Luminosity determination for the measurement of the total pp cross-section and the ρ-parameter with the ATLAS experiment at the LHC

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Importance of measuring σ_{tot} and the ρ-parameter

☑ The total proton-proton cross section is dominated by non-perturbative processes impossible to calculate precisely ⇨ the experimental approach is the only handle to determine σ_{tot} and ρ

☑ Measurements at various center of mass energies ⇨ determine energy evolution of σ_{tot} and ρ and test phenomenological models

$$\sigma^2_{tot} = \frac{16\pi(\hbar c)^2}{1+\rho^2} \left.\frac{d\sigma_{el}}{dt}\right|_{t\to 0}$$

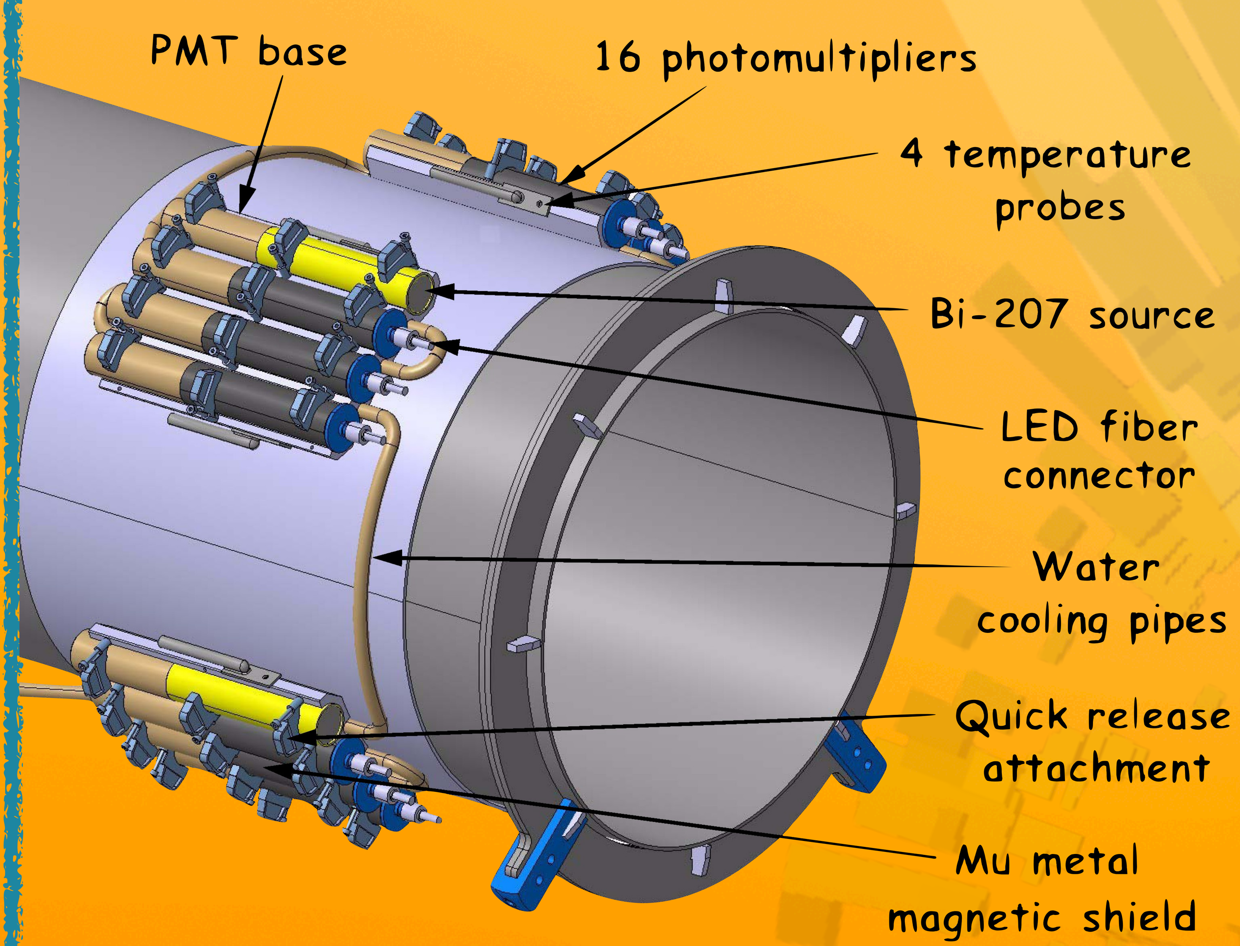
$$\rho = \left.\frac{Re[f_{el}(t)]}{Im[f_{el}(t)]}\right|_{t\to 0}$$

f_{el} = elastic-scattering amplitude

Analysis principle: Use high-β^* optics for small divergence of the beam at Interaction Point (IP) ⇨ Measure $d\sigma_{el}/dt$ at low $|t|$, with t the four-momentum transfer, sensitive to both Coulomb and strong amplitudes and their interference ⇨ Optical Theorem ⇨ extract ρ and σ_{tot}

Use of the luminosity-dependent method ⇨ requires a measurement of the luminosity in order to normalise the elastic cross section ⇨ high-precision luminosity measurement needed

LUCID and luminosity determination in ATLAS



The LUCID detector

- ✱ 16 PMTs for each side (A and C) at 17m from IP
- ✱ Measure Cherenkov light produced on PMT quartz window by charged particles
- ✱ Gain monitoring system using ^{207}Bi
- ✱ Single PMTs act as independent detectors or are combined in global algorithms

Backgrounds {Fig. 1}

- ✱ Constant rate in every bunch from ^{207}Bi activity
- ✱ Afterglow from nuclear de-excitation after collisions

⇨ Bkg evaluation from the rate in the bunch slot preceding the colliding one

β* = 90 m

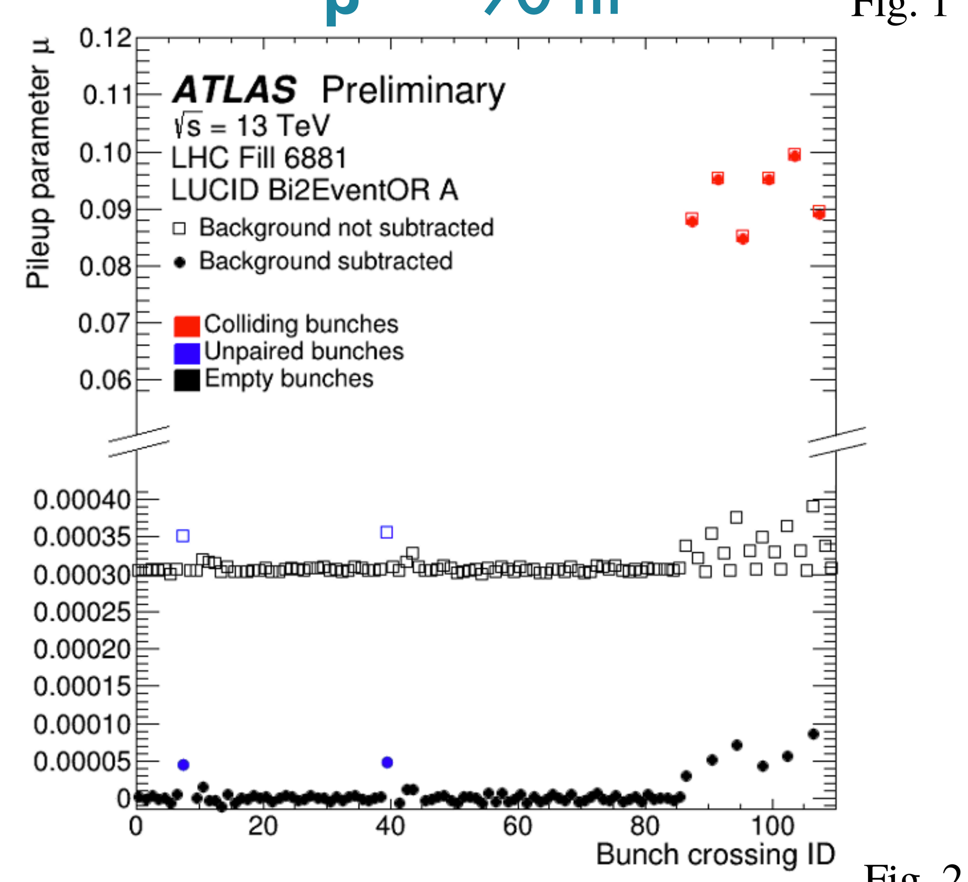


Fig. 1

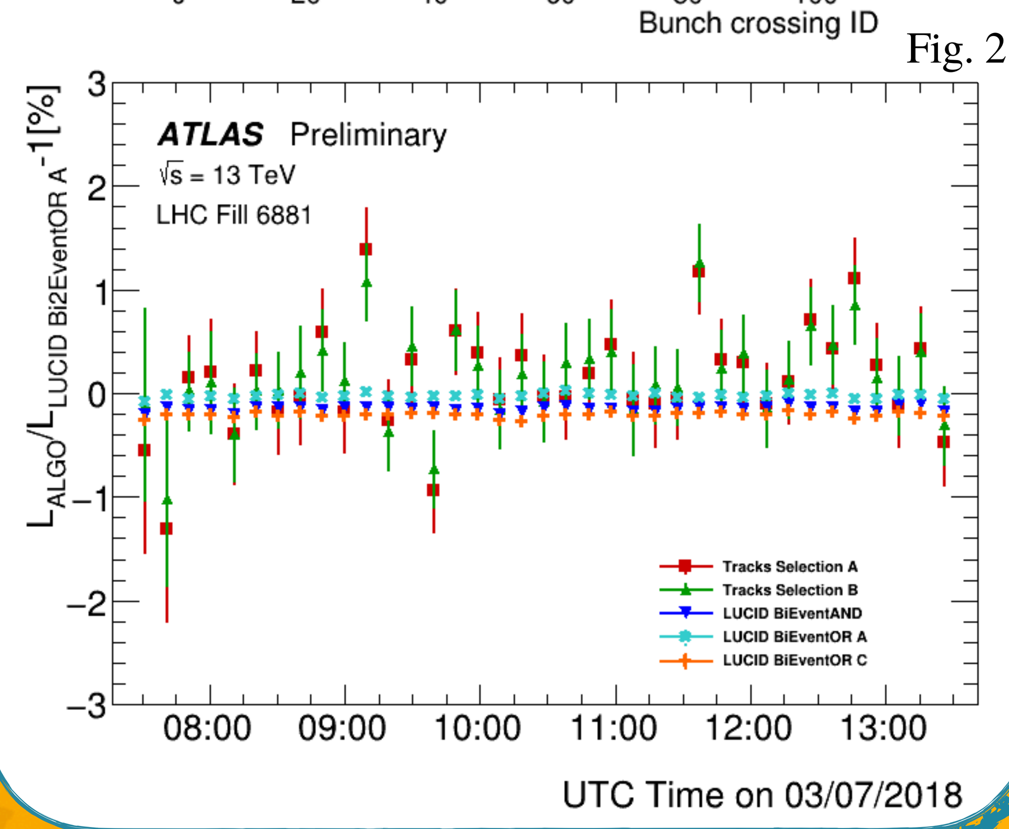


Fig. 2

Luminosity determination strategy with LUCID

1. Measure the background-subtracted bunch-averaged number of interactions $\langle\mu\rangle$ that take place in every colliding bunch pair, with various independent and stable LUCID algorithms calibrated in van der Meer (vdM) scans
2. Compare different detectors and algorithms (e.g. Track Counting, Beam Condition Monitor) to provide a reliable measurement and assess systematic uncertainties {Fig. 2 and 3}

Results for luminosity estimation at high β* runs

Main sources of systematic uncertainties

- ✱ Absolute calibration obtained with vdM scans
- ✱ Compatibility among detectors / algorithms {Fig. 3 and 4} ⇨ accounts for long-term stability, background subtraction uncertainty, luminosity scale difference between vdM and used samples {Table 1}

Table 1: Example of main run parameters in 2016

Parameters	2016 high-β^* runs	2016 vdM scan	High-lumi runs
Number of colliding bunches	$4-5$	32	2208
Average pile-up parameter μ	$0.002-0.006$	0.5	41
Instantaneous lumi (10^{27} cm^{-2}s^{-1})	$\sim 1.4-4$	$2.6\cdot 10^3$	$13\cdot 10^6$
β^* (m)	2500	19	0.4

β* = 2.5 km

Energy [TeV]	L_{tot} [μb^{-1}]	Precision	Ref.
13	$339.90\pm 0.14_{stat}\pm 6.8_{sys}$	2.15%	[3]

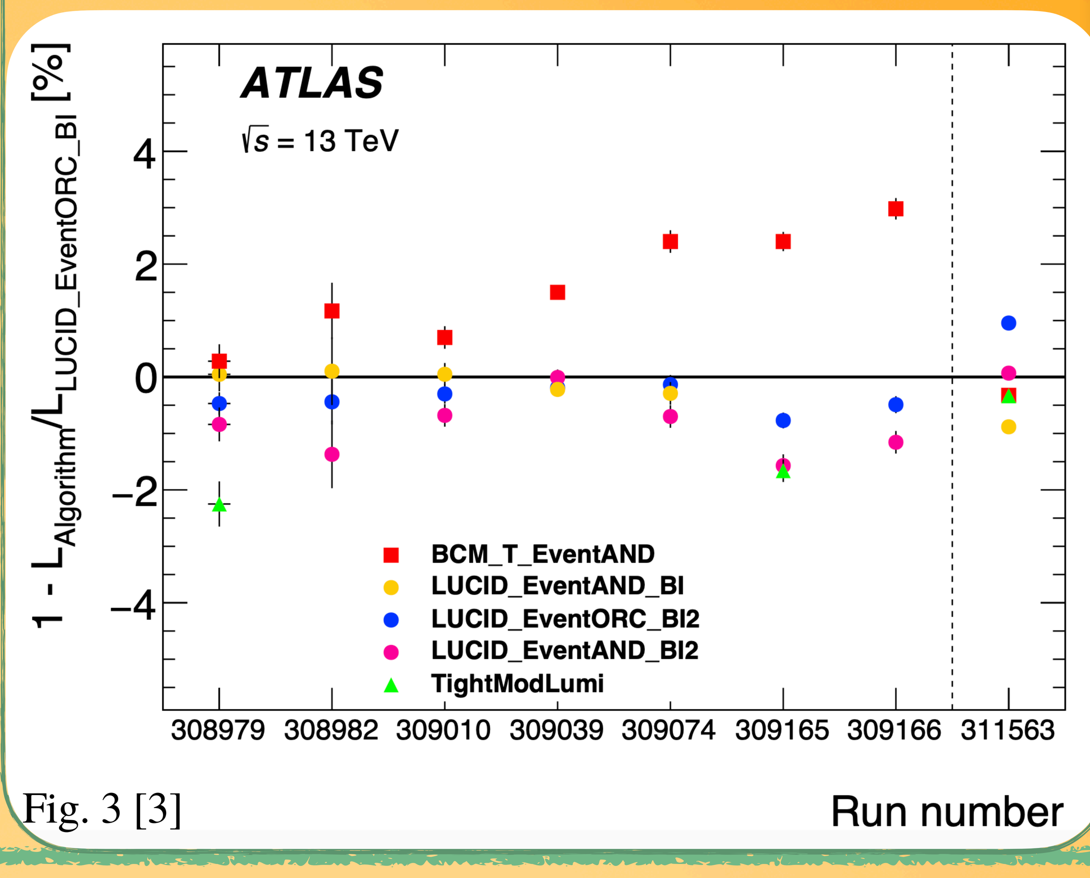


Fig. 3 [3]

β* = 90 m

Energy [TeV]	L_{tot} [μb^{-1}]	Precision	Ref.
7	$78.7\pm 0.1(stat.)\pm 1.9(syst.)$	2.3%	[1]
8	$496.3\pm 0.3(stat)\pm 7.3(syst.)$	1.5%	[2]
13	$(664\pm 7(stat.+syst.))\times 10^3$	1.0%	Preliminary

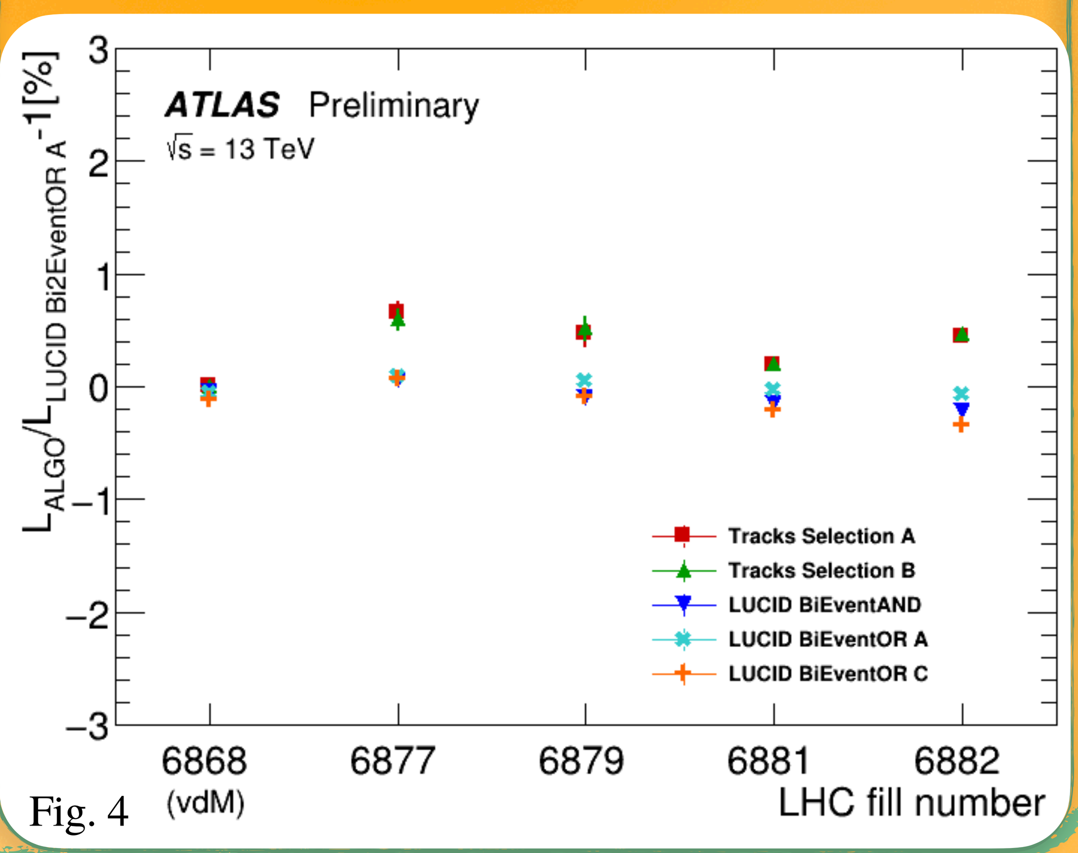


Fig. 4

Conclusions

Excellent precision in the luminosity measurement achieved in a luminosity regime up to seven orders of magnitude lower than in standard data-taking conditions, allows the most precise measurement of σ_{tot} and ρ at 13 TeV with β^* = 2.5 km [3].
The reported σ_{tot} value has a 2.2σ tension with respect to TOTEM result [4].

The latest luminosity measurement for 13 TeV runs with β^* = 90 m has been obtained with a preliminary 1% total uncertainty, making it the most precise for these low-luminosity runs.

References

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[2] ATLAS Collaboration, *Measurement of the total cross section from elastic scattering in pp collisions at $\sqrt{s}$ = 8 TeV with the ATLAS detector*. Physics Letters B, Volume 761, 2016, pages 158-178, ISSN 0370-2693, DOI: https://doi.org/10.1016/j.physletb.2016.08.020.
[3] ATLAS Collaboration, *Measurement of the total cross section from elastic scattering in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector*. arXiv: 2207.12246.
[4] TOTEM Collaboration, *First determination of the ρ parameter at $\sqrt{s}$ = 13 TeV: probing the existence of a colourless C-odd three-gluon compound state: TOTEM Collaboration*. The European Physical Journal C, Volume 79, no. 9, 2019, page 785.

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