Measurement of the inelastic proton-lead cross section at 5.02 TeV/nucleon pair center-of-mass energy

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Abstract

A measurement of the **inelastic proton-lead** (pPb) **cross section** at a nucleon-nucleon center-of-mass energy of 5.02 TeV is presented using the CMS detector at the LHC. Inelastic collisions are tagged using the **forward calorimeters (HF)** at pseudorapidities $3 < |\eta| < 5$. Two different event selections are used: (i) a **coincidence** of both sides of the detector, and (ii) a **single-sided** event selection. These two selections have different sensitivity to contributions from photon-induced (γp) collisions and hadronic diffractive interactions. The value of the hadronic inelastic cross section is measured within the CMS acceptance and **extrapolated** to its total value. The photon-induced contribution is subtracted. The final result is $\sigma_{inel} = 2.06 \pm 0.08$ b. The uncertainty is dominated by the **luminosity** determination. This result is consistent with the expectation from the Glauber approach.

Introduction

Total inelastic cross section: not calculable from first principles, **non-perturbative** aspects.
Possible coherence in multiple scattering processes: Glauber [1] and Gribov-Regge [2] approaches.
Contamination from **photo-hadronic** interactions ($\sim Z^2$) are subtracted in this analysis.
Cross sections are essential **input to MC** models (PYTHIA [3], HIJING [4], EPOS [5], QGSJetII [6]).
Glauber: neglects nucleon-nucleon **correlations** and **diffraction** (inelastic screening) in multiple scatterings ($\pm 10\%$ effects) [7].
Connection to proton-air cross section in **cosmic ray** experiments.
CMS HF calorimeter: measuring the **visible** xsec
BPTX: **zero bias** trigger and unpaired bunch trigger

Data, luminosity

296 bunch pairs, 7×10^9 Pb ions on 15×10^9 protons
Two short **van der Meer** scans
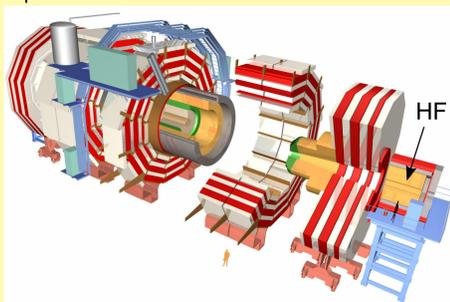(both beam direction configurations)
Systematic uncertainty: 3.5%
Luminosity determination is based on rate measurements with displaced beams and on bunch intensities, and **independent** of event counting.
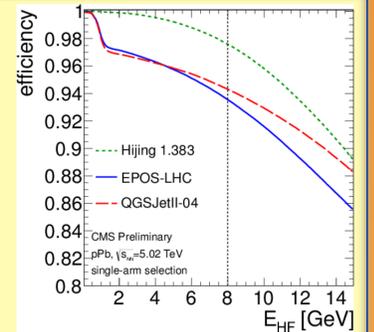
HF

Event counting

Inelastic events are **counted** (N_{inel}) and divided by the integrated luminosity:

$$\sigma_{inel} = \frac{N_{inel}}{\mathcal{L}}$$

Simulation: EPOS-LHC [5], QGSJetII-04 [6], HIJING [4] combined with GEANT4.
Electromagnetic interactions: STARLIGHT [8] and DPMJET 3 [9] or PYTHIA.
Event selection: • **single arm** HF: large acceptance for single diffraction and EM events, noisy
• **double** arm HF: coincidence, eliminates EM events and noise, reduced acceptance
Cut is made in E_{HF}, where E_{HF+} (E_{HF-}) is the max. energy in a HF tower on the +(-) side:

$$E_{HF} = \begin{cases} \max(E_{HF+}, E_{HF-}) & \text{single arm, threshold: 8 GeV} \\ \min(E_{HF+}, E_{HF-}) & \text{double arm, threshold: 4 GeV} \end{cases}$$

Composition of the event sample

Single-arm and double-arm selections have different **acceptance** for (single, double and central) **diffractive** and **non-diffractive** events. Within a given model one can estimate their contributions.

Cartoon of a single diffractive event:

Pb 1.6 TeV   p 4 TeV

Composition of the event sample (single arm):

Composition of the event sample before and after selections:

Model	Selection	SD [%]	DD [%]	CD [%]	ND [%]	∑ [%]	Ratio (MC)	Ratio (Data)
EPOS-LHC	No selection	4.5	4.5	1.1	90.0	100	-	
	Single-arm	1.7	2.4	0.7	88.9	93.7	0.969	
	Double-arm	1.1	1.8	0.5	87.3	90.8		
HIJING	No selection	-	-	-	100	100	-	0.966
	Single-arm	-	-	-	97.7	97.7	0.972	
	Double-arm	-	-	-	94.9	94.9		
QGSJETII-04	No selection	5.1	1.8	0.0	93.1	100	-	
	Single-arm	1.2	1.2	0.0	92.0	94.4	0.971	
	Double-arm	0.3	0.7	0.0	90.7	91.7		

Corrections

• **Noise** events: from non-colliding triggers (5.4 and 0.5% for single- and double-sided selections)
• Contribution from γp interactions (3.4 and 0.02%)
• Contribution from collision pileup (1.8%)
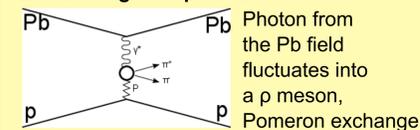• **Extrapolation** to full phase space (9 and 6%)
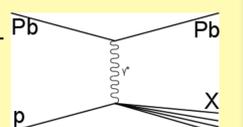

Efficiencies for single-sided selections:

Pileup correction: multiple collisions in the same bunch crossing are counted as a single collision. The pileup (λ) can be calculated from machine parameters, the measured inst. luminosity, and (iteratively) from the result of this analysis, σ_{inel}. The correction (about 2%) is then:

$$f_{PU} = \frac{\sum_{i=1}^{\infty} i \epsilon_{acc} \, \mathrm{Pois}(i; \lambda)}{\sum_{i=1}^{\infty} P_i \, \mathrm{Pois}(i; \lambda)} = \frac{\epsilon_{acc} \lambda}{\sum_{i=1}^{\infty} P_i \, \mathrm{Pois}(i; \lambda)}$$

Electromagnetic processes: corrected using STARLIGHT [8] simulations. Examples:

Photon from the Pb field fluctuates into a ρ meson, Pomeron exchange

interaction with quasi-real photon leads to proton breakup

Results

Visible cross section: σ_{vis}, all processes that pass selection cuts
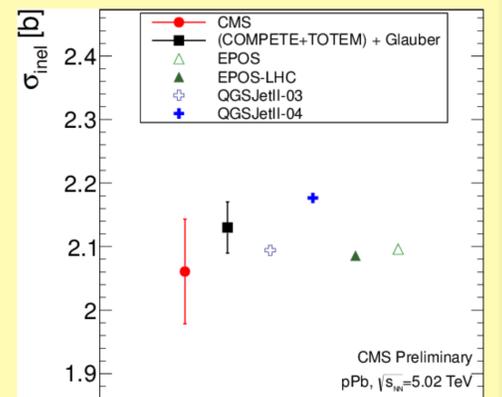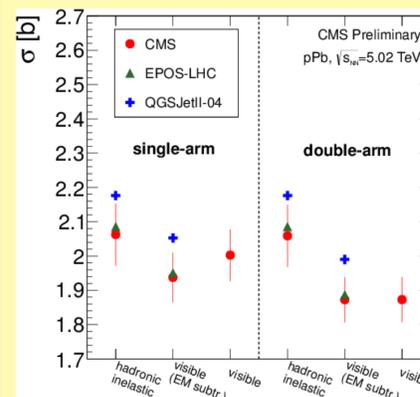**Visible hadronic** cross section: $\sigma_{vis,had}$, electromagnetic events subtracted from σ_{vis}
Hadronic inelastic cross section: σ_{inel}, the visible hadronic xsec extrapolated to full phase space
Systematic uncertainties: luminosity (3.5%), extrapolation to full phase space (0.5% and 1.6%), photo-nuclear contribution (0.2% and <0.1%), HF energy resolution (1.7% and 0.8%), selection cuts (0.6% and 0.2%) and variations of noise correction (1.2% and 0.2%), in total: 4.4% for both selections

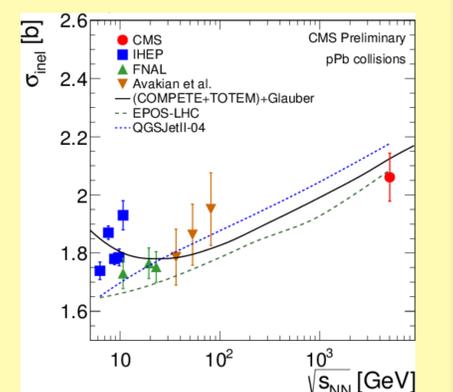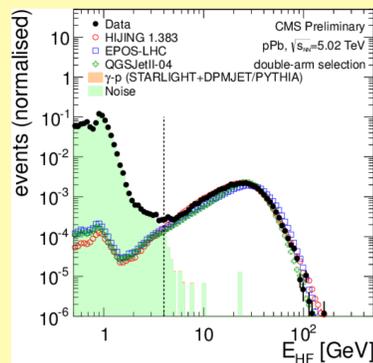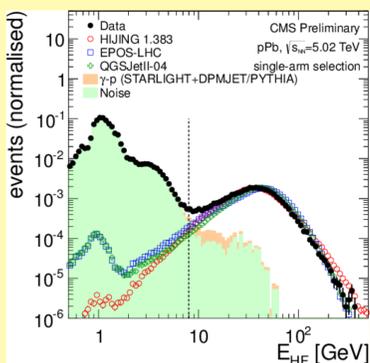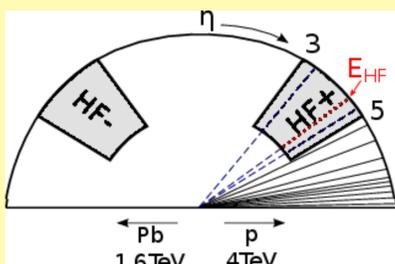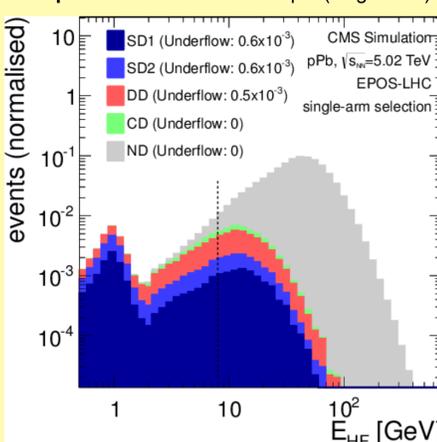| Selection	σ_{vis} (b)	$\sigma_{vis,had}$ (b)	σ_{inel} (b)
$E_{HF} > 8$ GeV (single-arm)	2.003	1.938	2.063
$E_{HF} > 4$ GeV (double-arm)	1.873	1.873	2.059

Averaged result: $\sigma_{inel} = 2.061 \pm 0.003$ (stat.) ± 0.039 (syst.) ± 0.072 (lumi.) barns
Model comparisons:

Hadronic inelastic proton-lead cross section as a function of **center-of-mass energy**. The lines show predictions by various models, and a Glauber calculation based on the proton-proton cross section from a global fit to world data.

Visible cross section measurements have been also carried out (without correction for electromagnetic processes) by the ALICE [10] (2.09 ± 0.06 and 2.12 ± 0.06 b) and LHCb [11] (2.09 ± 0.12 b), experiments using detectors in a similar η region.

Conclusions

The hadronic inelastic pPb cross section was measured at 5.02 TeV c.m. energy per nucleon pair. The result is compatible with the Glauber prediction of 2.13 ± 0.04 barns. Thus, screening and anti-screening effects seem to compensate each other. Other model predictions are also compatible with the result within experimental uncertainties, with the possible exception of QGSJETII-04.

References

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