Inelastic pp cross section measurements in CMS

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for the **CMS Collaboration**

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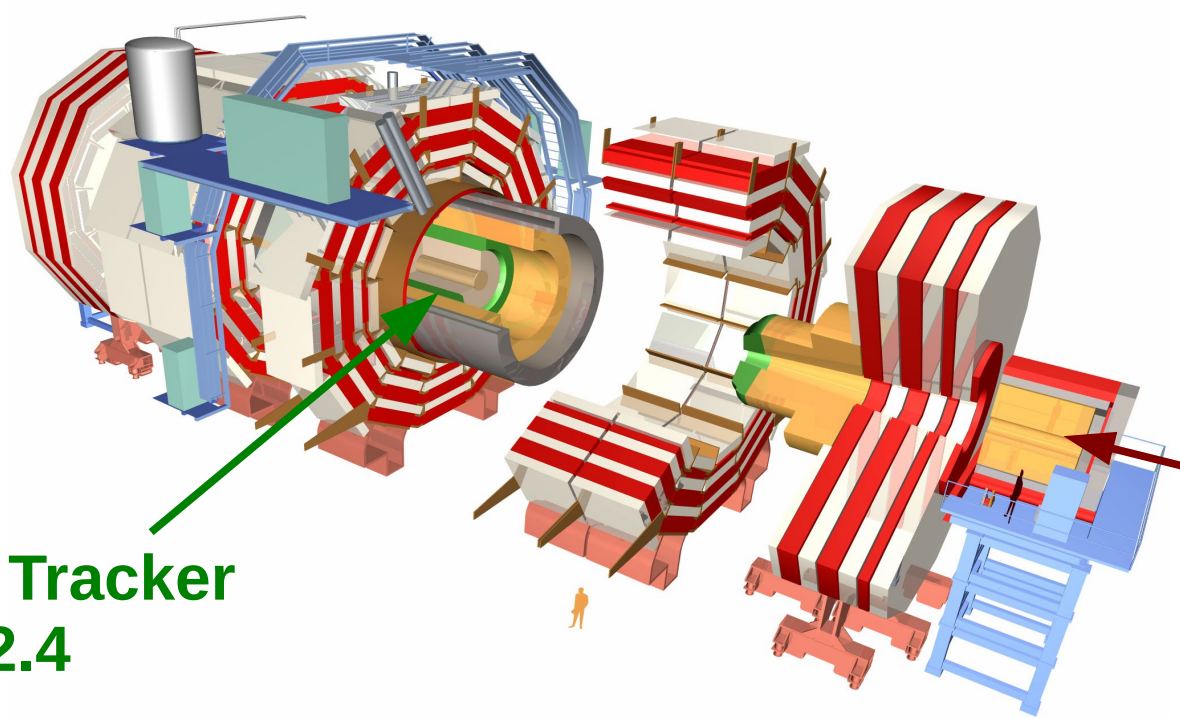
Outline

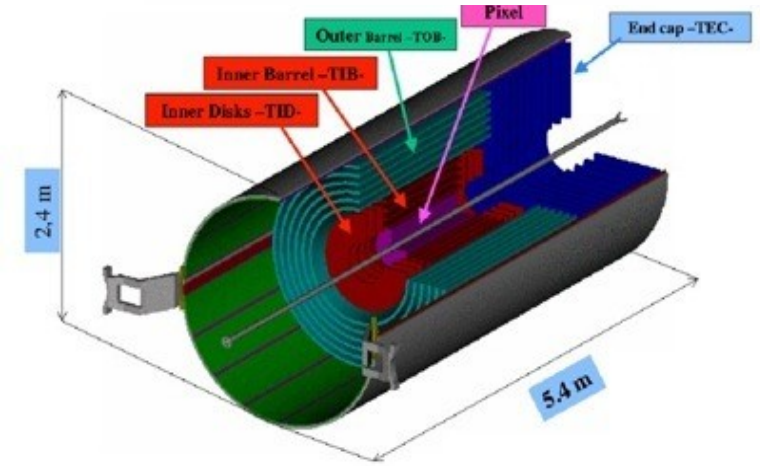
- CMS detector
- arXiv:1210.6718 – Measurement of the inelastic proton-proton cross section at √s = 7 TeV (submitted to PLB)
  - Event counting with single-sided trigger
    - Event selection
    - Event characterisation with ξ
    - Event selection efficiencies and corrections
    - Results for inelastic pp cross section with $\xi > 5 \times 10^{-6}$
  - Pile-up counting
    - Summary of the method
    - Results for the visible pp cross section
  - Comparisons to models

CMS detector



Inner Tracker
|η| < 2.4

Hadron Forward Calorimeter (HF)
2.9 < |η| < 5.2



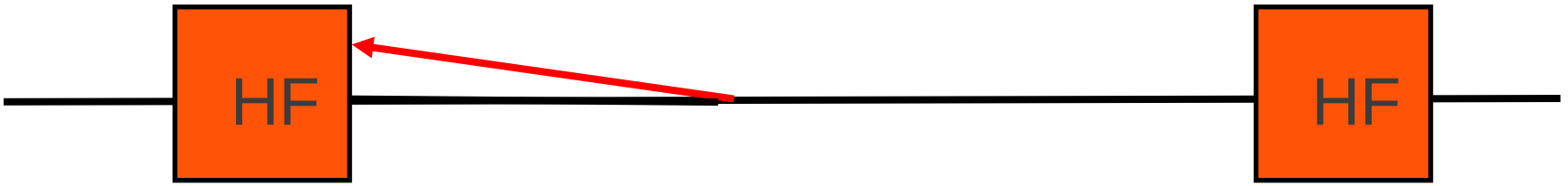
Event counting with single-sided trigger

Method overview

- Count proton-proton collisions in low pile-up data
- Use loose event selection criteria
- Subtract the background
- Correct for selection efficiency
- Correct for pile-up
- Calculate the cross section using independent luminosity measurement

Event selection

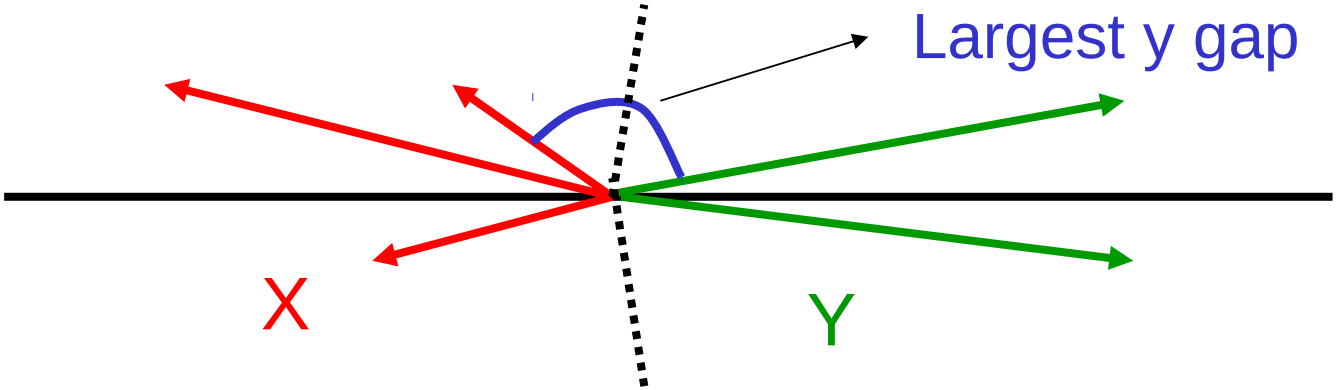
- Goal: as loose as possible selection to detect the largest possible cross section (smallest possible extrapolation)
- Single sided event selection is used: either HF has at least one hit above 5 GeV total energy



- Without using Tracker information, we cannot separate inelastic events in the same bunch crossing → need to use low pile-up data (λ = average number of collisions per bunch-crossing < 12%)
- Counted number of events in the data (after subtracting background): N_{inel}

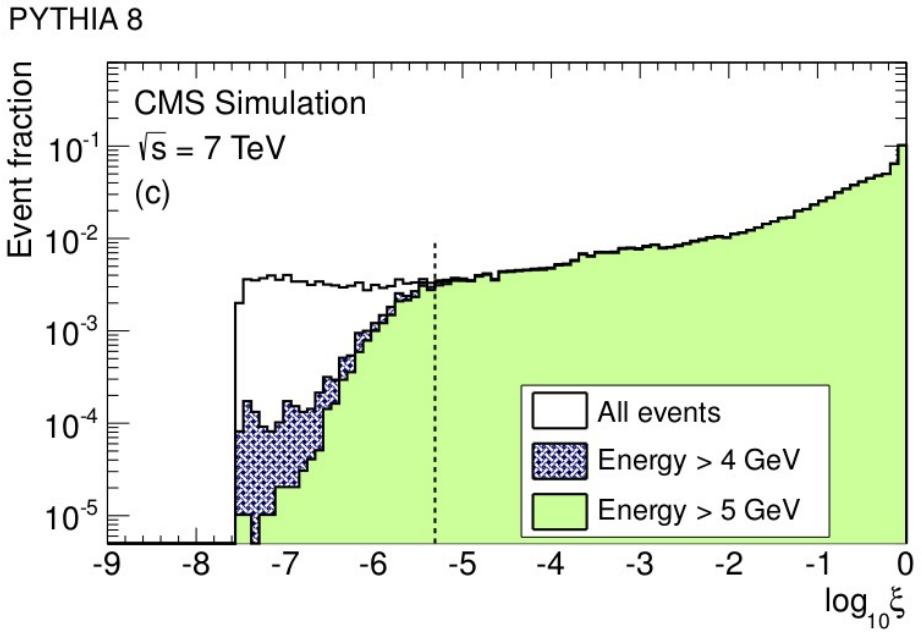
Event characterisation with ξ

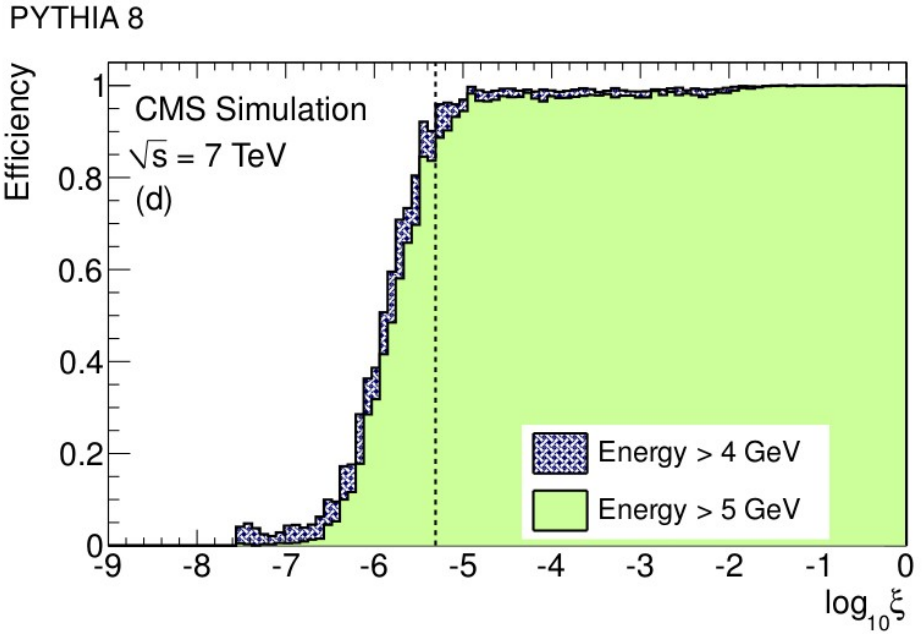
- Using generator level Monte Carlo



- $\xi = M_X^2/s$ where $M_X > M_Y$ the invariant mass of the system
- In case of single diffractive events, ξ is the fractional momentum loss of the scattered proton
- Events with small ξ can escape detection
- Useful to study the CMS (HF) event selection efficiency as a function of ξ

Event selection efficiency





ξ distribution of inelastic events

Efficiency vs ξ

- For $\xi > 5\times10^{-6}$, CMS has more than ~98% efficiency of detection
- (ATLAS & ALICE results are also available for $\xi > 5\times10^{-6}$)
- Let us measure the cross section of “high mass” events, defined by $\xi > 5\times10^{-6}$!

Efficiency from various models

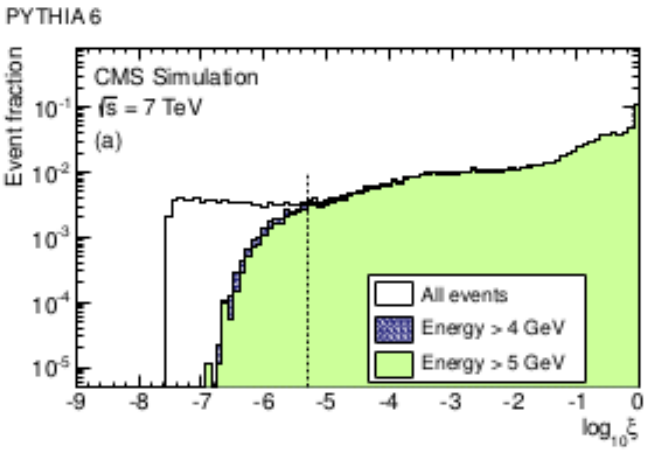
PYTHIA 6 D6T

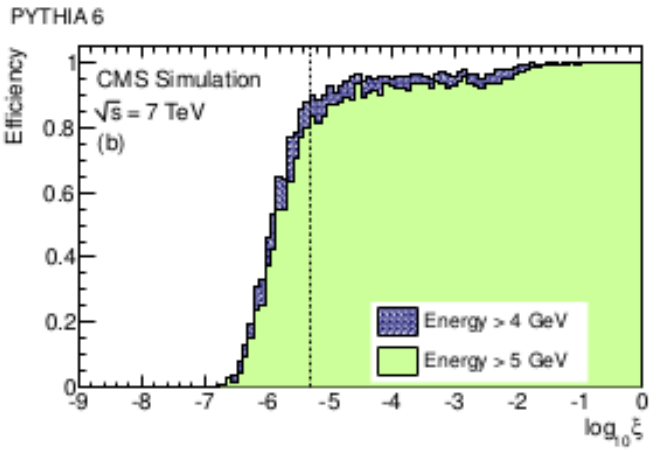
- All generated inelastic events
- HF hit > 4 GeV
- HF hit > 5 GeV

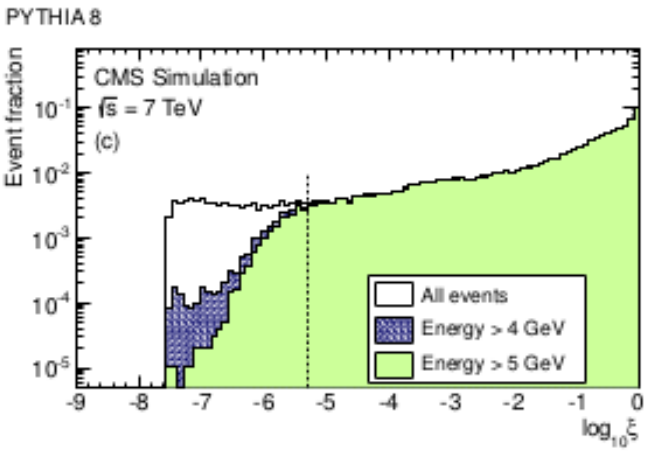
Full detector simulation

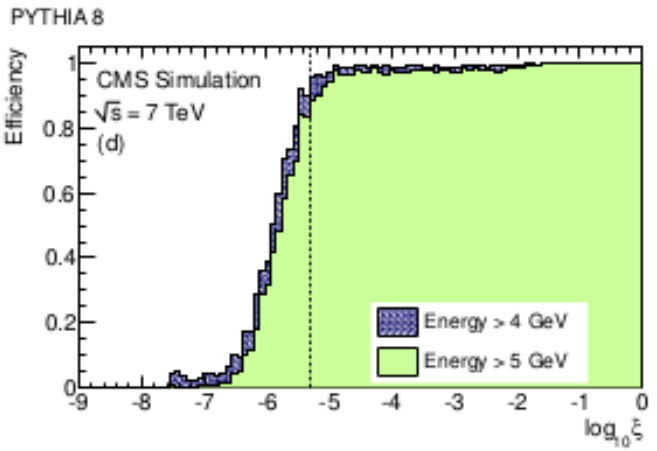
PYTHIA 8

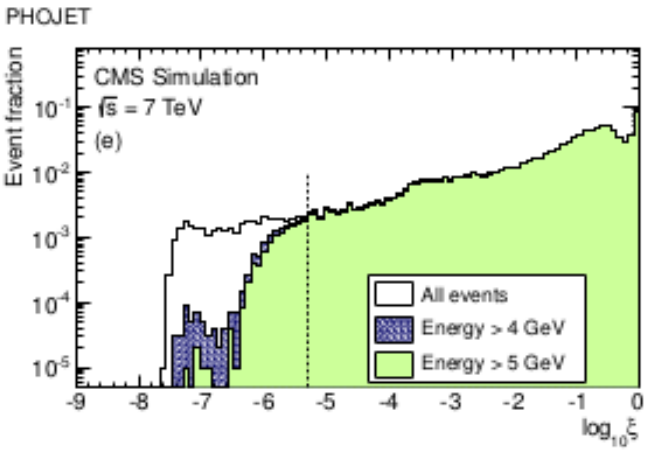
PHOJET

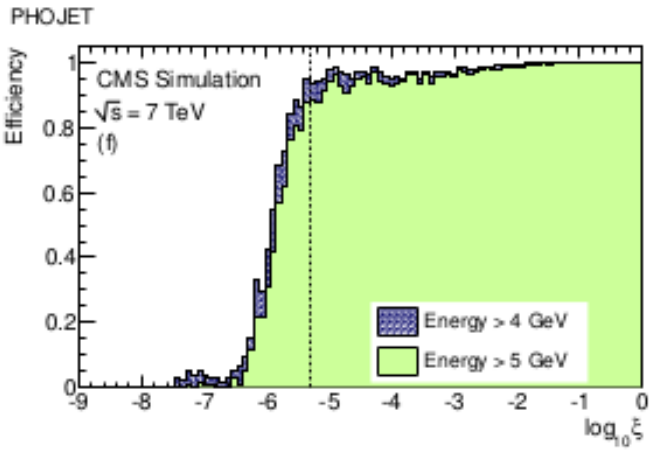




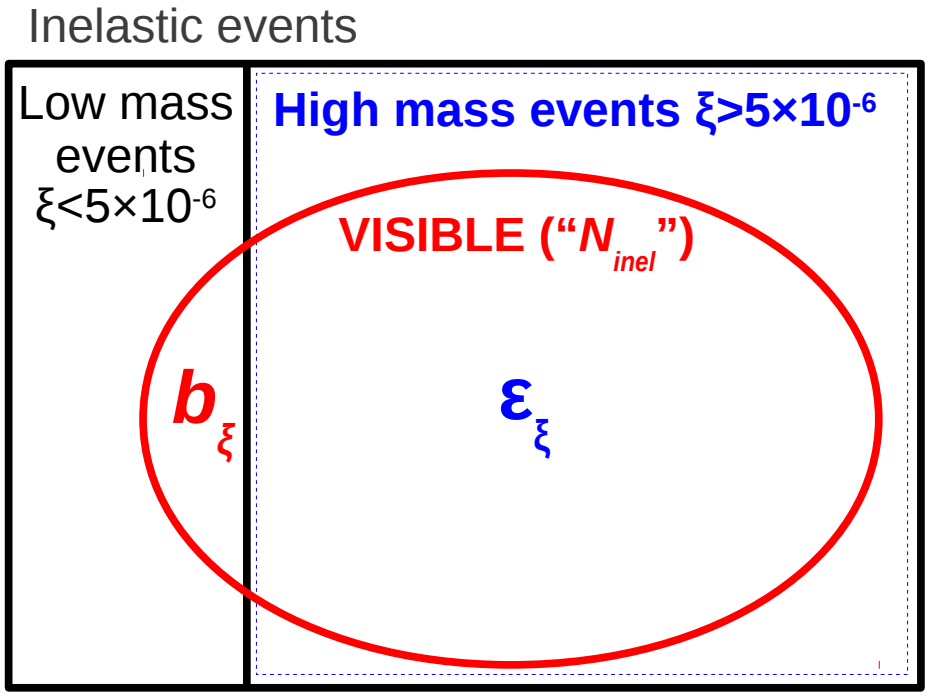








Definition of cross section



- b_ξ: fraction of visible events that are low mass (contamination)
- ε_ξ: fraction of high mass events that are visible (efficiency)

Pile-up correction

$$\sigma_{\text{inel}}(\xi > 5\times10^{-6}) = \frac{N_{\text{inel}}(1-b_\xi)(1+f_{\text{pu}})}{\epsilon_\xi \int L\,\mathrm{d}t}$$

Luminosity

Luminosity & pile-up correction

- The integrated luminosity is based on the Van der Meer scans
- The uncertainty of the luminosity is 4%: dominates the systematic uncertainties of this analysis
- Average pile-up (λ): number of collisions per bunch crossing
- More than one collision is also counted as one → $(1+f_{pu})$ correction

$$f_{\mathrm{pu}} = \frac{\Sigma_{i=2}^{\infty} P(i,\lambda)}{\Sigma_{i=1}^{\infty} P(i,\lambda)} = \frac{1-(1+\lambda)\mathrm{e}^{-\lambda}}{1-\mathrm{e}^{-\lambda}}$$
$$\sim \frac{\lambda}{2} - \frac{\lambda^2}{12} + \mathcal{O}\left(\lambda^3\right)$$

The pile-up is measured from data directly

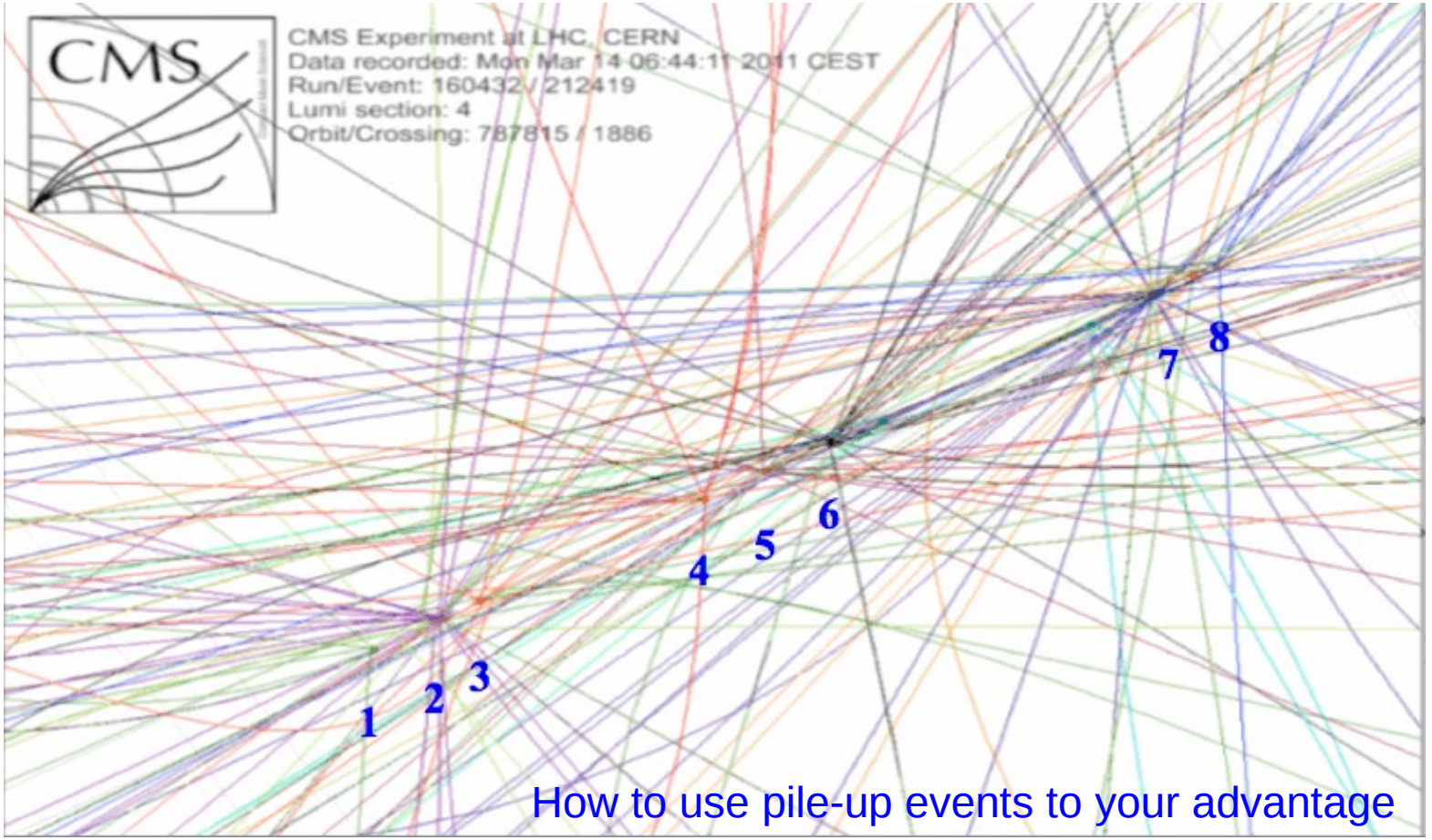
- Low pile-up data → small correction: f_{pu} ~ 0.0032 – 0.0491

Inelastic cross section with $\xi > 5 \times 10^{-6}$

- Average the σ values obtained under various (low) pile-up conditions → χ^2/ndof = 1.2 with the 5 GeV selection
- Systematics:
  - HF tower exclusion
  - Run-to-run luminosity variations
  - HF energy threshold
  - Model dependence

$$\sigma_{\text{inel}}(\xi > 5 \times 10^{-6}) = [60.2 \pm 0.2\,(\text{stat.}) \pm 1.1\,(\text{syst.}) \pm 2.4\,(\text{lum.})]\,\text{mb}$$

Pile-up counting method



Analysis method

- If we count the number of pile-up events as a function of the instantaneous luminosity, we can measure the pp cross section:

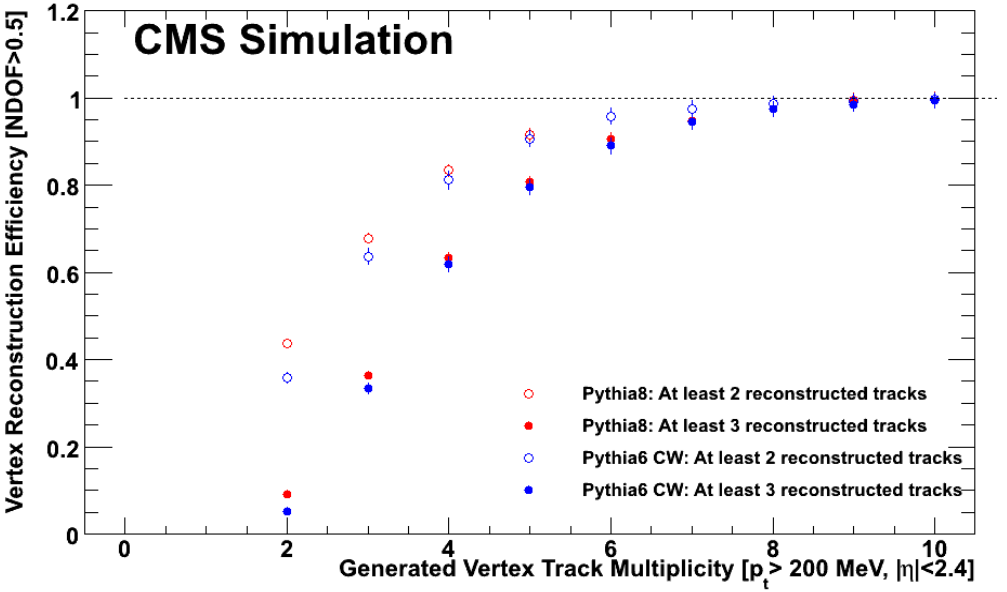
$$P(n) = \frac{(L \cdot \sigma)^n}{n!} e^{-L \cdot \sigma}$$

- Acquire the bunch crossing using a primary event:
  - the bunch crossing is recorded because there was an event that fired the trigger. We don't use this primary event, we only use it to record the bunch crossing.
- Count the number of pile-up events:
  - for any given bunch crossing, we count the number of vertices in the event.
- Correct the number of visible vertices for various effects:
  - vertex merging, vertex splitting, real secondary vertices…
- Fit the probability of having n = 0, … 8 pile-up events as a function of luminosity: using a Poisson fit, we obtain 9 values of $\sigma_{visible}$

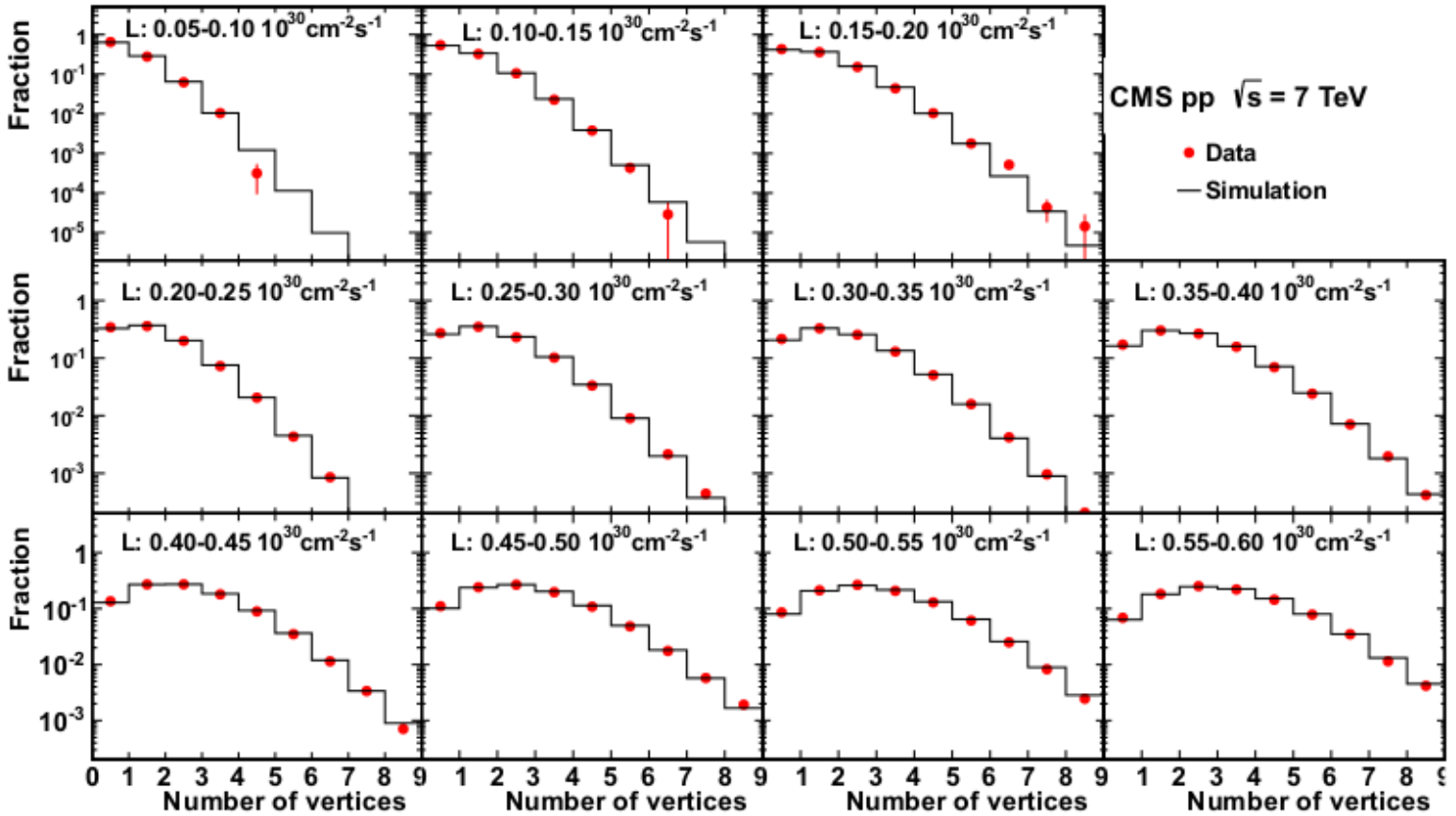
Vertices

- Real pile-up vertices are along the beam line
- Quality cuts:
  - At least 2, 3 or 4 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

- CMS vertex efficiency from `PYTHIA` simulation ~96% overall efficiency
- Bin-by-bin corrections for efficiency, vertex merging and fakes

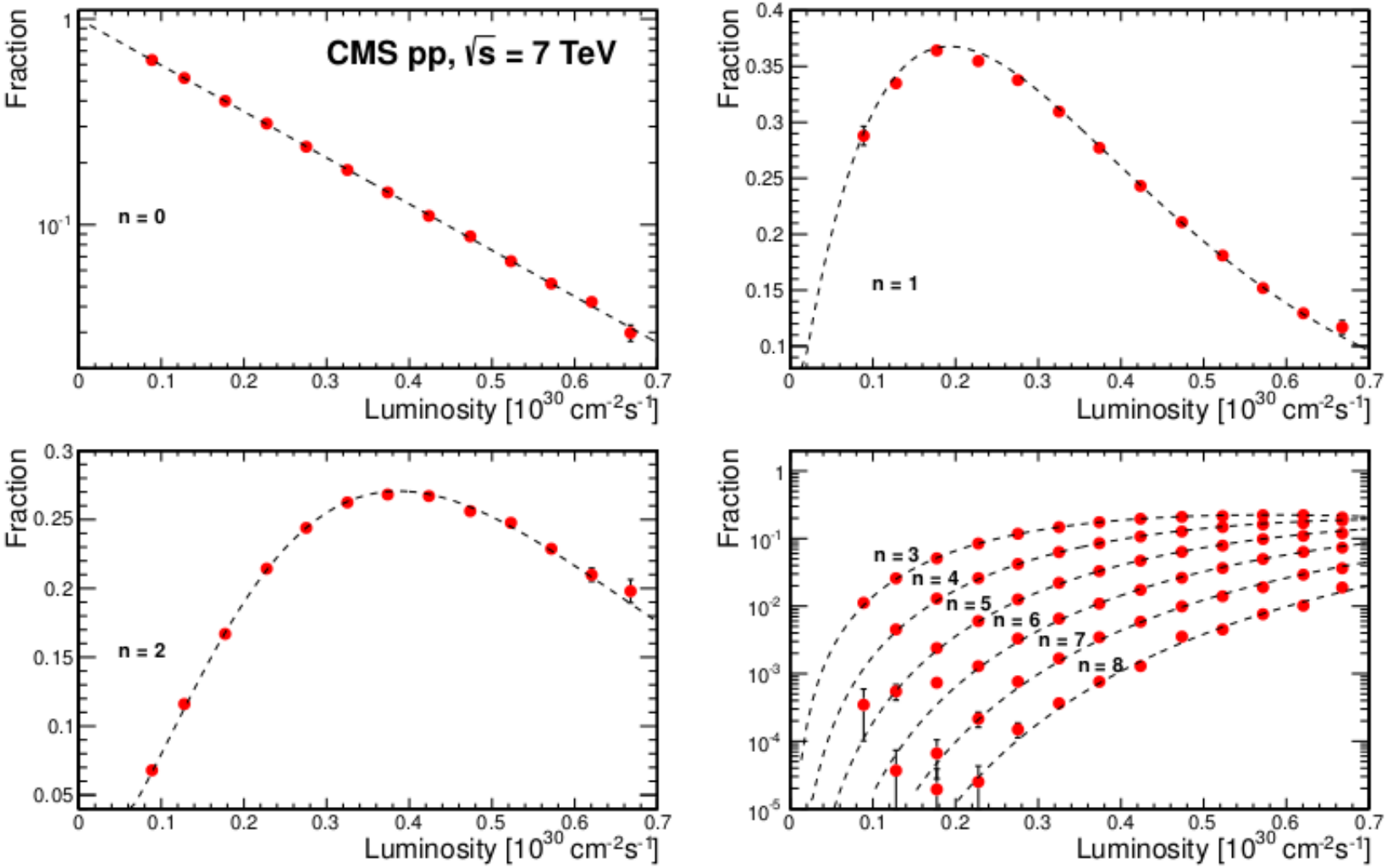


Simulation for vertex efficiency



- Not dependent on the specific physics model
- Data and MC divided into 13 luminosity bins
- In each luminosity bin we count the vertices

Corrected distributions



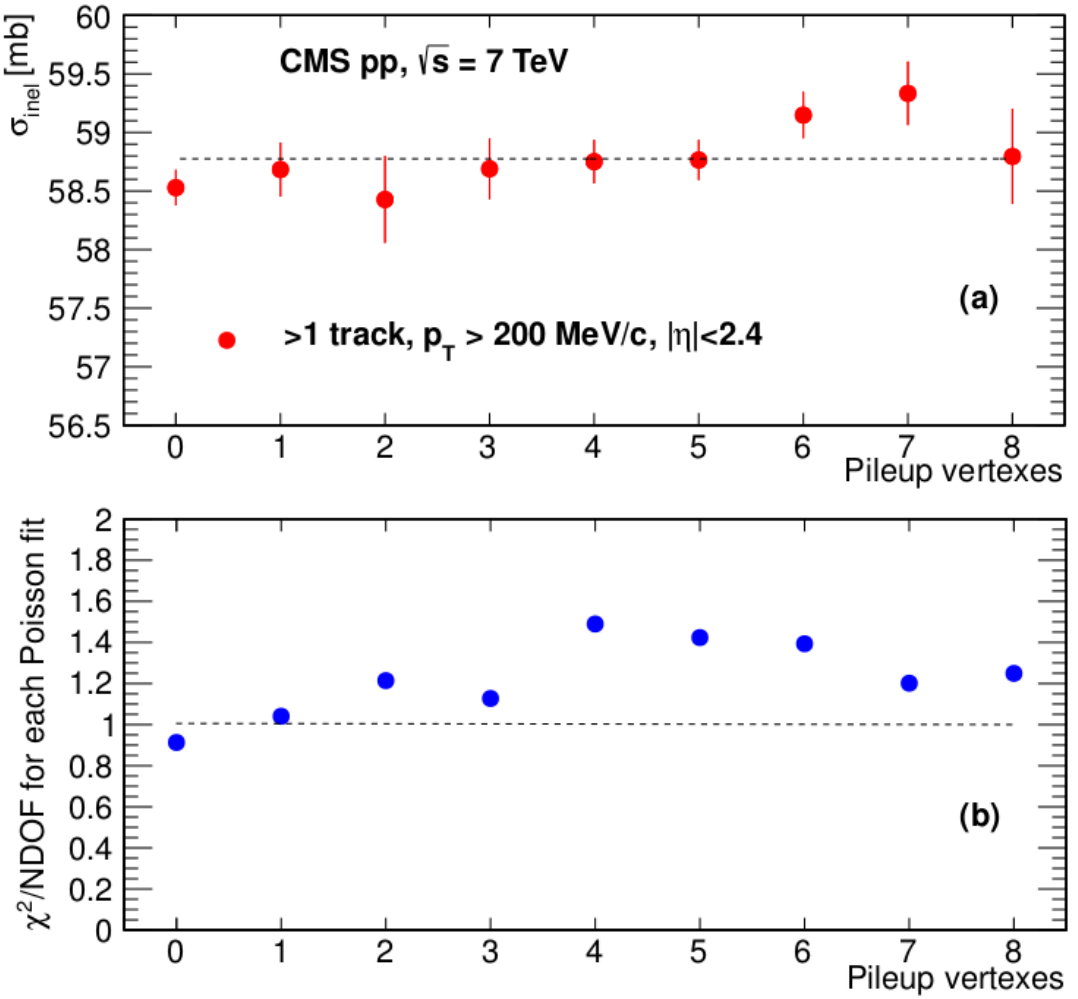
- After bin-by-bin corrections applied, the distributions are well fitted with Poisson distribution

Fitted cross section

- Visible pp cross section with at least 2 tracks $p_T > 200$ MeV in $|\eta| < 2.4$

  58.7 mb

- χ^2 of each fit close to 1
- Sources of systematics:
  - Different dataset
  - Changing fit limits
  - Minimum distance between vertices
  - Vertex quality requirement
  - Trying analytic method for corrections



Visible cross section results

With the same technique 3 different hadron level definitions of the visible cross section:

- 2 charged particles with $p_T > 200$ MeV in $|\eta| < 2.4$

$$\sigma_{vis} = 58.7 \pm 2.0 \text{ (syst.)} \pm 2.4 \text{ (lumi.) mb}$$

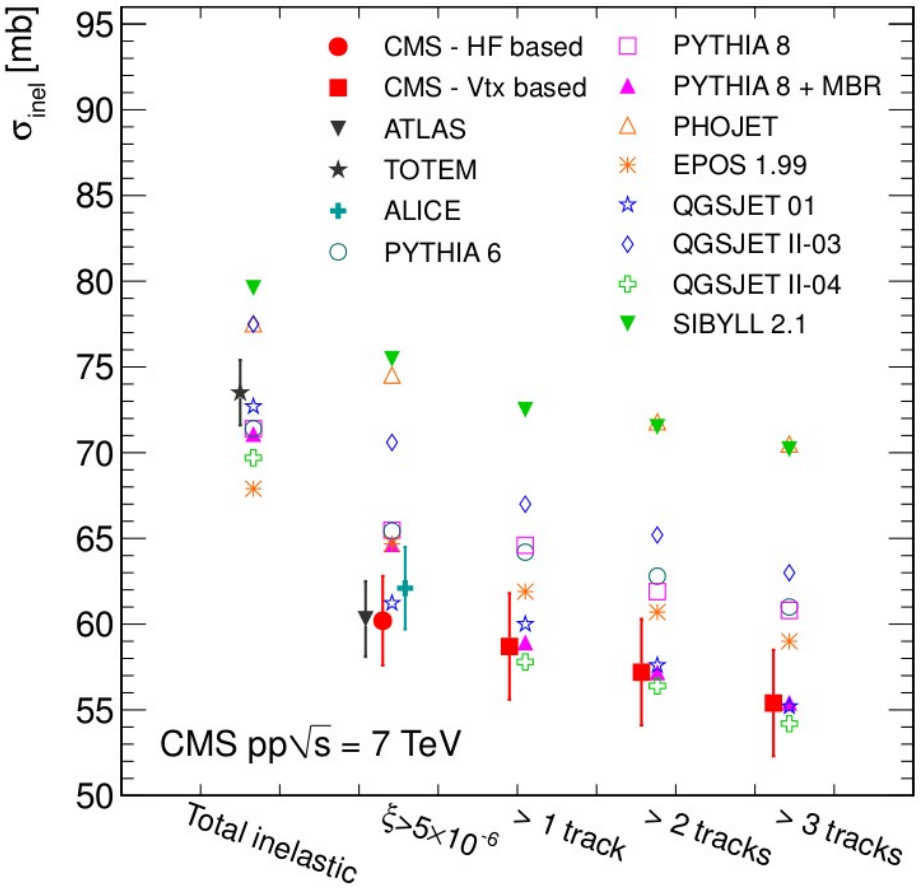
- 3 charged particles with $p_T > 200$ MeV in $|\eta| < 2.4$

$$\sigma_{vis} = 57.2 \pm 2.0 \text{ (syst.)} \pm 2.4 \text{ (lumi.) mb}$$

- 4 charged particles with $p_T > 200$ MeV in $|\eta| < 2.4$

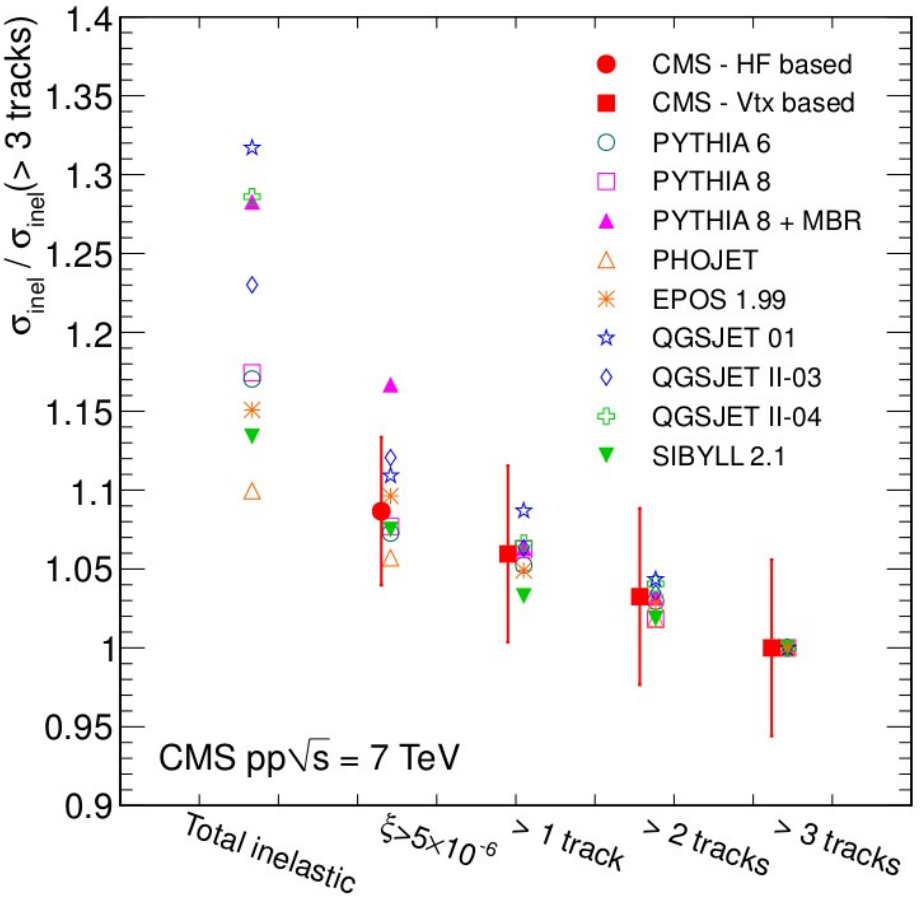
$$\sigma_{vis} = 55.4 \pm 2.0 \text{ (syst.)} \pm 2.4 \text{ (lumi.) mb}$$

Comparison to model expectations



- Pythia, Phojet and various models developed for cosmic-ray physics with ~1 mb uncertainty
- For $\sigma_{inel}(\xi > 5\times10^{-6})$ good agreement between ATLAS, ALICE and CMS

Comparison to model expectations



- Normalized to > 3 tracks point (errors are correlated)
- Most models agree in trend for the measured values but the extrapolation to total inelastic cross section shows large differences

Conclusions

- CMS measured the proton-proton inelastic cross section using two independent method and subdetector with different hadron-level definitions
- ATLAS, ALICE and CMS agreement for $\sigma_{inel}(\xi > 5\times10^{-6})$
- Pile-up events can also be used for cross section measurement → new method accessible at the LHC
- CMS can provide results for further tuning of the model parameters

Thank you for your attention!