Measurement of inelastic, diffractive and exclusive processes in pp collisions with CMS

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On behalf of the CMS experiment

Outline

- Measurement of the Total Inelastic $\sigma(pp)$ at 7 TeV
  - Pile-up and Vertex Reconstruction
  - Unfolding Methods & Results
  - Extrapolation Using MC Prediction

CMS PAS FWD-11-001

- Measurement of the $\gamma\gamma \to \mu\mu$ Exclusive Production at 7 TeV
  - Signal selection
  - Results

CMS PAS FWD-10-005

- Observation of Diffraction at CMS
  - Event Selection
  - Signal Enhancement

CMS PAS FWD-10-001
CMS PAS FWD-10-007

Total σ(*pp*): Basic Concepts

• We measure the total pp cross section in a new way, using pile-up (PU) events:

The probability of having n_{pileup} depends on the total σ(pp) cross section.

$$P(n_{pileup}) = \frac{(L\cdot\sigma)^{n_{pileup}}}{n_{pileup}!}\cdot e^{-(L\cdot\sigma)}$$

•The pile-up depends on the "Luminosity per bunch crossing": max. 2010 = ~0.6 10^{30} cm^{-2} s^{-1}

•Pile up events are recorded by a high efficient stable trigger

• The goal of the analysis is to count the number of vertices as a function of luminosity

Count (event by event) the number (N) of recorded vertices

⇩

Define the "primary" vertex and select the other N-1 PU events

⇩

Measure the fraction of events with 0 – 8 PU events as function of the instantaneous luminosity

⇩

Correct to account vertex reconstruction inefficiencies

⇩

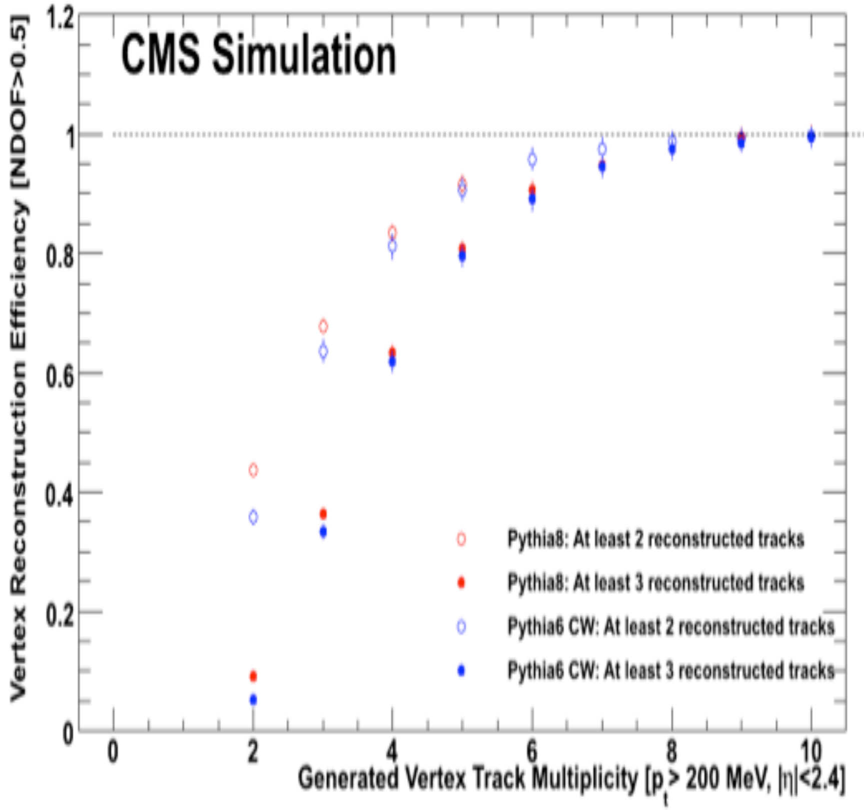
Fit the distribution with the appropriate Poisson

Total σ(*pp*): Event Selections

- **We select PU event large enough to make a vertex:**
  - **We count vertices requiring at least 2 tracks with $|\eta|<2.4$ && $p_t > 200$ MeV**
  - **Each track should have at least 2 pixel-tracker hits && 5 strip-tracker hits**

- **A cut on the vertex transverse position has been measured in data and used to reject "fake" (secondary) vertices:**
  - **Long lived particles**
  - **Algorithm splitting a single vertex in two**

- **The vertex track multiplicity is the key parameter: vertices having < 10 tracks are not always reconstructed**
- **Vertices closer than 60 μm are reconstructed as one**



Need to correct the PU distribution for the missing fraction of events at low multiplicity and for vertex merging

Total σ(*pp*): Unfolding Method

The visible number of vertices needs to be corrected to obtain the "real" number. This is done in luminosity bins (13).

An unfolding technique is used in each bin, according to the following steps:

1) **In each bin, calculate the theoretical distribution of pile-up events for that specific luminosity interval assuming a certain value for σtrial(pp)**

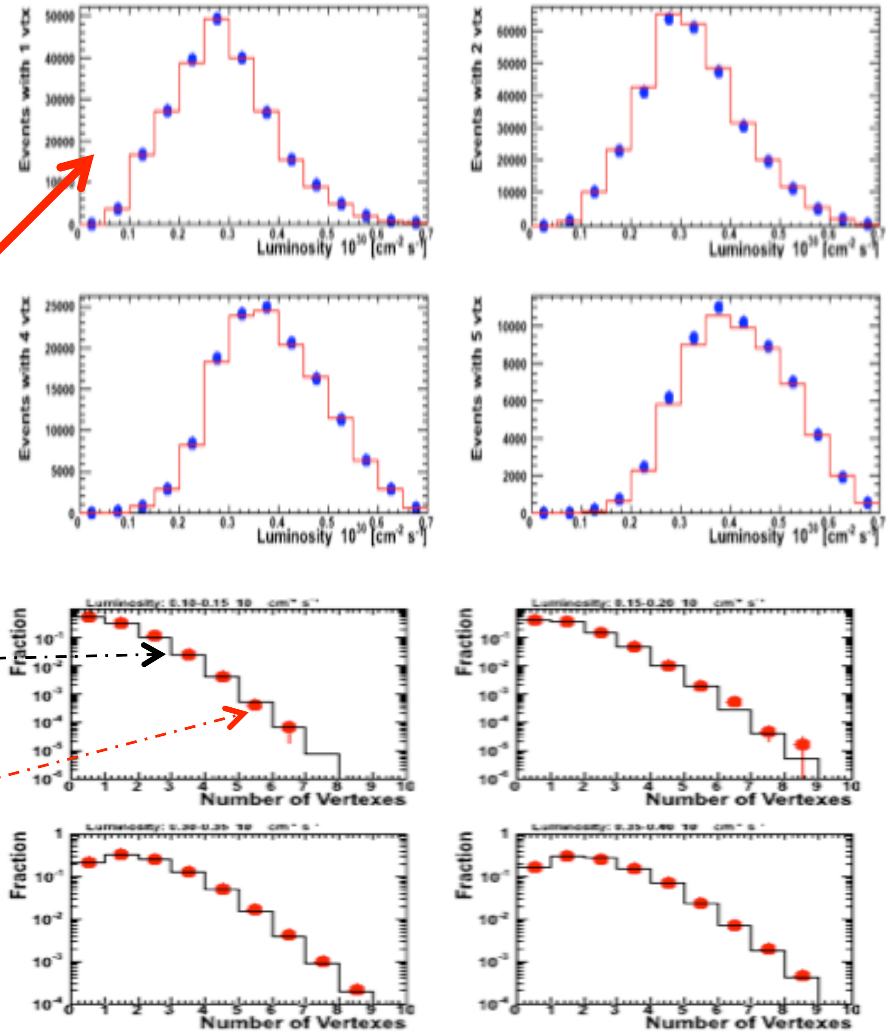
2) **Reweight the Monte Carlo to have the appropriate generated PU distribution.**

3) **Steps 1 and 2 have been repeated several times using different σtrial(pp) till good agreement data and MC**

4) **Calculate the generated PU distribution for events which pass the cuts**

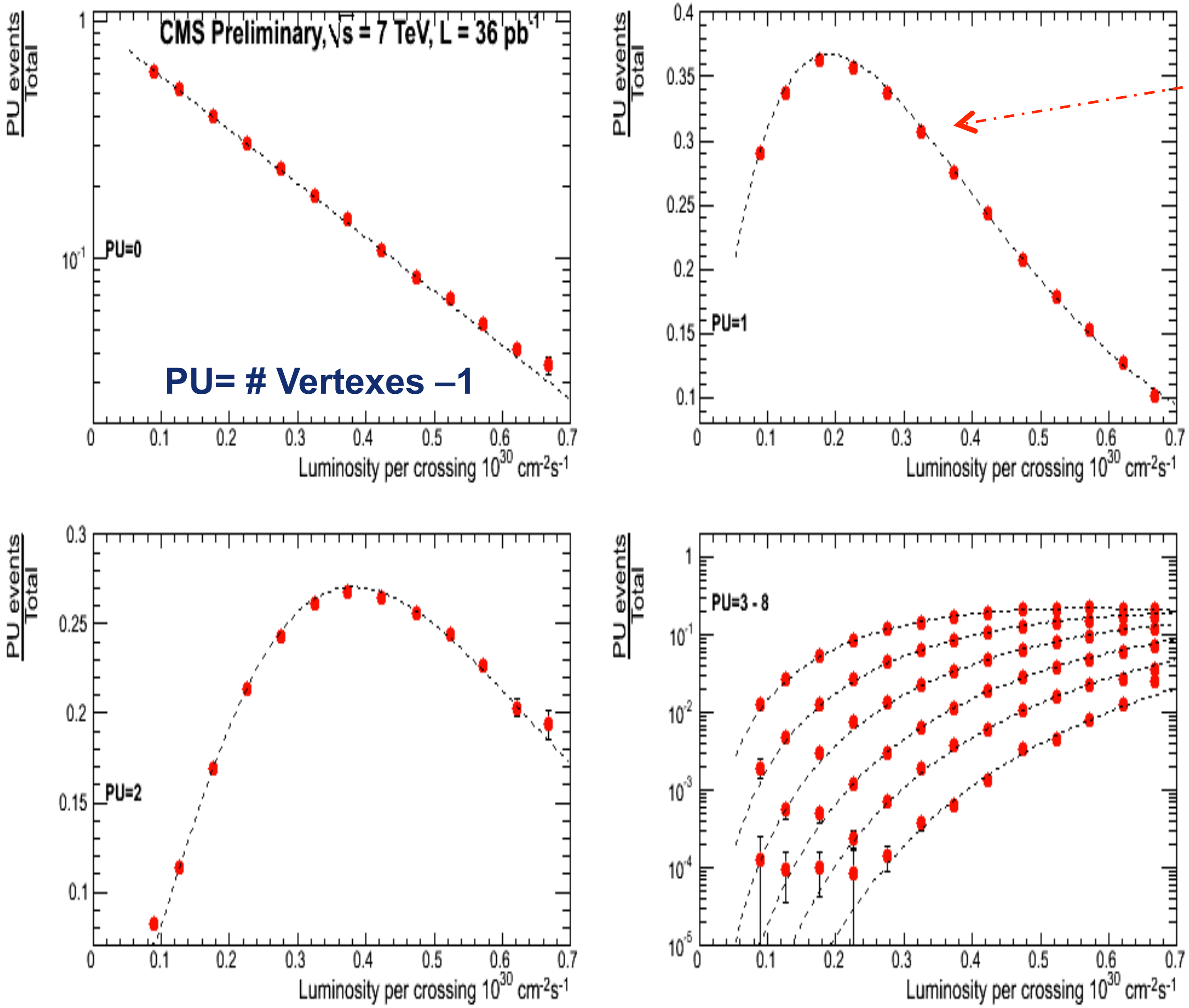
5) **Measure the pile-up distribution for MC events that pass the selection cuts.**

6) **Compute the bin-by-bin correction for each luminosity interval.**

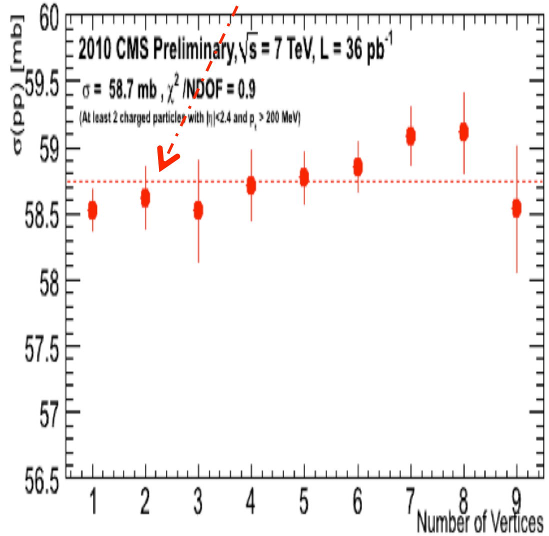


Total σ(*pp*): Poisson Fits

Using the correction functions, we unfold the measured vertex distributions to obtain the correct one which we fit to calculate σ



$$P(n_{pileup}) = \frac{(L\cdot\sigma)^{n_{pileup}}}{n_{pileup}!}\cdot e^{-(L\cdot\sigma)}$$



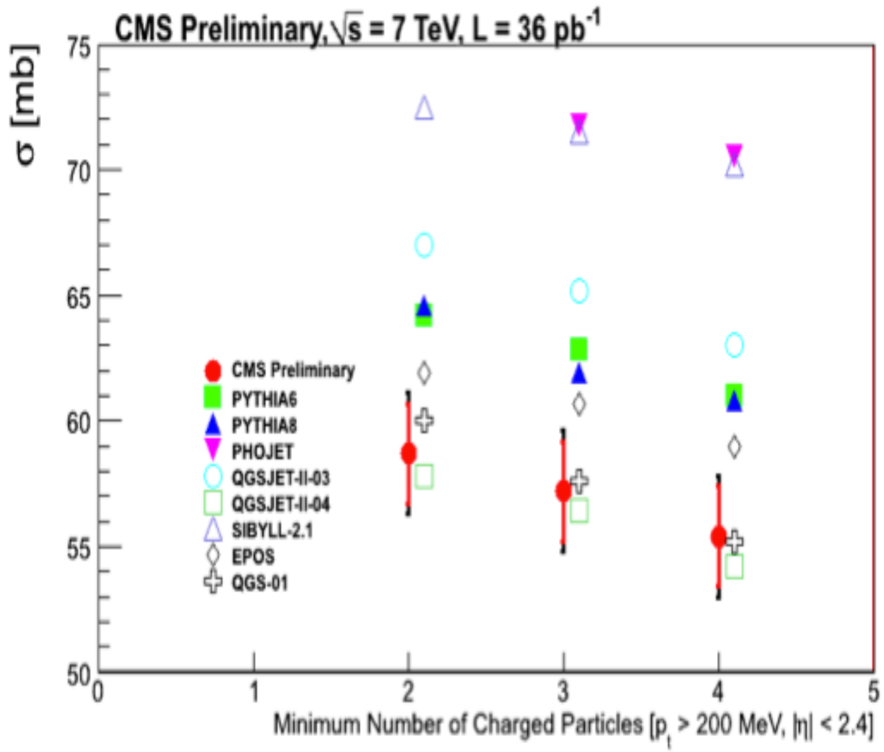
AVERAGE

$\sigma^{visible}_{2tracks}$ = **58.7 ± 0.1 mb**

Total σ(pp): Comparison with models and extrapolation

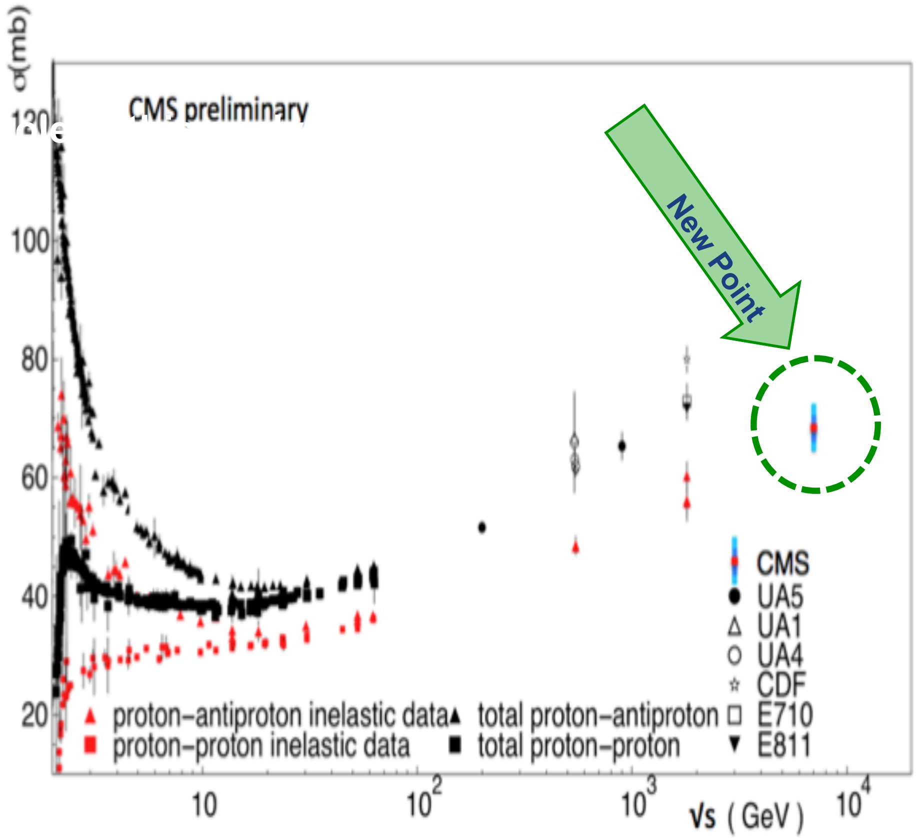
Visible σ

We compare our results with several MC models evaluating their predictions for the same interval that we measure



Total σ

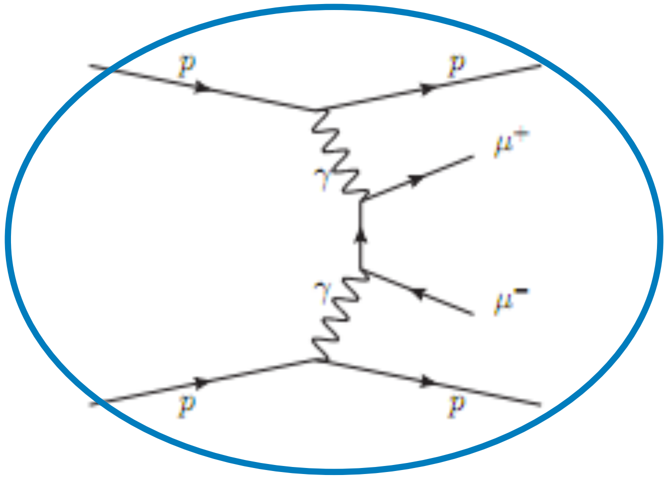
The total inelastic σ can be evaluated in a MC dependent way by extrapolation



σ_{tot} = **68.0 ± 2.0(Syst) ± 2.4(Lumi) ± 4.0 (Extr.) mb**

Exclusive Production: $\gamma\gamma$ −> $\mu\mu$

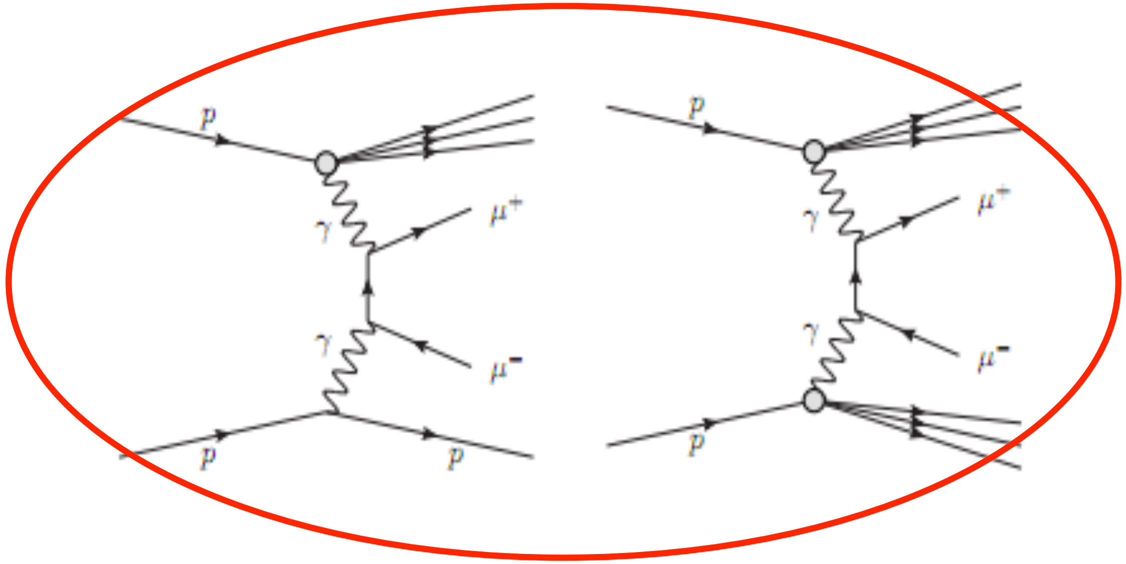
Exclusive Production



- Basically QED process
- Absolute calibration of luminosity

- Simulated using L_{pair} MC

Semi-Exclusive Production



- Unless both protons are detected, semi-exclusive p. are backgrounds
- Other backgrounds are:
  - QCD di-muon
  - Drell-Yan di-muon
- Separation done using kinematic distributions

Exclusive Production: Event Selection

The selection of the signal proceeds in three steps:

Trigger

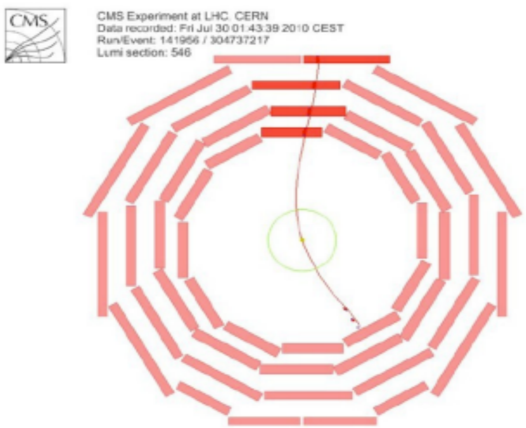
- Online: 2 muons, pt>3 GeV
- Muons reconstructed combining silicon tracker and chambers

Exclusivity

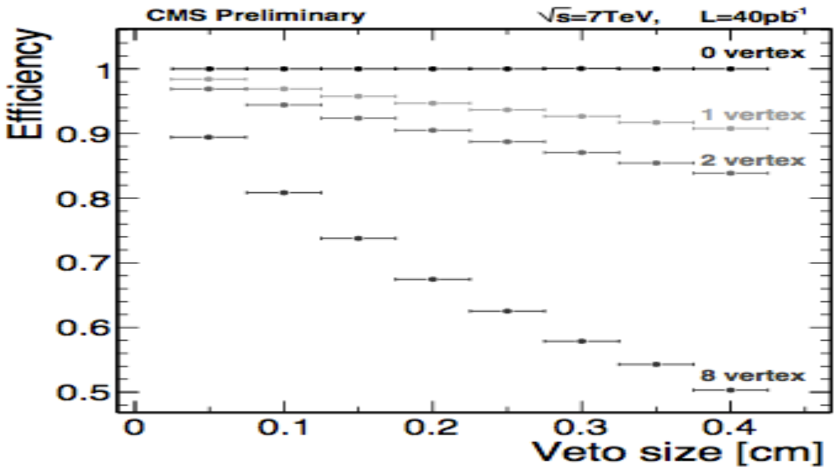
- 2 muons, no activity elsewhere:
- Valid vertex
- Dimuonic vertex separated by 2 mm from any other tracks

Kinematic

- muon p_t> 4 GeV ,$|\eta|$< 2.1
- $M(\mu^+\mu^-)$ > 11.5 (Upsilon)
- Back to back $(|\Delta\phi(\mu\mu)/\pi| > 0.9)$ & Balanced $|\Delta p_T(\mu\mu)| < 1.0$
- 3D angle < 0.95 π



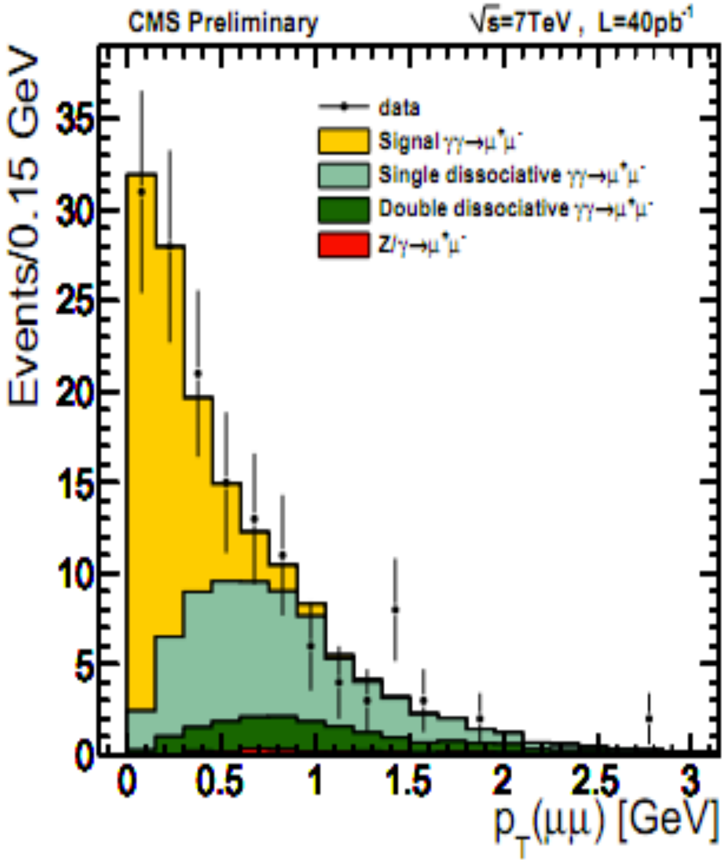
- $\mu\mu\ \Delta\varphi \sim \pi$
- $\mu\mu\ \Delta p_T \sim 0$



90% of 2010 Events

Exclusive Production: Final Results

The pp → pμ⁺μ⁻p contribution is extracted by performing a 1-D binned maximum-likelihood fit to the $p_T(\mu\mu)$ distribution.



three free parameters/prediction:

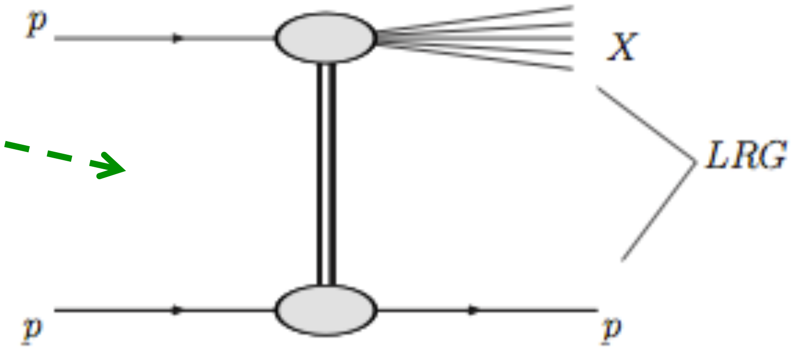
- **elastic signal yield relative to the LPAIR**
- **the single proton dissociation yield**
- **Exp. factor for the slope of p dissociation**

Selection	Variation from nominal yield
track veto size	3.6%
track quality	2.5%
Drell-Yan background	0.4%
double p−dissociation background	0.9%
Crossing-angle	1.0%
Tracking efficiency	0.1%
Vertexing efficiency	0.1%
Momentum scale	0.1%
Efficiency correlations in J/ψ control sample	0.7%
Muon and trigger efficiency statistical error	0.8%
Total	4.8%

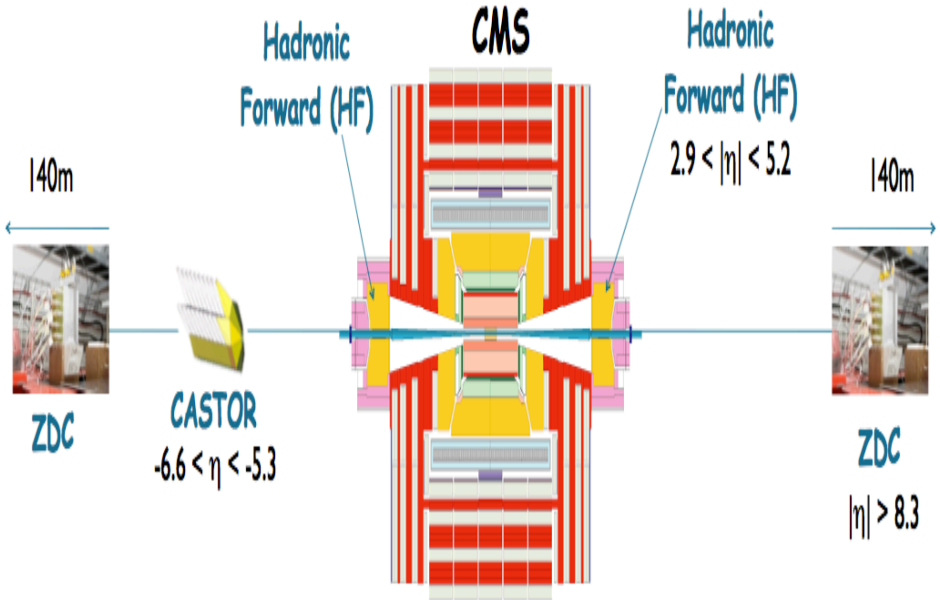
$$\sigma(pp \rightarrow p\mu^+\mu^-p) = 3.38_{-0.55}^{+0.58}(\text{stat.}) \pm 0.16(\text{syst.}) \pm 0.14\ (\text{lumi})\ \text{pb}$$

Observation of Diffraction

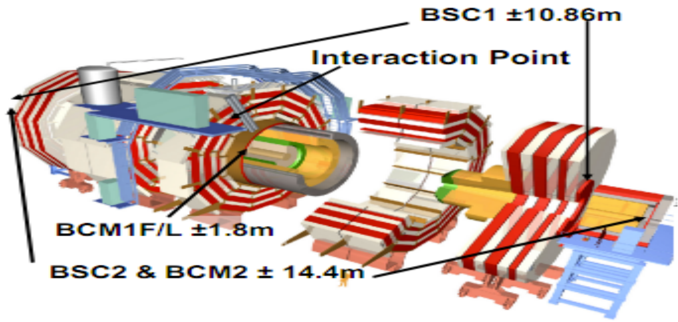
- **Observation of a diffractive signal dominated by the single diffractive reaction pp->pX**



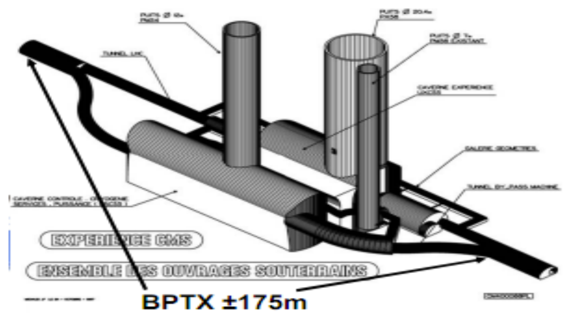
- **Data collected:**
  - **10 μb-1 at √s = 0.9 TeV**
  - **0.4 μb-1 at √s = 2.36 TeV**
  - **20 μb-1 at √s = 7 TeV**



Beam Scintillator Counter (BCS)



Beam Pickup Timing eXperiment (BPTX)



Diffraction:Event Selection Cuts

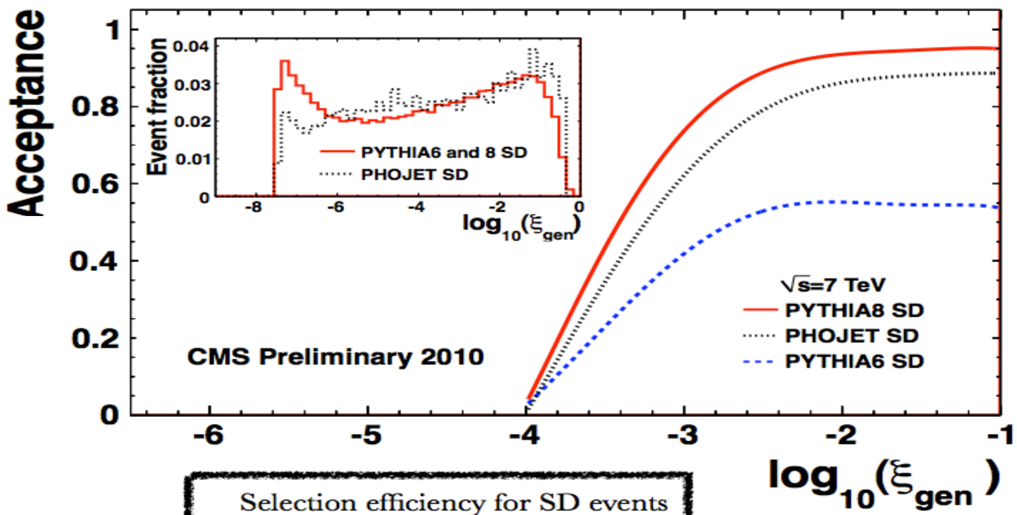
Online Selection

- Signal in either of the BCS, coincident with a signal from either of the two BPTX detectors, indicating at least one bunch crossing the IP

Offline Selection

- High quality primary vertex
- Beam Halo and beam background rejection
- Calorimeter noise cleaning

Acceptance for SD events at 7 TeV:



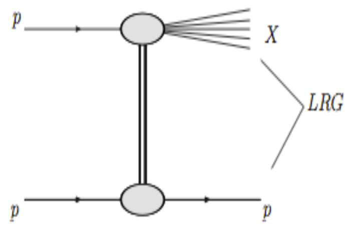
Selection efficiency for SD events

- PYTHIA6 D6T: 25%
- PYTHIA8: 43%
- PHOJET: 42%

- Discrepancy between PYTHIA6 with respect to either PYTHIA8 or PHOJET
- different simulation of diffractive system fragmentation
- absence of hard diffractive processes in PYTHIA6

fractional energy loss of the scattered proton p in pp → pX:

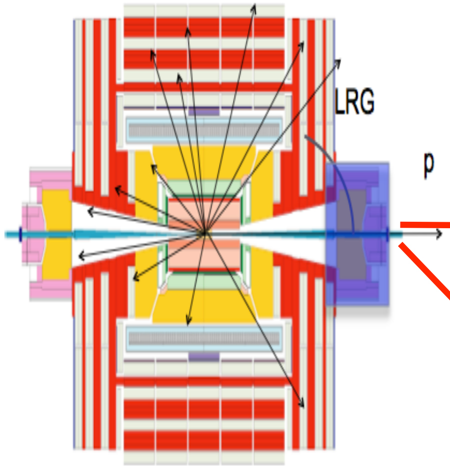
$$\xi = M_X^2/s$$



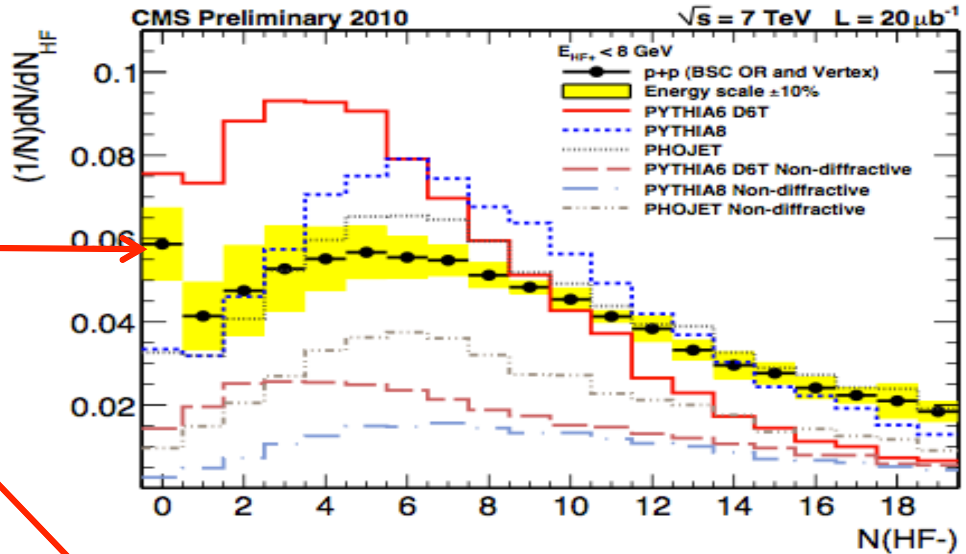
Observation Of Diffraction @ 7 TeV

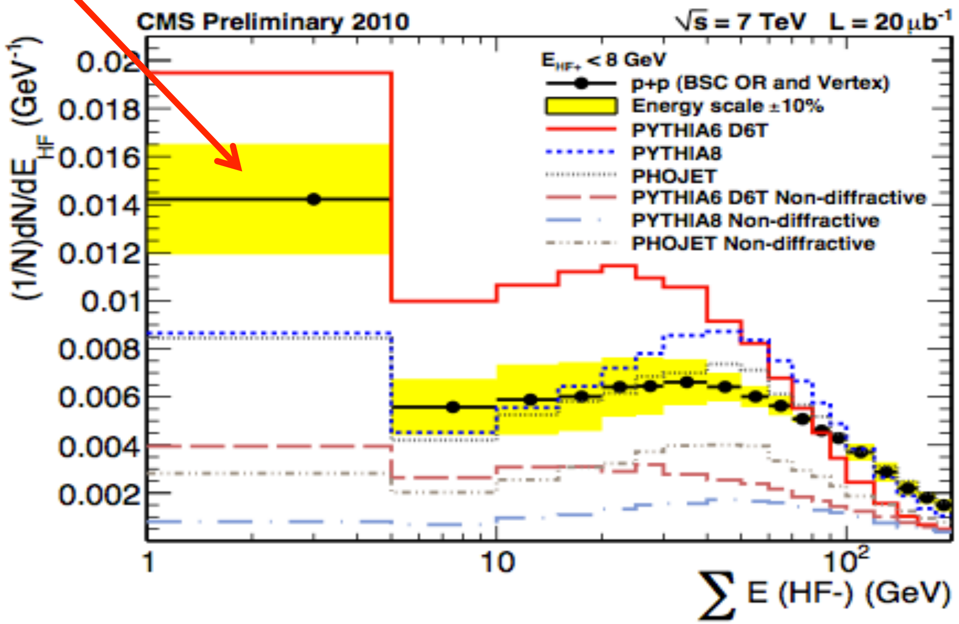
To enhance the diffractive component in the data, a cut was applied to the HF energy sum.

N_HF-:
multiplicity of calorimeter towers above threshold



Sum(E(HF)):
energy distributions in the calorimeters energy





None of the simulations considered describes all features of the data:

	Pythia 6 D6T	DW	CW	P0	Z1	Pythia 8	Phojet
distributions without diffractive enhancement							
Cal $\|\eta\| < 3$	fair	fair	fair	bad	ok	fair	very bad
Tracking	bad	bad	bad	fair	fair	ok	bad
Forward	ok	fair	fair	bad	fair	bad	bad
distributions with diffractive enhancement							
Tracking	bad	bad	bad	fair	fair	ok	fair
Forward	bad	bad	bad	bad	bad	bad	fair

Conclusions

- We measured the pp inelastic cross section for events with 2 or more charged tracks, $|\eta|<2.4$, pt>200 MeV: using MC dependent models we extrapolated the result to the total cross section:

  σ_{total}= 68.0 ± 2.0(Syst) ± 2.4(Lumi) ± 4.0 (Extr) mb

- The first measurement of the exclusive two-photon production of muon pairs, $pp \rightarrow p\mu^+\mu^-p$ is presented:

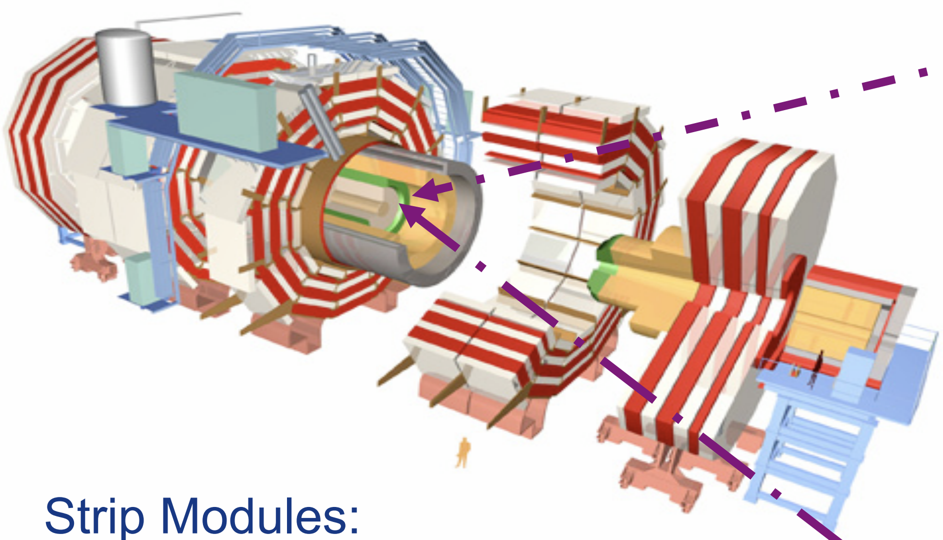
  $\sigma(pp \rightarrow p\mu^+\mu^-p) = 3.38_{-0.55}^{+0.58}$(stat.) ± 0.16(syst.) ± 0.14 (lumi) pb

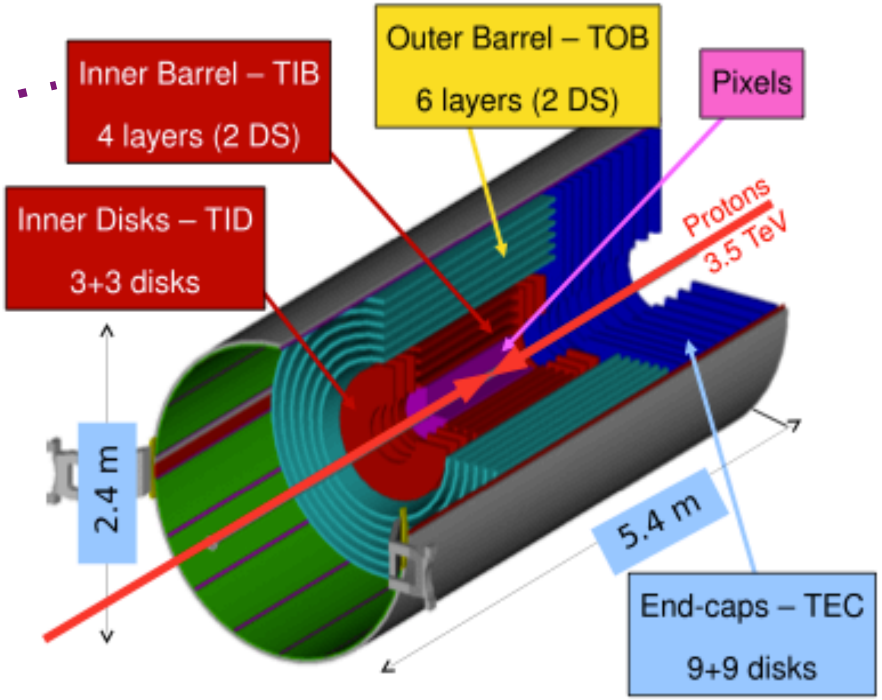
- Evidence of single-diffraction observation at the LHC at 0.9, 2.36 and 7 TeV centre-of-mass energy has been presented
- Uncorrected data have been compared to PYTHIA6, PYTHIA8 and PHOJET after simulation of the detector response none of the simulations considered describes all features of the data

Spares

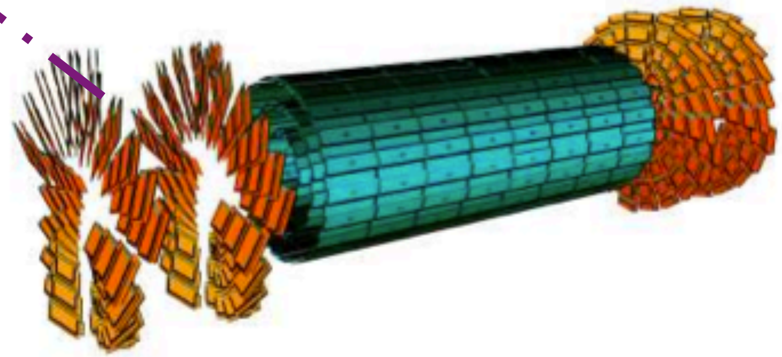
Total $\sigma(pp)$: Introduction

Made an extensive use of the CMS tracker system: its excellent spatial resolution plays a key role.

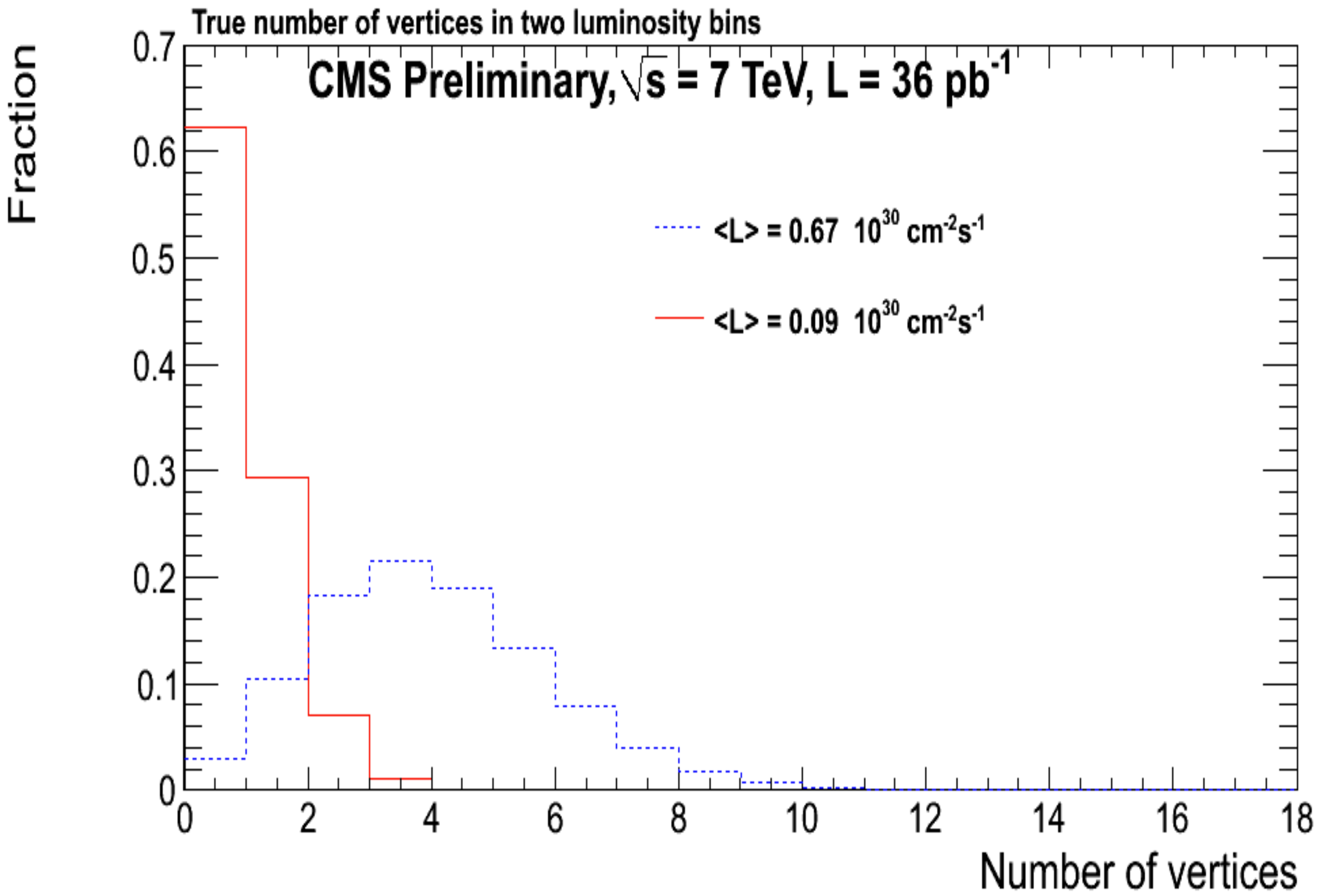




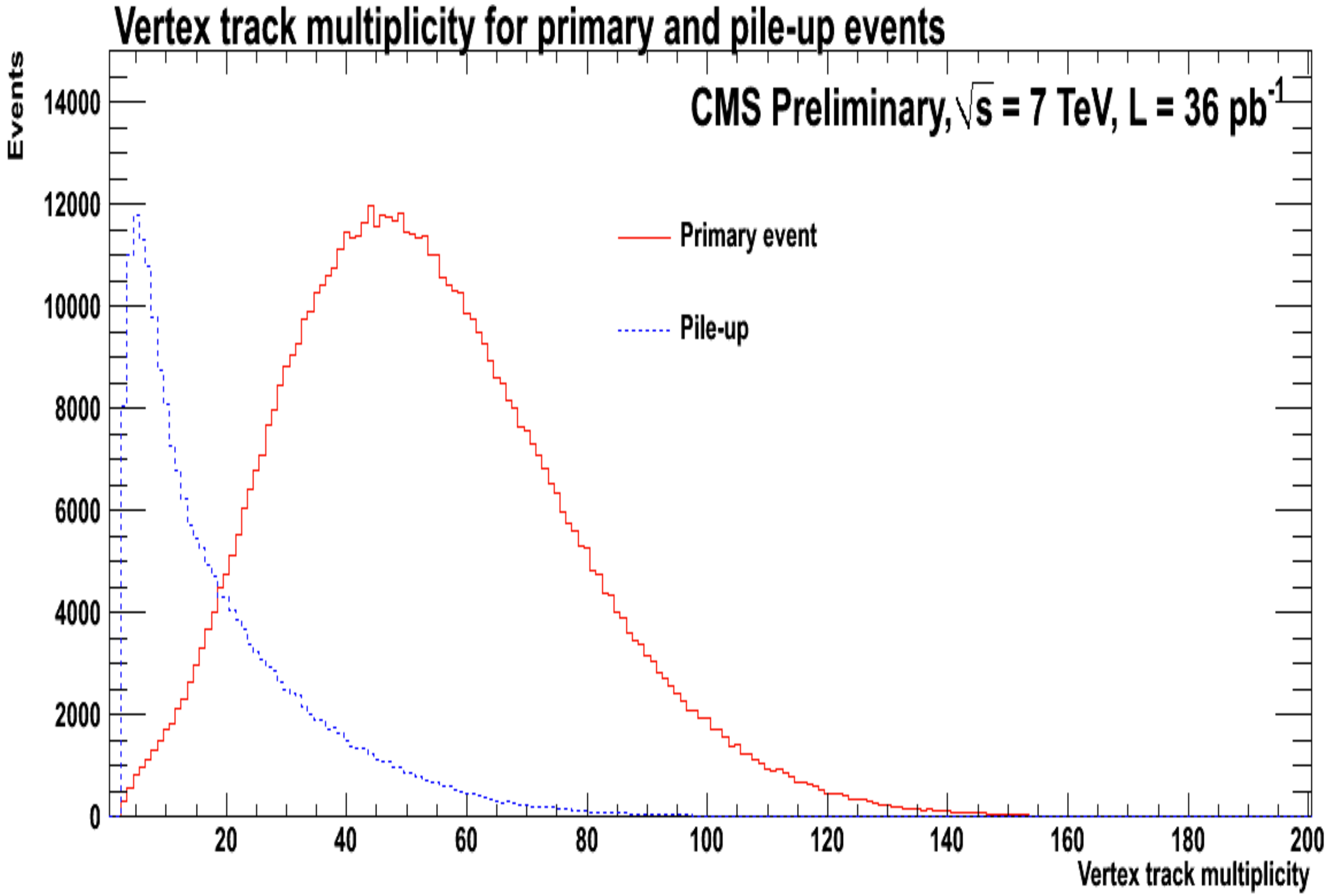
- Strip Modules:
  - 15148 modules (pitch 80-205 μm)
  - Single point resolution 20-60 μm
- Pixel modules:
  - 1440 pixel detectors
  - 100(r) x 150(z) μm^2
  - σ= 9 μm along r
  - σ= 20 μm along z



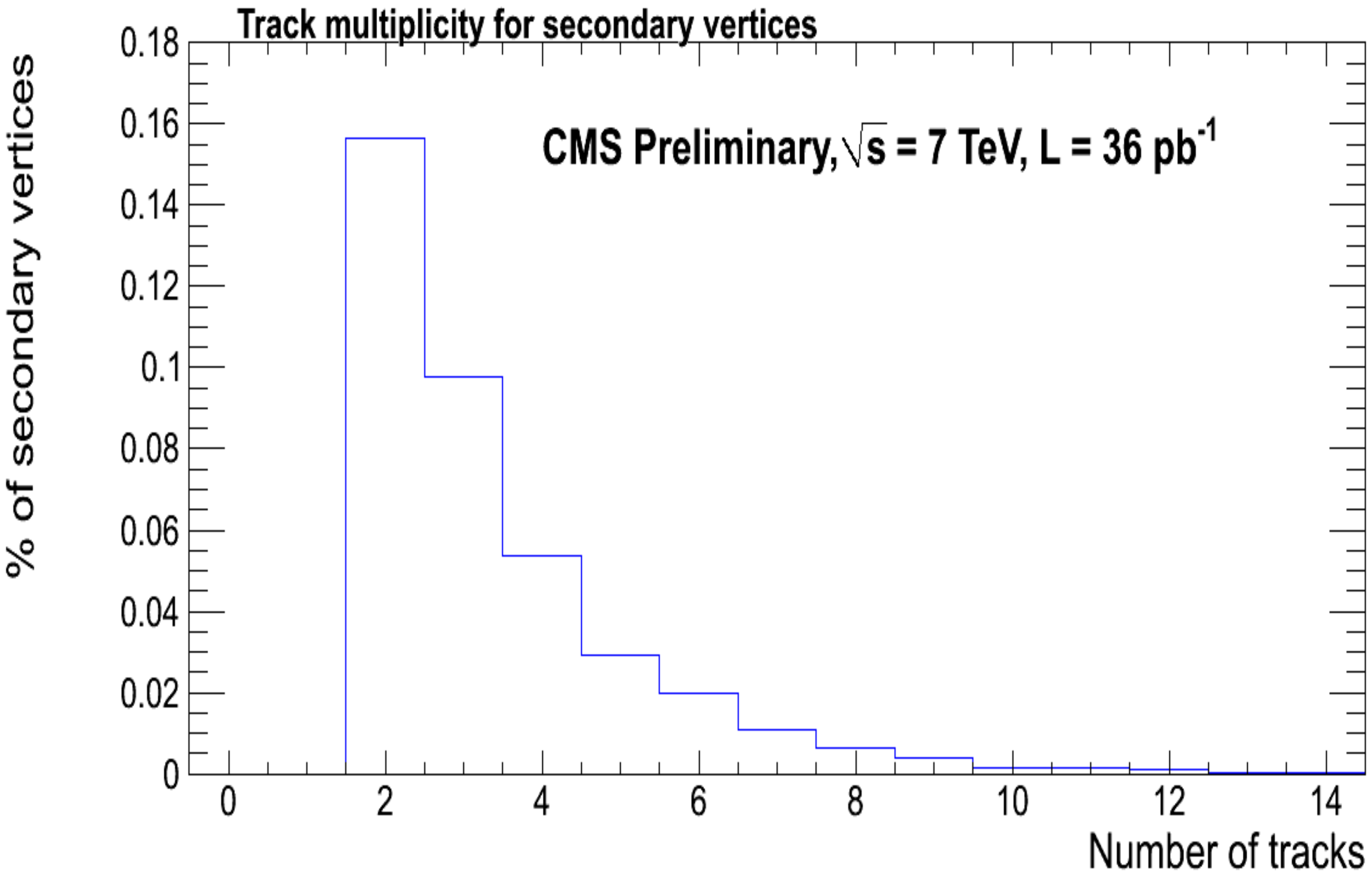
Number of vertices Vs Lumi



Vertex track Multiplicity in data

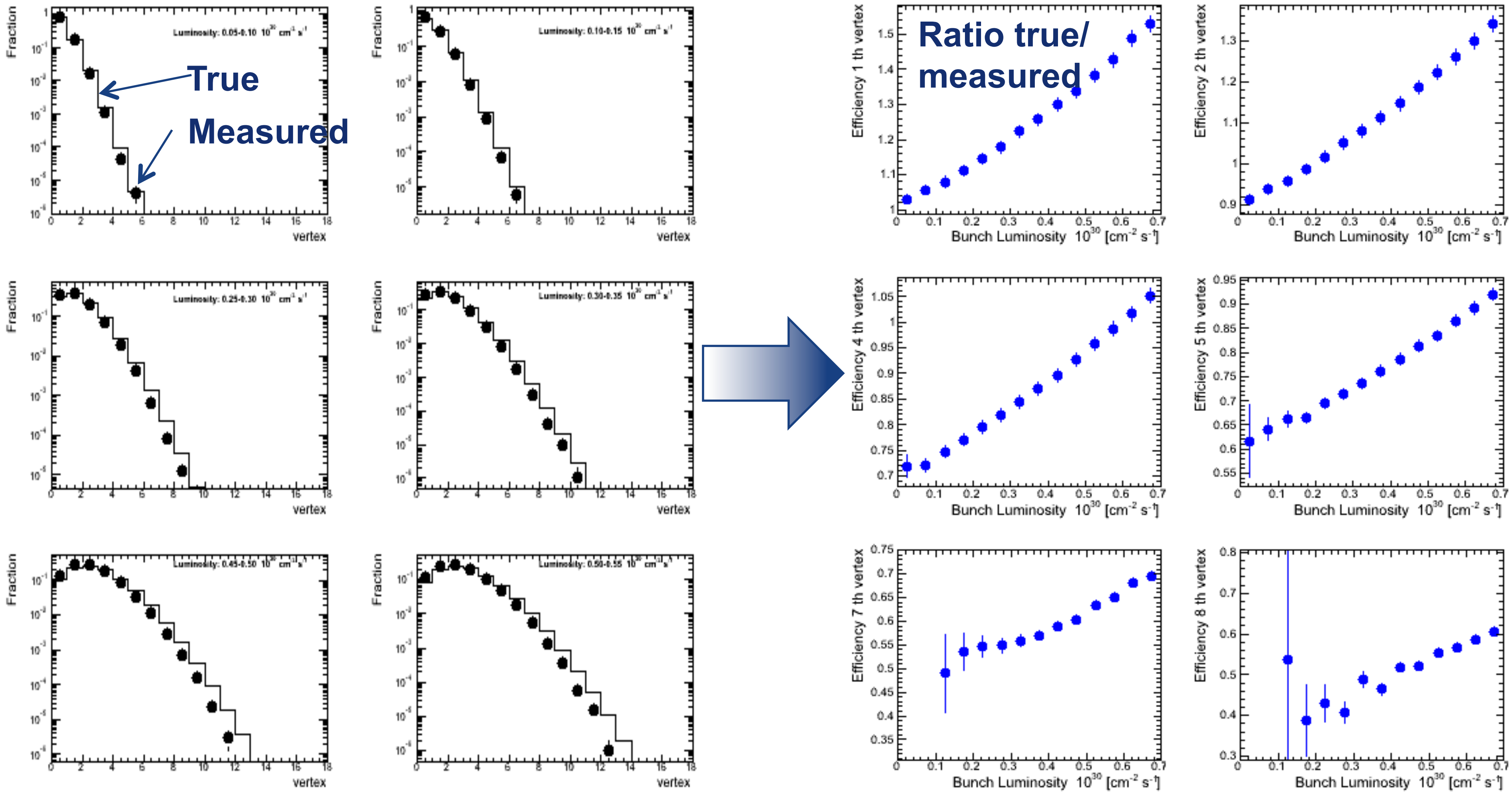


Fake Vertexes

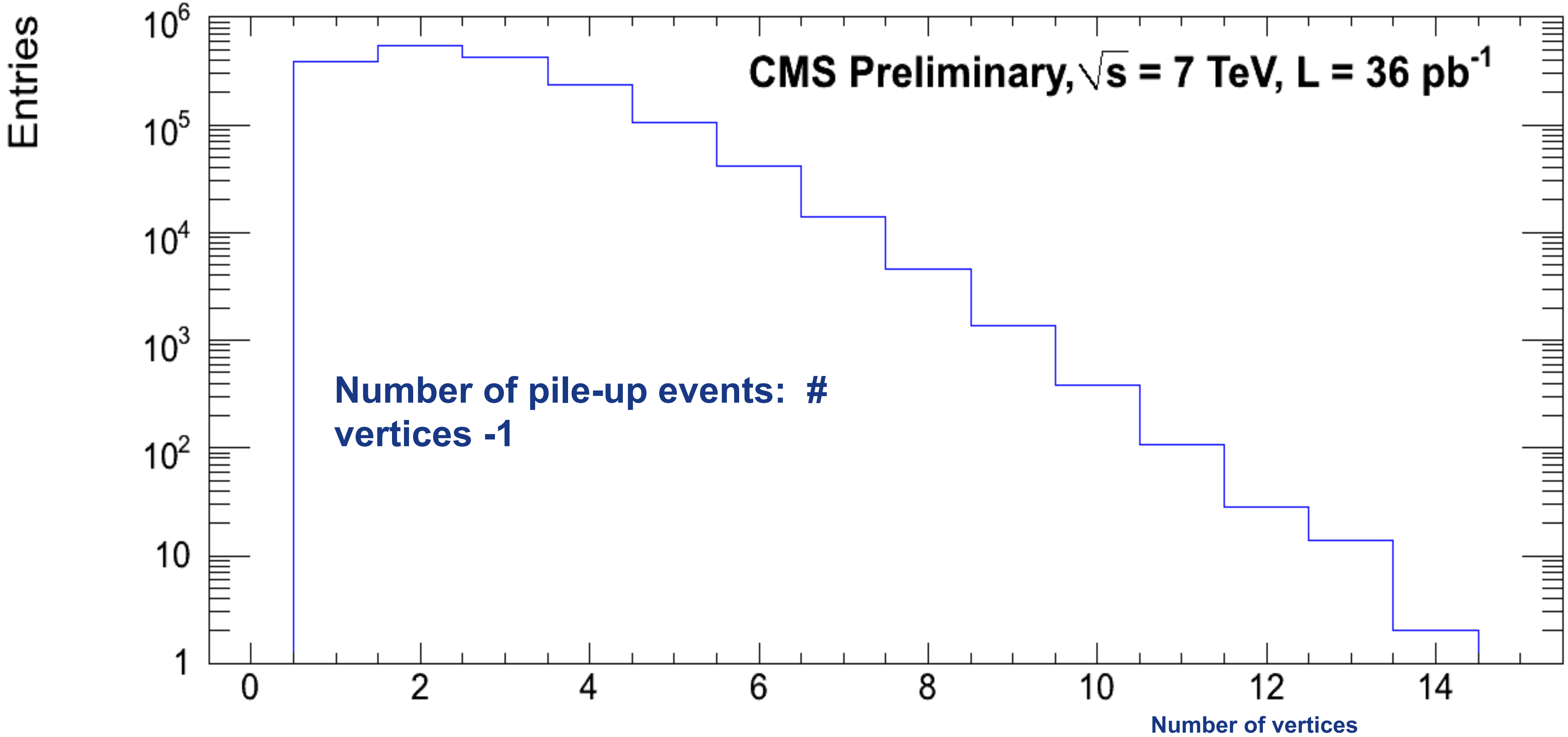


Generate a migration matrix

The simulation produces a set of "corrections" that we need to apply to the reconstructed vertex distributions



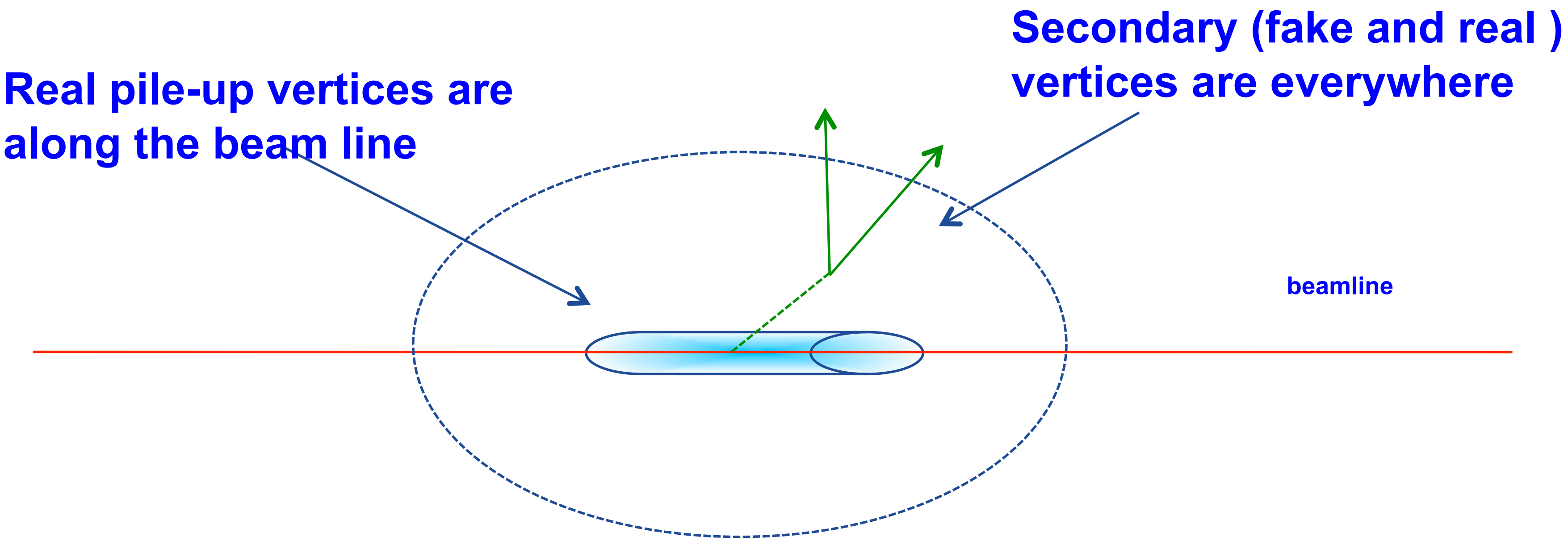
How many pile-up events are there?



We studied events with 0-8 pile-up events (non enough statistics to go further)

Vertex requirements

Position along the beam line:



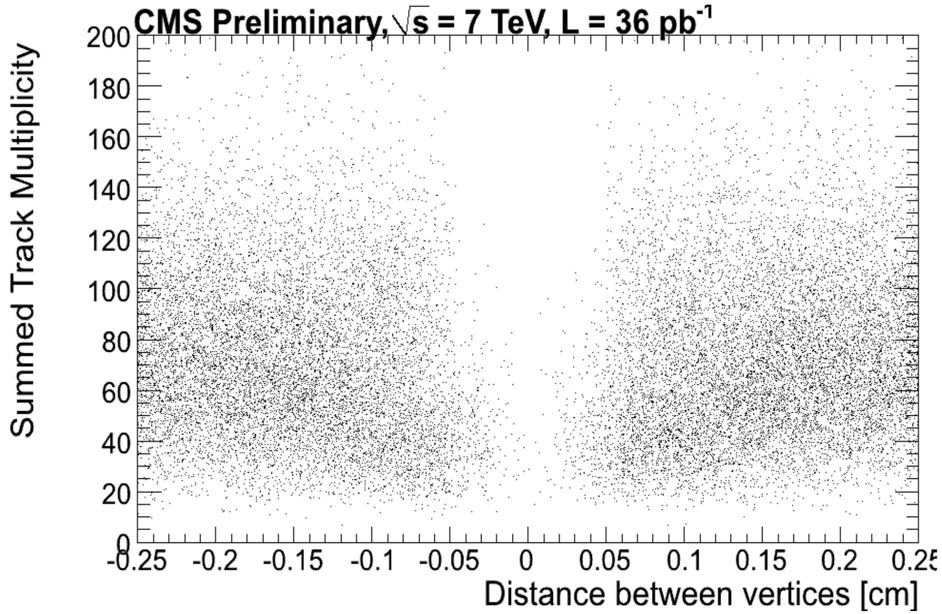
Quality cut:

At least 3 tracks with p_t>200 MeV in |eta|<2.4.
Each track should have at least 2 pixel hits and 5 strip hits
The vertex should pass an overall quality cut, NDOF>0.5

Vertex merging and secondary vertices

<u>Vertex merging:</u>

When two vertexes overlap they are merged into a single one.
This blind distance is ~ 0.06 cm

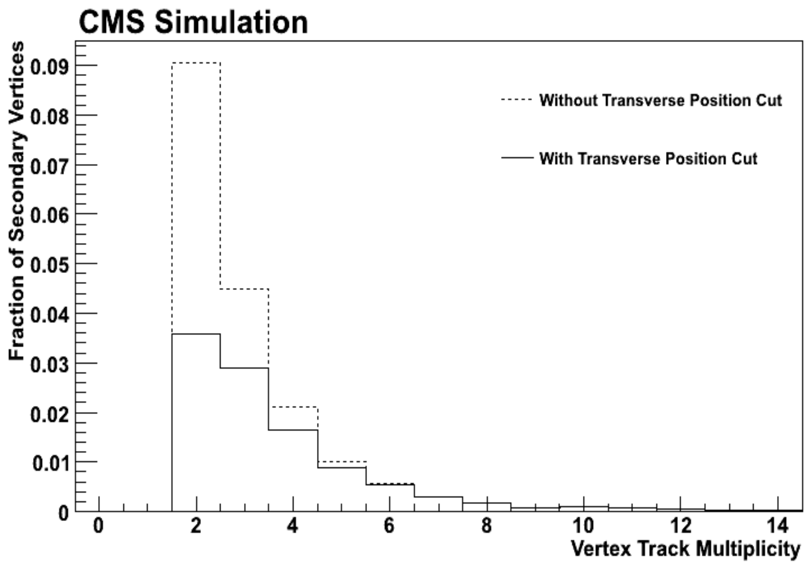


<u>Secondary vertices:</u>

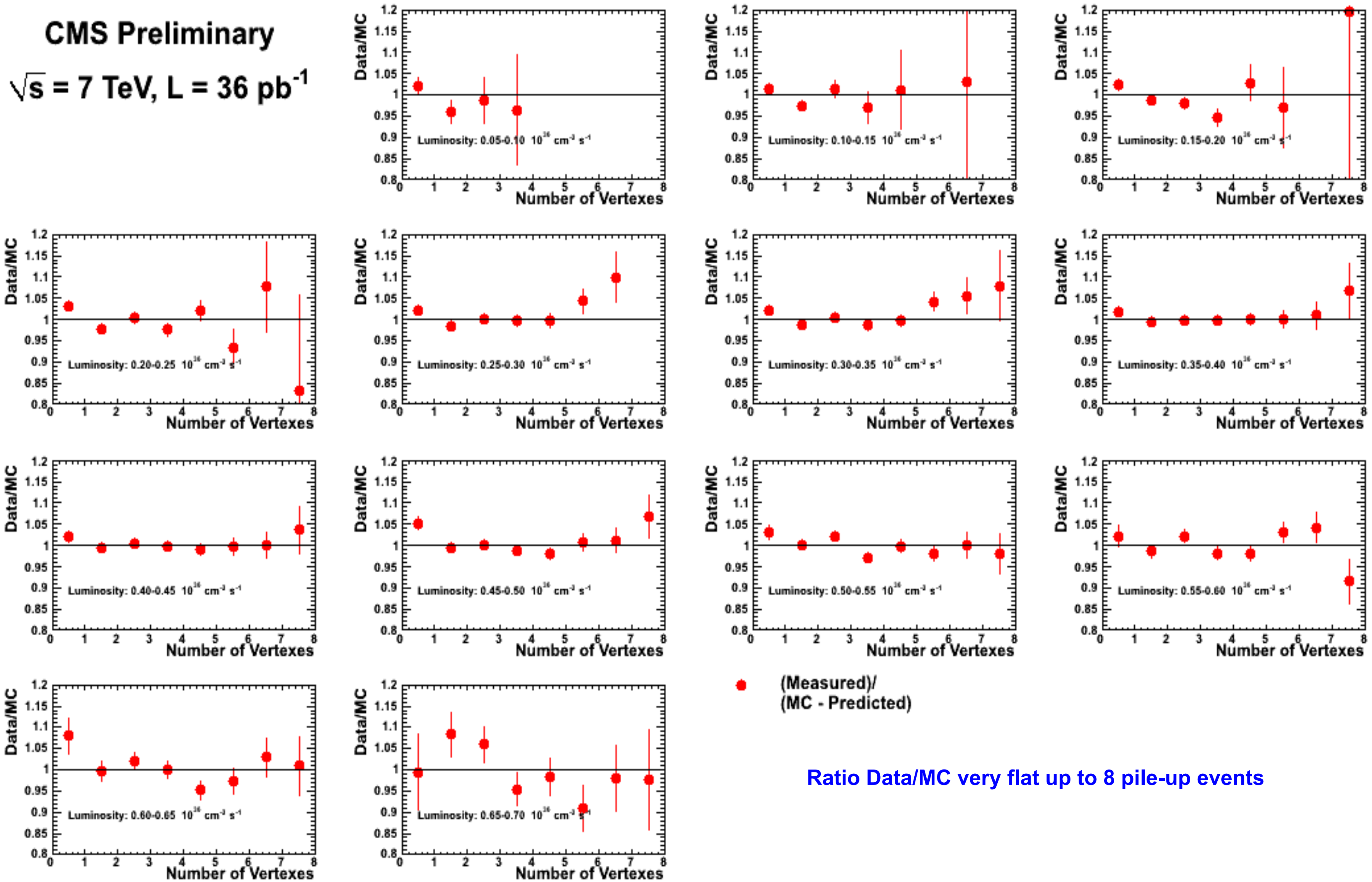
1.Fakes from the reconstruction program
2.Real non prompt decay

Both reduced by the request on the transverse position

Most evident at low track multiplicity

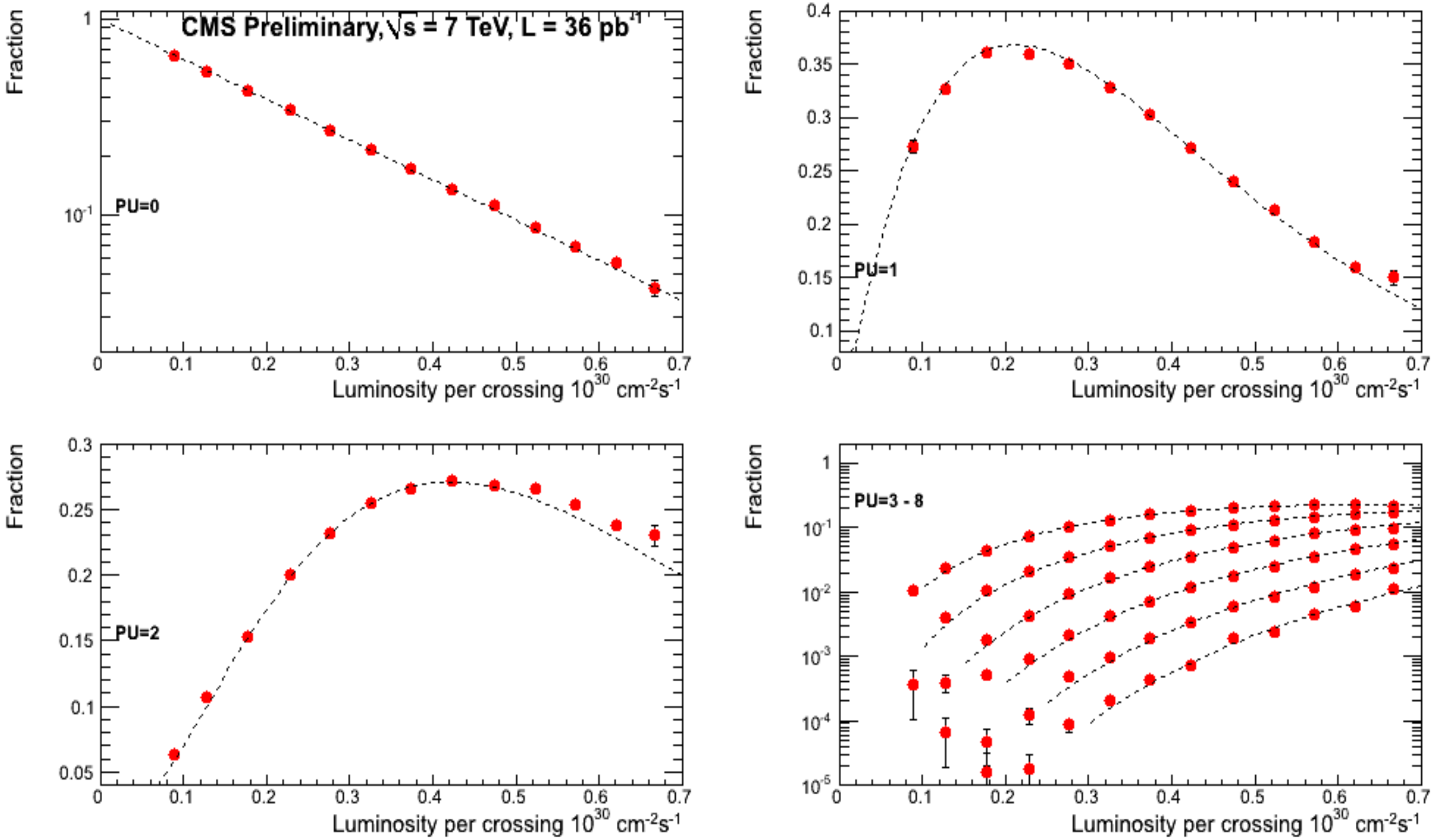


Correction functions



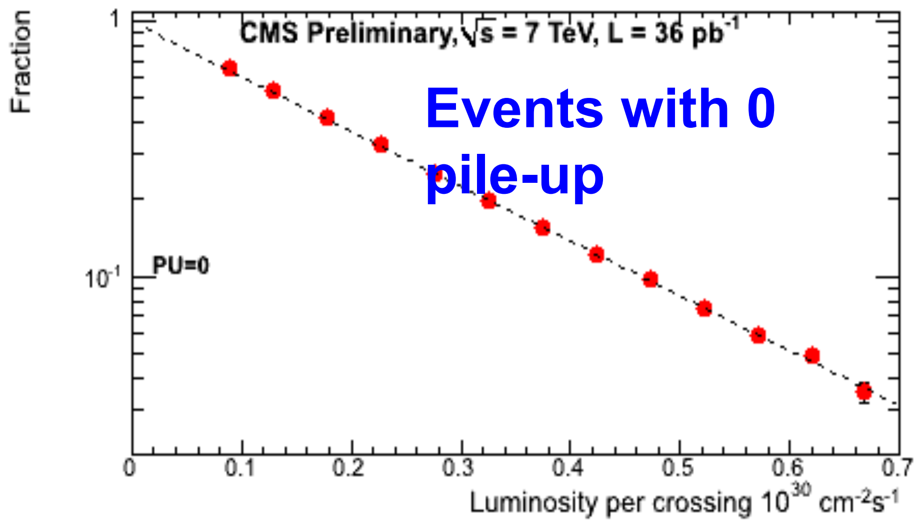
Ratio Data/MC very flat up to 8 pile-up events

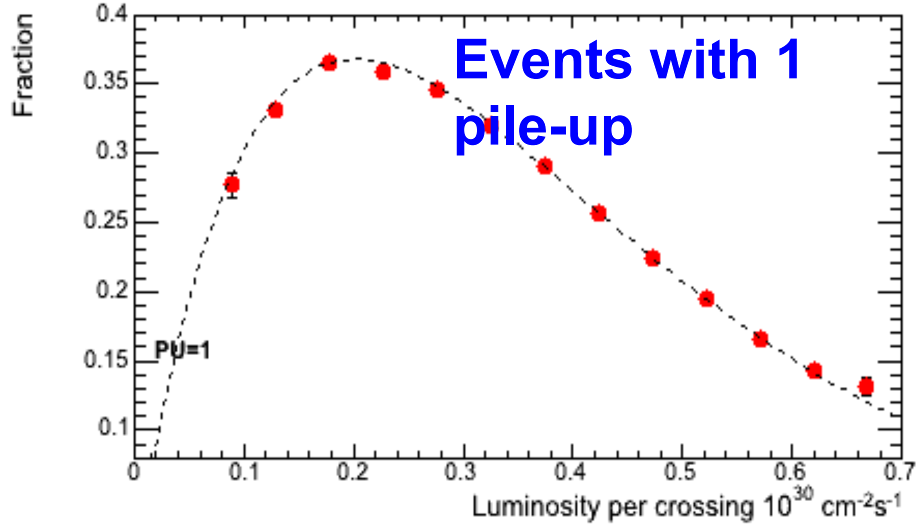
Data: uncorrected distributions

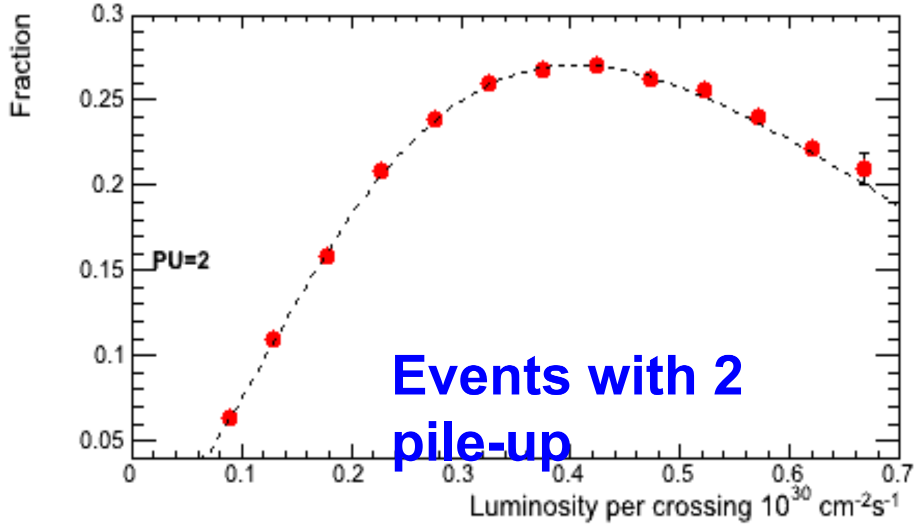


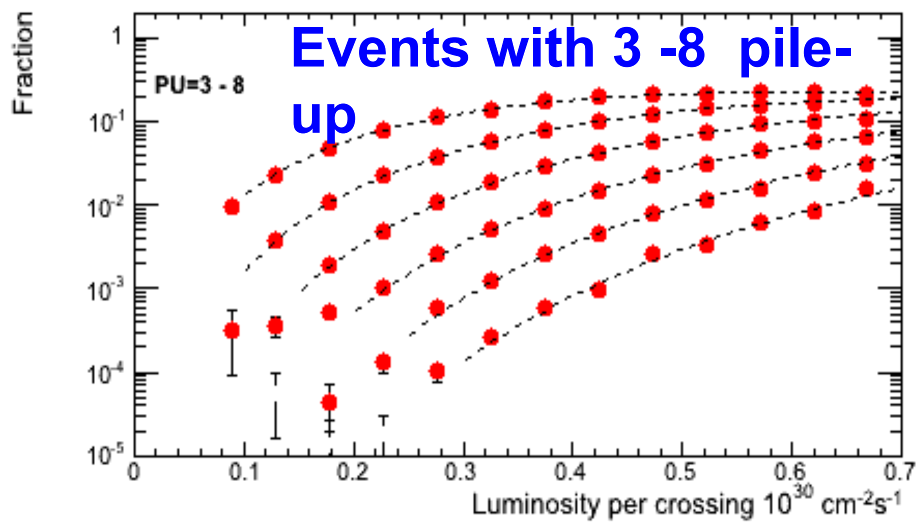
Given the very good CMS vertex efficiency, good fits even without corrections

Data: corrected distributions









Systematic Checks

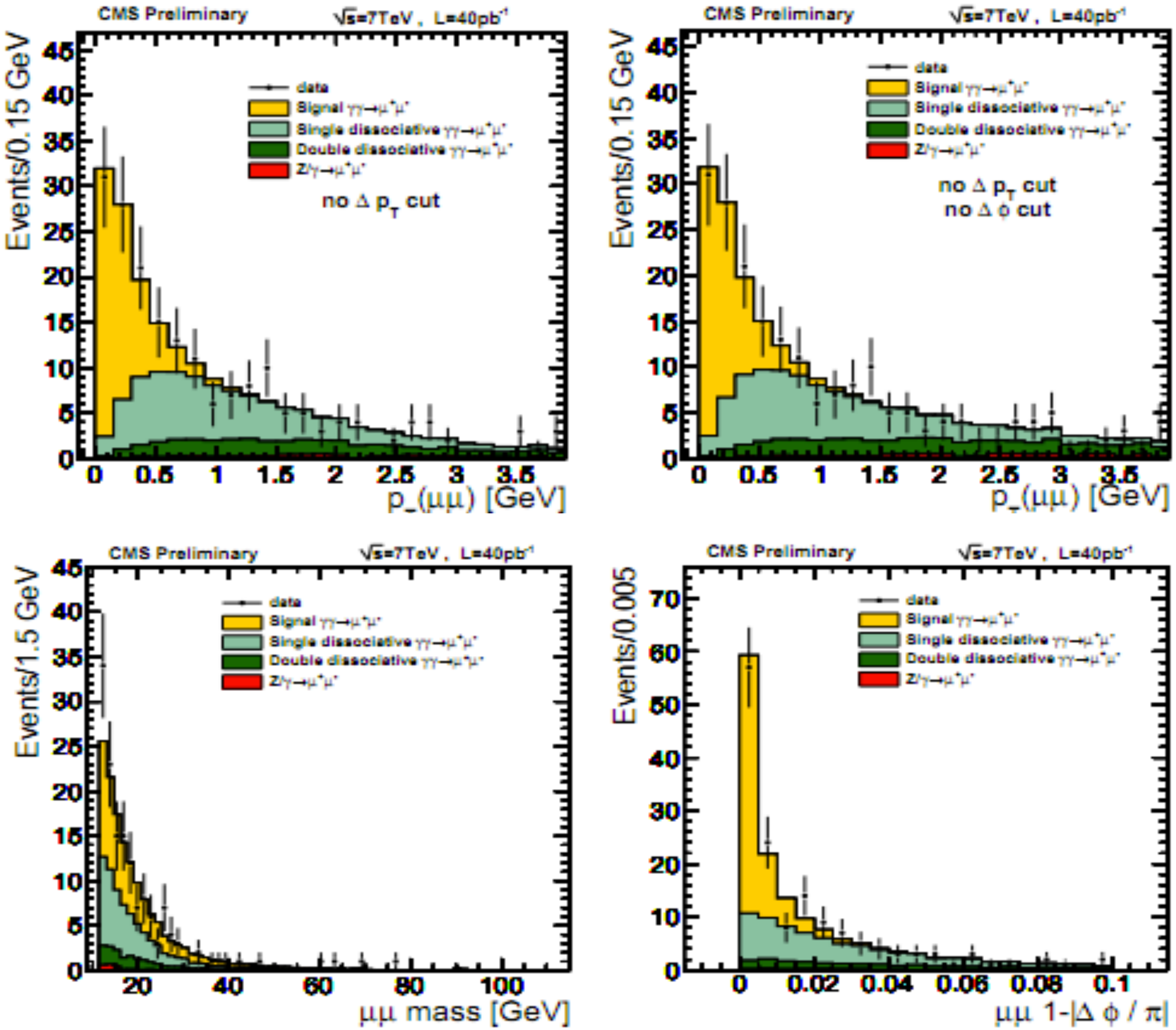
- We have performed 2 types of systematic checks:
  - **Variation of the luminosity values (±4%)**
  - **Modification of some of the analysis parameters**

Luminosity	$\Delta\sigma_{vtx}$
Scale the luminosity by +4%	-2.3
Scale the luminosity by -4%	+2.4

Analysis parameters	$\Delta\sigma_{vtx}$
Perform Analysis on a different dataset	+0.9
Change the fit upper limit from 0.6 to 0.5 $\cdot 10^{30} cm^{-2} s^{-1}$	0.3
Change the fit lower limit from 0.05 to 0.15 $\cdot 10^{30} cm^{-2} s^{-1}$: $\Delta\sigma_{vtx} = -0.3$	-0.3
Reduce the z-vertex range from 20 to 10 cm	-0.1
Change the ε correction by +0.02%	-0.4
Change the ε correction by -0.02%	0.3
Impose the minimum distance of ±1mm between two vertices	0.1

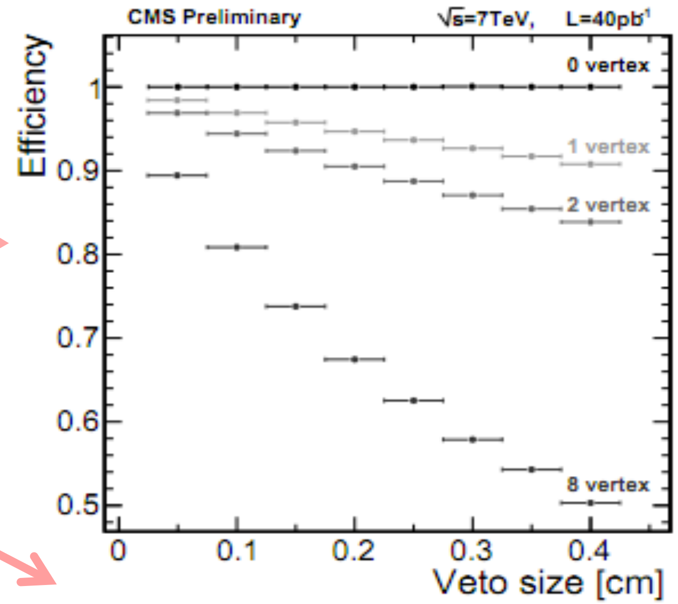
$$\sigma_{vtx} = 58.7 \pm 0.1(Stat) \pm 2.0(Syst) \pm 2.4(Lumi)\ mb$$

Exclusive Production:Control Plot

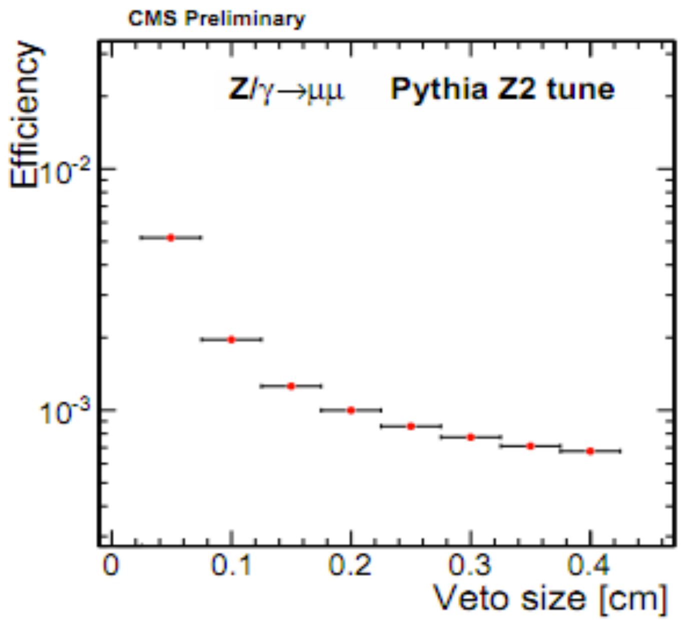


Efficiencies Correction

- Pile-up: During 2010, < 20% of the total luminosity with single interactions. Using min. bias events, introducing "fake di-muon events"
- Monte Carlo Simulation



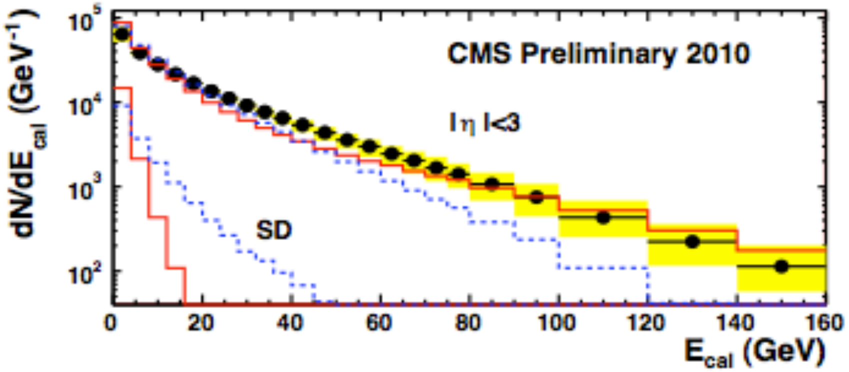
- Muon Efficiencies: Tag and Probe Method using inclusive J/Psi -> mmm and Z->mm.
- The resulting data/simulation ratio for the pair of (99.18 ± 0.14)% is applied as a correction to the efficiency.

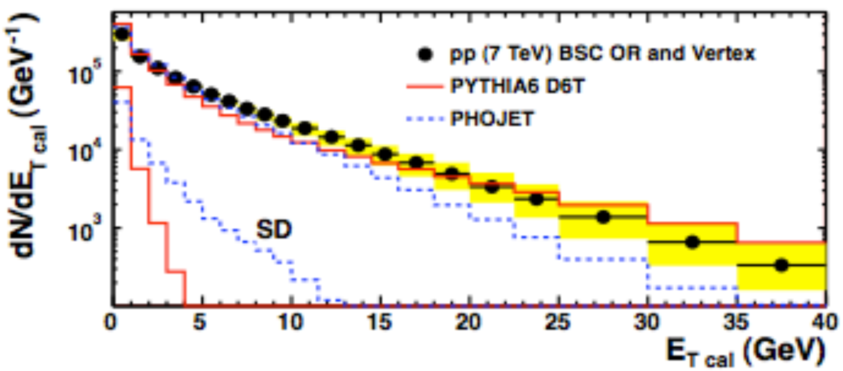


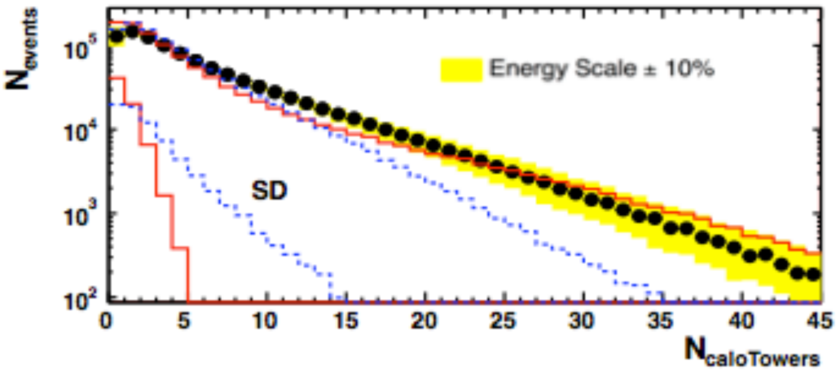
- Vertexing: efficiency to reconstruct primary vertex with only two tracks matching the Kalman Filter.
- The vertexing efficiencies agree between data and simulation at the 99.97%-level, and therefore no correction is applied.

Diffraction:MonteCarlo Simulation

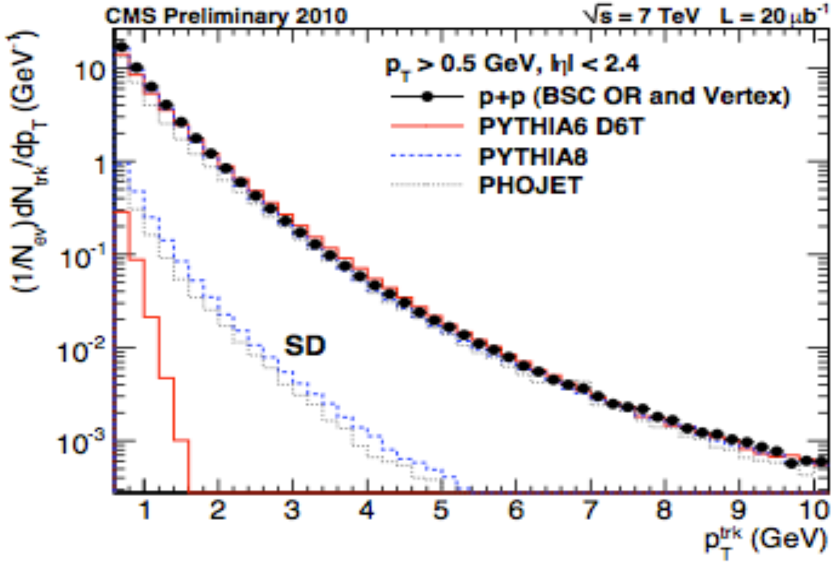
Calorimeter Distributions

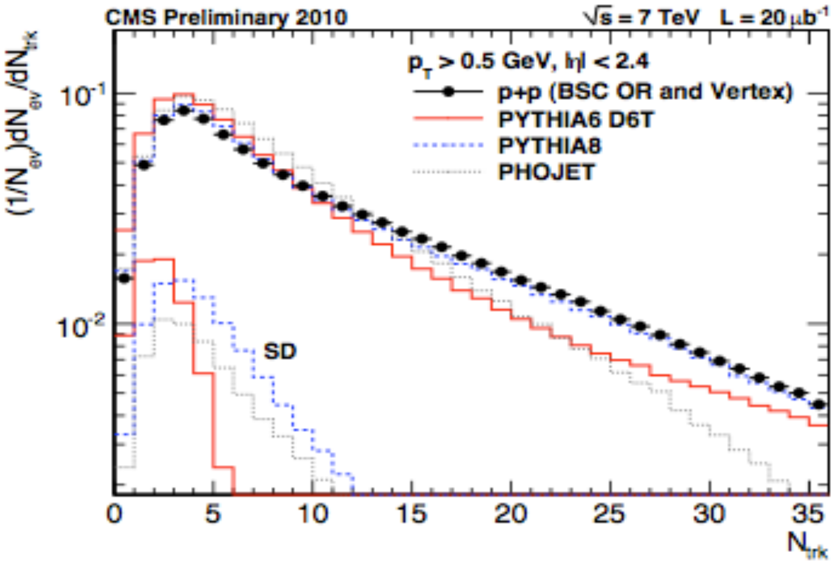






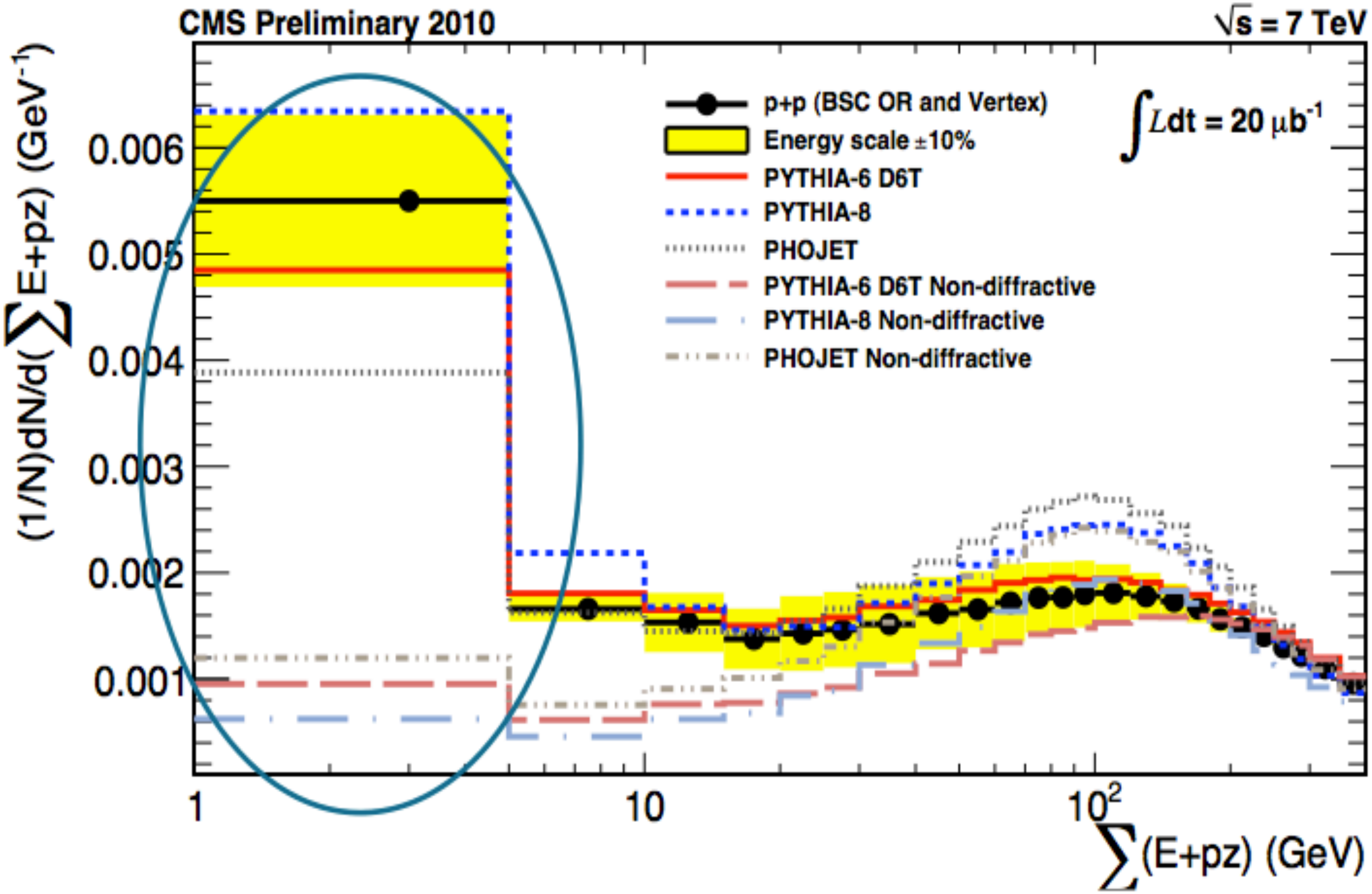
Inclusive Tracker Distributions





Observation of diffraction

- $\xi \sim \Sigma\,(E \pm p_z)$ if the proton emitting the pomeron moves in ± z direction
- diffractive events cluster at small values of $E \pm p_z$: $\sigma \sim 1/\xi$
- observation of diffractive peak in data



Fitted Cross Section

Each fit provides an estimate of the cross section.
The fit to these 9 values gives the final value:

σ(pp) = 58.7 mb

(2 charged particles with p_t>200 MeV in |eta|< 2.4)

ξ ($\xi = M_x^2/s$) interval: > 6 *10^{-5}