Open charm and charmonium production at LHCb

Mat Charles (Oxford)
on behalf of the LHCb collaboration

BEACH2010: IX International Conference on Hyperons, Charm and Beauty Hadrons
21-26 June 2010, Perugia

Antipasto (spring 2010) $O(nb^{-1})$

Charm peaks; first K_S paper

We are here

Primo piatto (summer 2010) $O(pb^{-1})$

Charm production studies

Secondo piatto (winter 2011) $O(100\ pb^{-1})$

First searches for NP in flavour physics

(e.g. mixing and CPV in charm; $B_s \to \mu\mu$)

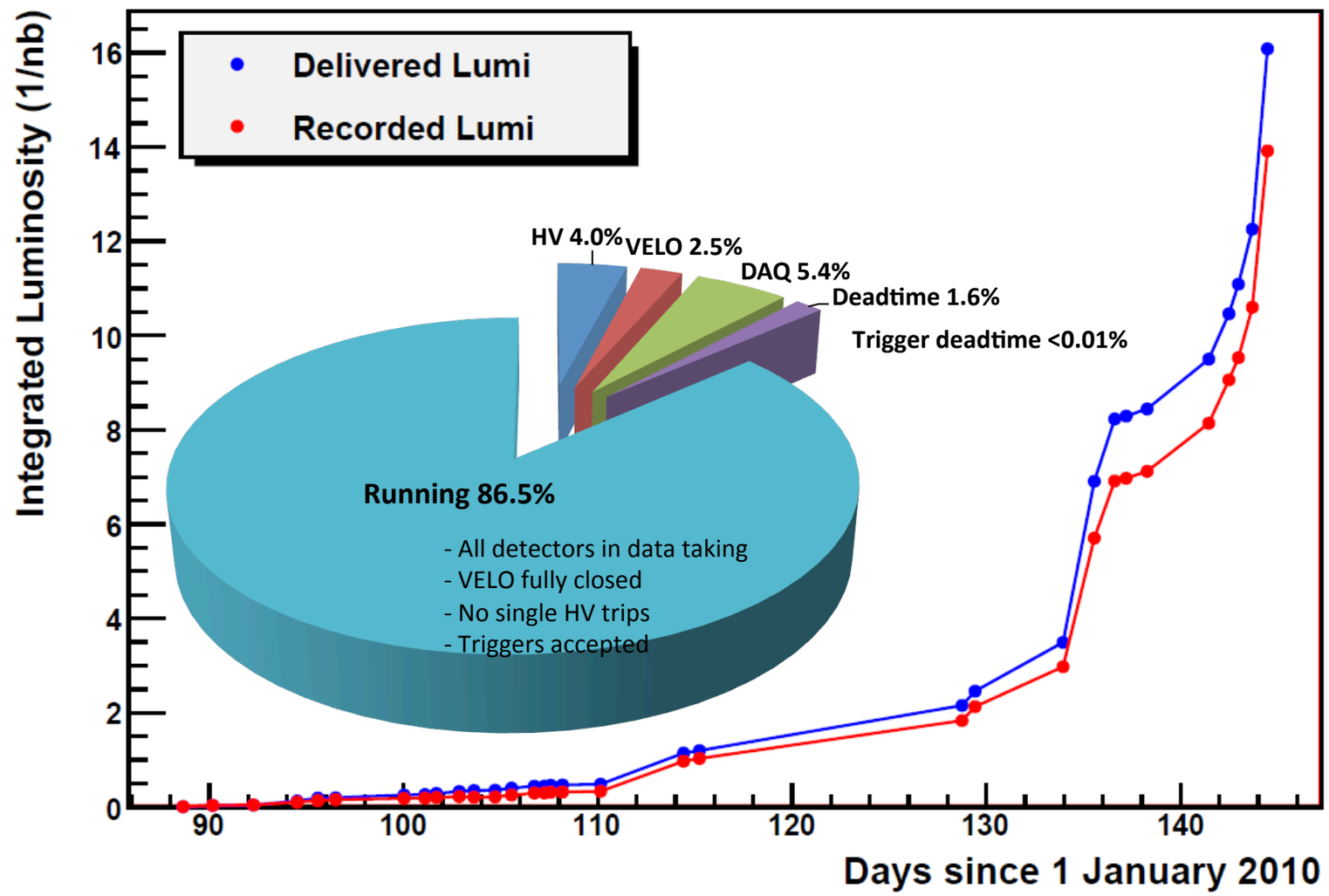
See talk by Jeroen van Tilburg for more

Dolce (2012?) $O(fb^{-1})$

High-luminosity flavour physics

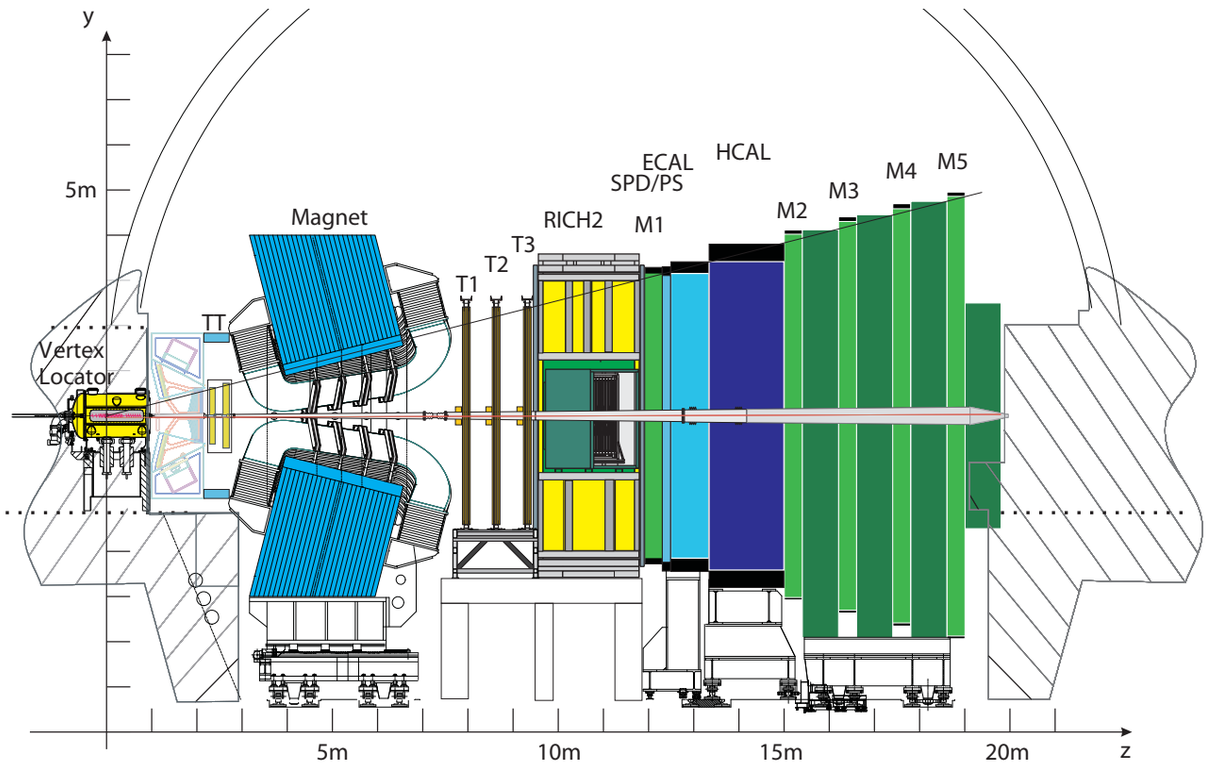
This talk

- Introduction
  - Our detector & acceptance
  - Luminosity measurements
- Charmonia
- Open charm
- Forthcoming attractions



See talk by Sebastian Bachmann for more

LHCb: Acceptance



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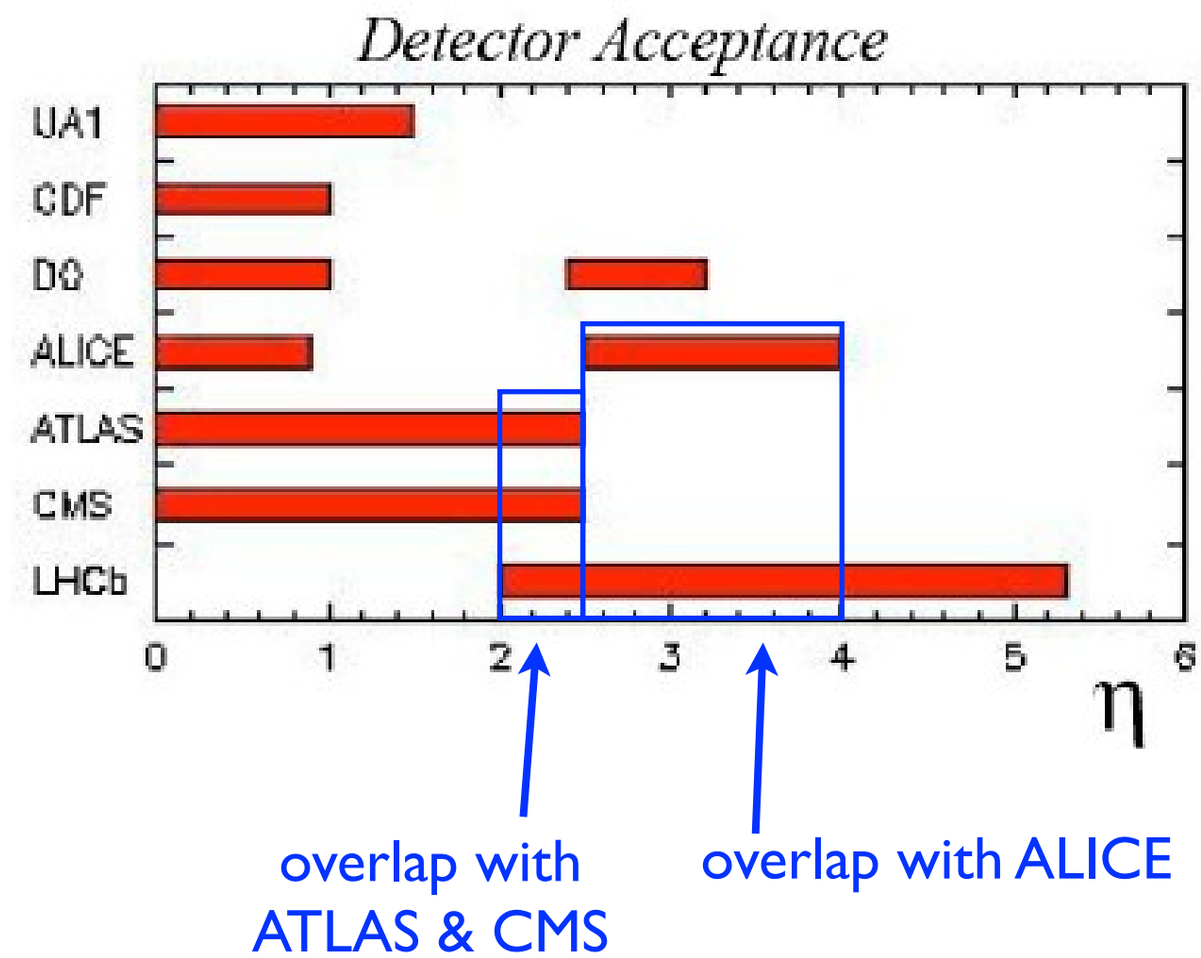


- Angular acceptance: $15 < \theta < 300$ mrad
- Coverage of very forward region where theoretical uncertainties are larger.

LHCb: Luminosity

- Luminosity comes directly from beam properties:

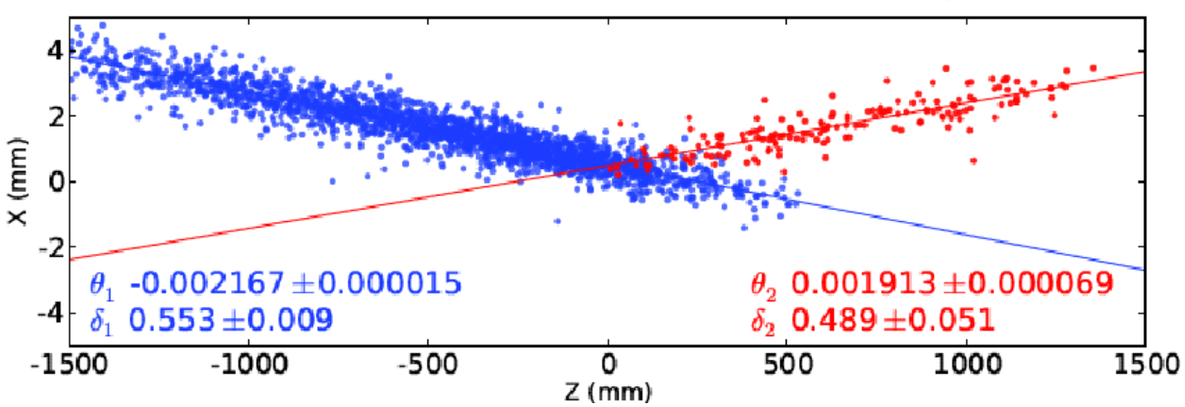
$$L = f \sum_{i}^{N} \frac{n_{1i} n_{2i}}{4 \pi \sigma_{xi} \sigma_{yi}}$$

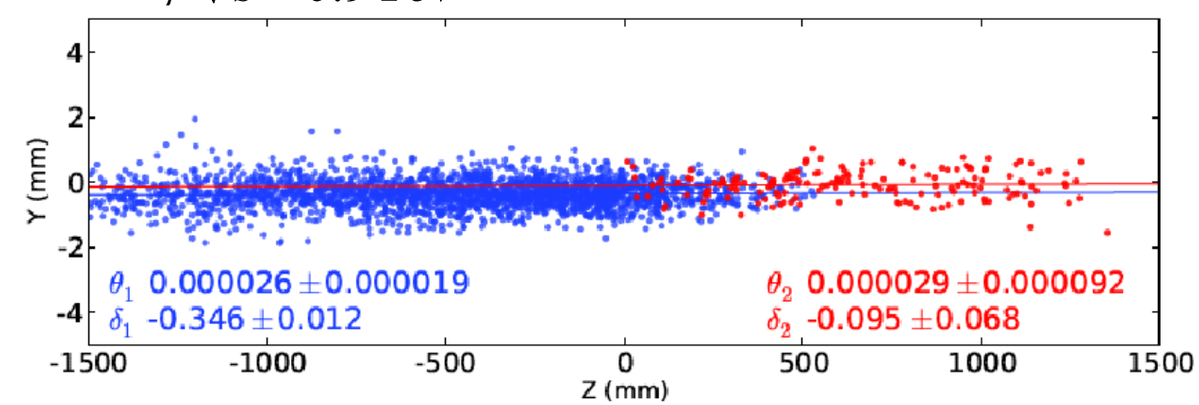
[+ crossing angle correction]

- n_{1i}, n_{2i} : nb of proton in bunches of collision I
- σ_x, σ_y : transverse bunch size
- f : frequency of collision
- N : number of bunches

- Beam positions & crossing angle measured regularly with precision vertex detector using beam-gas interactions:

LHCb preliminary 2009 data, $\sqrt{s} = 0.9\,TeV$





- Will also determine luminosity from Van der Meer scans
  - First scan already carried out in April; working...
- 2009 uncertainty ~ 15%; expected to be 5-10% by end 2010.

Charmonia

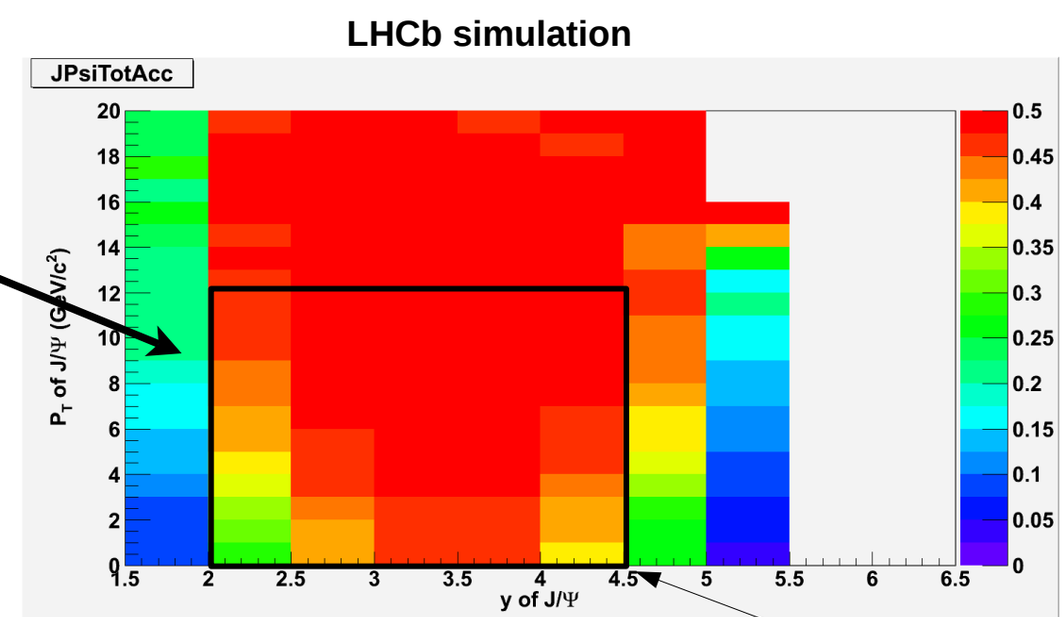
- What we want to accomplish
- Signals in the early data
- Evidence of secondary J/psi
- First look at raw p_T and rapidity spectra
- Towards a measurement

Charmonia: Motivation & plan

- Expect copious production of J/ψ at LHC:
  - Direct production
  - Feed-down from heavier charmonium states

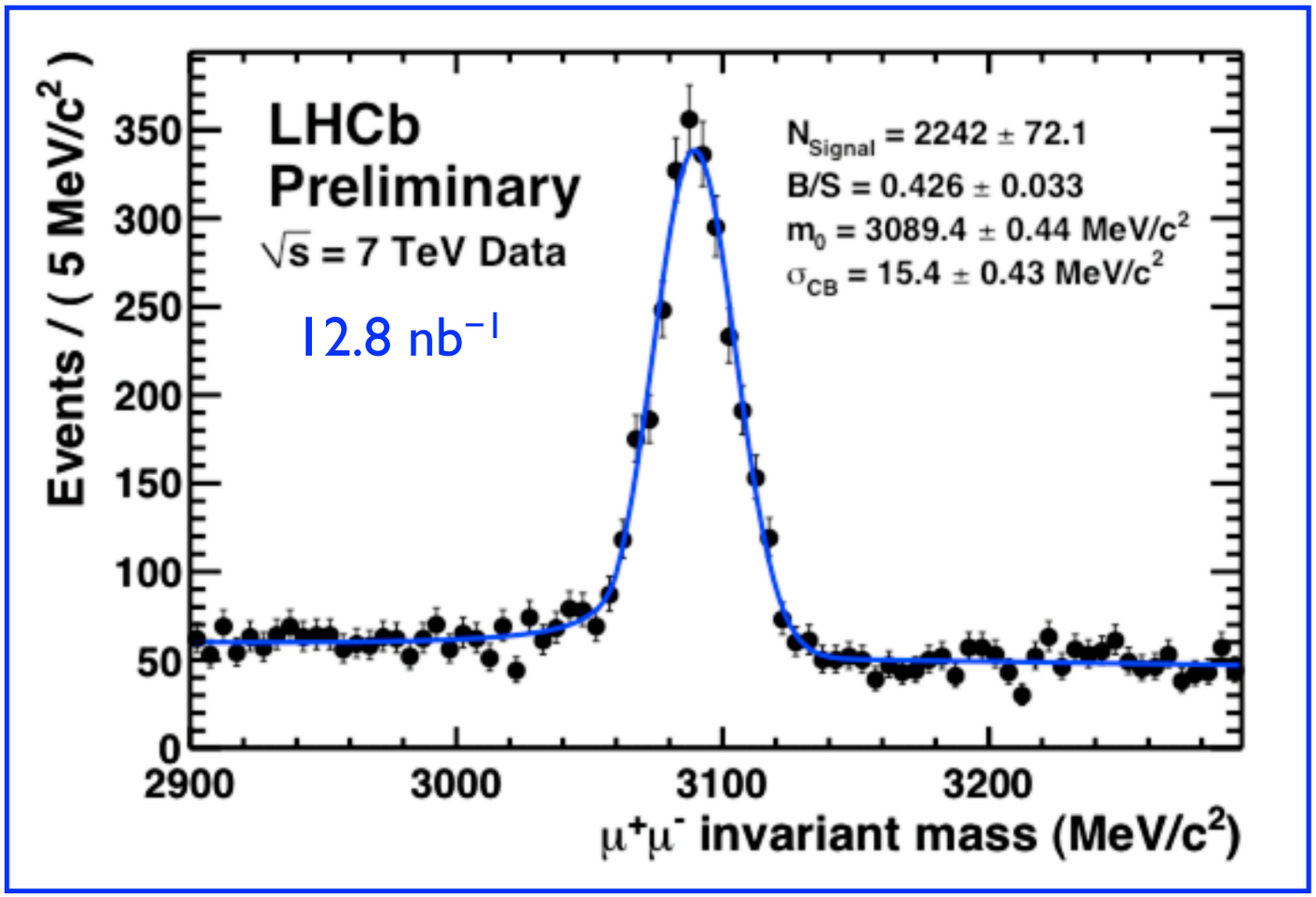
  prompt
  - Daughters of b-hadrons

  secondary
- Want to measure cross-section as fn of y, p_T for prompt and from-b (secondary) J/ψ separately
  - To better understand production process (colour-singlet vs colour-octet)
  - To improve LHCb simulation for later physics studies
- Full analysis will use O(10-20 pb^{-1})
  - High statistics needed for O(5x12) bins of y vs p_T...



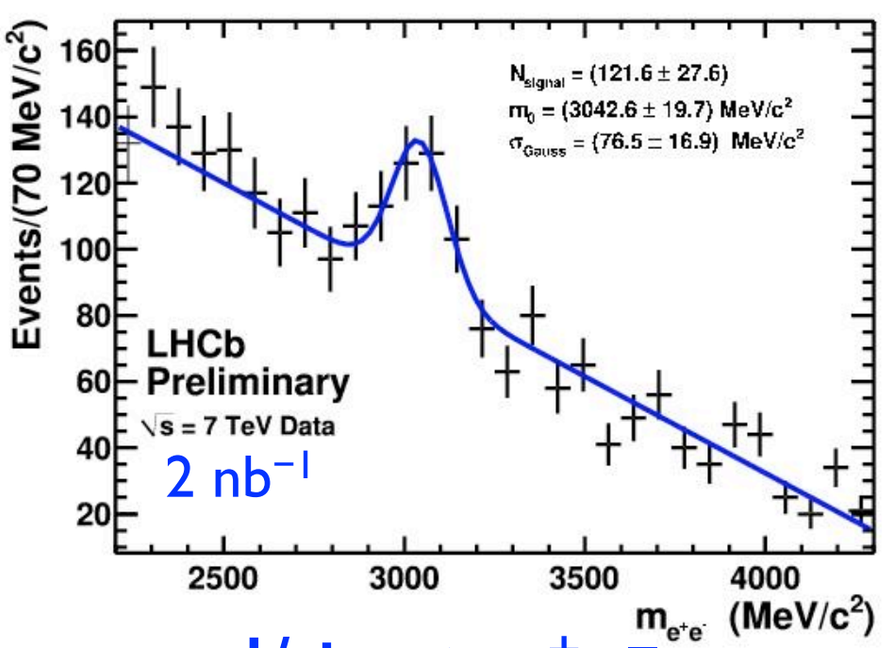
Plot shows detector acceptance... but polarization-dependent (see later)

Clear charmonium signals

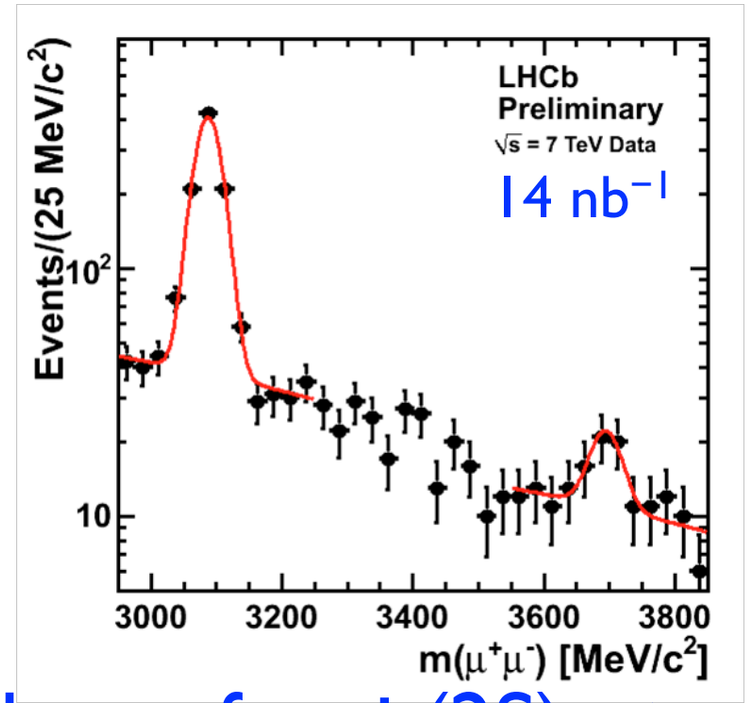


$J/\psi \rightarrow \mu^+\mu^-$

Includes cuts on p_T of J/ψ and of μ daughters



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



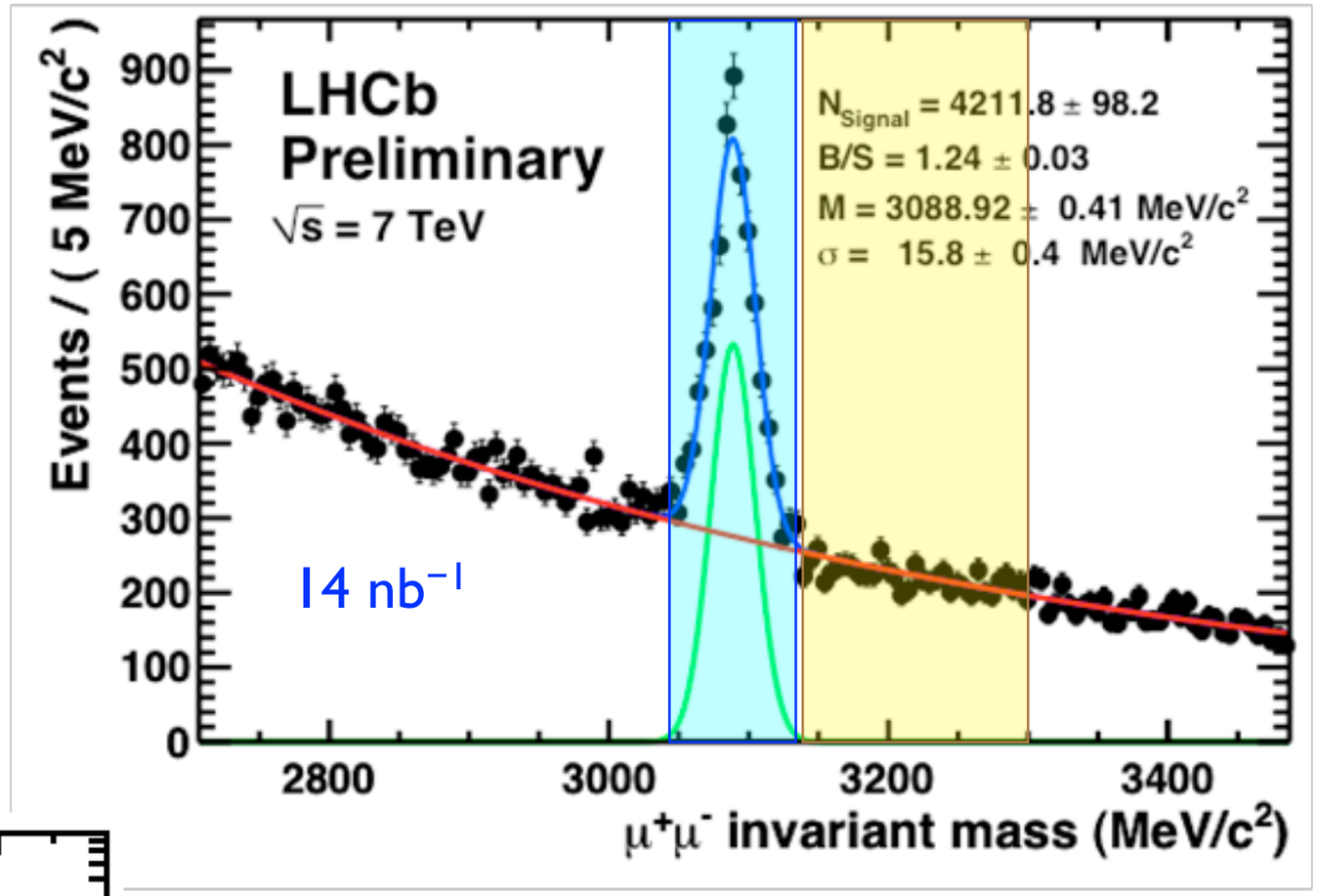
3.3σ

Evidence for $\psi(2S) \rightarrow \mu^+\mu^-$

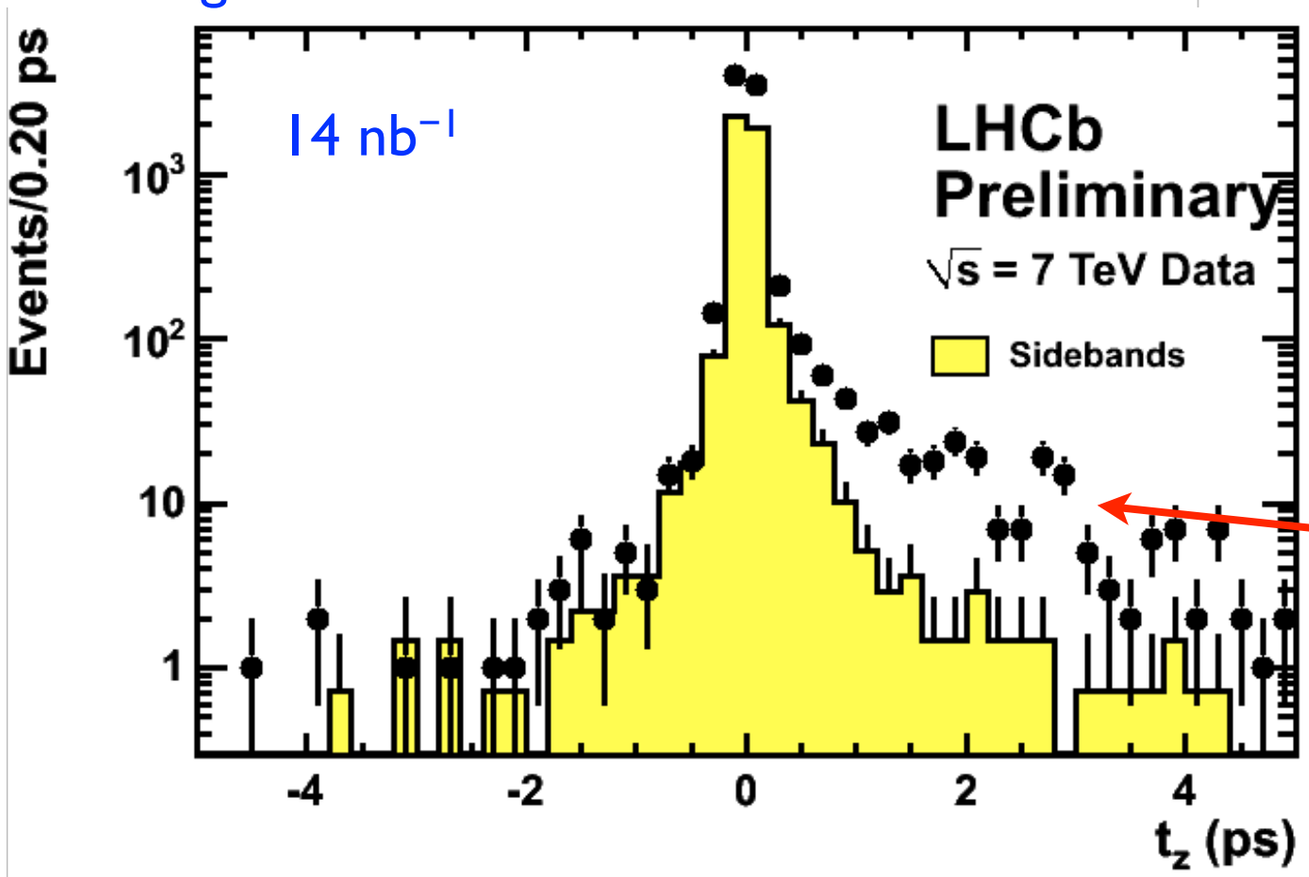
Prompt & secondary J/psi

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

Loose selection suitable for cross-section measurements in full range of y, p_T



Note log scale



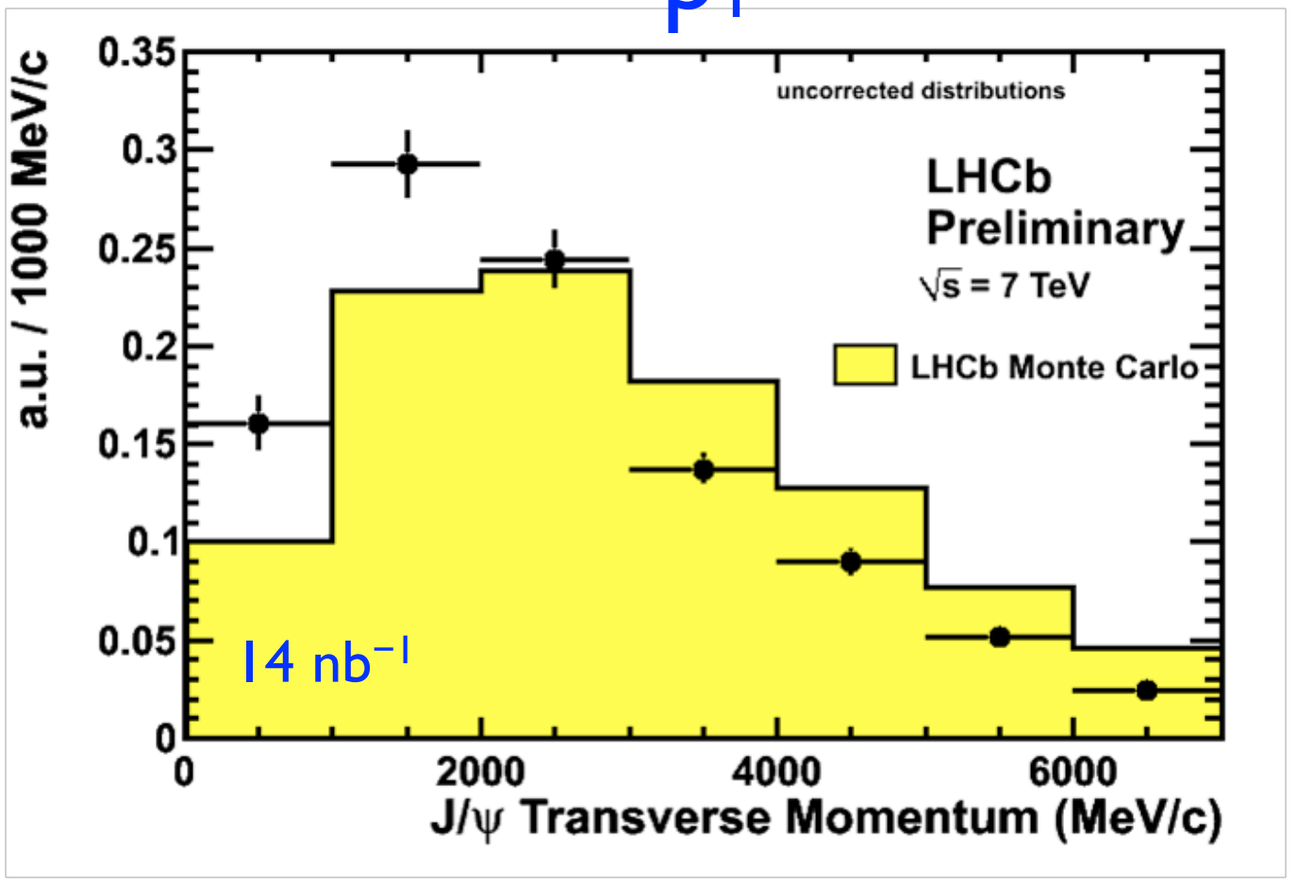
Pseudo-proper-time of J/ψ

Clear evidence of secondary production from long-lived B

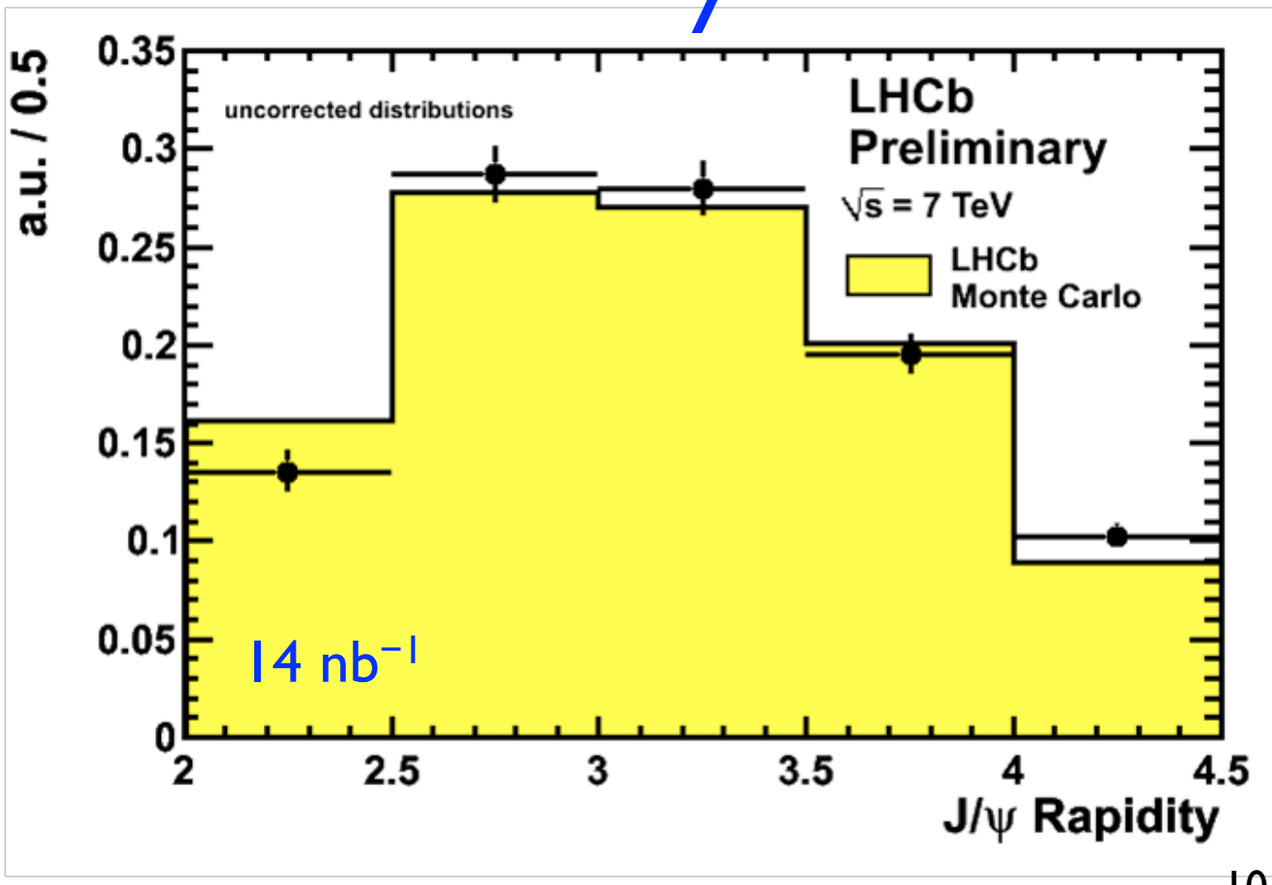
First look: J/ψ spectra in p_T and y

- Just 1D spectra for now! Full 2D distribution needs more statistics.
- Raw yields from bin-by-bin mass fits -- not corrected for efficiency.
- Prompt & secondary J/ψ mingled together

p_T

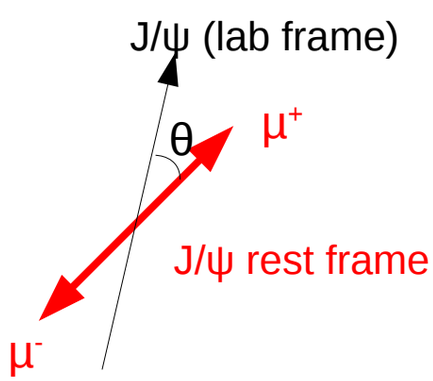


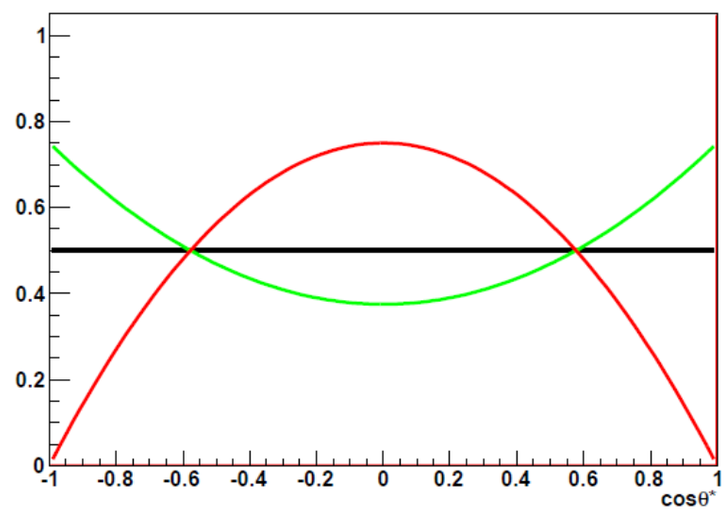
y



Further steps on the path to a measurement

Polarization of J/ψ is unknown, and strongly affects efficiency.
We will measure it later, but for first analysis treat as systematic.

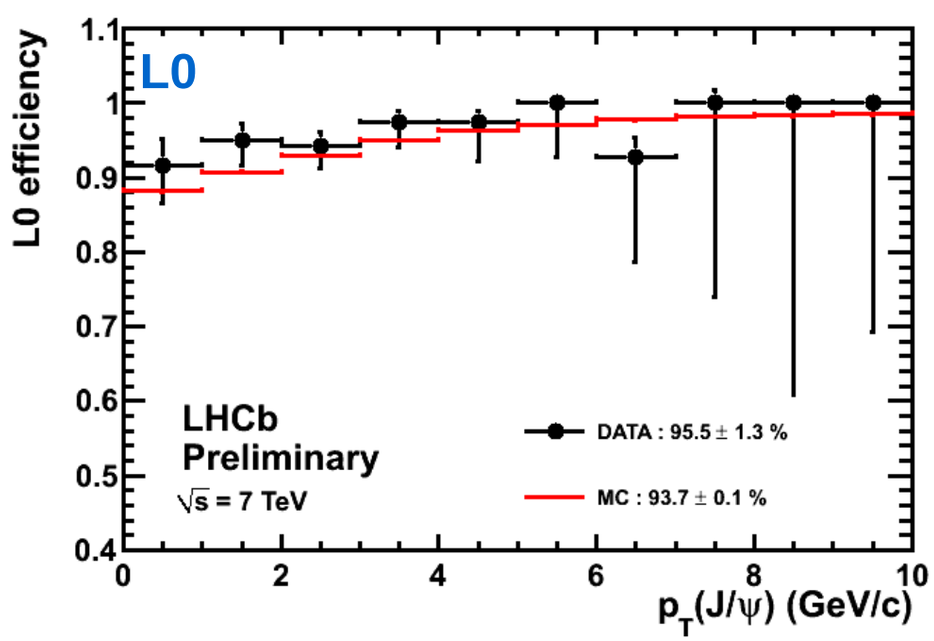


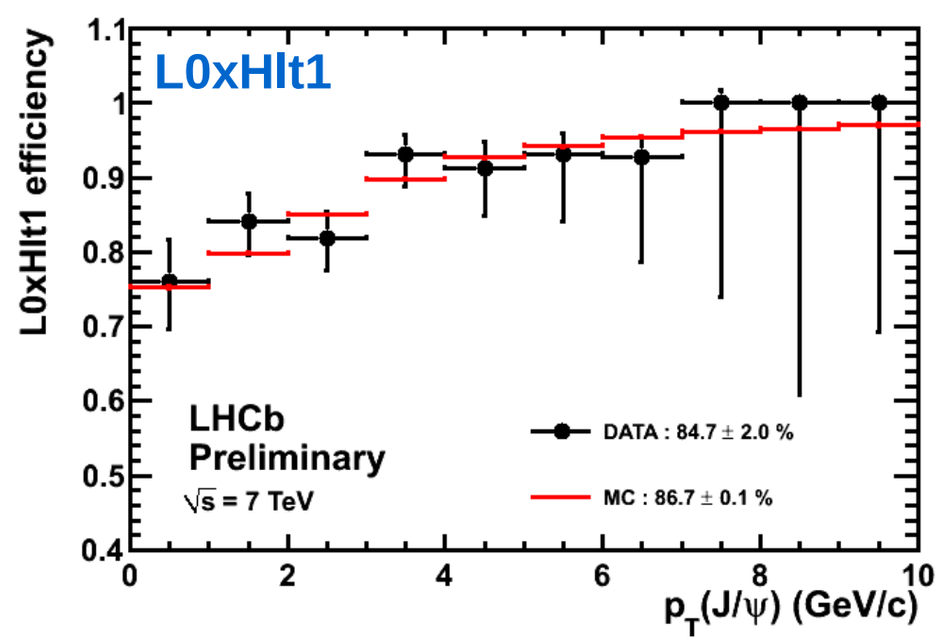


$$I(\cos\theta^*) = \frac{3}{2(\alpha+3)}(1+\alpha\cos^2\theta^*)$$

α=+1: transverse polarization
α=0: unpolarized
α=−1: longitudinal polarization

Trigger requires high-pT muon, affecting acceptance. Use independent triggers (copious in early data) to verify/correct MC.



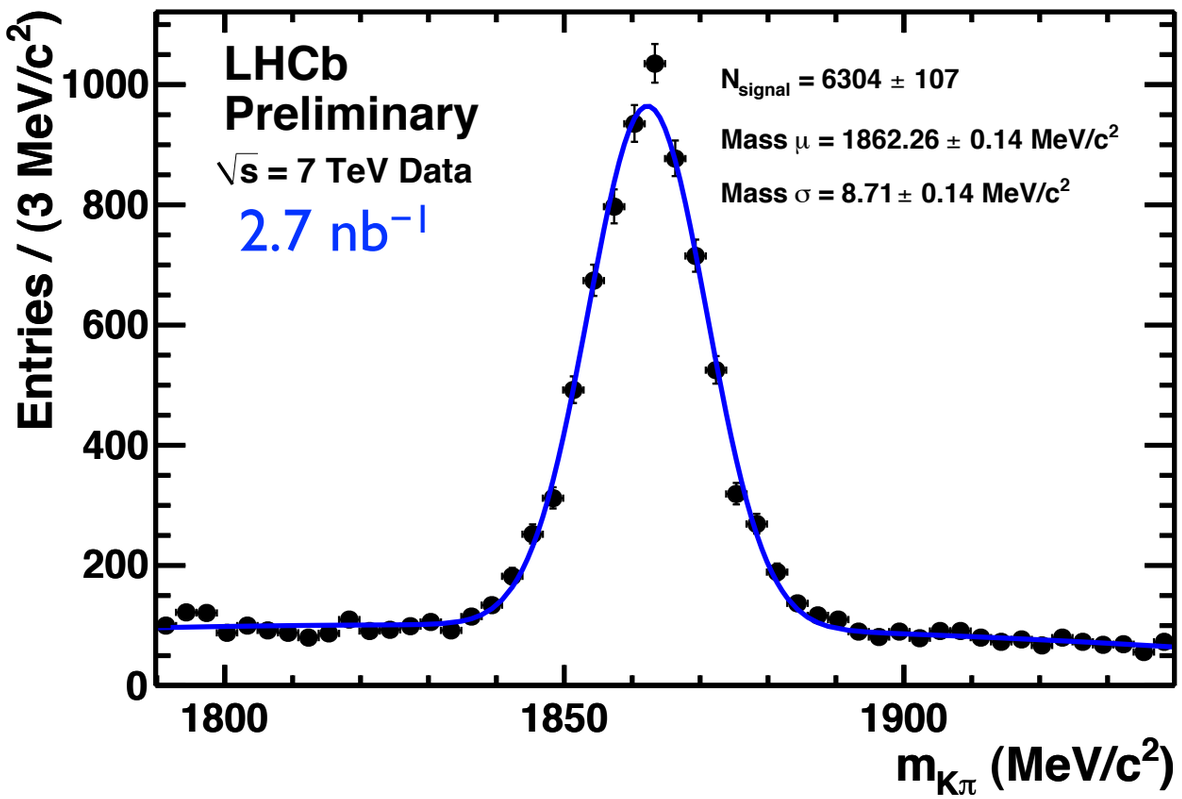


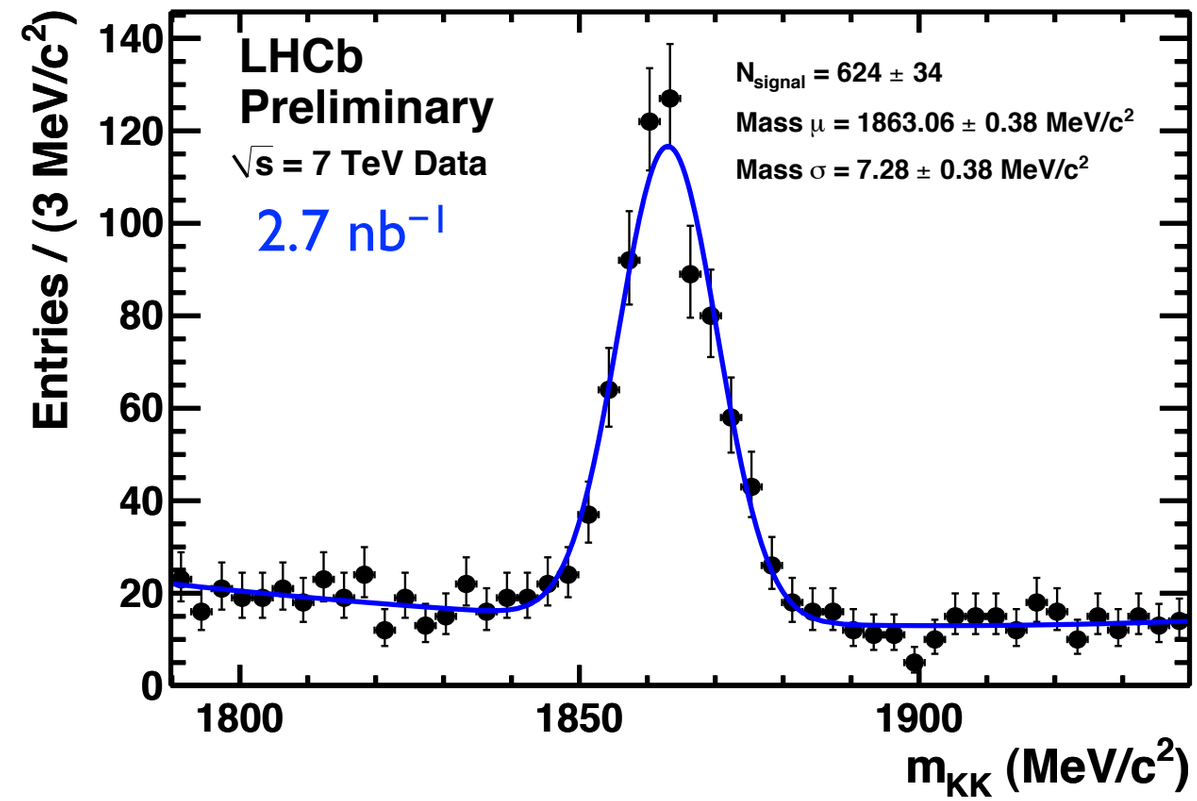
Open charm

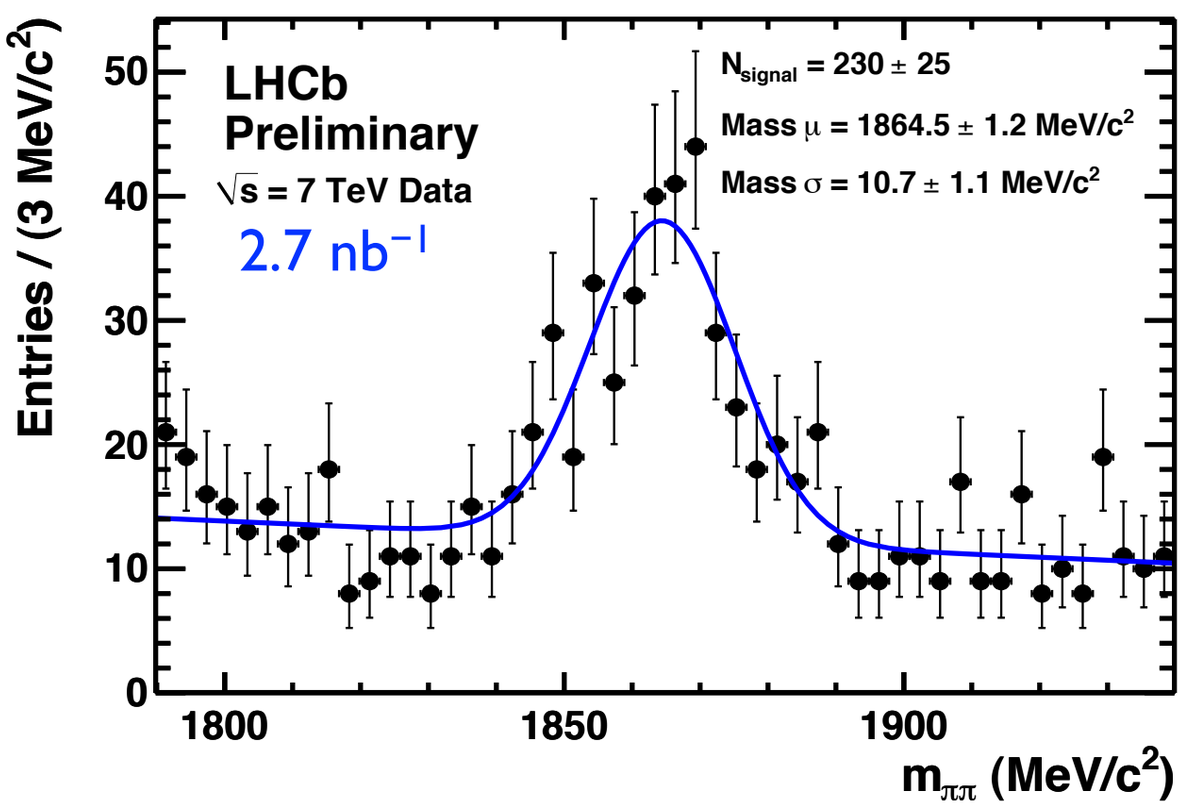
Similar situation for open charm:

- Signals and Dalitz plots in the early data
- Prompt-secondary discrimination
  - Trickier than J/ψ because of charm lifetime!
  - Using the impact parameter of the D
  - Using semi-leptonic B decays
- Towards production measurements
- Mixing and CPV

Untagged $D^0 \rightarrow h^+ h^-$



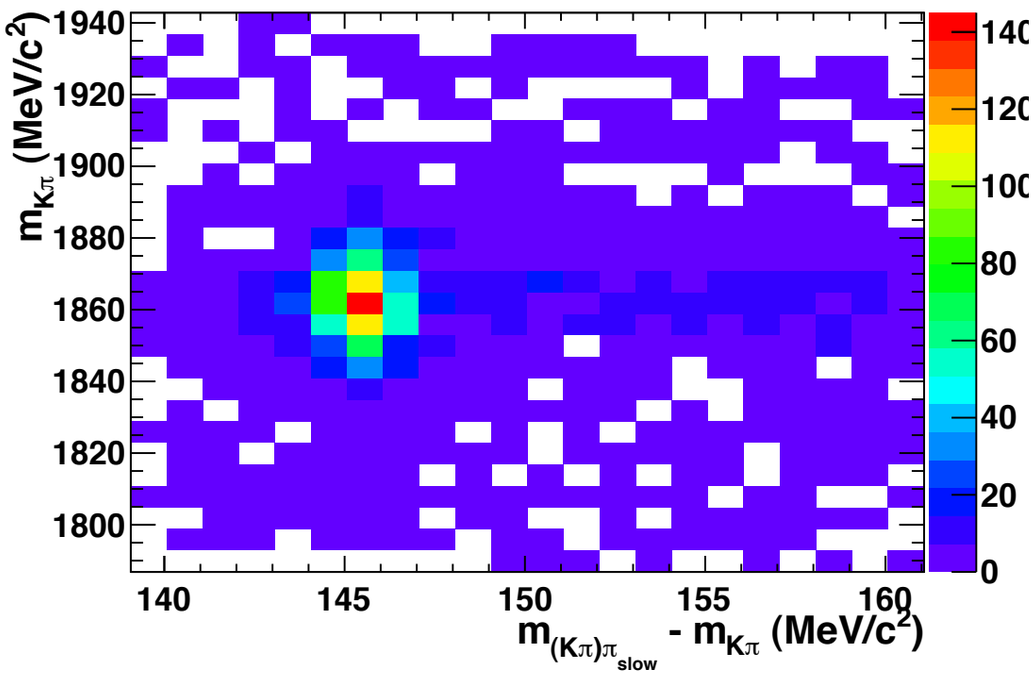




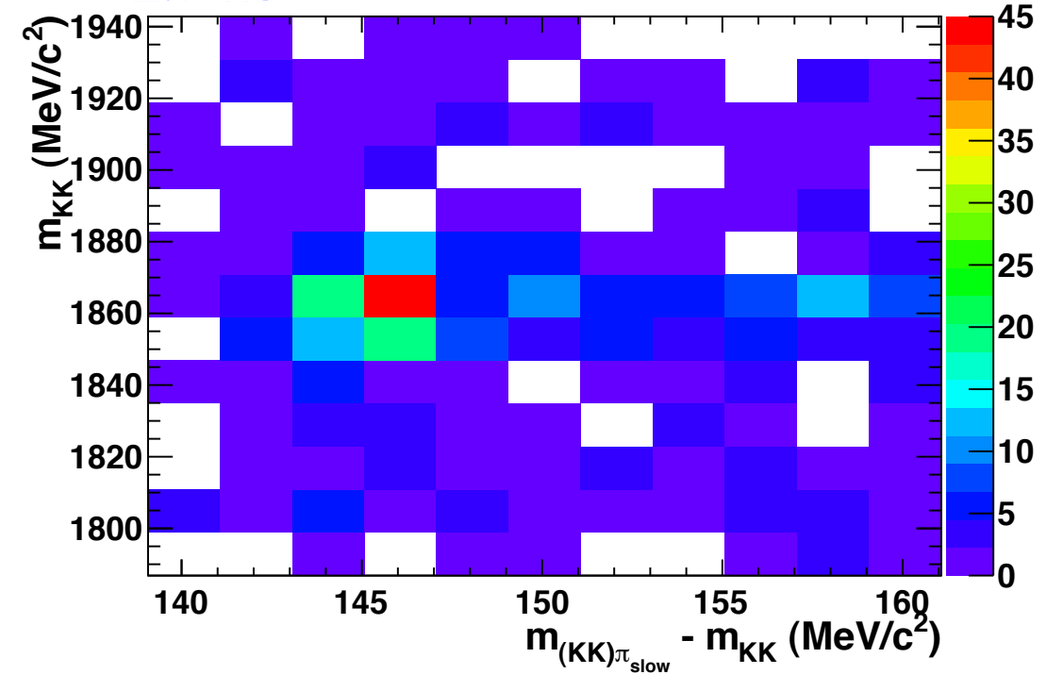
- Very clear $D^0 \rightarrow K^-\pi^+, K^-K^+$ peaks, benefitting from RICH
- Fewer handles for $D^0 \rightarrow \pi^-\pi^+$

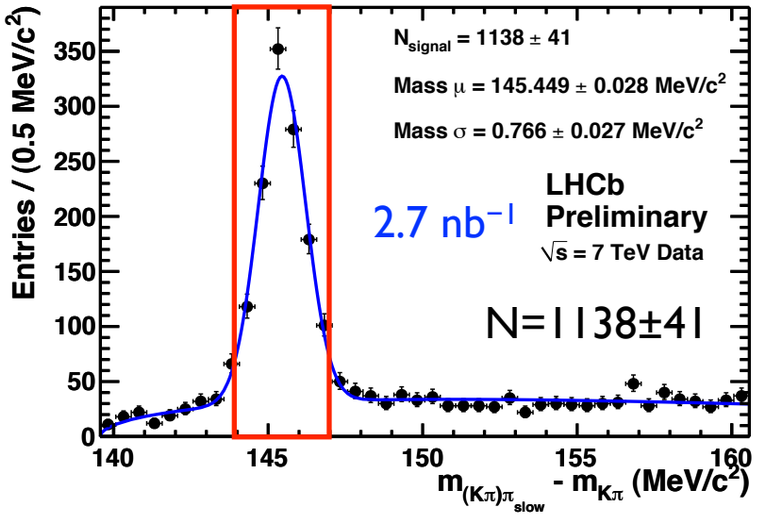
$D^{*+} \to D^0 \pi^+, D^0 \to h^+ h^-$

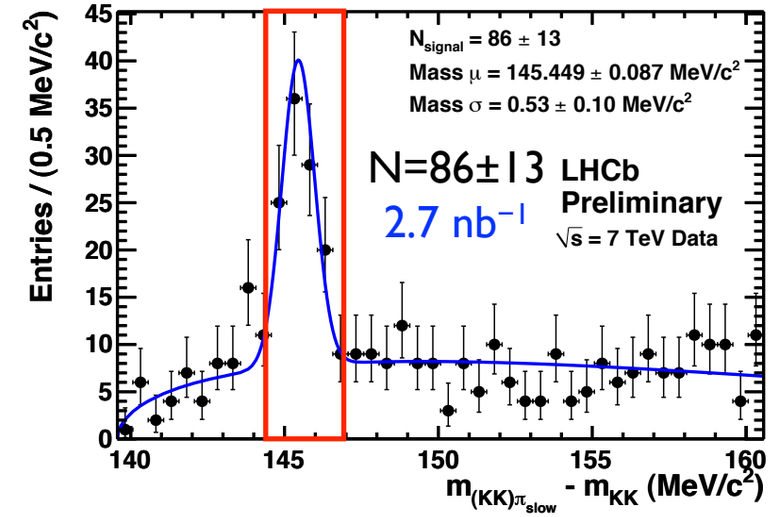
$K^-\pi^+$ 2.7 nb^{-1}



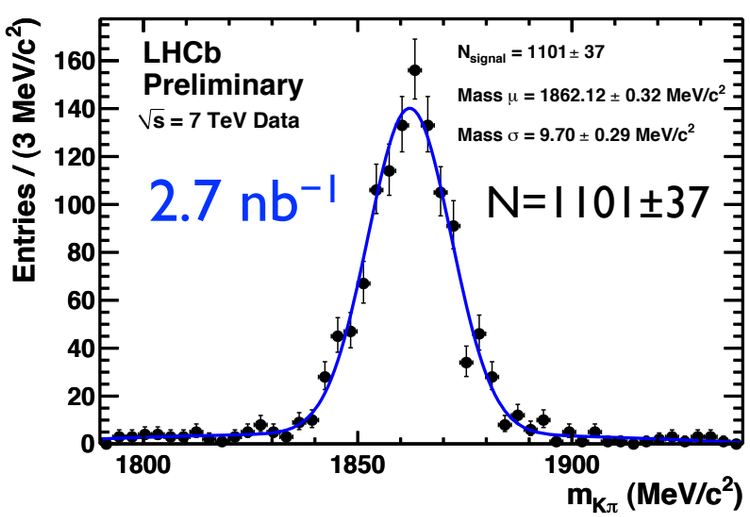
K^-K^+ 2.7 nb^{-1}



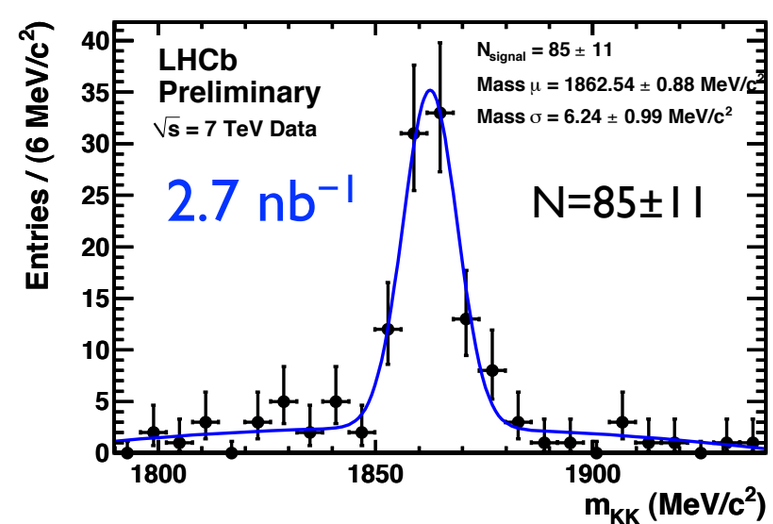




ΔM, taking full range of $m(D^0)$

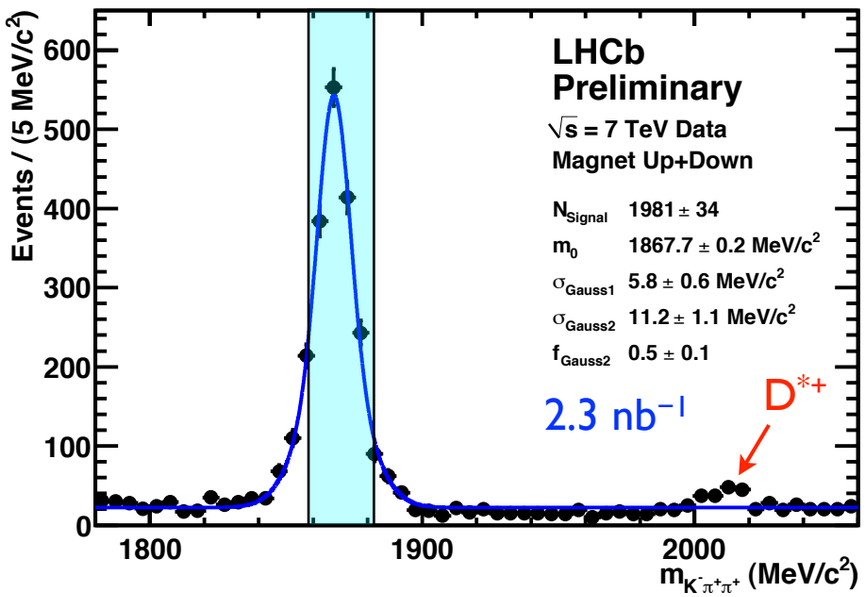


$m(D^0)$, applying 2σ cut on ΔM



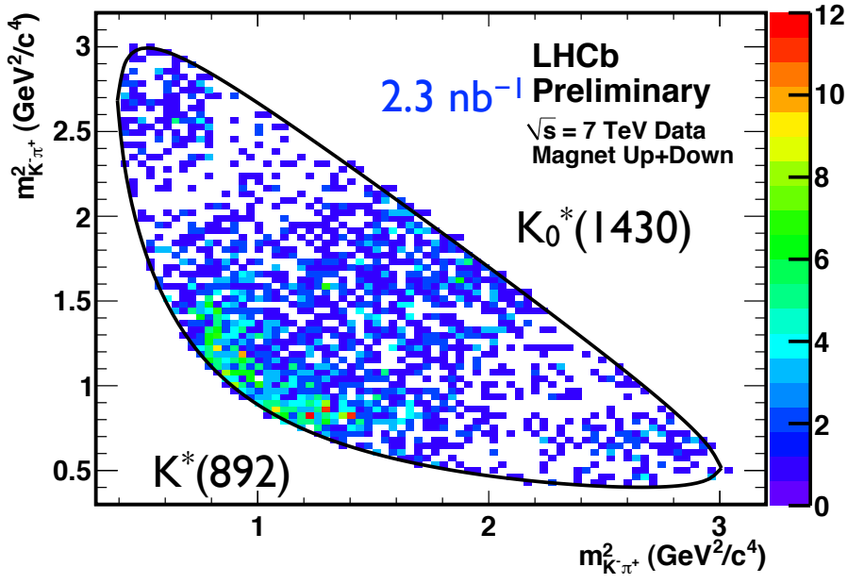
$D^+/D_s^+ \to K^- \pi^+ \pi^+$ and $K^- K^+ \pi^+$

$K^-\pi^+\pi^+$ mass spectrum

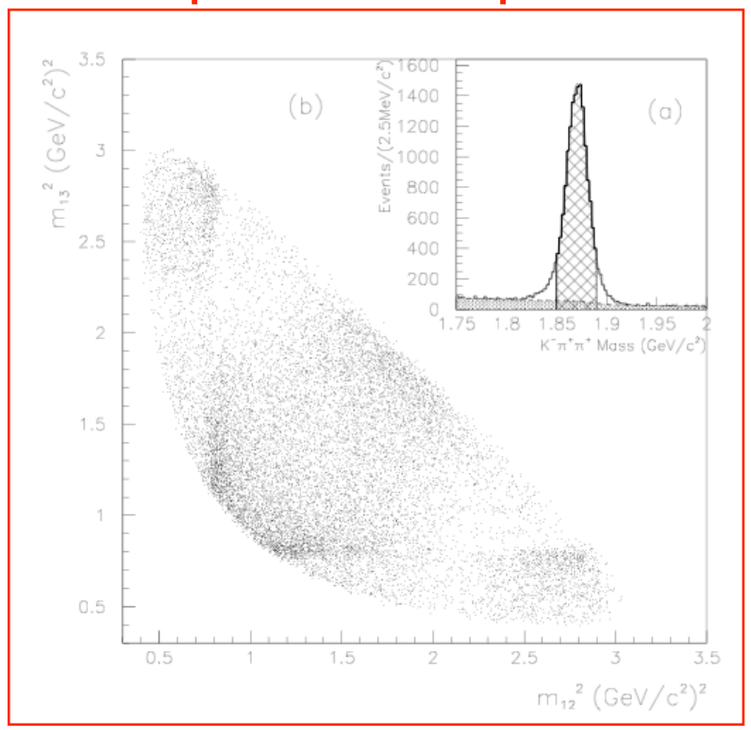


$D^+ \to K^-\pi^+\pi^+$

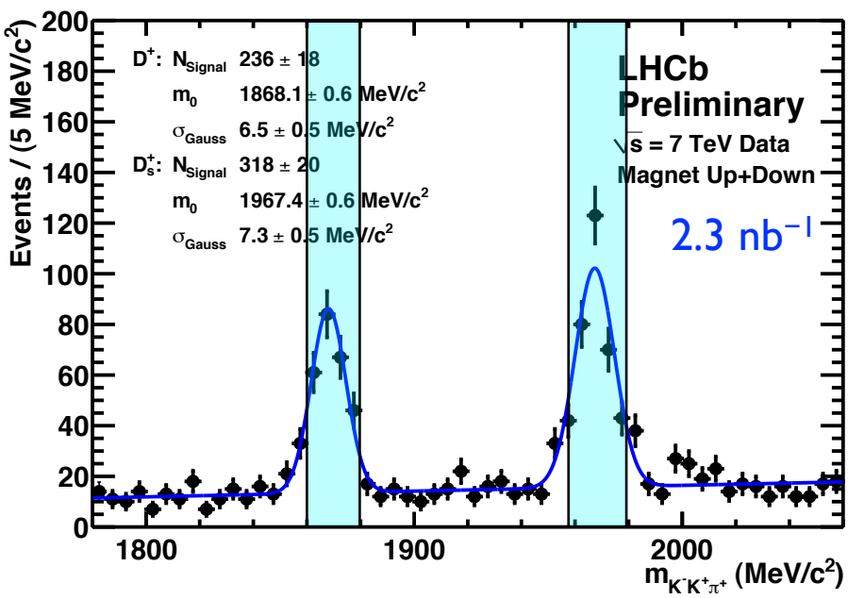
Dalitz plot (non-symmetric)



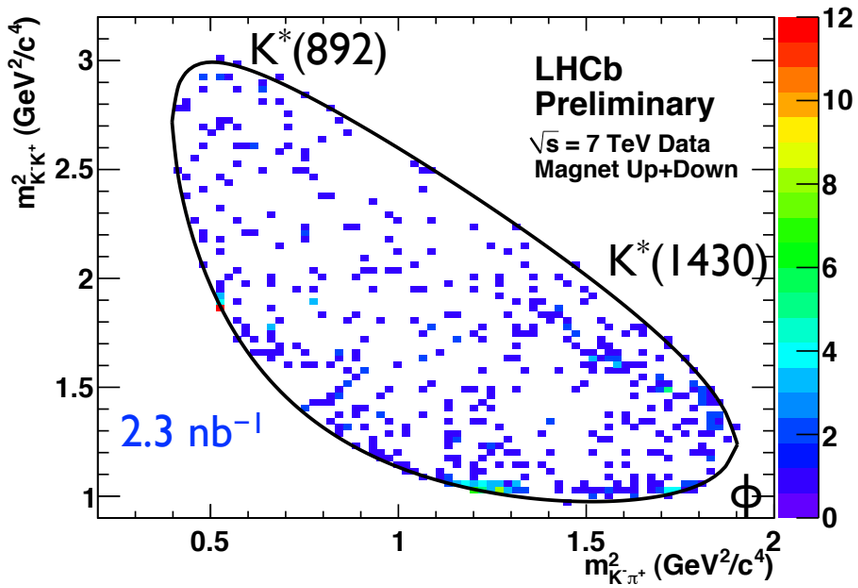
E791 plot for comparison



PRL 89:121801,2002

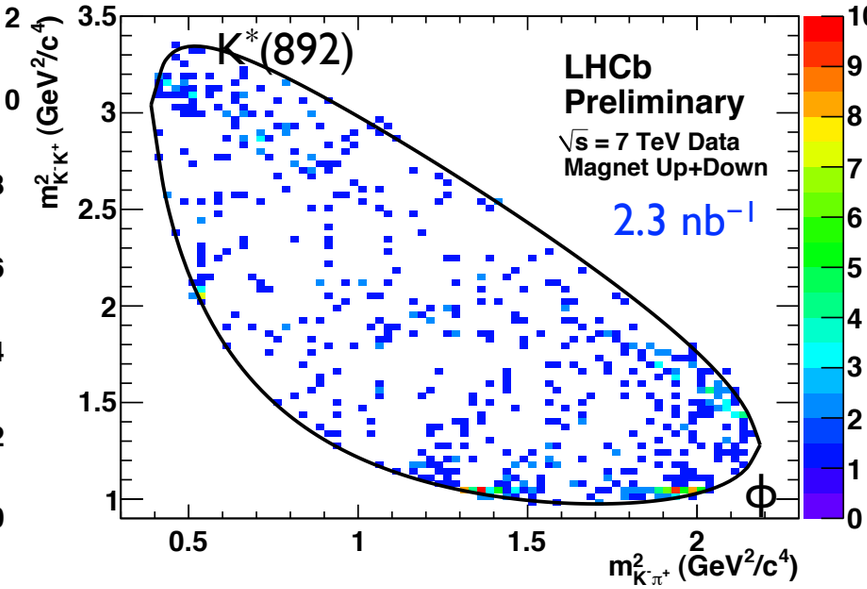


$K^-K^+\pi^+$ mass spectrum



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

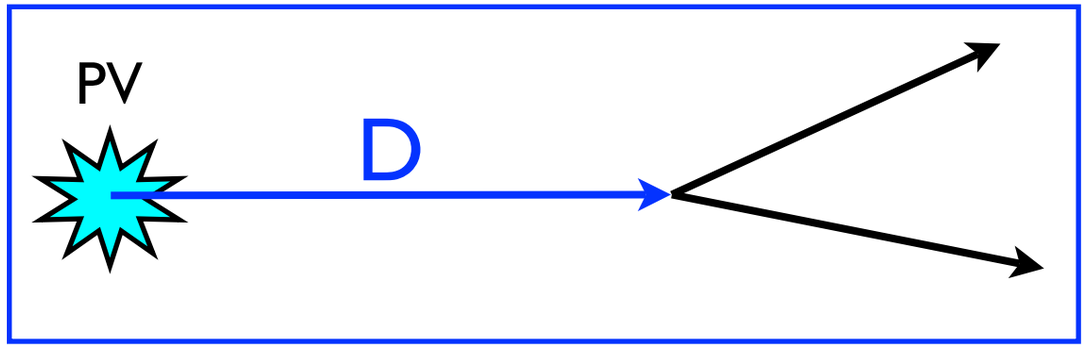
Dalitz plot



$D_s^+ \to K^-K^+\pi^+$

Dalitz plot

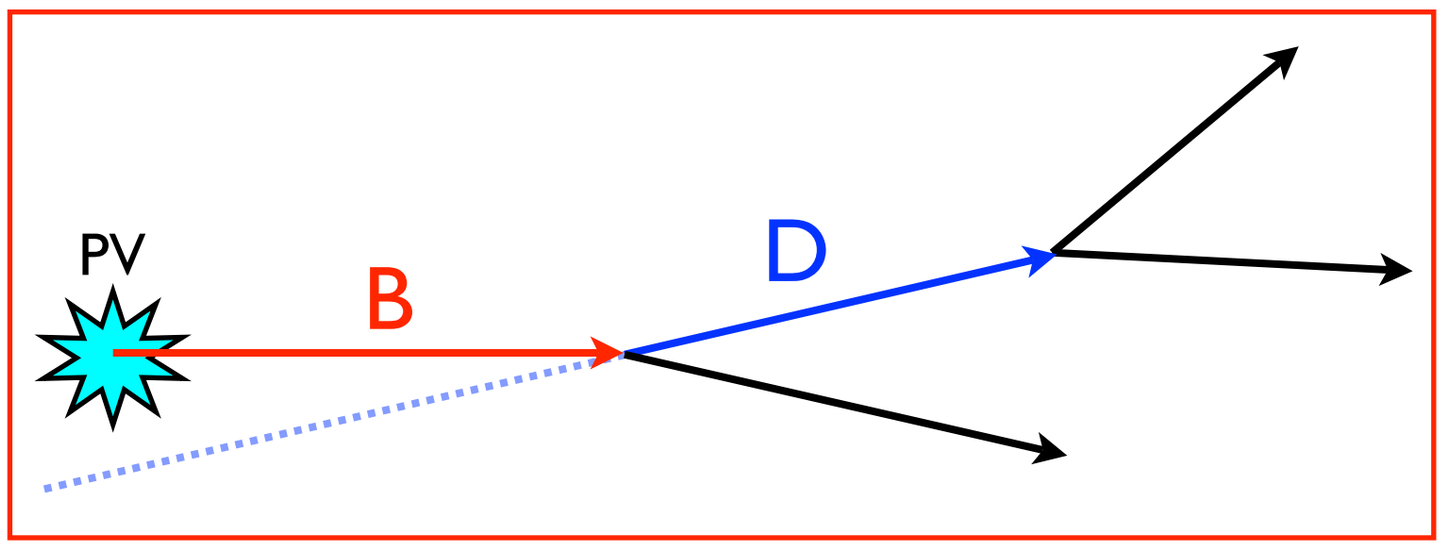
Prompt-secondary discrimination



Prompt charm:

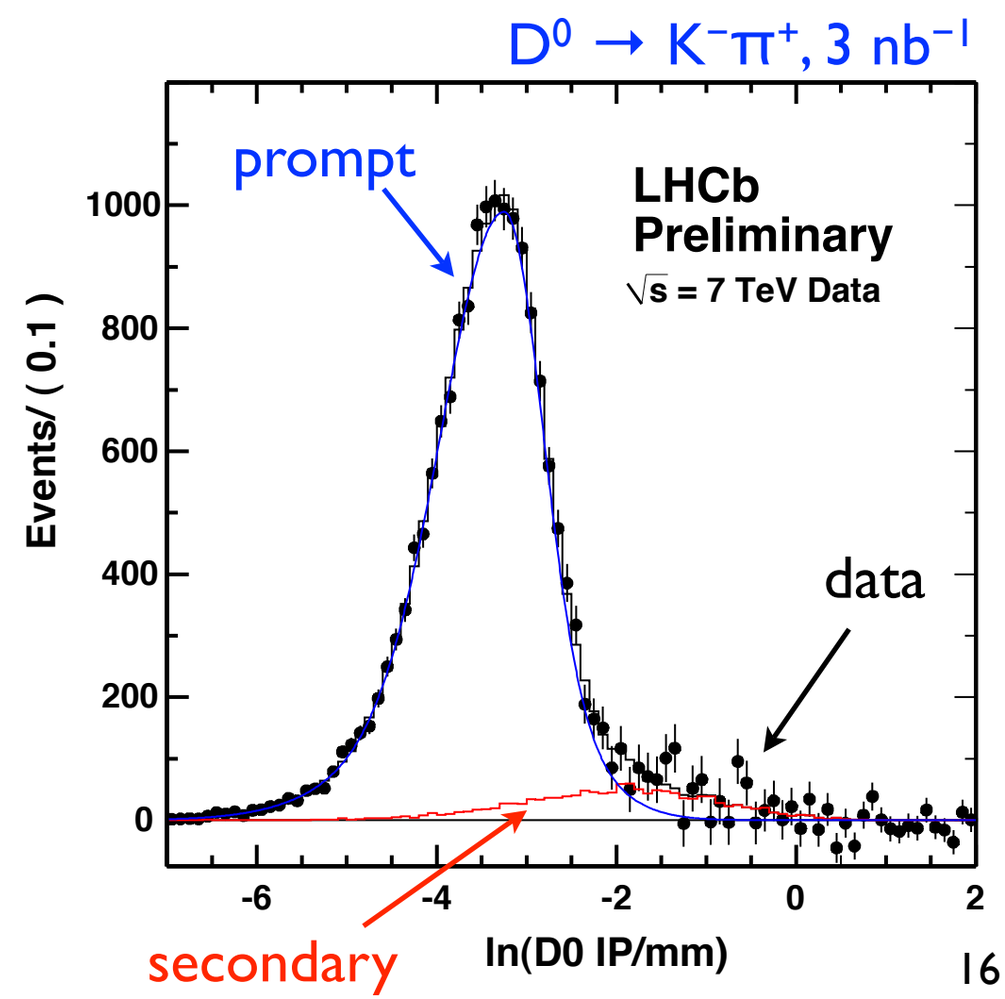
D points to primary vertex

Daughters of D don't in general



Secondary charm:

D doesn't point to PV in general

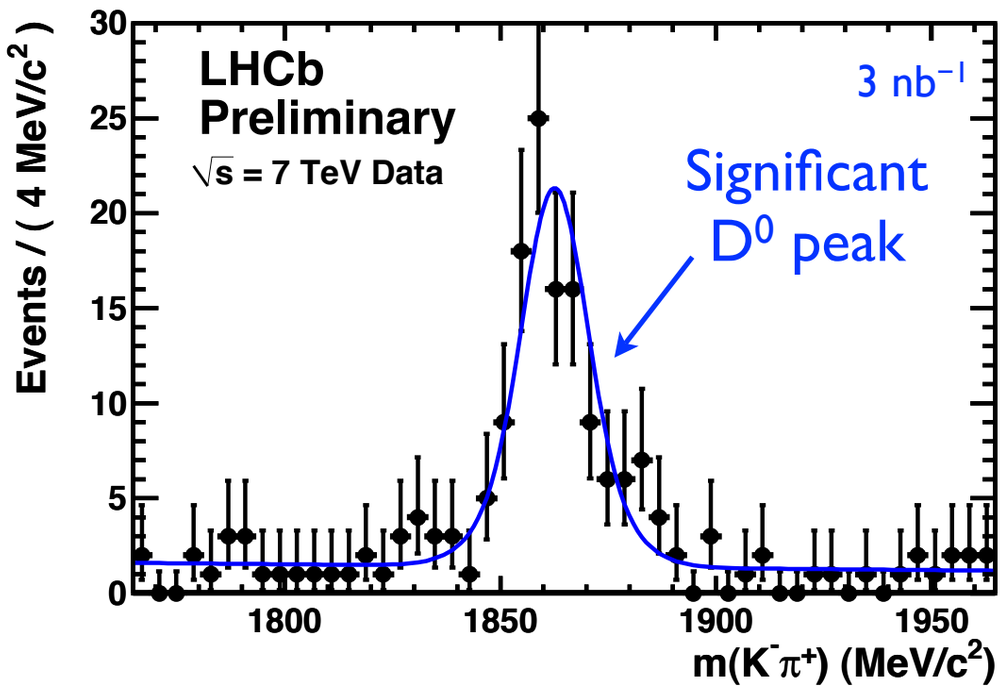


Can fit distribution of D^0 impact parameter to extract prompt and secondary charm yields separately.

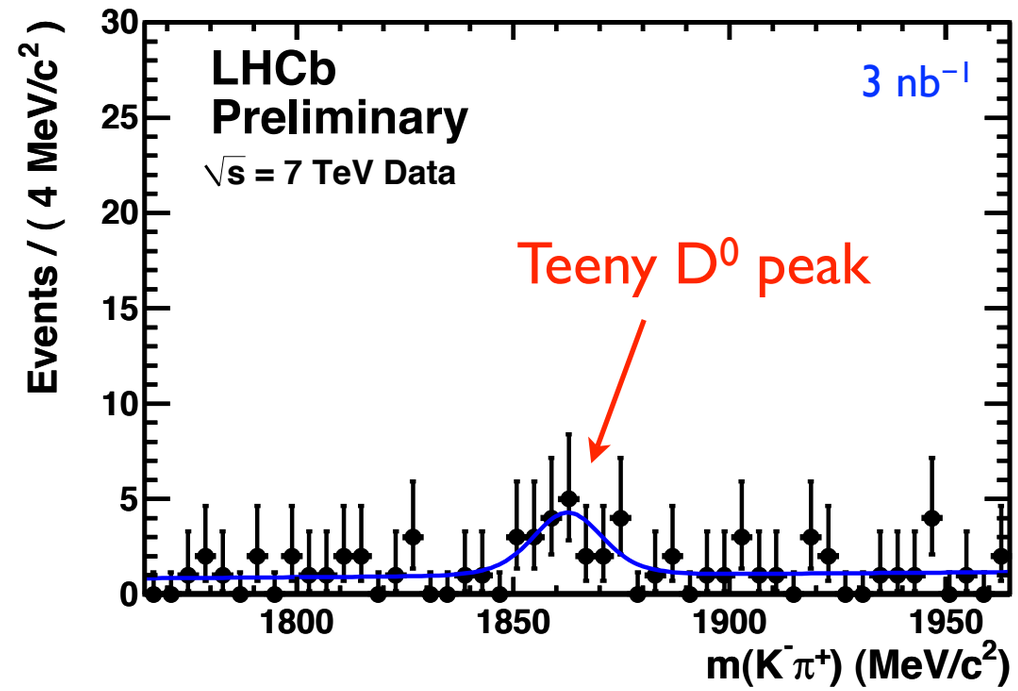
$D^0\mu^-$ vs $D^0\mu^+$: semi-leptonic B decays

Look for $D^0\mu^-$ (right-sign) and $D^0\mu^+$ (wrong-sign) vertices:

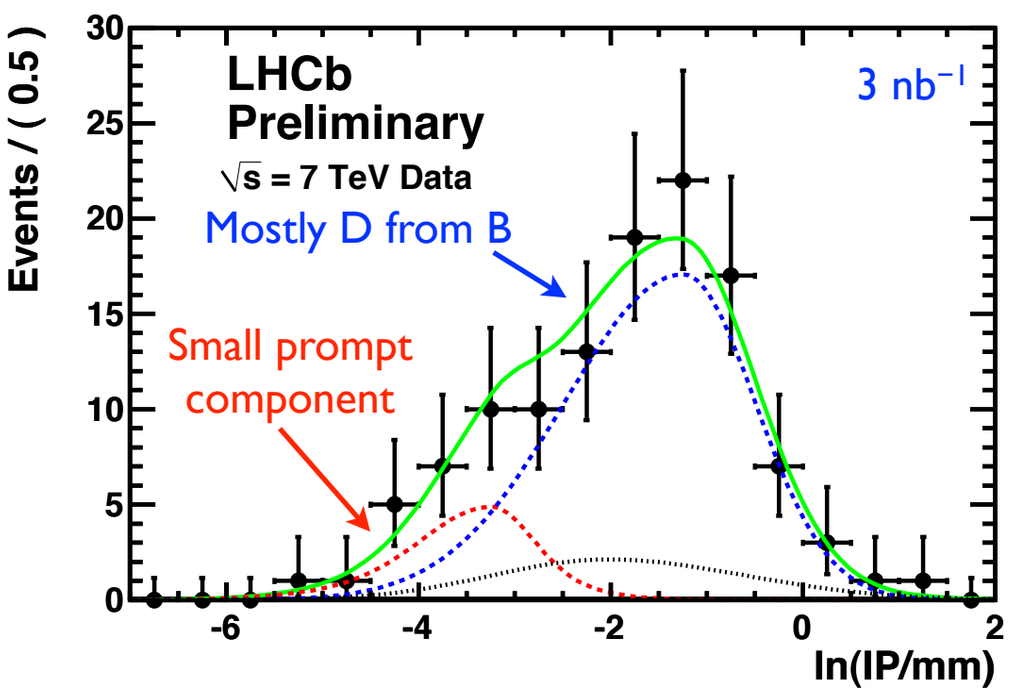
Right-sign candidates



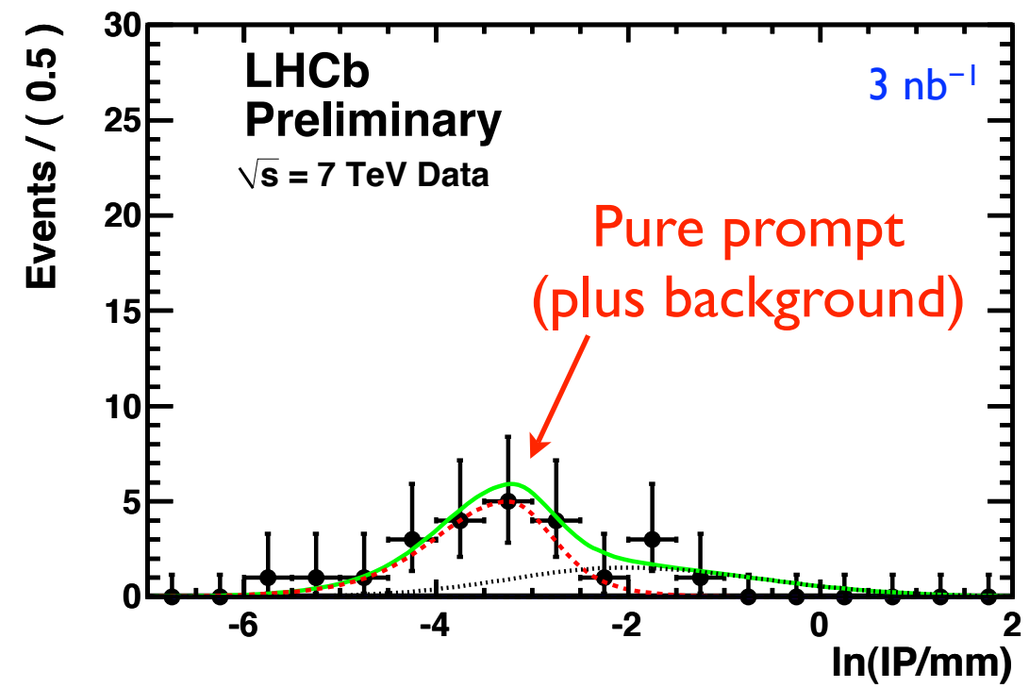
Wrong-sign candidates



$m(K^-\pi^+)$ for $D^0\mu$ combinations



$\log(D^0$ IP) for $D^0\mu$ combinations

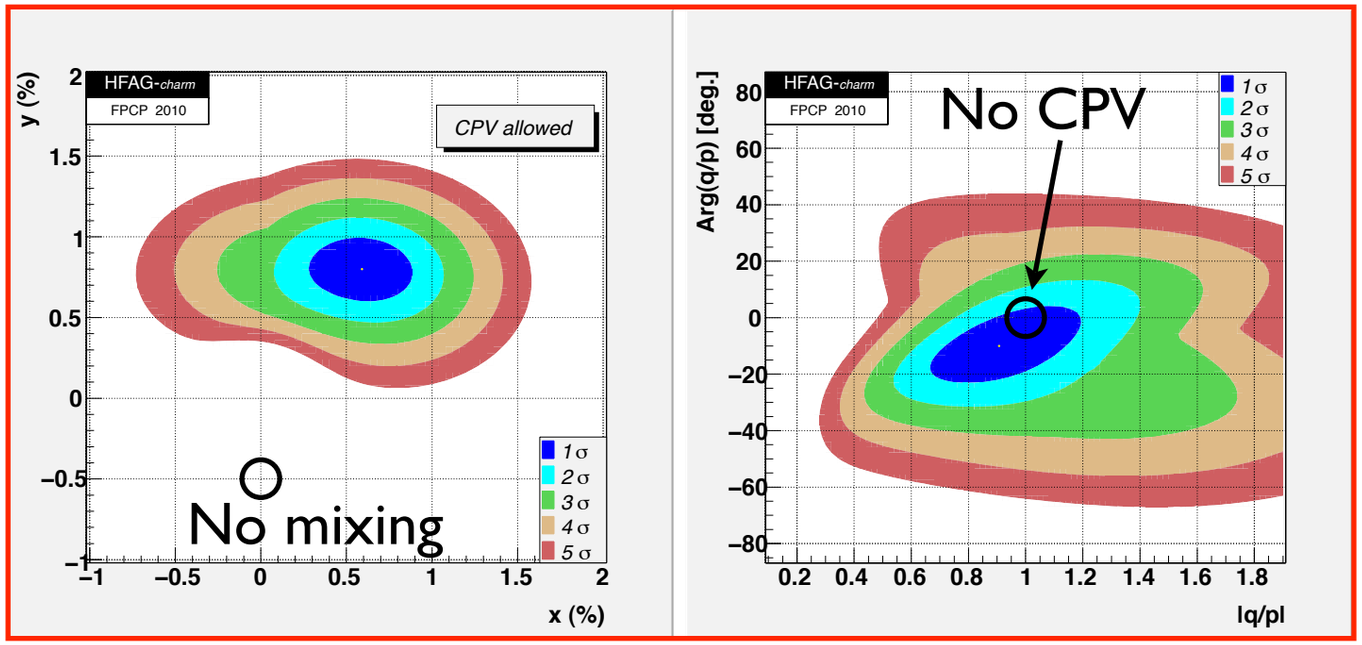


Towards production measurements

- As with charmonium, plan is to measure cross-section in bins of y, p_T.
- Preliminary result on O(few nb^{-1}) planned for summer.
- Paper on larger sample to follow.

Mixing and CP violation searches

- With O(100 pb^{-1}), we can start probing for NP in open charm
  - Measurement of y_{CP} with $D^0 \to K^-K^+$, $K^-\pi^+$ ... and indirect CPV (A_{CP})
  - Model-independent search for direct CP violation in $D^+ \to K^-K^+\pi^+$
  - Search for rare decay $D^0 \to \mu^+\mu^-$
  - ... and more channels open up with additional data (e.g. $D^0 \to K_S\pi^+\pi^-$)
- LHCb is a great detector to do this kind of physics
  - High rate (e.g. expect few 10^6 of $D^+ \to K^-K^+\pi^+$ in 100 pb-1)
  - Boost & precision vertexing give good lifetime resolution (expect 40ps from MC; alignment not yet optimal in data)
  - RICHes crucial for PID.
- For details of measurements see talk of Jeroen van Tilburg



Current HFAG limits on mixing, indirect CPV

Conclusions

- We see an abundance of charm at LHCb!
- We are working hard on first analyses: production cross-sections
- Mixing and CPV searches to follow once we have O(100 pb^{-1}) of data
- I hope this has whetted your appetites!

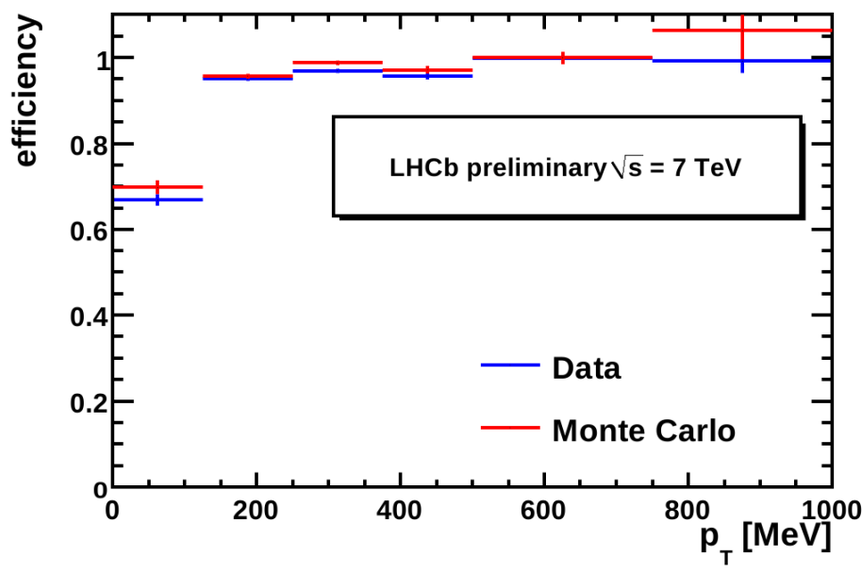
More stuff

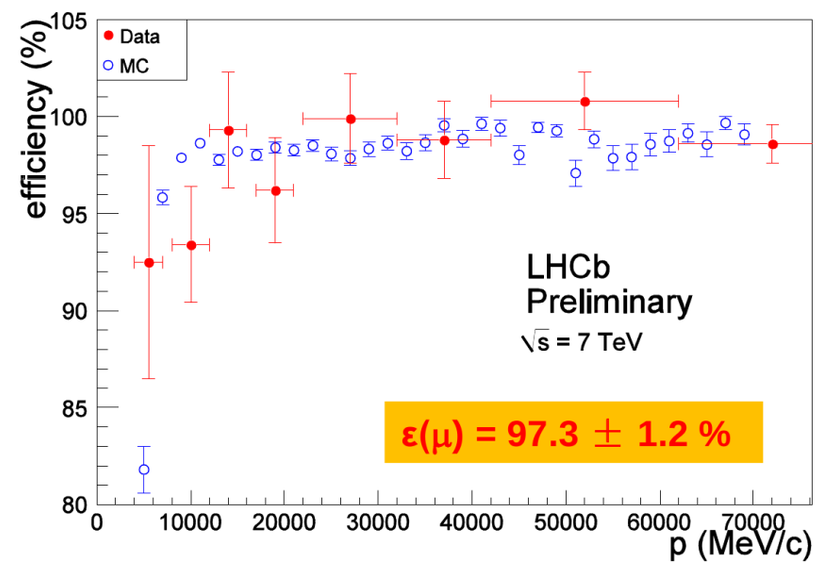
Efficiency from data

Reconstruction efficiency

Data driven methods :

- tracking efficiency using K_s sample
- muon ID using J/ψ





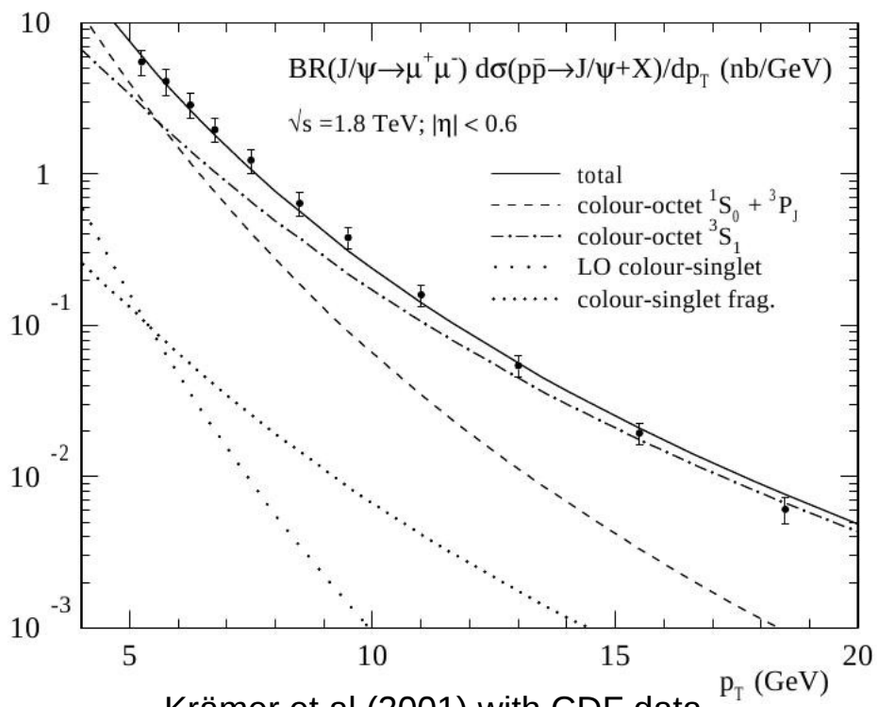
Good data/simulation agreement

See talks from F. Maciuc (Tracking and alignment in LHCb) and P. Xing (LHCb particle ID)

Motivations (1/2)

J/ψ production mechanism is not well understood

- colour-singlet model failed to reproduce CDF data (1997)
- colour-octet model introduced to explain the production rate but failed to reproduce the polarization



Krämer et al (2001) with CDF data

Measurement of this observable at higher energy will help in understanding the charmonium production mechanism.

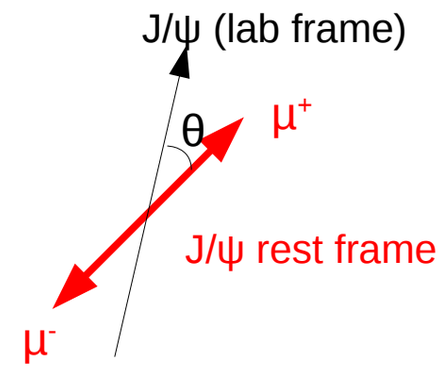
Polarization

Polarization effect

J/ψ polarization is unknown

Angular distribution strongly dependant on polarization

$$\frac{dN}{d\cos\theta} = \frac{1+\alpha\cos^2\theta}{2+2\times\alpha/3}, \quad \alpha = \left\{\begin{array}{c} +1: \textit{fully transverse} \\ -1: \textit{fully longitudinal} \\ 0: \textit{no polarization} \end{array}\right\}$$



LHCb angular acceptance is not trivial

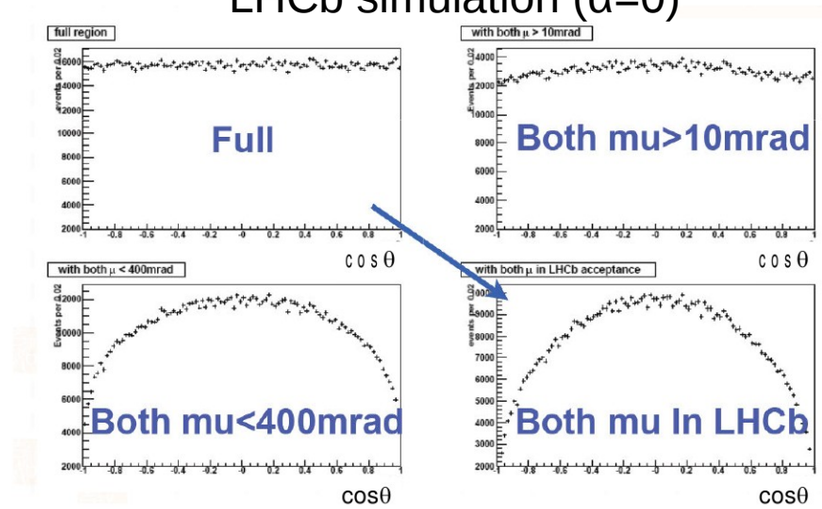
– detector creates artificial polarization

Polarization modifies the acceptance up to 20% in some (p_T,y) bins

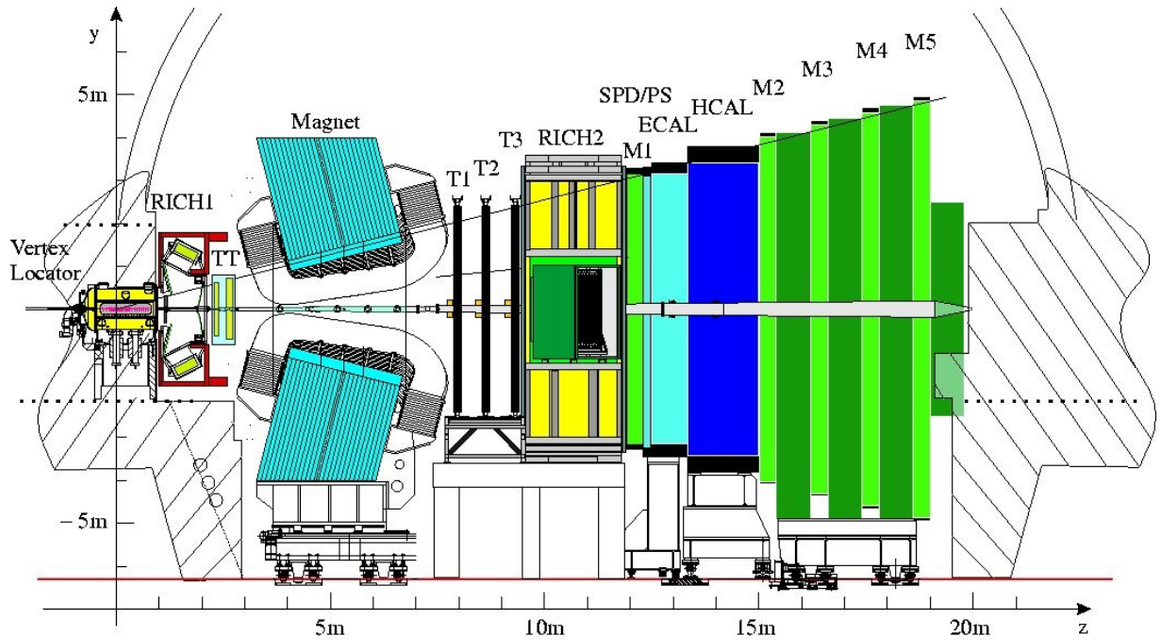
– 1st step : measure the cross section for 3 values of α (to be agreed among LHC experiments)

– 2nd step : measure the polarization

LHCb simulation (α=0)



The LHCb unique angular acceptance

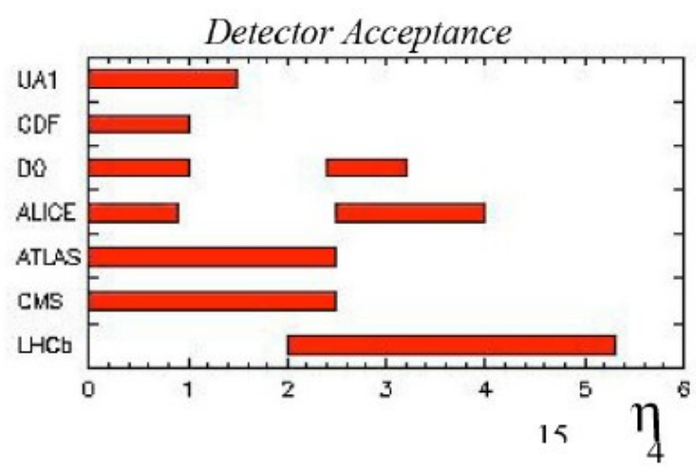


Forward spectrometer

- angular acceptance :

  15 < θ < 300 mrad

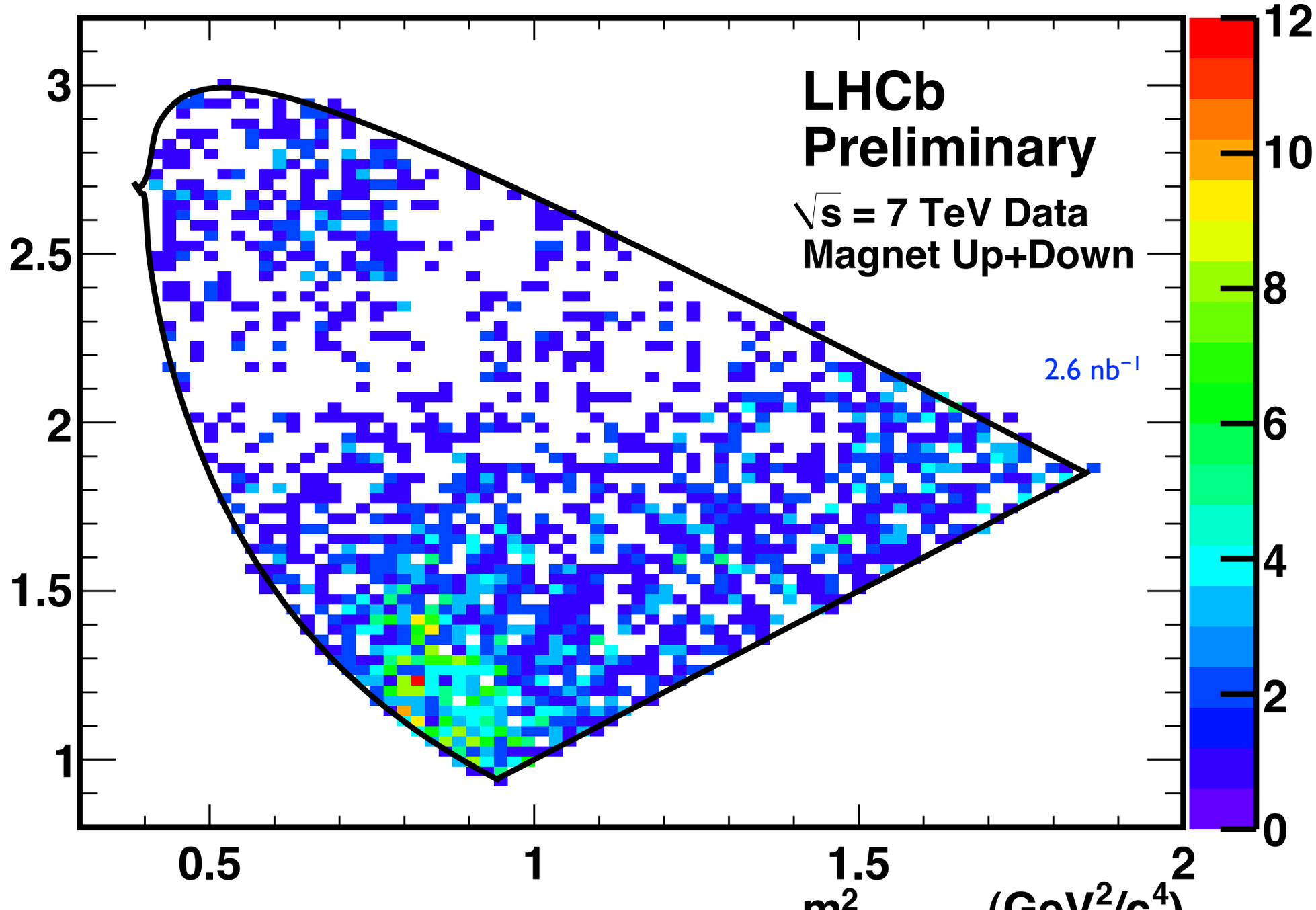
- Special coverage of LHCb experiment, where theoretical predictions are less accurate.



See talks from A. Golutvin (Status of and news from LHCb)

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

Dalitz plot (folded)



Sensitivity – D^0 Mixing Parameters

LHCb-2007- 049

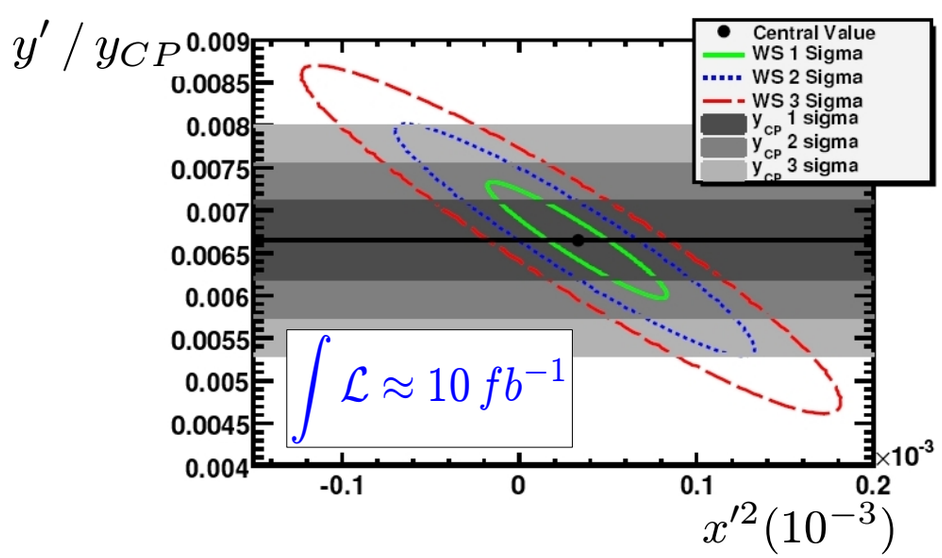
- Summary from selection

$$Bckgr/Signal = 2.56$$
$$N^{WS}_{Signal} = 46500 \pm 2200/fb^{-1}$$
$$\epsilon^{RS/WS}_{Signal} = (1.39 \pm 0.17) \cdot 10^{-3}$$

- Statistical errors

	$\sigma(x'^2) \cdot 10^{-3}$	$\sigma(y') \cdot 10^{-3}$
$LHCb[2fb^{-1}]$	± 0.064	± 0.87
$BABAR$	± 0.37	± 5.4
$Belle$	$^{+0.21}_{-0.23}$	$^{+4.0}_{-3.9}$

- Extract y_{CP} and (x'^2, y') from toy MC



- Sensitivity - combining likelihoods