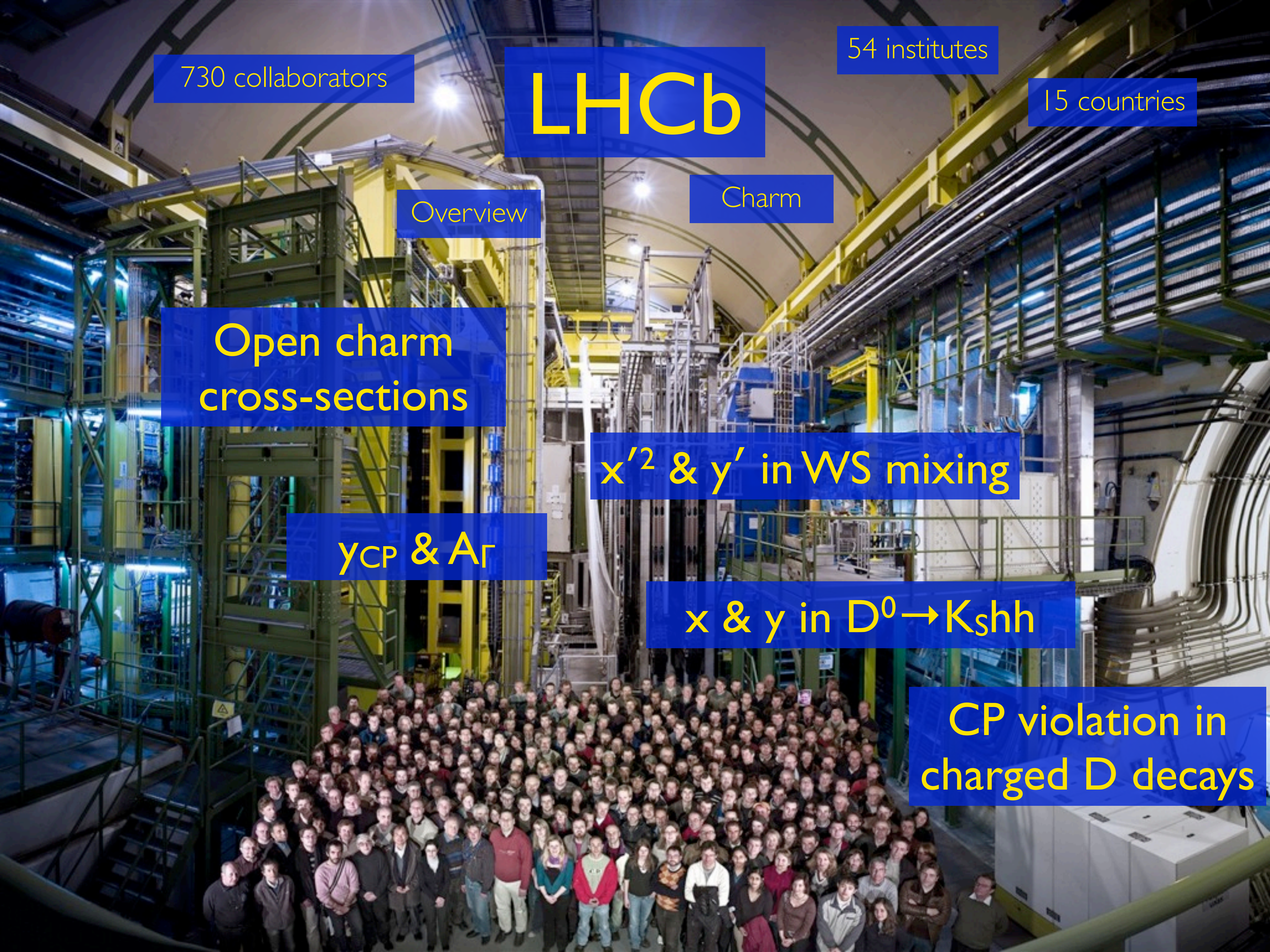
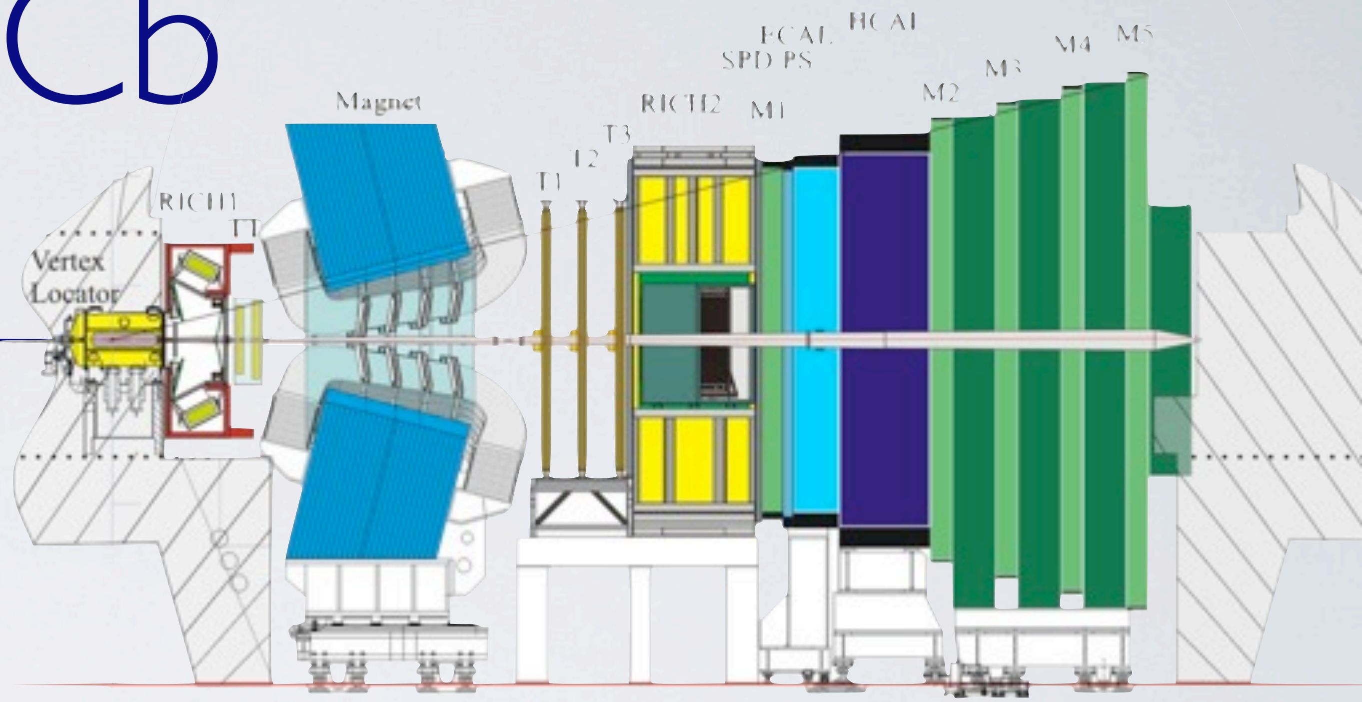
CP VIOLATION IN CHARM MIXING AT LHCb

Marco Gersabeck (CERN)
for the LHCb Collaboration
CKM Workshop 2010, Warwick, 9th September 2010


730 collaborators
LHCb
54 institutes
15 countries
Overview
Charm
Open charm cross-sections
x'^2 & y' in WS mixing
y_{CP} & A_Γ
x & y in $D^0 \rightarrow K_S hh$
CP violation in charged D decays

LHCb



- Trigger: input 40 MHz
  hardware: **μ**,**h**,**e**,**γ**; output 1 MHz,
  to storage **2 kHz**

- Vertex Locator:
  <10 μm position resolution
  ~40 fs proper time resolution
  used for impact parameter trigger

- RICH: 2 detectors with 3 radiators
  ⇒ excellent **π-K** separation over large momentum range (2-100 GeV/c)

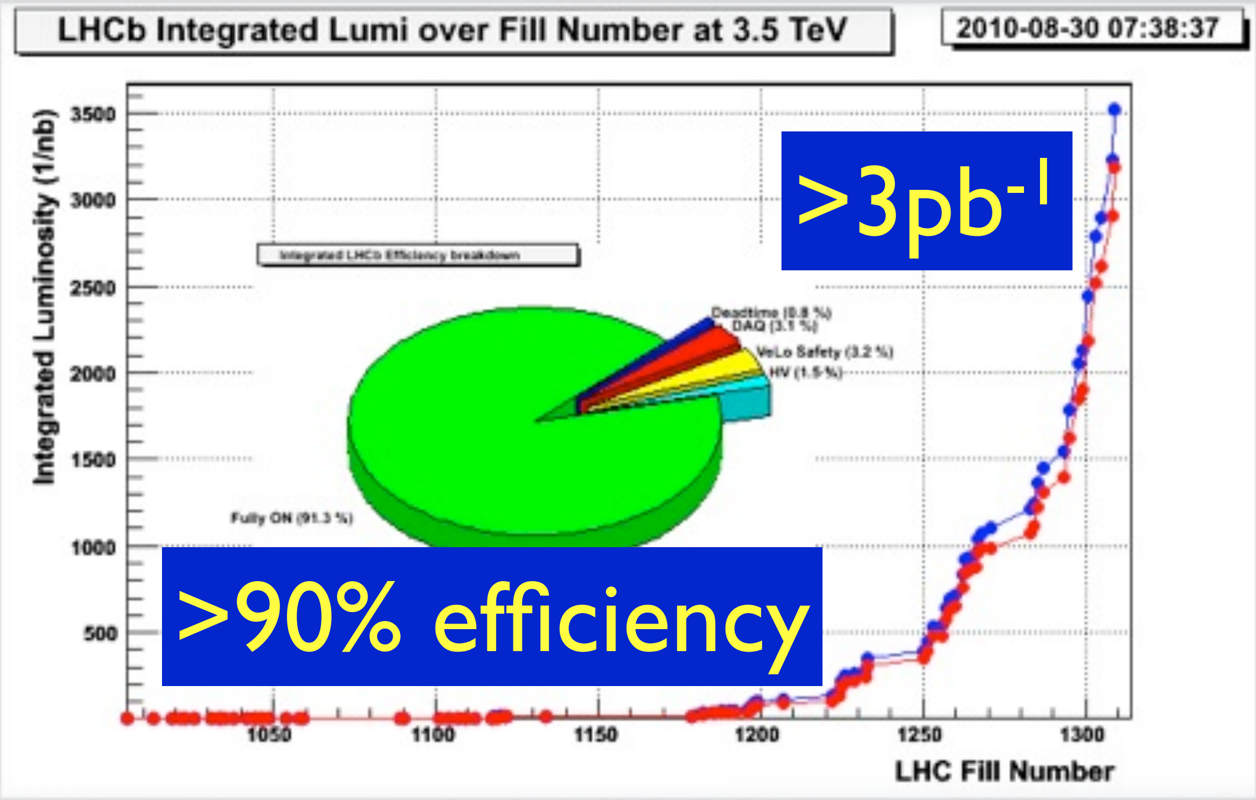
- 4 Tm dipole magnet, Si & straw trackers, calorimeters, muon stations

- moderate design luminosity (2×10^{32} cm^{-2}s^{-1}): ~1 interaction per bunch crossing

- nominal annual luminosity: 2 fb^{-1}

CHARM AT LHCb

- Unique regime:
  $2 < \eta < 5$, down to $p_T = 0$
- A blessing and a curse:
  5% - 10% of collisions
  contain charm quarks
- Prompt* charm ~10x more abundant than secondary charm from B decays



- Trigger:
  Designed to select B decays:
  - favours higher p_T secondary charm
  - benefit of more relaxed trigger conditions during early days
- Running conditions:
  Luminosity per bunch crossing equivalent to design values

* Prompt charm: charm mesons produced at the primary interaction point (incl. e.g. via D^* decays)

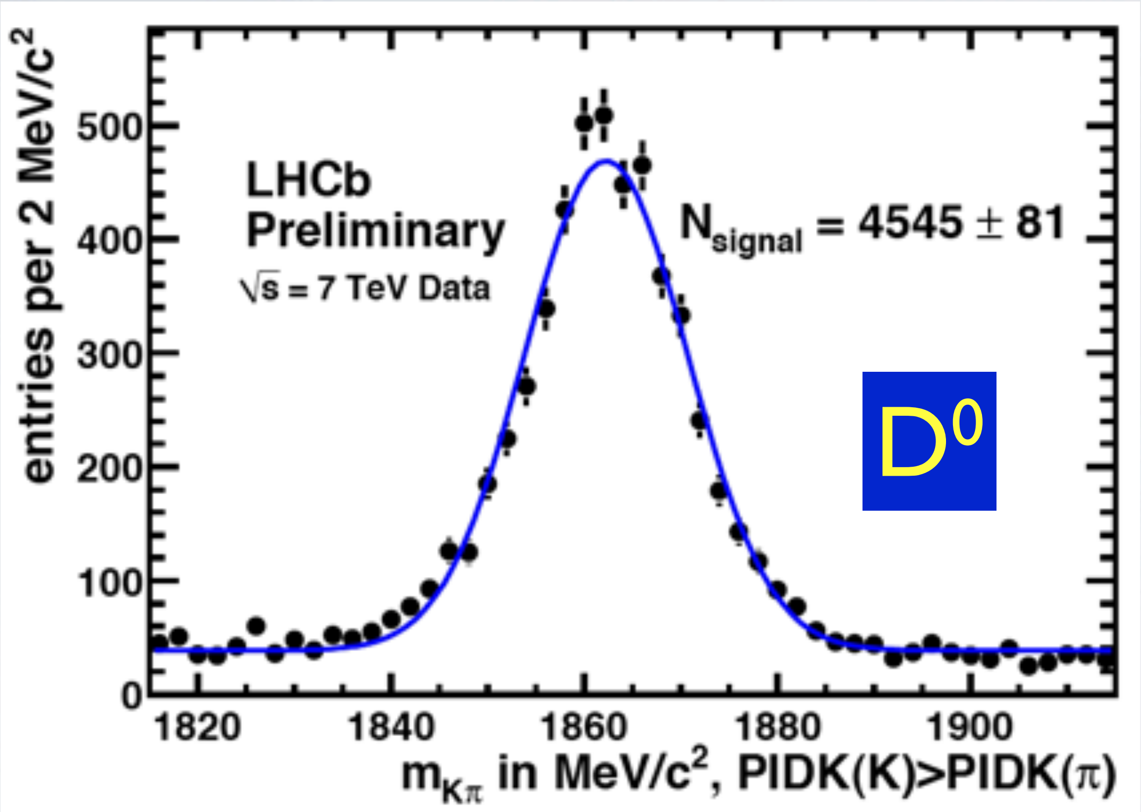
OPEN CHARM CROSS-SECTIONS

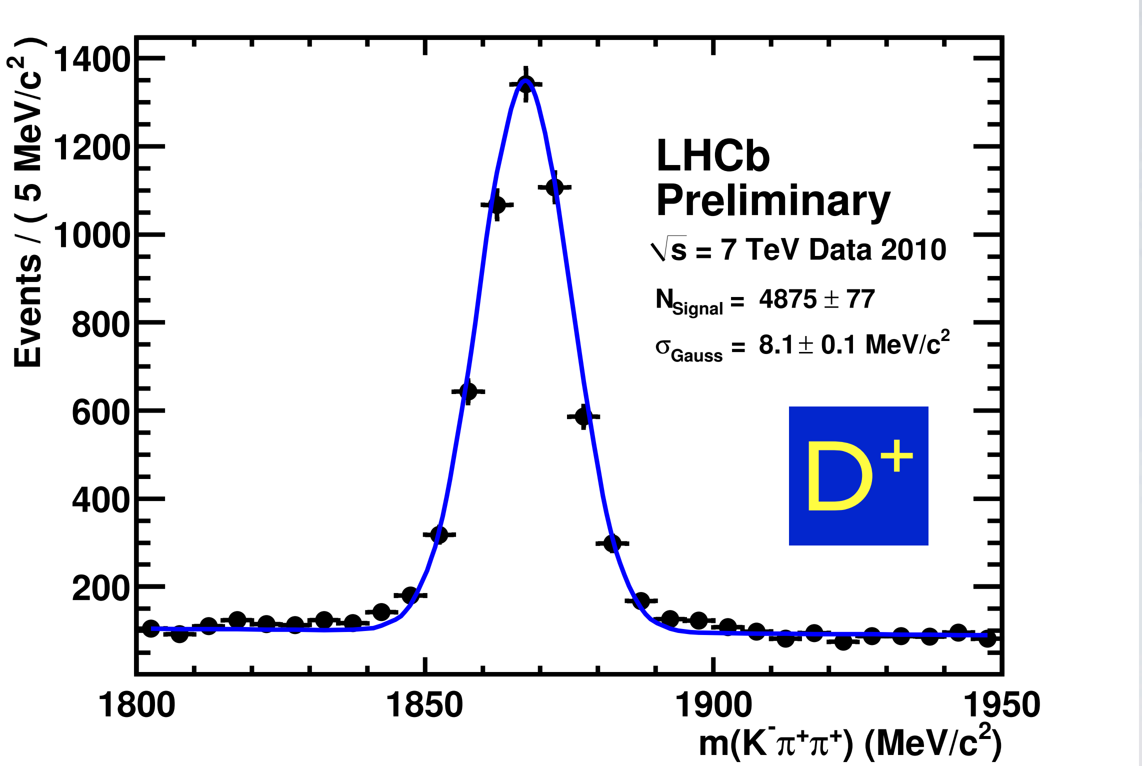
NEW RESULTS!

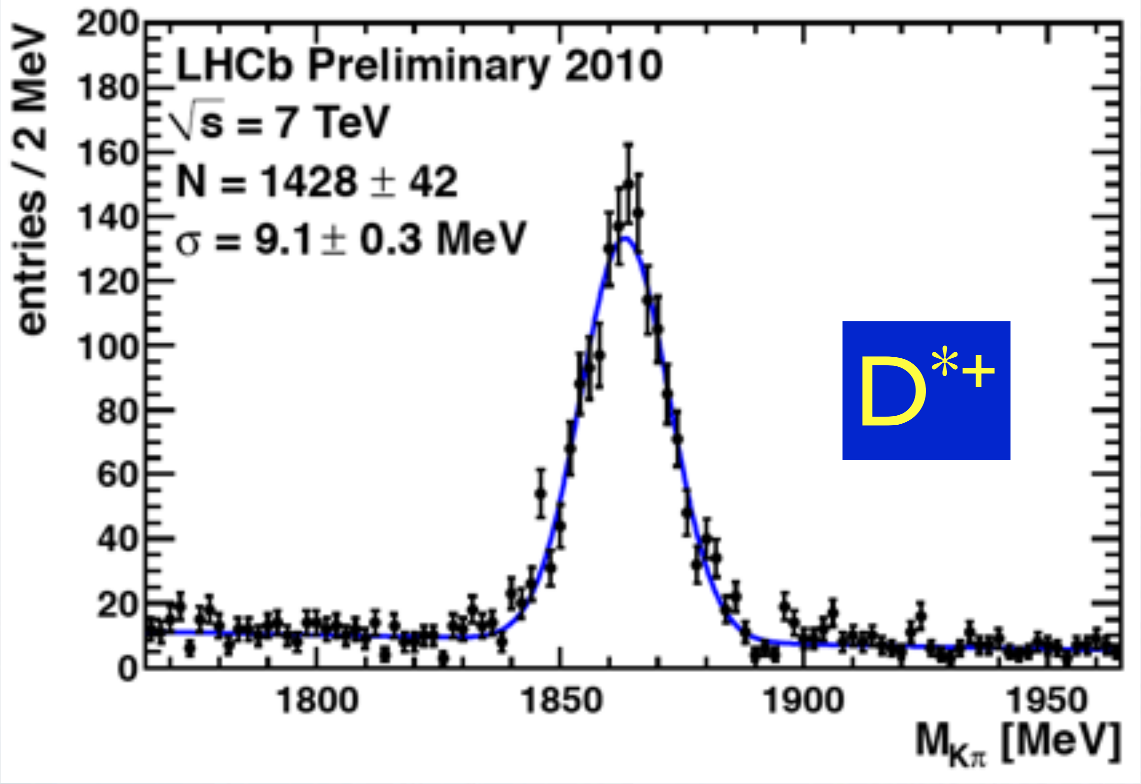
OPEN CHARM CROSS-SECTIONS

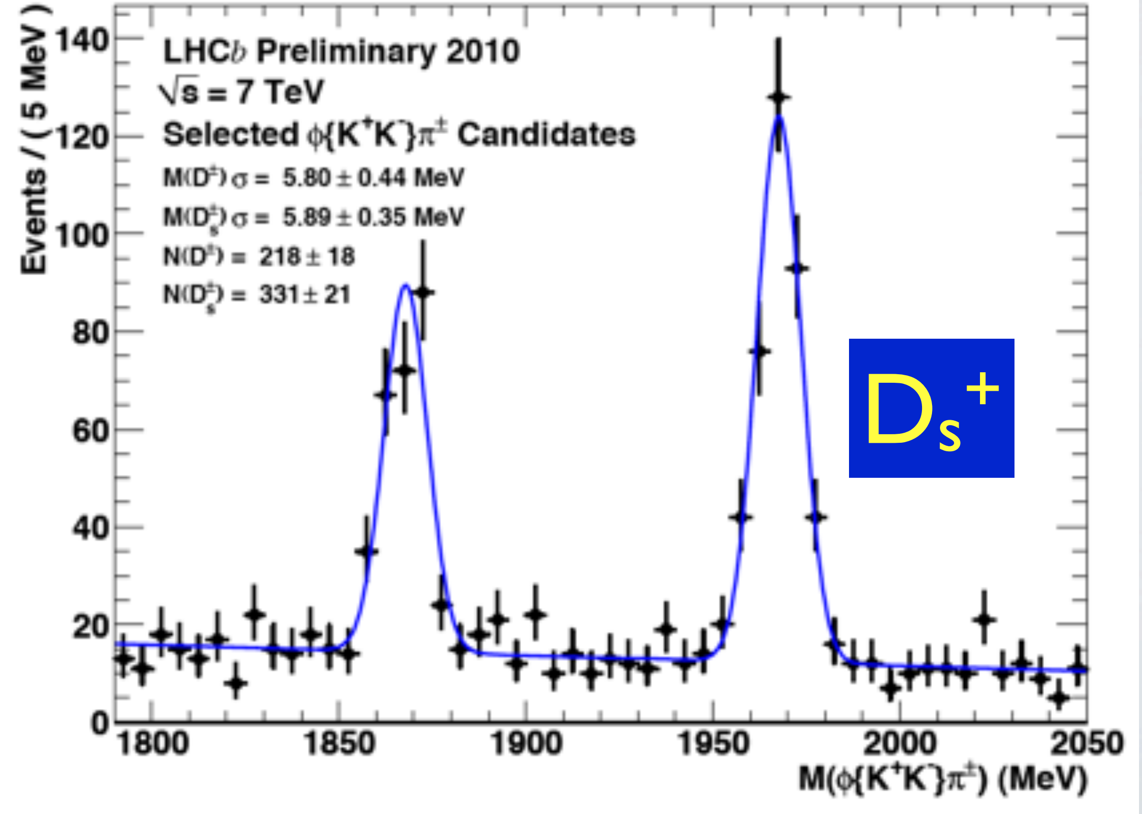
- First measurement at $\sqrt{s} = 7$ TeV
- Large uncertainties on theoretical extrapolations
- Can measure down to $p_T = 0$
- Access to all open charm hadrons
- Presented here:
  Preliminary cross-sections for D^0, D^{*+}, D^+, D_s^+ using 1.8nb^{-1}
- Work in progress:
  Cross-sections for D^0, D^{*+}, D^+, D_s^+, Λ_c^+ using 14nb^{-1}

RAW YIELDS 1.8nb^{-1}









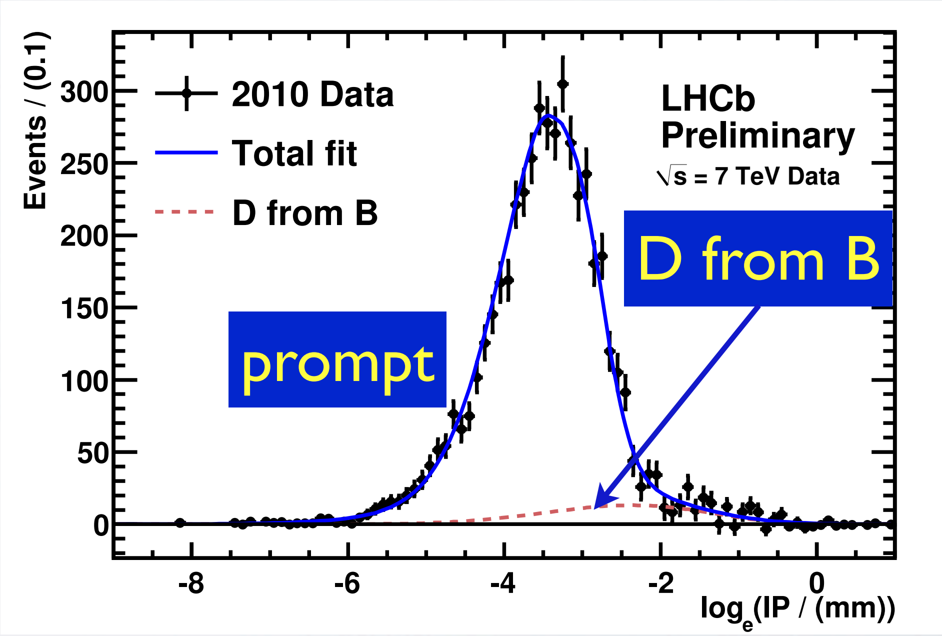
MEASUREMENT STRATEGY

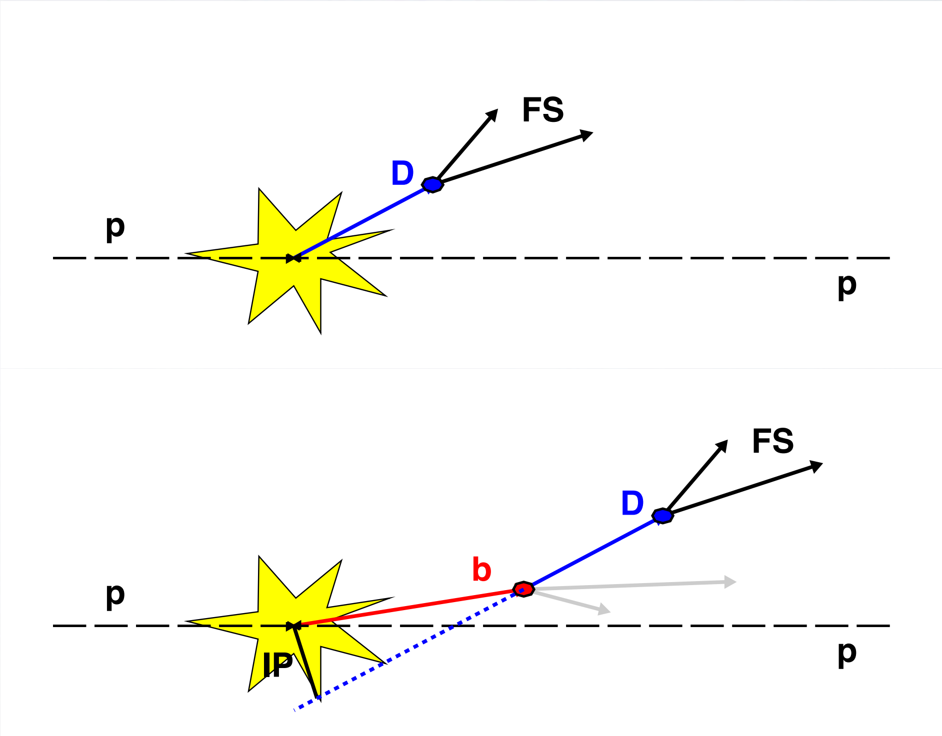
- Determine raw yields in bins of rapidity and transverse momentum
- Measure contamination from secondary charm on data
- Determine selection efficiency from MC simulation
  Extensive cross-checks performed on data
- Particle ID cut efficiency measured on data
- Use absolute luminosity measured by LHCb
- Take BF values from PDG

$$\sigma = \frac{N_{\text{signal}}}{\varepsilon_{\text{tot}} BF \mathcal{L}_{\text{int}}}$$

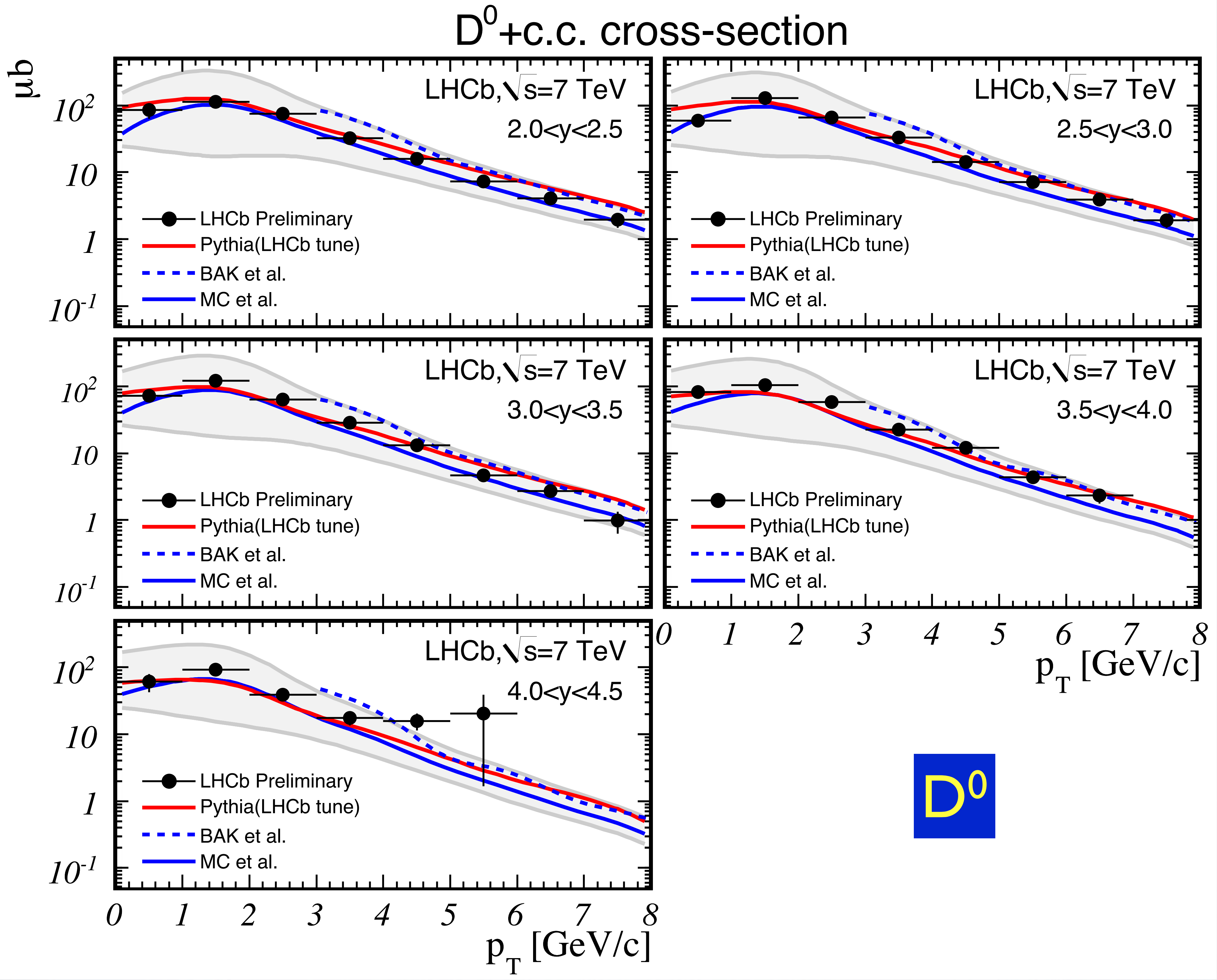
PROMPT-SECONDARY SEPARATION

- Selections favour prompt decays
- Residual background from D being decay product of other long-lived particles: **secondary charm**
- "Traditional" method:
  Measure secondary fraction from **D impact parameter** distribution
- Similar method needed for mixing and CPV measurements:
  Need to account for time dependence in addition!



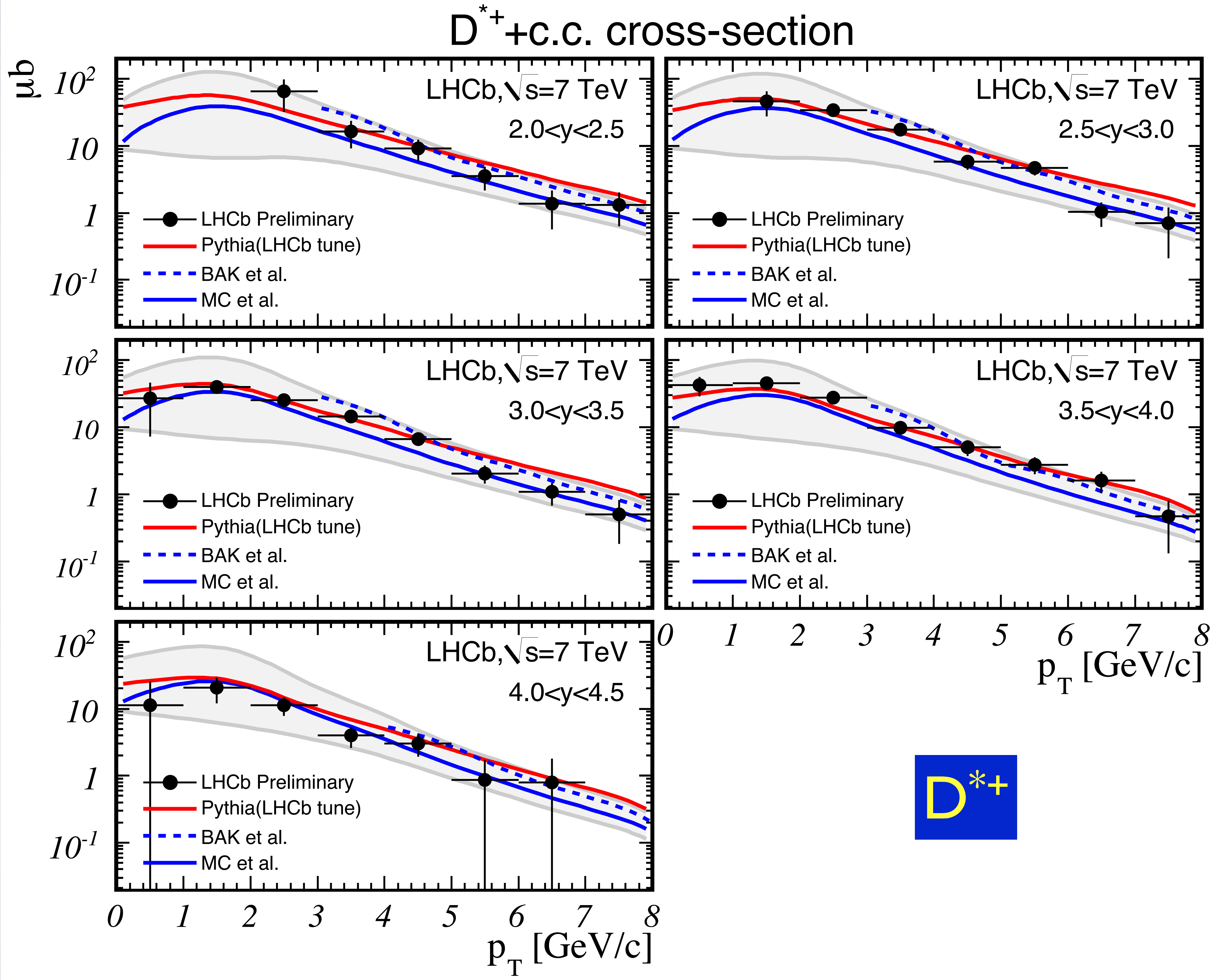


RESULTS

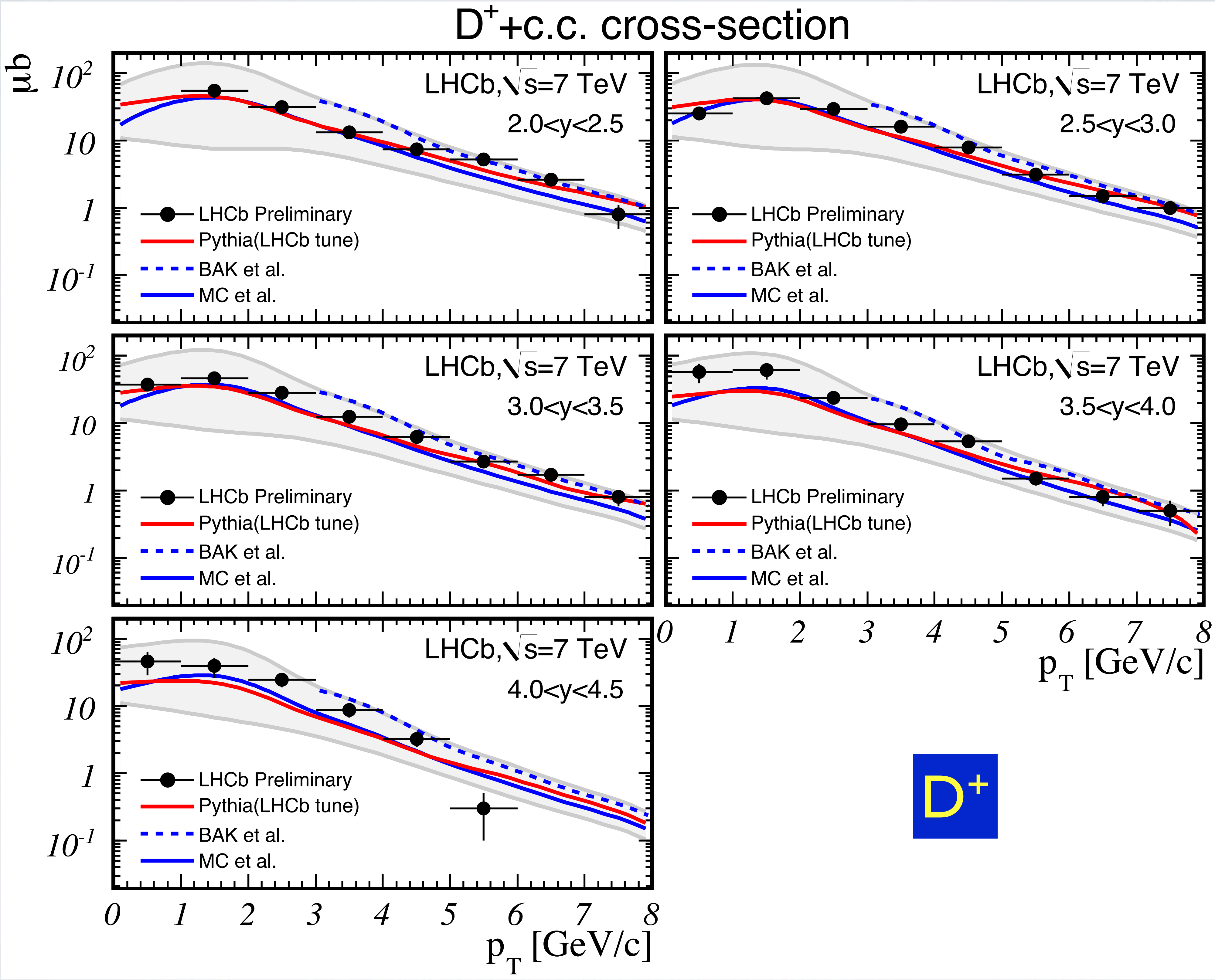


D^0+c.c. cross-section
μb
LHCb,√s=7 TeV
2.0<y<2.5
2.5<y<3.0
3.0<y<3.5
3.5<y<4.0
4.0<y<4.5
LHCb Preliminary
Pythia(LHCb tune)
BAK et al.
MC et al.
p$_T$ [GeV/c]
D^0

RESULTS


D*+ +c.c. cross-section
μb
LHCb,√s=7 TeV
2.0<y<2.5
2.5<y<3.0
3.0<y<3.5
3.5<y<4.0
4.0<y<4.5
LHCb Preliminary
Pythia(LHCb tune)
BAK et al.
MC et al.
p_T [GeV/c]
D*+

RESULTS


D+c.c. cross-section
μb
LHCb,√s=7 TeV
2.0<y<2.5
2.5<y<3.0
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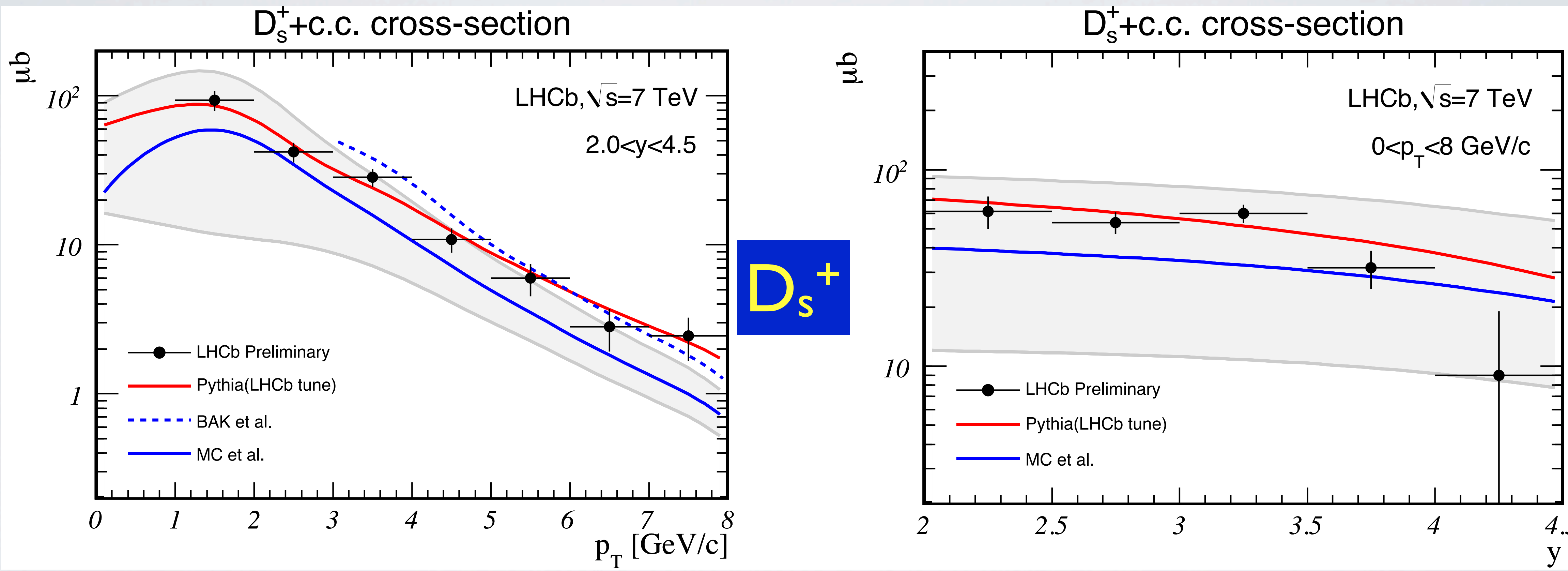
LHCb Preliminary
Pythia(LHCb tune)
BAK et al.
MC et al.
pT [GeV/c]
D+

RESULTS



D_s^++c.c. cross-section
μb
LHCb, √s=7 TeV
2.0<y<4.5
LHCb Preliminary
Pythia(LHCb tune)
BAK et al.
MC et al.
p_T [GeV/c]
D_s^+
D_s^++c.c. cross-section
μb
LHCb, √s=7 TeV
0<p_T<8 GeV/c
LHCb Preliminary
Pythia(LHCb tune)
MC et al.
y

MIXING & CP VIOLATION

COMMON STRATEGIES

- Acquire data set to **significantly improve world average**
- Use control modes/ normalisation channels for initial studies with data
- Perform systematic studies on data:
  - Prompt-secondary distinction
  - Lifetime acceptance correction

COMMON STRATEGIES - II

- Using prompt charm
  - More events
  - Need to measure contribution from secondary
- Using charm from B decays
  - Lower cross-section, but higher p_T = higher trigger efficiency
  - Need to precisely measure D production vertex

Focus on prompt for now

MIXING

MEASUREMENT STRATEGY

- Use "wrong sign" (WS) $D^{*+} \rightarrow D^0(K^+\pi^-)\pi_s^+$ decays
- Two contributions to decay:
  - DCS decay
  - CF decay after D^0 mixing
- Measure time x'^2 and y' in evolution of WS decays

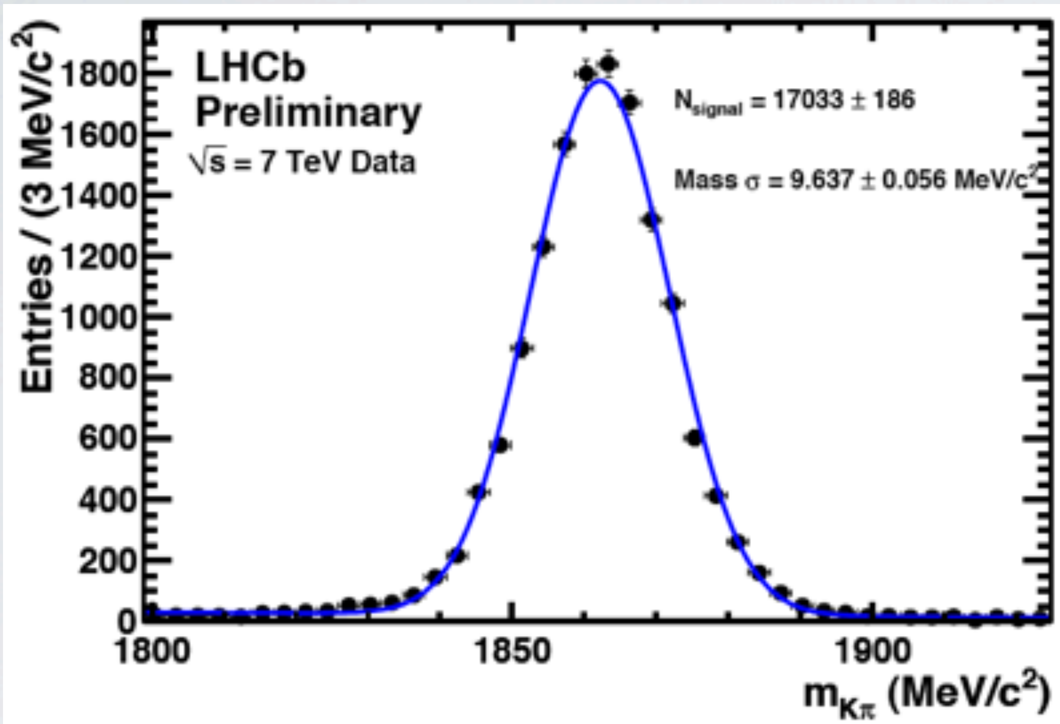
$$r_{WS}(t) \propto e^{-\Gamma t}\left(R_D + \sqrt{R_D}y'(\Gamma t) + \frac{1}{2}R_M(\Gamma t)^2\right)$$

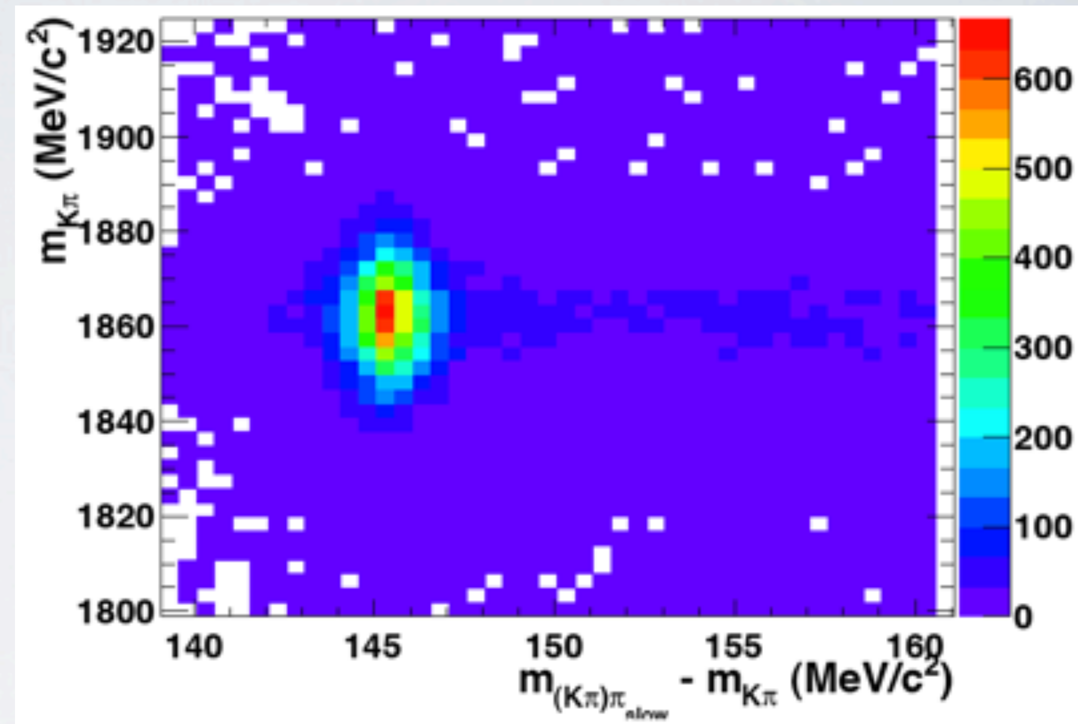
$$\begin{aligned} x' &\equiv x\cos\delta + y\sin\delta \\ y' &\equiv y\cos\delta - x\sin\delta \end{aligned}$$

$$R_M = (x^2+y^2)/2 = (x'^2+y'^2)/2$$

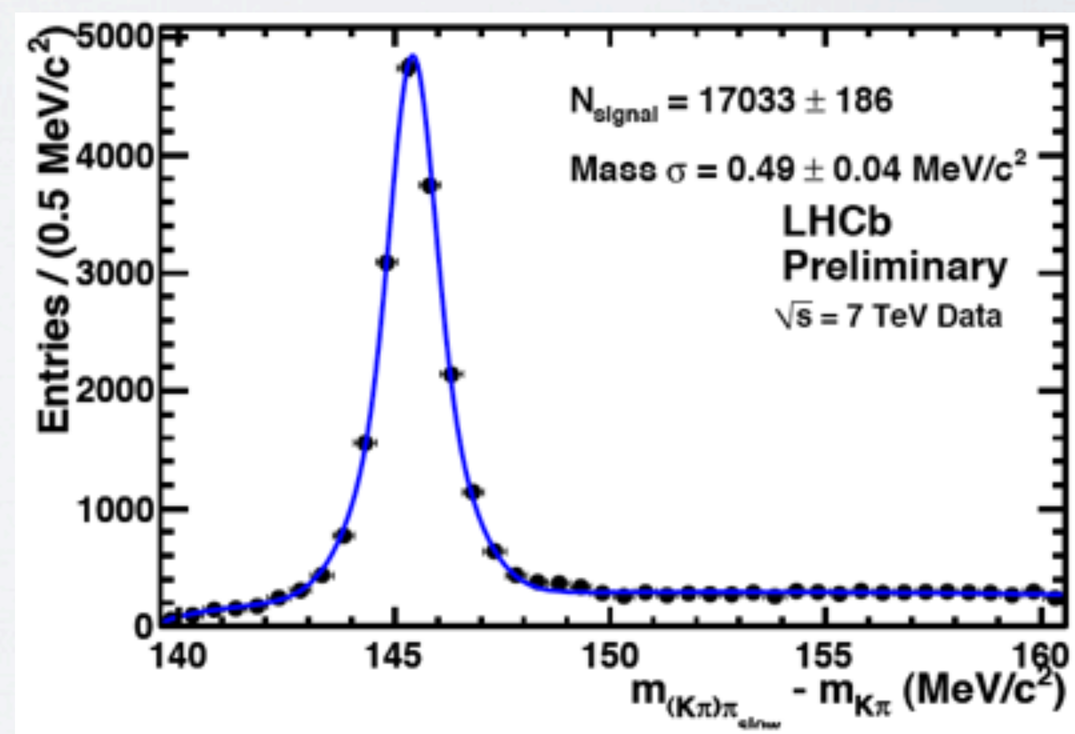
- δ: relative strong phase between two decay amplitudes
- R_D: ratio between DCS decay rate and CF decay rate

$D^{*+} \rightarrow D^0(K^-\pi^+)\pi_s$





124nb⁻¹



AVAILABLE DATA SET

- BR(WS) ~ BR(RS) / 250
- WS selection needs to be much tighter than RS to suppress background
- Expect about O(100) prompt WS candidates on tape by now
- Expect dataset for significant improvement in mixing measurement in the course of next year

Y_{CP} & A_{Γ}

MEASUREMENT STRATEGY

- Two ways to measure CPV in mixing:
- Lifetime ratio y_{CP} shows CPV if different from y

$$y_{\rm CP} = \frac{\tau(D^0 \to K^-\pi^+)}{\tau(D^0 \to K^-K^+)} - 1$$

$$y_{\rm CP} = y\cos\phi - \frac{1}{2}A_M\, x\sin\phi$$

- Lifetime difference in decay to CP eigenstate shows CPV if ≠0

$$A_\Gamma = \frac{\tau(\bar{D}^0 \to K^+K^-) - \tau(D^0 \to K^+K^-)}{\tau(\bar{D}^0 \to K^+K^-) + \tau(D^0 \to K^+K^-)}$$

$$A_\Gamma = \frac{1}{2}A_M y\cos\phi - x\sin\phi$$

- y_{CP}: can use untagged D^0 decays
- A_Γ: need flavour tagged D^0 decays: use decay chain $\mathbf{D^{*+} \to D^0 \pi_s^+}$

$$|\lambda_{KK}|^{\pm 1} = 1 \pm A_M/2$$

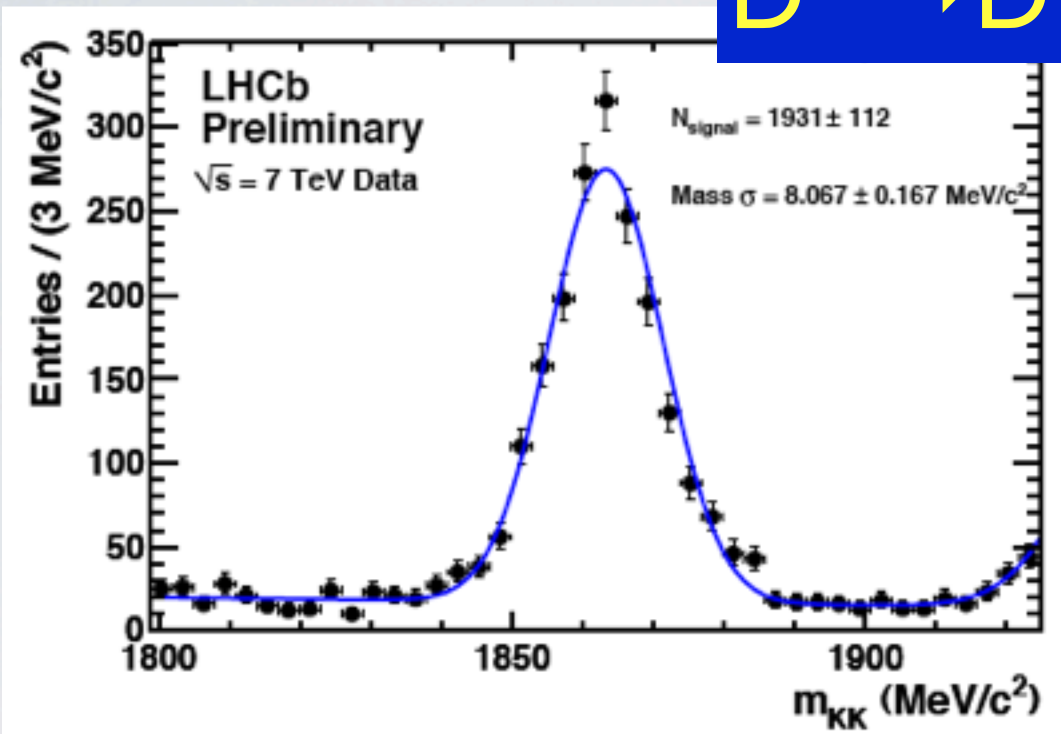
$$\arg(\lambda_{KK}) = \phi$$

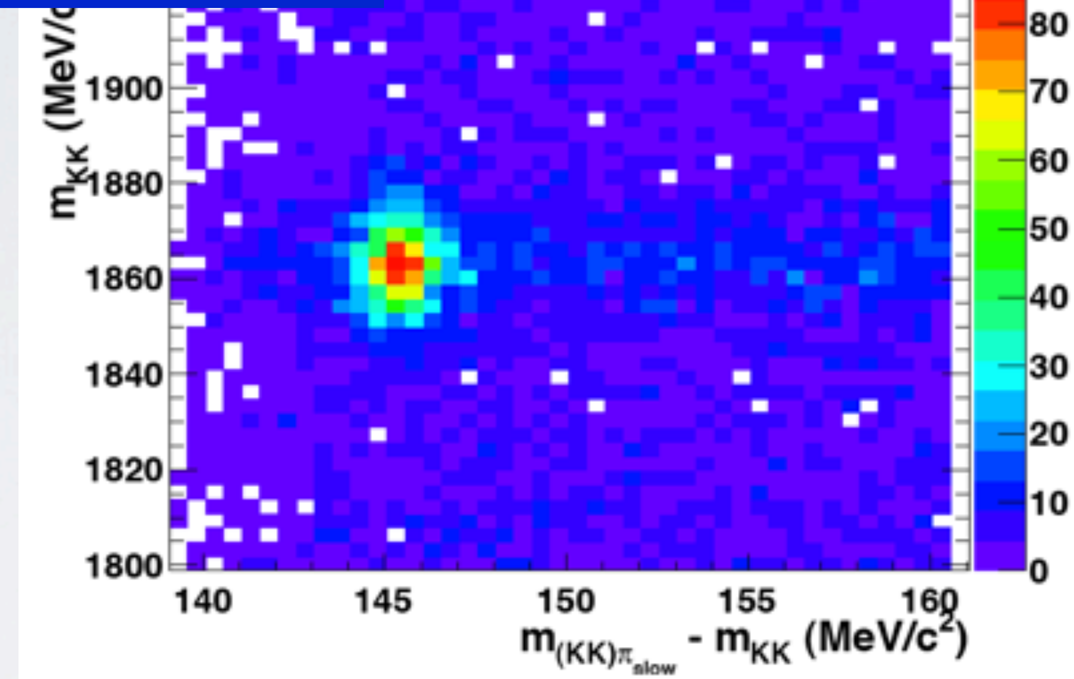
MEASUREMENT METHODS

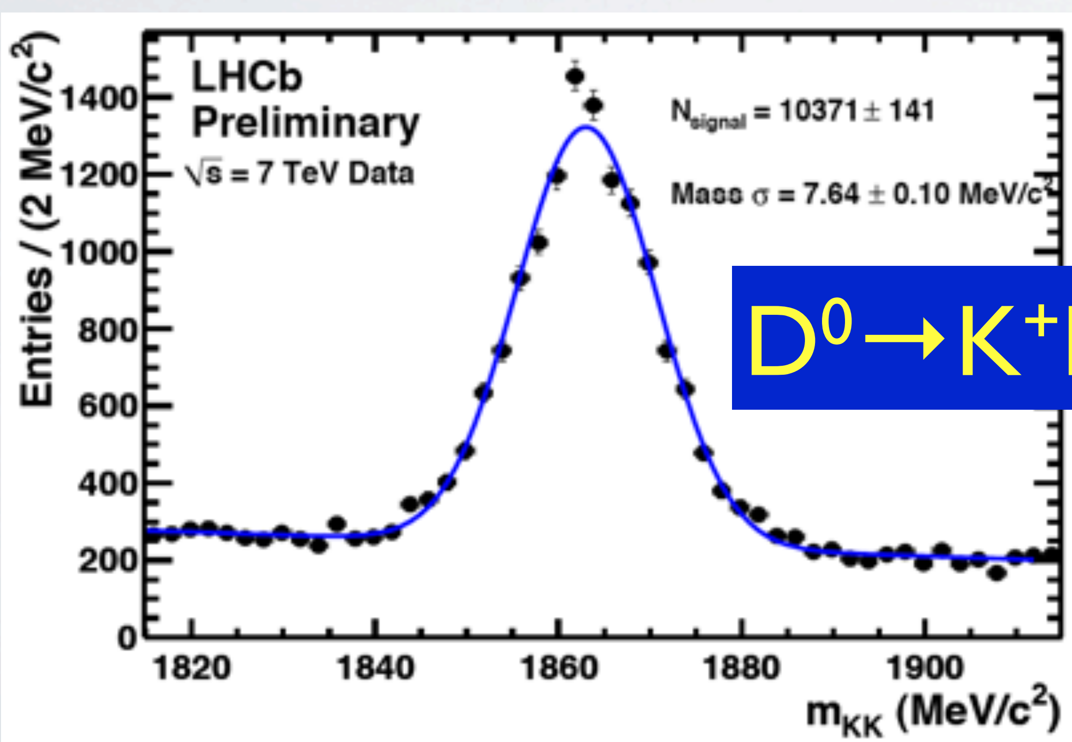
- Measure ratio of yields in bins of proper time while minimising proper time bias in selection:
  - Maximise cancellation of bias per bin
  - Potentially easier to control systematics
- Perform unbinned lifetime fits in individual modes:
  - Correct for proper time bias on event-by-event basis
  - Needs parametrisation of secondary IP distribution with time

$124\,nb^{-1}$

$D^{*+} \rightarrow D^0(K^+K^-)\pi_s$

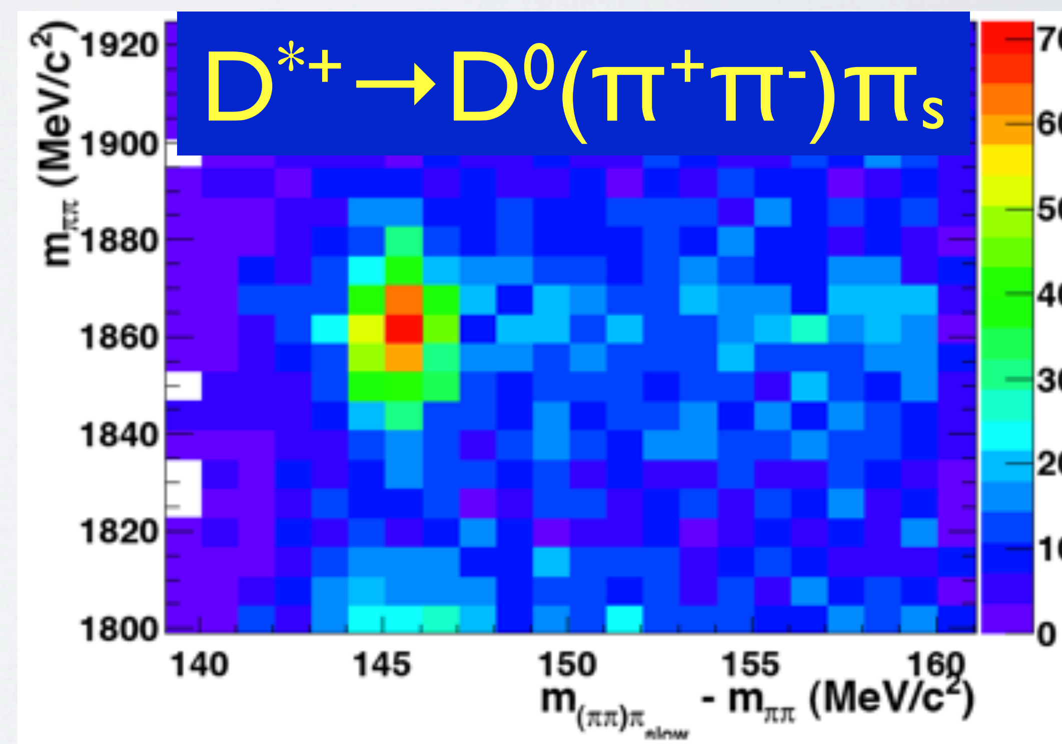






$D^0 \rightarrow K^+K^-$

$D^{*+} \rightarrow D^0(\pi^+\pi^-)\pi_s$



AVAILABLE DATA SET

- Currently approaching ball park of existing measurements
- Plan to perform measurements with at least a factor 2 increase in sensitivity
- Trigger rapidly evolving to accommodate changes in luminosity: final data set depends on trigger conditions
- Various selection strategies:
  cut based,
  neural net

$D^0 \rightarrow K_S hh$

MEASUREMENT STRATEGY

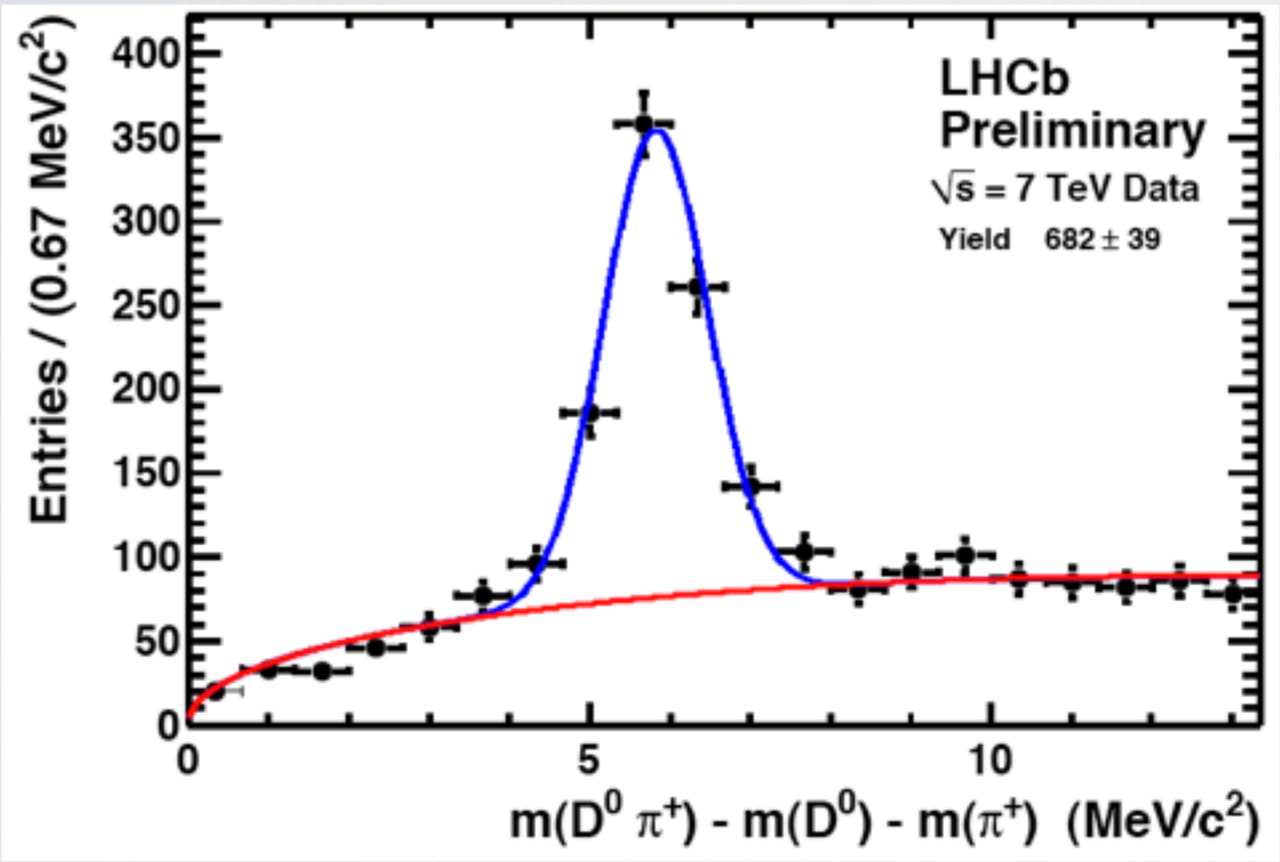
- Time dependent Dalitz plot analysis with ~10 resonances
- Access to individual mixing parameters **x** & **y** as well as CPV variables **|q/p|** & **ϕ**
- Recent BaBar & Belle measurements just reached statistical sensitivity to mixing
- Aim at significantly increasing sensitivity at LHCb: available end 2011
- Not an early analysis: very complex fit needs profound understanding of data and models

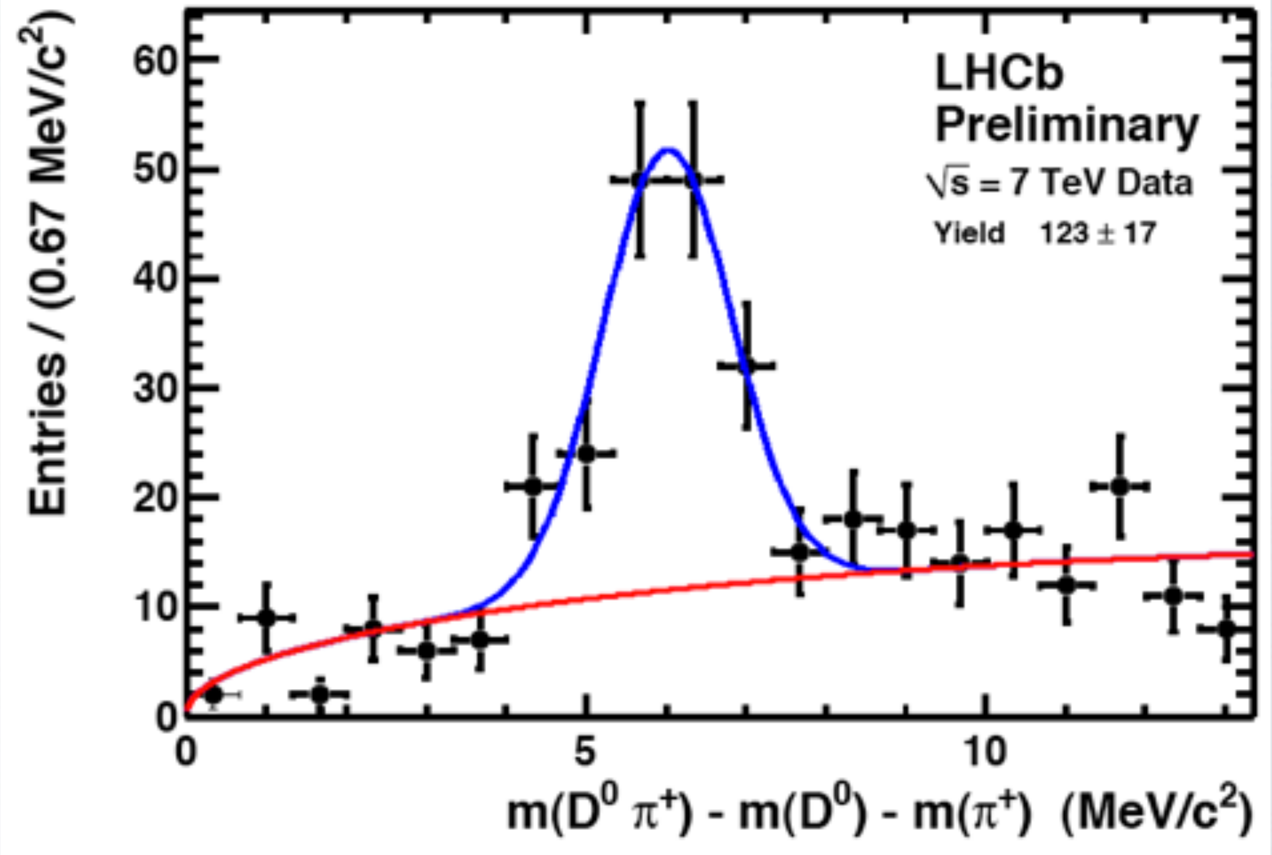
$D^0 \to K_S h^+ h^-$

$D^0 \to K_S \pi^+ \pi^-$

$124 nb^{-1}$

$D^0 \to K_S K^+ K^-$



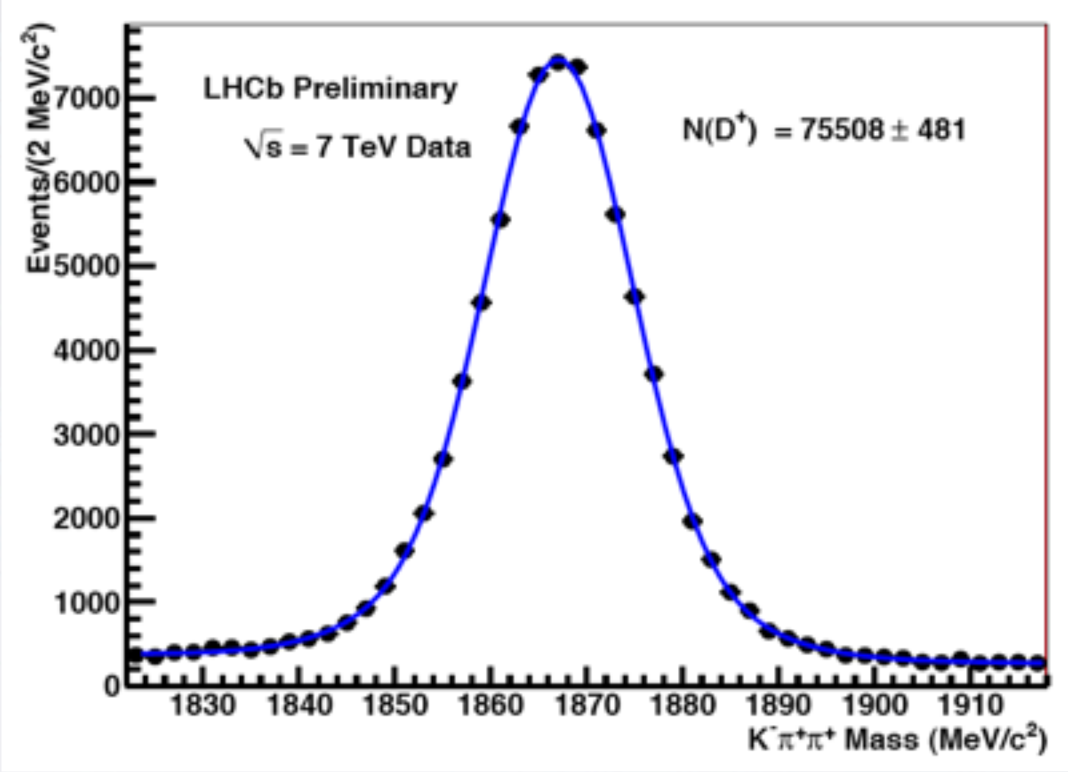


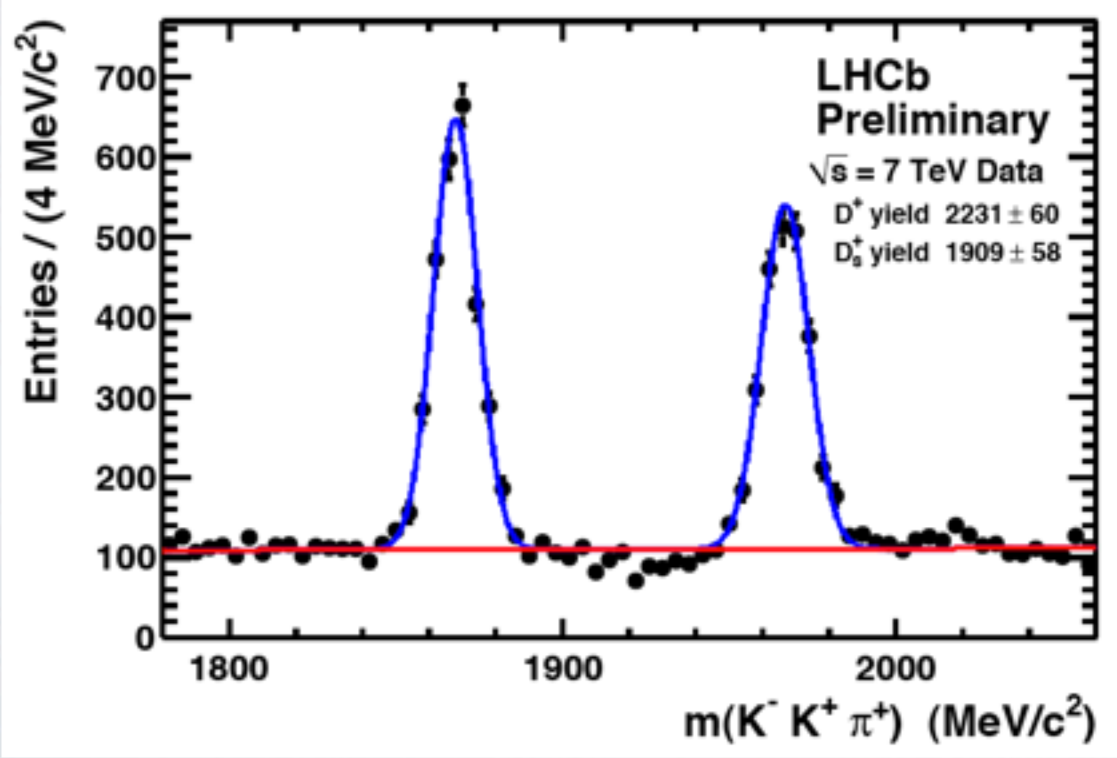
CP VIOLATION IN CHARGED D DECAYS

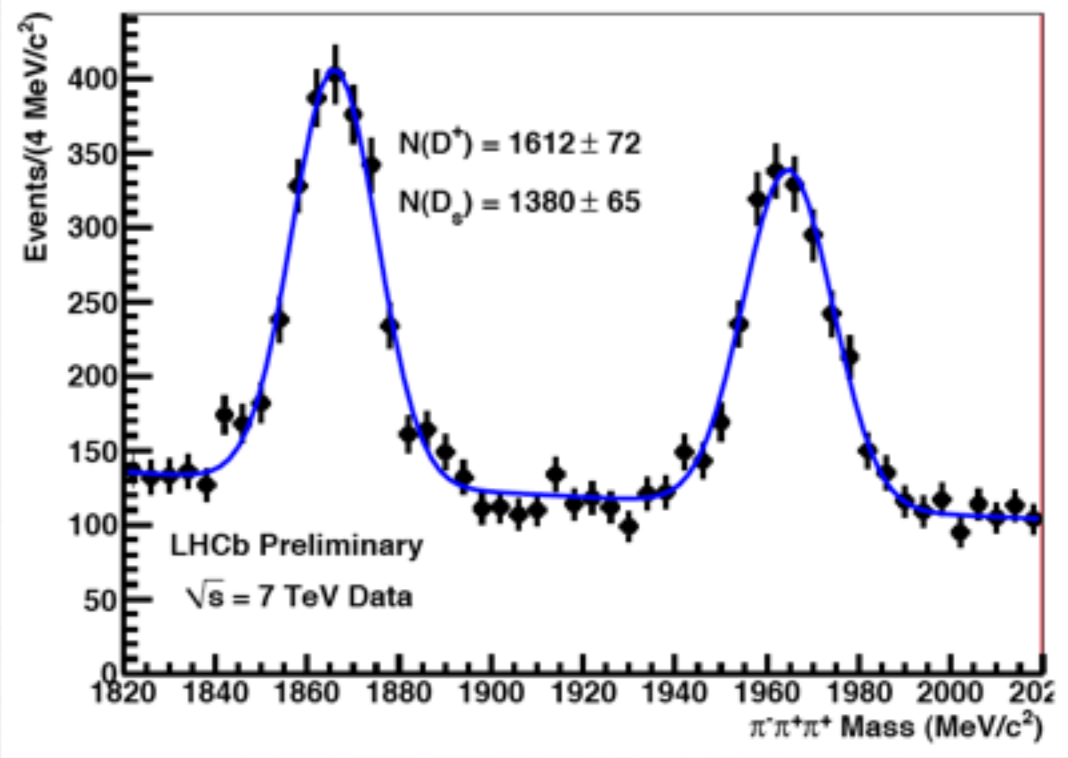
3-BODY DECAYS

128nb^{-1}

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





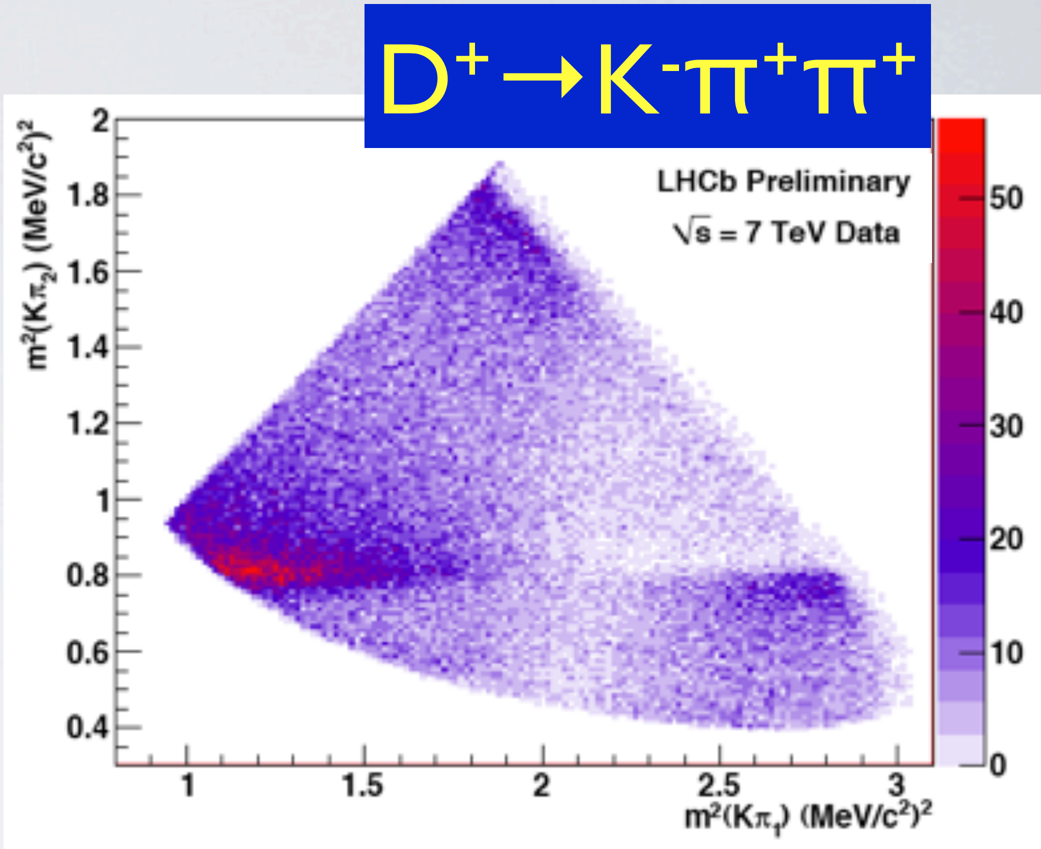


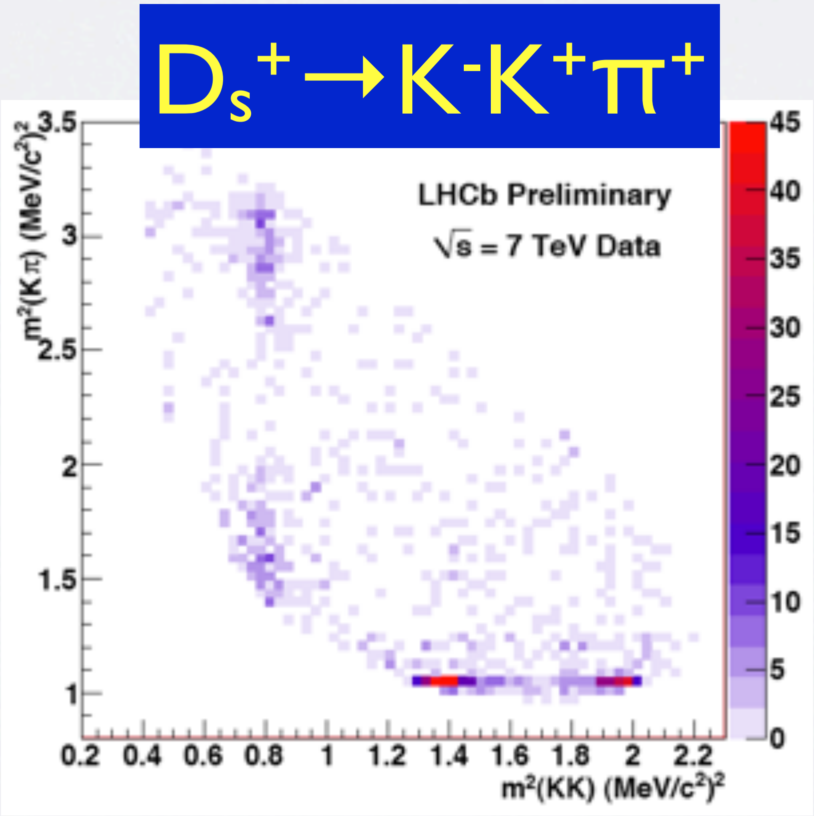
3-BODY DECAYS

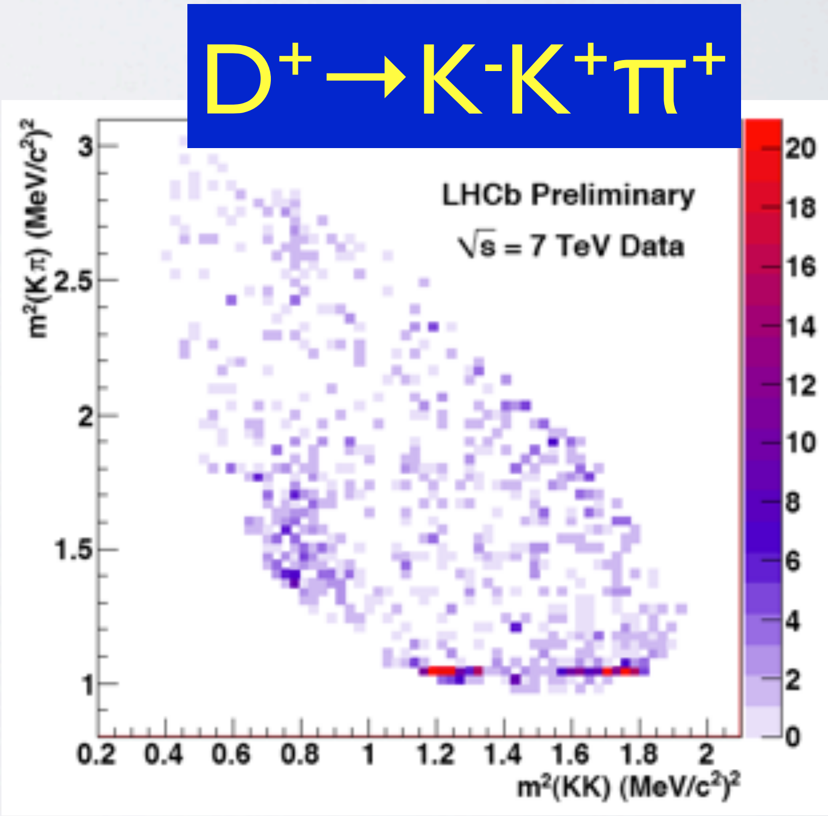
128nb^{-1}

- Search for CP asymmetries in 3-body charged D decays
- Main method:
  model independent asymmetry measurement in bins of Dalitz space

Phys.Rev.D80:096006,2009

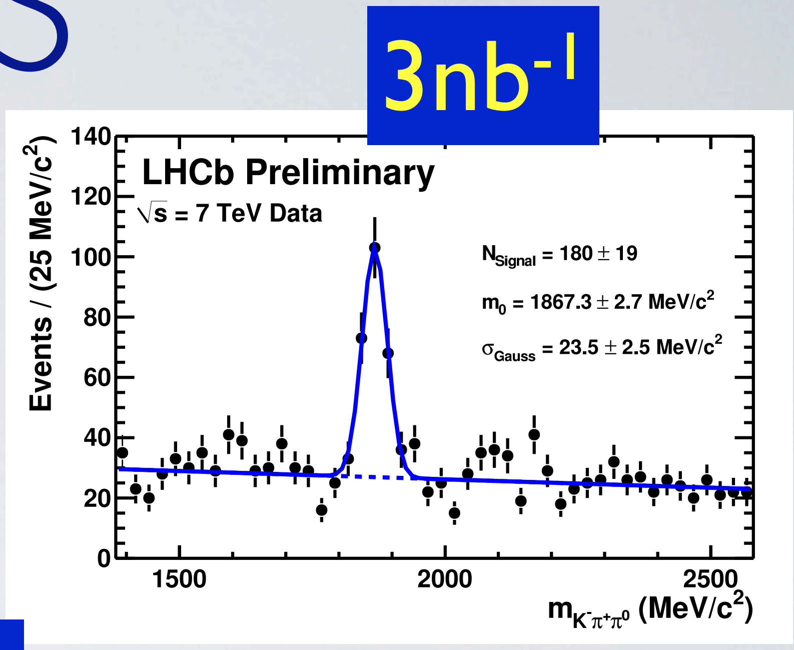




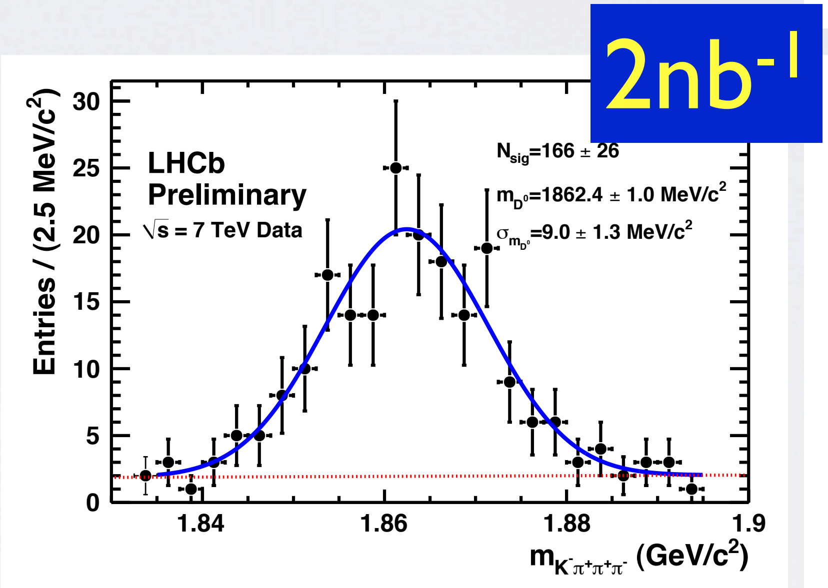


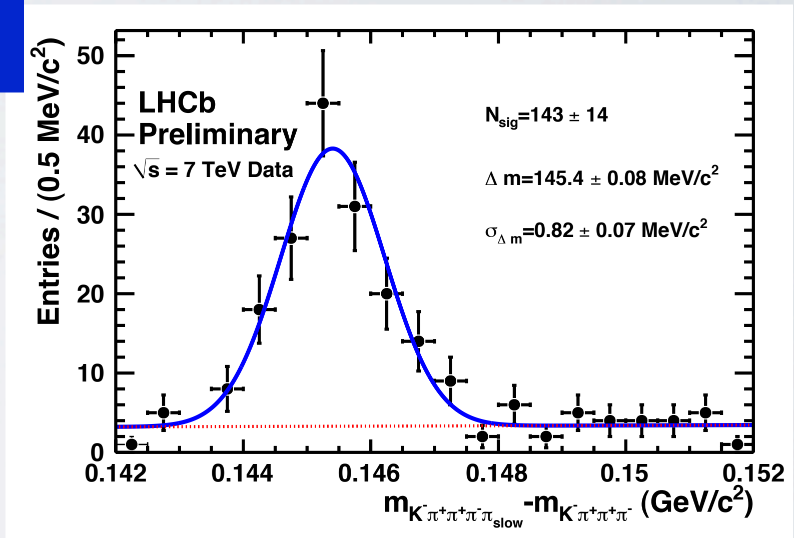
OTHER TOPICS

- Mixing measurement in **$D^0 \rightarrow K^+\pi^-\pi^0$**

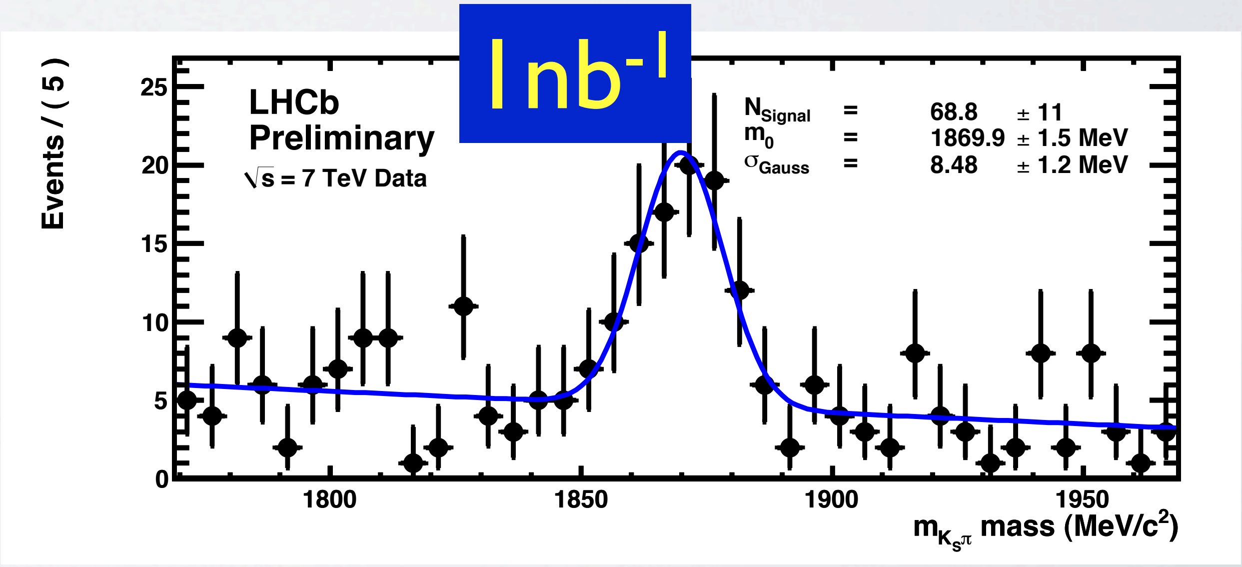


- T violation in 4-body D^0 decays: **$D^0 \rightarrow K^-K^+\pi^-\pi^+/K^-K^+\mu^-\mu^+$**





- Direct CP violation search in **$D^+ \rightarrow K_S K^+/K_S\pi^+$**



CONCLUSION

CONCLUSION

- LHCb detector works beautifully
- First presentation of charm cross-section results:
  - In broad agreement with theory
  - Higher precision to come
- Mixing and CPV analyses in preparation
- Acquired LHCb data sets approach existing data sets of other experiments
- Expect to acquire enough data to significantly increase sensitivities in the course of next year