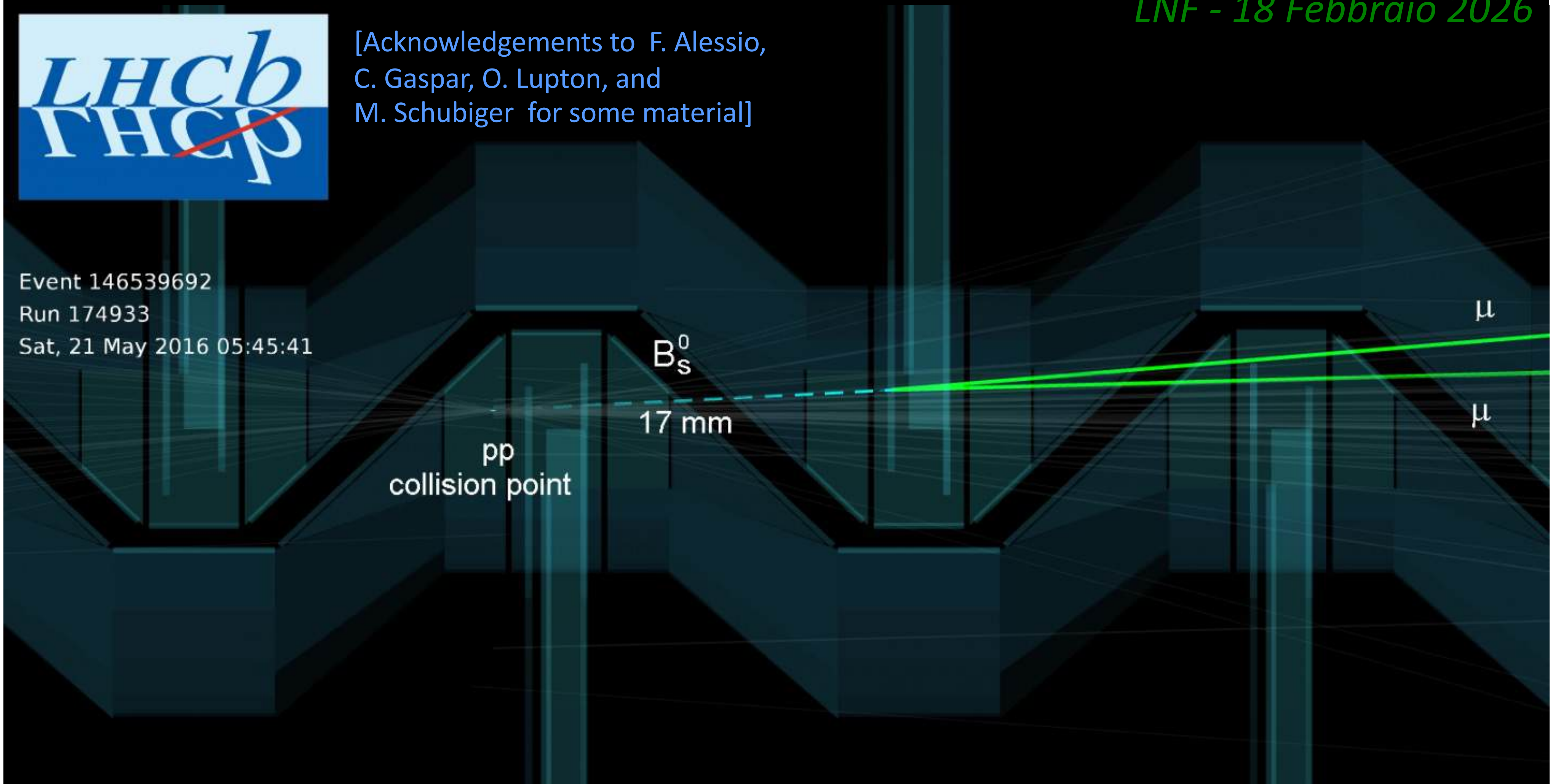
Barbara Sciascia, INFN
MasterClass IPPOG2026
LNF - 18 Febbraio 2026

[Acknowledgements to F. Alessio, C. Gaspar, O. Lupton, and M. Schubiger for some material]



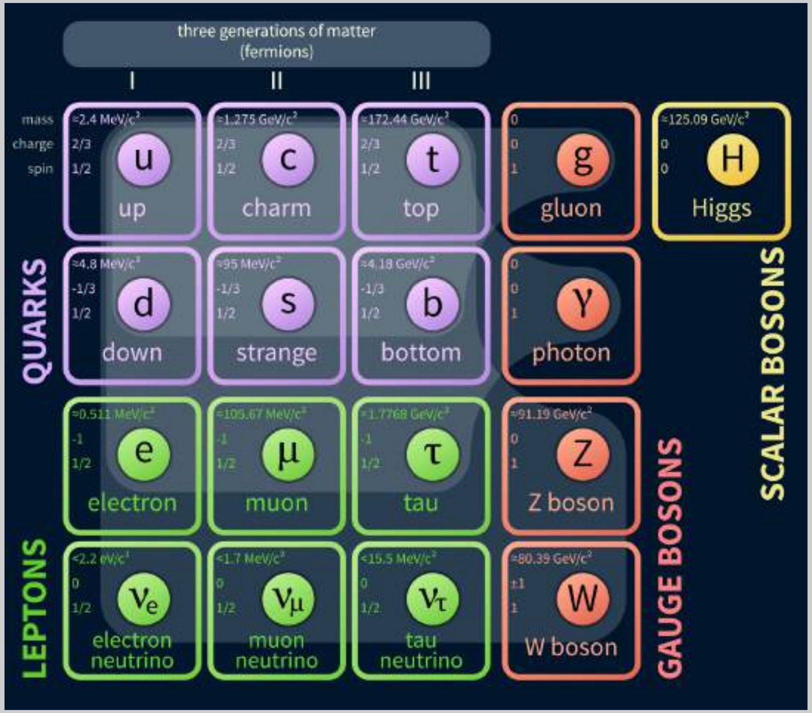
LHCb experiment

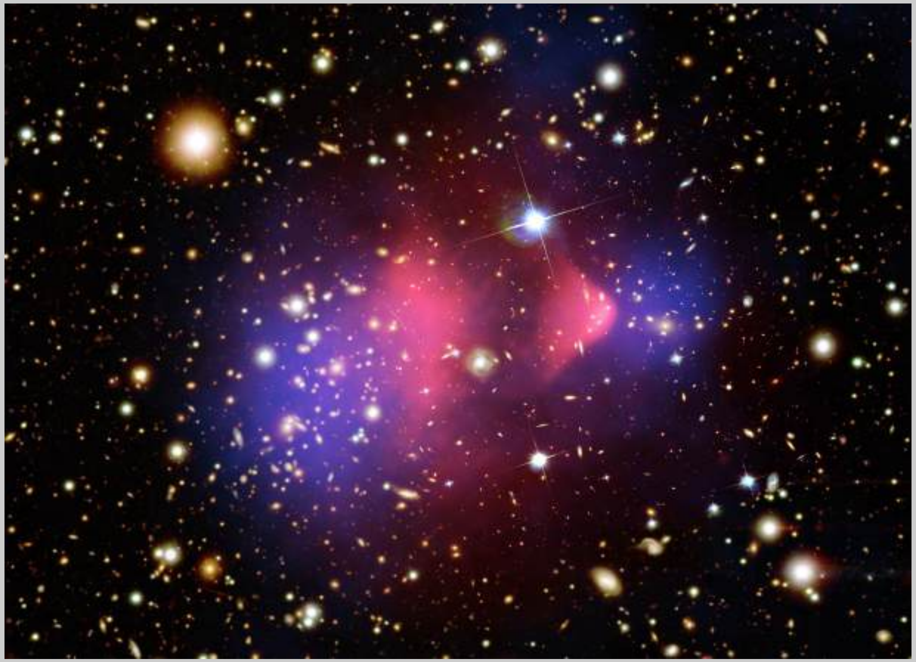
Happy people at LHCb

Rolf Lindner, the former LHCb Technical Coordinator, went through the footage of happy people he filmed during the assembly of the upgrade, showing that building a brand-new detector is hard work but can also be a lot of fun.

Open points: SM (and beyond)

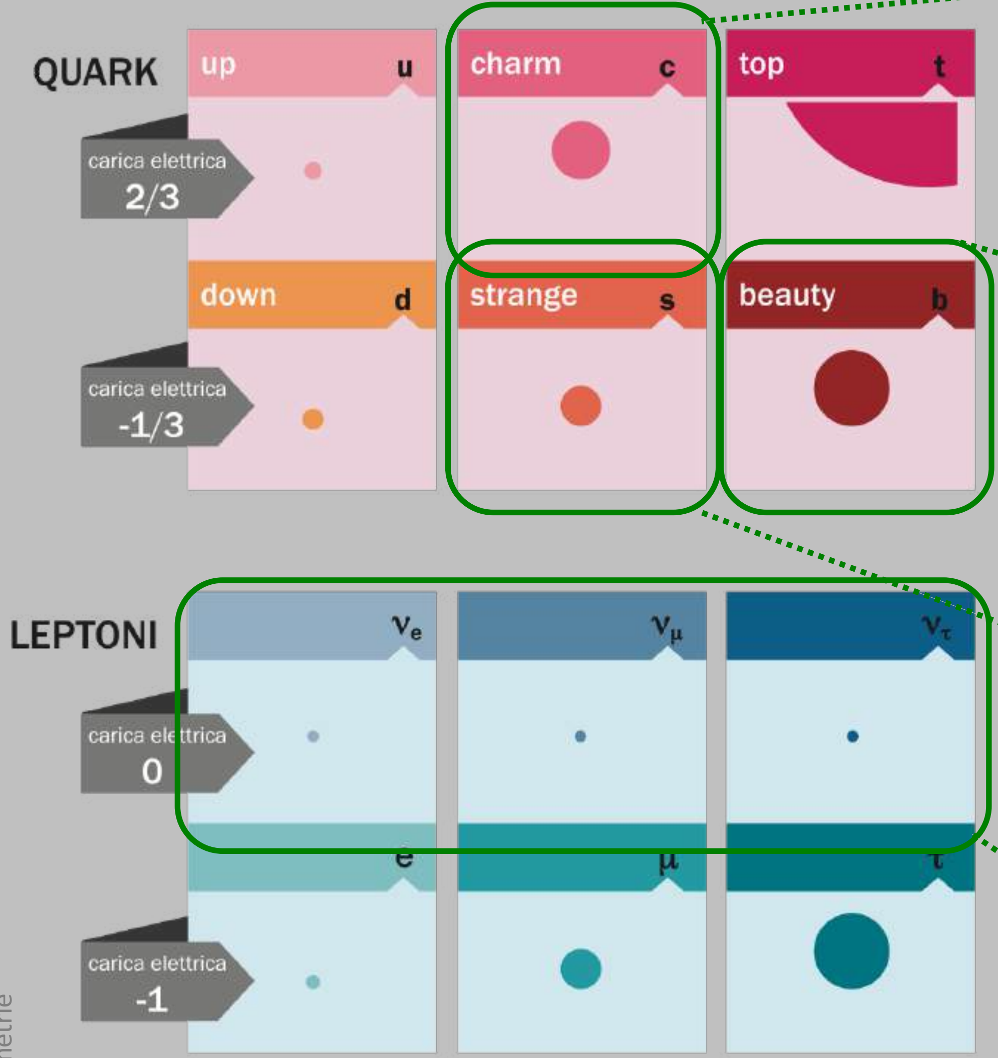
- No explanation for the quark hierarchy
- Why are there 3 families/generations?
- No real explanation for CP violation
- Why is it only found in the weak interaction?
- Mass value of the Higgs boson
- EW and strong unification
- …





- No explanation for baryogenesis
- Dark matter and dark energy
- Neutrino masses
- Gravity
- …

CP violation, key dates



Credits: Asimmetrie

2019:
LHCb@CERN

2001:
Babar@PEPII
Belle@KEK

1964: Cronin et al.

2020:
SuperKamiokande

Andrei Sakharov

[Christian Hirou/Gamma-Rapho, via Getty Images]

Le condizioni di Sakharov

[proposte nel 1967]

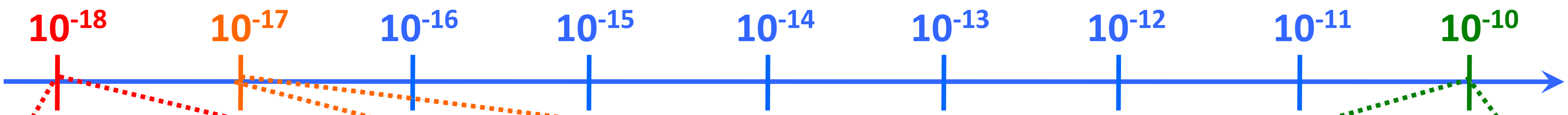
Necessary for evolution of matt... ...minated
universe, from symmetr... ...tate

(1) baryon nu... ...tion

(2) ... ...olation

... thermal inequilibrium

"Deve esserci una differenza tra materia e antimateria"



~ 10^{-18}

Se si assume che l'Universo non distingue tra materia e antimateria

~ 10^{-17}

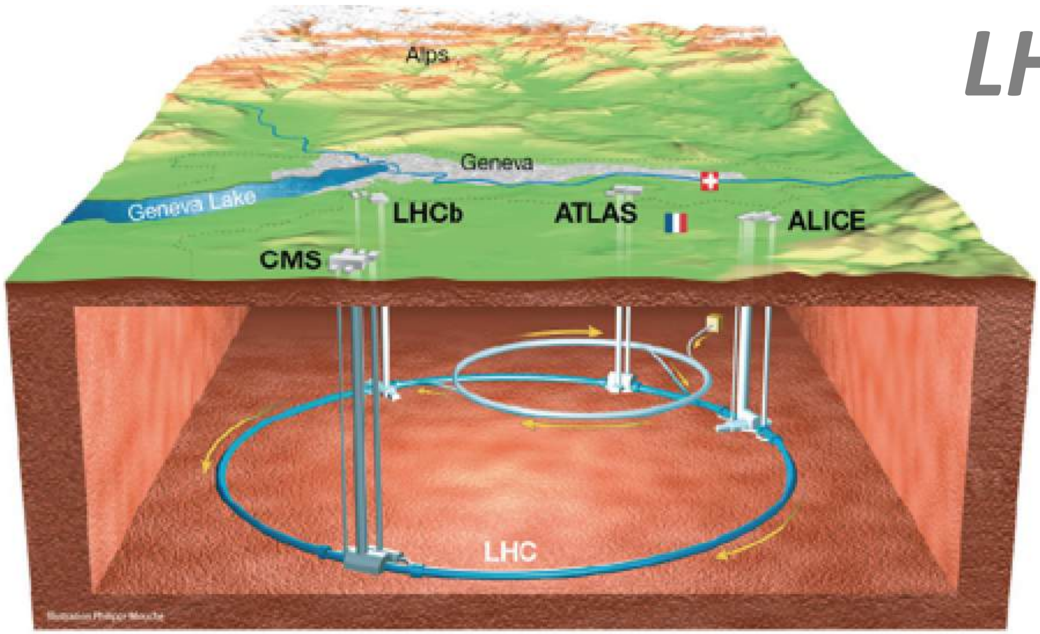
Dalla differenza tra materia e antimateria che misuriamo a terra

~ 6×10^{-10}

Dalla differenza tra materia e antimateria necessaria al Big Bang

LHCb at LHC in one slide

[https://lhcb-outreach.web.cern.ch/]

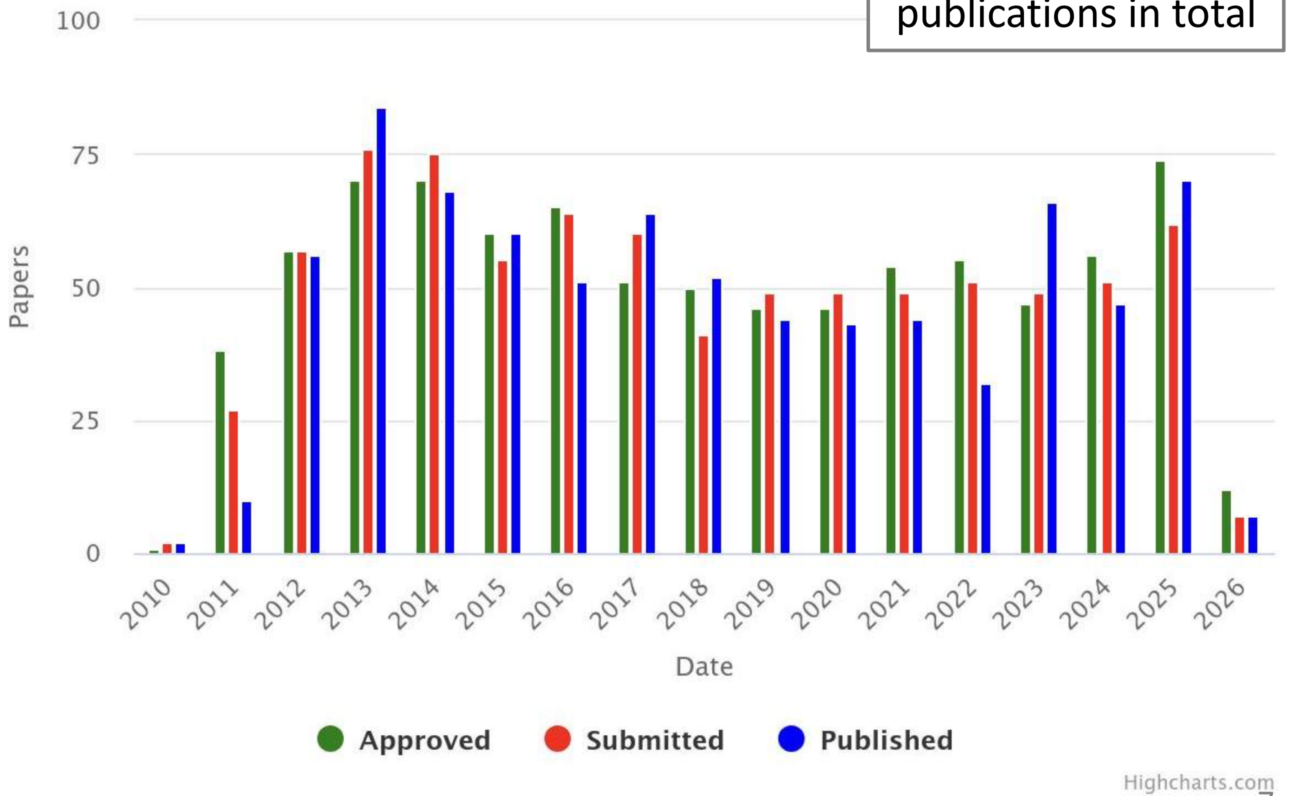


- 1859 members from 109 institutes in 28 countries [Feb 2026]

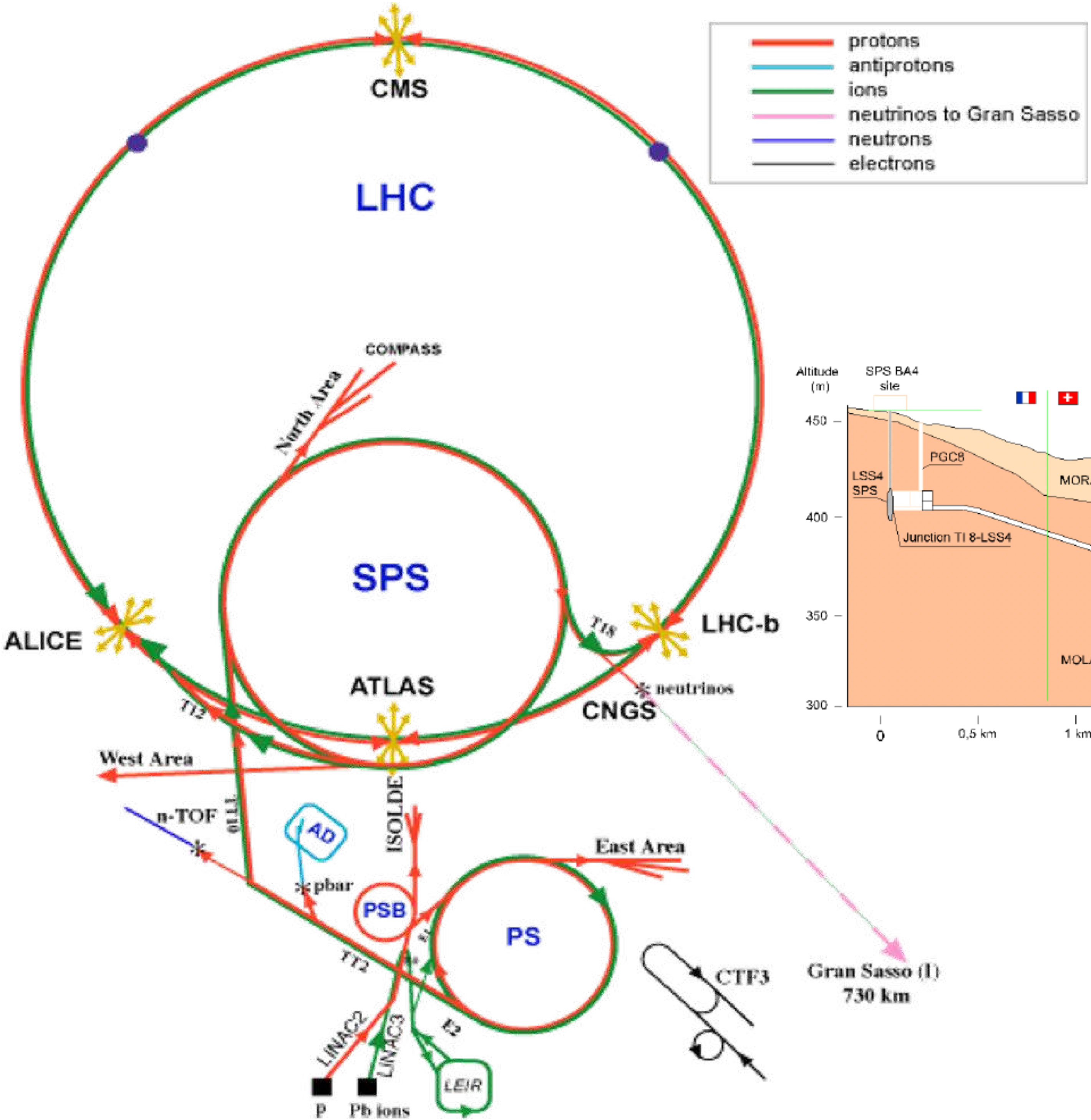
- Dedicated experiment for **precision measurements** of **CP violation** and **rare decays** of heavy-flavored hadrons

- pp collision at 7, 8, 13, 13.6 TeV collision energies

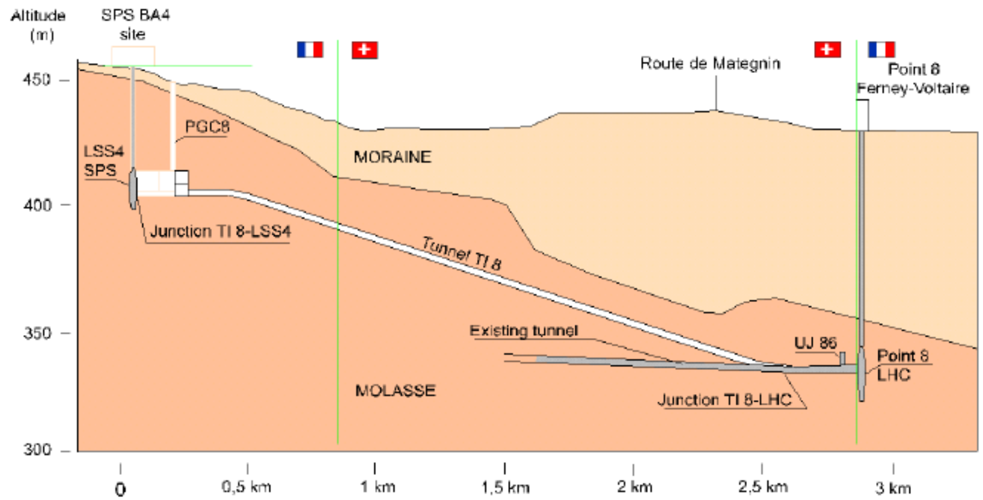
More than **800** publications in total



LHC complex

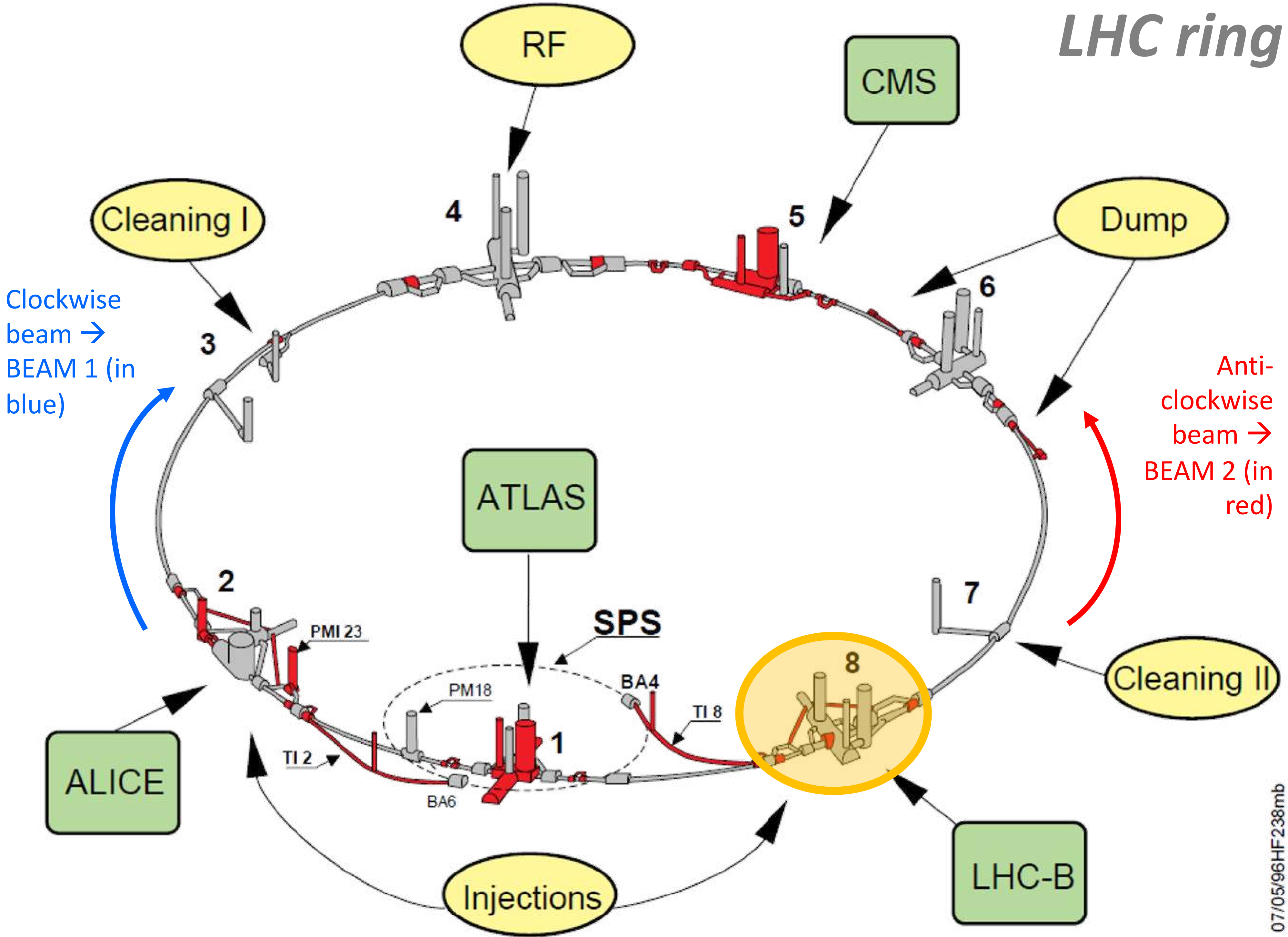


protons
antiprotons
ions
neutrinos to Gran Sasso
neutrons
electrons
CMS
LHC
COMPASS
North Area
SPS
ALICE
LHC-b
T18
ATLAS
CNGS
neutrinos
T12
West Area
n-TOF
TT10
AD
ISOLDE
East Area
pbar
PSB
PS
TT2
E1
E2
LINAC2
LINAC3
LEIR
P
Pb ions
CTF3
Gran Sasso (I)
730 km



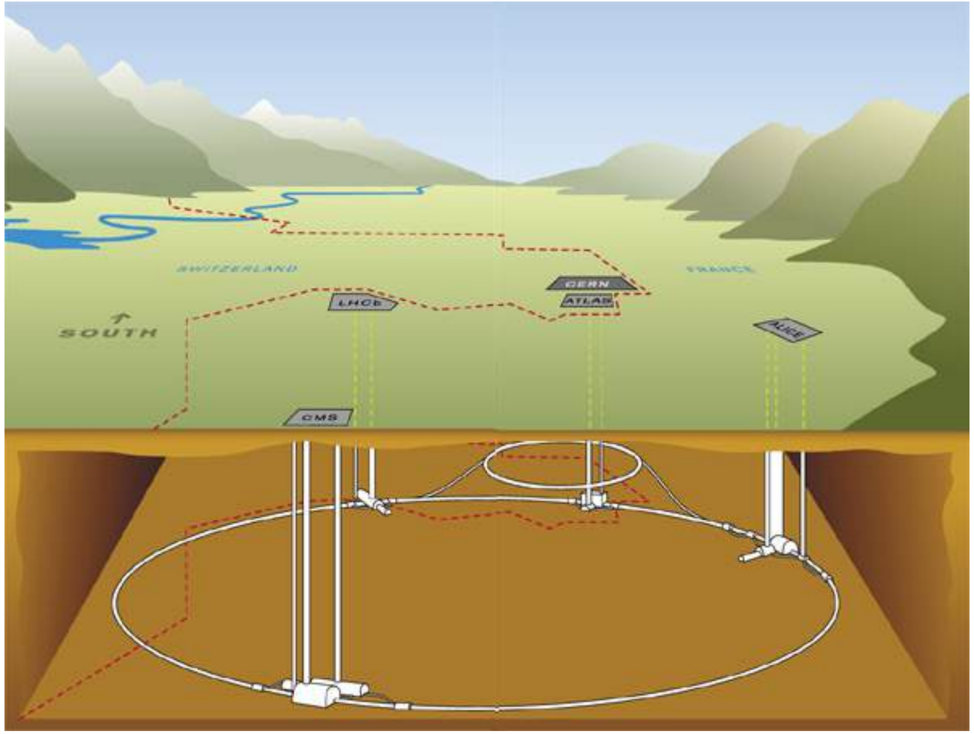
Altitude (m)
SPS BA4 site
450
400
350
300
Route de Mategnin
Point 8 Ferney-Voltaire
PGC8
LSS4 SPS
MORAINE
Junction TI 8-LSS4
Tunnel TI 8
Existing tunnel
UJ 86
Point 8 LHC
MOLASSE
Junction TI 8-LHC
0
0,5 km
1 km
1,5 km
2 km
2,5 km
3 km

LHC ring

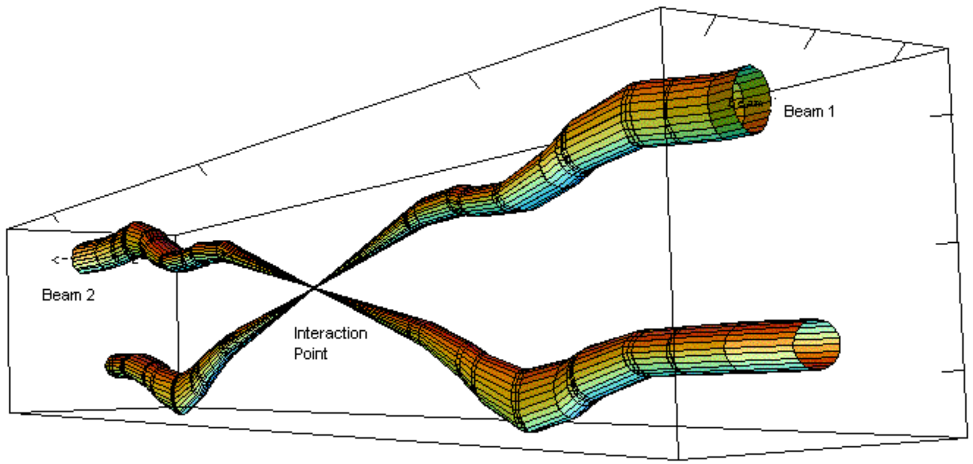


RF
CMS
Dump
Cleaning I
4
5
6
3
Clockwise beam → BEAM 1 (in blue)
Anti-clockwise beam → BEAM 2 (in red)
ATLAS
2
7
PMI 23
SPS
8
PM18
BA4
TI 8
Cleaning II
1
TI 2
BA6
ALICE
Injections
LHC-B
07/05/96HF238mb

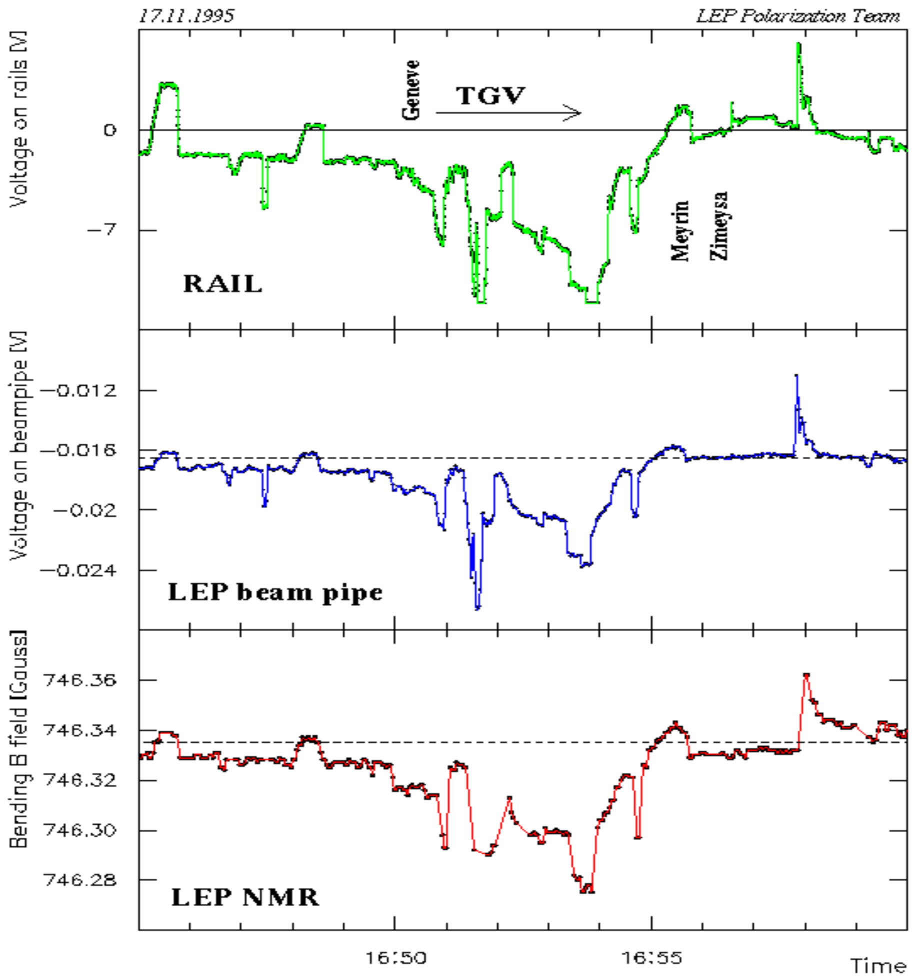
A lot of data: luminosity



$$L \approx \frac{N_1 N_2 f_{bc}}{4\pi\sigma_x\sigma_y}$$

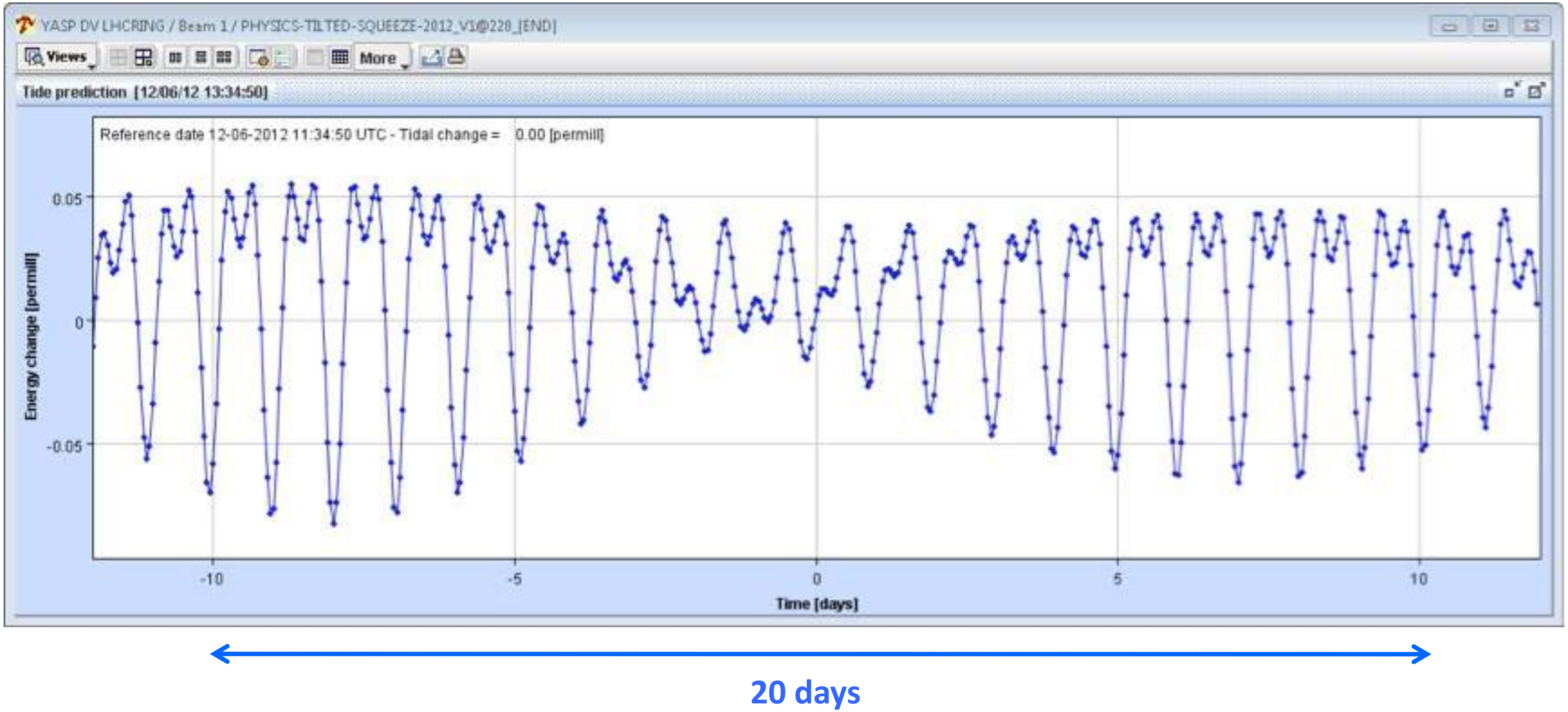


Relative beam sizes around IP1 (Atlas) in collision

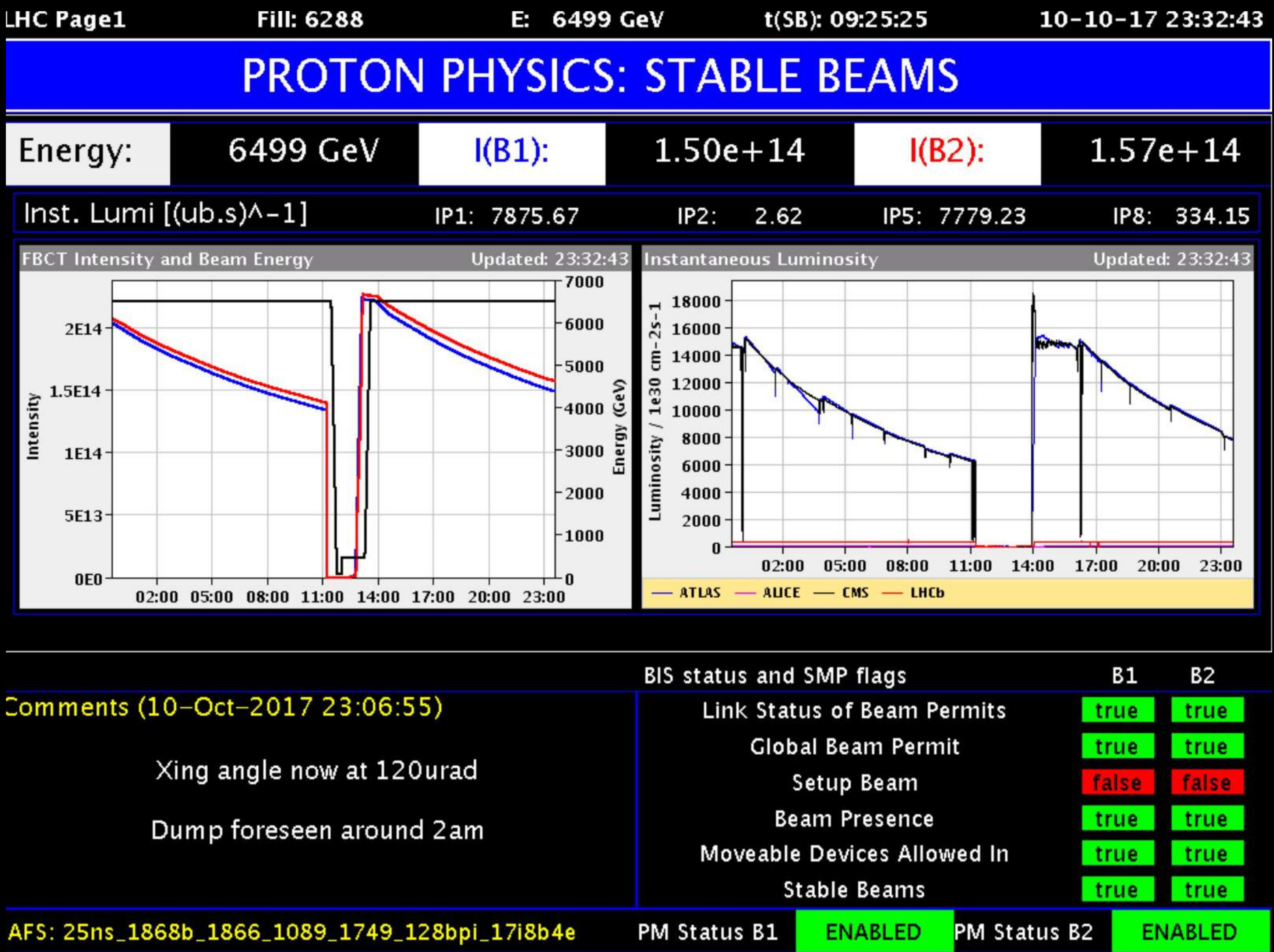


A lot of data: the Moon

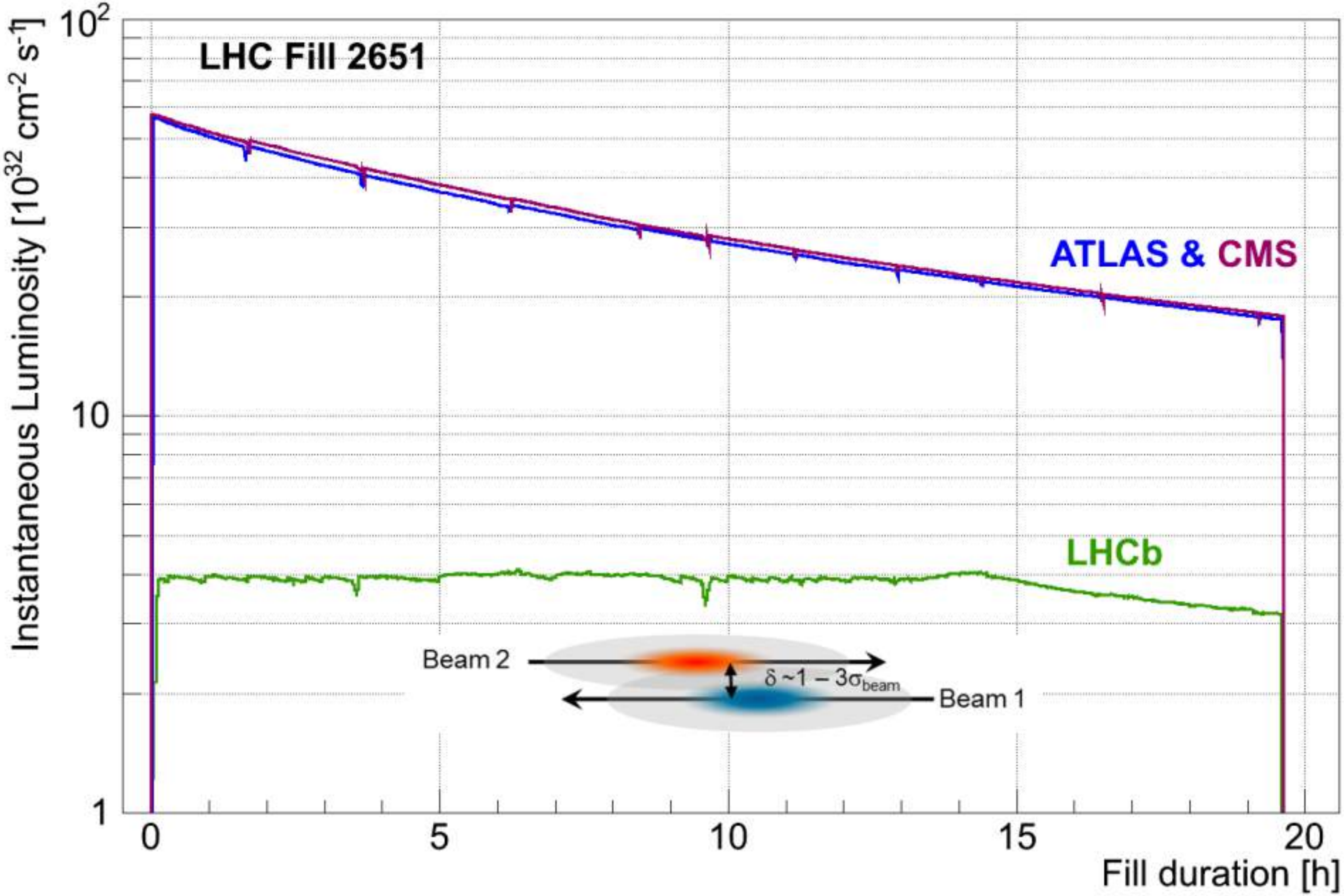
["Moon corrections map": small differences in gravitational force across LHC diameter.]



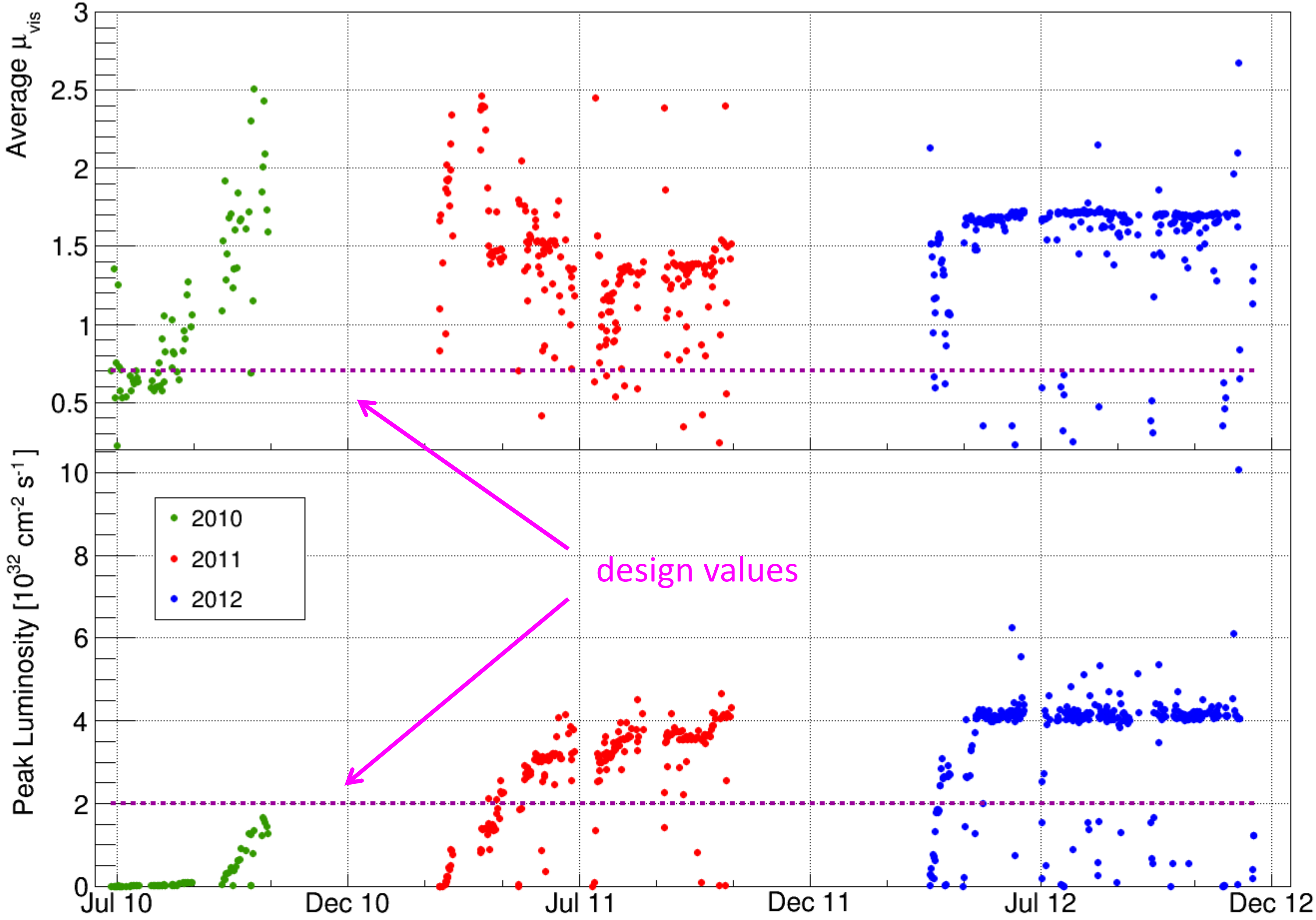
A lot of data: from control room



A lot of data: Luminosity leveling



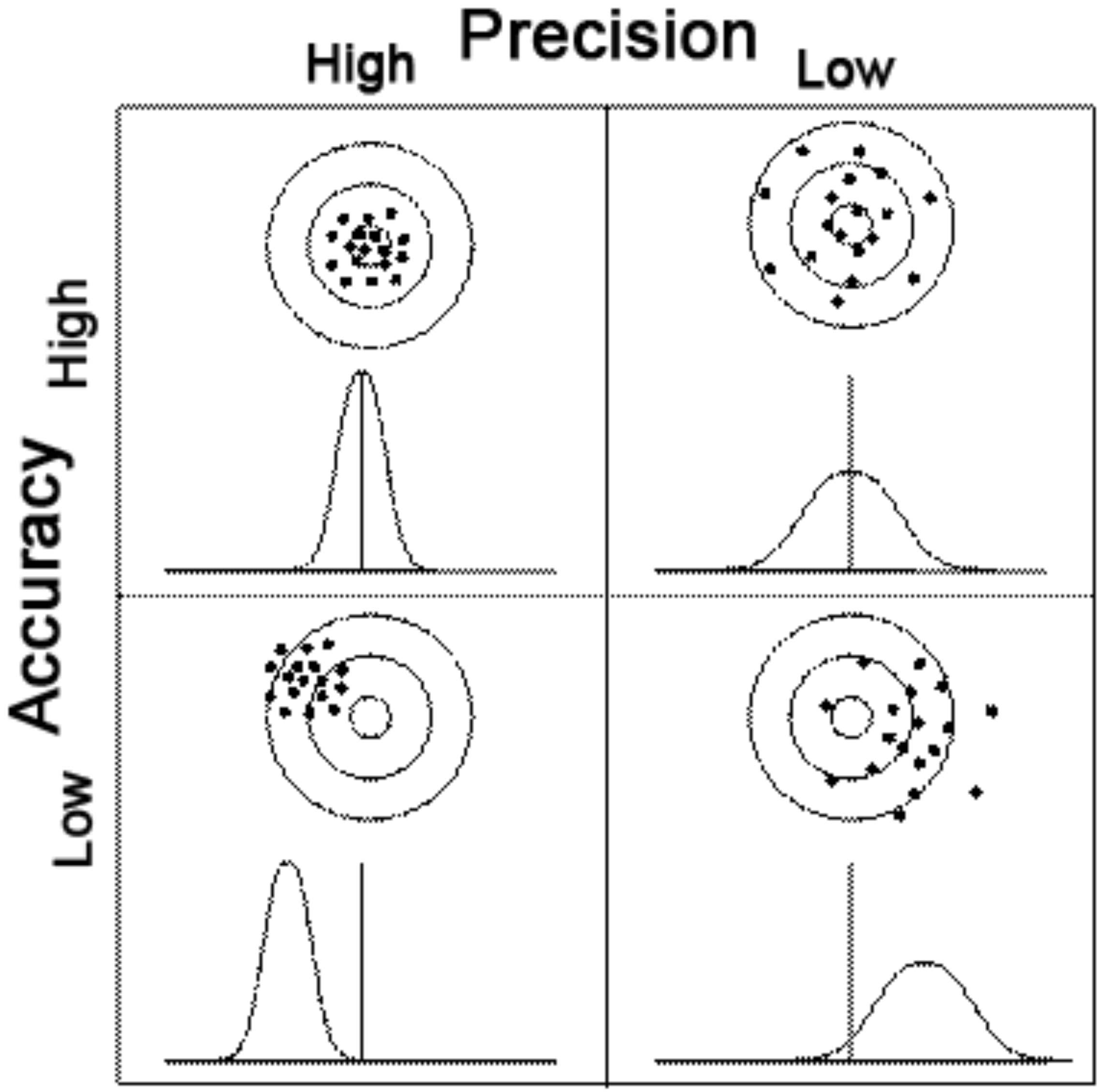
Run1 [2010-2012] operating conditions



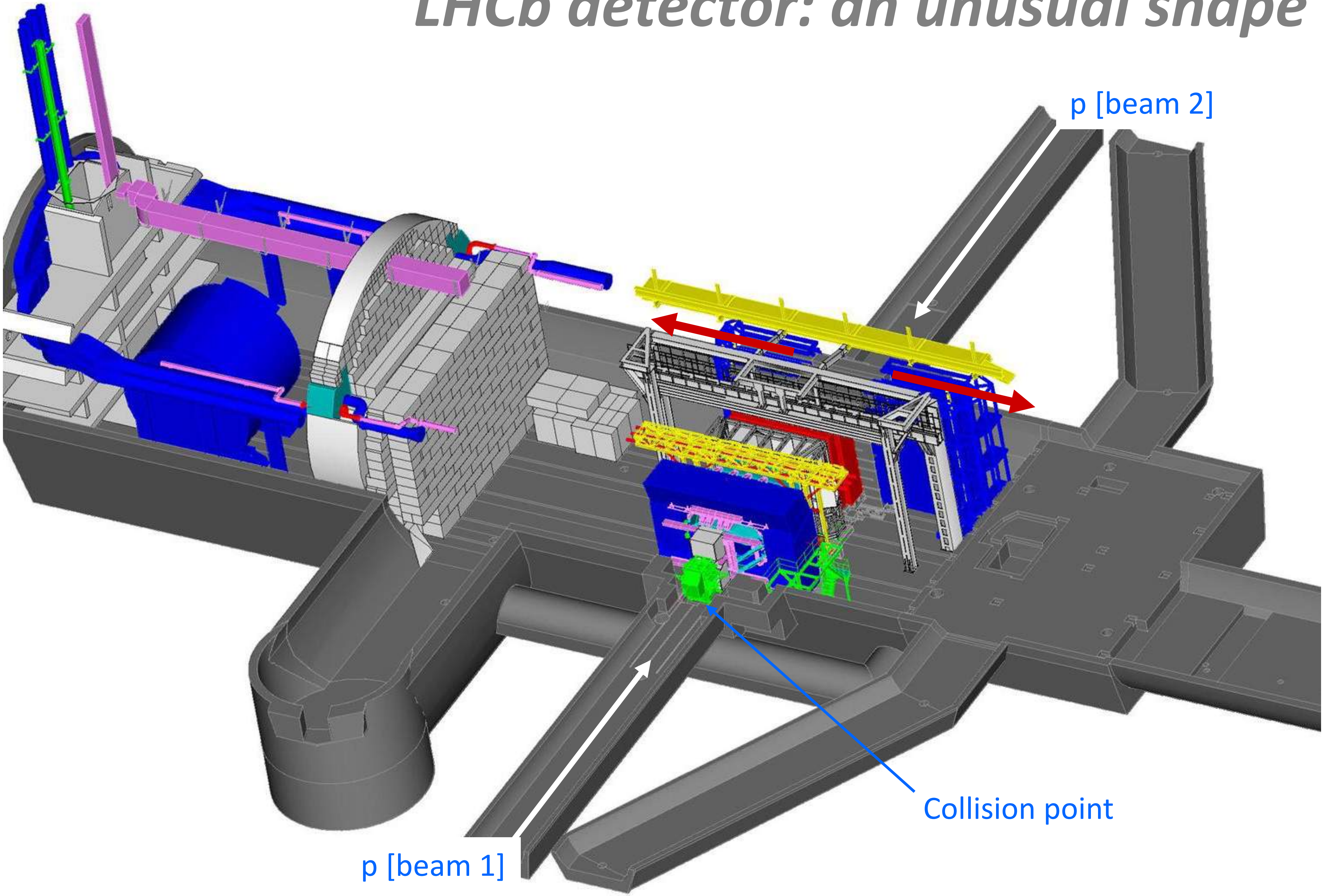
Intermezzo: statistical vs systematic errors

Precision ~ statistical error:
- well defined
- **more (and more) data**
- **Sqrt(n) at work!**

Accuracy ~ systematic:
- a lot of checks
- redundancy
- **you never know…**



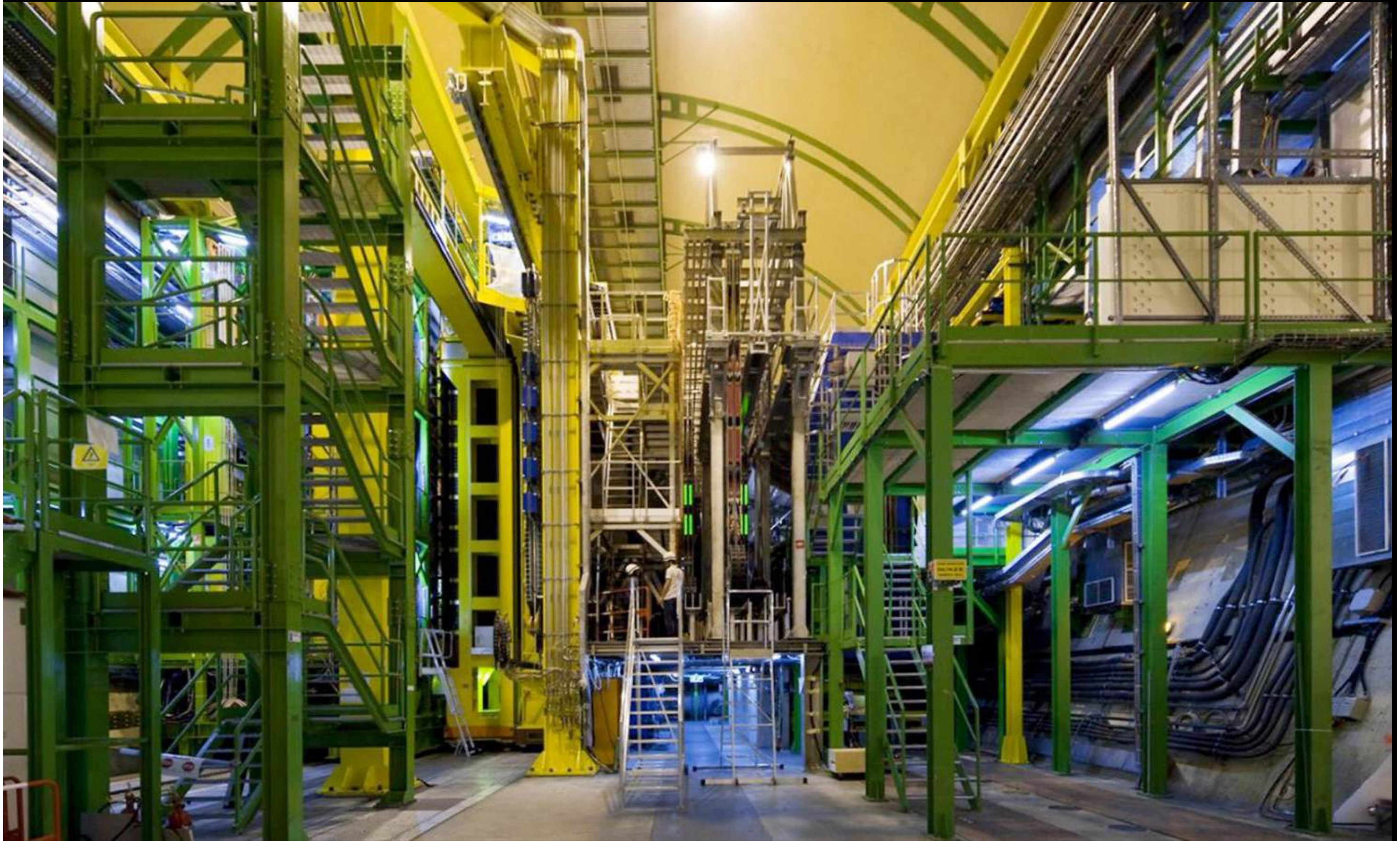
LHCb detector: an unusual shape



LHCb detector

[LHCb, A. Alves et al., The LHCb Detector at the LHC, JINST 3 (2008) S08005]

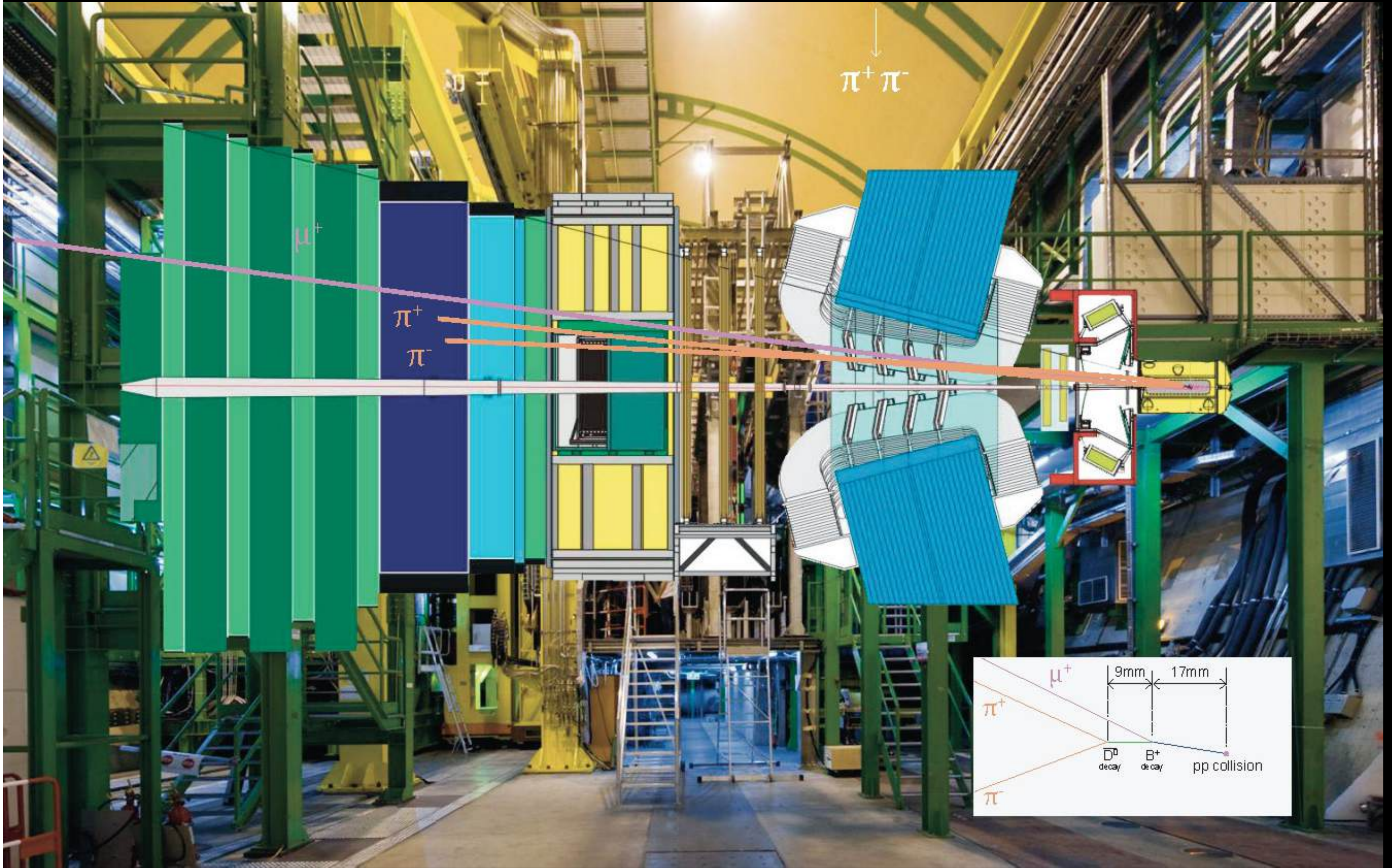
[LHCb Detector Performance Int.J.Mod..Phys. A30 (2015) 1530022]



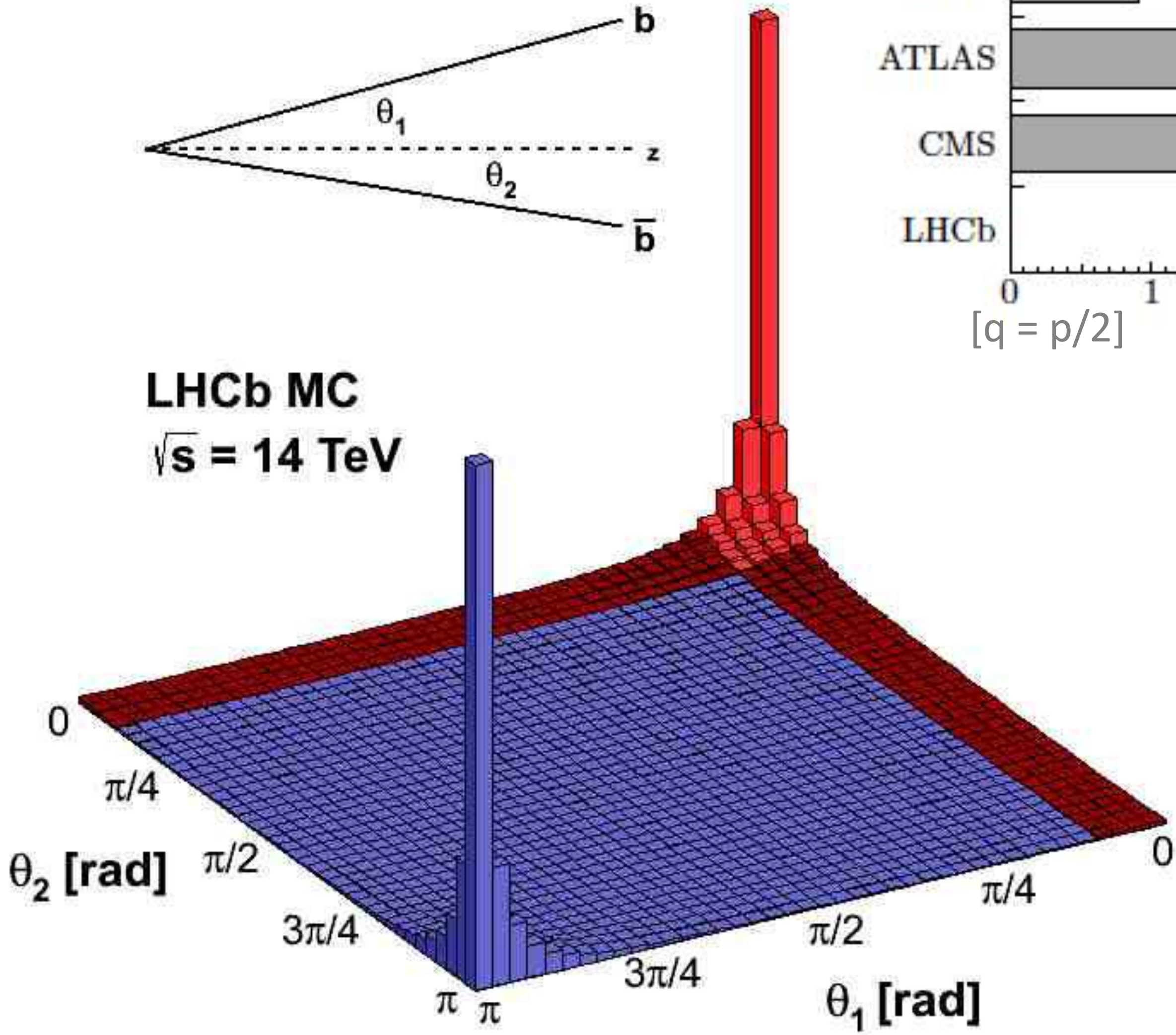
[LHCb, A. Alves et al., The LHCb Detector at the LHC, JINST 3 (2008) S08005]

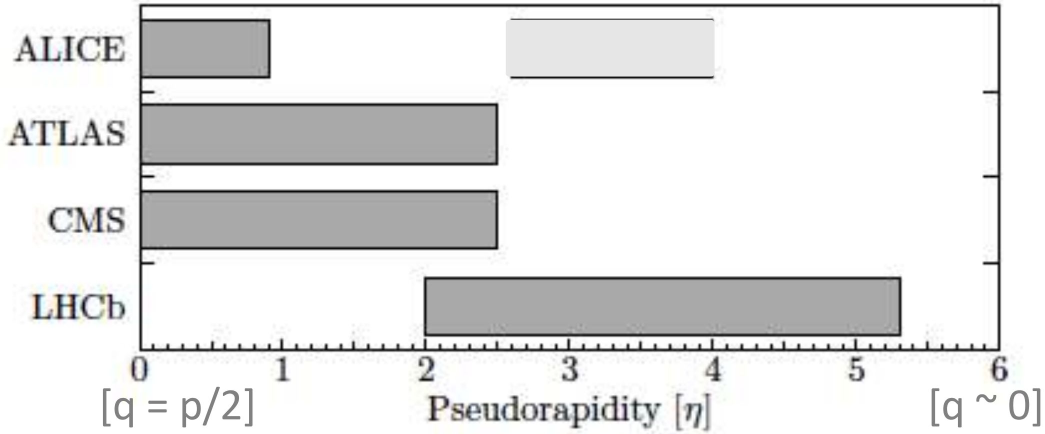
[LHCb Detector Performance Int.J.Mod..Phys. A30 (2015) 1530022]

LHCb detector



A lot of data: heavy flavor production





Extremely large **σ(bb)** and **σ(cc)** in LHC hadron collisions.

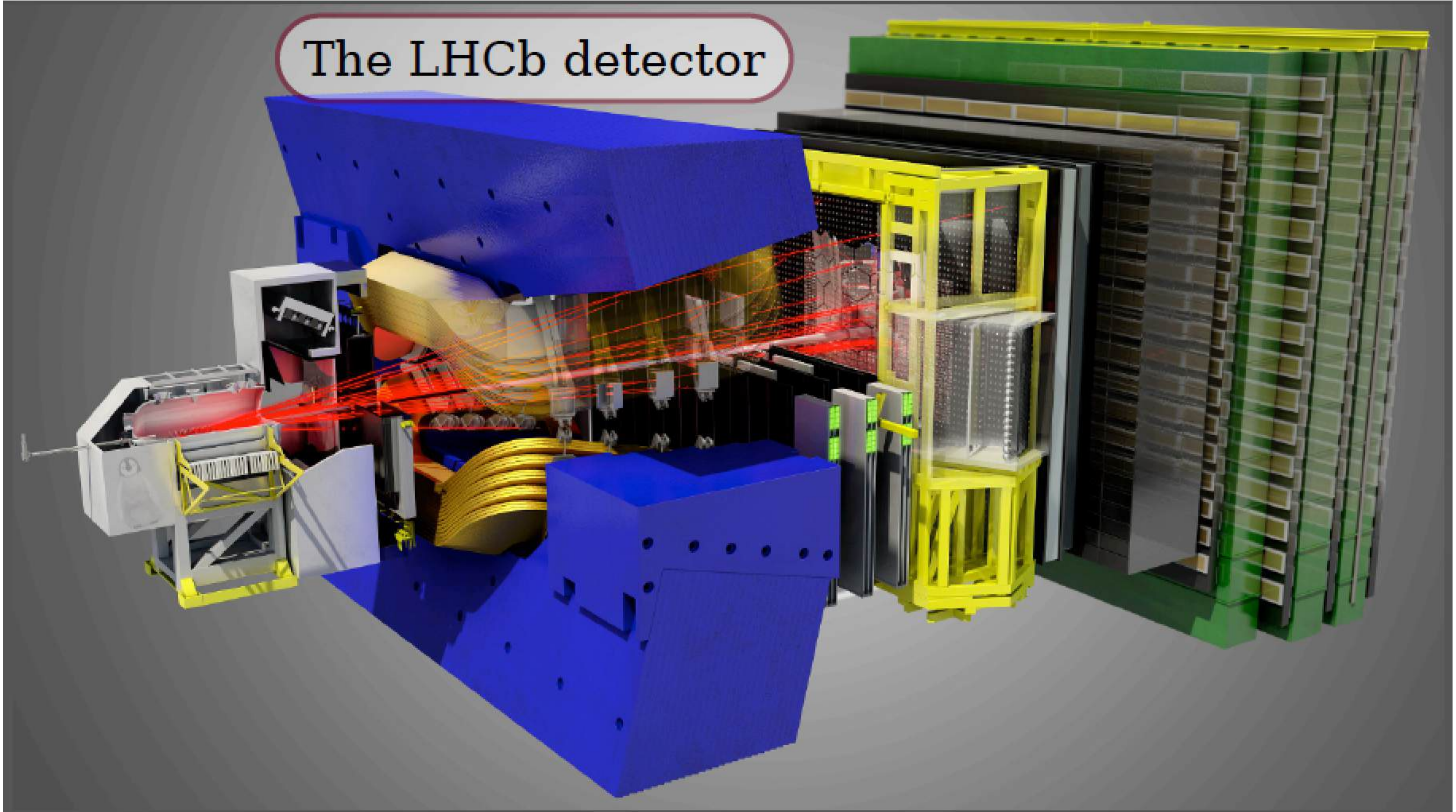
At 13TeV: **σ(bb) ~ 45 kHz** and **σ(cc) ~1MHz** cc **in LHCb acceptance** (HF cross section ×2 with respect Run 1)

LHCb detector - LS2

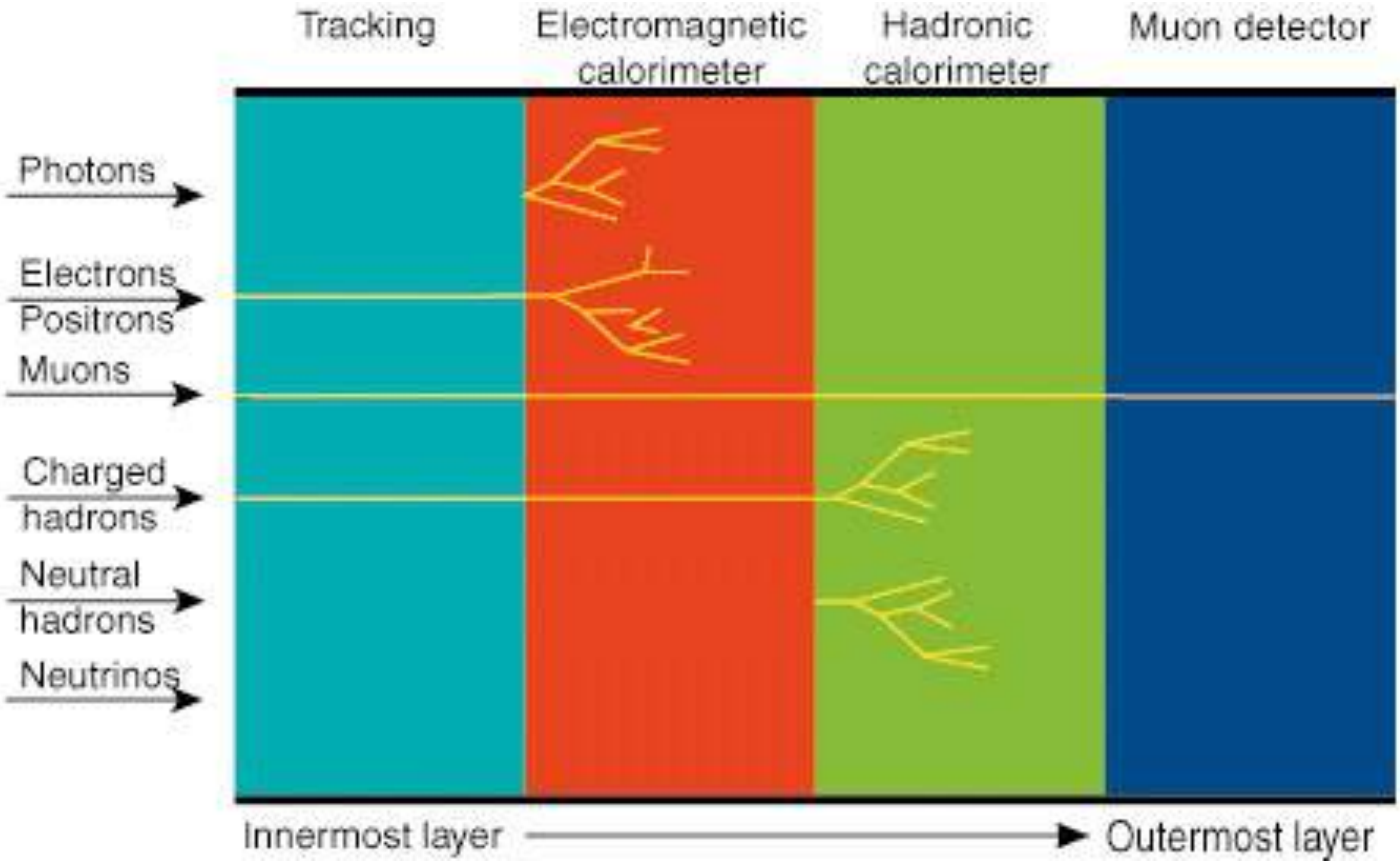
[http://lhcb-media.web.cern.ch/lhcb-media/]

LHCb hall end of LS2

LHCb detector - Run 2



Detectors


Tracking
Electromagnetic calorimeter
Hadronic calorimeter
Muon detector
Photons
Electrons
Positrons
Muons
Charged hadrons
Neutral hadrons
Neutrinos
Innermost layer
Outermost layer

An agent for future detectors?!?

https://arxiv.org/abs/2602.15039

arXiv > hep-ex > arXiv:2602.15039

Search...

Help | Advance

High Energy Physics – Experiment

[Submitted on 31 Jan 2026]

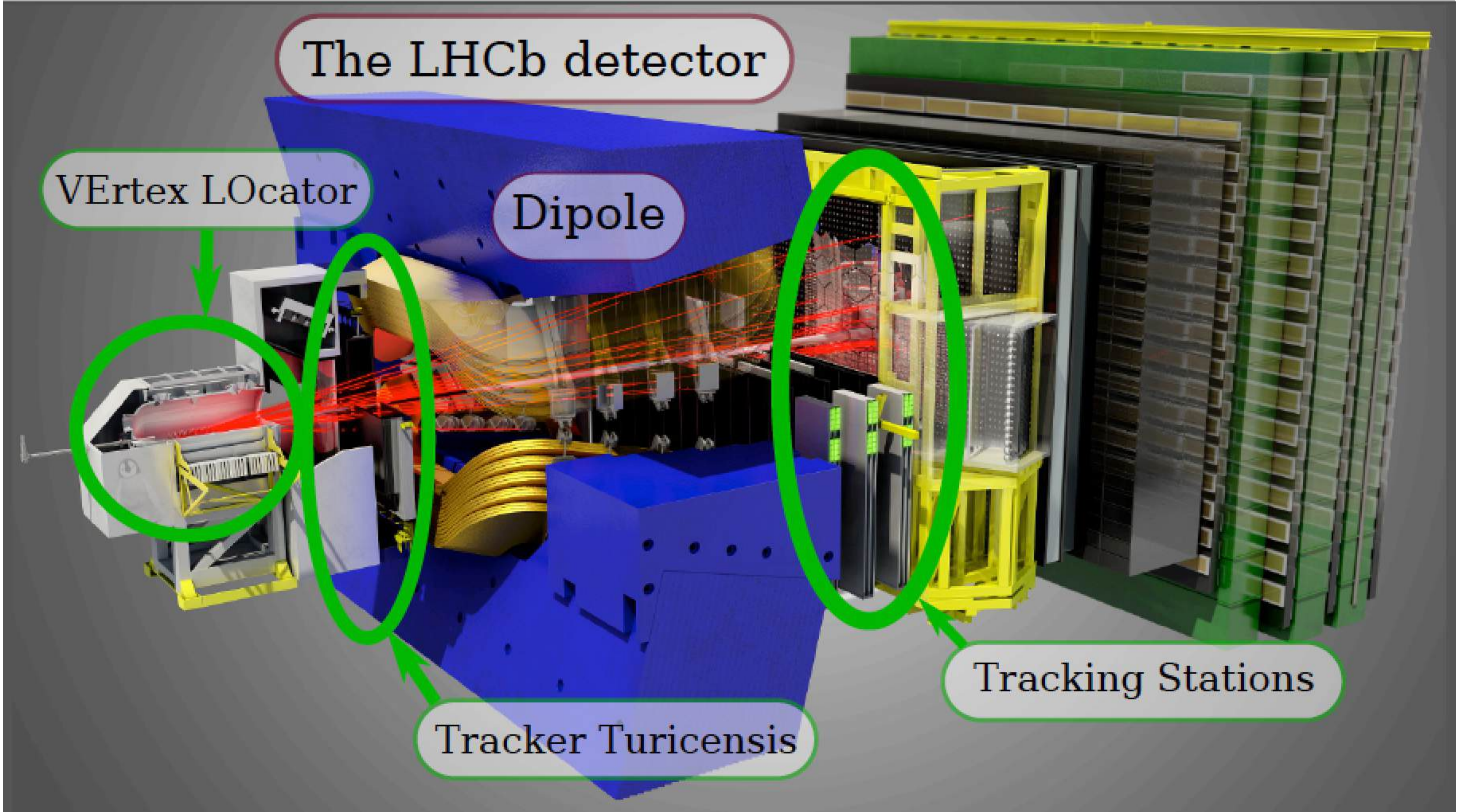
GRACE: an Agentic AI for Particle Physics Experiment Design and Simulation

Justin Hill, Hong Joo Ryoo

We present GRACE, a simulation-native agent for autonomous experimental design in high-energy and nuclear physics. Given multimodal input in the form of a natural-language prompt or a published experimental paper, the agent extracts a structured representation of the experiment, constructs a runnable toy simulation, and autonomously explores design modifications using first-principles Monte Carlo methods. Unlike agentic systems focused on operational control or execution of predefined procedures, GRACE addresses the upstream problem of experimental design: proposing non-obvious modifications to detector geometry, materials, and configurations that improve physics performance under physical and practical constraints. The agent evaluates candidate designs through repeated simulation, physics-motivated utility functions, and budget-aware escalation from fast parametric models to full Geant4 simulations, while maintaining strict reproducibility and provenance tracking. We demonstrate the framework on historical experimental setups, showing that the agent can identify optimization directions that align with known upgrade priorities, using only baseline simulation inputs. We also conducted a benchmark in which the agent identified the setup and proposed improvements from a suite of natural language prompts, with some supplied with a relevant physics research paper, of varying high energy physics (HEP) problem settings. This work establishes experimental design as a constrained search problem under physical law and introduces a new benchmark for autonomous, simulation-driven scientific reasoning in complex instruments.

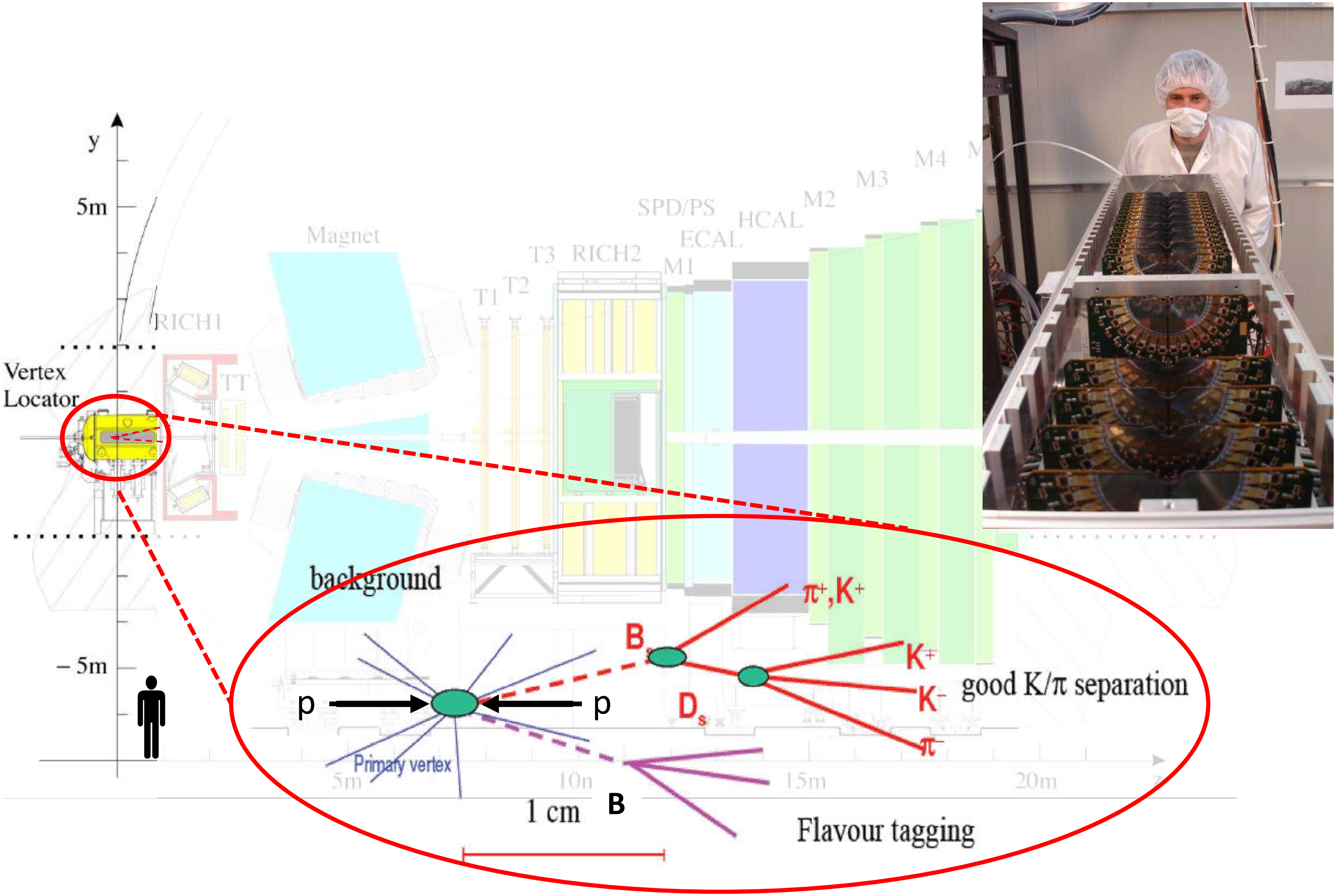
Comments: Both authors contributed equally. 43 pages, 12 figures, 6 tables, data can be found in this https URL
Subjects: **High Energy Physics – Experiment (hep-ex)**; Artificial Intelligence (cs.AI)
Cite as: arXiv:2602.15039 **[hep-ex]**
(or arXiv:2602.15039v1 **[hep-ex]** for this version)
https://doi.org/10.48550/arXiv.2602.15039

LHCb detector: tracking system



[Performance of the LHCb Vertex Locator JINST 9 (2014) 09007]

VELO



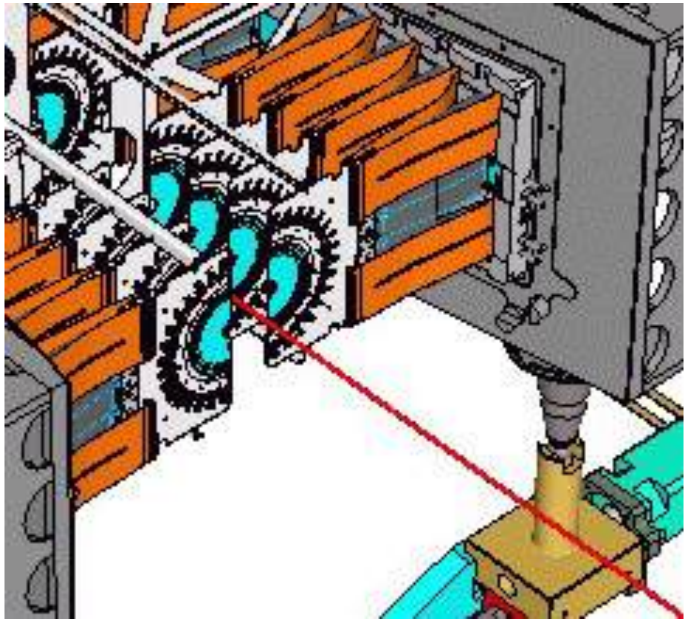
VELO

Silicon detector: 42 modules arranged along the beam, each providing a measurement of the r and f coordinates.

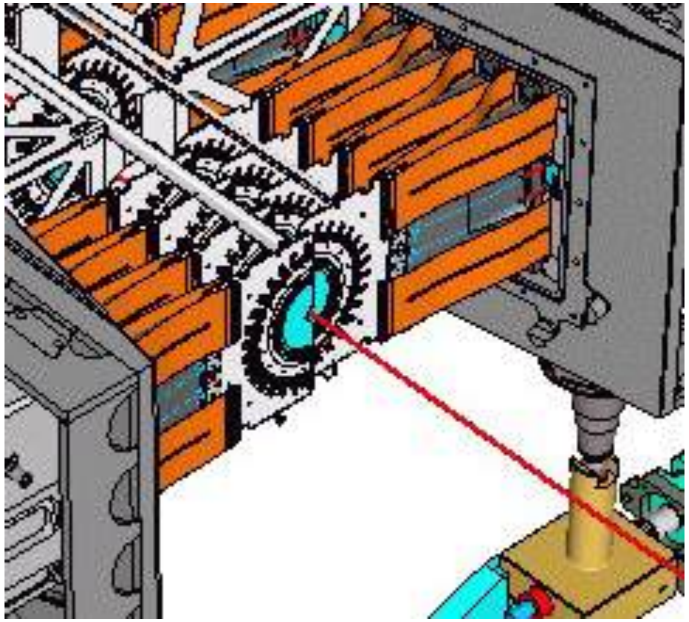
Performance (vertex reconstruction)
- decay time resolution: 45 fs
- impact parameter resolution: 20 µm

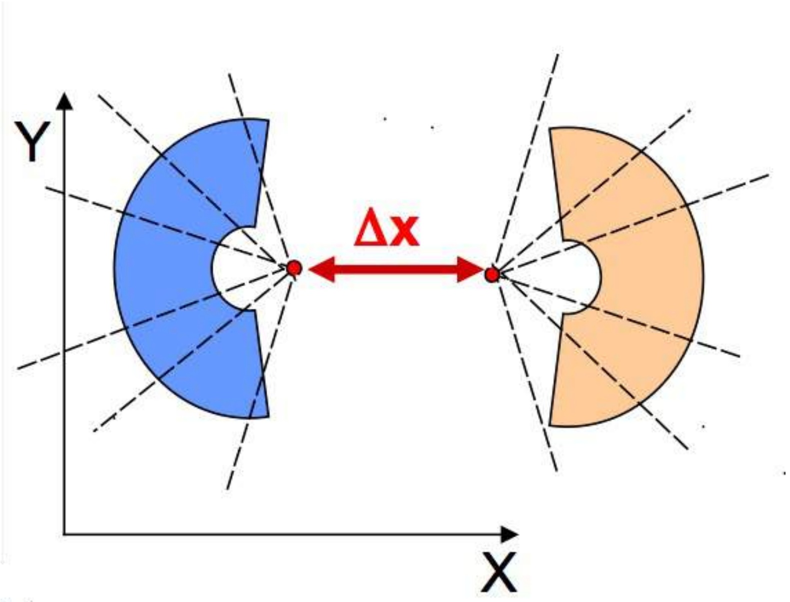
Detector safety: **modules retracted by 29 mm during injection**; 210 s to close; ~750 closing procedures in Run1

Opened at injection

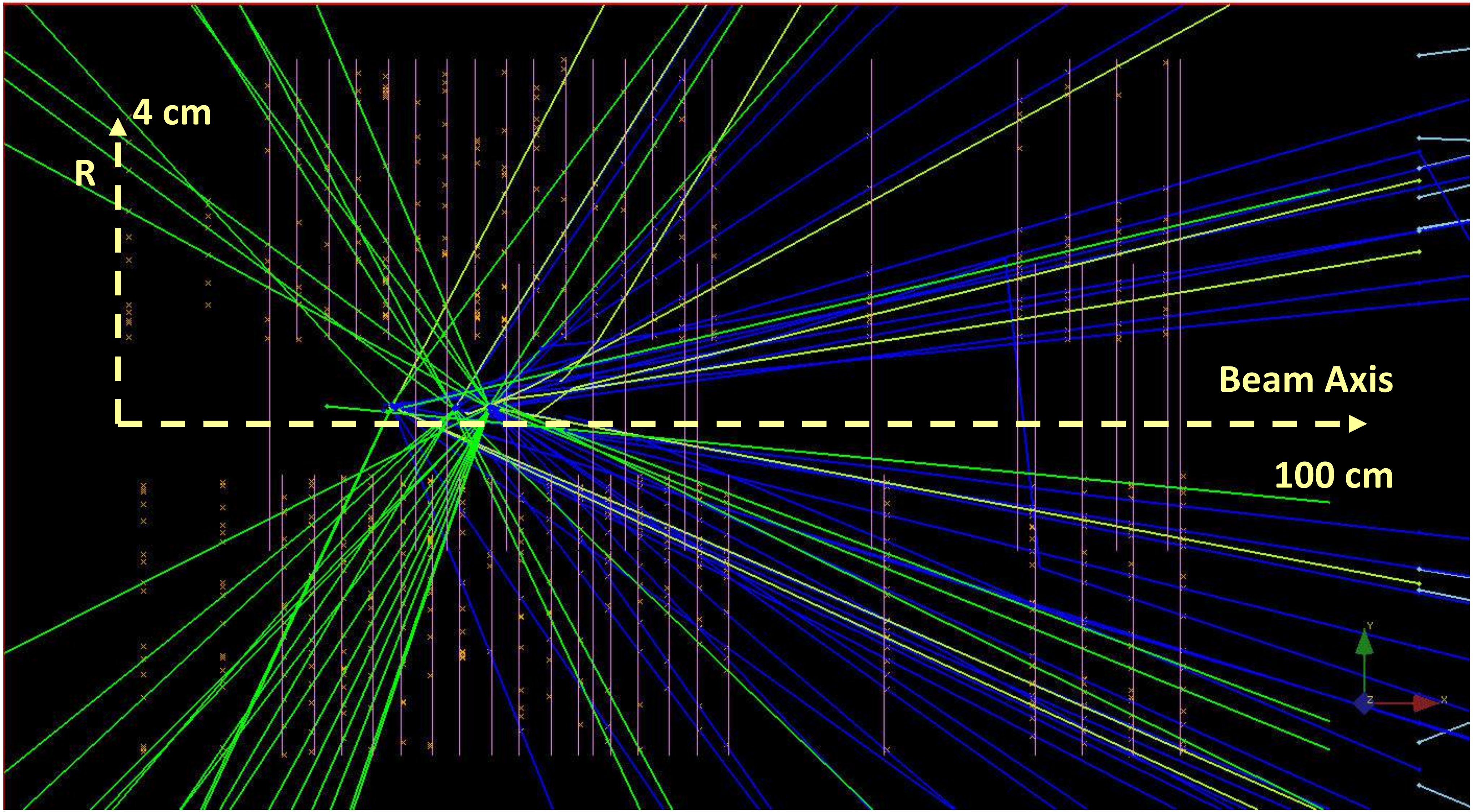


Closed when stable beam declared





VELO rz view

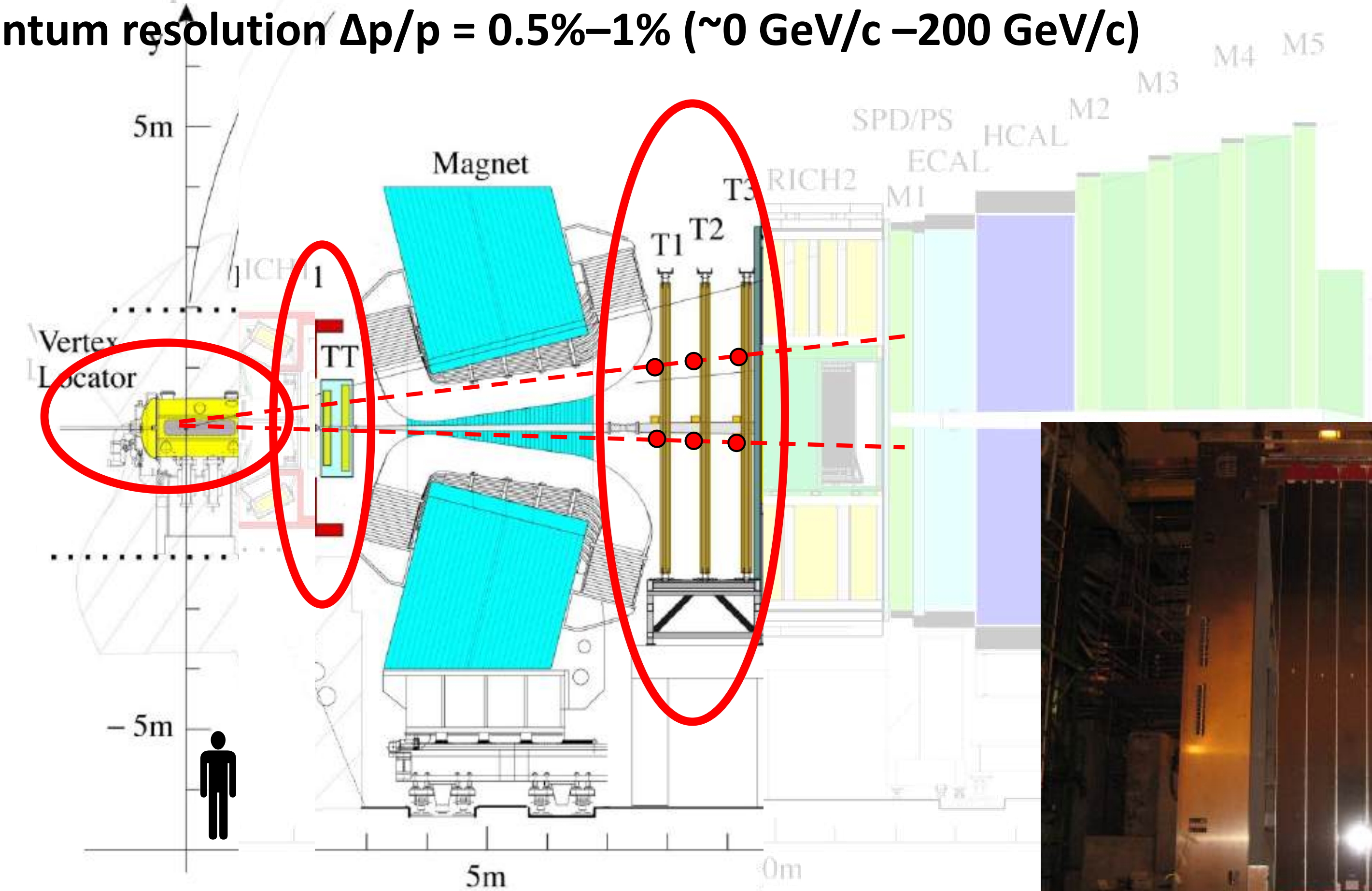


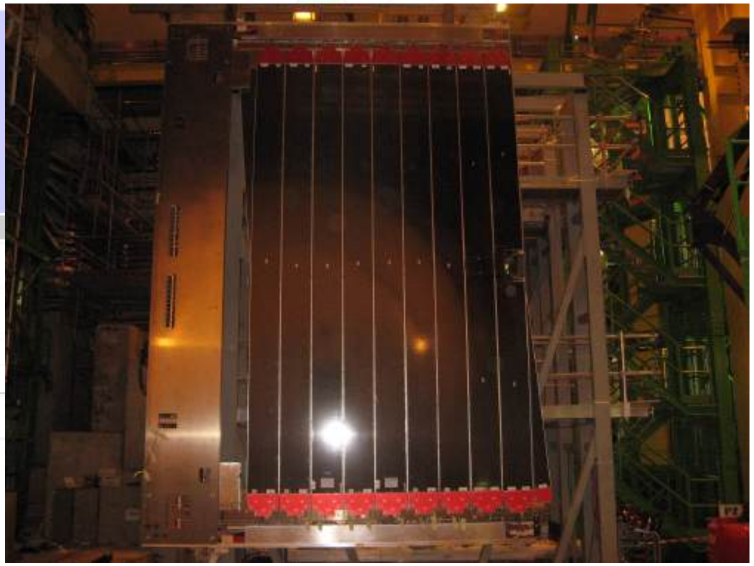
VELO

[Performance of the LHCb Outer Tracker JINST 9 (2014) P01002]
[Measurement of the track reconstruction efficiency at LHCb JINST 10 (2015) P02007]

Tracking system

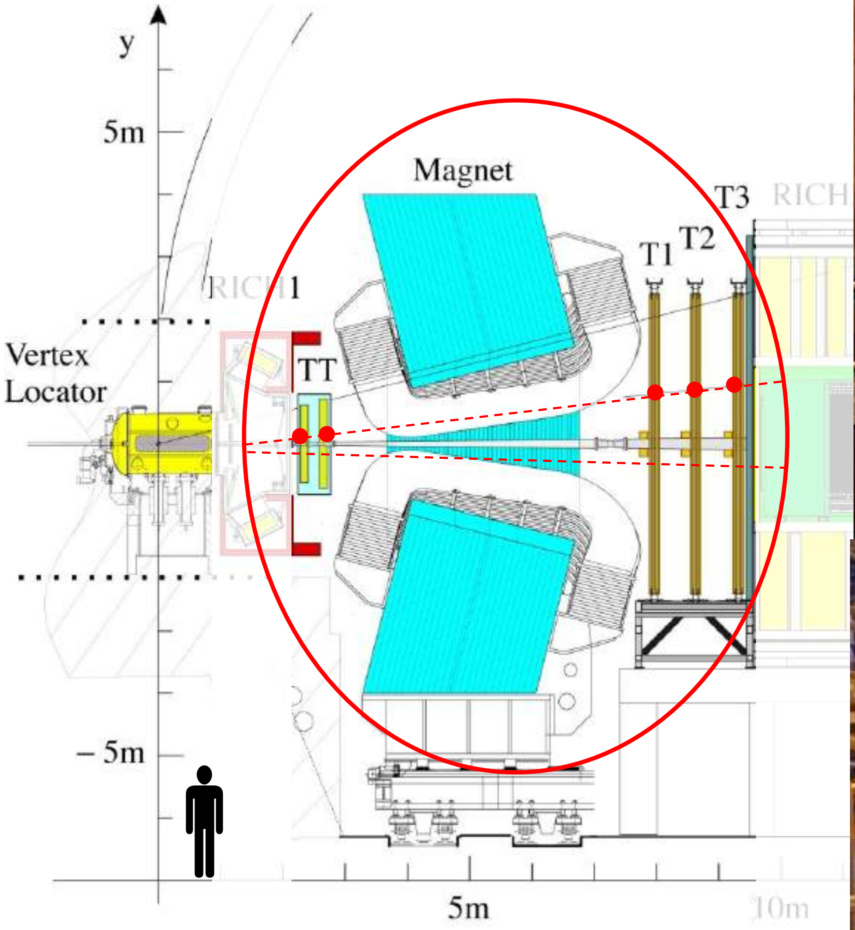
Tracker Turicensis (before the magnet): 4 plans of silicon m-strip, 8 m^2.
Tracker (after the magnet)
Inner (close to beam pipe): 3 stations, 4 plans of silicon m-strip, 4.2 m^2.
Outer: 3 stations, 4 plans of straw tubes
Momentum resolution Δp/p = 0.5%–1% (~0 GeV/c –200 GeV/c)





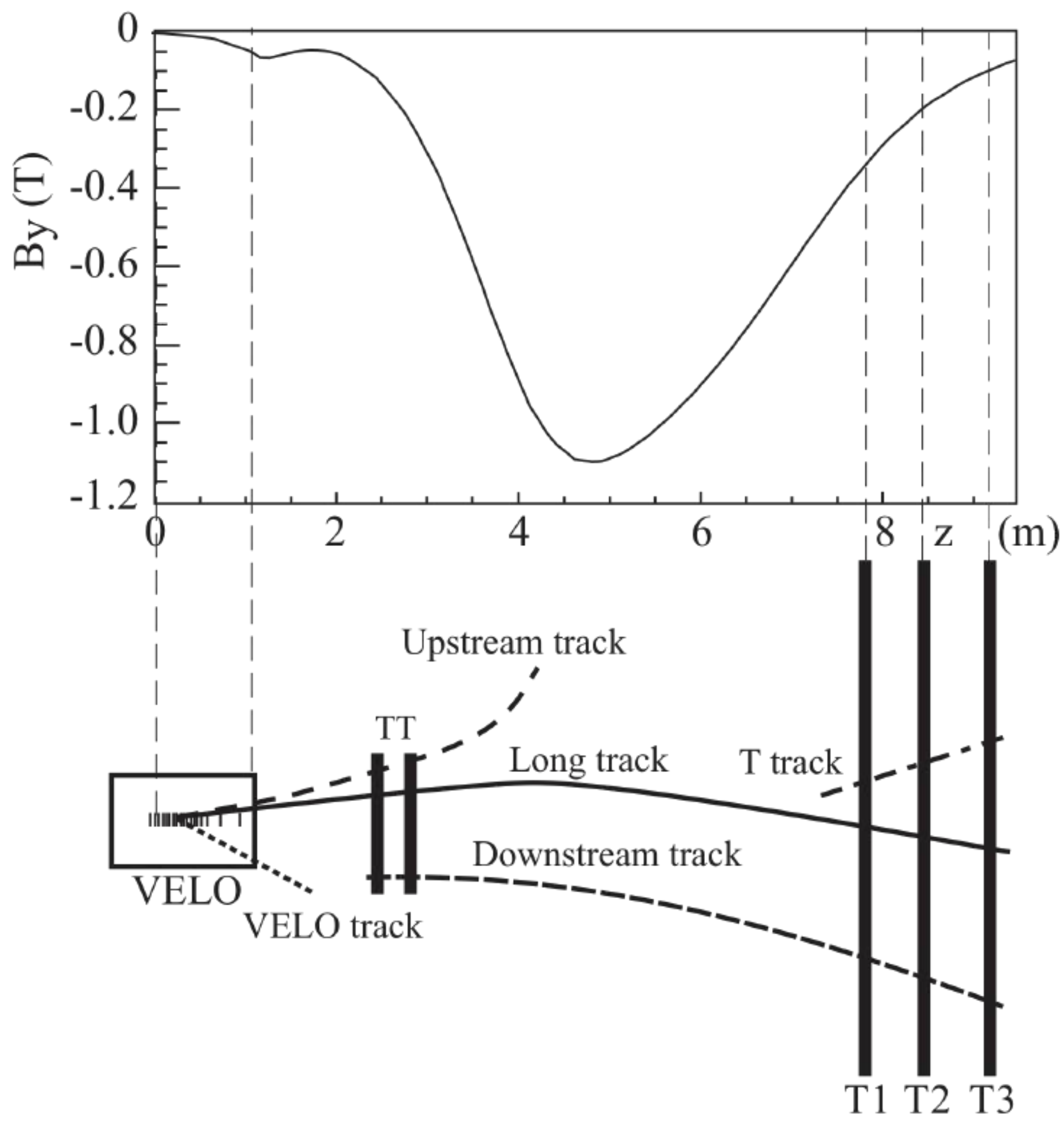
Magnet

Warm **dipole** magnet, bending power: 4 Tm
- Two triplets of magnets to compensate for its effect in LHC.



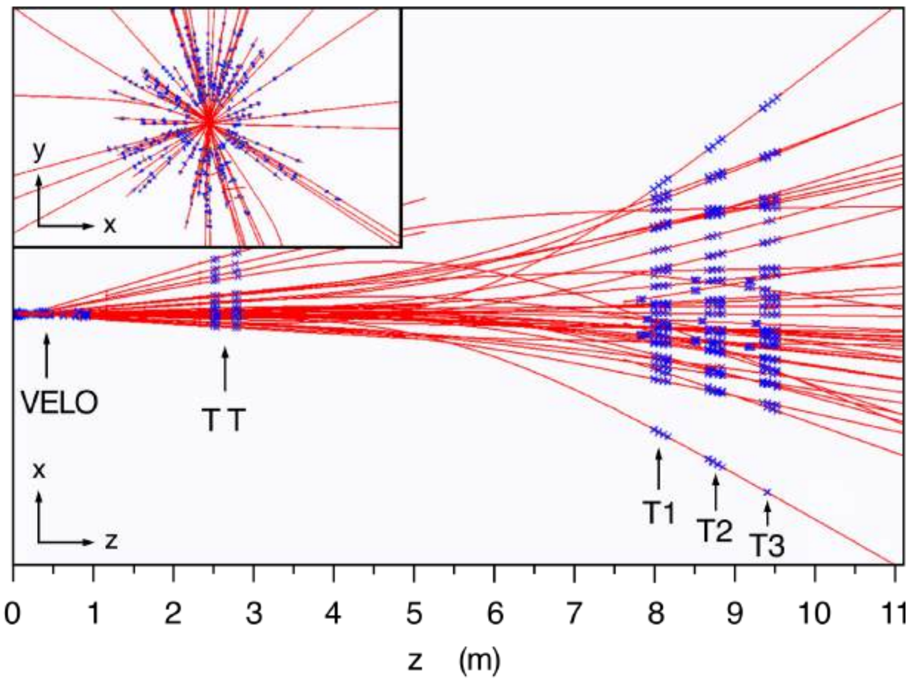
Weight: 1600 t
Power: 4200 kW
Cooling water = 150.000 l/h

Track reconstruction

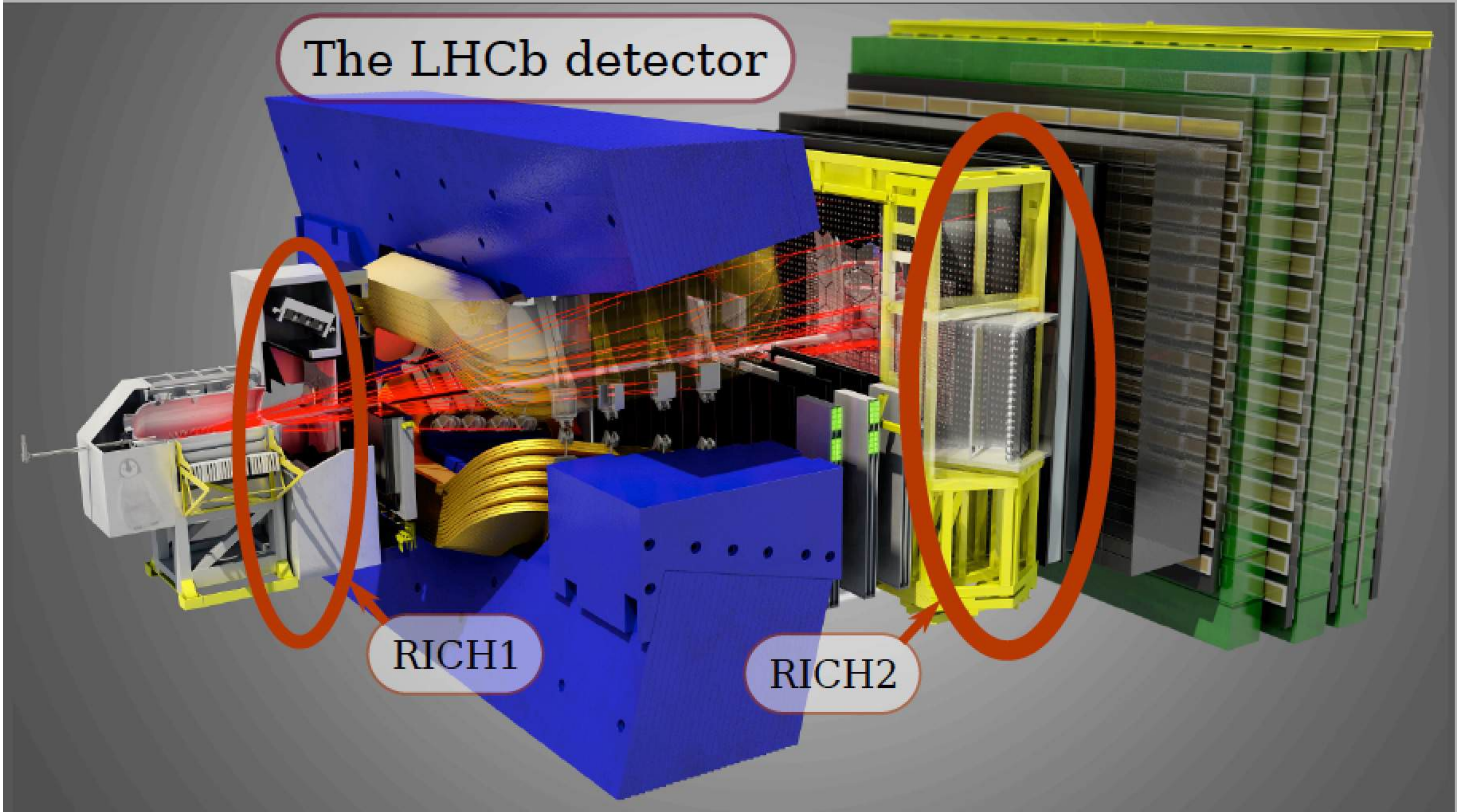


Dipole magnet implies an intrinsic charge asymmetry (left-right differences in the detector).

Direction of magnetic field changed regularly and data sets combined.

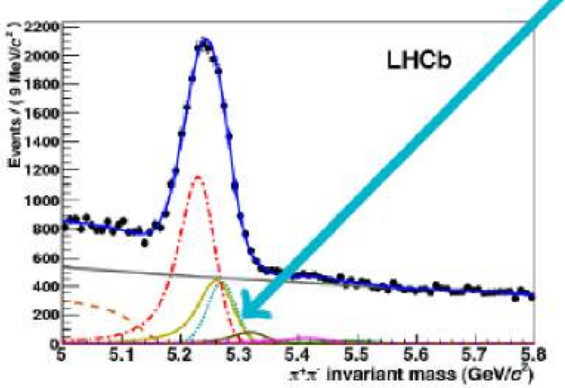


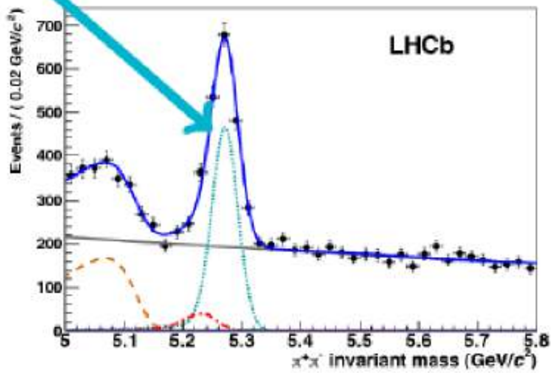
LHCb detector: RICHs

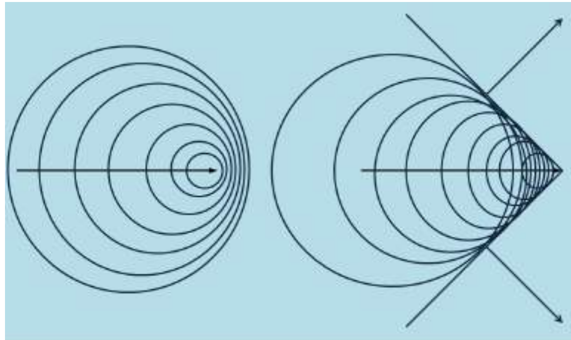


Cherenkov effect

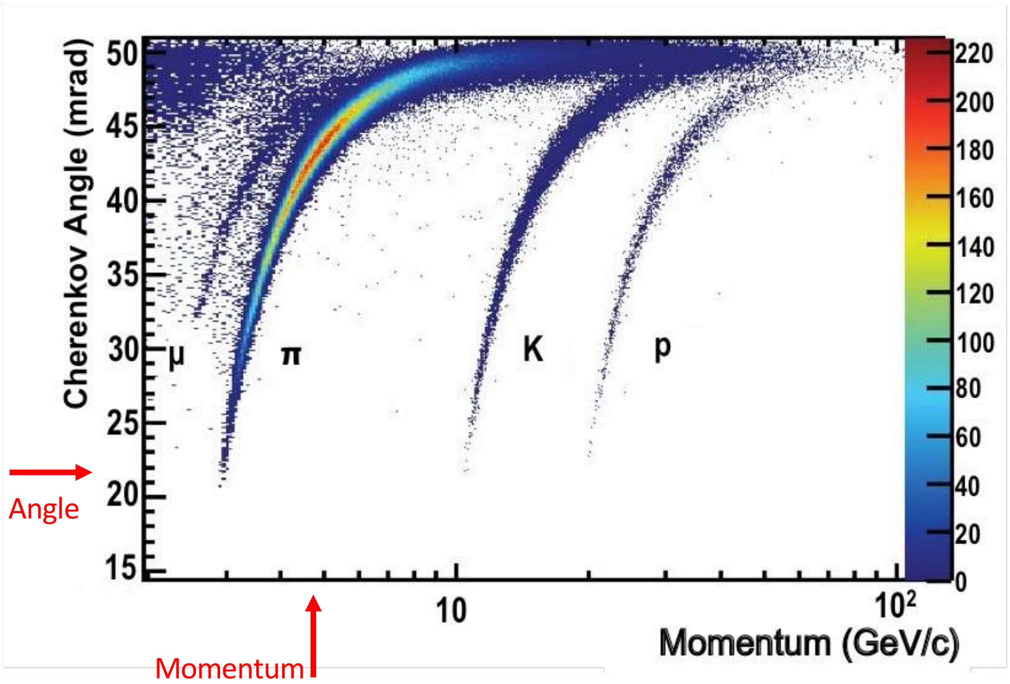
Without PID cuts — Signal — With PID cuts

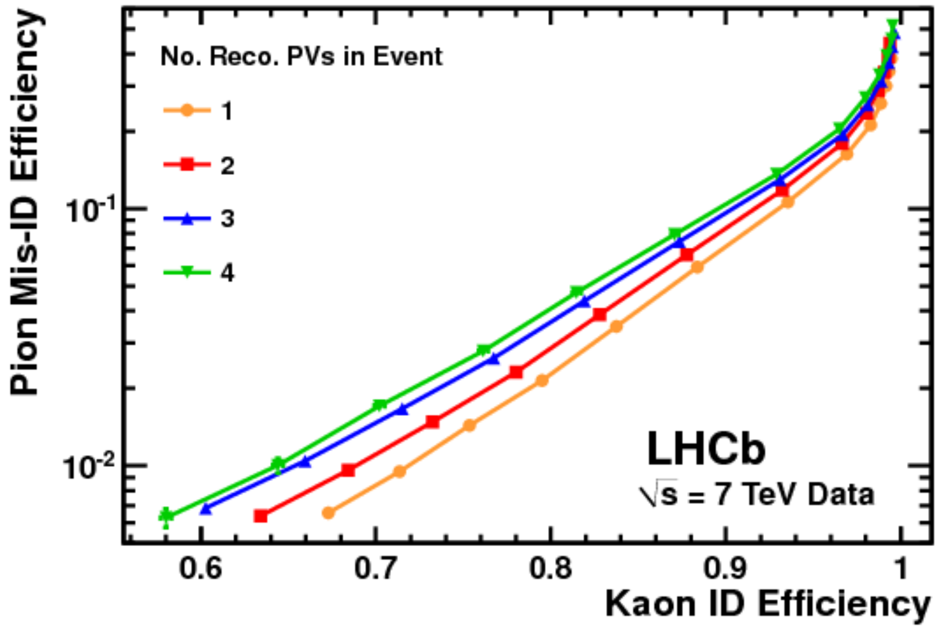






Invariant mass distribution for $B^0 \to \pi\pi$ decay ($B^0 \to \pi\pi$, $B^0 \to K\pi$, $B^0 \to$ 3-bodies, $B_s \to KK$, $B_s \to K\pi$, $\Lambda_b \to pK$, $\Lambda_b \to p\pi$)



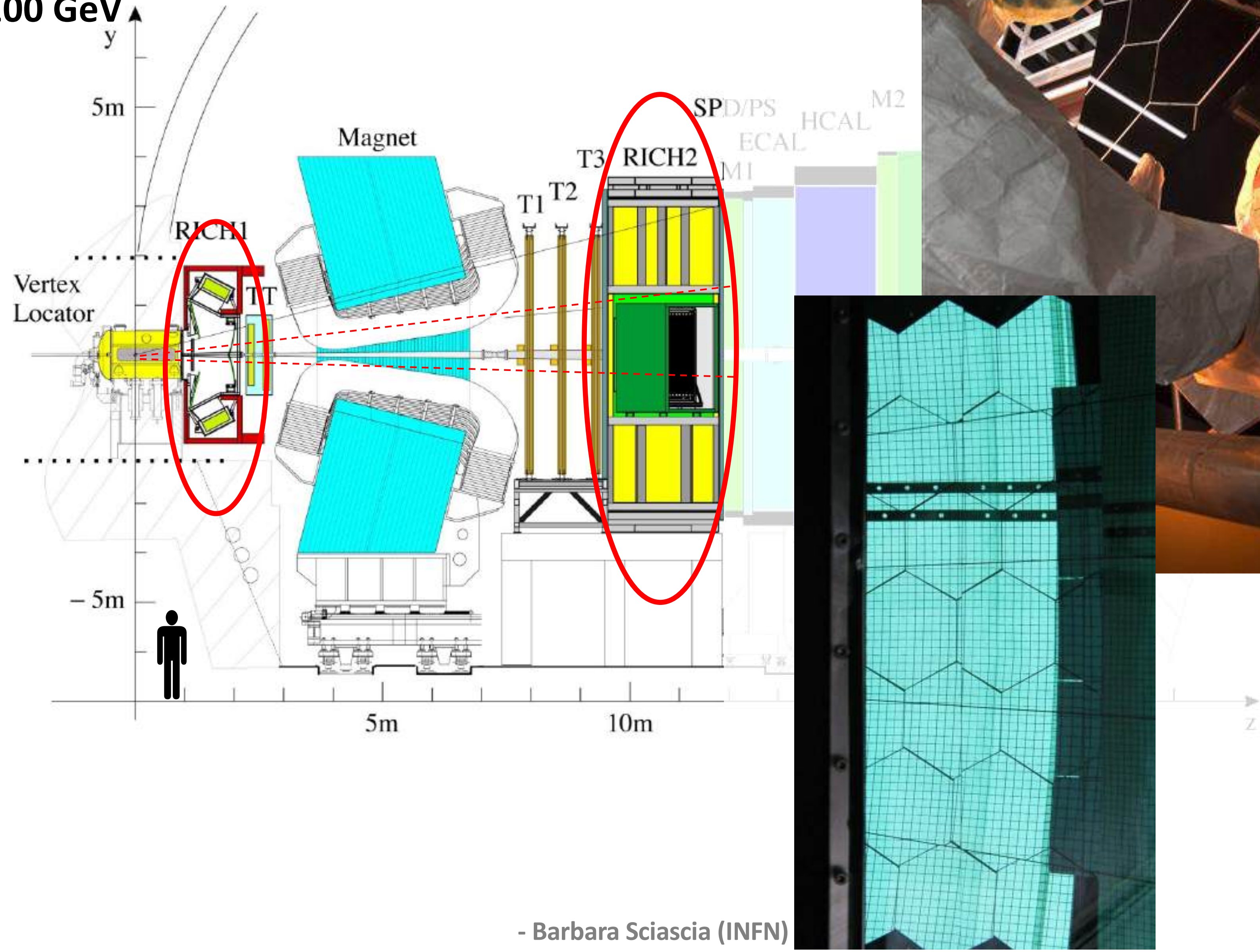


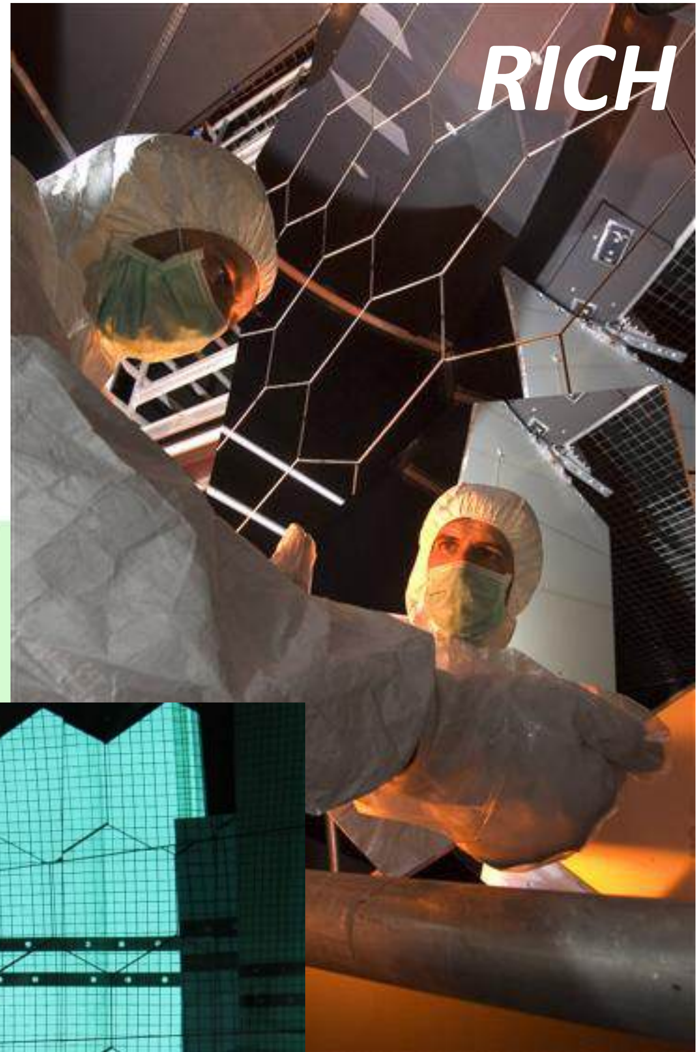
[Performance of the LHCb RICH detector Eur.Phys.J. C73 (2013) 2431]

RICH1 (upstream of magnet): 2<p<40 GeV [C_4F_{10}]

RICH2 (downstream of magnet): 15<p<100 GeV [CF_{10}]

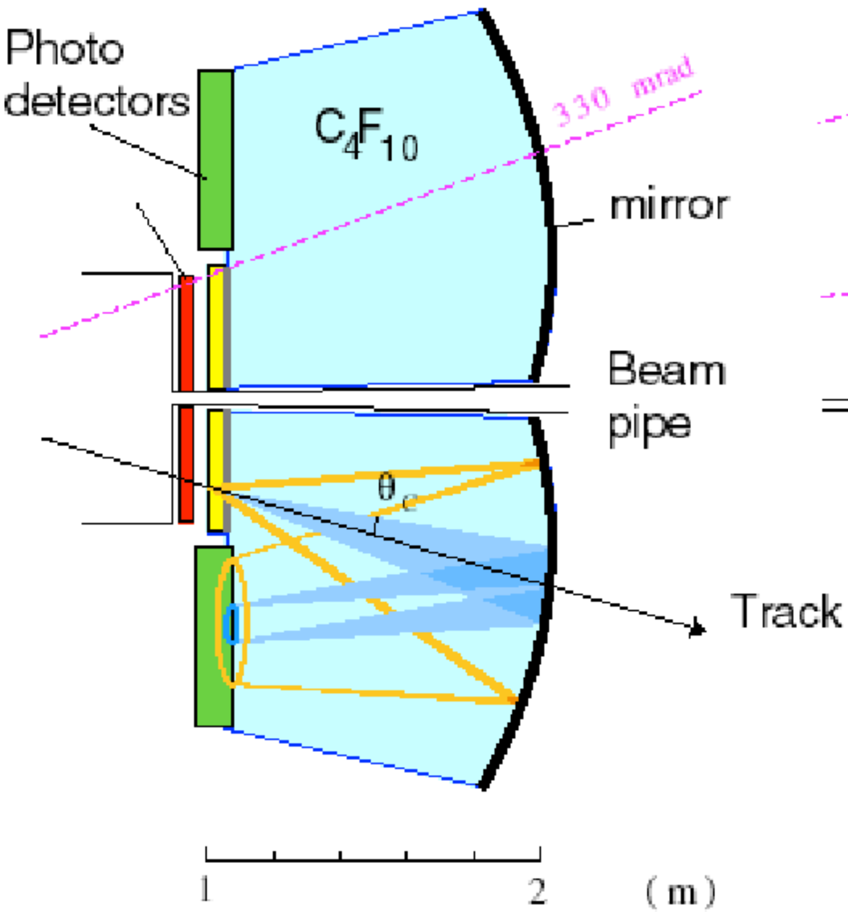
Kaon ID ~95% with pion misID ~10% integrated over 2<p<100 GeV

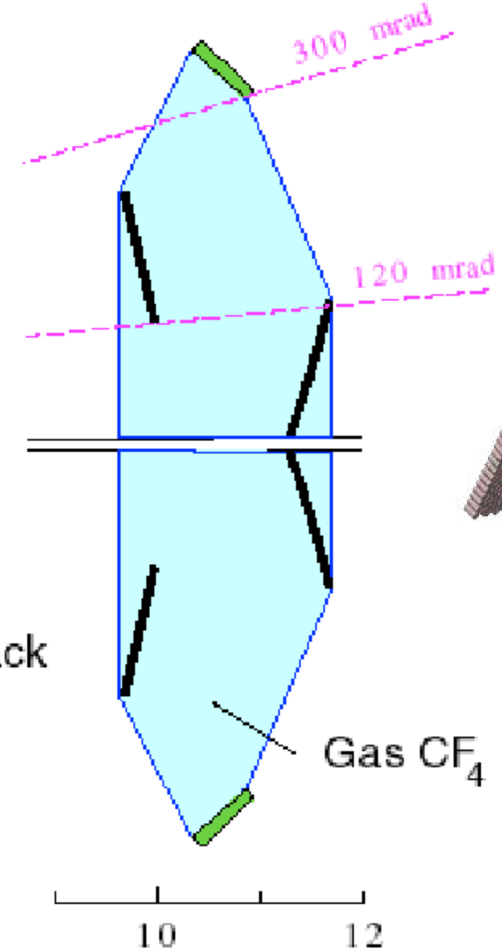


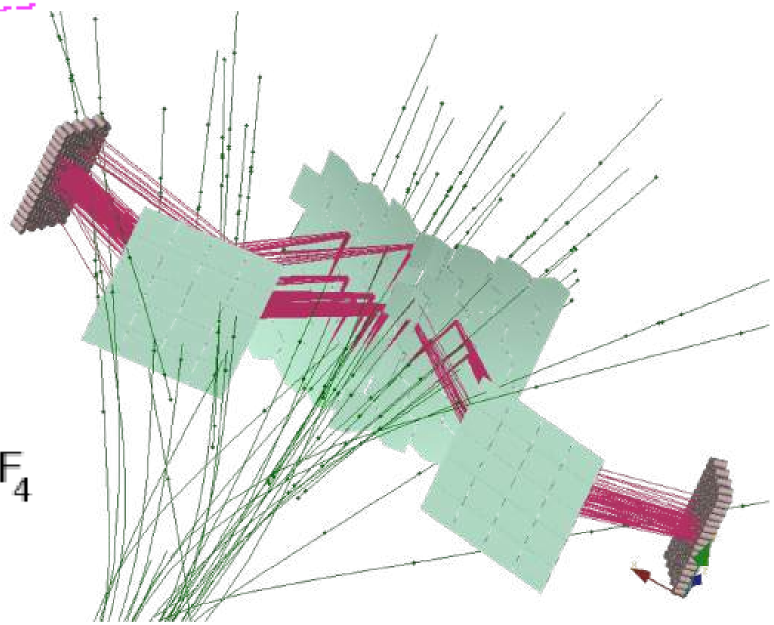


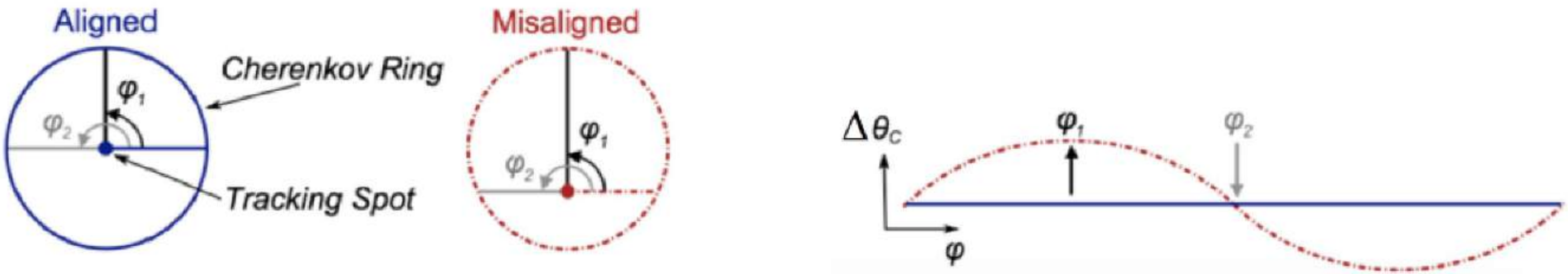
[Performance of the LHCb RICH detector Eur.Phys.J. C73 (2013) 2431]

RICH mirrors







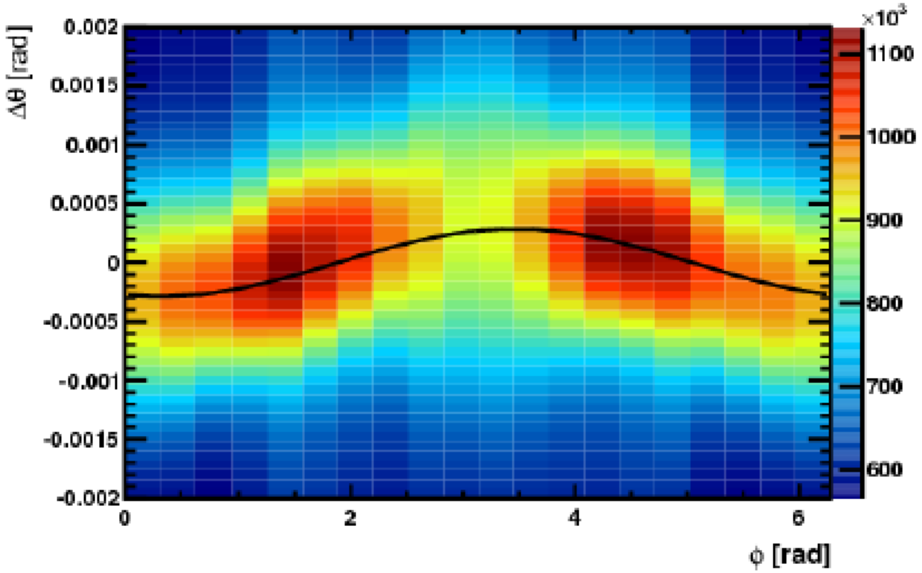


Alignment

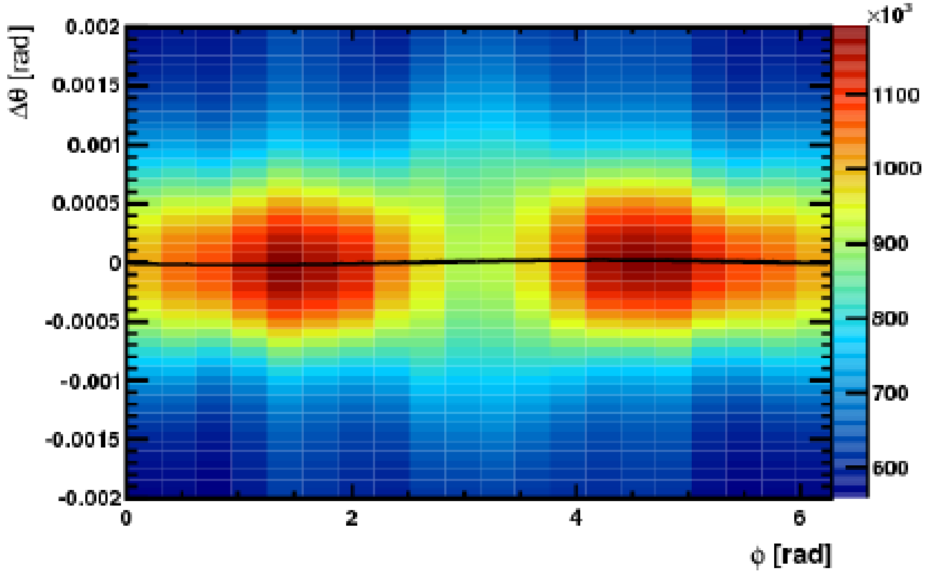
Alignments Run on the HLT-farm at the beginning of every fill;

[Monitor only]
- **RICH** mirror alignment: Alignment of all individual mirrors for rotations around x and y.

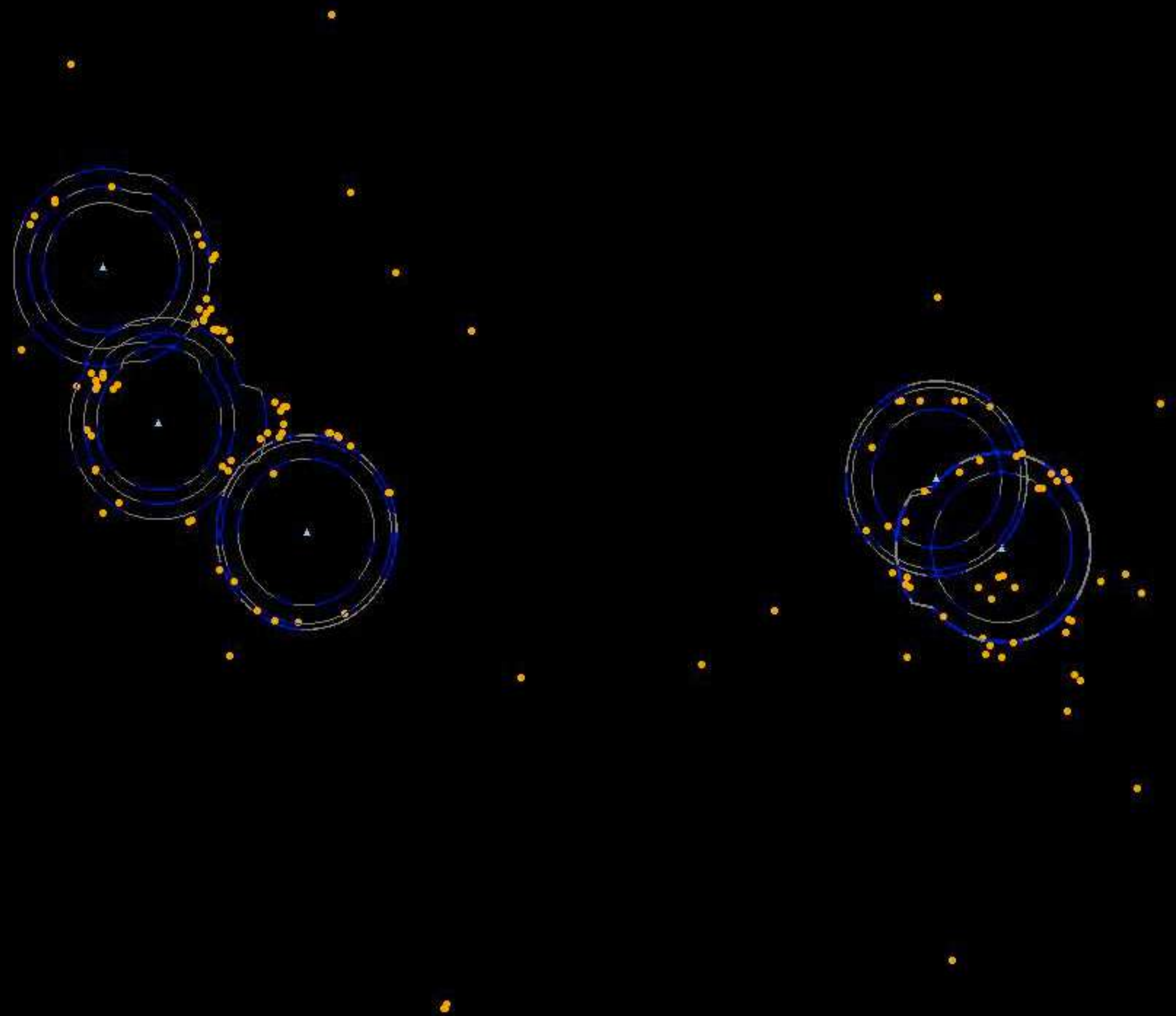
Before mirror alignment



After mirror alignment

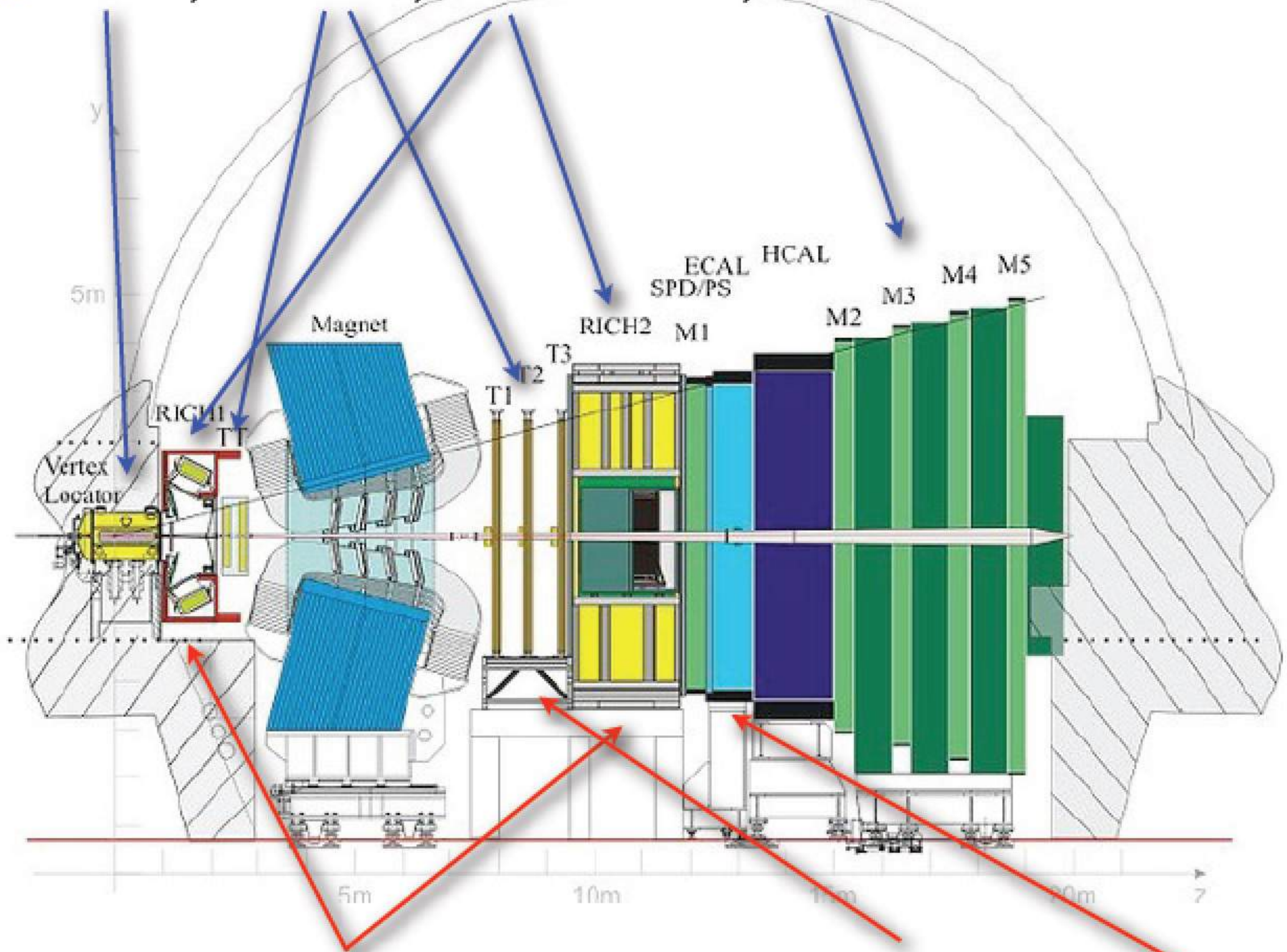


RICH



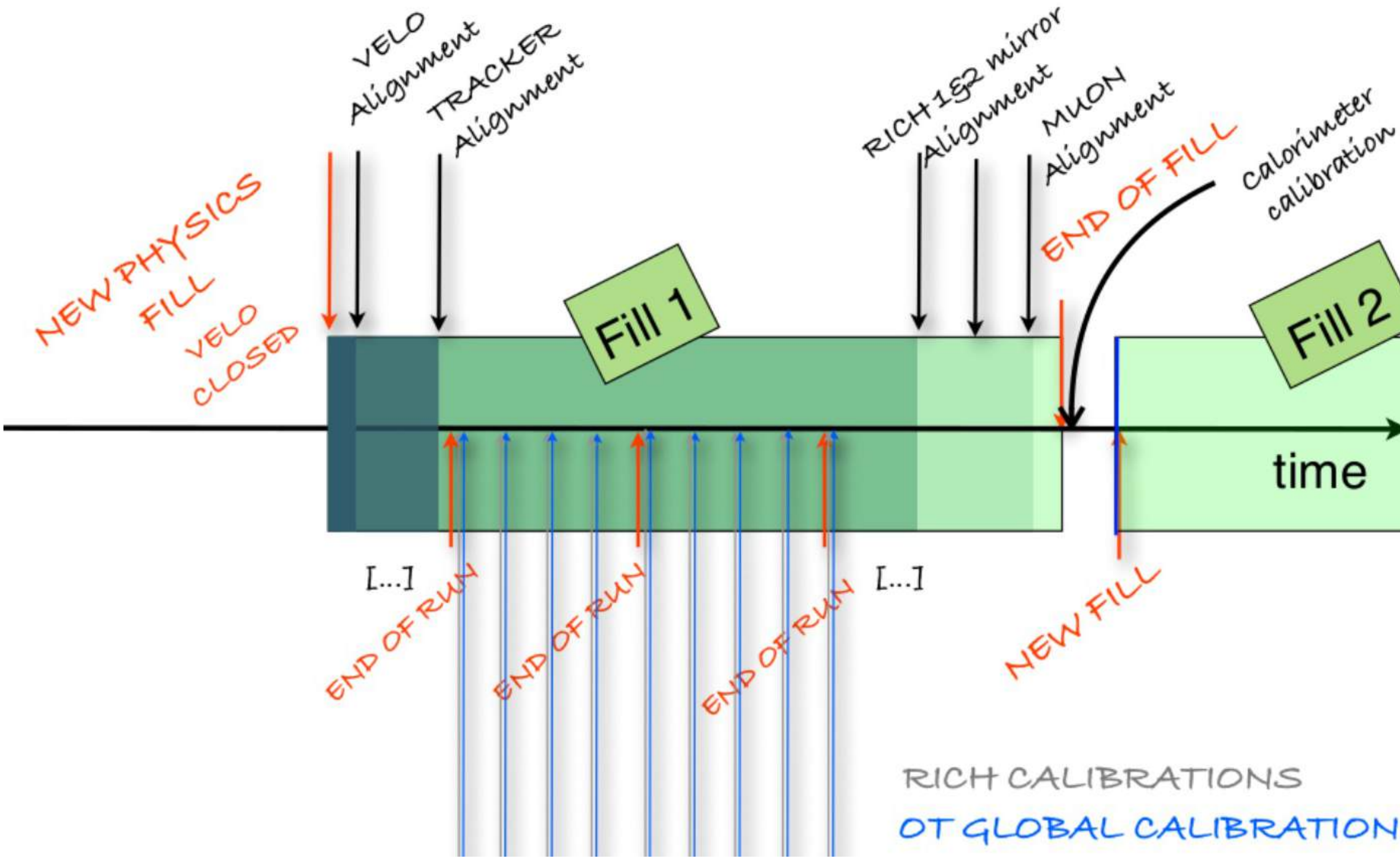
Real-time alignment and calibration

- Alignments: VELO, Trackers, RICH mirrors, Muon



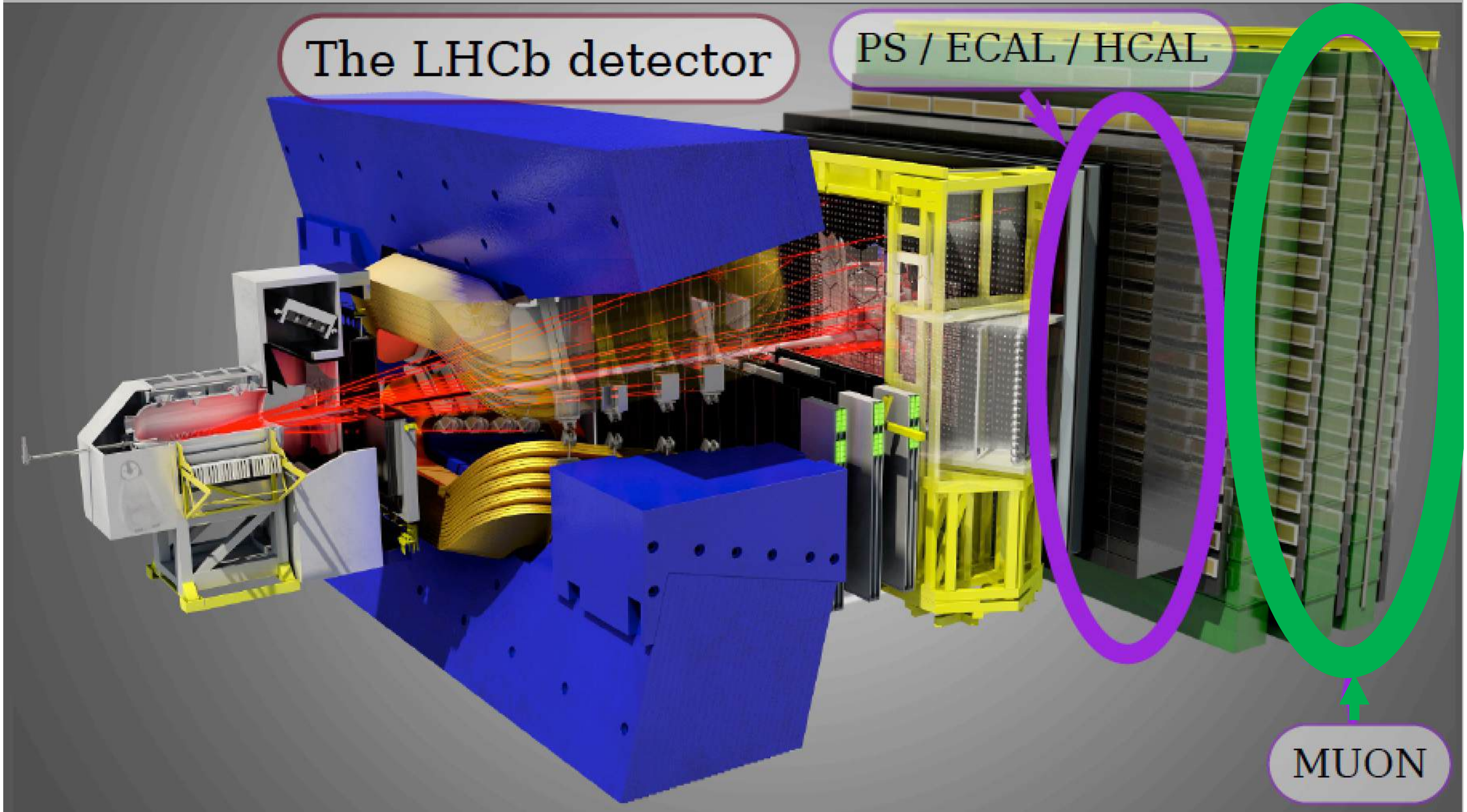
- Calibrations: RICH refractive index and HPDs, OT time, Calorimeters

Almost real-time alignment and calibration



[Update for Run 3: https://indico.cern.ch/event/1103637/contributions/4821829/]

LHCb detector: calorimeter and muon systems



[LHCb Detector Performance Int.J.Mod.Phys. A30 (2015) 1530022]

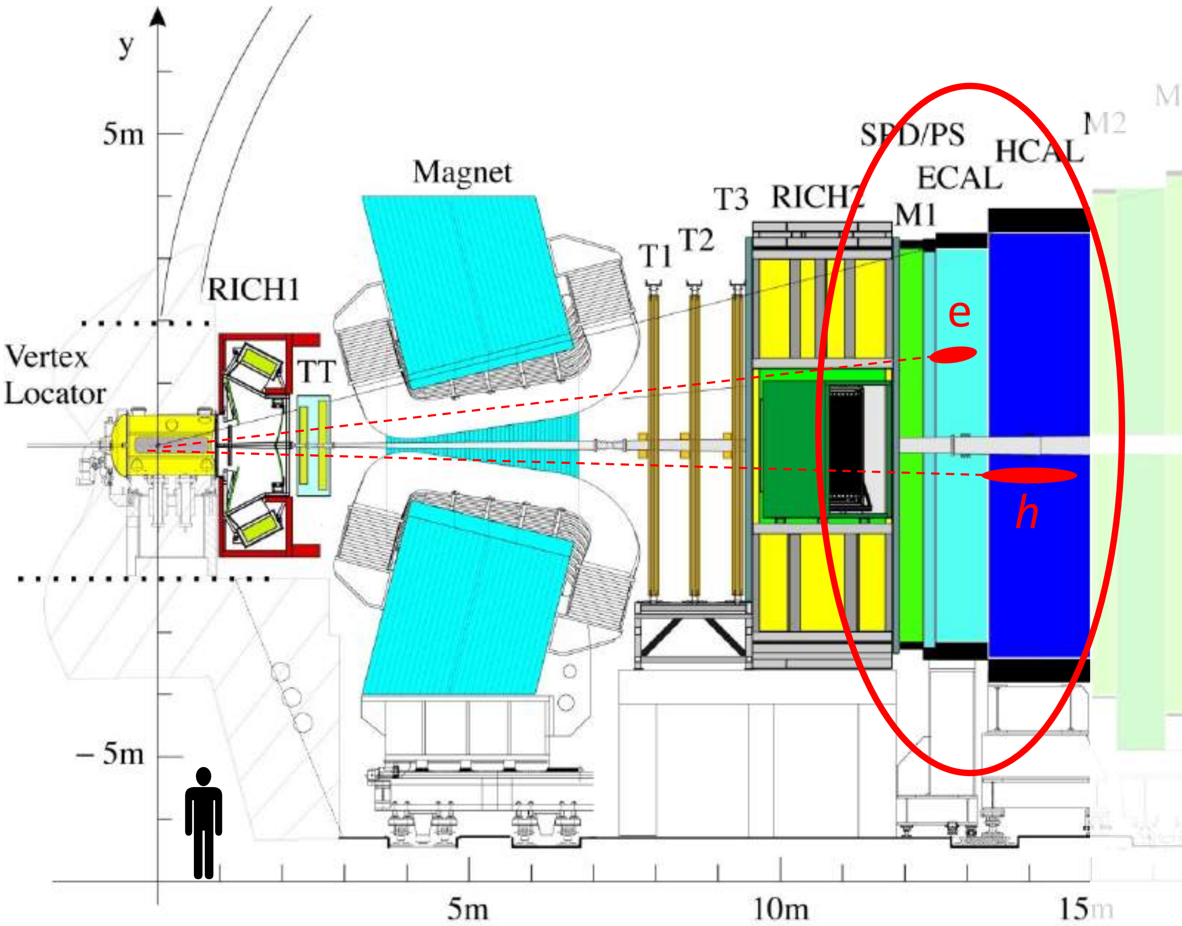
Calorimeter System

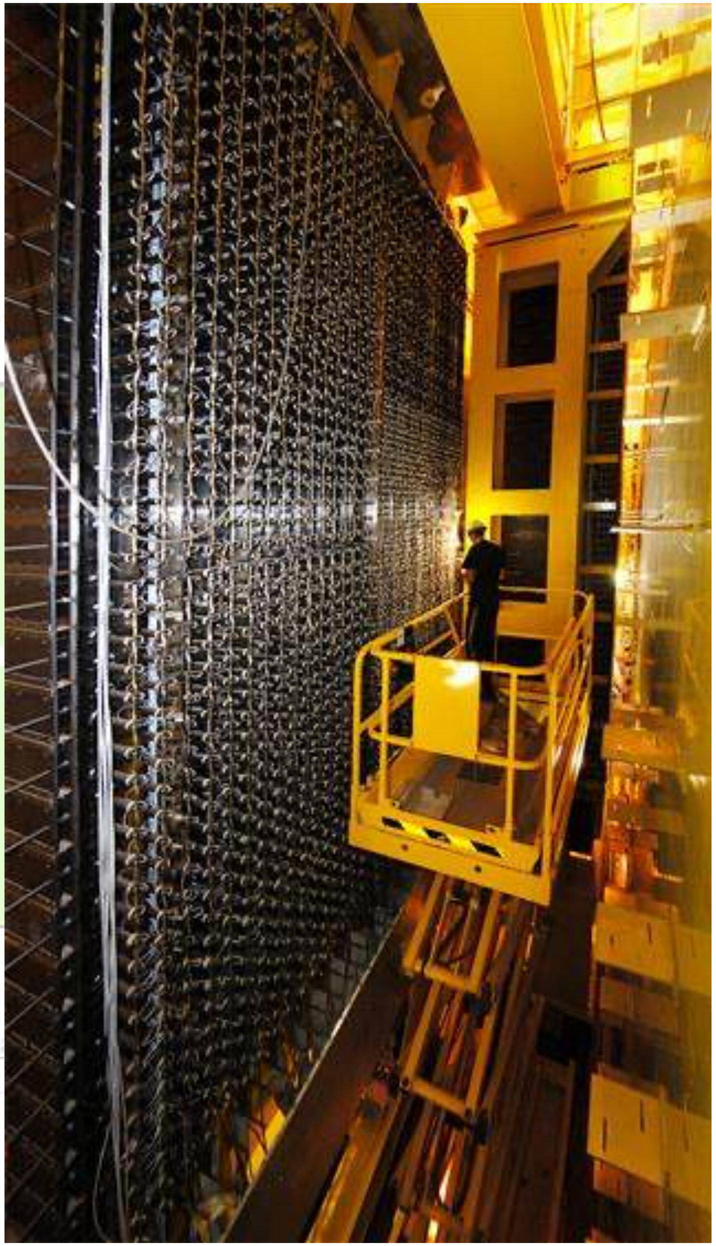
System of calorimeters to maximize γ/e and e/h separation

ECAL, HCAL: scintillator + absorber material planes

$\Delta E/E = 1\ \% \oplus 10\ \%/\sqrt{E}$ (GeV)

Used in the first level of the trigger [L0]





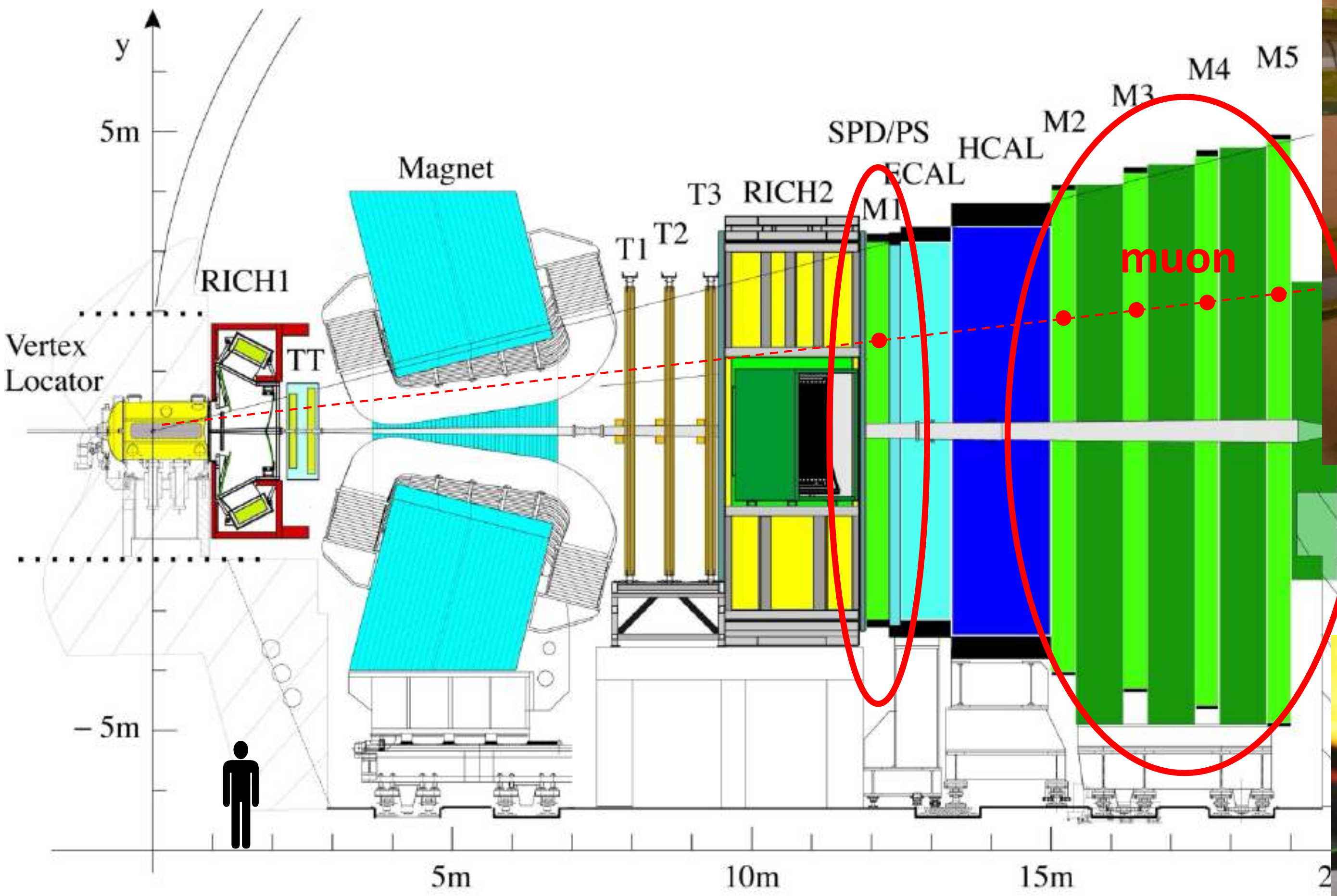
[Performance of the Muon Identification at LHCb JINST 8 (2013) P10020]
[Performance of the LHCb Muon system JINST 8 (2013) P02022]

Muon System

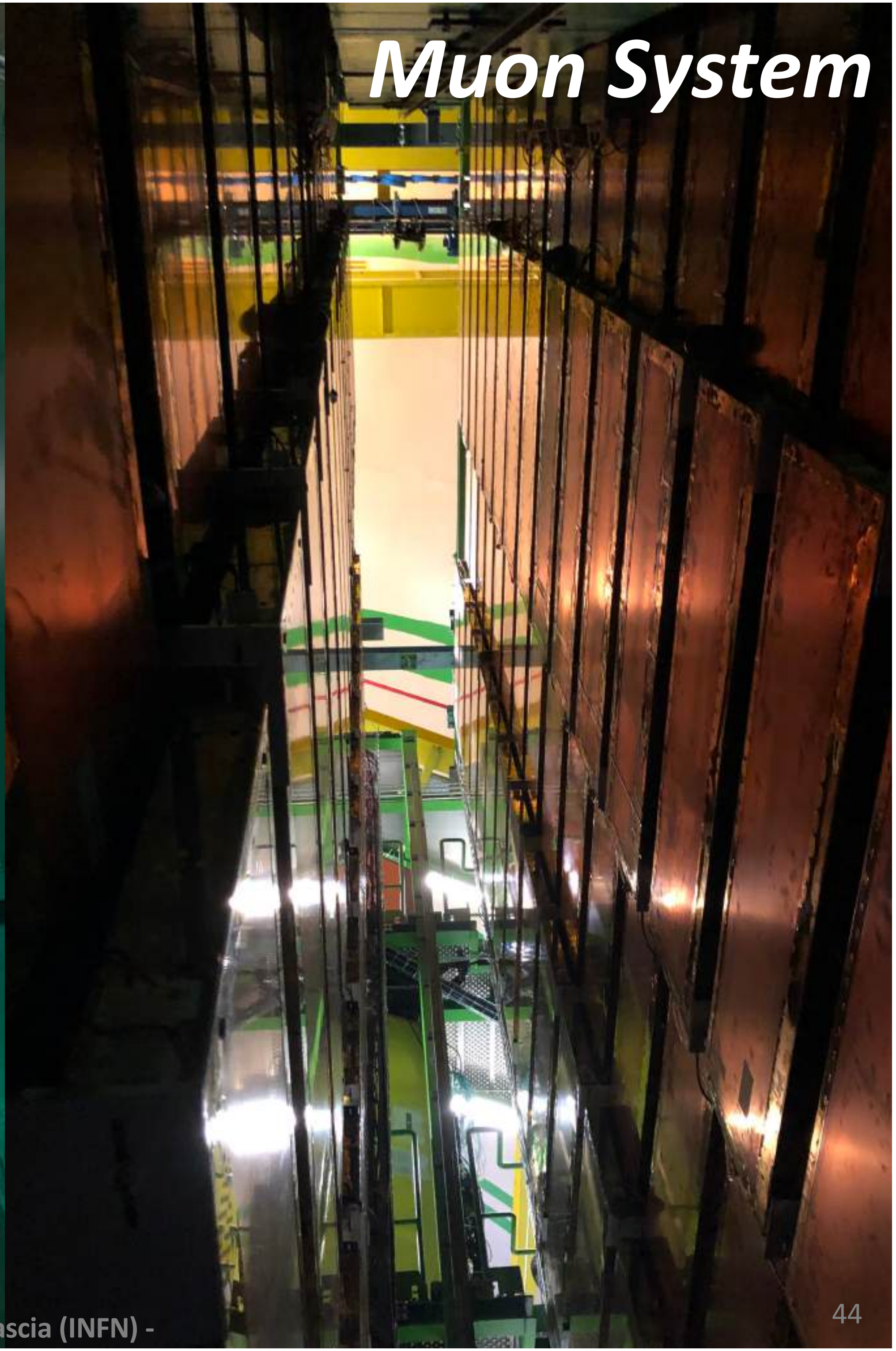
5 stations, each equipped with 276 multi-wire proportional chambers [different size]. Inner part of M1 equipped with 12 GEM detectors

μ identification ε(μ→μ) ~ 97 %, mis-ID ε(π→μ) ~ 1-3 %

Used in the first level of the trigger [L0]

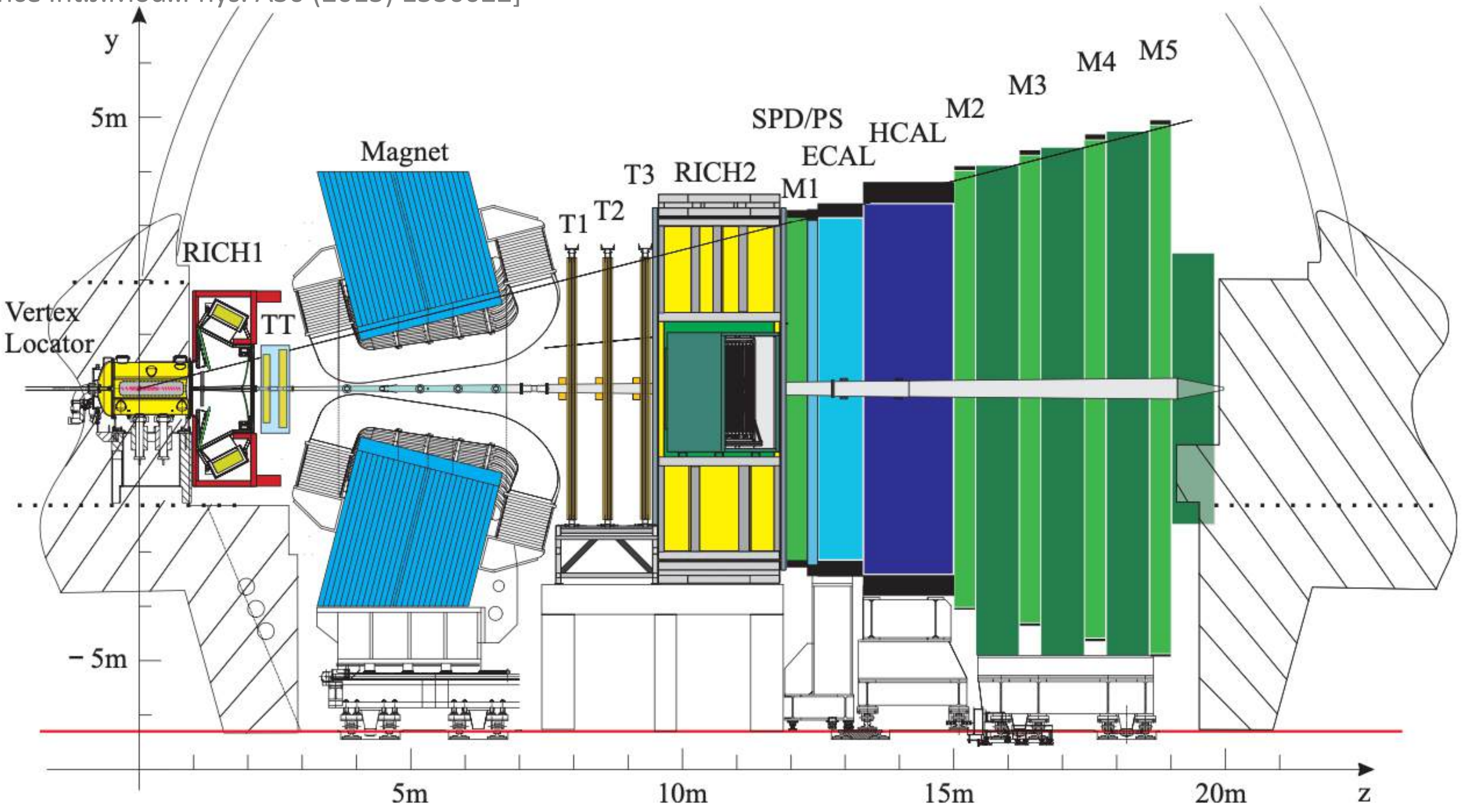


Muon System



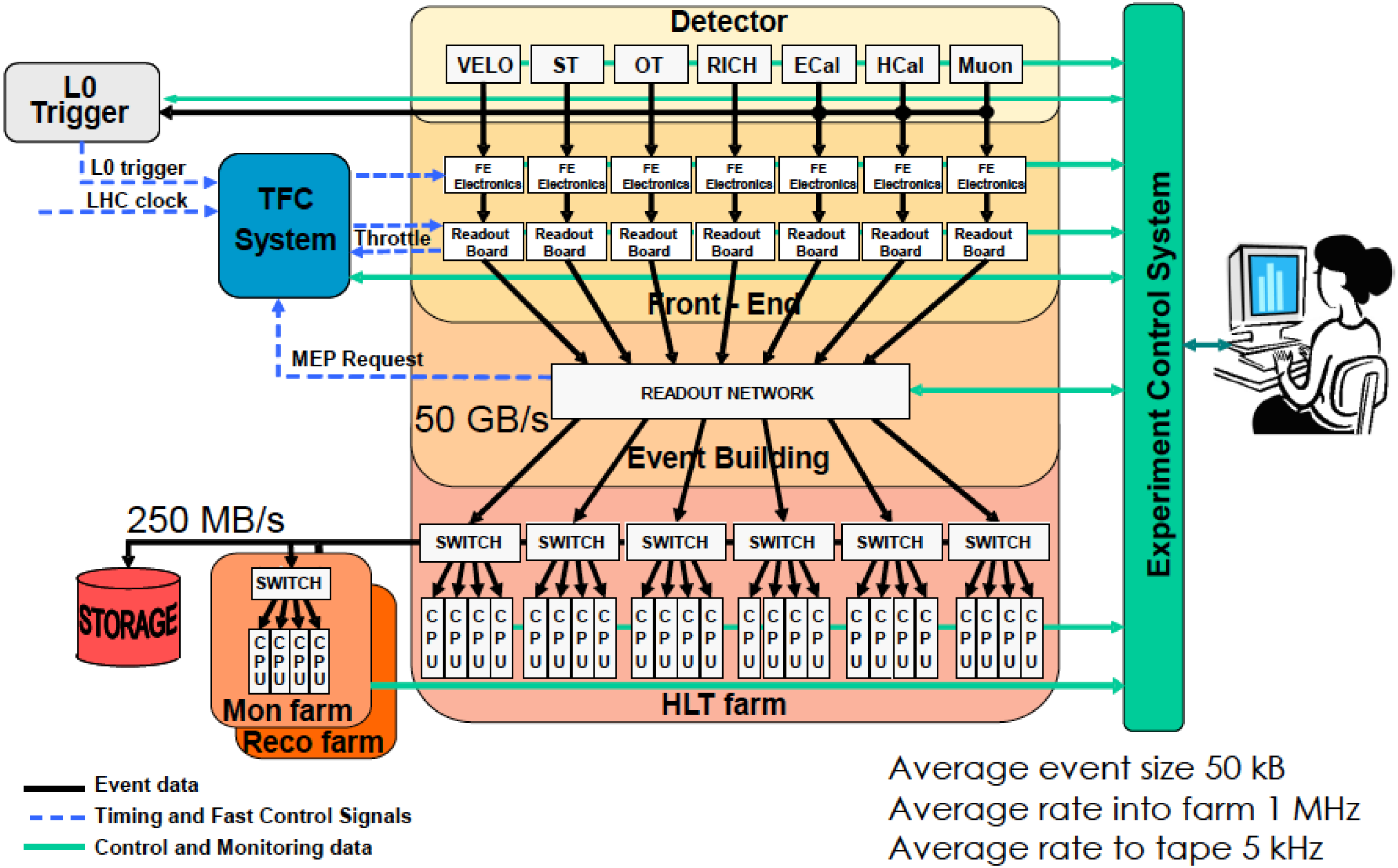
LHCb detector performance in one slide

[LHCb Detector Performance Int.J.Mod..Phys. A30 (2015) 1530022]



- High vertex resolution (VELO)
  $\sigma_{\rm IP} = 15 + 29/p_T\ \mu$m
  (B travel distance $\mathcal{O}(1\ \rm cm)$)
- Low momentum muon trigger
  $p_{T_\mu} > 1.75$ GeV (2018)
- Particle identification capabilities (RICH+CALO+MUON)
  $\epsilon_\mu \sim 98\,\%$ with $\epsilon_{\pi\to\mu} \lesssim 1\,\%$
- Excellent momentum resolution (T stations)
  $\sigma_p/p = 0.5 - 1.0\,\%$ ($p \in [2{,}200]$ GeV)
  → narrow mass peak

Collect data (DAQ, Run 1)

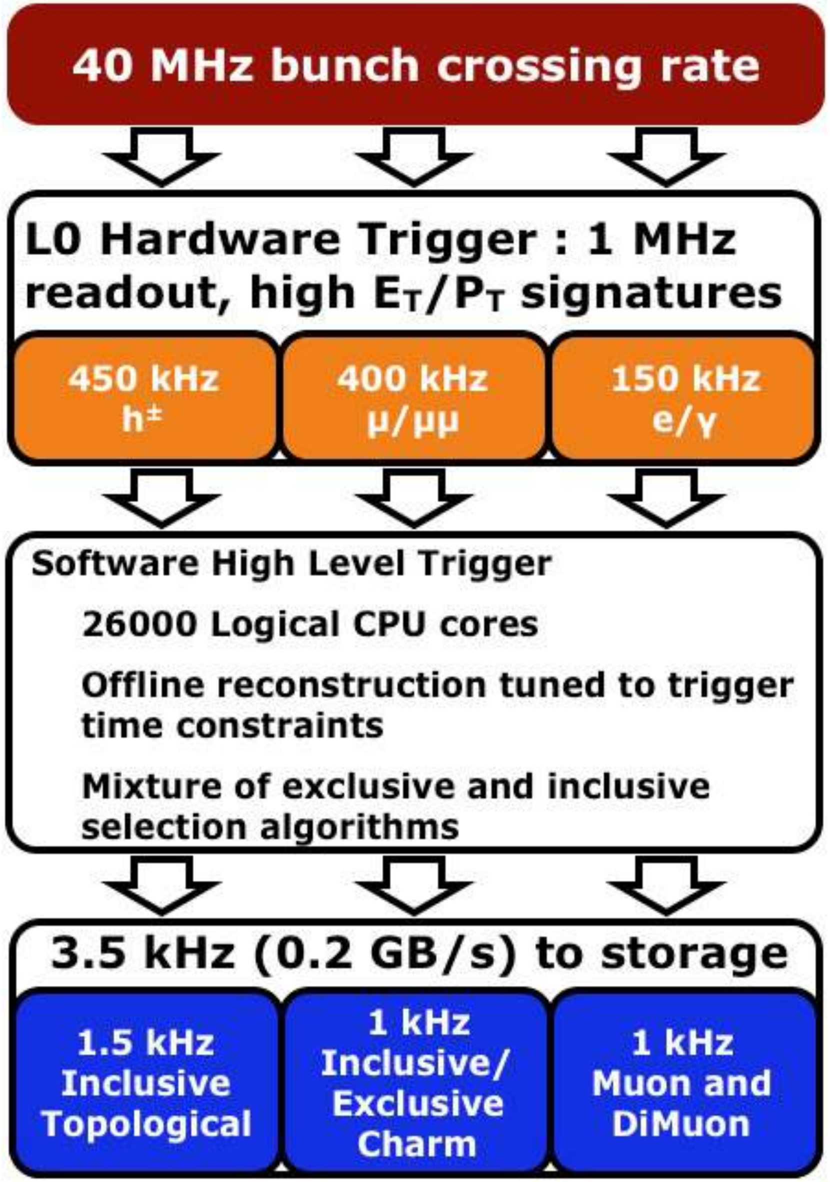


Average event size 50 kB
Average rate into farm 1 MHz
Average rate to tape 5 kHz

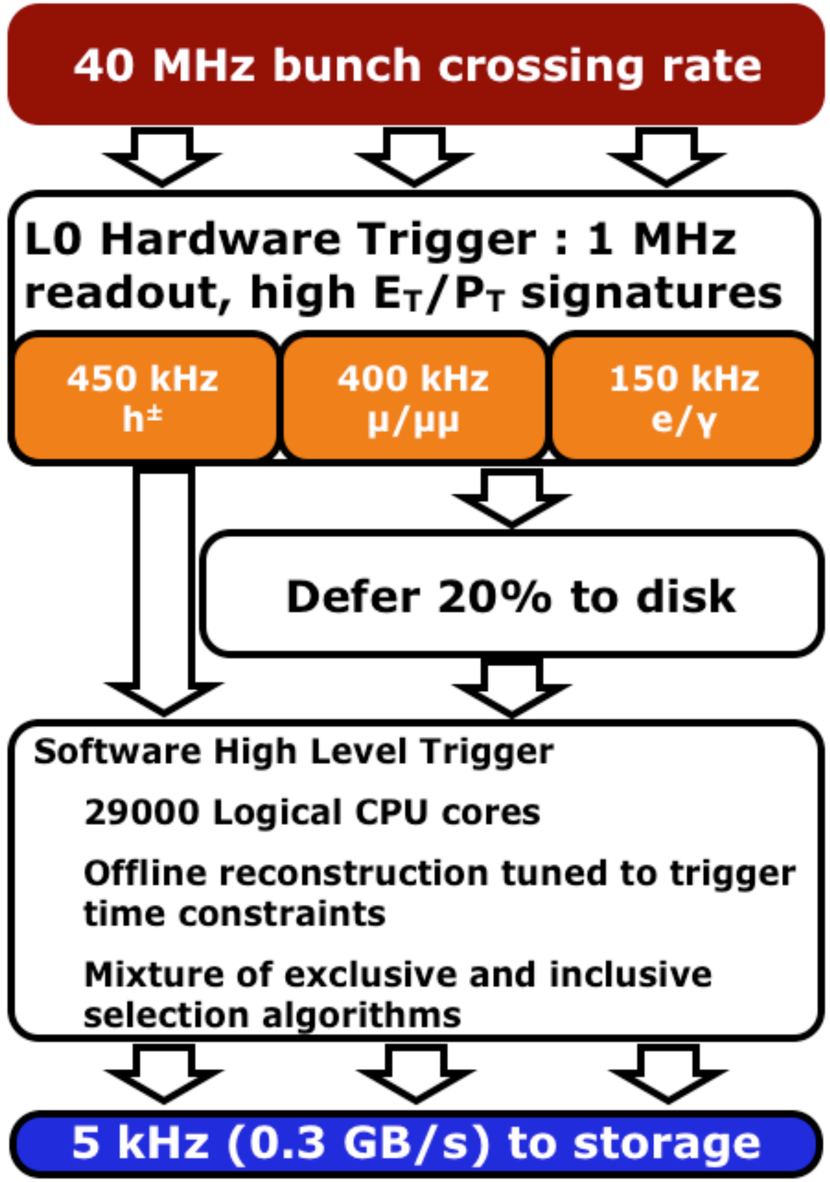
[arXiv:1211.3055; CERN-LHCb-DP-2012-004]
[arXiv:1310.8544v1]

Trigger, Run 1

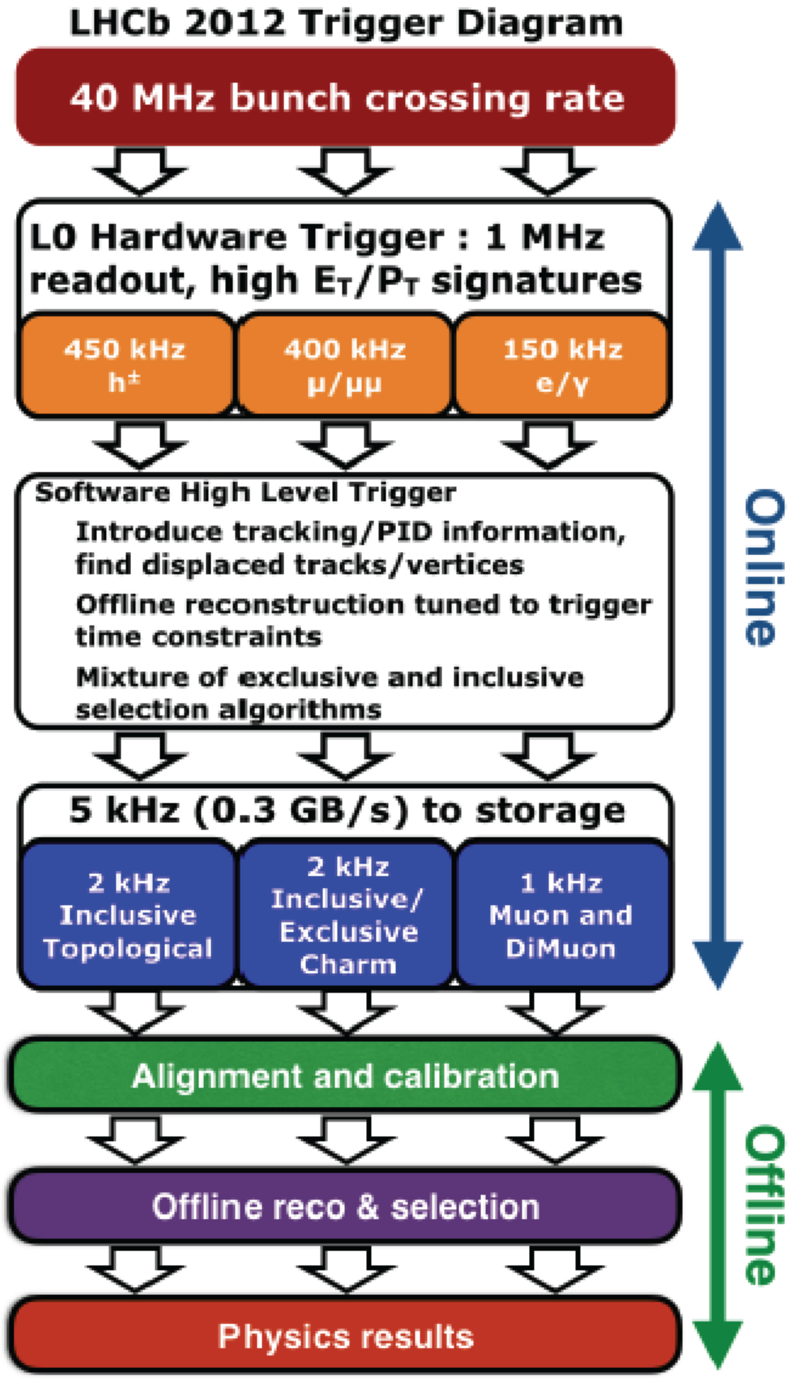
LHCb 2011 Trigger Diagram



LHCb 2012 Trigger Diagram



Trigger, Run 1

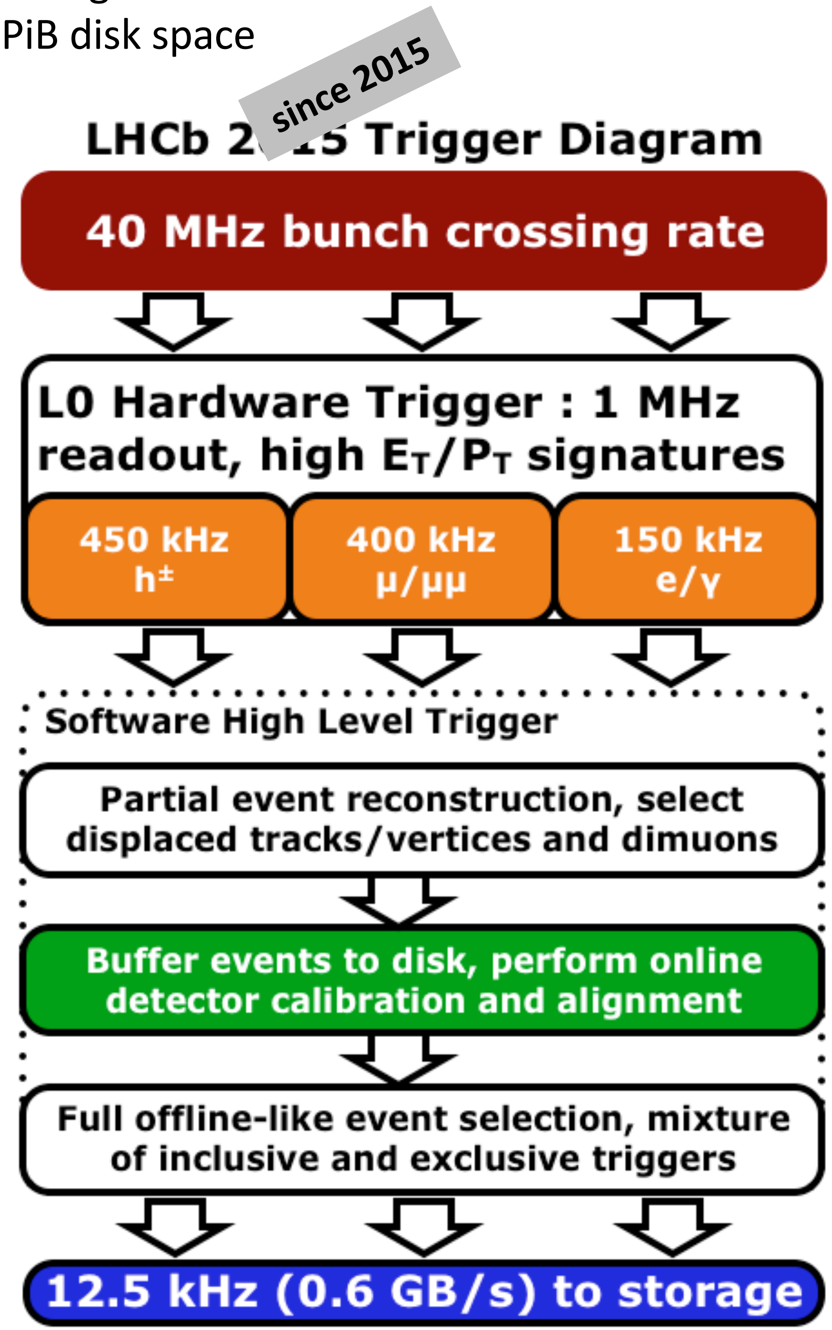


[~~"All I'm saying is now is the time to develop the technology to deflect an asteroid."~~]

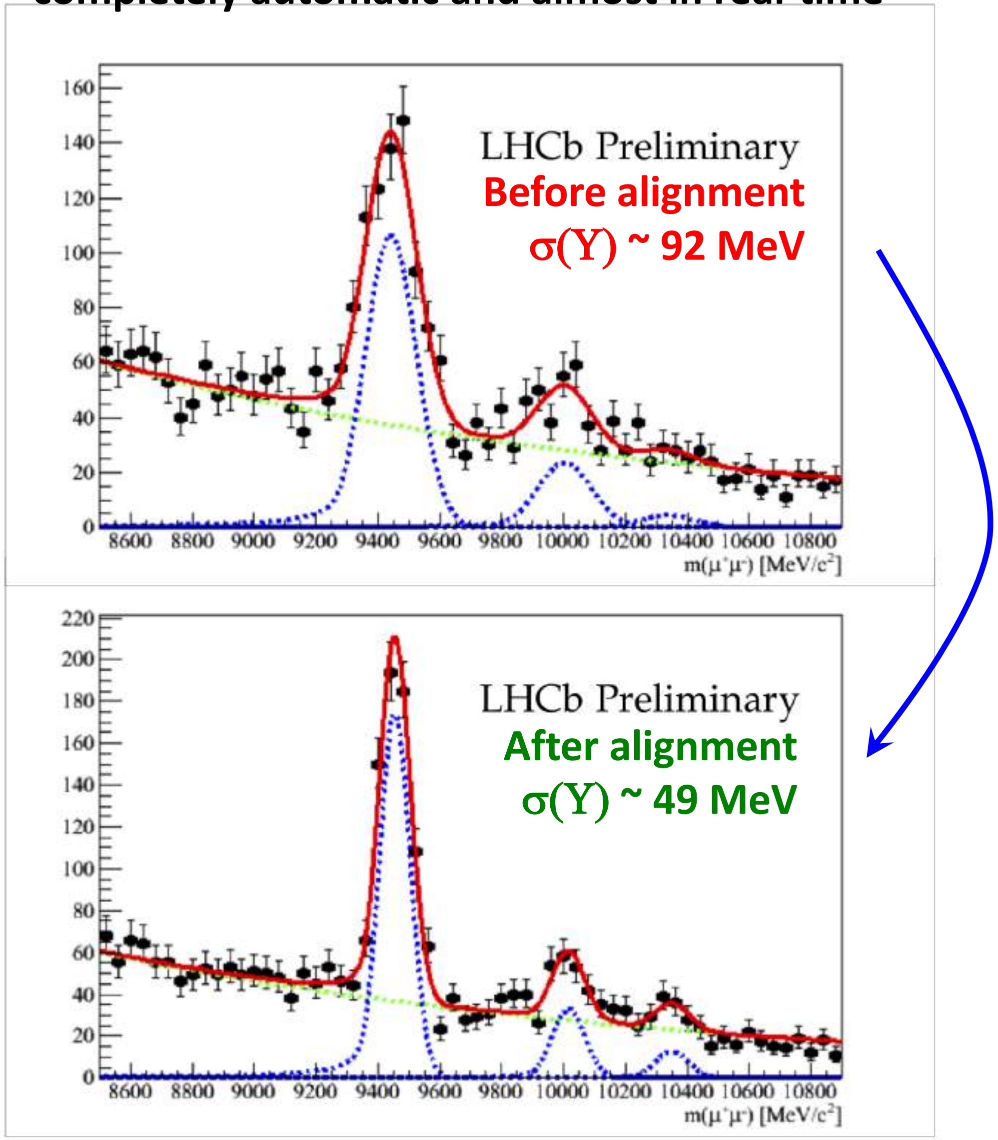
"All I'm saying is now is the time to run data reconstruction only once."

~50k logical cores
~5PiB disk space

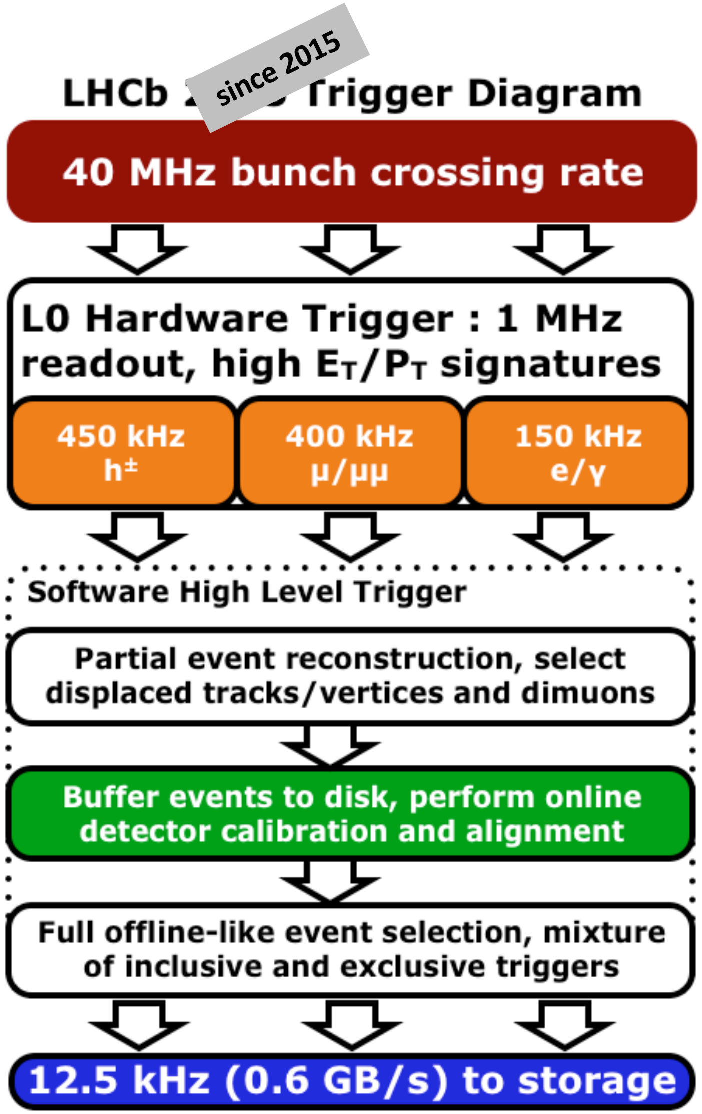
Trigger, Run 2

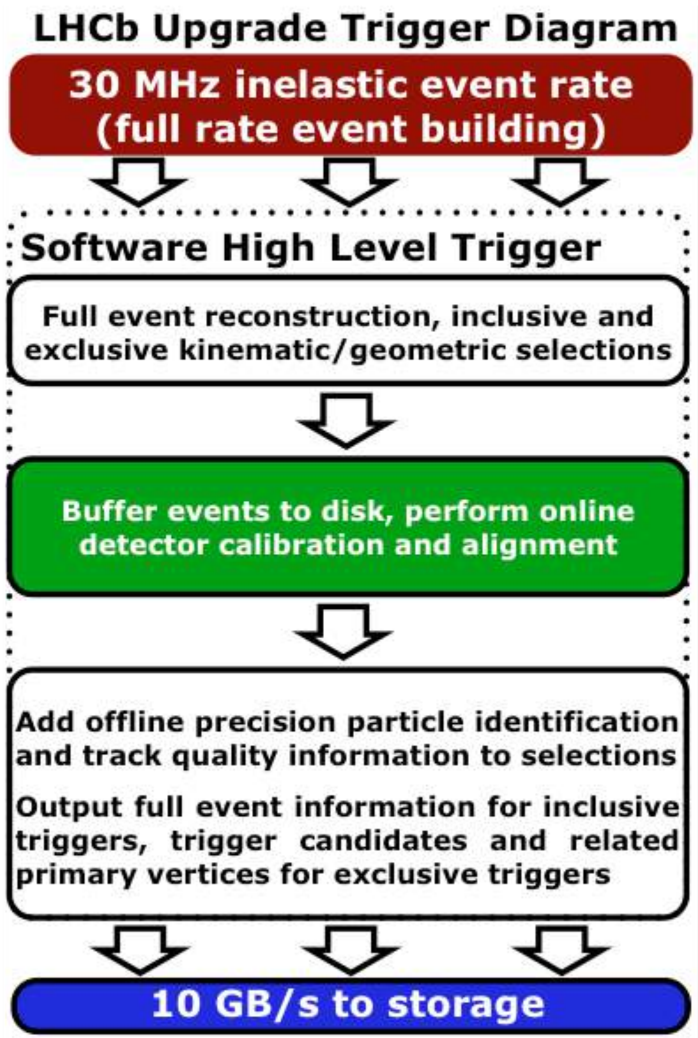


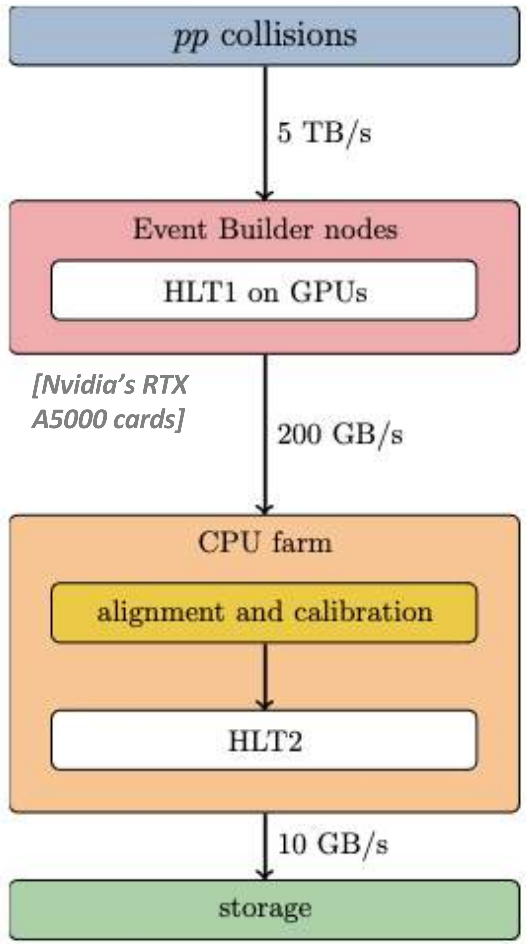
Same online and offline reconstruction and PID
- **prompt alignment and calibration**
- **completely automatic and almost in real-time**



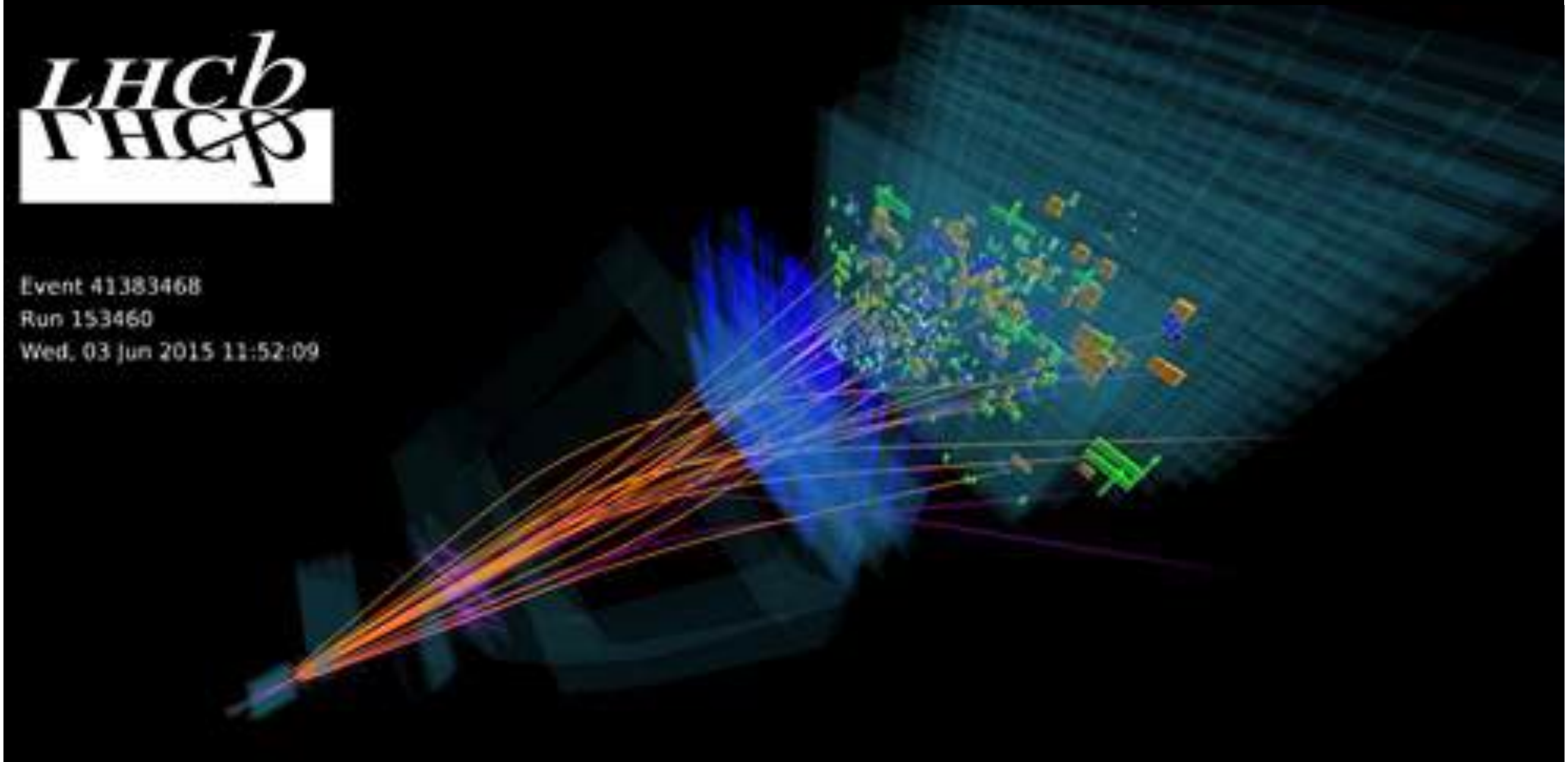
Trigger, Run 3 and beyond



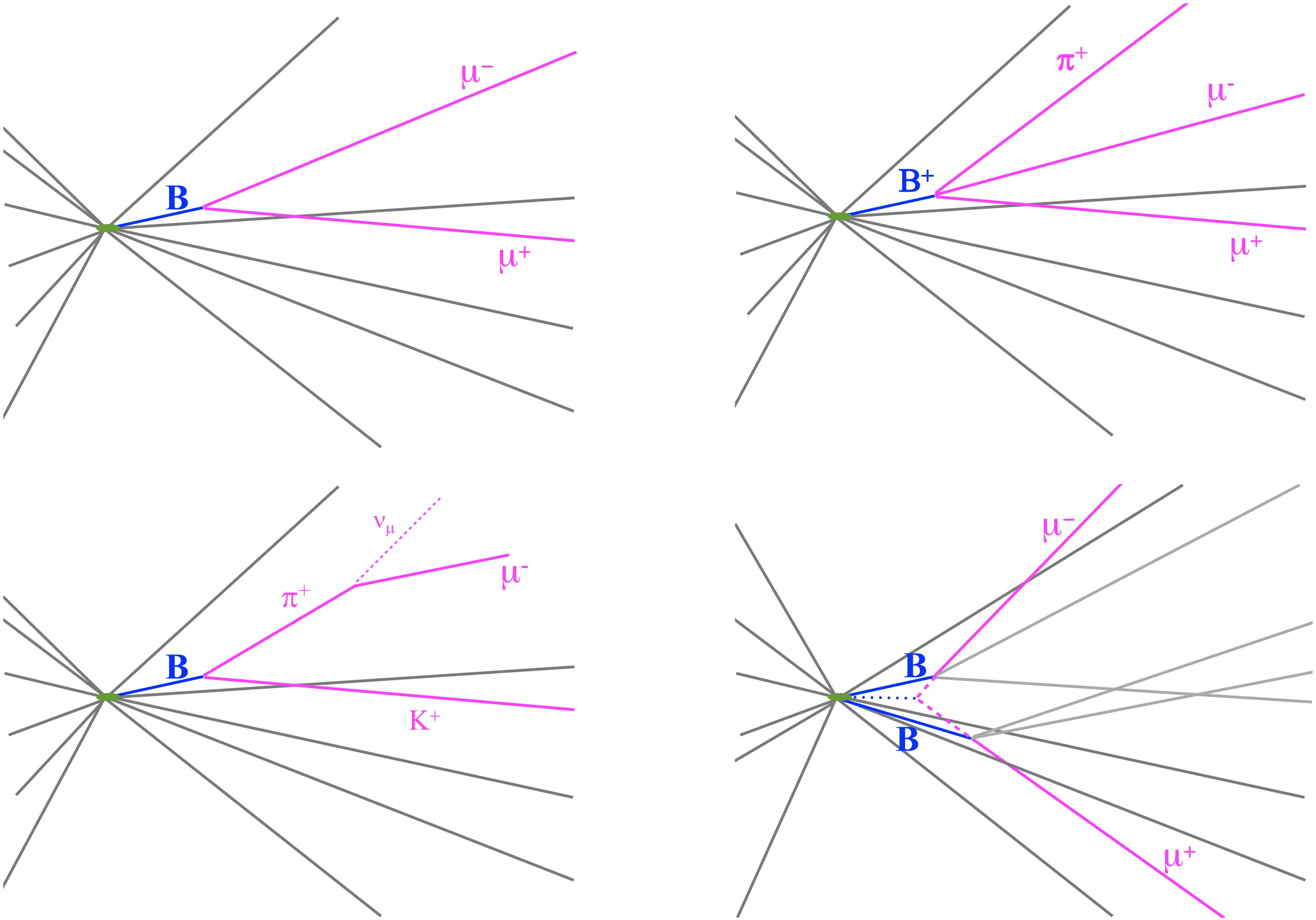


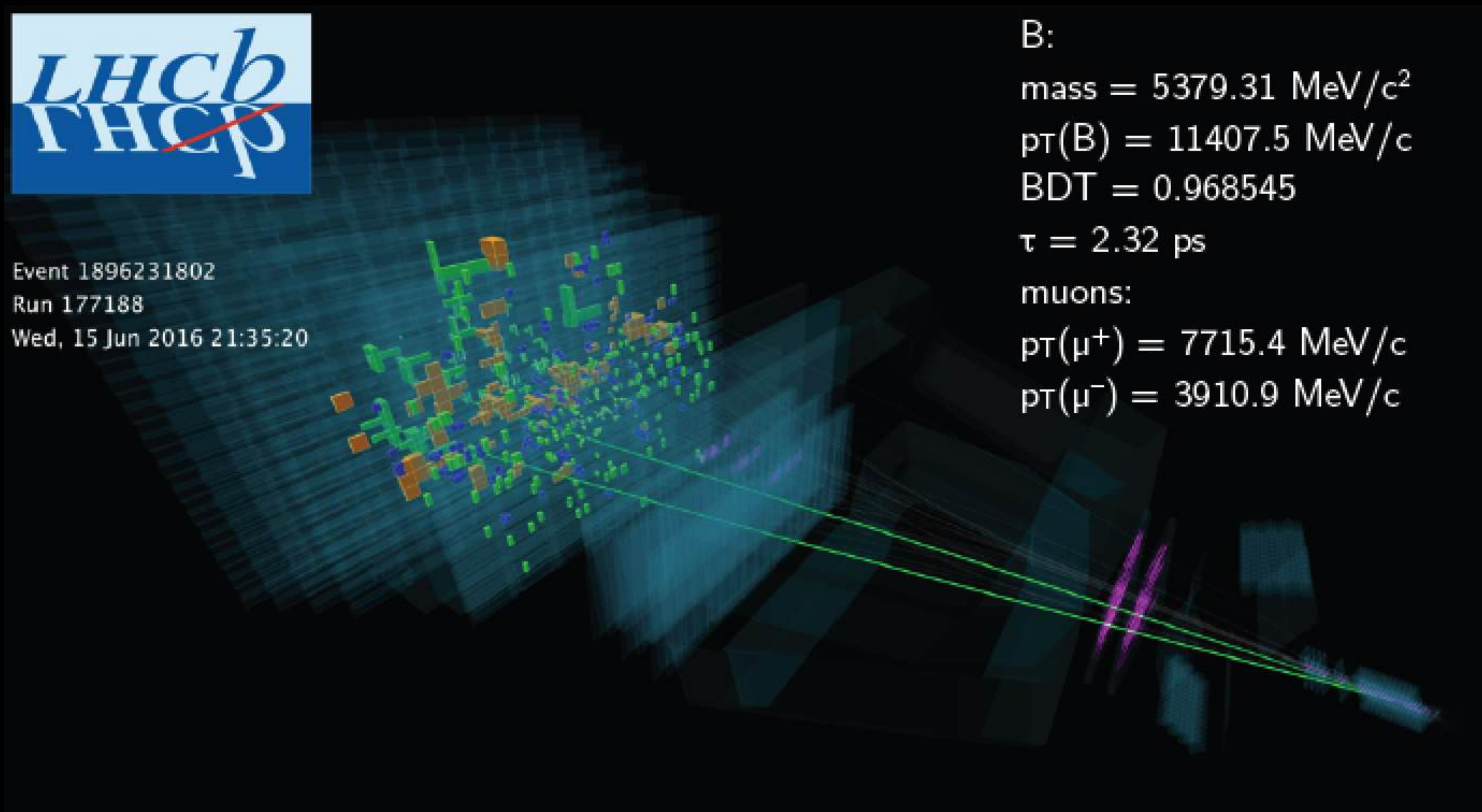


[More on Allen project: https://indico.cern.ch/event/1163086/contributions/4885204/]

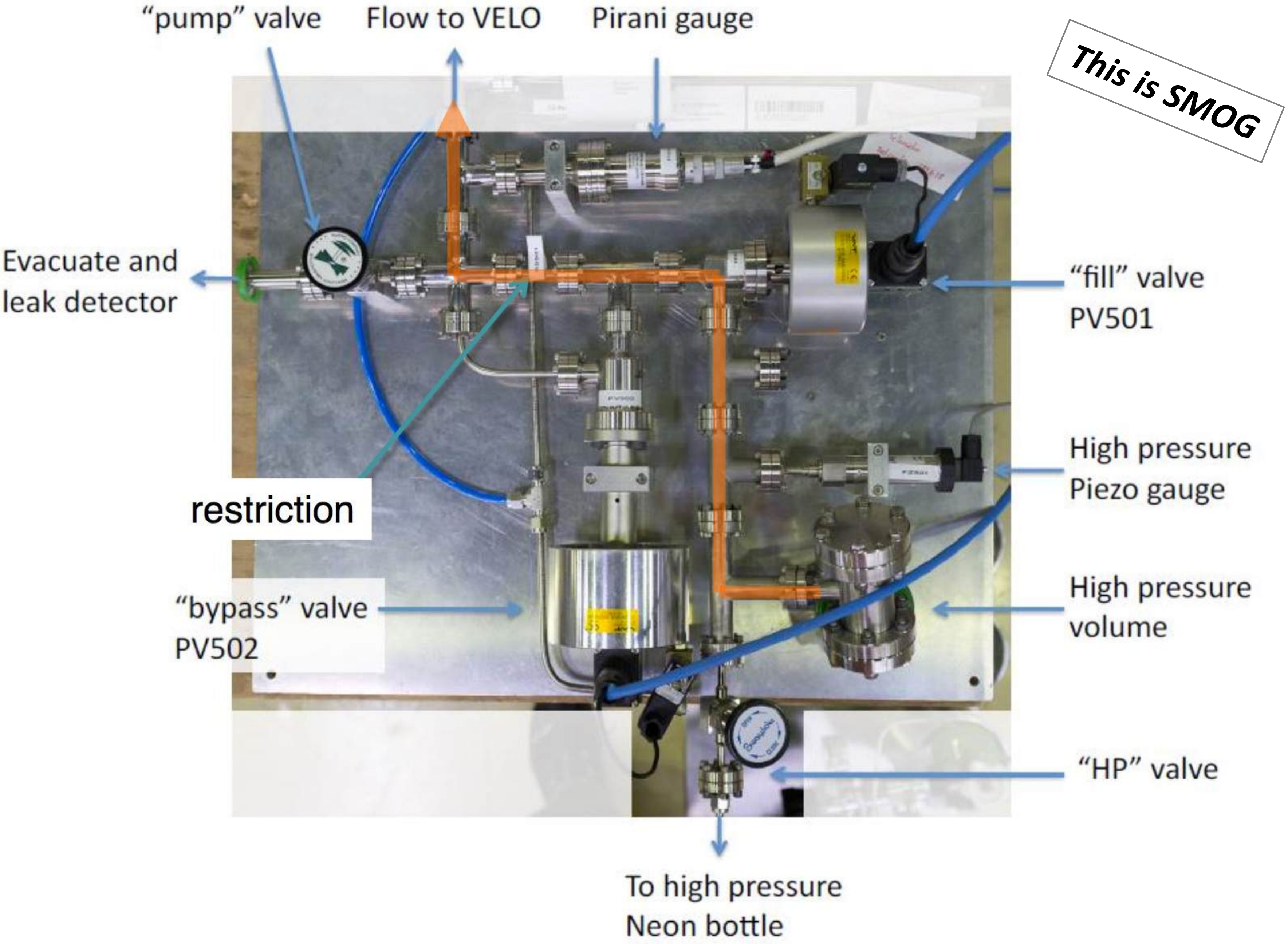

Event 41383468
Run 153460
Wed. 03 Jun 2015 11:52:09

$B_{(s)}$mm: signal and background topology




LHCb
Event 1896231802
Run 177188
Wed, 15 Jun 2016 21:35:20
B:
mass = 5379.31 MeV/c^2
p$_T$(B) = 11407.5 MeV/c
BDT = 0.968545
τ = 2.32 ps
muons:
p$_T$(μ$^+$) = 7715.4 MeV/c
p$_T$(μ$^-$) = 3910.9 MeV/c

System for Measuring the Overlap with Gas



SMOG: Beam Gas Imaging

$$N = L\sigma$$

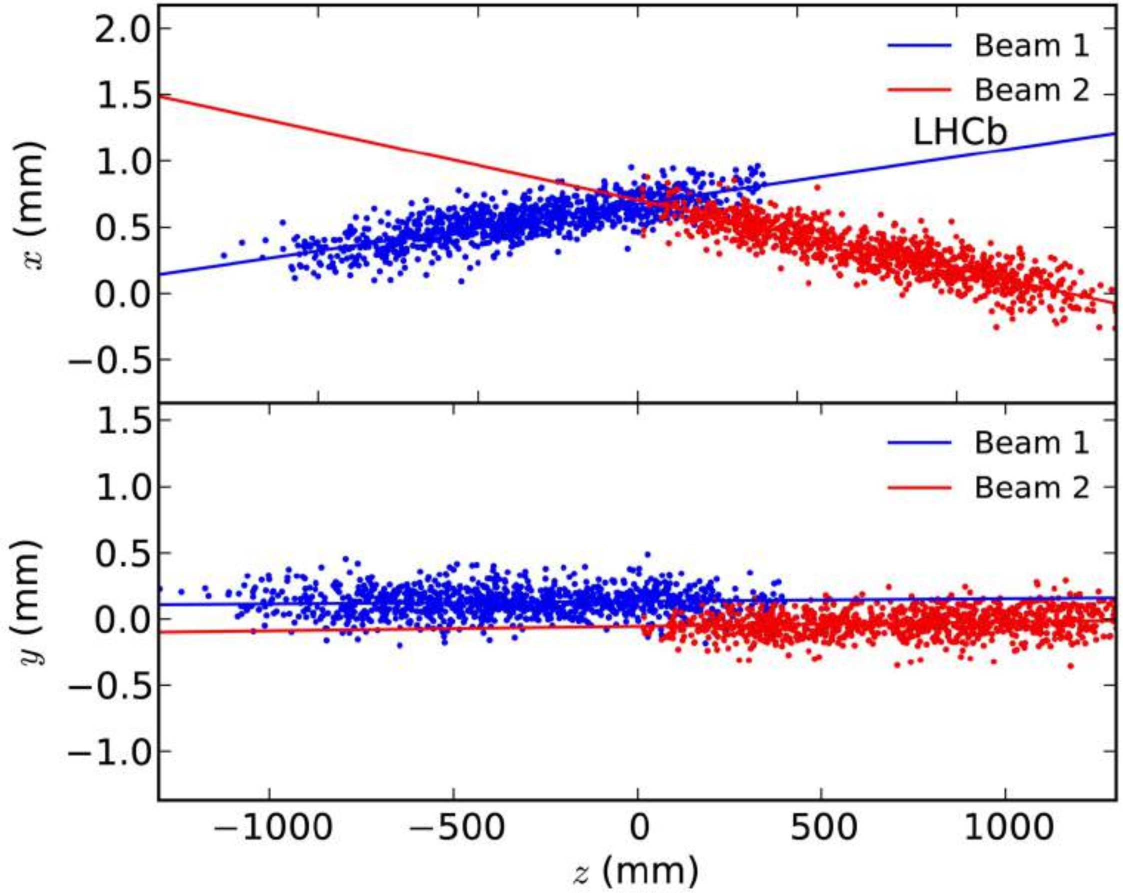
$$L = \frac{kN^2 f}{4\pi\sigma_x^*\sigma_y^*}$$

k = number of bunches = 2808
N = no. protons per bunch = 1.15×10^{11}
f = revolution frequency = 11.25 kHz
σ^*_x, σ^*_y = beam sizes at collision point

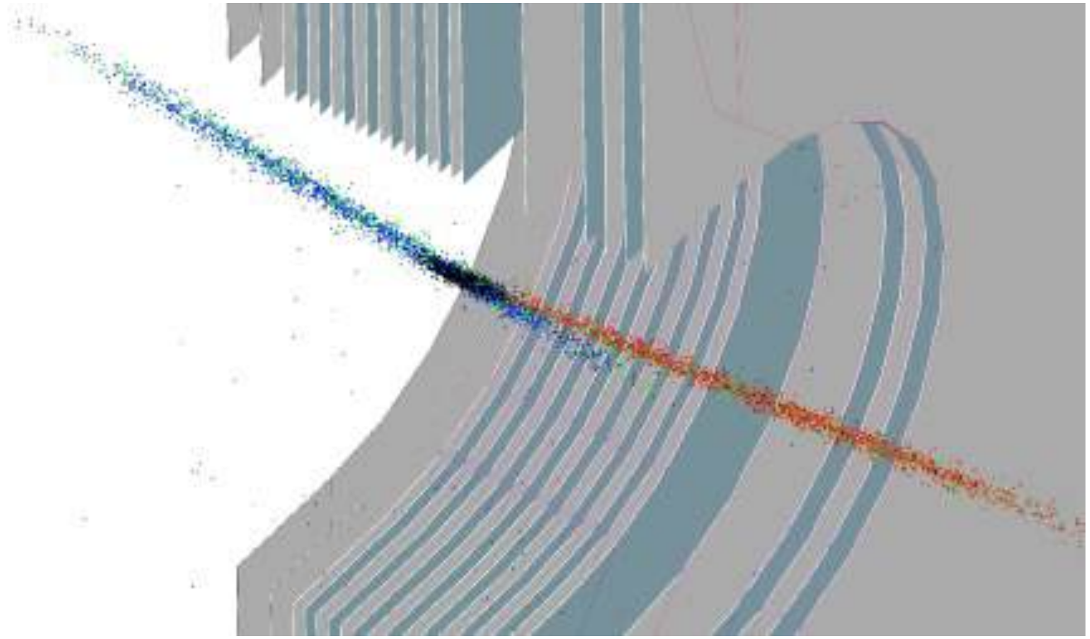
Original idea: determine luminosity by measuring beam profiles through beam-gas interaction (BGI).

First measurements using beam vacuum ~1×10^{-9} mbar (then increased to ~5×10^{-9} mbar by switching off VELO vacuum pumps).

[arXiv:1410.0149 [hep-ex]]

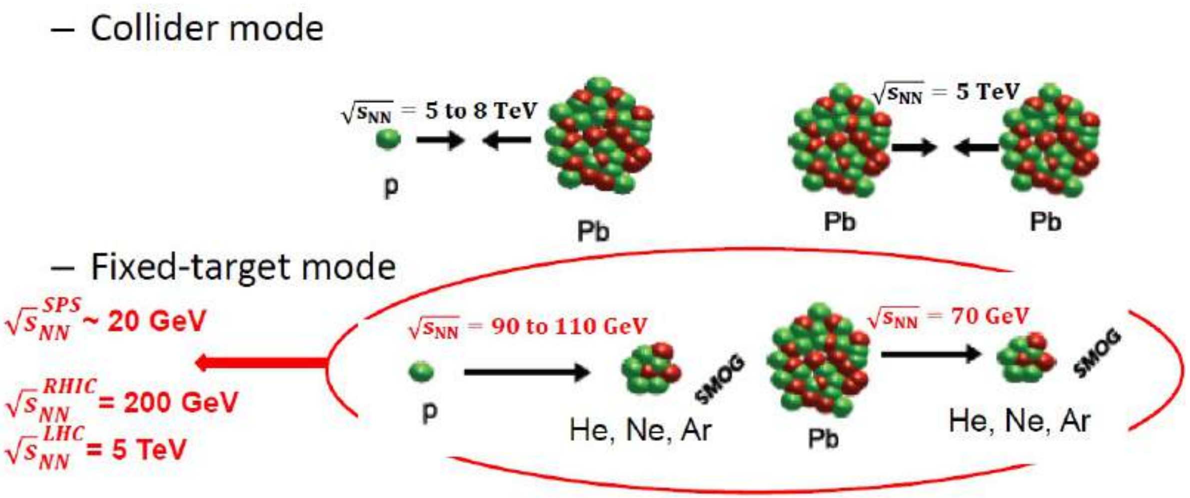


SMOG: fixed target physics



A device to inject gas (Ne) in the beam pipe around the VELO was developed: the SMOG

Pressure of injected gas 1-2 $\times 10^{-7}$ mbar
gas removed by two pumps at 20 m;
only noble gases can be used (He, Ne, Ar, maybe Kr and Xe toward end of run)

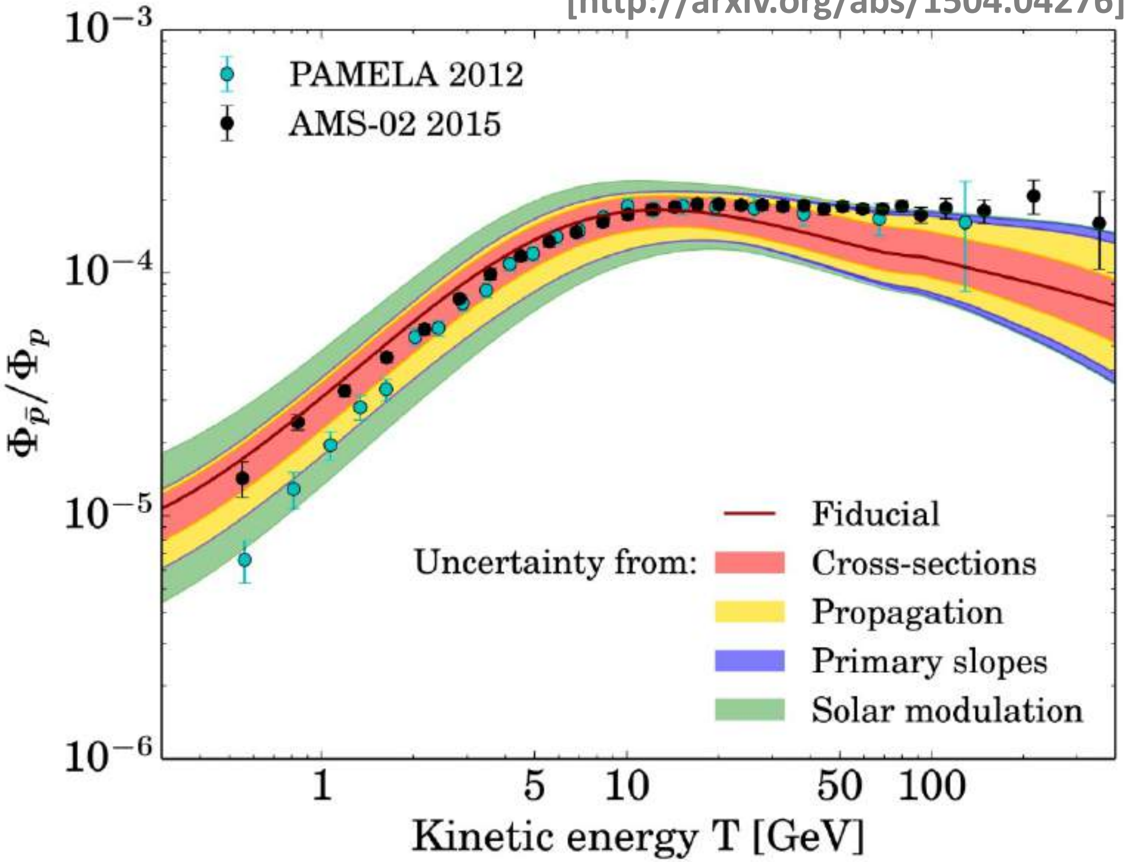


Presently LHCb is the only experiment capable of studying collisions of LHC beams on nuclei at rest.

SMOG: LHCb in the space

[LHCb-PUB-2016-011, https://cds.cern.ch/record/2145943/files/LHCb-PUB-2016-011.pdf]

[http://arxiv.org/abs/1504.04276]



LHCb - official start of Run 3

HEV: High Energy Ventilator

CERN against CoViD-19: https://indico.cern.ch/event/916953/

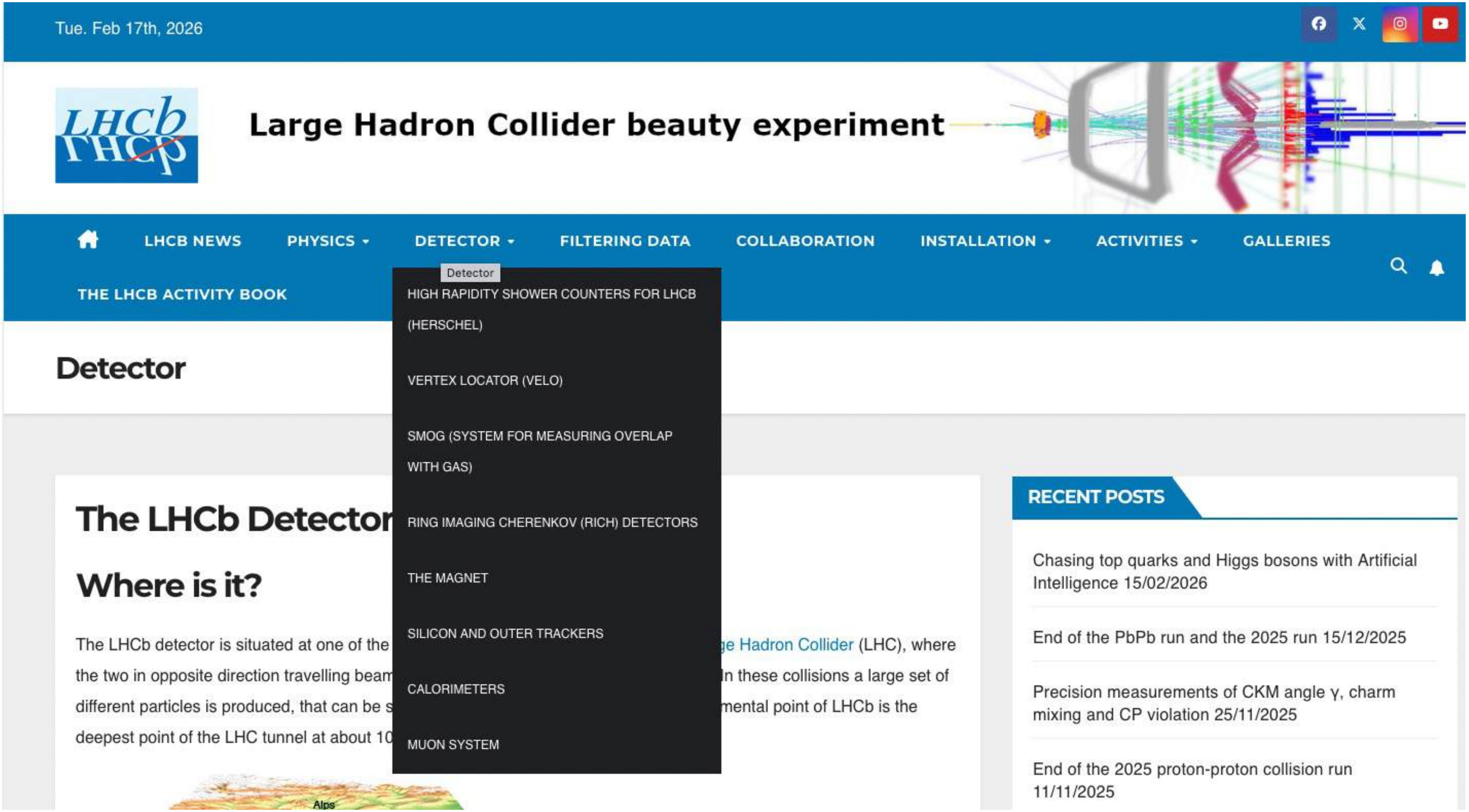
https://cerncourier.com/a/particle-physicists-propose-stripped-down-ventilator-to-help-combat-covid-19/
Video: https://www.youtube.com/watch?v=uIyLre4suT0
Original paper: https://arxiv.org/abs/2004.00534

HPLV: High Performance Low cost Ventilator

https://indico.cern.ch/event/1162368/

To go beyond

From here https://lhcb-outreach.web.cern.ch/detector/ a lot of material



Thanks!