The LHCb experiment

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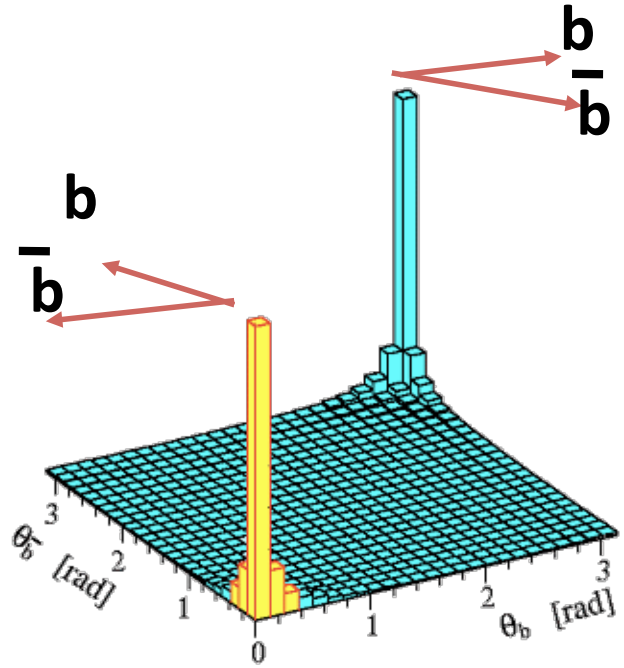
on behalf of the LHCb Collaboration

Outline:

- ***Physics Objectives***
- ***Validation of the detector performance with data***
- ***Measurement of production cross-sections***
- ***Goals and prospects for 2010-2011 LHC Run***

The LHCb Experiment



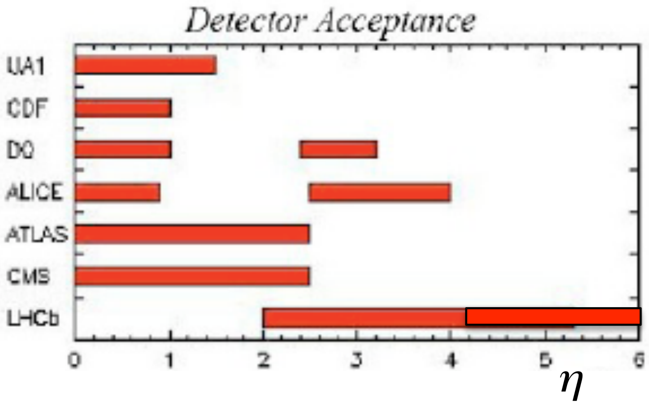
- ☐ *Advantages of beauty physics at hadron colliders:*
  - *High value of bb cross section at LHC:*

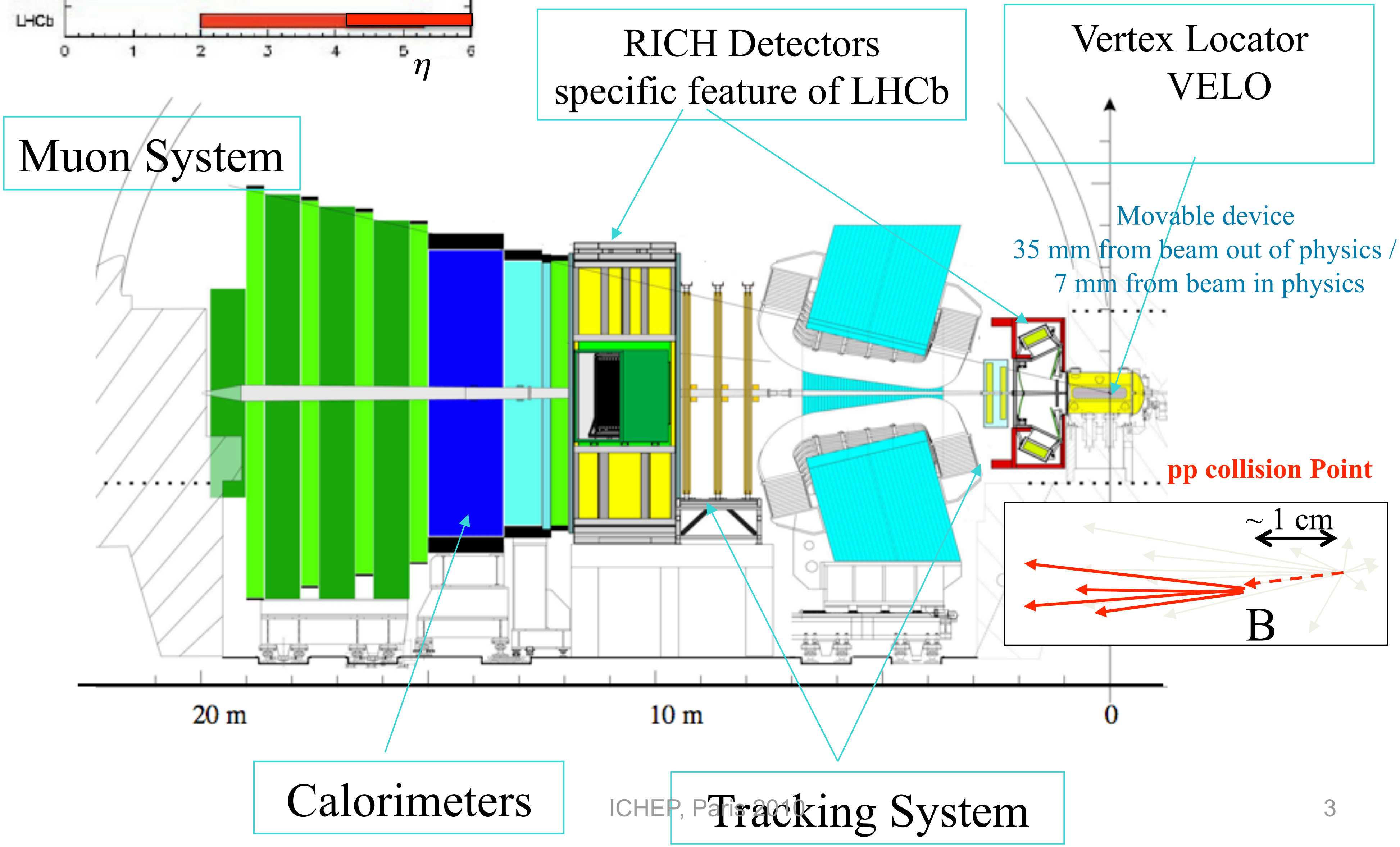
    $\sigma_{bb} \sim 300 - 500\ \mu b$ *at 7 - 14 TeV*

    (e+e- cross section at Y(4s) is 1 nb)
  - *Access to all quasi-stable b-flavoured hadrons*
- ☐ *The challenge*
  - *Multiplicity of tracks (~30 tracks per rapidity unit)*
  - *Rate of background events:* $\sigma_{inel} \sim 60$ *mb at* $\sqrt{s} = 7$ *TeV*
- ☐ *LHCb running conditions:*
  - *Luminosity limited to* $\sim 2\times10^{32}\ cm^{-2}\ s^{-1}$ *by not focusing the beam as much as ATLAS and CMS (currently all experiments are at the same conditions)*
    - *Maximize the probability of a single interaction per bunch crossing*

      At LHC design luminosity pile-up of >20 pp interactions/bunch crossing while at LHCb ~ 0.4 pp interaction/bunch
    - ***LHCb will reach nominal luminosity already at the end of 2010***
  - ***2fb^{-1} per nominal year (10^7s), ~ 10^{12} $b\bar{b}$ pairs produced per year***

The LHCb Detector (forward spectrometer)





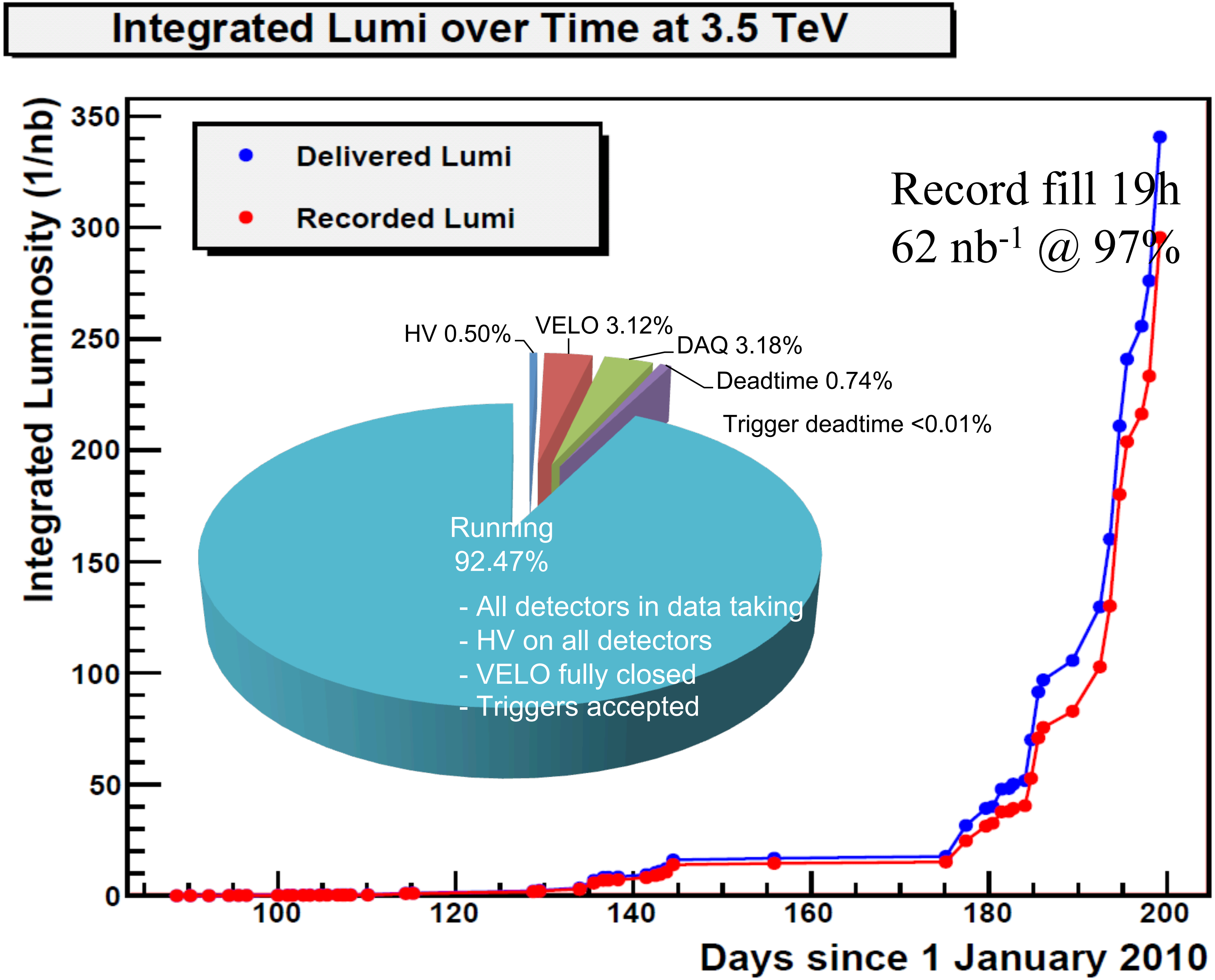
LHCb Collaboration *(day of the 1st collisions)*

LHCb shift

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

LHCb operation

Data are being reconstructed and analyzed (see talk of Marco Adinolfi)

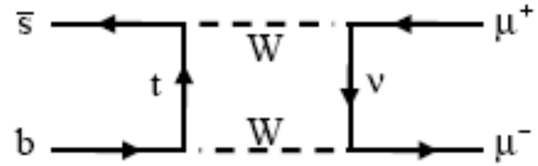


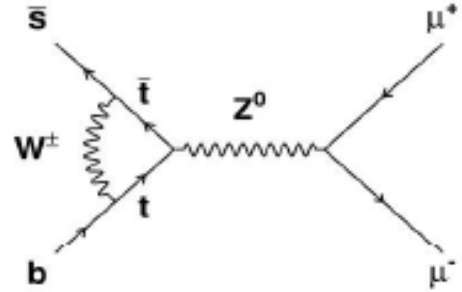
Main LHCb Physics Objectives

Search for New Physics in CP violation and Rare Decays

CPV:

B_s oscillation phase Φ_s (see talk of Gerhard Raven)
CKM angle γ in trees and loops
(see talks of Susan Haines & Ignacio Bediaga)
CPV asymmetries in charm decays



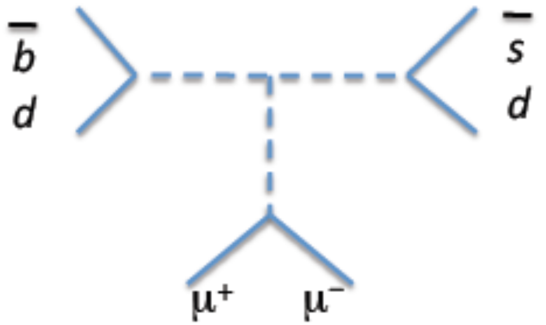


Rare Decays (see talk of Giampiero Mancinelli)

Helicity structure in $B \to K^*\mu\mu$ and $B_s \to \phi\gamma$, ϕee
FCNC in loops ($B_s \to \mu\mu$, $D \to \mu\mu$) and trees

***Very non-SM ideas:* Examples of FCNC in trees**

Leptonic: $B_{d,s} \to 4\mu$, $4e$
Semileptonic: $B_{d,s} \to K^*\mu\mu$, $\phi\mu\mu$



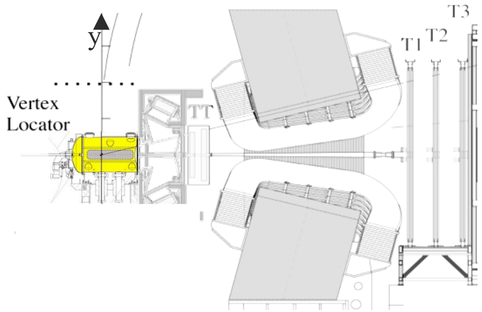
Hadronic: $B_{d,s} \to J/\psi\phi$, $\phi\phi$

Key ingredients of physics performance

(see talks of Silvia Borghi, Andrew Powell and Eric van Herwijnen)

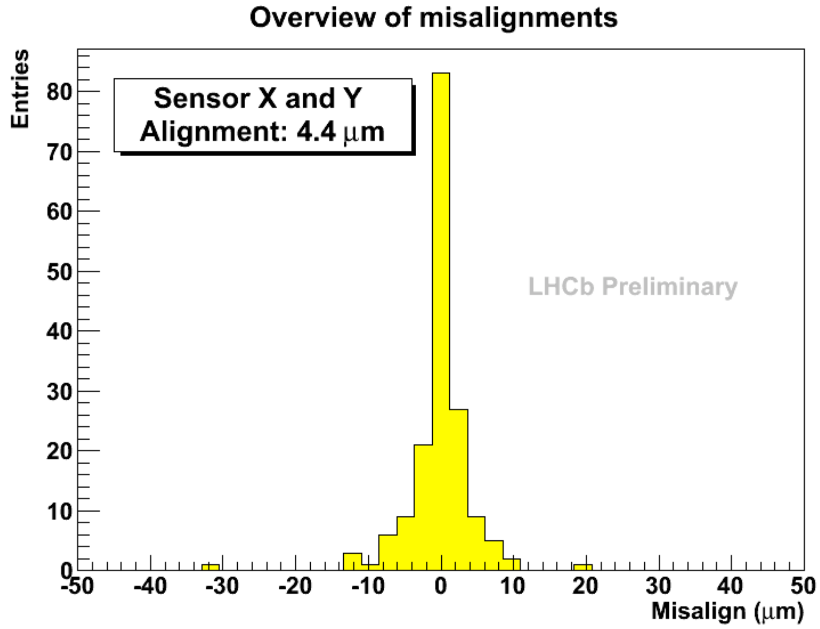
- *Detector alignment*
- *Impact parameter (IP) & Vertex reconstruction*
- *Tracking efficiency*
- *Invariant mass resolution*
- *PID (hadron, muon, electron, photon)*
- *Trigger efficiency*

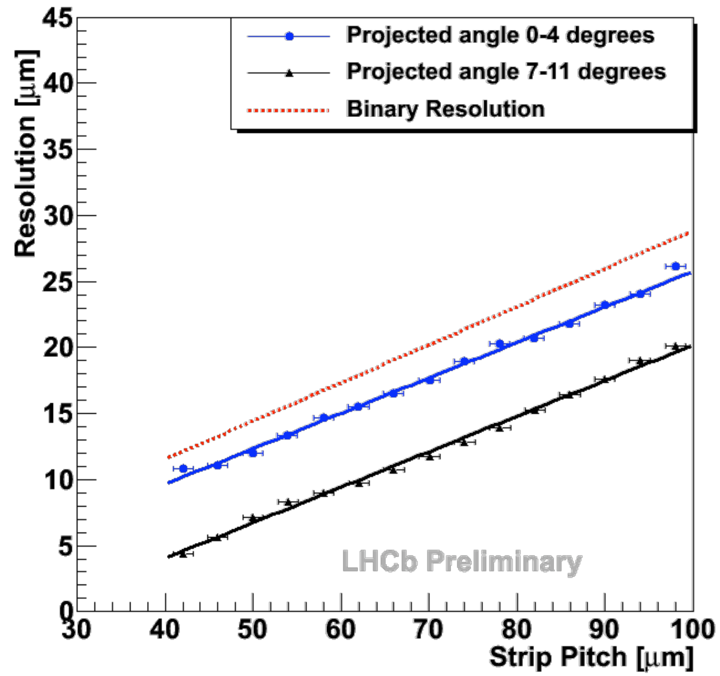
VErtex LOcator (VELO)



- *Cluster finding efficiency 99.7%*
- *Module and sensor alignment known to better than 5 μm*
- *VELO is opened during injection !*
  Fill-to-fill variation of two halves relative alignment < 5μm

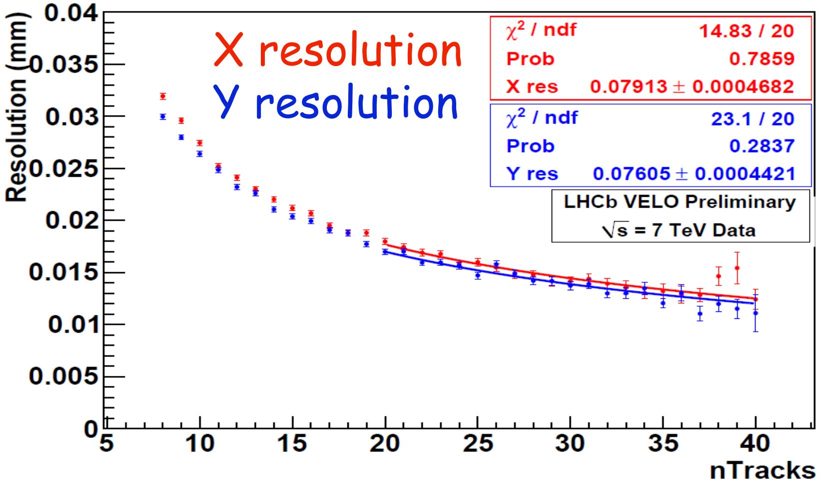
Best VELO hit resolution is 4 μm
Great achievement !!!





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



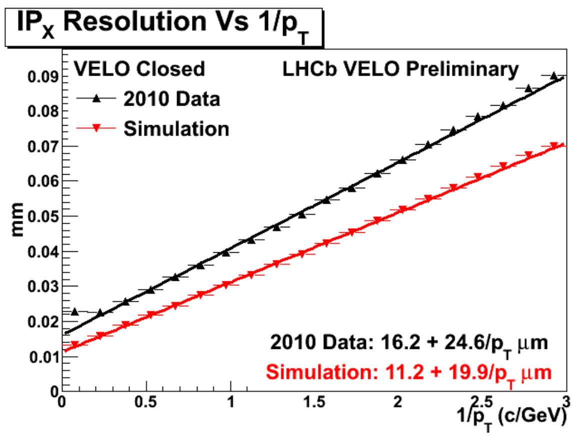
Resolution for PV with 25 tracks

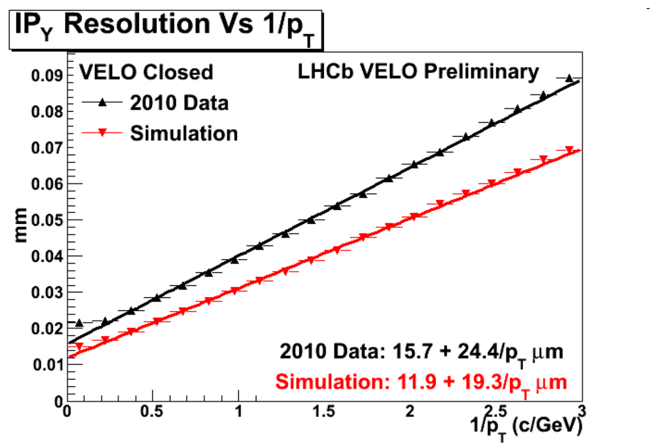
*~ 15 μm for **X** & **Y** and ~ 90 μm for Z*

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

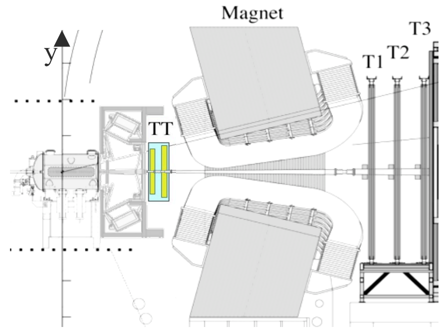
IP resolution ~20 μm for the highest p_t bins

Further improvement is expected with better alignment and material description





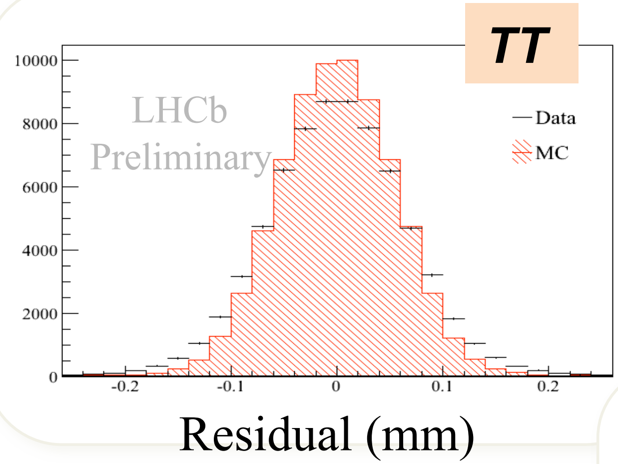
Silicon Trackers (IT/TT) and Outer Tracker (OT)

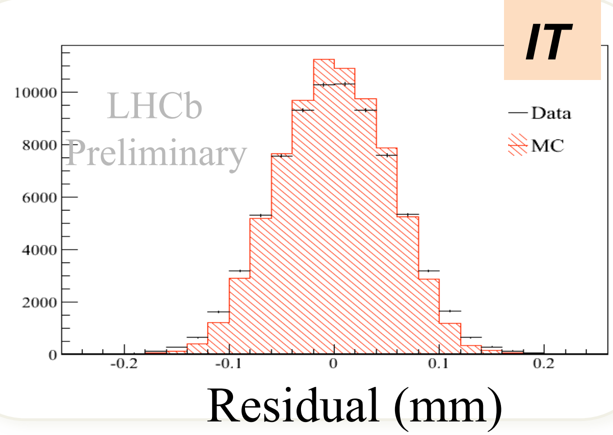


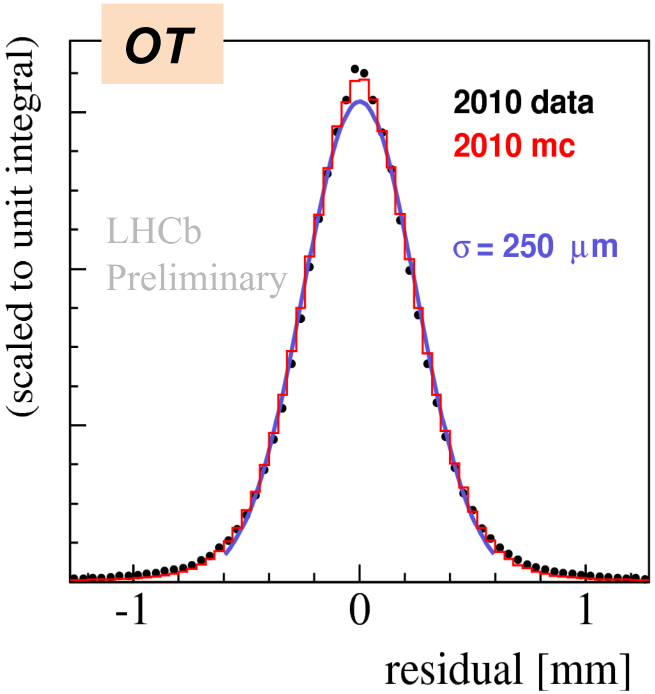
IT and TT alignment is ongoing

TT:
hit resolution 55 μm
misalignment 35 μm

IT:
hit resolution 54 μm
misalignment 16 μm





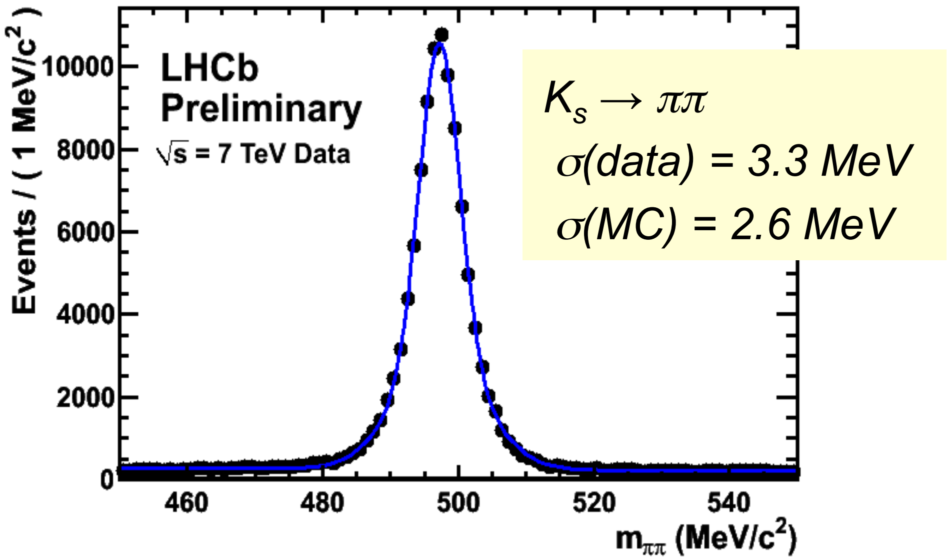


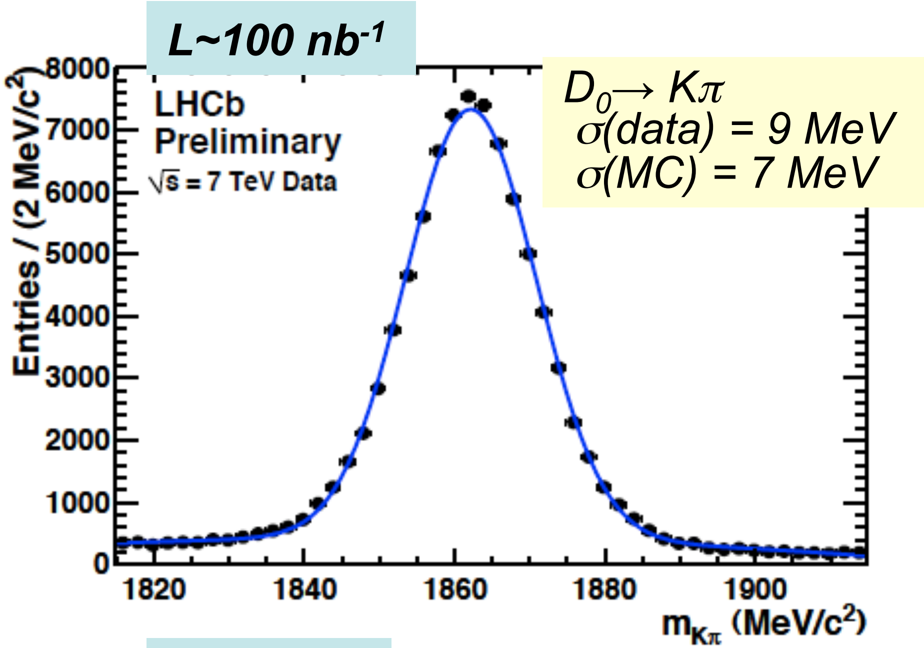
Space drift-time relation corresponds to expectation from test beam data

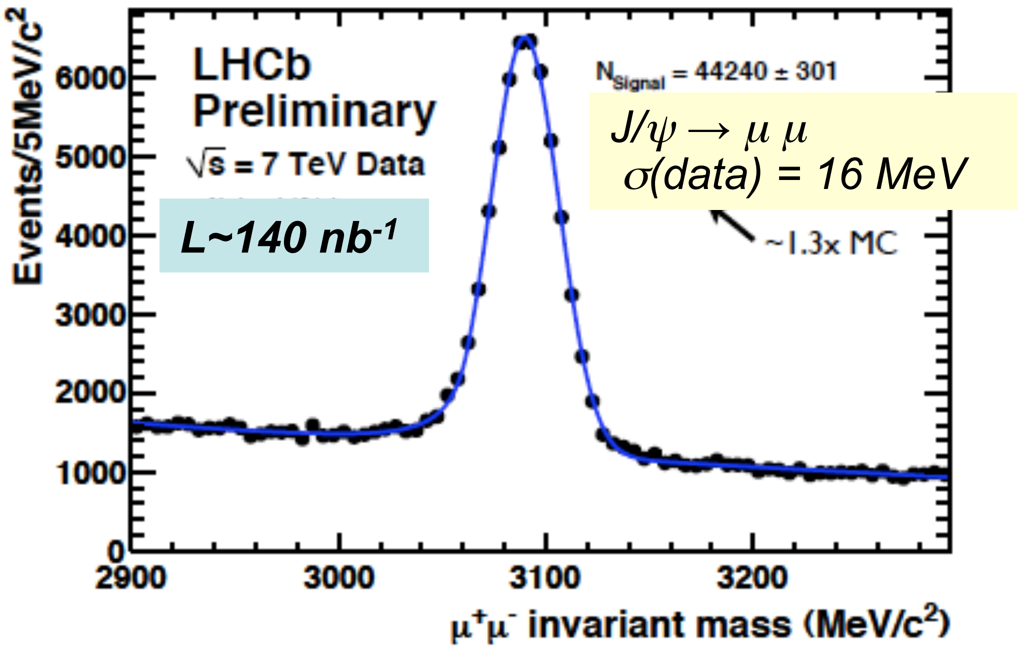
OT well aligned:
resolution 250 μm close to nominal

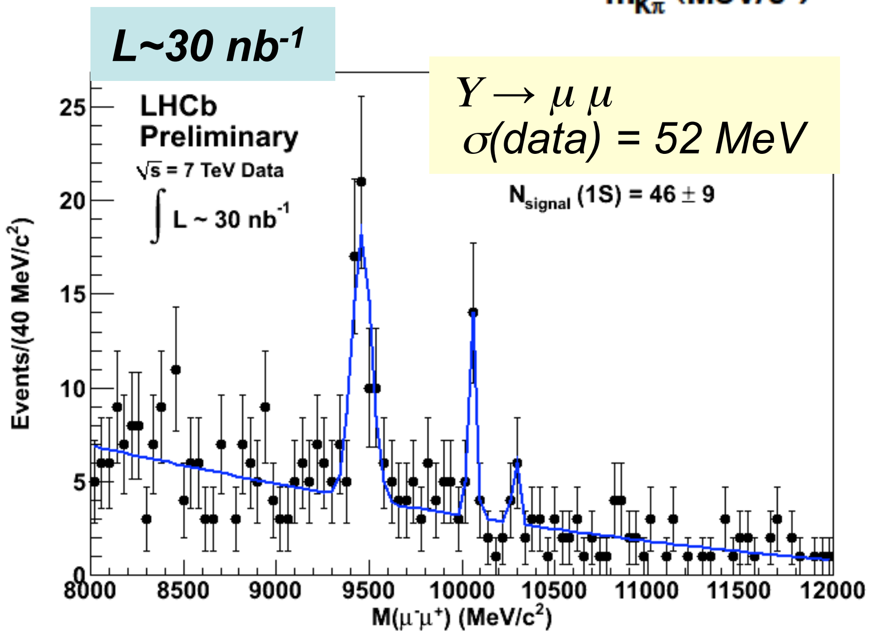
Signal peaks & present mass resolution

(Will be improved !!!)





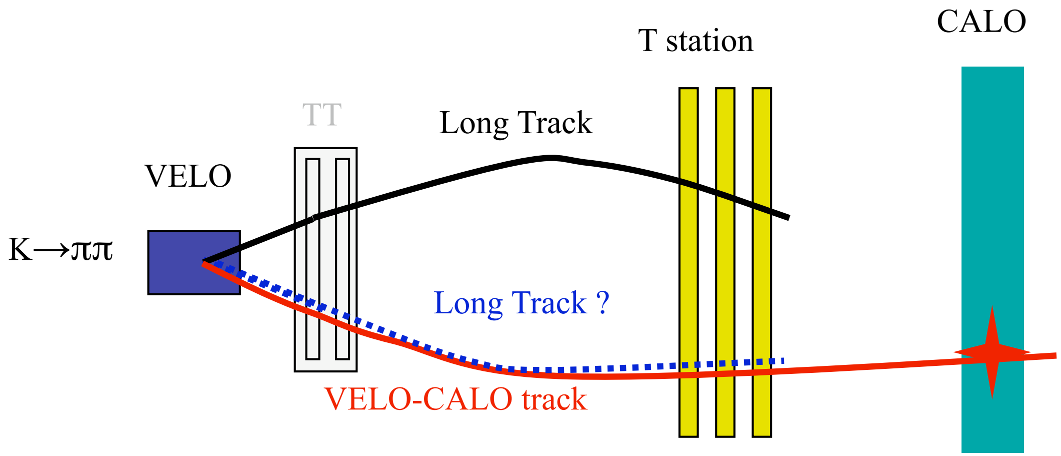




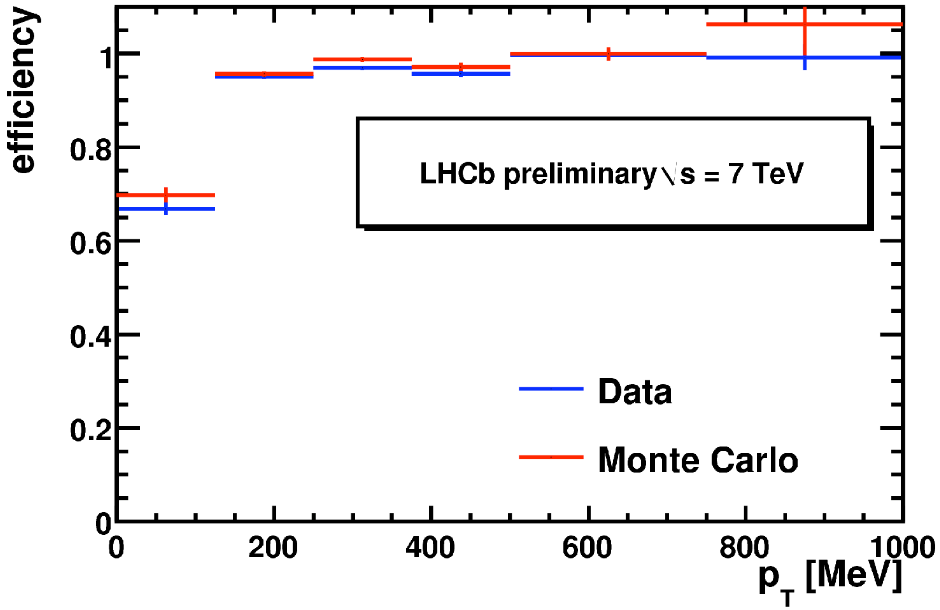
Tracking Efficiency

Obtained using K_S candidates:

$$\varepsilon = \frac{\mathit{Tracks}^{\,(VELO\,+\,IT/OT+CALO)}}{\mathit{Tracks}^{\,(VELO\,+\,CALO)}}$$



Efficiency as a function of p_T



- *Similar method can be used to evaluate the efficiency of VELO*
- *Other resonances can be reconstructed as well*

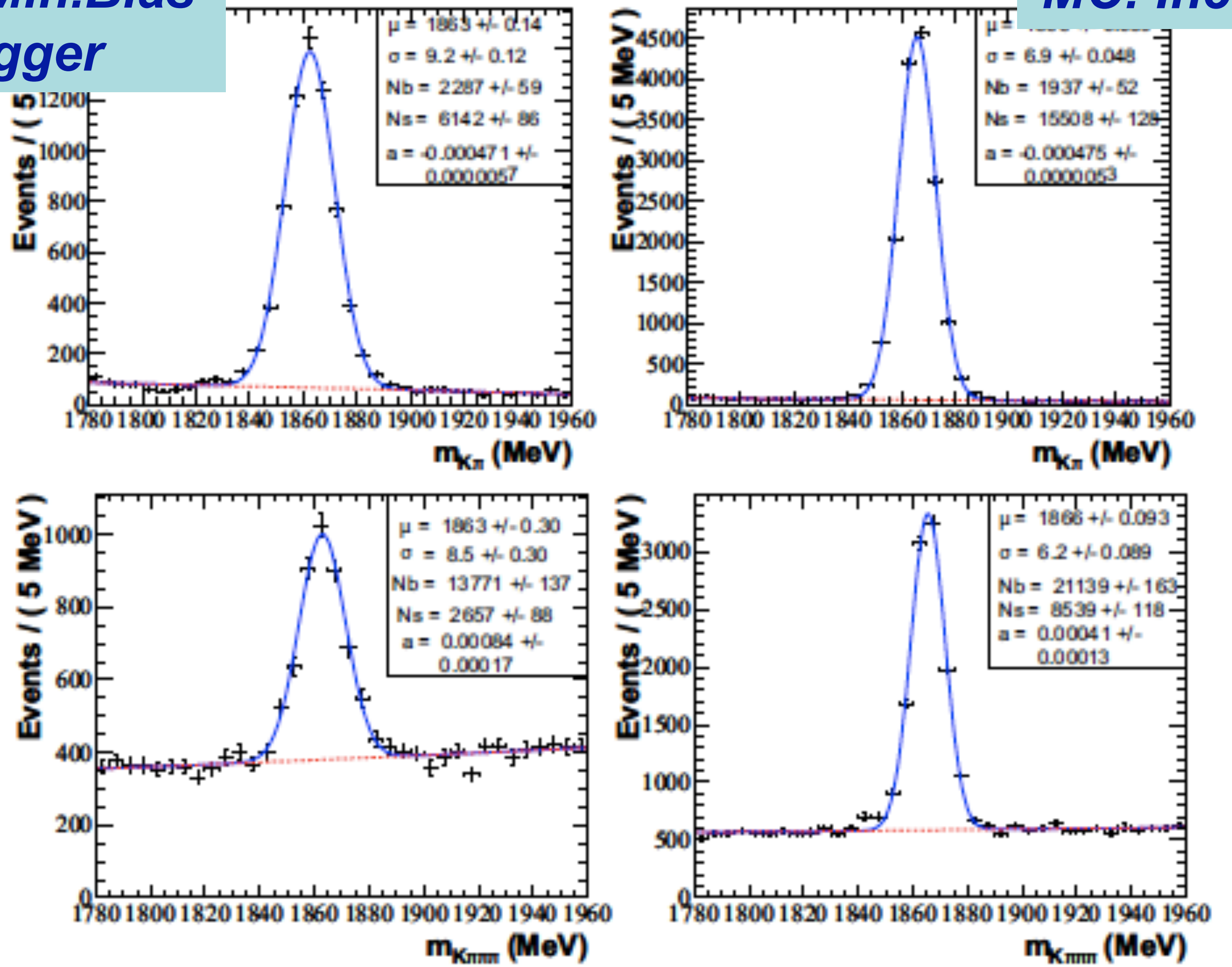
Tracking efficiency systematics

(D→Kπ vs D→K3π)

$\varepsilon(\text{Track}) \propto \sqrt{(N(K\pi\pi\pi)/N(K\pi) * BR(K\pi)/BR(K\pi\pi\pi)}$

Data: Min.Bias Trigger

MC: Incl. charm

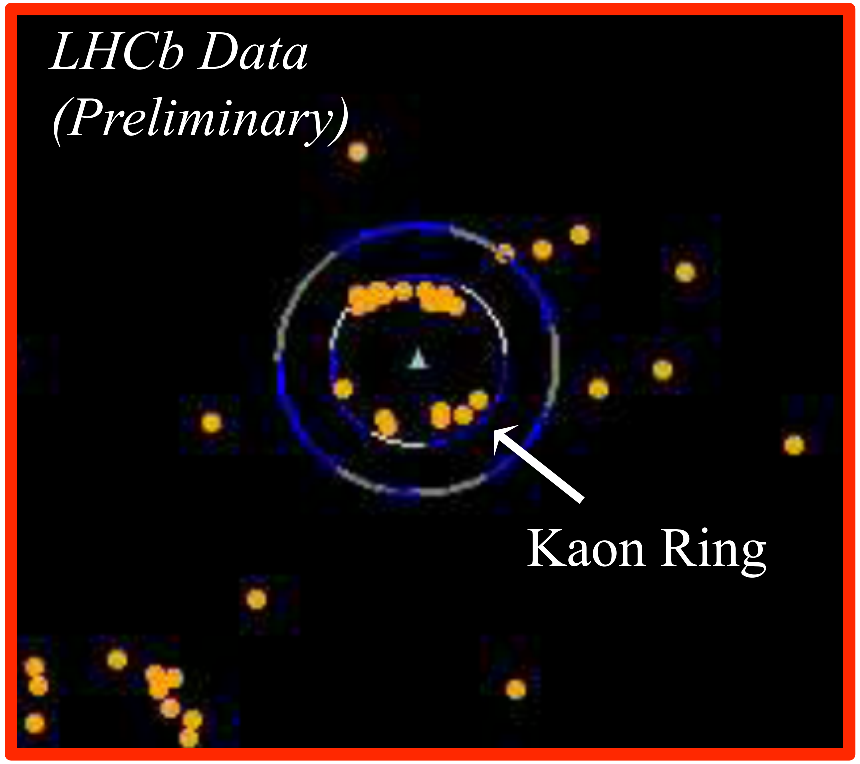


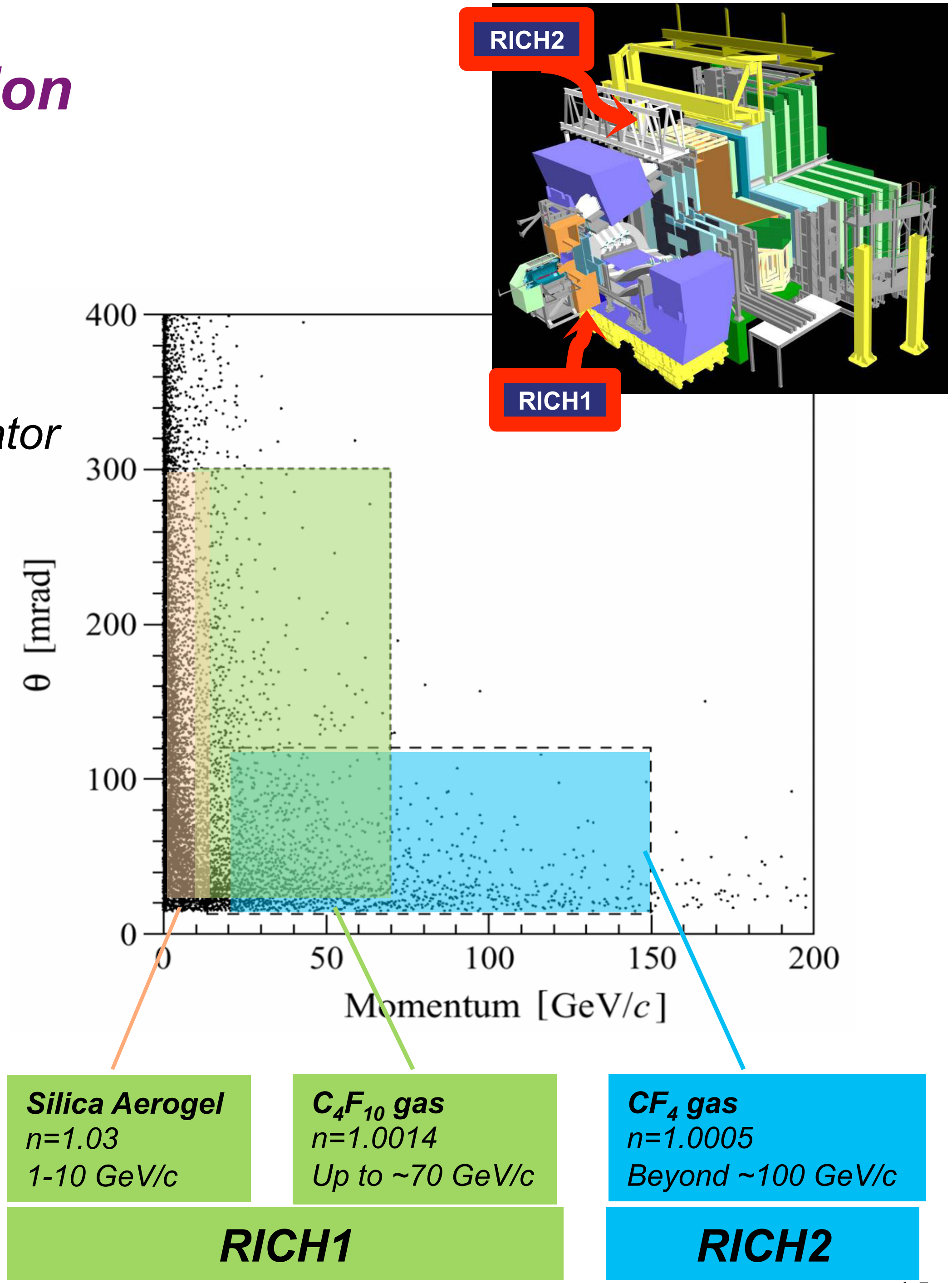
ε(Data) / ε(MC) = 1.00 ± 0.03

Particle Identification

RICH:

π / K / p separation
2 – 100 GeV/c
two gaseous and one aerogel radiator

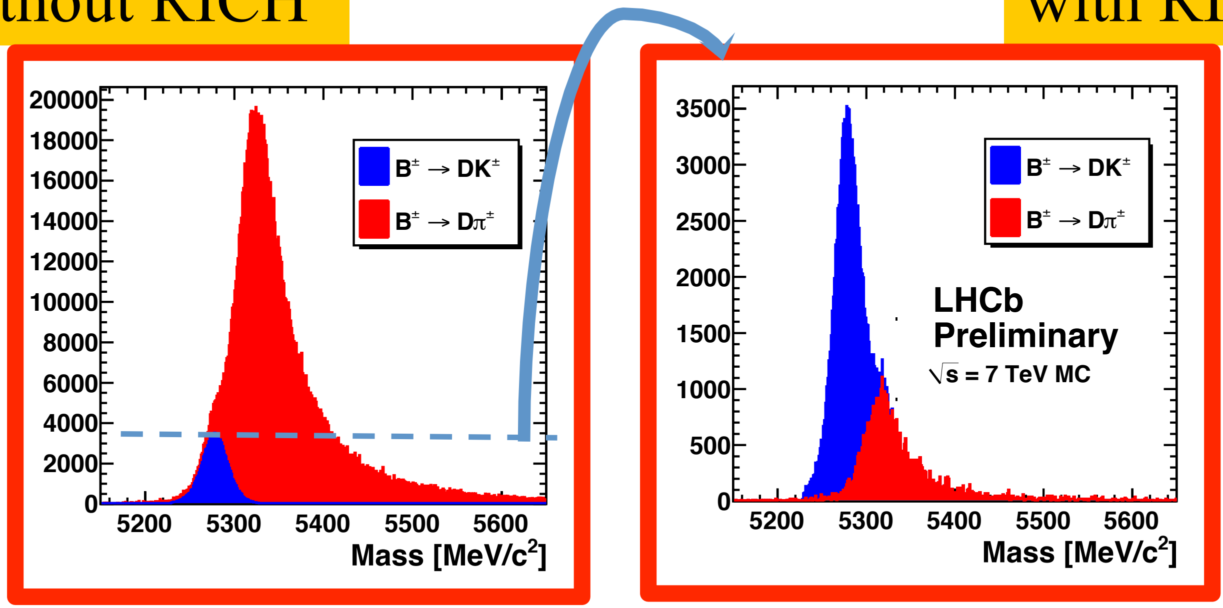


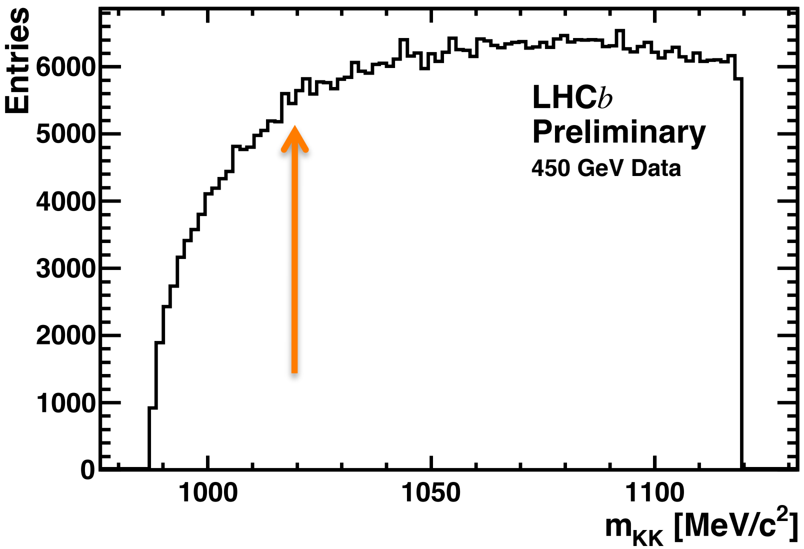


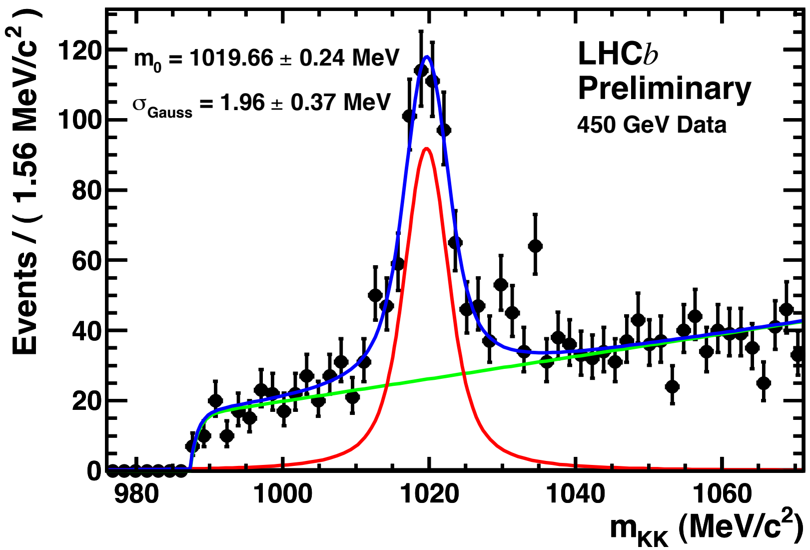
PID with RICH

without RICH

with RICH

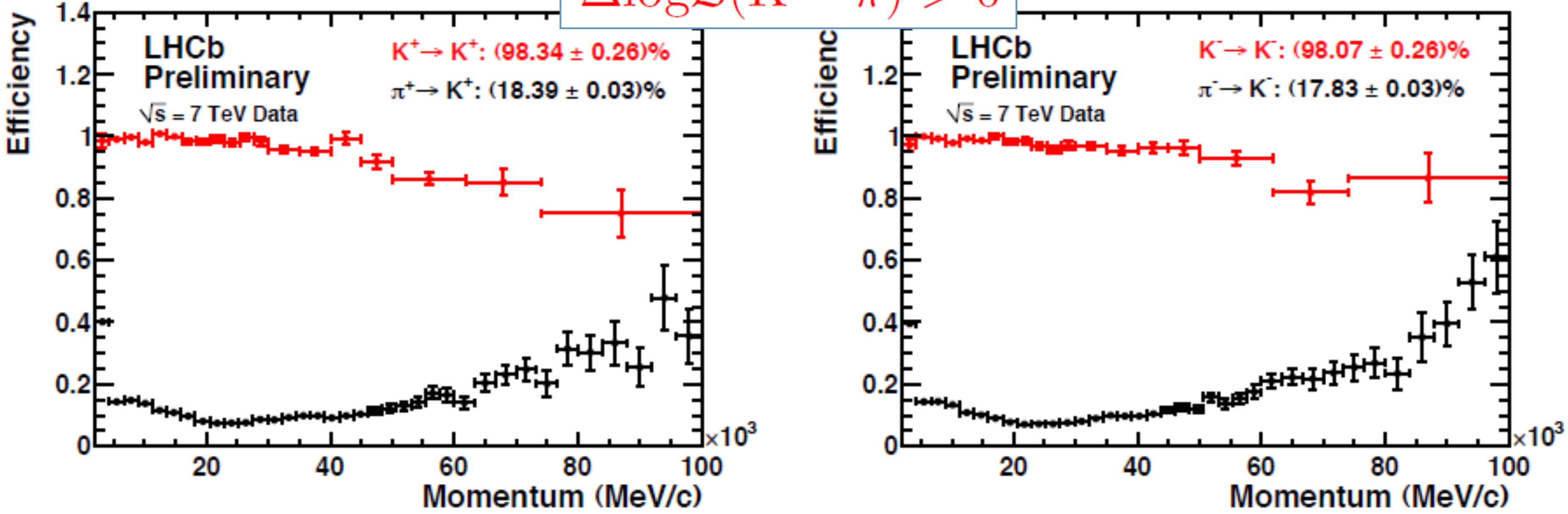




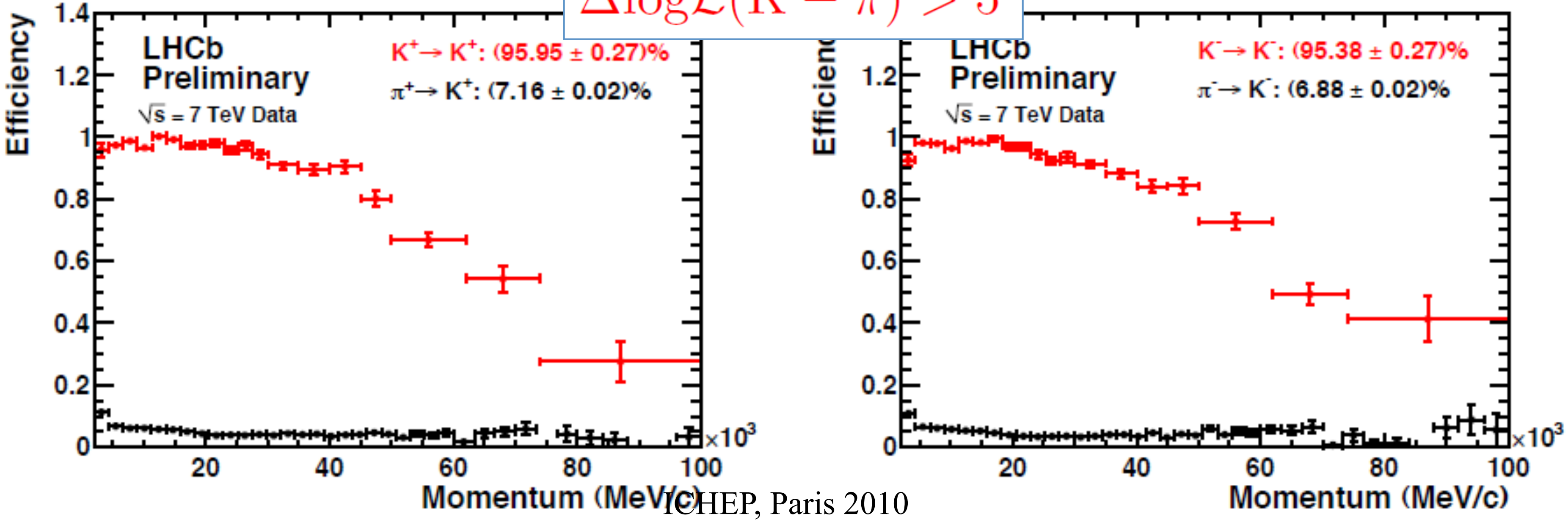


PID with RICH: *K/π separation*

$$\Delta\log\mathcal{L}(K-\pi) > 0$$



$$\Delta\log\mathcal{L}(K-\pi) > 5$$



Measurement of $\bar{p}/p$ ratio vs y and p_t

(see talk of Chris Blanks)

Use RICH to select high purity (>90%) samples of (anti)protons in bins of y and p_t

Performance evaluated on PID-unbiased calibration samples:

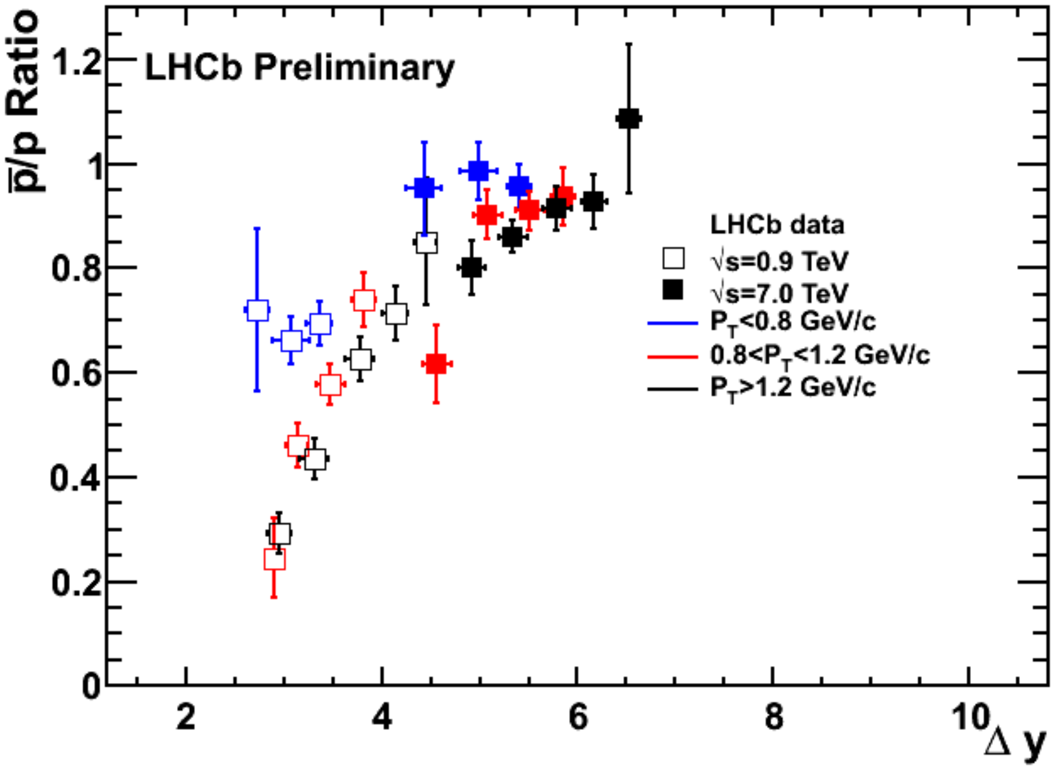
Use samples to study baryon transport by measuring ratio of $\bar{p}/p$ in kinematic bins

Results expressed vs Δy (rapidity interval w.r.t. beam) for different p_t bins

Large range in Δy covered.

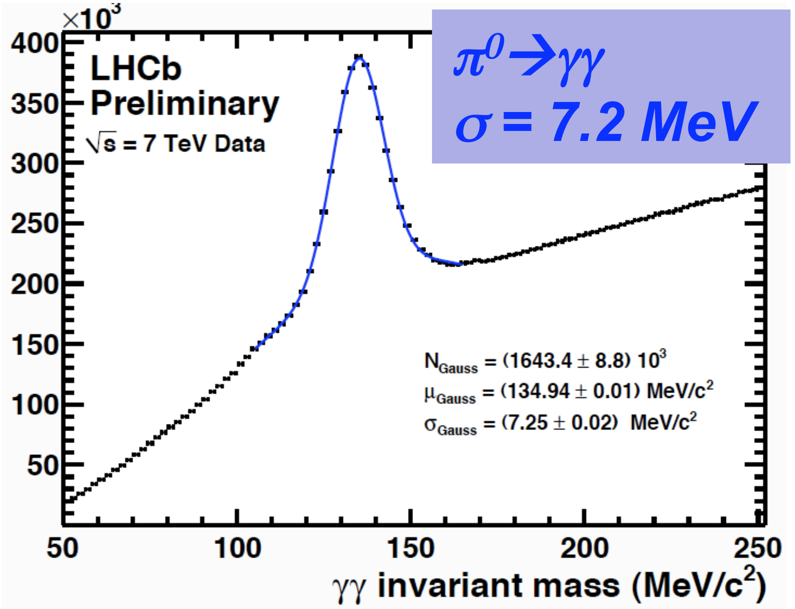
Some p_t dependence observed.

Where comparisons can be made, results compatible with previous measurements.



PID with Calorimeter

(Identification of electrons and photons)

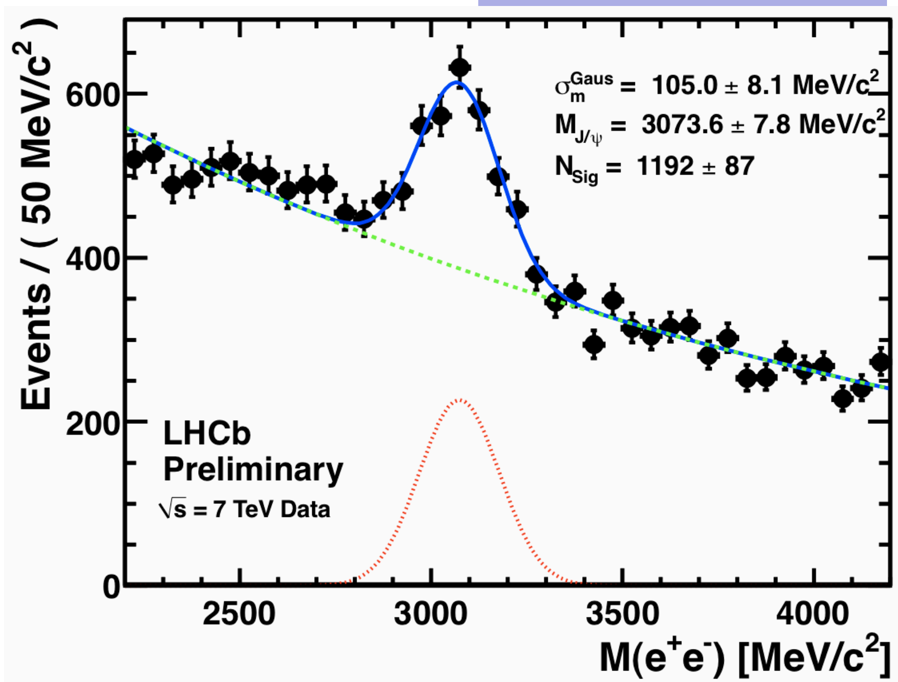


$\pi^0 \rightarrow \gamma\gamma$
σ = 7.2 MeV

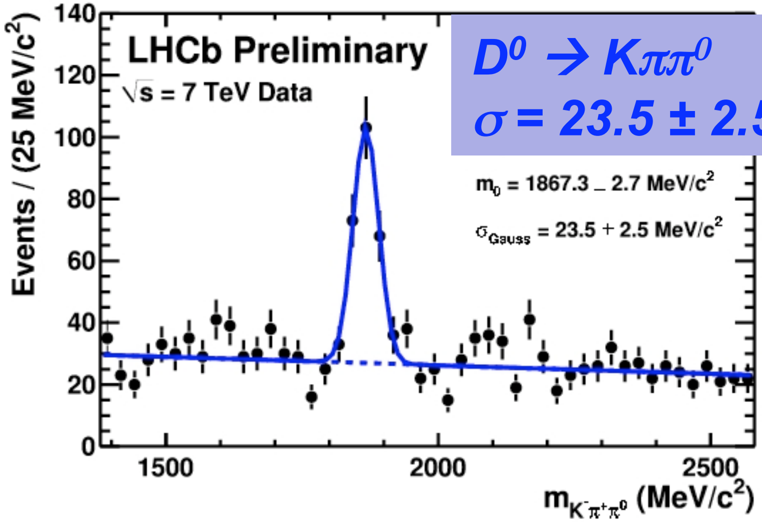
ECAL is calibrated to 2% level
π^0 resolution is better than expected

Clear J/ψ signal is reconstructed
in e^+e^- decay mode

L ~ 150 nb^{-1}
$J/\psi \rightarrow e^+e^-$
σ= 109 ± 8 MeV

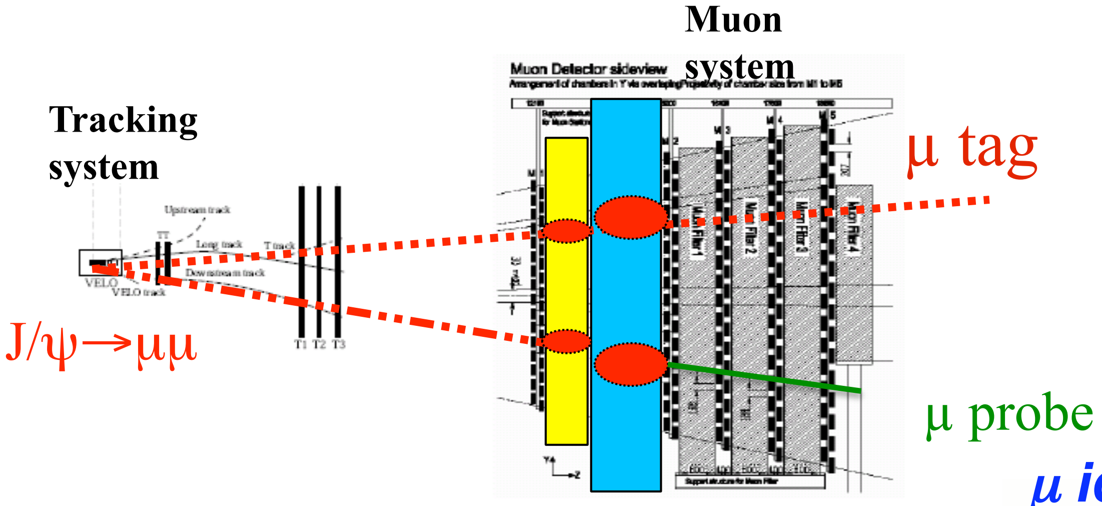


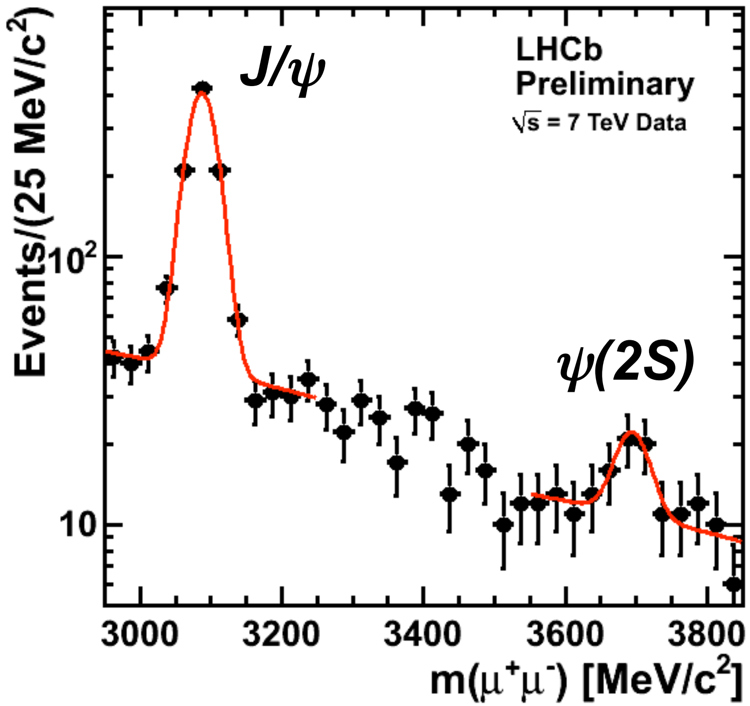
Reconstruction of D decays in the final states with neutrals looks encouraging !



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

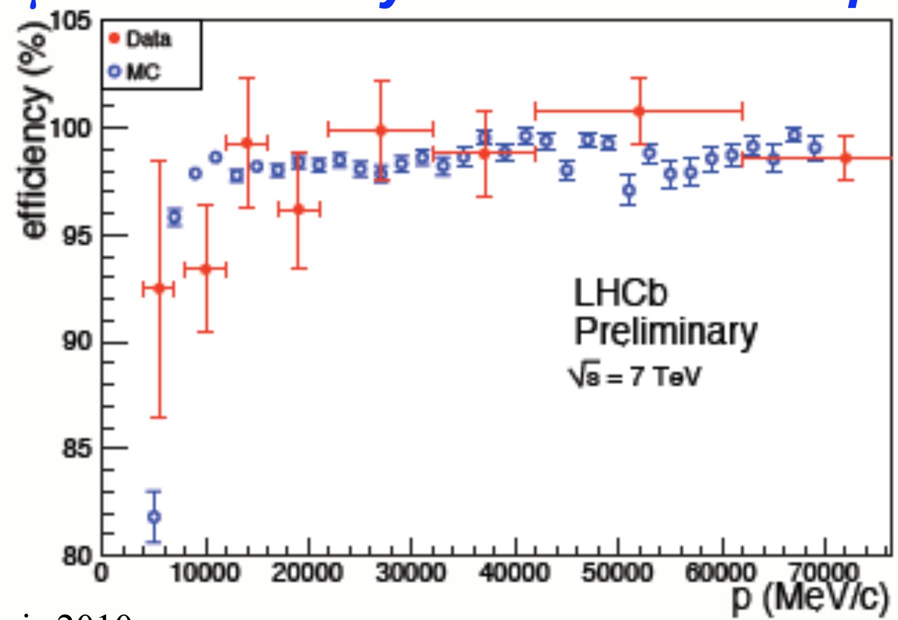
PID with MUON





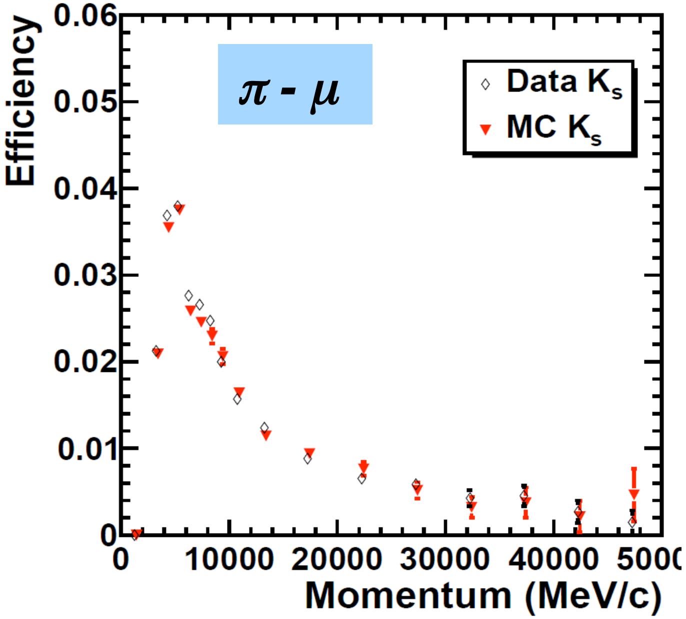
$\varepsilon(\mu) = (\, 97.3 \pm 1.2 \,)\%$

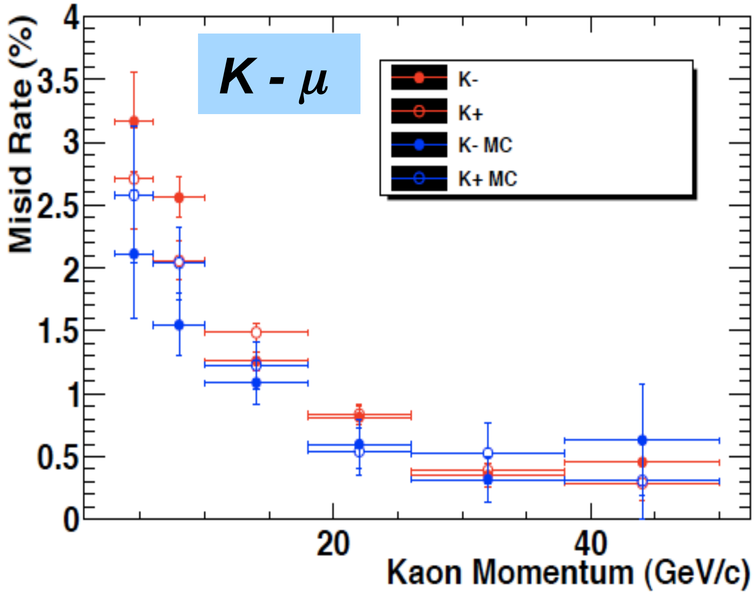
μ id. efficiency as a function of p



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



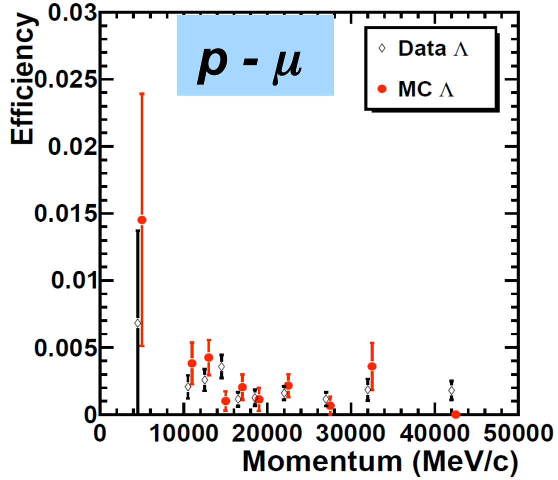


π,K→μ dominated by decays in flight

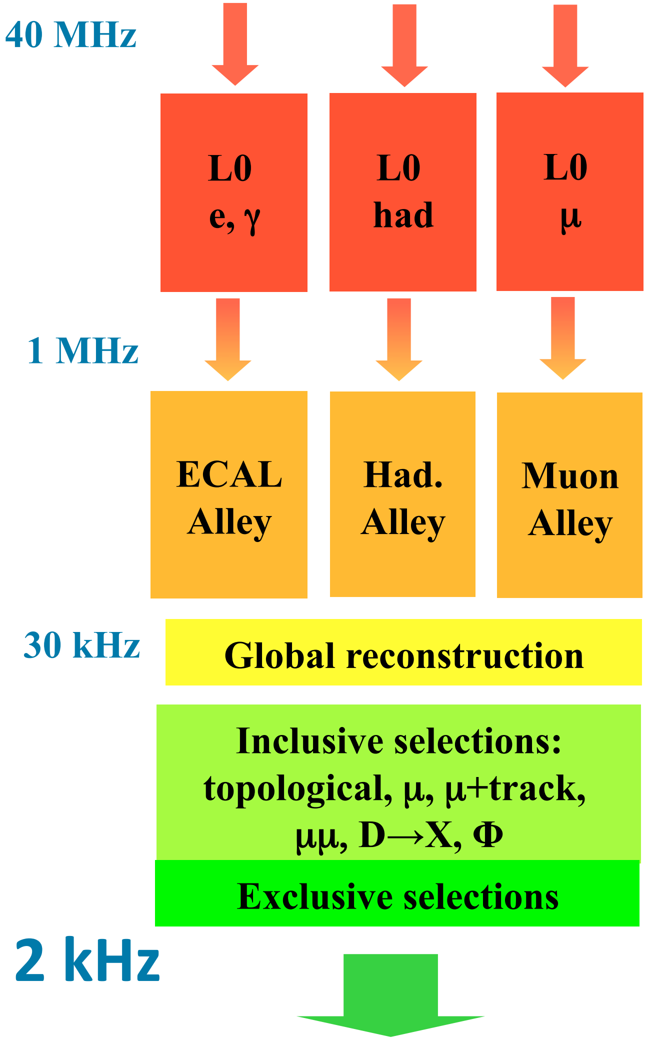
$\varepsilon_{K,\pi-\mu} < 1\%$ **for p > 20 GeV**

p→μ dominated by combinatorics in muon stations

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



LHCb Trigger



Level-0

'High-pt' signals in calorimeter & muon systems

HLT1

Associate L0 signals with tracks, especially those in VELO displaced from PV

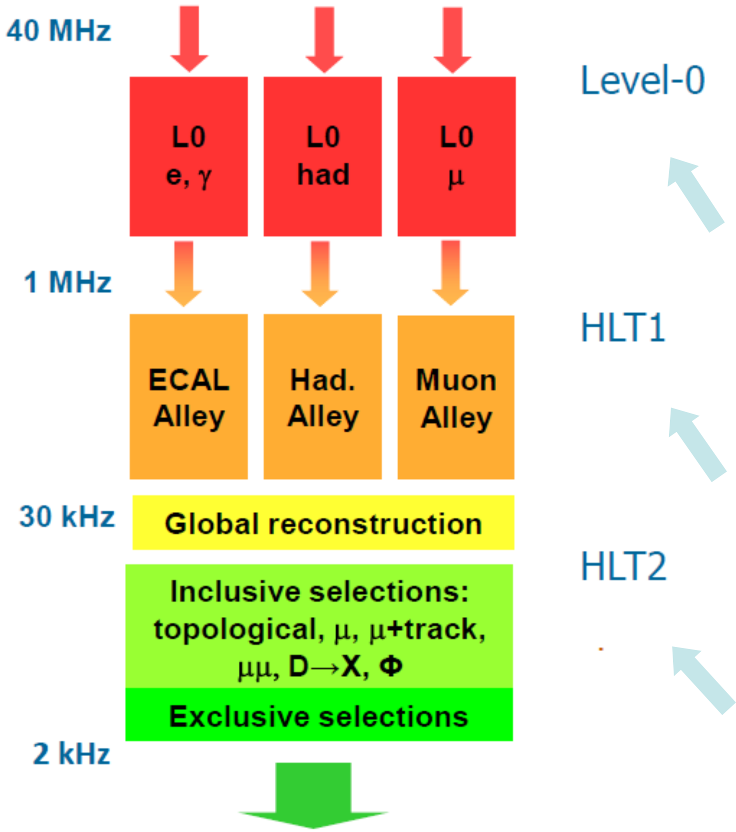
HLT2

Full detector information available. Continue to look for inclusive signatures, augmented by exclusive selections in certain key channels.

*At LHCb design luminosity **(2×10^{32} cm^{-2} s^{-1})** all thresholds must be optimised for B-physics, and consequently trigger efficiency for D decays from prompt-production is as low as ~ 10%. Still adequate for accumulating very large samples, but corresponding efficiencies for hadronic B-decays ~4x higher*

LHCb Trigger in 2010

For bulk of running foreseen this year, with luminosities up to a few 10^{30} cm^{-2} s^{-1} , we can afford to relax many of our trigger cuts, with large benefits for efficiencies



2010 approach

Apply very low pt cuts – main purpose of L0 is now to seed HLT1 regions of interest

Reduce requirements on track impact parameter w.r.t. nominal settings

Not needed at all initially, then introduce with rather loose suppression requirements

Boost trigger efficiencies for hadronic decays of promptly produced D's by factor 3-4 w.r.t. nominal settings. Golden opportunity for charm physics studies ! Total efficiencies for hadronic B decays now ~70%, with those for leptonic decay modes >90%.

Trigger Efficiencies

Take D*, $D^0 \rightarrow K\pi$ signal collected in minimum bias events

&

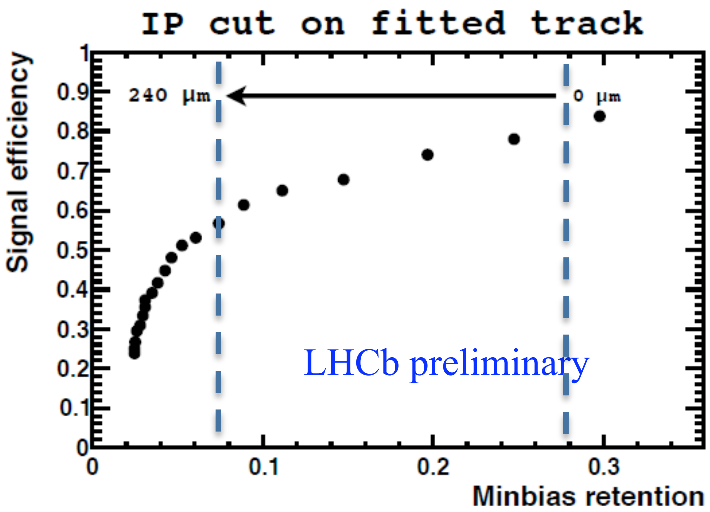
Evaluate L0*HLT1 performance with 2010 low luminosity trigger settings

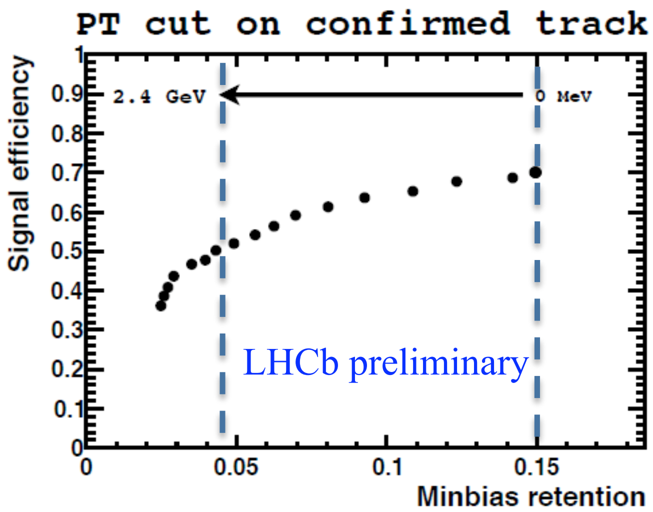
good agreement with MC

$Eff\text{-}trig_{L0*HLT1}(data) = 60 \pm 4$ %

MC expectation = 66 %

Performance of single-hadron HLT1 line on data

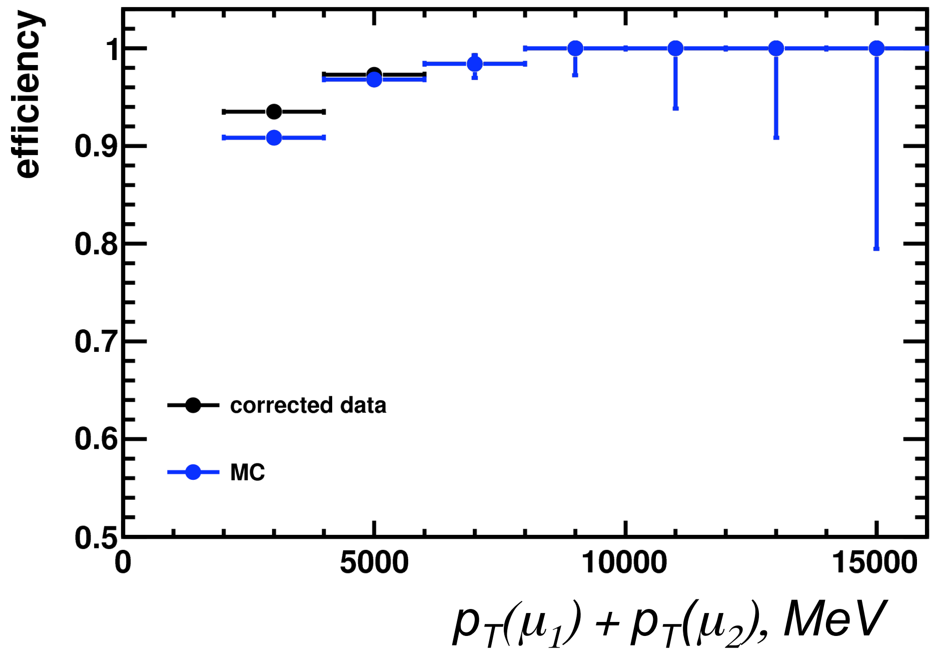




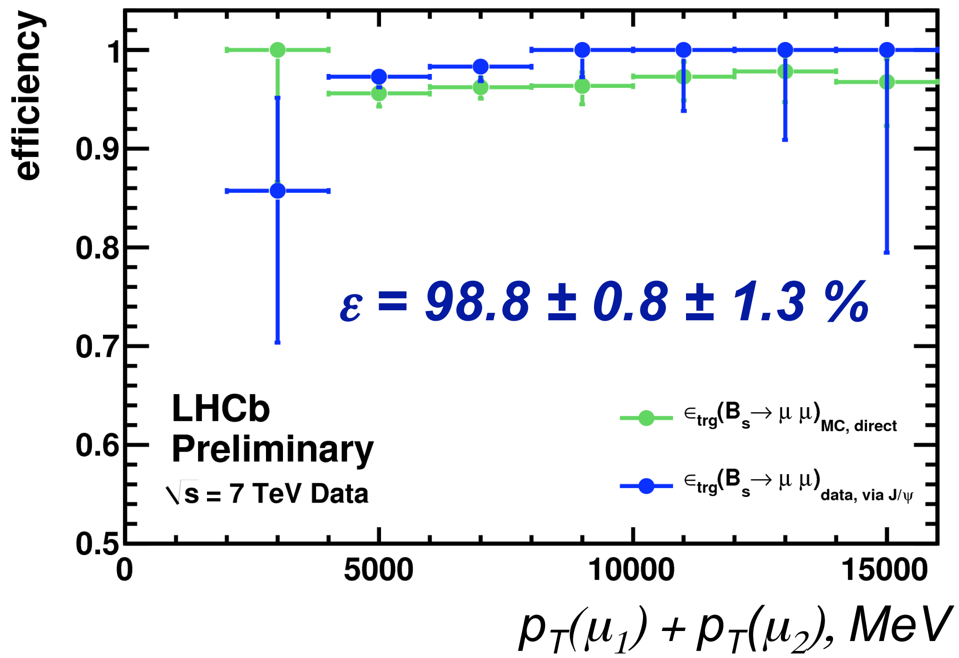
Trigger Efficiencies

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

L0 x HLT efficiency for J/ψ



HLT efficiency for Bs→μμ



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

Measurement of production cross sections at $\sqrt{s}$ = 7 TeV

- *Precision is dominated by systematic error on the luminosity measurement and tracking efficiency*
- *Used small sub-sample of collected data L ≤ 14 nb^{-1} : ~ 2 nb^{-1} with unbiased trigger and ~12 nb^{-1} with low HLT thresholds*
- *Luminosity determined using Van der Meer scan and beam gas events (only possible at LHCb). See talk of Massimiliano Ferro-Luzzi for more details*

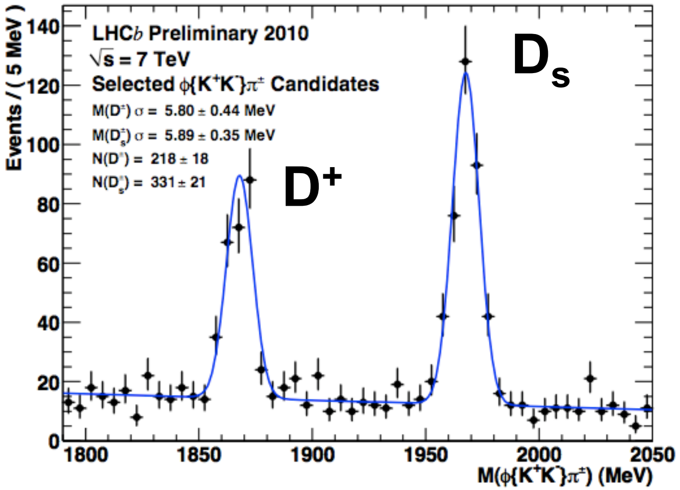
Open charm cross-sections (D^*, D^0, D^+, D_s) @ $\sqrt{s}$ = 7 TeV

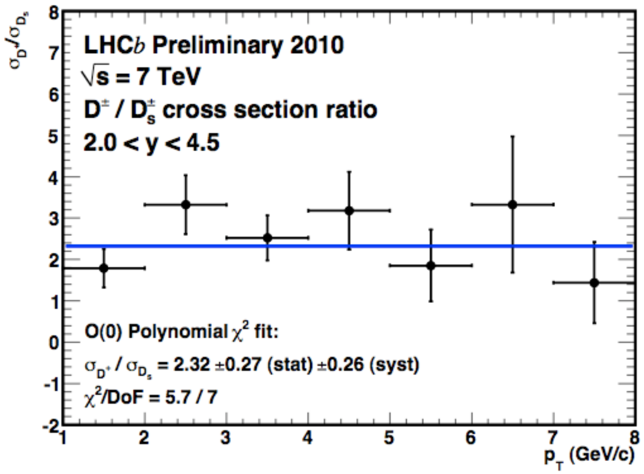
(see talk of Ivan Belyaev)

Open charm production cross-sections are being studied in forward region $2 < y < 5$ for D^*, D^0, D^+ and D_s. Final cross checks for systematics underway !

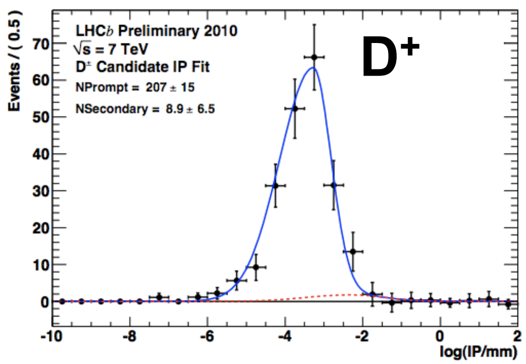
Measurement of $\sigma(pp \rightarrow D^+X) / \sigma(pp \rightarrow D_sX)$: many systematics drop out in the ratio

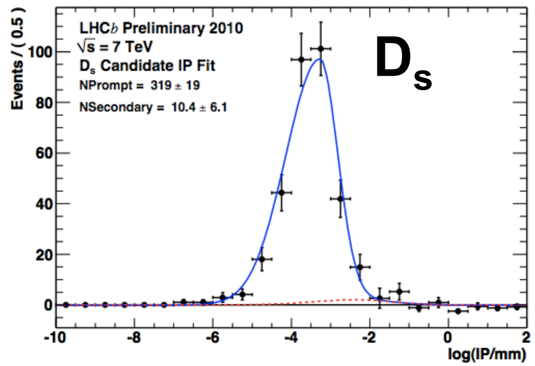
$L \sim 2\ nb^{-1}$





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



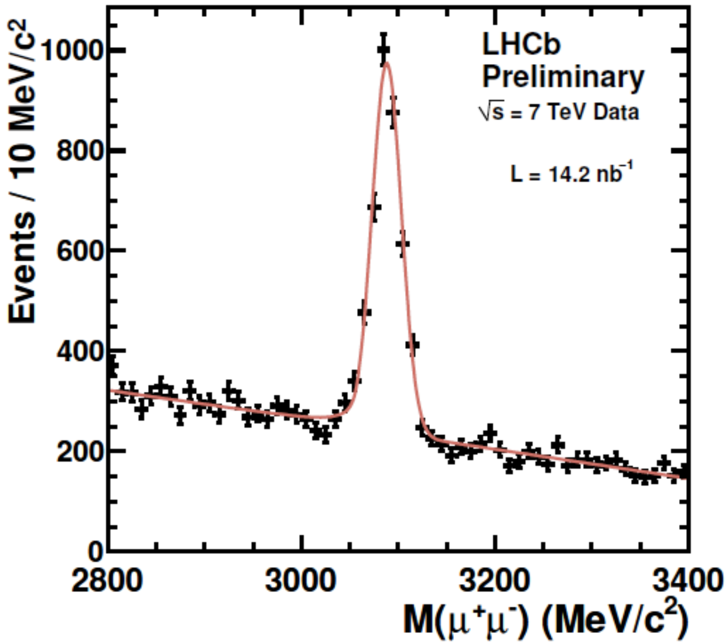


$\sigma(D^+)/\sigma(D_s) = 2.32 \pm 0.27 \pm 0.26$

in agreement with PDG 2008:

$f(c \rightarrow D^+) / f(c \rightarrow D_s) = 3.08 \pm 0.70$

J/ψ cross-section @ $\sqrt{s}$ = 7 TeV (see talk of Giovanni Passaleva)



For the cross section measurement use sub-sample of $J/\psi \rightarrow \mu\mu$ ($L \sim 14 nb^{-1}$)

Fit results ($2.5 < y < 4$, $p_T < 10$ GeV/c):

$N_{signal} = 2872 \pm 73$

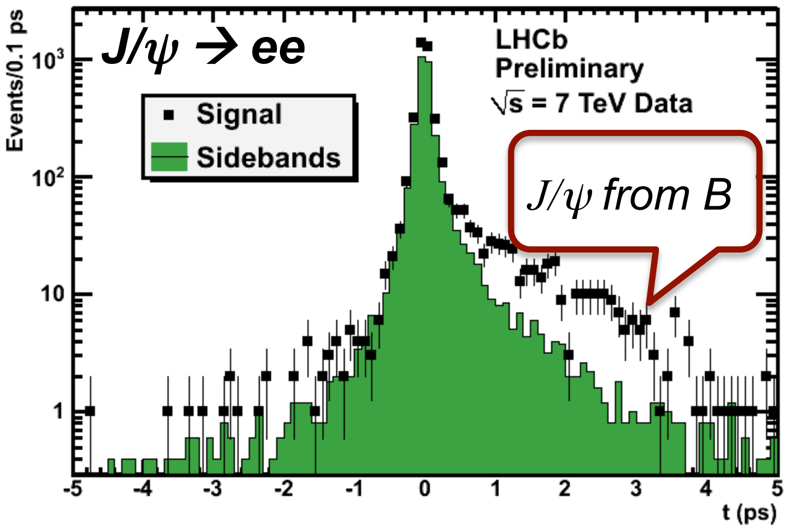
$M = 3088.3 \pm 0.4$ MeV/c^2

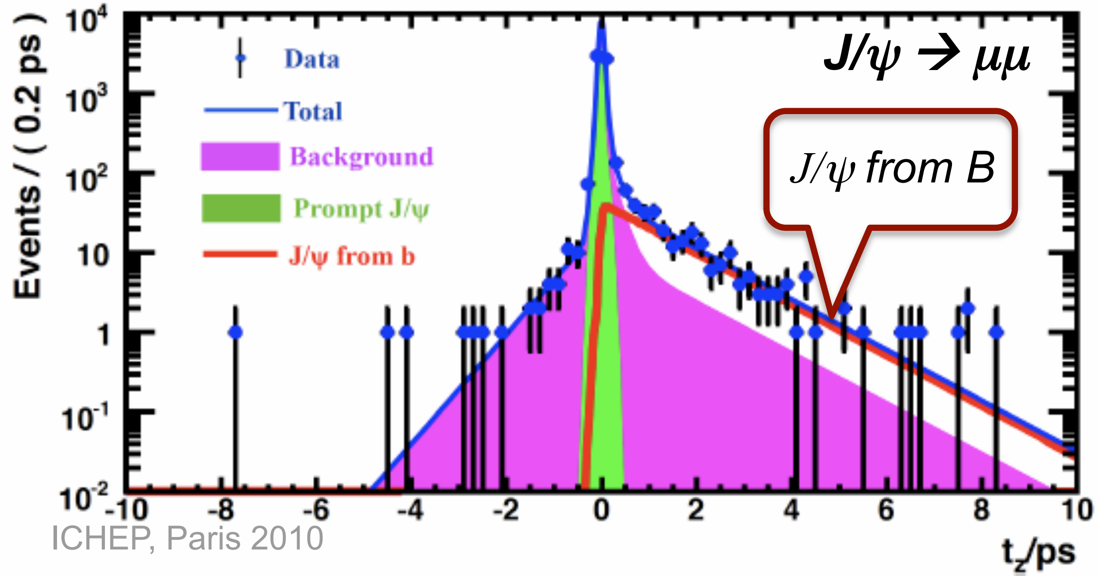
$\sigma = 15.0 \pm 0.4$ MeV/c^2

Fraction of J/ψ produced in b decays extracted from the fit to pseudo propertime, t_z:

$f_b = 11.1 \pm 0.8\%$ (316 ± 24 events)

Pseudo propertime: $t_z = d_z \times M(J/\psi) / p_z$

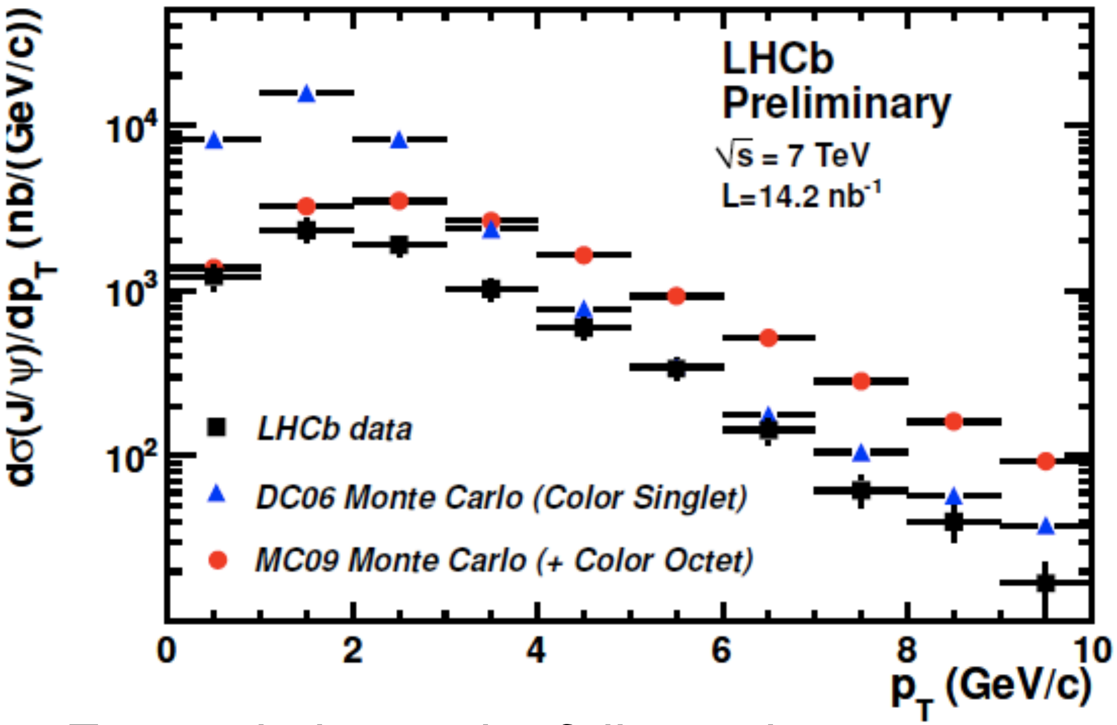




Prompt J/ψ and $b\bar{b}$ cross-sections @ $\sqrt{s}$ = 7 TeV

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

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



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

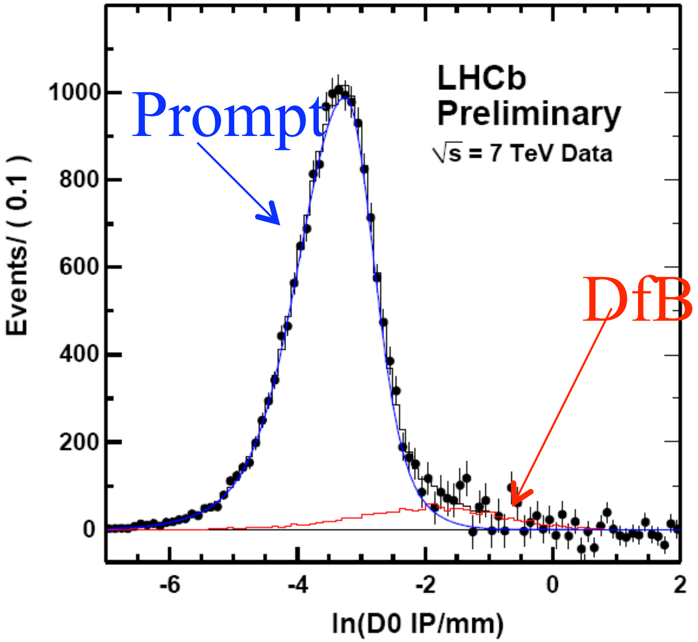
Extrapolation to the full angular acceptance using PYTHIA 6.4 and EvtGen:

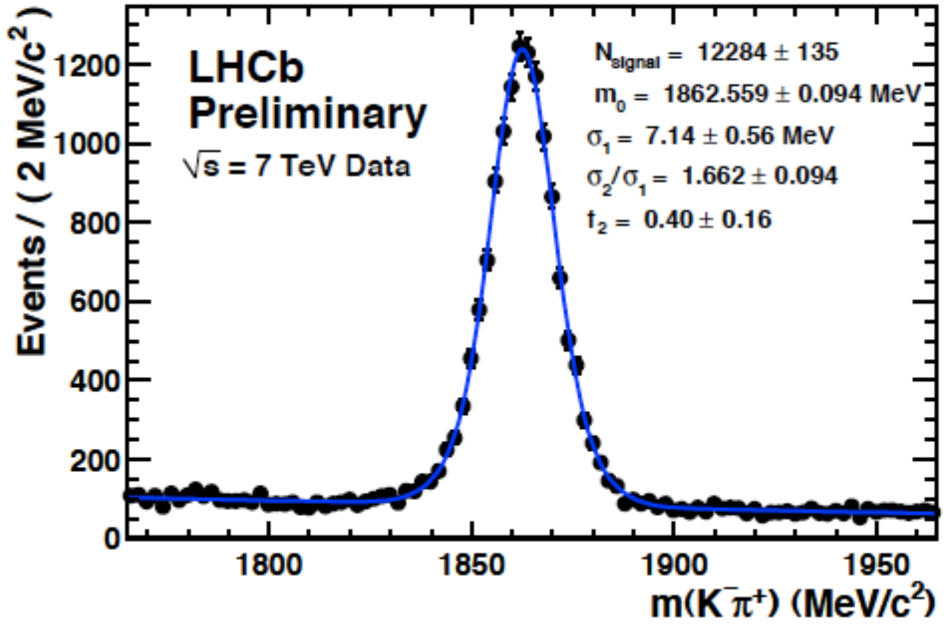
σ (pp → $b\bar{b}$X) = 319 ± 24 ± 59 μb

$b\bar{b}$ cross-section @ $\sqrt{s}$ = 7 TeV using $B \rightarrow D^0 \mu X$ events (see talk of Sheldon Stone)

$K^- \pi^+$ mass spectrum used to define signal shape

L ~ 3 nb^{-1}



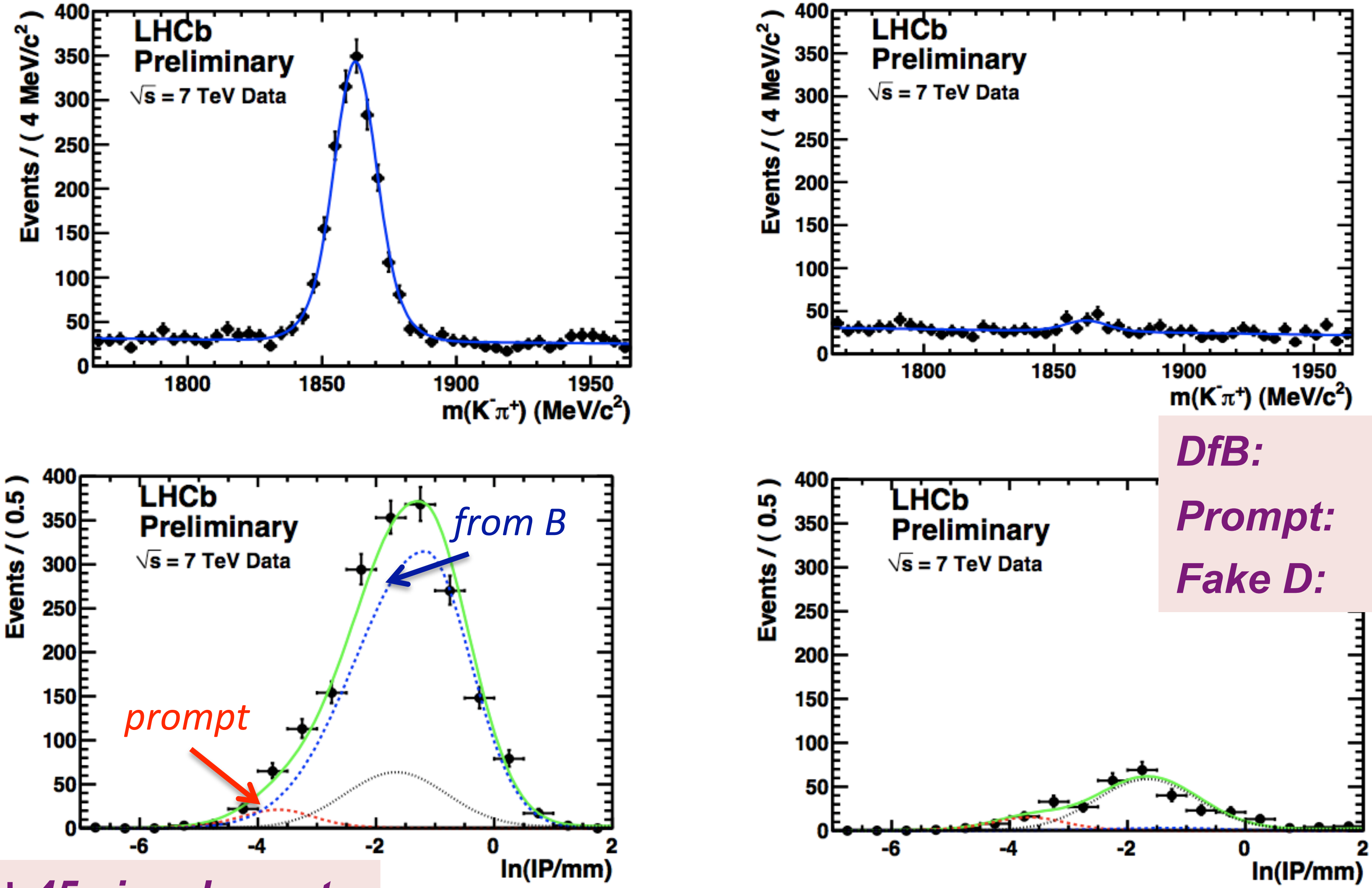


Impact Parameter (IP) D distribution used to separate prompt D and D produced in B decays (DfB)

$B \rightarrow D^0 X \mu \nu$ with $D^0 \rightarrow K\pi$

Correlate D^0 with the muon of the right (wrong) sign

Right sign **$L \sim 100\ nb^{-1}$** **Wrong sign**



DfB: 15 ± 16

Prompt: 51 ± 10

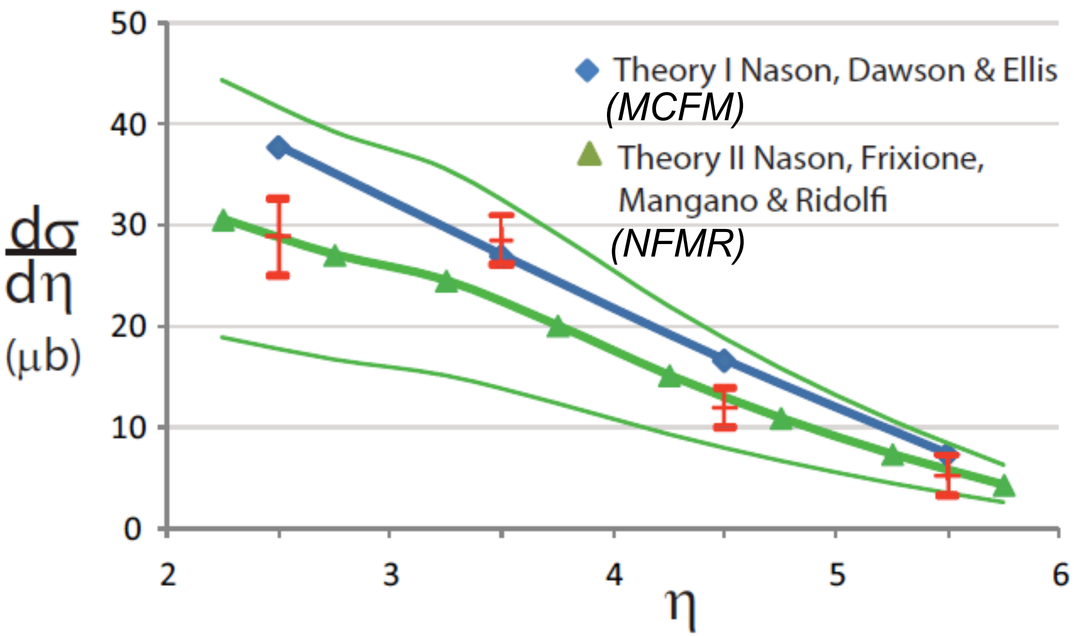
Fake D: 263 ± 8

1540 ± 45 signal events with D from B

$b\bar{b}$ cross-section @ $\sqrt{s}$ = 7 TeV

For the cross section measurement use sub-sample of L ~ 14 nb^{-1}

η	LHCb
2-6	74.9±5.3±12.8 μb
all	282±20±48 μb



Averaging between b → J/ψX and b → $D^0X\mu\nu$ gives

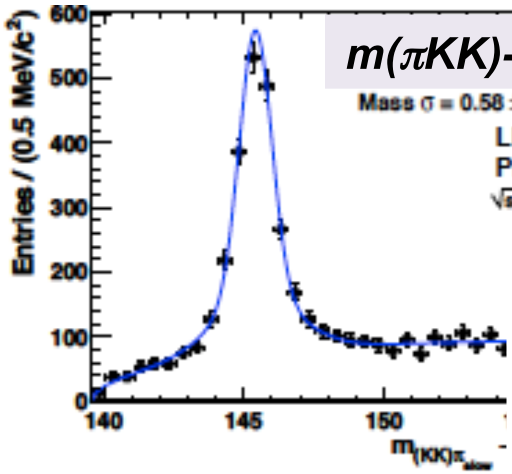
σ(pp → bbX) = 292 ± 15 ± 43 μb
(assuming LEP frag. fractions)

Theory:
MCFM 332 μb, NFMR 254 μb

Prospects for 2010-2011 Physics Run

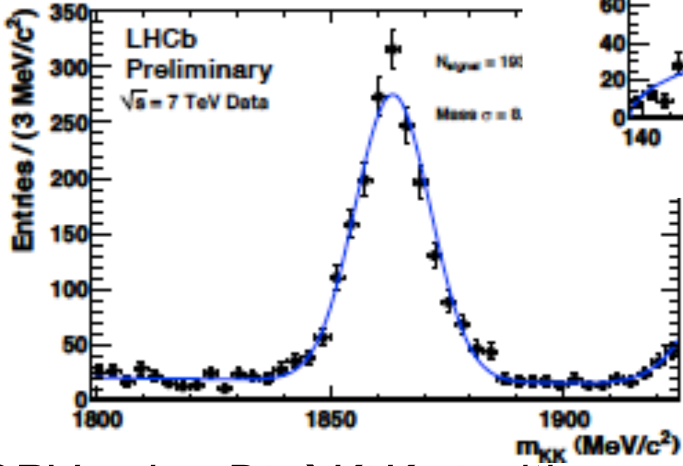
Charm of beauty experiment

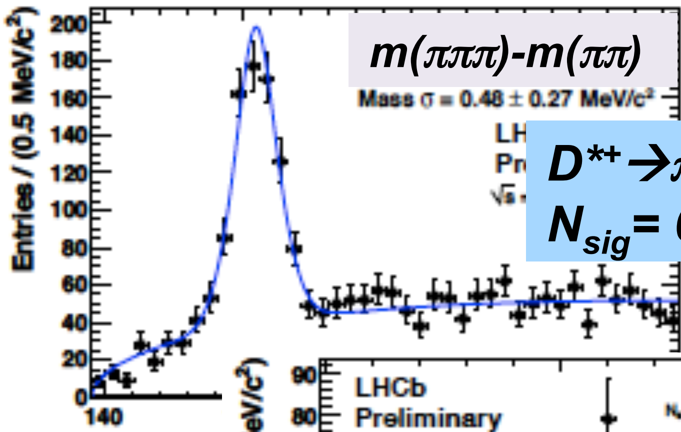
- *Excellent prospects for CPV studies; sensitivity < 0.1% is feasible at LHCb with first 100 pb^{-1} !!! Expect several million tagged $D^0 \rightarrow KK$ (BELLE 540 fb^{-1} analysis uses ~10^5 tagged $D^0 \rightarrow KK$ giving stat. precision on y_{CP}=0.32% and on A_Γ=0.30%)*



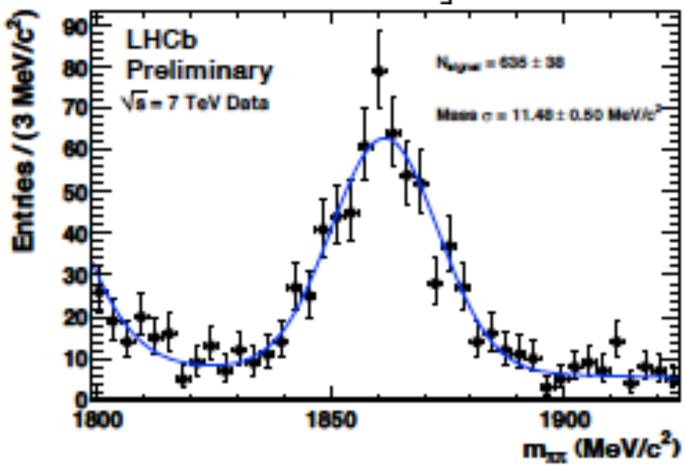
L ~ 100 nb^{-1}

$D^{*+} \rightarrow \pi^+ D^0(K^-K^+)$
N_{sig}= 1931±112





$D^{*+} \rightarrow \pi^+ D^0(\pi^-\pi^+)$
N_{sig}= 635±38

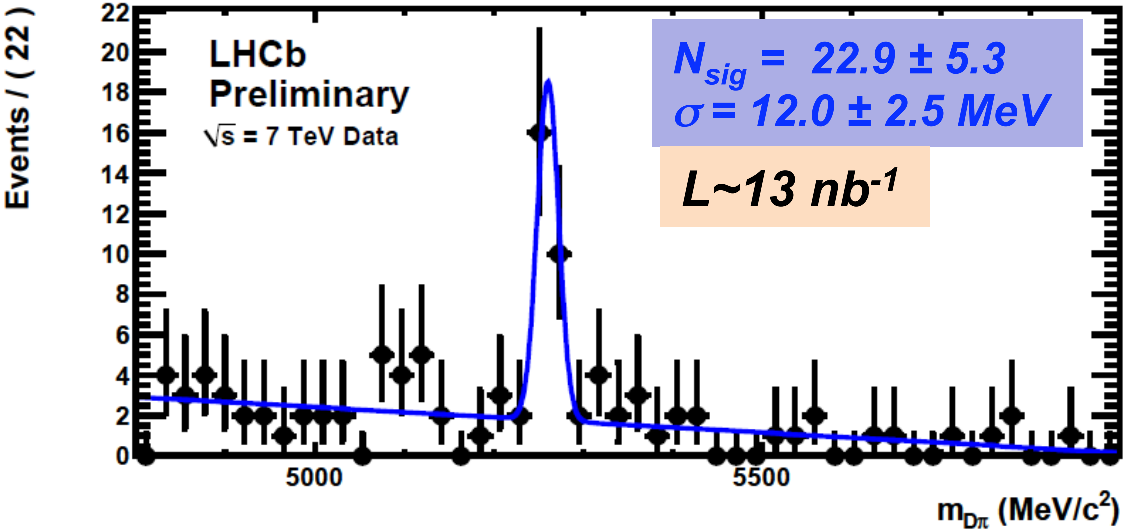


- *Search for direct CPV using $D^+ \rightarrow K^+K^-\pi^+$ with significant contribution from gluonic Penguins. Again LHCb can be confident in collecting several million events in 100 pb^{-1} , which is an order of magnitude increase on B-factories samples*

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

First fully reconstructed B mesons

$B \rightarrow D\pi$



N_{sig} = 22.9 ± 5.3
σ = 12.0 ± 2.5 MeV

L~13 nb⁻¹

First signal in charmed B decays combining two channels:

- *$B^0 \rightarrow D^+\pi^-$*
- *$B^+ \rightarrow D^0\pi^+$*

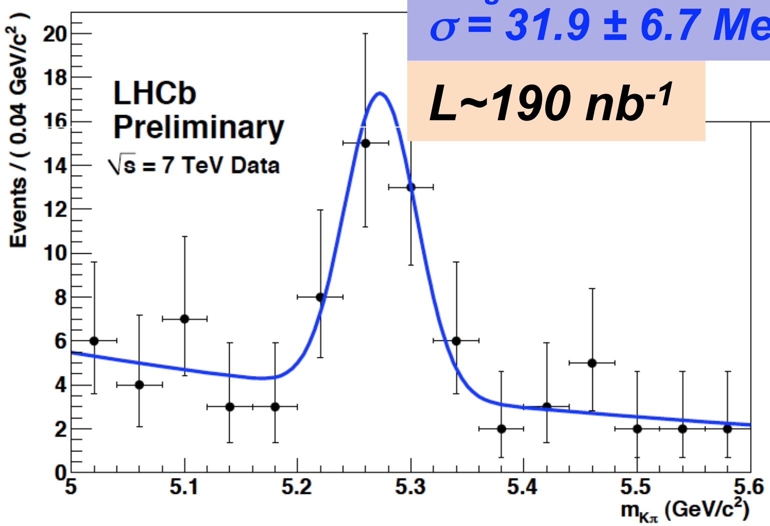
Excellent mass resolution !

Expect soon $B_s \rightarrow D_s\pi^-$ and Cabibbo-suppressed $B \rightarrow DK$

$B \rightarrow K\pi$

N_{sig} = 27.3 ± 6.1
σ = 31.9 ± 6.7 MeV

L~190 nb⁻¹

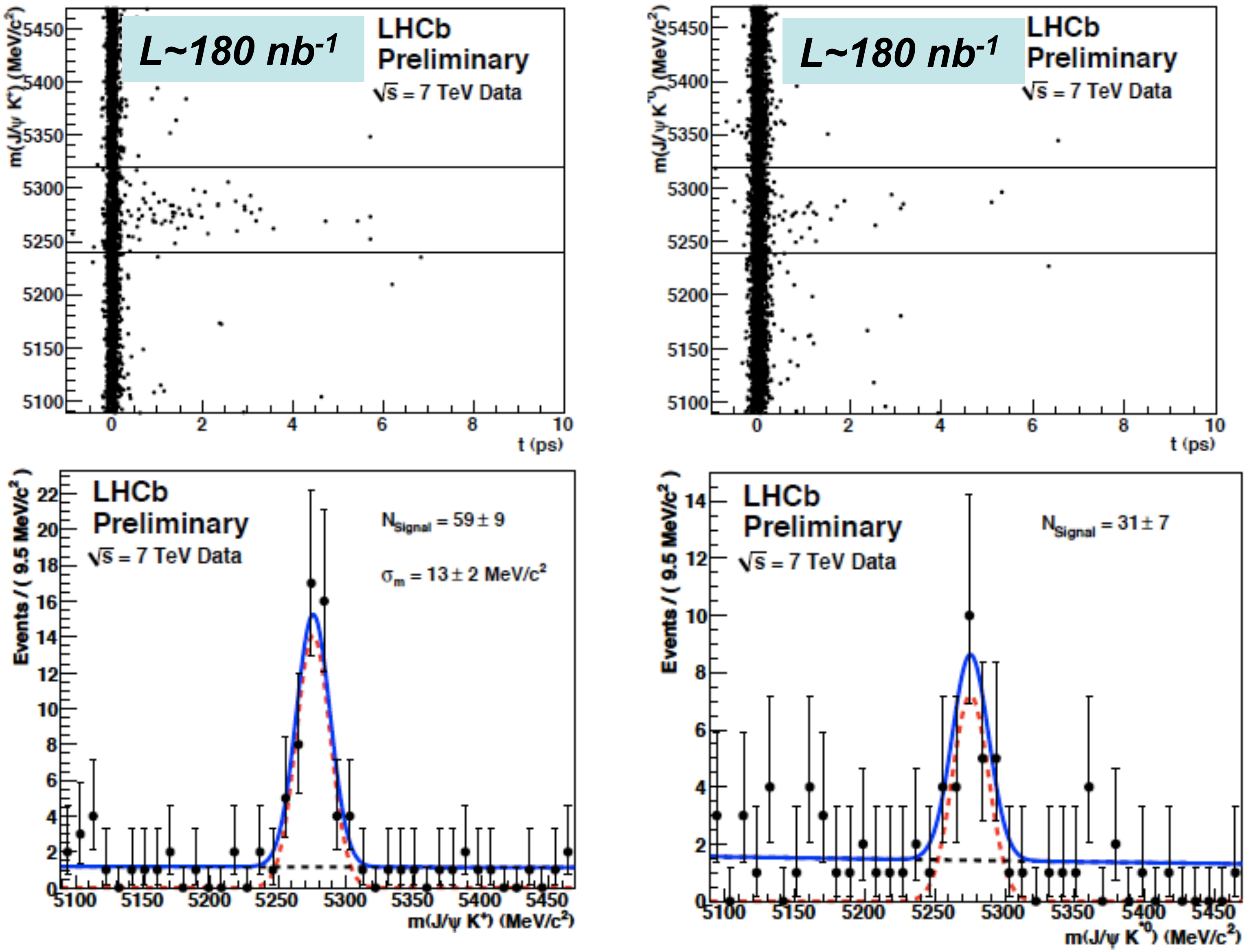


Observed number of signal events consistent with MC expectation

$B_s \rightarrow KK$ signal expected soon

$B \rightarrow J/\psi K^+$ & $B \rightarrow J/\psi K^{*0}$

Unbinned likelihood fit of m, t distributions

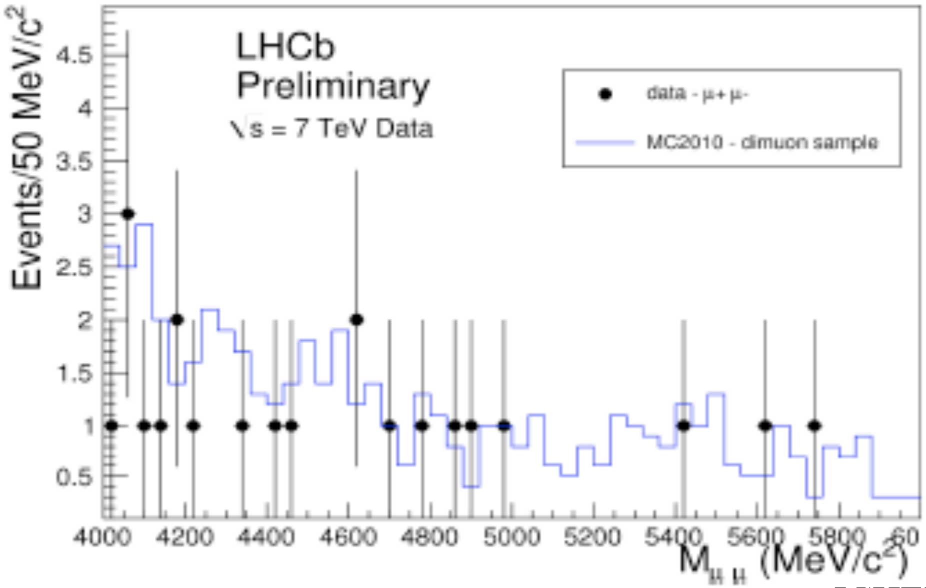


Observed number of signal events consistent with MC expectations

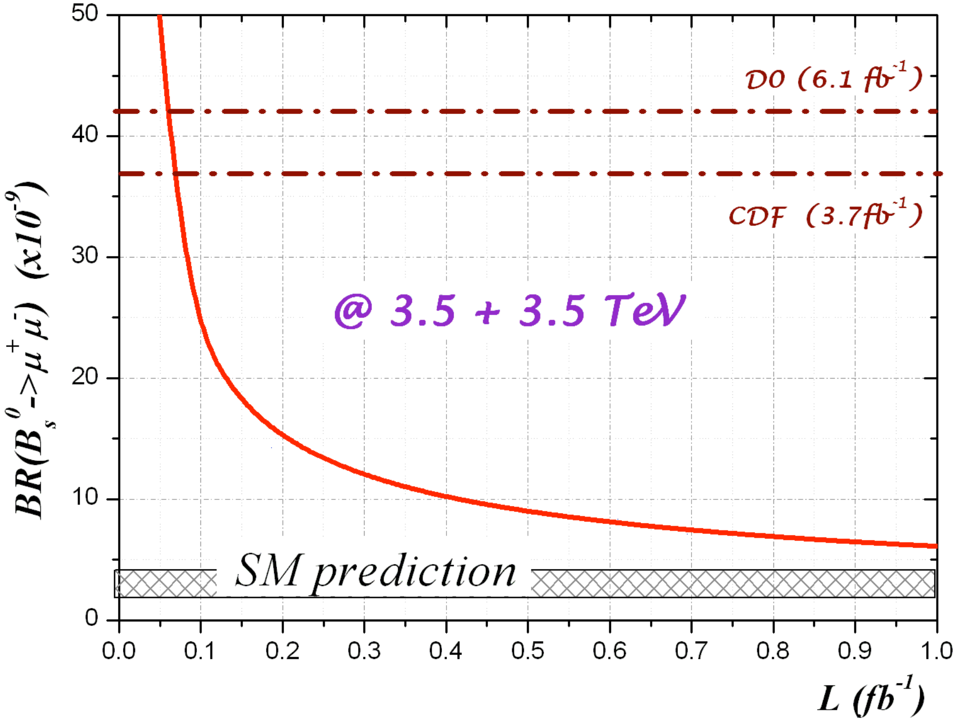
$B_s \rightarrow \mu\mu$

- 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: $BR \propto \tan^6\beta / M^4_A$
- For the SM prediction LHCb expects 10 signal in 1 fb^{-1}.

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



Exclusion limit @ 90% C.L.



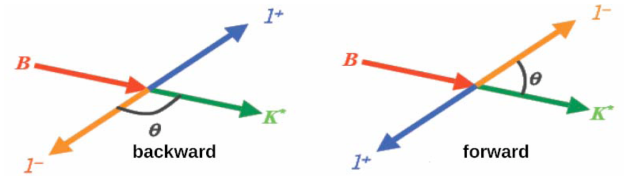
Exclusion of SM enhancement up to $BR(B_s \rightarrow \mu\mu) \sim 7\times10^{-9}$ should be possible with L~1 fb^{-1}

Current limit can be improved with < 100 pb^{-1}

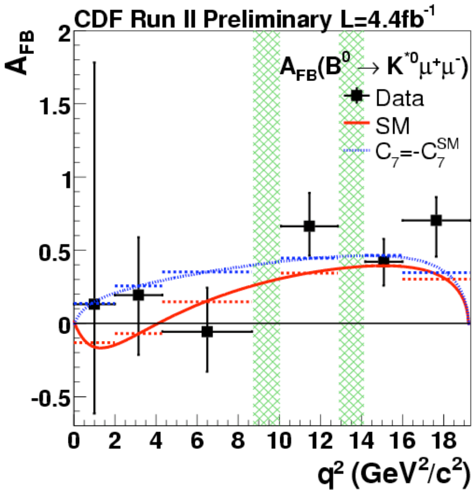
$B \to K^*\mu\mu$

Forward backward asymmetry, A_{FB}, is extremely powerful observable for testing SM vs NP. Intriguing hint is emerging !!!

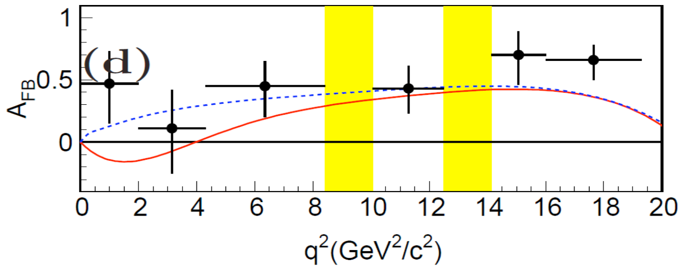
$$A_{FB}\left(s = m^2_{\mu^+\mu^-}\right) = \frac{N_F - N_B}{N_F + N_B}$$



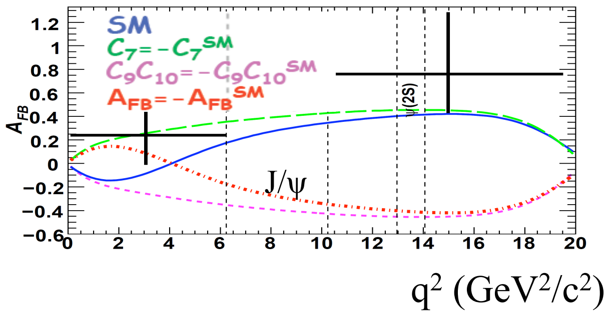
CDF: ~100 $K^*l^+l^-$ events



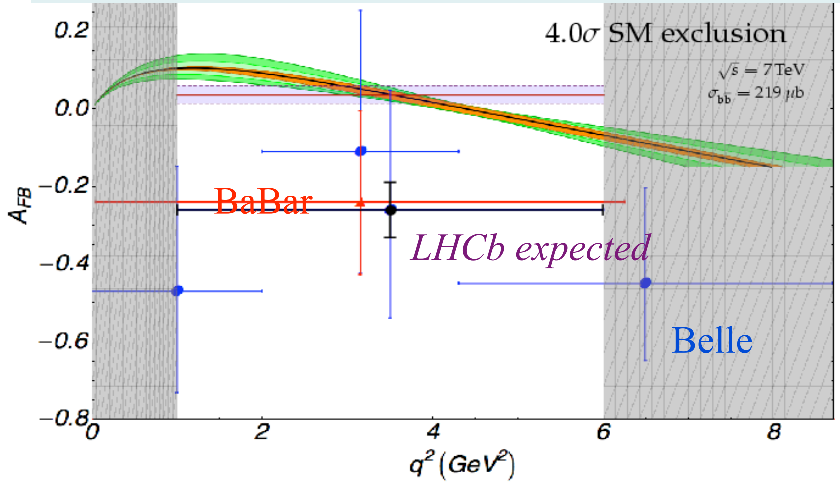
Belle: ~250 $K^*l^+l^-$ events



BaBar: ~100 $K^*l^+l^-$ events



Estimated error in the most sensitive bin assuming BELLE central value



Flipped sign in asymmetry definition

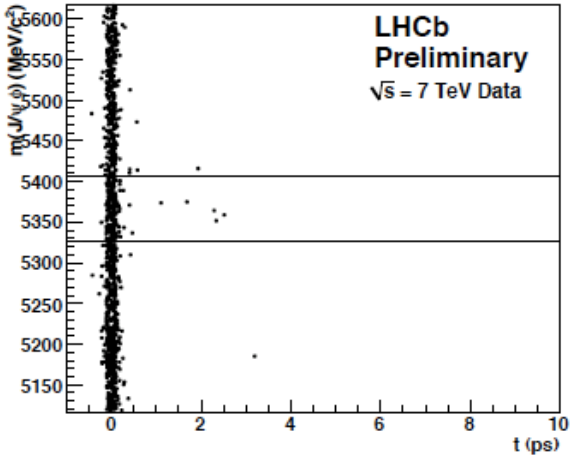
With 1 fb^{-1} LHCb expects ~1400 events, and should clarify existing situation. Expected accuracy in ***A_{FB} zero crossing point, cleanly predicted in SM, is ~0.8 GeV^2 in 1 fb^{-1}***

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

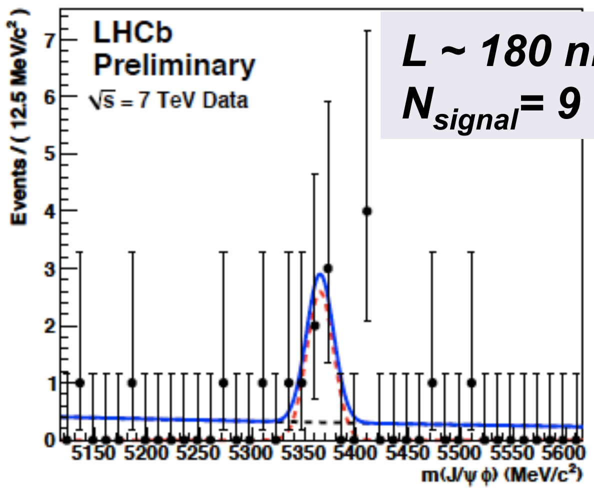
$\phi_s^{J/\psi\phi}$ = **-2β_s** *is very small and precisely predicted in SM*

→ Very sensitive to NP !!!

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



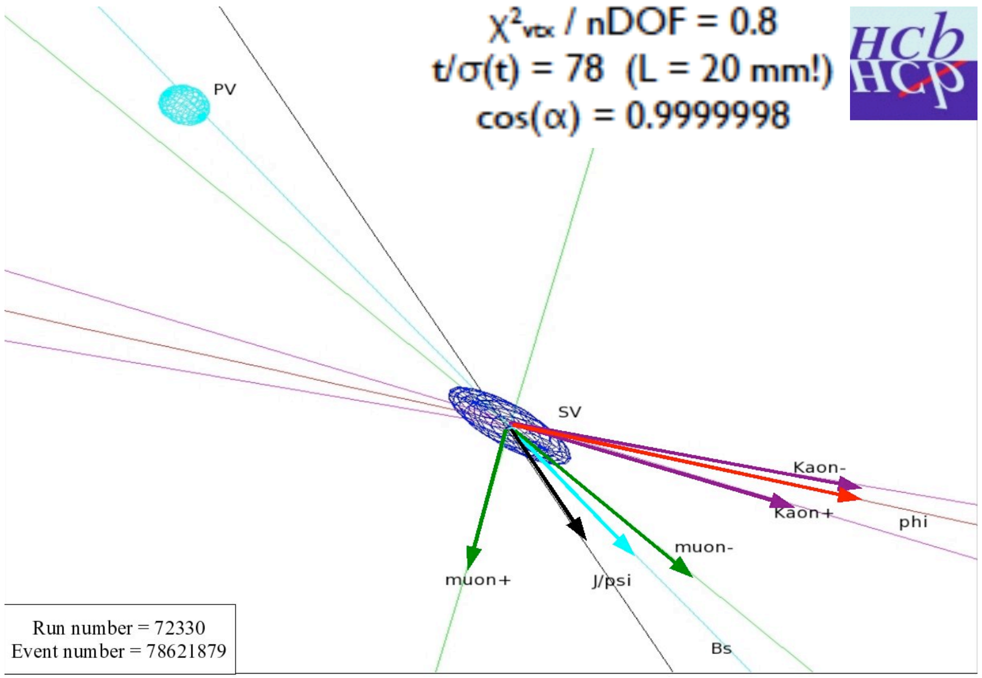
t > 0.3 ps



L ~ 180 nb^{-1}
N_{signal}= 9 ± 3

Number of signal events as expected

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



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

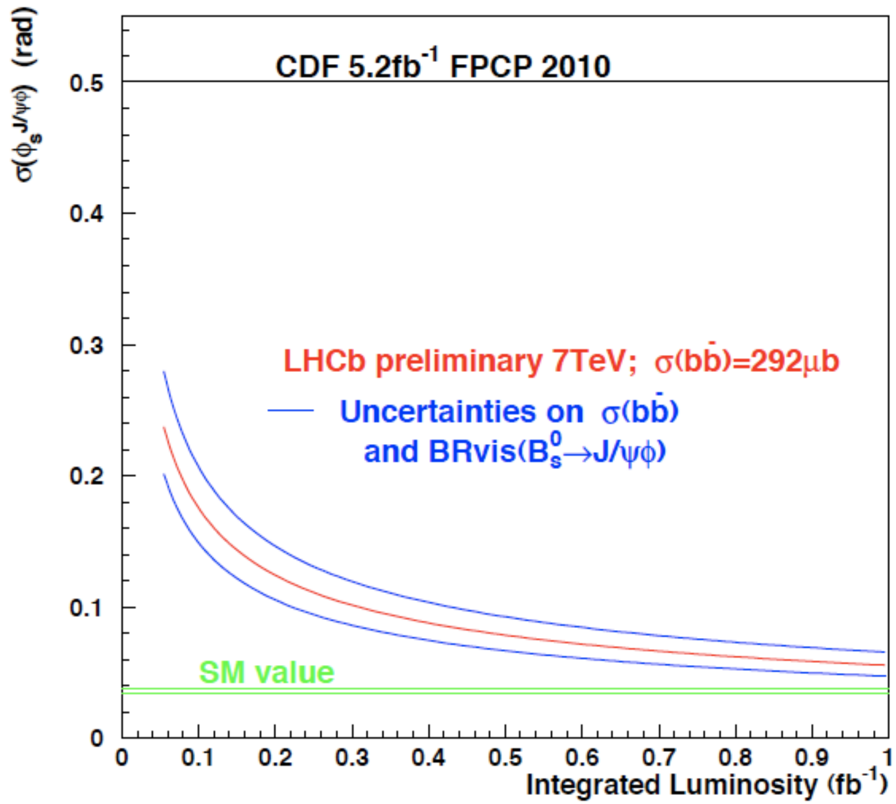
Expected sensitivity:

MC performance:

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

- $<\sigma_t>$ = 0.038 ps. Present resolution in data is ~ 1.6 worse but sufficient for Δm_s ~ 17.7/ps (adds 30% dilution to the sensitivity)

- Tagging performance $\varepsilon D^2 = 6.2\%$ will be tested with more data



Conclusion & Outlook

- *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 – see talk of Ronan McNulty)

  - ***First measurements of production cross-sections at $\sqrt{s}$ = 7 TeV for open charm, J/ψ and bb***

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

- ***$B_s \to \mu\mu$ and $B_s \to J/\psi\phi$ will reach new sensitivity regime with ~ 100 pb^{-1} Exciting prospects of discovery with full 1 fb^{-1} sample***

- *Preparation for LHCb upgrade to collect data at 5-10 times higher luminosity is underway (see talk of Marina Artuso)*

$\Delta A_{fs} = (a_{fs}(B_s) - a_{fs}(B_d)) / 2$ @ LHCb using semileptonic decays $B_{d,s} \rightarrow D\mu\nu$

- *Provide constrain "orthogonal" to recent D^0 measurement*
- *With 100 pb^{-1} expect statistical precision similar to that of D0*