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On behalf of the LHCb collaboration

29 August 2011

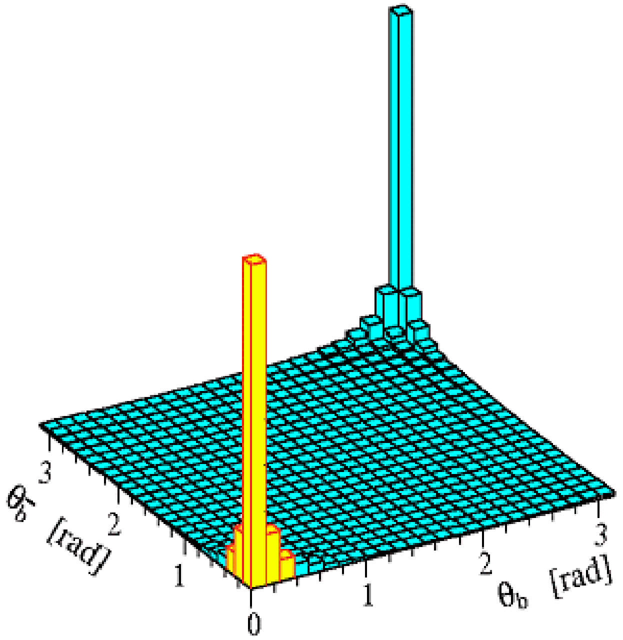
LHCb: From the detector to the first physics results

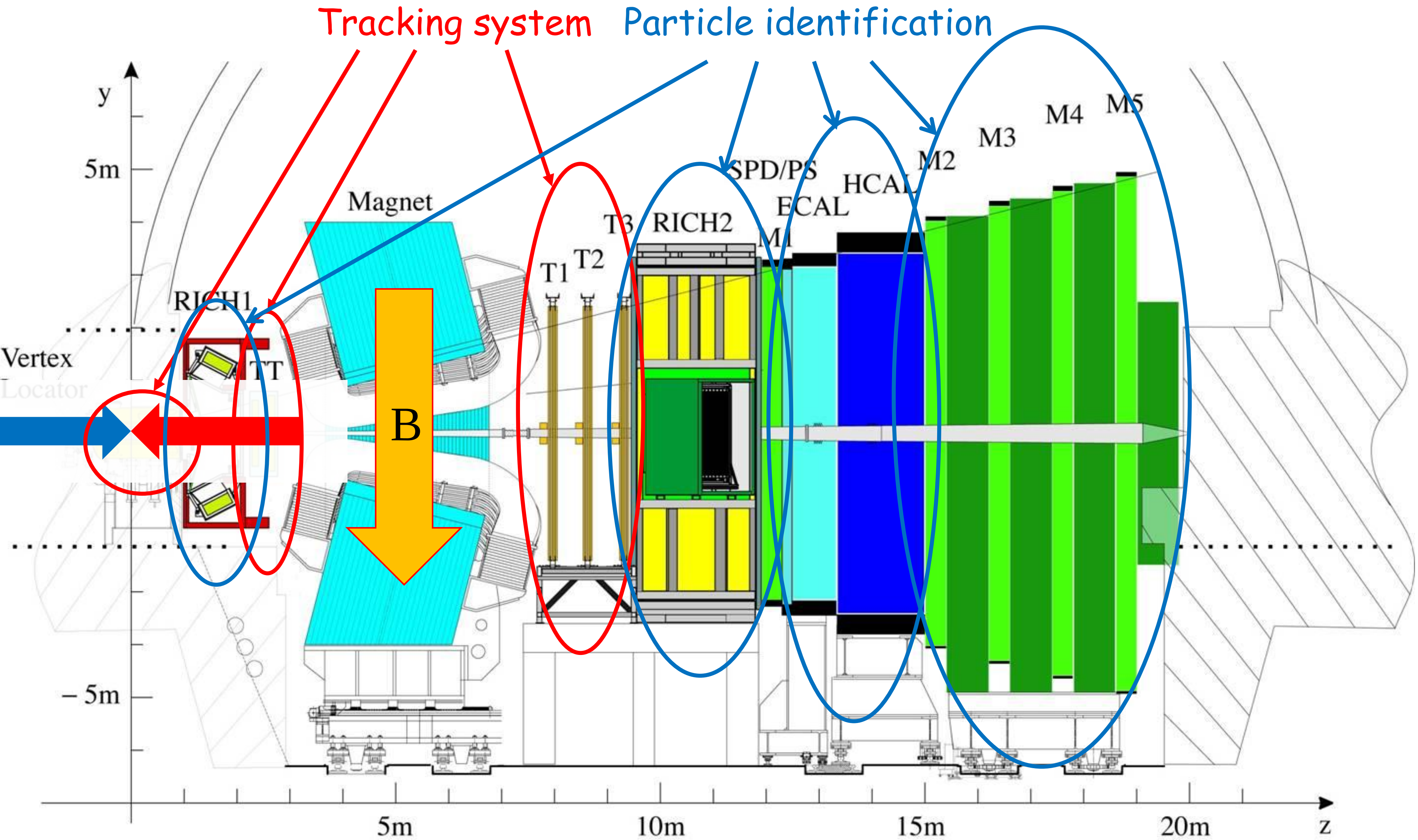
- **Detector description**
  - Some performance figures
- **Event selection**
  - Hardware and software triggers
  - Data processing
- **Some recent physics results**

The detector

- **B and D physics at the LHC are forward/backward**
  - The interacting partons have different x
  - The produced $b\bar{b}$ pair are boosted forward or backward, together
    - The detector can look only at one side, and get both b, very useful as we have both the signal b and the tagging b in the acceptance

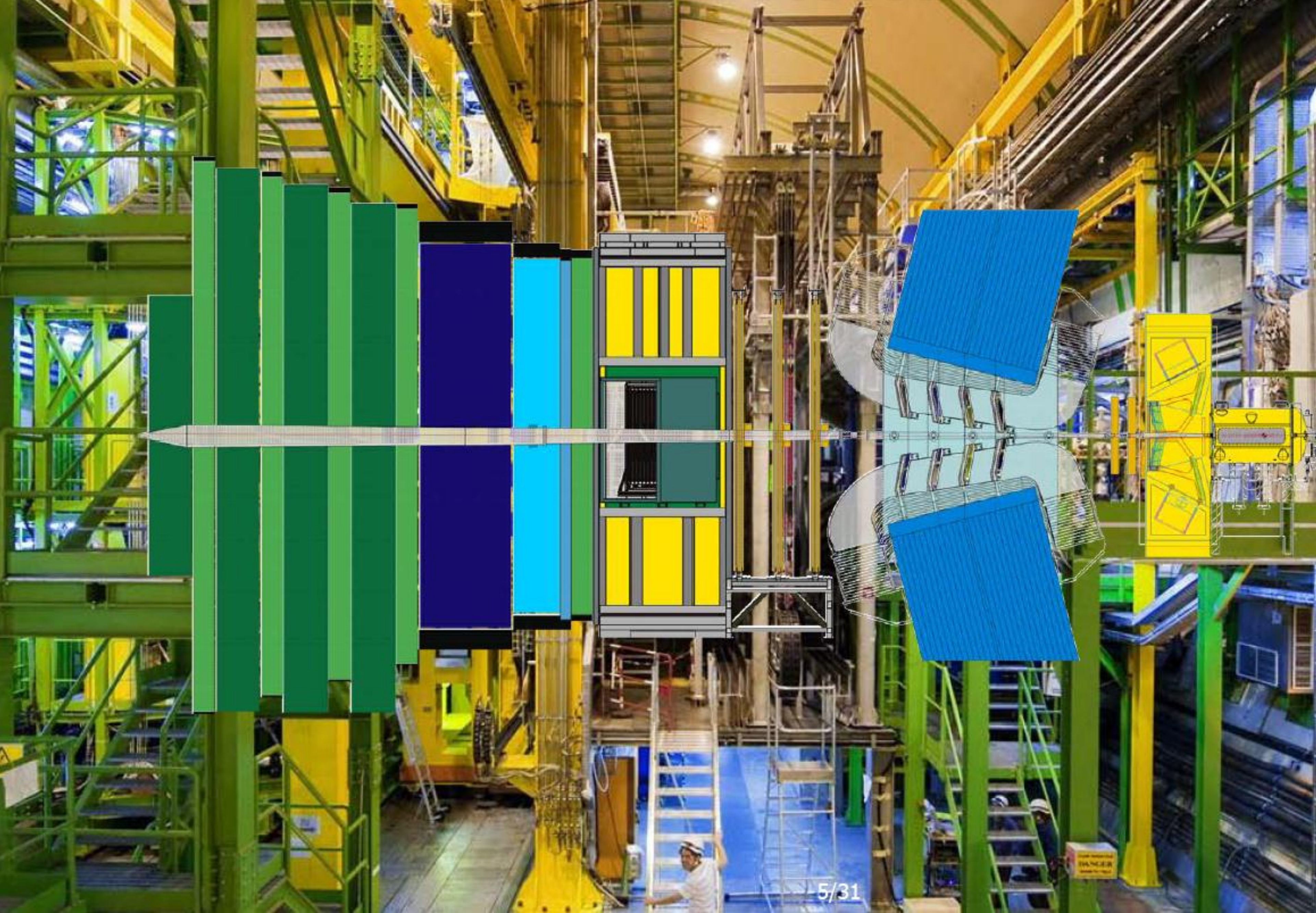
- **Single arm spectrometer**
  - Very good vertex detector
  - Dipole magnet for accurate momentum measurement
  - Good particle ID over a large momentum range
  - Should fit in an existing LEP cavern...



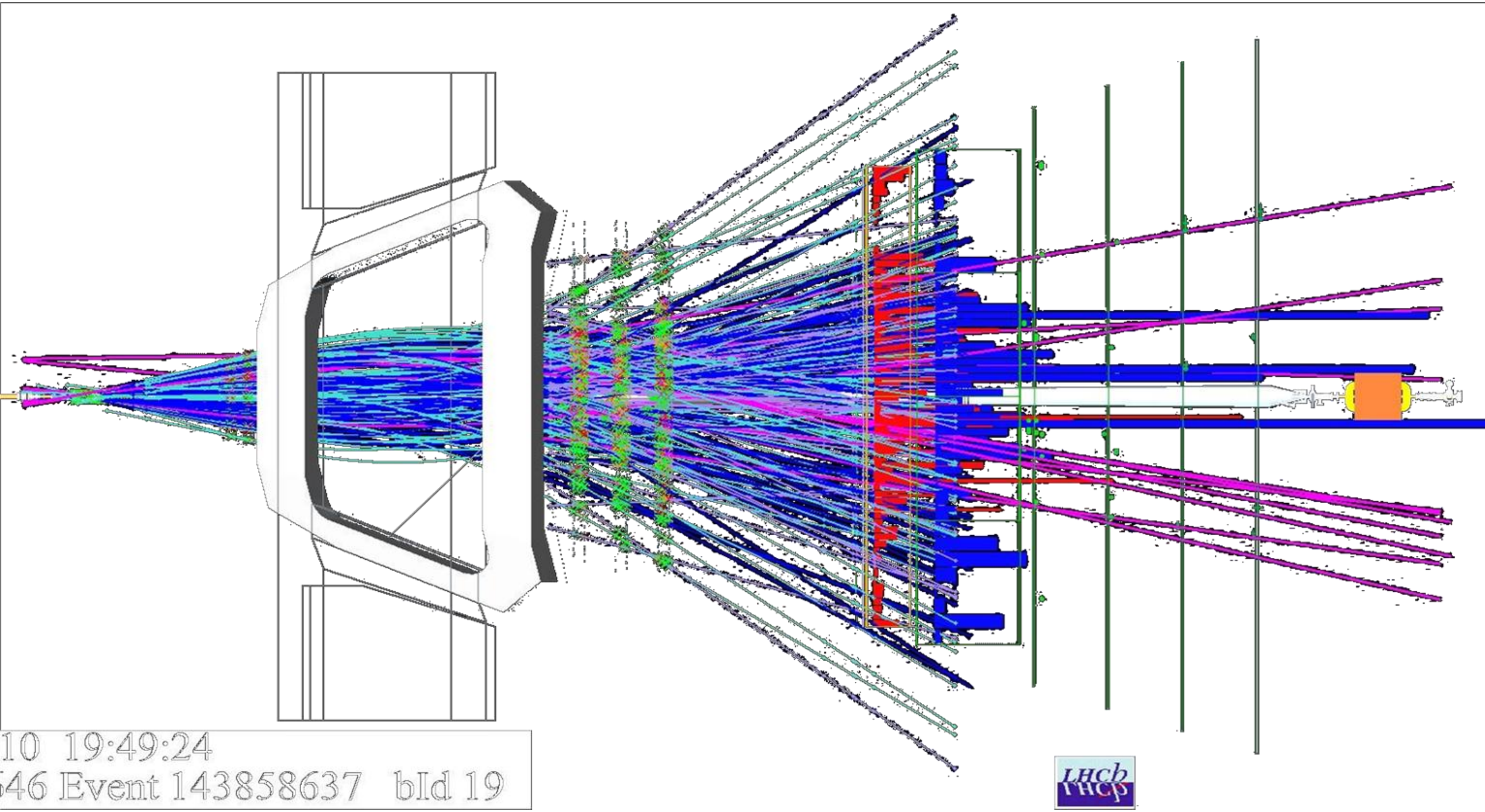

Tracking system
Particle identification
y
5m
– 5m
Magnet
RICH1
TT
Vertex
Locator
B
T1
T2
T3
RICH2
SPD/PS
M1
ECAL
HCAL
M2
M3
M4
M5
5m
10m
15m
20m
z

The LHCb Detector

The LHCb Detector



A typical event...

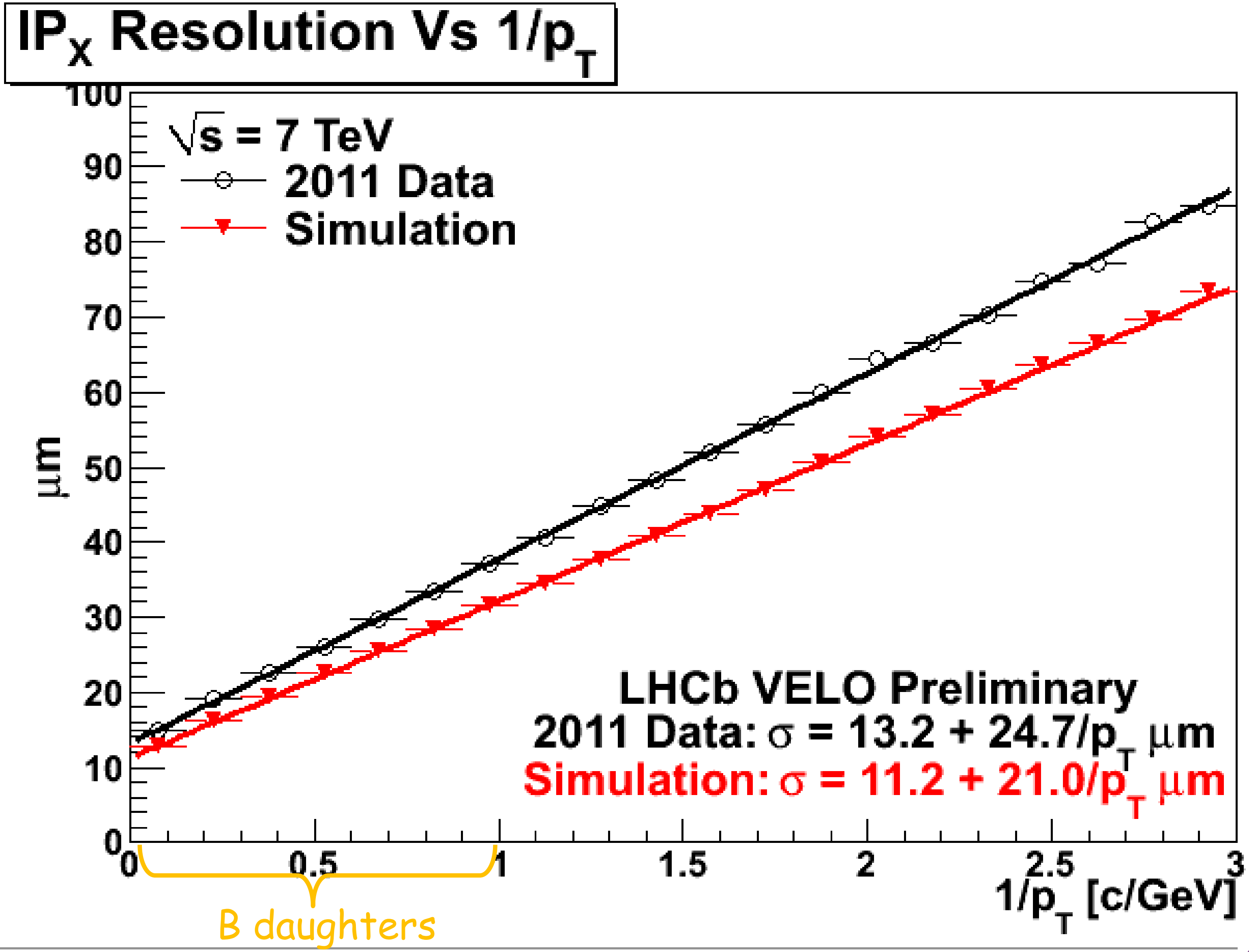


Main components

◆ Vertex detector

- Should measure the primary vertex, and the B decay vertex
  - Flight distance of the order of a few centimetres
  - Primary vertex with typically 40 particles
    - ➔ Including backward going tracks
- Measurements as close as possible to the interaction point,
  - i.e. of the beams ! Sensor at 7.5 mm in operation
  - Retracts to a ‘garage’ position if LHC is not in “Stable beam” mode, to give more space for beam injection and tolerate beam excursions before it is fully stable
- Very accurate silicon detector
  - Strip pitch from 40 to 100 micrometers
  - Need to position back the detector mechanically for each fill with a precision of a few micrometers !
  - Minimize the multiple scattering between the real vertex and the measuring sensors

- Impact parameter resolution summarizes the performance

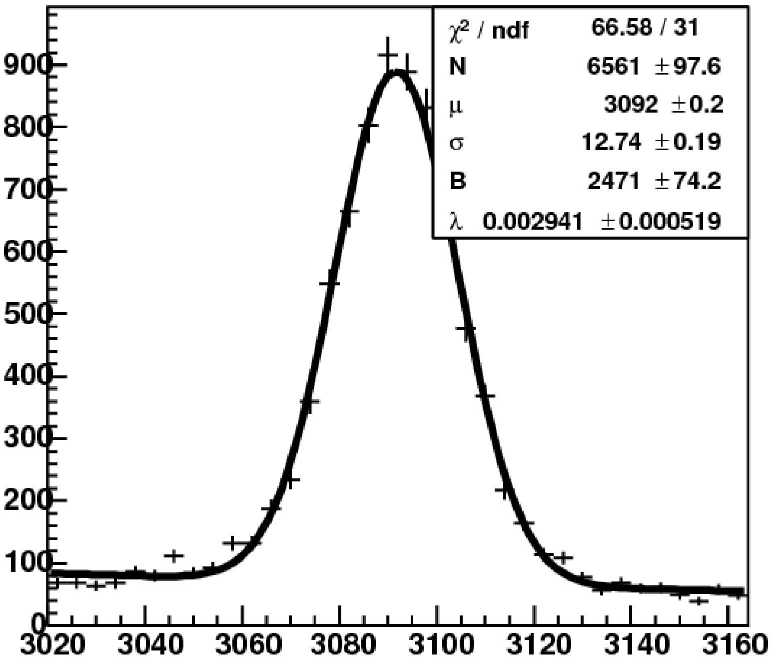


◆Trackers

- Silicon strip detectors (TT, IT) or straw tubes (OT)
- Over 99% of the channels are working perfectly
- Main function: Measure the momentum
  - Accurate field map, measured when no detector was around
  - Integrated $\int B.dl \approx 4$ Tm
  - Re-measured this winter on one accessible zone (~600 points), confirm the values for the field, with a shift of 10 mm along the beam

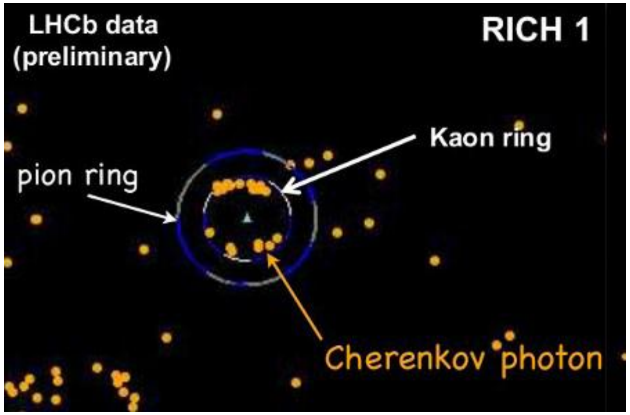
- Performance is measured on the J/Ψ mass resolution

- **13 MeV resolution**,
  - MC expectation: ~10 MeV
- Alignment is not yet perfect
  - Somme effects still to be understood

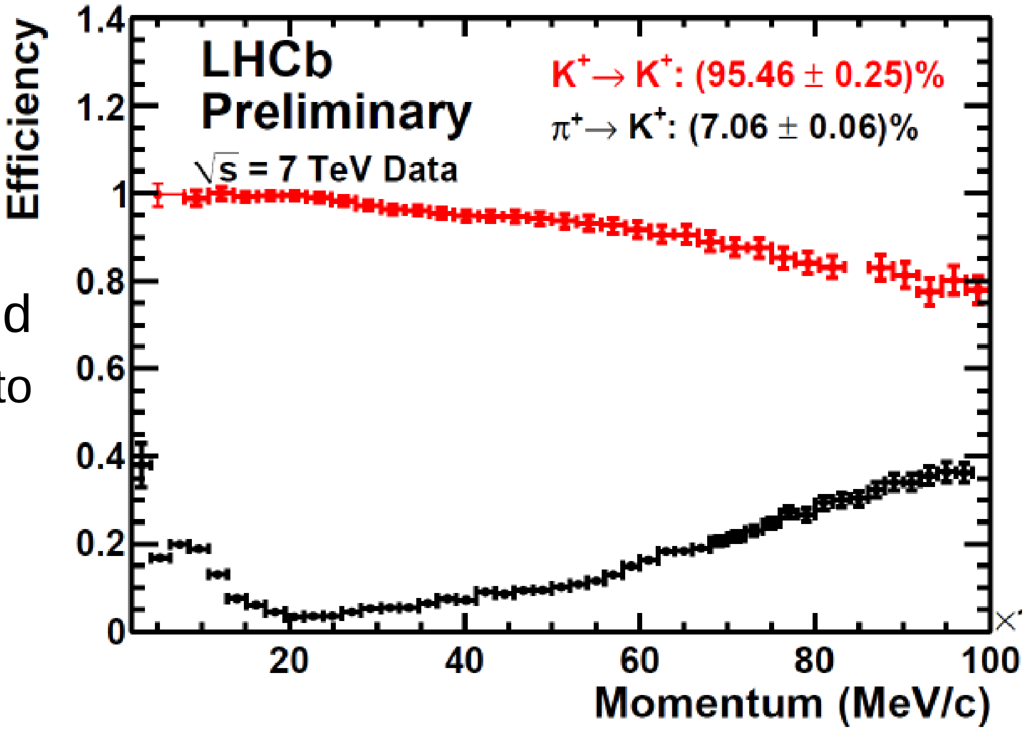


◆Particle identification with the RICH

- About 500 HPD devices, 32x32 cells each.
  - ½ million cells!
- A charged particle produces Cerenkov photons, that are located on a ring centred around the track's position
- 2 detectors, the first one with 2 radiators



  - Gives π/K separation for a large momentum range



- Careful alignment required
  - The HPD are sensitive to magnetic field
  - Variation of the gas refractive index with temperature...

Calorimeter to identify electrons, photons, π^0

- ~6000 cells in the electromagnetic calorimeter
- SPD to distinguish charged/neutral, PreShower to identify early showers, i.e. electromagnetic
  - Resolution conform to expectation

Hadronic calorimeter

- ~1500 cells, mainly for the hardware trigger

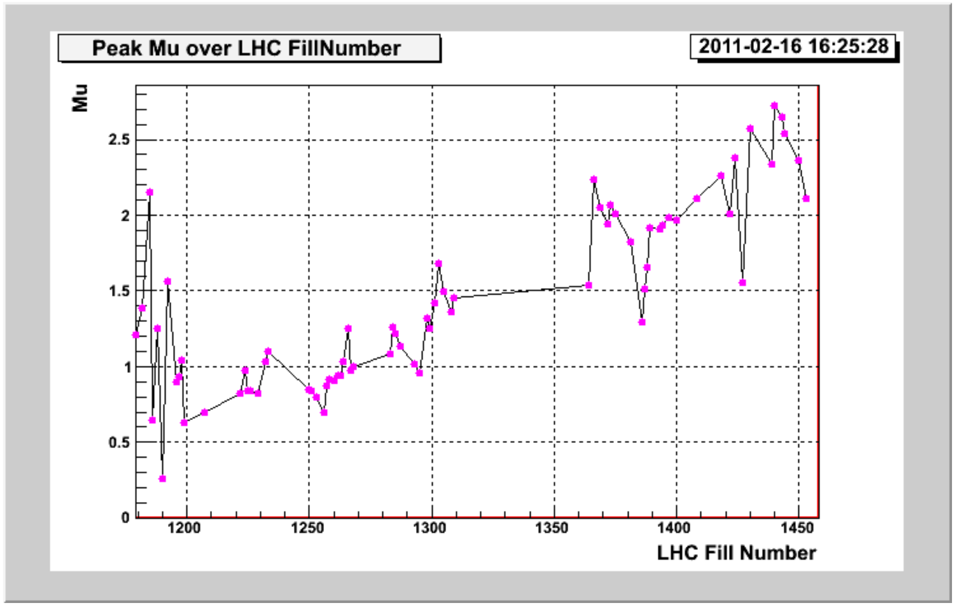
5 stations of muon detector

- ~1300 MWPC + a few GEM chambers
- Over 99% efficient
  - Gaps in OR to be insensitive to local problems.
- Muon identification, and hardware trigger
  - Cells are projective in the 5 stations
  - Almost aligned hits, non-pointing gives the deflection by the magnetic field, i.e. an estimate of the momentum

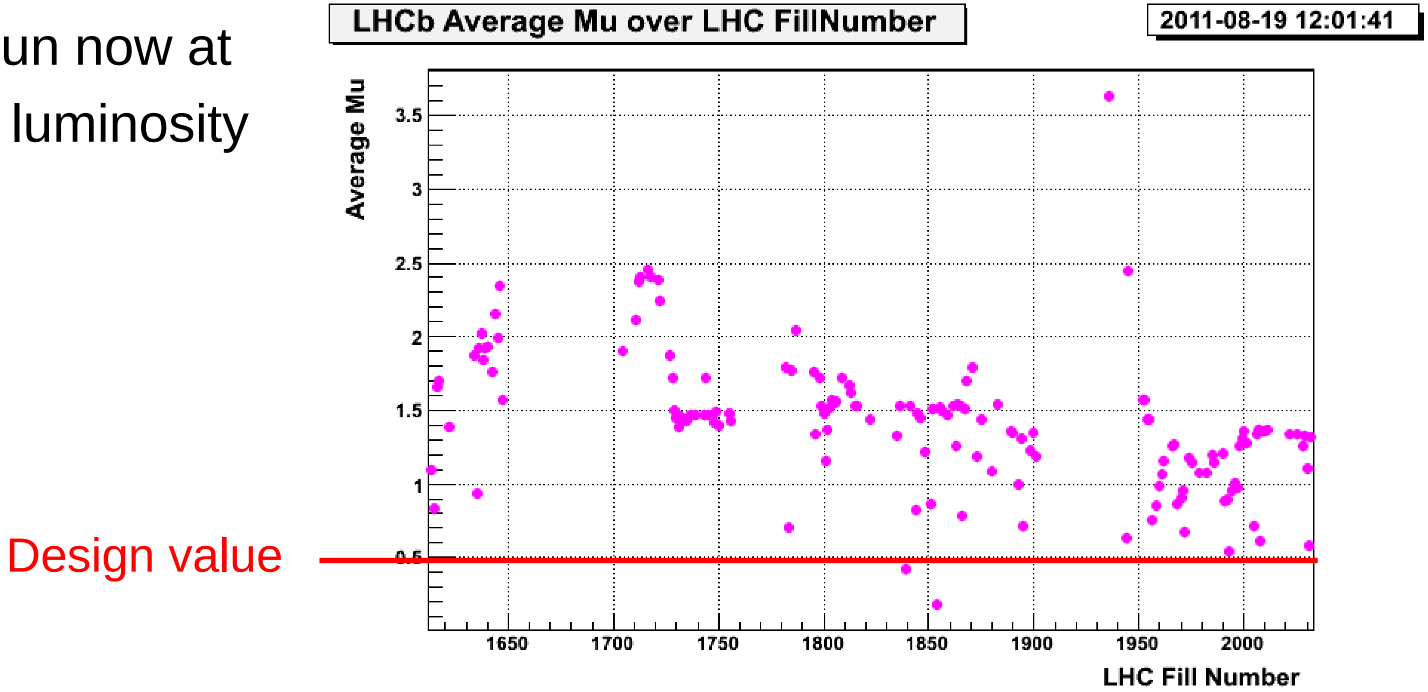
Event selection

◆LHCb runs at a limited luminosity

- Originally, a single interaction per beam crossing was required
  - Easier to associate primary vertex and B decay
  - Average number of interaction per crossing μ = 0.4
- But LHC has now a smaller than designed number of bunches
  - Same luminosity with less bunches = more interaction per crossing
- We worked in 2010 with up to 2.5 interactions per crossing

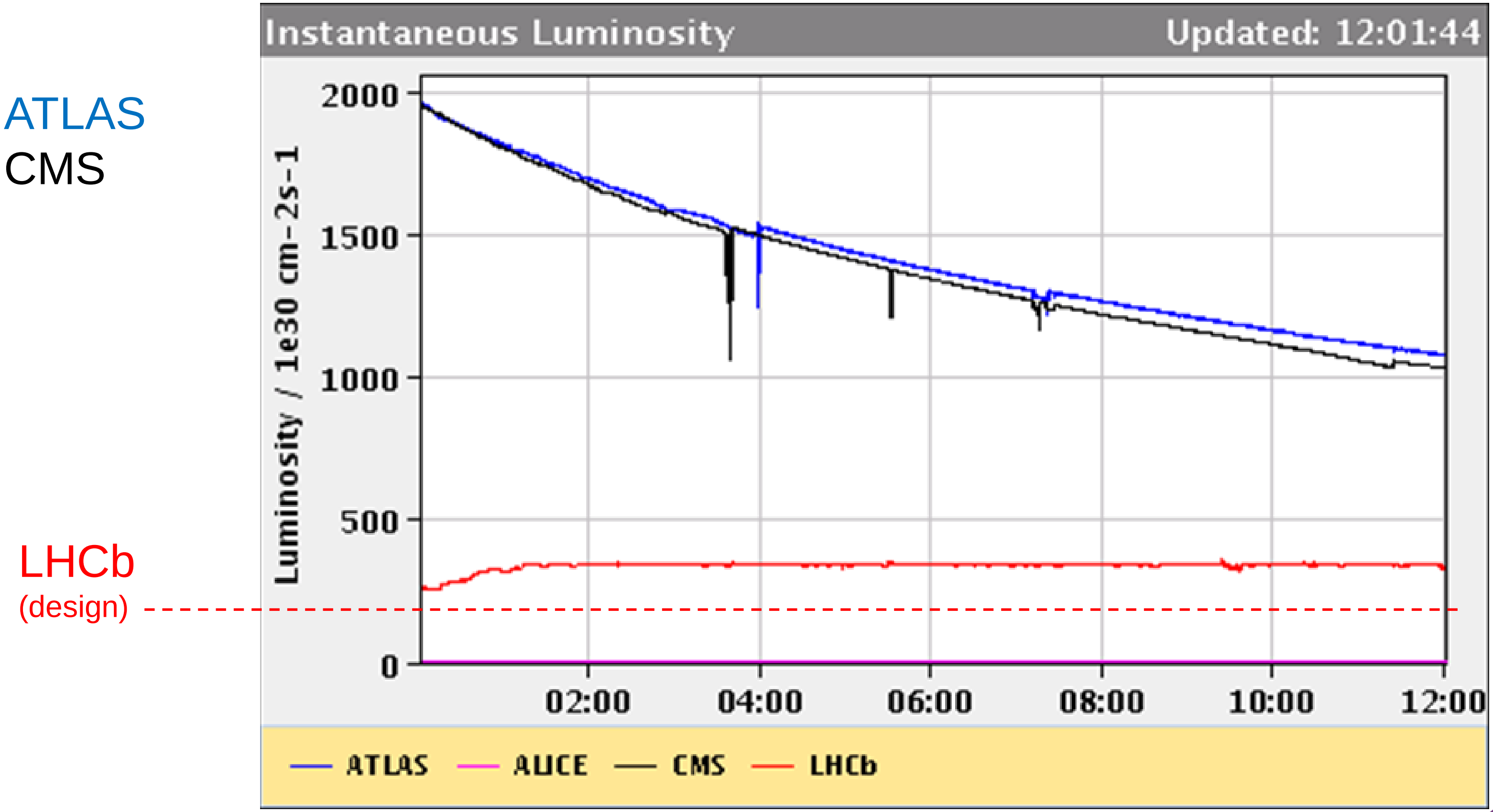


- In 2011 the LHC has more bunches, with 50 ns bunch separation.
  - One detector (OT) sees the signals from previous and next crossings
  - We had to reduce the number of interactions per crossings
- Our running conditions is now $\mu \leq 1.5$
  - This means at a luminosity of $3.5\ 10^{32}\ cm^{-2}s^{-1}$
  - This is 1.5 times the design value, with half the number of bunches!
  - We designed LHCb for $\mu \sim 0.4$!
- But we run now at constant luminosity



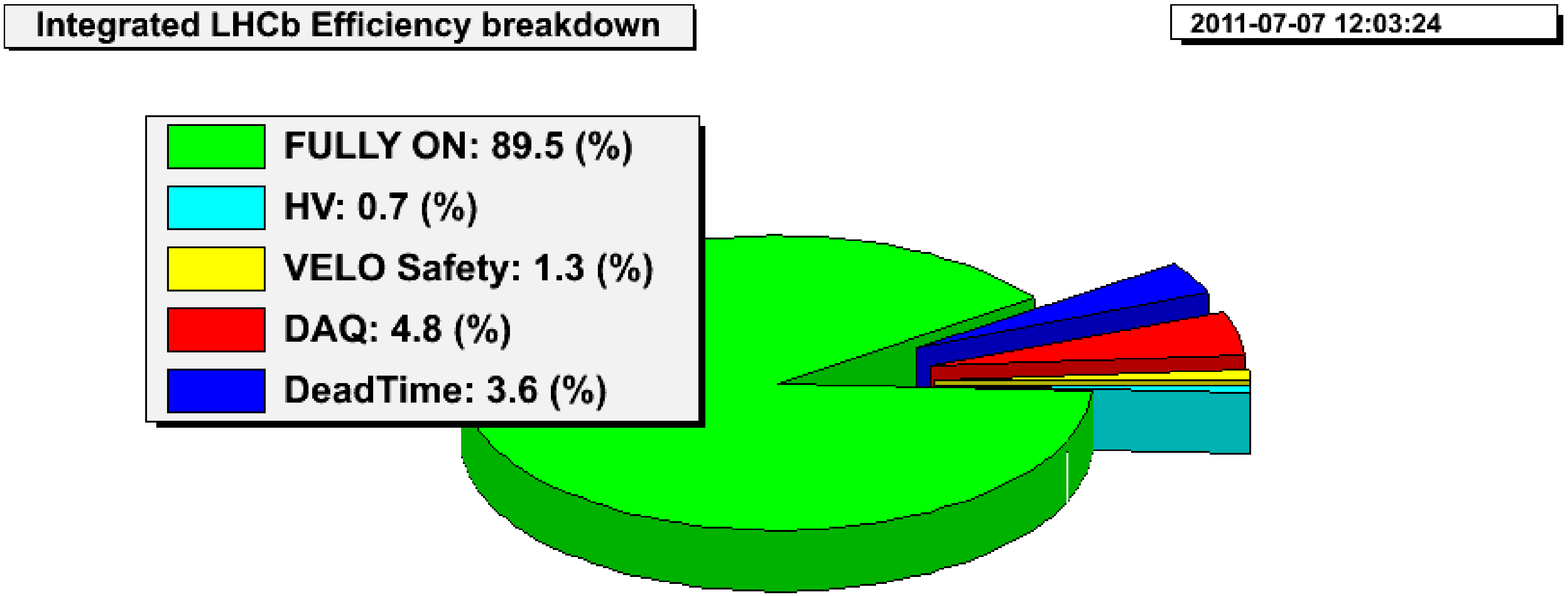
◆Luminosity levelling

- Separate the beams in the vertical plane to decrease the overlap, and thus the rate of collisions (luminosity)
- Start with a very modest, and increase slowly (~30 minutes) to avoid detector trips
- All data taken in the same pile-up conditions!



Overall efficiency OK

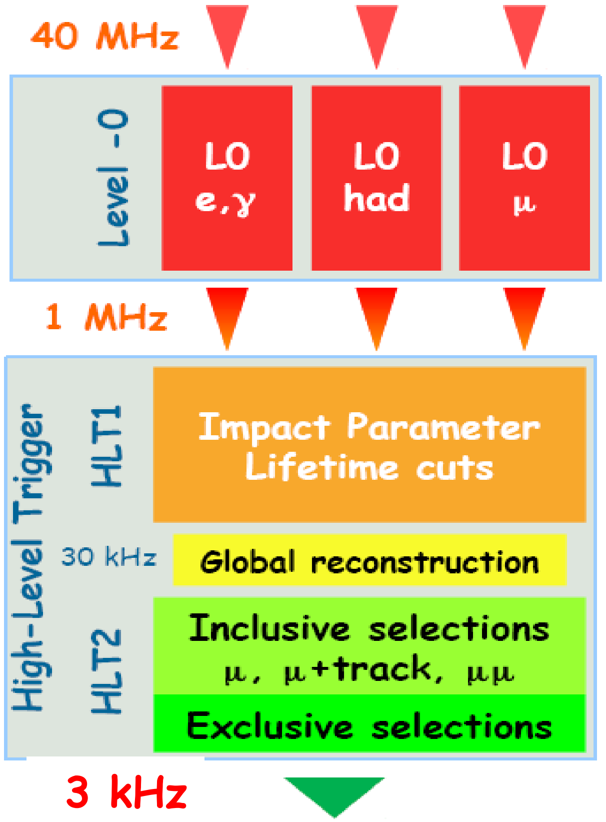
◆ **Monitor of the operational losses**



- We should also apply the trigger and selection efficiencies, but this is channel dependent and is part of the selection efficiency.

◆Event selection in several steps

- Interaction rate about ~10 MHz
  - 40 MHz clock, only ~1/3 with beams
- Hardware trigger (L0) at about **800 kHz**
  - Events with a muon over ~1 GeV Pt
  - Or with a local Hadronic transverse energy over 3.6 GeV
  - Also triggers on e, γ, π° with similar thresholds
  - In principle 1 MHz rate is feasible, but the high occupancy gives high dead time now
    - ➔Work in progress to gain 10-15%
- Software trigger in a ~1350 CPU farm
  - ~20000 copies of the code are running in parallel
    - ➔25 ms per event in average
  - **~3 kHz** output rate



HLT1: topology

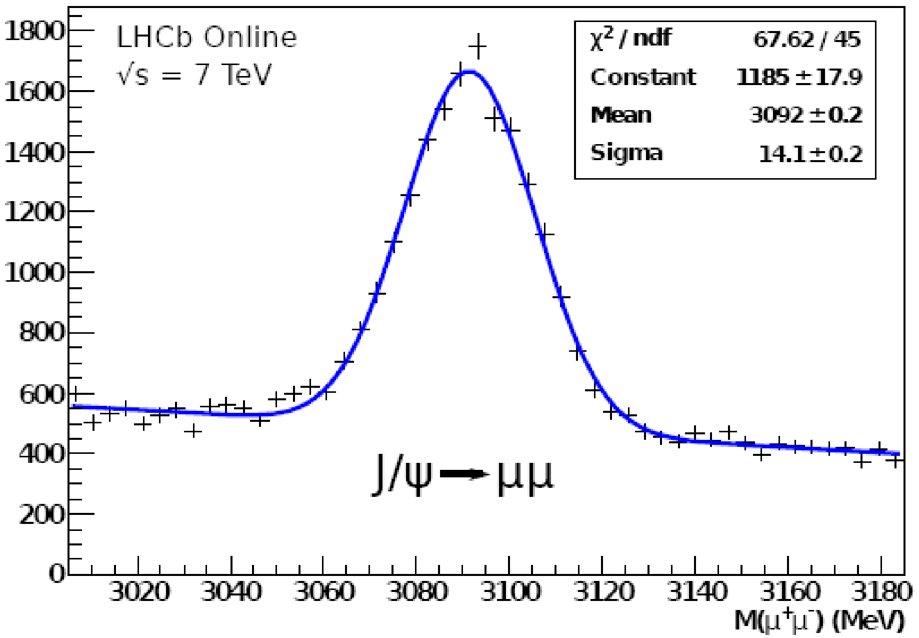
- Idea: Find a track with high impact parameter to the Primary Vertex and high enough momentum
  - 100 micrometers
  - 1 GeV Pt
- For that, reconstruct all Velo tracks, select those with impact parameter, measure their momentum by the full tracking
  - As a B decay has several tracks fulfilling these requirements, no need to be 100% efficient per track
- For muon triggers, this track should be validated as muon

HLT2: Selection by physics channel

- Full event reconstruction, but no particle ID.
- Topological trigger to find a displaced vertex with high enough mass
- Many specific channels for dedicated studies
  - J/Ψ, Φ, $D \rightarrow K\pi$, ...

◆Online monitoring of physics candidates

- Mass plots



- Efficiency as expected

  2010 low lumi settings

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

◆We have also several technical triggers

- Luminosity: random sampling of crossings
  - Luminosity by counting the fraction of empty crossings = $e^{-\mu}$ where μ is the average number of interaction per event (Poisson)
- Sampling of unbiased events at various levels

◆Offline selection: The stripping

- Data is reconstructed fully, and a series of preliminary analyses is run, to select events per (group of) physics channels.
  - Should reduce the rate of <10Hz per channel
    - ➔Should get a manageable set of < 100,000,000 events per year!
  - Several output streams corresponding to the various physics groups

- Run in semi-online mode
  - Data quality validation using an 'Express stream'
    - ➔Result available within a few hours
  - Reconstruction takes about 1 second per event
    - ➔A file is about 80k events → One day of CPU
  - We write a raw data file every 25 seconds at 3 kHz...
    - ➔A few thousand files per day = a few thousand jobs continuously !

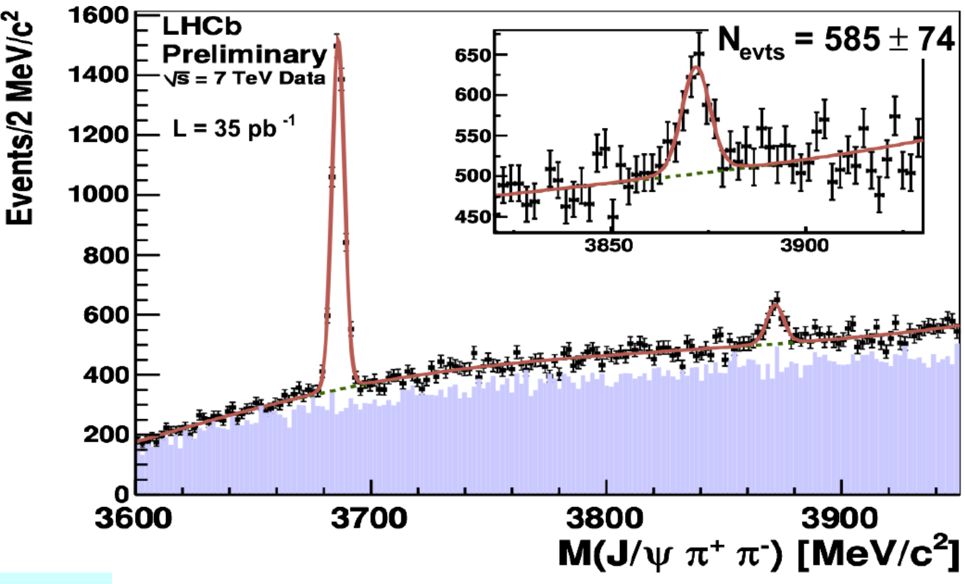
- The various output streams are merged to get files of reasonable size.
  - All is ready in principle 2-3 days after data taking.

Some physics results

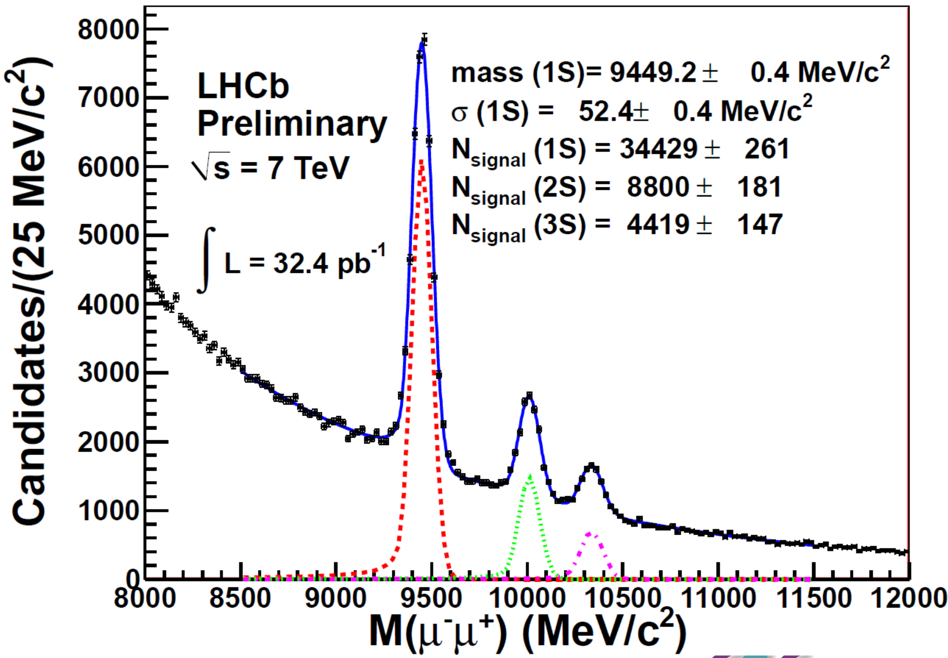
- **Spectroscopy**
  - Find known resonances in various channels
    - And look for less clear ones...
      - ➔ Mass resolution and good PID are key components
    - See poster on quarkonium production

X(3872)

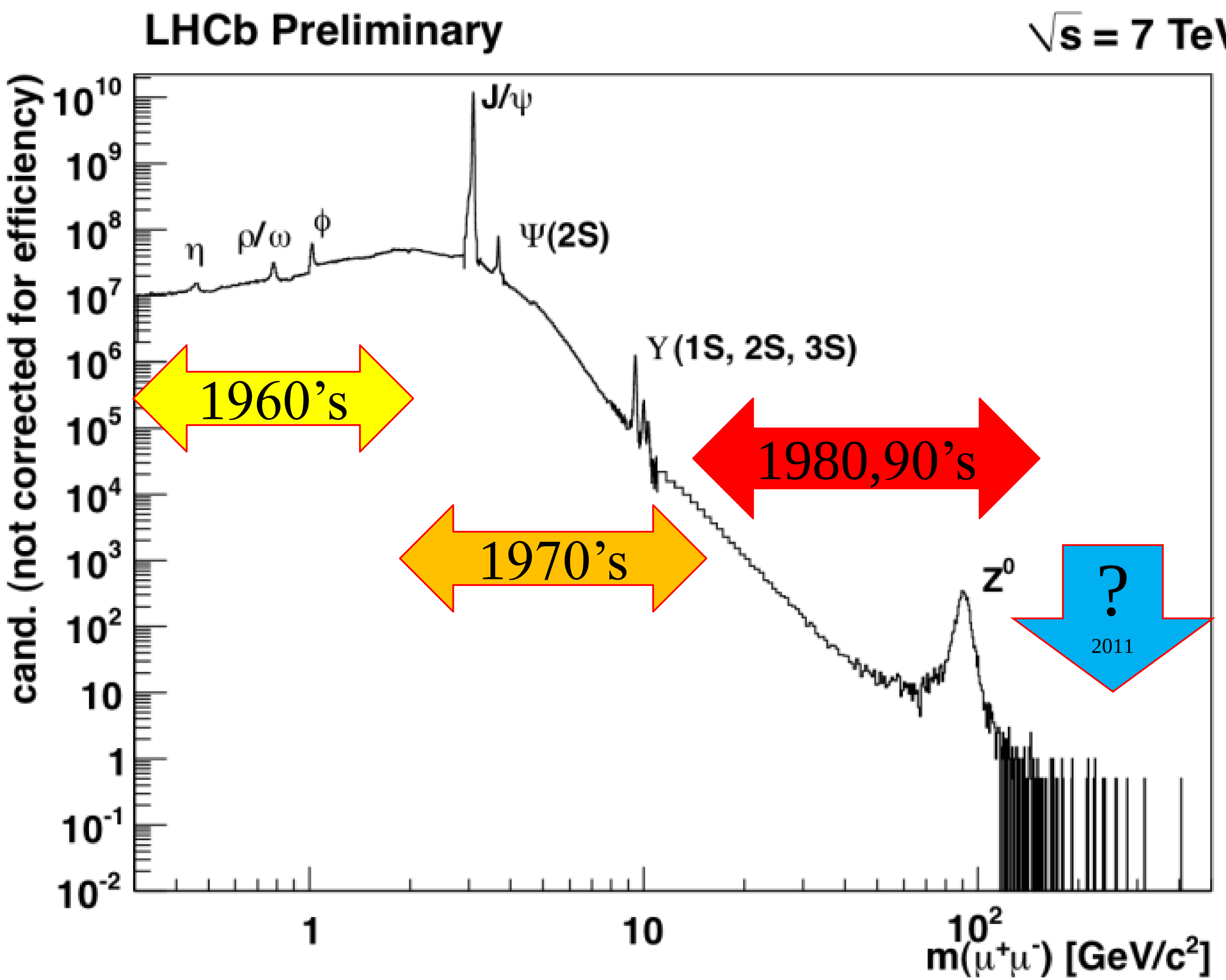
$M_{X(3872)} = [3871.96 \pm 0.46(stat) \pm 0.10(sys)]\ MeV/c^2$



Upsilon region



◆Dimuon mass spectrum (log scales)

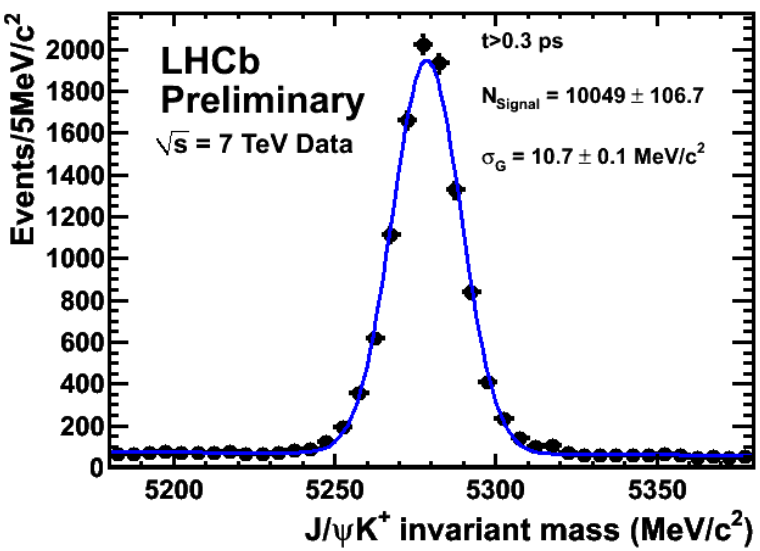


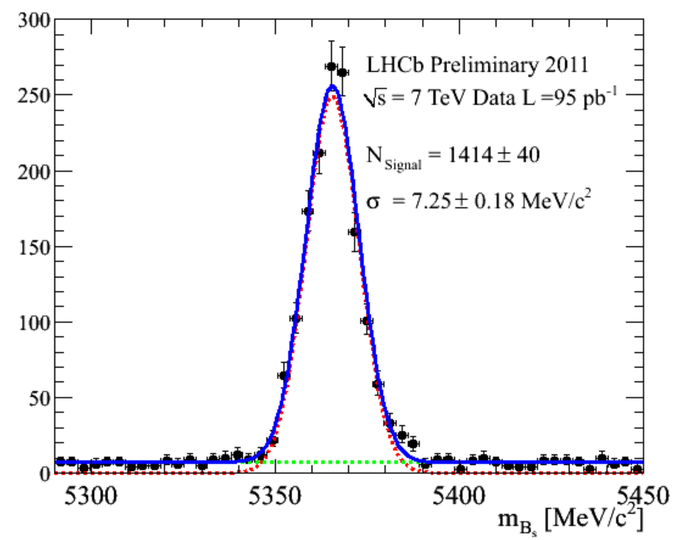
◆Mass measurements

LHCb-CONF-2011-027: masses [MeV/c²]

		LHCb	PDG [MeV/c²]
$M(B^+ \to J/\psi K^+)$	=	$5279.27 \pm 0.11\,(\text{stat}) \pm 0.20\,(\text{syst})$	5279.17 ± 0.29
$M(B^0 \to J/\psi K^{*0})$	=	$5279.54 \pm 0.15\,(\text{stat}) \pm 0.16\,(\text{syst})$	5279.50 ± 0.30
$M(B^0 \to J/\psi K^0_S)$	=	$5279.61 \pm 0.29\,(\text{stat}) \pm 0.20\,(\text{syst})$	5279.50 ± 0.30
$M(B^0_s \to J/\psi \phi)$	=	$5366.60 \pm 0.28\,(\text{stat}) \pm 0.21\,(\text{syst})$	5366.30 ± 0.60
$M(\Lambda_b \to J/\psi \Lambda)$	=	$5619.49 \pm 0.70\,(\text{stat}) \pm 0.19\,(\text{syst})$	5620.2 ± 1.6
$M(B^+_c \to J/\psi \pi^+)$	=	$6268.0 \pm 4.0\,(\text{stat}) \pm 0.6\,(\text{syst})$	6277 ± 6

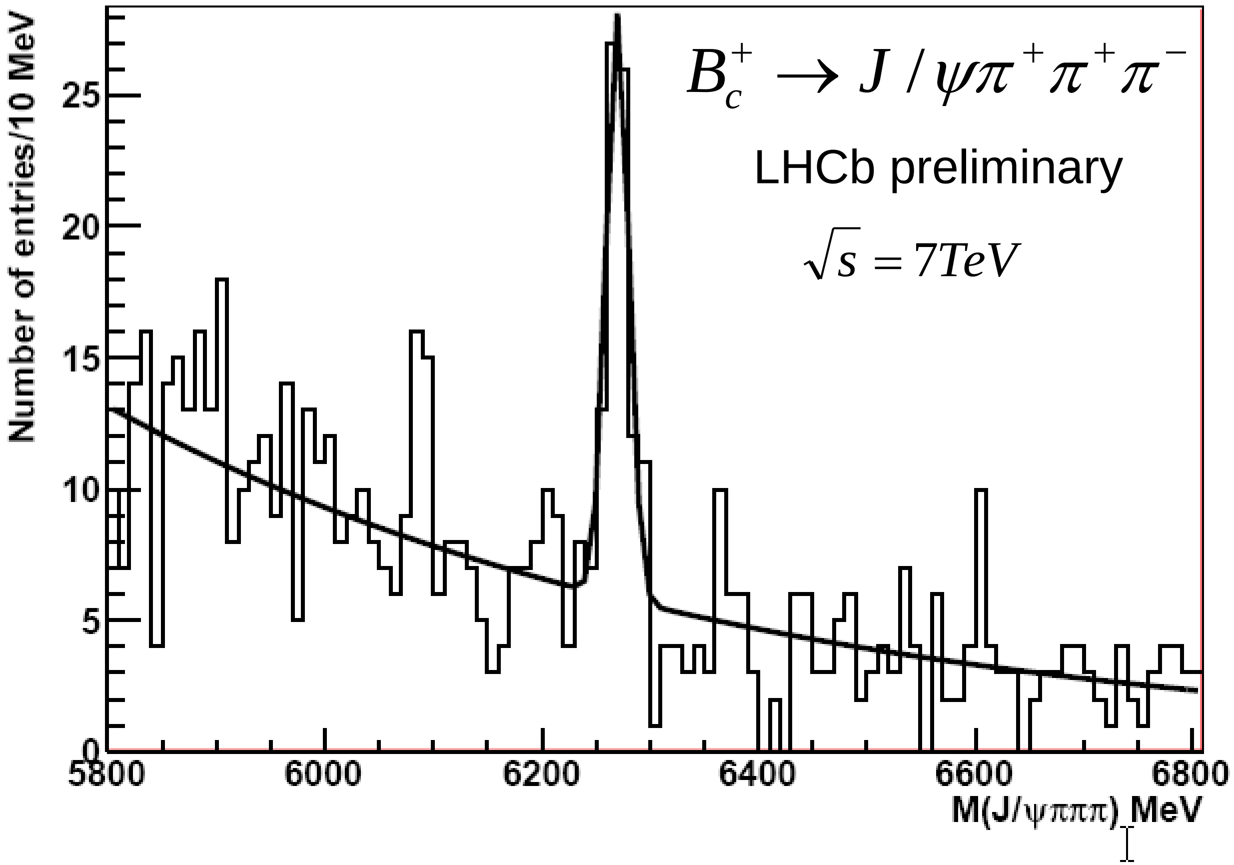
World-best mass measurements!





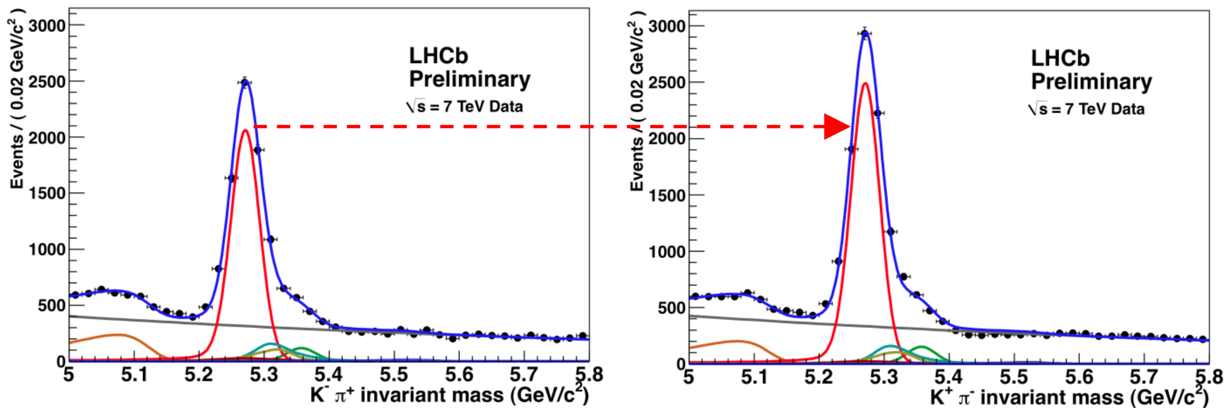
◆New decay modes

- First observation of $B_c^+ \to J/\psi\pi^+\pi^+\pi^-$
- Branching fraction ratio
  - BR($B_c^+ \to J/\psi\pi^+\pi^+\pi^-$)/BR($B_c^+ \to J/\psi\pi^+$) = 3.0 ± 0.6 ± 0.4



CP asymmetries

◆ Raw asymmetries are clear: particle/antiparticle



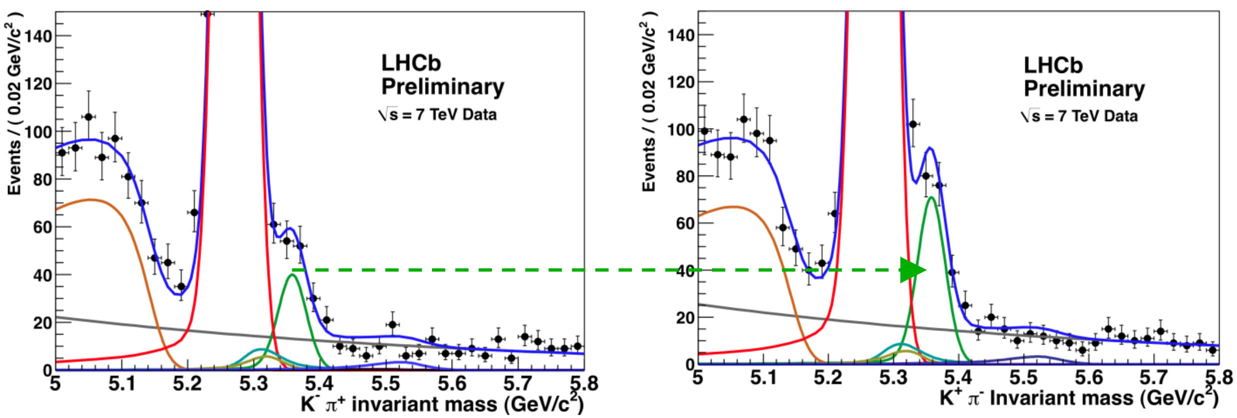
$B^0 \to K^+\pi^-$

$\overline{B}^0 \to K^-\pi^+$

Selection optimized for $A_{CP}(B^0 \to K\pi)$

Asymmetry = -0.095 ± 0.011

B^0



Selection optimized for $A_{CP}(B_S^0 \to \pi K)$

Asymmetry = 0.28 ± 0.08

$B_s^0 \to K^-\pi^+$

$\overline{B}_s^0 \to K^+\pi^-$

B^0_S

Extract physical asymmetries

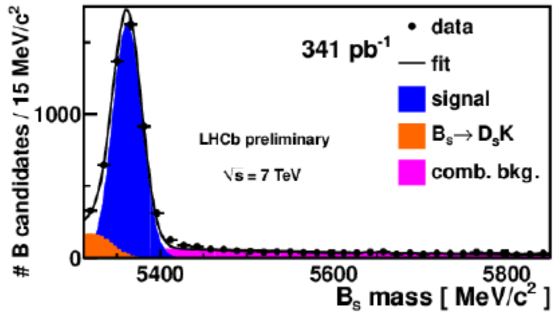
- Use control channels to measure the detector asymmetries
  $D^* \to D^0(K\pi)\pi_s$ $D^* \to D^0(KK)\pi_s$ and untagged $D \to K\pi$
- Production asymmetries measured by $B^0 \to J/\psi(\mu\mu)K_0^*(K\pi)$

Results

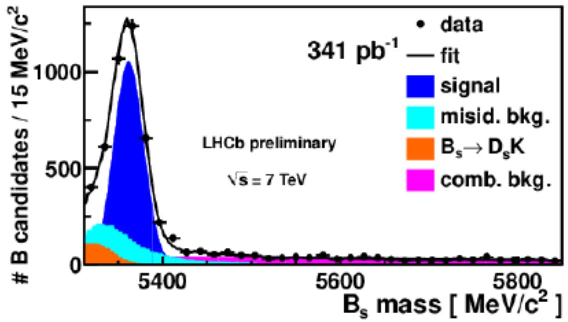
- $A_{CP}(B^0 \to K^+\pi^-) = -0.088 \pm 0.011$ (stat) ± 0.008 (syst)
  - First 5σ measurement of CP violation in the B system in hadron collider
- $A_{CP}(B_S^0 \to \pi^+K^-) = 0.27 \pm 0.08$ (stat) ± 0.02 (syst) (preliminary)
  - First evidence of CP violation in $B_S \to \pi K$

Measurement of Δm_s

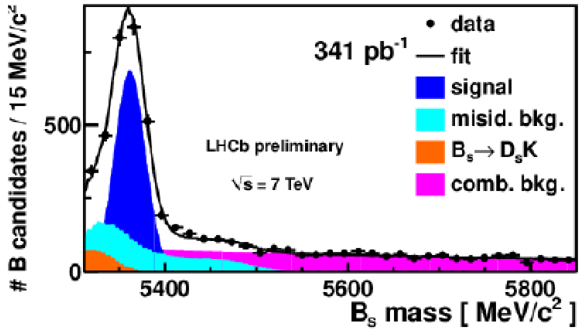
- Δm_s – mixing frequency in B_s using $B_s^0 \to D_s^- \pi$ with 3 different D decay



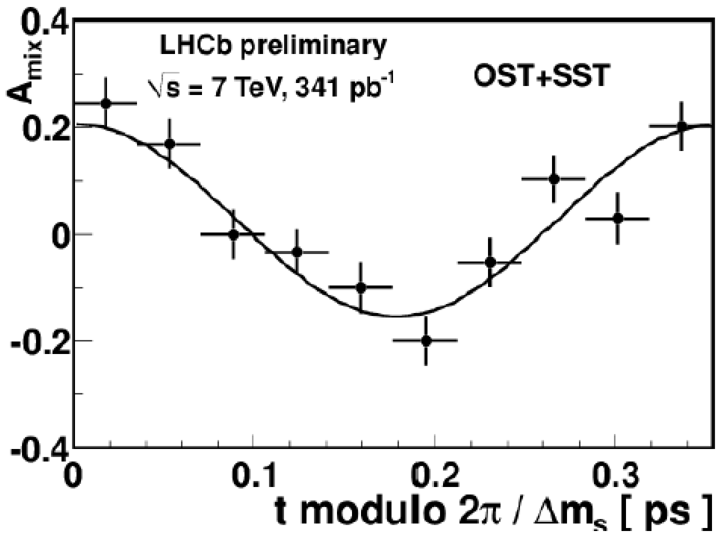
$B_s^0 \to D_s^-(\varphi\pi^-)\pi^+$



$B_s^0 \to D_s^-(K^* K^-)\pi^+$



$B_s^0 \to D_s^-(K^- K^+ \pi^-)\pi^+$

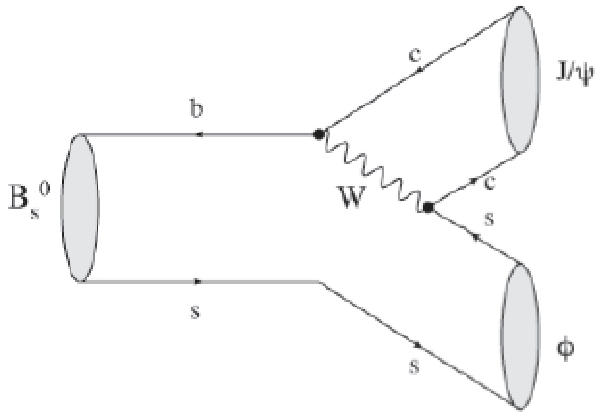


Mixing amplitude

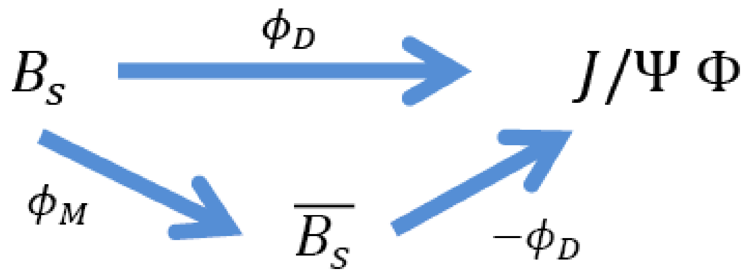
$\Delta m_s = 17.725 \pm 0.041\, stat \pm 0.025\, syst\ ps^{-1}$

φ_s measurement in B_s mixing

- Bs->J/$\Psi\phi$ is dominated by tree diagram. (penguin contribution is in order of 10^{-3}-10^{-4})

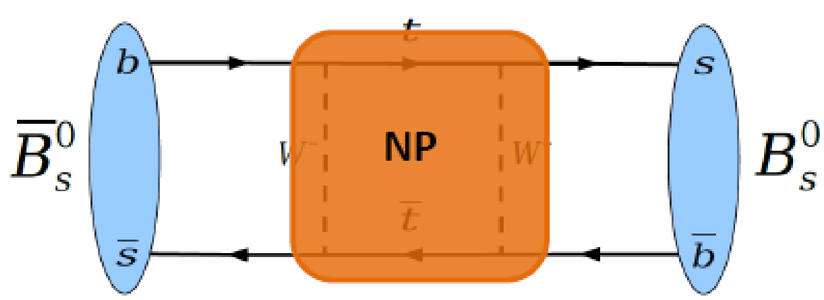


- Interference between direct & mixing decays gives a CP violating phase $\phi_S=\phi_M-2\phi_D$.



- ϕ_S in SM is small and well predicted: $\phi_S=0.0363\pm0.017$ rad
- Good sensitivity for New Physics:

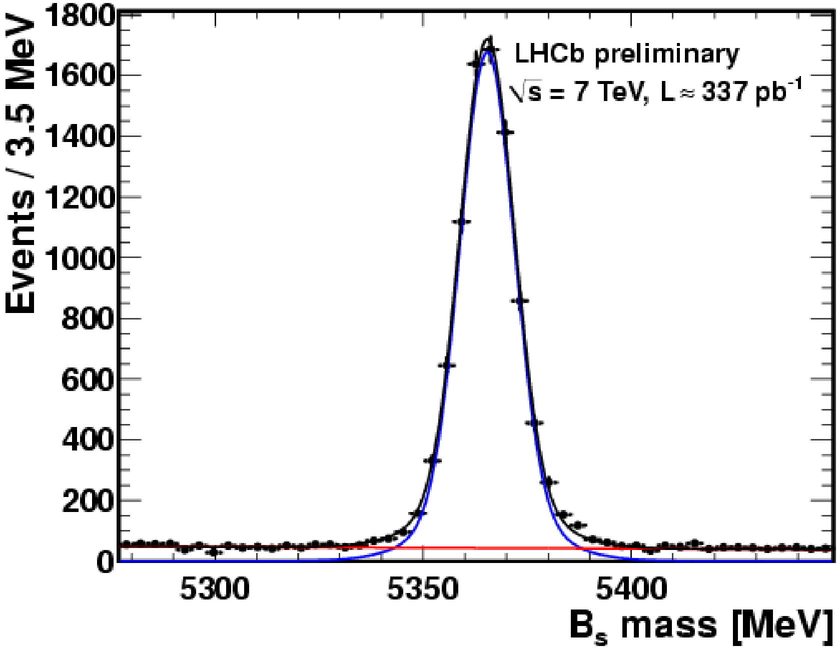
  $\phi_S=\phi_S^{SM}+\phi_S^{NP}$



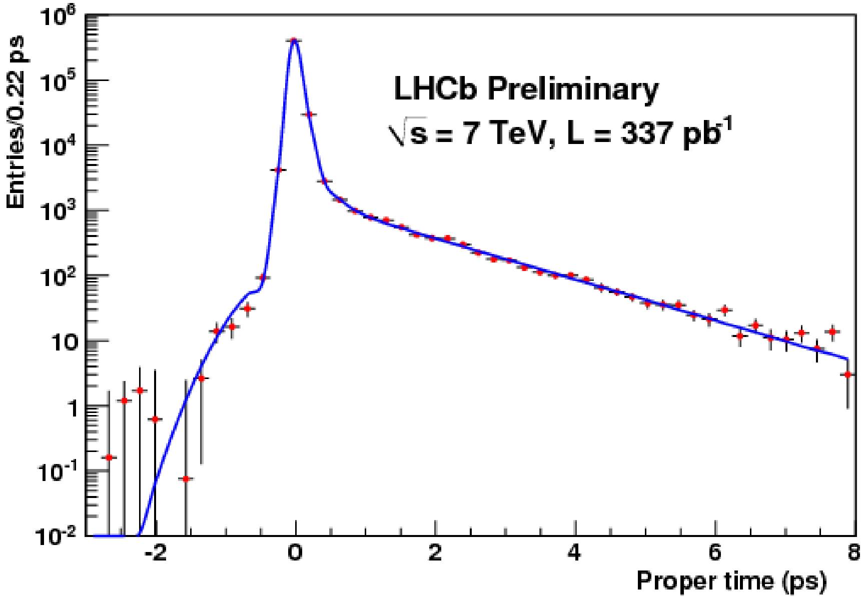
$B_s \to J/\Psi\phi$ signal
Preliminary result with 337 pb^{-1}

data up to end of June 2011
approved by the collaboration last week

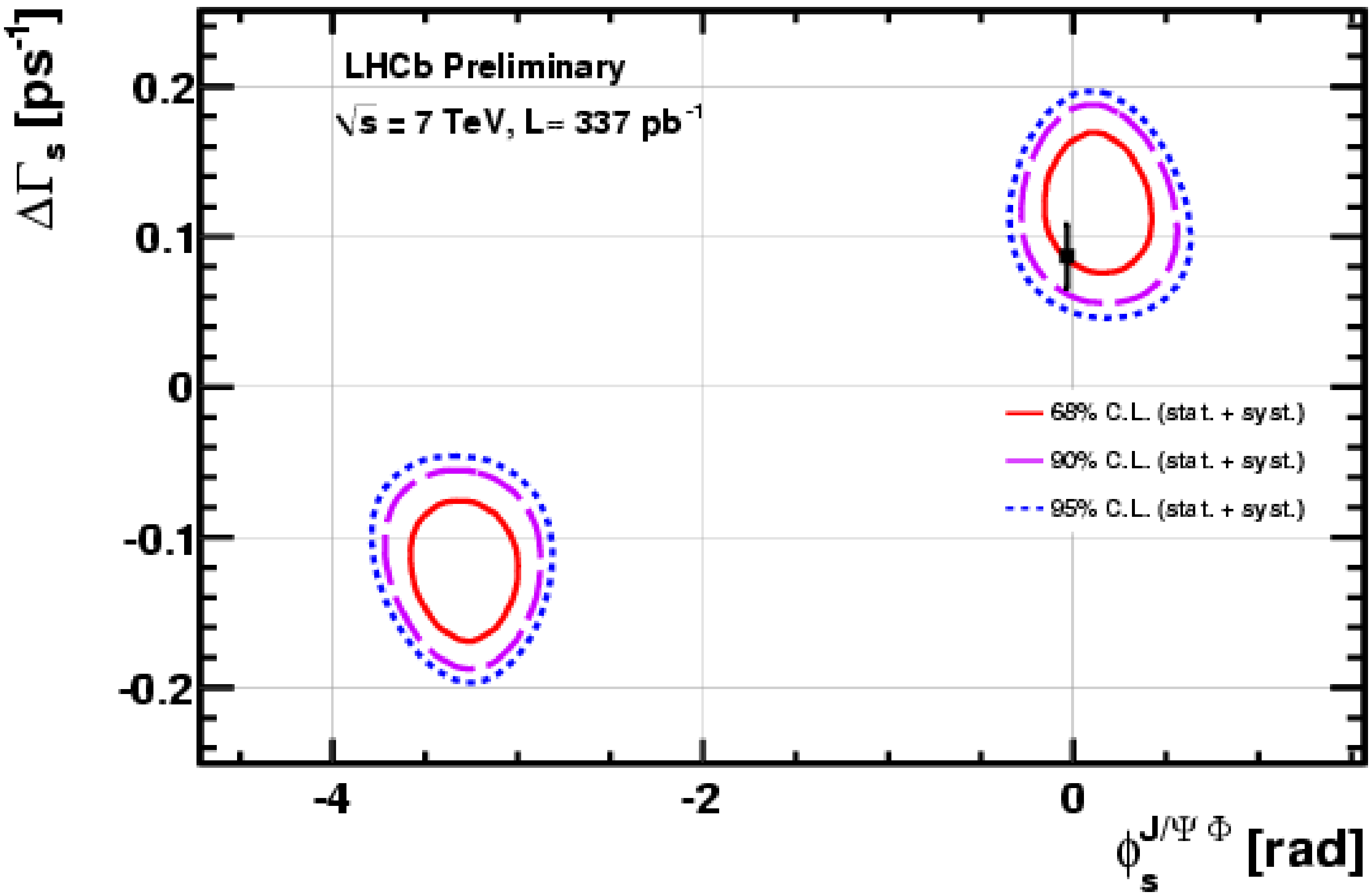
8276 ± 94 signal candidates



Effective time resolution 50 fs



World best result



ϕs = 0.13 ± 0.18 $stat$ ± 0.07 sys rad

$\Delta\Gamma s$ = 0.123 ± 0.029 $stat$ ± 0.008 $sys\ ps^{-1}$

Γs = 0.656 ± 0.009 $stat$ ± 0.008 $sys\ ps^{-1}$

Rare decays: $B_s \to \mu\mu$

- Ultra rare decays
  - FCNC and helicity suppressed
- SM predicts (via box and penguin diagrams):

  $BR(B_s \to \mu\mu) = (3.2 \pm 0.2) \cdot 10^{-9}$

With ~300 pb-1 of LHCb data we expect ~3.2 $B_s \to \mu\mu$ events from Standard Model

CDF reported the observation:

$BR(B_s \to \mu\mu) = (1.8^{+1.1}_{-0.9}) \cdot 10^{-8}$ **arxiv: 1107.2304**

- LHCb presents preliminary result with 300 pb^{-1} LHCb-CONF-2011-037:

$BR(B_s^0 \to \mu\mu) < 1.3\ (1.6) \cdot 10^{-8}$ at 90%(95%)C.L.

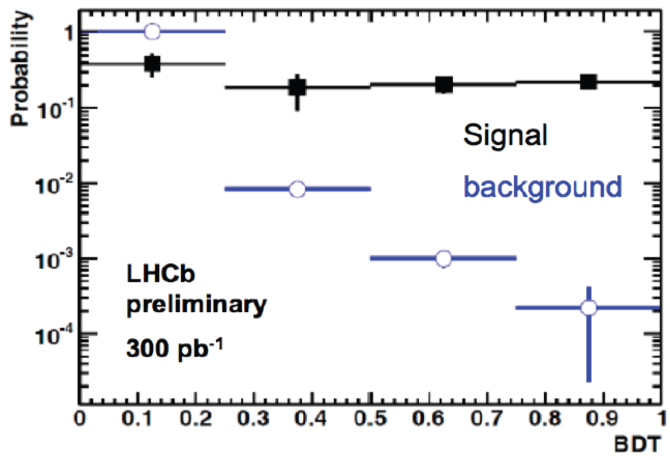
- Combining with preliminary result with 37 pb^{-1} PLB 699(2011) 330

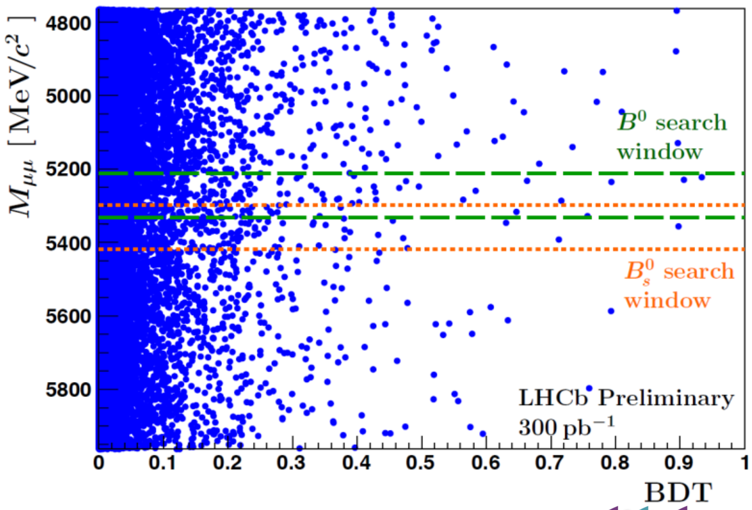
$BR(B_s^0 \to \mu\mu) < 1.2\ (1.5) \cdot 10^{-8}$ at 90%(95%)C.L.

- Combining with CMS observation LHCb-CONF-2011-047:

$BR(B_s^0 \to \mu\mu) < 0.9\ (1.1) \cdot 10^{-8}$ at 90%(95%)C.L.

Excess seen by CDF is not confirmed





Conclusion

- **LHCb is working as expected**
  - The detector performs (almost) as in the simulation
  - Higher instantaneous luminosity
    - 1.5 times the design values, with half the number of bunches
- **World class measurements already obtained**
  - With 2010 data (37 pb^{-1}) and the spring 2011 (300 pb^{-1}) data
    - Already very competitive with B-factories and Tevatron
  - Another 350 pb^{-1} already collected in 2011
    - Hope to reach 1000 pb^{-1} this year
- **Hope to see the sign of New Physics soon!**