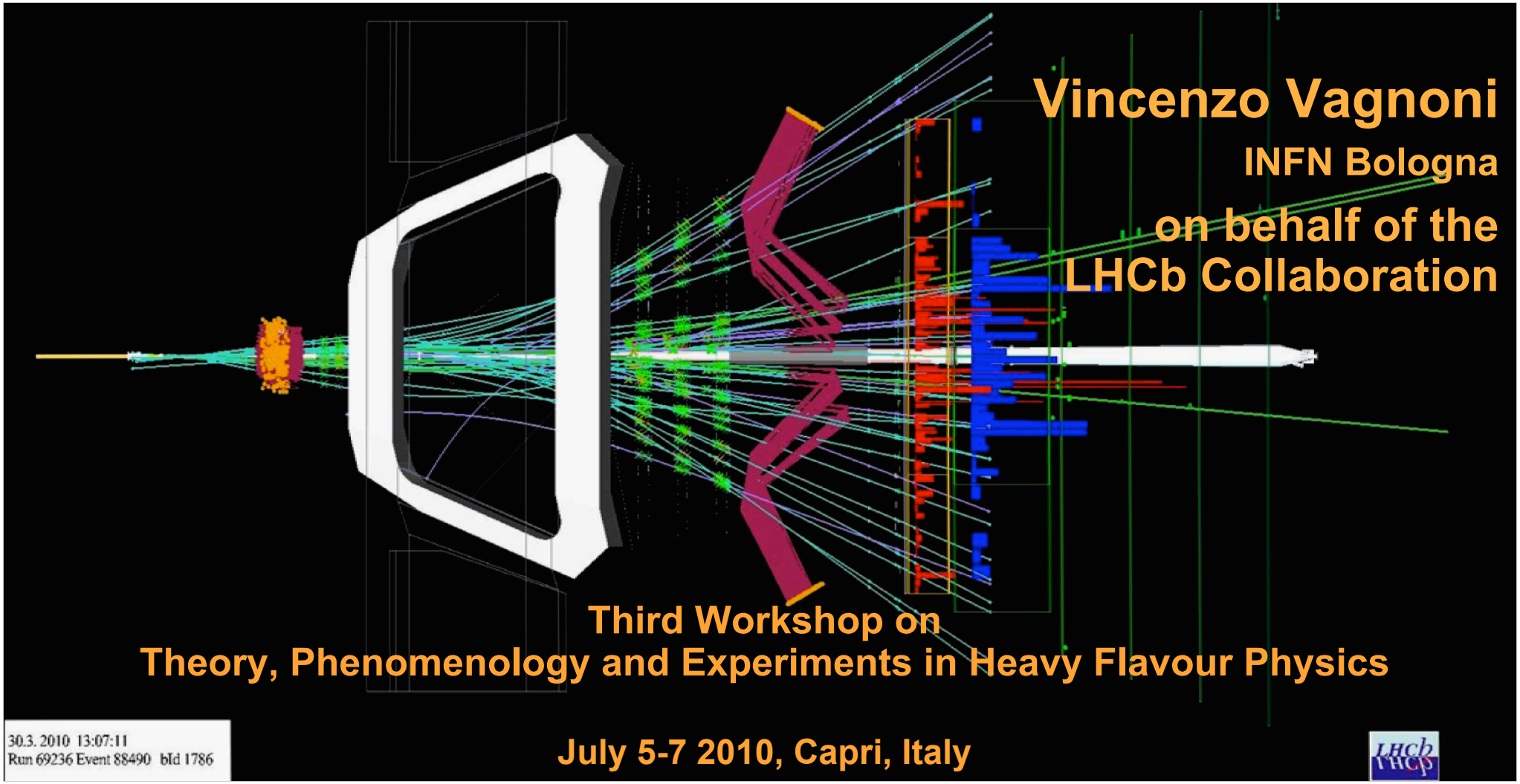
CP Violation at LHCb
Early Results and Prospects



Vincenzo Vagnoni
INFN Bologna
on behalf of the LHCb Collaboration

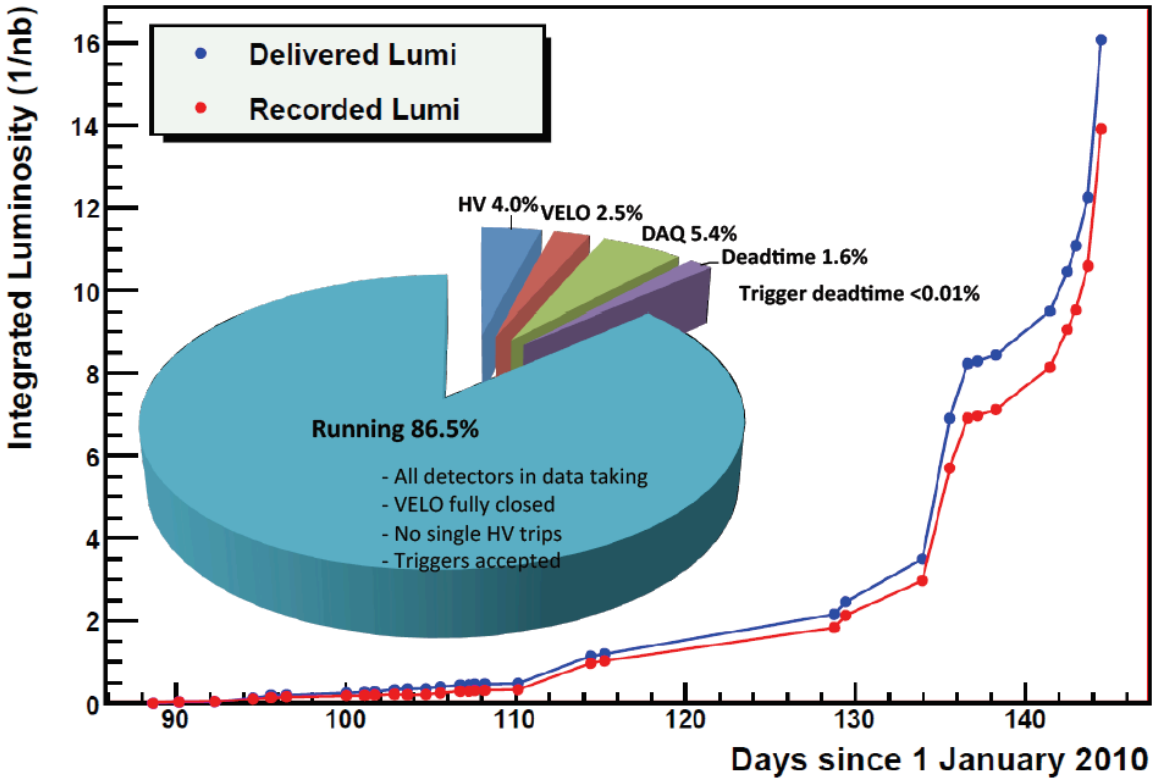
Third Workshop on
Theory, Phenomenology and Experiments in Heavy Flavour Physics

July 5-7 2010, Capri, Italy

The LHCb Collaboration

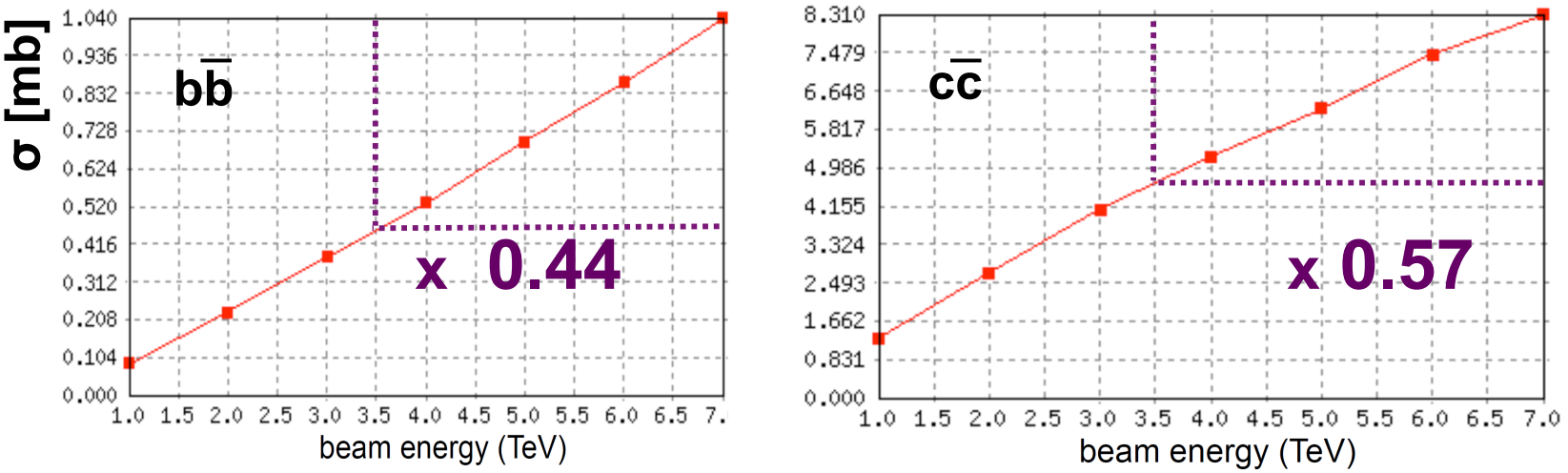
Are we ready for B Physics?

- LHCb started physics run at 7 TeV since March 31st: how far did we go for B Physics?
- Not so far yet, limited integrated luminosity, but
  - Bulk of lumi delivered in a handful of solar days
  - High efficiency of LHCb DAQ
  - Detector and trigger fully operational
- First B candidates showing up
  - It is just matter of how fast the machine will ramp up!



√s=7 TeV only? Don't panic

- **Bottom and charm production cross sections just get a reduction of a factor 0.5 → limited effect on physics reach**
  - **What really matters, instead, is the real value of the beauty production cross section → measure it!**



Scaling with energy predicted by Pythia 6.4

LHCb key features

- **LHCb is a dedicated B physics experiment, though can do charming things as well**
  - **Large beauty production cross section**
    - **Expected in the range 200-500 μb for a c.m.s. energy of 7-14 TeV**
  - **All b-hadron zoology available**
    - **B^+, B^0, B_s, B_c, b-baryons**
- **LHCb acceptance optimised for forward $b\bar{b}$ production → Forward single arm spectrometer $1.9<\eta<4.9$**
  - **b-hadrons produced at low angle**
  - **Correlated $b\bar{b}$-production in same hemisphere**

LHCb luminosity outlook

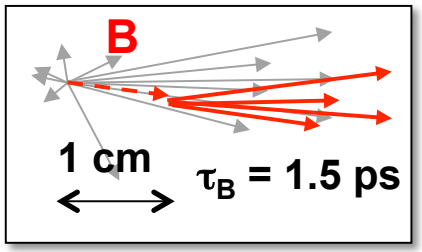
- **Instantaneous lumi at IP8 intentionally moderated to $2x10^{32}$ $cm^{-1}s^{-2}$ (design value) in order to limit the number of multiple interactions per bunch crossing**
  - **$2x10^{32}$ is not a magic number → optimal running conditions could be even reached with somewhat higher lumi**
  - **Nominal LHCb year → L=2 fb^{-1}**
    - **10^{12} $b\bar{b}$ pairs at 14 TeV in 4π**
- **In 2010 a first phase with a reduced number of bunches**
  - **LHC could not exceed a lumi around $10^{31}cm^{-2}s^{-1}$**
- **Luminosity now rapidly increasing, although with still few bunches**
  - **Many interactions per crossing → not ideal conditions, but still manageable**
- **Don't have a crystall ball, but the programme is to collect 200 pb^{-1} in 2010 and 1 fb^{-1} in 2011**

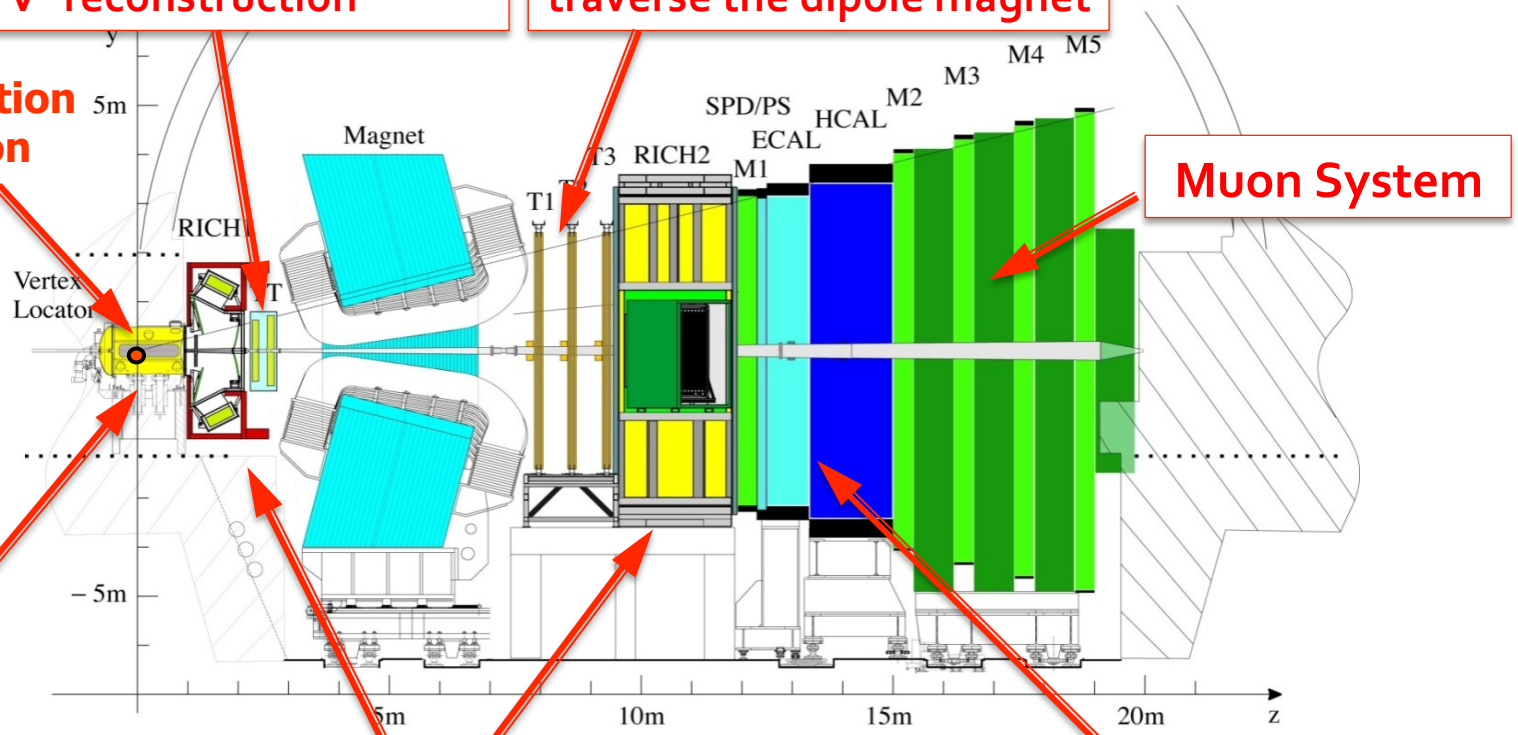
LHCb Detector

Tracking Station: p for lower energy tracks and long lived V° reconstruction

Tracking Stations: p of charged particles that traverse the dipole magnet

Interaction region





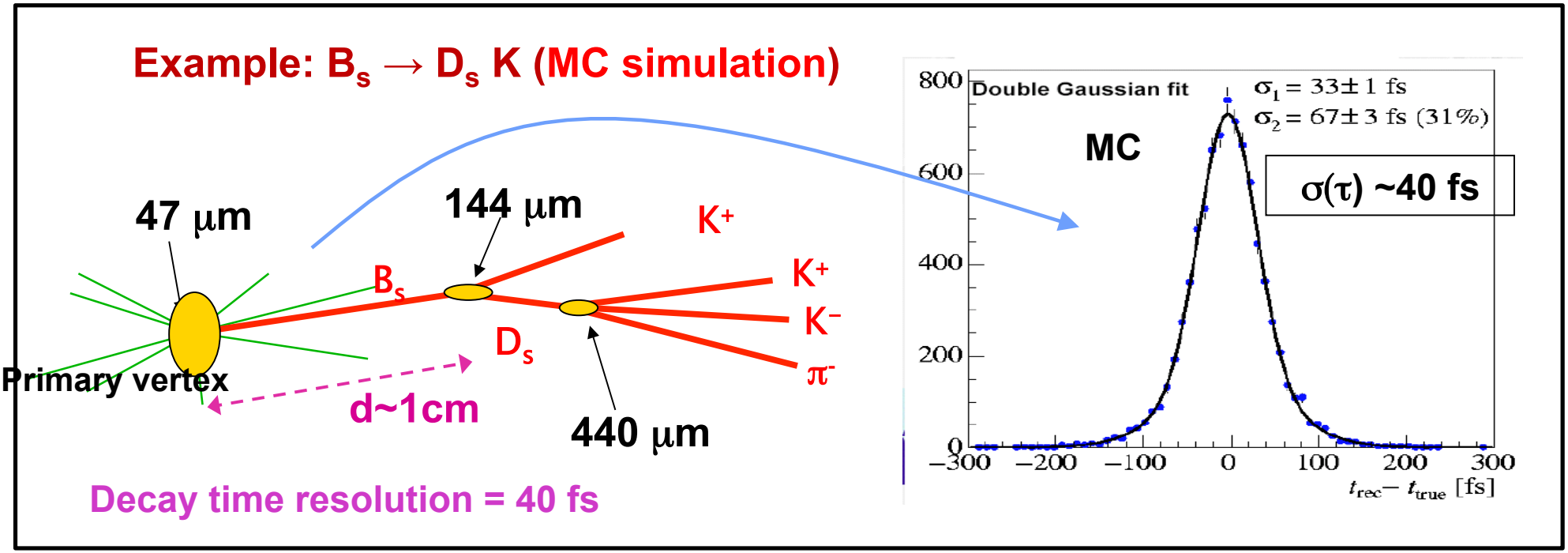
Muon System

VELO:
primary vertex
impact parameter
displaced vertex

RICH:
p, K, π discrimination

Calorimeter Systems:
PID: h, e, γ, π°

Vertexing is crucial for trigger and offline selection

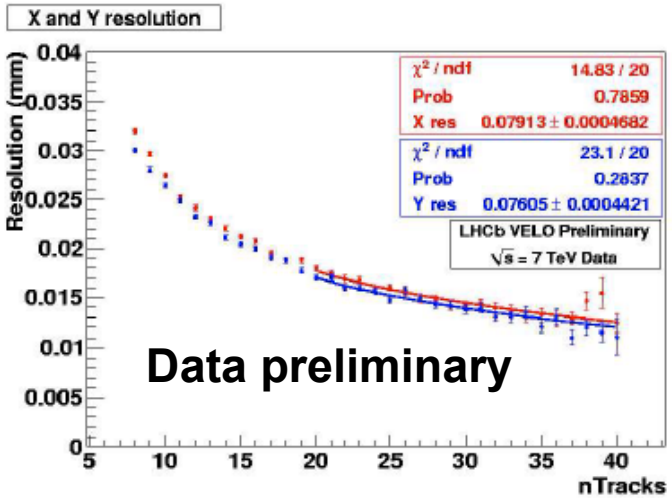


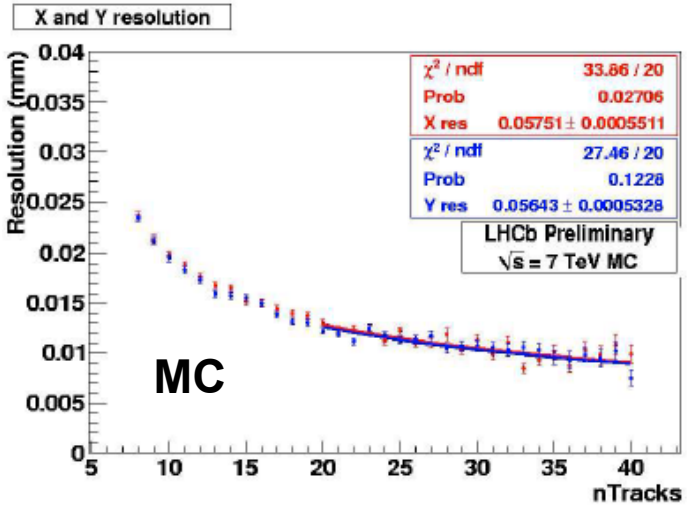
Trigger on impact parameter

Measurement of decay distance (and then proper decay time)

Resolution on primary vertex

- **Primary Vertex (PV) is determined by fitting to a common vertex all the track segments reconstructed in the vertex detector**
  - **Still about 40% difference between data and MC, but rapidly improving**





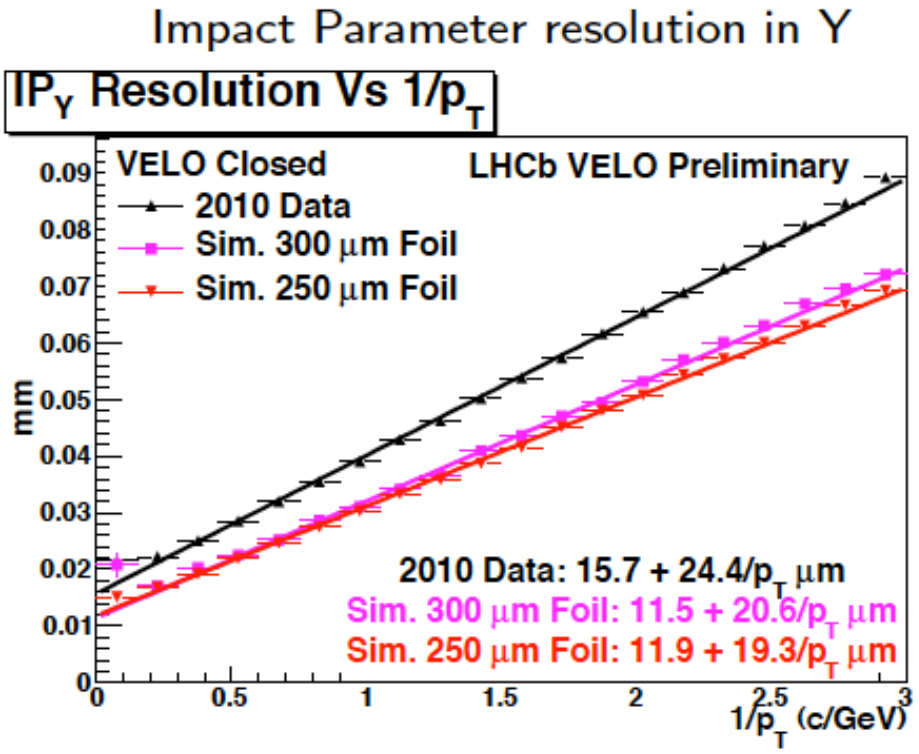
	MC	Data
$\Delta x(\mu m)$	11.5	15.8
$\Delta y(\mu m)$	11.3	15.2
$\Delta z(\mu m)$	57	91

Average resolutions for n. tracks = 25

X and Y resolutions as a function of the number of tracks forming the vertex

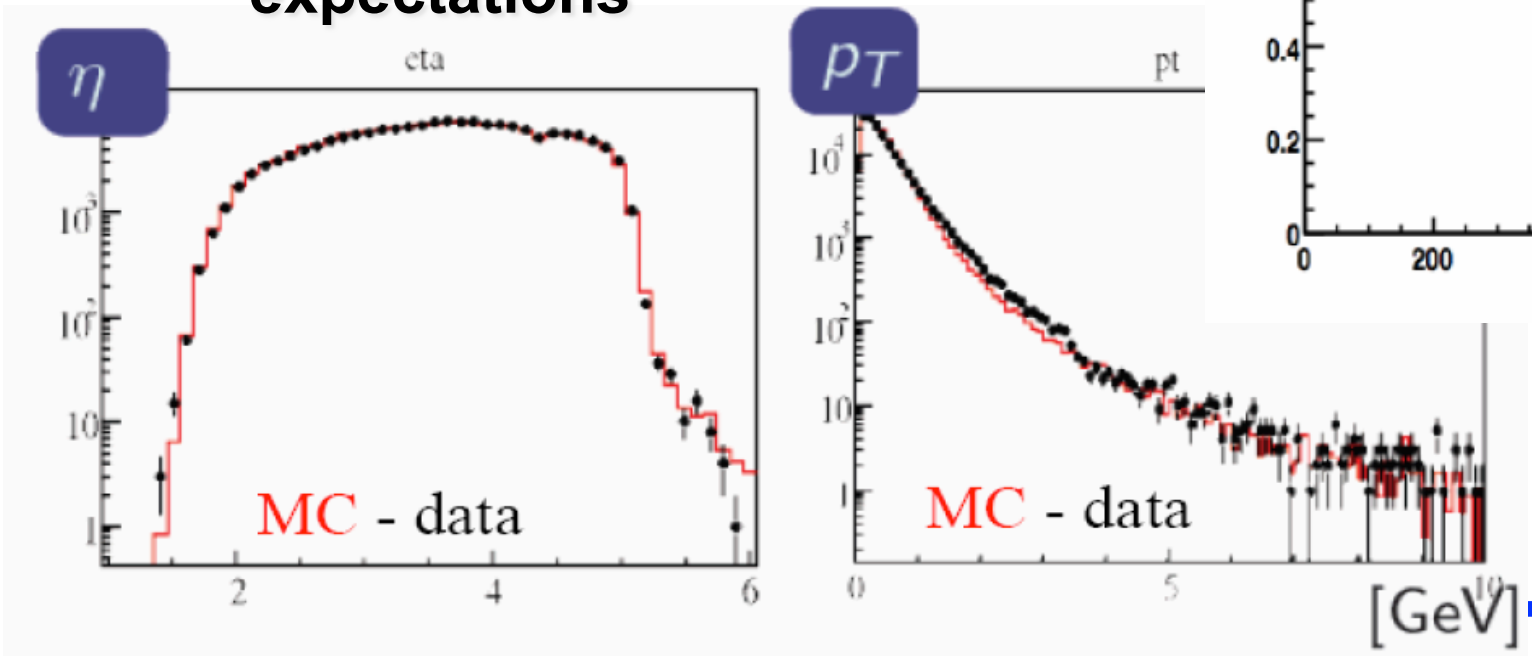
Resolution on impact parameters

- **Impact parameter (IP)**
  - Closest approach of a track to a primary vertex
- **IP resolution is mainly due to**
  - Multiple scattering in the detector material and beam pipe
  - VELO misalignments and hit resolutions.
- **15-40% discrepancy between MC and data**
  - Not dramatic, but lot of work going on to understand and fix some residual effects

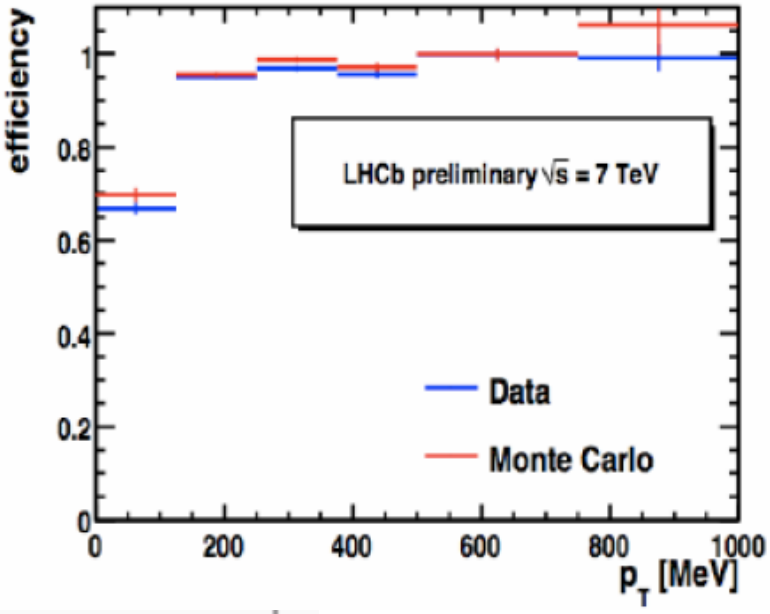


Tracking efficiency in data and MC

- **Good agreement between data and MC for track inclusive distributions and efficiency**
  - **Overall performances close to expectations**

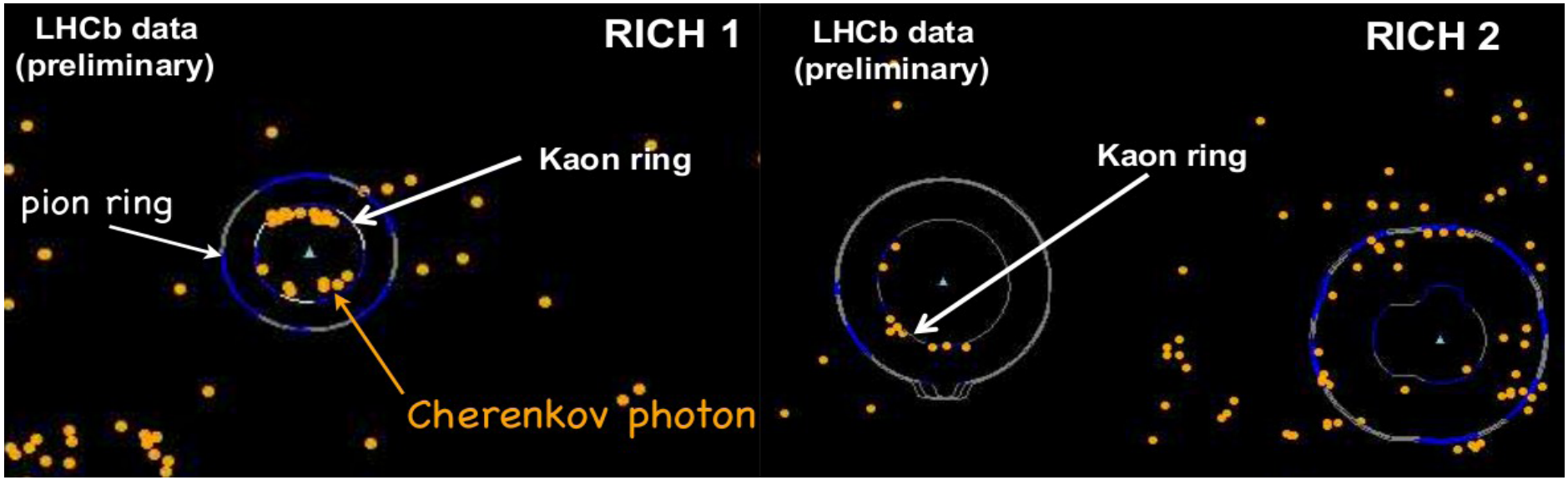


Tracking efficiency vs p_T



Hadronic Particle Identification

- RICH aligned with tracking system
- K and π rings clearly visible

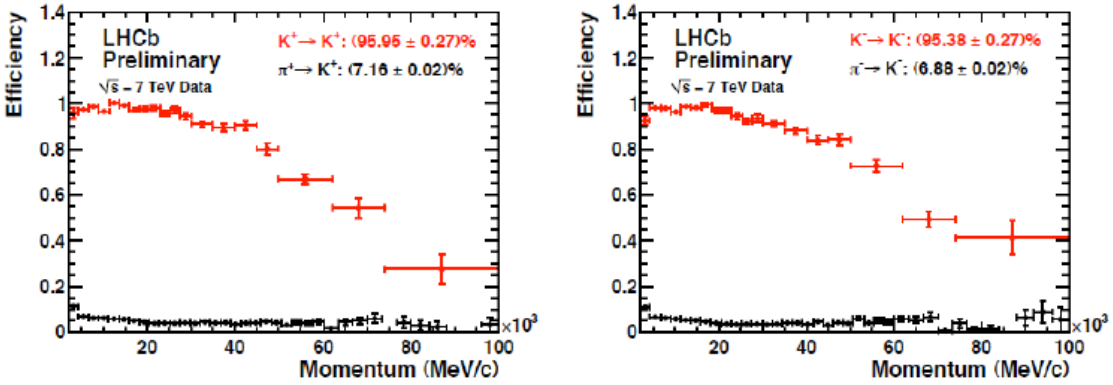


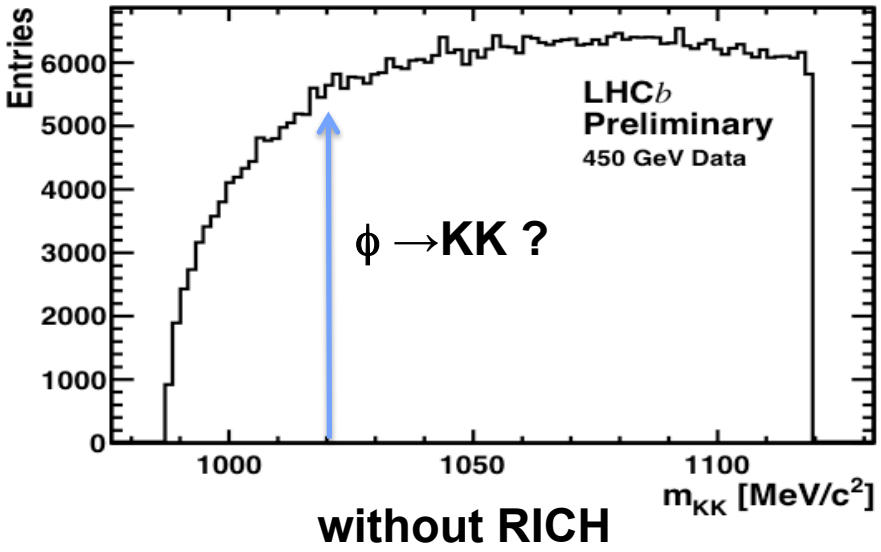
Calorimeter and Muon ID in Ulrik's talk

RICH PID

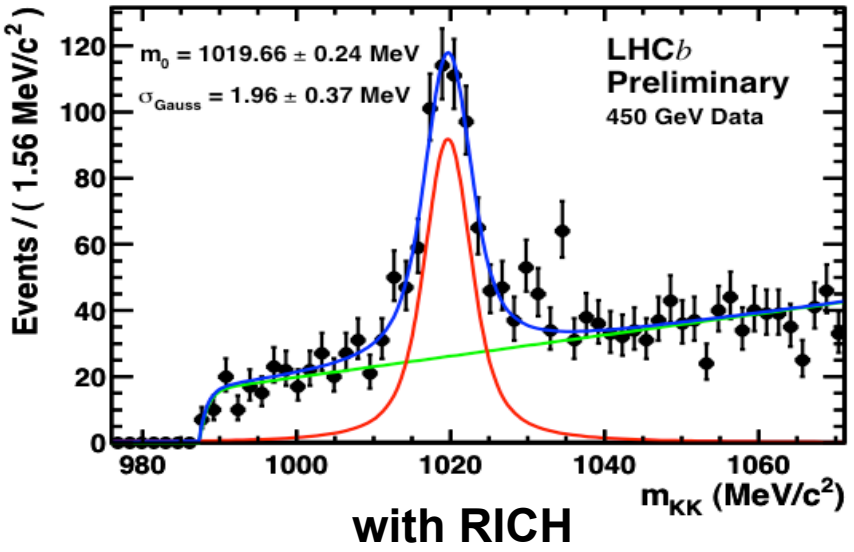
- **Alignment and calibration work ongoing**
  - Angular resolutions close to expectations
- **Efficiencies and misidentification rates will be calibrated with real data (K_S, Λ, ϕ and D*)**

Efficiency and misid rate vs momentum for charged Kaons





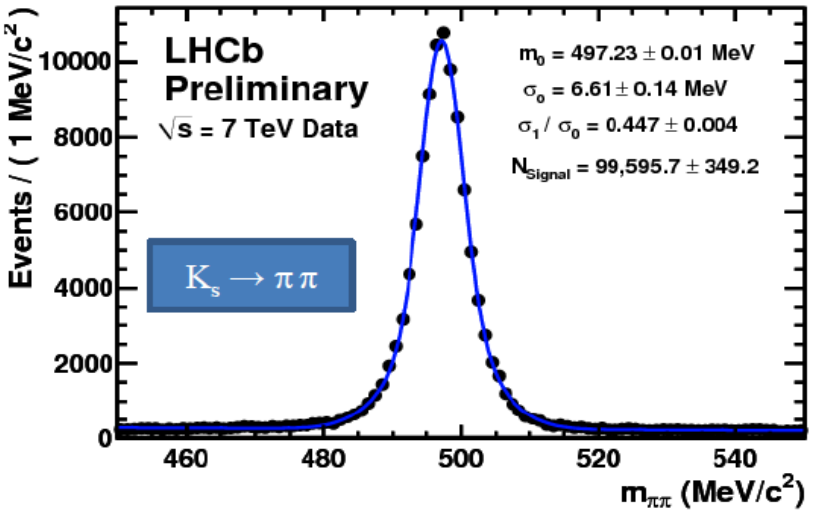
without RICH

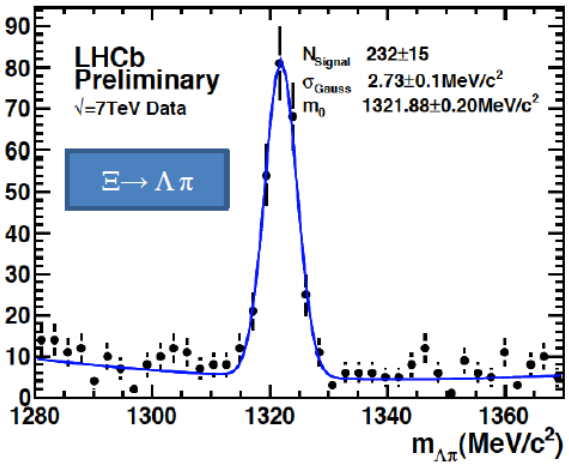


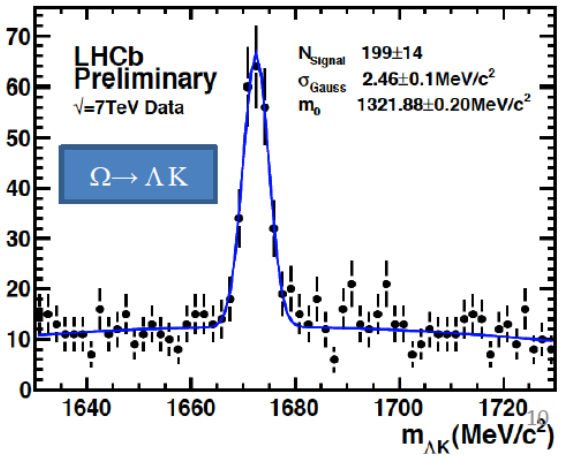
with RICH

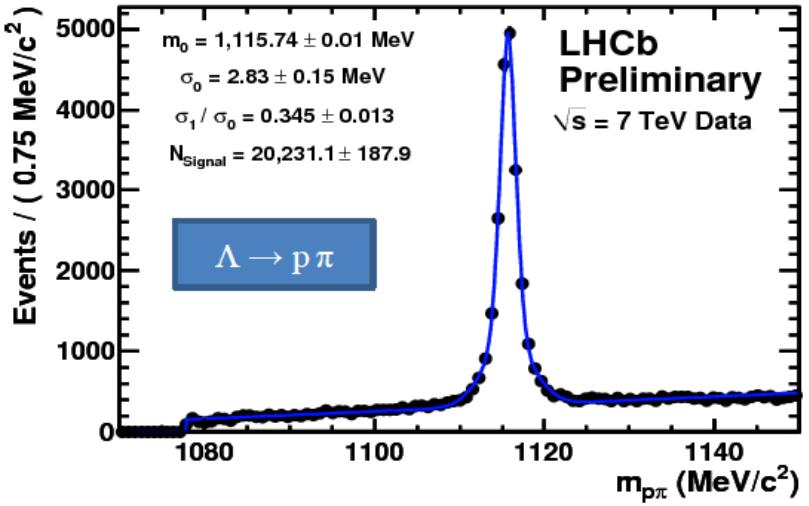
V^0 decays

- **Significant samples of long lived strange particles starting to be available**
  - **Long life allows selection of pure samples without need of PID observables → samples are to a large extent PID unbiased and can be used for calibrating RICH system response**





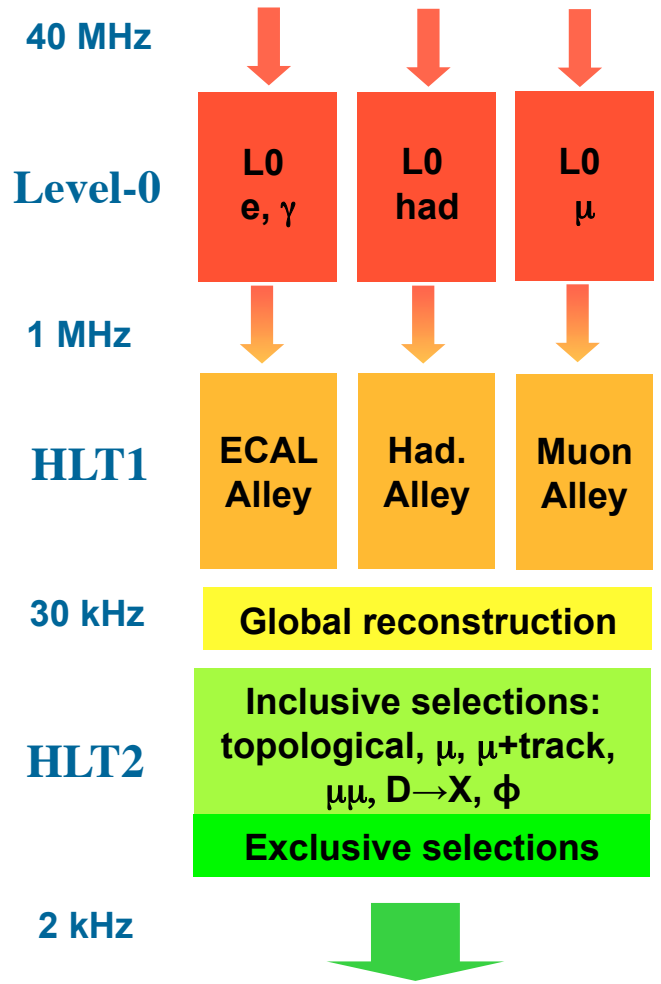




LHCb trigger design

- **Using design luminosity the trigger is optimized for B physics**
- **But, low luminosity in 2010…**
  - **some 10^{31} $cm^{-2}s^{-1}$**
  - **trigger thresholds can be relaxed → large gain in D efficiency → good year for charm physics!**

	charm	had. B	Lep. B
Nominal lumi	10%	40%	90%
Low lumi (2010)	50%	80%	>90%



Large transverse energy and momentum in calorimeter and muon systems

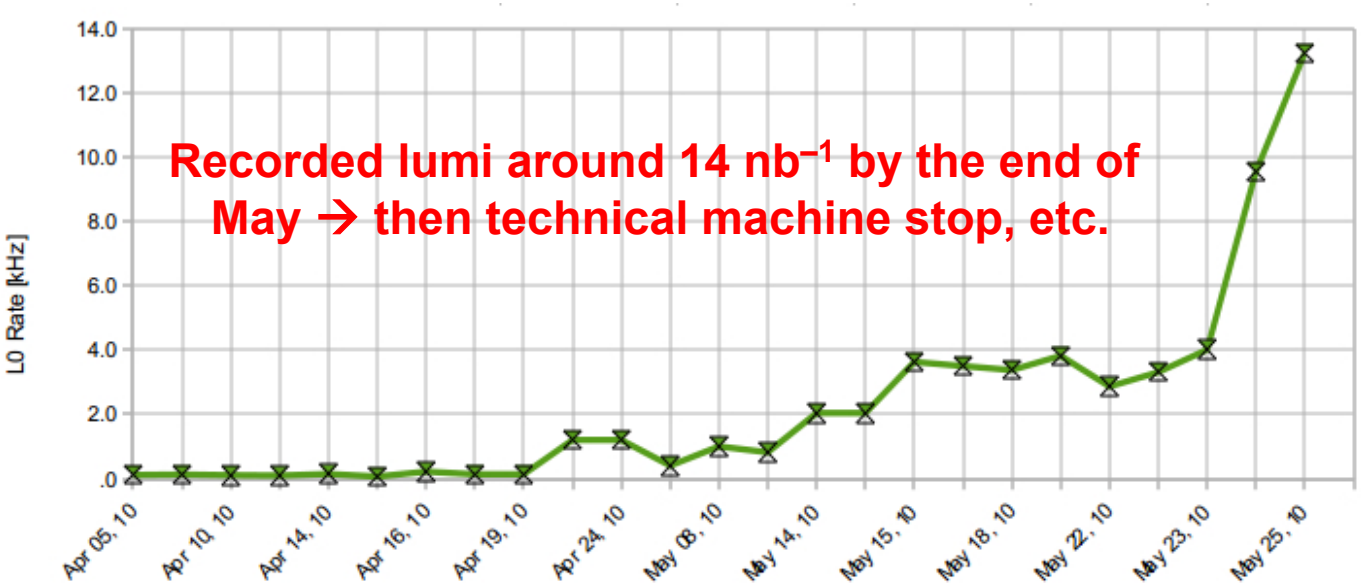
Associate Level-0 signals with tracks, especially those in VELO displaced from Primary Vertex

Full detector info available for inclusive and exclusive selections

Trigger startup in this early phase

Interaction rate	L0 output rate	HLT1 output rate	HLT2 output rate
Up to 2 kHz	Up to 2 kHz		
Up to 25 kHz	Up to 25 kHz	2 kHz	
Up to 300 kHz	Up to 300 kHz	10 kHz	2 kHz

- **L0 always passing through so far**
  - **minimum bias and random triggers**
- **Couple of weeks of HLT1 exercising real rejection**
- **During summer expect 2 months of continuous running**
  - **Lot of stat. expected**



LHCb B physics programme Main Items

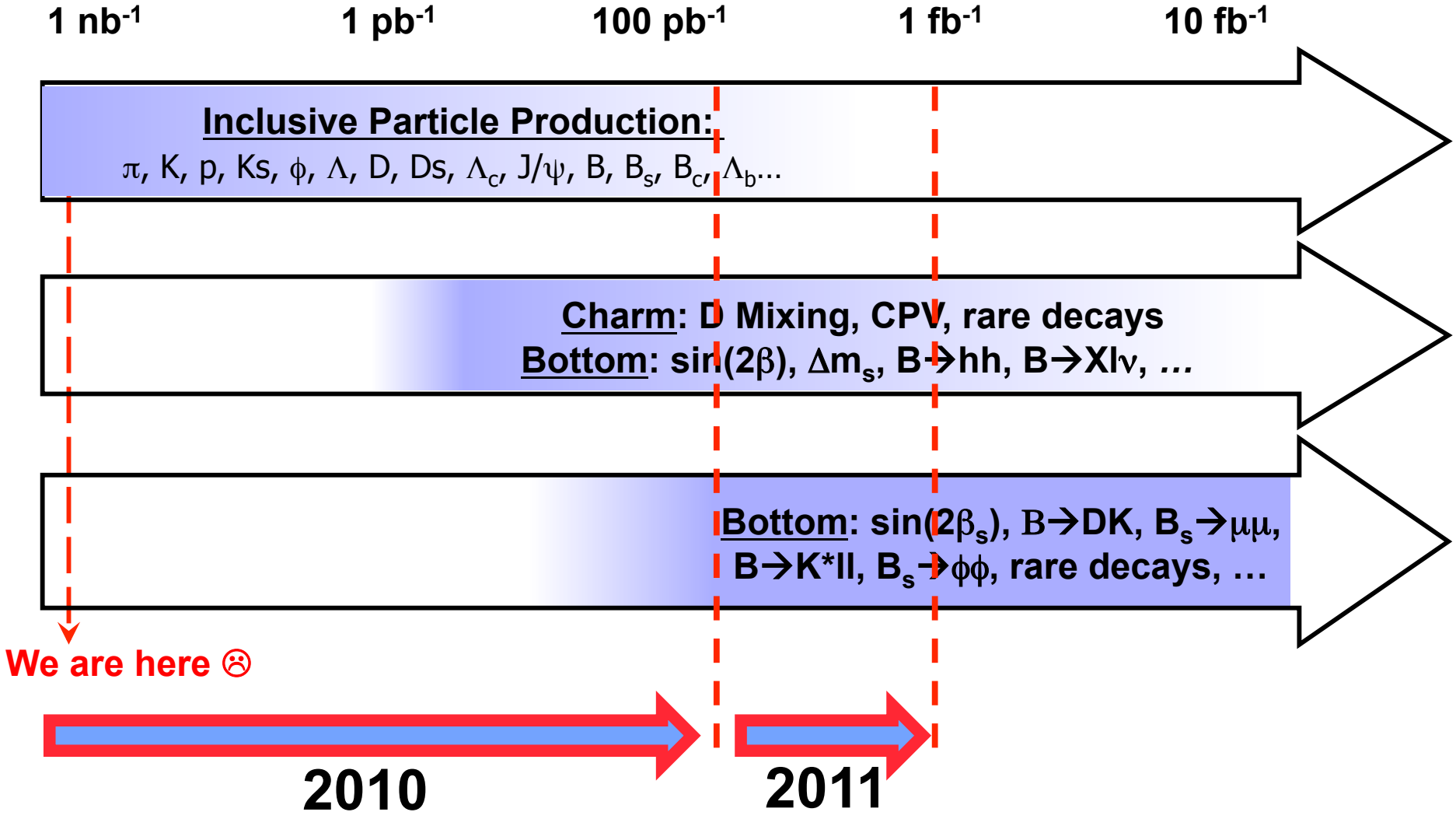
Selected key measurements

- Search for $B_s \to \mu\mu$
- Mixing-induced CP violation in $B_s \to J/\psi\phi$, $B_s \to \phi\phi$, ...
- Charmless 2-body B decays
- CKM angle γ from tree-level B decays
- $B_s \to \phi\gamma$ and other radiative B decays
- Asymmetries in $B^0 \to K^* l^+ l^-$ decays

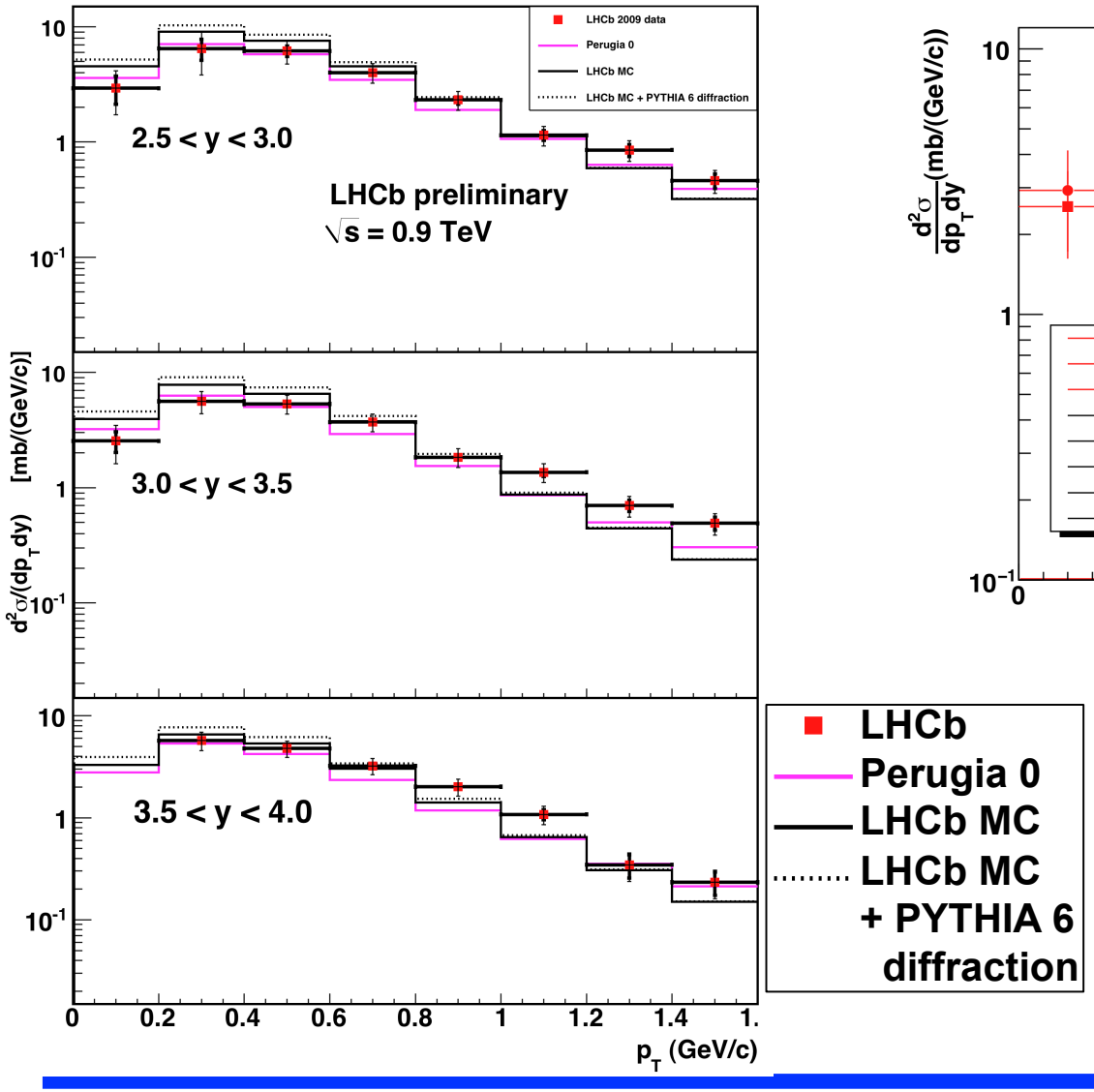
Roadmap note

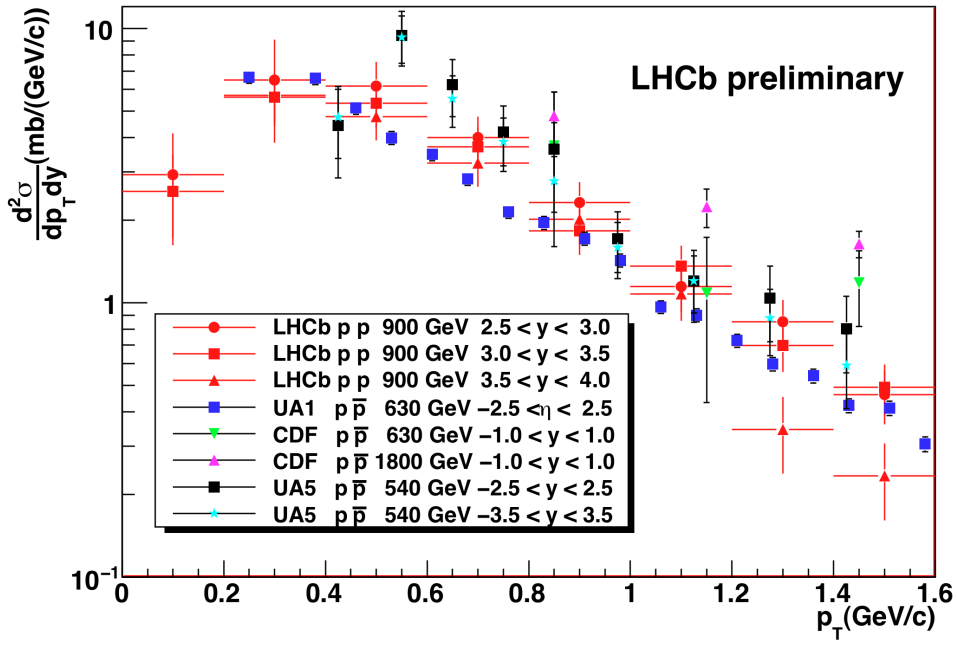
- LHCb-PUB-2009-029, arXiv:0912.4179v2 [hep-ex], Feb 2010
- Nominal assumptions there:
  - 2 fb^{-1} per year at 25 ns bunch spacing
  - $\sqrt{s}$ = 14 TeV
  - Beauty production cross section 500 μb

2010-2011 physics roadmap



Prompt K_S production (2009)

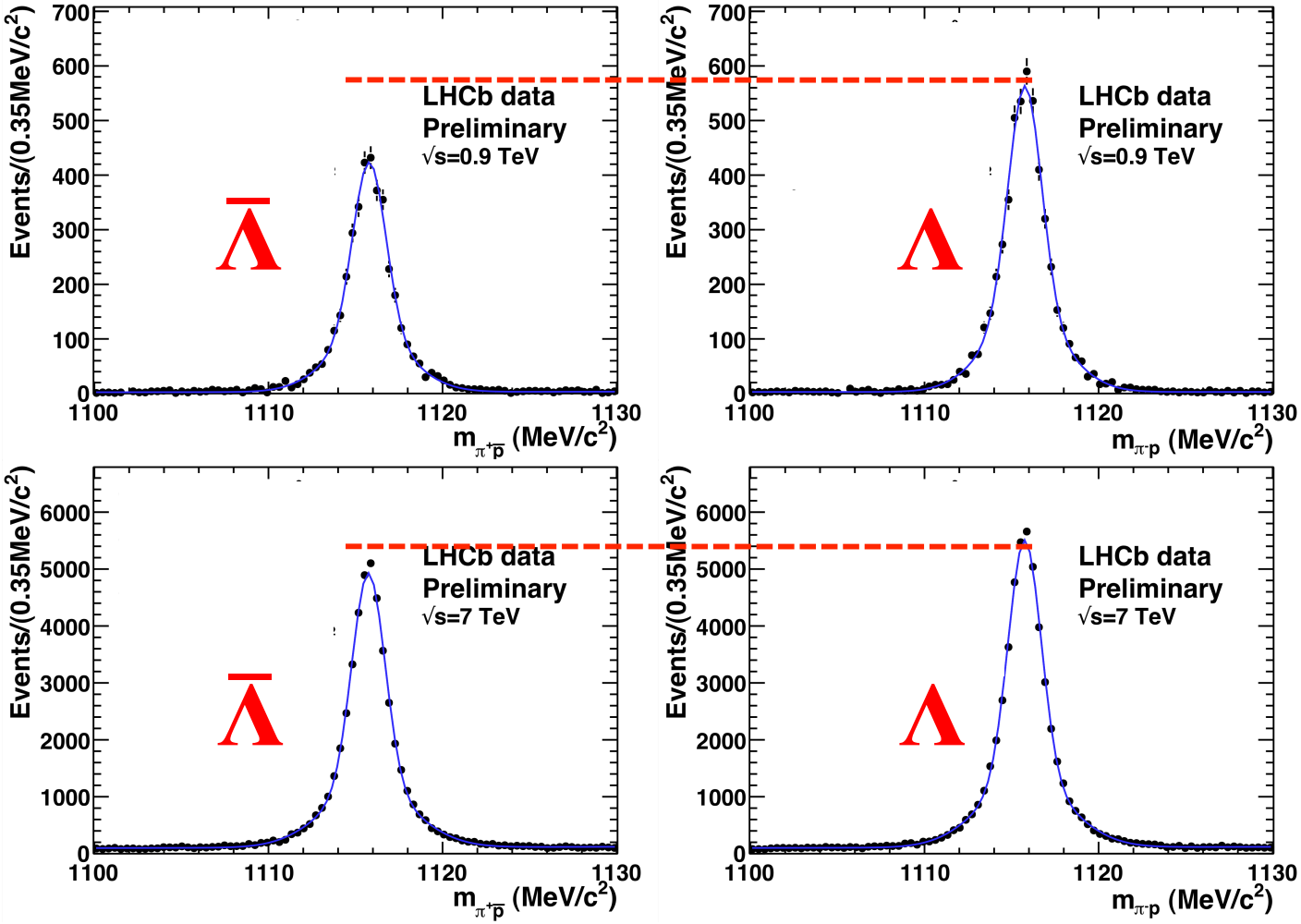




- Using 2009 data (0.9 TeV)
- Reconstruct $K_S \rightarrow \pi^+\pi^-$ pointing back to primary vertex in bins of p_T and rapidity
  - First pp results at this energy

Prompt Λ and $\bar{\Lambda}$ production

- $\sqrt{s}$ = 0.9 TeV
  - VELO "half closed" (10mm)
- $\sqrt{s}$ = 7 TeV
  - VELO closed

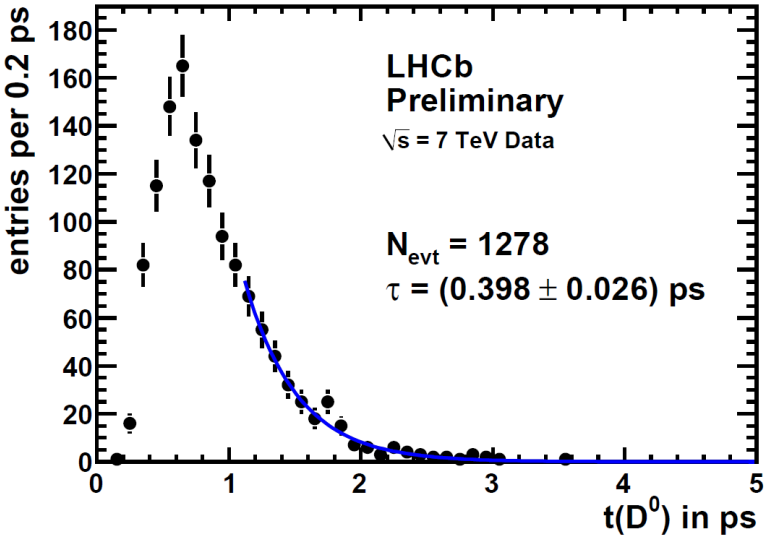


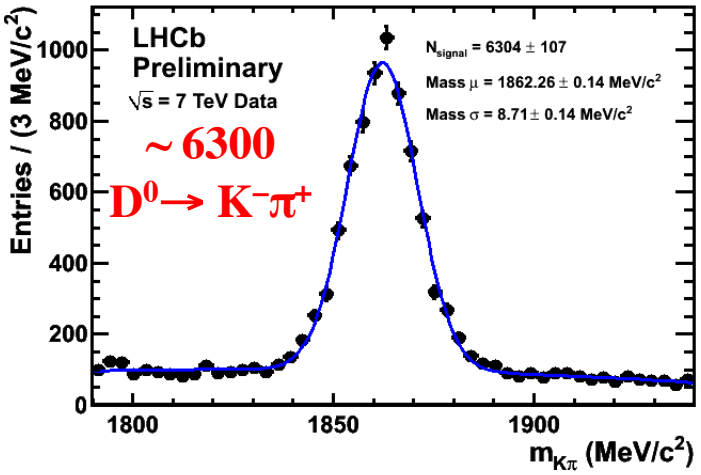
- no PID used: $\Lambda/\bar{\Lambda}$ separated on Armenteros-Podolansky plot

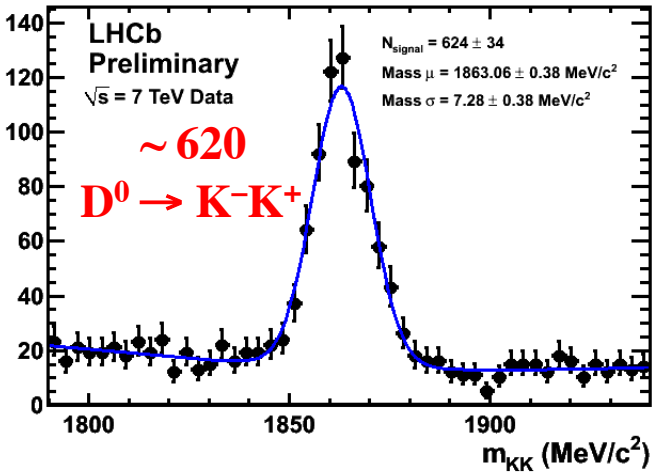
First clean heavy flavour signals available (not yet B eh!)

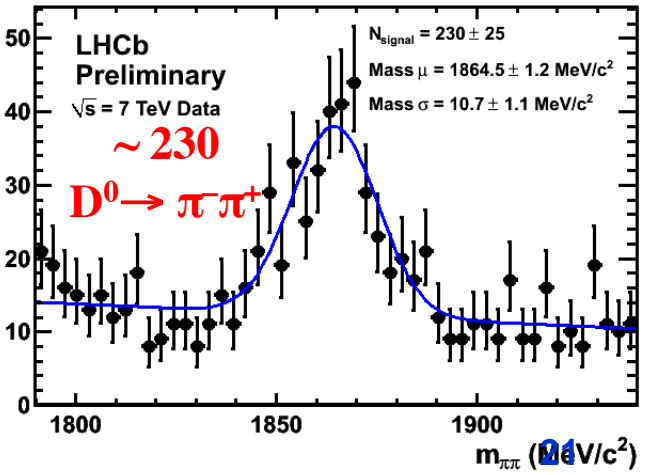
in ~ 2.7 nb^{-1}

- Clean sample of $D^0 \to h^+h^-$
- Simple check: measurement of D^0 lifetime
  - Use pure $D^0 \to K^-\pi^+$ selection (S/B ~ 22)
  - Simple minded approach for the moment
    - Fit only the tail of the proper time distribution, where efficiency is constant
    - $\tau(D^0) = 0.398 \pm 0.026$ ps (stat. only)
    - Good agreement with PDG: 0.4101 ± 0.0015 ps



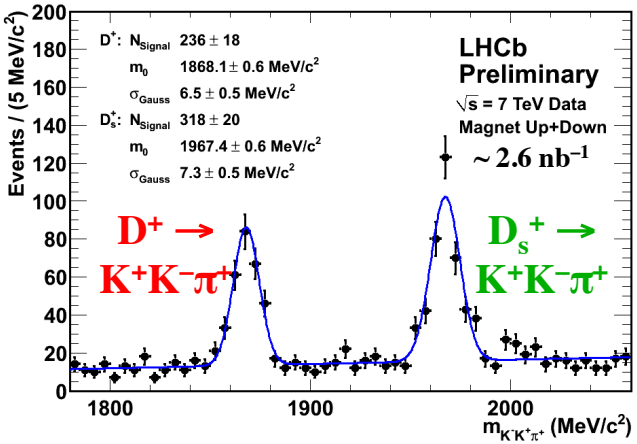


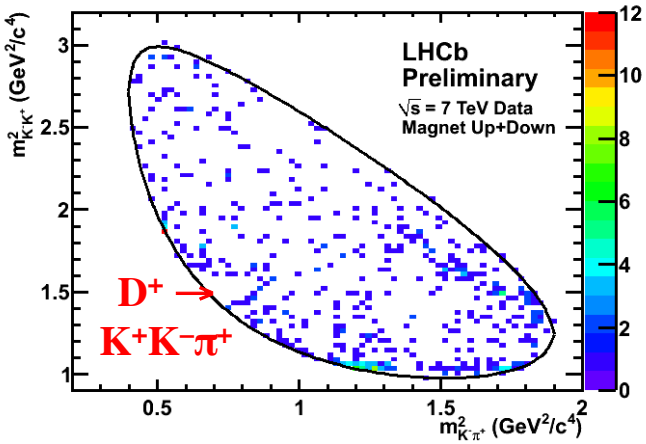


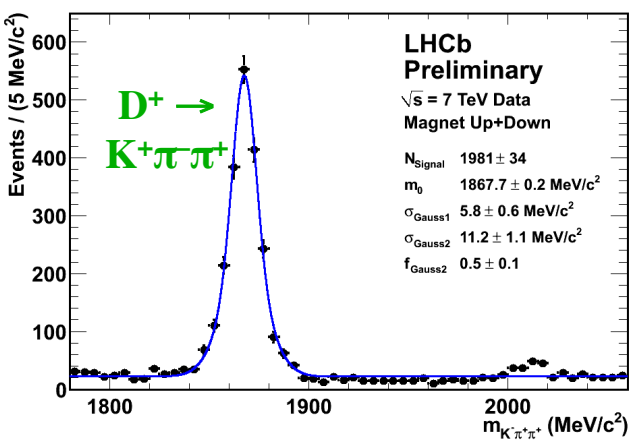


Direct CP violation studies in the charm sector

- **Relevant modes**
  - Singly Cabibbo-suppressed decays, where NP may enter in gluonic Penguin
  - 3-body decays with Dalitz plot analyses
- **$D^+ \to K^+K^-\pi^+$ is an excellent mode**
  - With also the good feature of having Cabibbo-favoured $D_s^+ \to K^+K^-\pi^+$ and $D^+ \to K^+\pi^-\pi^+$ decays to be used as control channels

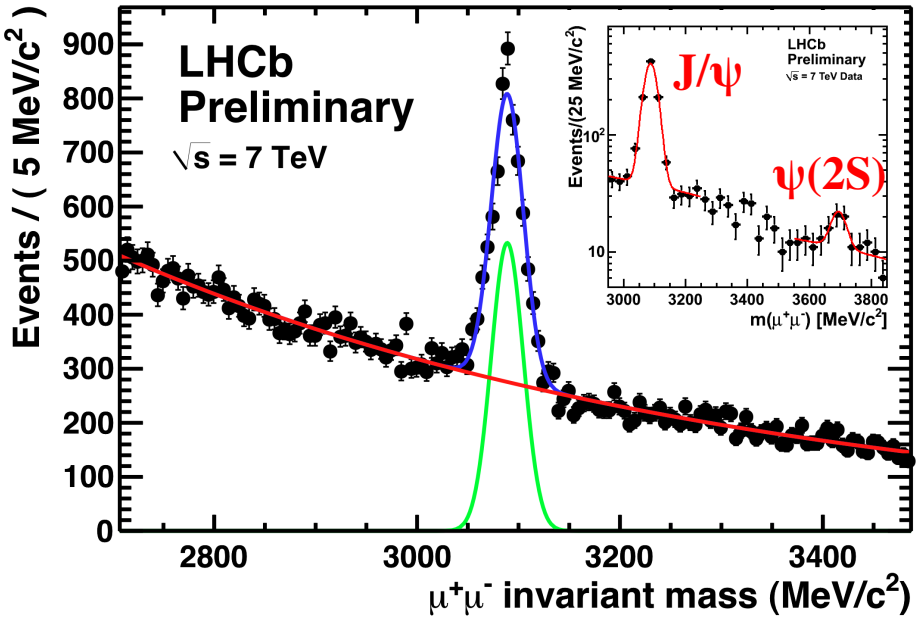


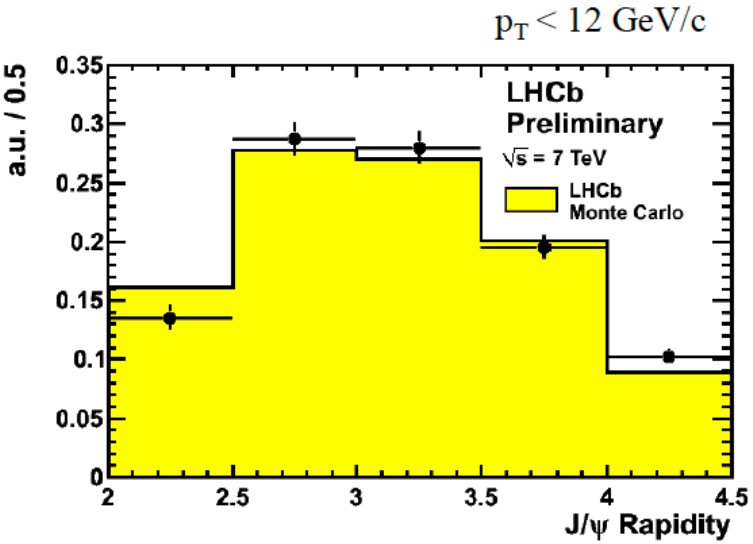




- **About 5 million events ere expected in 0.1 fb^{-1}**
  - an order of magnitude more than B-factory samples

$J/\psi \rightarrow \mu^+\mu^-$

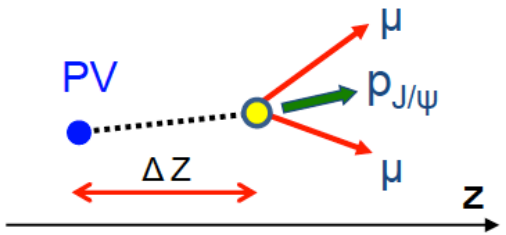




- **J/ψ signal very rich → extremely important for calibration issues**
  - alignment, tracking studies, proper time calibration
  - momentum resolution, mass scale
  - Muon identification

- **ψ's play a central role in the LHCb physics programme**
  - quarkonium production, polarization, etc.
  - bottom physics with both inclusive and exclusive and b → J/ψ decays

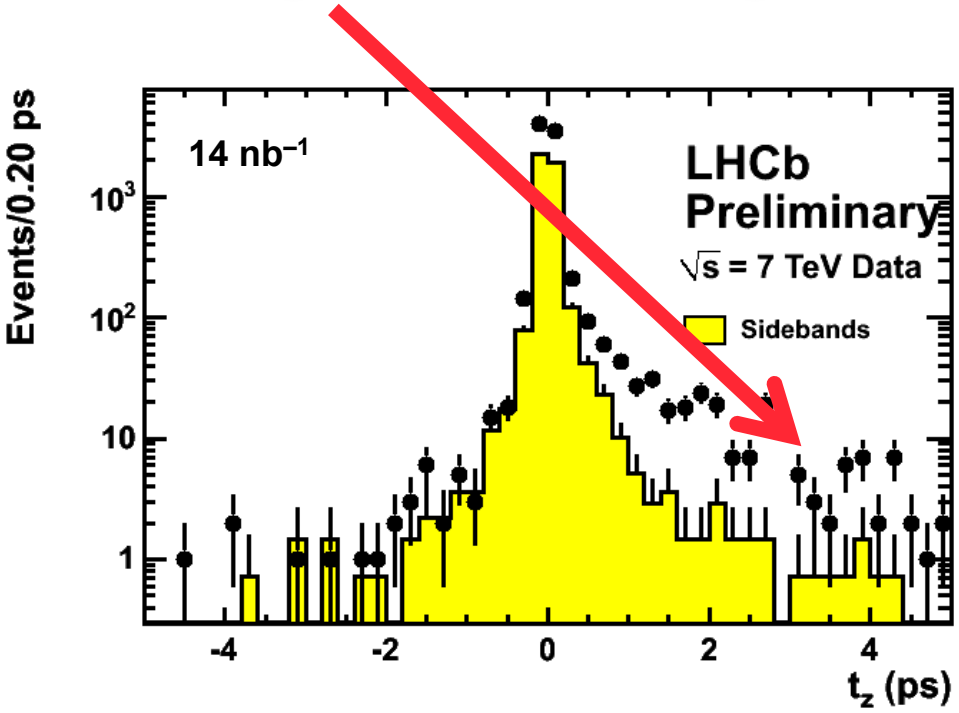
J/ψ pseudo proper time

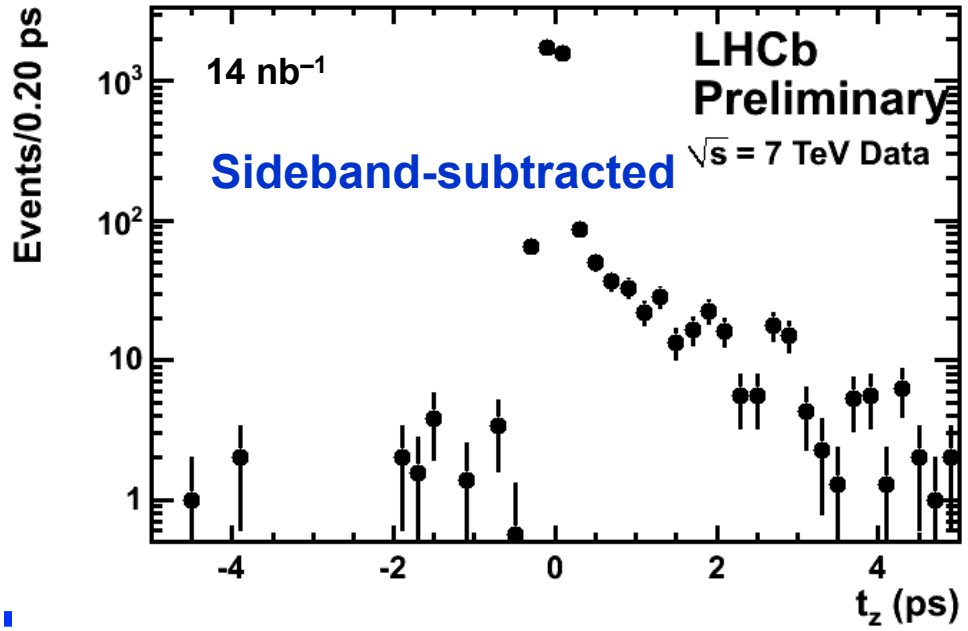


t_z pesudo proper time

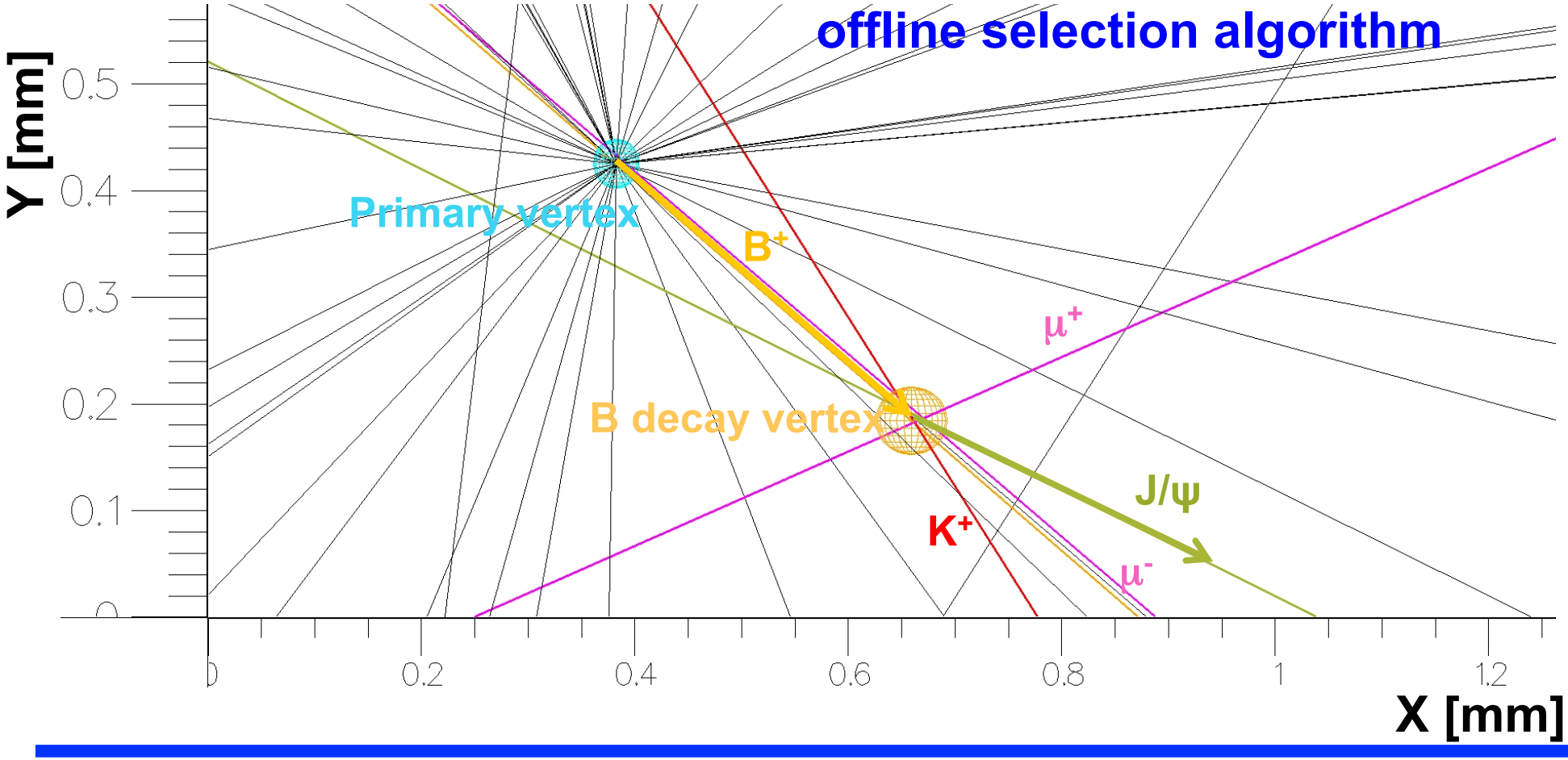
$$t_z = \left(z_{J/\psi} - z_{PV}\right)\frac{m_{J/\psi}}{p_{z,J/\psi}}$$

- Long tail due to long-lived signals from decays of B hadrons



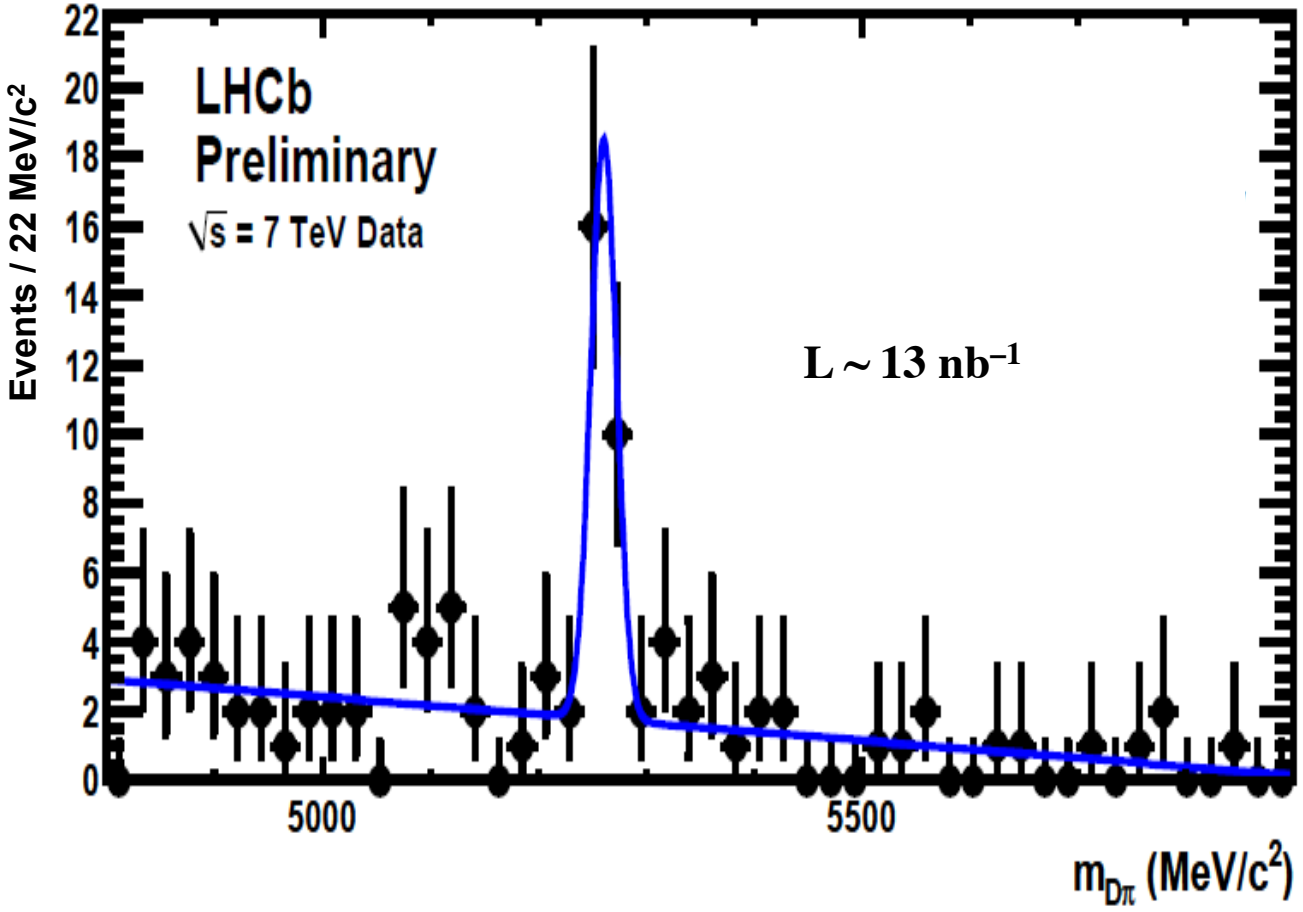


$B^+ \rightarrow J/\psi\, K^+$ candidate (x-y plane projection)



Exclusive hadronic B decays

First signal seen combining two modes $B^0 \to D^+\pi^-$ and $B^+ \to D^0\pi^+$

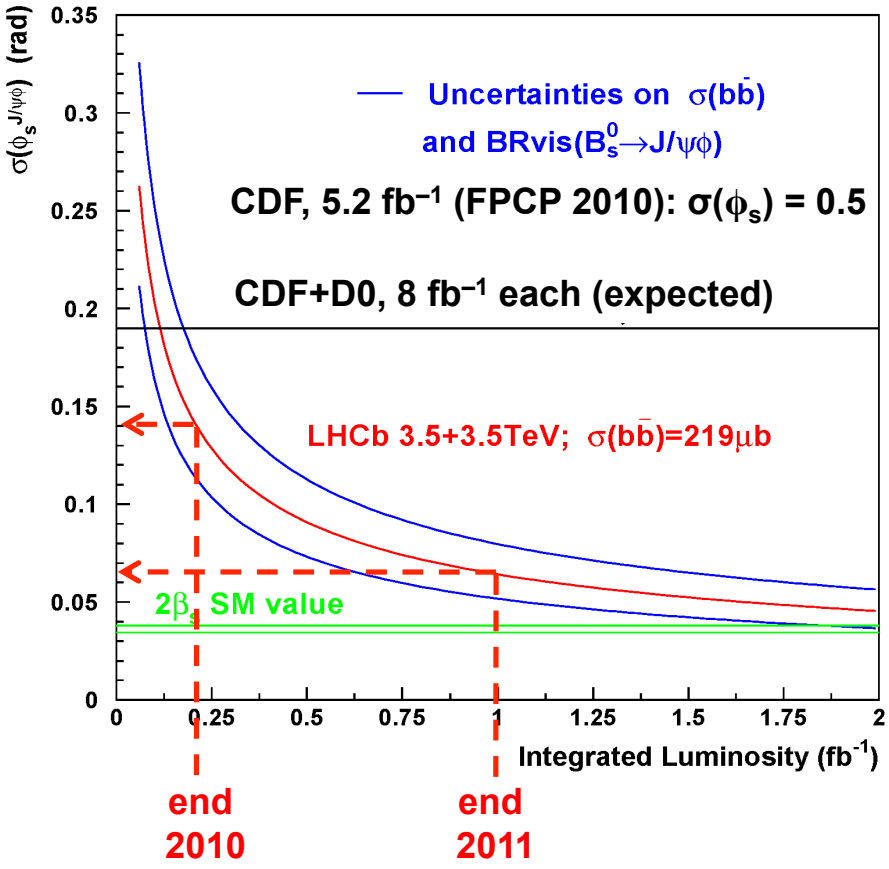


Prospects for Mixing-induced CPV in $B_s \to J/\psi\phi$

- B_s mixing phase can be accessed with $B_s \to J/\psi\phi$ in the same way as 2β with $B^0 \to J/\psi K^0$
- Phase $2\beta_s$ small in SM, hence very sensitive to NP contributions
  - $2\beta_s = 0.036 \pm 0.002$ rad (SM)
- LHCb expectation
  - With 1 fb^{-1} and full time and angular analysis of flavour-tagged $B_s \to J/\psi\phi$ decays:

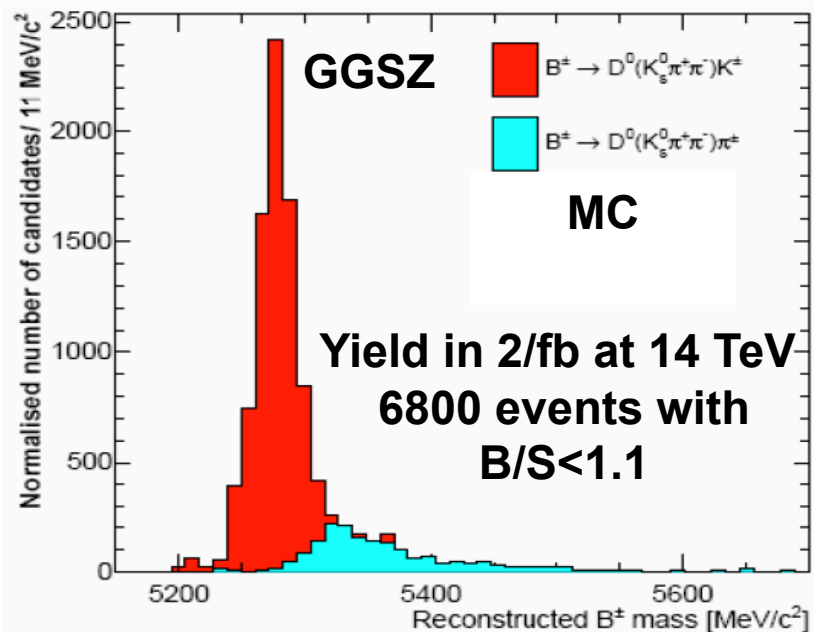
$$\sigma(\varphi_s(J/\psi\phi)) \sim 0.07 \text{ rad}$$

- Already during 2010 stat. for competitive sensitivity is expected



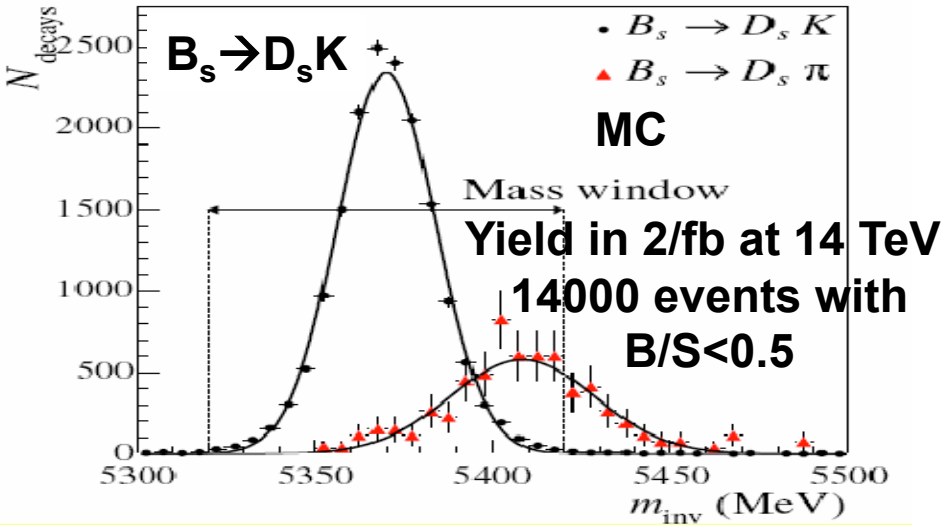
Prospects with γ from tree decays

- Tree-level determination of CKM angle γ using interference between b→c and b→u tree-level diagrams in $B_{(s)} \to D_{(s)}K$



ADS/GLW modes

Mode	MC Yield: 14TeV, 2fb^{-1}	MC B/S
B →D(Kπ)K	84k	0.6
B →D_{sup}(Kπ)K	1.6k	0.6
B →D(Kπππ)K	53k	0.2
B →D_{sup}(Kπππ)K	0.55k	3.1
B →D(hh)K	11.4k	1.4
B^0 →D(Kπ)K^*	3.2k	0.25
B^0 →D_{sup}(Kπ)K^*	0.3k	< 10
B^0 →D(hh)K^*	0.4k	< 8

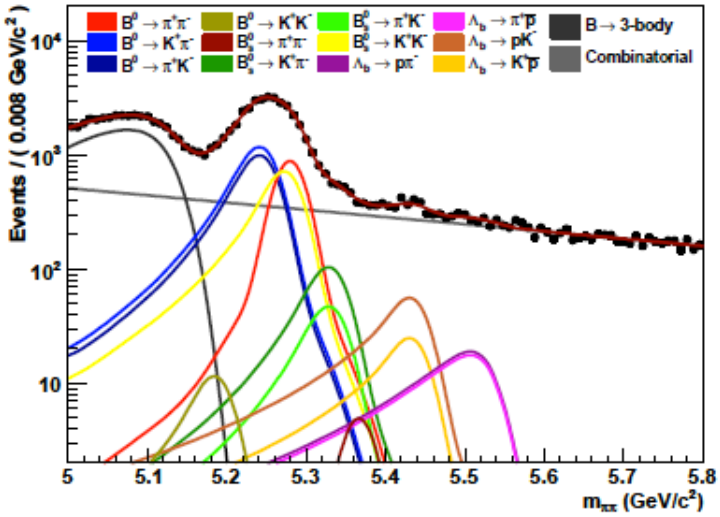


- combined precision expected with 1 fb^{-1} at 7 TeV:

σ(γ) ~ 7 degrees

Prospects with charmless charged 2-body B decays

- **Competitive measurements already possible with L=200 pb^{-1}**
  - E.g. $B_s \to K\pi$ charge asymmetry, relative BR's, …
  - $B_s \to KK$ Lifetime
- **With 500 pb^{-1} we will overcome the B-factory stat. in the B_d sector and measurements of time dependent CP asymmetries will be possible**
  - Maybe first measurement of $B_s \to KK$ time dependent CPV
- **Time dep. CP asymm. sensitive to γ and NP**



	Current knowledge	LHCb stat.
$\mathcal{A}^{CP}_{K^+\pi^-}$	$-0.098^{+0.012}_{-0.011}$	0.008
$\mathcal{A}^{CP}_{\pi^+K^-}$	$0.39 \pm 0.15 \pm 0.08$	0.05
$\mathcal{A}^{CP}_{p\pi^-}$	$0.03 \pm 0.17 \pm 0.05$	0.05
$\mathcal{A}^{CP}_{pK^-}$	$0.37 \pm 0.17 \pm 0.03$	0.03
$\mathcal{A}^{dir}_{\pi^+\pi^-}$	0.38 ± 0.06	0.13
$\mathcal{A}^{mix}_{\pi^+\pi^-}$	-0.65 ± 0.07	0.13
$\mathrm{Corr}(\mathcal{A}^{dir}_{\pi^+\pi^-}, \mathcal{A}^{mix}_{\pi^+\pi^-})$	0.08	−0.03
$\mathcal{A}^{dir}_{K^+K^-}$	**Unmeasured**	0.15
$\mathcal{A}^{mix}_{K^+K^-}$		0.11
$\mathrm{Corr}(\mathcal{A}^{dir}_{K^+K^-}, \mathcal{A}^{mix}_{K^+K^-})$		0.02
$\frac{\mathcal{BR}(B^0\to\pi^+\pi^-)}{\mathcal{BR}(B^0\to K^+\pi^-)}$	0.264 ± 0.011	0.006
$\frac{\mathcal{BR}(B^0\to K^+K^-)}{\mathcal{BR}(B^0\to K^+\pi^-)}$	$0.020 \pm 0.008 \pm 0.006$	0.005
$\frac{f_s}{f_d}\frac{\mathcal{BR}(B_s^0\to K^+K^-)}{\mathcal{BR}(B^0\to K^+\pi^-)}$	$0.347 \pm 0.020 \pm 0.021$	0.006
$\frac{f_s}{f_d}\frac{\mathcal{BR}(B_s^0\to \pi^+K^-)}{\mathcal{BR}(B^0\to K^+\pi^-)}$	$0.071 \pm 0.010 \pm 0.007$	0.004
$\frac{f_s}{f_d}\frac{\mathcal{BR}(B_s^0\to \pi^+\pi^-)}{\mathcal{BR}(B^0\to K^+\pi^-)}$	$0.007 \pm 0.004 \pm 0.005$	0.002
$\frac{f_{\Lambda_b}}{f_d}\frac{\mathcal{BR}(\Lambda_b\to p\pi^-)}{\mathcal{BR}(B^0\to K^+\pi^-)}$	$0.0415 \pm 0.0074 \pm 0.0058$	0.0016
$\frac{f_{\Lambda_b}}{f_d}\frac{\mathcal{BR}(\Lambda_b\to pK^-)}{\mathcal{BR}(B^0\to K^+\pi^-)}$	$0.0663 \pm 0.0089 \pm 0.0084$	0.0018

LHCb stat. sensitivity with 500 fb^{-1}

Summary

- **LHCb is fully operational**
  - Recorded lumi so far around 14 nb^{-1}
  - Even with such a low luminosity, many interesting signals already observed
- **Currently LHCb expects to collect approximately L=0.2 fb^{-1} in 2010 and L=1 fb^{-1} at the end of 2011 at $\sqrt{s}$=7 TeV**
  - Center of mass energy of 7 TeV does not represent a major problem for 2010–2011, factor 2 in $b\bar{b}$ production cross section (value of which is still unknown)
- **New Physics searches already very competitive with 2010-2011 run**
  - In particular using D decays, measuring the B_s mixing phase from $B_s \rightarrow J/\psi\varphi$, γ with tree decays from $B \rightarrow DK$ modes and with loops from $B \rightarrow hh$ modes
- **Waiting for more statistics…… thank you!**