First Results and Prospects from the LHCb Experiment

Franz Muheim
University of Edinburgh

On behalf of the
LHCb collaboration

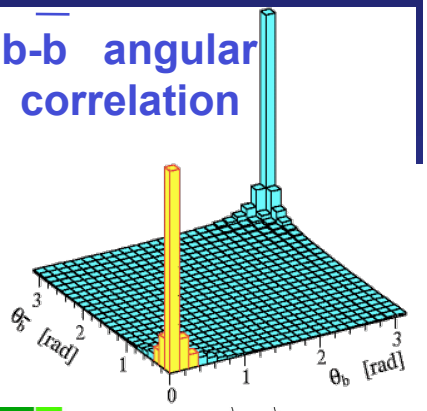
Flavor Physics and CP Violation 2010

Outline

- LHCb Experiment
- Detector Performance
- Minimum Bias Events
- Charm Production
- Early B Physics Prospects
- Outlook and Conclusions

LHCb Experiment

LHCb Experiment

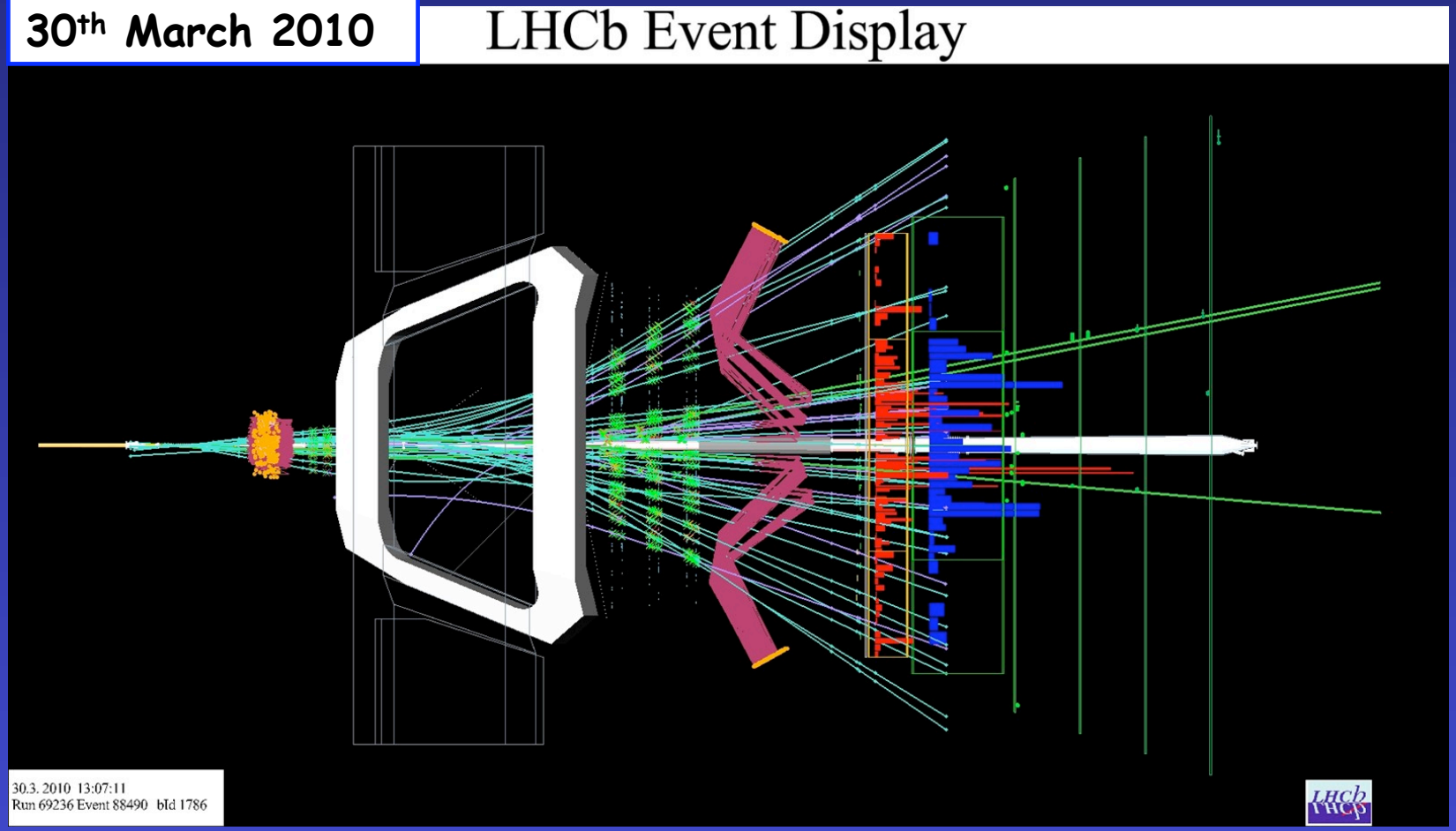


Crucial for LHCb physics programme

- optimised geometry and choice of luminosity
- **Trigger** efficient in hadronic & leptonic modes
- excellent tracking and **Vertexing** (σ_m, σ_τ)
- excellent particle ID - **RICH**

First LHCb Events at 7 TeV

30th March 2010

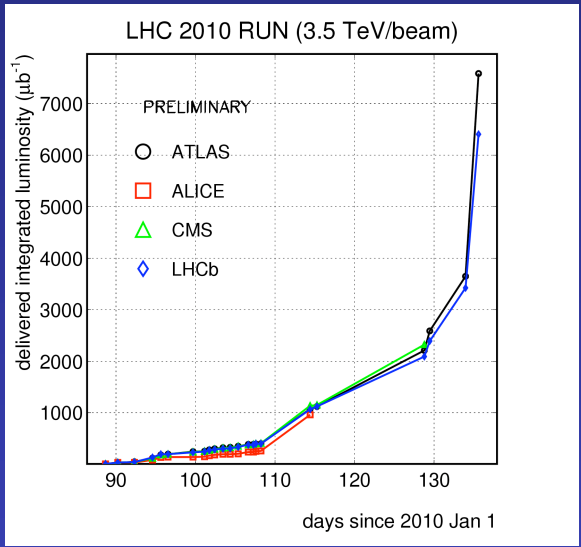


LHC Collisions at 7 TeV

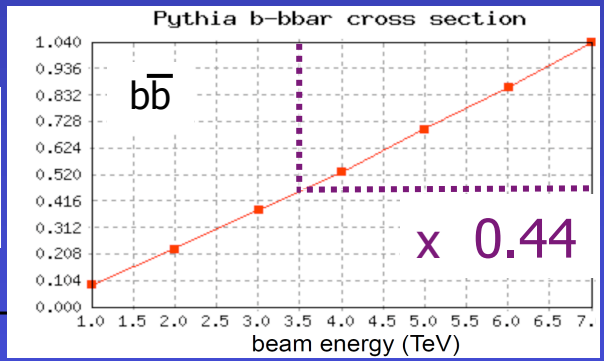
30th March 2010

Luminosity

- LHC is ramping up



  - Expect O(200 pb^{-1}) in 2010
  - 0.2 to 1 pb^{-1} summer conferences

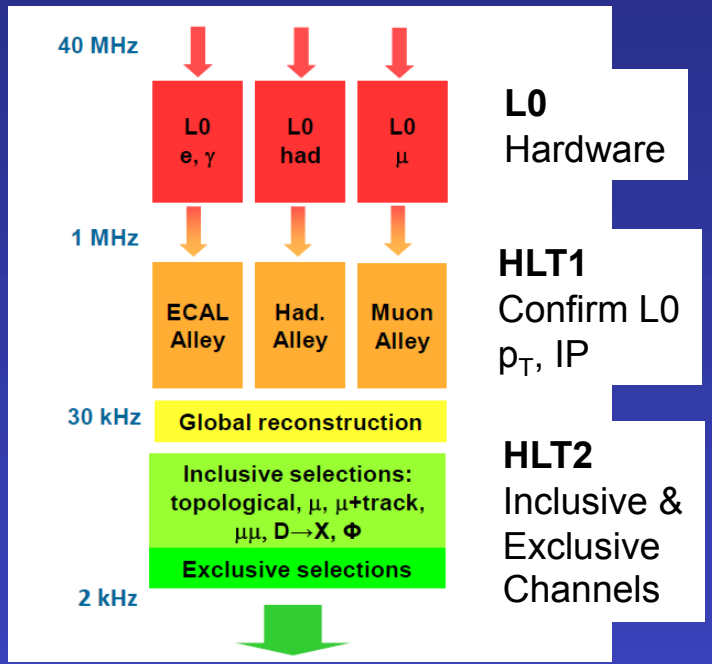


- Sensitivity Studies (MC)
  - At E_{cm} = 14 TeV
  - Event yields 2 fb^{-1} per annum
  - LHCb design luminosity of $2x10^{32}$ $cm^{-2}s^{-1}$
  - Cross section (b-bbar) = 500 μb

- Outlook/Comparison
  - For 2011 expect design luminosity and ~ 1 fb^{-1} of data
  - Lower energy, smaller cross section large uncertainty
  - Small reduction in statistical precision for 2011
  - Last LHCC meeting: "With current luminosity projections LHCb is the only detector capable to achieve almost completely its full physics potential during the 2010-2011 run

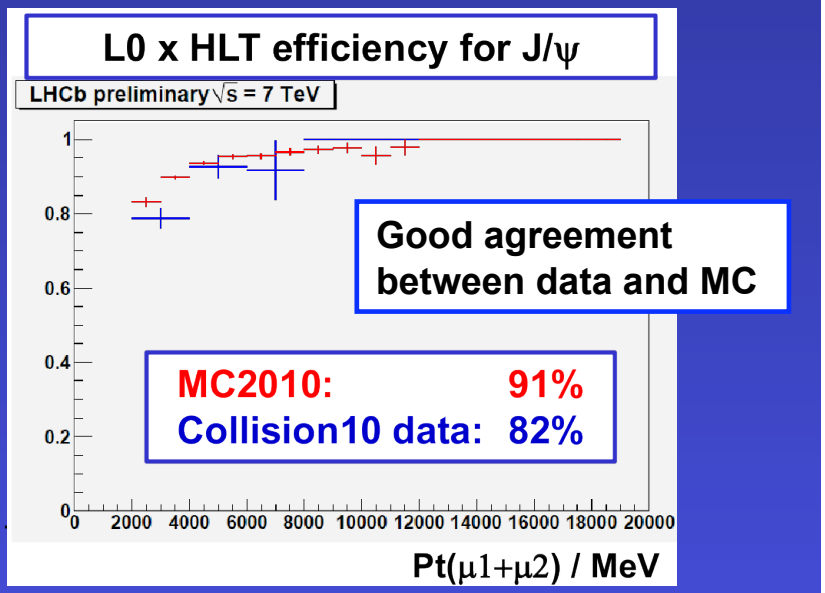
LHCb Trigger

- Trigger Strategy

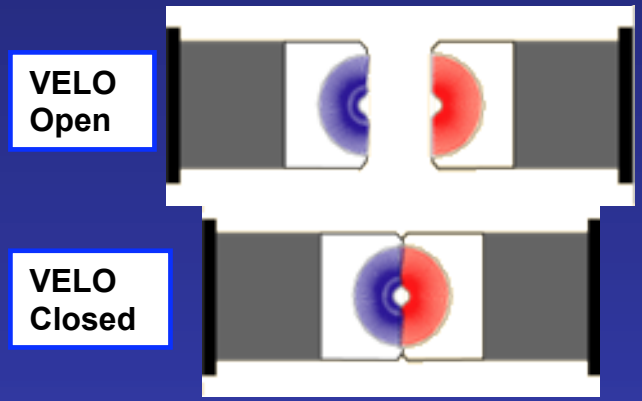


- Trigger Implementation
  - Lower collision rate in 2010 allows to lower thresholds
  - Benefits charm physics

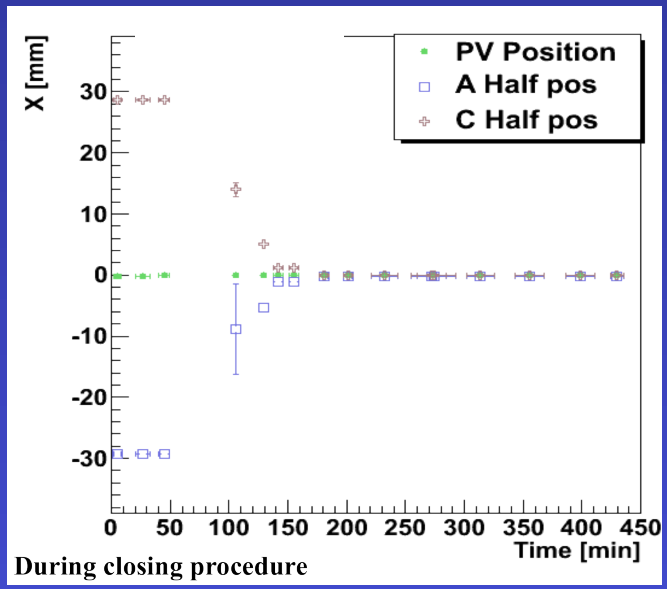
- 2010 Trigger Operations
  - L0 - Min. Bias trigger
    low E_T and p_T cuts
    All stored, rate < 2 kHz
  - L0 x HLT1 (current status)
    up to L0 rate of 25 kHz
    Looser IP cuts
  - HLT2 will be phased in
    25 kHz < L0 rate < 300 kHz

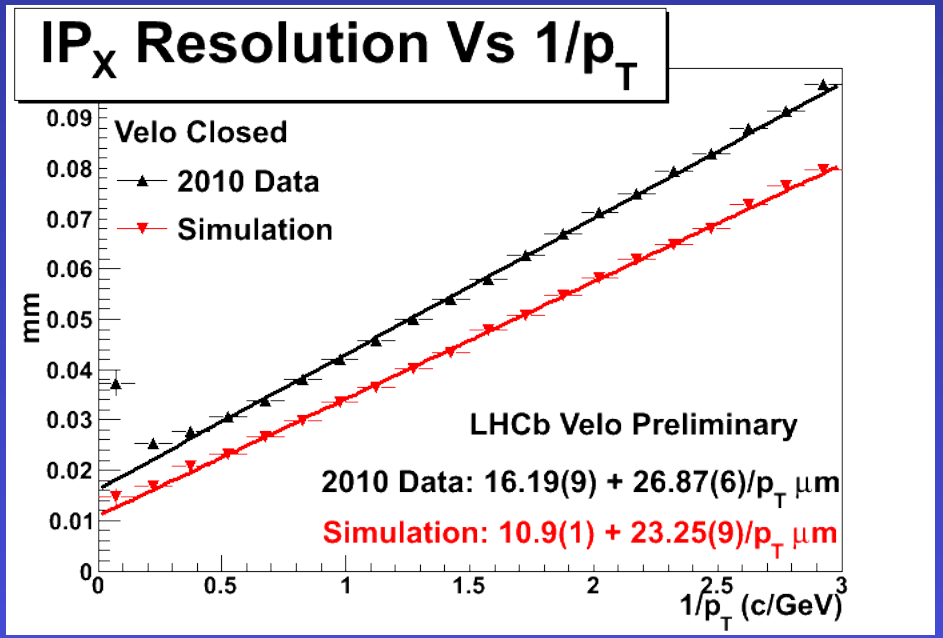


VELO - VErtex LOcator



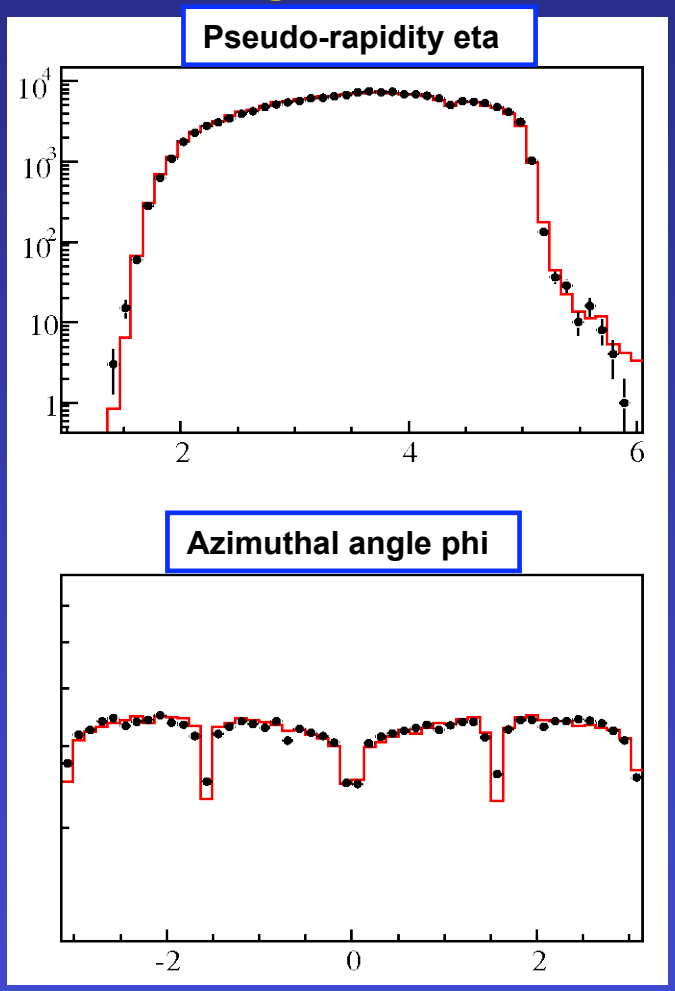
- VELO Performance
  - Closing VELO in 10 min to 10 um accuracy
  - Alignment with primary vertices
  - Hit residual as expected
  - Impact parameter resolution ~ $1/p_T$
  - Performance close to expectations

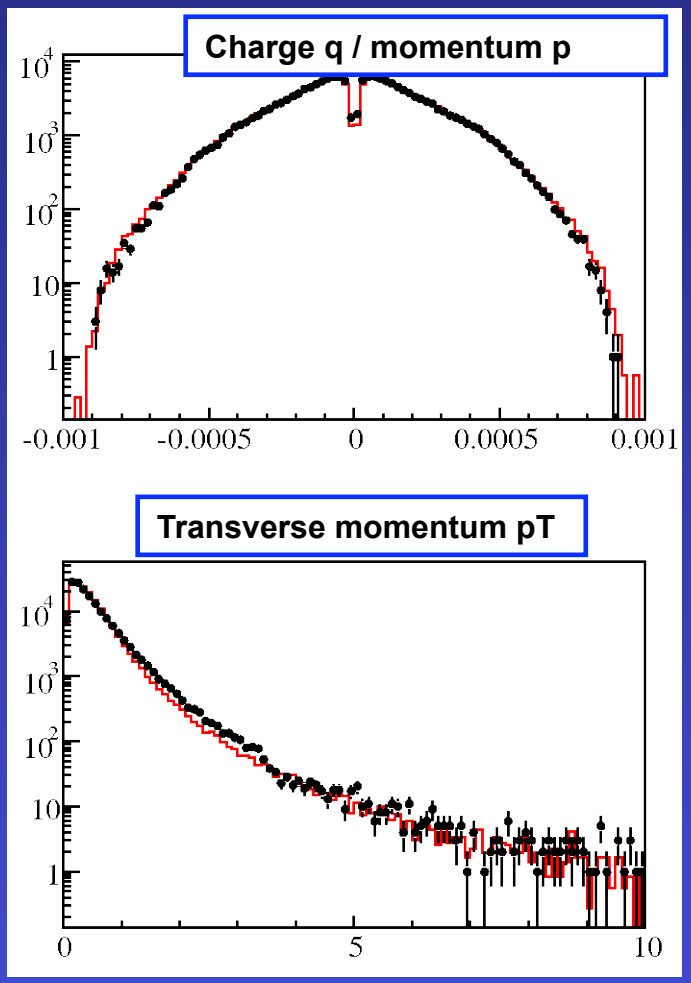




VELO and Tracking Stations

- Good agreement between data and MC



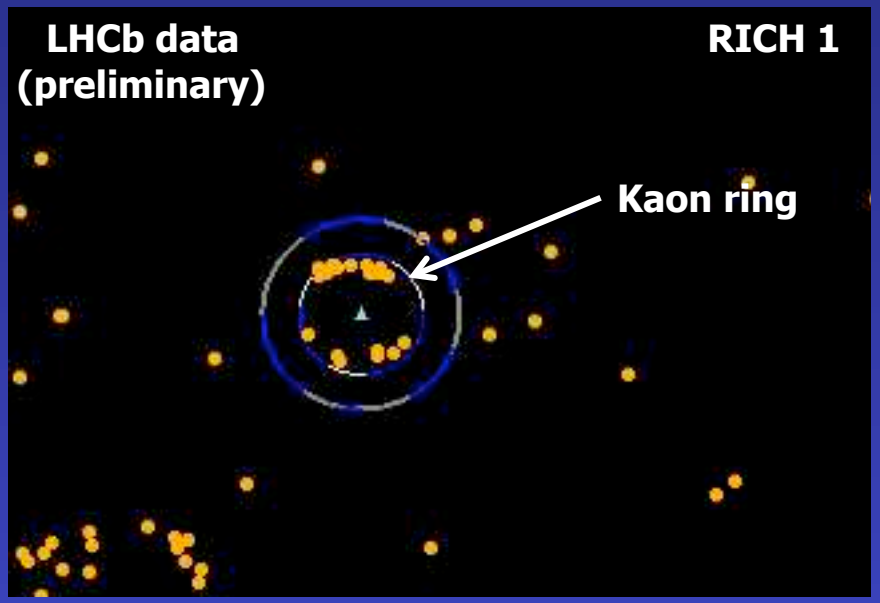


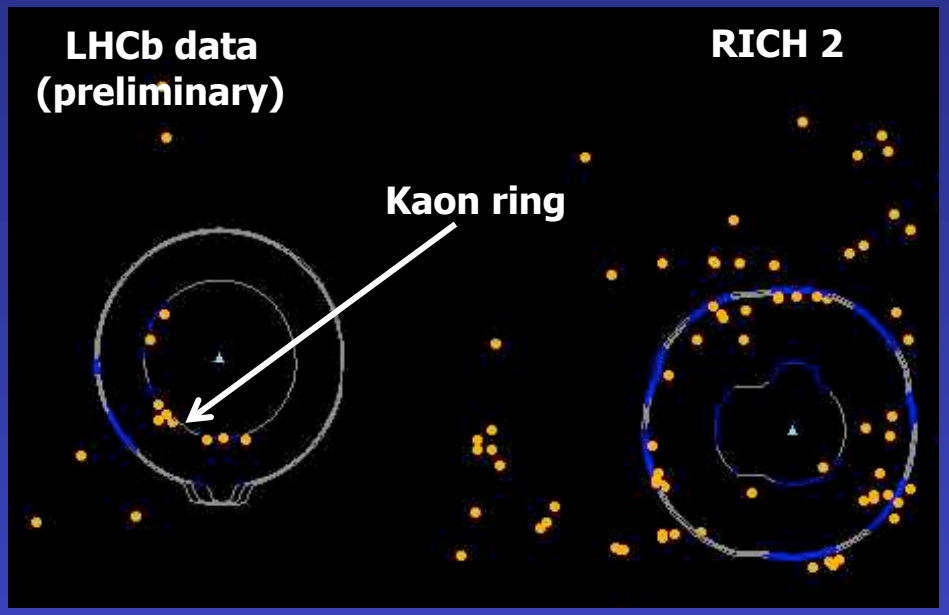
Ring Imaging Cherenkov Counters

RICH1

Nov/Dec 2009
LHC beams $\sqrt{s}$ = 900 GeV

RICH2

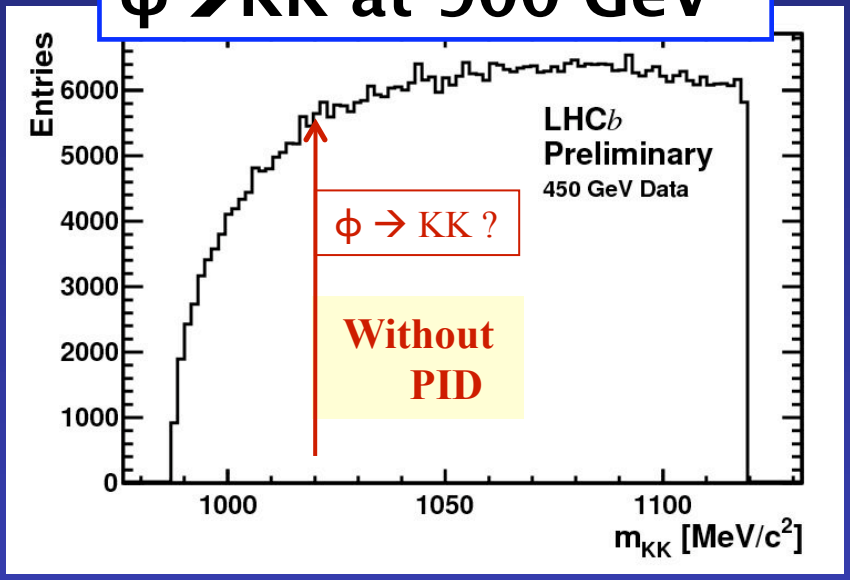


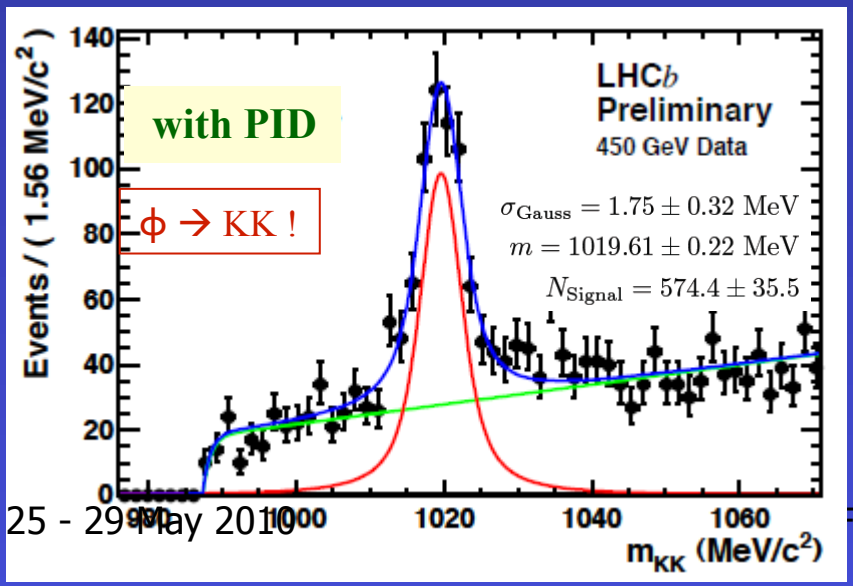


Orange points → photon hits
Continuous lines → expected distribution for each particle hypothesis

Particle Identification

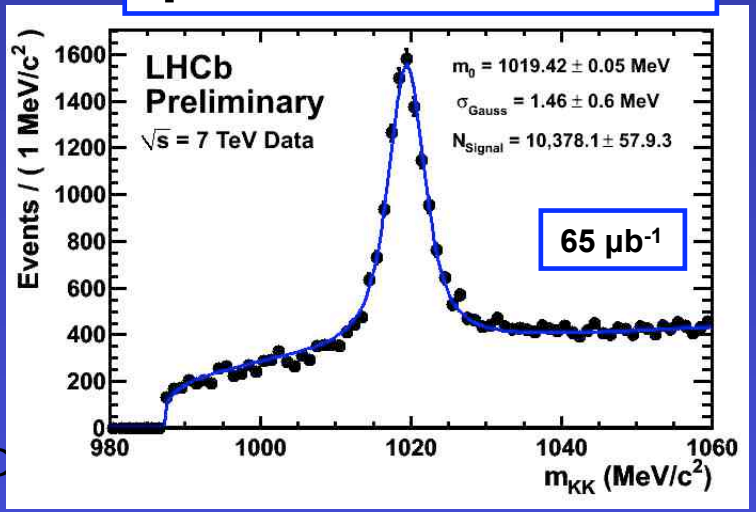
ϕ➔KK at 900 GeV





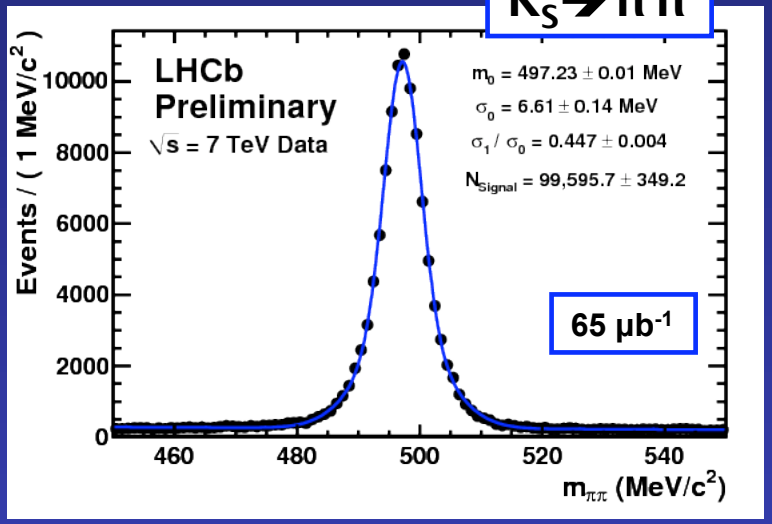
- PID Performance
  - Alignment and Calibration underway
  - Angular resolutions close to expectations
  - Calibration of efficiencies and Mis-id rates with data (K_S, Λ, ϕ and D^{*+})

ϕ➔KK at 7 TeV

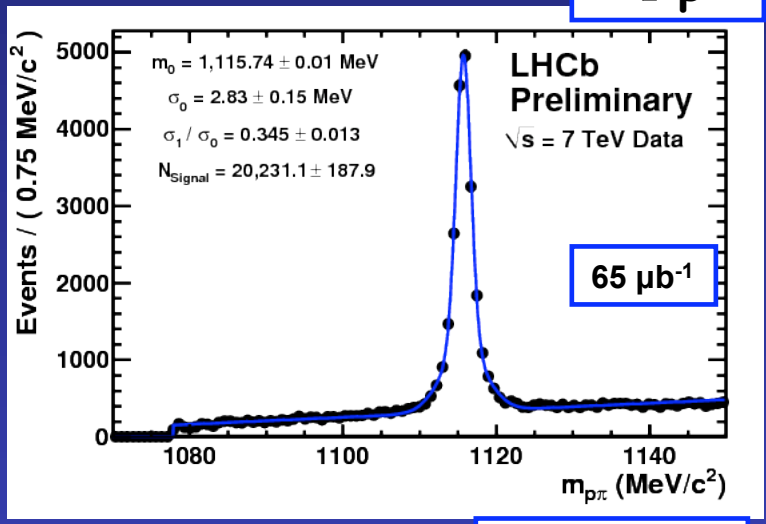


Strange Hadrons at √s = 7 TeV

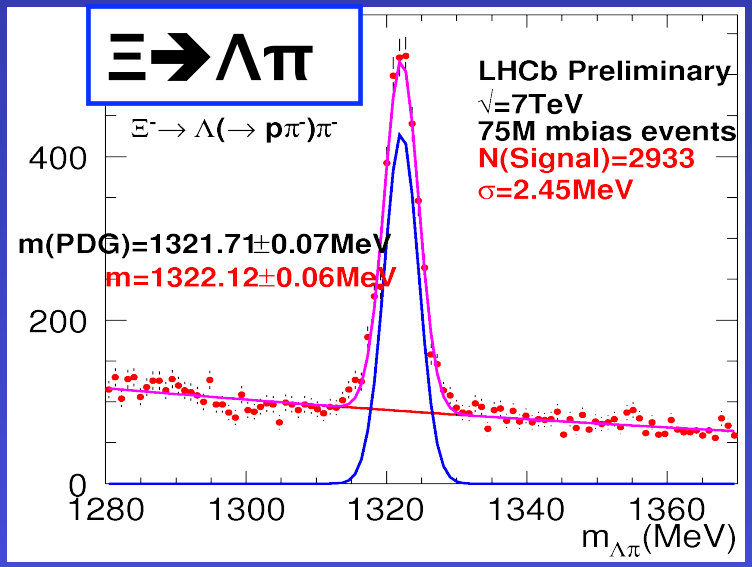
$K_S \rightarrow \pi\pi$



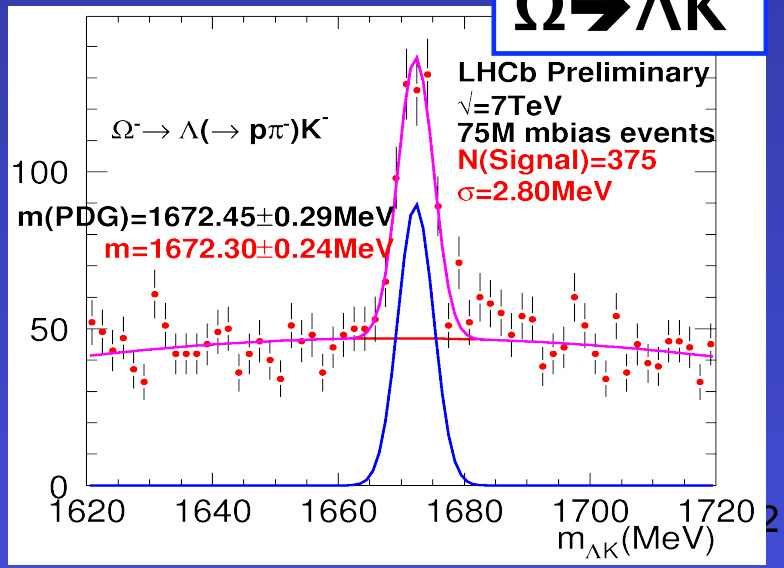
$\Lambda \rightarrow p\pi$



$\Xi \rightarrow \Lambda\pi$



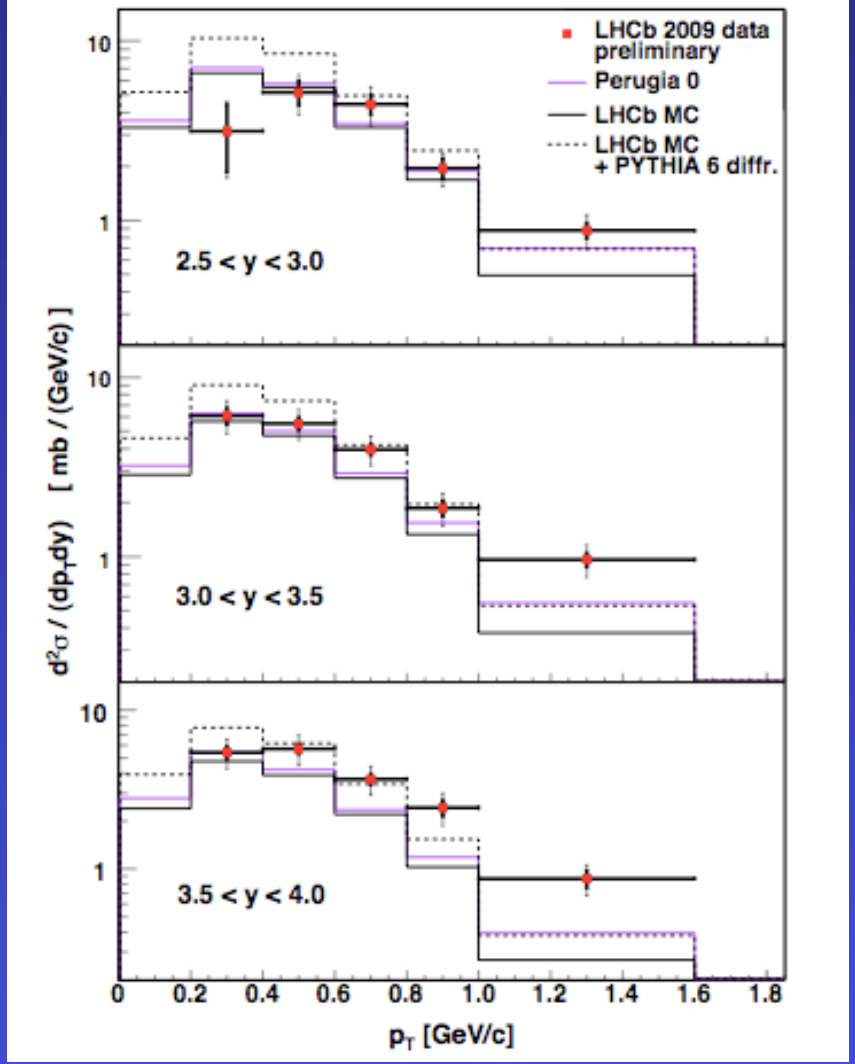
$\Omega \rightarrow \Lambda K$



K_S^0 Production at 900 GeV

LHCb Preliminary

$K_S \rightarrow \pi\pi$



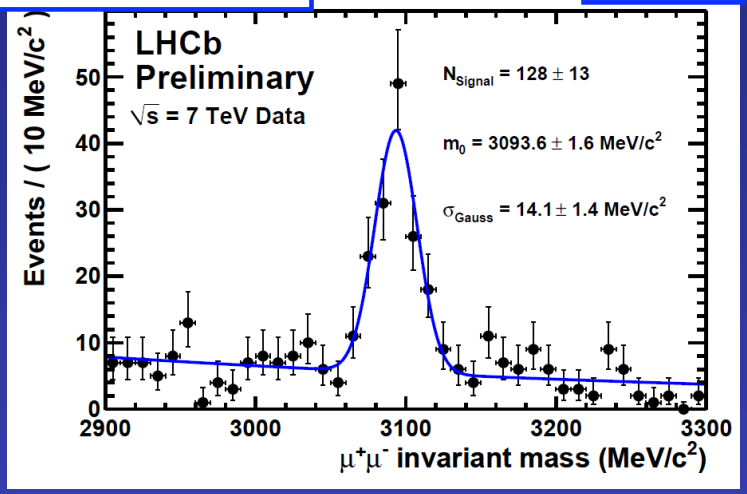
First LHCb Physics Result

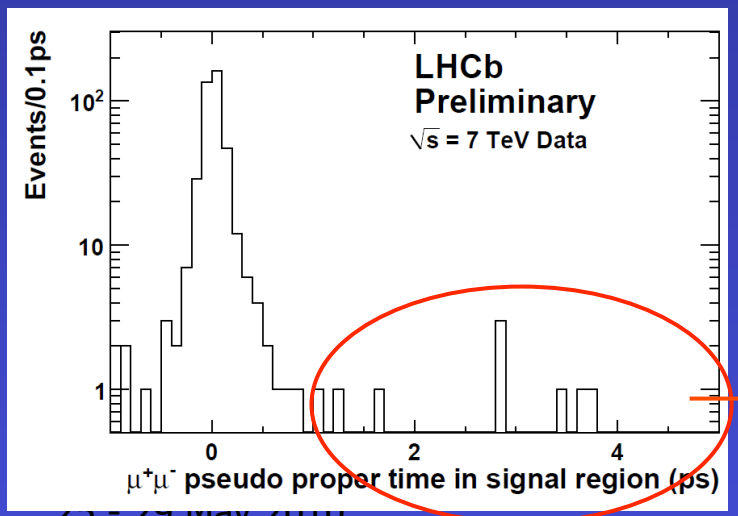
- 2009 Data Sample
  - $\sqrt{s}$ = 900 GeV
  - 6.8±1.0 μb^{-1}
- Measurement
  - K_S reconstruction in $\pi\pi$ mode
  - Vertex detector (open) not used
- Luminosity
  - from beam-beam and beam-gas
  - Achieved 15% precision
- Results
  - Transverse Momentum p_T
  - in 3 bins of rapidity y
  - Consistent with Pythia 6.4 and Perugia0 tuning
- Outlook
  - Final K_S, Λ, Λbar and p, pbar at $\sqrt{s}$ = 900 GeV & 7 TeV in preparation

$J/\psi \rightarrow \mu^+\mu^-$ at $\sqrt{s}$ = 7 TeV

J/ψ➔μμ

0.8 nb^{-1}





- Muon system
  - Fully operational
  - Pion and kaon misidentification rates close to MC expectations
- $J/\psi \rightarrow \mu^+\mu^-$
  - 128 candidates in 0.8 nb^{-1} tight muon selection
  - To measure muon efficiency larger data set required
  - Pseudo proper time

$$\frac{\left(\vec{V}_{J/\psi} - \vec{V}_1\right) \cdot \vec{p}_{J/\psi} m_{J/\psi}}{p^2_{J/\psi}}$$

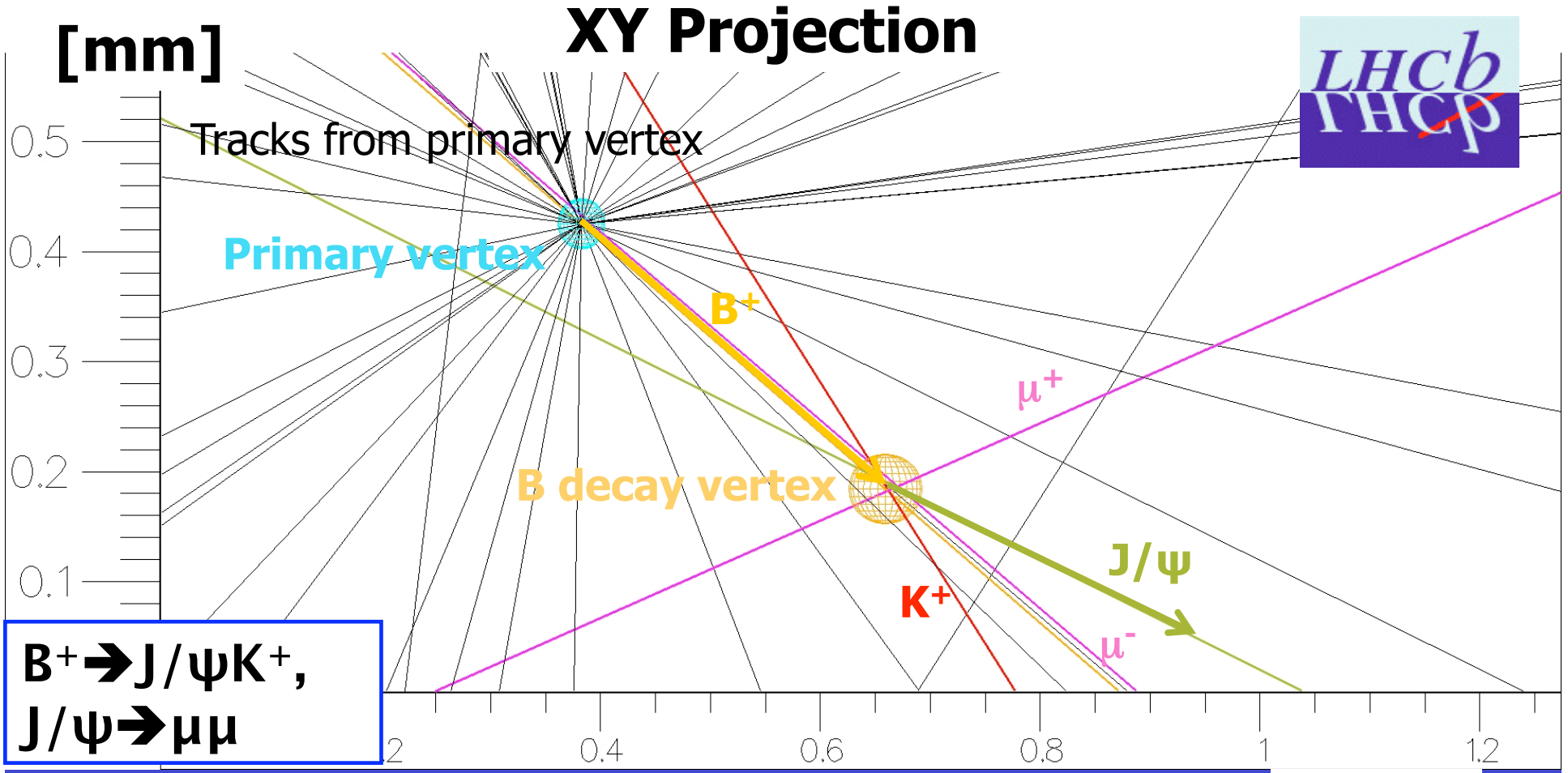
Candidates for inclusive J/ψ from B decays

Are any of these from exclusive B decays?

$B^+ \rightarrow J/\psi K^+$ candidate

21 April 2010: LHCb observes first reconstructed Beauty Particle

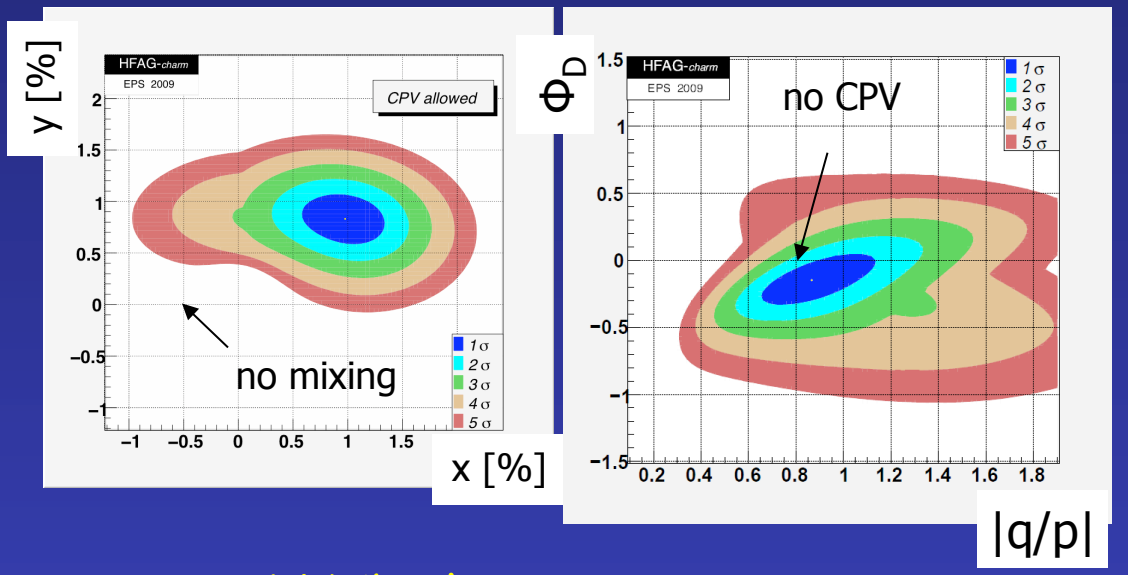
All Observables far from cut values



$B^+ \rightarrow J/\psi K^+$, $J/\psi \rightarrow \mu\mu$

Charm – the First-Year Beauty?

- Mixing
  - Well established
  - SM prediction limited precision
- CP violation
  - Weak limits
  - Negligible in SM
  - Large New Physics contribution possible
  - Needs sensitivity below <0.1%
- Precision Charm Physics
  - Crucial for future heavy flavour programme
- LHCb
  - Competitive with 100 pb^{-1}

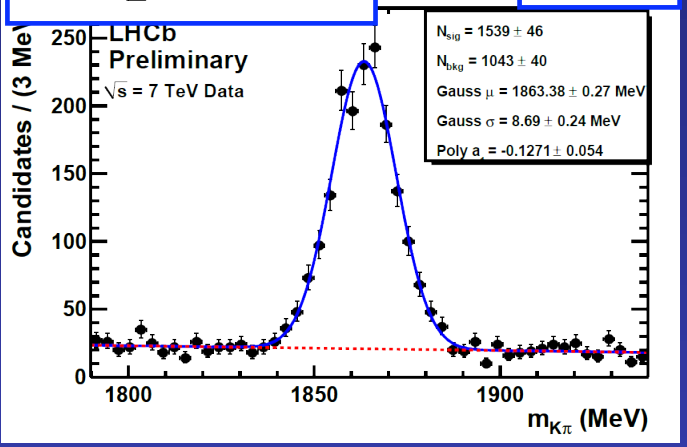


- LHCb charm programme
  - Charm signals in first month of 7 TeV data
  - Yields benefit from lower trigger thresholds
  - Open charm production for summer conferences
  - y_{CP}, A_Γ, … with 100 pb^{-1}

D^0 Mesons at $\sqrt{s}$ = 7 TeV

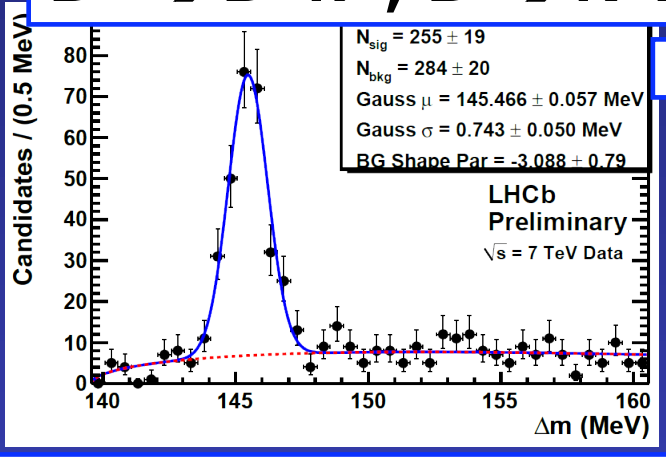
$D^0 \rightarrow K^-\pi^+$

0.8 nb^{-1}



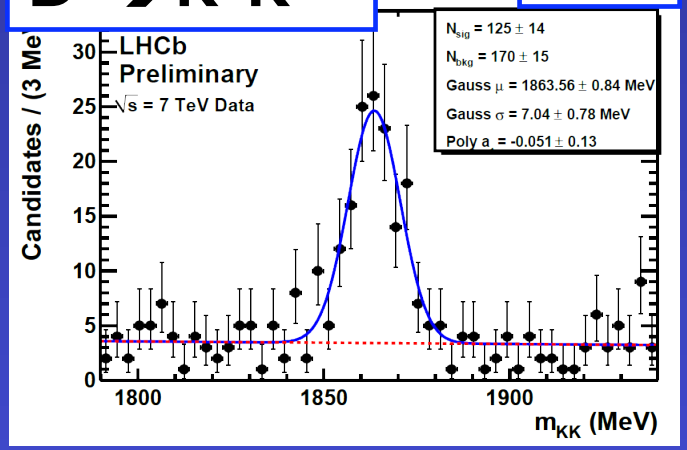
$D^{*+} \rightarrow D^0\pi^+$, $D^0 \rightarrow K^-\pi^+$

0.8 nb^{-1}



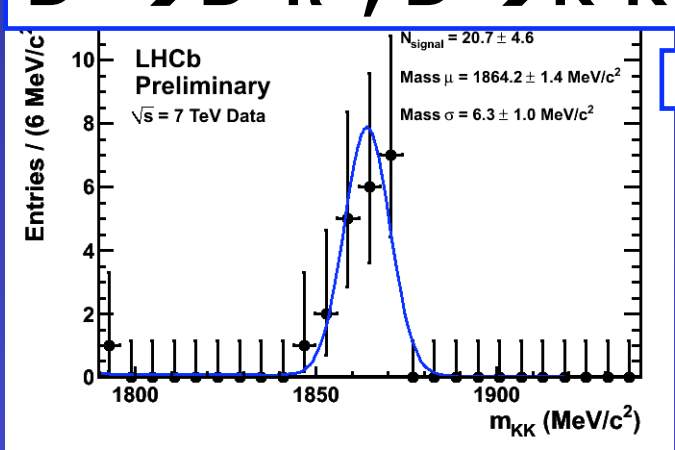
$D^0 \rightarrow K^-K^+$

0.8 nb^{-1}



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

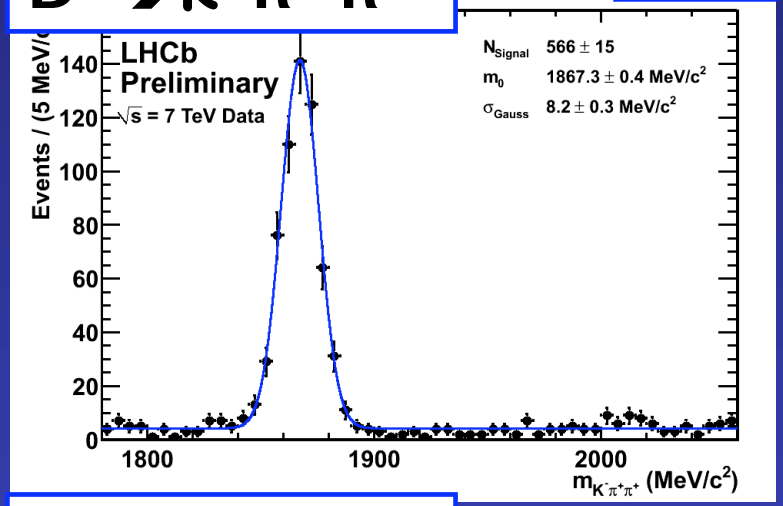
0.8 nb^{-1}



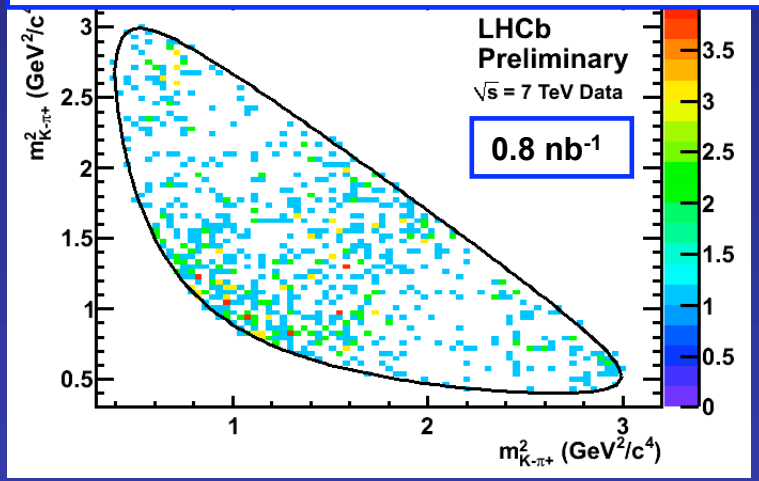
Expect several million tagged $D^0 \rightarrow KK$ in 100 pb^{-1}

Charm Hadrons at $\sqrt{s}$ = 7TeV

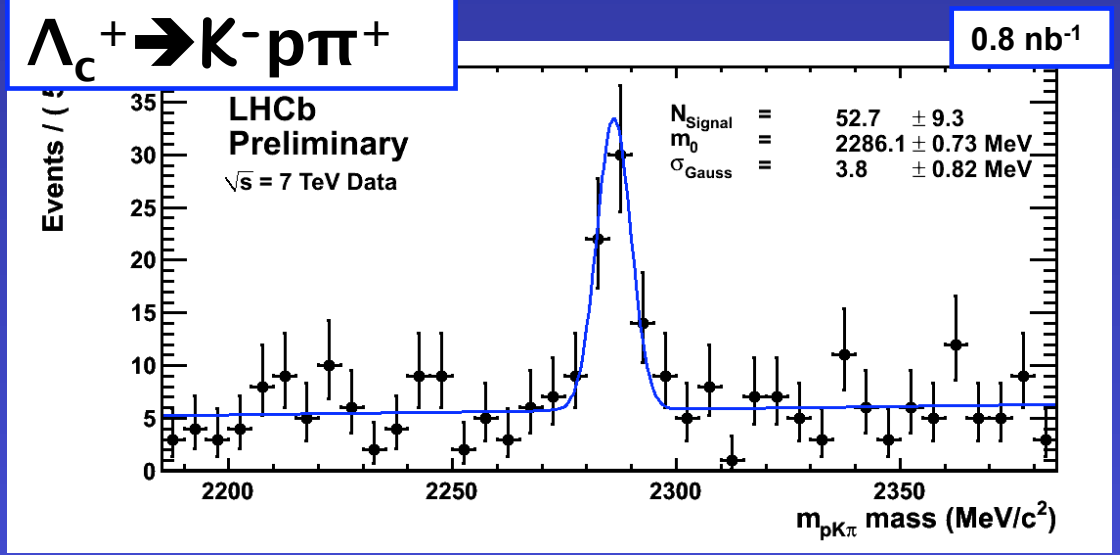
$D^+ \rightarrow K^-\pi^+\pi^+$



$D^+ \rightarrow K^-\pi^+\pi^+$ Dalitz plot



$\Lambda_c^+ \rightarrow K^-p\pi^+$

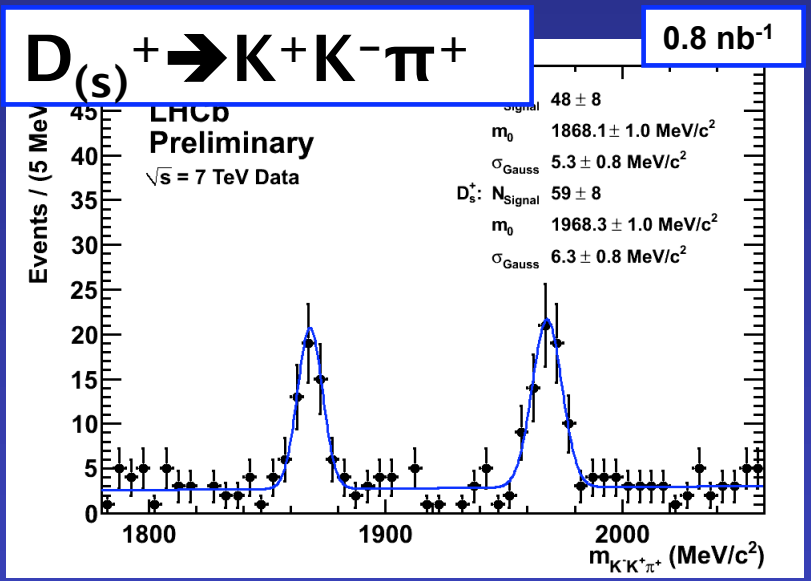


- **RICH PID**
  - Essential for charmed hadrons D^0, D^+, D_s^+ and Λ_c^+

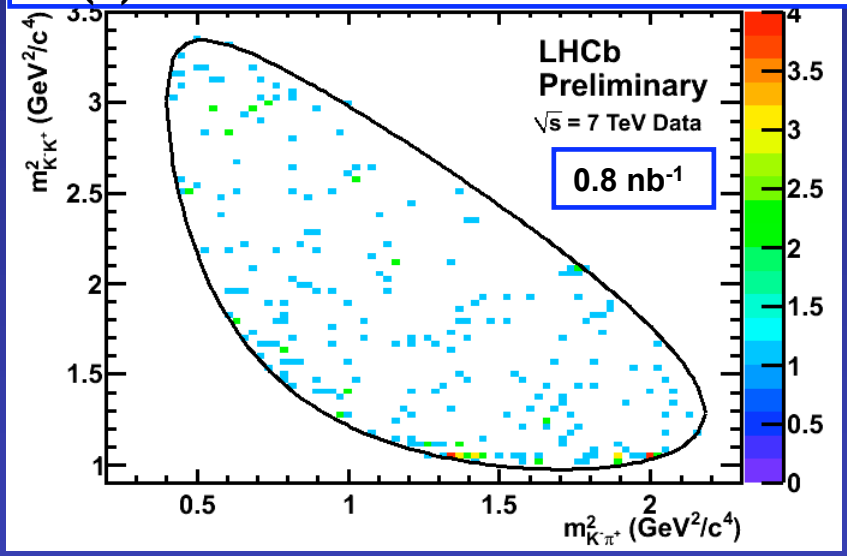
$D_{(s)}^+ \to K^+K^-\pi^+$ at $\sqrt{s}$ = 7 TeV

- D_s mesons
  - Important for B_s physics

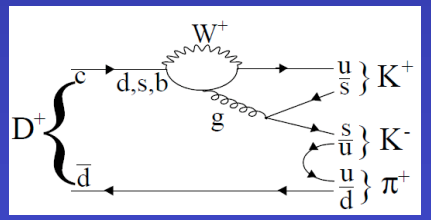
$D_{(s)}^+ \to K^+K^-\pi^+$



$D_{(s)}^+ \to K^+K^-\pi^+$ Dalitz Plot

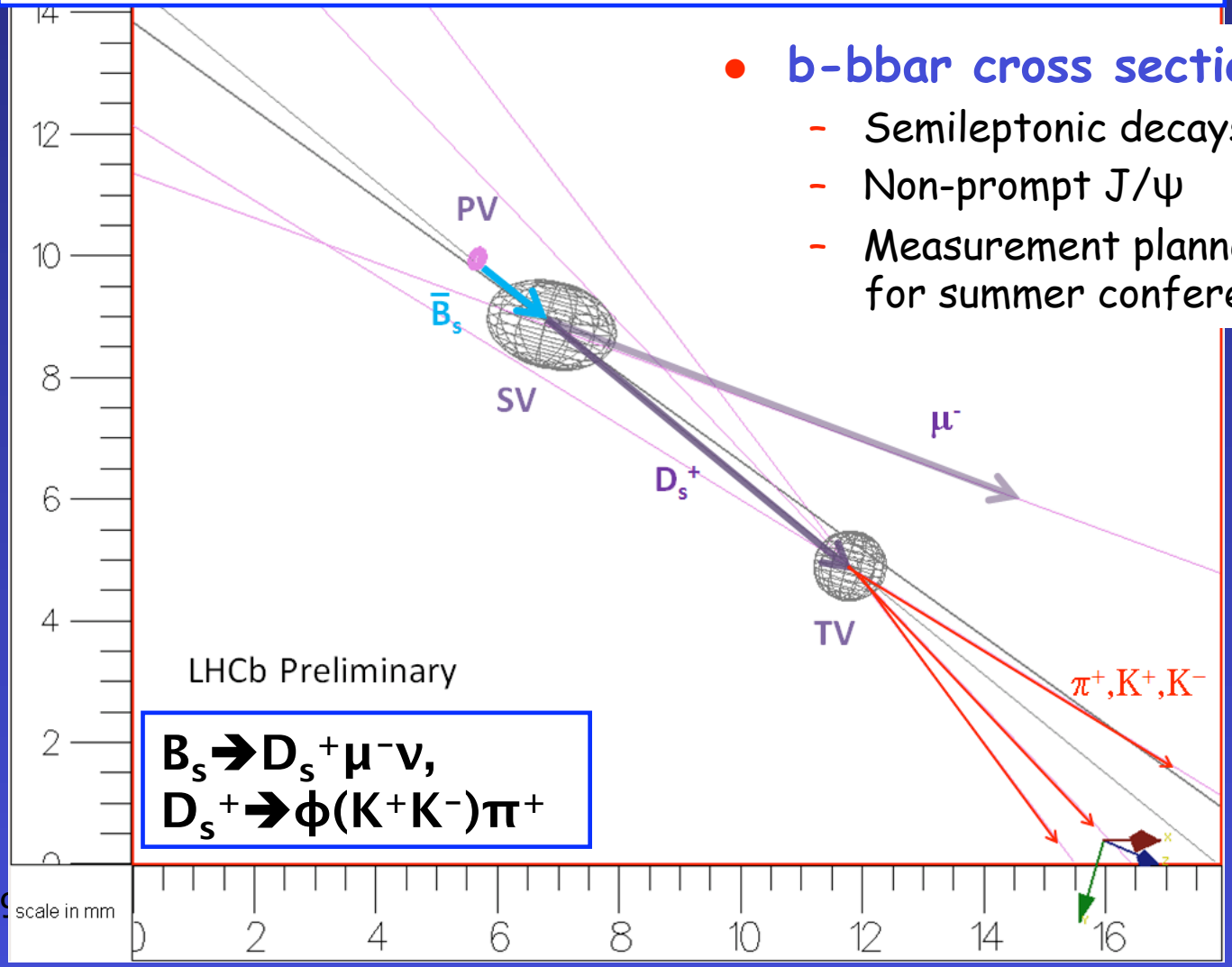


- Direct CP violation in charm decays
  - $D^+ \to K^+K^-\pi^+$ is Cabibbo suppressed, can interfere with gluonic Penguin, sensitive to New Physics
  - Control channels - Cabibbo favoured $D_s^+ \to K^+K^-\pi^+$ and $D^+ \to K^+\pi^-\pi^+$
  - Expect several million events in 100 pb^{-1}



B Production at $\sqrt{s}$ = 7 TeV

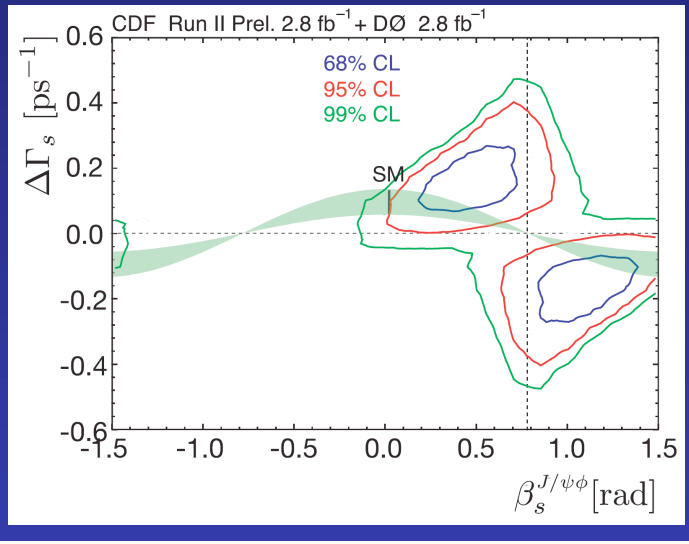
First B_s Candidate with good S/B, consistent with expectations, Expect ~100k events in 100 pb^{-1}

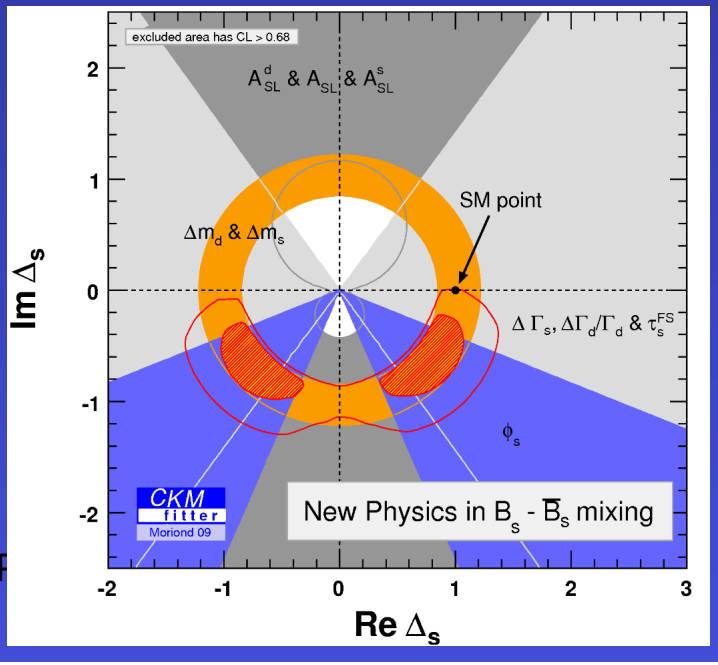


- **b-bbar cross section**
  - Semileptonic decays
  - Non-prompt J/ψ
  - Measurement planned for summer conferences

Probe New Physics in CP

- Is there NP in B_s^o-B_s^o mixing?
  - $B_s \rightarrow J/\psi\phi$ is golden mode at hadron colliders
  - Very precise SM prediction for small weak phase $\phi_s = -2\beta_s$
  - $\phi_s(J/\psi\phi) = -0.0368 \pm 0.0017$
- Current Results
  - From CDF and D0
  - Prefer non-zero ϕ_s
- Weak Limits on new physics
  - Weak phase in B_s mixing ϕ_s is not well measured yet
  - New Physics could be around the corner!

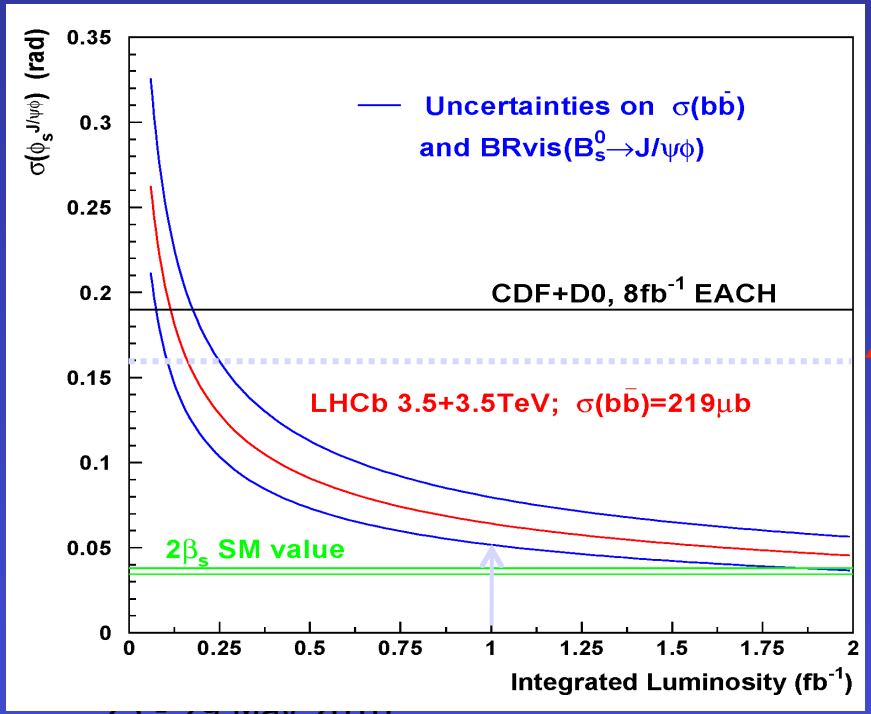




$$\mathrm{Re}(\Delta_q)+i\mathrm{Im}(\Delta_q)=\frac{\langle B^o|H^{full}|\bar{B}^o\rangle}{\langle B^o|H^{SM}|\bar{B}^o\rangle}$$

Prospects with $B_s \rightarrow J/\psi\phi$

- Probe New Physics
  - In box diagrams
- Expected Sensitivity
  - yield: 117k in 2 fb^{-1}
  - $\sigma(\phi_s) \sim 0.07$ with 1 fb^{-1}



- Exciting Prospects
  - If ϕ_s at Tevatron central value
  - LHCb will make 5σ discovery of new physics in this run
- Additional measurements
  - CP-eigenstate $B_s \rightarrow J/\psi f_0(980)$, $f_0(980) \rightarrow \pi^+\pi^-$

Precision required to establish ϕ_s = 0.7 at 5σ

- Probe New Physics
  - in penguin diagrams
  - Best mode $B_s \rightarrow \phi\phi$

A_{fs} – CP Violation in Mixing

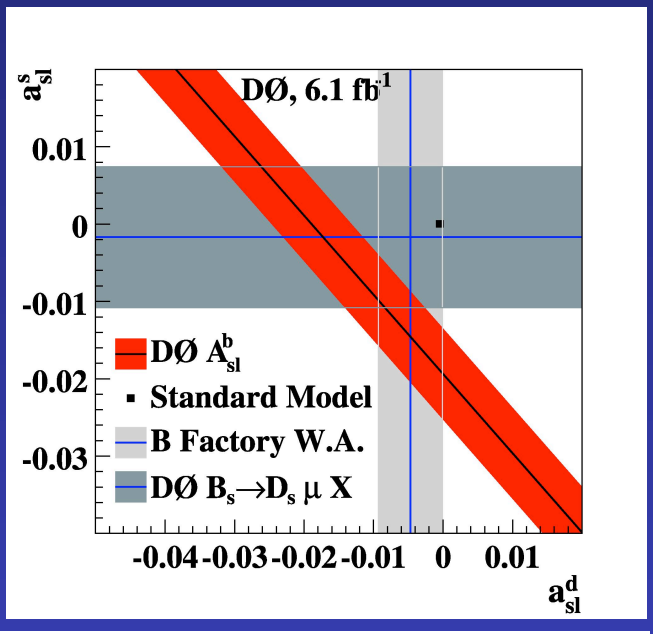
- Flavour specific Asymmetry
  - New D0 measurement

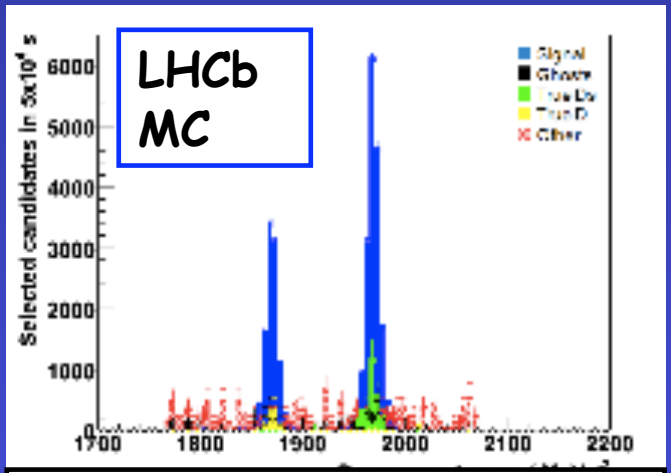
$$A_{sl}^{b} = (-0.957 \pm 0.251\,(\text{stat}) \pm 0.146\,(\text{syst}))\%$$

- A_{fs} at LHCb
  - MC sensitivity study for untagged $B_{s(d)} \to D_{s(d)}\mu\nu$ & $B_s \to D_s\pi$

$$A_{fs}^{unt,q} = \frac{\Gamma(B_q^0 \text{ or } \bar{B}_q^0 \to f) - \Gamma(B_q^0 \text{ or } \bar{B}_q^0 \to \bar{f})}{\Gamma(B_q^0 \text{or} \bar{B}_q^0 \to f) + \Gamma(B_q^0 \text{ or } \bar{B}_q^0 \to \bar{f})}$$

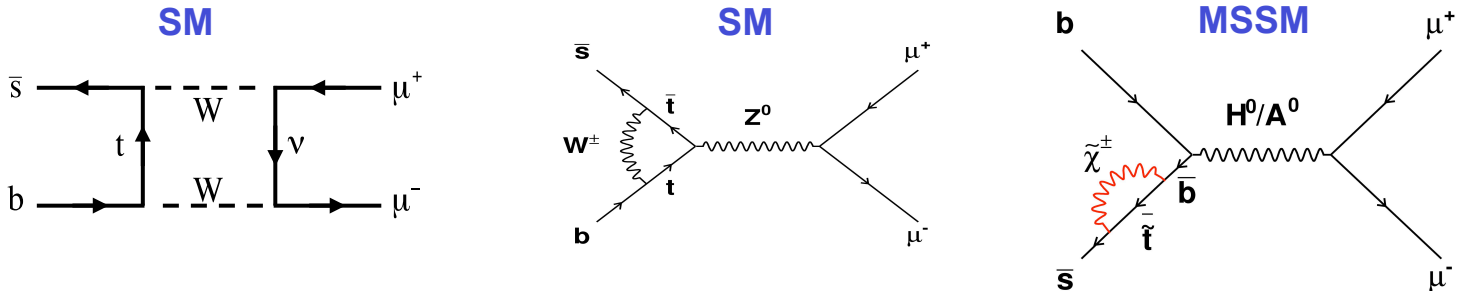
- Key Method: $\Delta A_{fs} = A_{fs}^{s} - A_{fs}^{d}$
  - Expect ~1M $B_{s(d)} \to D_{s(d)}\mu\nu$ events in 1 fb^{-1} at 7 TeV
  - Statistical sensitivity for ΔA_{fs} at 0.1% level
  - Method is robust against production, detector asymmetries



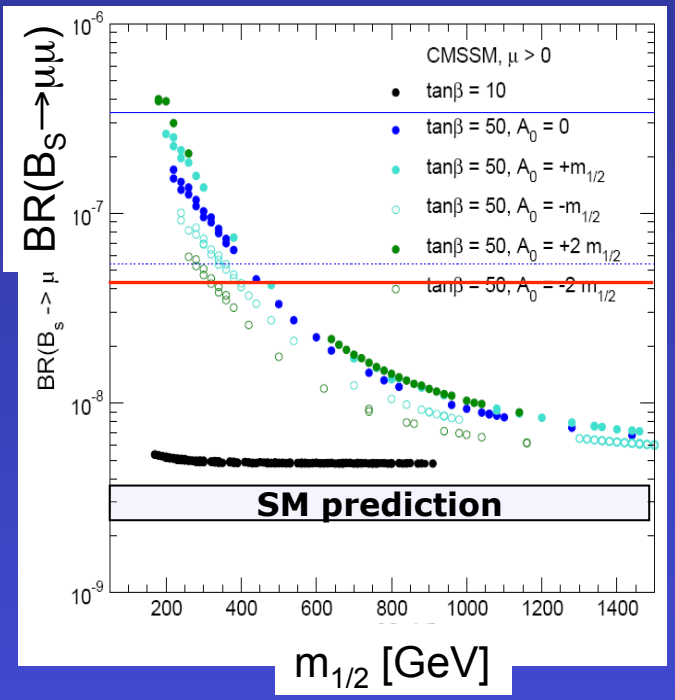


R. Lambert, PhD Thesis, Edinburgh, 2009
N. Brook et al., Public LHCb note 2007

New Physics in $B_s \to \mu^+\mu^-$

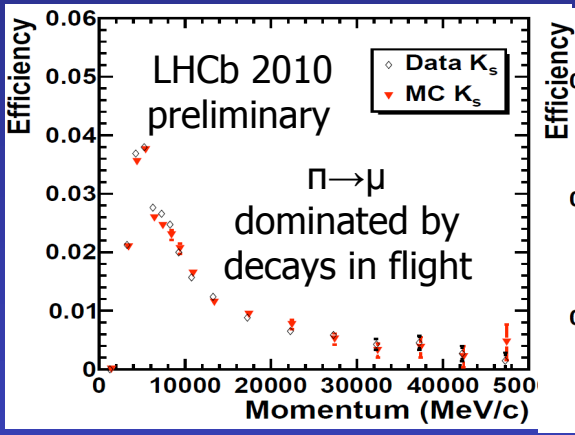


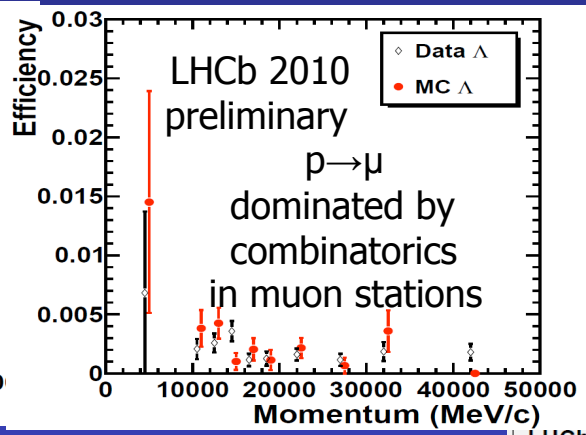
- Highly suppressed in SM
  - Prediction
    $BR(B_S \to \mu^+\mu^-) = (3.86 \pm 0.15) \times 10^{-9}$
  - could be strongly enhanced in SUSY
- Constrained MSSM
  - $BR(B_S \to \mu^+\mu^-) \sim \tan^6\beta / M_H^2$
  - Predicts much larger $BR(B_S \to \mu^+\mu^-)$ ~ a few 10^{-9} to 10^{-7}
  - Dependent on gaugino mass $m_{1/2}$

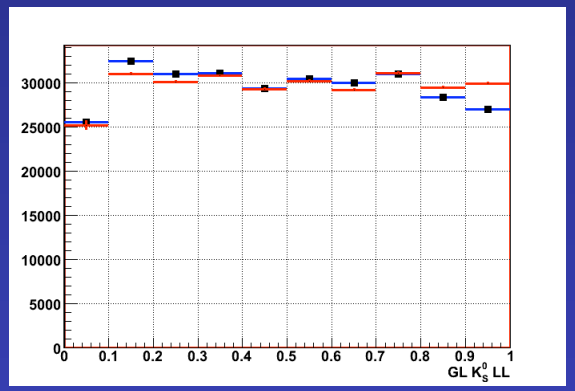


Studies for $B_s \to \mu^+\mu^-$

- Muon Identification
  - Using K_S and Λ decays
- Geometrical Likelihood
  - Using K_S decays

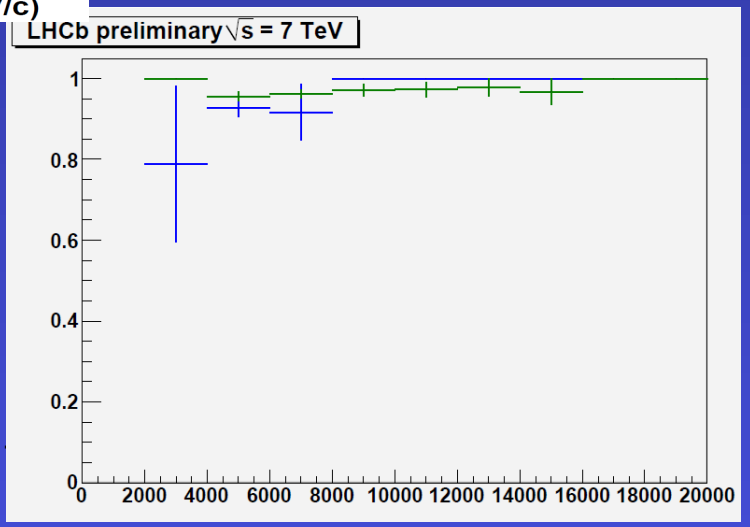




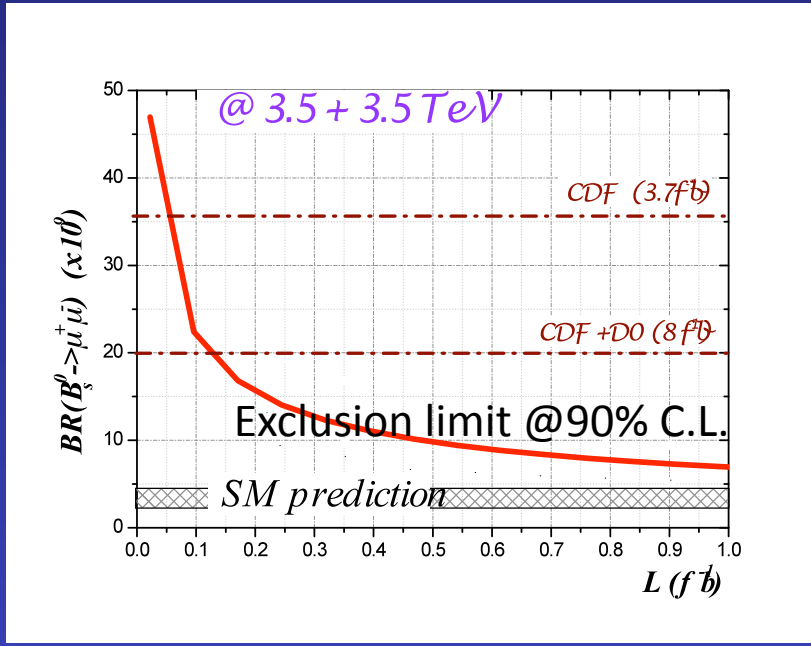


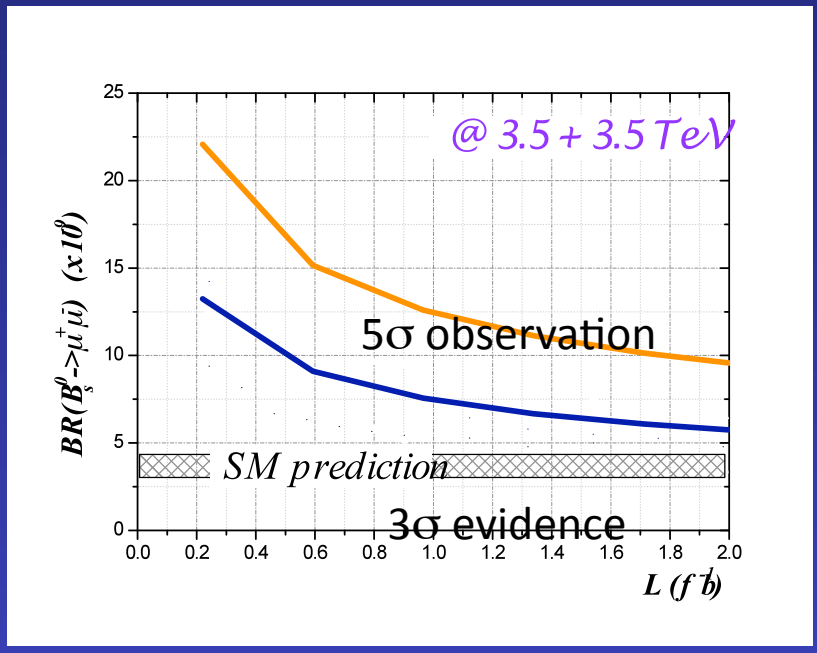
- Trigger efficiency
  - L0xHLT1
  - using $J/\psi \to \mu^+\mu^-$

Good agreement between data and MC



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



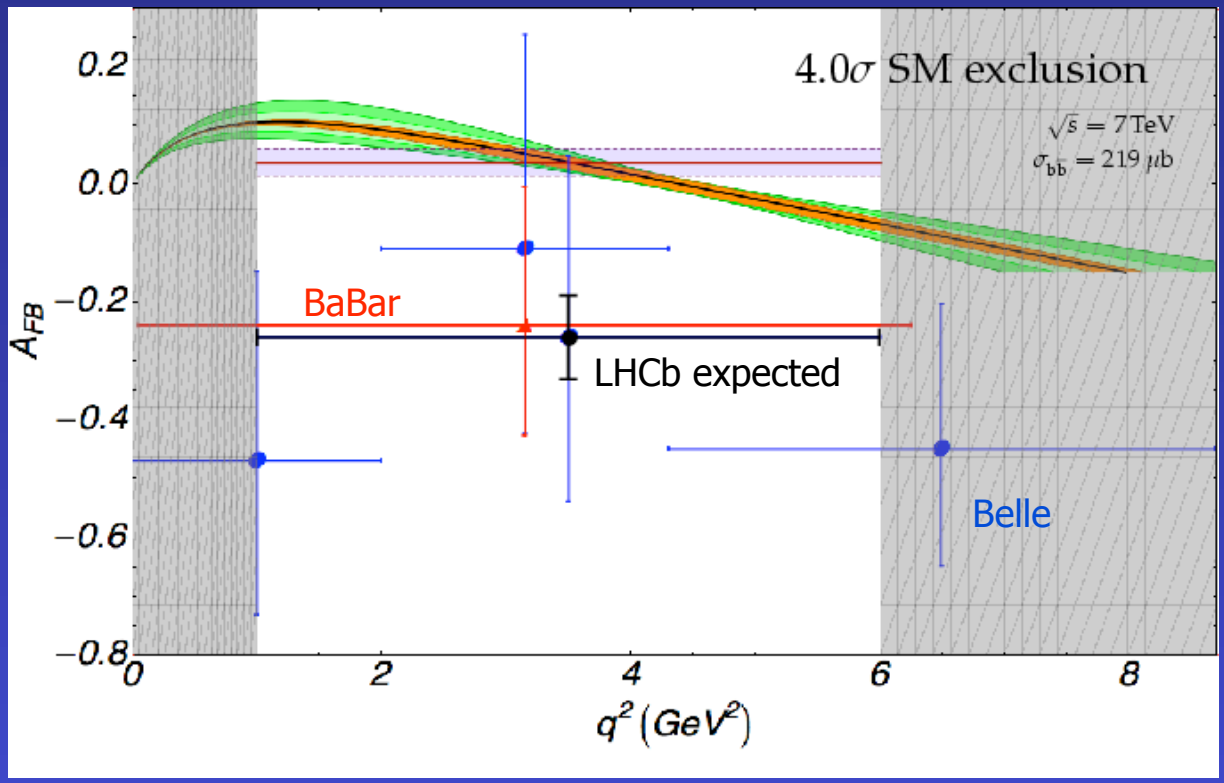


- **Expected Sensitivity**
  - 200 pb^{-1} to improve upon expected Tevatron limit with 8fb^{-1}
  - 3 fb^{-1} for 3σ evidence and
    10 fb^{-1} for 5σ observation of SM value @ 14TeV

Prospects with B→K*μμ

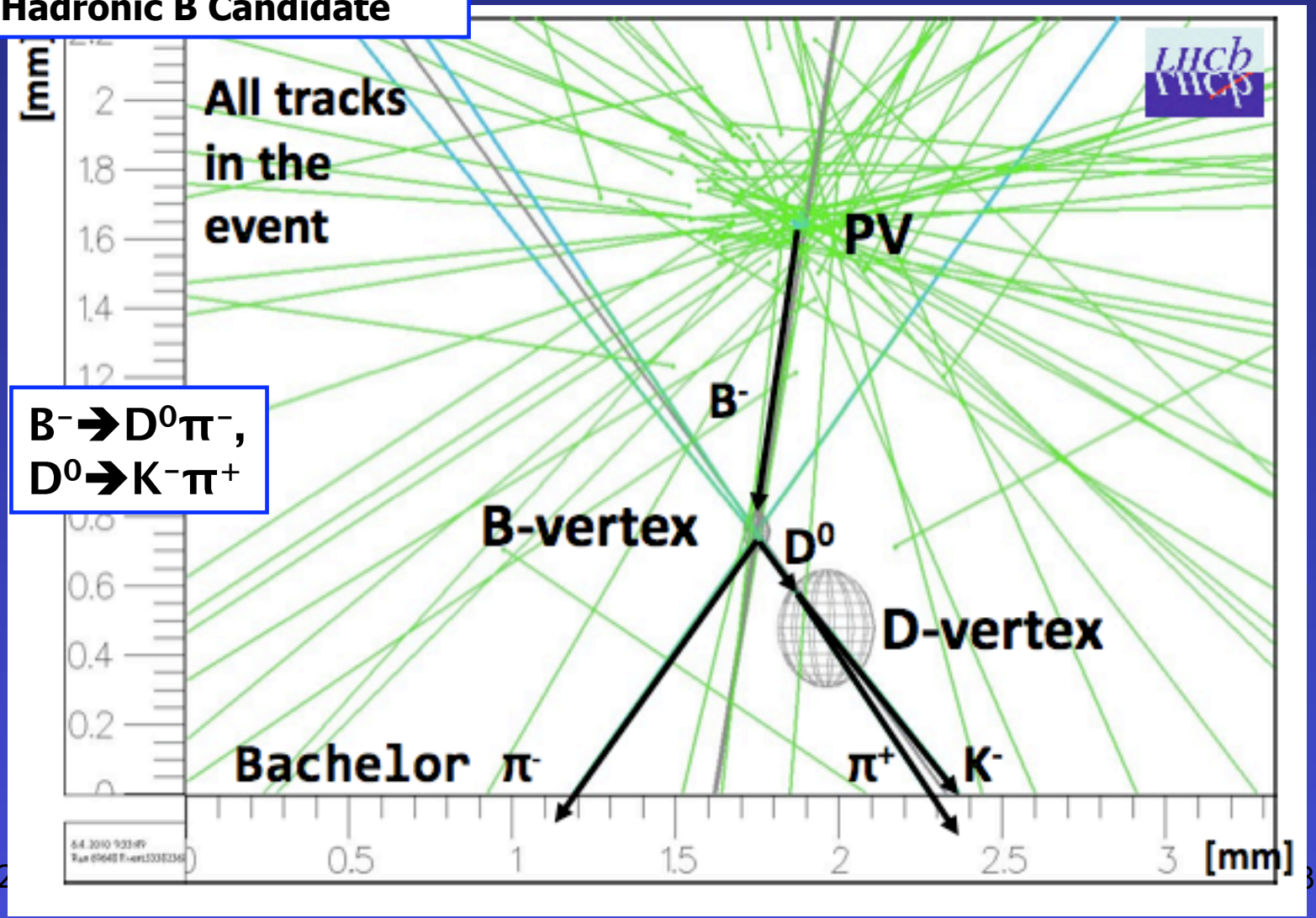
With 1 fb^{-1} LHCb expects 1200 events with $q^2 < 6$ GeV^2

At Belle central value, SM could be excluded at 4σ



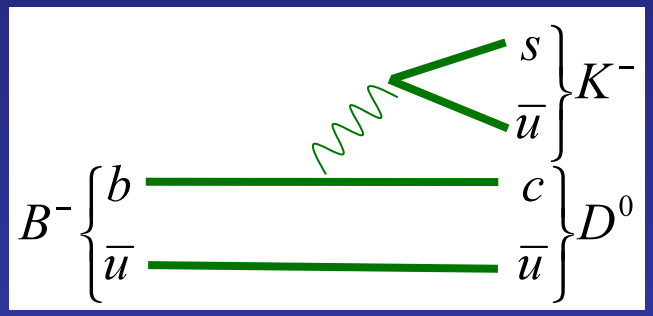
Hadronic B decays

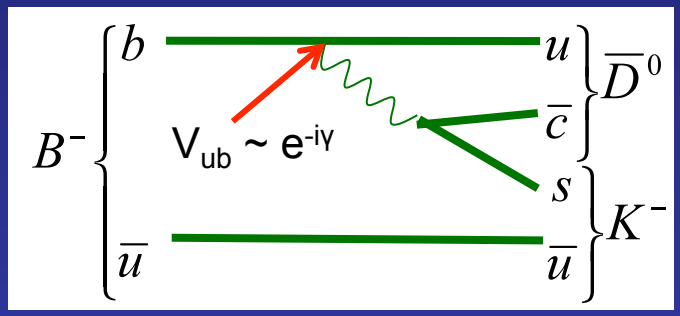
First fully reconstructed Hadronic B Candidate



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

CKM angle γ from $B^+ \to D^0 K^+$





- **"ADS+GLW" Strategy**
  - Diagrams interfere, sensitive to CKM angle CKM angle γ
  - Measure the relative rates of $B^- \to DK^-$ and $B^+ \to DK^+$ decays with D's in final states such as: $K^-\pi^+$ and $K^+\pi^-$, $K^-\pi^+\pi^-\pi^+$ and $K^+\pi^-\pi^+\pi^-$, K^+K^-
  - Similar method for neutral $B^0 \to DK^{*0}$ decays (GLW)
  - Will also use Dalitz plot of D^0 decays into a 3- body CP eigenstate $D^0 \to K_S^0\pi^+\pi^-$

Atwood, Dunietz and Soni, Phys. Rev. Lett. 78, 3257 (1997).

Gronau, London, Wyler, PLB. 253, 483 (1991)

Giri, Grossman, Soffer, Zupan, PRD 68, 050418 (2003).

- **Prospects for CKM angle γ**
  - With 100 pb-1 can improve upon B-factories
  - Expect 70 doubly Cabibbo suppressed events in ADS
  - Estimated precision 7^o in 1 fb^{-1}

No time to discuss here

- CP asymmetries in gluonic b→s penguin decays
  - $B_s \to \phi\phi$, K*K*
- Charmless Hadronic B Decays
  - Time-dependent B_d, $B_s \to hh$ analysis, B_s mixing - $B_s \to D_s\pi$
- Radiative penguin decays
  - $B_s \to \phi\gamma$, $B_s \to K^*\gamma$
- Radiative CKM angle γ
  - 3-body Dalitz decays, $B_s \to D_s K$
- CKM angle sin2β
  - $B_d \to J/\psi K_S$
- CKM angle α
  - $B \to \rho\pi$
- Spectroscopy
  - X, Y, Z, …
- Unexpected
  - Long lived particles, e.g. hidden valleys

Outlook

- **<≈1 pb-1 Summer 2010**
  - Charm and B cross sections at 7 TeV and high rapidity
  - with D and J/psi mesons and semileptonic B decays
- **~200 pb-1 2010**
  - Compete with or improve upon Tevatron and B-factories
  - $B_s \to J/\psi\phi$, $B_s \to \mu\mu$, , $B_d \to K^*\mu\mu$, Bs mixing, CKM angle γ,
- **~1 fb-1 2011**
  - Start of full LHCb physics programme
  - Probe new physics in CP Violation and rare heavy flavour decays
- **LHC Physics in ~2015**
  - New Physics (NP) will hopefully be discovered by ATLAS/CMS and LHCb
  - New Physics will very likely show up in Flavour observables
  - Better Flavour Physics will be required to elucidate NP flavour structure or probe NP at higher mass scale
- **LHCb Upgrade**
  - LHC is a Super Flavour factory, O(1MHz) rate of b-quarks
  - Operate experiment at ~10 times design luminosity

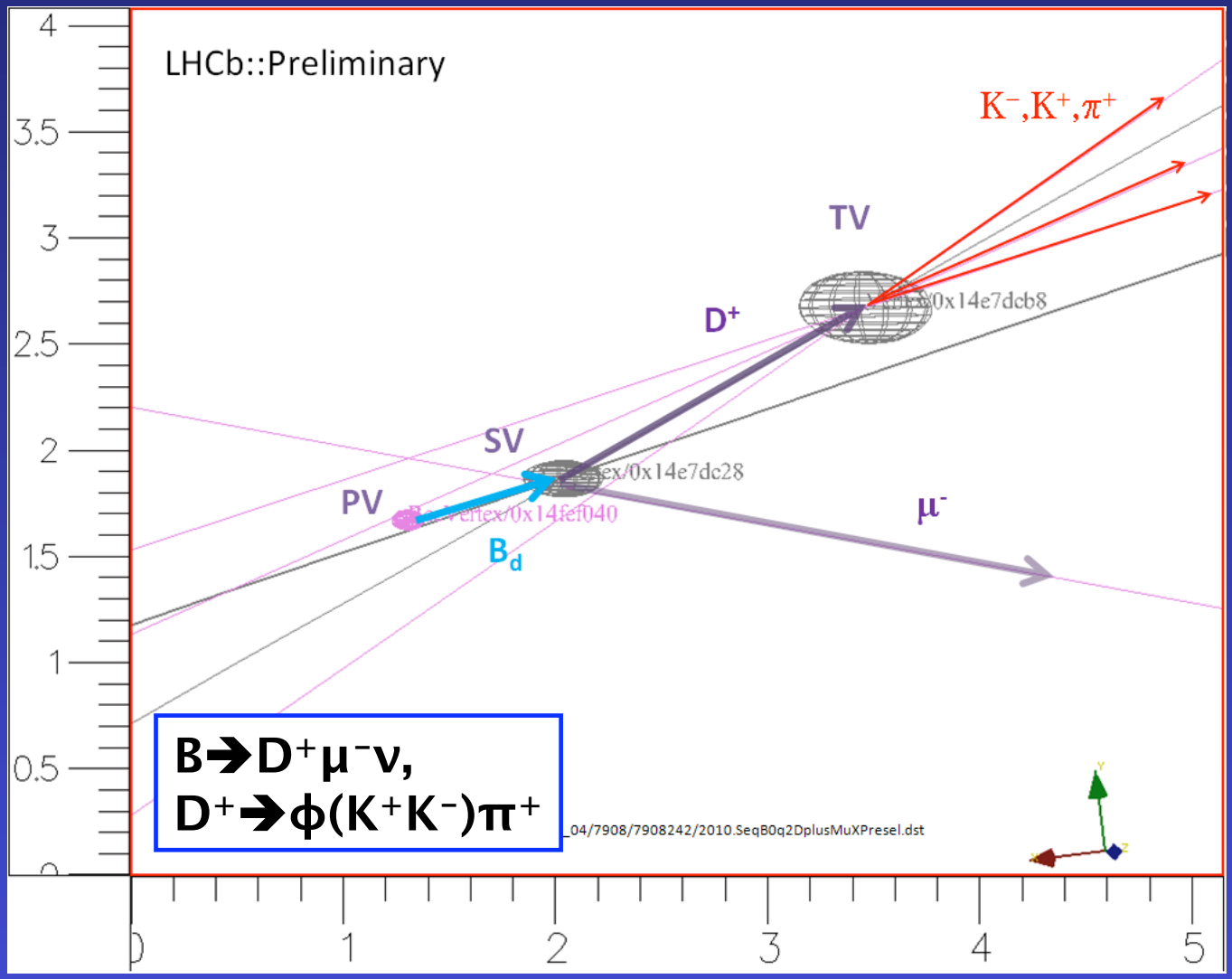
See talk by Frederic Machefert

Conclusions

- **LHCb experiment is fully commissioned**
  - All detectors are working close to expectations
- **Data taking with LHC beams at 7 TeV**
  - Detector performance close to expectations
  - Alignment and calibraton well underway
  - Trigger, Vertex detector and Particle ID close to expectations
- **LHCb Detector Performance is excellent**
  - Many strange and charm hadrons already observed
  - First Beauty particles observed
  - Exciting prospects with 100 pb^{-1} in 2010
- **Looking forward to analyse full 2010/11 LHC data set**
  - Could observe New Physics with this run
- **LHCb upgrade R&D has started**

Backup Slides

B Production at √s = 7 TeV



LHCb Upgrade Plans

- **Status of LHC Physics in ~2015**
  - New Physics may or may not be discovered by ATLAS/CMS and LHCb
  - New Physics will very likely show up in Flavour observables
- **Flavour physics beyond the first phase of LHC**
  - Better Flavour Physics will be required
    to elucidate the NP flavour structure or probe NP at higher mass scale
  - LHC is a Super Flavour factory
    10^6 Hz of b-quarks produced ➔ LHCb Upgrade
- **LHCb Upgrade Strategy**
  - running at 10 times design luminosity, i.e. at ~ 2×10^{33} $cm^{-2}s^{-1}$
  - read out full experiment at 40 MHz, currently at 1 MHz
  - → vertex and photon detector needs to be replaced
  - Upgrade expected at ~ 2016, R&D has started

See talk by Frederic Machefert

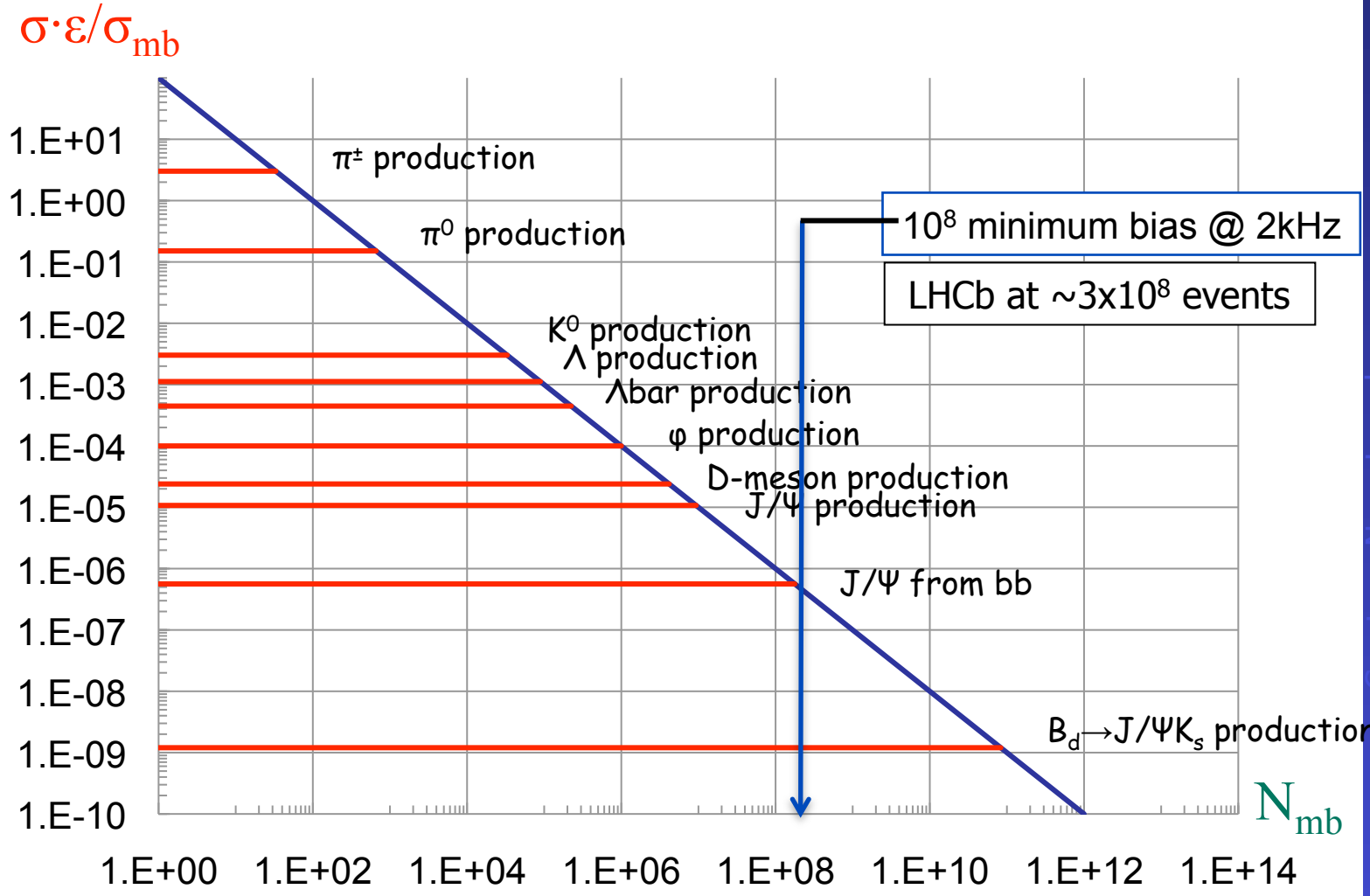
Outlook

- **<≈1 pb^{-1} summer**
  - Charm and B cross sections at 7 TeV and high rapidity using D, J/psi and semileptonic decays
- **~200 pb^{-1} 2010**
  - Compete with or improve on Tevatron and B-factories
  - $B_s \to J/\psi\phi$, $B_s \to \mu\mu$, , $B_d \to K^*\mu\mu$, B_s mixing, CKM angle γ,
- **~1 fb^{-1} 2011**
  - LHCb physics programme
  - Probe new physics in CP Violation and rare heavy flavour decays

- **No time to discuss**
  - CP asymmetries in gluonic $b \to s$ penguin decays,
    - $B_s \to \phi\phi$, K^*K^*
  - Charmless Hadronic B Decays, time-dependent
    - B_d, $B_s \to hh$ analysis
  - CKM angle γ
    - 3-body Dalitz decays
  - Radiative penguin decays
    - $B_s \to \phi\gamma$, $B_s \to K^*\gamma$
  - CKM angle sin2β
    - $B_d \to J/\psi K_S$
  - CKM angle α
    - $B \to \rho\pi$
  - Spectroscopy X, Y, Z,
- **LHCb upgrade**
  - After ~2015

See talk by Frederic Machefert

Minimum Bias

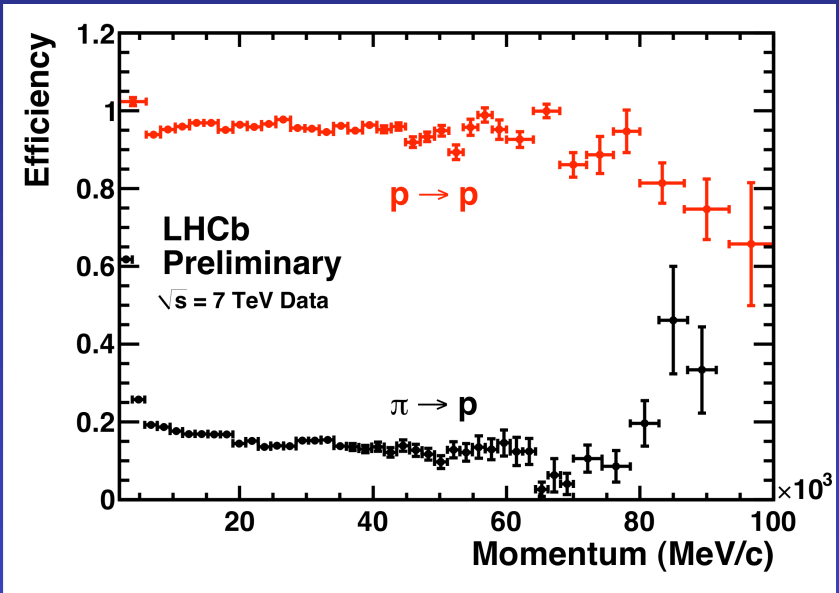


Courtesy, Nuno Leandro

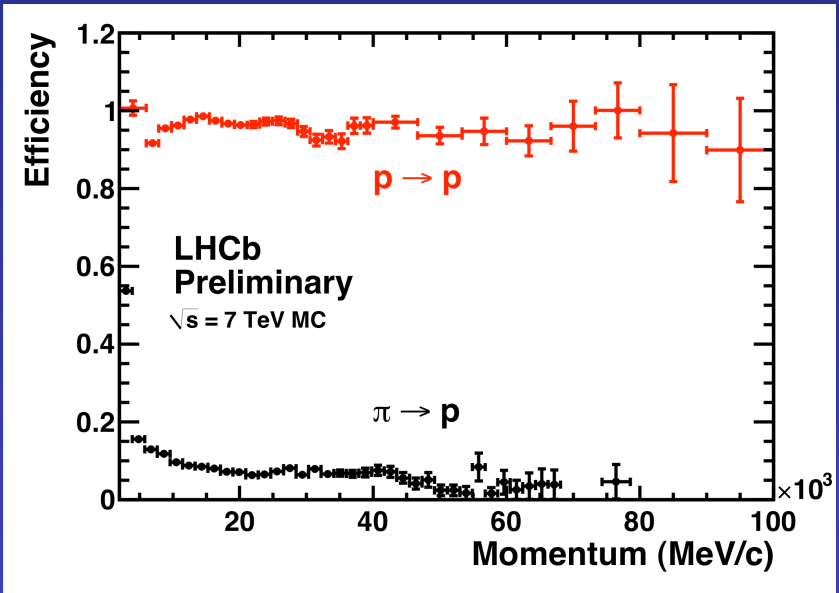
RICH PID Performance

Example of performance: p-π discrimination

Data



Monte Carlo



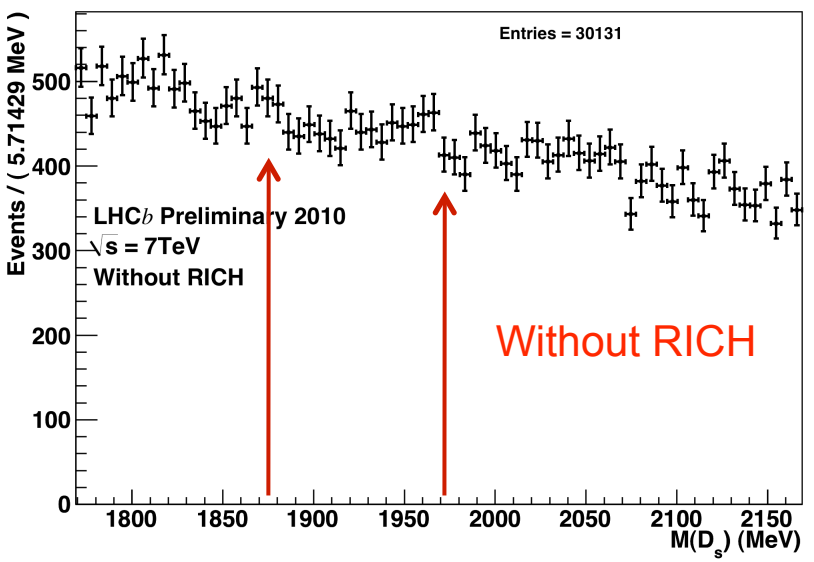
$$\Delta \log \mathcal{L}(\mathrm{p} - \pi) > 0$$

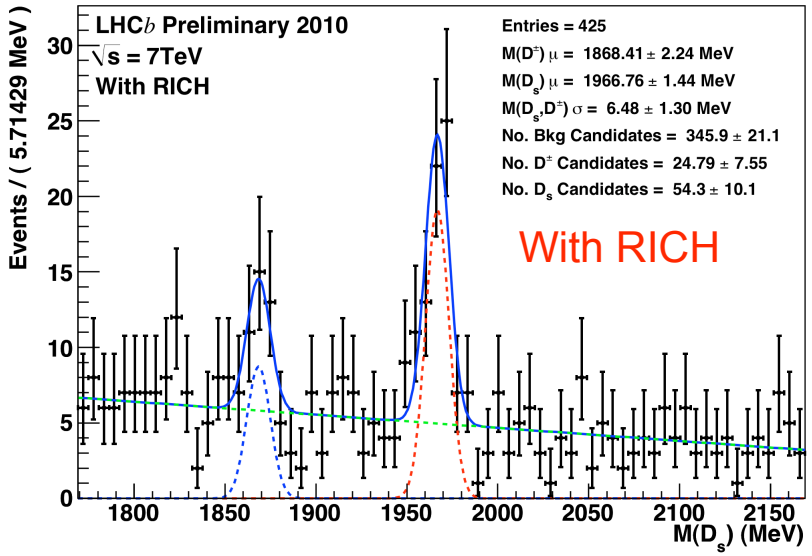
- Alignment and calibration still in early stages
- Thus, impressive to have such reasonable agreement between MC and data so soon!
- Expect marked improvements in the coming weeks

$D_s \rightarrow \phi\pi$ $\sqrt{s}$ = 7 TeV data

$D_{(s)}^{+} \rightarrow \phi\pi^{+}$, $\phi \rightarrow KK$

- **RICH PID**
  - Crucial for D_s
  - Facilitated finding first B candidate $B^{+} \rightarrow J\backslash\psi K^{+}$
  - Particle zoo is increasing each day: Λ_c, Ω^{-}, ...
  - PID performance results will appear soon
- **Exciting Outlook**
  - After a few weeks of data taking, RICH is running very well and used to produce first results
  - Looking forward to increasing data sets for physics analysis





The End