

Principle (Technical Proposal 1998)

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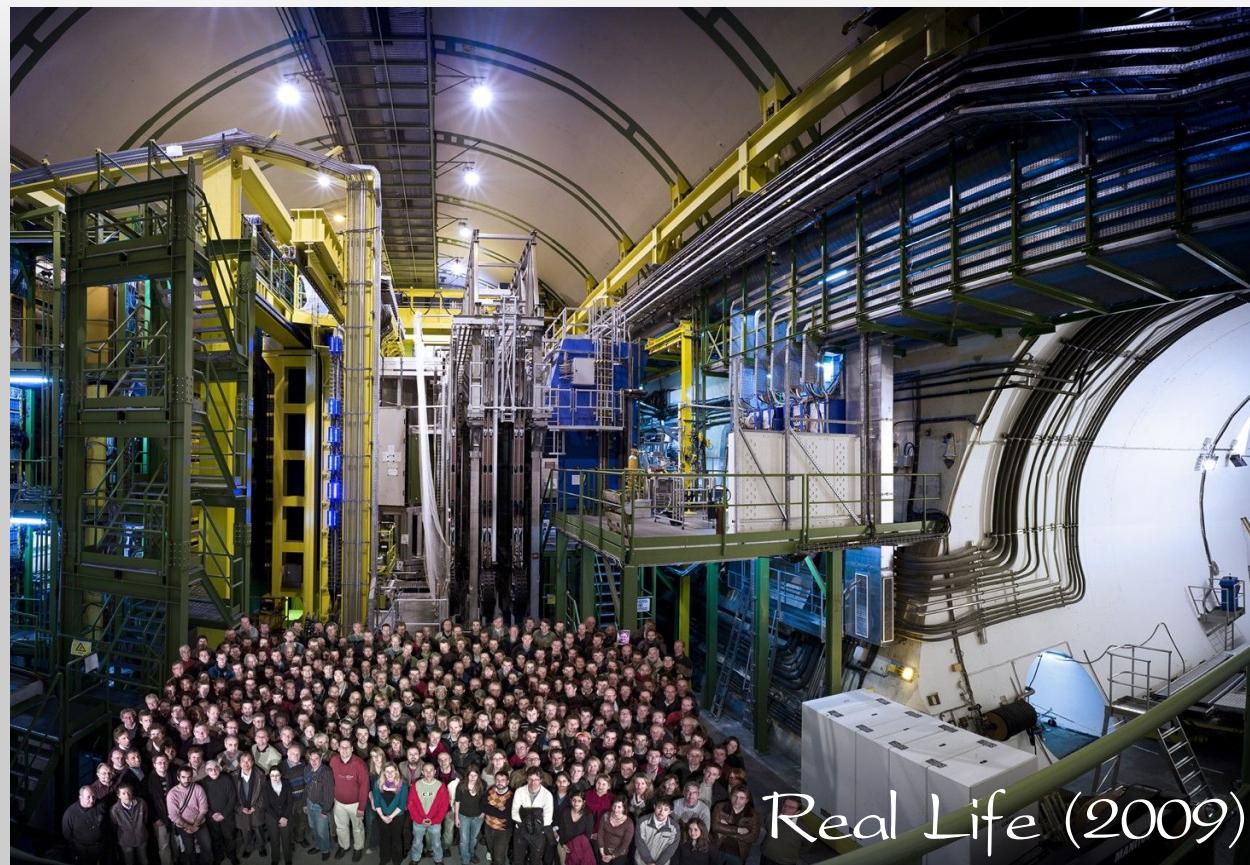


 on behalf of the
LHCb Collaboration

Rencontres du Vietnam
Physics at LHC and beyond
August 11, 2014

Run I Legacy Performance of LHCb

from Principle to Real Life



Real Life (2009)

The Challenge of LHCb

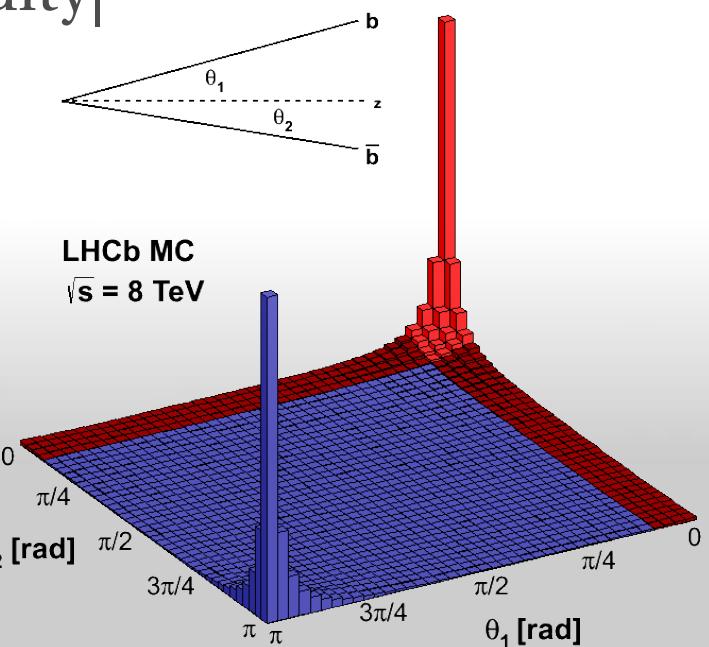
LHCb is the experiment devoted to heavy flavours at the LHC.

- ✓ Exploiting large $b\bar{b}$ production at high |rapidity|
- ✗ But need to identify heavy flavour decays from **huge hadronic background**
- ✗ High particle density in this rapidity region, experimental challenge

⇒ Forward detector with key features:

$(2 < \eta < 5)$

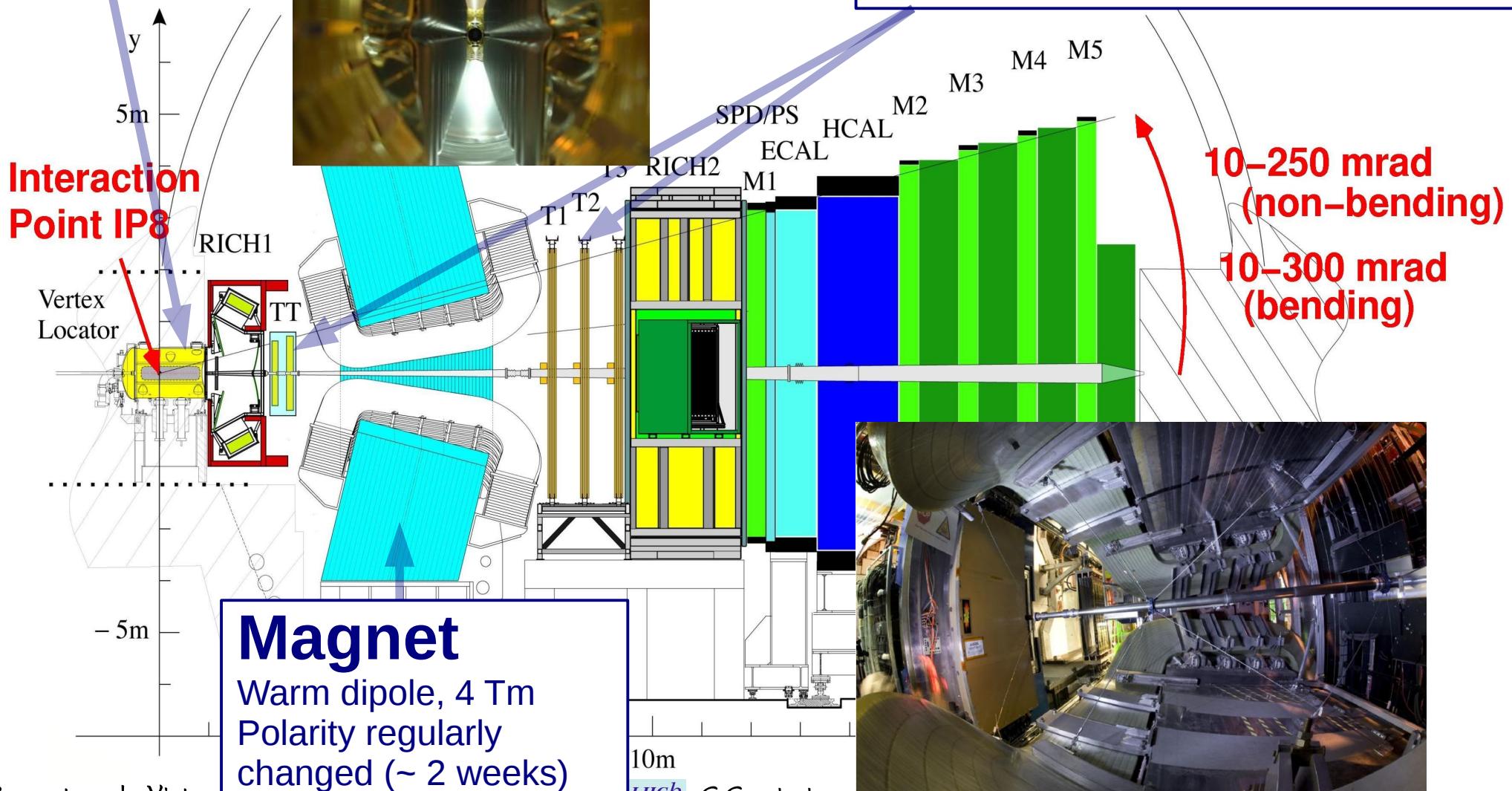
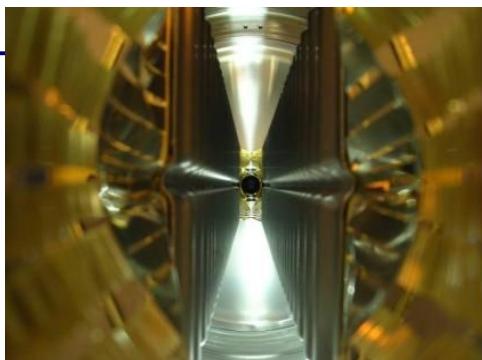
- Daring vertex detector design
- Excellent particle ID: π/K separation in 1-100 GeV/c range
- Fast, efficient and flexible high-bandwidth Trigger System
- Operating at lower pileup/luminosity than ATLAS/CMS



The Detector: Tracking

Vertex Locator

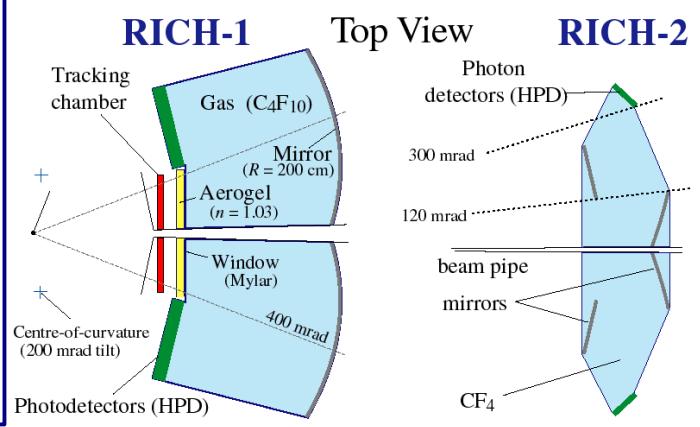
Si μ -strips sensors, orthogonal to beam, $r\phi$ geometry, movable device from 30 to 8 mm from beam!



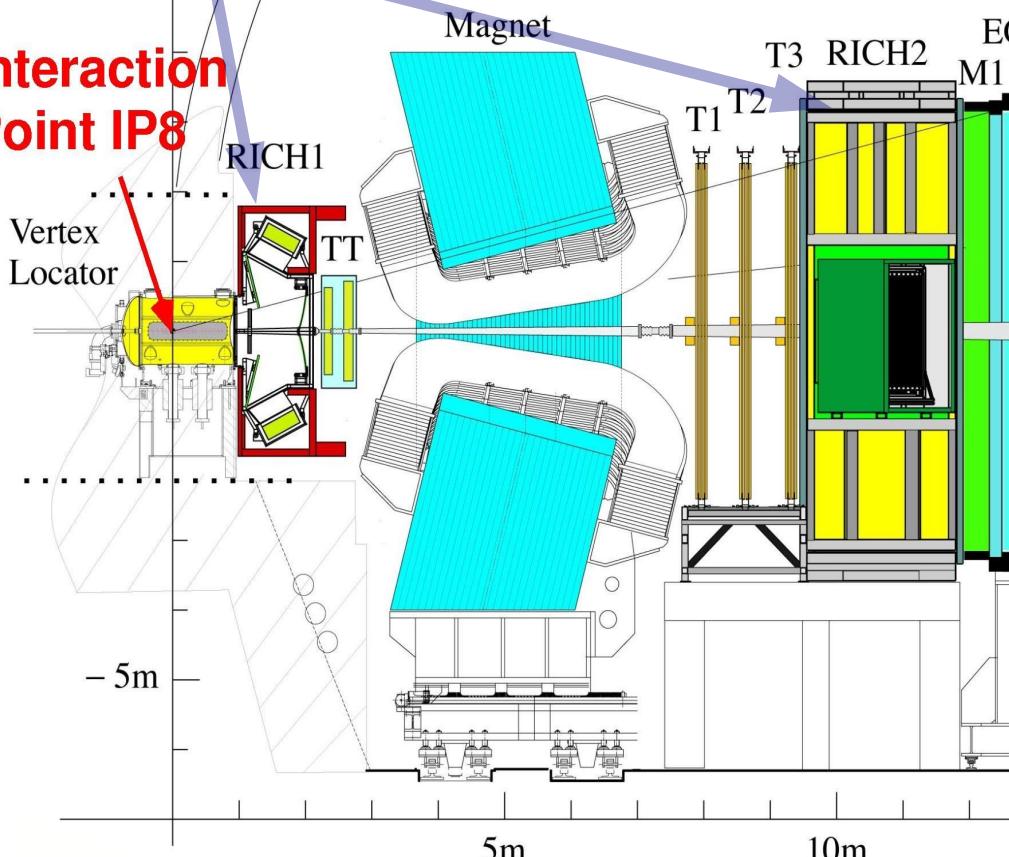
The Detector: Particle ID

RICHs

2 detectors using 3 radiators for π/K separation in wide momentum range (1-100 GeV/c). Readout by custom HPDs



Interaction Point IP8



Calorimeter System

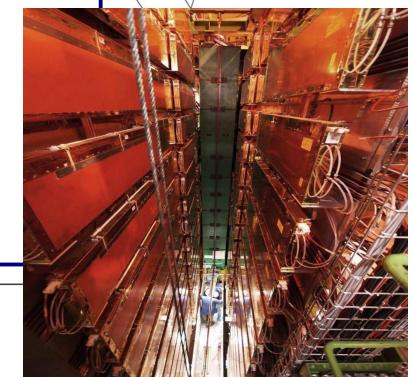
Scintillator Pad Detector, PreShower (Pb/scint. pads), ECAL (Pb/scint. tiles), HCAL (Fe/scint. tiles)



10–250 mrad (non-bending)
10–300 mrad (bending)

Muon System

5 stations, 1 before CALOs
MWPC, except GEMs for the inner part of M1



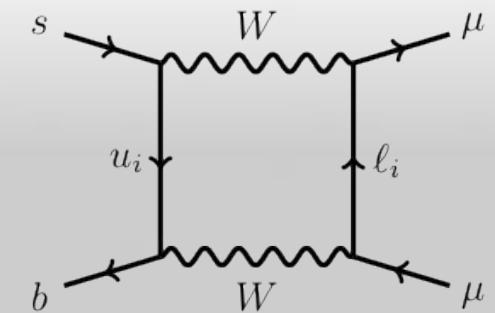
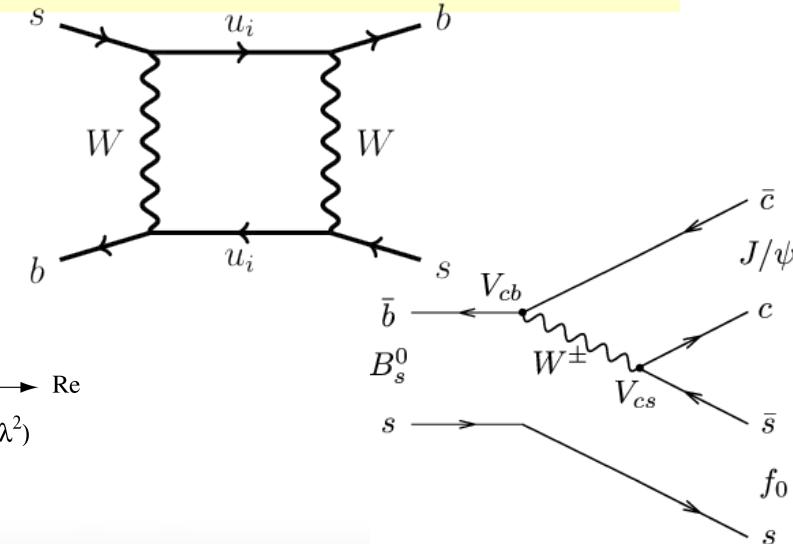
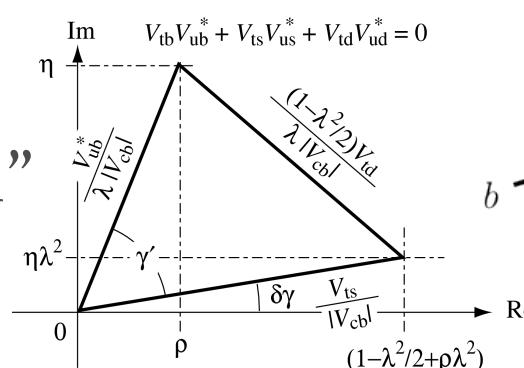
An evolving Physics case

Focus in 1998 (Technical Proposal)

- Test validity of CKM paradigm using “golden” CPV processes

Today

- After the successful B-factories and Tevatron programs, demonstrating the SM description of CPV at tree level, focus moved to loop processes sensitive to New Physics at higher scales
- Broaden physics program to include CPV in charm, b-baryons...
- ...and a rich program in flavour spectroscopy (exotica, double heavy states, ...) and more (EW physics, proton-lead collisions...)
 - evolution of trigger design and operation strategy toward a more general-purpose forward detector



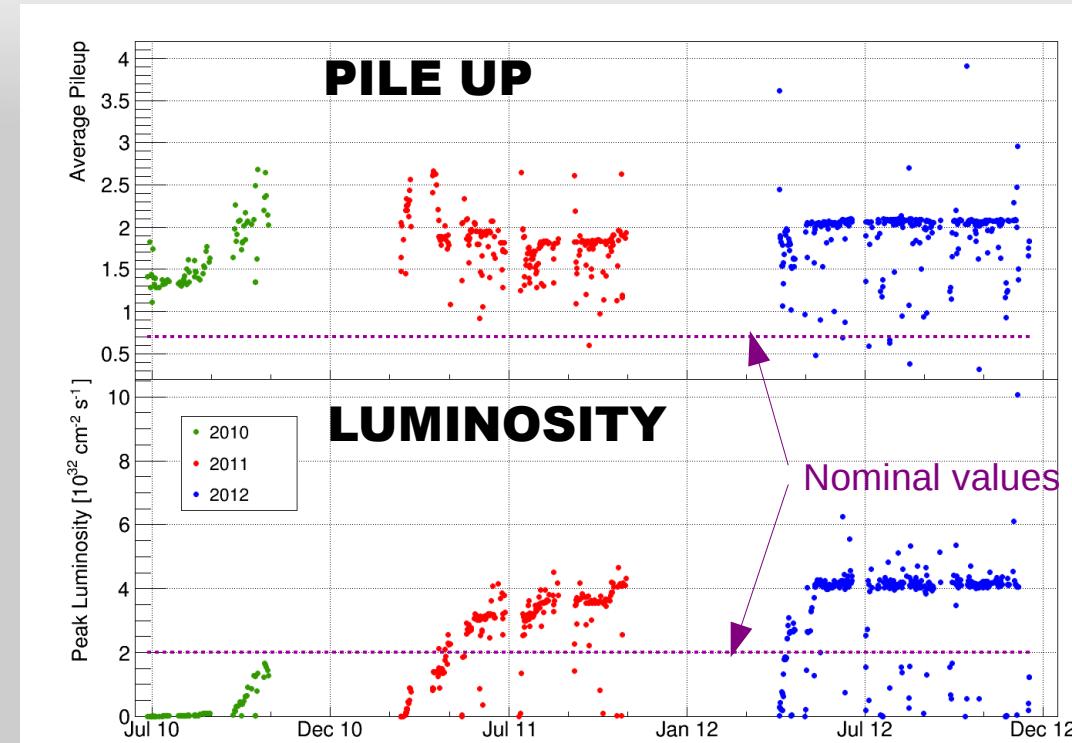
LHCb Operation

Principle

- 25 ns bunch spacing, 2808 bunches, 14 TeV
- Fight pile-up events: work at $\mu=0.7$ visible interactions/crossing
(maximize number of events with single interaction)
- Luminosity = $2 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$, 2 fb^{-1} per year

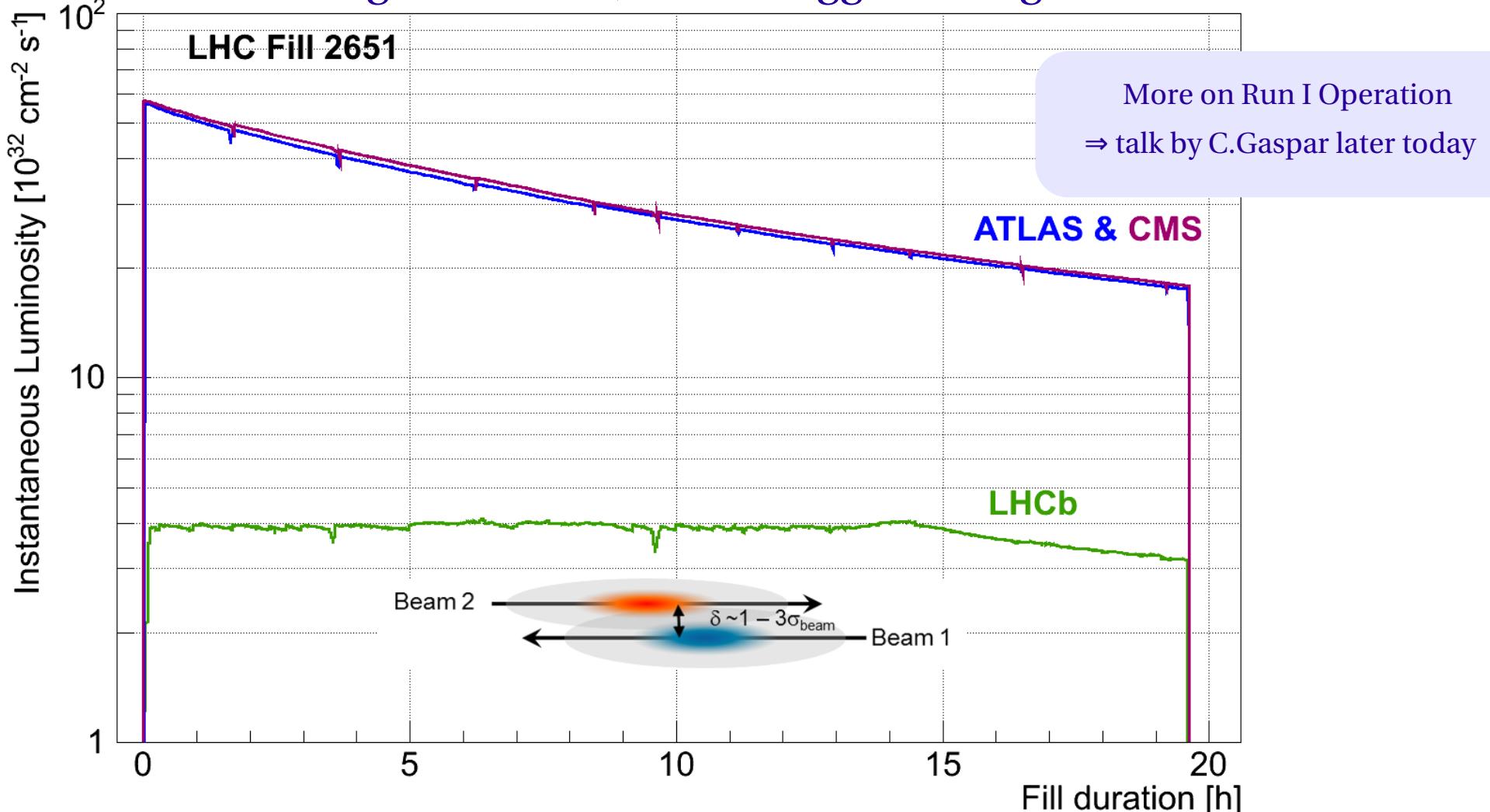
Real Life

- 50 ns bunch spacing, 7/8 TeV
 < 1300 bunches
 - Pile-up up to $\mu=3$
 - Learn by experience:
 - verify detector & physics performance under these harsh conditions
 - exploit trigger flexibility to adapt its configuration
 - Push luminosity for rare decays
⇒ 2012 “compromise” working point
- $\mathcal{L} = 4 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$ $\mu=2.1$



Luminosity levelling

- Luminosity adjusted dynamically to required level during fills by beam transverse displacement
- Great interplay between machine and experiment!
- Maximum integrated lumi., stable trigger configuration

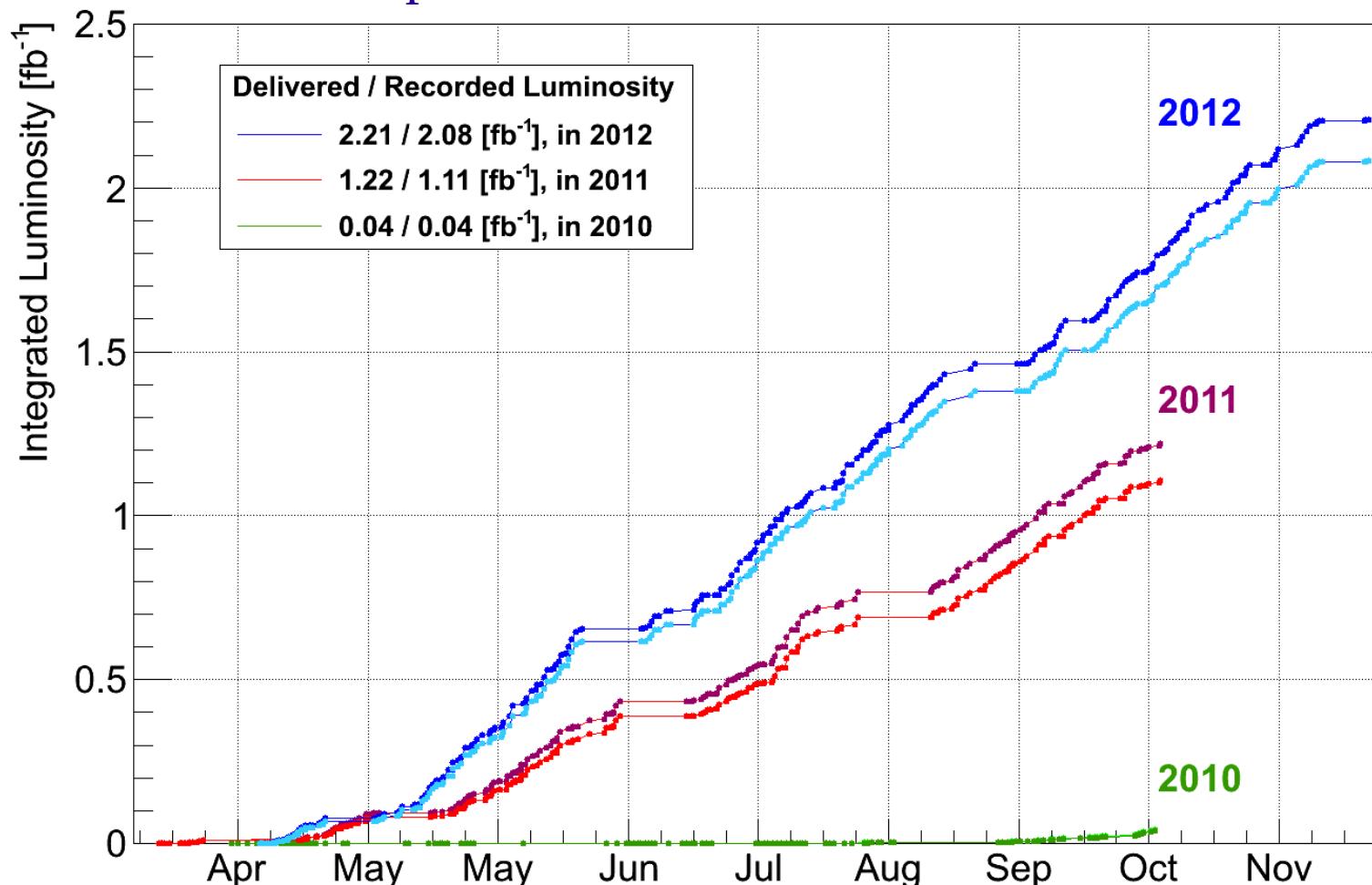


Integrated Luminosity

After data quality requirements:

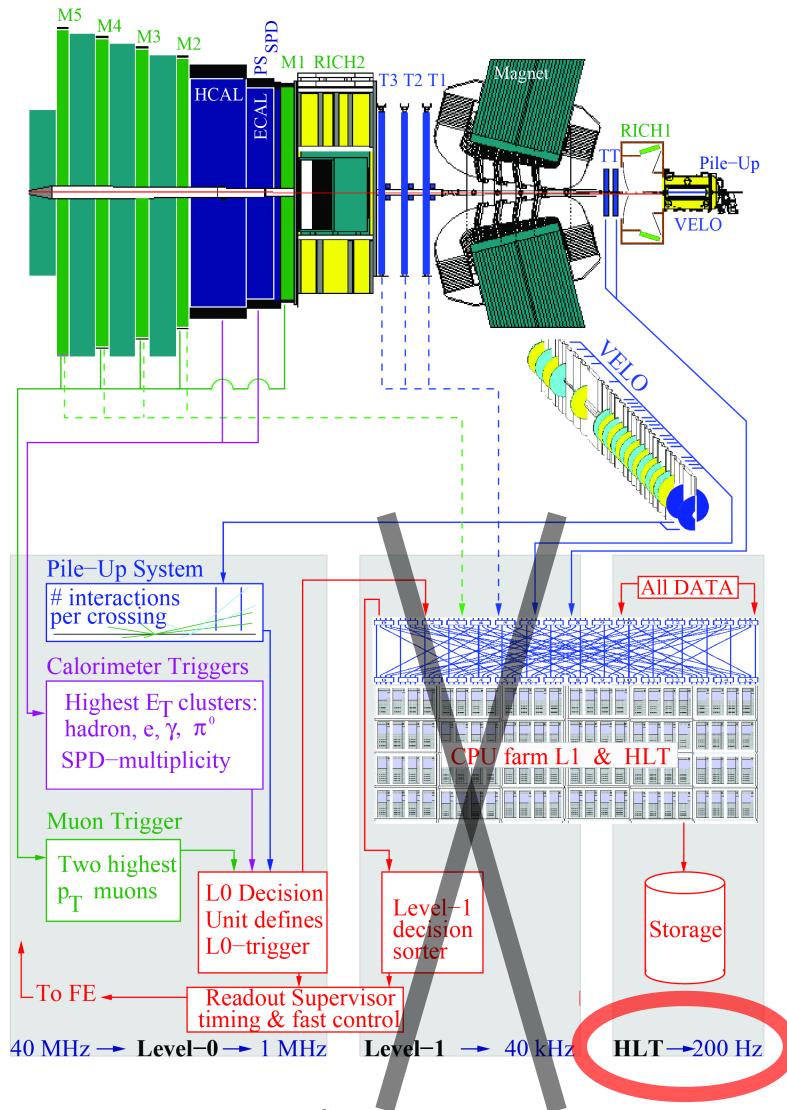
- 1.0 fb^{-1} in 2011@7 TeV
- 2.0 fb^{-1} in 2012@8 TeV (nominal lumi/year of TDR!)

+ 1.6 nb^{-1} proton-Pb@ $\sqrt{s}=5 \text{ TeV}$



The LHCb Trigger

Principle (trigger TDR 2003)



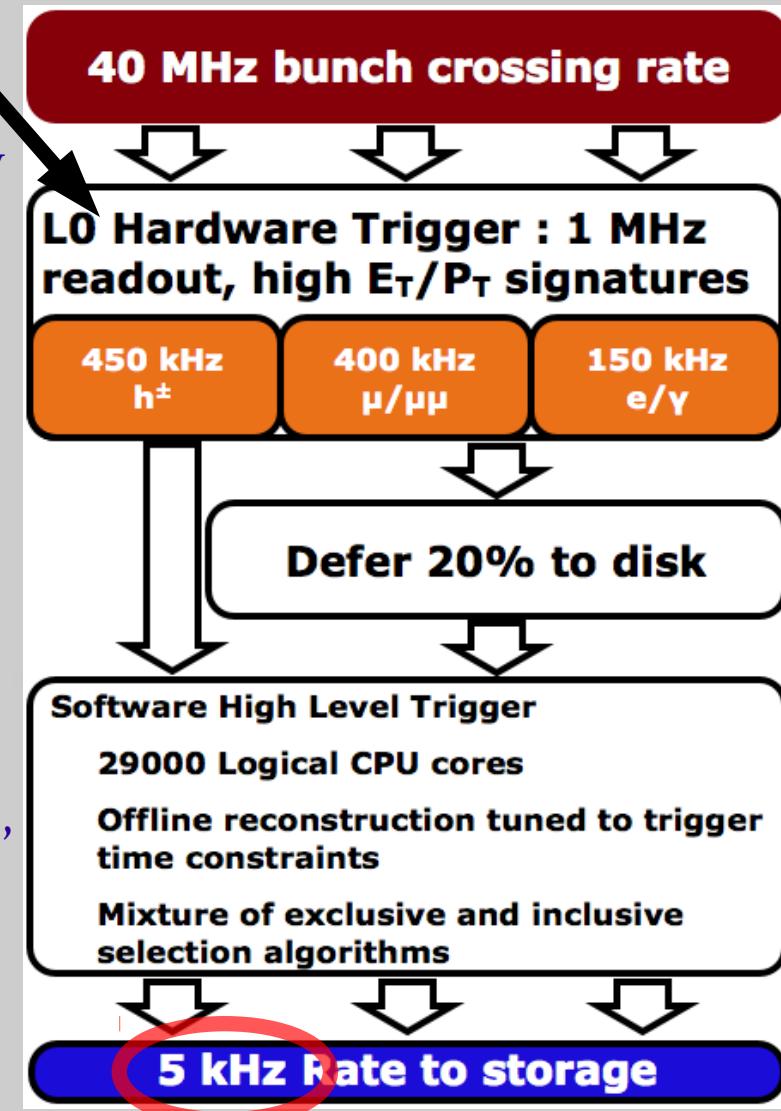
L1 removed in 2005

⇒ full 1 MHz software trigger with
2 kHz output! big gain in flexibility

Real Life

Pile-up veto removed from L0 (replaced by global cut on track multiplicity)

Maximize output rate for wider physics program (charm physics, hadron spectroscopy, data mining)



Further development for Run II,
expect to reach 12.5 kHz!
⇒ talk by K.Hennessy on Friday

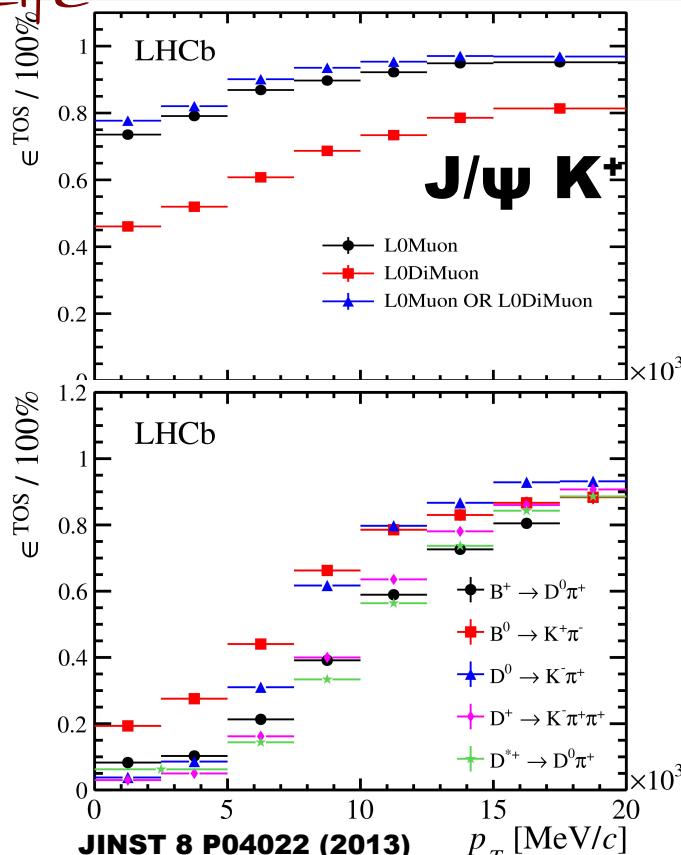
L0 Trigger

Principle (trigger TDR 2003)

| Decay Channel | $\epsilon_{L0}(\%)$ |
|---|---------------------|
| $B^+ \rightarrow J/\psi(\mu^+\mu^-)K^+$ | 90.3 ± 0.4 |
| $B^0 \rightarrow K^+\pi^-$ | 54.1 ± 0.8 |

trigger TDR CERN/LHCC 2003-031

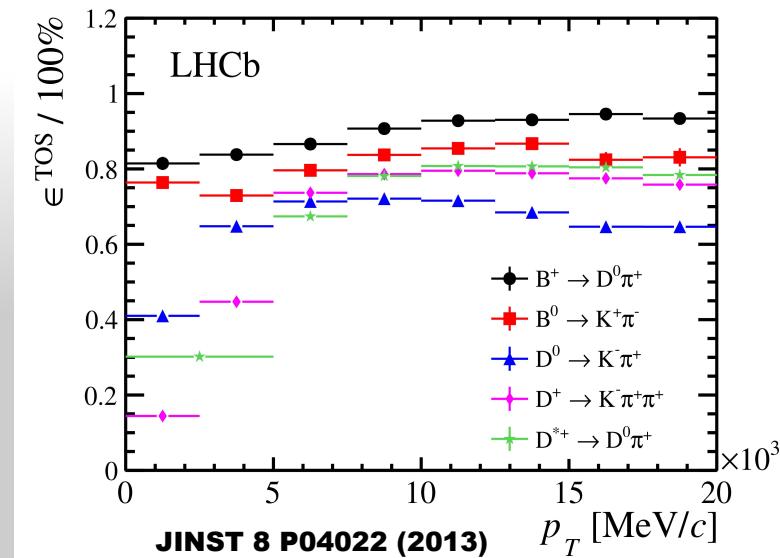
Real Life



Trigger Performance

High Level Trigger

- HLT1: fast track/vertex reconstruction, selects tracks from their p_T /displacement, and high-mass dimuons



- HLT2: full reconstruction and inclusive/exclusive selections, also using MVA algorithms
- Performance/flexibility well beyond original design

Principle

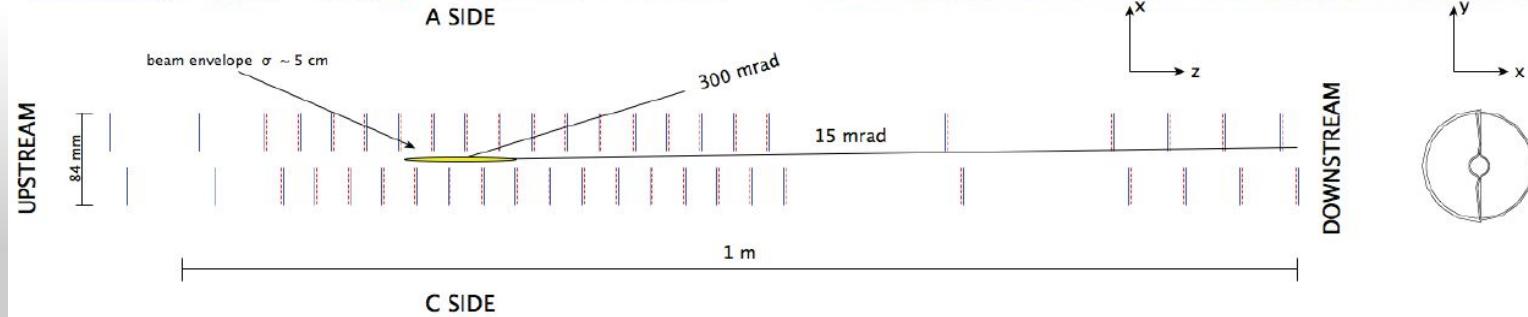
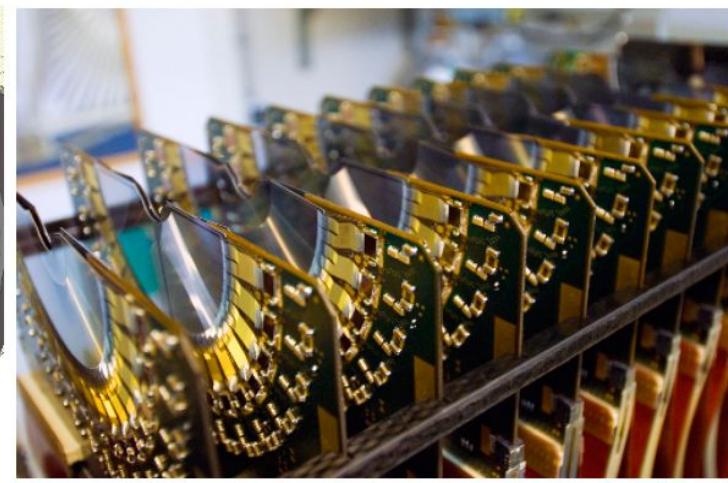
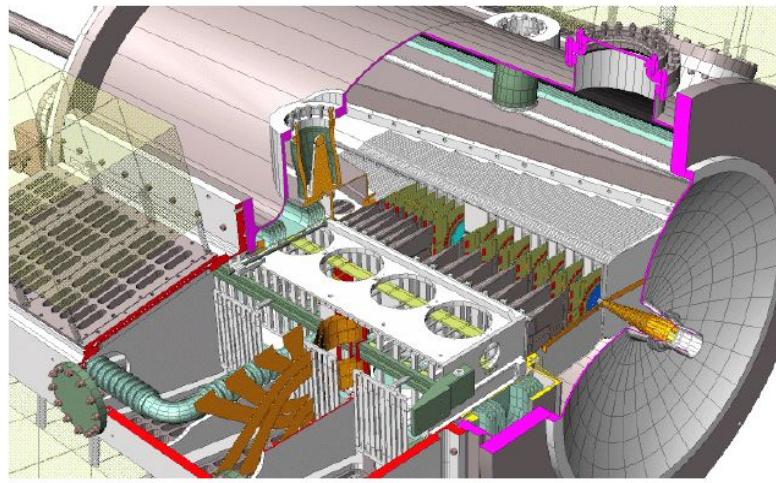
Daring design:

- Detector halves moving from 30 to **8 mm** from axis when stable beam declared

Concerns:

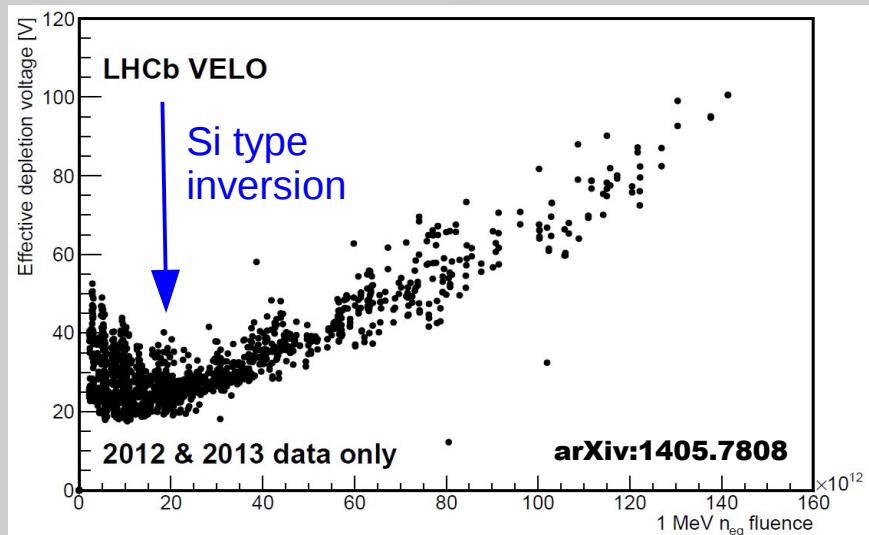
- Safety!
- Radiation damage
fluence up to $5 \times 10^{13} n_{\text{eq}} / (\text{cm}^2 \text{ fb}^{-1})$
⇒ complete spare detector built

The VErtex LOcator



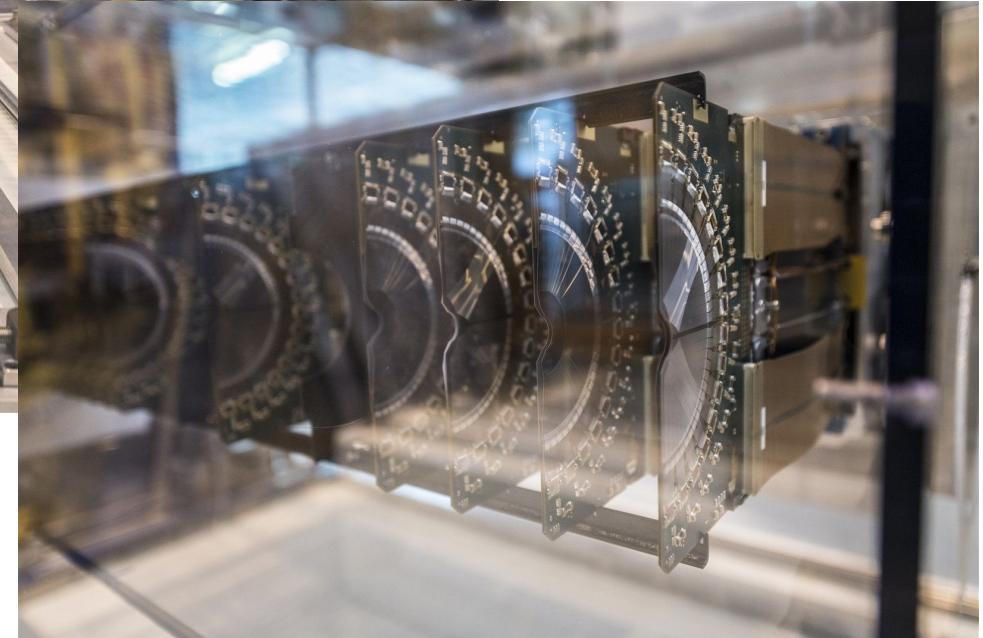
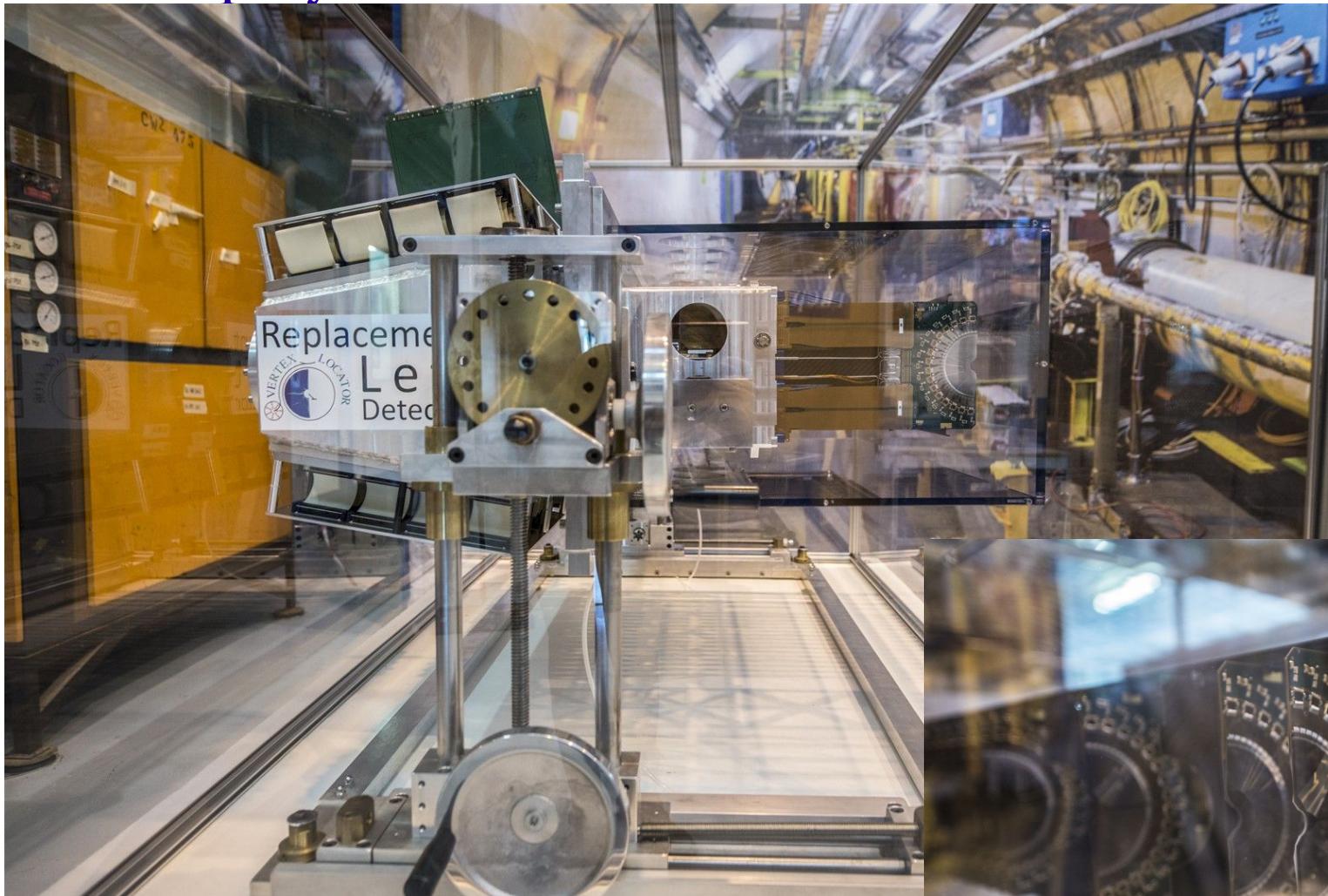
Real Life

- Beam orbit proved to be very stable
- Effect of rad. damage well controlled, effects on performance acceptable
- Detector replacement not foreseen during Run II



VELO Spare detector

On display at LHCb site (Point 8), main LHCb tourist attraction!

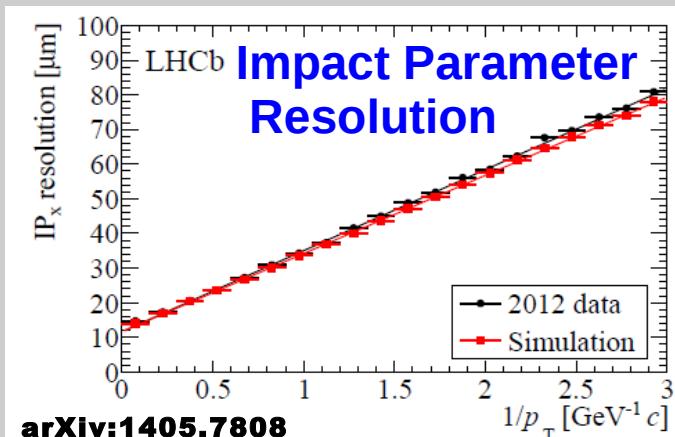
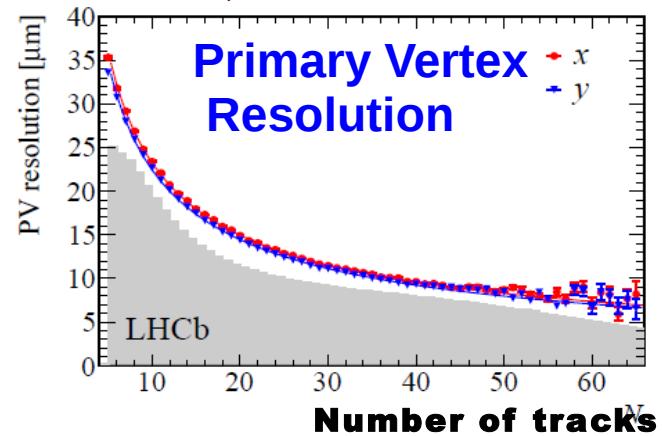


VELO Performances

Principle

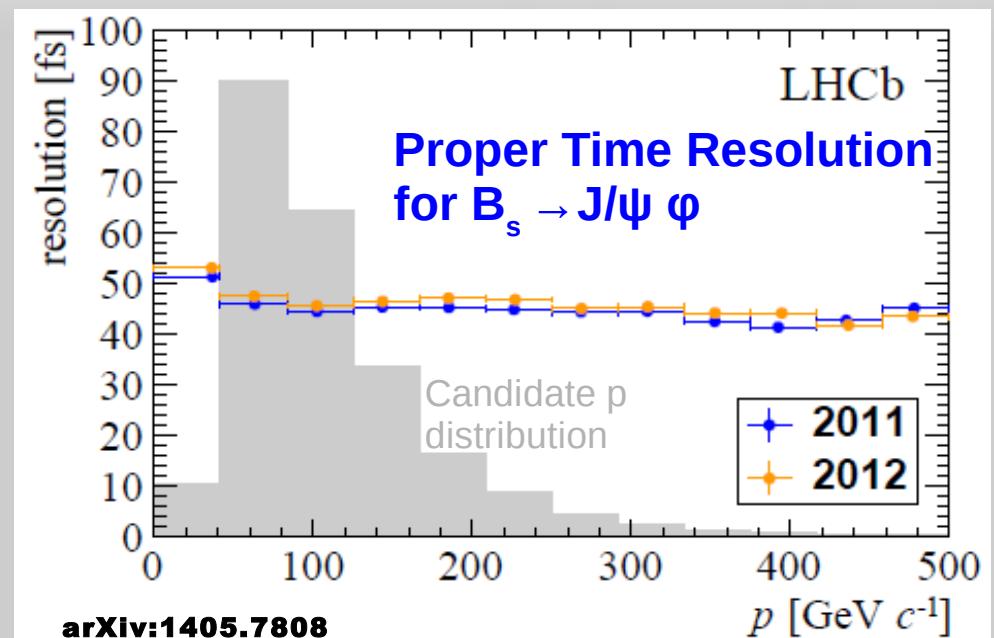
- Simplified TDR simulations (2003):
aim at proper time resolution ~ 40 fs for $B_s \rightarrow J/\psi \phi$

Real Life



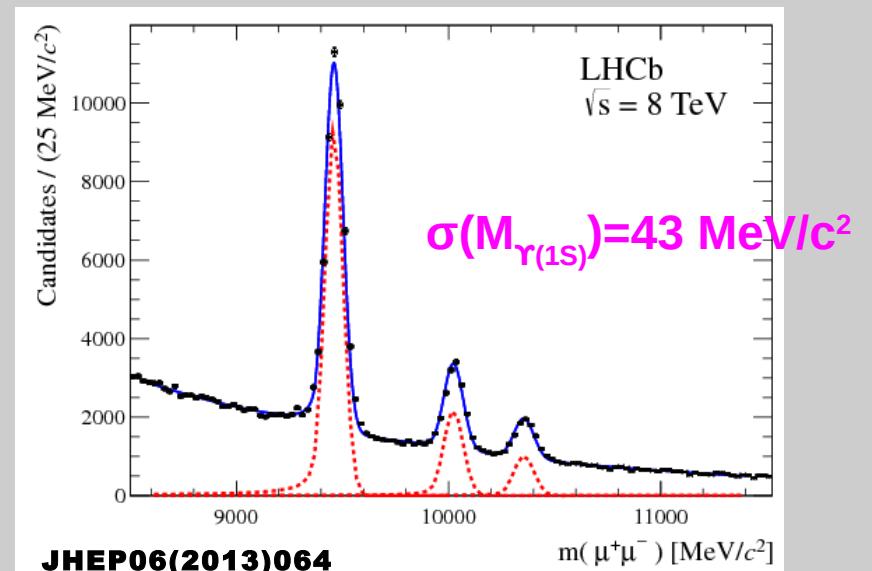
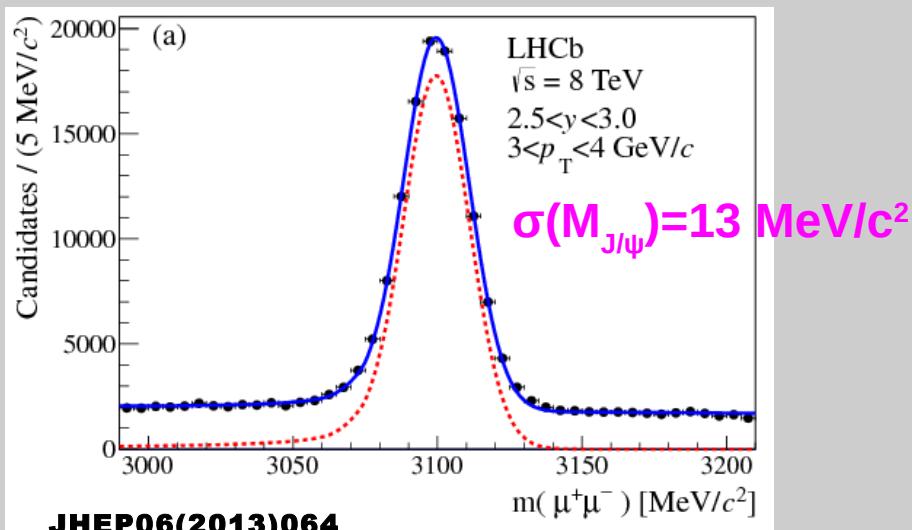
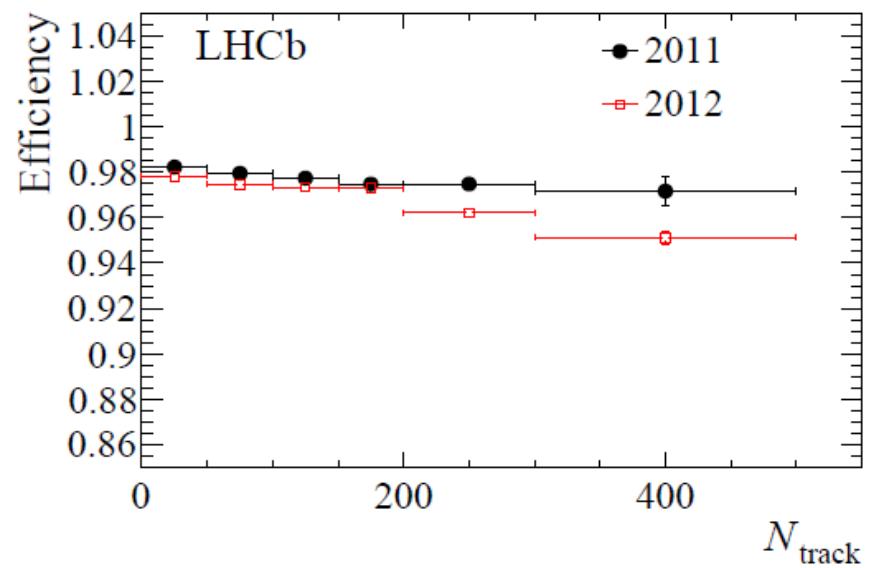
- Detector response in good agreement with simulations
- Achieved average proper time resolution **45 fs**

PRD87 (2013) 11, 112010

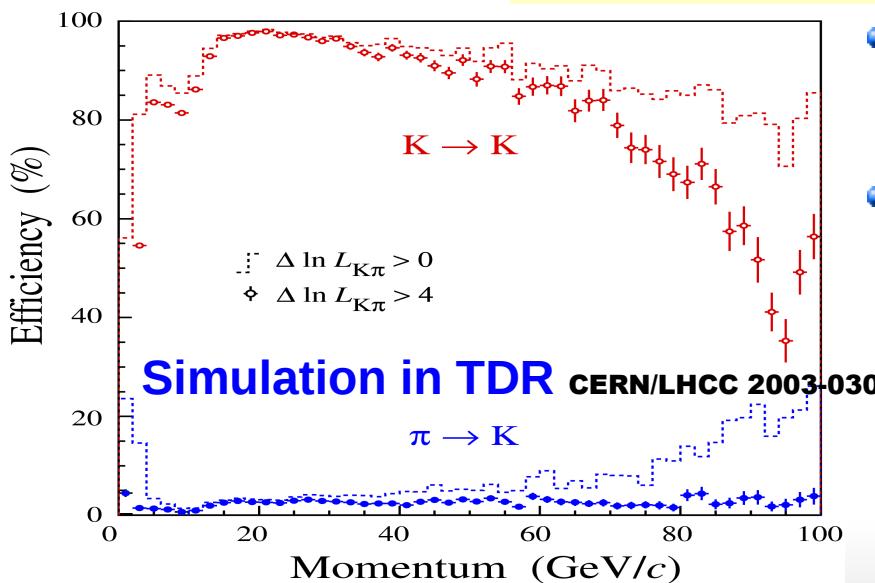


Tracking Performances

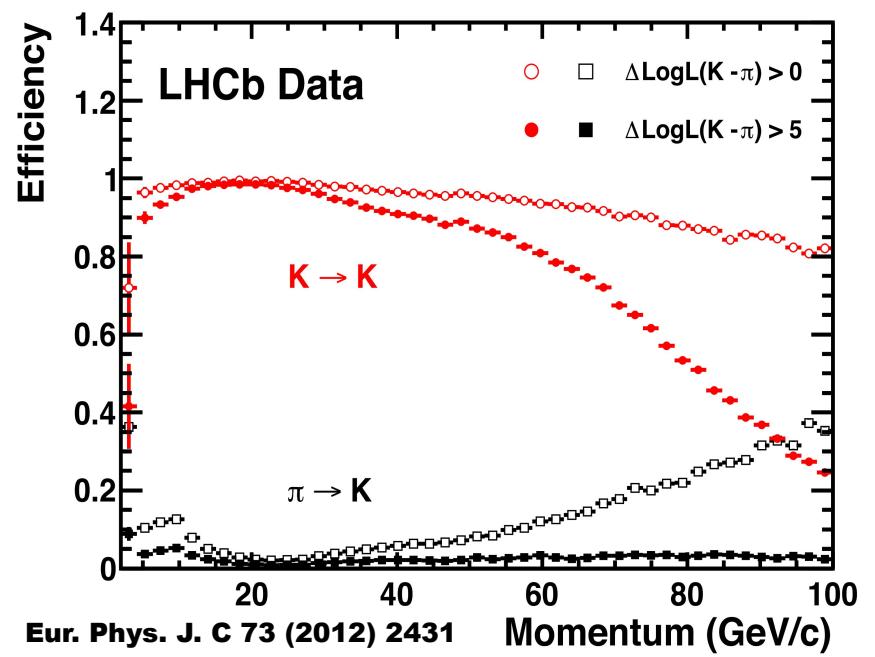
- Main tracker performances also in line with expectations
- Aging effects in Outer Tracker: understood and fixed
- Track finding efficiency only slightly reduced in crowded events
- Momentum resolution
0.4 – 0.6% for $p < 100 \text{ GeV}/c$
- Best mass resolution for quarkonia at LHC!



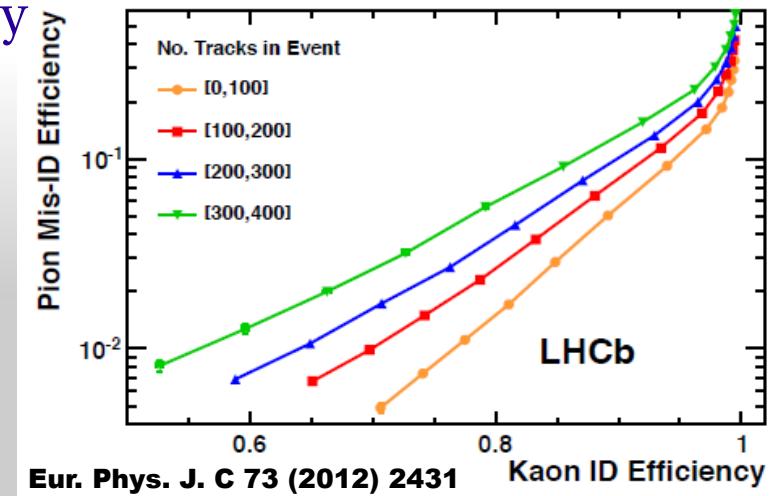
RICH Performances



Real Life



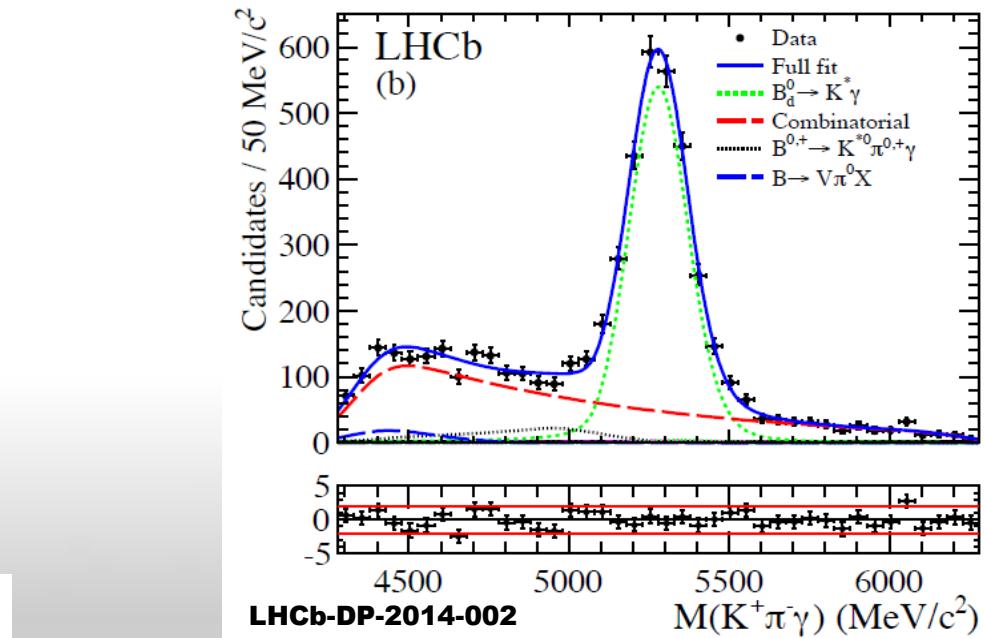
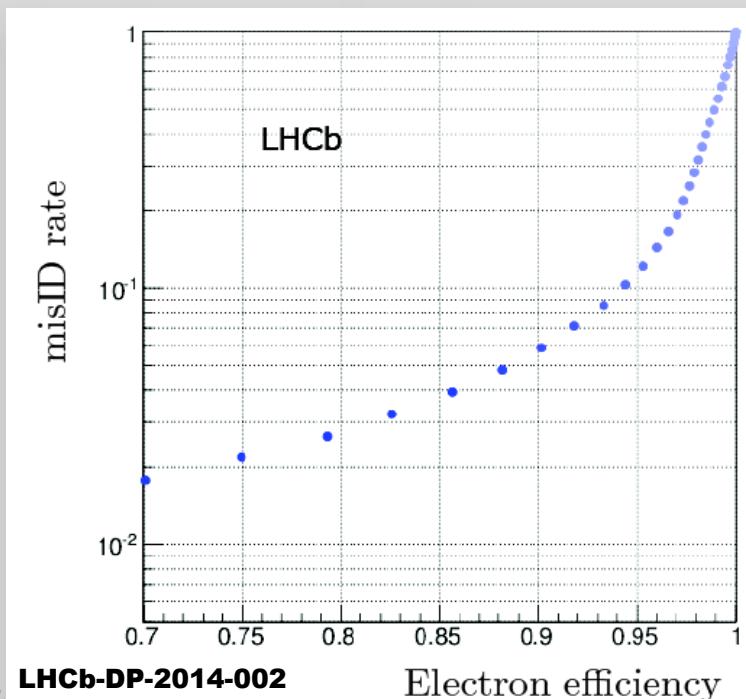
- RICH1 covering low (2-60 GeV/c) p region, using Aerogel and C_4F_{10} radiators
- RICH2 covers higher momenta with CF_4 radiator
- Detector suffering most from higher track multiplicity



- Aerogel performance slightly worse than expected
- Though, overall performance close to expectations

Calorimeter Performances

- Calorimeter system identifies electrons/photons/ π^0 /neutral hadrons combining information from
 - Scintillating pad detector
 - Preshower
 - ECAL
 - HCAL
- Achieved expected resolution of $<9 \text{ MeV}/c^2$ on π^0 mass

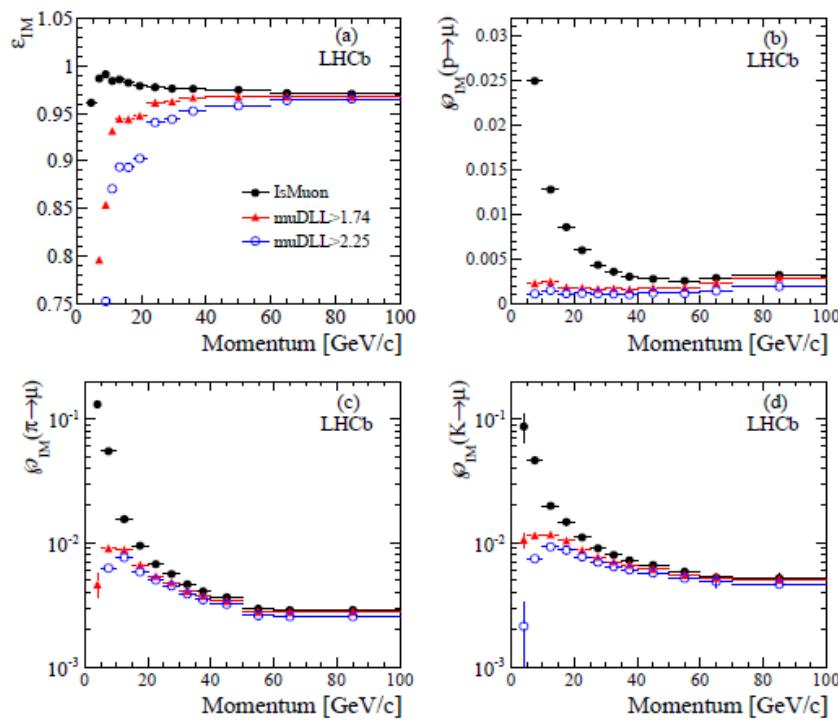
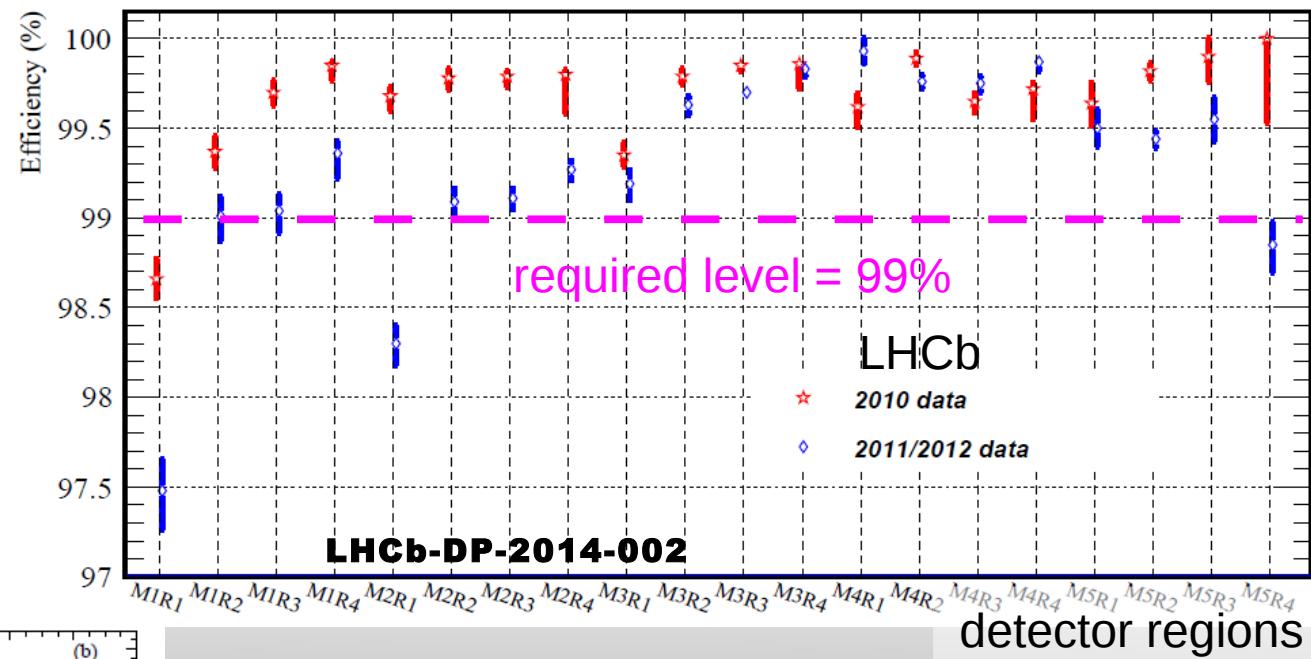


Example of radiative decay: $B^0 \rightarrow K^*\gamma$
 $\sigma=93 \text{ MeV}/c^2$, dominated by ECAL

- Electron identification performance in line with expectations: 5.5% misID rate for 90% efficiency

Muon Performances

- Detector efficiency beyond expectations



- Muon identification performances agree well with expectations:
misID rate for hadrons < 0.6%
for efficiency = 93%

JINST 8 P10020 (2013)

Physics Performances

- Benchmark numbers on B_s oscillations (statistical uncertainties with 1 fb^{-1}) :

Principle (TDR 2003)

$$\sigma(\Delta m_s) = 0.015 \text{ ps}^{-1}$$

$$\sigma(\Delta \Gamma_s) = 0.017 \text{ ps}^{-1}$$

$$\sigma(\phi_s) = 0.09 \text{ rad}$$

Real Life (1 fb^{-1} results)

$$\sigma(\Delta m_s) = 0.023 \text{ ps}^{-1}$$

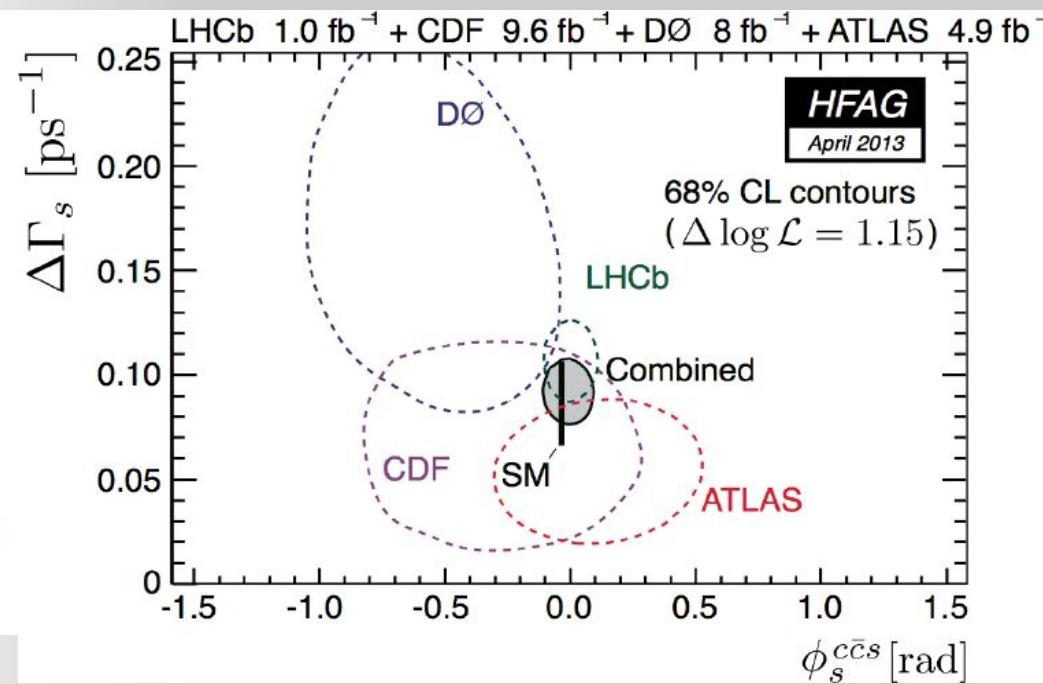
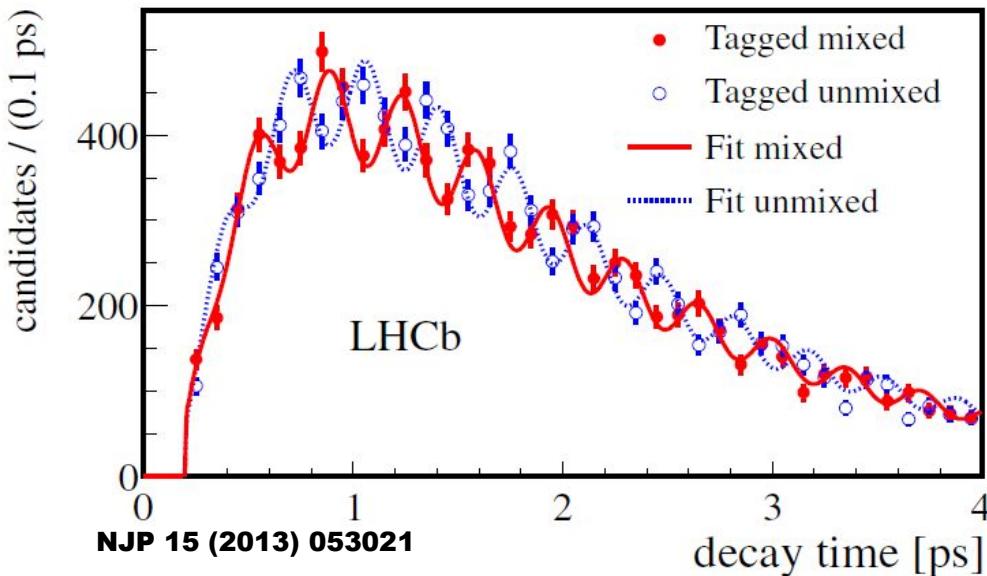
NJP 15 (2013) 053021

$$\sigma(\Delta \Gamma_s) = 0.011 \text{ ps}^{-1}$$

PRD87 (2013) 11, 112010

$$\sigma(\phi_s) = 0.07 \text{ rad}$$

Measurements still limited by statistics!



Physics Performances

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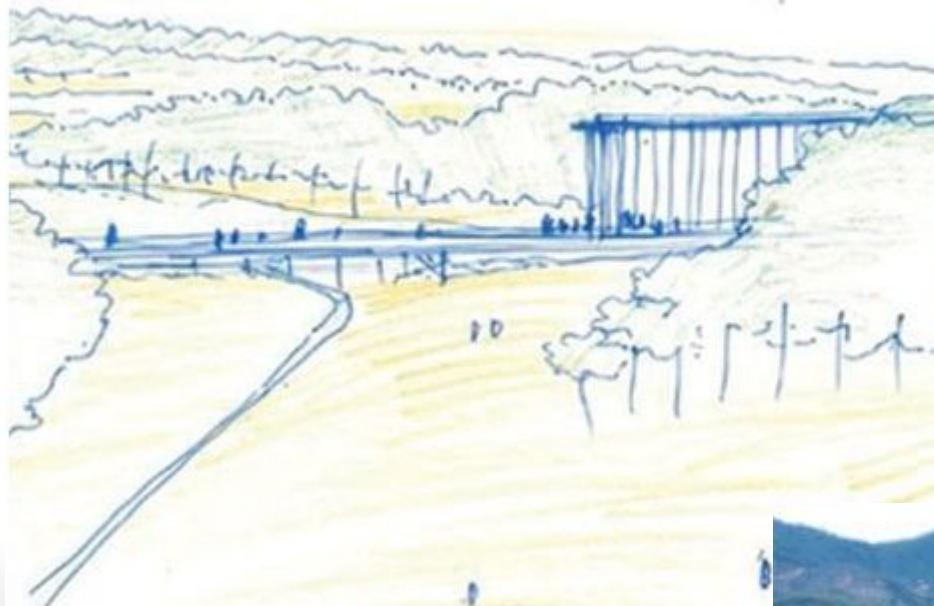
Most cited LHCb physics results today:

1. $B_s \rightarrow \mu\mu$
2. CPV in $D^0 \rightarrow hh$ decays
3. $b\bar{b}$ production
4. J/ψ production
5. Φ_s measurement
6. b fragmentation fractions
7. X(3872) quantum numbers

| Decay Modes | Visible Br. fraction | Offline Reconstr. |
|---|----------------------|-------------------|
| $B_d^0 \rightarrow \pi^+ \pi^- + \text{tag}$ | 0.7×10^{-5} | 6.9 k |
| $B_d^0 \rightarrow K^+ \pi^-$ | 1.5×10^{-5} | 33 k |
| $B_d^0 \rightarrow \rho^+ \pi^- + \text{tag}$ | 1.8×10^{-5} | 551 |
| $B_d^0 \rightarrow J/\psi K_S + \text{tag}$ | 3.6×10^{-5} | 56 k |
| $B_d^0 \rightarrow \bar{D}^0 K^{*0}$ | 3.3×10^{-7} | 337 |
| $B_d^0 \rightarrow K^{*0} \gamma$ | 3.2×10^{-5} | 26 k |
| $B_s^0 \rightarrow D_s^- \pi^+ + \text{tag}$ | 1.2×10^{-4} | 35 k |
| $B_s^0 \rightarrow D_s^- K^+ + \text{tag}$ | 8.1×10^{-6} | 2.1 k |
| $B_s^0 \rightarrow J/\psi \phi + \text{tag}$ | 5.4×10^{-5} | 44 k |

“golden” channels mentioned in TP (1998)

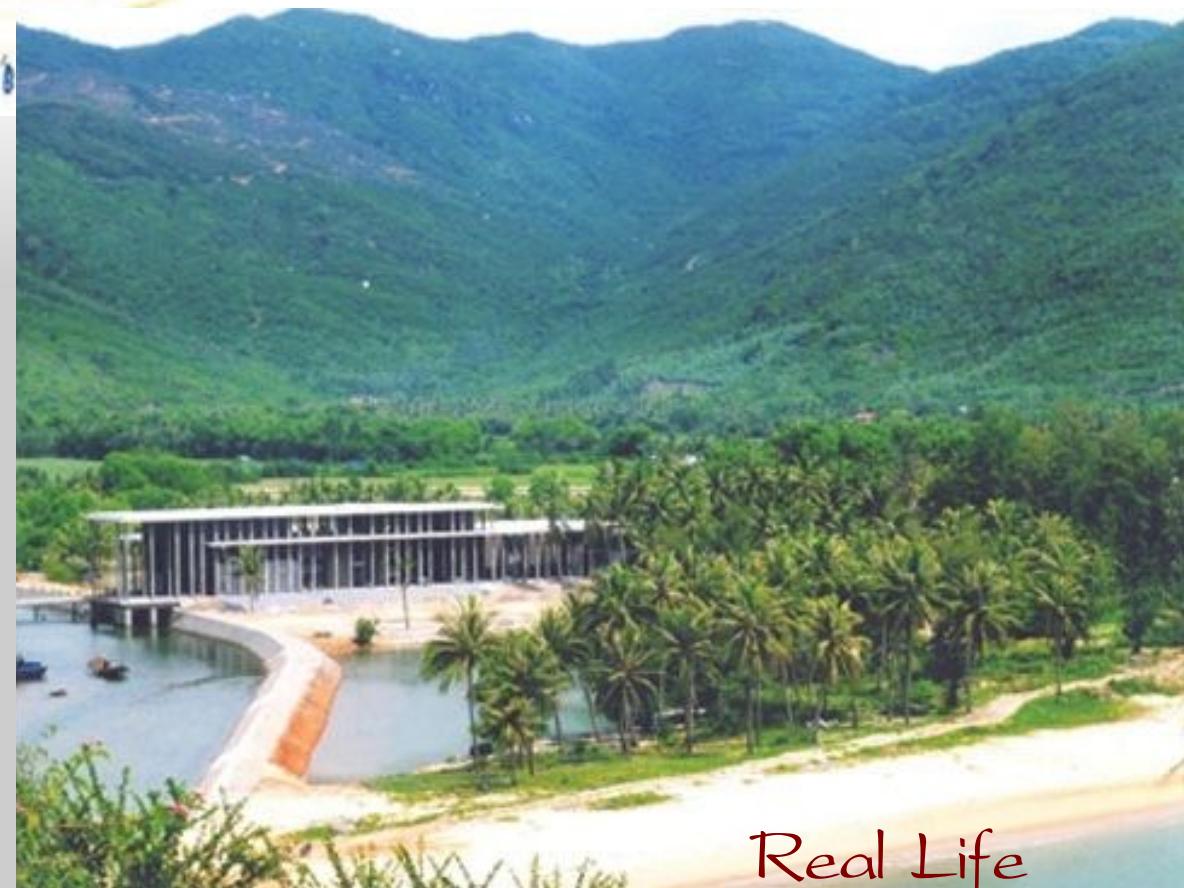
Principle



- LHCb detector looking forward to be able to acquire much more data:
 - Run II plans
⇒ talk by K.Hennessy on Friday
 - Upgrade plans, aiming at increase luminosity by up to 5x from 2019 and collect $>50 \text{ fb}^{-1}$
⇒ talk by O.Steinkamp on Friday

Conclusions

- Reality sometimes beyond (realistic) dreams!



Real Life