Diffraction & Forward Physics in CMS

results and perspectives

Patricia Rebello Teles

on behalf of CMS Collaboration

ISMD2014

8th to 12nd September

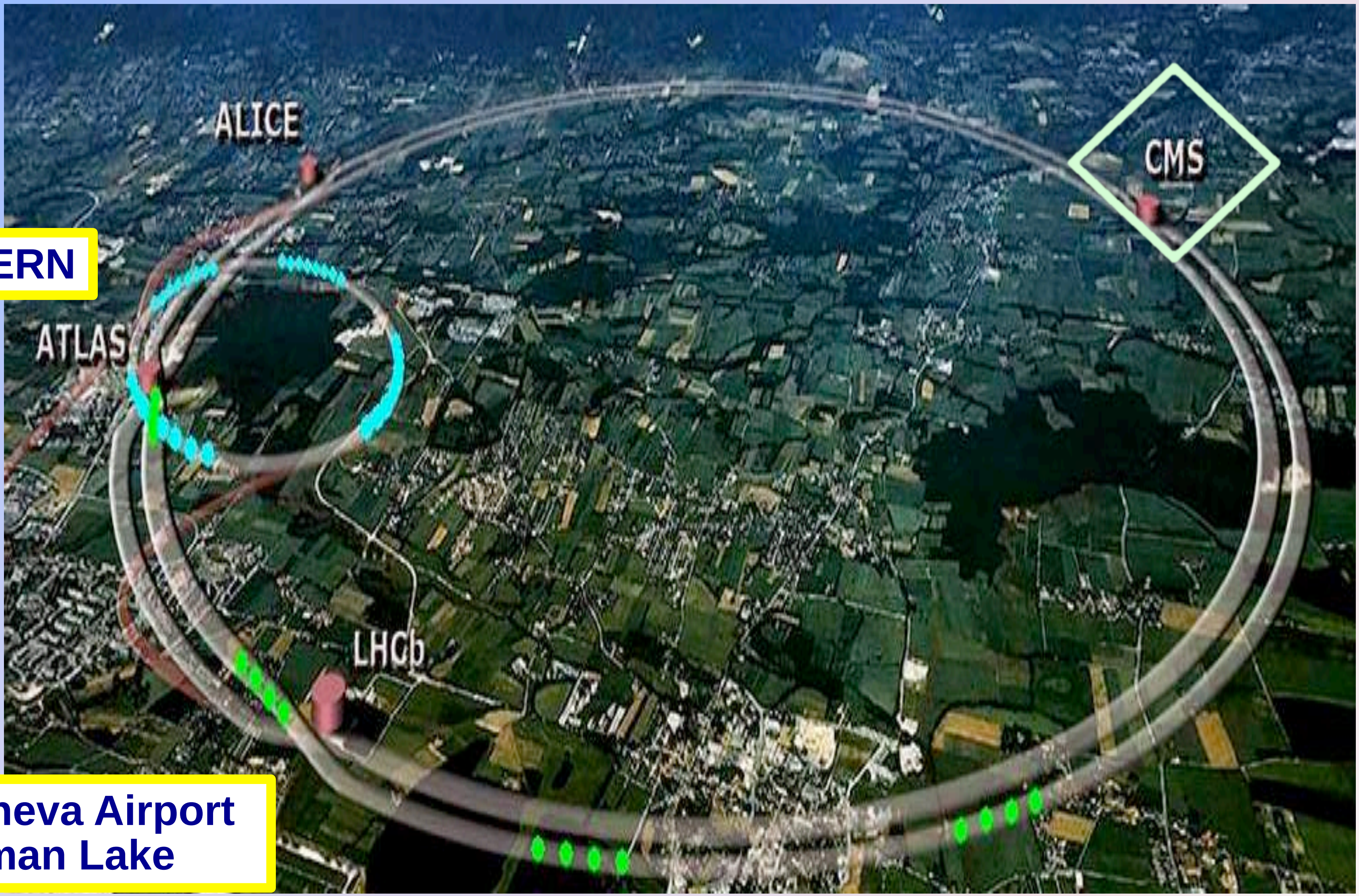
Bologna, Italy

Outline

- ✧ **Forward Region apparatus**:
  - ❖ LHC and CMS detectors;
- ✧ **Diffraction**:
  - ❖ "Proton-Proton diffraction cross sections at 7 TeV" (CMS-PAS-FSQ-12-005)
- ✧ **Forward jets**:
  - ❖ "Mueller-Navelet dijet azimuthal decorrelations in pp at 7 TeV" (CMS-PAS-FSQ-12-002)
- ✧ **The CMS-TOTEM Precision Proton Spectrometer**
- ✧ **Summary**

1. **All FSQ public results at https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFSQ**
2. **"Recent CMS results on forward physics", Grzegorz Brona on behalf of CMS Collaboration, LHC Working Group meeting on forward/diffractive physics Lawrence & Kansas City, September 2014.**
3. **"Exclusive and Diffractive Physics with CMS", Sandro Fonseca on behalf of CMS Collaboration, PANIC 2014, August 2014.**

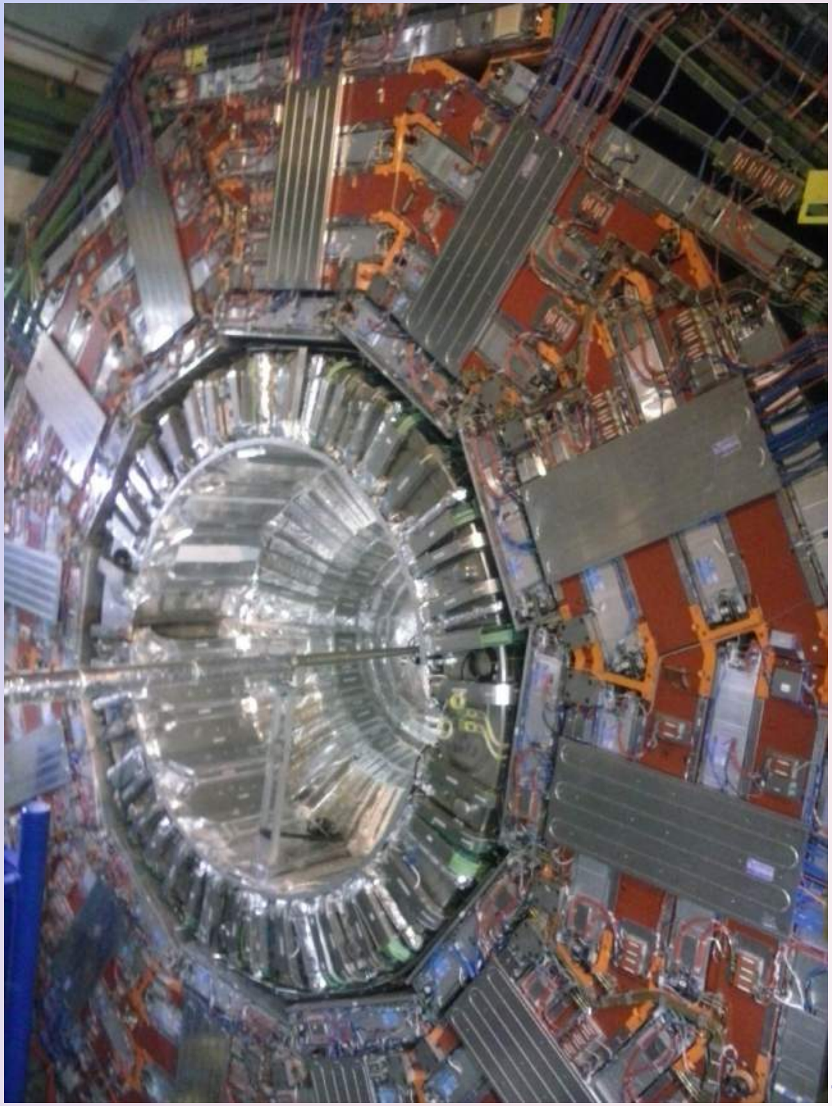
Large Hadron Collider @ CERN



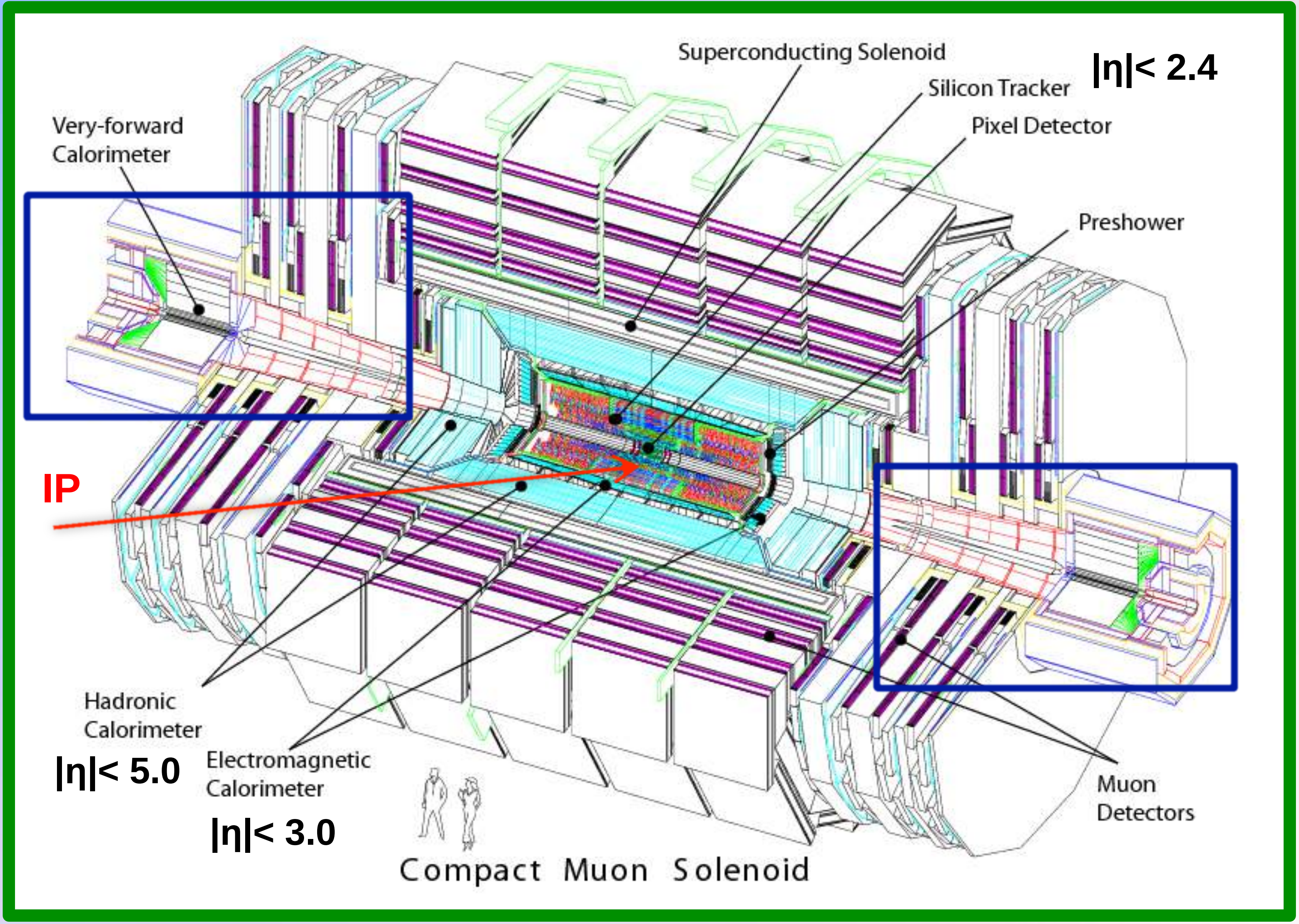
CERN

Geneva Airport
Leman Lake

The Compact Muon Solenoid (central)



The CMS central & forward detectors



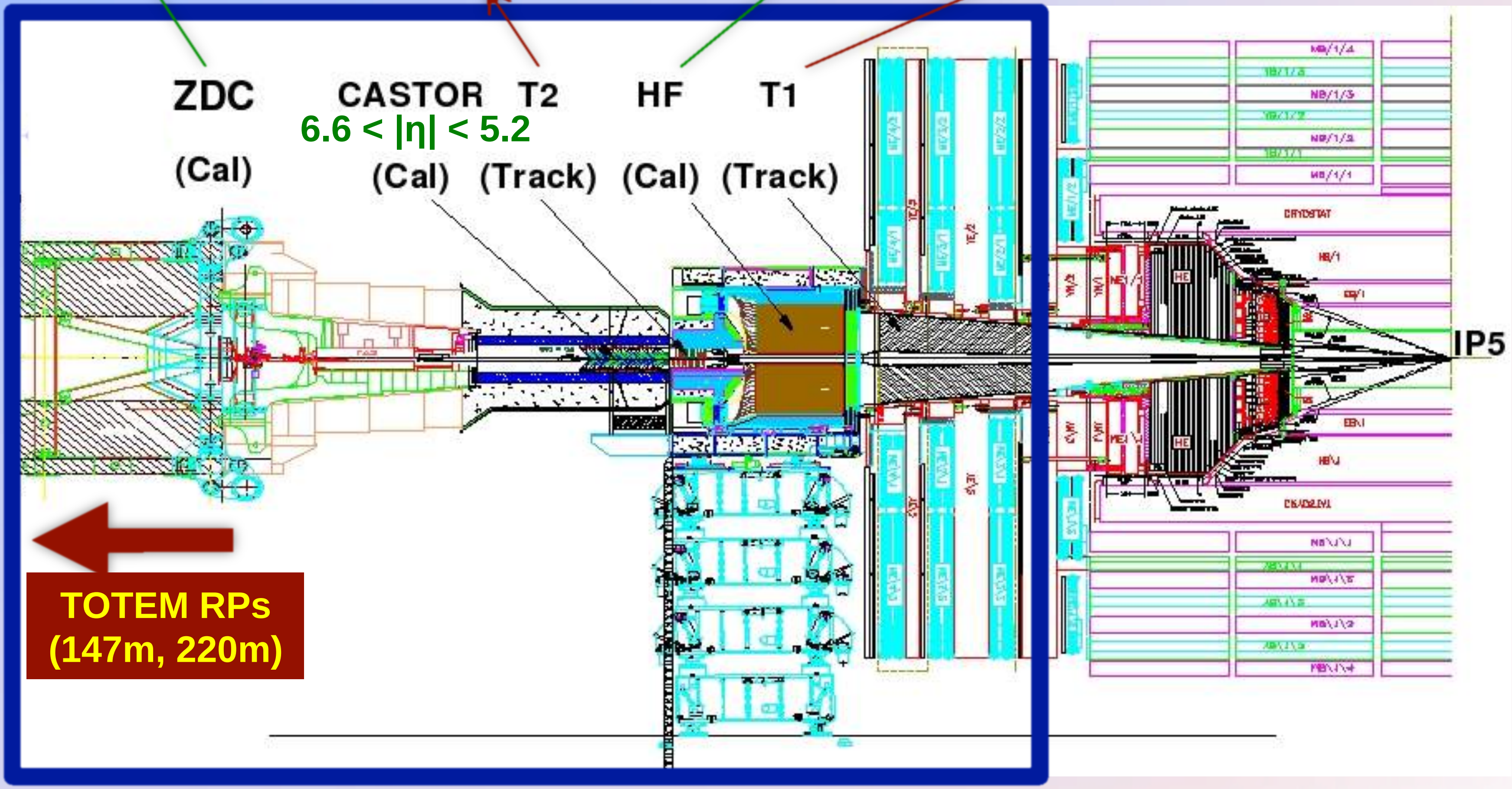
Forward Region - The CMS & TOTEM Collaborations (both sides)

Zero Degree Calo
|η|>8.4

Totem (T2)
5.2 < |η| < 6.5

Hadronic Forward**
3.0 < |η| < 5.0

Totem (T1)
3.1 < |η| < 4.7



TOTEM RPs
(147m, 220m)

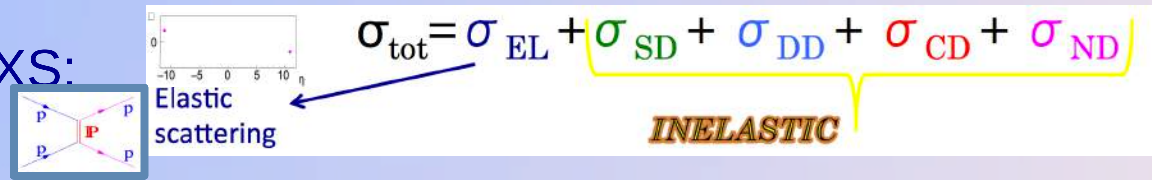
Beam Scintilator Counters (BSC)** : 3.0 < |η| < 5.0
Forward Showers Counters (FSC) : 6.0 < |η| < 8.0

Diffraction
@ CMS

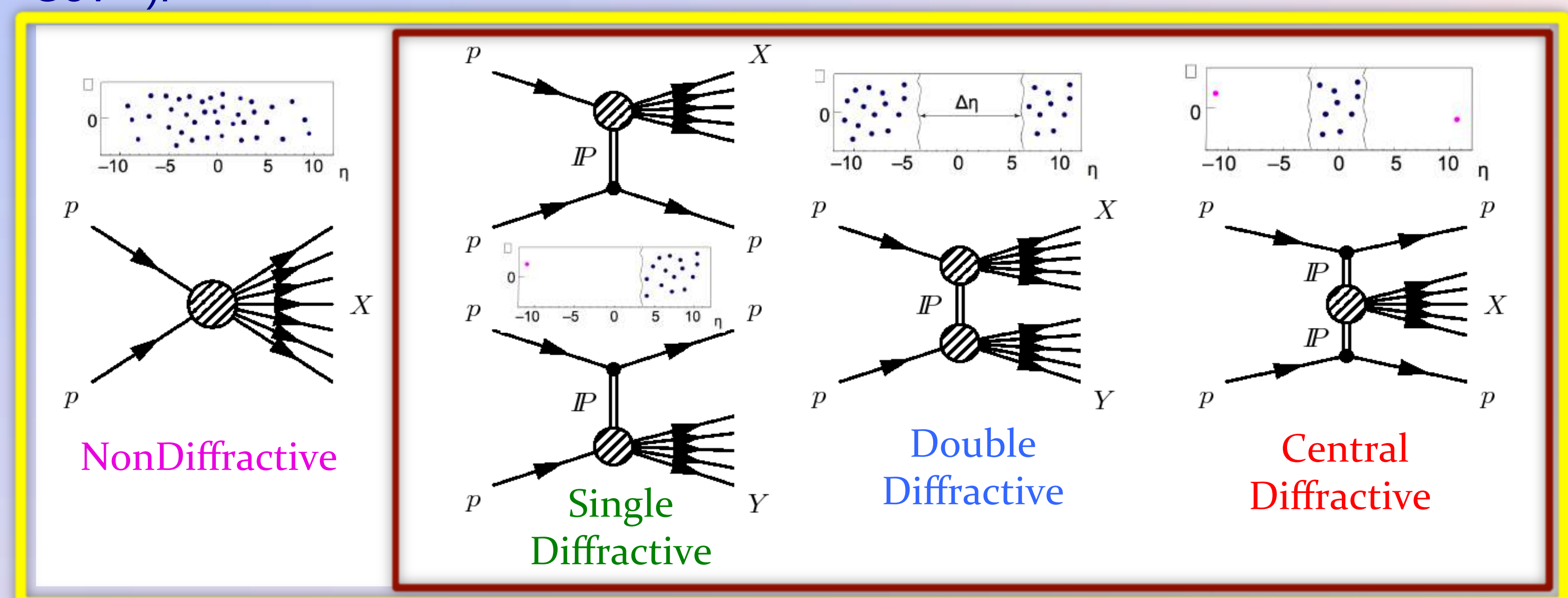
"Proton-Proton diffraction dissociation XS @ 7TeV"

CMS-PAS-FSQ-12-005

- The **total pp** XS:



- At LHC: **20% elastic** (~25mb TOTEM@7TeV, Europhys.Lett. 101 (2013) 21002), **80% inelastic** (~69mb CMS@7TeV, Phys.Lett.B 722 (2013) 5-27);
- Inside the inelastic part: **diffractive processes**, characterized by large rapidity gap (**LRG**) => $\Delta y = y_{max} - y_{min}$, where $y = (1/2) \ln [(E+p_z)/(E-p_z)]$;
- **Hadronic interactions** with LRG are mediated by Pomeron exchange (Regge theory; trajectory $\alpha(t)=1+\varepsilon+\alpha'.t$, being $t=(p_1-p_2)^2$, at Py8 MBR tune with $\alpha' = 0.25$ GeV^{-2}).



CMS-PAS-FSQ-12-005

- **Important measurement**;
- **PYTHIA8-MBR** (Minimum Bias Rockefeller) and **PYTHIA8-4C** (with diffraction from Schuler & Sjostrand) used for comparison;
- **Data** collected at **2010**: **low pileup** scenario (most suitable for diffractive event selection using an LRG signature);
- Signal in both BPTX (**B**eam **P**ick-up **T**iming E**x**periment) detectors and activity in any of the BSC (3.2 < |η| < 4.7) => presence of two bunches along with minimal activity in central CMS detector (Min Bias trigger);
- **SD and DD separated with CASTOR** (6.6 < |η| < 5.2);
- No vertex requirement: to accept low to moderate diffractive masses (12< M_x<100 GeV);
- Diffractive offline selection: **LRG within |η|<4.7** (HF not used; limiting central CMS detector coverage); proton momentum loss ξ reconstructed from particles in |η| < 4.7

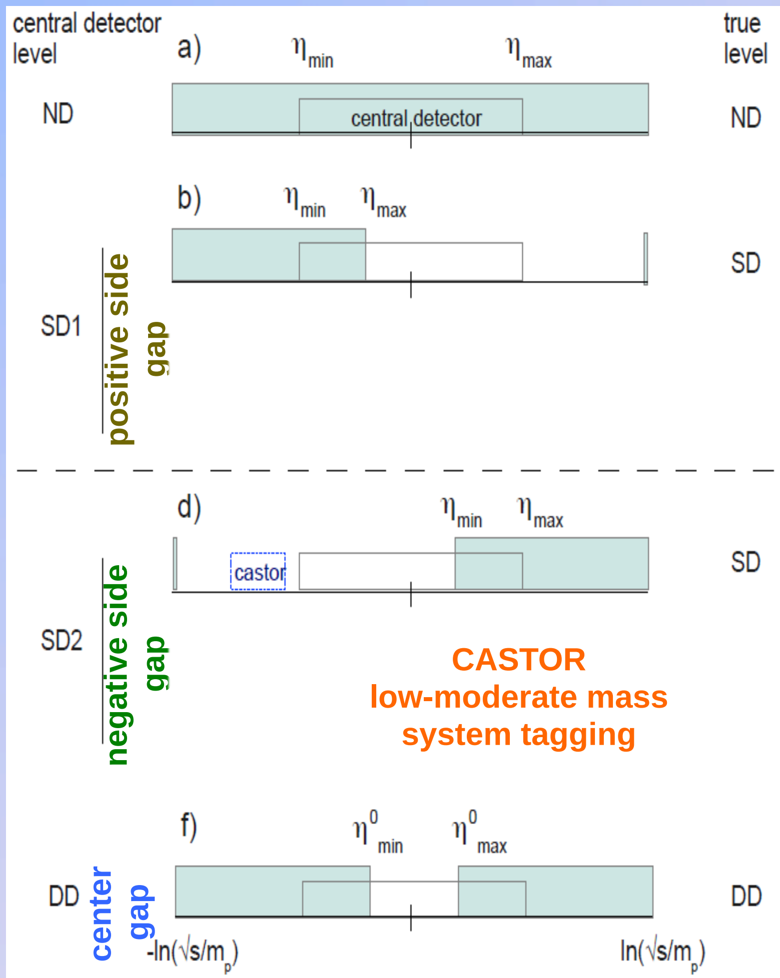
$$\xi^{\pm} = \frac{\sum(E^i \mp p_z^i)}{\sqrt{s}} \qquad \xi = \frac{M_X^2}{s}$$

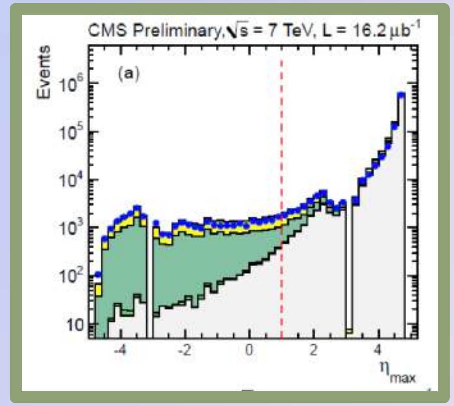
- ✓ Detector level; “i” runs over all Particle Flow objects measured in the central detector; dissociated system occurs on the ±z side of the detector.

Three experimental topologies

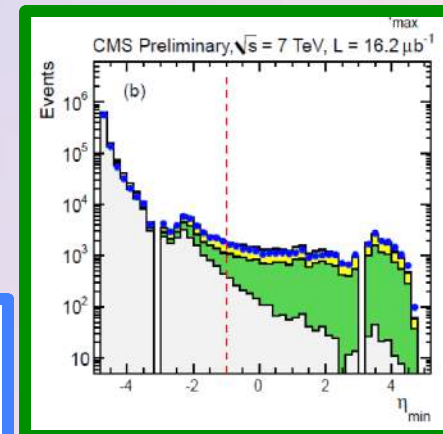
based on the position of the LRG

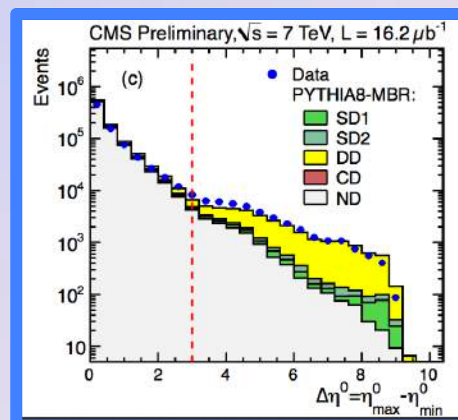
CMS-PAS-FSQ-12-005





Distributions for the MinBias data samples compared with PY8-MBR predictions.





$$|\eta| \lesssim \ln(\sqrt{s}/m_p) = 8.92$$

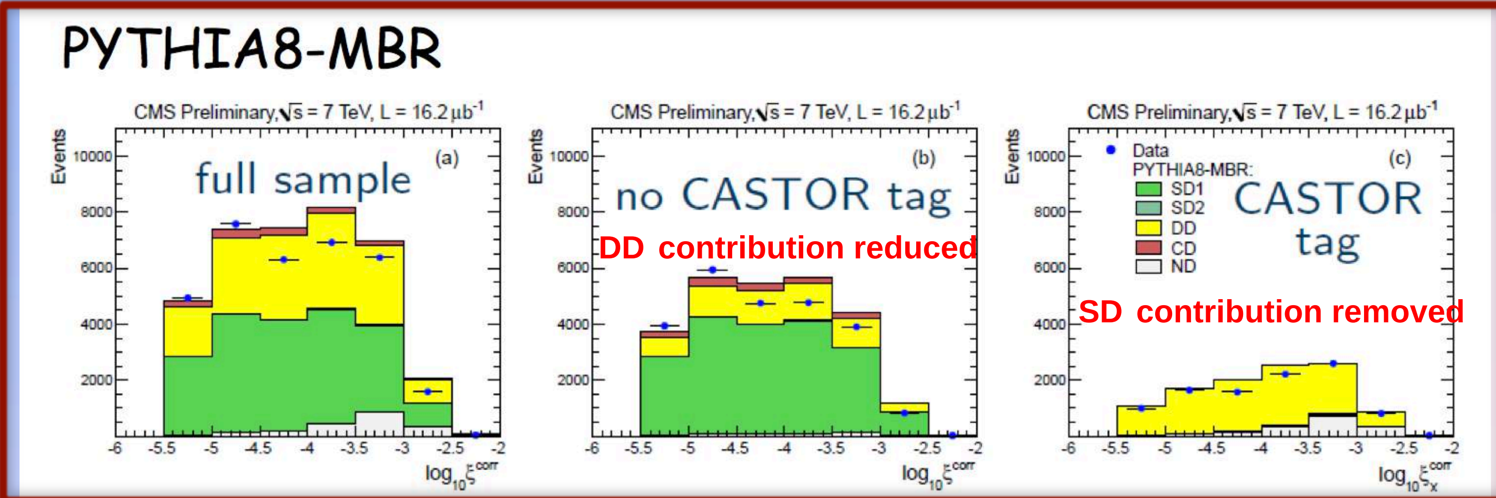
Cuts to select the samples for SD1, SD2 and DD topologies with a central LRG signature: $\eta_{max} < 1$, $\eta_{min} > -1$ & $\Delta\eta^0 > 3$, respectively.

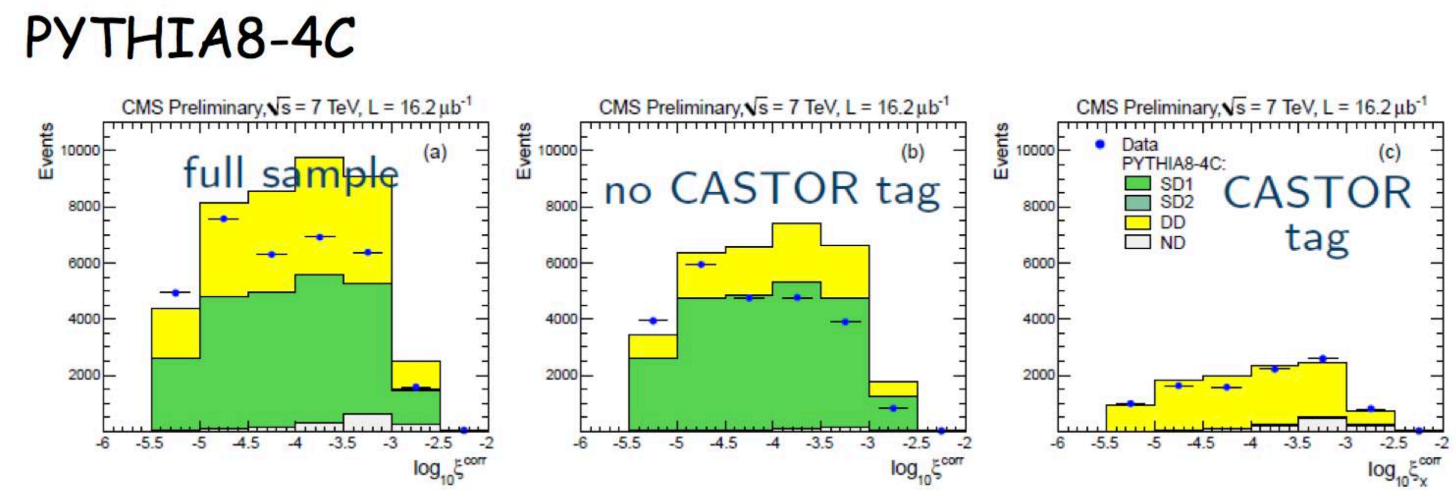
$\eta_{max(min)}$ highest (lowest) η of the particle candidate with $|\eta|<4.7$

SD and DD contribution from SD2 event sample

(three samples according CASTOR tagging; η > -1)

CMS-PAS-FSQ-12-005





BETTER

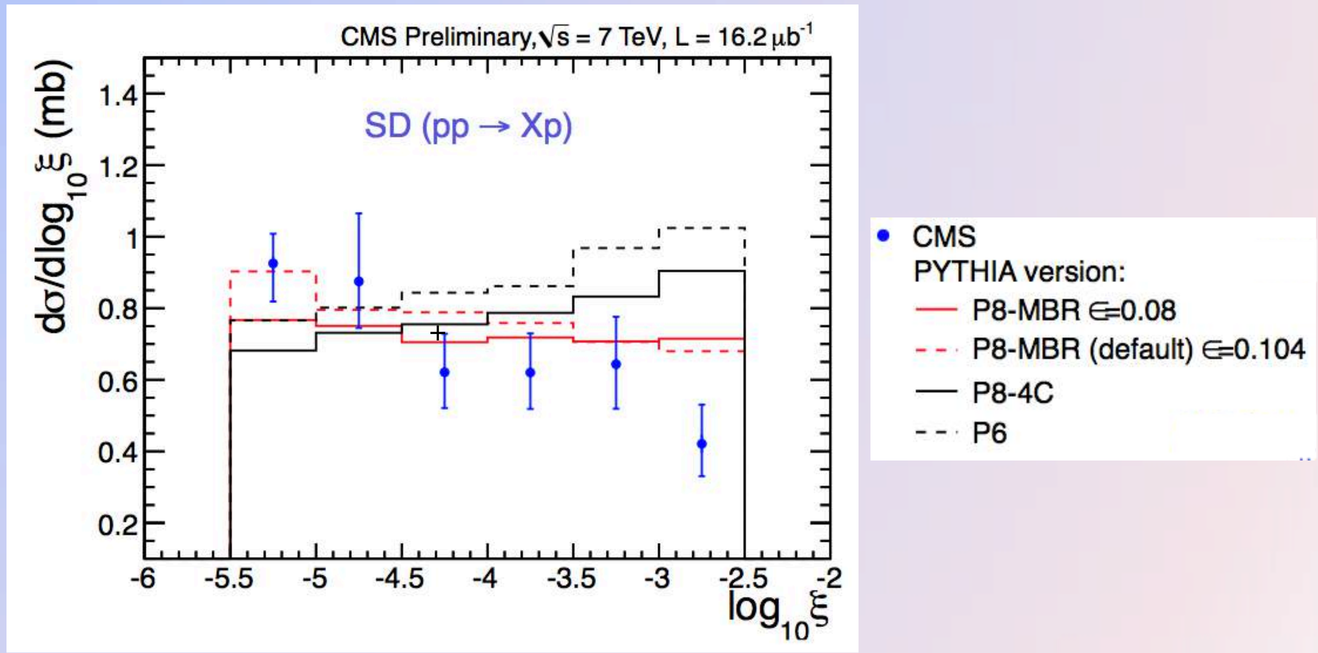
SD XS from SD2 event sample

CMS-PAS-FSQ-12-005

$$\frac{d\sigma^{SD}}{d\log_{10}\xi} = \frac{N^{data}_{noCASTOR} - (N_{DD} + N_{CD} + N_{ND})^{MC}}{acc \cdot \mathcal{L} \cdot (\Delta \log_{10}\xi)_{bin}}$$

At - 5.5 < $\log_{10}\xi$ < -2.5 region:

$\sigma^{SD}_{Total} = 4.27 \pm 0.04(stat.)^{+0.65}_{-0.58}(syst.)$ mb

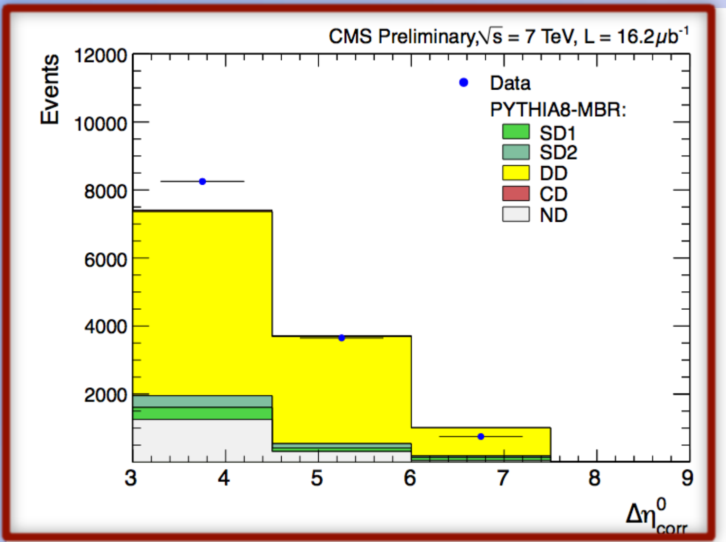


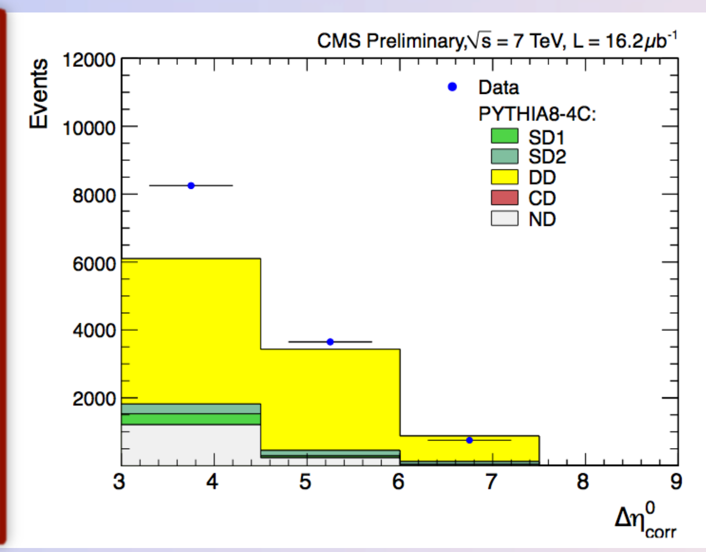
- Comparison with **PYTHIA8-MBR**, PYTHIA8-4C, and PYTHIA6 MC simulations;
- Two values of Pomeron intercept in MBR model
- **PYTHIA8-4C do not reproduce the falling behavior of SD**.

DD XS from DD event sample

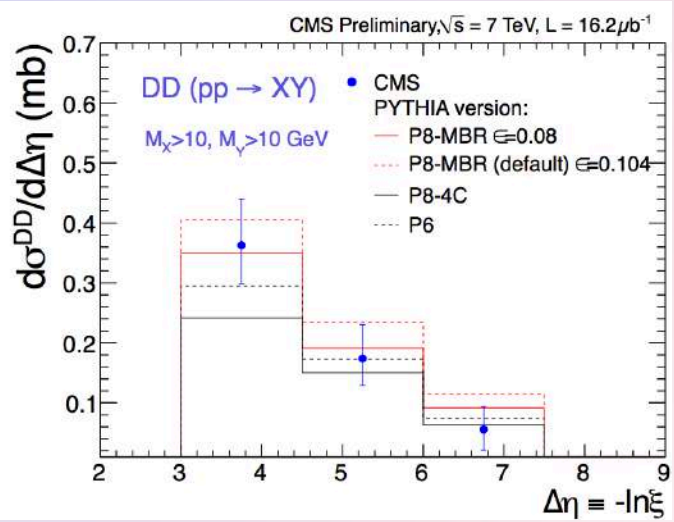
CMS-PAS-FSQ-12-005

B
E
T
T
E
R





$$\frac{d\sigma^{DD}}{d\Delta\eta} = \frac{N^{data} - (N_{ND} + N_{SD} + N_{CD})^{MC}}{acc \cdot \mathcal{L} \cdot (\Delta\eta)_{bin}}$$



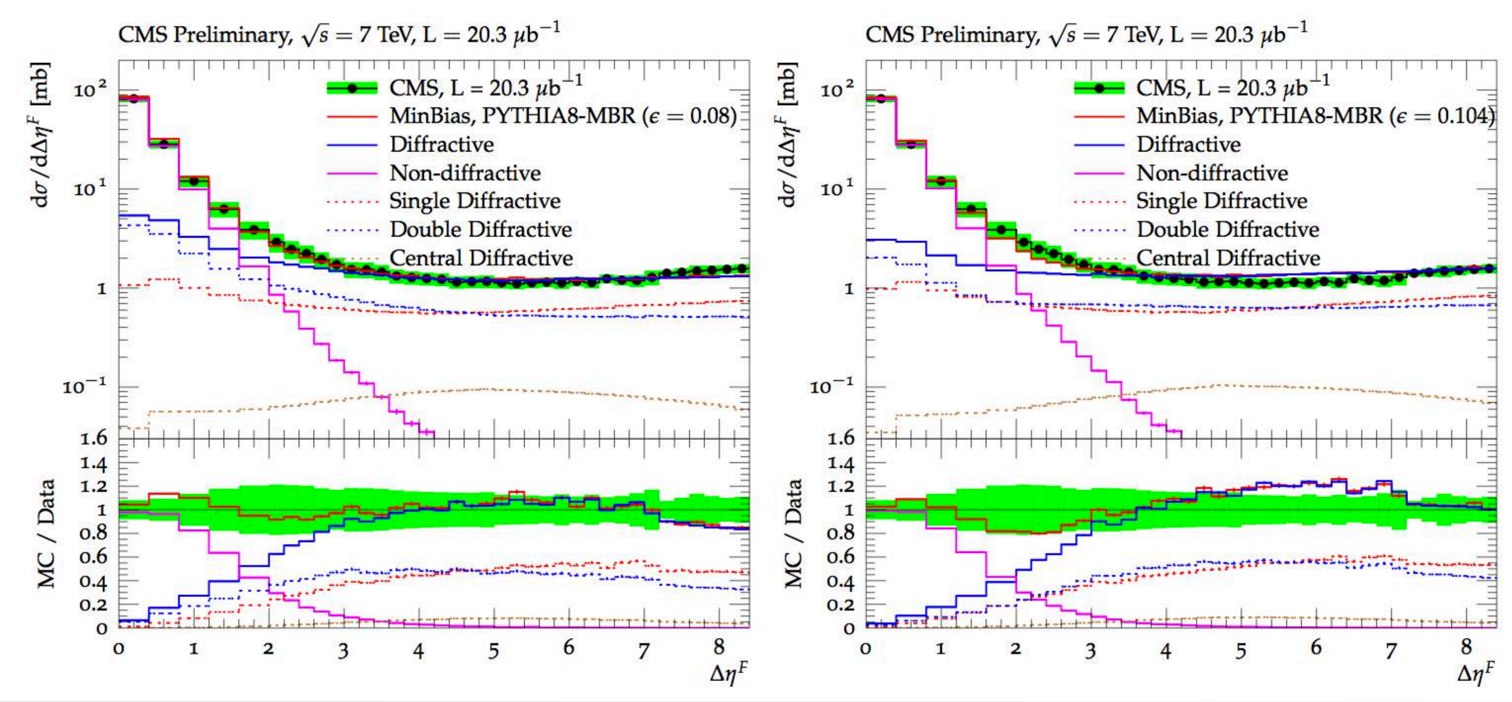
Over the region

$\Delta\eta > 3$, $M_X > 10$GeV, $M_Y > 10$GeV

$\sigma^{DD} = 0.93 \pm 0.01(stat.)^{+0.26}_{-0.22}(syst.)$ mb

Differential XS of the forward rapidity gap ($\Delta\eta^F$)

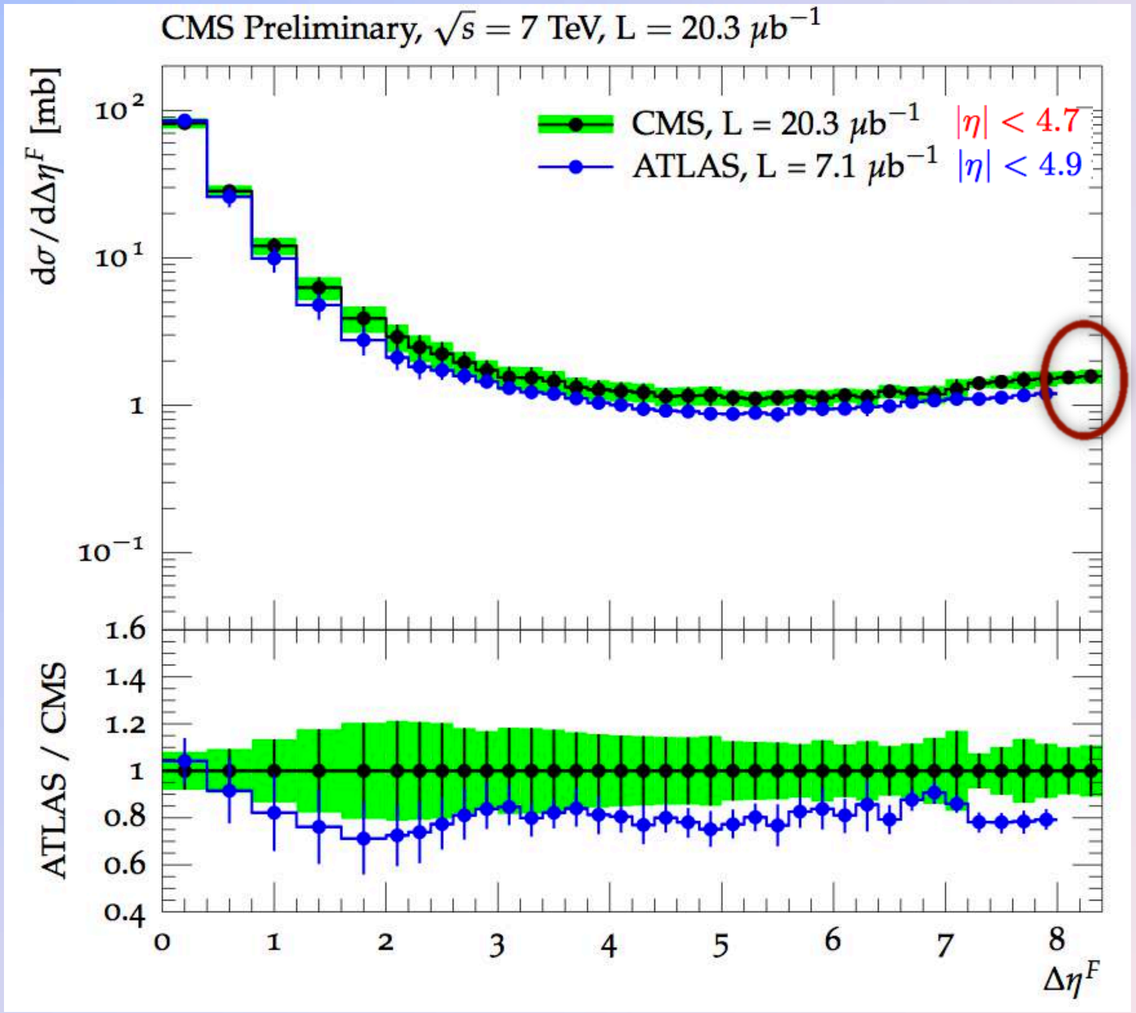
- Alternative approach to the study of diffractive events; ATLAS comparison (next slide);
- Exponential falling for ND contribution;
- Diffractive plateau at $\Delta\eta^F > 3$ with mixture of SD and DD events;
- For all stable final-state particles with **pT > 200 MeV in |η| < 4.7;**
- **Good description using PYTHIA8-MBR with ε = 0.08 intercept.**



Differential XS of the forward rapidity gaps ($\Delta\eta^F$)

"Comparison with ATLAS measurement"

CMS-PAS-FSQ-12-005



The CMS result extends the ATLAS measurement by 0.4 unit of gap size.

Forward Jets @CMS

"Azimuthal angle decorrelations of Mueller-Navelet jets @ 7TeV"

CMS-PAS-FSQ-12-002

- **Hard processes** ($\sqrt{s} \geq p_T >> \Delta_{QCD}$) => data well-described by pQCD within the **DGLAP** evolution equation (p_T ordered);
- **Semi-hard processes** ($\sqrt{s} >> p_T >> \Delta_{QCD}$) => the asymptotic region ($\sqrt{s} \to \infty$) is described by **BFKL** approach: **the number of emitted partons increases with an increasing rapidity interval $\Delta y = |y_1 - y_2|$ between the MN jets** and, hence, the **MN jets are no longer back-to-back ($\Delta\varphi = \pi$) in azimuth leading to a decorrelation**; observation of such decorrelations indicates the presence of BFKL contributions.

$$\frac{1}{\sigma}\frac{d\sigma}{d(\Delta\phi)}(\Delta y, p_{\mathrm{Tmin}}) = \frac{1}{2\pi}\left[1 + 2\sum_{n=1}^{\infty} C_n(\Delta y, p_{\mathrm{Tmin}}) \cdot cos(n(\pi - \Delta\phi))\right]$$

$$C_n(\Delta y, p_{\mathrm{Tmin}}) = \langle cos(n(\pi - \Delta\phi))\rangle < 1$$

Measurements conditions:

- Up to $\Delta y < 9.4$ (between the MN jets): two jets with $p_T > 35$ GeV and $|y| < 4.7$; anti-kT algorithm with jet size R = 0.5

Observables:

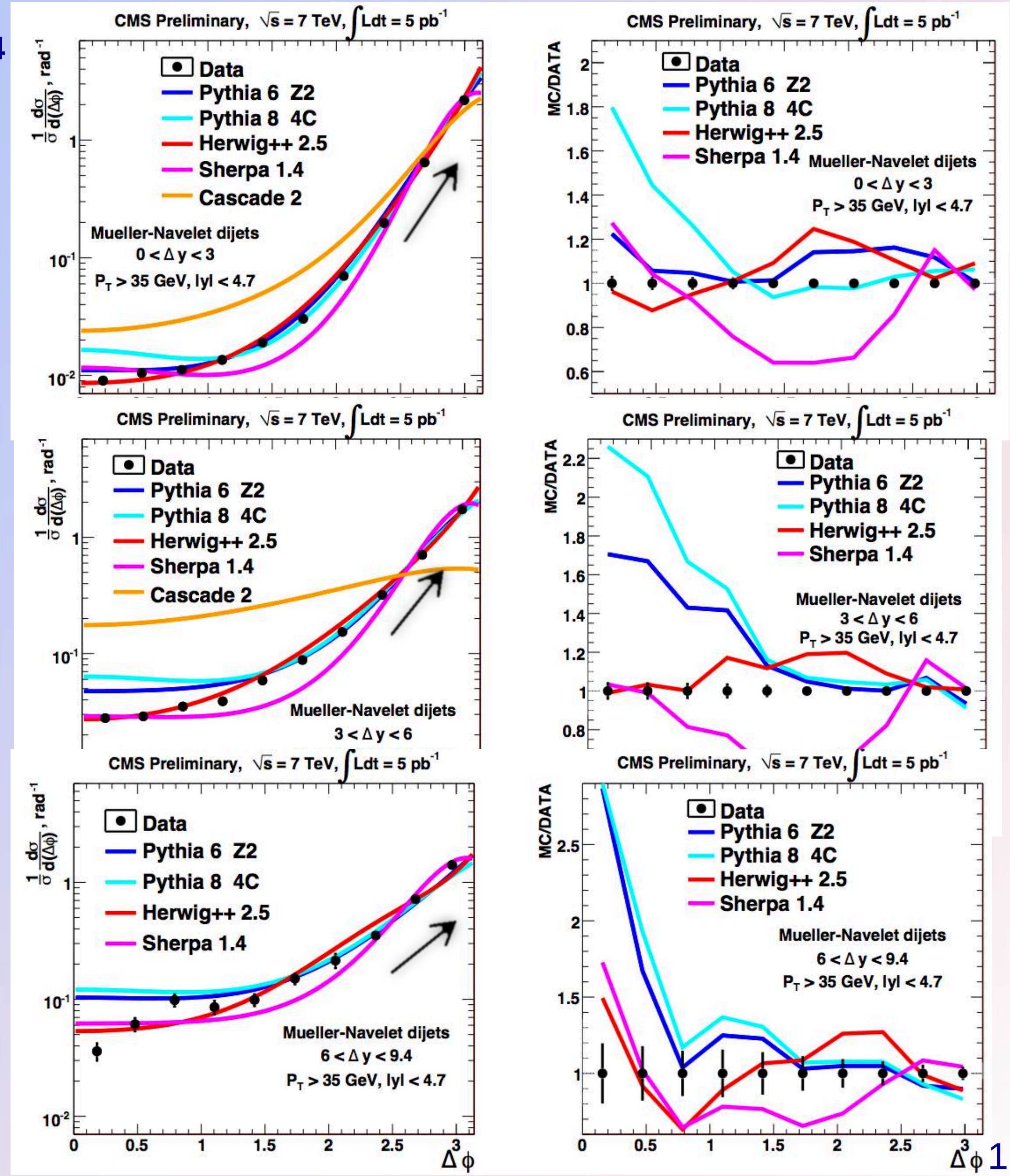
- Azimuthal, $\Delta\varphi$, distributions as a function of Δy;
- Average cosines: $C_n = \langle cos(n(\pi-\Delta\varphi))\rangle$ with n=1,2,3;
- Ratios: C_2/C_1 , C_3/C_2.

Δϕ distributions in three rapidity intervals:

$\Delta y < 3.0$, $3.0 < \Delta y < 6.0$ and $6.0 < \Delta y < 9.4$

CMS-PAS-FSQ-12-002

- azimuthal decorrelation raises with increasing |Δy|;
- **HERWIG++**: the best description in all bins;
- PYTHIAs: with too large decorrelation;
- SHERPA: too large correlation;
- CASCADE: too large decorrelation.



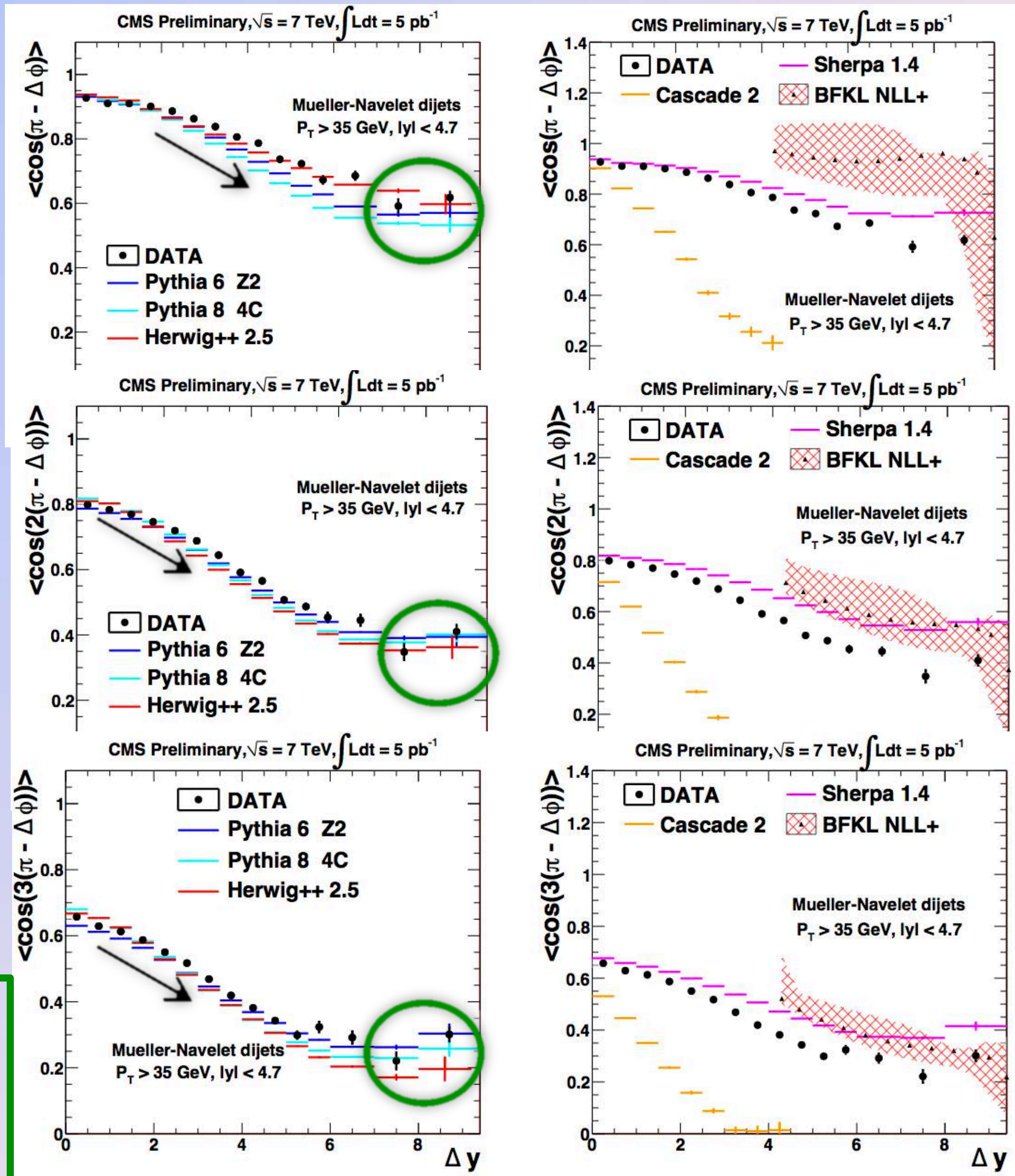
Comparison plots for the average cosine C_n

The measured average cosines decrease with increasing Δy indicates increasing decorrelation of jets in azimuthal angle.

CMS-PAS-FSQ-12-002

- **PYTHIA/HERWIG**: agree slightly with the data;
- SHERPA: is above the data;
- CASCADE: much below the data;
- NLL BFKL: much above the data in the case of C1.

Note: the newer NLL BFKL claimed to be better (http://arxiv.org/abs/arXiv:1309.3229)

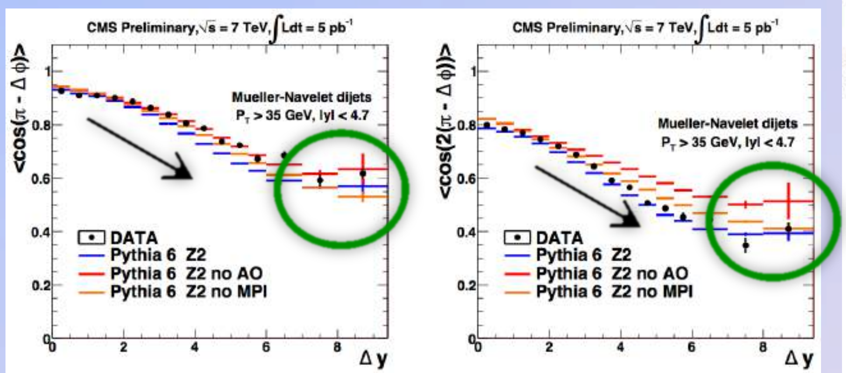


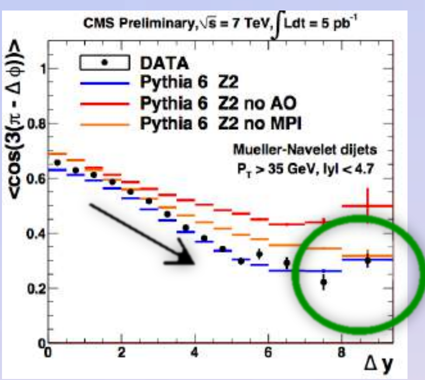
At large values of Δy, additional emissions are becoming kinematically suppressed due to energy-momentum conservation near the phase-space boundary. Thus coplanarity of MN jets restores resulting in increase of average cosines

Polar angle ordering (AO) effects in the parton showering and multiparton interactions (MPI)

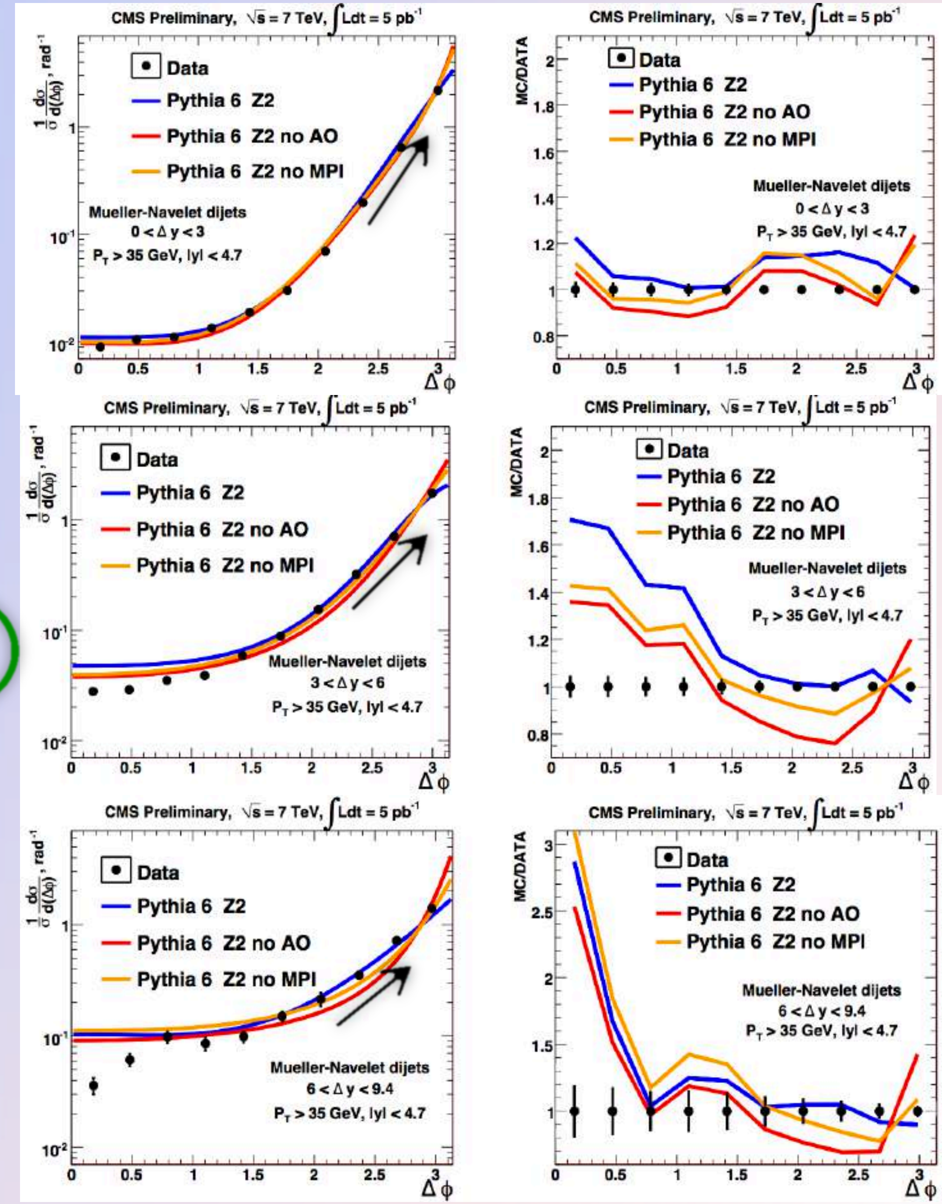
CMS-PAS-FSQ-12-002

- The azimuthal angle decorrelation depends also on:
  - MPI: produce additional jets not correlated with those from the primary interaction;
  - AO effects;
- C_n are very sensitive.





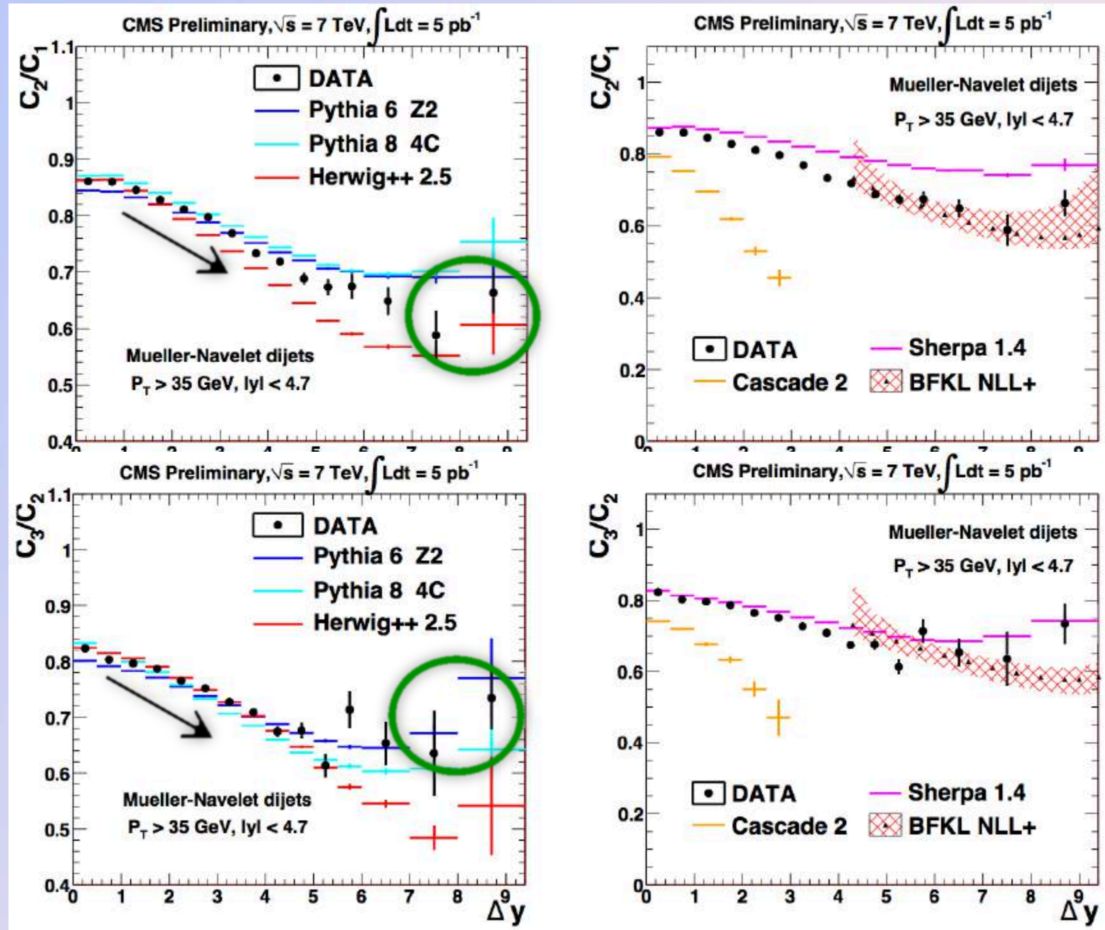
Good description of the data requires polar angle ordering in parton showering.



Comparison plots for the ratios of Cn:

CMS-PAS-FSQ-12-002

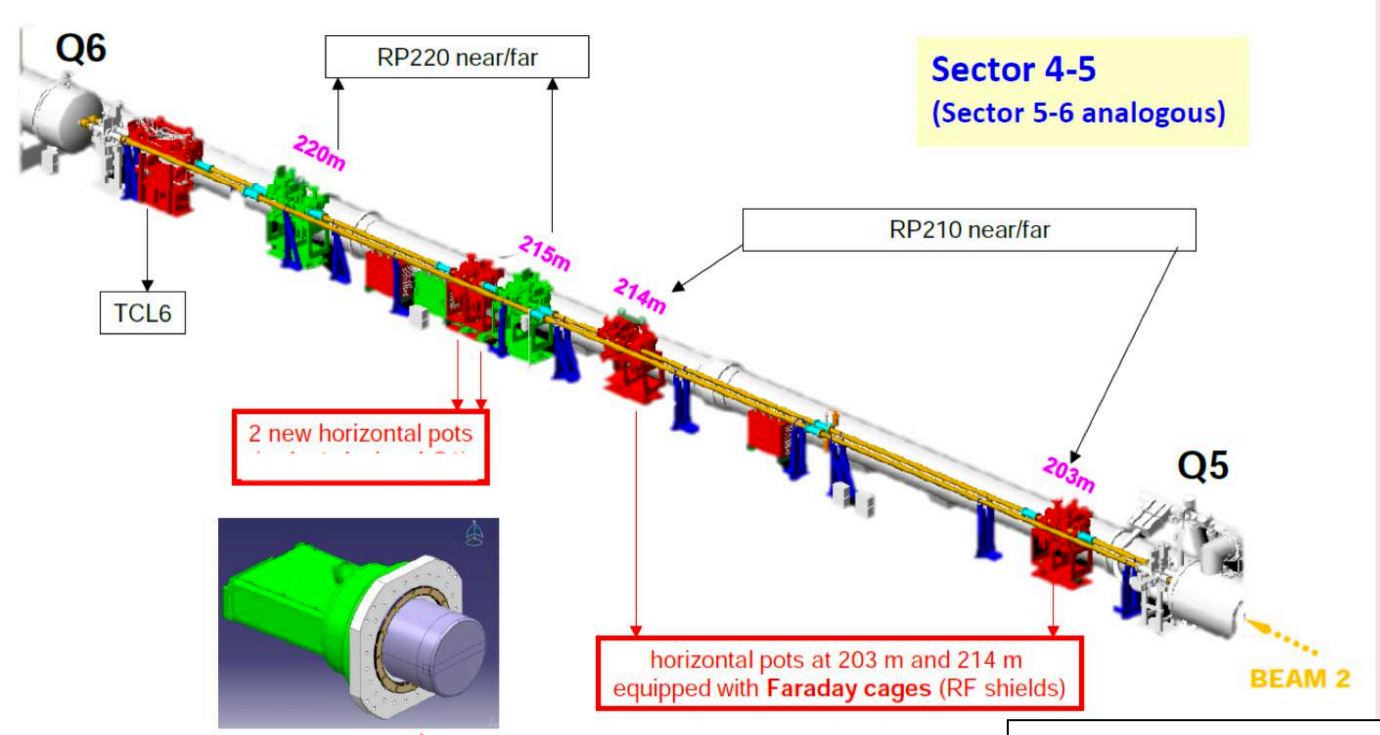
- Expected to be more sensitive to BFKL effects;
- **PYTHIA/HERWIG**: good agreement at low Δy, but at large Δy discrepancies;
- SHERPA: is above the data;
- CASCADE: is far below the data;
- **NLL BFKL** calculation describes the ratios quite well, especially C_2/C_1.



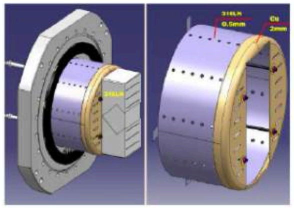
CMS-TOTEM
Precision Proton Spectrometer

the way to high PU Run2 LHC

CMS-TOTEM Precision Proton Spectrometer (CT-PPS)

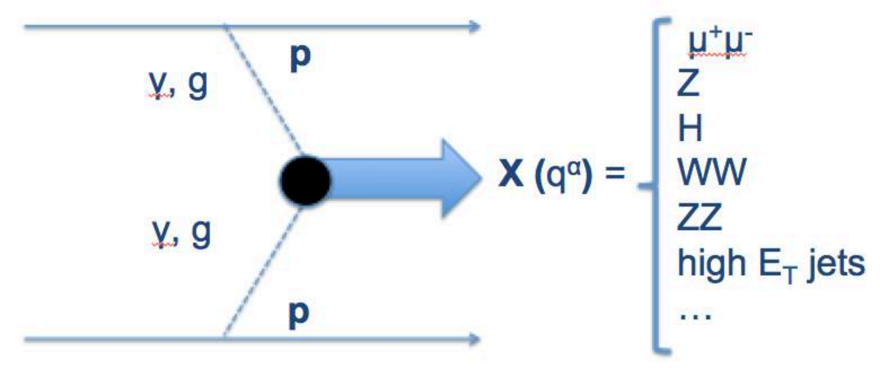


two horizontal cylindrical RPs equipped with timing detectors, for PU rejection.



two horizontal box-shaped RPs equipped with tracking detectors to measure the displacement of the scattered protons with respect to the beam.

Central Exclusive Production : p p -> p ⊕ X ⊕ p



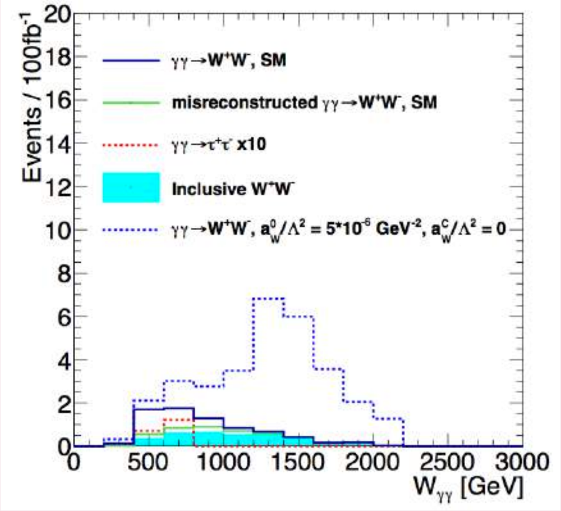
- provides a unique method to access a variety of physics topics at **high luminosity LHC**;
- q^α is constrained by proton`s momentum loss $\boldsymbol{\xi_p}$ and the four momentum transfer squared at the proton vertex, **t** (Mandelstam variable)

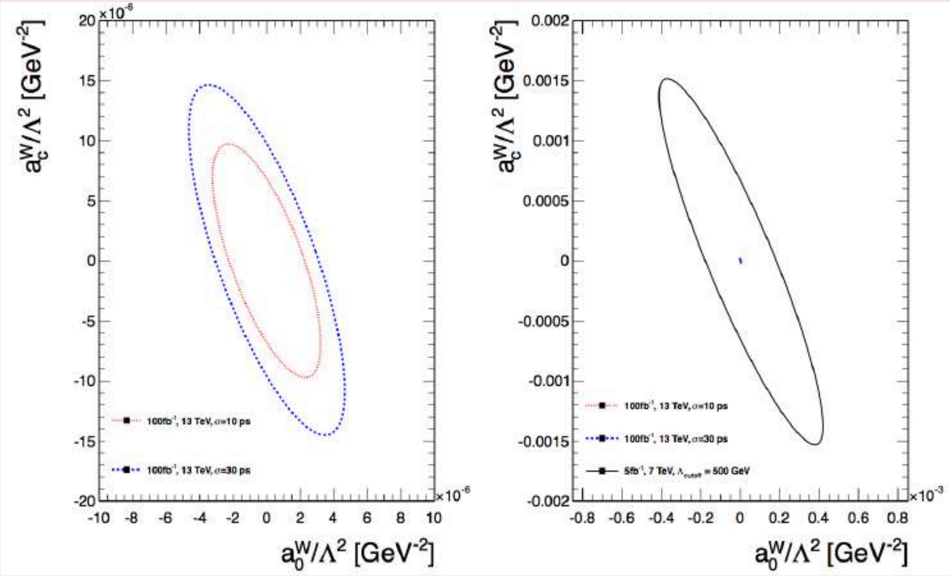
Physics Motivations

- **LHC as photon collider :** Measurement of central production of W^+W^-, e^+e^-, $\mu^+\mu^-$ and $\tau^+\tau^-$ pairs by photon-photon collisions.
- High sensitivity for anomalous quartic gauge couplings (aQGC), including the γγZZ and γγγγ SM-forbidden vertices.
- Exclusive two and three jet events with mass up to ~700-800 GeV;
- Test of pQCD mechanisms of exclusive production;
- Gluon jet factory: gluon jet samples with small contribution of quark jets
- Search for new resonances in CEP: clean events (no underlying pp event); Independent mass measurement from pp system;
- J^{PC} quantum numbers 0^{++}, 2^{++} .

The central exclusive WW production and aQGC sensitivity

- The WW mass reconstructed from the momenta of the scattered protons for a sample of SM events and aQGC.
- **MC studies** for 100 fb^{-1} @ LHC13 with 50 pileup interactions, in the $0 < |t| < 4$ GeV^2 and $0.01 < \xi < 0.2$ region.





95% C.L. excluded regions for the anomalous parameters.

The resulting limits are of the order of

$$a_0^W/\Lambda^2 = 2 \times 10^{-6}\ (3 \times 10^{-6}),$$
$$a_C^W/\Lambda^2 = 7 \times 10^{-6}\ (10 \times 10^{-6})$$

for a 10ps (30ps) time resolution.

According these MC preliminary studies, one could reach **two orders of magnitude better than achieved so far**!!

More details at ISMD2014`s poster session

Summary

- **Two interesting CMS results presented:**
  - ✓ **Inclusive SD and DD XS measured at 7 TeV; BFKL effects through azimuthal decorrelations in MN jets.**
- **Forward and Diffractive physics – perfect testing ground for models and theories**
  - ✓ **https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFSQ;**
  - ✓ **MC comparisons and tuning are very important. See also Stradling and Platzer`s nice talks at ISMD2014;**
  - ✓ **Many 8TeV analyses (with 2012 Data, ~20fb^{-1}) in progress.**
- **The CT-PPS:**
  - ✓ **promising future for the CMS Forward and Diffractive program at LHC Run2.**