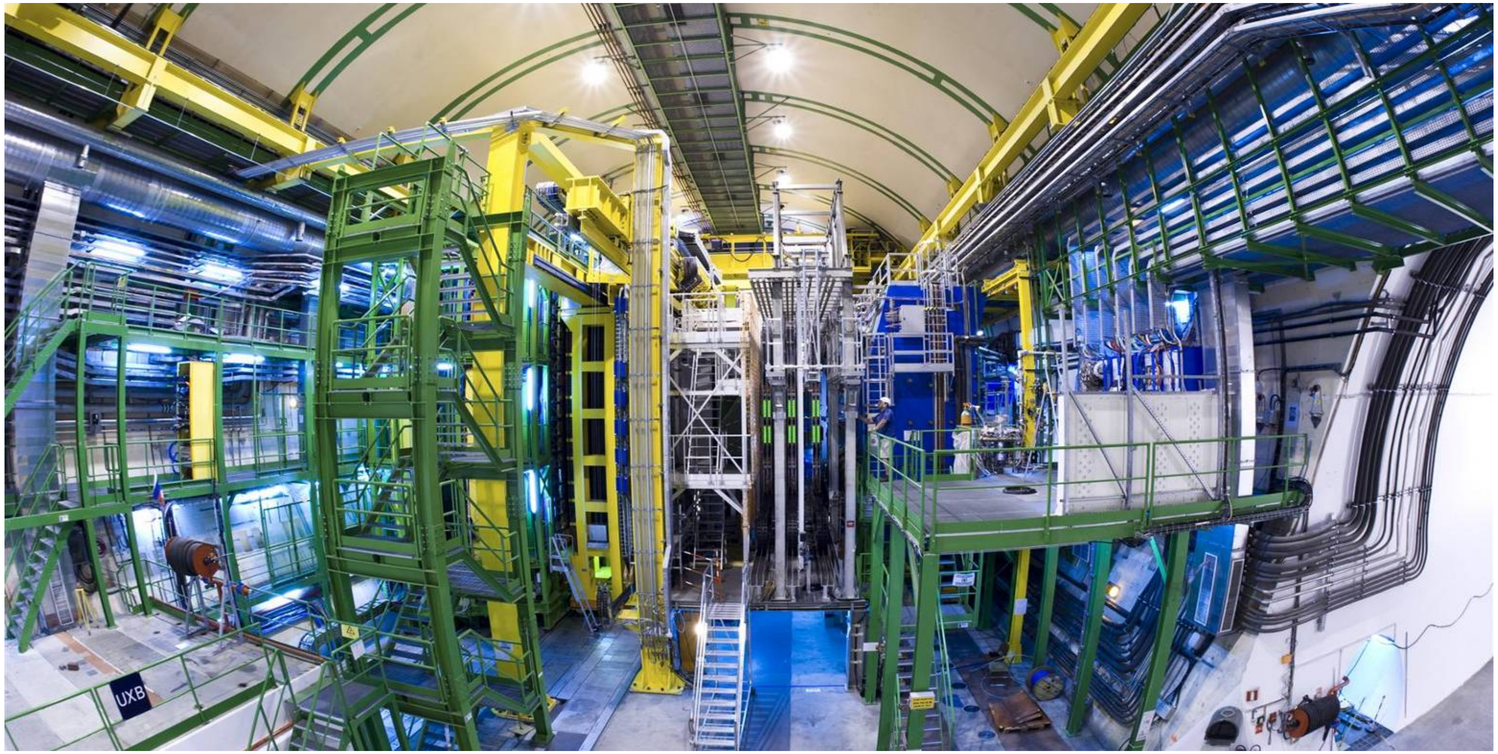
Operation and Performance of the LHCb Experiment



Patrizia de Simone

on behalf of the LHCb Collaboration

Epiphany Conference Cracow, 10-12 January 2011

LHC as a *b-factory*

- ✓ *$b\bar{b}$-pairs produced with high cross-section at LHC*

  from PYTHIA $\sqrt{s}$ = 7, 10, 14 TeV

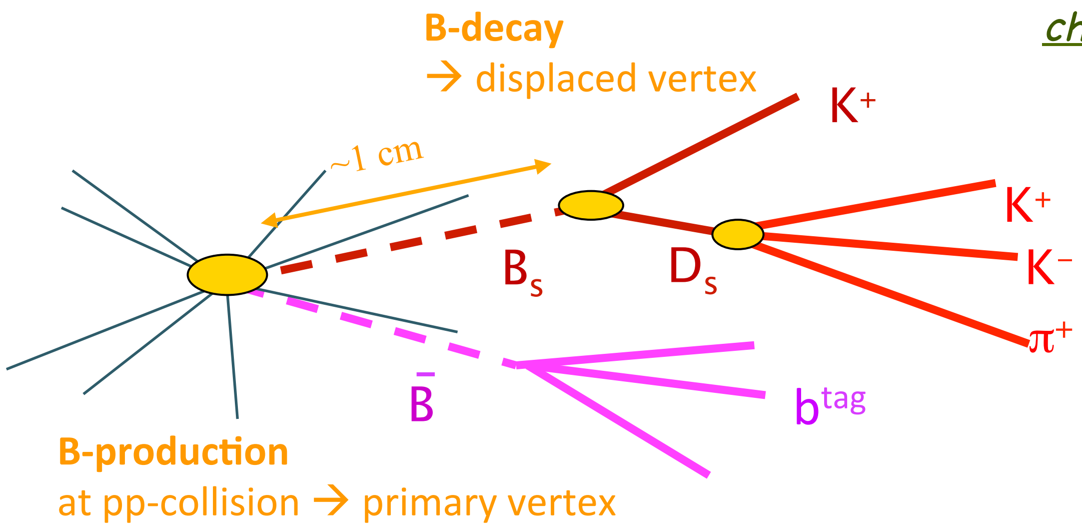
  $\sigma_{inel} \approx$ (0.89, 0.95, 1) × 80 mb

  $\sigma_{b\bar{b}} \approx$ (0.44, 0.67, 1) × 500 μb → ≈ (4.4, 6.7, 10.)10^{11} $b\bar{b}$ produced in 1 year at $2X10^{32}$ $cm^{-2}s^{-1}$

  charm production 10 × larger

- ✓ all species of particles containing a b-quark are produced
  (B_u^+, B_u^-, B_d^0, $\bar{B}_d^0$, B_c^+, B_c^-, B_s^0, $\bar{B}_s^0$, Λ_b, etc.)

- ✓ the mean B decay flight distance ≈ 1 cm



challenge to select the events of interest:

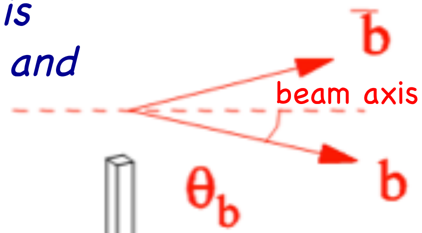
- ✓ $\sigma_{b\bar{b}}$ < 1% σ_{inel}
- ✓ B decays of interest typically have BR < 10^{-5}
- ✓ **need high statistics and high selectivity**

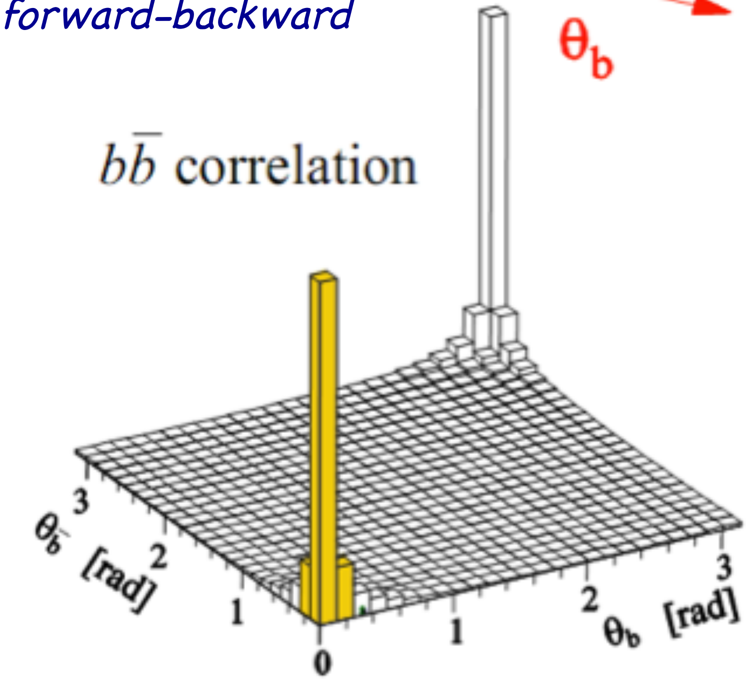
The LHCb Experiment

exploting the abundant bb production at LHC to

- ✓ high precision studies of CP violation and rare decays with beauty and charm hadrons
- ✓ search of New Physics probing the flavour structure of the SM

bb-pair production is strongly correlated and sharply peaked forward-backward

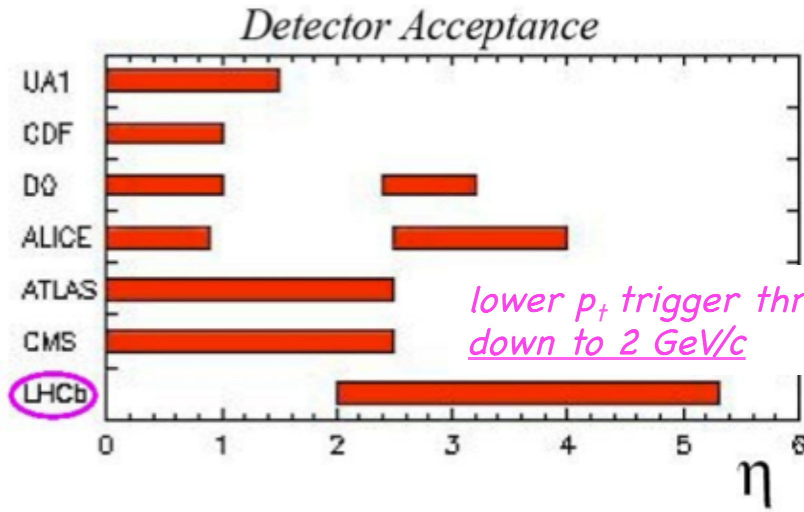




single arm forward spectrometer

angular coverage : 15 < θ < 250 mrad (V)
15 < θ < 300 mrad (H)

→ unique coverage 2 < η < 5 for high energy pp collisions



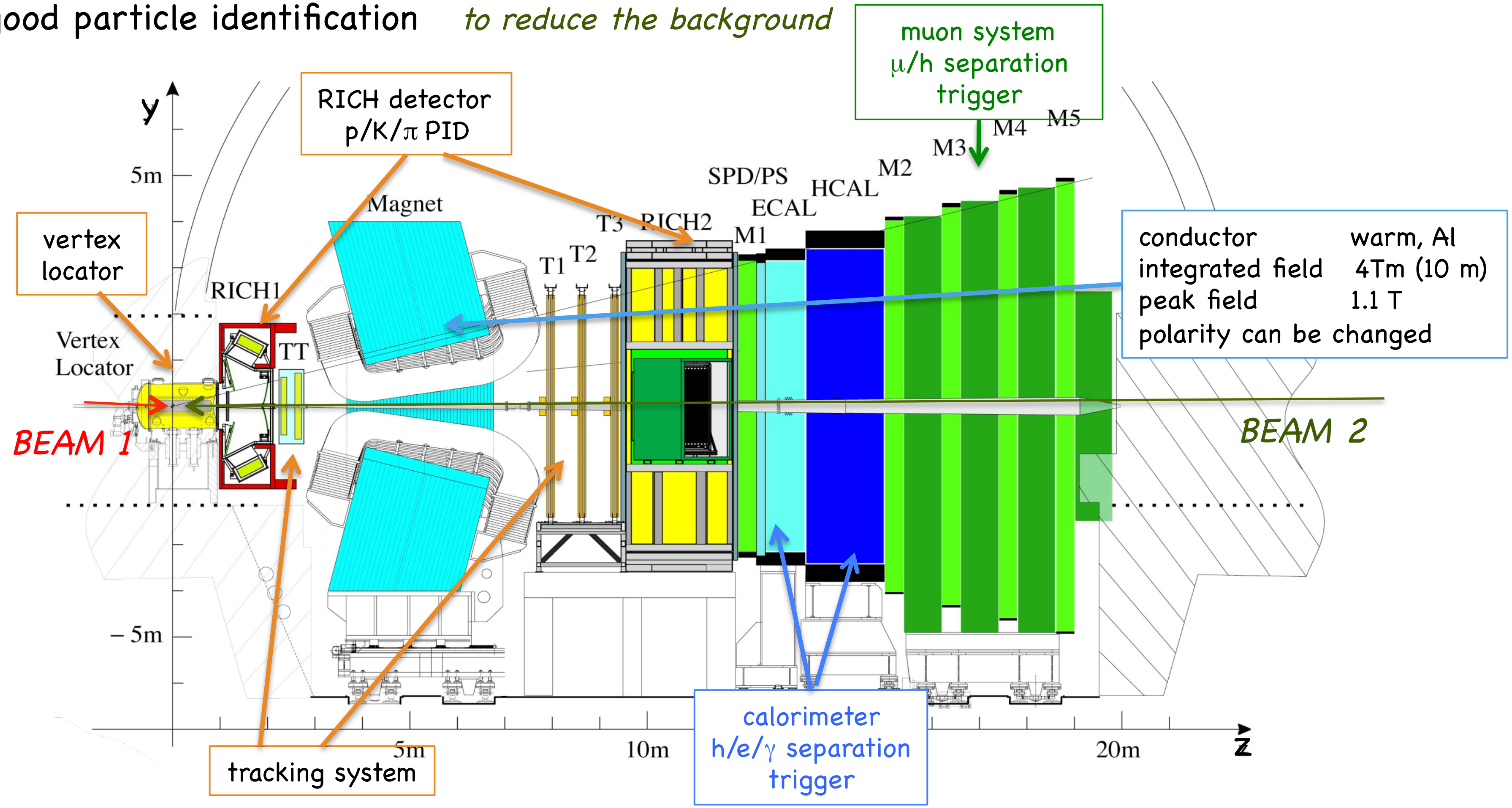
lower p_t trigger threshold down to 2 GeV/c

The LHCb Detector

- ✓ flexible, fast and highly selective trigger *to reduce the minimum bias*
- ✓ excellent vertexing (proper time resolution)

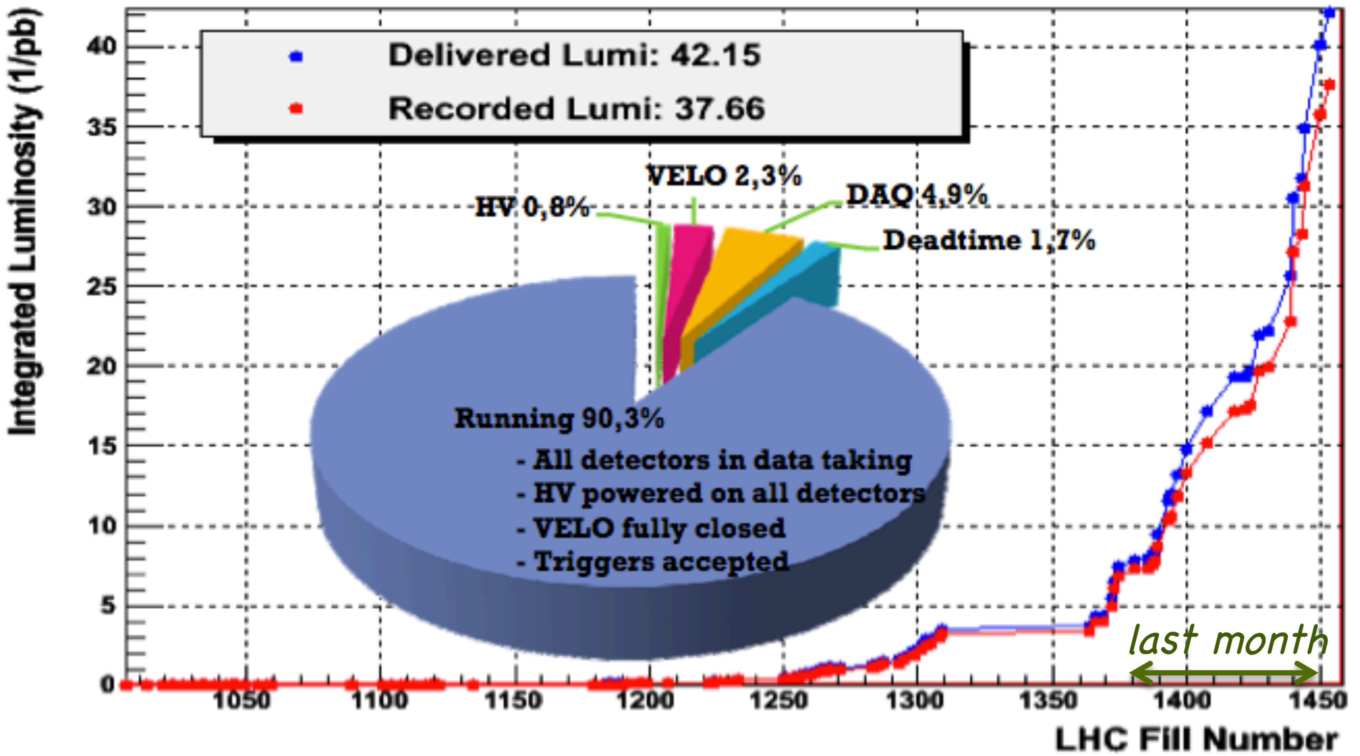
to distinguish B-decays from background and to resolve fast B_s oscillations

- ✓ excellent tracking (momentum and mass resolution) *to reduce the background*
- ✓ good particle identification *to reduce the background*



Integrated Luminosity at √s = 7 TeV

from 30th March to 29th October 2010



- ✓ L_{peak}^{LHC} in LHCb ≅ 1.7×10^{32} cm^{-2} s^{-1} with 344 colliding bunches
- ✓ overall data taking efficiency of ≈ 90% over the year
- ✓ recorded luminosity ≈ 37 pb^{-1} corresponds to ≈ 10^{10} bb-pairs produced

LHCb running conditions

$$L = \sum_{i=1}^{N_{bb}} \frac{f_{rev} \cdot N_i^1 \cdot N_i^2 \cdot S}{4\pi \cdot \varepsilon \cdot \beta^*}$$

nominal running conditions

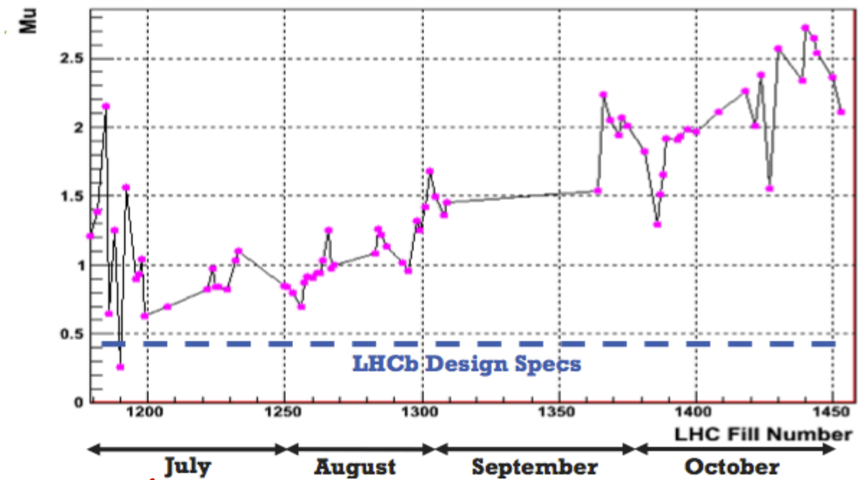
$$L = 2 \times 10^{32}\, cm^{-2} s^{-1}$$

- ✓ N_{bb} = 2622 number of colliding bunches per beam
- ✓ f_{rev} = 11.245 kHz bunch revolution frequency
- ✓ $N_i^{1,2} \approx 10^{11}$ number of protons per bunches
- ✓ $S \approx$ 673 mrad beams crossing angle at LHCb
- ✓ $\varepsilon_N = \varepsilon\gamma$ = 3.75 μm normalized emittance for E_{beam}= 7 TeV
- ✓ β^* = 10 m beta function

expected number of visible pp interactions per bunch crossing in LHCb acceptance: **Mu ≅ 0.4**

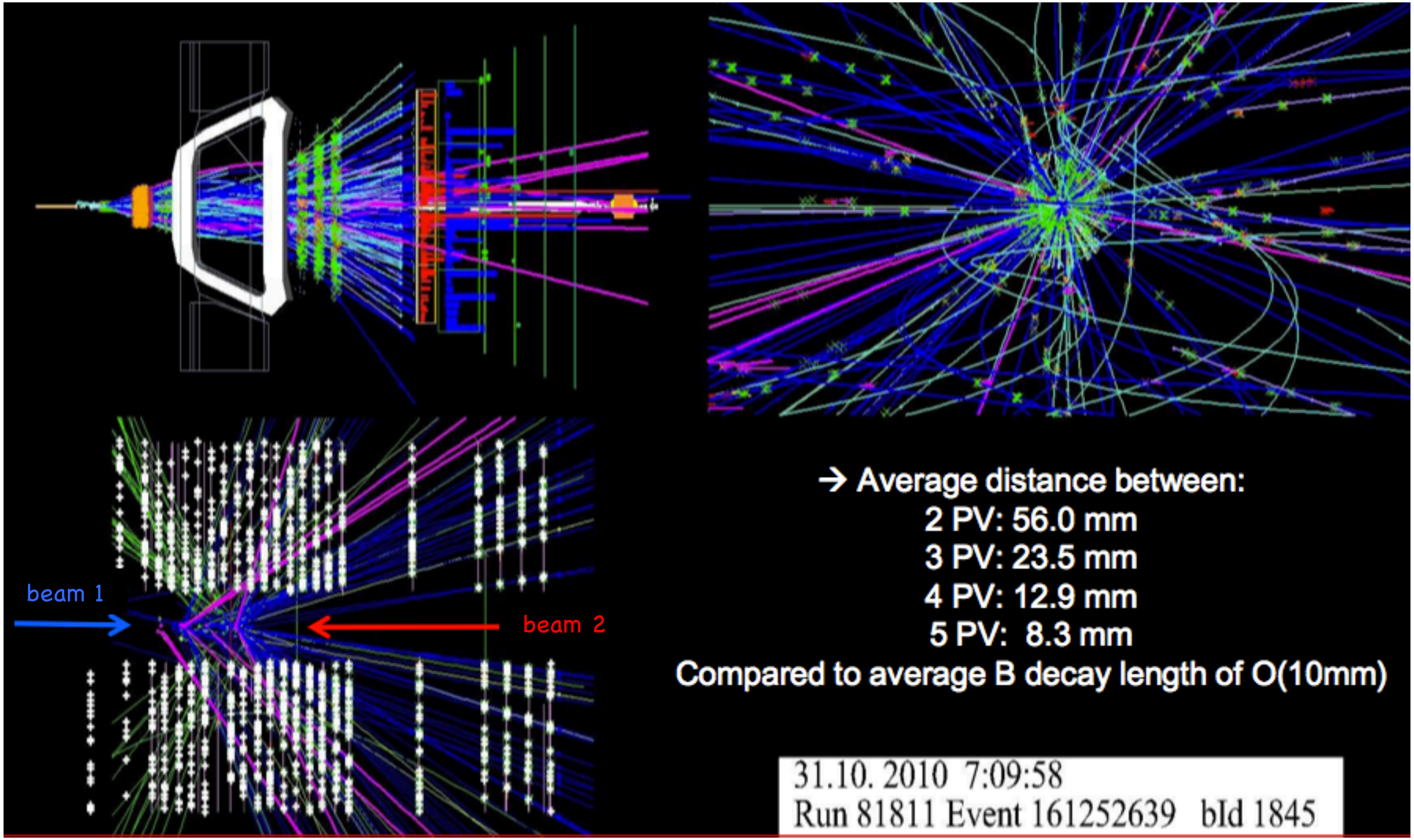
in 2010 LHC reached ≈ 80% of the design luminosity for LHCb with N_{bb} = 344 and β^* = 3.5 m thus with an higher ***Mu***

- ✓ more vertices per collision
- ✓ more tracks and event complexity
- ✓ increase the readout rate per bx
- ✓ increase event size and processing time



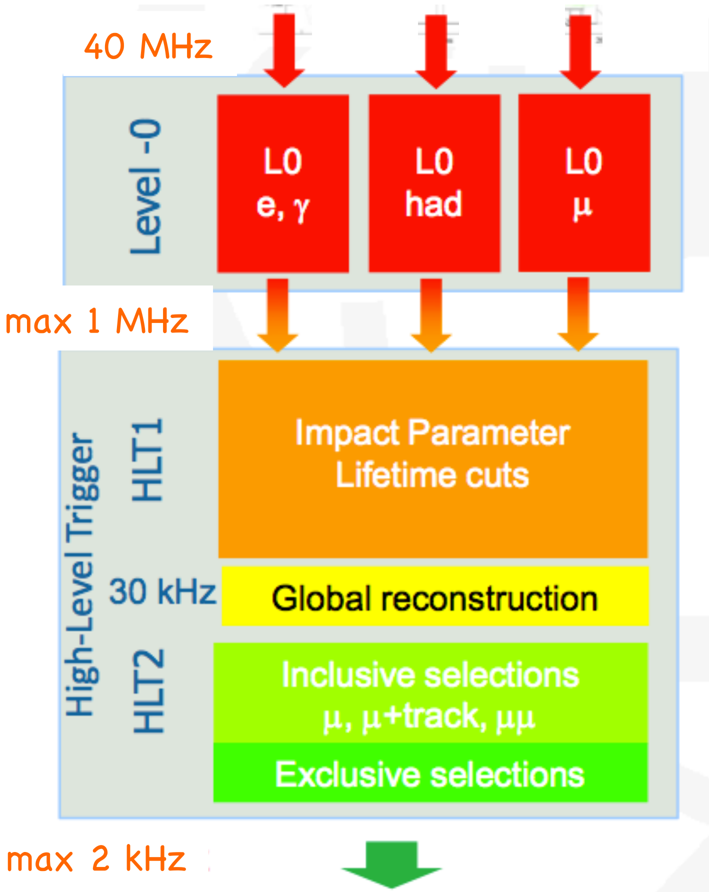
flexibility of the trigger → ***upgrades "on the fly" !!***

Example of one event with high Mu



LHCb trigger *nominal*

- ✓ to reduce the input rate 10 MHz down to 2 kHz (*limit imposed by offline resource*) while keeping a good efficiency on interesting B decays (*typically have BR < 10^{-5}*)



storage: *event size ≈ 35 kB*

Level 0 Customized Hardware Trigger *L0*

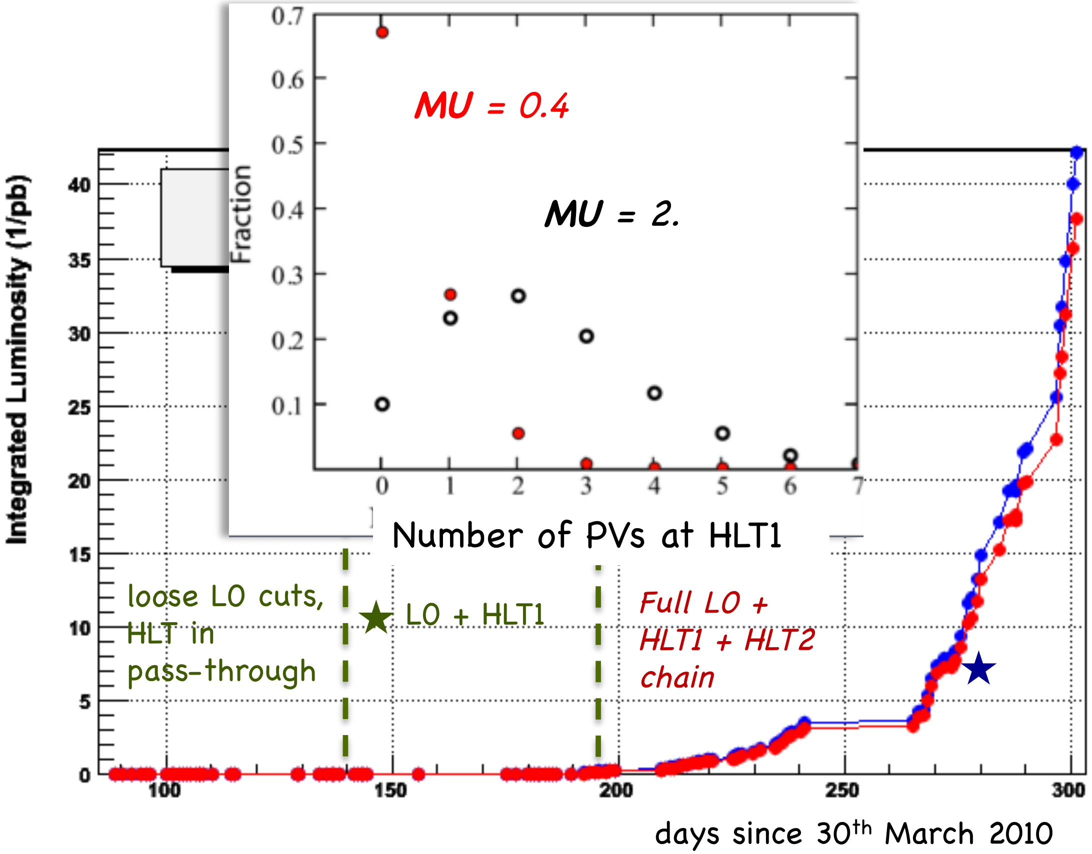
- ✓ pile-up, calorimeter and muon systems
- ✓ search for high-p_t/E_t μ, e, γ, hadron candidates

High Level software Trigger *HLT*

C++ algorithms running on 16000 processors forming the Event Filter Farm (EFF)

- ✓ *HLT1* finds vertex in VELO and tracks with high Impact Point and p_t to confirm or reject the L0 candidates
- ✓ *HLT2* global event reconstruction + inclusive/exclusive selections

LHCb trigger *2010*



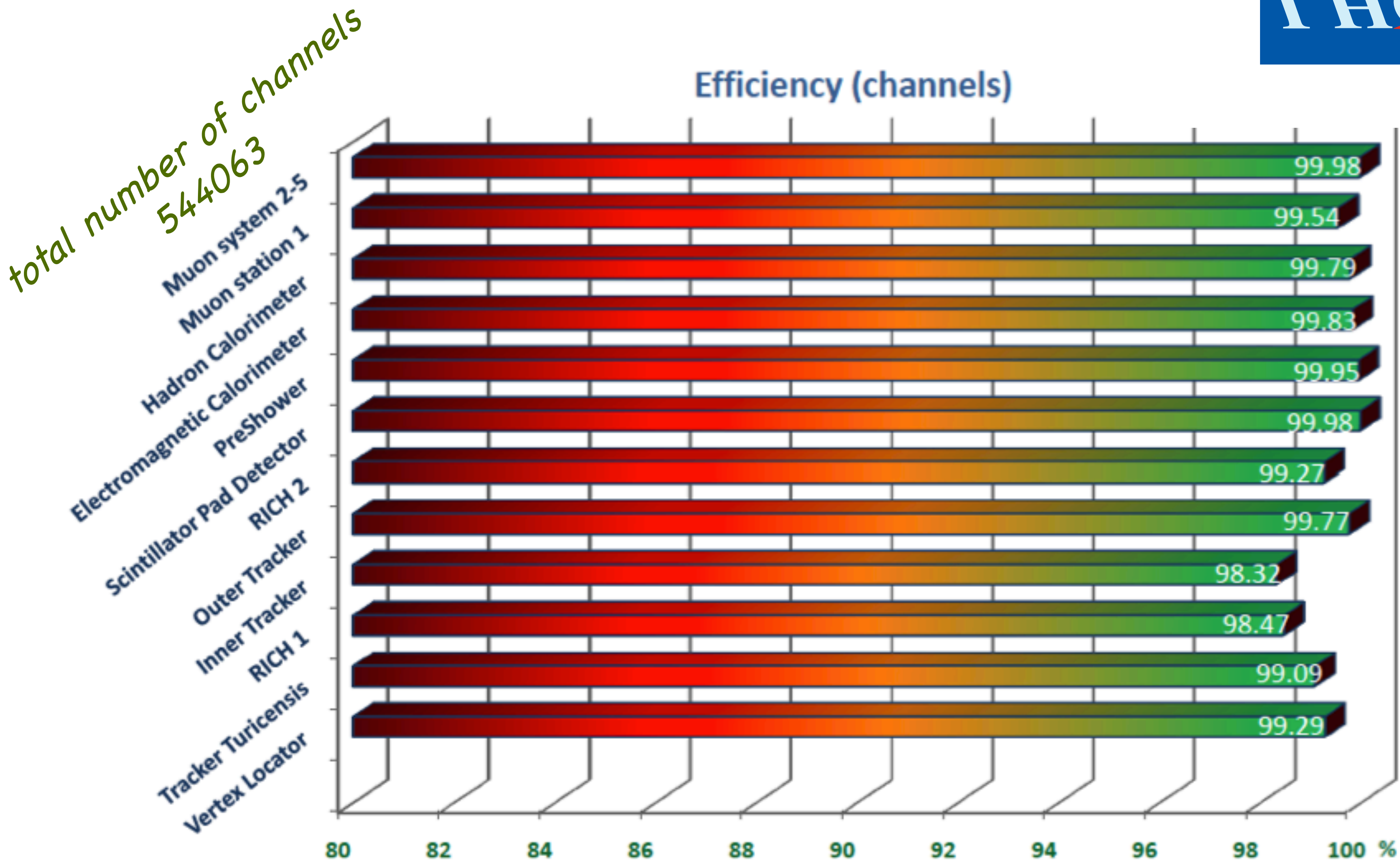
★ ε_{tr} on hadronic decays of prompt D are ≈ 4 times higher w.r.t. nominal settings

★ added 400 nodes in less than 3 days in order to double the EFF capacity

another upgrade by 400 nodes during the winter shutdown

- ✓ increase the thresholds in L0
  → reduce the HLT input rate
  the input rate to the EFF kept ≈300 kHz
- ✓ introduce Global Event Cuts
  → SPD (scintillator layer in front of the calorimeter) multiplicity + number of VELO hits
  → remove events with high track multiplicity
  → to reduce the processing time
- ✓ avoid to reach the bandwidth limitations
  → *event size at high **MU** ≈ 65 kB*

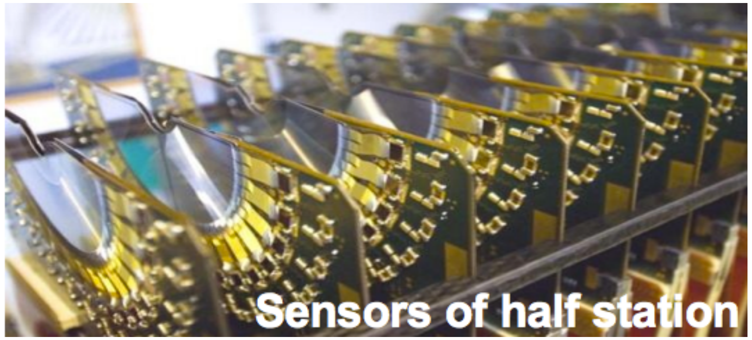
Detector status overview



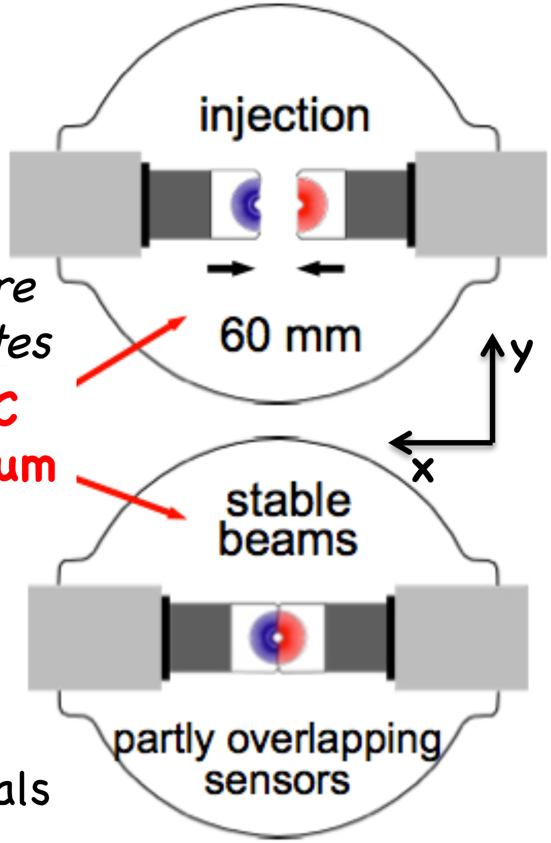
the detector hardware behaved extremely well during the 2010

VErtex LOcator (VELO)

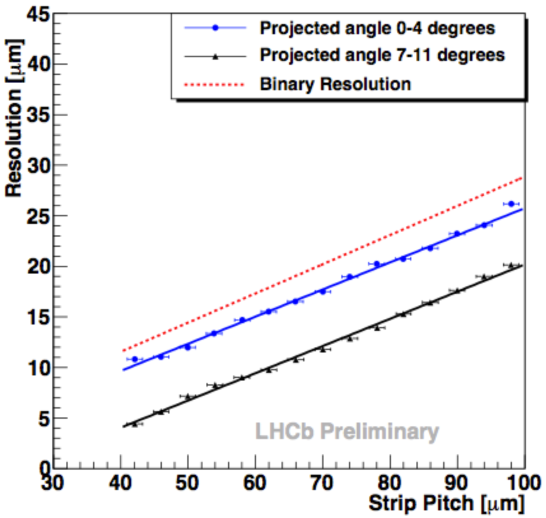
- ✓ 2 halves with 42 semi circular silicon sensors orthogonal to the beam, rϕ geometry
- ✓ VELO halves move at every fill from 30 to 7 mm from the beam axis
- ✓ module and sensor alignment known to *better than 5 μm* *target < 2 μm*
- ✓ strip pitch between 40 and 100 μm

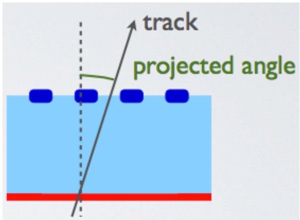


closing procedure takes few minutes



LHC vacuum



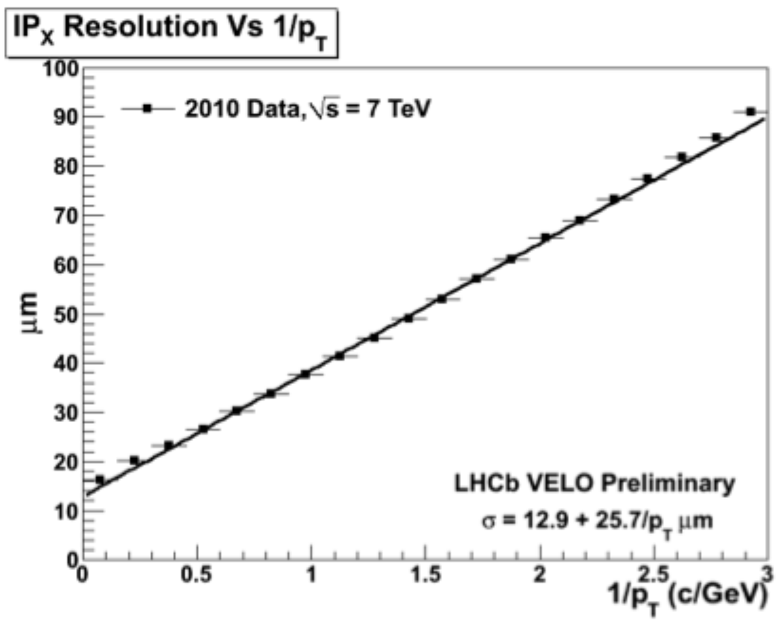


- ✓ *hit resolution* mainly due to **projected angle** and **strip pitch**
- ✓ *best resolution 4μm*
- ✓ measured using hit-track residuals

Vertexing

Impact Parameter resolution

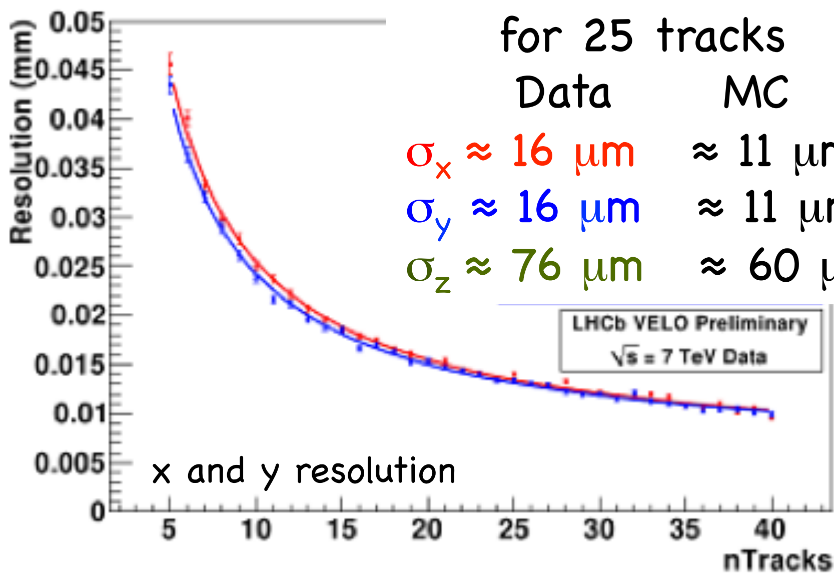
- ✓ assume all tracks originate from primary Interaction Point
- ✓ measure the resolution as the spread of IP distribution



- ✓ IP resolution ≈20% worse than MC prediction, but still excellent

Primary Vertex resolution

- ✓ measure the resolution by randomly splitting the track sample in two
- ✓ comparing vertices with same multiplicity
- ✓ <u>method validated with MC</u>



for 25 tracks

	Data	MC
σ_x	≈ 16 μm	≈ 11 μm
σ_y	≈ 16 μm	≈ 11 μm
σ_z	≈ 76 μm	≈ 60 μm

<u>MC</u> $\sigma(\tau) \approx 40$ fs on b-hadrons decay times

Silicon Tracker

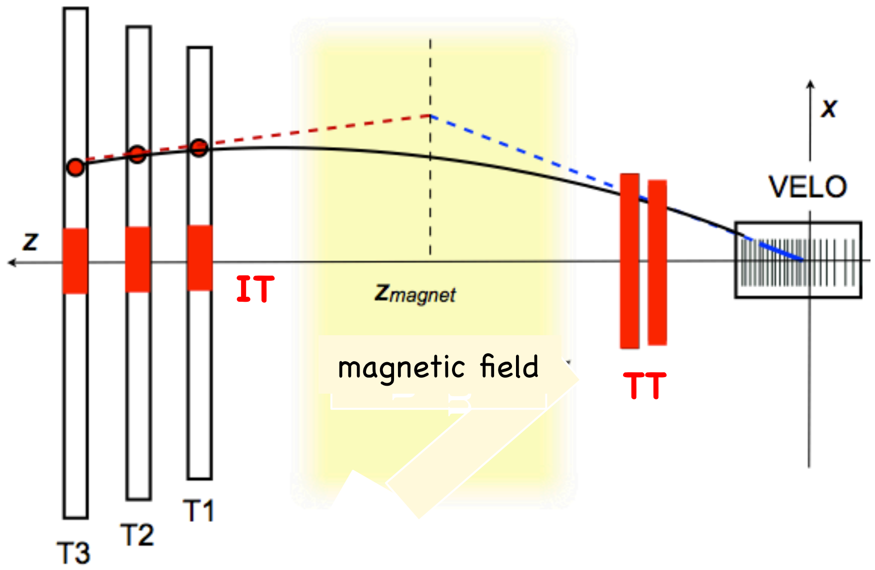
TT Tracker Turicensis

- ✓ 2 stations with 500 μm thick strip sensors
- ✓ 4 layer/stations x-u-v-x orientation with ±5° stereo angle
- ✓ pitch 183 μm

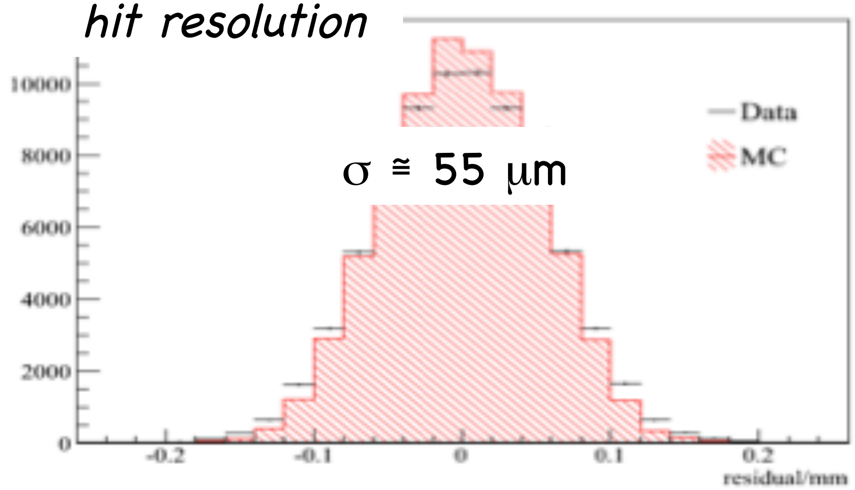
IT Inner Tracker *(higher flux in inner region)*

- ✓ 3 stations with 320 μm/410 μm thick strip sensors
- ✓ 4 layer/station x-u-v-x orientation with ±5° stereo angle
- ✓ pitch 198 μm

B field in y-dir *charged particles deflected in x-dir*



hit resolution



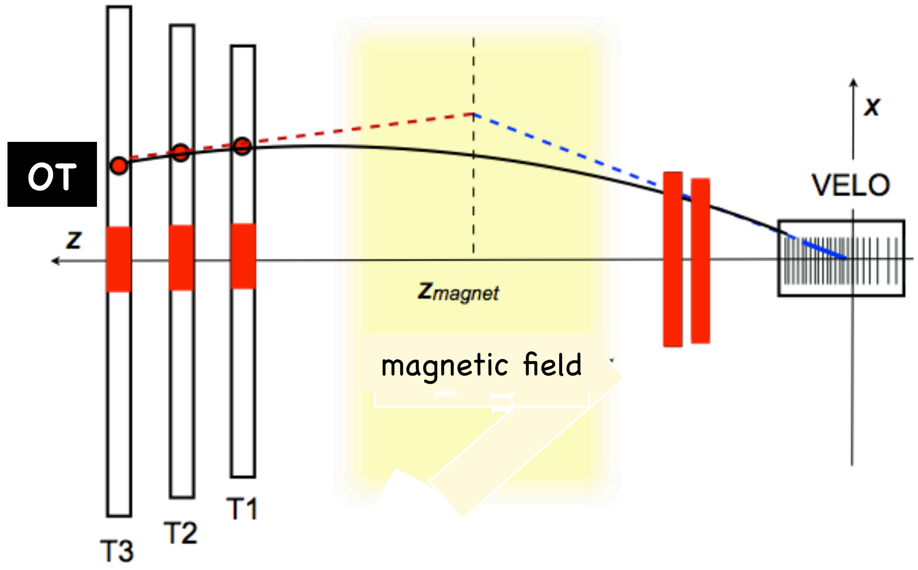
the ST sensor alignment precision is ≅35 μm for TT, and ≅16 μm for IT

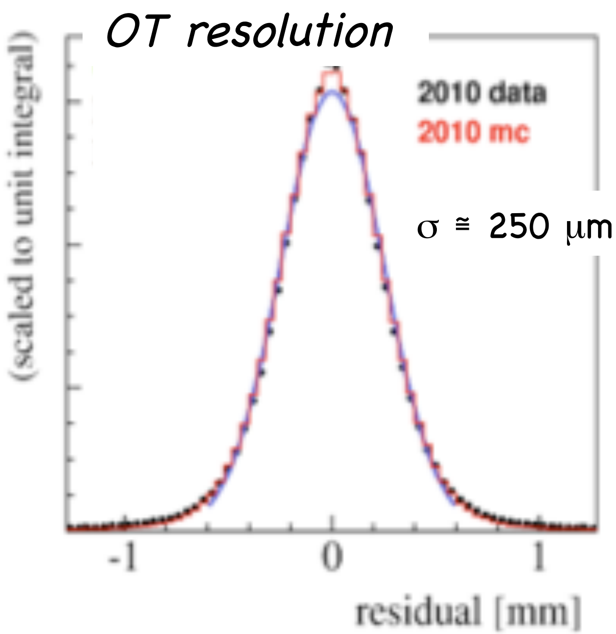
Outer Tracker

OT Outer Tracker

- ✓ 3 stations, each with 4 double layers of ≅ 5 mm diameter straw tubes
- ✓ x-u-v-x orientation with ±5° stereo angle
- ✓ gas $Ar/CO_2/O_2$ 70/28.5/1.5

B field in y-dir *charged particles deflected in x-dir*



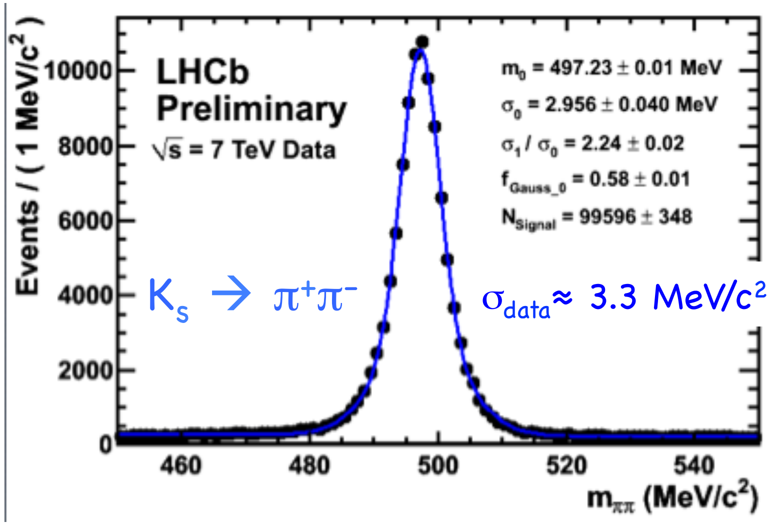


from residual of the R(t) relation

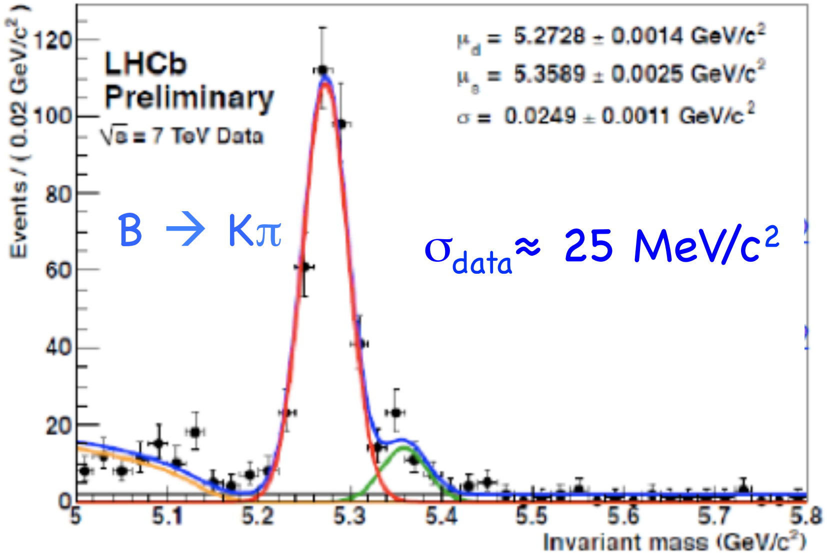
OT well aligned →
<u>resolution in very good agreement with MC</u>

Tracking performances

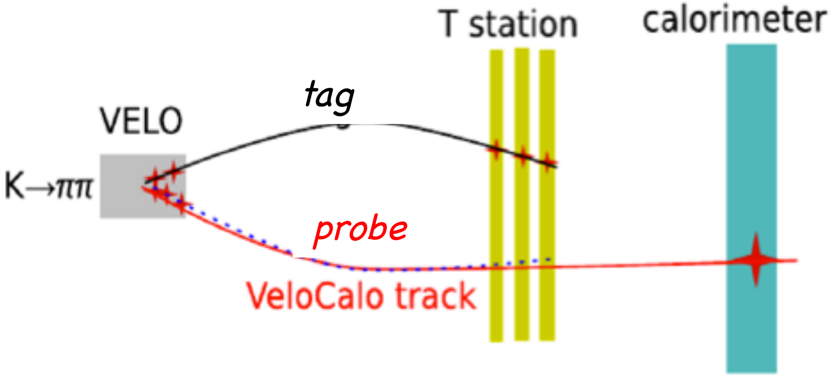
$\delta p/p \approx 0.45\% \rightarrow$ excellent mass resolution

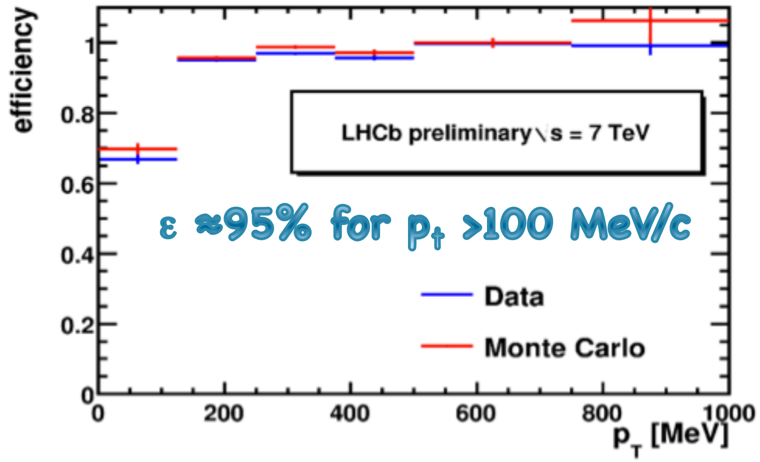


σ_{mass}'s in good agreement with MC

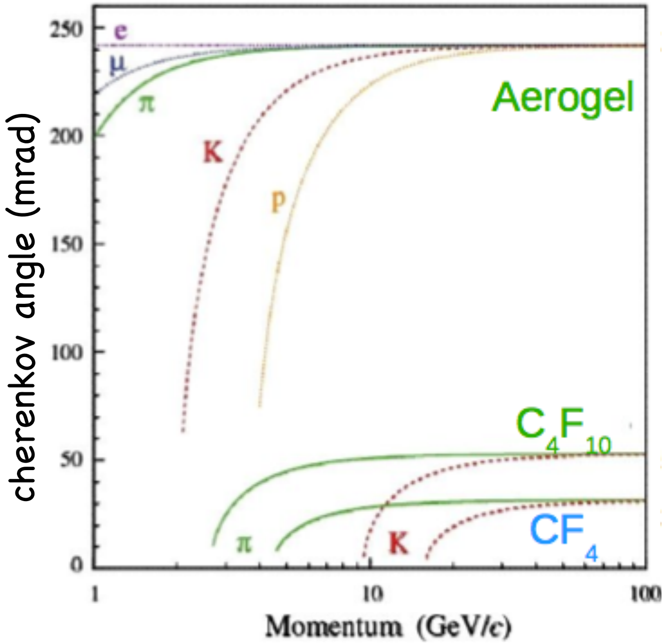


efficiency with *tag* and *probe* method using $K_s \rightarrow \pi^+\pi^-$





RICH detectors



2 Ring Imaging Cherenkov detectors with 3 radiators

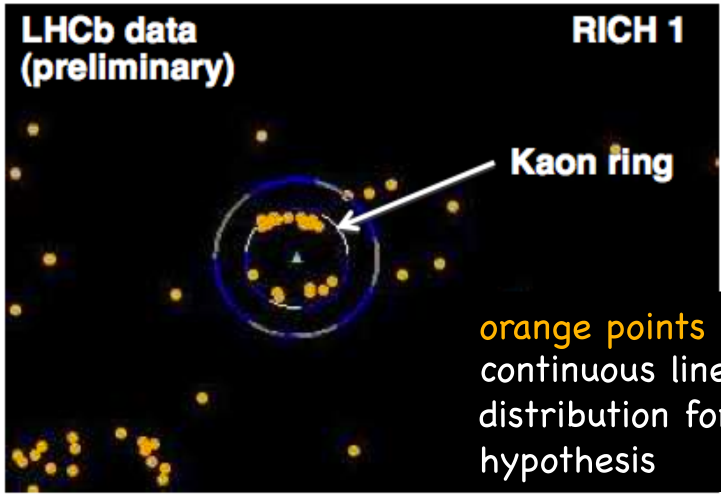
RICH1

- ✓ Silica Aereogel (n=1.03) 1 – 10 Gev/c
- ✓ C_4F_{10} (n=1.0014) up to ≅ 70 Gev/c

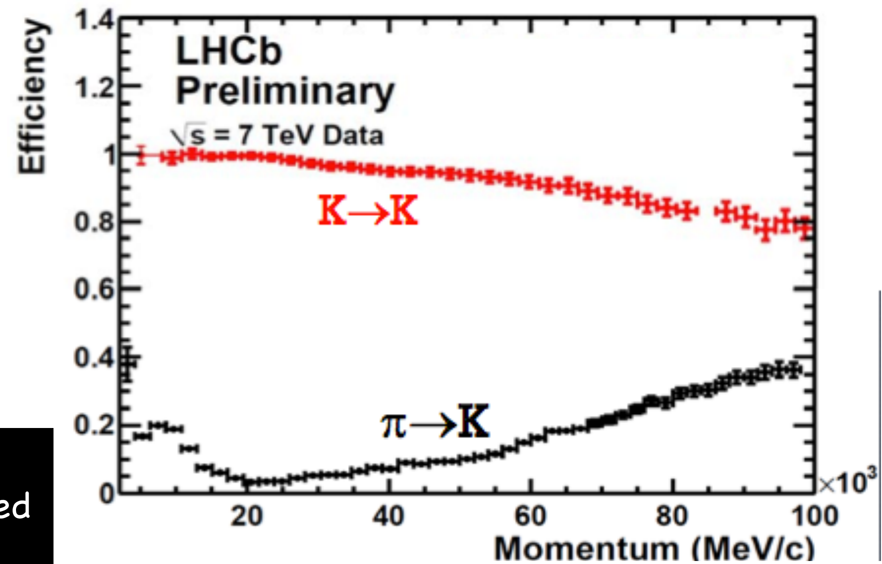
RICH2

- ✓ CF_4 (n=1.0005) beyond ≅ 100 GeV/c

vital for good K/π/p discrimination



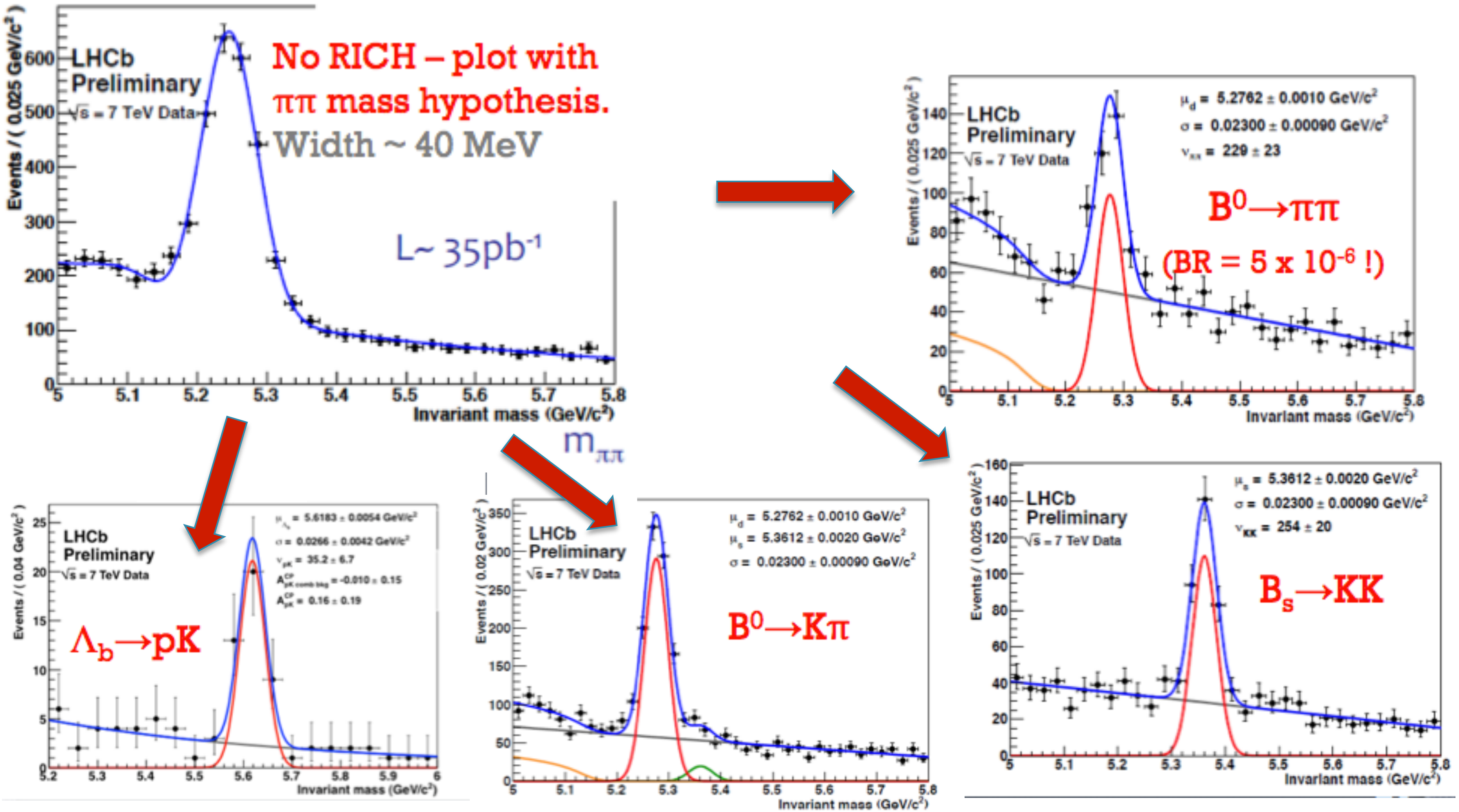
orange points → γ hits
continuous lines → expected distribution for particle hypothesis



ε(K) ≅95% with ≅5% of π/K mis-ID

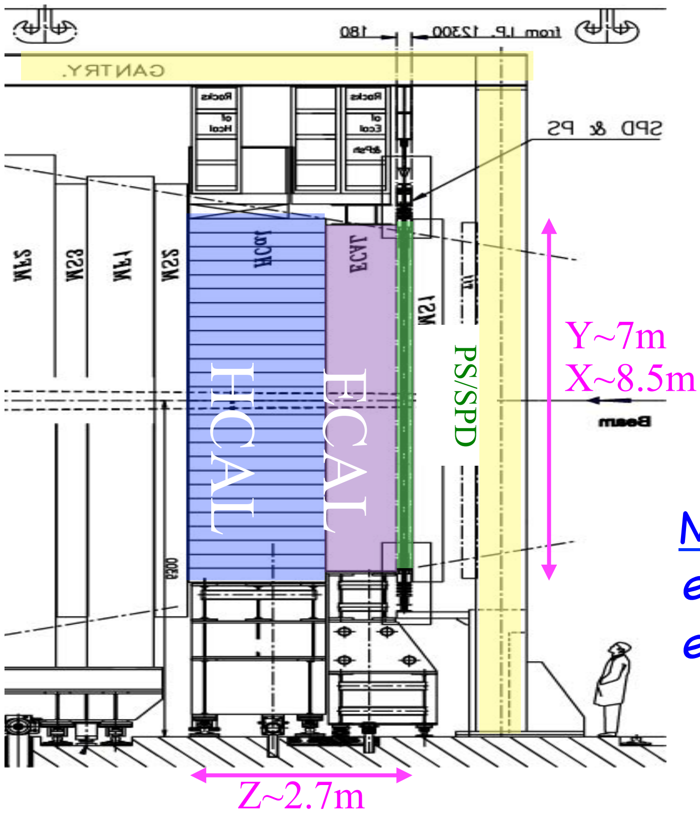
PID with RICH

it allows separation of topologically identical final states, **e.g. B → hh**



Calorimeters

- ✓ to trigger on e,γ,h candidates with high E_t at the L0 level
- ✓ to identify e, γ and π^0



time aligment at 1 ns level

Scintillator Pad Detector (SPD)/PreShower (PS) 2.5 X_0 Pb converter sandwiched between two scintillator planes 15 mm thick, light collected with WLS fibers

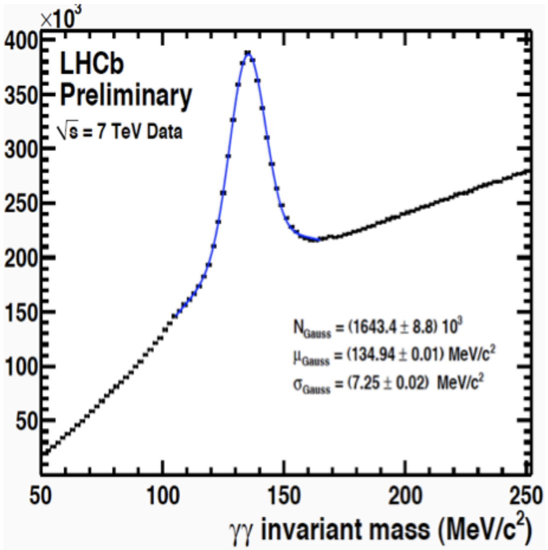
Electromagnetic Calorimeter (ECAL) Shashlik technology, 66 layers of 2mm Pb / 4mm scintillator (25 X_0), light collected with WLS fibers

Hadronic Calorimeter (HCAL) iron-scintillator tiles (5.6 λ_i)

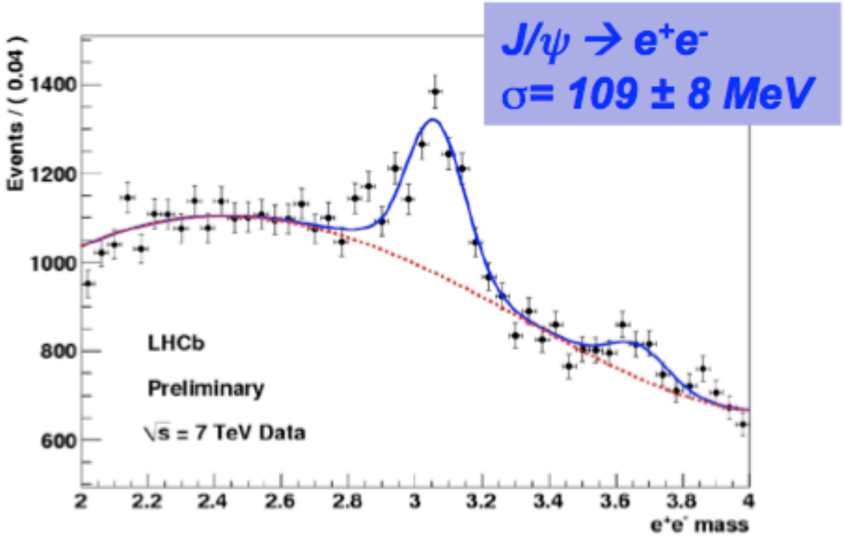
$M\pi^0$ resolution ≅ 7.2 MeV *even better than expected !*

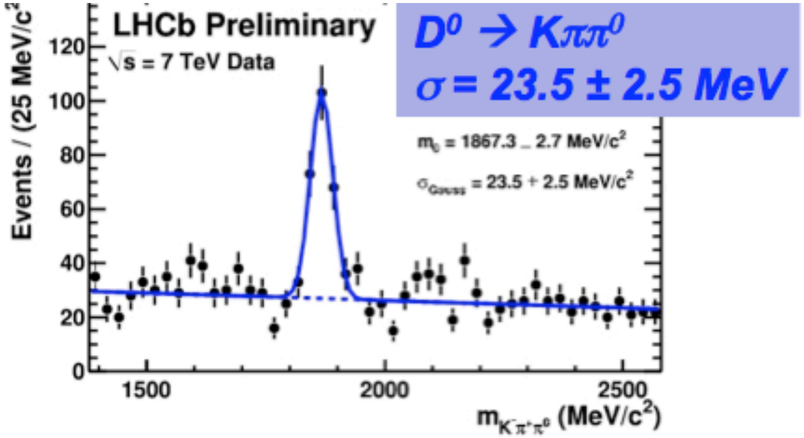
ECAL $$\frac{\sigma}{E} \approx \frac{9\%}{\sqrt{E}} \oplus 0.8\%$$

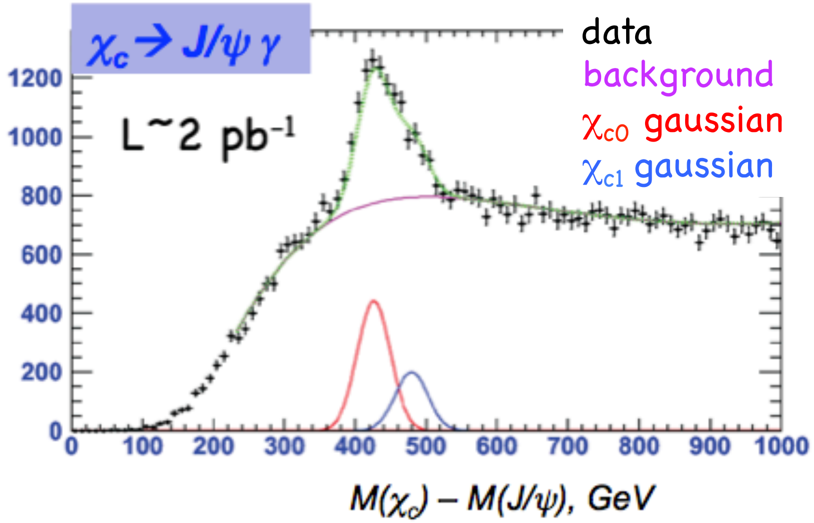
HCAL $$\frac{\sigma}{E} \approx \frac{69\%}{\sqrt{E}} \oplus 9\%$$

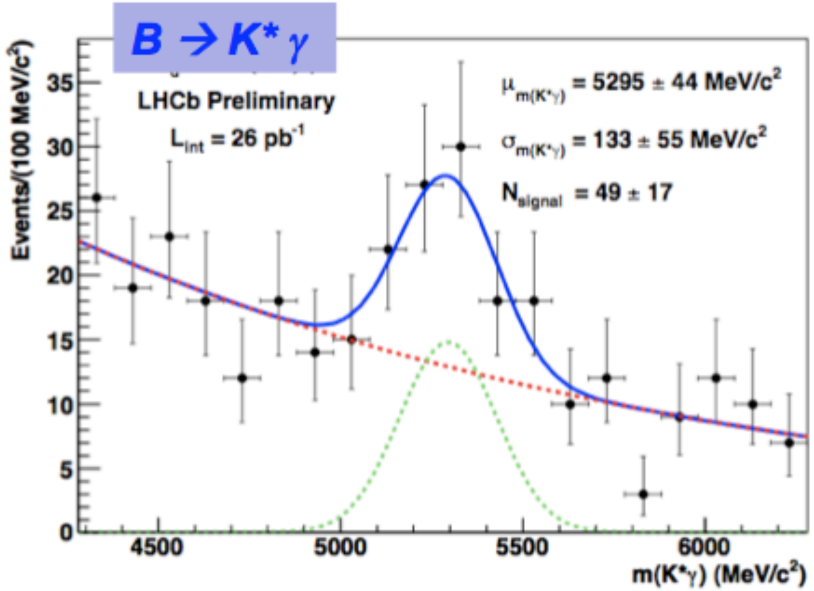


PID with calorimeter





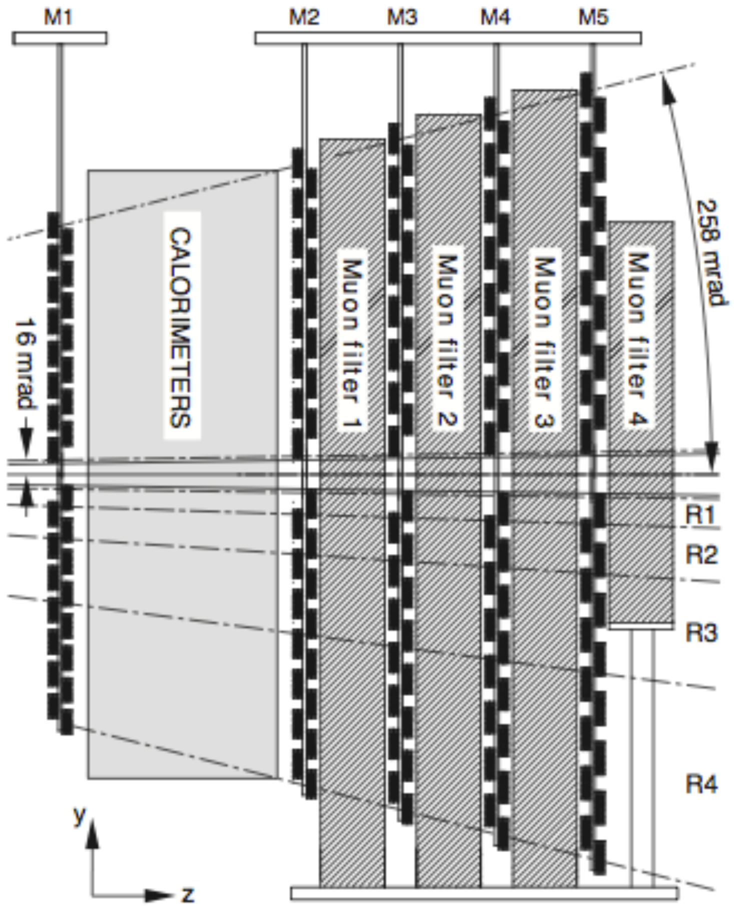




Muon

- ✓ to trigger on muon candidates with high p_t at the L0 level
- ✓ to identify muons

5 stations 4 are sandwiched with iron filters → **M1** (before) and **M2-M5** (behind) the calorimeters, instrumented with **MWPC** (2 double gaps) except the highest rate region (the inner area of **M1**) with **tripleGEM**



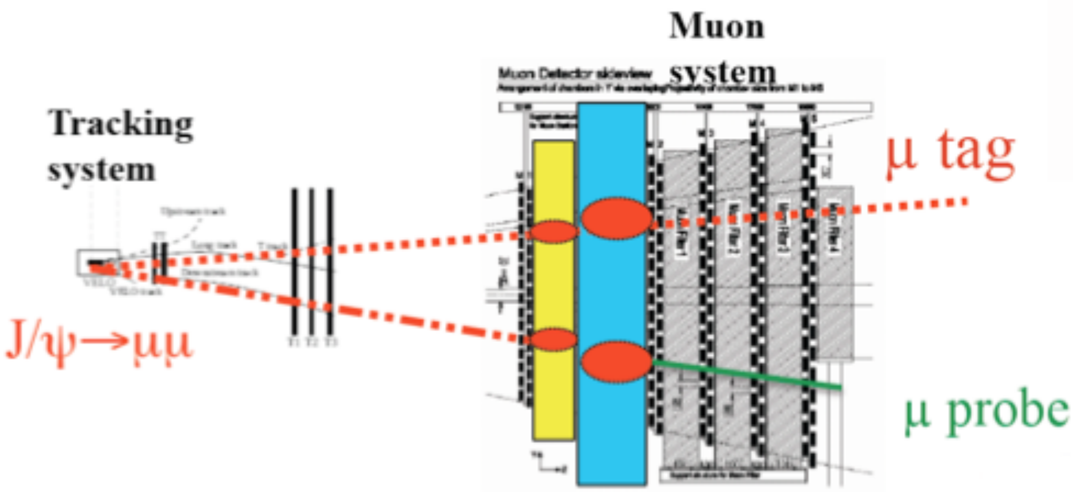
- ✓ gas mixture: Ar/CO2/CF4
- ✓ total interaction length of the calorimeters and the iron absorbers ≈ 20 λ_i → minimum $p_\mu \approx$ 6 GeV/c

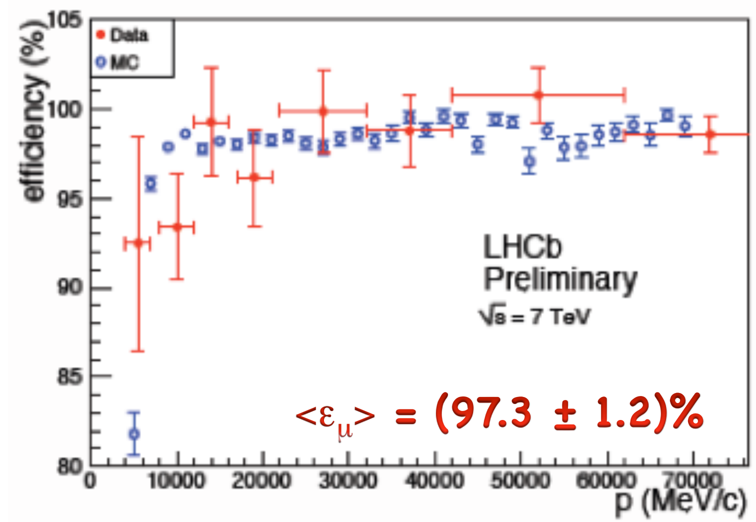
- ✓ the detectors provide space point measurements of the tracks → logical pads
- ✓ the geometry of the 5 stations is projective

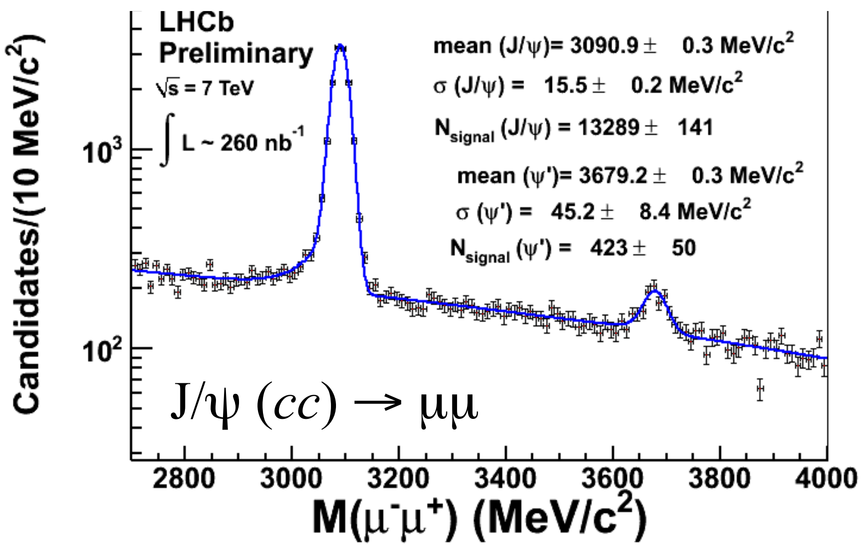
the efficiency of the muon stations is stable and > 99% as expected

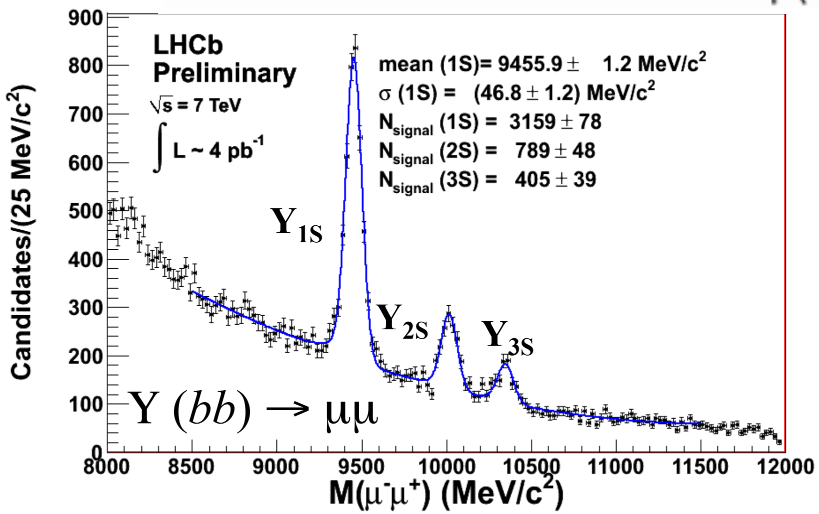
PID with muon

efficiency with the tag and probe method using of J/ψ →μμ



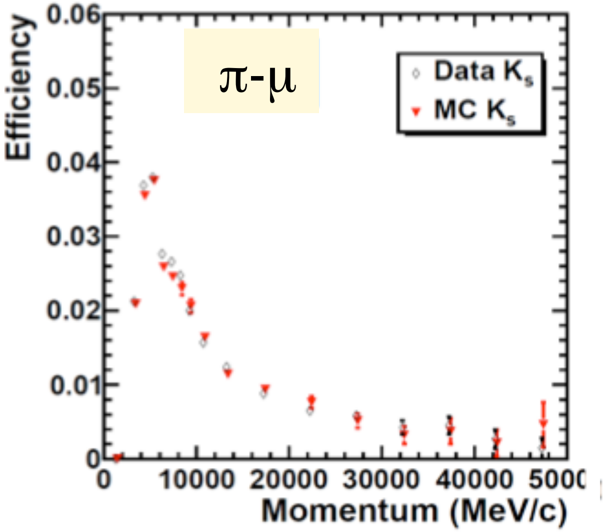


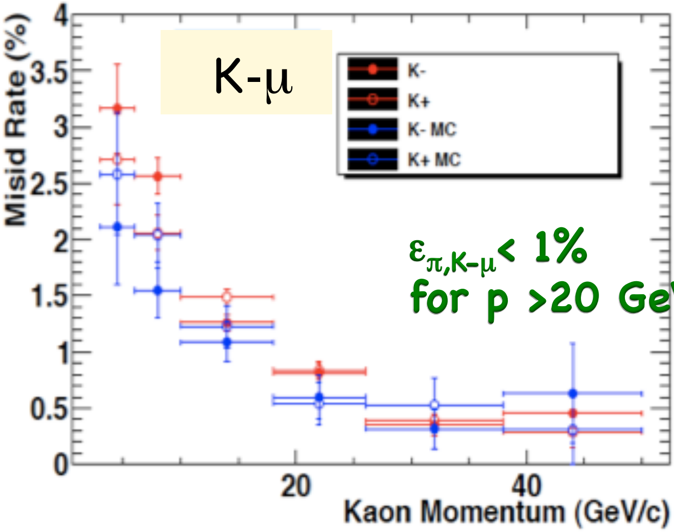




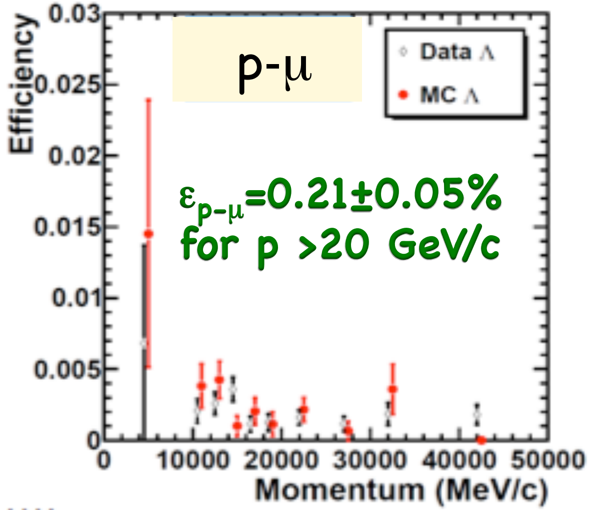
PID with muon

$\mu-\pi$, $\mu-K$ and $\mu-p$ misidentification rates have been determined using large samples of $K_s \rightarrow \pi\pi$, $\phi \rightarrow KK$ and $\Lambda \rightarrow p\pi$ decays





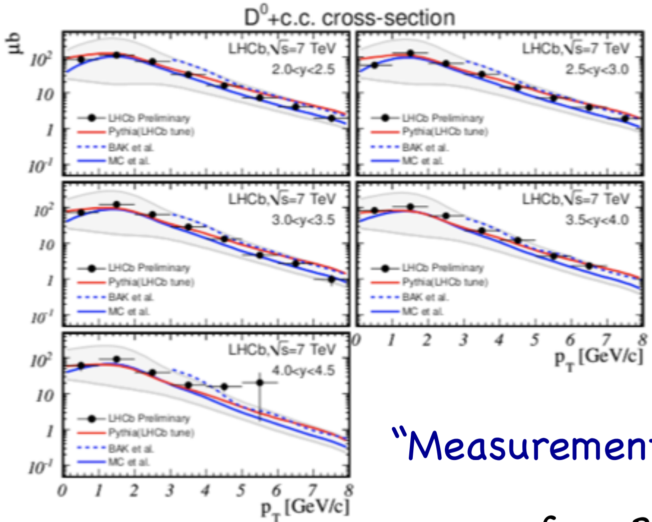
$\varepsilon_{\pi,K-\mu} < 1\%$
for p >20 GeV/c



LHCb first physics results

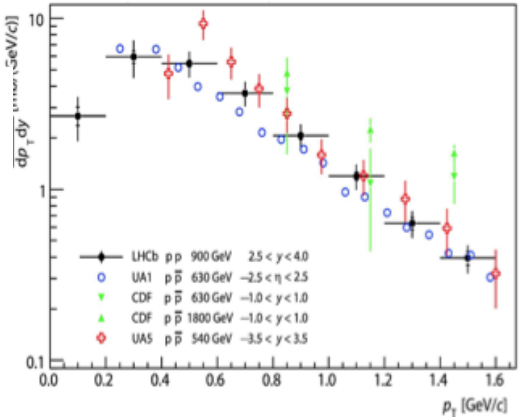
"Prompt charm production in pp collisions at $\sqrt{s}$ = 7 TeV "

LHCb-CONF-2010-013



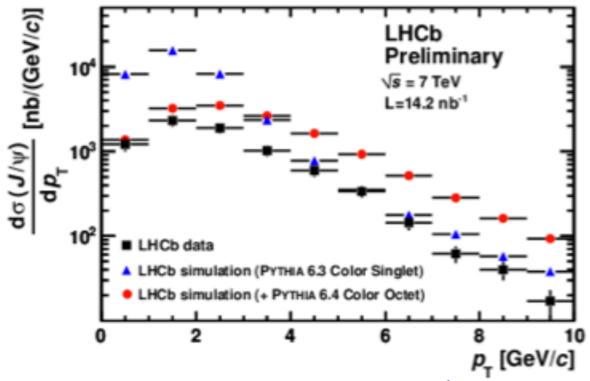
"Measurement of K^0_s production in pp collisions at $\sqrt{s}$ = 0.9 TeV "

PLB 693 (2010) 69



"Measurement of J/ψ production cross-section at $\sqrt{s}$ = 7 TeV in LHCb"

LHCb-CONF-2010-010



"Measurement of $\sigma(pp \to b\bar{b}X)$ at $\sqrt{s}$ = 7 TeV in the forward region"

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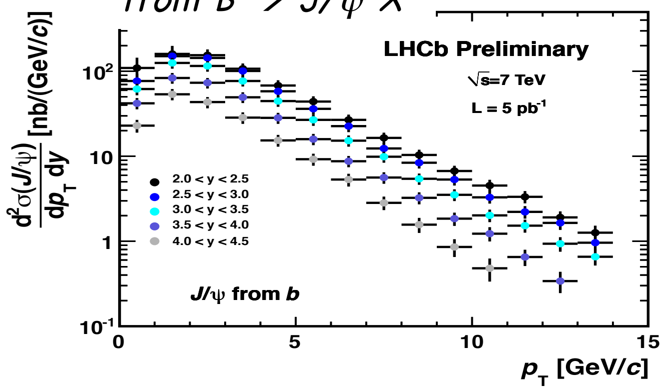
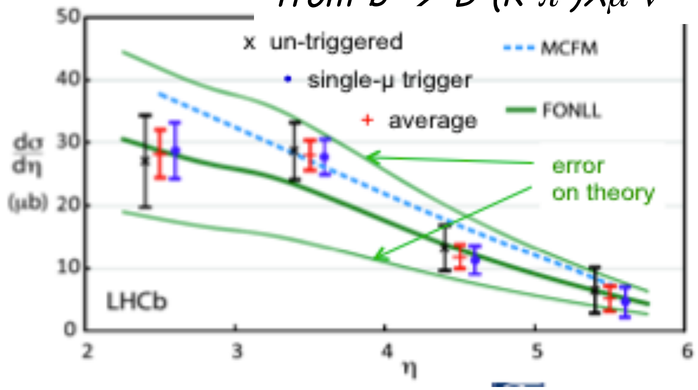
from B → J/ψ X



from b → $D^0(K^+\pi^-)X\mu^-\bar{\nu}$



Other talks at this conference

- ✓ Prompt J/ψ and b->$J/\psi X$ production in pp collision at $\sqrt{s}$ = 7 TeV
  Emanuele Santovetti
- ✓ Studies of hadronic B decays with early LHCb data
  Rudolf Oldeman
- ✓ Prospects for CP violation in $B_s \to J/\psi\ \phi$ from first LHCb data
  Roel Aaij
- ✓ W and Z production in forward region at LHCb
  Katharina Mueller
- ✓ Particle production studies at LHCb
  Bogdan Popovici

Summary and outlook

- ✓ The challenges of this first year of running in extreme conditions have been overcome → being able to follow the luminosity growth

- ✓ The performance of the detector and the quality of the data collected are excellent
  - about 37 pb^{-1} of useful data with an efficiency above 90%
  - performance close to the expectations
  - first important physics results emerging

- ✓ Looking forward to a successful physics run in 2011 → expect to collect ≅ 1 fb^{-1}
  - maximum instantaneous luminosity of $\cong 3 \times 10^{32}$ $cm^{-2}s^{-1}$ at the LHCb Interaction Region
  - maximum **MU** of 2.5 *(detector operations seems feasible and possible)*
  - with 1-2 fb^{-1} of data we can make precise measurements in areas with great discovery potential

- ✓ The preparation for the LHCb upgrade to collect data at 5-10 times higher luminosity is underway