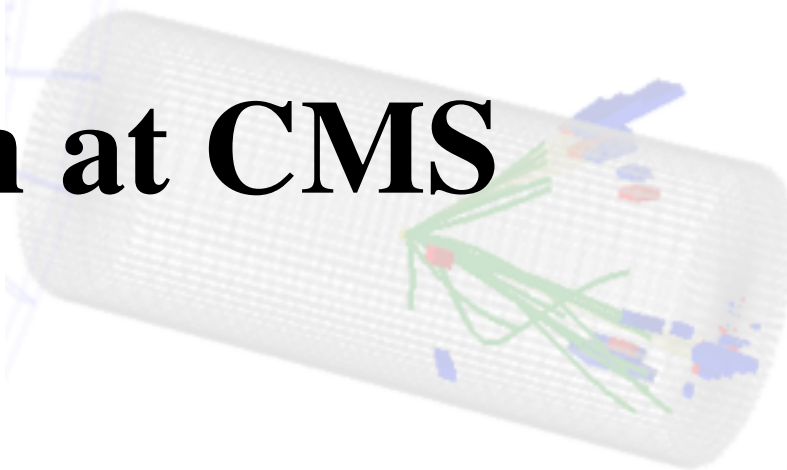


Diffraction at CMS



Sercan Sen

The University of Iowa

On behalf of the CMS Collaboration

MPI@LHC 2012, CERN

- Hard Diffraction in pp collisions at 7TeV,
 - Diffractive contribution to dijet production, [arXiv:1209.1805 \[hep-ex\]](#), *submitted to PRD*
 - W/Z production with gaps, [EPJ C72 \(2012\) 1839](#)
- Implementing forward and diffractive analyses to the Mcplots and Rivet, [mcplots.cern.ch](#),

The project is supervised by **Peter Skands**.

- Conclusion

Hard Diffraction in pp collisions

Motivation

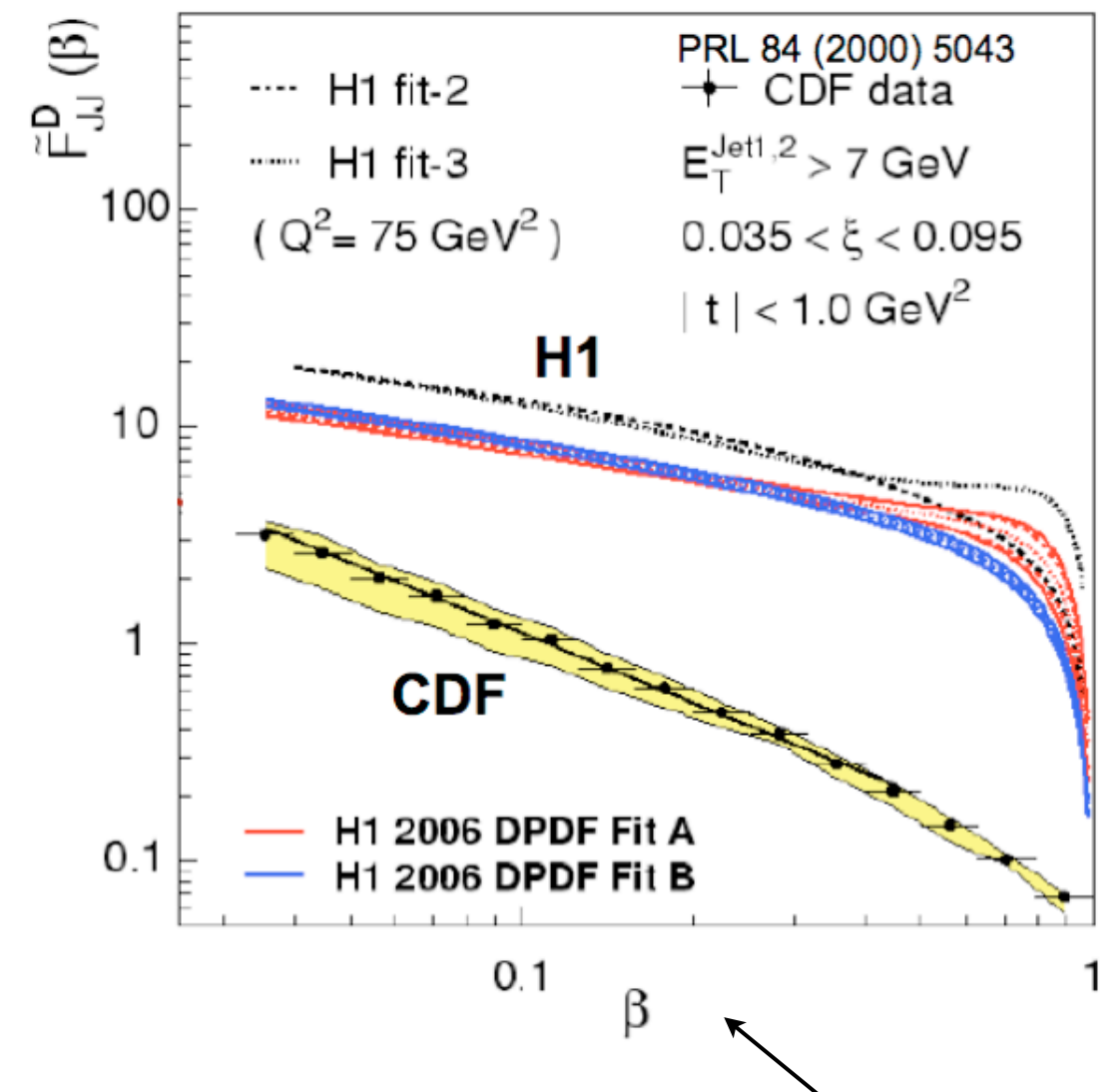
- First measurement of **diffractive PDF** at HERA (ep).
- Measurement of structure function $\sim 10x$ smaller than HERA's dPDFs prediction at Tevatron ($p\bar{p}$). Discrepancy is explained by additional color exchange which spoil the gap formation.

Soft interactions / re-scattering of the spectator partons fill the gap and hence suppress the visible σ_{diff} . **Gap Survival Probability (S^2)** ~ 0.1 at Tevatron, i.e suppression by factor of 10.

Theoretical predictions for LHC at 7 TeV $\langle |S|^2 \rangle \sim 0.05$

CMS measured inclusive dijet cross-section as a function of ξ which leads to the measurement of diffractive structure function dPDF and gap survival probability (S^2) in pp collisions at the LHC.

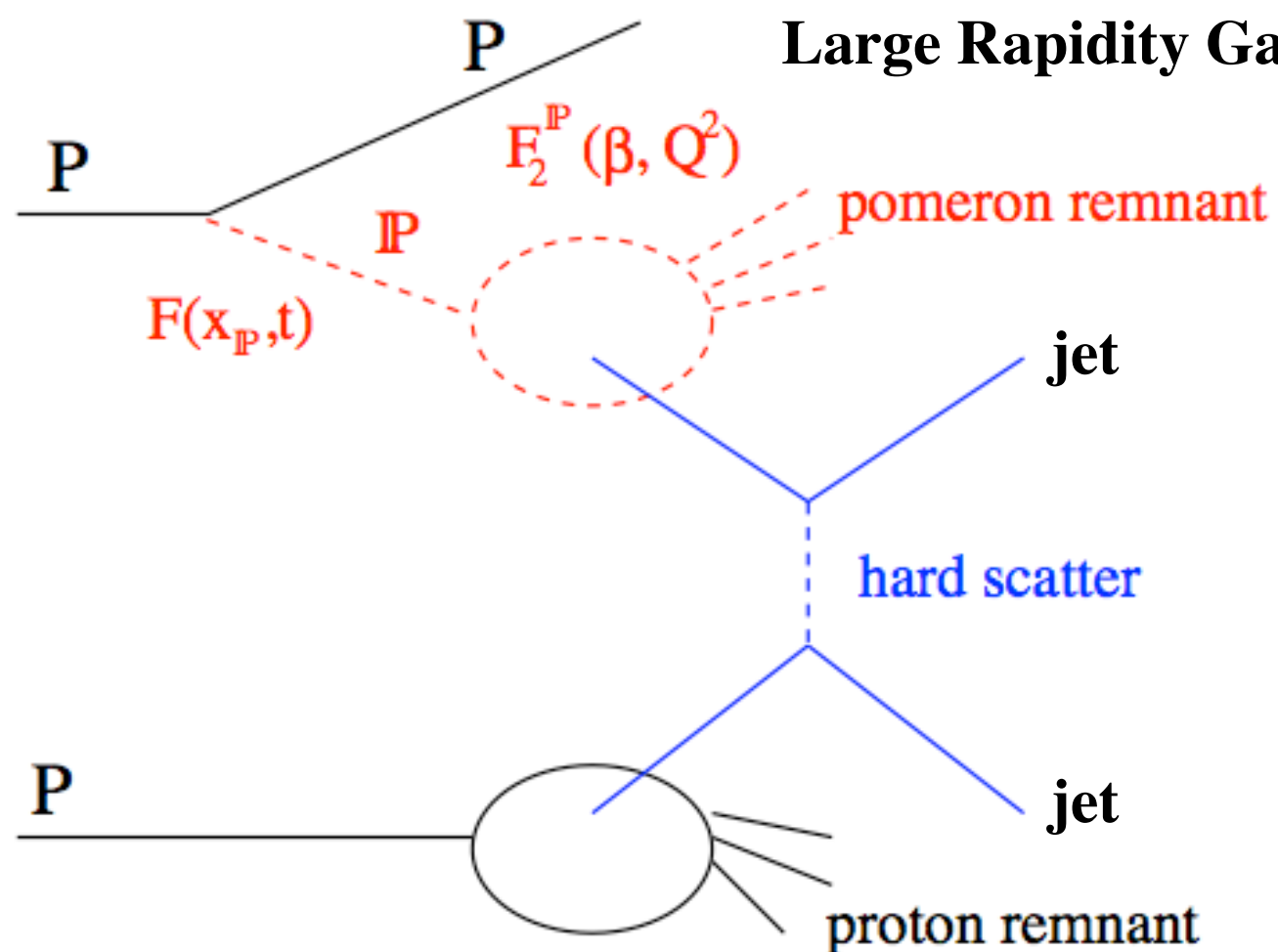
breakdown of QCD factorization



Momentum fraction of parton in Pomeron

Hard Diffraction

Single-diffractive dijet production



X system contains **high- p_T jets** (W/Z, heavy quarks) and is separated from the proton by a **large rapidity gap**, with $\Delta y \geq 3$ or 4 units.

In early LHC running no proton taggers were available for CMS.

dPDF : Pomeron flux x PDF

hard scattering cross section

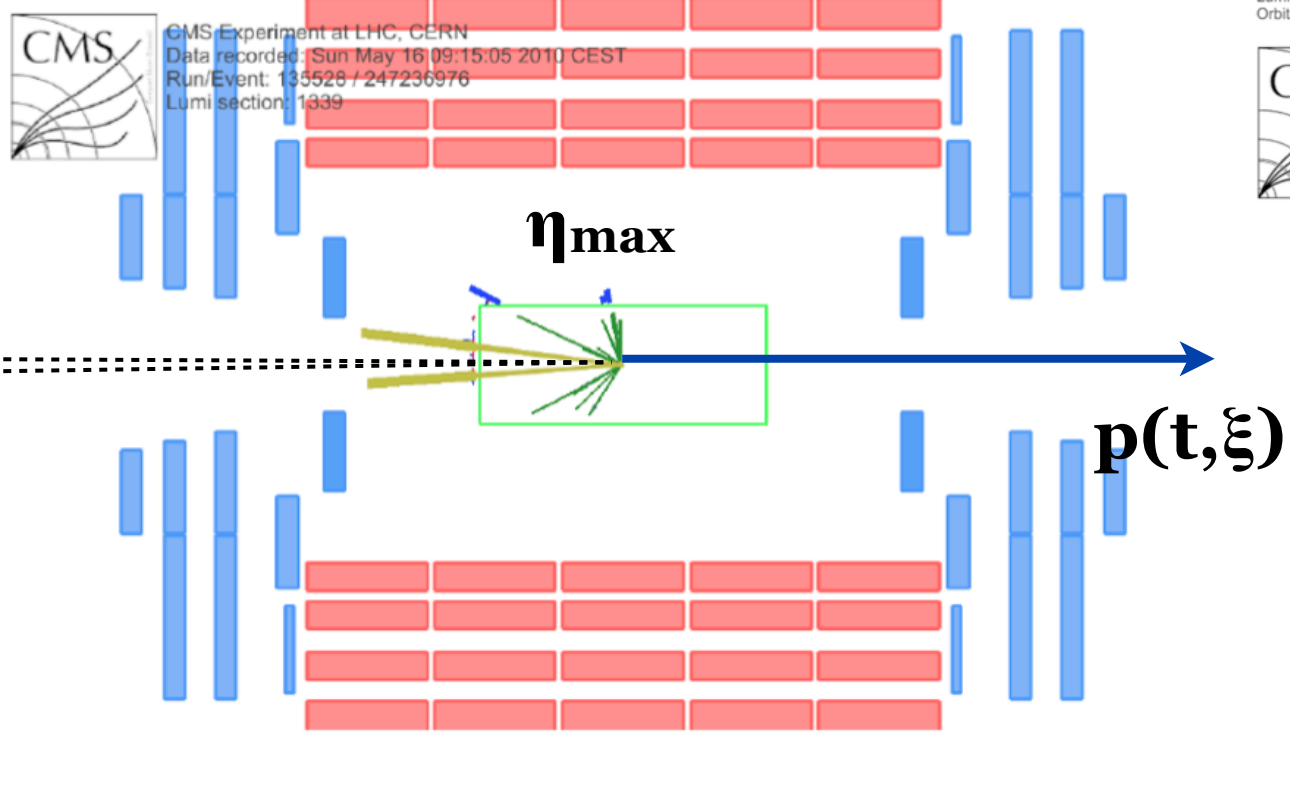
$$\frac{d\sigma}{d\zeta dt} = \sum \int dx_1 dx_2 d\hat{t} f(\zeta, t) f_{\mathbb{P}}(x_1, \mu) f_p(x_2, \mu) \frac{d\hat{\sigma}(\hat{s}, \hat{t})}{d\hat{t}}$$

proton PDF

Hard Diffractive event candidates

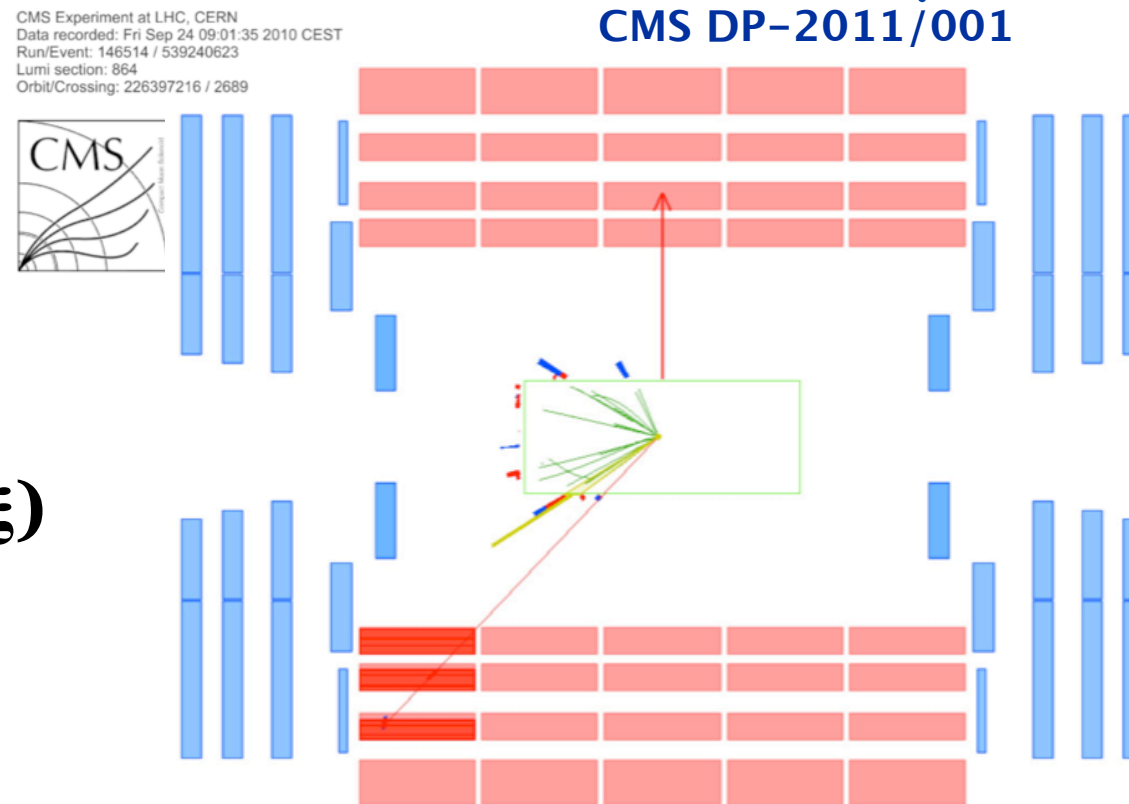
Diffractive dijet candidate

CMS DP-2010/036



Diffractive $W \rightarrow \mu\nu$

CMS DP-2011/001



very forward particles
undetected in $|\eta| < 4.9$

$$\xi \rightarrow \tilde{\xi}^{\pm} = \frac{\sum (E^i \pm p_z^i)}{\sqrt{s}} \cong \left(\frac{M_X}{\sqrt{s}} \right)^2$$

η_{\max} : most forward particle

η_{\min} : most backward particle

ξ : fractional momentum loss of the proton

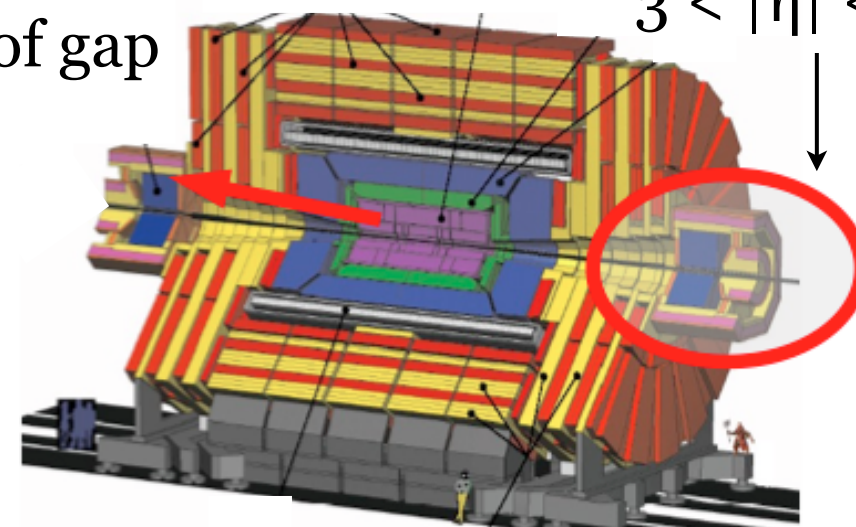
Requiring a forward gap

$E_{\text{HF}} < 4 \text{ GeV}$

~ 1.9 unit of gap

Forward
Calorimeter (HF)

$3 < |\eta| < 5$



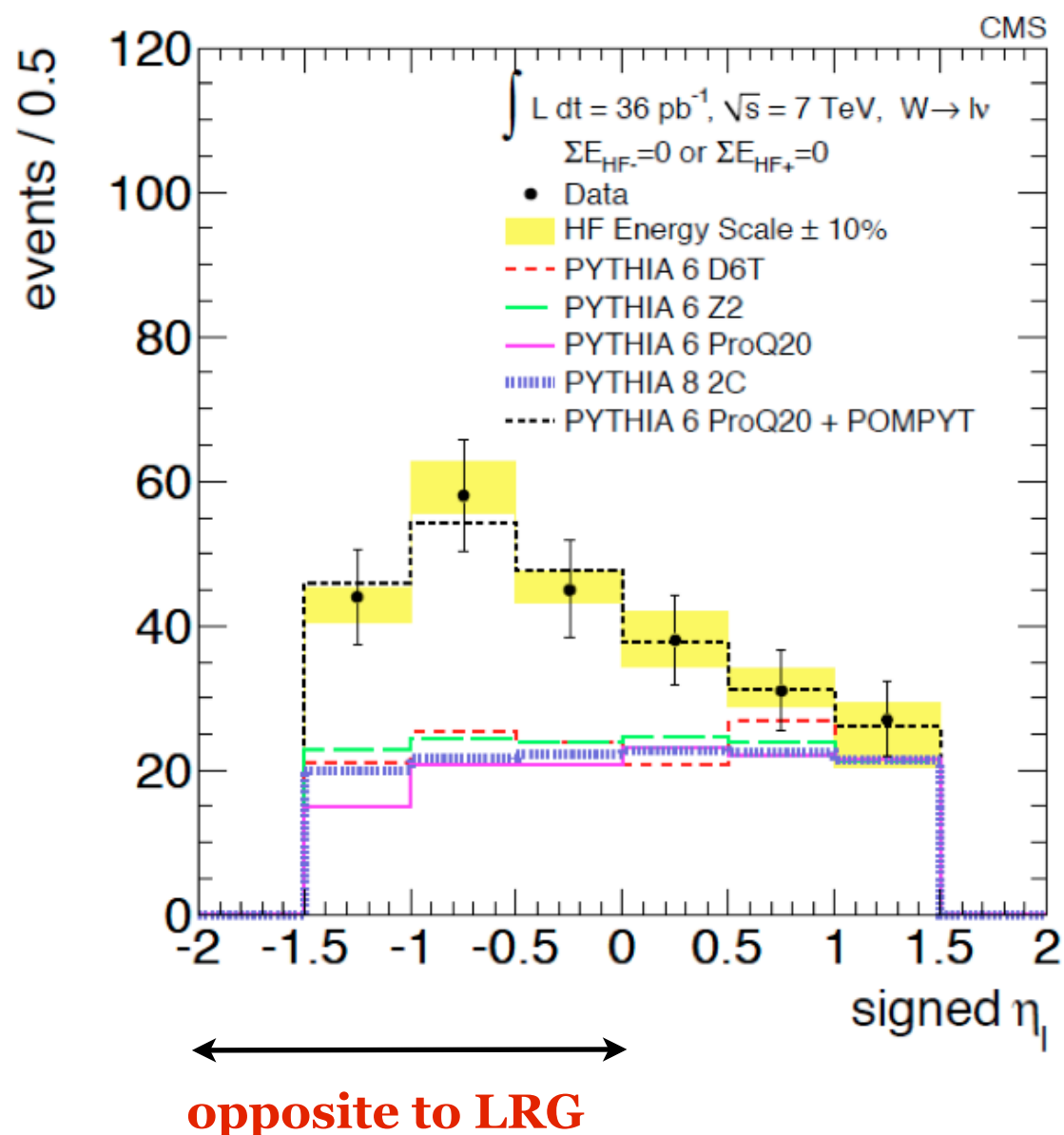
W/Z Events with Large Rapidity Gap

2010 CMS data, 36 pb^{-1} .

$W \rightarrow l\nu$: isolated electron or muon with $p_T > 25 \text{ GeV}/c$, $|\eta| < 1.4$, missing $E_T > 30 \text{ GeV}$ (neutrino), $M_{l\nu} > 60 \text{ GeV}$ (similar cuts for $Z \rightarrow ll$)

Signed lepton η distribution in events with a LRG:

$\eta_{\text{lepton}} < 0$: lepton and gap are in **opposite sides**
 $\eta_{\text{lepton}} > 0$: lepton and gap are in **the same side**



- First evidence of diffractive W production at the LHC.
- Non-diffractive MC is flat. Diffraction is needed.
- **Large asymmetry** is observed. Sum of non-diffractive and diffractive MC (PYTHIA6+POMPYT) describes the asymmetry.

Diffractive component: $50.0 \pm 9.3(\text{stat}) \pm 5.2(\text{syst})\%$

Fraction of W/Z events with a forward gap:

$W \rightarrow l\nu$: $1.46 \pm 0.09(\text{stat.}) \pm 0.38(\text{syst.}) \%$

$Z \rightarrow ll$: $1.57 \pm 0.25(\text{stat.}) \pm 0.42(\text{syst.}) \%$

Hadron level definition (dijet)

Event selection: $p_T^{j1,j2} > 20 \text{ GeV}/c$, $|\eta^{j1,j2}| < 4.4$

ξ Reconstruction:

ξ is approximated by $\tilde{\xi}^+$ (i.e., system X going in the $-z$ direction) and $\tilde{\xi}^-$.

E^i and p_z^i are the energy and longitudinal momentum of the i^{th} final-state particle

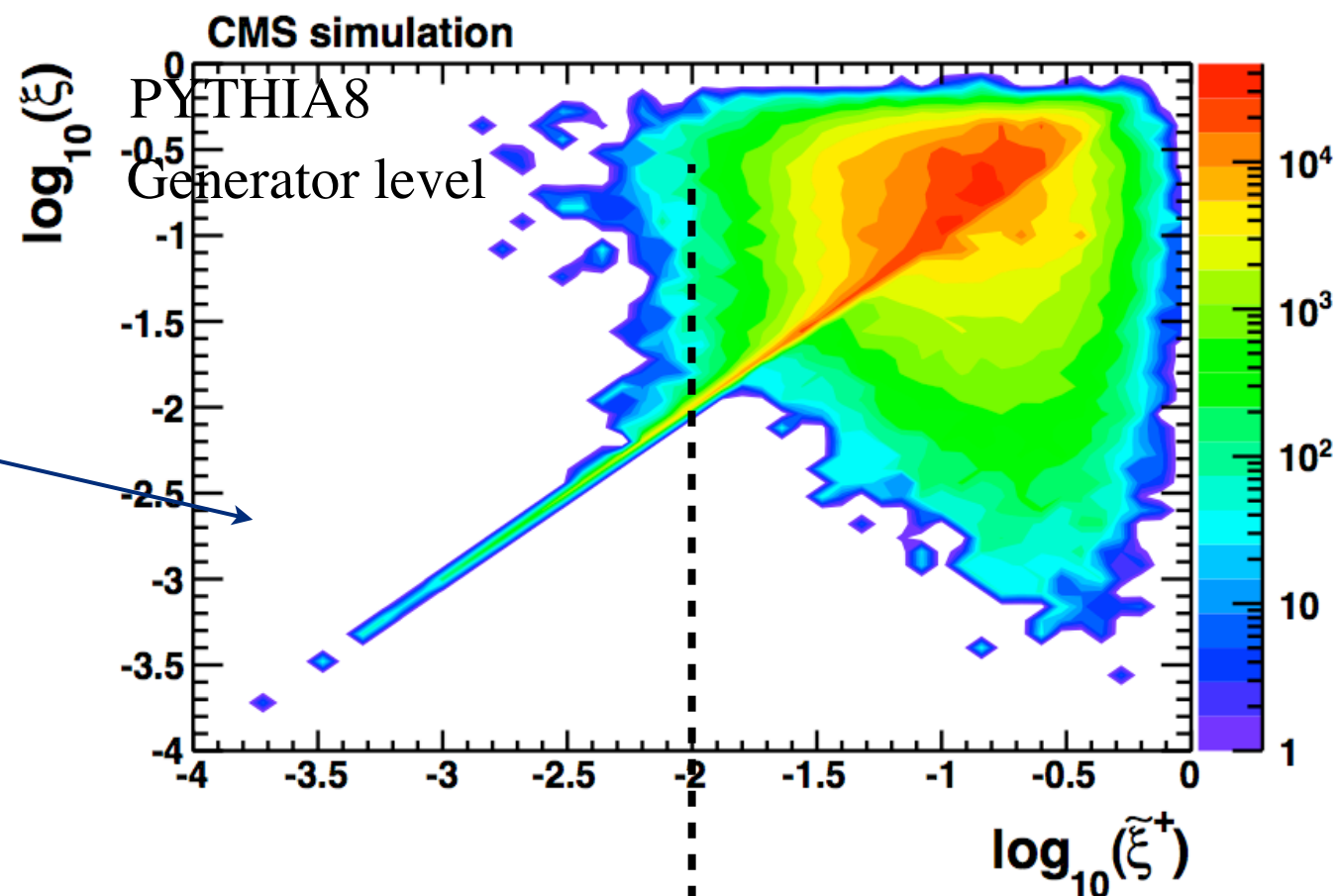
$$\tilde{\xi}^{\pm} = \frac{\sum (E^i \pm p_z^i)}{\sqrt{s}}$$

$$\begin{aligned} \tilde{\xi}^+ &\longrightarrow -\infty < \eta < 4.9 \\ \tilde{\xi}^- &\longrightarrow -4.9 < \eta < +\infty \end{aligned}$$

In the region of low $\tilde{\xi}^{\pm}$, this variable is a good approximation of ξ for single diffractive events.

$$\tilde{\xi}_{\text{Rec}}^{\pm} = C \tilde{\xi}^{\pm}$$

$$C = 1.45 \pm 0.04$$



Monte Carlo simulation

Model	PDF	dPDF	Parameter tune	Process
PYTHIA6	CTEQ6L1	none	Z2, D6T	Non-diffractive jets
PYTHIA8	CTEQ5L	H1 fit B	Tune 1	Diffractive plus non-diffractive jets
POMPYT	CTEQ6L1	H1 fit B	PYTHIA6 D6T	Diffractive jets only
POMWIG	CTEQ6L1	H1 fit B	HERWIG	Diffractive jets only
POWHEG	CTEQ6M	H1 fit B	PYTHIA8 tune1	Diffractive jets only

- Diffractive dijets events simulation with POMPYT, POMWIG and PYTHIA8
- Ingelman and Schlein approach:
 - ▶ proton emits a Pomeron with fractional momentum ξ
 - ▶ and Pomeron interacts with the other proton
- **Same dPDFs** (H1 fit B)
- Parametrization of **Pomeron flux** in **POMPYT** and **POMWIG** is **based on QCD fits to the HERA**.
- POMWIG, **Central diffraction** dissociation contribution, 1%.
- POMPYT, **Reggeon exchange** contribution found less than 2% in $\xi < 0.01$.
- NLO calculation with POWHEG + PYTHIA8

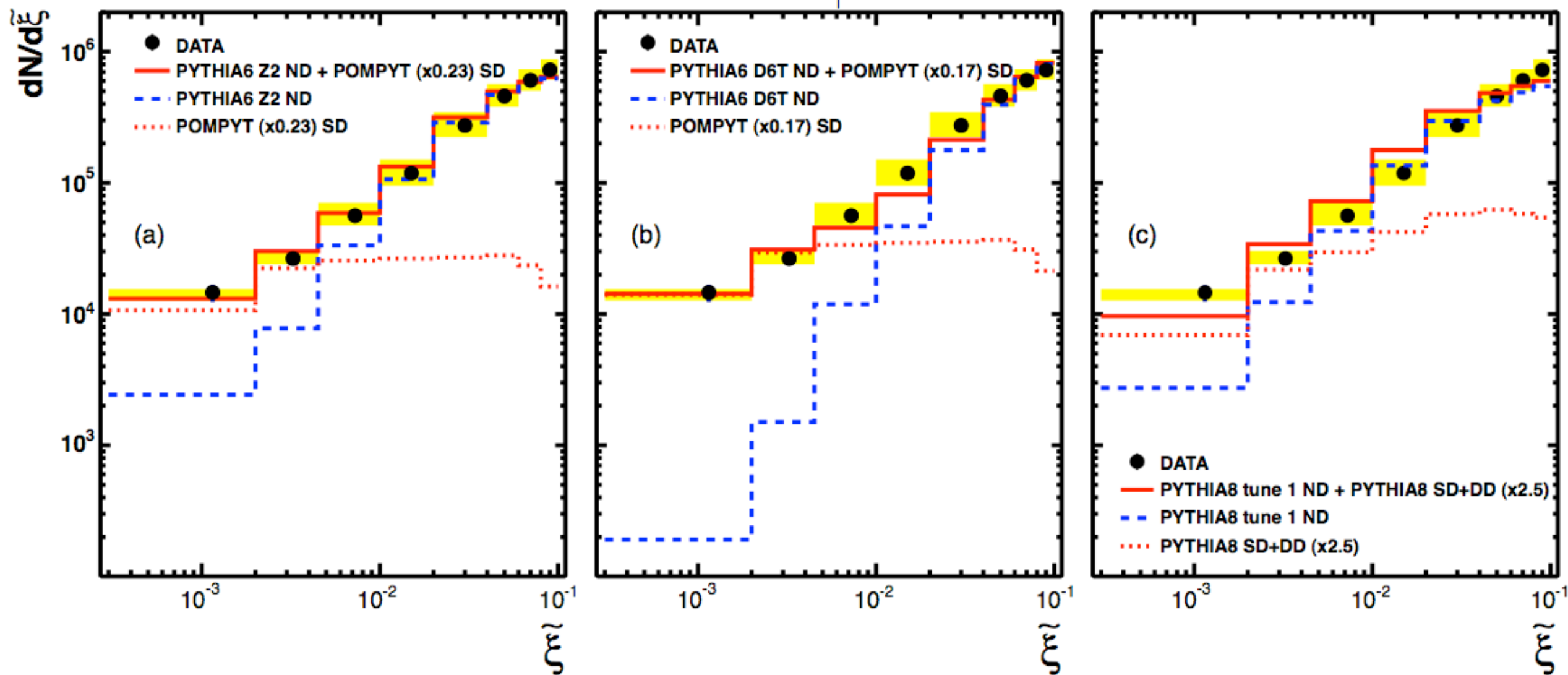
Detector level ξ distribution

- CMS 2010 data, PU ~ 0.09 , $L = 2.7 \text{ nb}^{-1}$
- at least two jets with $p_T^{j1,j2} > 20 \text{ GeV}/c$, $|\eta^{j1,j2}| < 4.4$, Anti-kT 0.5

The data is only described with the **sum of non-diffractive and diffractive** models.

Diffractive contribution is scaled by minimising the difference between data and MC.

CMS, $\sqrt{s} = 7 \text{ TeV}$, $L = 2.7 \text{ nb}^{-1}$, $pp \rightarrow \text{jet}_1 \text{ jet}_2$, $|\eta^{j1,j2}| < 4.4$, $p_T^{j1,j2} > 20 \text{ GeV}$

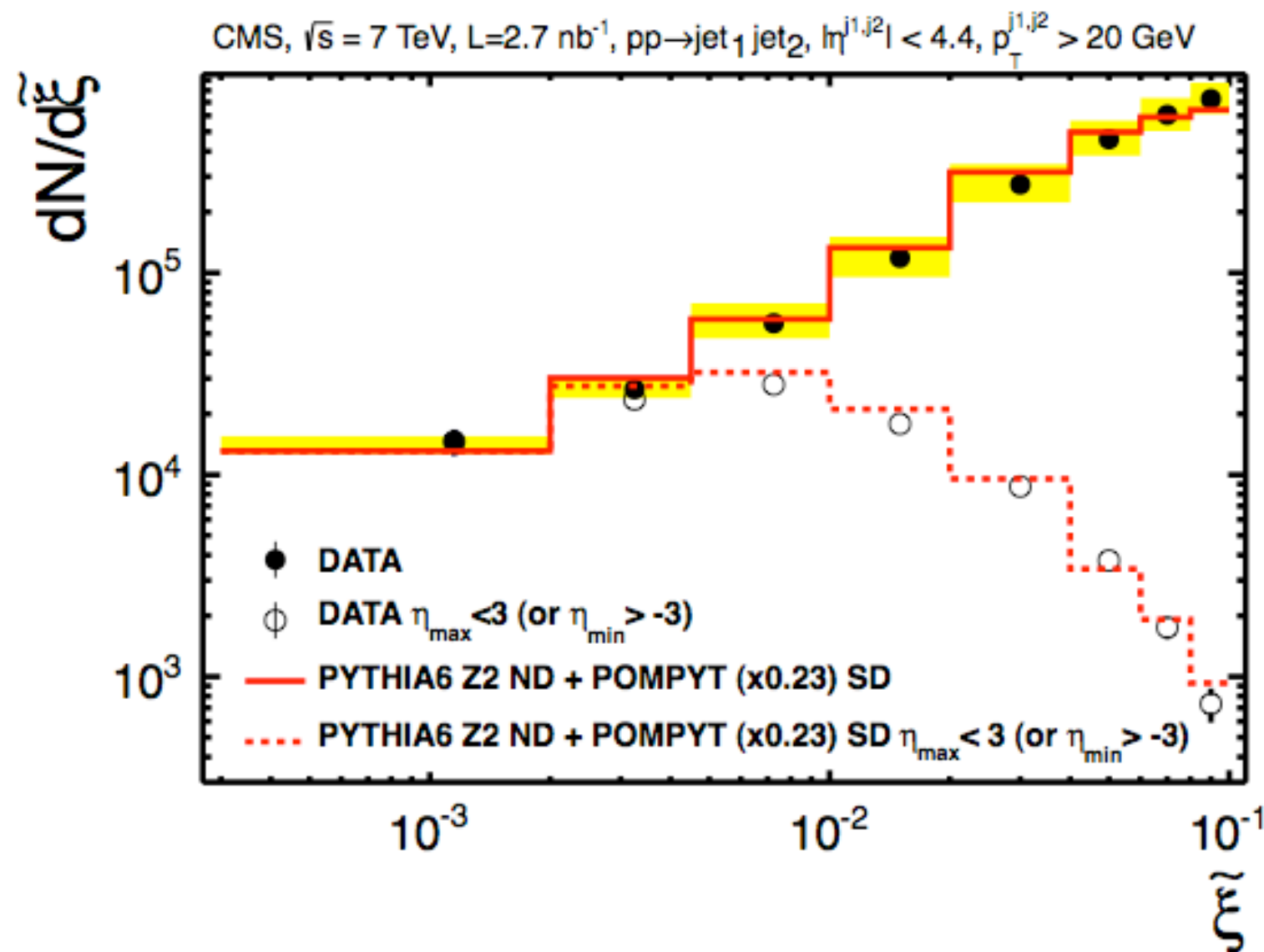


Detector level ξ distribution with gap selection

$|\eta_{\max}| < 3$ ($|\eta_{\min}| > -3$) cut

Enhances the diffractive contribution and selects the dijet system opposite to the gap.

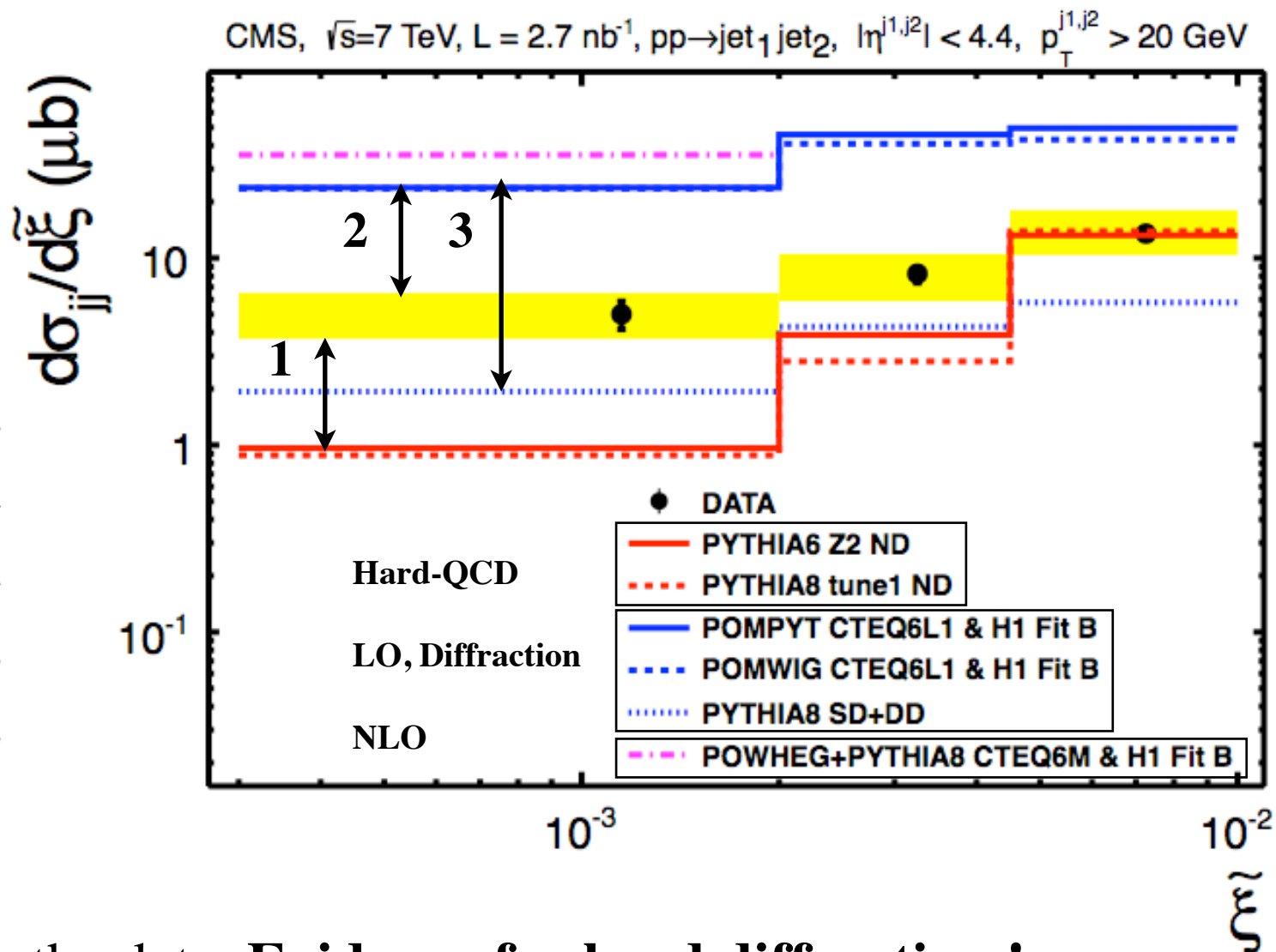
Gap requirement reject events at high values of ξ .



Corrected Results

Fully corrected and unfolded results in three bins of ξ

$\tilde{\xi}$ bin	$d\sigma_{jj}/d\tilde{\xi}$ (μb)
$0.0003 < \tilde{\xi} < 0.002$	$5.0 \pm 0.9(\text{stat.})_{-1.3}^{+1.5}(\text{syst.})$
$0.002 < \tilde{\xi} < 0.0045$	$8.2 \pm 0.9(\text{stat.})_{-2.4}^{+2.2}(\text{syst.})$
$0.0045 < \tilde{\xi} < 0.01$	$13.5 \pm 0.9(\text{stat.})_{-3.1}^{+4.5}(\text{syst.})$



1 Non-diffractive MCs are not describe the data. **Evidence for hard diffraction !**

2 POMPYT and **POMWIG (LO)** diffractive MCs predicts more events than observed, by a **factor of ~5**.

3. PYTHIA8 diffractive cross section is lower than POMPYT and POMWIG due to the **different Pomeron flux** parametrization.

Rapidity Gap Survival Probability $\langle |S^2| \rangle$

Lowest ξ bin

(Non-diffractive contribution is small)

upper limit of $\langle |S^2| \rangle$

$$\sigma_{\text{meas}} / \sigma_{\text{MC}} = 0.21 \pm 0.07 \text{ (LO)}$$

$$\sigma_{\text{meas}} / \sigma_{\text{MC}} = 0.14 \pm 0.05 \text{ (NLO)}$$

(because measured cross section includes low-mass DD events where the particles in dissociated system escapes undetected in the forward region)

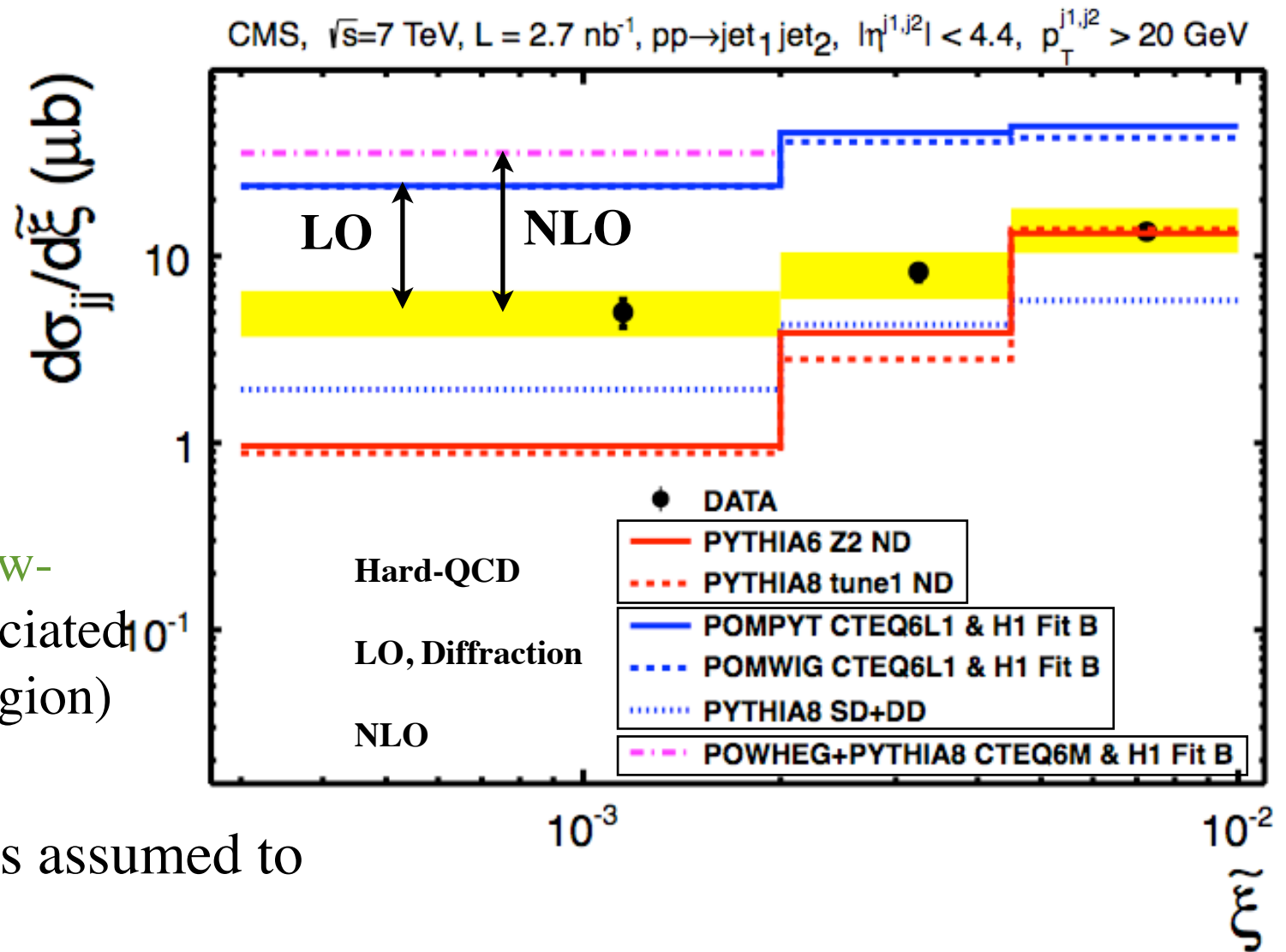
proton dissociative events in the data is assumed to be 41% (particle level PYTHIA8)

dPDFs also includes proton dissociation 23%

$$\langle |S^2| \rangle = 0.12 \pm 0.05 \text{ (LO)}$$

$$\langle |S^2| \rangle = 0.08 \pm 0.04 \text{ (NLO)}$$

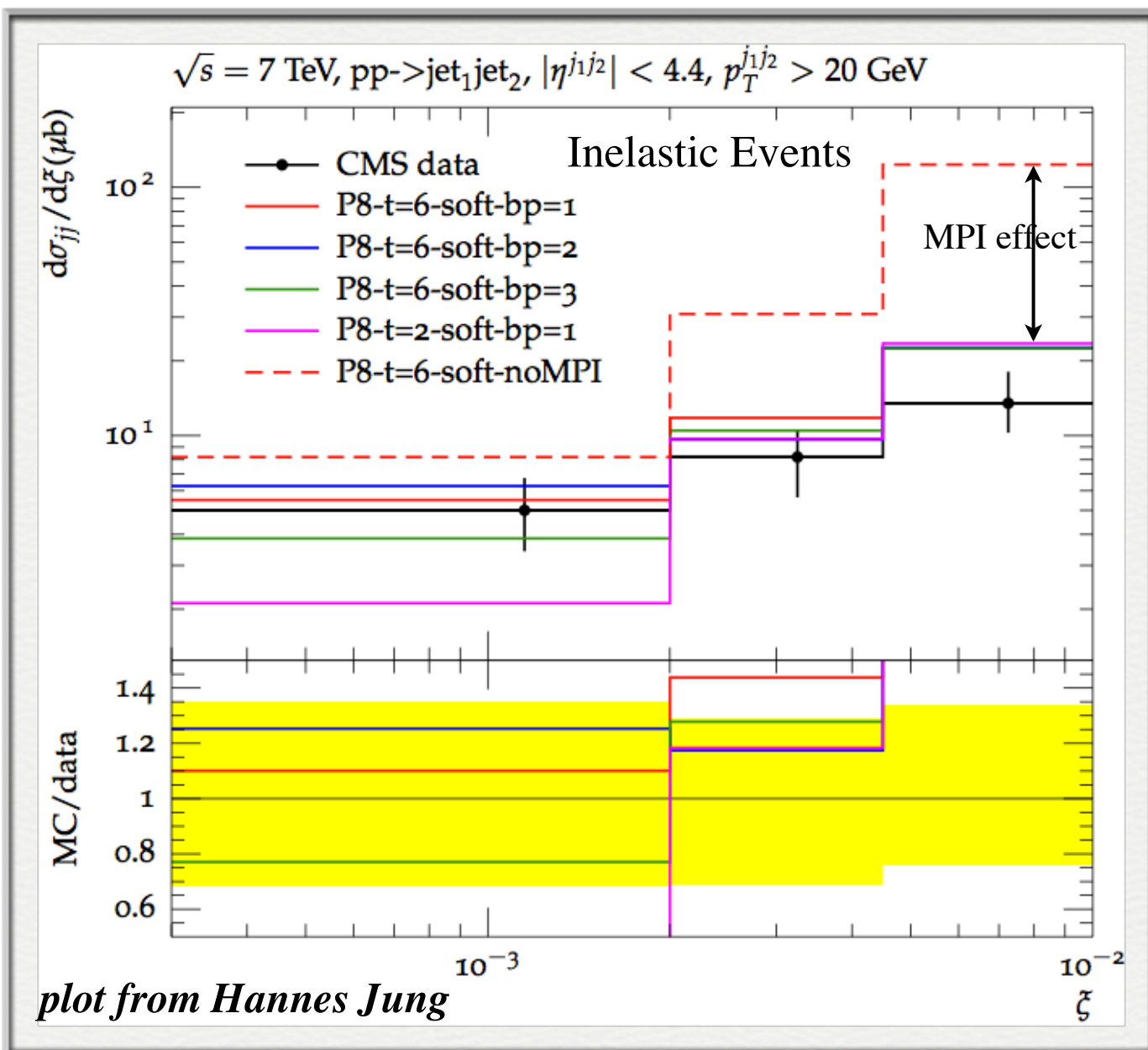
$\langle |S^2| \rangle$ depends the nature of the color singlet (Pomeron, W/Z or photon) exchange which generates the LRG as well as the parton momentum x .



$$\text{CDF: } 0.035 < \xi < 0.095$$

$$\text{CMS: } 0.0003 < \xi < 0.002$$

MPI effect on Hard Diffraction



bprofile changes have very little effect:

- MPI between the Pomeron and proton does not make a large effect on diffractive dijet xsection.

pp tune has much larger effect:

- LHC tune (tune6 a.k.a. 4Cx) has a better description than Tevatron tune (tune 2).

- switching off MPI (between the proton remnants) has a large effect both at large and low ξ values.

mode **Diffraction:bProfile** (default = 1; minimum = 0; maximum = 3)

Choice of impact parameter profile for the incoming hadron beams.

option **0** : no impact parameter dependence at all.

option **1** : a simple Gaussian matter distribution; no free parameters.

option **2** : a double Gaussian matter distribution, with the two free parameters *coreRadius* and *coreFraction*.

option **3** : an overlap function, i.e. the convolution of the matter distributions of the two incoming hadrons, of the form $\exp(-b^{\text{expPow}})$, where *expPow* is a free parameter.

from Pythia8 manual,

<http://home.thep.lu.se/~torbjorn/pythia81html/Welcome.html>

Implementing forward and diffractive analyses to the Mcplots and Rivet

Menu

- [Front Page](#)
- [LHC@home 2.0](#)
- [Generator Versions](#)
- [Generator Validation](#)
- [Update History](#)

Analysis filter:

- [ALL pp/ppbar](#)
- [ALL ee](#)
- Specific analysis:

Jets

- [Transverse Minor](#)
- [Transverse Thrust](#)
- [Di-jet \$\chi\$](#)
- [Di-jet \$\Delta\phi\$](#)
- [Di-jet mass](#)
- [HT](#)
- [Jet Fragmentation](#)
- [Differential shape](#)
- [Integral shape](#)
- [Jet multiplicity](#)
- [Ratios of jet multiplicity](#)
- [\$d\sigma\(\text{jet}\)/dp_T\$](#)
- [R32 vs HT](#)
- [R32 vs \$p_T\$](#)
- [Jets + Veto](#)

Underlying Event

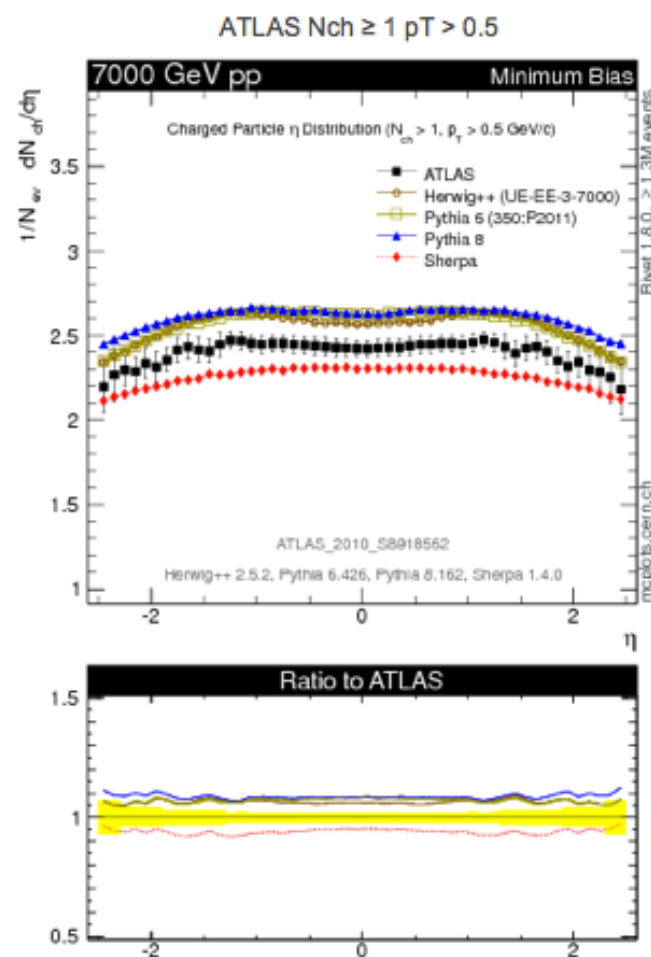
Minimum Bias,
Z (Drell-Yan) W+Jets,
total cross-sections, b Physics.

A simple browsable repository of MC (Monte Carlo) plots comparing High Energy Physics event generators to a wide variety of available experimental data, for tuning and reference purposes.

Minimum Bias : η Distributions

Generator Group: [Main](#) [Herwig++](#) [Pythia 6](#) [Pythia 8](#) [Sherpa](#) [Custom](#)
 Subgroup: [Default](#) [LHC Tunes](#) [Tevatron Tunes](#)

pp @ 7000 GeV

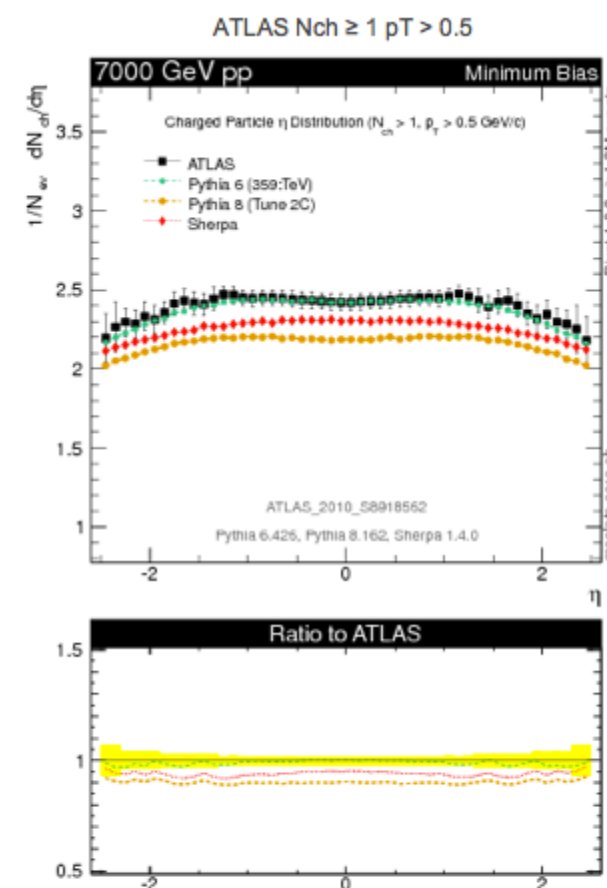


[\[pdf\]](#) [\[eps\]](#) [\[png\]](#) [more →](#)

Minimum Bias : η Distributions

Generator Group: [Main](#) [Herwig++](#) [Pythia 6](#) [Pythia 8](#) [Sherpa](#) [Custom](#)
 Subgroup: [Default](#) [LHC Tunes](#) [Tevatron Tunes](#)

pp @ 7000 GeV



[\[pdf\]](#) [\[eps\]](#) [\[png\]](#) [less ←](#)
[\[ATLAS\] reference](#)
[\[Pythia 6 \(359:TeV\)\] param](#)
[\[Pythia 8 \(Tune 2C\)\] param](#)
[\[Sherpa\] param](#)
[\[steer\]](#)

Current event generators on the site

Generator	Version
alpgenherwigjimmy	<input type="text"/>
alpgenpythia6	<input type="text"/>
epos	<input type="text"/>
herwig++	<input type="text" value="2.6.1a"/>
herwig++powheg	<input type="text"/>
phojet	<input type="text"/>
pythia6	<input type="text"/>
pythia8	<input type="text"/>
sherpa	<input type="text"/>

It is a very up-to-date repository with the most recent versions of the generators & tunes.

Possible to select different tunes for a given generator version:

pythia8 8.170

default default-CD default-MBR default-noFsr default-noRap early tune-1 tune-2c tune-2m tune-4c tune-4cx tune-A2

developer version:
mcplots-dev.cern.ch

Two new event generators are recently added to the site: **EPOS** and **PHOJET**

Two new tunes/models: Pythia8 **Central diffraction** and Pythia **MBR** model
(comes with Pythia8 8.165)

16 forward & diffractive analyses from LHC are recently added to the mcplots & Rivet

The papers have been asked to be uploaded to the **HepDATA** (if they are not already there)

Total inelastic cross sections: ATLAS, CMS

Total elastic cross section: TOTEM

Diffractive cross sections: ALICE

Inclusive Forward Jets: CMS

dN/deta in forward rapidities: TOTEM

Energy Flow: CMS

Transverse Energy Flow: ATLAS

Rapidity Gaps: ATLAS

Hard Diffraction: CMS

Identified Particles: LHCf, LHCb

Heavy Flavours: ATLAS, LHCb

Footnotes:

* Some analyses routines are in validation status. e.g, waiting for validation by the experiment or Rivet.

* Some papers are not yet available on HepDATA since HepDATA accepts only published papers.

Recently Added Analyses

Total Cross Sections

- ATLAS Collaboration, **Measurement of the inelastic proton-proton cross-section at $\sqrt{s} = 7$ TeV with the ATLAS detector**, [Nat. Commun. 2 \(2011\) 463](#)
- CMS Collaboration, **Measurement of the inelastic pp cross section at $\sqrt{s} = 7$ TeV**, [arXiv:1210.6718](#)
- The TOTEM Collaboration, **Proton-proton elastic scattering at the LHC energy of $\sqrt{s} = 7$ TeV**, [arXiv:1110.1385](#).

Inclusive-Jet

- CMS Collaboration, **Measurement of the inclusive production cross sections for forward jets and for dijet events with one forward and one central jet in pp collisions at $\sqrt{s} = 7$ TeV**, [arXiv:1202.0704](#)
- CMS Collaboration, **Ratios of dijet production cross sections as a function of the absolute difference in rapidity between jets in proton-proton collisions at $\sqrt{s} = 7$ TeV**, [arXiv:1204.0696](#).

dN/d η

- The TOTEM Collaboration, **Measurement of the forward charged particle pseudorapidity density in pp collisions at $\sqrt{s} = 7$ TeV with the TOTEM experiment**, [CERN-PH-EP-2012-106](#)

Recently Added Analyses

(Transverse) Energy flow

- CMS Collaboration, **Measurement of energy flow at large pseudorapidities in pp collisions at $\sqrt{s} = 0.9$ and 7 TeV**, [J. High Energy Phys. 11 \(2011\) 148](#)
- ATLAS Collaboration, **Measurements of the pseudorapidity dependence of the total transverse energy in proton-proton collisions at $\sqrt{s} = 7$ TeV with ATLAS**, [arXiv:1208.6256](#)

Rapidity Gaps and Diffraction

- CMS Collaboration, **Evidence for hard-diffractive dijet production in pp collisions at $\sqrt{s} = 7$ TeV**, [arXiv:1209.1805](#)
- ATLAS Collaboration, **Rapidity gap cross sections measured with the ATLAS detector in pp collisions at $\sqrt{s} = 7$ TeV**, [Eur. Phys. J. C72 \(2012\) 1926](#)
- ALICE Collaboration, **Measurement of inelastic, single- and double-diffraction cross sections in proton-proton collisions at the LHC with ALICE**, [arXiv:1208.4968](#).

Recently Added Analyses

Identified particles

- LHCf Collaboration, **Measurement of forward neutral pion transverse momentum spectra for $\sqrt{s} = 7\text{TeV}$ proton-proton collisions at LHC**, <http://arxiv.org/abs/1205.4578>, Phys. Rev. D.
- LHCb Collaboration, **Measurement of V_0 production ratios in pp collisions at $\sqrt{s} = 0.9$ and 7 TeV**, [J. High Energy Phys. 08 \(2011\) 034](#)
- LHCb Collaboration, **Measurement of prompt hadron production ratios in pp collisions at $\sqrt{s} = 0.9$ and 7 TeV**, [Eur.Phys.J. C72 \(2012\) 2168](#)

Heavy flavours

- LHCb Collaboration, **Measurement of $\sigma(pp \rightarrow b\bar{b}X)$ at $\sqrt{s} = 7\text{ TeV}$ in the forward region**, [Phys. Lett. B 694 \(2010\) 209-216](#)
- ATLAS Collaboration, **Measurement of the b-hadron production cross section using decays to $D^{*+}\mu^{-}X$ final states in pp collisions at $\sqrt{s} = 7\text{ TeV}$ with the ATLAS detector**, [Nuclear Physics B 864 \(2012\) 341–381](#).

First measurements of hard diffraction at the LHC

- ▶ The dijet cross section as a function of ξ has been measured.
 - The low- ξ data show a significant contribution from **diffractive dijet production**, observed for the first time at the LHC.
 - **The gap survival probability estimated at LO and NLO** from the comparison of the measured cross section to diffractive MC predictions based on dPDFs from HERA.
 - **MPI has a large effect** both on large and low- ξ values.
- ▶ Observation of **diffractive W/Z production** with large rapidity gap.

Backup

$$\frac{d\sigma_{jj}}{d\tilde{\zeta}} = \frac{N_{jj}^i}{L \cdot \epsilon \cdot A^i \cdot \Delta\tilde{\zeta}^i}$$

N_{jj}^i is the measured number of dijet events in the i -th $\tilde{\zeta}$ bin.

A^i : Bin-by-bin corrections between generated and reconstructed ξ

$\Delta\tilde{\zeta}^i$ is the bin width.

L : integrated luminosity

ϵ : trigger efficiency

Uncertainty source	$0.0003 < \tilde{\zeta} < 0.002$	$0.002 < \tilde{\zeta} < 0.0045$	$0.0045 < \tilde{\zeta} < 0.01$
1. Jet energy scale	(+26; -19)%	(+21; -20)%	(+28; -16)%
2. Jet energy resolution	(+6; -4)%	(+4; -3)%	(+3; -2)%
3. PF energy, p_T threshold, C	(+7; -15)%	(+14; -8)%	(+12; -11)%
4. MC model uncertainty	(+5; -3)%	(+2; -14)%	(+3; -1)%
5. One-vertex selection	(+6; -0)%	(+0; -1)%	(+1; -0)%
6. Jet objects (Calorimeter, PF)	(+0; -4)%	(+0; -4)%	(+2; -4)%
7. $\tilde{\zeta}^+, \tilde{\zeta}^-$ difference	$\pm 8\%$	$\pm 8\%$	$\pm 11\%$
8. Trigger efficiency	$\pm 3\%$	$\pm 3\%$	$\pm 3\%$
9. Luminosity	$\pm 4\%$	$\pm 4\%$	$\pm 4\%$
Total error	(+30; -26)%	(+27; -29)%	(+33; -23)%

CMS Detector

