technische universität
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LHCb

Luminosity plans for Run3

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LHCb Starterkit-For-All Full Run 3 Edition
14/03/2022

How to measure lumi?

mean bunch luminosity $$\langle \mathscr{L}_b \rangle = \frac{\langle \mu_{inel} \rangle f_r}{\sigma_{inel}} = \frac{\langle \mu_{vis} \rangle f_r}{\sigma_{vis}}$$ with $$\mu_{vis} = \varepsilon\mu$$ $$\sigma_{vis} = \varepsilon\sigma$$

f_r = LHC revolution frequency (11245 Hz)

σ_{inel} = total inelastic pp cross-section

μ_{inel} = number of inelastic pp collision per bunch crossing

ε = acceptance x efficiency of luminosity detector

μ_{vis} = visible collision per bunch crossing

σ_{vis} = effective cross section

relative luminosity measurement

consists in counting interactions, the specific observable depends on counter

absolute luminosity measurement

determined from dedicated measurements using the Van der Meer scan (Run 1-2) or Beam Gas Imaging (Run1)methods

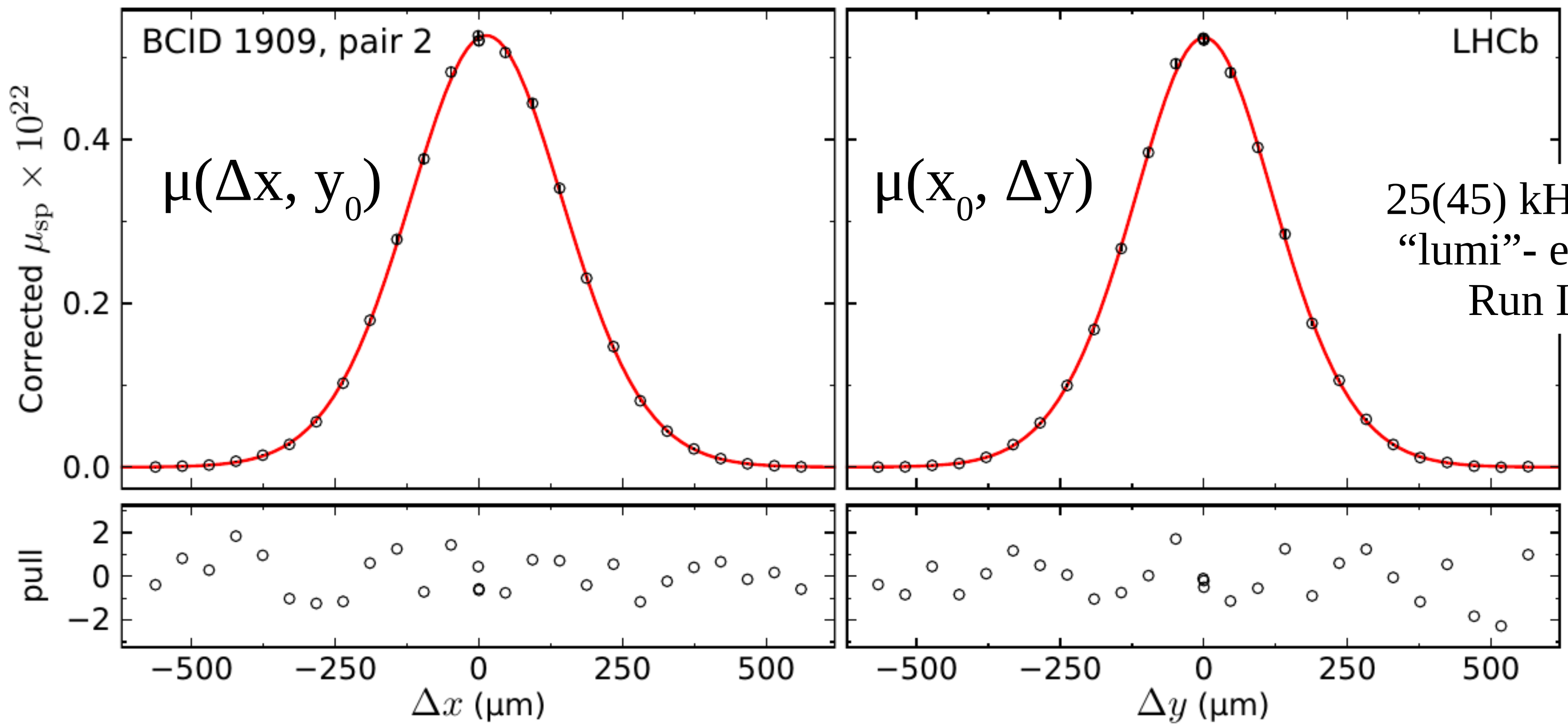
Absolute luminosity

Eur. Phys. J. C (2021) 81:26

- Van der Meer (VdM) scans performed once per year and per energy in dedicated LHC fills
- beams separated on the transverse plane in steps Δx and Δy
- μ measured per step per counter
- assuming XY factorizability, the visible cross-section per counter is given by

$$\sigma_{vis} = \frac{\int \mu(\Delta x, y_0) d\Delta x \cdot \int \mu(x_0, \Delta y) d\Delta y}{\mu(x_0, y_0) N_1 N_2}$$

with $N_{1,2}$ the number of particles in the 2 bunches, determined with a combination of LHC measurements



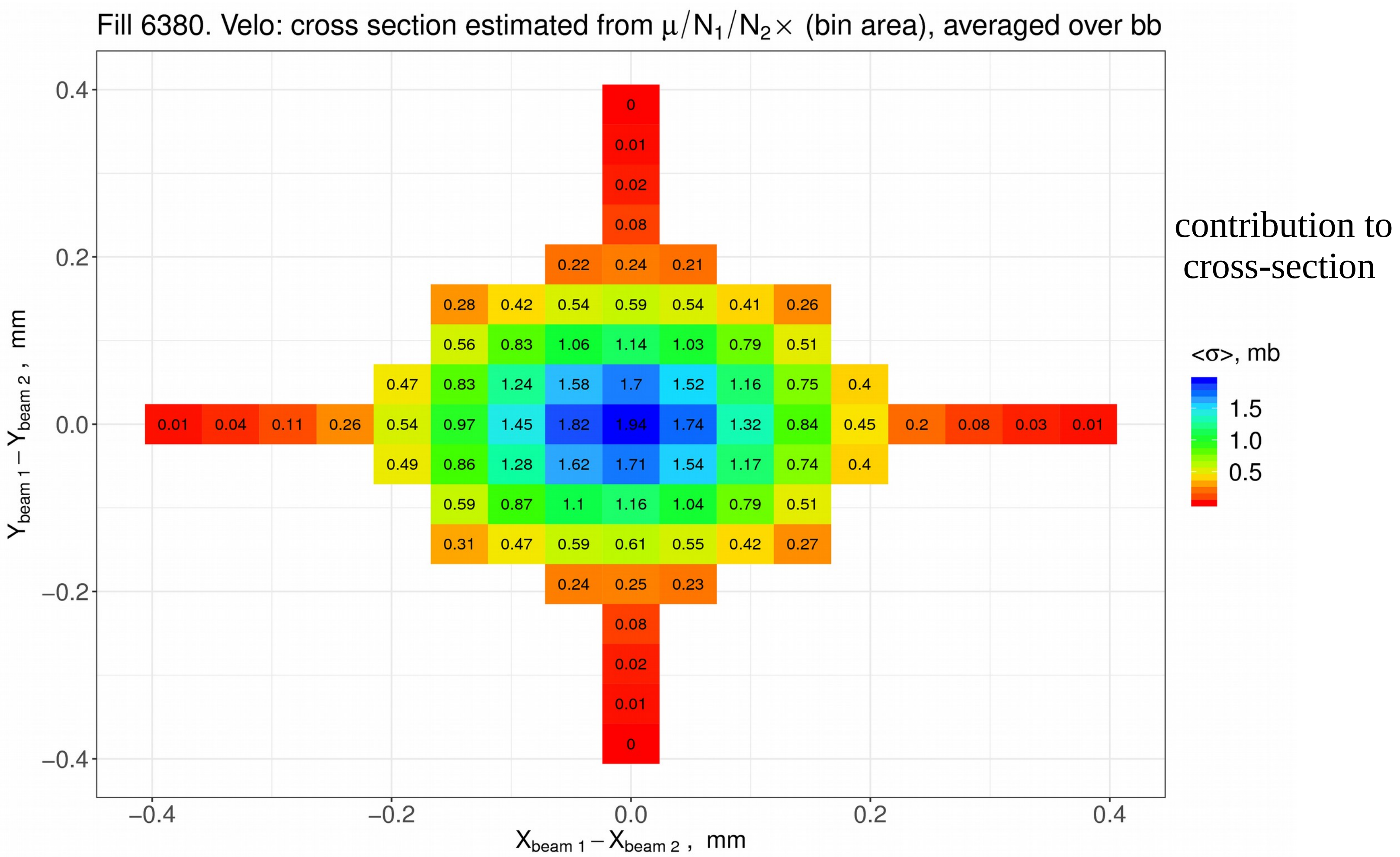
25(45) kHz rate of "lumi"- events in Run I (II)

Absolute luminosity

Run 3

- in Run 2 already used **2D VdM** scan for the central region, to reduce systematic related to factorizability assumption
  - will become default in Run3
- in Run 3 > number of pp interactions wrt Run 1-2: need to verify linearity of counters from typical VdM μ<1 to μ~5 during physics
  - introduce **emittance scans** at the beginning of each fill = mini VdM scan (only central region) at ~physics conditions

2D VdM scan in the region mostly contributing to the integral



Absolute luminosity

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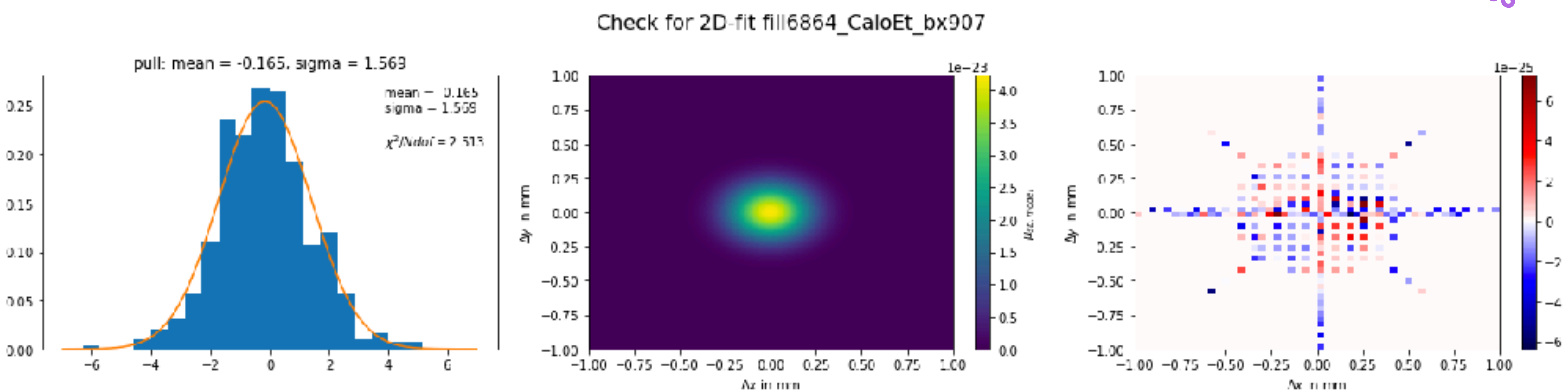
code to automatise analysis of emittance scans being developed

WORK IN PROGRESS



J. Ellbracht

Relative luminosity

Possible methods:

- linear
- log0
  - μ is calculated from the fraction of empty events (e.g. # VELO tracks < 2 or # of vertices =0) assuming Poisson statistics

$$\mu = -\log P(0) = -\log \frac{N_0^{trig}}{N^{trig}}$$

  - reduces possible non-linearities and instabilities in lumi counters
- Probability Generating Functions (PGF)

$$\mu \propto \log \frac{\sum z^{N_j}}{n}$$

with n the number of events and z can be tuned to suppress busy events (link)

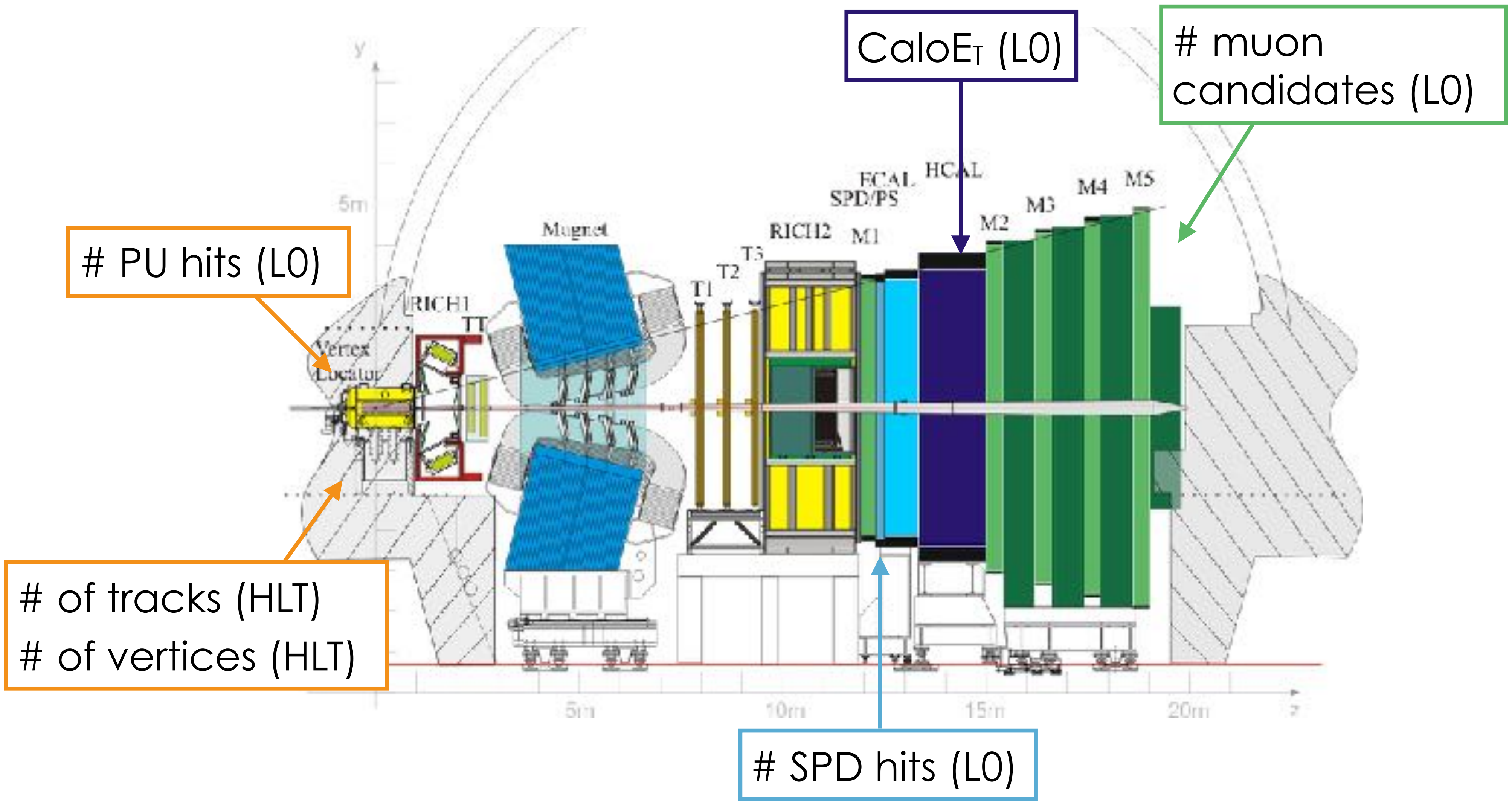
RUN 1-2: log0 method since μ~1

RUN 3: given the 5x μ, it is difficult to say what will be the most accurate method between log0 (with higher trigger rate than previous runs) and PGF

Counters

- main characteristics of counters: **linearity** (response vs μ) and **stability** (efficiency vs time)
  - calibration of the individual detectors fundamental: eg for VELO IV scans, CCE scans, HV tuning…
- any dependence on pile-up, LHC filling scheme, bunch spacing… needs to be evaluated and either corrected for or source of systematics
- high level quantities (e.g. tracks) are usually cleaner than low level ones (e.g. hits)

RUN 1-2



Counters

RUN 3

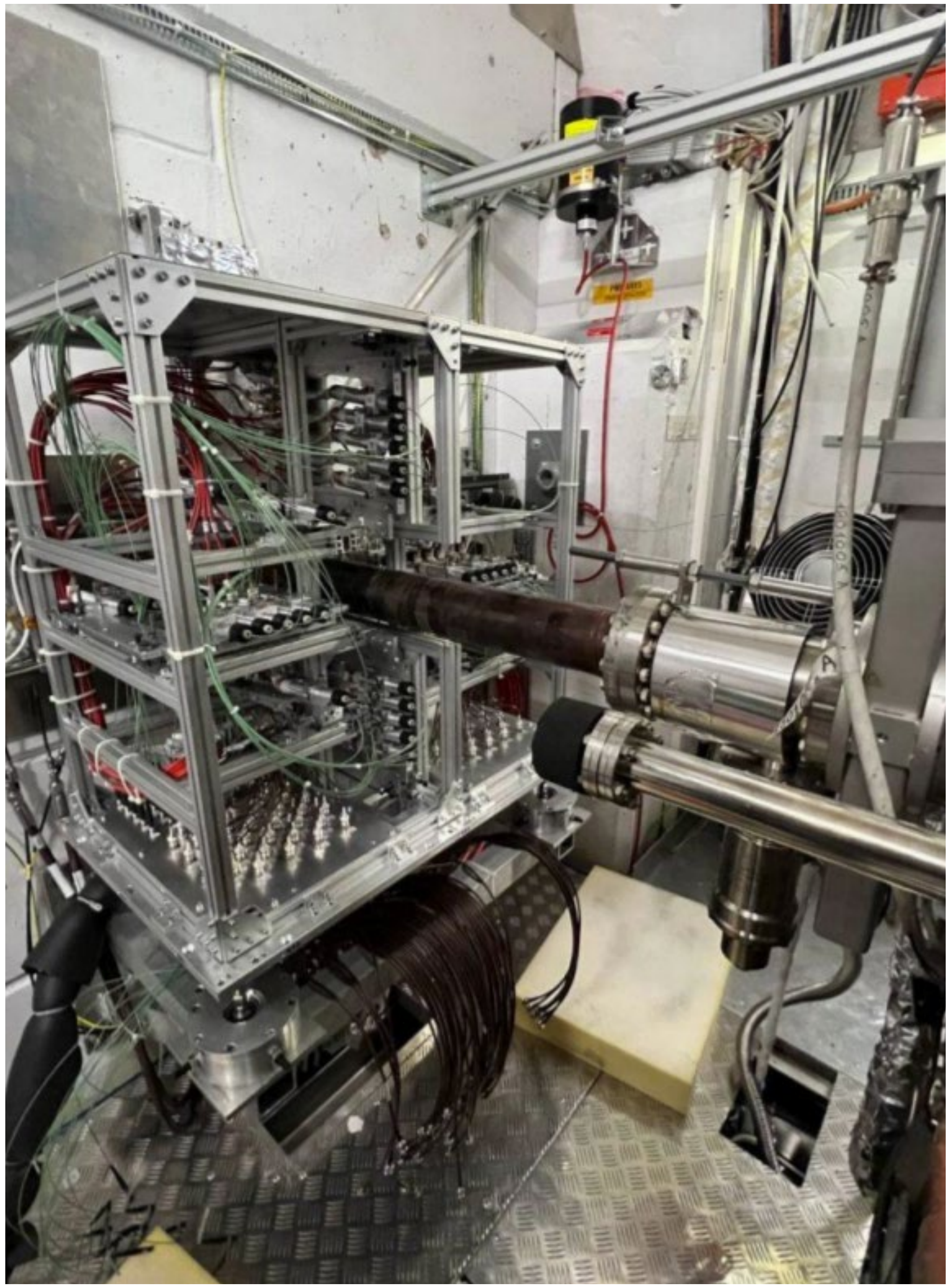
PLUME: the first dedicated lumi counter of LHCb!

mainly motivated by online purposes

- luminosity should be provided to the LHC every few seconds (~3s)
- it should be measured with a precision of order 10%
- it should be provided at all times even if LHCb is not taking data or is off
- LHC requires a luminosity measurement per bunch

detector fully installed

- hodoscope of 2x24 counters
- each counter consists of a PMT and a quartz tablet
- it measures the rate of coincidences between the 2 layers
- background rate from eb, be, (ee) is subtracted during online operation



Counters

RUN 3

proposals from subdetectors experts

ECal & HCal

ECal multiplicity (# cells with E > threshold)
ECal/HCal total energy deposited
possibility of a counter per FE board (~200)

Muon

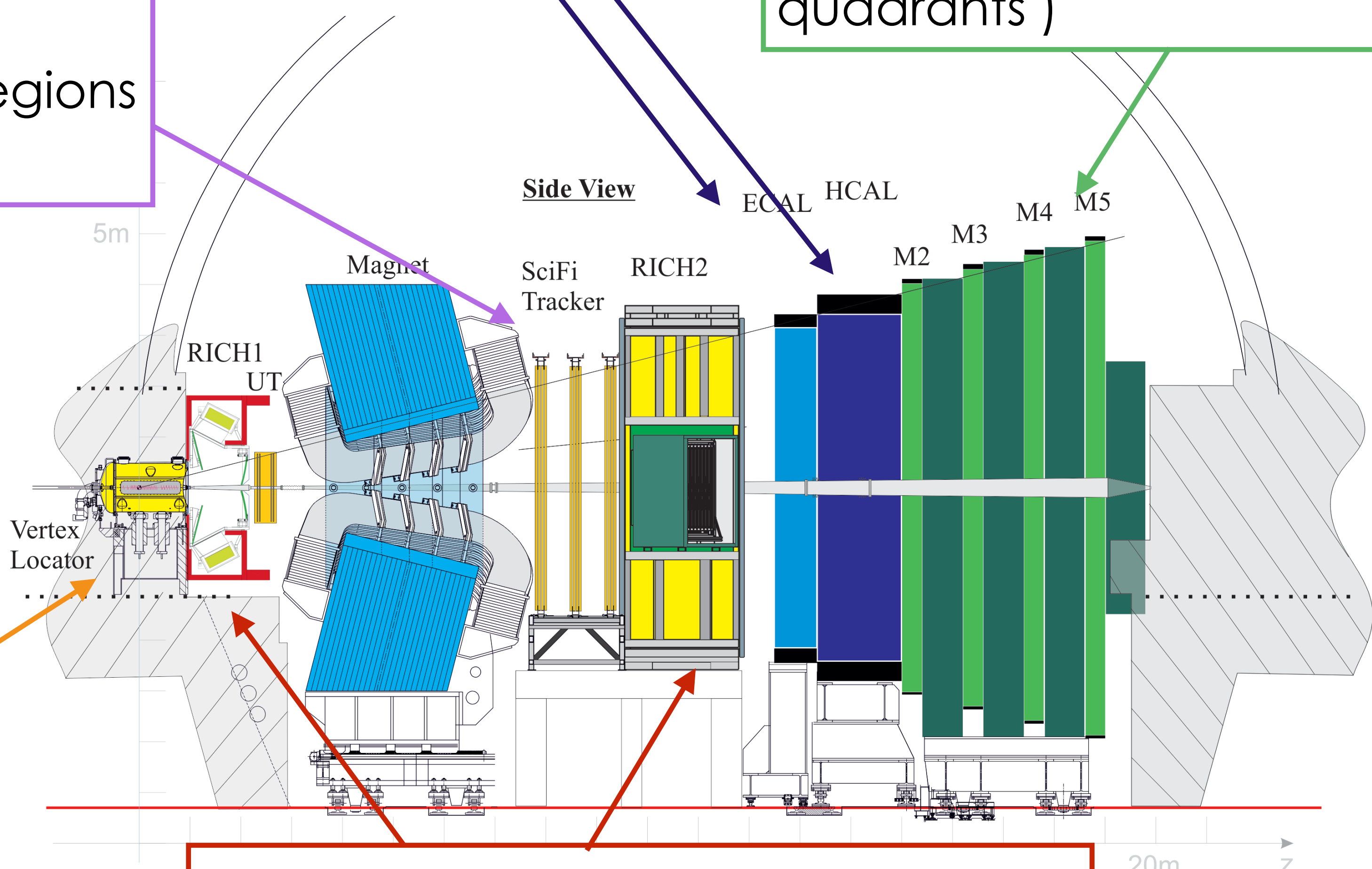
# of hits or muon track segments in more interesting regions (M2R2, M2R3, M3R2, M3R3 + split in 4 quadrants)

SciFi

# of clusters
# of clusters in low occupancy regions
# of SciFi track segments

VELO

# of vertices
# of vertices in fiducial volume
# of tracks
# of tracks in fiducial volume
# of tracks in different eta bins
# of clusters
# of clusters in outer sensors

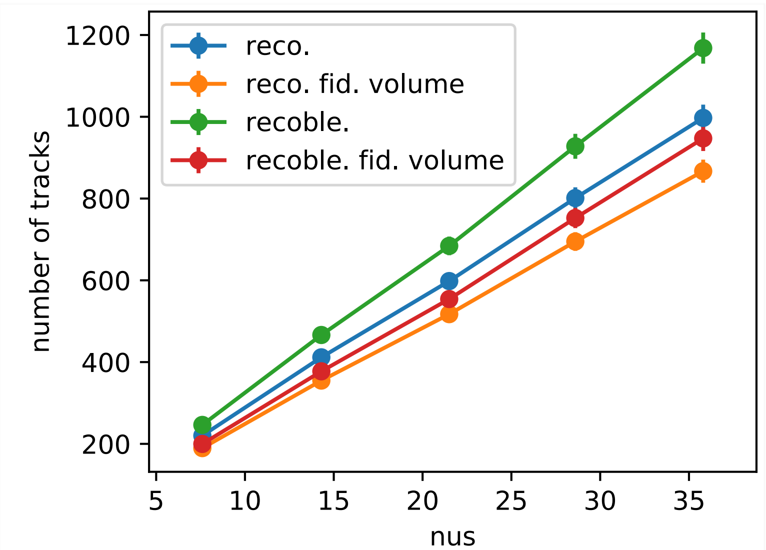


hits in each detector
of hits in low occupancy regions

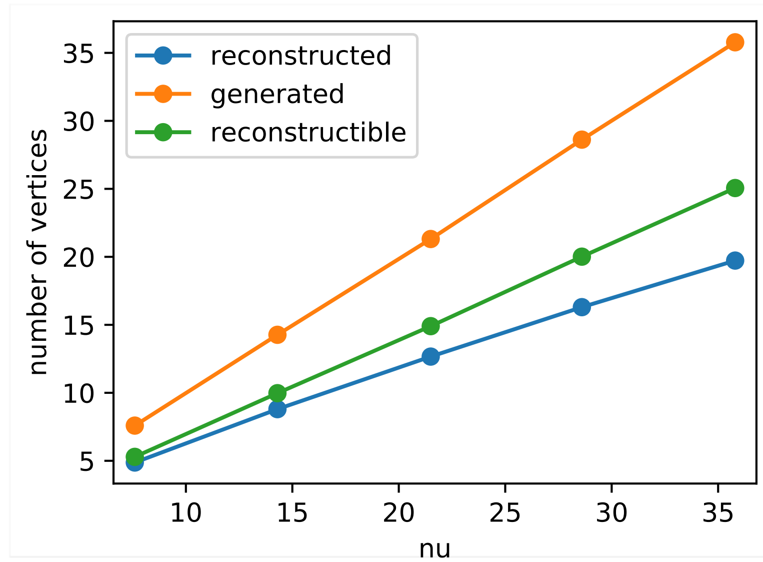
RICH1 & RICH2

Counters

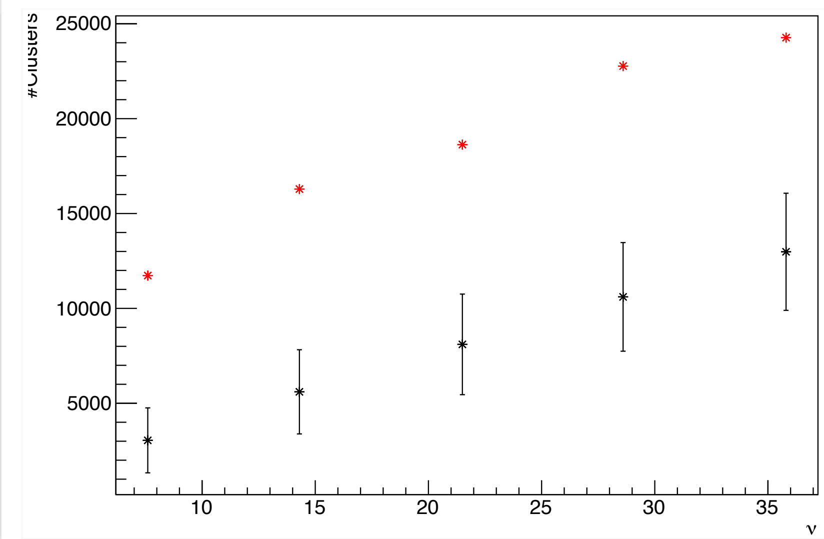
WORK IN PROGRESS

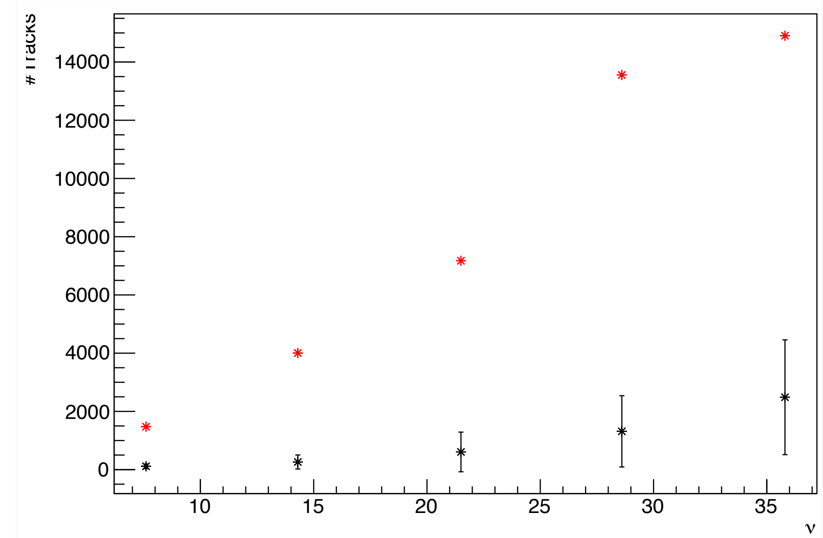


VELO - A. Beck

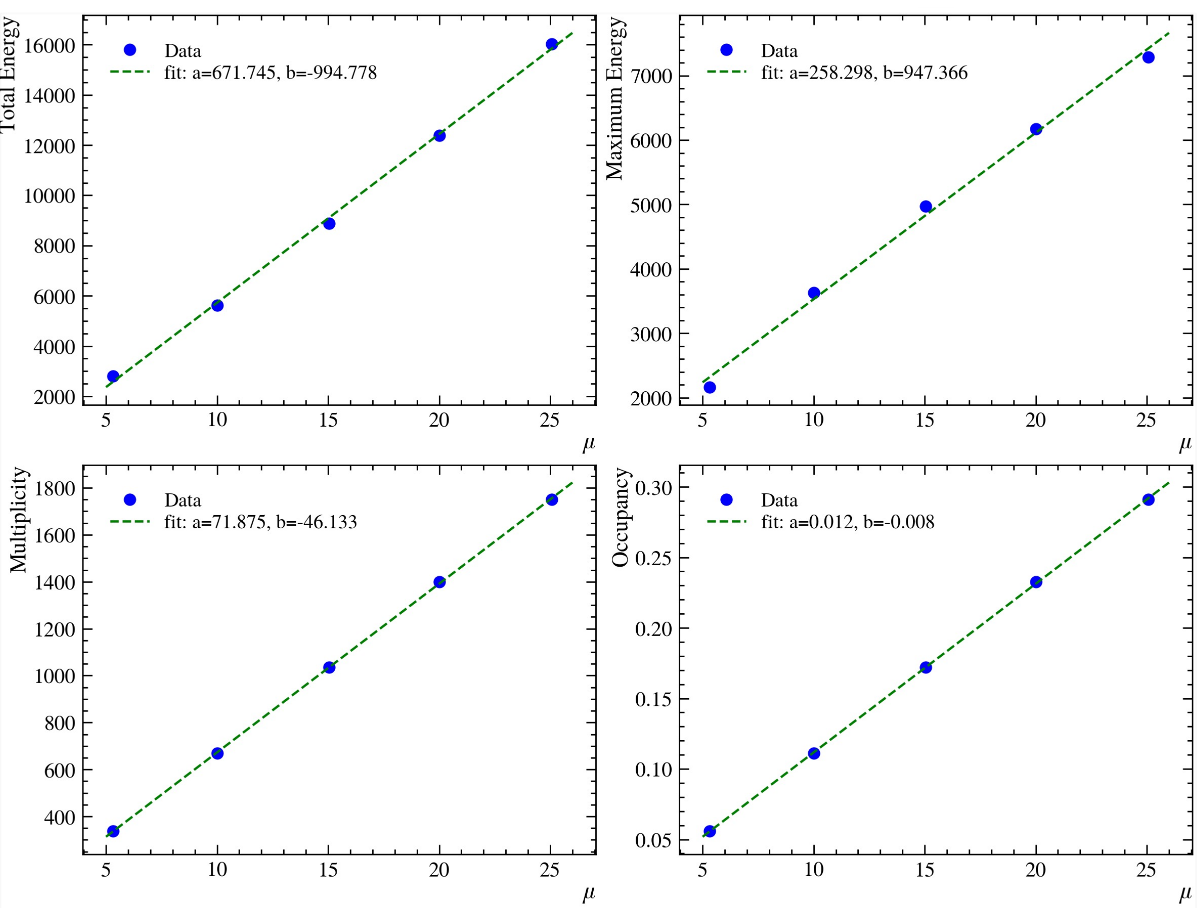


SciFi - P. D'Argent

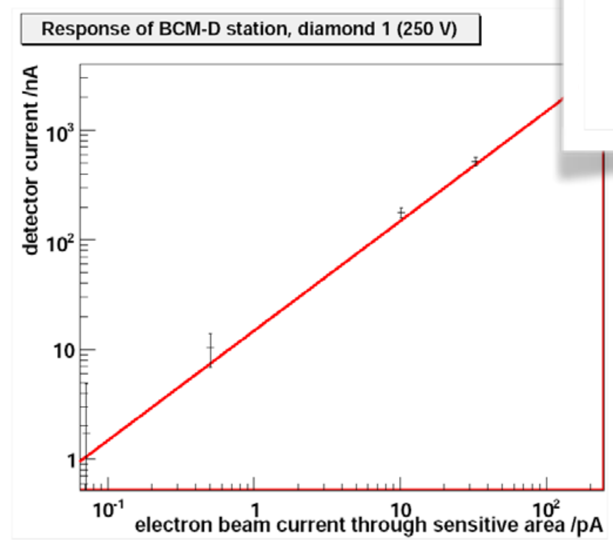




ECal - C. Mancuso



BCM - H.Stevens



for more details see the lumi counter meeting

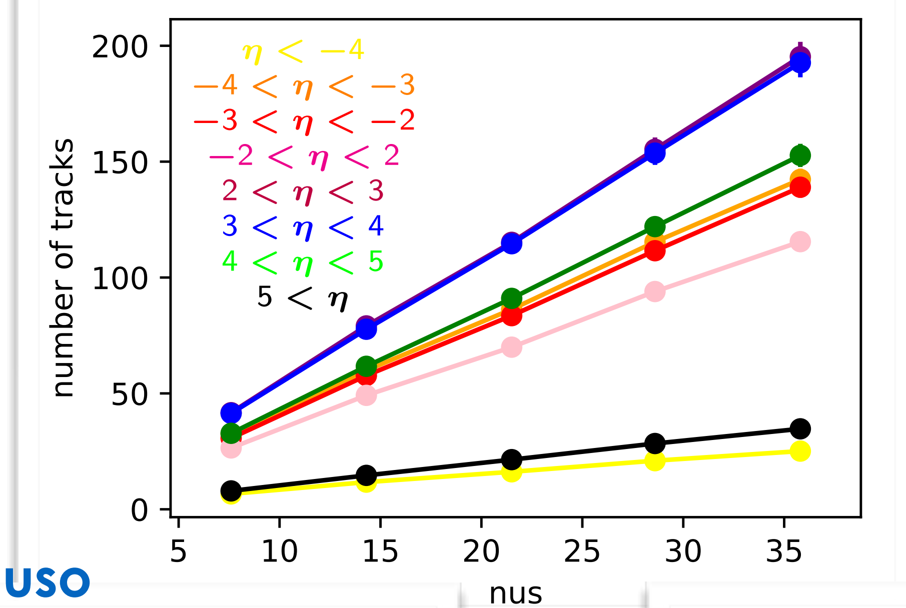
Counters

WORK IN PROGRESS

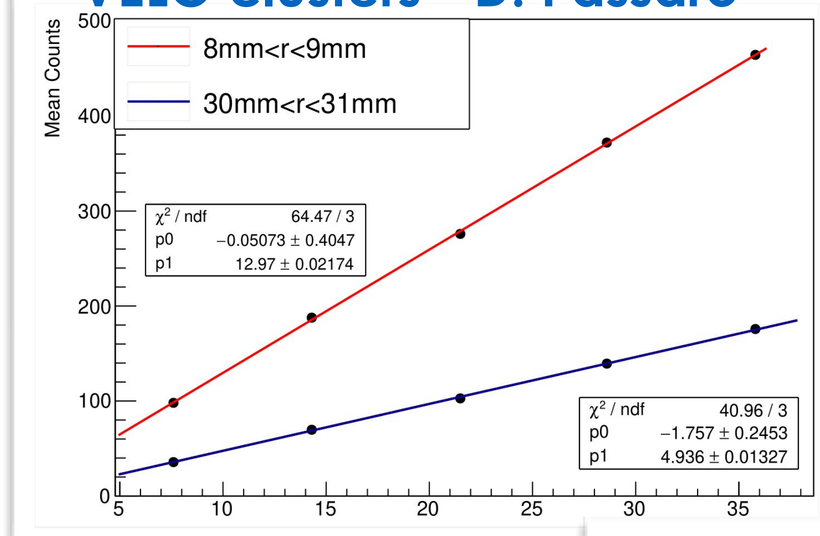
to exploit the advantages of the log0 method despite 5xμ:

- counters from regions with low occupancy
  - these regions are typically less affected by radiation damage and hence the response is more stable in time/less calibrations needed
- high granularity
  - with the advantage of monitoring performances in different region independently and in the long-term

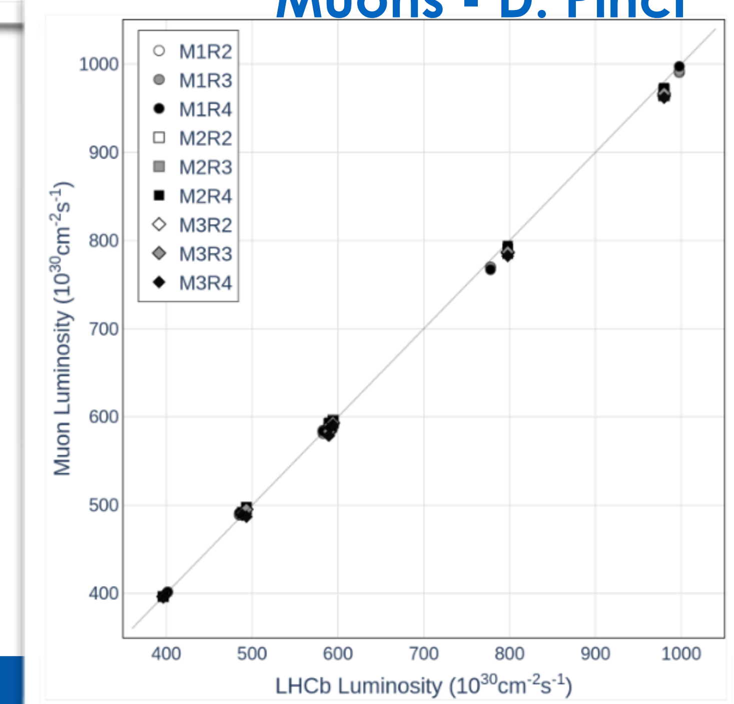
VELO - A. Beck



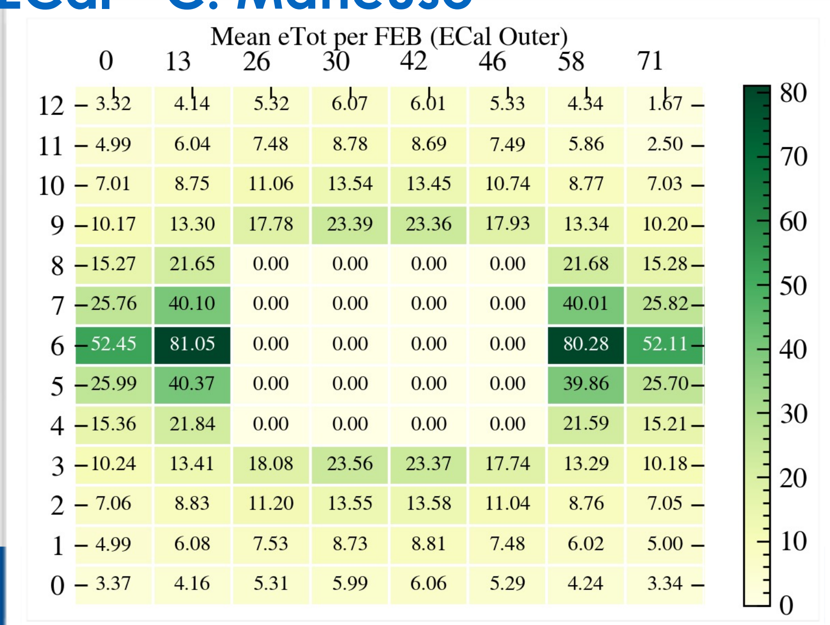
VELO clusters - D. Passaro



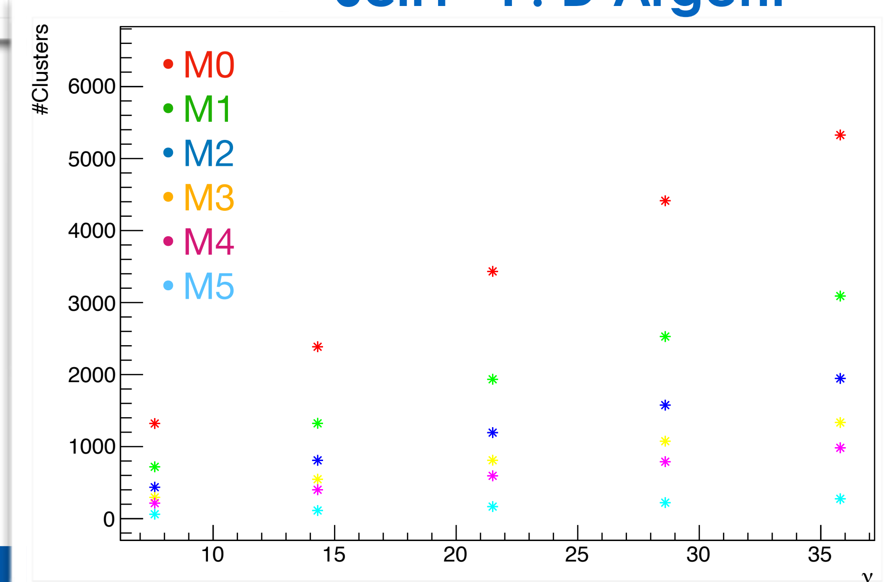
Muons - D. Pinci



ECal - C. Mancuso



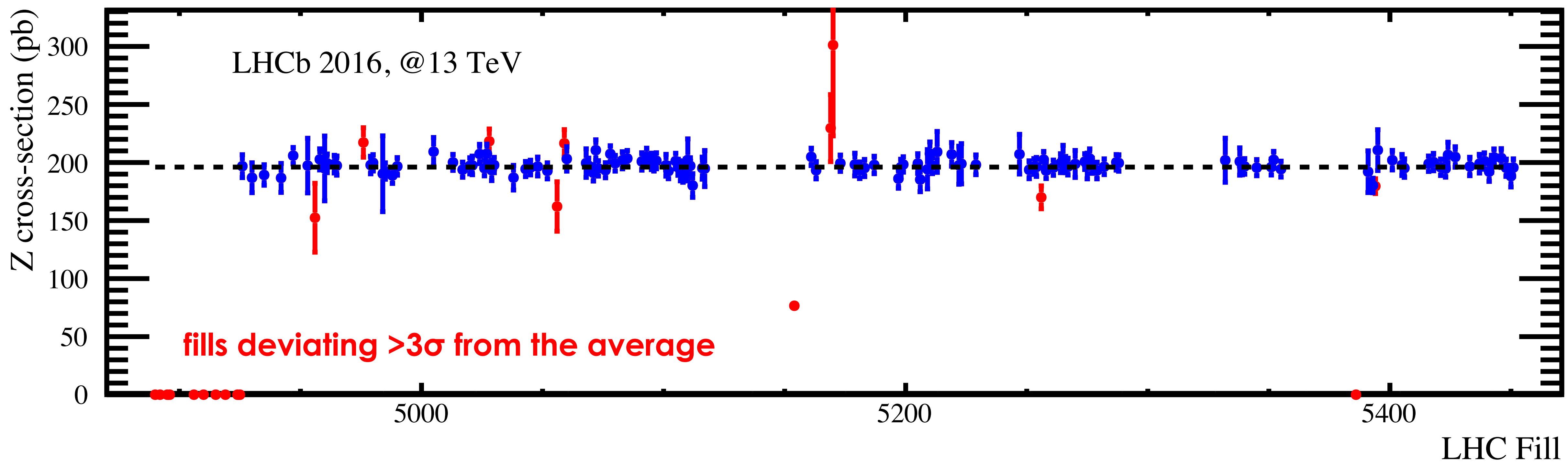
SciFi - P. D'Argent



Counters

WORK IN PROGRESS

Some physics channels are good candidates to monitor the integrated lumi!



- number of $Z \to \mu\mu$ candidates can be used as counter
- ratio $N(Z \to \mu\mu)/N(\text{other counter})$ in relatively short time (a few hours?) to monitor relative drifts
- can not be calibrated directly in VdM (one step takes 10s only), but could be cross-calibrated wrt any other counter
- triggered in standard physics stream:
  - more affected by biases (for ex: dependence of μ reconstruction efficiency on pile-up)
  - but will have very different systematics

X. Zhu talk

Counters

why do we need so many counters?

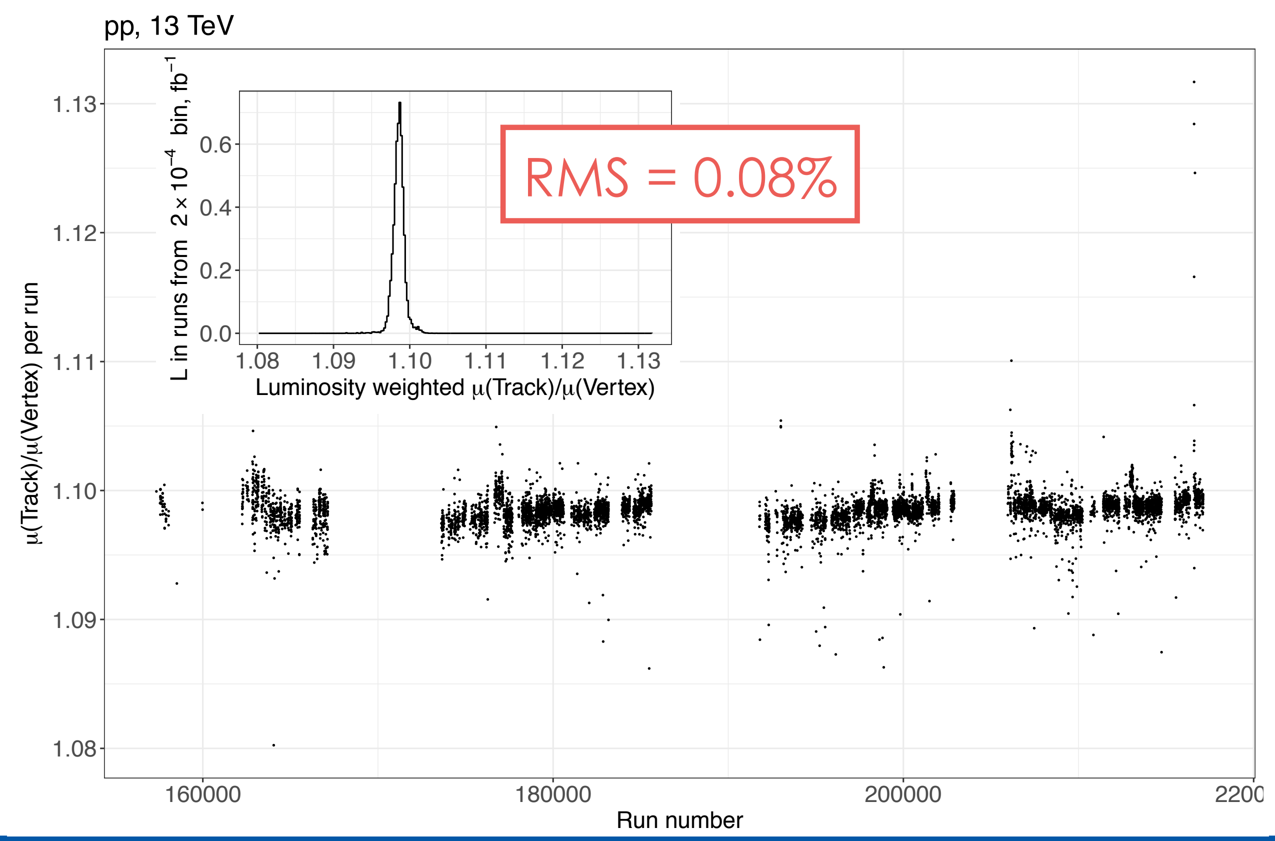
having many observables and as different as possible from each other is crucial to

- cross-check their stability in time
- to correct for various efficiency dependences and/or assign systematics

RUN 3: we plan to have online monitoring comparing the various counters

Additional advantages for detectors:

- excellent measure of the performance of the detector
- long-term stability control
- absolute comparison of performance across all years, guaranteed by Van der Meer scans



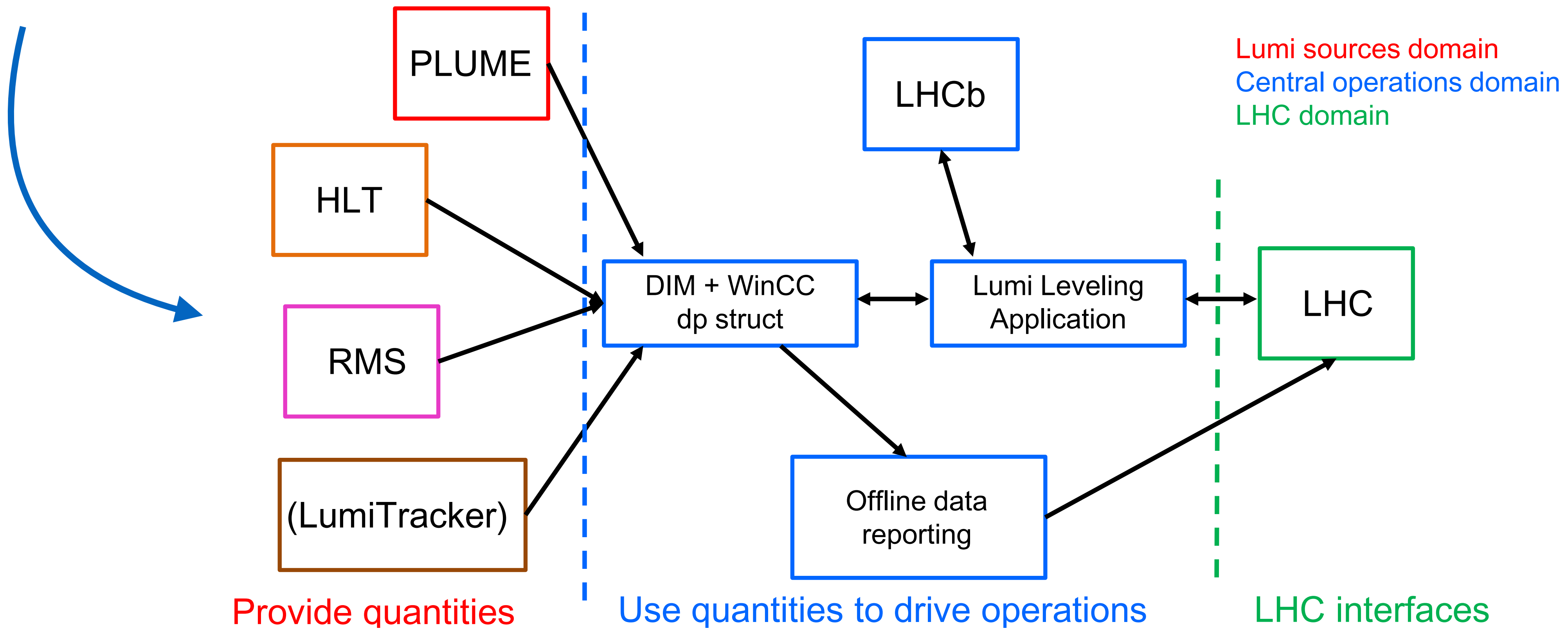
Online vs Offline

Online luminosity

- needed for lumi levelling, reporting of quantities to both LHC and LHCb (center and width of luminous region, beam shapes, integrated delivered/recorded lumi…), monitoring
- hierarchy of counters: the first one provides μ, the rest for monitoring (Run1,2 L0 CaloE$_T$, Run 3 PLUME)
- required precision: <10%
- in Run 3 per bunch lumi

Offline luminosity

- needed for physics analyses
- most stable counter (Run 1,2 VELO tracks for pp) used for lumi determination, the rest for cross-checks, corrections and systematics
- required precision: best possible (for pp reached ≤2%, for PbPb ~4%)
- measured per bunch



F. Alessio

Online vs Offline

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Counters via ECS

To cross-check and as back-up for PLUME

- VELO FPGA clusters: per bunch
- muon hits (luMUONmeter): maybe can "sync" with bunches
- RICH currents
- BCM current

Counters via HLT

For offline analysis and online monitoring

- randomly triggered crossings
- 30 kHz rate
- background subtracted from ee, be, eb crossings

Plan

- first VdM scan expected in September

before the VdM scan:

- emittance scan as early as possible to calibrate PLUME and any detector already commissioned (likely ECal, HCal, Muons)
  - trigger in passthrough mode
  - code for absolute calibration in preparation by the PLUME team
  - monitoring jobs need to be setup
- put in operation levelling application
- add inputs from other detectors as soon as commissioned
  - cross-calibrated with PLUME or with following emittance scans
  - HLT1 lumi line currently in preparation (see S. Xian talk)

after VdM scan: at least 3 months needed to perform the analysis aiming at 5% uncertainty

- input from LHC should be the same
- but our detectors are new: stability and efficiency dependences need to be determined, corrections applied and systematics calculated

Data flow

ODIN	generate the triggers
HLT 1	compute counters, select and "stream" events
Monitoring	analyse and publish
HLT 2	compute more counters, "nanofy" and stream events

30 kHz random trigger shared as 70:15:10:5 in bb:be:eb:ee

nano-events only contain lumi counters

Run 1: lumi and uncertainty stored in lumi tuple

Run 2: lumi per run available in a .csv file from the twiki (it's responsibility of the user to check if all the data were processed)

Run 3: have a tool (outside DaVinci) to compute lumi based on measurements per run and actual files processed

- implementation still to be defined

WORK IN PROGRESS

Summary

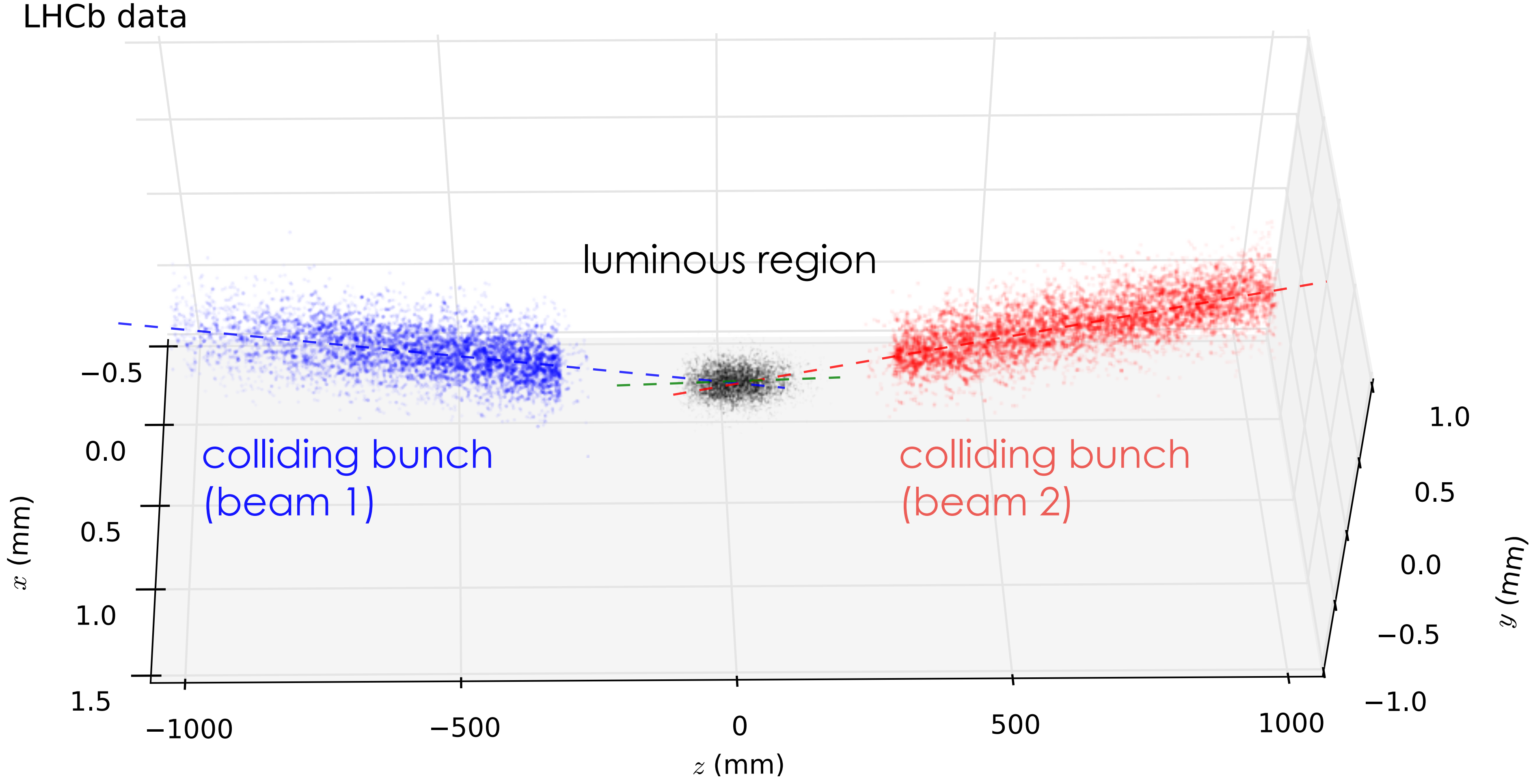
- several changes expected in Run 3, due to the different running conditions and especially a new detector
- both online and offline luminosity require **absolute calibration**
  - at the moment this is foreseen to be determined with VdM scan in September (several months for the processing of data needed after that)
  - prior to VdM scan, emittance scans
- first **emittance scan** to be performed as soon as possible to calibrate PLUME and any detector already commissioned (likely ECal, HCal, Muons)
  - other detectors will be cross-calibrated with PLUME afterwards (or with following emittance scans)

a lot of activities ongoing in preparation for Run 3!

Back up

Beam Gas Imaging

- Beam Gas Imaging (BGI) unique to LHCb thanks to SMOG
- alternative method for absolute calibration by recording beam images with beam-gas interactions
- (partly) different systematics than VdM: combining the 2 methods reduces the uncertainty on the cross-section
- used in Run 1, since then no sufficient person power: for Run 3 no one available yet



What contributes to offline precision?

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- lumi uncertainty is the dominant in many cross-section measurements

RUN 1

Method	Absolute calibration σ_{vis} (mb)	Weight	Uncertainty	Relative calibration uncertainty	Total uncertainty
pp at $\sqrt{s} = 8$ TeV					
BGI	60.62 ± 0.87	0.50	1.43% (0.59%)		
VDM	60.63 ± 0.89	0.50	1.47% (0.65%)		
Average	60.62 ± 0.68		1.12%	0.31%	1.16%
pp at $\sqrt{s} = 7$ TeV					
BGI	63.00 ± 2.22	0.13	3.52% (1.00%)		
VDM	60.01 ± 1.03	0.87	1.71% (1.00%)		
Average	60.40 ± 0.99		1.63%	0.53%	1.71%

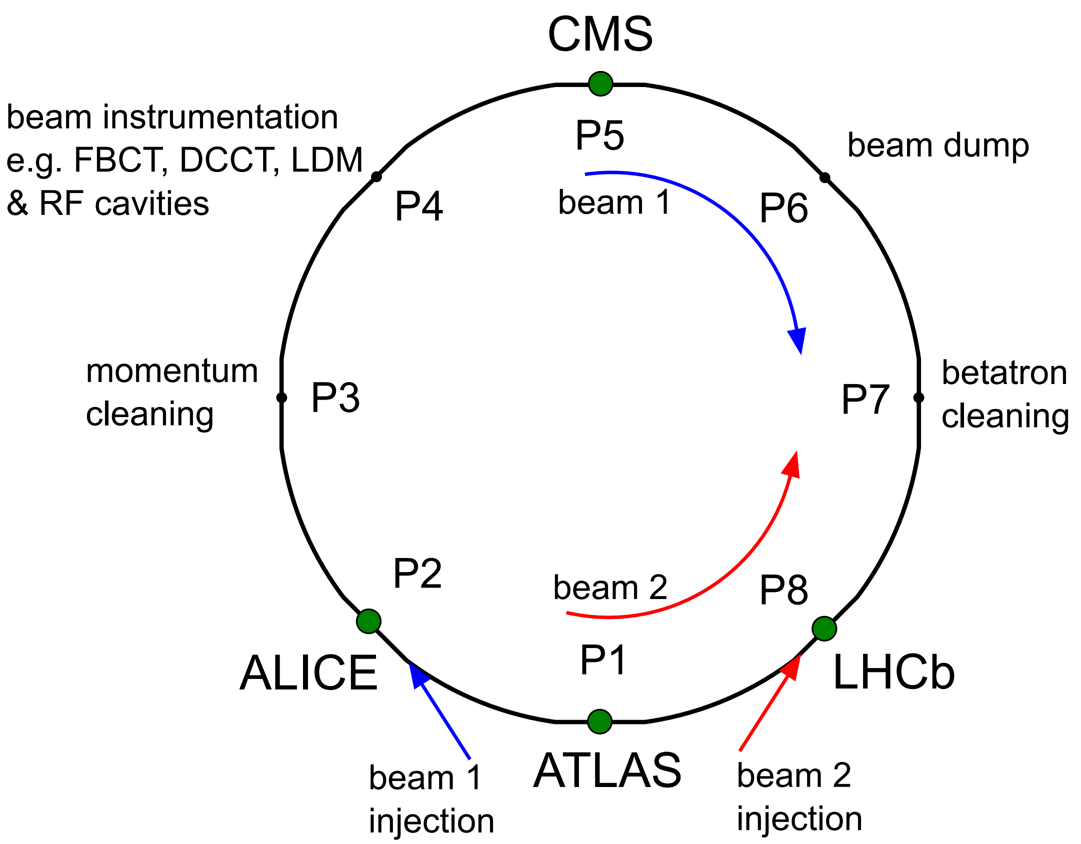
RUN 2

offline luminosity with σ = 2% for pp Run 2 at 13 and 5.02 TeV (only VdM scan)
document in preparation

- lumi uncertainty mainly comes from the uncertainty on absolute calibration
- 3 main sources to absolute calibration uncertainty:
  - X-Y non-factorizability
  - beam orbit drifts: monitored by Beam Position Monitors (BPMs) around LHC
  - beam-beam interaction (bunch deformations): model based corrections

N12 determination

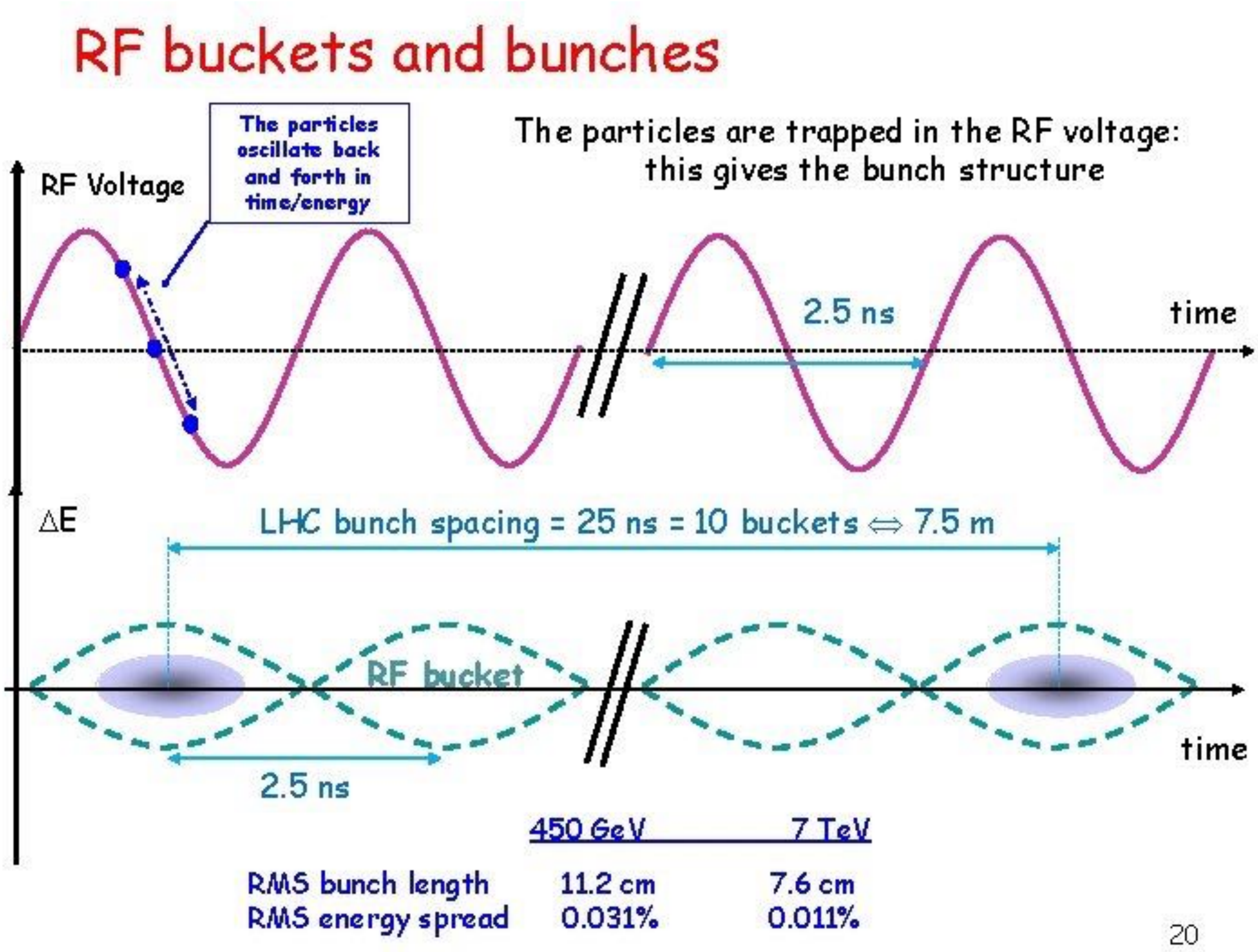
- total beam intensities are determined from total beam currents (slowly) measured with high accuracy by LHC direct-current current-transformers (DCCT),
- background (1-2%) in nominally empty LHC bunches or buckets is determined either with LHC equipment (BSRL) and/or with beam-gas interactions in LHCb and subtracted
- charge fraction per bunch is measured with LHC fast transformers (FBCT)



typical N_1N_2 uncertainty: ~0.2-0.3%

Beam structure

link to presentation



Online luminosity

Lumi leveling

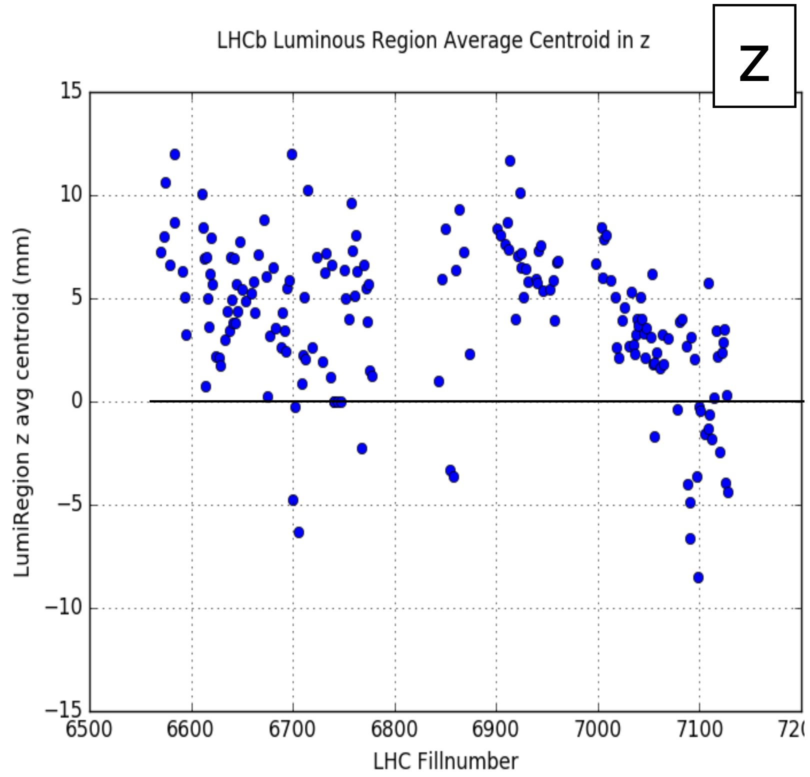
- target value of μ set by LHCb
- lumi leveling application requests adjustments when measured μ>|3|% from target
- based on the info provided LHC tunes beams separation

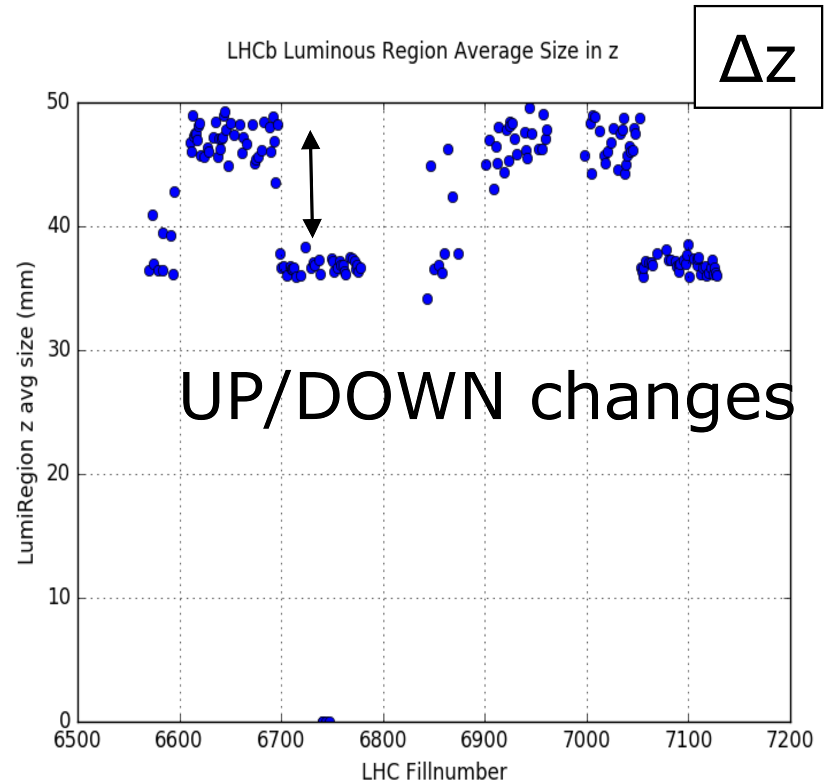
Reporting

- in real-time for monitoring
- offline for analysis
- quantities needed for both LHC and LHCb:
  - μ per bunch
  - integrated delivered and recorded lumi
  - center and width of luminous region (x,y,z)
  - beam shapes (x,y) for beam 1 and 2

What's to be done for Run 3?

- framework to provide luminosity is solid, only some adaptations needed
  - update to the new sources of μ
  - add monitoring
  - set-up a framework to generate automatically reports fill-by-fill

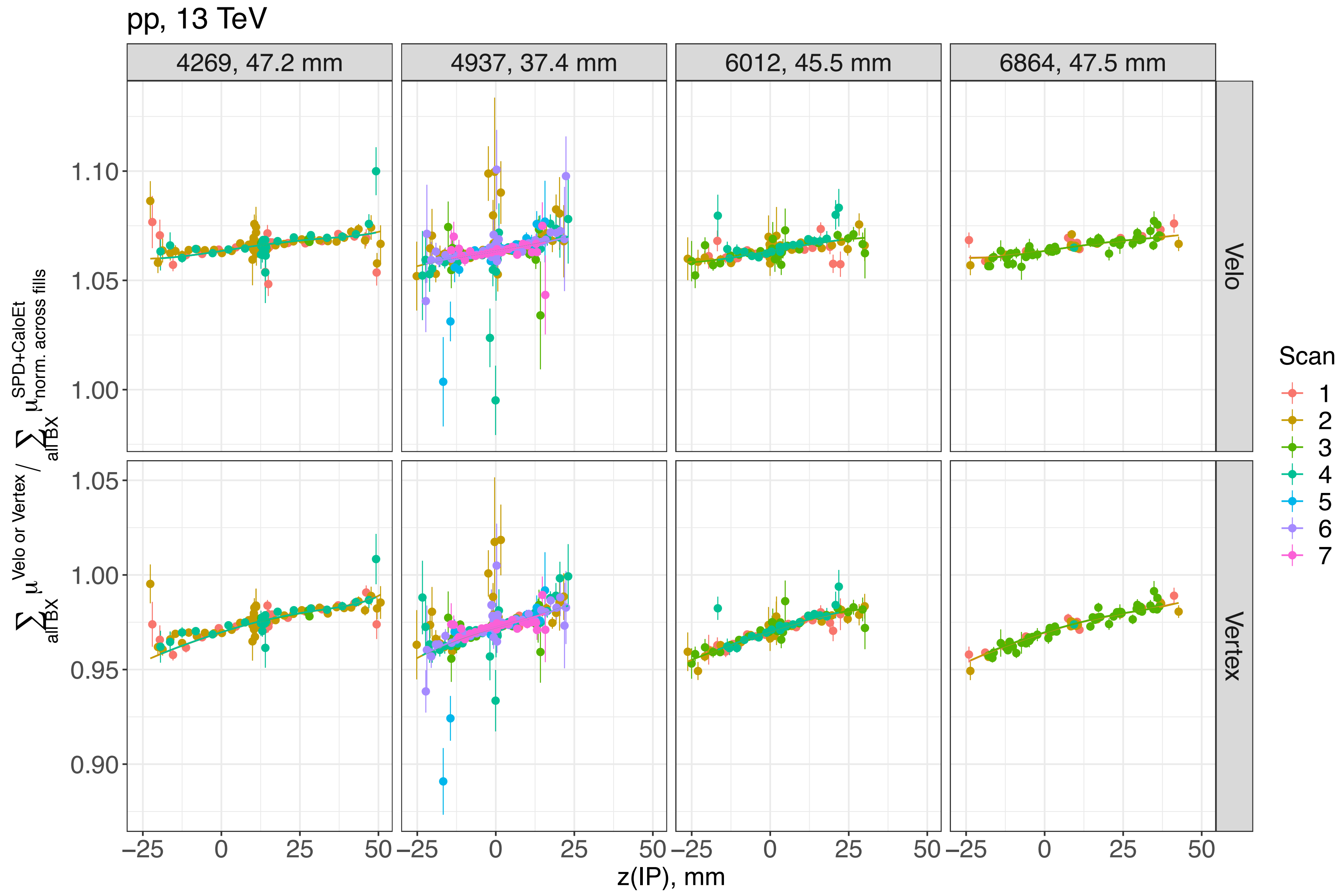




Efficiency correction

efficiency correction

- efficiency of # of VELO tracks or vertices depends on z position of the luminous region

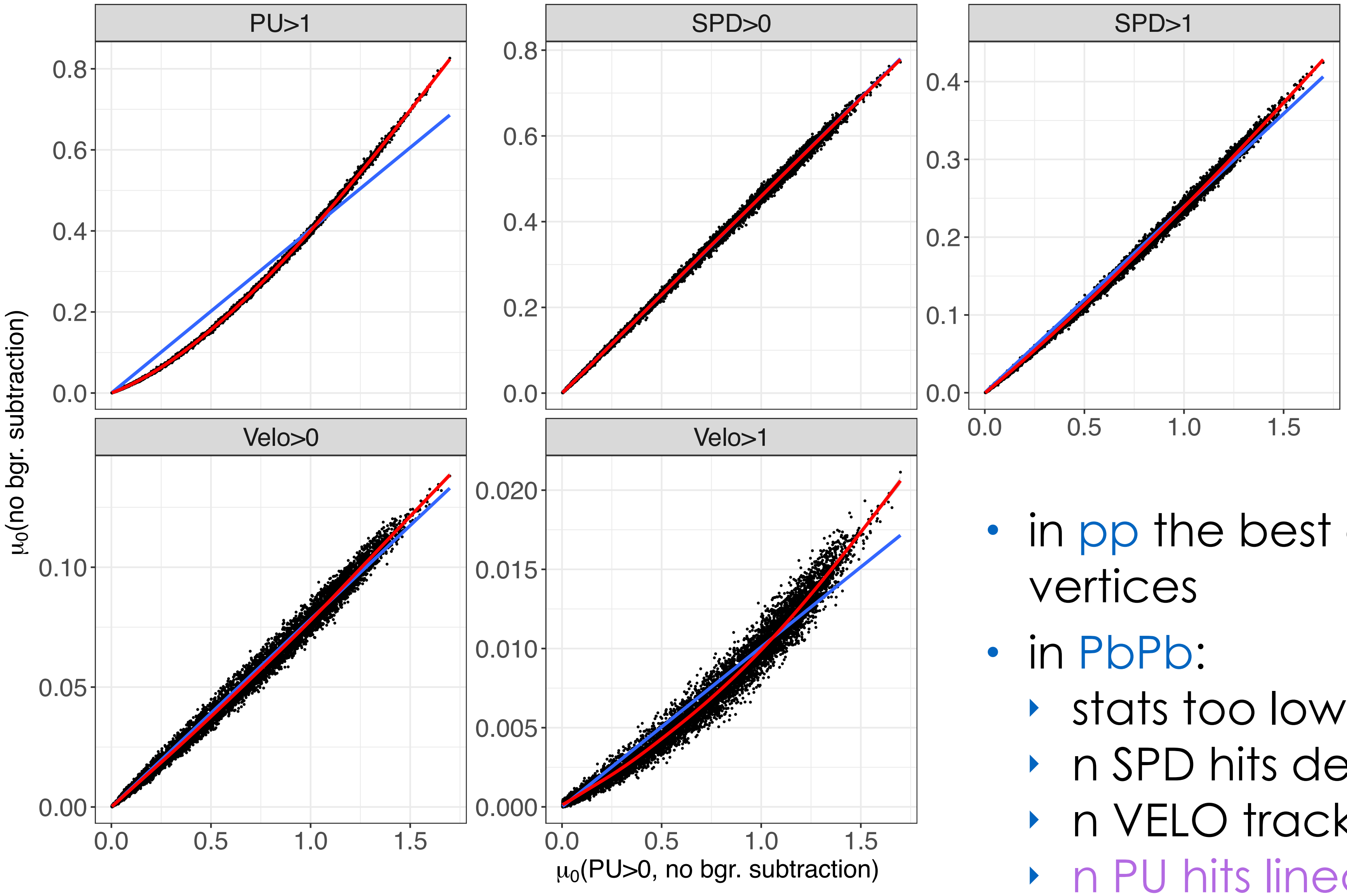


PbPb luminosity

note in preparation

choice of best lumi counter

- different conditions wrt pp interactions:
  - little activity in the detector (spectra dominated by EM interactions)
  - hard interactions with a vertex, significant E_T in calo and many tracks are rare



cuts defining an empty event must be minimised

- in pp the best counters are VELO tracks and vertices
- in PbPb:
  - stats too low to use vertices
  - n SPD hits depends on material activation
  - n VELO tracks non-linear (~2%)
  - n PU hits linear and high stats

MAIN COUNTER