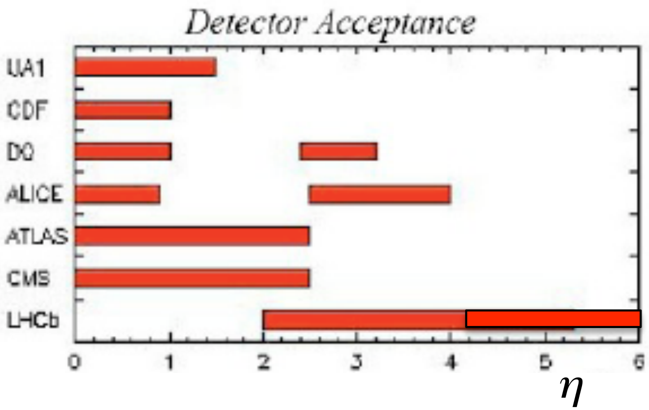
Status and Results from LHCb

@ La Thuile 2011 - *Les Rencontres de Physique de la Vallée d'Aoste*

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

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

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



LHCb is fully instrumented to provide:

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

&

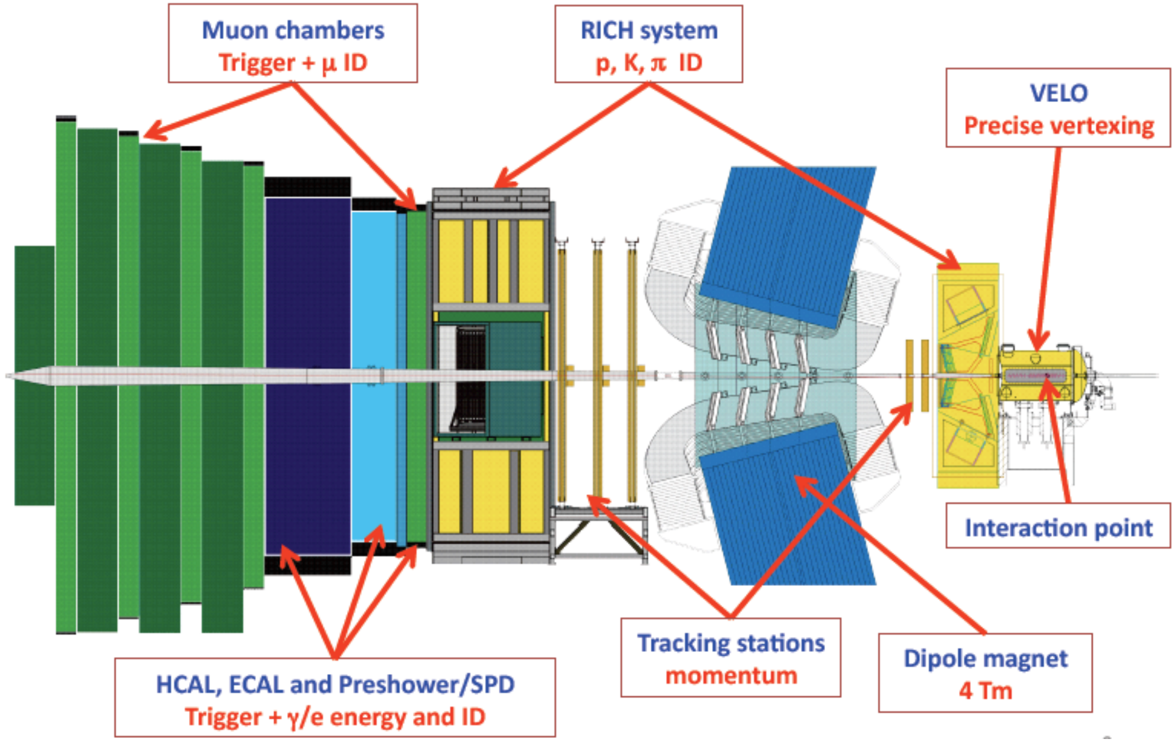
Flexible Trigger to low P_t particles

In particular well suited for flavour physics:

- Large bb (& cc) cross sections

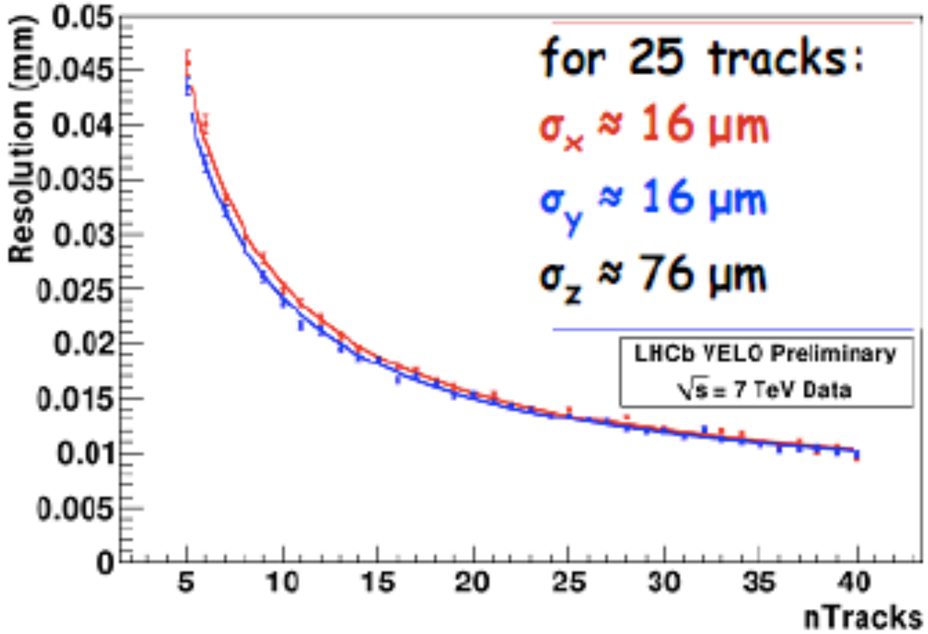
- All B hadron species available

- Long decay flight
~ 1cm for b hadrons



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

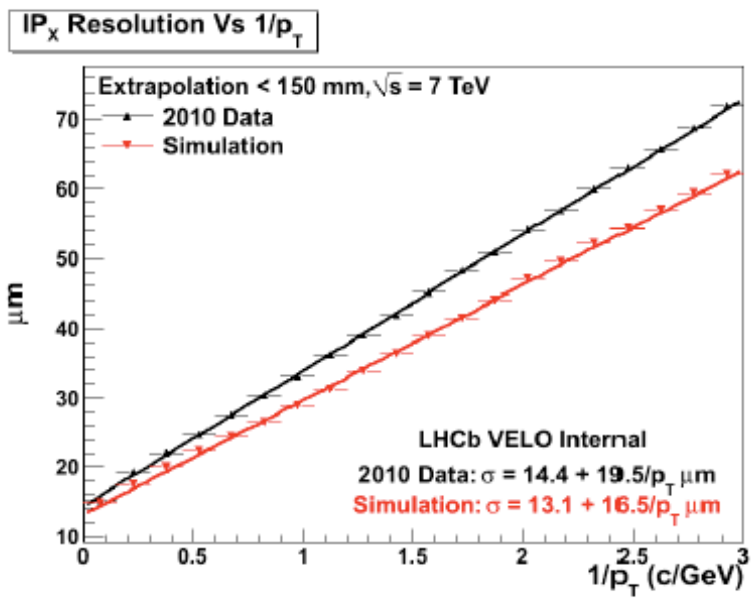


Resolution for PV with 25 tracks

*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

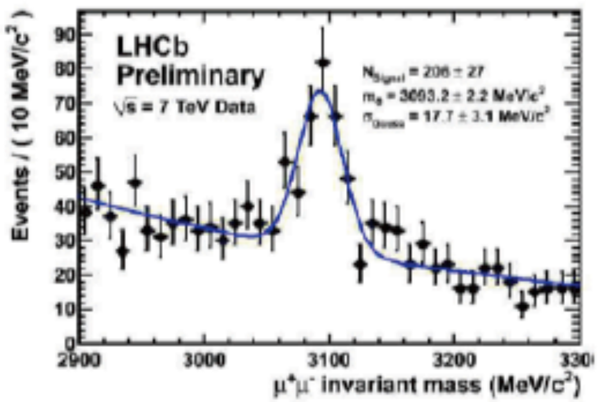
- *slope determined by multiple scattering, not an alignment effect*
- *improvement of material description is ongoing*



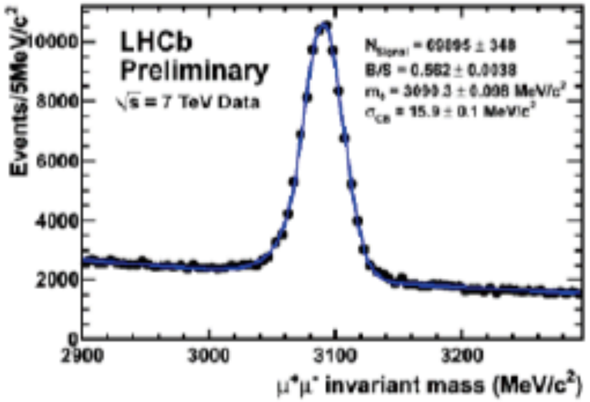
Tracking: excellent mass resolution demonstrated

Evolution of J/ψ → μ⁺μ⁻ mass resolution with time (MC ~ 12 MeV/c²)

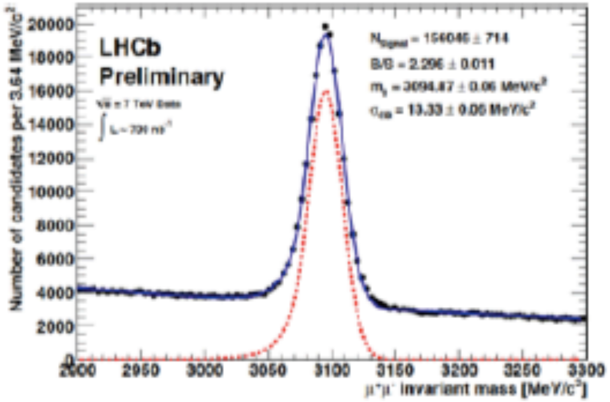
May: σ ~ 18 MeV/c²



August: σ ~ 16 MeV/c²

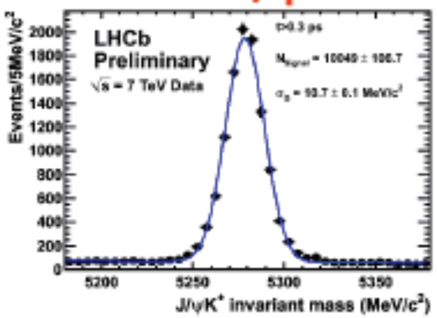


November: σ ~ 13 MeV/c²



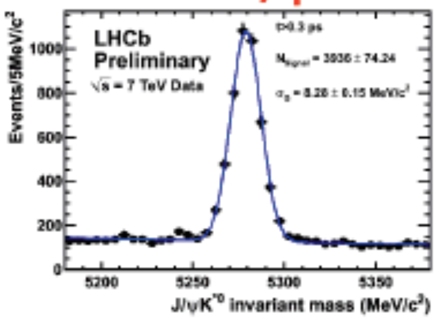
Different B hadron species in J/ψX final states

B⁺ → J/ψK⁺



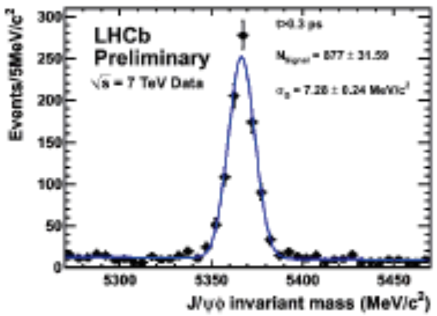
σ~11 MeV/c²

B⁰ → J/ψK*⁰



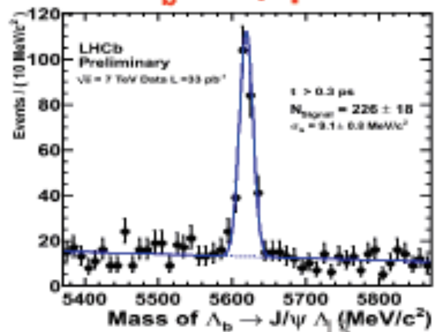
σ~8 MeV/c²

B_s → J/ψφ



σ~7 MeV/c²

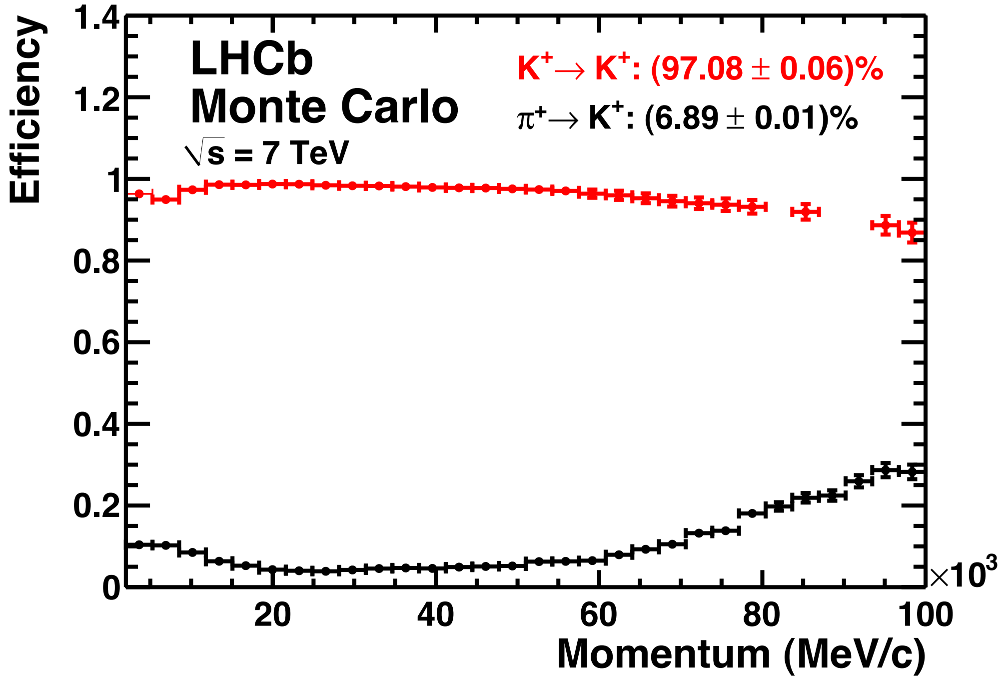
Λ_b → J/ψΛ



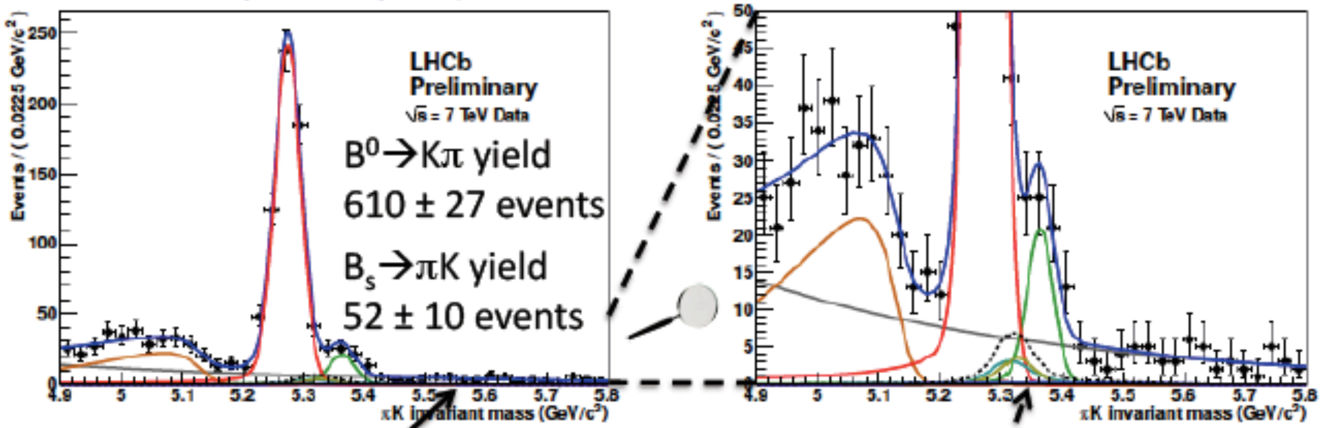
σ~9 MeV/c²

PID: RICH

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



mass resolution
σ = (21.3 ± 0.7) MeV/c²

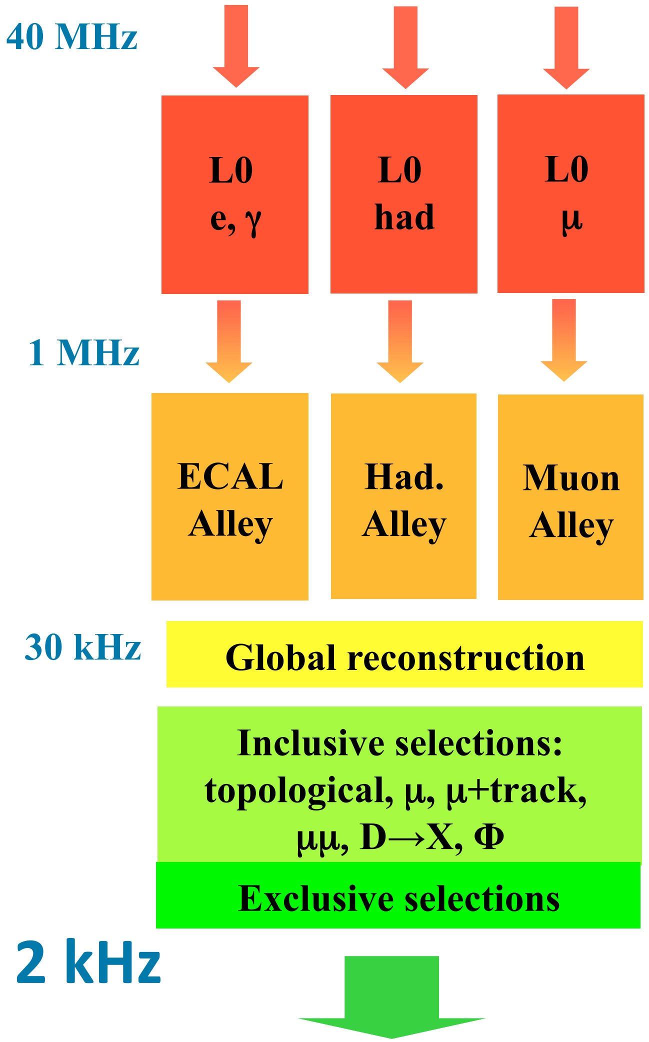


Tighter kinematic and PID selection cuts provide strong suppression of combinatorial background events

$B^0 \rightarrow \pi\pi$
$B_s \rightarrow KK$

Dashed curve is basically the sum of these two modes: their lineshapes are fixed from MC

LHCb Trigger



Stripped for physics

Level-0

'High-pt' signals in calorimeter & muon systems

HLT1

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

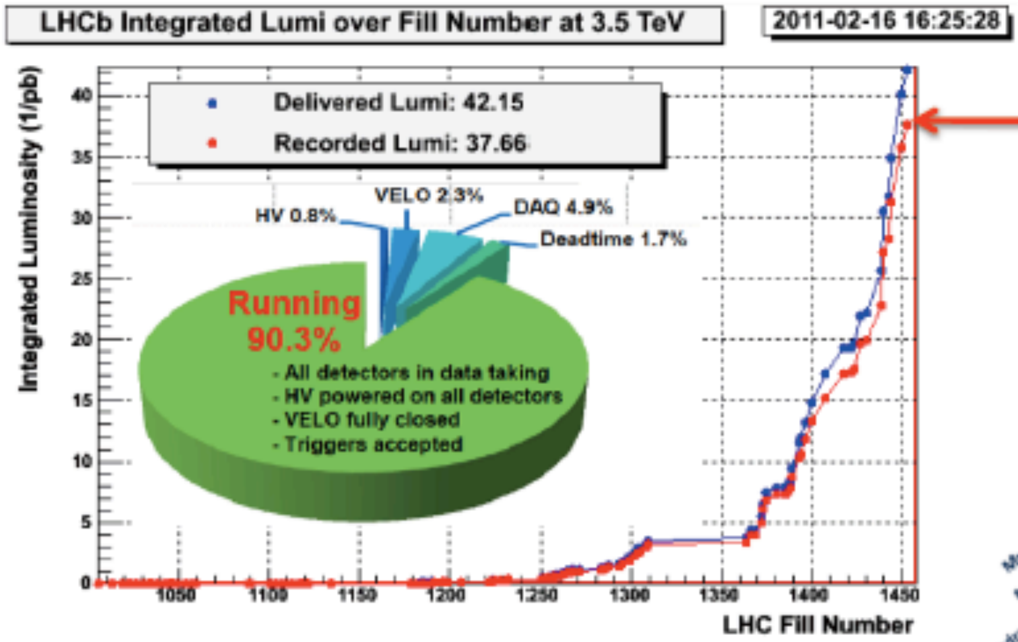
HLT2

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

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%

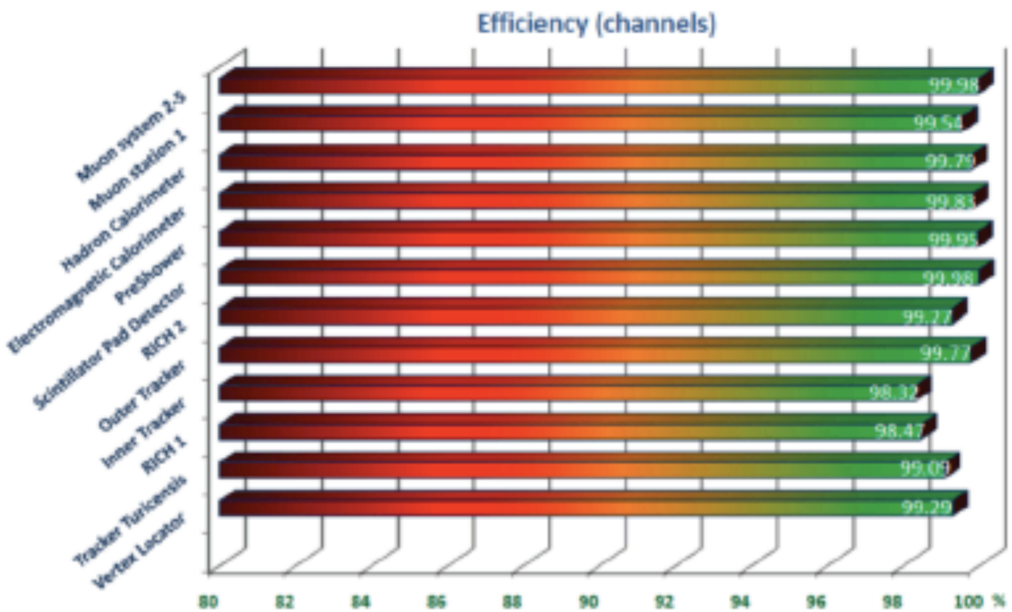
LHCb Operation in 2010



Recorded approximately 37 pb^{-1} in 2010 run with all detectors fully operational

Data taking efficiency around 90% over the year

Largest part of data taken during last month of running

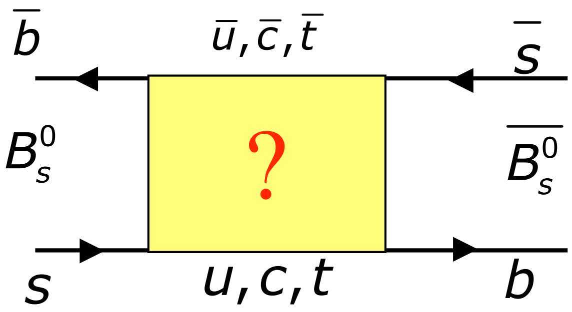


all sub-detectors >99% efficient

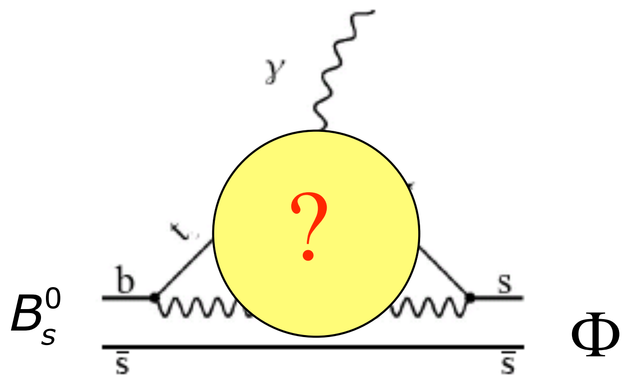
LHCb Physics Programme

- *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 !***



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

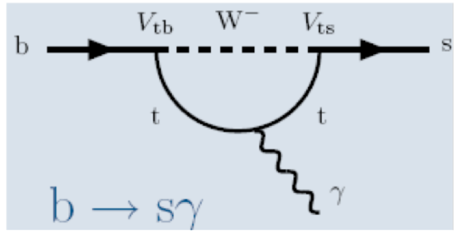


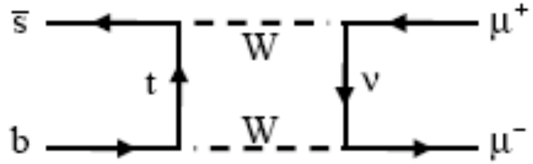
Sensitivity to masses, couplings, spins and phases of New Particles

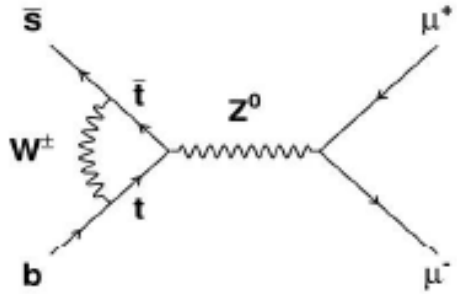
Main LHCb Physics Objectives

Search for New Physics in CP violation and Rare Decays

Correlation between photon helicity and b-flavour







CPV:

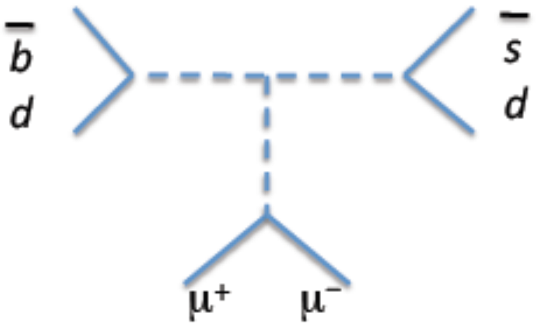
B_s oscillation phase Φ_s
CKM angle γ in trees and loops
CPV asymmetries in charm decays

Rare Decays

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

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

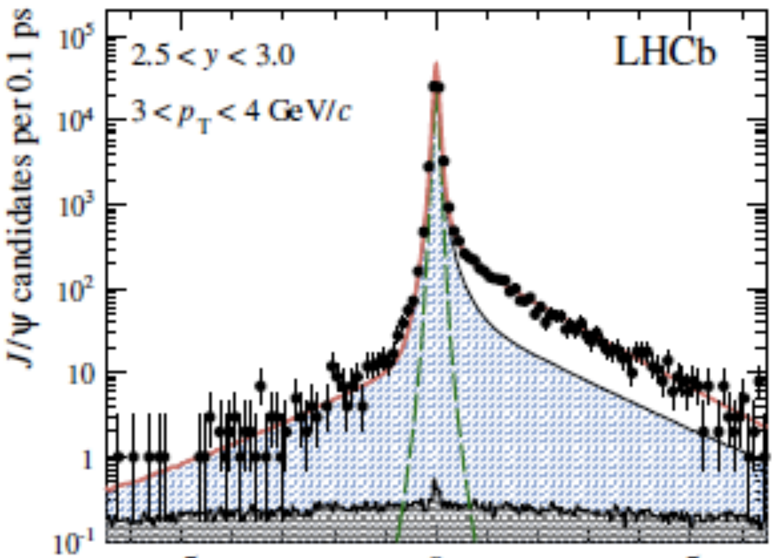
Leptonic: $B_{d,s} \rightarrow 4\mu, 4e$
Semileptonic: $B_{d,s} \rightarrow K^*\mu\mu, \phi\mu\mu$



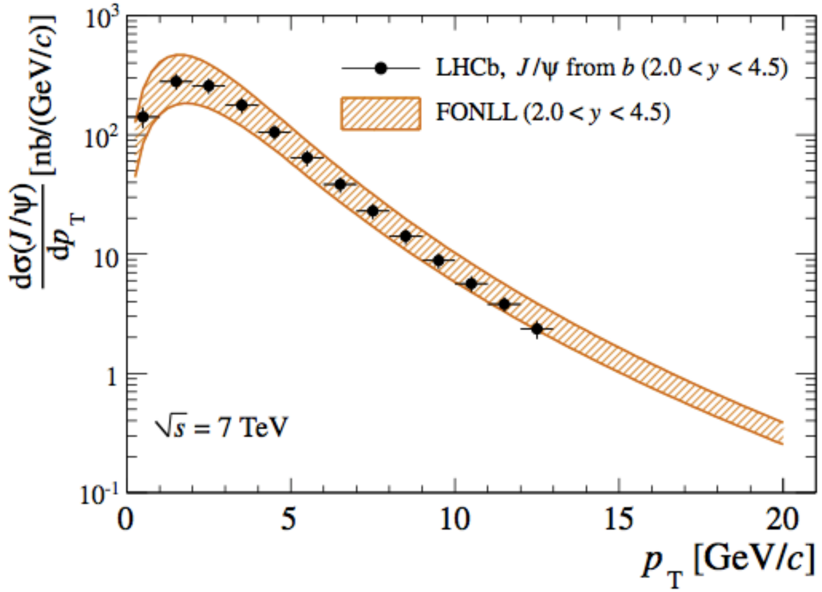
Hadronic: $B_{d,s} \rightarrow J/\psi\phi, \phi\phi$

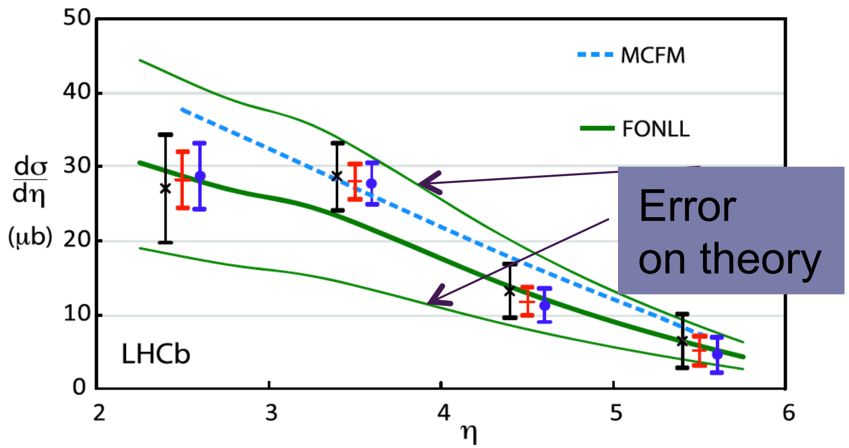
b cross section @ $\sqrt{s}$ = 7 TeV

Using J/ψ produced in B decays: $\sigma(J/\psi$ from b, $2<y<4.5) = 1.14\pm0.01\pm0.16\ \mu b$
→ $\sigma(pp \to bbX) = 288\pm4\pm48\ \mu b$



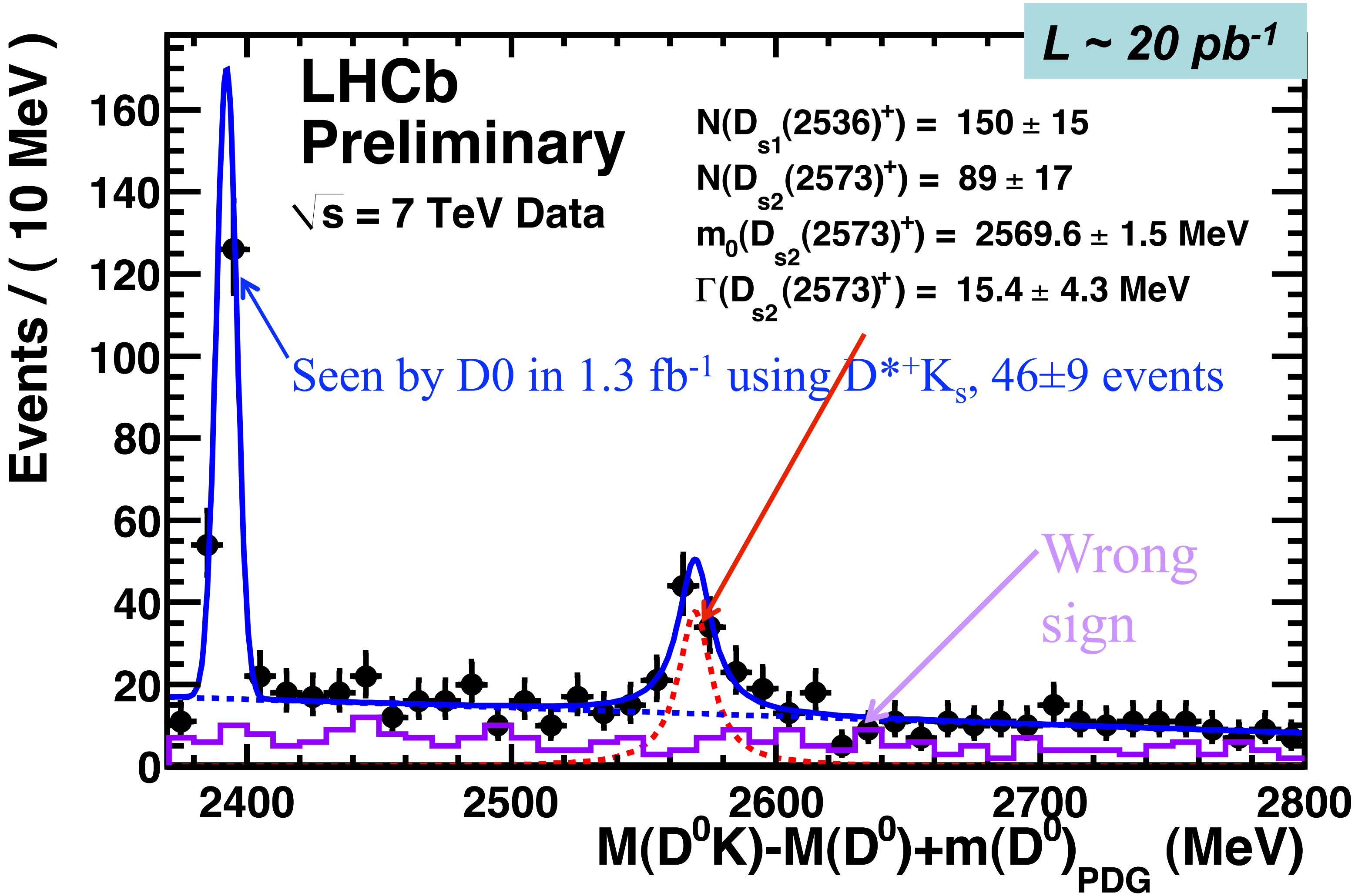
$$t_z = \frac{(z_{J/\psi} - z_{PV}) \times M_{J/\psi}}{p_z}$$





Excellent agreement with LHCb published value measured in $b \to D^0 \mu\nu X$:
$\sigma(pp \to bbX) = 284\pm20\pm49\ \mu b$

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



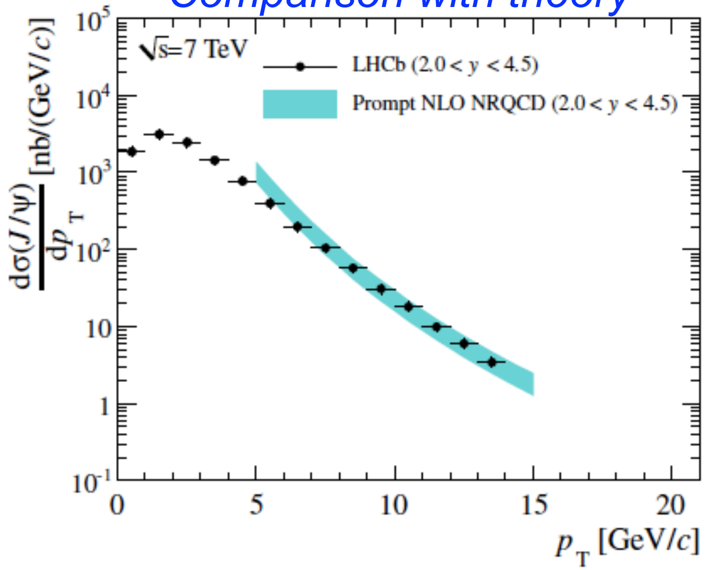
Prompt J/ψ and open charm cross-sections @ √s = 7 TeV

Prompt J/ψ production:

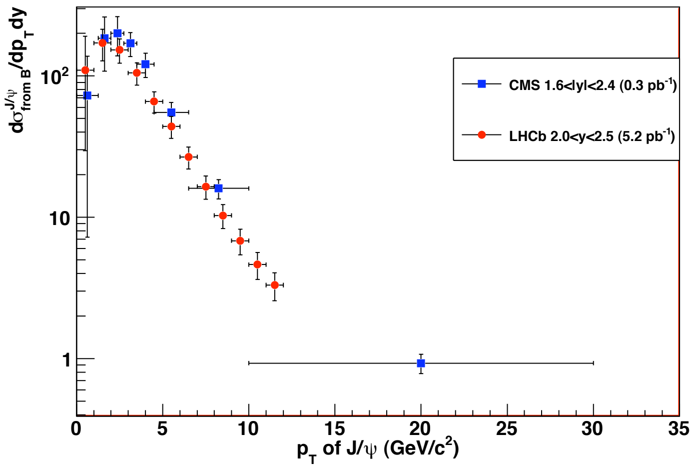
σ(prompt J/ψ, P_t<14 GeV/c, 2<y<4.5) =
= ($10.52 \pm 0.04 \pm 1.40^{+1.64}_{-2.20}$) μb

in good agreement with ALICE and CMS

Comparison with theory



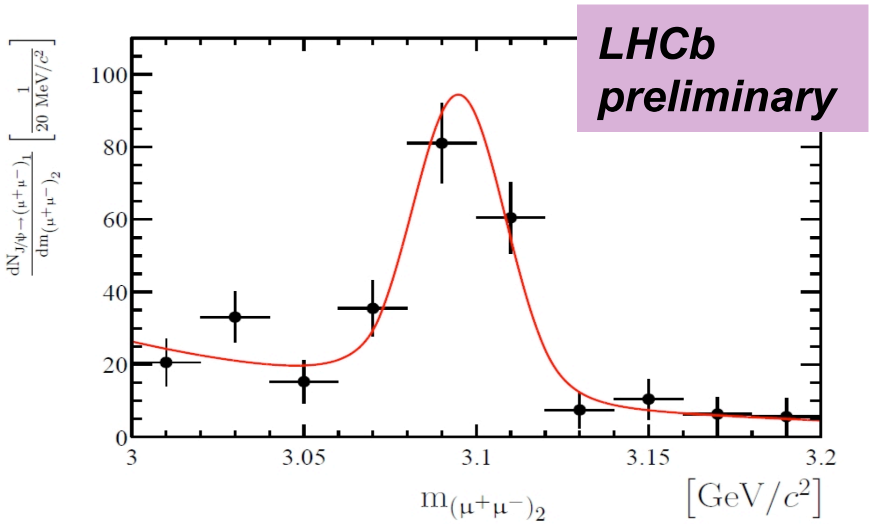
Comparison with CMS
in the overlapping region



N(2J/ψ) = 136.7±17.5
σ(2J/ψ, P_t (J/ψ)<10 GeV, 2<y(J/ψ)<4.5) =
= 5.6 ± 1.1 ± 1.2 nb

Open charm cross-sections
(D, D^0, D^+, D_s and Λ_c) have been measured as well*

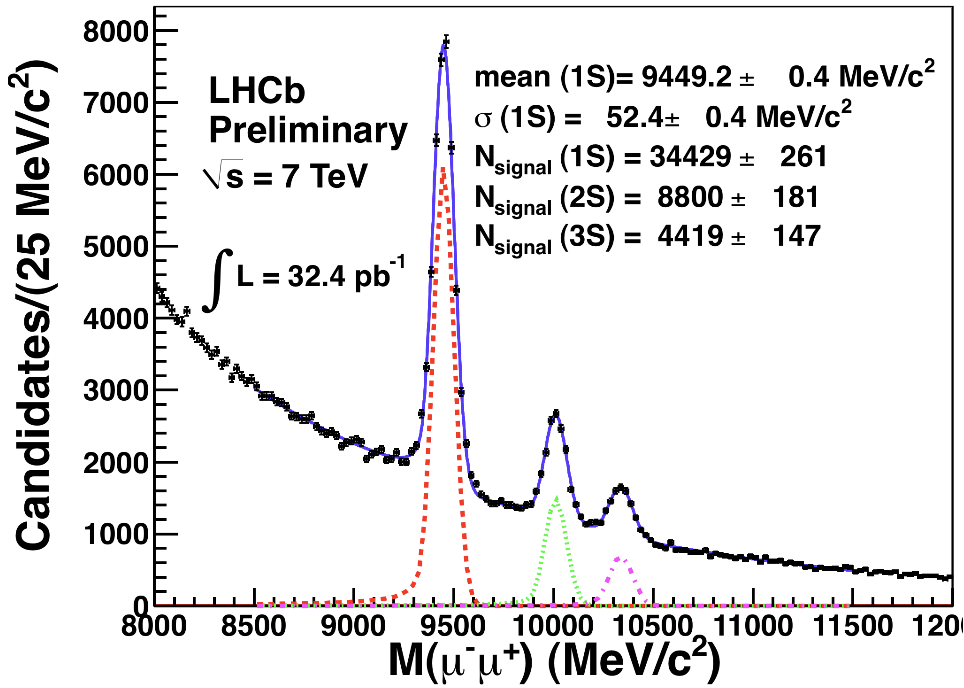
As expected huge charm production in the forward direction: ~20 × b



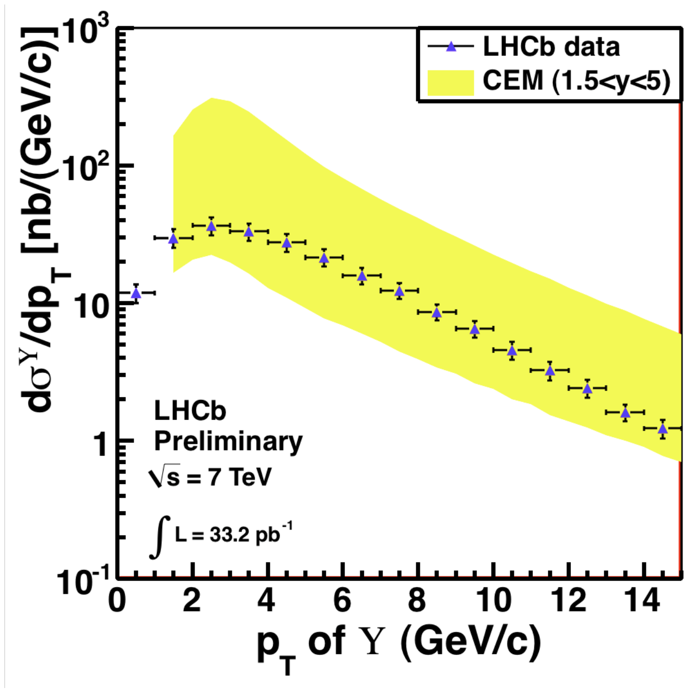
Upsilon production @ $\sqrt{s}$ = 7 TeV

LHCb preliminary:

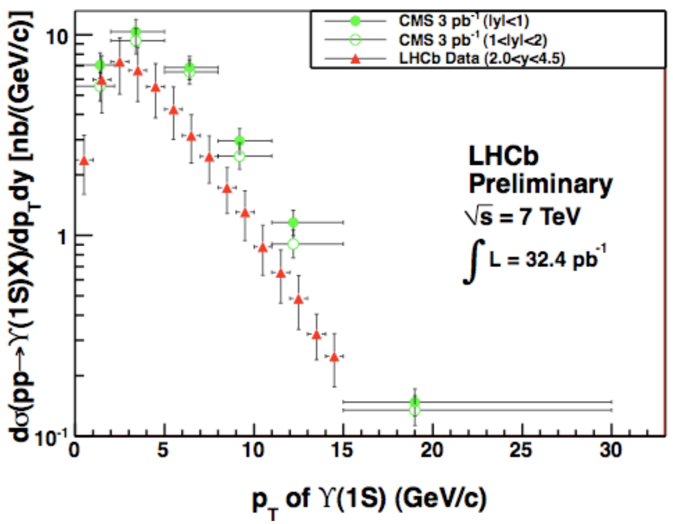
$\sigma(\Upsilon(1S), P_t < 15\ \text{GeV}, 2<y<4.5) =$
$= 108.3 \pm 0.7 \pm ^{30.9}_{25.8}\ \text{nb}$



Comparison with theory

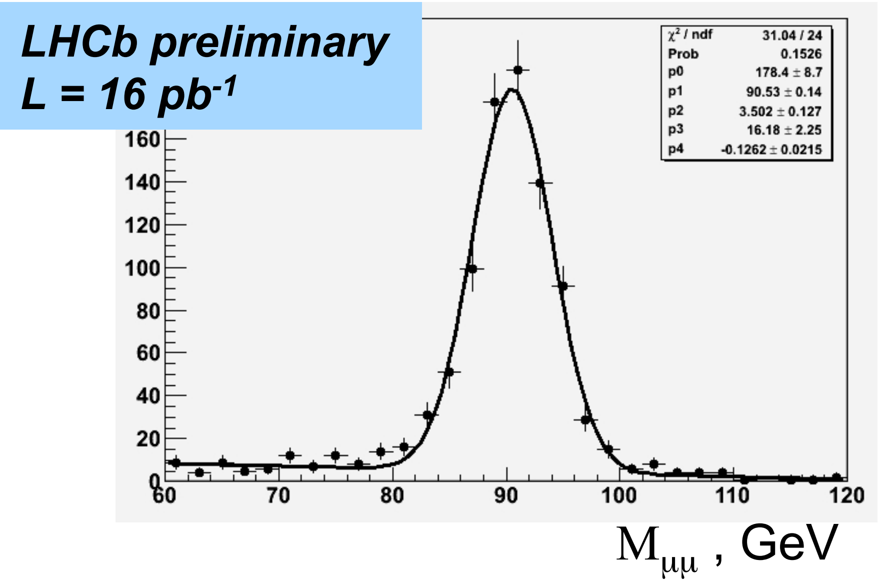


Comparison with CMS
(no overlap in y)

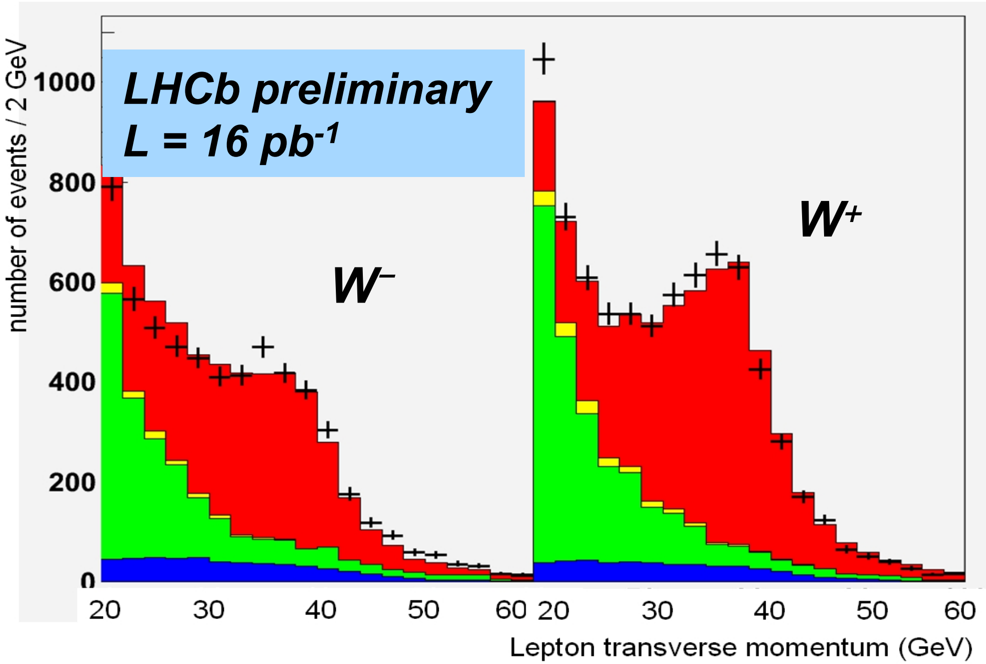


Z & W in the forward direction

Z: 2 μ, each with $P_t > 20$ GeV/c



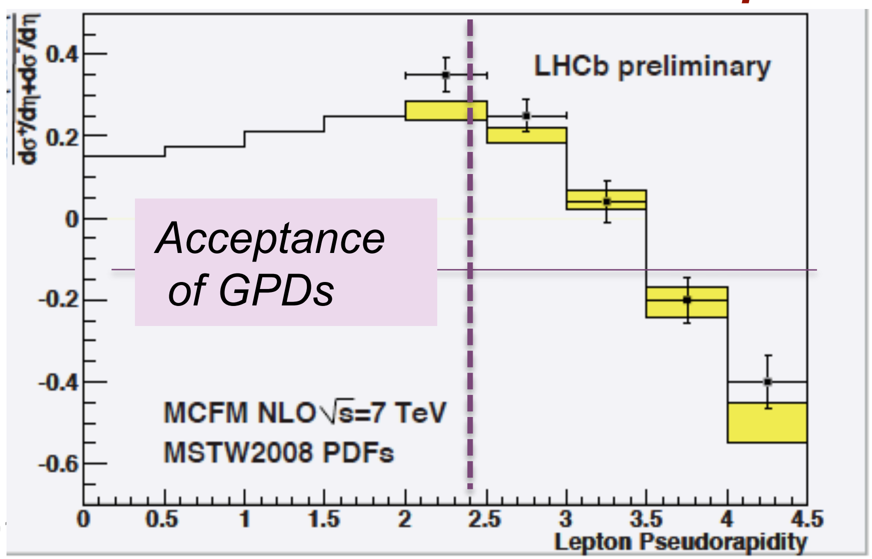
W: single isolated μ with $P_t > 20$ GeV/c & small P_t opposite



- Measurement of 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.

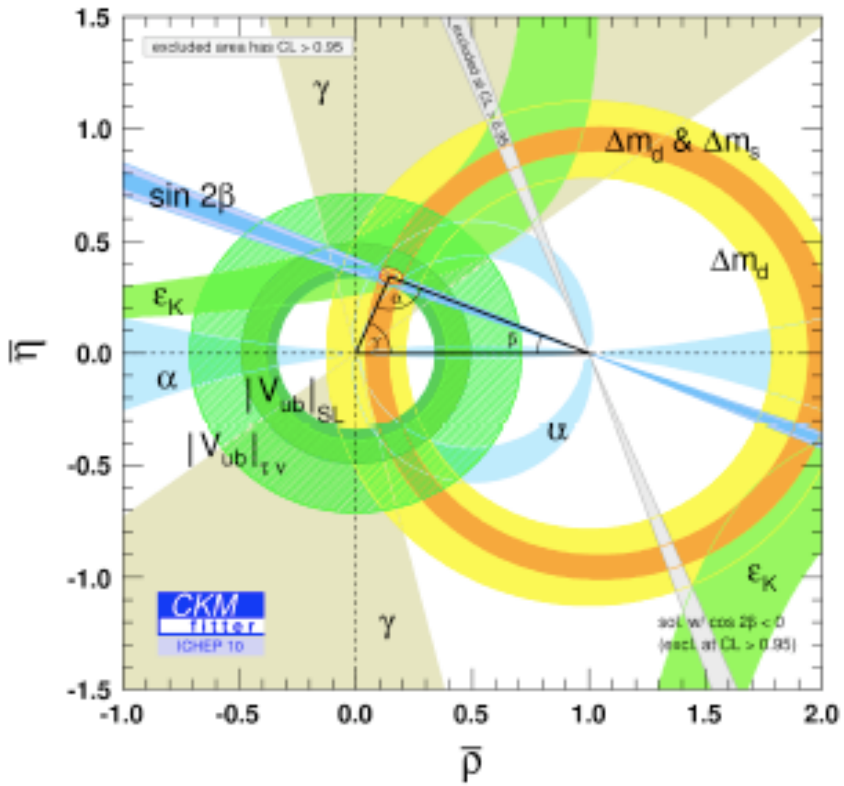
- Knowledge of PDF
  Will help to improve accuracy on A_{FB} and M_W.
  LHCb is complementary to GPDs and may provide vital input with high statistics data samples.

Switch-over in W^+/W^- in LHCb acceptance



What is left for the Unitarity Triangle test ???

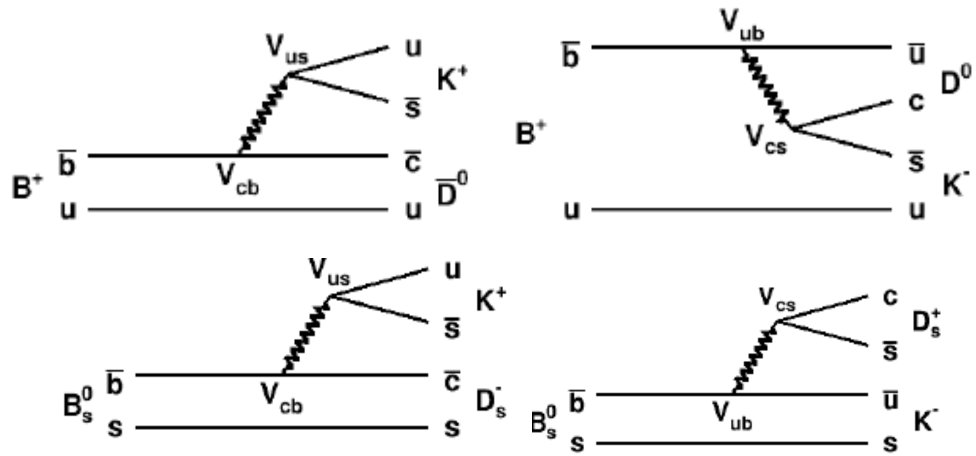
- *Precision test of the Unitarity Triangle is limited by accuracy of its sides, $|V_{ub}|$ and $(f_{Bd}\sqrt{B_d})/(f_{Bs}\sqrt{B_s})$ in particular*
- *Several possible hints for NP effects (A_{SL}, V_{ub} from $B \rightarrow \tau\nu$)*
- *Large contribution from NP not excluded*
- ***Precision measurement of γ in trees is important !!!***



Two strategies at LHCb

- *Time-independent CPV: $B^+ \rightarrow D^0 K^+$, also $B^0 \rightarrow D^0 K^{*0}$*

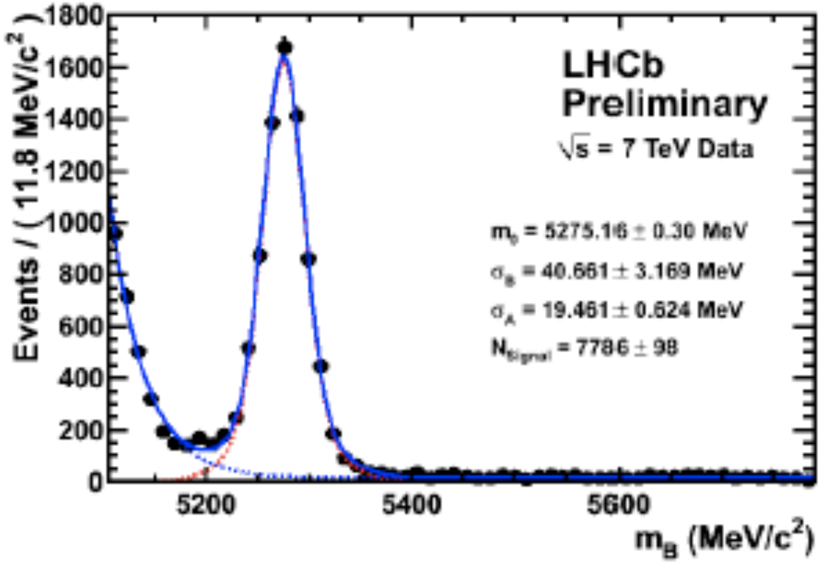
- *Time-dependent CPV: $B_s \rightarrow D_s K^+$, also $B^0 \rightarrow D^- \pi^+$*



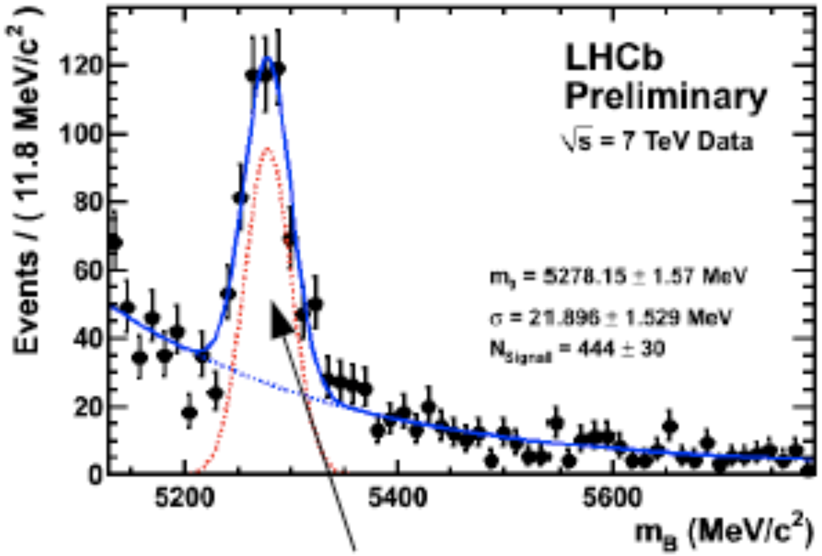
LHCb yields in $B^+ \to D\pi^+$ & $B^+ \to DK^+$

(LHCb takes shape !)

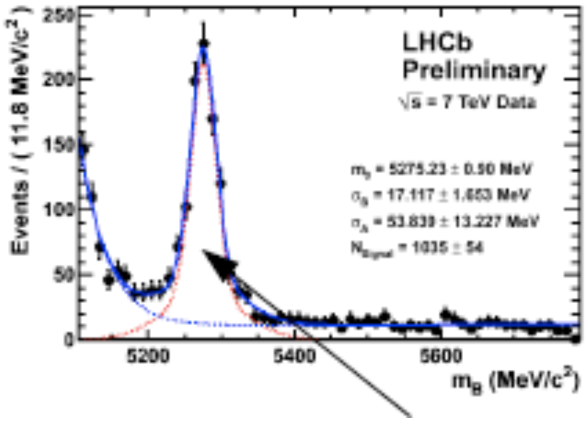
$B^\pm \to D\pi^\pm$ with $D \to \pi K$



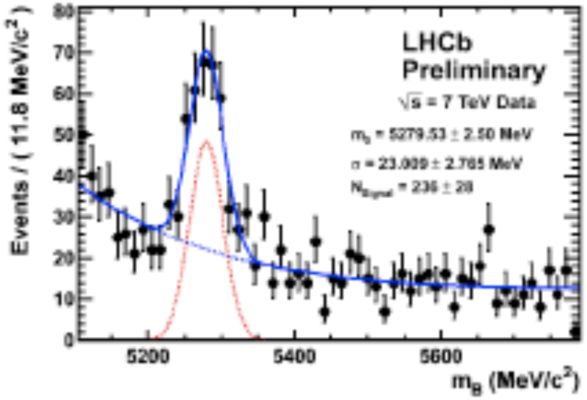
$B^\pm \to DK^\pm$ with $D \to \pi K$



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



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

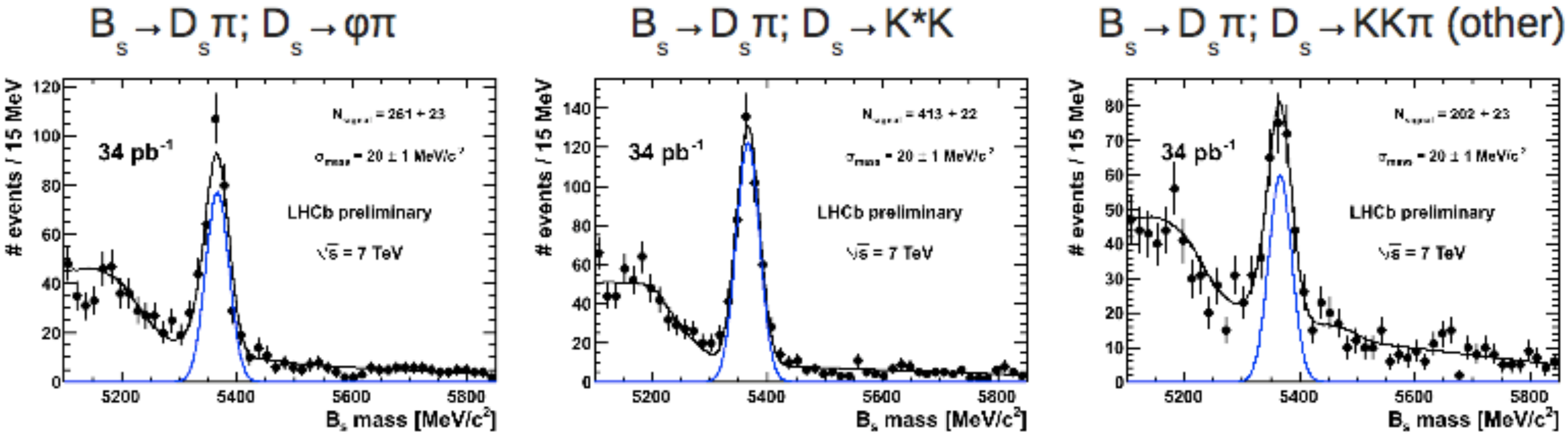


LHCb yield: 444 ± 30 / 34 pb^{-1}
CDF yield: 516 ± 37 / fb^{-1}

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



- ***$D_s K$ 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°

Use multi-body B decays to measure γ more accurately

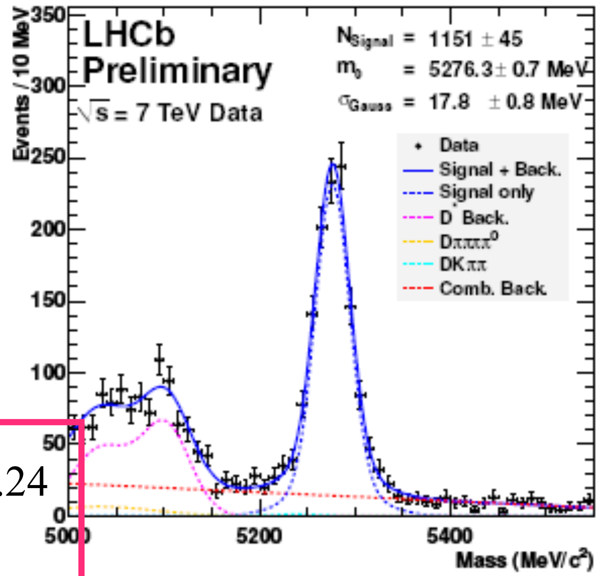
Significant improvement in accuracy compare to current PDG values:

$$\frac{BF(B^0 \rightarrow D^-(\pi^+\pi^-\pi^+))}{BF(B^0 \rightarrow D^-\pi^+)} = 2.36 \pm 0.11 \pm 0.24$$

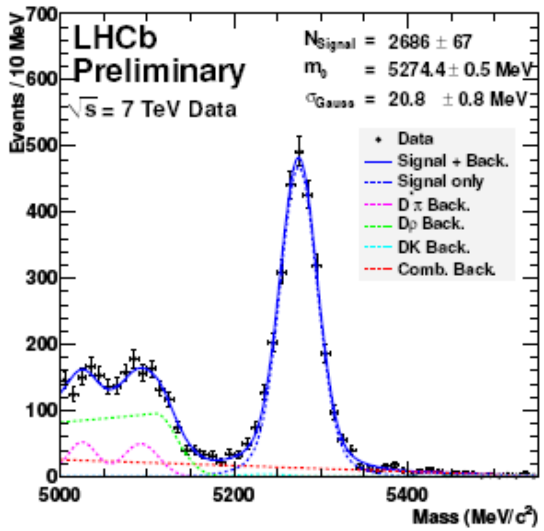
$$\frac{BF(B^+ \rightarrow D^0(\pi^+\pi^-\pi^+))}{BF(B^+ \rightarrow D^0\pi^+)} = 1.26 \pm 0.07 \pm 0.12$$

Yields are 25-40% of the single π bachelor yields → should be helpful in early measurements of γ

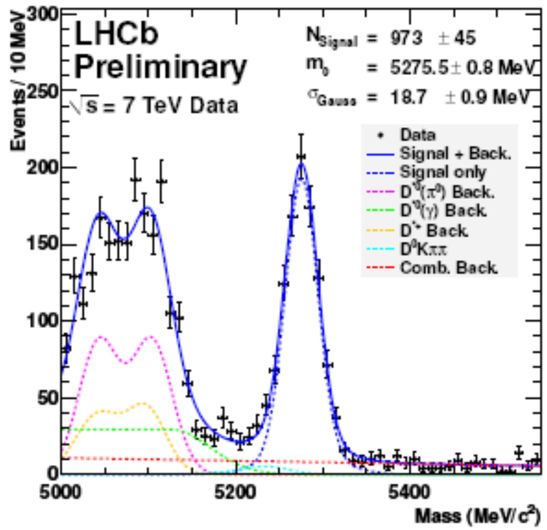
$B^0 \rightarrow D^-\pi^+\pi^-\pi^+$



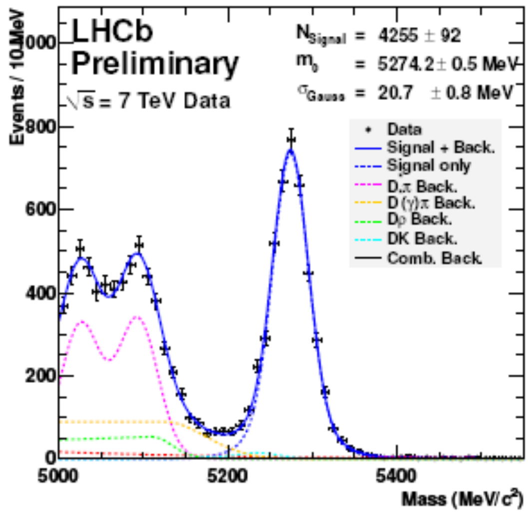
$B^0 \rightarrow D^-\pi^+$



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

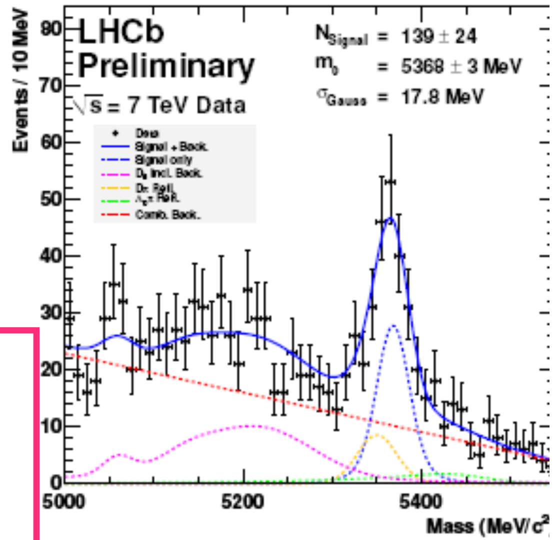


$B^+ \rightarrow D^0\pi$

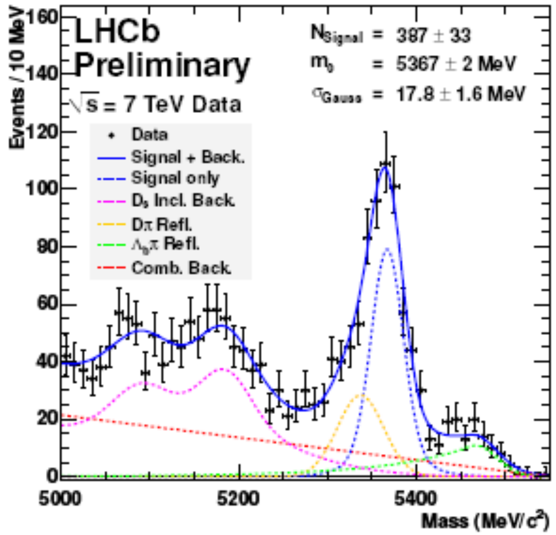


Multi-body B_s and Λ_b decays

$B_s \to D_s\pi\pi\pi$



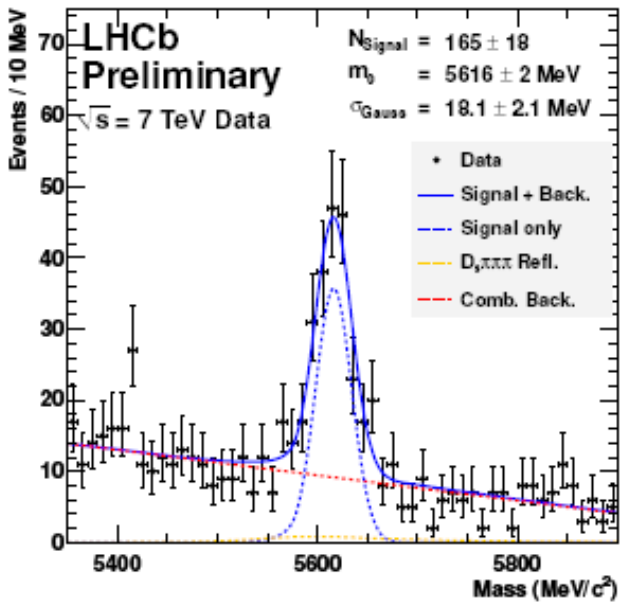
$B_s \to D_s\pi$



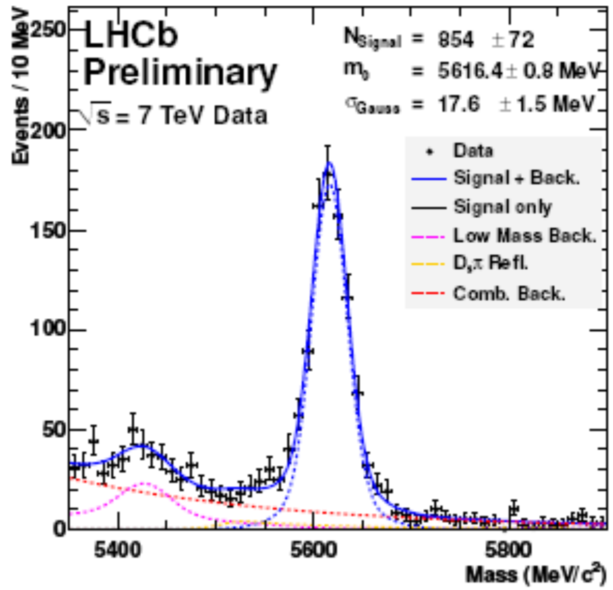
$$\frac{BF(B_s \to D_s(\pi^+\pi^-\pi^+))}{BF(B_s \to D_s\pi^+)} = 2.22 \pm 0.41 \pm 0.25$$

$$\frac{BF(\Lambda_b^0 \to \Lambda_c^+(\pi^+\pi^-\pi^+))}{BF(\Lambda_b^0 \to \Lambda_c^+\pi^+)} = 1.33 \pm 0.15 \pm 0.14$$

$\Lambda_b \to \Lambda_c\pi\pi\pi$

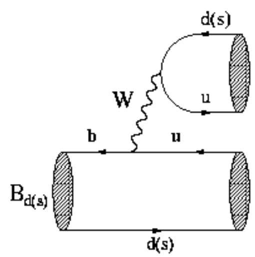


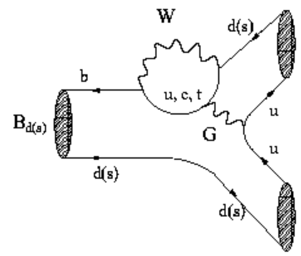
$\Lambda_b \to \Lambda_c\pi$

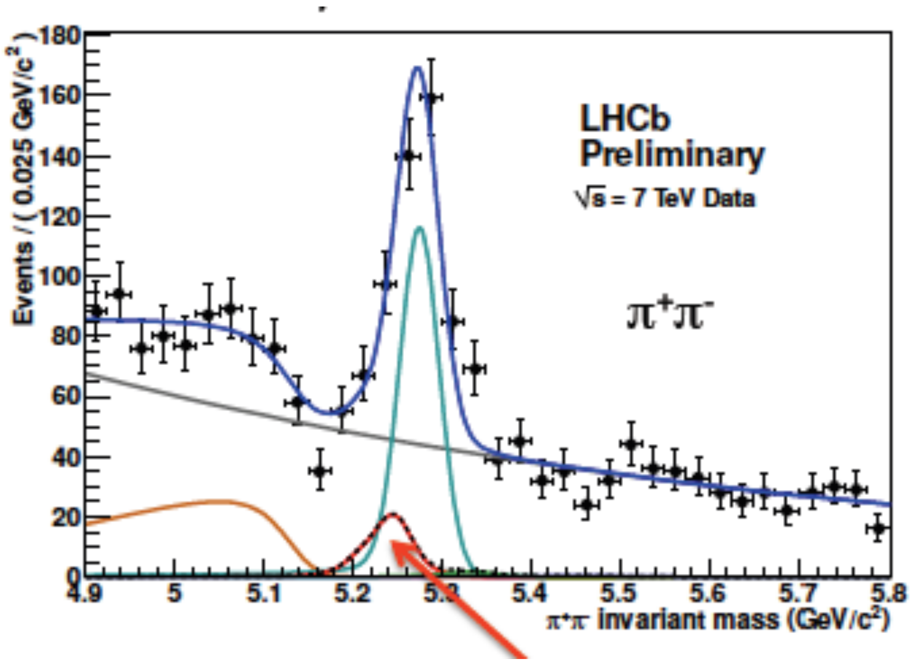


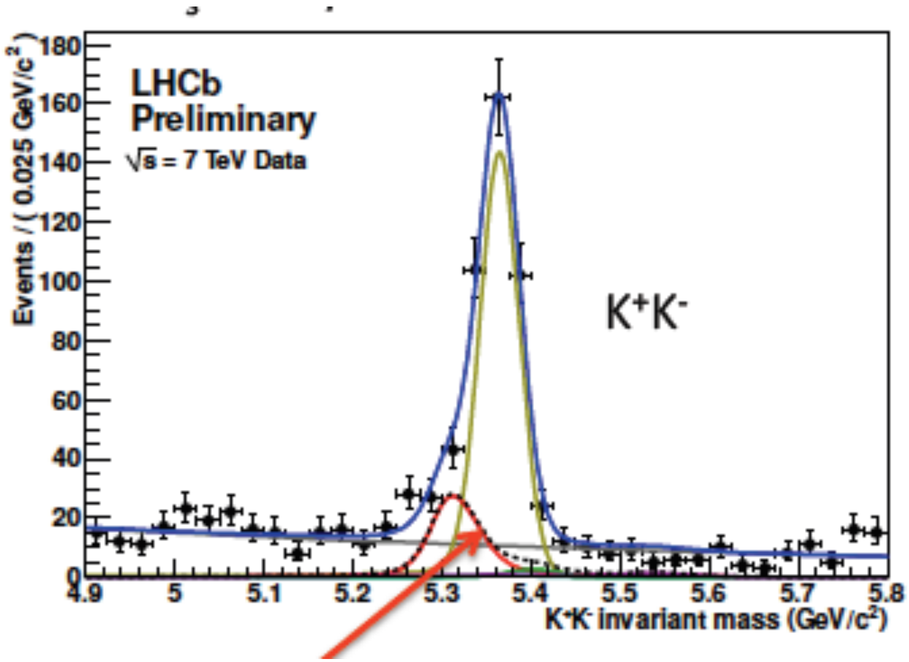
Prospects for γ measurement in $B_s \rightarrow K^+K^-$ & $B_d \rightarrow \pi^+\pi^-$

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 yields: 275±24 $B_d \rightarrow \pi^+\pi^-$ & 333 ± 21 $B_s \rightarrow K^+K^-$ in 37 pb^{-1}*
  c.f. CDF in 1 fb^{-1} 1307±64 $B_s \rightarrow K^+K^-$ & 1121±63 $B_d \rightarrow \pi^+\pi^-$

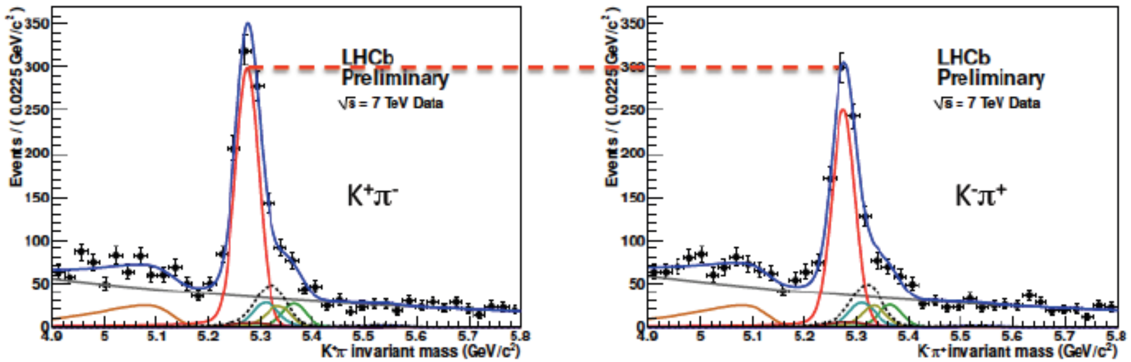
- *Expect first time-dependent measurements in 2011/2012 (including measurement of B_s lifetime in CP-even K^+K^- final state*

Direct CP violation in $B_{d/s} \to K\pi$

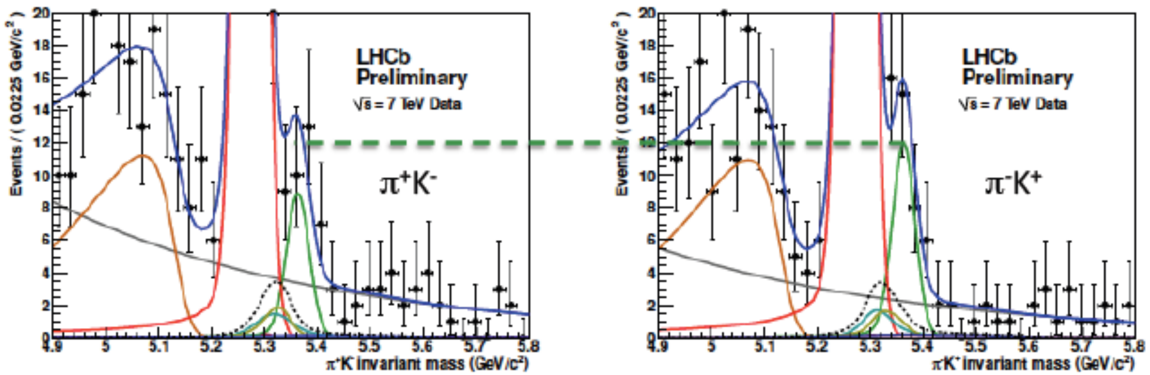
Direct A_{CP} in 2-body B decays have been measured by the B-factories and CDF

- *CP violation is well established in $B^0 \to K^+\pi^-$ (Average A_{CP}=$-0.098\pm^{0.012}_{0.011}$)*
- *$A_{CP}(B_s \to \pi^+ K^-) = 0.39\pm0.15\pm0.08$ (CDF with 1 fb^{-1})*

Raw CP asymmetry in $B^0 \to K\pi$ decays: -0.086 ± 0.033



Raw CP asymmetry in $B_s \to \pi K$ decays: 0.15 ± 0.19



Correct for possible detector and production asymmetries:

- *Detector asymmetries from data taken with opposite magnet polarities using $D^* \to D^0(K\pi, KK, \pi\pi)\pi_s$ & untagged $D^0 \to K\pi$ decays*

A_D = -0.004 ± 0.004

- *B production asymmetries from $B^+ \to J/\psi K^+$*

A_P = -0.025 ± 0.014 ± 0.010

Direct CP violation in $B_{d/s} \rightarrow K\pi$

LHCb preliminary:

$$A_{CP}(B^0 \to K^+\pi^-) = -0.074 \pm 0.033 \pm 0.008$$

$$A_{CP}(B^0_s \to \pi^+K^-) = 0.15 \pm 0.19 \pm 0.02$$

In agreement with HFAG averages

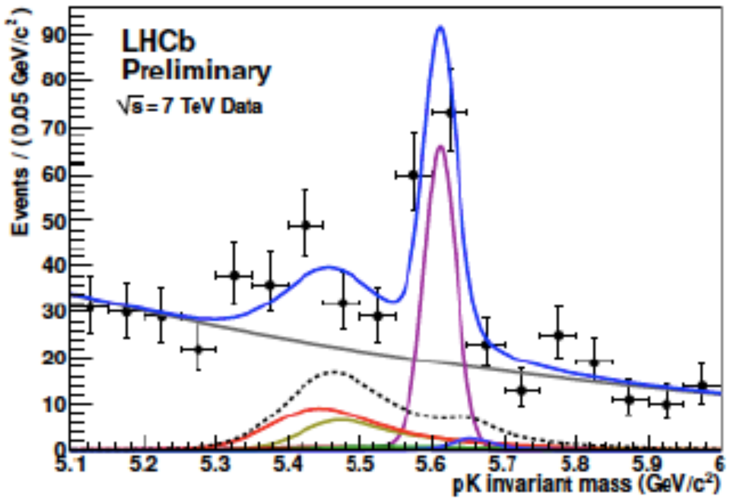
$$A_{CP}(B^0 \to K^+\pi^-) = -0.098^{+0.012}_{-0.011}$$

$$A_{CP}(B^0_s \to \pi^+K^-) = 0.39 \pm 0.17$$

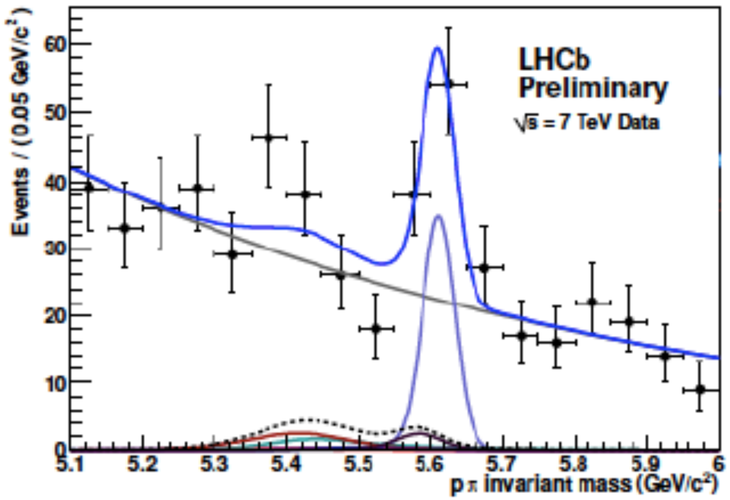
Excellent prospects for A_{CP} observation in Λ_b baryons with $L \sim 1\ fb^{-1}$

LHCb yields in 37 pb^{-1} :

$\Lambda_b \rightarrow pK$ yield: 76 ± 12 events

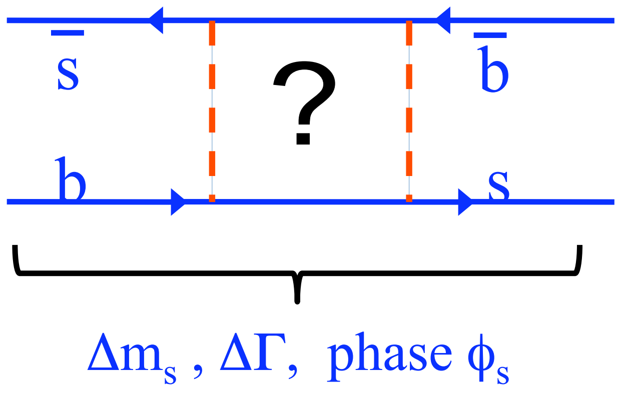


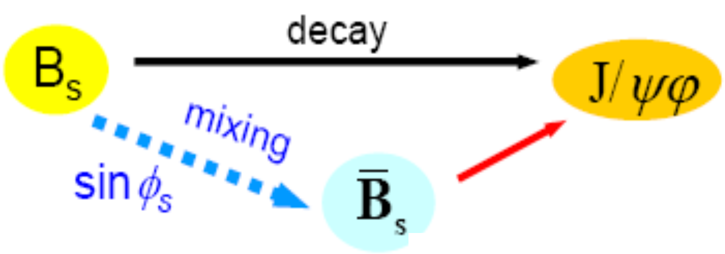
$\Lambda_b \rightarrow p\pi$ yield: 41 ± 10 events



B_s mixing phase $2\beta_s$

Provides the best way to search for new phases in the box diagrams



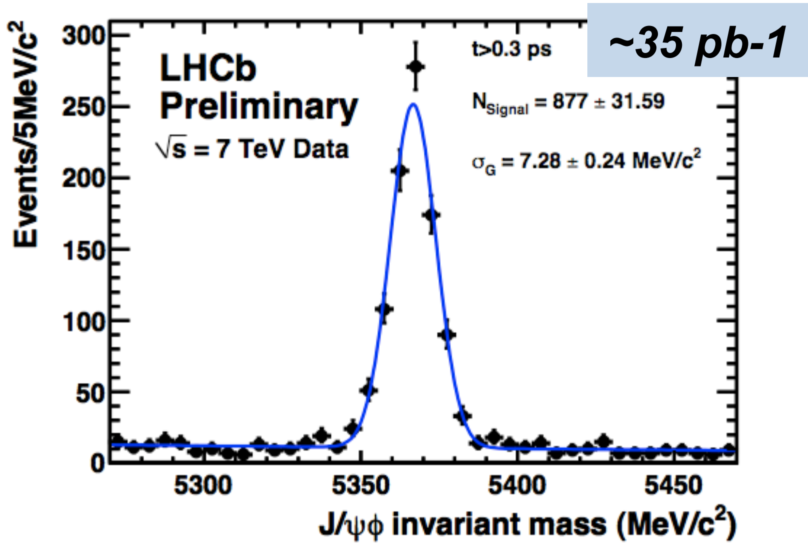


$$\phi_s^{SM} = -2\beta_s \approx -0.04$$

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

For details be in time for the talk of Olivier Leroy in the afternoon !

- *$B_s \rightarrow J/\psi\phi$ signal at LHCb is as clean as $B \rightarrow J/\psi K$ signals in e^+e^- - collisions at BELLE and BaBar*

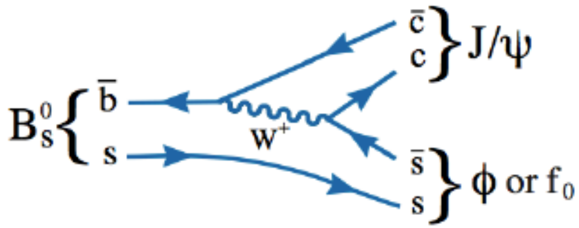


- *B lifetimes*
- *B_d and B_s oscillations*
- *Flavour tagging performance*

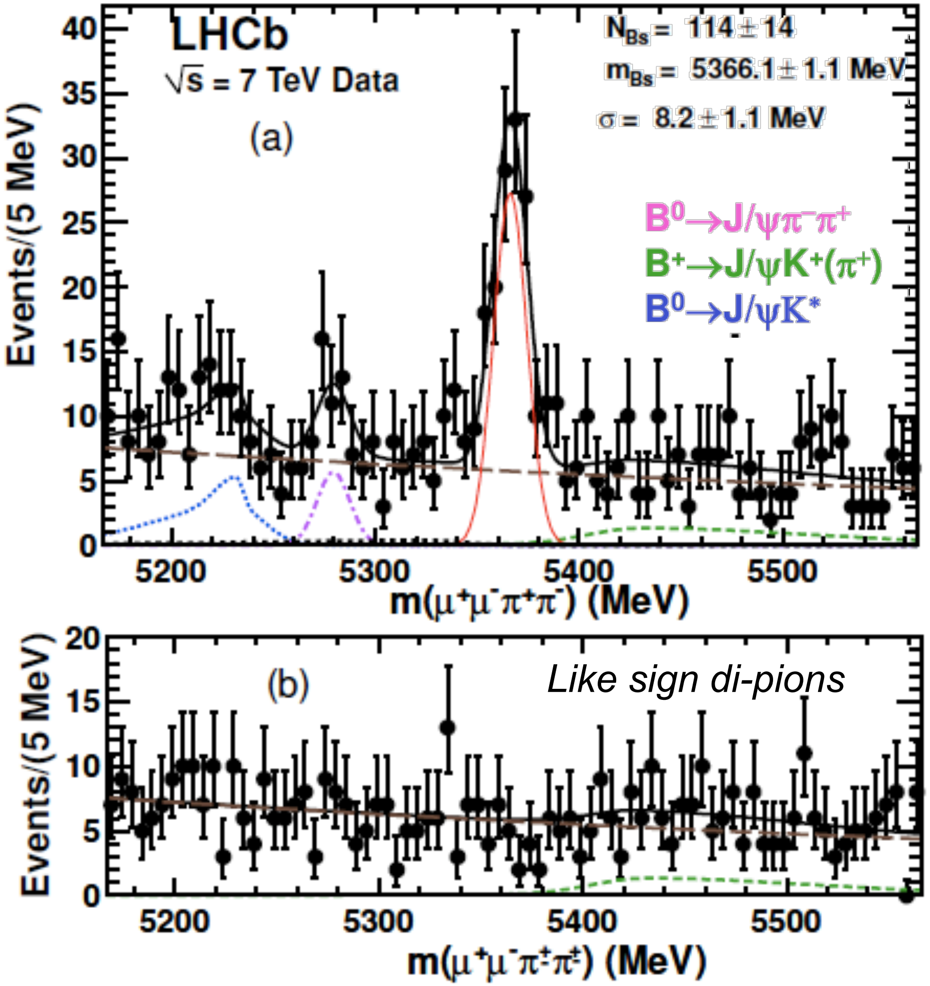
First observation of $B_s \rightarrow J/\psi f_0(980)$ decays

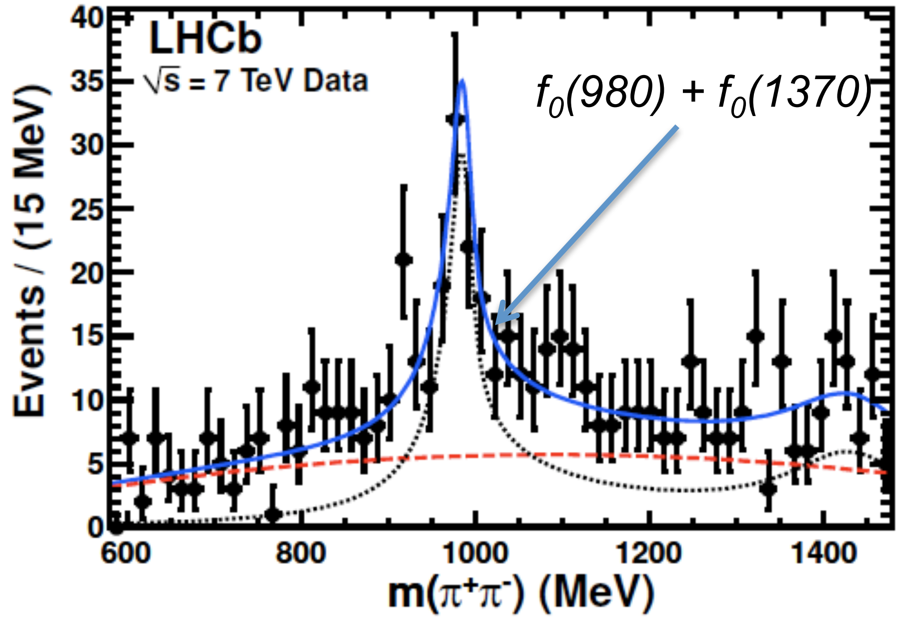
arXiv:1102.0206 [hep-ex]

- *$B_s \rightarrow J/\psi\, f_0$, $f_0 \rightarrow \pi^+\pi^-$ is CP-eigenstate*
  No angular analysis needed
- *Looks promising for ϕ_s measurement since BR is large*



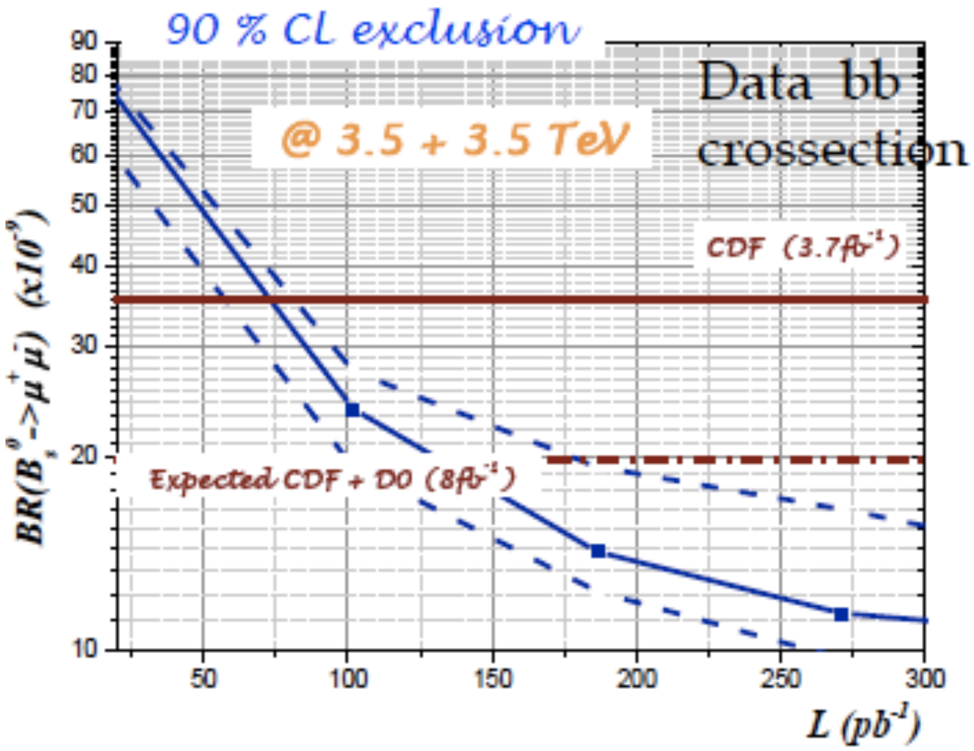
$$\frac{\Gamma(B_s \rightarrow J/\psi f_0,\ f_0 \rightarrow \pi^+\pi^-)}{\Gamma(B_s \rightarrow J/\psi \phi,\ \phi \rightarrow K^+K^-)} = 0.252^{+0.046+0.027}_{-0.032-0.033}$$



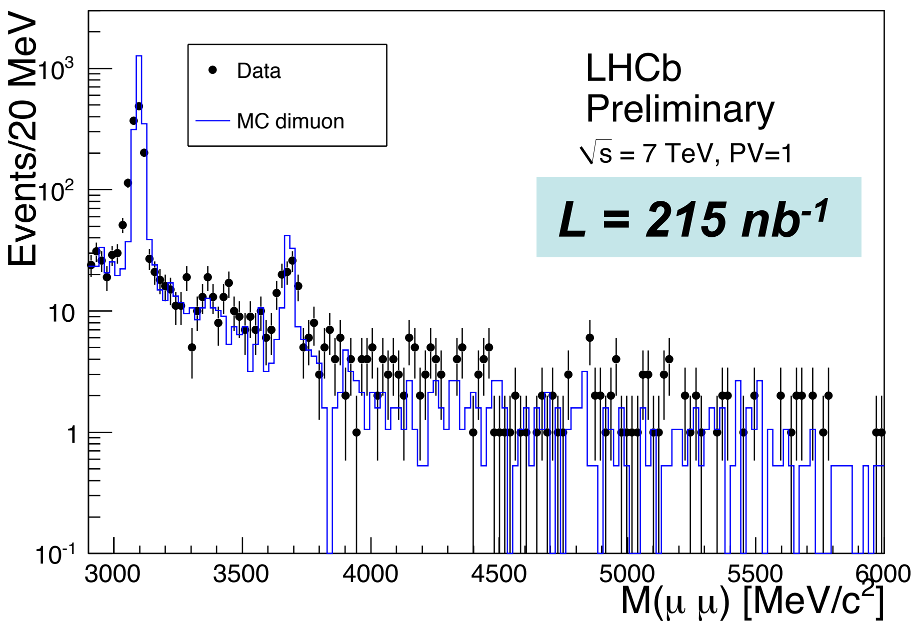


Search for $B_s \to \mu\mu$

- 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: $BR \propto \tan^6\beta / M^4_A$



Background expected from MC is in good agreement with data



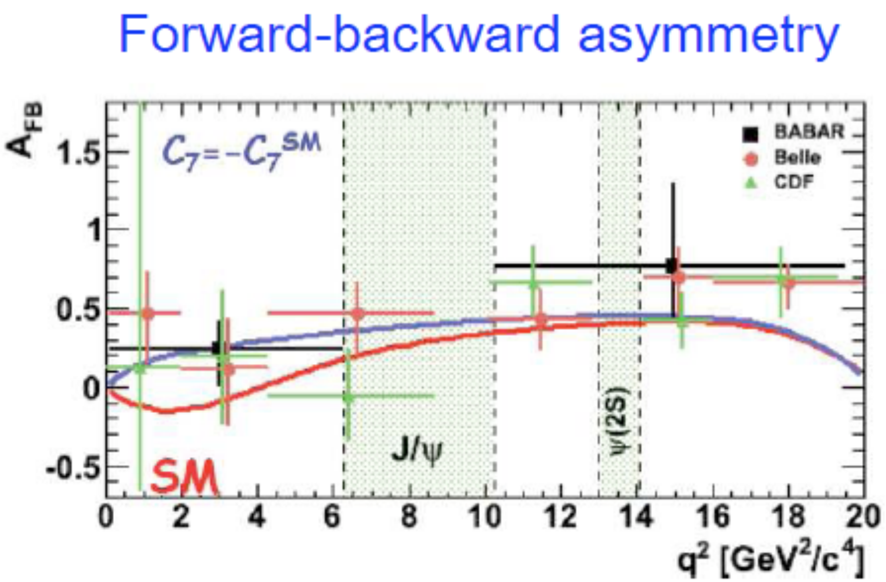
Very interesting sensitivity possible even with 40 pb^{-1} !!!

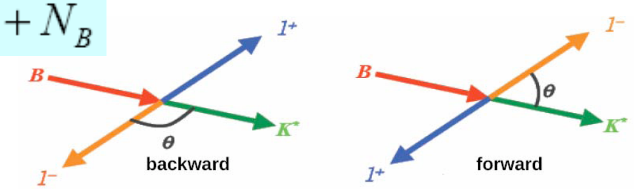
First presentation of $B_s \to \mu\mu$ from LHCb on Friday afternoon by Gaia Lanfranchi !

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

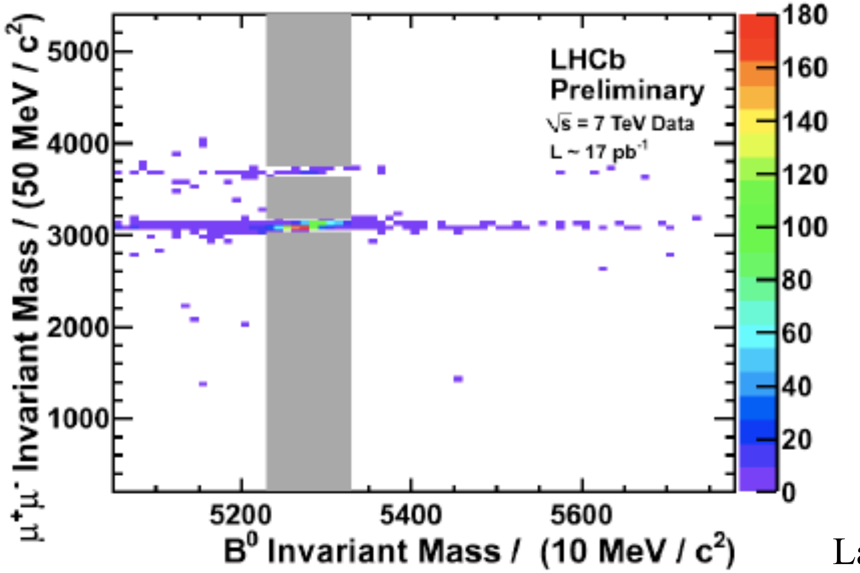
Forward backward asymmetry, A_{FB}, is extremely powerful observable for testing SM vs NP
Intriguing hint is emerging !!!

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





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

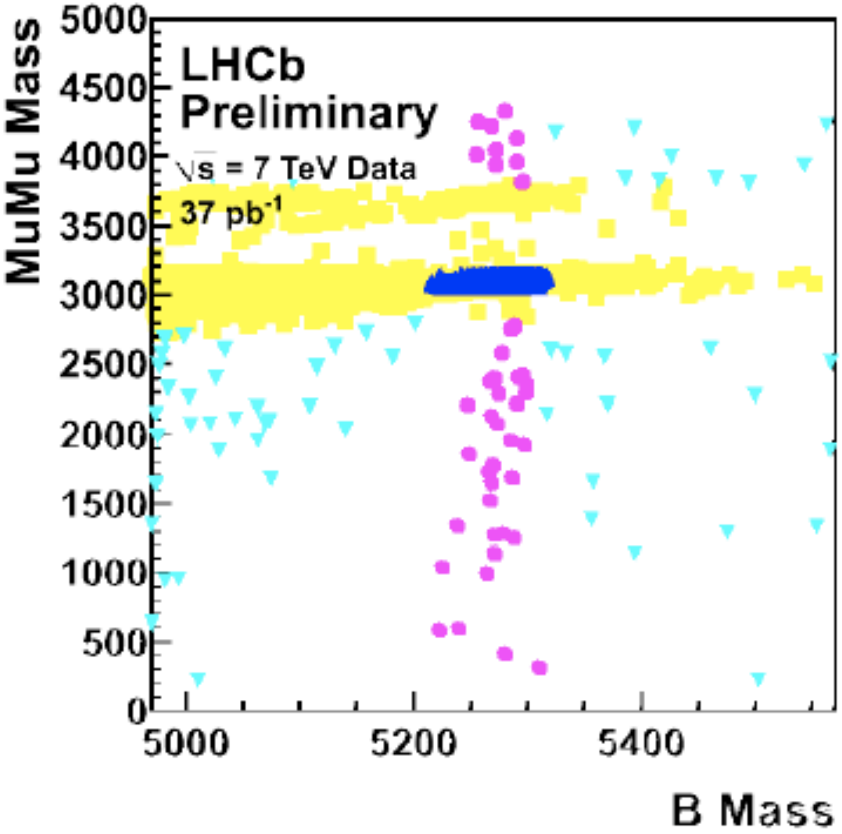


- *Signal region blinded but background level low as expected*
- *With 1 fb^{-1} LHCb expects ~1400 events, and should clarify existing situation. Expected accuracy in* ***A_{FB} zero crossing point is ~0.8 GeV^2 in 1 fb^{-1}***

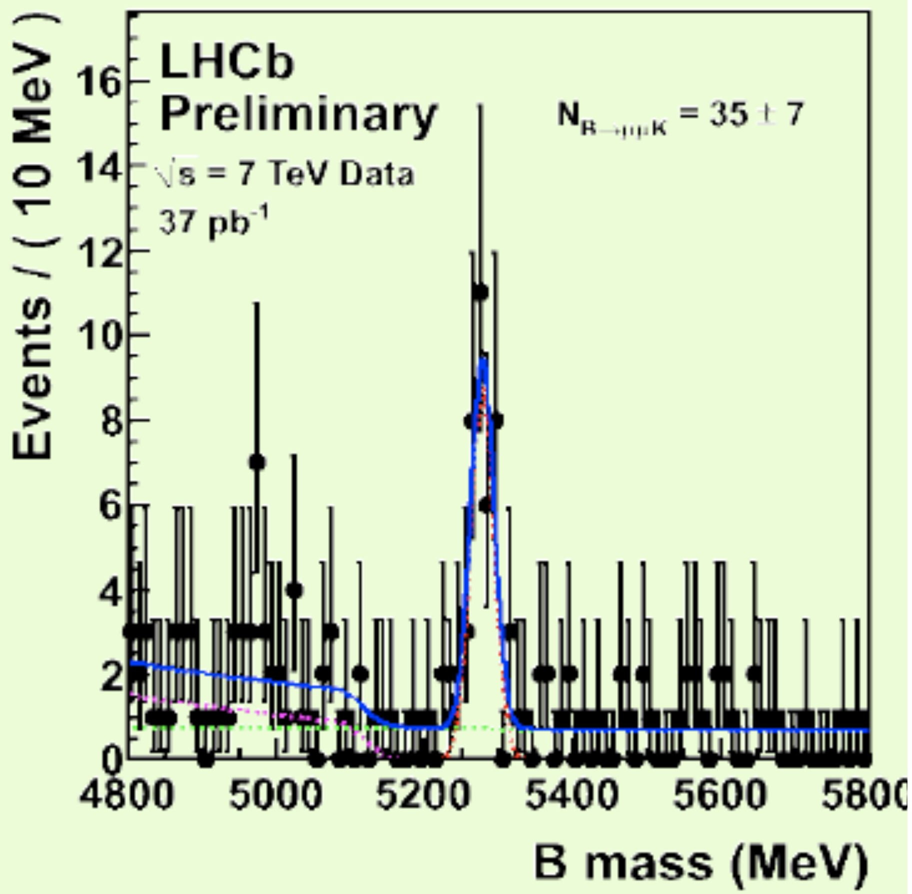
$B \to K\mu\mu$ is seen !!!

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

Cuts trained on $B \to J/\psi K$ signal



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



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

Conclusions

- *LHCb has deserved the title of "GPD" in the forward direction*

  - ***A concept of the forward spectrometer at the LHC 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, Y(1S) and W / Z***

  - ***A couple of the first observations in the well explored area of B physics***
    - $B_s \rightarrow D_{s2} X \mu \nu$
    - $B_s \rightarrow J/\psi f_0(980)$

    and more in the pipe line…

- ***$B_s \rightarrow \mu\mu$ and $B_s \rightarrow J/\psi\phi$ have reached interesting sensitivity regime in ~ 37 pb^{-1}***

- *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 …*