

Soft and Hard Diffraction at 7 TeV observed with CMS

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On behalf of the CMS Collaboration

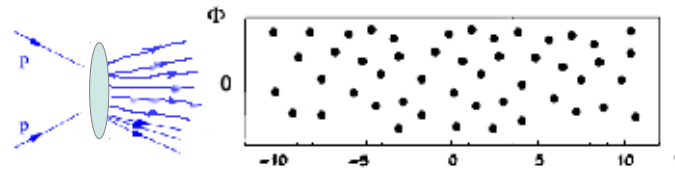
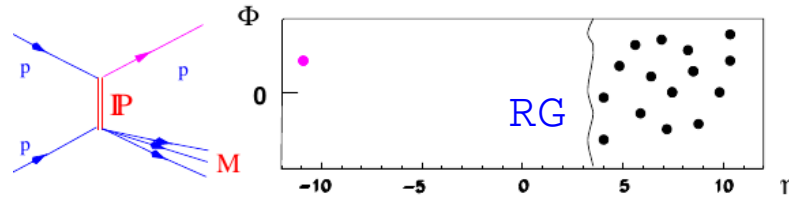
HSQCD 2016: Hadron Structure and QCD: from LOW to HIGH energies

*27 Jun-1 Jul 2016
Gatchina*

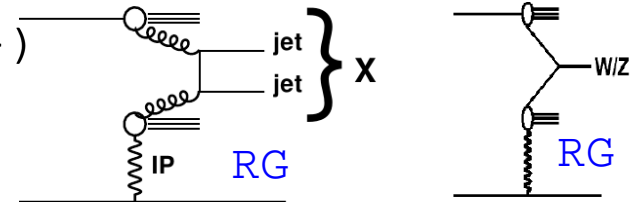
INTRODUCTION

Non-diffractive events

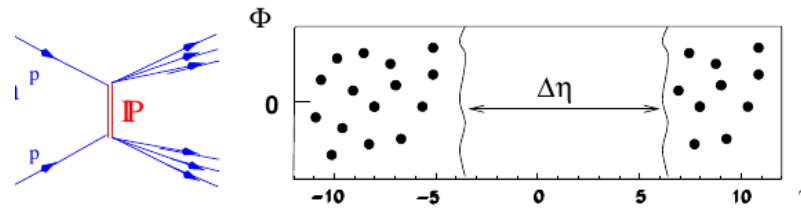
Single Diffraction



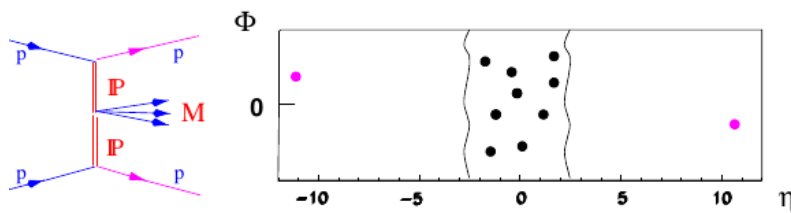
(semi -)
hard



Double Diffraction

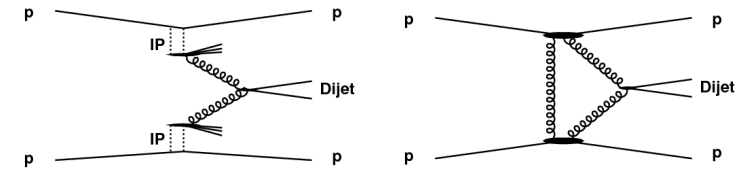


Central Diffraction (DPE)



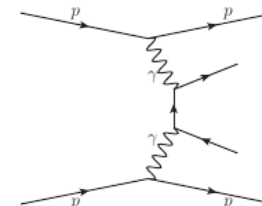
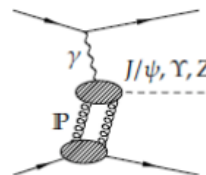
inclusive

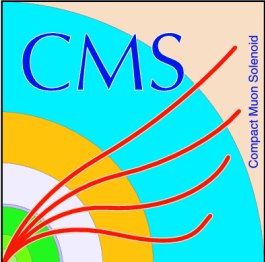
exclusive



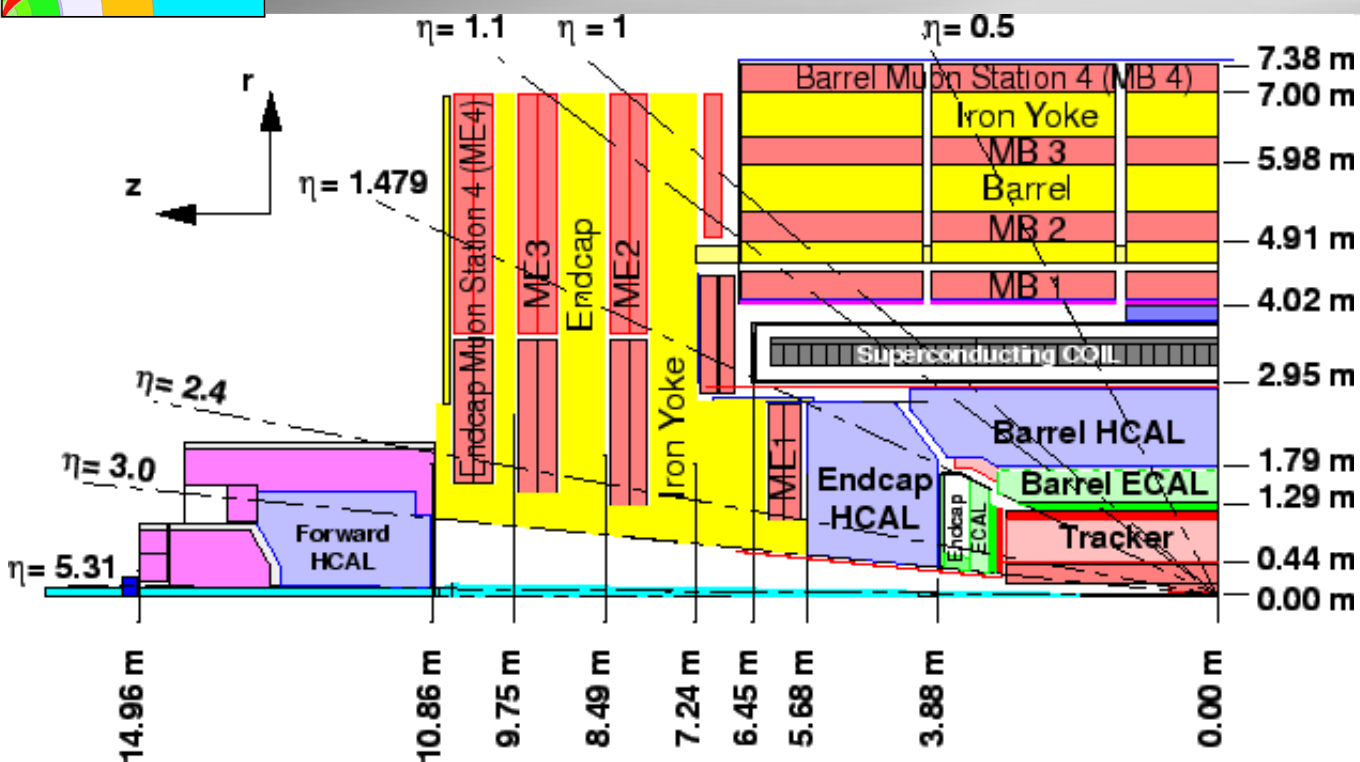
... central exclusive production ($\gamma\gamma$)

... photoproduction (γ -Pomeron)





CMS central detector



Muons

(CSC+DT+RPC)
 $|\eta| < 2.4$

Tracker

(Pixel+SiStrip)
 $|\eta| < 2.4; P_t > 100 \text{ MeV}$

ECAL

PbWO4: $|\eta| < 3$

HCAL

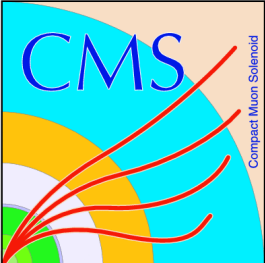
central: scint.+brass : $|\eta| < 3$
 $\Delta\eta \times \Delta\phi = 0.087 \times 0.087$

HF: steel+quartz : $2.9 < |\eta| < 5.2$
 $\Delta\eta \times \Delta\phi \sim 0.175 \times 175$

Castor

$-6.6 < \eta < -5.2$

Calorimetry + tracking → Particle Flow Objects



Soft diffractive x-section

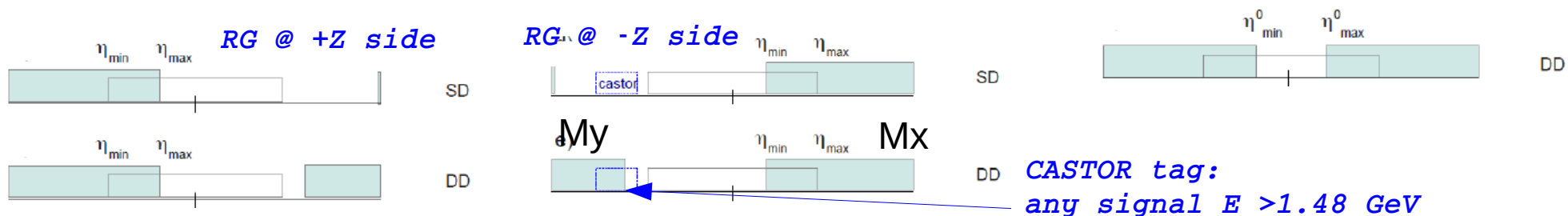
Data: Low-PU (~ 0.14) 2010 data at $\sqrt{s} = 7$ TeV

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

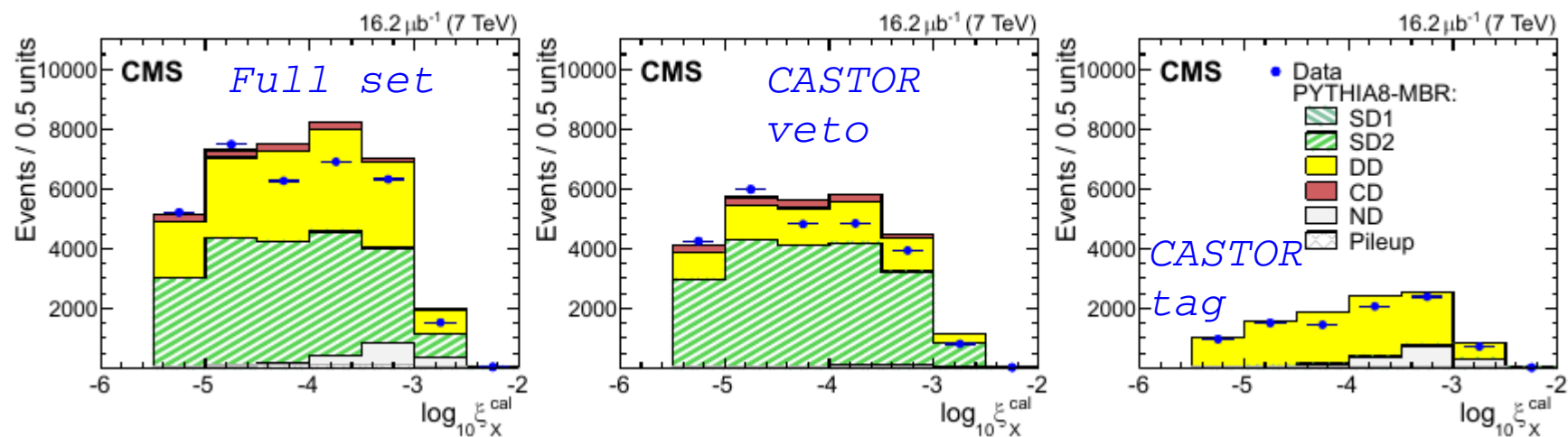
At least 2 particle candidates in the BSC acceptance $|\eta| < 4.7$

No vertex requirement ($M_x < 100$ GeV)

MC: Pythia8+Minimum Bias Rockefeller model based on renormalized Regge model
Pythia8-4C



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





Soft diffractive

x-section

Corrections from det.level:

$$\xi_x = M_x^2 / s \leftarrow \xi = \frac{\sum(E^i + p_z^i)}{\sqrt{s}}$$

→ corrected x-section

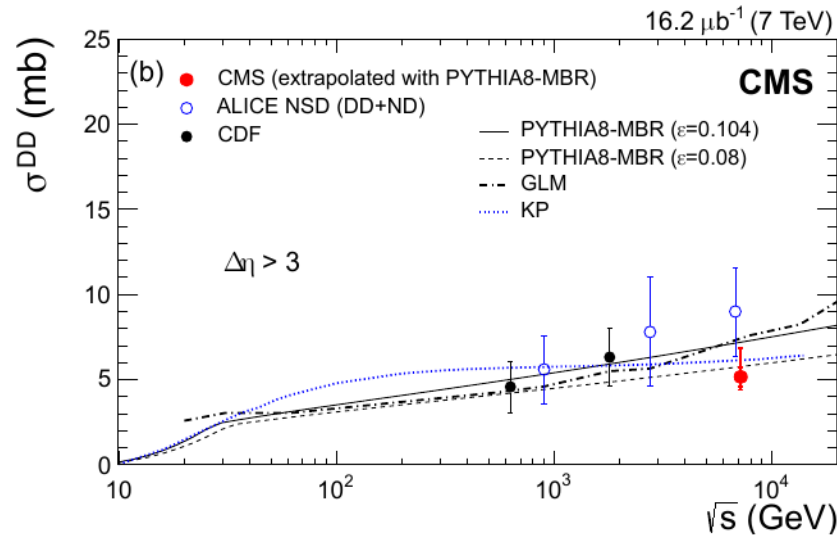
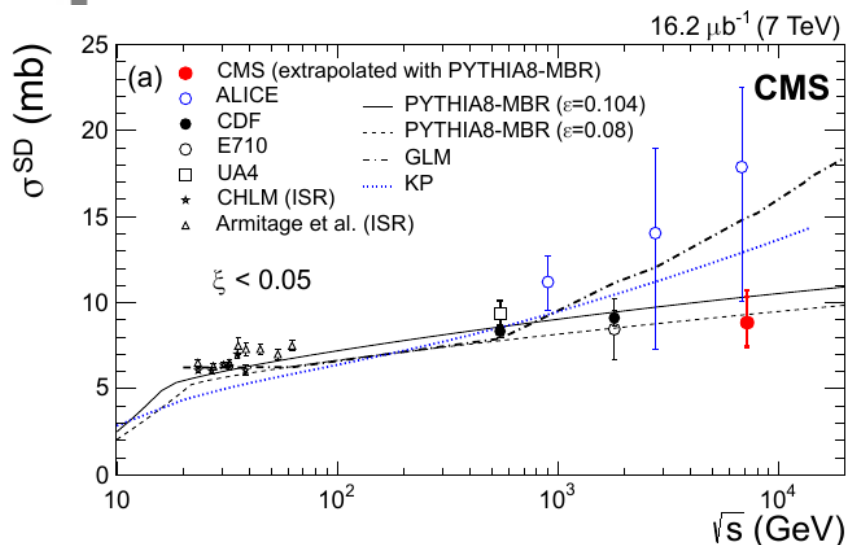
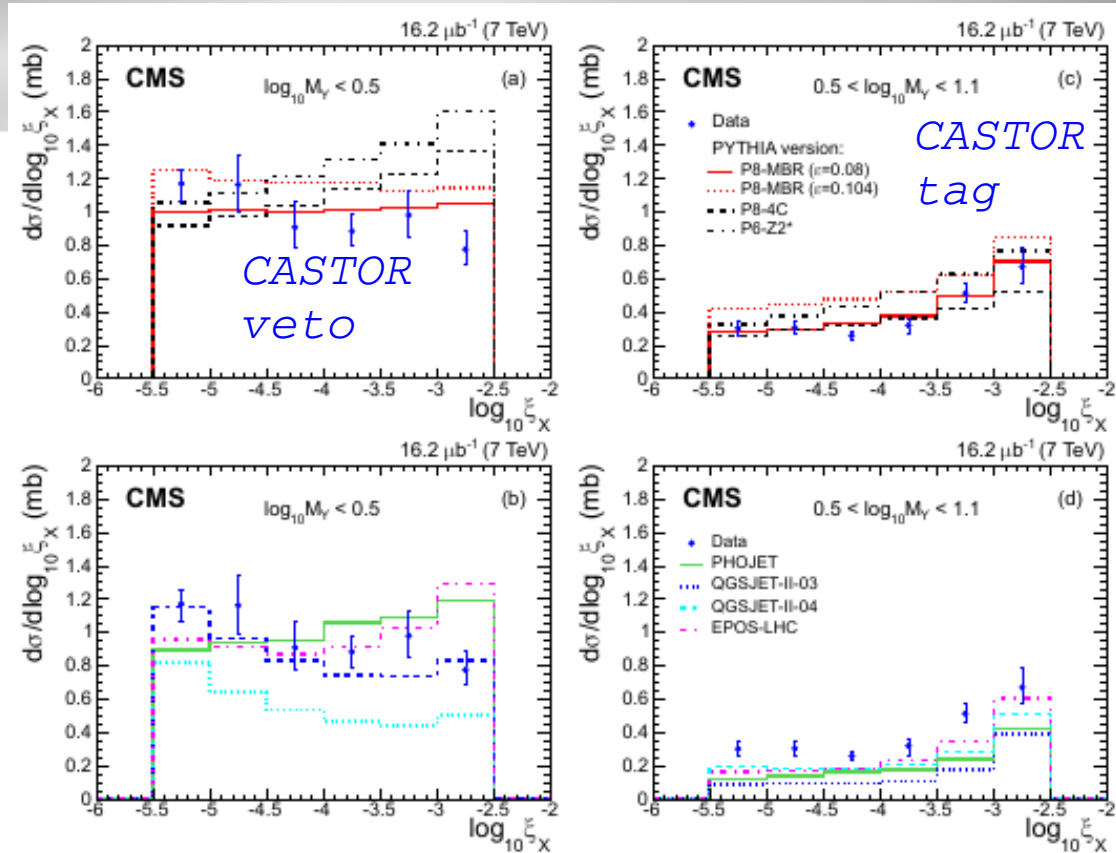
"SD" sample:

Extrapolation: Pythia-MBR $\epsilon=0.08$

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

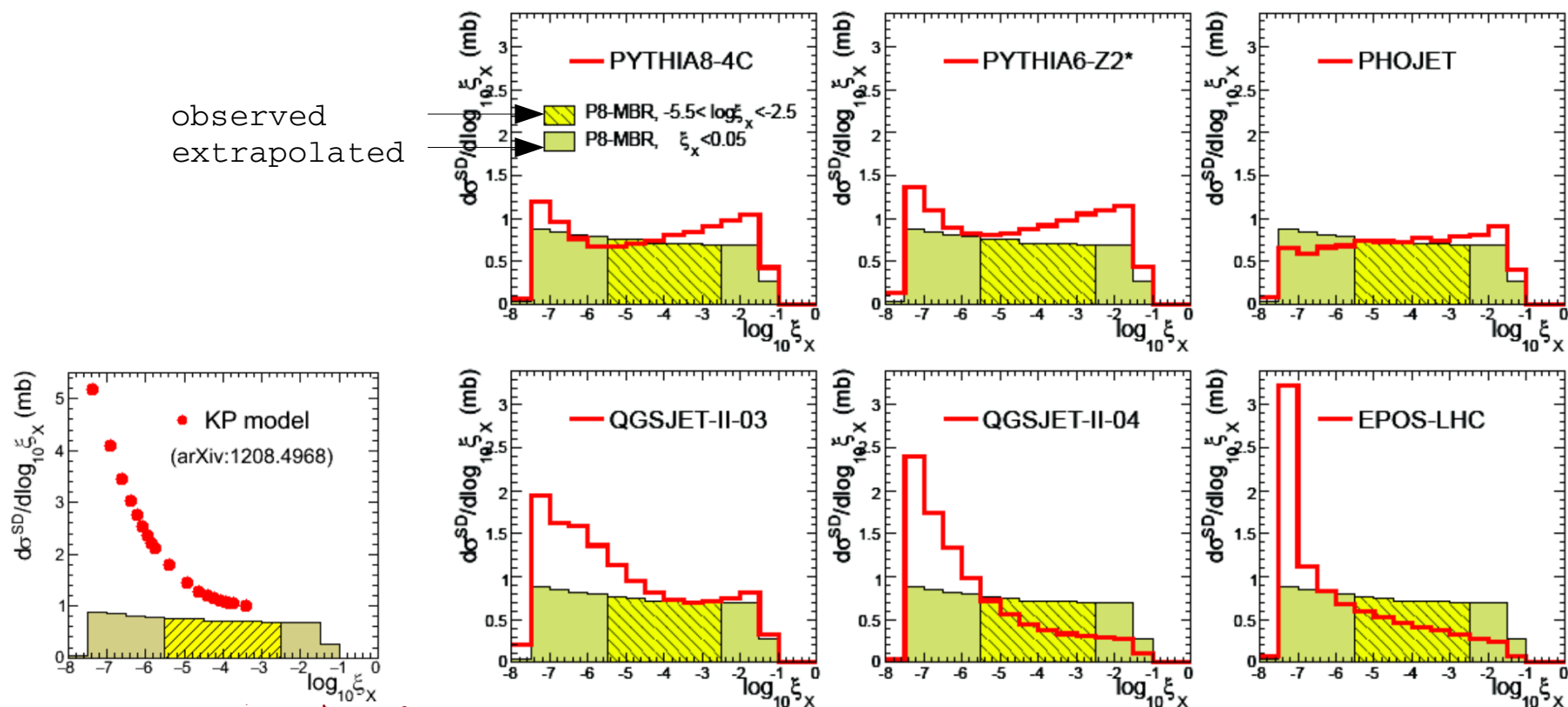
$$\sigma^{DD} = 5.17 \pm 0.08 \text{ (stat)}_{-0.57}^{+0.55} \text{ (syst)}_{-0.51}^{+1.62} \text{ (extrap)} \text{ mb}$$

$\xi < 0.05$
 $|\eta| > 3$

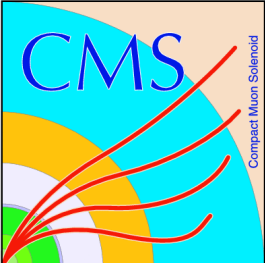


R.Ciesielski, comparison of different MC predictions:

(EDS-Blois, 2015)

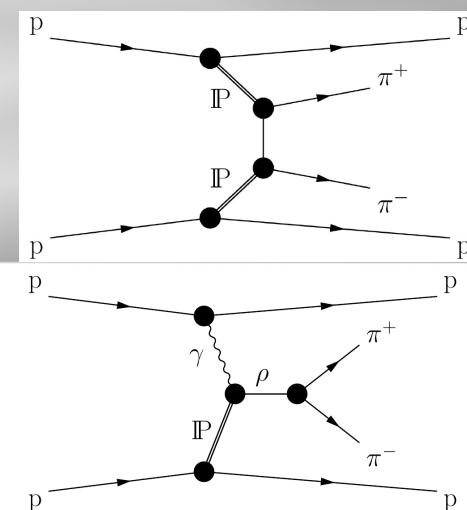


Large variation in MC predictions, especially for low ξ



Exclusive pions

FSQ-12-004

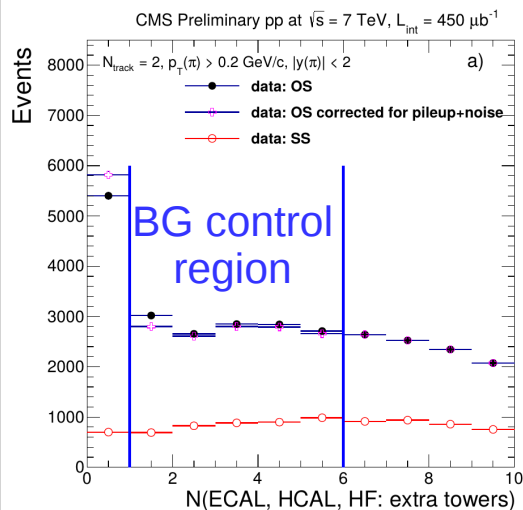


Data: Low-PU 2010 data at $\sqrt{s} = 7 \text{ TeV}$; 450 ub^{-1}

Trigger: ZeroBias (BPTX)

Selection: Two good tracks: $p_t > 0.2 \text{ GeV}$, $|y(\pi)| < 2$
+ veto on calorimeter towers

BG estimation: same sign tracks + accounting for bin migration



MC:

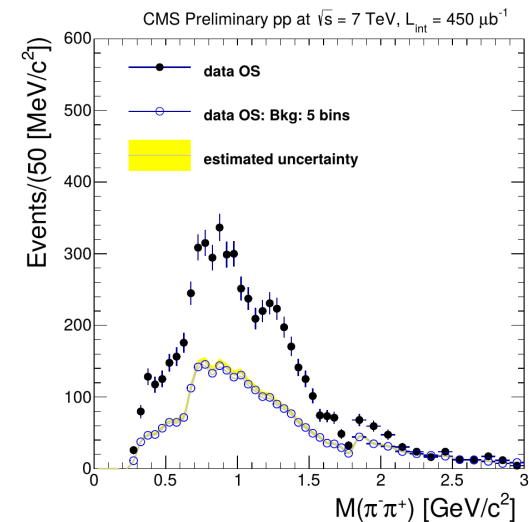
Pythia8-4C
Pythia8-MBR
(also account for SD+DD)
Starlight (γ IP only)
Dime MC (exclusive)

Hadron level thresholds:

Extra particles	pseudorapidity range	Veto threshold
Photons	$ \eta < 1.5$	$E < 0.52 \text{ GeV}$
Photons	$1.5 < \eta < 3.0$	$E < 2.18 \text{ GeV}$
Hadrons	$ \eta < 1.3$	$E < 1.18 \text{ GeV}$
Hadrons	$1.3 < \eta < 3.0$	$E < 1.95 \text{ GeV}$
Hadrons	$2.9 < \eta < 4.9$	$E < 4.0 \text{ GeV}$
Charged Particles	$ \eta < 2.4$	$p_T > 0.2 \text{ GeV}/c$

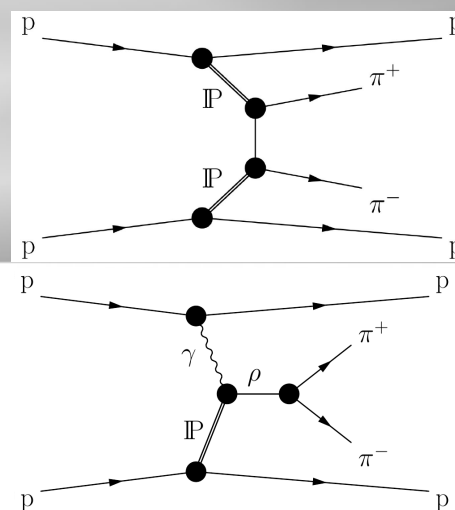
+ unfolding and PU correction

Resulting BG contribution and uncertainty level (as Pythia 4C vs MBR):



Exclusive pions

FSQ-12-004



Cross section:

Selected data corrected for instantaneous bunch-by-bunch luminosity:

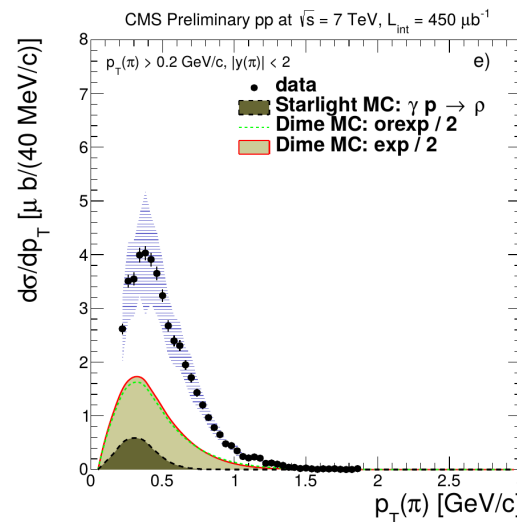
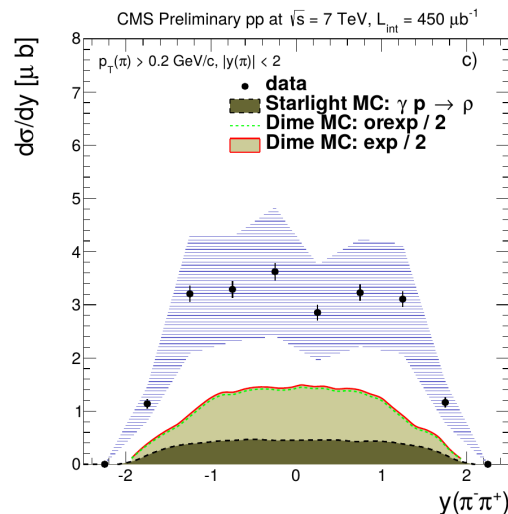
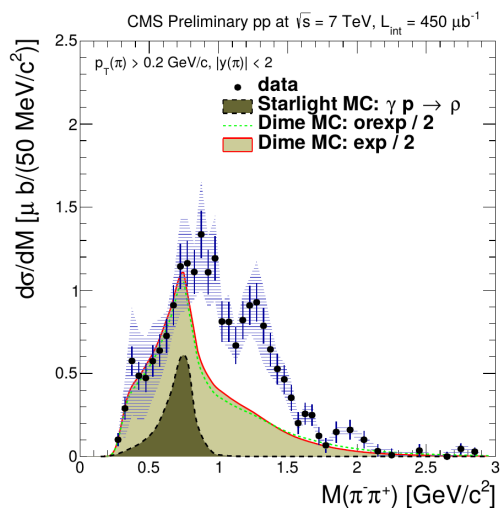
$$\varepsilon_{\text{excl}}(\mathcal{L}_{\text{bunch}}) = \frac{N_{\text{zero-bias}}^{\text{excl}}(\mathcal{L}_{\text{bunch}})}{N_{\text{zero-bias}}(\mathcal{L}_{\text{bunch}})} \approx e^{-\bar{n}} = e^{-\mathcal{L}_{\text{bunch}} \cdot \sigma_{\text{inelastic}} / f}$$

$\langle \varepsilon \rangle \sim 40\%$

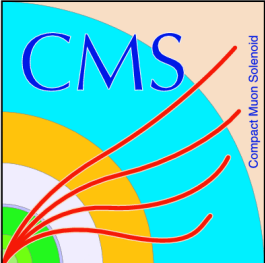
$$\sigma_{\pi^+\pi^-} = 20.5 \pm 0.3 \text{ (stat)} \pm 3.1 \text{ (syst)} \pm 0.8 \text{ (lumi)} \mu\text{b}$$

BG subtraction method gives ~20% of variation in x-section value

Differential cross section:

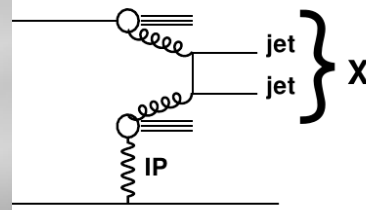


Starlight and Dime MC do not account for low-mass p-dissociation and for specific resonance production



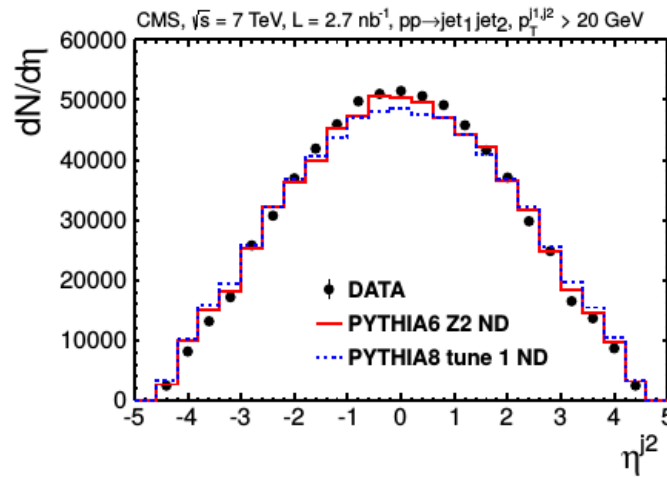
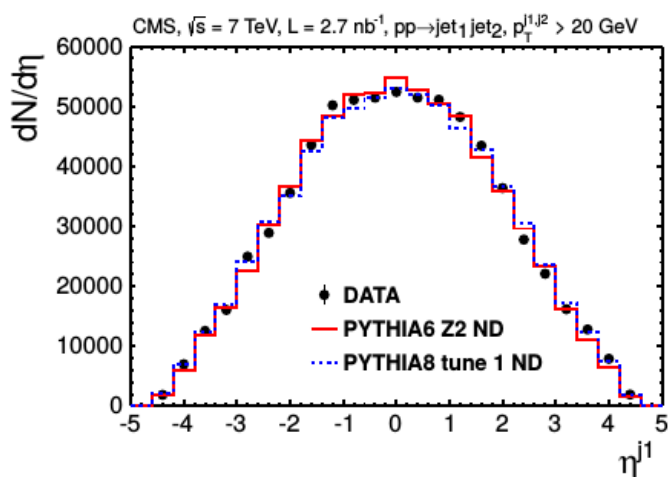
Hard diffraction -dijets

Phys. Rev. D 87 (2013) 012006

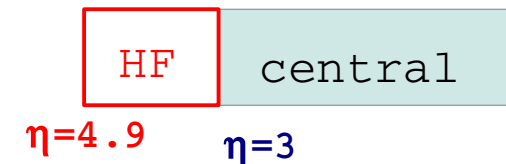
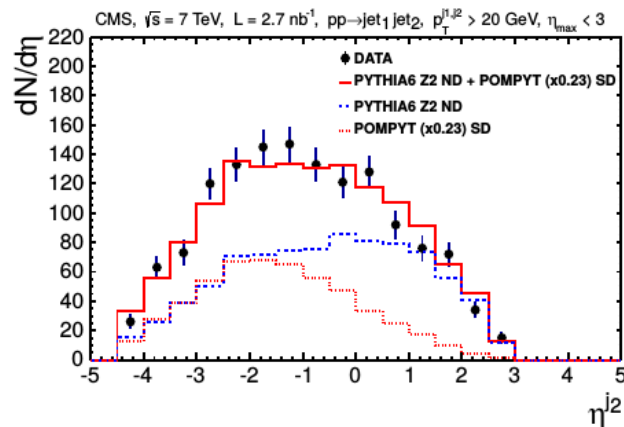
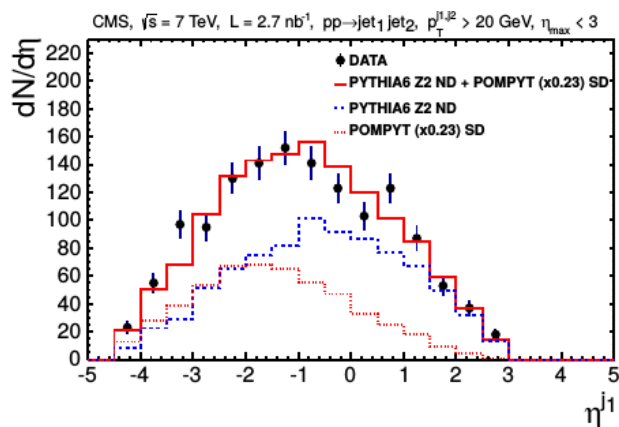


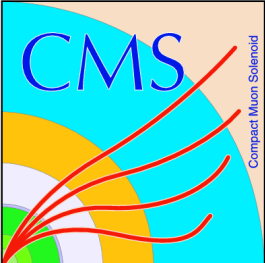
Low PU data; Event selection:

- Trigger: ≥ 1 jet: $P_t > 6 \text{ GeV}$
- good vertex && no beam BG
- ≥ 2 PFjets: $E > 0.2$ (4) Gev (central and HF jets), $P_t > 20 \text{ GeV}$, $|\eta| < 4.4$



+ LRG: most forward jet in the event to satisfy $\eta_{\max} < 3$ (or most backward $\eta_{\min} > -3$).





Hard diffraction - dijets

PRD 87 (2013) 012006 <http://arxiv.org/abs/arXiv:1209.1805> ; FWD-10-004

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

C-detector effect corrections ~ 1.45

Cross-section - data vs MC:

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

- PYTHIA 6, 8tune1 :non-diffractive
- POMPYT, POMWIG :SD with HERA dPDF and tune
- PYTHIA8 :SD+DD with HERA dPDF
- POWHEG : NLO

Data/MC - estimates for RG survival probability (after correction)

0.21 ± 0.07 from POMPYT and POMWIG

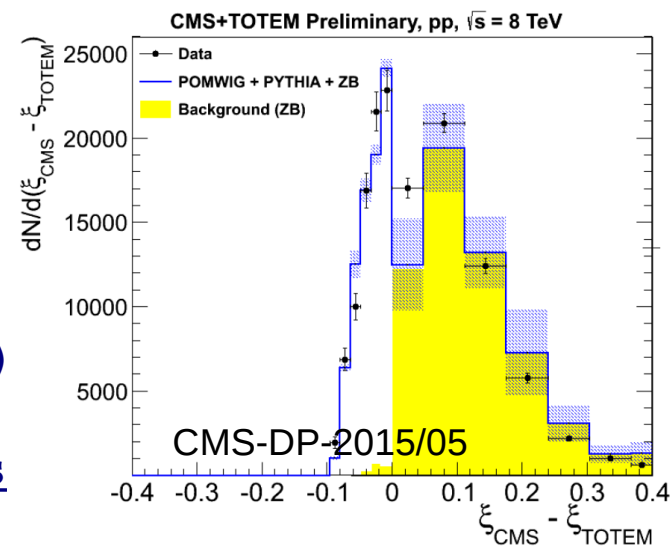
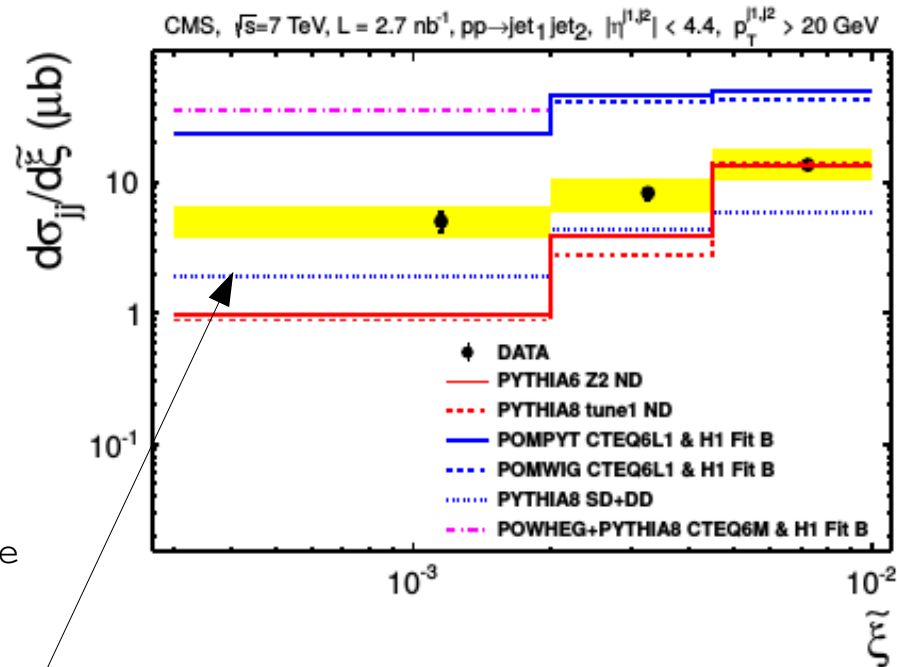
$\Rightarrow \langle |S^2| \rangle = 0.12 \pm 0.05$

0.14 ± 0.05 from POWHEG

$\Rightarrow \langle |S^2| \rangle = 0.08 \pm 0.04$

**CMS+TOTEM (8 TeV, special $b^*=90m$ run in 2012)
Proton tagging with RP**

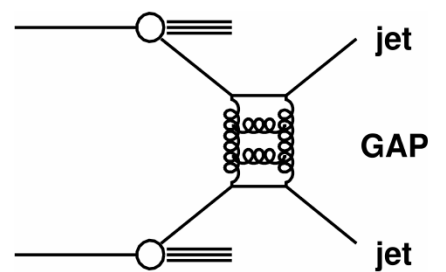
- ongoing analysis





Hard diffraction - jet-gap-jet

CMS-FSQ-12-001

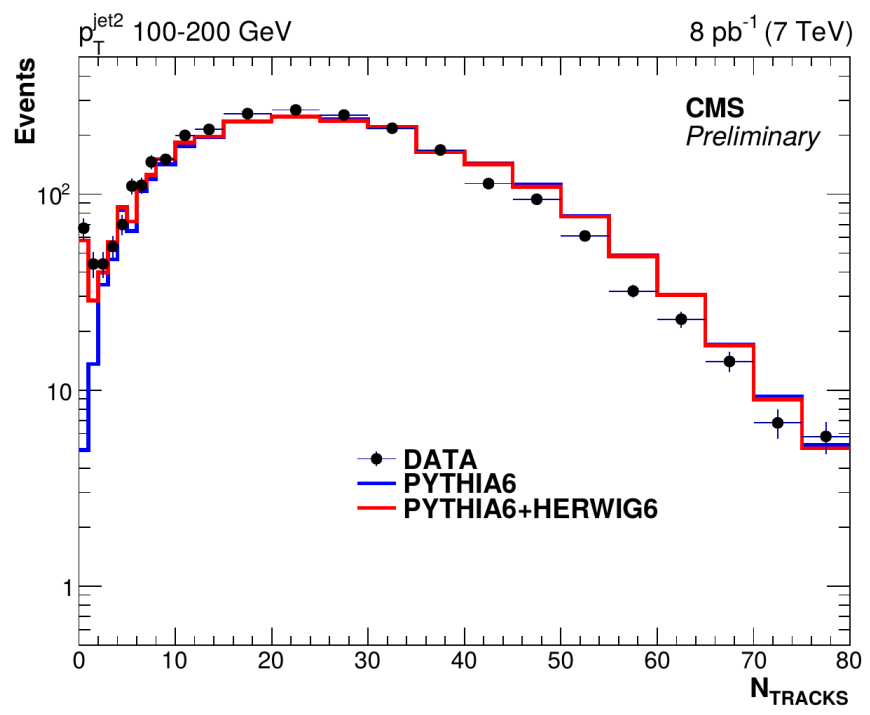


Colour singlet exchange - BFKL dynamics

Data: 8pb^{-1} at $\sqrt{s} = 7\text{ TeV}$

Selection: 0 or 1 vtx, 2 jets with $p_t > 40\text{ GeV}$ and $|\eta_{1,2}| > 1.5$

Observable: charged particles multiplicity in the gap

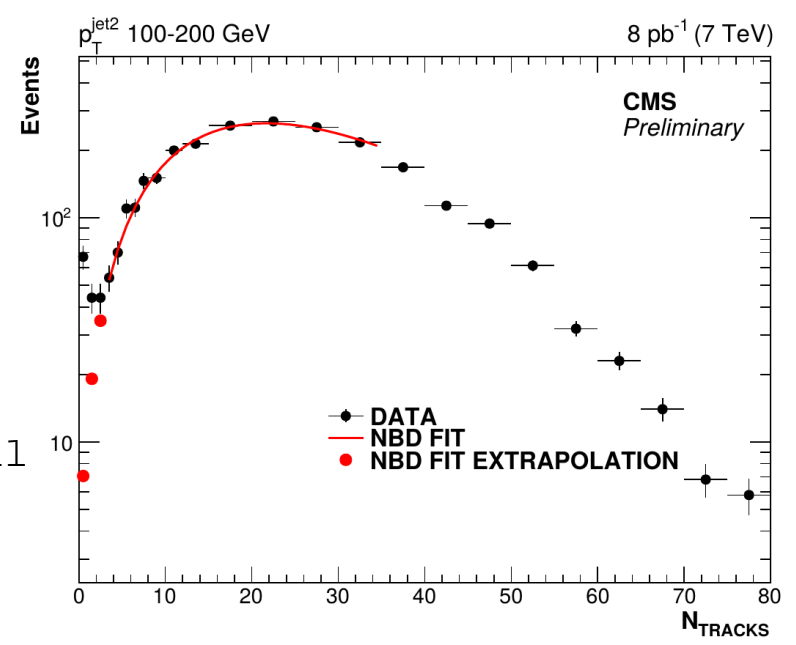


Pythia6 - LO DGLAP

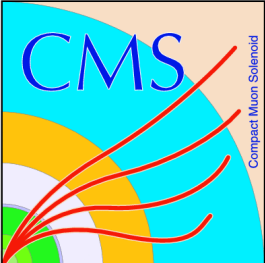
Herwig6 - LL BFKL (Mueller-Tang)

Gap events - Pythia+Herwig

Background estimation:

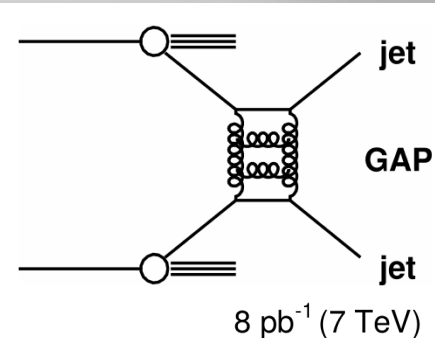


$N_{BG}(0)$: Negative Binomial Distribution fit extrapolated to $N=0$



Hard diffraction - jet-gap-jet

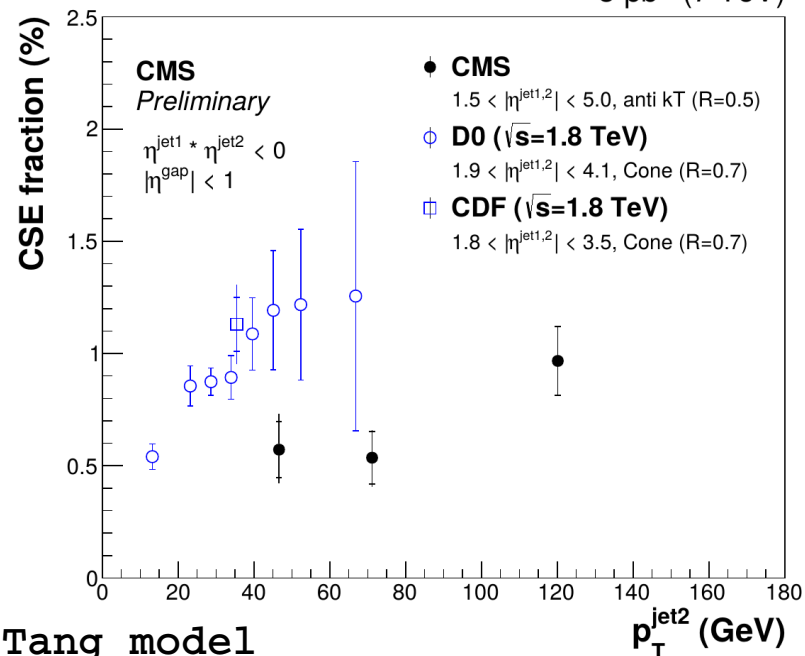
CMS-FSQ-12-001



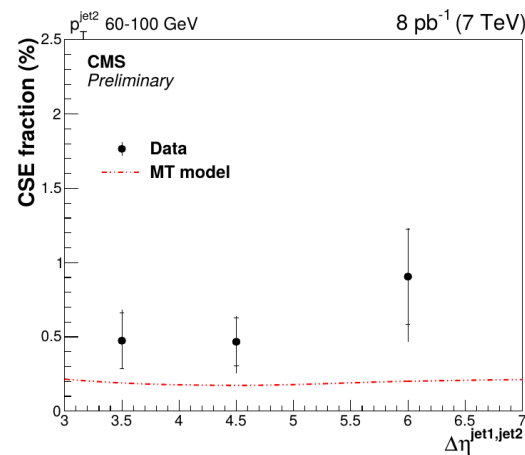
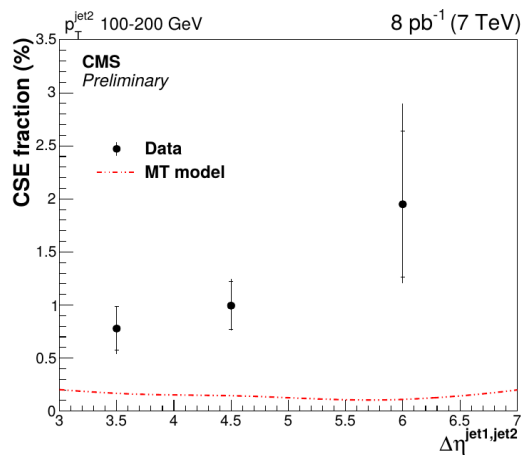
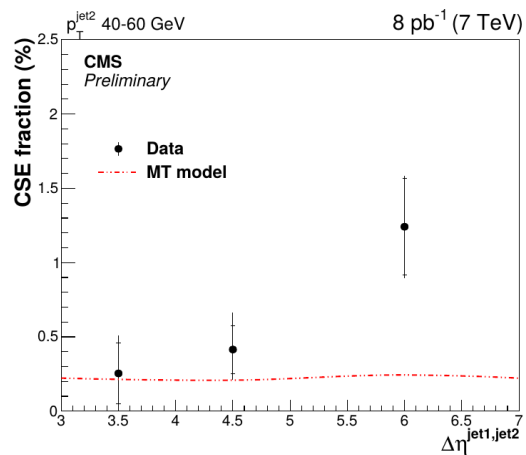
$$N(\text{CSE}) = N(0) - N_{\text{BG}}(0)$$

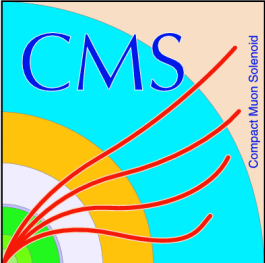
$$\text{CSE fraction} = N(\text{CSE})/N$$

- Comparison to CDF/D0 @1.8 TeV:
Suppression ~ factor 2
- CDF/D0 observation for 0.63 and 1.8 TeV:
Decrease of CSE fraction with p_T

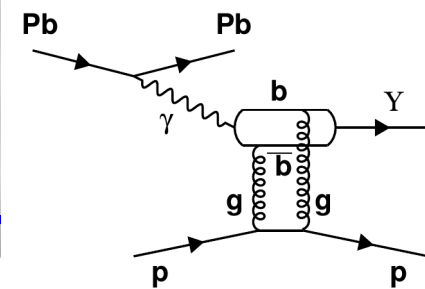


- CSE fraction vs gap size: data vs Mueller-Tang model





Exclusive Υ photoproduction in pA



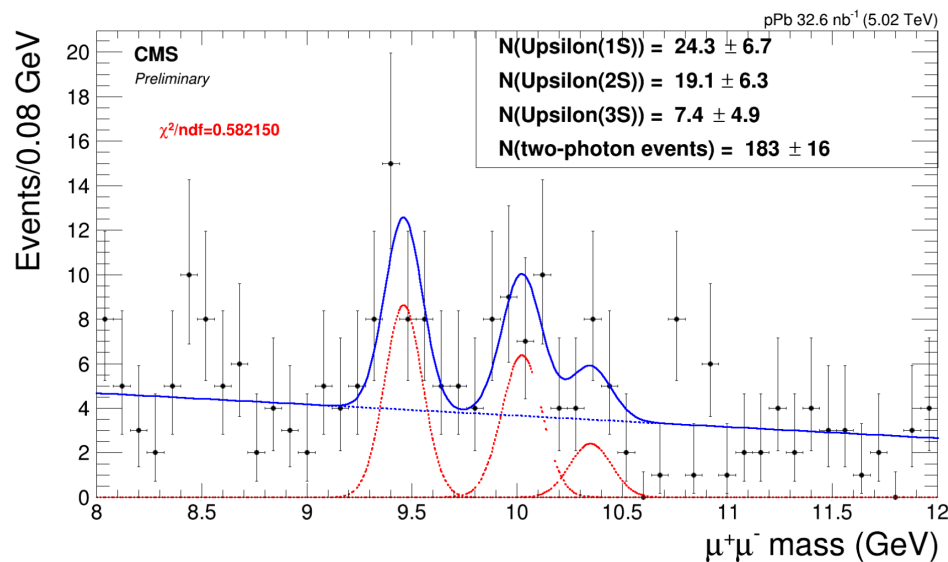
Data: 32.6 nb⁻¹ at sqrt(NN) = 5.02 TeV

Selection: 1 vtx, two OS muons:

$p_t(\mu) > 3.3$ GeV; $|y(\mu)| < 2.2$; $p_t(\mu\mu) : [0.1-1.0]$ GeV;

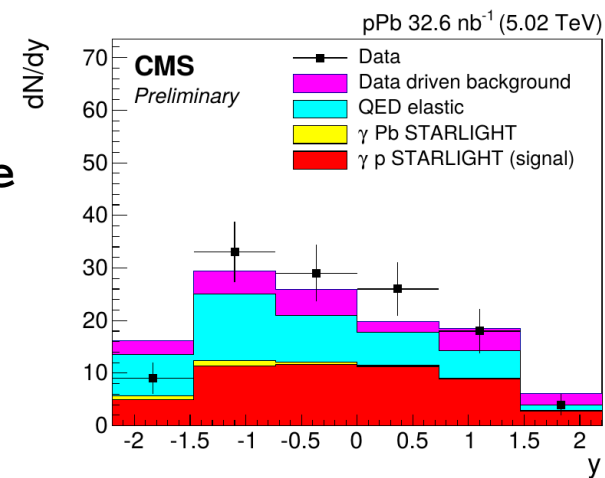
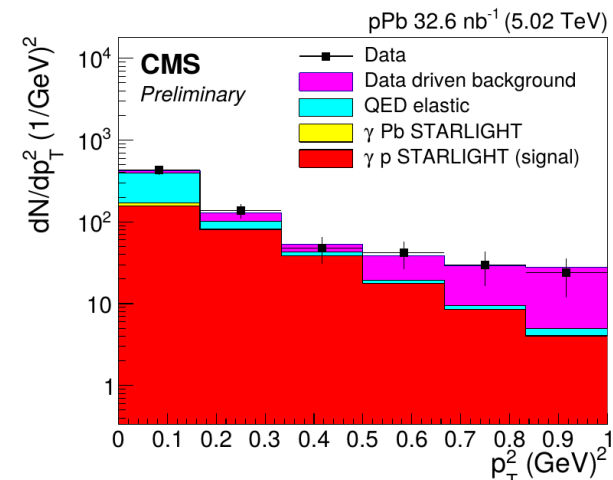
$M(\mu\mu) : [9.12-10.64]$ GeV; $|y(\mu\mu)| < 2.2$;

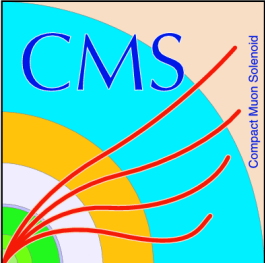
Exclusivity: no other tracks above 2 GeV



Data-driven BG allows to account for inclusive Υ , DY and also for semi-exclusive production (no reliable MC predictions)

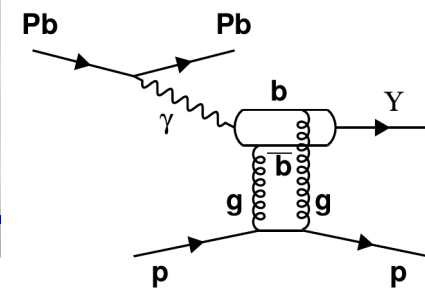
MC: Starlight





Exclusive Υ photoproduction in pA

CMS-FSQ-13-009



Production cross-section:

Corrected for BG and acceptance, unfolded data

in bins of $|t| \sim p_t^2$:

$$\frac{d\sigma_Y}{d|t|} = \frac{N^{Y(nS)}}{\mathcal{L} \times \Delta|t|}$$

$b = 4.5 \pm 1.7(\text{stat}) \pm 0.6(\text{syst}) \text{ GeV}^{-2}$
in a good agreement with HERA results

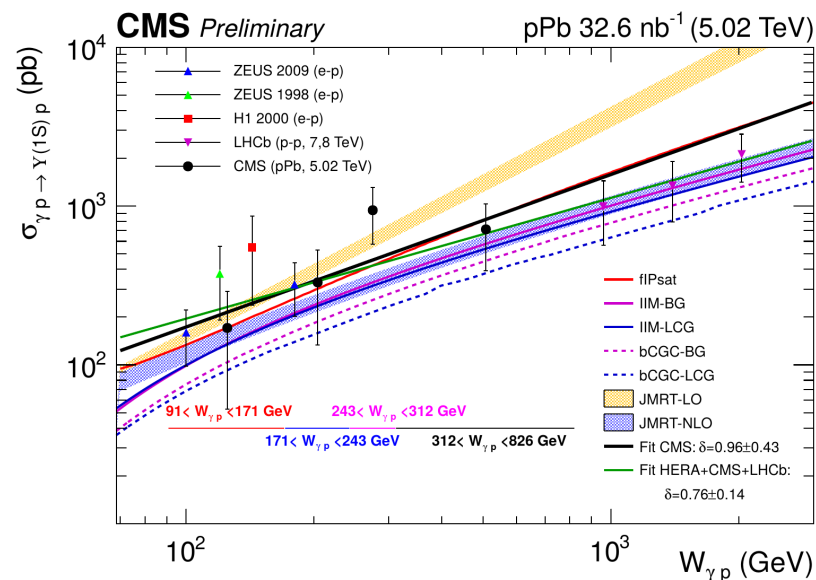
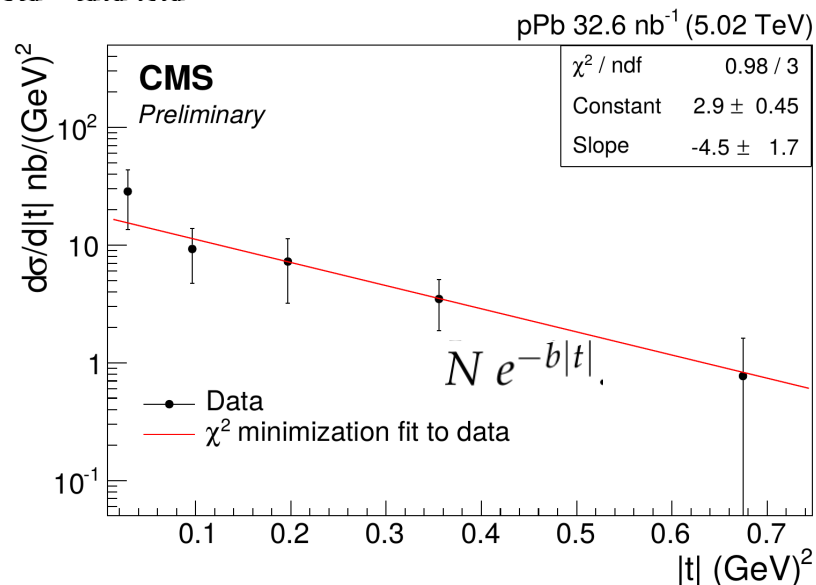
in bins of y as a function of Υp energy:

$$\sigma_{\gamma p \rightarrow Y(1S)p}(W_{\gamma p}^2) = \frac{1}{\Phi} \frac{d\sigma_{Y(1S)}}{dy}, \quad W_{\gamma p} = \sqrt{2E_p M_Y \exp(y)}$$

$$d\sigma/dt \sim [xG(x, Q^2)]^2, \quad x = M_Y^2/W_{\gamma p}^2 \sim [10^{-4}, 10^{-2}]$$

= > Sensitive to gluon density at low x

In agreement with previous observations



Summary

- **Inclusive SD and DD**
 - cross-section measurements for
- $-5.5 < \log(\xi) < -2.5$ (SD) and $M_x > 10, M_y > 10, \Delta\eta < 3$ (DD)
= > good agreement with Pythia-MBR
- **(semi-)exclusive pion production**
 - the integrated (visible) cross-section (including proton dissociation) observed to be $\sim 20 \text{ ub}^{-1}$
 - the differential cross-sections exceed the predictions of *exclusive production* MC, especially for $p_t(\pi\pi) > 0.5 \text{ GeV}$
- **CSE in jet-gap-jet events**
 - fraction of CSE events is in a good agreement with earlier measurements and can be in general described with LL-BFKL MC
= > however the gap size dependence deviates from the MC prediction
- **Y photoproduction in pA collisions**
 - sensitive to gluon density at low x
 - complimentary to HERA and LHCb measurements
 - in a good agreement with MC predictions and earlier data