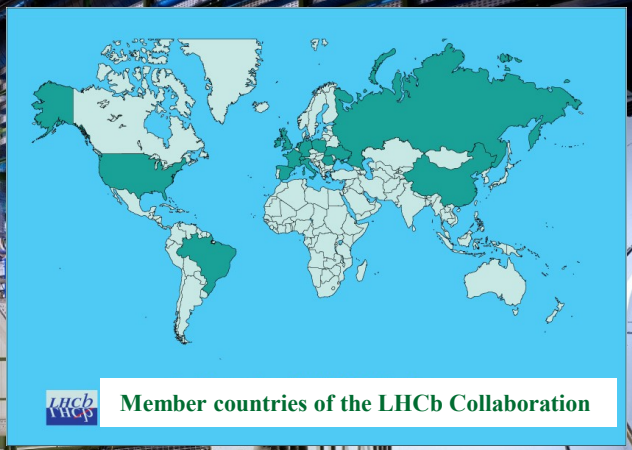
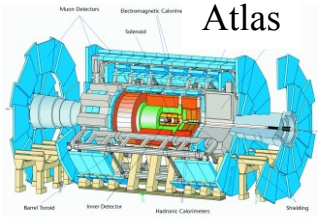
# Status of LHCb - the "beauty" experiment

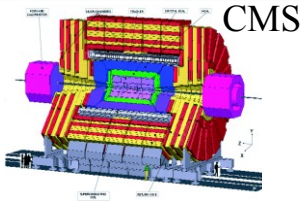
730 members
15 countries
54 institutes




Andreas Schopper on behalf of the LHCb Collaboration

# LHC(b) physics goals




## Motivation of LHC experiments

✓ ***search for New Physics*** beyond the Standard Model (SM) !

**Direct search** by general purpose detectors: **Atlas & CMS**

✓ search for ***new heavy non-SM particles produced*** at LHC energy

**Indirect search** by specialised detector: **LHCb**

✓ search for deviations from Standard Model predictions due to ***virtual contributions of new heavy particles in loop processes***

➢ discovery potential for New Physics extends to mass scales far in excess of the LHC centre-of-mass energy

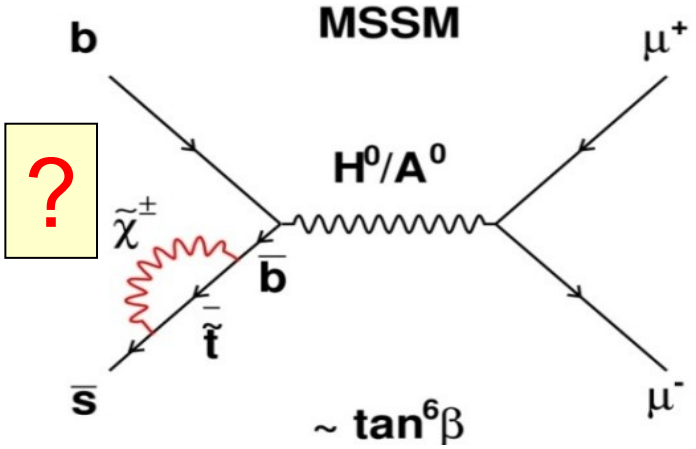
➢ perform precision measurements of ***CP violating phases*** and ***rare heavy-quark decays*** that are very precisely predicted by the theory of the Standard Model


→ **these precision measurements can be best performed by studying Beauty-decays**

# B-decays in the Standard Model and beyond

virtual particles appear in loop mediated processes

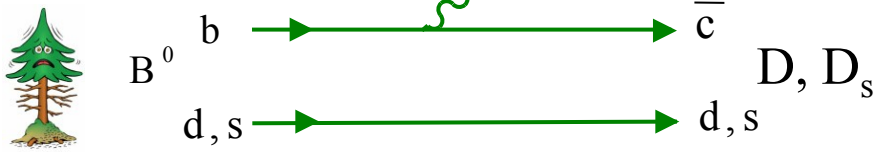
$B_s \rightarrow \mu^+\mu^-$ "s-channel penguin"



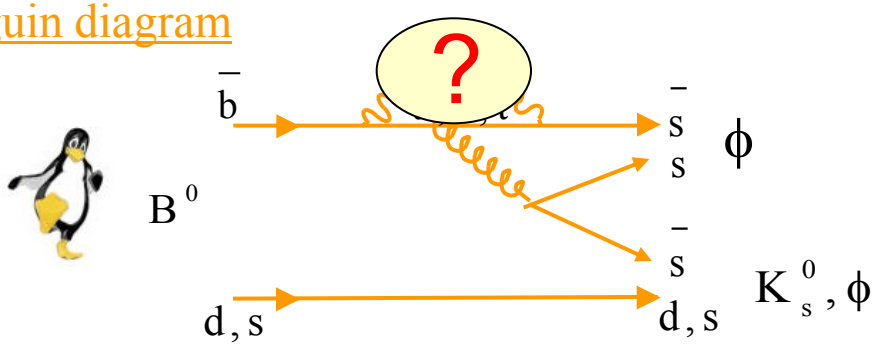

loop diagrams

**New Physics**

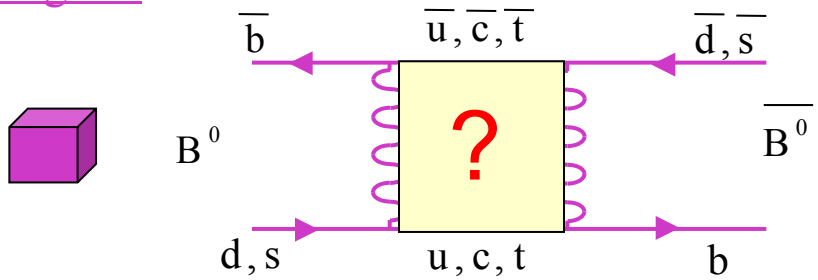
Tree diagram




Penguin diagram




Box diagram




meson := $(q\bar{q})$ **B-meson: $(q\bar{b})$**
baryon := $(qqq)$ B-baryon: $(qqb)$

# Historical example of "indirect" discoveries

**CP violation** (matter-antimatter asymmetry) **in the kaon-system**
→ **prediction of third quark family**

1973: M. Kobayashi, T. Maskawa, theoretical mechanism for CP-violation in the Standard Model requires b- and t-quark

M. Kobayashi and T. Maskawa, *Prog. Theor. Phys.* ***49***, 652 (1973).

2001: experimental proof of **CP violation in B-system** by B-factories (BELLE & BaBar)

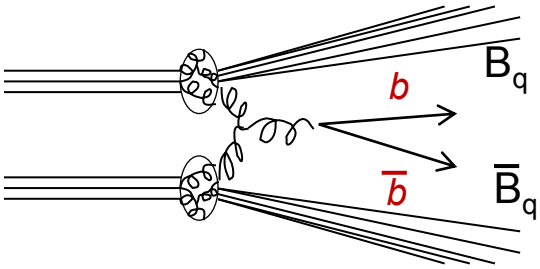
B. Aubert *et al. (BaBar Collab.), Phys. Rev. Lett.* ***87***, 091801 (2001).
K. Abe *et al. (Belle Collab.), Phys. Rev. Lett.* ***87***, *091802* (2001).

2008: Nobel prize in physics

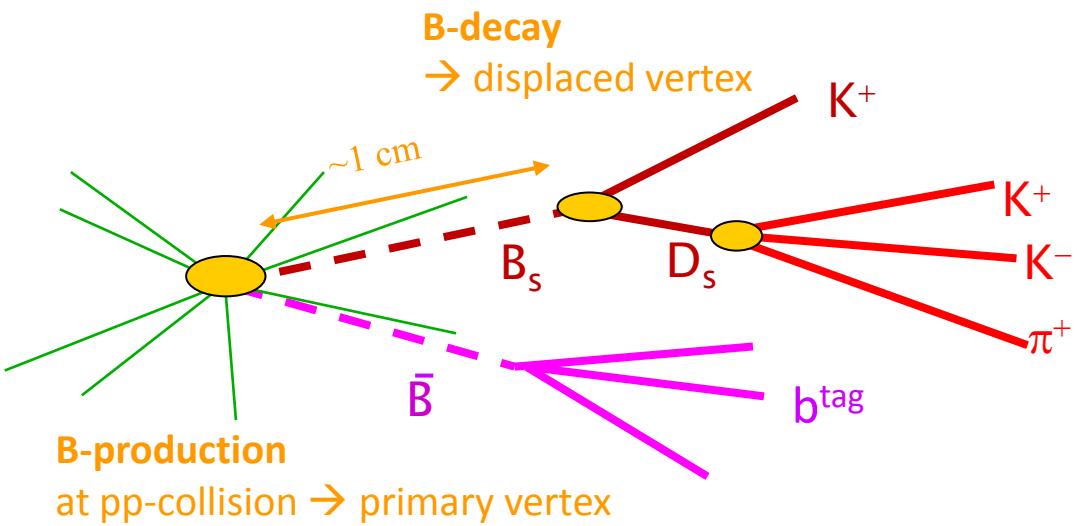
" for the discovery of the **origin of the broken symmetry** which predicts the existence of at least three families of quarks in nature"

# LHC as a *b*-factory

- ✓ ***bb̄*-pairs produced with high cross-section at LHC energy**
  ($10^{12}$ $b\bar{b}$ produced in 2 years at $L=2\cdot10^{32}$ $cm^{-2}s^{-1}$ )
- ✓ **all species of particles containing a b-quark are produced**
  ($B_u^+$, $B_u^-$, $B_d^0$, $\bar{B}_d^0$, $B_c^+$, $B_c^-$, $B_s^0$, $\bar{B}_s^0$, $\Lambda_b$ , etc.)



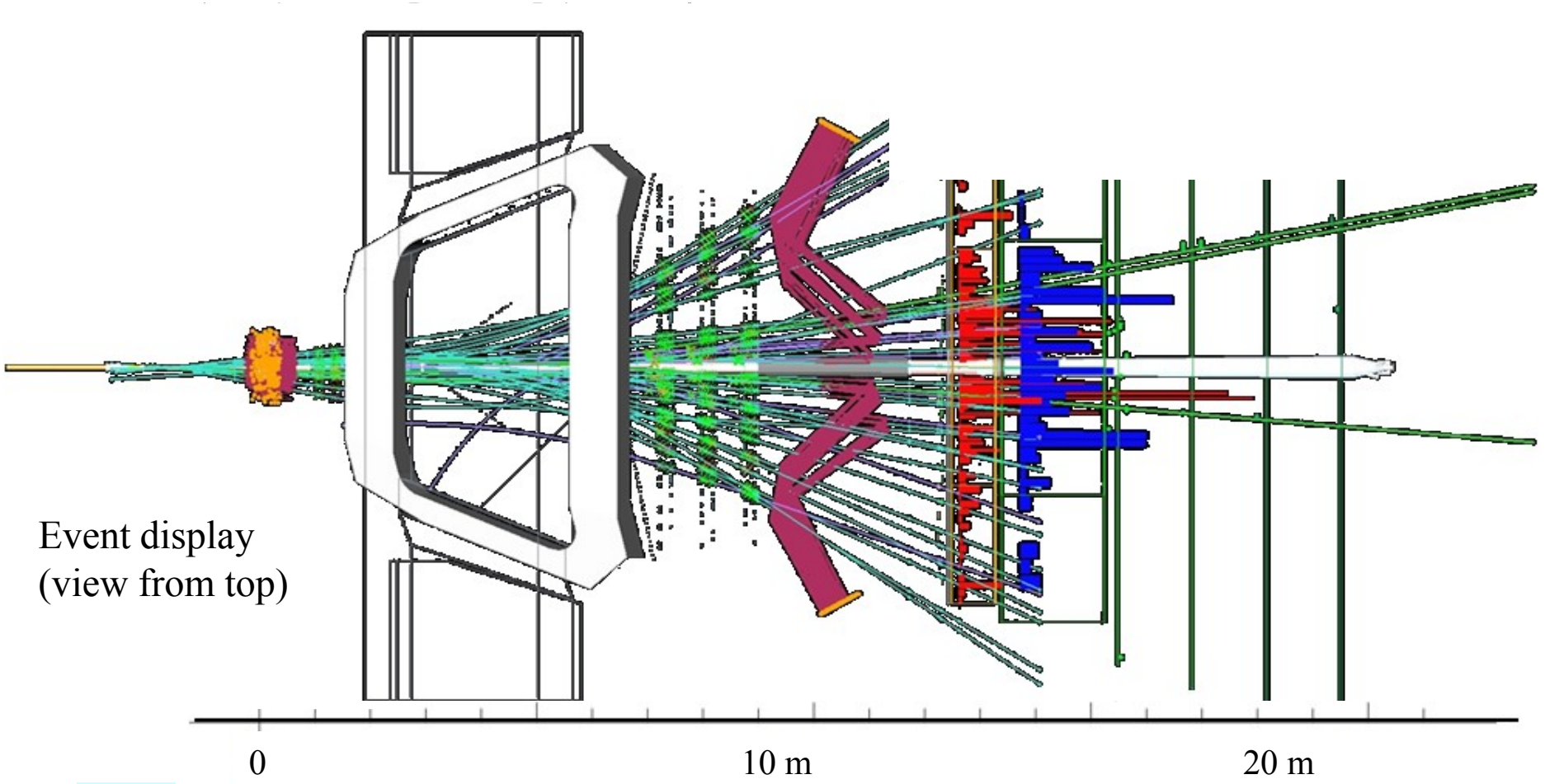

- ➢ ***bb̄*-pair production is strongly correlated and sharply peaked forward-backward**
  → detector with forward geometry (unique $2 < \eta < 6$ coverage)
- ➢ **B decays have long flight-distance ~1 cm** (important to distinguish B-decays from other background decays, and essential for time-dependent CP violation measurements)



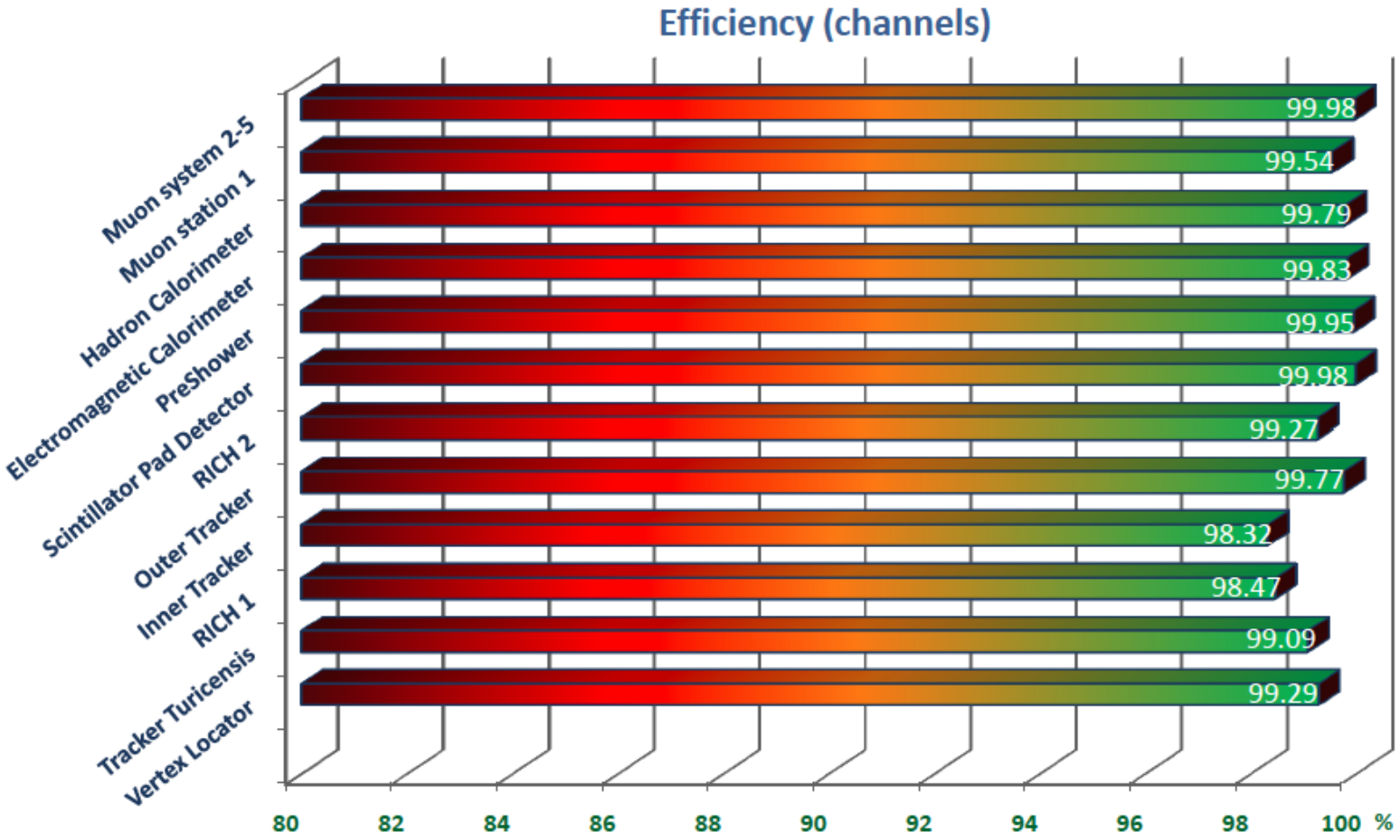

Big challenge to select events of interest:

- ✓ $\sigma_{b\bar{b}}$ is less than 1% of total inelastic cross section
- ✓ B decays of interest typically have BR < $10^{-5}$
- ➢ **Need high statistics and high selectivity!**

# The LHCb Detector
# A forward spectrometer



# Detector efficiencies



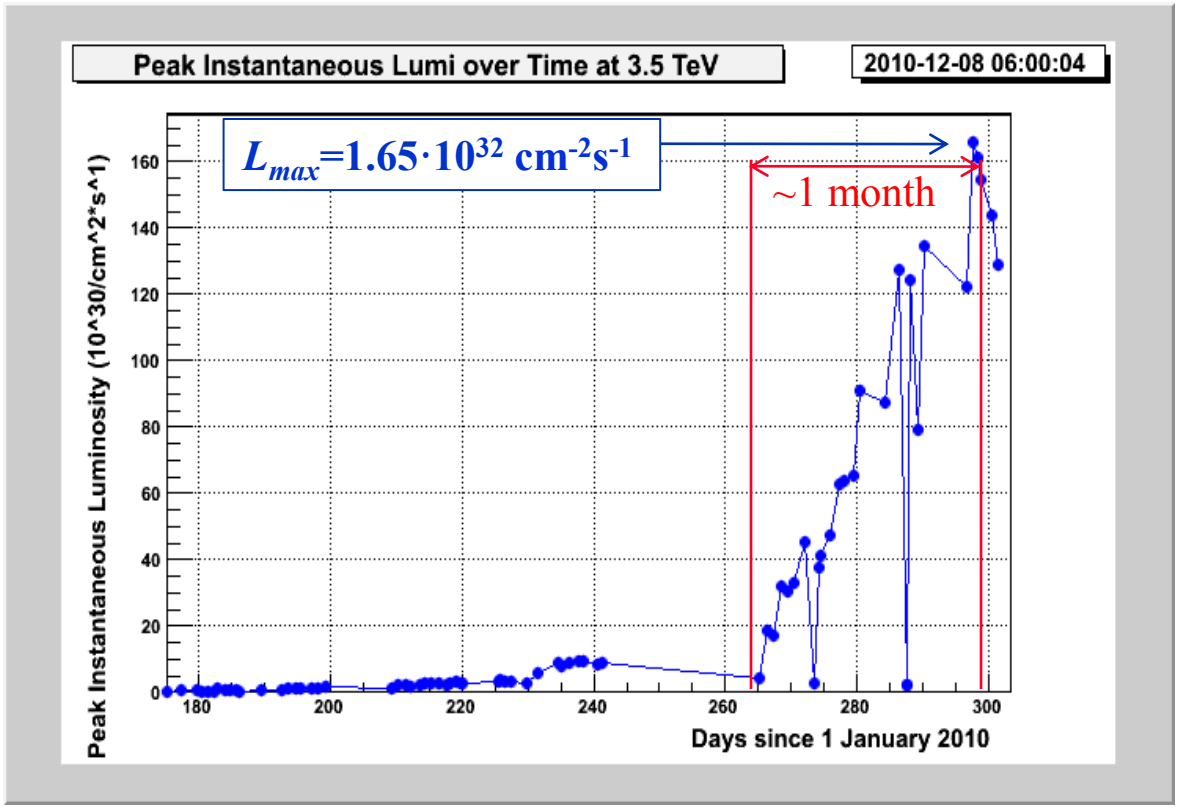

➢ all detector components ~ 99 % efficient !

# LHC(b) operation in 2010

Outstanding machine performance → many thanks to our LHC colleagues!!!

Peak luminosity evolution with time:

- peak luminosity increased within ~1 month by factor 100! ($L$~$10^{30}$ to $10^{32}$ cm$^{-2}$s$^{-1}$)
- for LHCb reached almost nominal $L$ ($L$=1.6·$10^{32}$ cm$^{-2}$s$^{-1}$, nominal 2·$10^{32}$ cm$^{-2}$s$^{-1}$!)



# LHC(b) operation in 2010

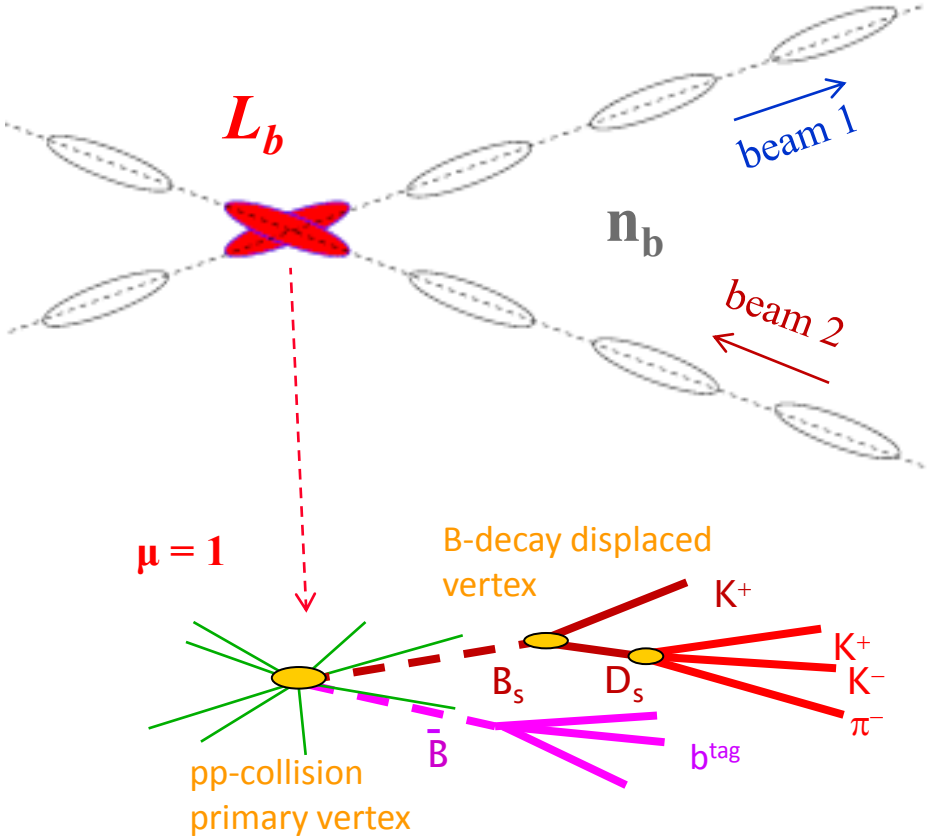
Evolution of average number of visible pp-collisions per bunch crossing:

$L = n_b \cdot L_b \propto n_b \cdot \mu$

LHCb design:

$L = 2 \cdot 10^{32}$ ; $n_b \sim 2600$ → $\langle\mu\rangle \sim 0.4$

- maximizes fraction of ***single interaction*** bunch crossings



# LHC(b) operation in 2010

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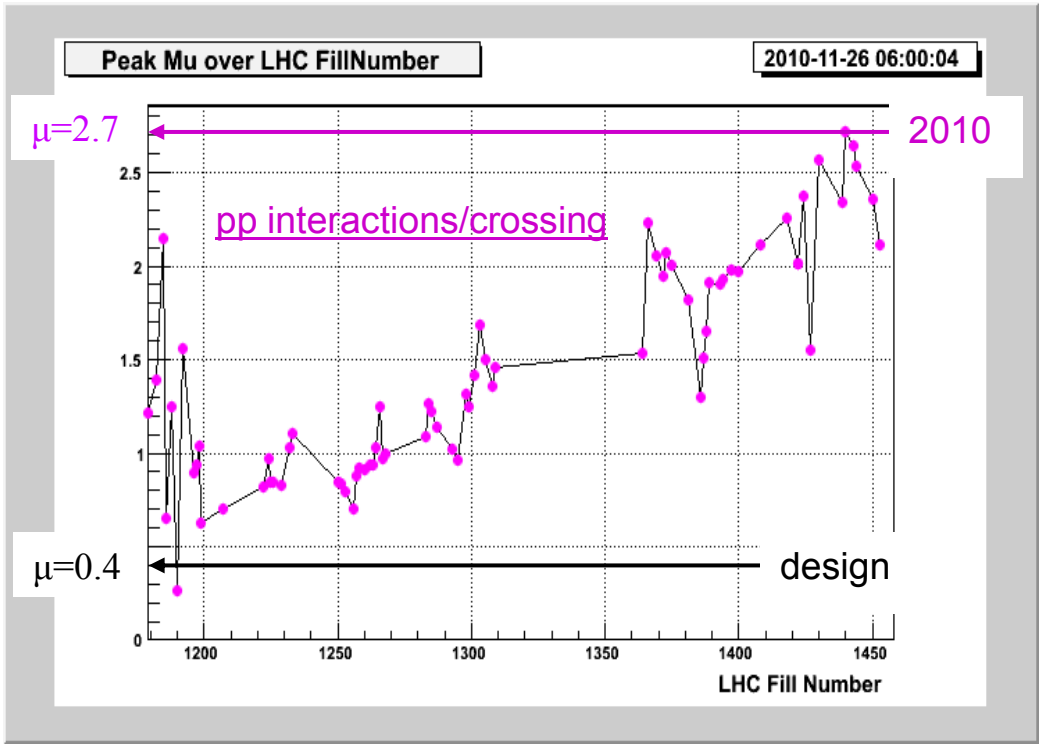
2010 run:

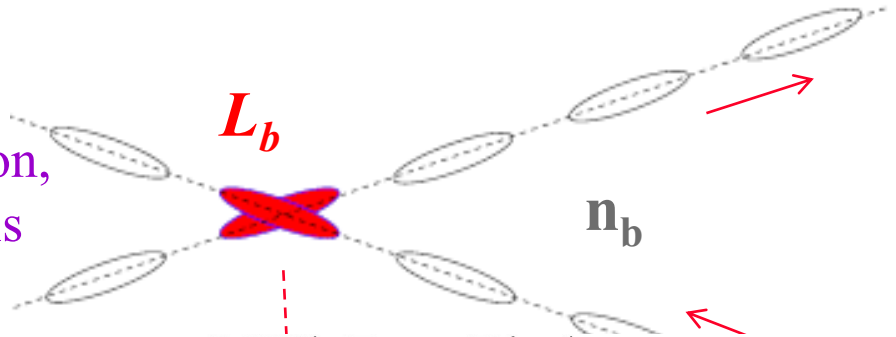
$L = 1.6 \cdot 10^{32}$ ; $n_b = 344$ → $\mu_{max} = 2.7$

- > 6 times nominal!

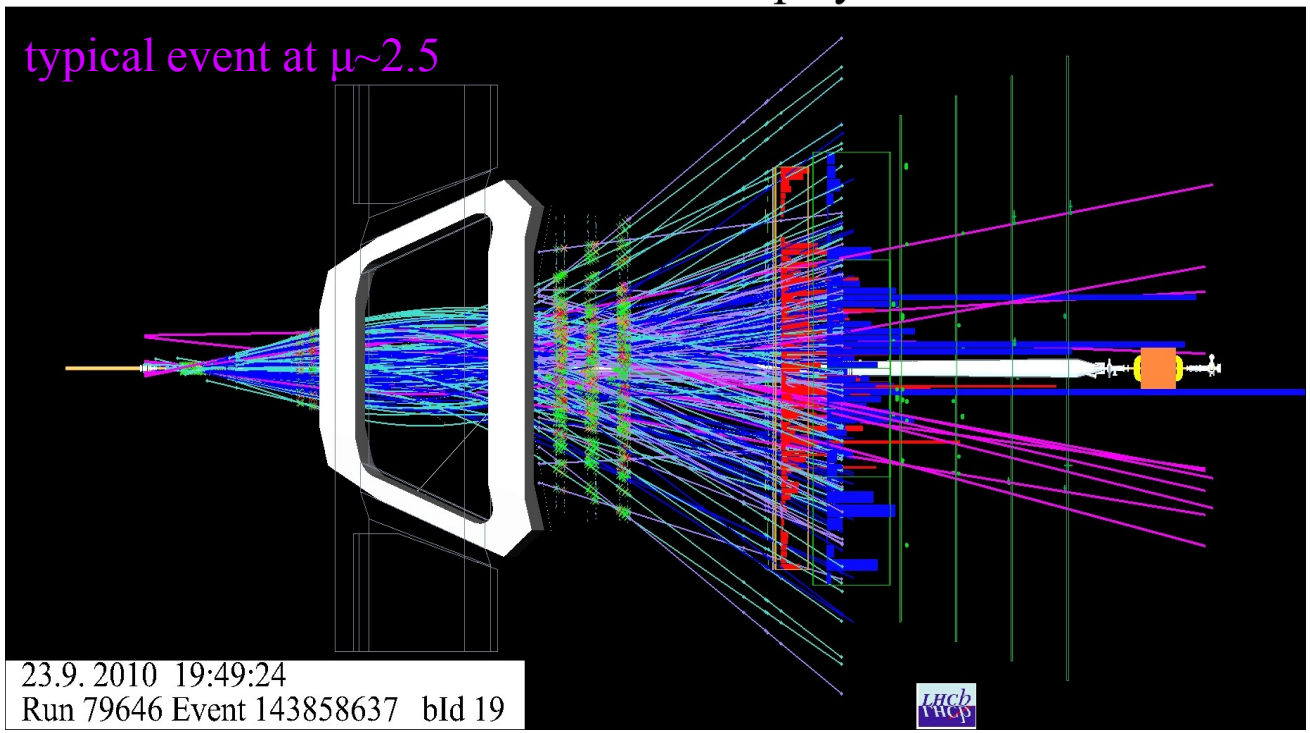


# High multiplicity events

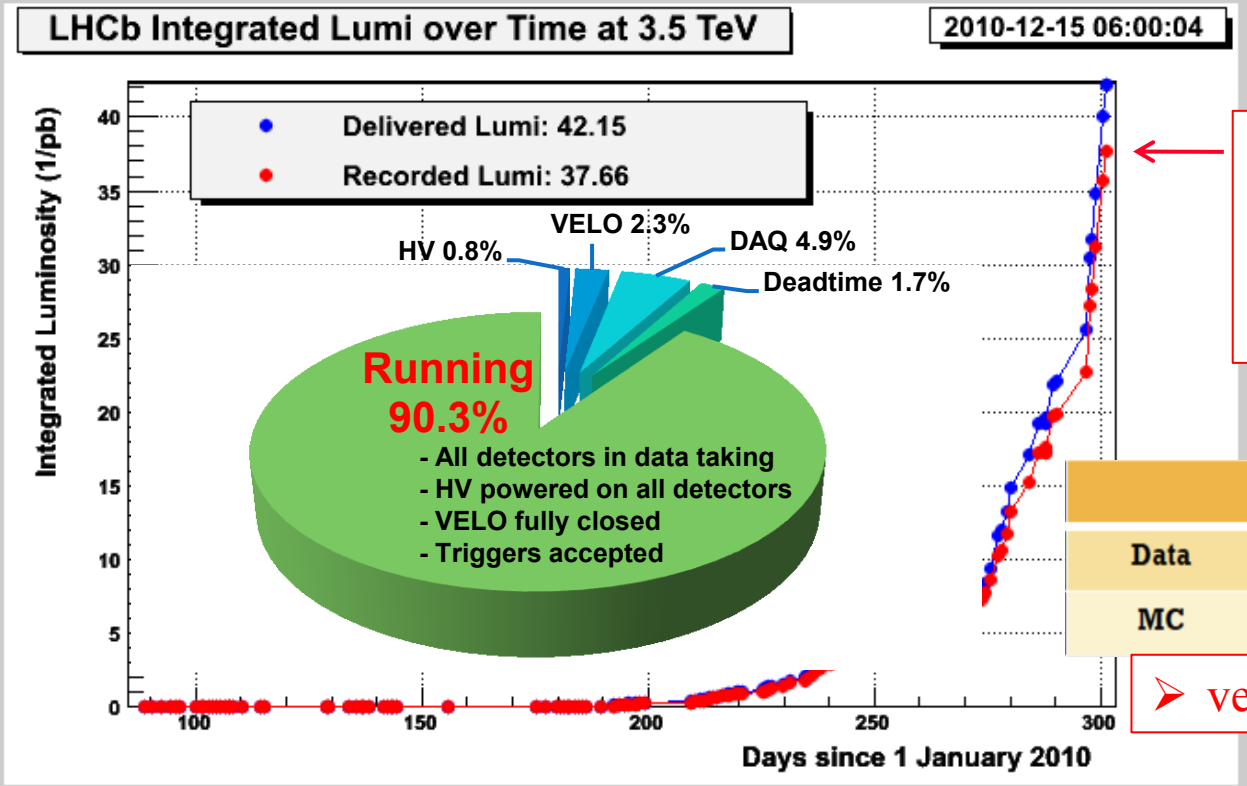
- ***high track multiplicity and many vertices*** in each collision event
- big challenge for detector operation, trigger, reconstruction and analysis




LHCb Event Display



# LHCb performance in 2010




~37 pb$^{-1}$ integrated luminosity recorded with all sub-detectors fully operational!

| | Muon trigger ($J/\psi$) | Hadron trigger ($D^0$) |
|---|---|---|
| Data | 94.9±0.2% | 60±4% |
| MC | 93.3±0.2% | 66% |

➢ very high selection efficiencies

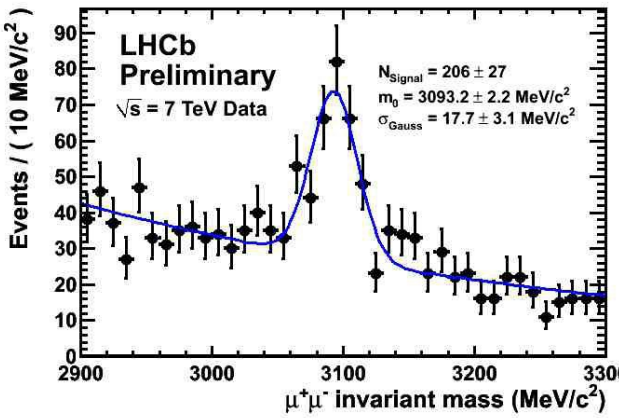
- LHCb fully operational on first day of proton run!
- overall data taking efficiency of ~90% over the year
- major part of data accumulated in the last month of running with very efficient trigger
- at nominal $L \sim 2 \cdot 10^{32}$ cm$^{-2}$s$^{-1}$ LHCb expects to collect ~1000 pb$^{-1}$ in 2011

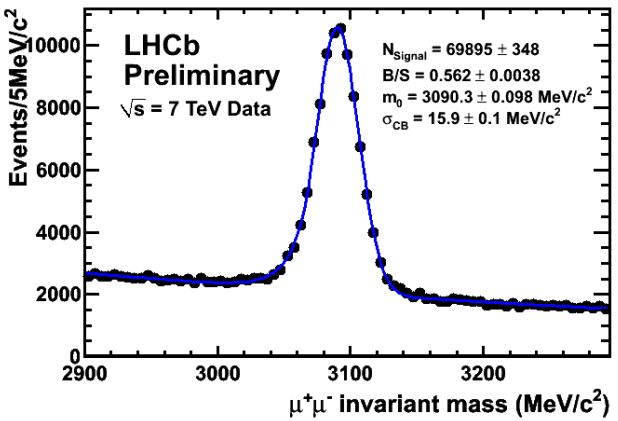
Can we do B-physics already with the 2010 data sample?

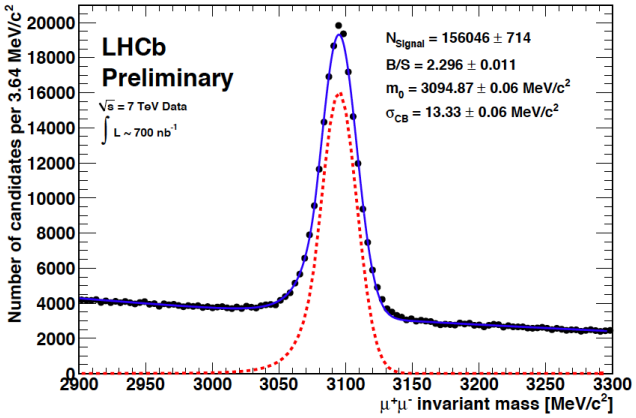
# Detector performance: mass resolution important to separate signal from background

**Evolution of mass resolution over time**: for $J/\psi \rightarrow \mu\mu$ ; ideal resolution $\sigma_{MC}$=12 MeV

- May: σ~18 MeV
- August: σ~16 MeV
- November: σ~13 MeV

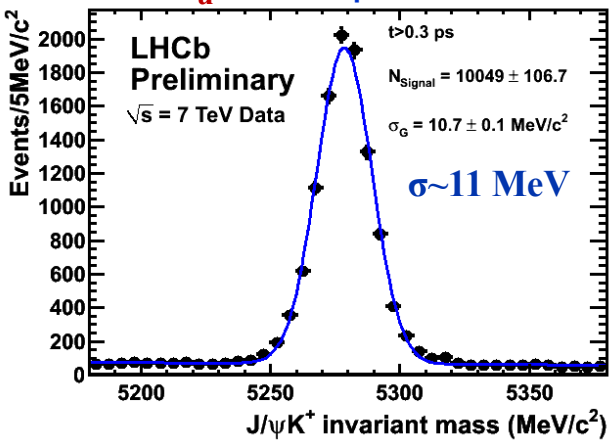


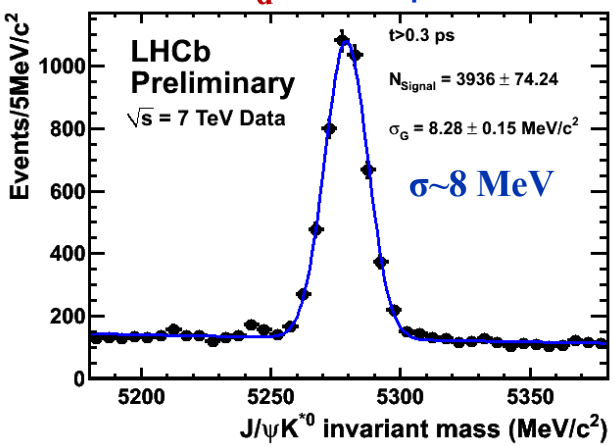




**Detection of different B species**: for $B \rightarrow J/\psi\ X$ with 34 $pb^{-1}$ ~ full statistics

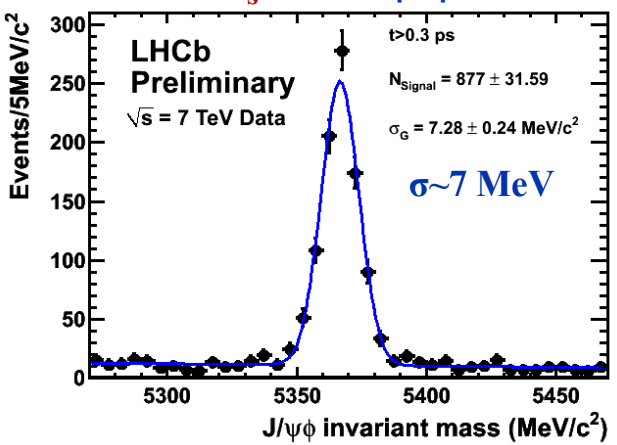
$B_u^+ \rightarrow J/\psi\ K^+$




$B_d^0 \rightarrow J/\psi\ K^*$




$B_s^0 \rightarrow J/\psi\ \varphi$



# Measurement of $b\bar{b}$-cross section at $\sqrt{s}$ = 7 TeV

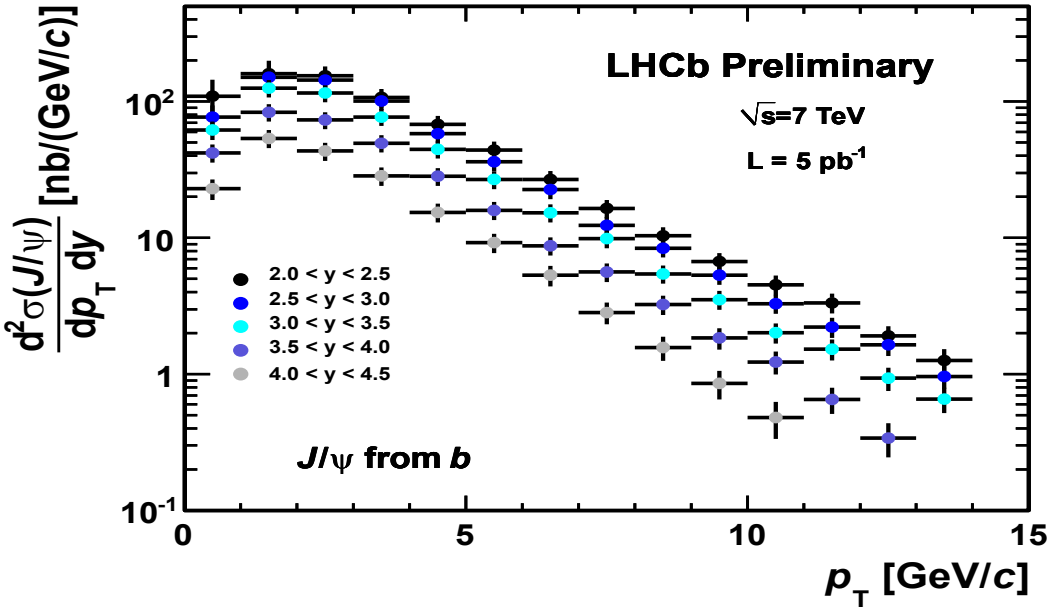
**From B → J/ψ X**

$\sigma$ ($J/\psi$ from $b$) = 1.16 ± 0.01 ± 0.17 μb

($p_T < 14$ GeV/$c$, $2 < y < 4.5$)

total $b\bar{b}$ cross-section in 4π:

$$\sigma(pp \to b\bar{b}X) = 295 \pm 4 \pm 48\ \mu b$$




✓ measured also charm cross-section

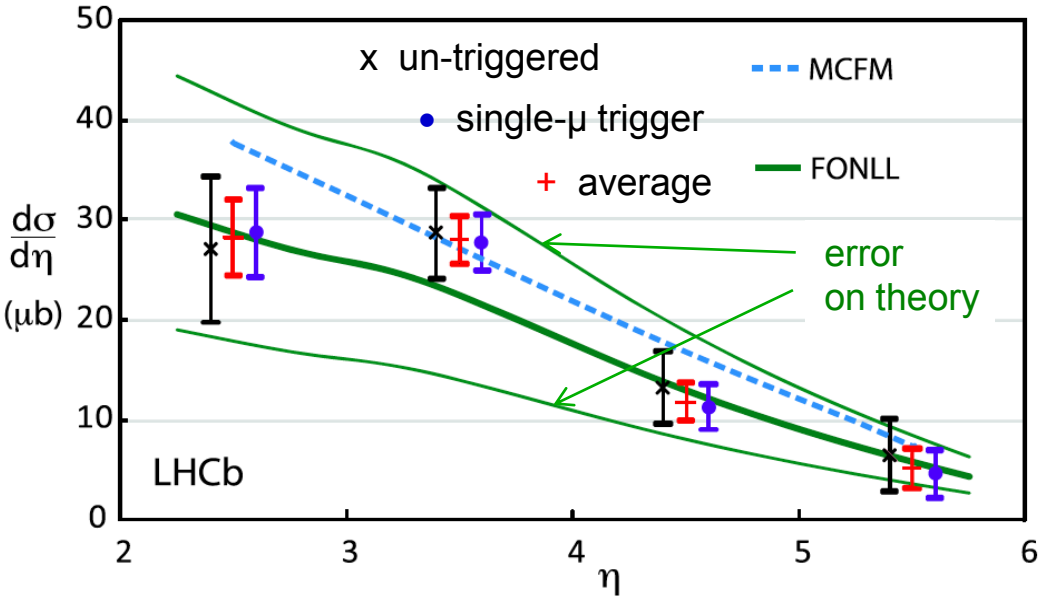
➢ ~20 · $b\bar{b}$ cross-section

**From $B^0 \to D^0 X^+ \mu^- \nu$ with $D^o \to K^- \pi^+$**

total $b\bar{b}$ cross-section in 4π:

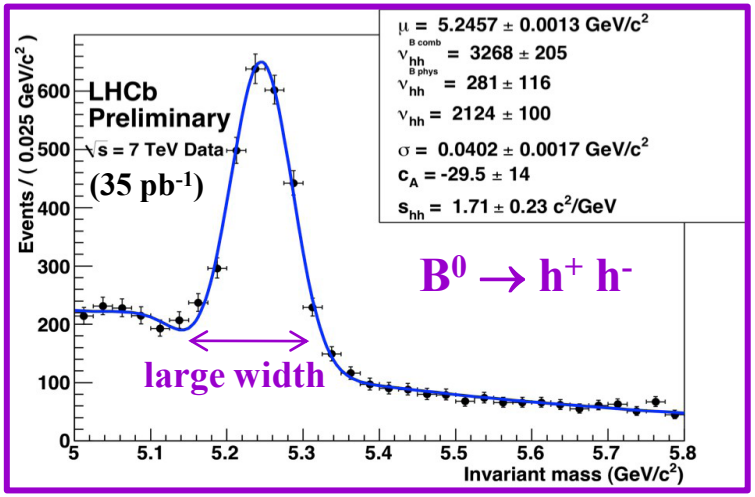
$$\sigma(pp \to b\bar{b}X) = 284 \pm 20 \pm 49\ \mu b$$

[Physics Letters B 694 (2010) 209]

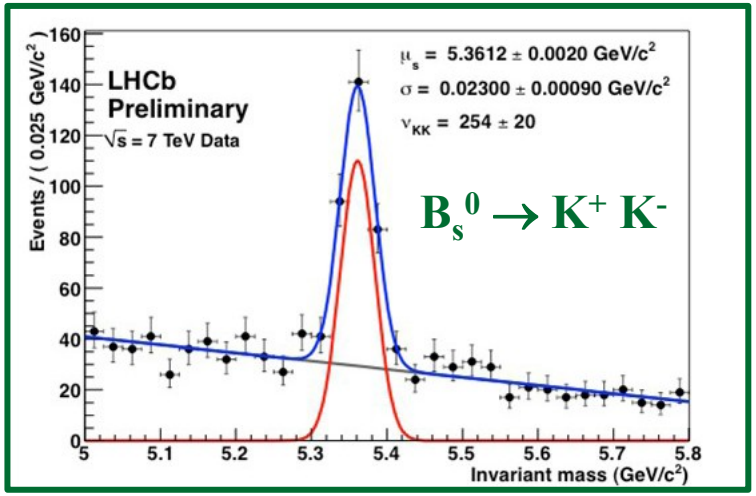


# Detector performance: Particle Identification on B→hh

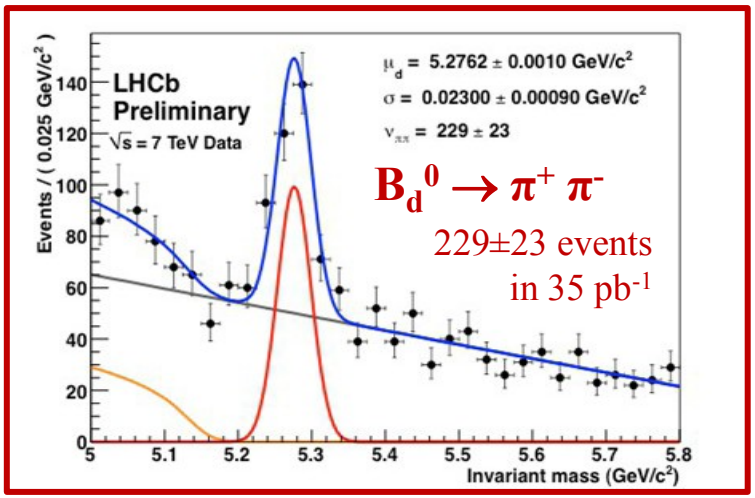
No particle identification → any 2 hadrons!




particle identification of 2 K

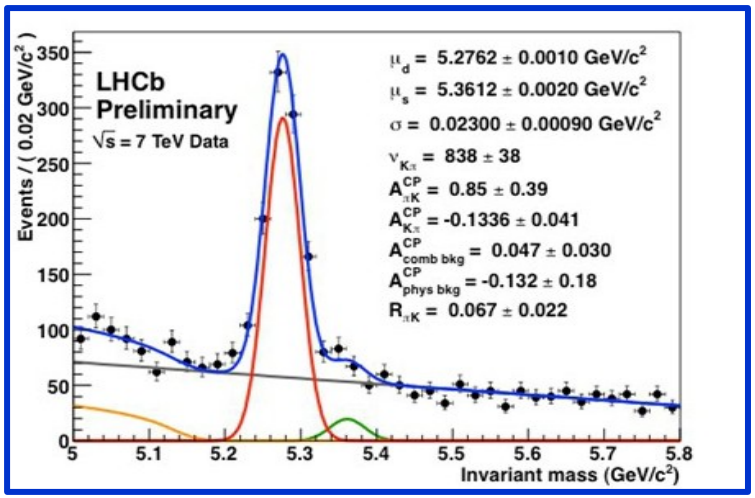



particle identification of 2 π
$BR(B \to \pi^+\pi^-) = 5 \times 10^{-6}$ !




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

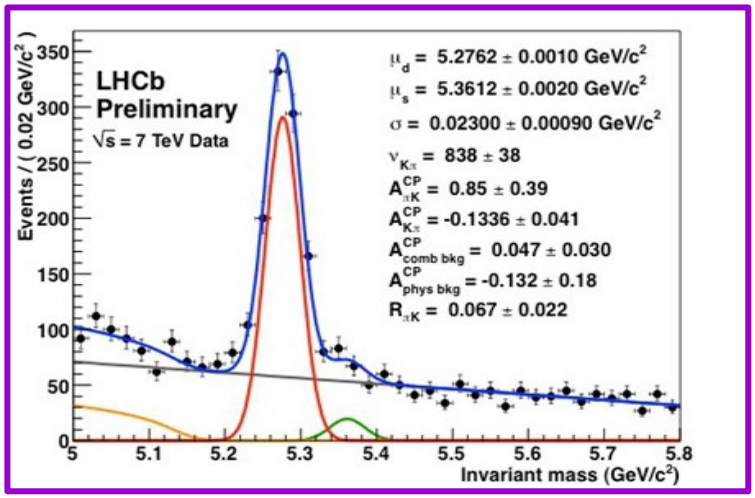
particle identification of 1 π and 1 K




Expectations 2011:
LHCb: 6500 ev./fb$^{-1}$
(CDF: 1100 ev./fb$^{-1}$)

# Evidence for CP violation in B-system in first data ?

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




$B_s^0/B_d^0$ yield = (10.7±2.0)%,

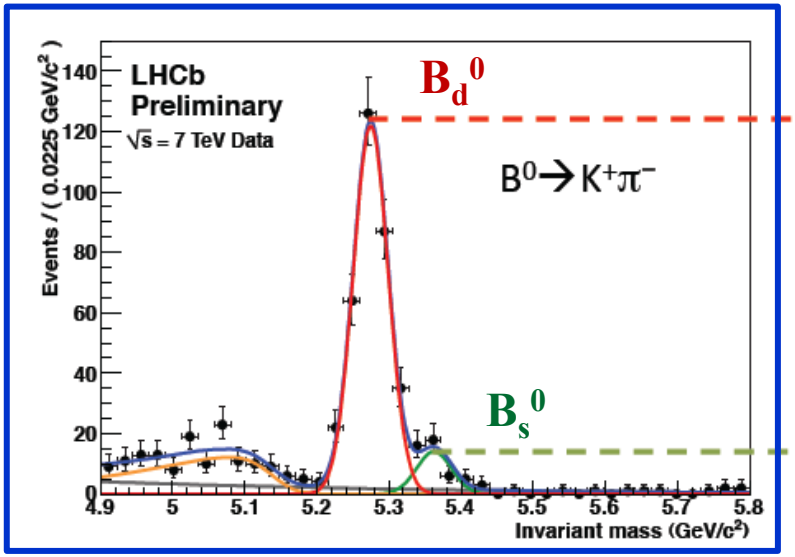
$A_{CP}(B_d^0)$=-0.134±0.041
(HFAG: -0.098±0.012)

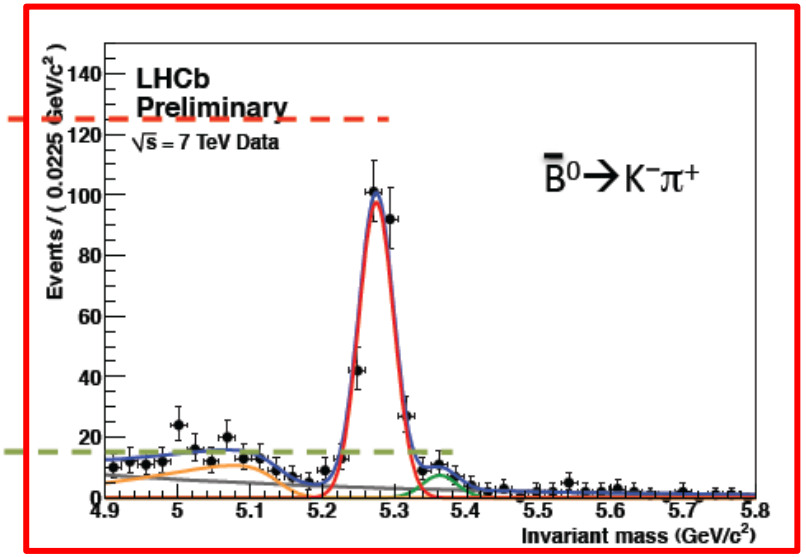
$A_{CP}(B_s^0)$=-0.43±0.17
(CDF: 0.39±0.15±0.08 in 1 fb$^{-1}$)

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

CP violation → particle and anti-particle behave differently!

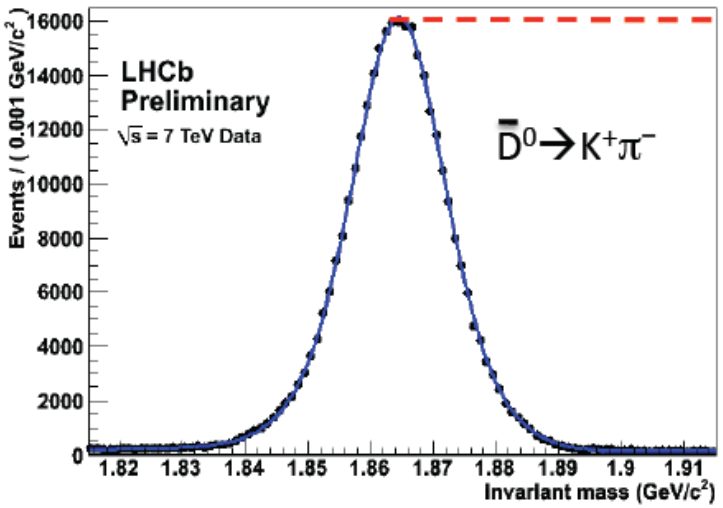
$B^0$ $\bar{B}^0$

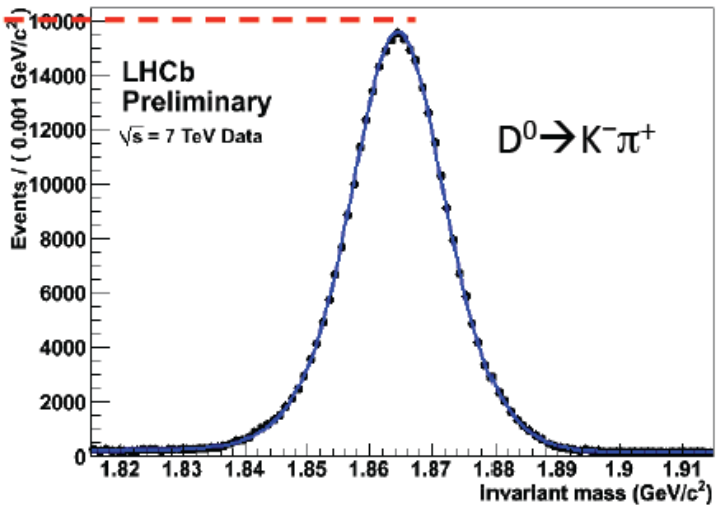


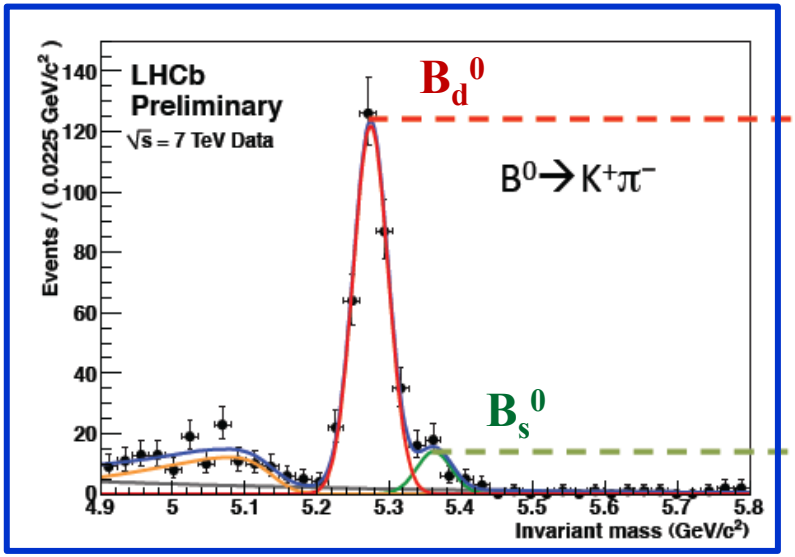



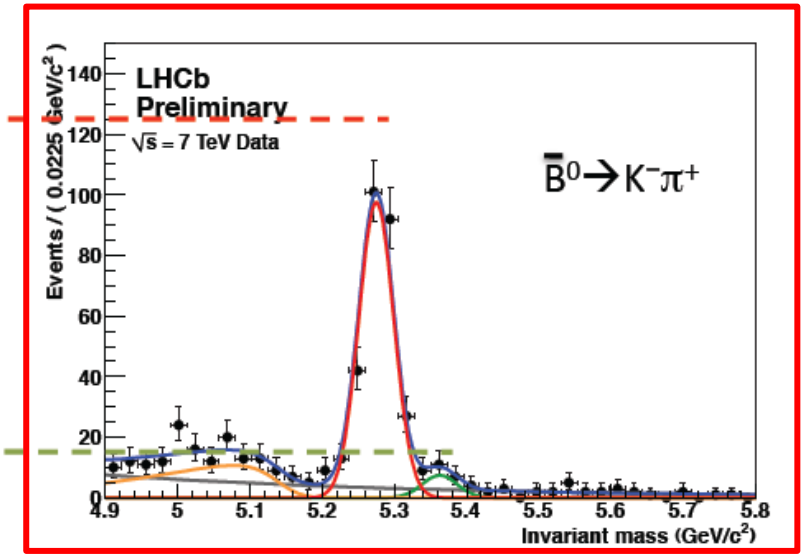
# Evidence for CP violation in B-system in first data ?

And a fair comparison…



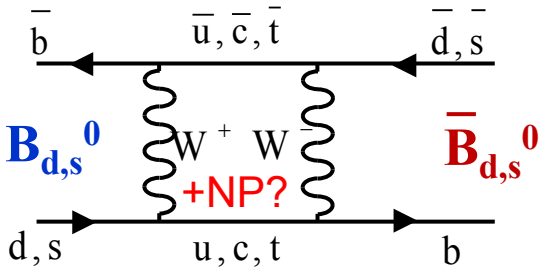



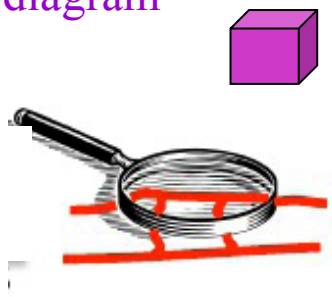



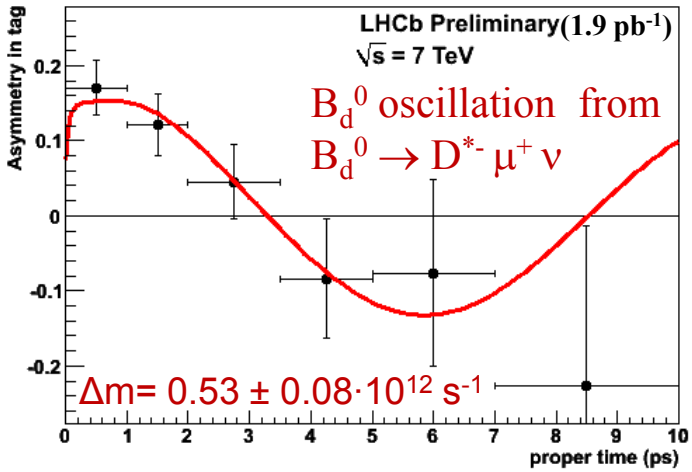
# Probing New Physics in loop decays: CPV in $B_s \to J/\psi\phi$

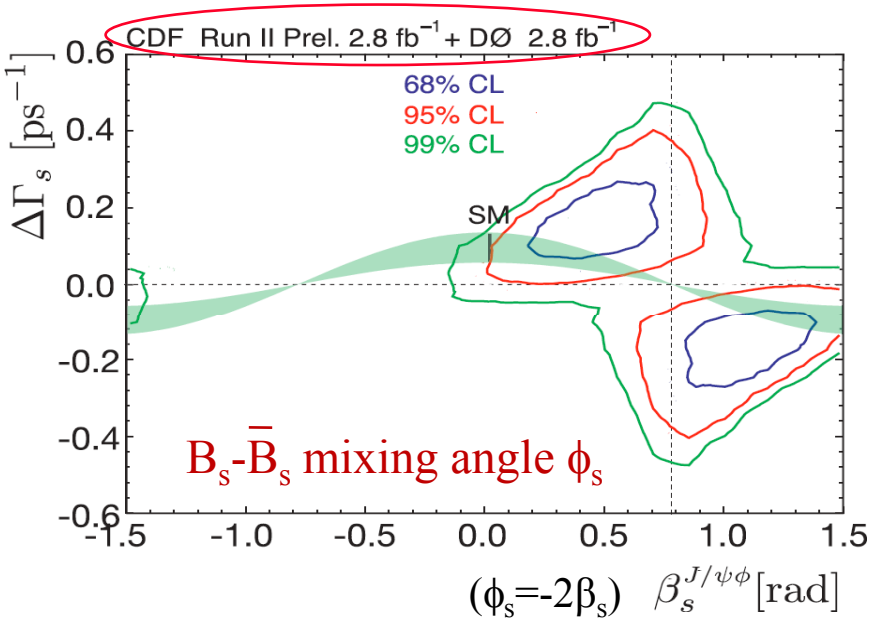
- ✓ $B^0$ and $\bar{B}^0$ are mixing via box diagram



- ✓ mixing phase very precisely known in Standard Model:
  $\phi_s = -2\beta_s = -0.042 \pm 0.0014$
- ✓ sensitive to New Physics effects
- ➢ $\phi_s = \phi_s(SM) + \phi_s(NP)$



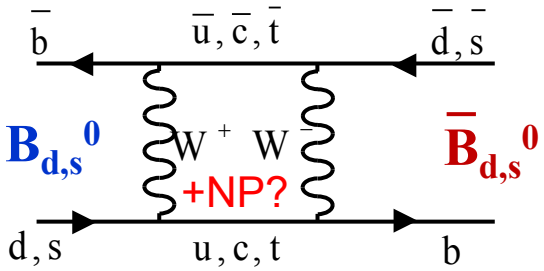



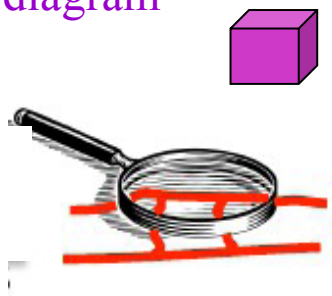

- ✓ measure CP violation in $B_s^{(-)} \to J/\psi\,\varphi$
- ➢ $B_s$ mixing phase $\Phi_s$ is analogous to the measurement in $B_d$ system, with which BaBar & BELLE validated the CKM model

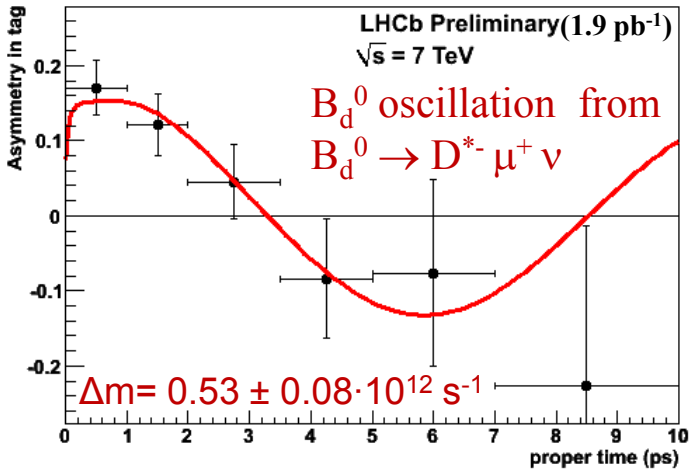
- ➢ first combined Tevatron result showed ~2σ deviation from Standard Model
- ➢ down to ~1σ with 2010 CDF/D0 results

# Probing New Physics in loop decays: CPV in $B_s \to J/\psi\varphi$

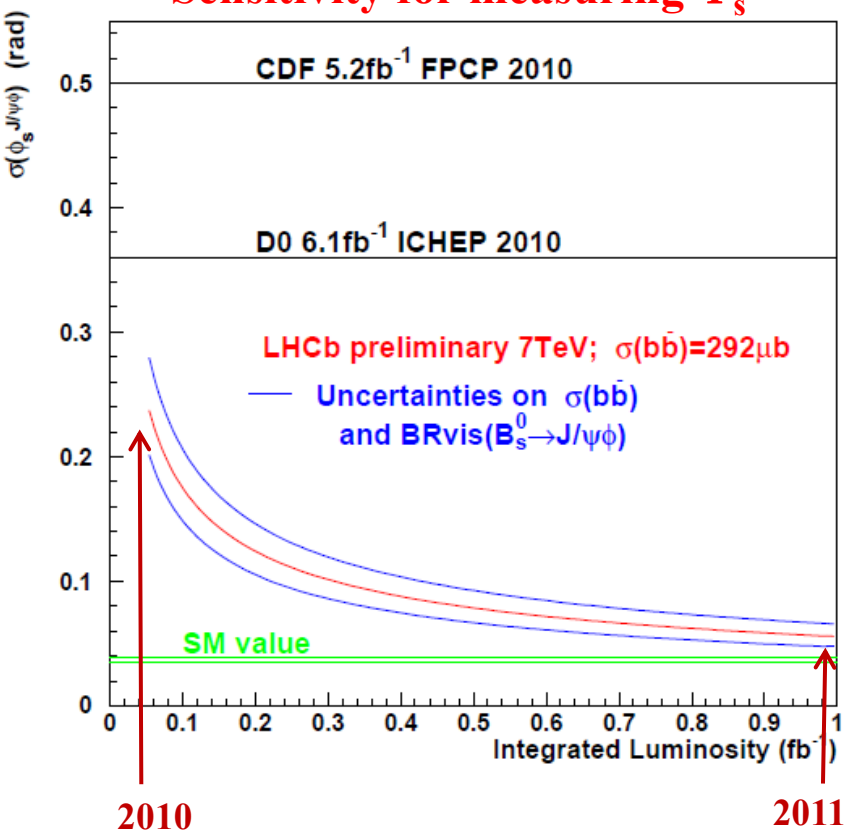
- ✓ $B^0$ and $\bar{B}^0$ are mixing via box diagram






## Sensitivity for measuring $\Phi_s$

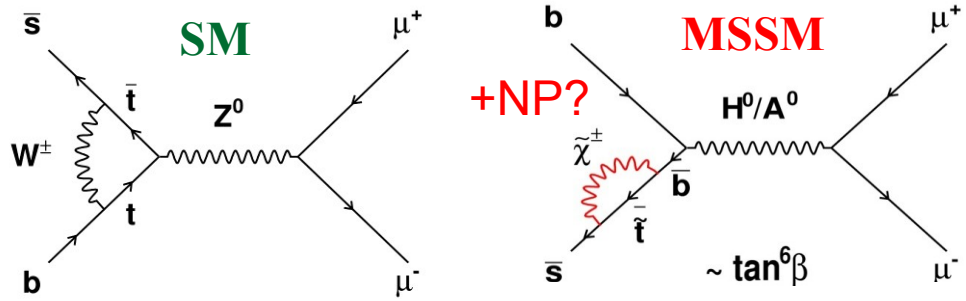



- ✓ measure CP violation in $B_s^{(-)} \to J/\psi\,\varphi$
- ➢ $B_s$ mixing phase $\Phi_s$ is analogous to the measurement in $B_d$ system, with which BaBar & BELLE validated the CKM model

- ✓ analysis of 2010 data well advanced
- ➢ expect competitive result with best world measurements, with this years data set
- ➢ potential to discover New Physics down to the SM predictions with next year's data

# Probing New Physics in loop decays: $B_s \to \mu\,\mu$

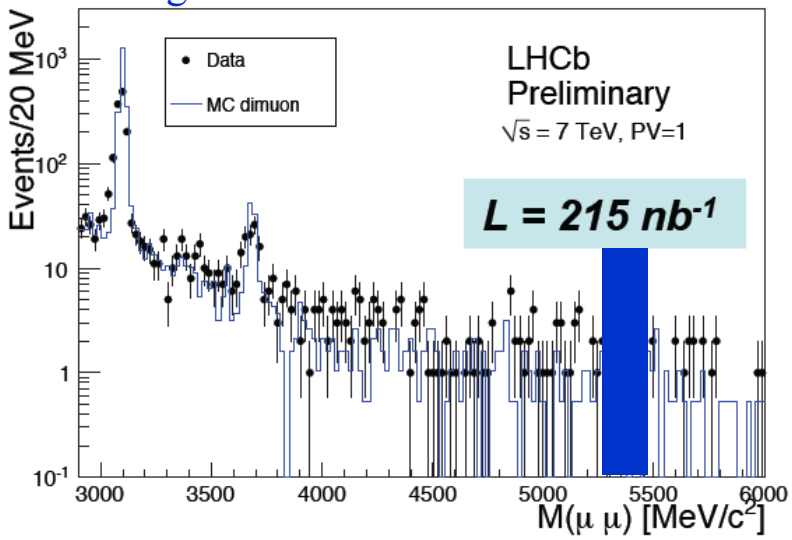
$B_s \to \mu\,\mu$ : the **super** rare loop decay

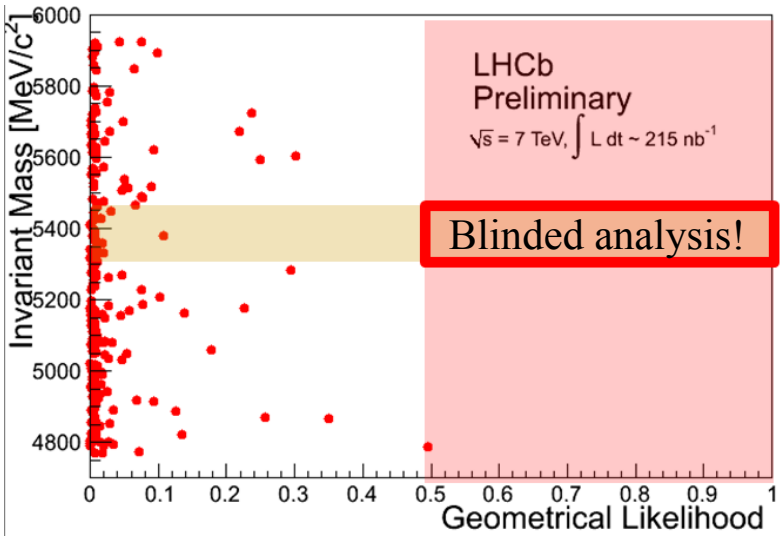



BR = $(3.2 \pm 0.2)\times\mathbf{10^{-9}}$ in SM


- ✓ sensitive to New Physics, can be strongly enhanced in SUSY with scalar Higgs exchange
- ✓ sensitive probe for MSSM with large tanβ:
  $B(B_S \to \mu^+\mu^-) \sim \tan\beta^{\,6} / M_A^{\,4}$

Background well under control!



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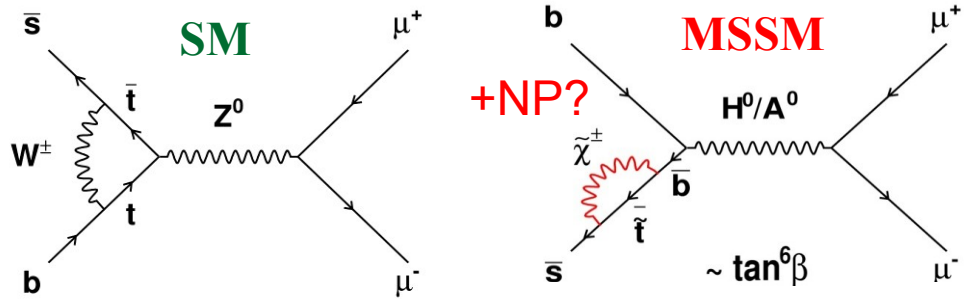


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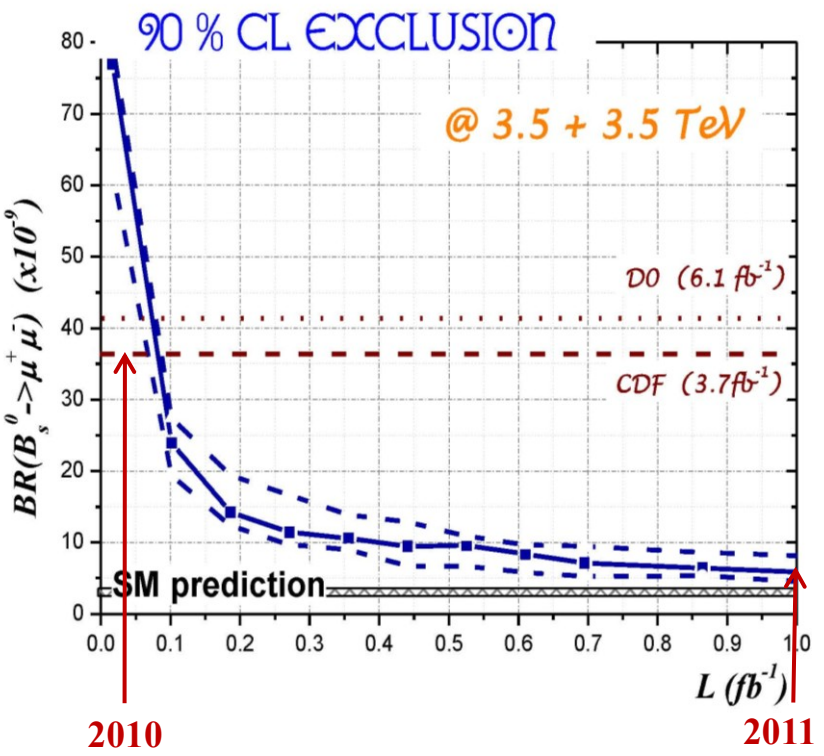


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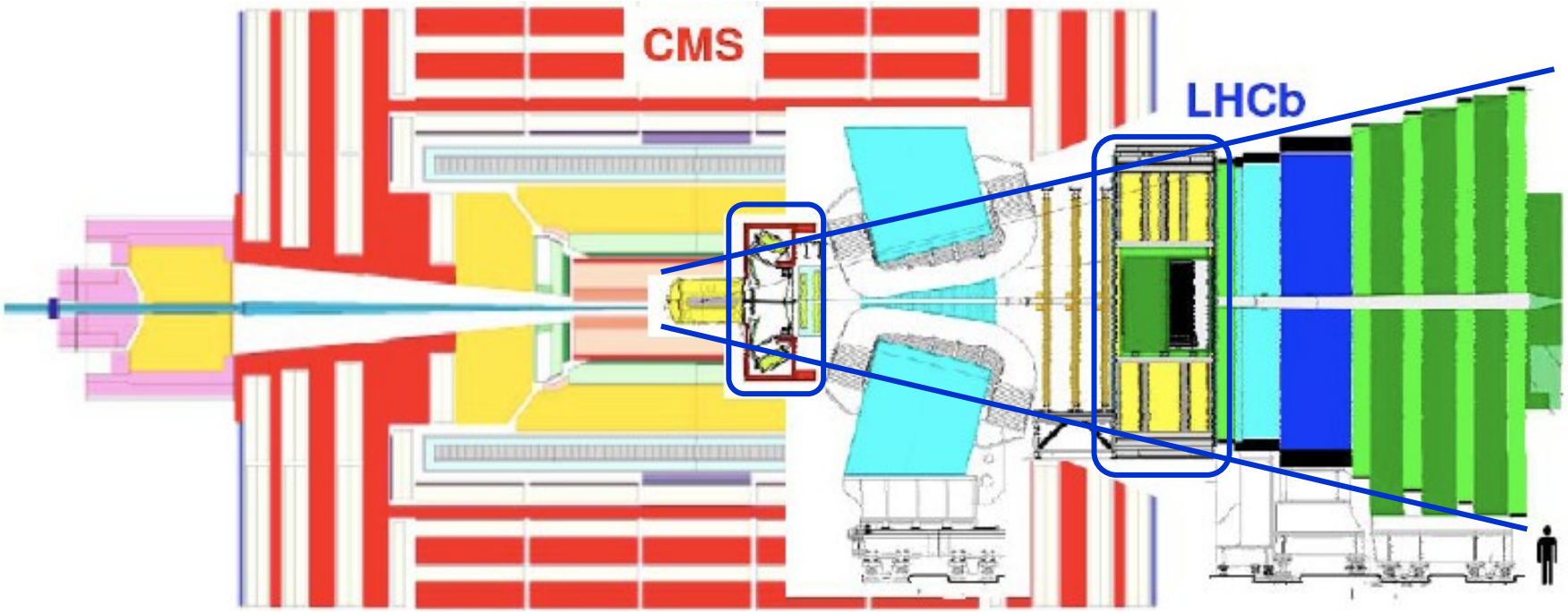
- ✓ analysis of 2010 data well advanced, "un-blinding" for winter conferences!
- ➢ expect competitive result with best world measurements, with this years data set
- ➢ potential to discover New Physics down to the SM predictions with next year's data

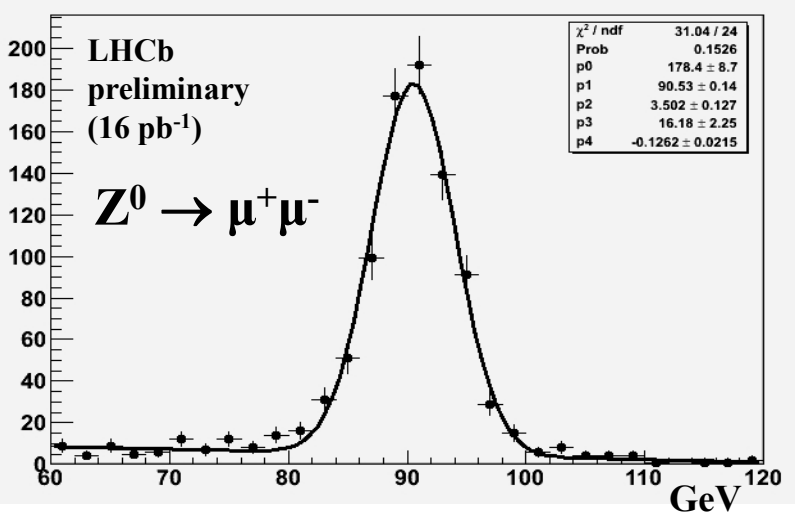
# LHCb as a "General Purpose Detector"

Specific feature of LHCb:

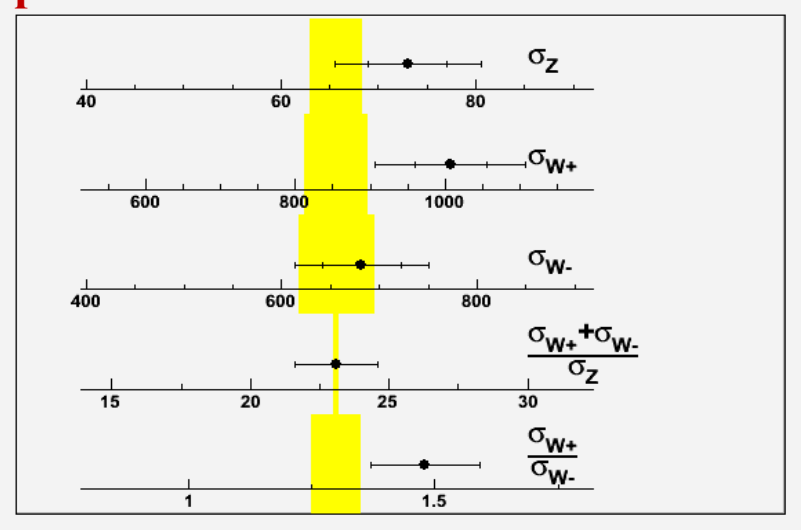
- ✓ particle detection in the forward region (down to beam-pipe)
- ✓ special particle identification capability in particular for hadrons due to RICH detector



# Production of Z and W in forward direction

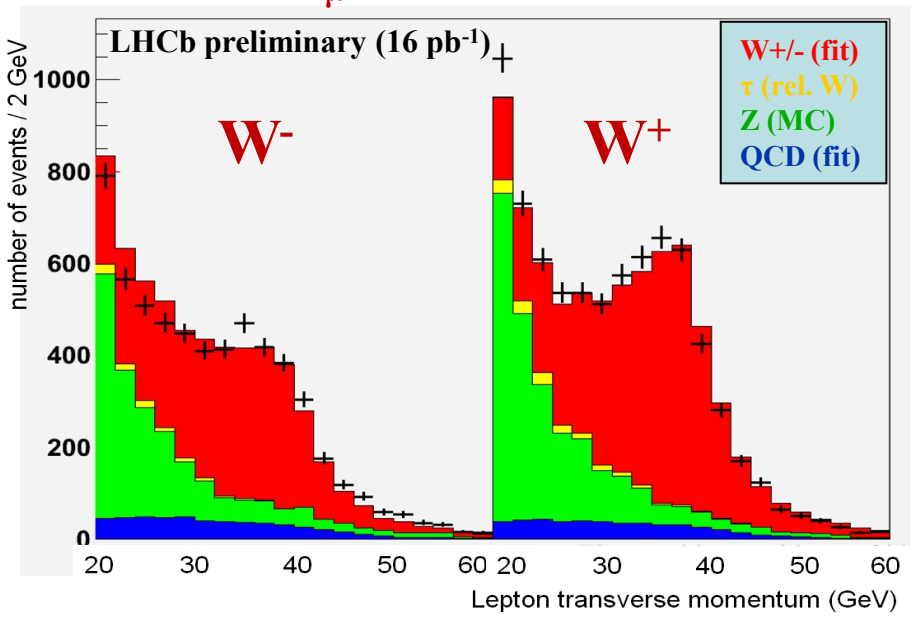



production cross-section σ

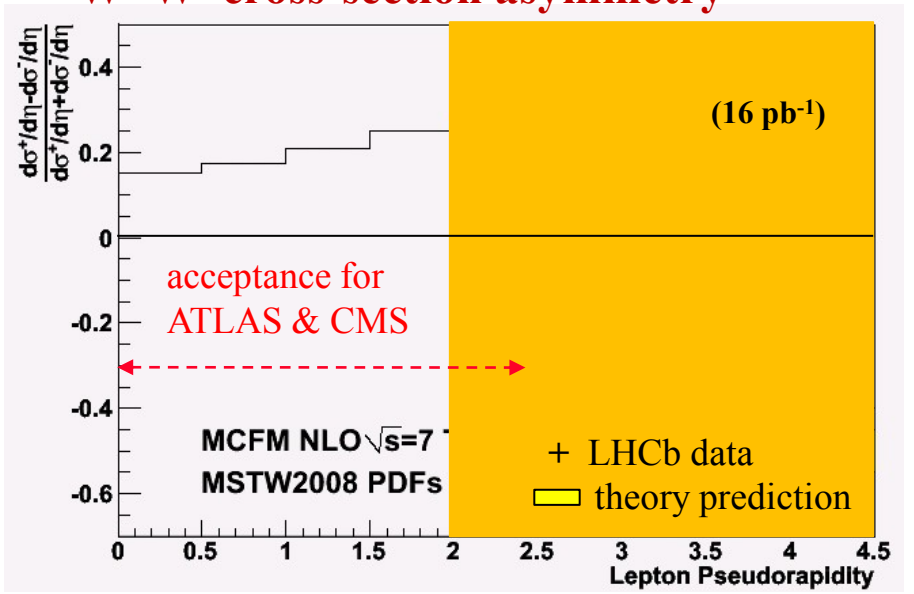



W/Z ratios test SM at 6%

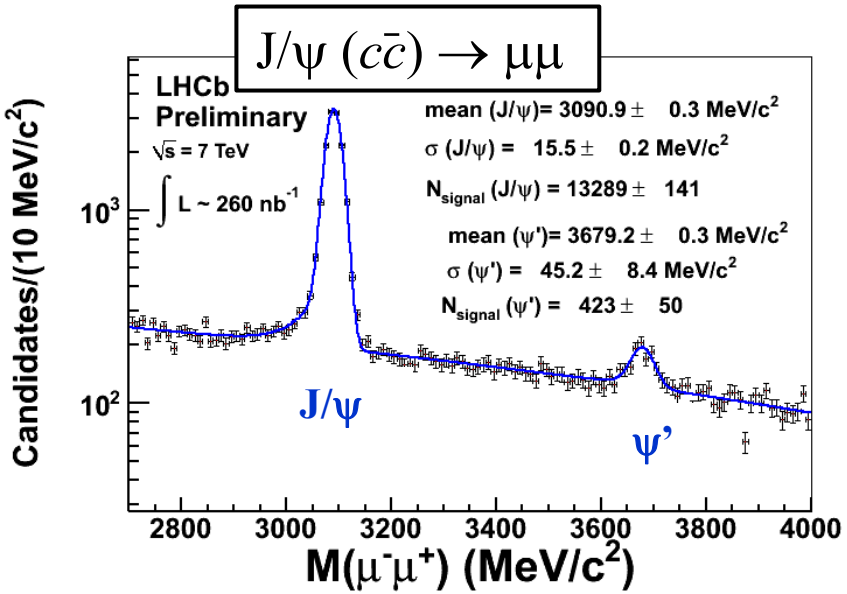
$W^{\pm} \rightarrow \mu^{\pm} \nu_{\mu}$

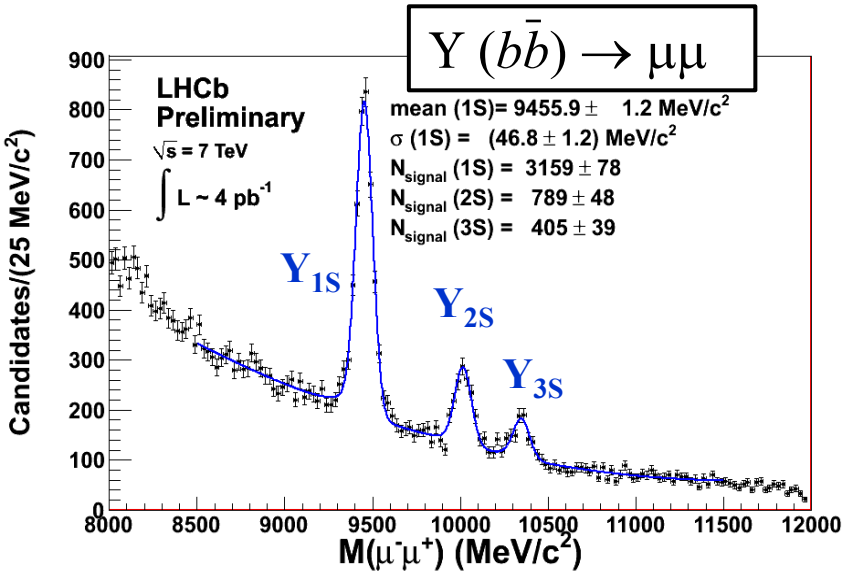


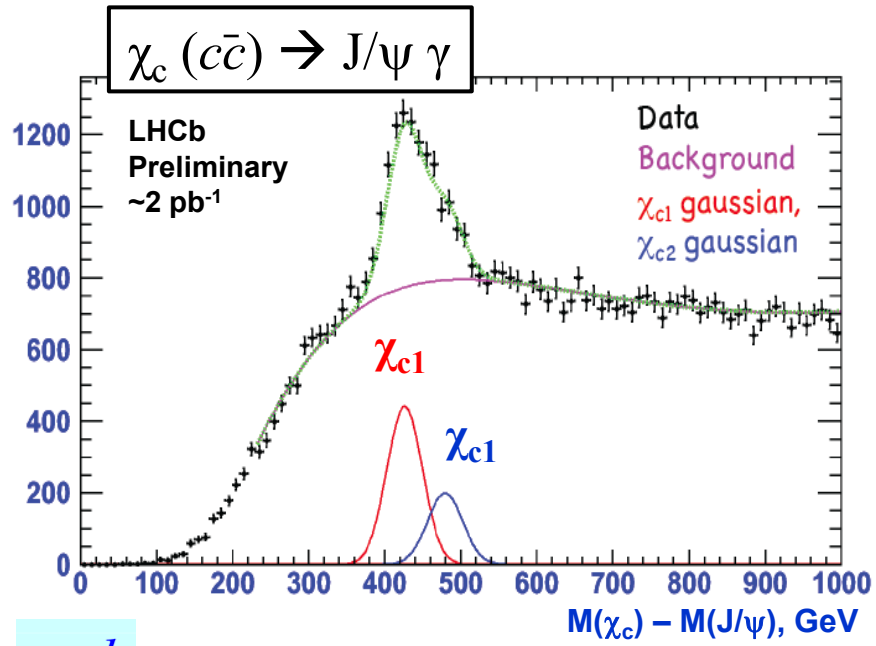

$W^+ W^-$ cross-section asymmetry

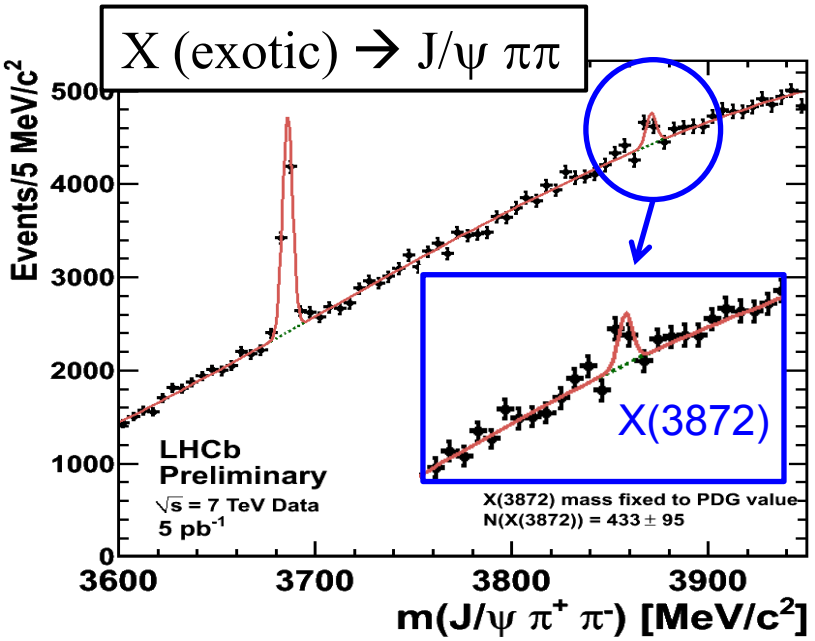


# Spectroscopy of mesons ($q\bar{q}$)

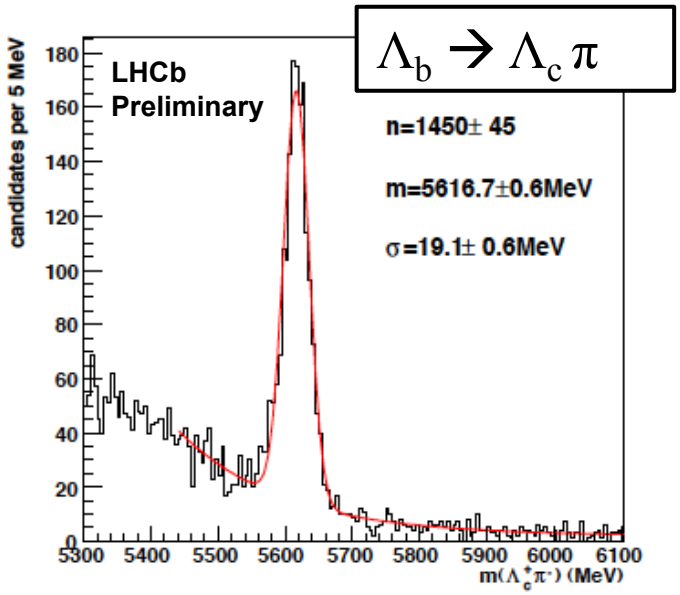


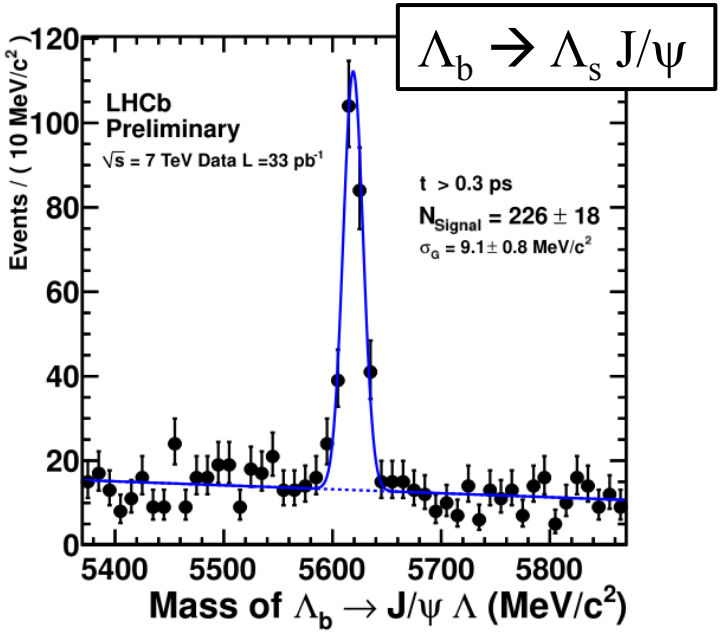



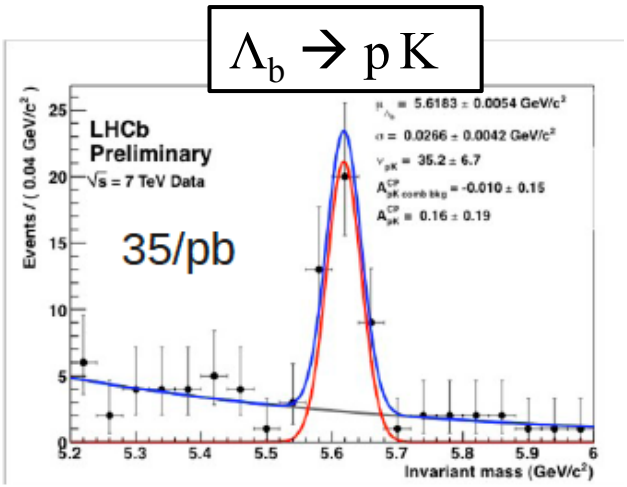



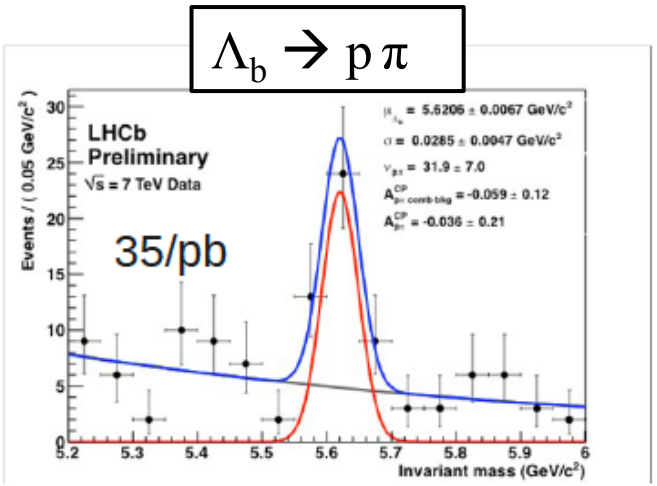



# Reconstruction of B-baryon $\Lambda_b$(*udb*) decays thanks to particle identification performance



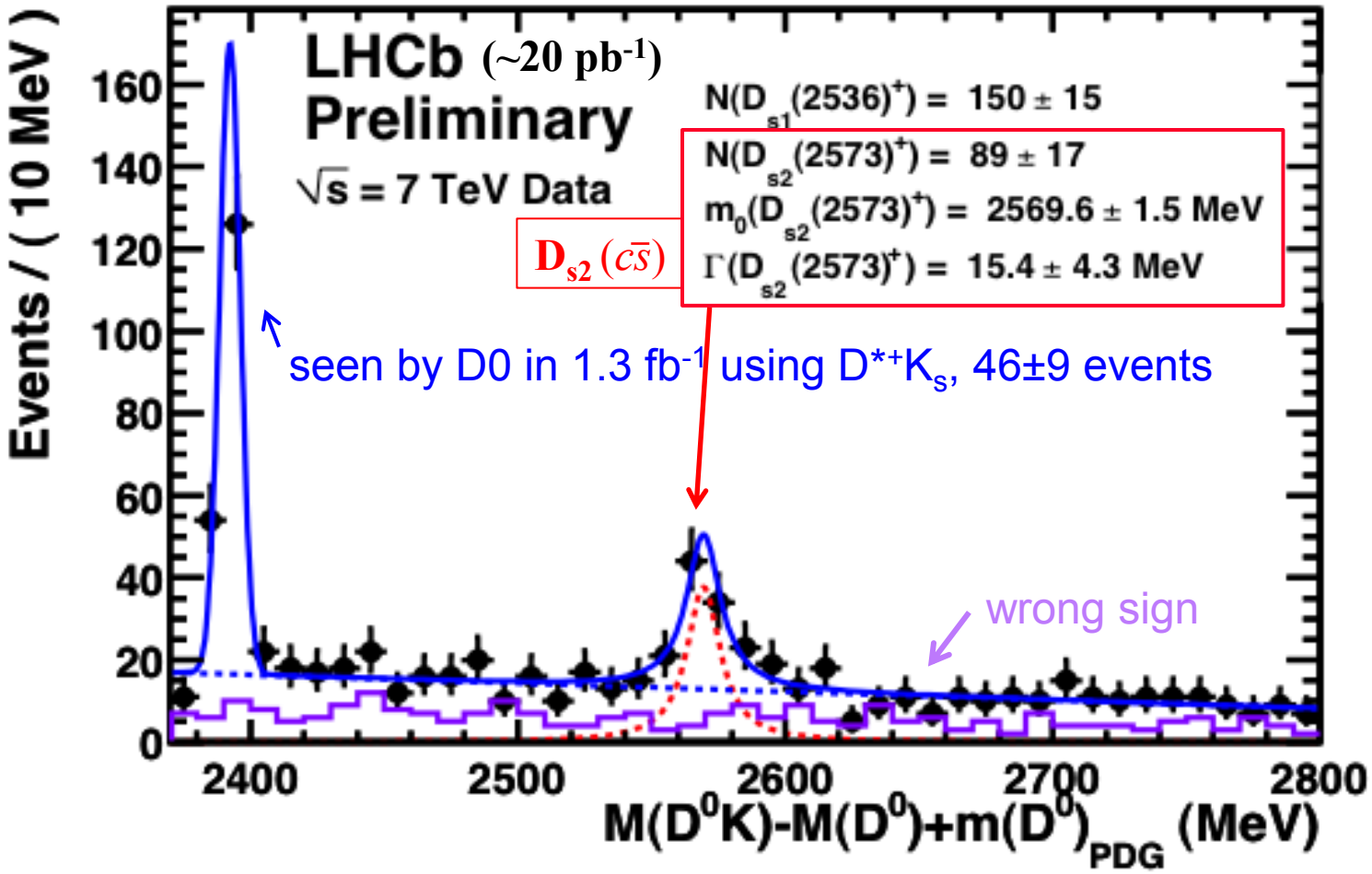




- excellent prospects for observation of CP violation with L ~ 1 fb$^{-1}$

# First observation of new semileptonic $B_s^0$ decay

**First observation of $B_s \to D_{s2} X \mu \nu$ with $D_{s2} \to D^0 K^+$**




➢ **and more first observations in the pipeline… !**

# Summary

- ✓ Fantastic performance of the accelerator complex!
- ✓ LHCb fully operational from the start-up
- ✓ Detector performing very well according to expectations
- ✓ Efficient data taking and analysis despite very challenging luminosity conditions
- ✓ (Re-)"discovered" many Standard Model processes with high precision
- ✓ First results from this years data will be competitive with world best measurements (many new results to be presented at winter conferences early next year)
- ✓ Best world precision measurements already expected with 2011 data, with potential for New Physics discoveries!

LHCb is a beauty(-full) experiment

thanks to **your** support!

# 2010 a beauty-full year !

## Day of first collisions


## End-of-the-year event