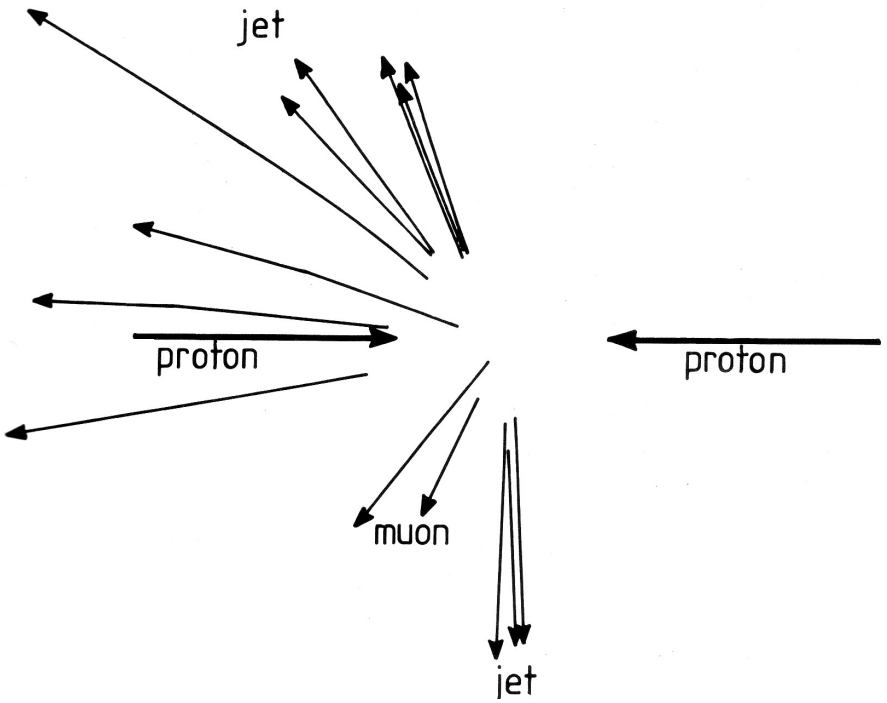


JETS

Alone or with Vector Bosons

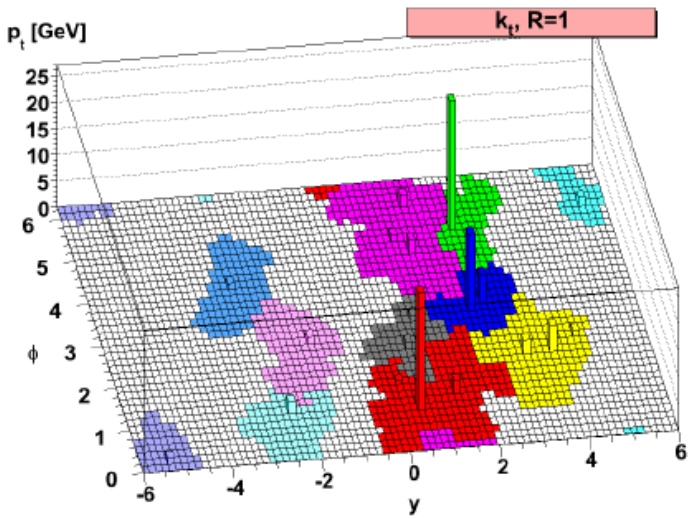
(acknowledgements: Jeff Berryhill and Chiara Roda [ICHEP 2015])

Jets @ hadron machines

- Dualism jet←→parton;
(unphysical) attempt to match the two
- Cone algorithms, based on

$$\Delta R = \sqrt{\Delta\eta^2 + \Delta\varphi^2}$$

- **non infrared safe**
- problem of black towers

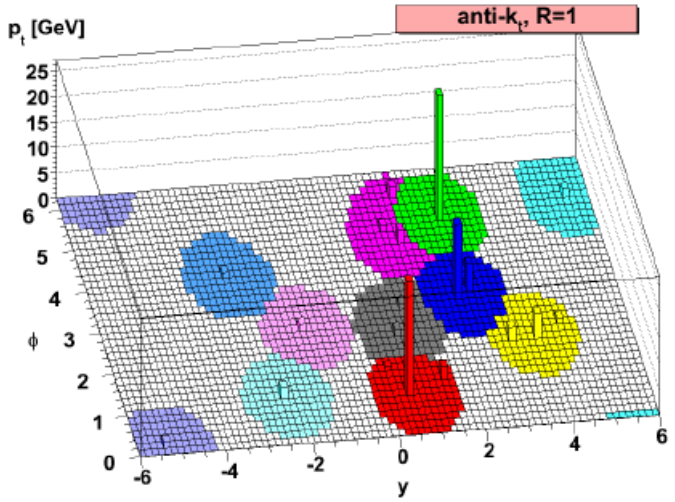


- Recombination algorithms: P=1 k_T algorithm, P=-1 anti-k_T algorithm

$$d_{ij} = \min(k_{Ti}^{2P}, k_{Tj}^{2P})\Delta R^2_{ij}$$

$$d_i = k_{Ti}^{2P} \; R \; ; \text{ parameter } R \approx 1$$

$$\text{if } \; d_{ij} \leq d_i \text{ join}$$

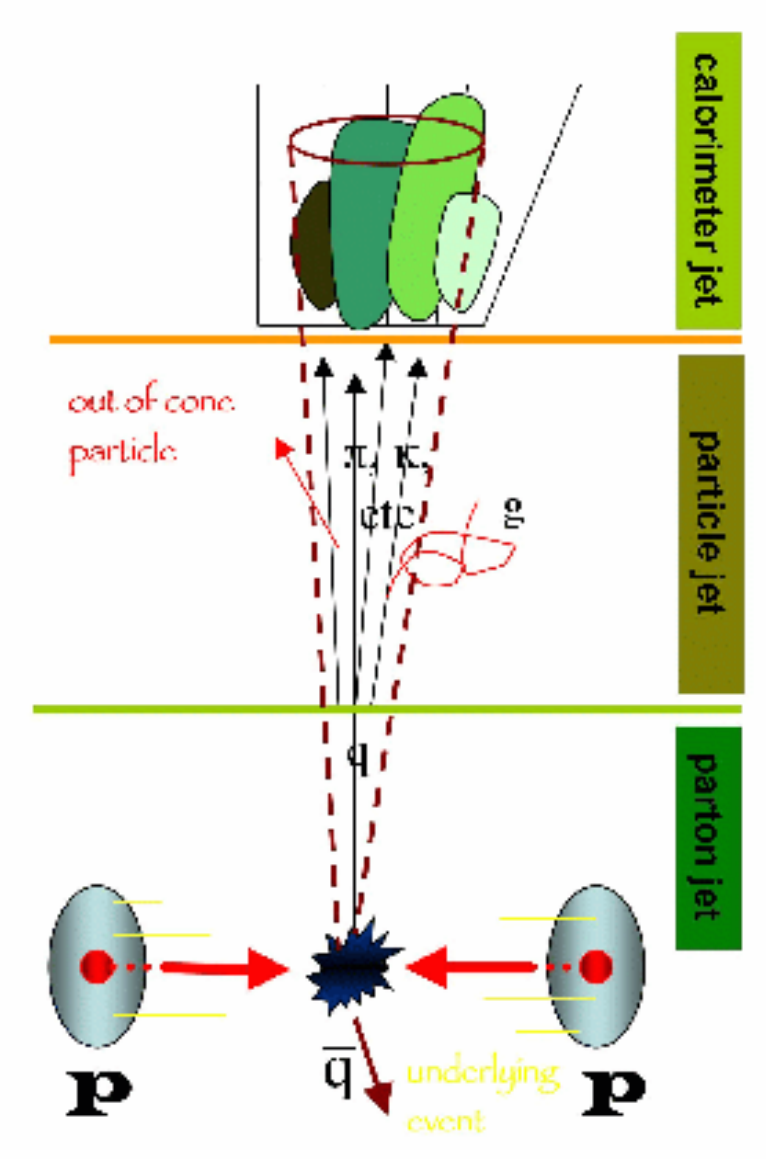


Jet Energy Corrections

Determine true "particle"or "parton" jet E_T from measured jet E_T

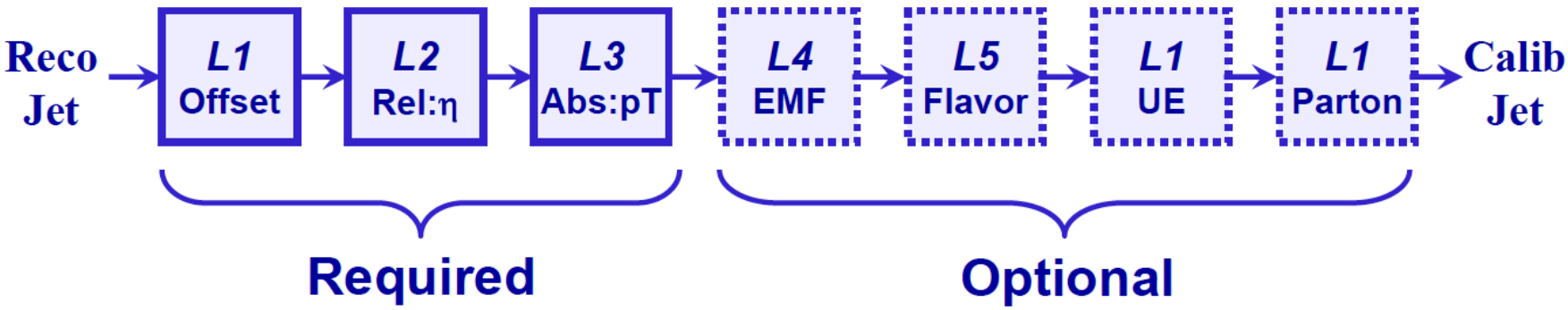
- Non-linear response
- not-instrumented regions
- Response to different particles
- Out of cone E loss
- Spectator interactions
- Underlying event

Note that the "elements" of a jet can be calorimeter towers or "particles" from particle flow reconstruction

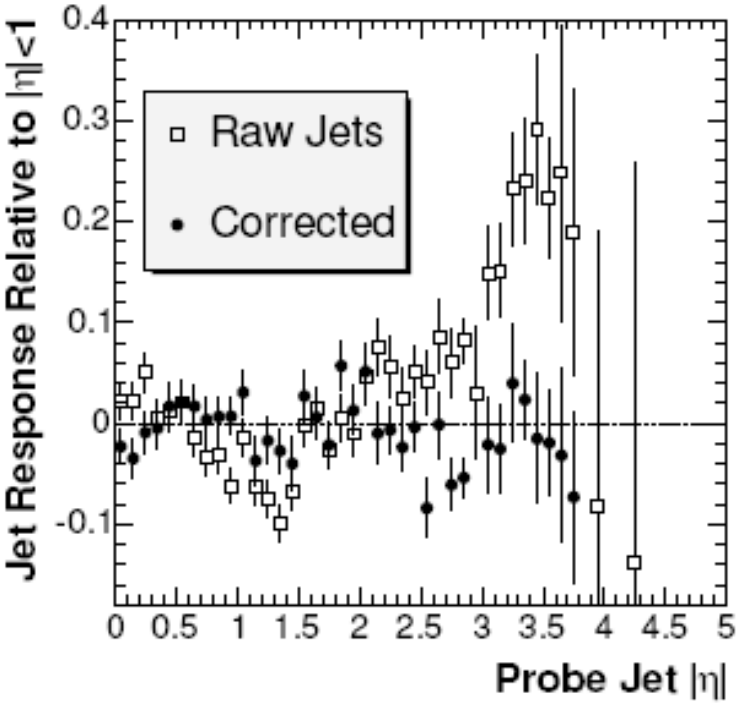


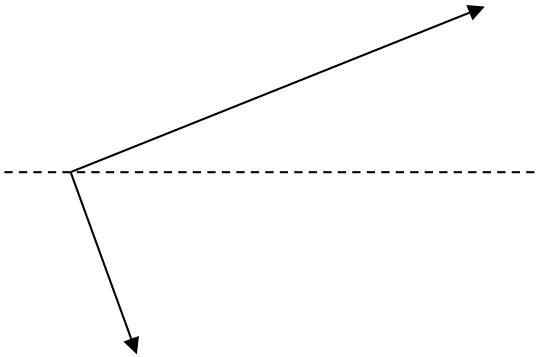
Factorized Jet Corrections

1. Offset: removal of pile-up and residual electronic noise.
2. Relative (η): variations in jet response with η relative to control region.
3. Absolute (p_T): correction to particle level versus jet p_T in control region.
4. EM fraction: correct for energy deposit fraction in em calorimeter
5. Flavor: correction to particle level for different types of jet (b, τ, etc.)
6. Underlying Event: luminosity independent spectator energy in jet
7. Parton: correction to parton level



Jet Equalization with dijet balancing

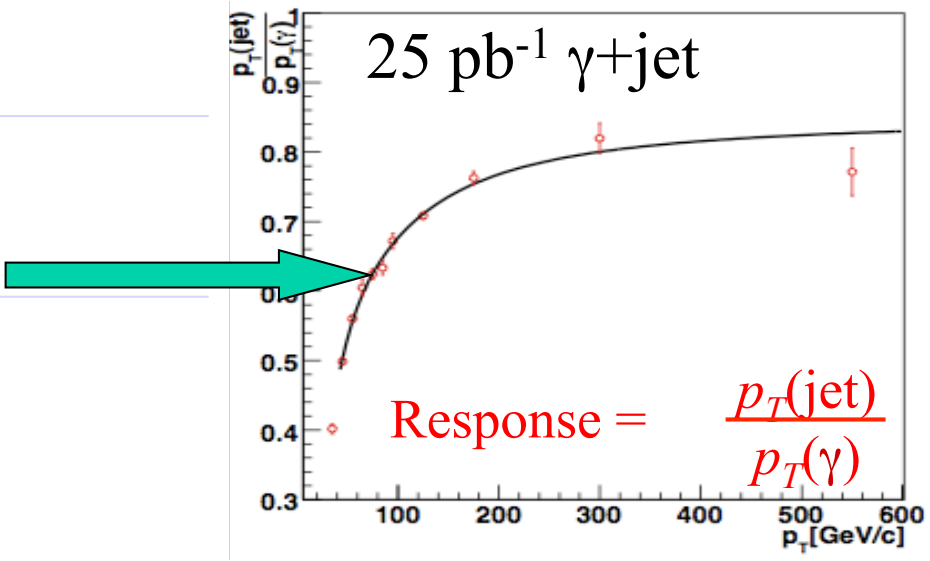




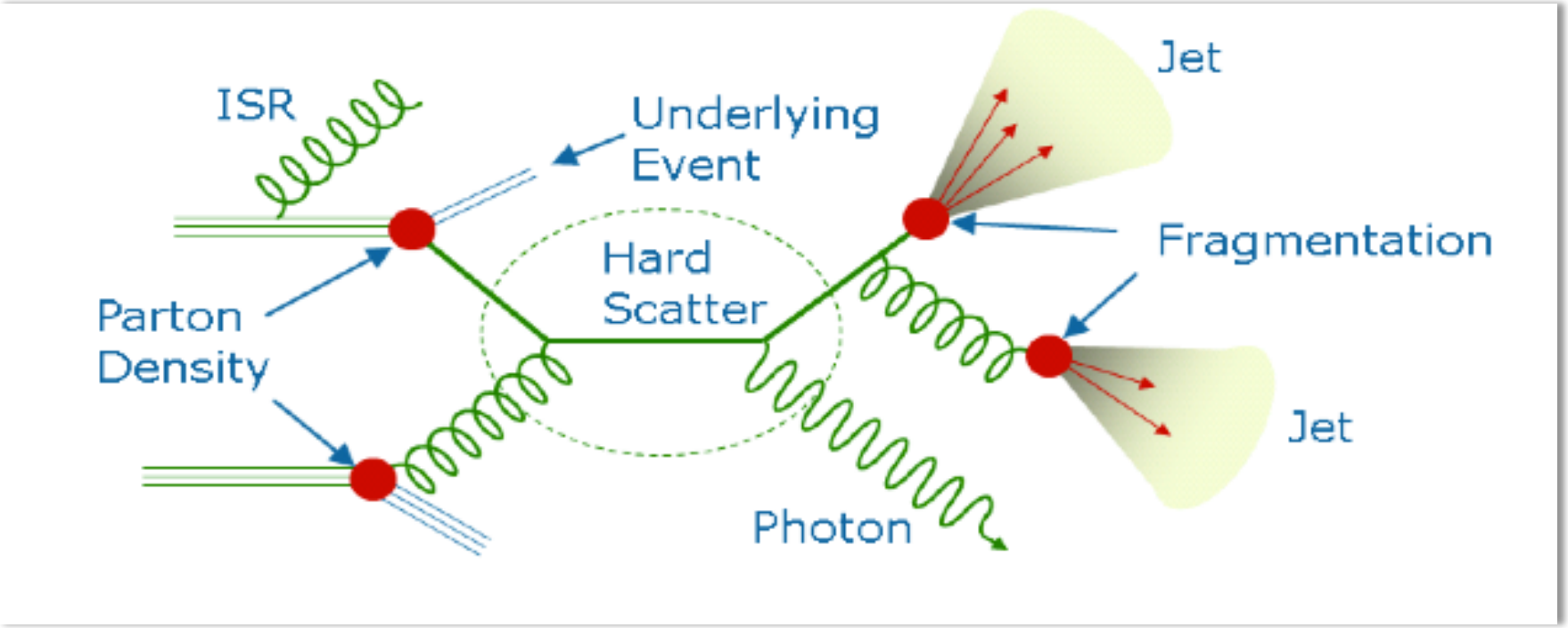
- We can quickly equalize at " low Et" until we run out of statistics
- One must assume equalization holds at higher energy (but data vs MC needed for this)

Absolute energy scale:

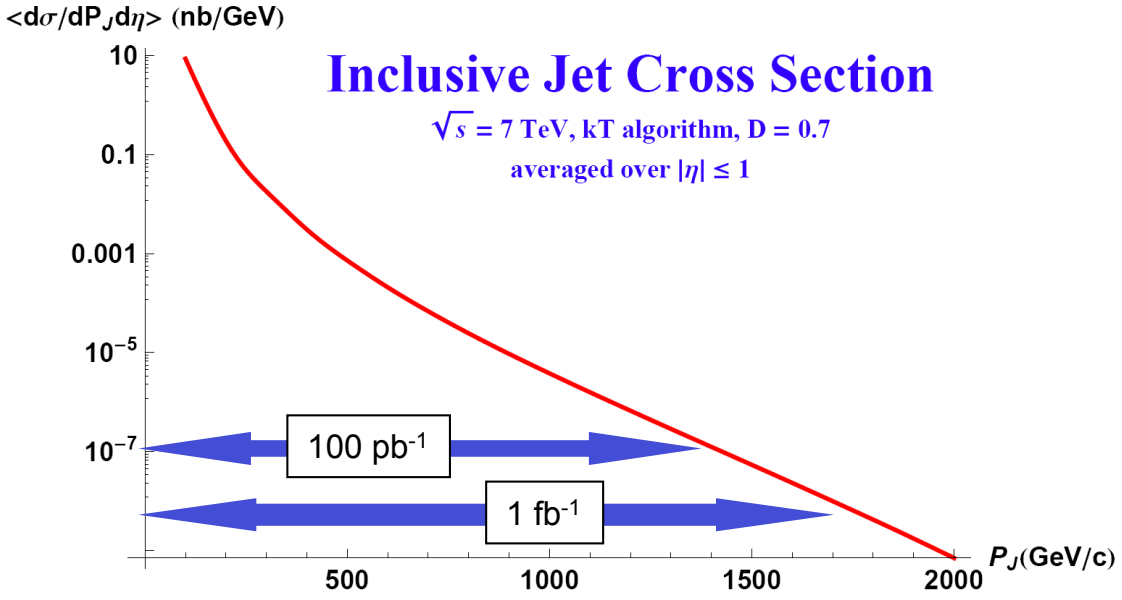
- use γ+jet or Z+jet



γ+jet a complex event



Inclusive Jet Physics

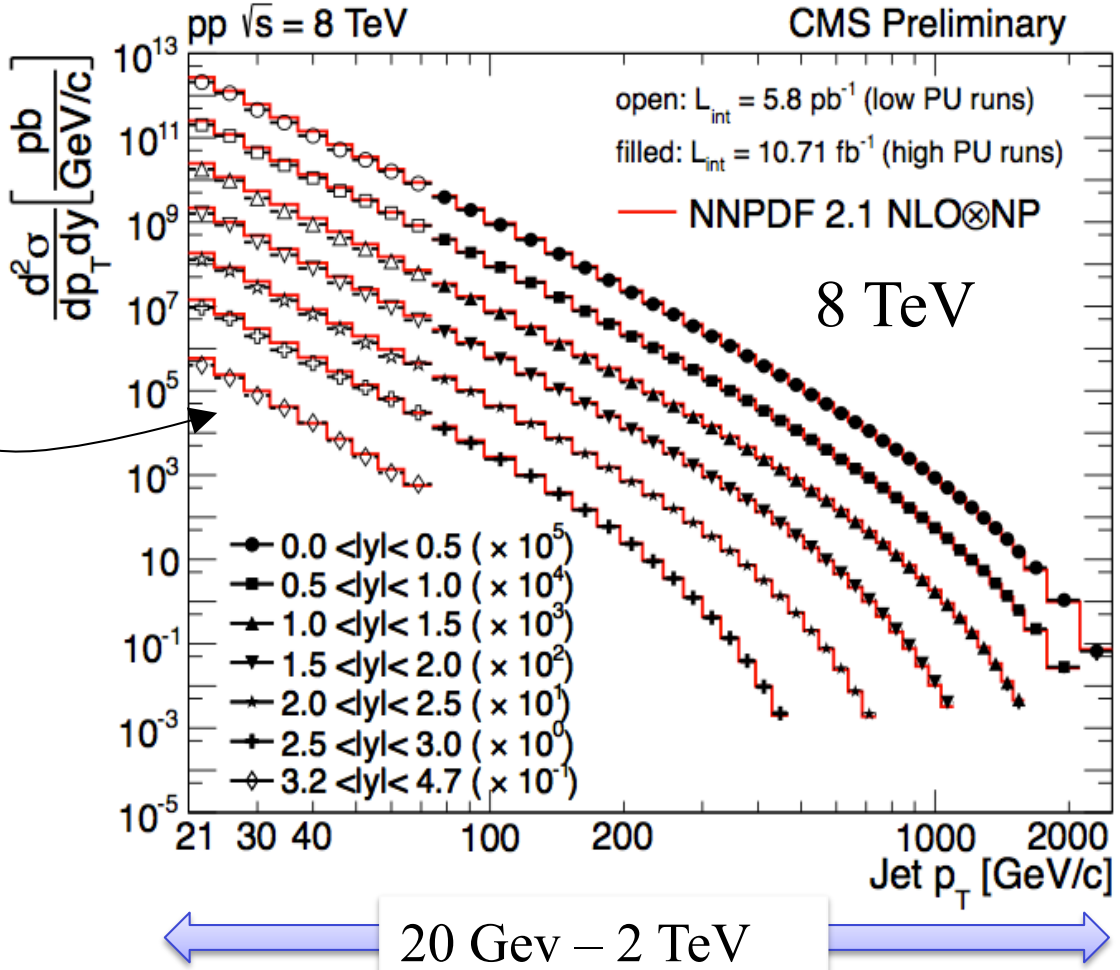


NLO QCD jet spectrum – no detector effects included

- Jets with E_T's of around 1.4 TeV with 100 pb^{-1}
- Jets with E_T's of around 1.7 TeV after the first fb^{-1}
- As a rule of thumb, the sensitivity to a contact interaction Λ is roughly 4x the E_T of the most energetic jet.

STDM-2013-11 CMS-PAS-FSQ-12-031 CMS-PAS-SMP-12-012

Inclusive cross-section @ 8 TeV



Low pile-up data to extend to the low p_T range down to 20 GeV and |y|<4.7

11 orders of magnitude

20 Gev – 2 TeV

LHC data allows pQCD tests in a new kinematic regime – extended in p_T and y
Covers 11 orders of magnitude / two jet sizes
Reference prediction: NLOJET + NNPDF2.1 but other PDF tested

CMS-PAS-SMP-12-028 CMS-PAS-SMP-12-027 arXiv 1406:470

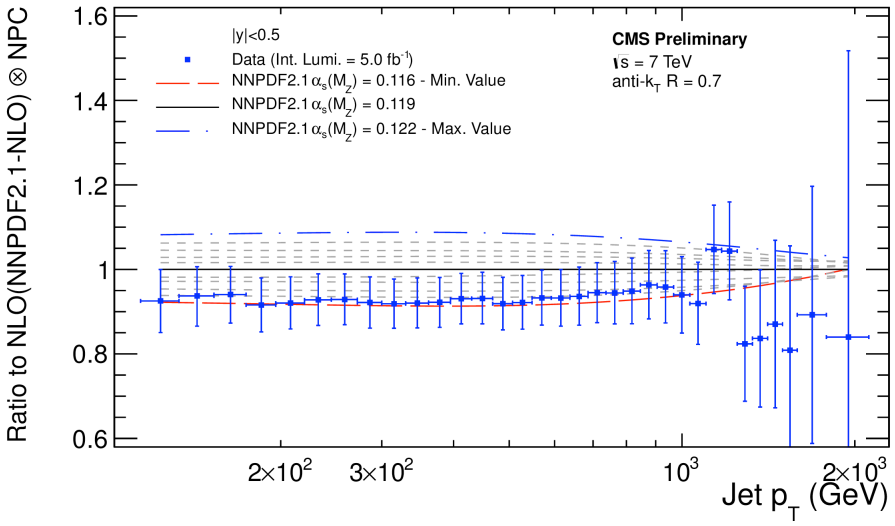
α_s measurement

World average (2014)

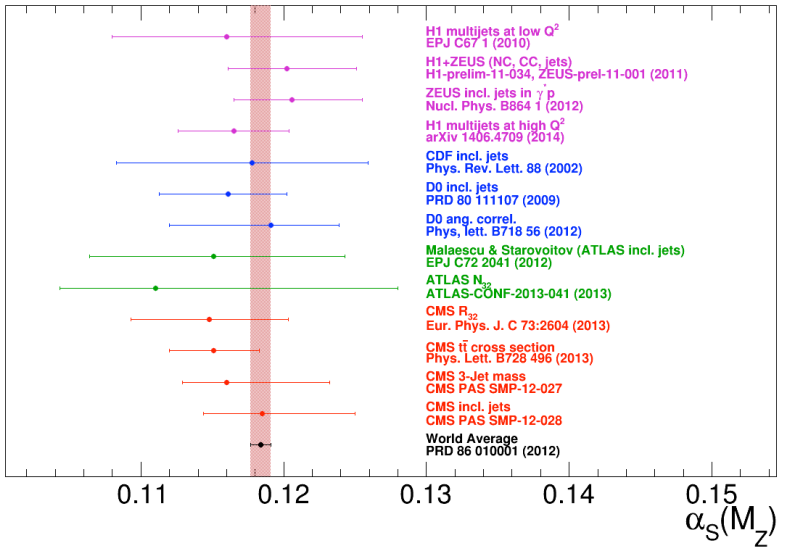
$\alpha_s(M_Z) = 0.1185 \pm 0.0006$ (0.5%)

CMS Most recent: inclusive jet (5%)

$$\alpha_s(M_Z) = 0.1185 \pm 0.0019(\text{exp}) \pm 0.0028(PDF)$$
$$\pm 0.0004(NP) \pm^{0.0055}_{0.0022} (scale)$$



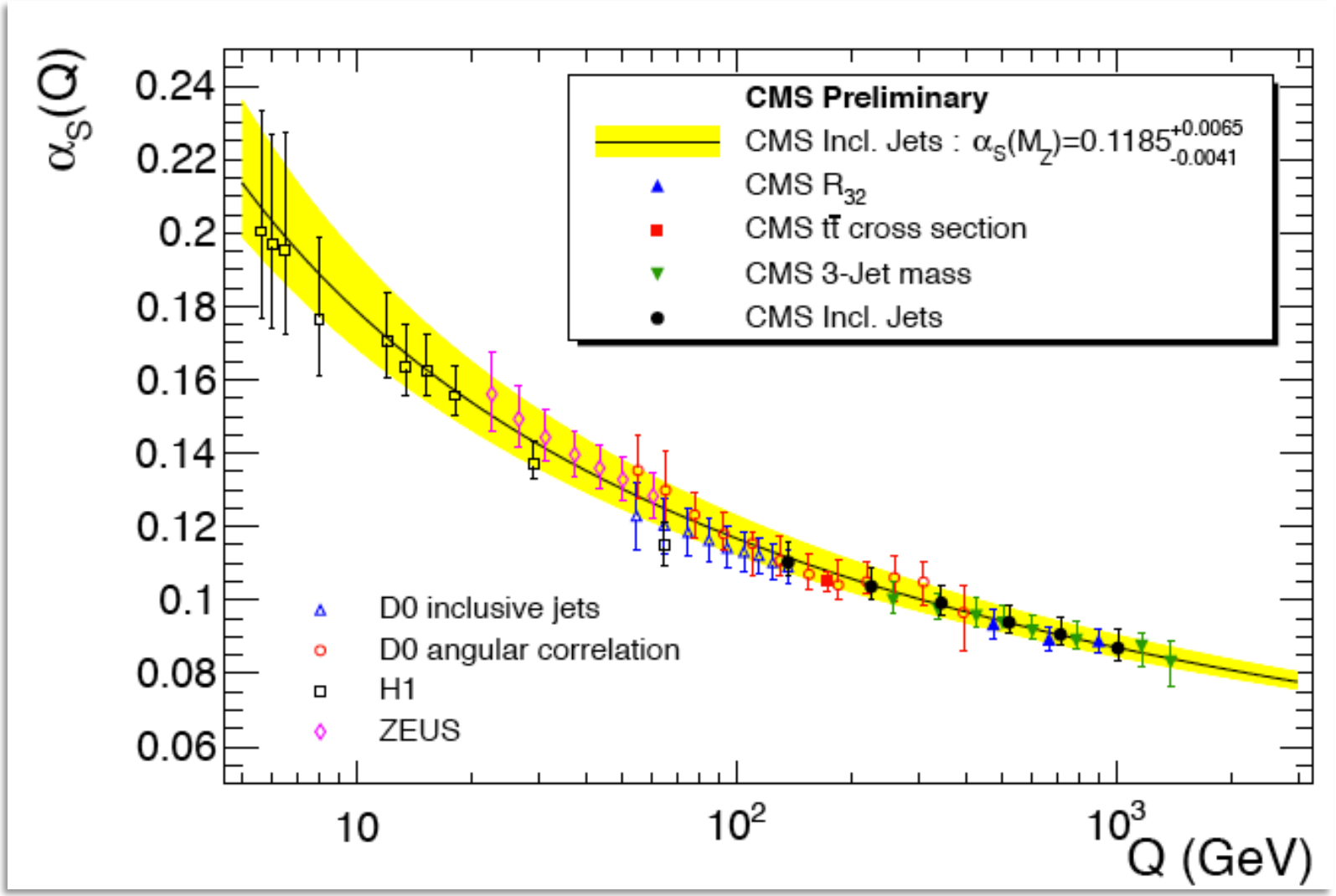
Ratio of measured inclusive jet to NNLO prediction, with various α_s inputs



https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMP

All measurements consistent with world average
Impressive proof of $\alpha_s(Q)$ running up to the TeV region

Running of α_s



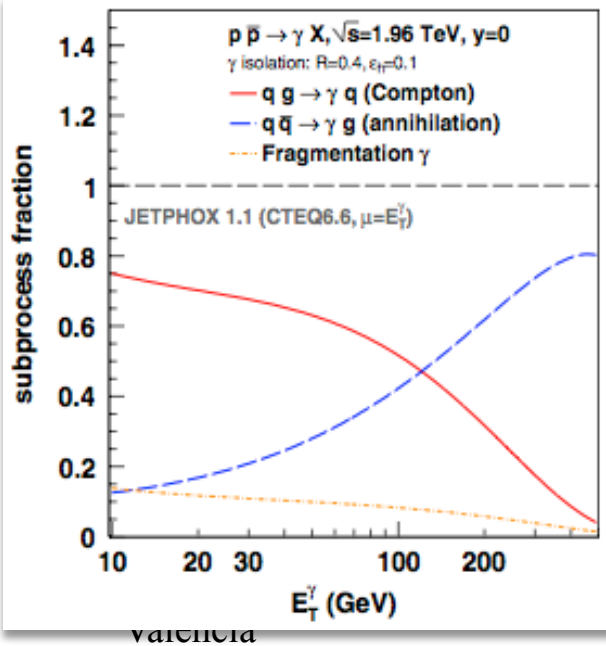
back to W and Z, but γ before !

VECTOR BOSONS PLUS JETS

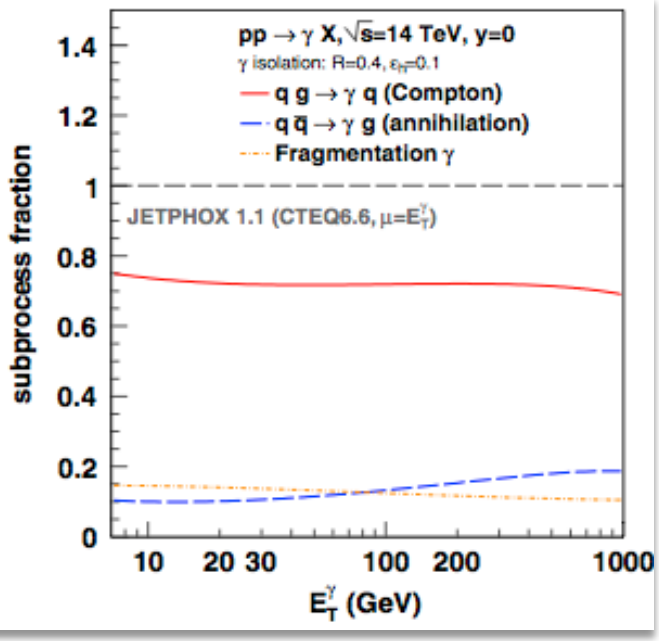
Isolated photon production

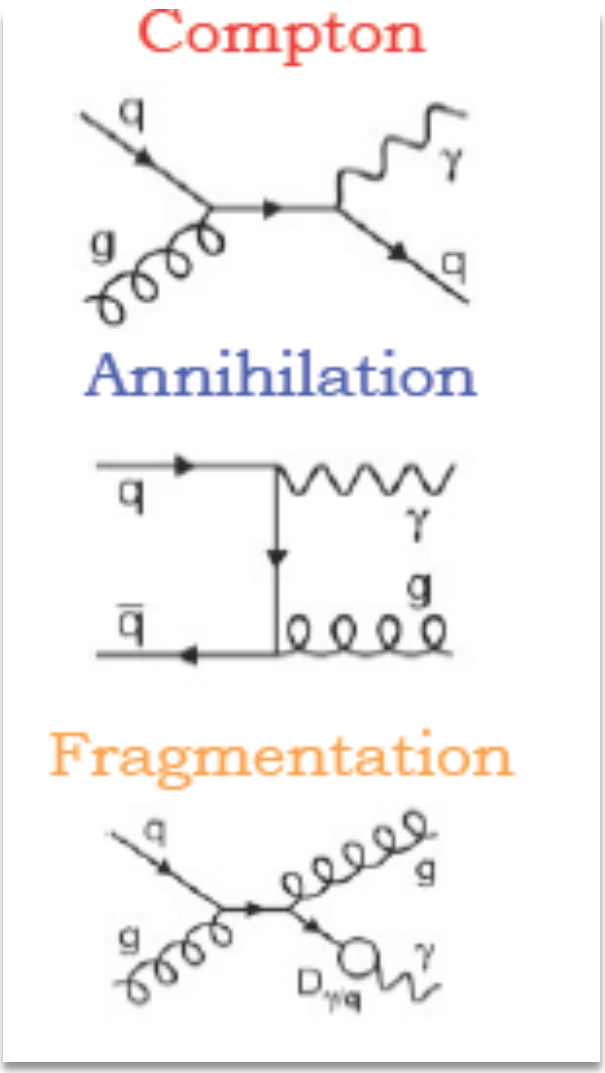
- Photon is used as clean/uncolored probe for underlying parton-parton interaction
- Test pQCD but also sensitive to non-prompt photons produced in fragmentation processes
- Provide information on PDFs

Tevatron



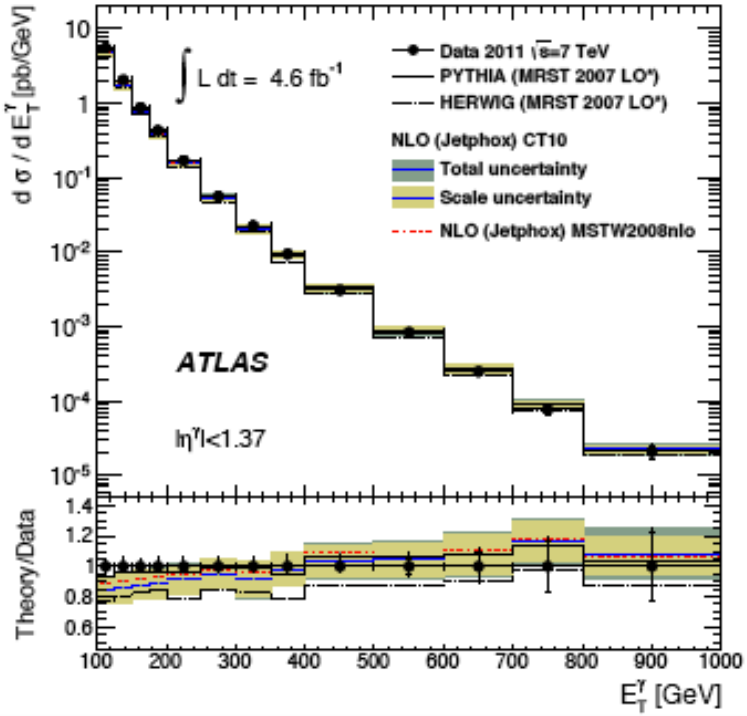
LHC – 14 TeV



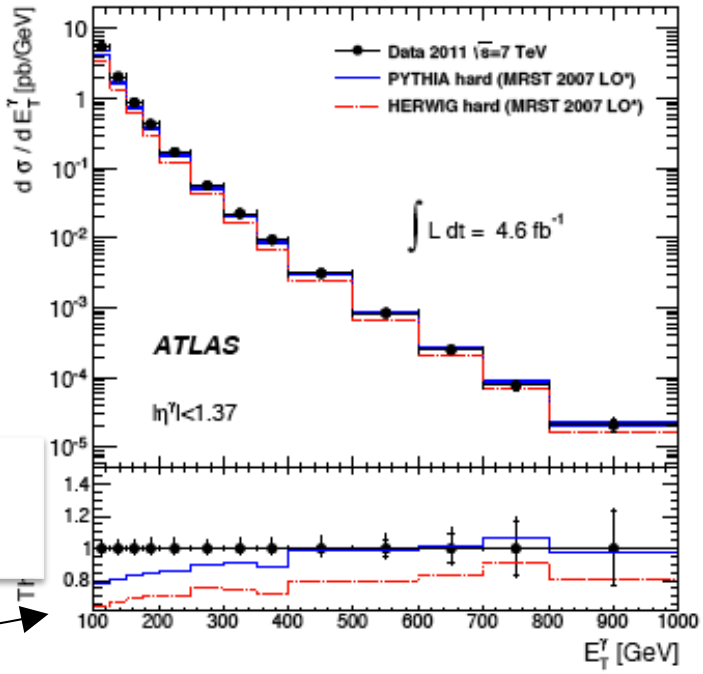


Phys.Rev.D 89, 052004 (2014) ATL-PHYS-PUB-2013-018

Isolated photon production



7 TeV



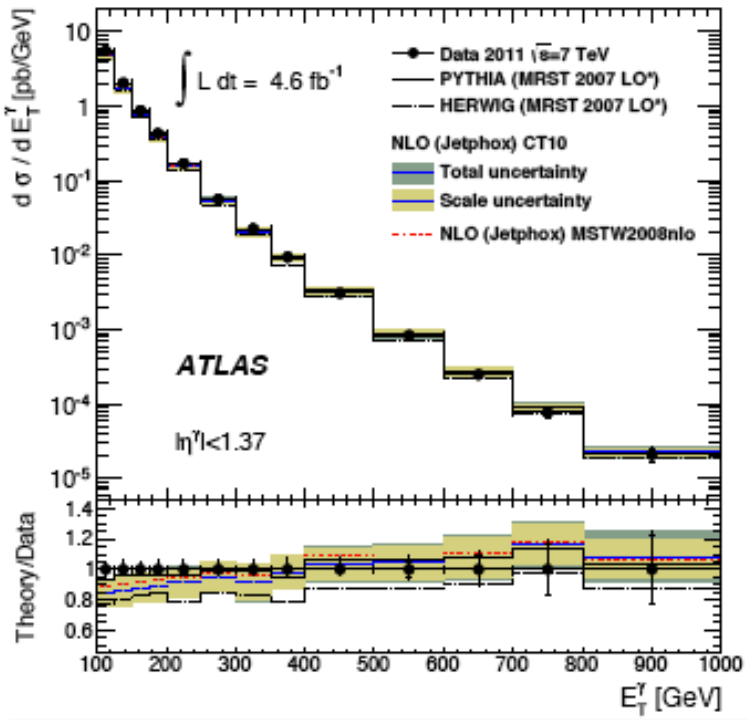
No γ from fragmentation

- New measurement extend the range from 0.1-1TeV E_T and 5 orders of magnitude
- NLO prediction (Jetphox+MSTW or CT10) describe very well the data up to high E_T
- Data demonstrate the need to have fragmentation photon to describe the data

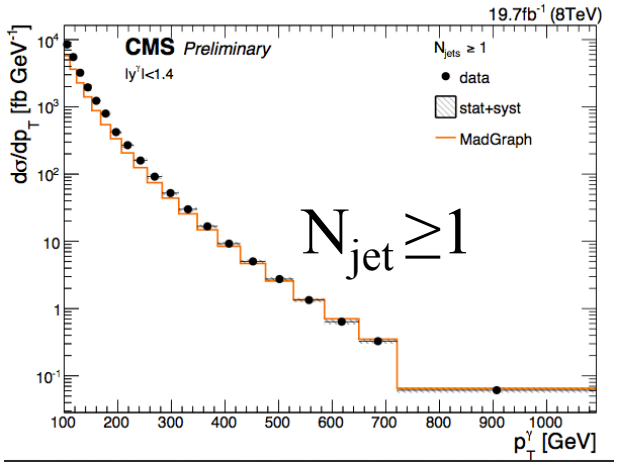
Data is also used to verify the sensitivity to the gluon-PDF and show some tensions with all PDFs expectially with ABM shows a too soft gluon-PDF.
Measurement limited by scale uncertainty, NNLO prediction would help.

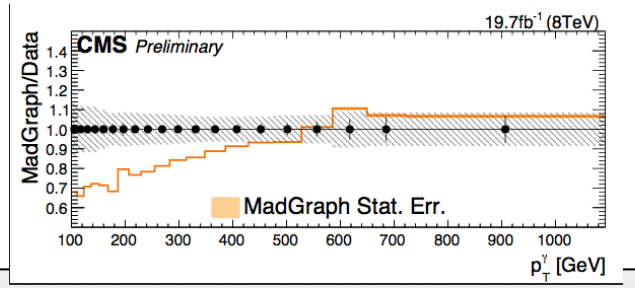
CMS-PAS-SMP-14-005

Isolated photon production



8 TeV





4 times more statistics → halving of statistical uncertainty

Comparison is at LO … but NLO is coming

- New measurement extend the range from 0.1-1TeV E_T and 5 orders of magnitude
- NLO prediction (Jetphox+MSTW or CT10) describe very well the data up to high E_T
- Data demonstrate the need to have fragmentation photon to describe the data

Data is also used to verify the sensitivity to the gluon-PDF and show some tensions with all PDFs expectially with ABM shows a too soft gluon-PDF.
Measurement limited by scale uncertainty, NNLO prediction would help.

W+jet – ATLAS & CMS

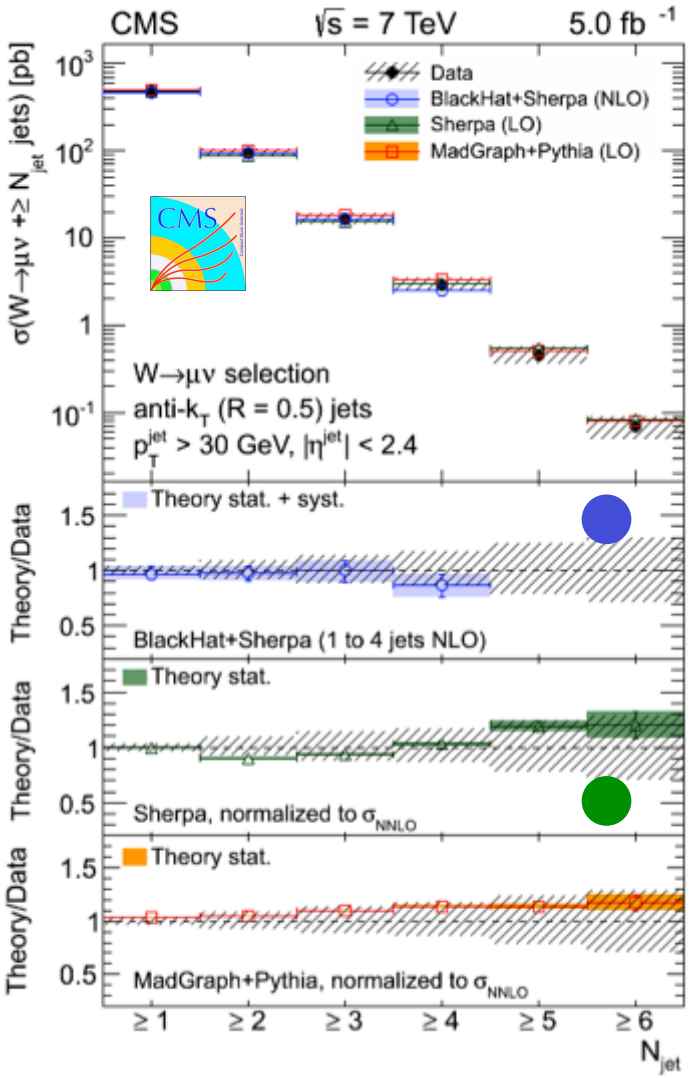
A detailed comparison on a high statistics sample and in a large kinematics range → precious information to validate/tune the predictions.

Tested variables: 1^{st} , 2^{nd}, 3^{rd} 4^{th}-leading jet p_T and η, H_T,S_T (Sum p_T including or not lepton and neutrino), angular separation of jets, invariant mass of lead-subleading jets. Inclusive and exclusive distributions…

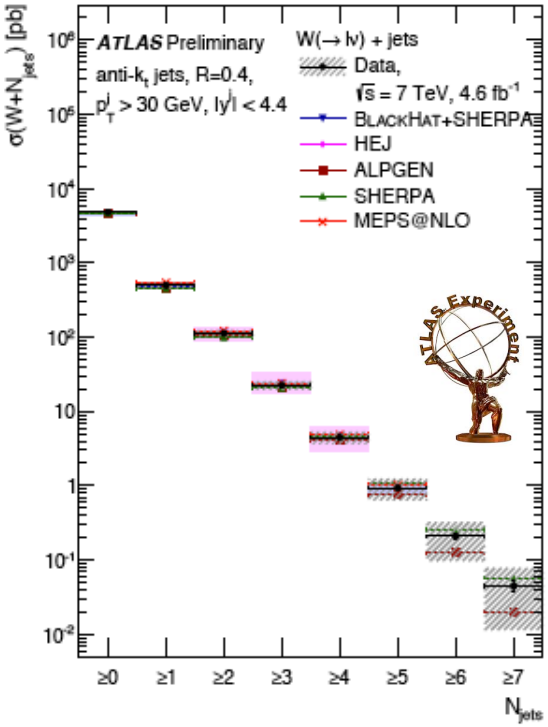
Predictions: NLO calculations, resummation calculations, MC generators NLO,LO + PS

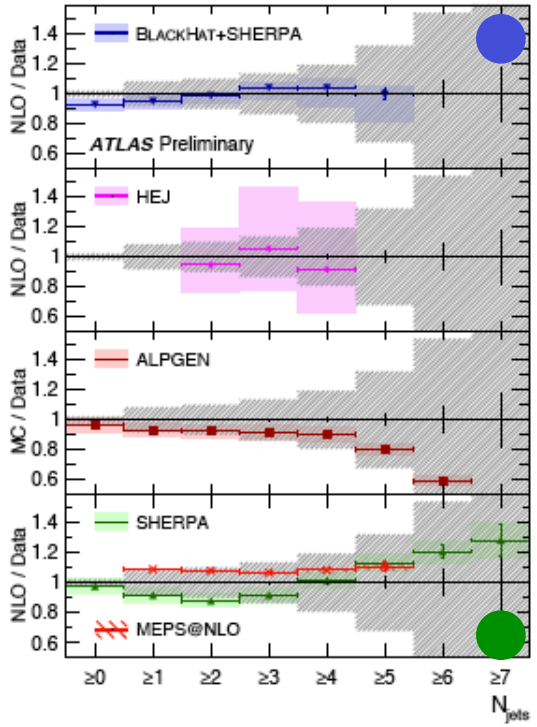
CMS-PAS-SMP-12-023 ATLAS-CONF-2014-035

W+jet – ATLAS & CMS



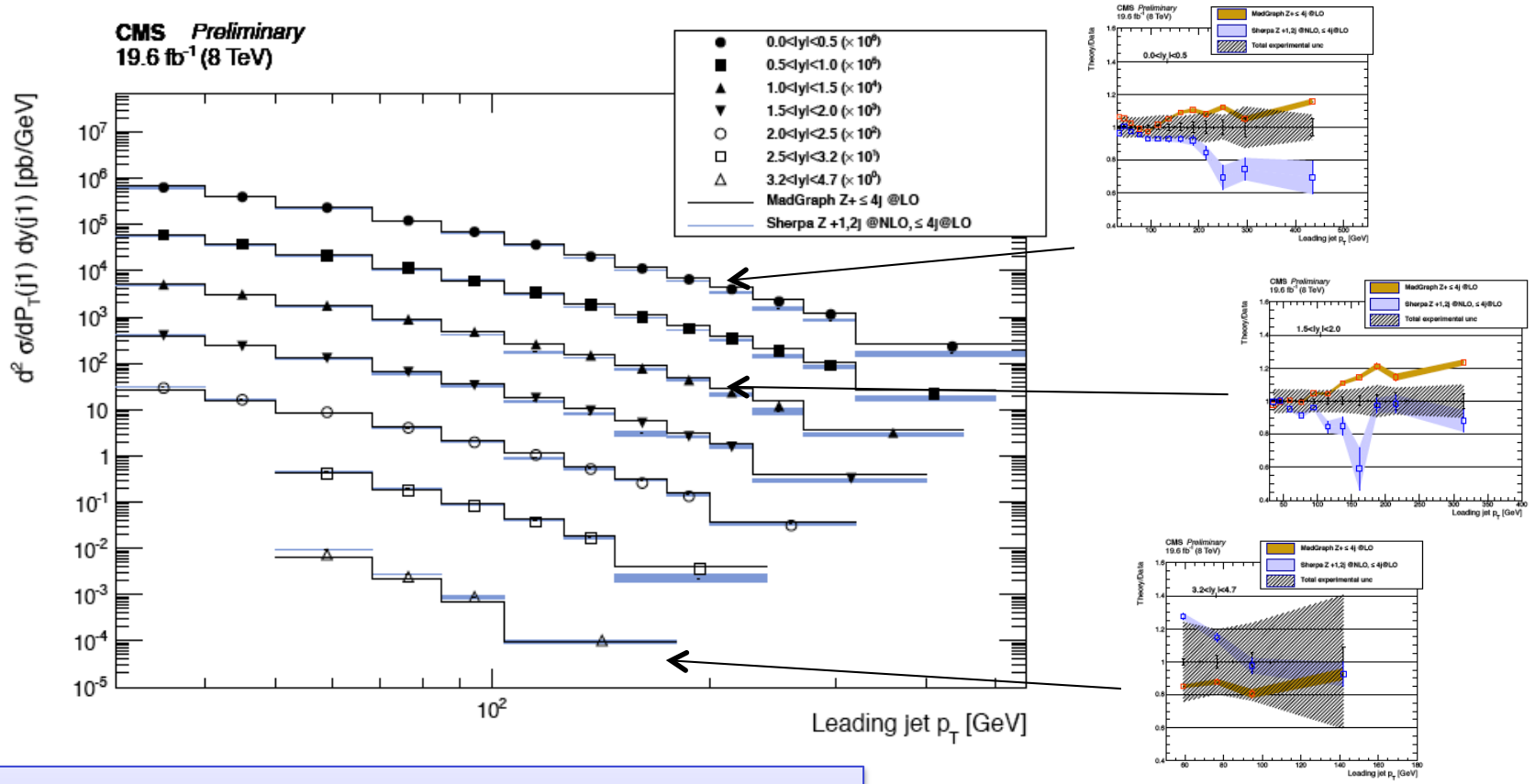
Jet multiplicity





Jet multiplicity well reproduced up to ≥7 jets on 5 order of magnitudes !
Best overall description NLO+PS (BlackHat +Sherpa) with some exception for high H_T, S_T distributions.

Double differential Z+jet @ 8



First double differential measurement Z+jet
Jet up to $|\eta|<4.7$ – $30 < p_T < 550$ GeV
Largest experimental uncertainty JES
Predictions: MadGraph norm.NNLO / Sherpa2
(NLO 1j,2j /LO<=4j)

MadGraph overshoot for $p_T$jet > 100 GeV
Reasonable description from Sherpa2, some regions to investigate

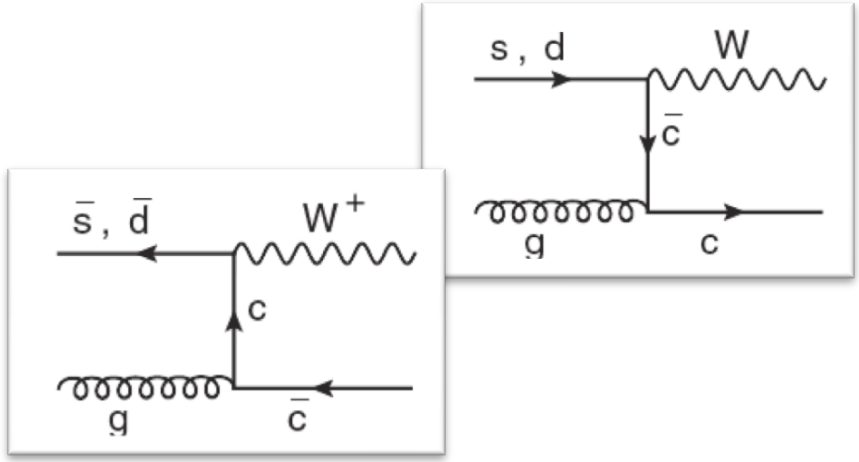
JHEP 05 (2014) 068 JHEP 02(2014)013

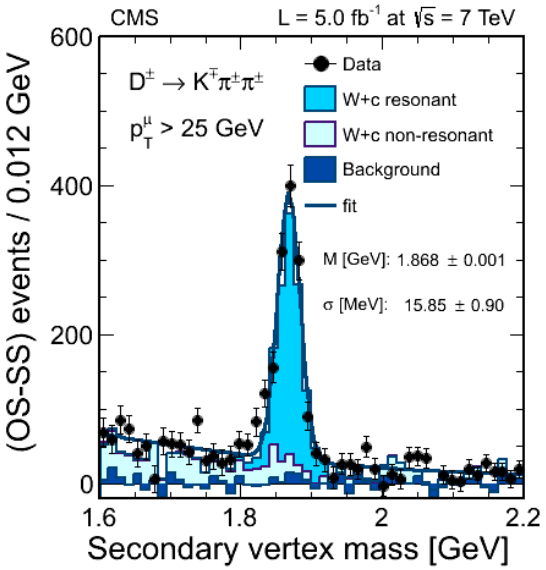
W+charm - LHC

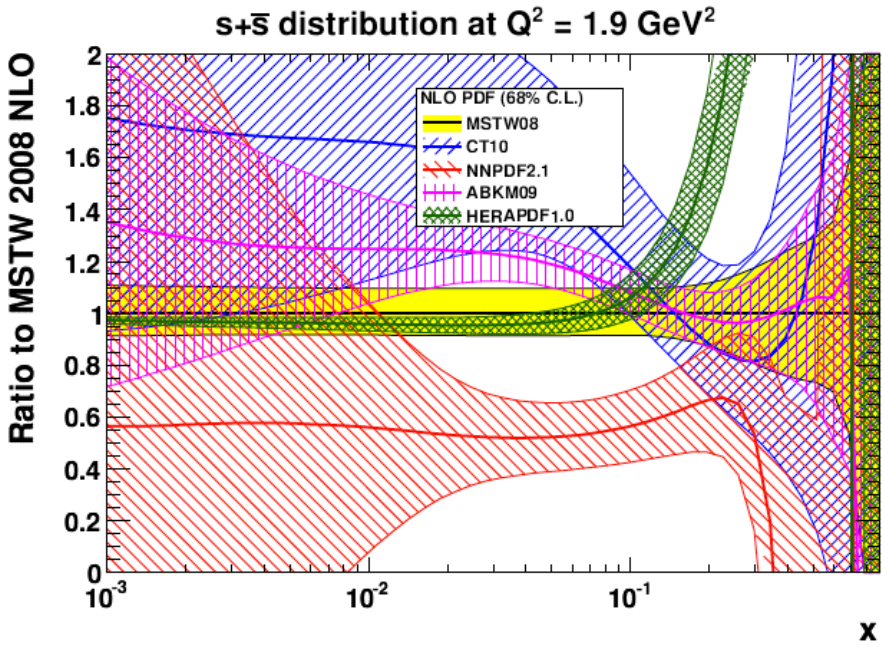
Probes the strange content of the proton

• contribution from d quark about ~10% (Cabibbo suppressed)

• Different PDFs assume different level of suppression of s-quark w.r. to d-quark sea.







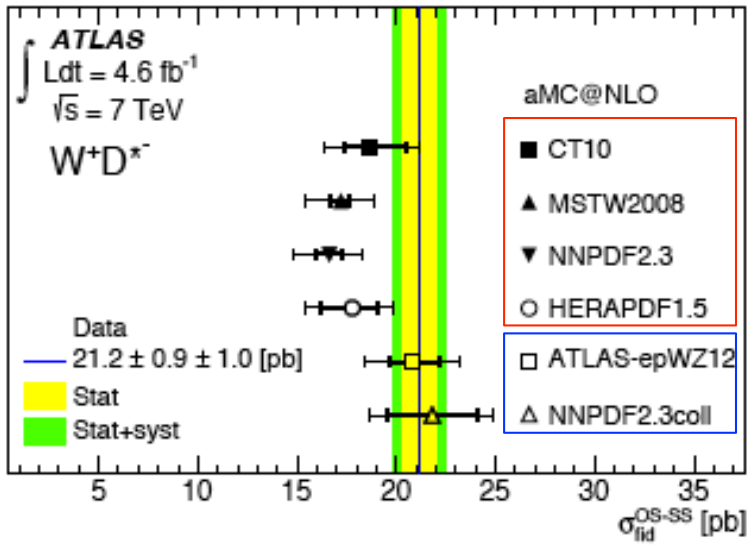
JHEP05(2014)068 arXiv:1402.6263 arXiv:1312.6283

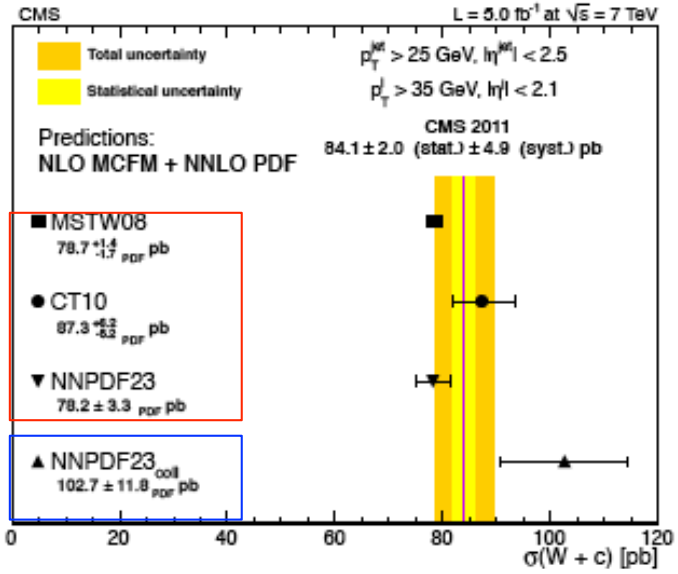
W+c – LHC

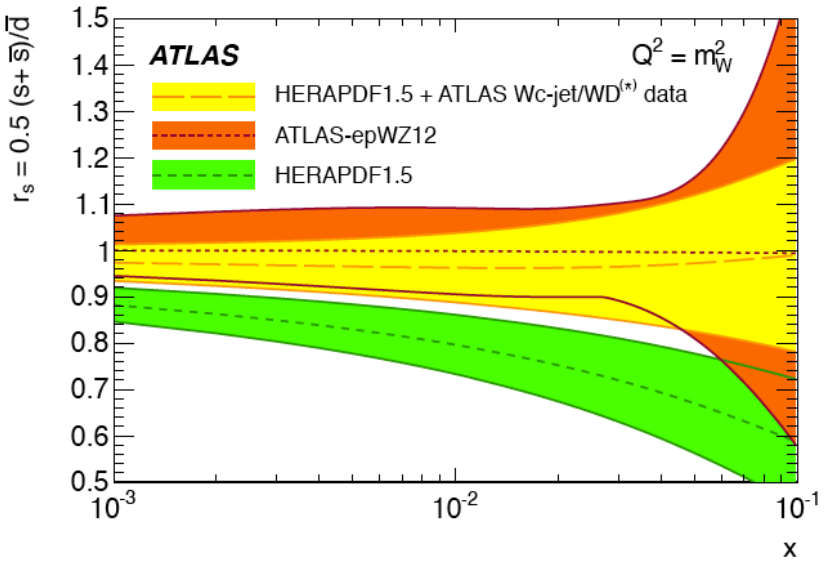
ATLAS → no s-sea suppression w.r. to light flavour sea

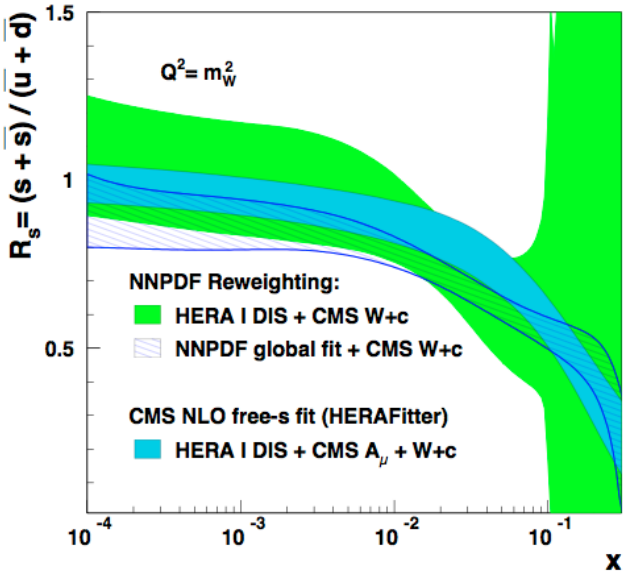
CMS → consistent with s-sea suppression

Fit s-quark PDF: HERAPDF including W +c data







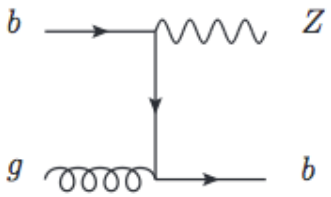


Z+b/bb cross-sections - ATLAS

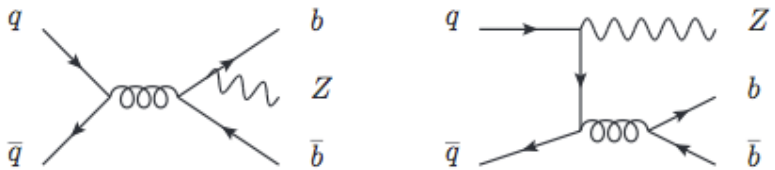
Test of NLO/LO multileg predictions

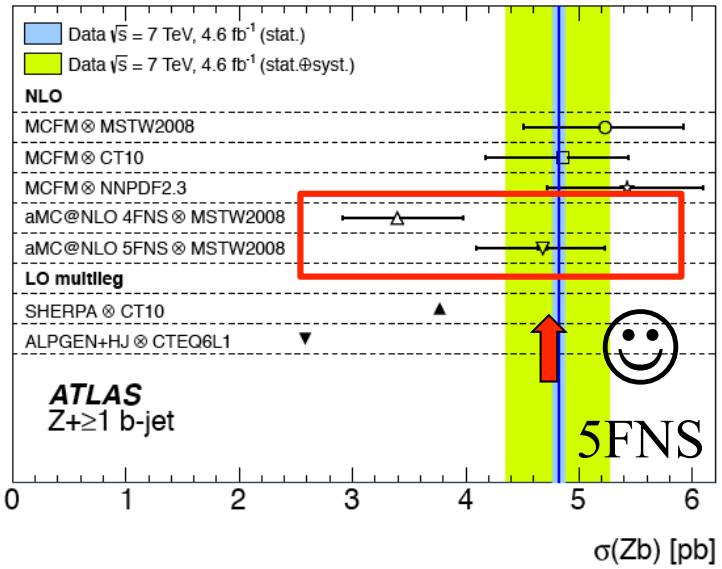
Test of Number Flavour schemes (4NFS / 5NFS)

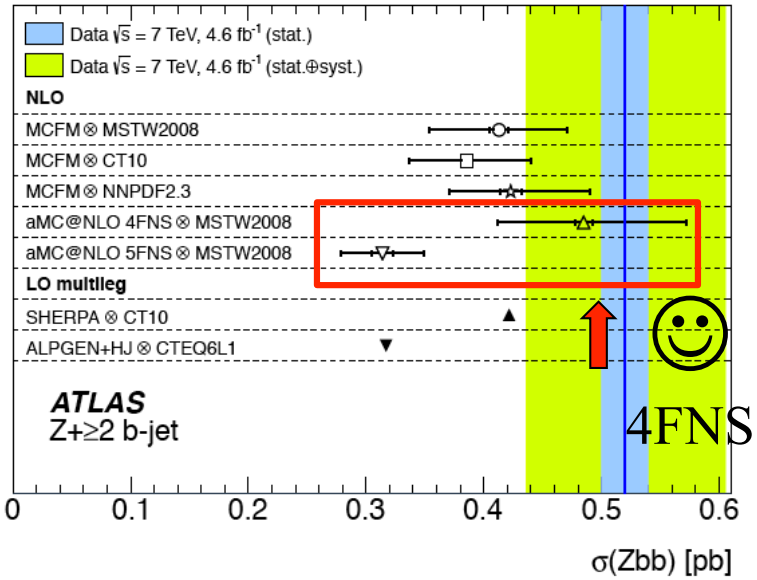
5FNS



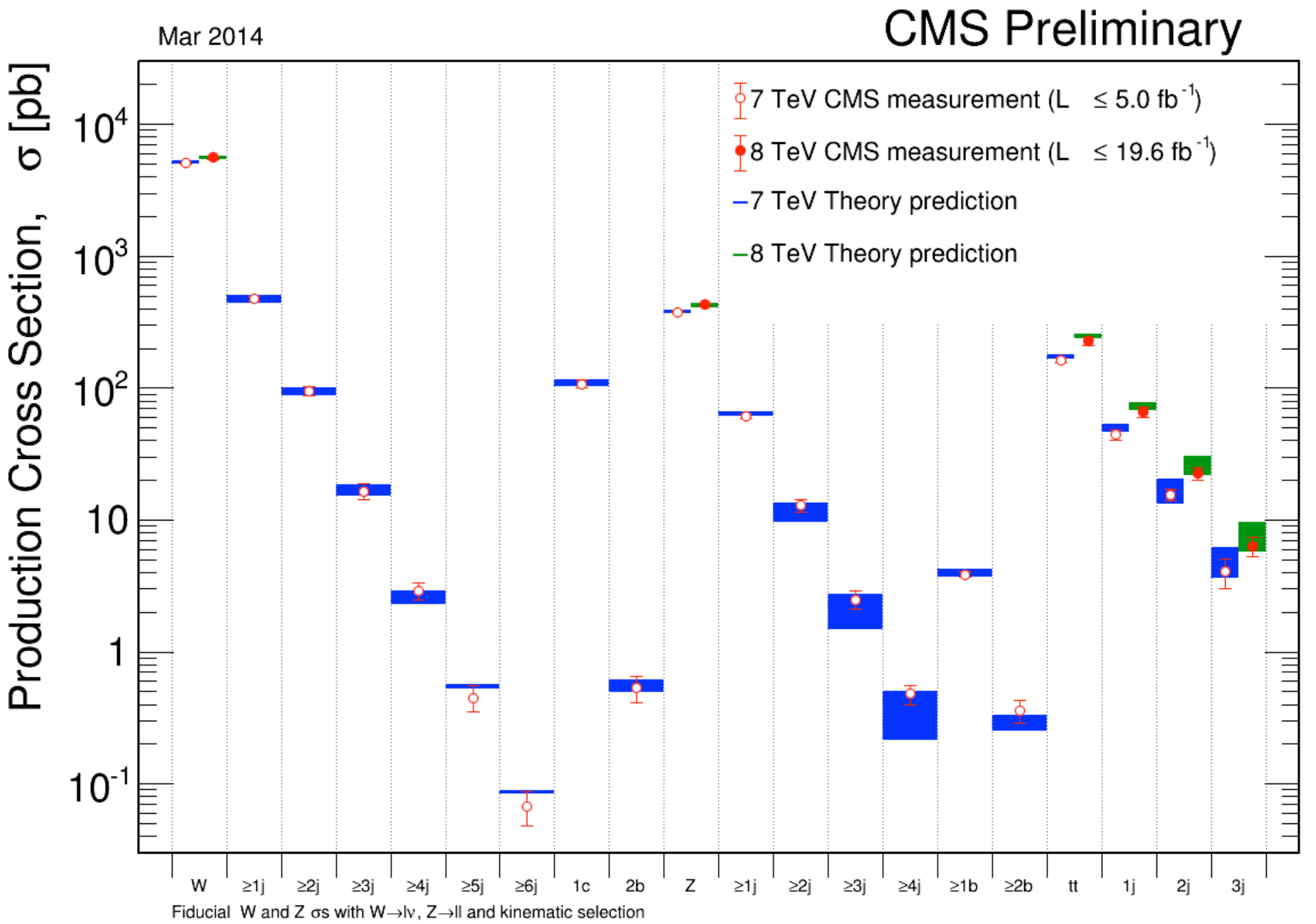
4FNS and 5FNS







MCFM agrees well with data
NLO is still too affected by scale uncertainty to be sensitive to PDFs
Double differential distributions are also compared to different predictions


CMS Preliminary
Mar 2014
Production Cross Section, σ [pb]
7 TeV CMS measurement (L ≤ 5.0 fb-1)
8 TeV CMS measurement (L ≤ 19.6 fb-1)
7 TeV Theory prediction
8 TeV Theory prediction
W
≥1j
≥2j
≥3j
≥4j
≥5j
≥6j
1c
2b
Z
≥1j
≥2j
≥3j
≥4j
≥1b
≥2b
tt
1j
2j
3j
Fiducial W and Z σs with W→lν, Z→ll and kinematic selection