Overview of ALICE luminosity-determination methodology in Run 2

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for the ALICE Collaboration

LHC Lumi Days

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Outline

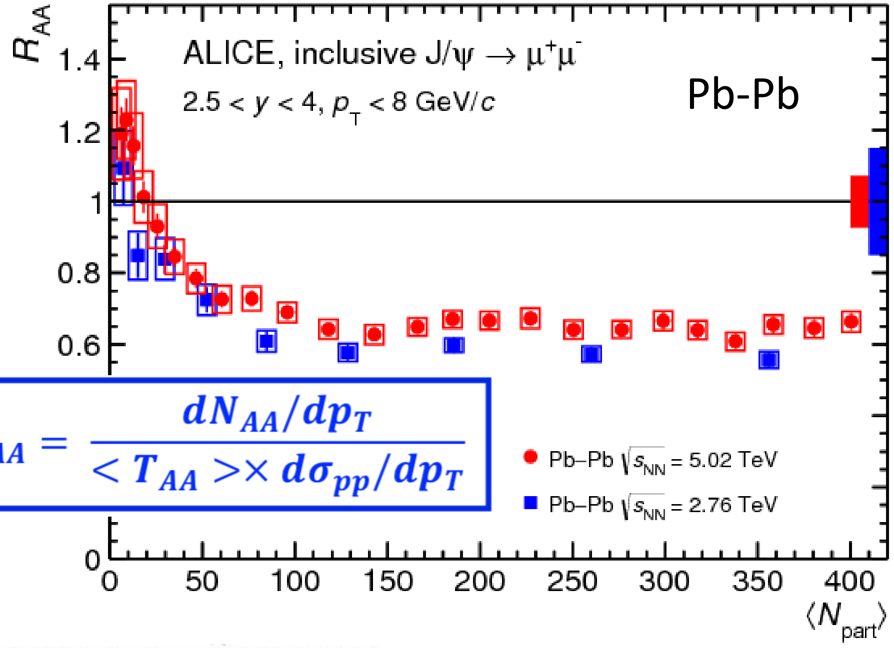
- ALICE in a nutshell
- The ALICE Luminometers
- vdM scan analysis
  - corrections to the rates
  - corrections to the beam widths
  - non factorisation
  - reproducibility
- Long-term stability and consistency
- Summary of uncertainties
- Run3 prospects

A Large Ion Collider Experiment

- Designed for heavy-ion collisions
  - characterise the hot and dense QCD medium and probe deconfinement
  - explore the partonic structure of nuclei via EM interactions

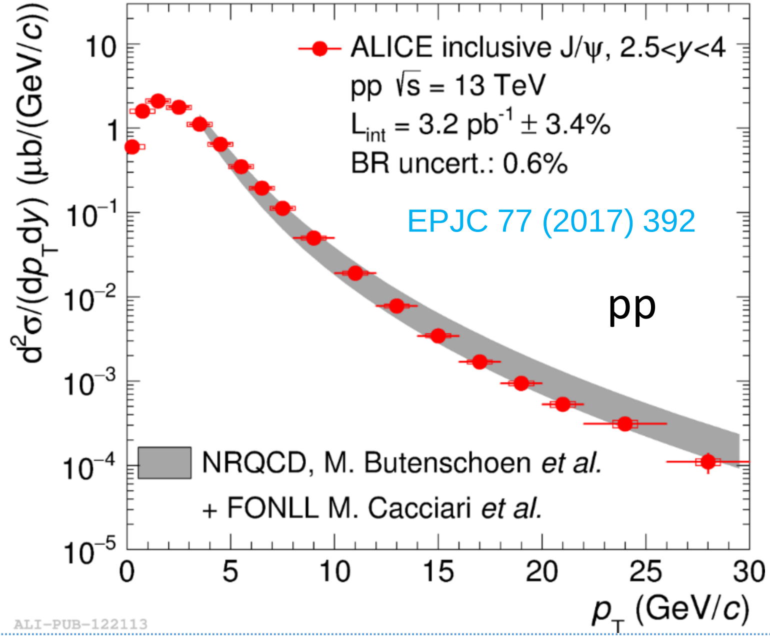
- Rich physics program in pp collisions:
  - reference for heavy-ion measurements (e.g. in R_{AA})
  - test QCD at unprecedented energies

PLB 766 (2017) 212

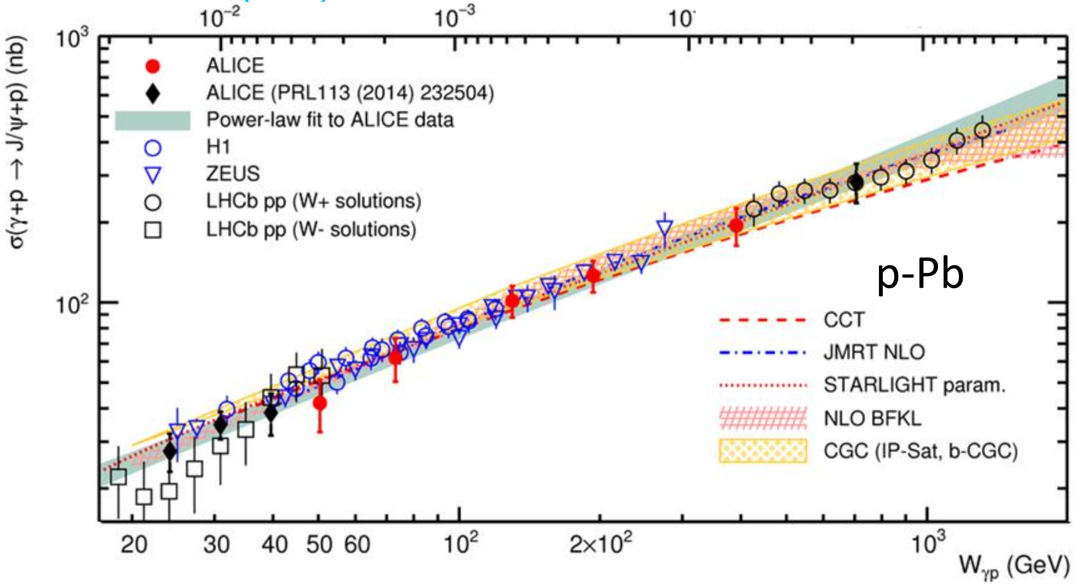


$$R_{AA} = \frac{dN_{AA}/dp_T}{< T_{AA} > \times\, d\sigma_{pp}/dp_T}$$

EPJC 77 (2017) 392



EPJC 79 (2019) no.5 402



Cross-section measurements are crucial to all of these aspects!

ALICE luminometers (1)

- **V0 (pp, p-Pb, Pb-Pb)**

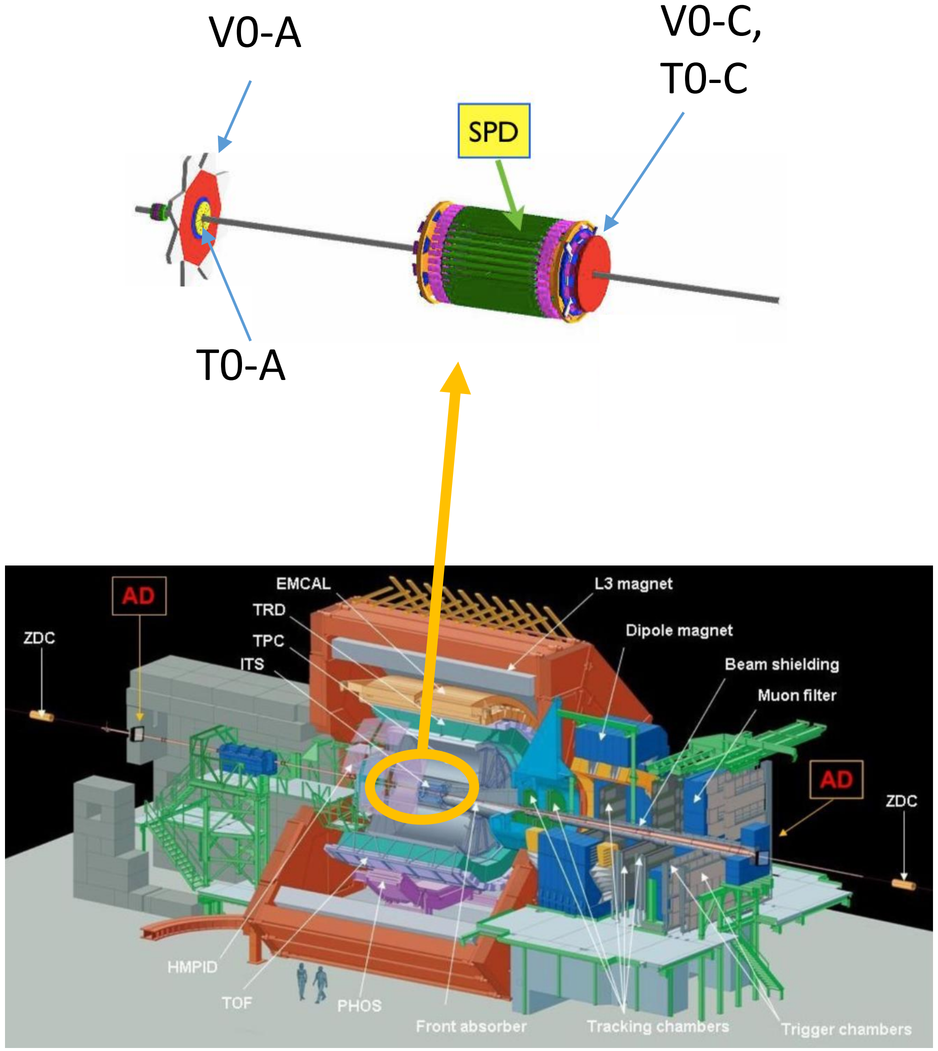
  - two **scintillator** arrays on opposite side (A and C) of the IP
    (**$2.8 < \eta < 5.1$** ; **$-3.7 < \eta < -1.7$**)

  - coincidence of A and C side for pp and p-Pb collisions
  - amplitude trigger for Pb-Pb collisions

- **T0 (pp, p-Pb)**

  - two **Cherenkov** detector arrays on opposite sides of the IP
    (**$4.61 < \eta < 4.92$** ; **$-3.28 < \eta < -2.97$**)

  - coincidence of A and C side
    with hardware cut on the signal arrival time difference



All luminosity algorithms are based on **event-counting**

ALICE luminometers (2)

- **Neutron Zero Degree Calorimeters ZN (p-Pb, Pb-Pb)**

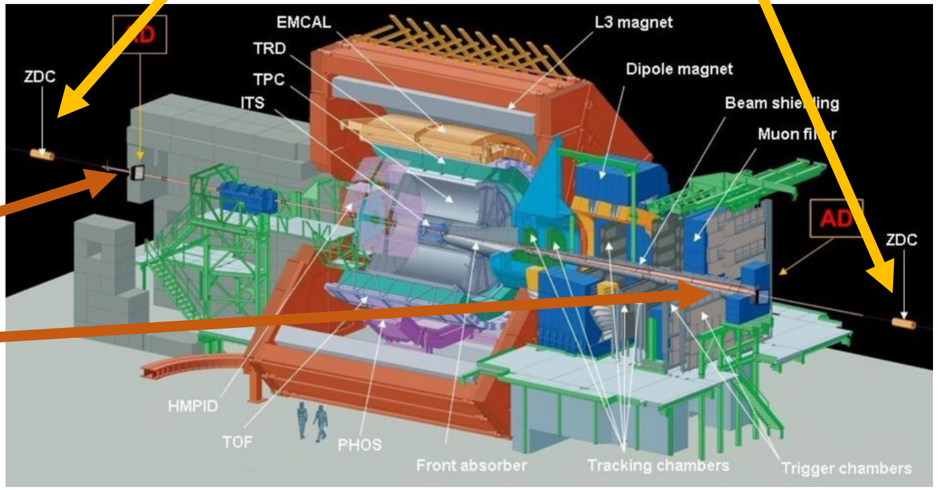
  - two **spaghetti calorimeters** on opposite sides of the IP, at ±114 m
  - single-arm (remnant side for p-Pb) or OR-trigger

- **ALICE Diffractive detector AD (pp)**

  - two **scintillators** on opposite sides of the IP, at +17 and -20 m ($\mathbf{4.7 < \eta < 6.3}$; $\mathbf{-7 < \eta < -4.9}$)
  - coincidence of A and C side
  - being commissioned as luminometer

ZDC

AD



All luminosity algorithms are based on **event-counting**

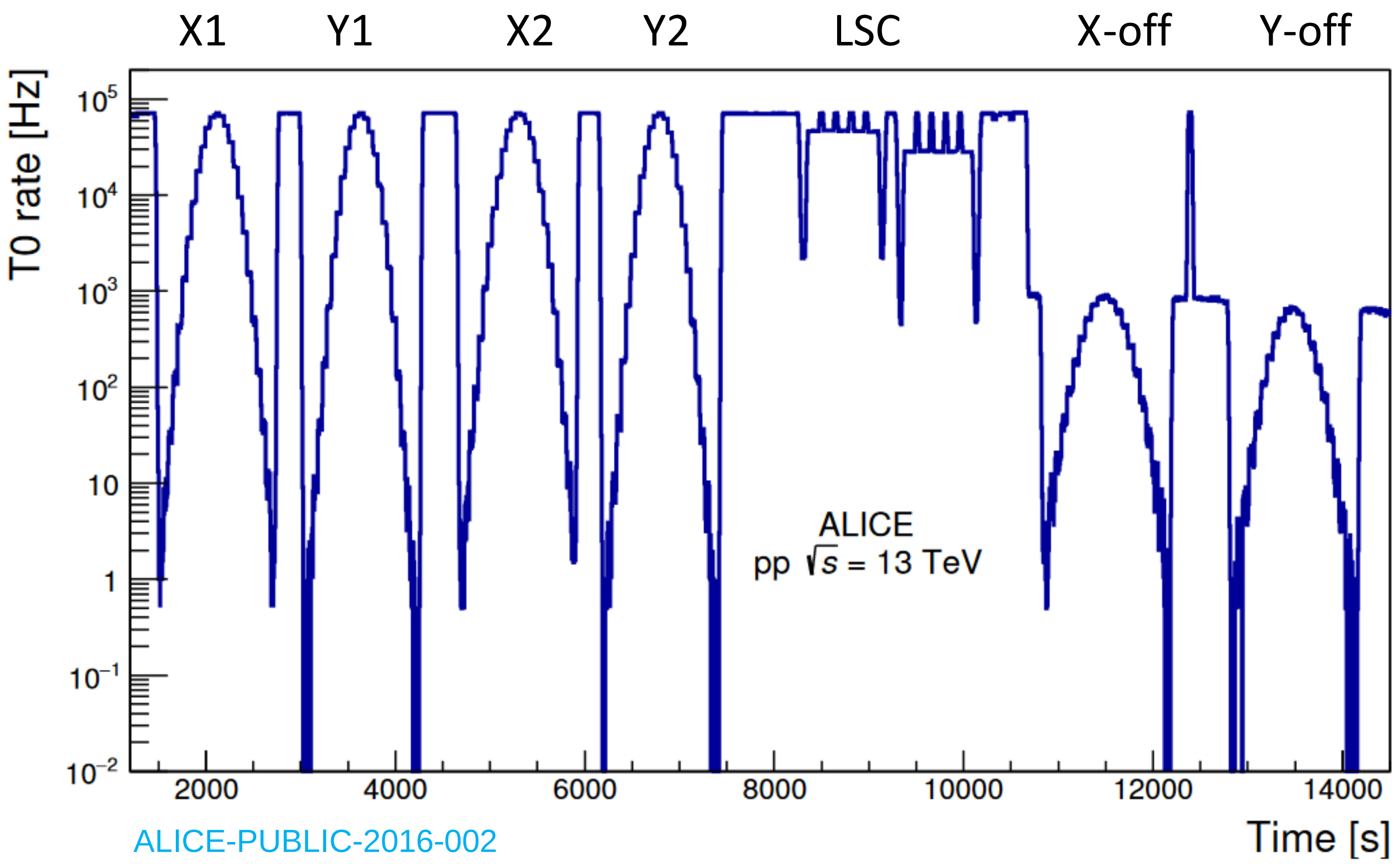
ALICE vdM scans in Run2

Year	Fill	System	Notes	Results
2015	4269	pp 13 TeV		ALICE-PUBLIC-2016-002
2015	4634	pp 5 TeV		ALICE-PUBLIC-2016-005
2015	4690	Pb-Pb 5 TeV		work in progress
2016	4937	pp 13 TeV		work in progress
2016	5533	p-Pb 8 TeV		ALICE-PUBLIC-2018-002
2016	5568	Pb-p 8 TeV		ALICE-PUBLIC-2018-002
2017	6012	pp 13 TeV		work in progress
2017	6380	pp 5 TeV		ALICE-PUBLIC-2018-014
2018	6864	pp 13 TeV		work in progress
2018	*7440*	*Pb-Pb 5 TeV*	*skew quad. issue @ IP2*	
2018	7483	Pb-Pb 5 TeV		work in progress

ALICE standard scan sequence

- **Two standard, symmetric scans** (X1-Y1, X2-Y2)
  - -6 σ_{beam} -> +6 σ_{beam} in steps of 0.5 σ_{beam}
  - 30 s/step
- **Length-scale** calibration
  - 5 steps of ~ σ_{beam} each
  - beams kept at a distance of ~ Σ
- **Offset** scan
  - typical offset ~ 4σ_{beam}
  - input to non-factorisation fits
- **Bunch intensity** measurements:
  - LHC instrumentation
  - ATLAS BPTX
  - LHCb ghost charge

  (**thanks to all!**)



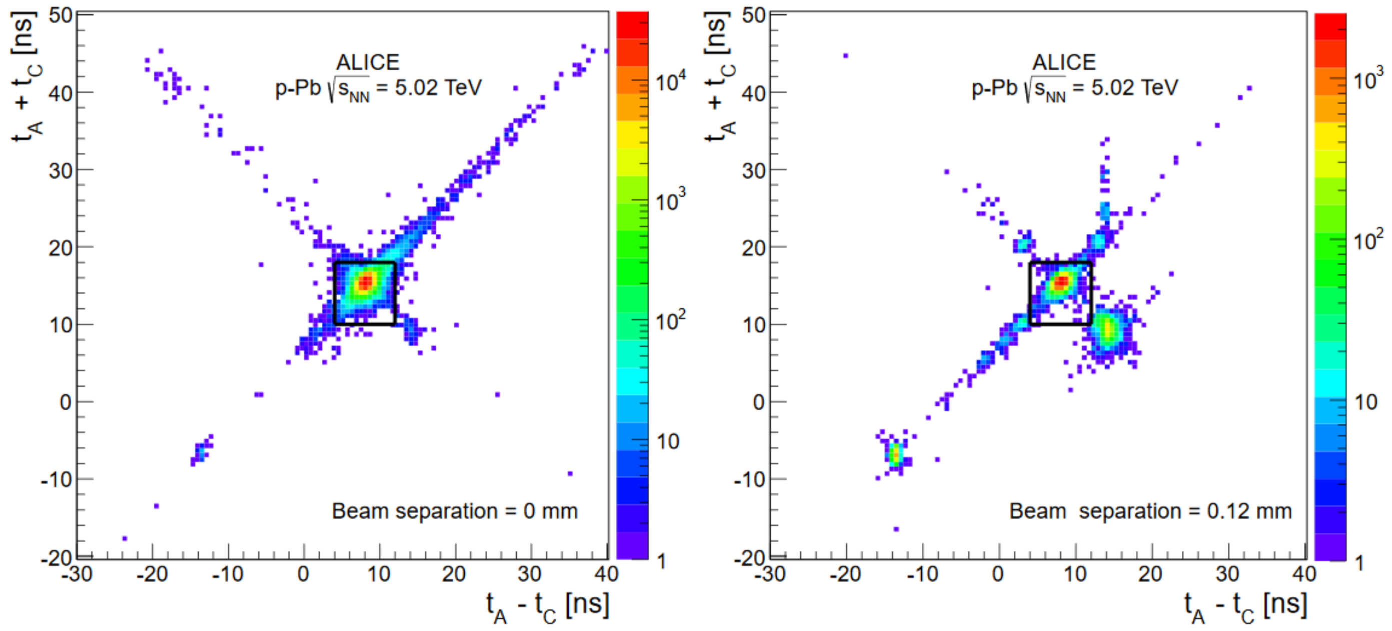
From raw to physical rates (1)

Three corrections are applied to the measured trigger rates:

JINST 9 (2014) 1100

- **Background** correction

  - estimate fraction of counts from beam-gas, satellites, after-pulsing
  - **use timing information** to tag events as bkg
  - statistics-limited for Pb-Pb
  - change cuts for systematics



- Pile-up correction

  Poissonian distribution of A&C coincidences:

  - $R_{A\&C}/f_{LHC}$ = P(A&C > 0; μ_{vis}) + P(A&C=0; μ_{vis})*P(A!C>0; μ_{vis})*P(C!A>0; μ_{vis})
  - Equation is solved numerically at each separation step to find μ_{vis}

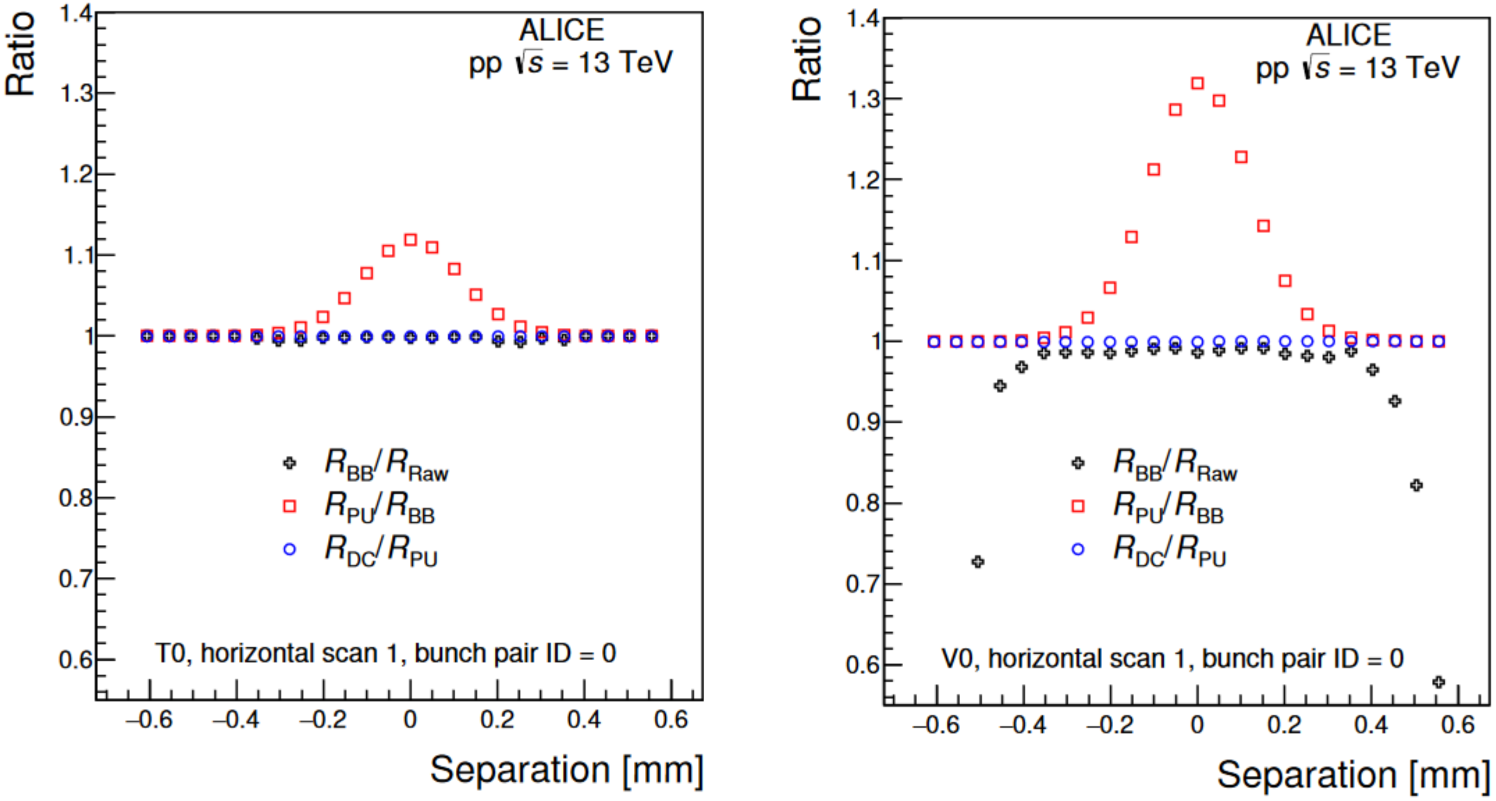
- Intensity decay correction

From raw to physical rates (2)

Three corrections are applied to the measured trigger rates:

- **Background correction**
- **Pile-up correction**
- **Intensity decay correction**

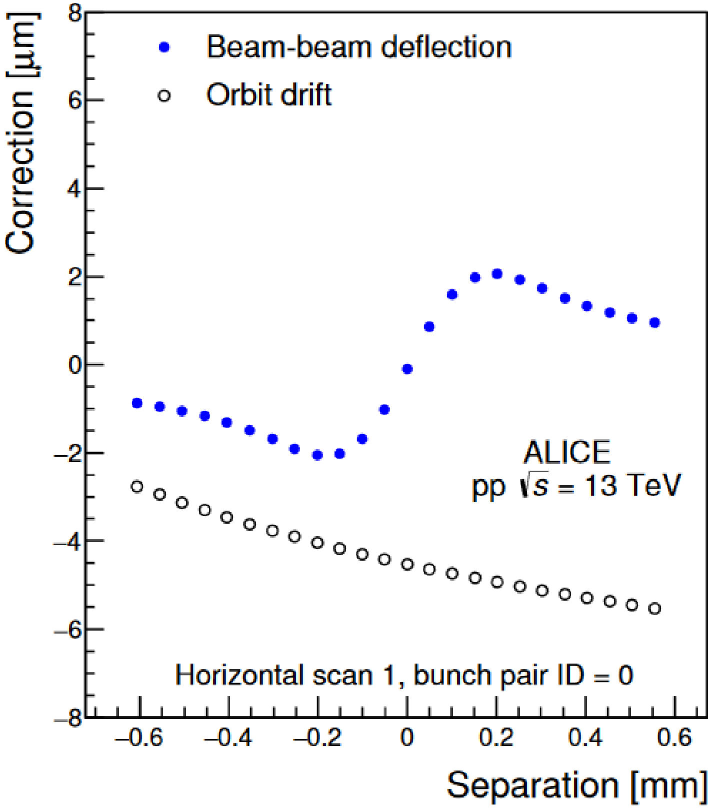
ALICE-PUBLIC-2016-002



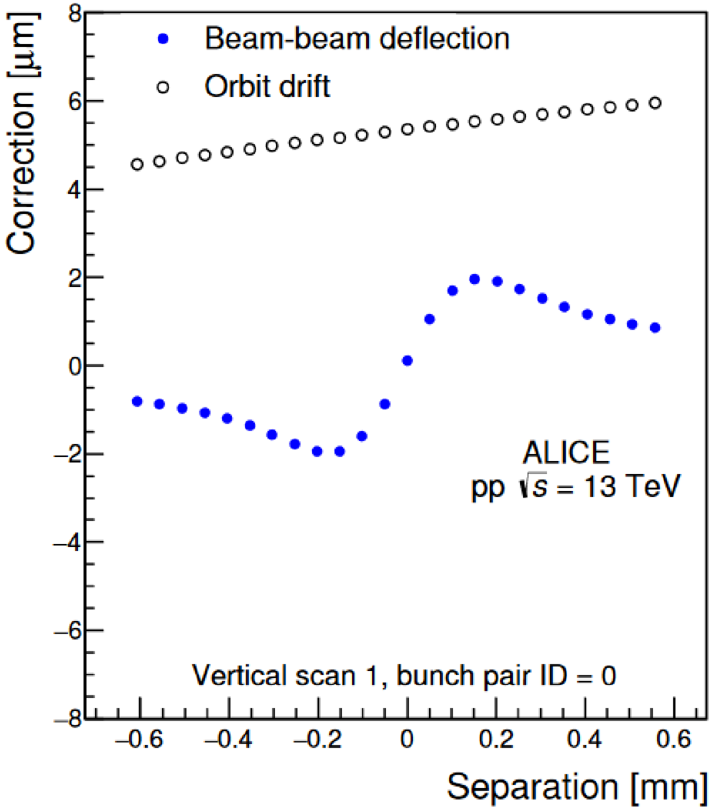
Corrections to the separation

- **Beam-beam deflection** corrections
  - evaluated with the procedure established in the LHC Luminosity Calibration & Measurement WG, based on the MAD-X code
  - using the Python wrapper kindly provided by the LHC experts (thanks!)
  - vary tunes, β^* and Σ for systematics
  - **up to 2% effect** on cross sections

- **Orbit drift corrections** are evaluated via the BPM data, fitted with a model for the LHC optics (YASP) and extrapolated to IP2
  - **full size of the effect taken as systematic uncertainty**



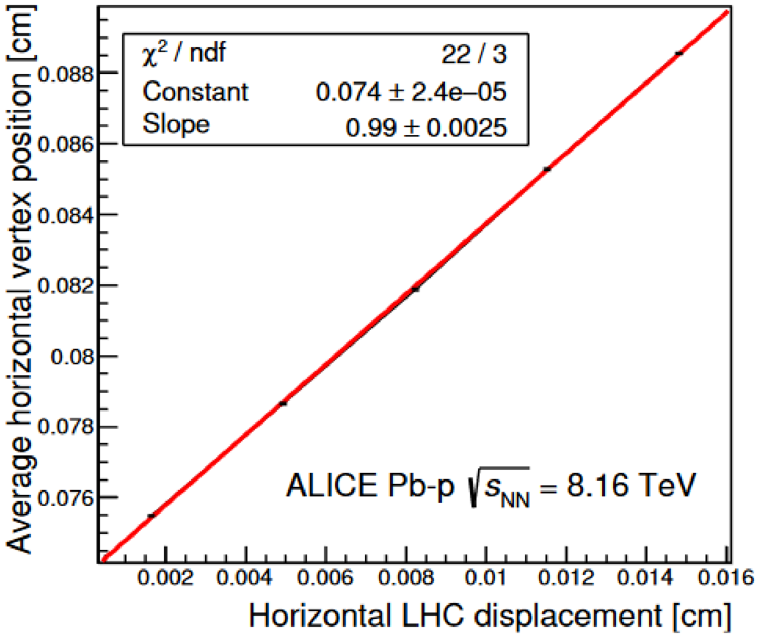
ALICE-PUBLIC-2016-002

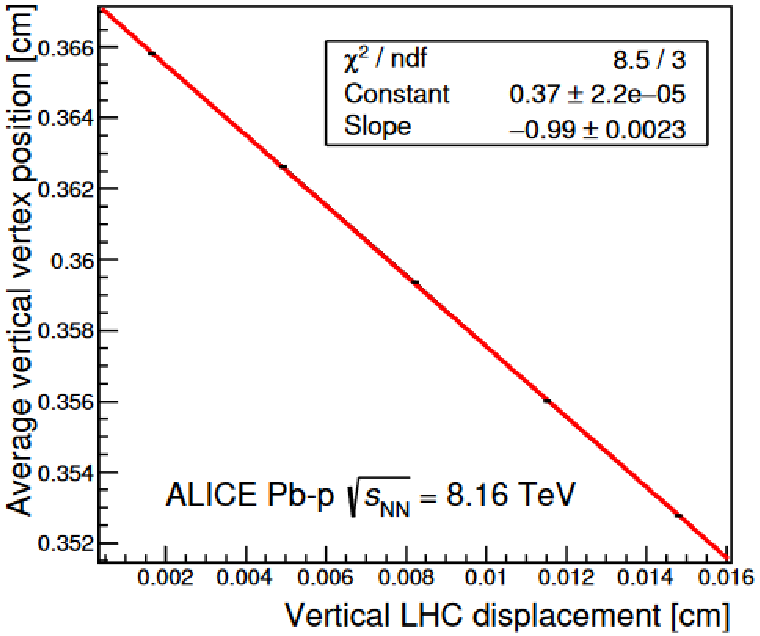


Length-scale calibration

- Length-scale calibration
  - 5 steps of ~ σ_{beam} each
  - beams kept at a distance of ~ Σ
- Calibration factor estimated as **the slope of the measured vs nominal** beam-spot position
- Systematic uncertainty: **inflate stat. uncertainties** until χ^2/dof = 1

ALICE-PUBLIC-2018-002





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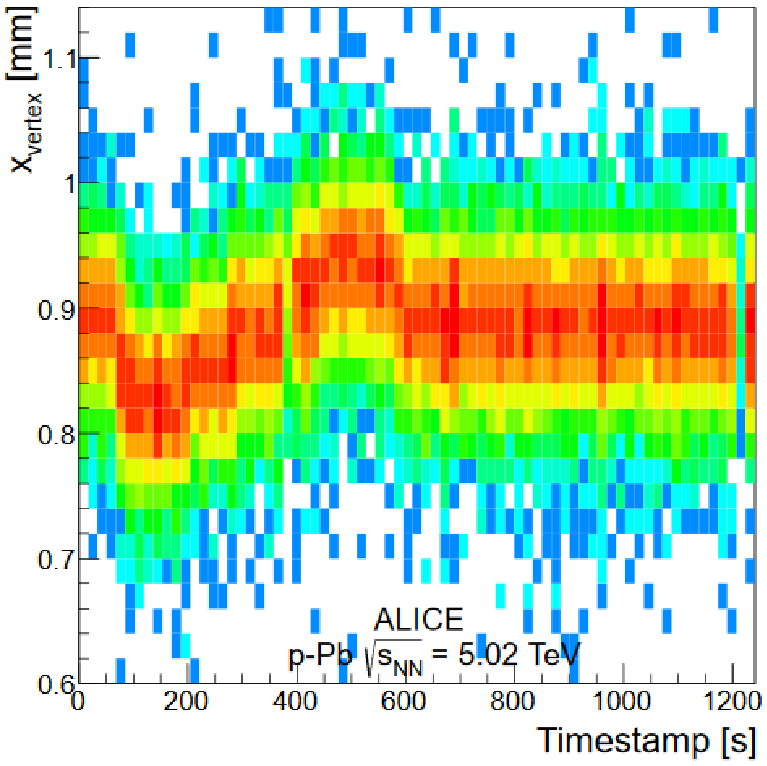


Fits to the vdM scan curve

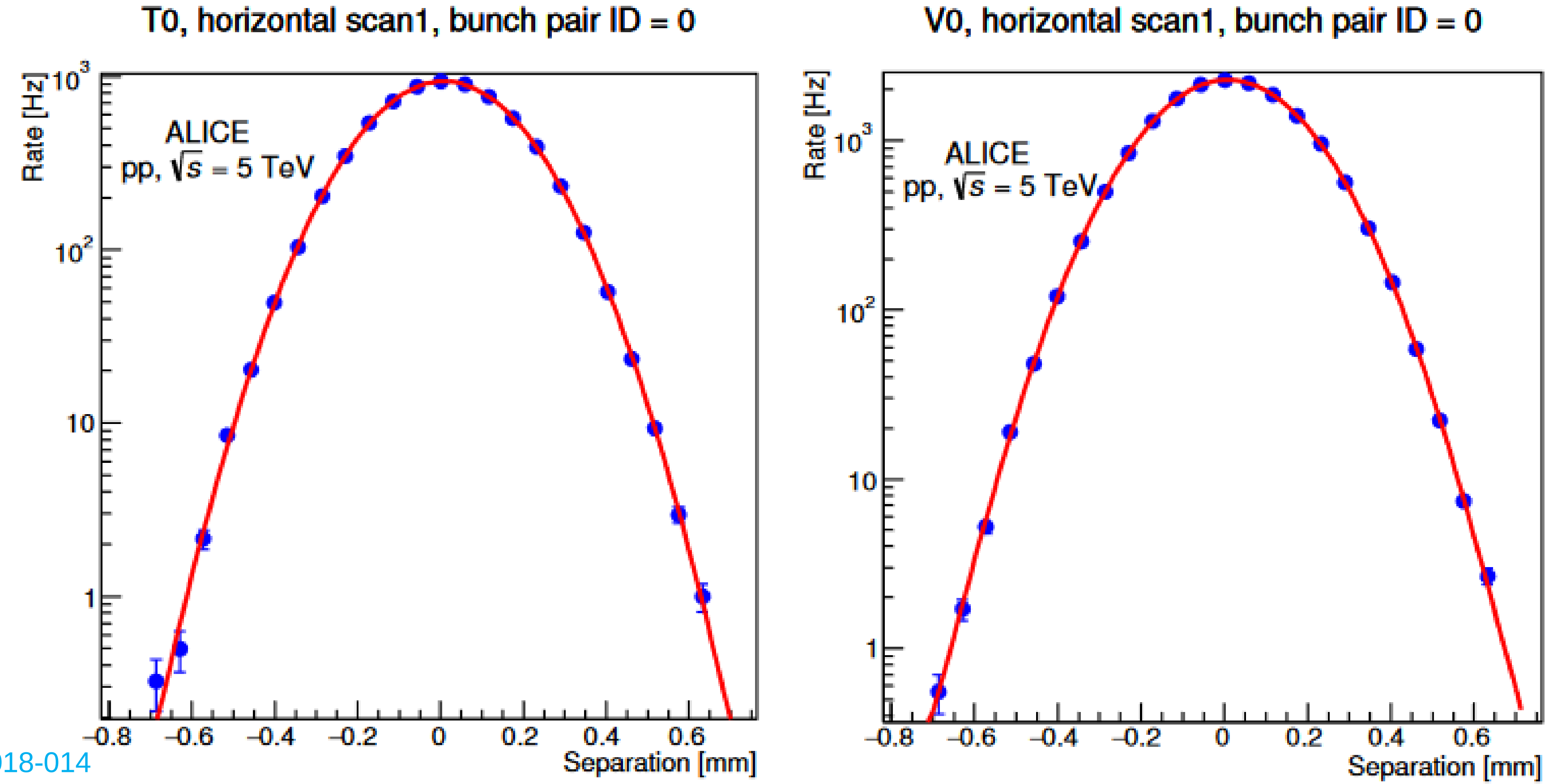
The fitting function:

$$R(\Delta x,0) = R(0,0)\exp\left[-(\Delta x-\mu)^2/2\sigma^2\right]\left[1+p_2(\Delta x-\mu)^2+p_4(\Delta x-\mu)^4+p_6(\Delta x-\mu)^6\right]$$

typically yields χ^2/dof ~ 1

Gaussian model and numerical integration
used for systematics

Double-Gaussian fits typically describe data very poorly



ALICE-PUBLIC-2018-014

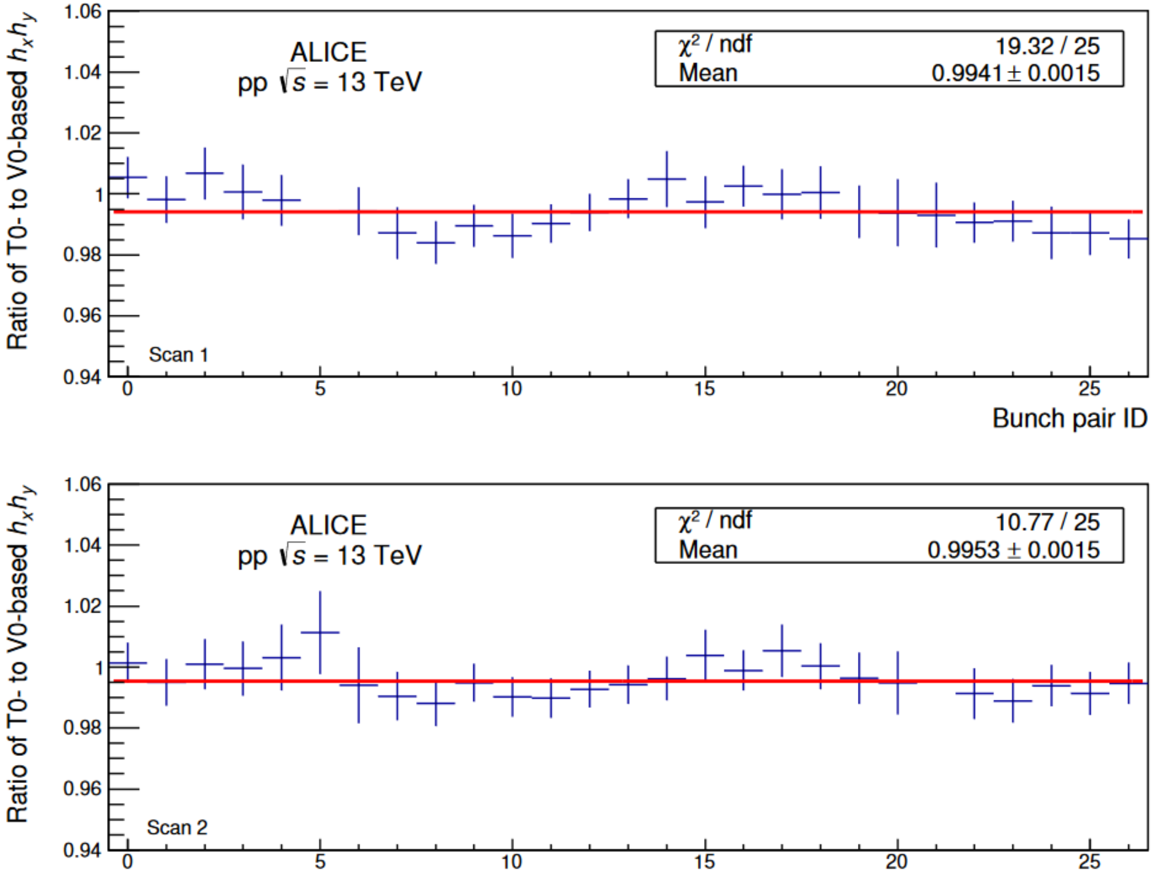
Fits to the vdM scan curve

The fitting function:

$$R(\Delta x, 0) = R(0,0)\exp\left[-(\Delta x - \mu)^2/2\sigma^2\right]\left[1 + p_2(\Delta x - \mu)^2 + p_4(\Delta x - \mu)^4 + p_6(\Delta x - \mu)^6\right]$$

typically yields χ^2/dof ~ 1

Consistency between the T0- and V0-based beam widths is typically good (~0.5% or less)



ALICE-PUBLIC-2016-002

Non-factorisation correction

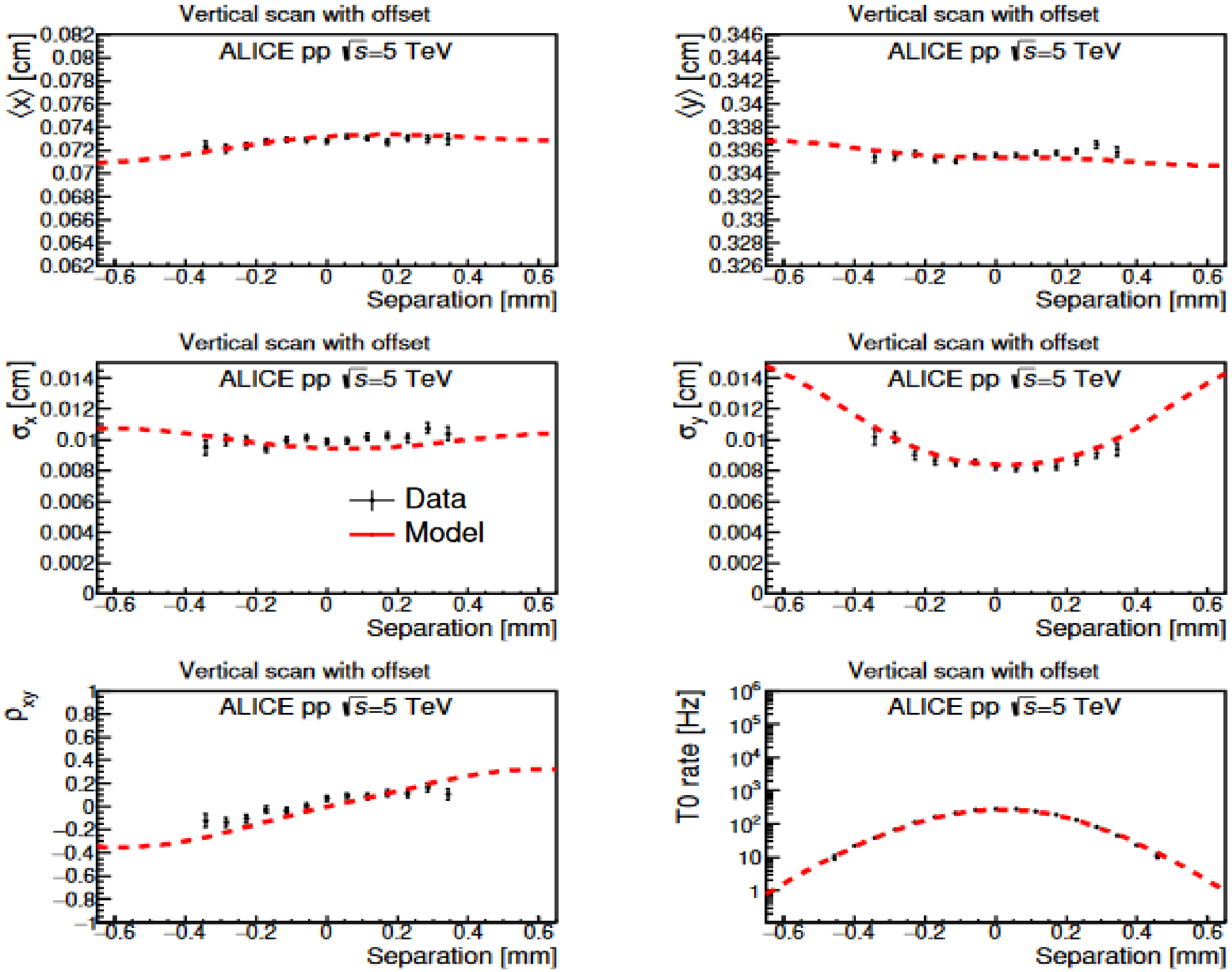
Simultaneous **fit of μ_{vis} and luminous region parameters** vs beam separation, using the method originally proposed by ATLAS
(see e.g. CERN-THESIS-2015-054)

The method was able to catch the large non-factorisation correction of the (in-)famous July 2012 scans
(see ALICE-PUBLIC-2017-002)

Bunch-by-bunch correction not always possible due to statistics
→ perform **bunch-integrated correction** and use single bunches for checks

Typical effect in Run2 scans: **~1% (or less)**

Full size of the correction used as uncertainty



ALICE-PUBLIC-2016-005

More in the talk by M. Dyndal

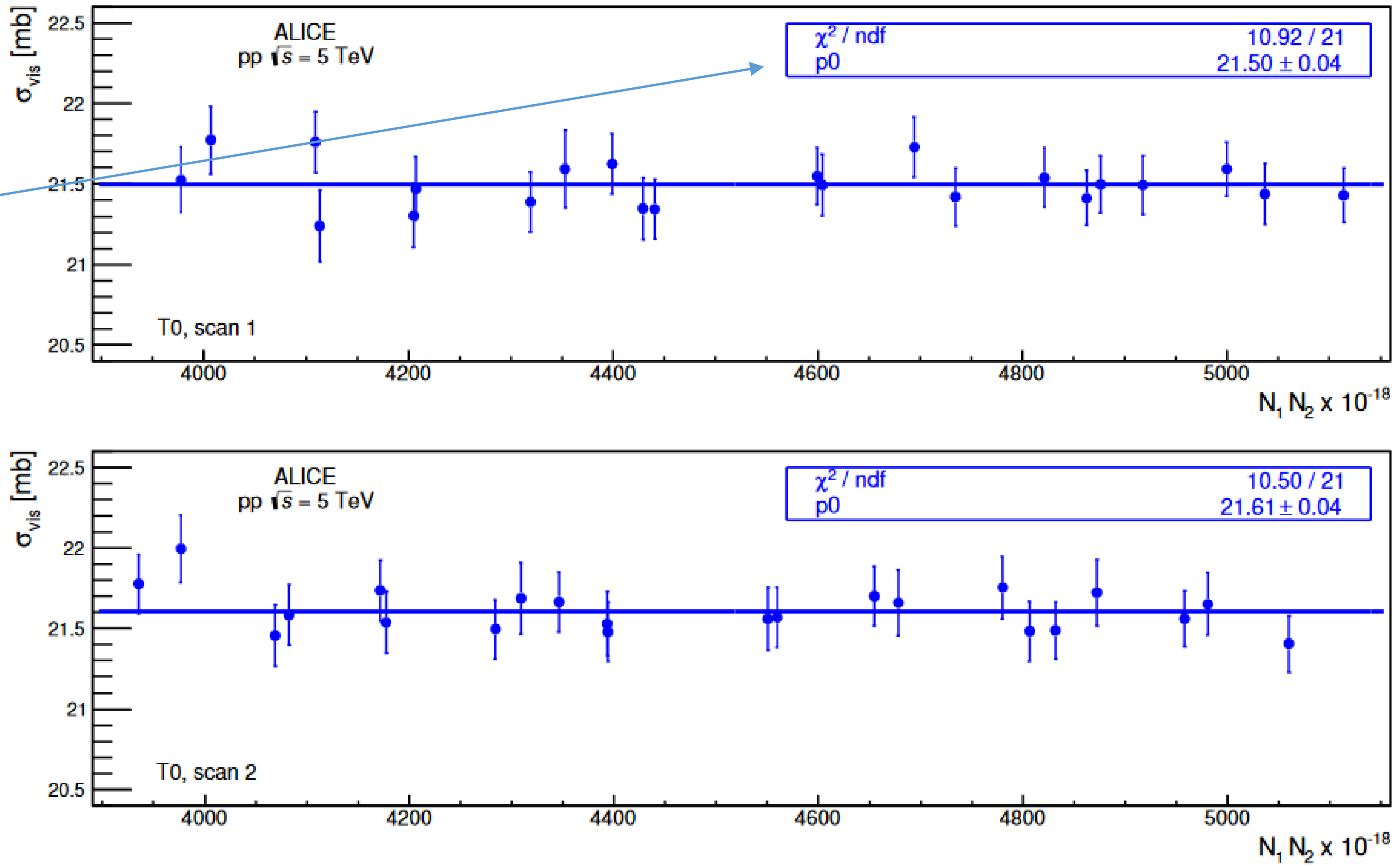
Reproducibility of results

Bunch-to-bunch:

- compute χ^2/dof of pol0 fit
- if > 1, rescale stat. uncertainties accordingly

Scan-to-scan:

- assign full difference between scans as uncertainty



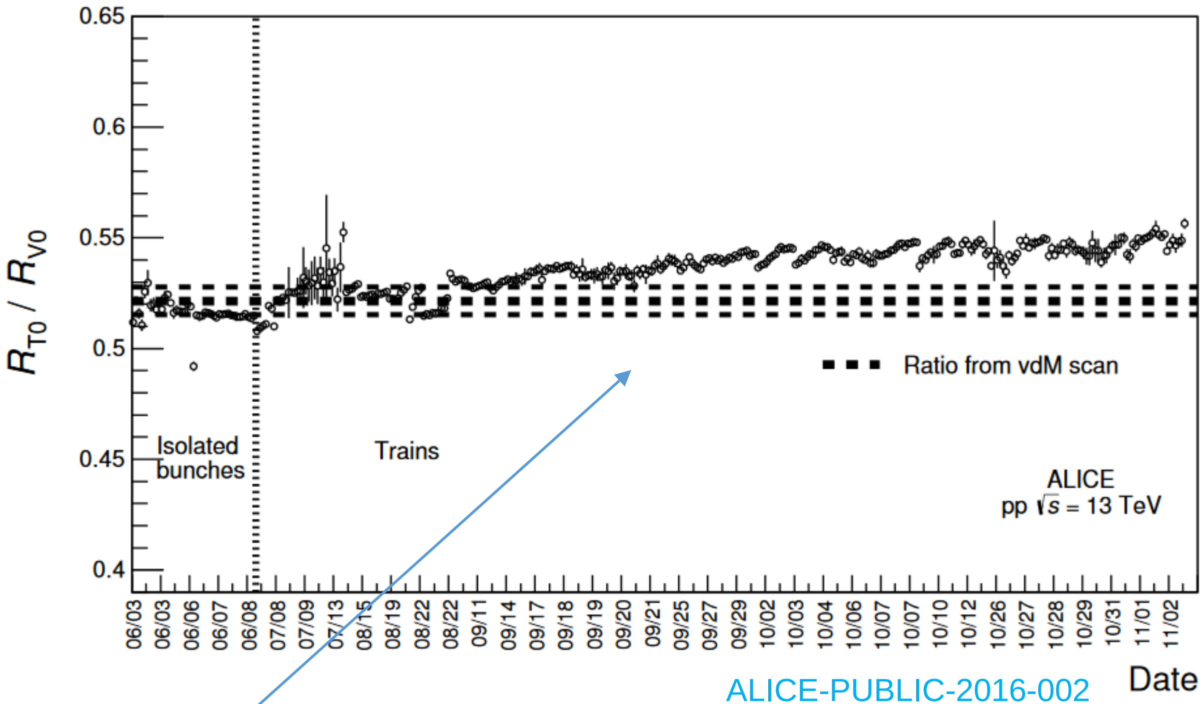
ALICE-PUBLIC-2016-005

Long-term stability and consistency (1)

The luminosity is **evaluated for each run from the luminosity-trigger counts**, corrected as in the vdM scan

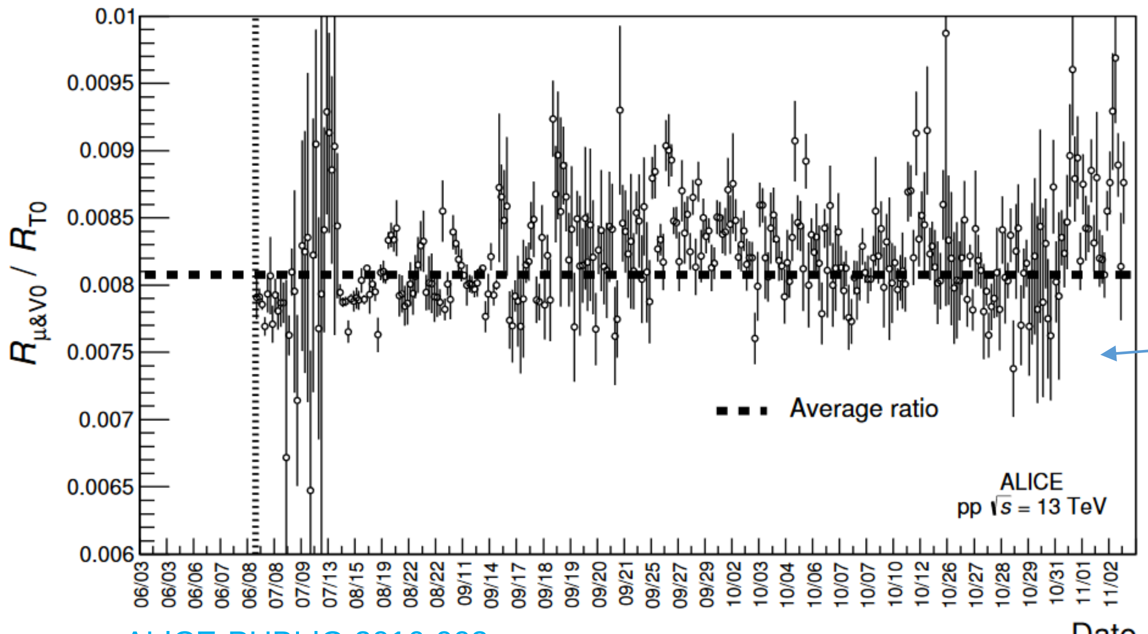
The **stability and consistency** of our two main luminometers is evaluated via the **ratio of T0- to V0**-based luminosities

The **RMS (wrt unity) of the distribution** over runs is quoted as uncertainty, after subtracting the stastistical component and the contribution from the vdM



ALICE-PUBLIC-2016-002

V0 ageing was an issue during the 2015 pp 13 TeV campaign
→ use only T0, check ratio to muon triggers for stability



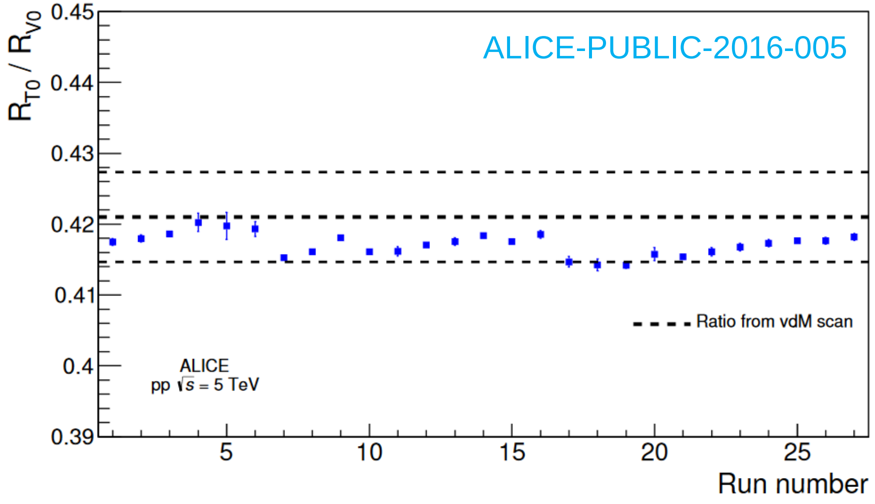
ALICE-PUBLIC-2016-002

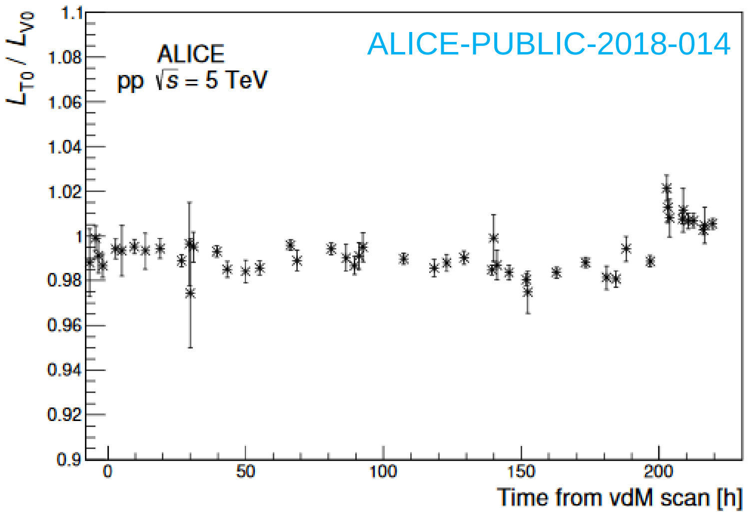
Situation looks better in 2016-17-18 thanks to lower HV and μ_{vis}

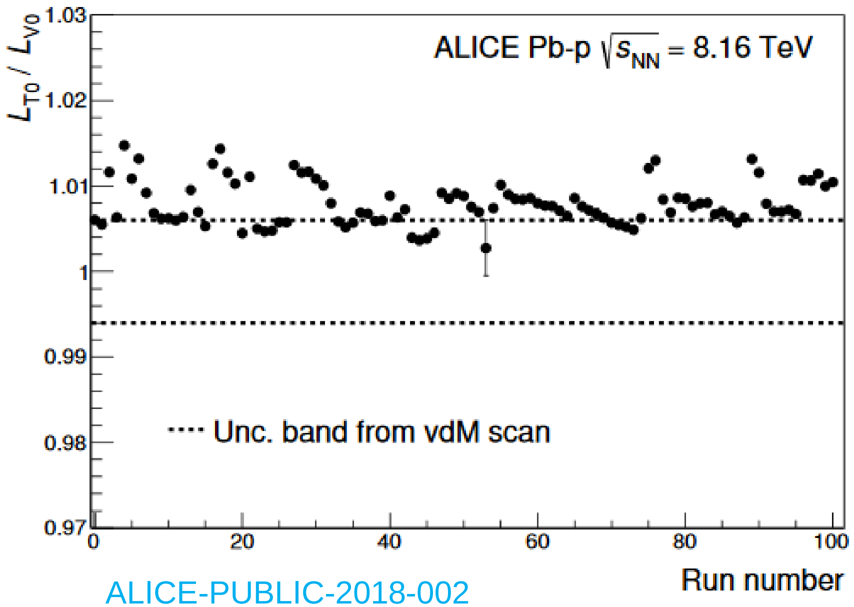
Long-term stability and consistency (2)

The stability and consistency of our two main luminometers is evaluated via the ratio of T0- to V0-based luminosities

The RMS (wrt unity) of the distribution over runs is quoted as uncertainty, after subtracting the stastistical component and the contribution from the vdM







ALICE-PUBLIC-2018-002

Period	Duration	μ_{vis} range for V0 (spacing)	Uncertainty
pp 13 TeV 2015	5 months	0.001-0.1 (isolated) 0.001-0.01 (25 ns & 50 ns)	0.6% (isol.) 2.7% (trains)
pp 5 TeV 2015	5 days	< 0.05 (isol.) 0.003-0.005 (25 ns)	0.4%
p-Pb 8 TeV 2016	8 days	0.007-0.1 (100_200 ns)	1.1%
Pb-p 8 TeV 2016	9 days	0.007-0.1 (100_200 ns)	0.6%
pp 5 TeV 2017	11 days	0.003-0.04 (25 ns)	1.1%

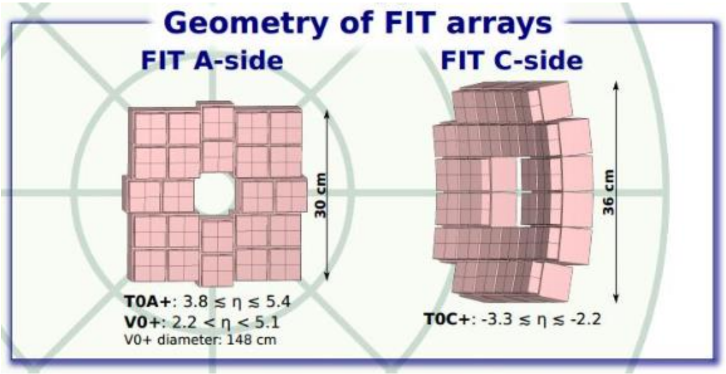
Uncertainty	pp 13 TeV 2015	pp 5 TeV 2015	p-Pb 8 TeV 2016	Pb-p 8 TeV 2016	pp 5 TeV 2017	*Other periods*
Non-factorisation	0.9%	1%	0.6%	0.9%	0.1%	
Orbit drift	0.8%	<0.1%	0.7%	0.3%	0.1%	
Beam-beam deflection	0.8%	0.4%	<0.1%	0.4%	0.5%	
Dynamic β^*	0.3%	0.2%	<0.1%	<0.1%	0.2%	
Background	0.1% (T0), 0.7% (V0)	0.3% (T0), 1.1% (V0)	<0.1% (T0), 0.5% (V0)	0.3% (T0), 0.6% (V0)	0.2% (T0), 1.1% (V0)	
Pile-up	0.7%	0.7%	included in *	included in *	0.5%	
Length-scale calibration	0.5%	1%	0.5%	0.8%	0.2%	
Fit model	0.6%	0.7%	0.5% (T0), 0.4% (V0)	0.6% (T0), 0.9% (V0)	0.5%	
Σ consistency (T0 vs V0)	0.6%	0.2%	0.2%	0.4%	<0.1%	
Intensity decay	0.4%	0.7%	0.6%	0.7%	0.9%	
Bunch-to-bunch consist.	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	
Scan-to-scan consist.	<0.1%	0.5%	0.6%	0.1%	0.5% (T0), 0.4% (V0)	
Beam centreing	<0.1%	0.1%	0.1%	0.1%	0.2%	
Bunch intensity	0.6%	0.4%	0.3%	0.3%	0.4%	
Long-term stability & consist.	0.6% (isol.) 2.7% (trains)	0.4%	1.1%*	0.6%*	1.1%	
Total	**3.4% (T0)**	**2.1% (T0), 2.3% (V0)**	**1.8% (T0), 1.9% (V0)**	**1.8% (T0), 2.0% (V0)**	**1.8% (T0), 2.1% (V0)**	***5% (prel.)***

Run 3 prospects

Fast Interaction Trigger
replaces 3 detectors in ALICE:
T0, V0, and FMD

https://cds.cern.ch/record/781854/files/lhcc-2004-025.pdf

https://cds.cern.ch/record/1603472/files/ALICE-TDR-015.pdf



FIT will consist of two arrays of Cherenkov radiators with MCP-PMT sensors (T0+) and of a single, large-size scintillator ring (V0+)

(FIT = T0+ and V0+ for ALICE after LS2)

(+ ZDC and AD, which will stay)

Summary

- The ALICE luminosity uncertainty is in the 2-3% range for pp and p-Pb
  → generally adequate
  → for some measurements (e.g. J/ψ cross section), the lumi unc. Is non-negligible wrt stat. and other syst.

- Dominant contribution from long-term consistency (especially for long periods)
  → background subtraction and pile-up correction in physics runs not fully understood

- Occasionally, non-factorisation yields large (~1%) uncertainties

- Now working hard to get a solid result for Pb-Pb, with similar precision, and to finalise all pp results

- Run 3:
  → similar (or slightly harsher) running conditions as Run2 for pp and p-Pb
  → significant increase of luminosity for Pb-Pb…
  → … but better hardware