Charm production and rare charm decays at LHCb

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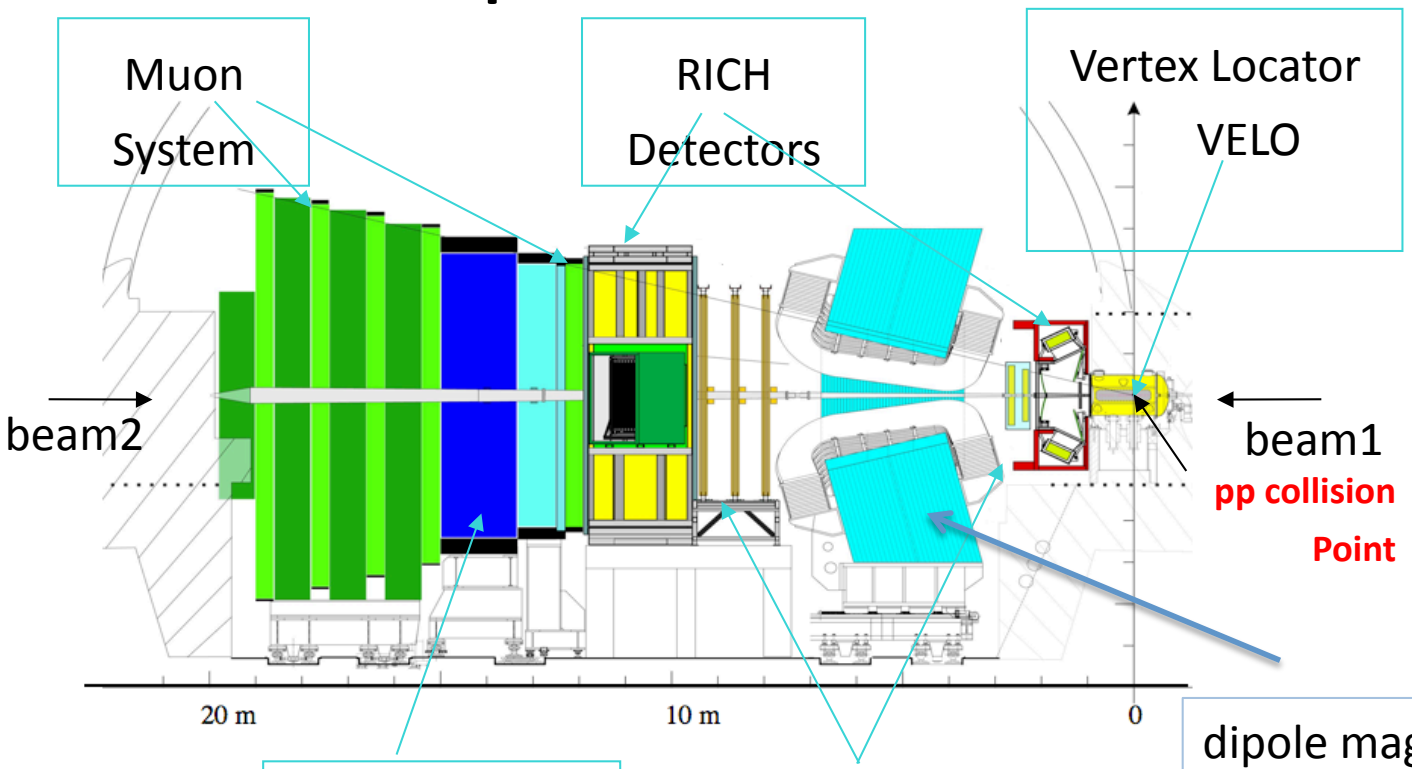
on behalf of the LHCb collaboration

Topics

- Observation of double charm production involving open charm, with 355pb^{-1}
  - arXiv:1205:0975, accepted by JHEP
- Measurement of the D_s^+-D_s^- production asymmetry, with 1fb^{-1}
  - Physics Letters B 713 (2012), pp. 186-195
- Search for the $D^0 \rightarrow \mu\mu$ decay, with 0.9fb^{-1}
  - Preliminary, LHCb-CONF 2012-005

All 3 measurements performed at $\sqrt{s}$=7TeV (pp collisions)

A little reminder of the LHCb spectrometer



dipole magnet
periodic swap of B to check/cancel systematics

Pseudo-rapidity coverage → 2 to 5
Originally designed for b physics, but now is pursuing a wide charm physics program

Double charm production (i)

- c-anti c cross section measured √s=7TeV using inclusive production of open charm mesons at LHCb and found to be very large, σ=(6100 ± 934)μb, and in agreement with QCD predictions (LHCb-CONF-2010-013)
  - about 1/10 of the inelastic cross section
  - about 20 times the bbar cross section (PLB 694 (2010) 209)

- Also prompt J/Ψ production measured to be large, σ=(10.5± 2.5)μb for 2<y<4.5 and pT<14GeV/c, and compared to different theory predictions (Eur. Phys. J. C (2011) 71:1645)

- To shed more light on the charm and quarkonium production mechanisms, study the associated production of two charm resonances, hidden (J/Ψ)+open charm hadron (D0, D+, Ds+, Λ+c) or double open charm hadron
  - test single parton scattering QCD predictions and look for contributions of intrinsic charm and double parton scattering (DPS)

- Double J/ψ production already published (Phys. Lett. B 707 (2012) 5259) and found consistent with theory (arXiv:1204.1058, arXiv:1106.2184)
  - statistics of the publication (37.5pb^{-1}) not enough to tell if DPS is at play

Double charm production (ii)

First observation of J/ψC(C̄) and CC open charm states in hadronic collisions

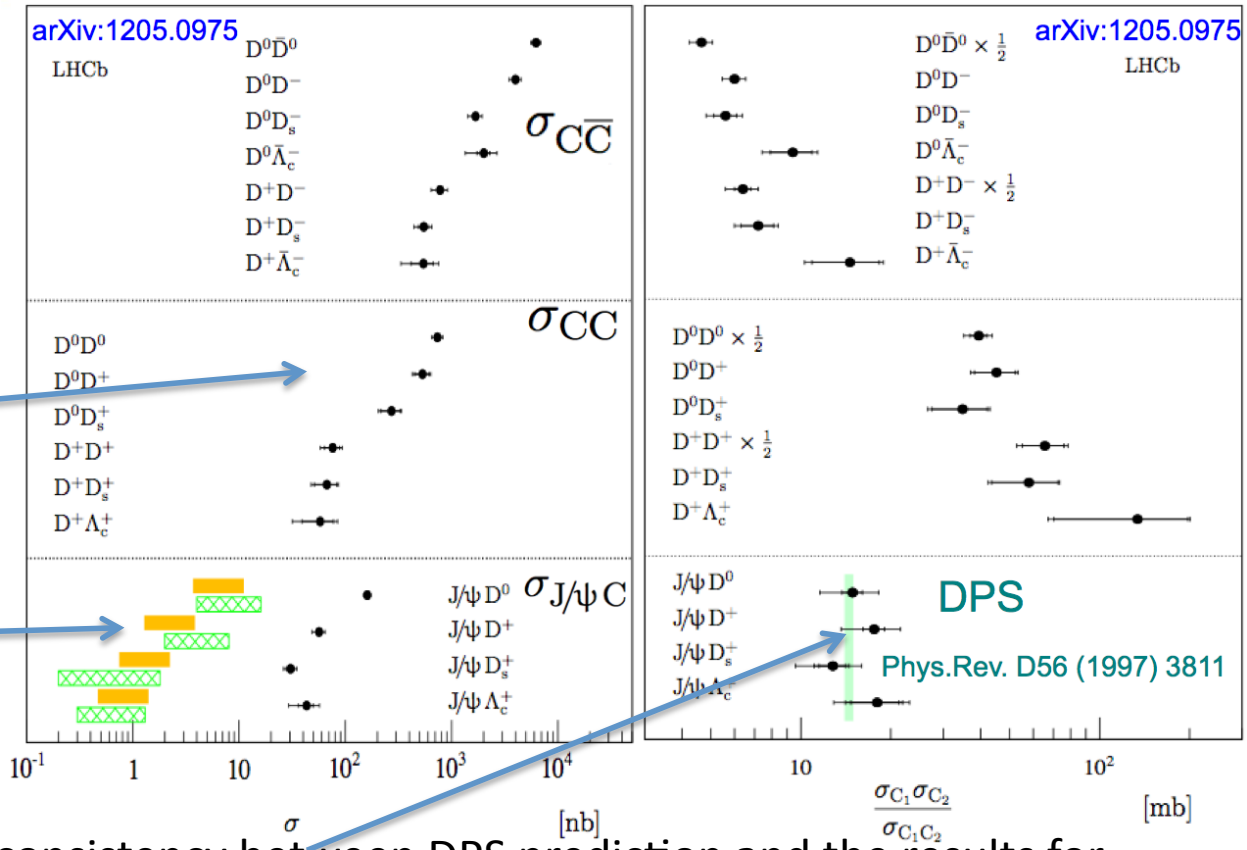
the ratio CC/CC̄ turns out to be about 10%

gg fusion predictions

Phys.Rev. D57 (1998) 4385

Eur. Phys. J C61 (2009) 693

significantly underestimate the cross-sections

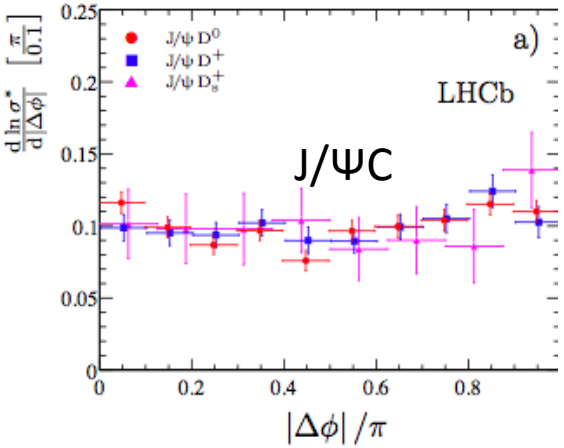


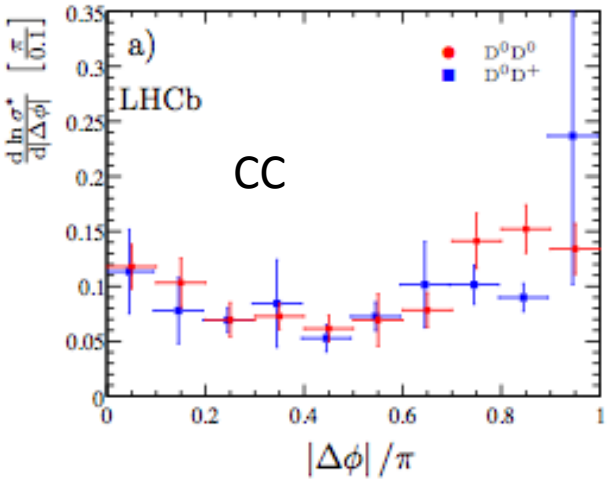
Good consistency between DPS prediction and the results for J/ψC modes and for CC modes (1204.1058v1)

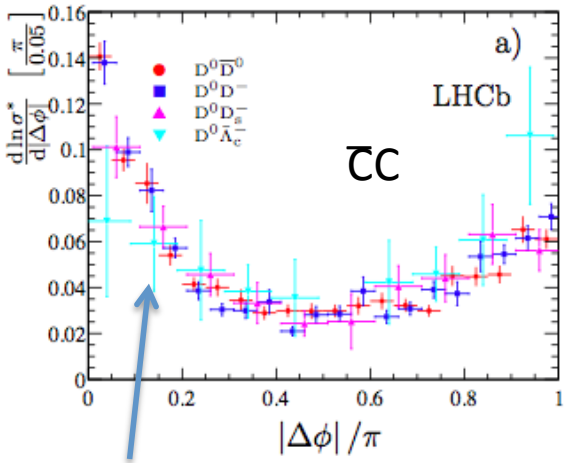
$$\sigma_{\mathrm{DPS}}(\mathrm{C_1C_2}) = \begin{cases} \frac{1}{2}\frac{\sigma(\mathrm{C_1}) \times \sigma(\mathrm{C_1})}{\sigma_{\mathrm{eff}}^{\mathrm{DPS}}}, & \text{for } \mathrm{C_1} = \mathrm{C_2} \\ \frac{\sigma(\mathrm{C_1}) \times \sigma(\mathrm{C_2})}{\sigma_{\mathrm{eff}}^{\mathrm{DPS}}}, & \text{for } \mathrm{C_1} \neq \mathrm{C_2}. \end{cases}$$

Double charm production (iii)

azimuthal correlations

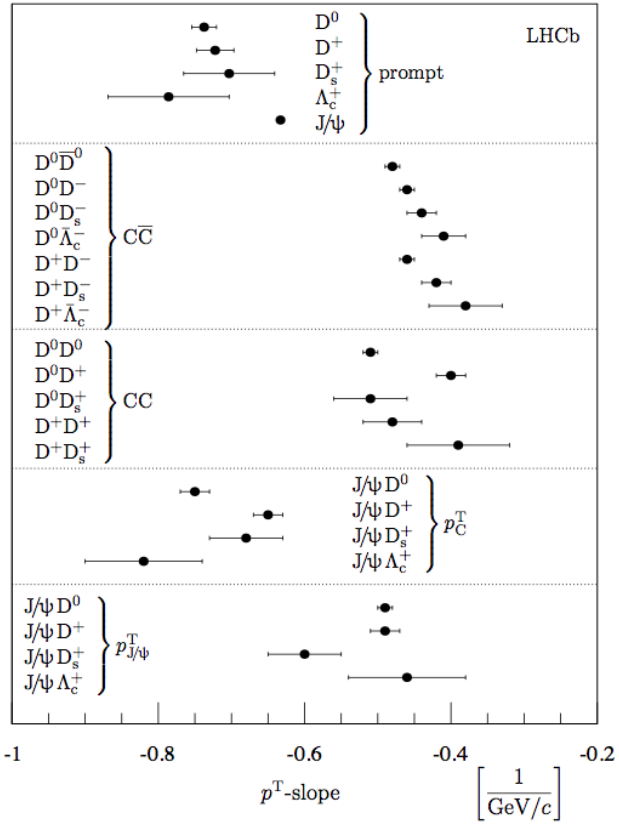






suggestive of gluon spitting process

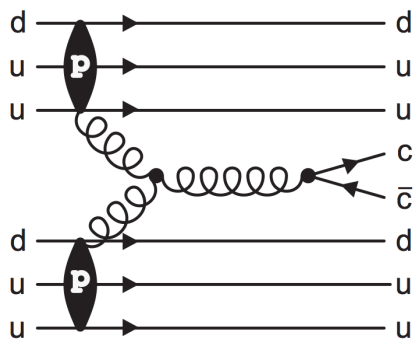
interesting discrepancy between single and double open charm production



transverse momentum slopes

D_s^+ production asymmetry (i)

- Production diagrams are symmetric but hadronization may not be



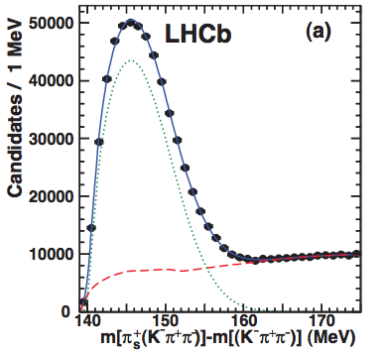
with the proton valence quarks can only form a baryon
→ an excess of c-bar mesons could be expected

- measurement of prompt (i.e not from b) production cross section asymmetry using the $D_s^+ \rightarrow \phi\pi$ decay with $\phi \rightarrow KK$

$$A_P = \frac{\sigma(D_s^+) - \sigma(D_s^-)}{\sigma(D_s^+) + \sigma(D_s^-)}$$

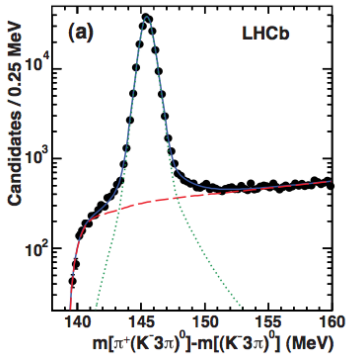
D_s^+ production asymmetry(ii)

- $D_s^+ \rightarrow \phi\pi$ is Cabibbo-Favored (CF) decay so that only detection asymmetry matters
  - need to determine π^+/π^- efficiency asymmetry
  - kinematically reconstruct D^{*+}-tagged $D^0 \rightarrow K3\pi$ decays with only 3 pions



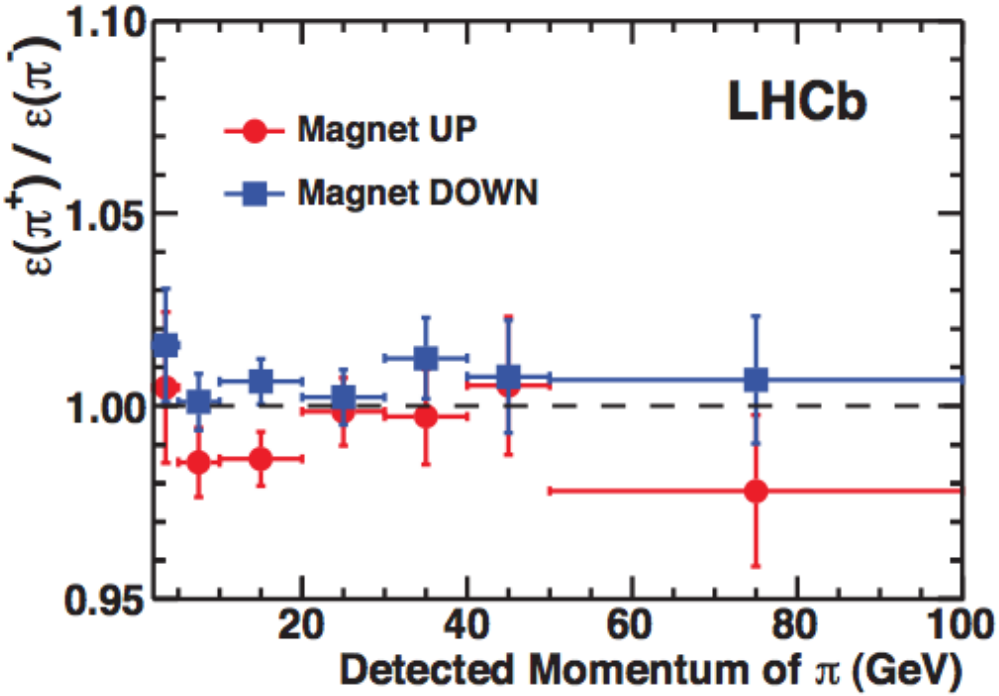
Δm partially reconstructed

  - and then count how many times the fourth pion is also reconstructed



Δm fully reconstructed

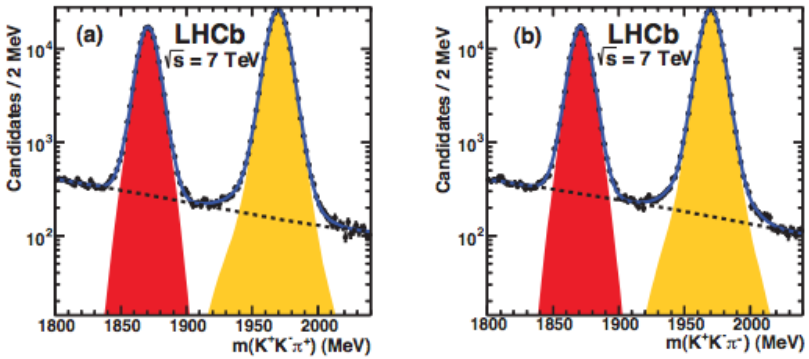
D_s^+ production asymmetry(iii)



suggestive of a "small" left-right reconstruction asymmetry in the detector

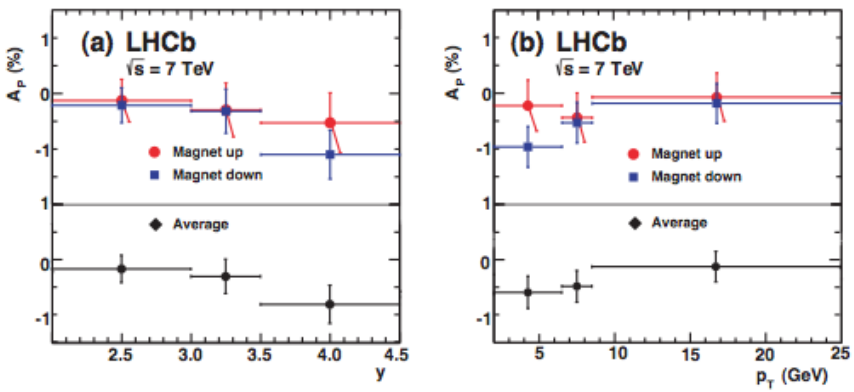
this measurement also important ingredient to study CPV in charm and beauty

D_s^+ production asymmetry (iv)



$$A_P = \frac{\sigma(D_s^+) - \sigma(D_s^-)}{\sigma(D_s^+) + \sigma(D_s^-)} = (-0.33 \pm \overset{\text{stat}}{0.22} \pm \overset{\text{syst}}{0.10})\%.$$

for 2<y<4.5
p_T>2GeV/c



consistent with theory predictions:
(Phys.Lett.B298(1993)218., Eur.Phys.J.C17 (2000)137)

Also measured by LHCb at √s=7TeV $A_P(D^0)$ = (–1.08 ± 0.32 ± 0.12) %

Preminary(LHCb-CONF-2011-023)

Search for the $D^0 \rightarrow \mu\mu$ decay (i)

Present best published upper limit → Belle: $1.4 \cdot 10^{-7}$ @90% C.L.
An intriguing new result from Babar (arXiv: 1206.5419v1): $[0.6,8.1] \cdot 10^{-7}$ @90% C.L.

Theory: FCNC

- short distance contribution: 10^{-18} in SM, can be enhanced by e.g. RPV SUSY
- long distance contributions (SM):
  1 single particle contribution $<10^{-18}$
  2 two-photon contribution

$$\mathcal{BR}^{(\gamma\gamma)}(D^0 \to \mu^+\mu^-) \simeq 2.7 \times 10^{-5} \mathcal{BR}(D^0 \to \gamma\gamma)$$ Phys.Rev. D66 (2002) 014009

present best UL on $D^0 \rightarrow \gamma\gamma$ is from Babar: $2.2 \cdot 10^{-6}$ @90% C.L. Phys.Rev. D85 (2012091107
so the UL to the two-photon contribution to $BR(D^0 \rightarrow \mu\mu)$ is $6 \cdot 10^{-11}$ @90% C.L.

So there are more than 3 orders of magnitudes of "clean" physics to be investigated

SUSY with RPV correlates this decay with D mixing and $BR(D^0 \rightarrow \mu\mu) \leq 4.8 \times 10^{-9} \left(\frac{300 \text{ GeV}}{m_{\tilde{d}_k}} \right)^2$
[Phys.Rev. D79 (2009) 114030]

Search for the $D^0 \rightarrow \mu\mu$ decay (ii)

$$\mathcal{B}(D^0 \to \mu^+\mu^-) = \frac{N_{D^{*+}\to D^0(\to\mu^+\mu^-)\pi^+}}{N_{D^{*+}\to D^0(\to\pi^+\pi^-)\pi^+}} \frac{\varepsilon_{\pi\pi}}{\varepsilon_{\mu\mu}} \cdot \mathcal{B}(D^0 \to \pi^+\pi^-) = \alpha \cdot N_{D^{*+}\to D^0(\to\mu^+\mu^-)\pi^+}$$

α is the single event sensitivity

$$\frac{\varepsilon_{tot}(\pi\pi)}{\varepsilon_{tot}(\mu\mu)} = \frac{\varepsilon_{sel}(\pi\pi)}{\varepsilon_{sel}(\mu\mu)} \cdot \frac{(\varepsilon_{trig}(\pi\pi) \mid sel)}{(\varepsilon_{trig}(\mu\mu) \mid sel)}$$

two main backgrounds:

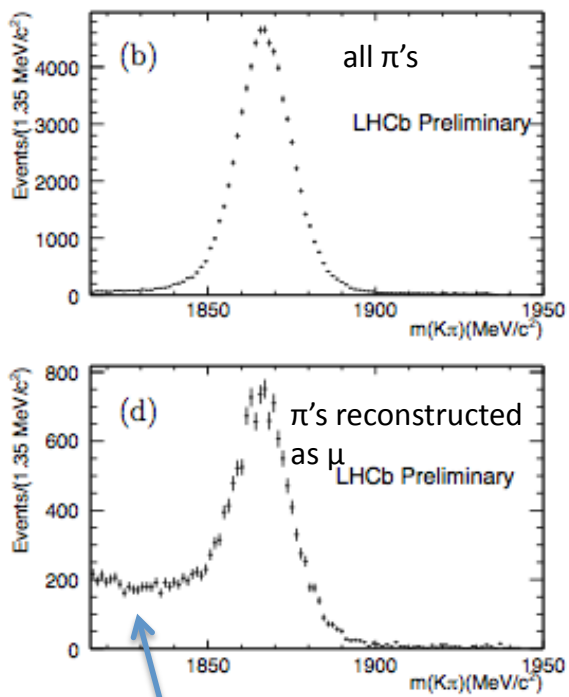
1) combinatorial (mostly from bbar)
2) peaking (mostly from $D^0 \rightarrow \pi\pi$)

Selection with cuts followed by a BDT trained on a independent data sample

Single $\pi \rightarrow \mu$ mis-ID probability measured from data using $D^0 \rightarrow K\pi$ decays and cross-checked using $K^0_s \rightarrow \pi\pi$ decays

Preliminary (LHCb-CONF 2012-005)

$D^0 \rightarrow K\pi$



contribution from $D^0 \rightarrow K\mu\nu$ (evaluated from MC)

Search for the $D^0 \rightarrow \mu\mu$ decay (iii)

$D^{*+} \rightarrow D^0(\rightarrow \pi^+\pi^-)\pi^+$ yield extracted with an unbinned extended two-dimensional fit in mass and $\Delta m = m(\pi\pi\pi) - m(\pi\pi)$

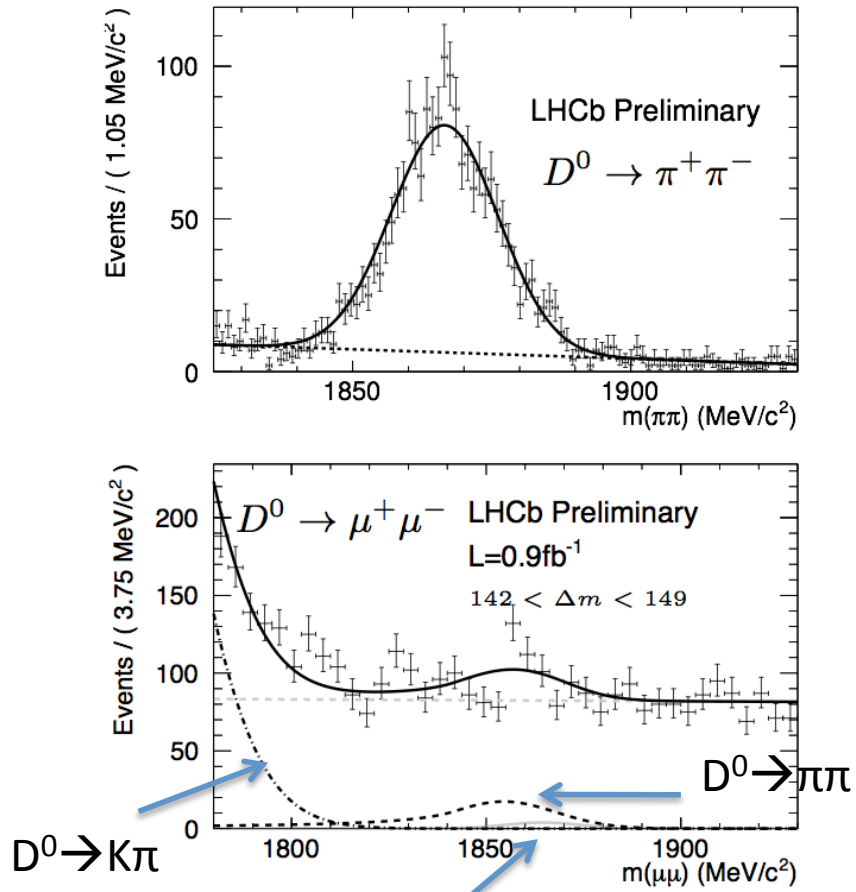
Single event sensitivity :
$\alpha = (1.96 \pm 0.23) \cdot 10^{-10}$

Also un-binned maximum likelihood 2d fit to extract $BR(D^0 \rightarrow \mu\mu)$

- Two-dimensional fit in $M(\mu\mu)$ and Δm
- Signal: gaussian(M) × double gauss (Δm)
- $D^0 \rightarrow \pi^+\pi^-$ mis-ID: Crystal Ball(M) × double gauss (Δm)
- $D^0 \rightarrow K^-\pi^+$ tail mis-ID: gaussian(M) × gaussian (Δm)
- Combinatorial background: expo(M) × f(Δm)

$$f(\Delta m) = \left(\frac{\Delta m}{a}\right)^2 \left(1 - e^{\frac{\Delta m - \Delta m_0}{c}}\right) + b \cdot \left(\frac{\Delta m}{d} - 1\right)$$

Preliminary (LHCb-CONF 2012-005)



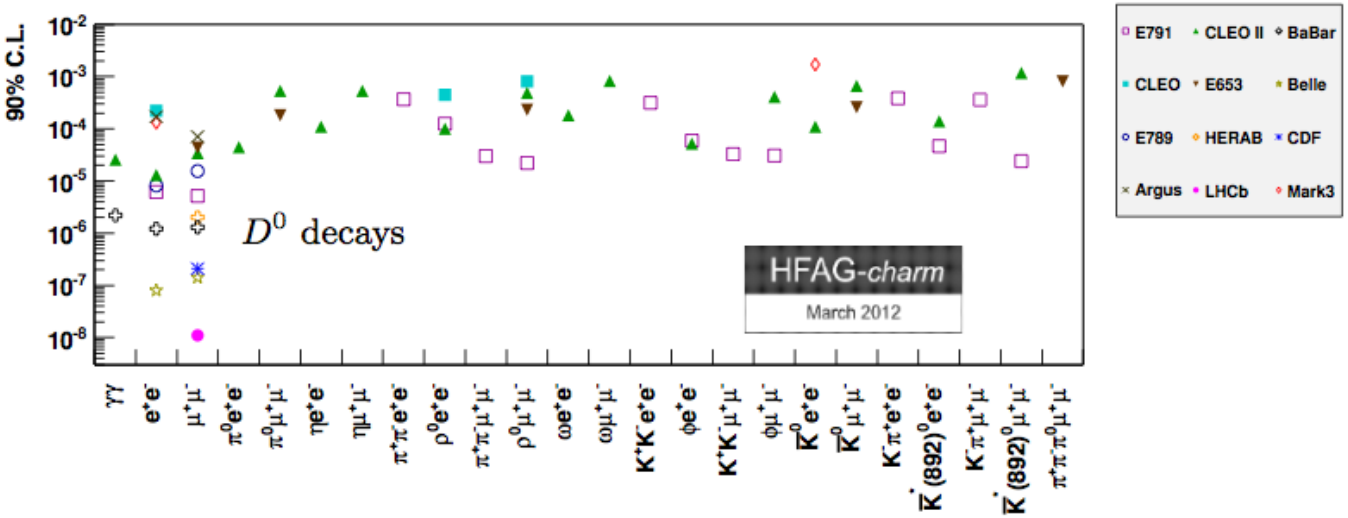
Search for the $D^0 \rightarrow \mu\mu$ decay (iv)

$$\mathcal{B}(D^0 \to \mu^+\mu^-) < 1.3\ (1.1) \cdot 10^{-8} \quad \text{at } 95\ (90)\%\text{CL}$$

Preliminary (LHCb-CONF 2012-005)

not in agreement with the Babar findings

Summary of D^0 FCNC decay modes



for the first time we are jumping with the sensitivity into a new order of magnitude of BR's!

Conclusions

- Observation of double charm production involving open charm in many modes
  - interesting indication of DPS at play in pp at $\sqrt{s}$=7TeV
- Measurement of the D_s^+-D_s^- production asymmetry as (-0.33±0.22±0.10)%
- New world best (preliminary) upper limit on FCNC $D^0 \rightarrow \mu\mu$ decay at $1.3 \cdot 10^{-8}$ @95%C.L.