LHCb: status & news

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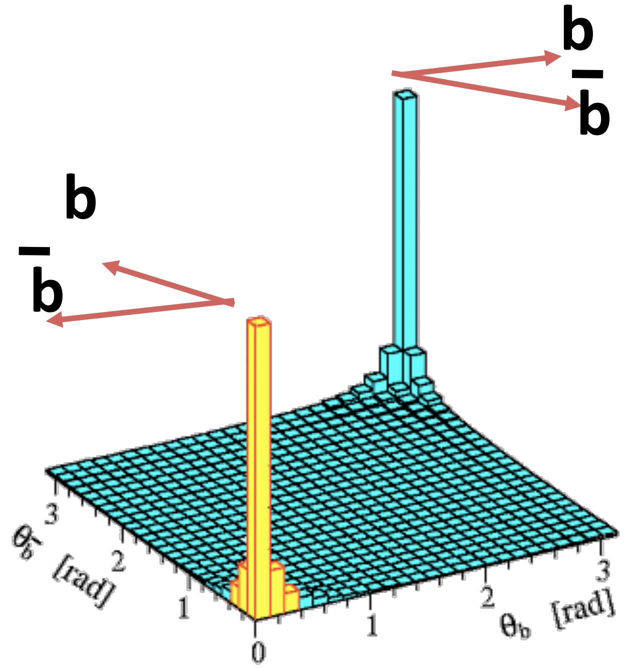
on behalf of the LHCb Collaboration

Outline:

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

(see also talk of Victor Egorychev: LHCb first results)

The LHCb Experiment

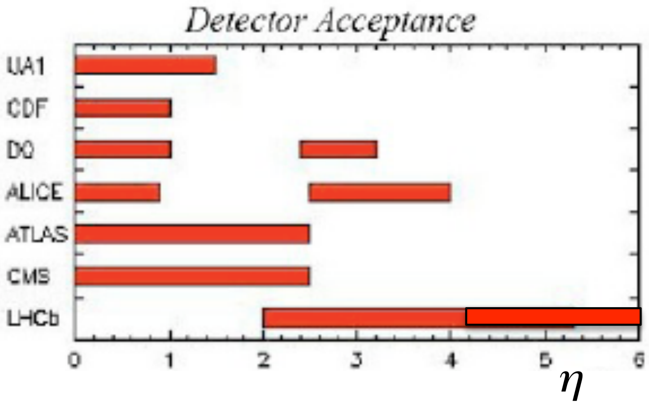


- ☐ *Advantages of beauty physics at hadron colliders:*
  - ■ *High value of bb cross section at LHC:*

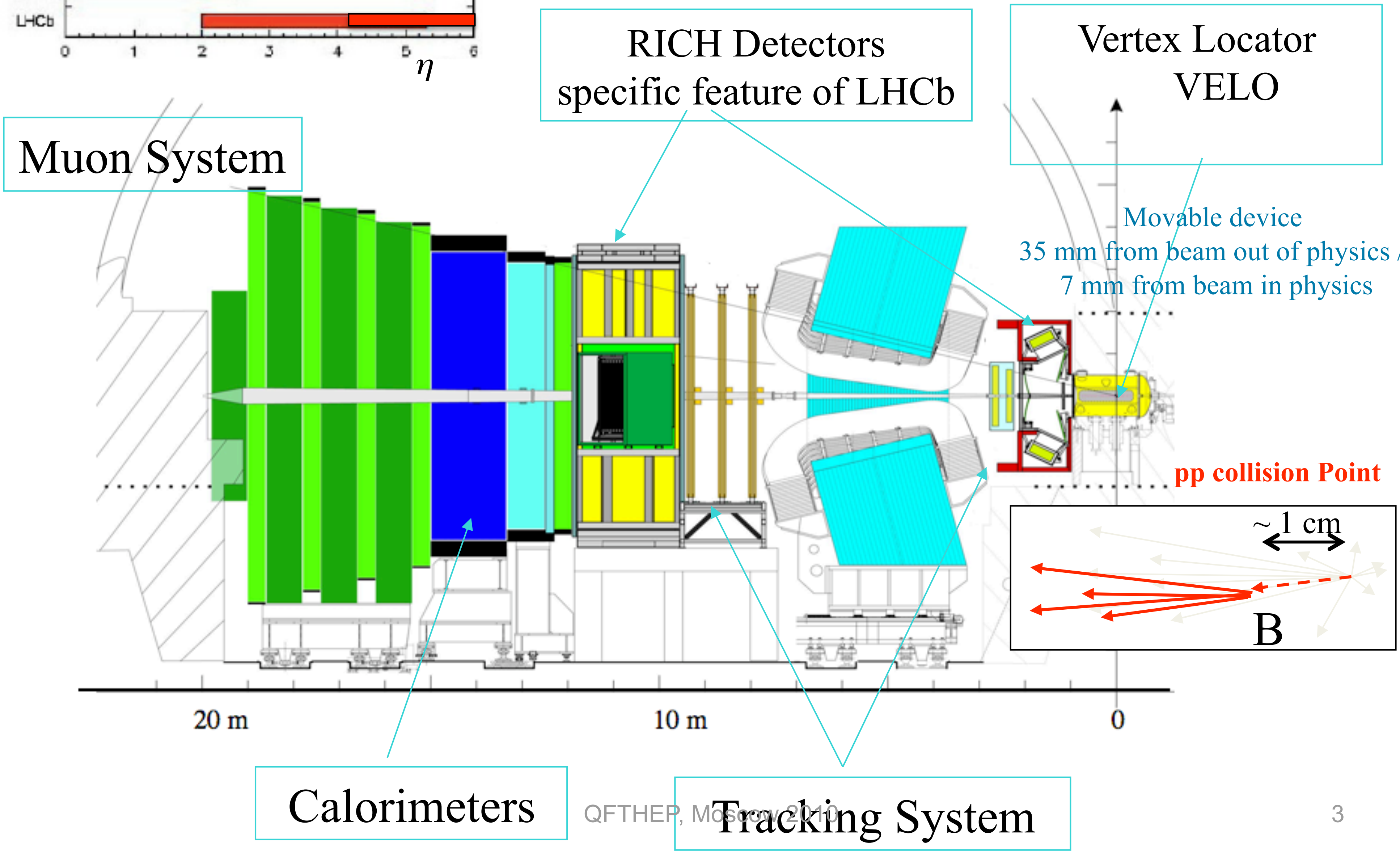
    $\sigma_{bb} \sim 300 - 500\ \mu b$ *at 7 - 14 TeV*

    (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)



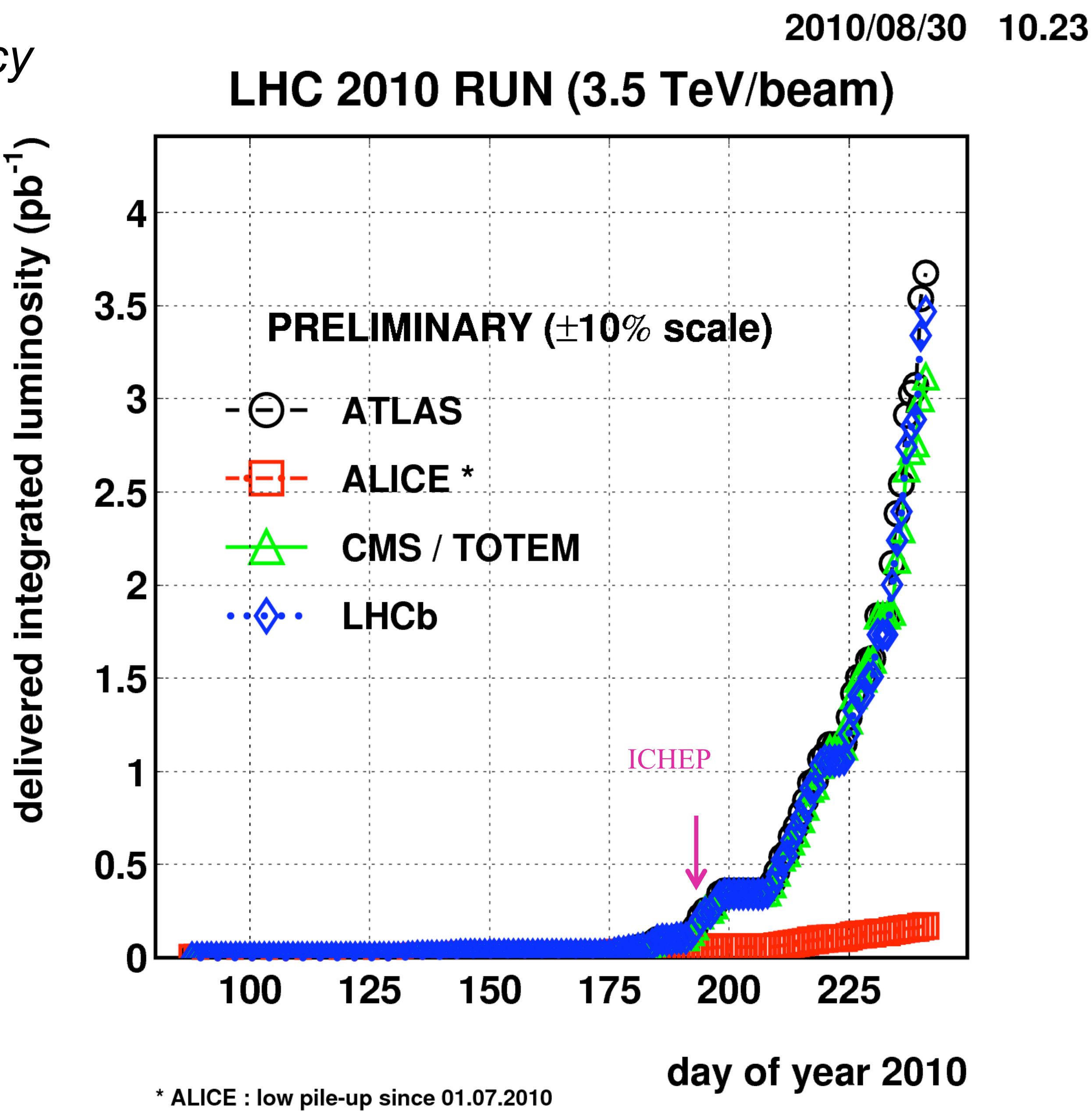
LHCb Collaboration *(day of the 1st collisions)*

LHCb shift

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

LHCb operation

- LHCb operation efficiency > 90%
- Over 3 pb^{-1} recorded by each ATLAS, CMS and LHCb
- Currently $L \sim 10^{31}\ cm^{-2}\ s^{-1}$ at start of fill
- Goal for 2010 to reach $10^{32}\ cm^{-2}\ s^{-1}$ looks realistic
- Expect 30-50 pb^{-1} this year and ~1 fb^{-1} per experiment in 2011

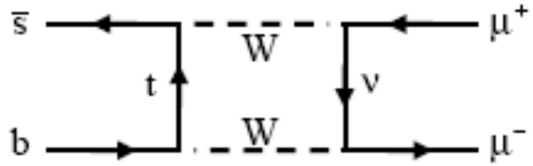


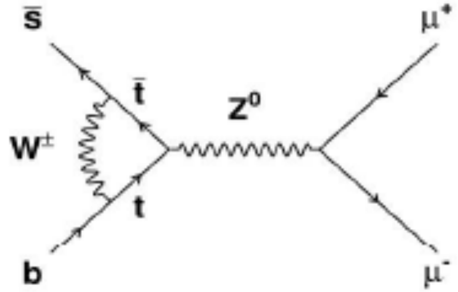
Main LHCb Physics Objectives

Search for New Physics in CP violation and Rare Decays

CPV:

B_s oscillation phase Φ_s
CKM angle γ in trees and loops
CPV asymmetries in charm decays



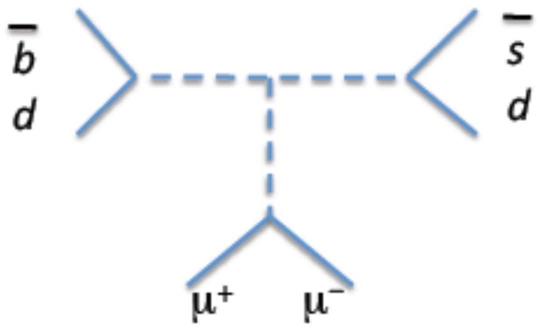


Rare Decays

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

<u>Very non-SM ideas:</u> Examples of FCNC in trees

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

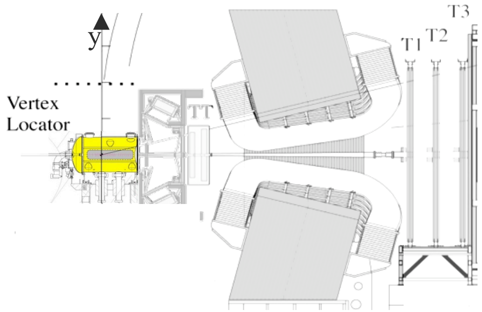


Hadronic: $B_{d,s} \to J/\psi\phi, \phi\phi$

Key ingredients of physics performance

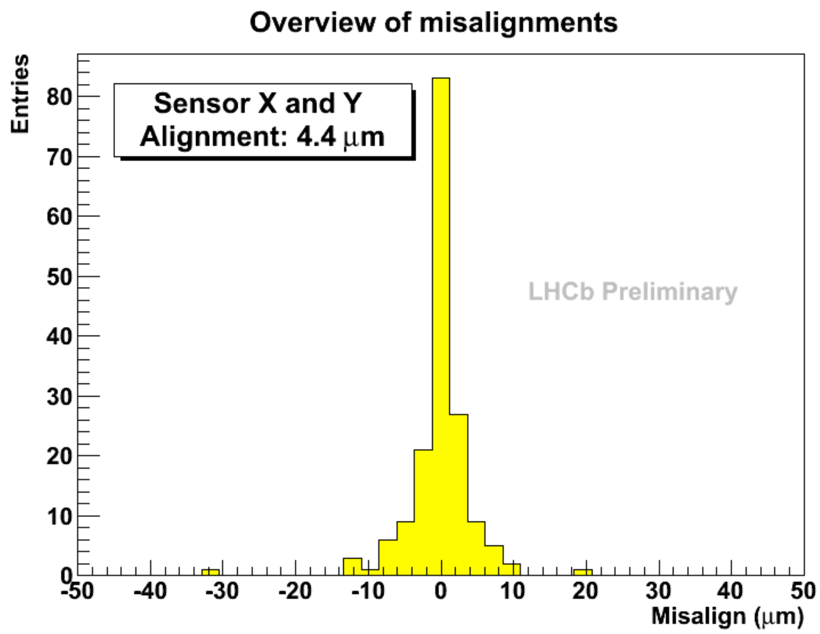
- *Detector alignment*
- *Impact parameter (IP) & Vertex reconstruction*
- *Tracking efficiency*
- *Invariant mass resolution*
- *PID (hadron, muon, electron, photon)*
- *Trigger efficiency*

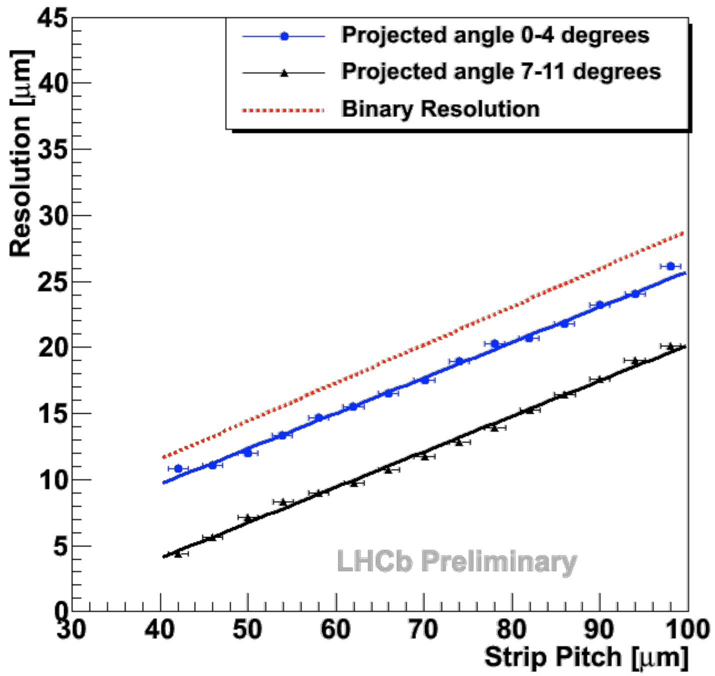
VErtex LOcator (VELO)



- 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

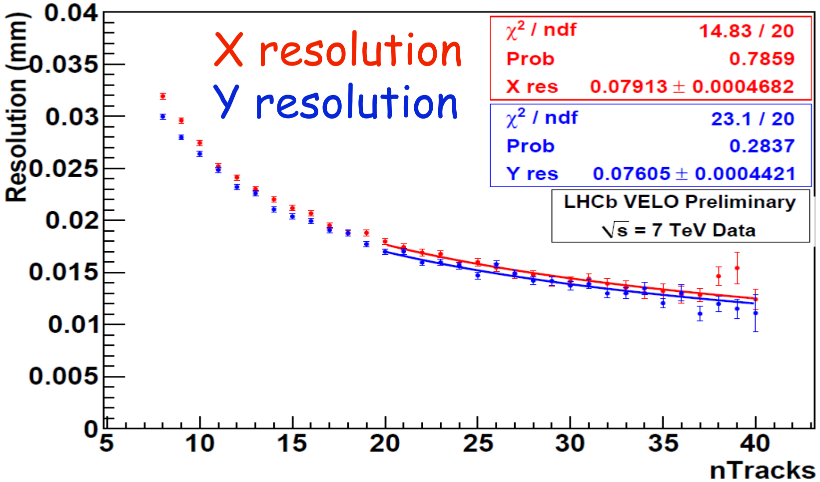
Best VELO hit resolution is 4 μm
Great achievement !!!





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



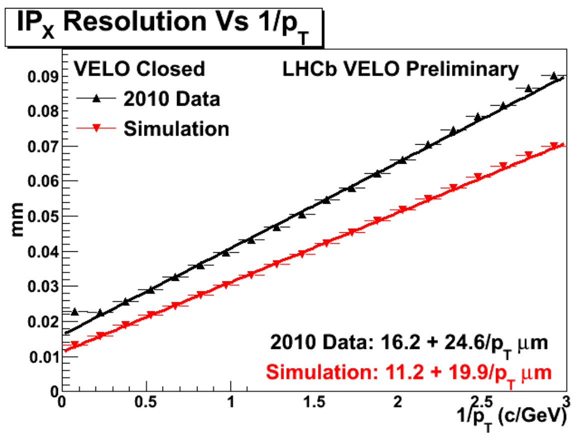
Resolution for PV with 25 tracks

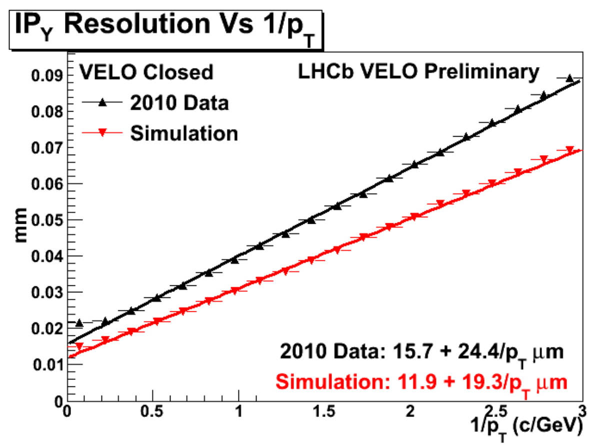
*~ 15 μm for **X** & **Y** and ~ 90 μm for Z*

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

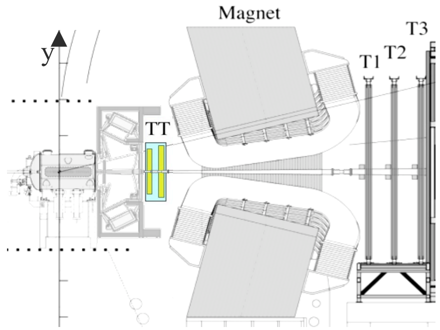
IP resolution ~20 μm for the highest p_t bins

Further improvement is expected with better alignment and material description



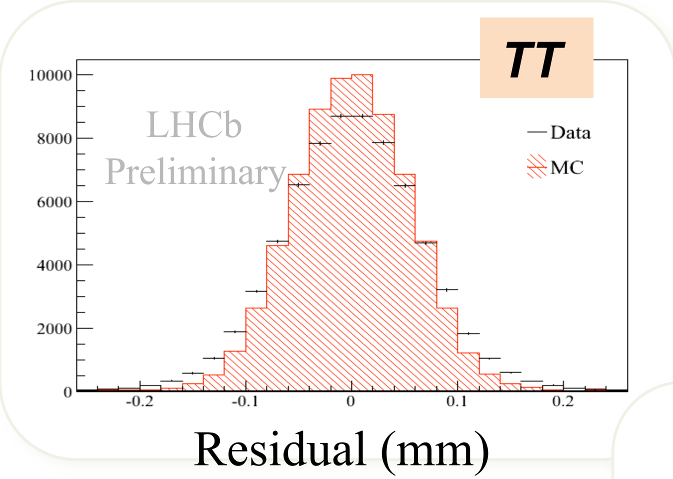


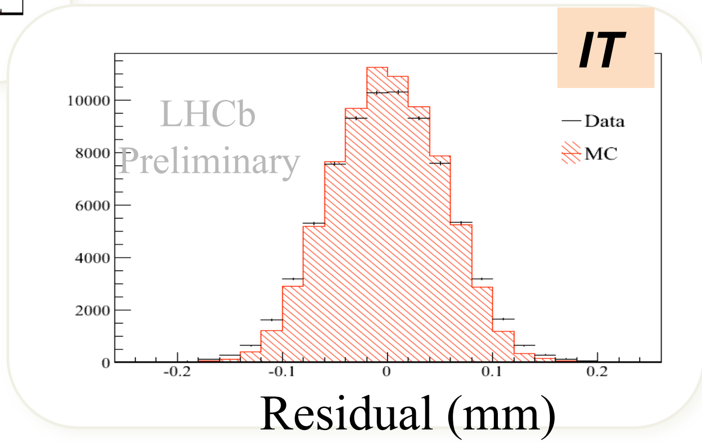
Silicon Trackers (IT/TT) and Outer Tracker (OT)

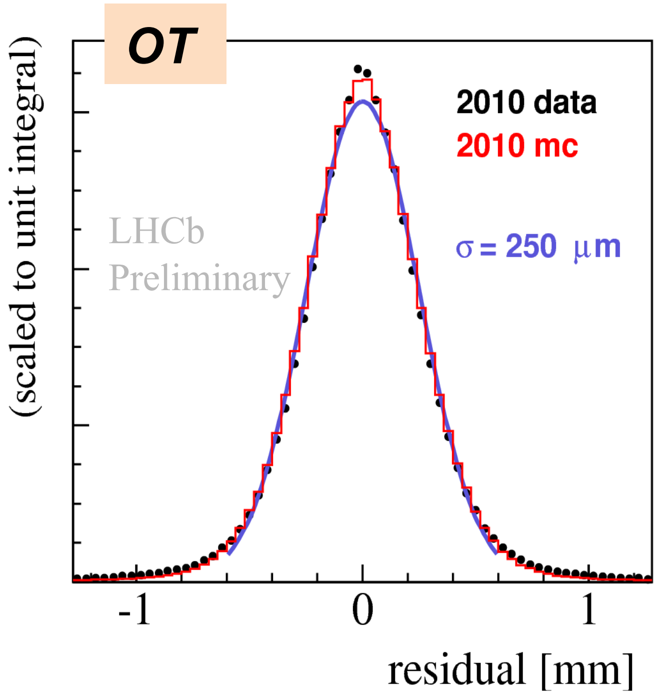


IT and TT alignment is ongoing

TT:
hit resolution 55 μm
misalignment 35 μm
IT:
hit resolution 54 μm
misalignment 16 μm





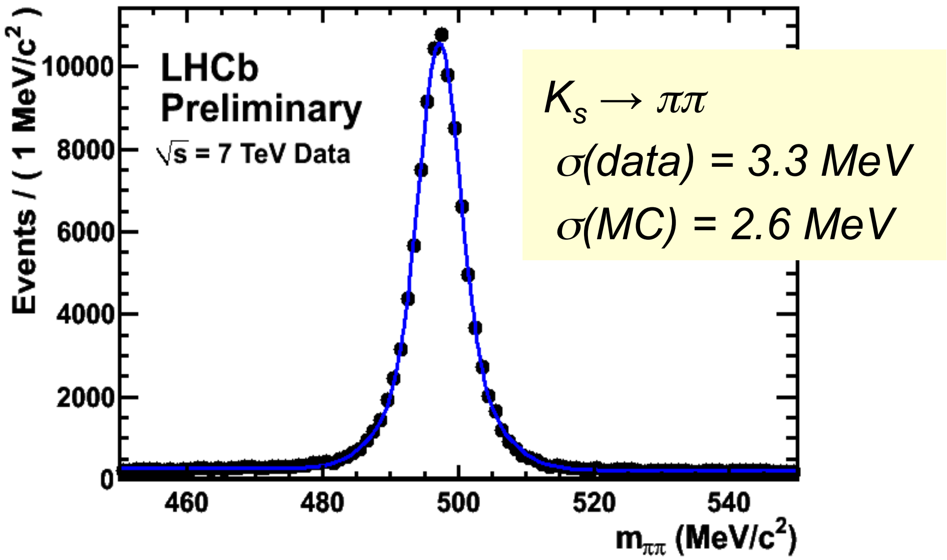


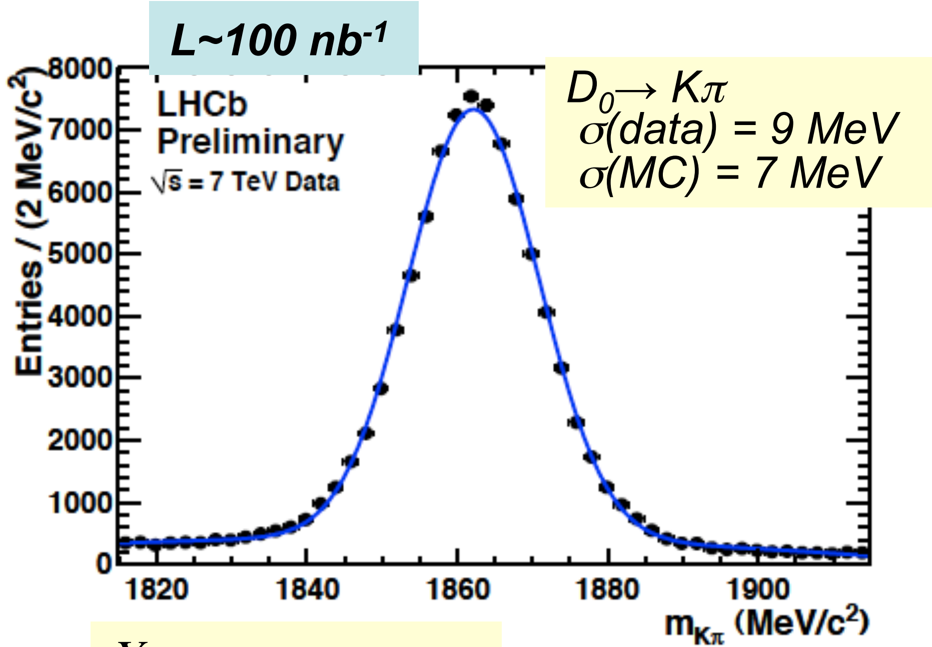
Space drift-time relation corresponds to expectation from test beam data

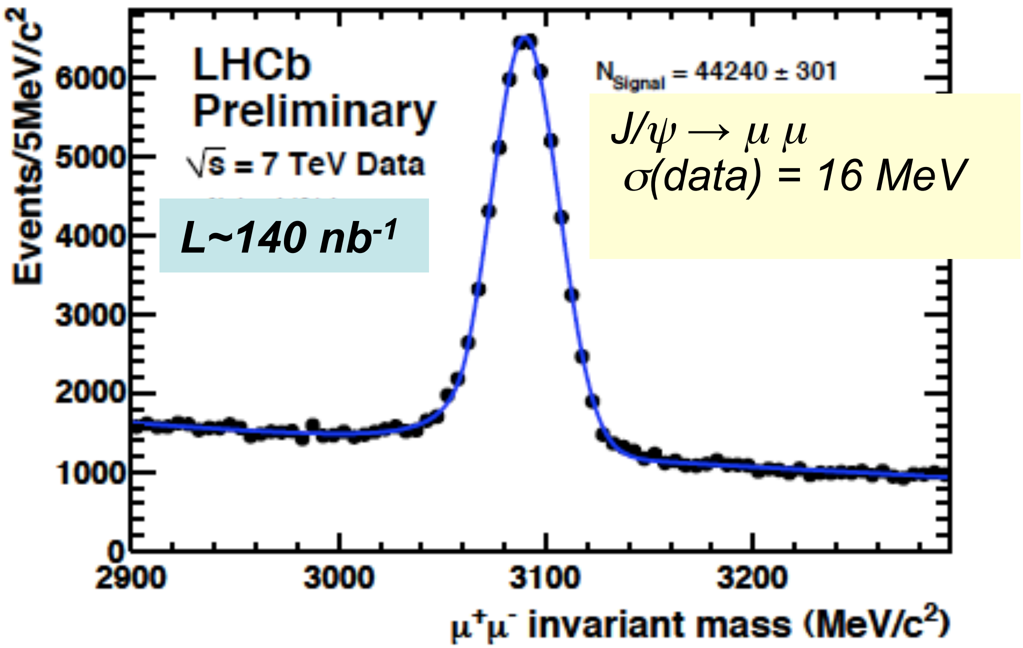
OT well aligned:
resolution 250 μm close to nominal

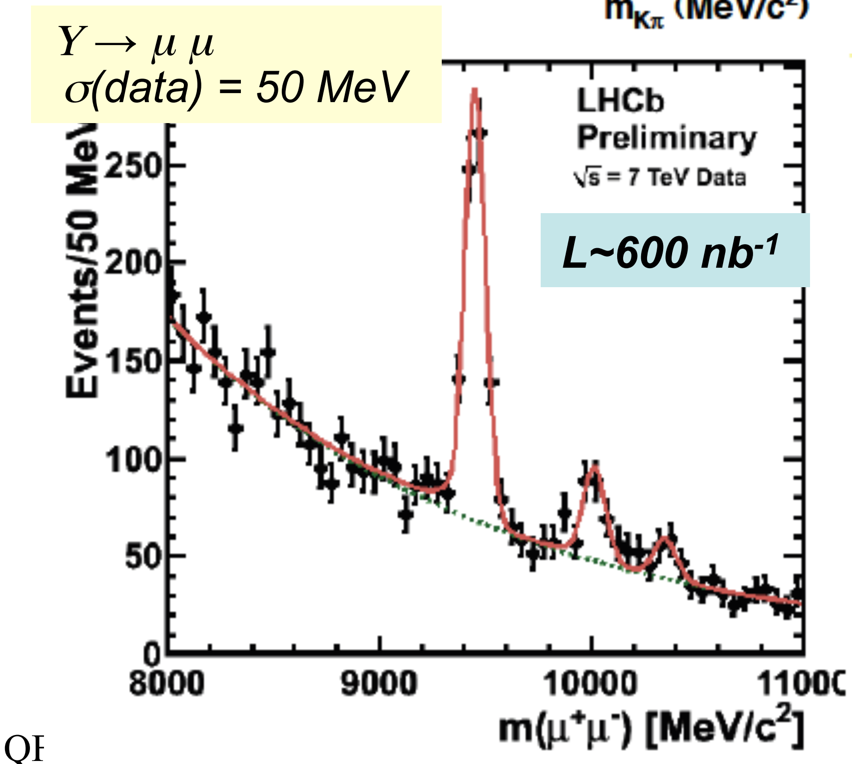
Signal peaks & present mass resolution

(Will be improved !!!)





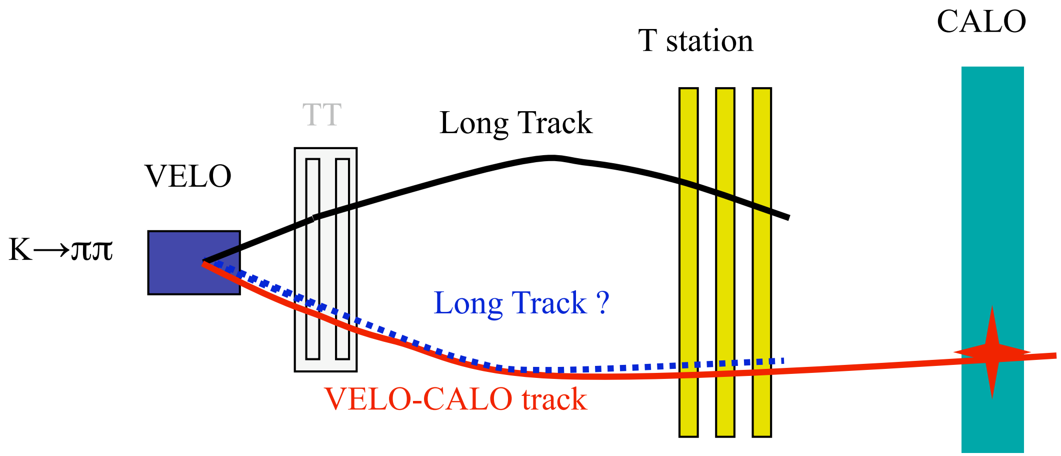




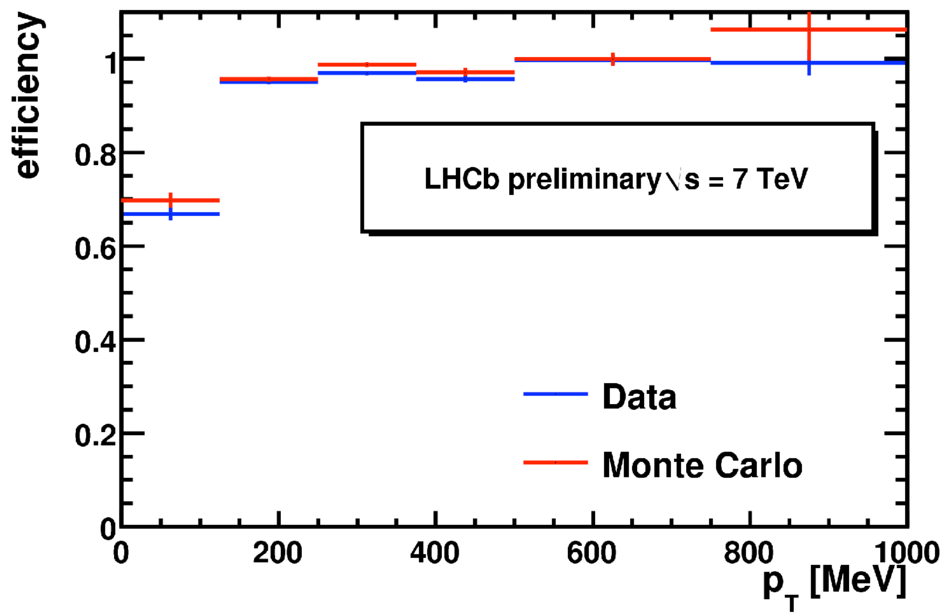
Tracking Efficiency

Obtained using K_S candidates:

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



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*

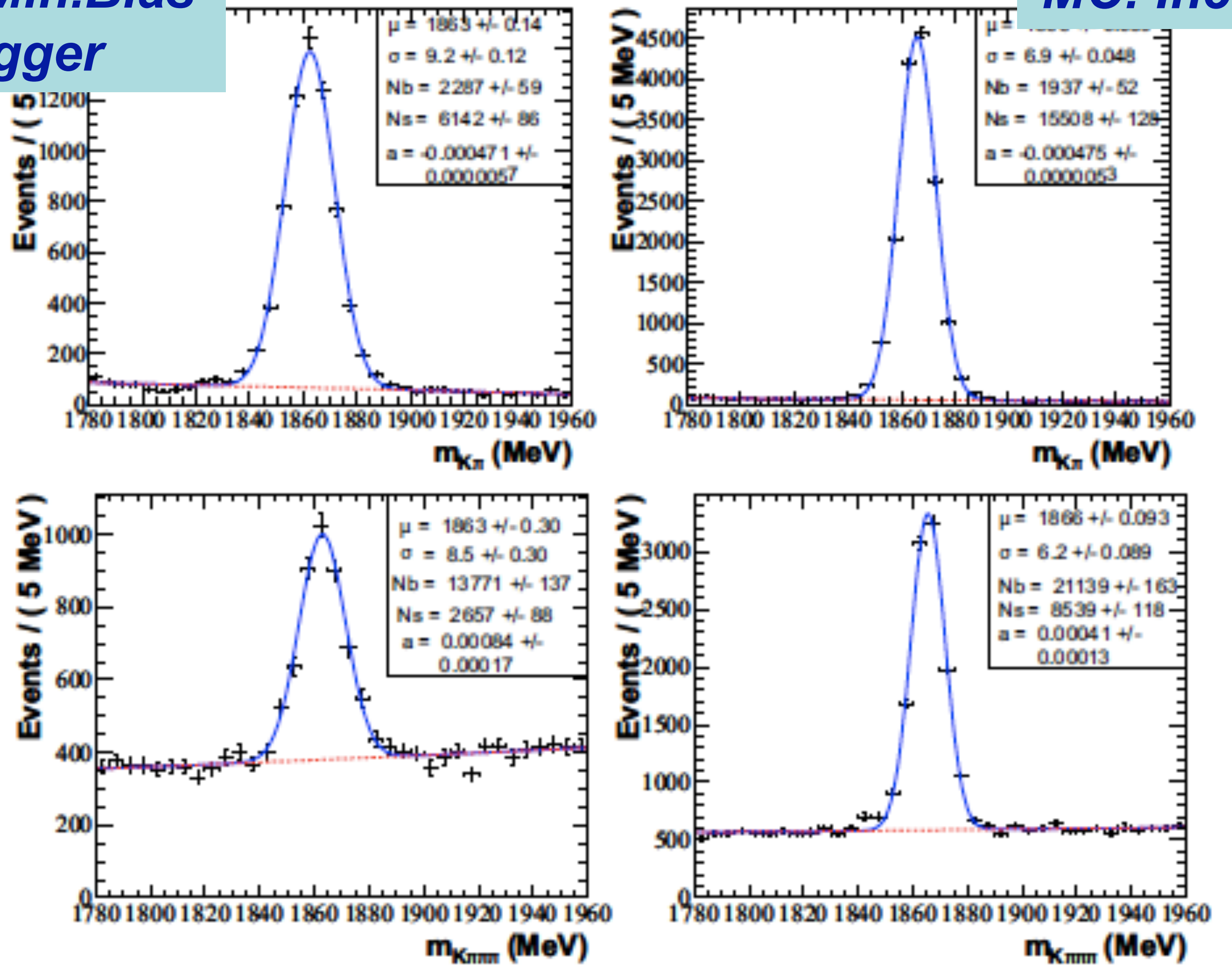
Tracking efficiency systematics

(D→Kπ vs D→K3π)

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

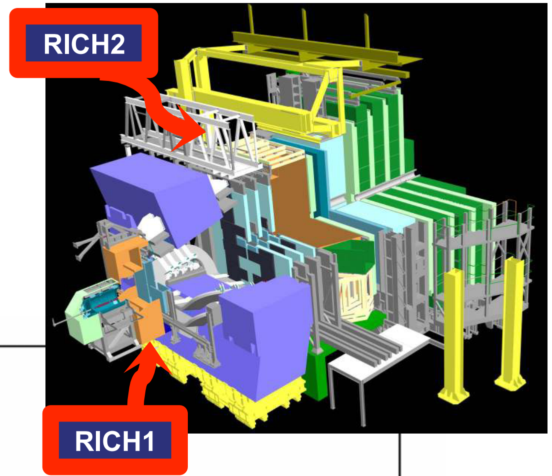
Data: Min.Bias Trigger

MC: Incl. charm



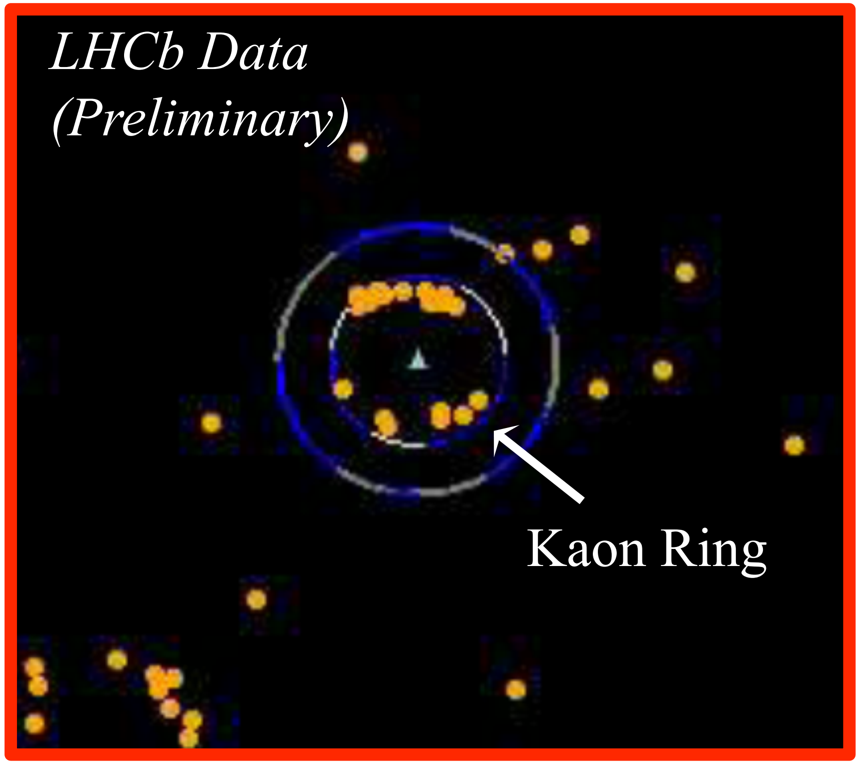
ε(Data) / ε(MC) = 1.00 ± 0.03

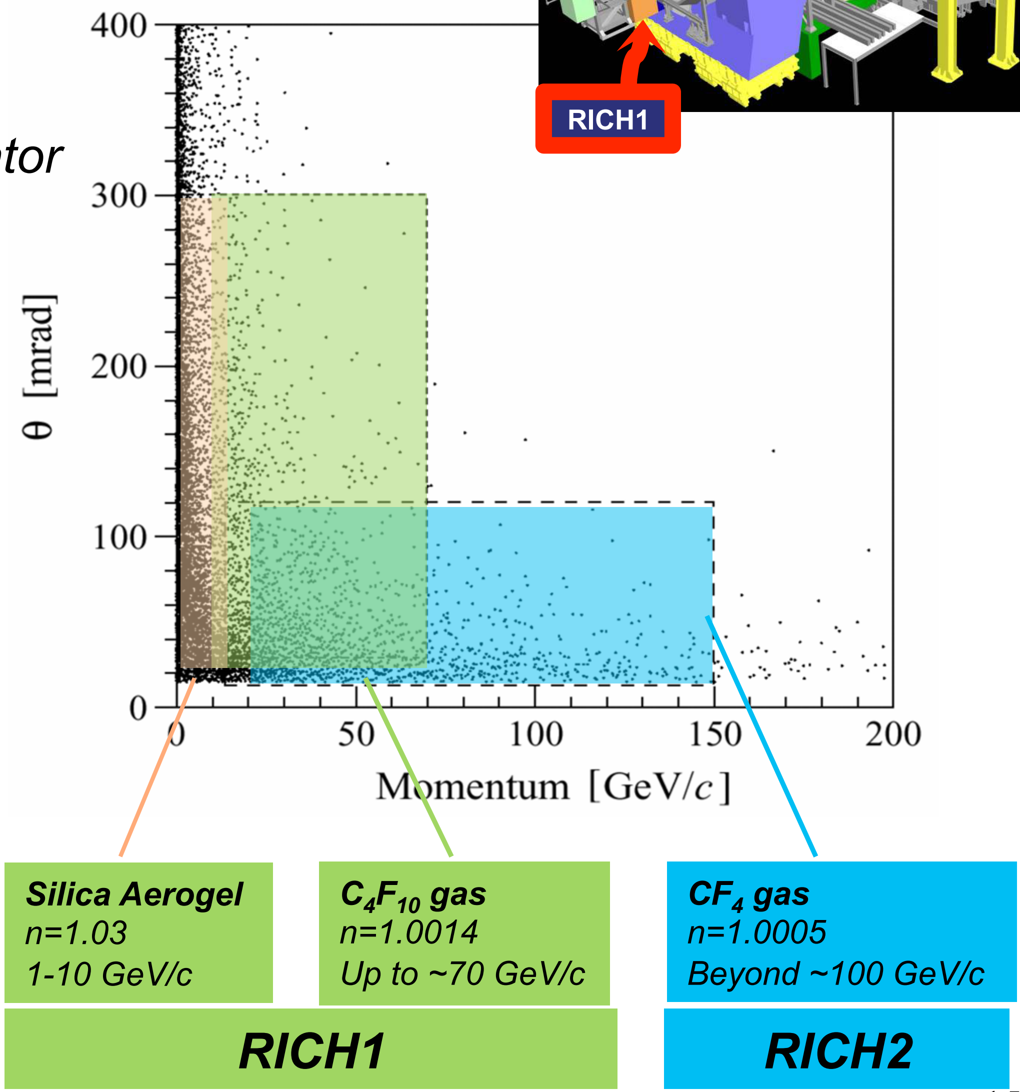
Particle Identification



RICH:

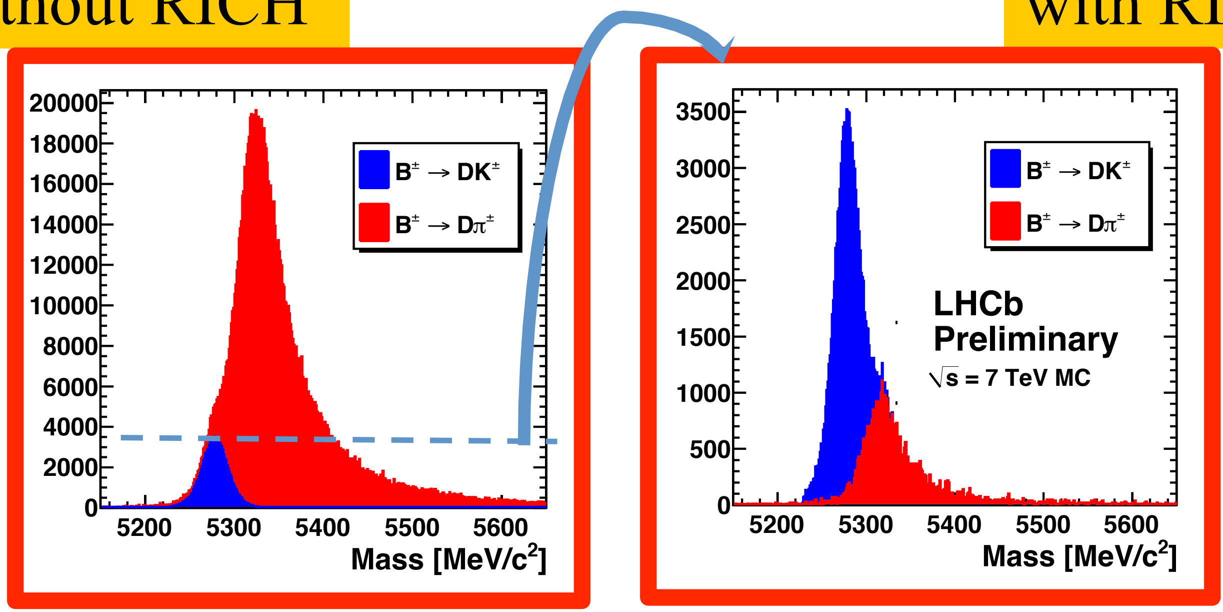
π / K / p separation
2 – 100 GeV/c
two gaseous and one aerogel radiator

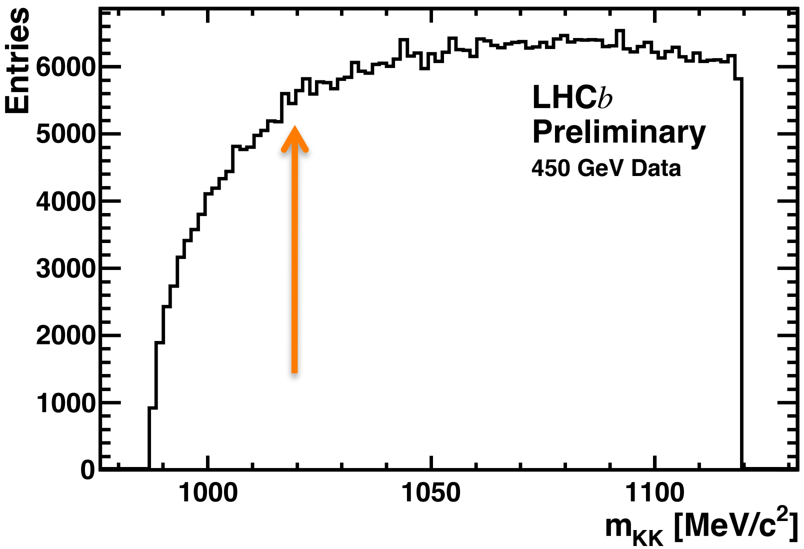


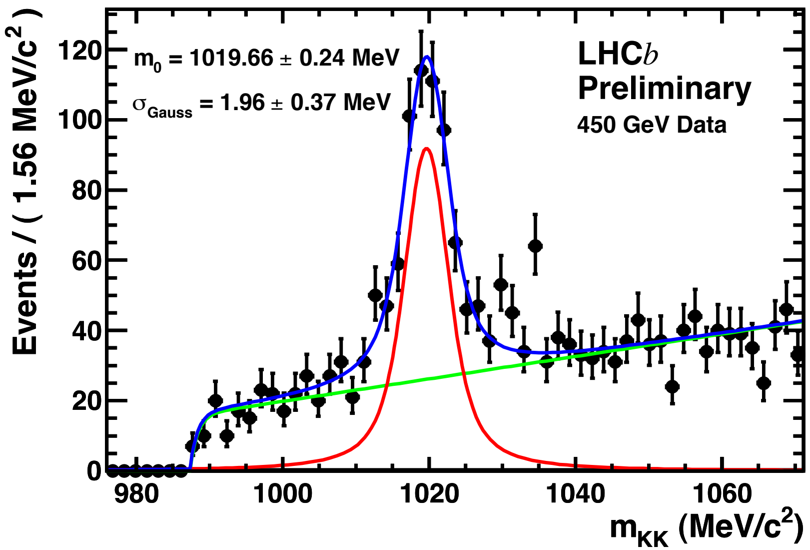


PID with RICH

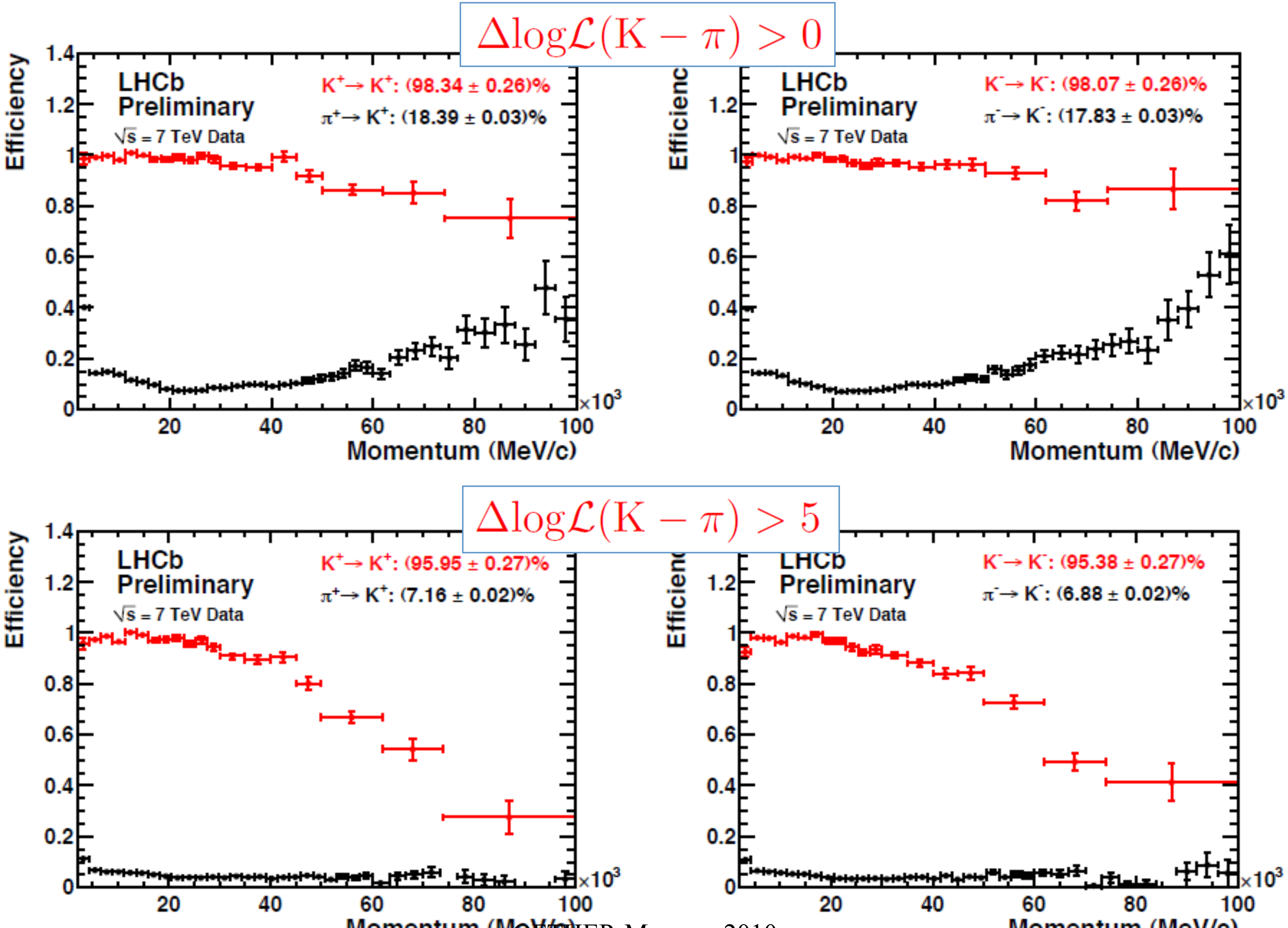
without RICH   with RICH







PID with RICH: *K/π separation*



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

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:

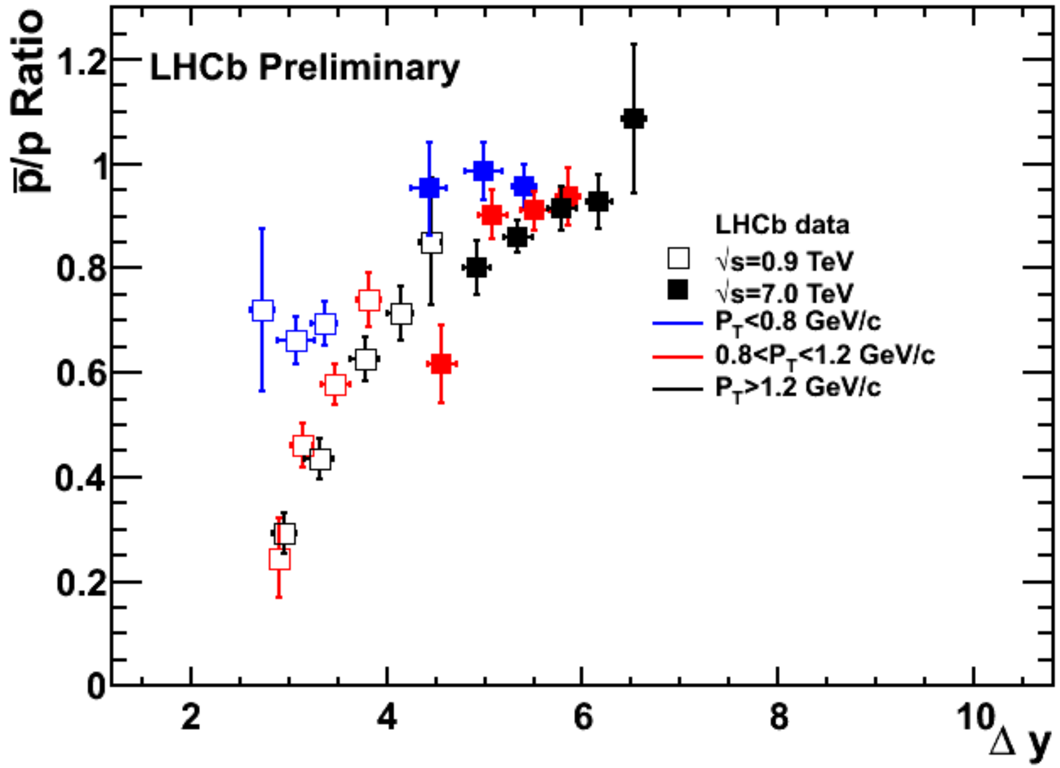
Use samples to study baryon transport by measuring ratio of $\bar{p}/p$ in kinematic bins

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

Large range in Δy covered.

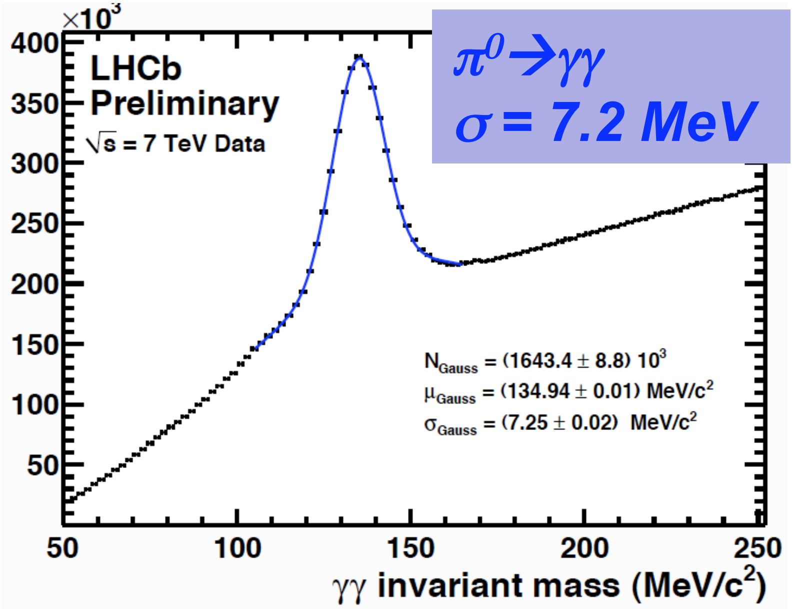
Some p_t dependence observed.

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



PID with Calorimeter

(Identification of electrons and photons)

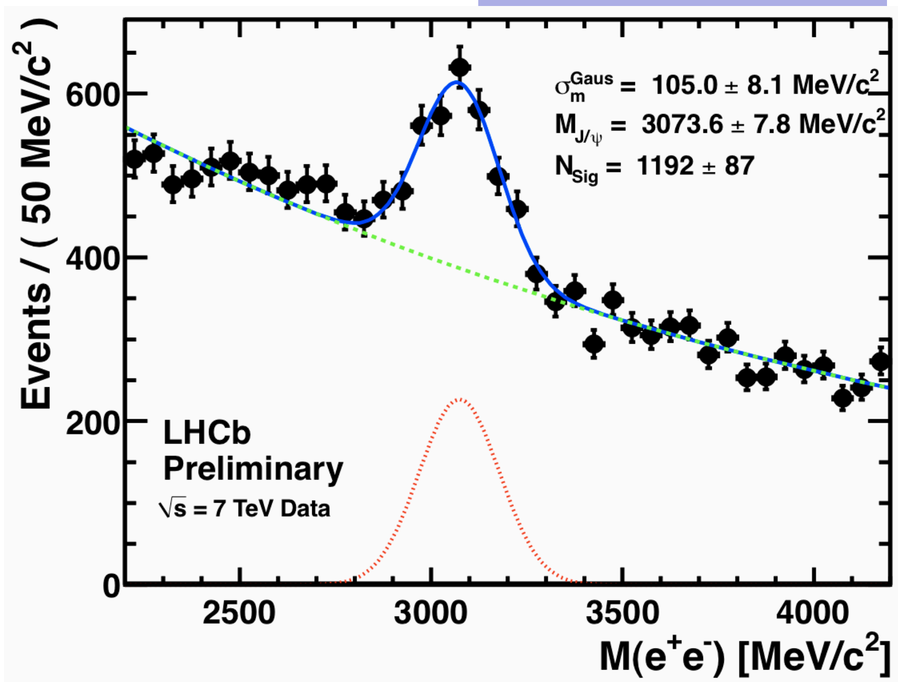


$\pi^0 \rightarrow \gamma\gamma$
σ = 7.2 MeV

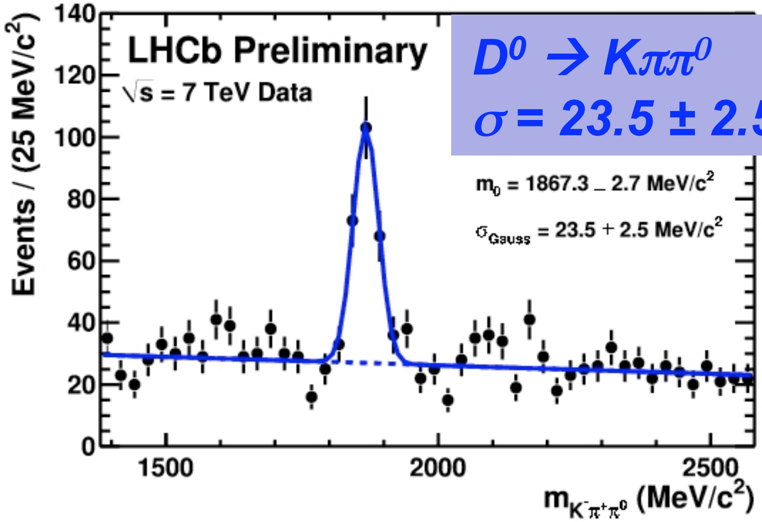
ECAL is calibrated to 2% level
π^0 resolution is better than expected

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

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



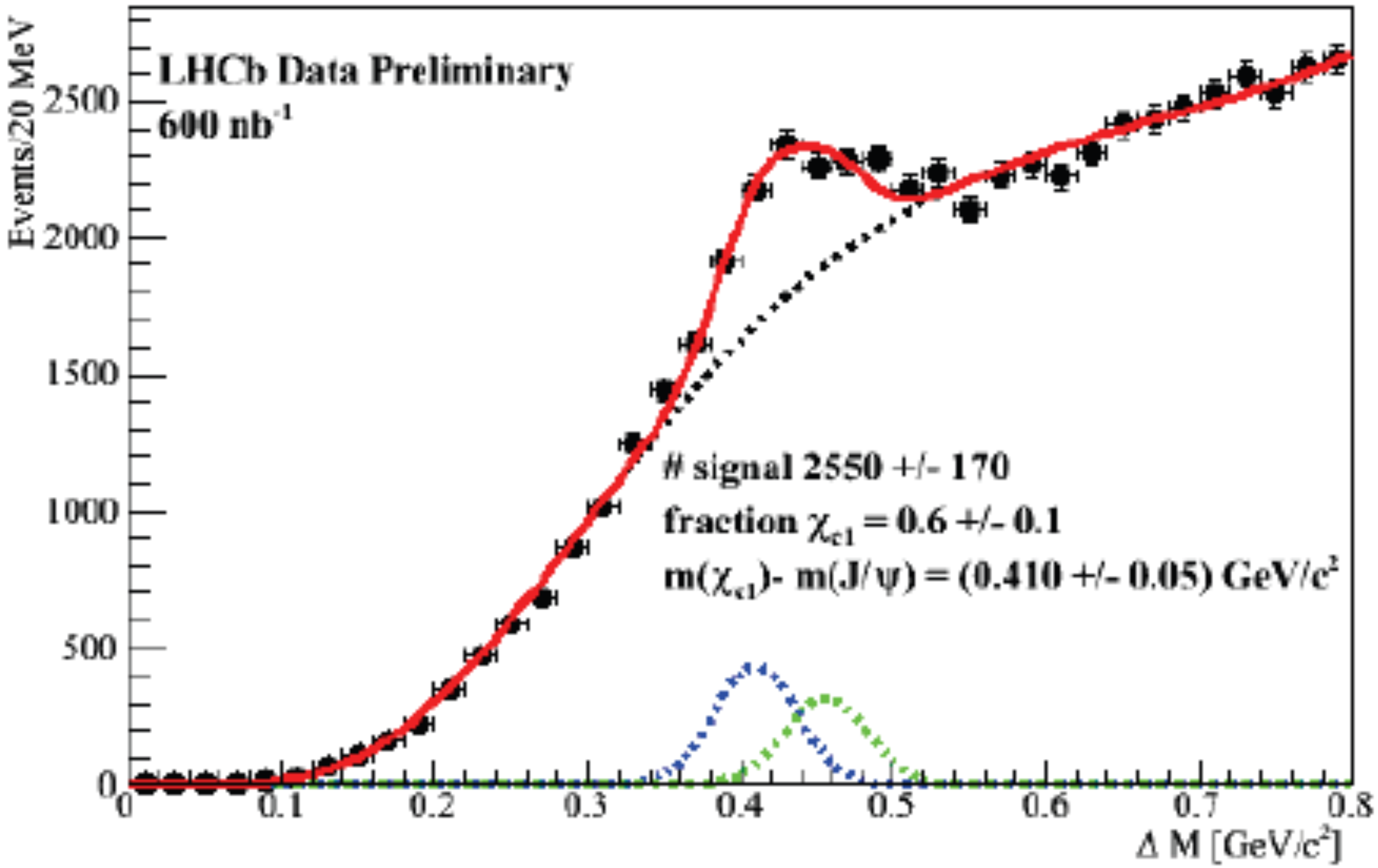
Reconstruction of D decays in the final states with neutrals looks encouraging !



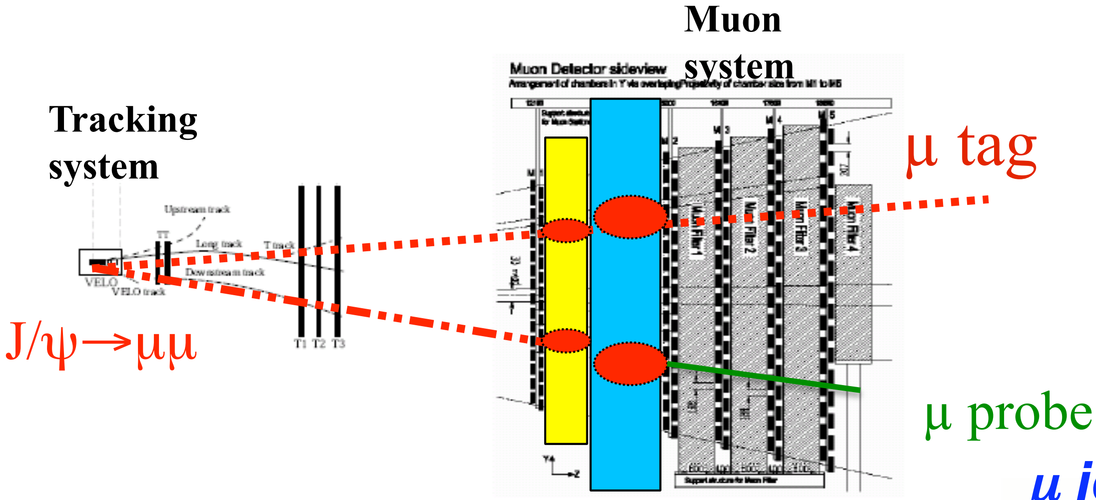
$D^0 \rightarrow K\pi\pi^0$
σ = 23.5 ± 2.5 MeV

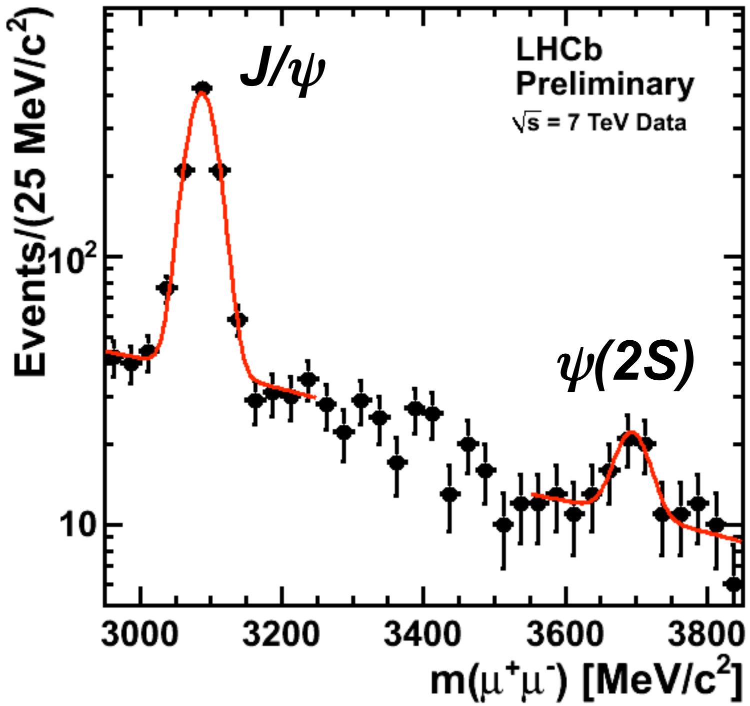
χ_c *signal with LHCb calorimeter*

σ fixed to 27 MeV (MC value)

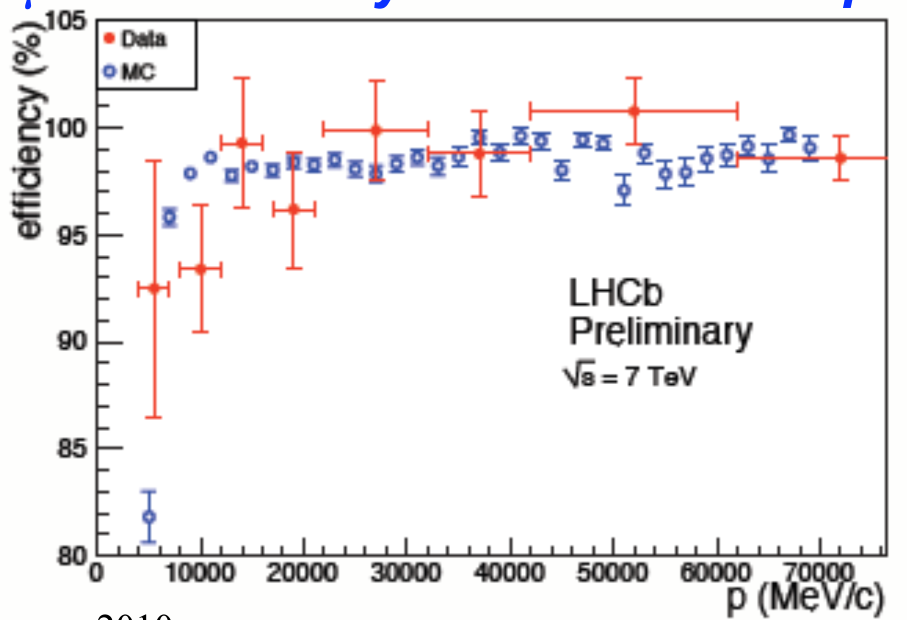


PID with MUON





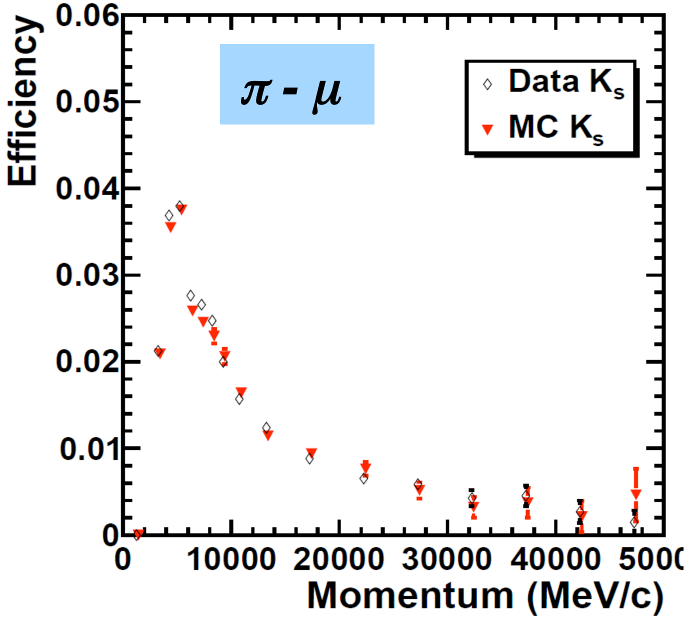
μ id. efficiency as a function of p

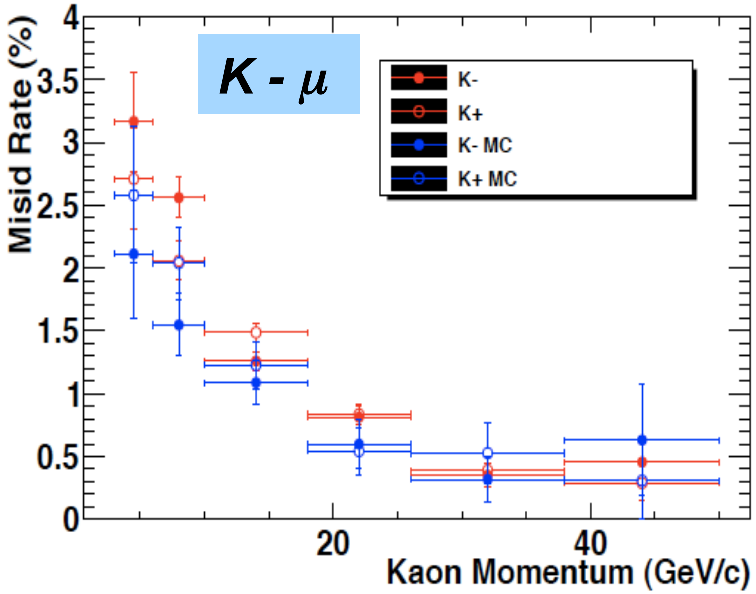


$\varepsilon(\mu) = (\,97.3 \pm 1.2\,)\%$

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



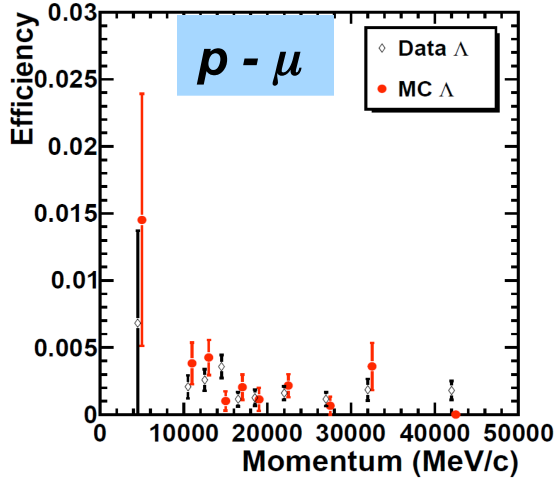


π,K→μ dominated by decays in flight

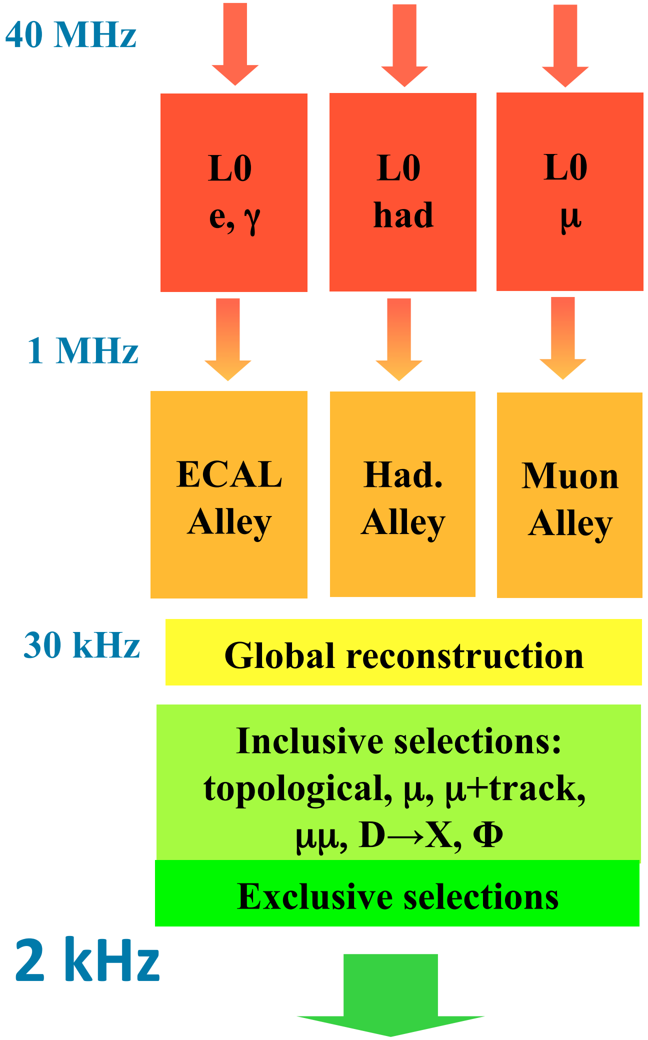
$\varepsilon_{K,\pi-\mu} < 1\%$
for p > 20 GeV

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

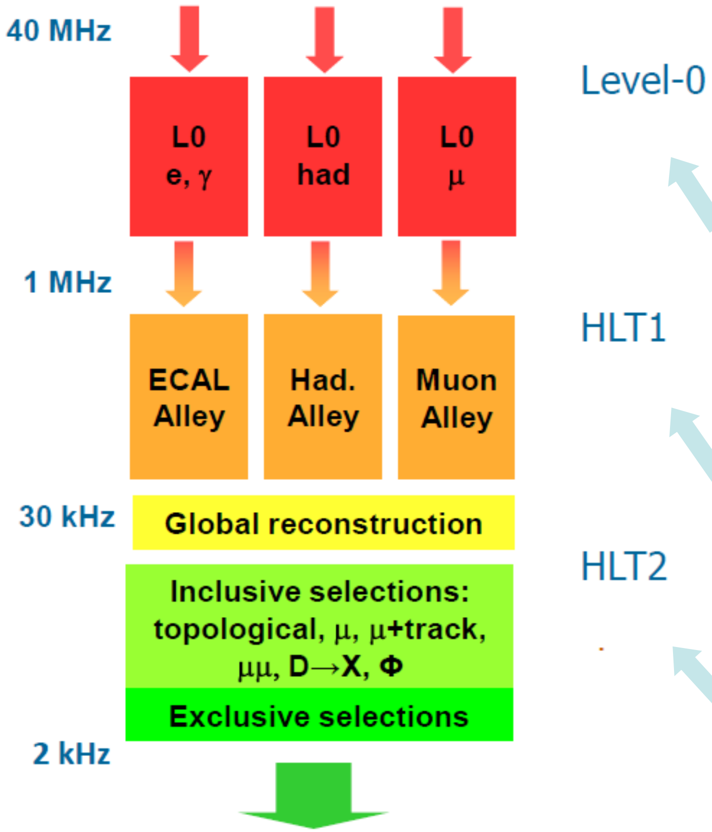
HLT2

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

At LHCb design luminosity ***(2 x 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%.

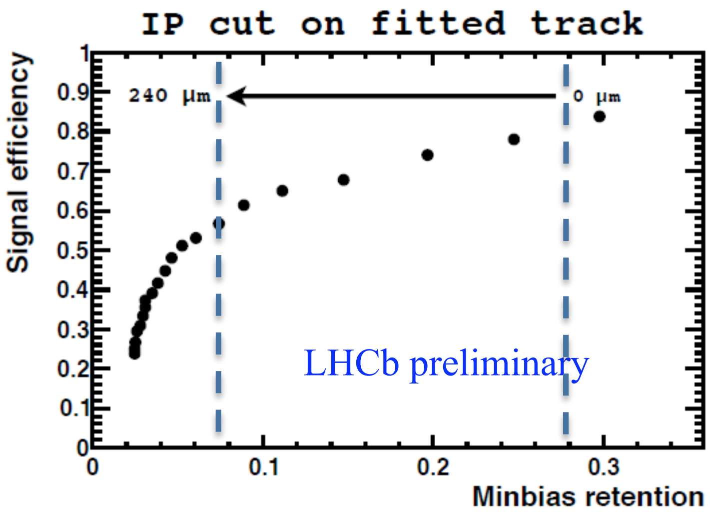
Trigger Efficiencies

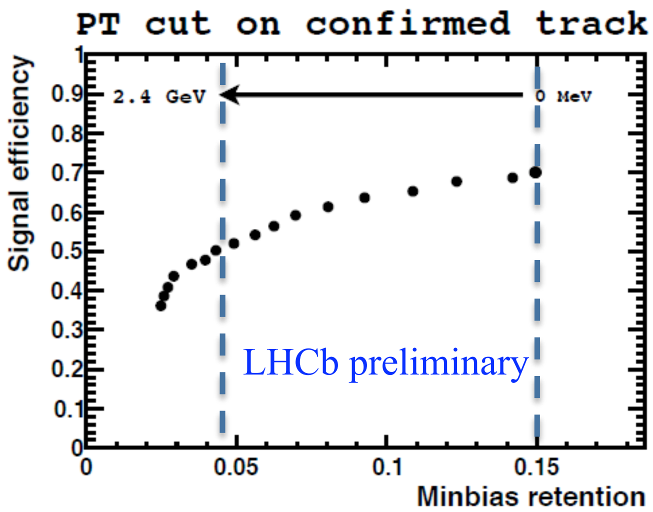
Take D^*, $D^0 \to K\pi$ signal collected in minimum bias events
&
Evaluate L0*HLT1 performance with 2010 low luminosity trigger settings

good agreement with MC

$Eff\text{-}trig_{L0*HLT1}(data) = 60 \pm 4$ %
MC expectation = 66 %

Performance of single-hadron HLT1 line on data

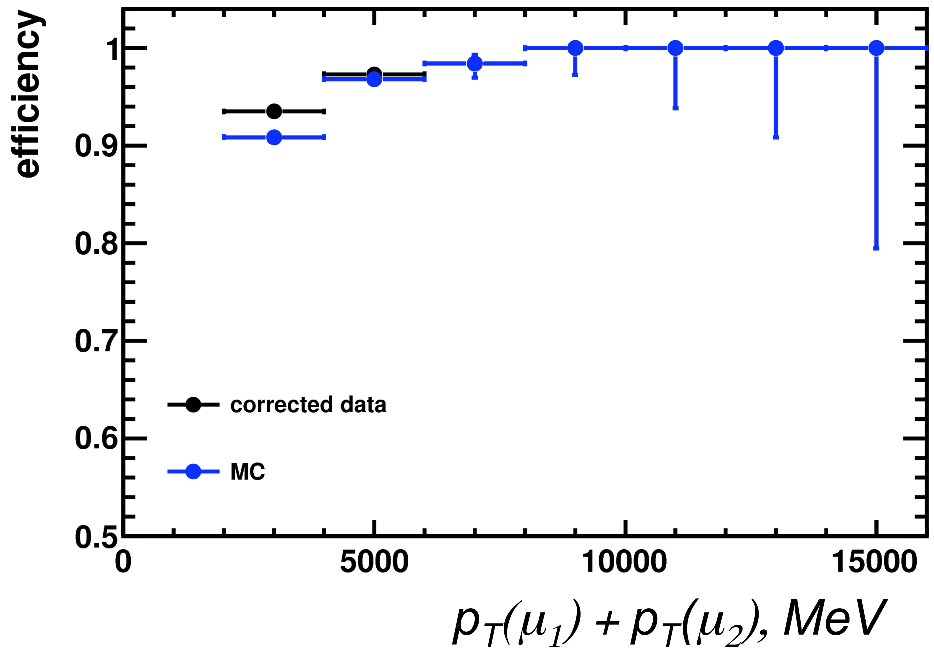




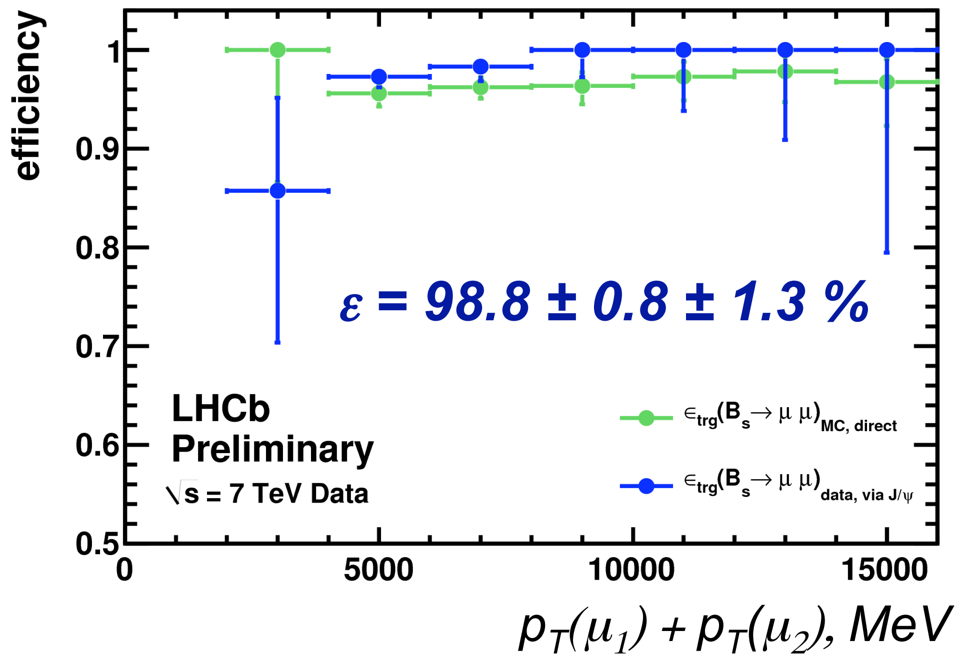
Trigger Efficiencies

- *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

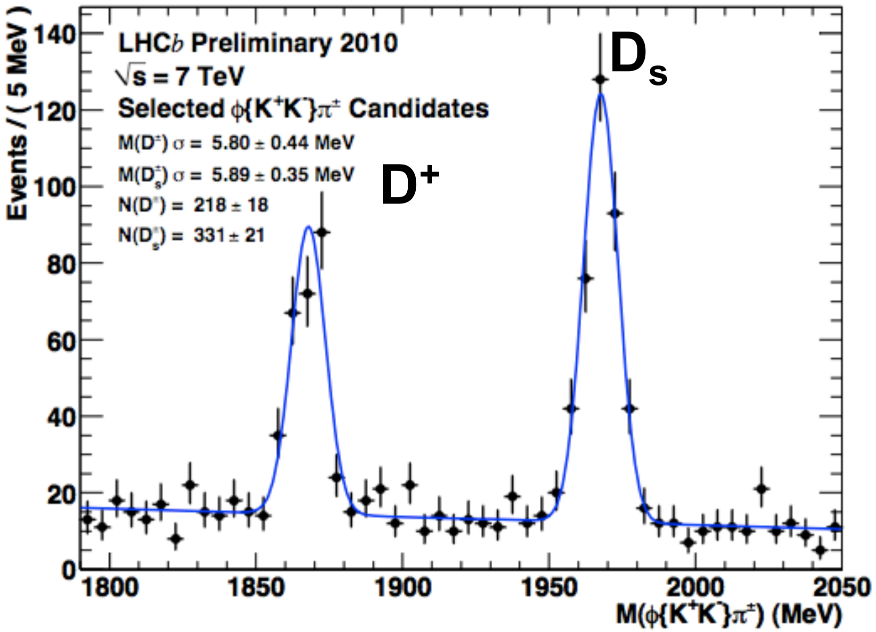
- *Precision is dominated by systematic error on the luminosity measurement and tracking efficiency*
- *Used small sub-sample of collected data L ≤ 14 nb^{-1} : ~ 2 nb^{-1} with unbiased trigger and ~12 nb^{-1} with low HLT thresholds*
- *Luminosity determined using Van der Meer scan and beam gas events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

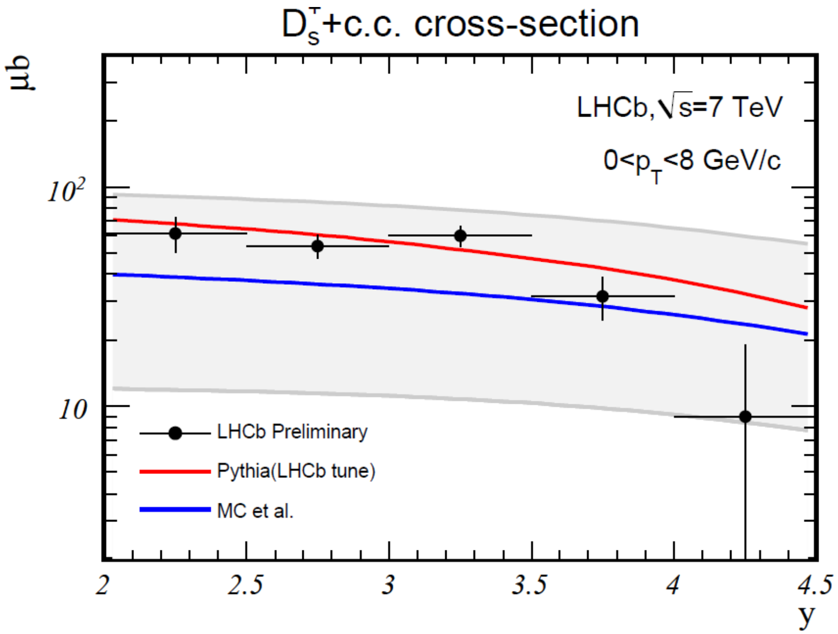
Open charm cross-sections (D^*, D^0, D^+, D_s) @ $\sqrt{s}$ = 7 TeV

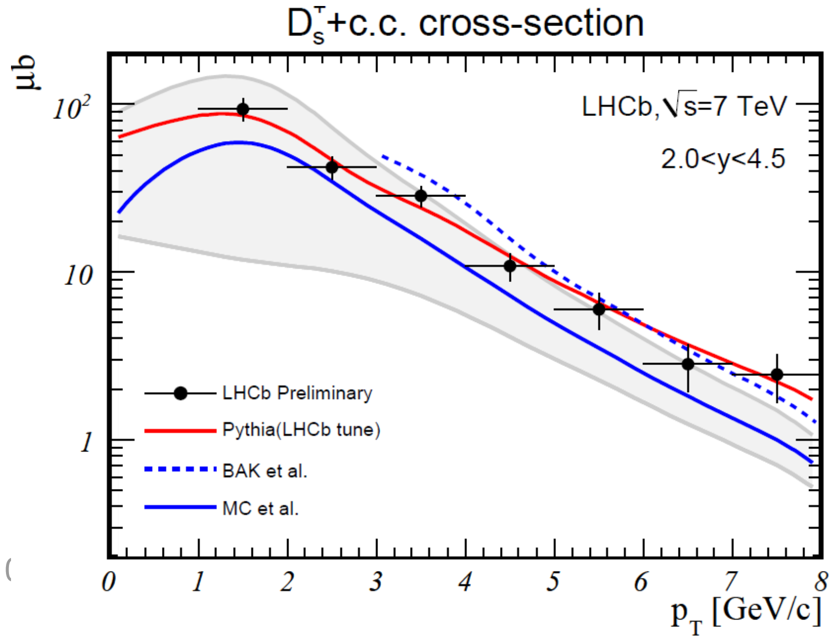
Open charm production cross-sections are being studied in forward region $2 < y < 5$ for D^*, D^0, D^+ and D_s.

As expected charm production is huge !!!

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

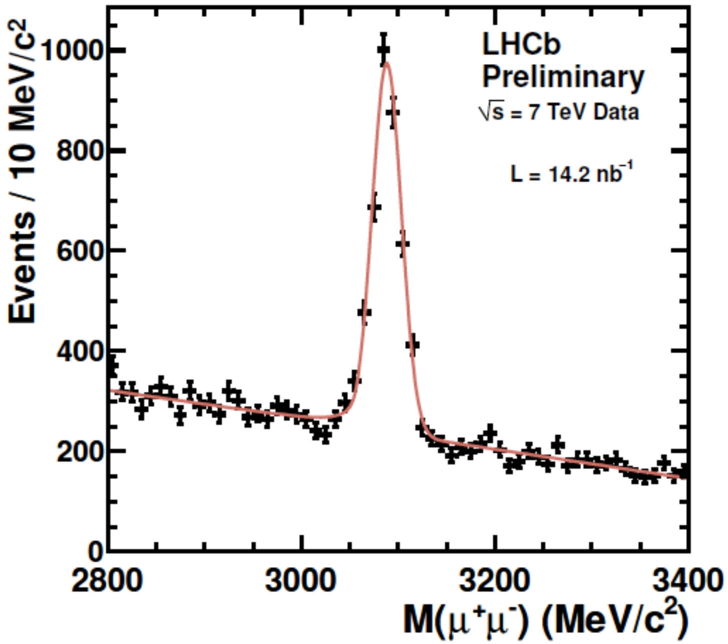






IP distribution used to separate prompt from secondary $D^{0,+}$, D_s candidates

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



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):

$N_{signal} = 2872 \pm 73$

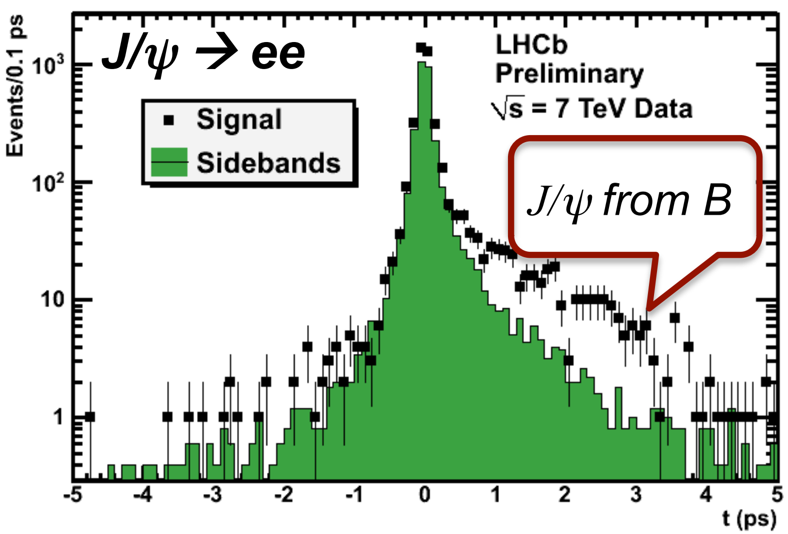
$M = 3088.3 \pm 0.4$ MeV/c^2

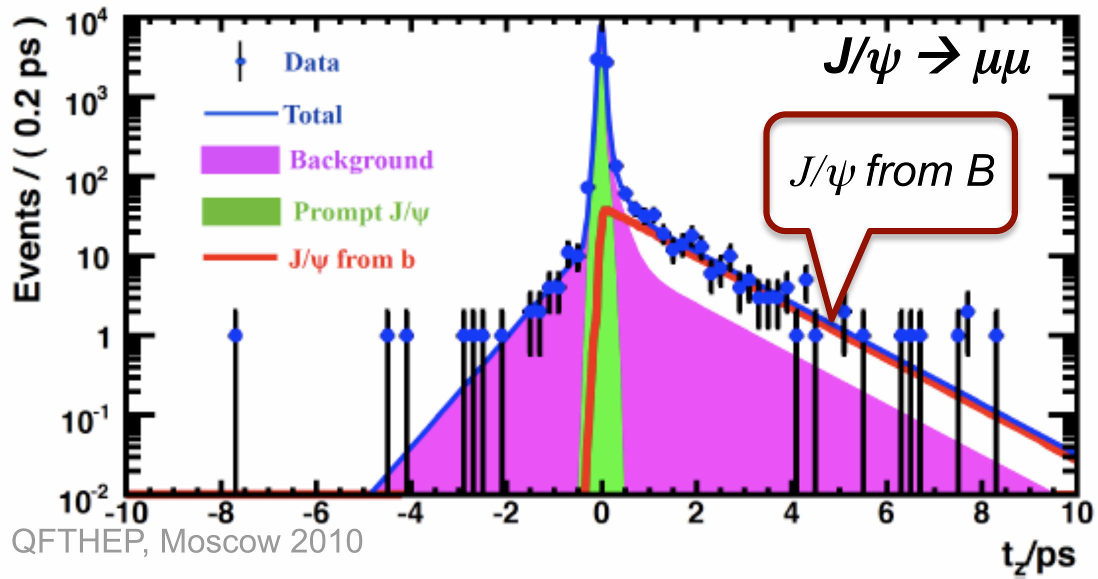
$\sigma = 15.0 \pm 0.4$ MeV/c^2

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

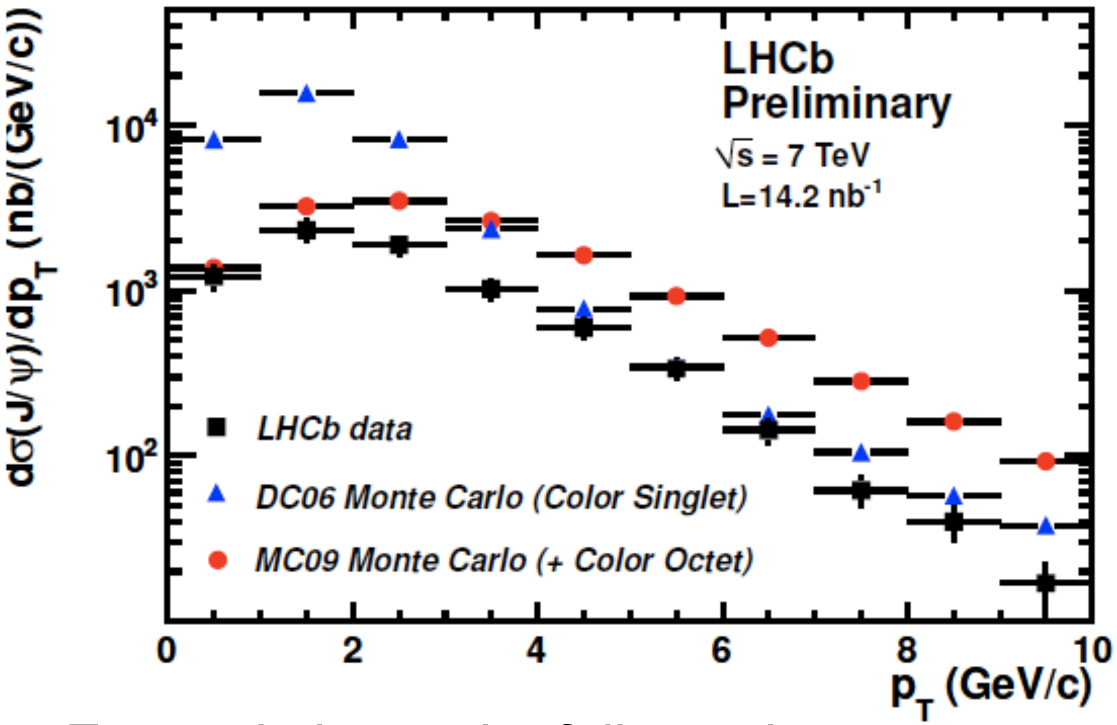




Prompt J/ψ and $b\bar{b}$ cross-sections @ $\sqrt{s}$ = 7 TeV

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

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



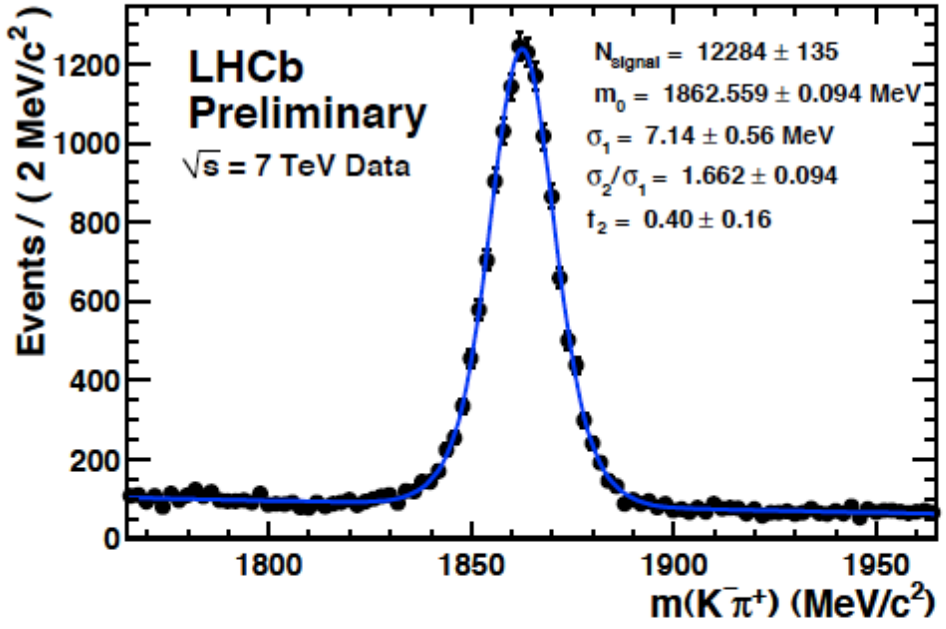
Data favour neither color singlet nor color octet model !!!

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

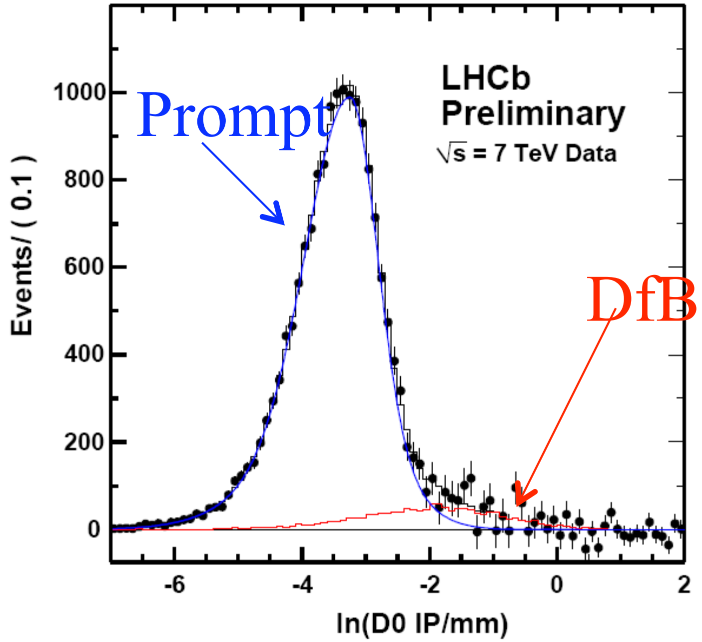
σ(pp → $b\bar{b}$X) = $319 \pm 24 \pm 59$ μb

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

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



$L \sim 3\ nb^{-1}$

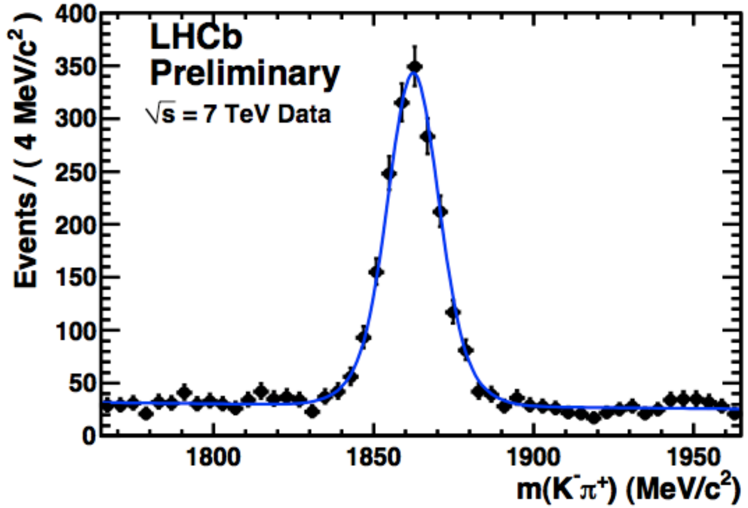


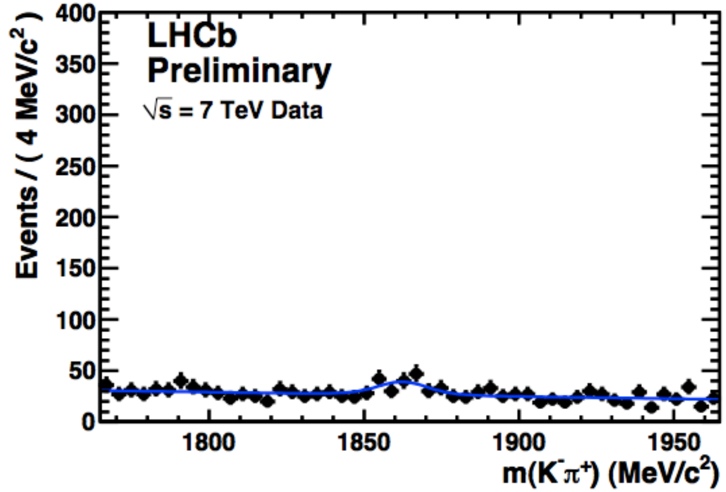
Impact Parameter (IP) D distribution used to separate prompt D and D produced in B decays (DfB)

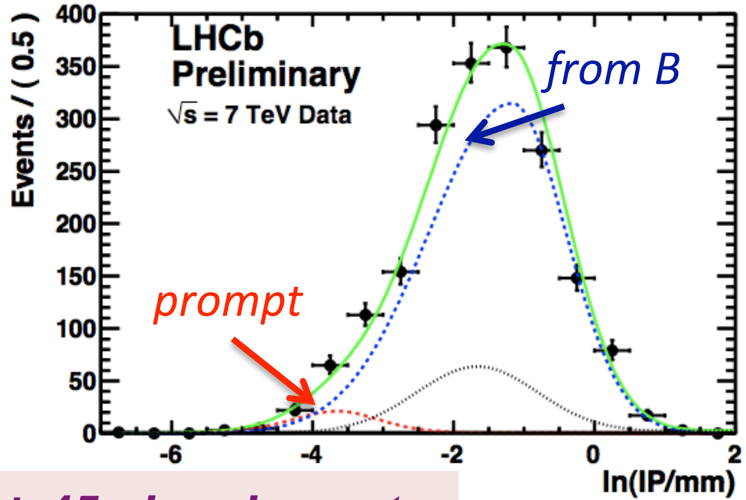
B → $D^0 X\mu\nu$ with $D^0 \to K\pi$

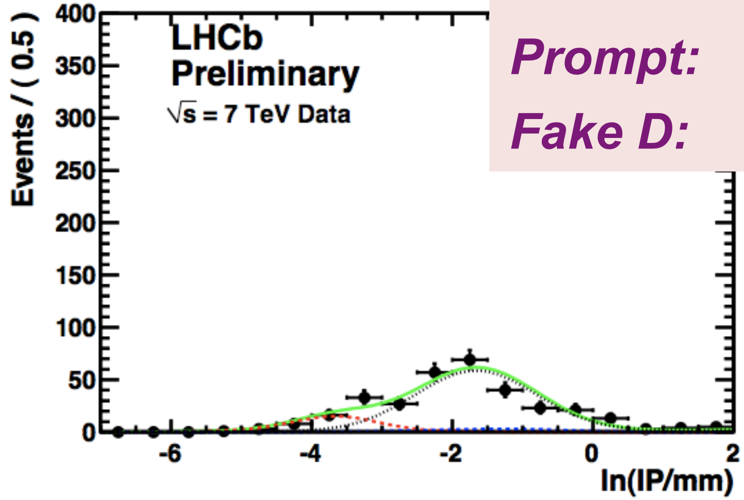
Correlate D^0 with the muon of the right (wrong) sign

Right sign | **L ~ 100 nb^{-1}** | **Wrong sign**









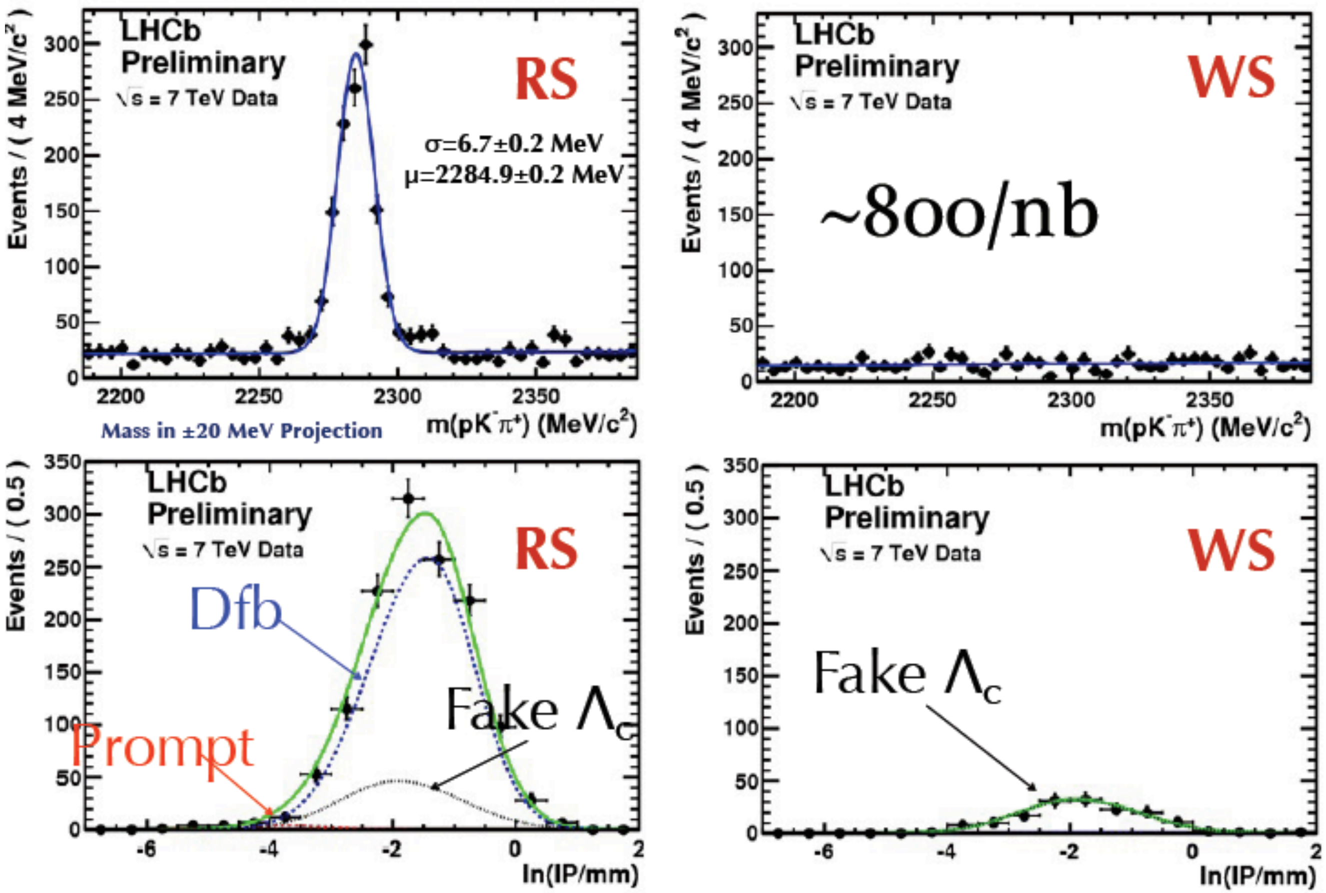
DfB: 15 ± 16
Prompt: 51 ± 10
Fake D: 263 ± 8

1540 ± 45 signal events with D from B

Same technique can be exploited to reconstruct $b \rightarrow D^{+} / D_s / \Lambda_c X \mu^- \nu$ decays

Essential information for determination of b - fragmentation fractions

Example: $\Lambda_b^o \rightarrow \Lambda_c^+ X \mu^- \nu$



Semileptonic b Yields @ 0.8 pb^{-1}

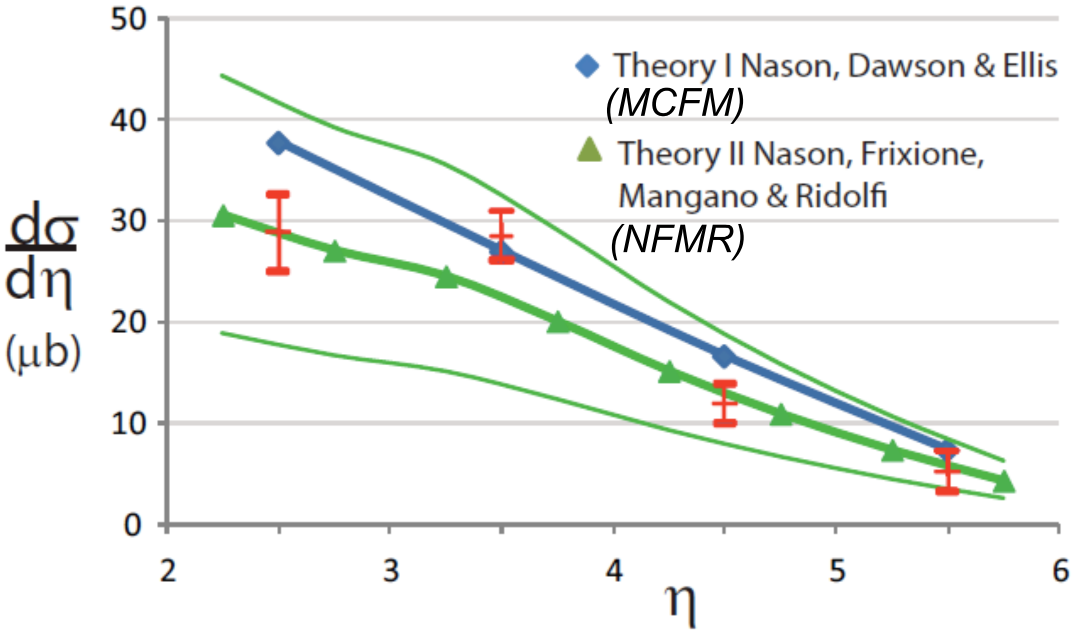
Fit yields not efficiency corrected.

	Yields	Dfb	Prompt	Mass SB
D+	**RS**	**3649±82**	**209±29**	**2059±24**
	WS	28.2±30	92±15	1371±18
	RS + nu reco	2774±62	0.0±4	826±15
Ds	**Inclusive RS**	**964±52**	**0±1**	**1468±19**
	Inclusive WS	50±32	19±24	920±15
	Inclusive + nu reco	767±38	0±5	711±13
	phi+K*(892) (nu reco)	562±26	0±3	111±5
Λc	**RS**	**1100 ± 38**	**14 ± 7**	**231 ± 8**
	WS	3 ± 10	**0 ± 4**	160 ± 6

$b\bar{b}$ 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^{0}X$\mu\nu$ gives

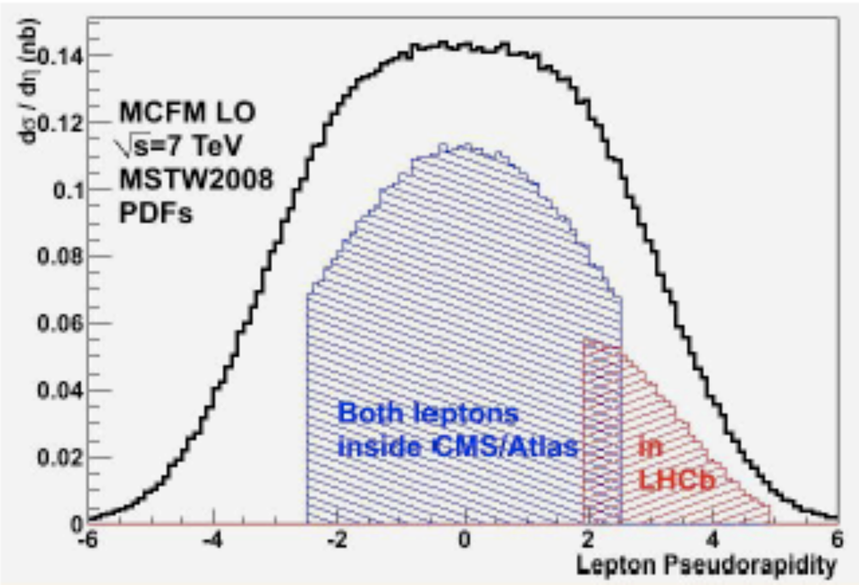
σ(pp → bbX) = 292 ± 15 ± 43 μb
(assuming LEP frag. fractions)

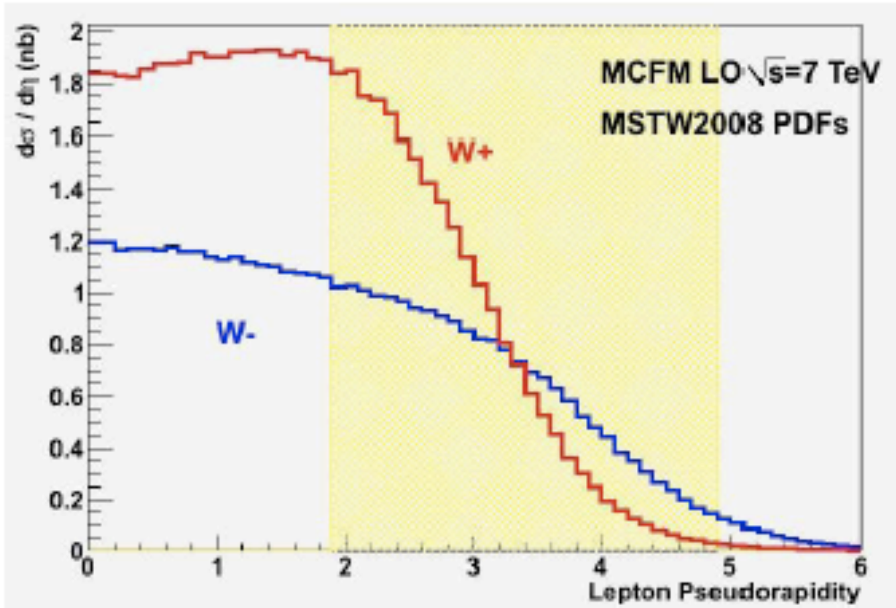
Theory:
MCFM 332 μb, NFMR 254 μb

Prospects for 2010-2011 Physics Run

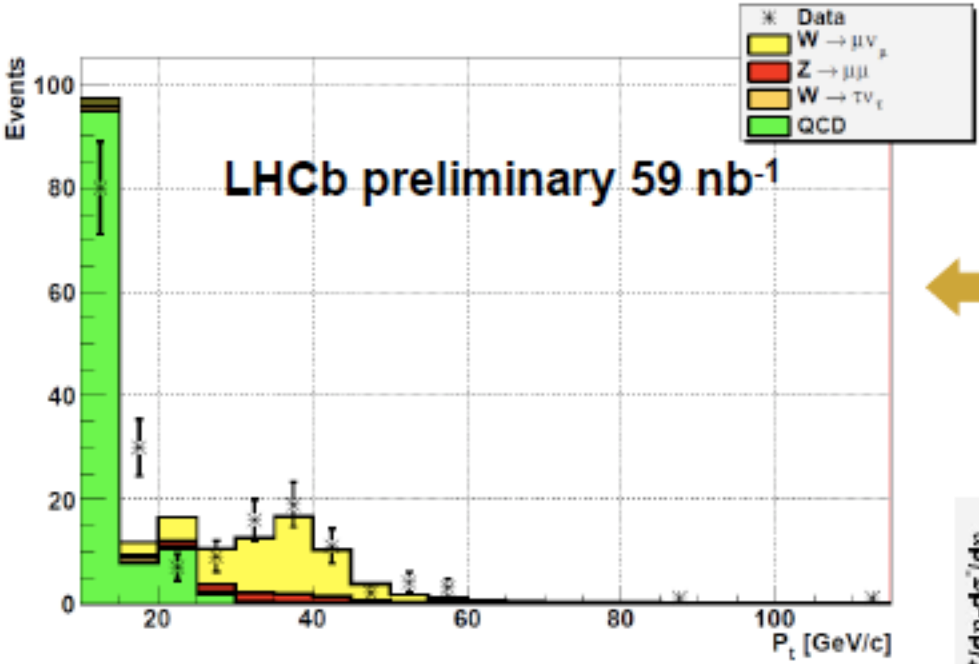
Electroweak physics at LHCb

Unique η coverage of LHCb allows for very interesting W,Z production studies such as switch-over in W^+ / W^- ratio in acceptance





Observation of first W bosons in LHCb

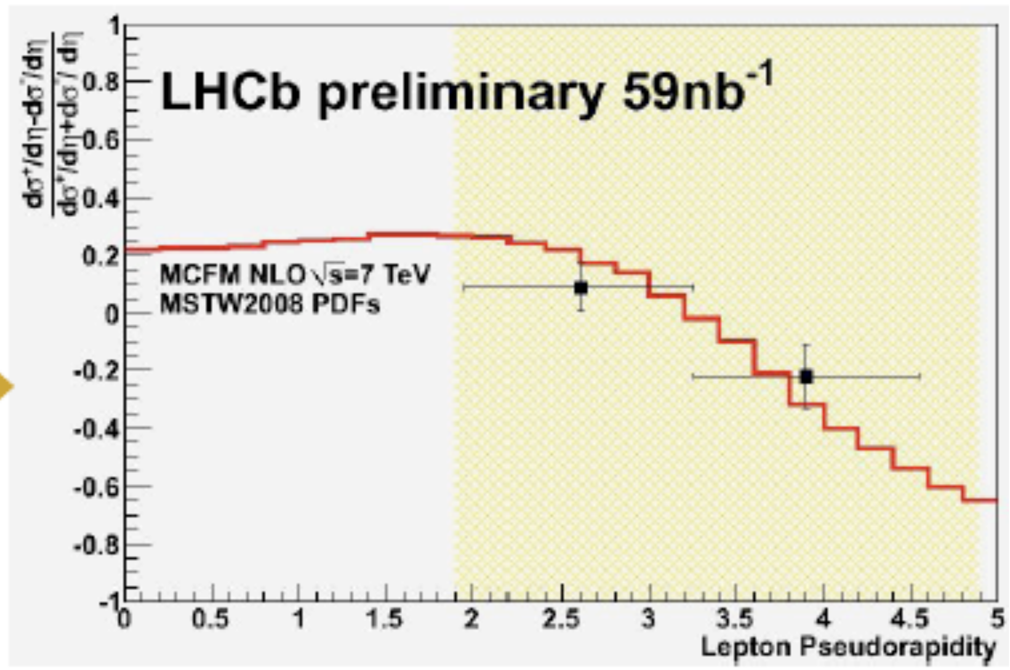


W events being accumulated

μ p_t spectrum after pre-selection

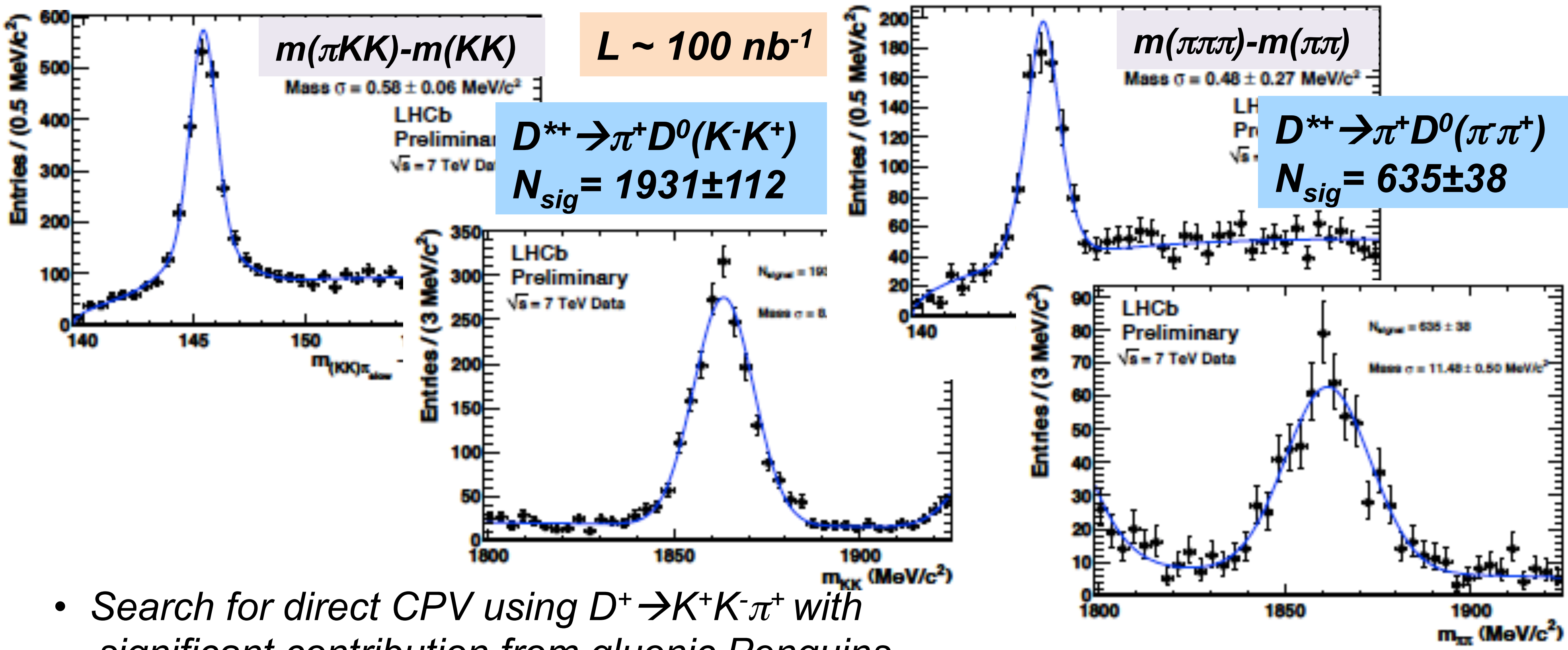
Already able to probe asymmetry between W^+ and W^- productions

(Stat errors only)



Charm of beauty experiment

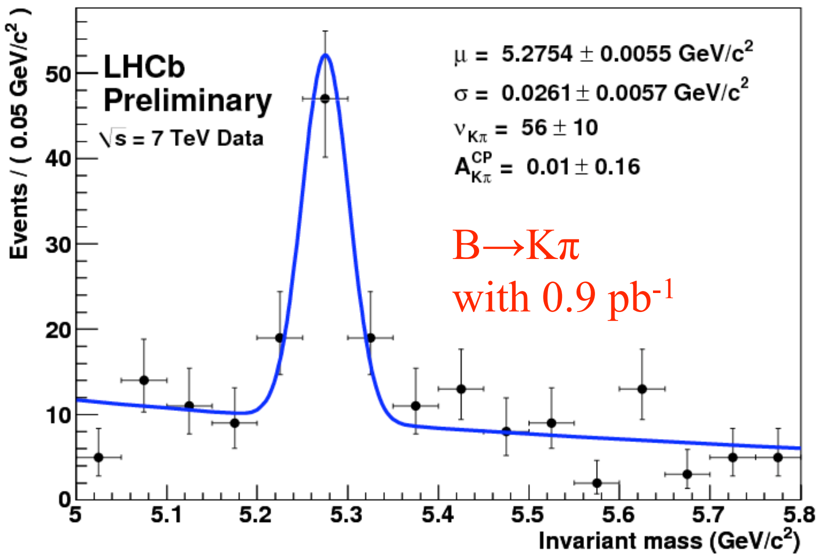
- *Excellent prospects for CPV studies; sensitivity < 0.1% is feasible at LHCb with first 100 pb^{-1} !!! Expect several million tagged $D^0 \rightarrow KK$ (BELLE 540 fb^{-1} analysis uses ~10^5 tagged $D^0 \rightarrow KK$ giving stat. precision on y_{CP}=0.32% and on A_Γ=0.30%)*

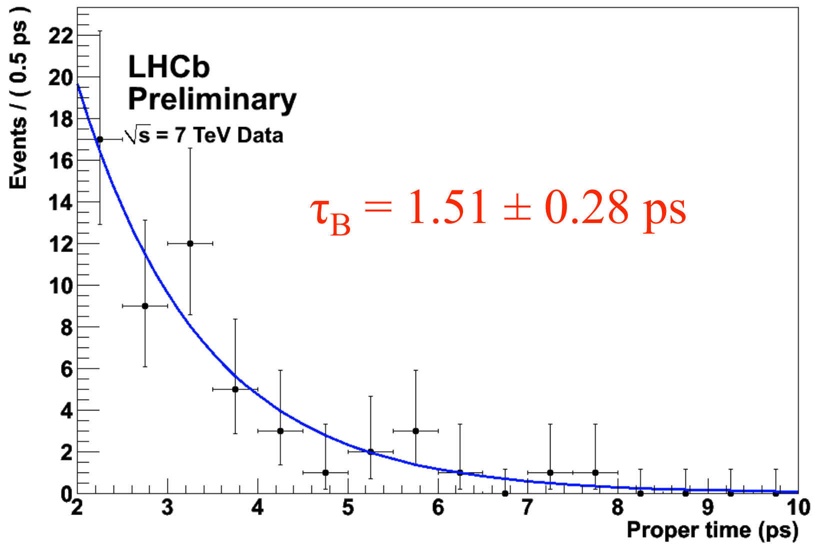


- *Search for direct CPV using $D^+ \rightarrow K^+K^-\pi^+$ with significant contribution from gluonic Penguins. Again LHCb can be confident in collecting several million events in 100 pb^{-1} , which is an order of magnitude increase on B-factories samples*

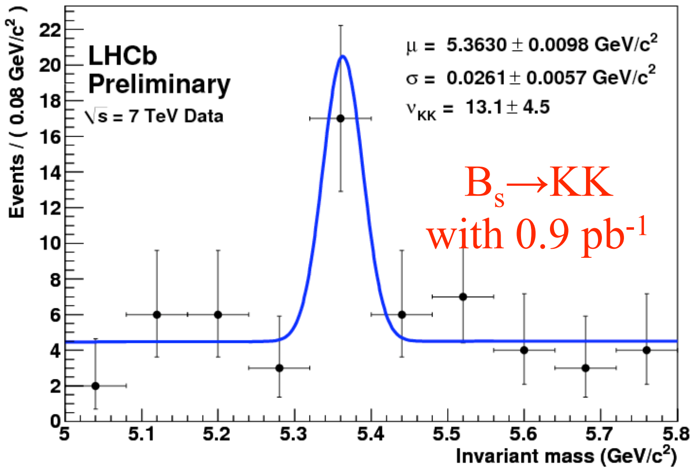
- *Similar opportunities in many other D physics topics, e.g. search for $D^0 \rightarrow \mu\mu$*

Study of $B_{(s)} \rightarrow hh'$ ($h' = \pi$, K, p) at LHCb sensitive to CKM angle γ via Penguin loops





Excellent mass resolution demonstrated. Yield so far agrees with expectations

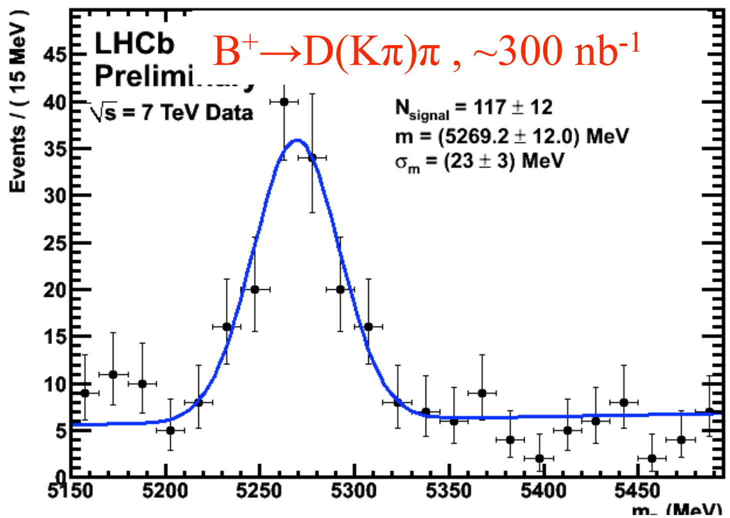


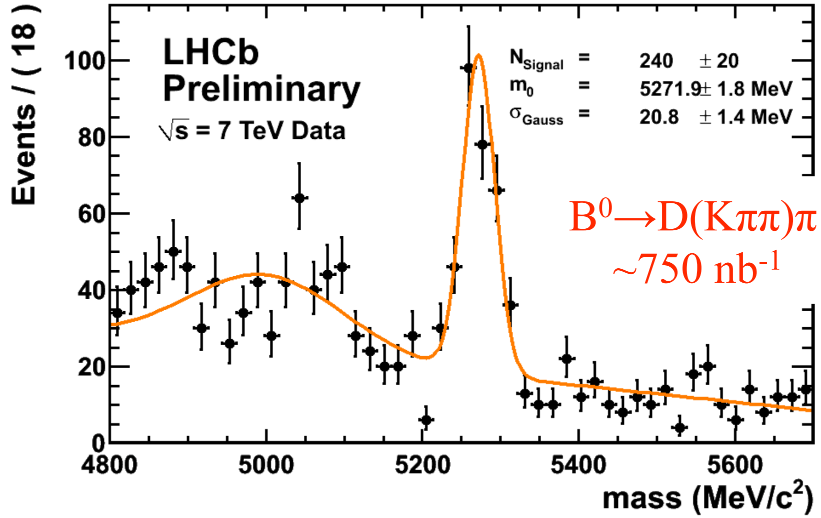
With a few 100 pb^{-1} the sample size will become largest in the world in both B^0 and B_s decays

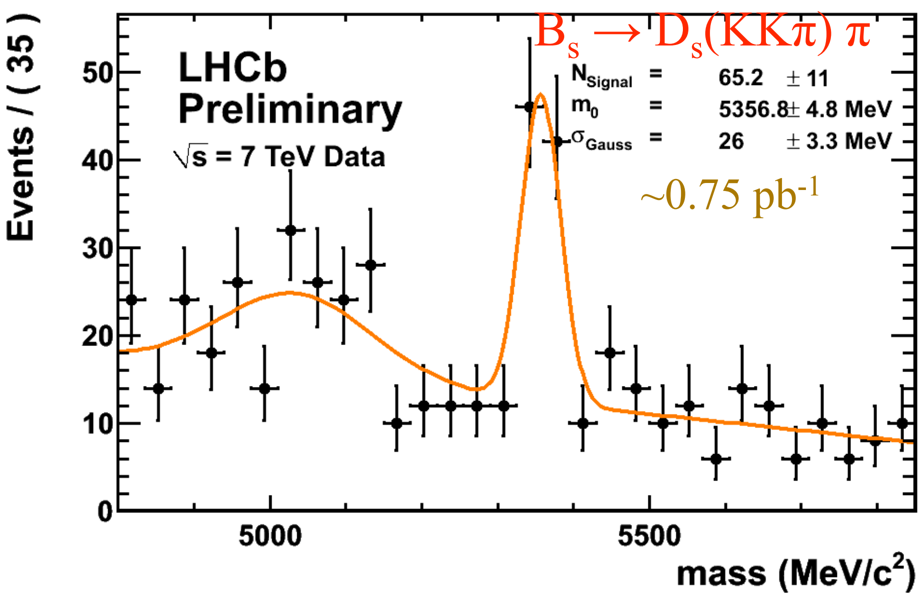
Multibody hadronic final states in $B_{(s)} \rightarrow D_{(s)}K$ is the road to measure γ in trees

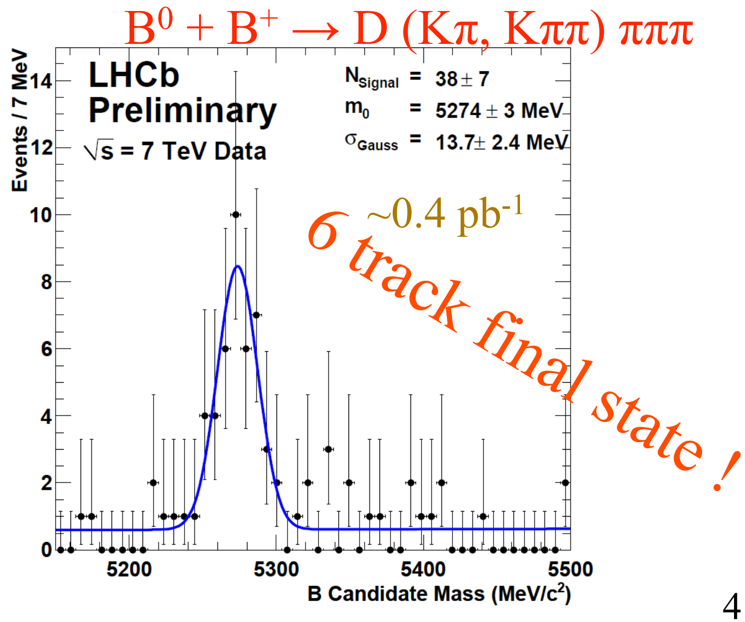
First signals are observed at ~ expected rate

→ Opportunity for better accuracy in γ with 2010-2011 data







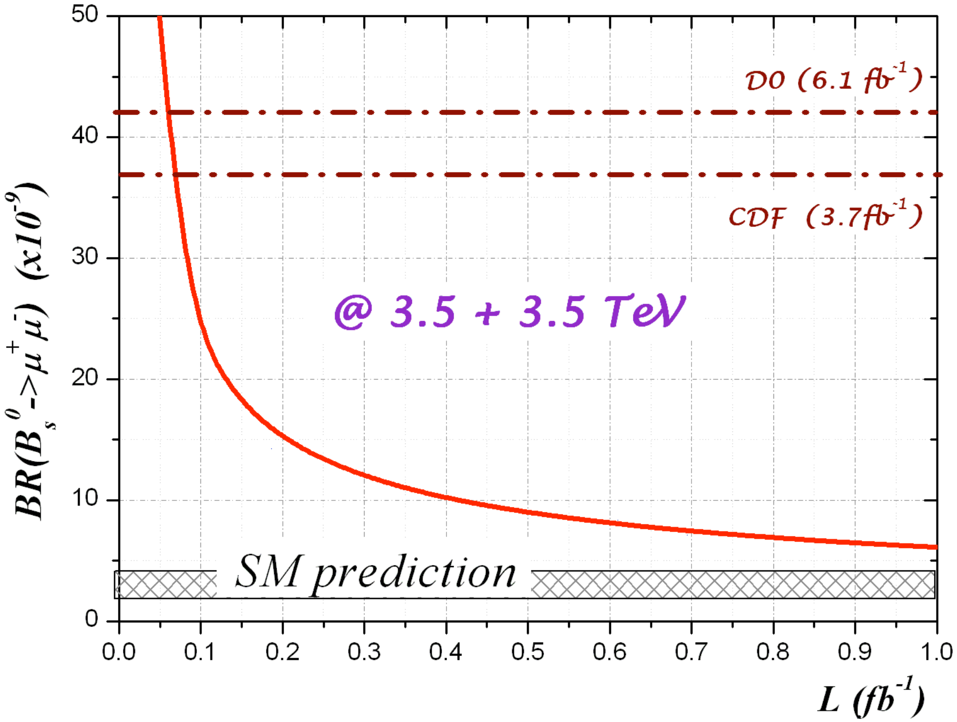


2010

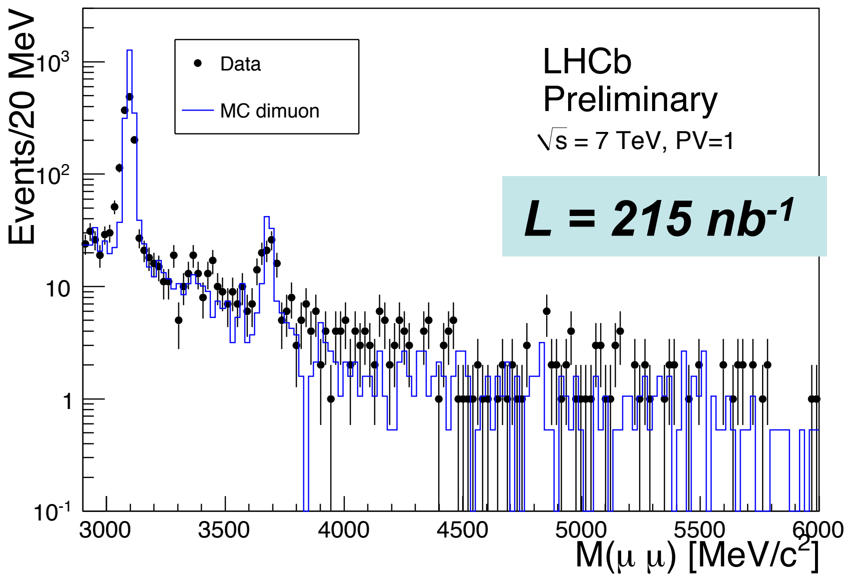
$B_s \to \mu\mu$

- Super rare decay in SM with well predicted $BR(B_s \to \mu\mu) = (3.2\pm0.2)\times10^{-9}$
  $BR(B_d \to \mu\mu) = (1.1\pm0.1)\times10^{-10}$
- 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}.

Exclusion limit @ 90% C.L.



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



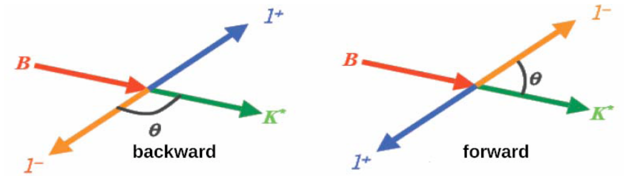
Exclusion of SM enhancement up to $BR(B_s \to \mu\mu) \sim 7\times10^{-9}$ should be possible with $L\sim1$ fb^{-1}

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

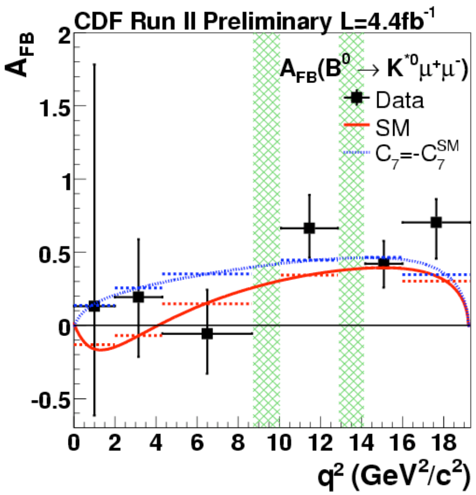
$B \rightarrow K^*\mu\mu$

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

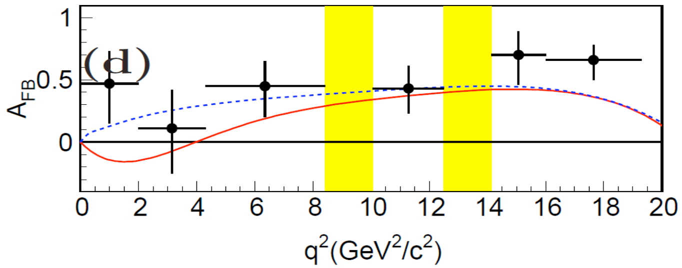
$$A_{FB}\left(s = m^2_{\mu^+\mu^-}\right) = \frac{N_F - N_B}{N_F + N_B}$$



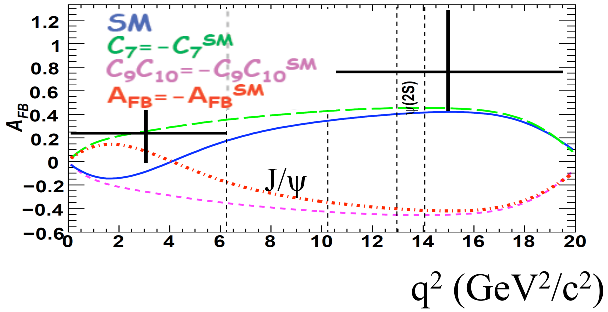
CDF: ~100 $K^*l^+l^-$ events



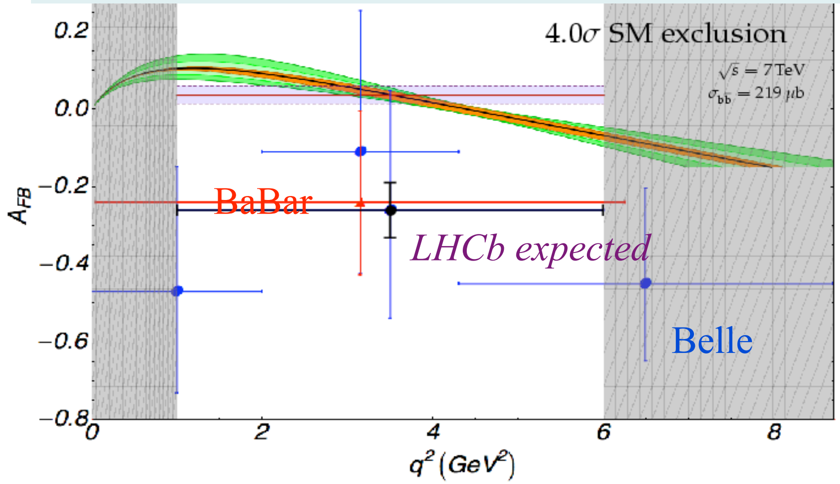
Belle: ~250 $K^*l^+l^-$ events



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



Estimated error in the most sensitive bin assuming BELLE central value



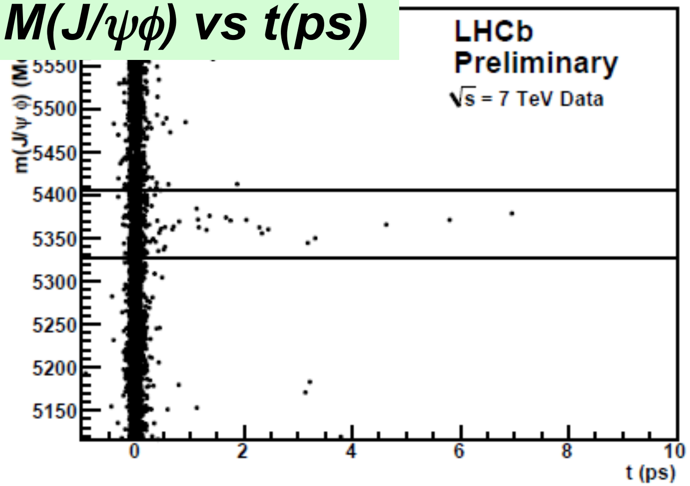
Flipped sign in asymmetry definition

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 $B_s \rightarrow J/\psi\phi$

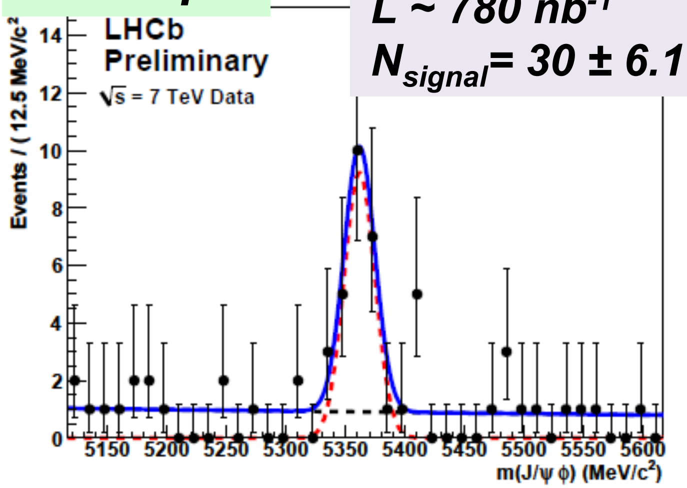
$\phi_s^{J/\psi\phi}$ = -2β_s is very small and precisely predicted in SM
→ Very sensitive to NP !!!

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



t > 0.3 ps

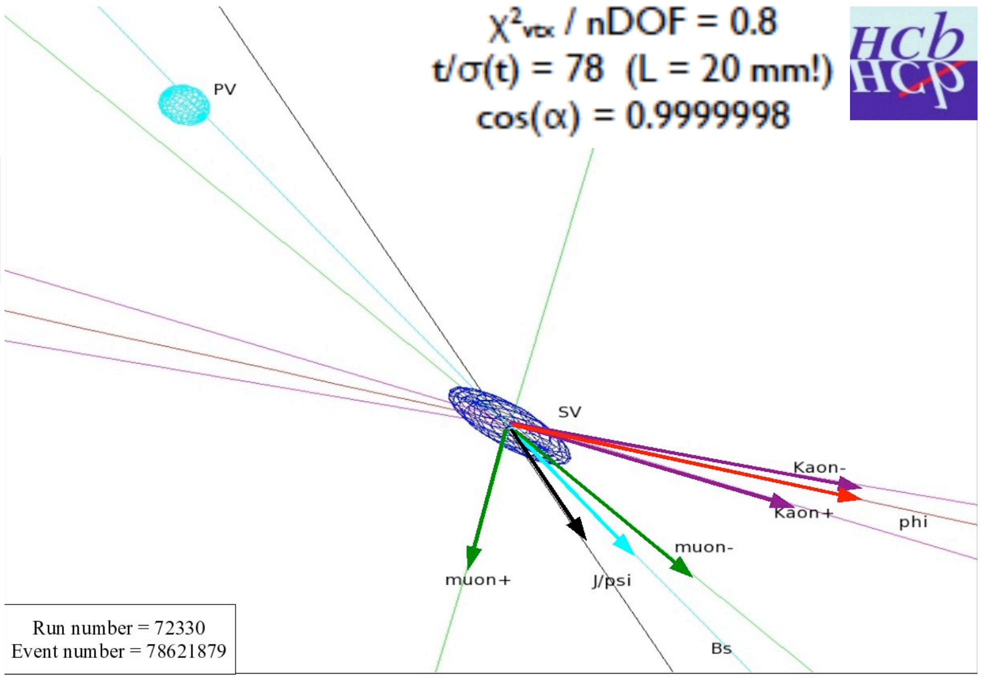
L ~ 780 nb^{-1}
N_{signal}= 30 ± 6.1



Number of signal events as expected

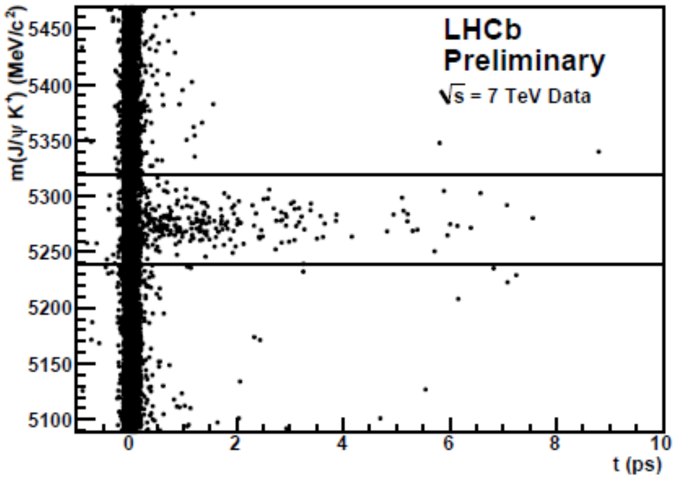
$m(\mu\mu)$ = 3072 MeV/c²
$m(KK)$ = 1020 MeV/c²
$m(\mu\mu KK)$ = 5343 MeV/c²

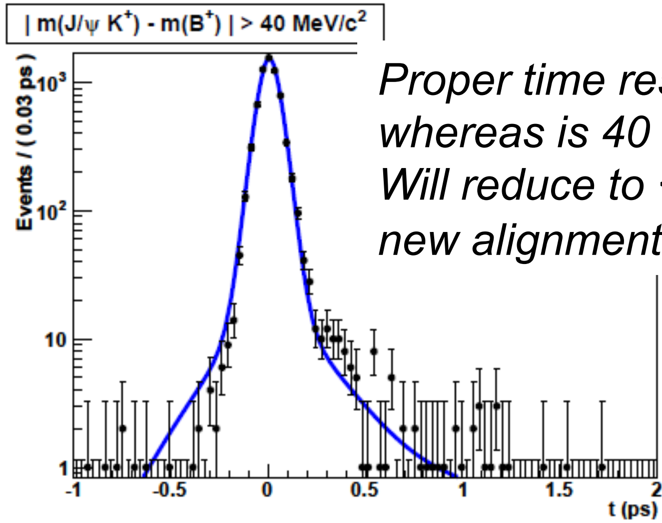
χ^2_{vtx} / nDOF = 0.8
$t/\sigma(t)$ = 78 (L = 20 mm!)
$\cos(\alpha)$ = 0.9999998



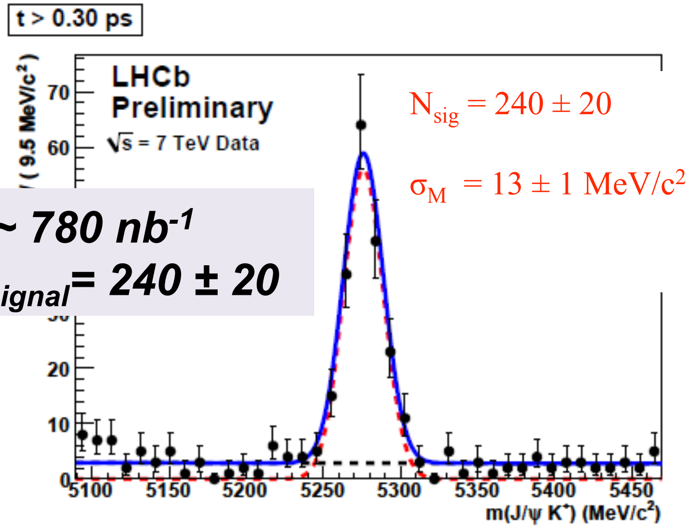
$B \rightarrow J/\psi K^+$ & proper time resolution

Unbinned likelihood fit of m and t distributions

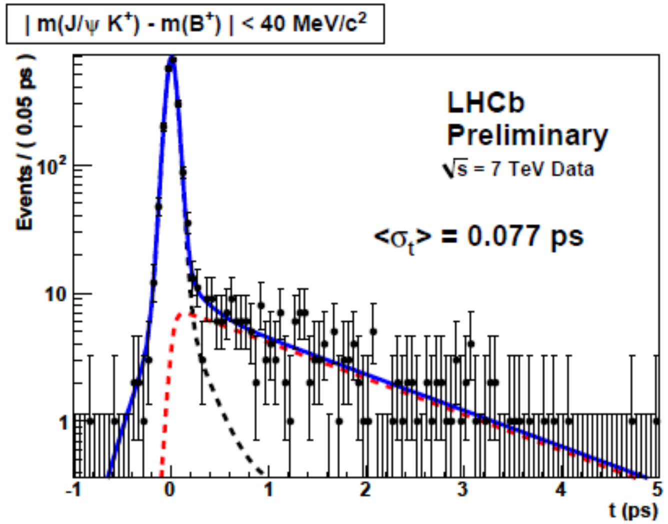




Proper time resolution 77 fs, whereas is 40 fs in MC: Will reduce to < 60 fs with new alignment



$L \sim 780\ nb^{-1}$
$N_{signal} = 240 \pm 20$



Observed number of signal events consistent with MC expectations

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

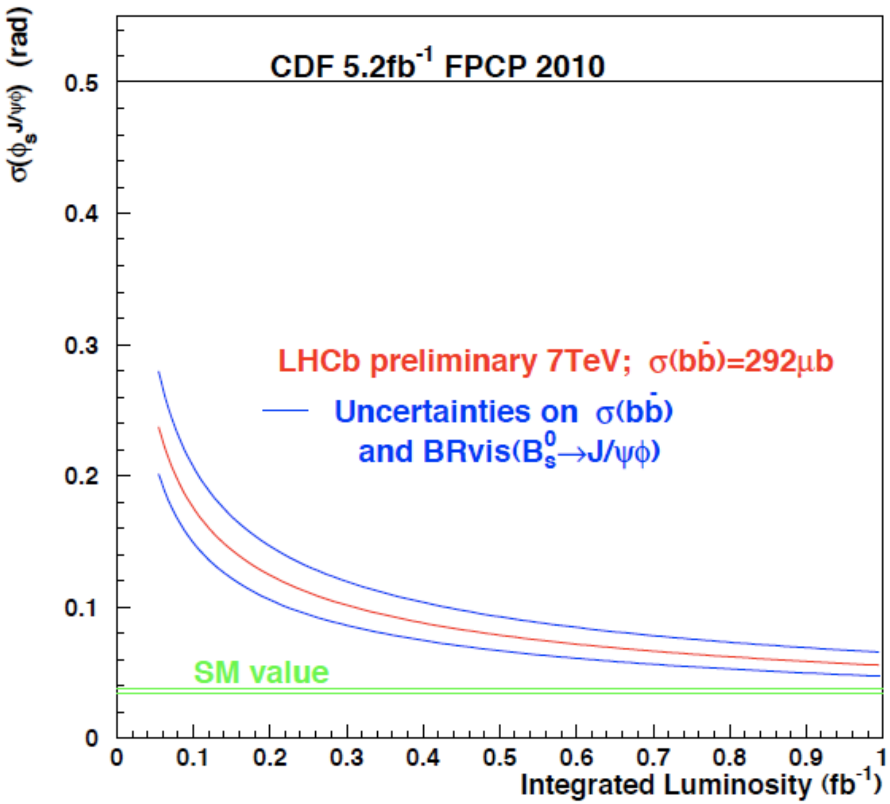
Expected sensitivity:

MC performance:

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

- $<\sigma_t>$ = 0.040 ps. Present resolution worse in data but sufficient for $\Delta m_s \sim 17.7/ps$ (will add 40% 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)*

  - ***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}*

- ***$B_s \rightarrow \mu\mu$ and $B_s \rightarrow J/\psi\phi$ 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*

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.

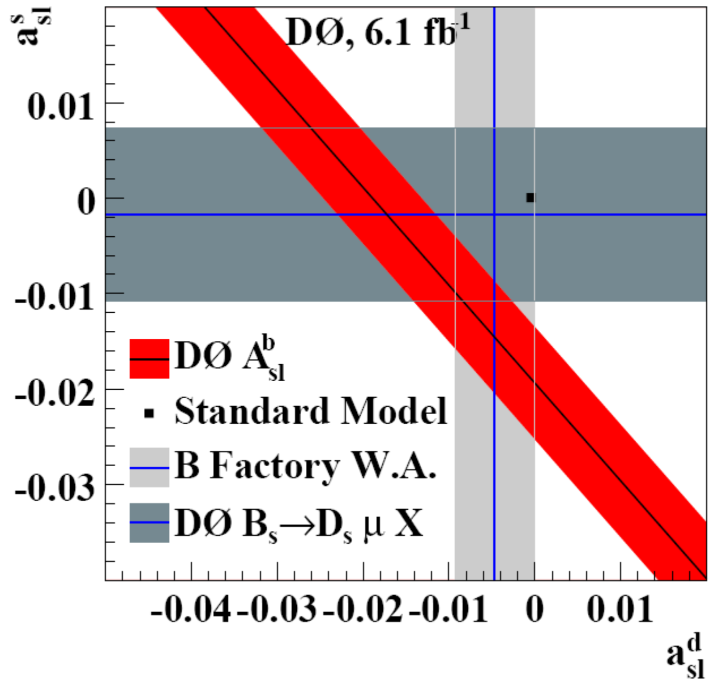
D0 collaboration: arXiv:1007.0395 [hep-ph]

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

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

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

3σ tension with SM

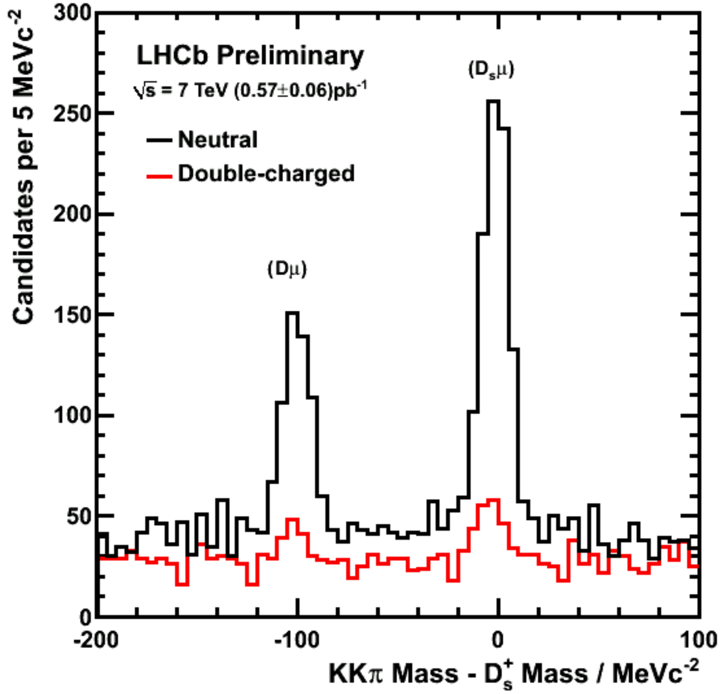


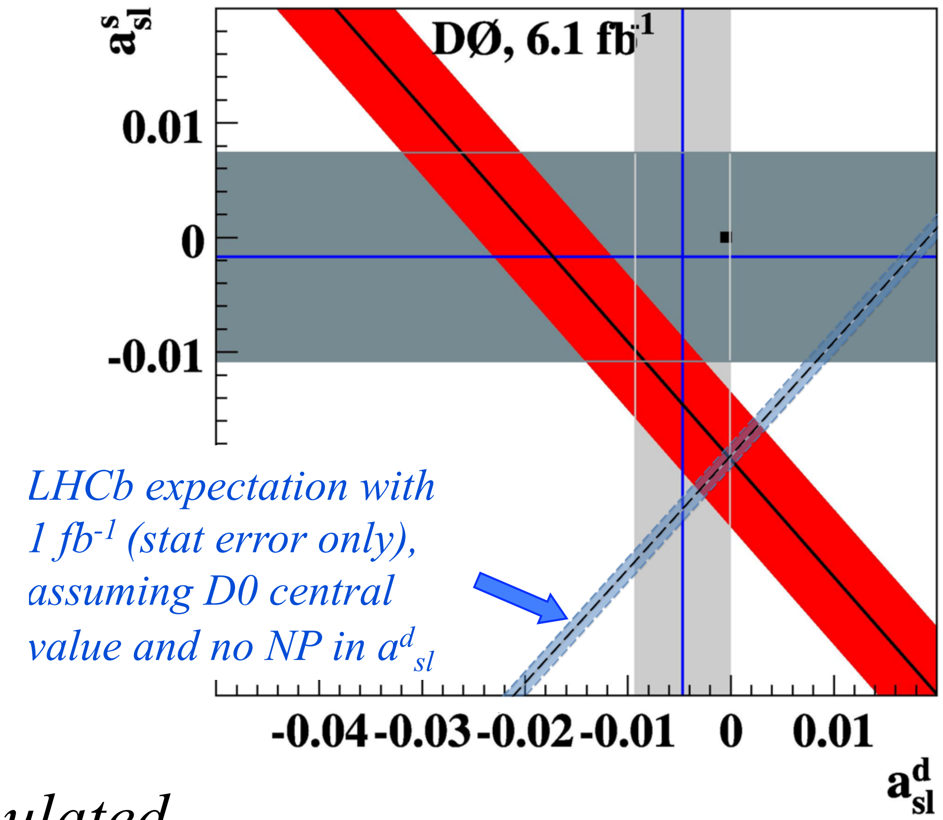
CDF performed preliminary measurement with 1.6 fb^{-1} which used IP significance

$$A_{SL} = 0.0080 \pm 0.0090(stat) \pm 0.0068(syst)$$

[CDF note 9015]

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





Events already being accumulated