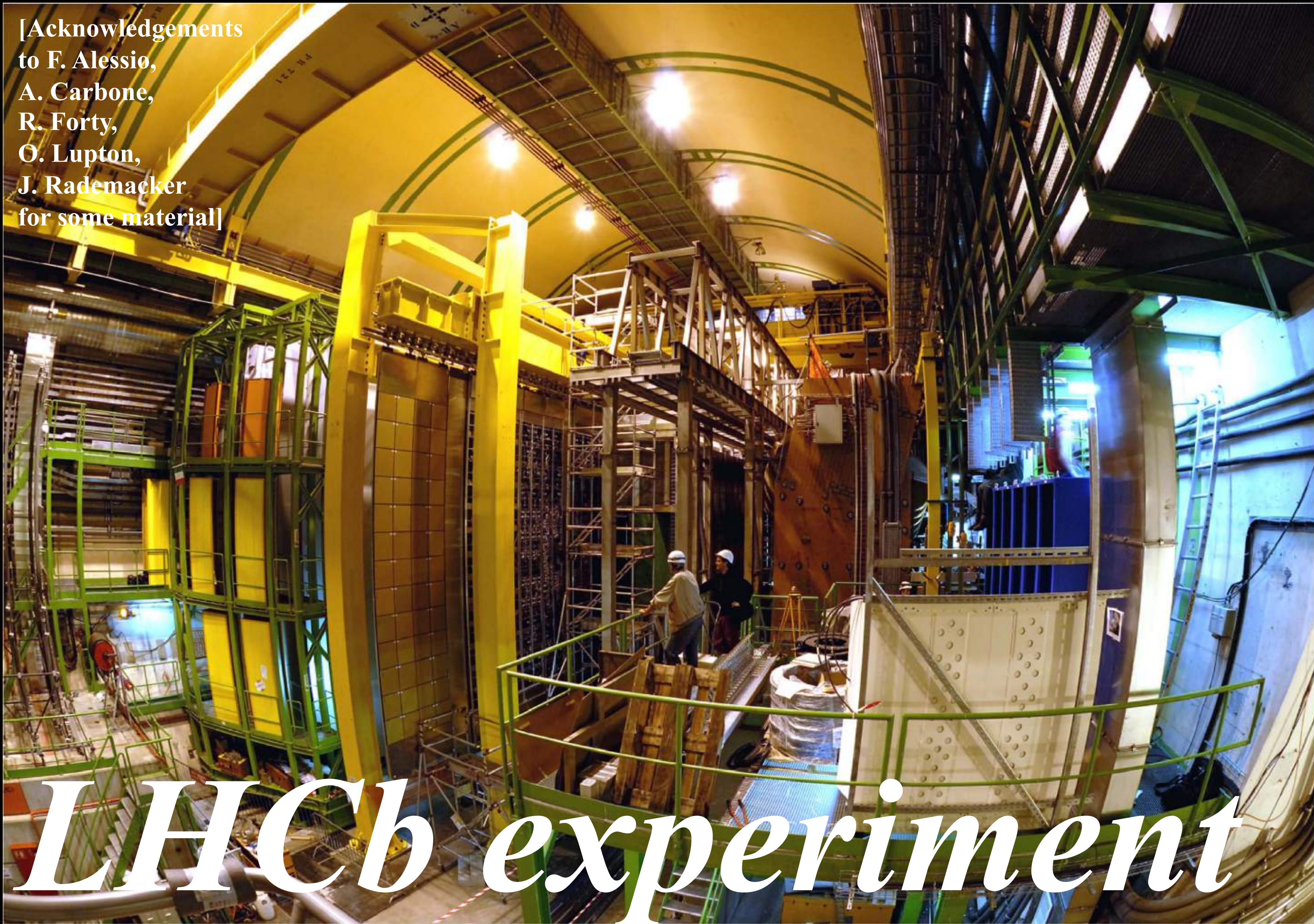
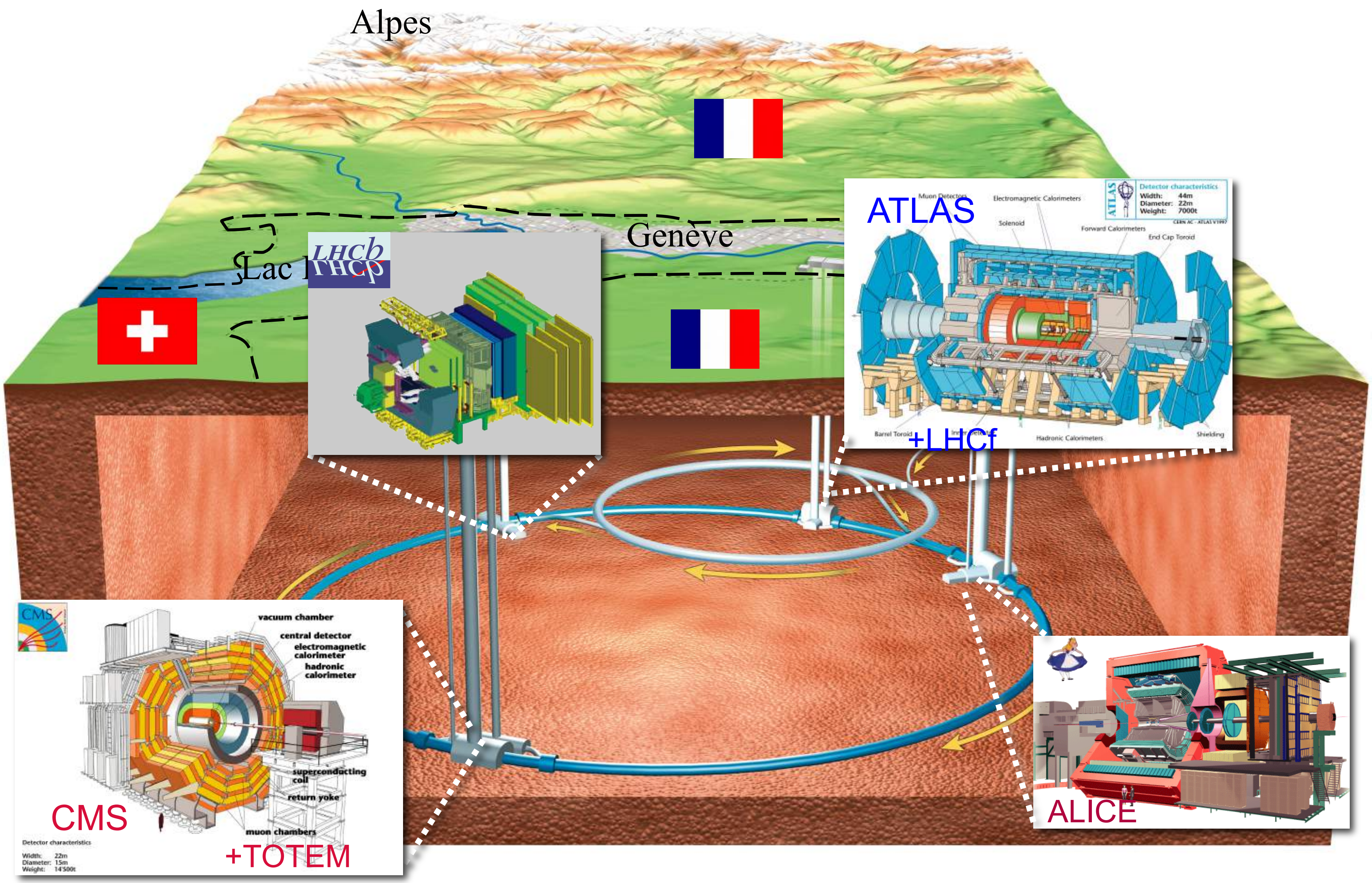

[Acknowledgements
to F. Alessio,
A. Carbone,
R. Forty,
O. Lupton,
J. Rademacker
for some material]
LHCb experiment

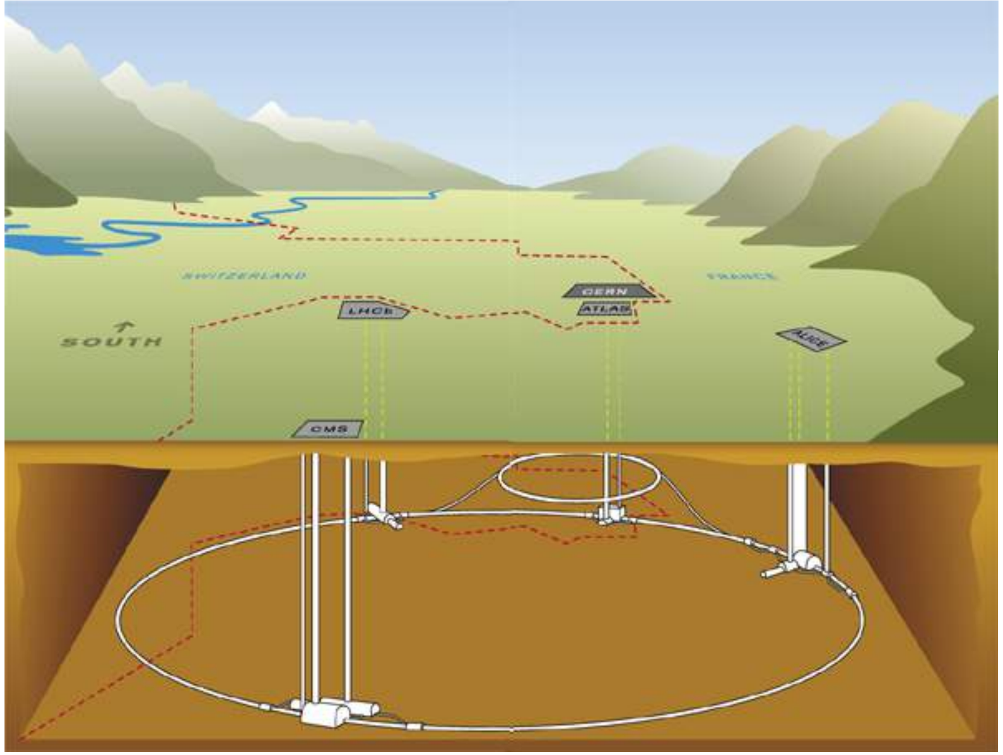
LHC @ CERN



Alpes
Genève
Lac
LHCb
ATLAS
+LHCf
CMS
+TOTEM
ALICE
vacuum chamber
central detector
electromagnetic calorimeter
hadronic calorimeter
superconducting coil
return yoke
muon chambers

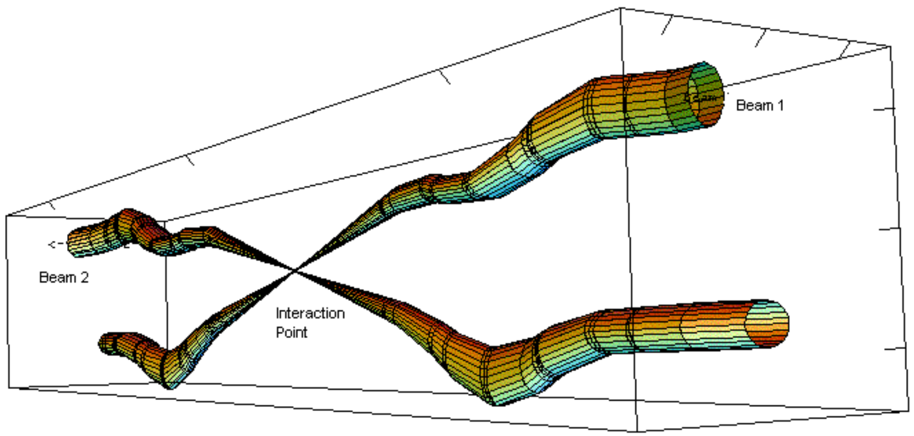
LHC per la prima volta a 13 TeV

LEP e LHC @ CERN

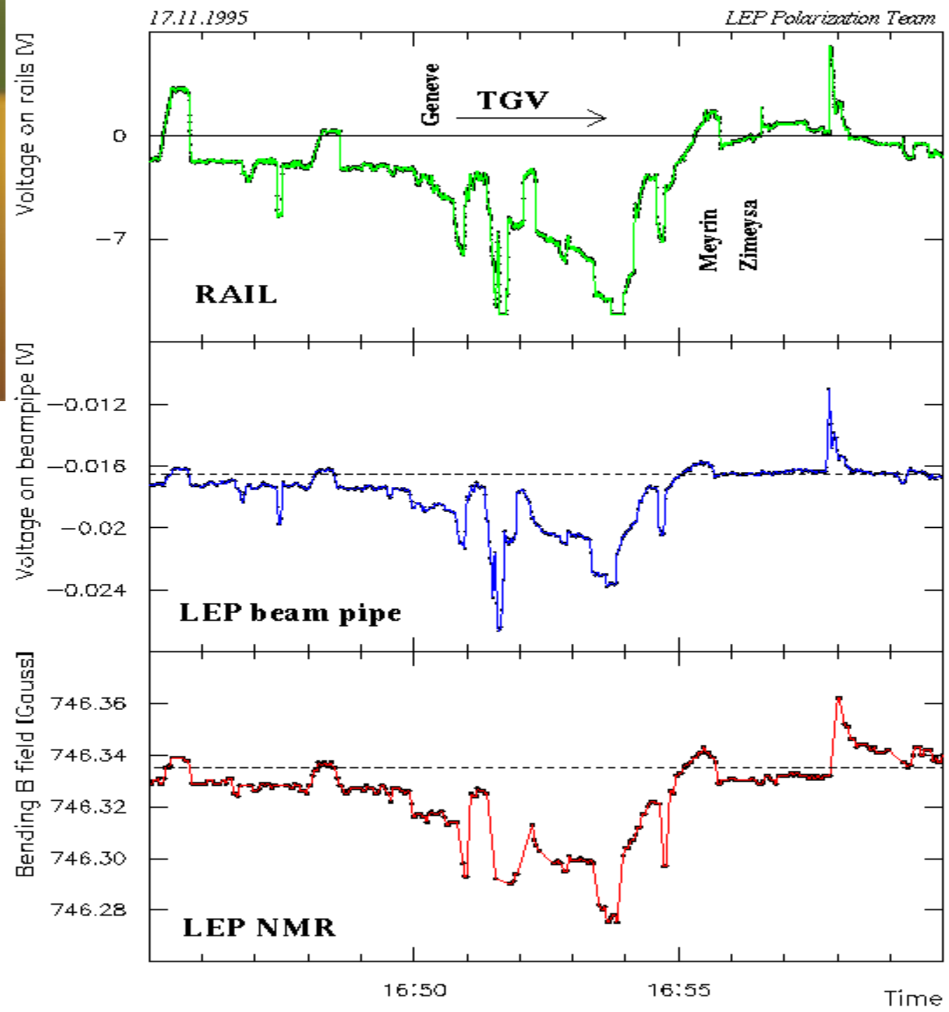


Il TGV

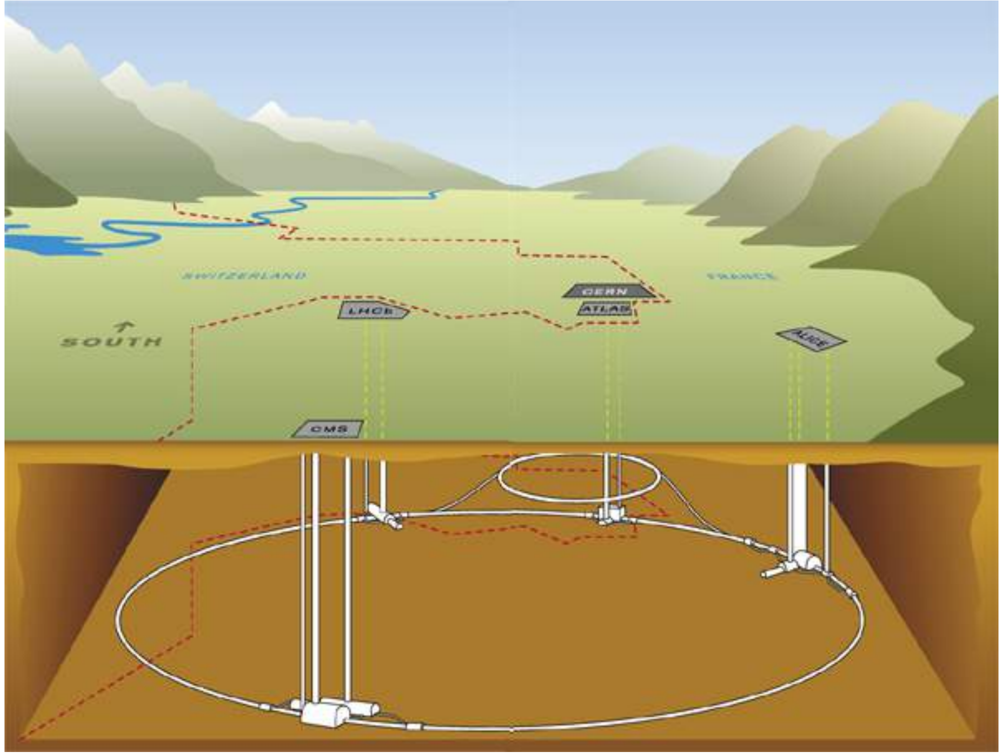
Le correnti indotte dal passaggio del treno sulla beam pipe di LEP cambiano il campo magnetico.



Relative beam sizes around IP1 (Atlas) in collision



LEP e LHC @ CERN

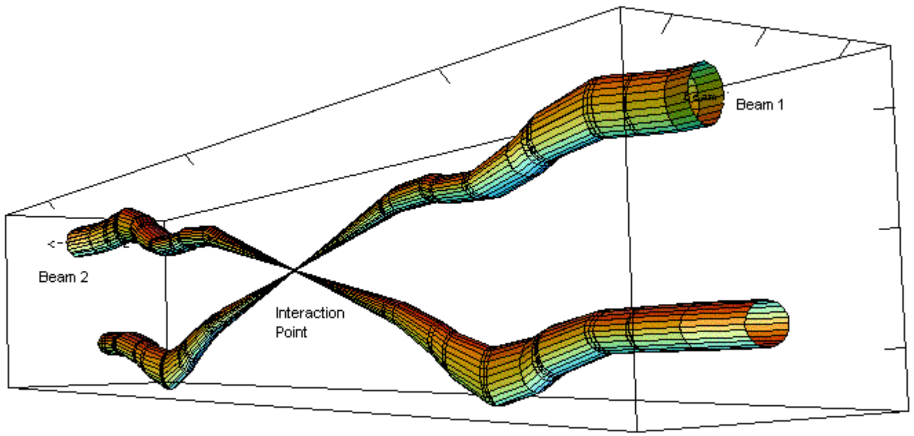


LA LUNA

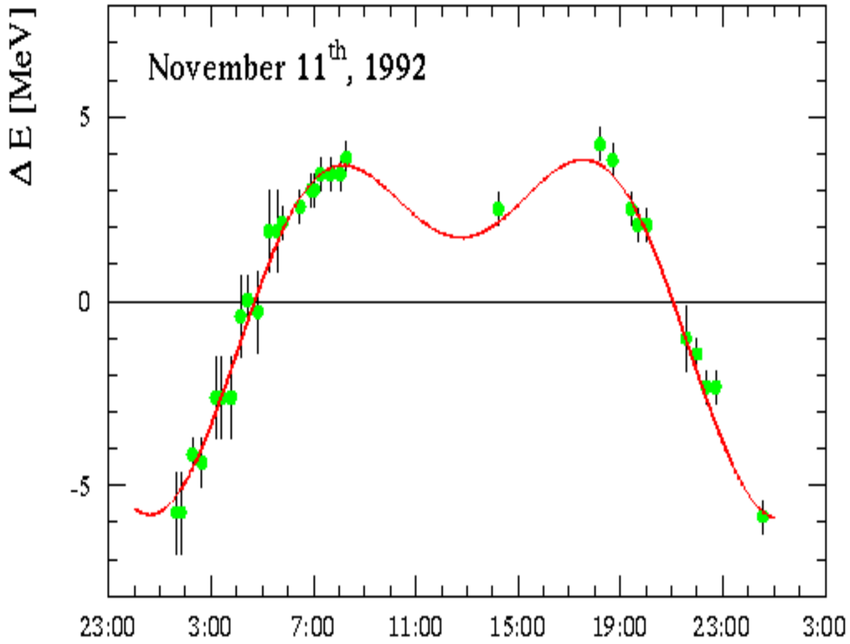
LEP a mezzanotte è circa ~300 μm più lungo che a mezzogiorno

→ $e^{\pm}$ vedono meno campo magnetico

→ E e' piu' piccola

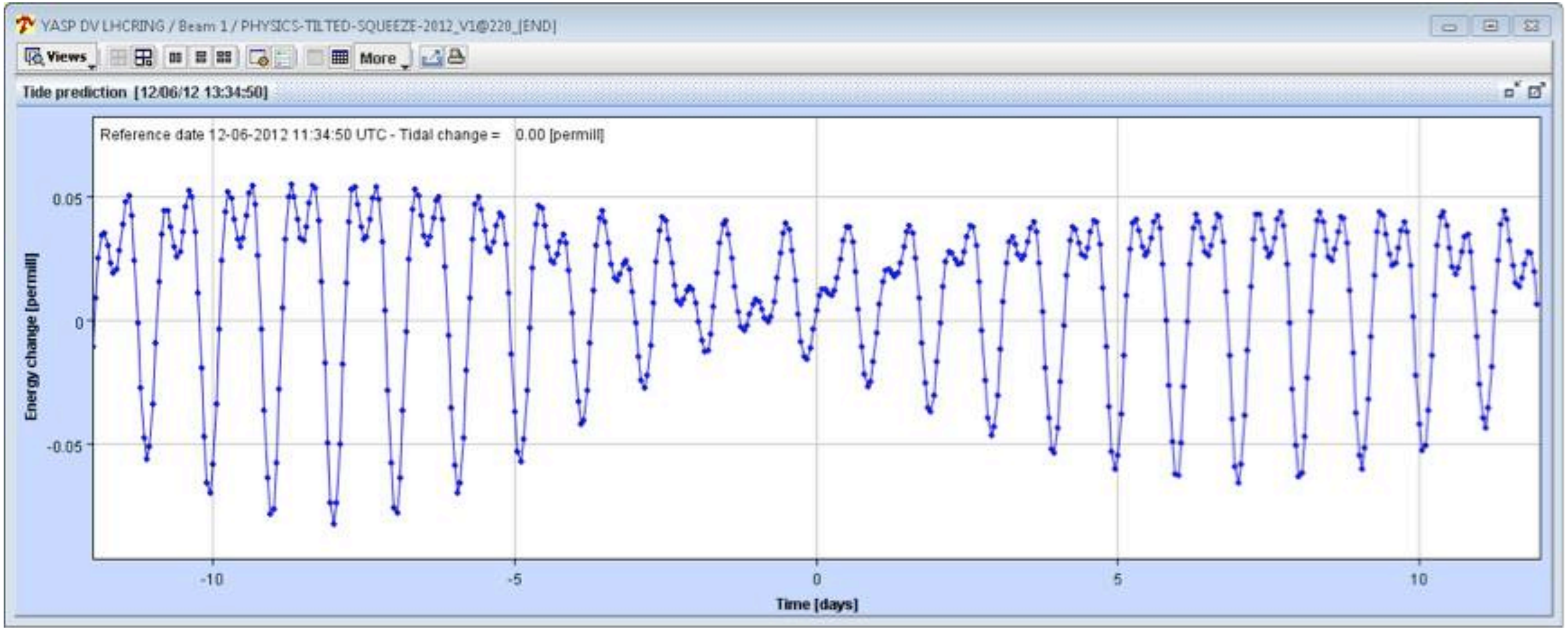


Relative beam sizes around IP1 (Atlas) in collision

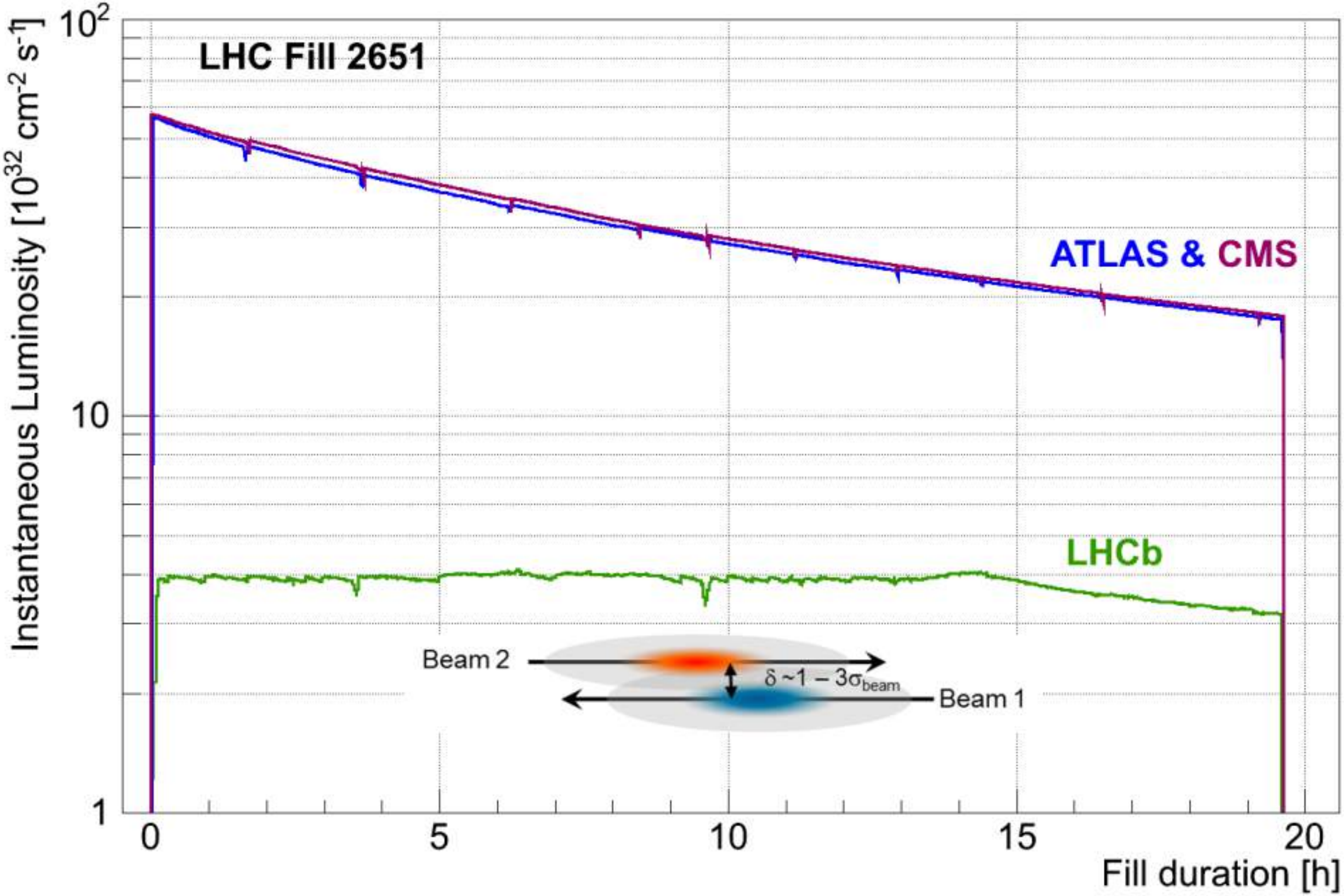


LHC: Moon correction

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

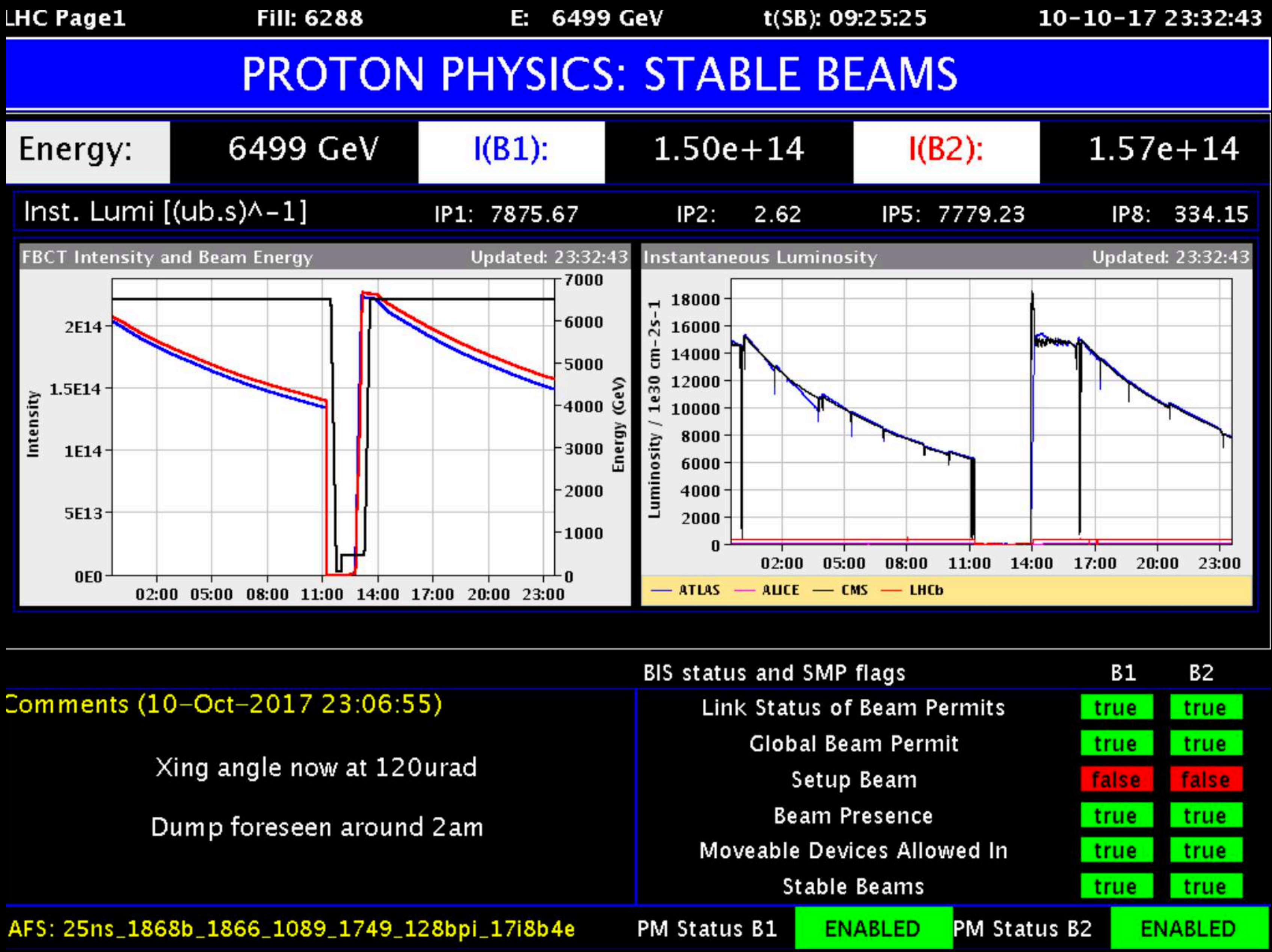


20 days

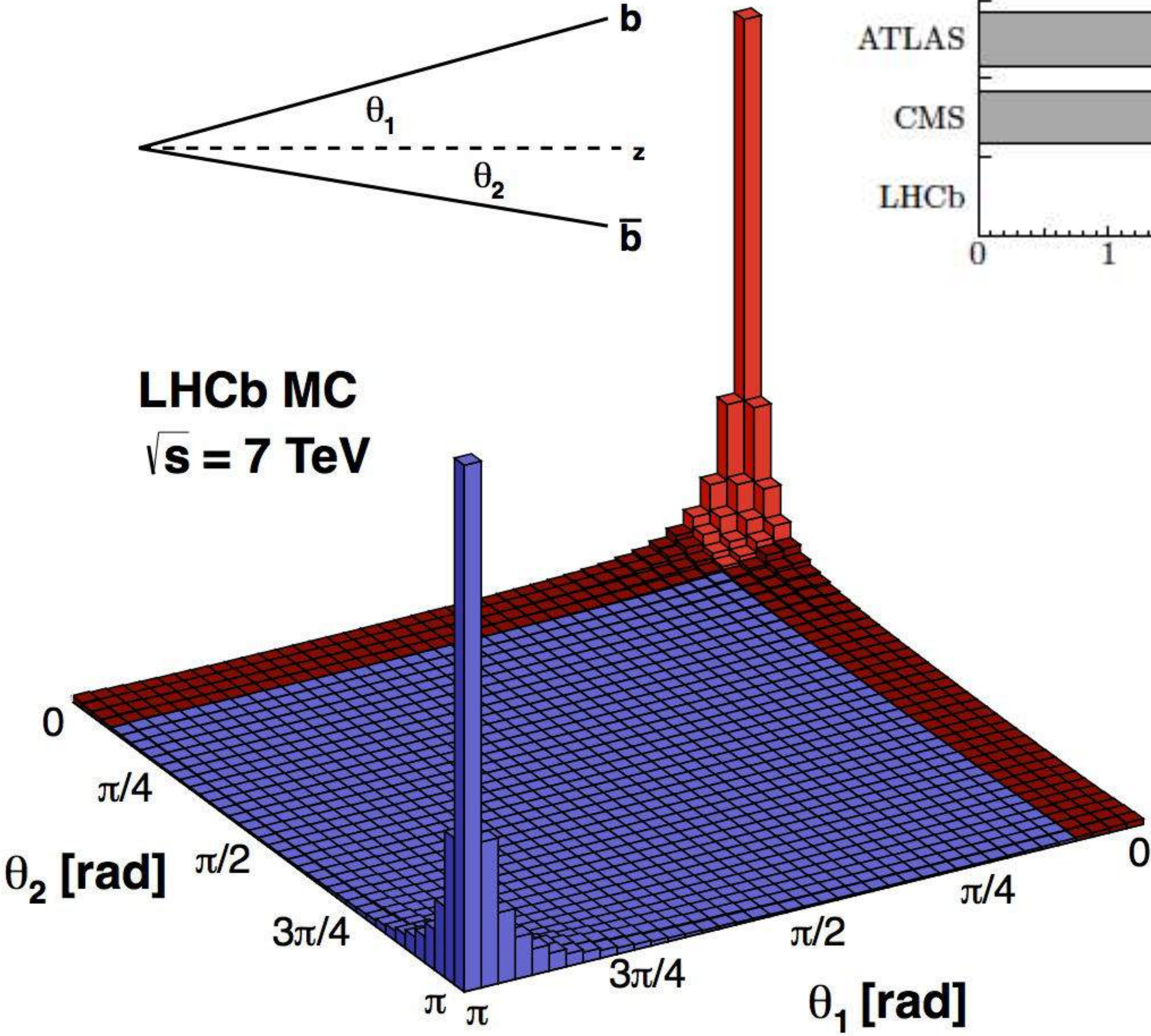


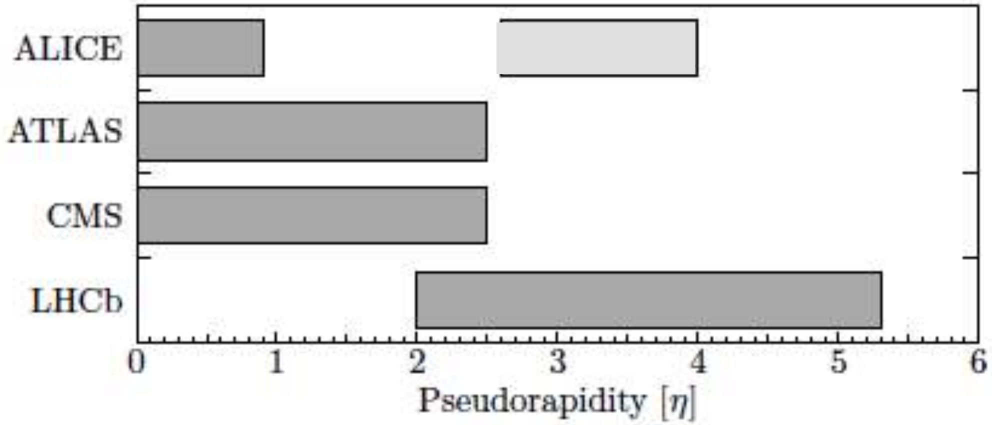
LHC Fill 2651
Instantaneous Luminosity [10^{32} cm^{-2} s^{-1}]
10^2
10
1
0
5
10
15
20
Fill duration [h]
ATLAS & CMS
LHCb
Beam 2
Beam 1
$\delta \sim 1 - 3\sigma_{beam}$

Luminosity leveling

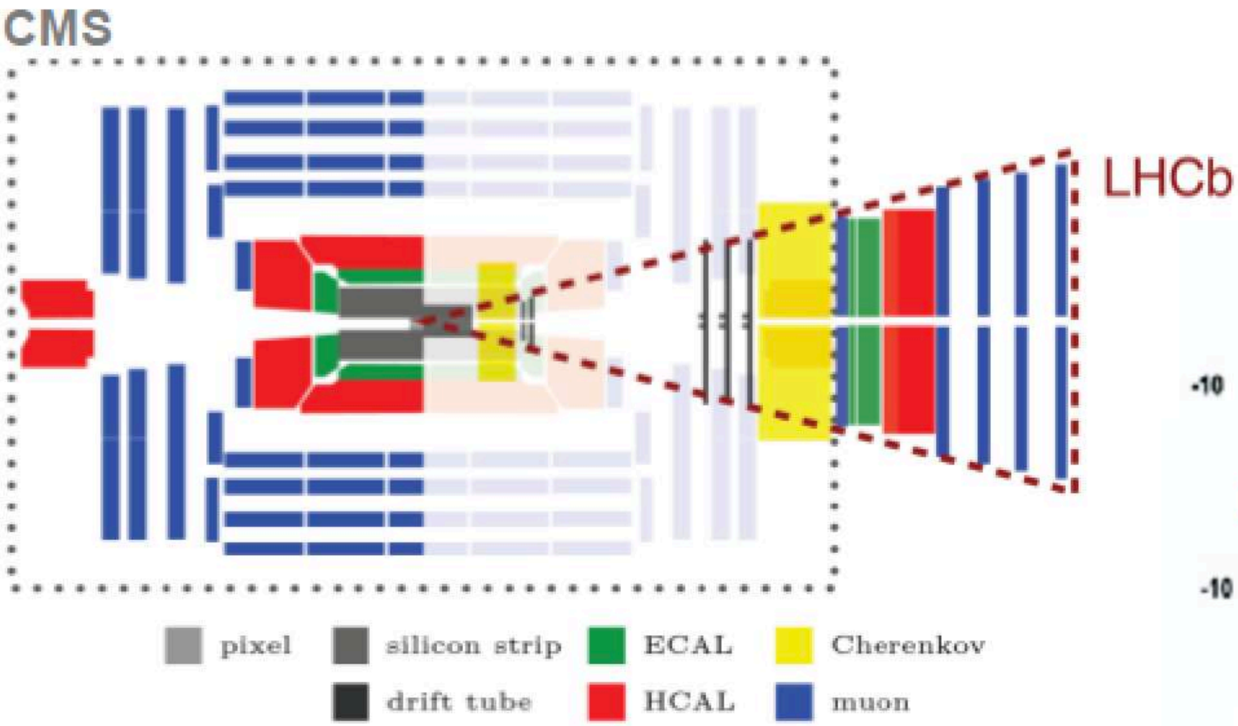


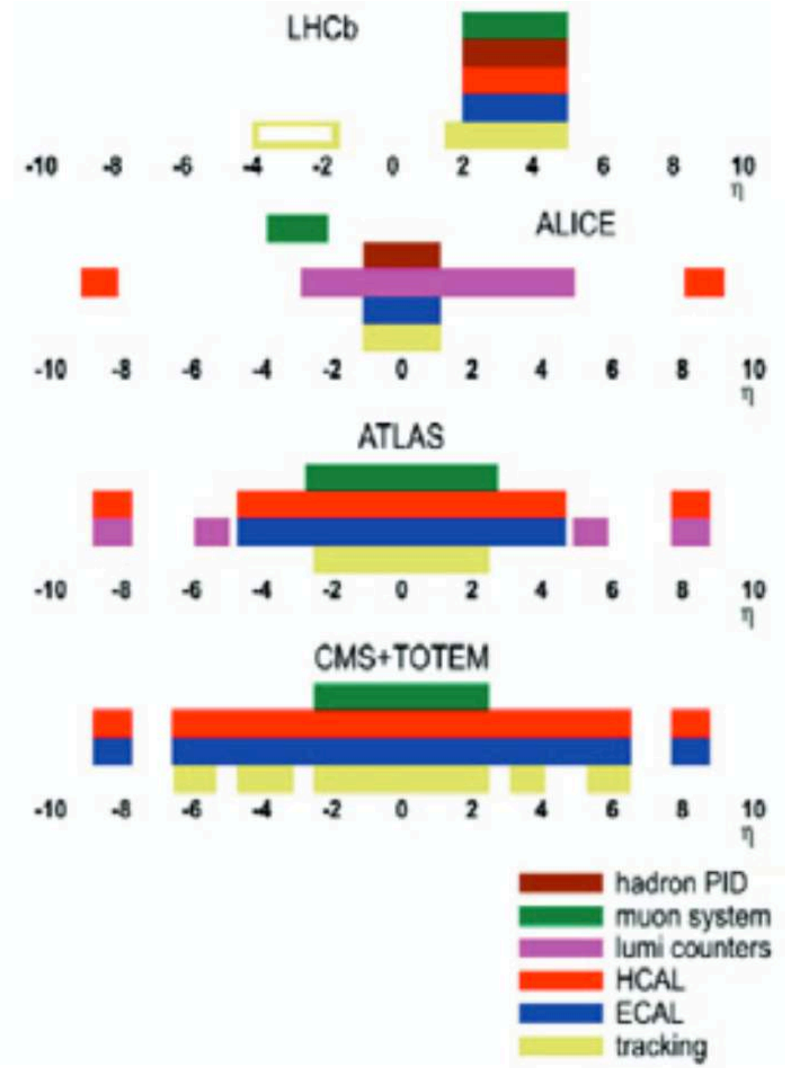
LHCb

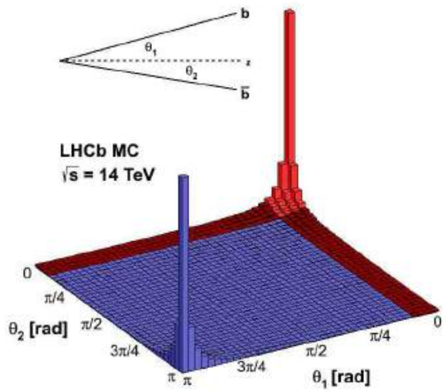

b
θ1
z
θ2
b̄
LHCb MC
√s = 7 TeV
0
π/4
θ2 [rad]
π/2
3π/4
π
π
3π/4
π/2
π/4
0
θ1 [rad]


ALICE
ATLAS
CMS
LHCb
0
1
2
3
4
5
6
Pseudorapidity [η]

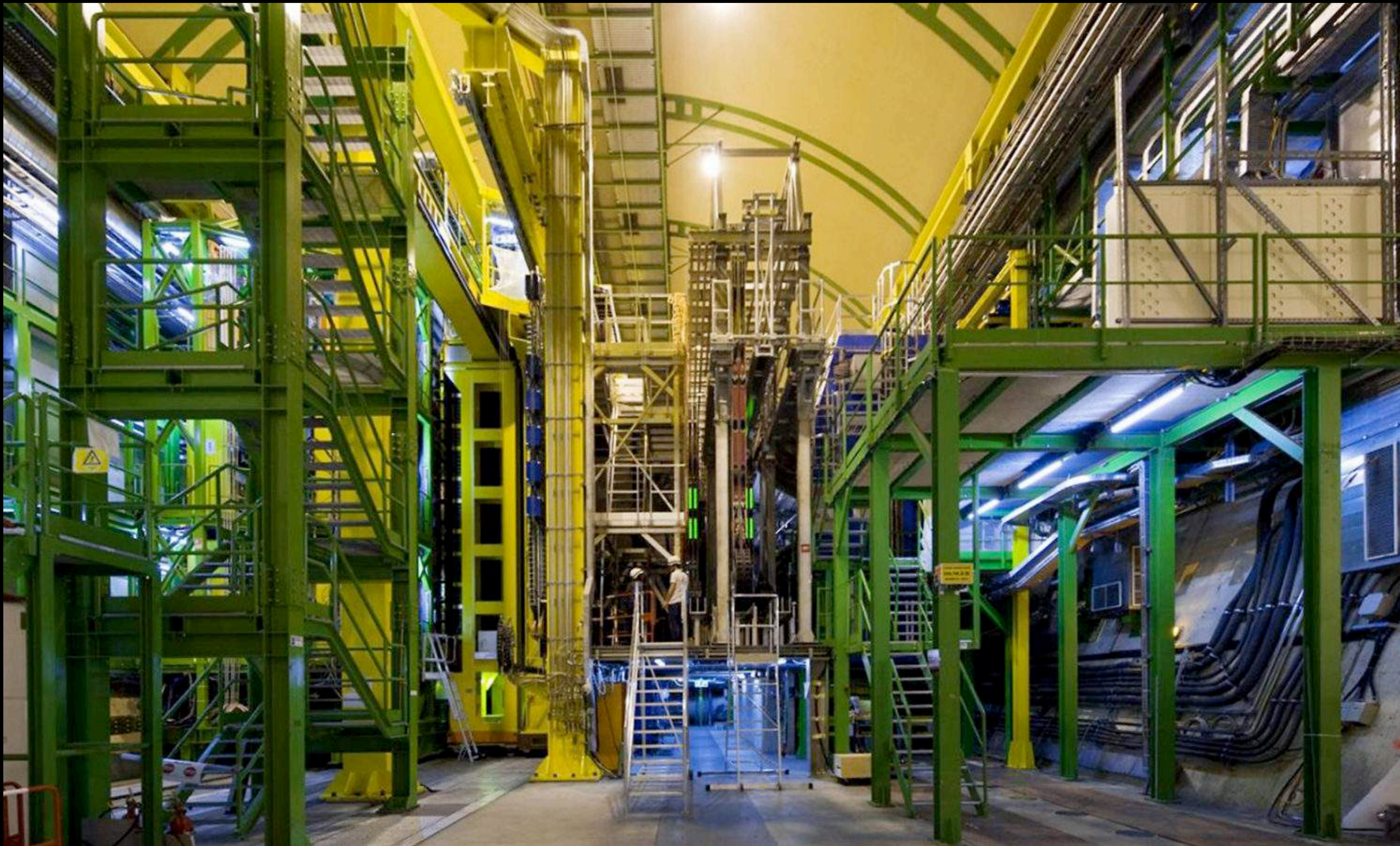
LHCb

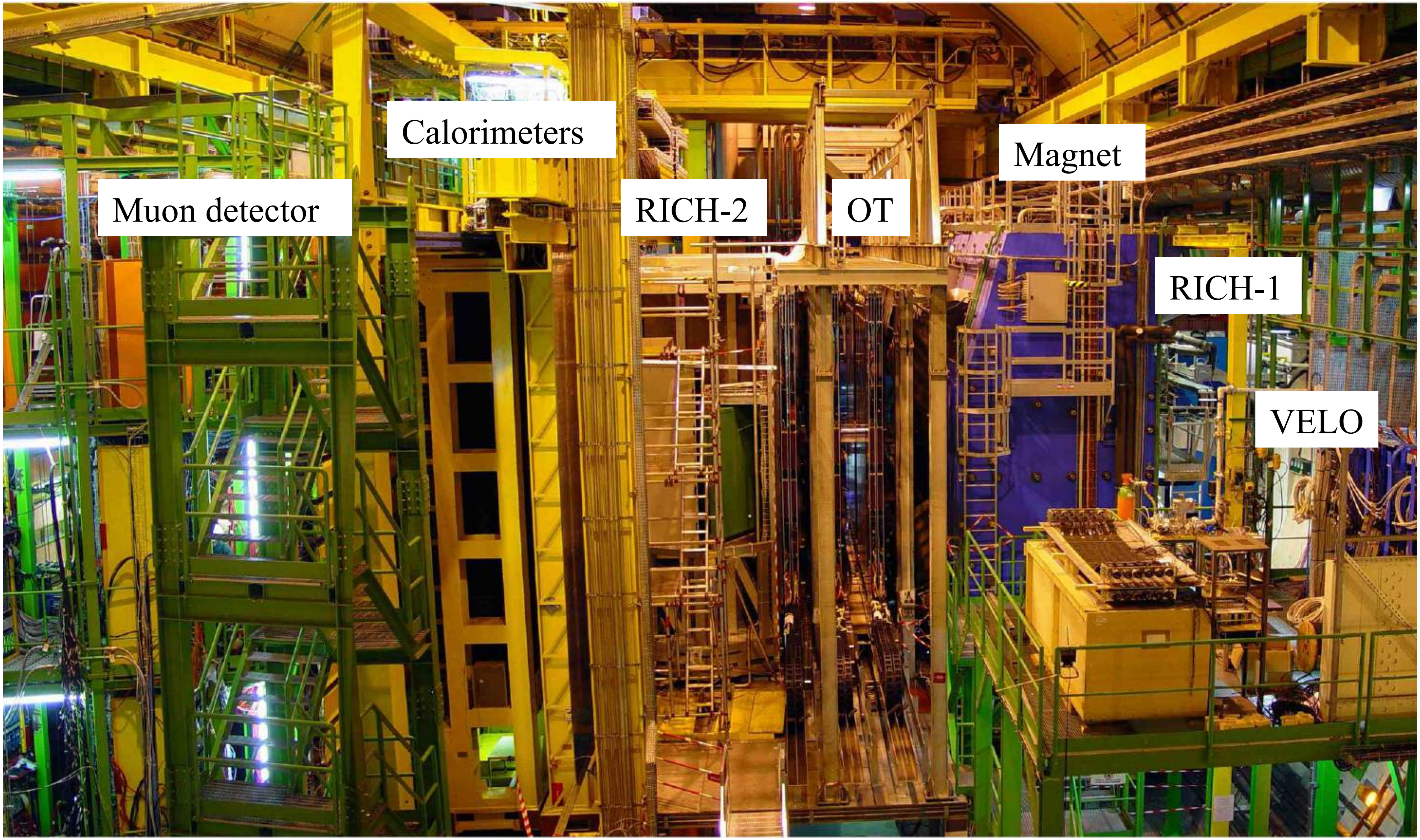

CMS
LHCb
pixel
silicon strip
ECAL
Cherenkov
drift tube
HCAL
muon


LHCb
ALICE
ATLAS
CMS+TOTEM
hadron PID
muon system
lumi counters
HCAL
ECAL
tracking

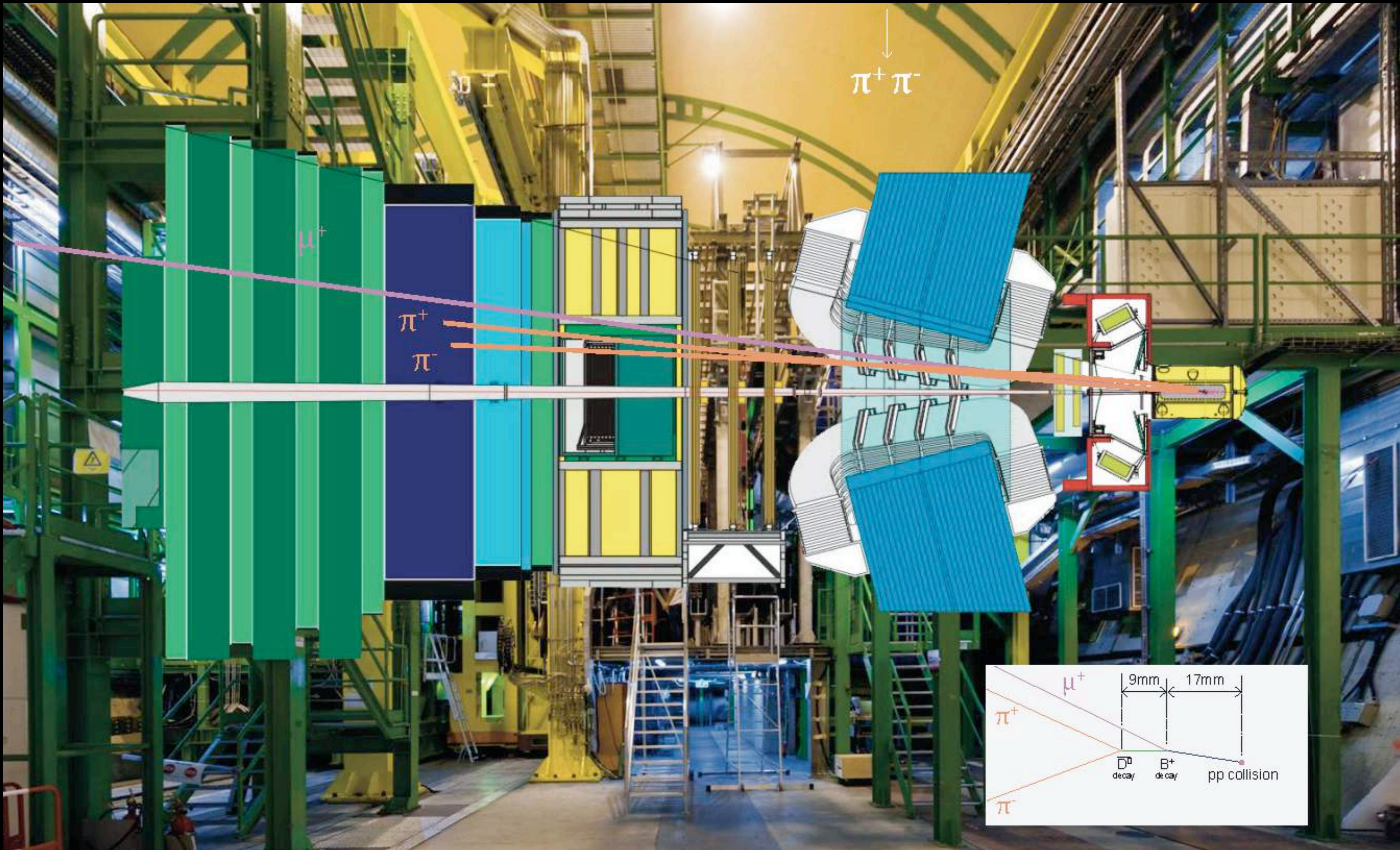

LHCb MC
√s = 14 TeV
θ2 [rad]
θ1 [rad]

LHC

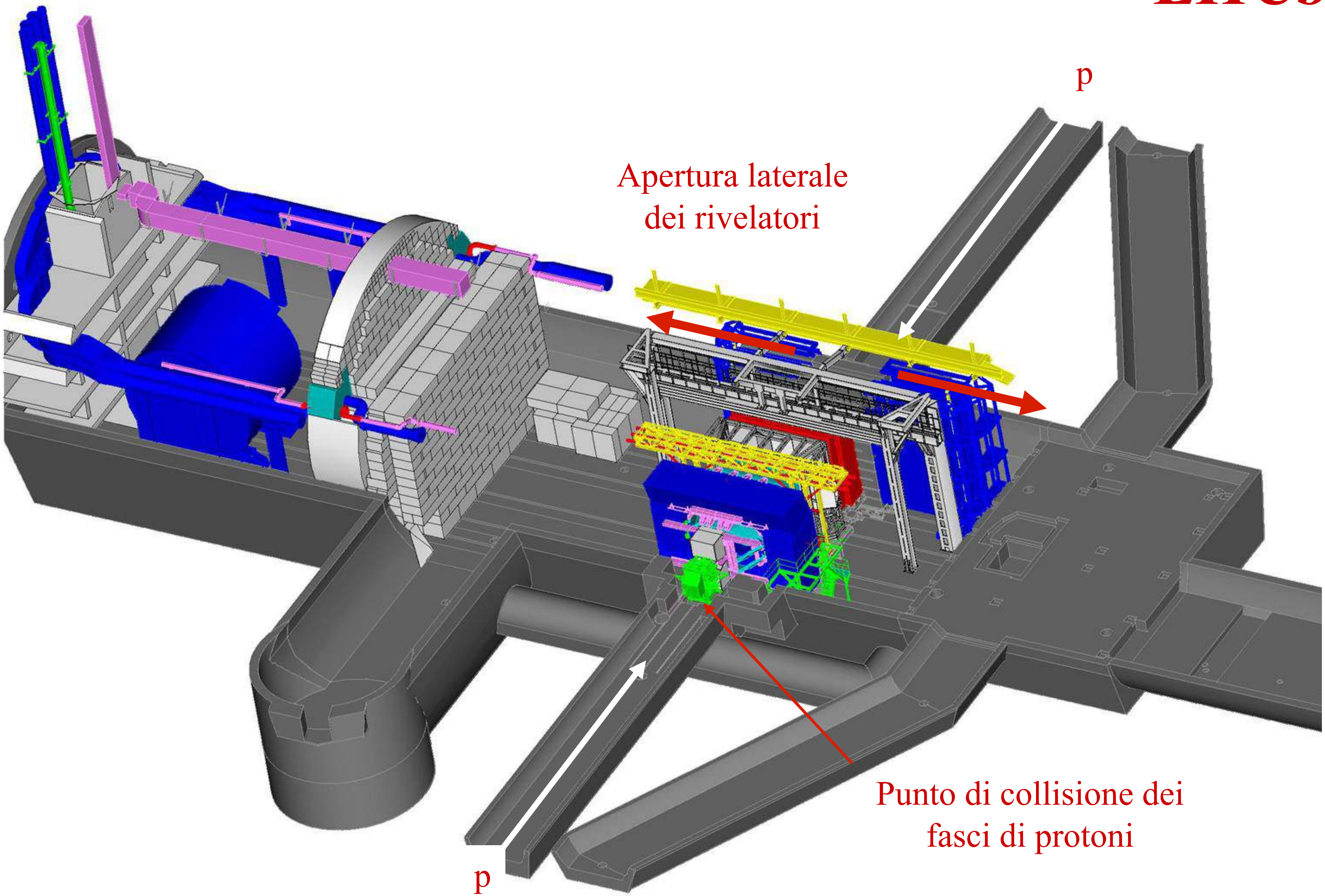



Calorimeters
Magnet
Muon detector
RICH-2
OT
RICH-1
VELO

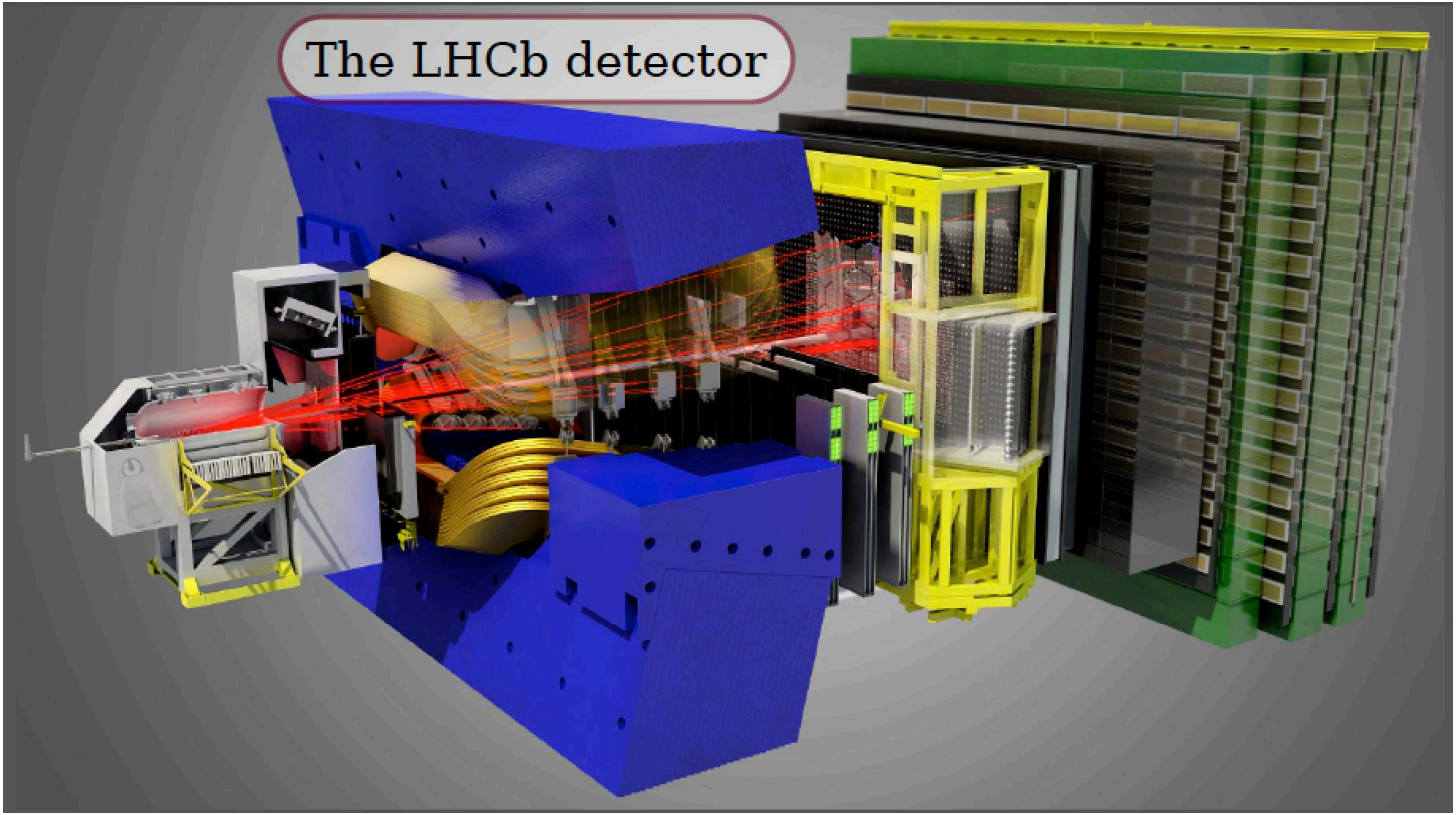
LHC



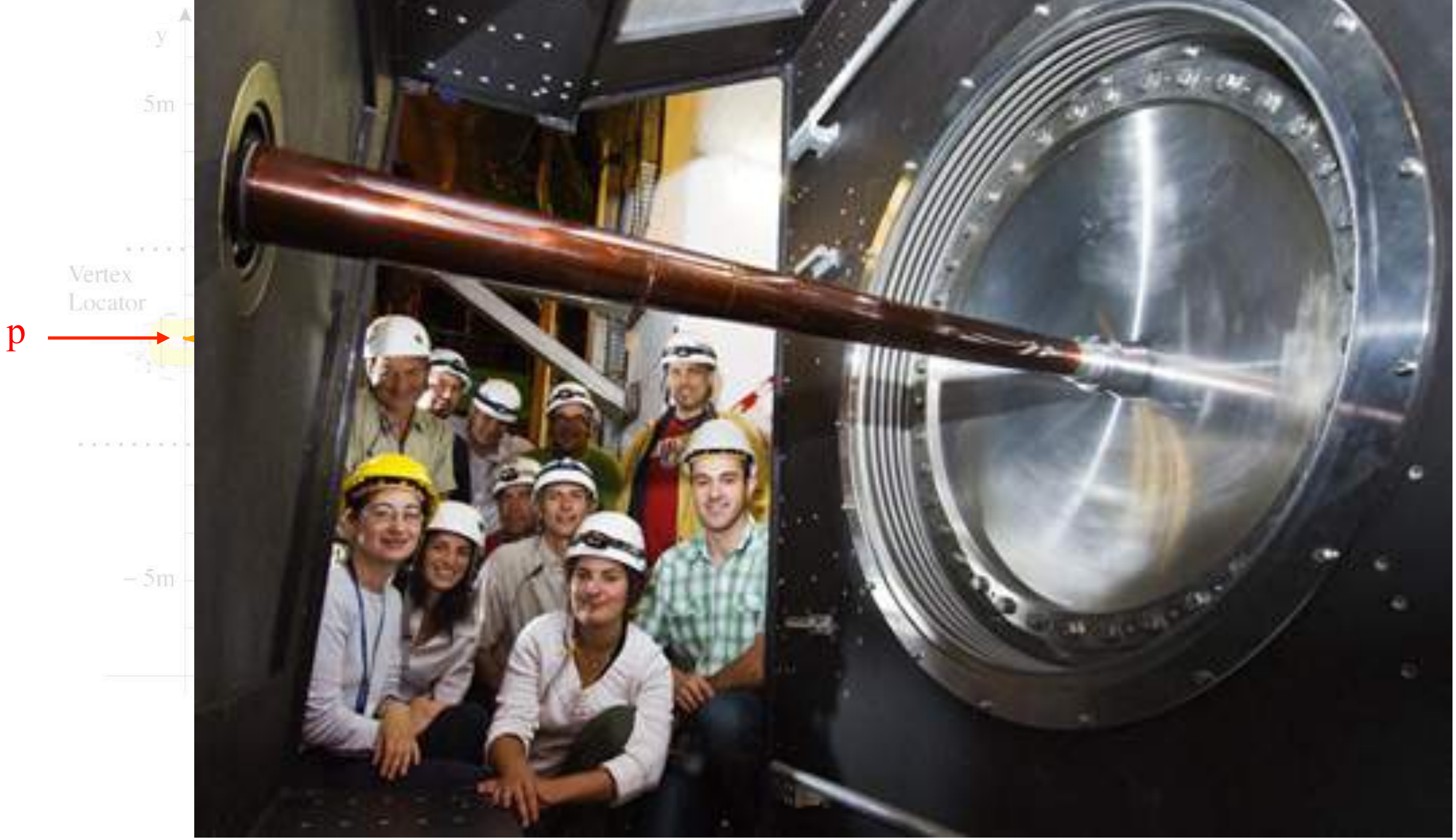
LHCb


p
Apertura laterale
dei rivelatori
Punto di collisione dei
fasci di protoni
p

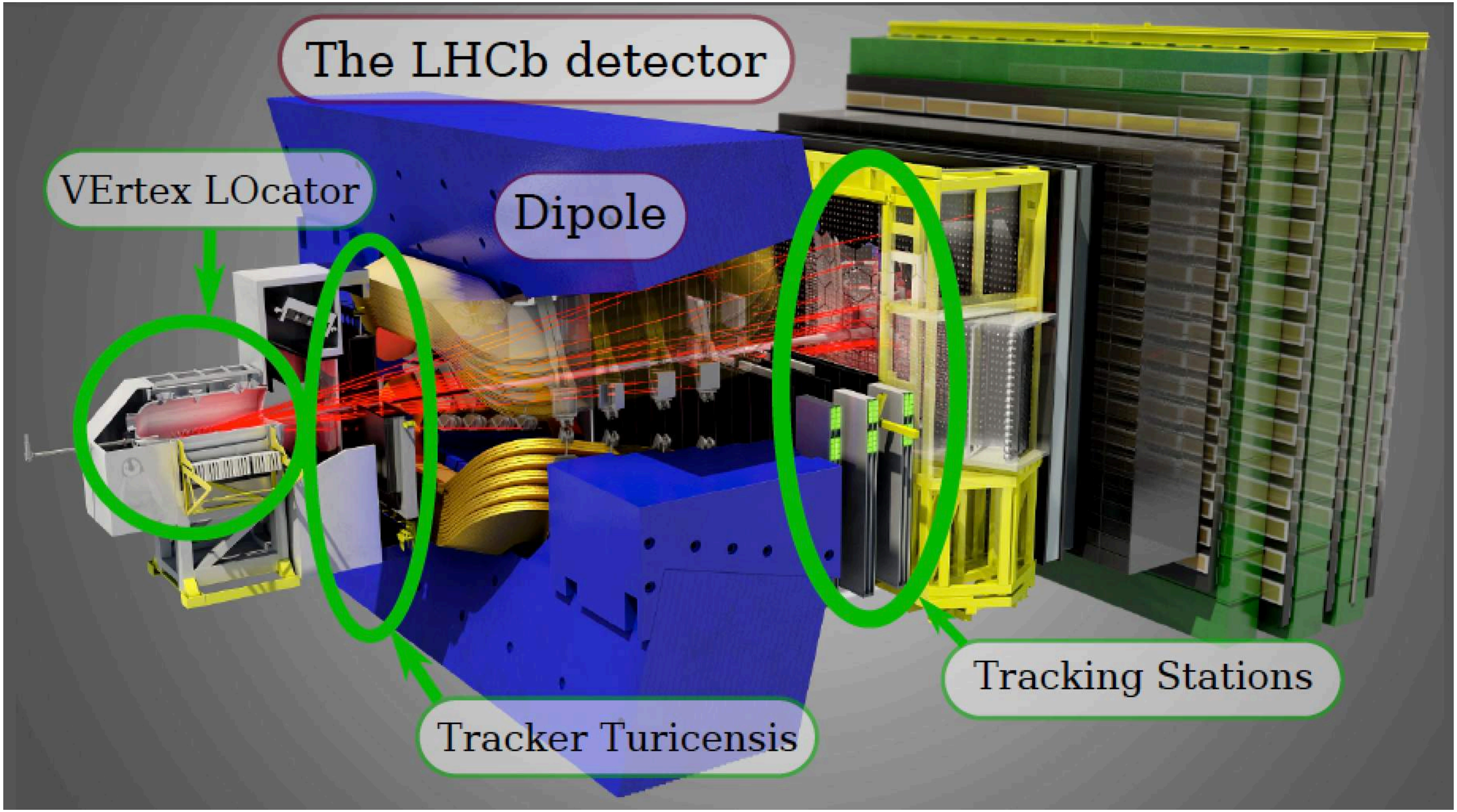
LHCb detector



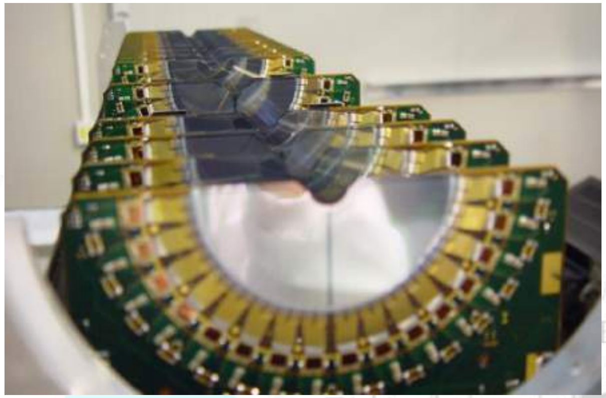
Punto di collisione e beam pipe

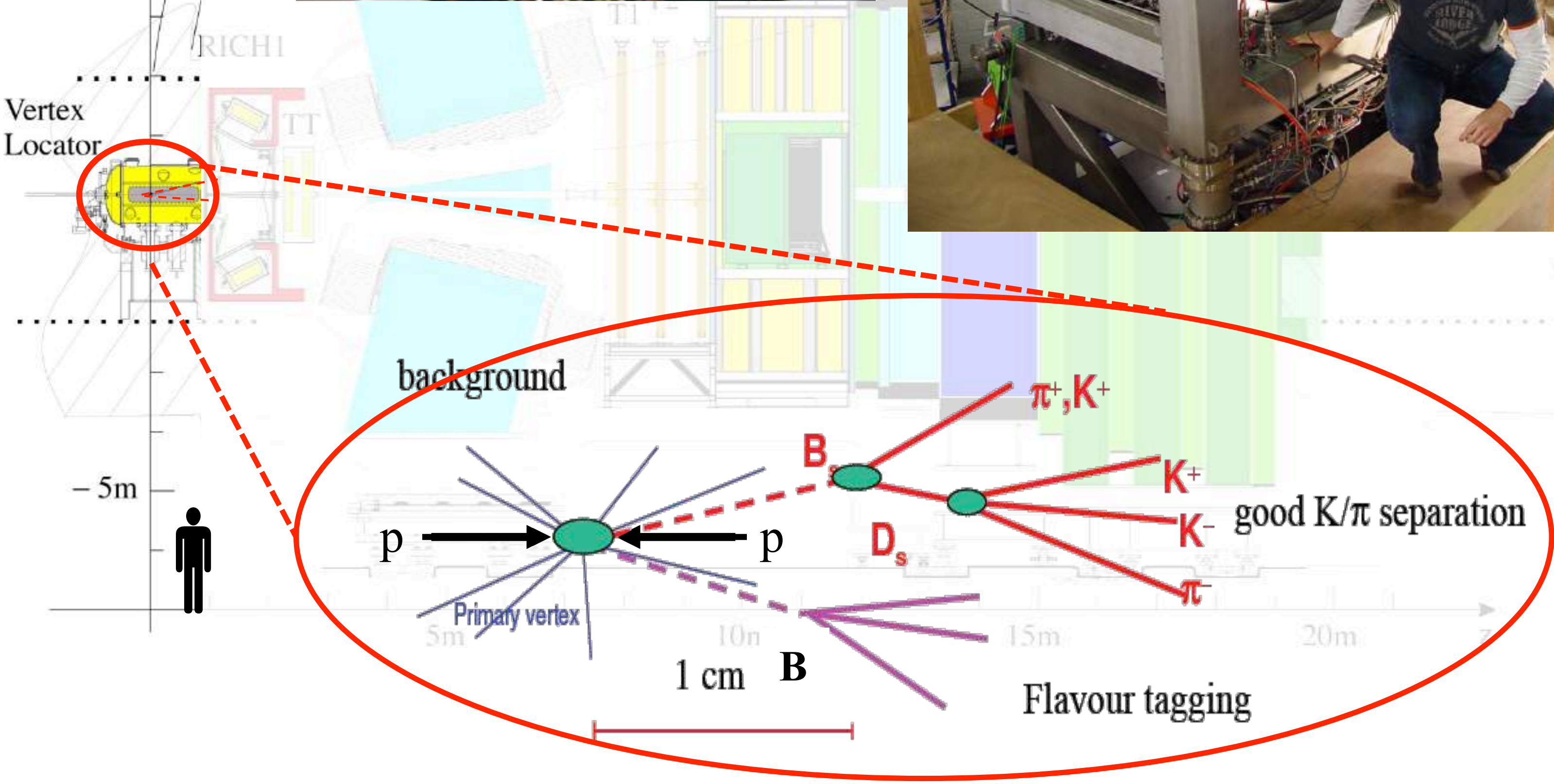


LHCb detector: tracking system



VELO



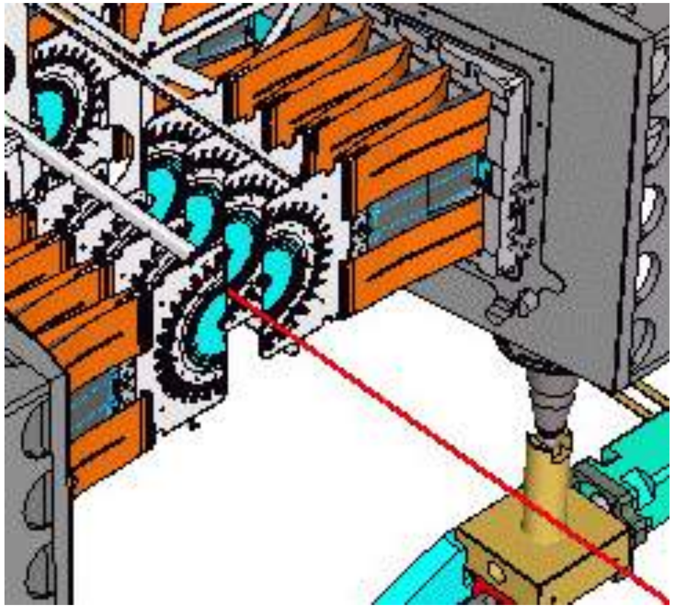

y
5m
RICH1
TT
Vertex Locator
– 5m
5m
10m
15m
20m
background
p
p
Primary vertex
B_s
D_s
π+,K+
K+
K-
π-
good K/π separation
1 cm
B
Flavour tagging

VELO

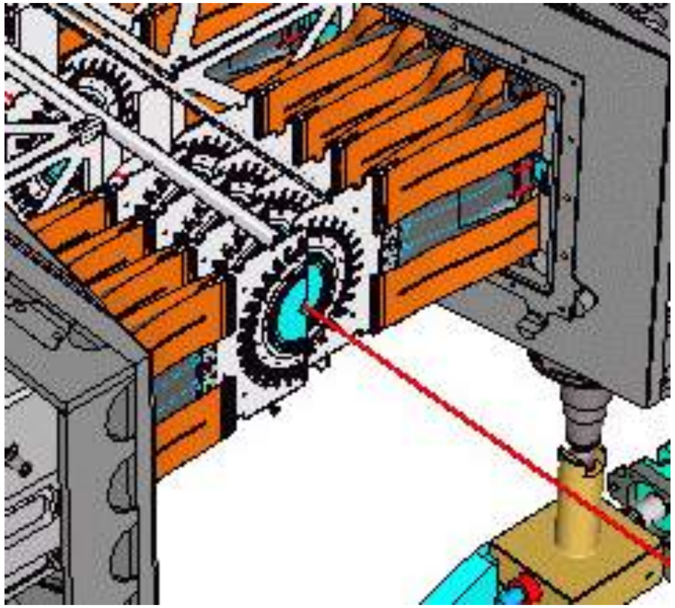
Silicon detector: 42 modules arranged along the beam, each providing a measurement of the r and ϕ coordinates.

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

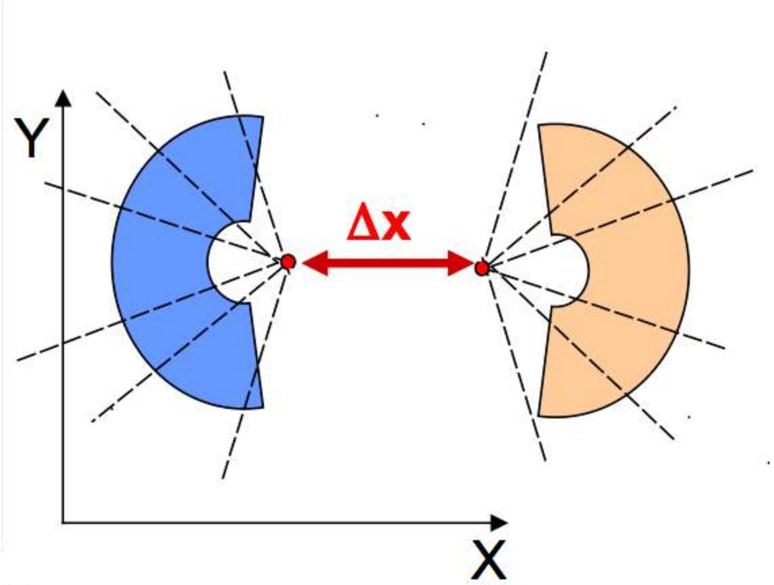
Detector safety: **modules retracted by 29 mm during injection**; 210 s to close; ~750 closing procedures in Run1



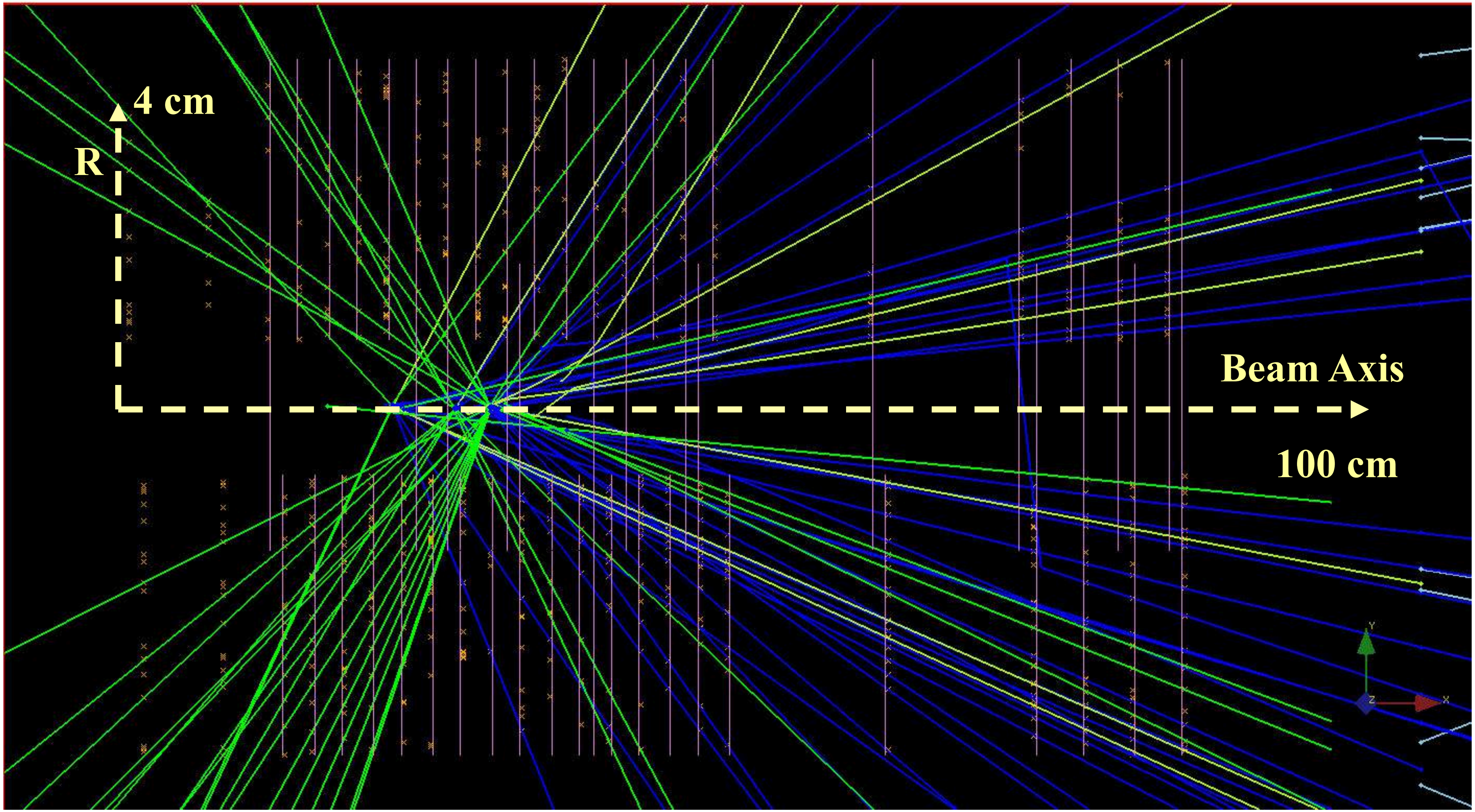
Opened at injection



Closed when stable beam declared



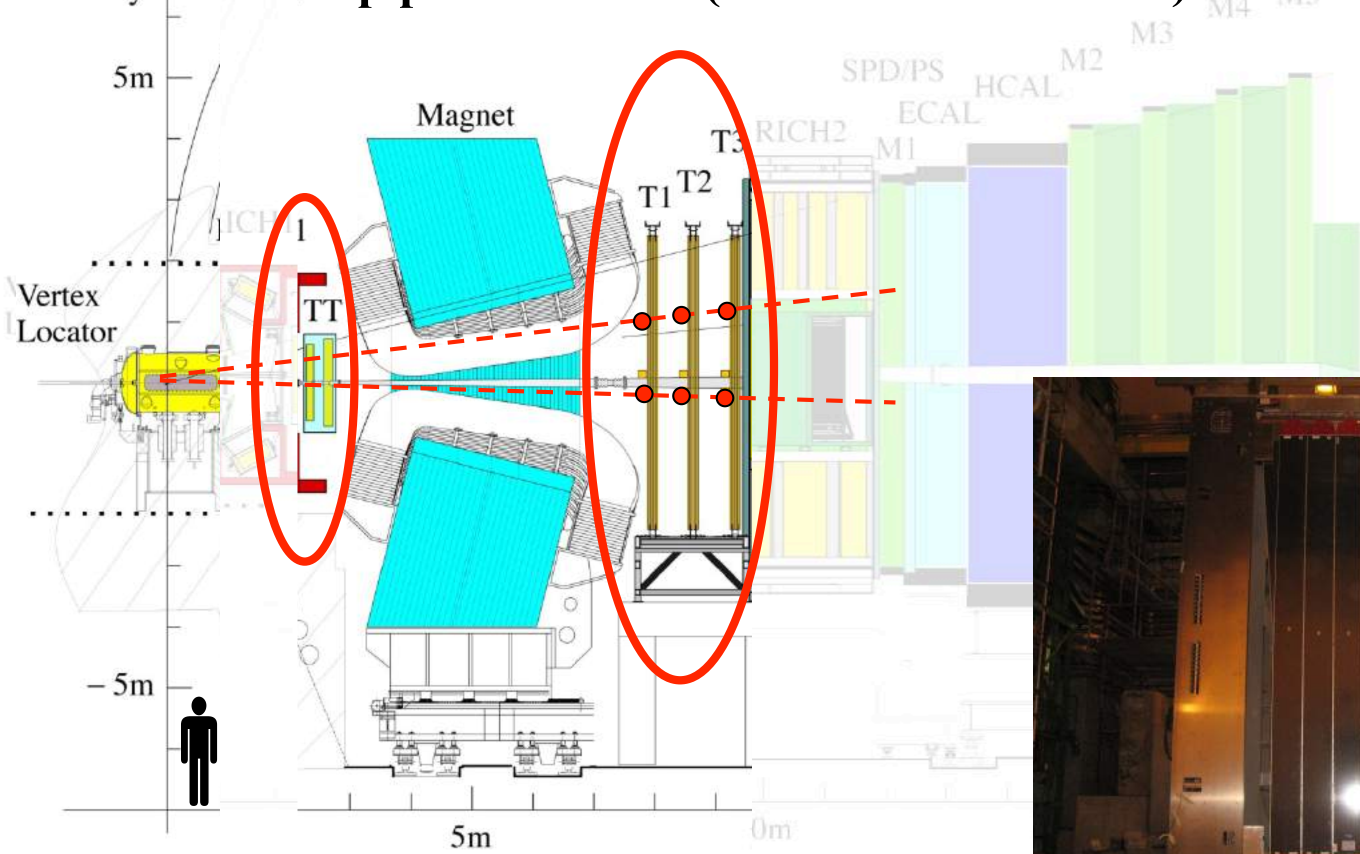
VELO rz view

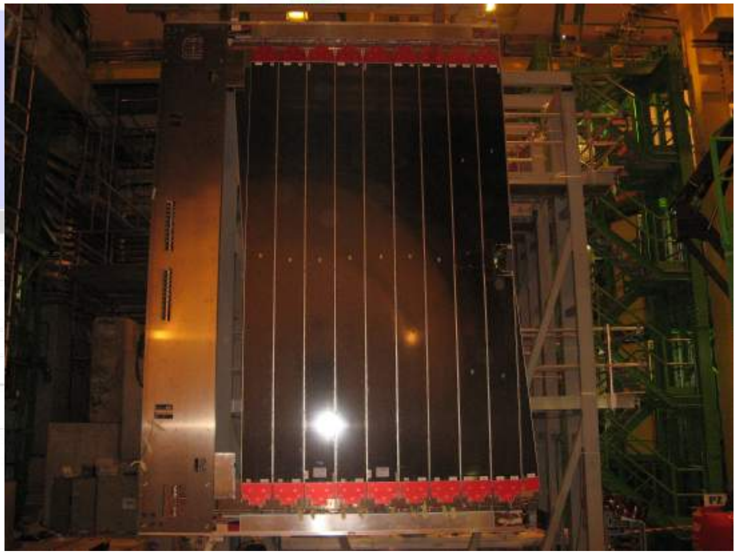


[Performance of the LHCb Outer Tracker JINST 9 (2014) P01002]
[Measurement of the track reconstruction efficiency at LHCb JINST 10 (2015) P02007]

Tracking system

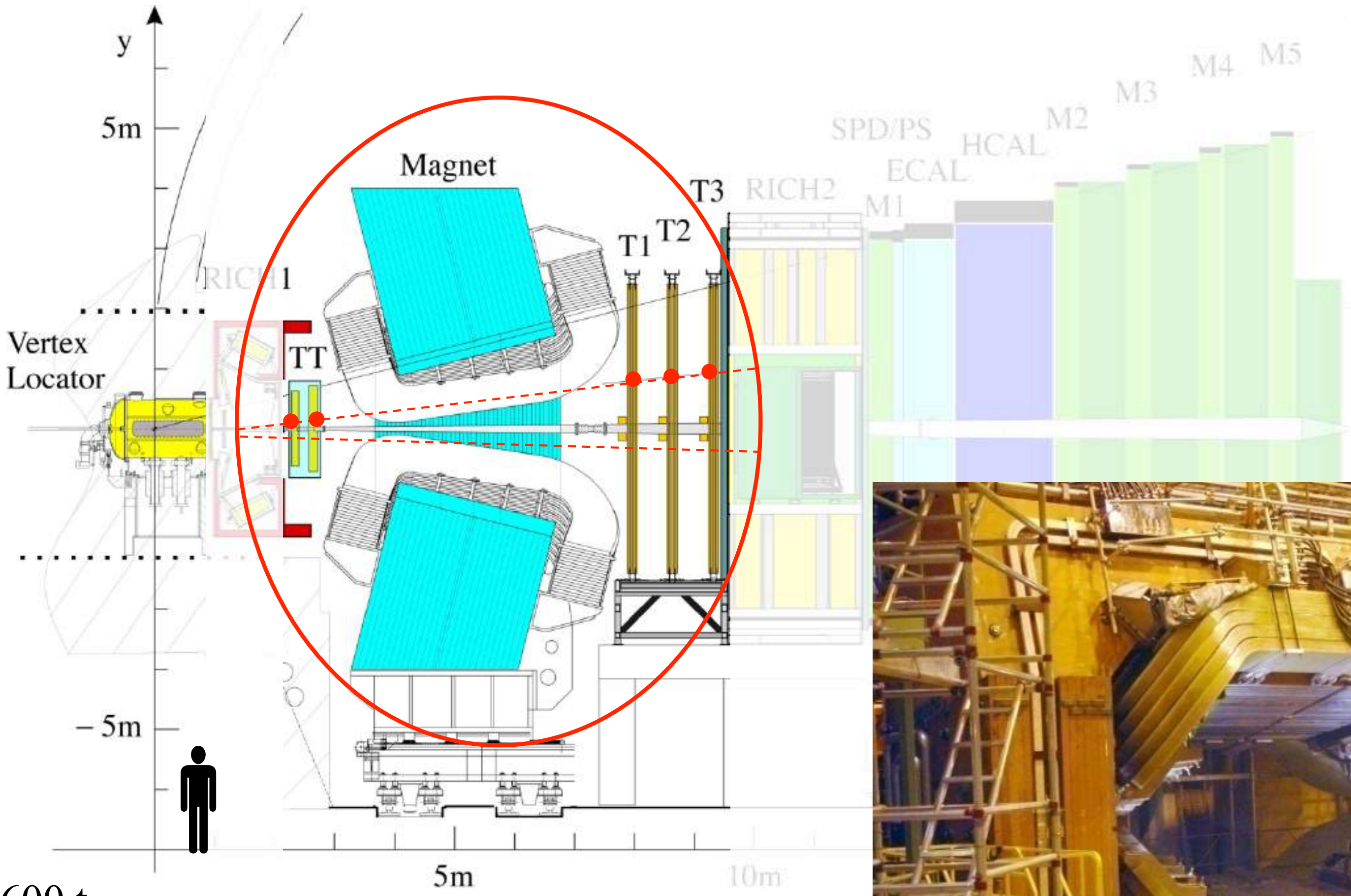
Tracker Turicensis (before the magnet): 4 plans of silicon μ-strip, 8 m^2.
Tracker (after the magnet)
Inner (close to beam pipe): 3 stations, 4 plans of silicon μ-strip, 4.2 m^2.
Outer: 3 stations, 4 plans of straw tubes
Momentum resolution Δp/p = 0.5%–1% (~0 GeV/c –200 GeV/c)





Magnet

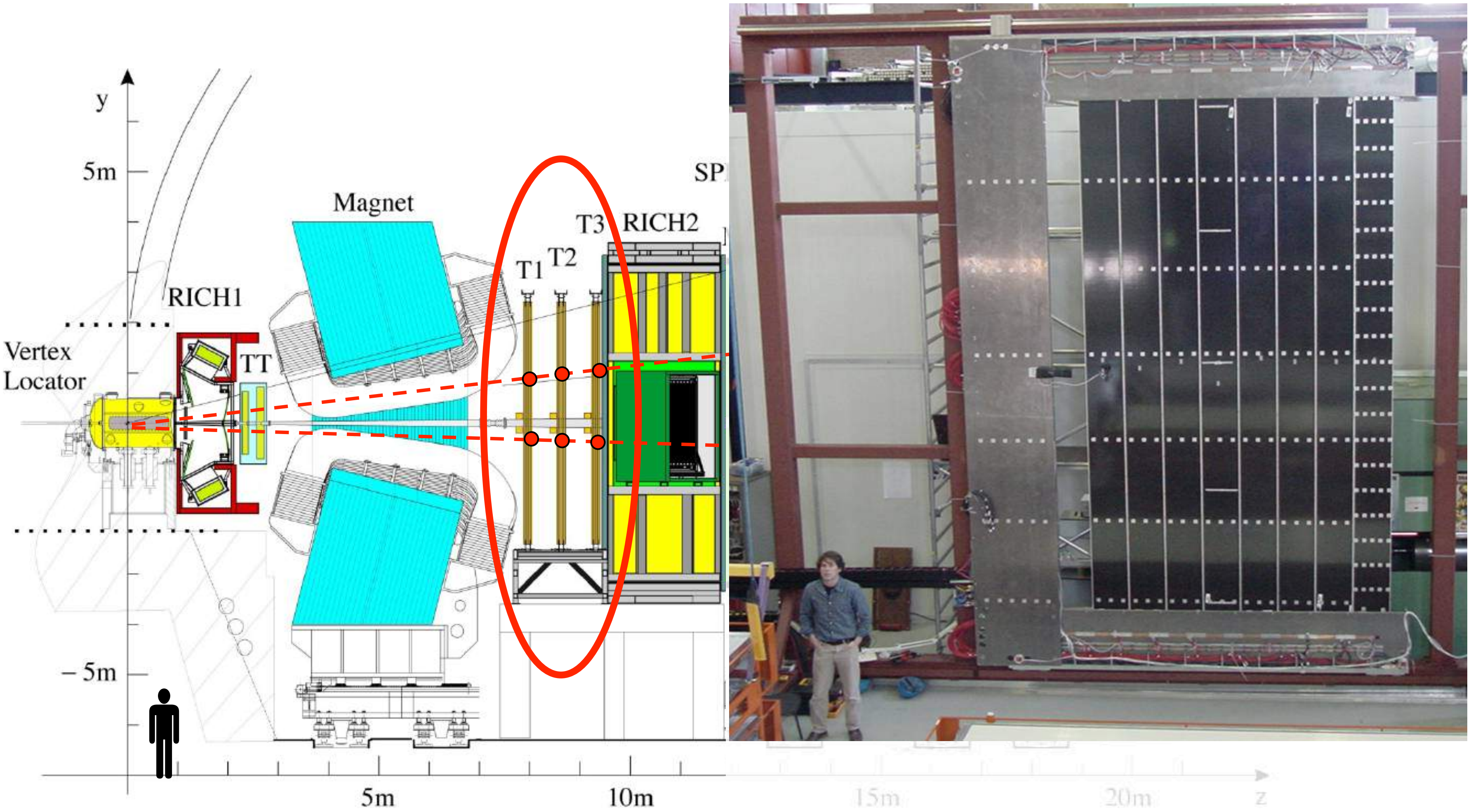
Warm **dipole** magnet, bending power: 4 Tm
- Two triplets of magnets to compensate for its effect in LHC.



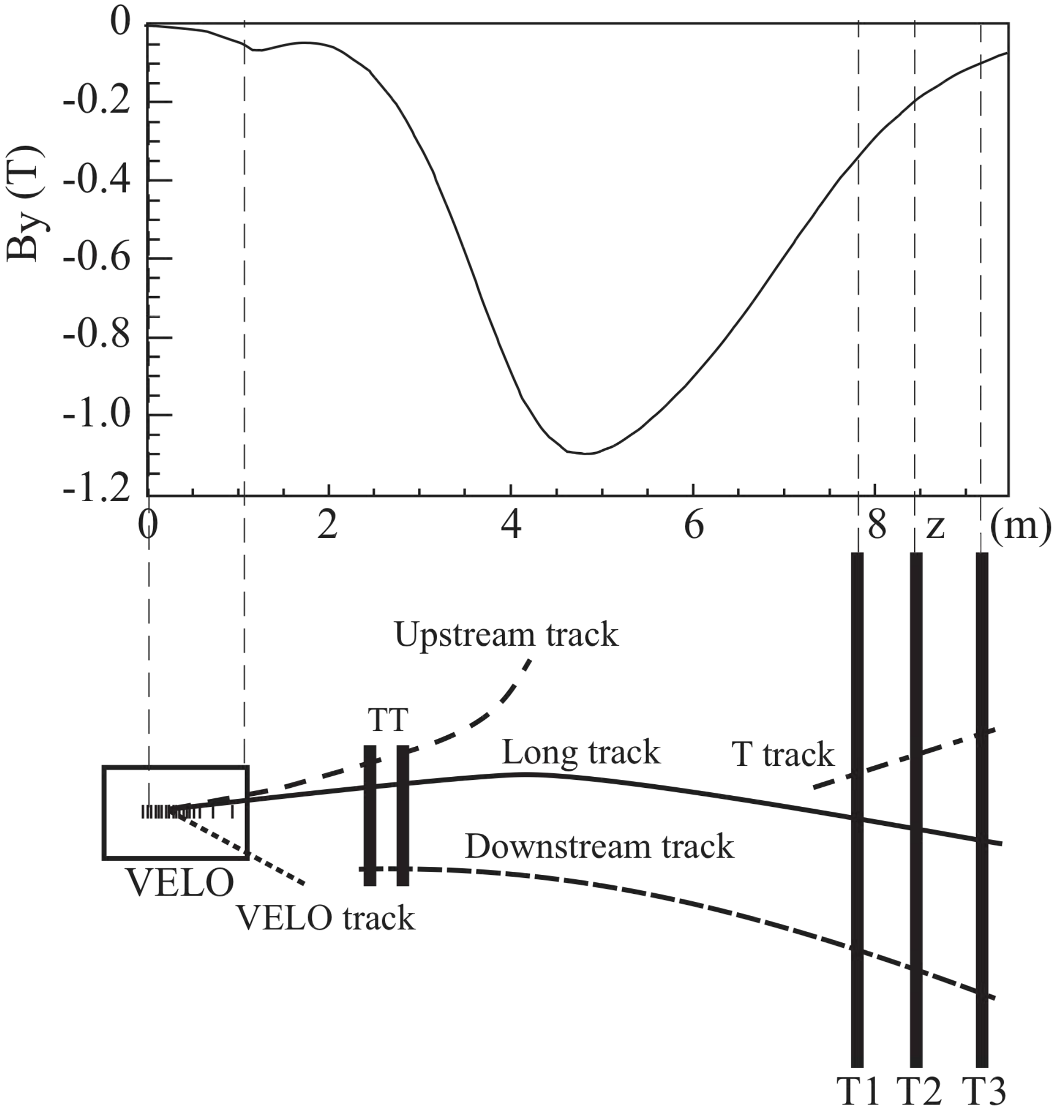
Peso = 1600 t
Potenza = 4200 kW

Acqua di raffreddamento = 150.000 l/h

OT: Outer Tracker

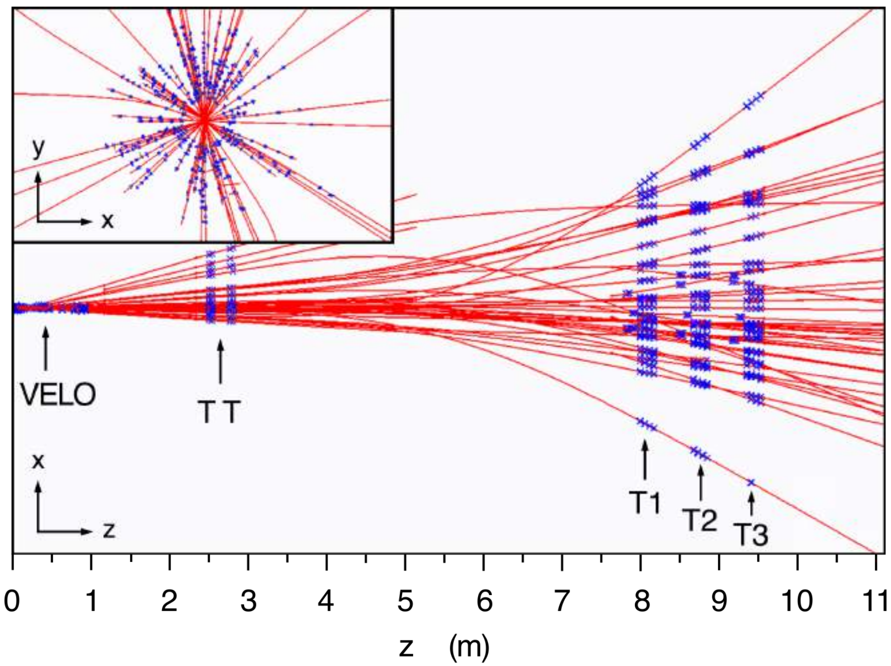


Track reconstruction

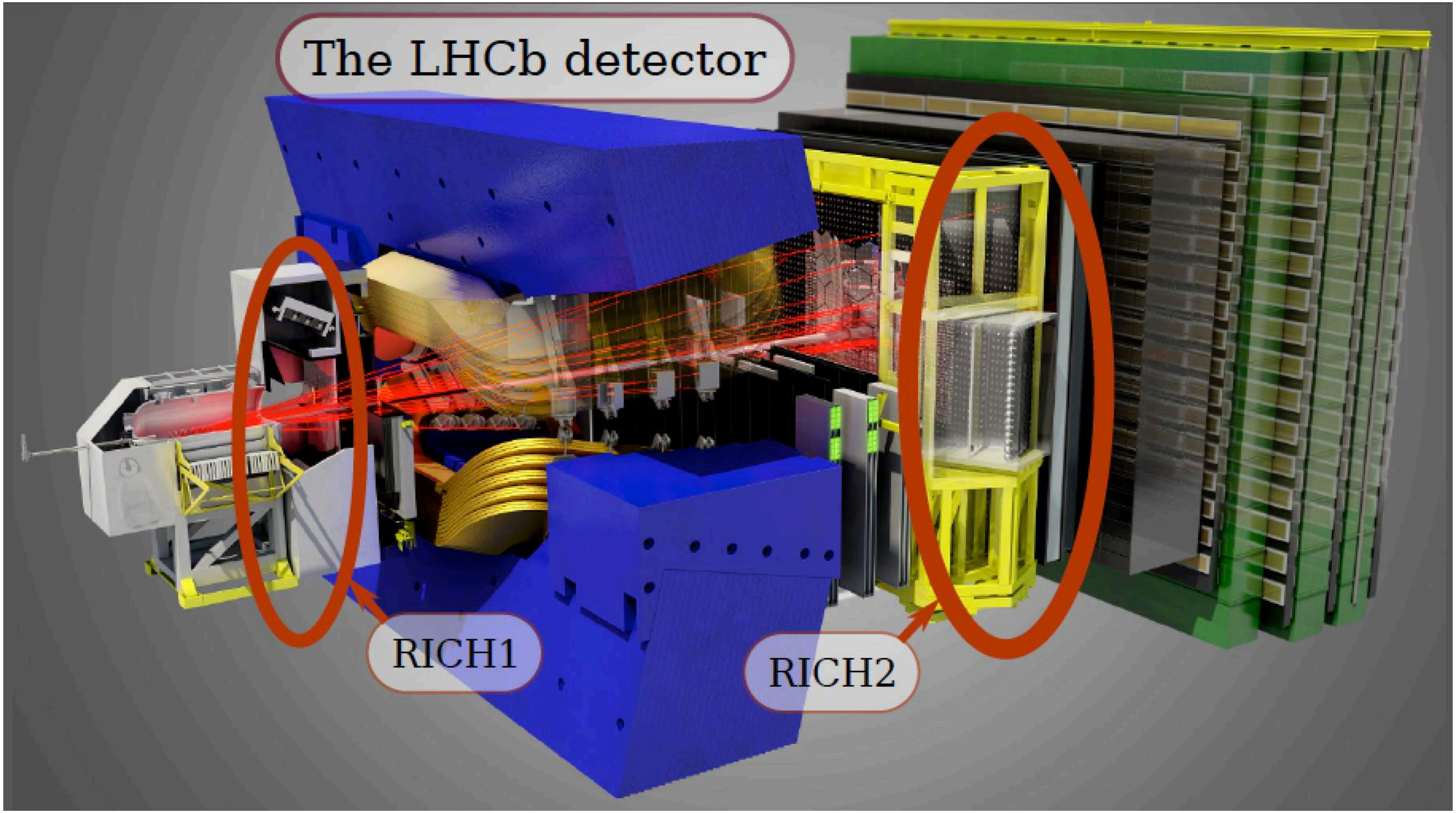


Dipole magnet implies an intrinsic charge asymmetry (left-right differences in the detector).

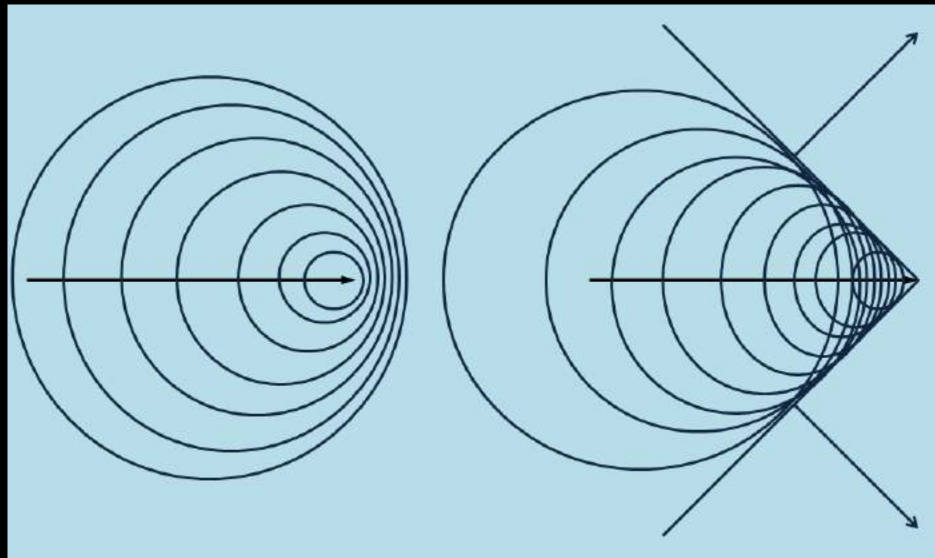
Direction of magnetic field changed regularly and data sets combined.



LHCb detector: RICHs



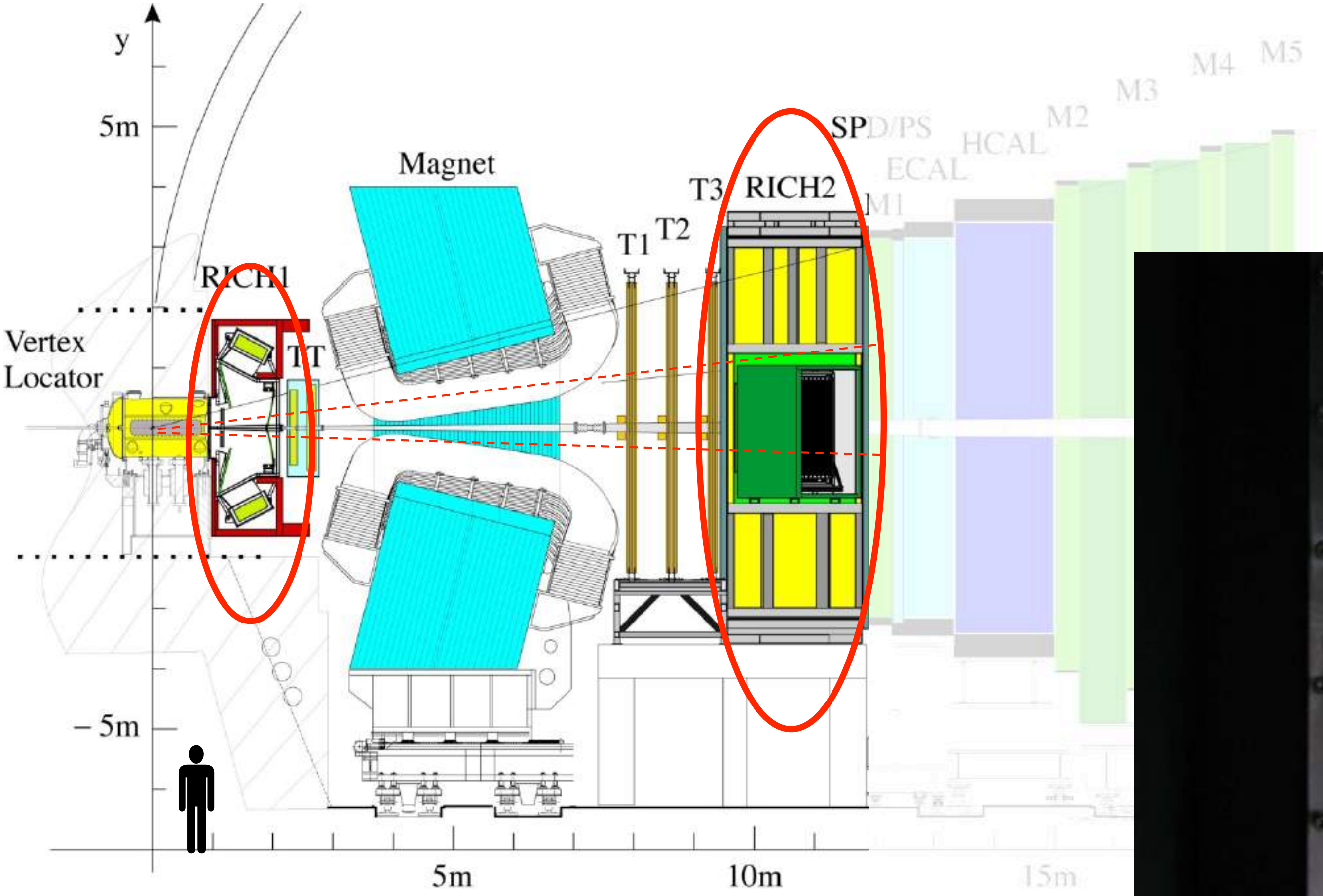
Effetto Cherenkov

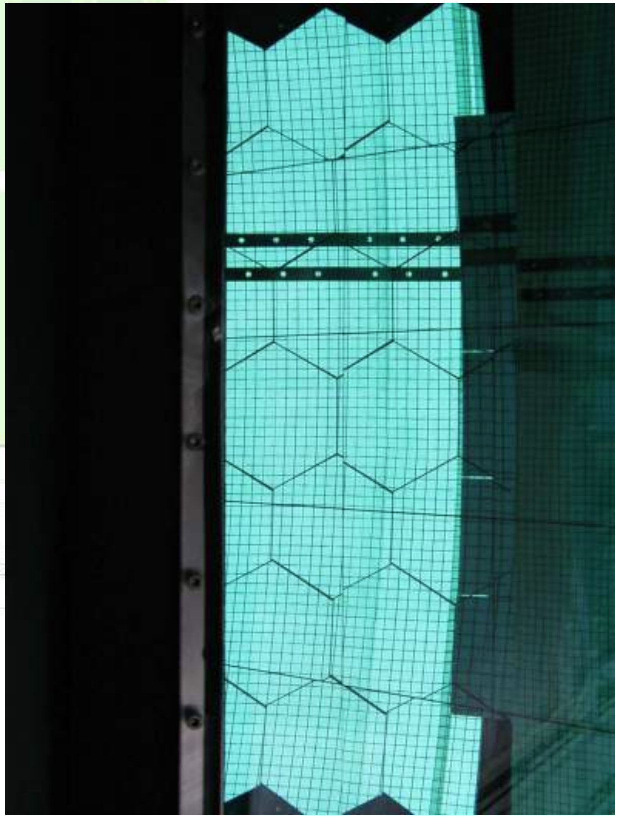


[Performance of the LHCb RICH detector Eur.Phys.J. C73 (2013) 2431]

RICH

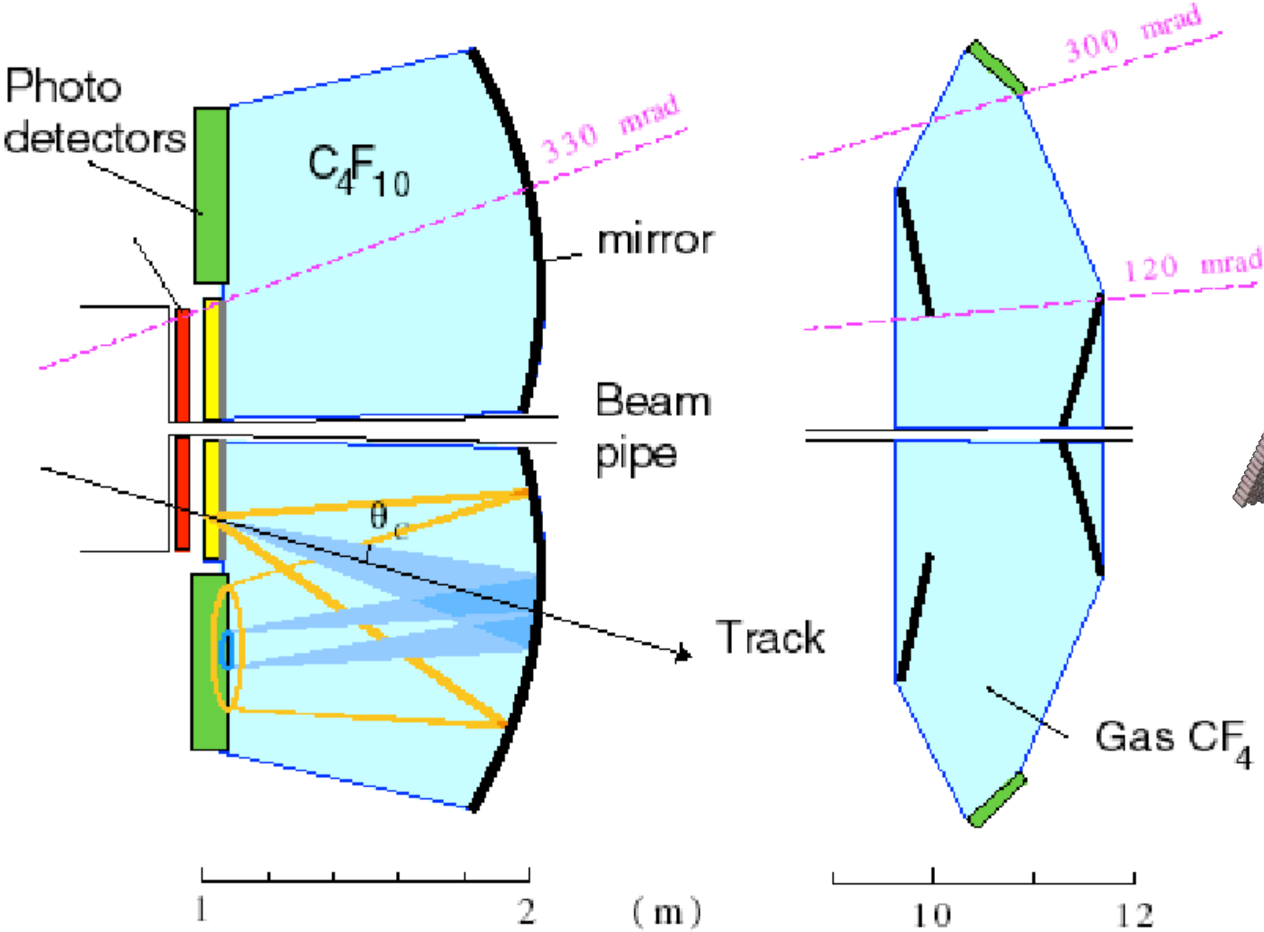
RICH1 (upstream of magnet): 2<p<40 GeV [C_4F_{10}]
RICH2 (downstream of magnet): 15<p<100 GeV [CF_{10}]
Kaon ID ~95% with pion misID ~10% integrated over 2<p<100 GeV

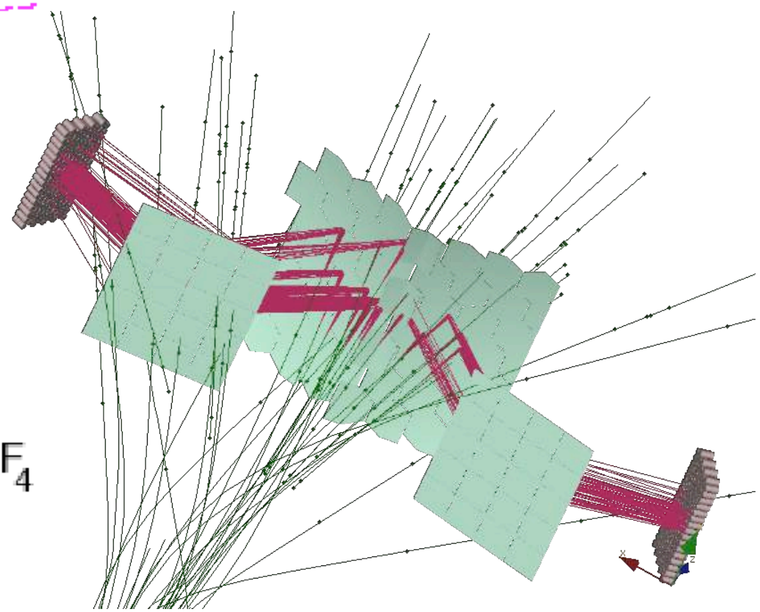


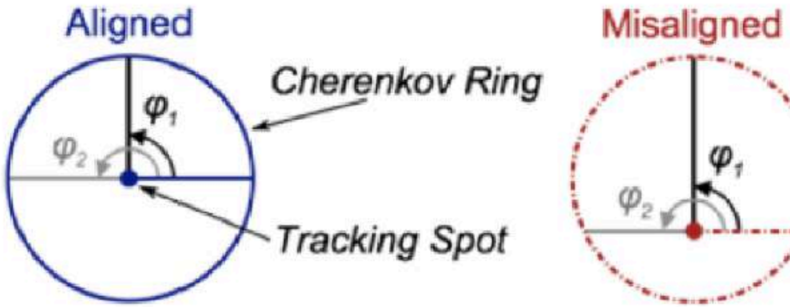


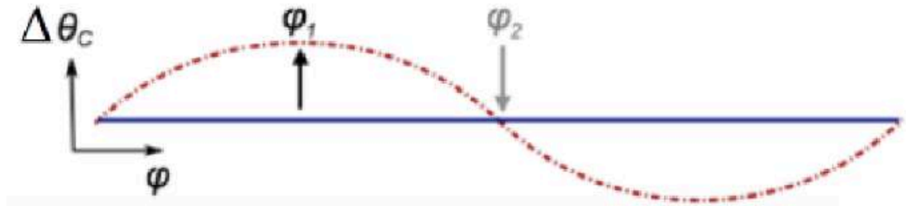
[Performance of the LHCb RICH detector Eur.Phys.J. C73 (2013) 2431]

RICH mirrors

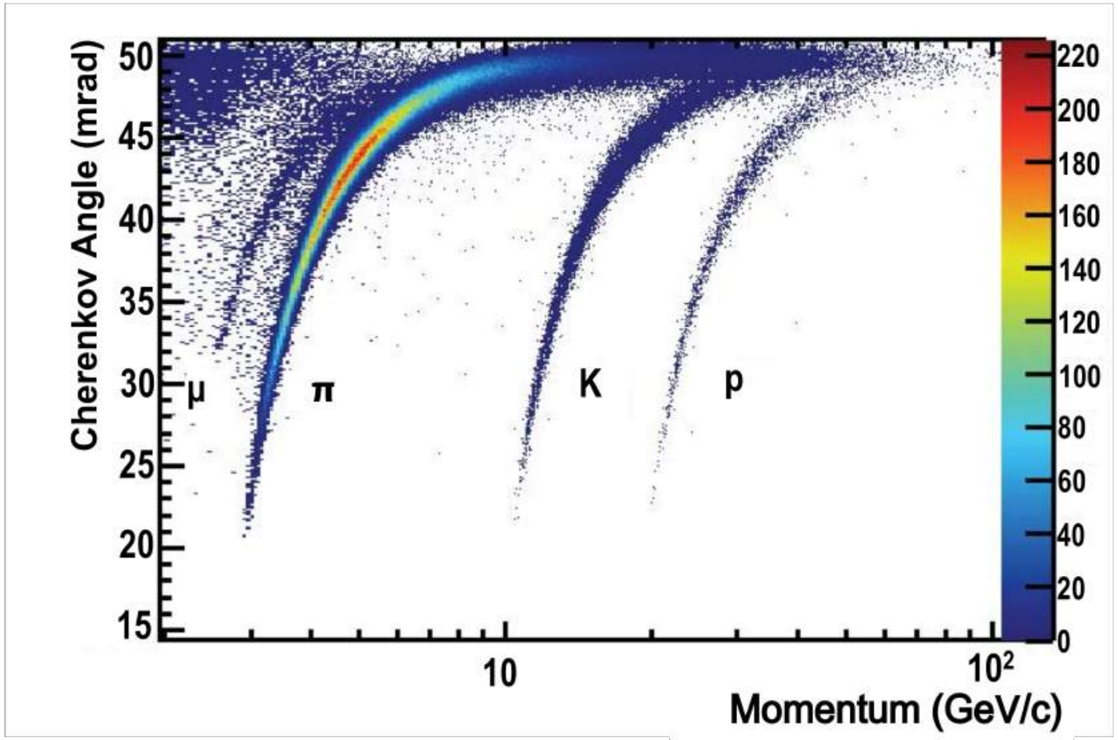


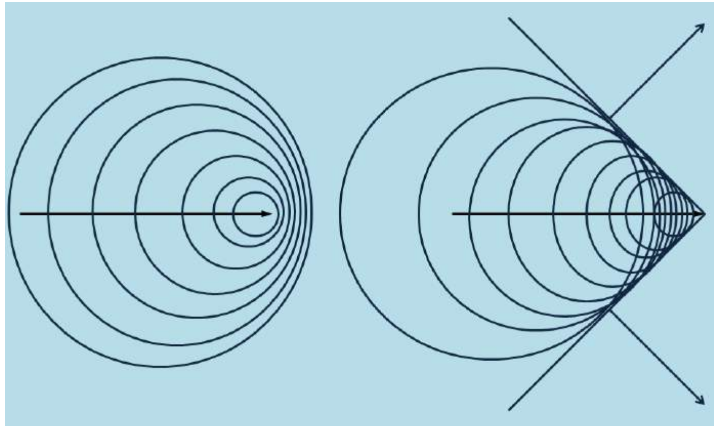




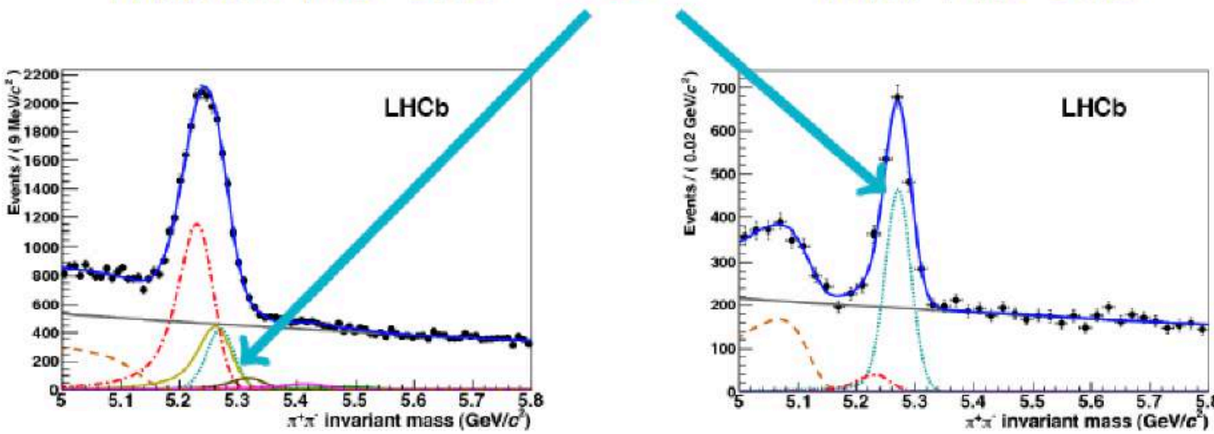


Cherenkov effect





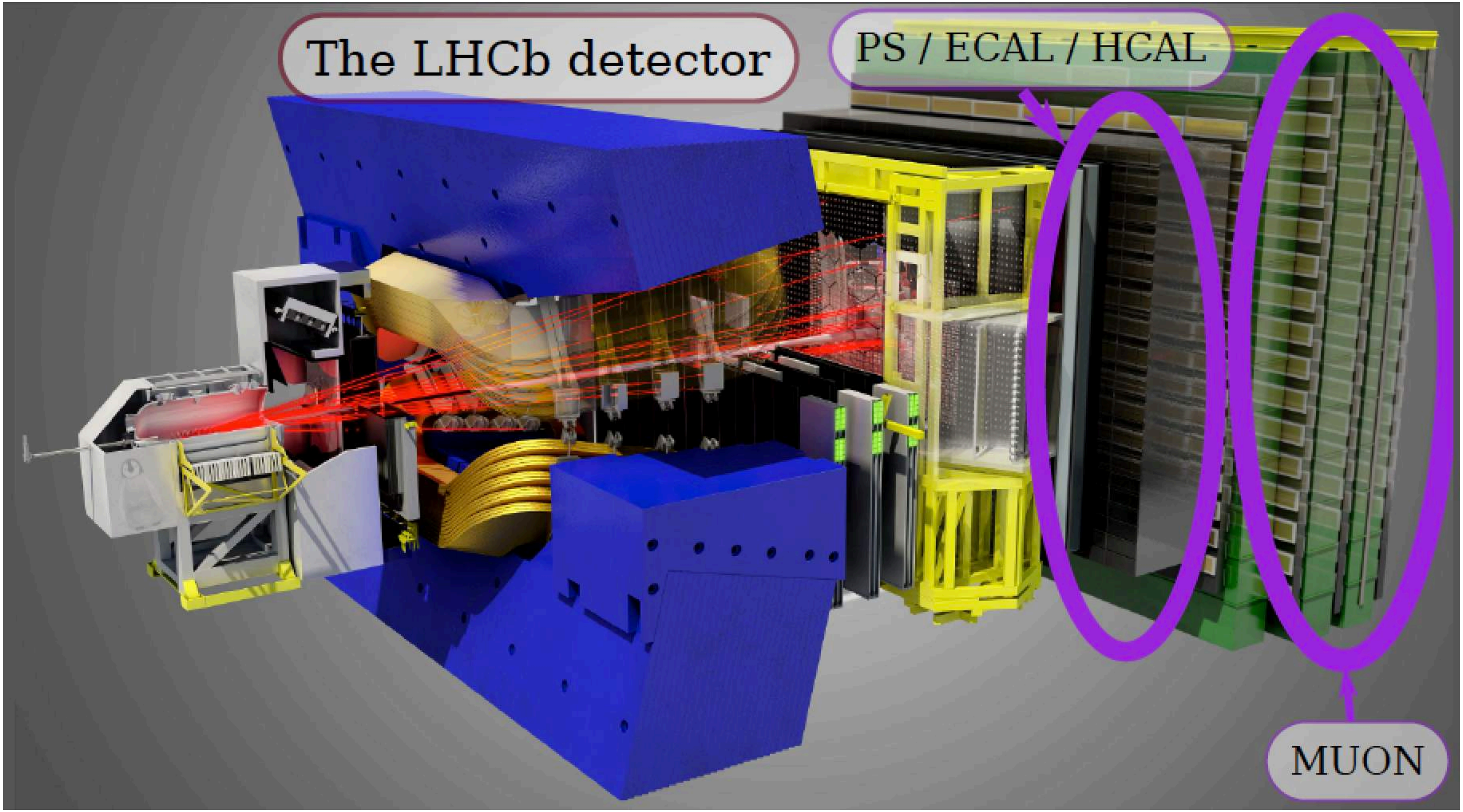
Without PID cuts Signal With PID cuts



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, $B_s \to KK$, $B_s \to K\pi$, $\Lambda_b \to pK$, $\Lambda_b \to p\pi$)

Effetto Cherenkov

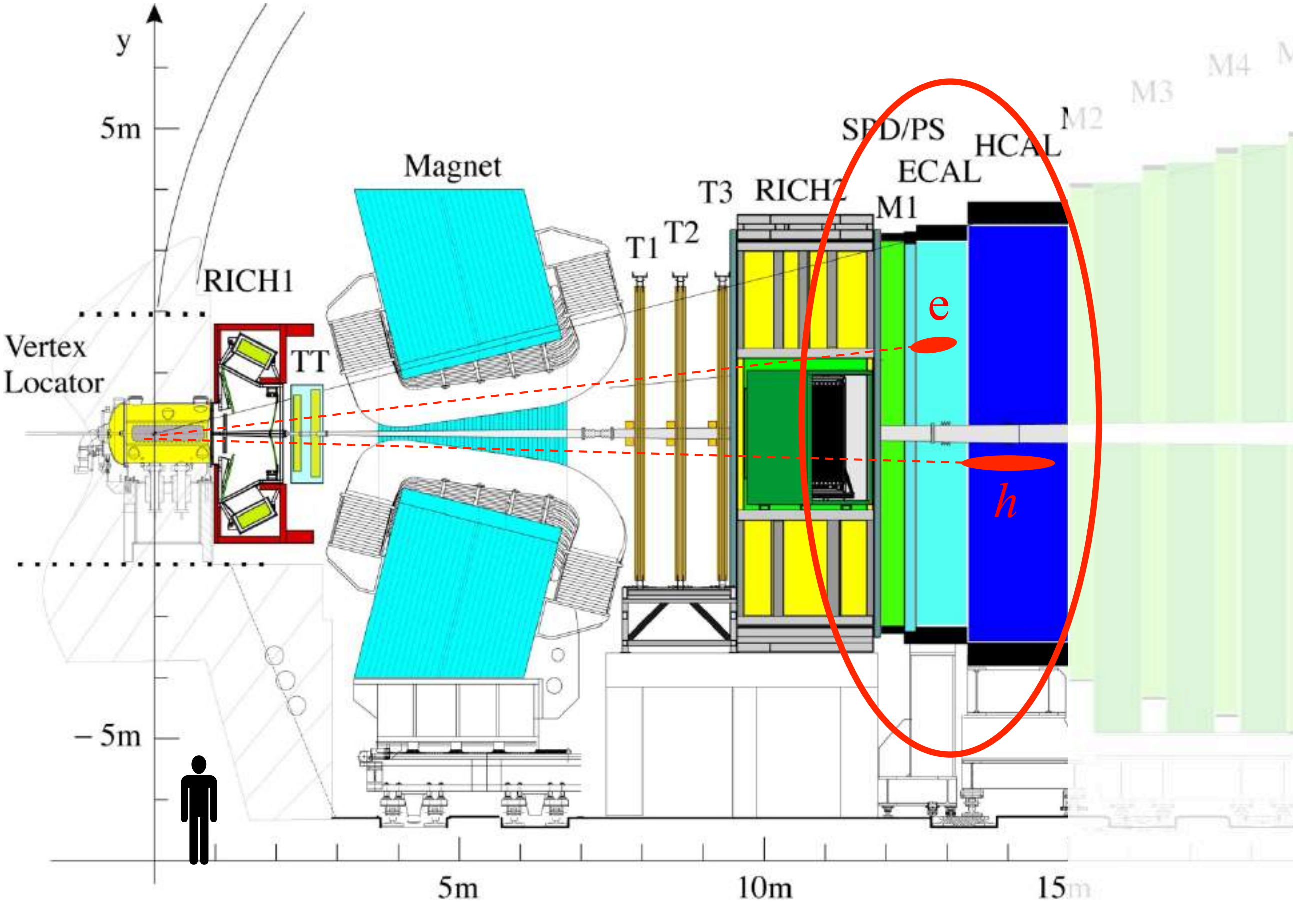
LHCb detector: calorimeter and muon systems

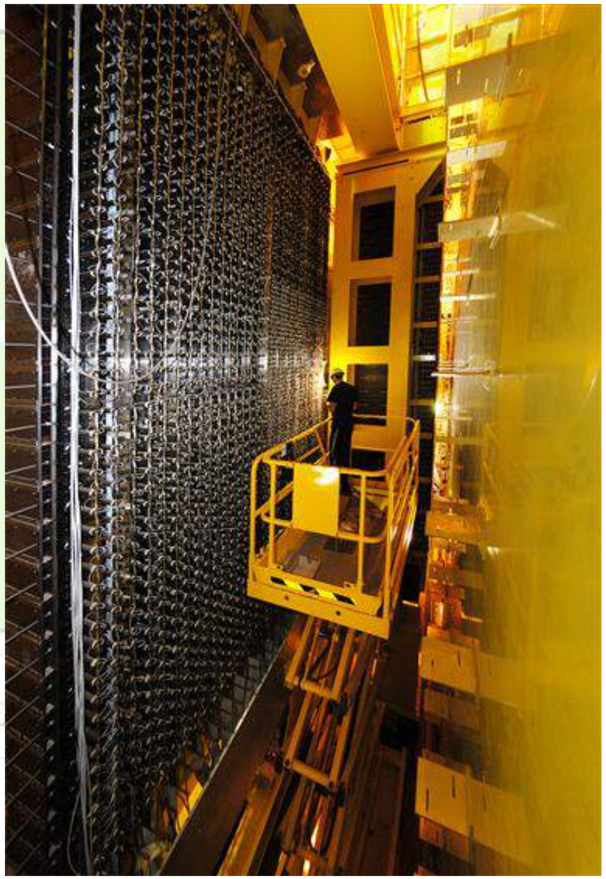


[LHCb Detector Performance Int.J.Mod.Phys. A30 (2015) 1530022]

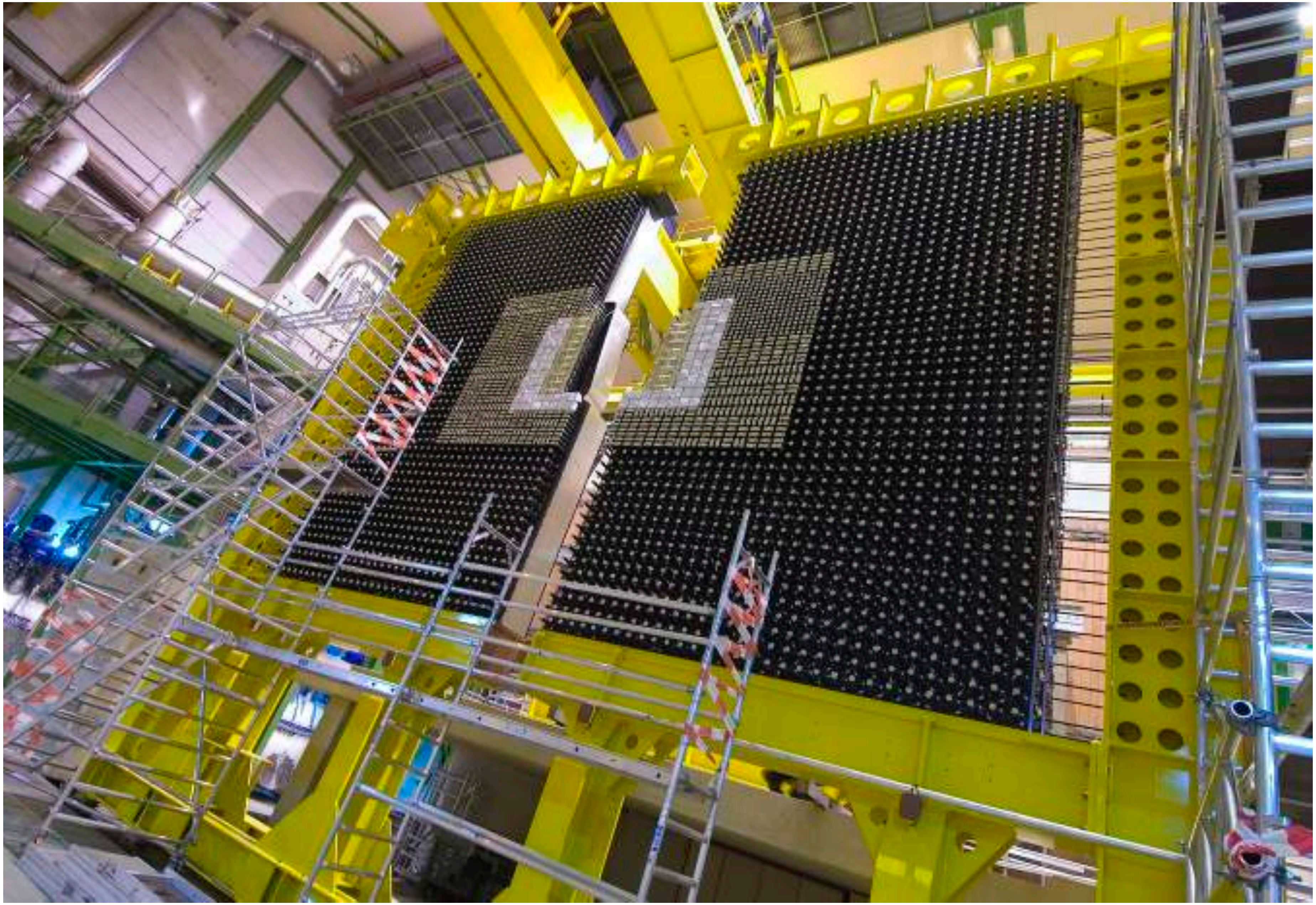
Calorimeter System

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]





Calorimetro



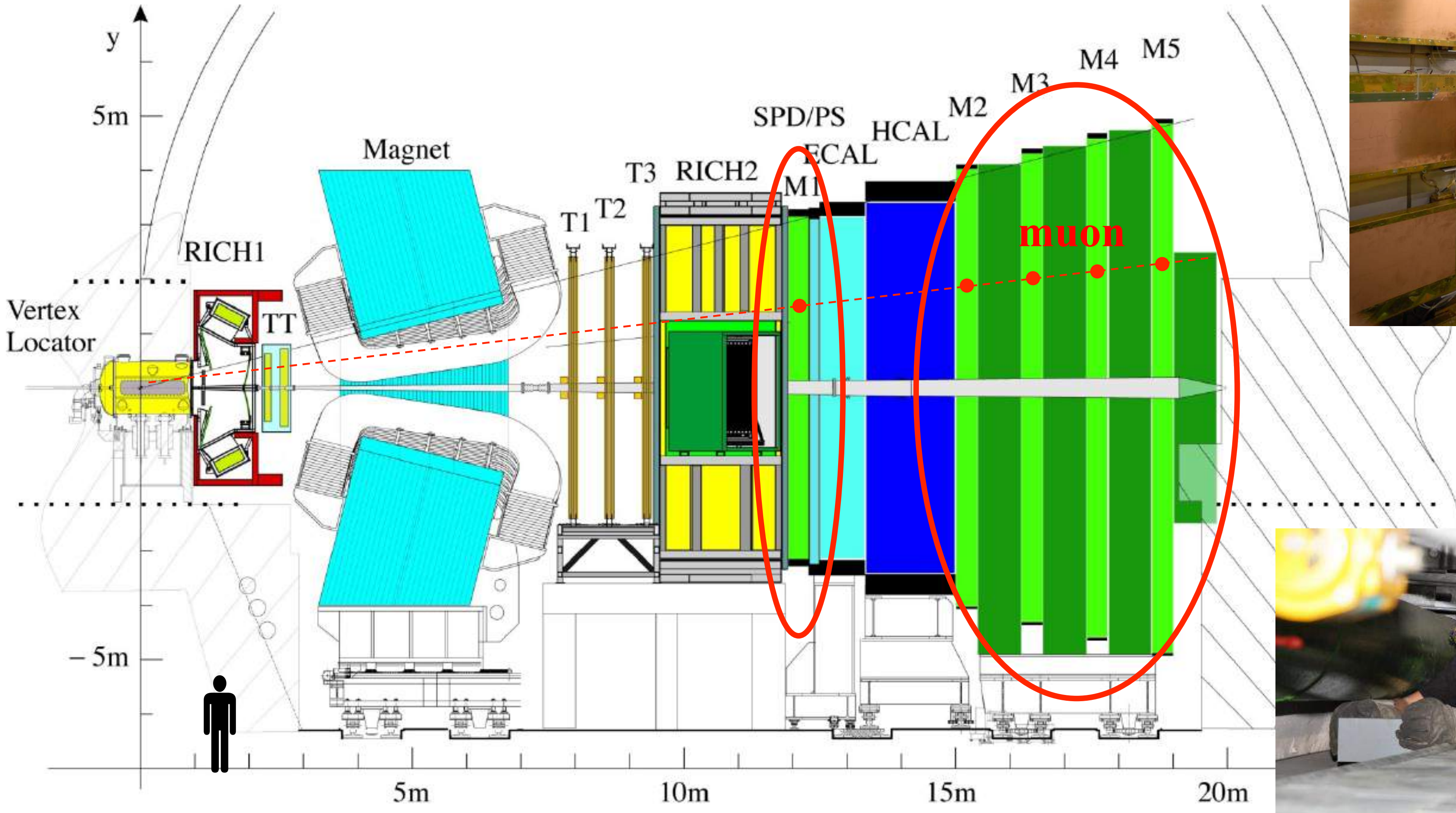
[Performance of the Muon Identification at LHCb JINST 8 (2013) P10020]
[Performance of the LHCb Muon system JINST 8 (2013) P02022]

Muon System

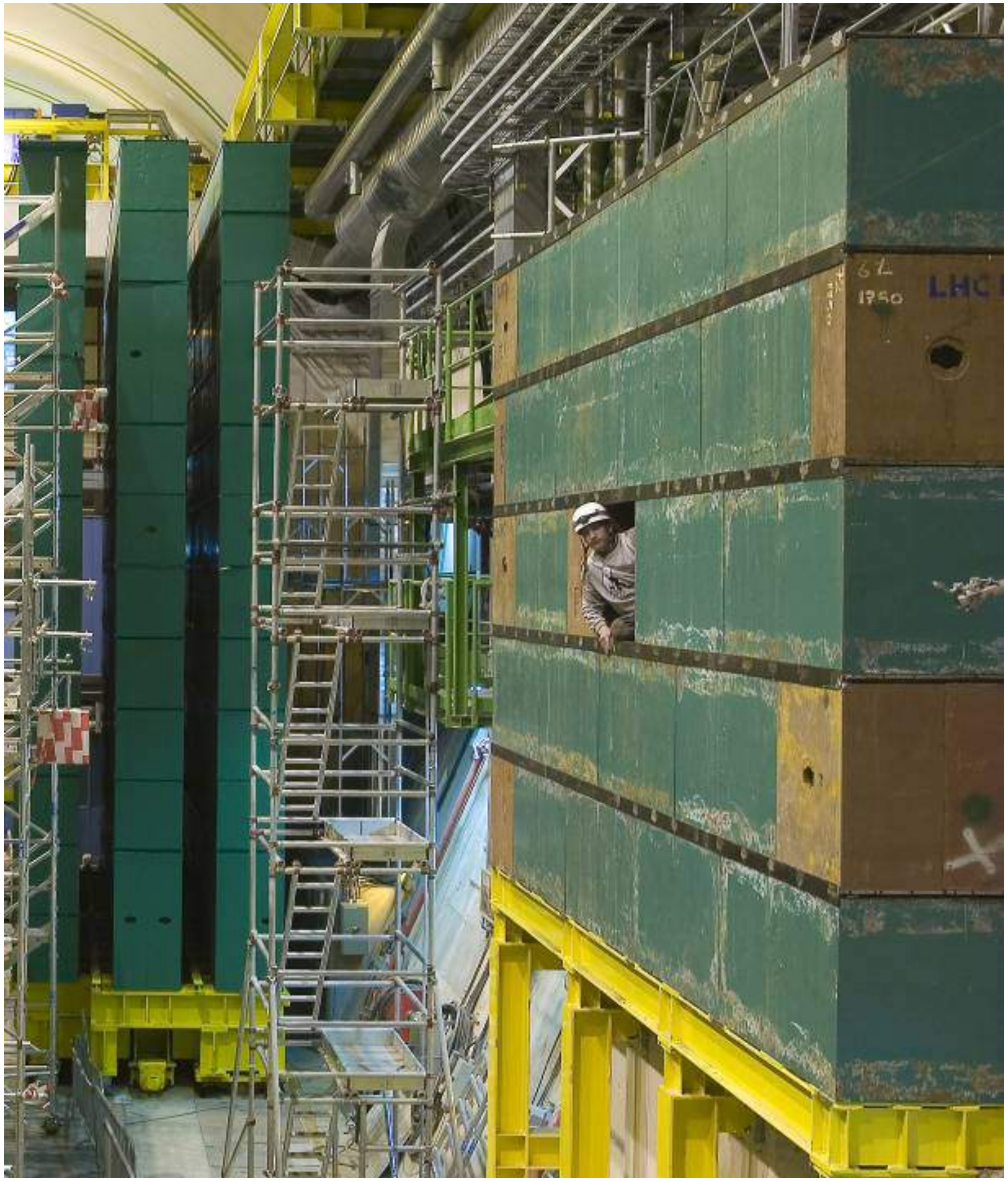
5 stations, each equipped with 276 multi-wire proportional chambers [different size]. Inner part of M1 equipped with 12 GEM detectors

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

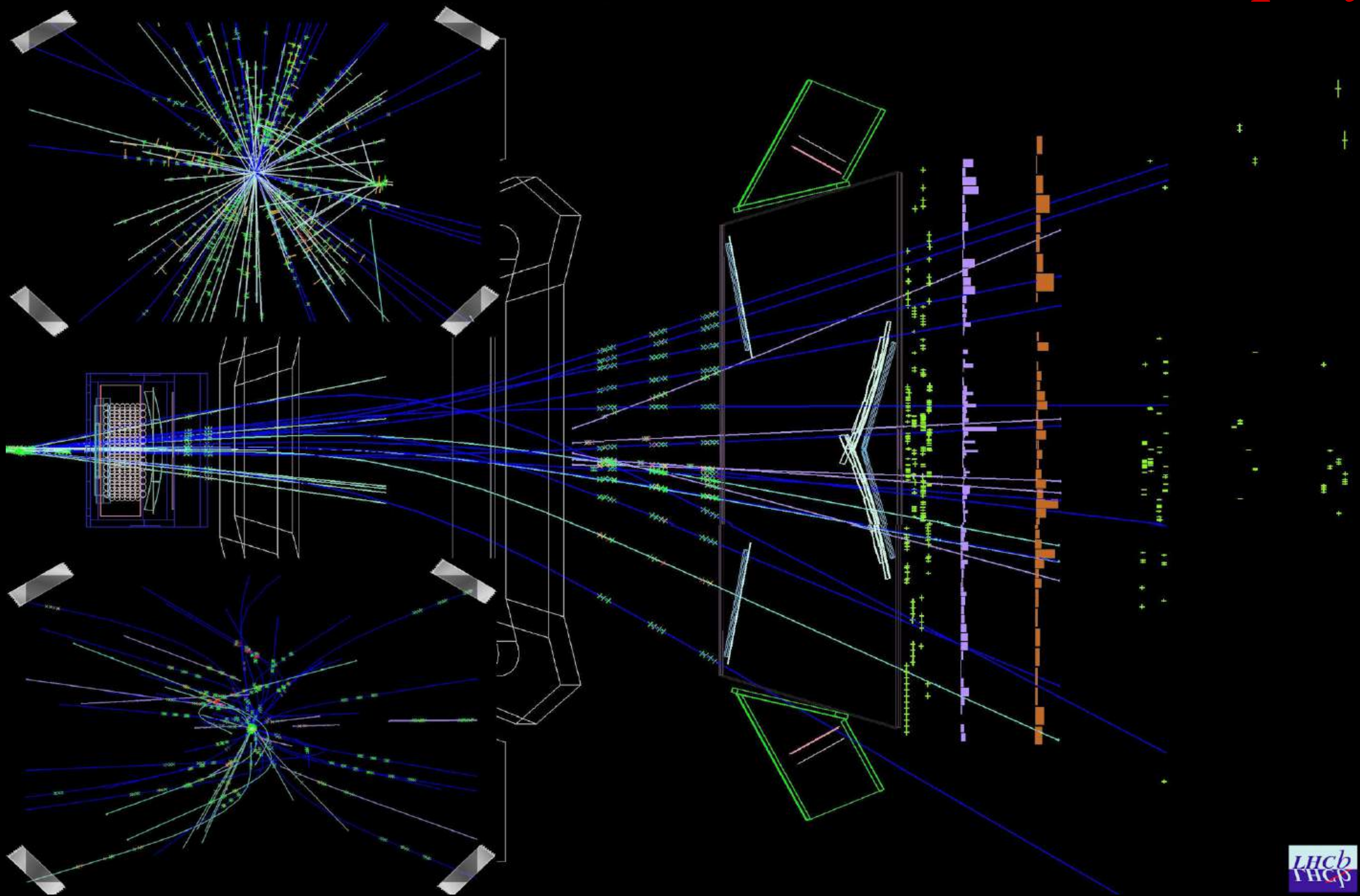
Used in the first level of the trigger [L0]



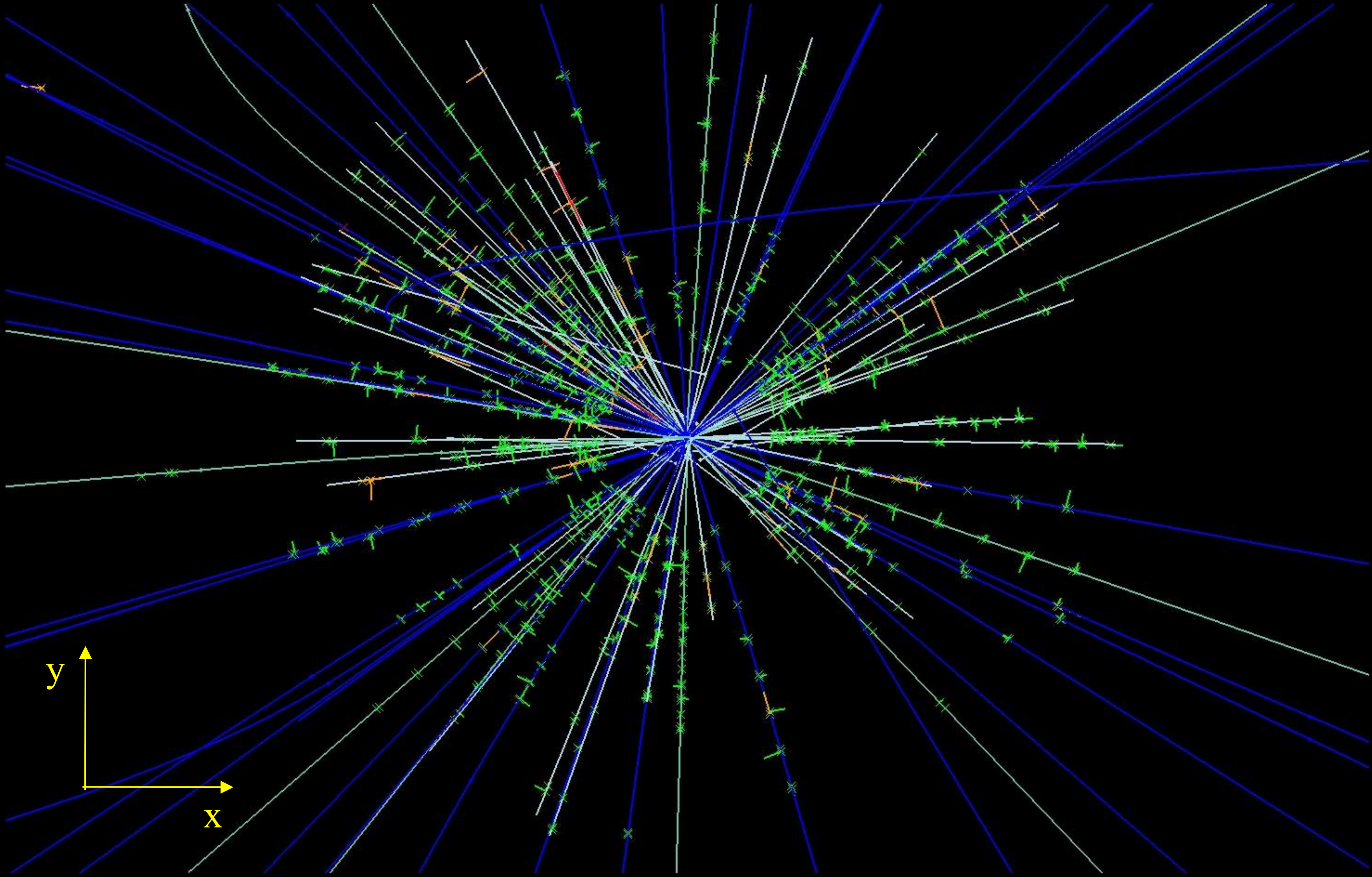
Muon System



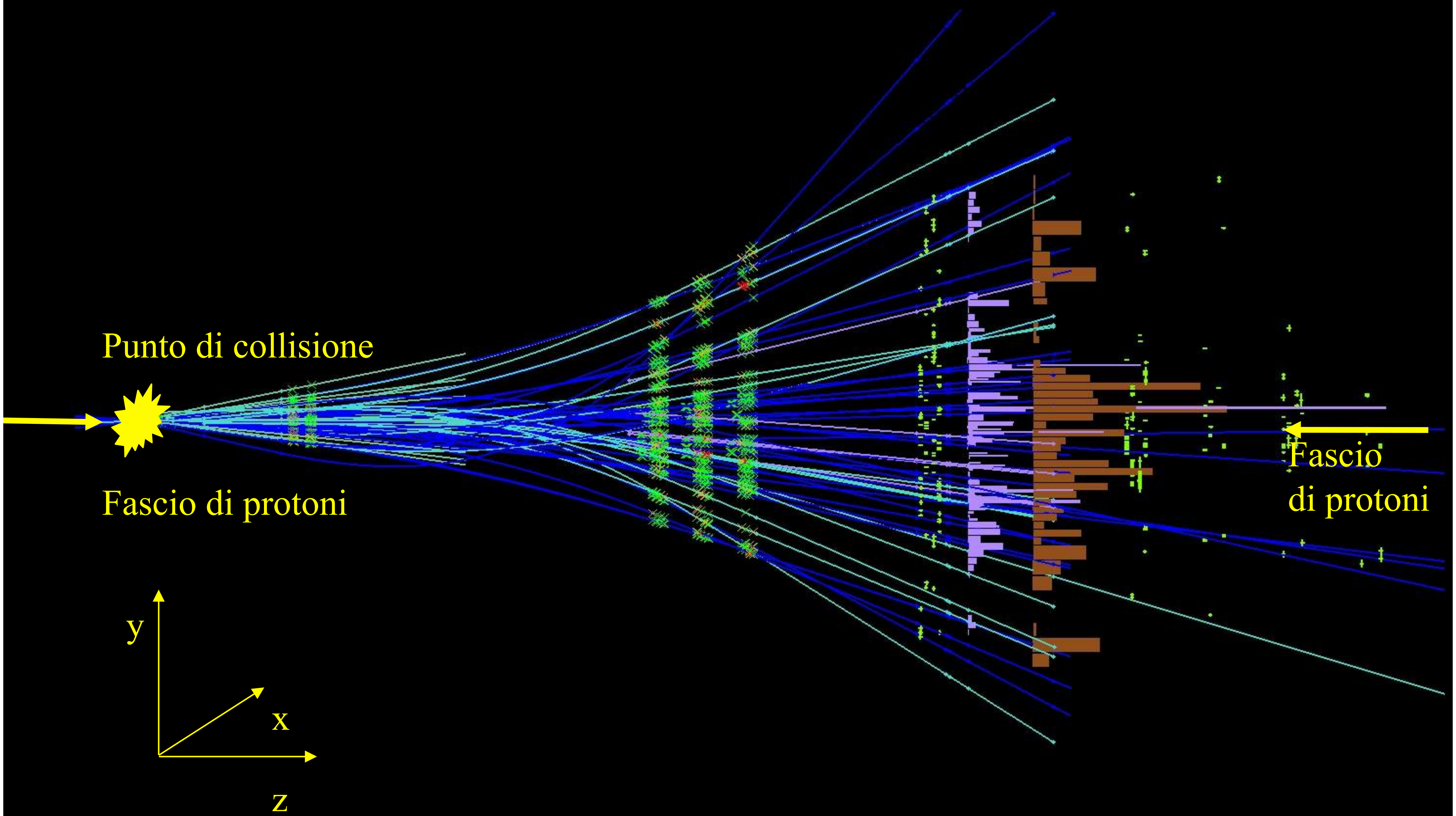
Event display



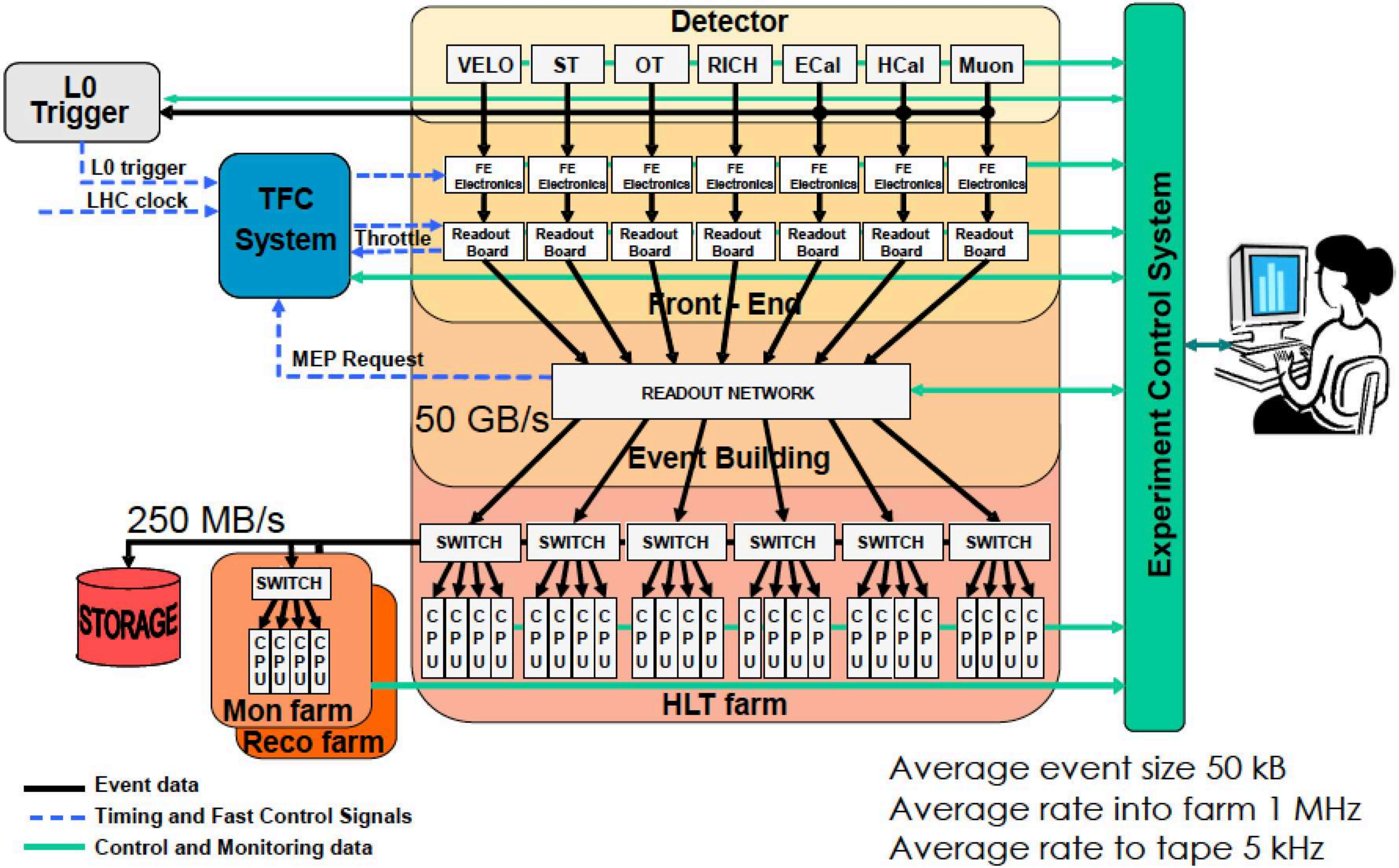
Evento a LHCb



Evento a LHCb

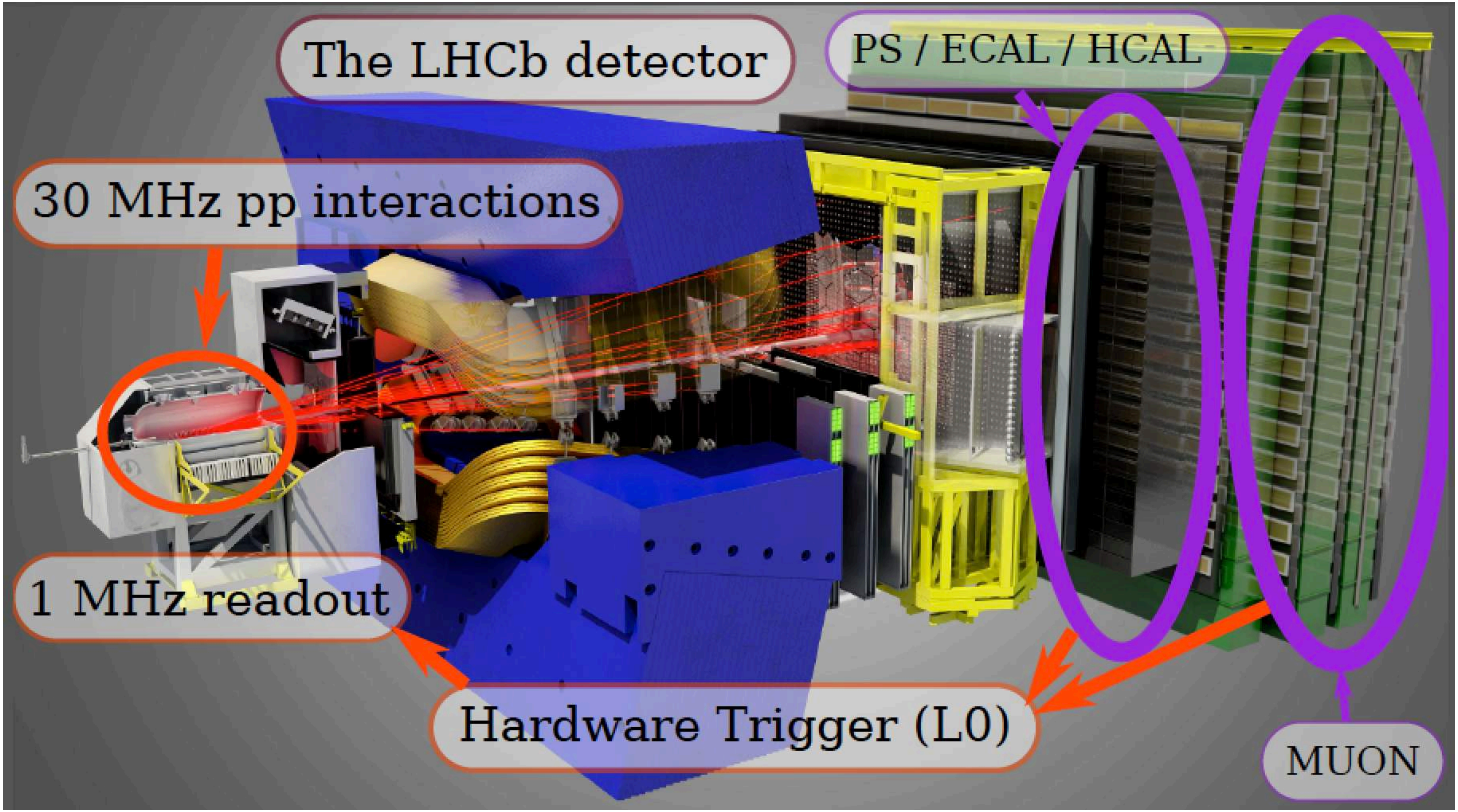


Collect data (DAQ)

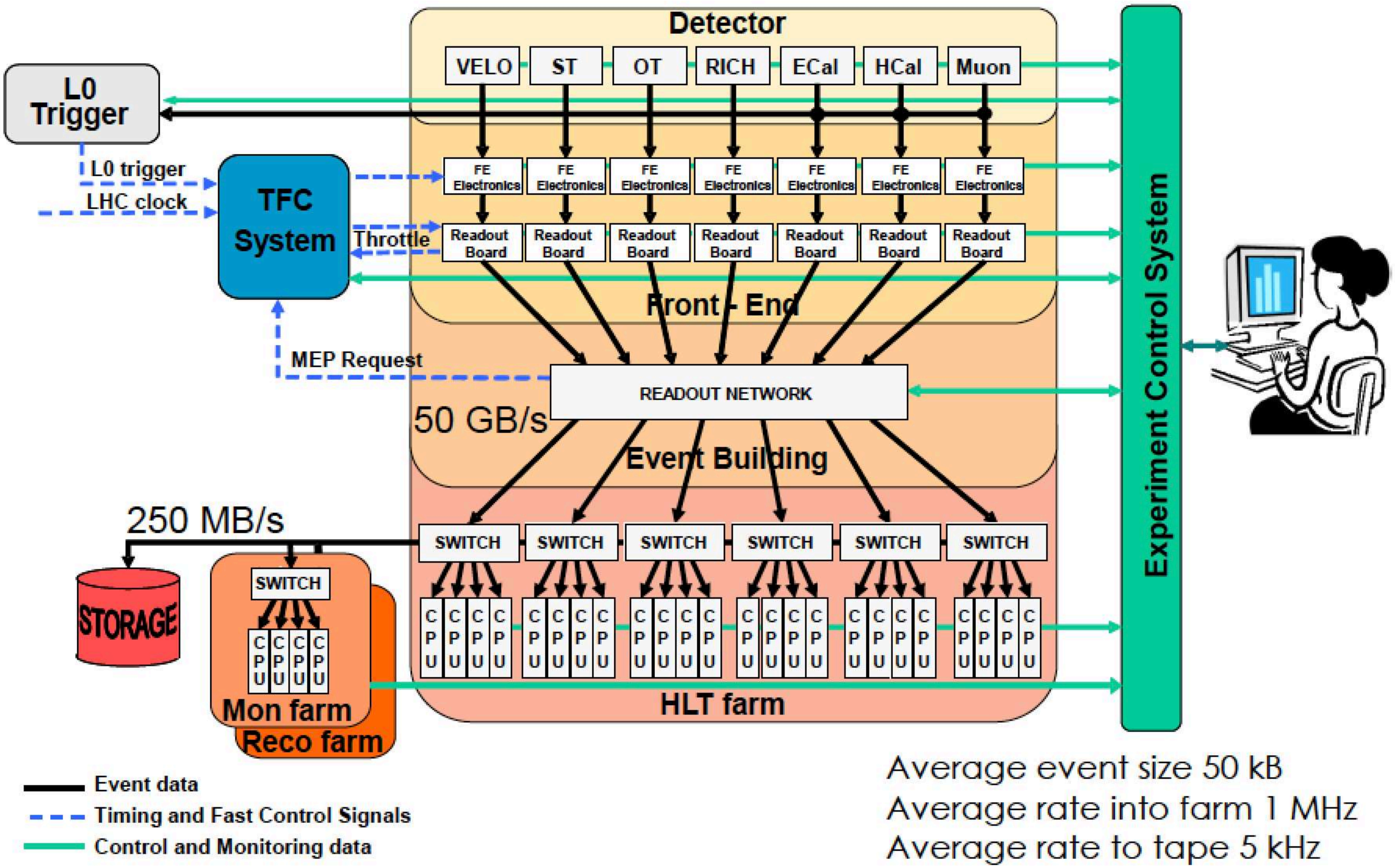


Average event size 50 kB
Average rate into farm 1 MHz
Average rate to tape 5 kHz

Hardware trigger



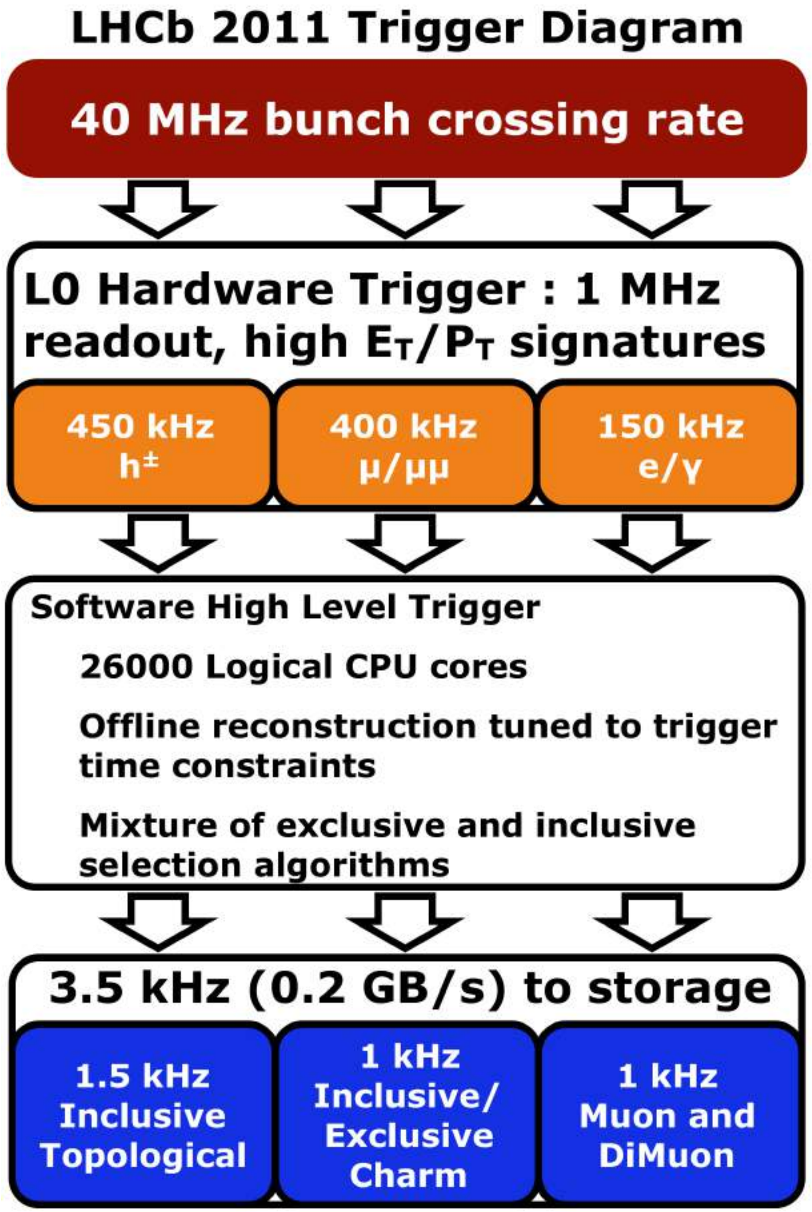
Collect data (DAQ)

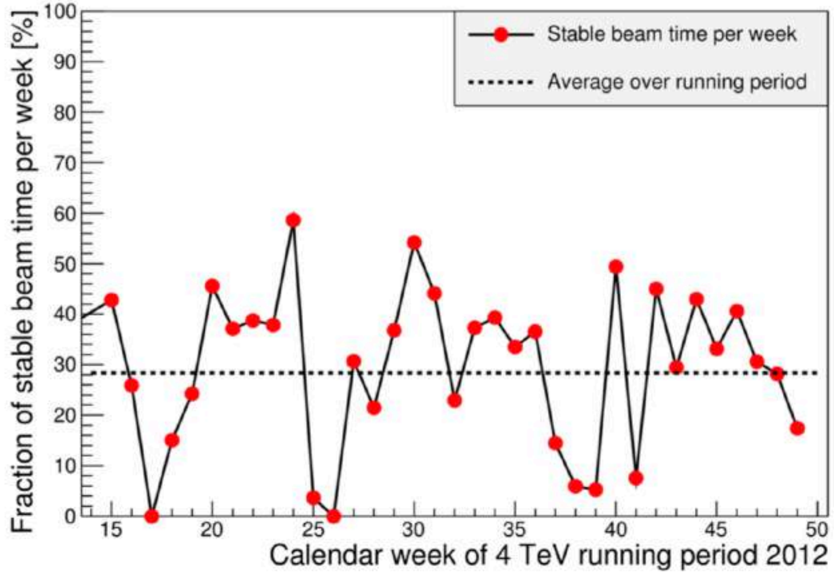


Average event size 50 kB
Average rate into farm 1 MHz
Average rate to tape 5 kHz

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

Trigger



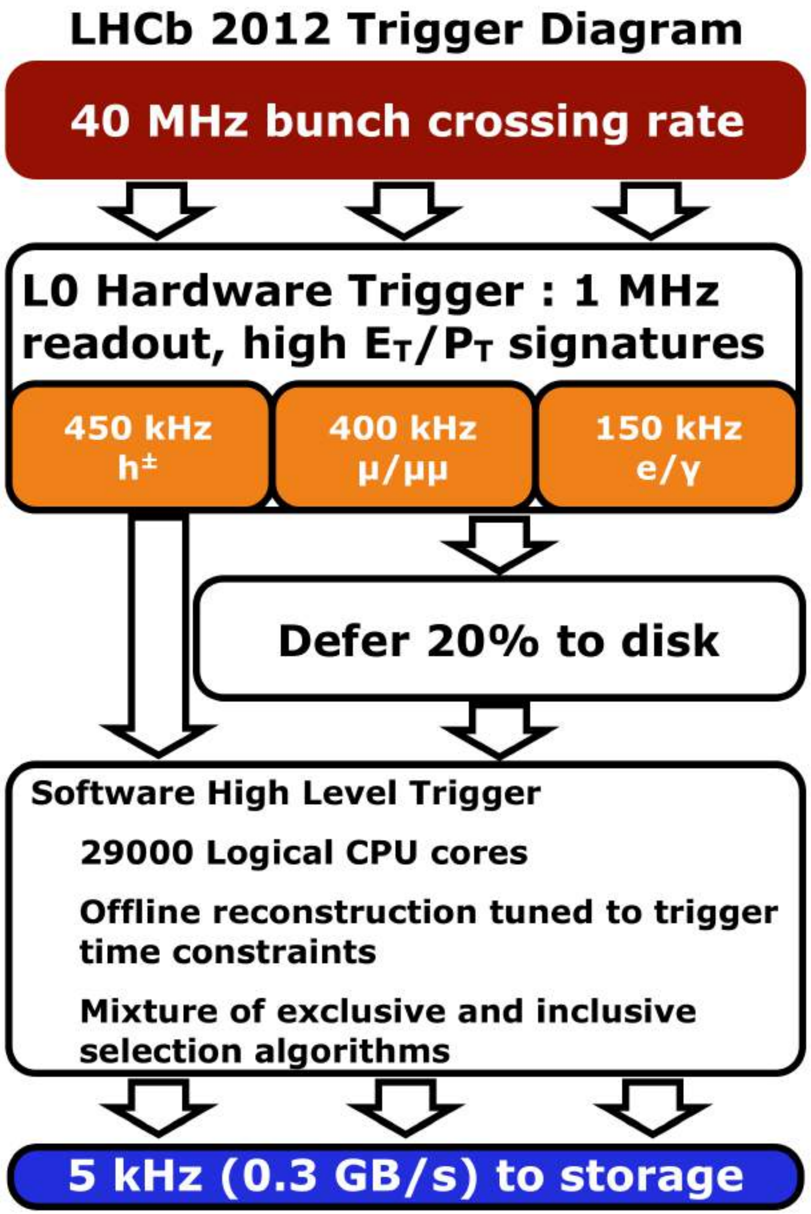


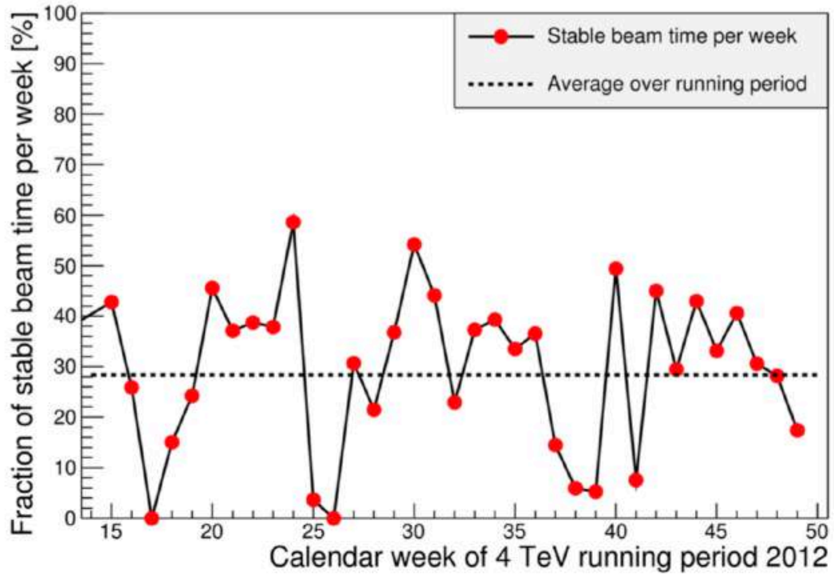
- The average fraction of stable beams time per week was ~30%

- Try to <u>defer computing needs</u> to time without beams

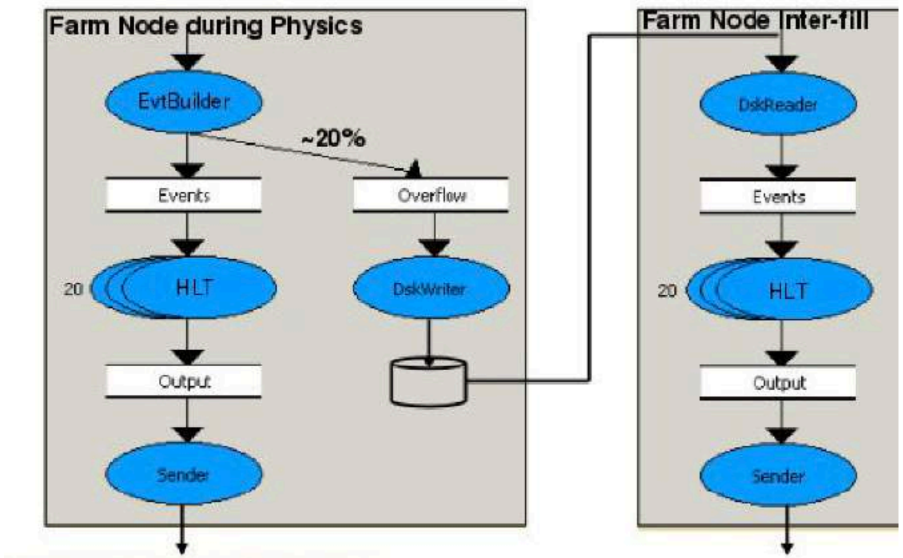
[arXiv:1211.3055; CERN-LHCb-DP-2012-004]
[arXiv:1310.8544v1]

Trigger



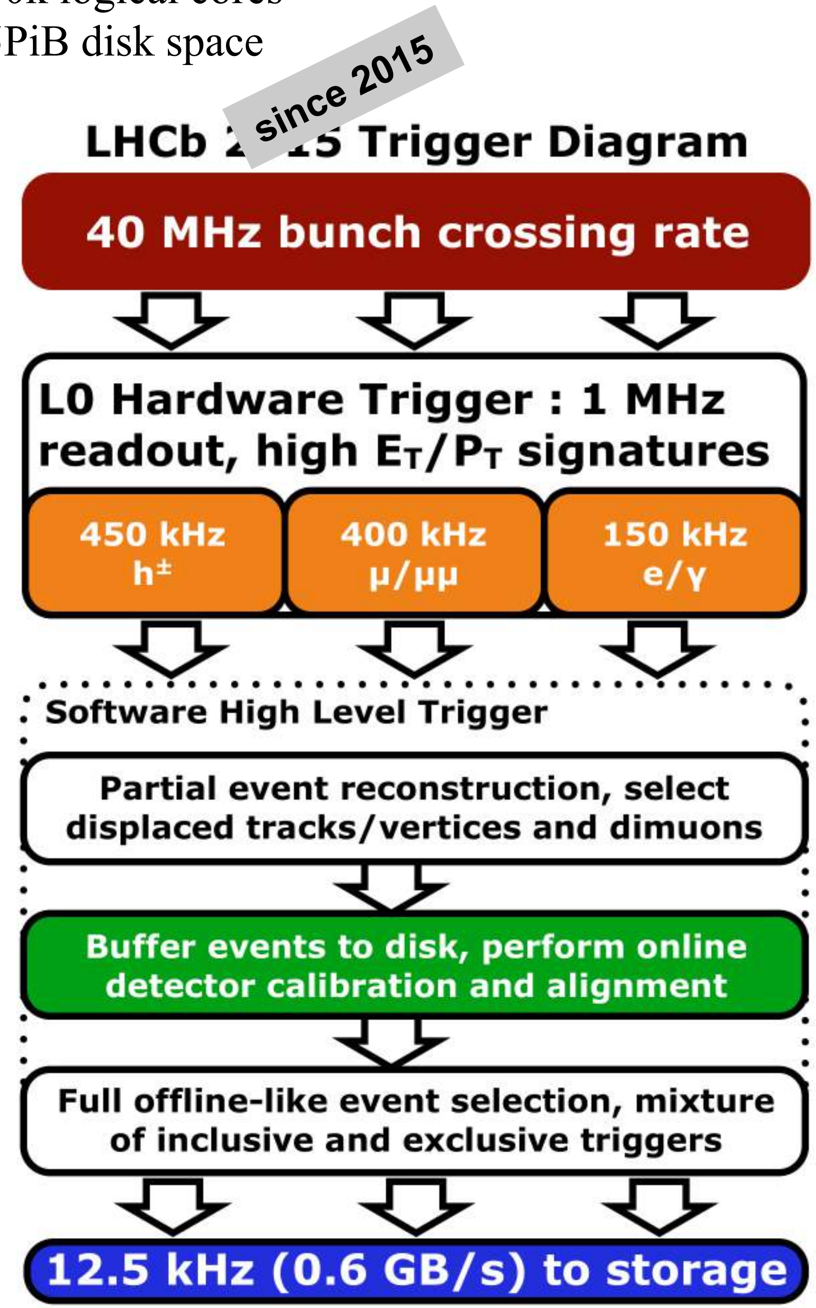


Deferred HLT

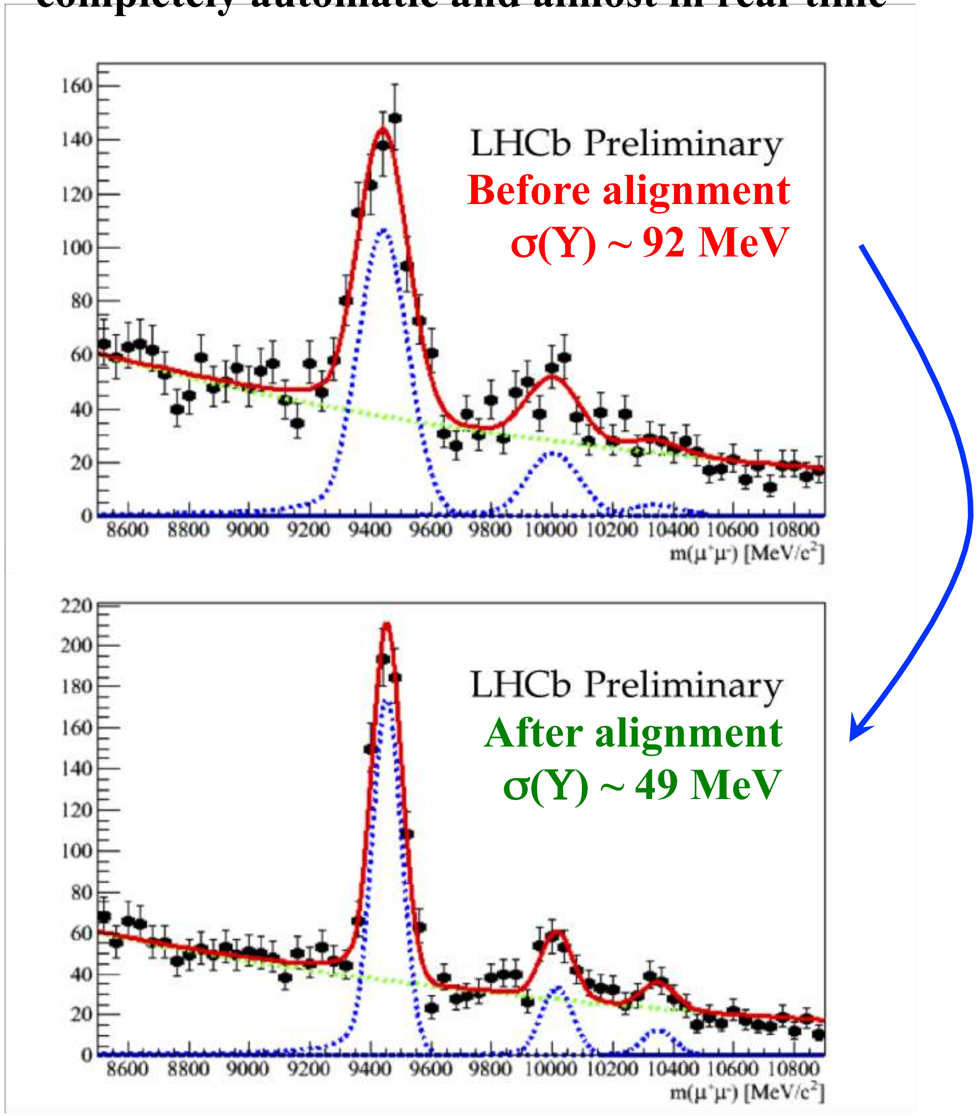


Trigger

~50k logical cores
~5PiB disk space



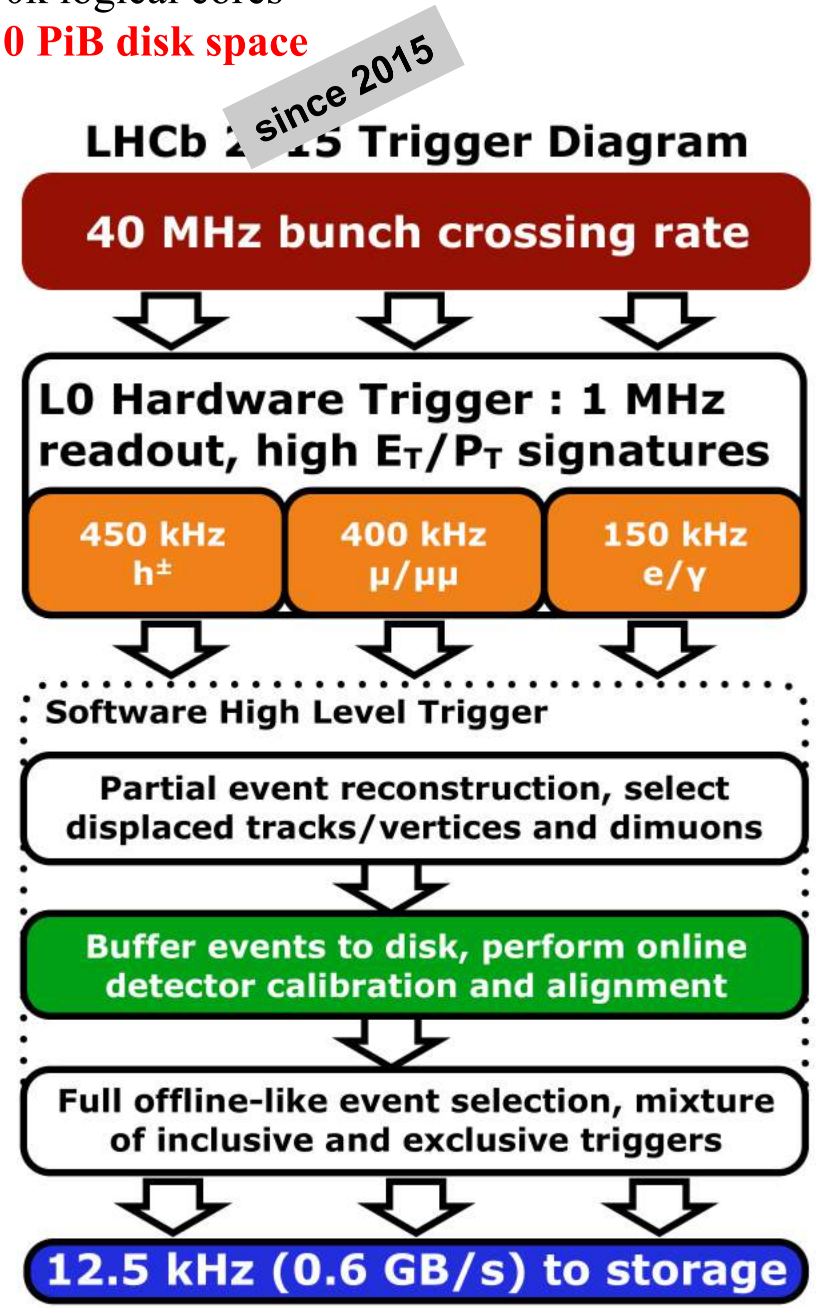
Same online and offline reconstruction and PID
- **prompt alignment and calibration**
- **completely automatic and almost in real-time**



~50k logical cores

~10 PiB disk space

Trigger buffer

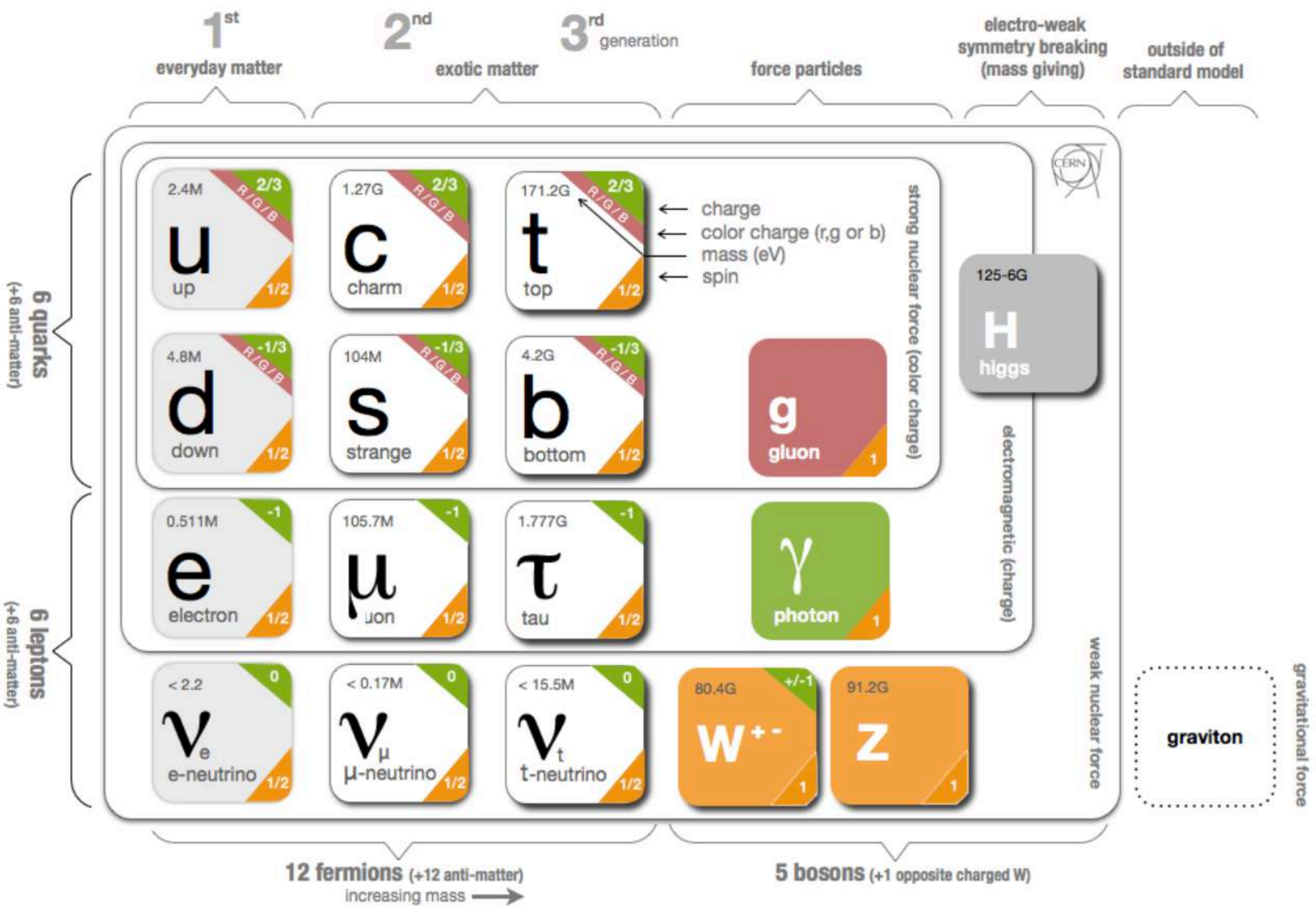


From 2015 experience, ~1 disk per day is replaced due to unrecoverable errors: until 2015, mirror the 5 PiB of disk space in a second chunk of 5 PiB disks.

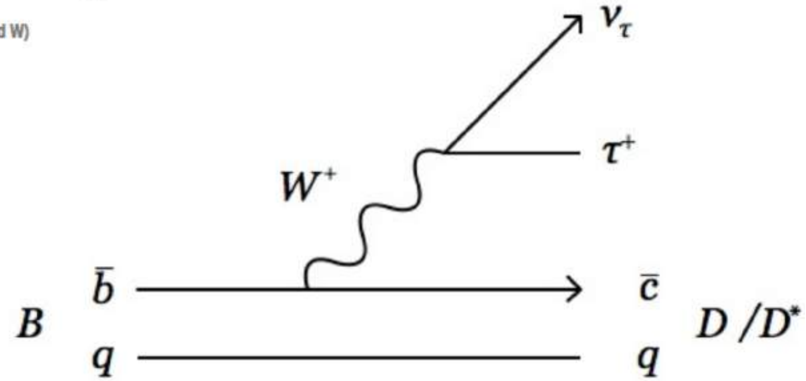
Un-mirroring the disks doubles our buffer with the risk of per mil loss of data: **since 2016 total farm disk space is ~10PiB**.

This means more data and/or more time to reconstruct them.

SM



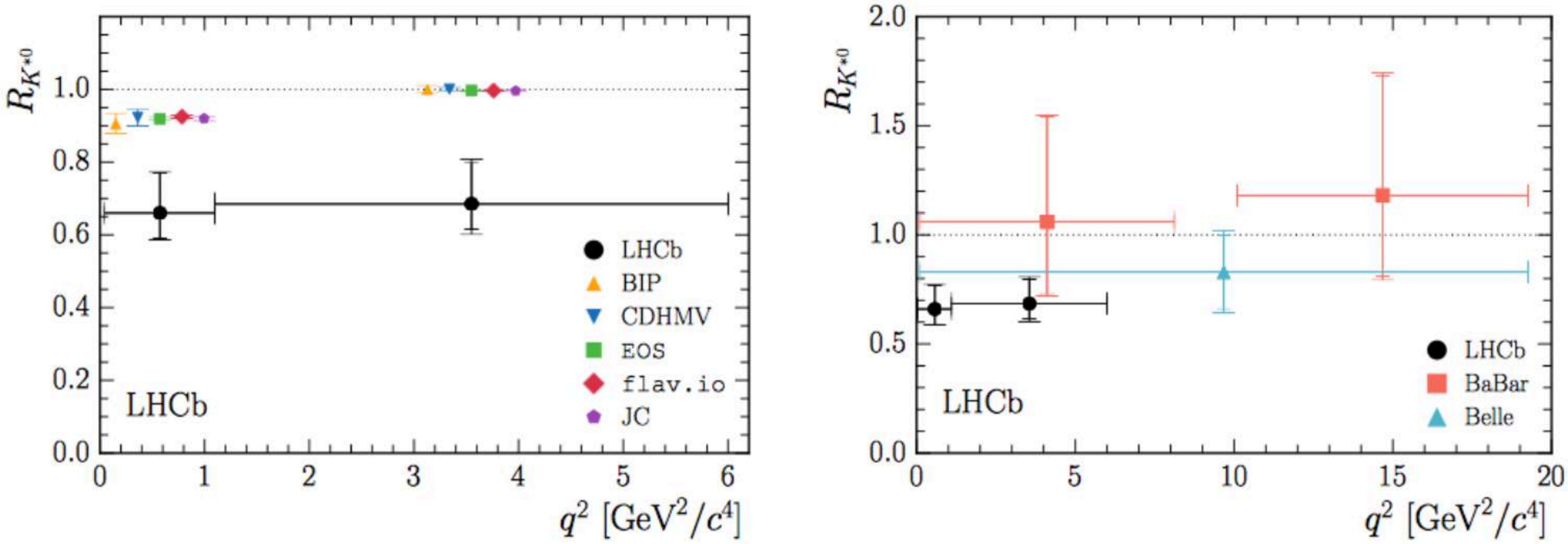
1st
everyday matter
2nd
exotic matter
3rd generation
force particles
electro-weak symmetry breaking (mass giving)
outside of standard model
2.4M 2/3 R/G/B u up 1/2
1.27G 2/3 R/G/B c charm 1/2
171.2G 2/3 R/G/B t top 1/2
charge
color charge (r,g or b)
mass (eV)
spin
strong nuclear force (color charge)
125-6G H higgs
4.8M -1/3 R/G/B d down 1/2
104M -1/3 R/G/B s strange 1/2
4.2G -1/3 R/G/B b bottom 1/2
g gluon 1
0.511M -1 e electron 1/2
105.7M -1 μ μon 1/2
1.777G -1 τ tau 1/2
γ photon 1
electromagnetic (charge)
< 2.2 0 νe e-neutrino 1/2
< 0.17M 0 νμ μ-neutrino 1/2
< 15.5M 0 ντ τ-neutrino 1/2
80.4G +/-1 W+- 1
91.2G Z 1
weak nuclear force
graviton
gravitational force
6 quarks (+6 anti-matter)
6 leptons (+6 anti-matter)
12 fermions (+12 anti-matter)
increasing mass
5 bosons (+1 opposite charged W)



ν_τ
τ^+
W^+
$\bar{b}$
$\bar{c}$
B
D/D^*
q
q

Beyond SM

[LHCb-PAPER-2017-013]



2.1 – 2.4 standard deviations from the Standard Model

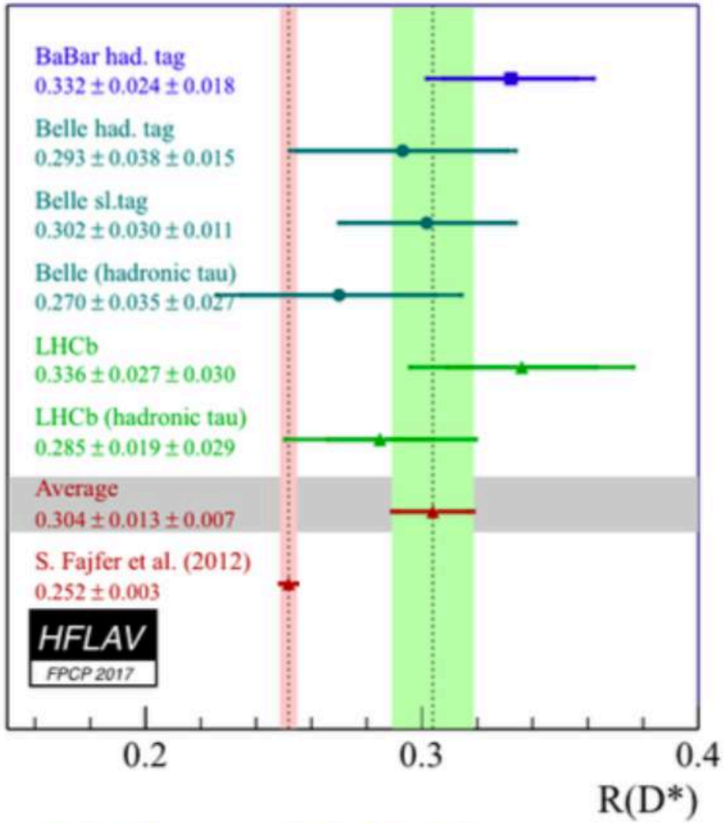
$$0.660\ {}^{+\ 0.110}_{-\ 0.070}\,(\mathrm{stat}) \pm 0.028\,(\mathrm{syst}) \quad \text{for } 0.045 < q^2 < 1.1\ \ \mathrm{GeV}^2/c^4$$

$$0.685\ {}^{+\ 0.113}_{-\ 0.069}\,(\mathrm{stat}) \pm 0.047\,(\mathrm{syst}) \quad \text{for } 1.1 < q^2 < 6.0\ \ \mathrm{GeV}^2/c^4$$

2.4 – 2.5 standard deviations from the Standard Model

Beyond SM

PAPER-2017-017 PAPER-2017-017



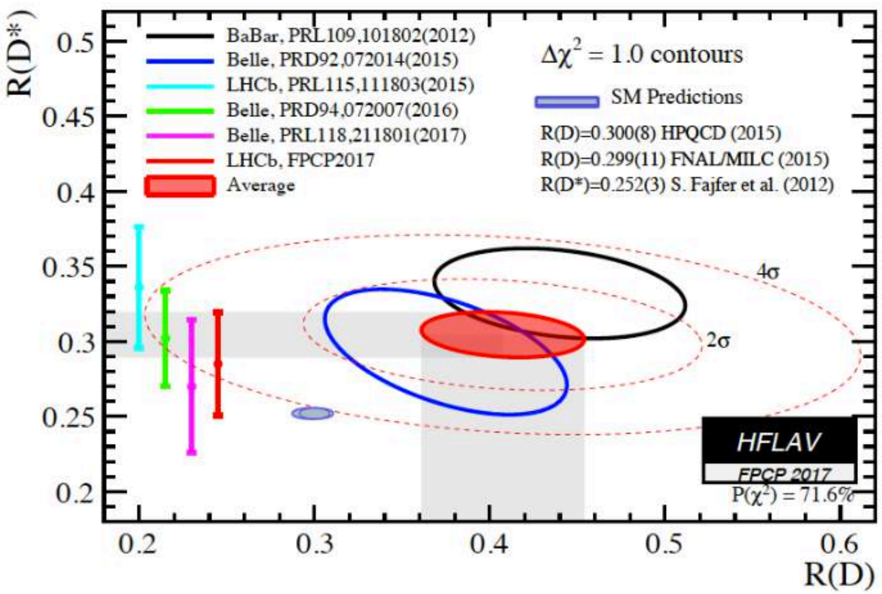
New LHCb measurement gives

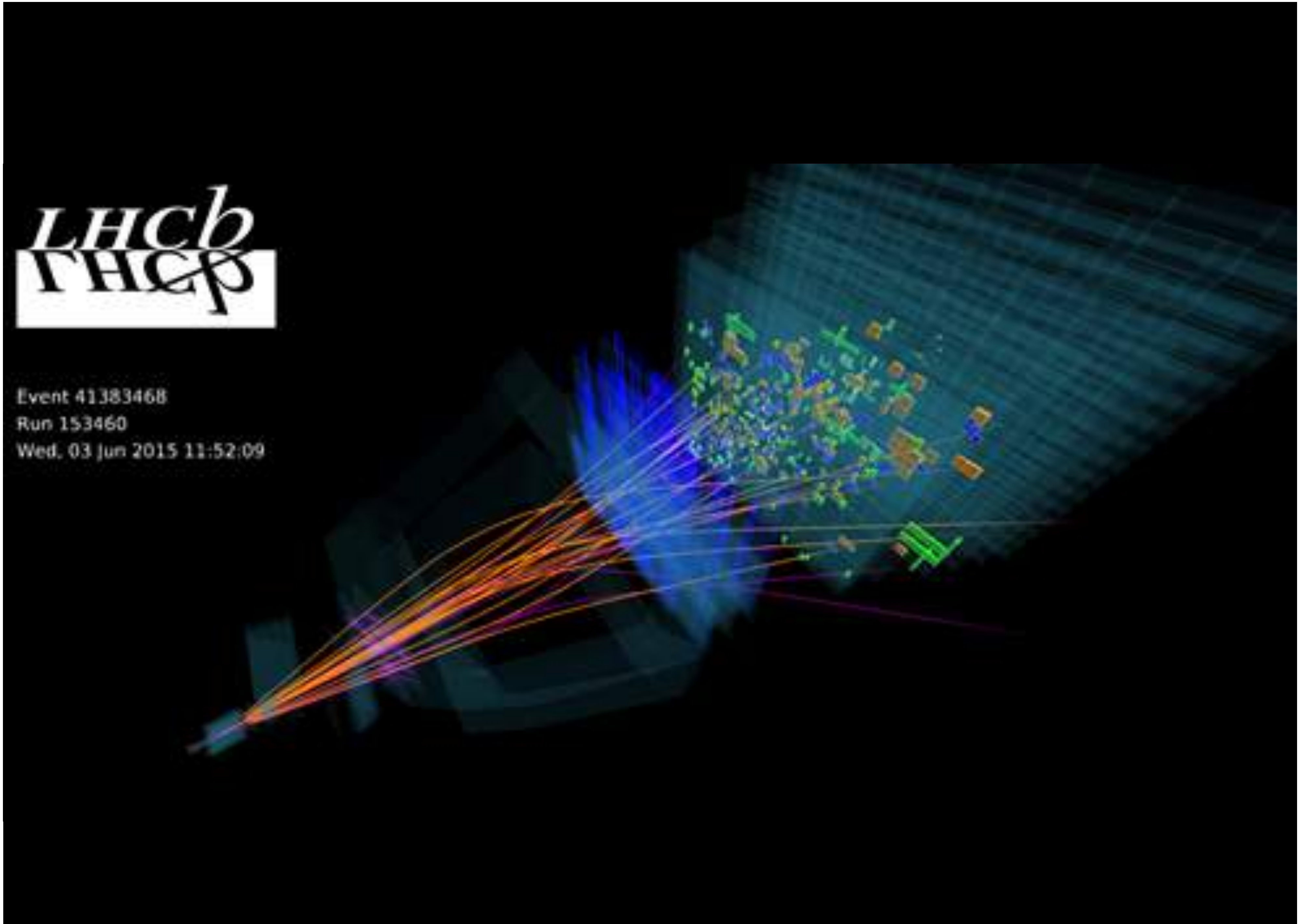
$$\mathcal{R}(D^{*-}) = 0.286 \pm 0.019 \pm 0.025 \pm 0.021$$

Compatible with SM expectation

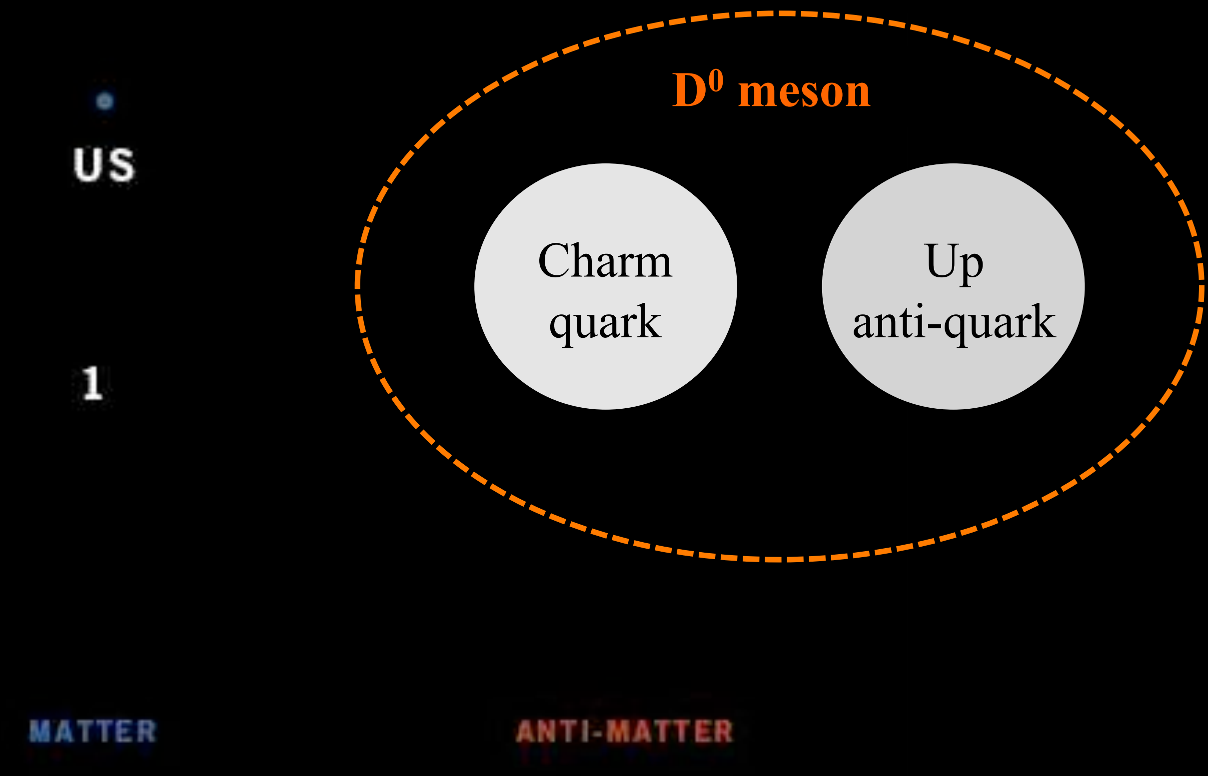
but also fully supporting previous measurements of high value

- R(D) and R(D*) combination at ~4σ from the SM
- Major updates are coming with Run-2 data

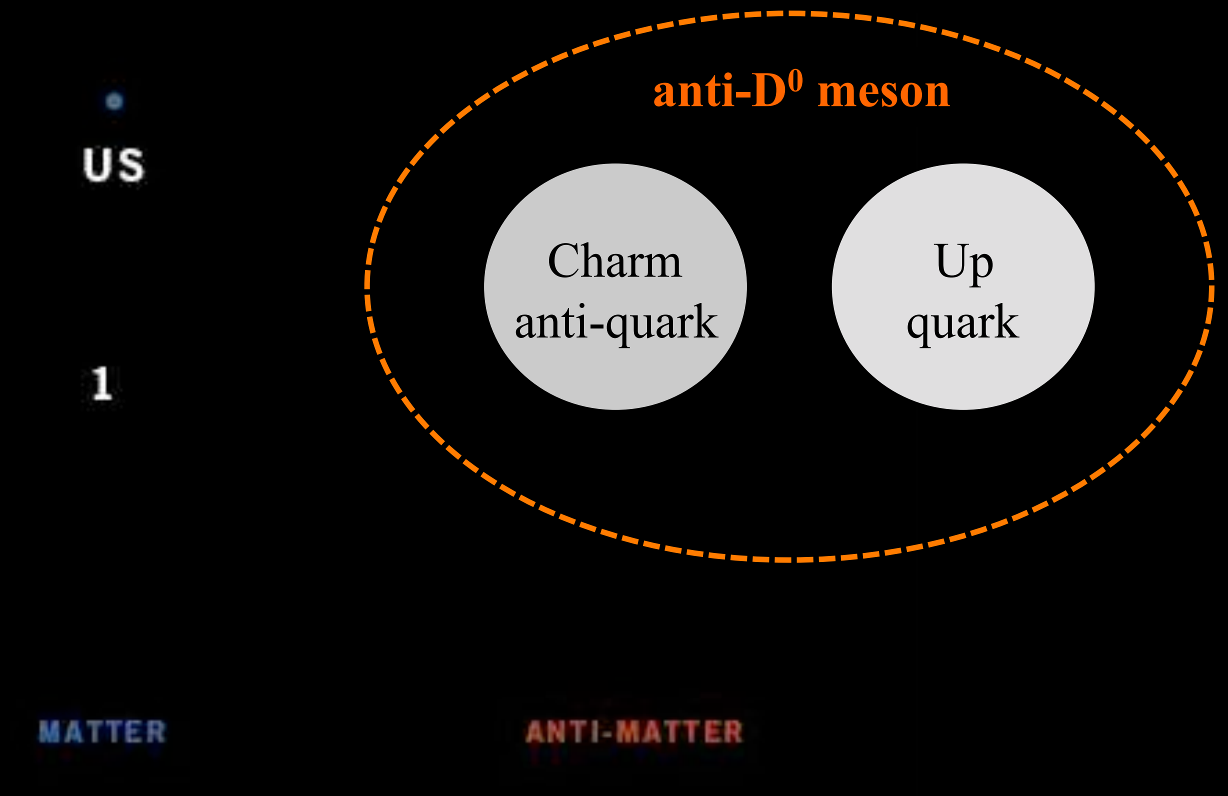



LHCb
Event 41383468
Run 153460
Wed, 03 Jun 2015 11:52:09

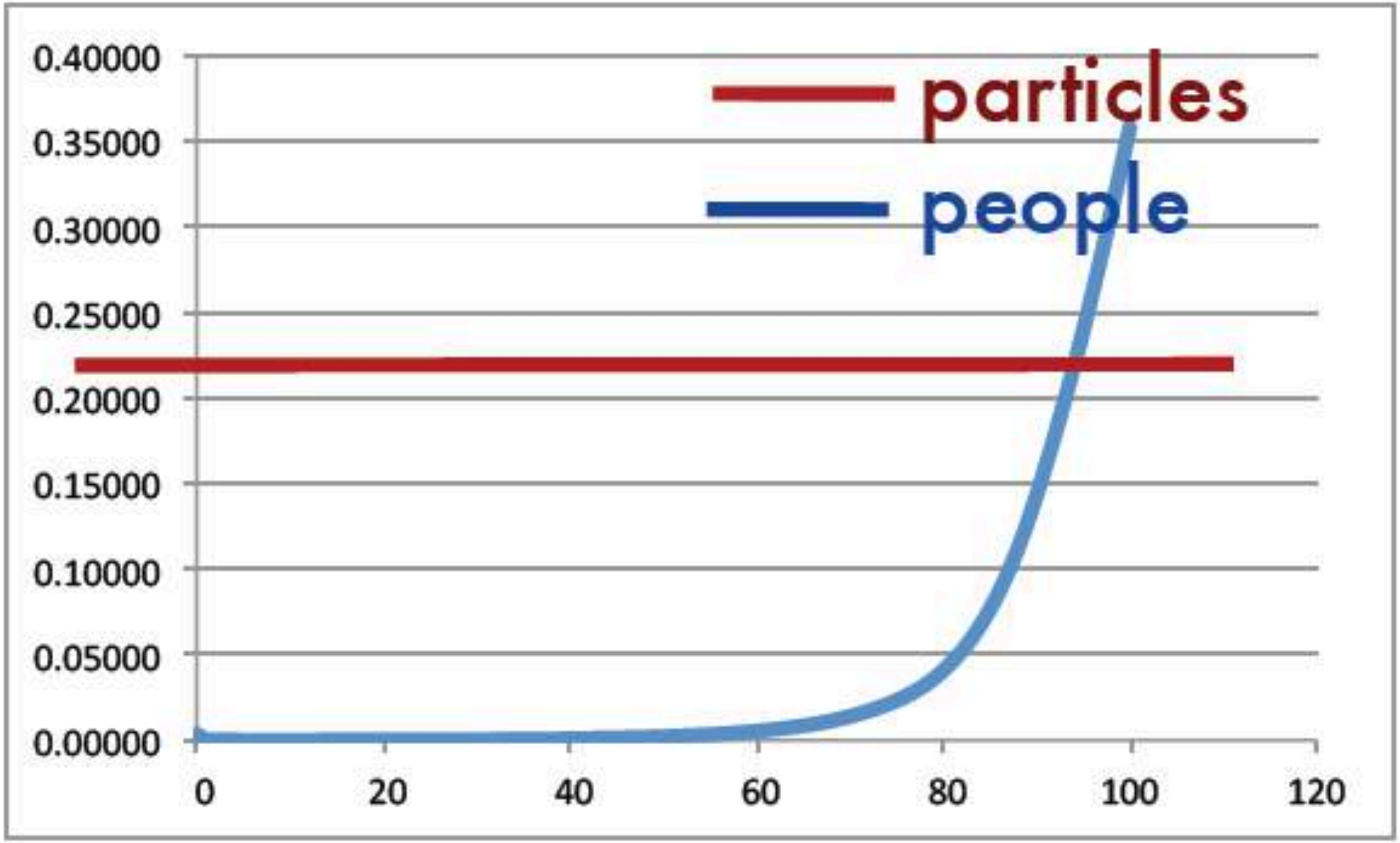
Materia e Antimateria



Materia e Antimateria



Probabilità di "decadimento"



Tempi di dimezzamento e vita media

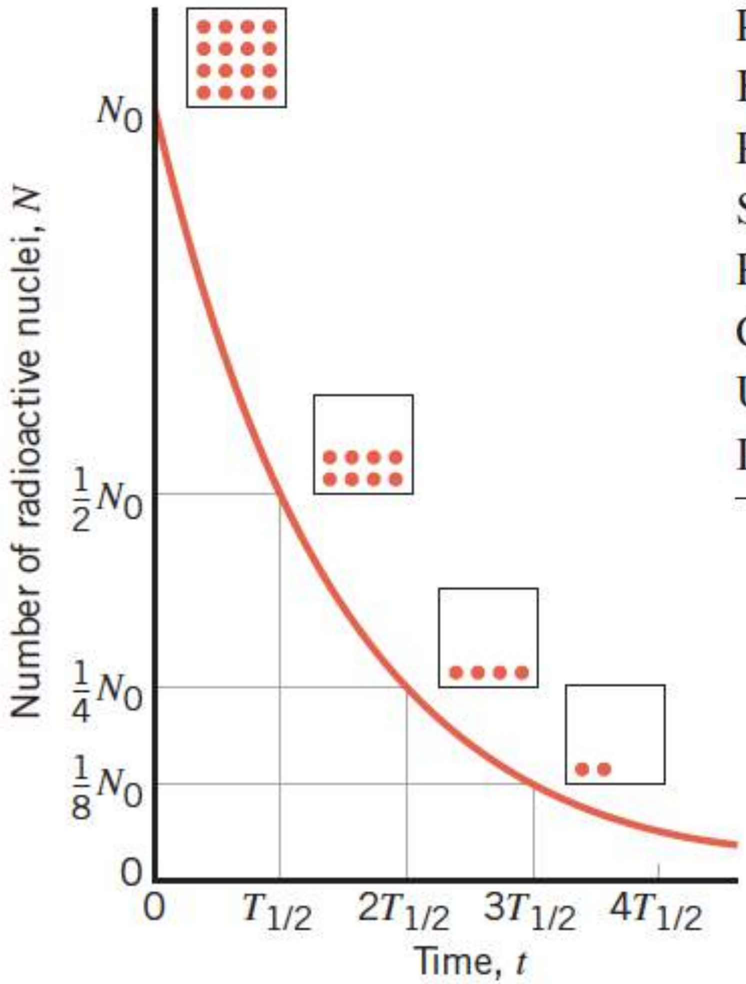
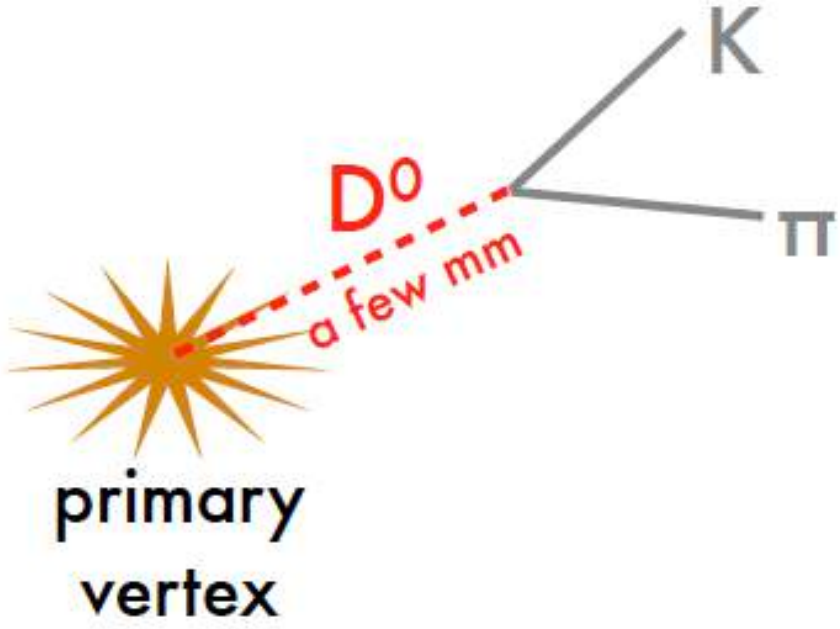


Table 31.2 Some Half-Lives for Radioactive Decay

Isotope		Half-Life
Polonium	$^{214}_{84}Po$	1.64×10^{-4} s
Krypton	$^{89}_{36}Kr$	3.16 min
Radon	$^{222}_{86}Rn$	3.83 d
Strontium	$^{90}_{38}Sr$	29.1 yr
Radium	$^{226}_{88}Ra$	1.6×10^{3} yr
Carbon	$^{14}_{6}C$	5.73×10^{3} yr
Uranium	$^{238}_{92}U$	4.47×10^{9} yr
Indium	$^{115}_{49}In$	4.41×10^{14} yr

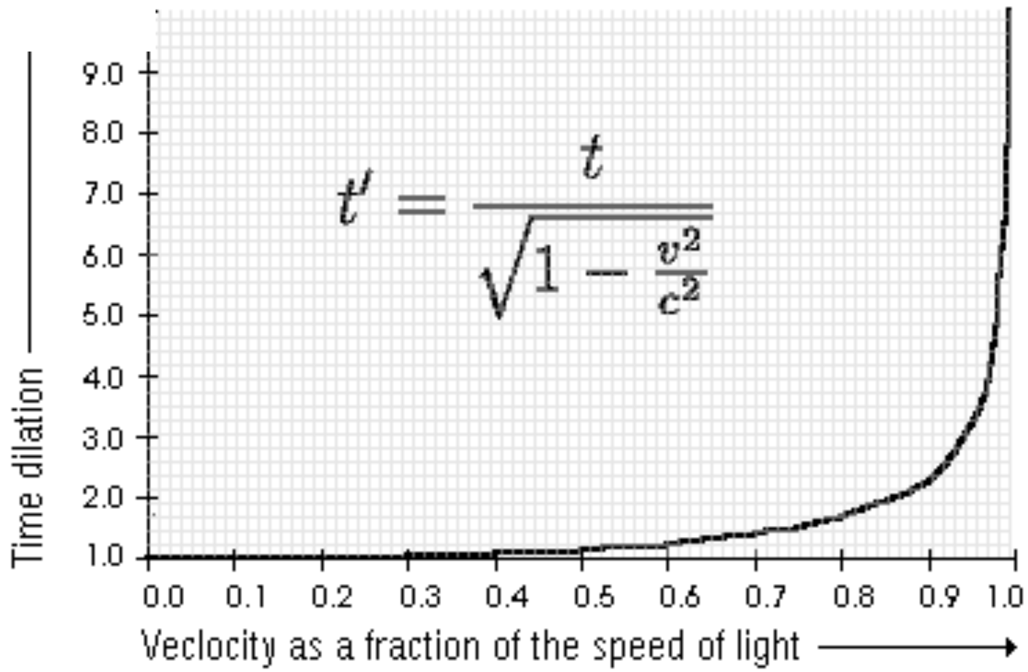
$$N = N_0 \cdot e^{-\frac{t}{\tau}} \quad \Rightarrow \quad \tau = \frac{T_{1/2}}{\ln 2} = \frac{T_{1/2}}{0.693}$$

Cinematica



Vita media: t ~ 0.4 ps
Velocità: v ~ c (0.9992)

Lunghezza:
classica: v × t ~ 0.12 mm
relativistica: ~ 3 mm



Particle Data Group

$$m_{D^0}^2 = m_K^2 + m_\pi^2 + 2\sqrt{m_K^2 + p_K^2}\sqrt{m_\pi^2 + p_\pi^2} - 2 p_K p_\pi \cos\vartheta$$

$\boxed{D^0}$

$I(J^P) = \frac{1}{2}(0^-)$

Mass $m = 1864.84 \pm 0.05$ MeV
$m_{D^\pm} - m_{D^0} = 4.77 \pm 0.08$ MeV
Mean life $\tau = (410.1 \pm 1.5) \times 10^{-15}$ s
$c\tau = 122.9\ \mu$m
$\left|m_{D_1^0} - m_{D_2^0}\right| = (0.95^{+0.41}_{-0.44}) \times 10^{10}\ \hbar\ \mathrm{s}^{-1}$
$(\Gamma_{D_1^0} - \Gamma_{D_2^0})/\Gamma = 2y = (1.29^{+0.14}_{-0.18}) \times 10^{-2}$
$\left|q/p\right| = 0.92^{+0.12}_{-0.09}$
$A_\Gamma = (-0.125 \pm 0.526) \times 10^{-3}$
$K^+\pi^-$ relative strong phase: $\cos\delta = 0.97 \pm 0.11$
$K^-\pi^+\pi^0$ coherence factor R ... $= 0.82 \pm 0.07$

D^0 DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Topological modes				
0-prongs	[aaa]	(15 ± 6) %		–
2-prongs		(70 ± 6) %		–
4-prongs	[bbb]	(14.5 ± 0.5) %		–
6-prongs	[ccc]	$(6.4 \pm 1.3) \times 10^{-4}$		–

http://pdg.lbl.gov

Misura dell'impulso

$$\vec{F} = q\vec{v} \times \vec{B}$$

[se v e B perpendicolari]

$$F = qvB$$

$$F = ma \quad \Rightarrow \quad a = \frac{v^2}{R}$$

$$qvB = m\frac{v^2}{R} \quad \Rightarrow R = \frac{p}{qB}$$