Soft QCD
at CMS

E.Kuznetsova

(PNPI NRC KI, Gatchina)
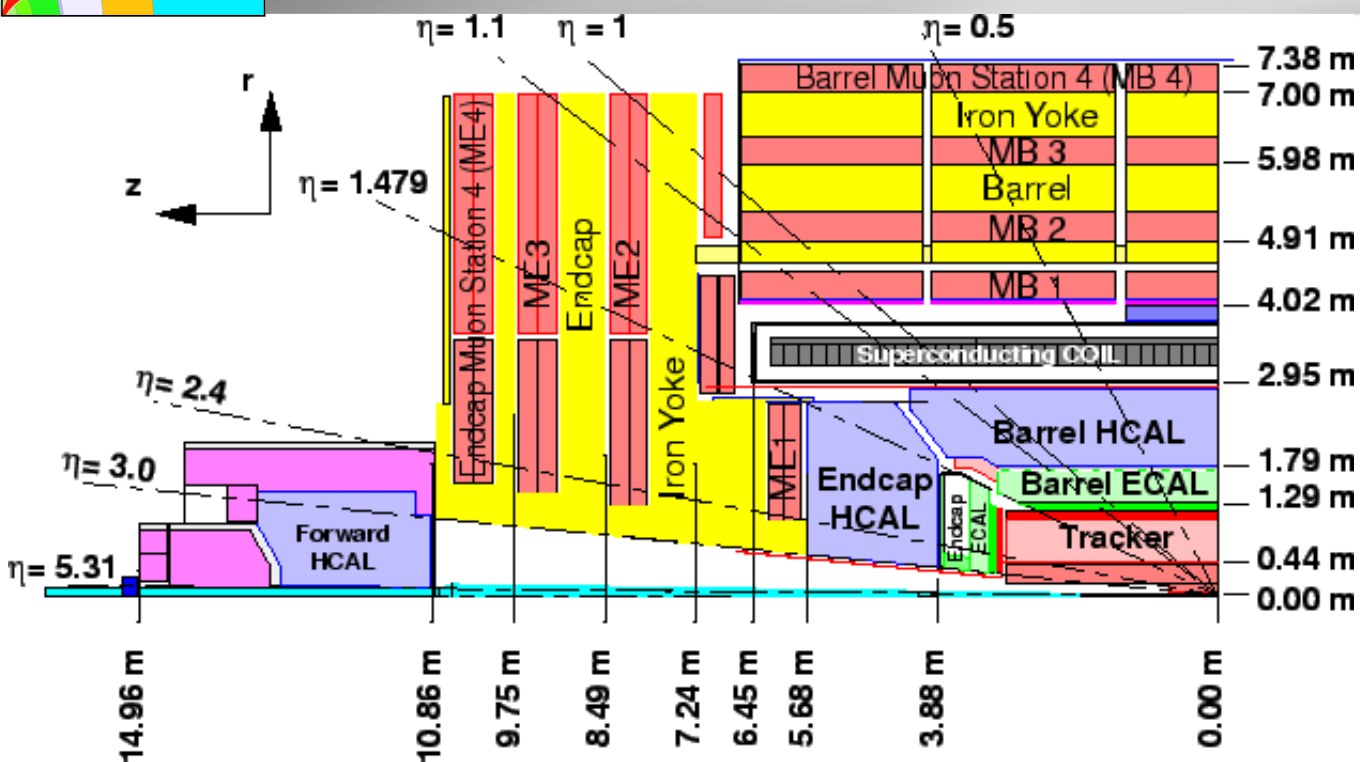
on behalf of the CMS Collaboration

LHCP 2015

31 Aug-5 Sept 2015
St.Petersburg

CMS central detector

Muons

(CSC+DT+RPC)

$|\eta|<2.4$

Tracker

(Pixel+SiStrip)

$|\eta|<2.4$

$P_t \gtrsim 100$ MeV

Calorimetry + tracking →

Particle Flow Objects

ECAL

PbWO4: $|\eta|<3$

HCAL

central: scint.+brass : $|\eta|<3$

$\Delta\eta \times \Delta\varphi = 0.087 \times 0.087$
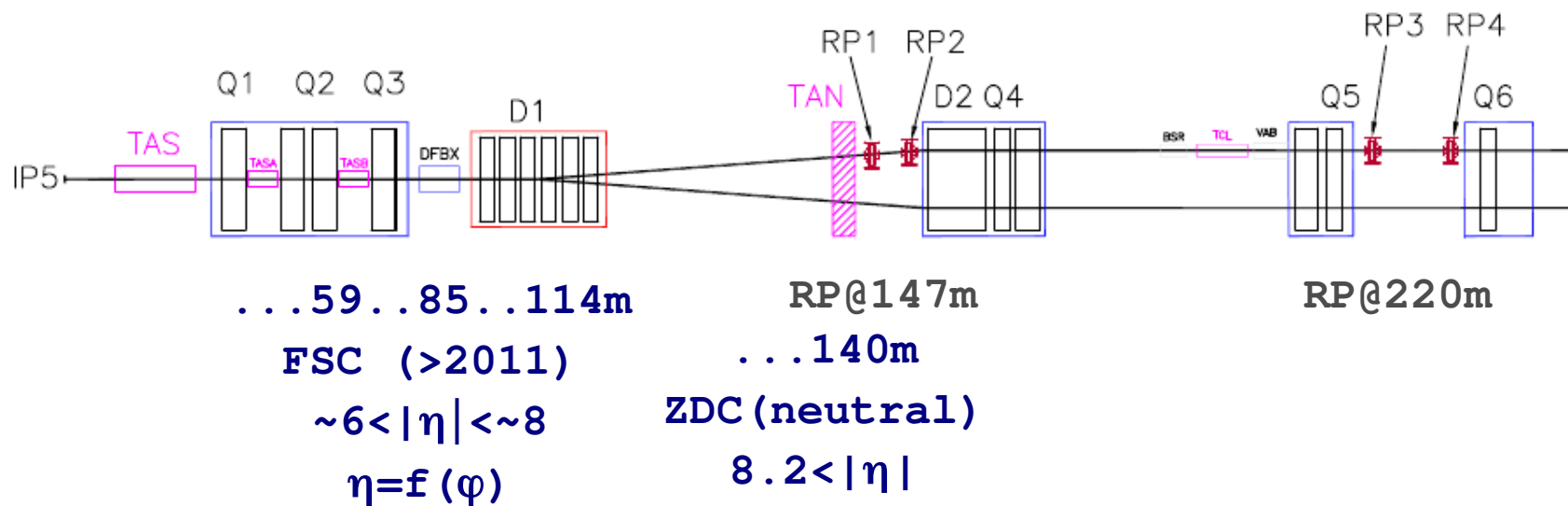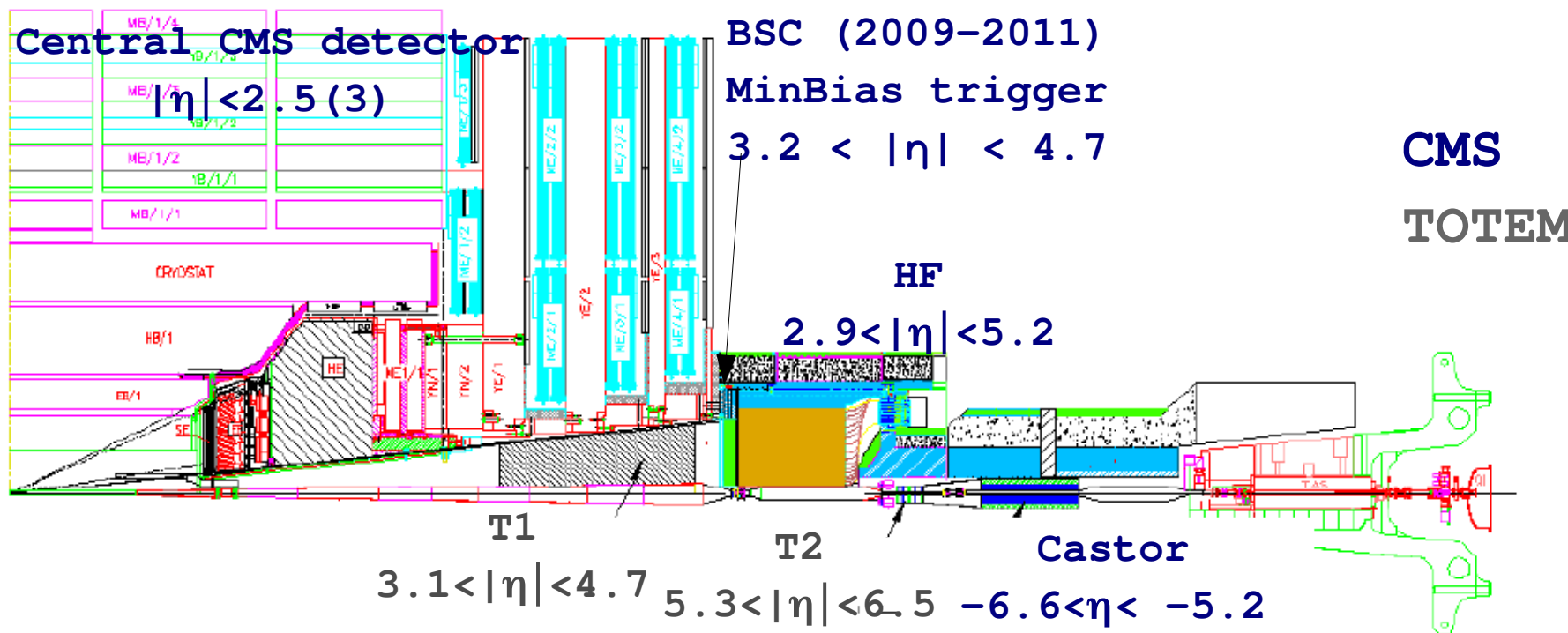
HF: steel+quartz : $2.9<|\eta|<5.2$

$\Delta\eta \times \Delta\varphi \sim 0.175 \times 0.175$

Central CMS detector $|\eta|<2.5(3)$

BSC (2009-2011)
MinBias trigger
$3.2 < |\eta| < 4.7$

CMS

TOTEM

HF
$2.9<|\eta|<5.2$

T1
$3.1<|\eta|<4.7$

T2
$5.3<|\eta|<6.5$

Castor
$-6.6<\eta<-5.2$

...59..85..114m
FSC (>2011)
$\sim6<|\eta|<\sim8$
$\eta=f(\varphi)$

RP@147m
...140m
ZDC(neutral)
$8.2<|\eta|$

RP@220m

Underlying events studies with leading track-jets:

     sqrt(s)= 2.76 TeV

Hard/soft transition leading charged particle / jet cross section: **sqrt(s)= 7 TeV**

Mininum Bias - soft diffraction (update):

     sqrt(s)= 7 TeV

Minimum Bias - charged particles multiplicity:

     sqrt(s)= 13 TeV

UE

Data: **sqrt(s) = 2.76 TeV**

    0.3 nb^{-1}, PU 6.2%

(in comparison to 0.9 and 7 TeV)

    Jet-enhanced MinBias data

Jets: **track-based jets**

    tracks pT > 0.5 GeV and |η| < 2.5

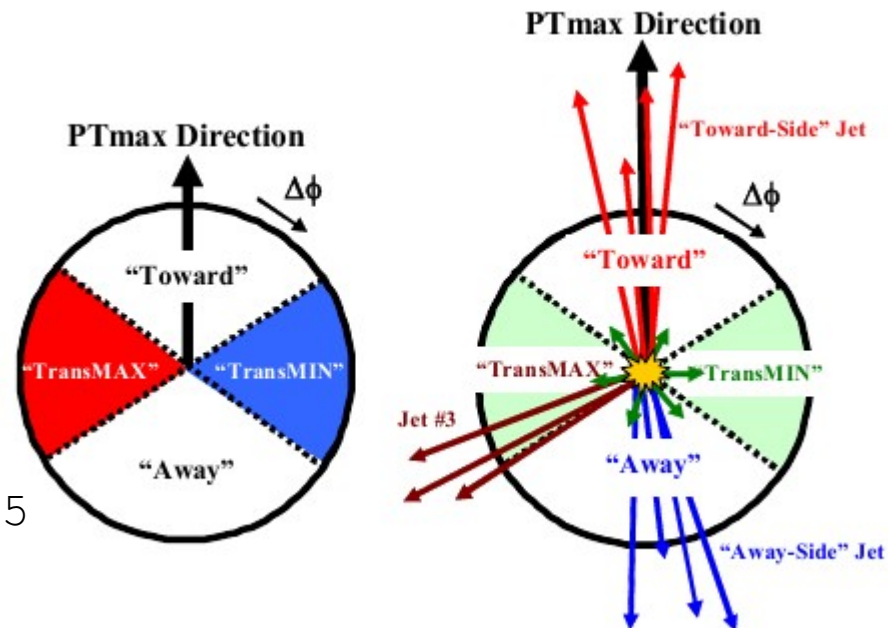   SisCone 0.5: pT(jet) > 1.0 GeV

          |η(jet)| < 2.0

TransMIN – MPI mostly

TransMAX – MPI + (FSR,ISR)

Observables:

    Hard scale: pT(leading track-jet)

In the transverse region: (60°<|$\Delta\phi$|<120°)

      Charged particle density

      Charged particle transverse momentum density
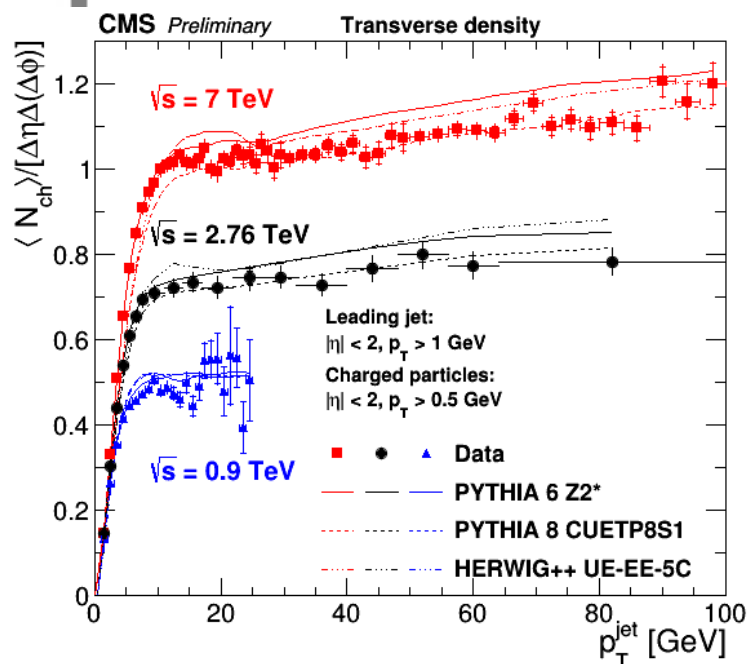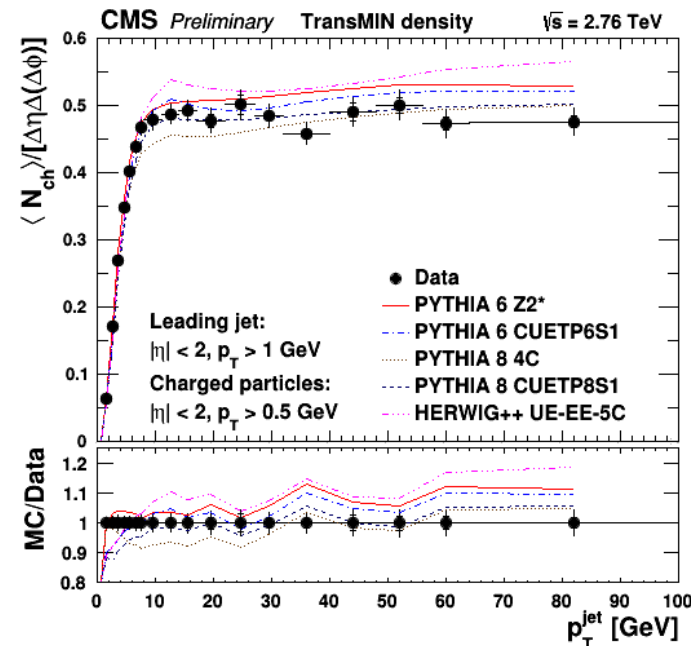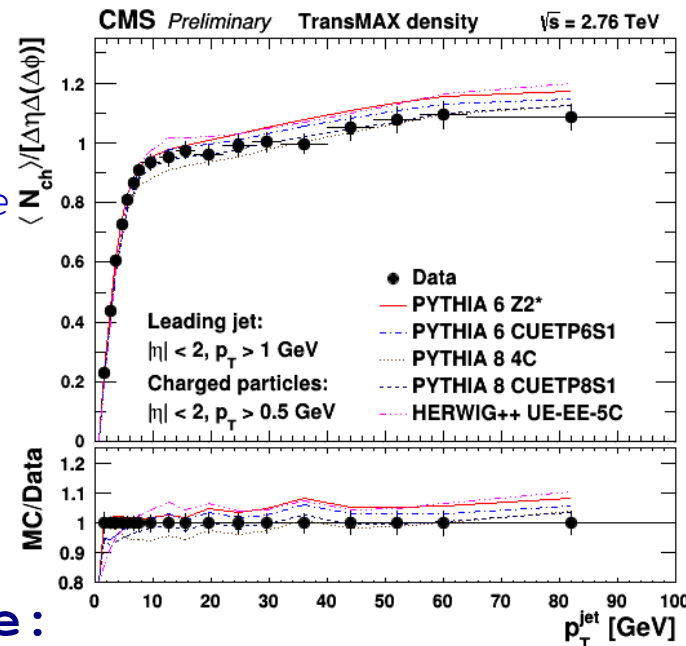
UE

Visible difference dependencies on the hard scale

Energy dependence:
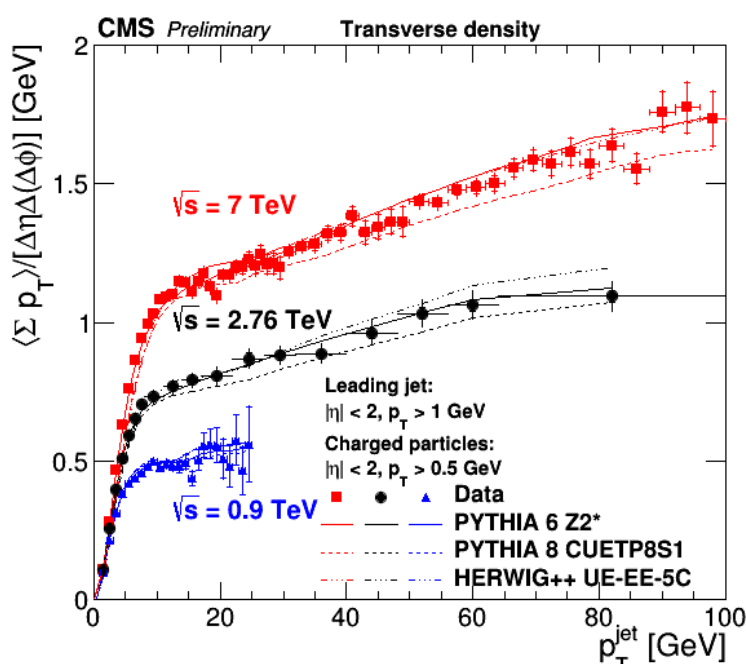
Recent tunes of Pythia and Herwig describe data within 5-10%

The energy dependence is well reproduced by MC

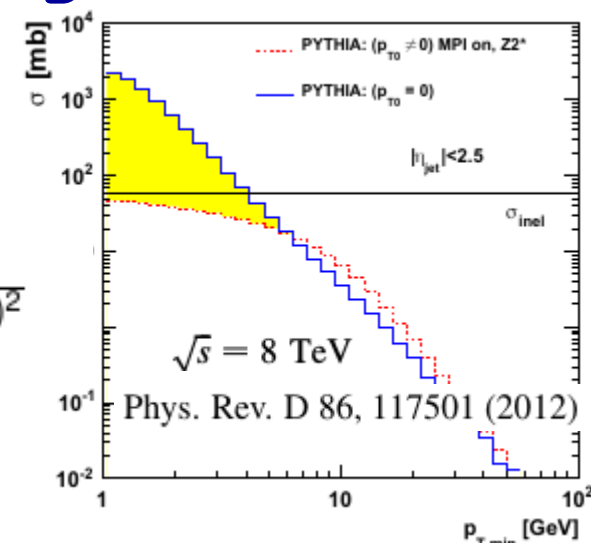# Leading charged particle and charged-particle jet

Motivation:

2->2:
$$\sigma_{int}(p_{T,min}) = \int_{p_{T,min}} dp_T \frac{d\sigma}{dp_T}$$

$P_{T_{min}} \rightarrow 0 \Rightarrow \sigma_{int} \sim 1/P^2_{T_{min}}$

$$\sigma_{int} > \sigma_{inel}$$

Pythia:
$$\sigma \rightarrow \sigma \times \frac{\alpha_s^2(p_{T0}^2+p_T^2)}{\alpha_s^2(p_T^2)} \frac{p_T^4}{(p_{T0}^2+p_T^2)^2}$$

PYTHIA: ($p_{T0} \neq 0$) MPI on, Z2*
PYTHIA: ($p_{T0} = 0$)

$|\eta_{jet}|<2.5$

σ_{inel}

$\sqrt{s} = 8$ TeV

Phys. Rev. D 86, 117501 (2012)

Event x-section of leading charged particles (charged-particle jets):

$$r(p_T^{min}) = \frac{1}{N_{evt}} \int_{p_T^{min}} dp_T^{lead} \left(\frac{dN}{dp_T^{lead}}\right) \longrightarrow \frac{1}{N_{evt}} \sum_{p_{Tlead}>p_{Tmin}} \Delta p_{Tlead} \left(\frac{\Delta N}{\Delta p_{Tlead}}\right)$$

Low pT region:

Sensitive to MPI, probes pQCS – non pQCD transition region,
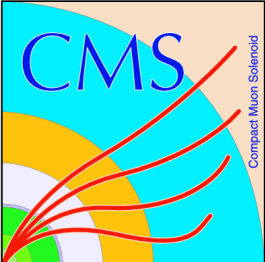
low-x physics

Data: **Low-PU (~0.04) 2012 data at sqrt(s)= 8 TeV; CMS-TOTEM run**

MinBias with TOTEM T2 (>90% of total inelastic sample)

Selection:
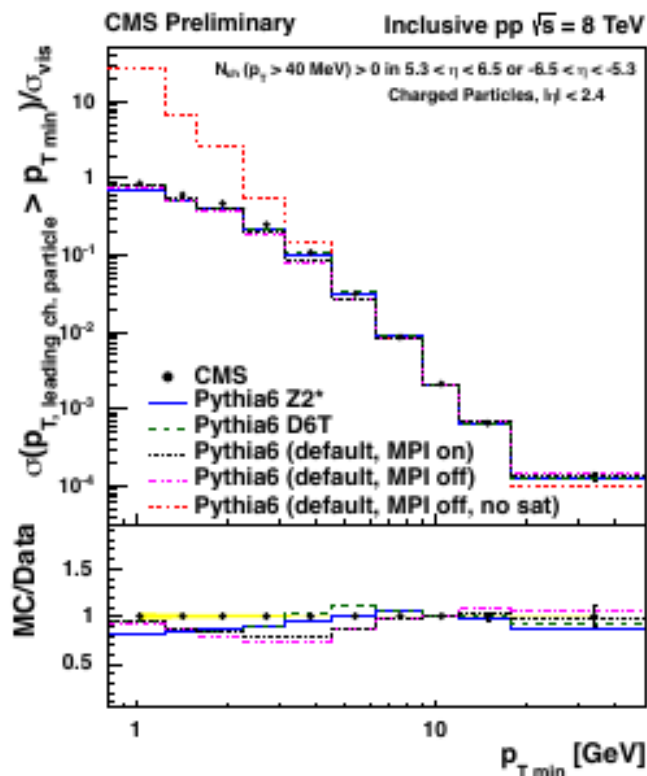
Leading track: $|\eta|<2.4$, pT >400 MeV (normalization sample)
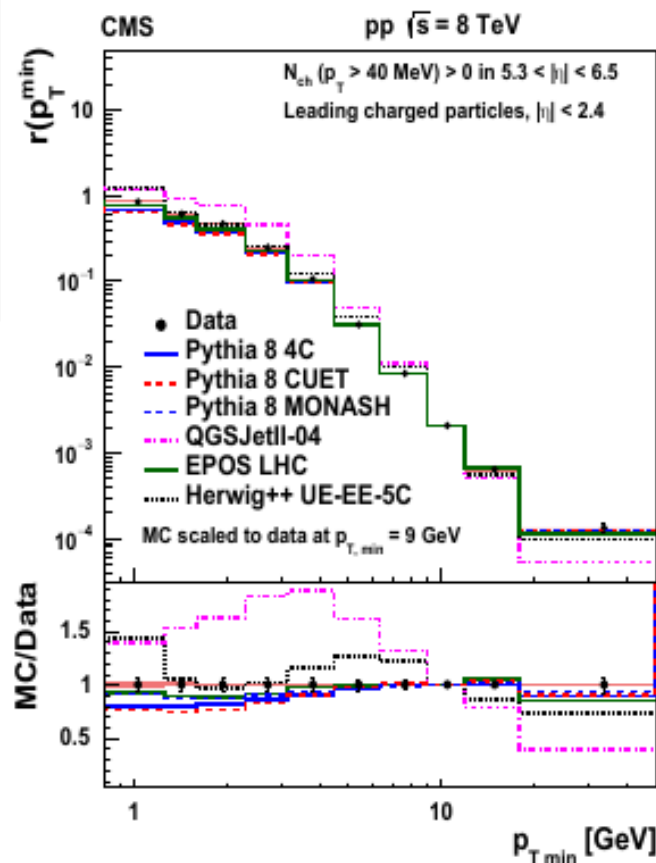Leading track-jets: anti-kt 0.5: $|\eta|<1.9$, pT(jet) >1.0 GeV

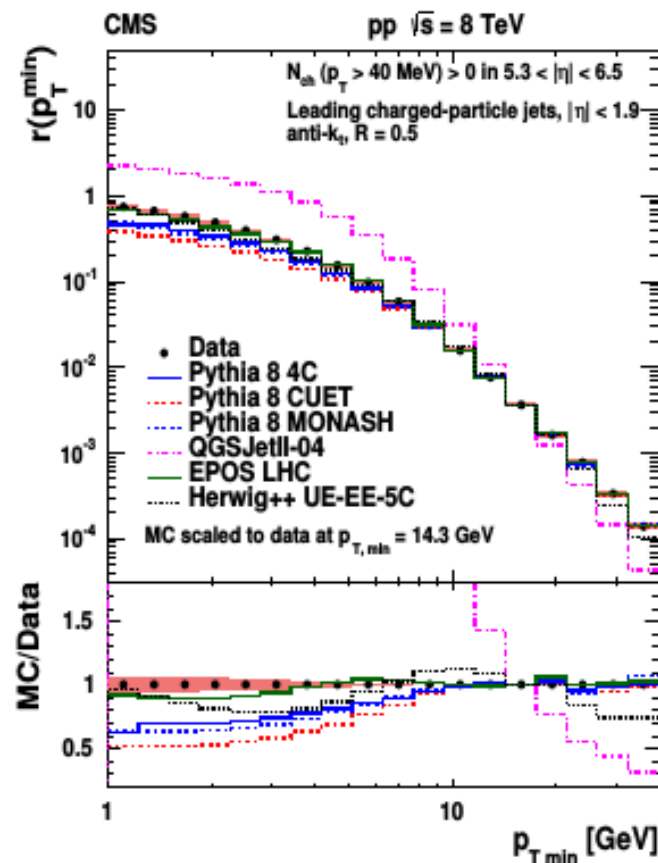# Leading charged particle and charged-particle jet
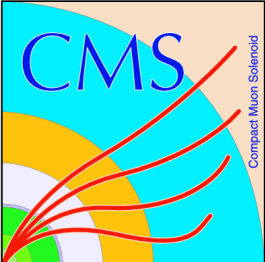
MPI: small contribution

Best description – EPOS

Leading particle

Leading track-jet

Soft diffractive x-section (update)

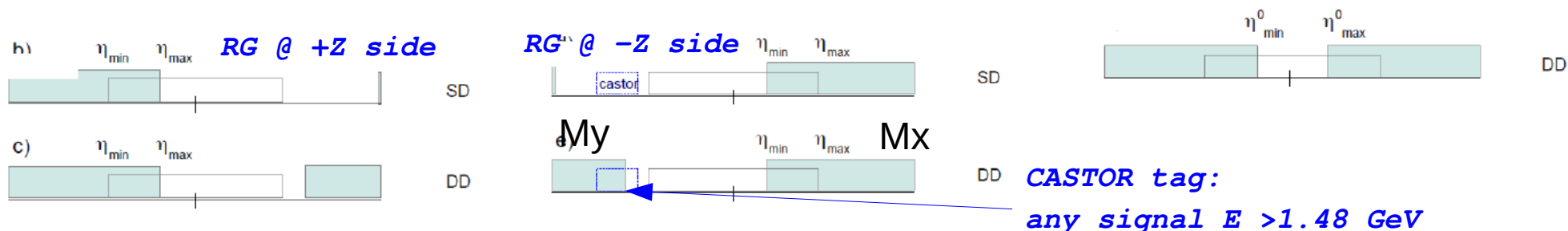**Data:** **Low-PU (~0.14) 2010 data at sqrt(s)= 7 TeV**

Selection: MinBias with BSC (~total inelastic sample) + LRG topology

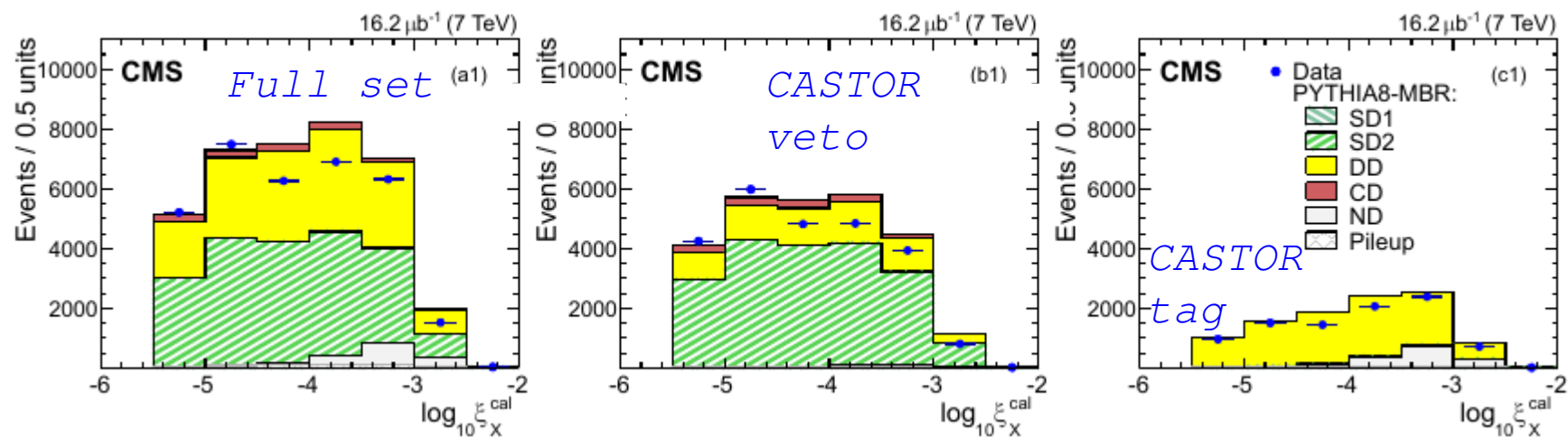At least 2 particle candidates in the BSC acceptance **$|\eta|<4.7$**
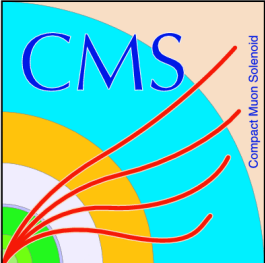No vertex requirement ($M_x<100$ GeV)

MC: Pythia8+Minimum Bias Rockfeller model **based on renormalized Regge model**

Pythia8-4C

RG @ +Z side   *RG" @ −Z side*

My   Mx

CASTOR tag:
any signal E >1.48 GeV

"SD" sample: detector-level distribution ξ: (data vs Pythia-MBR)

Soft diffractive x-section

Corrections from det.level:

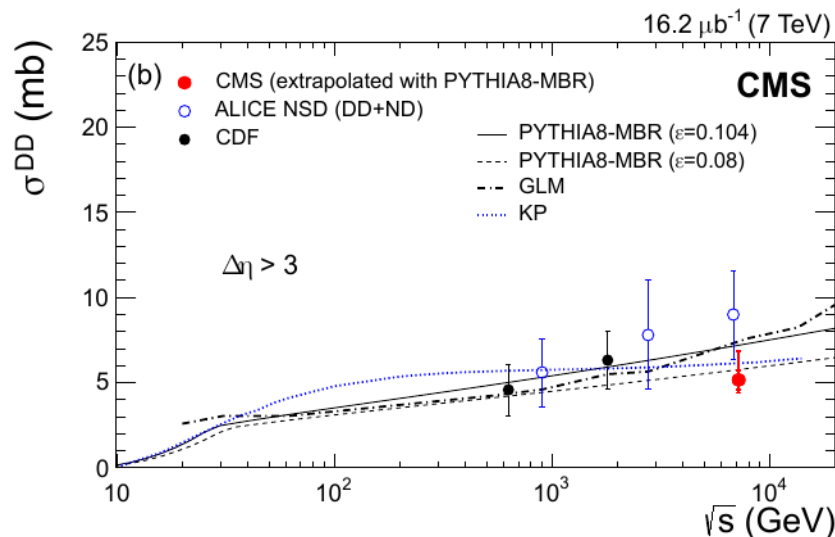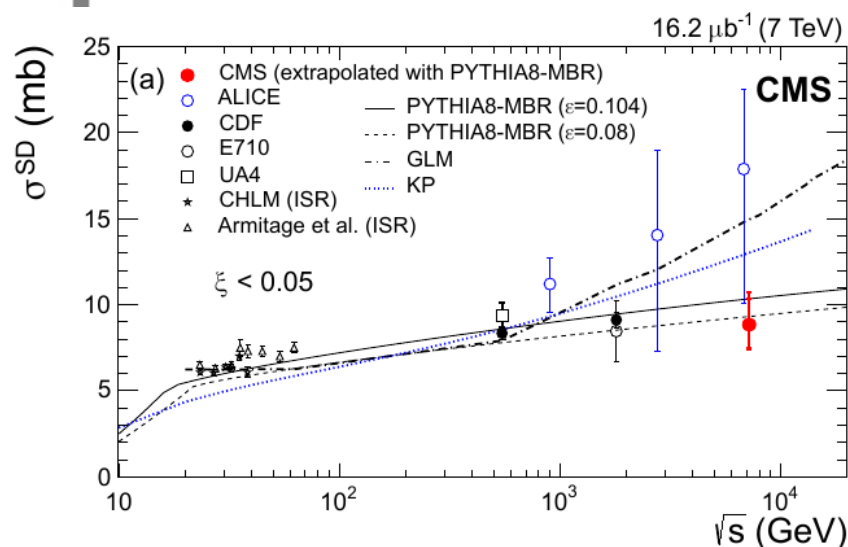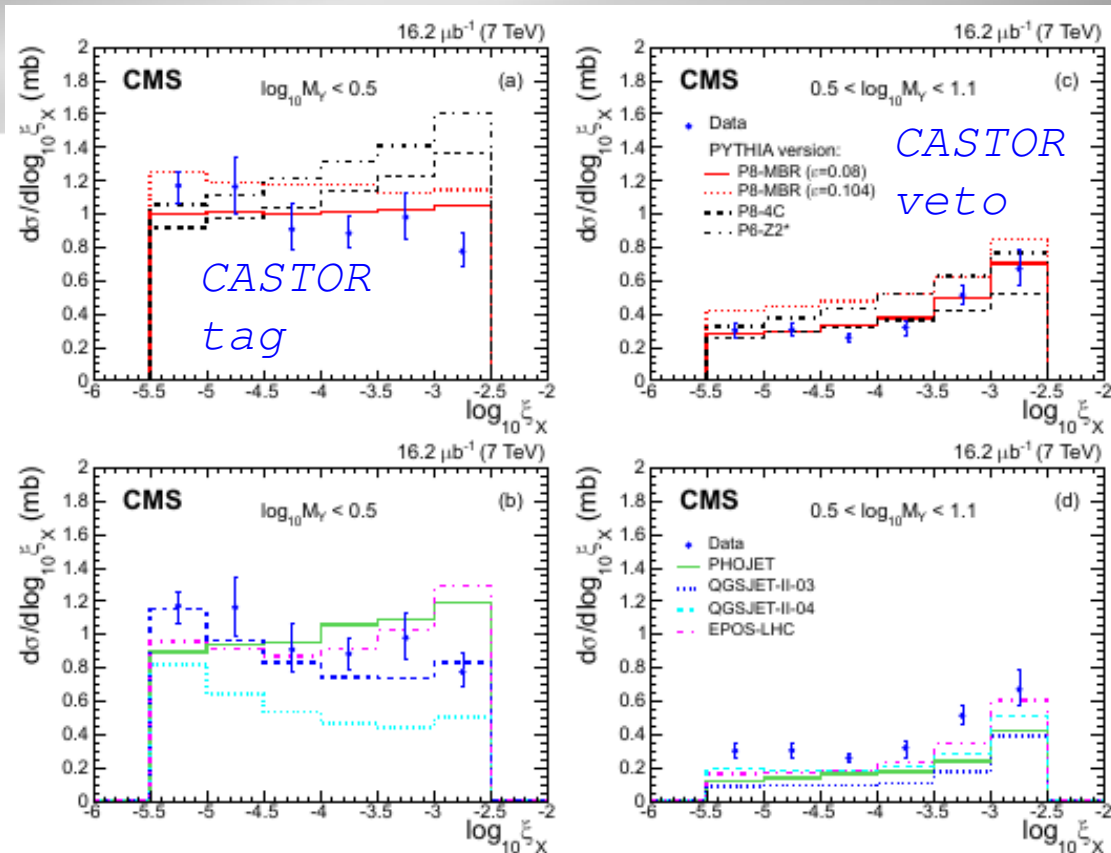$\xi = M_x^2/s$ ← $\tilde{\zeta} = \dfrac{\sum(E^i + p_z^i)}{\sqrt{s}}$,

→ **corrected x-section**

"SD" sample:

Extrapolation: Pythia-MBR ε=0.08

$\sigma^{SD} = 8.84 \pm 0.08\,(\text{stat})^{+1.49}_{-1.38}\,(\text{syst})^{+1.17}_{-0.37}\,(\text{extrap})\,\text{mb}$

$\xi < 0.05$

$\sigma^{DD} = 5.17 \pm 0.08\,(\text{stat})^{+0.55}_{-0.57}\,(\text{syst})^{+1.62}_{-0.51}\,(\text{extrap})\,\text{mb}$

$|\eta| > 3$

CASTOR tag

CASTOR veto

Data: **sqrt(s) = 13 TeV, CMS@0T,** PU $\lesssim$ 5%
ZeroBias events (BPTX trigger)
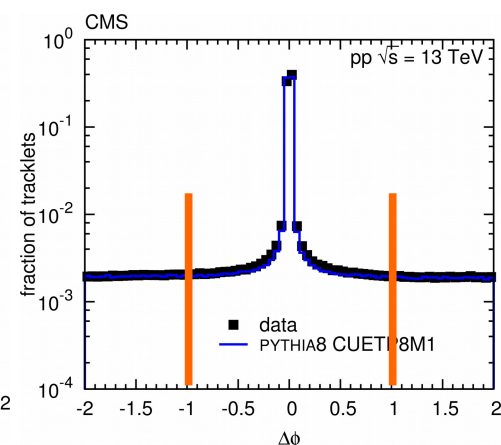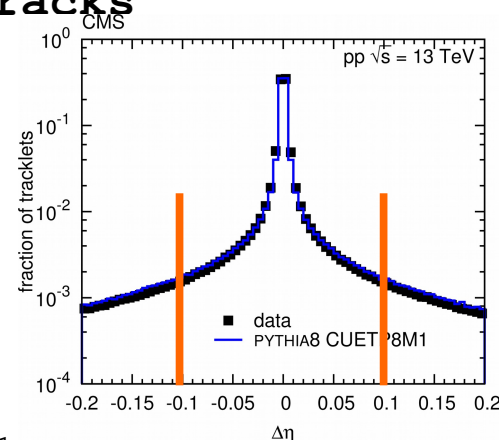
Tracks: **pixel (3 layers) based tracks**

Tracklet:

use feature of straight tracks: find a combination of two hits in different layers of pixel
Sensitive to tracks pT > 40 MeV
|η|<2
+ tracklet-based vertexing
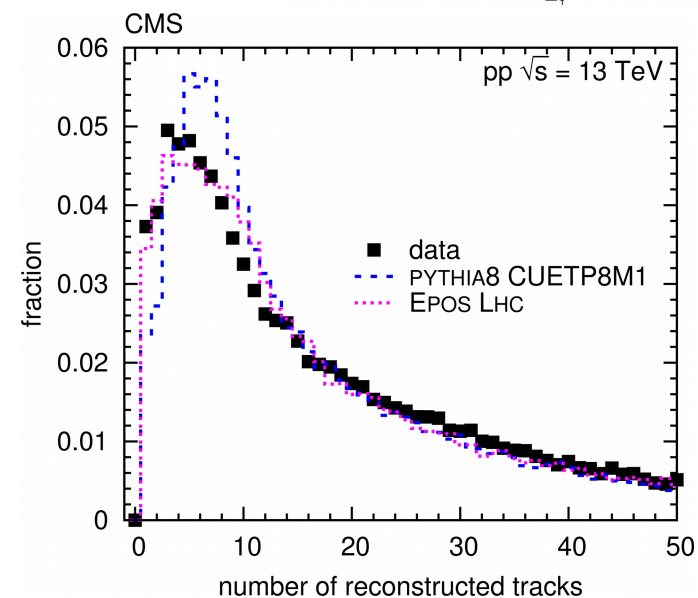+ corrections using PYTHIA8 CUETP8M1

Tracks from pixel hits triplets:

three aligned hits fitted to a straight line

|η|<1.8, |z0|<20cm
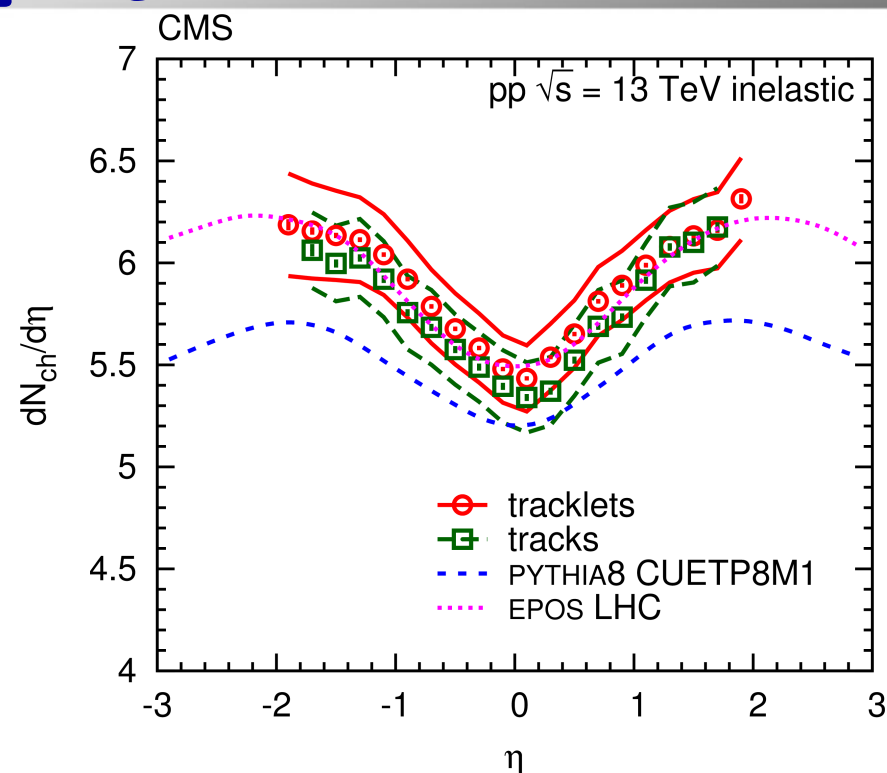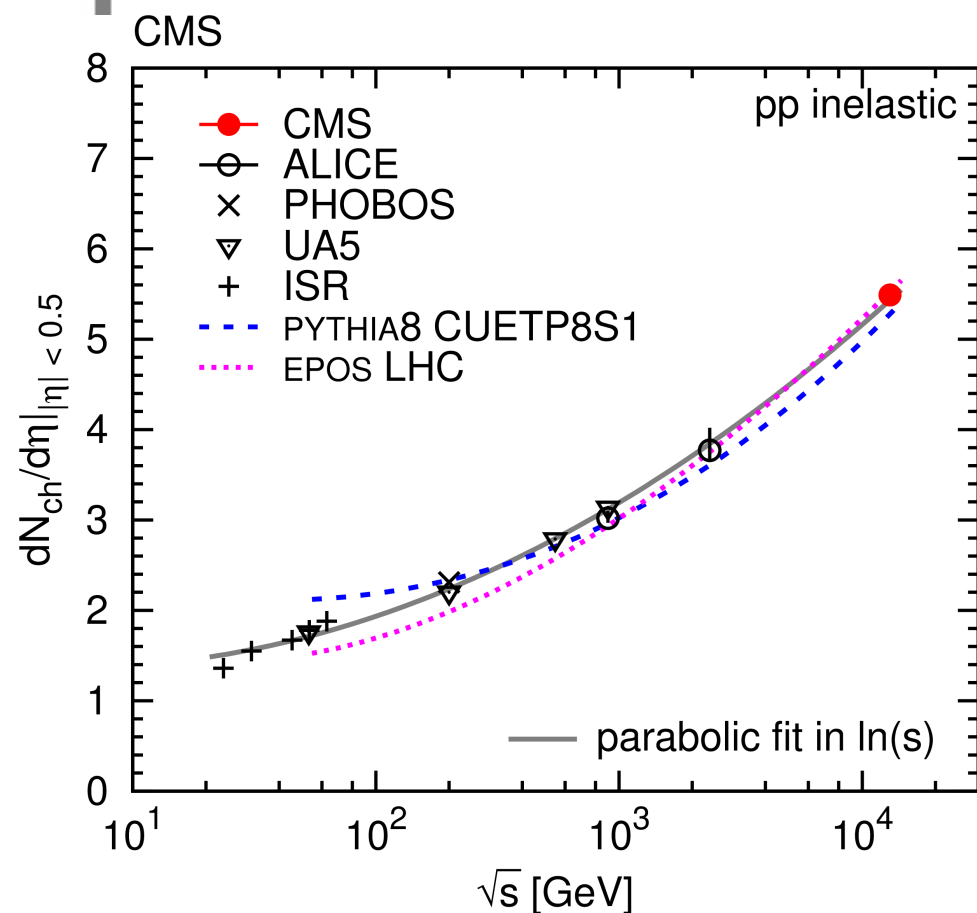*Good performance for pT > 50 MeV*
+ vertexing
+ corrections

Inelastic event selection efficiency 86-90%

Charged particles multiplicity @ 13 TeV

Good agreement between the two approaches and EPOS-LHC

CMS
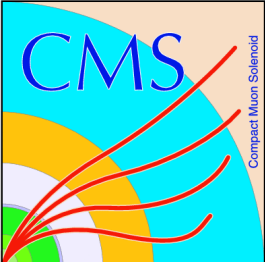
pp $\sqrt{s}$ = 13 TeV inelastic

tracklets
tracks
PYTHIA8 CUETP8M1
EPOS LHC

$dN_{ch}/d\eta$

η

CMS

pp inelastic

- ● CMS
- ○ ALICE
- × PHOBOS
- ▽ UA5
- + ISR
- - - PYTHIA8 CUETP8S1
- ⋯ EPOS LHC

parabolic fit in ln(s)

$dN_{ch}/d\eta|_{|\eta| < 0.5}$

$\sqrt{s}$ [GeV]

Inelastic events:

dNch/dη(|η|<0.5) = 5.49

± 0.01(stat)

± 0.17(syst)

- **Excellent CMS performance allows a wide range of (soft) QCD studies**
  - forward instrumentation (optional, **at special runs**)
  - possible combination with TOTEM data (**at special runs**)
    - very inclusive MinBias trigger
    - extended tracking acceptance with T2
      (e.g. $dN_{ch}/d\eta$ measurements for extended η region, 2012)
    - TOTEM Roman Pot taggers

- **Underlying events, MPI studies (RunI)**
  - track-jets allows to go down to low PT values

- **Inclusive diffractive cross-section (RunI)**

- **Charged particle multiplicities at 13 TeV**
  - **first LHC RunII publication!**

- **Looking forward for more data from RunII also in common CMS-TOTEM data-taking**

Backup
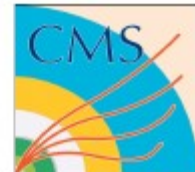
Data: Low-PU (~0.04) 2012 data at sqrt(s)= 8 TeV; special run (β*=90m)

Trigger: T2(TOTEM)MinBias trigger -> CMS: 5.3<|η|<5.6

Online time synchronization -> offline data merging (event-by-event)

Selection:

T2: inclusive   (≥1tr OR)
    NSD-enhanced (≥1tr AND)
    SD-enhanced (!(≥1tr AND))
    p_t>40 MeV   (performance)

CMS: good vertex (>1 tr)
    tracks:
        high purity
        quality + |η|<2.2
        p_t>100 MeV

+ corrections + extrapolation to p_t=0 (MC)

SD-enchanced: 26% of inclusive; contains ~50% NSD (MC)

Uncertainties:

TOTEM:

Source	Inclusive	NSD-enhanced	SD-enhanced
Event and primary track selection ($C_{sel}(\eta)$)	3–5%	4–6%	9–16%
Tracking efficiency	3.9%	3.9%	3.9%
Trigger efficiency	0.1%	0.1%	0.1%
Model dependence	1–4%	1–4%	1–4%
Correction to $p_T = 0$	0.2%	0.2%	0.2%
Statistical	0.1%	0.1%	0.1%
Total	5–7%	6–8%	10–17%

CMS:

Source	Inclusive	NSD-enhanced	SD-enhanced
Tracking efficiency data-MC discrepancy	5–6%	5–6%	5–6%
Primary selection (including alignment)	4–5%	4–5%	4–5%
Non-primaries in the double-Gaussian peak	5%	5%	5%
Material effects	3–6%	3–6%	3–6%
High-multiplicity events	3%	3%	3%
Event selection	2–3%	2–3%	13–15%
Tracking efficiency dependence on energy spectrum and magnetic field	2%	2%	2%
Track quality criterion	1%	1%	1%
Correction to $p_T = 0$	0.5%	0.5%	0.5%
Trigger efficiency	0.2%	0.2%	0.2%
Statistical	0.1%	0.1%	0.1%
Total (after averaging half-arms)	10–12%	10–12%	16–18%

NSD enhanced at mid rapidity:
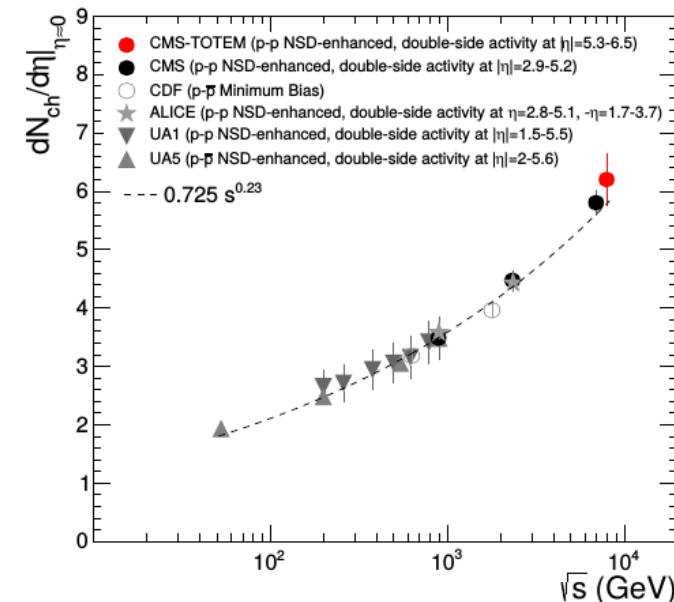
No MC for the whole η region and all subsets
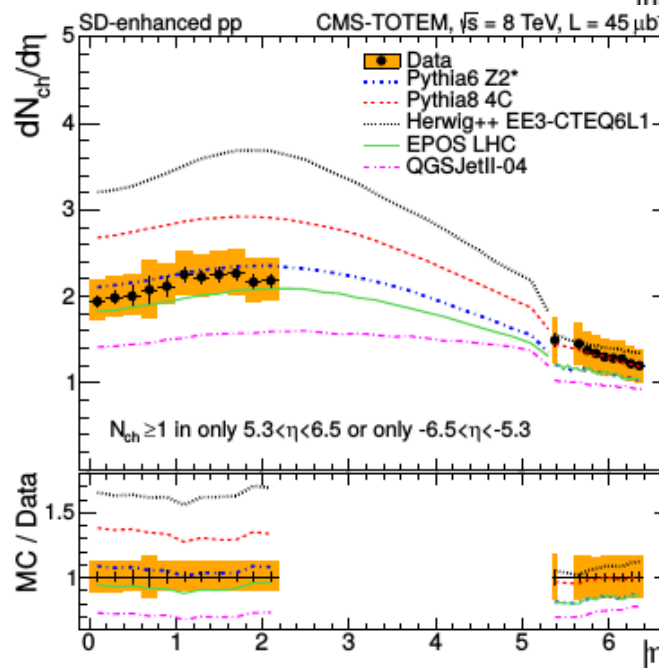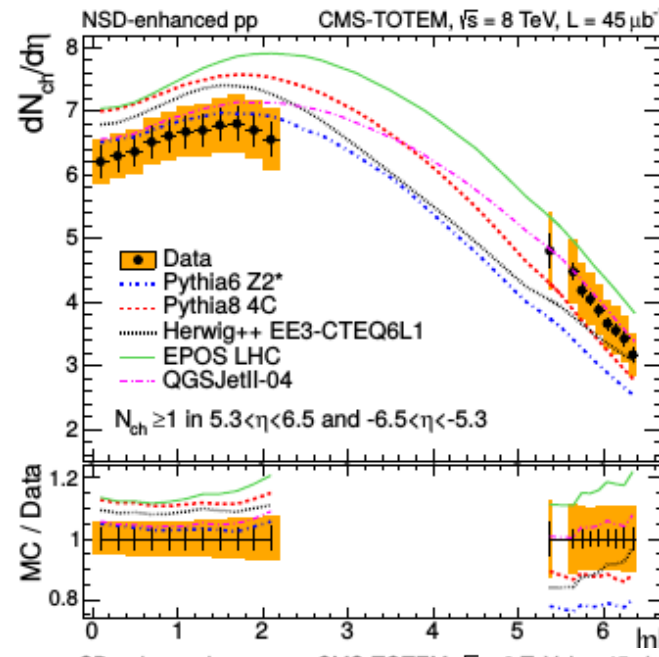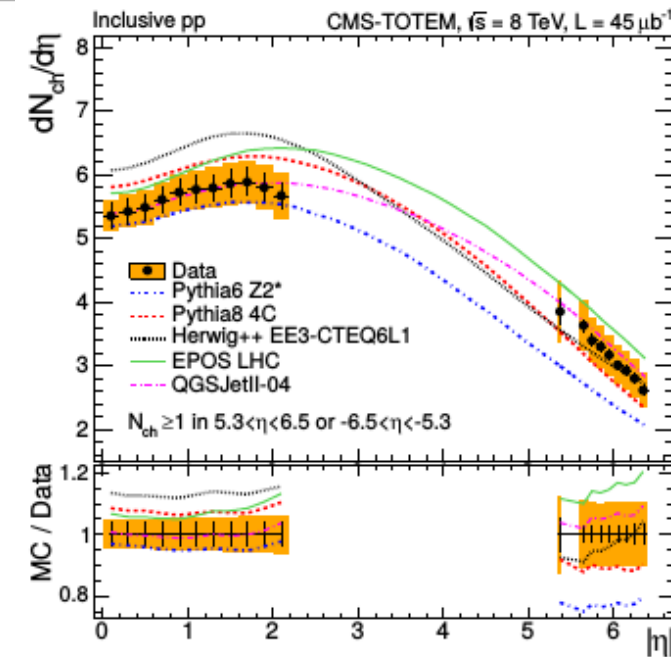
Soft diffractive x-section

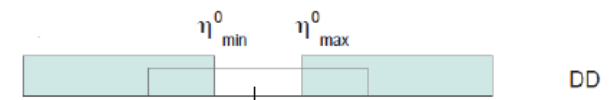**Data:**   **Low-PU (~0.14) 2010 data at sqrt(s)= 7 TeV**
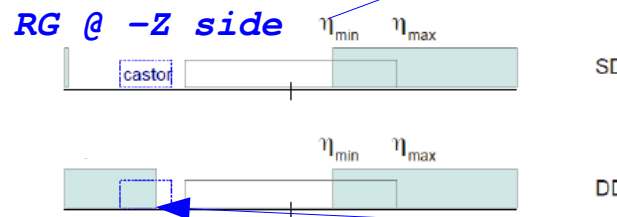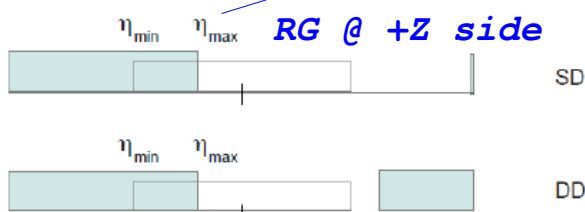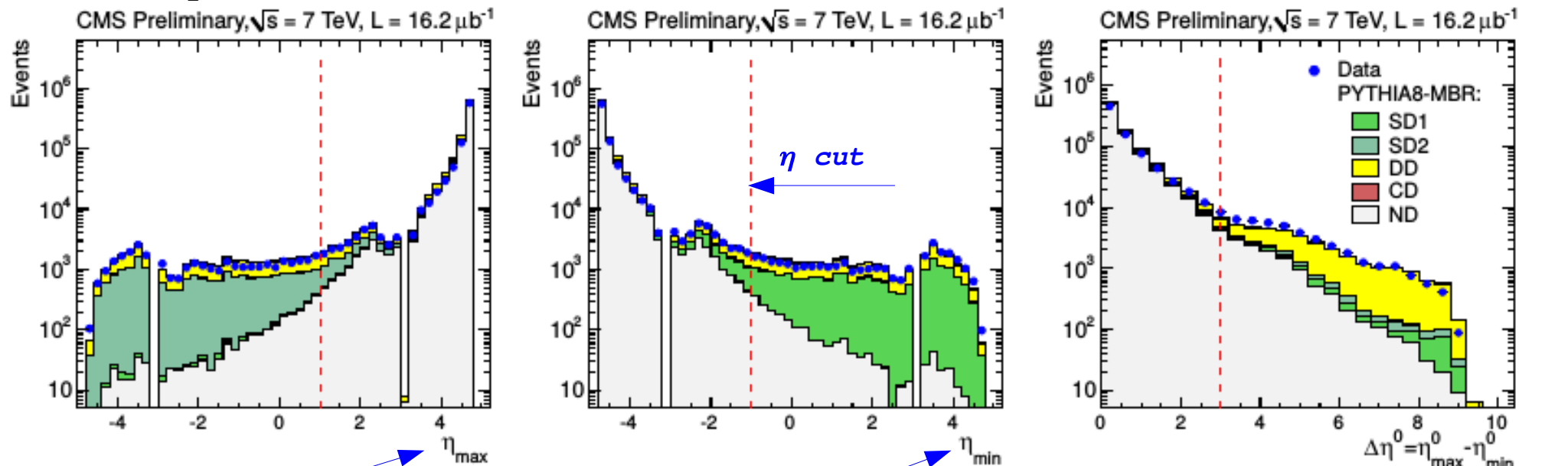
Selection: **MinBias with BSC (~total inelastic sample) + LRG topology**

     At least 2 particle candidates in the BSC acceptance $|\eta|<4.7$

     No vertex requirement ($M_x<100$ GeV)

MC: Pythia8+Minimum Bias Rockfeller model based on renormalized Regge model

     Pythia8-4C

Soft diffractive x-section

MC (gen. level): η **cut (SD)**

CASTOR tag (DD)

3.2 < M_Y < 12 GeV

12 < M_X < 394 GeV
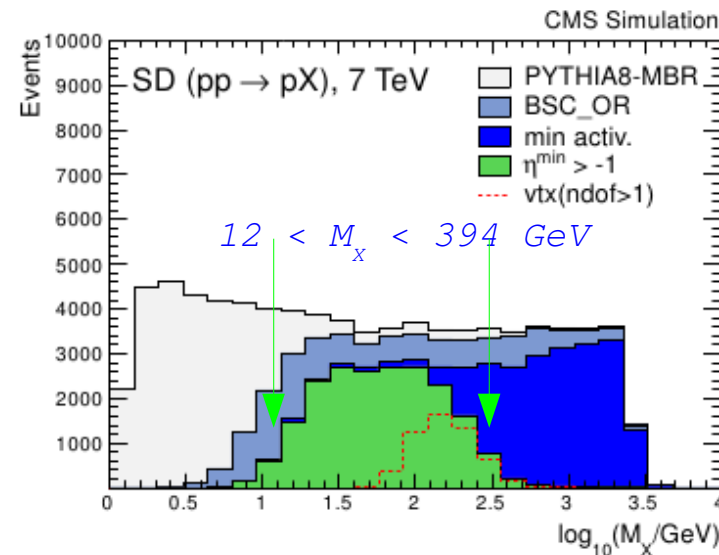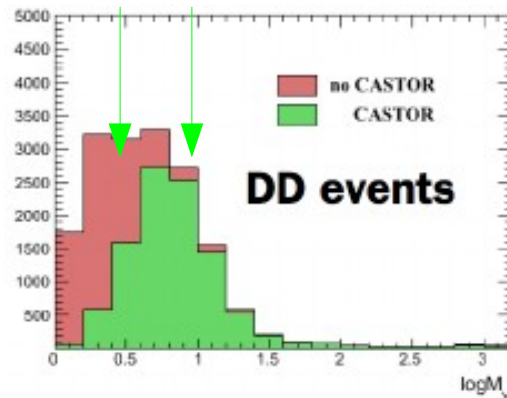
DD MC (gen. Level); selection efficiency
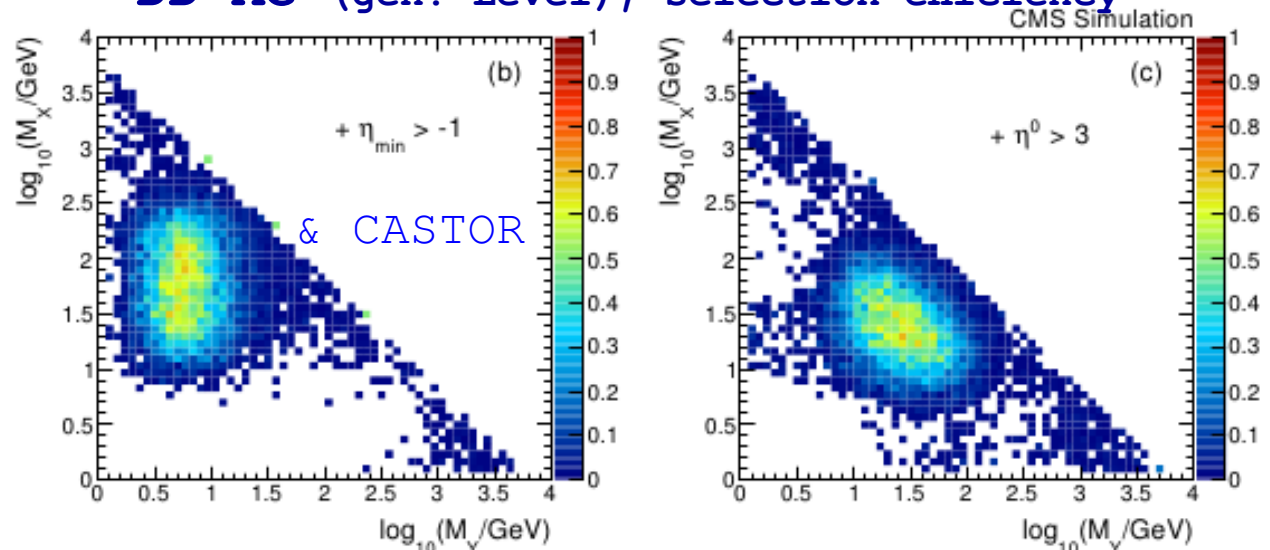
& CASTOR

$$\xi = M_x^2/s \quad \longleftarrow \quad \xi = \frac{\sum(E^i + p_z^i)}{\sqrt{s}}$$
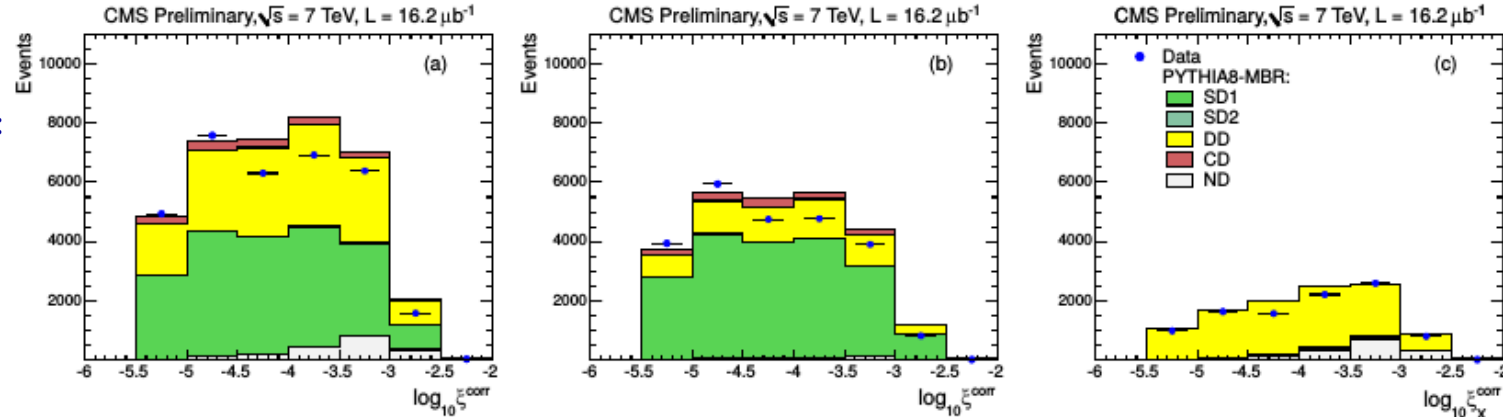
=> ξ **needs to be corrected for undetected particles**

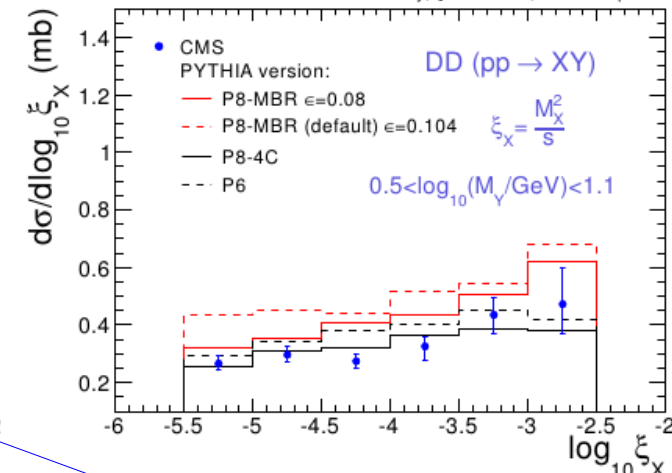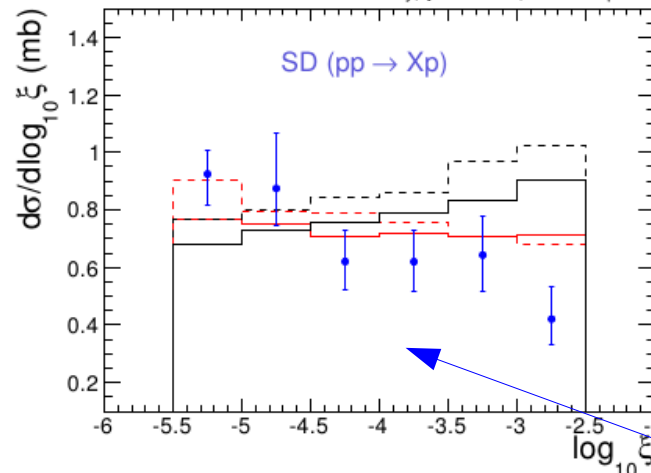**(a MC based ξ dependent correction)**
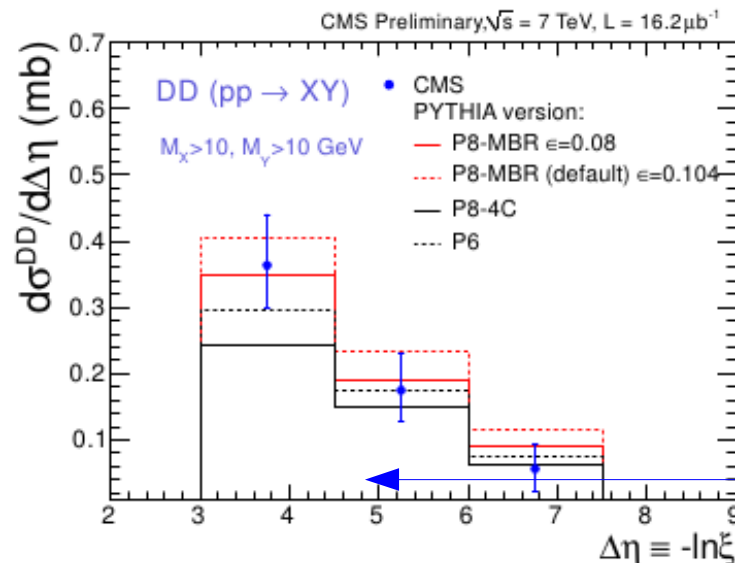
Soft diffractive x-section

Detector-level distribution ξ:

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

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

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

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

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

MBR – data:

good agreement

$\alpha_{IP}(0)$: 1.080 vs 1.104 (MBRdef)