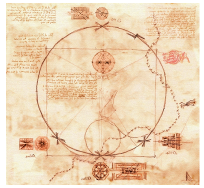
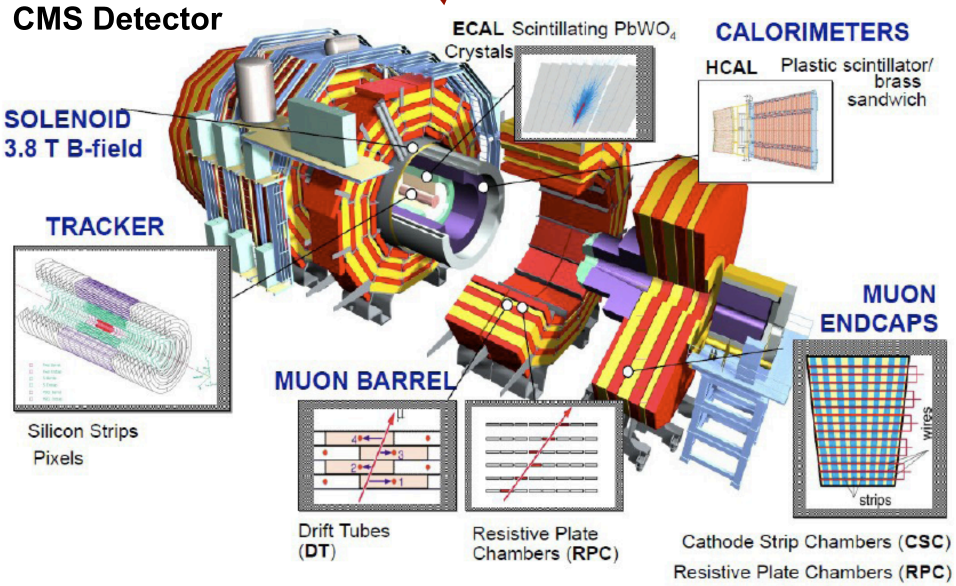
ATLAS & CMS: from Requirements to Design, to Performance and Results

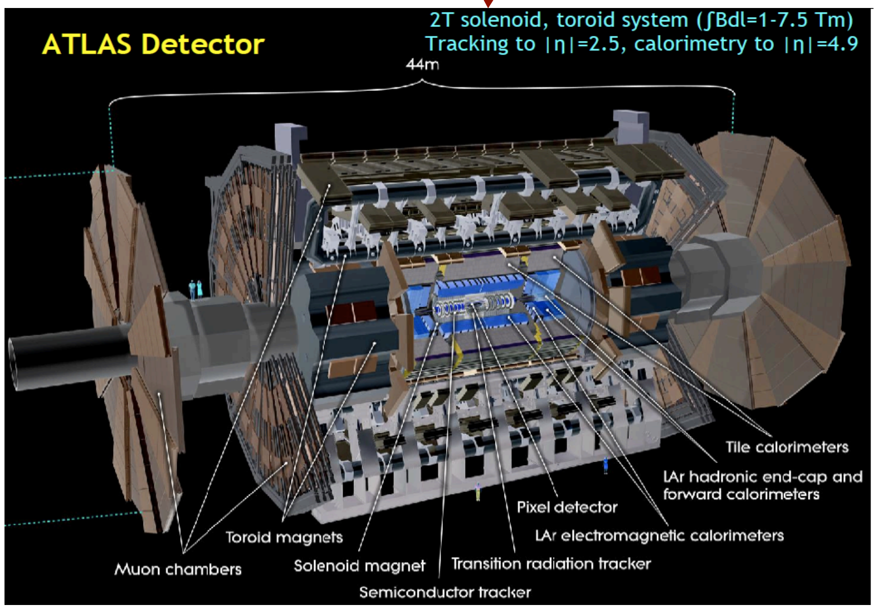


With Material borrowed from J. Virdee and P. Jenni, as well as several Presentations at this Summer Conferences

References: The LHC and its Experiments

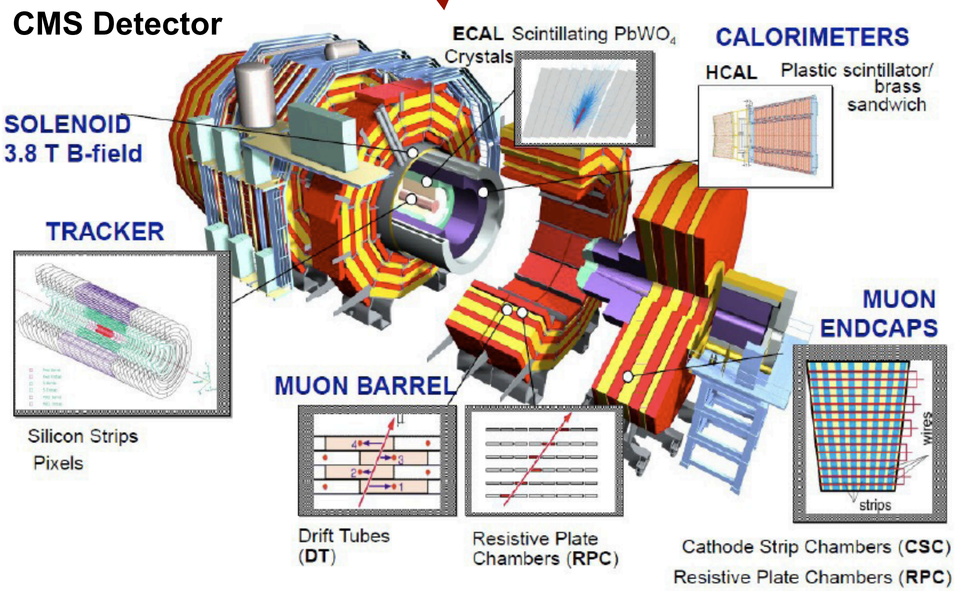
2008 JINST 3 S08003   2008 JINST 3 S08004

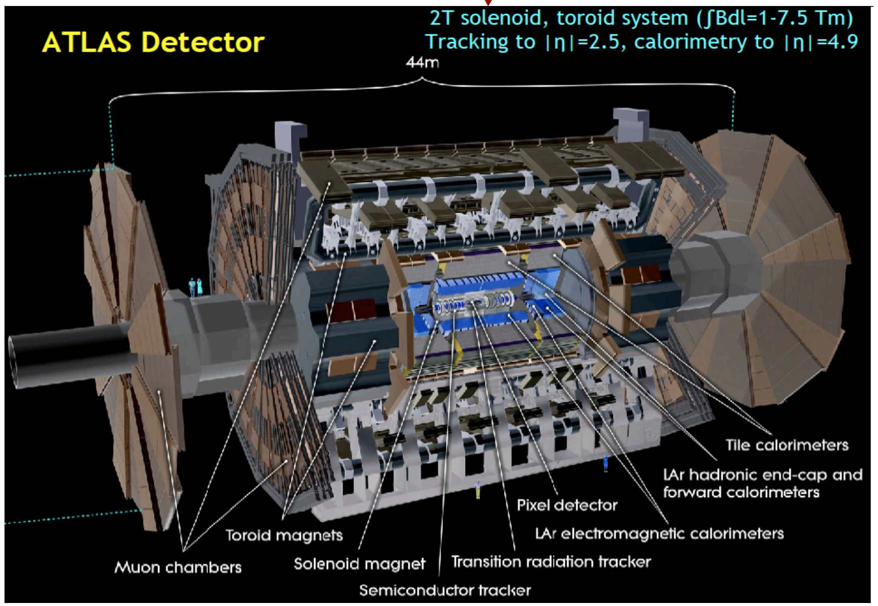




The Physics Goals and Challenges for ATLAS and CMS

- EWK Spontaneous Symmetry braking & the Origin of Mass: the Higgs sector
  - A new Symmetry to solve the Fine-Tuning Problem: SUSY
    - Other possibilities: Z', warped extra dimensions etc.





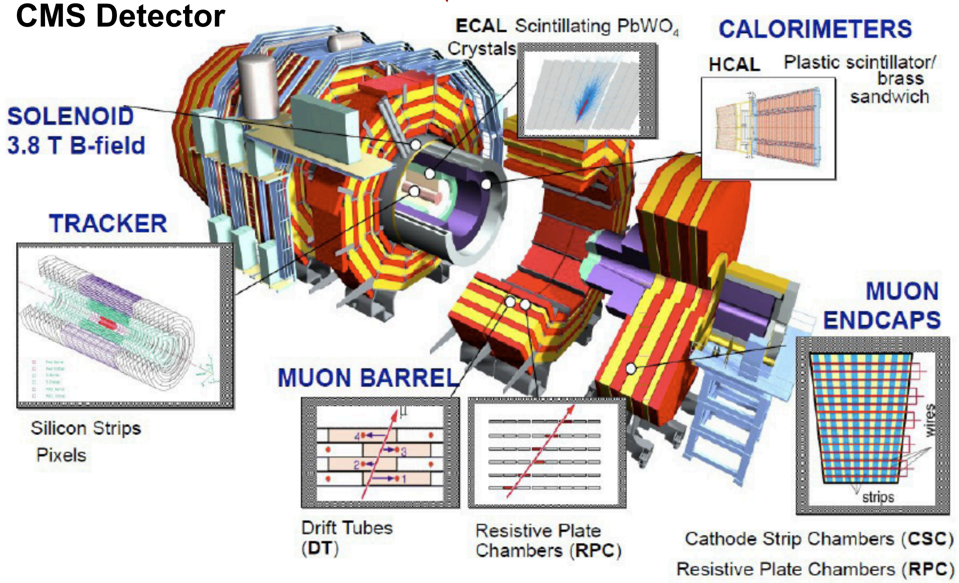
ATLAS & CMS: from Requirements to Design

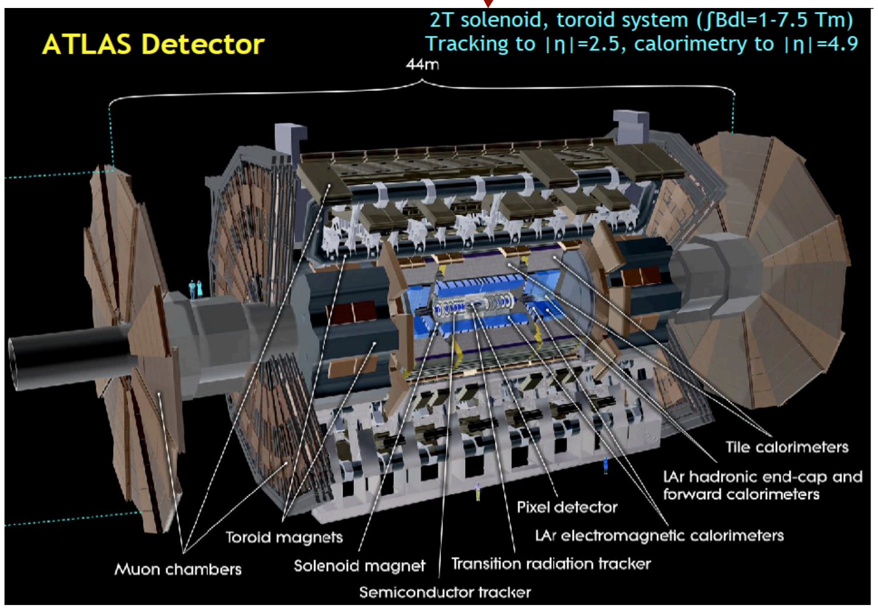
The Physics Goals and Challenges for ATLAS and CMS

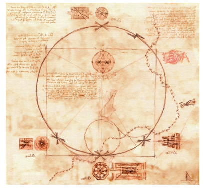
The Known Unknowns

The Un-Known Unknowns…

Develop a robust experimental strategy aimed at ensuring broad sensitivity to any new physics within LHC energy domain



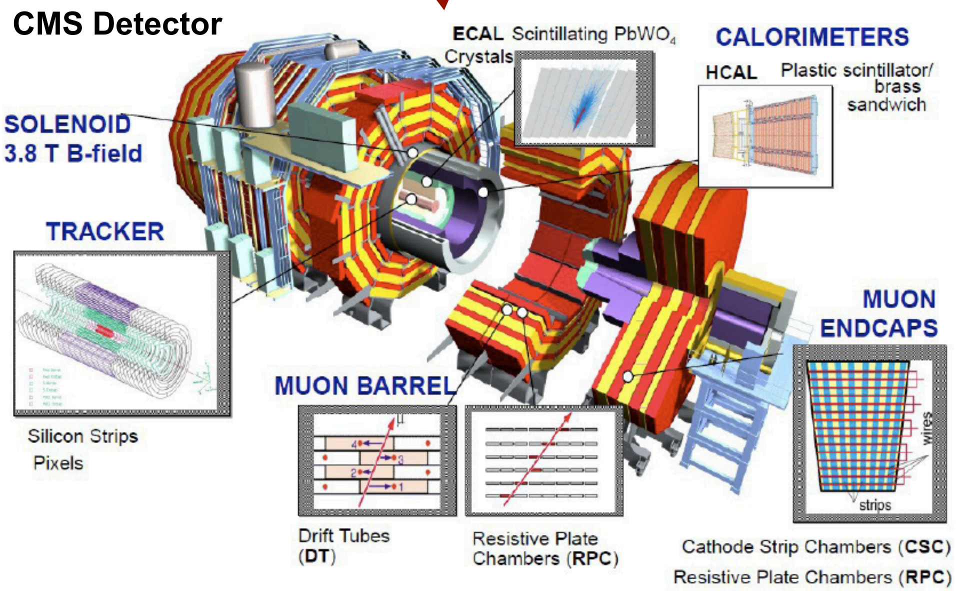


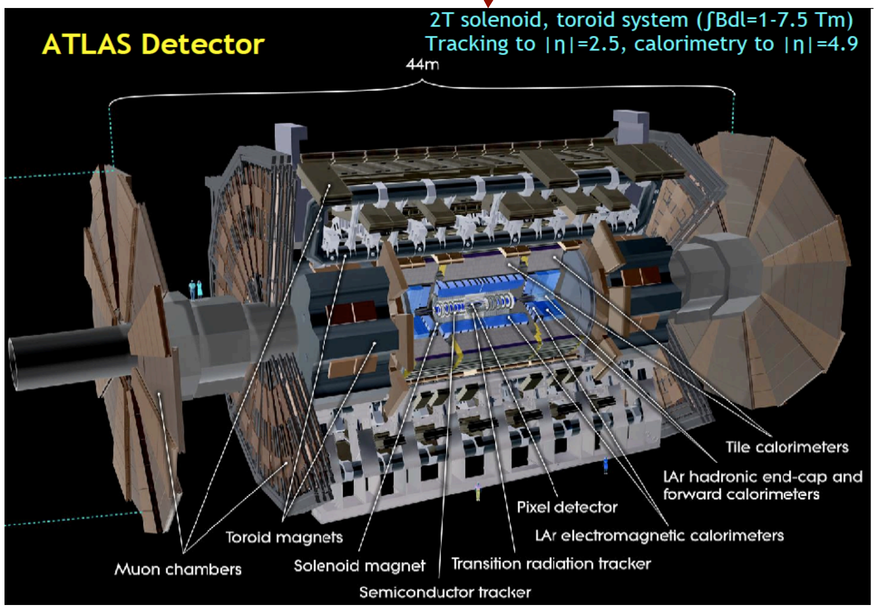


ATLAS & CMS: from Requirements to Design

The Physics Goals and Challenges for ATLAS and CMS

Any new particle produced at the LHC will either decay into known particles
this is the case for (almost) all charged particles
OR
Any new stable neutral particle will escape the detector unseen,
and be manifest through Missing Transverse Energy, like a neutrino

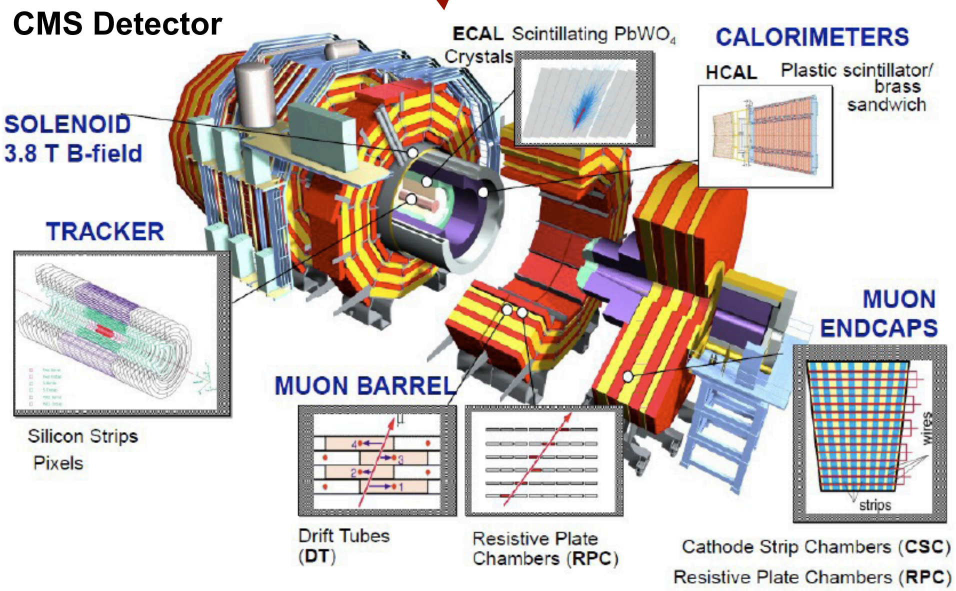


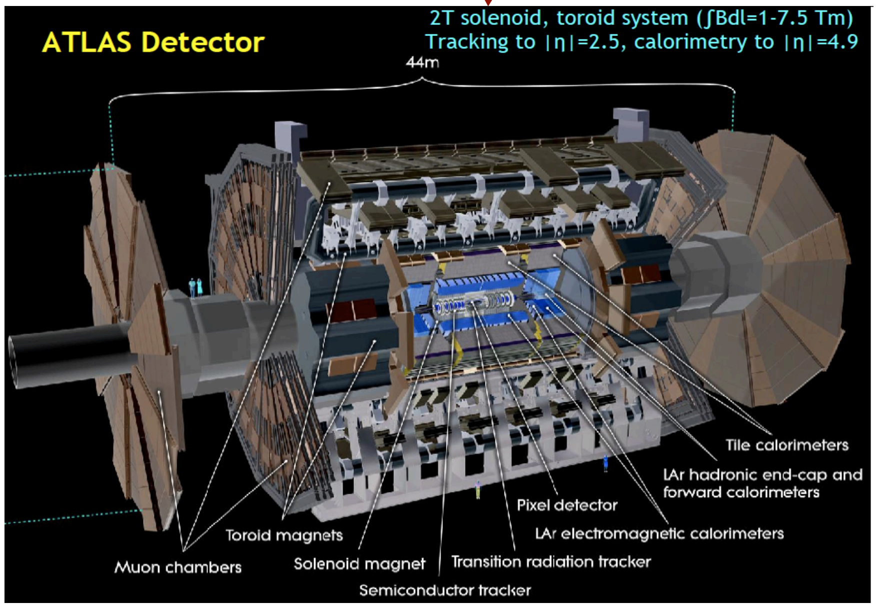


The Physics Goals and Challenges for ATLAS and CMS

The "General Purpose" LHC Detector should Identify and Measure Precisely

Photons, Leptons (e, μ, τ), charged & neutral hadrons, Jets, MET

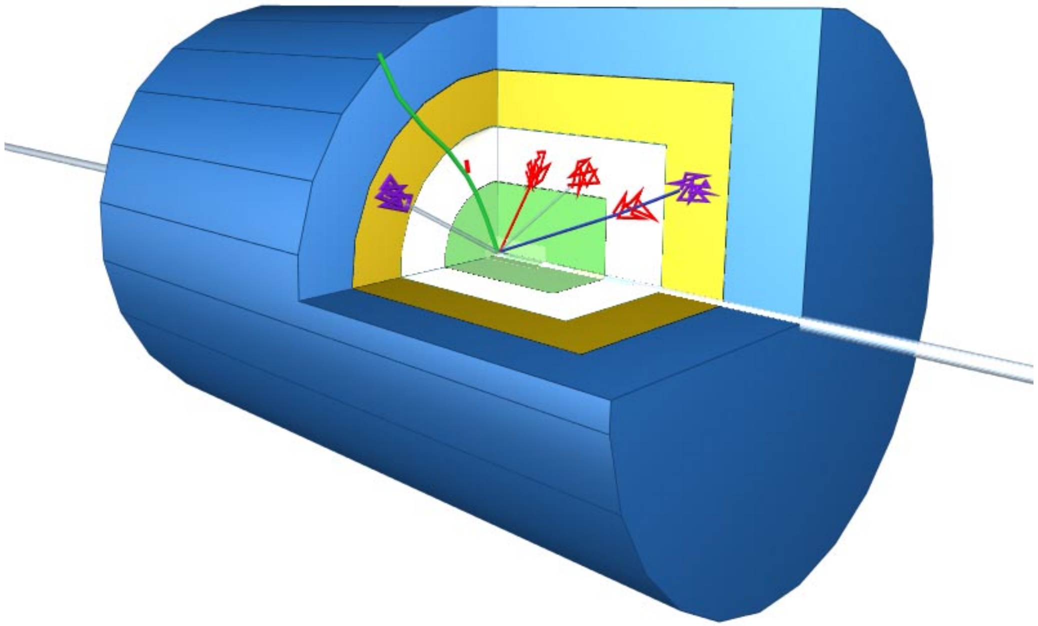




The Generic Collider Detector

"From spherical cows, to cylindrical onions…"

Four concentric Detector Layers, each dedicated to a specific task,
And a Magnetic Field:
Together they allow the reconstruction
(identification and determination of energy and direction)
of all particles generated in an event



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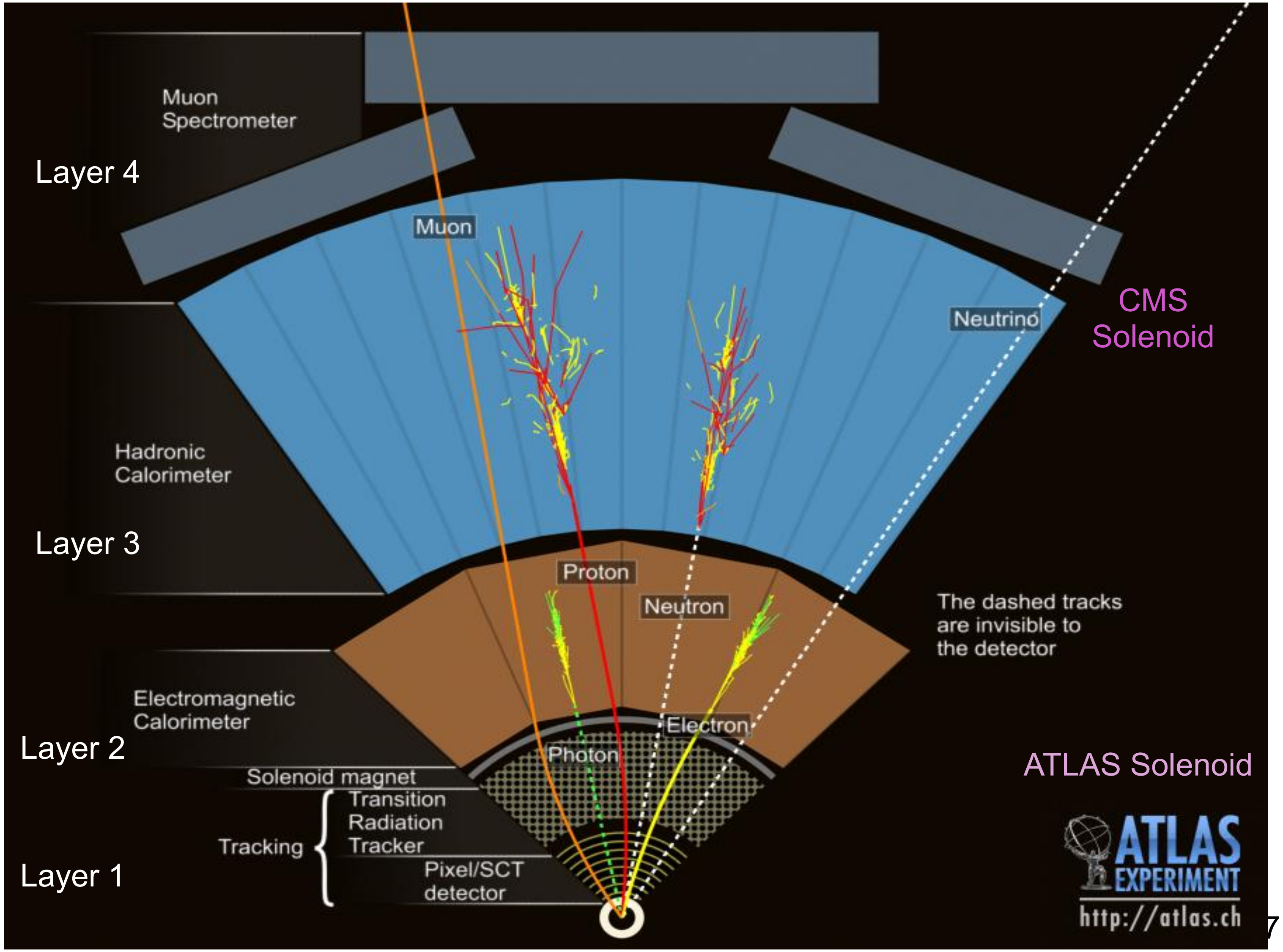
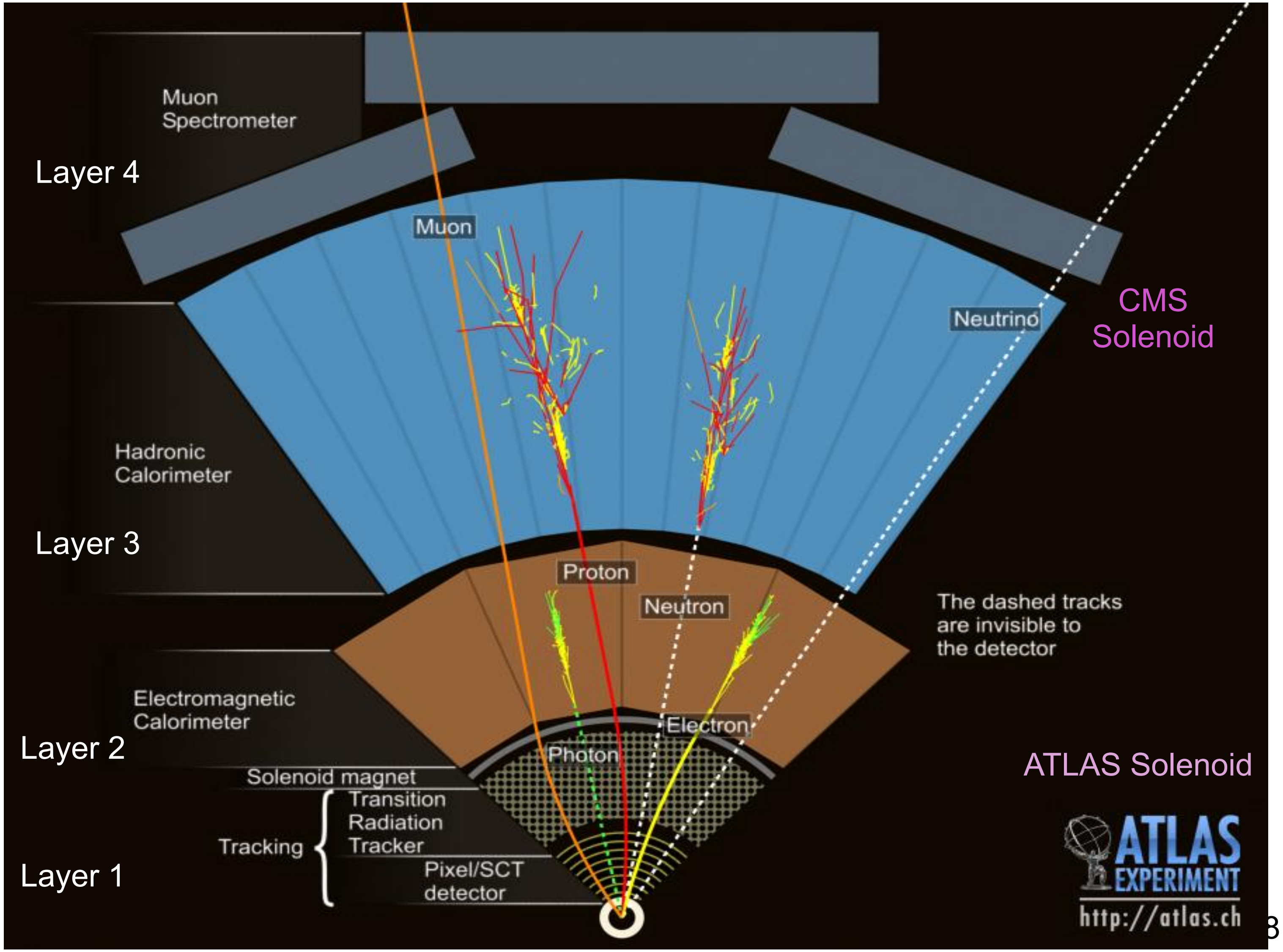
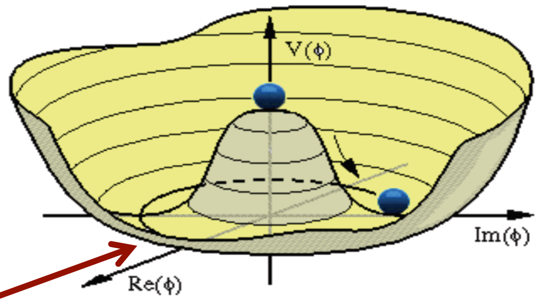


The General Purpose LHC Detector
Specific Performance Requirements

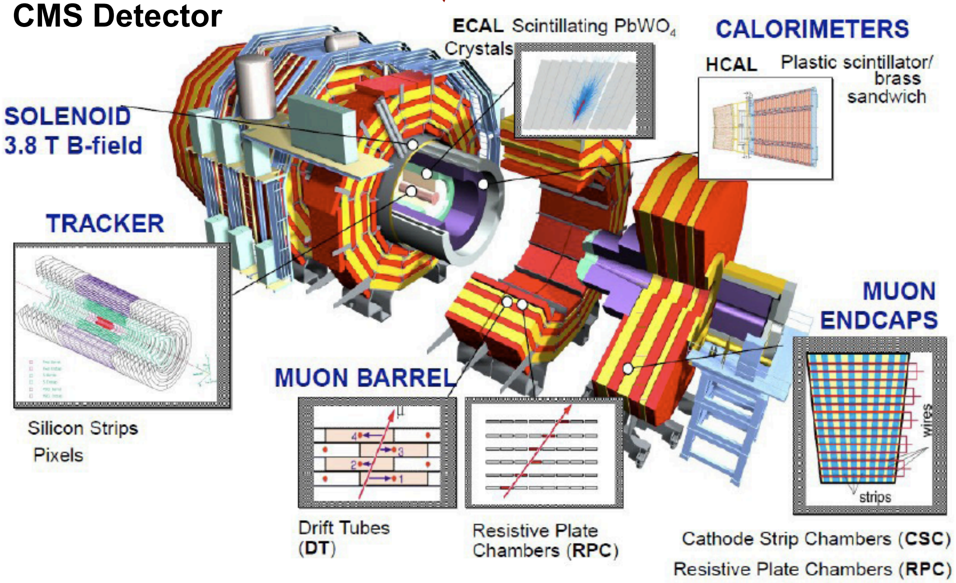


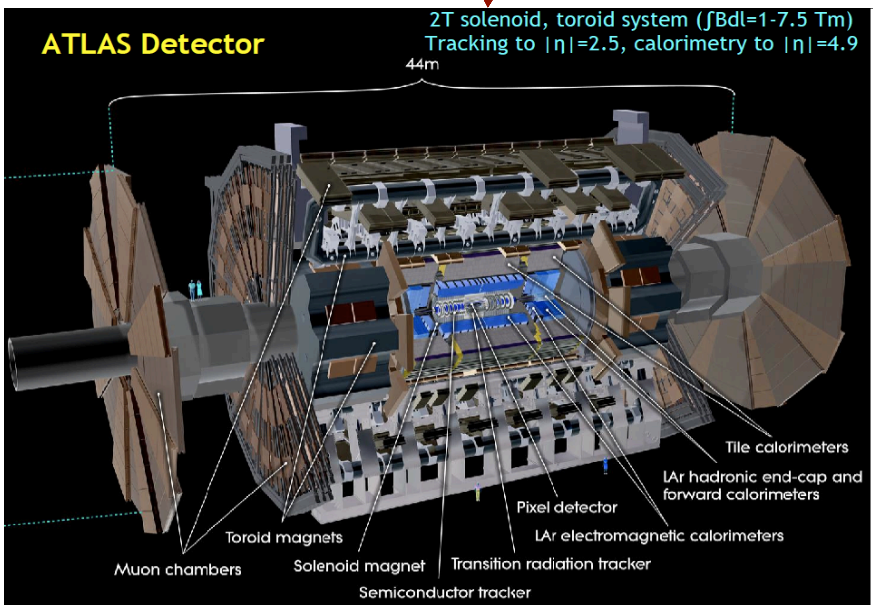
ATLAS & CMS:
from Requirements to Design

The Higgs Sector
has been used to set many of
the required Performance Benchmarks



H -> ZZ -> 4l
H -> WW ->llνν
H -> γγ





ATLAS & CMS: from Requirements to Design

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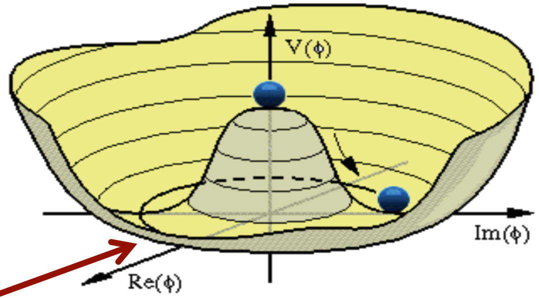

H -> ZZ -> 4l
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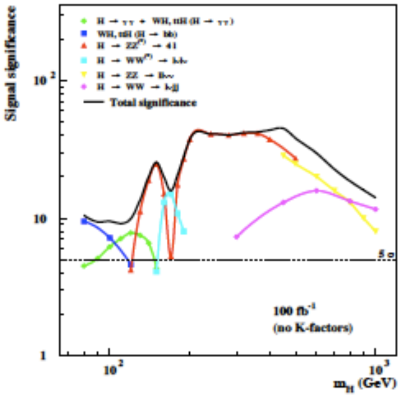
ATLAS

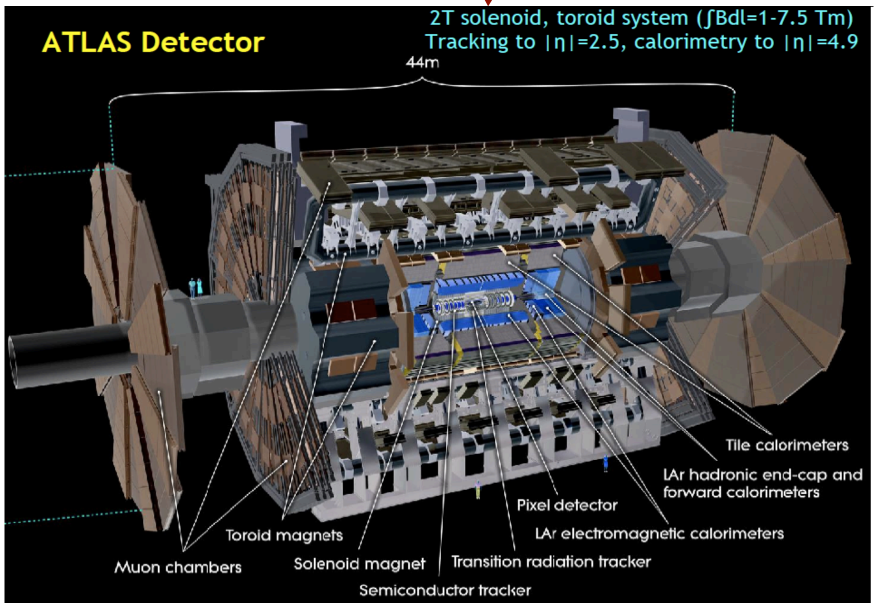
ATLAS DETECTOR AND PHYSICS PERFORMANCE



Technical Design Report

Issue:	1
Revision:	0
Reference:	ATLAS TDR 15, CERN/LHCC 99-15
Created:	25 May 1999
Last modified:	25 May 1999
Prepared By:	ATLAS Collaboration

Volume II



Production Rates at LHC

General event properties

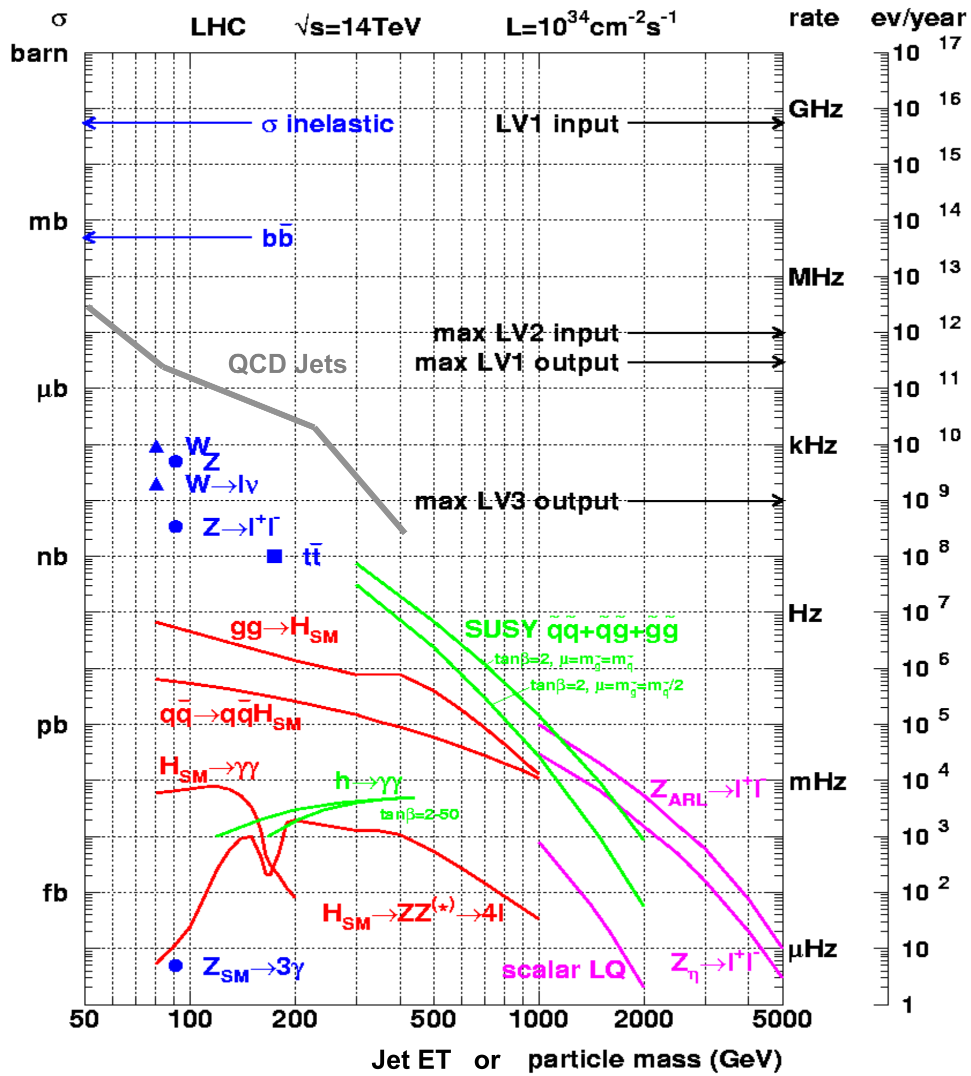
Heavy flavour physics

Standard Model physics including QCD jets

Higgs searches

Searches for SUSY

Examples of searches for 'exotic' new physics



Production Rates at LHC

Higgs Production & decay into clean channels is a RARE process

⇒ **LHC a High Luminosity Collider**

Massive Event rates:

Bunches cross at 40MHz
~25 interactions / crossing

Can store only ~ 200Hz of Interesting events

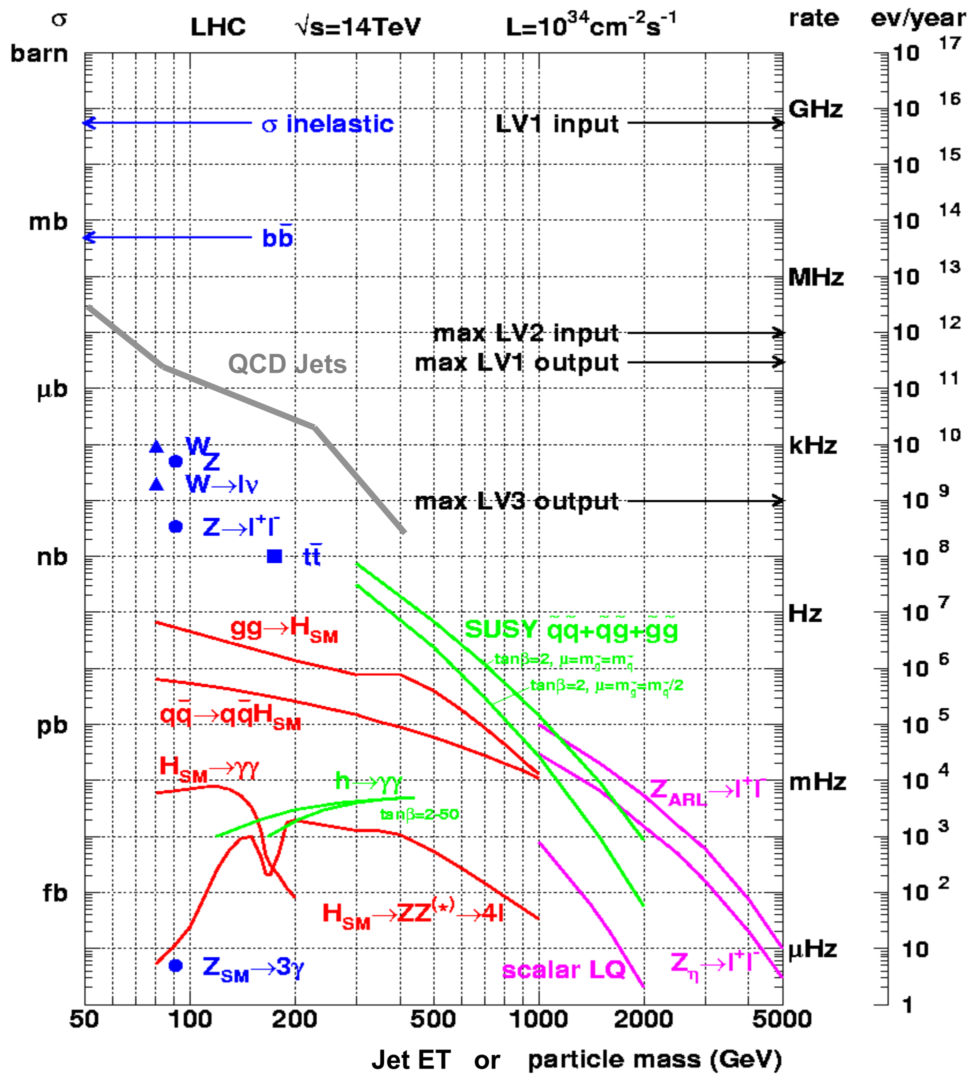
⇒ **Need Highly Selective Trigger!**

⇒ **See Trigger Lecture**

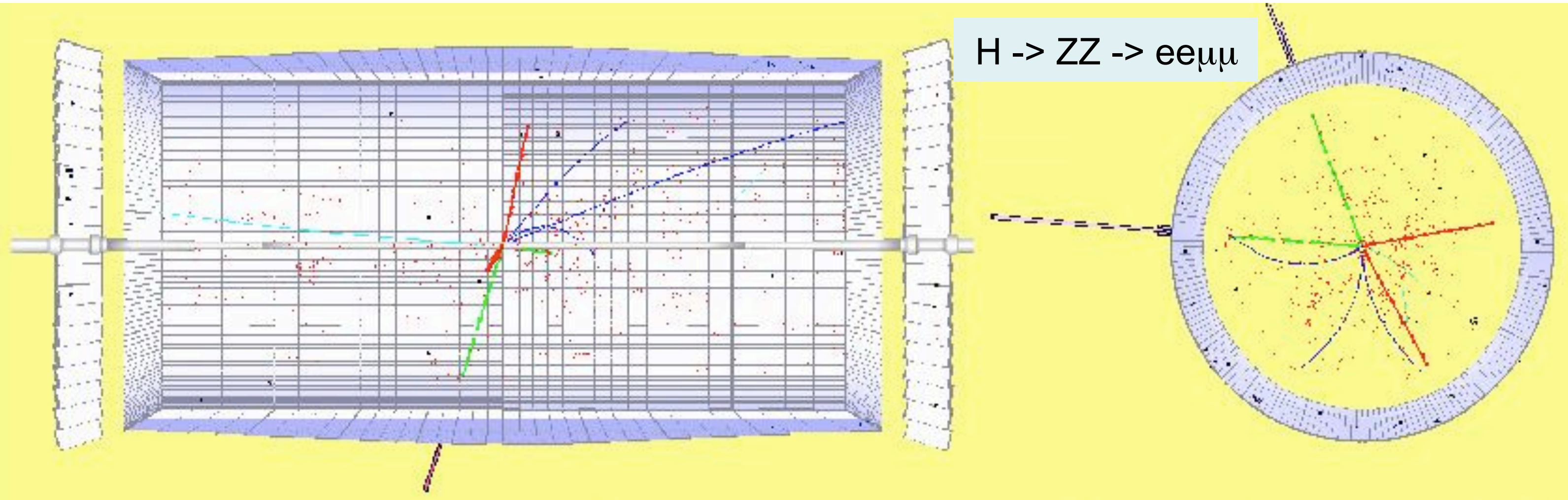
Massive Particle rates:

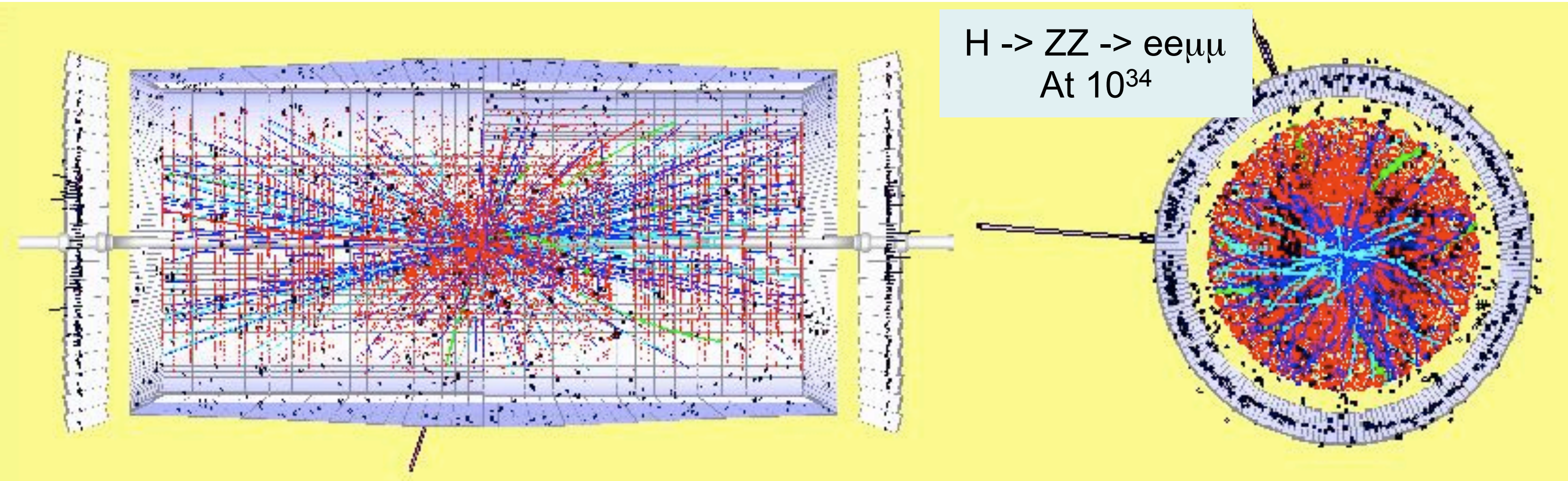
⇒ **Need very fast, very granular Radiation Hard Detectors!**

⇒ **Major new Detector Challenges**



The Challenges of High Luminosity & Event Pileup





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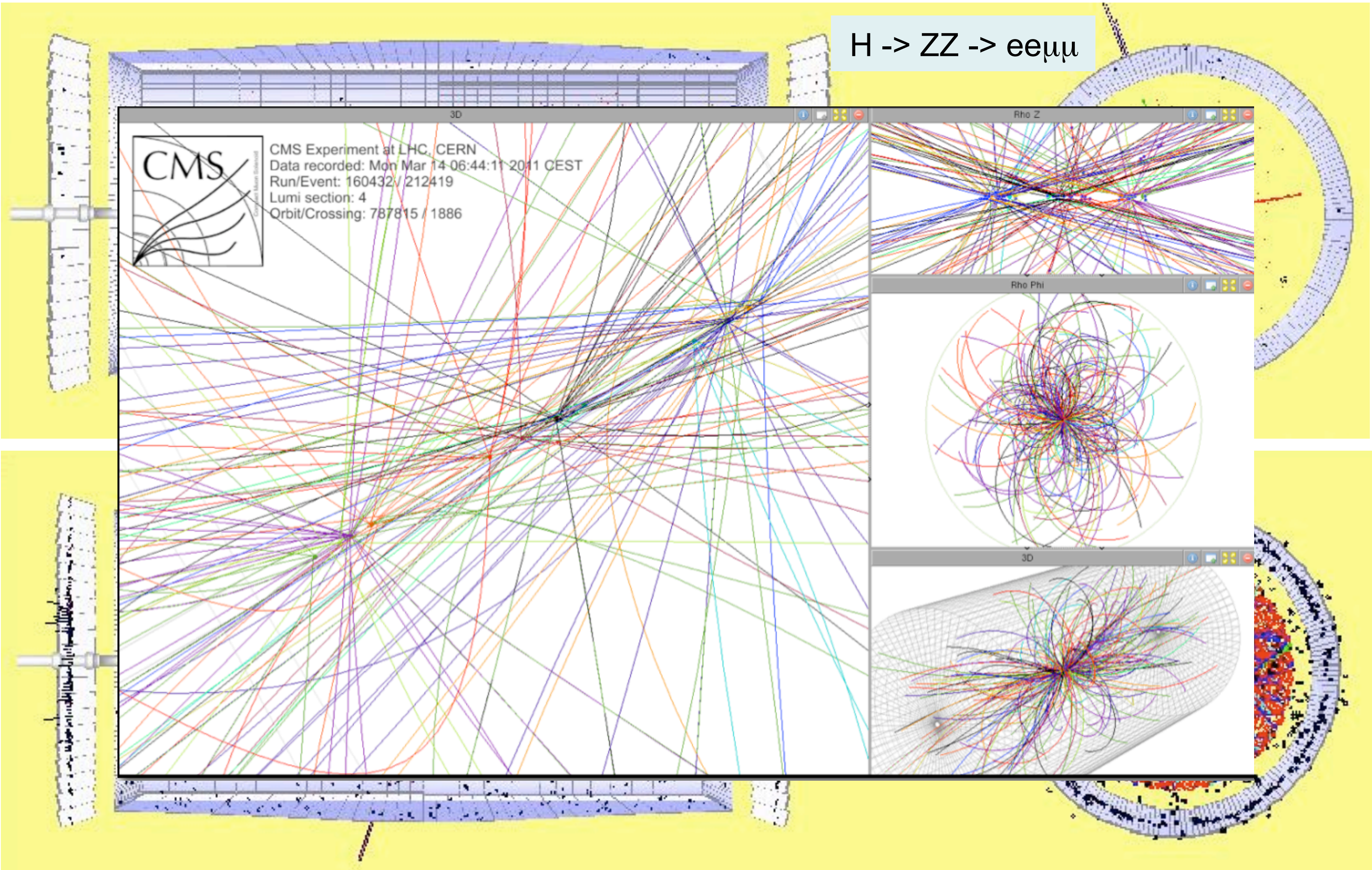
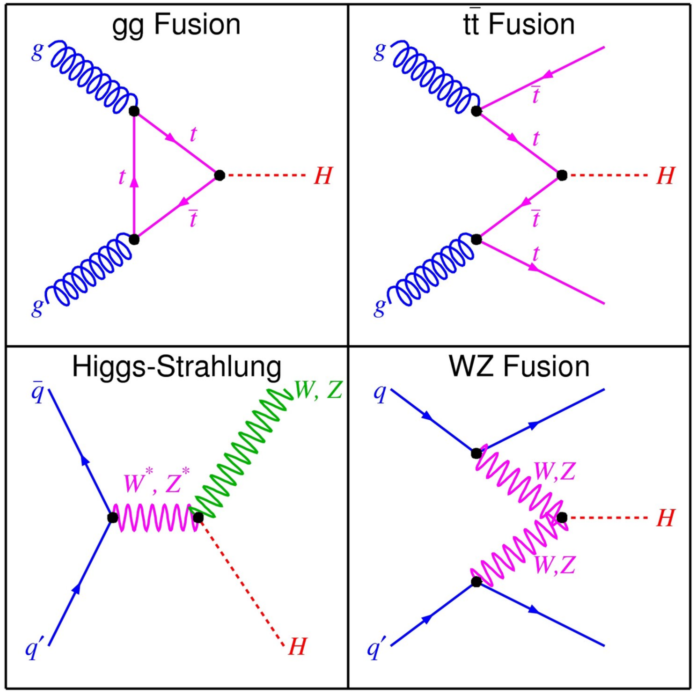
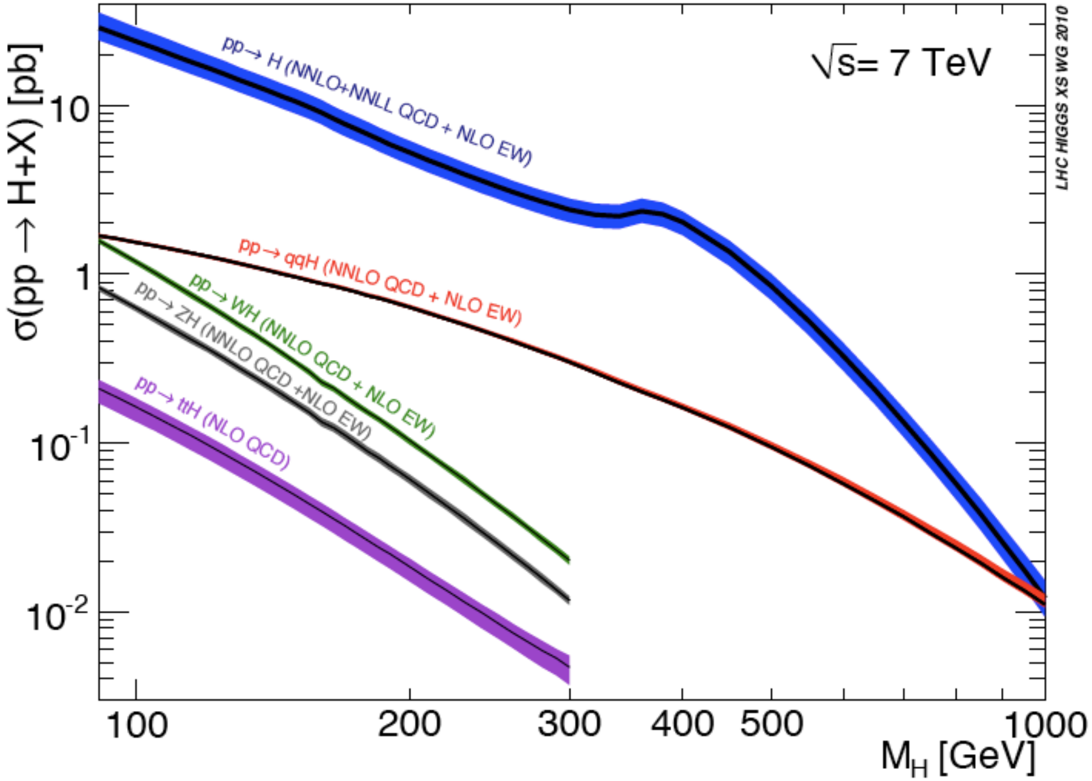


Higgs Production at LHC

Gluon-gluon fusion is dominant over most of the Higgs Mass range



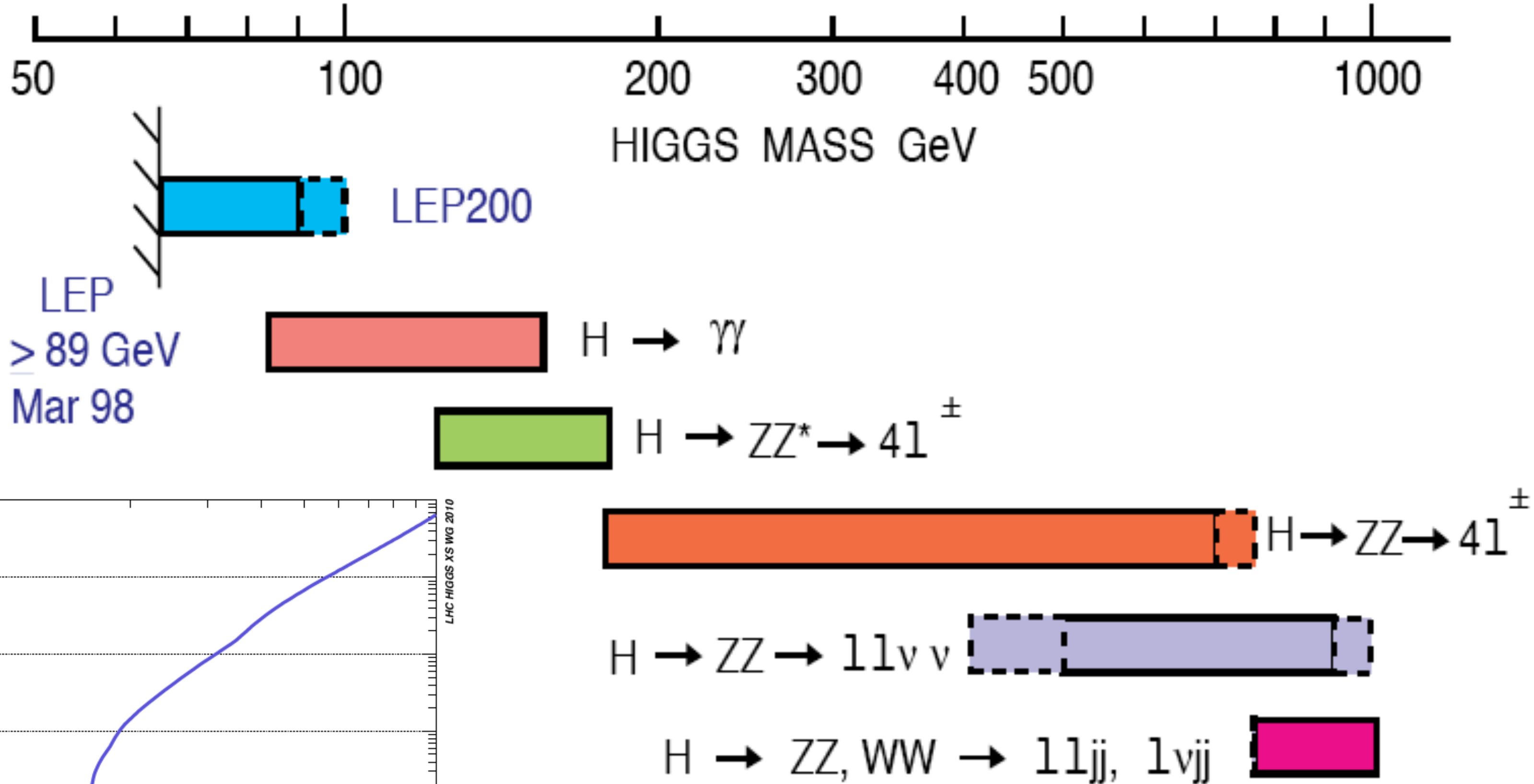


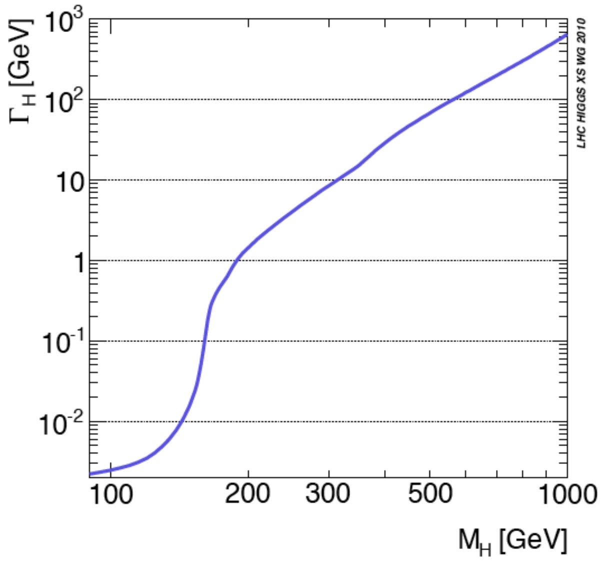
W/Z Fusion is important at high mH as well as in non SM Higgs scenarios quark jets in forward direction

⇒ Jet reconstruction up to high $|\eta| < 5$

Higgs benchmark decays as function of M_H

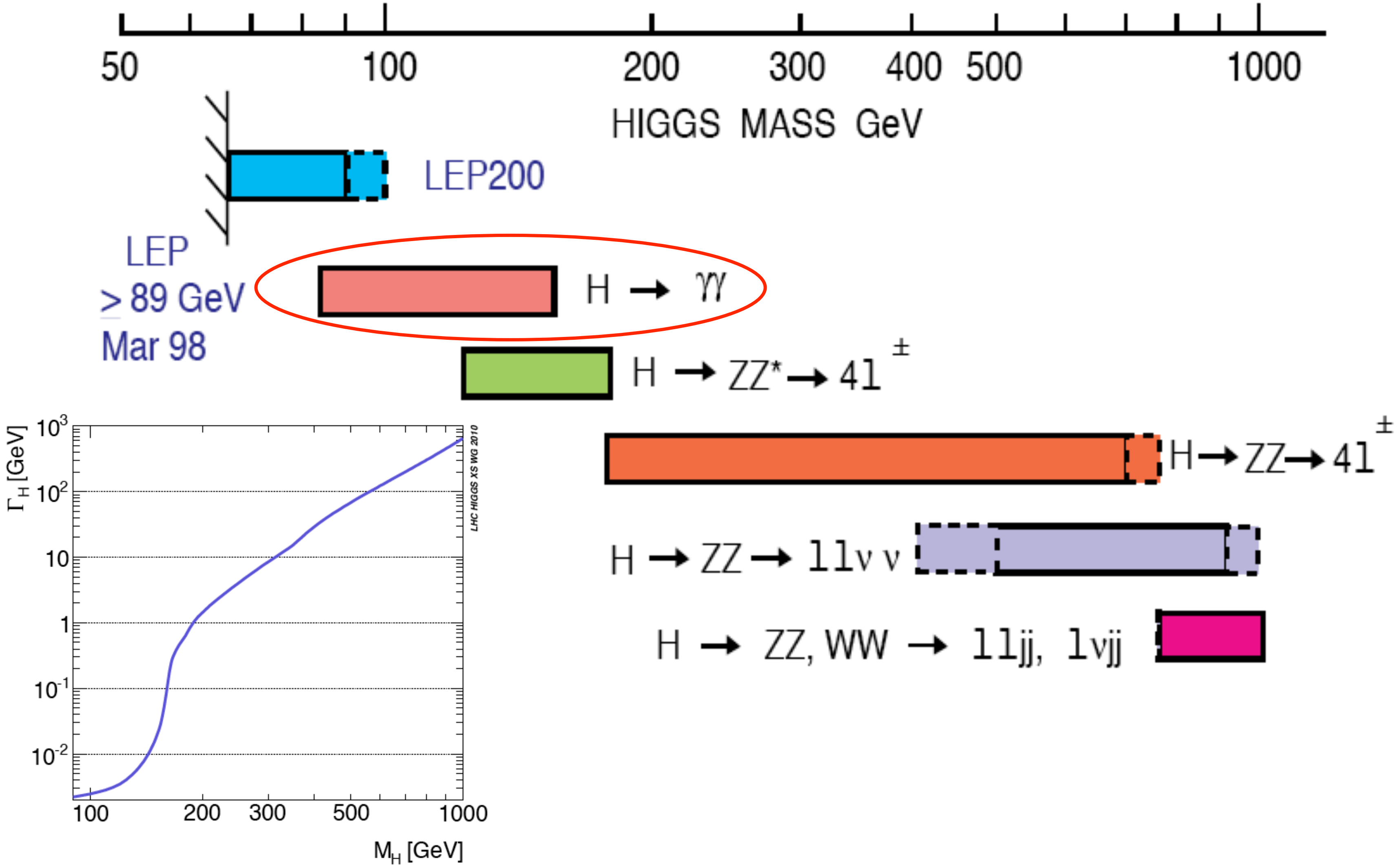
The landscape in 90’s





H -> γγ => ECAL performance requirements

The landscape in 90's



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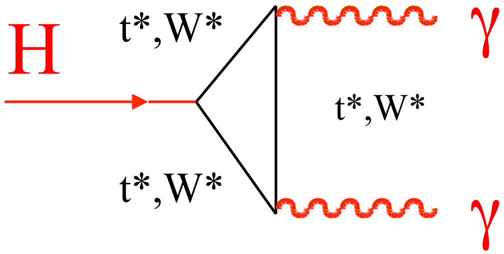
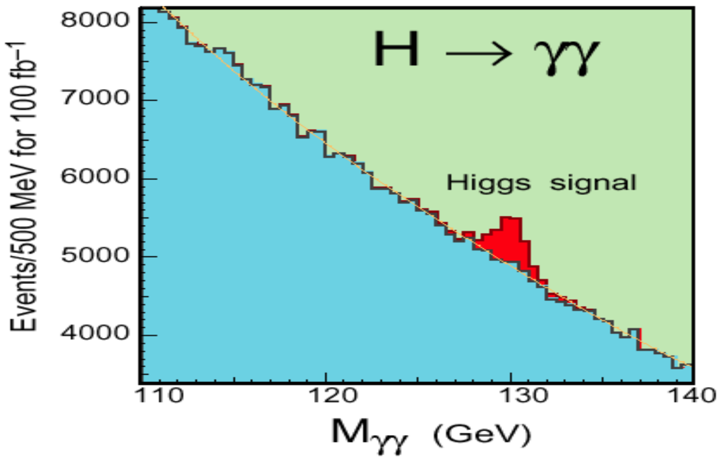
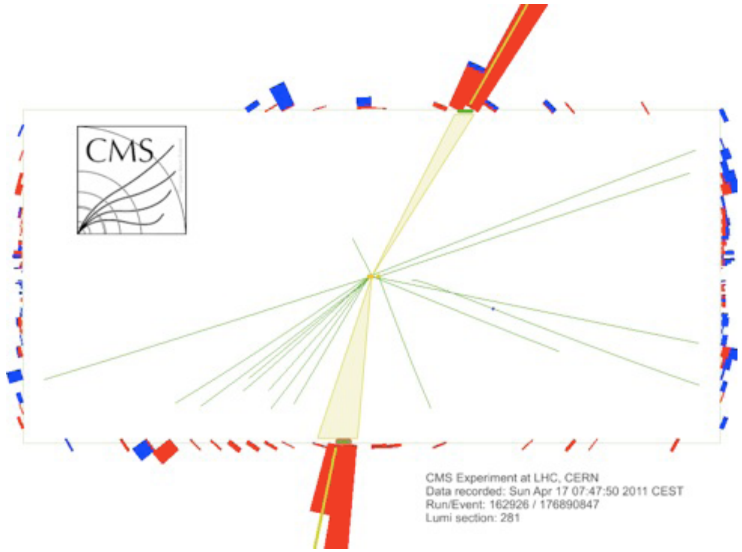


e.g. 2 isolated photons:
p_T > 25, 40 GeV with |η| < 2.5





Natural width of Higgs is small (~MeV)

Signal: ~1000's of events/yr @L = 10^{34} $cm^{-2}s^{-1}$

Backgrounds (QCD) are large (S/B ~ 0.1)

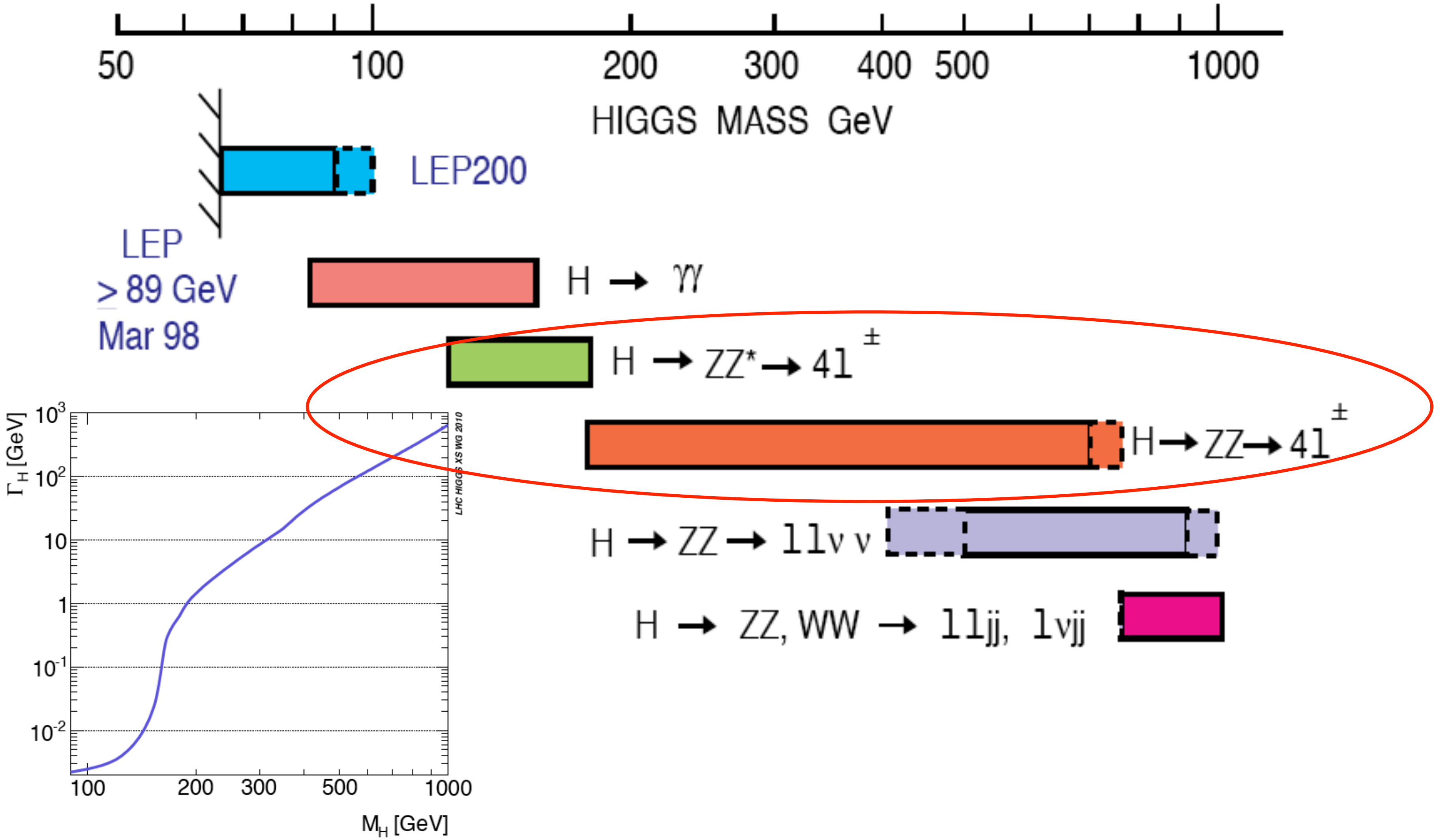
⇨**excellent mass resolution** is required

Mass measurement: Excellent energy resolution, measurement of photon direction

Background suppression: π^0 rejection, efficient photon isolation

H -> ZZ $^{(*)}$ => Muon Identification & Tracking Performance Requirements

The landscape in 90's



H -> ZZ $^{(*)}$ -> 4l => Muon Identification & Tracking Performance Requirements

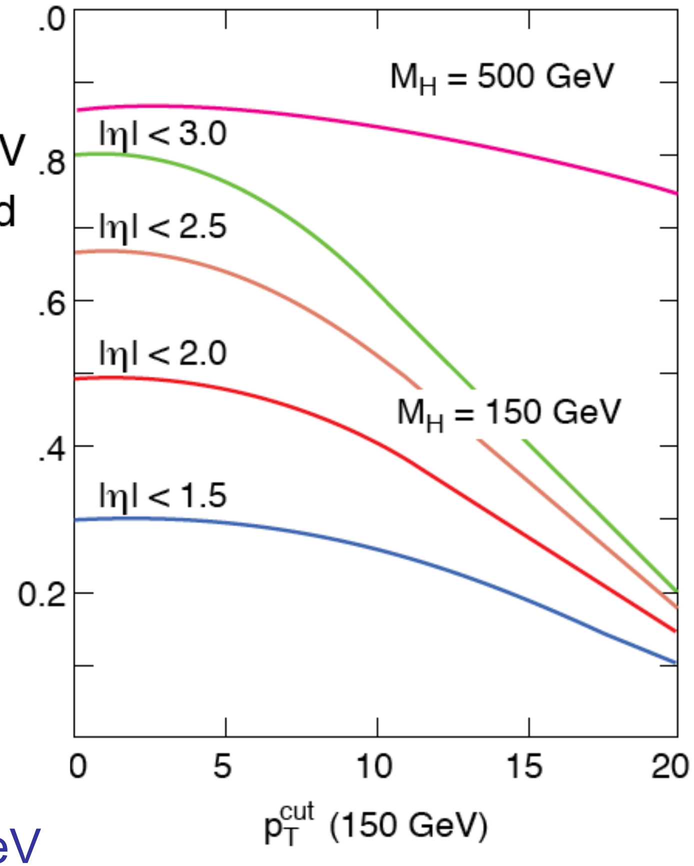
$130 \leq M_H \leq 800$ GeV

ZZ*

Γ_H (M_H=150 GeV) ≈ 15 MeV observed width is dominated by instrumental mass resolution

ZZ

Γ_H(M_H=500 GeV) ≈ 65 GeV for M_H≥300 GeV observed width is dominated by natural width



Background

Irreducible : ZZ*, Zg*
Reducible : t t, Z bb

ZZ
t t

Di-lepton mass resolution at m_Z better than Γ_Z

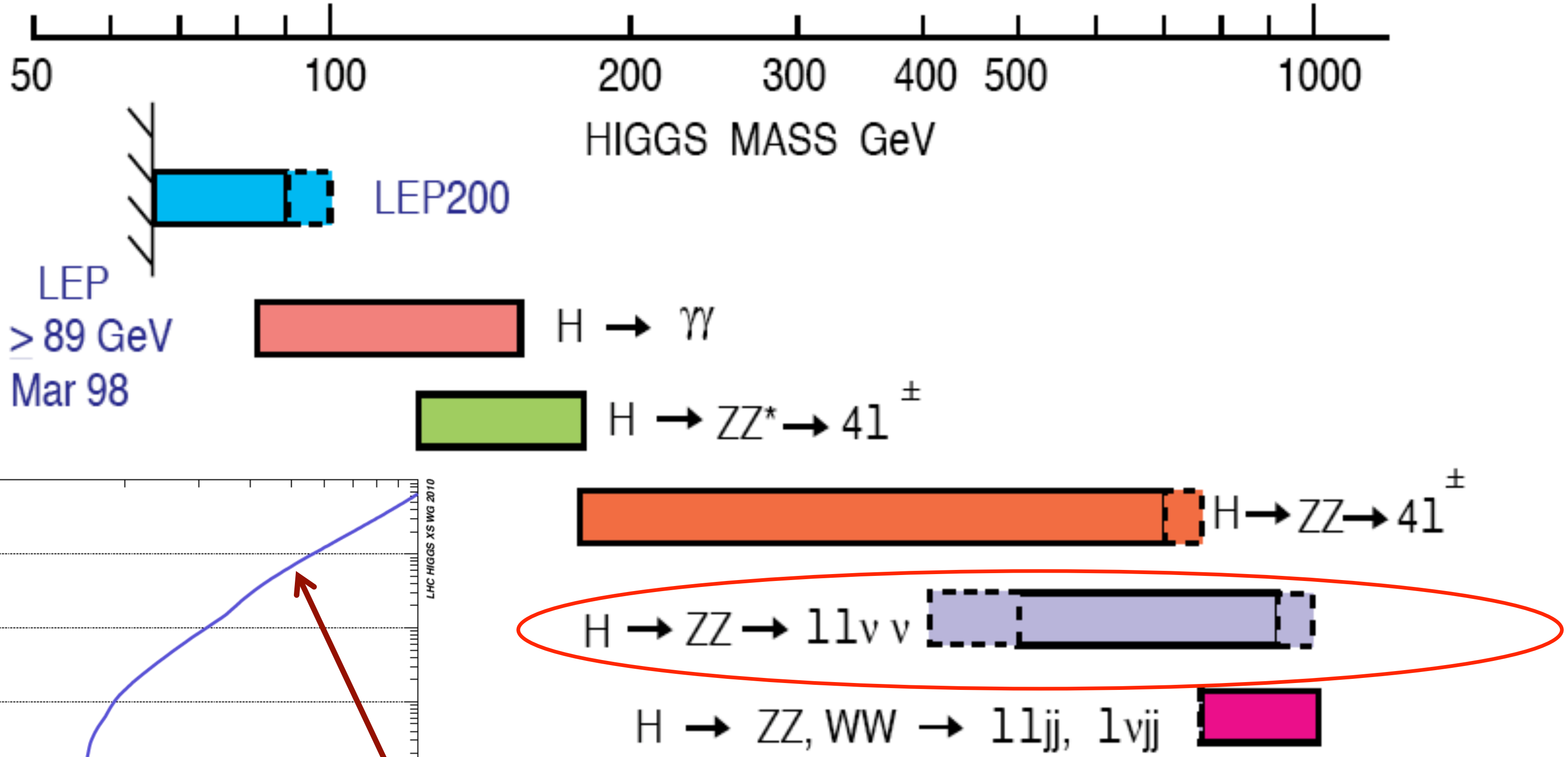
Good momentum resolution: dP/P ~1% at 100GeV

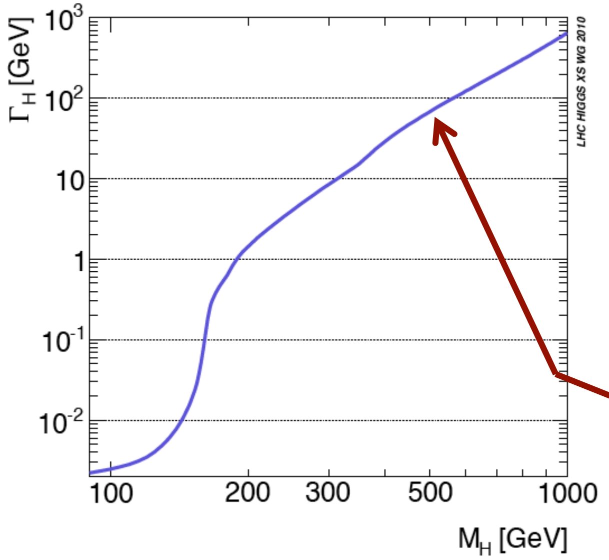
Charge determination up to 1TeV => dP/P ~ 10% at 1TeV

Large geometric coverage, high efficiency at high luminosity for lepton isolation

Higgs benchmark decays as function of M_H

The landscape in 90's





High Mass => High Energy ν & large Missing E_T
High Mass => Higgs no longer a narrow resonance…

H -> ZZ -> $ll\nu\nu$ => Missing Transverse Energy Performance Requirements

For a 600GeV Higgs, expect MET > 150GeV

At these high masses, the Higgs is no longer a narrow resonance…

$\Rightarrow$ In this regime MET resolution is not crucial

What is Crucial is good control of fake MET tails

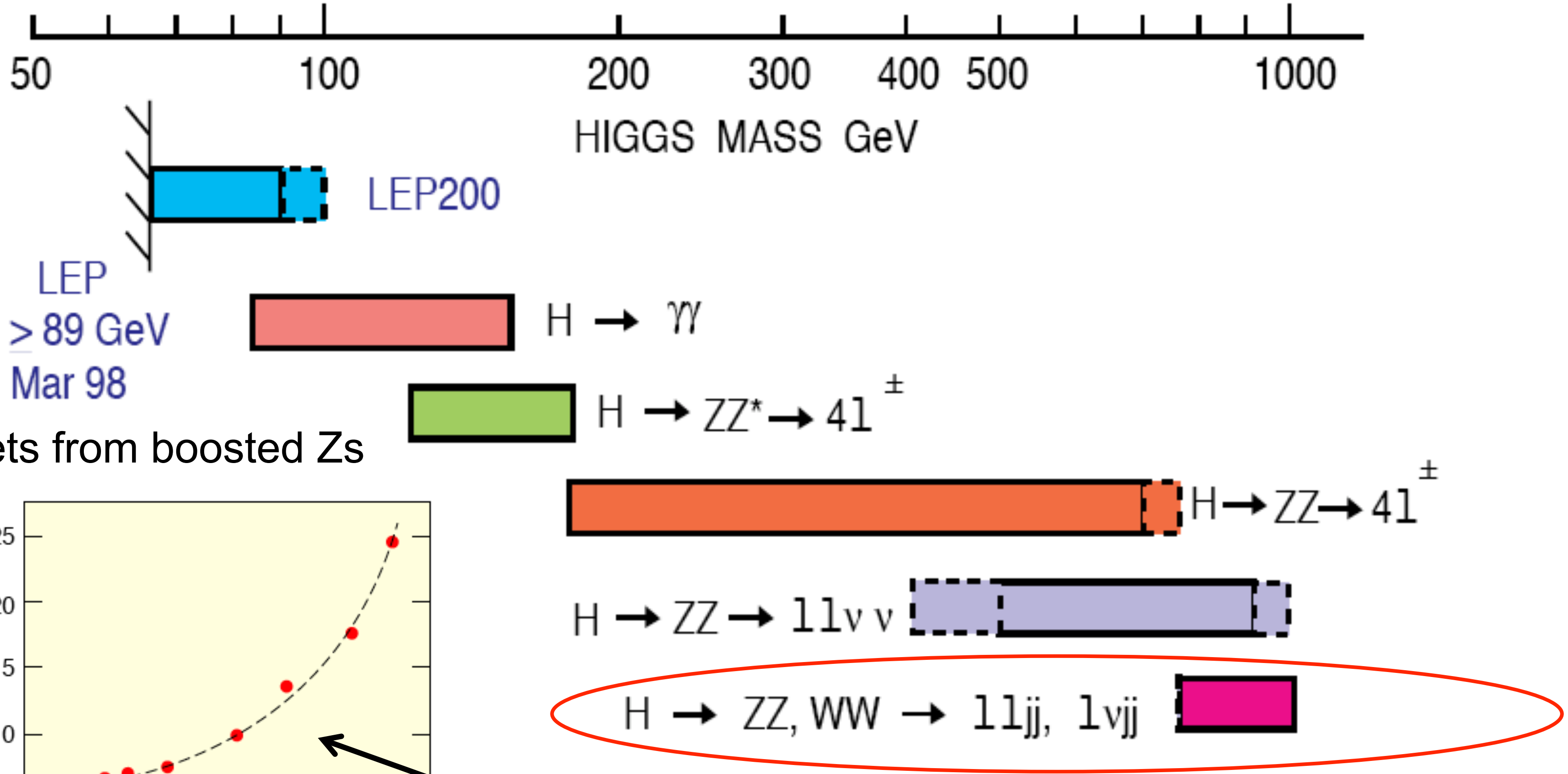
$\Rightarrow$ Calorimetric Coverage down to small angles: $|\eta| < 5$

Good hadronic energy resolution with small non-Gaussian tails

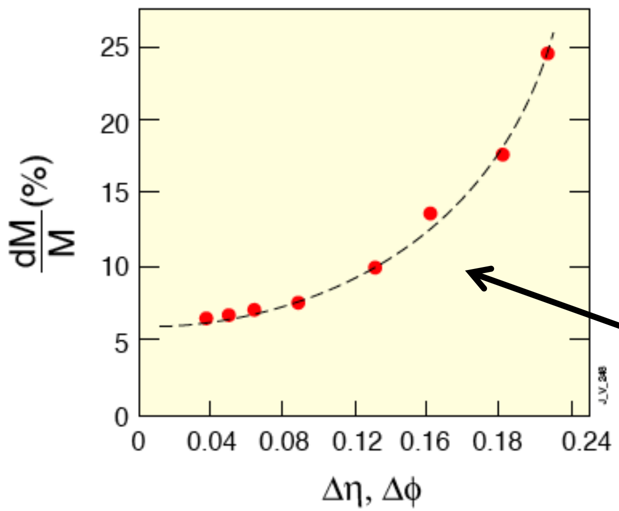
$\Rightarrow$ Hermetic: No pointing gaps/dead regions

Higgs benchmark decays as function of M_H

The landscape in 90's



Di-jets from boosted Zs



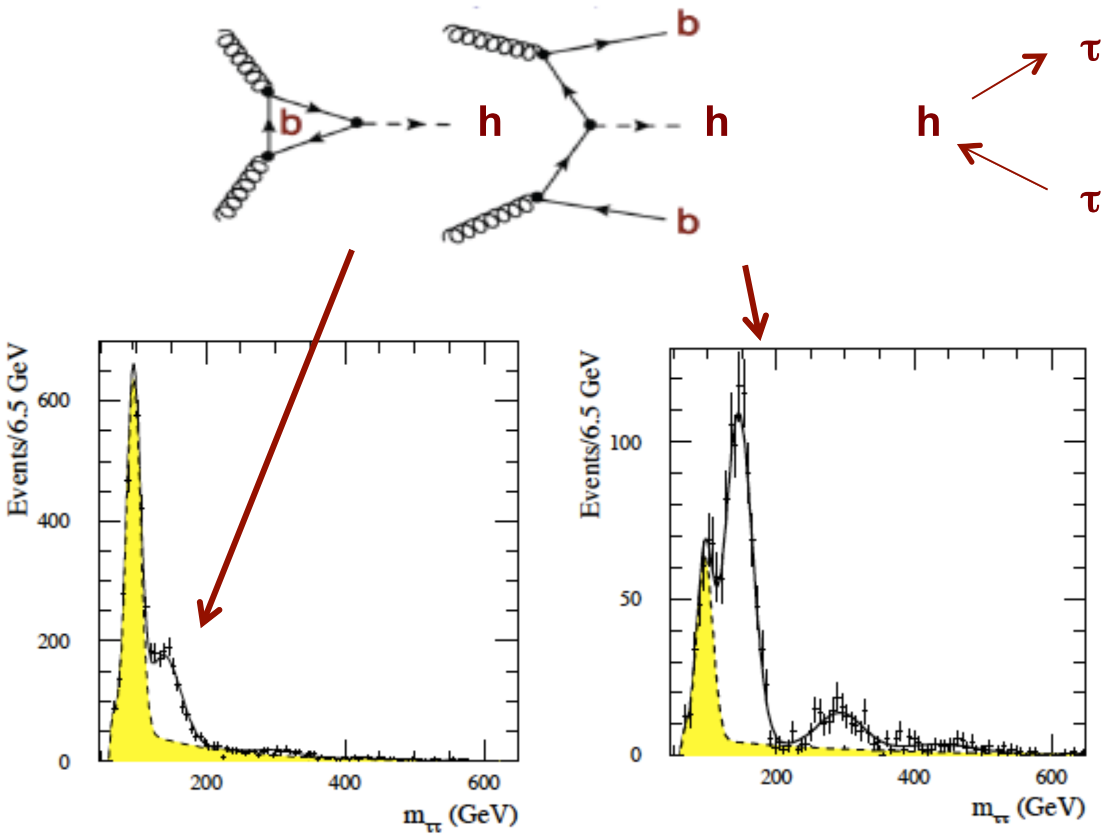
Boosted W/Z => the two jets are close in η−φ space

Choose hadronic calorimeter cell size < 0.1

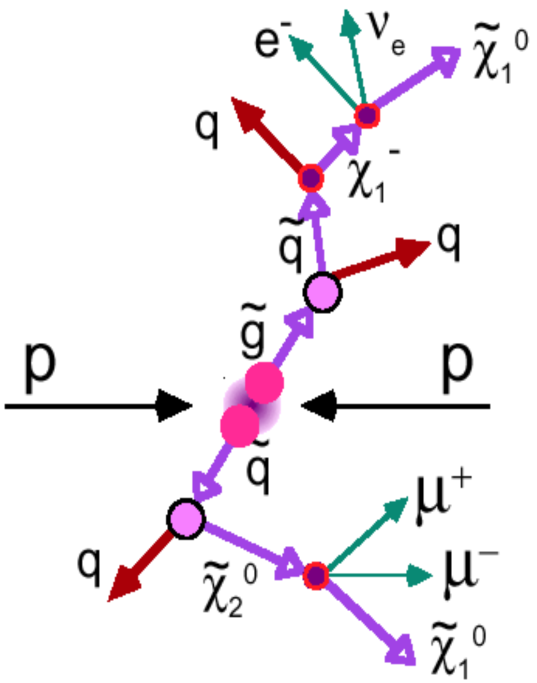
MSSM Higgs: additional benchmark channels

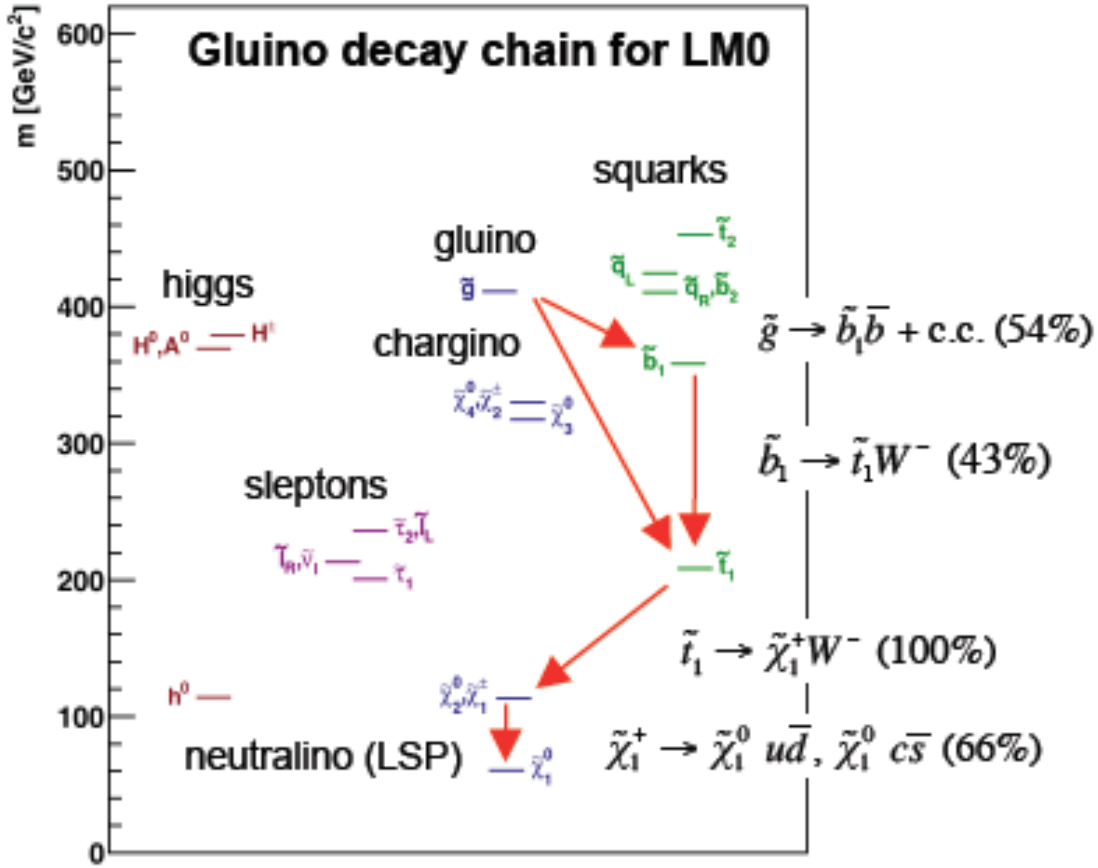
At high values of tanβ Higgs coupling to b and τ are substantially enhanced
Requires b and τ tagging & reconstruction

=> Pixel Vertex Detectors



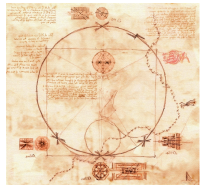
SUSY





Several high-P_T jets; Large missing $E_{T;}$ Charged Leptons; b-quarks

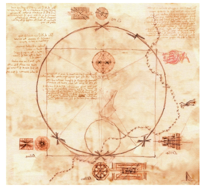
ATLAS Technical Design Report



- Due to the experimental conditions at the LHC, the detectors require fast, radiation-hard electronics and sensor elements. In addition, high detector granularity is needed to handle the particle fluxes and to reduce the influence of overlapping events.
- Large acceptance in pseudorapidity with almost full azimuthal angle coverage is required.
- Good charged-particle momentum resolution and reconstruction efficiency in the inner tracker are essential. For offline tagging of τ-leptons and b-jets, vertex detectors close to the interaction region are required to observe secondary vertices.
- Very good electromagnetic (EM) calorimetry for electron and photon identification and measurements, complemented by full-coverage hadronic calorimetry for accurate jet and missing transverse energy measurements, are important requirements, as these measurements form the basis of many of the studies mentioned above.
- Good muon identification and momentum resolution over a wide range of momenta and the ability to determine unambiguously the charge of high p_T muons are fundamental requirements.
- Highly efficient triggering on low transverse-momentum objects with sufficient background rejection, is a prerequisite to achieve an acceptable trigger rate for most physics processes of interest.

ATLAS TDR 14,
25 May 1999

CMS Technical Proposal

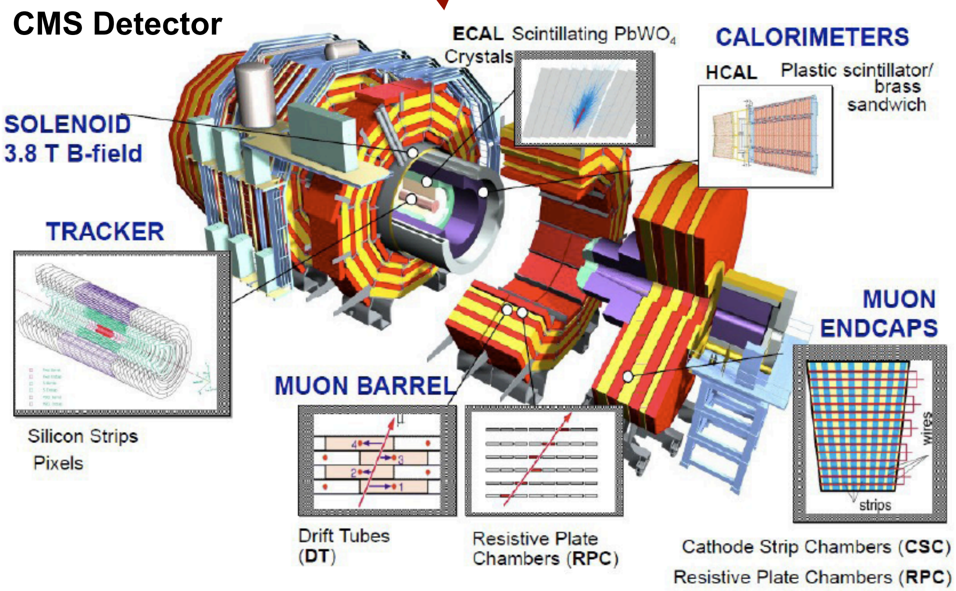


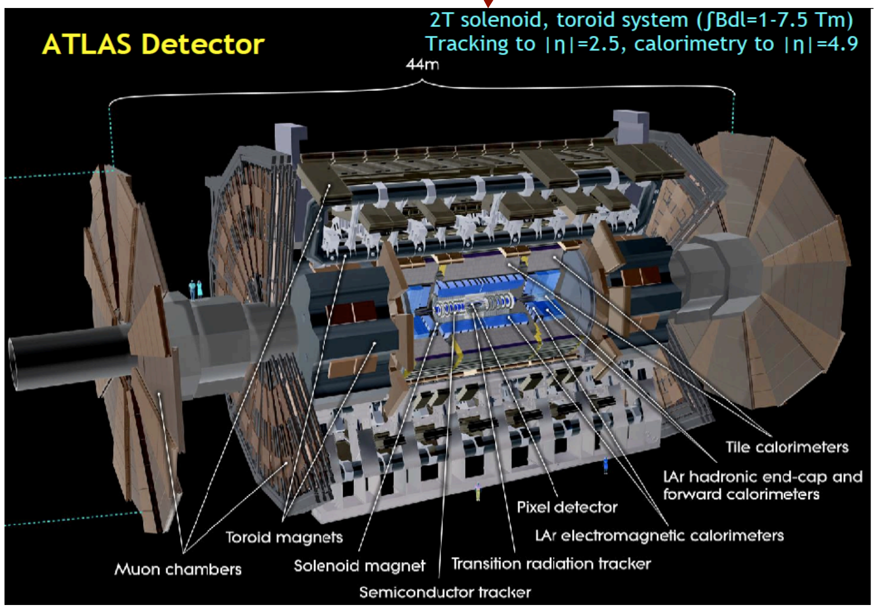
The detector requirements for CMS to meet the goals of the LHC physics programme can be summarised as follows:

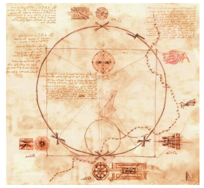
- Good muon identification and momentum resolution over a wide range of momenta and angles, good dimuon mass resolution ($\approx 1\%$ at 100 GeV), and the ability to determine unambiguously the charge of muons with $p < 1$ TeV;
- Good charged-particle momentum resolution and reconstruction efficiency in the inner tracker. Efficient triggering and offline tagging of τ's and b-jets, requiring pixel detectors close to the interaction region;
- Good electromagnetic energy resolution, good diphoton and dielectron mass resolution ($\approx$ 1% at 100 GeV), wide geometric coverage, π^0 rejection, and efficient photon and lepton isolation at high luminosities;
- Good missing-transverse-energy and dijet-mass resolution, requiring hadron calorimeters with a large hermetic geometric coverage and with fine lateral segmentation.

ATLAS and CMS:

Two different approaches to a common set of Goals and Challenges



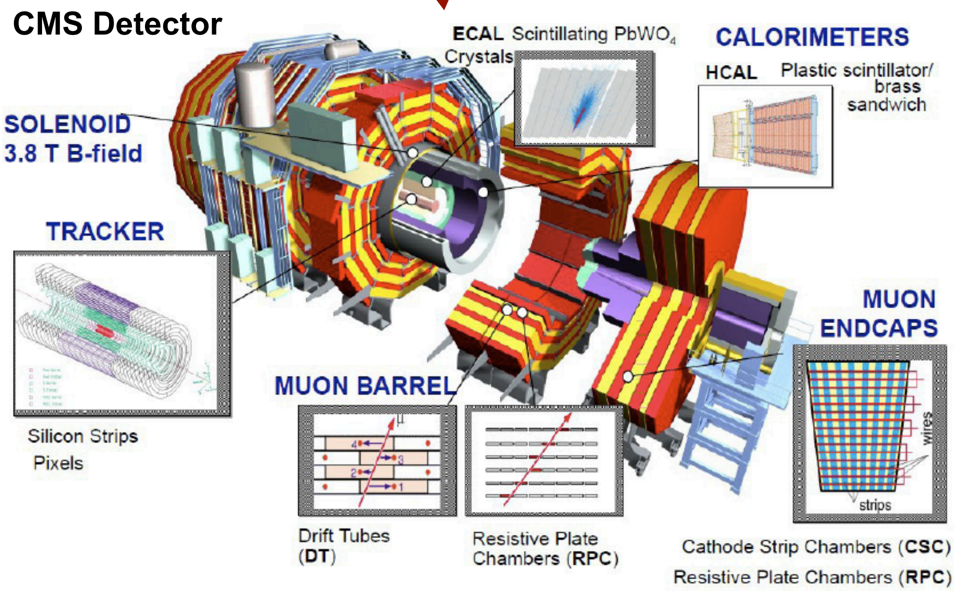


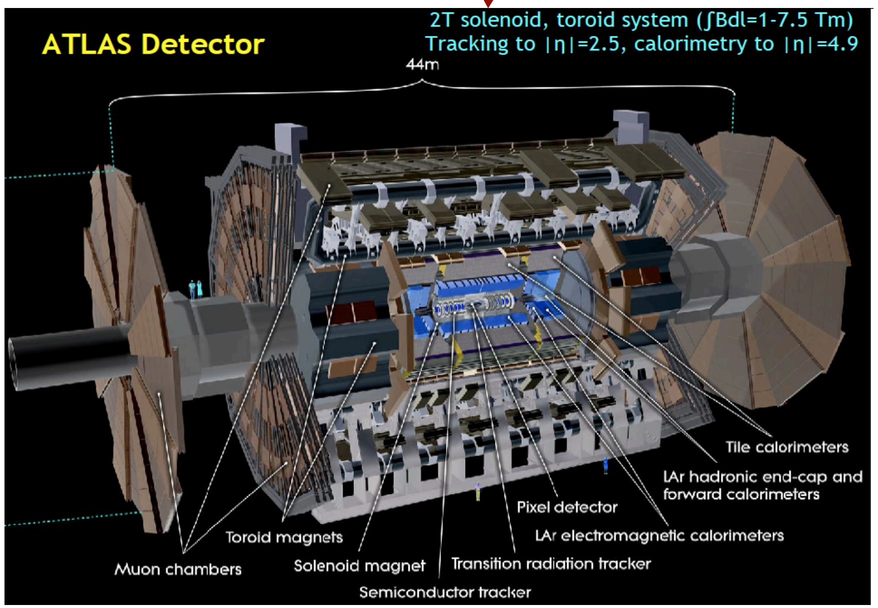


ATLAS & CMS: from Requirements & Design to Performance & Results

Translating this common set of Goals & Challenges into the designs of ATLAS and CMS was largely driven by the strategy and the choice of magnetic field configuration for the μ momentum measurement:

The different, complementary, choices of the two collaboration led to very different architectures for the ATLAS and CMS detectors





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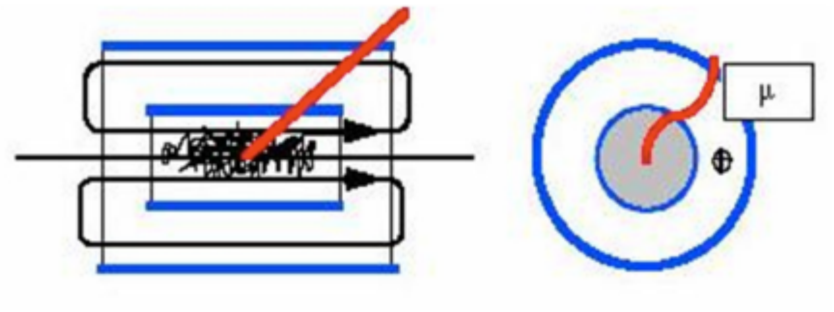
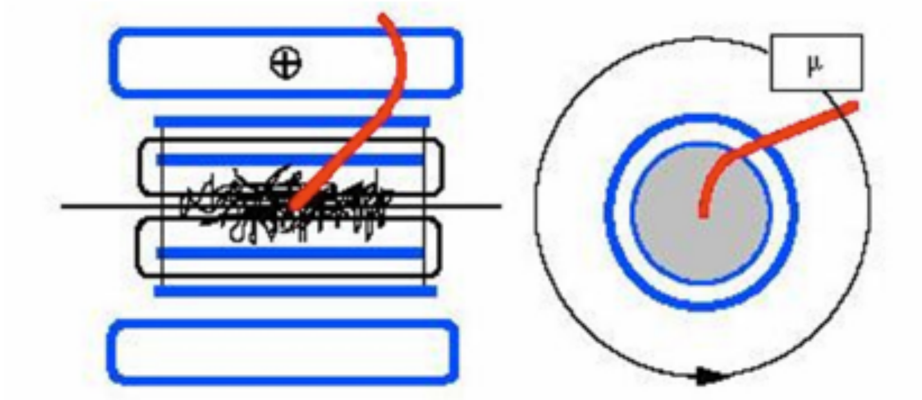
Standalone Muon System for ID & L1
Combined Inner Tracker + Muons for Precision Pt

CMS Compact Muon Solenoid



Standalone Muon System for ID, L1
AND Precision Pt

ATLAS A Toroidal LHC ApparatuS



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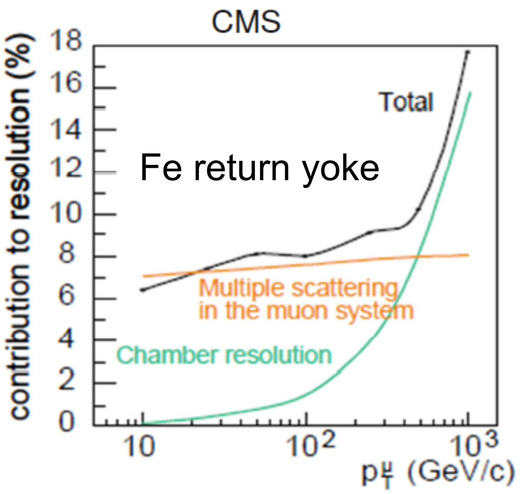

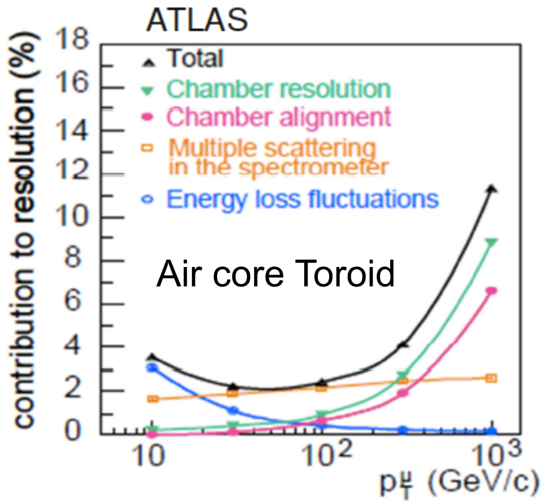

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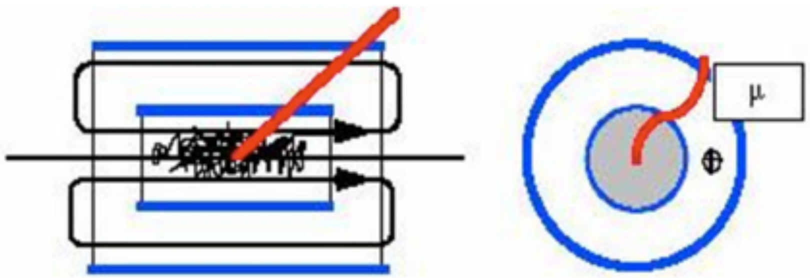
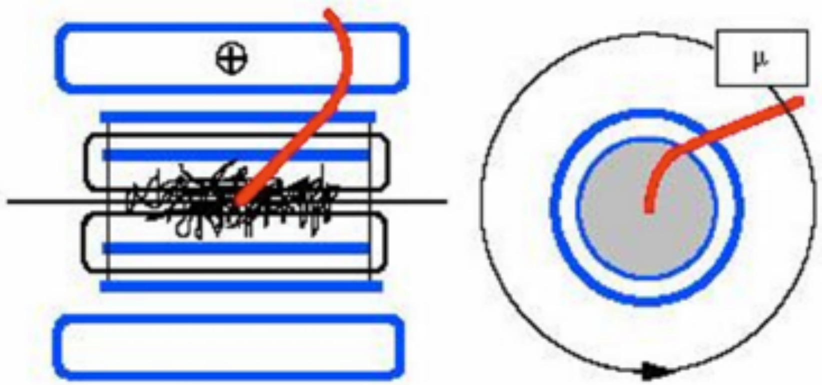
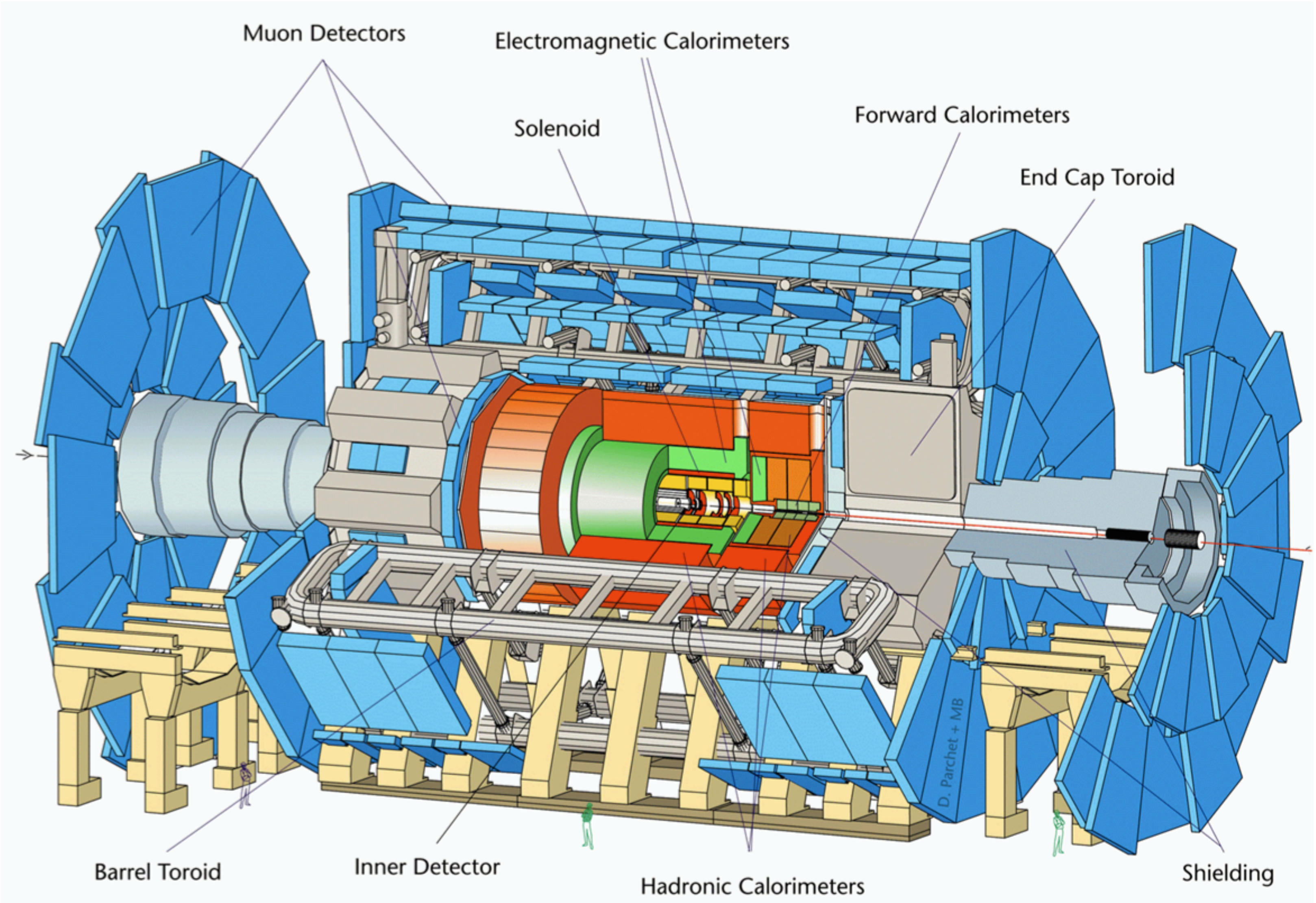


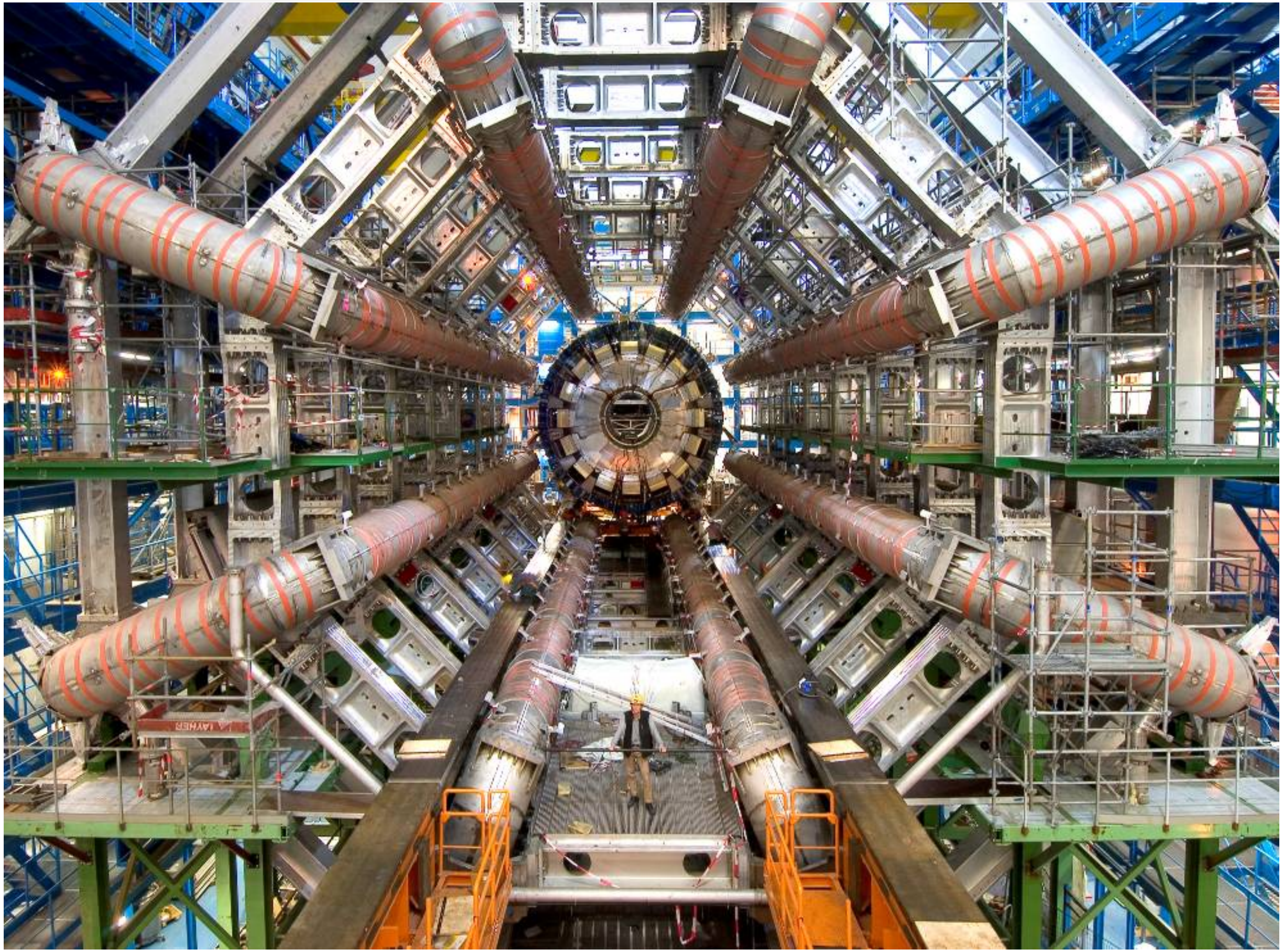
ATLAS A Toroidal LHC ApparatuS



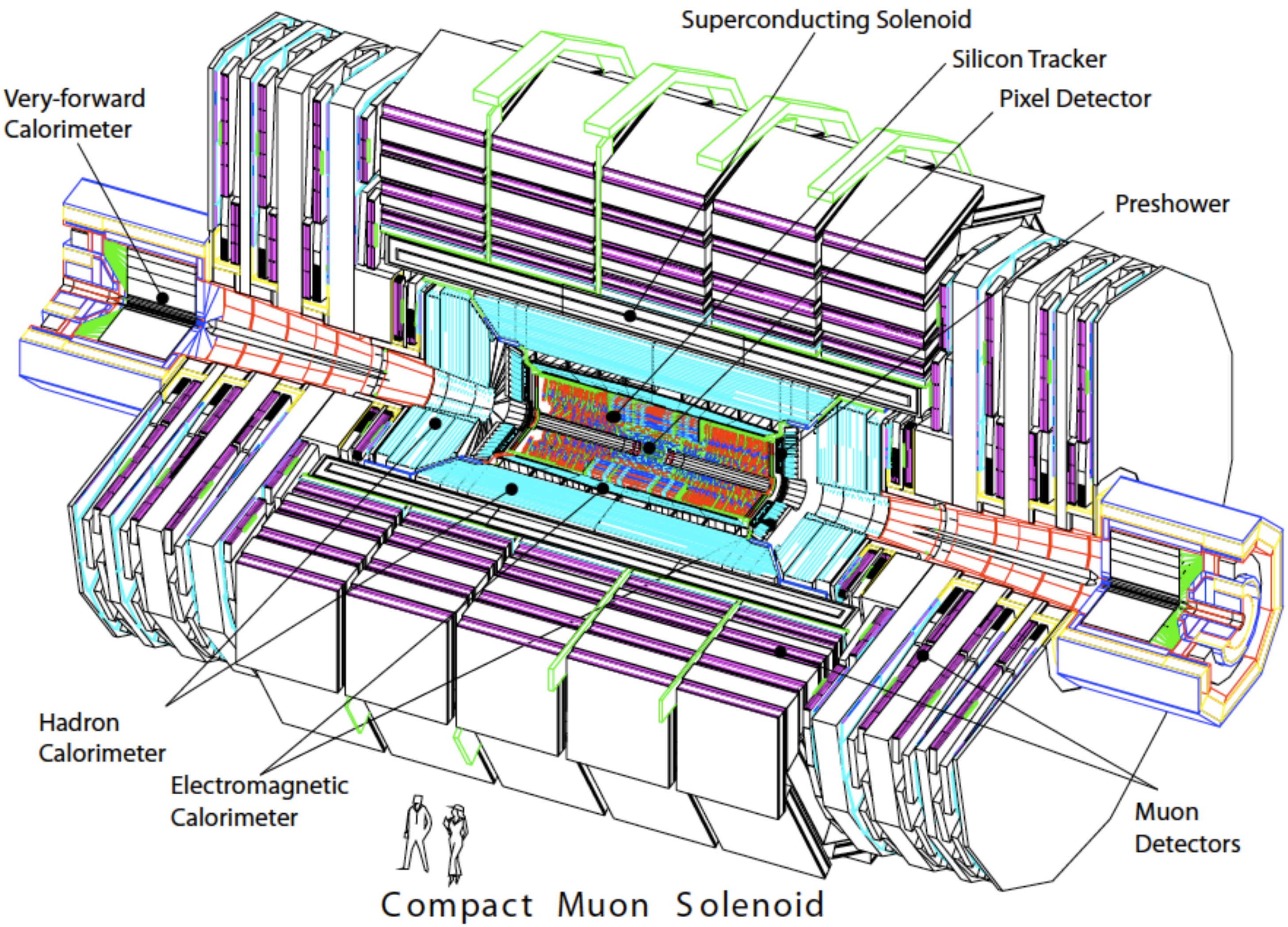
A Toroidal LHC ApparatuS



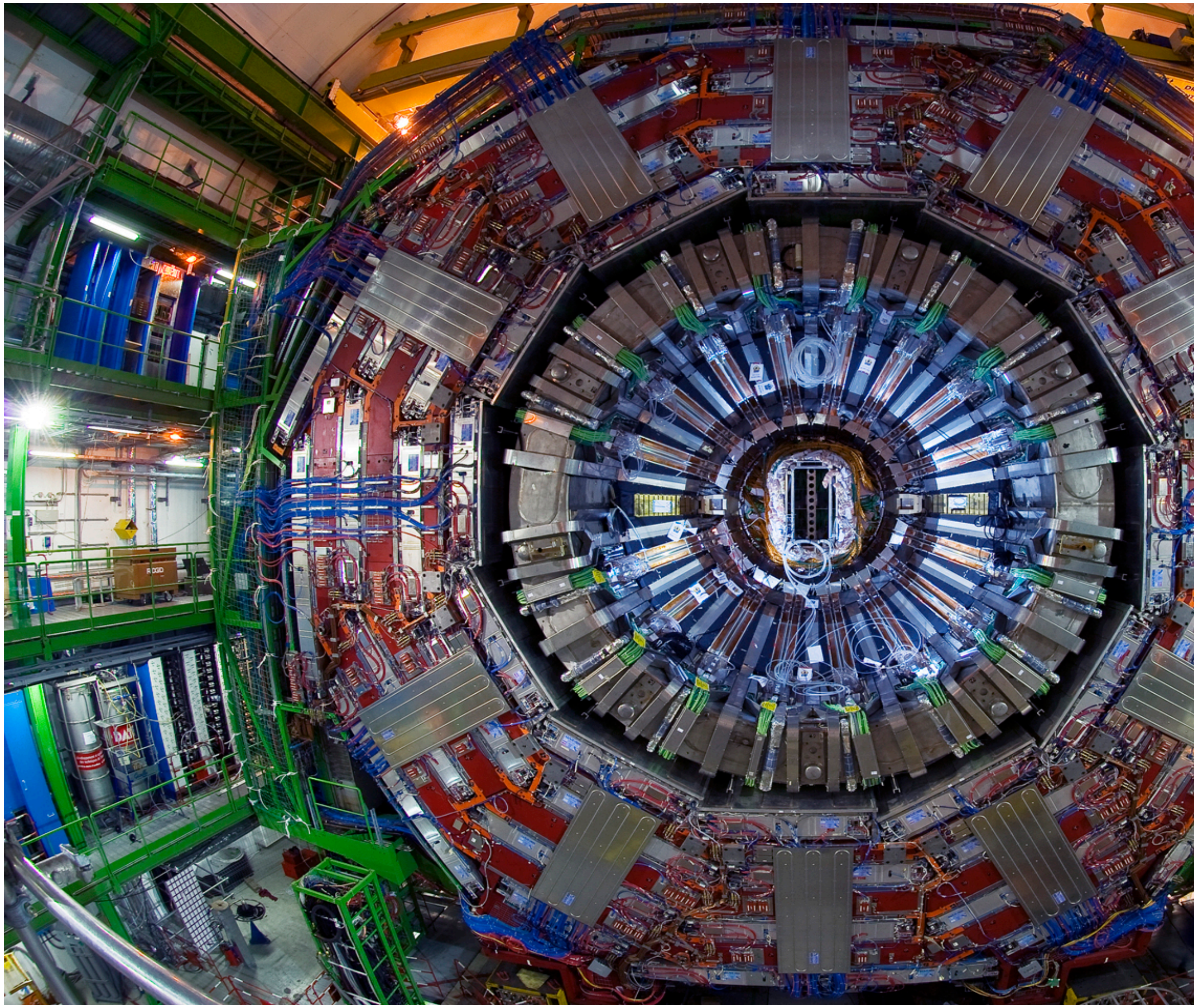
A Toroidal LHC ApparatuS

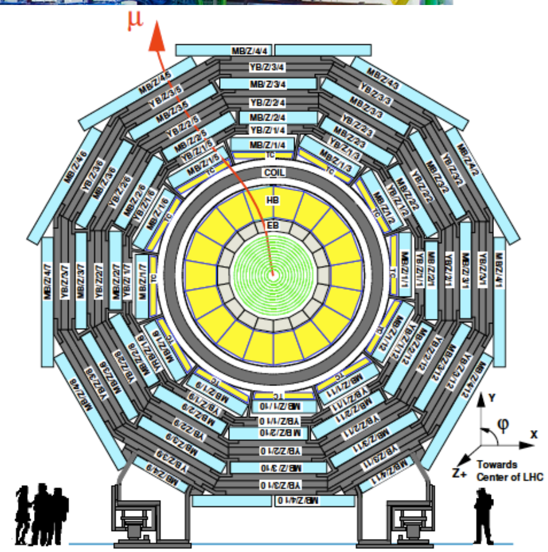


Compact Muon Solenoid

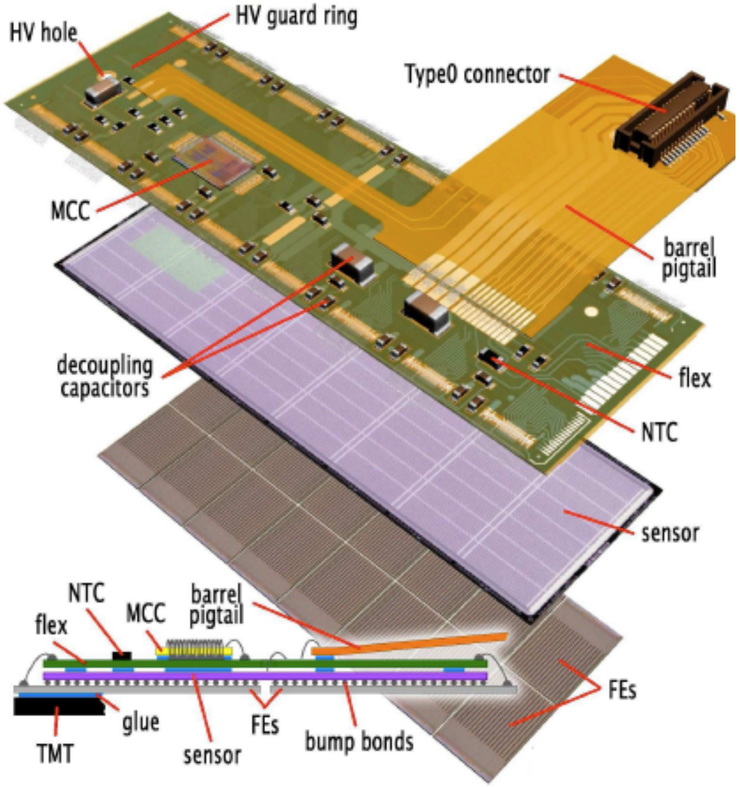


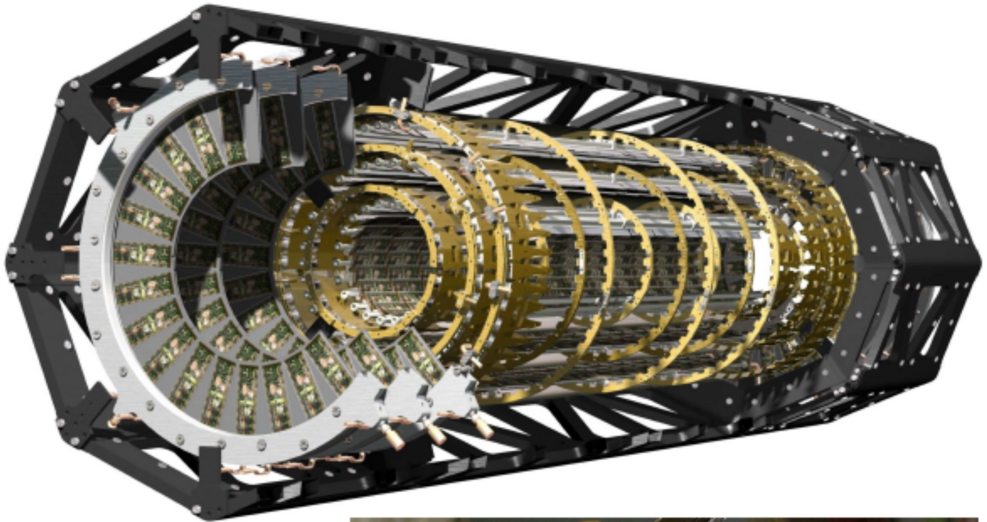
Compact Muon Solenoid

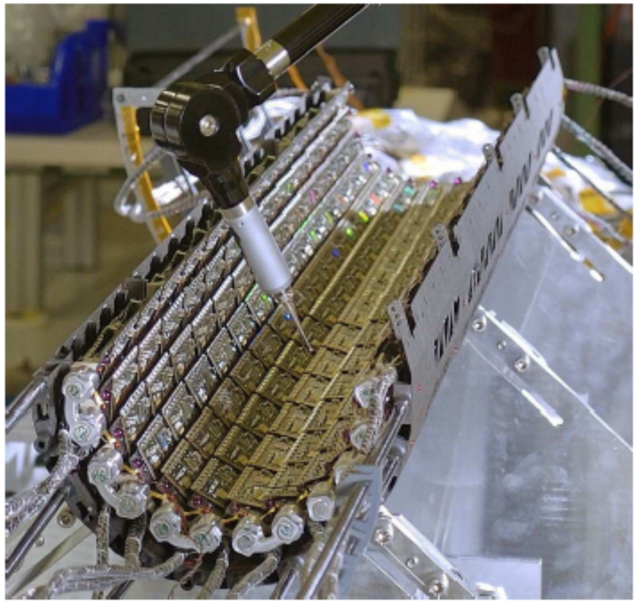




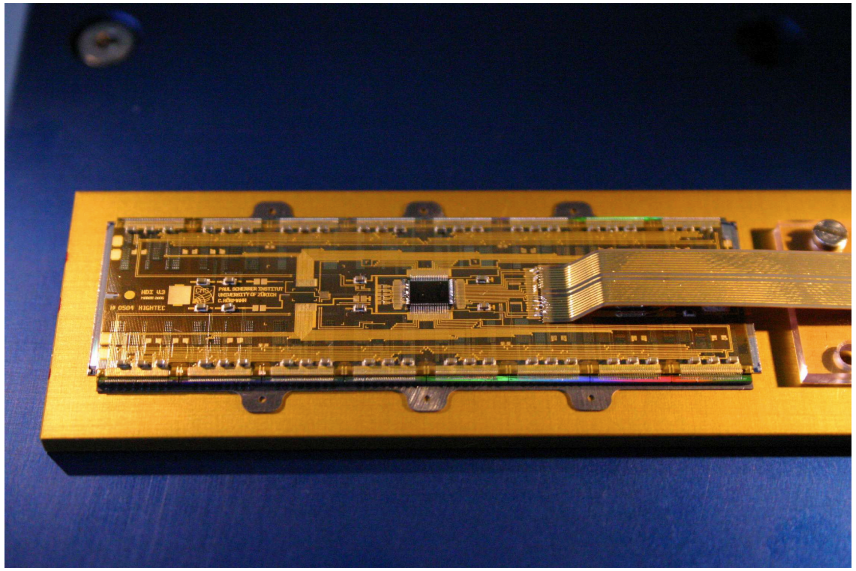
Pixel Vertex Detectors:
ATLAS

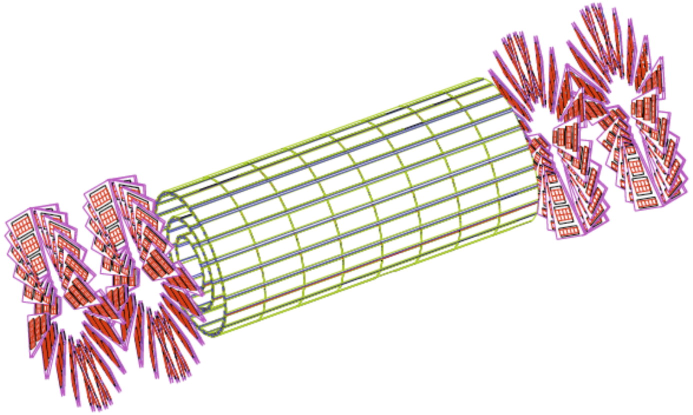


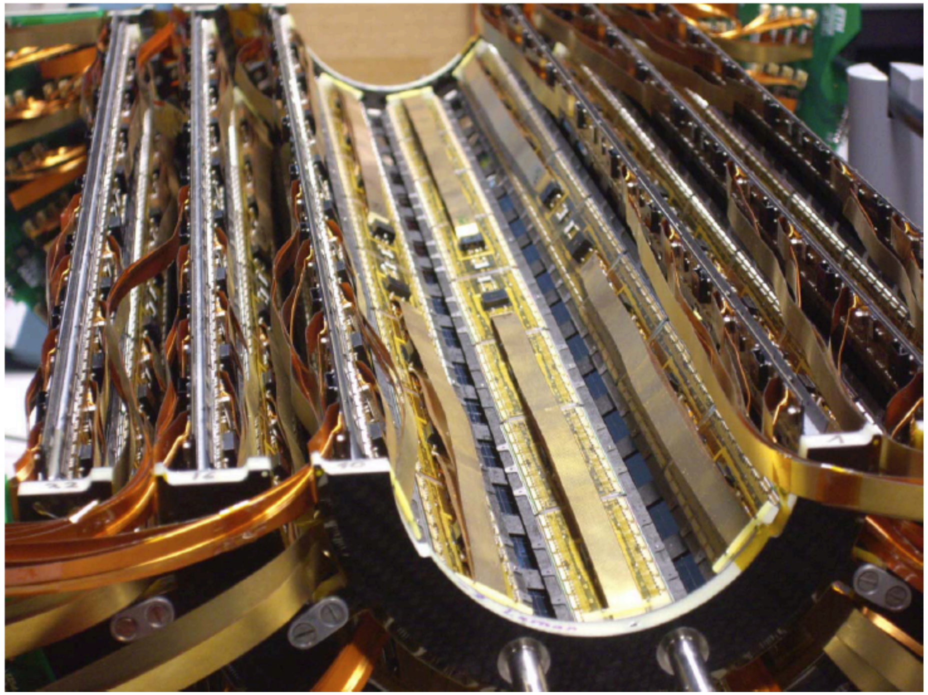




Pixel Vertex Detectors: CMS

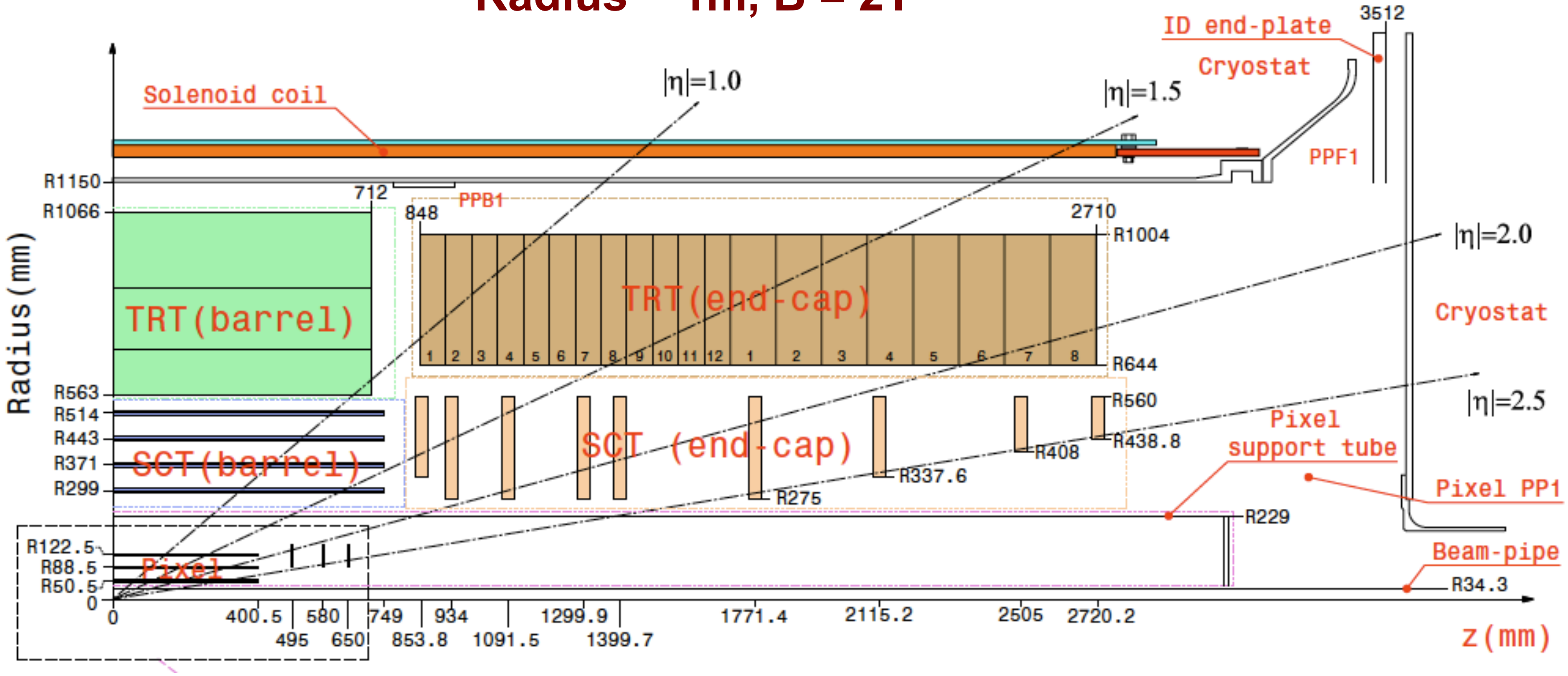






Inner Trackers:
ATLAS

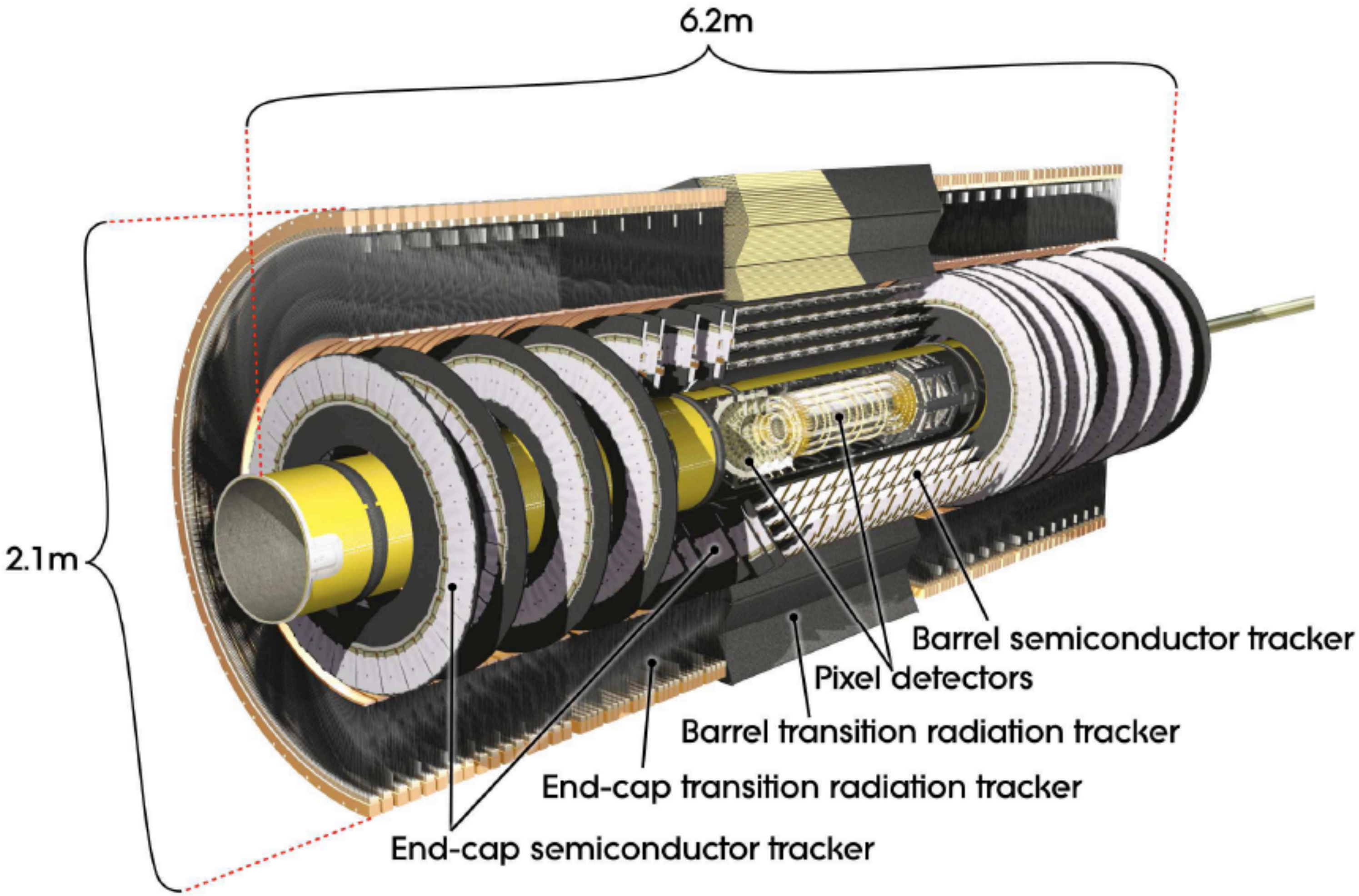
Radius ~ 1m, B = 2T



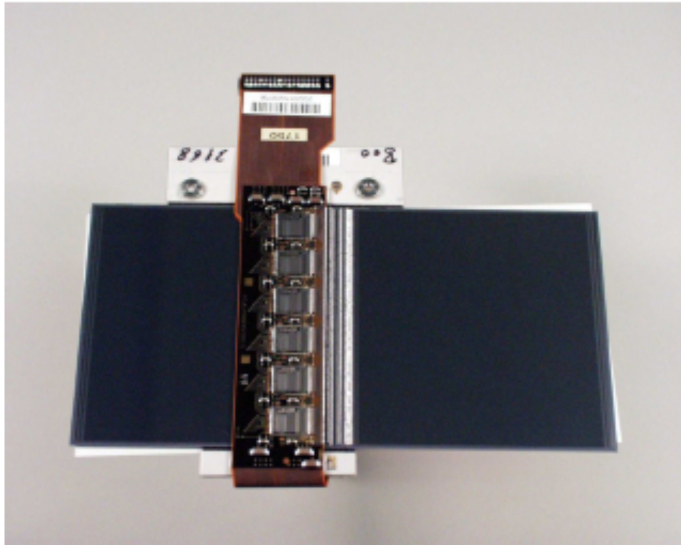
3 Vertex Pixel Layers
4 Inner Silicon Layers (Stereo)
36 TRT Hits

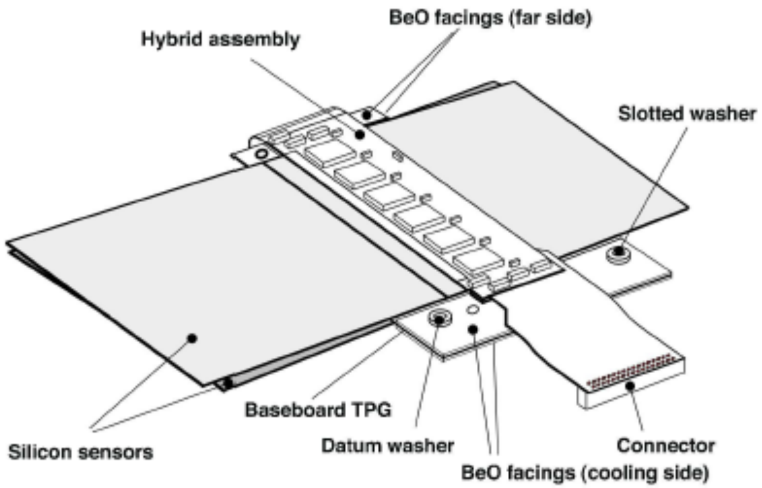
In addition to Tracking, Transition Radiation also provides e ID

Inner Trackers: ATLAS

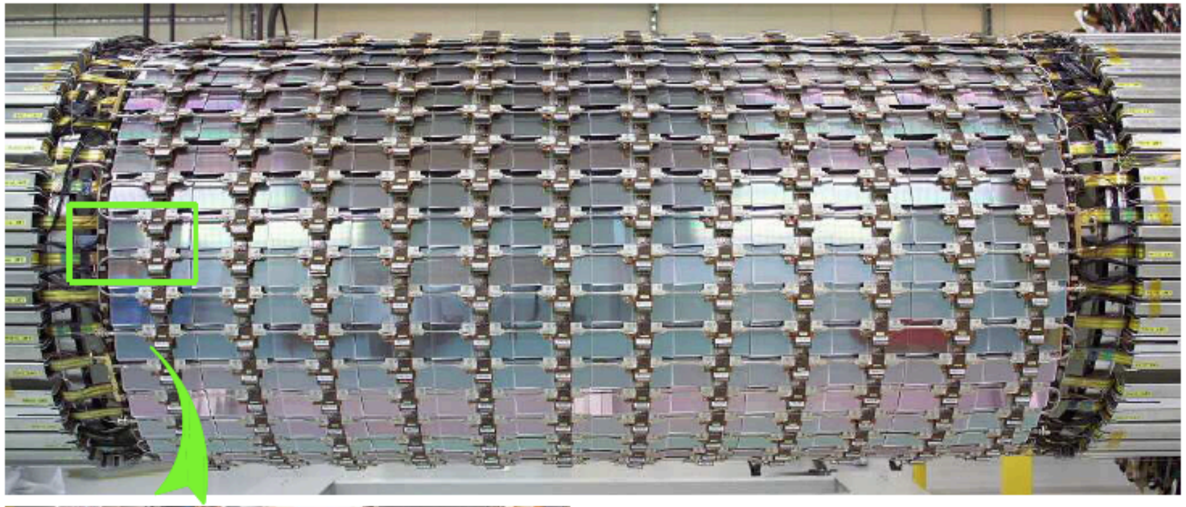


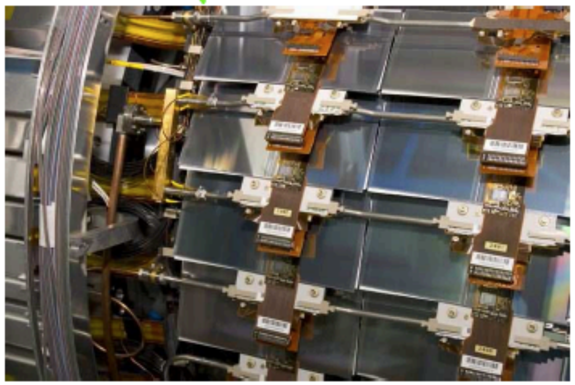
Inner Trackers: ATLAS

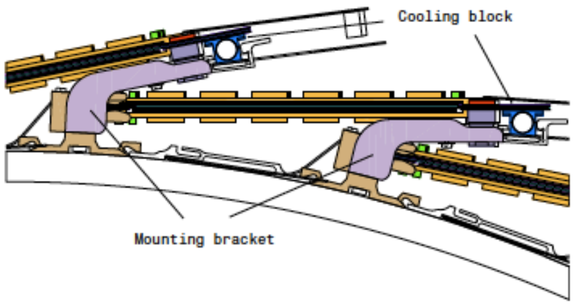


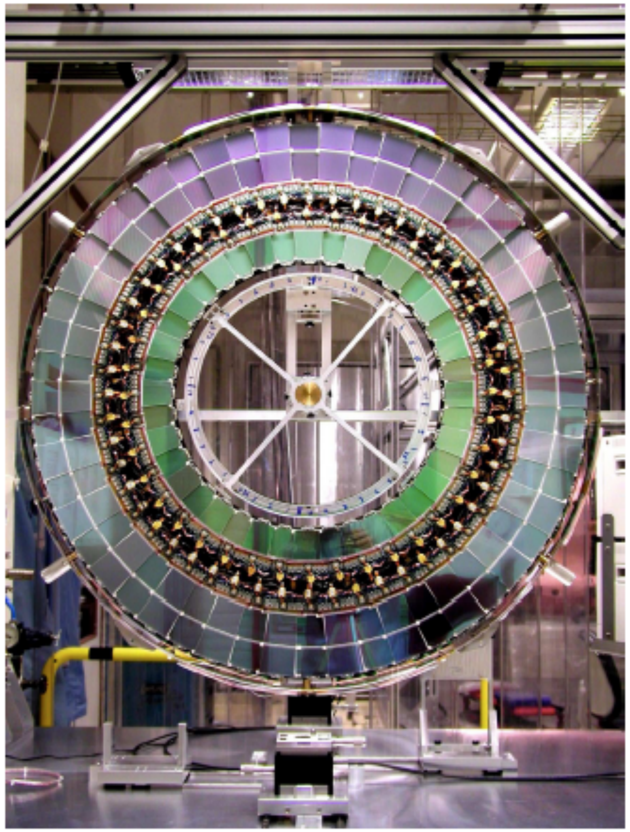


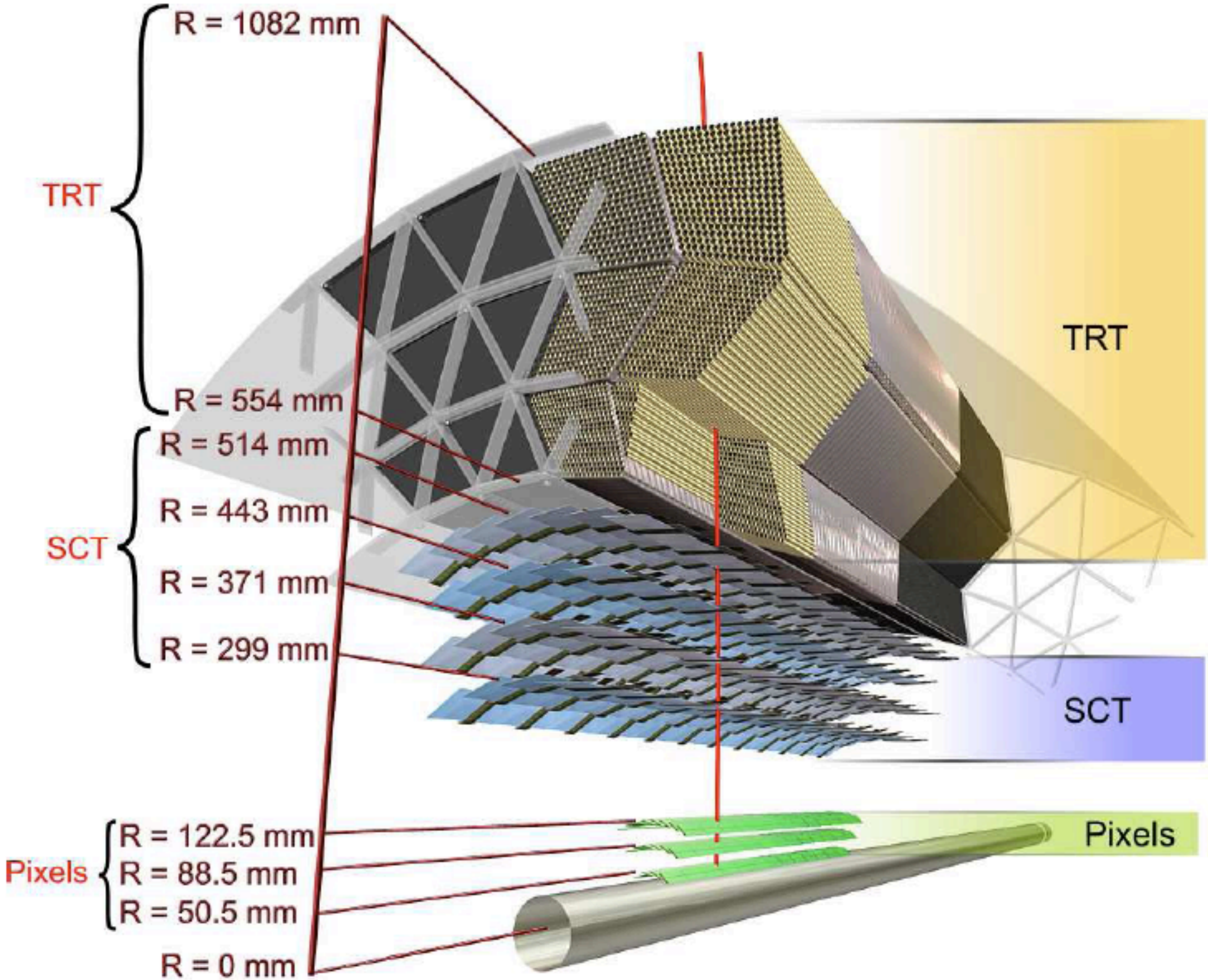
Inner Trackers: ATLAS





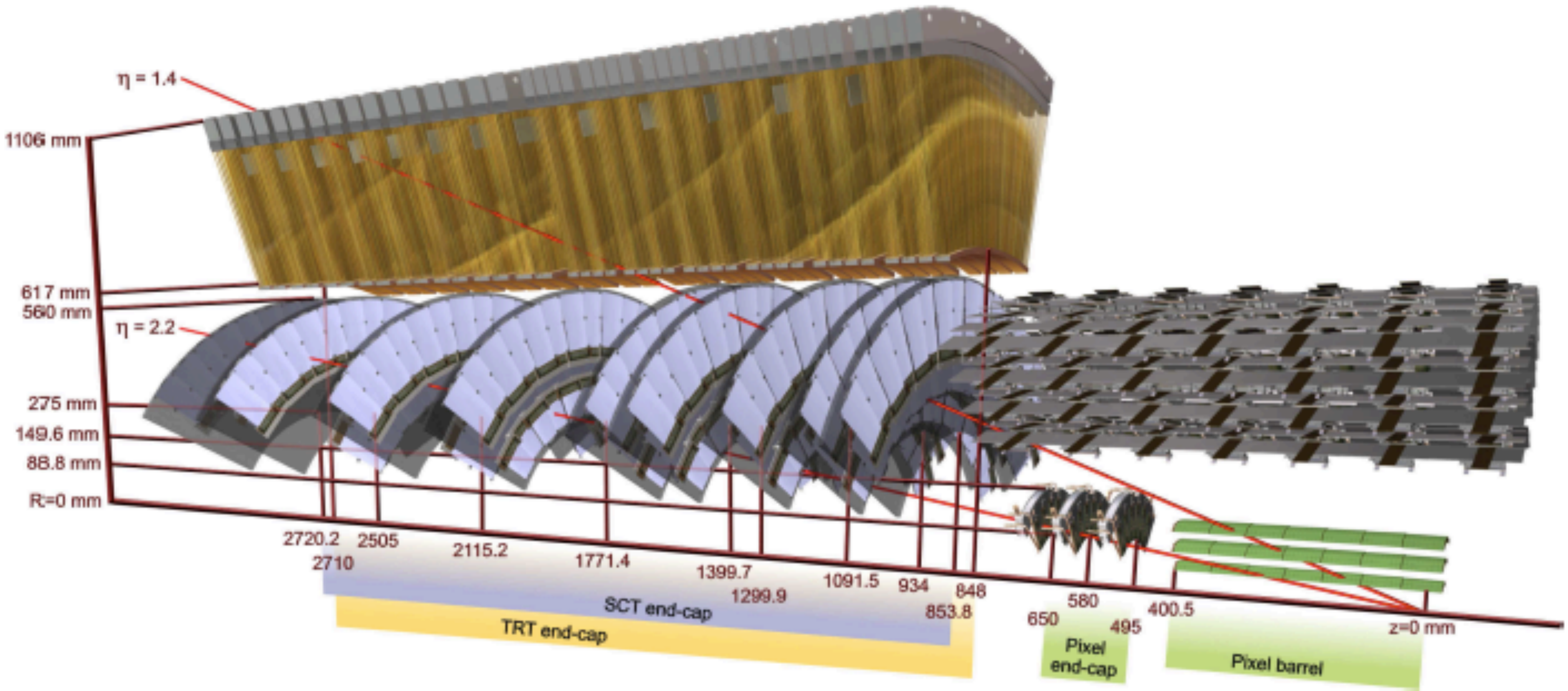




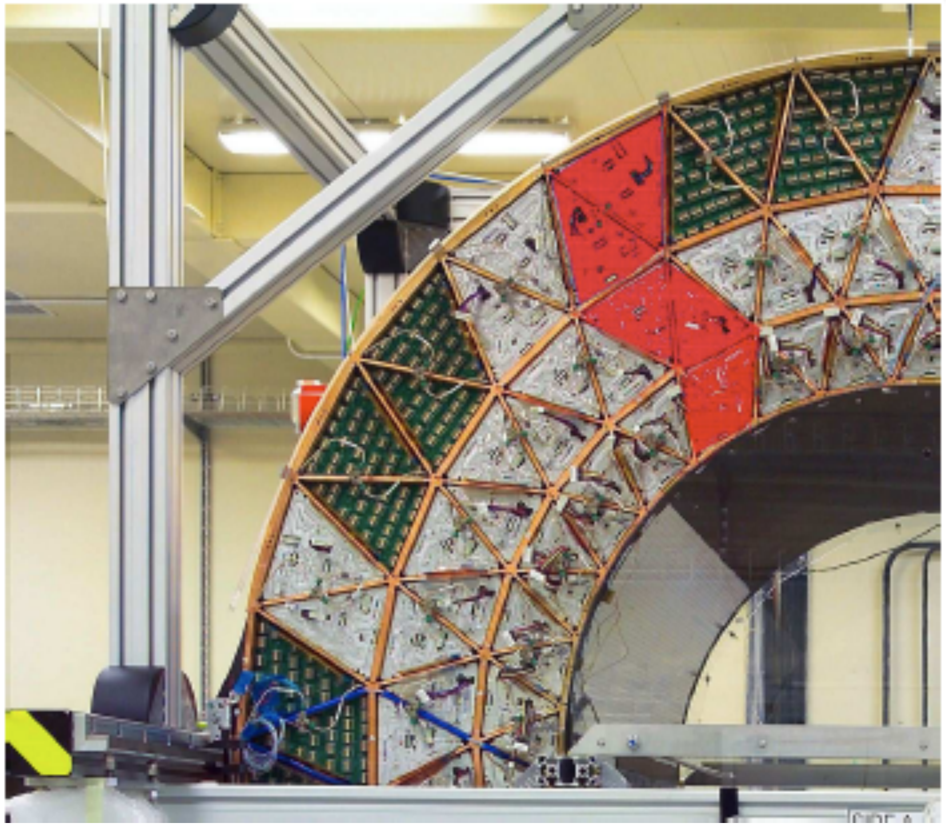


R = 1082 mm
TRT
R = 554 mm
R = 514 mm
R = 443 mm
SCT
R = 371 mm
R = 299 mm
R = 122.5 mm
Pixels
R = 88.5 mm
R = 50.5 mm
R = 0 mm
TRT
SCT
Pixels

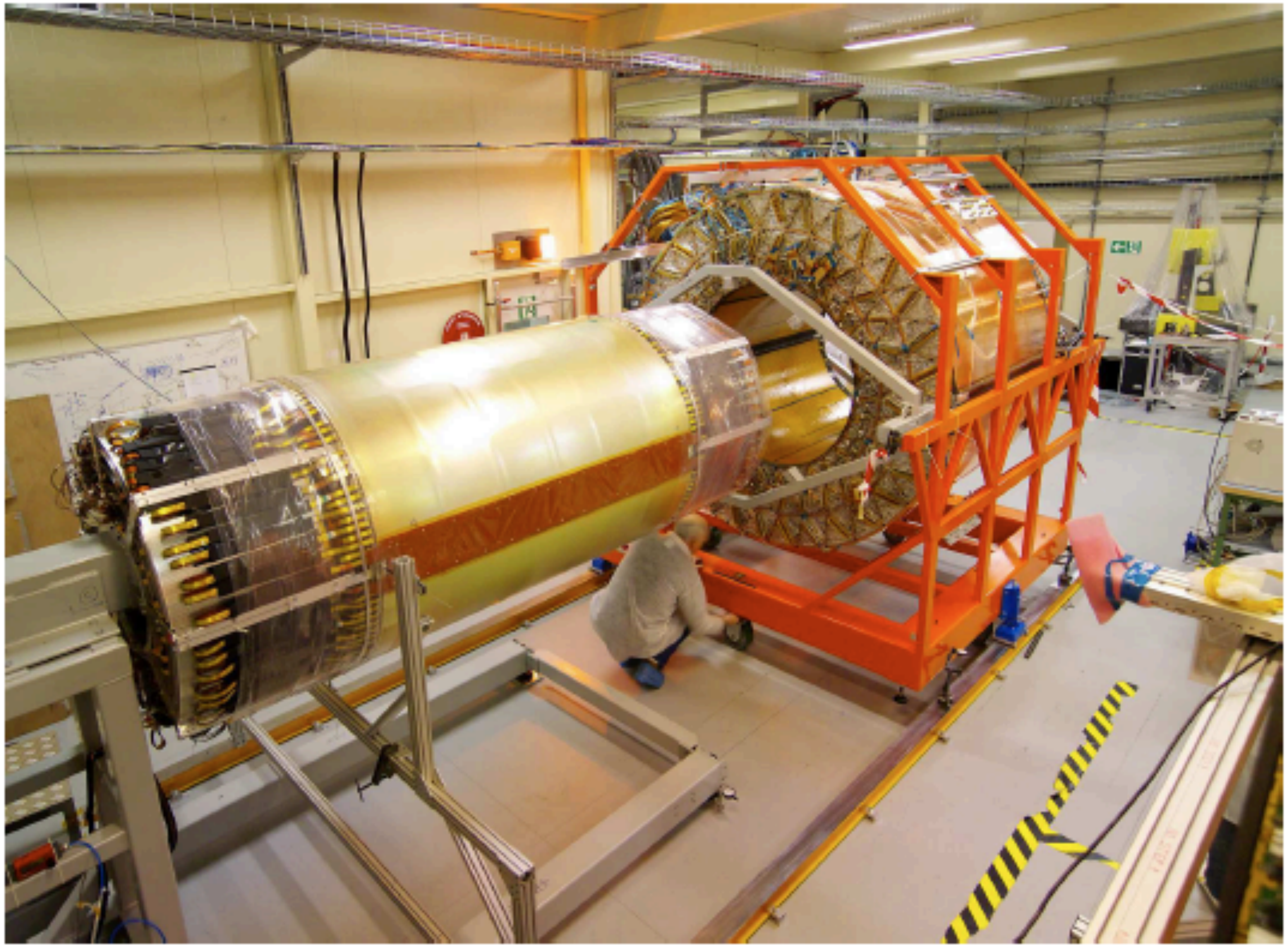
Inner Trackers: ATLAS



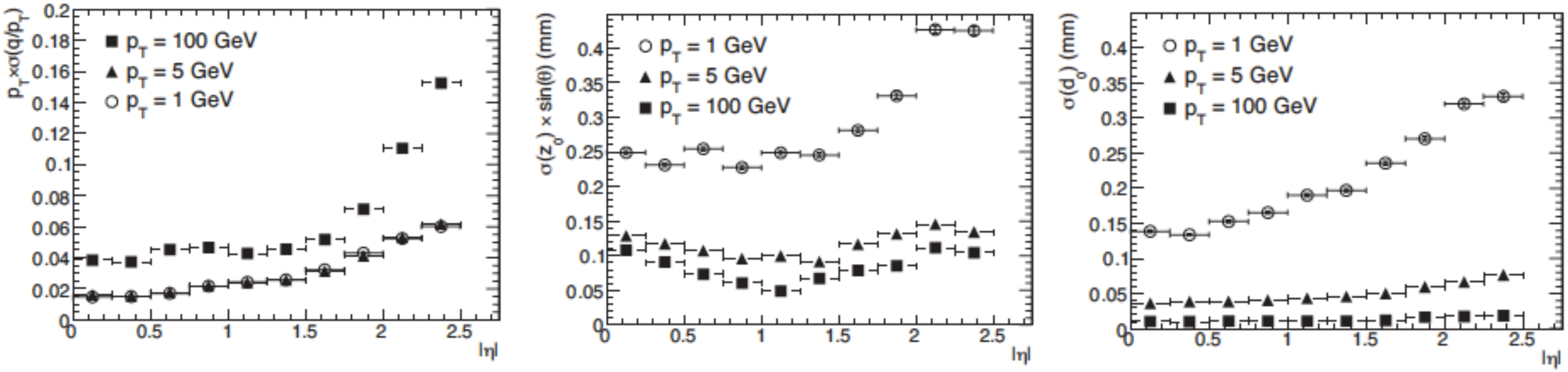
Inner Trackers:
ATLAS



Inner Trackers:
ATLAS



Inner Trackers: ATLAS



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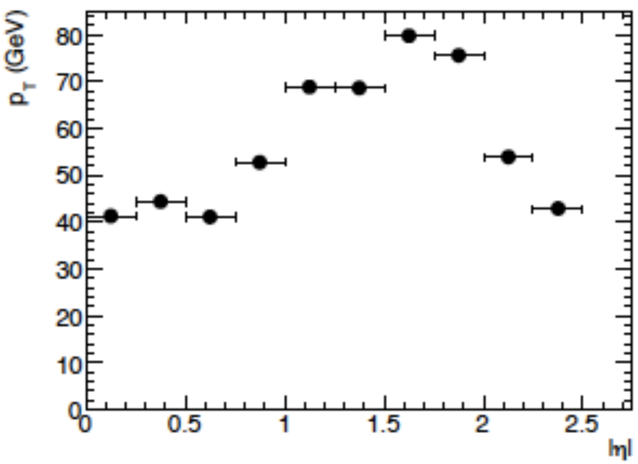
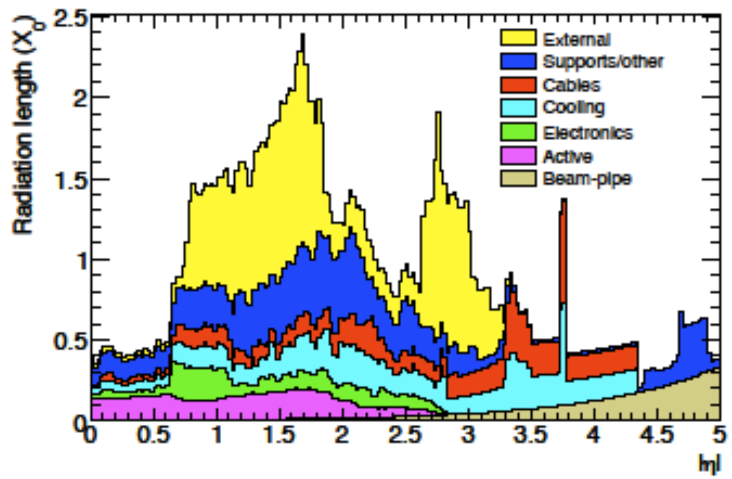
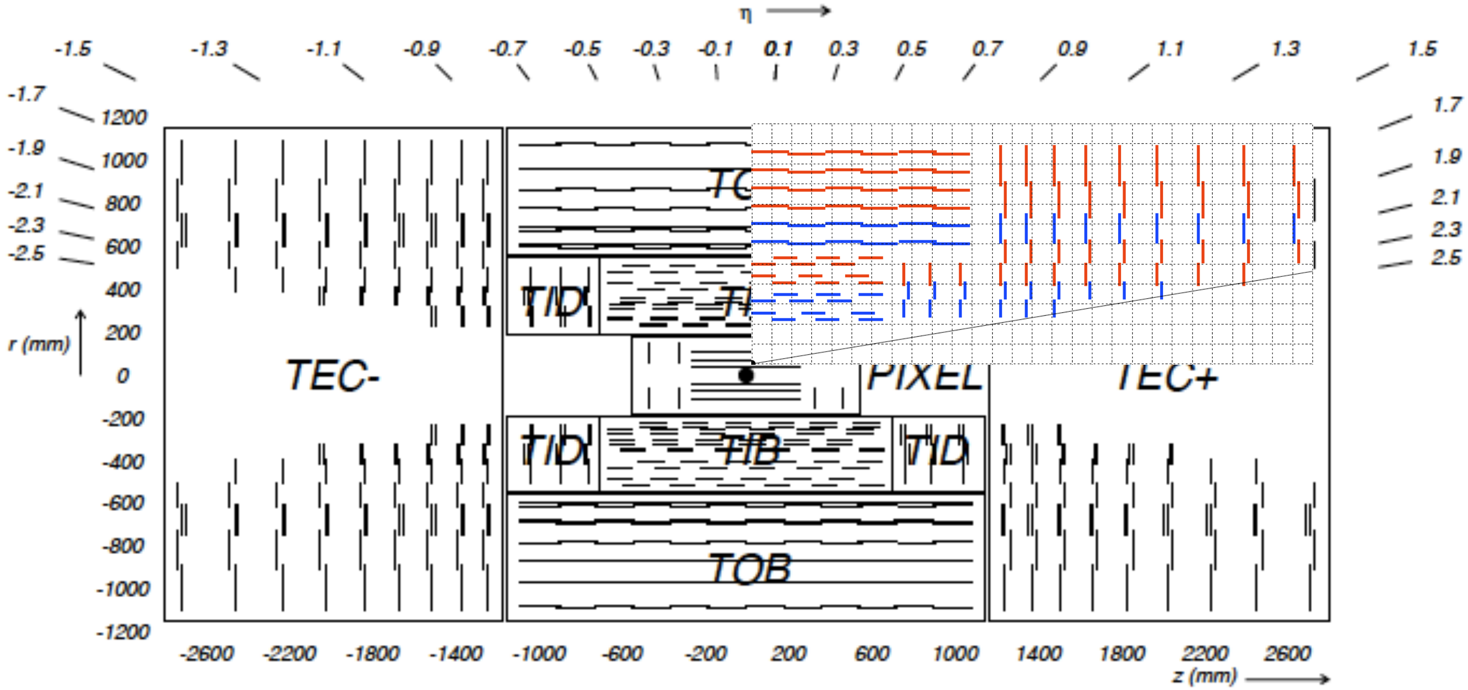




Inner Trackers:
CMS

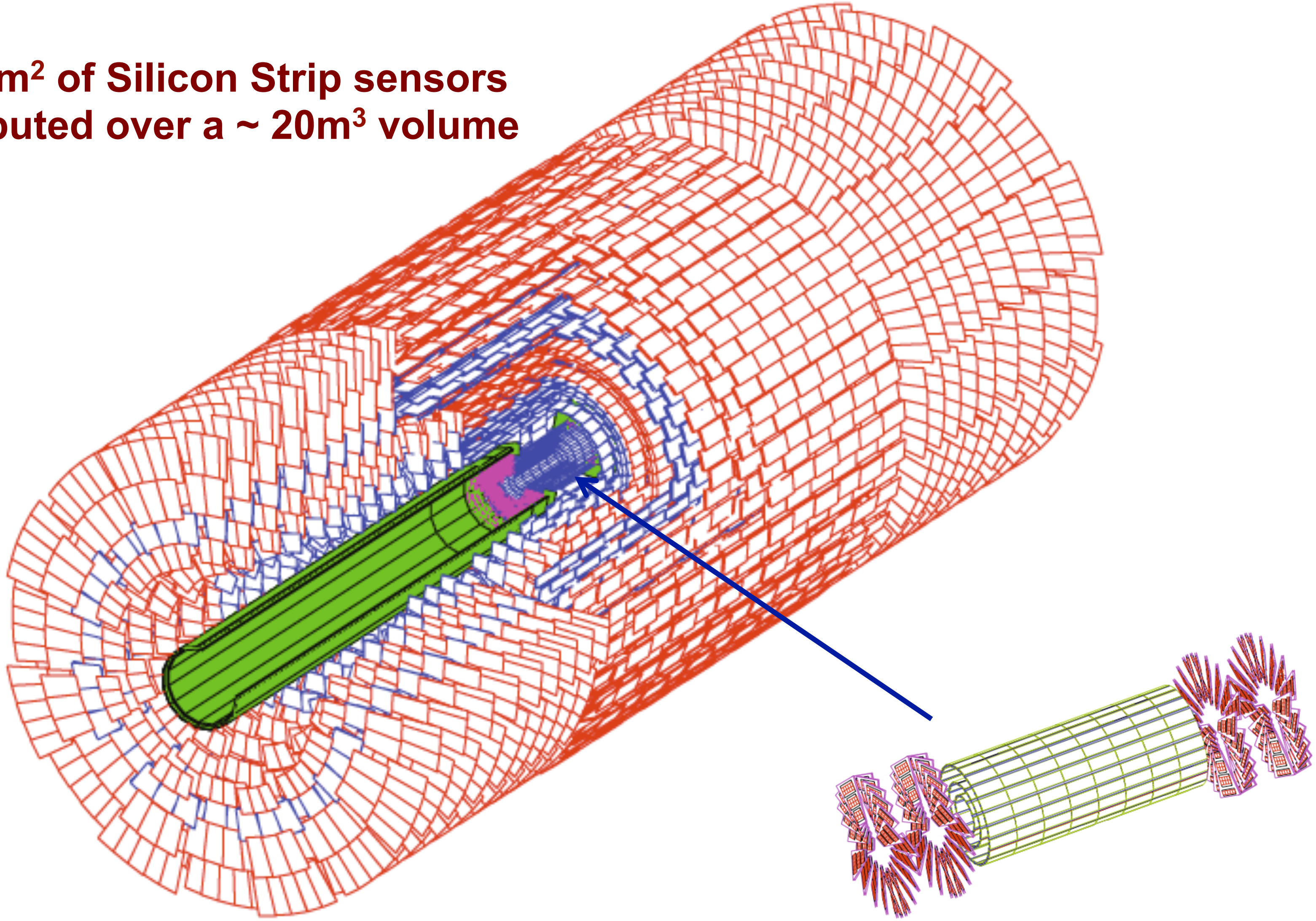
Radius ~ 1m, B = 2T



An All Silicon Tracker:
3 Vertex Pixel Layers
10 Silicon Strip Layers (4 Stereo, 6 r-phi)

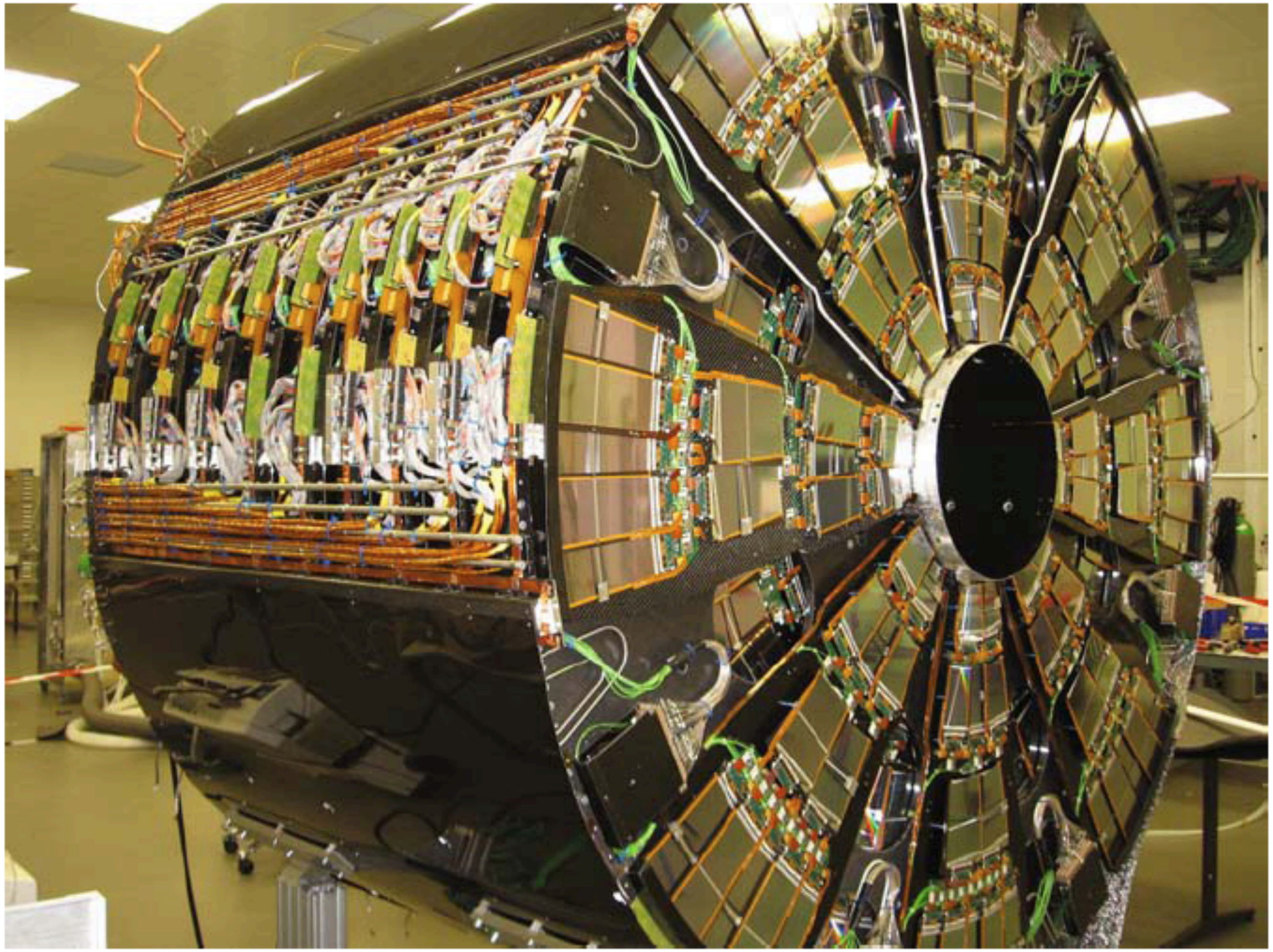
Inner Trackers: CMS

~ 210m^2 of Silicon Strip sensors
Distributed over a ~ 20m^3 volume

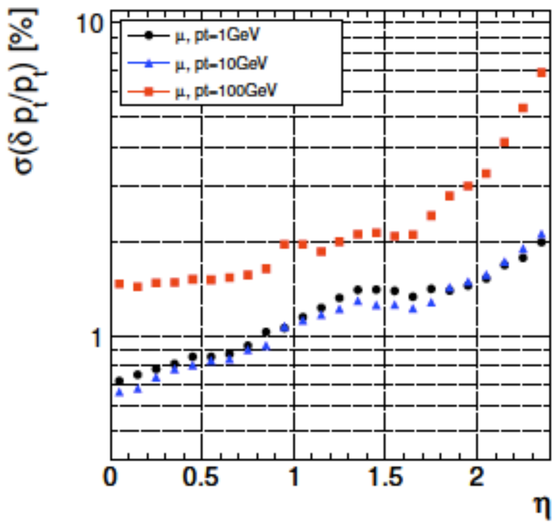


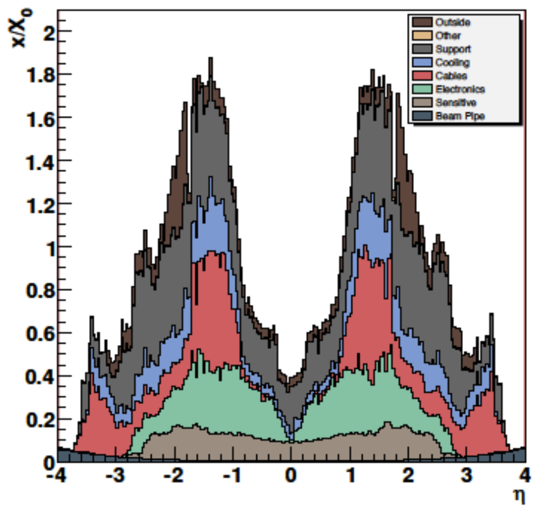
Inner Trackers:
CMS

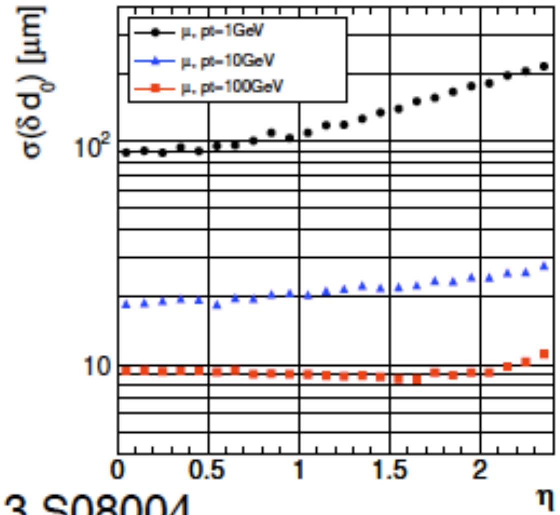
Inner Trackers: CMS

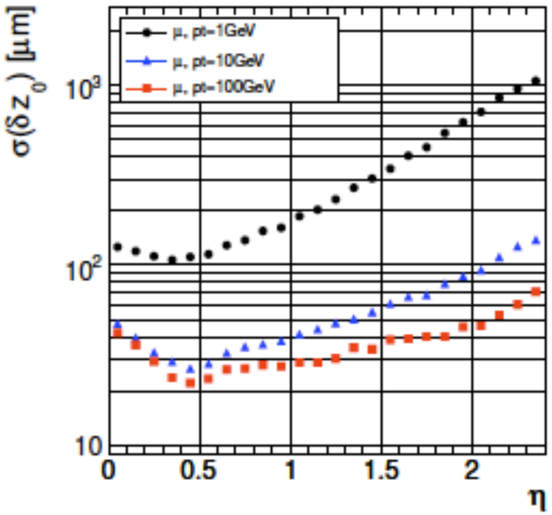


Inner Trackers: CMS









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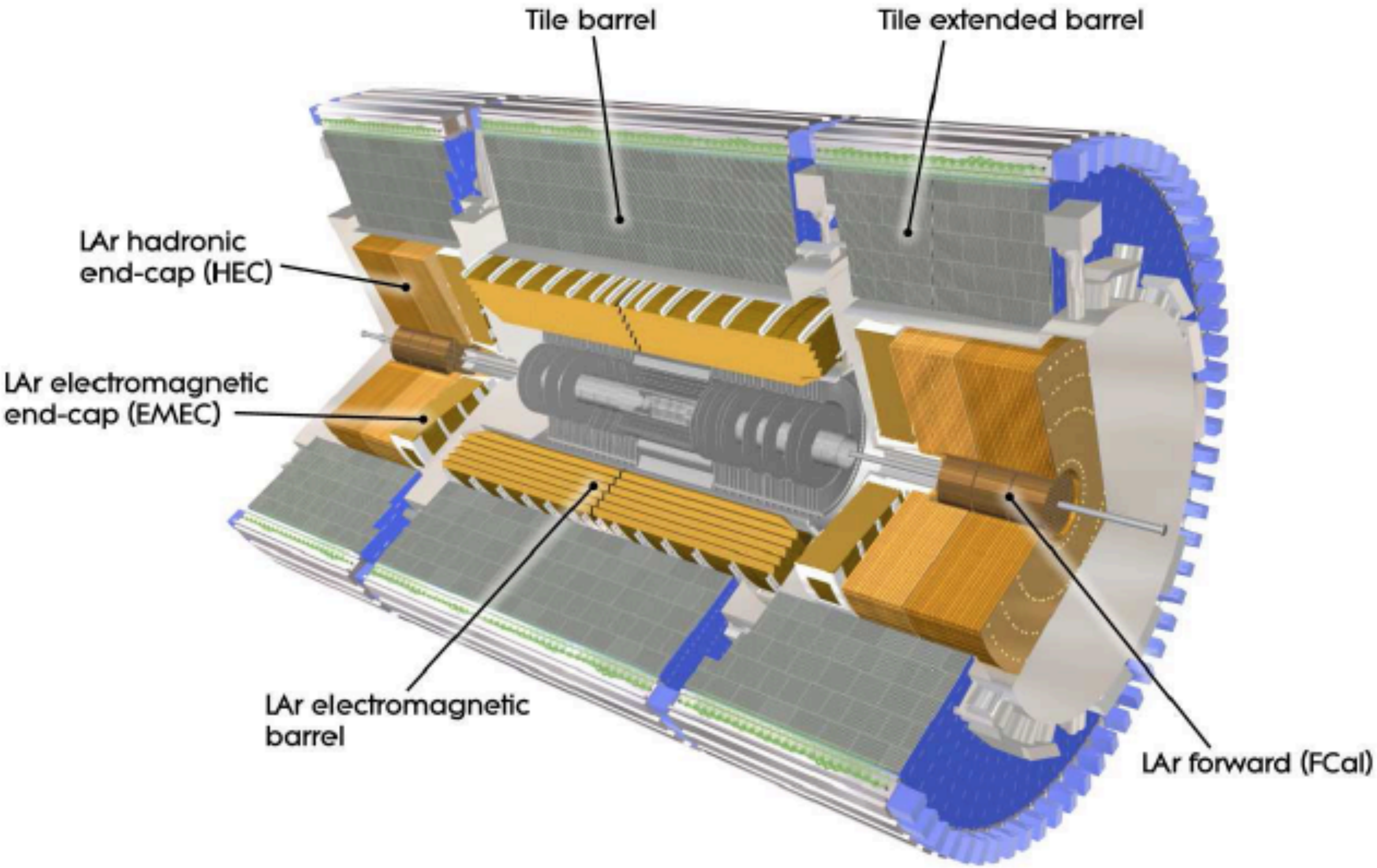
Calorimeters: ATLAS

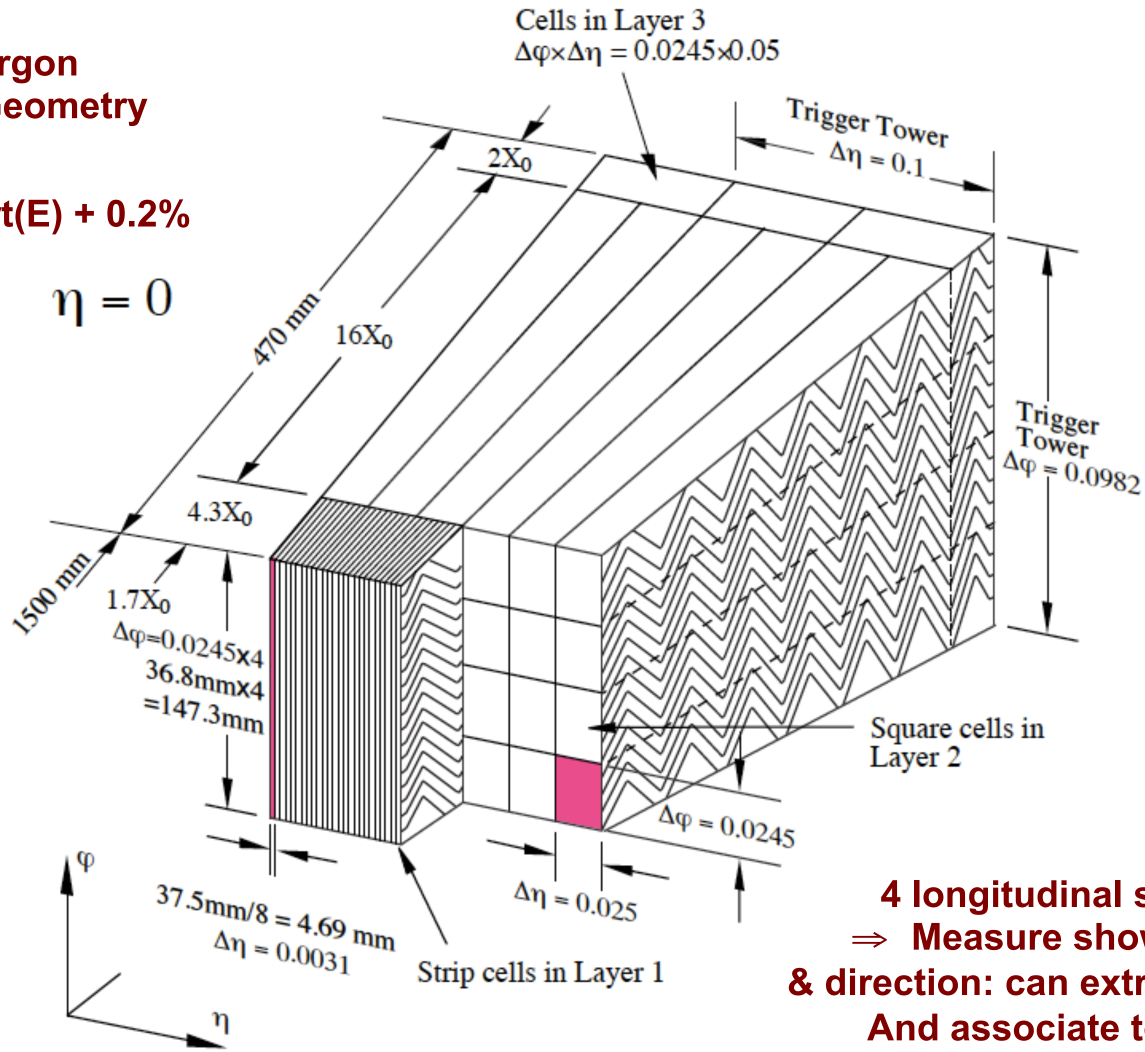


Calorimeters:
ATLAS ECAL

Liquid Argon
Accordion Geometry

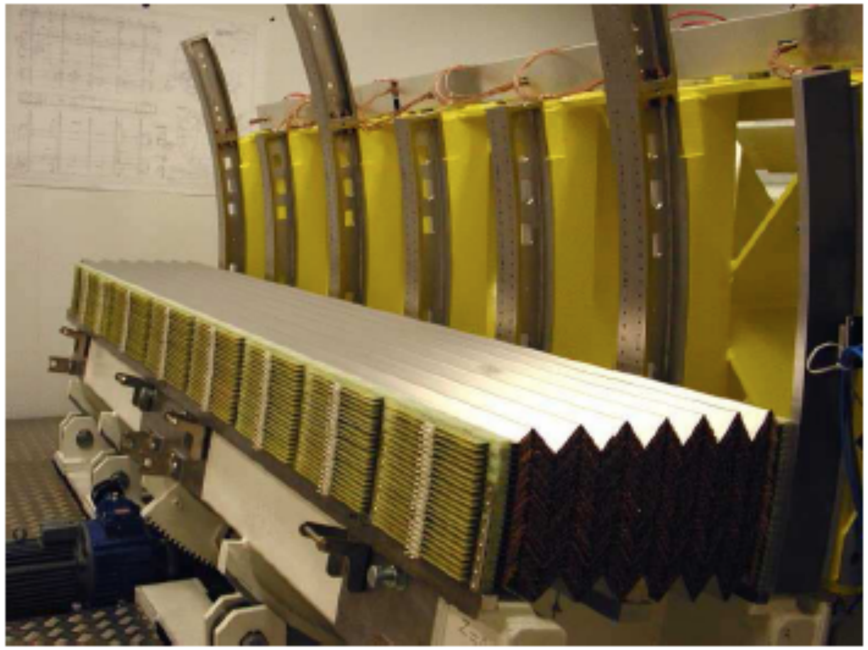
$\delta E/E \sim 10\%/\mathrm{sqrt}(E) + 0.2\%$

$\eta = 0$



4 longitudinal sampling layers
⇒ Measure shower development
& direction: can extrapolate to beam line
And associate to a given vertex

Calorimeters:
ATLAS



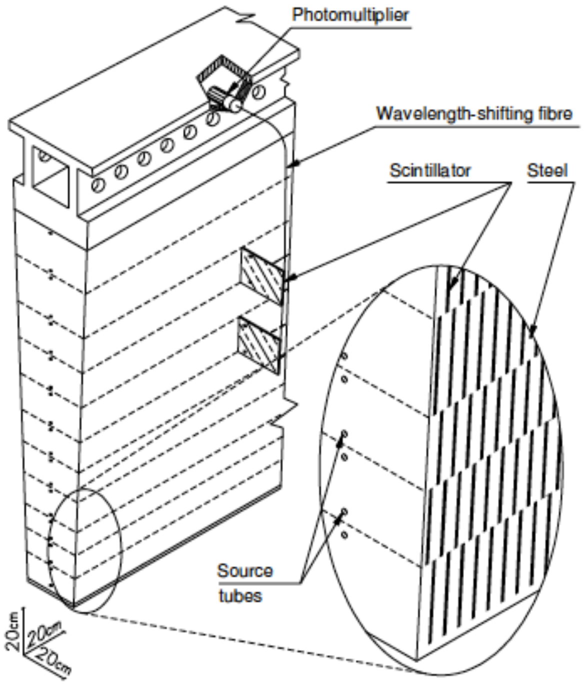
Barrel Module
Under construction

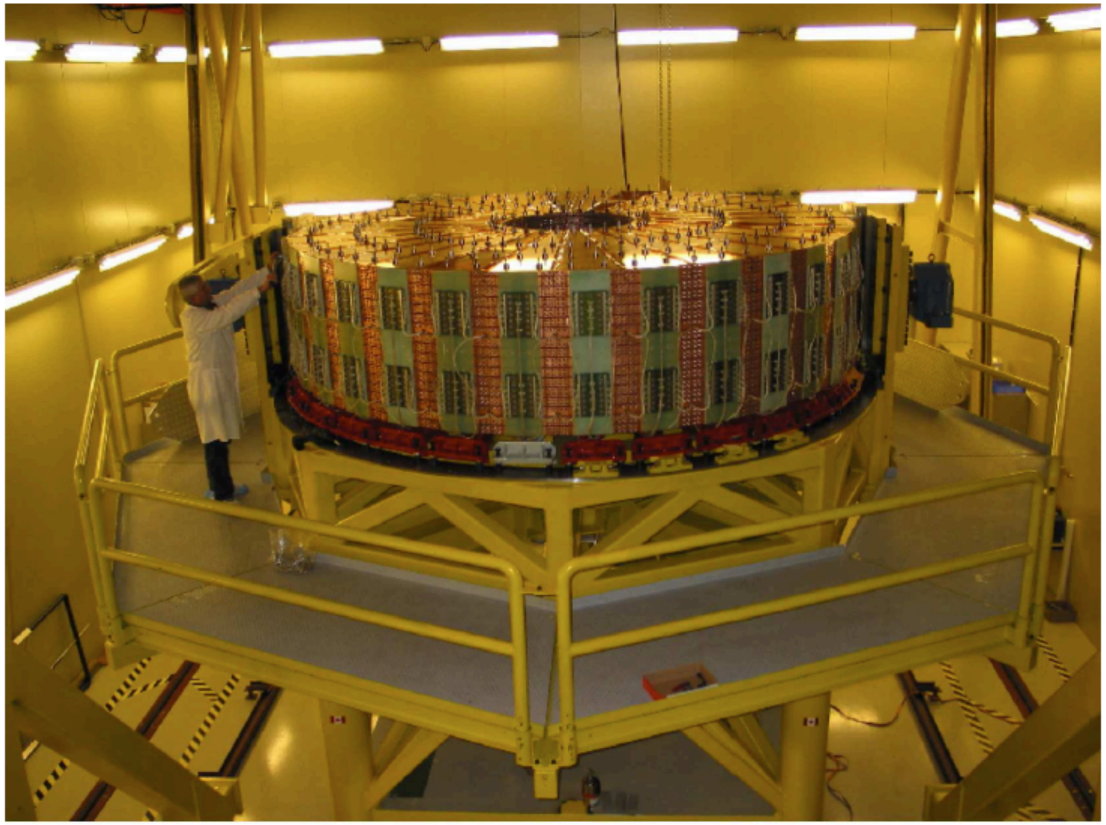
End-Cap Module

Calorimeters:
ATLAS HCAL

Tile Barrel Module

$\delta E/E \sim 55\%/\mathrm{sqrt}(E) + 6\%$

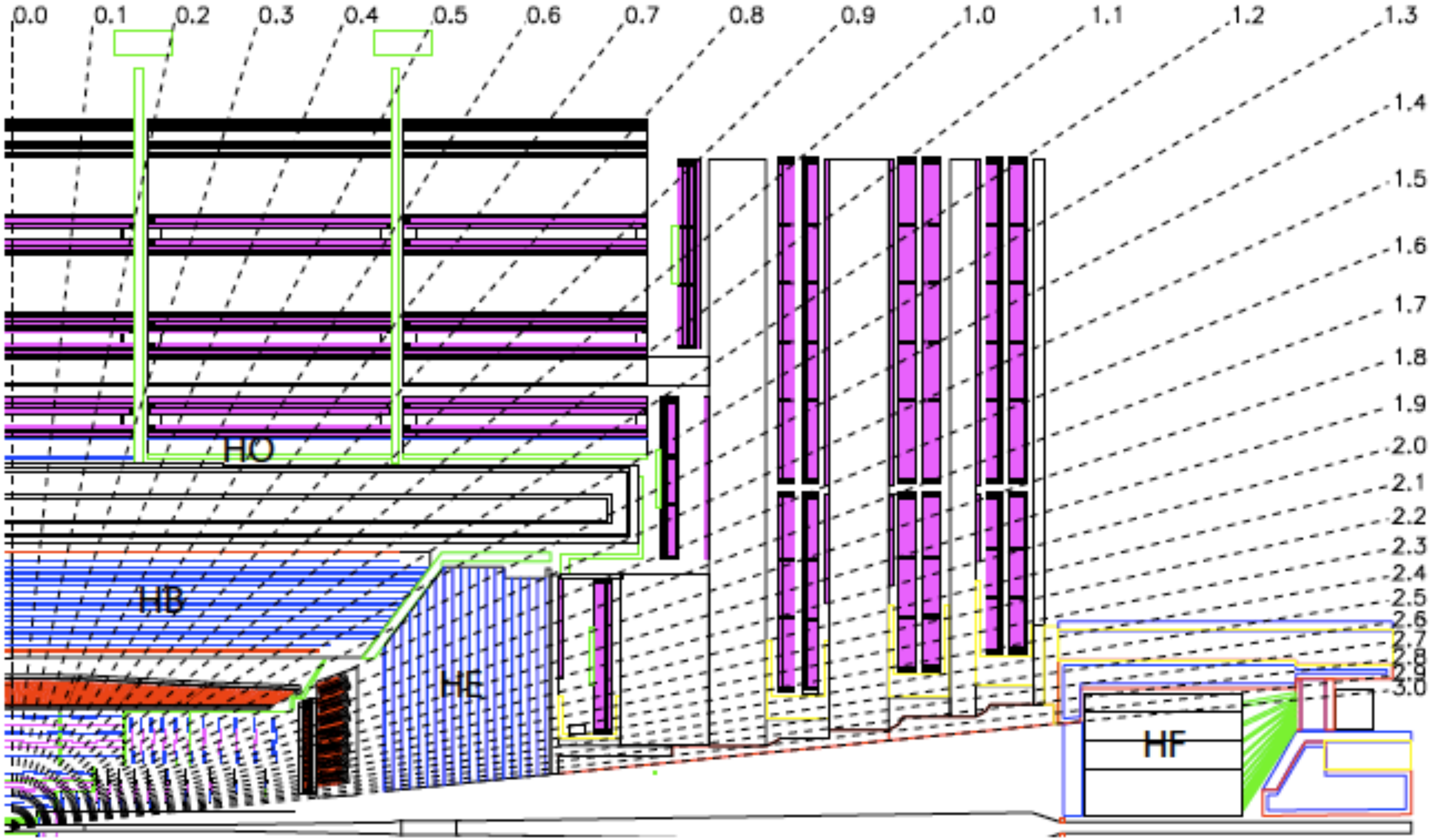




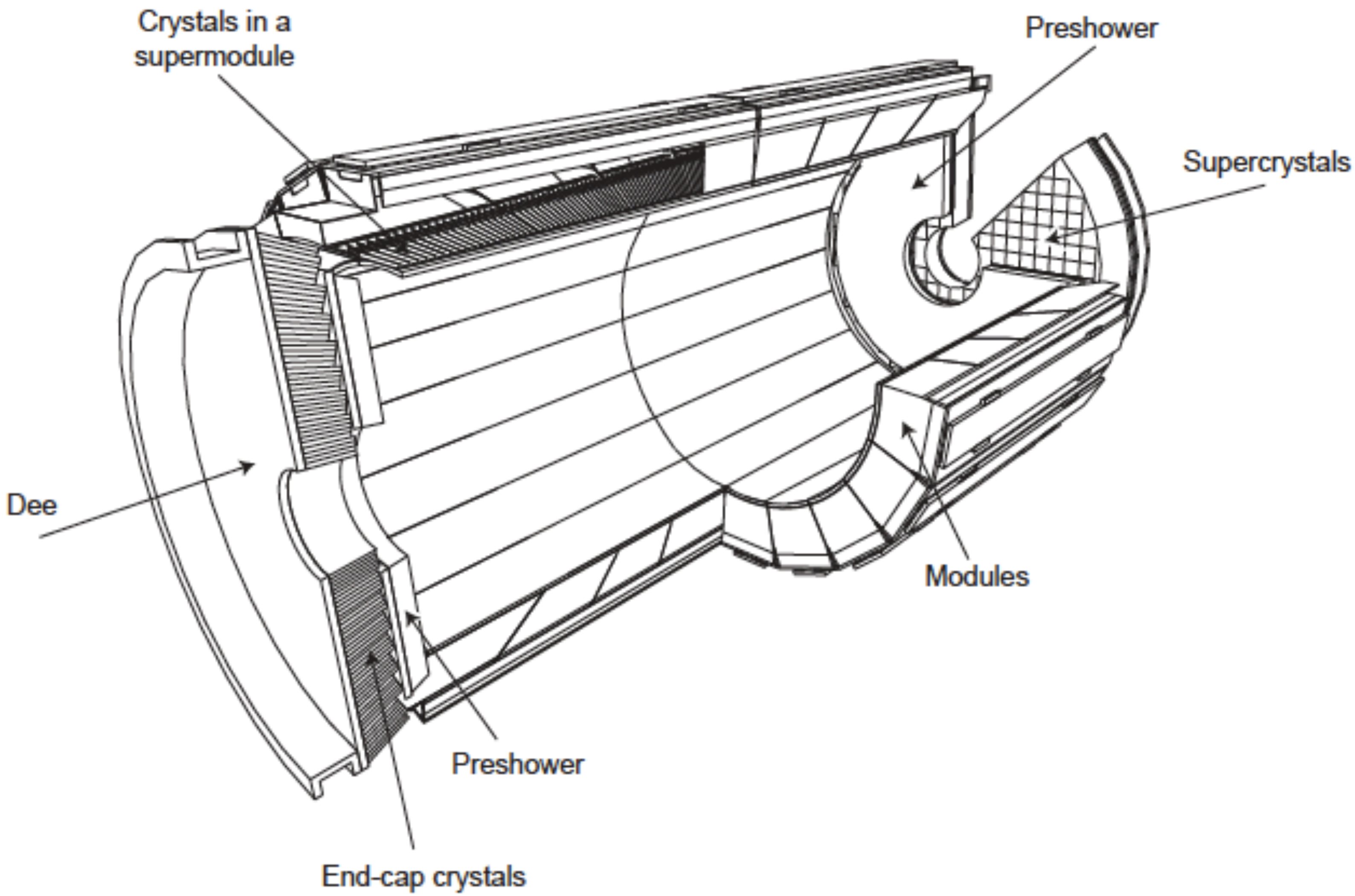
A completed CU LAr Hadronic End-Cap

$\delta E/E \sim 100\%/\mathrm{sqrt}(E) + 10\%$

Calorimeters: CMS

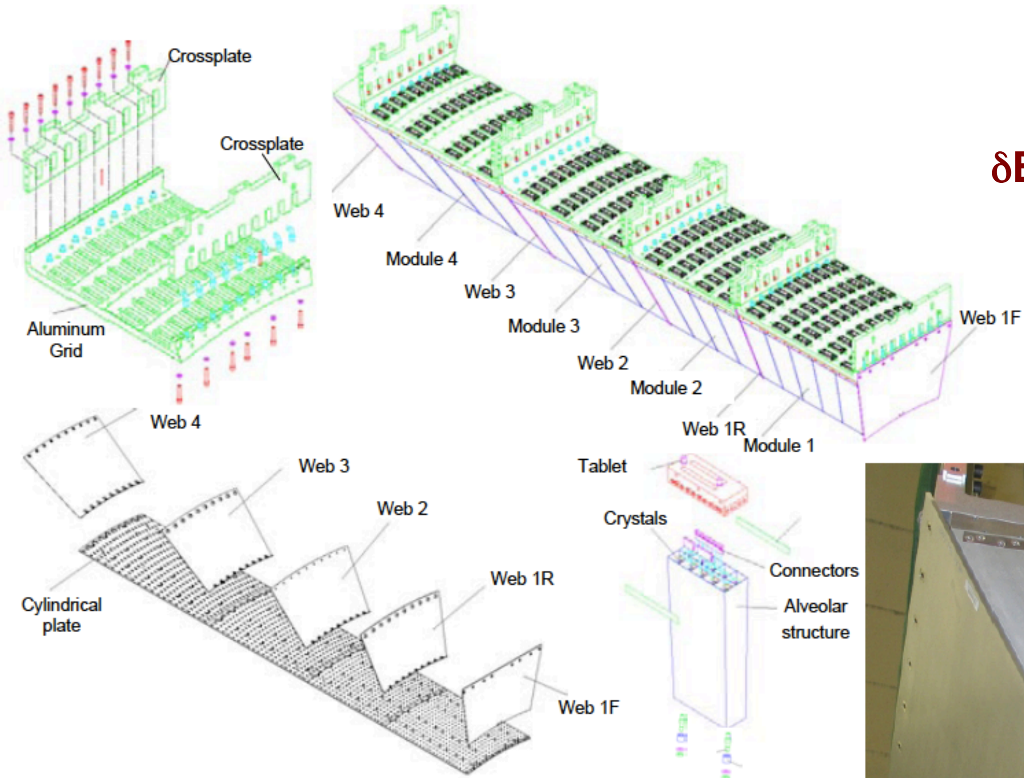


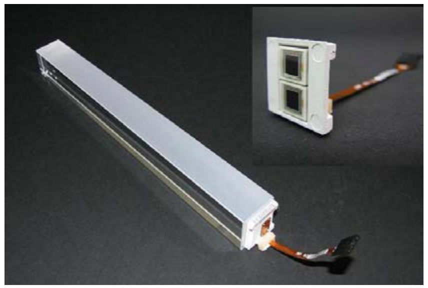
Calorimeters:
CMS ECAL



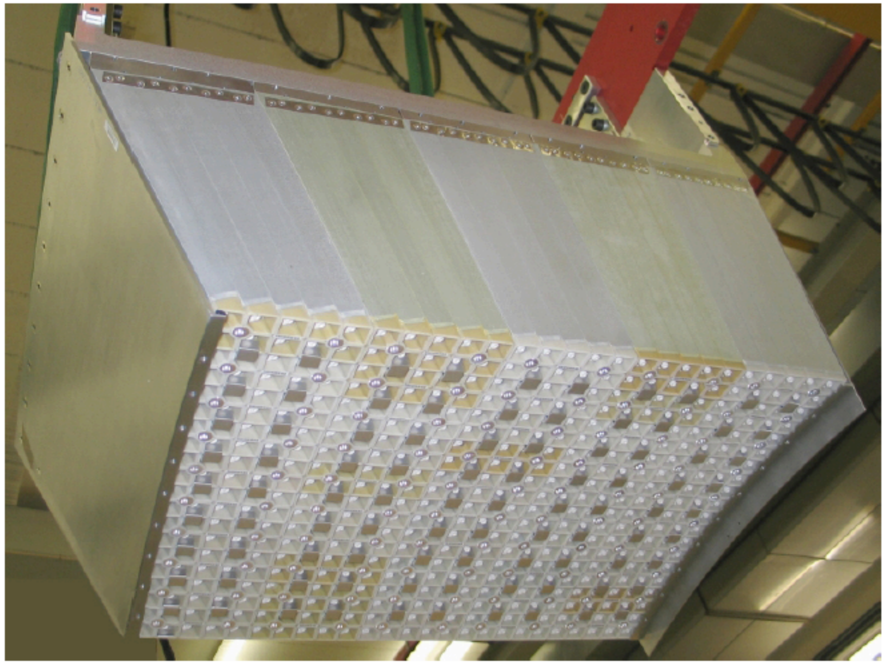
Calorimeters:
CMS

$\delta E/E < 3\%/\mathrm{sqrt}(E) + 0.125/E + 0.3\%$

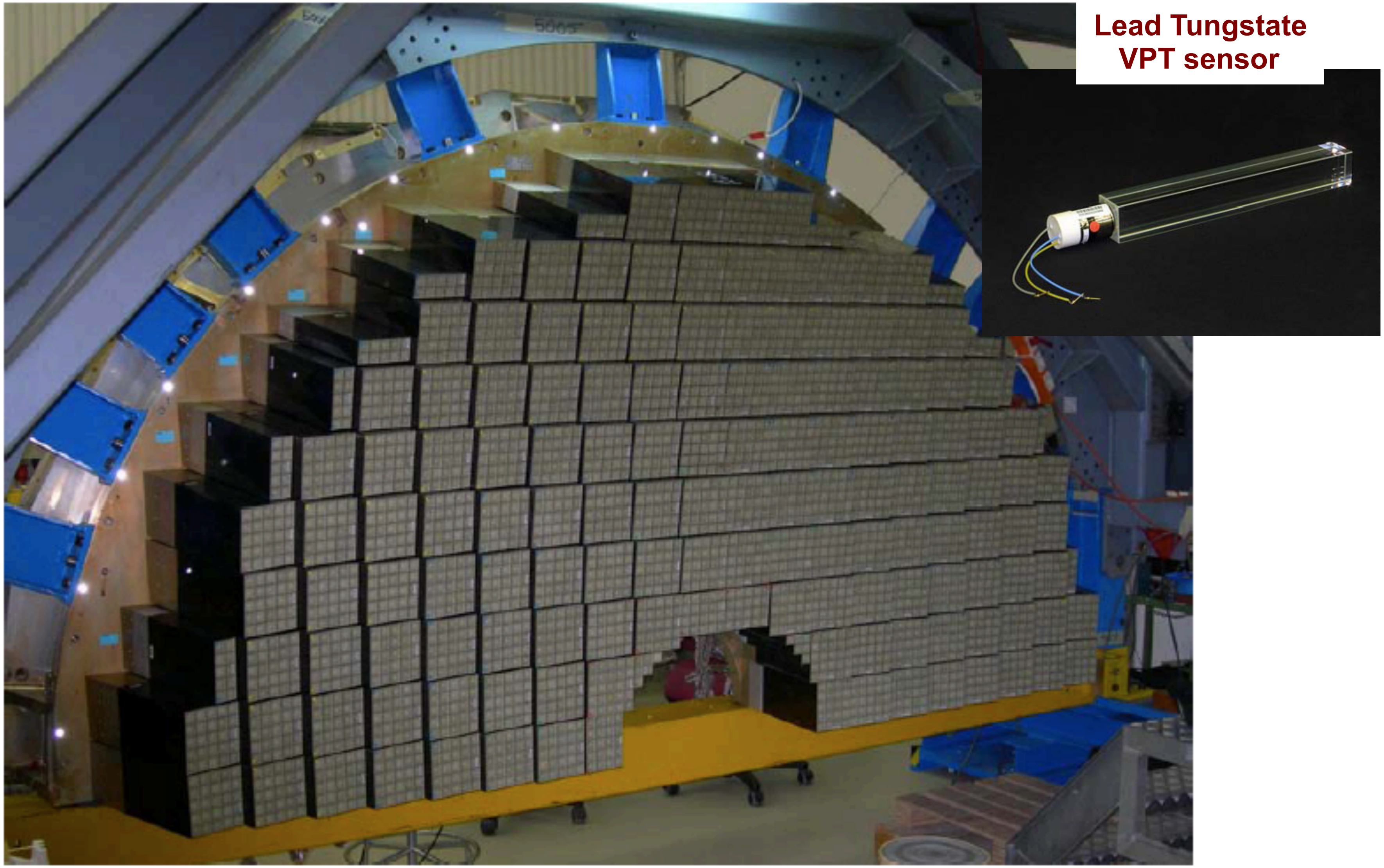




Lead Tungstate
Si APV sensor

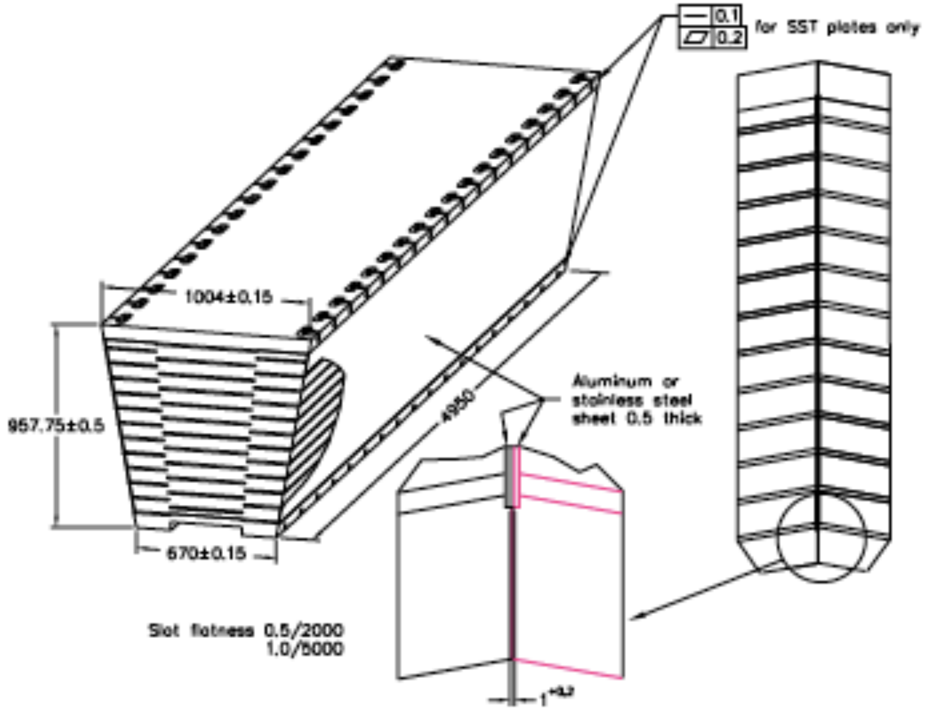


Calorimeters:
CMS



Lead Tungstate
VPT sensor

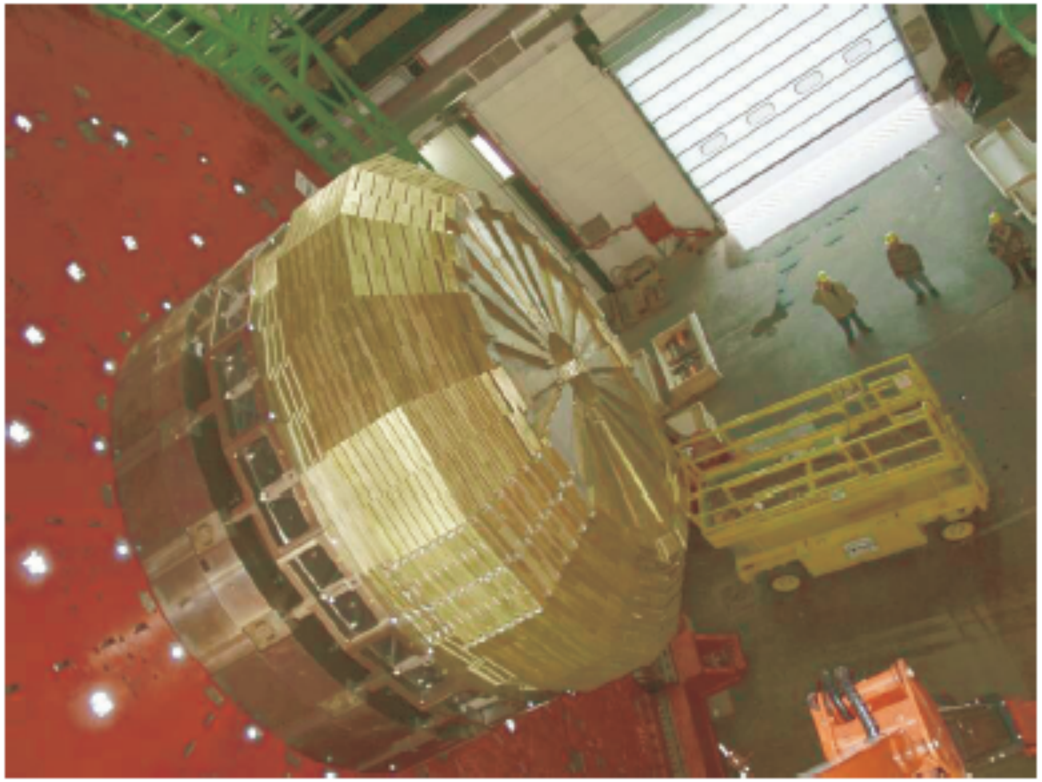
Calorimeters: CMS HCAL Barrel



Brass Scintillator

$\delta E/E \sim 100\%/\mathrm{sqrt}(E) + 0.5\%$

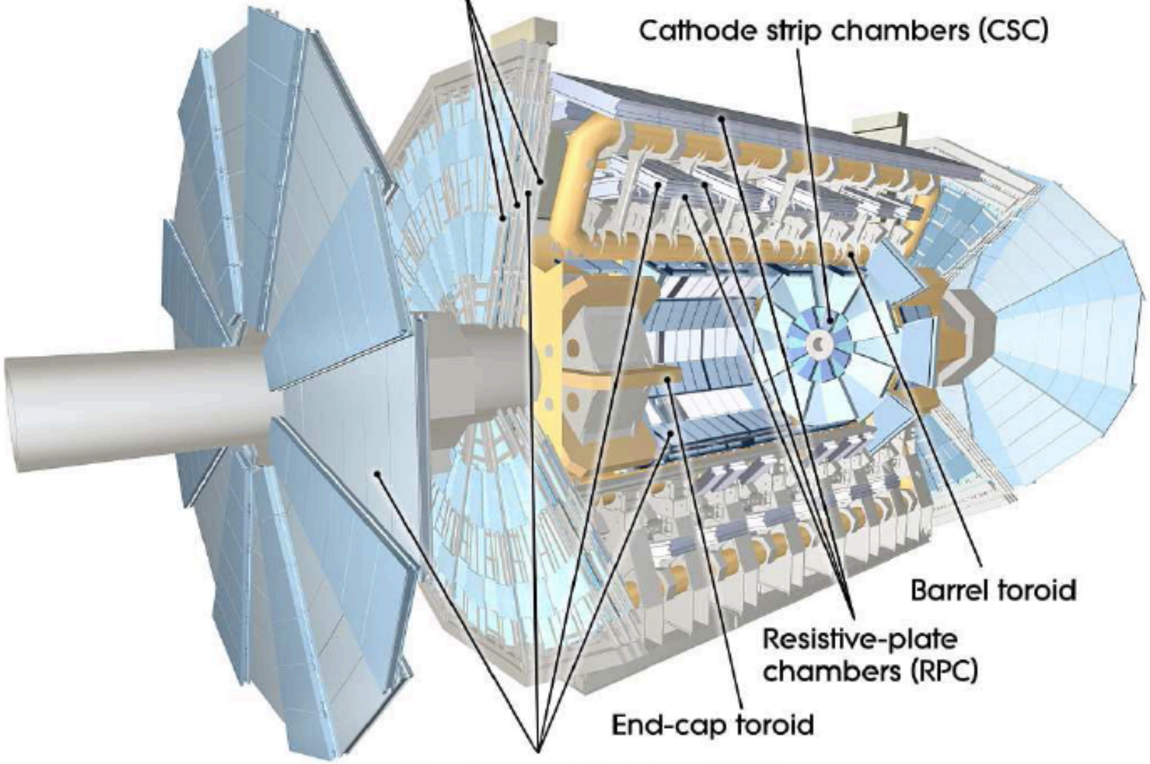
Calorimeters: CMS HCAL End-Cap



Brass Scintillator

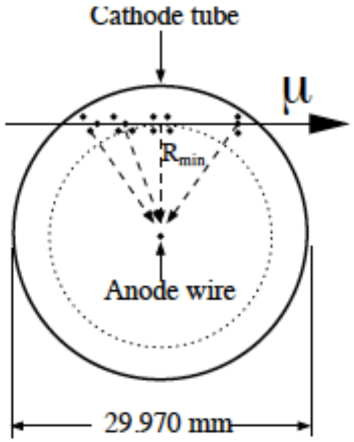
$\delta E/E \sim 100\%/\mathrm{sqrt}(E) + 0.5\%$

Muon Spectrometer: ATLAS

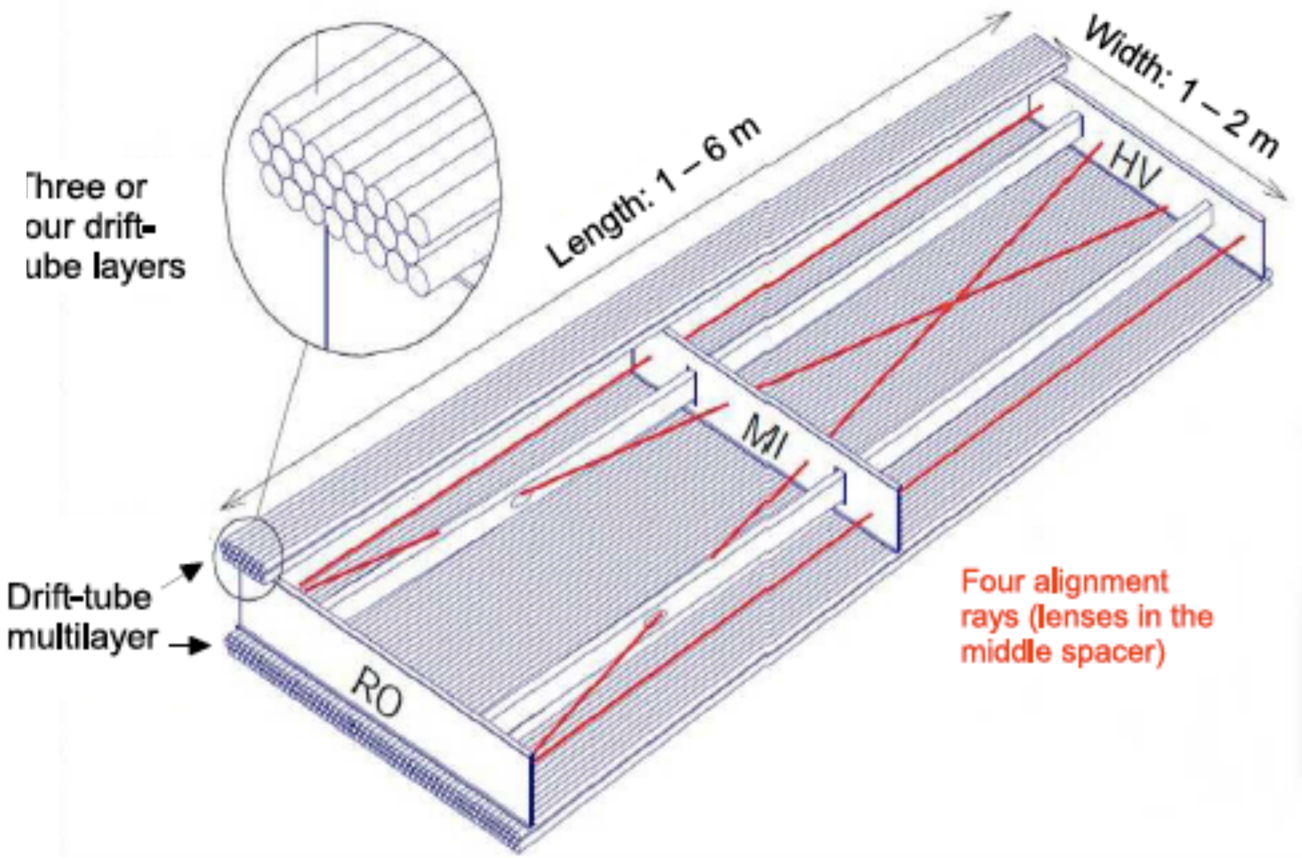


Monitored drift tubes	MDT
- Coverage	$\lvert\eta\rvert < 2.7$ (innermost layer: $\lvert\eta\rvert < 2.0$)
- Number of chambers	1088 (1150)
- Number of channels	339 000 (354 000)
- Function	Precision tracking
Cathode strip chambers	**CSC**
- Coverage	$2.0 < \lvert\eta\rvert < 2.7$
- Number of chambers	32
- Number of channels	31 000
- Function	Precision tracking
Resistive plate chambers	**RPC**
- Coverage	$\lvert\eta\rvert < 1.05$
- Number of chambers	544 (606)
- Number of channels	359 000 (373 000)
- Function	Triggering, second coordinate
Thin gap chambers	**TGC**
- Coverage	$1.05 < \lvert\eta\rvert < 2.7$ (2.4 for triggering)
- Number of chambers	3588
- Number of channels	318 000
- Function	Triggering, second coordinate

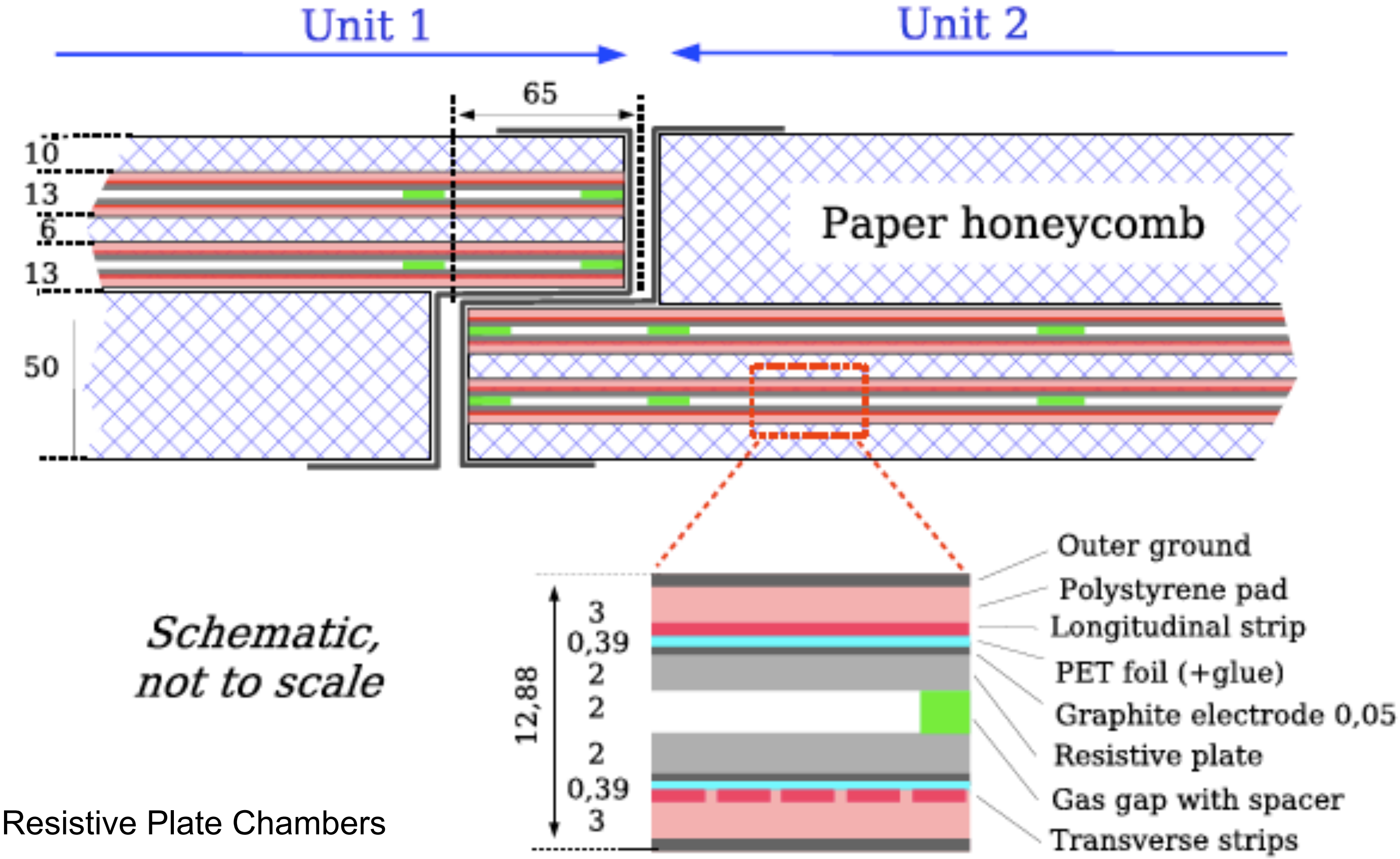
Muon Spectrometer: ATLAS Drift Tubes MDT



Monitored Drift Tubes



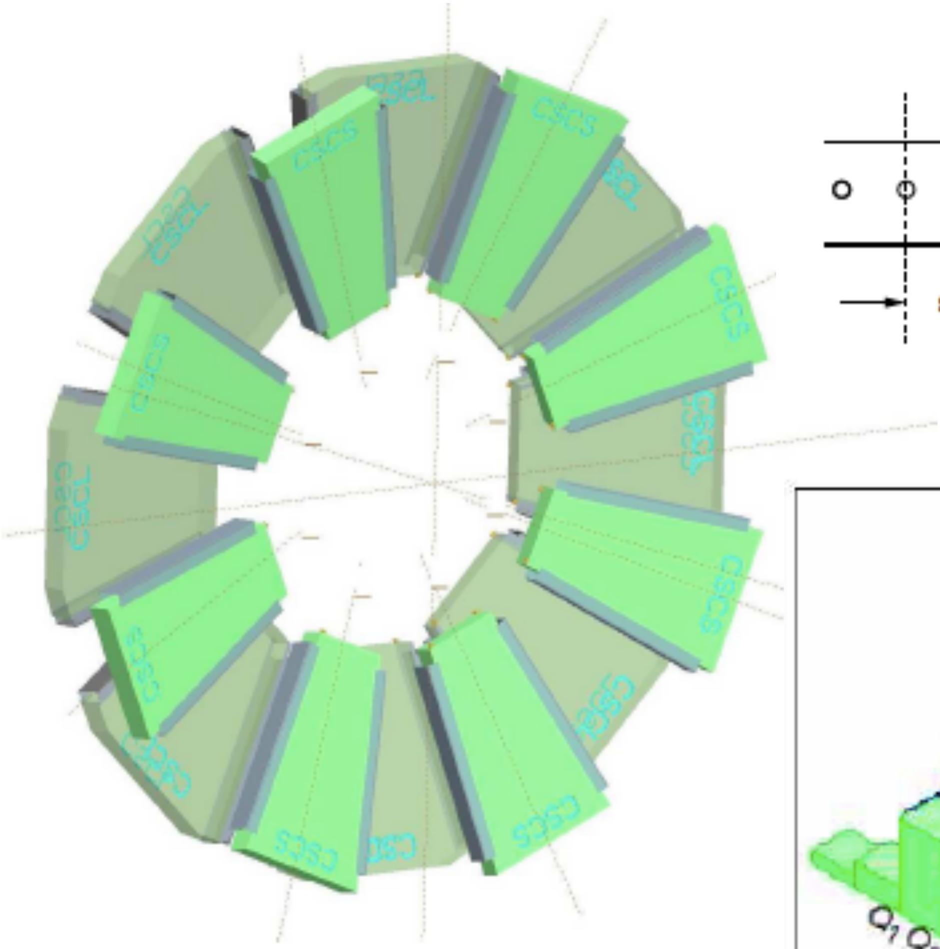
Muon Spectrometer:
ATLAS Resistive Plate Chambers RPC



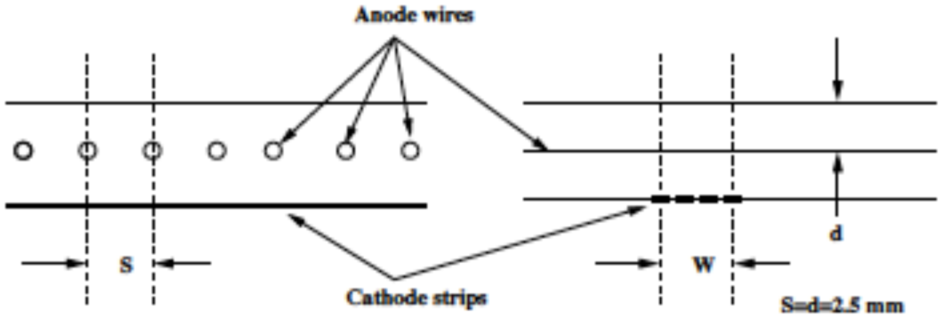
Schematic, not to scale

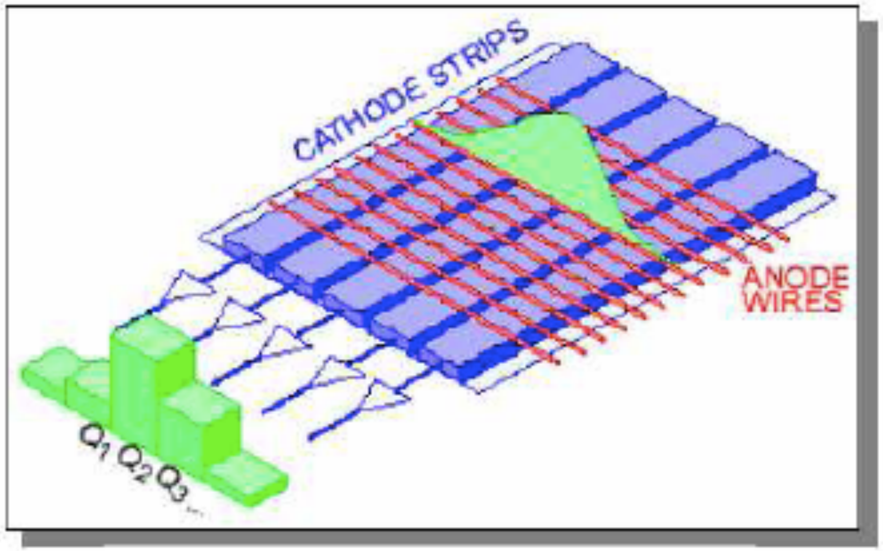
Resistive Plate Chambers

Muon Spectrometer:
ATLAS Cathode Strip Chambers CSC



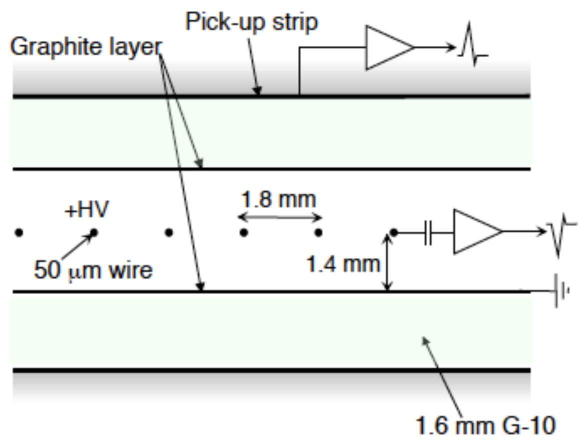
Cathode Strip Chambers

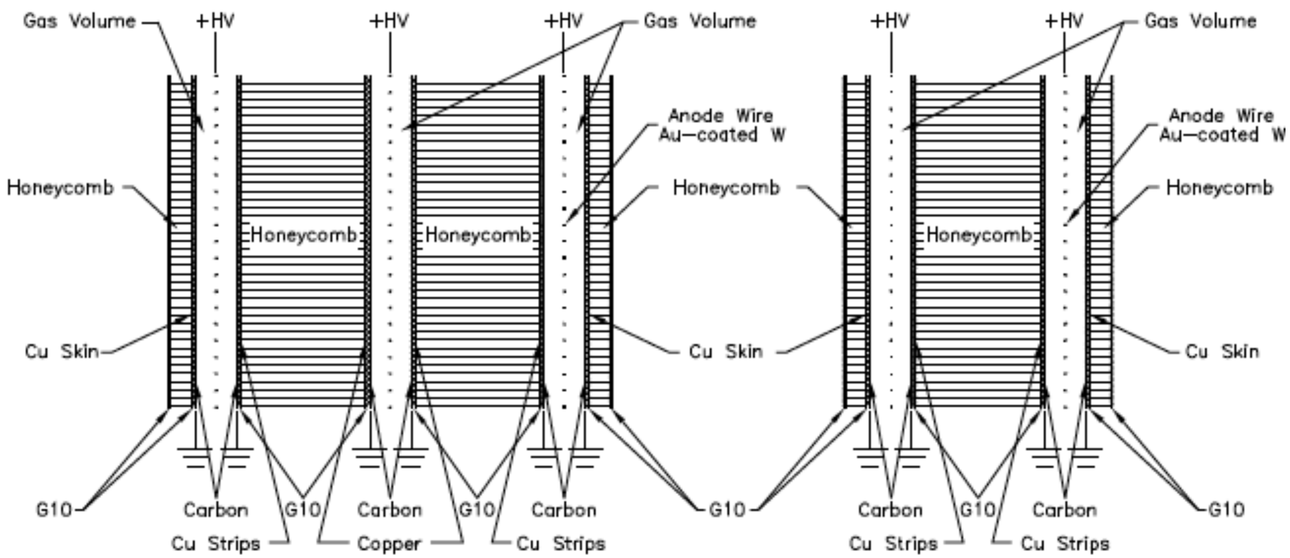




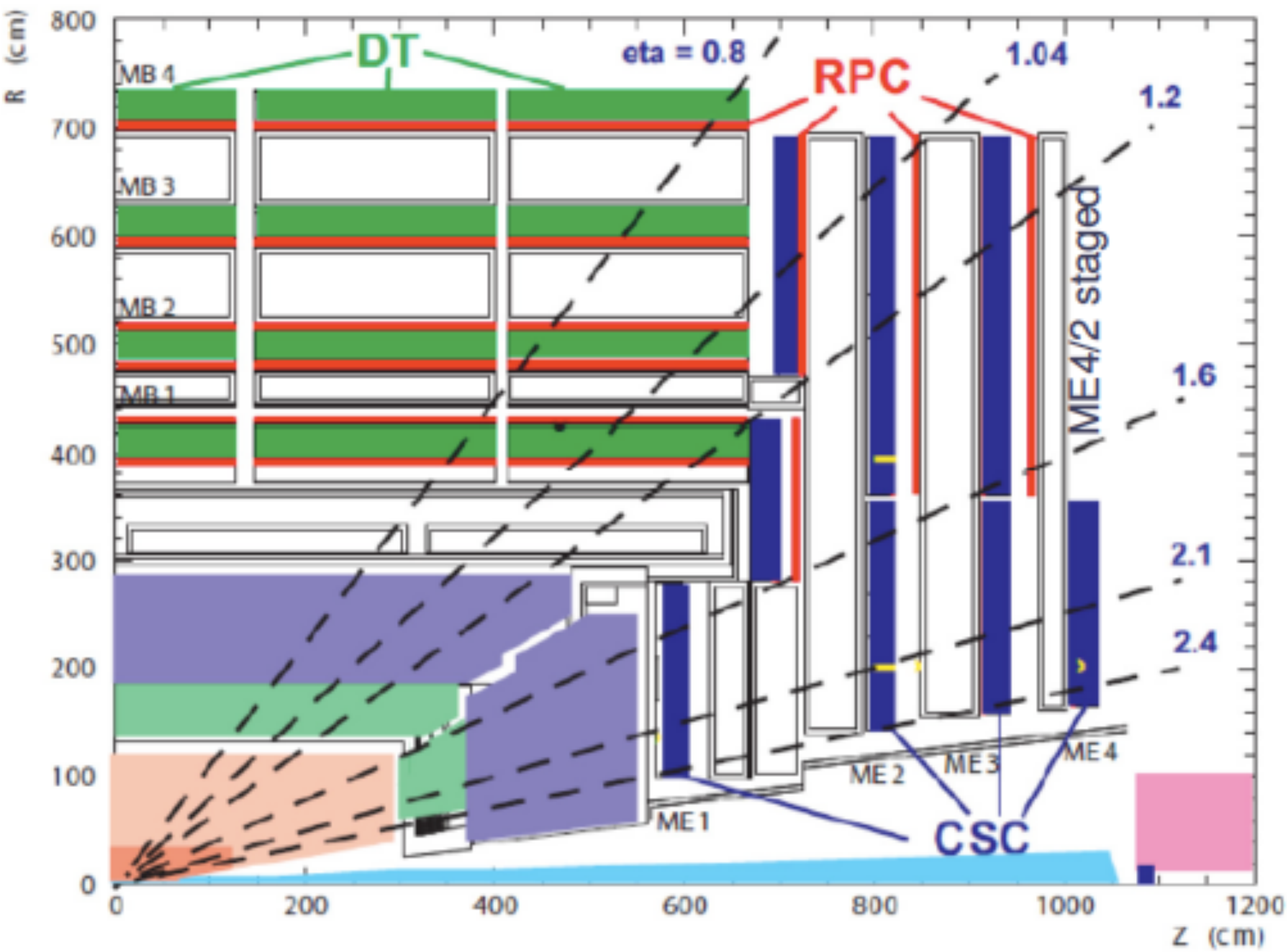
Muon Spectrometer:
ATLAS Thin Gap Chambers TGC

Thin Gap Chambers

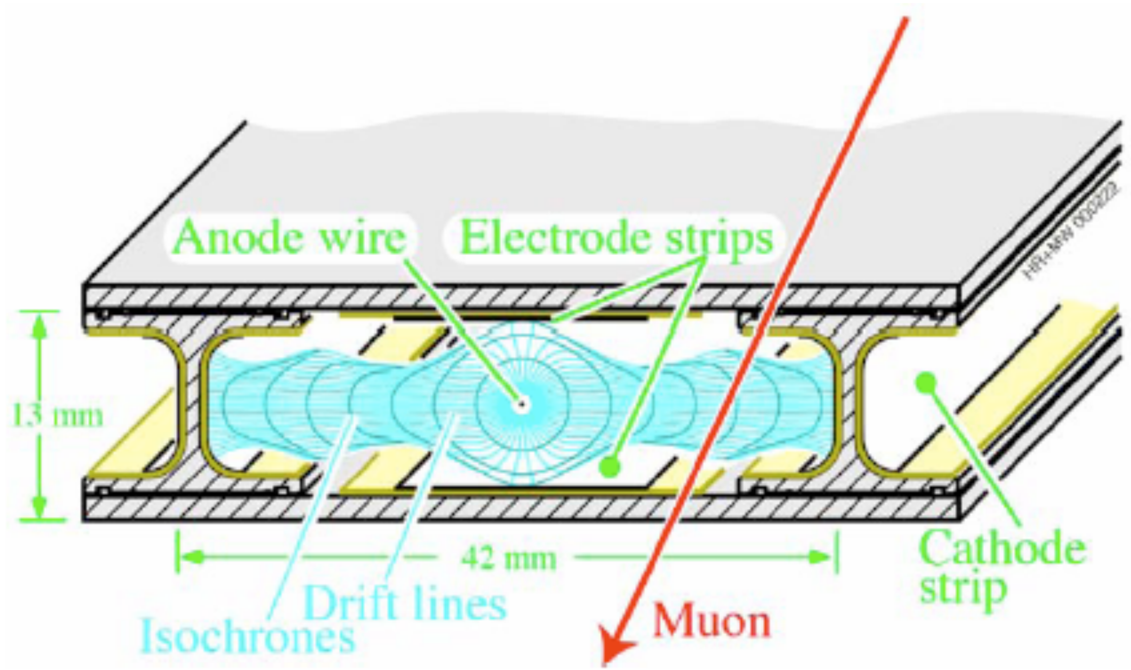




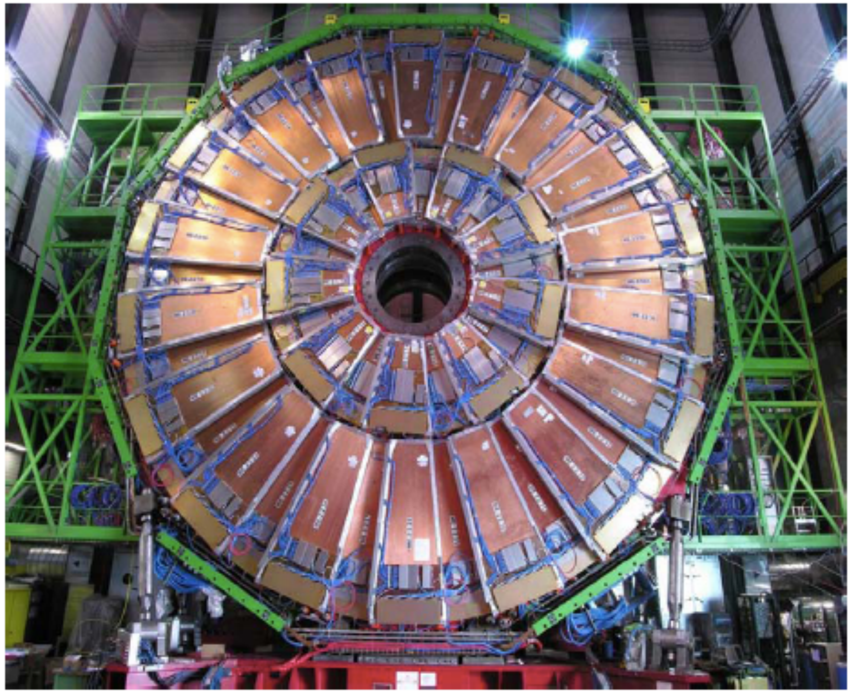
Muon Spectrometer: CMS

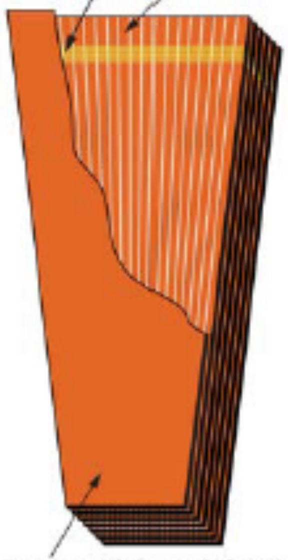


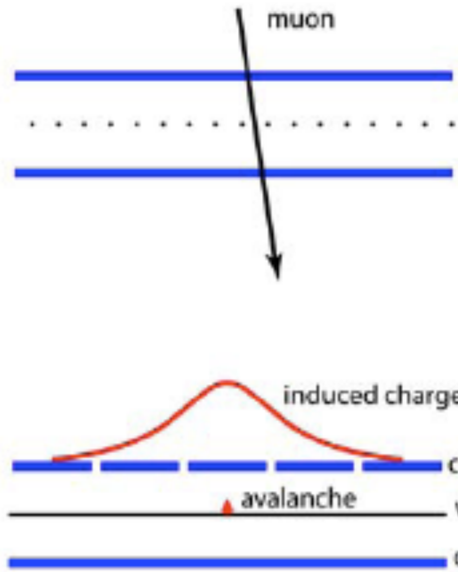
Muon Spectrometer:
CMS DT



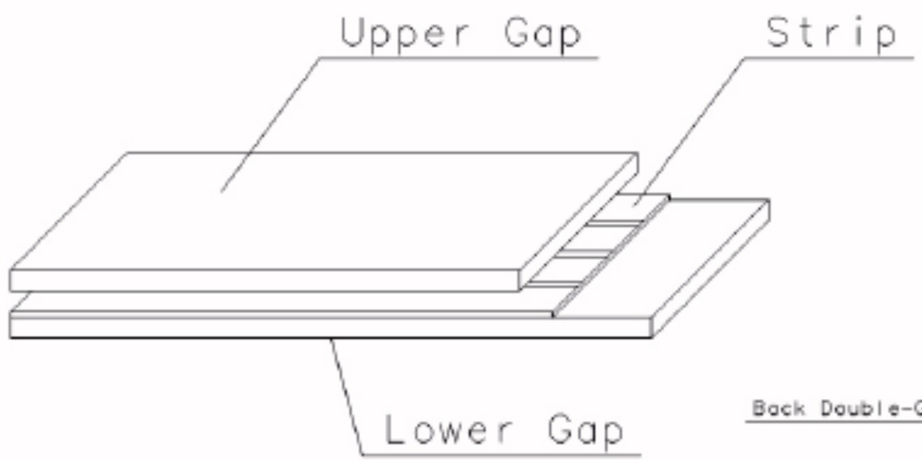
Muon Spectrometer:
CMS CSC

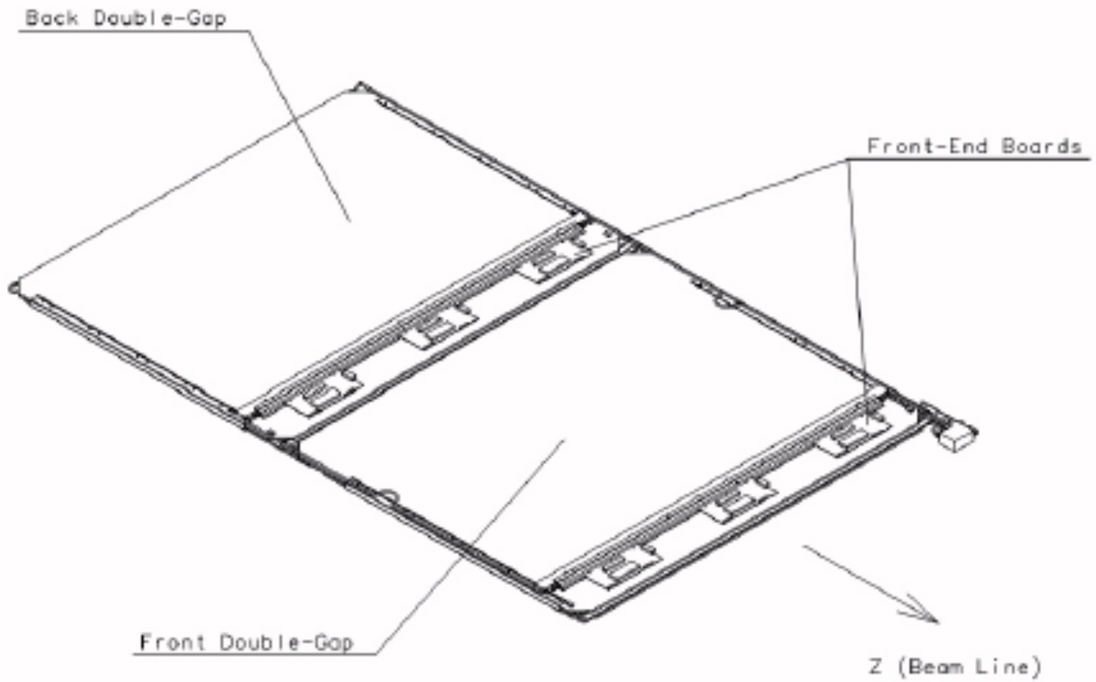




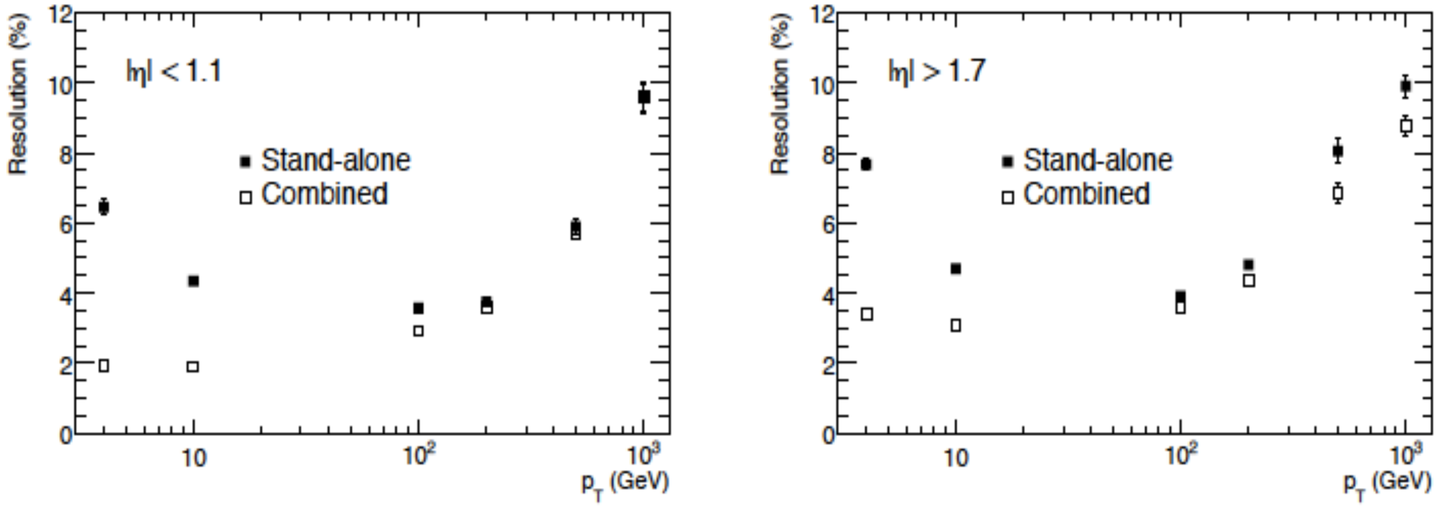


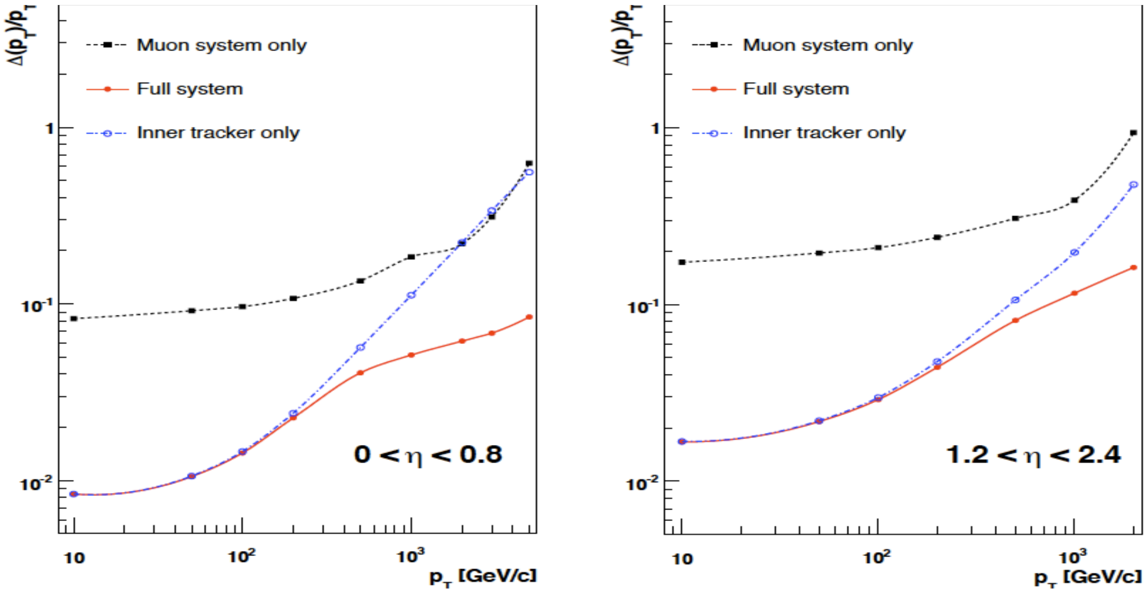
Muon Spectrometer: CMS RPC





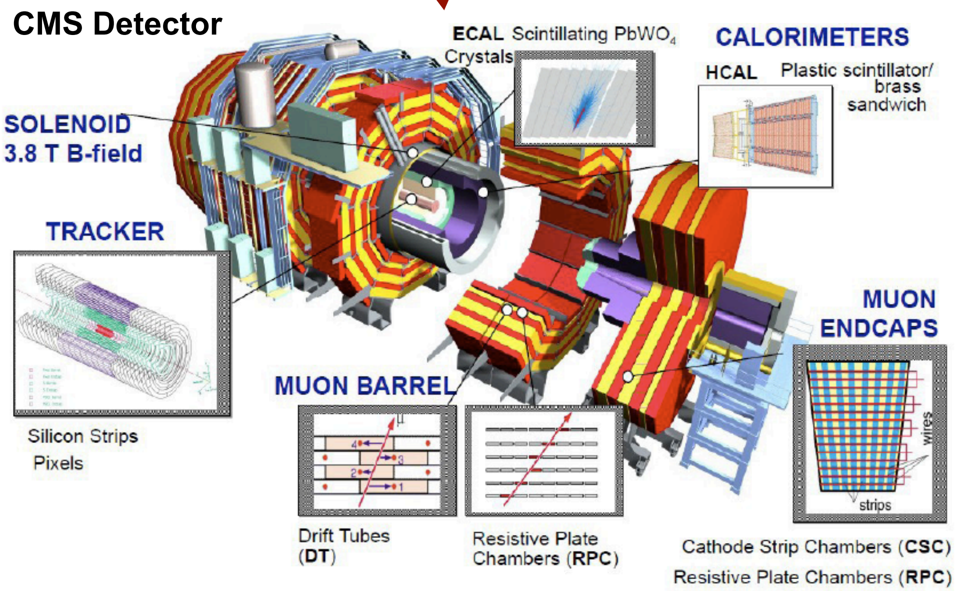
Muon Spectrometers, Expected Resolution: ATLAS and CMS

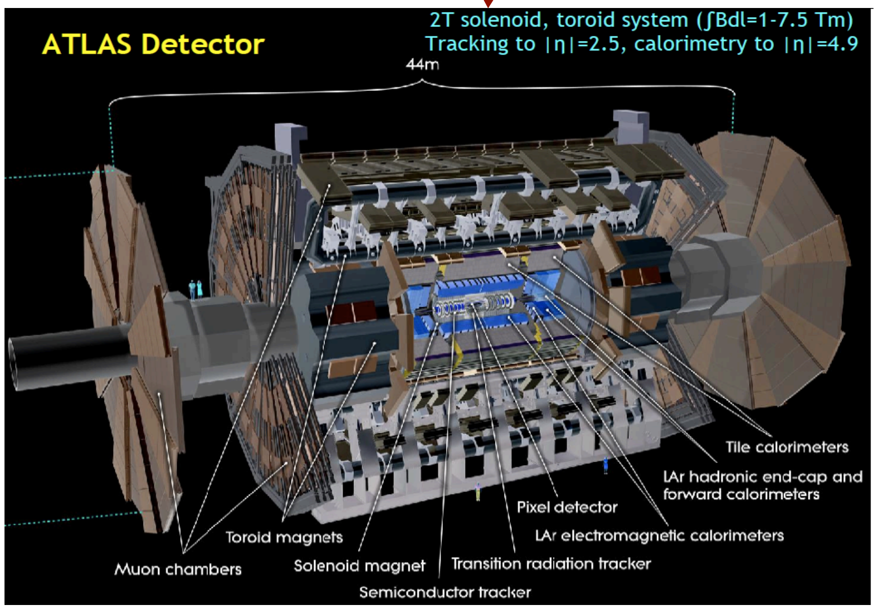




ATLAS and CMS:

Two different approaches to a common set of Goals and Challenges





ATLAS & CMS:
from Requirements & Design to Performance & Results

ATLAS and CMS Experiments

Imperial College London

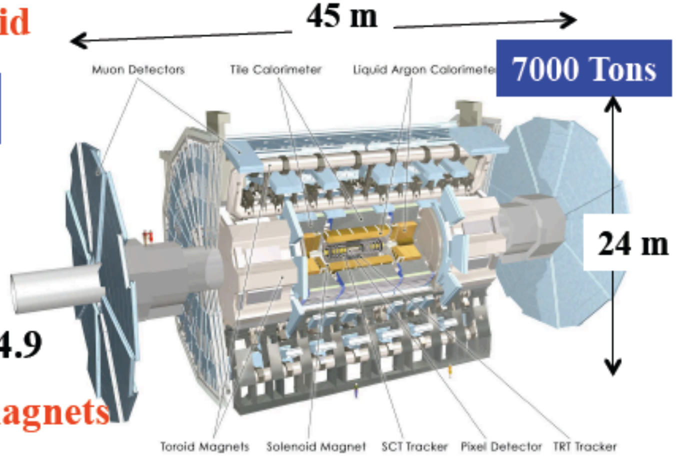
Inner detector: pixel+SCT+TRT B = 2T solenoid
$\sigma/p_T \approx 10.05\% p_T \oplus 1\%$ $|\eta| < 2.5$

ATLAS

EM Calo: Lead-LAr calorimeter
$\sigma/E \approx 10\%/\sqrt{E} \oplus 0.7\%$ $|\eta| < 3.2$

Hadronic calorimeter:
Steel+Scintillator $\sigma/E \approx 50\%/\sqrt{E} \oplus 3\%$ $|\eta| < 3.2$
Copper+LAr $\sigma/E \approx 100\%/\sqrt{E} \oplus 10\%$ $3.1 < |\eta| < 4.9$

Muon spectrometer: superconducting toroid magnets
$\sigma/p_T \approx 2\%$@ 50 GeV $|\eta| < 2.7$

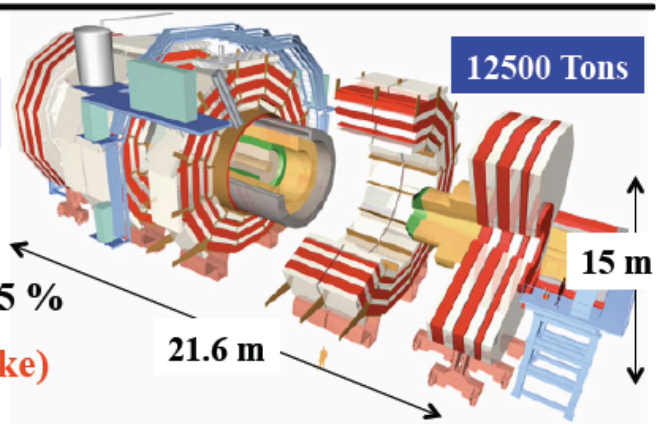


Silicon tracker $|\eta| < 2.5$, B = 3.8T solenoid
$\sigma/p_T \approx 1.5 \cdot 10^{-4} p_T \oplus 0.005$

CMS

Calorimetry $|\eta|_{ECAL} < 3$, $|\eta|_{HCAL} < 5$
ECAL: PbWO4 crystals, high resolution M(γγ)
$\sigma/E \approx 2.8\%/\sqrt{E} \oplus 12\%/E \oplus 0.3\%$
HCAL: brass+Scintillator $\sigma/E \approx 100\%/\sqrt{E} \oplus 0.05\ \%$

Muon Spectrometer: B = 2T (solenoid return yoke)
$\sigma/p_T \approx 1\%$@ 40 GeV $|\eta| < 2.4$

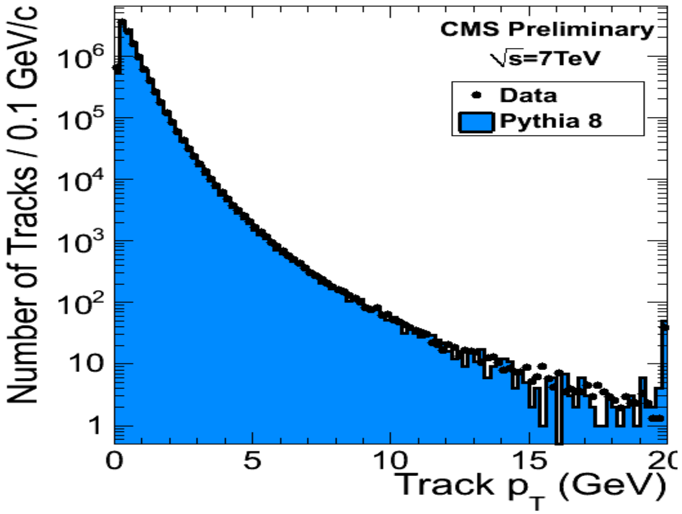


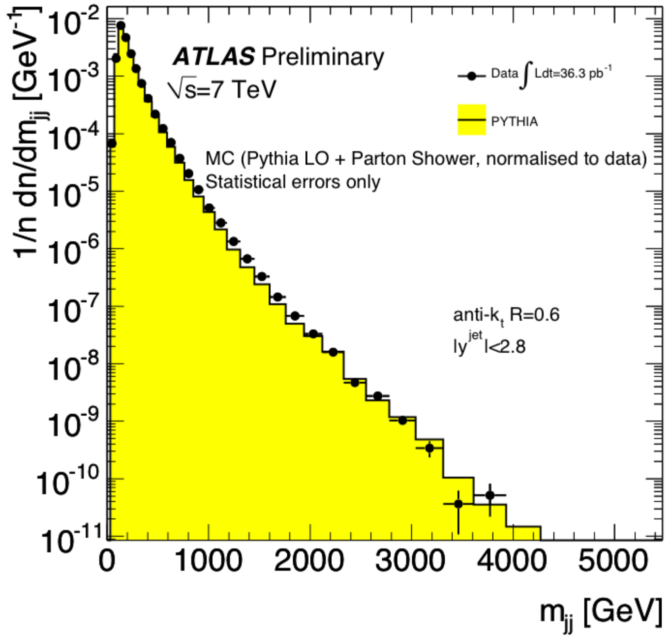
Higgs Searches at the LHC: M. Vázquez Acosta (Imperial) SUSY2011 Conference, 30/08, 2011 - 7

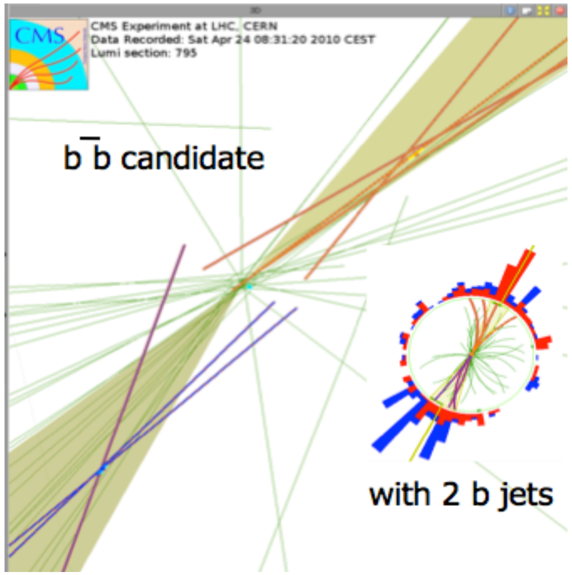
CMS De
SOLENOID
3.8 T B-fiel
TRACK
Silicon Strip
Pixels

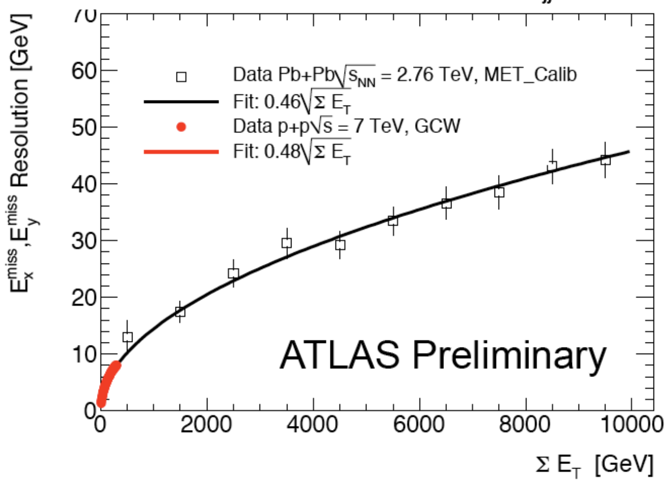
dl=1-7.5 Tm)
ry to |η|=4.9
Tile calorimeters
onic end-cap and
calorimeters
imeters

ATLAS & CMS: Tracks and Jets

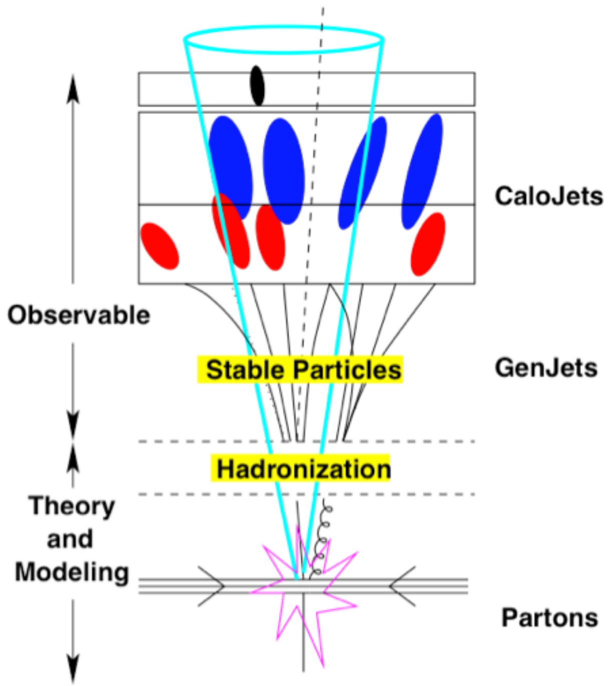


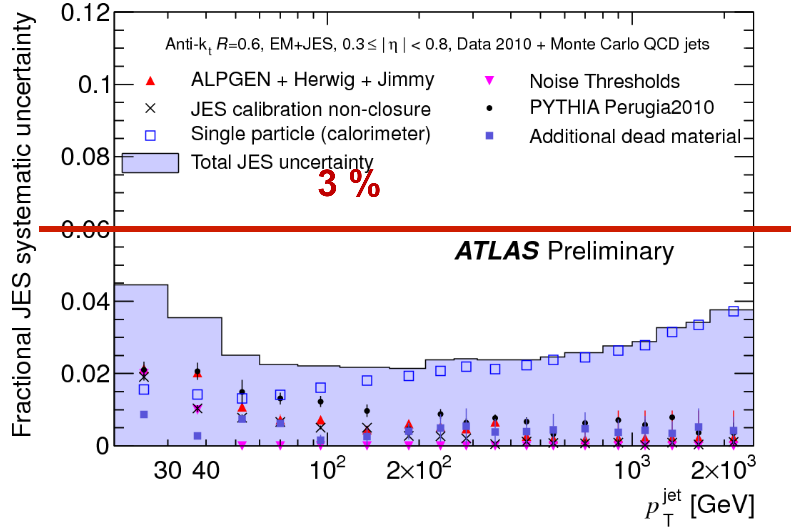


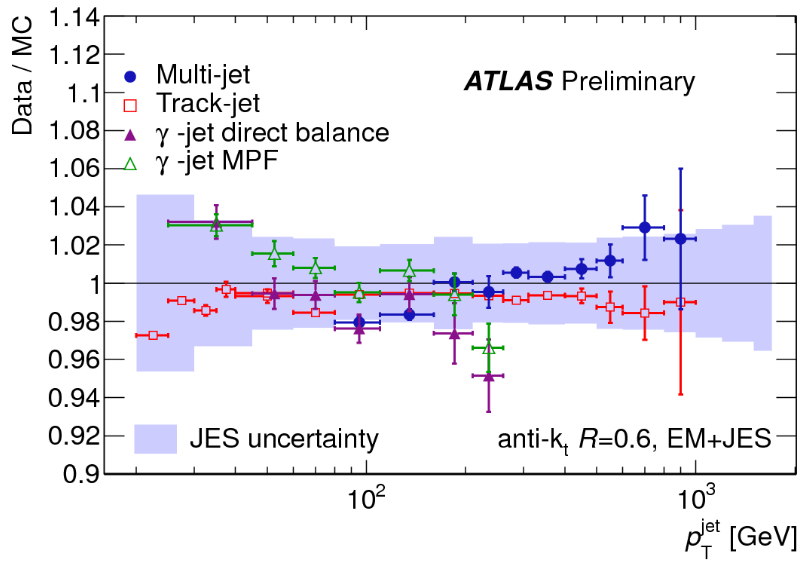




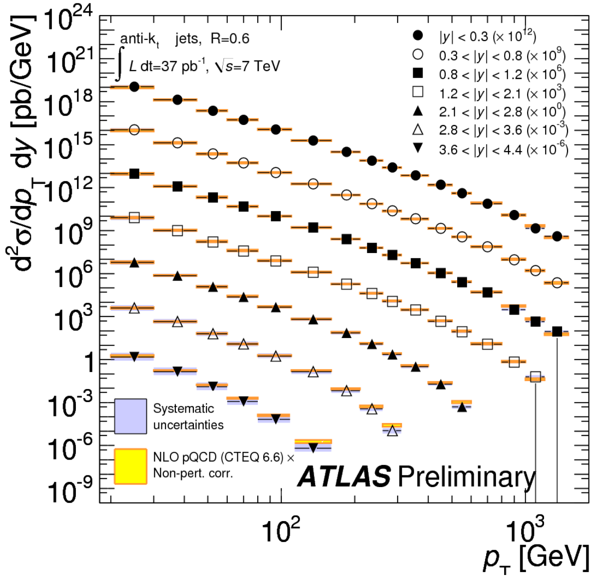
A considerable effort went into understanding the Jet Energy Scale (JES), the dominant source of uncertainties for most jet measurements

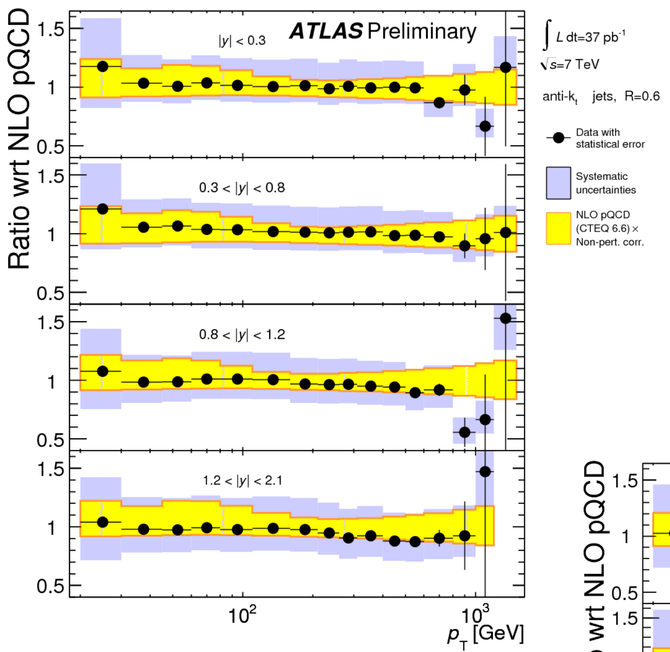




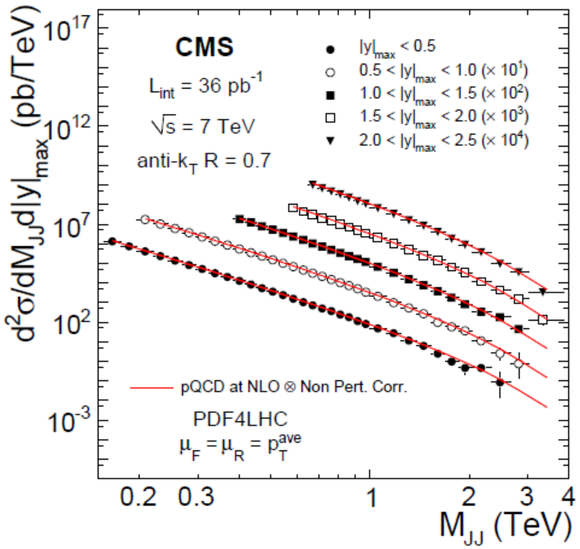


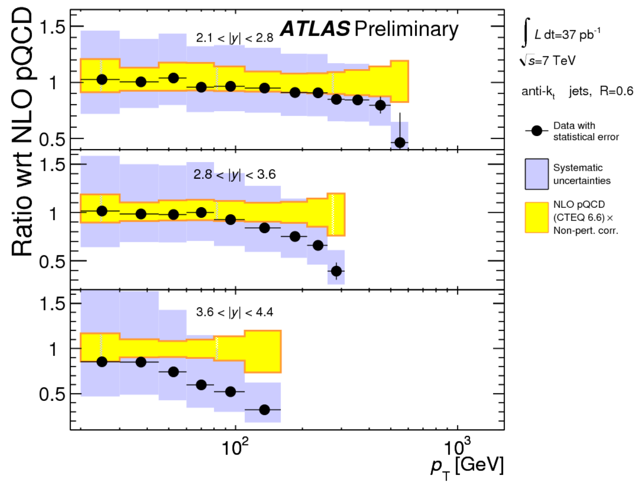
ATLAS and CMS: Tracks and Jets





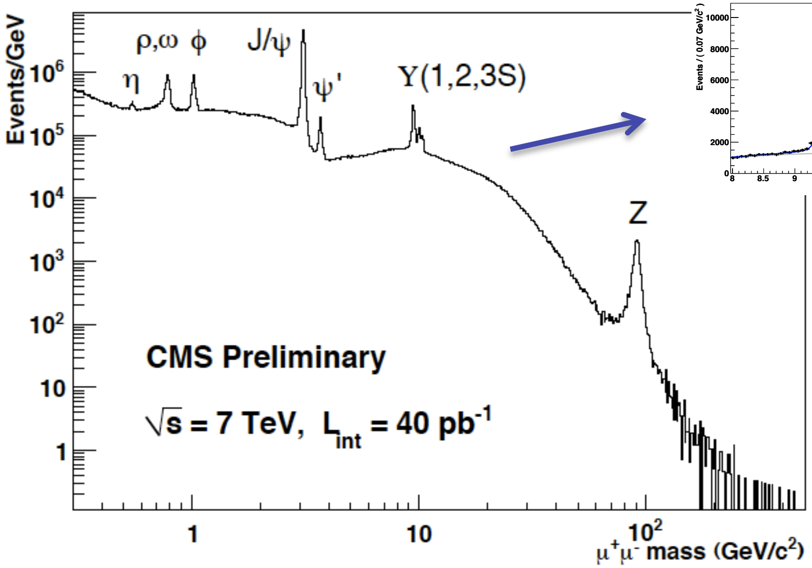
In general very good agreement with expectation

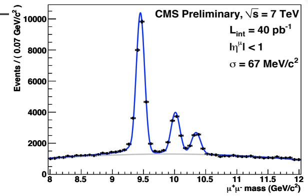


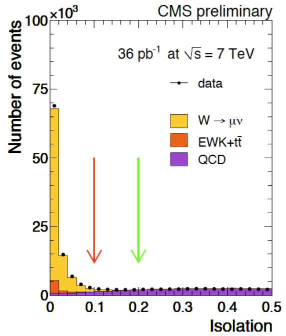


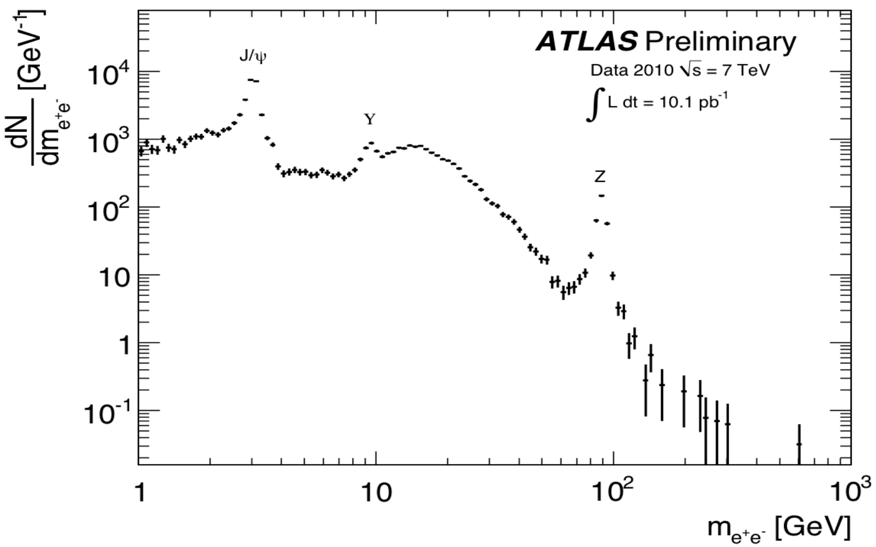
But not everywhere…

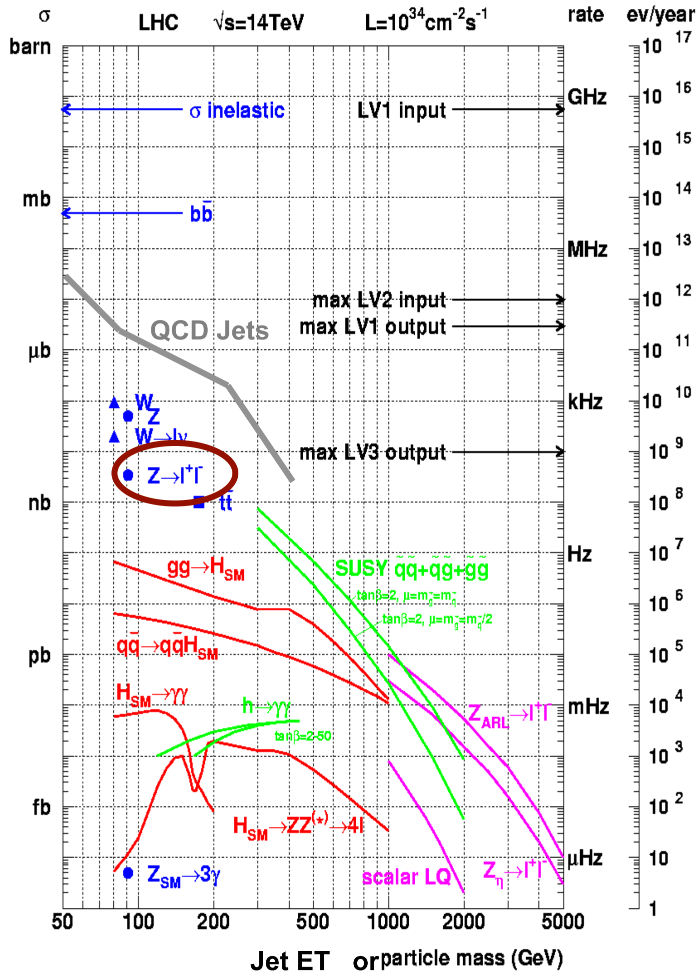
Electrons and Muons



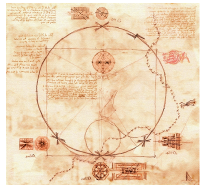






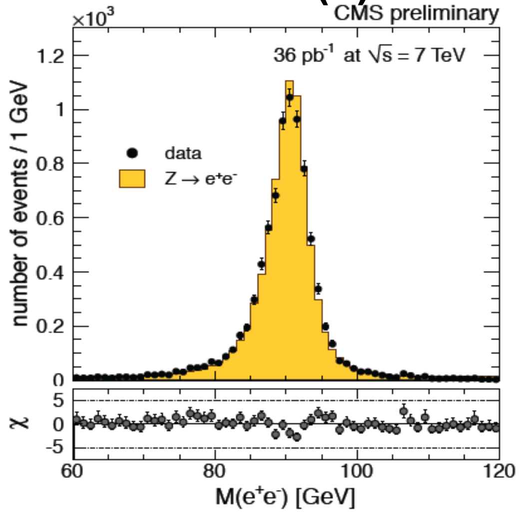


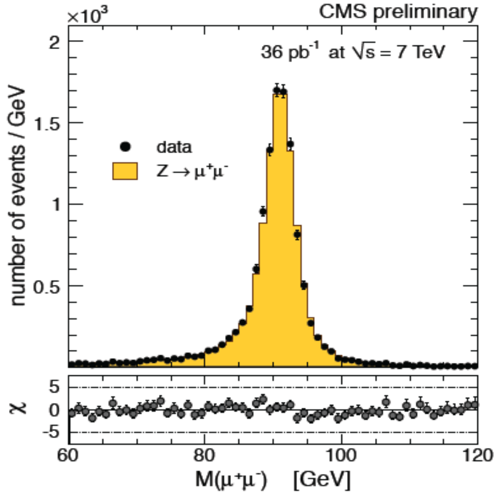
W and Z bosons as Standard Candles
CMS 2010 data ~ 36pb^{-1}

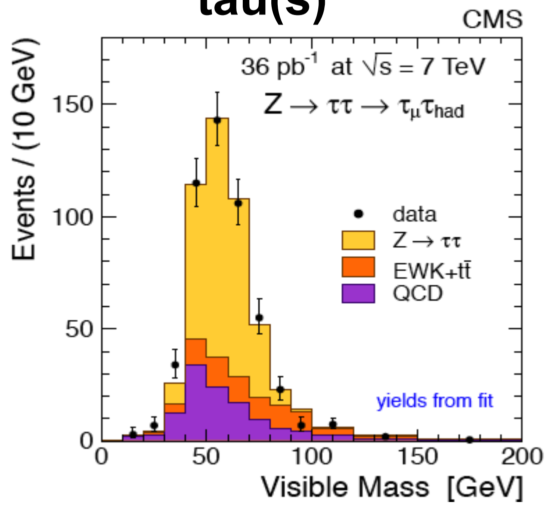


electron(s) | muon(s) | tau(s)

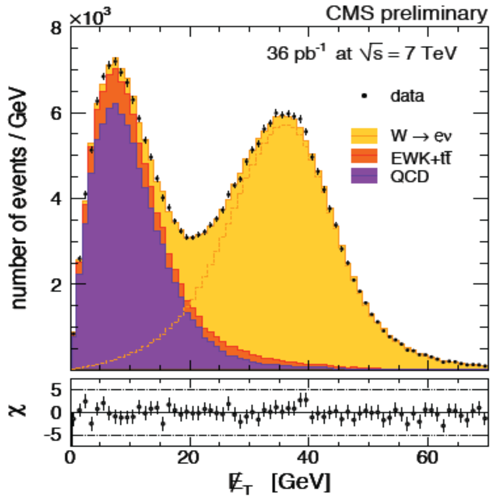
Z boson

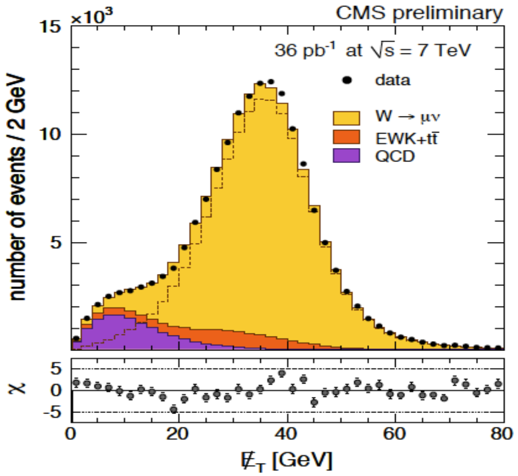


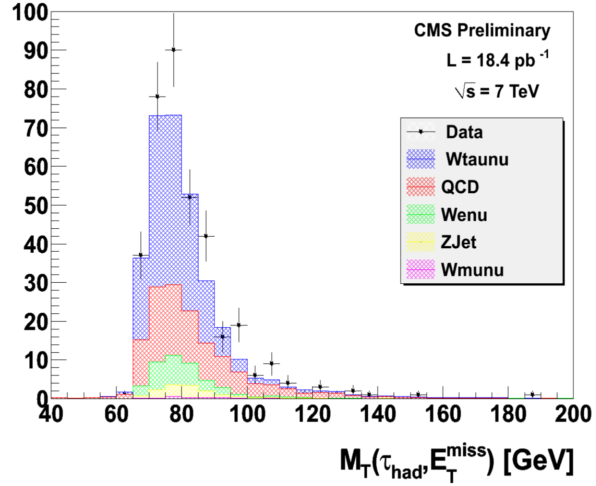




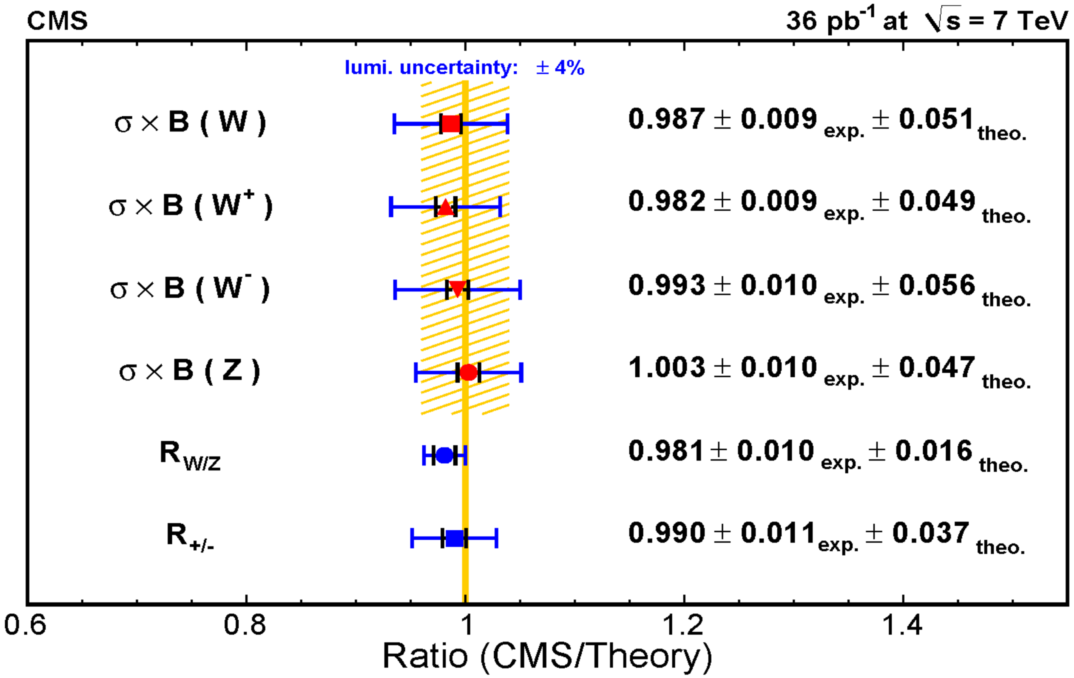
W boson

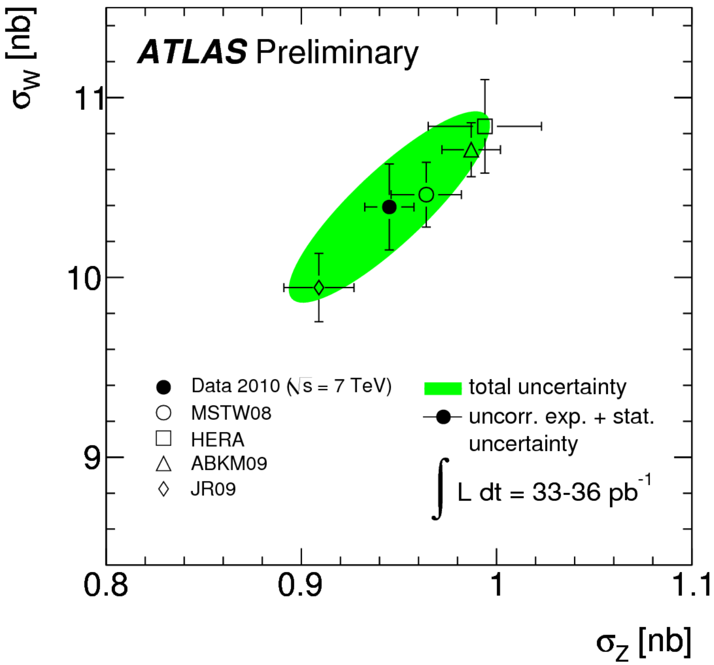






W and Z bosons as Standard Candles

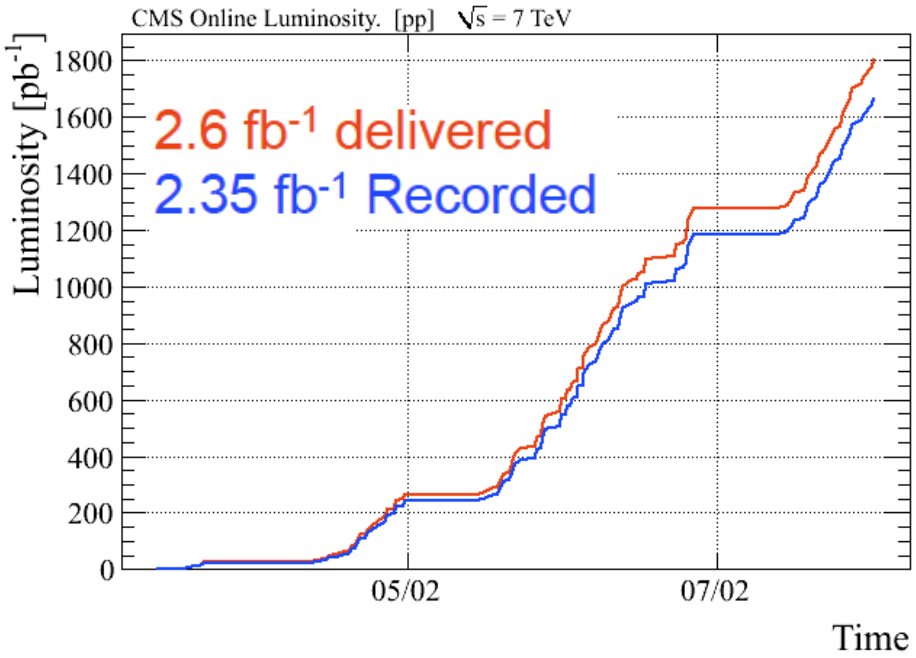


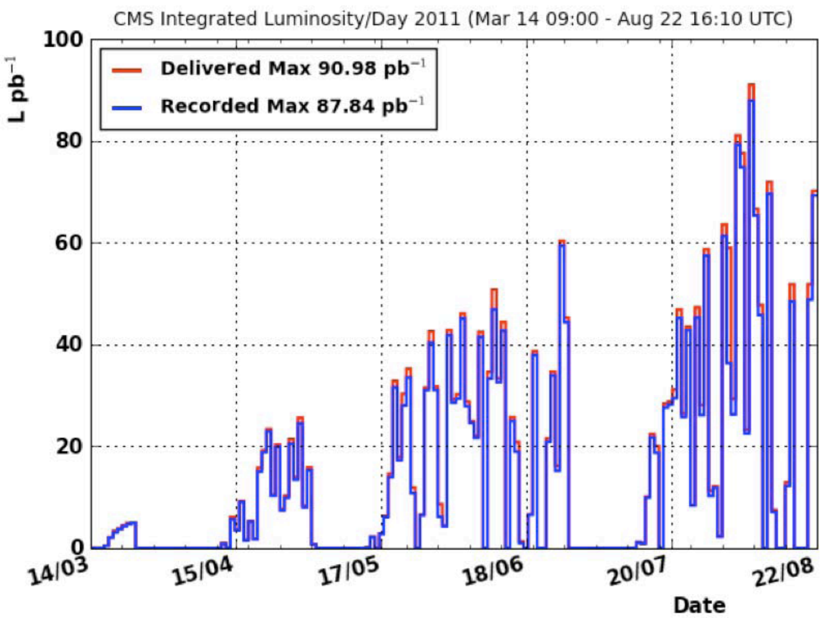


2011 LHC Operations

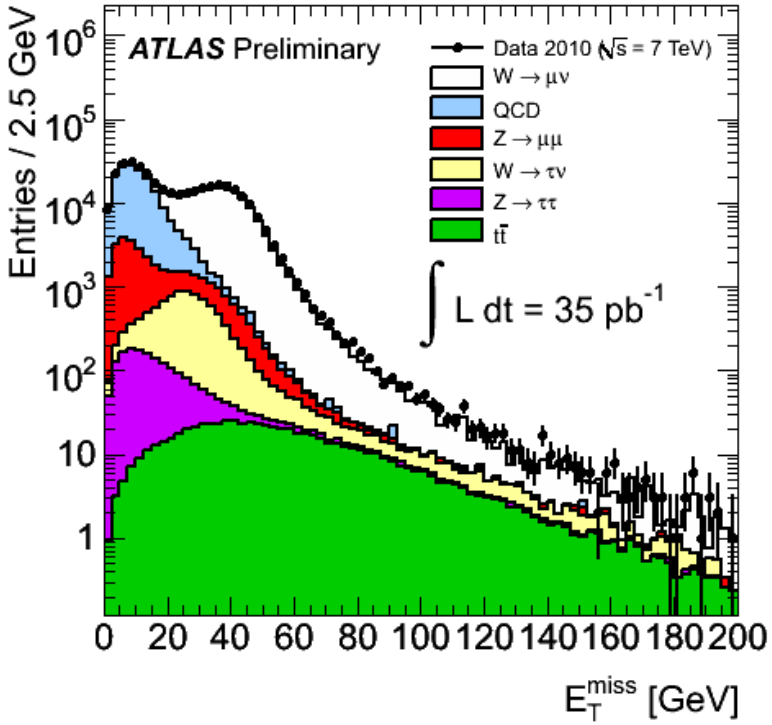
2010 data set ~ $36pb^{-1}$
Now are closing in on 100 times as much

On a good day, the LHC delivers over $80pb^{-1}$
At a peak luminosity of ~ $1.5\ 10^{33}$



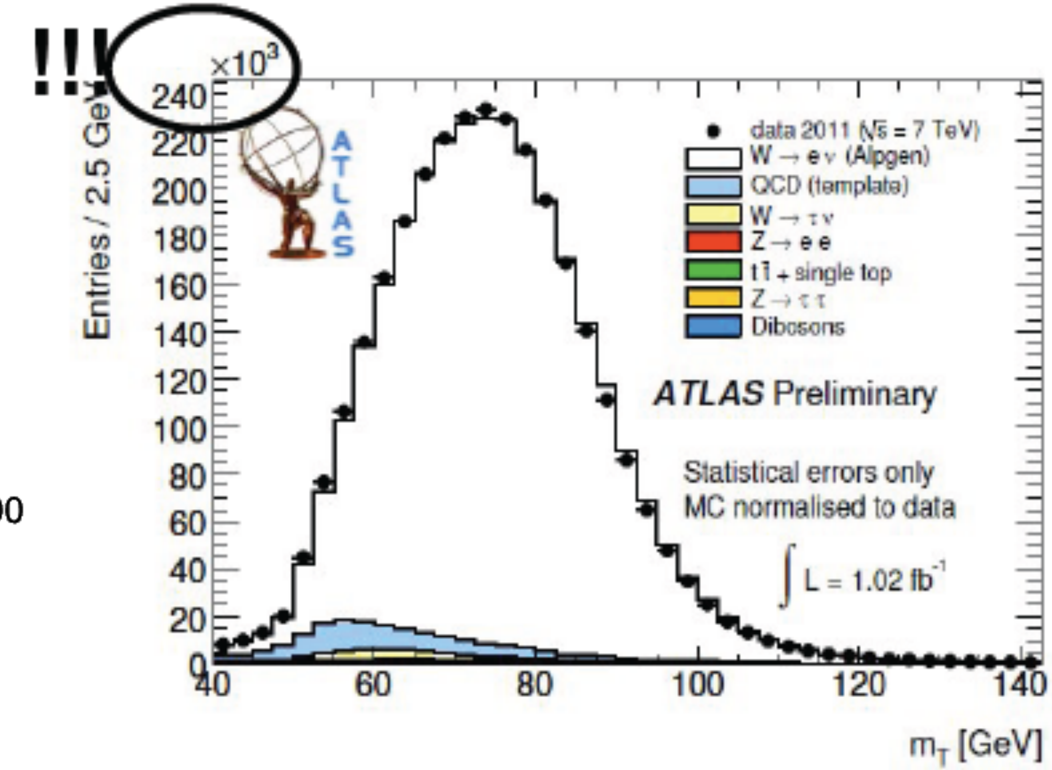


W and Z bosons as Standard Candles
2011 data ~ 1fb^{-1}



Missing transverse energy from the W → μ + ν decays

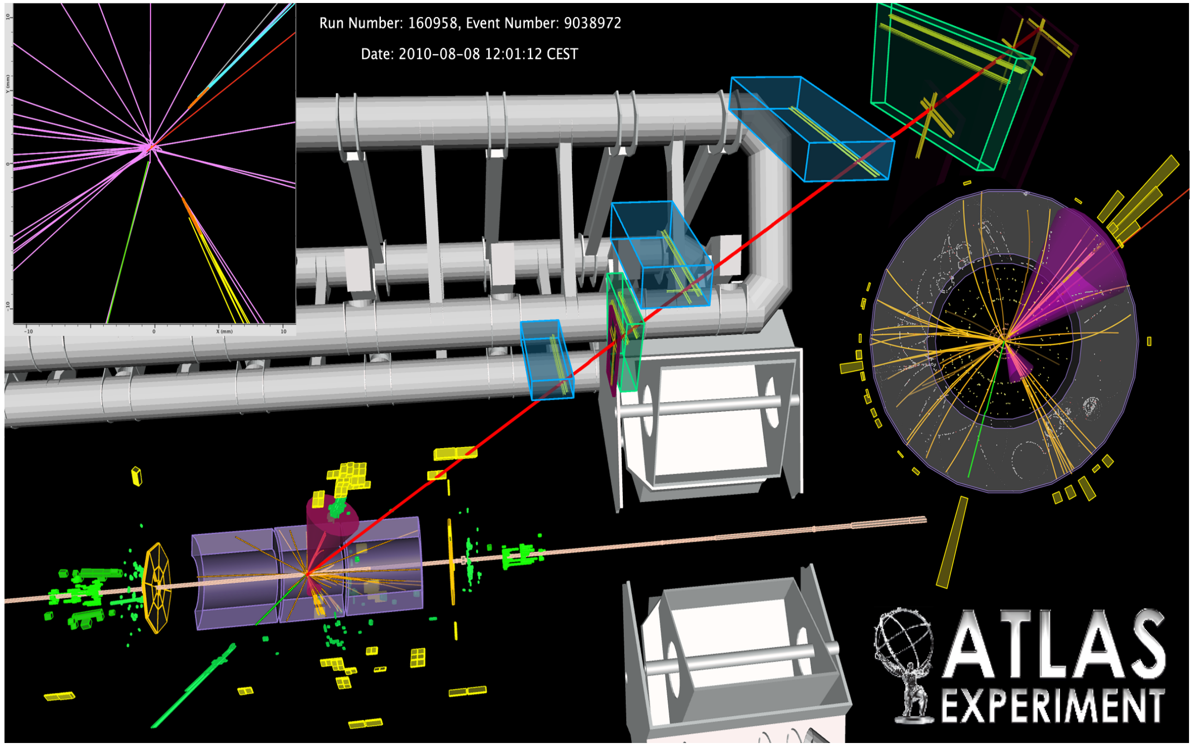
W transverse mass
μ with p_T>20 GeV, E_T^{miss}>25 GeV

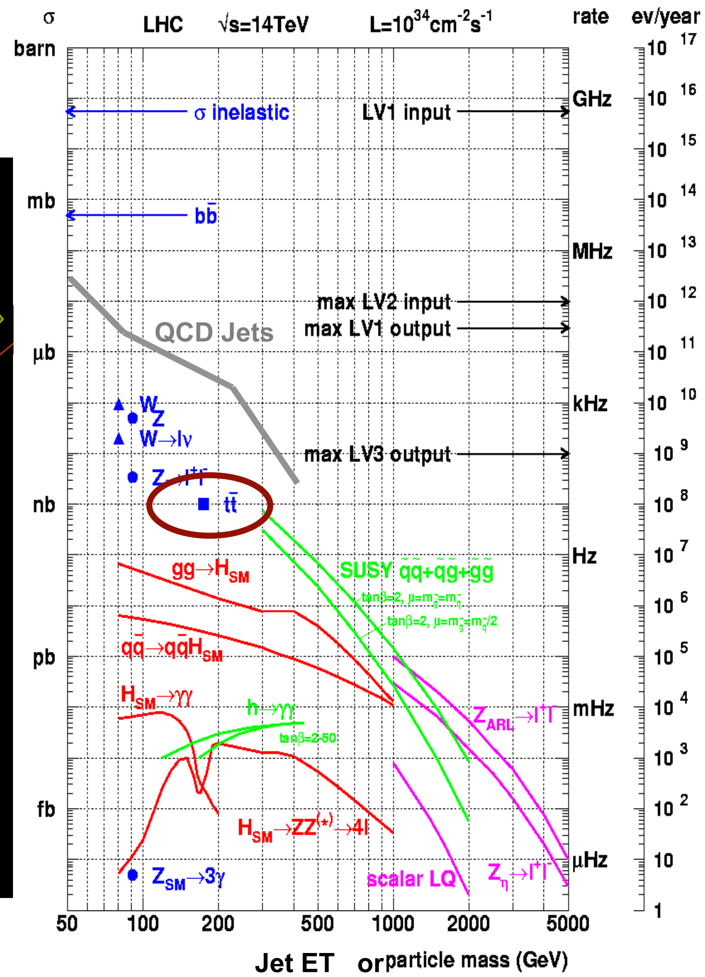


$$m_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}}^{\ell} p_{\mathrm{T}}^{\nu} (1 - \cos(\phi^{\ell} - \phi^{\nu}))}$$

Top Quark Cross-Section measurement

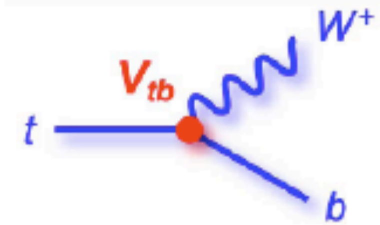
A Top Candidate Event: eμ + 2 b-jets + MET
Ideal channel to probe detector performance



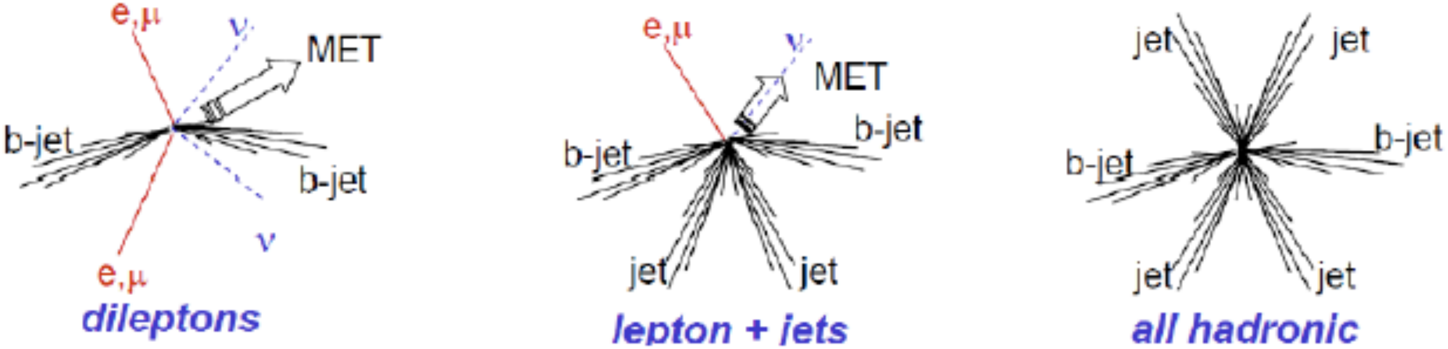


Top Quark Cross-Section measurement

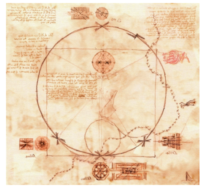
- Top decays before it can hadronize
  - almost exclusively t->Wb



- Top pair event classification according to W decays



Branching ratio:	~5%	~30%	~46%
Backgrounds:	few (mainly Z+jets)	moderate (mainly W+jets)	huge (mainly QCD)



Top Quark Cross-Section measurement

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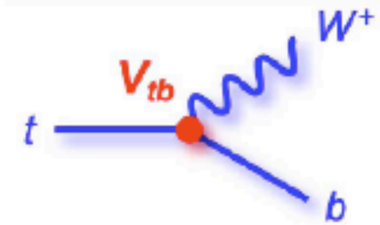
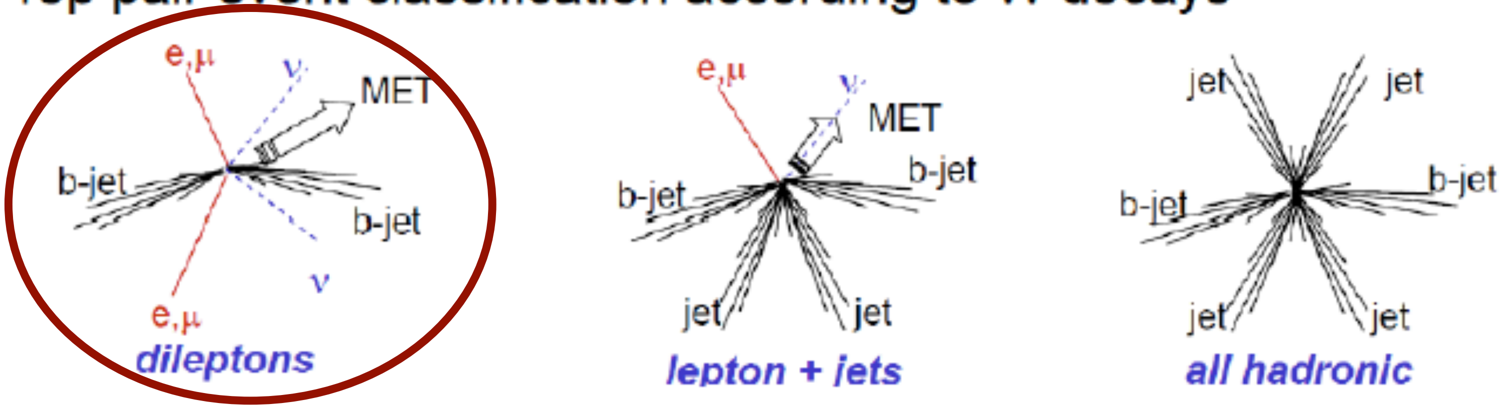


- Top pair event classification according to W decays

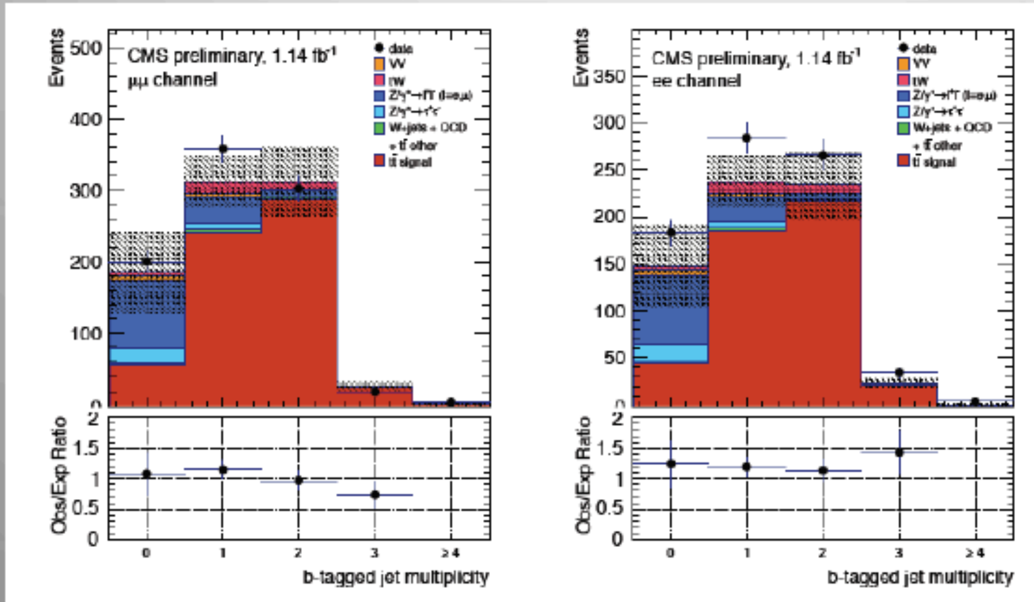


Branching ratio:	~5%	~30%	~46%
Backgrounds:	few (mainly Z+jets)	moderate (mainly W+jets)	huge (mainly QCD)

CMS: Di-lepton analysis

- Require 2 leptons (e,μ) and 2 b-tagged jets
- Robust cut and count method

CMS-TOP-11-005



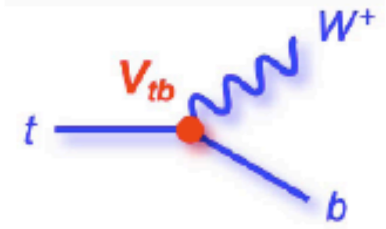
NEW

1.1 fb^{-1}

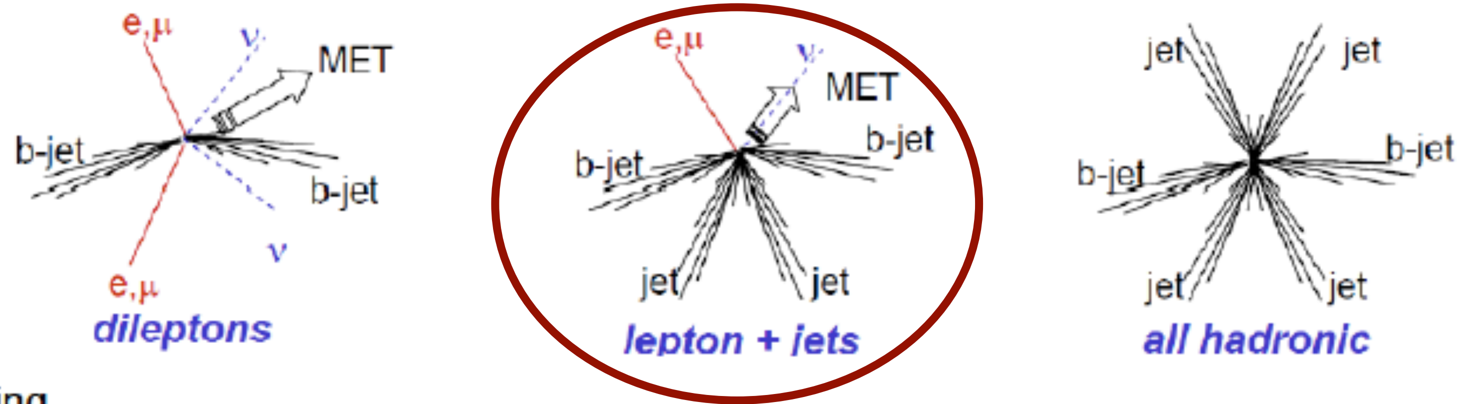
$$\sigma(t\bar{t}) = 169.9 \pm 3.9(stat) \pm 16.3(syst) \pm 7.6(lumi.)\ \text{pb}$$

Top Quark Cross-Section measurement

- Top decays before it can hadronize
  - almost exclusively t->Wb



- Top pair event classification according to W decays

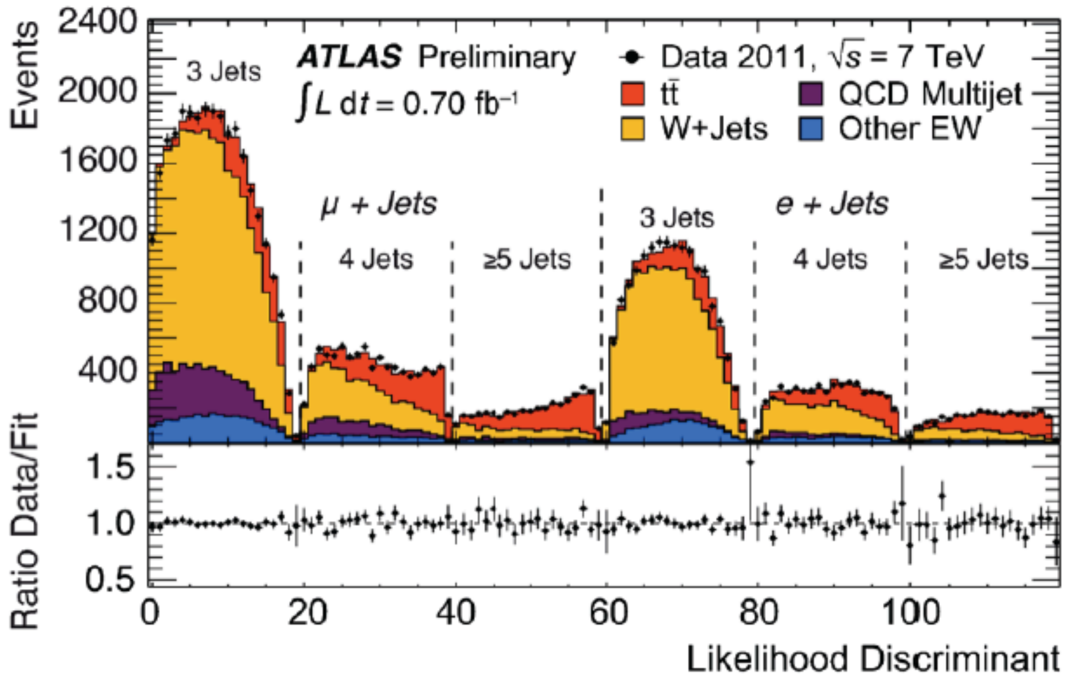


Branching ratio:	~5%	~30%	~46%
Backgrounds:	few (mainly Z+jets)	moderate (mainly W+jets)	huge (mainly QCD)

Top Quark Cross-Section measurement

ATLAS: Lepton+Jets

- Include both muon and electron channels; untagged
- Make use of kinematical differences between ttbar ad W+jets



ATLAS-CONF-2011-121

0.70 fb^{-1}

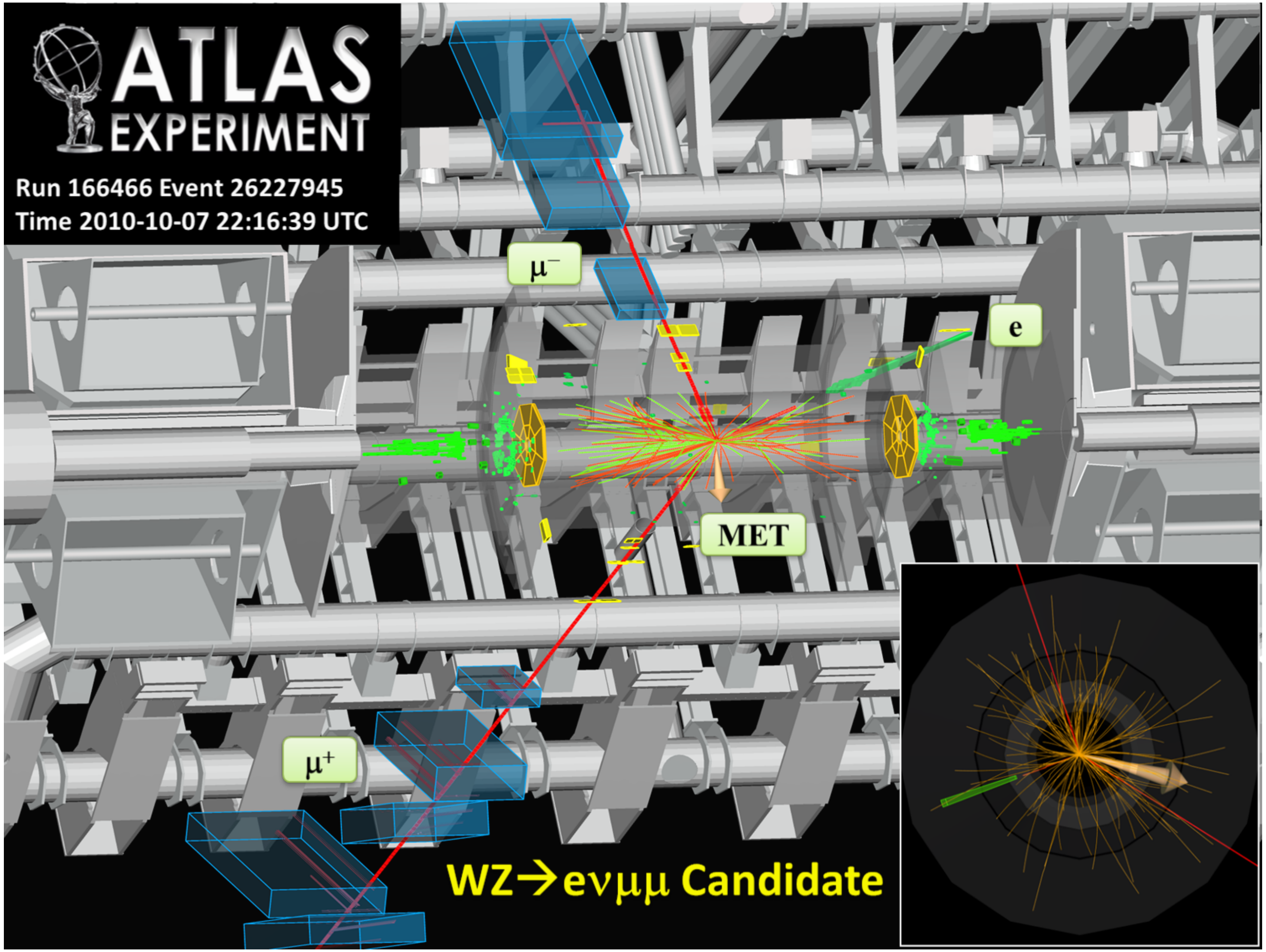
NEW

$$\sigma_{t\bar{t}} = 179.0 \pm 3.9\,(\mathrm{stat}) \pm 9.0\,(\mathrm{syst}) \pm 6.6\,(\mathrm{lumi})\ \mathrm{pb}$$

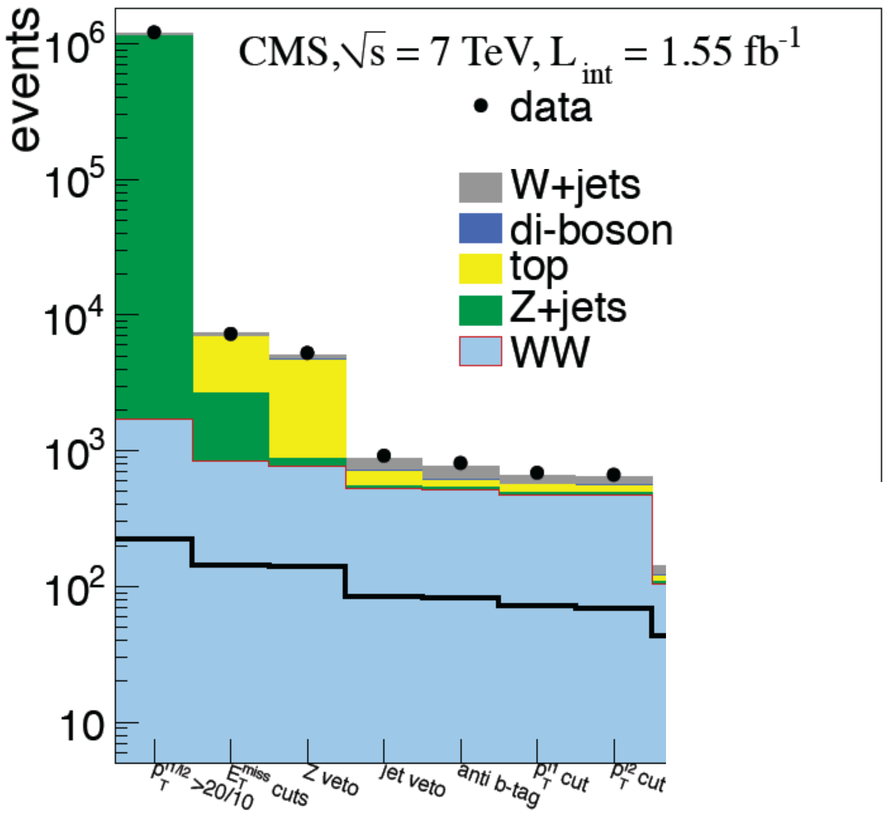
7% precision!!
August 2011

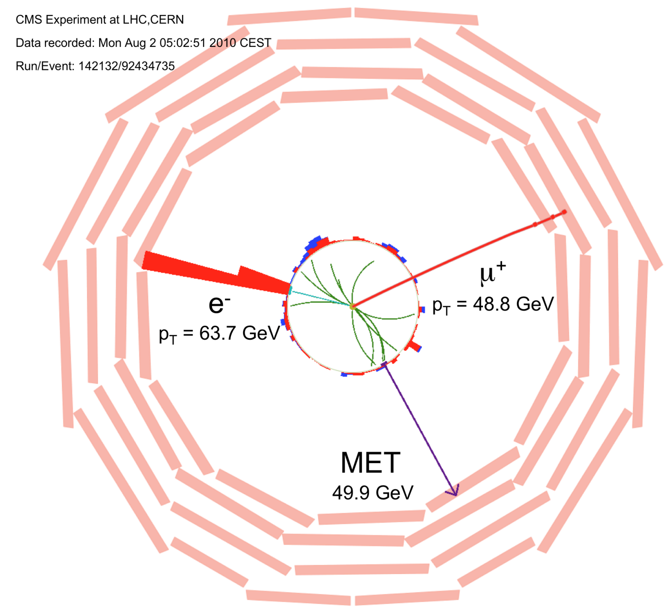
Single most precise measurement

Di-Boson Production



WW Production





Strategy:

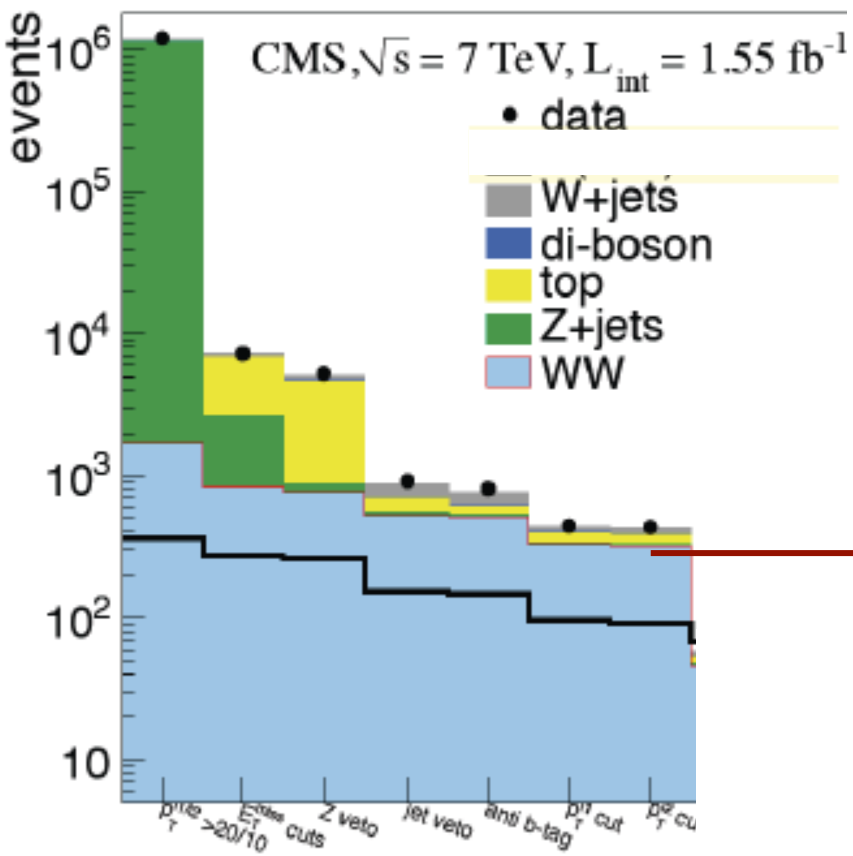
Select clean sample of WW events using distinctive Leptonic decay signature

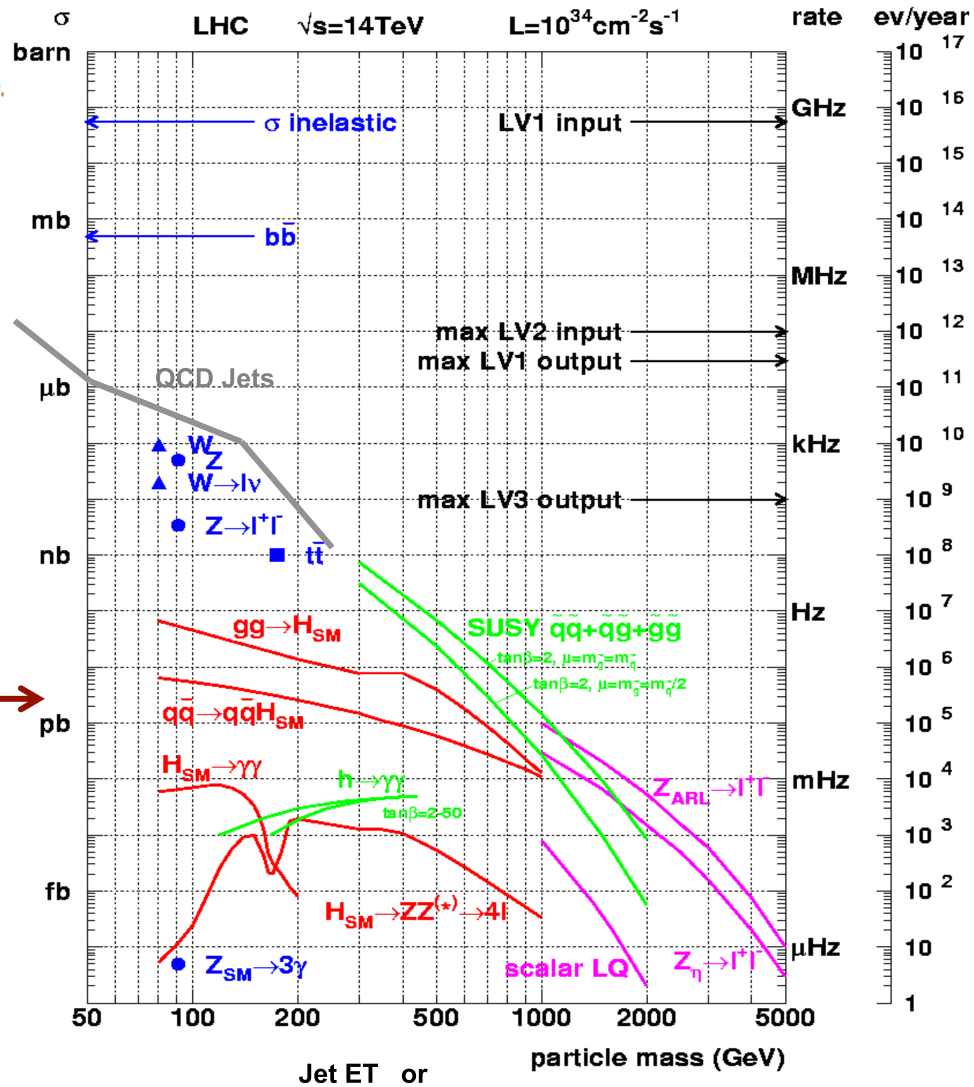
2 High P_T, Isolated Leptons (e, μ)
Substantial MET

Veto events with $M_{ll} \sim M_Z$
veto events with ‘s (top)

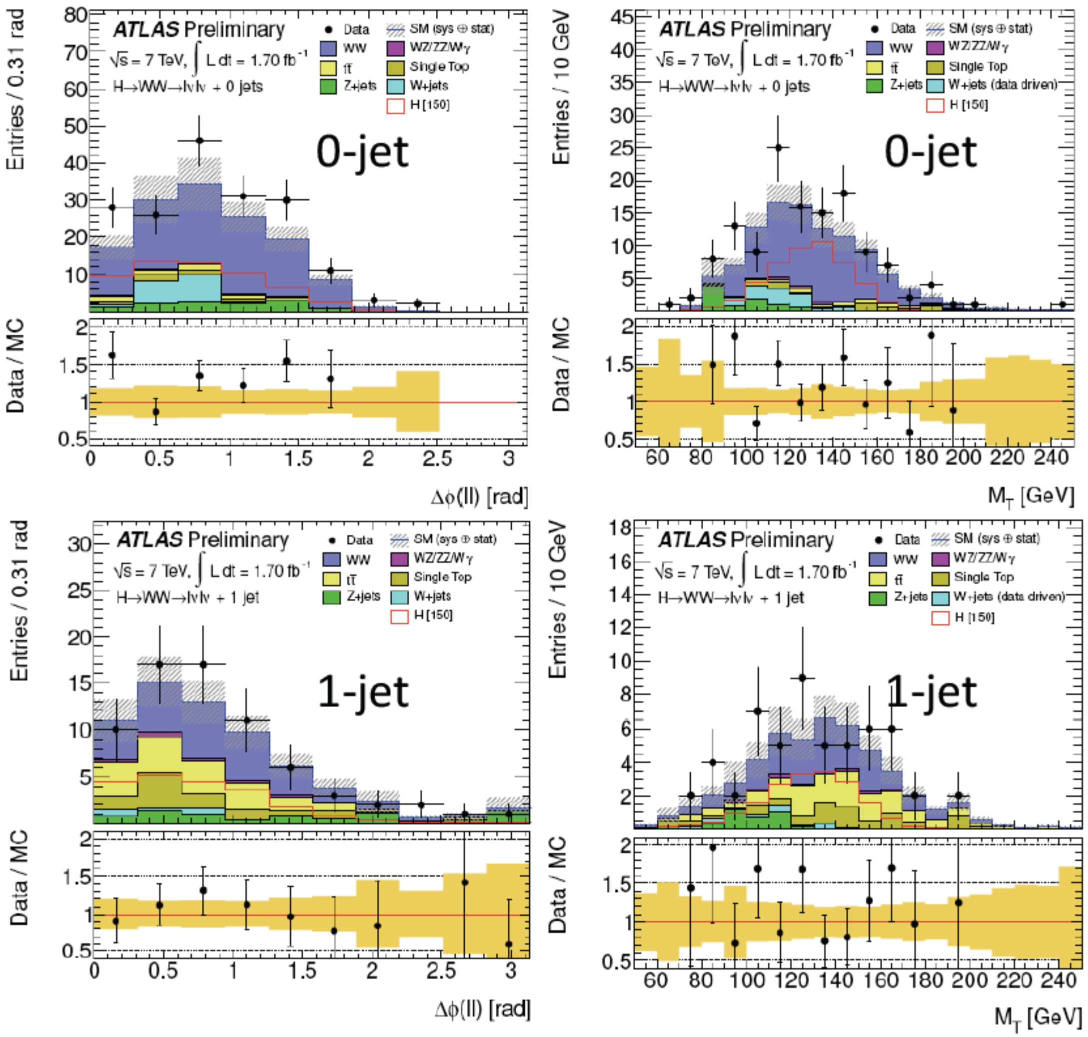
WW Production

$\sigma_{W^+W^-} = 41.1 \pm 15.3\,(\text{stat}) \pm 5.8\,(\text{syst}) \pm 4.5\,(\text{lumi})$ pb.





WW Production



$H \rightarrow WW \rightarrow 2l2\nu$: when Performance exceeds Initial Expectation…

Main Irreducible Background is
Non-resonant WW production:
~ 43pb vs ~ 10pb for M_H ~ 160GeV

$\Rightarrow$ Solid understanding of WW production
Required for H->WW Search

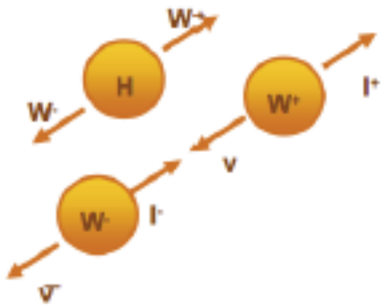
Strategy:

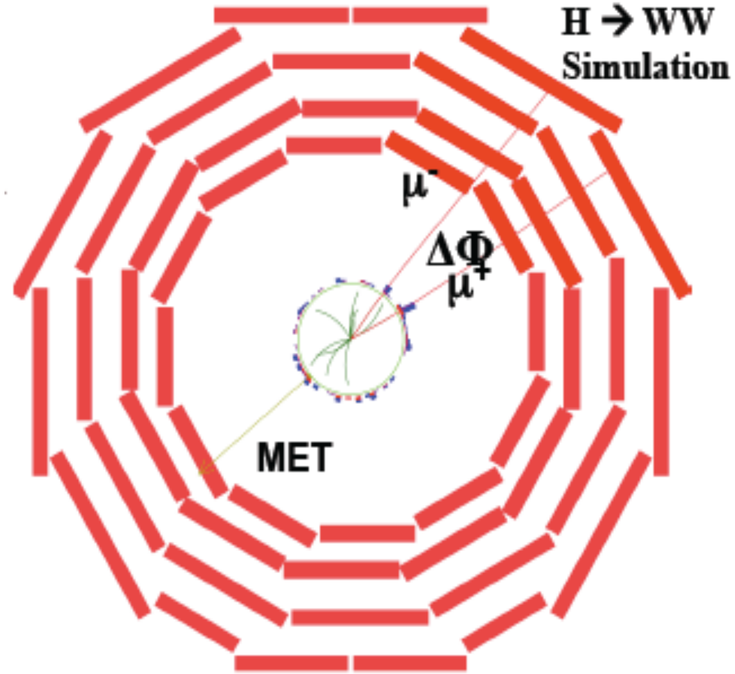
Select clean sample of WW events, using distinctive Leptonic decay signature

2 High P_T, Isolated Leptons (e, μ)
Substantial MET

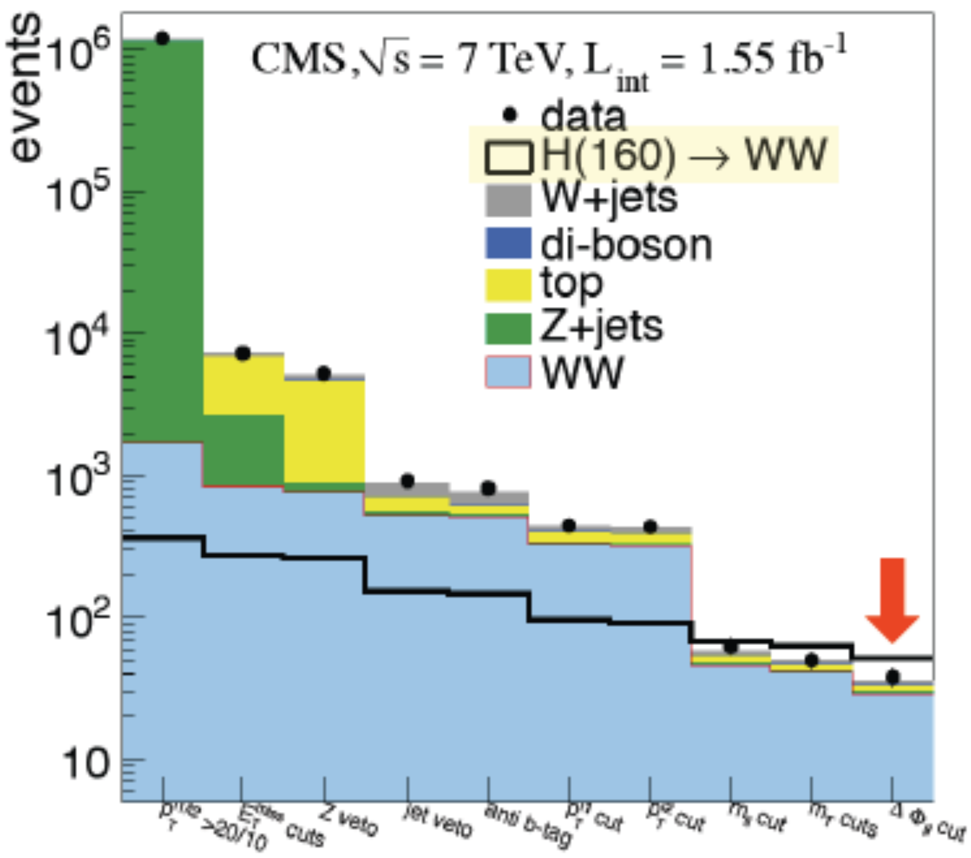
Exploit Helicity Driven Topology of H->WW

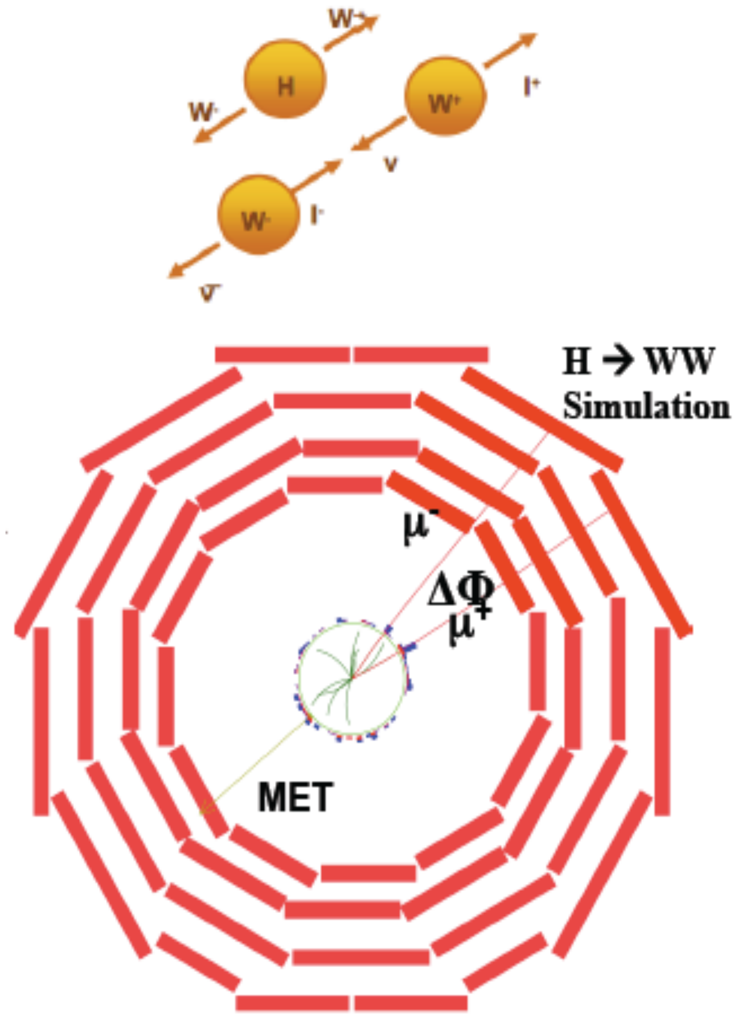
Small Lepton Opening Angle
MET and Lepton P_T closely aligned



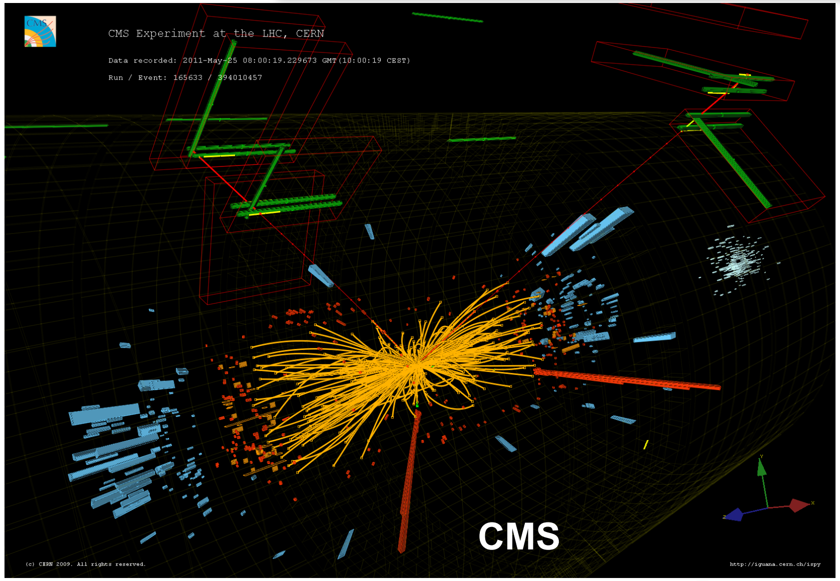


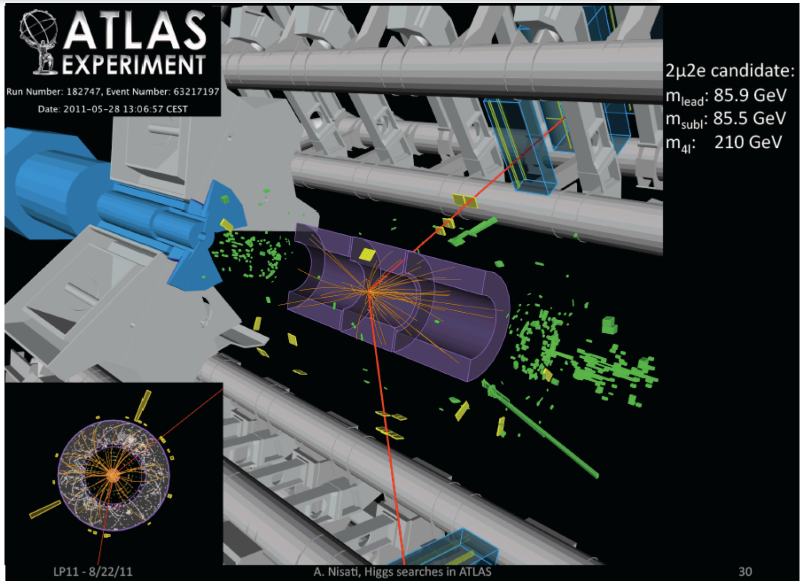
H -> WW -> 2l2ν: when Performance exceeds Initial Expectation…

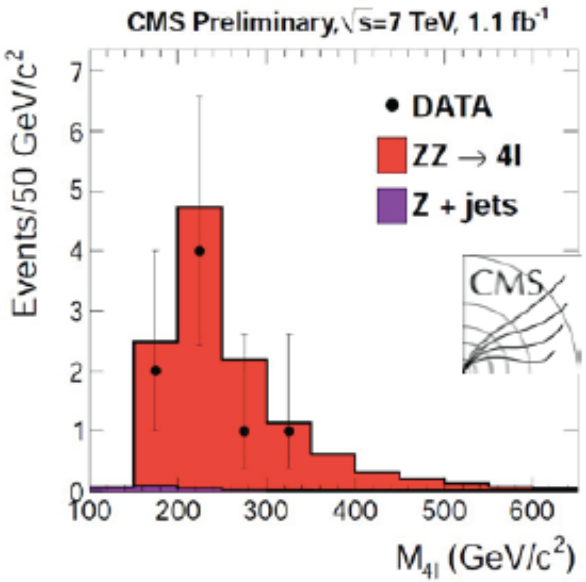


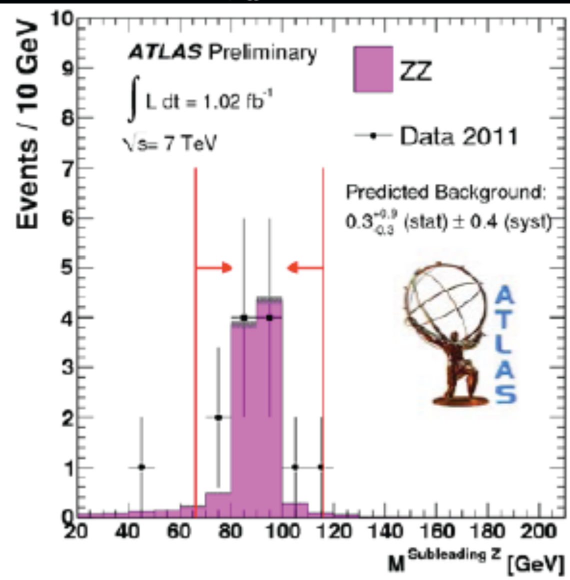


ZZ Production









Higgs Search Channels as function of M_H: A more Contemporary Picture

Primary Higgs Search Channels vs M_H

Low Mass:

H -> $\gamma\gamma$ WW ZZ

H -> $\tau\tau$

VBF H -> $\tau\tau$ bb WW

V H -> bb

Intermediate Mass:

H -> WW ZZ

VBF H -> WW ZZ

High Mass:

H -> ZZ (4l, ll$\nu\nu$, llqq) WW

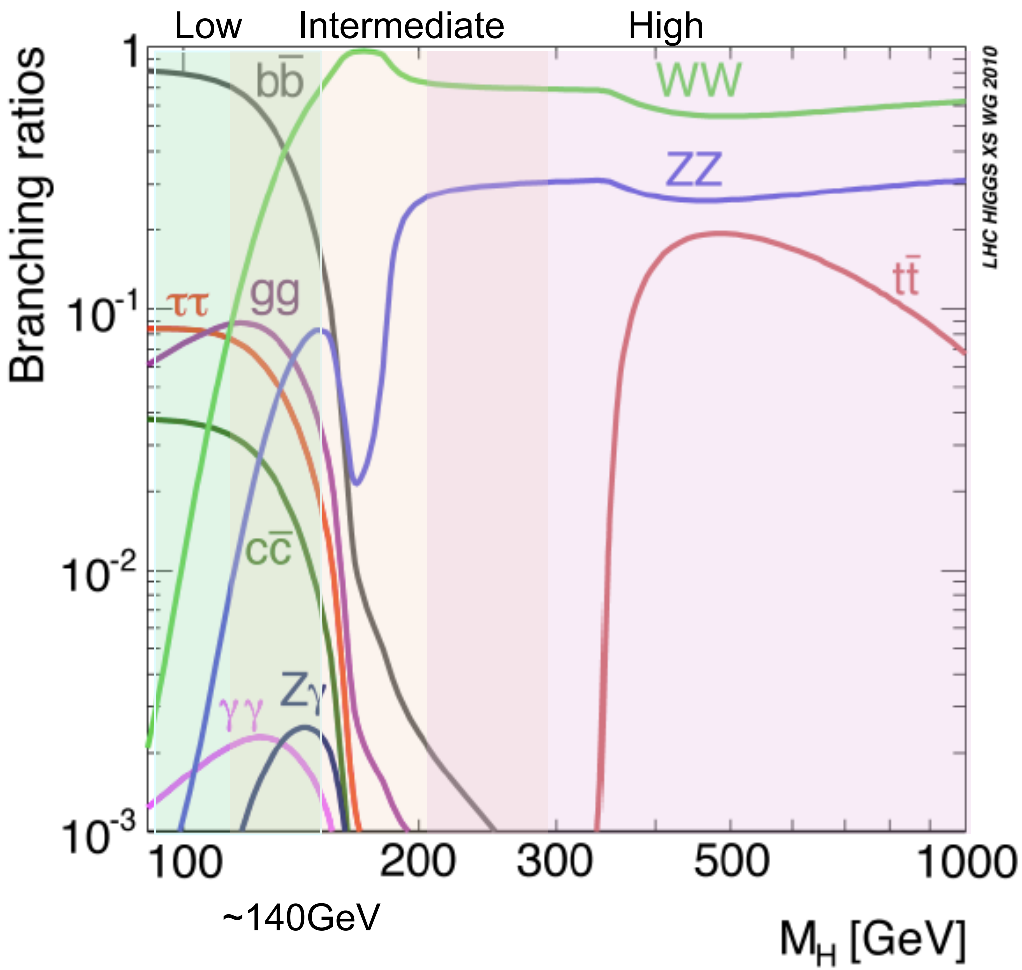
VBF H -> ZZ WW

MSSM Higgs:

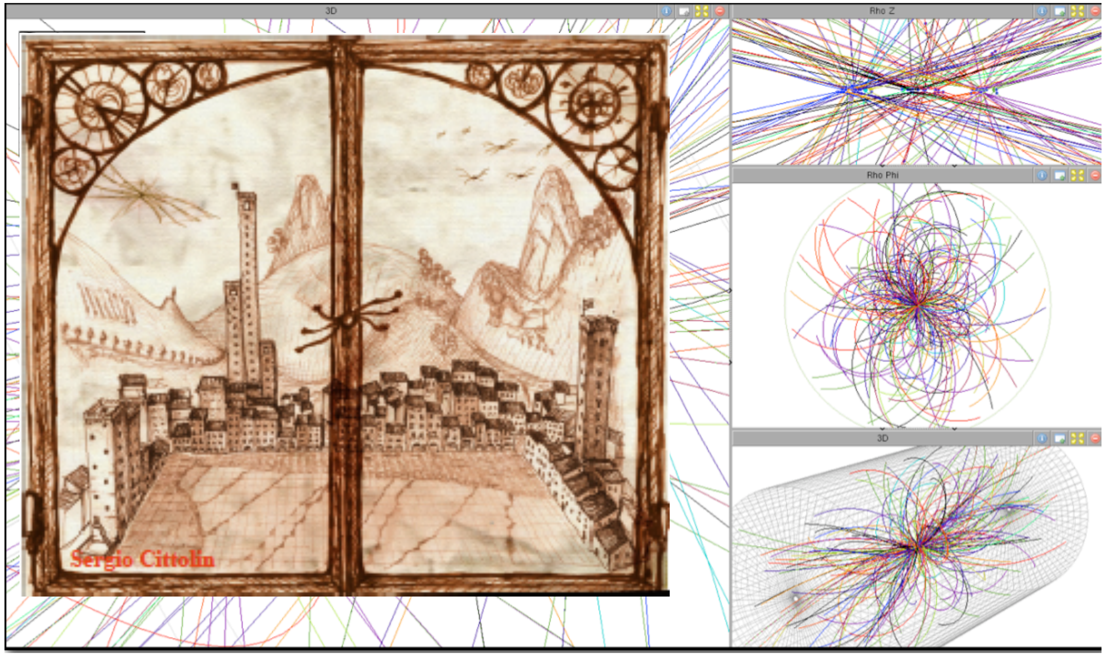
H -> $\tau\tau$

bb H -> $\tau\tau$

A more Contemporary Picture



Outlook for 2011 - 2012



The LHC and its Experiments are working well

Accumulating several fb^{-1} at sqrt(s)7TeV allows for a broad exploration of the Higgs sector
⇒ The Higgs story will ~~begin~~ continue to unfold in the months ahead:

Will it be that the last piece of the SM falls into place?
Will it the be that the first piece of New Physics shows up?
Will we have to completely re-think things?

Watch this space!

Back up

Particle Flow in CMS

Particle Flow in CMS

3.8T Solenoid Field of the CMS Experiment

Combined with >2.2m ECAL Inner Diameter

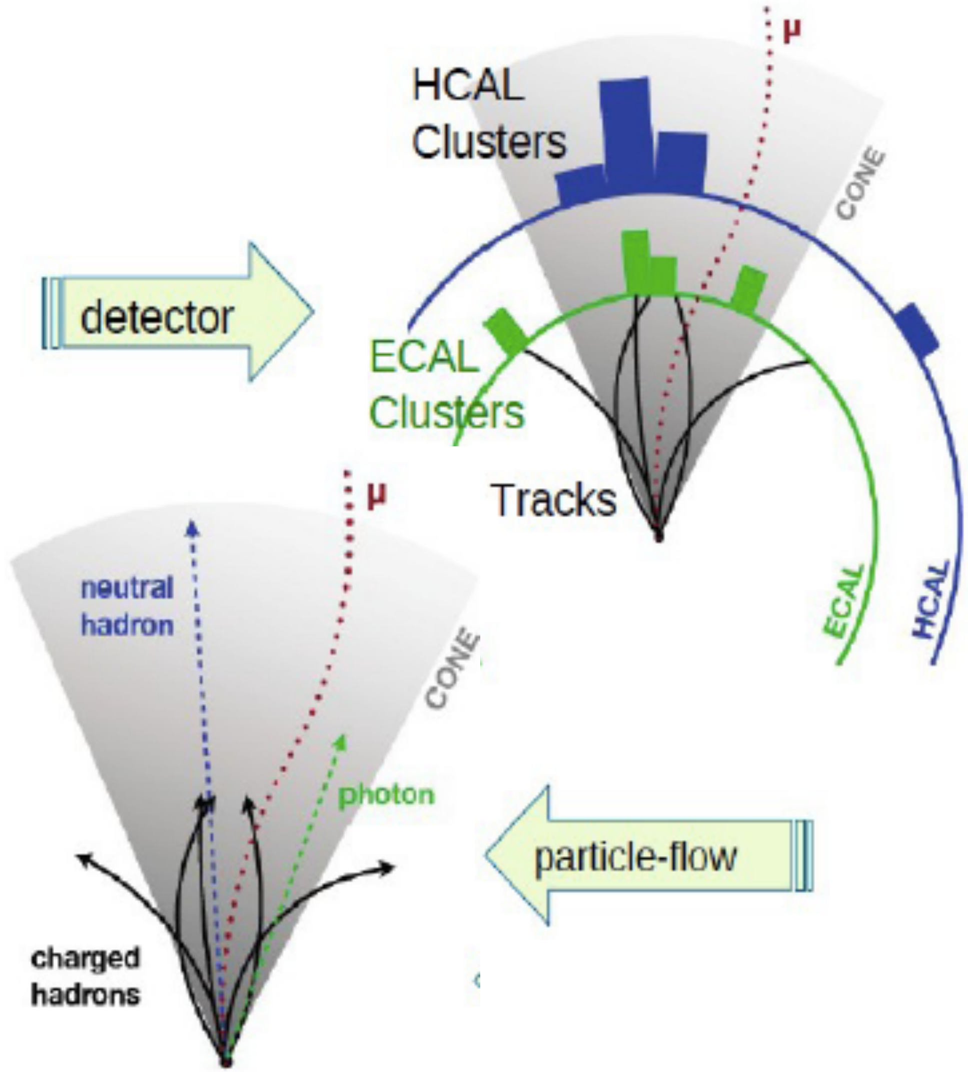
=> Good Charged Particle separation in Calorimeters

Charged Particles are swept out by B field and Accurately Reconstructed in Silicon Tracker, down to p_T ~ 200MeV

Fine ECAL lateral segmentation allows Identification and Accurate Reconstruction of Electrons and Photons

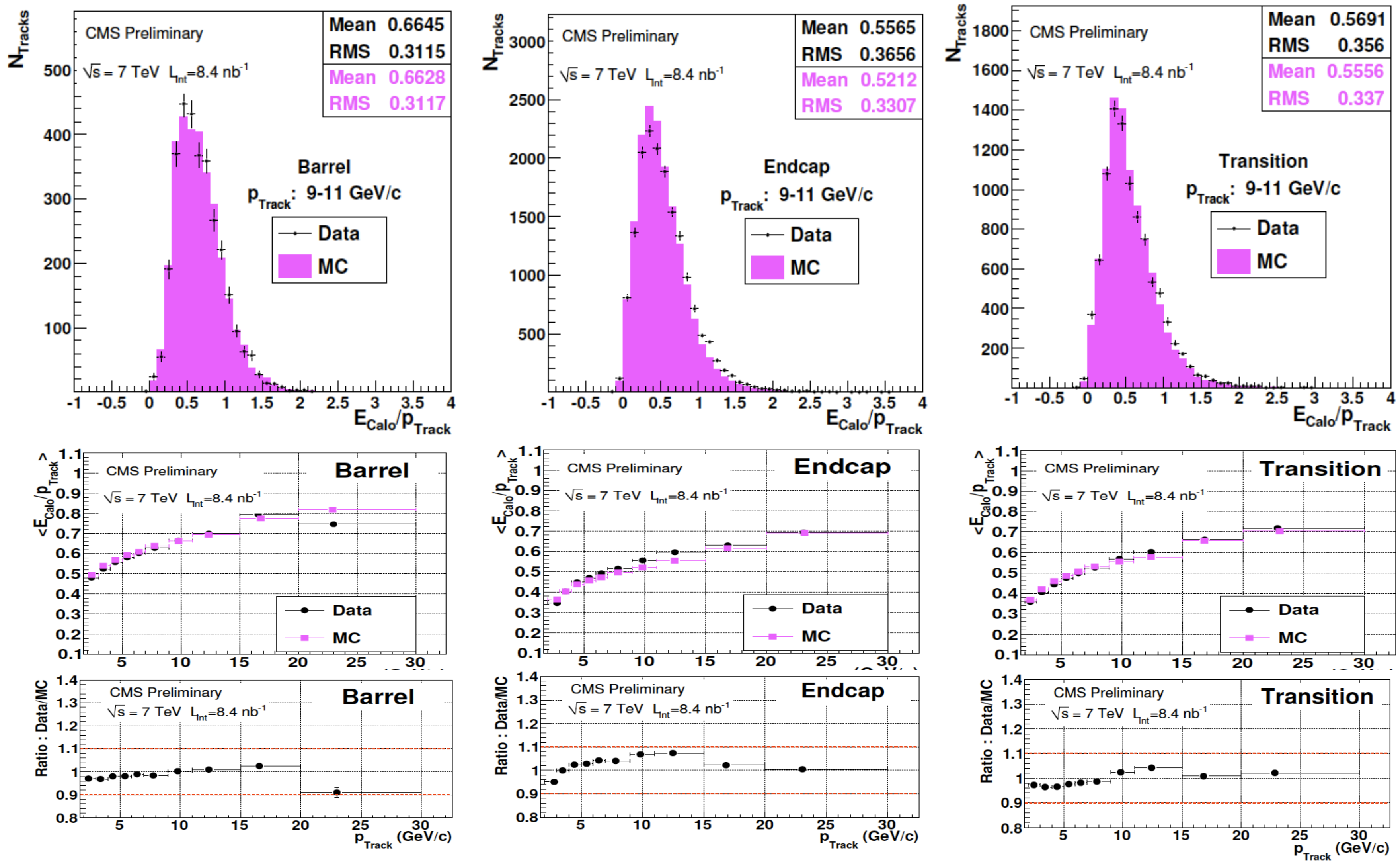
Stable Neutral Particles (~10% of Jet Energy) are reconstructed using ECAL and HCAL combined

=> CMS Very Well Suited to Particle Flow

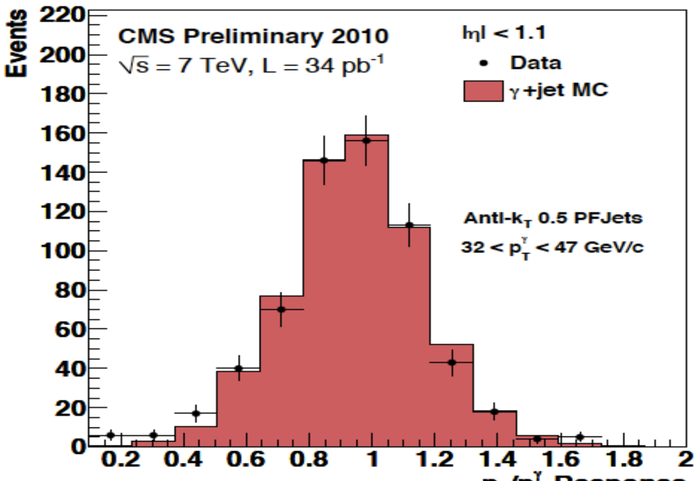


Single Pions
=> Calorimeter Response for Hadrons

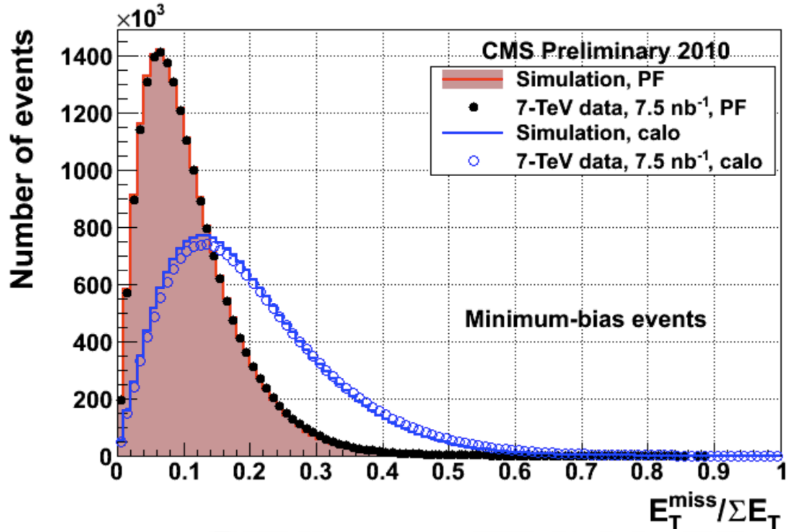
CMS PAS JME-10-008

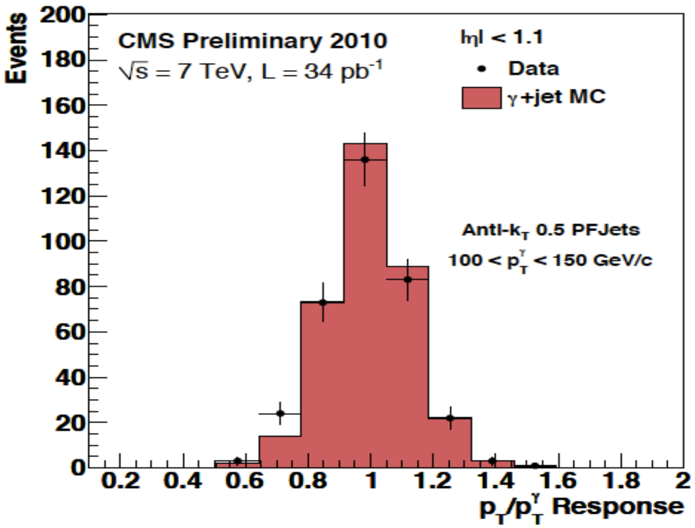


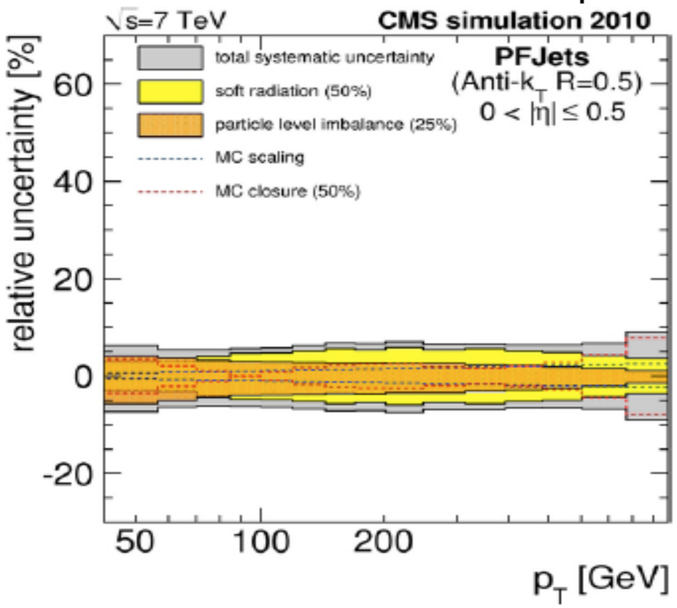
Particle Flow Gives Enhance Resolution and Robust Performance in CMS



CMS PAS JME-10-014

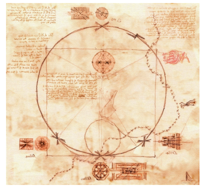






MSSM H -> $\tau\tau$
Hadronic Tau reconstruction in CMS

MSSM H -> ττ
Hadronic Tau reconstruction in CMS



In the **MSSM**, for large tanβ couplings to down-type fermions ~ proportional to tanβ:

Production cross-section is substantially enhanced, and the ττ decay Branching Ratio is large over the full h/H mass range

The H -> ττ channel can probe the large tanβ MSSM regime already with ~ few x $10pb^{-1}$

With higher Integrated Luminosity can contribute to low mass Higgs search

Requires Efficient and Highly Selective τ lepton reconstruction

To discriminate against QCD background

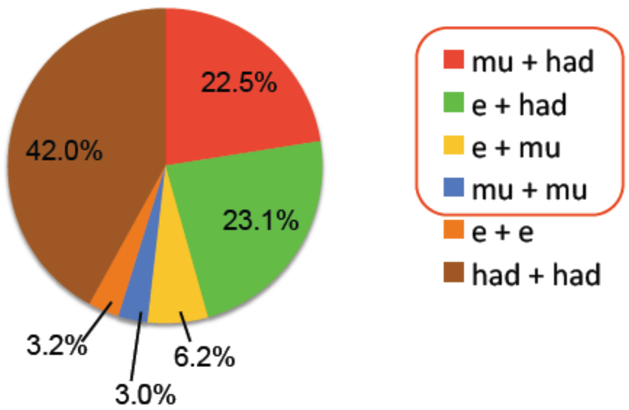
Requires good reconstruction of event kinematics

To discriminate against Z -> ττ background
And reconstruct M_H

MSSM H -> ττ
Hadronic Tau reconstruction in CMS

- **Hadronic final states account for about 2/3 of tau decays**
- **These are narrow low multiplicity jets**
  - **One or three charged track + 0, 1, 2 (3) π^0(s)**
- **Exploit high B field and high ECAL granularity for detailed Particle Flow reconstruction of t hadronic final states**

Decay Mode	Resonance	Mass (MeV/c^2)	Branching ratio(%)
$\tau^- \rightarrow e^- \bar{\nu}_e \nu_\tau$			17.8 %
$\tau^- \rightarrow \mu^- \bar{\nu}_\mu \nu_\tau$			17.4 %
$\tau^- \rightarrow h^- \nu_\tau$			11.6 %
$\tau^- \rightarrow h^- \pi^0 \nu_\tau$	ρ	770	26.0 %
$\tau^- \rightarrow h^- \pi^0 \pi^0 \nu_\tau$	$a1$	1200	10.8 %
$\tau^- \rightarrow h^- h^+ h^- \nu_\tau$	$a1$	1200	9.8 %
$\tau^- \rightarrow h^- h^+ h^- \pi^0 \nu_\tau$			4.8 %
Other hadronic modes			1.7%



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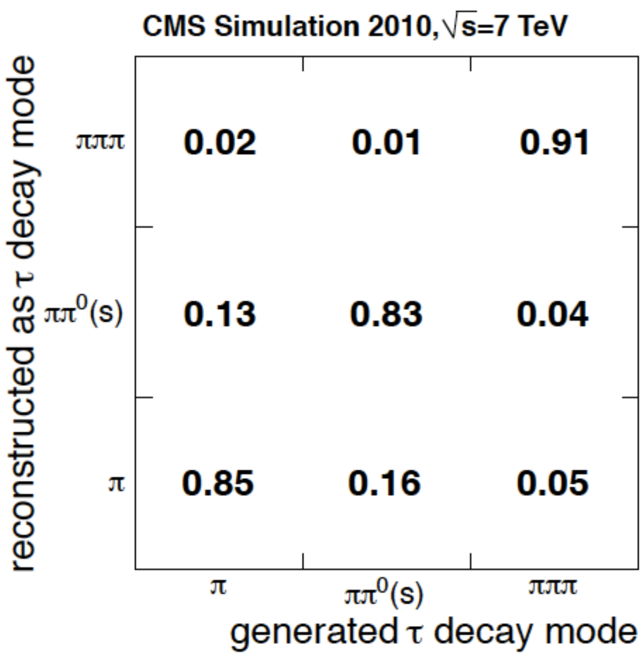

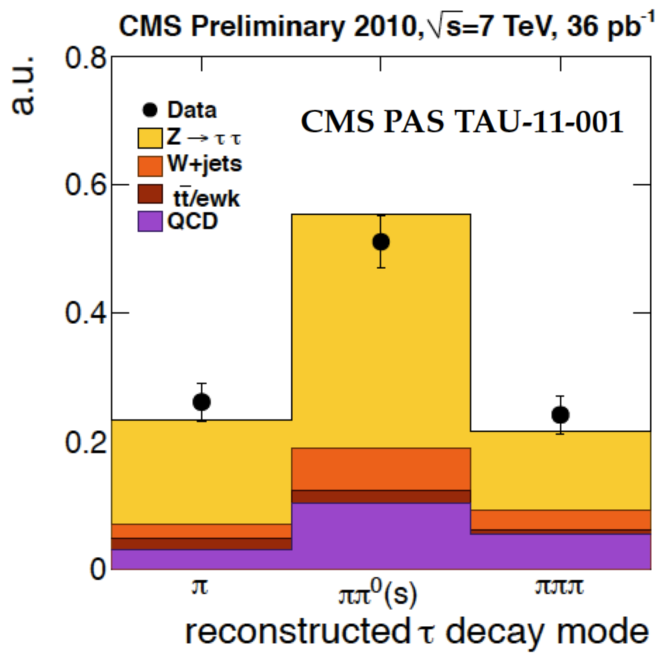

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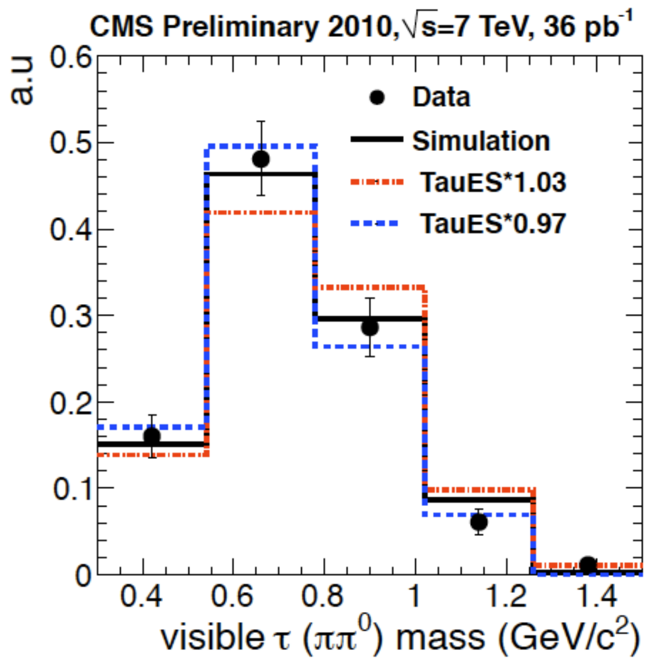

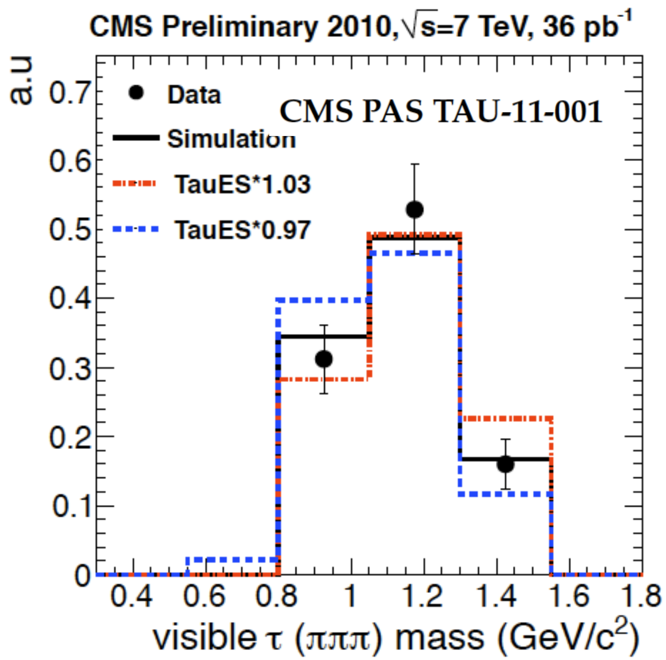

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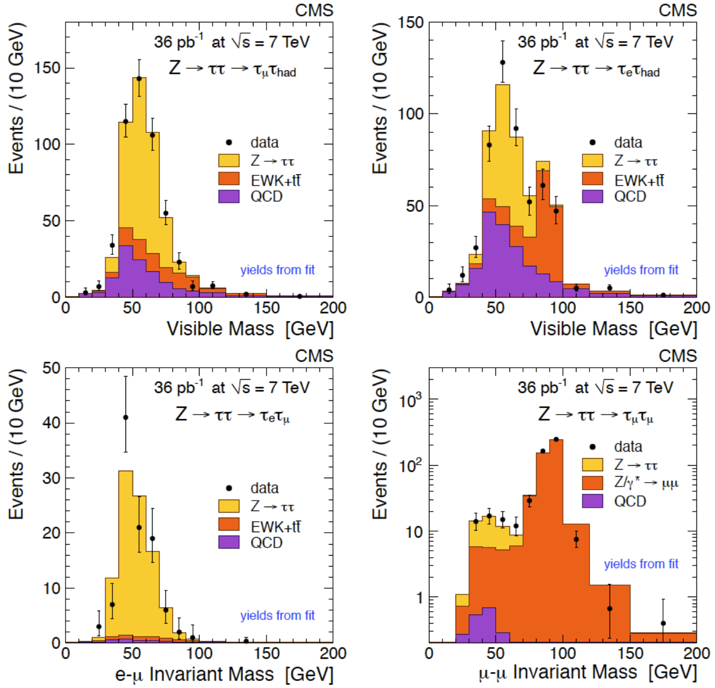
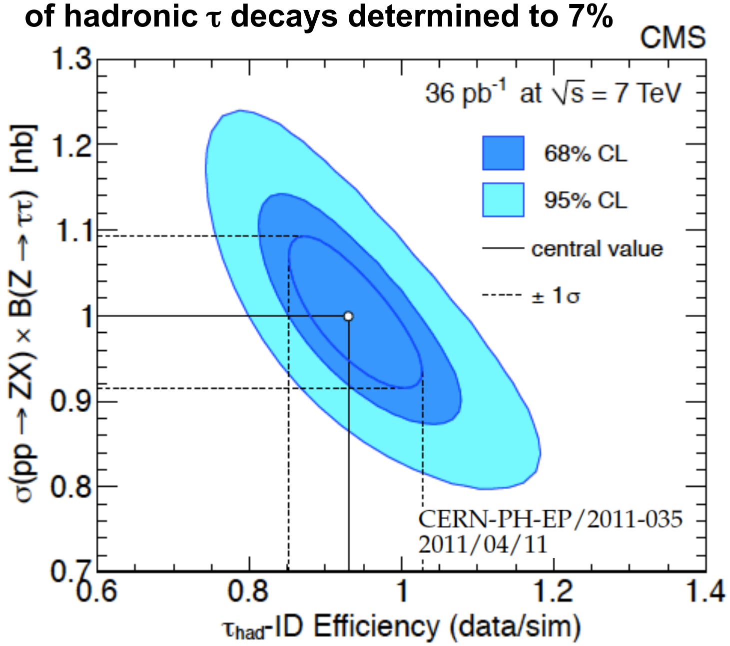


Fit to Z -> $\tau\tau$ cross-section => Reconstruction efficiency of hadronic τ decays determined to 7%



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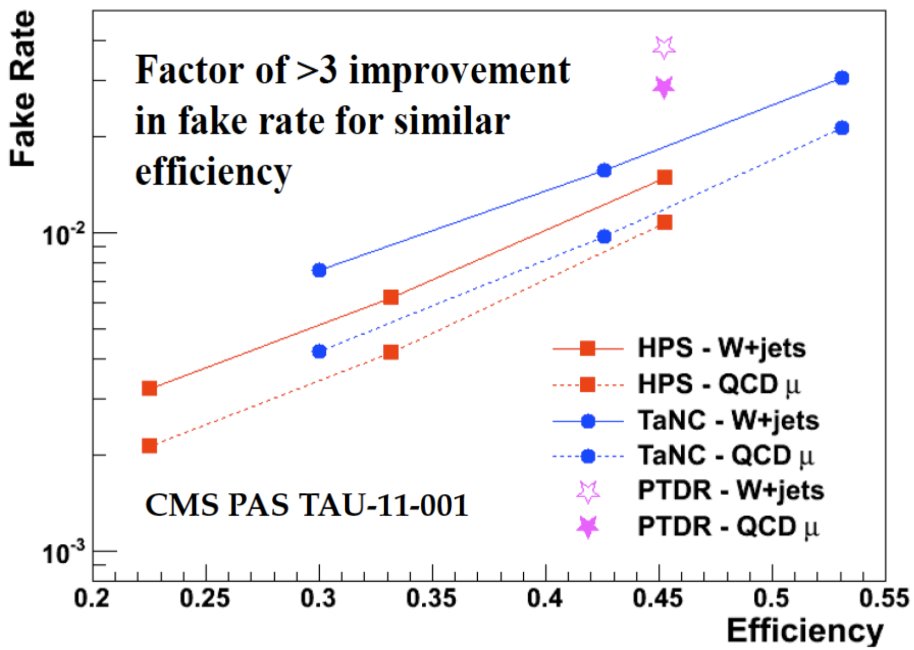


MSSM H -> $\tau\tau$
Results with 36pb^{-1}

CMS PAS HIG-10-002

Select final states with

$e\tau_{had}$, $\mu\tau_{had}$, $e\mu$

(Drell-Yan => too much background for ee & $\mu\mu$)

For e/μ τ_{had} require

e/μ with p_T > 15GeV; $|\eta|$ < 2.1
Oppositely charged τ_{had}; p_T > 20GeV; $|\eta|$ <2.3

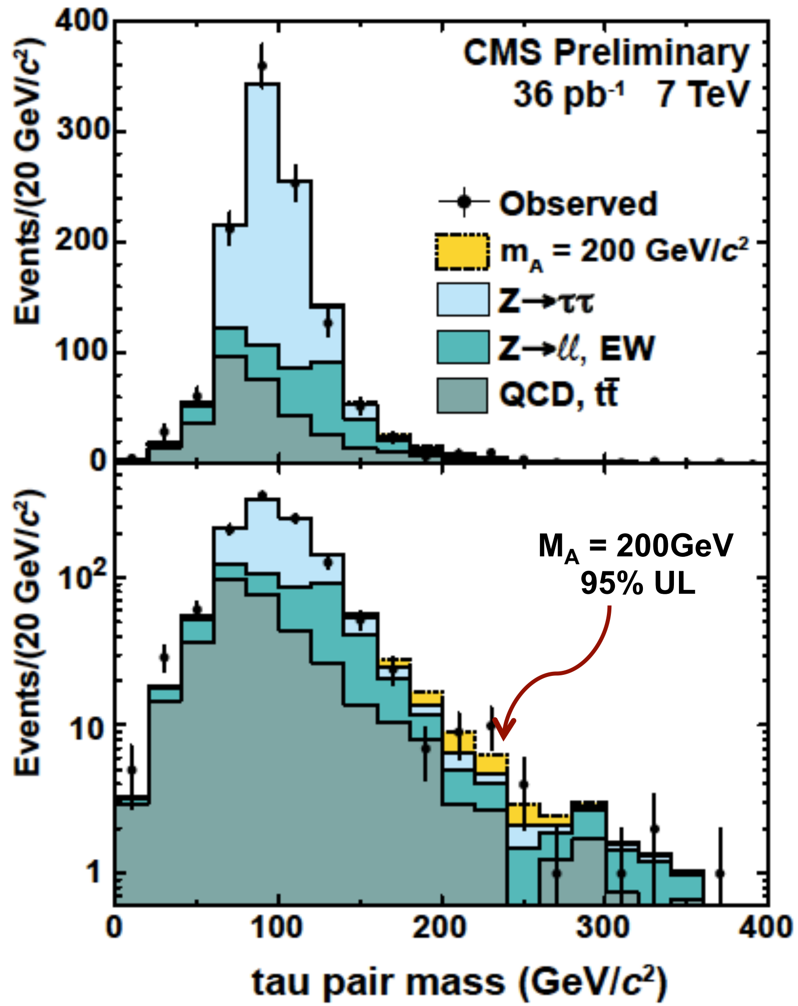
In addition require M_T < 40GeV (W+Jets veto)

For eμ require

opposite charge,
each with p_T > 15GeV; M_T < 50GeV

Veto events with extra e or μ

$$M_T = \sqrt{2 p_T^{\ell} E_T^{miss} \cdot (1 - \cos\Delta\phi)}$$



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For eμ require

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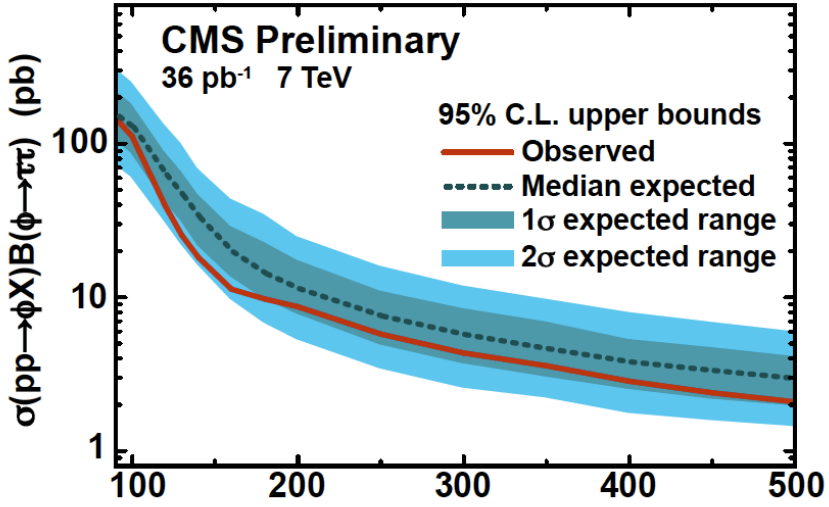
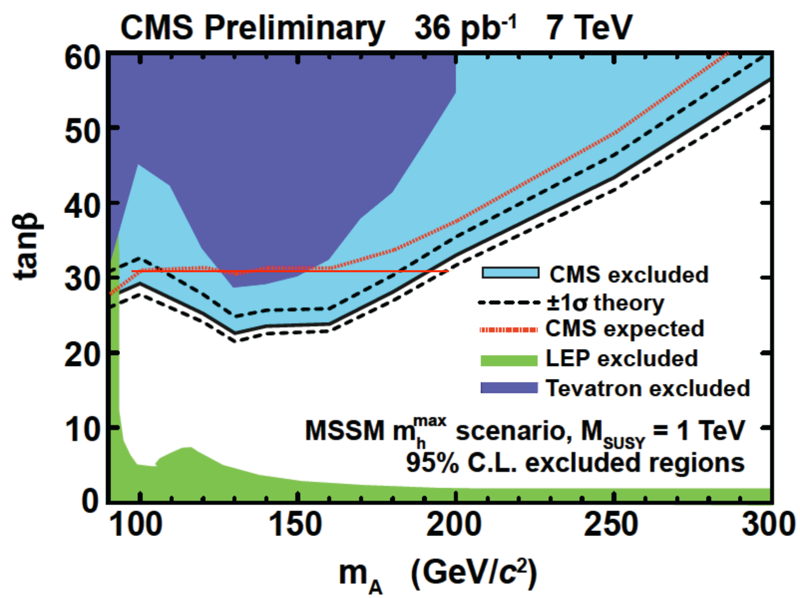
Veto events with extra e or μ

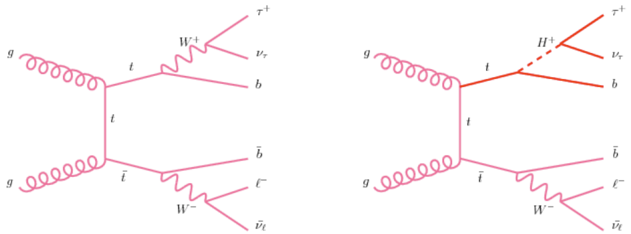
=> 36pb^{-1} allows tanβ > 30 region to be excluded for M_H < 200GeV

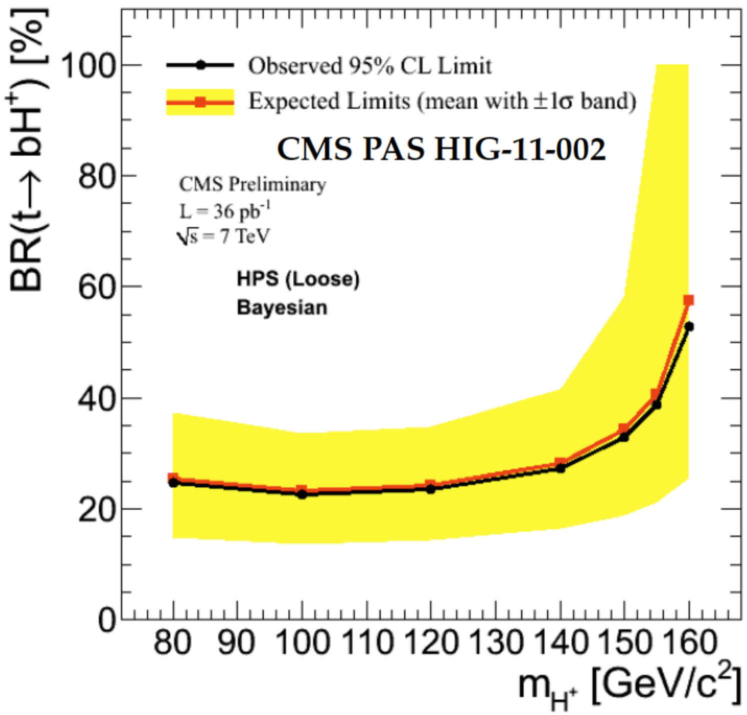




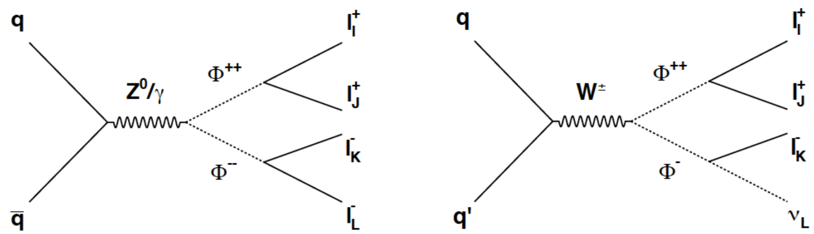
Charged Higgs Searches

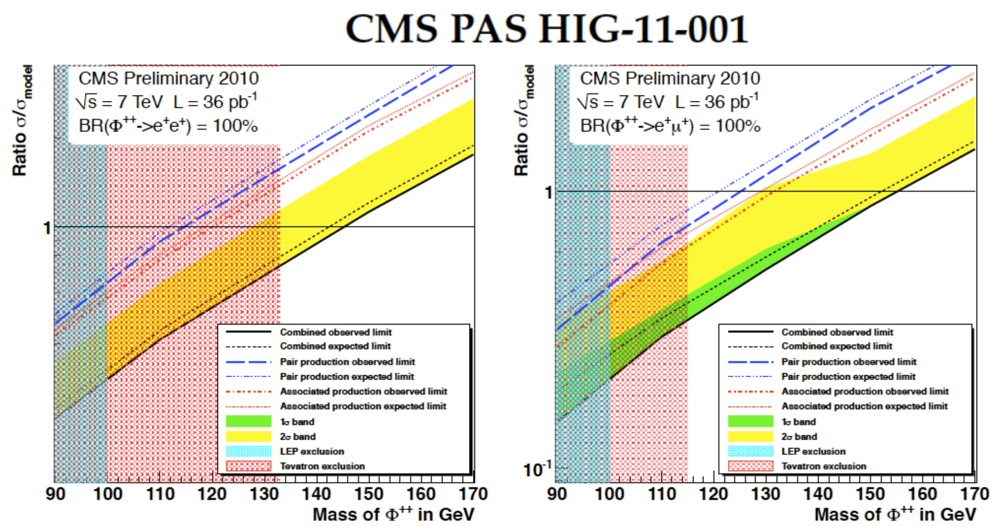
Search for H^+ in top decays





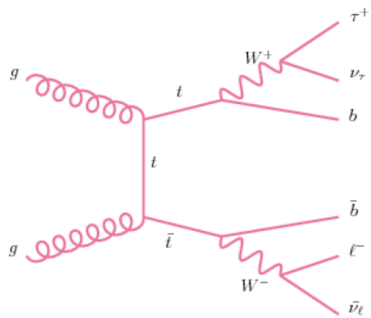
Search for H^{++} in leptonic decays

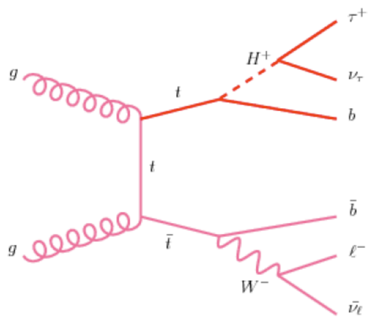


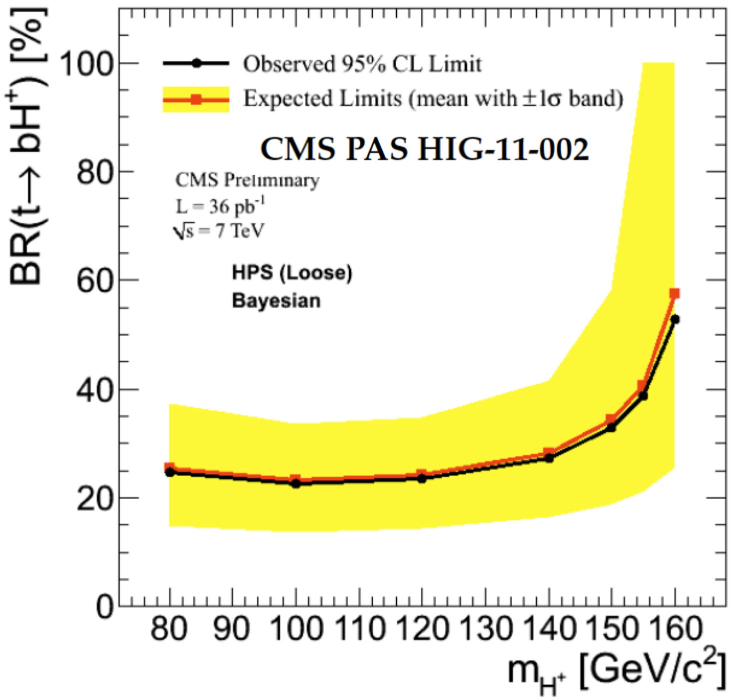


For more details, see the talk by A. Kumar in the afternoon parallel session

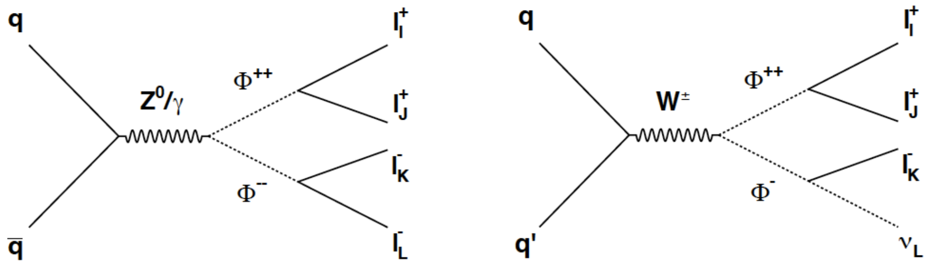
Search for Charged Higgs in top quark decays

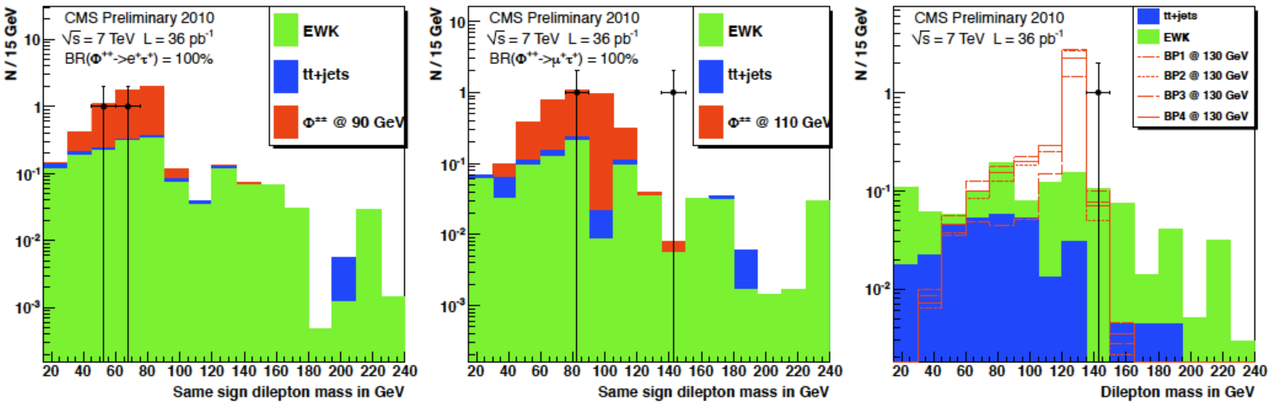




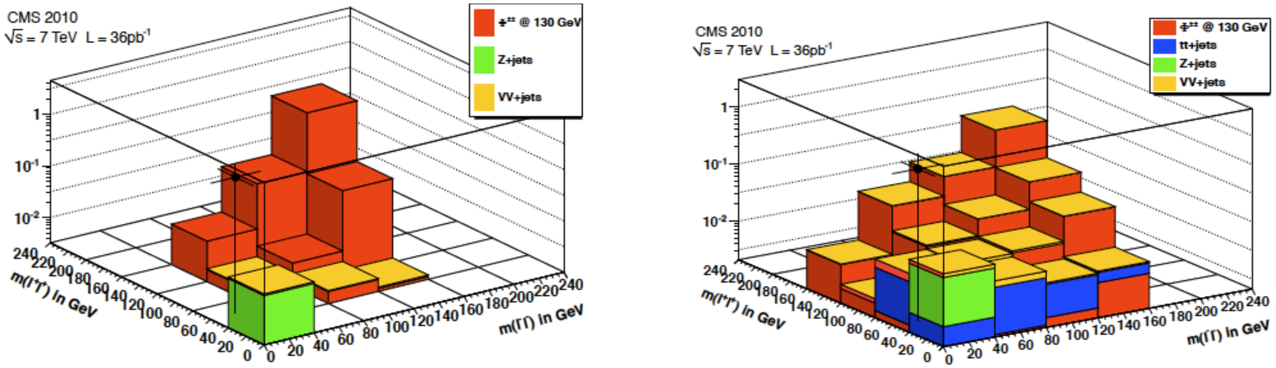


Search for Doubly Charged Higgs in leptonic decays





CMS PAS HIG-11-001



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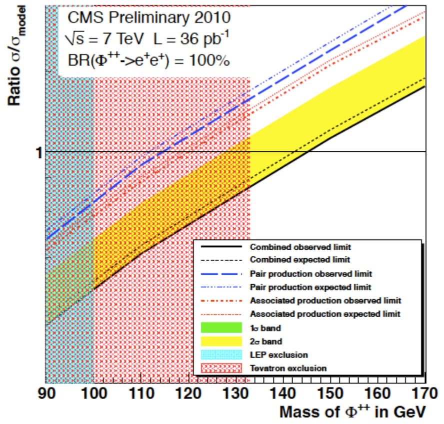
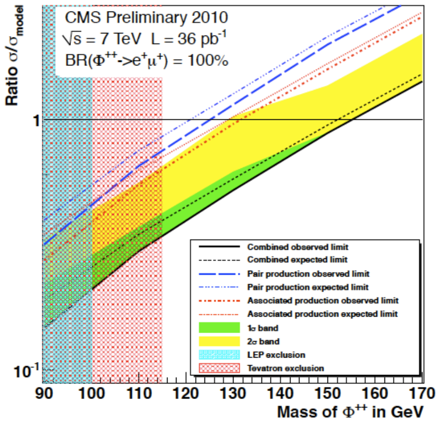
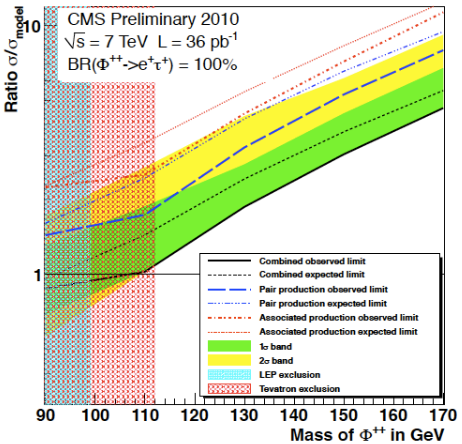
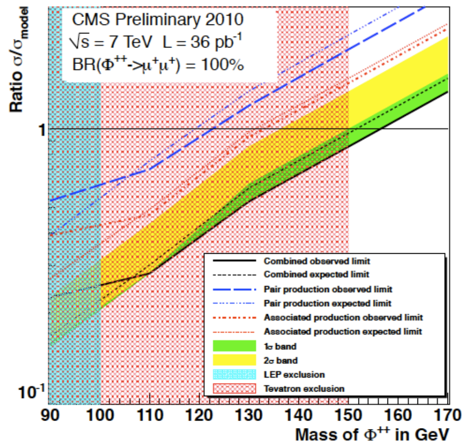
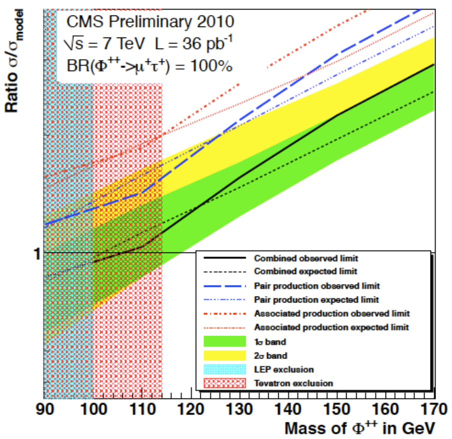


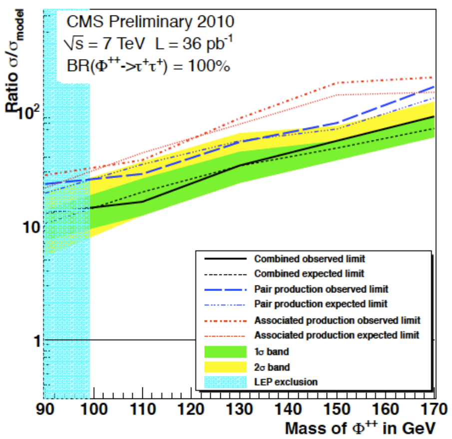






CMS PAS HIG-11-001

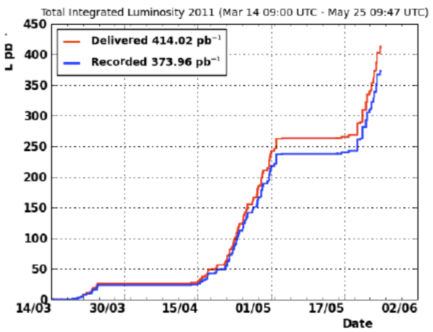


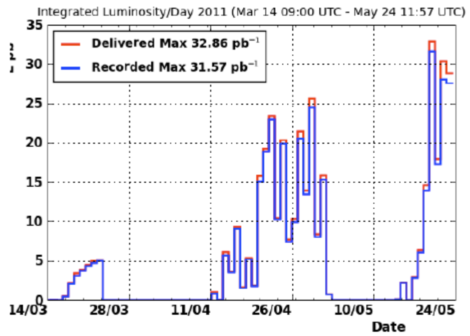


Prospects for 2011 - 2012

CMS operations

~414pb^{-1} delivered by LHC and **374pb^{-1}** collected by CMS. **We have recorded up to~ 32pb^{-1}/day. ~150pb^{-1}** of data delivered in 5 days; **Data taking efficiency >90%**;





As of today we are crusing at a "speed " > 0.6fb^{-1}/month and it could still improve by a factor 1.5-1.7.

G.TONELLI CERN/INFN/UNIPI WGM65 May 25 2011

May 25 2001

1fb^{-1} for Summer Conferences is within reach

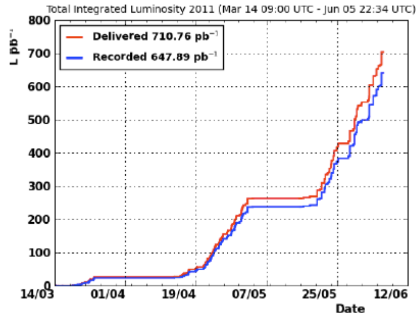
5 ~ 10fb^{-1} before long shutdown plausible (even conservative?)

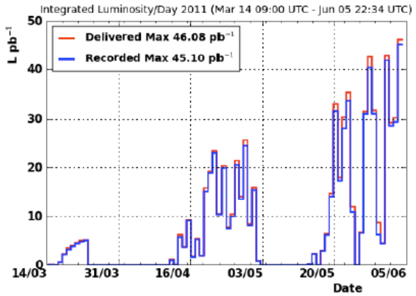
June 06 2011

LHC and CMS operations

1092 bunches in LHC (1042 colliding in CMS); **new world record in peak luminosity** for hadron colliders **1.27e33**.

~711pb^{-1} delivered by LHC and **~648pb^{-1}** collected by CMS. **CMS data taking efficiency >91%. We can now record more than 45pb^{-1}/day.**

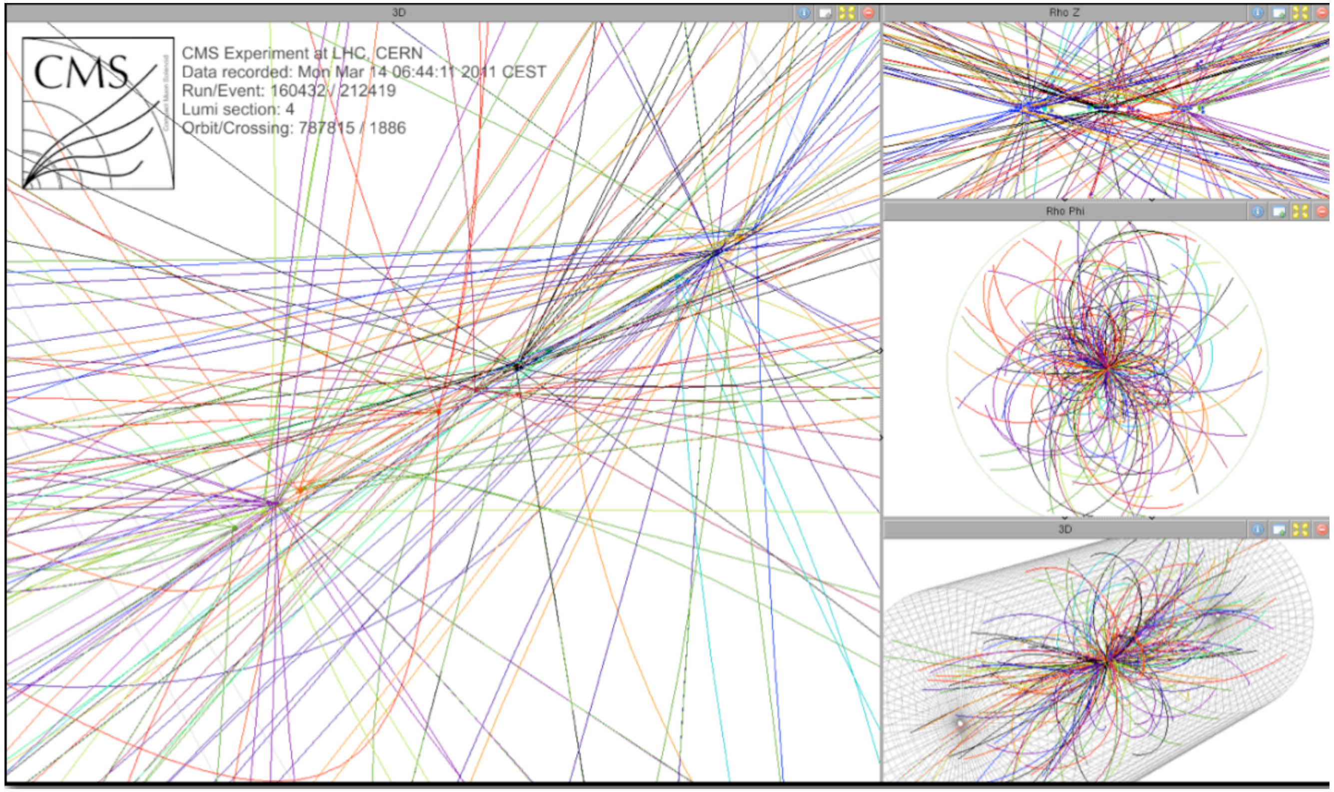




The goal of collecting 1fb^{-1} of data before the end of June is within reach.

G. Tonelli, CERN/INFN/UNIPI P-LHC_Perugia June 06 2011 31

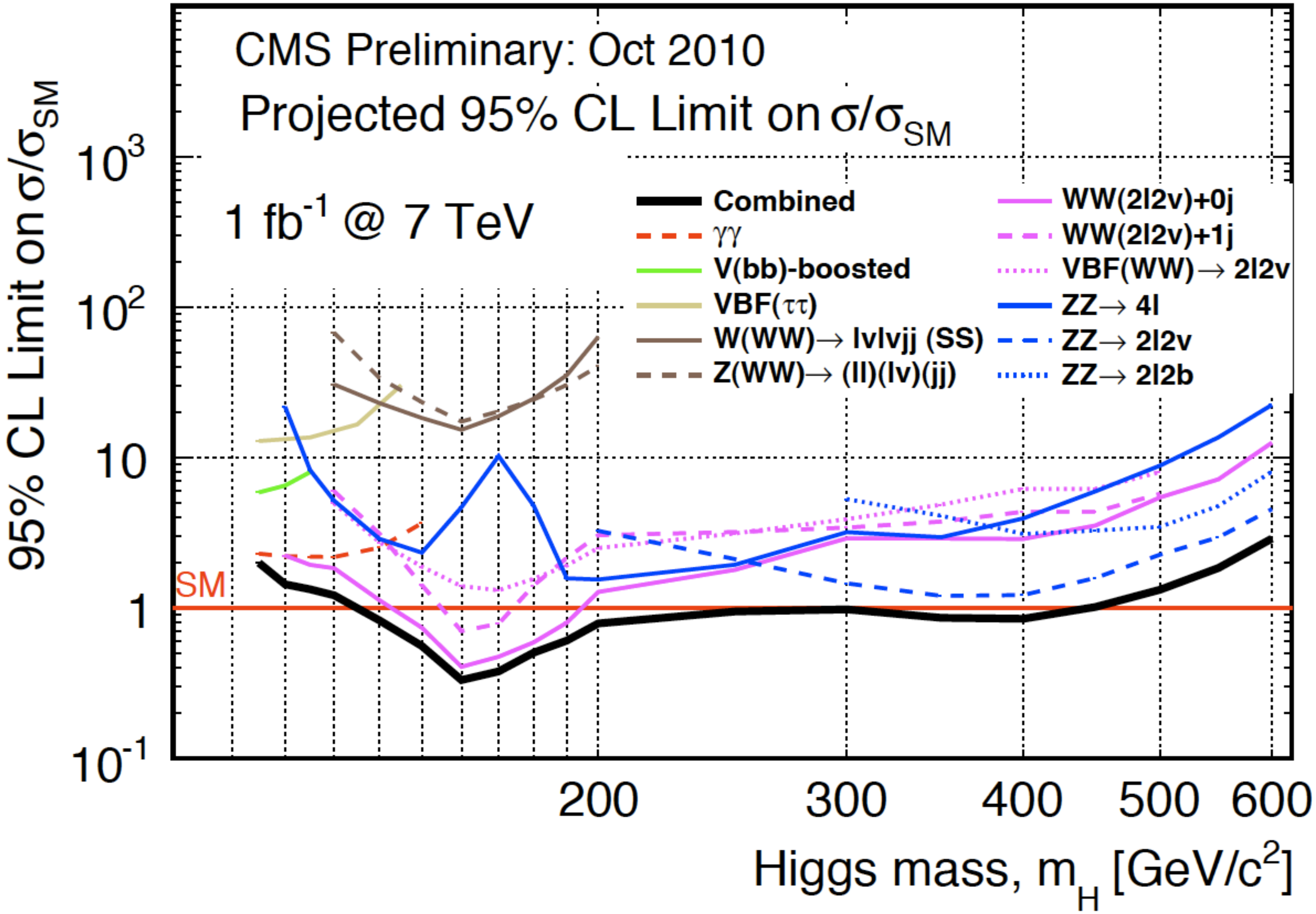
High Luminosity at LHC: Trigger selectivity, Pile-up, CPU, etc.



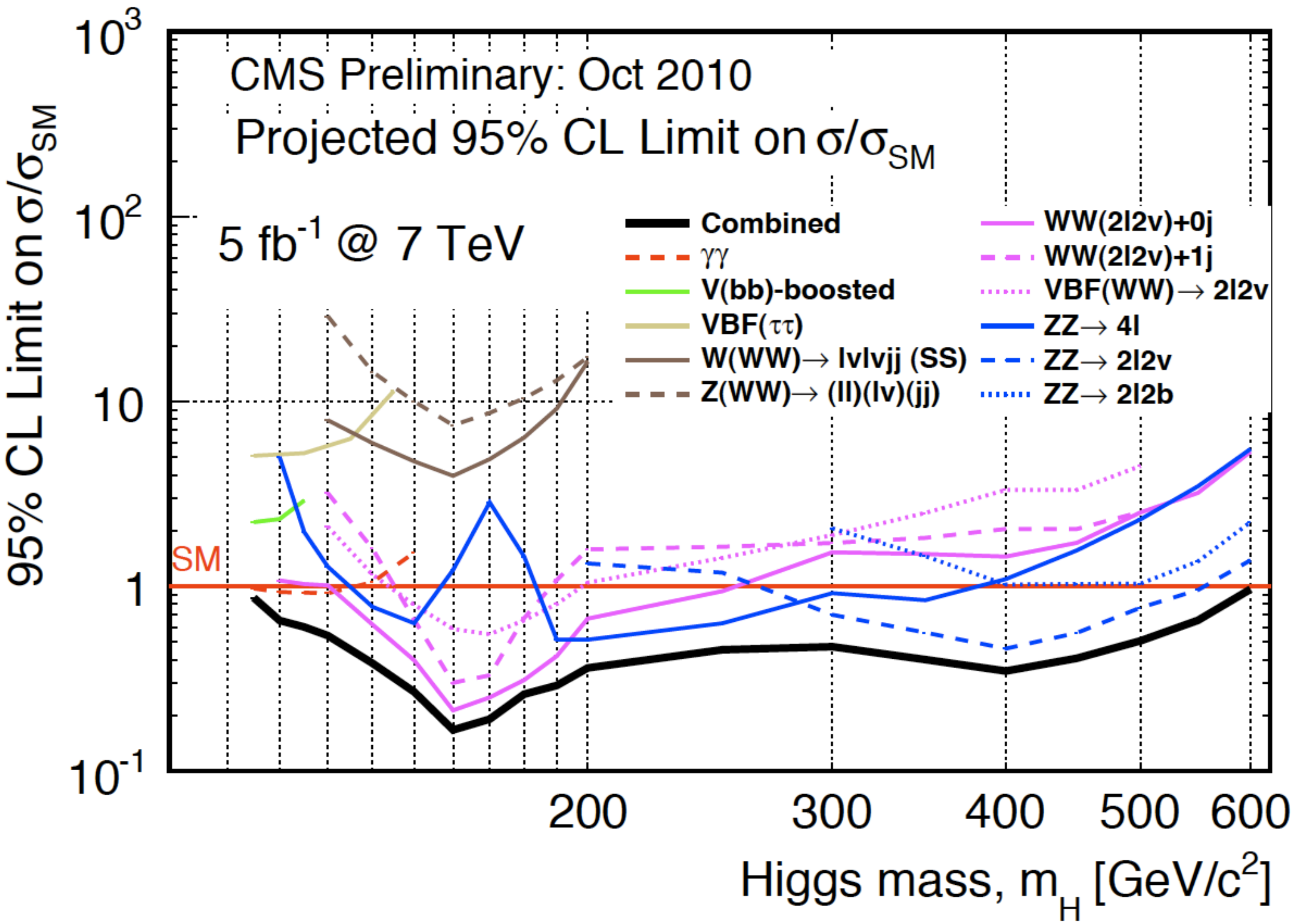
Operating at ~ 1.5×10^{33} with 50ns bunch structure presents many challenges
Our experience so far makes us confident that we will make effective use of these data

=> Can make useful projections for higher accumulated Luminosity

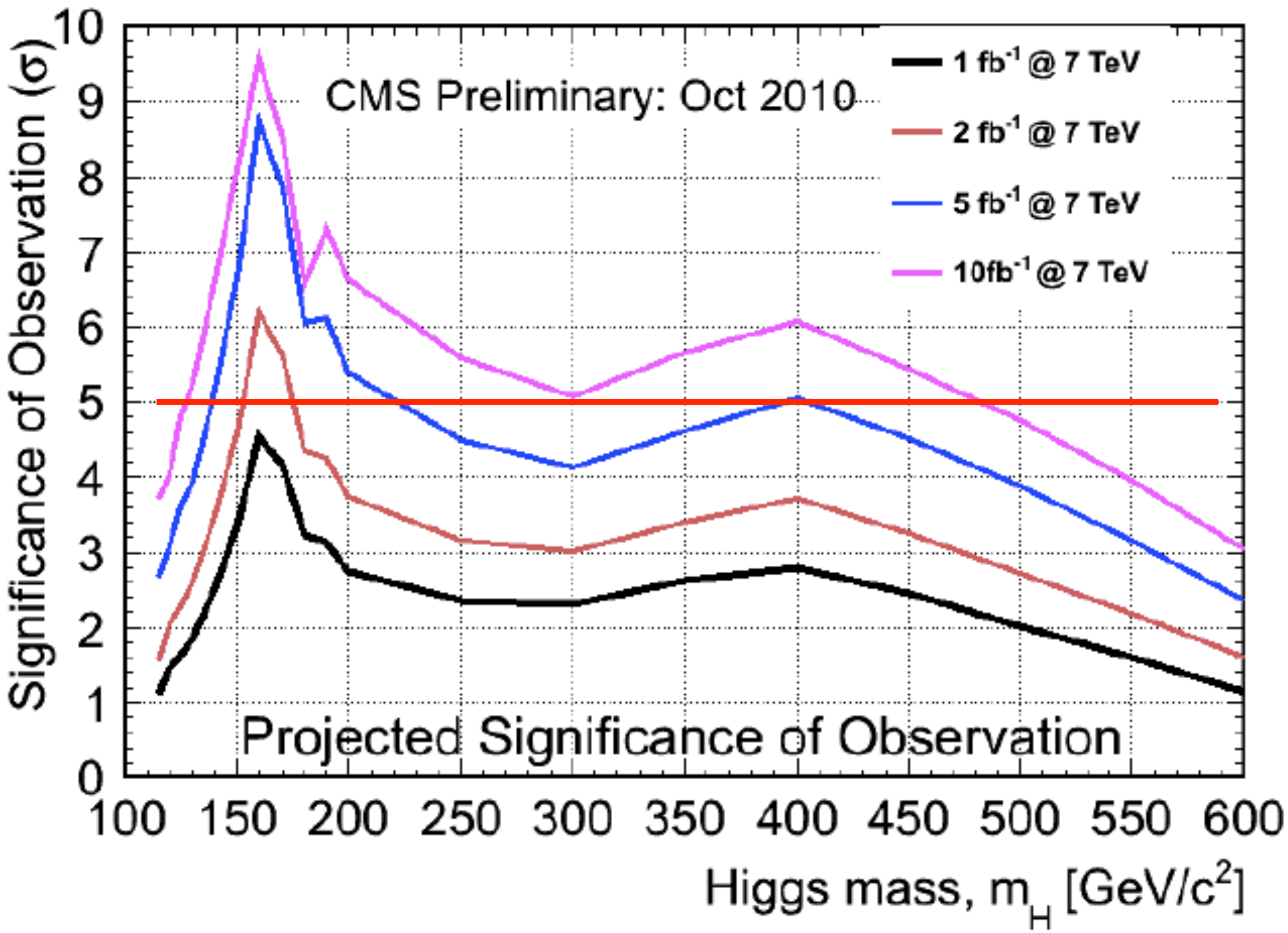
CMS Higgs Search Prospects with $1 fb^{-1}$



CMS Higgs Search Prospects with 5fb^{-1}



CMS Higgs Discovery Prospects with 1 - 10fb^{-1}



ZZ Production