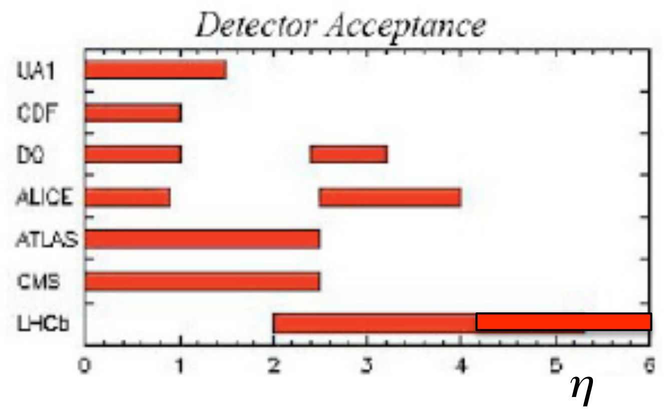
Status of the LHCb experiment

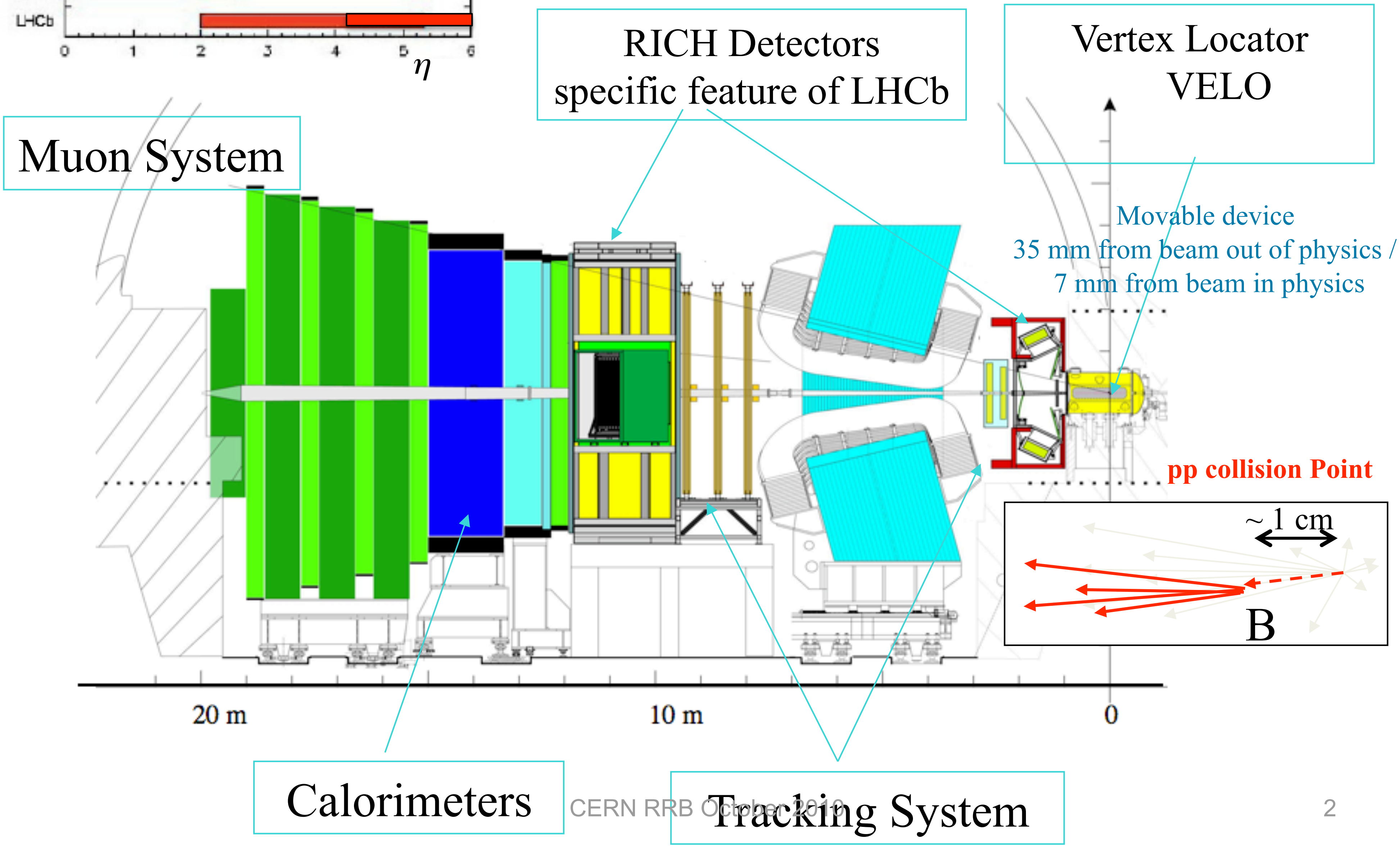
Andrey Golutvin (Imperial College & ITEP & CERN)
on behalf of the LHCb Collaboration

Outline:

- ***LHCb operation***
- ***Validation of the detector performance with data***
- ***First physics results***
- ***Goals and prospects for 2010-2011 LHC Run***
- ***Preparation of LHCb upgrade***
- ***Collaboration matters***
- ***Conclusion***

The LHCb Detector (forward spectrometer)





LHCb Collaboration *(day of the 1st collisions)*

LHCb shift model

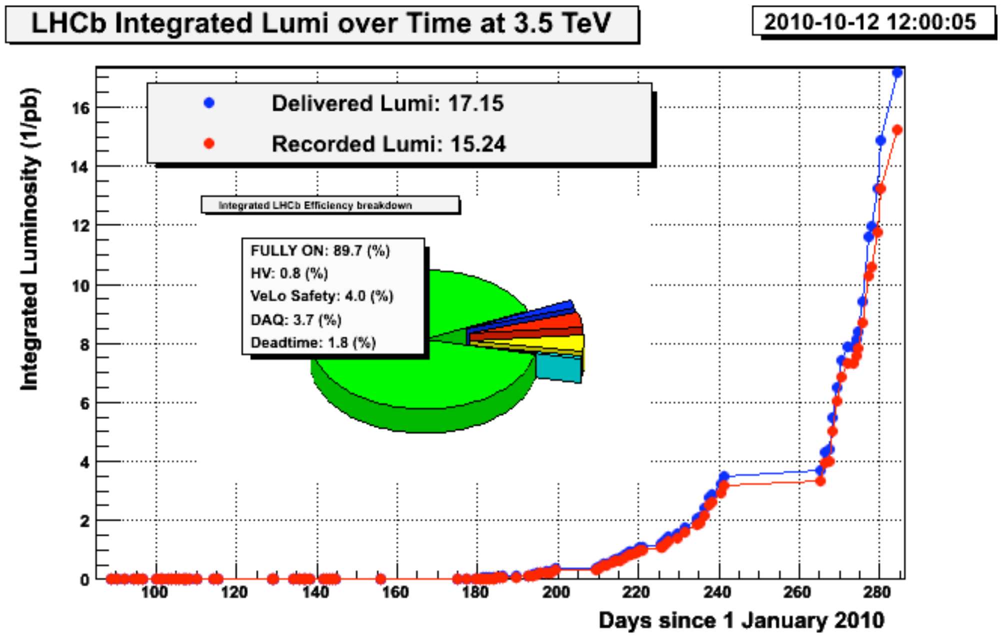
(typical day of data taking: 2 main shifters + many experts on call)

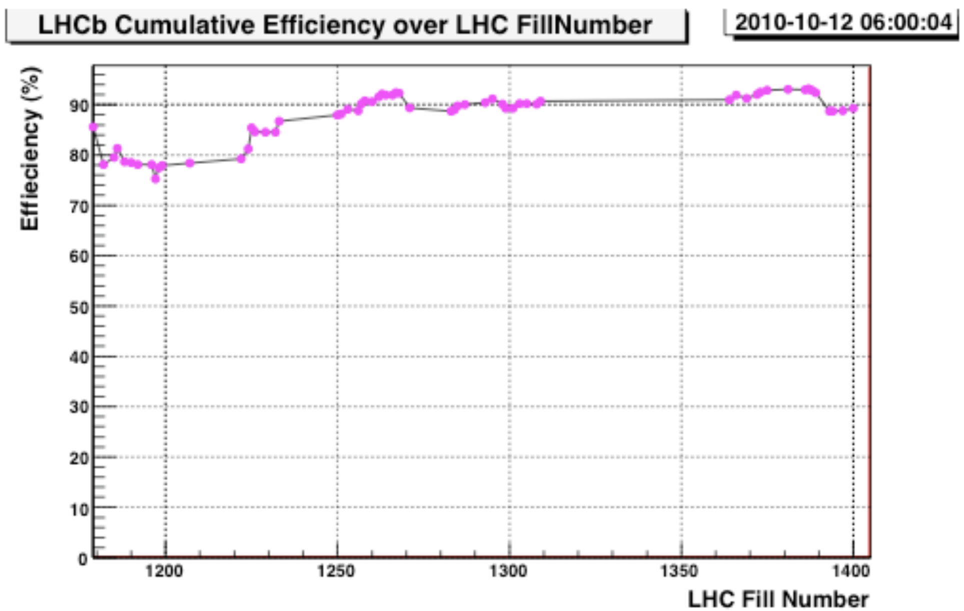
Very effective and highly automatized organization of data taking

Each LHCb institute is expected to provide ~1.5 × (number of authors) Data taking shifts per month

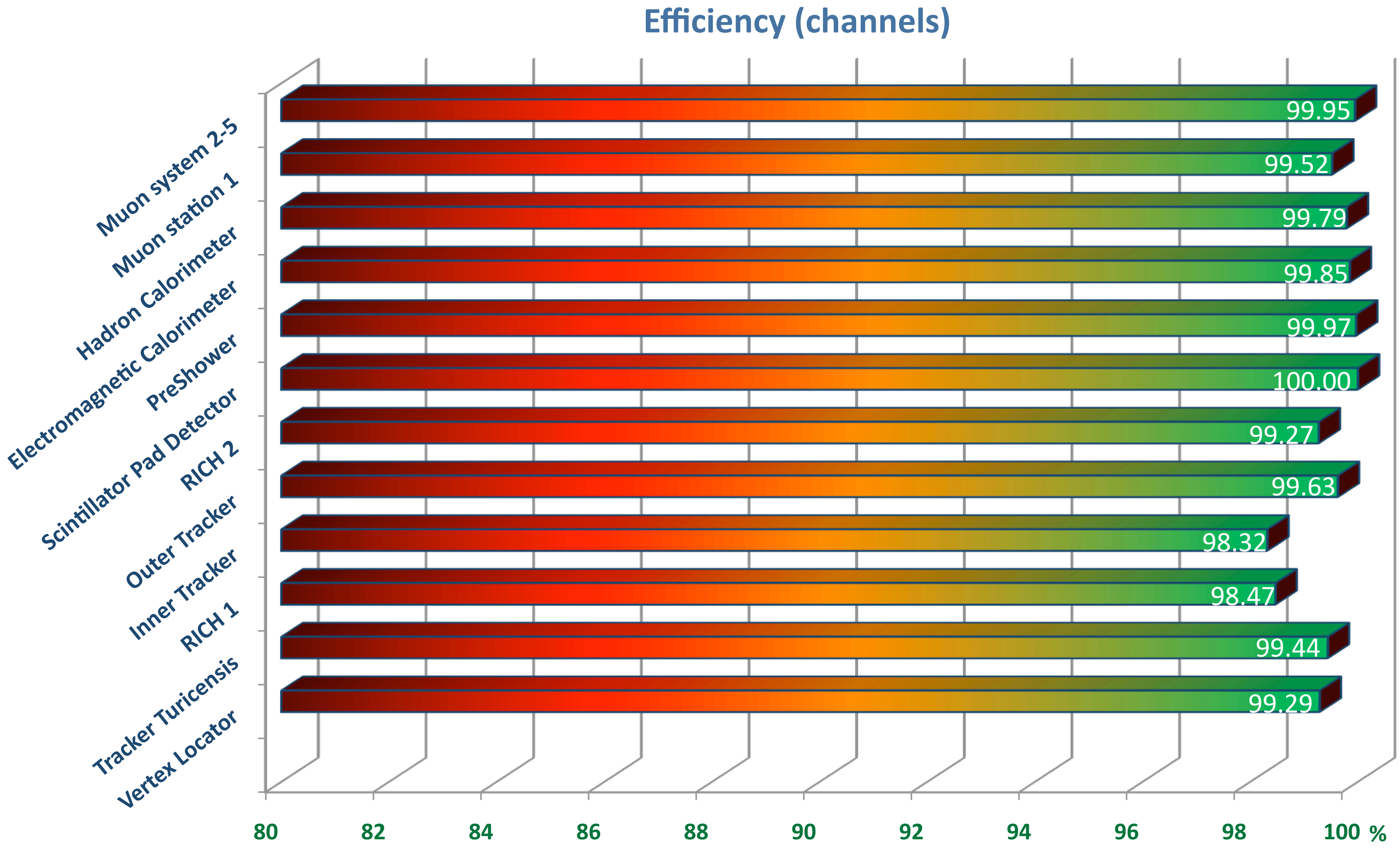
LHCb operation

- Recorded integrated luminosity > 15 pb^{-1}
- LHCb operation efficiency ~ 90%
- Goal for 2010 to reach 10^{32} cm^{-2} s^{-1} is now a reality
- Expect ~50 pb^{-1} this year and ~1 fb^{-1} in 2011

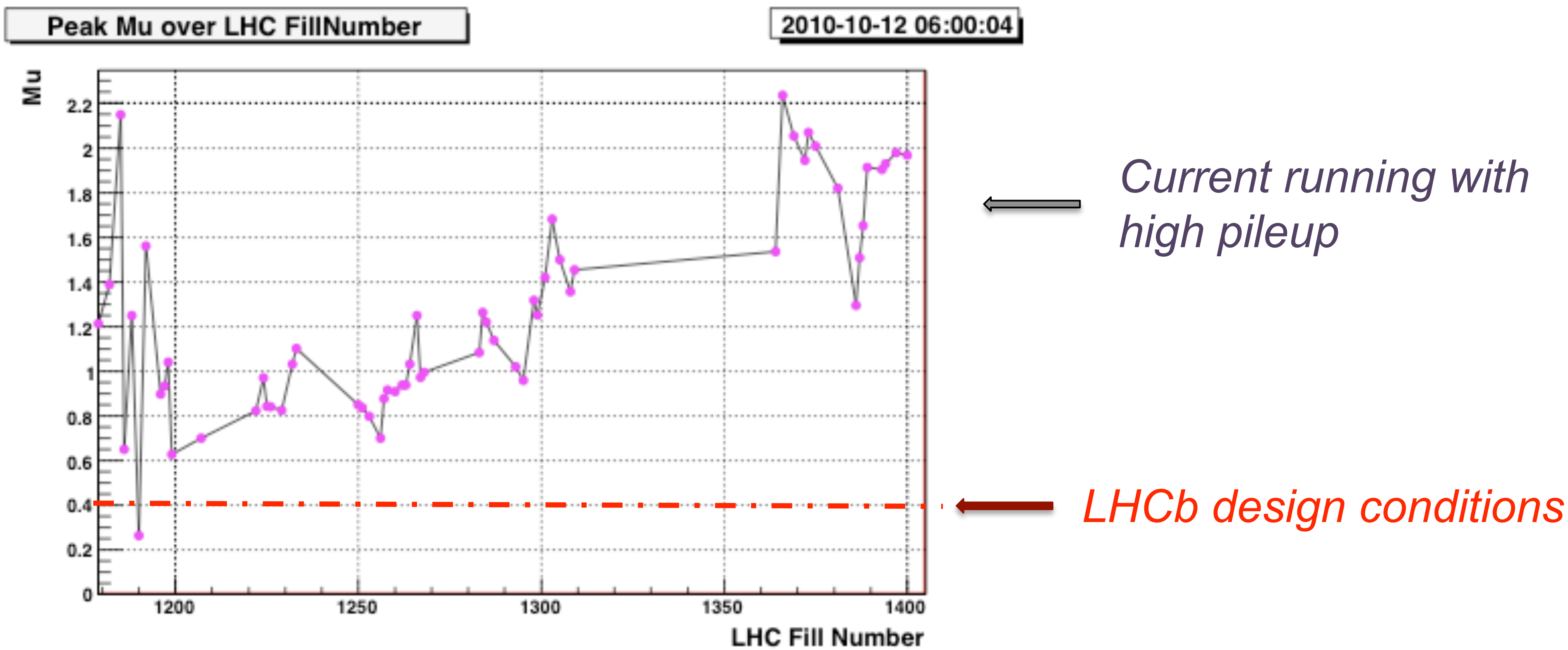




Detector Efficiency



Running conditions



In order to maximize integrated L and physics reach in 2010
LHCb runs at β^* = 3.5 m (nominal value 10 m)

→ ***Significantly higher pile-up requires more attention to trigger, computing, reconstruction and analysis***

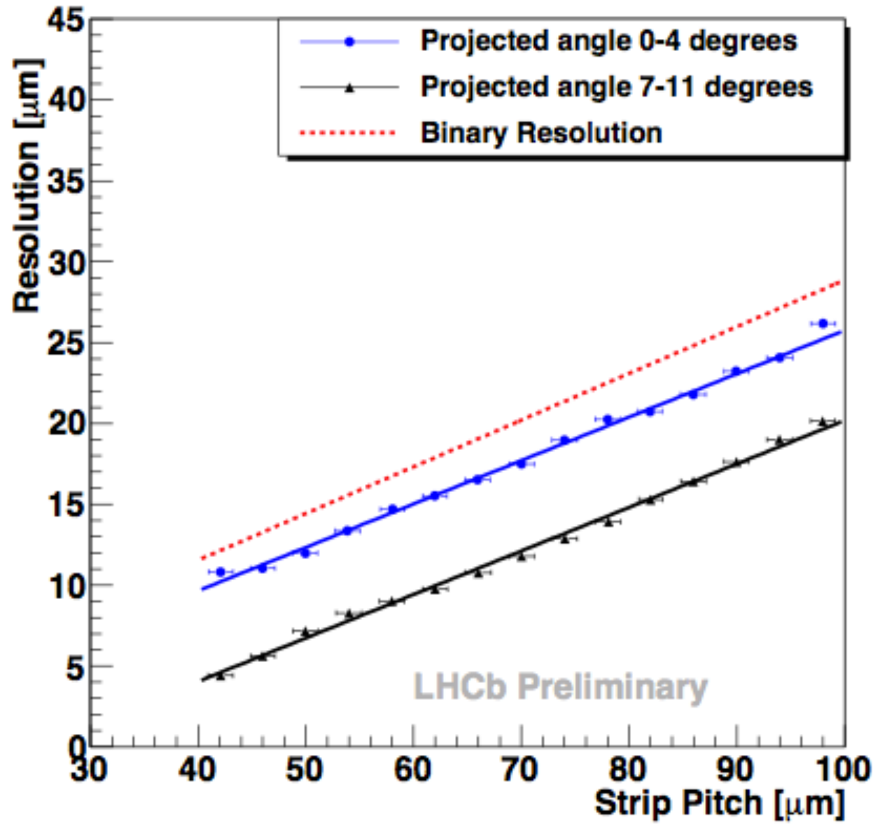
Key ingredients of physics performance

- *Detector alignment*
- *Impact parameter (IP) & Vertex reconstruction*
- *Tracking efficiency*
- *Invariant mass resolution*
- *PID (hadron, muon, electron, photon)*
- *Trigger efficiency*

VErtex LOcator (VELO)

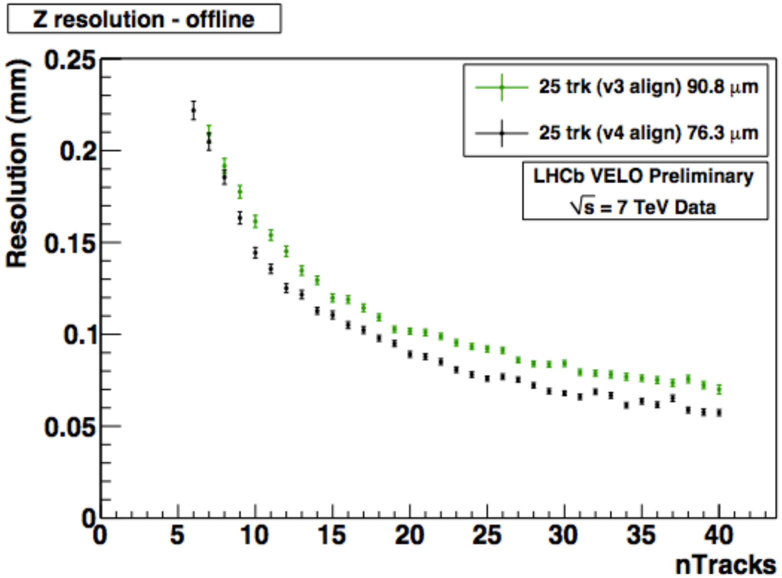
Best VELO hit resolution is 4 μm

Record resolution achieved at LHC
Great achievement !!!



Primary Vertex (PV) & Impact Parameter (IP) resolution

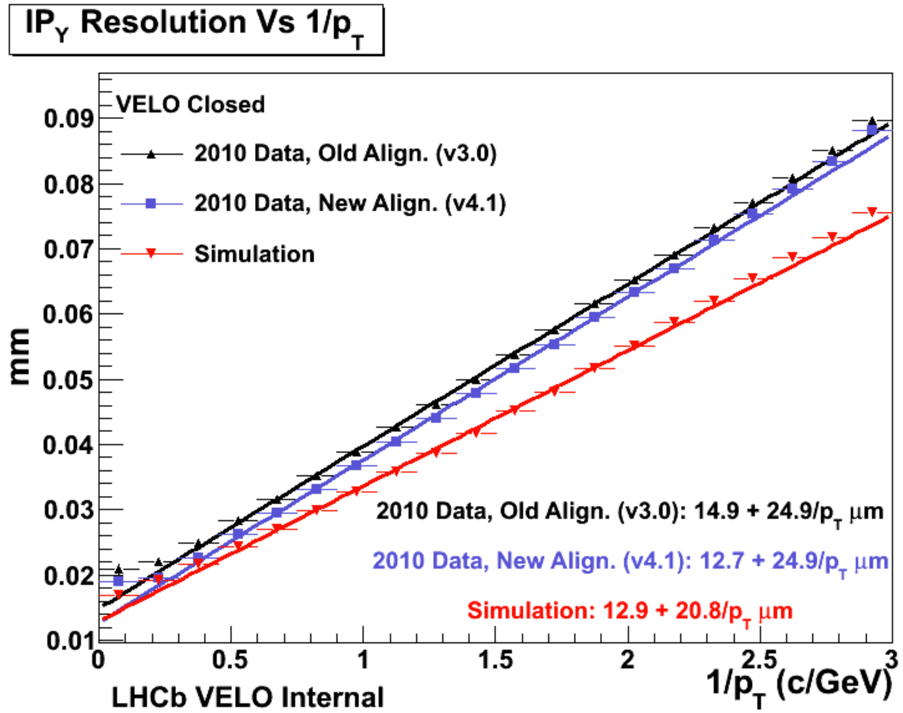
PV resolution evaluated in data using random splitting of the tracks in two halves and comparing vertices of equal multiplicity



Resolution for PV with 25 tracks

~ 13 μm for ***X*** *&* ***Y*** *and ~ 75 μm for* ***Z***

worse than MC: 11 μm for X & Y and 60 μm for Z



IP resolution < 20 μm for the highest p_t bins in agreement with expectation

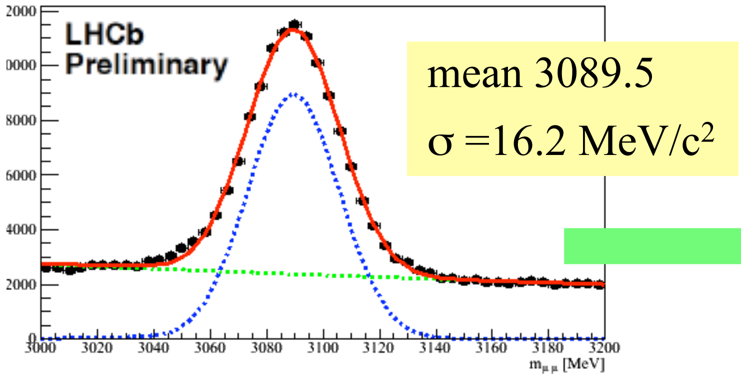
Further improvement is expected
However requires dedicated attention !!!

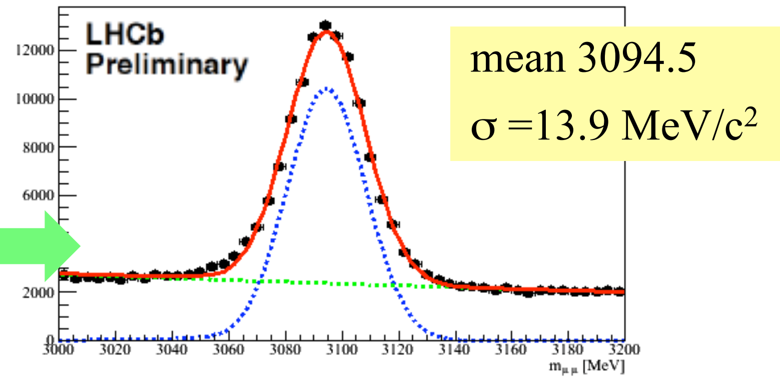
Signal peaks & present mass resolution

(Continuous improvement !!!)

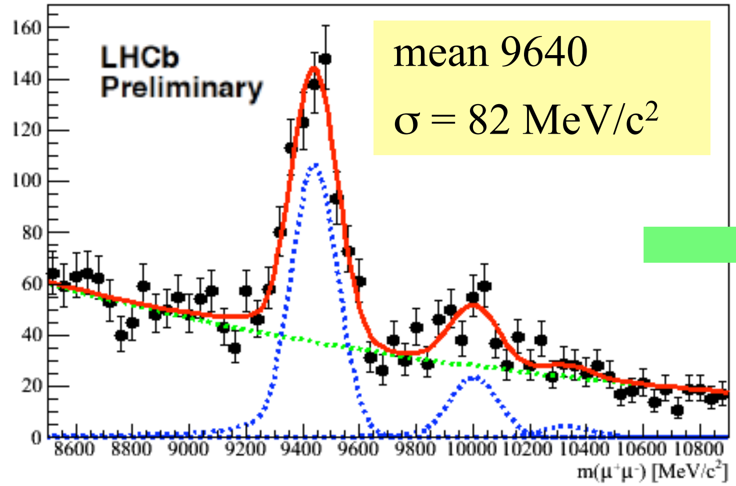
- *New alignment of all tracking system*
- *Good improvement in momentum resolution for high momentum tracks and mass resolution*

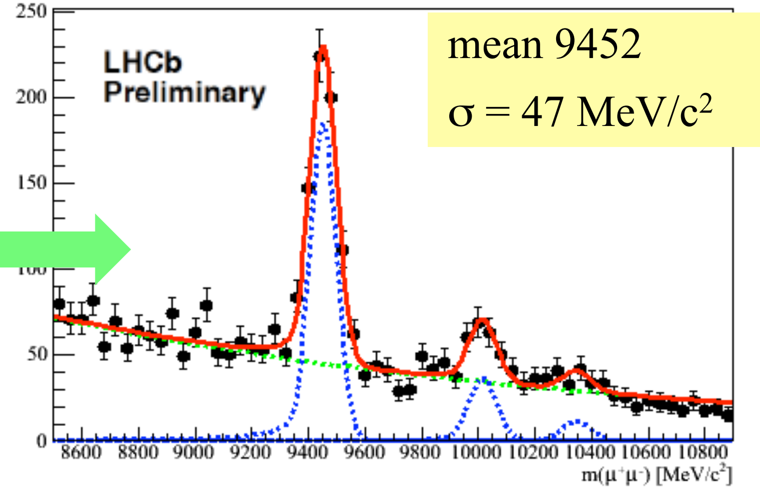
J/ψ → $\mu^+\mu^-$





Y → $\mu^+\mu^-$

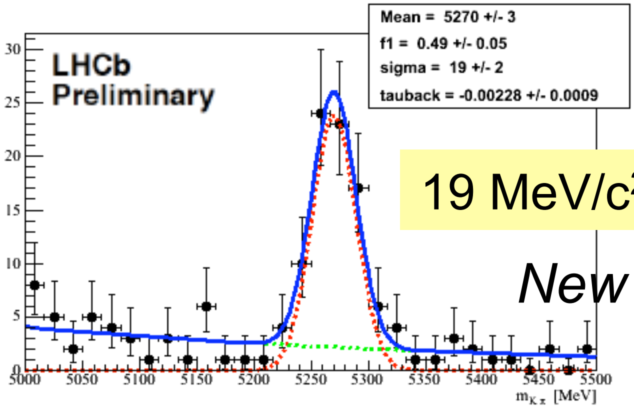




Signal peaks & present mass resolution

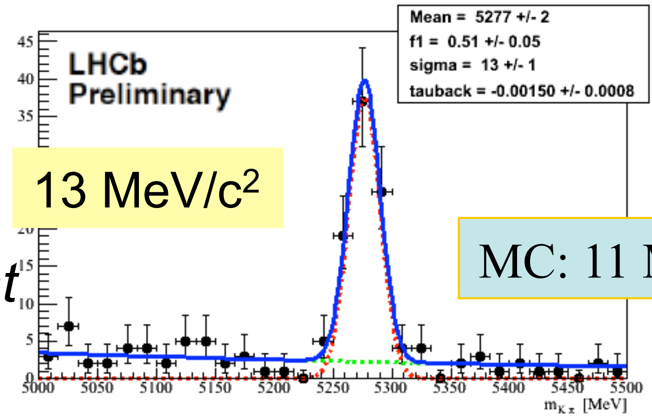
Mass resolutions approaching MC expectations

$B^+ \rightarrow J/\psi K^+$



19 MeV/c^2

New alignment →

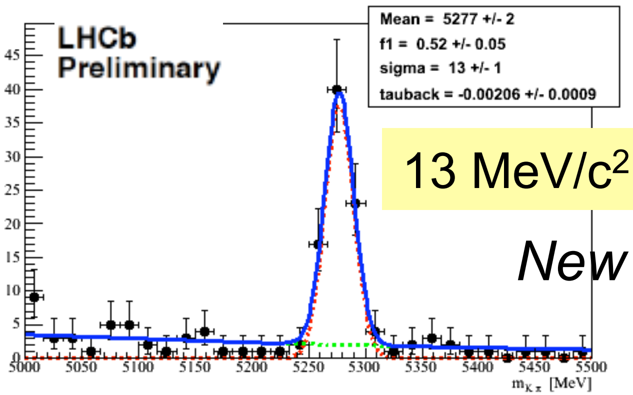


13 MeV/c^2

MC: 11 MeV/c^2

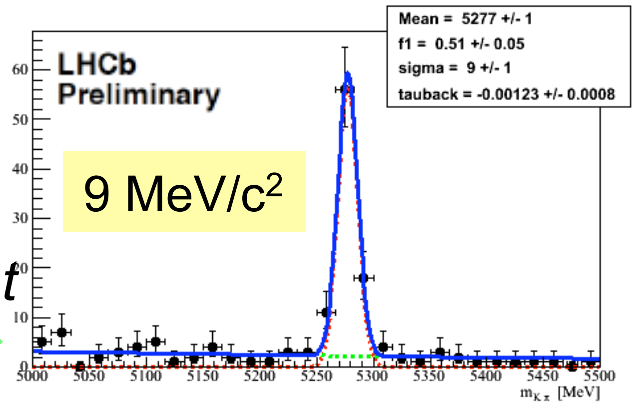
With J/ψ mass constraint ↓

$B^+ \rightarrow J/\psi K^+$



13 MeV/c^2

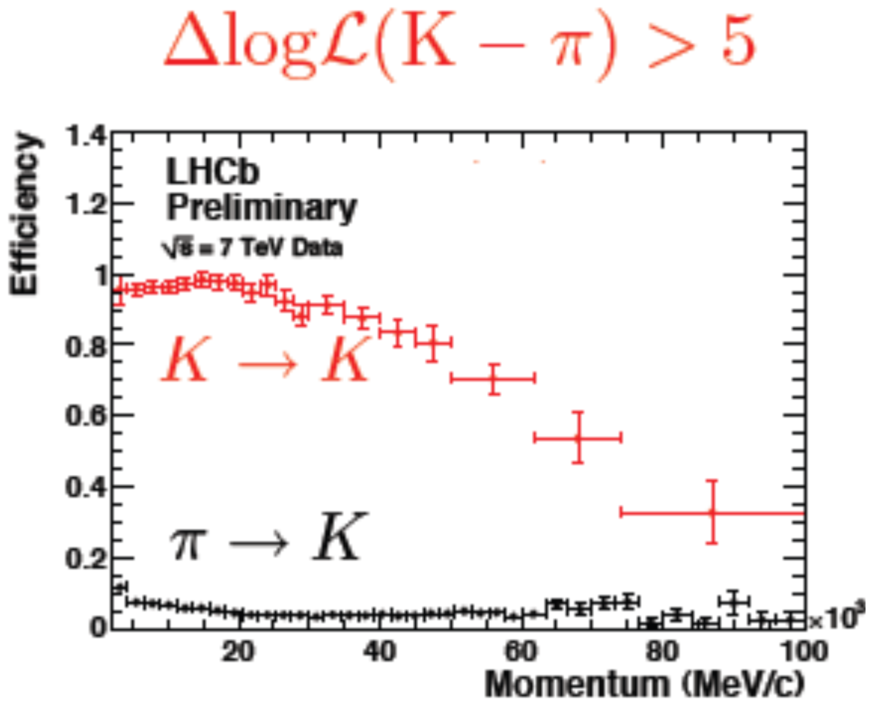
New alignment →

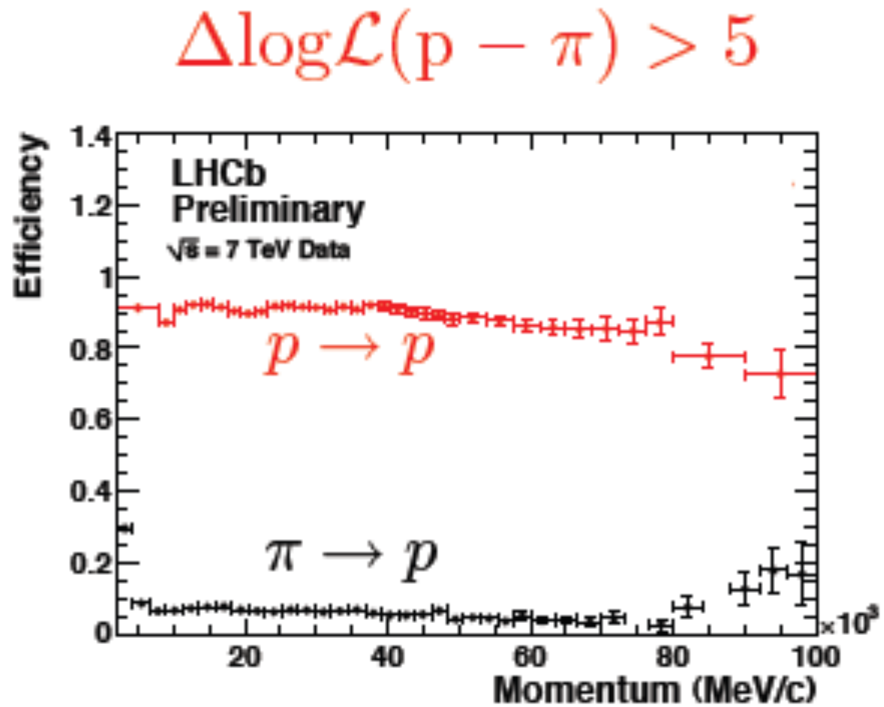


9 MeV/c^2

PID with RICH: p / K / π separation

- *PID performance measured on data using selected samples of pions, kaons and protons*
- *Improvement of PID at high momentum expected from better mirror and sensor alignment*

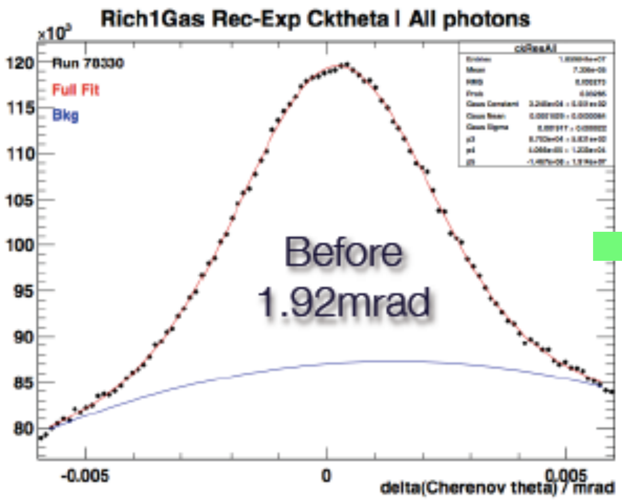


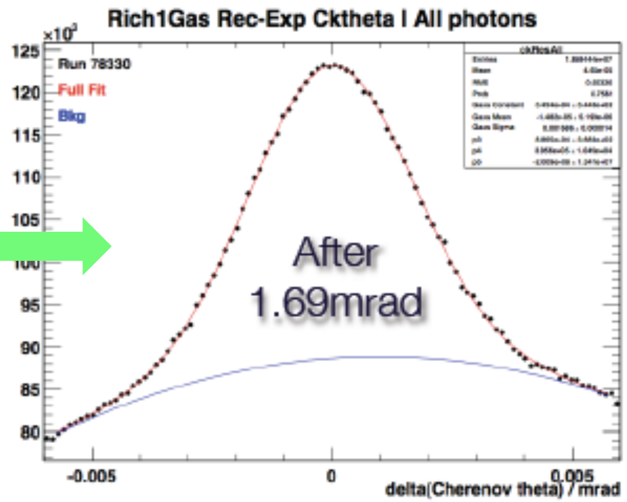


RICH alignment

- *Alignment of sensors for RICH1 and RICH2 progressing well*
- *Significant improvement of Cherenkov angle resolution*
  → will be implemented in the next reconstruction version

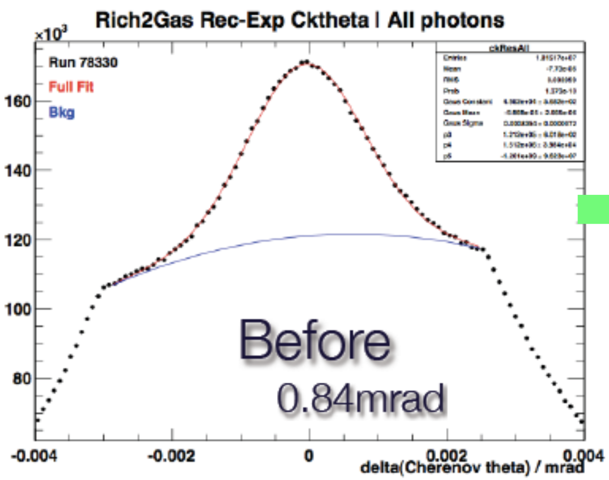
RICH1

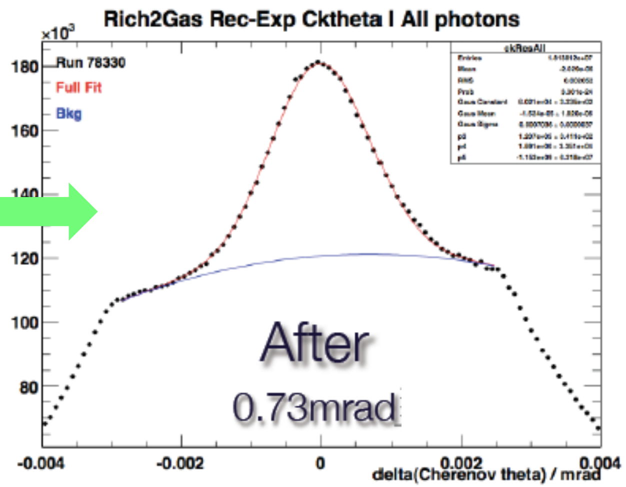




MC: 1.57 mrad

RICH2

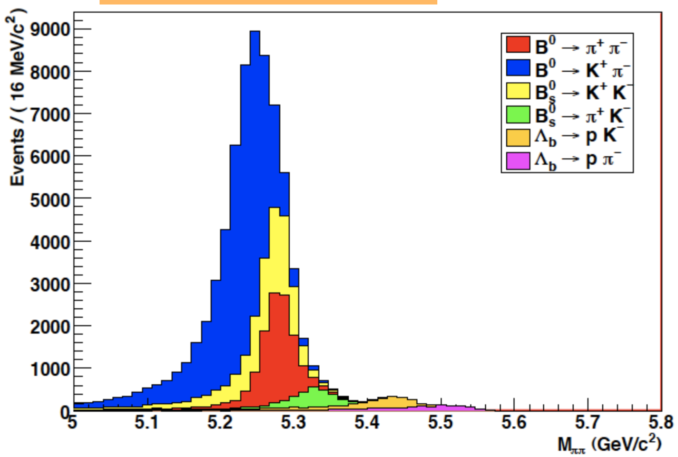




MC: 0.67 mrad

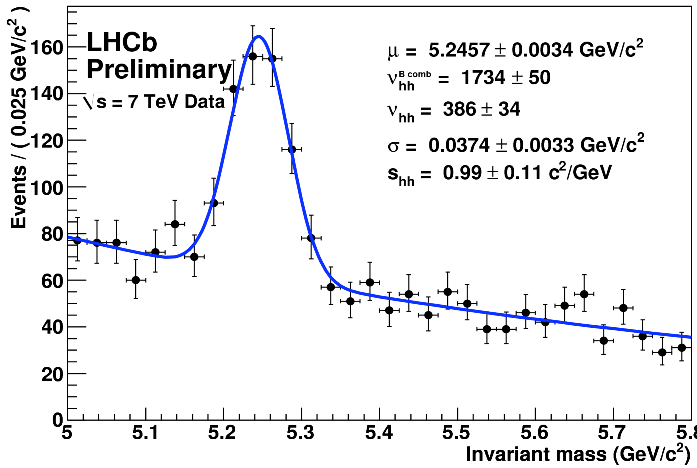
Crucial use of PID from RICH: $B_{(s)} \rightarrow K\pi$, KK, $\pi\pi$

MC: B→hh



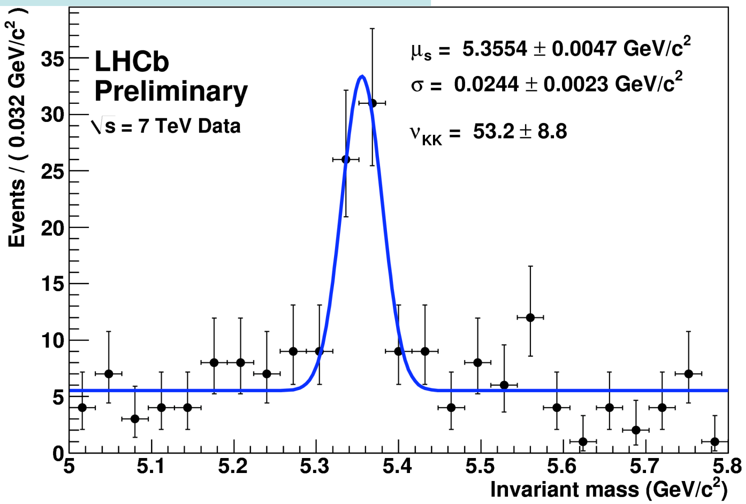
No PID: B→ hh

Peak includes all main B→hh decay modes

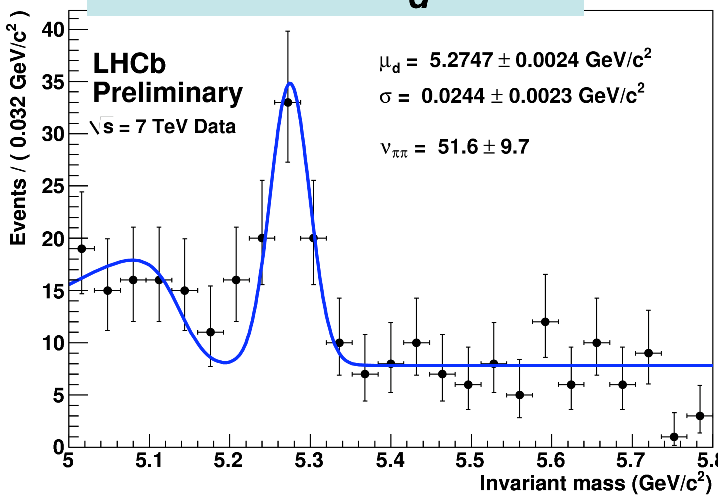


First clean single mode mass peaks ever produced at hadron colliders thanks to RICH

With PID: $B_s \rightarrow KK$

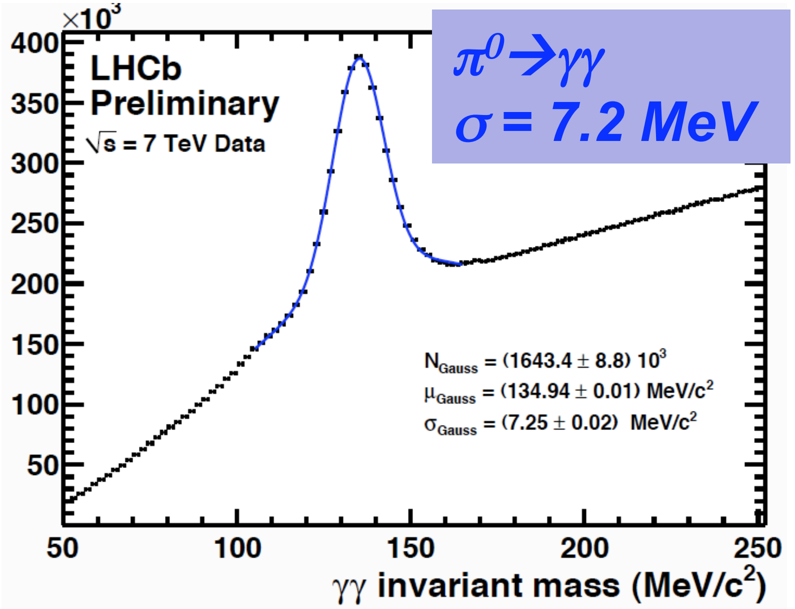


With PID: $B_d \rightarrow \pi\pi$



PID with Calorimeter

(Identification of electrons and photons)

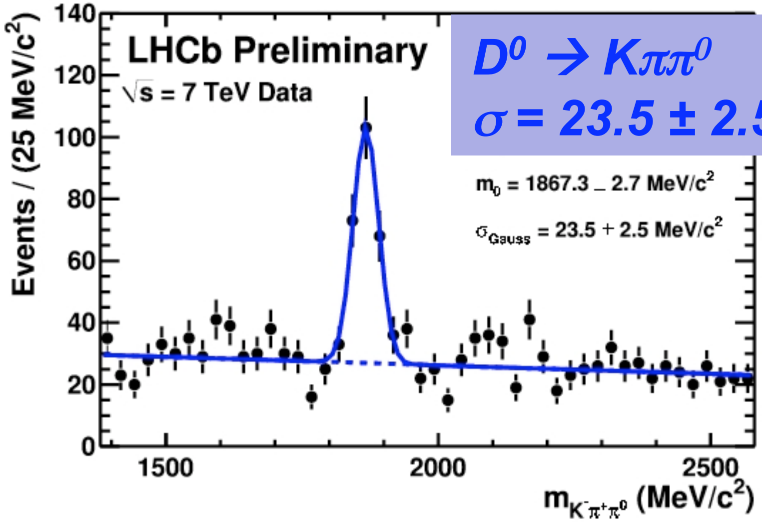


$\pi^0 \rightarrow \gamma\gamma$
σ = 7.2 MeV

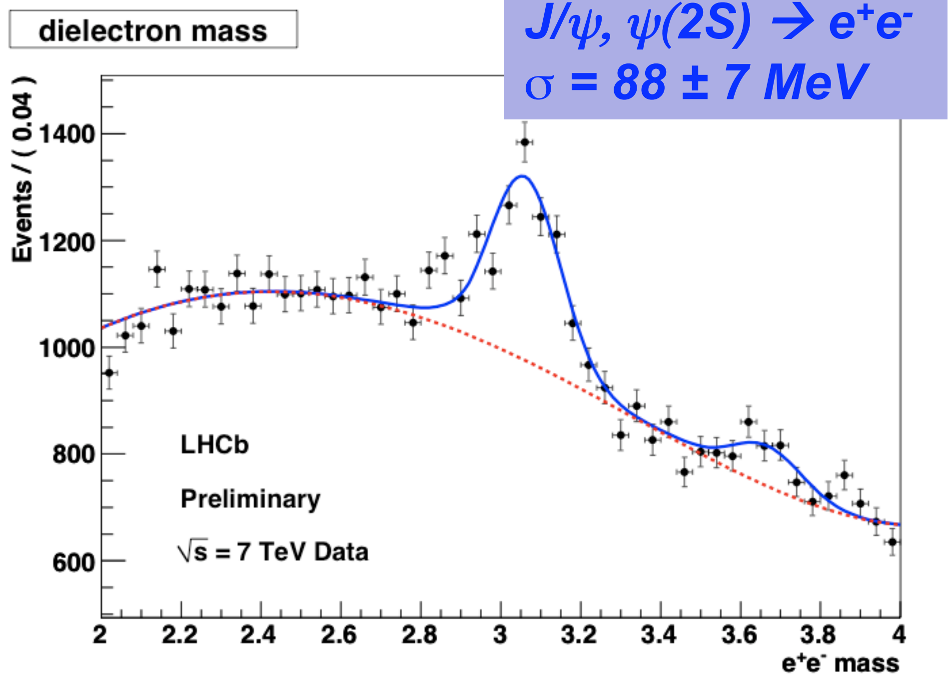
ECAL is calibrated to 2% level
π^0 resolution is better than expected

Clear J/ψ and $\psi(2S)$ signals are reconstructed in e^+e^- decay mode

Reconstruction of D decays in the final states with neutrals looks encouraging !



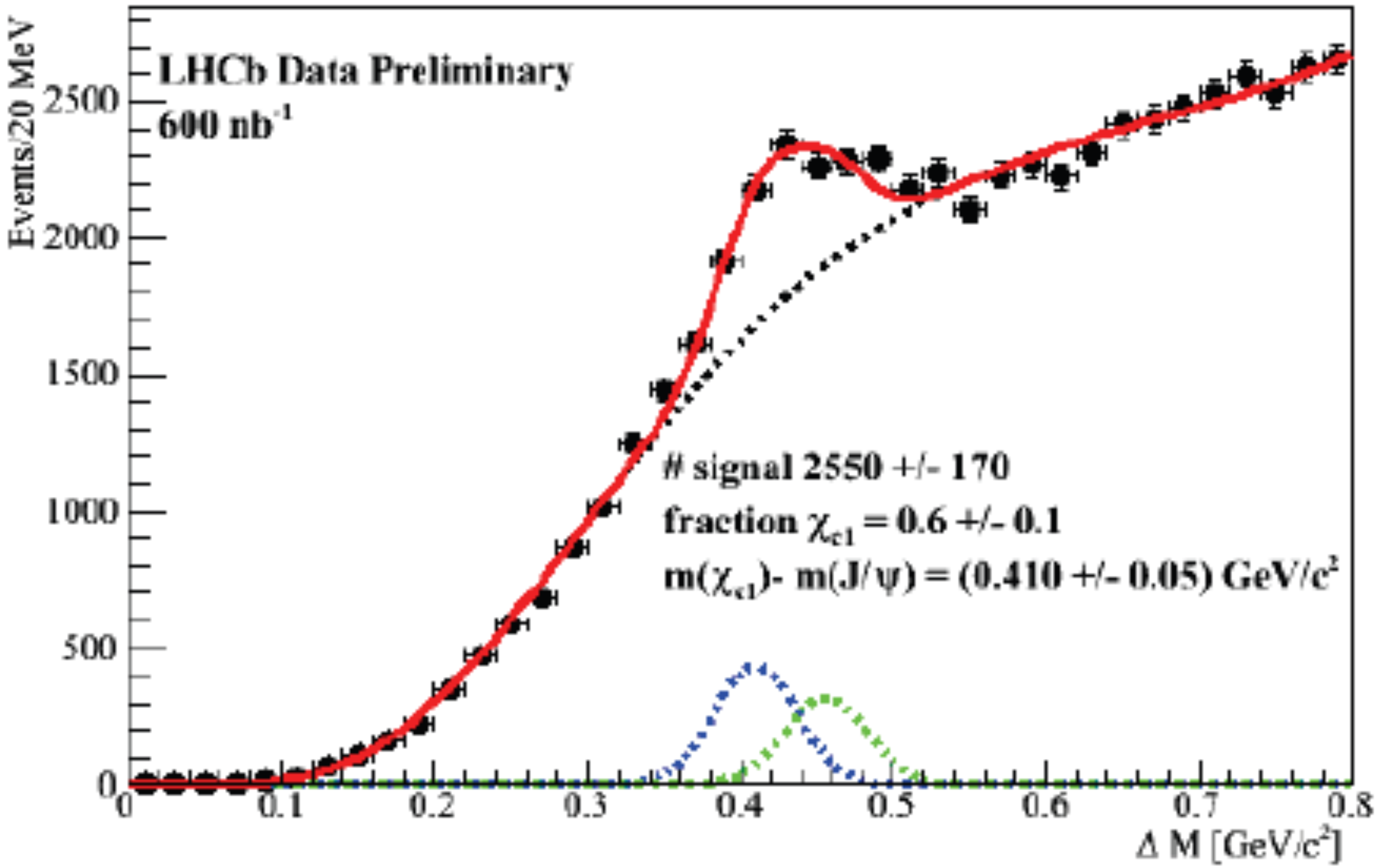
$D^0 \rightarrow K\pi\pi^0$
σ = 23.5 ± 2.5 MeV



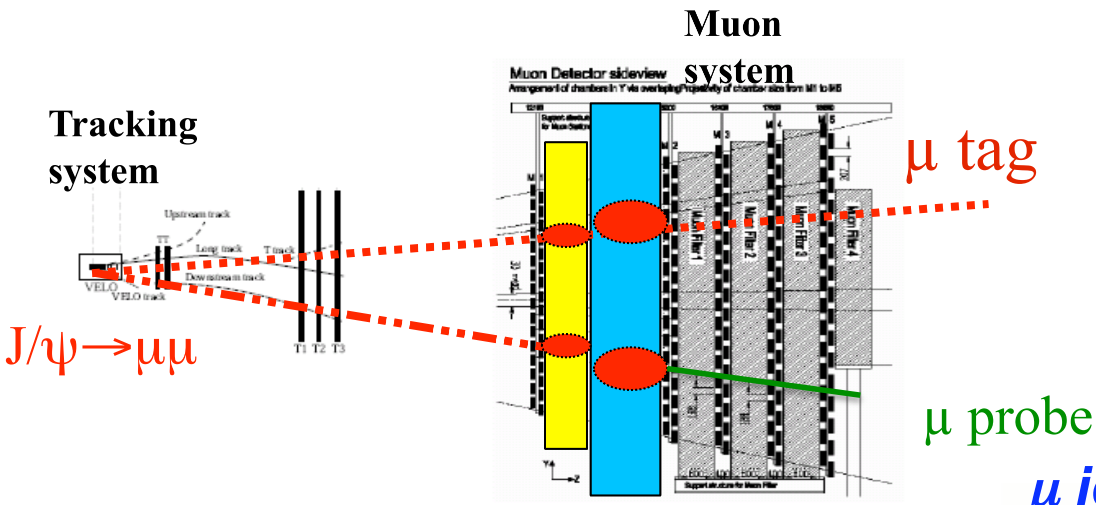
J/ψ, $\psi(2S) \rightarrow e^+e^-$
σ = 88 ± 7 MeV

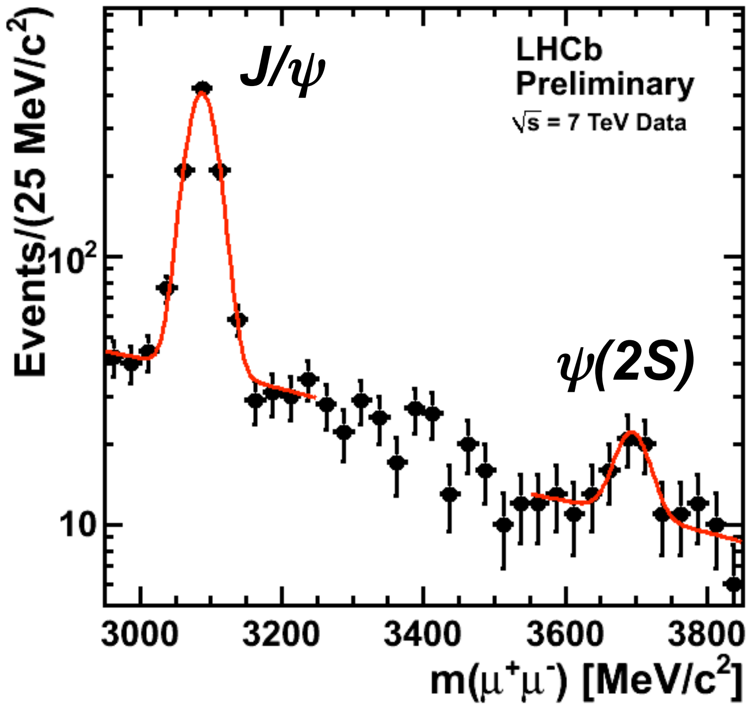
χ_c *signal with LHCb calorimeter*

σ fixed to 27 MeV (MC value)



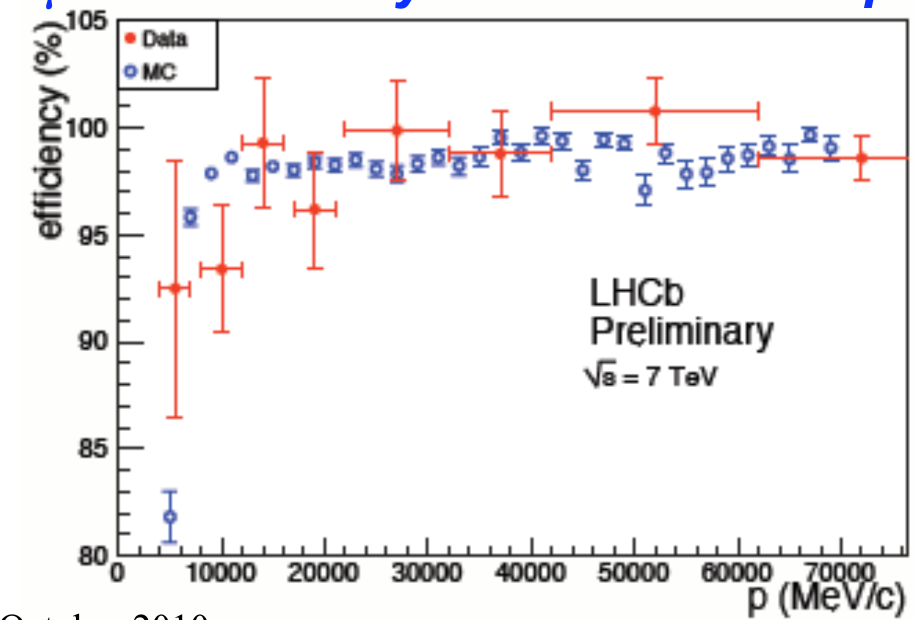
PID with MUON





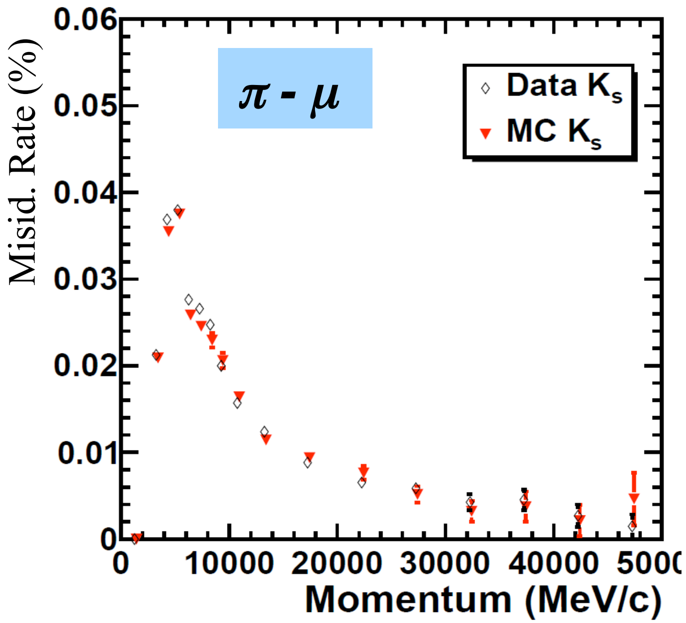
$\varepsilon(\mu)$ = (97.3 ± 1.2)%

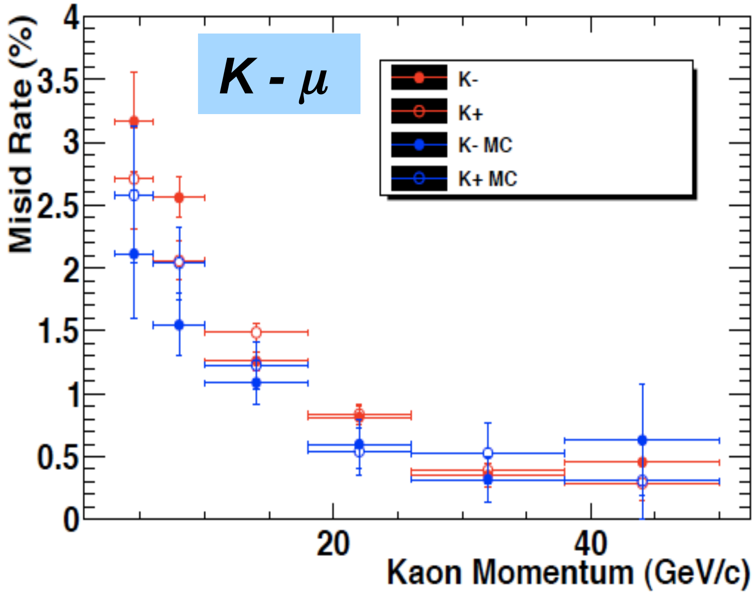
μ id. efficiency as a function of p



PID with MUON

μ–π, μ–K and μ–p misidentification rates have been determined using large samples of $K_S \rightarrow \pi\pi$, $\phi \rightarrow$ KK and $\Lambda \rightarrow p\pi$ decays



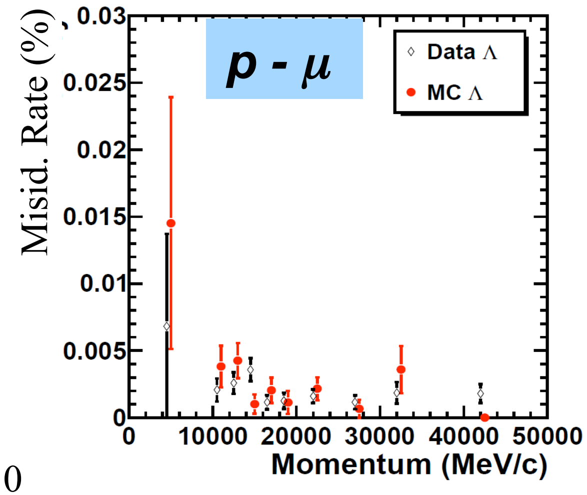


π,K→μ dominated by decays in flight

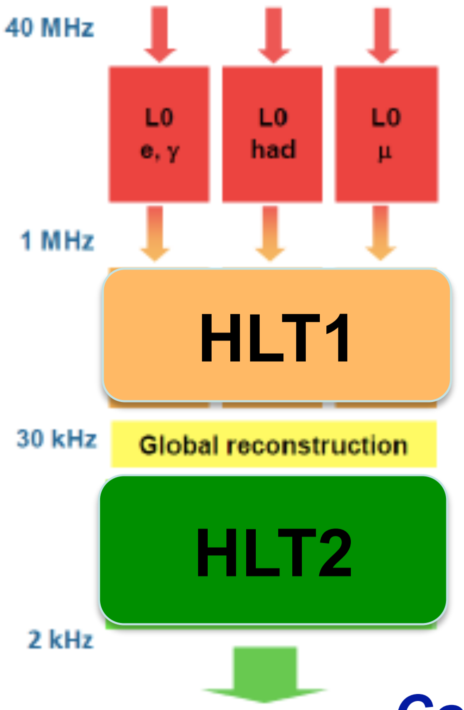
$\varepsilon_{K,\pi-\mu} < 1\%$ for p > 20 GeV

p→μ dominated by combinatorics in muon stations

$\varepsilon_{\mu\text{-}p}$ = 0.21 ± 0.05%



Trigger & Online



L0
- *Only 20% of computing farm was available until recently → main limitation is CPU used in HLT*
- *L0 is fully operational*
- *Run with increasing thresholds as luminosity increased*
- *Efficiency on charm reconstruction decreases rapidly with increasing thresholds. Core B physics is very little affected*

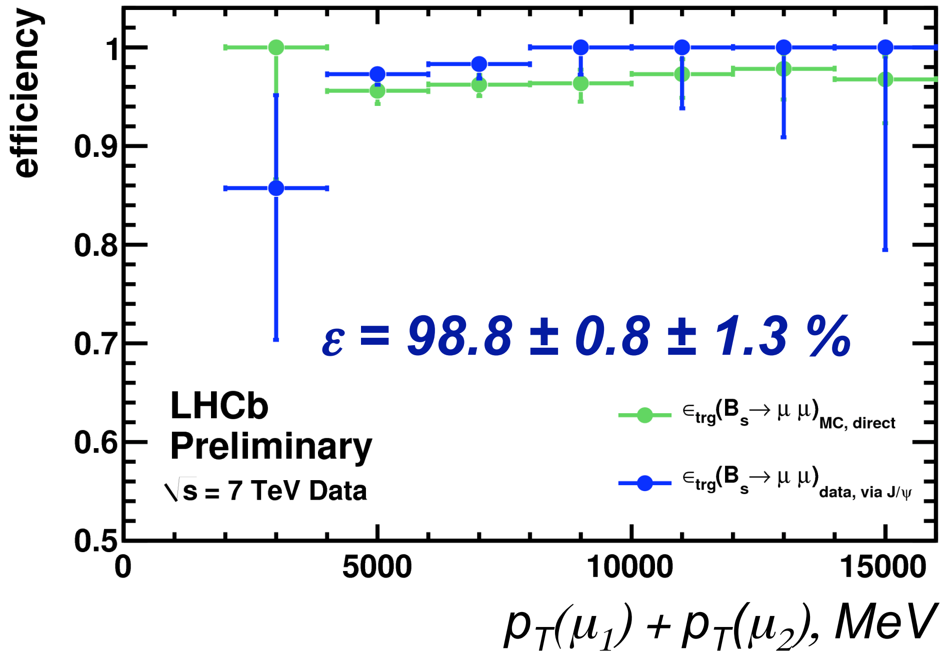
Completion of the Computing Farm

- *In the beginning of 2010 decided to wait until the end of 2011 with the installation of the rest of the farm to get best performance (even at cost of some data loss)*
- *Tremendous increase of LHC luminosity → crash-program to bring in at least part of CPU well before original deadline*
- *Last week 400 servers installed and brought to operation in< 5 days increasing CPU power of the farm by a factor 2.5 !*

Many thanks to the On-line group for this fantastic success !!!

Trigger Efficiencies

- *Measure performance of L0 × HLT1 on data (using lifetime unbiased HLT1 lines) for $J/\psi \rightarrow \mu\mu$*
- *Transport results to harder p_t spectrum expected for $B_s \rightarrow \mu\mu$*



Data agree well with MC

LHCb trigger concept has been proven with data !!!

LHCb is currently running with the pile-up higher than expected at nominal conditions

First physics results:

Production cross-sections at $\sqrt{s}$ = 7 TeV

- *Open charm*
- *J/ψ*
- *$b\bar{b}$*

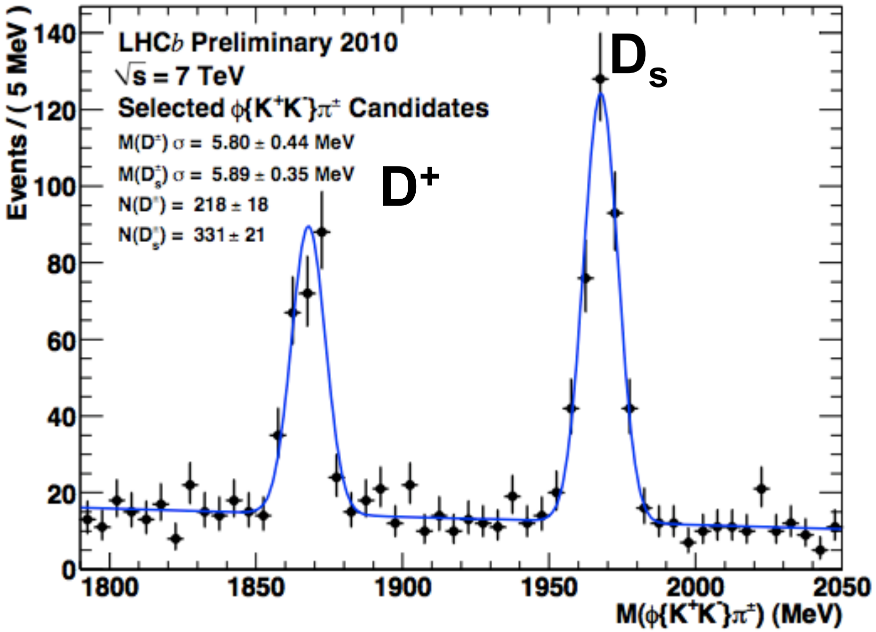
Open charm cross-sections (D^*, D^0, D^+, D_s) @ $\sqrt{s}$ = 7 TeV

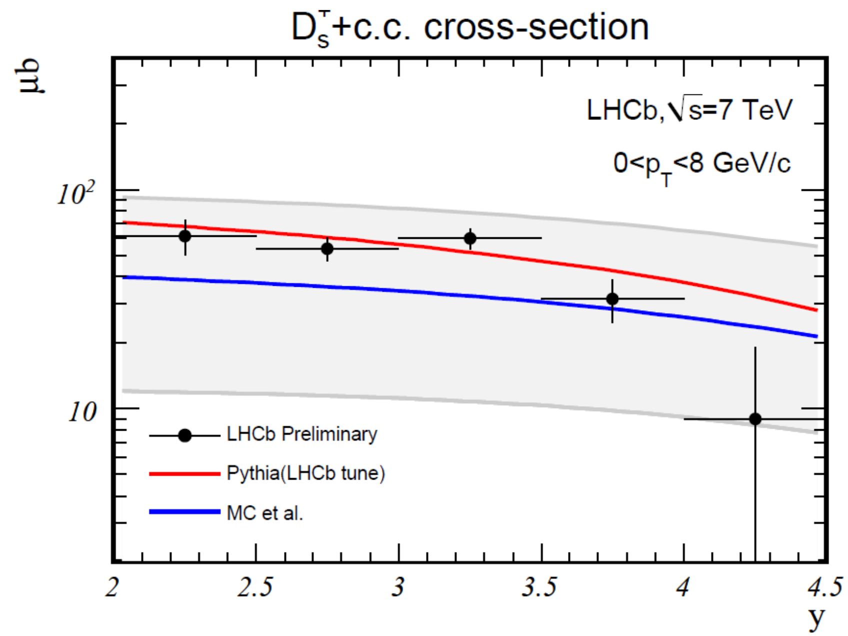
Open charm production cross-sections have been measured in forward region $2 < y < 5$ for D^*, D^0, D^+ and D_s.

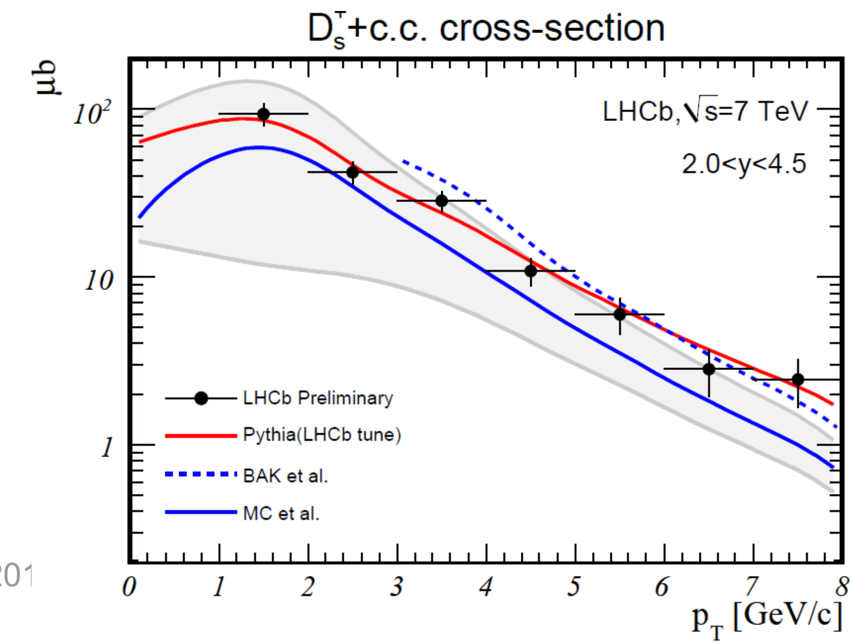
As expected charm production is huge !!!

$\sigma(pp \rightarrow ccX) \approx 20 \times \sigma(pp \rightarrow bbX)$

→ Good prospects for charm programme



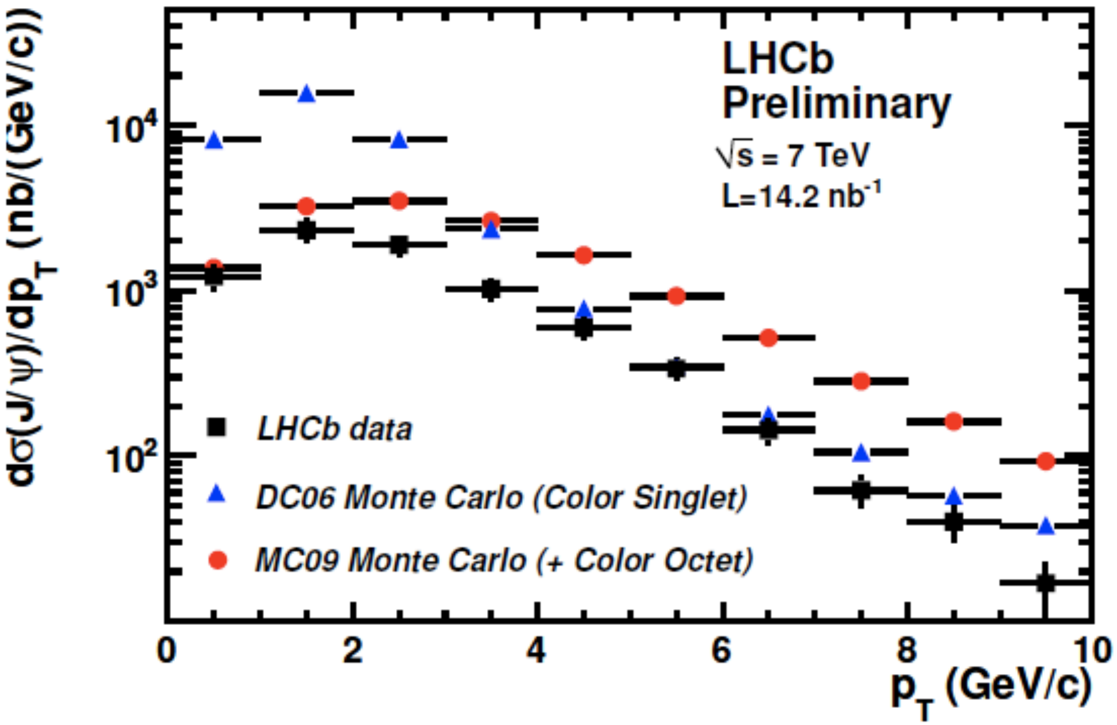




IP distribution used to separate prompt from secondary D^0, D^+ and D_s candidates

J/ψ cross-sections @ $\sqrt{s}$ = 7 TeV

σ(inclusive J/ψ, p_T < 10 GeV/c, 2.5 < y < 4) = $7.65 \pm 0.19 \pm 1.10^{+0.87}_{-1.27}$ µb,
where the third error is due to unknown J/ψ polarization; will be measured in 2nd pass.

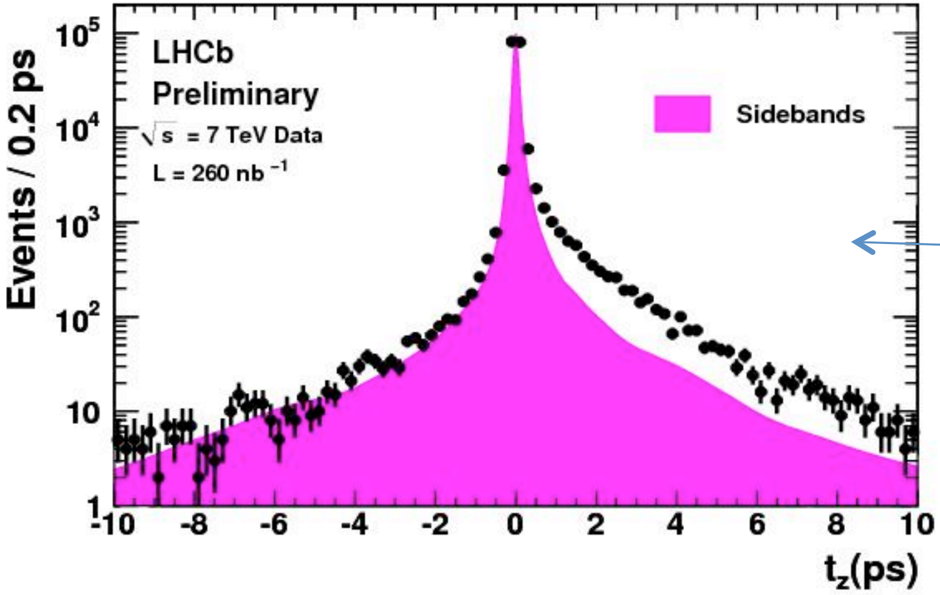


Data favour neither color singlet nor color octet model !!!

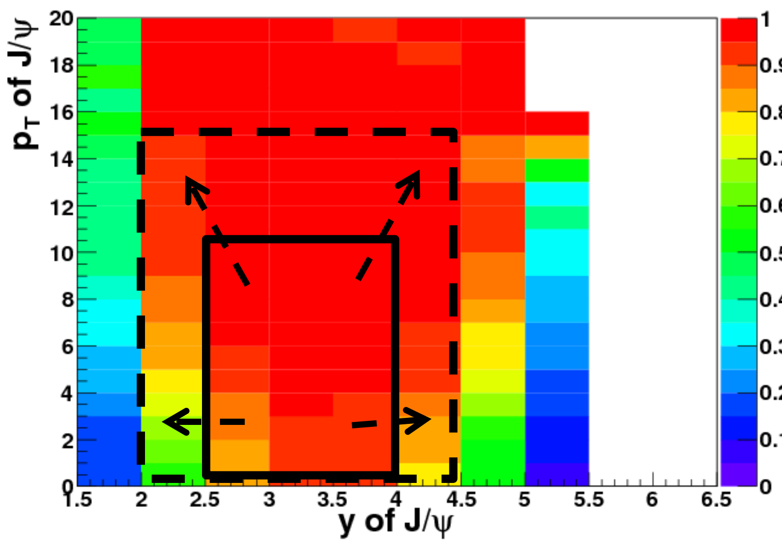
J/ψ production from b decays:

σ(J/ψ from b p_T < 10 GeV/c, 2.5 < y < 4) = 0.81 ± 0.06 ±0.13 µb

J/ψ cross-section: future plans



Pseudo propertime: $t_z = d_z M(J/\psi)/p_z$ used to separate prompt and J/ψ from b decays

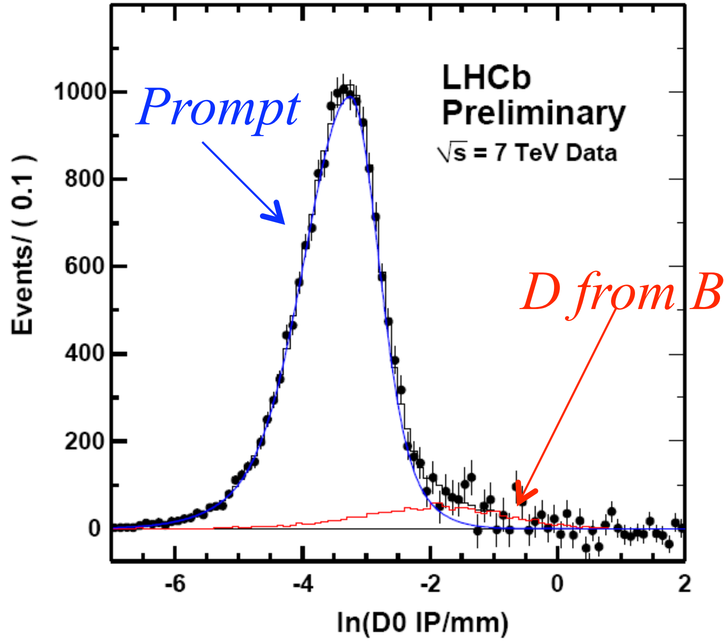


Using data collected in 2010 (several 100 k events / pb^{-1}):

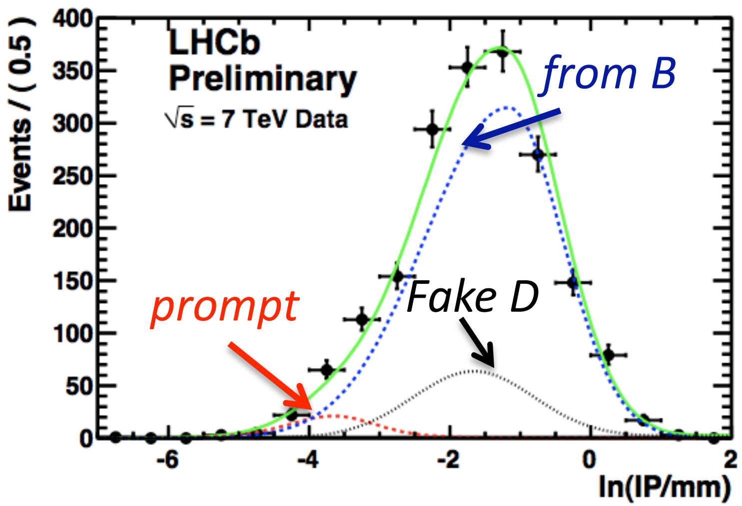
- *Will measure also J/ψ polarization*
- *Region of measurement (y, p_T) will be extended in order to provide an overlap with GPDs*

$b\bar{b}$ cross-section @ $\sqrt{s}$ = 7 TeV using $B \rightarrow D^0 \mu X$ events

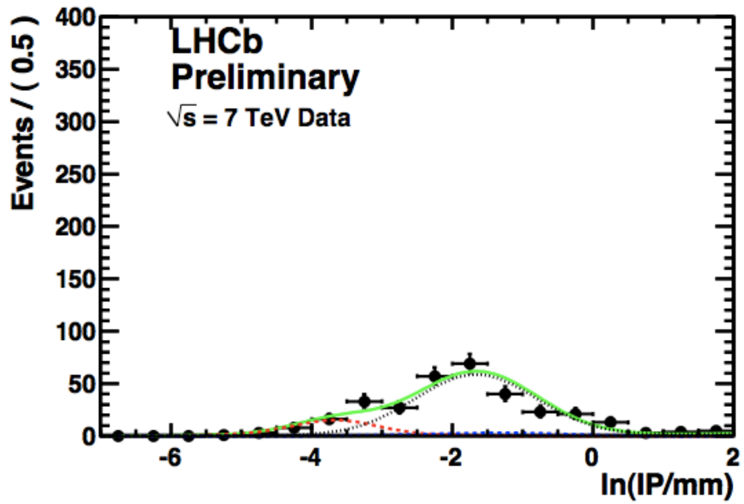
- $BR(b \rightarrow D^0 \mu \nu X) = (6.82 \pm 0.35)\%$
- *Impact Parameter (IP) D distribution used to separate prompt D and D produced in B decays*
- *Correlate D^0 with the muon charge*



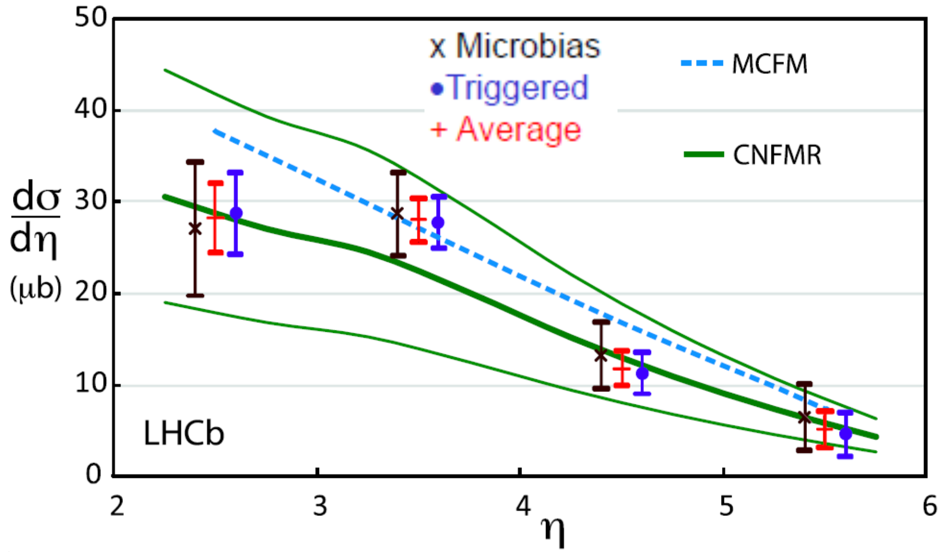
Right sign



Wrong sign



$b\bar{b}$ cross-section @ $\sqrt{s}$ = 7 TeV
(published in PLB)



Shapes and scales agree well with expectation. Validates QCD predictions at LHC energies

$\sigma(pp \to H_b X)$ = 75.3 ± 5.4 ± 13.0 μb for 2<η<6, any p_T, $\sqrt{s}$=7 TeV

Extrapolating to 4π using PYTHIA 6.4: **$\sigma(pp \to \bar{b}bX)$ = 284 ± 20 ± 49 μb**

Theory:
MCFM 332 μb,
NFMR 254 μb

Averaging with prel. result from b→J/ψ:X ***$\sigma(pp \to \bar{b}bX)$ = 292 ± 15 ± 43 mb***

→ b rate (at least) as high as assumed in LHCb sensitivity studies.

Prospects for 2010-2011 Physics Run

Channels potentially sensitive to big effects of New Physics:

- $B_s \rightarrow \mu\mu$
- *CP Violation in charm*
- *CP Violation in* $B_s \rightarrow J/\psi\phi$
- *Test D0 result on* a^s_{SL} *(and/or* a^d_{SL} *)*

Actual LHCb physics programme is much much wider !!!

$B_s \rightarrow \mu\mu$

- ❑ *Super rare decay in SM with well predicted* $BR(B_s \rightarrow \mu\mu) = (3.2\pm0.2)\times10^{-9}$
  $BR(B_d \rightarrow \mu\mu) = (1.1\pm0.1)\times10^{-10}$
- ❑ *Sensitive to NP, in particular new scalars In MSSM:* $BR \propto \tan^6\beta / M^4_A$

Analysis in 3 parameter space:

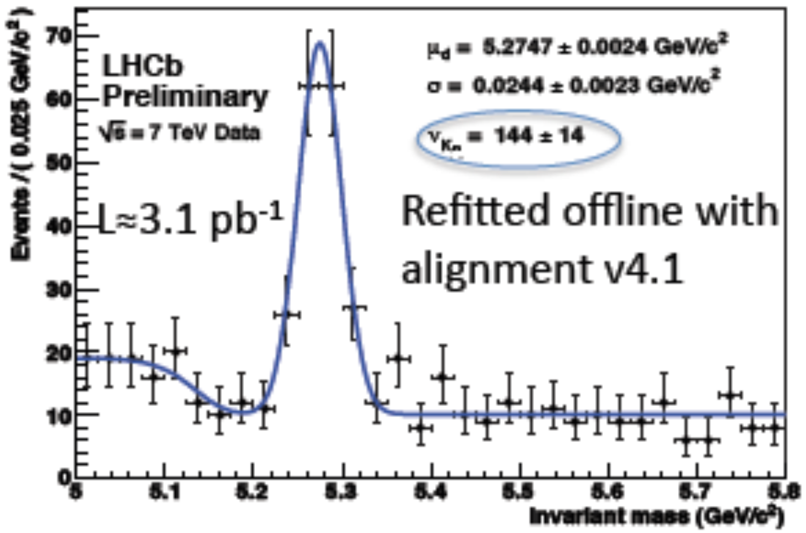
- *Geometrical Likelihood (GL)*
- *PID Likelihood*
- *Invariant Mass*

Control Channels:

- $B^{(+)} \rightarrow J/\psi K^{*,+}$ **,** $B_s \rightarrow J/\psi\phi$ ***(normalization, PID)***
- $B \rightarrow hh$ ***(normalization, GL, mass)***

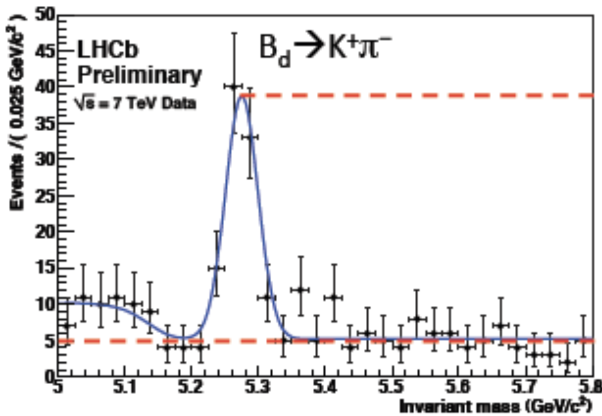
Excellent mass resolution demonstrated for new alignment !!!

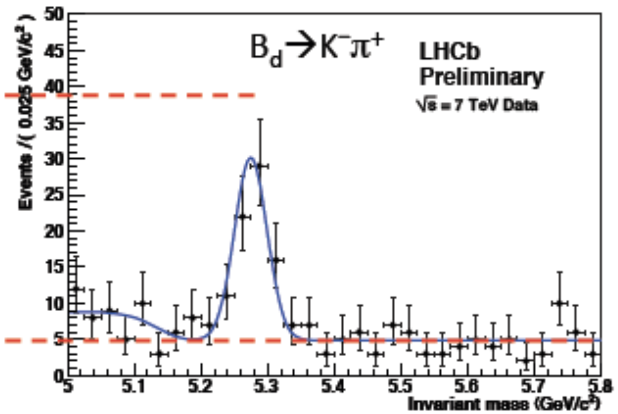
Observed yield of $B \rightarrow K\pi$ ***is 144 ev.***
w.a. $BR(B \rightarrow K\pi) = (19.4\pm0.6)\times10^{-6}$



First look at direct CP asymmetry:

$A^{CP}_{K\pi} = -0.1407 \pm 0.097$ (W.A.: -0.098 ± 0.012)

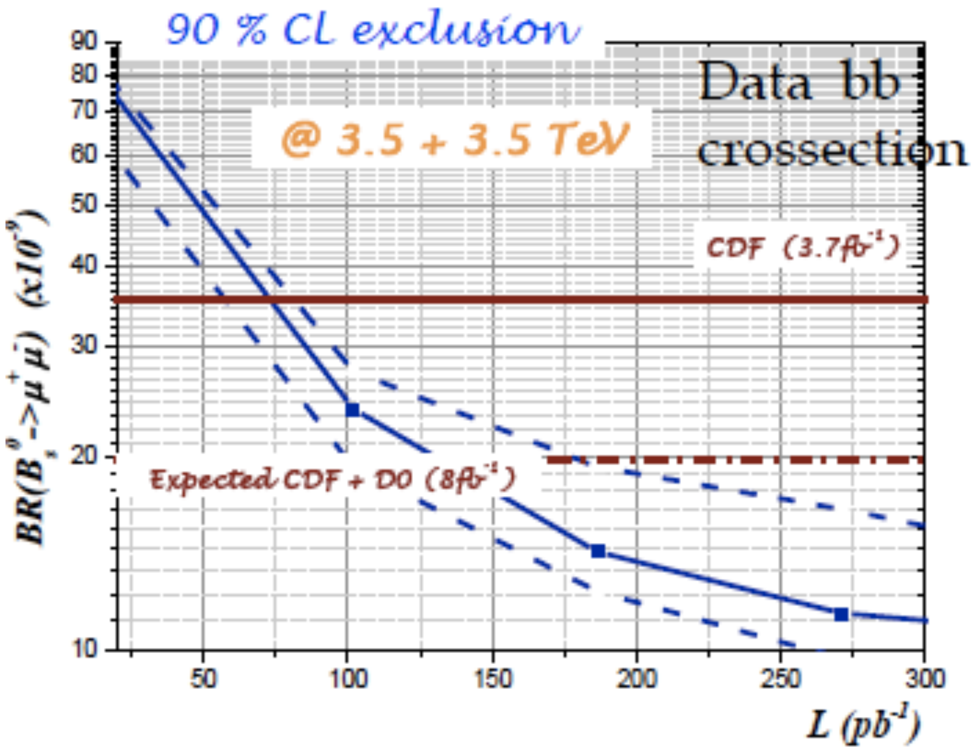


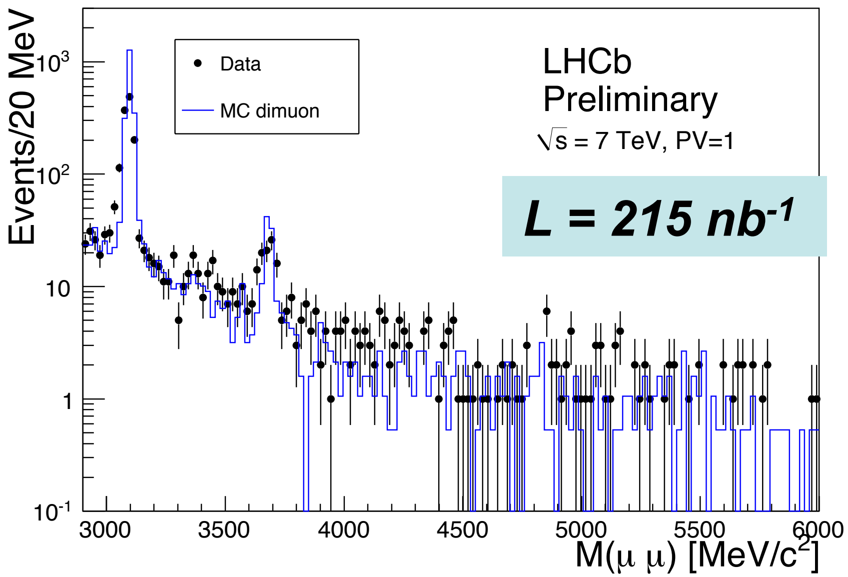


$B_s \rightarrow \mu\mu$

For the SM prediction LHCb expects 10 signal events in 1 fb^{-1}.

Background expected from MC is so far in good agreement with data





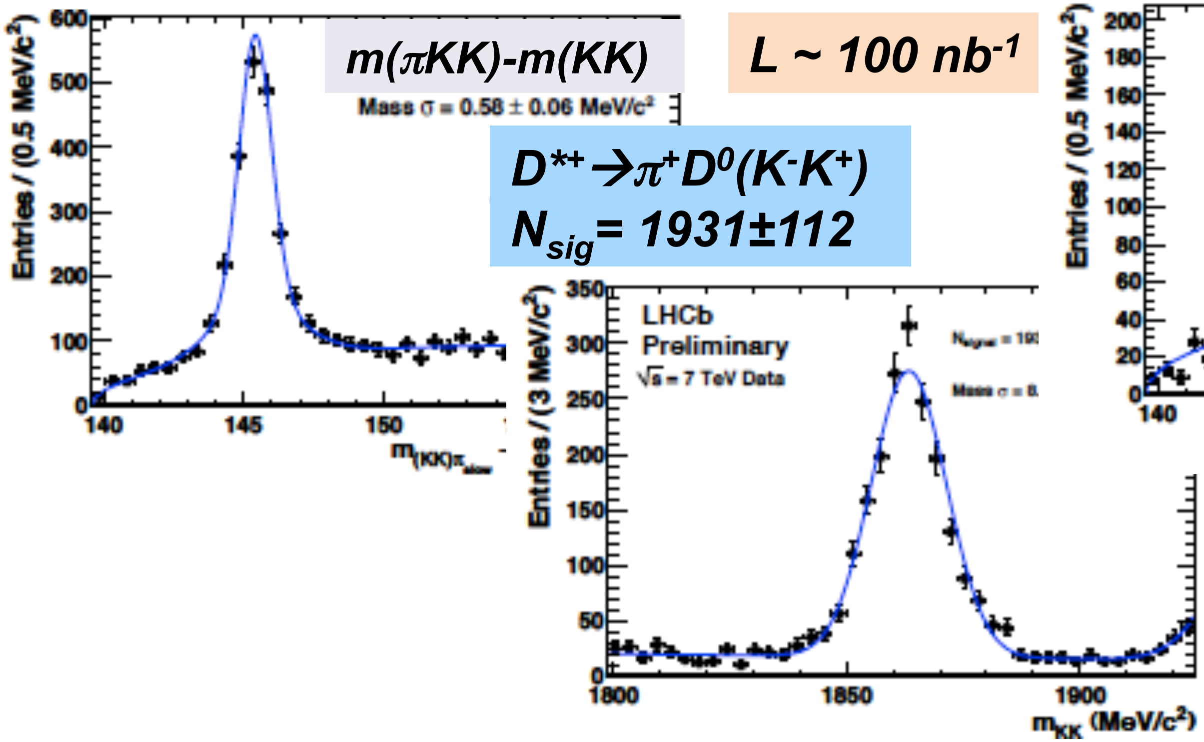
Analysis improvement underway
Very interesting sensitivity possible even with 50 pb^{-1} !!!

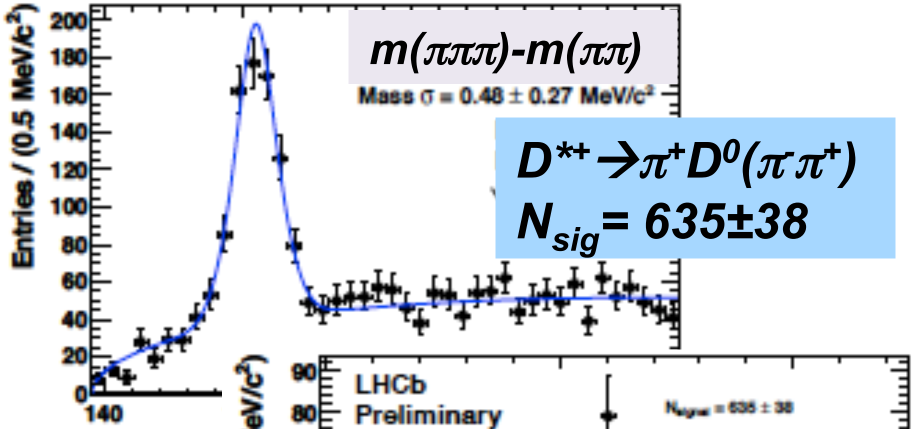
With L ~ 1 fb^{-1} exclusion of SM enhancement up to $BR(B_s \rightarrow \mu\mu) \sim 7\times10^{-9}$

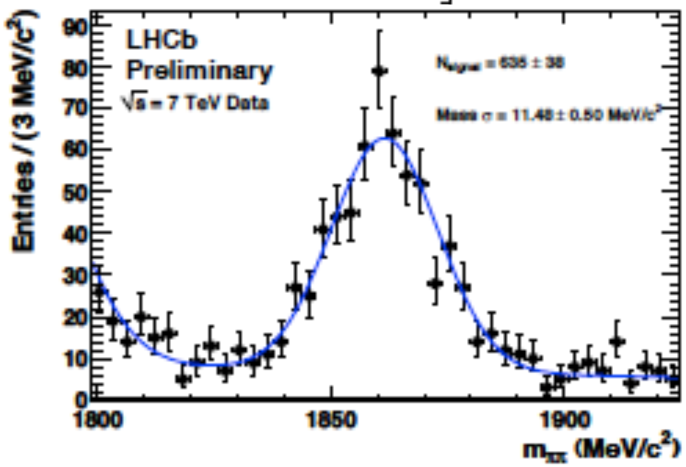
CPV studies in charm sector

(also important for CPV measurements in hadronic B decays)

- *Excellent prospects for CPV studies; sensitivity < 0.1% is feasible at LHCb with first 100 pb^{-1} !!! Expect several million tagged $D^0 \rightarrow KK$ (BELLE 540 fb^{-1} analysis uses ~10^5 tagged $D^0 \rightarrow KK$ giving stat. precision on y_{CP}=0.32% and on A_Γ=0.30%)*





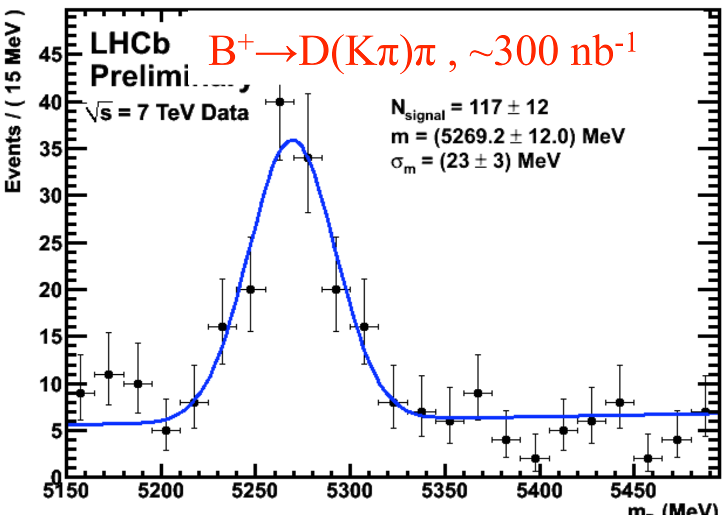


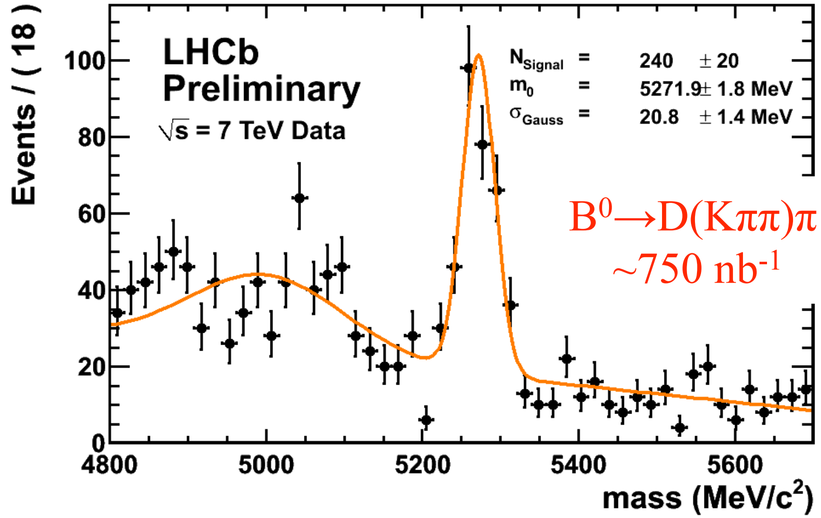
- *Search for direct CPV using $D^+ \rightarrow K^+K^-\pi^+$ with significant contribution from gluonic Penguins.*
  Again LHCb can be confident in collecting several million events in 100 pb^{-1} , which is an order of magnitude increase on B-factories samples

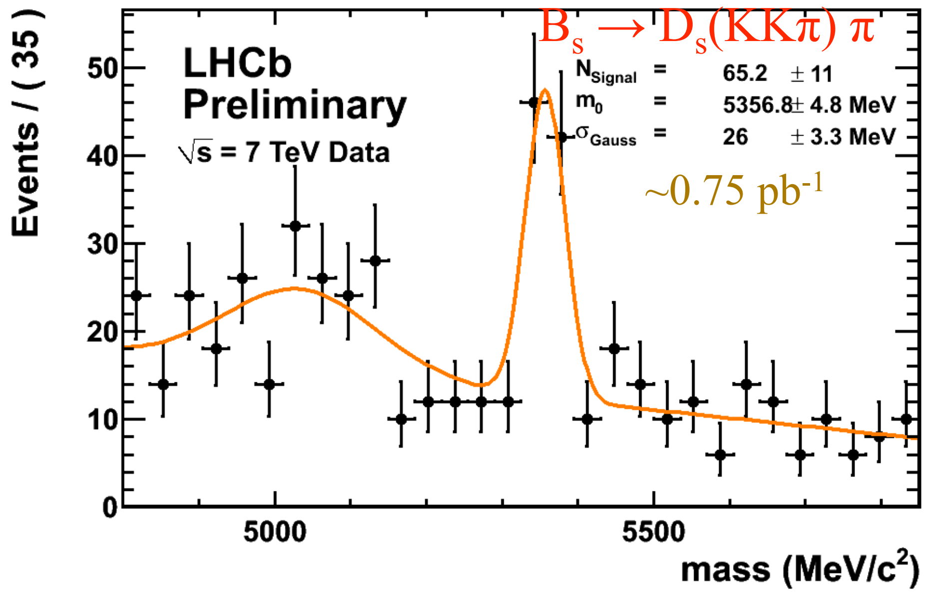
- *Similar opportunities in many other D physics topics, e.g. search for $D^0 \rightarrow \mu\mu$*

Multibody hadronic final states in $B_{(s)} \rightarrow D_{(s)}K$ is the road to measure CKM angle γ in trees

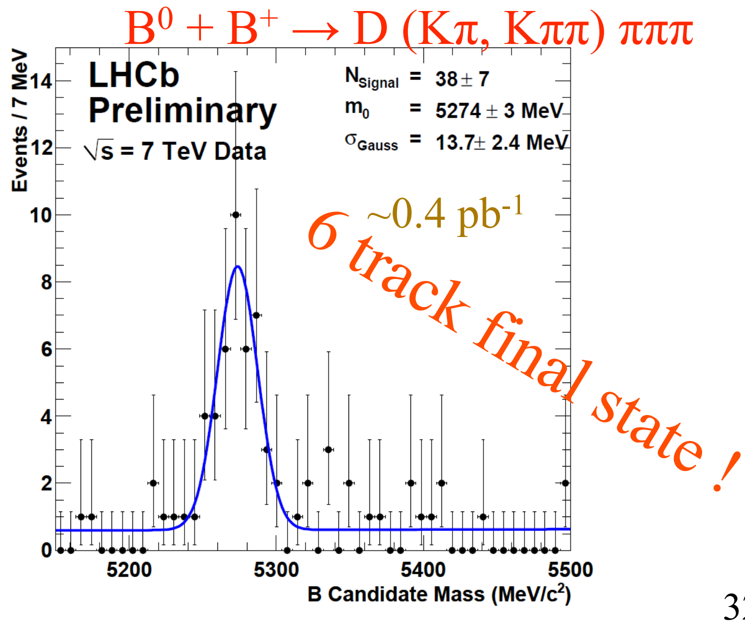
First signals are observed at ~ expected rate
→ Opportunity for better accuracy in γ with 2010-2011 data







2010

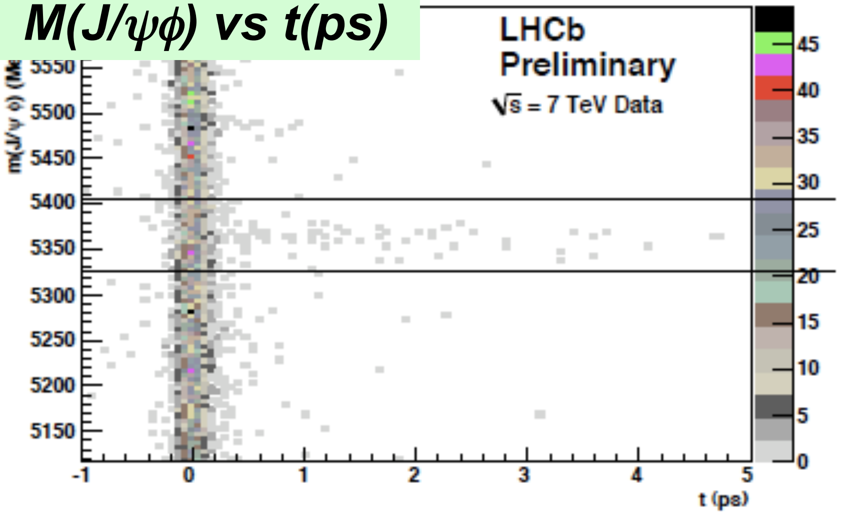


CPV in $B_s \to J/\psi\phi$

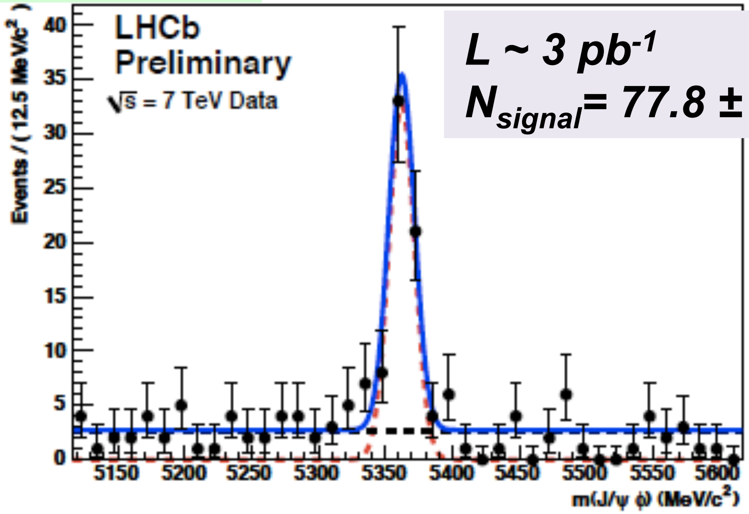
$\phi_s^{J/\psi\phi}$ = **$-2\beta_s$** is very small and precisely predicted in SM

→ **Very sensitive to NP !!!**

$B_s \to J/\psi\phi$
$M(J/\psi\phi)$ vs $t(ps)$



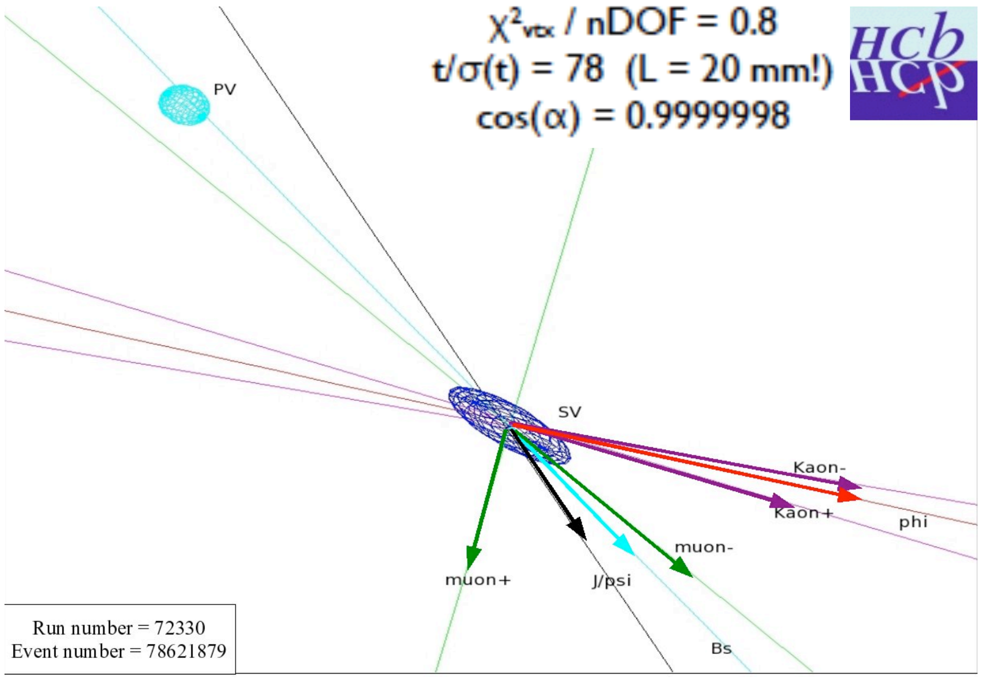
t > 0.3 ps



$L \sim 3\ pb^{-1}$
$N_{signal} = 77.8 \pm 11$

Number of signal events as expected

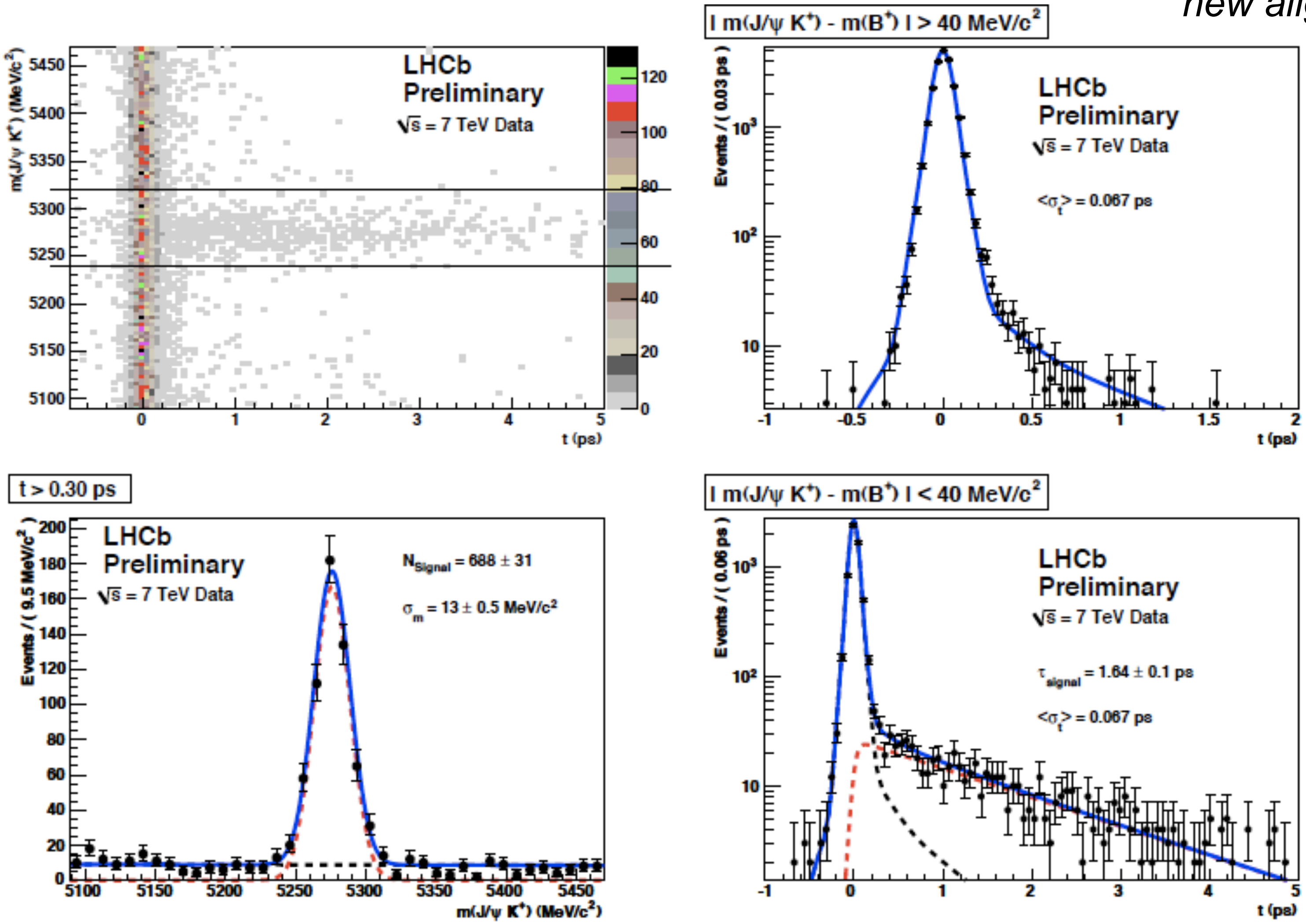
$m(\mu\mu)$ = 3072 MeV/c²
$m(KK)$ = 1020 MeV/c²
$m(\mu\mu KK)$ = 5343 MeV/c²



$B \rightarrow J/\psi K^+$ & proper time resolution

Unbinned likelihood fit of m and t distributions

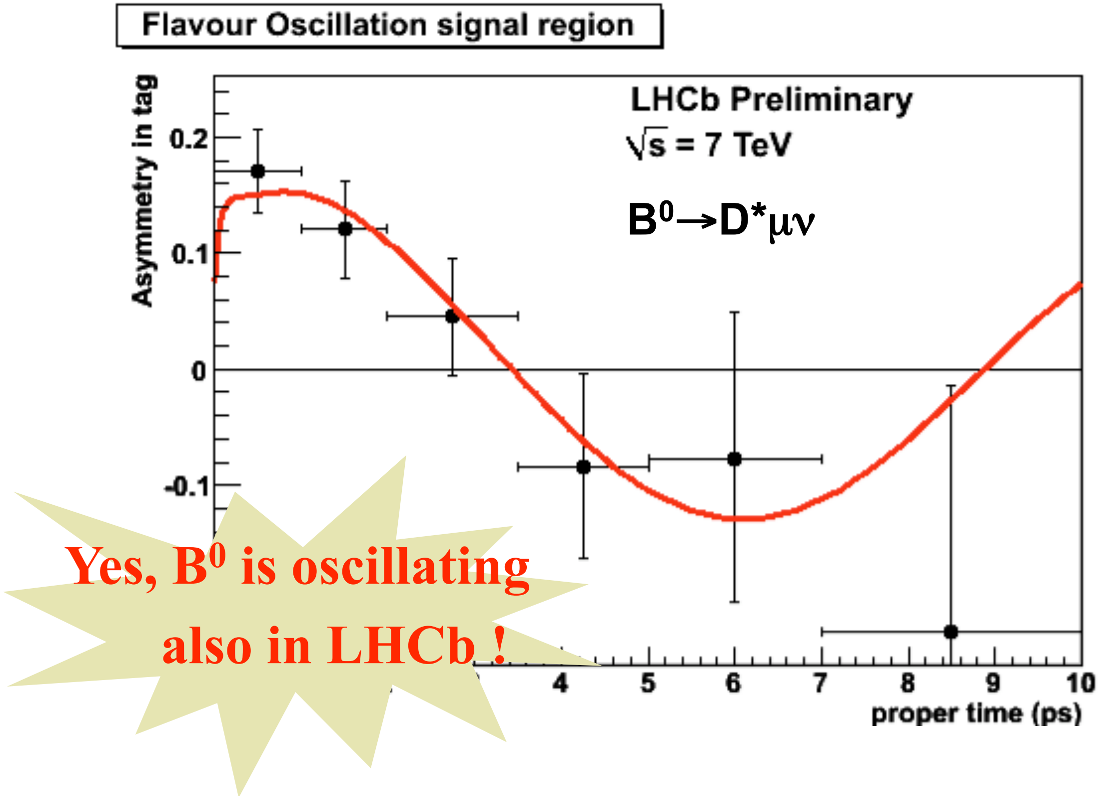
Proper time resolution 67 fs, whereas is 40 fs in MC: Will reduce to < 60 fs with new alignment

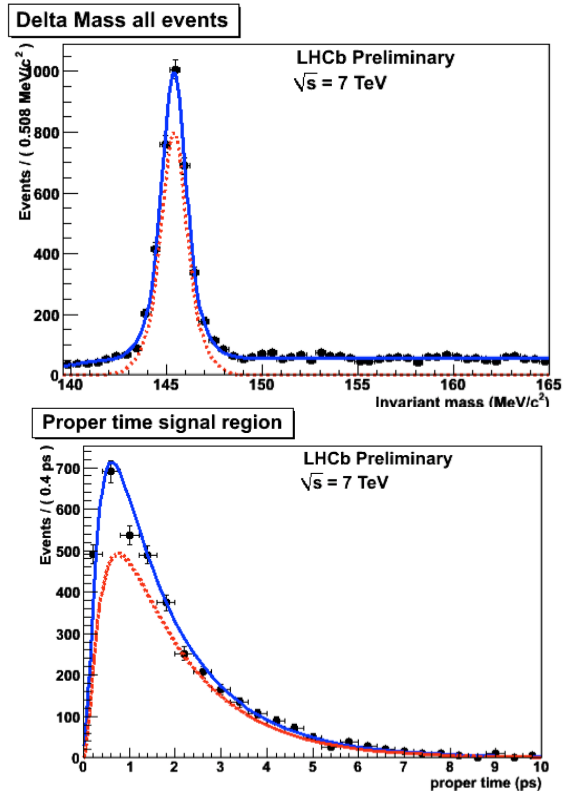


Observed number of signal events consistent with MC expectations

B → J/ψK⁺ & flavour tagging

First signal of flavour oscillation from $B^0_d \to D^{*-}(D^0\pi^-)\mu^+\nu$ *events .*





Very preliminary estimate of tagging already
at ~ 60% of nominal performance

CPV in $B_s \rightarrow J/\psi\phi$

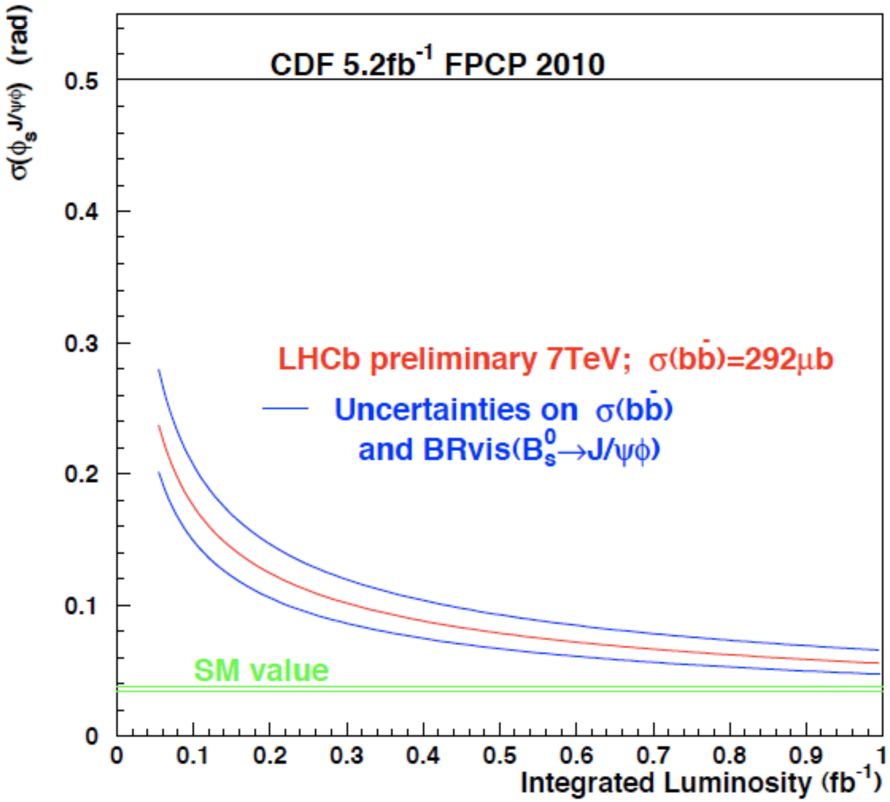
Expected sensitivity:

MC performance:

-50k events / fb^{-1} consistent with number of $B_s \rightarrow J/\psi\phi$ candidates seen in data

-<σ_t> = 0.040 ps. Present resolution worse in data but sufficient for Δm_s ~ 17.7/ps (will add 40% dilution to the sensitivity)

- Tagging performance εD^2 = 6.2% will be tested with more data



Preparations towards LHCb upgrade

- *Current running conditions are optimal to study the effects of multiple interactions → one of the key challenges for the Upgrade*

- *In order to fully exploit physics in the very forward direction (not only in the flavour sector) implement flexible software trigger:*

  - *Replace all the detector electronics so that the system can be readout at the 40 MHz beam crossing rate*
  - *Construct new vertex detector*
  - *Optimize tracking*

- *Preparations have started from the organizational and resource sides. In order to speed up data processing and exploit running at significantly higher than nominal luminosity, the Swiss groups are requesting ~0.6 MCHF to increase CPU power of the computing farm*

- ***LOI is being prepared for submission***

Collaboration matters

- *The status of the accounts healthy. No cash flow problems foreseen.*
- ***More resources need to be spent on central tasks.***
- *Pierluigi Campana (INFN, Frascati) has been elected as Spokesperson He will start his 3 years mandate in summer 2011.*
- *Ulrich Straumann (University of Zurich) has been re-elected for the second term of the CB Chair. His second term ends in December 2012.*
- *Rolf Lindner has taken up as the Technical Coordinator starting from July 1, 2010.*
- *Guy Wilkinson (University of Oxford) has been re-elected for a second one year as Physics Coordinator. His second term ends in December 2011.*

Conclusion I

- *First data are being used for calibration of the detector and trigger in particular*

  - ***LHCb trigger concept has been proven with data***

  - *Charm resonances and B mesons have been reconstructed (even Z & W candidates)*

  - ***First measurements of production cross-sections at √s = 7 TeV for open charm, J/ψ and $b\bar{b}$*** *(published)*

- *LHCb is currently running at extreme conditions (μ up to ~2 rather than nominal μ = 0.4) far beyond the design specifications. Good testing bench for trigger, DAQ, reconstruction and computing model.* ***Attracting more resources to these central tasks will have a direct impact on physics output !!!***

  Many thanks to the on-line team for the prompt increase in computing power with fantastic efficiency.

Conclusion II

- ***High class measurements in the charm sector should be possible with 50 pb^{-1}***

- ***$B_s \rightarrow \mu\mu$ and $B_s \rightarrow J/\psi\phi$ will reach interesting sensitivity regime with ~ 50 pb^{-1}. Exciting prospects of discovery with full 1 fb^{-1} sample***

- *Preparation for an LHCb upgrade is underway*

New physics in a^s_{sl} (&/or a^d_{sl}) ?

If New Physics enhances CP-violation in $B^0_S \to J/\psi\Phi$, it will likely also dominate over the (negligible) SM CP-violation predicted in the like-sign lepton asymmetry.

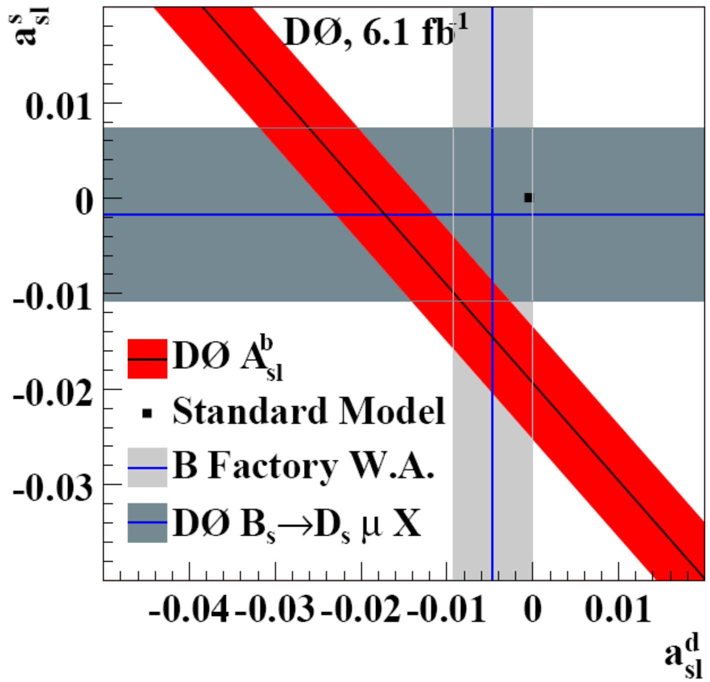
D0 collaboration: arXiv:1007.0395 [hep-ph]

$$A^b_{sl} = \beta_d a^d_{sl} + \beta_s a^s_{sl}, \quad \beta_d \approx \beta_s \approx 0.5$$

$$A^b_{sl}(\mathrm{SM}) = (-2.3^{+0.5}_{-0.6}) \times 10^{-4}$$

$$A^b_{sl} = -0.00957 \pm 0.00251\,(\mathrm{stat}) \pm 0.00146\,(\mathrm{sys})$$

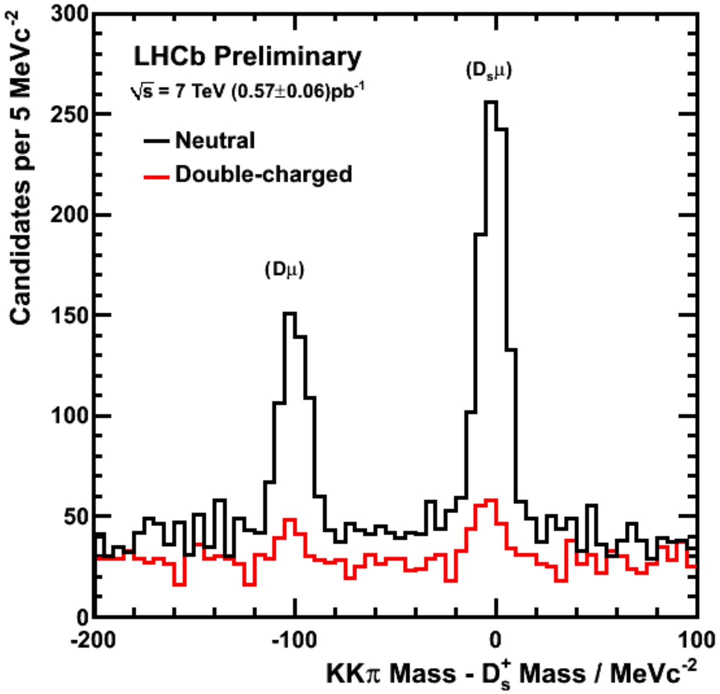
3σ tension with SM

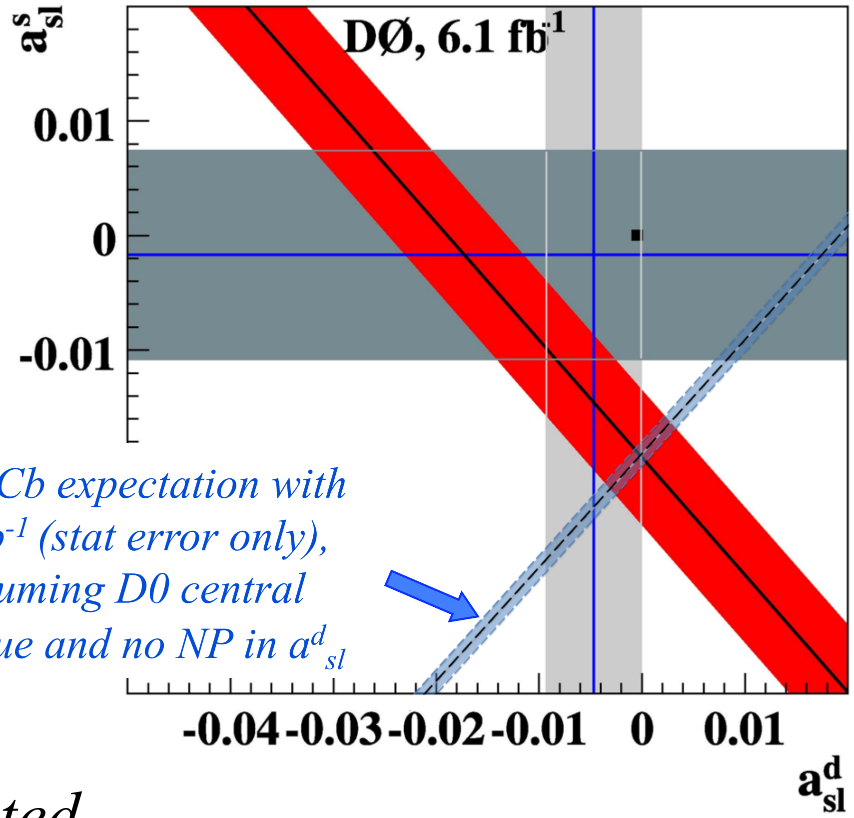


CDF performed preliminary measurement with 1.6 fb^{-1} which used IP significance

$$A_{SL} = 0.0080 \pm 0.0090(stat) \pm 0.0068(syst)$$ [CDF note 9015]

LHCb proposes to measure a^s_{sl} - a^d_{sl}, by determining the difference in the asymmetry measured in $B_s \rightarrow D_s(KK\pi)\mu\nu$ & $B^0 \rightarrow D^+(KK\pi)\mu\nu$ - same final state suppresses biases. Provides orthogonal constraint to D0 dileptons.





Events already being accumulated