Results and Prospects from LHCb

PSROC2011 LHC Symposium

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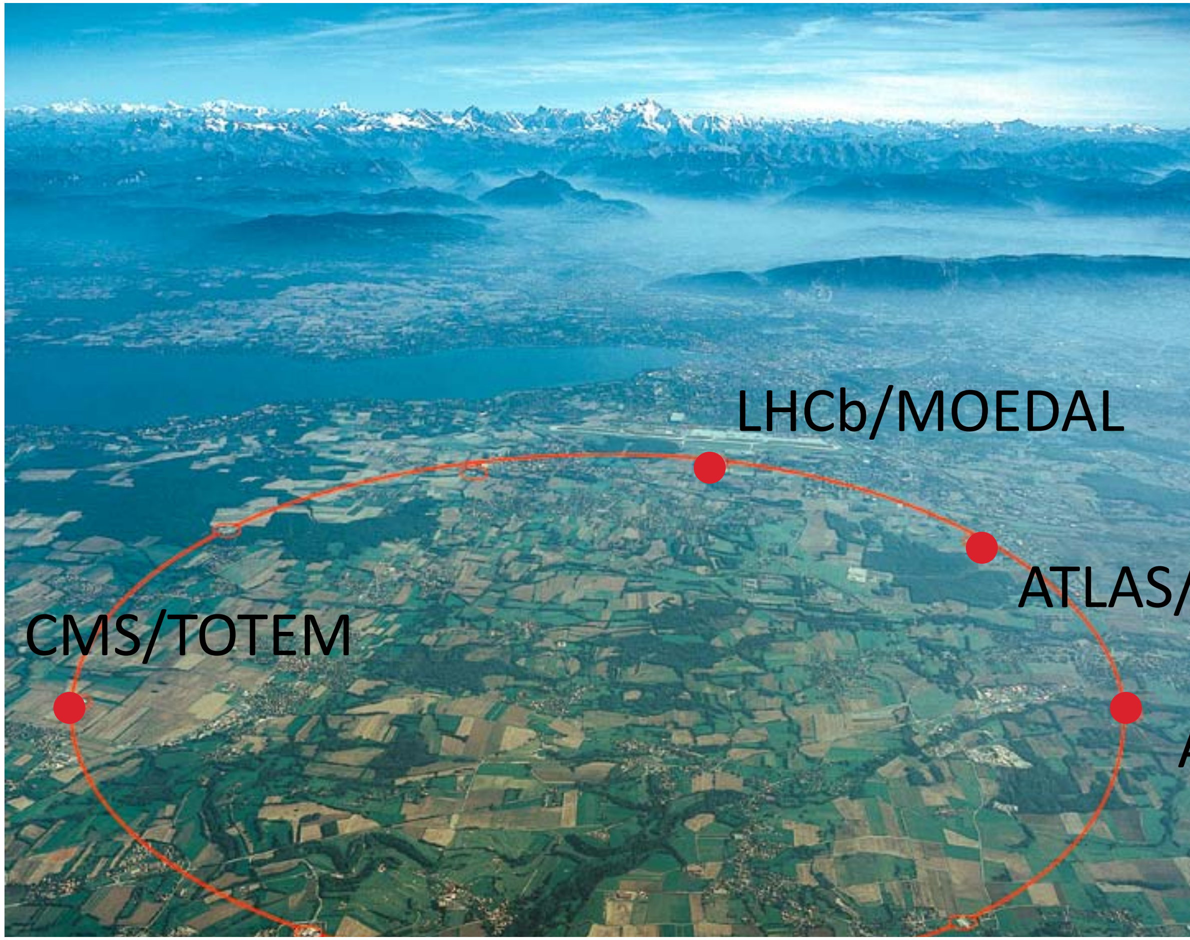
Tatsuya NAKADA

Laboratory for High Energy Physics (LPHE)
Swiss Federal Institute of Technology Lausanne (EPFL)
Lausanne, Switzerland

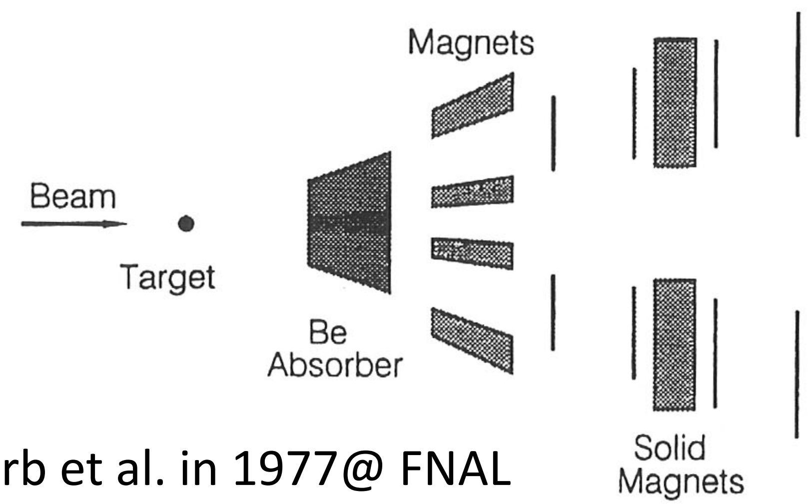
LHCb at CERN



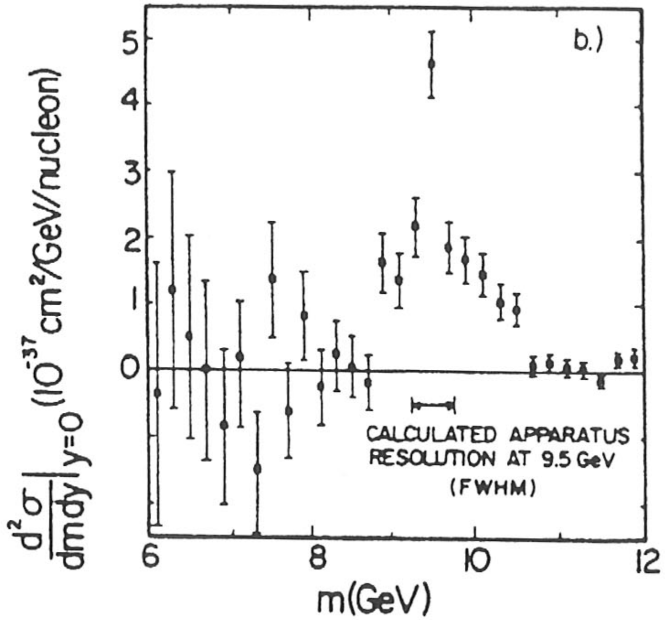
Two general purpose experiments (ATLAS and CMS), one dedicated b-experiment (LHCb), and one dedicated heavy ion experiment (ALICE).

B Physics@Hadron machine

- b-qark first discovered by a hadron machine in 1977



S. Herb et al. in 1977@ FNAL



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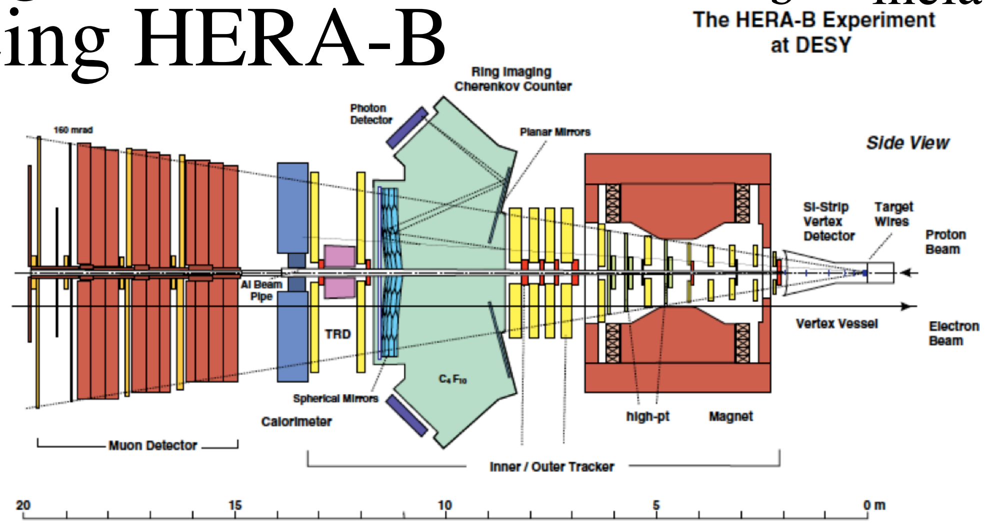
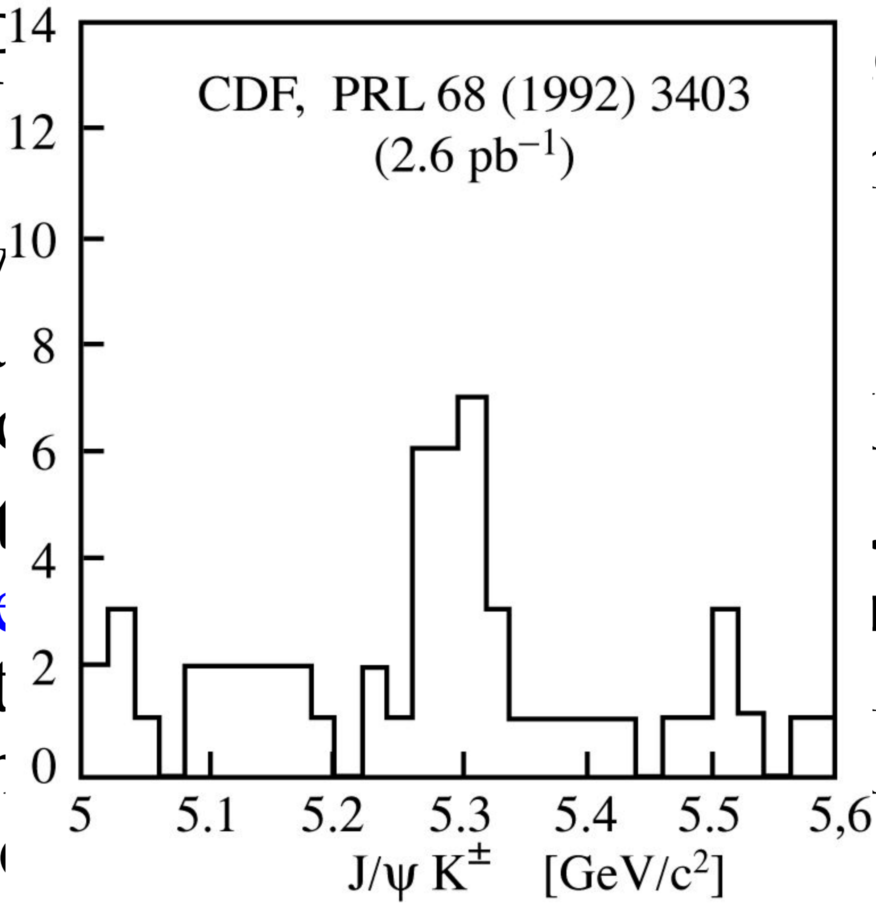
- Experiments at hadron machines, i.e. fixed target, with "limited" results: CERN: Beatrice FNAL:E866/E789/E772, E771
  b cross section measurements (with large error bars)
  → simply not enough b's and too small $\sigma_b/\sigma_{inelastic}$
  The last attempt being HERA-B



B F chine



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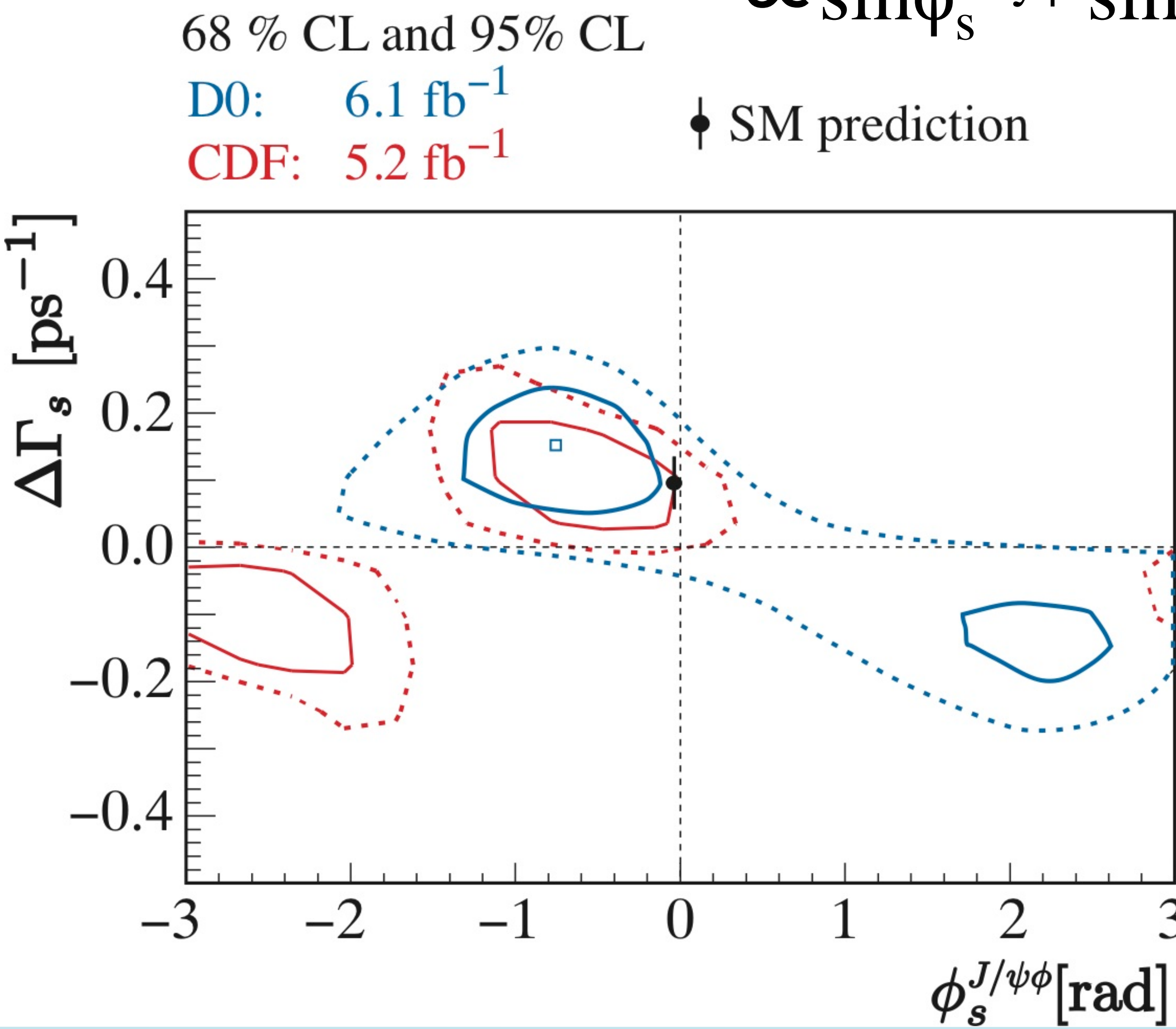
- 1992 CDF reconstructed $B \rightarrow J/\psi K$
  B physics with a hadron machine at high energy looks feasible!
  D0 and CDF contributed a lot in lifetimes, CPV, and oscillations. (in particular for B_s)

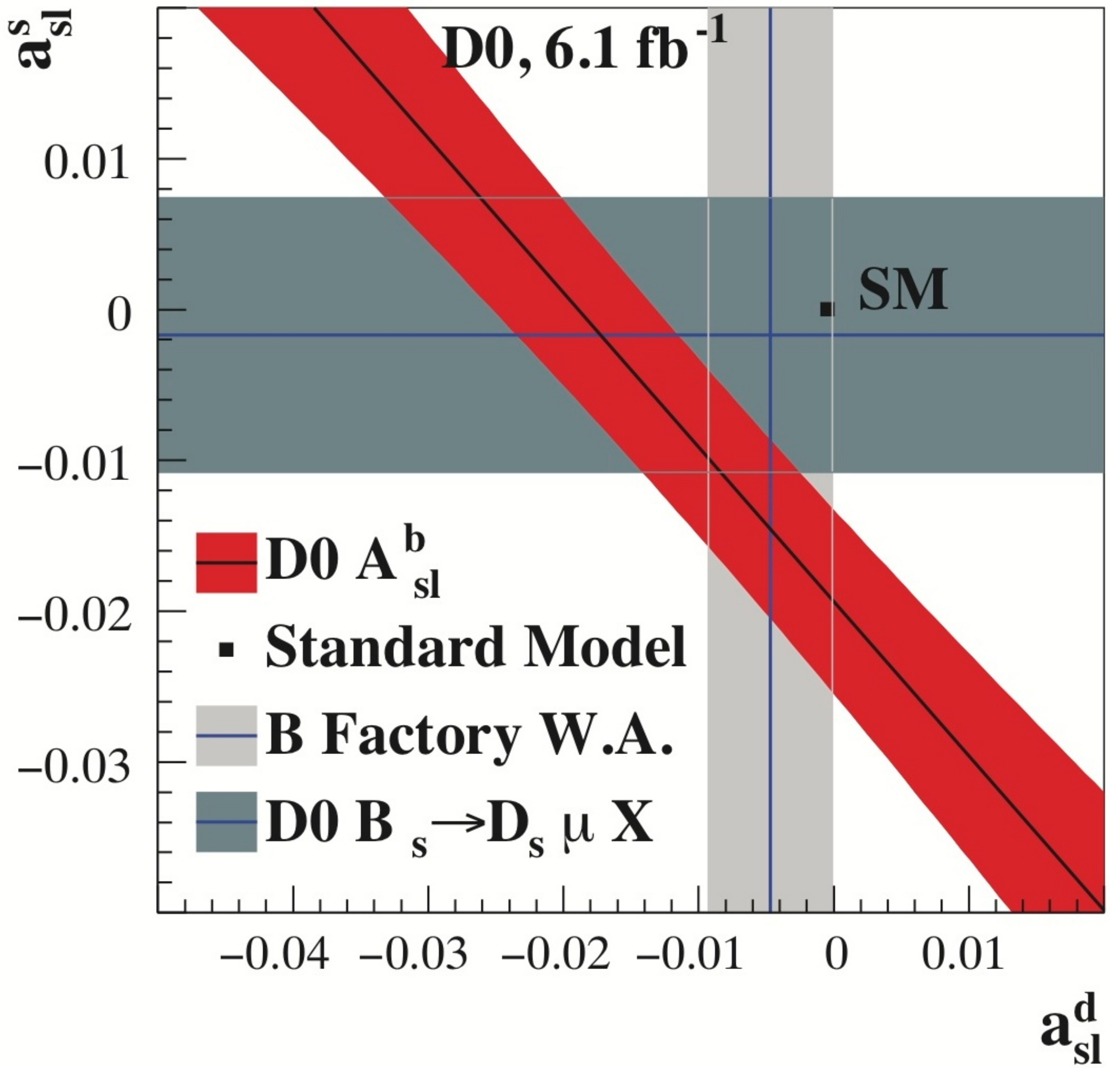
New physics in B_s @ hadron machine?

- CPV in $B_s \rightarrow J/\psi\phi$ time dependent CP asymmetry $\propto \sin\phi_s^{J/y\phi} \sin\Delta mt$



New physics in B_s @ hadron machine?

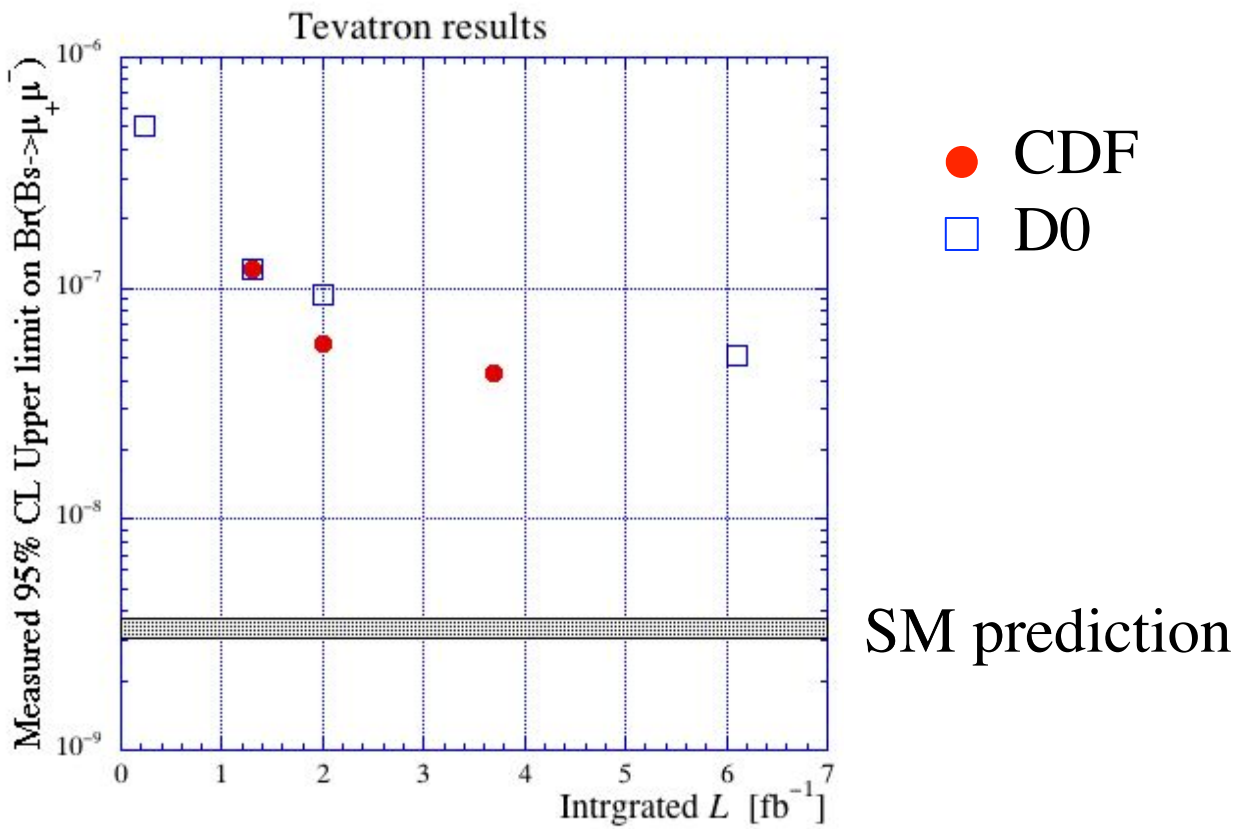
CPV in B_s-$\overline{B}_s$ oscillations



$\Pr(\overline{B}_s \rightarrow B_s)$
$\neq \Pr(B_s \rightarrow \overline{B}_s)$

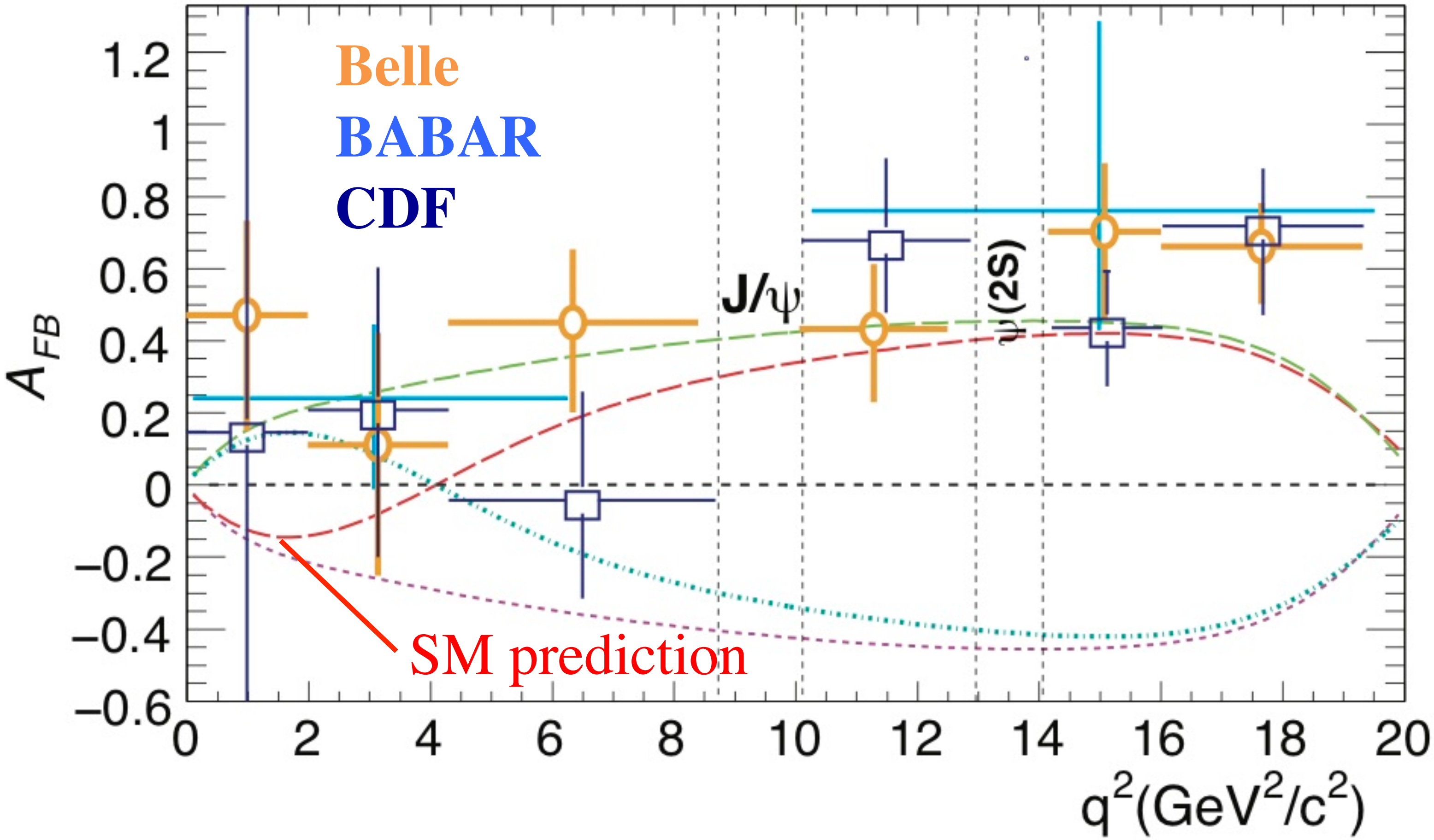
New physics in B_s @ hadron machine?

- $B_s \rightarrow \mu^+\mu^-$ GIM and helicity surpressed in the Standard Model.
- New physics can introduce large enhancement
- Current Tevatron observed limits still large



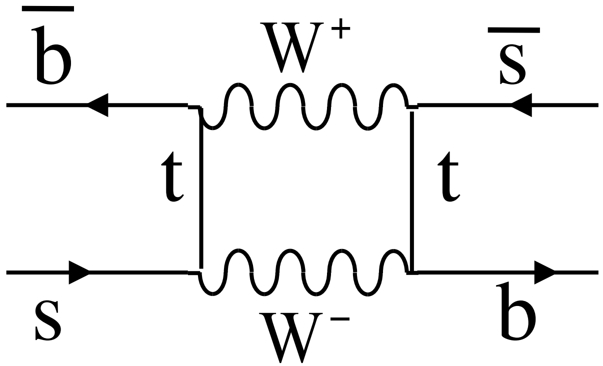
New physics in B_d @ hadron machine?

- A_{FB} in $B_d \to K^{*0}\mu+\mu-$

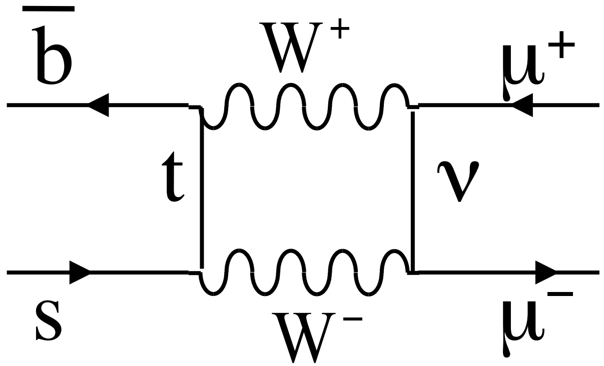


They are somehow related

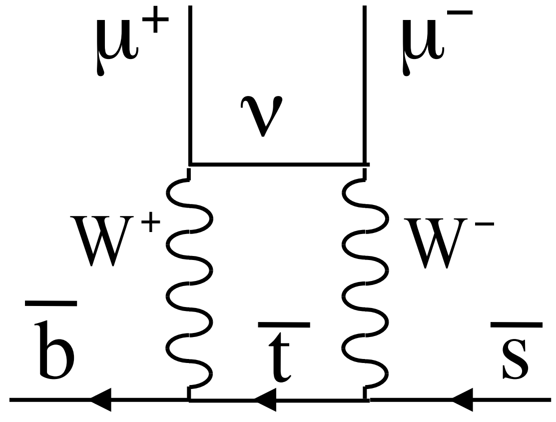
CPV in $J/\psi\phi$
and B_s-$\overline{B}_s$ oscillation
$\propto \arg(M_{12})$



$B_s \rightarrow \mu\mu$



$B_d \rightarrow K^*\mu\mu$



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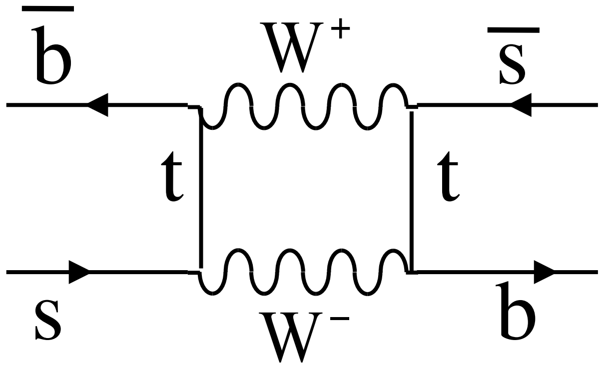
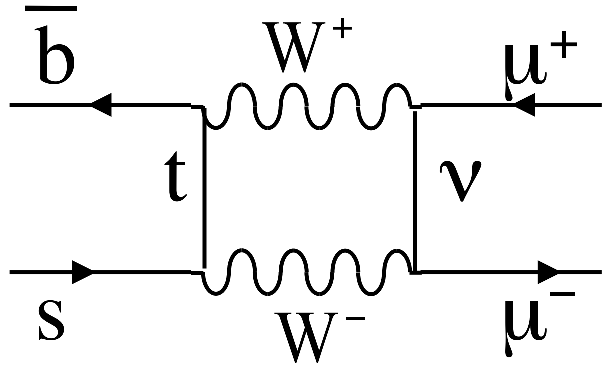
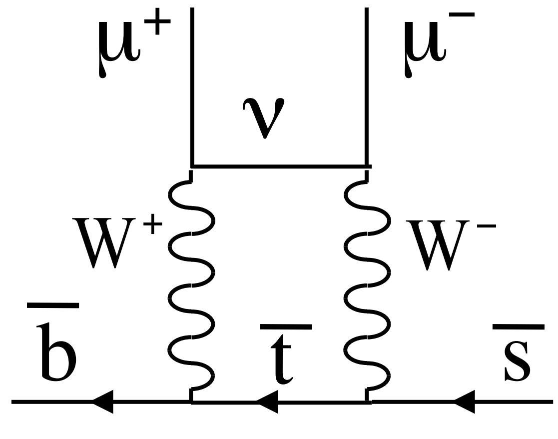
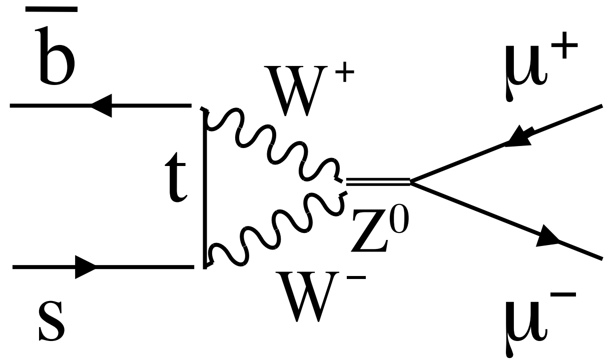
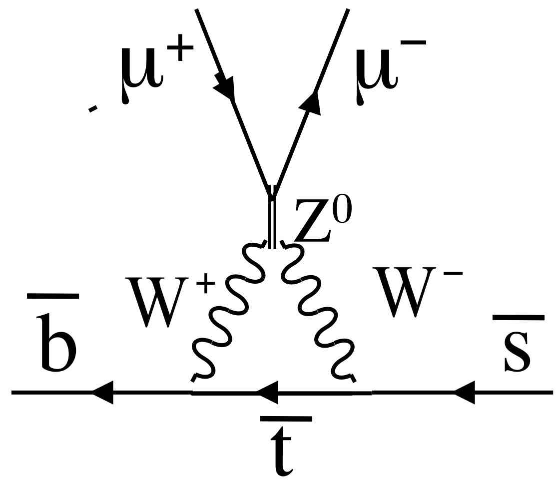






and more related diagrams





They are somehow related

CPV in J/ψϕ
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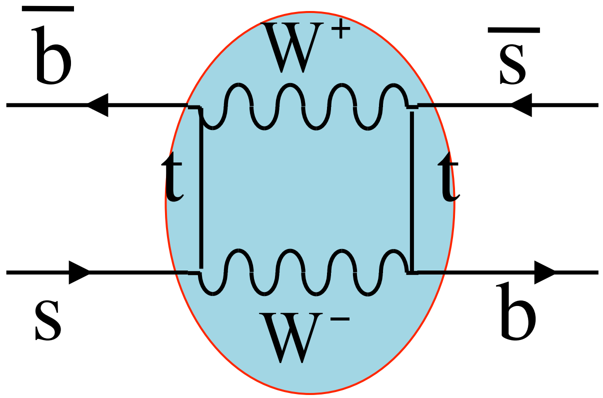
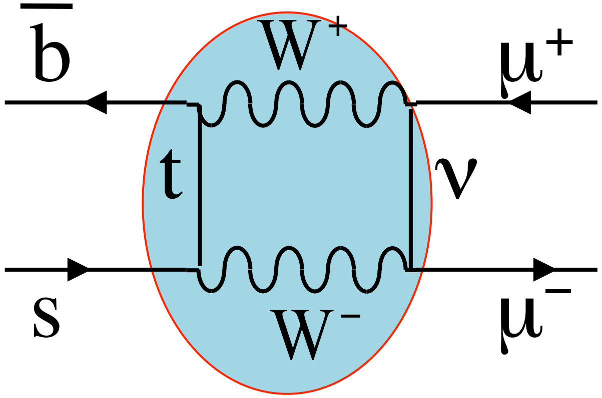
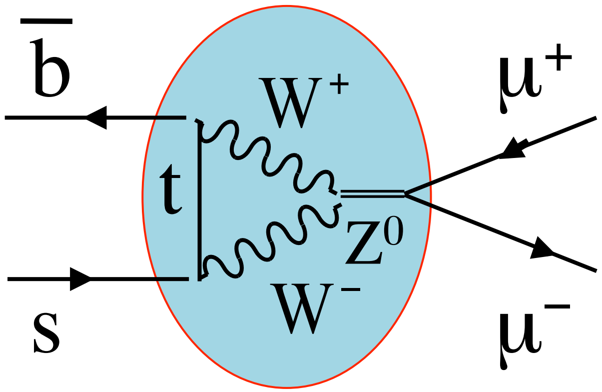
∝ arg(M_{12})

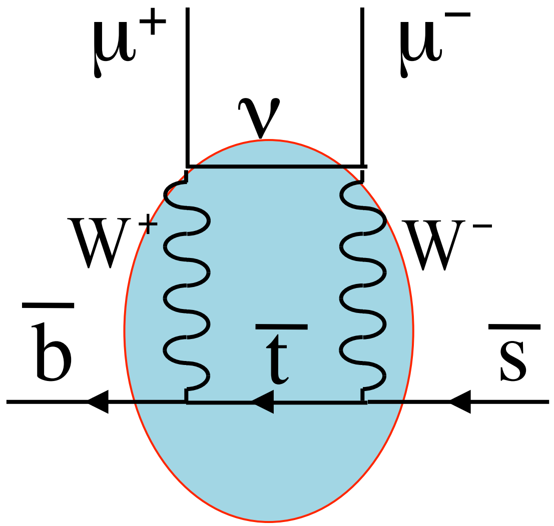


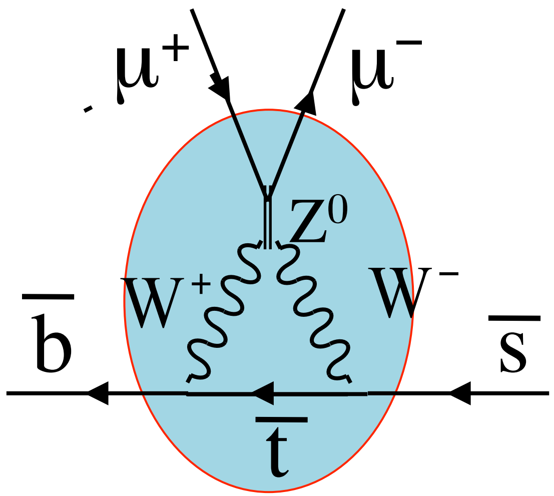
$B_s \to \mu\mu$





$B_d \to K^* \mu\mu$





All could contain
loop of virtual
New Particles

More topics with hadron machines

- CP asymmetries in $B_u \rightarrow K^{\pm}\pi^0 \neq B_d \rightarrow K^{\pm}\pi^{\mp}$!
  - Experimentally established effect by Belle (Nature 2008)
  - Physics interpretation, Standard Model due to hadrnic interaction effect or New Physics

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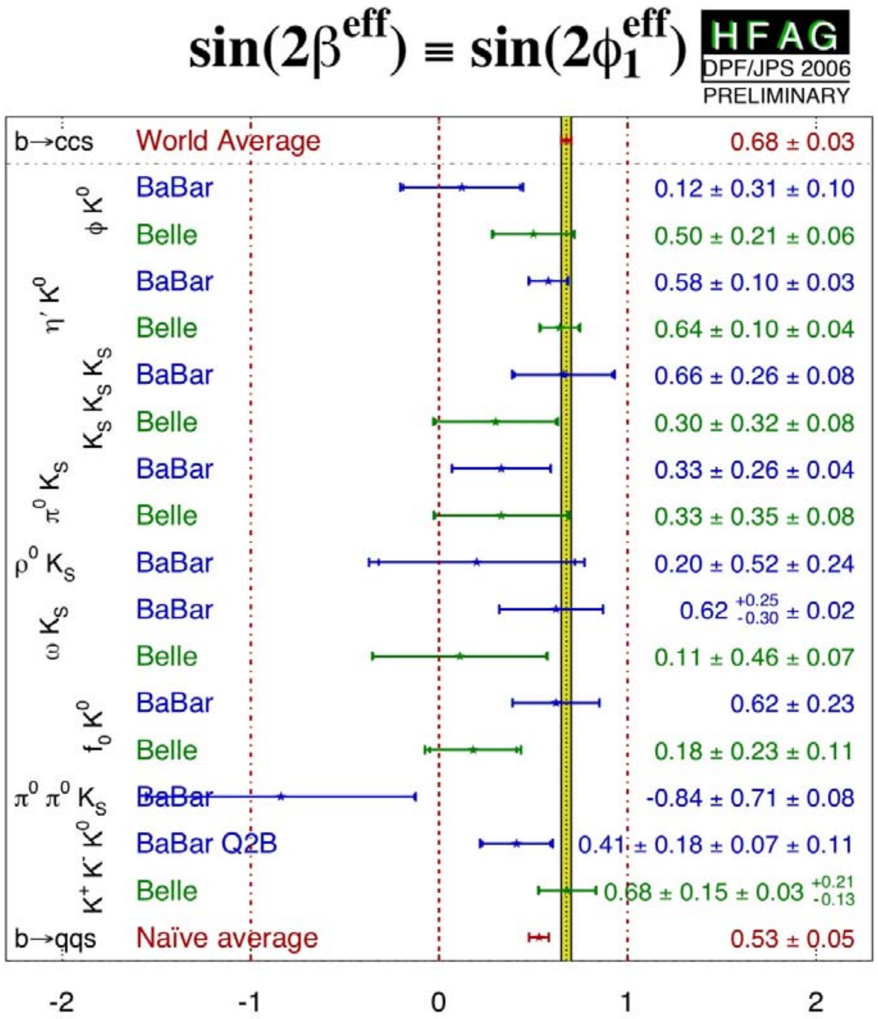
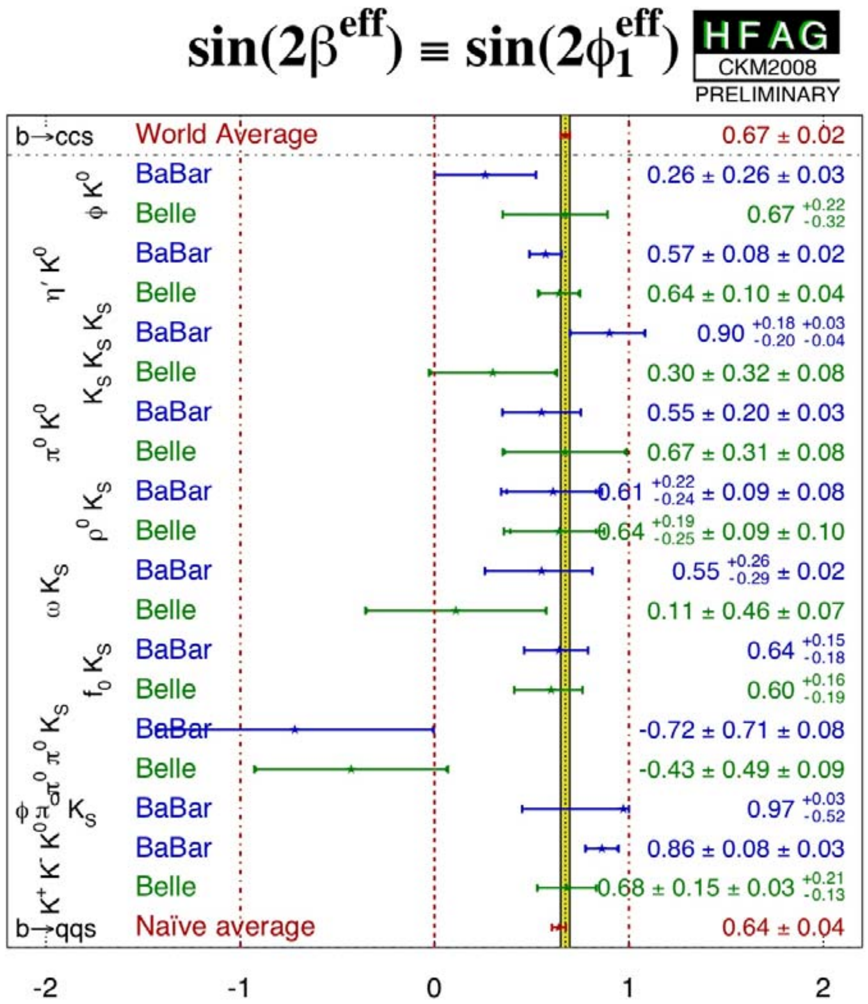


sin(2β^eff) ≡ sin(2φ1^eff)
HFAG
DPF/JPS 2006
PRELIMINARY
b→ccs World Average 0.68 ± 0.03
φ K0
BaBar 0.12 ± 0.31 ± 0.10
Belle 0.50 ± 0.21 ± 0.06
η′ K0
BaBar 0.58 ± 0.10 ± 0.03
Belle 0.64 ± 0.10 ± 0.04
KS KS KS
BaBar 0.66 ± 0.26 ± 0.08
Belle 0.30 ± 0.32 ± 0.08
π0 KS
BaBar 0.33 ± 0.26 ± 0.04
Belle 0.33 ± 0.35 ± 0.08
ρ0 KS
BaBar 0.20 ± 0.52 ± 0.24
ω KS
BaBar 0.62 +0.25 -0.30 ± 0.02
Belle 0.11 ± 0.46 ± 0.07
f0 K0
BaBar 0.62 ± 0.23
Belle 0.18 ± 0.23 ± 0.11
π0 π0 KS
BaBar -0.84 ± 0.71 ± 0.08
K+ K- K0
BaBar Q2B 0.41 ± 0.18 ± 0.07 ± 0.11
Belle 0.68 ± 0.15 ± 0.03 +0.21 -0.13
b→qqs Naïve average 0.53 ± 0.05
-2
-1
0
1
2



sin(2β^eff) ≡ sin(2φ1^eff)
HFAG
CKM2008
PRELIMINARY
b→ccs World Average 0.67 ± 0.02
φ K0
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Belle 0.60 +0.16 -0.19
π0 π0 KS
BaBar -0.72 ± 0.71 ± 0.08
Belle -0.43 ± 0.49 ± 0.09
φ π0 KS
BaBar 0.97 +0.03 -0.52
K+ K- K0
BaBar 0.86 ± 0.08 ± 0.03
Belle 0.68 ± 0.15 ± 0.03 +0.21 -0.13
b→qqs Naïve average 0.64 ± 0.04
-2
-1
0
1
2

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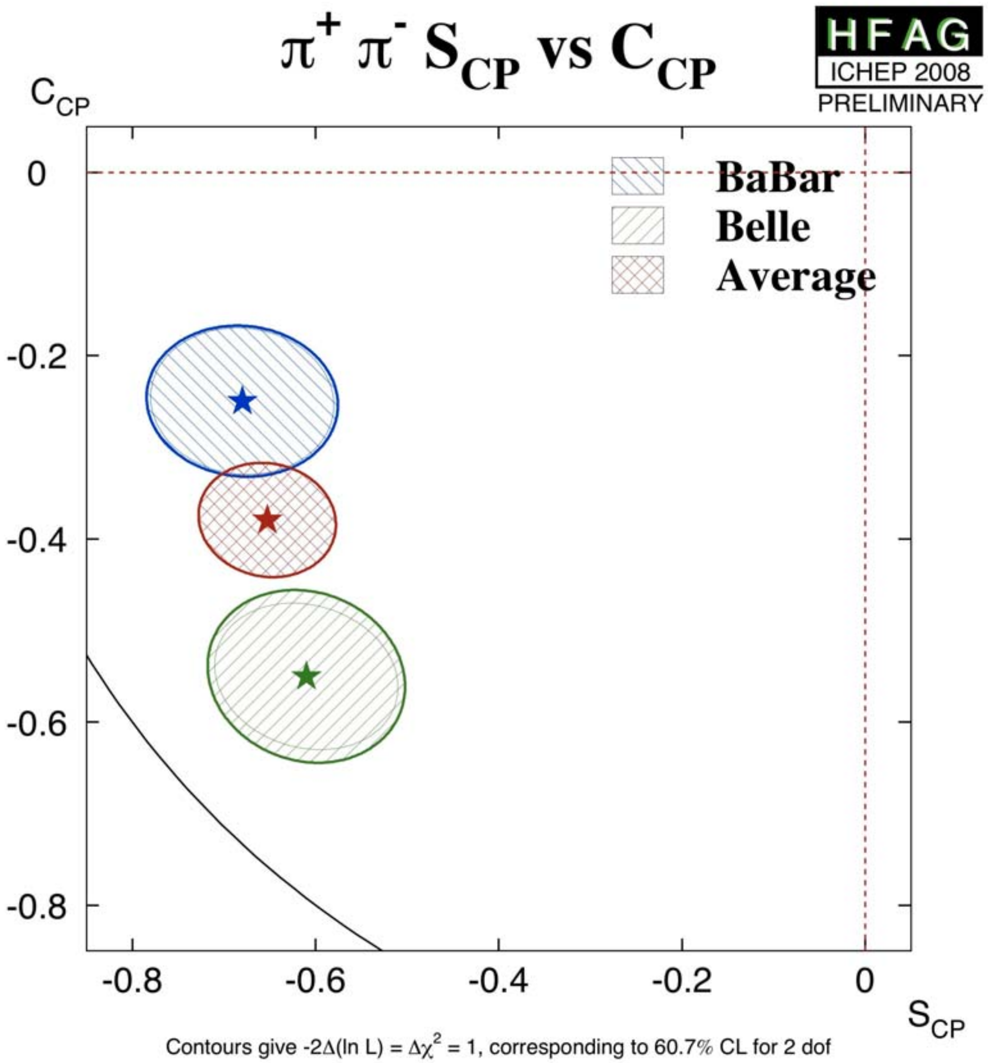
$\pi^+ \pi^-$ S_{CP} vs C_{CP}
HFAG
ICHEP 2008
PRELIMINARY
C_{CP}
0
-0.2
-0.4
-0.6
-0.8
BaBar
Belle
Average
-0.8
-0.6
-0.4
-0.2
0
S_{CP}
Contours give $-2\Delta(\ln L) = \Delta\chi^2 = 1$, corresponding to 60.7% CL for 2 dof

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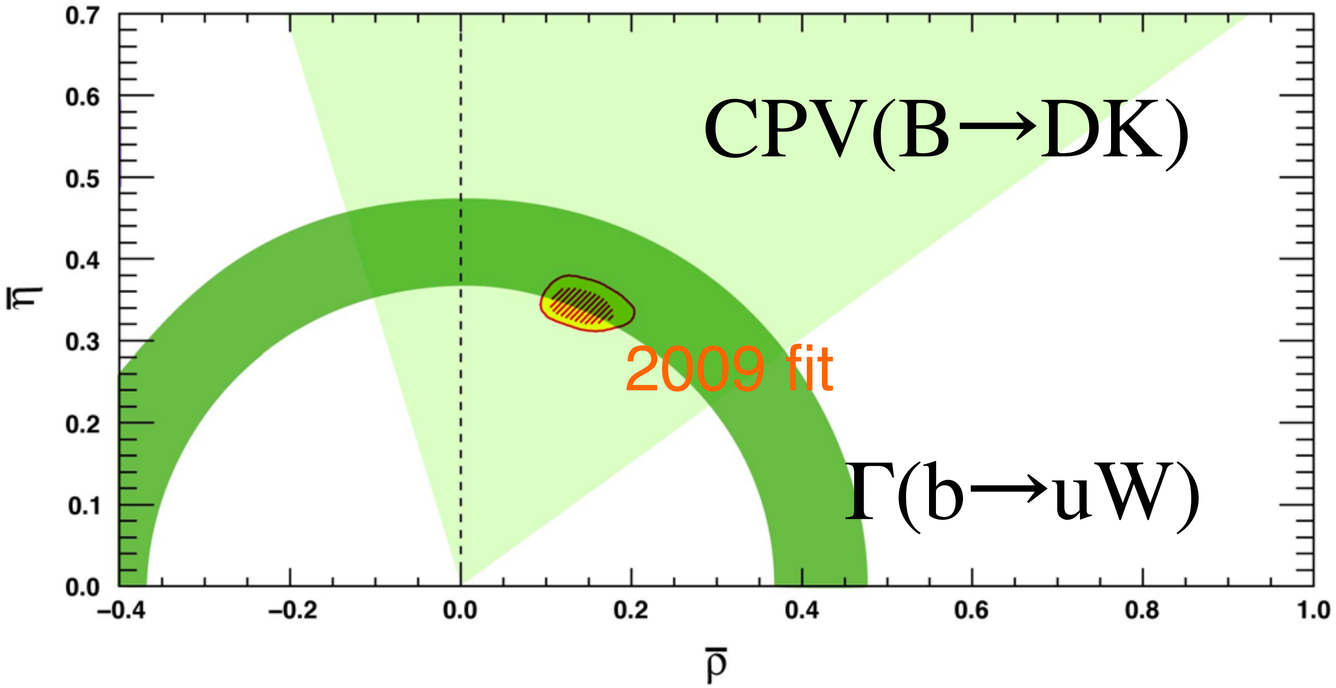
CPV(B→DK)
2009 fit
Γ(b→uW)
η̄
ρ̄
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
−0.4
−0.2
0.0
0.2
0.4
0.6
0.8
1.0

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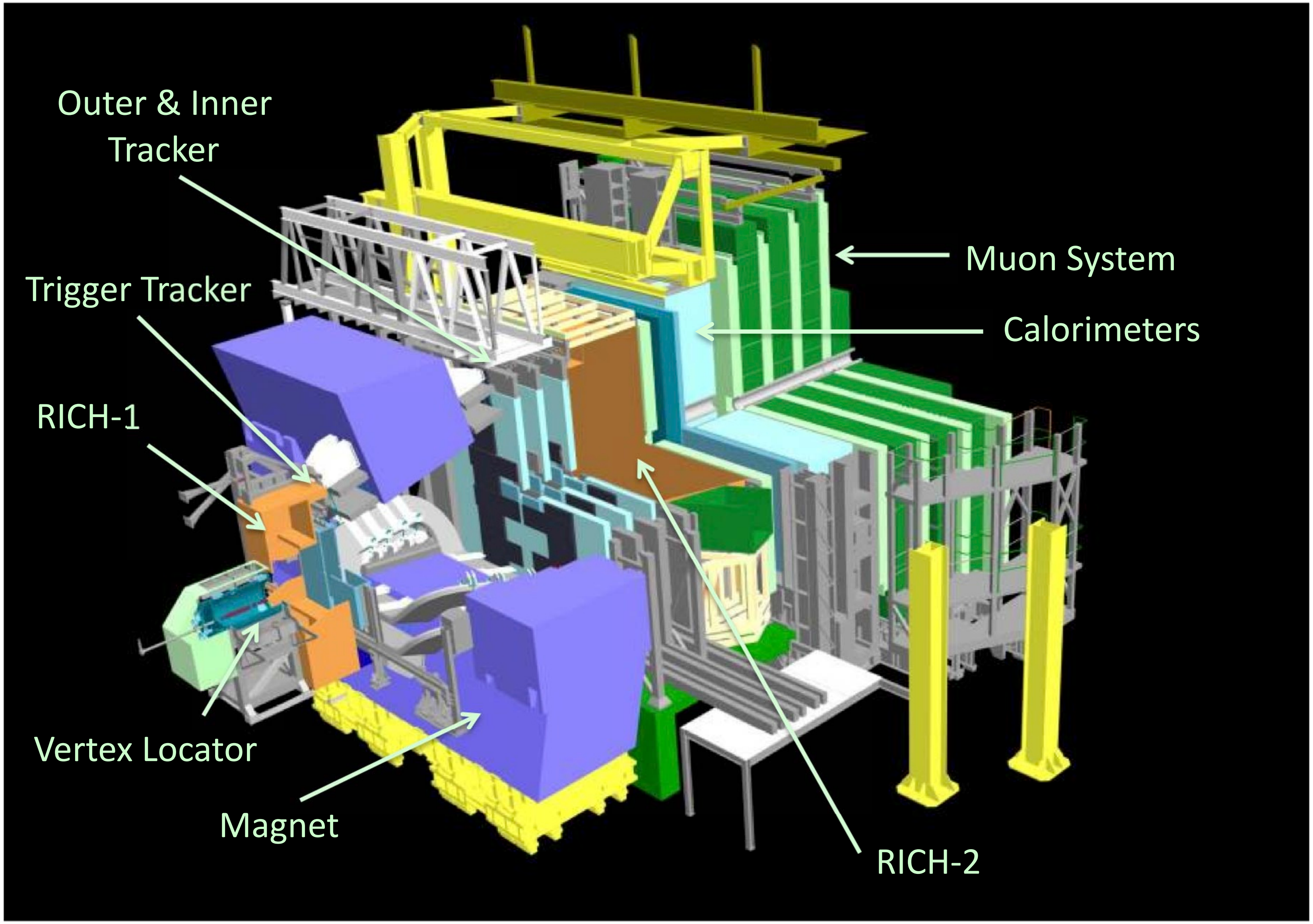
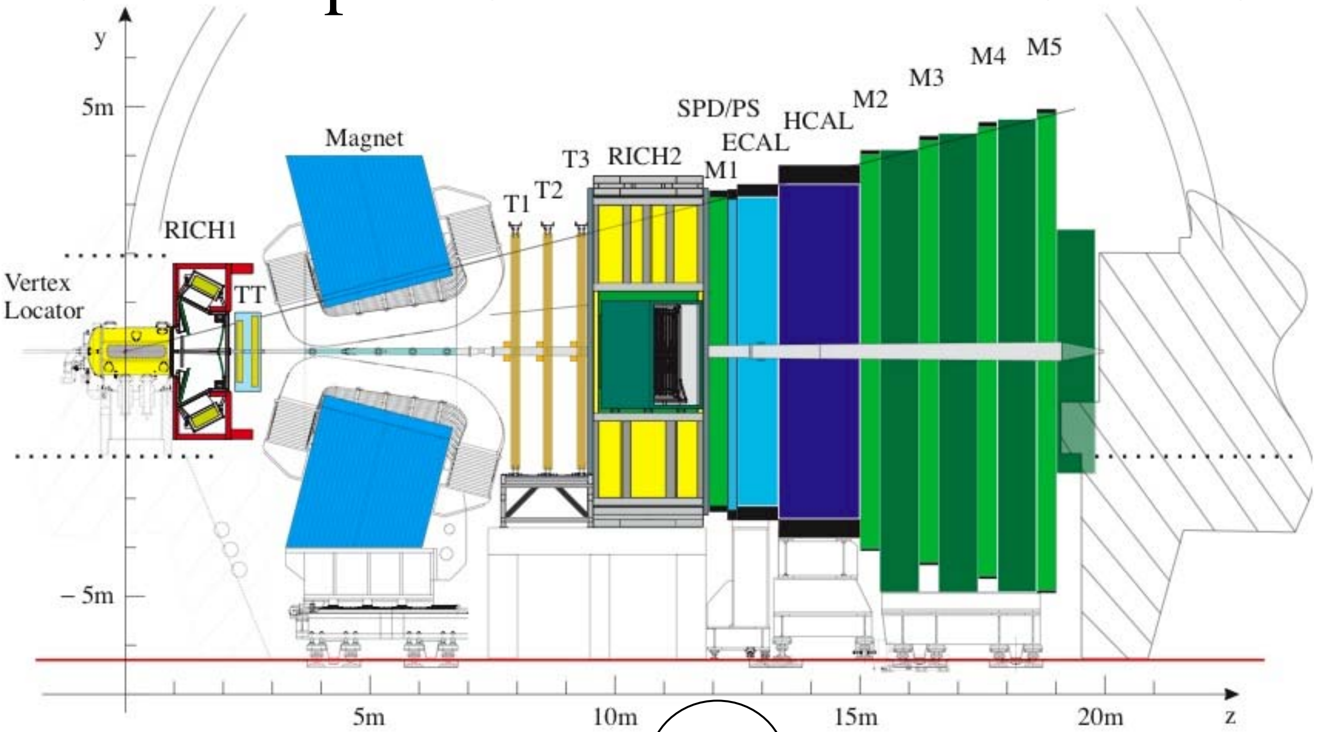
LHCb Detector

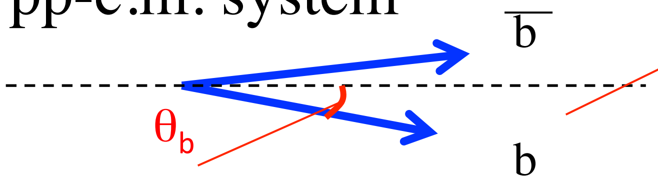


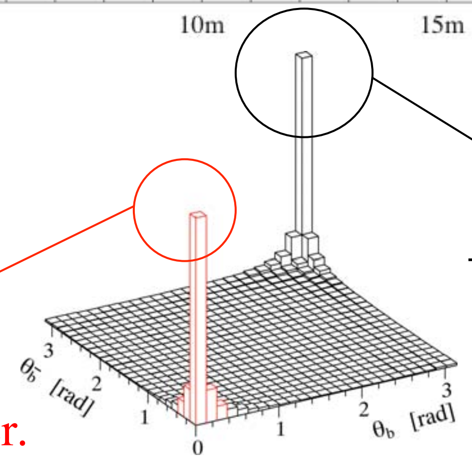
Quick reminder for LHCb

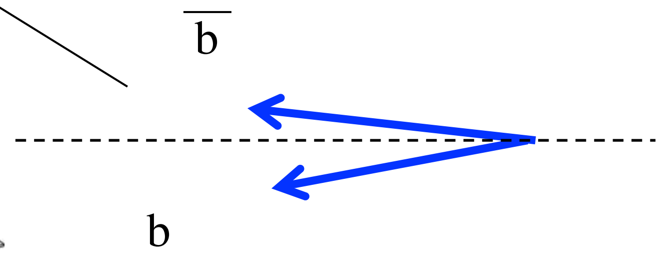
LHCb is a forward spectrometer dedicated for flavour physics



pp-c.m. system







Both b and b̄ are in the spectrometer.

Quick reminder for LHCb

Forward: p_T threshold can be set low: → high b efficiency

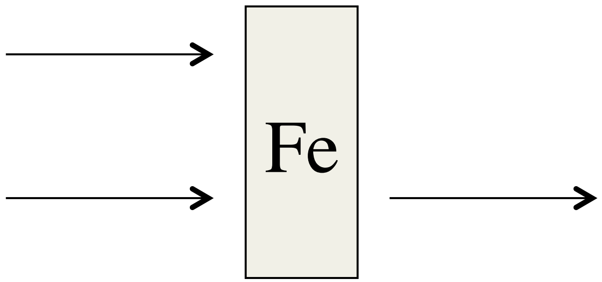
For triggering…. $p > p_{min}$

muon: identification

hadron: energy resolution

$p < p_{min}$

$p > p_{min}$



$\sigma_E/E \approx \sqrt{70\%}/\sqrt{E}$

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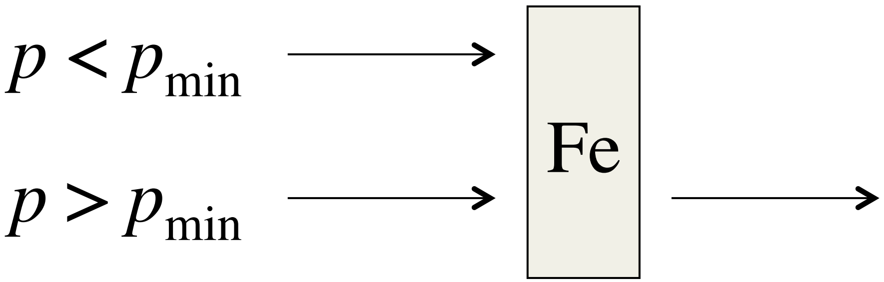
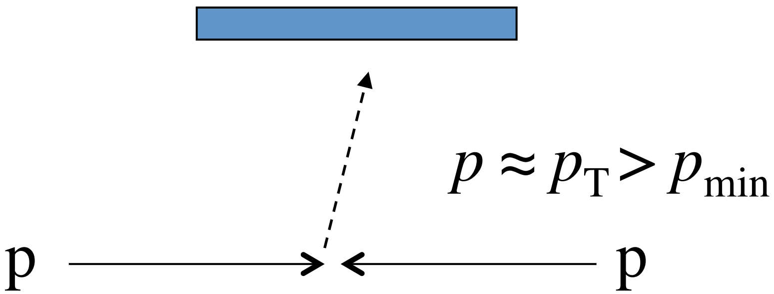


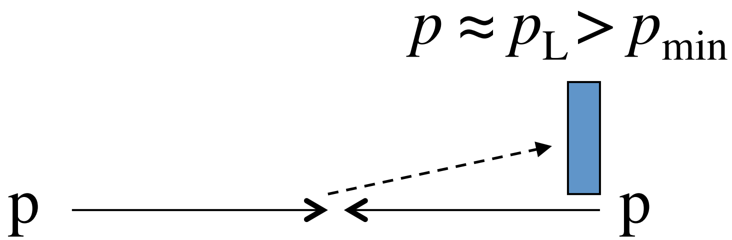
hadron: energy resolution

$\sigma_E/E \approx \sqrt{70\%}/\sqrt{E}$

central detector

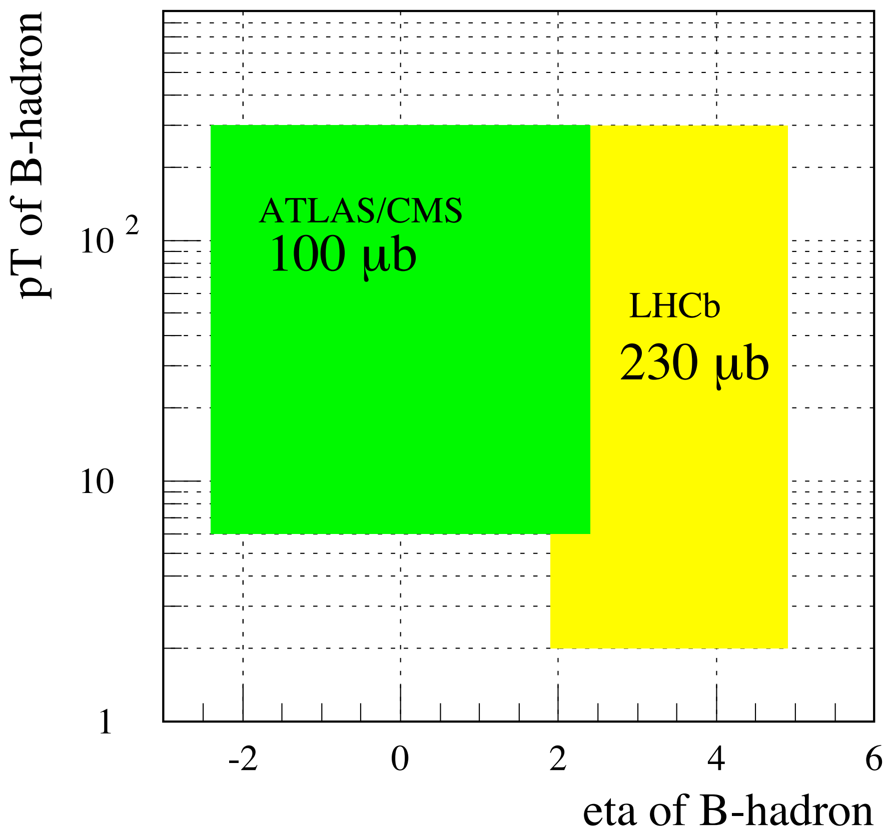


forward detector



Quick reminder for LHCb

Can exploit low p_T particles to trigger more b-hadron events



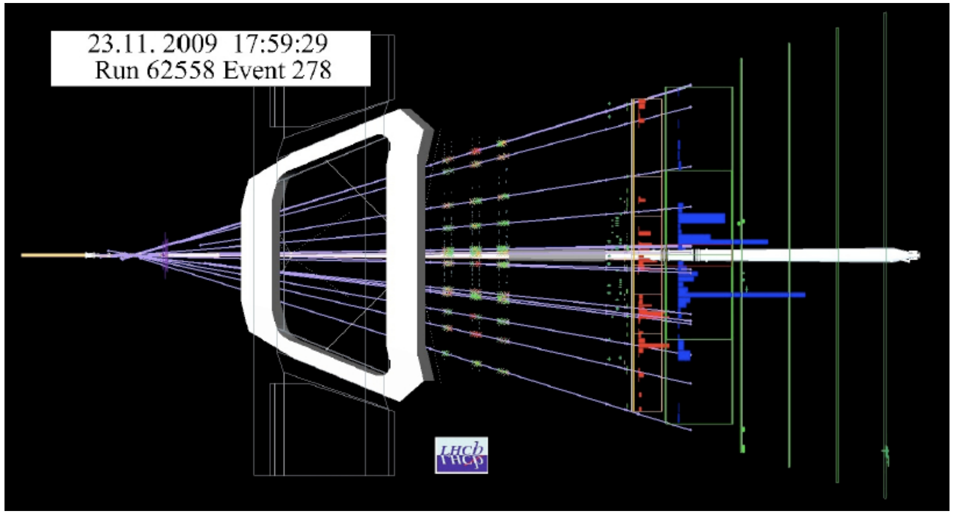
$\sigma_{b\bar{b}}$ expected in pp collisions at $\sqrt{s}$ = 14 TeV: 500μb

5×10^{11} $b\bar{b}$ pairs in 10^7 s with $L = 10^{32}$ cm^{-2}s^{-1}

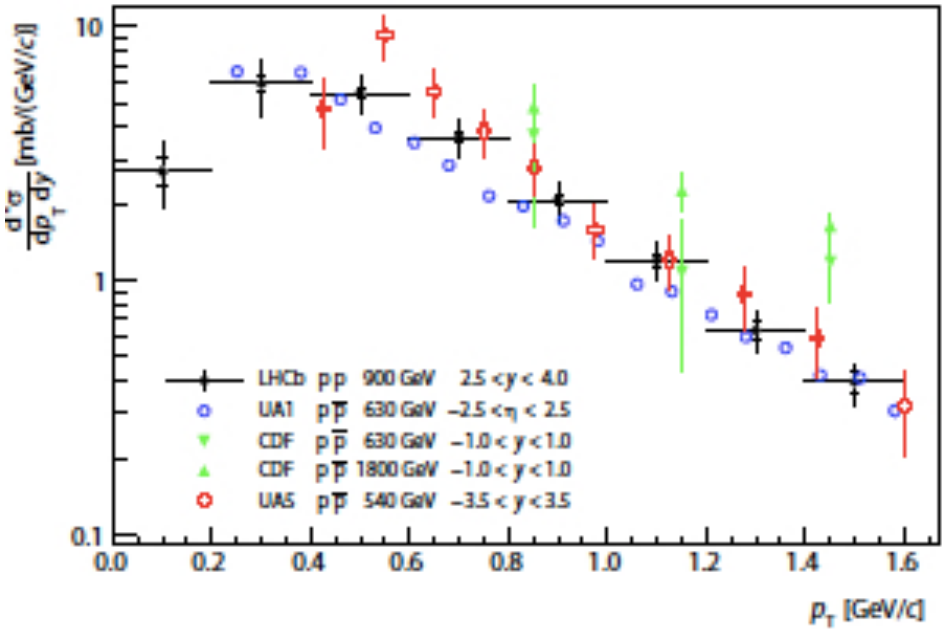
First level trigger based on medium p_T trigger (hardware)
40MHz→1MHz
readout@1 MHz to PC farm
Software trigger for the rest
1MHz→2 kHz
data logging@2 KHz for offline
Very flexible and efficient trigger

23rd November 2009

- First collisions took place at LHC
- 2009 run: $\int L\,dt \approx 7\ \mu b^{-1}$, at $\sqrt{s} = 900$ GeV



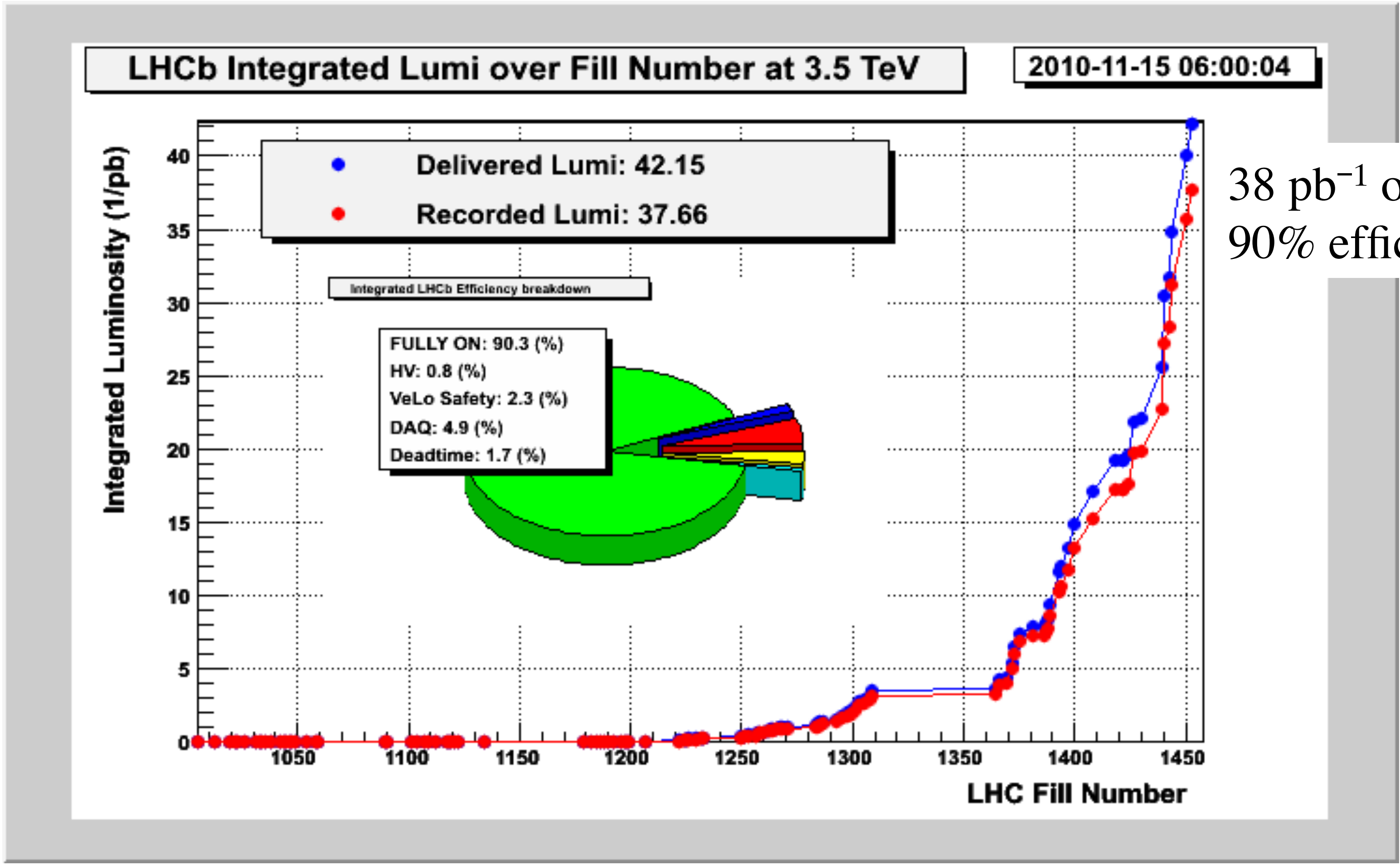
One of the first event



K_S^0 cross sections
(PLB2010)

LHC running in 2010

- Since March 2010, running at $\sqrt{s}$ = 7 TeV with a steady improvement in $\int L dt$ and very high DAQ efficiency



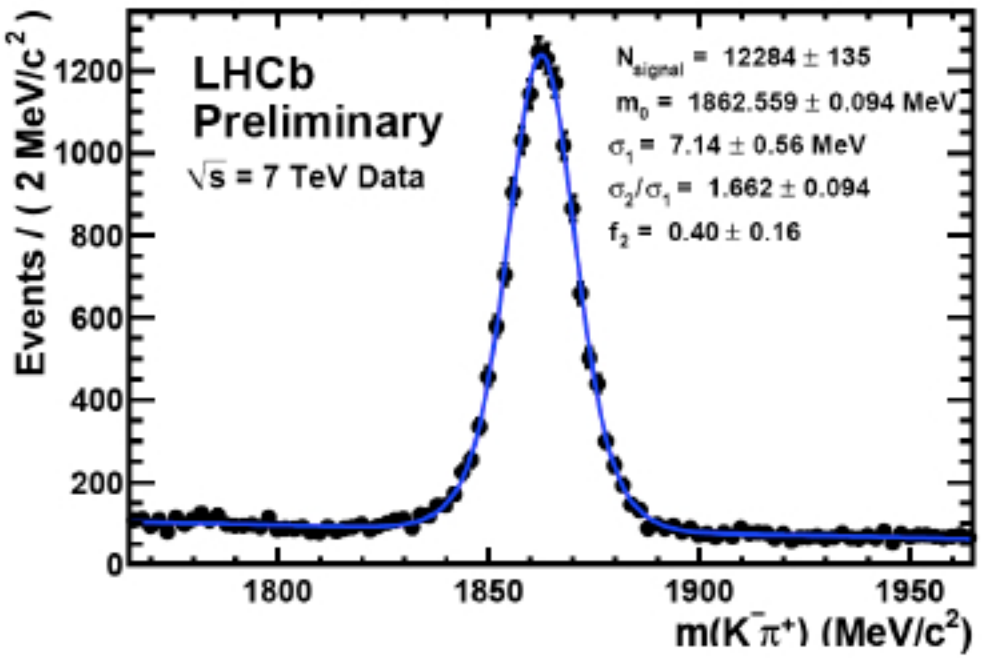
38 pb^{-1} of data recorded
90% efficiency

$\sigma_{b\bar{b}}$ measurements with very early data

b detection from $b \to D^0(K^-\pi^+)\mu^-X$ (PLB 2010)

$\int L\, dt = 25\ nb^{-1}$ data

Inclusive D:

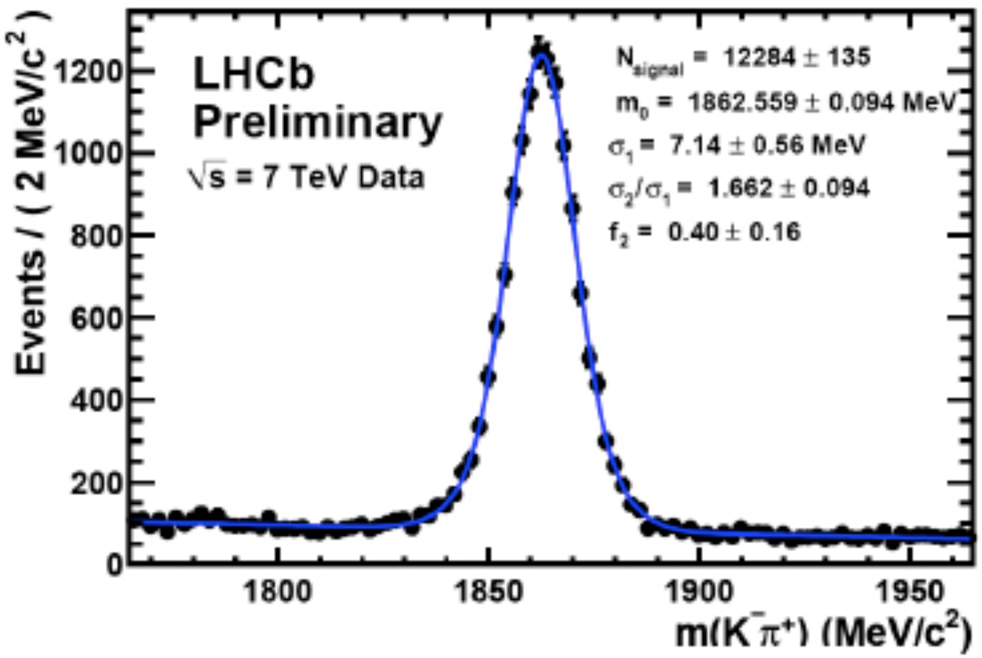


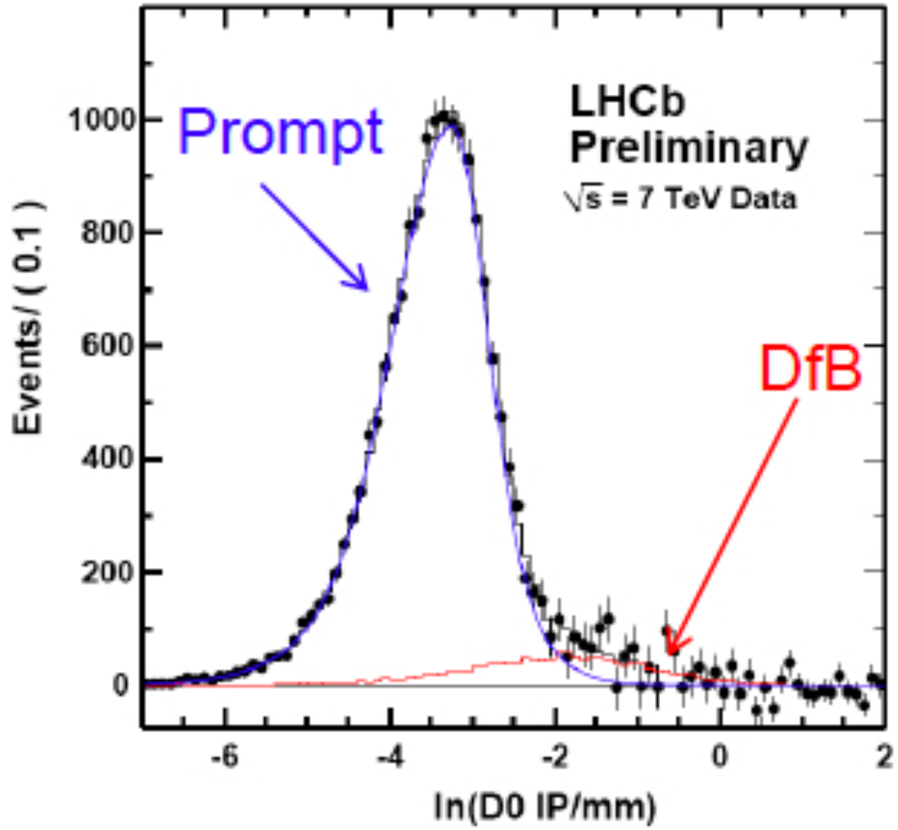
Clean D signal with hadron PID

$\sigma_{b\bar{b}}$ measurements with very early data

b detection from $b \to D^0(K^-\pi^+)\mu^- X$

Inclusive D:
dominated by the prompt production





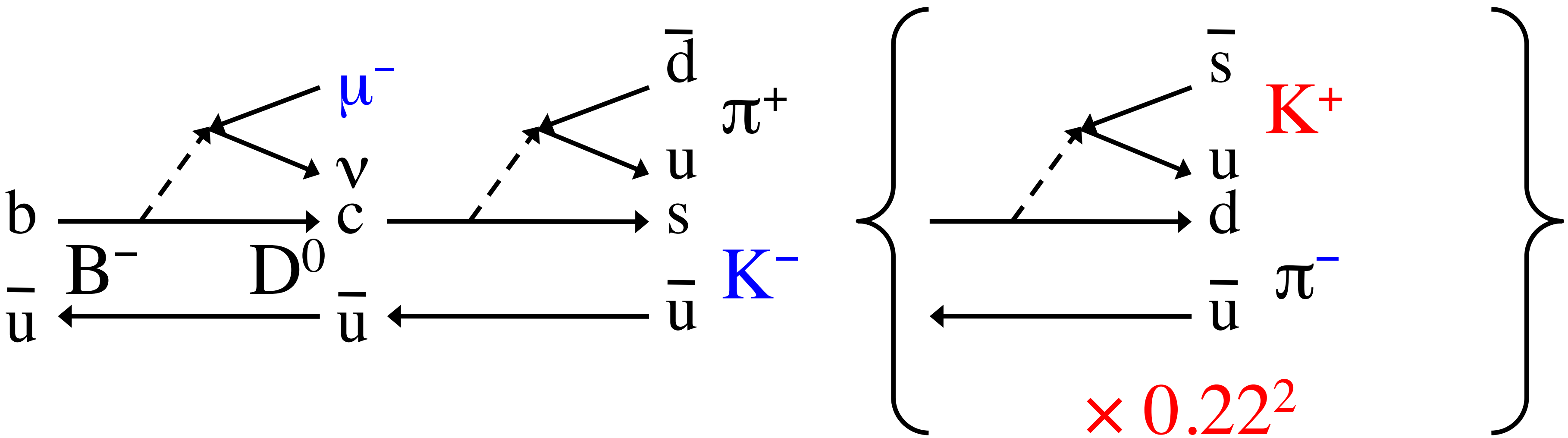
IP(D from $b \to D$) > IP (prompt D)

$\sigma_{b\bar{b}}$ measurements with very early data

b detection from $b \to D^0(K^-\pi^+)\mu^- X$

Adding μ with a right sign enhances D from b:

e.g. $B^- \to D^0(\to K^-\pi^+)\mu^- X$ [$B^- \to D^0(\to K^+\pi^-)\mu^- X$ only through DCSD]



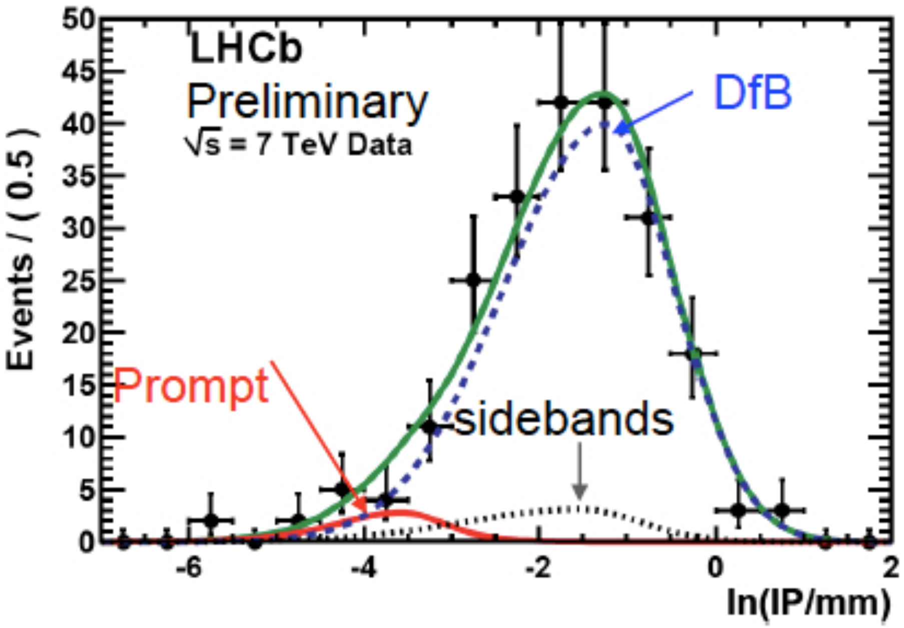
$\sigma_{b\bar{b}}$ measurements with very early data

b detection from $b \to D^0(K^-\pi^+)\mu^-X$

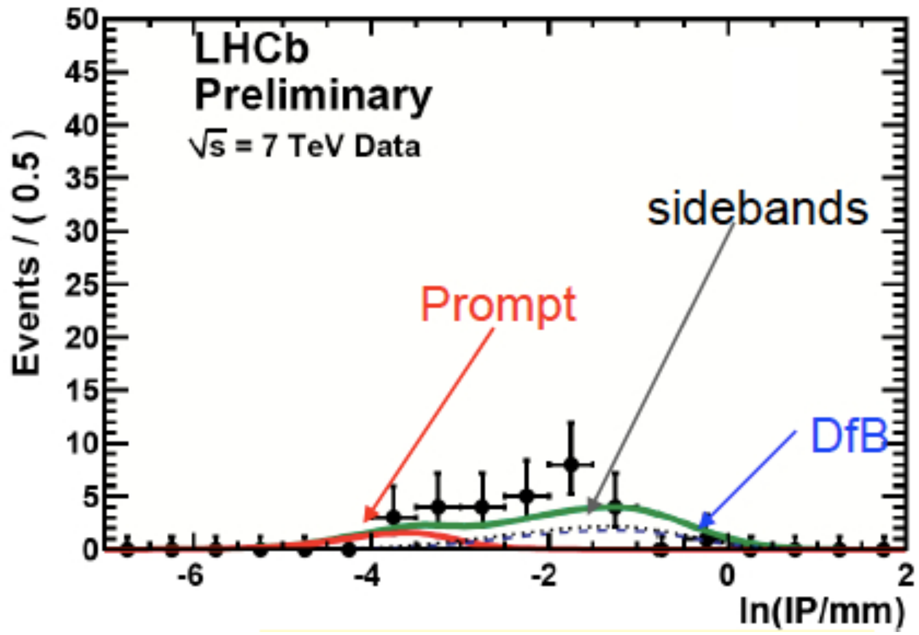
Adding μ with a right sign enhances D from b:

e.g. $B^- \to D^0(\to K^-\pi^+)\mu^-X$ [$B^- \to D^0(\to K^+\pi^-)\mu^-X$ only through DCSD]

with right sign muons

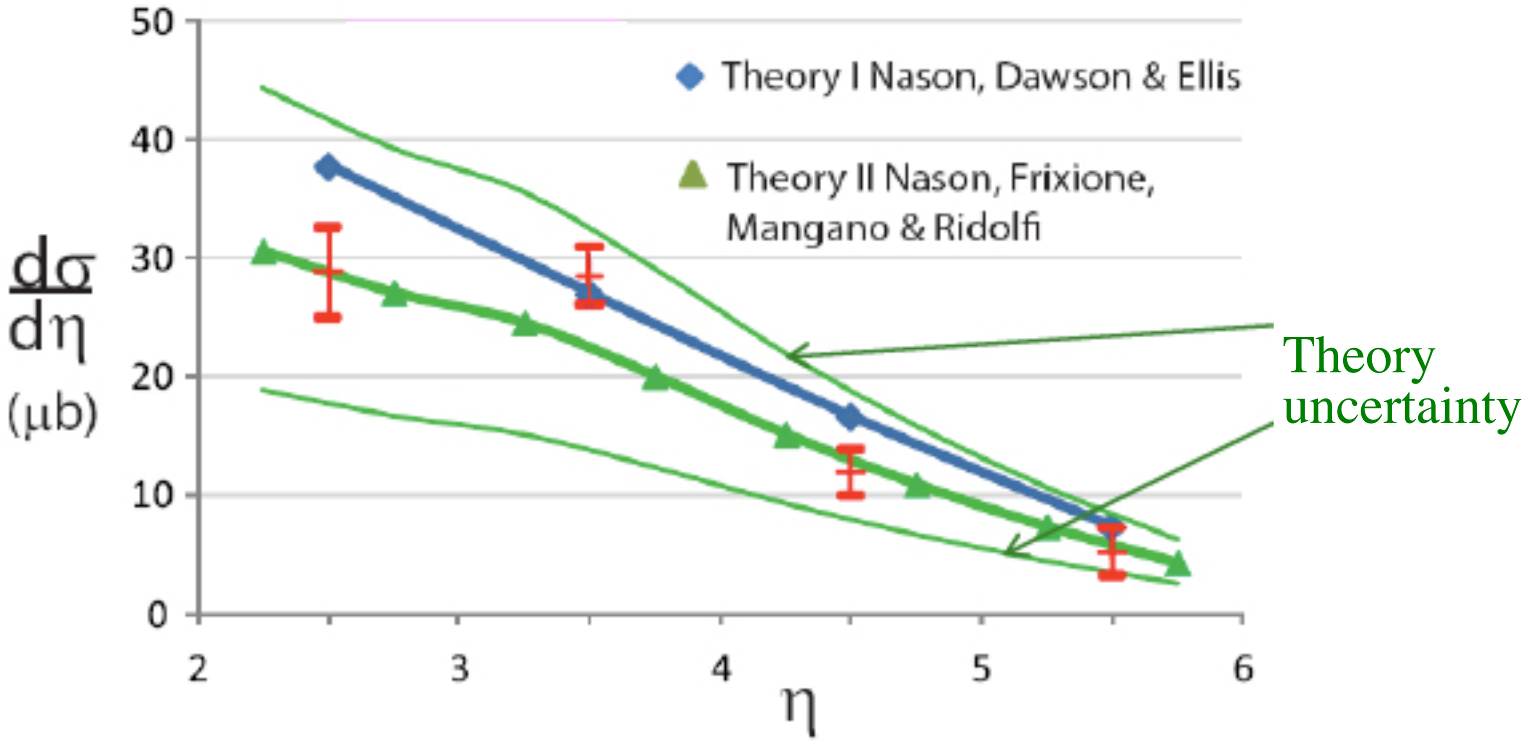


with wrong sign muons



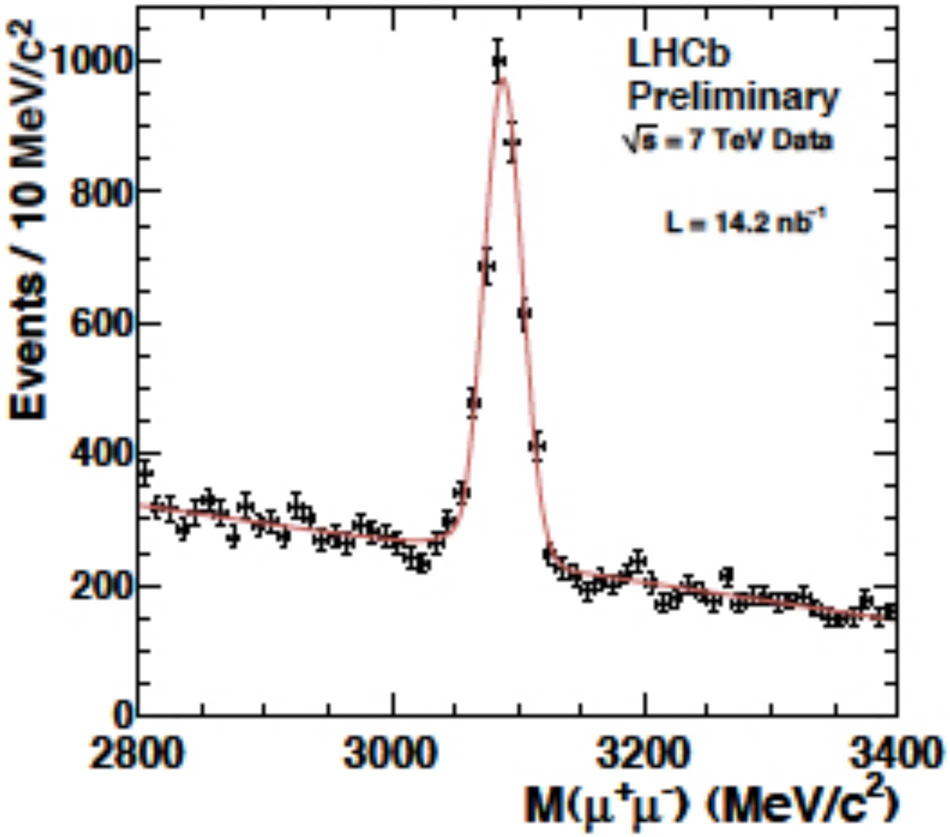
$\sigma_{b\bar{b}}$ measurements with very early data

b detection from $b \to D^0(K^-\pi^+)\mu^- X$



$\sigma_{b\bar{b}}$ measurements with very early data

b detection from $b \rightarrow J/\psi X$

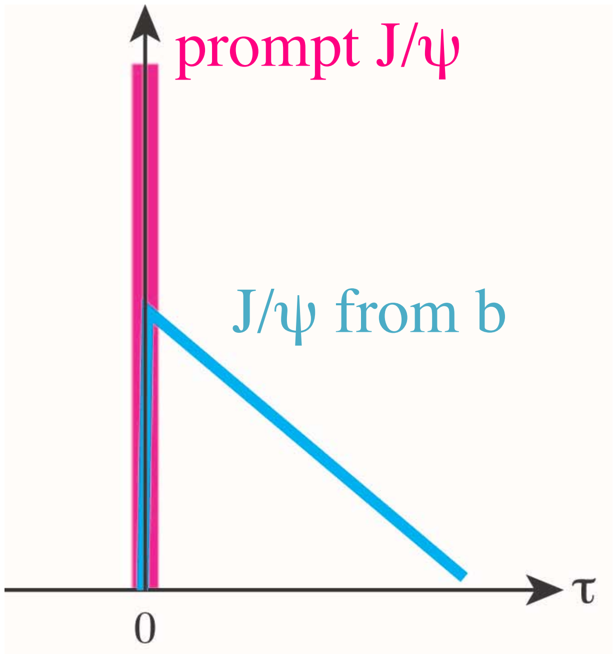


Clean $\mu^+\mu^-$ mass distribution
with $\int L\,dt = 14\ \text{nb}^{-1}$ data

$\sigma_{b\bar{b}}$ measurements with very early data

b detection from $b \rightarrow J/\psi X$

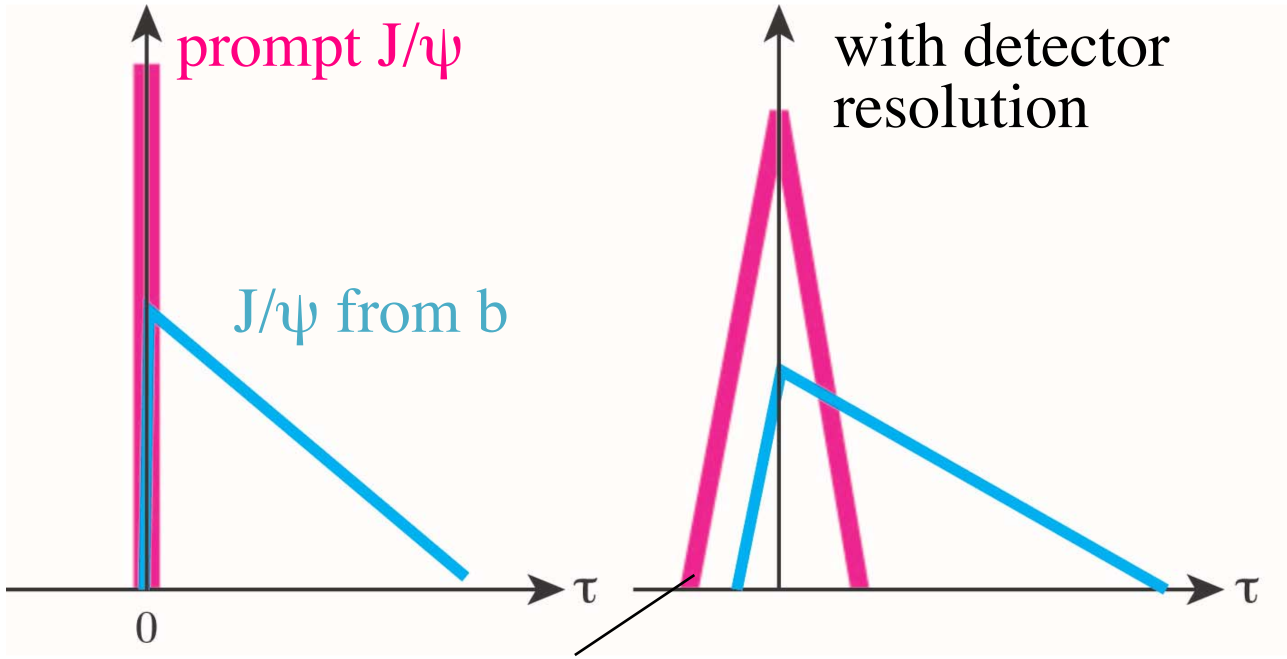
proper time distribution of J/ψ



$\sigma_{b\bar{b}}$ measurements with very early data

b detection from b→J/ψX

proper time distribution of J/ψ

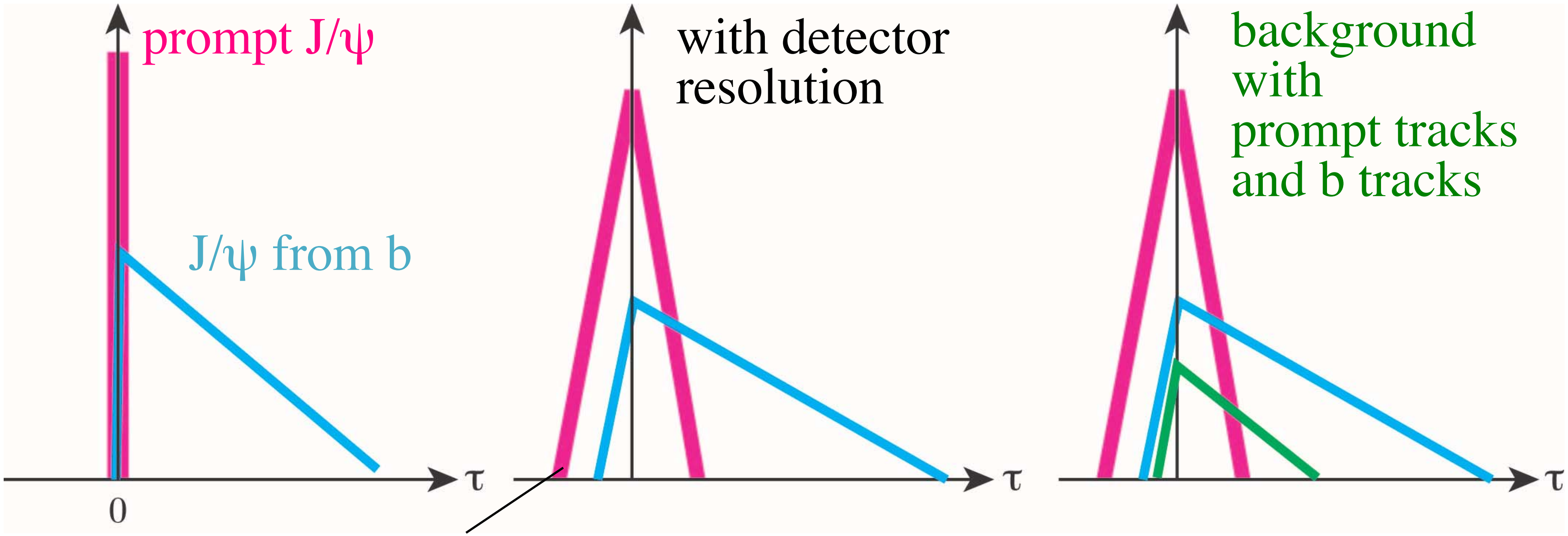


negative proper time important for studying resolution

$\sigma_{b\bar{b}}$ measurements with very early data

b detection from $b \rightarrow J/\psi X$

proper time distribution of J/ψ

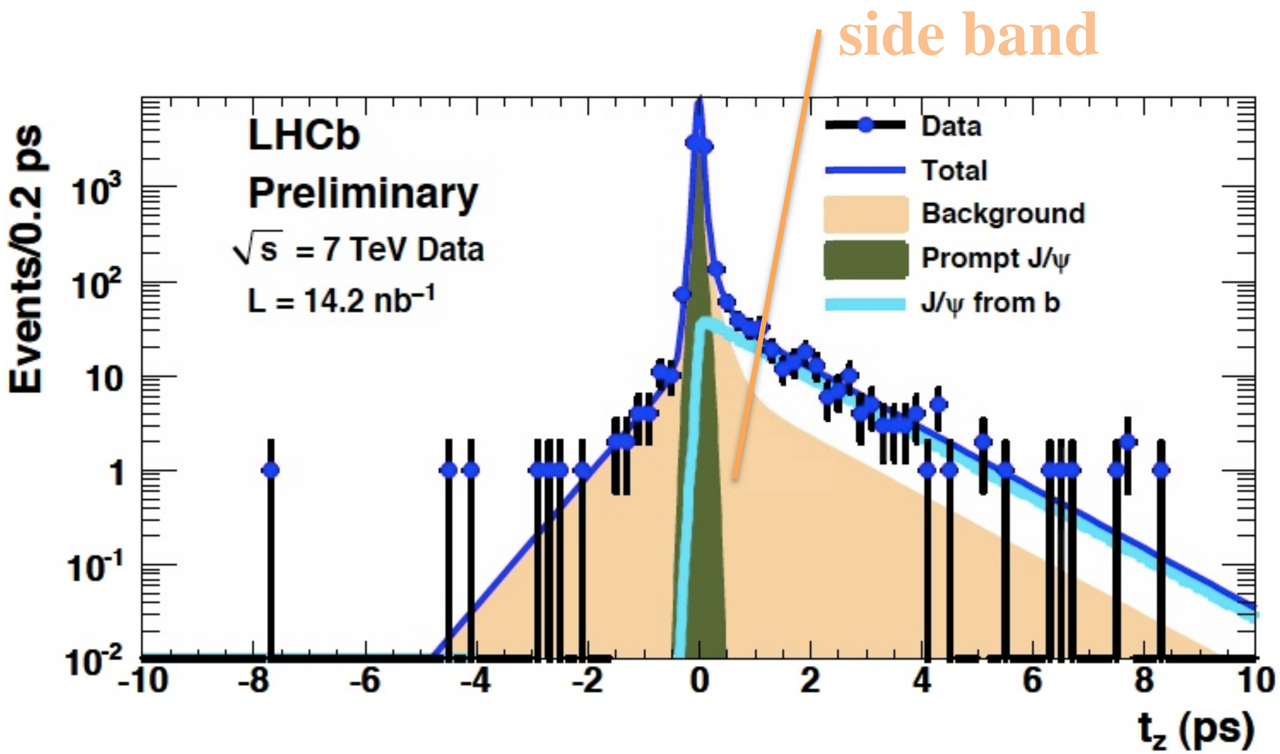


negative proper time important for studying resolution

$\sigma_{b\bar{b}}$ measurements with very early data

b detection from b→J/ψX

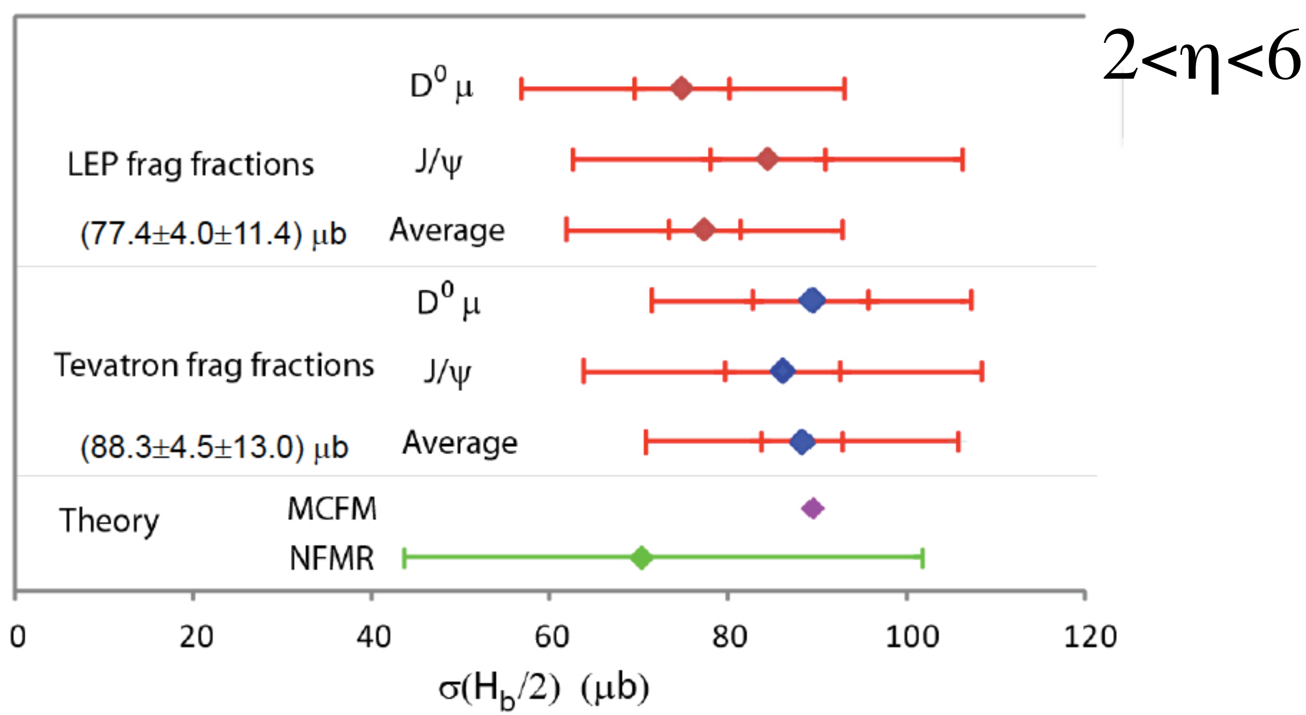
Proper time distribution with $\int L\, dt = 14\ nb^{-1}$ data



J/ψ with a long proper time due to b-hadron decays

$\sigma_{b\bar{b}}$ measurements with very early data

LHCb $\sigma_{b\bar{b}}$ from $b \rightarrow D^0 \mu X$ and $\rightarrow J/\psi X$

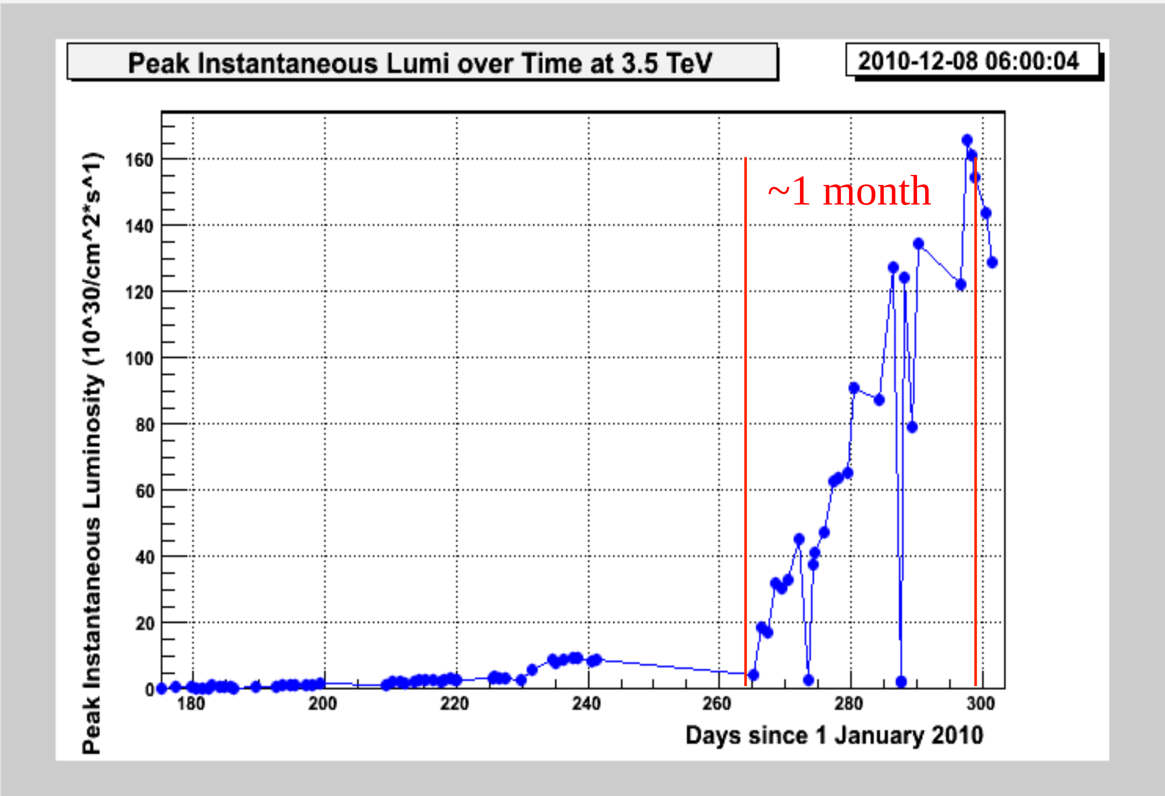


σ_{bb} in 4π = 292 ± 15 ± 43 μb (with LEP $B_u/B_d/B_s/\Lambda_b$)

→agree with the Pythia used for the performance studies

Comments on 2010 running condition

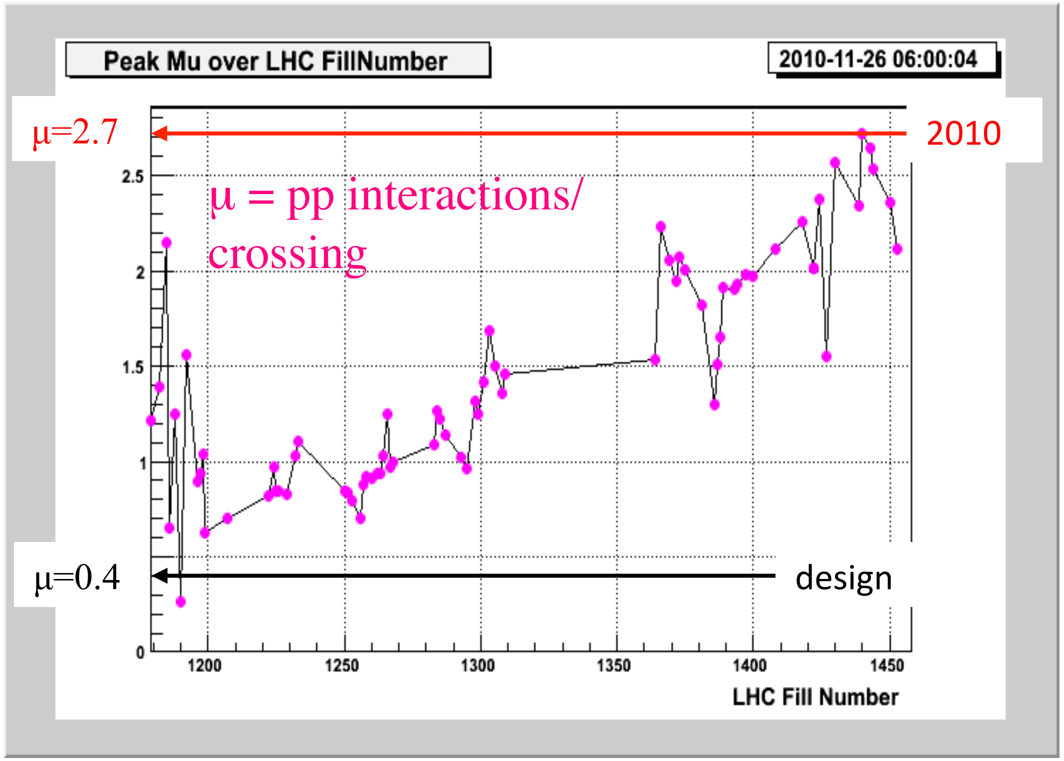
- Most of the data at $\sqrt{s}$ = 7 TeV with
  - $n_{\text{p-bunch}} \approx 10^{11}$ ⇔ already nominal value
  - $\beta^* = 3.5$ m ⇔ nominal 0.55 m for 10^{34} cm^{-2}s^{-1}
  - n_{bunch} = up to 344 ⇔ nominal = 2808
  - $L \approx 1\times10^{32}$ cm^{-2}s^{-1} ⇔ nominal = 10^{34} cm^{-2}s^{-1}



Factor 100 increase in ~one month

Comments on 2010 running condition

- Most of the data at $\sqrt{s}$ = 7 TeV
  at 80% of the LHCb nominal luminosity (2×10^{32})
  with 10% of bunches, i.e.
  > 6 times more pp interactions/bunch-crossing than designed



Multiple primary vertices
Higher track multiplicities

⇩

More difficult to trigger
More backgrounds

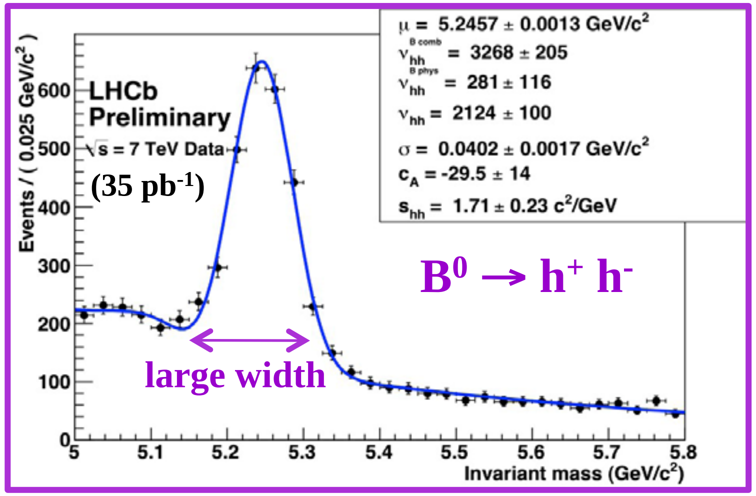
But the detector worked well as you will see now.

Prospect for B→hh

- Particle identification is crucial

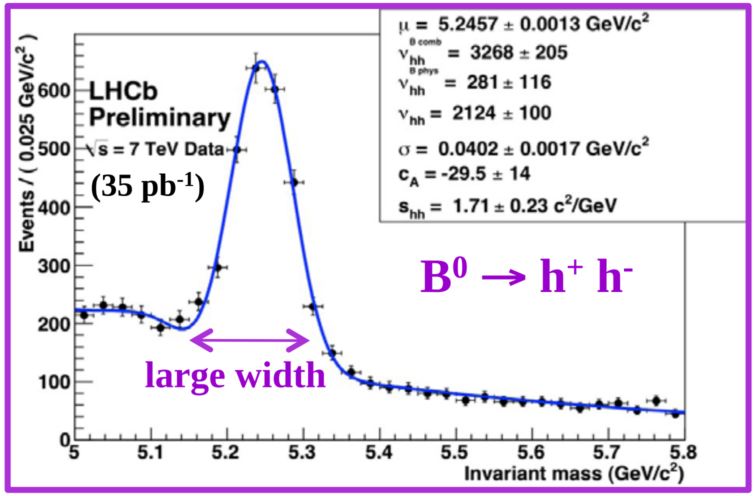
Prospect for B→hh

No particle identification → any 2 hadrons!

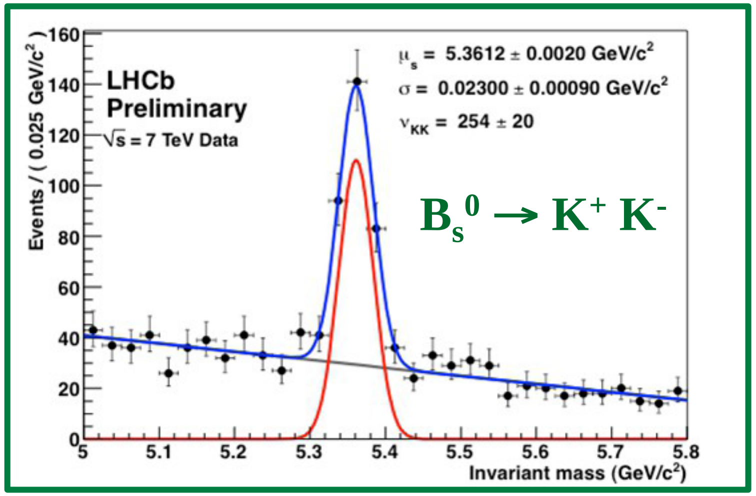


Prospect for B→hh

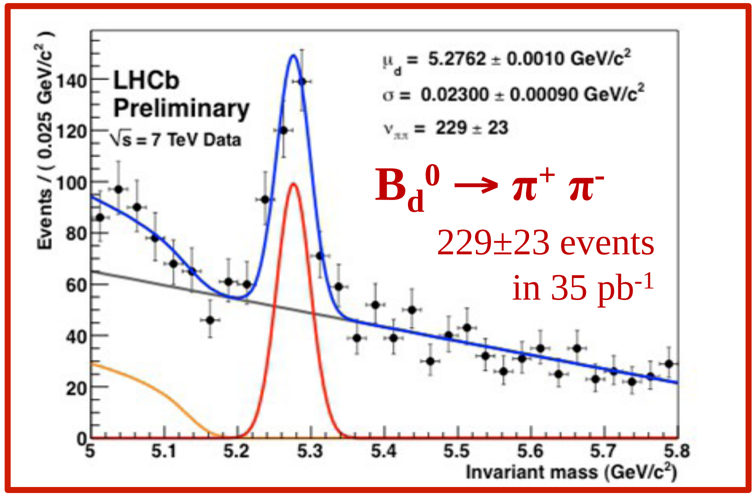
No particle identification → any 2 hadrons!



particle identification of 2 Kaons



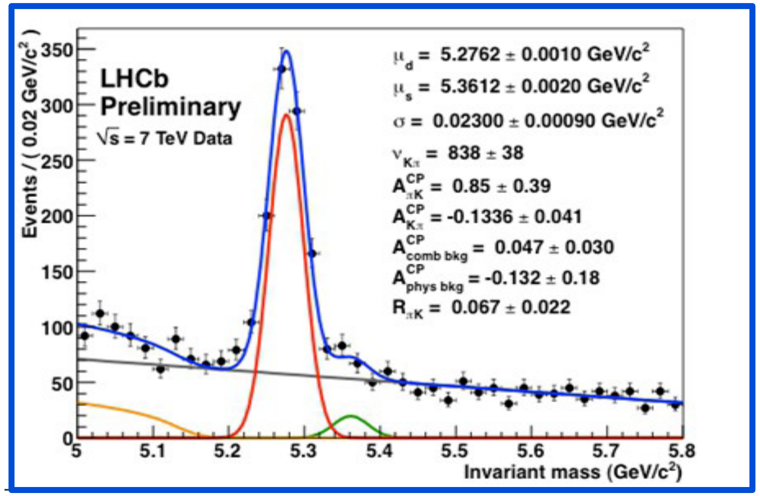
particle identification of 2 π
BR($B \to \pi^+\pi^-$) = 5 x 10^{-6} !



particle identification of 1 π and 1 K

Expectations 2011:
LHCb: 6500 ev./fb^{-1}
Belle 1.5k

$B_d^0 \to K\pi$ & $B_s^0 \to K\pi$
(will get as many Kπ in <1 fb^{-1} as Belle in 1000 fb^{-1})

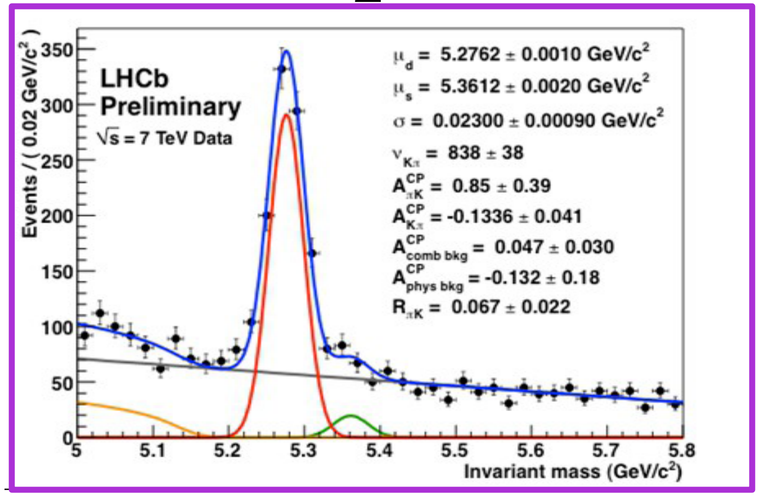


Prospect for B→hh

- Particle identification is crucial
- Promising signature in the raw charge asymmetries

Prospect for B→hh

$B_d^0 \rightarrow K\pi$ &
$B_s^0 \rightarrow K\pi$

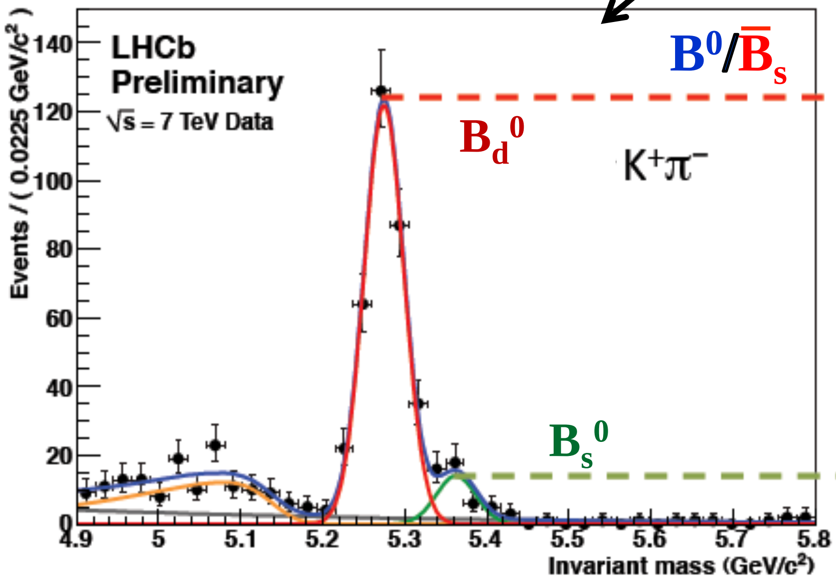


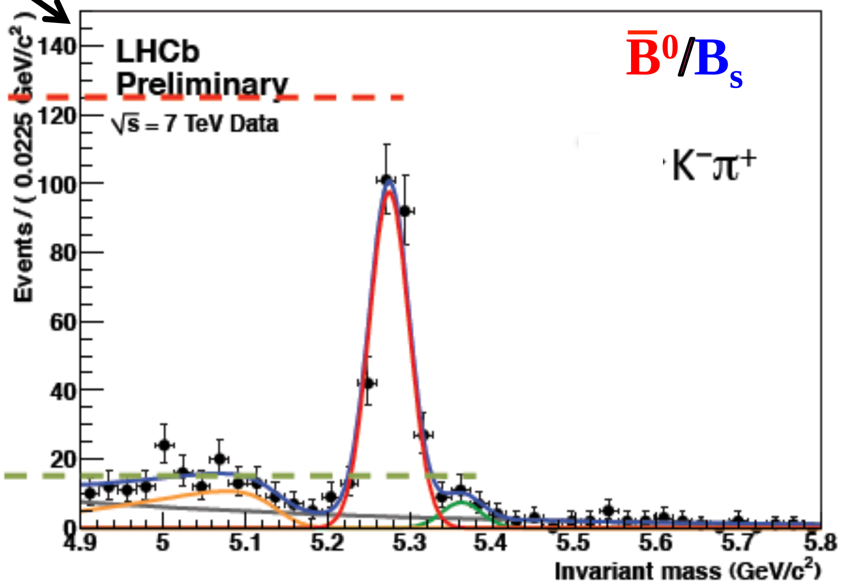
B_s^0/B_d^0 yield = (10.7±2.0)%,

$A_{CP}(B_d^0)$= −0.134±0.041
(HFAG: −0.098±0.012)

$A_{CP}(B_s^0)$=0.43±0.17
(CDF: 0.39±0.15±0.08 in 1 fb^{-1})

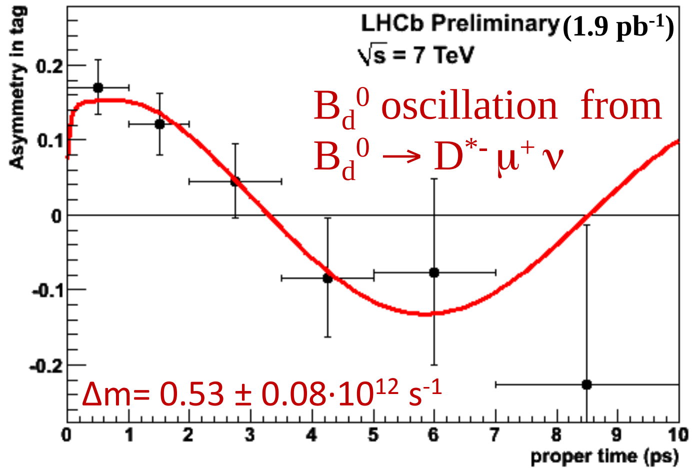
- ❖ only raw asymmetries
- ❖ not accounted for production & detector asymmetries
- ➢ this is not a physics result yet!





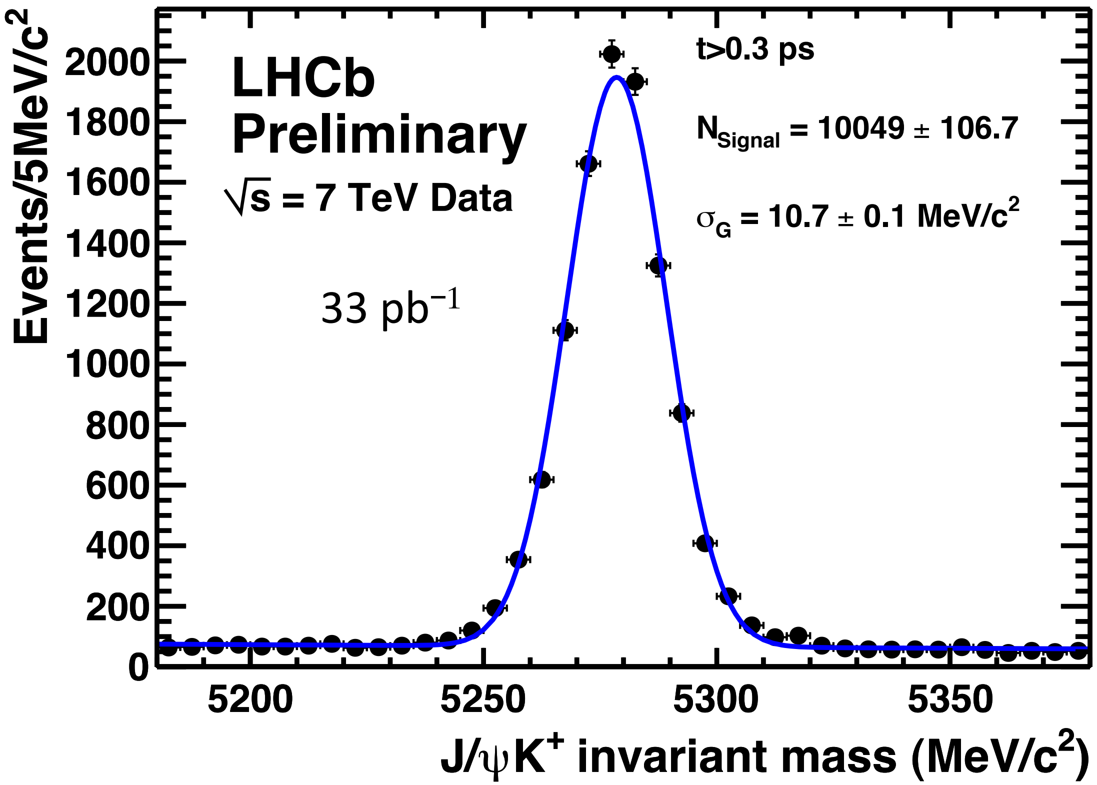
Prospect for CPV in $B_s \to J/\psi\phi$

- First step is to observe B^0-$\overline{B}^0$ oscillations



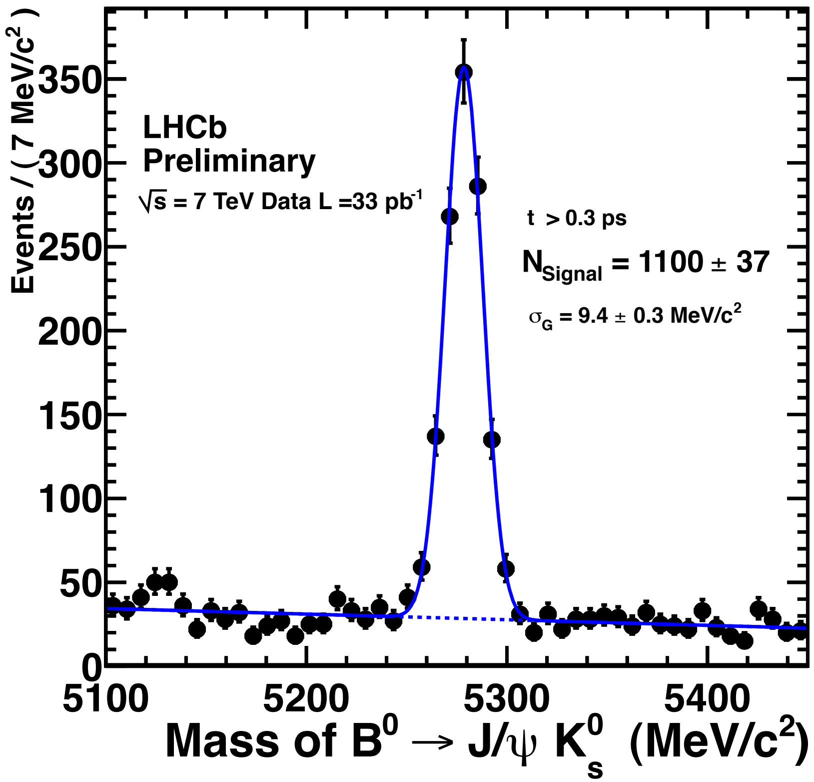
Prospect for CPV in $B_s \to J/\psi\phi$

- First step is to observe B^0-$\overline{B}^0$ oscillations
- Reconstruct $B^+ \to J/\psi K^+$ final states



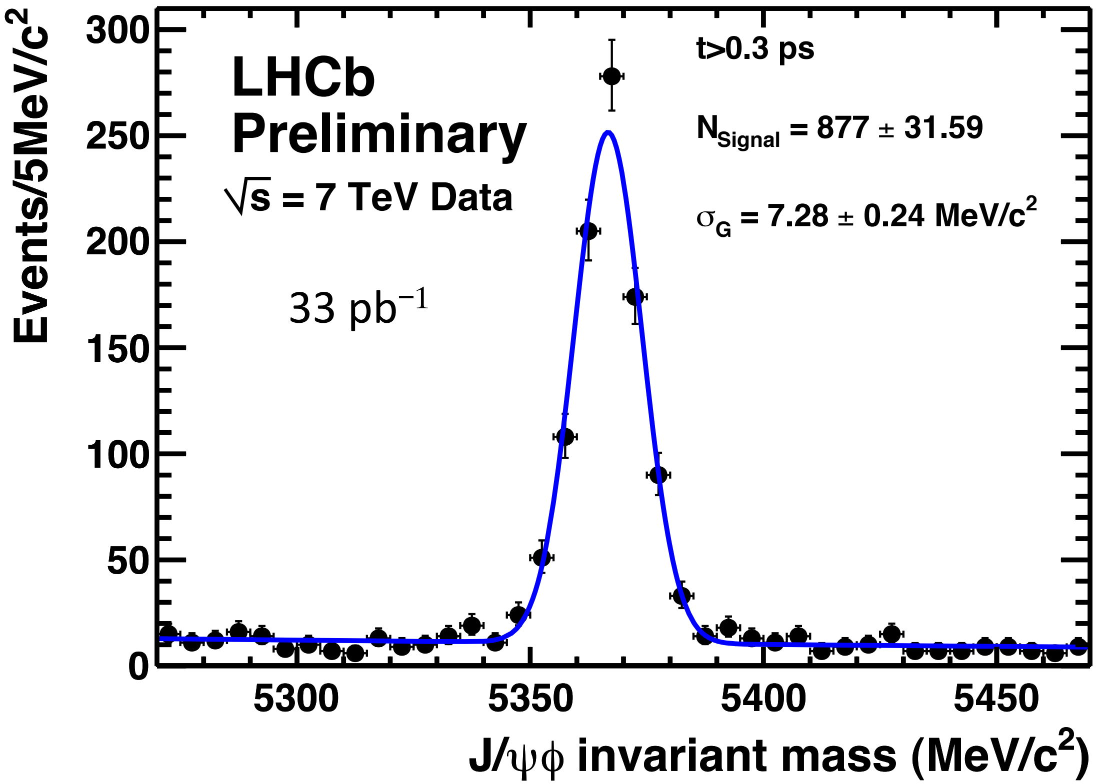
Prospect for CPV in $B_s \to J/\psi\phi$

- First step is to observe B^0-$\overline{B}^0$ oscillations
- Reconstruct $B^+ \to J/\psi K^+$ final states
- Reconstruct $B^0 \to J/\psi K_S$ final states



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

- First step is to observe B^0-$\overline{B}^0$ oscillations
- Reconstruct $B^+ \rightarrow J/\psi K^+$ final states
- Reconstruct $B^0 \rightarrow J/\psi K_S$ final states
- Reconstruct $B_s \rightarrow J/\psi\phi$ final states

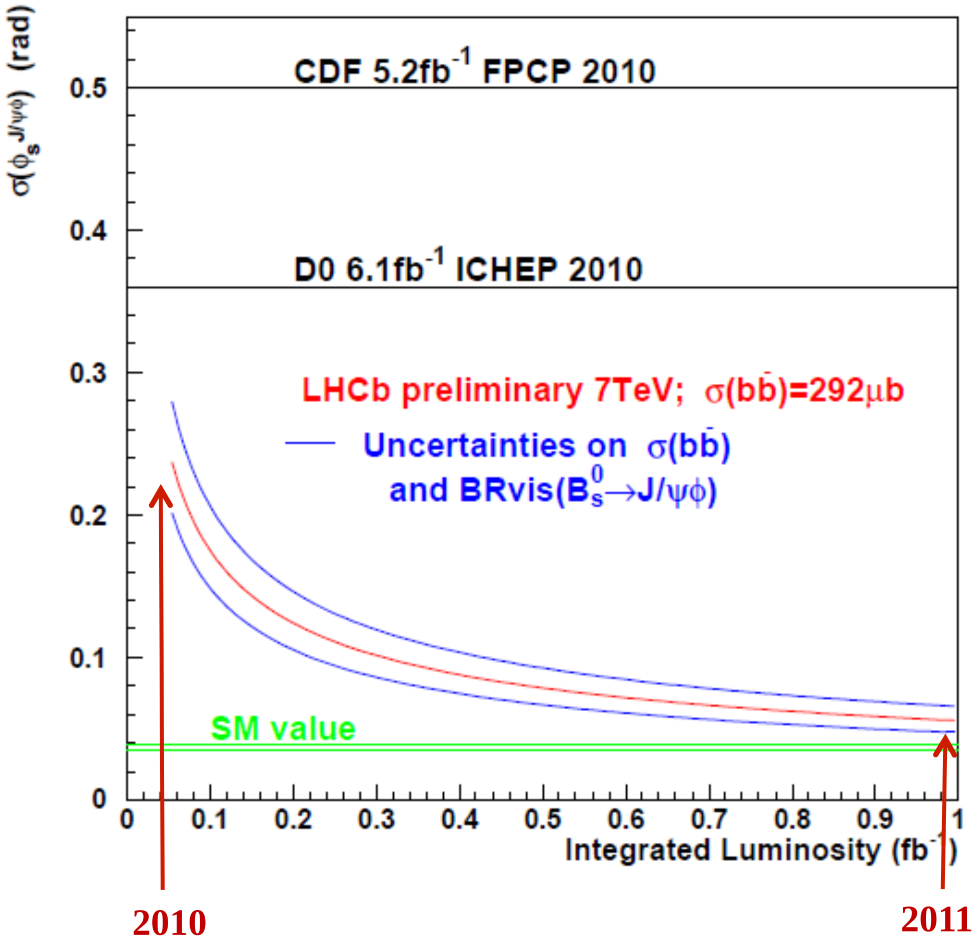


Prospect for CPV in $B_s \to J/\psi\phi$

- First step is to observe B^0-$\overline{B}^0$ oscillations
- Reconstruct $B^+ \to J/\psi K^+$ final states
- Reconstruct $B^0 \to J/\psi K_S$ final states
- Reconstruct $B_s \to J/\psi\phi$ final states
- On going work:
  - B_s-$\overline{B}_s$ oscillations
  - angular acceptance
  - fit model
  - etc.
  - and other final sates,
    e.g. $B_s \to J/\psi f_0(980)$ observed (pure CP eigenstate)

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

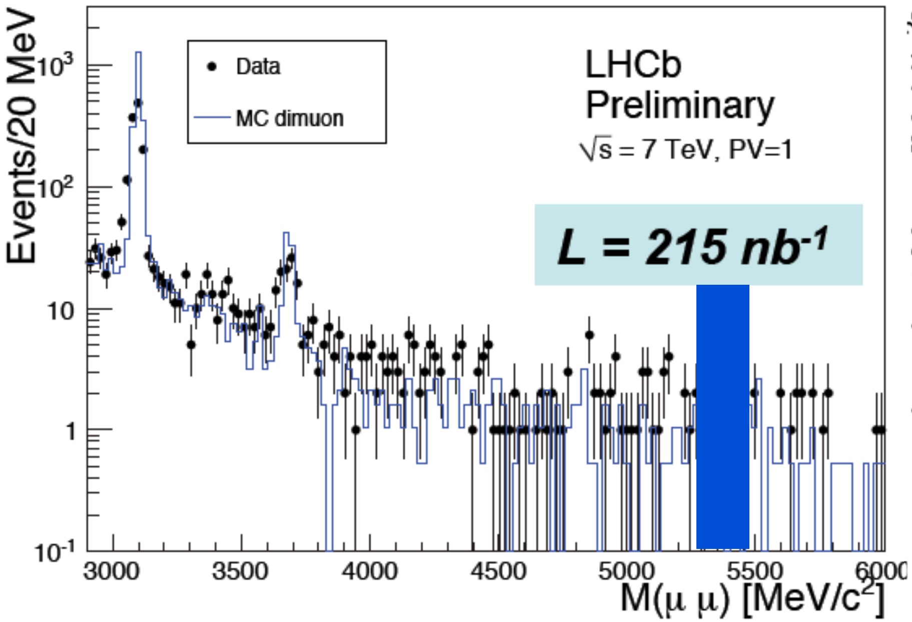
- Based on, measured b cross sections and $B_s \rightarrow J/\psi\phi$ reconstruction performance,

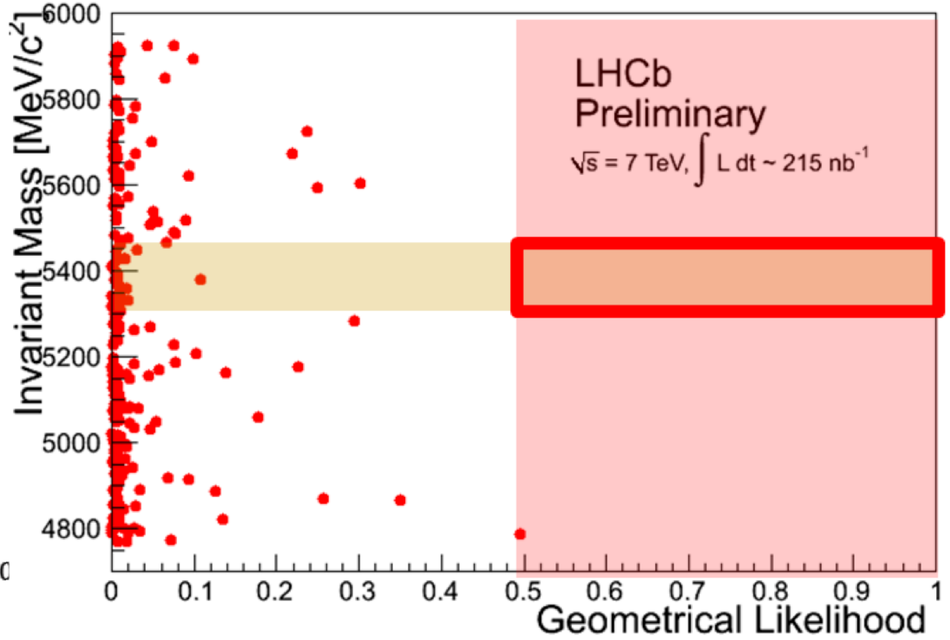


Prospect for $B_s \to \mu^+\mu^-$

- Decays can be characterised by
  - Invariant mass
  - $B \to$ two-particle decay topology
  - Muon identification
- All can be studied by data:
  - invariant mass and topology by $B \to \pi^+\pi^-$ decays
  - Muon ID by $K_s \to \pi^+\pi^-$, semileptonic decays, etc.

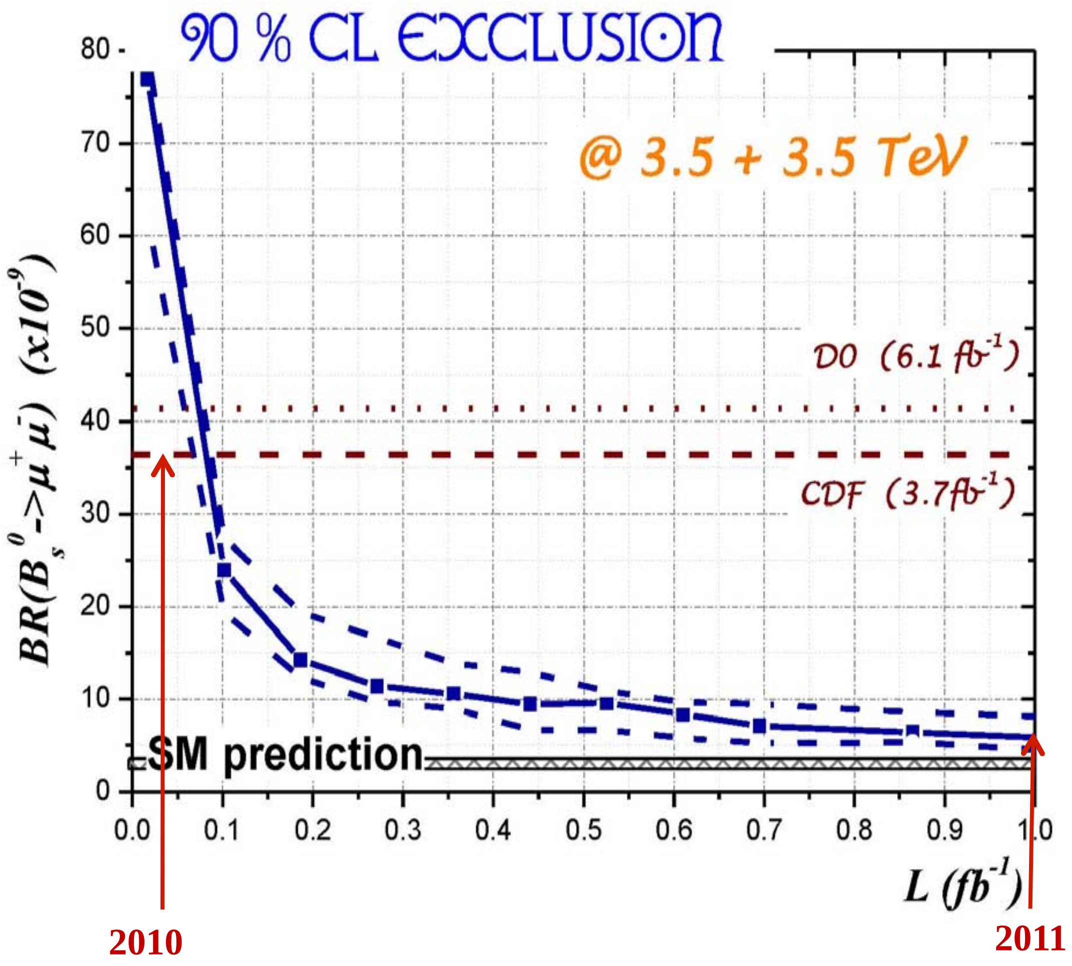
Background well described by MC





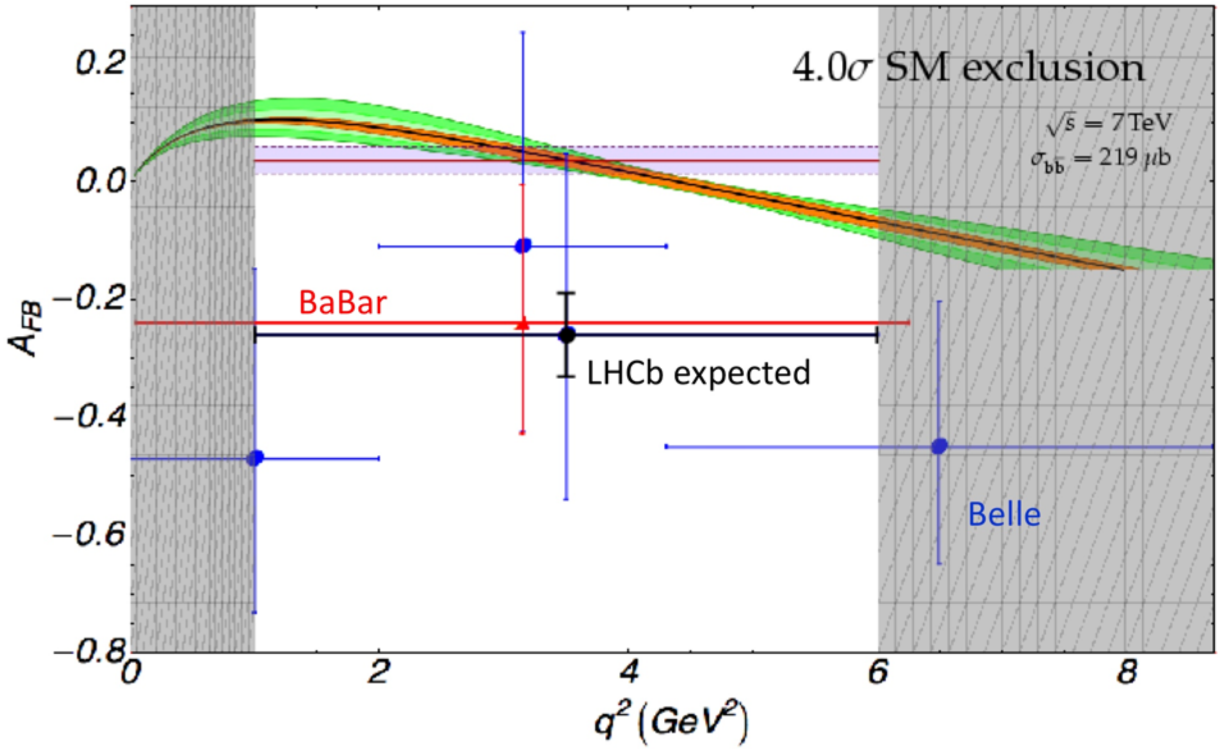
all the cuts are being tuned with a smaller sample

Prospect for $B_s \to \mu^+\mu^-$



LHCb how about $B_d \to K^{*0}\mu^+\mu^-$?

With 1 fb^{-1} LHCb expects 1200 events

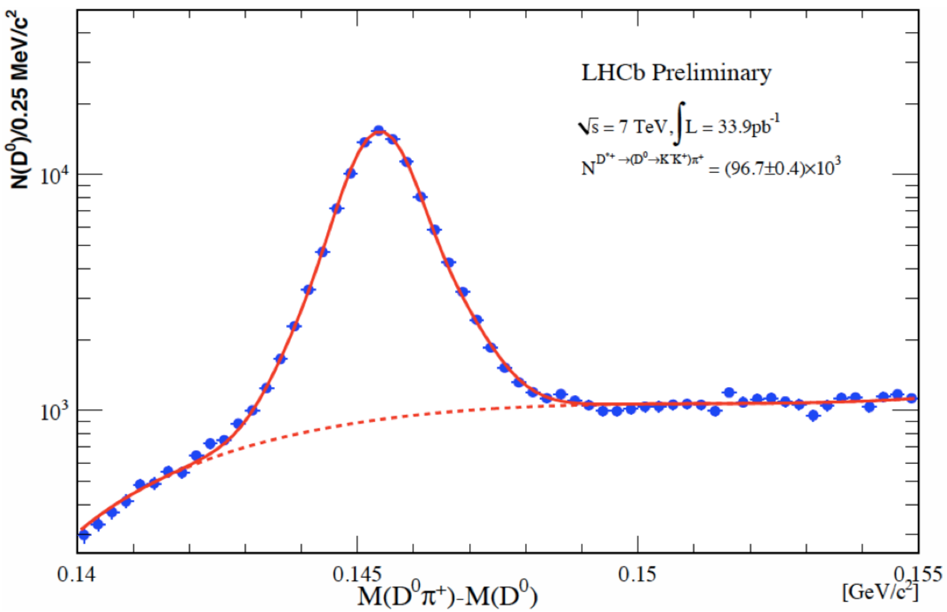


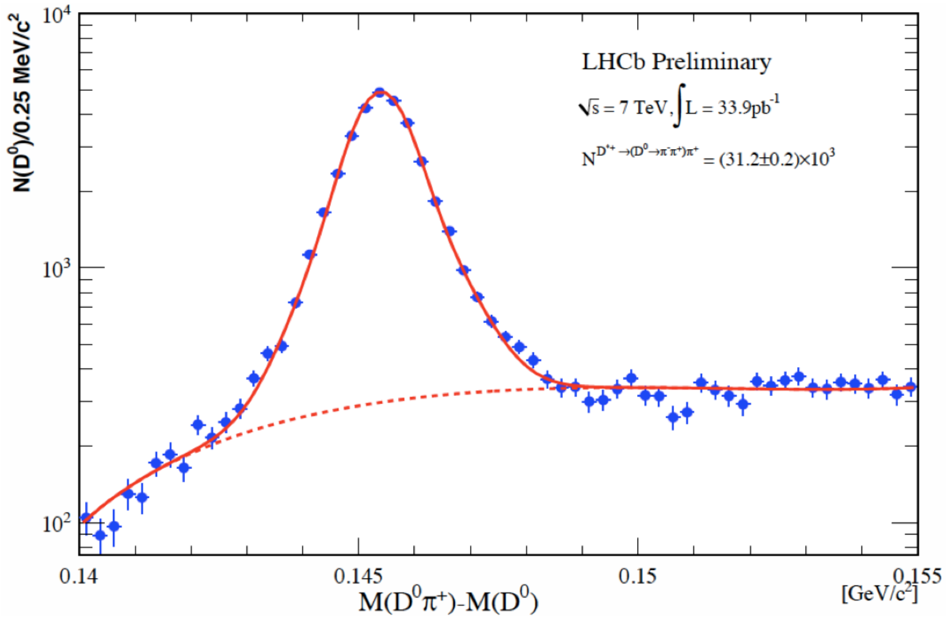
If the current BABAR and Belle results are correct, LHCb could exclude SM prediction with 4σ significance

Fantastic charm potential of LHCb

Initial flavour tagged D^0 decays: 34 pb^{-1}

$D^{*+} \to D^0\pi^+$, $D^0 \to K^+K^-$ and $\pi^+\pi^-$



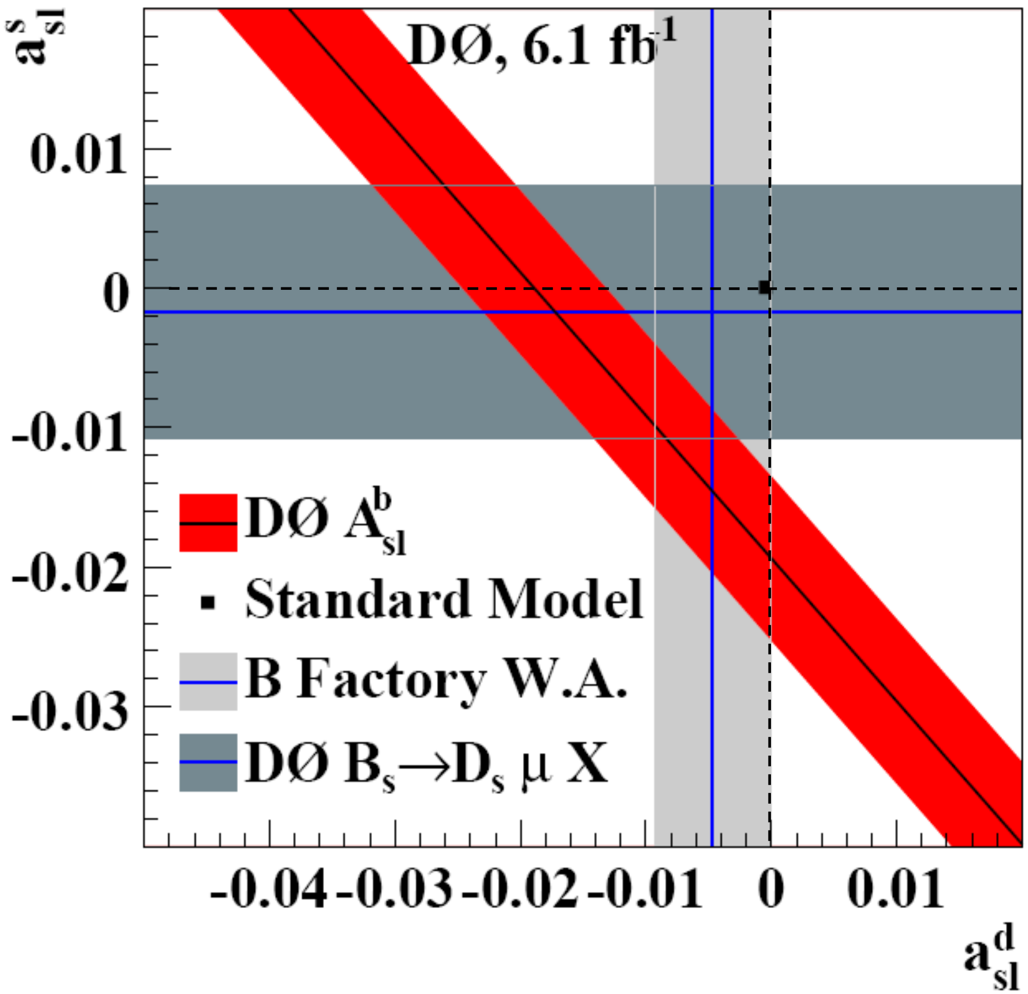


97k for $\pi^+\pi^-$ 31k for $\pi^+\pi^-$

(162k for $K^+\pi^-$)

Promising start for D^0 oscillation and CP violation studies

Current situation with a^{s}_{SL}?



LHCb how about a^{s}_{SL}?

How to deal with

-possible $B_s^0 / \overline{B}_s^0$ production asymmetry in pp $2<\eta<6$

-controlling detection and background asymmetries to $< 10^{-3}$

LHCb how about a^s_{SL}?

How to deal with
-possible B_s^0 / $\overline{B}_s^0$ production asymmetry in pp $2<\eta<6$
-controlling detection and background asymmetries to $< 10^{-3}$

Inclusive muon pairs difficult to control systematic errors…

LHCb how about a^{s}_{SL}?

How to deal with
-possible B_s^0 / $\overline{B}_s^0$ production asymmetry in pp $2<\eta<6$
-controlling detection and background asymmetries to $< 10^{-3}$

Inclusive muon pairs difficult to control systematic errors…

Time dependent B_s decay asymmetry
    $D_s^+(K^+K^-\pi^+)\pi^-$ vs $D_s^-(K^+K^-\pi^+)\pi^+$
    production or detection asymmetry from data

LHCb how about a^s_{SL}?

How to deal with

-possible $B_s^0 / \overline{B}_s^0$ production asymmetry in pp $2<\eta<6$

-controlling detection and background asymmetries to $< 10^{-3}$

Inclusive muon pairs difficult to control systematic errors…

Time dependent B_s decay asymmetry

$D_s^+(K^+K^-\pi^+)\pi^-$ vs $D_s^-(K^+K^-\pi^+)\pi^+$

production or detection asymmetry from data

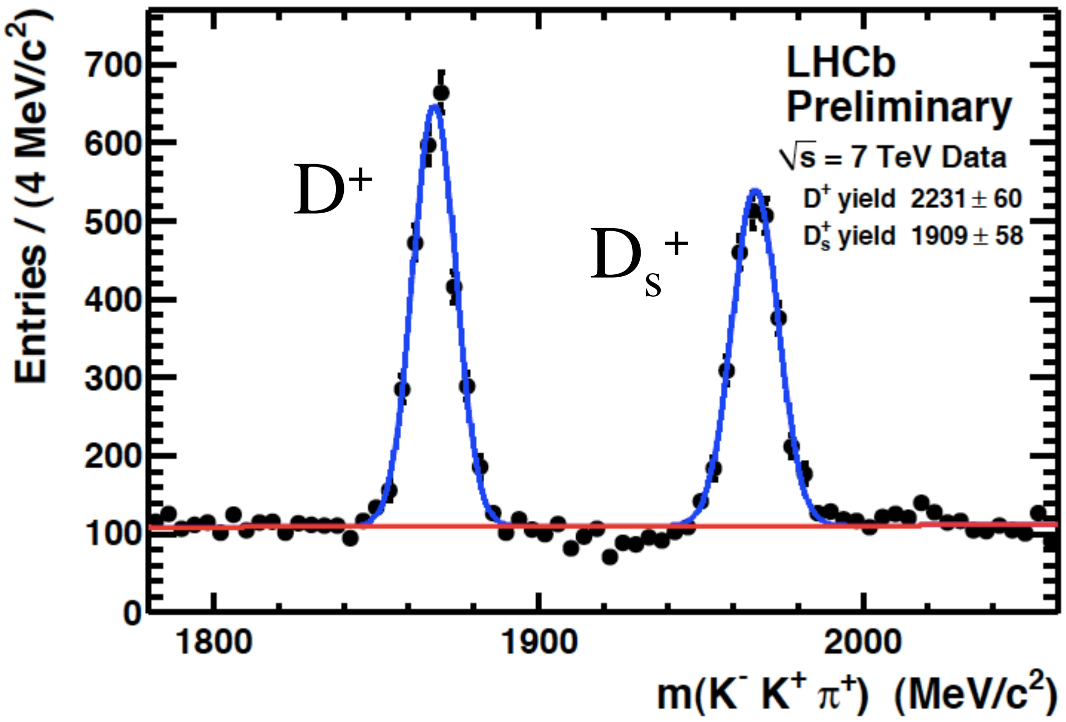
B_d and B_s time depended CP asymmetries from the same final ftates: i.e.

$B_d \to D^+(K^+K^-\pi^+)\mu^-X$ - c.c. and $B_s \to D_s^+(K^+K^-\pi^+)\mu^-X$ - c.c.

difference depends only on $a^s_{SL} - a^d_{SL}$

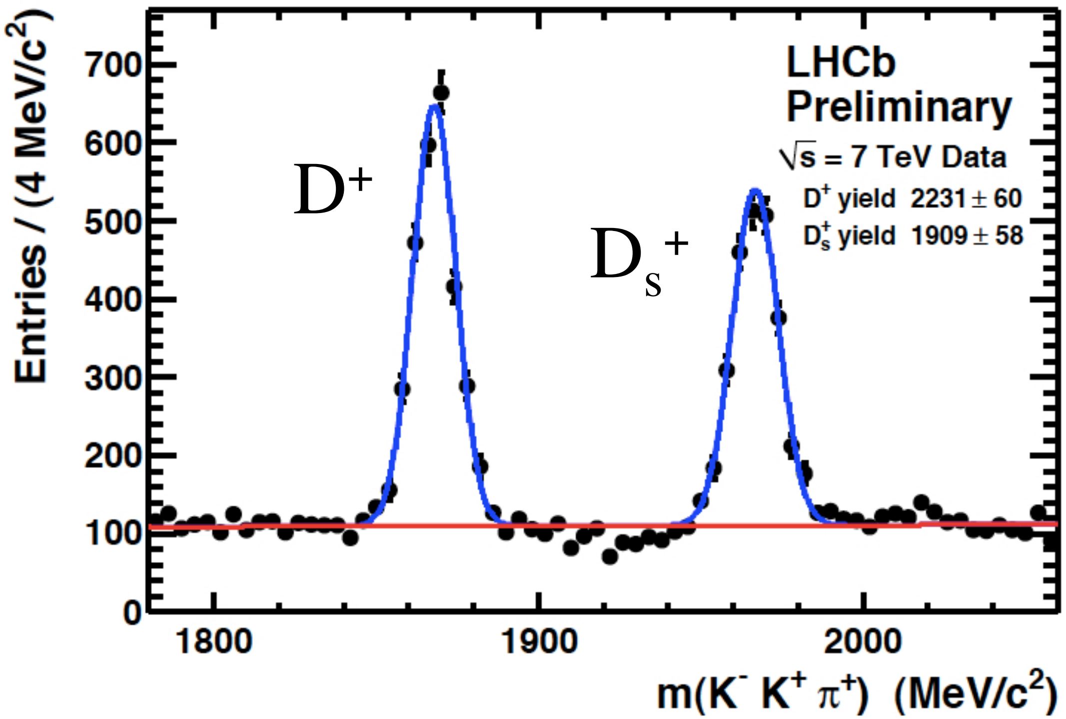
LHCb how about a^s_{SL}?

$D^+ \rightarrow K^+K^-\pi^+$ and $D_s^+ \rightarrow K^+K^-\pi^+$
with 124 nb^{-1} data



LHCb how about a^s_{SL}?

$D^+ \to K^+K^-\pi^+$ and $D_s^+ \to K^+K^-\pi^+$ with 124 nb^{-1} data



Expected statistical errors on

$$\Delta_{SL} \equiv a^s_{SL} - a^d_{SL}$$

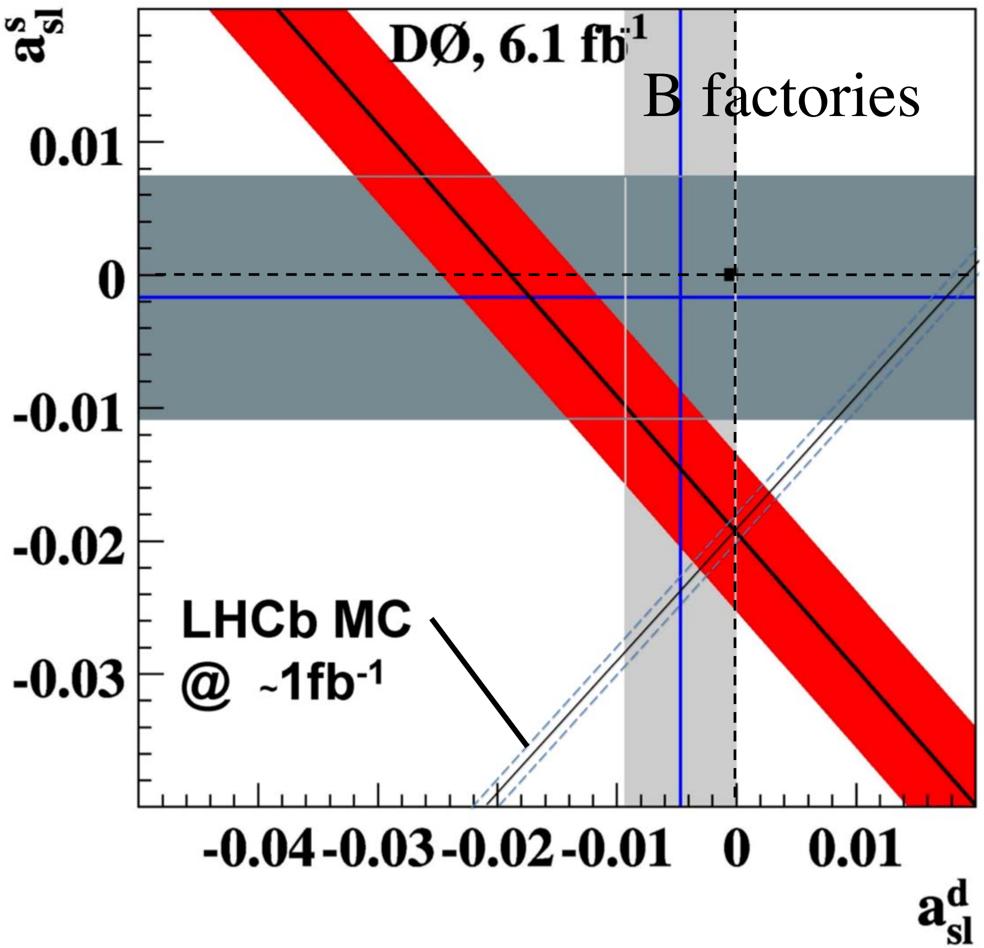
$$6.3\times10^{-4}$$

with 1 fb^{-1} of data

Systematic errors still to be investigated

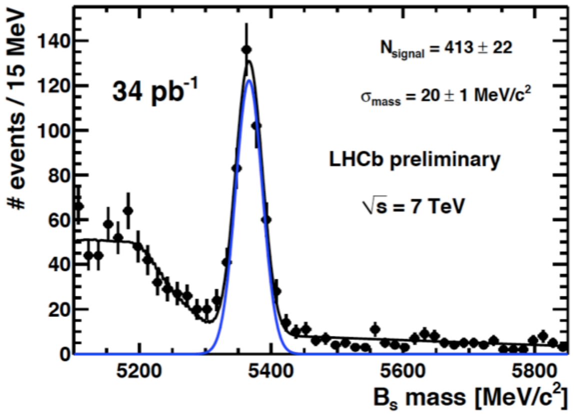
LHCb how about a^{s}_{SL}?

LHCb expected performance with 1 fb^{-1} data
assuming Δ_{SL}(LHCb measured) = A^{b}_{SL}(D0 now)



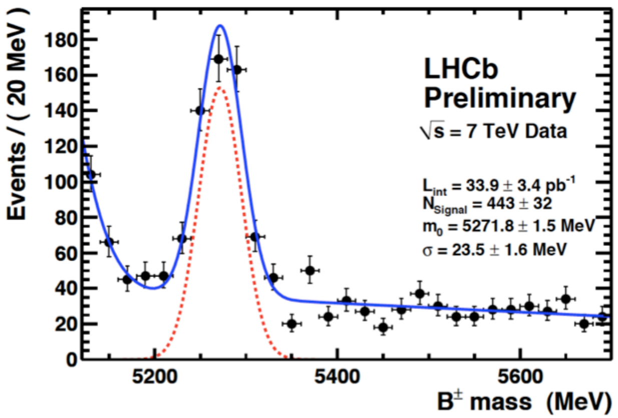
B reconstruction in hadronic modes

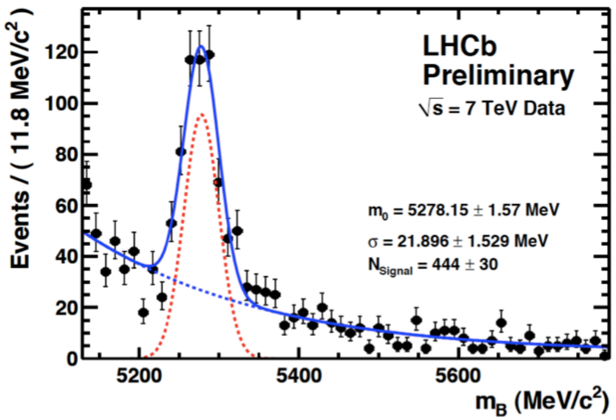
- For B_s oscillation studies



$B_s \to D_s^+(\phi\pi^+)\pi^-$

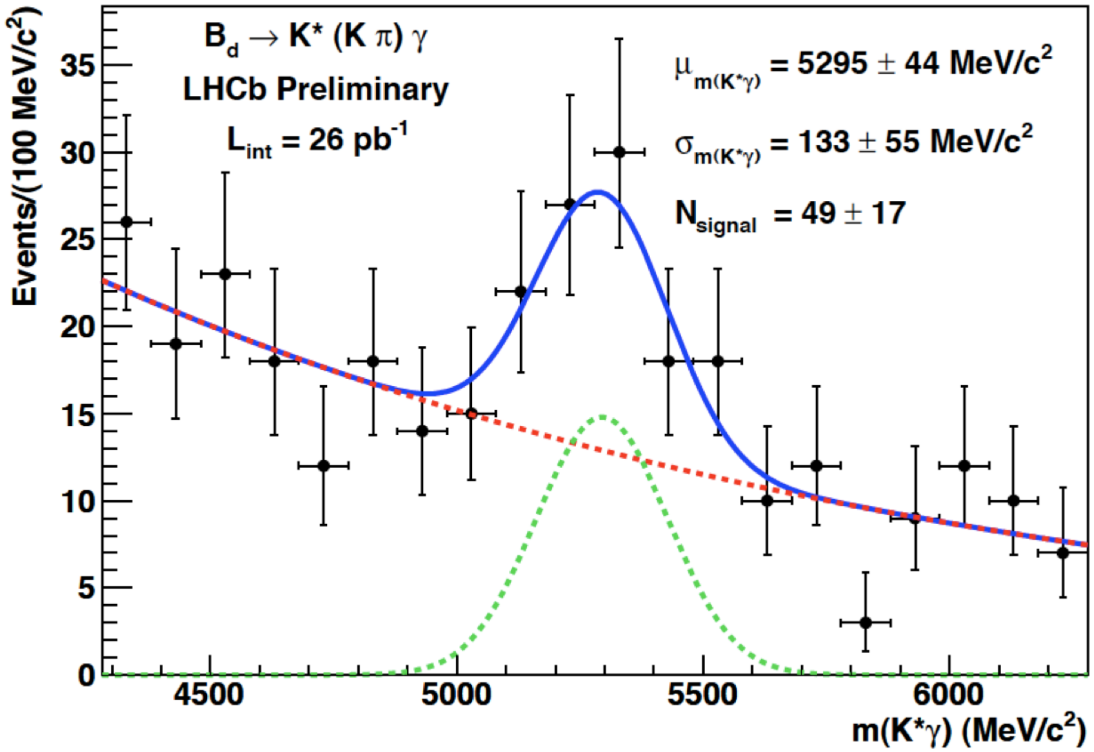
- Bench mark channels for γ studies





- and more… $B^\pm \to D(K_s\pi^+\pi^-)\pi^\pm$ $B^\pm \to D(K^\mp\pi^\pm)K^\pm$

And even radiative B decays



- with an ultimate goal to study CPV in $B_s \to \phi\gamma$ photon polarization studies

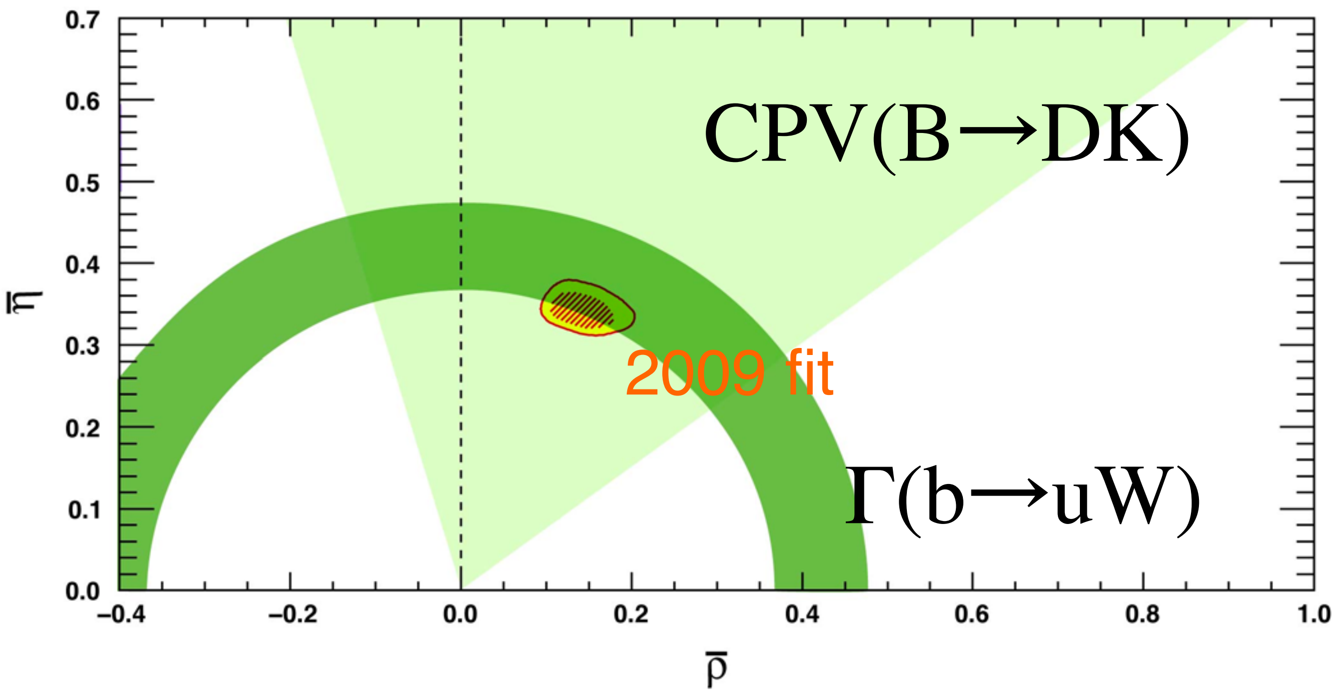
Conclusions

- LHCb has started successful data taking at $\sqrt{s} = 7$ TeV, publishing physics results, including b physics
- Majority of data collected were at close to the LHCb nominal luminosities, $\sim 10^{32} cm^{-2} s^{-1}$, but with almost one order of magnitude less number of bunches, resulting in many events with more than one pp interactions.
- However, LHCb detector could reconstruct clean B signals, due to excellent PID, momentum measurement and vertex determination even in those conditions.
- High event readout rate (~1 MHz) followed by complete software based trigger allowed LHCb to follow the luminosity evolution effectively.

Conclusions

- We expect to collect 1 fb^{-1} data in 2011, in a condition close to the nominal running, i.e. average pp interaction per bunch crossing of <1. (number of bunches will be steadily increased)
- Extrapolating the 2010 studies, with 1 fb^{-1} data we expect to produce interesting results in $B_s \rightarrow \mu\mu$, CPV in $J/\psi\phi$, B_s oscillations, $B_s \rightarrow K^{\mp}\pi^{\pm}$, $B_d \rightarrow \pi^+\pi^-$, as well as many charm studies including D^0 oscillations and CP violation. If we continue to run in 2012, improved γ measurements and $K^{*0}\mu^+\mu^-$ studies could emerge.
- Finally it gets exciting!

Now



CPV(B→DK)
2009 fit
Γ(b→uW)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
−0.4
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
η̄
ρ̄

May be a surprise!

LHCb with 10 fb^{-1}