Status and Results from LHCb

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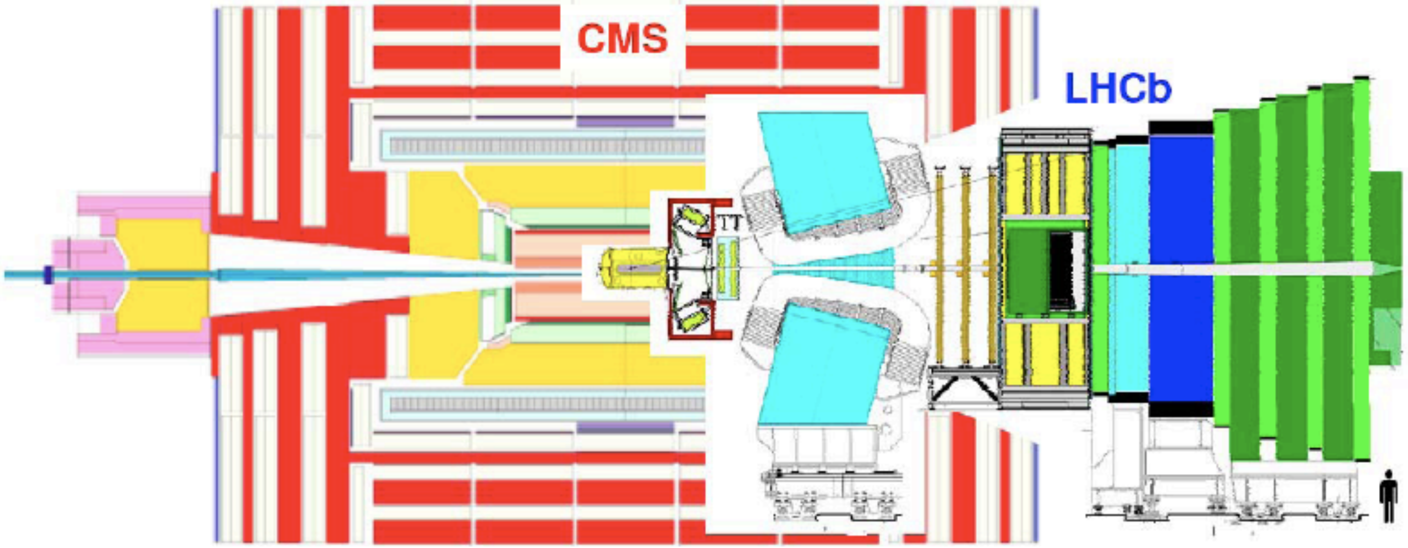
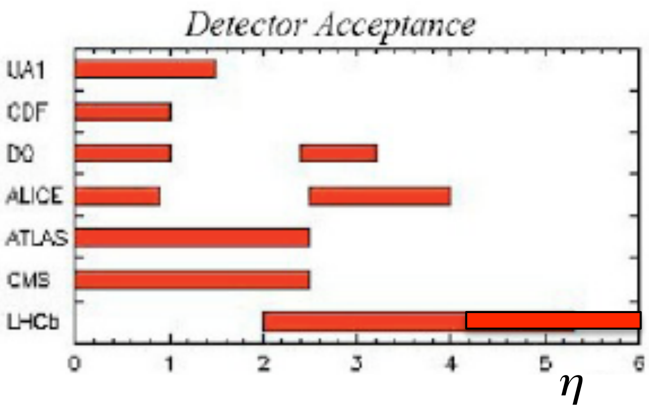
on behalf of the LHCb Collaboration

LHCb is General Purpose Detector in the forward direction ($2 < \eta < 6$)

(designed to take data @ 2×10^{32} cm^{-2}s^{-1})





LHCb is fully instrumented to provide:

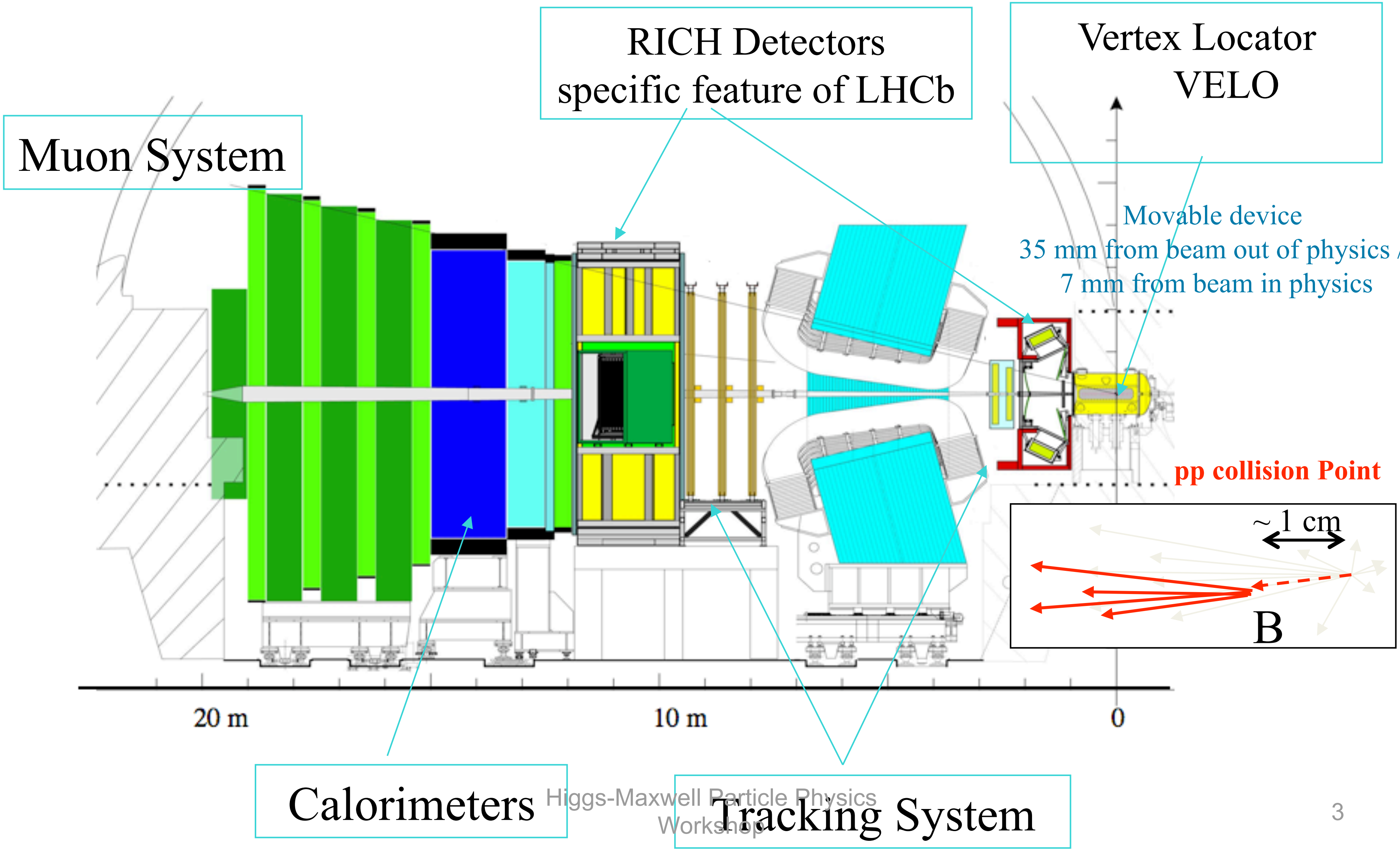
- *Vertexing*
- *Tracking*
- *PID (hadron, muon, electron, photon)*

&

Flexible Trigger to low P_t particles

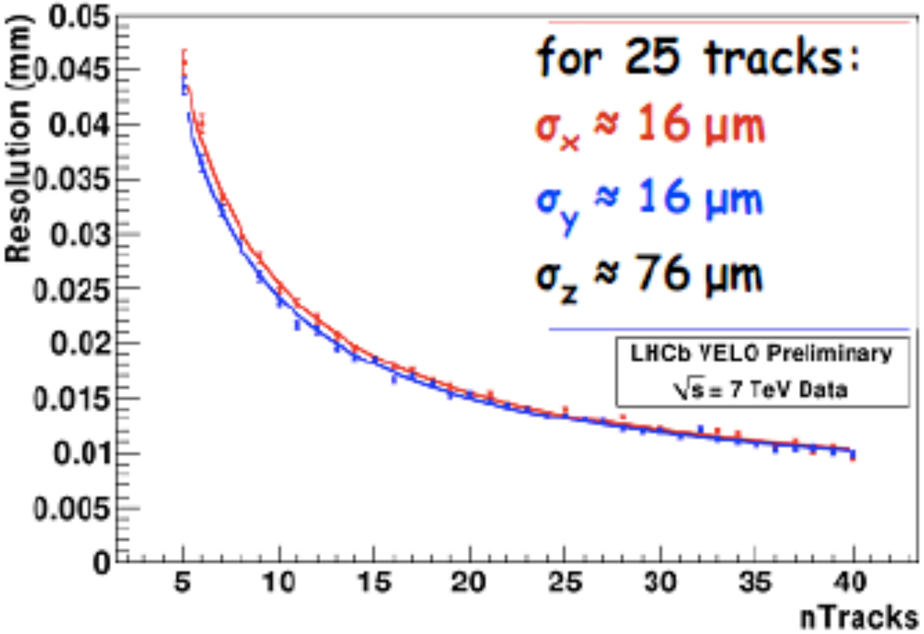
The LHCb Detector

Forward spectrometer *very well suited for flavour physics in particular*



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

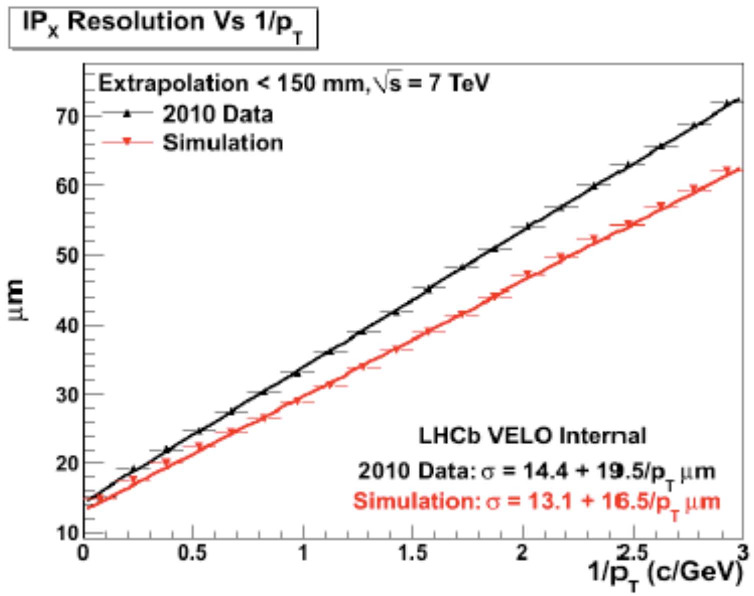


Resolution for PV with 25 tracks

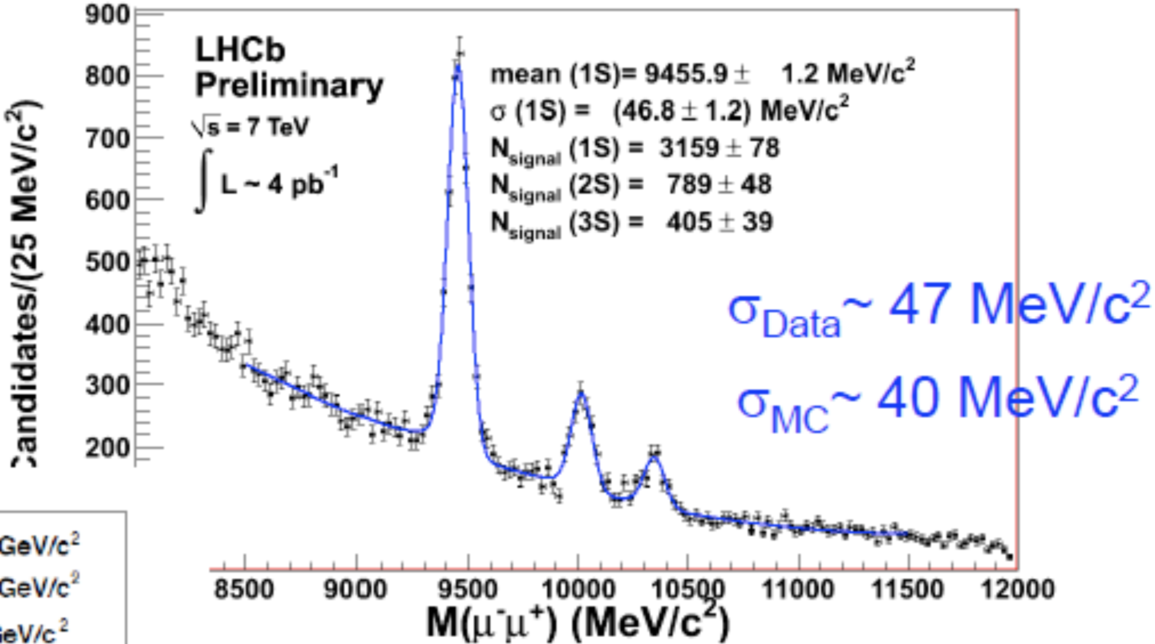
Data: 16 μm for X & Y and 76 μm for Z
MC: 11 μm for X & Y and 60 μm for Z

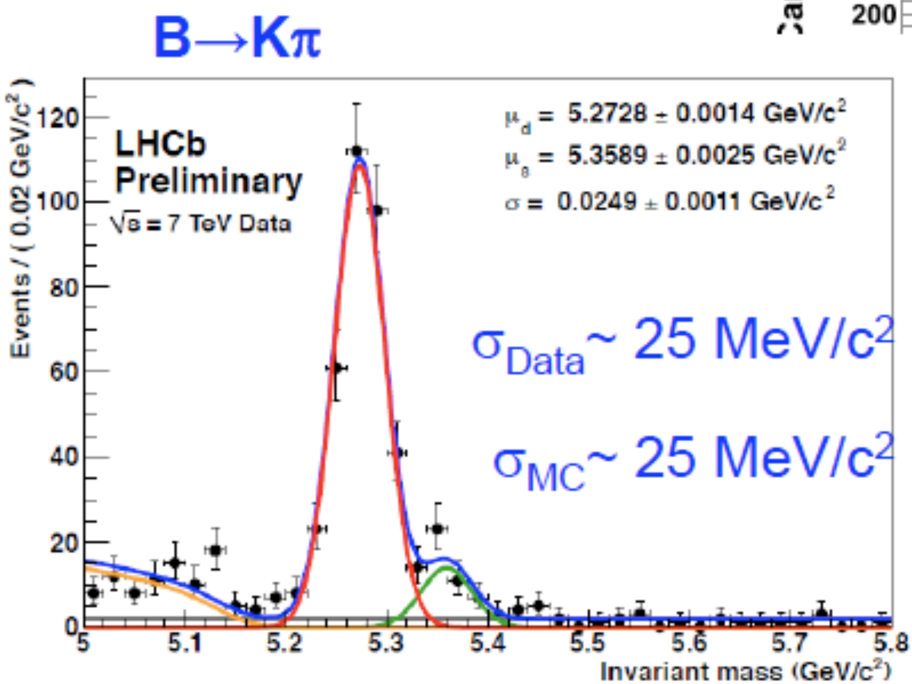
IP resolution ~15 μm for the highest p_t bins

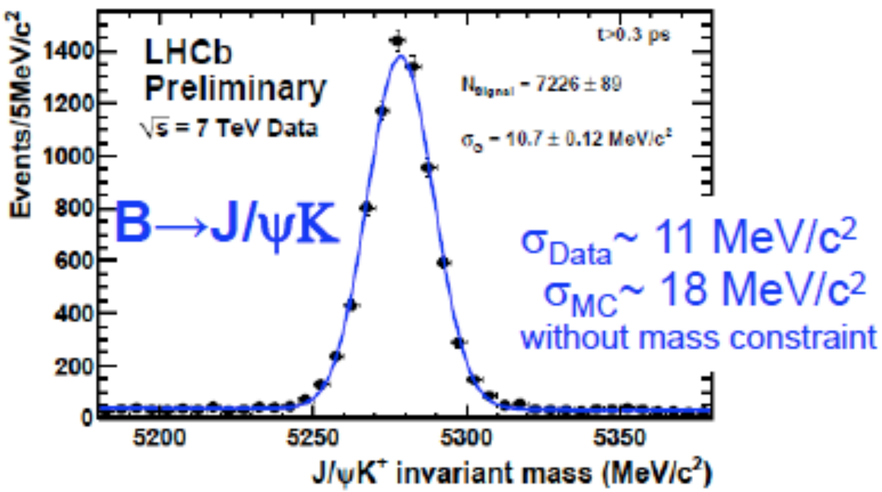
- *slope determined by multiple scattering, not an alignment effect*
- *improvement of material description is ongoing*



Tracking: excellent mass resolution demonstrated

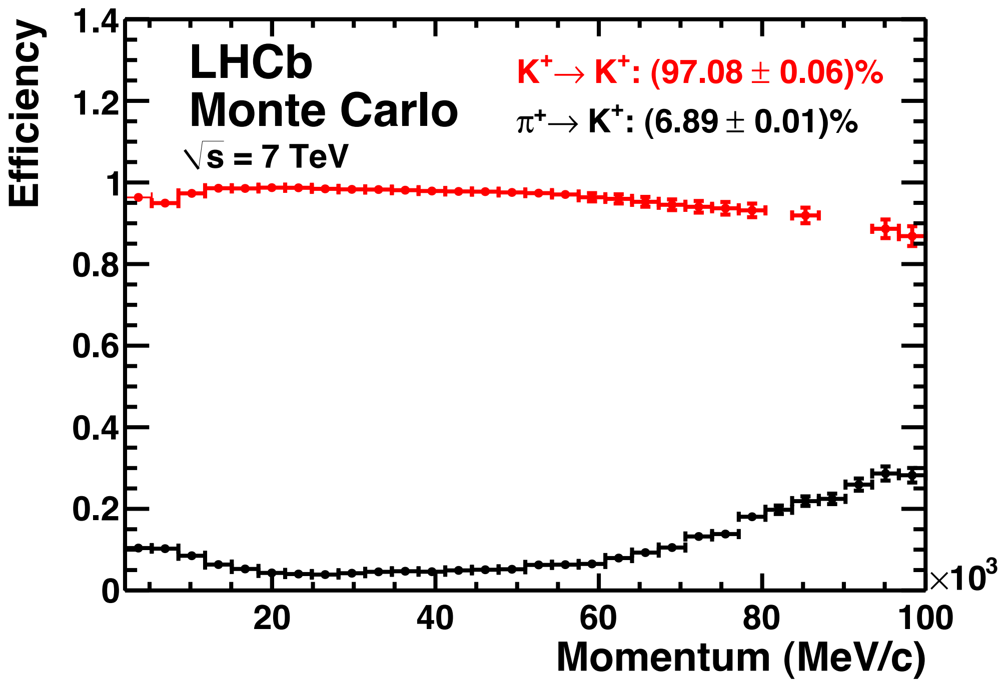


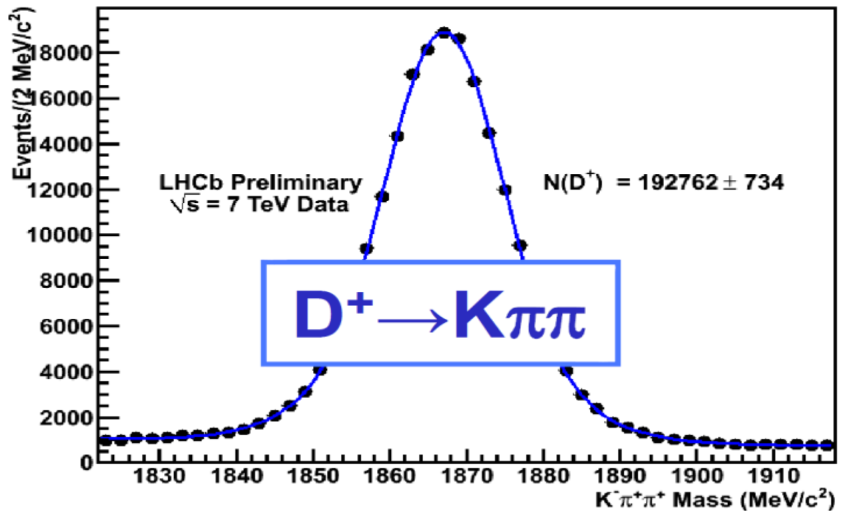


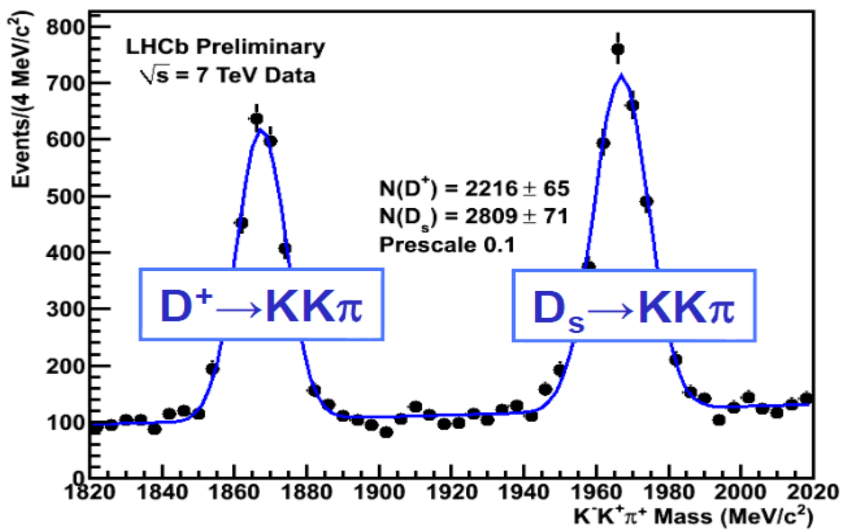


PID: RICH

Enables clean reconstruction of various hadronic decay channels of $D_{(s)}$ and $B_{(s)}$ mesons

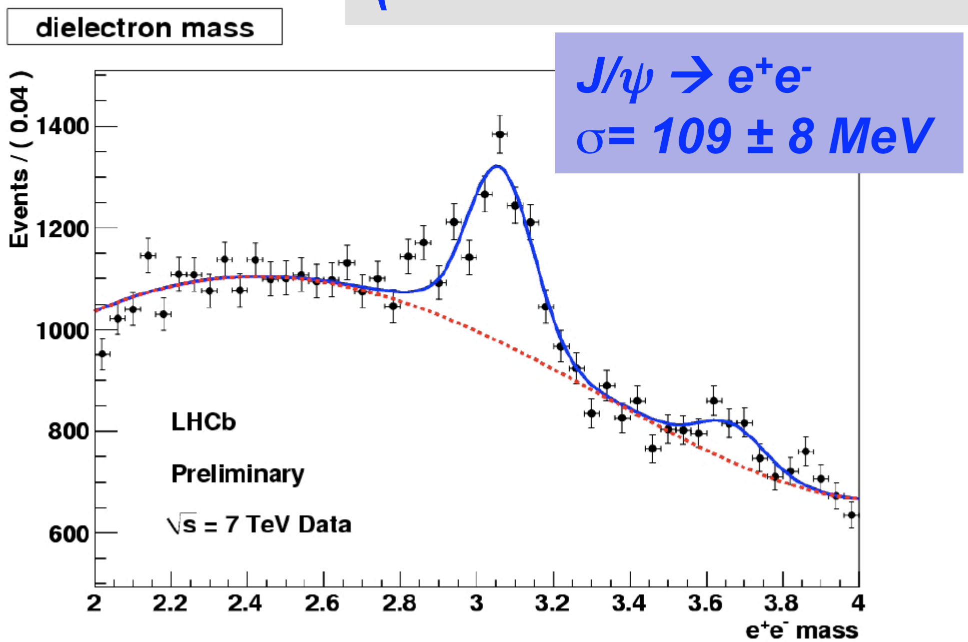


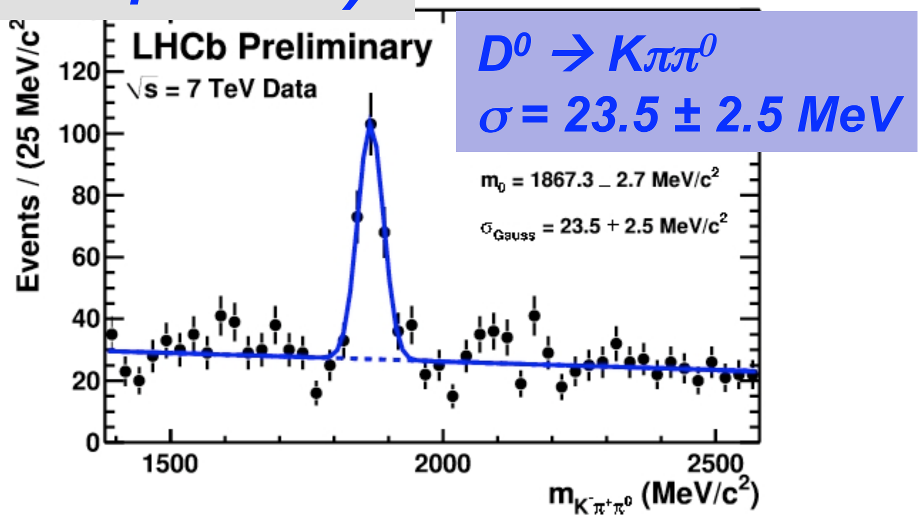


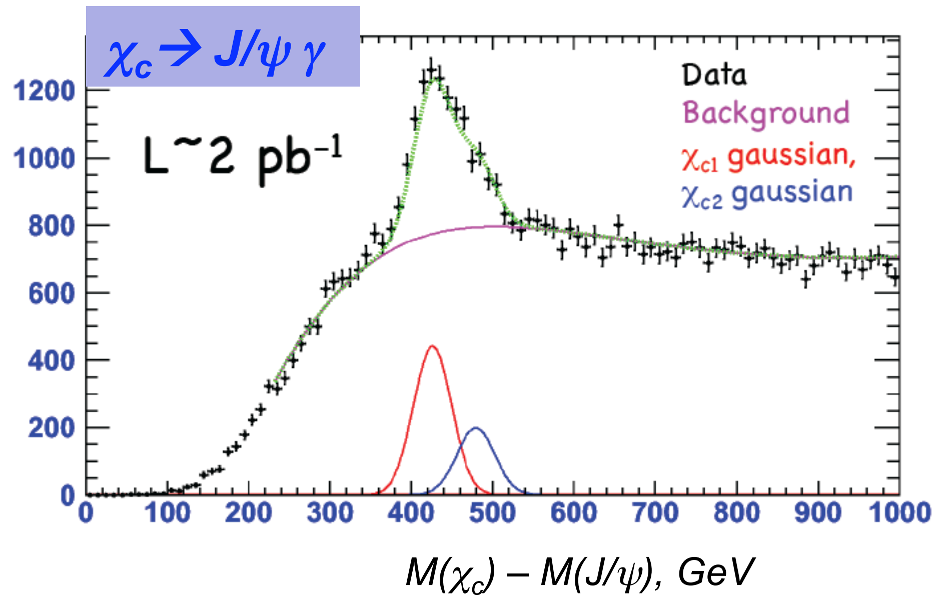


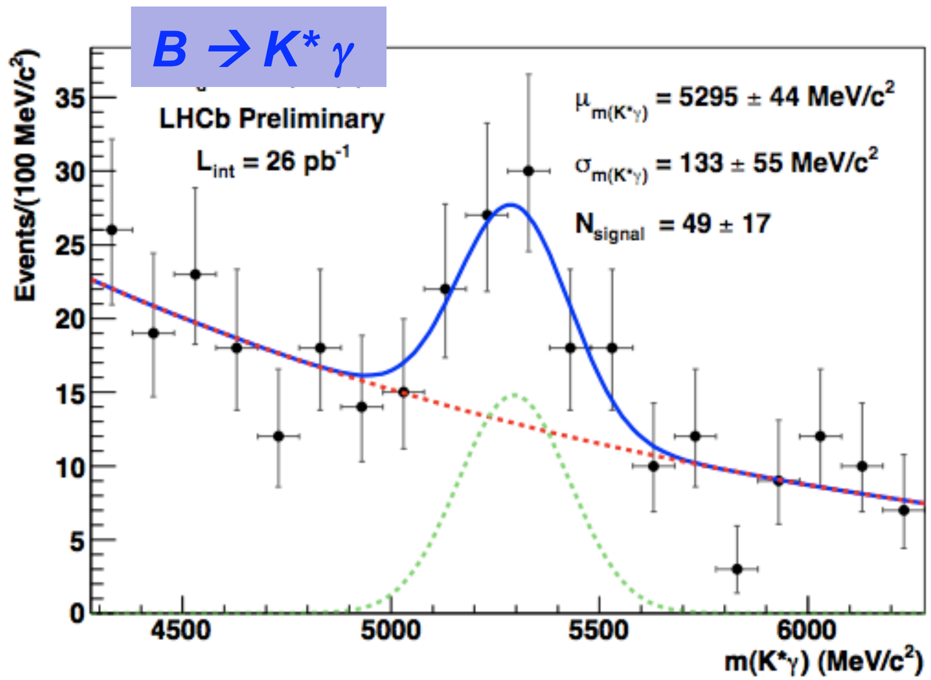
PID with Calorimeter

(Identification of electrons and photons)

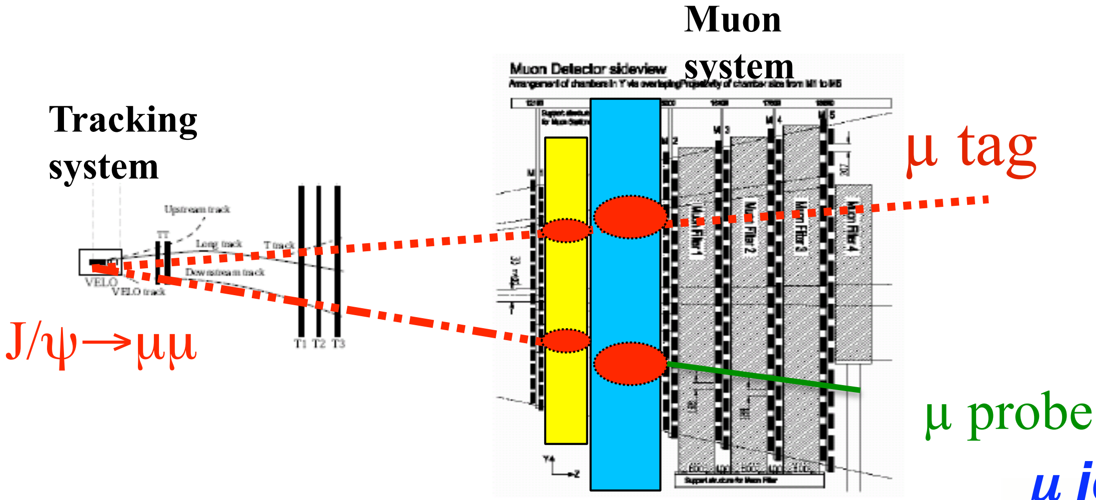


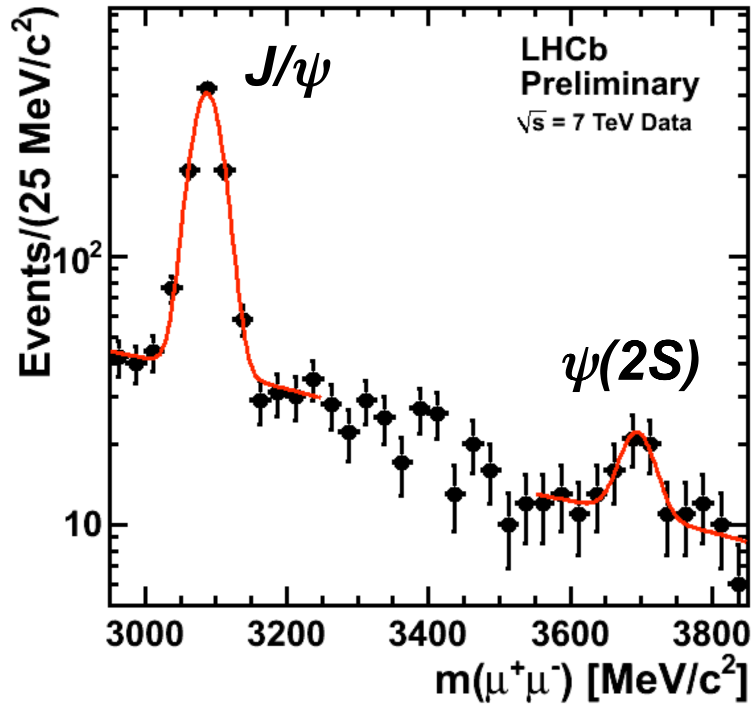




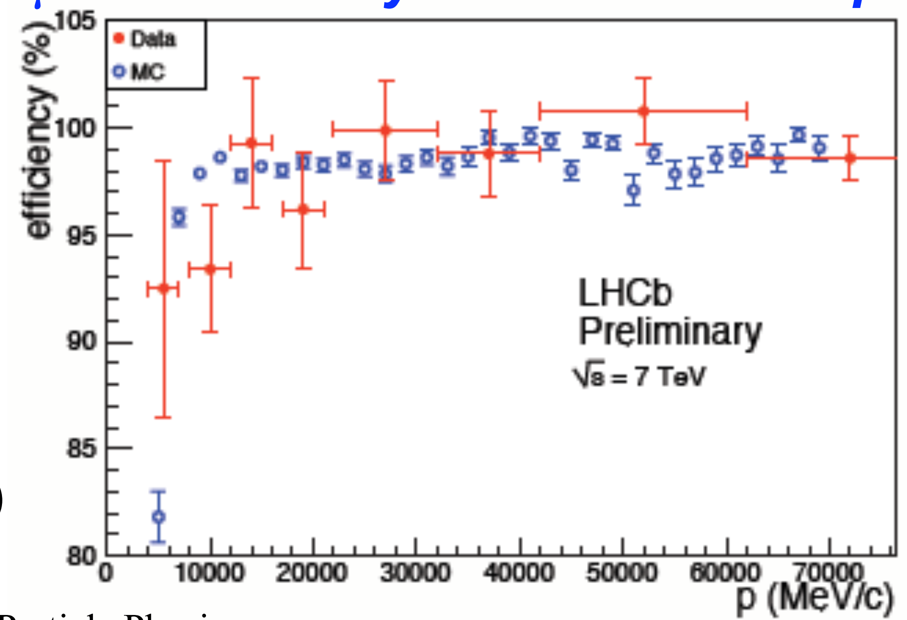


PID with MUON





μ id. efficiency as a function of p

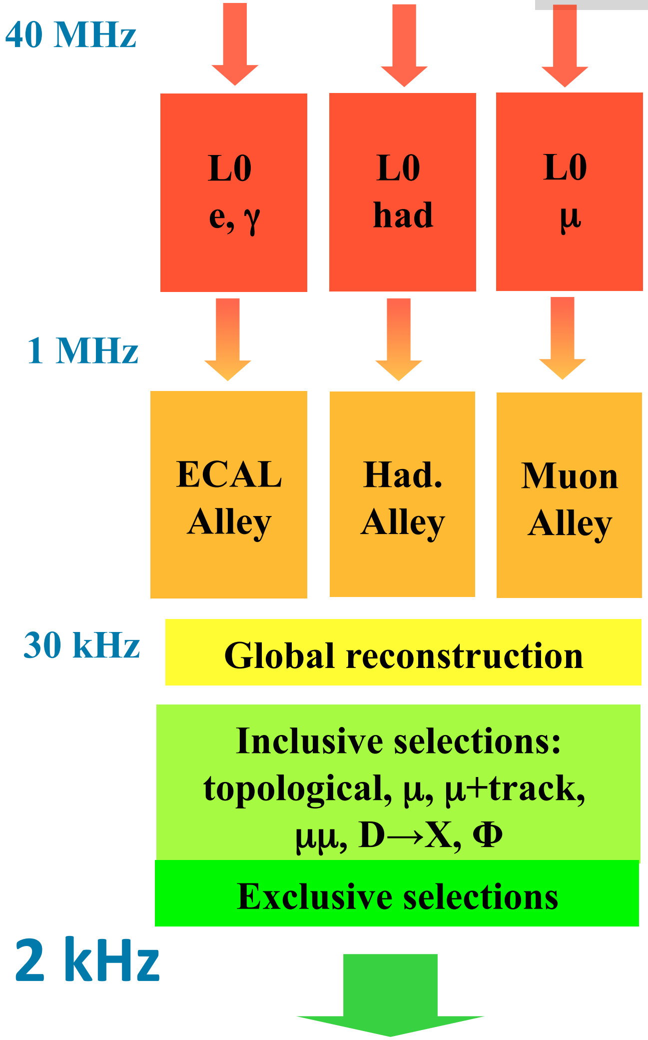


$<\varepsilon(\mu)> = (97.3 \pm 1.2)\%$

$\varepsilon_{K,\pi-\mu} < 1\%$ for $p > 20$ GeV
(dominated by decays in flight)

$\varepsilon_{\mu\text{-}p} = 0.21 \pm 0.05\%$
(dominated by combinatorics in the muon stations)

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.

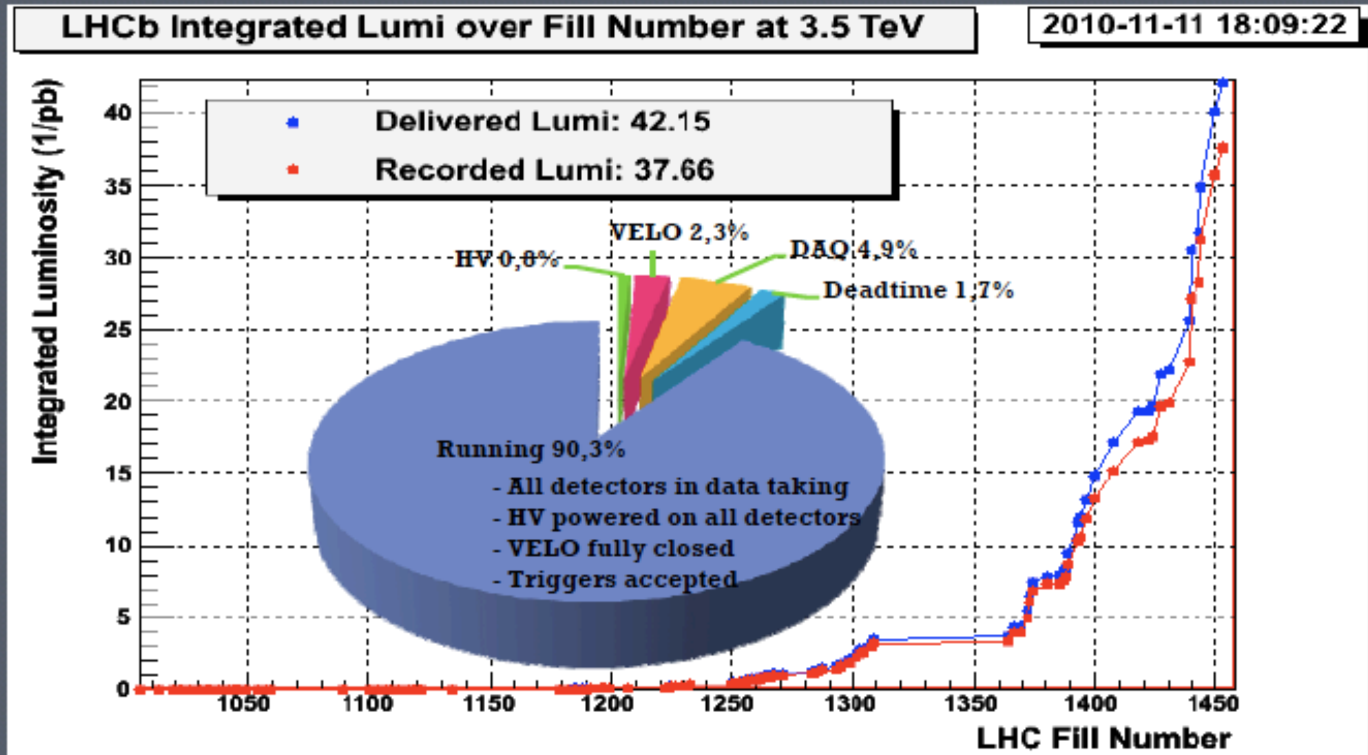
*At LHCb design luminosity **(2×10^{32} cm^{-2} s^{-1})** all thresholds must be optimised for B-physics, and consequently trigger efficiency for D decays from prompt-production is as low as ~ 10%. Boost trigger efficiencies for prompt D's by factor 3-4 w.r.t. nominal settings by reducing P_t threshold when running at low LHC rate*

LHCb Operation

2010 run

$6.8\ \mu b^{-1}$ at $\sqrt{s} = 0.9$ TeV in 2009
$0.31\ nb^{-1}$ at $\sqrt{s} = 0.9$ TeV in 2010
$37.7\ pb^{-1}$ at $\sqrt{s} = 7$ TeV in 2010
(~90% of delivered lumi)

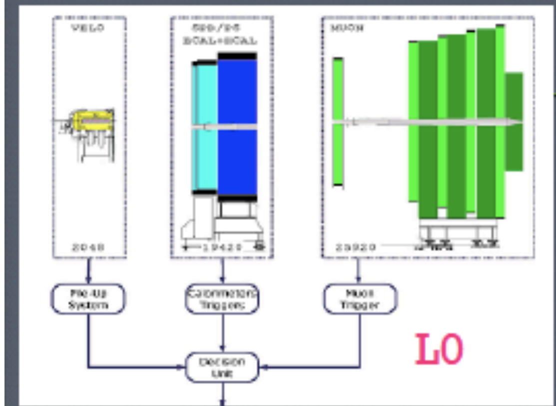
From 30th March to 29th October

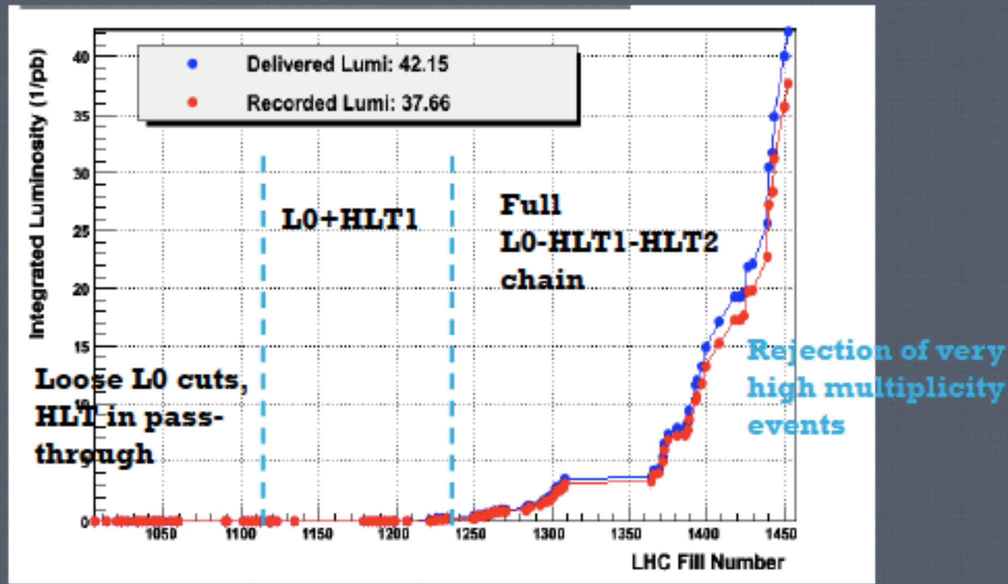


Last month

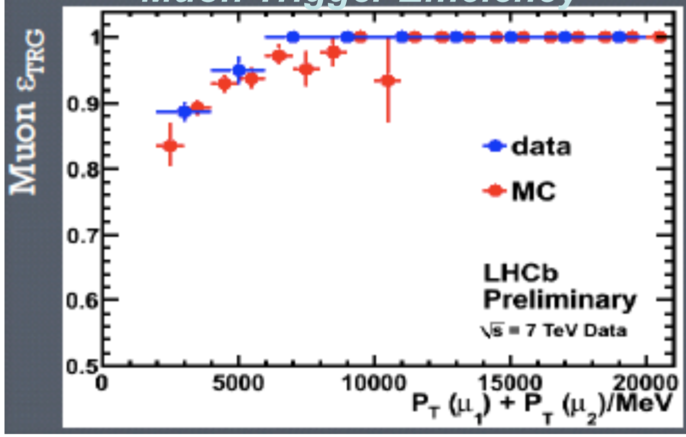
LHCb Operation

Trigger





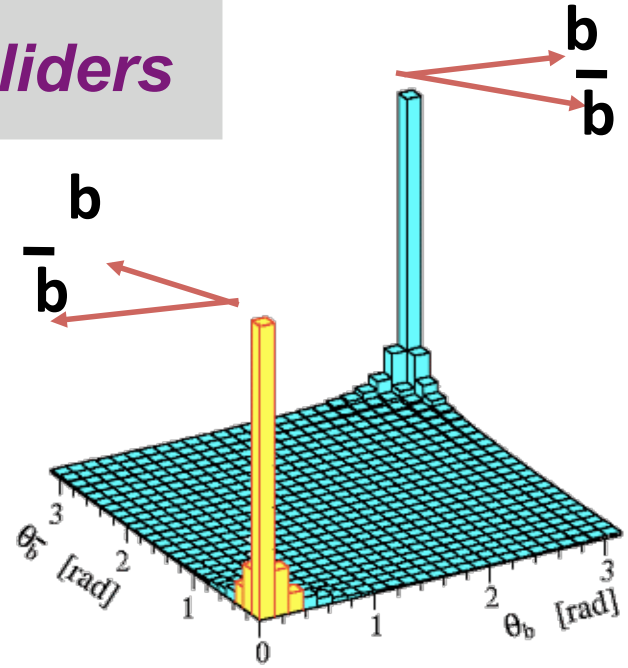
Muon Trigger Efficiency



Trigger efficiencies L0xHLT1 determined on data using the tag-and-probe methods:

	Muon trigger (J/ψ)	Hadron trigger (D^0)
Data	94.9±0.2%	60±4%
MC	93.3±0.2%	66%

Advantages of b physics at hadron colliders

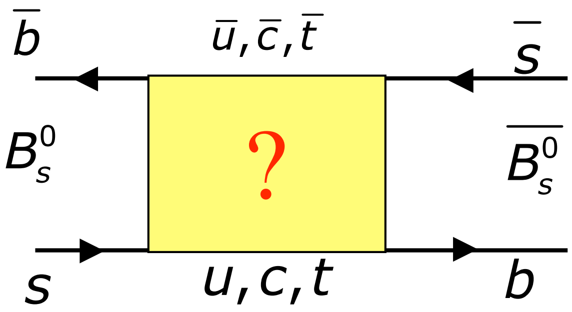


- ☐ *Advantages of beauty physics at hadron colliders:*
  - ■ *High value of bb cross section at LHC:*
    σ_{bb} ~ 300 - 500 μb at 7 - 14 TeV
    (e+e- cross section at Y(4s) is 1 nb)
  - ■ *Access to all quasi-stable b-flavoured hadrons*
- ☐ *The challenge*
  - ■ *Multiplicity of tracks (~30 tracks per rapidity unit)*
  - ■ *Rate of background events: σ_{inel}~ 60 mb at $\sqrt{s}$ = 7 TeV*
- ☐ *Nominal LHCb running conditions:*
  - ■ *Luminosity limited to ~2×10^{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 μ ~ 0.5 pp interaction/bunch
    - ***LHCb reached nominal luminosity but with μ~2 !!!***
  - ■ ***Expect ~2fb^{-1} in 2011/2012 Run (~10^{12} $b\bar{b}$ pairs produced)***

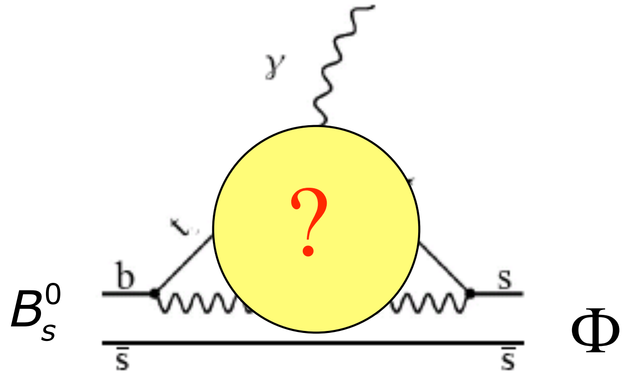
LHCb Physics Programme

- Main LHCb objective is to search for the effects induced by New Physics in CP violation and Rare decays using the FCNC processes mediated by loop (box and penguin) diagrams

- NP effects could be different in boxes and penguins
  → **study different topologies separately !**



$\Phi_s \neq \Phi_s^{SM}$



Sensitivity to masses, couplings, spins and phases of New Particles

New Physics Search Strategy

- ***Phases***

  CPV processes are the only measurements sensitive to the phases of New Physics e.g. measurements of $\boldsymbol{\beta}$ **,** $\boldsymbol{\beta_s}$ **&** $\boldsymbol{\gamma}$

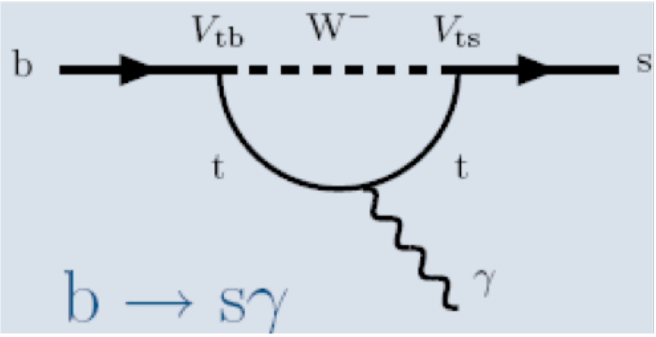
- ***Masses and magnitude of the couplings of new particles***

  Inclusive BR($b \rightarrow s\gamma$*) indirectly constrains the scale of NP masses* $\Lambda > 10^3$ *TeV for generic coupling (flavour problem)*

  Look at specific cases with enhanced sensitivity e.g. helicity suppression in $\boldsymbol{B_s \rightarrow \mu\mu}$ *decay gives increased sensitivity to SUSY with extended Higgs sector*

- ***Helicity structure of the couplings***

  Use the correlation between photon polarization and b flavour in $\boldsymbol{b \rightarrow s\gamma}$



$b \rightarrow \gamma_L + (m_s/m_b) \times \gamma_R$

$\phi\gamma$ *produced in* B_s *and* $\overline{B}_s$ *decays do not interfere*

$\rightarrow$ *corresponding CP asymmetry vanishes*

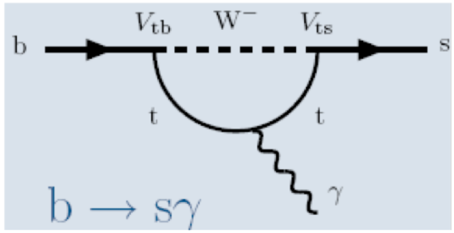
Significantly non-zero $\boldsymbol{A_{CP}}$ ***indicates a presence of right-handed current in the penguin loop***

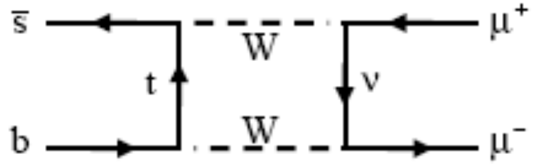
Similar study using $\boldsymbol{B \rightarrow K^*\mu^+\mu^-}$ **&** $\boldsymbol{K^*e^+e^-}$

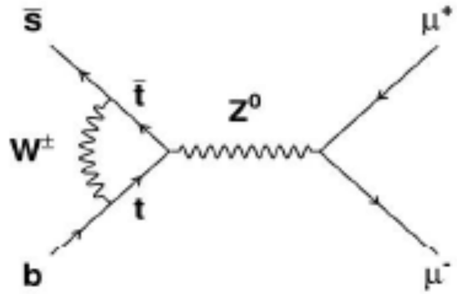
Main LHCb Physics Objectives

Search for New Physics in CP violation and Rare Decays

Correlation between photon helicity and b-flavour







CPV:

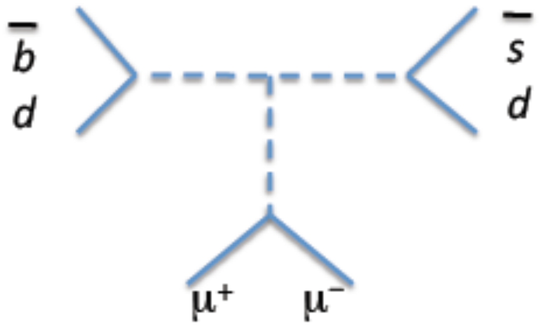
B_s oscillation phase Φ_s
CKM angle γ in trees and loops
CPV asymmetries in charm decays

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

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

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

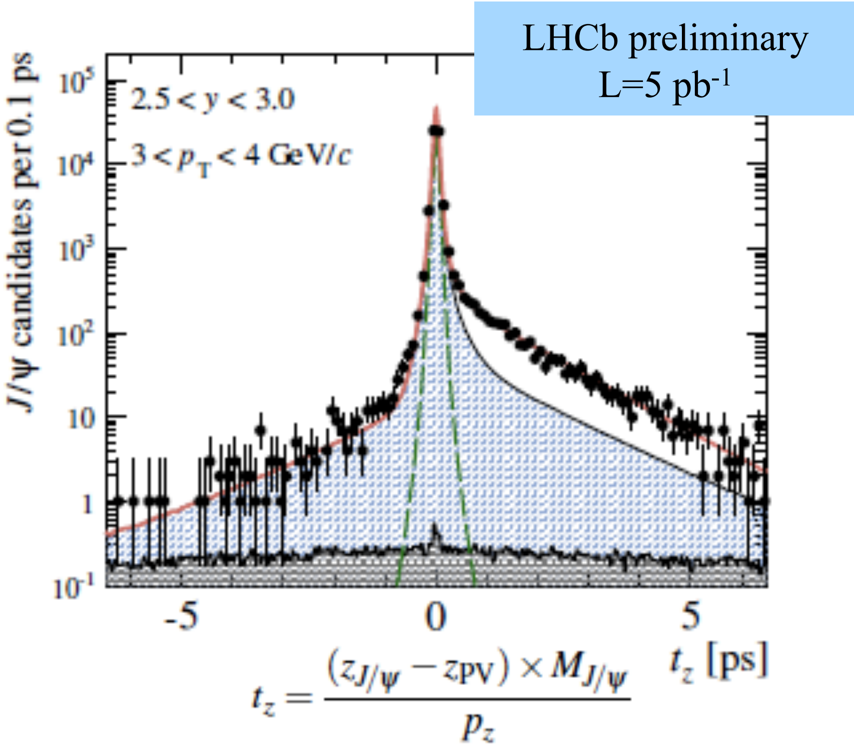


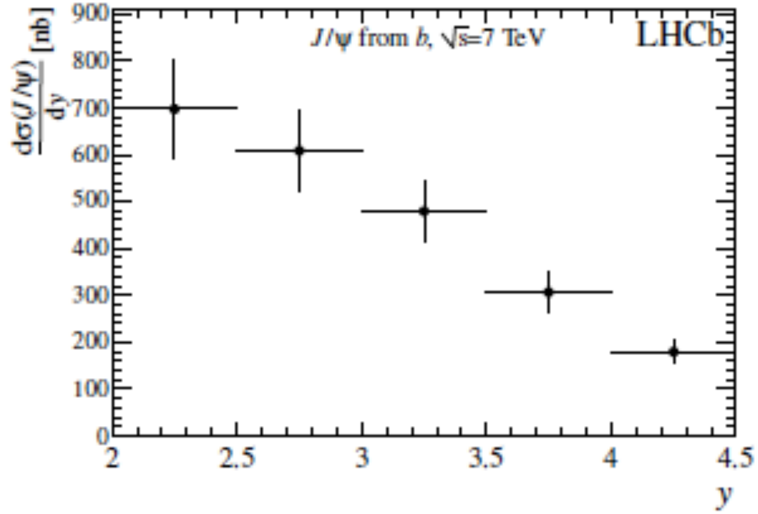
Hadronic: $B_{d,s} \to J/\psi\phi, \phi\phi$

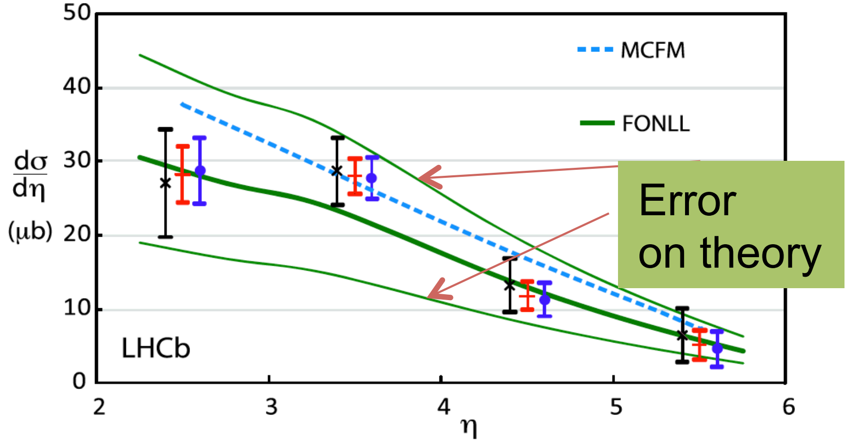
b cross section @ √s = 7 TeV

Using J/ψ produced in B decays: $\sigma(J/\psi$ *from b,* $2<y<4.5) = 1.16 \pm 0.01 \pm 0.17\ \mu b$

→ $\sigma(pp \rightarrow bbX) = 295 \pm 4 \pm 48\ \mu b$





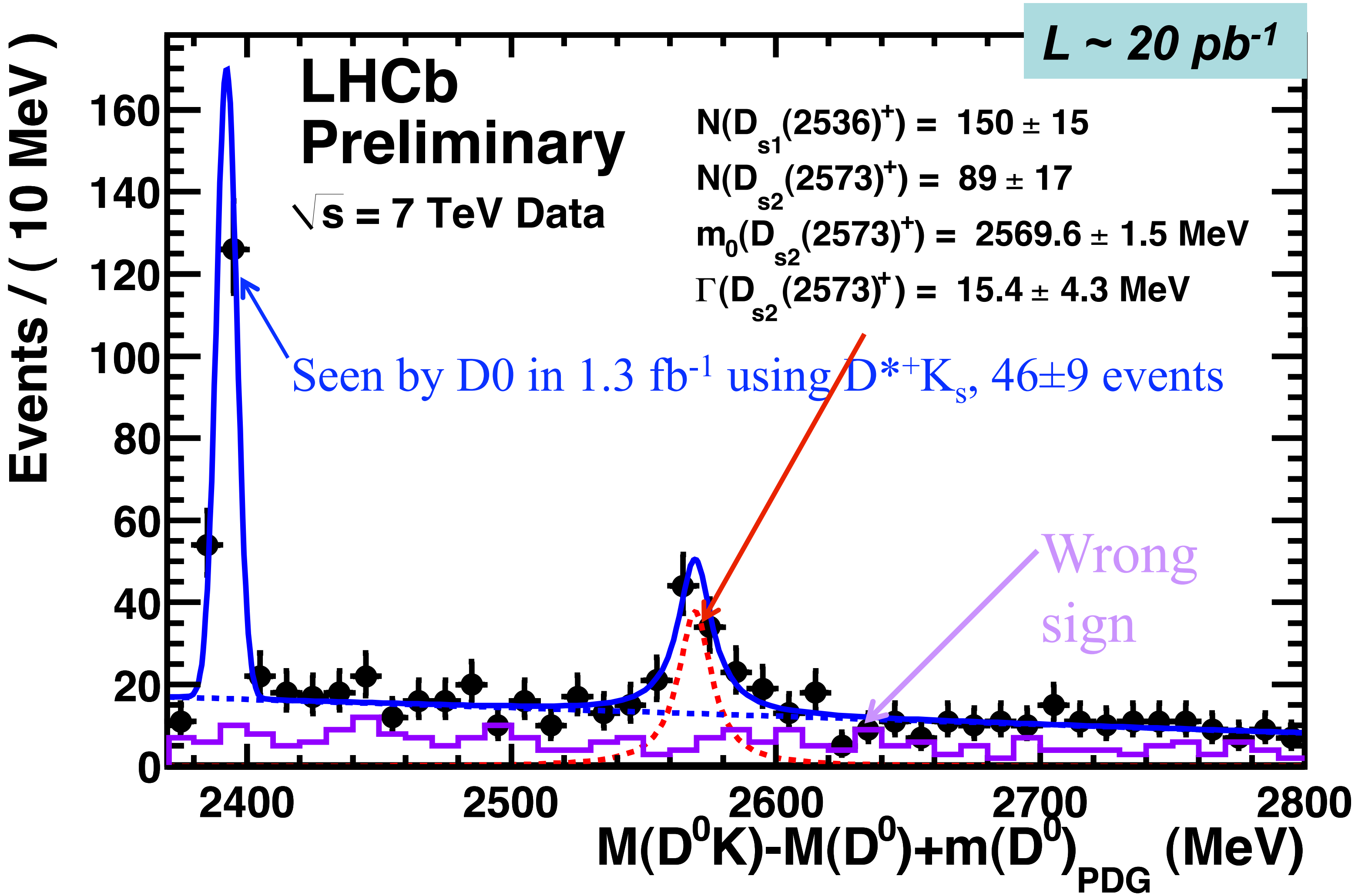


Using semileptonic B decays:

$\sigma(pp \rightarrow bbX$ *in* $2<\eta<6) = 75.3 \pm 5.4 \pm 13.0\ \mu b$

→ $\sigma(pp \rightarrow bbX) = 282 \pm 20 \pm 48\ \mu b$

First observation of new semileptonic B_s decay: $B_s \rightarrow D_{s2}X\mu\nu$, $D_{s2} \rightarrow D^0K^+$

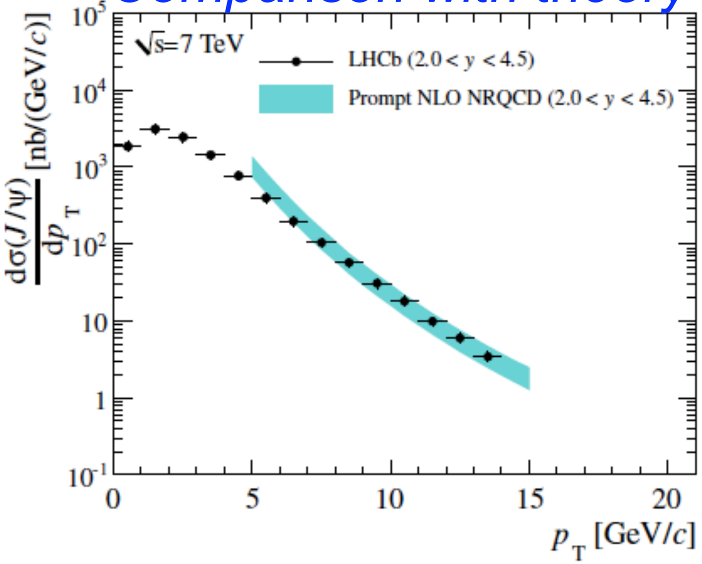


Prompt J/ψ and open charm cross-sections @ $\sqrt{s}$ = 7 TeV

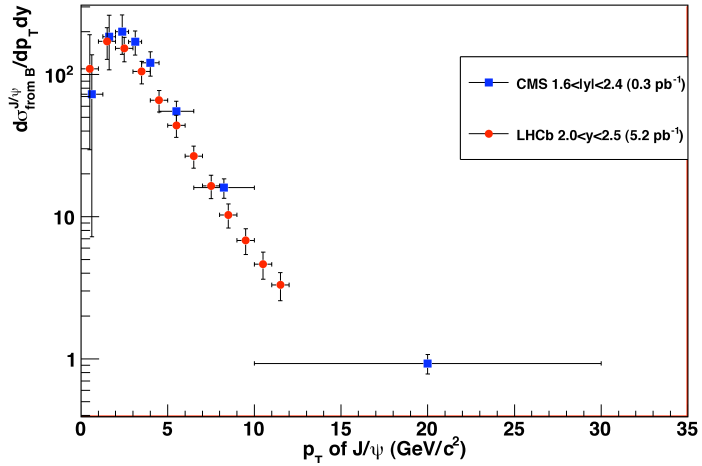
Prompt J/ψ production:

σ(prompt J/ψ, P_t<14 GeV/c, 2<y<4.5) =
= ($10.8 \pm 0.05 \pm 1.51^{+1.69}_{-2.25}$) μb

Comparison with theory

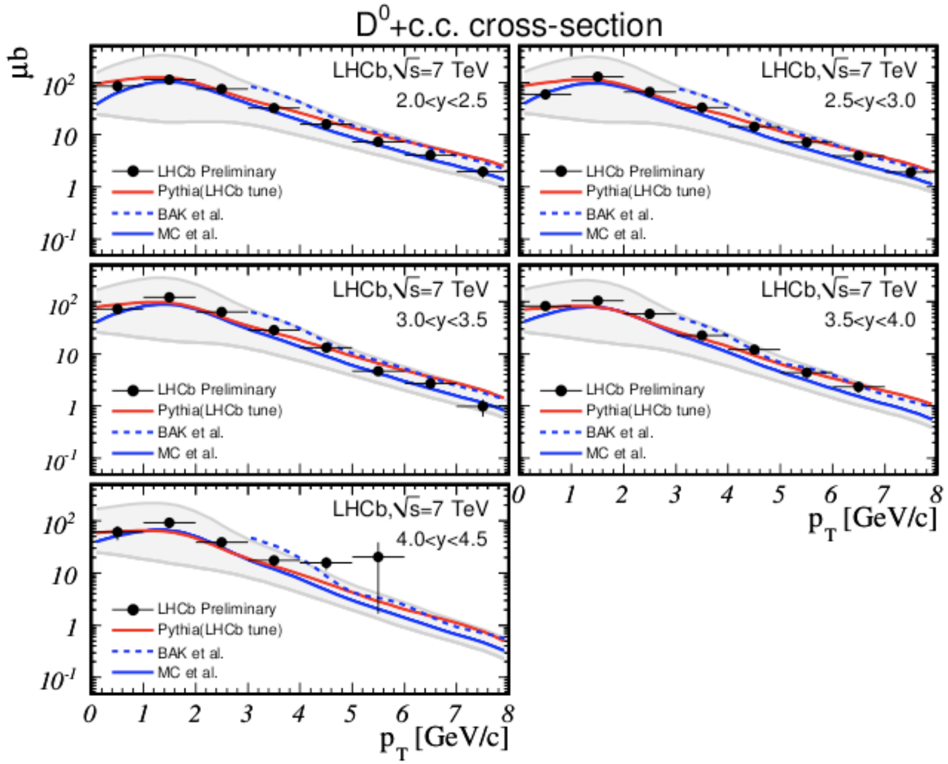


Comparison with CMS
in the overlapping region



Open charm cross-sections

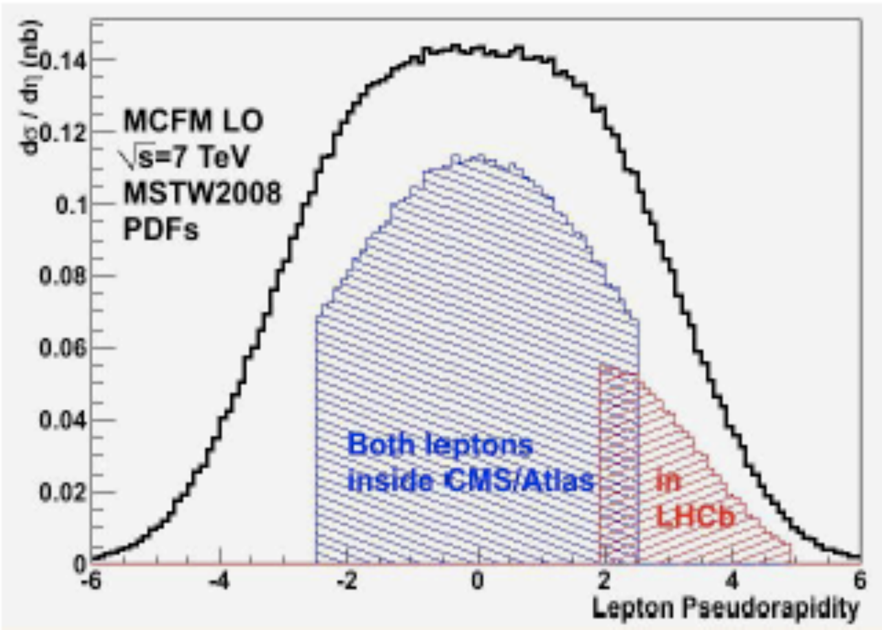
(D, D^0, D^+, D_s and Λ_c) have been measured as well*

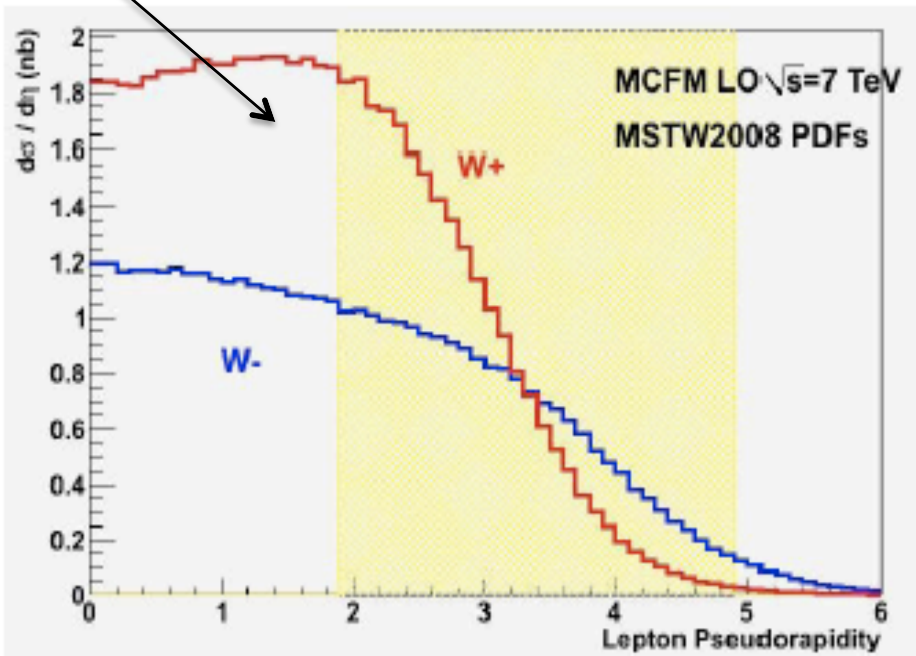


As expected huge charm production in the forward direction: ~20 × b

Production of W and Z in the forward direction

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

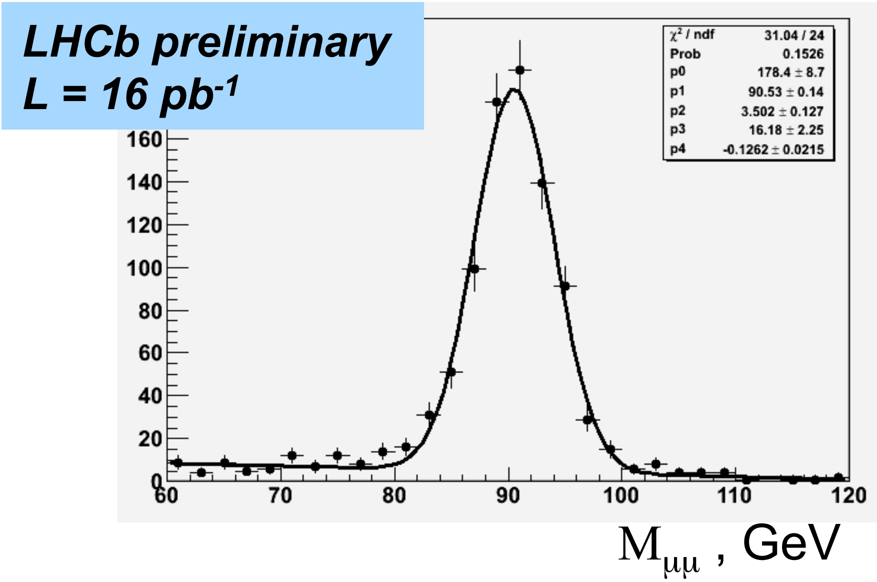




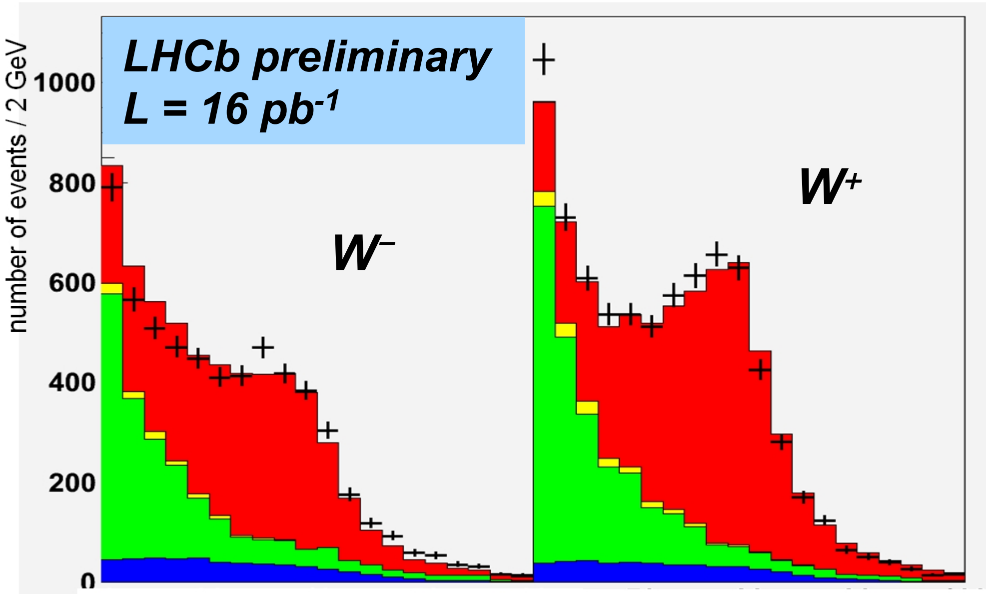
Very important to improve valence and sea quark distributions inside proton !!!

Z & W

Z: 2 μ, each with P_t > 20 GeV/c

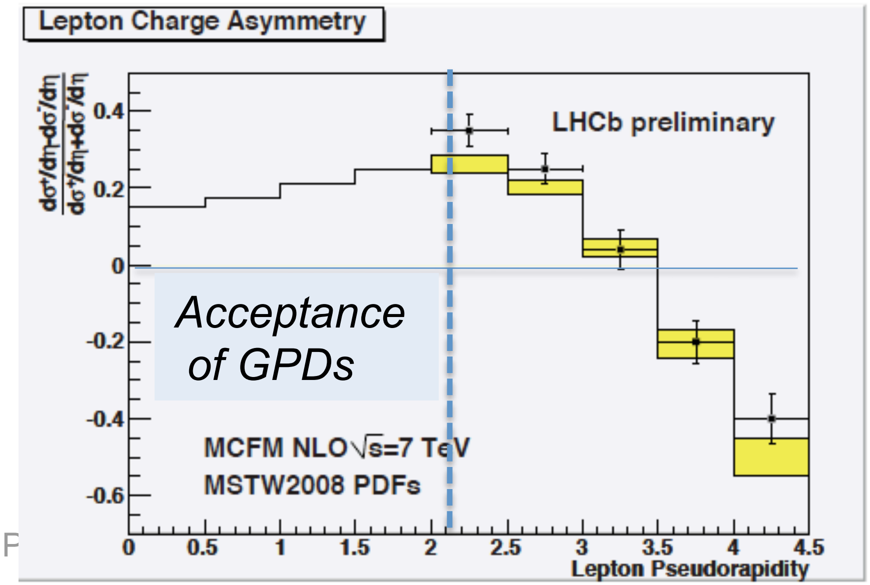


W: single isolated μ with P_t > 20 GeV/c & small P_t opposite



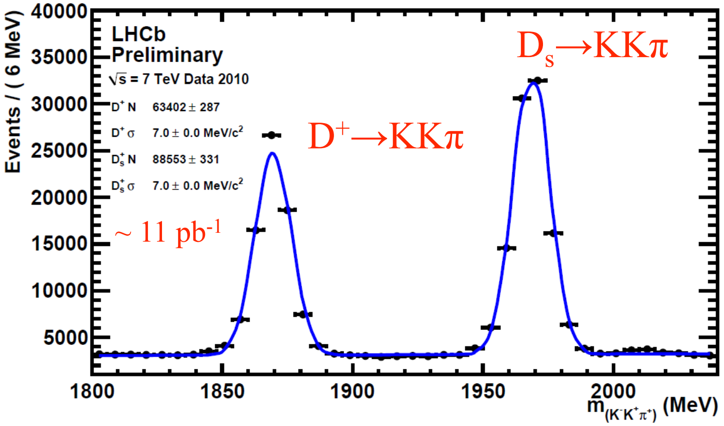
- $\sin^2(\theta_W)$ can be extracted from A_{FB}. In LHCb acceptance Z production occurs predominantly through collision of valence and sea quark, so axis of A_{FB} measurement is well defined, and dilution low.

- Knowledge of PDF is very important to improve accuracy on A_{FB} and M_W. LHCb is complementary to GPDs and may provide vital input with high statistics data samples

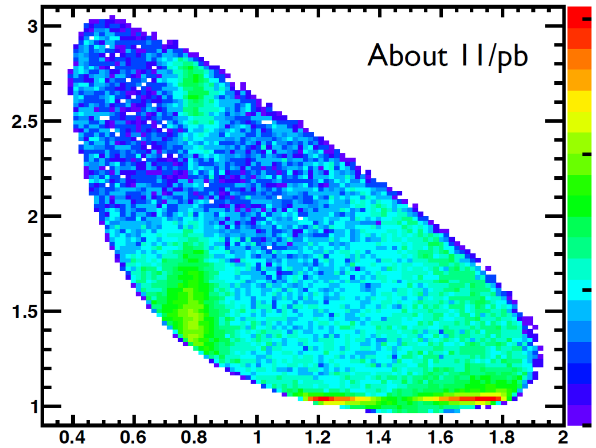


Charm of beauty experiment

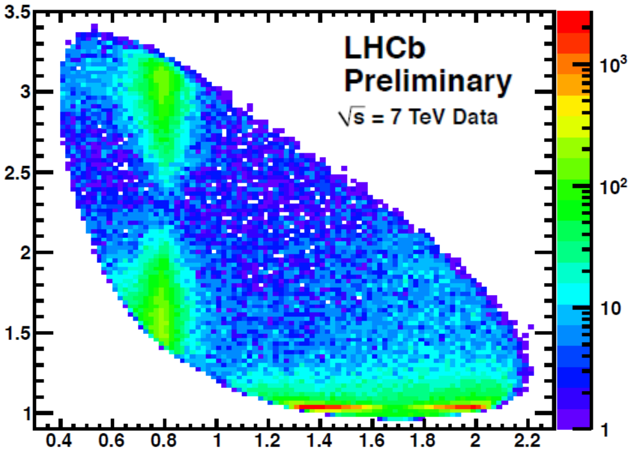
- *Excellent prospects for CPV studies; sensitivity < 0.1% is feasible at LHCb with first 100 pb^{-1} !!! Expect several million tagged $D^0 \rightarrow KK$ (BELLE 540 fb^{-1} analysis uses ~10^5 tagged $D^0 \rightarrow KK$ giving stat. precision on y_{CP}=0.32% and on A_Γ=0.30%)*
- *Search for direct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

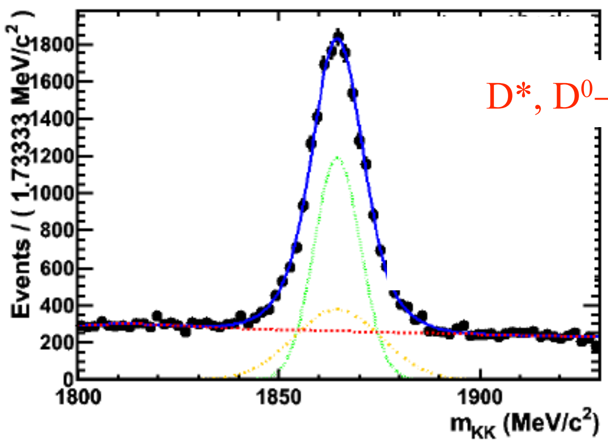


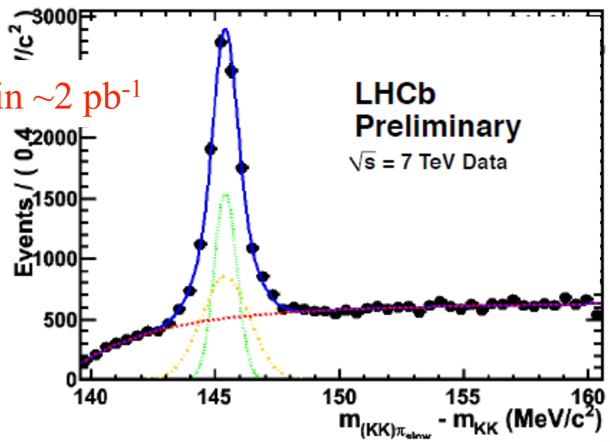
$D^\pm \rightarrow K^+K^-\pi^+$



$D_s^\pm \rightarrow K^+K^-\pi^+$







Sample sizes in low multiplicity modes already similar to those of B-factories !

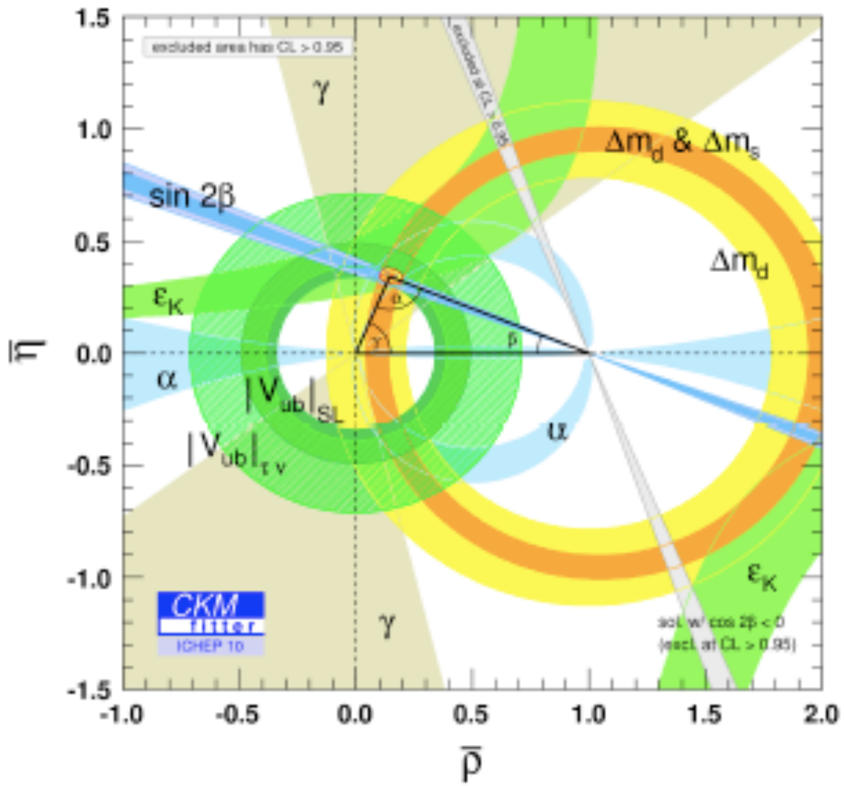
What is left for the Unitarity Triangle test ???

- *Precision test of the Unitarity Triangle is limited by accuracy of its sides, $|V_{ub}|$ and $(f_{Bd}\sqrt{B_d})/(f_{Bs}\sqrt{B_s})$ in particular*

- *Several possible hints for NP effects (A_{SL}, V_{ub} from $B \rightarrow \tau\nu$)*

- *Large contribution from NP not excluded*

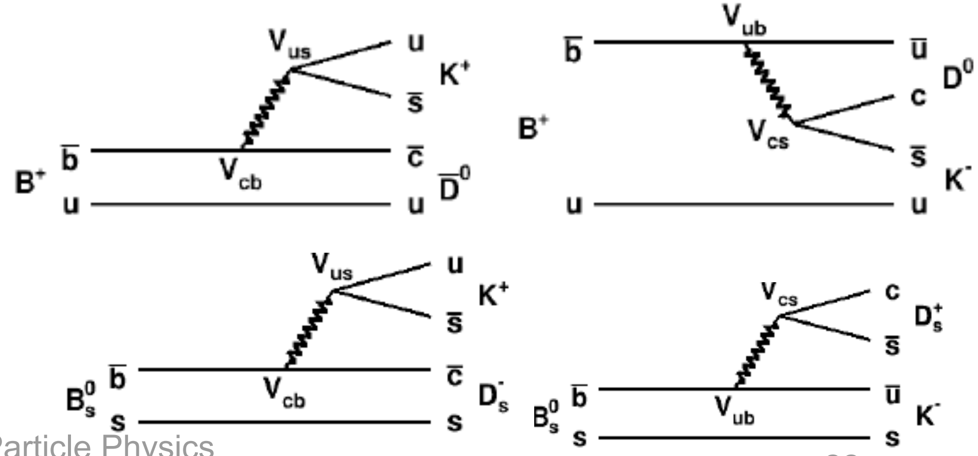
- ***Precision measurement of γ in trees is important !!!***



Two strategies at LHCb

- *Interference between tree amplitudes gives CP violation effects that depend on their weak phase difference (γ)*

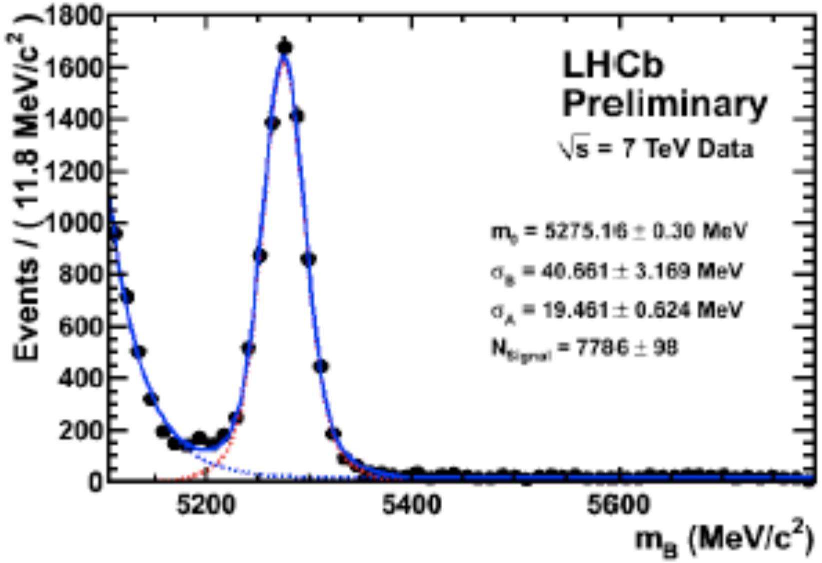
- *Amplitudes with weak phase diff. (γ) Different final states interfering via mixing gives sensitivity to ($\gamma - 2\beta_s$)*



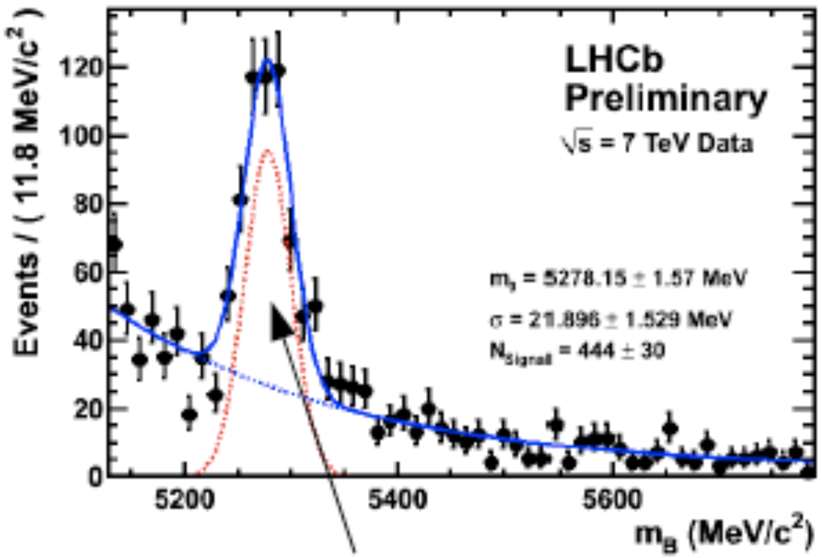
LHCb yields in $B^+ \rightarrow D\pi^+$ & $B^+ \rightarrow DK^+$

(LHCb takes shape !)

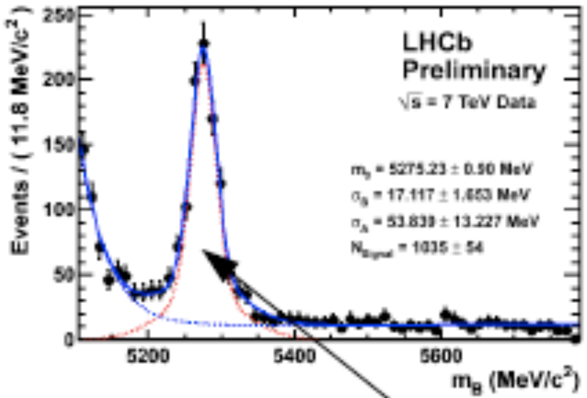
$B^\pm \rightarrow D\pi^\pm$ with $D \rightarrow \pi K$



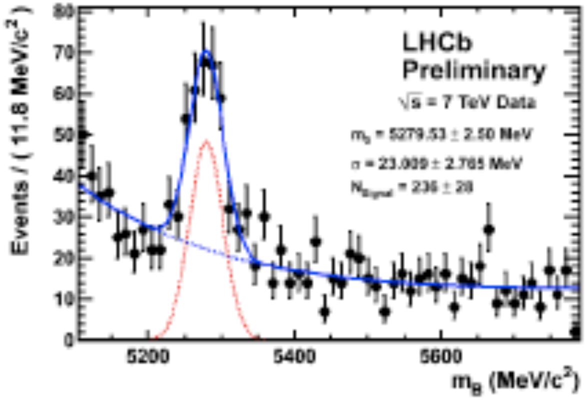
$B^\pm \rightarrow DK^\pm$ with $D \rightarrow \pi K$



$B^\pm \rightarrow D\pi^\pm$ with $D \rightarrow KK$



$B^\pm \rightarrow D\pi^\pm$ with $D \rightarrow \pi\pi$

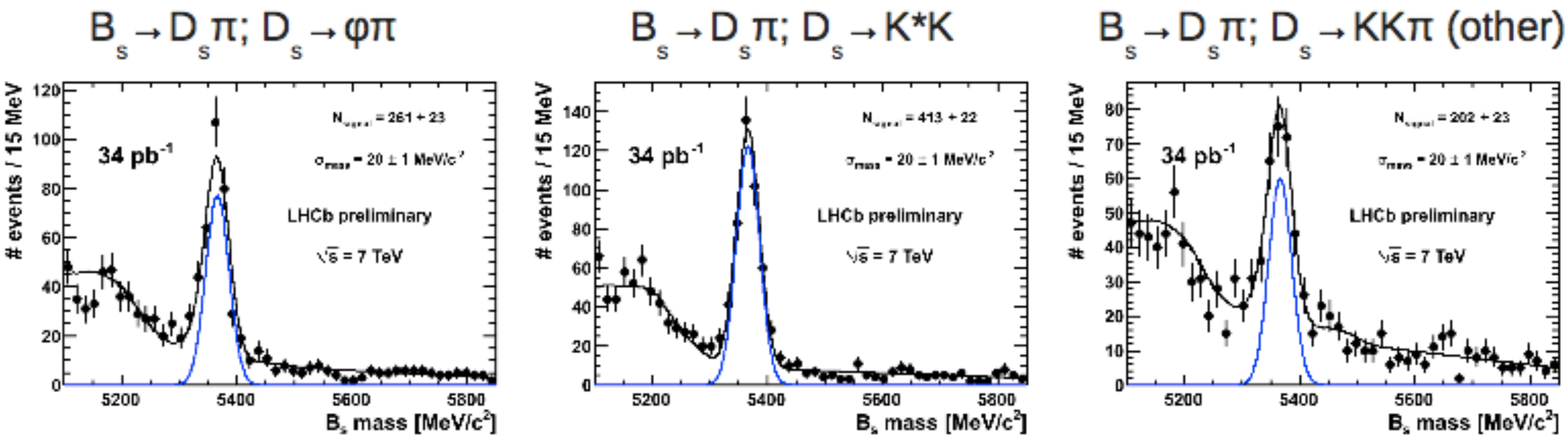


LHCb yield: 444 ± 30 / 34 pb^{-1}
CDF yield: 516 ± 37 / fb^{-1}

LHCb yield: 1035 ± 54 / 34 pb^{-1}
CDF yield: 718 ± 36 / fb^{-1}

Prospects for γ measurement in $B_s \rightarrow D_s K$

Large signals for $B_s \rightarrow D_s\pi$ useful for Δm_s measurement

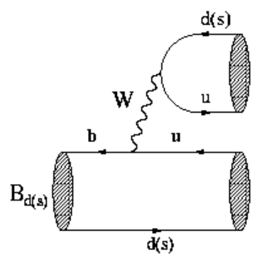


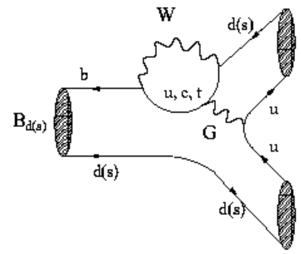
- ***D_sK final state under study***
- ***Expect world's first time-dependent CPV analysis for $B_s \rightarrow D_s K$ analysis in 2011***

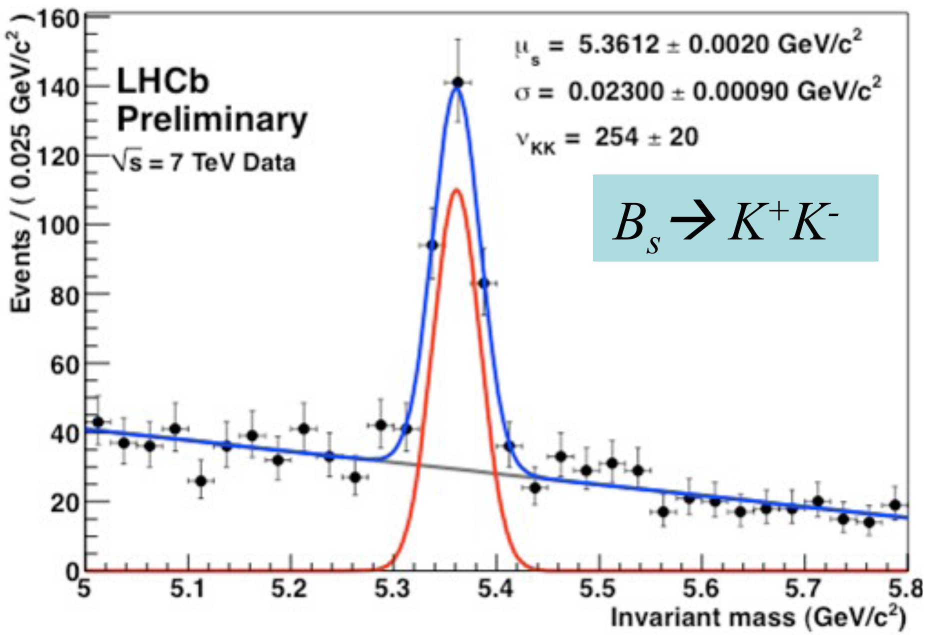
Combined estimated sensitivity for γ in 2011/2012 Run is ~7°

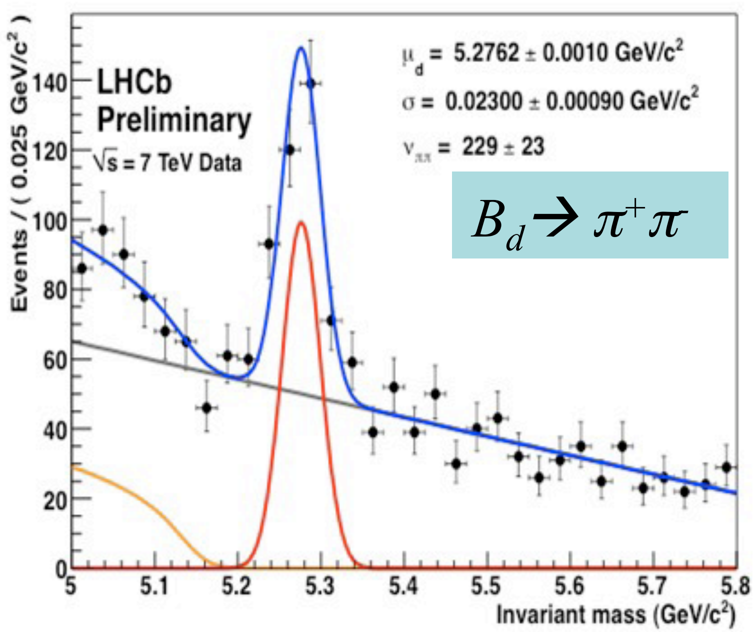
Prospects for γ measurement in $B_s \rightarrow K^+K^-$ & $B_d \rightarrow \pi^+\pi^-$

Large penguin contribution in both $B_s \rightarrow KK$ & $B_d \rightarrow \pi\pi$
→ Sensitive to NP effects in time-dependent CP asymmetries (exploit U-spin symmetry)





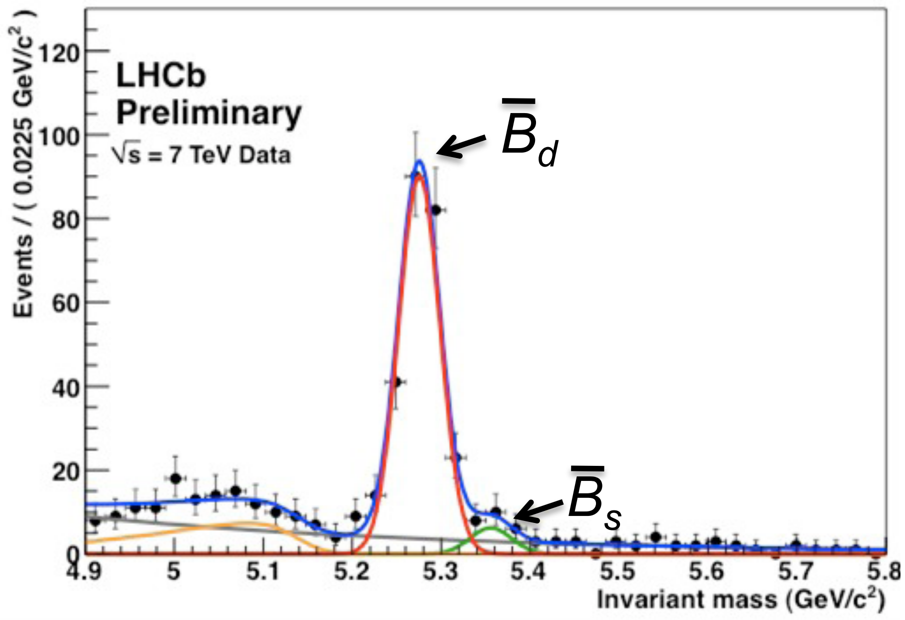




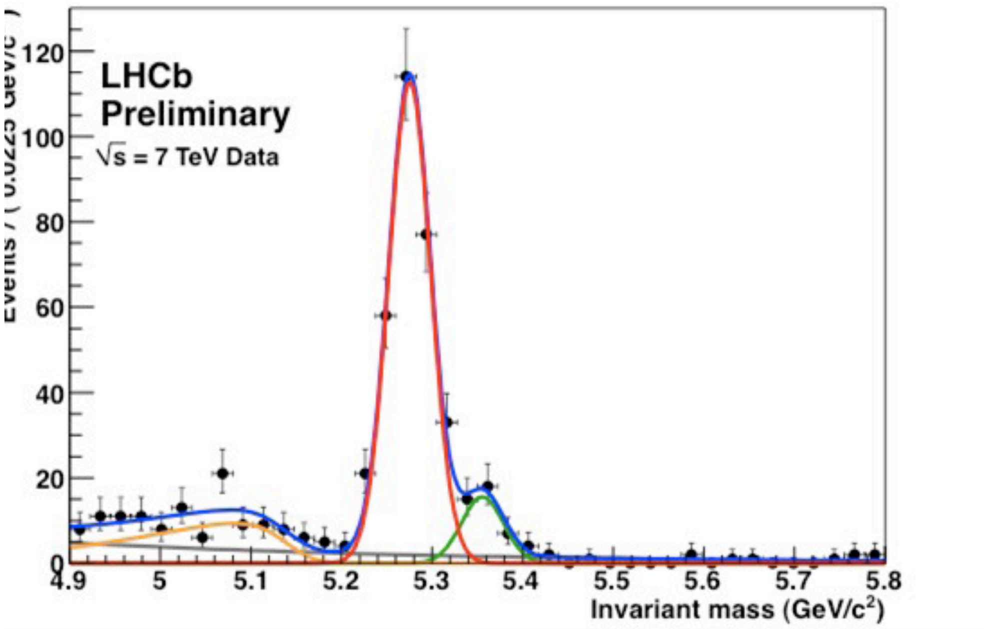
- *LHCb yiels in ~35 pb^{-1}: 254±20 $B_s \rightarrow K^+K^-$ & 229±23 $\pi^+\pi^-$*
  c.f. CDF in 1 fb^{-1} 1307±64 $B_s \rightarrow K^+K^-$ & 1121±63 $B_d \rightarrow \pi^+\pi^-$
- *Expect first time-dependent measurements in 2011/2012 (including measurement of B_s lifetime in CP-even K^+K^- final state*

Prospects for direct CP violation in $B_{d/s} \to K\pi$

$\overline{B}_{d/s} \to K^- \pi^+$

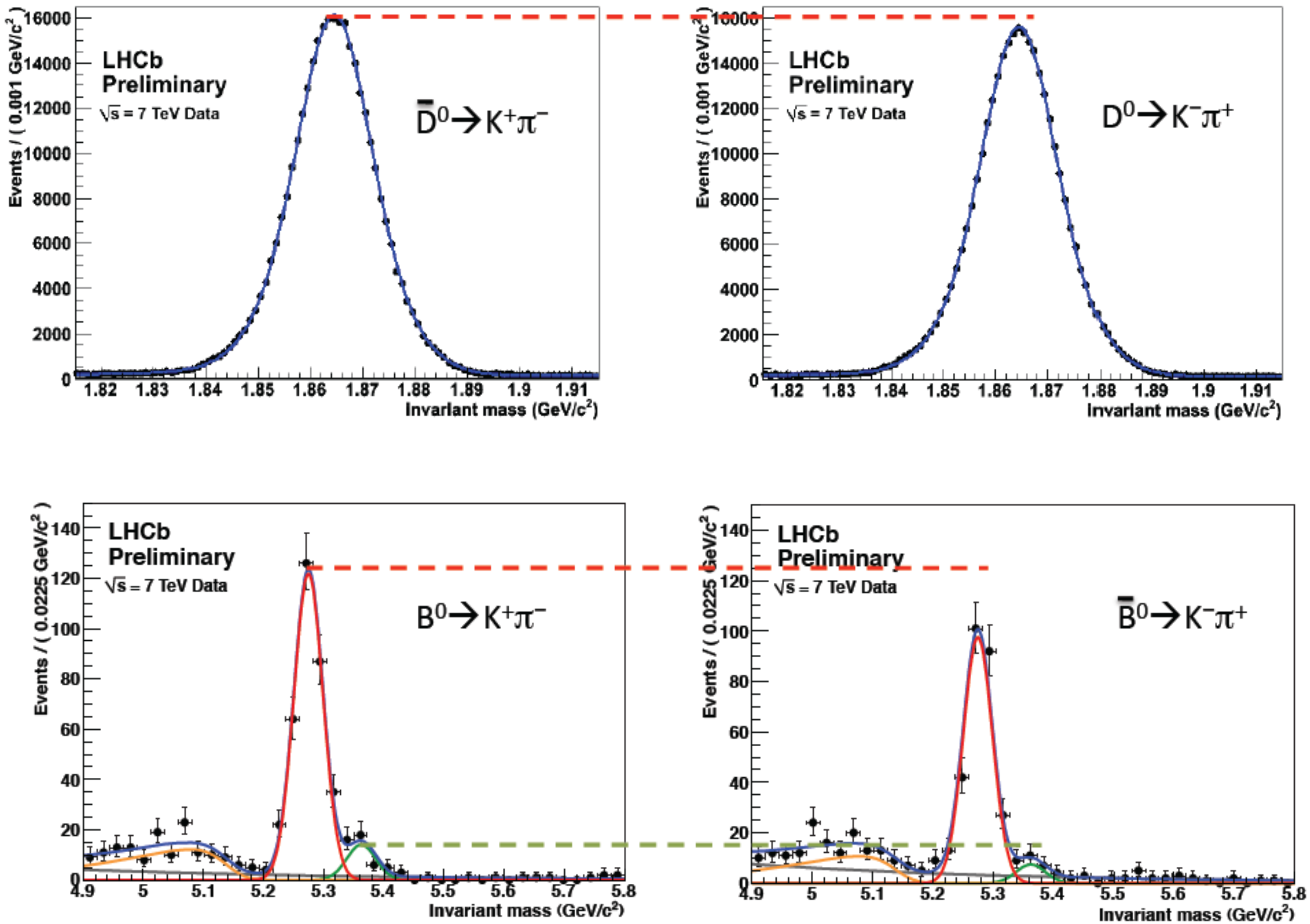


$B_{d/s} \to K^+ \pi^-$



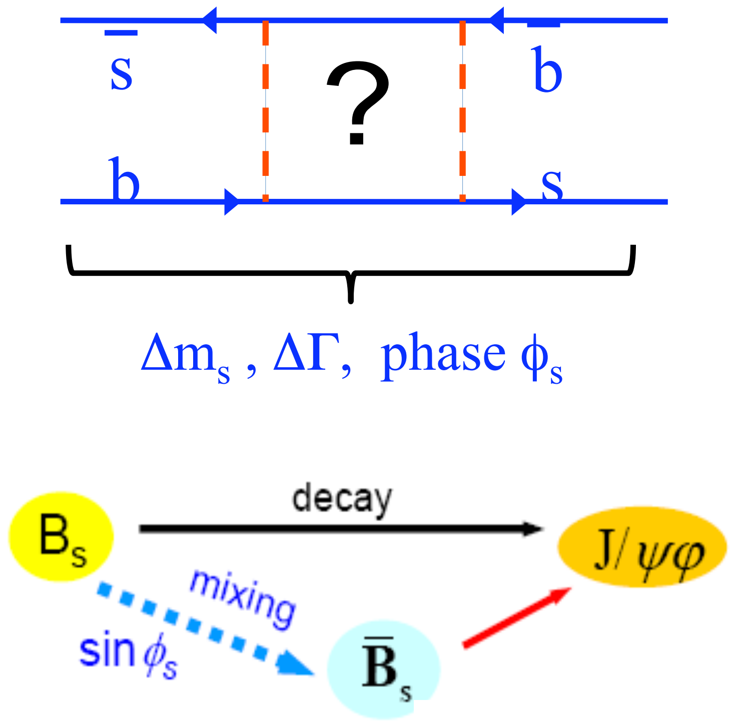
- ***Raw asymmetries clearly visible in data: direct CPV > 3σ***
- *Central values consistent with expectations and previous measurements*
- *Evaluation of systematic uncertainties is ongoing*

And a fair comparison…



B_s mixing phase $2\beta_s$

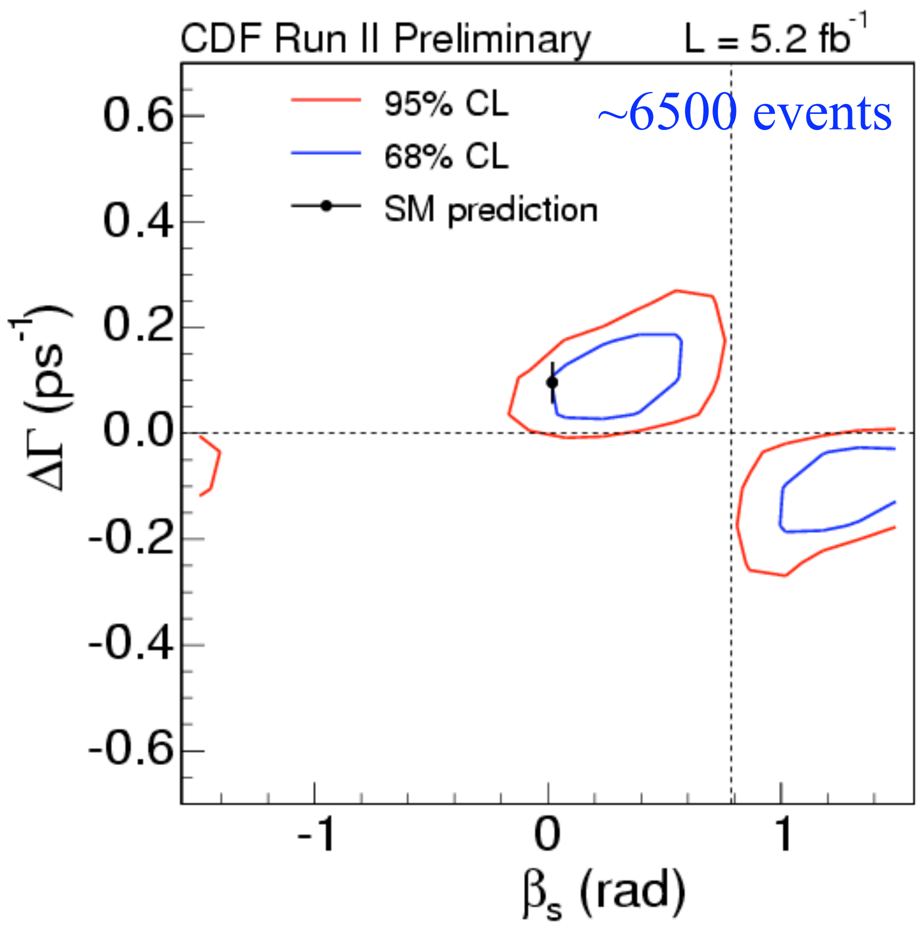
analogous to measurement in B_d system, with which BaBar/BELLE validated CKM model, but uses B_s mesons and can only be performed at hadron colliders



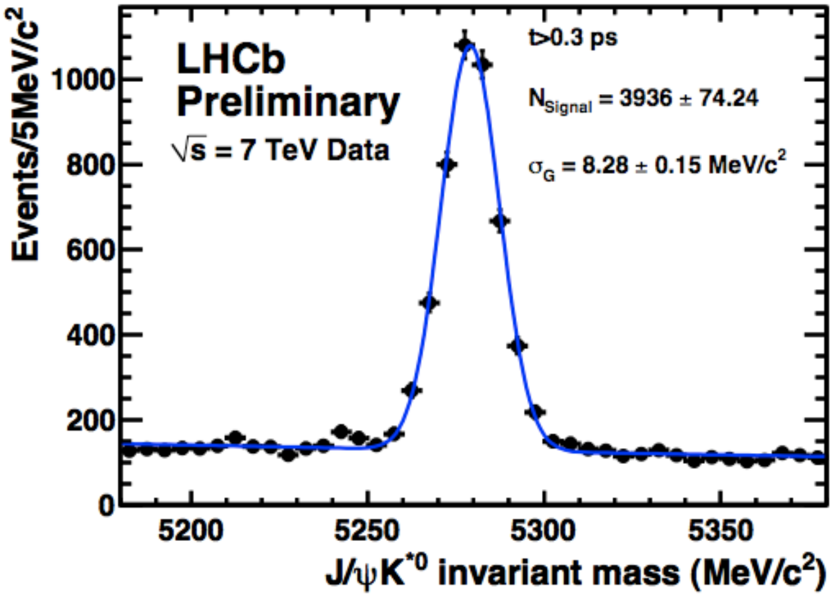
$$\phi_s^{SM} = -2\beta_s \approx -0.04$$

$$A_{CP}(t) \rightarrow \sin\phi_s$$

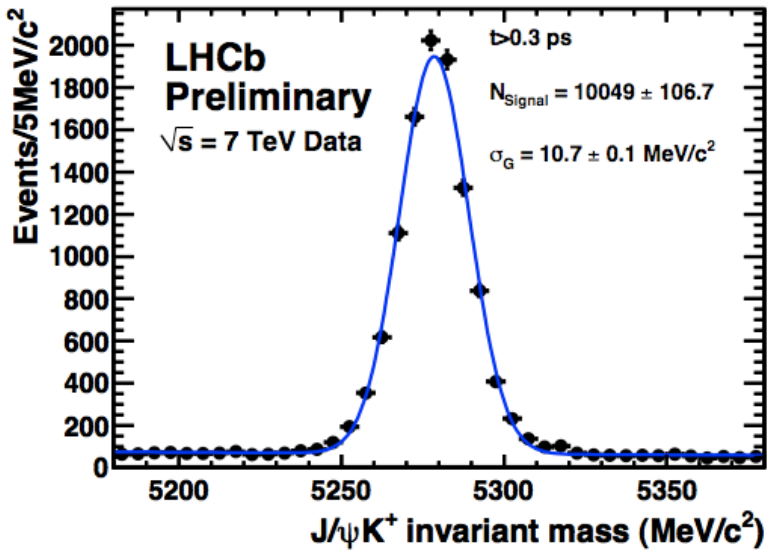
CPV in $B_s \rightarrow J/\psi\ \phi$



After trigger and selection the signal events for $B^{0,+} \rightarrow J/\psi K^{*,+}$ at LHCb are almost as clean as in e^+e^- - collisions at BELLE and BaBar



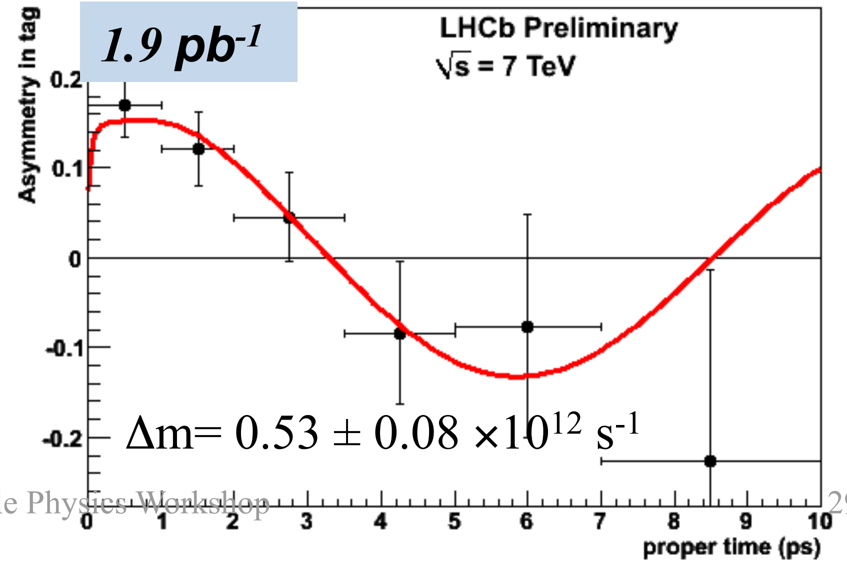
~ 34 pb-1



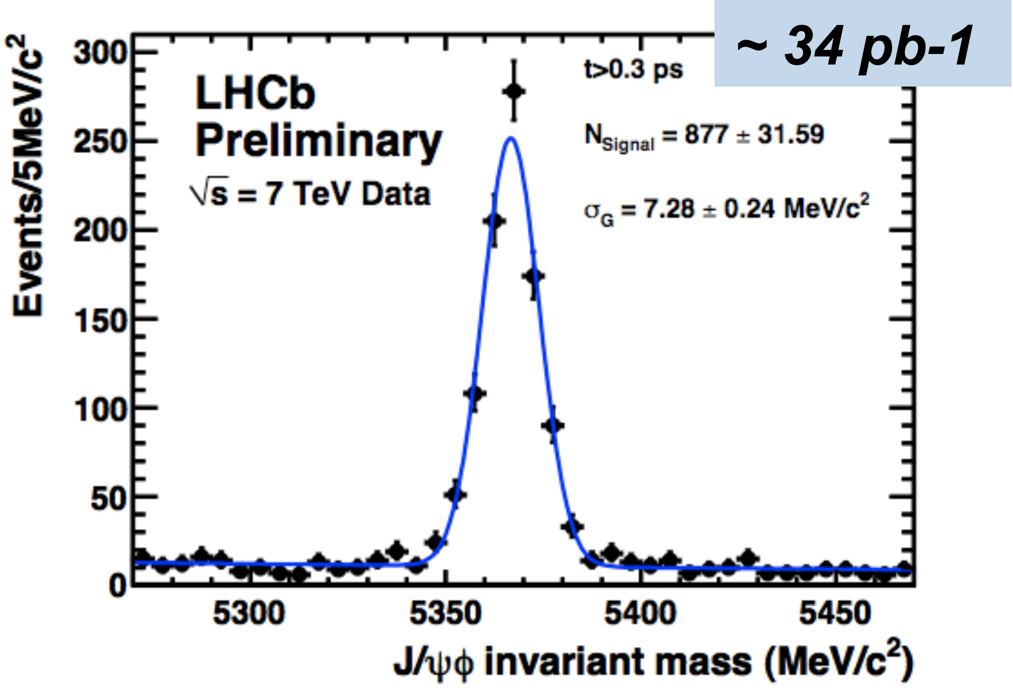
And LHCb observe clear signal for B_d oscillation with just 2 pb^{-1}
→ very useful to study tagging efficiency for CP Violation measurements !

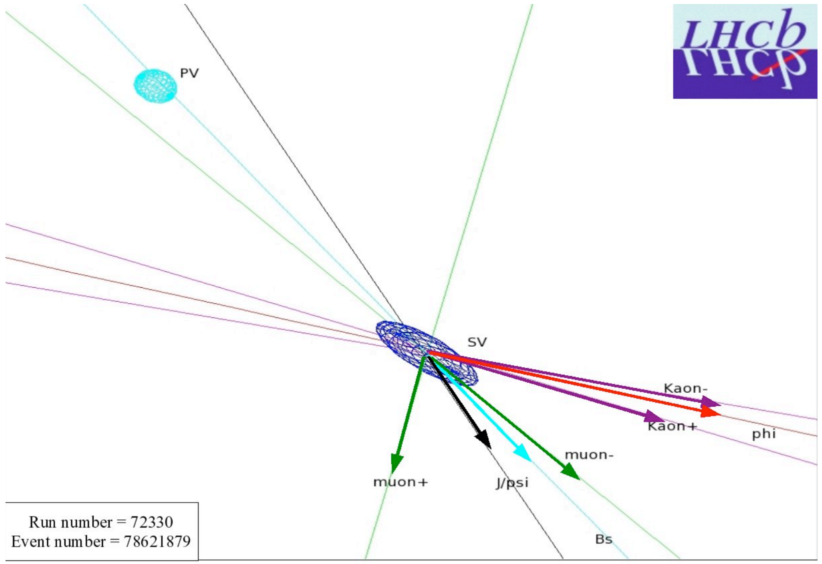
Uncalibrated tagging algorithms applied to $B^0 \rightarrow D^{*-}(D^0\pi^-)\mu^+\nu$ evts :

~60% of expected performance
Calibration & tuning ongoing



Very clean $B_s \rightarrow J/\psi\phi$ signal



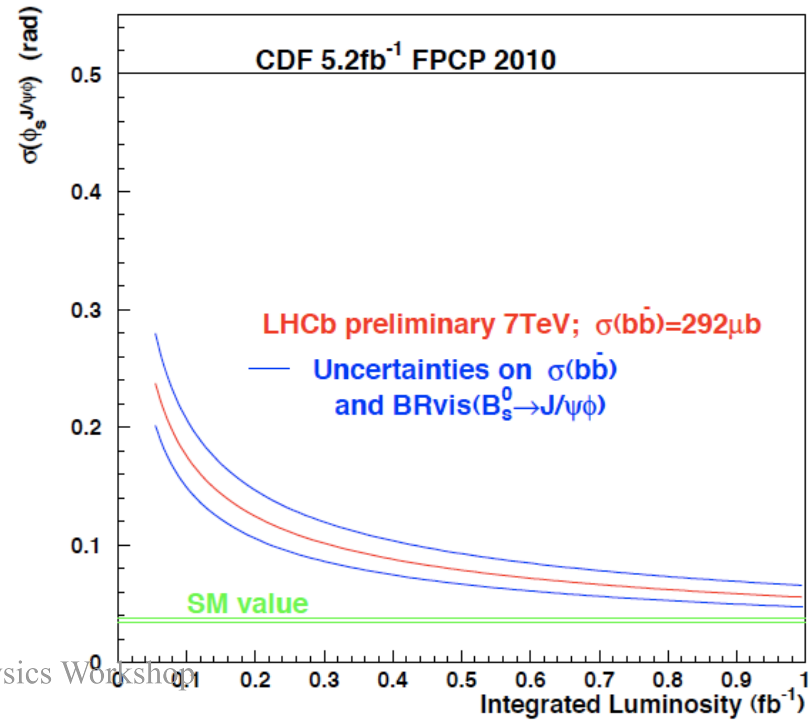


Expected sensitivity for $2\beta_s$

Event yield consistent with number of $B_s \rightarrow J/\psi\phi$ candidates seen in data

$\langle\sigma_t\rangle$ = 0.040 ps. Present time resolution worse in data but sufficient for Δm_s ~ 17.7/ps

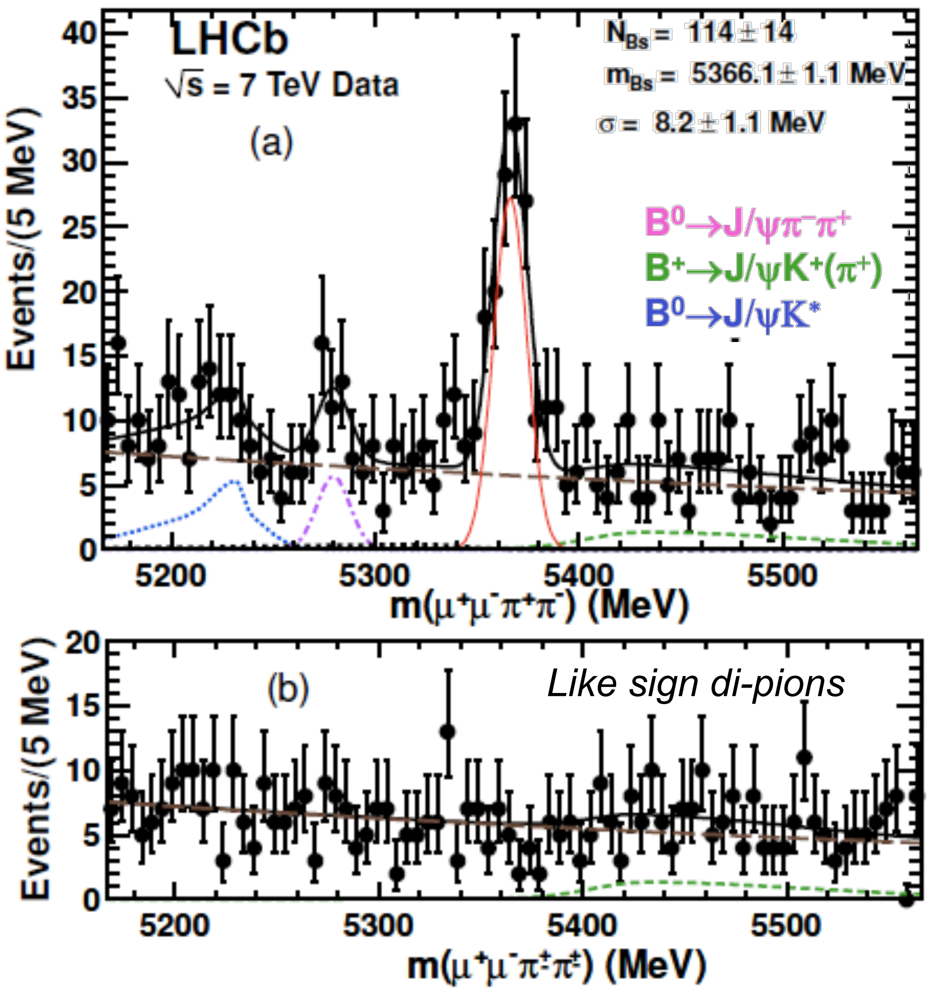
Tagging performance is being tuned using data

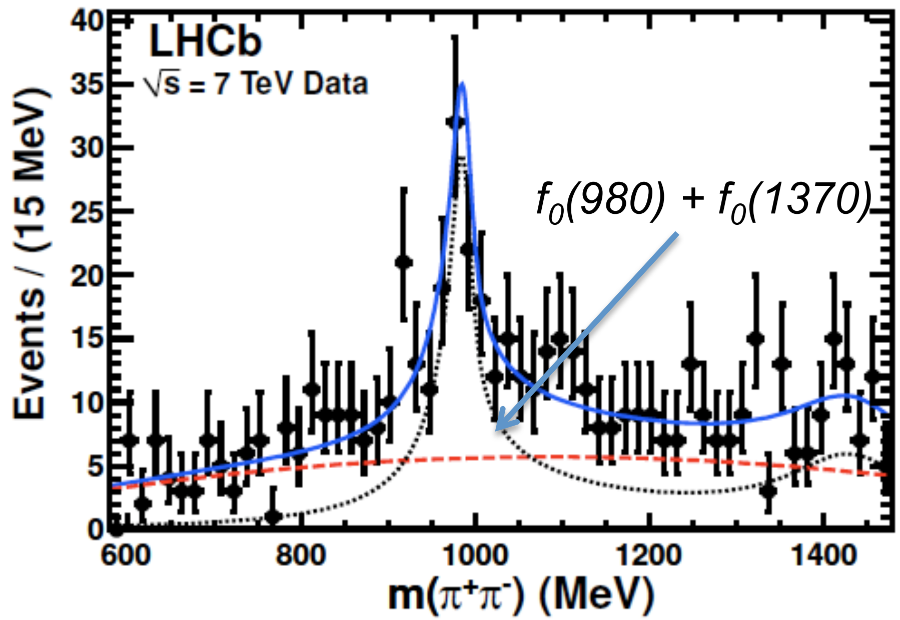


First observation of $B_s \rightarrow J/\psi f_0(980)$ decays

- *$B_s \rightarrow J/\psi\, f_0$, $f_0 \rightarrow \pi^+\pi^-$ is CP-eigenstate*
- *Looks promising for ϕ_s measurement since BR is large:*

$$\frac{\Gamma(B_s \rightarrow J/\psi f_0,\ f_0 \rightarrow \pi^+\pi^-)}{\Gamma(B_s \rightarrow J/\psi\phi,\ \phi \rightarrow K^+K^-)} = 0.252^{+0.046+0.027}_{-0.032-0.033}$$

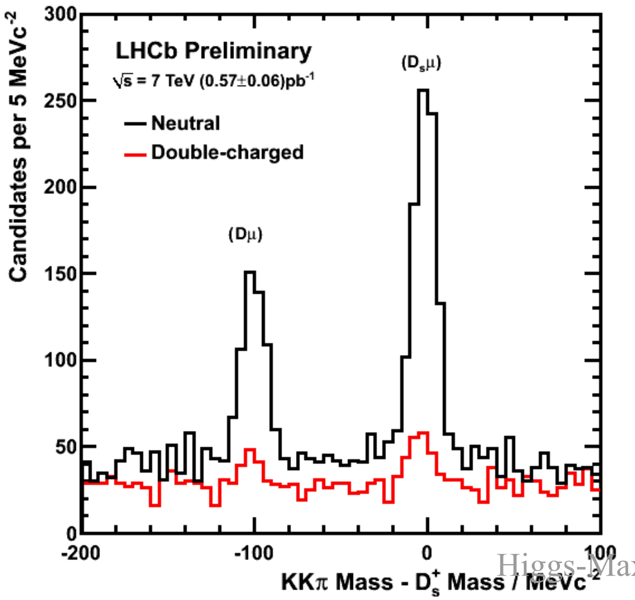


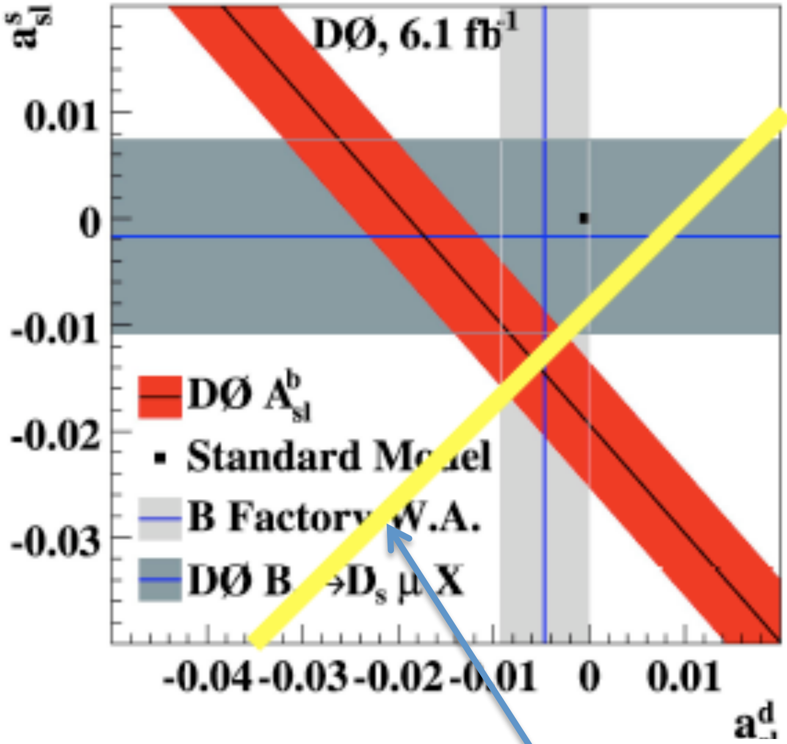


Search for CP violation in mixing

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.

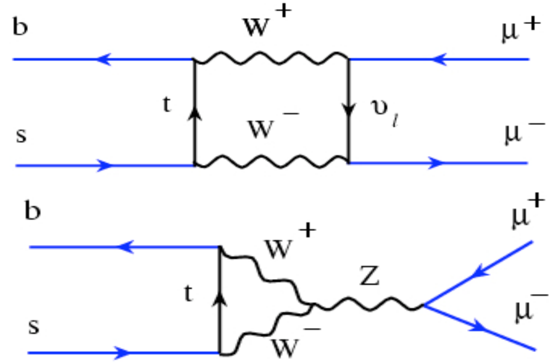
- *Inclusive like-sign dileptons sensitive to combination of effects from B_d and B_s mixing*
- *Alternative approach: study difference of effects in $B_d \to D^+\mu\nu X$ and $B_s \to D_s^+\mu\nu X$*
- *Use common final state $D, D_s \to KK\pi$ so that most systematics cancel*



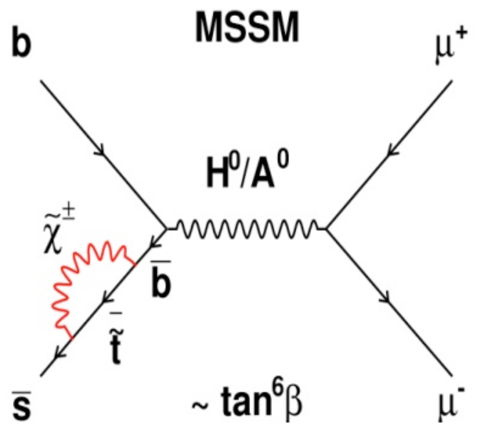


LHCb expectation with $1\ fb^{-1}$ (stat error only), assuming D0 central value and no NP in a^d_{sl}

Search for $B_s \to \mu\mu$ decay



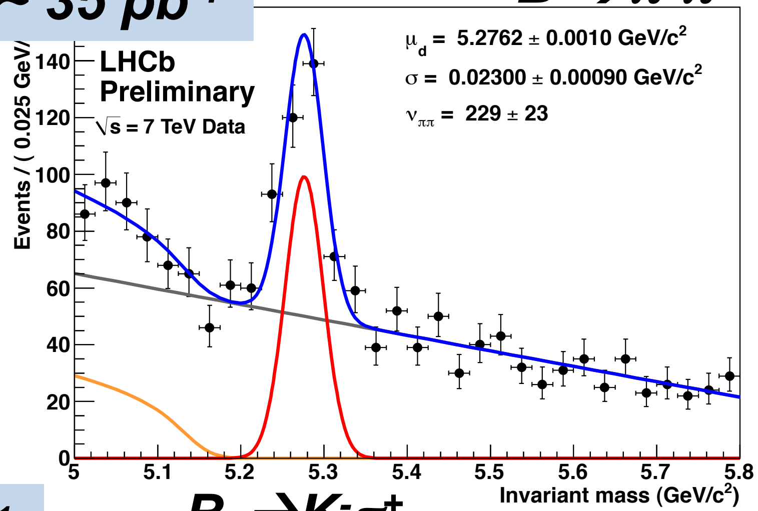
- Super rare decay in SM with well predicted $BR(B_s \to \mu\mu) = (3.2 \pm 0.2)\times 10^{-9}$
  $BR(B_d \to \mu\mu) = (1.1 \pm 0.1)\times 10^{-10}$
- Sensitive to NP, in particular new scalars
  In MSSM: $BR \propto \tan^6\beta / M^4_A$



Main control channels:
$B \to \pi\pi$, $B_s \to KK$

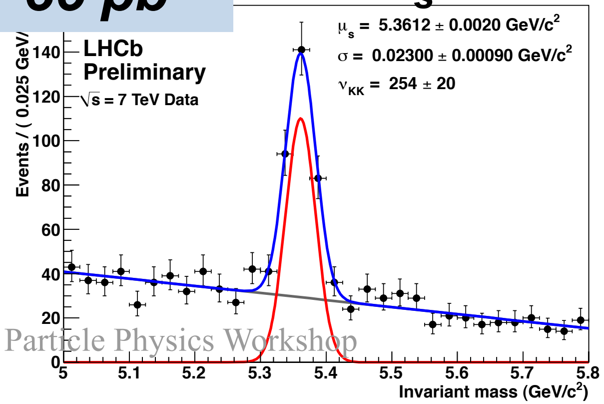
~ 35 pb^{-1}

$B^0 \to \pi^+\pi^-$



~ 35 pb^{-1}

$B_s \to K^-\pi^+$



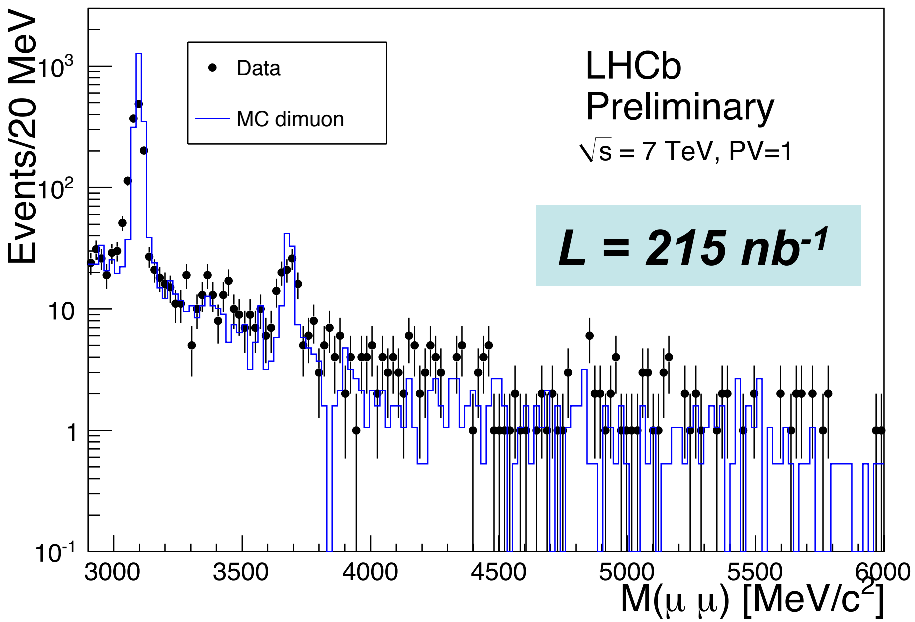
Observed yields:

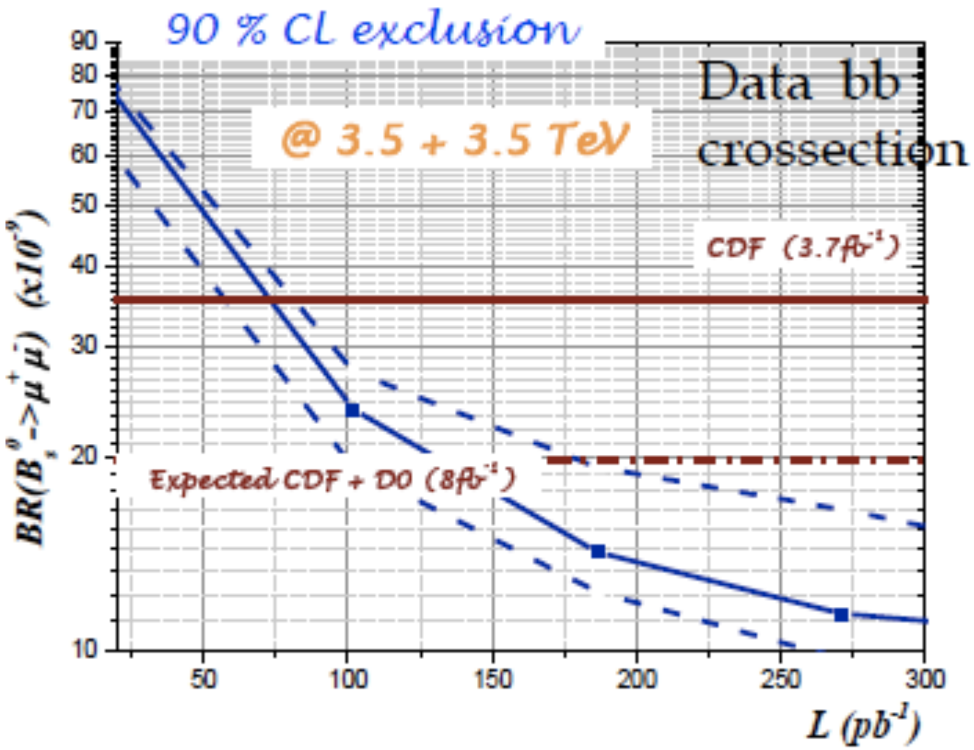
229±23 ev. for $B^0 \to \pi\pi$ with BR ~ 5×10^{-6}
254±20 ev. for $B_s \to K\pi$ with BR ~ 3×10^{-5}

Prospects for $B_s \rightarrow \mu\mu$

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

Background expected from MC is in good agreement with data





Very interesting sensitivity possible even with 40 pb^{-1} !!!

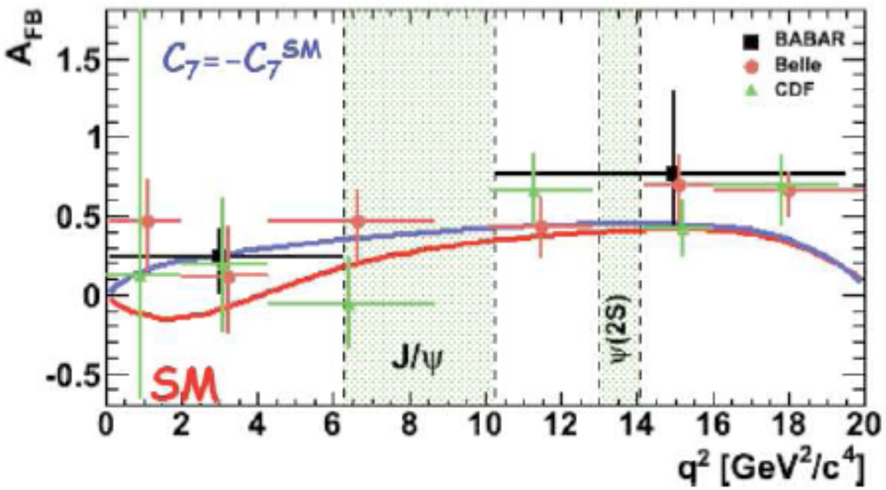
With L ~ 1 fb^{-1} exclusion of SM enhancement up to BR($B_s \rightarrow \mu\mu$) ~ 7×10^{-9}

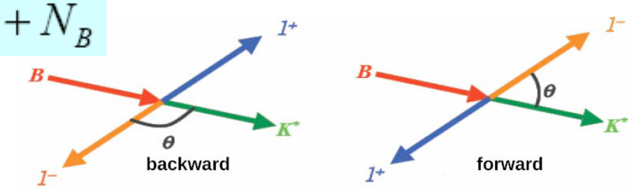
Test of NP helicity structure: B → $K^*\mu\mu$, K^*ee, $B_s \to \phi\gamma$

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

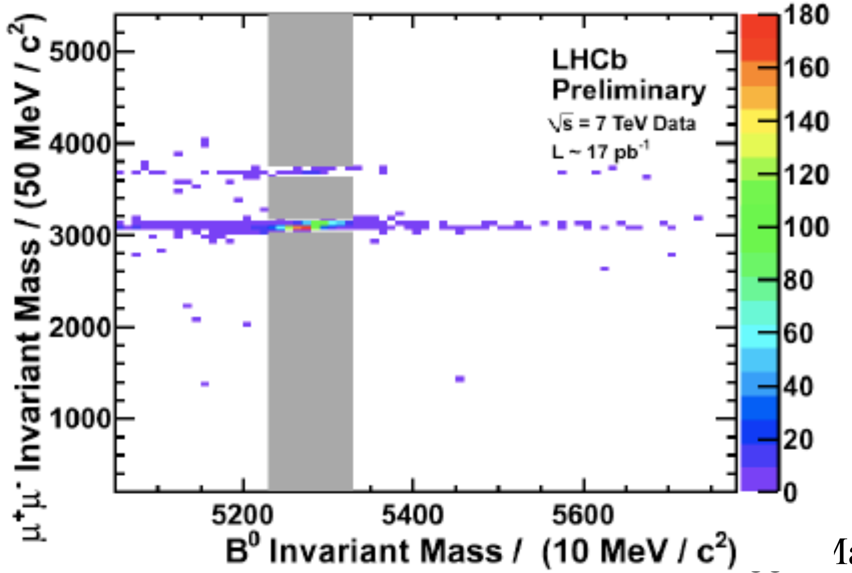
$$A_{FB}\left(s = m^2_{\mu^+\mu^-}\right) = \frac{N_F - N_B}{N_F + N_B}$$

Forward-backward asymmetry





- *BELLE, BaBar and CDF consistent with each other and SM*
- *Flipped C_7 scenario looks however more favoured from A_{FB} data*

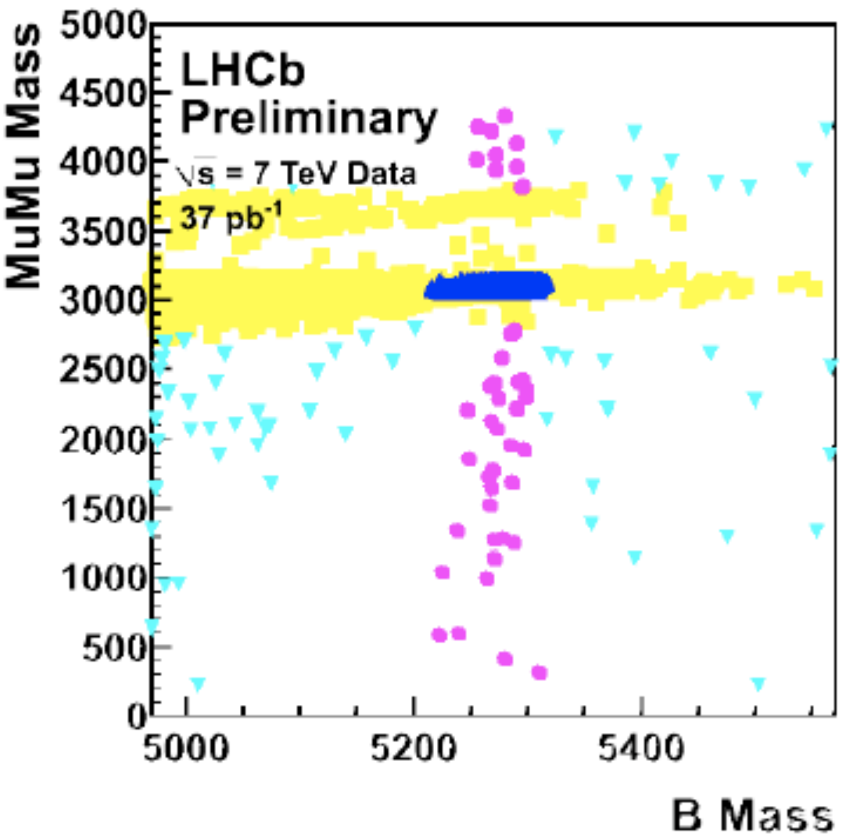


- *Signal region blinded but background level low as expected*
- *With 1 fb^{-1} LHCb expects ~1400 events, and should clarify existing situation. Expected accuracy in* ***A_{FB} zero crossing point is ~0.8 GeV^2 in 1 fb^{-1}***

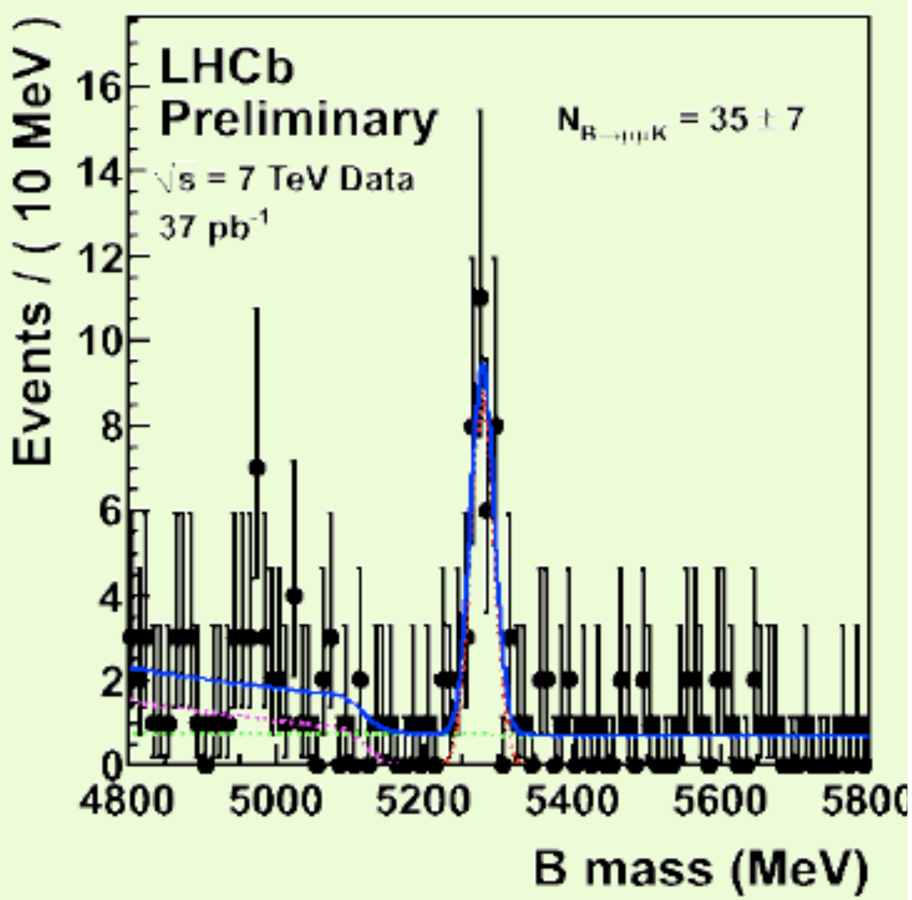
$B \rightarrow K\mu\mu$ is seen !!!

($BR \sim 5 \times 10^{-7}$)

Cuts trained on $B \rightarrow J/\psi\, K$ signal



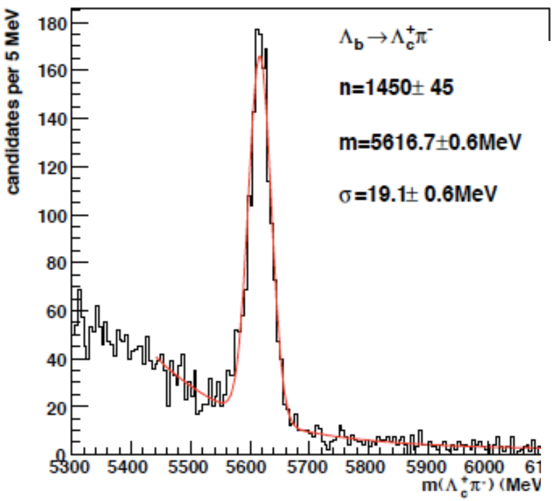
Observe 35 $B^+ \rightarrow \mu\mu K^+$ events in 37 pb^{-1}

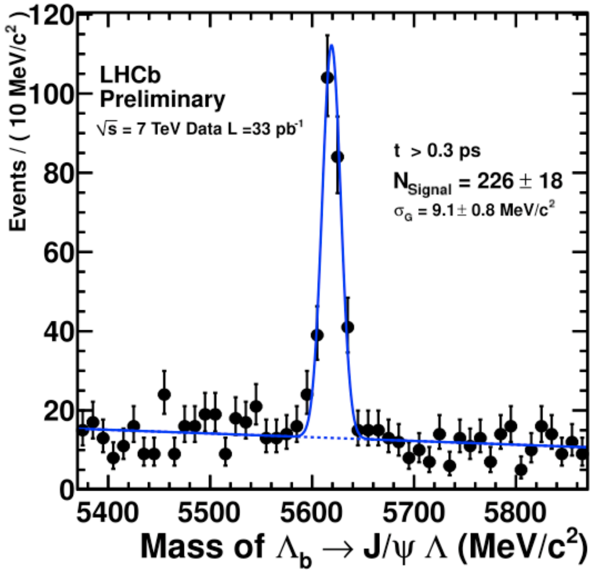


B mass fit to events outside of $c\bar{c}$ veto

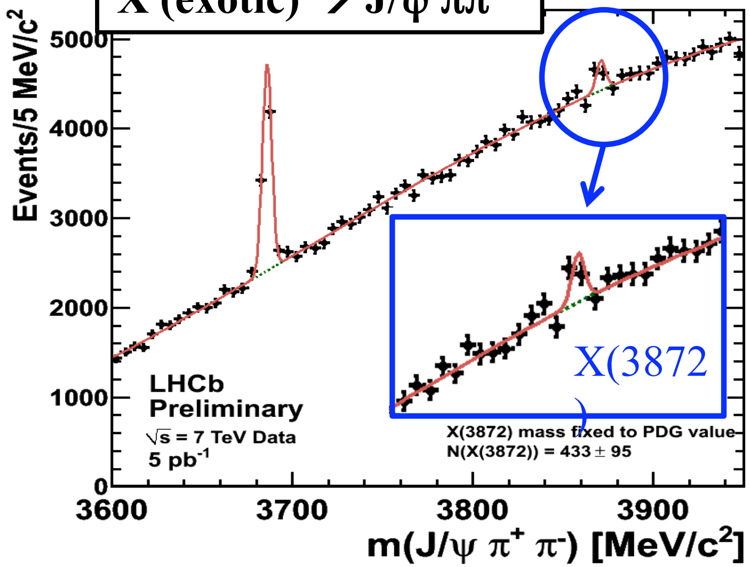
“Standard” physics: *Excellent spectroscopy possible with LHCb*

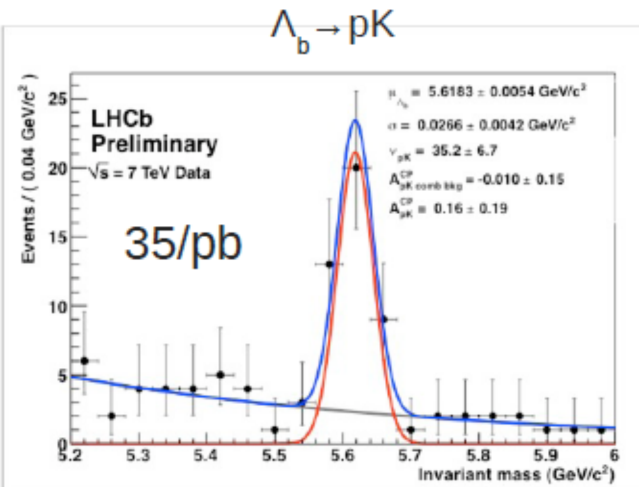
Λ_b baryons

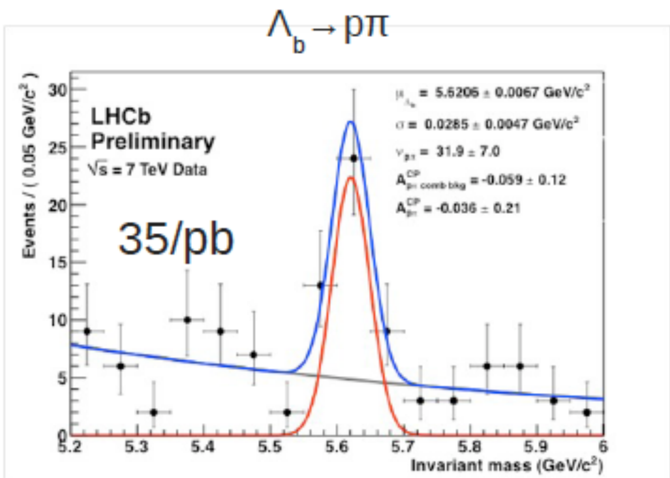




X (exotic) → J/ψ ππ







Excellent prospects for A_{CP} observation with $L \sim 1\ fb^{-1}$

Conclusion

- *First data are being used for calibration of the detector and trigger in particular. LHCb may be called GPD in the forward direction*

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

  - *Heavy flavour resonances and mesons have been reconstructed (Z & W candidates as well)*

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

- ***High class measurements in the charm sector should be possible with 40 pb^{-1}***

- ***$B_s \rightarrow \mu\mu$ and $B_s \rightarrow J/\psi\phi$ will reach interesting sensitivity regime with ~ 40 pb^{-1}. Exciting prospects of discovery with full 1 fb^{-1} sample***

- *Expect 25-50 times more data in next year(s) Run. This will allow for high discovery potential in these two measurements, and in many more …*