LHC diffraction results

Luiz Mundim
for ATLAS and CMS collaborations

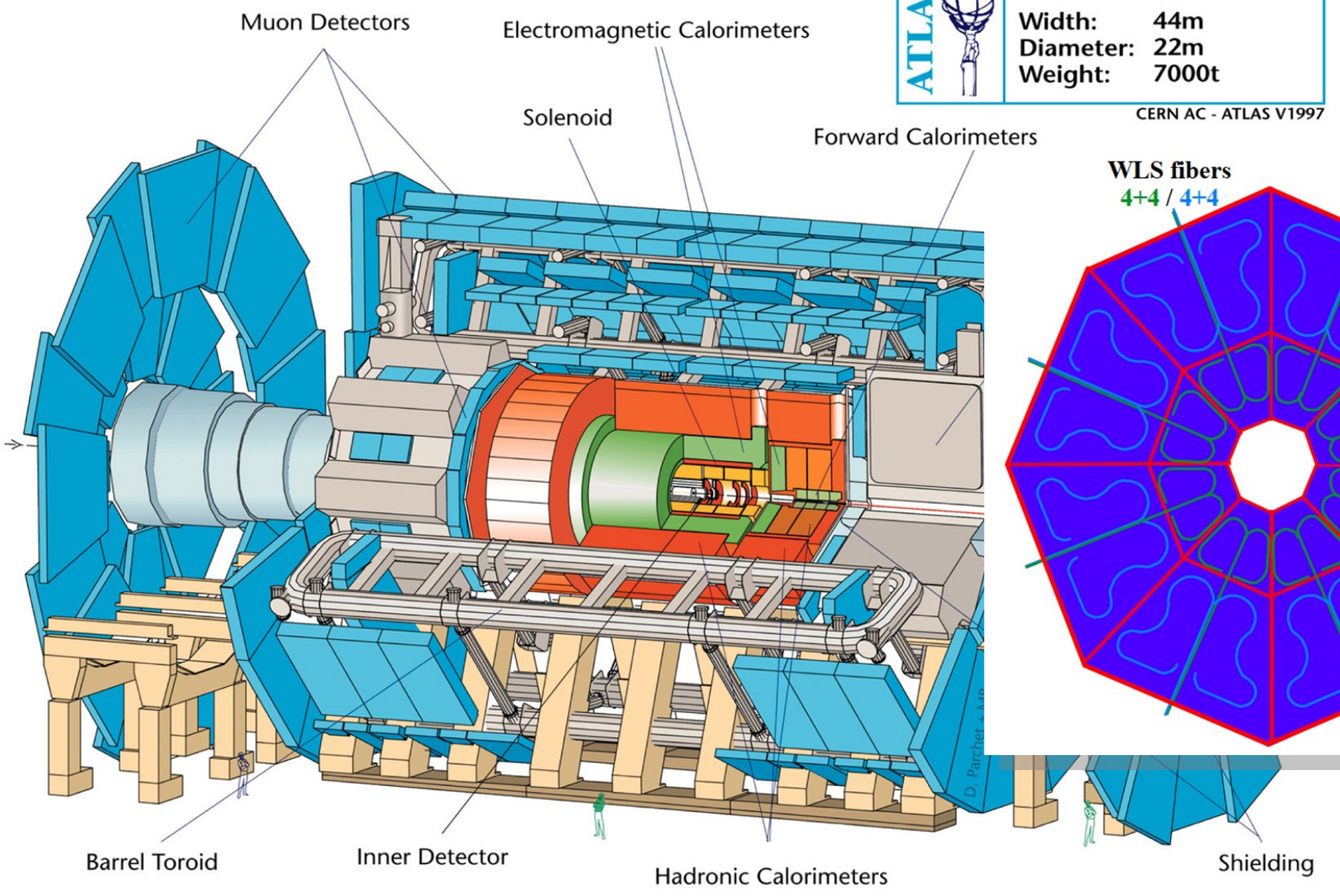
Outlook

- ATLAS detector
- ATLAS results
  - Inelastic pp cross section
  - Rapidity gap cross section

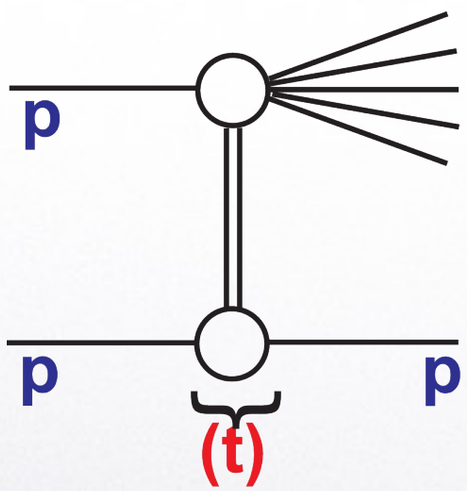
- CMS detector
- CMS results
  - Evidence of hard diff. dijet
  - Inel. pp cross section
  - Exc. $\gamma\gamma$ and e^+e^- production

ATLAS results

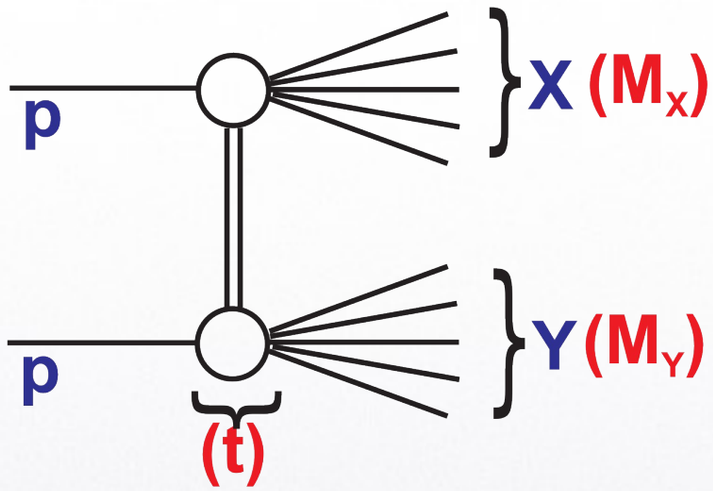
ATLAS detector



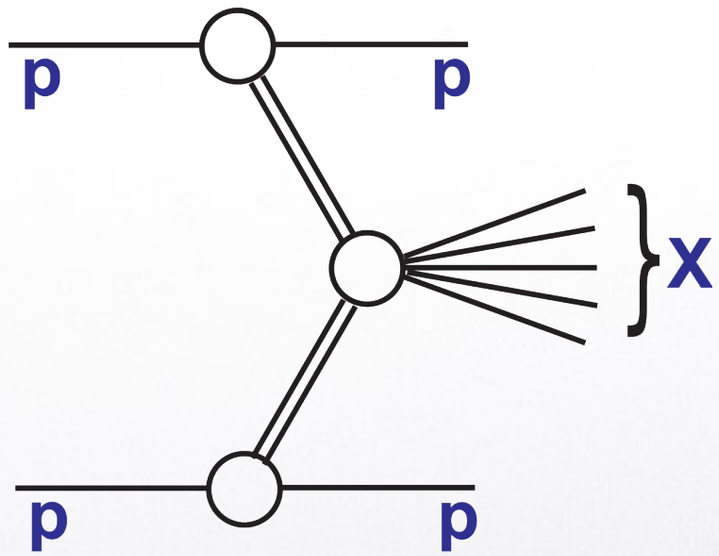
Diffractive topologies



SD



DD



CD

inelastic *pp* cross section

First measurement of total inelastic cross section at $\sqrt{\sigma} = 7$ TeV, using an integrated luminosity of $20.3 \pm 0.7\ \mu b^{-1}$ taken by ATLAS during a 8h fill in March 31st, 2010.

http://cdsweb.cern.ch/record/1342115

Data

- peak instantaneous luminosity = 1.2×10^{27} cm^{-2} s^{-1}
  - mean number of interactions per crossing = 0.01
- uses scintillator counters to detect inelastic collisions (MBTS)
- measurement restricted to a kinematic range of $\xi > 5 \times 10^{-6}$ ($M_X > 15.7$ GeV)

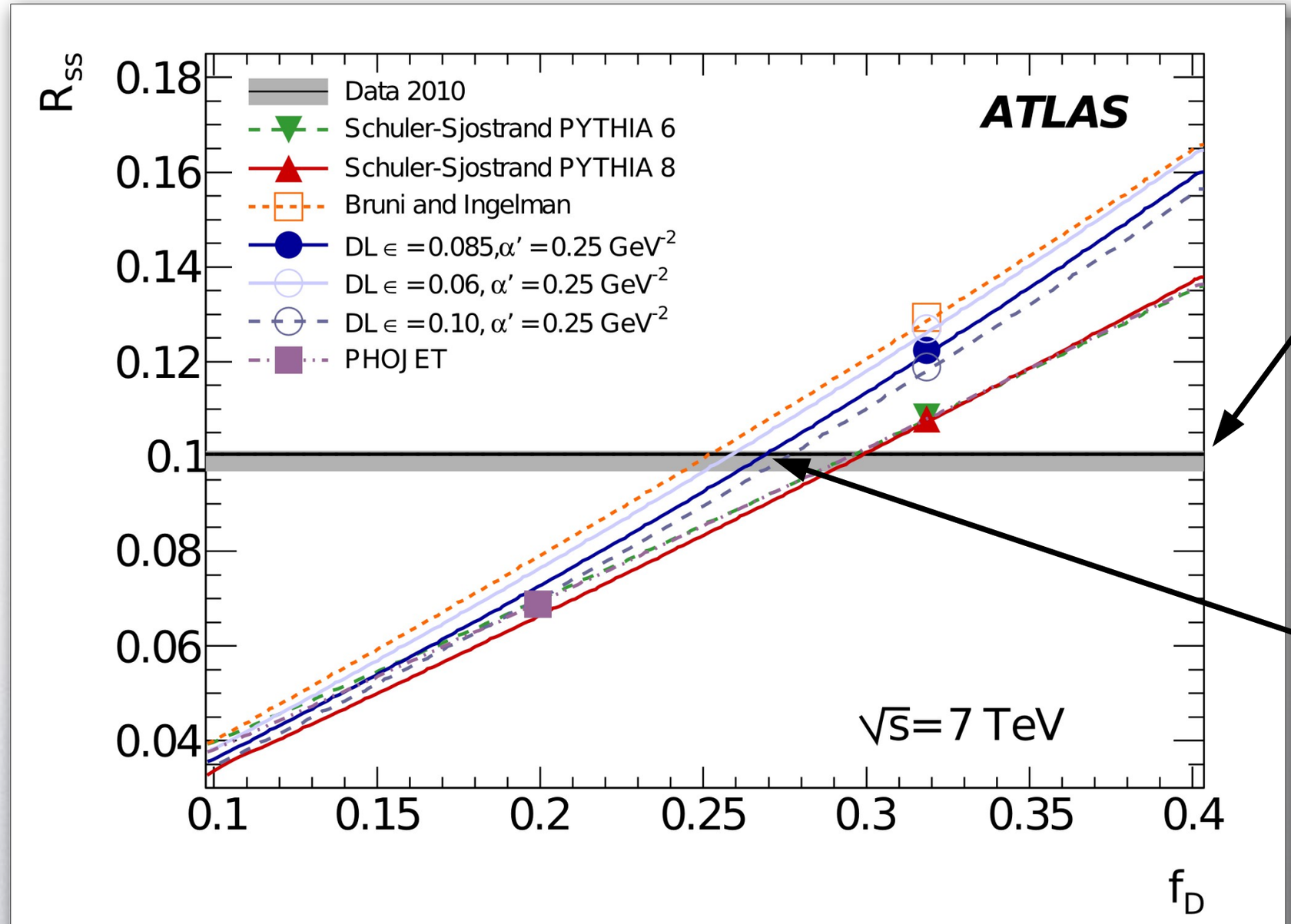
MC

- PYTHIA6, PYTHIA8 and PHOJET
  - to predict properties of inelastic collisions
    - ✔ $pp \rightarrow pX$ (SD);
    - ✔ $pp \rightarrow XY$ (DD)
    - ✔ ND
  - extrapolate to $\xi > M_p/\sqrt{s}$

Event selection

- $\xi = M_x / \sqrt{s} > 5 \times 10^{-6} \longrightarrow \epsilon_{MBTS} > 50\%$
- inclusive sample: 2 or more hits with charge > 0.15 pC on MBTS ($2.1 < |\eta| < 3.8$)
- diffractive sample: single-sided events

fraction of diffractive events



$$R_{ss} = \frac{N_{inc}}{N_{dif}}(\%)$$

$$f_D = 26.9^{+2.5}_{-1.0}\,\%$$

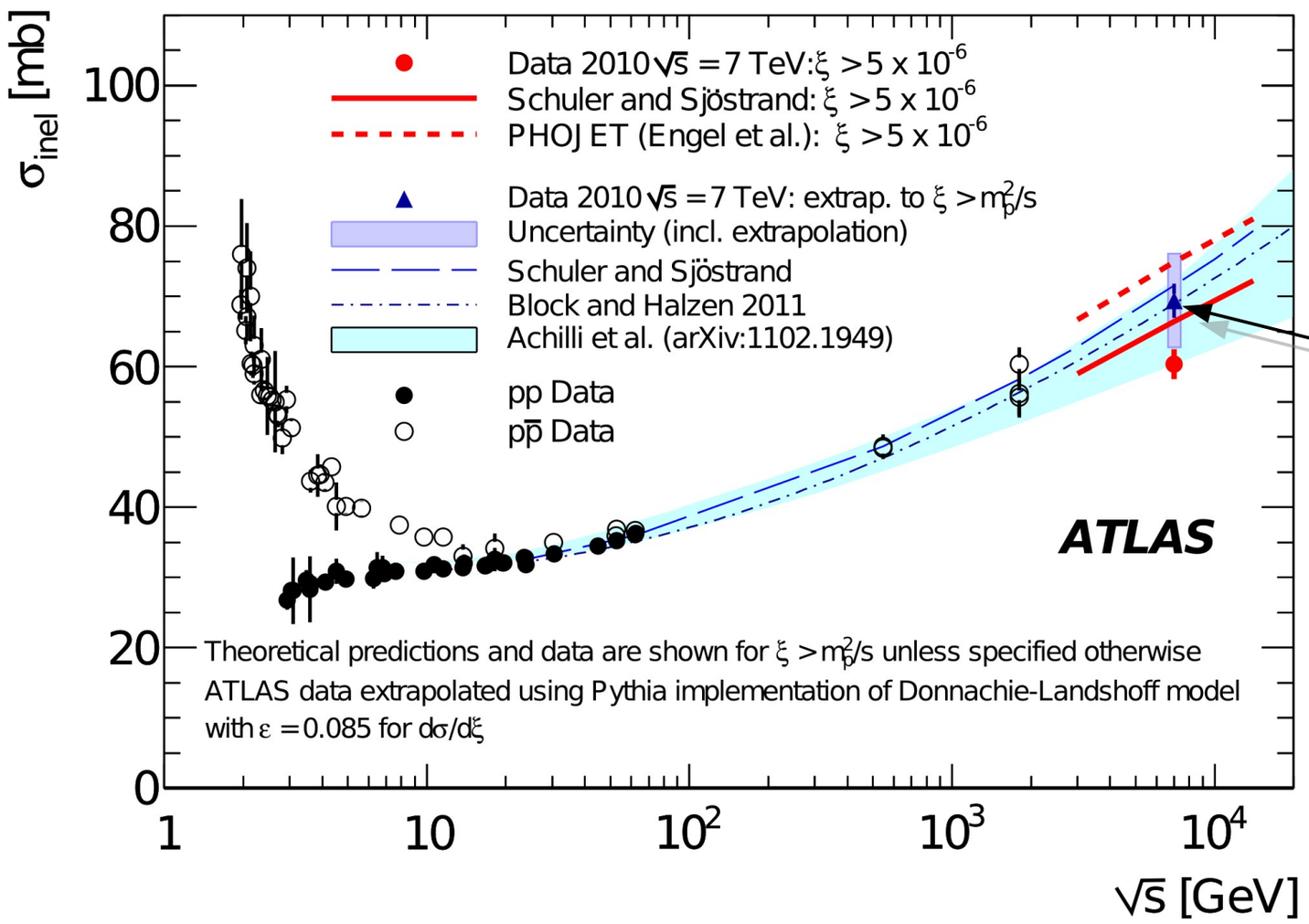
the cross section

$$\sigma_{inel}\left(\xi > 5\times10^{-6}\right) = \frac{\left(N - N_{BG}\right)}{\epsilon_{trig} \times \int L\,dt} \times \frac{1 - f_{\epsilon < 5\times10^{-6}}}{\epsilon_{sel}}$$

$$\sigma_{inel} = \sigma_{ND} + \sigma_{SD} + \sigma_{DD}$$

MC-dependent correction factor

Inelastic cross section



$69.4 \pm 2.4^{exp} \pm 6.9^{extr}$ mb

Rapidity gap cross section

Inelastic cross section is measured differentially in terms of $\Delta\eta^F$ at $\sqrt{\sigma}$= 7 TeV, using an integrated luminosity of 7.1μb^{-1} collected during the first LHC run.

A new algorithm is presented to identify rapidity gaps in the final state of minimum bias data.

http://cdsweb.cern.ch/record/1416082

Data

- peak instantaneous luminosity = 1.1×10^{27} cm^{-2} s^{-1}
  - mean number of interactions per crossing = 0.005
- uses MBTS as trigger
- Liquid Argon (EM) calorimeter
- Hadronic calorimeter

MC

- PYTHIA 6
  - DL (ε=1.085; α'=0.25GeV) as default for MC-based corrections
  - other MC models for uncertainties

Event selection

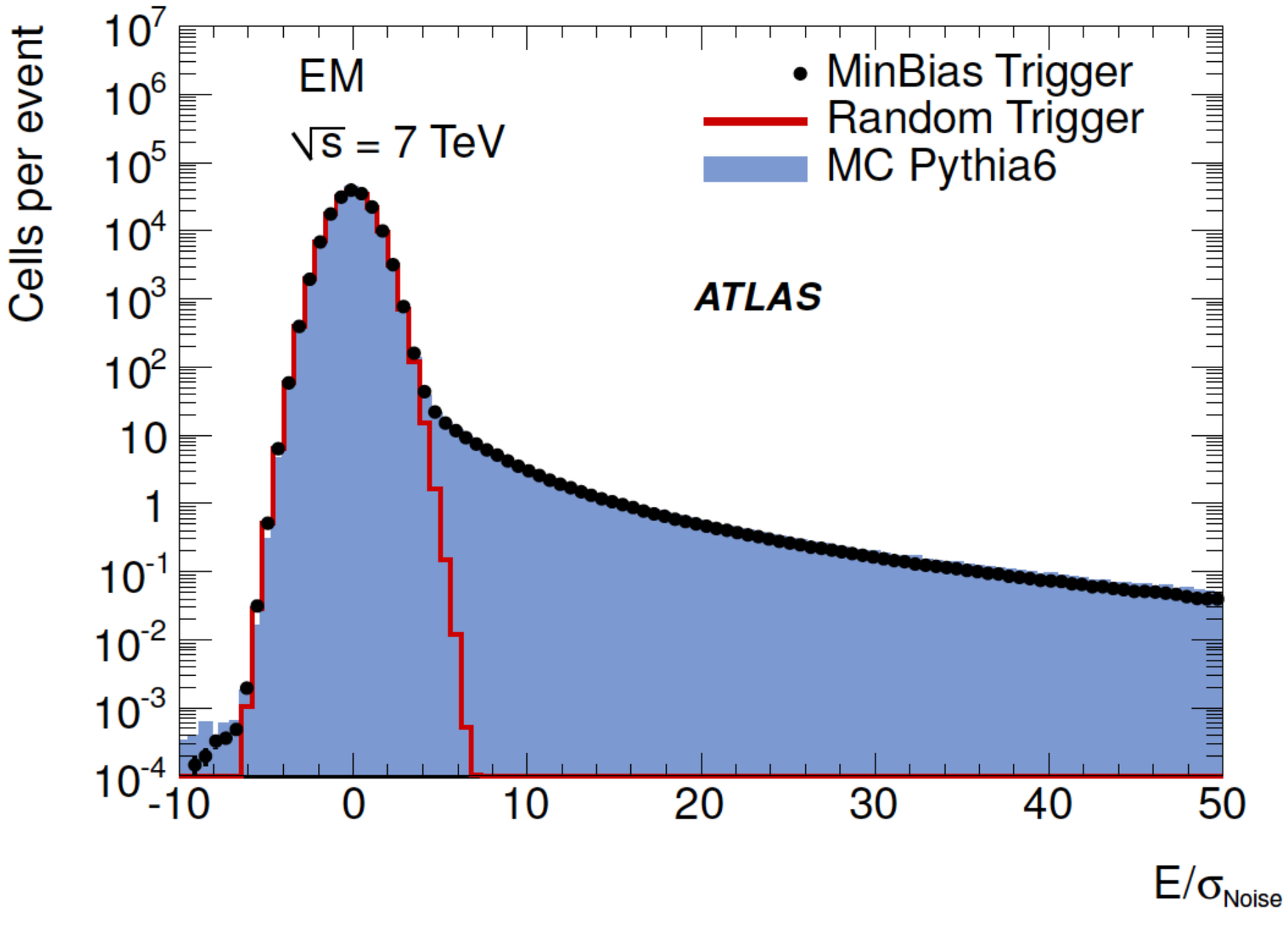
- events with hits in at least 2 segments of MBTS with charge > 0.15 pC

Rapidity gap reconstruction

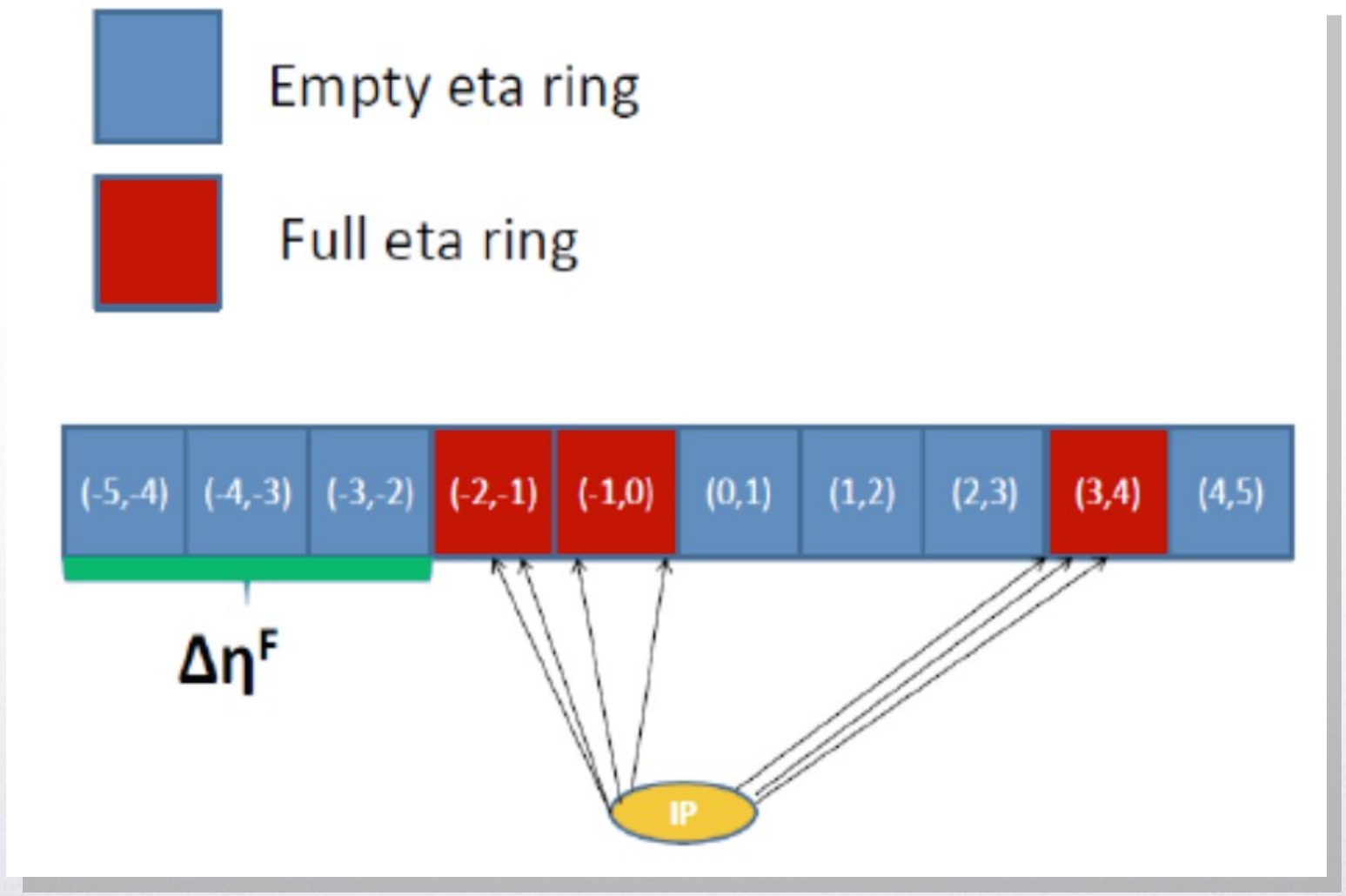
- clusters with cells for which $S(E/\sigma_{noise})>4$
- at least one cell (outside the tile cal.) with $S>S_{th}(\eta)$
- the measured energy of the clusters are discriminated using a given value of p_T^{cut}

An interval of η is taken as having final state particles if at least one cluster passes the noise suppression requirements and has $p_T > p_T^{cut}$ or if there is at least one good inner detector track with $p_T > p_T^{cut}$

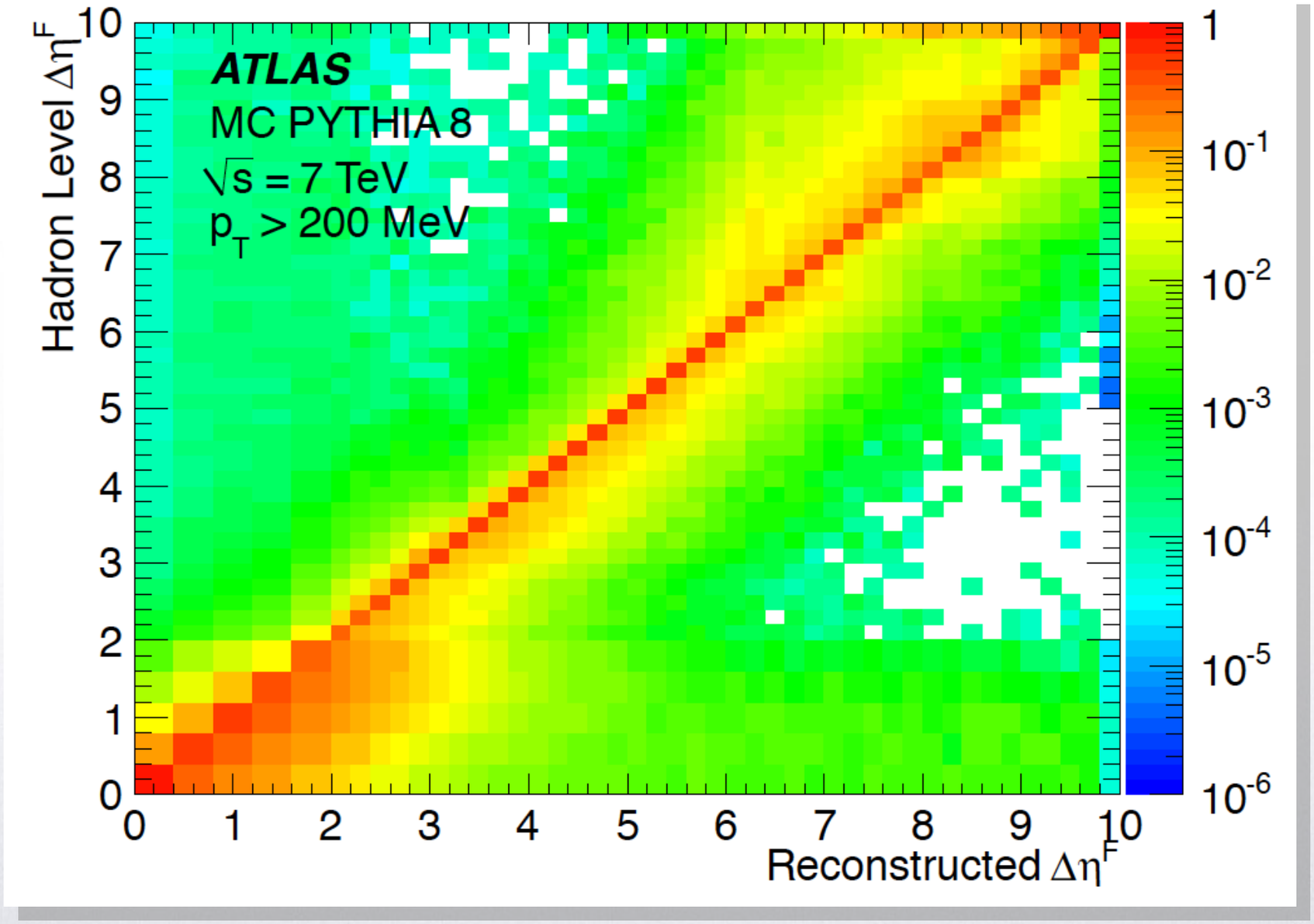
Cell energy significance



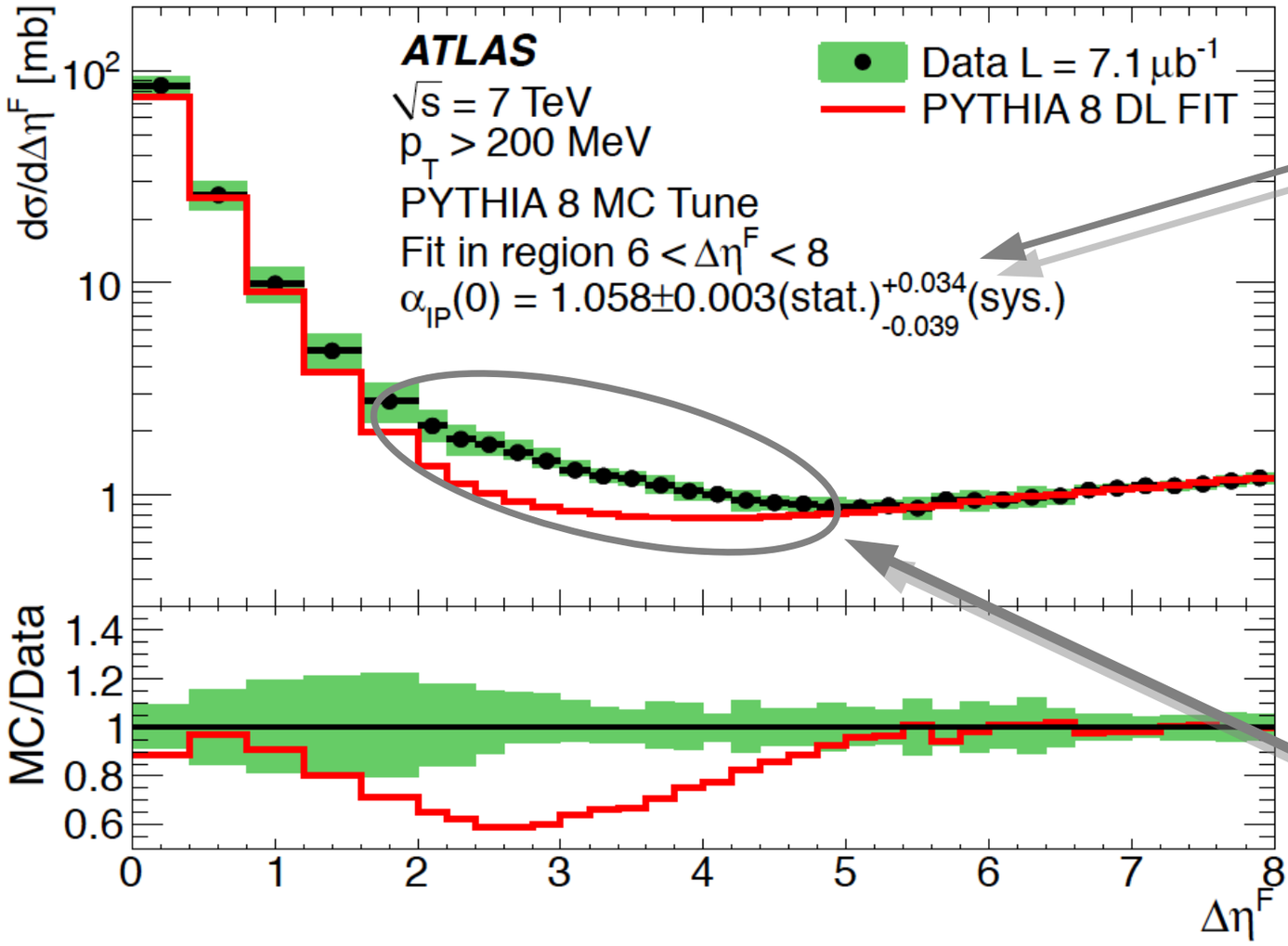
Definition of $\Delta\eta^F$



hadron level x reconstruction



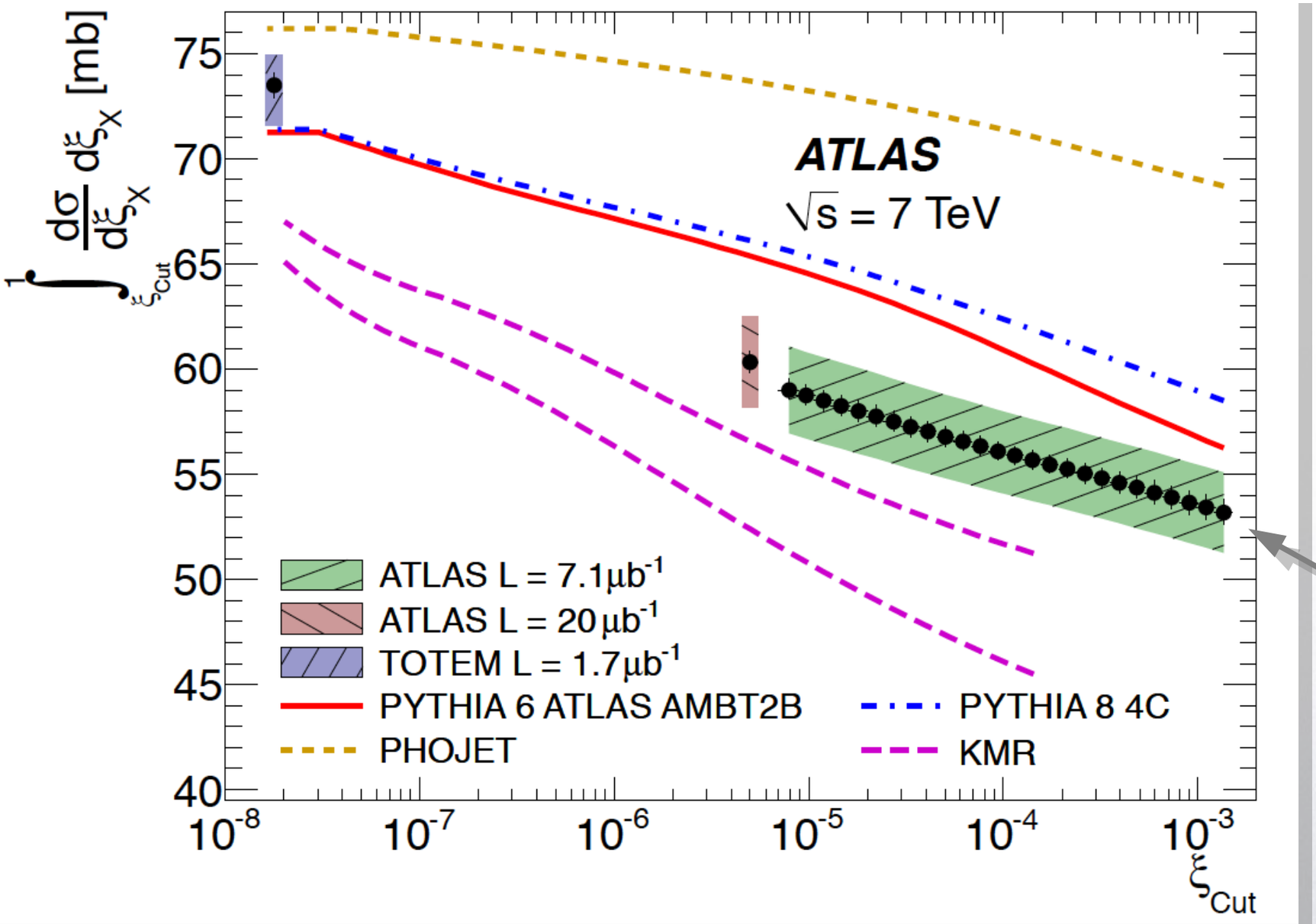
PYTHIA8 DL fit



Default DL
$\alpha_{IP} = 1.085$

- modeling of large hadronic fluctuation (ND)?
- sub-leading trajectory exchange?
- lack of CD component in PYTHIA model?

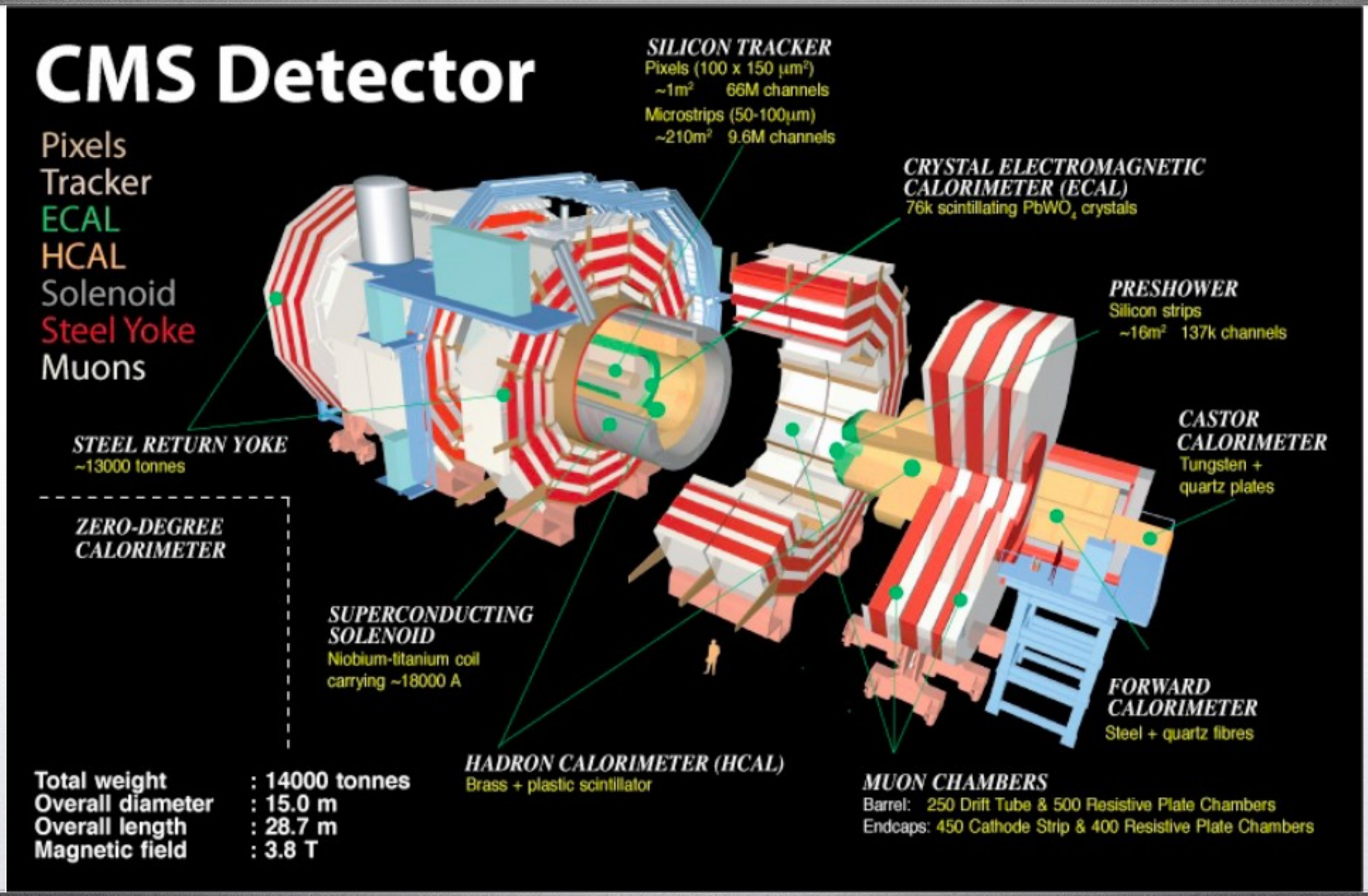
Inelastic cross section



$$\log_{10}\xi_{CUT} = -0.45\,\Delta\eta^{F}_{CUT} - 1.52$$

PYTHIA8

CMS results


CMS Detector
Pixels
Tracker
ECAL
HCAL
Solenoid
Steel Yoke
Muons
SILICON TRACKER
Pixels (100 x 150 μm²)
~1m² 66M channels
Microstrips (50-100μm)
~210m² 9.6M channels
CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
76k scintillating PbWO4 crystals
PRESHOWER
Silicon strips
~16m² 137k channels
CASTOR CALORIMETER
Tungsten + quartz plates
STEEL RETURN YOKE
~13000 tonnes
ZERO-DEGREE CALORIMETER
SUPERCONDUCTING SOLENOID
Niobium-titanium coil carrying ~18000 A
HADRON CALORIMETER (HCAL)
Brass + plastic scintillator
FORWARD CALORIMETER
Steel + quartz fibres
MUON CHAMBERS
Barrel: 250 Drift Tube & 500 Resistive Plate Chambers
Endcaps: 450 Cathode Strip & 400 Resistive Plate Chambers
Total weight : 14000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T

Evidence for hard diffractive dijet production

The cross section for dijet production with $p_T^{jet} > 20$ GeV is measured as function of the fractional momentum loss in SD pp collisions at $\sqrt{\sigma} = 7$ TeV, using the CMS detector with an integrated luminosity of 2.7 nb^{-1}

http://cms-physics.web.cern.ch/cms-physics/public/FWD-10-004-pas.pdf

Data

- integrated luminosity = 2.7 nb^{-1}
  - average pile-up of 0.09
- jet trigger with p_T > 6 GeV (uncorrected)

MC

- ND
  - PYTHIA6 (Z2 AND D6T)
  - PYTHIA8
- Diffractive dijets
  - POMPYT
  - POMWIG

  } IP flux → HERA
  - PYTHIA8

✔ dPDF → H1 fit B
✔ CD neglected

Event selection

- at least two jets with p_T>20 GeV within |η|<4.4 (standard CMS quality cuts)
- High quality vertex (|z|<24cm; tracks with |η|<2.5)
- more then 25% of high quality tracks (if N_{trks}>10)
  - reduce noise and beam related background
- to enhance the diff. contribution: $\eta_{max(min)}$<3(>-3)
  - gap of 1.9 units (rejects most of the pile-up events)

the diffractive cross section (theoretical)

over all parton flavours

Pomeron flux

partonic cross section

$$\frac{d\sigma}{d\xi dt} = \sum \int dx_1 dx_2 x_1 x_2 f(\xi,t) f_{I\!P}(x_1,\mu) f_p(x_2,\mu)\hat{\sigma}$$

$f_{diff}(\xi,t,x_1,\mu)$

proton dPDF

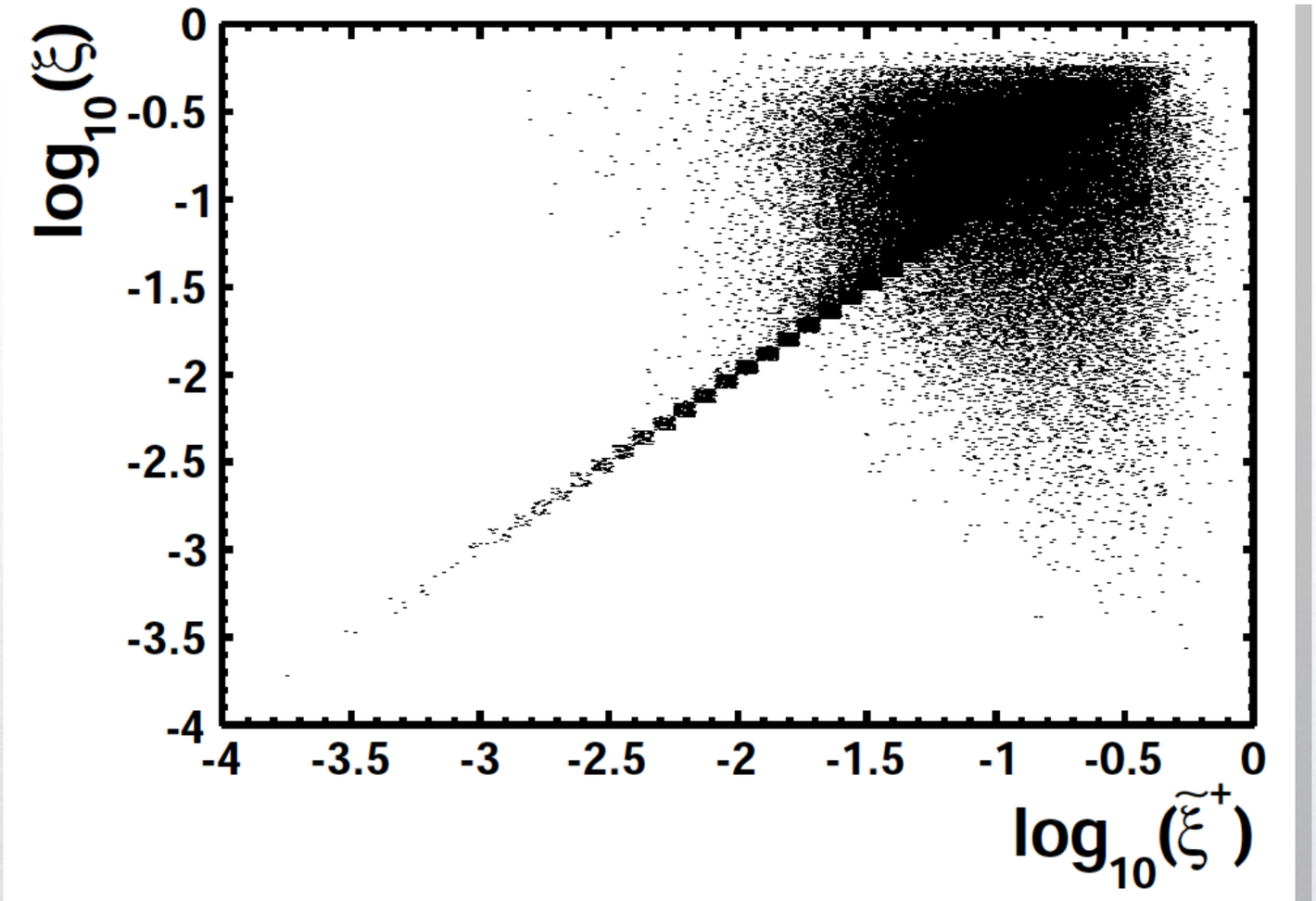
Pomeron structure function

proton inclusive PDF

Consistent with HERA data

Proton momentum loss

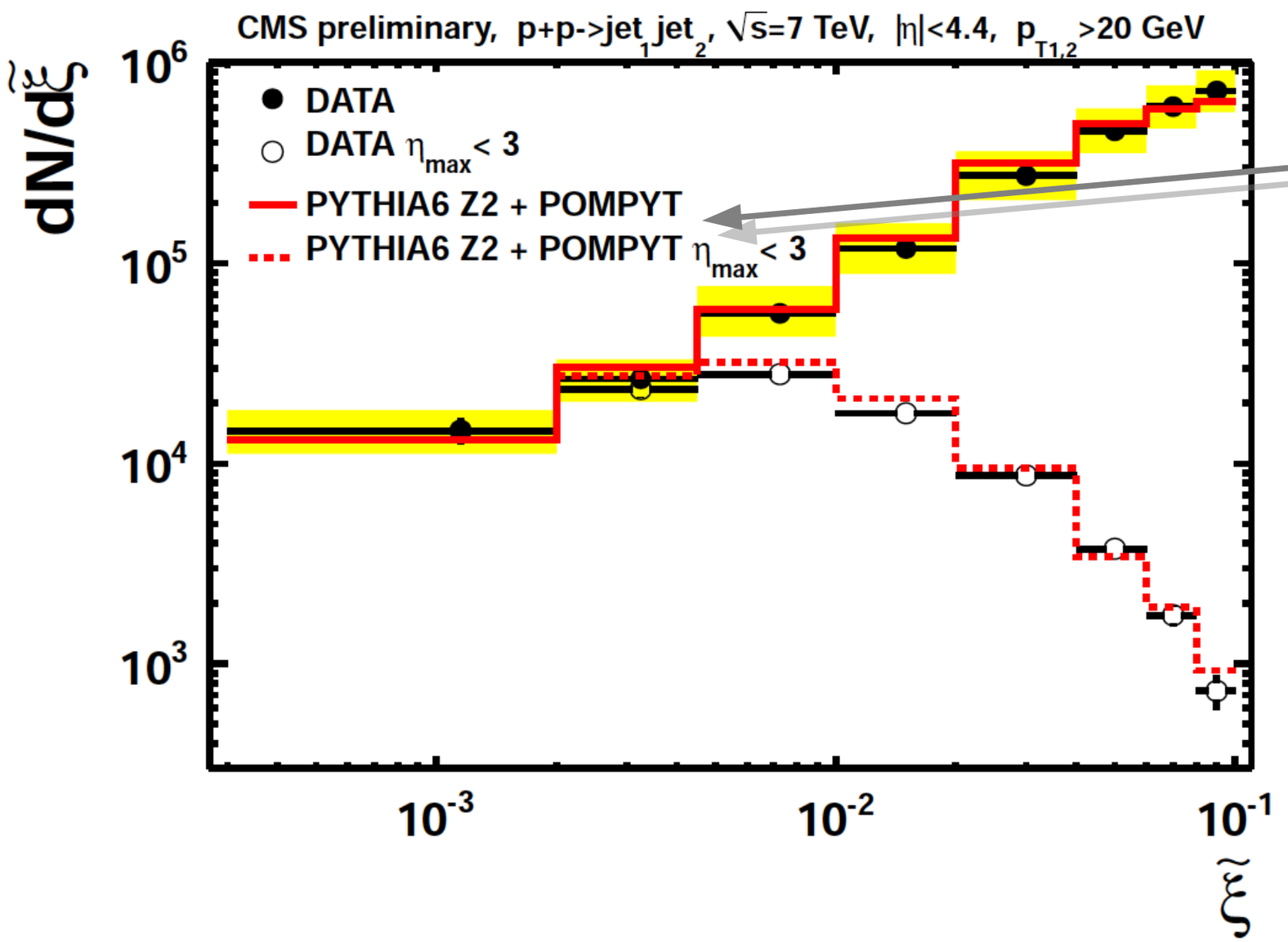
$$\xi \longrightarrow \tilde{\xi}^{\pm} = \frac{\sum \left(E^i \pm p_z^i\right)}{\sqrt{s}} \simeq \frac{M_X^2}{s} \qquad \begin{cases} \tilde{\xi}^{+} & \rightarrow \eta < +4.9 \\ \tilde{\xi}^{-} & \rightarrow \eta > -4.9 \end{cases}$$



$$\xi^{\pm}_{rec} = C\xi^{\pm}$$

C = 1.45 ± 0.04

$\tilde{\xi}_{rec}$ distribution



relative normalization

the dijet cross section (experimental)

 # dijet events (PU corrected)

$$\frac{d\sigma_{jj}}{d\tilde{\xi}} = \frac{N^i_{jj}}{\mathcal{L} \cdot \epsilon \cdot A^i \cdot \Delta\tilde{\xi}^i}$$

bin width

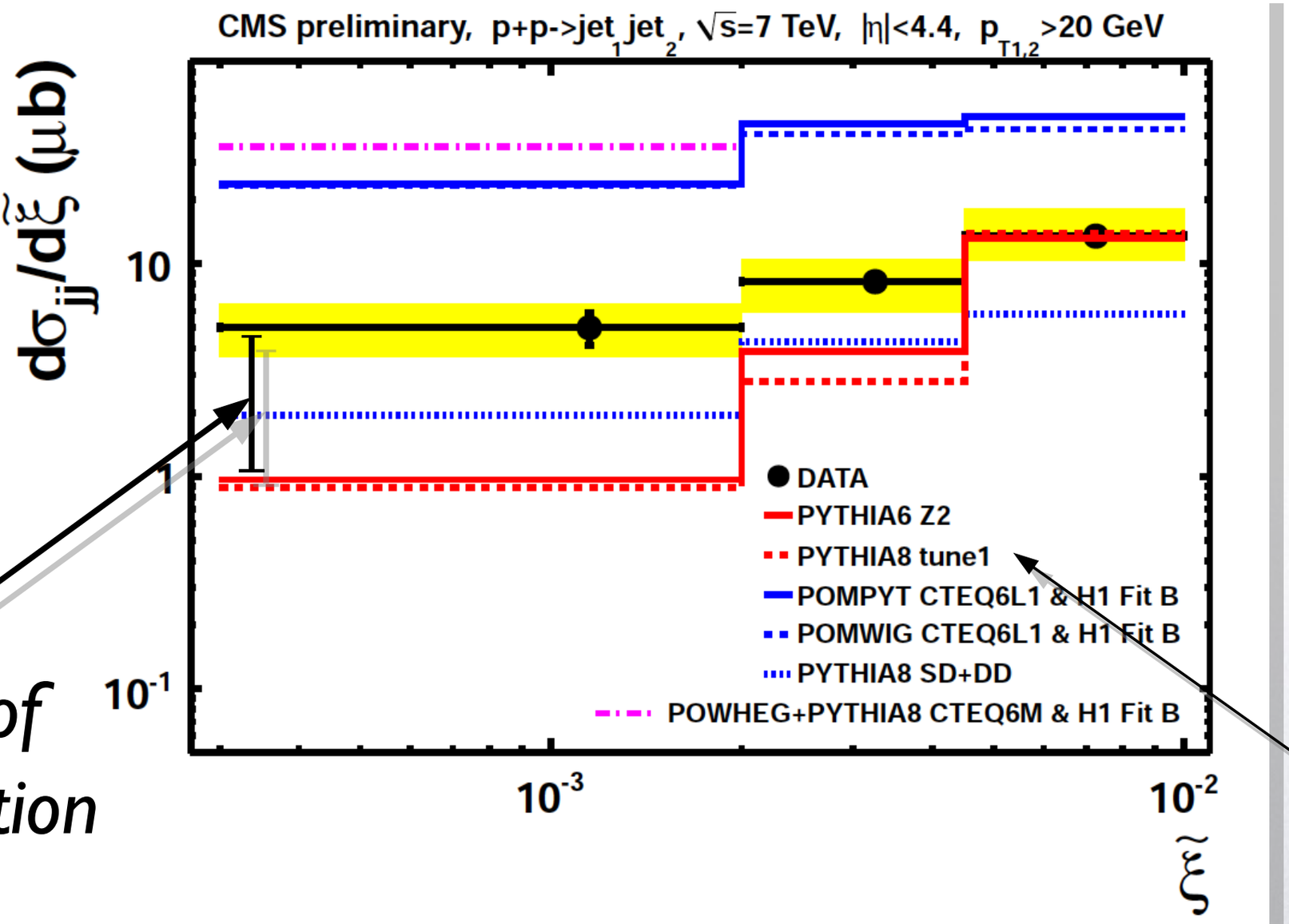
Luminosity

trigger eff.

N_{rec}/N_{gen}

→ *geom. accep.*
+ resolution

Data vs MC (1)

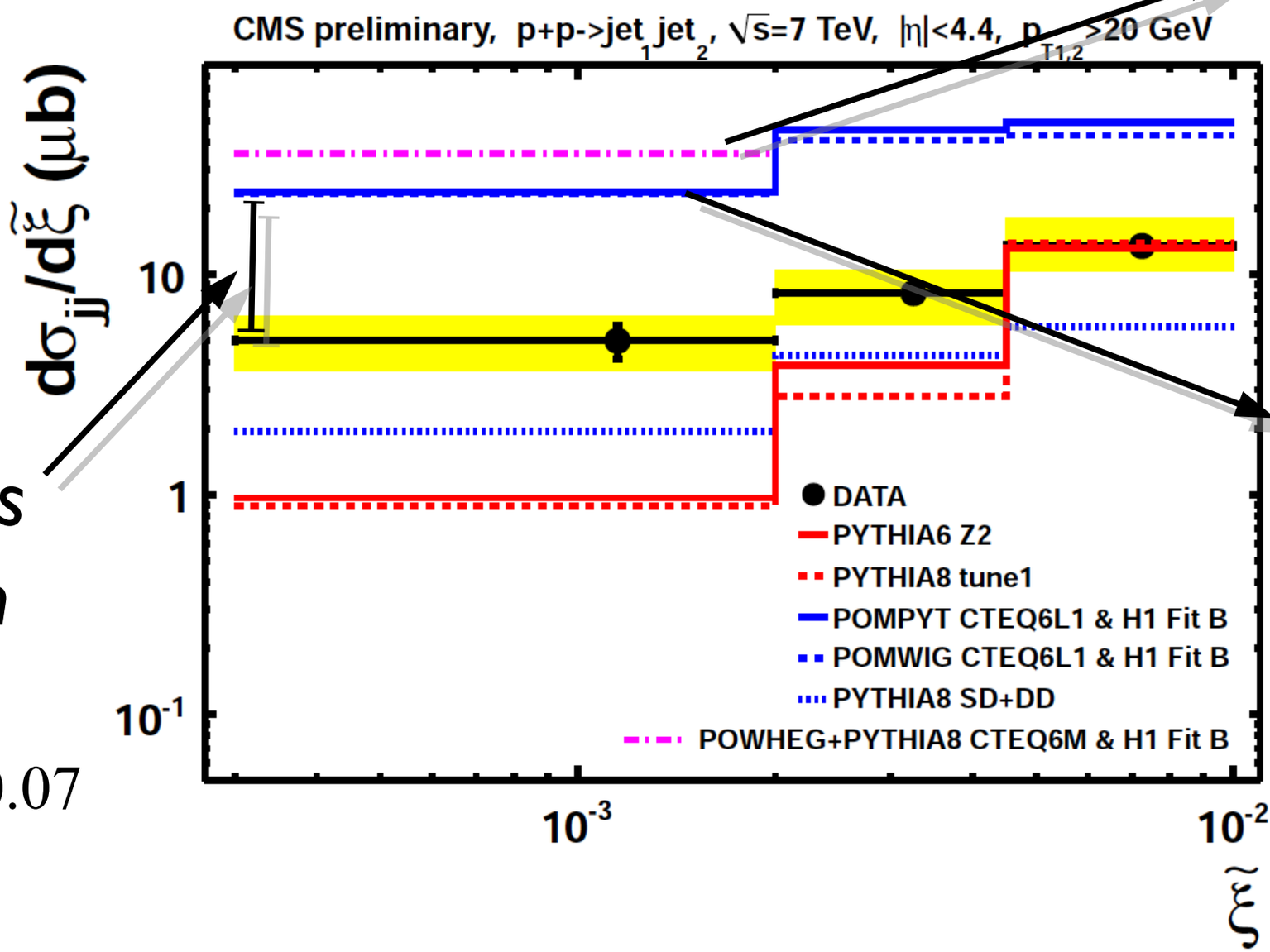


Evidence of hard diffraction

without hard diff.

data vs MC (II)

$$\epsilon_{GSP}^{NLO} = 0.08 \pm 0.04$$



$$\epsilon_{GSP}^{LO} = 0.12 \pm 0.05$$

overestimates the x-section

$$\frac{\sigma_{\exp}}{\sigma_{pred}} = 0.21 \pm 0.07$$

just an estimation!

assuming PYTHIA8 par.

inelastic pp cross section

Measurement of total inelastic cross section at $\sqrt{s} = 7$ TeV, using an integrated luminosity of 2.78 μb^{-1} taken by CMS.

https://cdsweb.cern.ch/record/1433413/files/QCD-11-002-pas.pdf

Data

- based on HF calorimeter
  - pileup: 0.12 – 0.07

- BPTX AND → zero-bias trigger

- BPTX XOR → background

- Random trigger → noise estimation

MC

- PYTHIA 6
- PYTHIA 8
- PHOJET

Event selection

- more than 5(4) GeV in any of the HFs

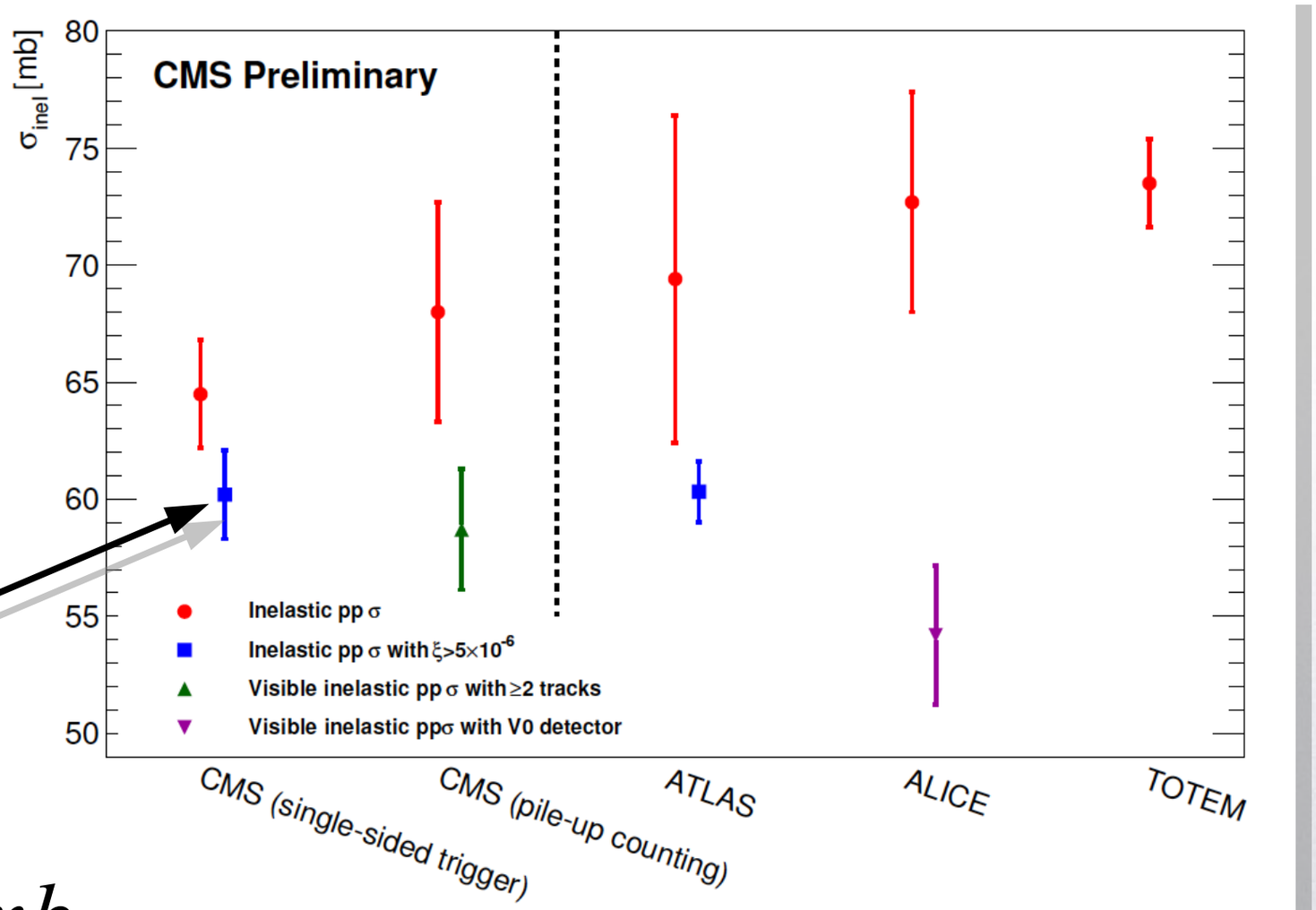
the cross section

fraction of bkg events($\xi<\xi_{cut}$)

$$\sigma_{inel}\left(\xi>5\times10^{-6}\right)=\frac{N_{inel}\left(1-f_{\xi}\right)F_{pileup}}{\mathcal{L}\ \epsilon_{\xi}}$$

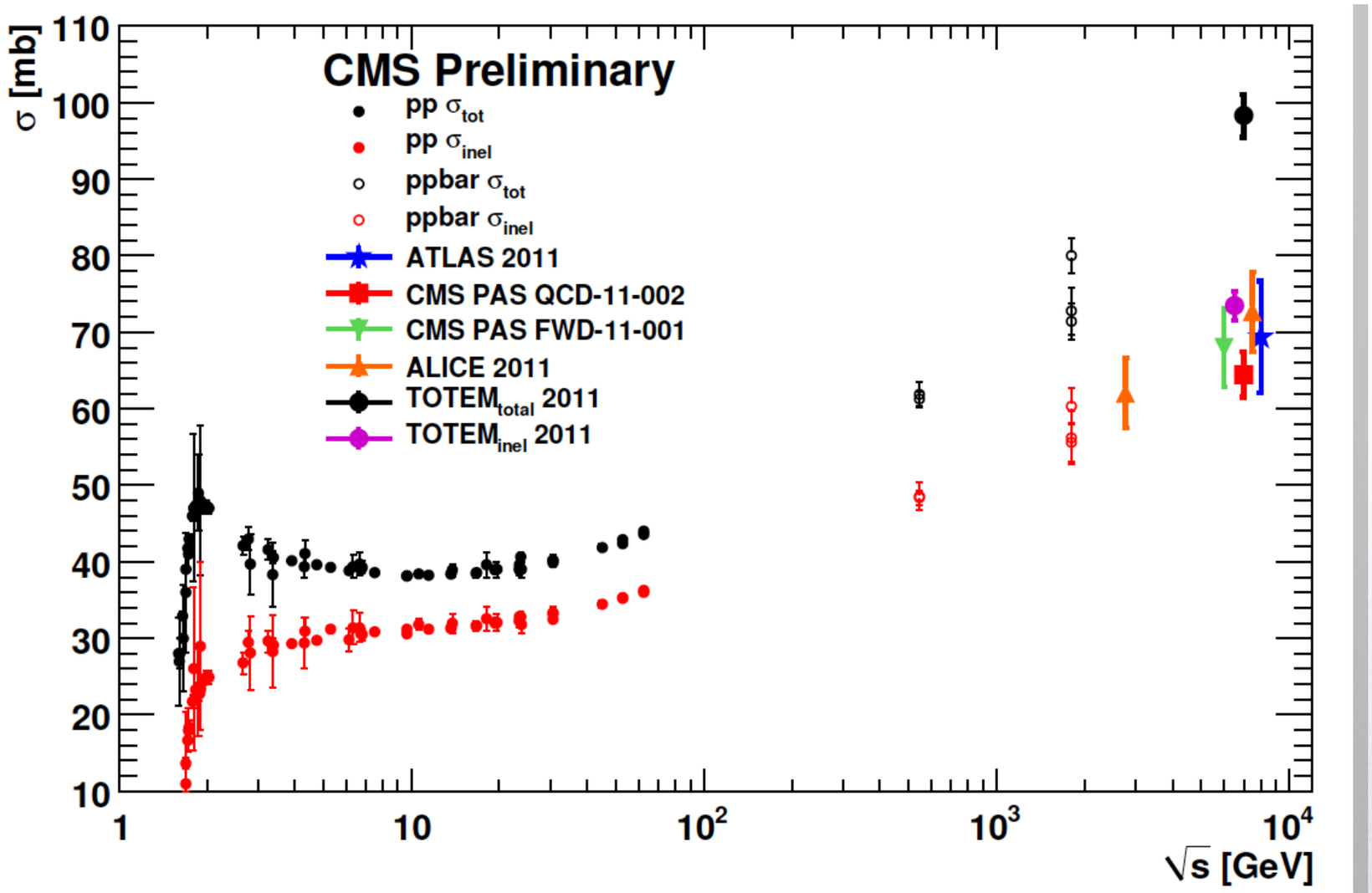
efficiency

Experimental measurement of the Inelastic pp cross section



$$60.2 \pm 0.2^{stat} \pm 1.1^{syst} \pm 2.4^{\mathcal{L}}\ mb$$

σ_{inel} x collision energy

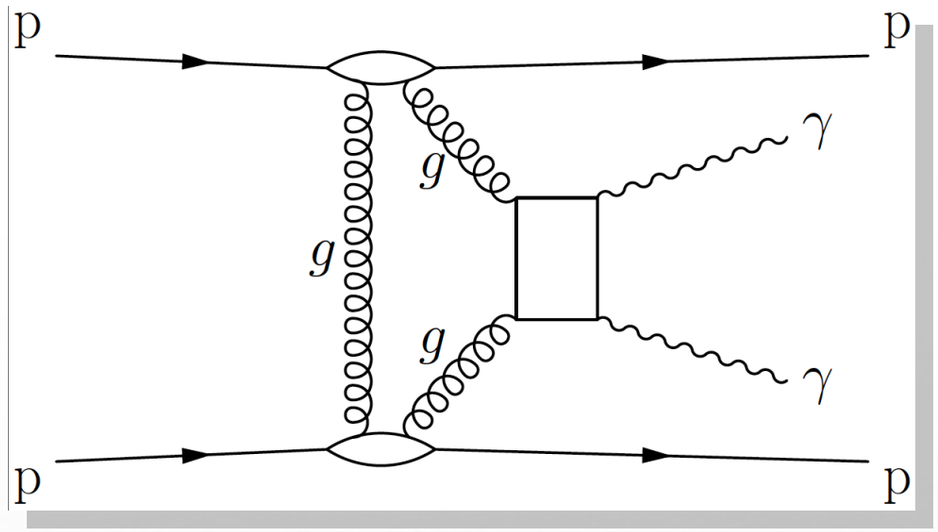


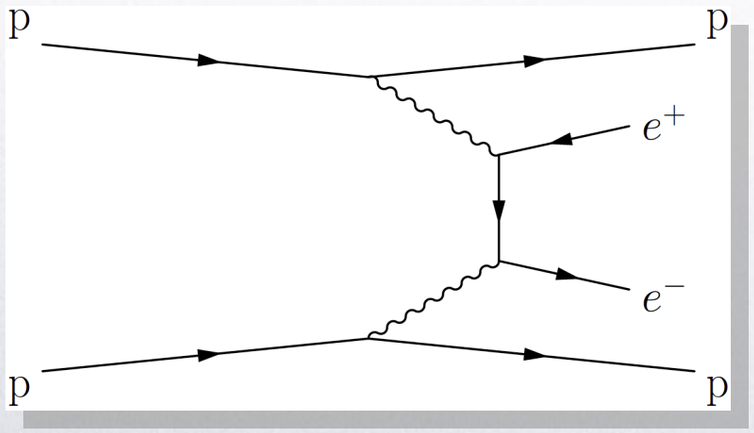
exclusive $\gamma\gamma$ and e^+e^- pair

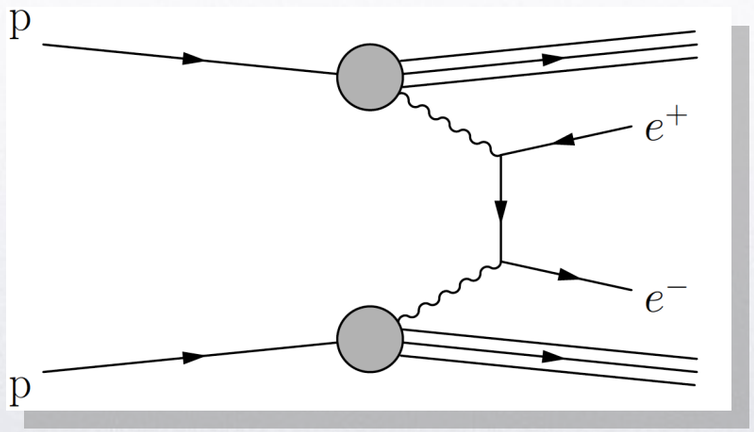
Search for central exclusive $\gamma\gamma$ production and observation of central exclusive e^+e^- production at $\sqrt{\sigma} = 7$ TeV at CMS as an ideal way to improve the understanding of diffractive processes and the dynamics of IP exchange; the dielectron also provides an excellent control sample for other exclusive channels, since this is a QED process known with an accuracy better than 1%.

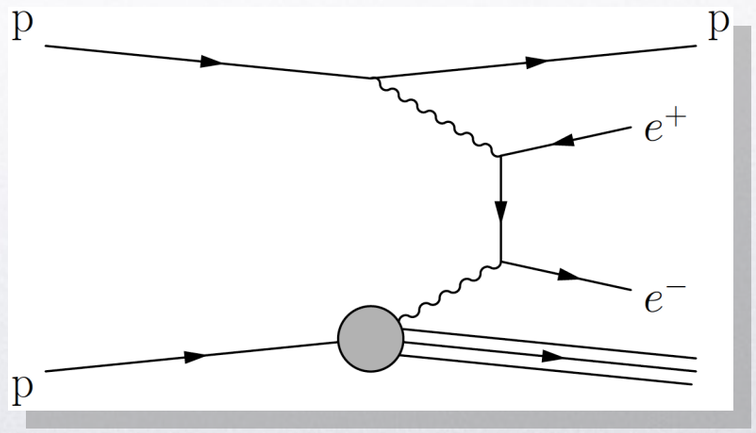
http://cms-physics.web.cern.ch/cms-physics/public/FWD-11-004-pas.pdf

exclusive diagrams









Data

- integrated luminosity of 36 pb^{-1}
  - ➢ no PU events
- 2 (L1/HLT) triggers of EM shower with E_T> 5 GeV
  - ➢ HLT: $\sphericalangle$ >2.5 rad + low had activity
- ECAL+tracker+HCAL+μ ch.

MC

- EXHUME ($\gamma\gamma$)
- LPAIR (e^+e^-)
- LUND(JETSET) for the fragmentation of the excited proton

Event selection

- 2 γ(e) with E_T> 5.5 GeV and $|\eta|$<2.5
- rejection of cosmic ray (t<2ns; ϕ>2.5 rad)
- no additional particles in the subdetectors

Expected events

Table 4: Summary of the number of background events expected for both exclusive diphoton and dielectron analyses with statistical uncertainties.

exclusive $\gamma\gamma$ production		exclusive e^+e^- production	
Background	Events	Background	Events
exclusive e^+e^-	0.11 ± 0.03	exclusive Y(1S,2S,3S) $\to e^+e^-$	negligible
cosmic ray	negligible	cosmic ray	0.04 ± 0.01
non-exclusive	1.68 ± 0.40	non-exclusive	0.80 ± 0.28
exclusive $\pi^0\pi^0$ and $\eta\eta$	negligible	exclusive $\pi^+\pi^-$	negligible
Total	1.79 ± 0.40	Total	0.84 ± 0.28

Table 5: Predicted numbers of dielectron events to be observed for both exclusive and semi-exclusive e^+e^- production for an integrated luminosity of $36\,pb^{-1}$.

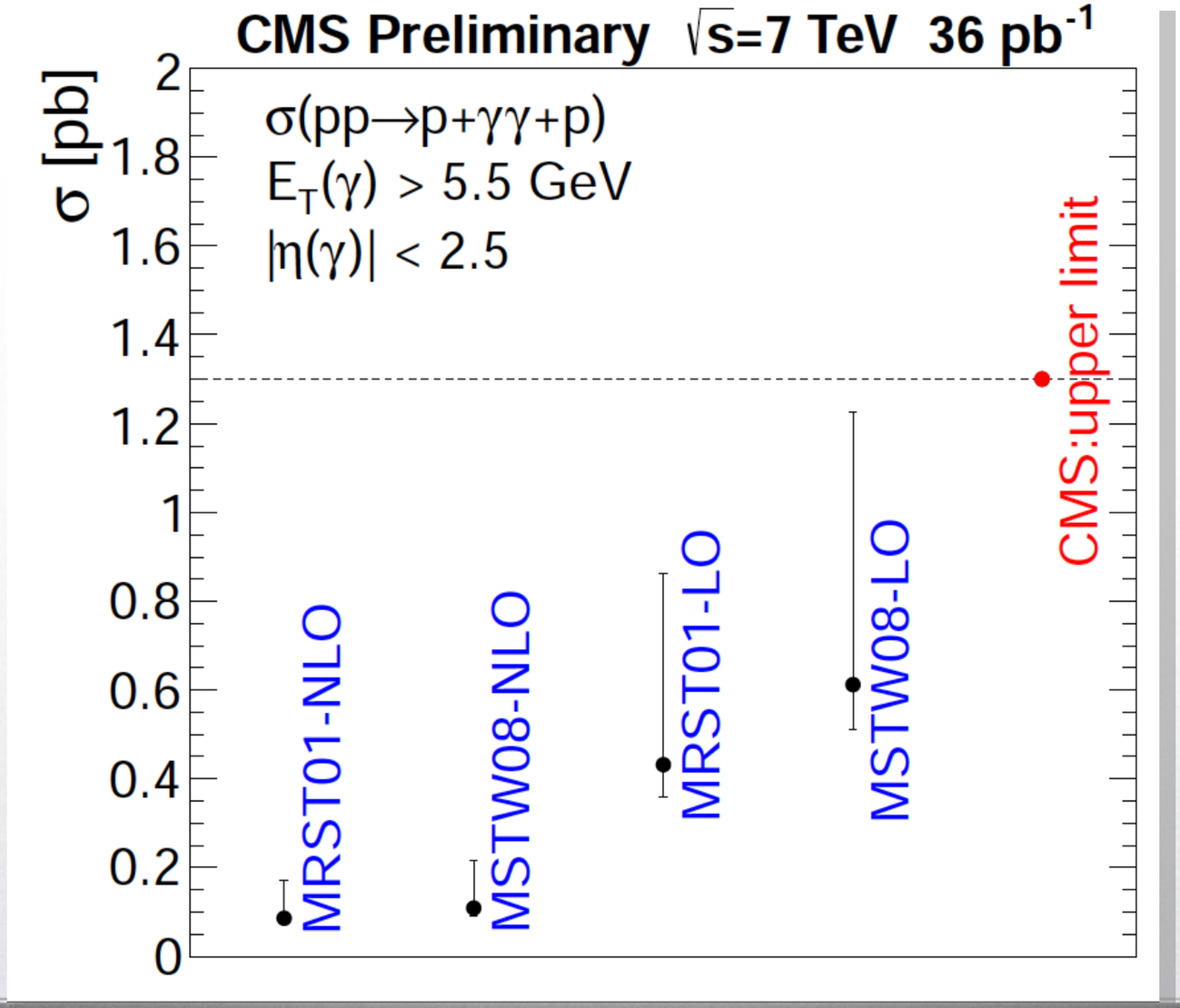
Process	$\mathcal{L}$	σ	ε	nEvents
el-el	$36\pm1.4\,pb^{-1}$	3.74 ± 0.04 pb	0.0481 ± 0.0055	6.48 ± 0.07 (theo.)±0.78 (syst.)
inel-el	$36\pm1.4\,pb^{-1}$	3.34 ± 0.67 pb $\times2$	0.0343 ± 0.0035	8.25 ± 1.65 (theo.)±0.90 (syst.)
inel-inel	$36\pm1.4\,pb^{-1}$	3.52 ± 0.70 pb	0.0117 ± 0.0011	1.48 ± 0.29 (theo.)±0.15 (syst.)
Total				16.2 ± 1.7 (theo.)±1.2 (syst.)

Selected events

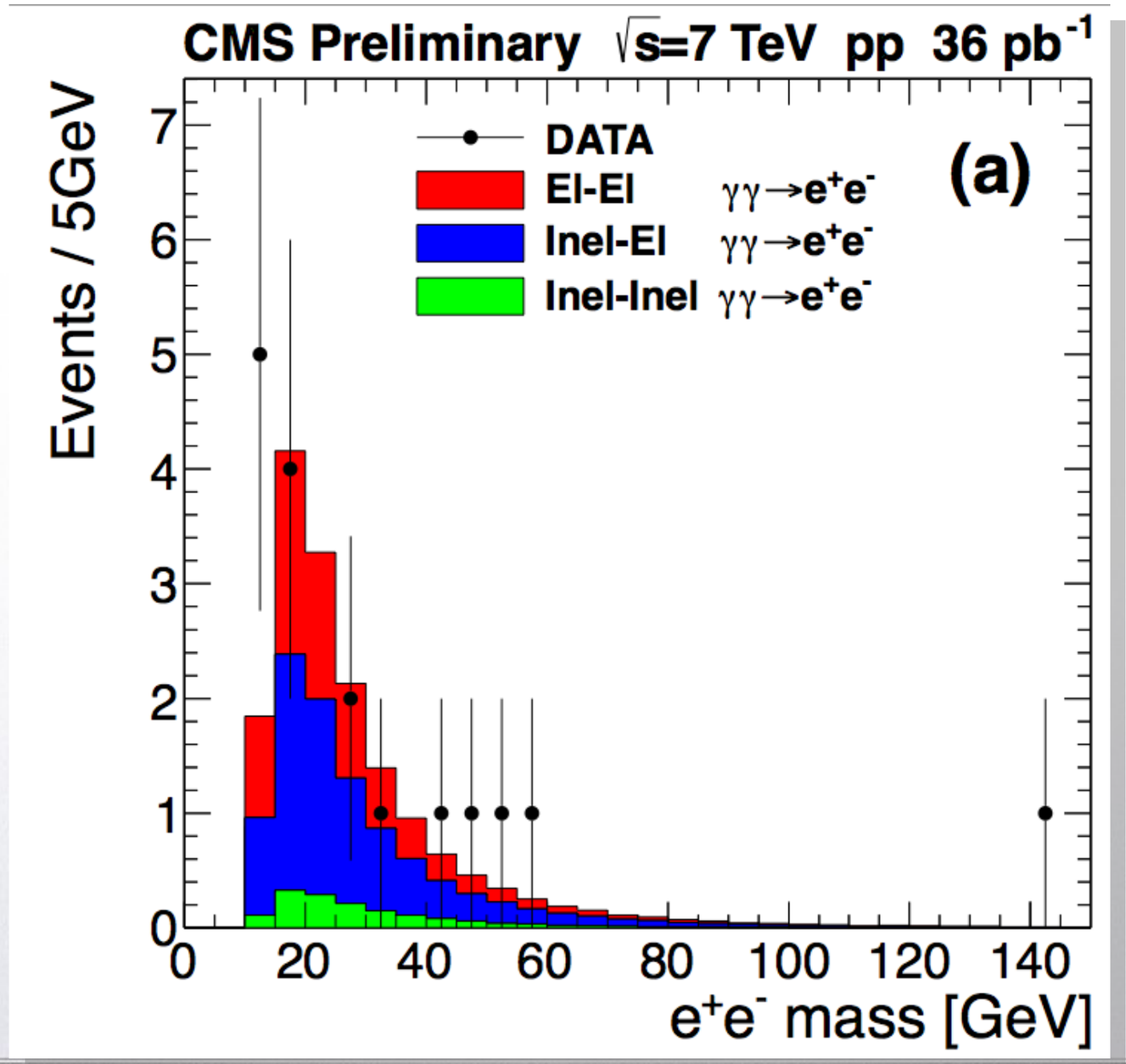
Table 1: Number of diphoton (dielectron) candidates remaining after each selection step.

exclusive diphoton analysis		exclusive dielectron analysis	
selection criterion	events remaining	selection criterion	events remaining
Trigger	3 023 496	Trigger	3 023 496
Photon reconstruction	1 683 526	Electron reconstruction	132 271
Photon identification	40 692	Electron identification	2 648
Cosmic ray rejection	34 234	Cosmic ray rejection	2 129
Exclusivity requirement	0	Exclusivity requirement	17

Central exclusive γγ cross section (limits)



exclusive e^+e^- (Data vs MC)

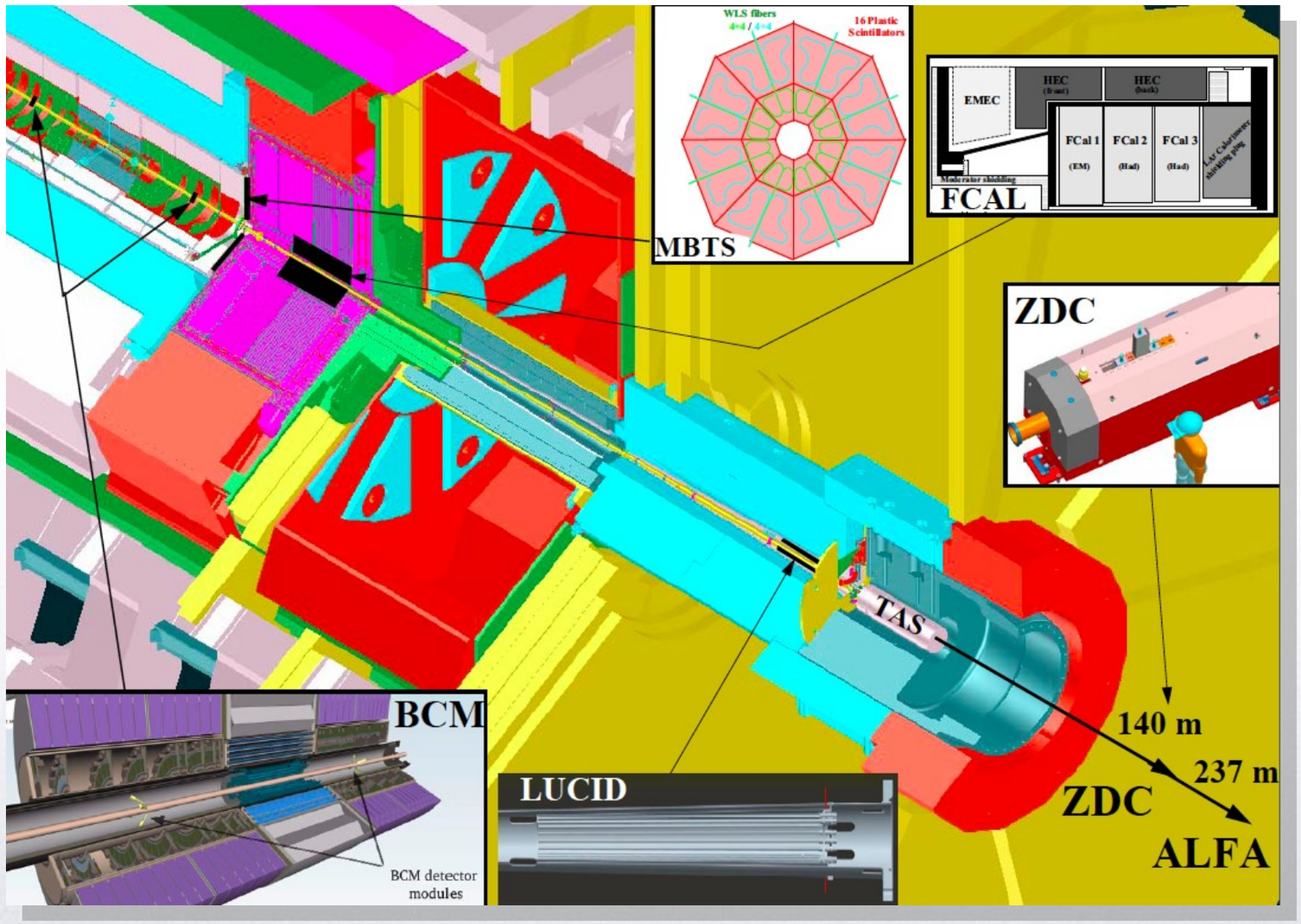


Final remarks

- both ATLAS and CMS showed good capabilities for diffraction studies
- The inelastic *pp* cross section measured by both ATLAS and CMS was presented, showing good agreement
- the dijet production cross section measurement shows strong evidence of hard diffraction, being well described with a GSP compatible with the one measured at CDF
- an upper limit for the cross section of the exclusive production of central $\gamma\gamma$ is presented and is compatible with the LO and NLO calculation
- the number of exclusive e^+e^- found in the data was 17 events, as predicted by LPAIR generator
- pileup is a major problem for the forward analysis, so forward proton taggers would greatly improve all diffractive analysis

Backup

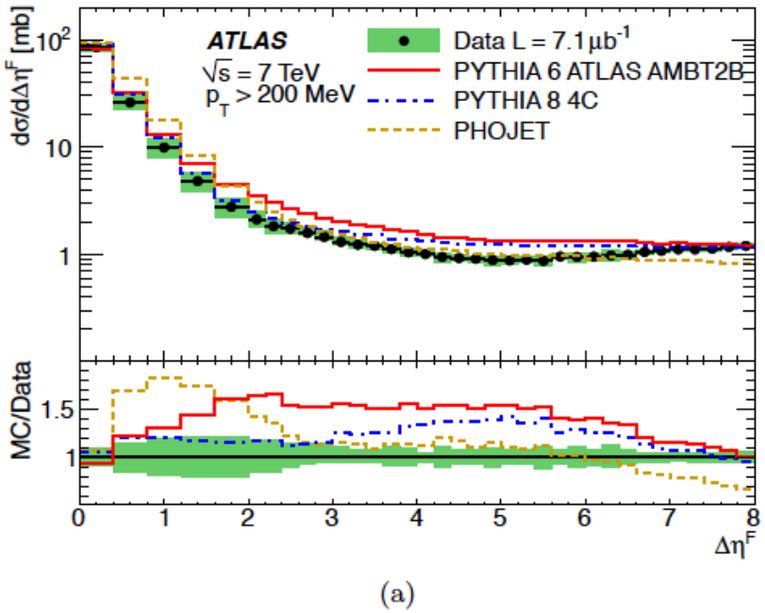
ATLAS forward detectors



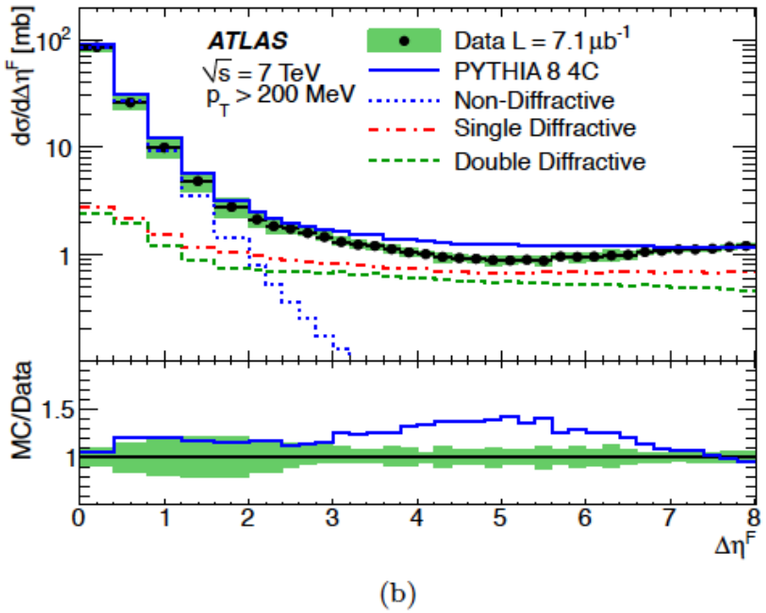
the gap cross section

$$\frac{d\sigma}{dtdM_X^2} = G_{3I\!P}(0) s^{2\alpha_{I\!P}(t)-2} \left(M_X^2\right)^{\alpha_{I\!P}(0)-2\alpha_{I\!P}(t)} f(t)$$

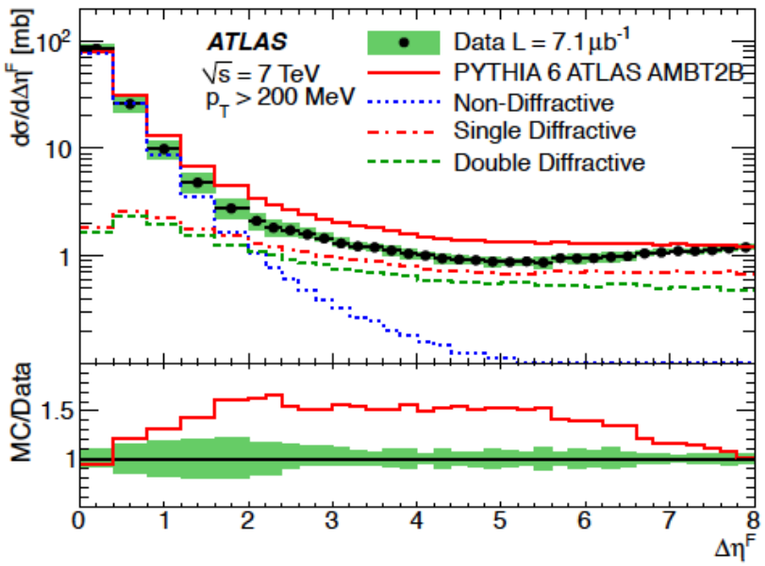
Differential cross section



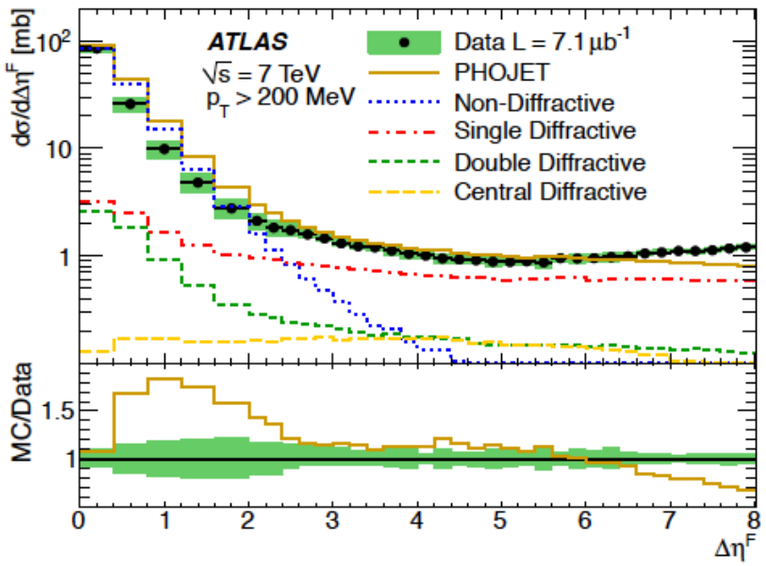
(a)



(b)



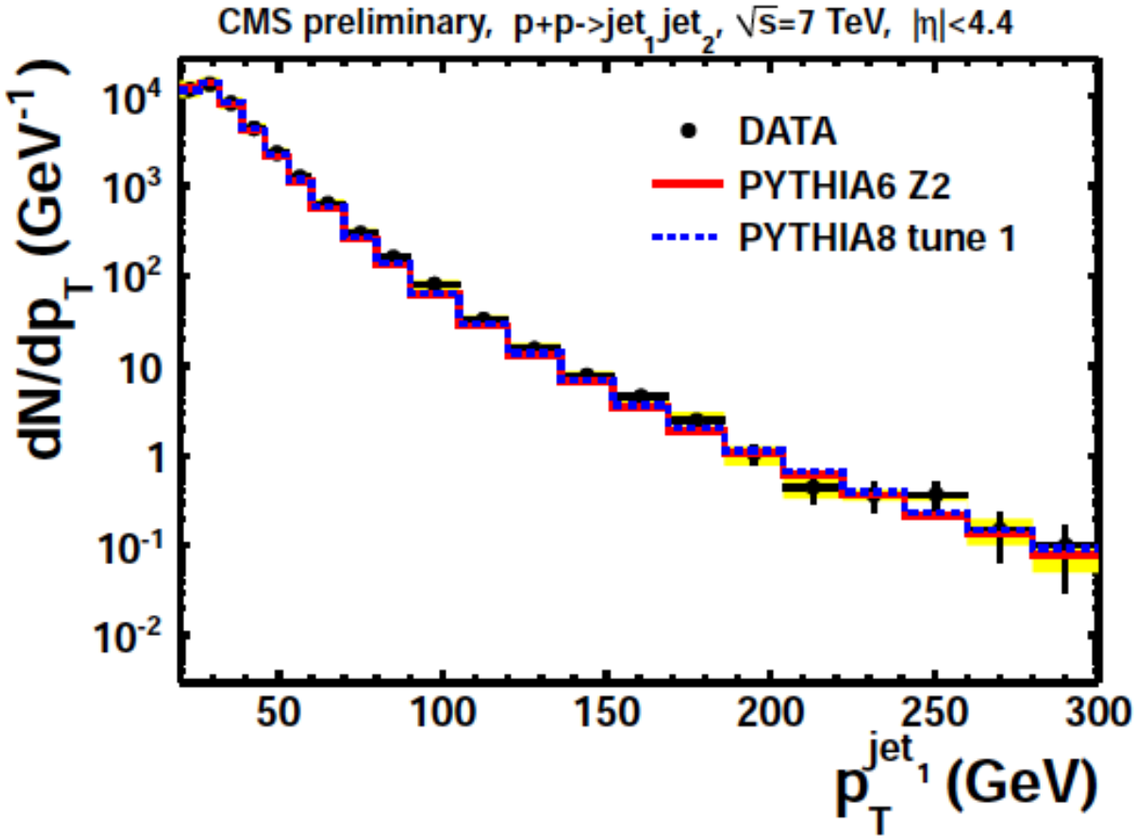
(c)

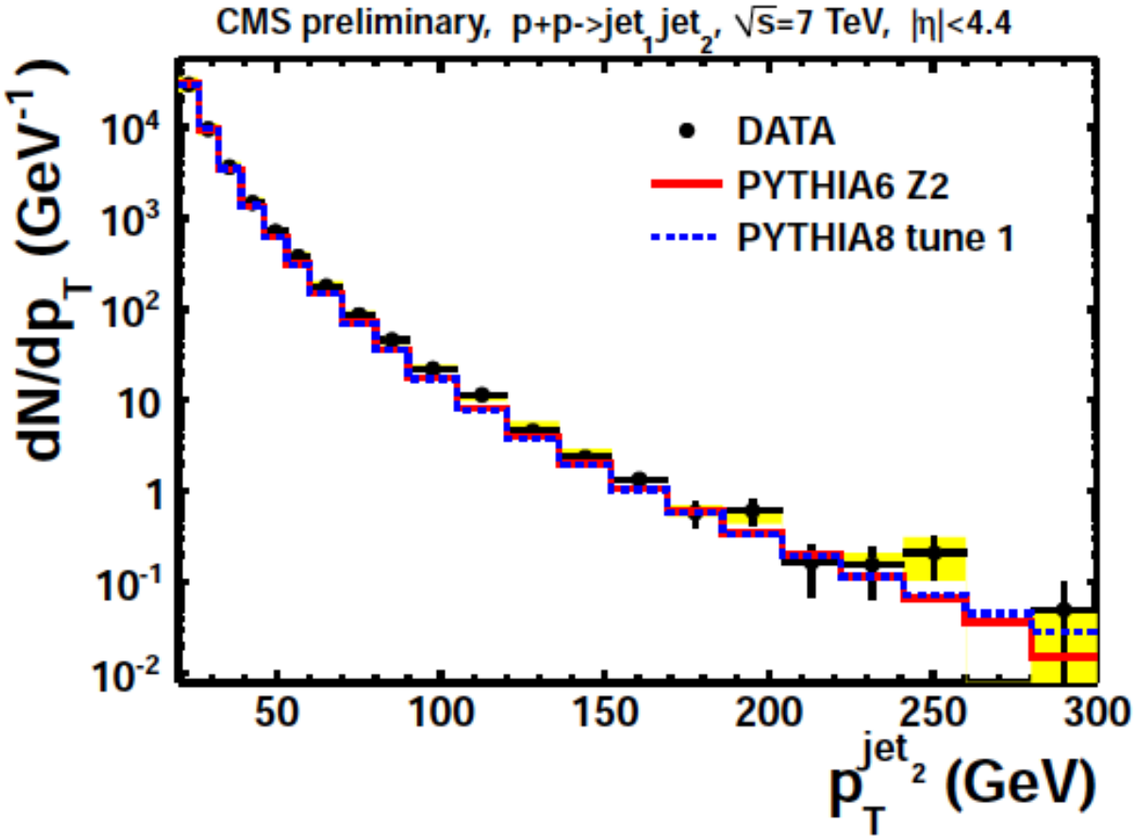


(d)

hard diffraction

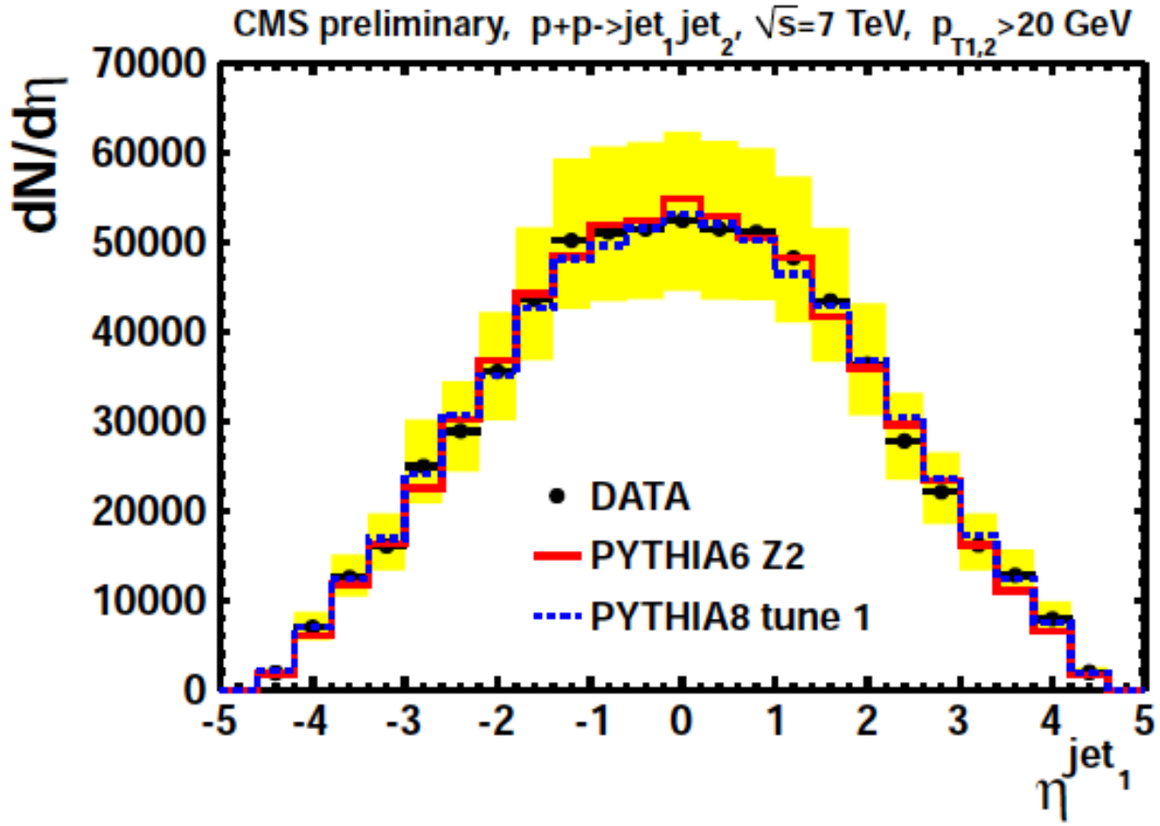
MC-Data comparison

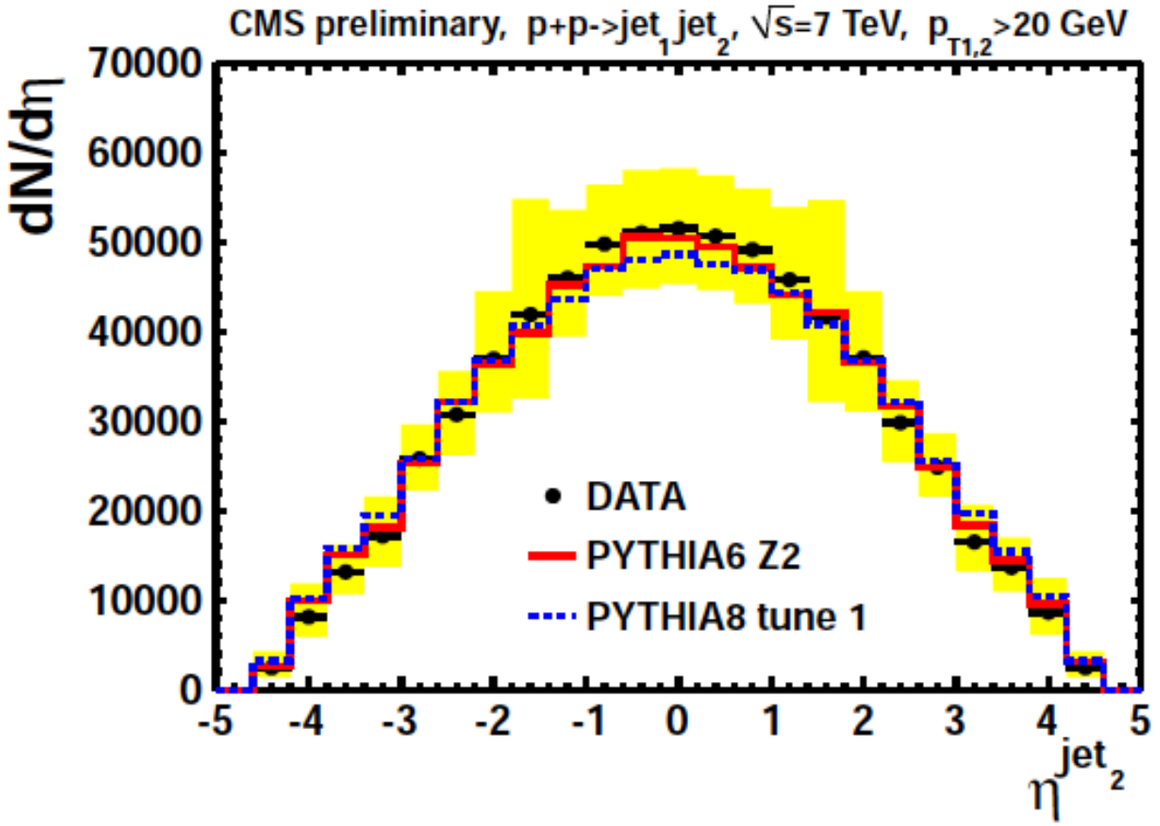




hard diffraction

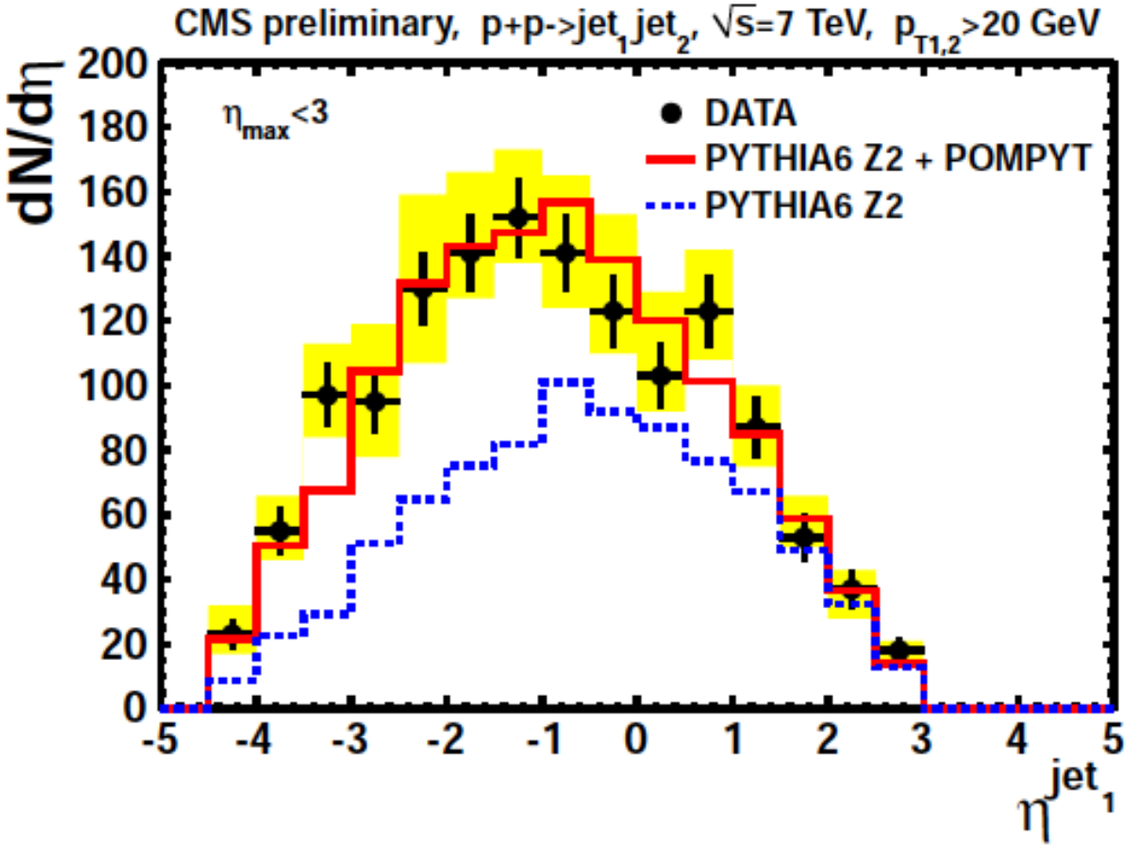
MC-Data comparison

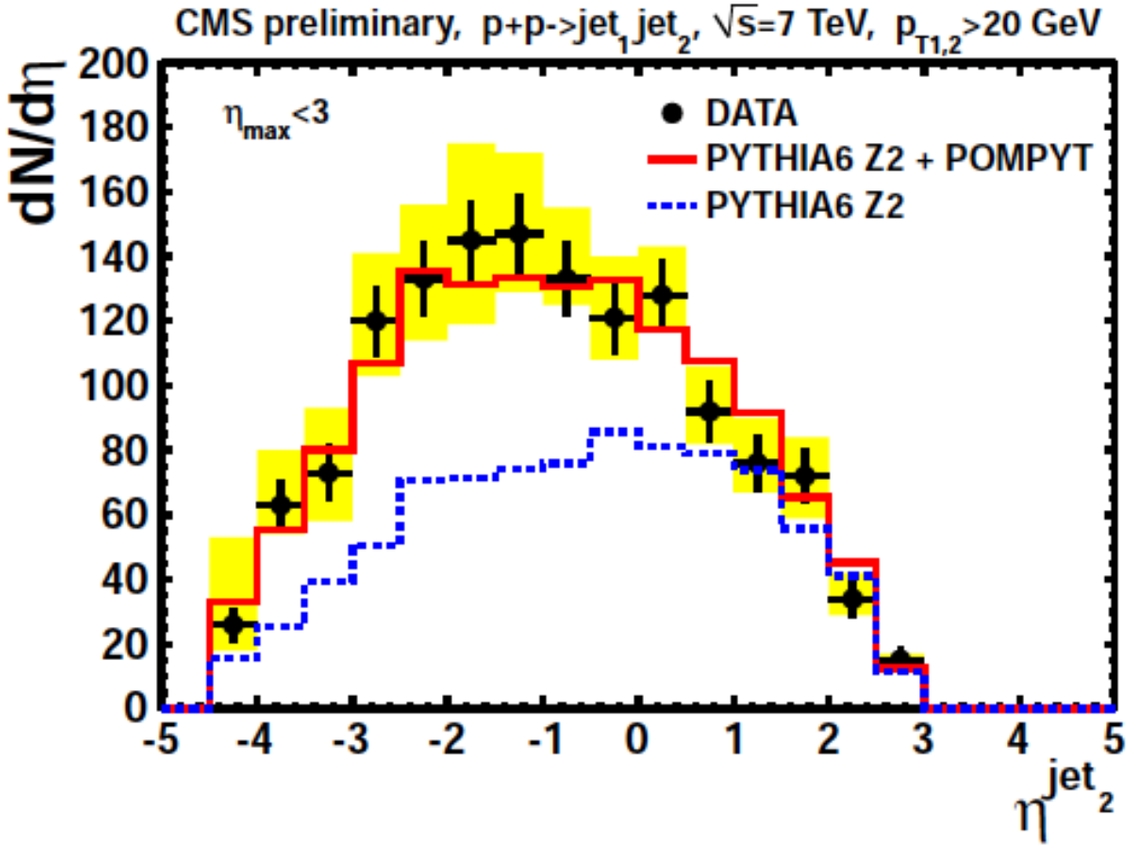




hard diffraction

MC-Data comparison (η_{max}<3)





Systematic uncertainties

Uncertainty source	$0.0003 < \tilde{\xi} < 0.002$	$0.002 < \tilde{\xi} < 0.004$	$0.0045 < \tilde{\xi} < 0.01$
1. Jet energy scale	$(+26/-19)\%$	$(+21/-20)\%$	$(+28/-16)\%$
2. Jet energy resolution	$(+5/-3)\%$	$(+2/-1)\%$	$(+3/-1)\%$
3. Calorimeter energy scale	$(+7/-14)\%$	$(+14/-8)\%$	$(+12/-10)\%$
4. MC uncertainty	$(+5/-6)\%$	$(+3/-14)\%$	$(+3/-3)\%$
5. HF threshold	$(+0/-6)\%$	$(+2/-0)\%$	$(+2/-0)\%$
6. Tracks p_T threshold	$(+0/-1)\%$	$(+1/-0)\%$	$(+0/-2)\%$
7. One vertex selection	$(+6/-0)\%$	$(+0/-1)\%$	$(+1/-0)\%$
8. Calorimeter jets	$(+0/-4)\%$	$(+0/-4)\%$	$(+2/-4)\%$
9. $\tilde{\xi}^+, \tilde{\xi}^-$ difference	$\pm 8\%$	$\pm 8\%$	$\pm 11\%$
10. η_{max} (η_{min}) cut	$(+0/-0)\%$	$(+3/-0)\%$	$(+9/-0)\%$
11. Trigger efficiency	$\pm 3\%$	$\pm 3\%$	$\pm 3\%$
12. Luminosity	$\pm 4\%$	$\pm 4\%$	$\pm 4\%$

Table 1: The systematic uncertainties on the cross section in the three $\tilde{\xi}$ bins.

inclusive cross section for forward jets and for dijets

Measurement of the inclusive production cross section for forward jets and for dijets events with at least one in the central and another in the forward pseudo rapidity regions at $\sqrt{s} = 7$ TeV, using the CMS detector.

→ provides information on multi-parton production with LRG

https://cdsweb.cern.ch/record/1421692/files/FWD-11-002-submitted.pdf

Data

- inclusive forward jets
  → jet trigger with p_T >15 GeV
- dijet measurement
  → 2 jets with ΣE_T> 30 GeV
- integrated luminosity of
  3.14 ± 0.14 pb^{-1}
- HCAL, ECAL and HF

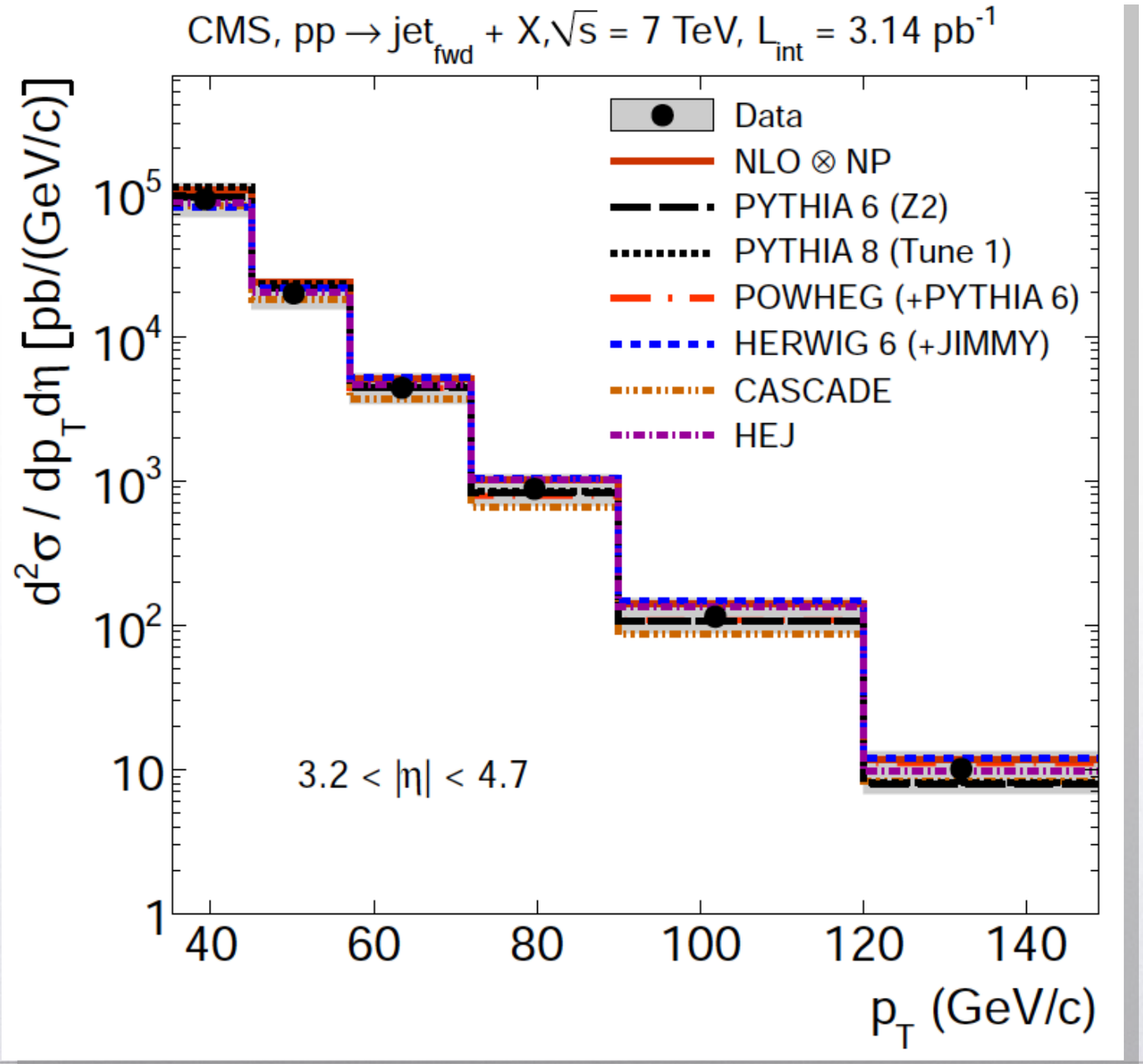
MC

- PYTHIA6 (D6T & Z2)
- PYTHIA8 (1)
- HERWIG6
  - underlying event → JIMMY
- HERWIG++
- + NLO predictions

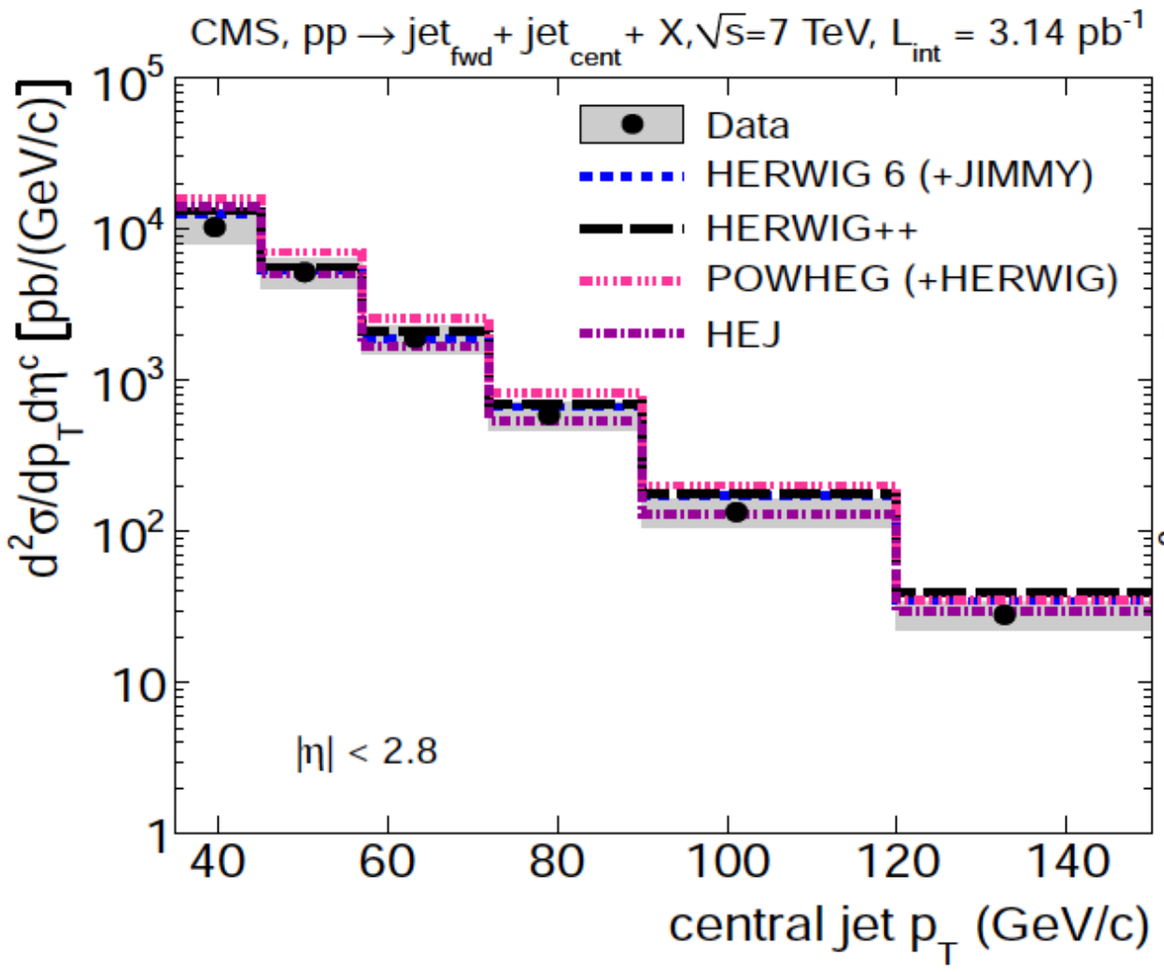
Event selection

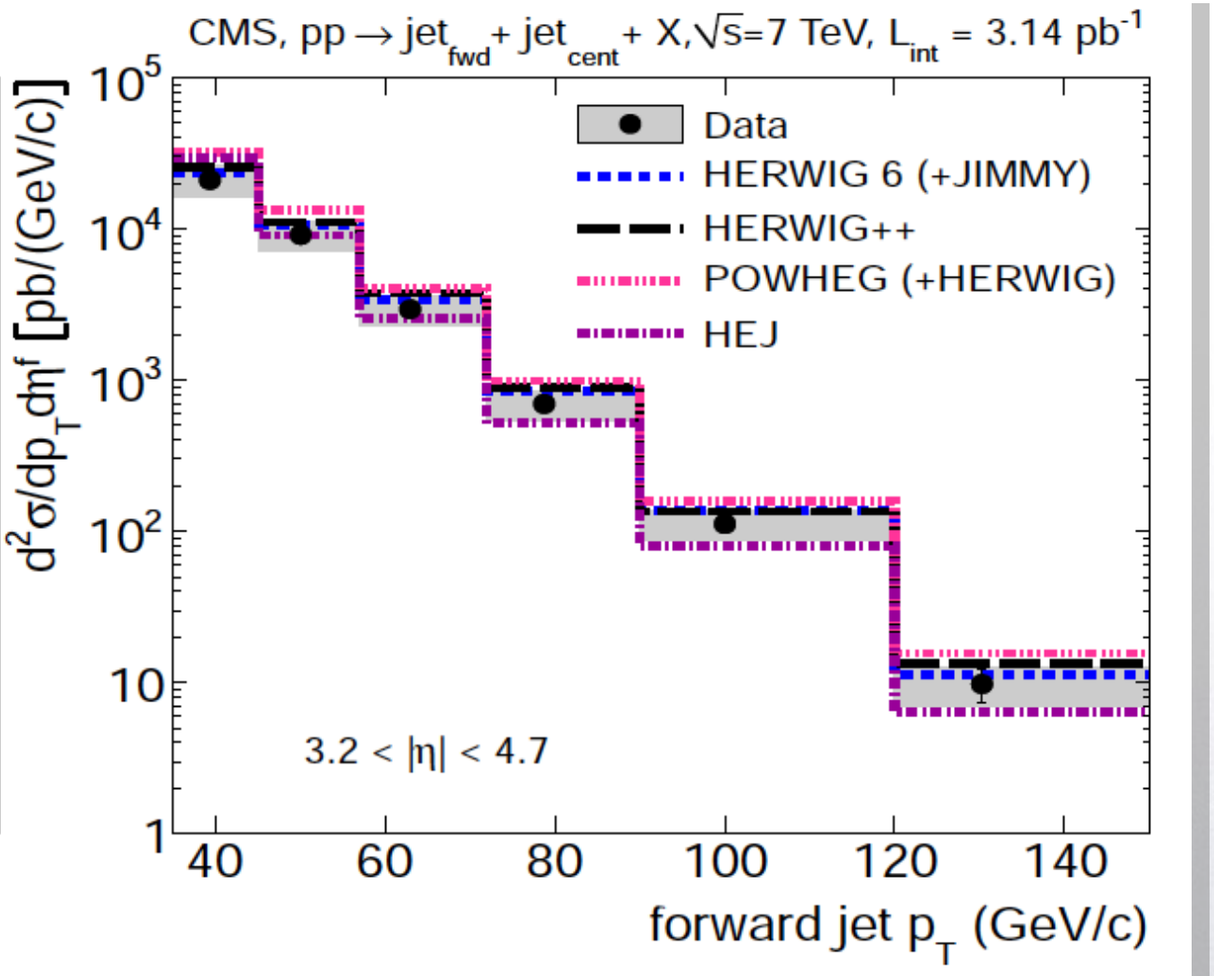
- primary vertex with at least 5 tracks
- |z| < 24cm
- > 25% of good tracks in events with more than 10 tracks
- events with anomalous noise in HF (like hit in the PMT window) are rejected
- jets (anti-k_T; R=0.5) with p_T> 35 GeV/c

inclusive forward jets



forward-central dijets





forward-central dijets