

# OPEN HEAVY FLAVOR IN ALICE

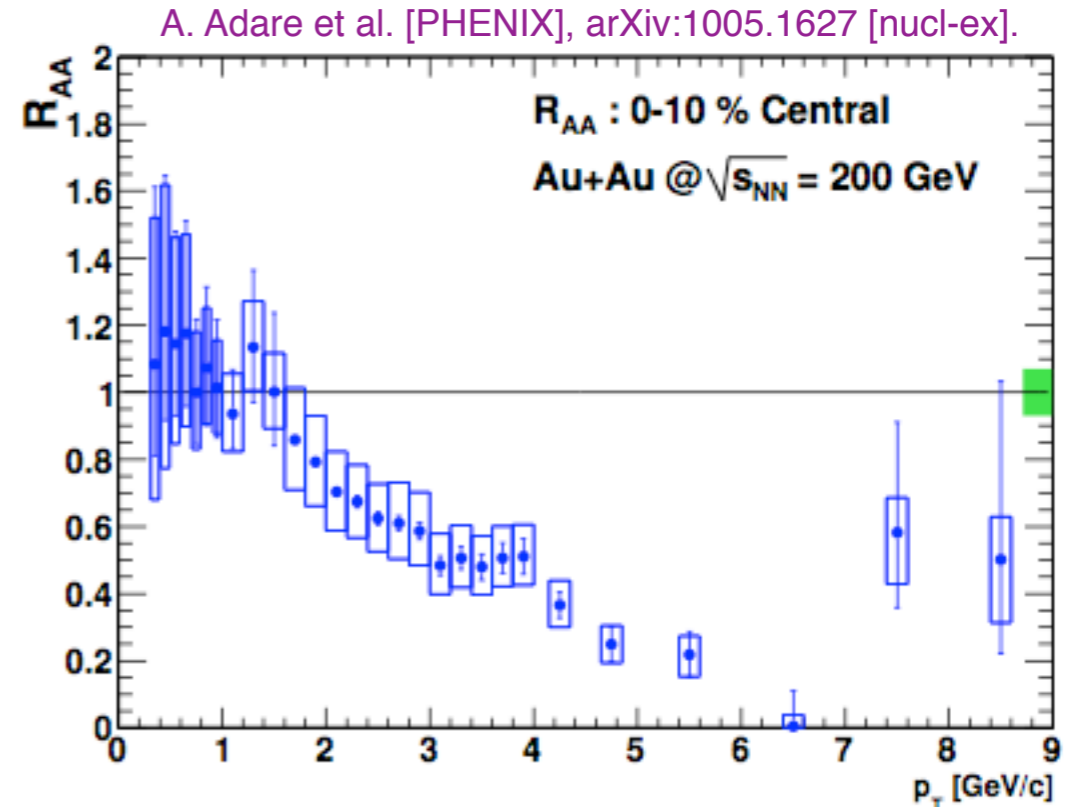
ZAIDA CONESA DEL VALLE  
(EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH,  
CERN, GENEVA, SWITZERLAND)  
ON BEHALF OF THE ALICE COLLABORATION

– HIGH-PT PROBES OF HIGH-DENSITY QCD AT THE LHC –

- \* (very-short) Introduction
- \* Open heavy flavor measurements in proton-proton interactions
  - Analysis techniques and results ( $d\sigma/dp_T, d\sigma/dy$ ):
    - D mesons, single electrons, single muons
- \* Open heavy flavor results in PbPb collisions
  - Differences on the analysis techniques and results ( $R_{AA}, R_{CP}$ ):
    - D mesons, single electrons, single muons
  - Comparison of the results
- \* Conclusions

# INTRODUCTION

- \* Heavy flavor production are a tool to test pQCD calculations (pp coll.)
- \* Heavy flavor particles are suppressed at RHIC (AB coll.)
- \* We expect (based on theoretical grounds) a mass hierarchy on the energy loss :  
 $R_{AB}(h) < R_{AB}(c) < R_{AB}(b)$
- \* ... but let's now see what data say...

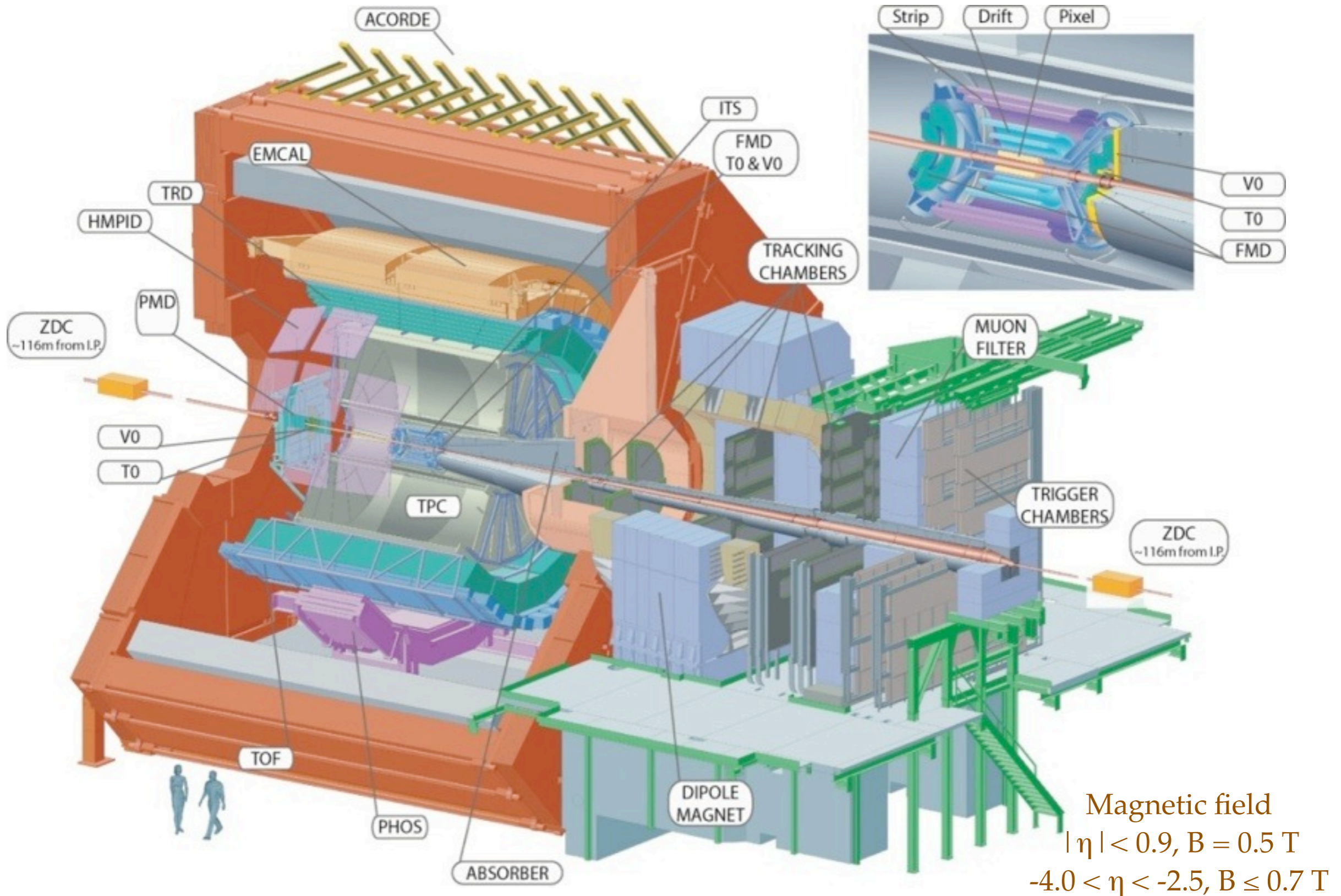


[ PHENIX: A. Adare et al. [PHENIX], arXiv:1005.1627 [nucl-ex].  
 + M. Durham QM2011 talk  
 STAR: Phys. Rev. Lett. **98** (2007) 192301 ]

[cf. talk W. Horowitz]

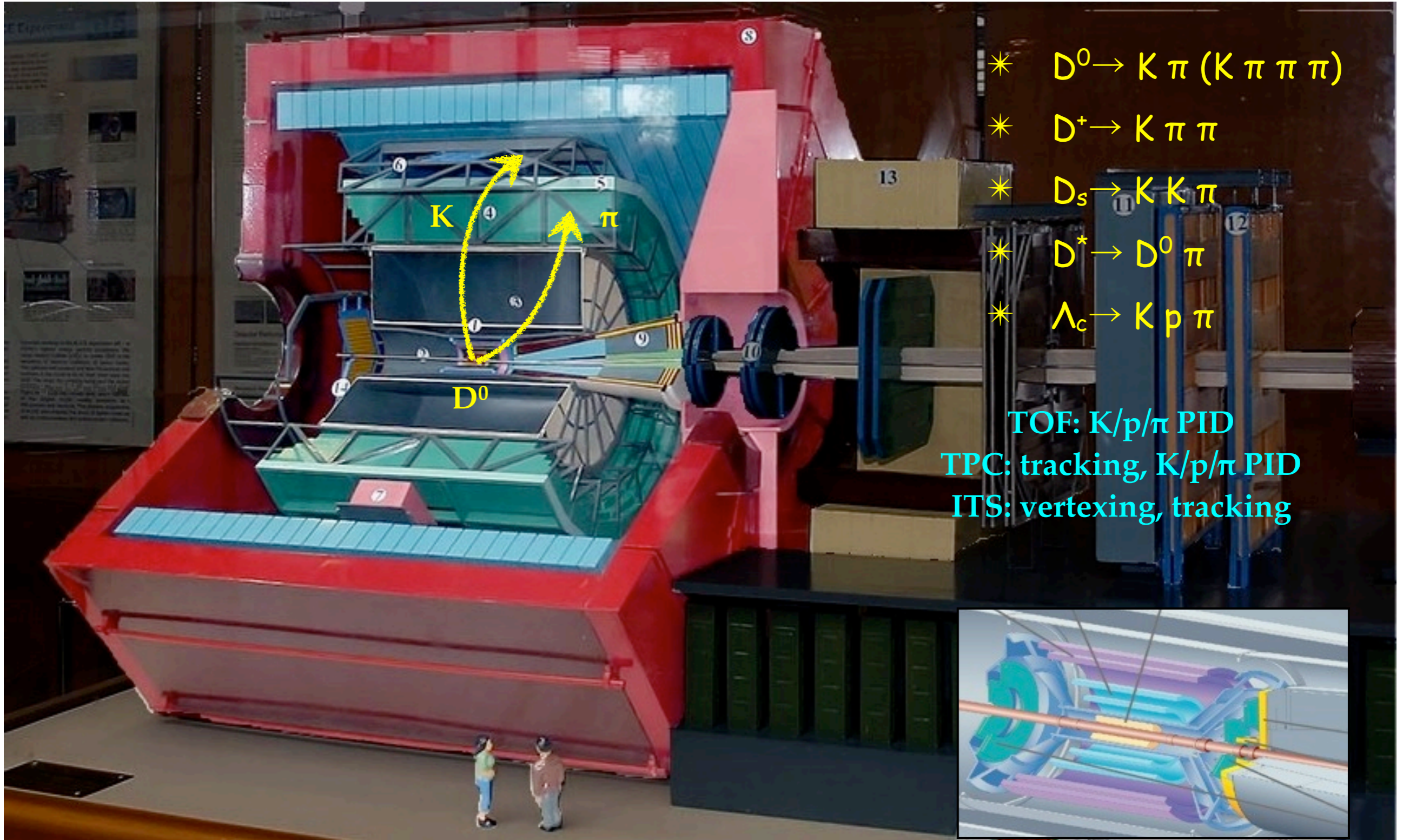
System	pp	pp	pp	pp	PbPb
$\sqrt{s_{NN}}$ [TeV]	7	7	2.76	2.76	2.76
trigger	MB	$\mu$ -trigger	MB	$\mu$ -trigger	MB
Data-taking	April-Aug 2010	April-Sept 2010	March 2011	March 2011	Nov 2010
$N_{events}$	100-180 M		65 M		17 M
$\langle L \rangle$ [nb <sup>-1</sup> ]	1.6 (out of 3.9)	16	1.1	20	2.7 $\mu$ b <sup>-1</sup>

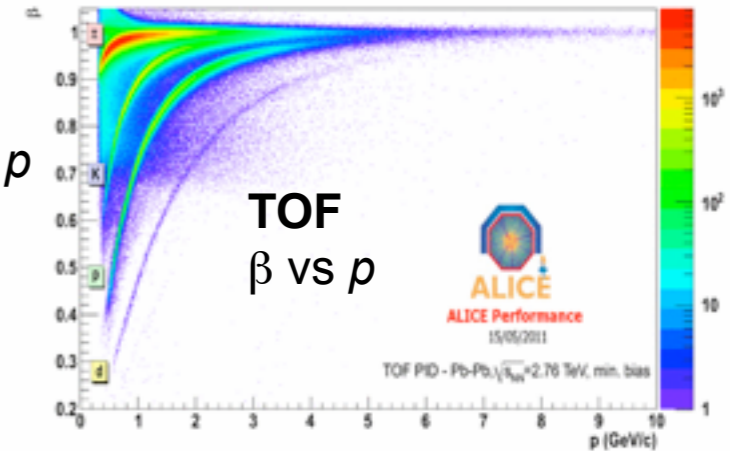
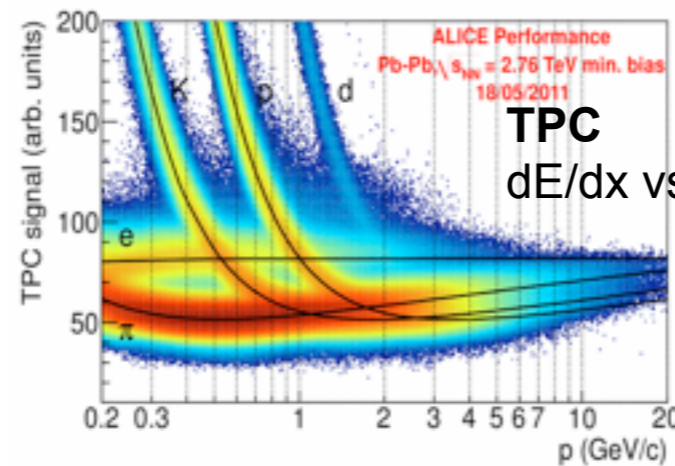
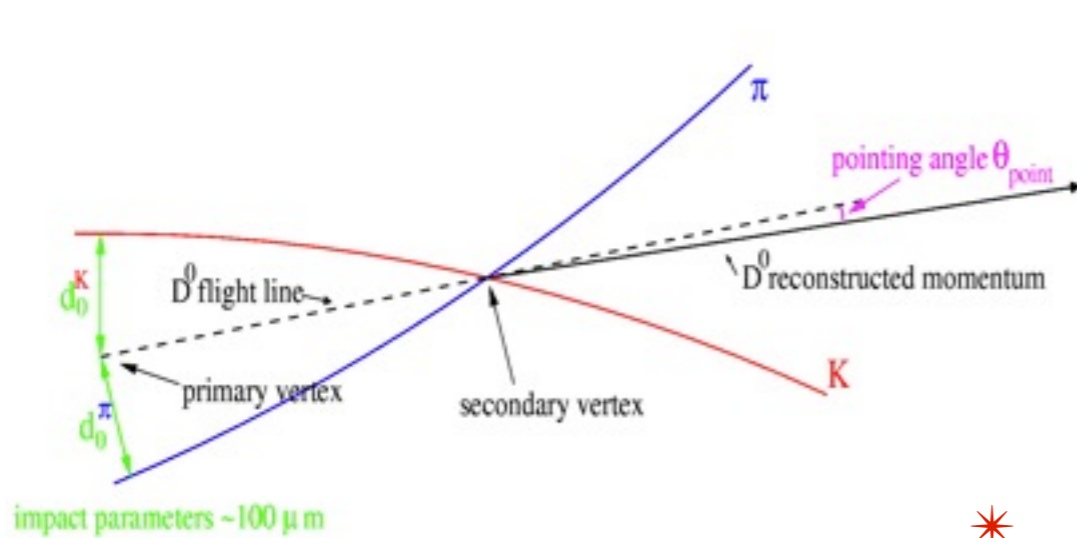
# THE ALICE EXPERIMENT



# MEASUREMENTS IN P-P COLLISIONS

System	pp	pp	pp	pp	PbPb
$\sqrt{s_{NN}}$ [TeV]	7	7	2.76	2.76	2.76
trigger	MB	$\mu$ -trigger	MB	$\mu$ -trigger	MB
Data-taking	April-Aug 2010	April-Sept 2010	March 2011	March 2011	Nov 2010
$N_{\text{events}}$	100-180 M		65 M		17 M
$\langle L \rangle$ [ $\text{nb}^{-1}$ ]	1.6 (out of 3.9)	16	1.1	20	$2.7 \mu\text{b}^{-1}$





\* Selection strategy: displaced vertexes

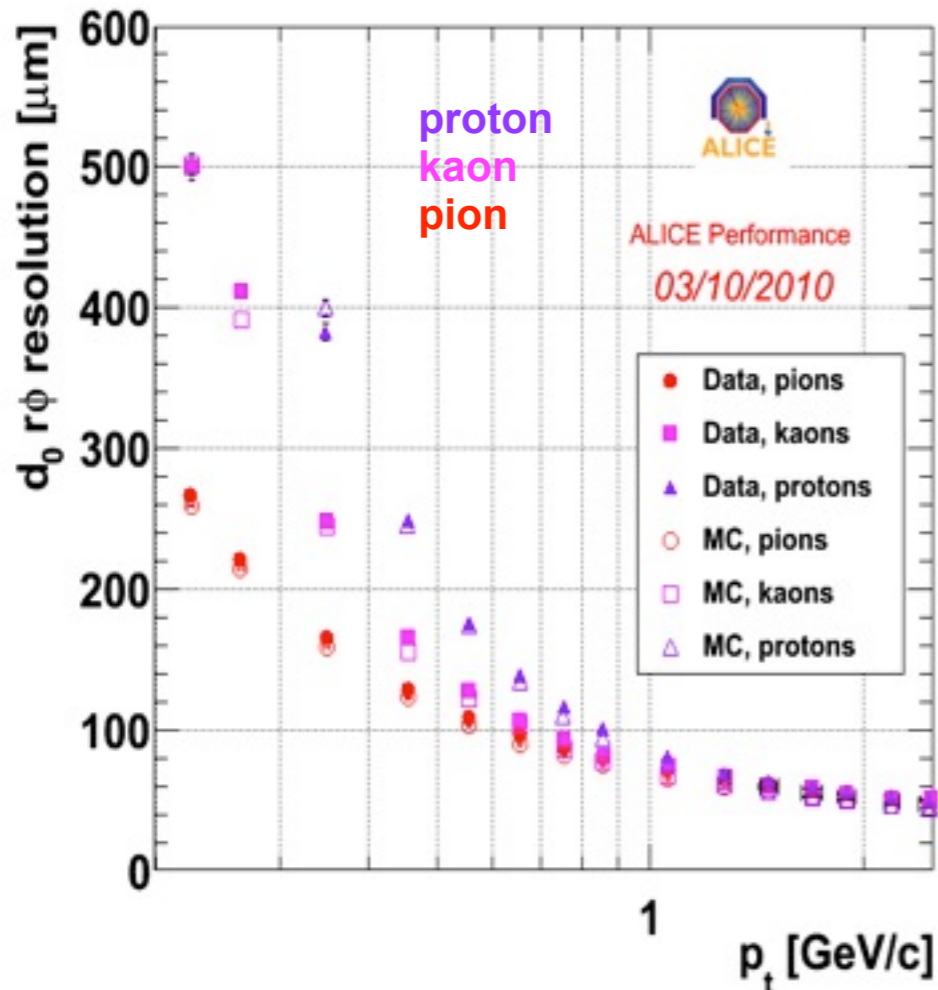
\* Main topological cuts:

- ▶ Impact parameter of the tracks,
- ▶ Angle between the meson flight line and the particle momentum.

\* Particle identification: K identification thanks to the TPC+TOF helps to reject background at low  $p_T$

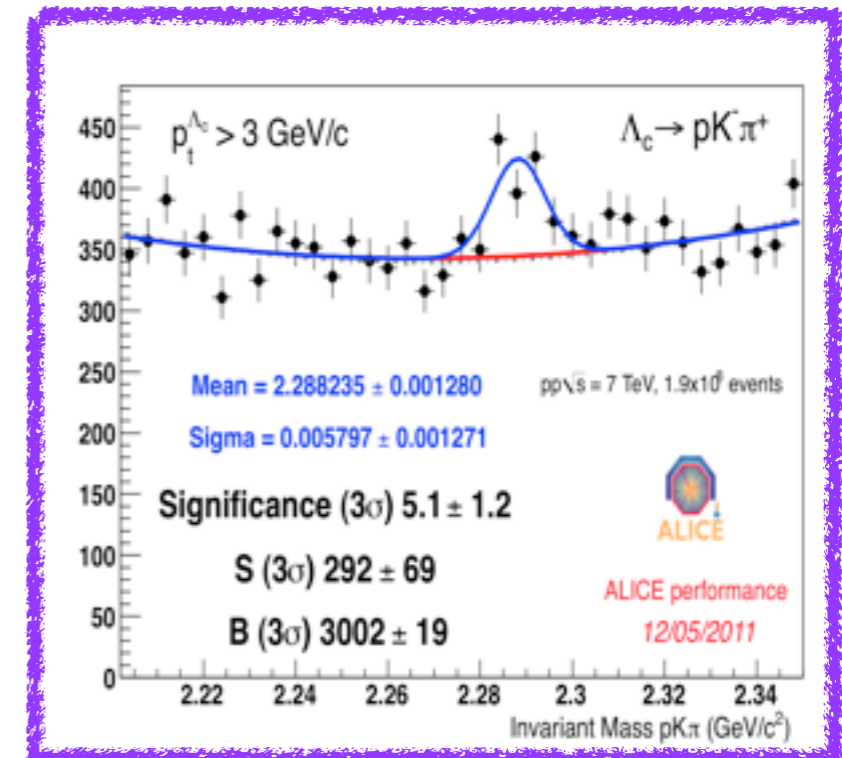
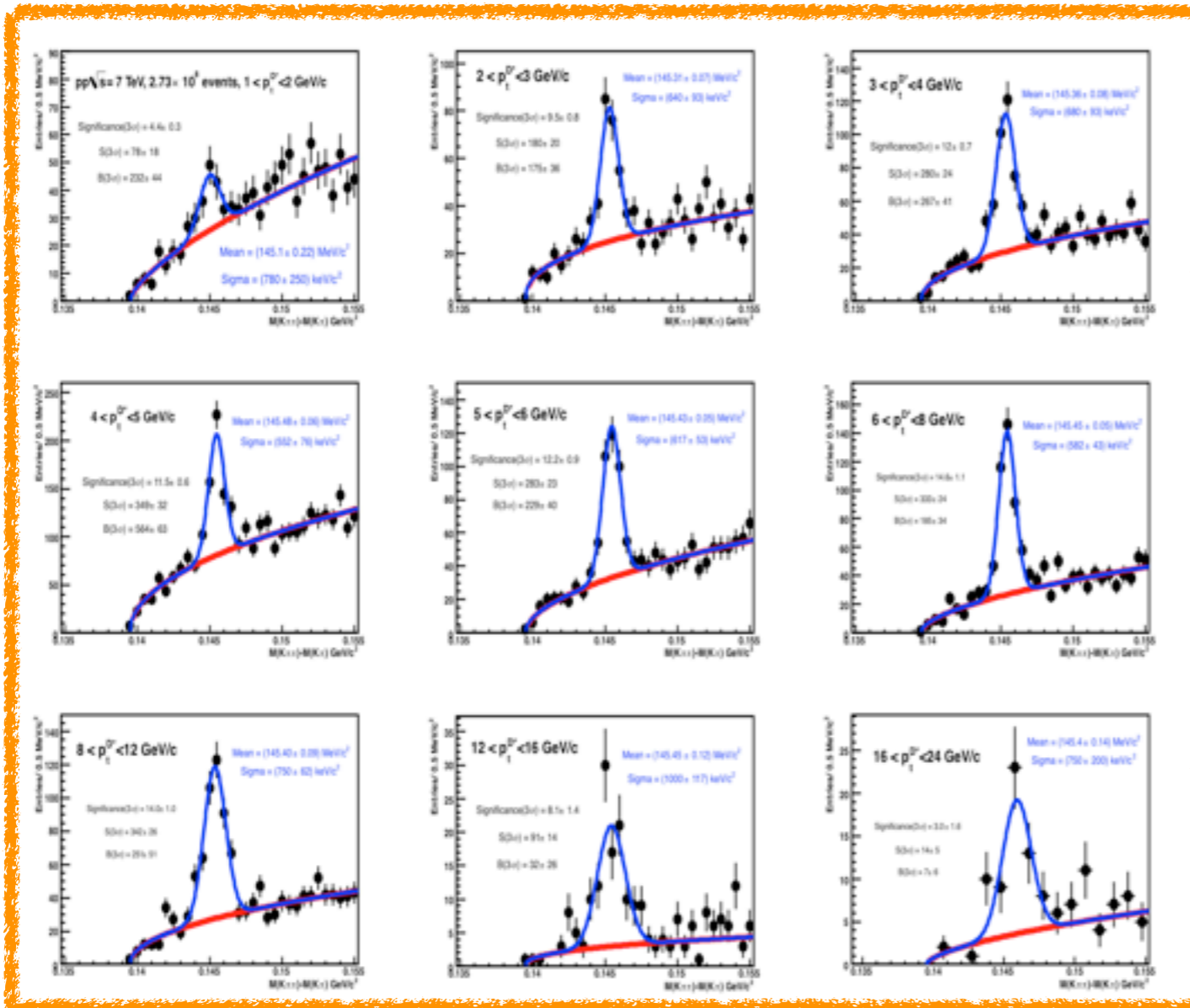
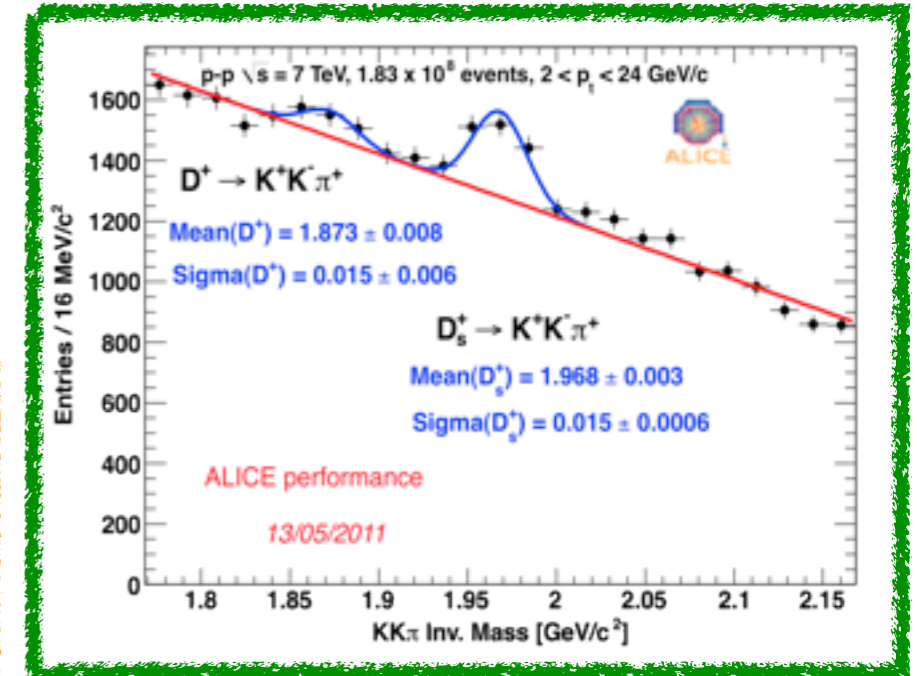
- ▶ TPC allows K/ $\pi$  separation up to  $\sim 0.6$  GeV/c,
- ▶ TOF allows K/ $\pi$  separation up to  $\sim 2$  GeV/c.

\* pQCD (FONLL) driven feed-down subtraction for the moment.



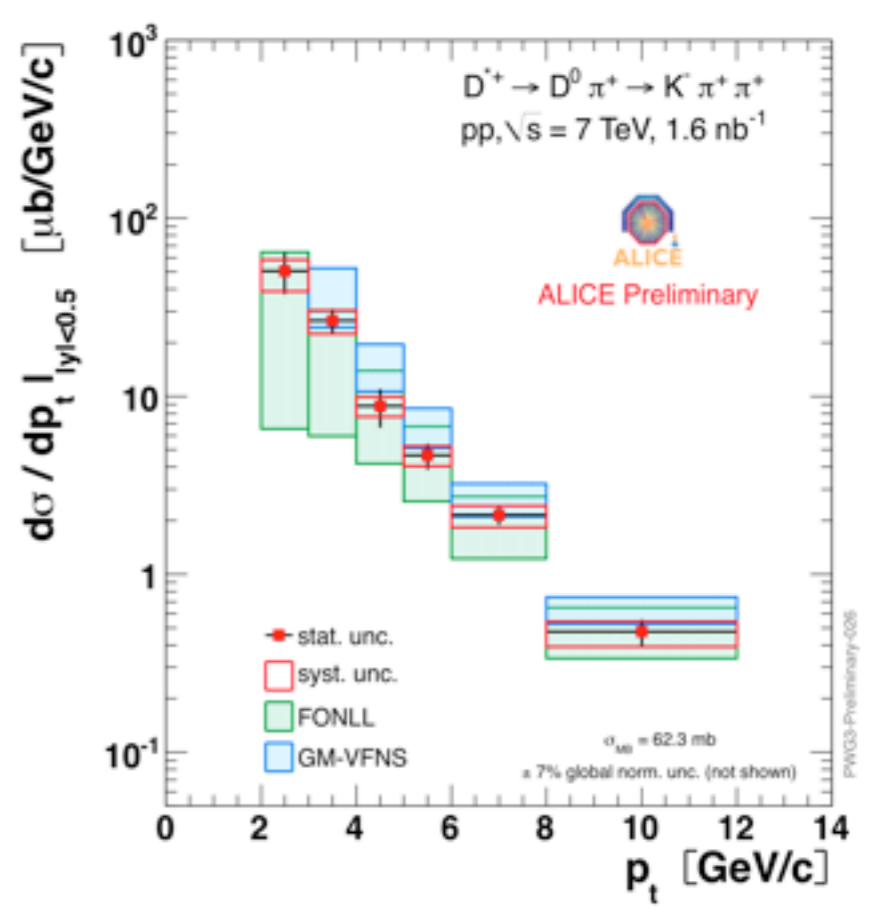
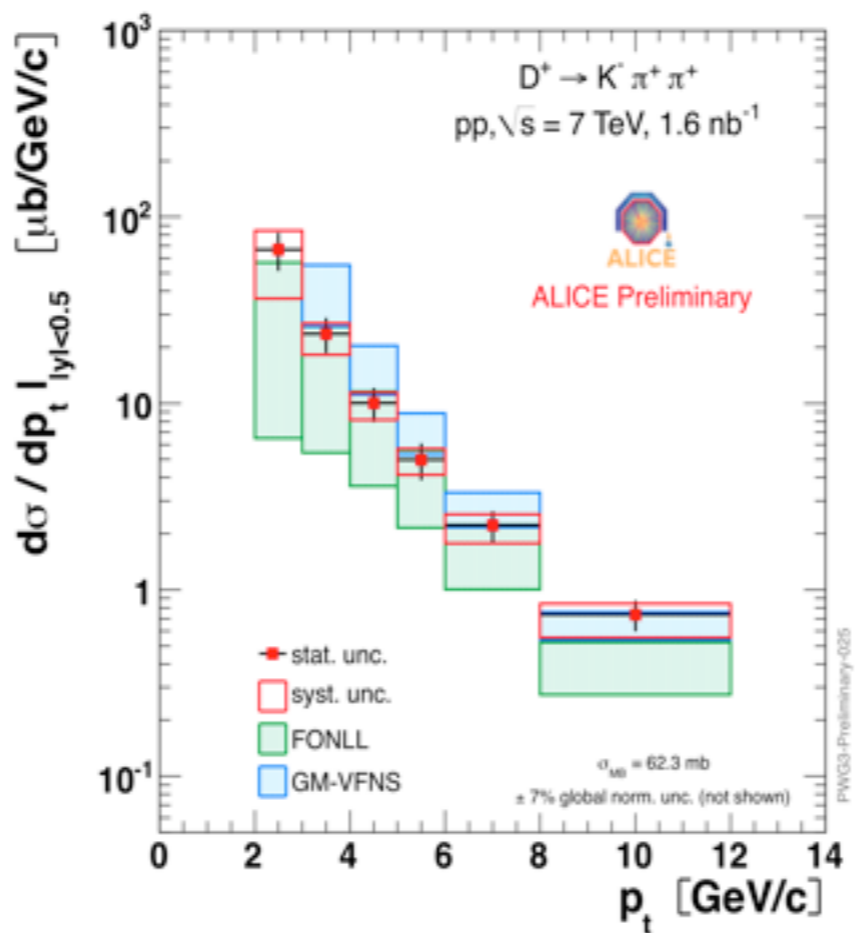
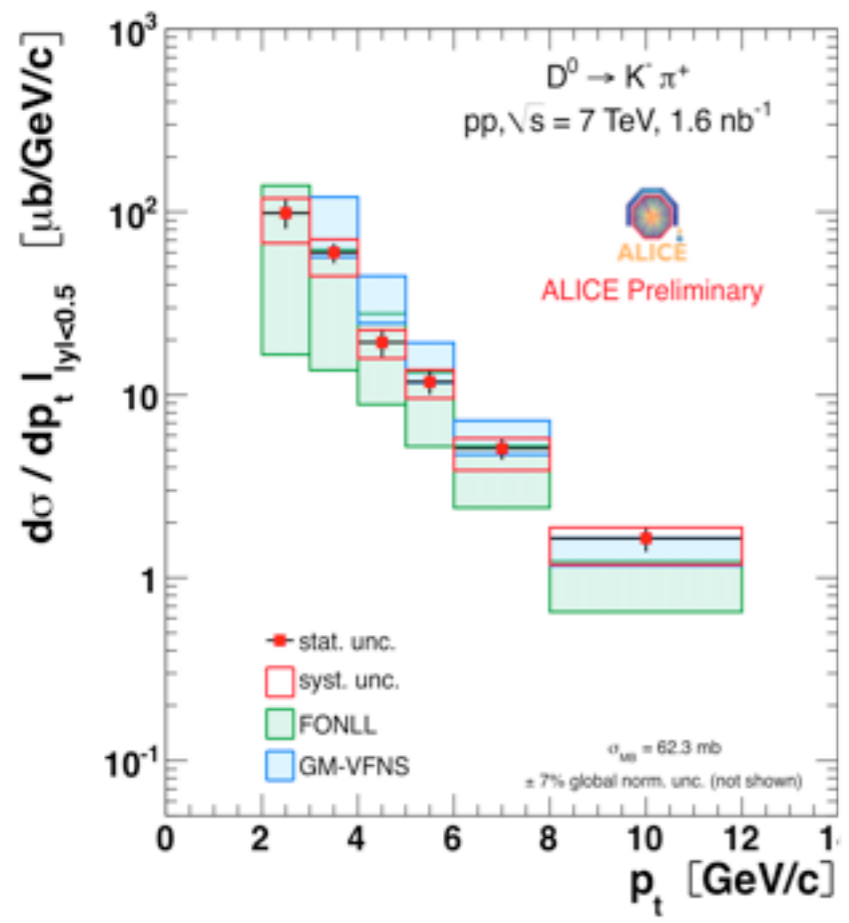
# SNAPSHOT OF THE CHARM HADRON ZOO

- \*  $D^0, D^+, D^*$  measured from 1 to 20 GeV/c with the full 2010 sample
- \* Rare  $D_s$  &  $\Lambda_c$  starting to show up...
- \* Work in progress...





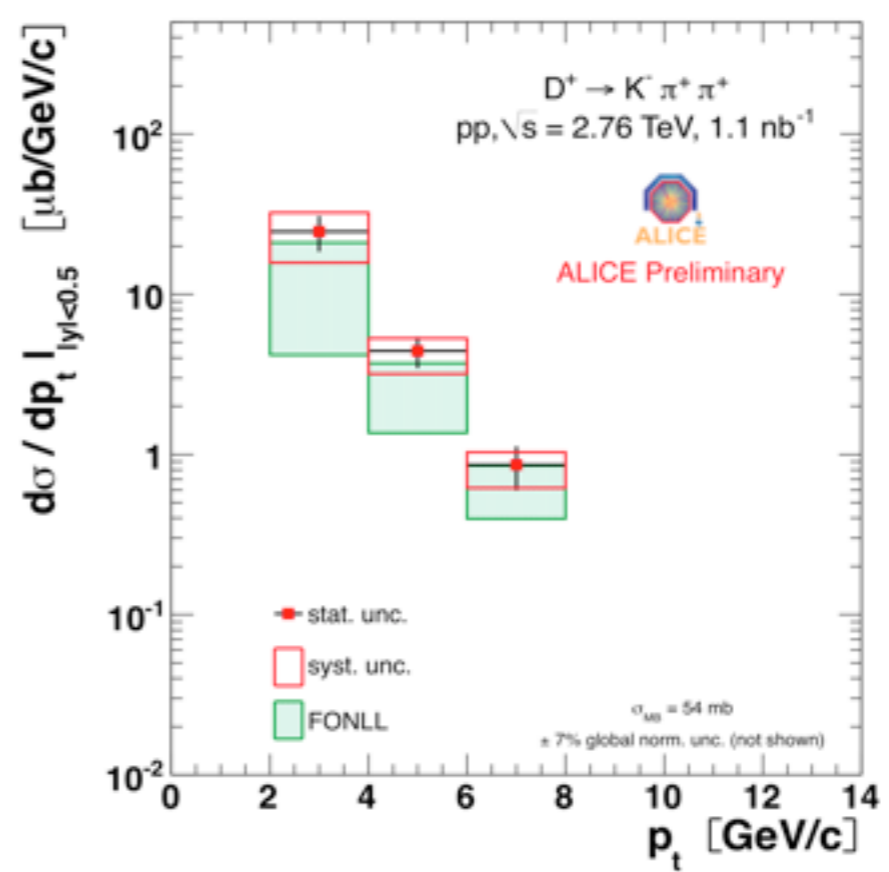
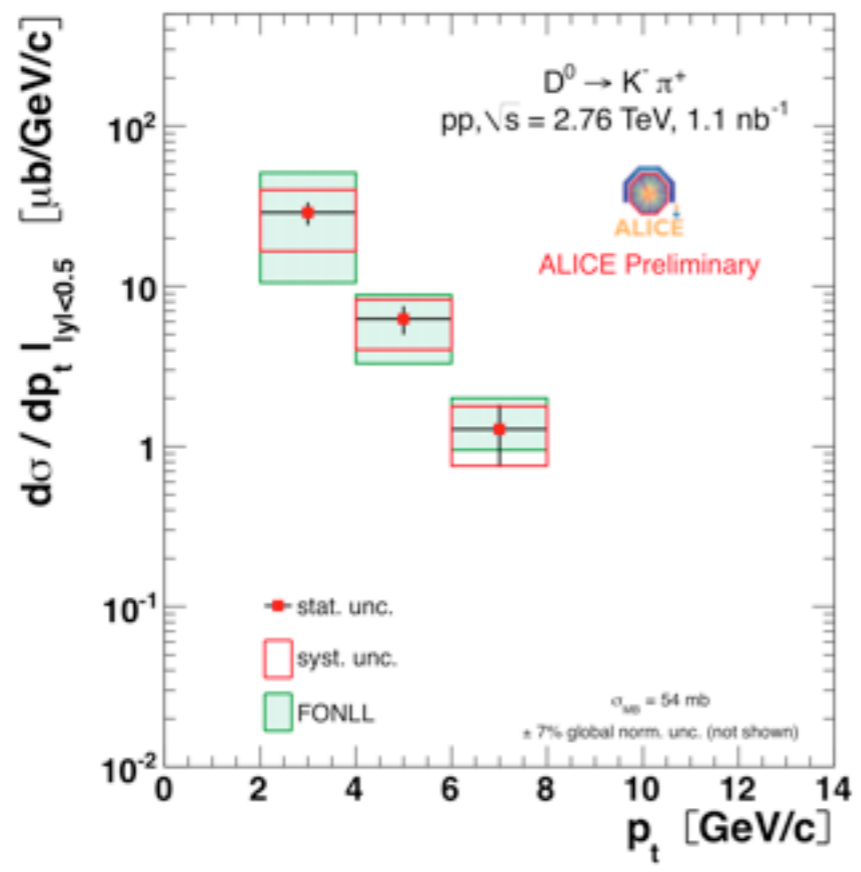
# D MESON CROSS-SECTIONS AT 7 TEV



FONLL: Cacciari et al., private comm.  
GM-VFNS: Kniehl et al., private comm.

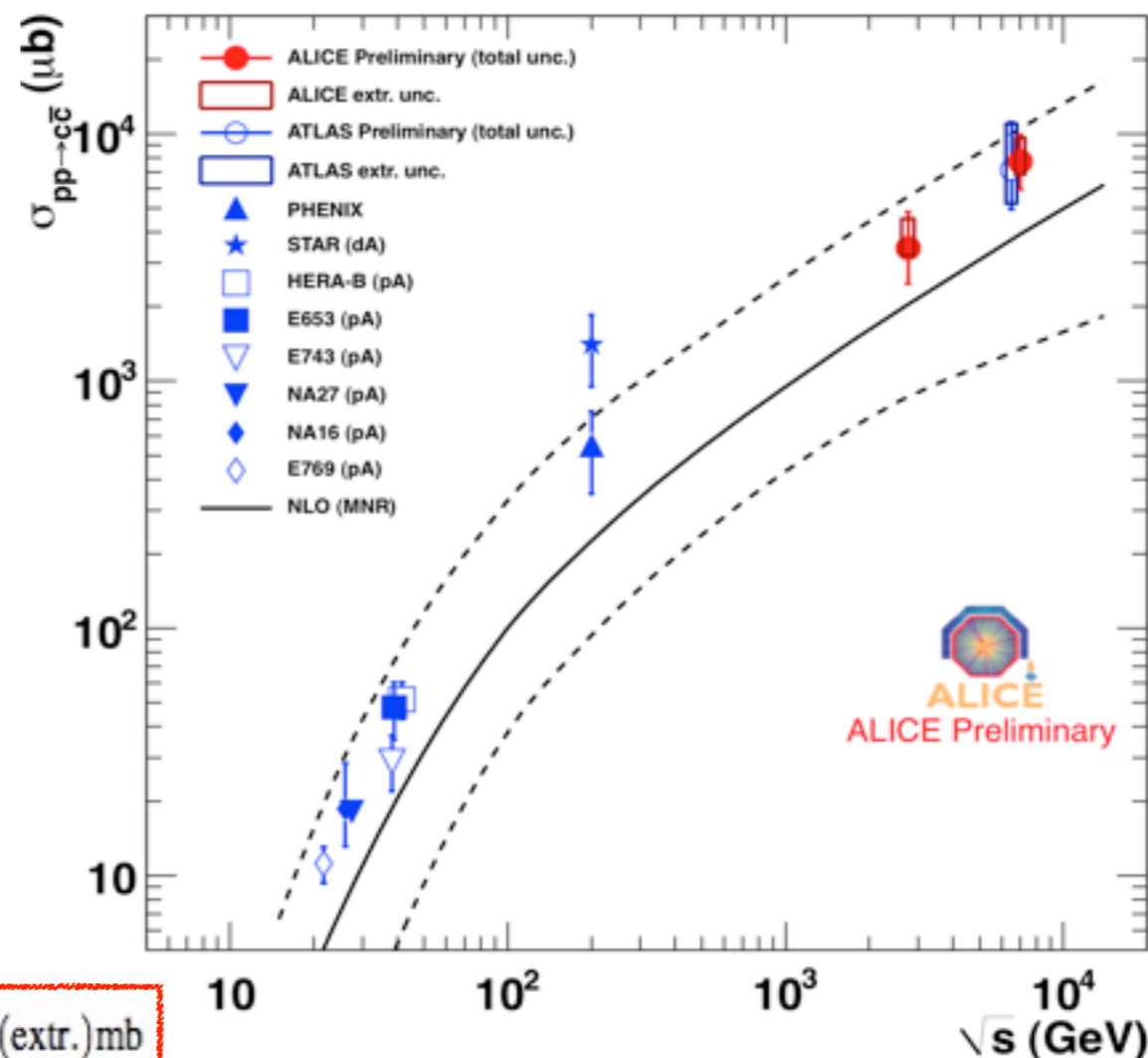
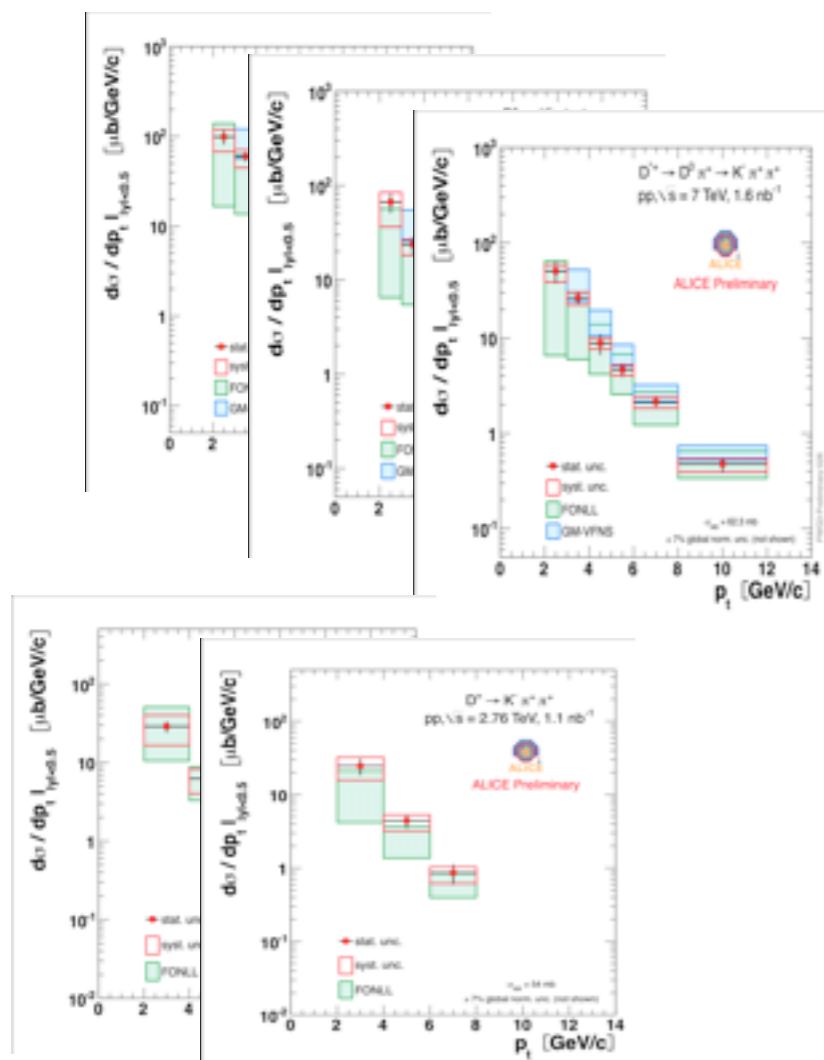
- \*  $2 < p_t < 12 \text{ GeV}/c$ , with  $1.6 \text{ nb}^{-1}$  ( $\sim 20\%$  of 2010 statistics)
- \*  $y$  acceptance is  $p_t$ -dependent ( $\Delta y \sim 1.0$  to  $1.6$ ): data scaled to  $|y| < 0.5$
- \* well described by pQCD predictions (FONLL and GM-VFNS)

# D MESON CROSS-SECTIONS AT 2.76 TEV



FONLL: Cacciari et al., private comm.  
GM-VFNS: Kniehl et al., private comm.

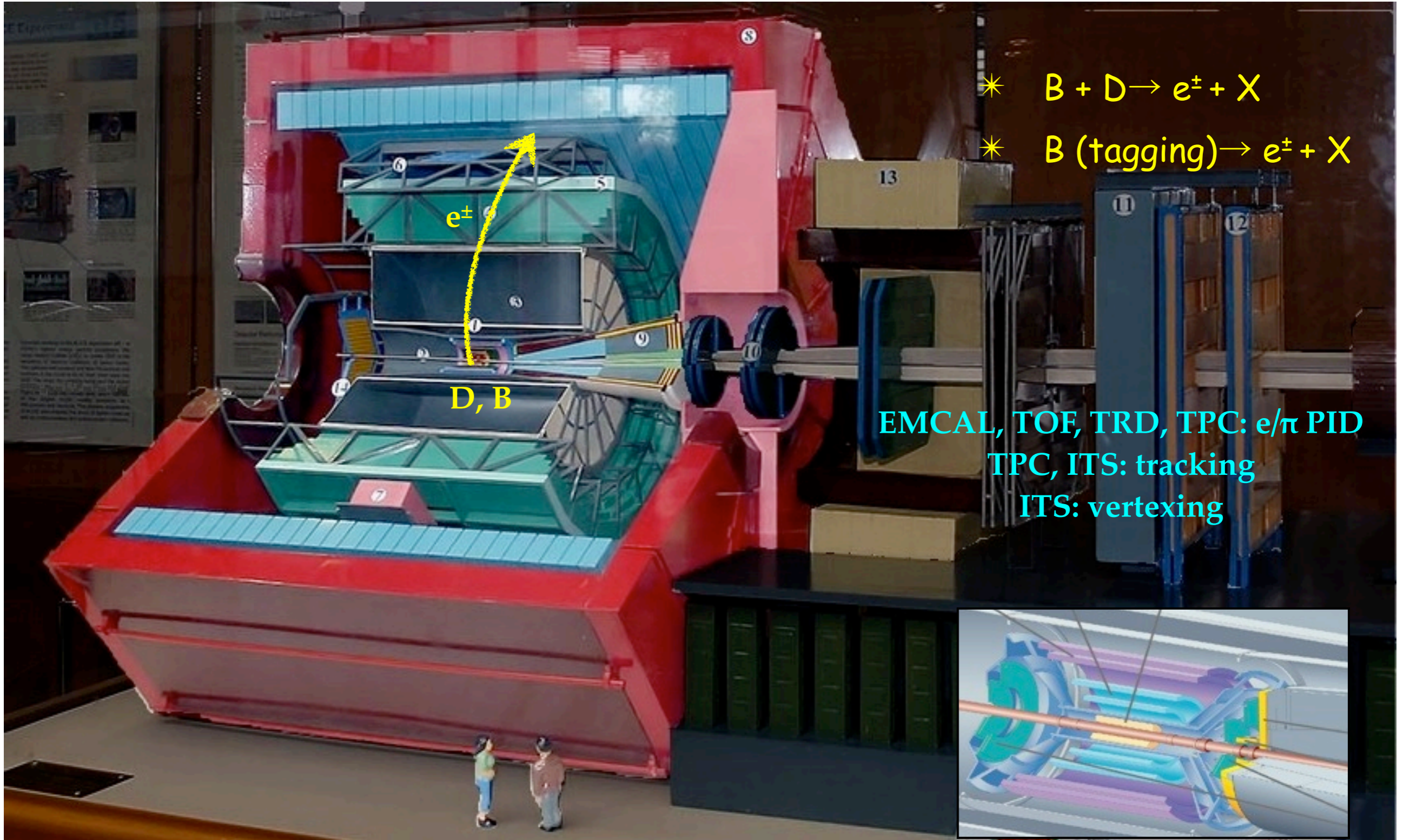
- \*  $2 < p_t < 8 \text{ GeV}/c$ , with  $1.1 \text{ nb}^{-1}$  (3 days of data-taking, ~2 months ago)
- \*  $y$  acceptance is  $p_t$ -dependent ( $\Delta y \sim 1.0$  to  $1.6$ ): data scaled to  $|y| < 0.5$
- \* well described by pQCD predictions (FONLL and GM-VFNS)



$$\sigma_{c\bar{c}}^{tot}(\text{ALICE}, 2.76\text{TeV}) = 3.45 \pm 0.41(\text{stat.})^{+0.72}_{-0.84}(\text{syst.}) \pm 0.17(\text{lum.})^{+1.09}_{-0.24}(\text{extr.})\text{mb}$$

$$\sigma_{c\bar{c}}^{tot}(\text{ALICE}, 7\text{TeV}) = 7.73 \pm 0.54(\text{stat.})^{+0.74}_{-1.38}(\text{syst.}) \pm 0.44(\text{lum.})^{+1.90}_{-0.87}(\text{extr.})\text{mb}$$

- \* Extrapolation down to  $p_T=0$  and full rapidity using FONLL
- \* Good agreement with ATLAS measurement
- \* Measurements show a consistent behavior vs MNR (NLO) with  $\sqrt{s}$



## \* High quality tracks

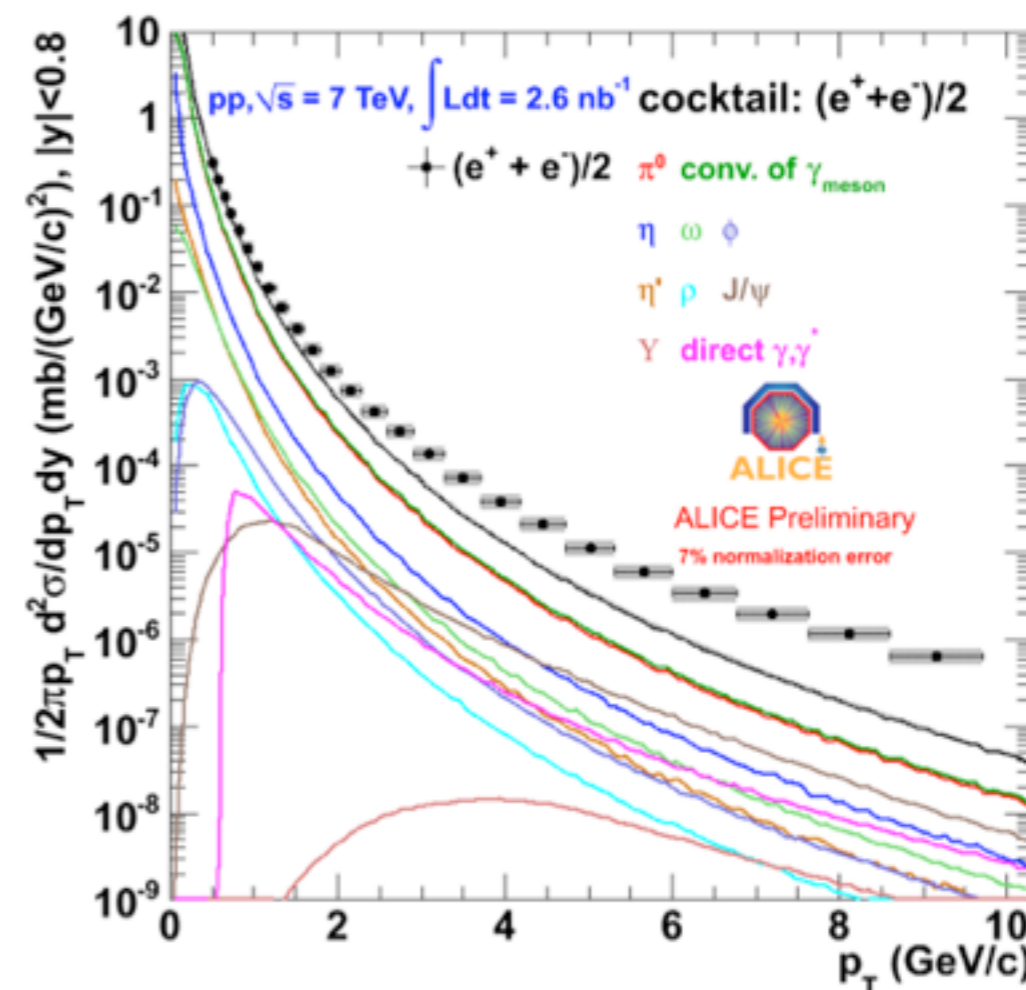
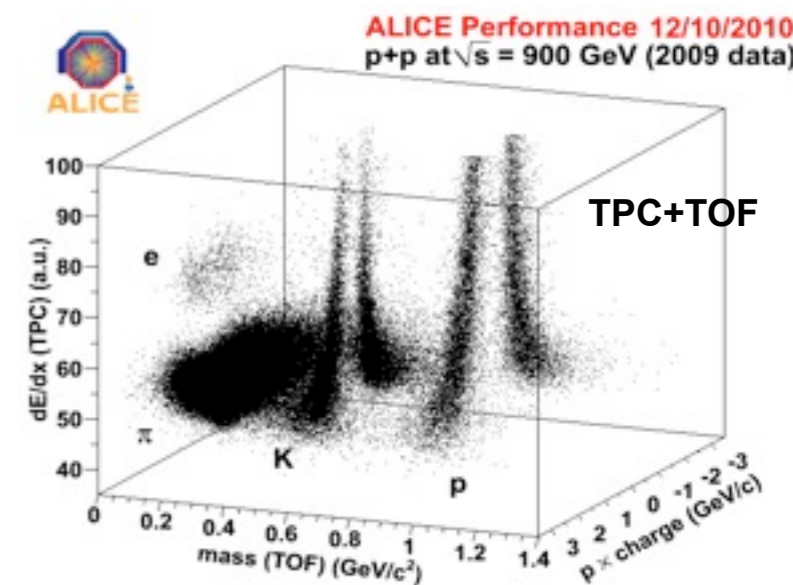
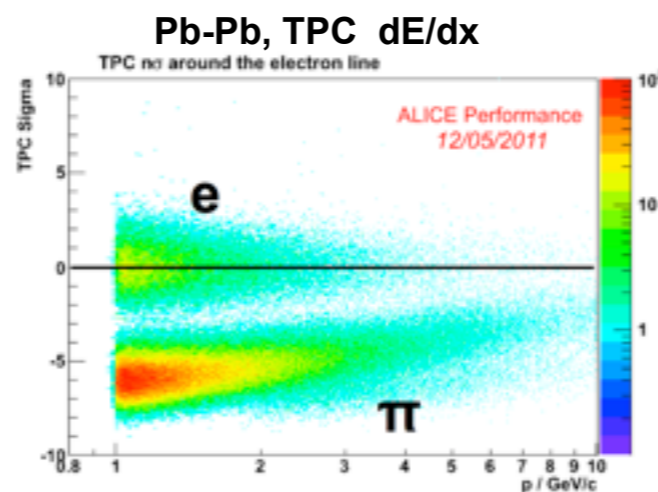
- ▶ Hit in the innermost ITS layer to reduce the conversions

## \* Electron identification

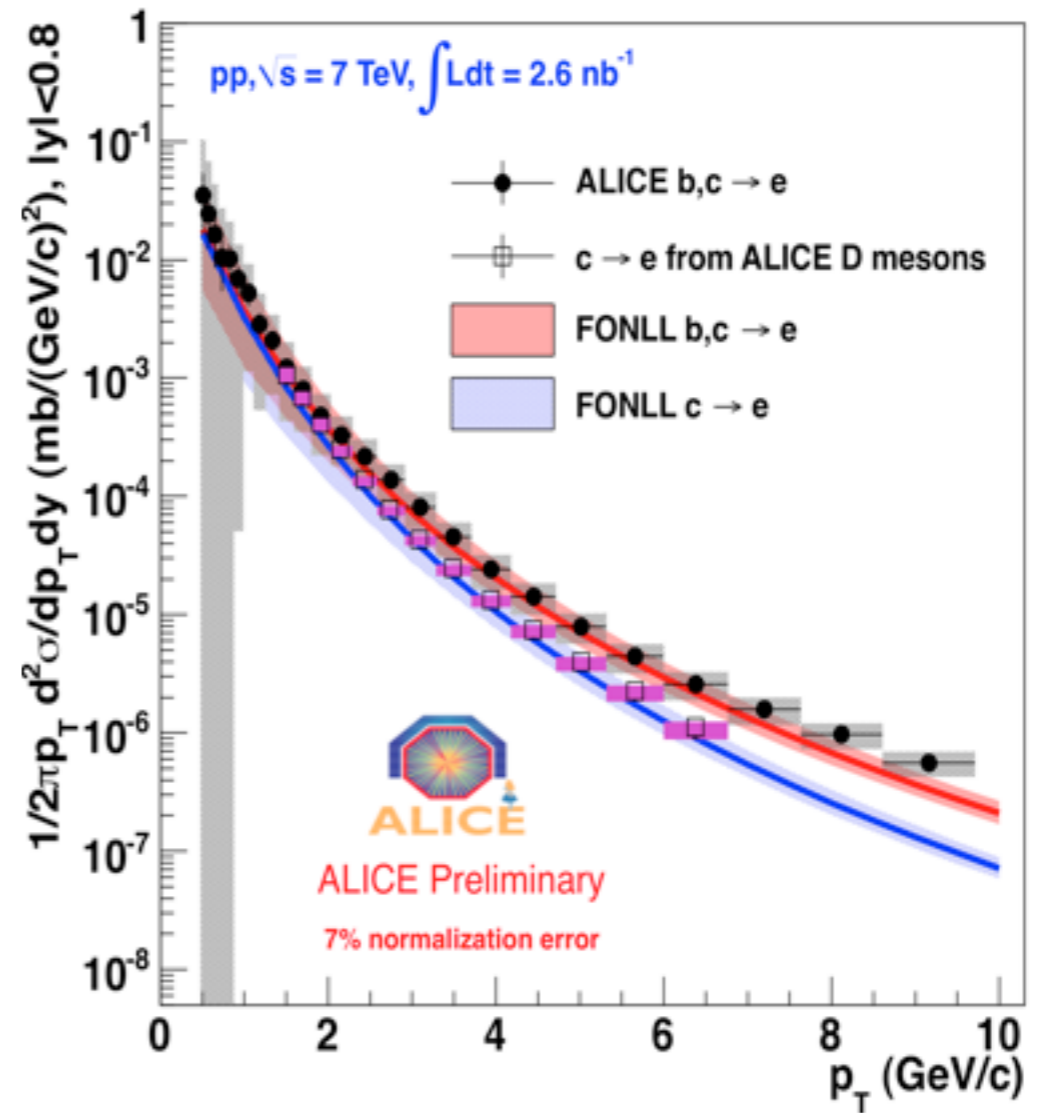
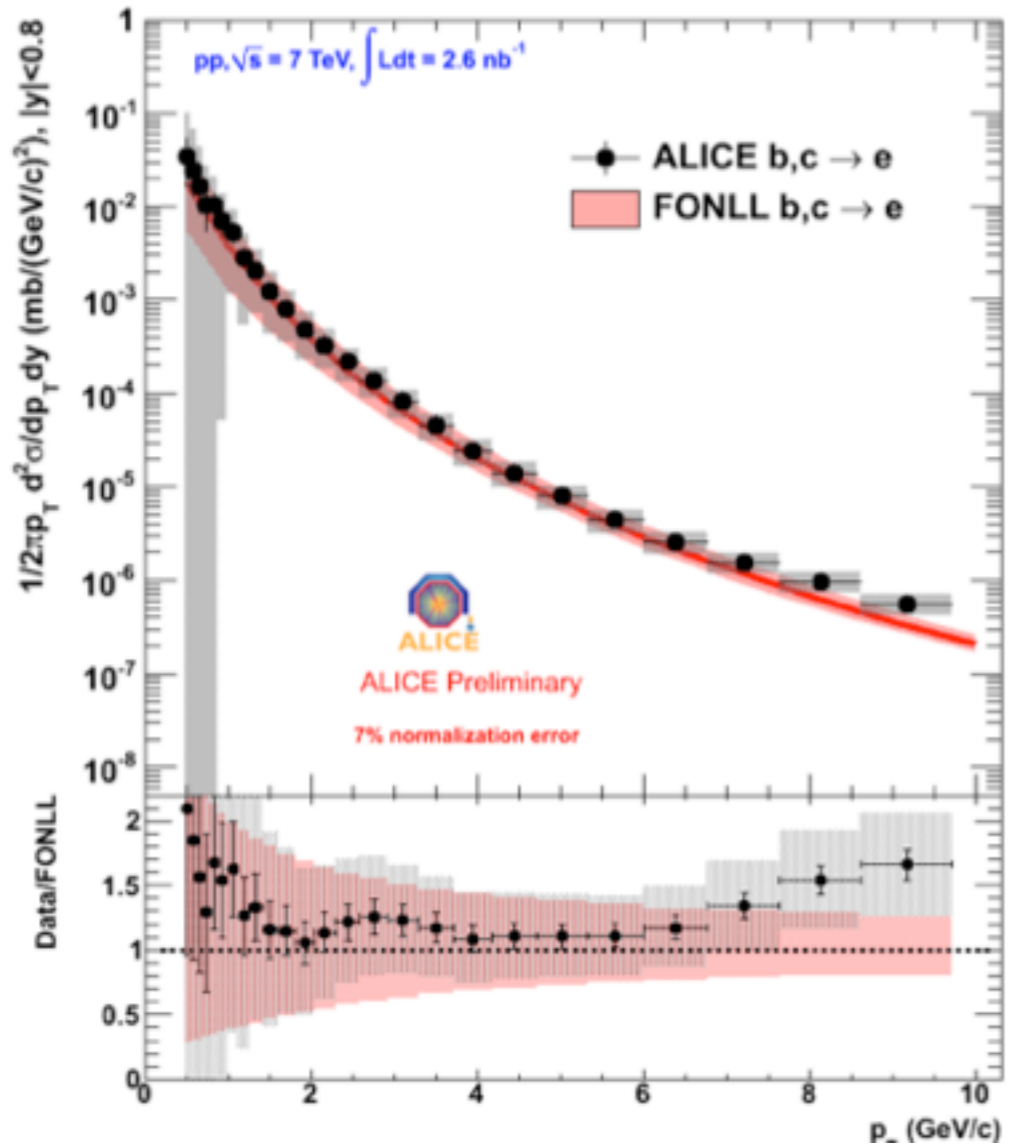
- ▶ TOF to reject K, p
- ▶ TPC dE/dx
- ▶ TRD (+EMCAL) in pp collisions for now.
- ▶ hadron contamination measured fitting the TPC dE/dx in P slices

## \* How To disentangle heavy flavor

- ▶ Cocktail of the non-heavy flavor sources.
- ▶ Select displaced electrons (b-tagging,  $c\tau \sim 500\mu\text{m}$ ) in pp collisions for the moment.

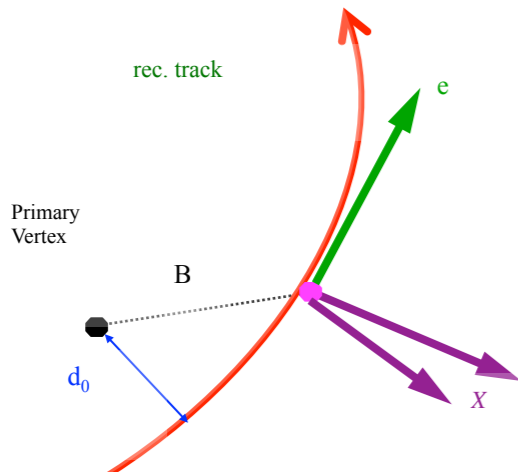


# HEAVY FLAVOR ELECTRONS

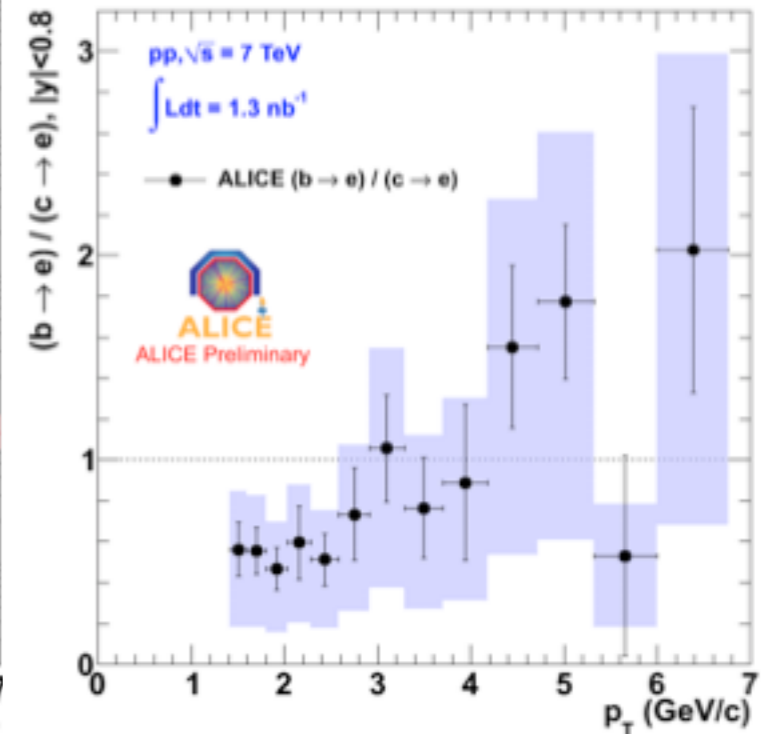
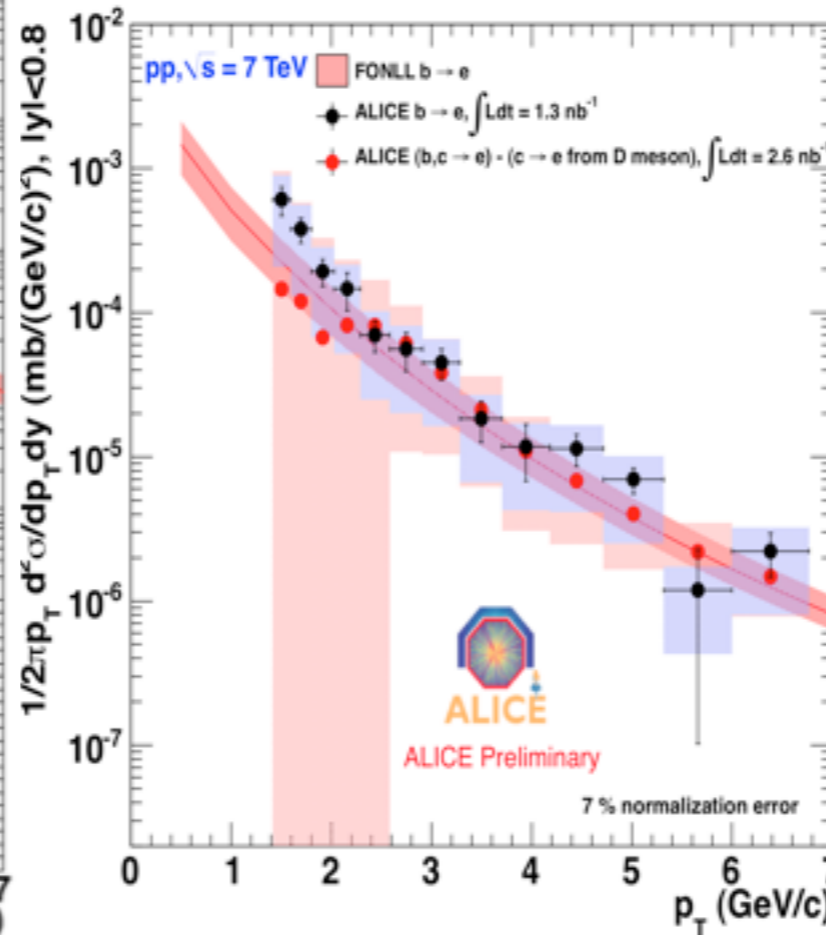
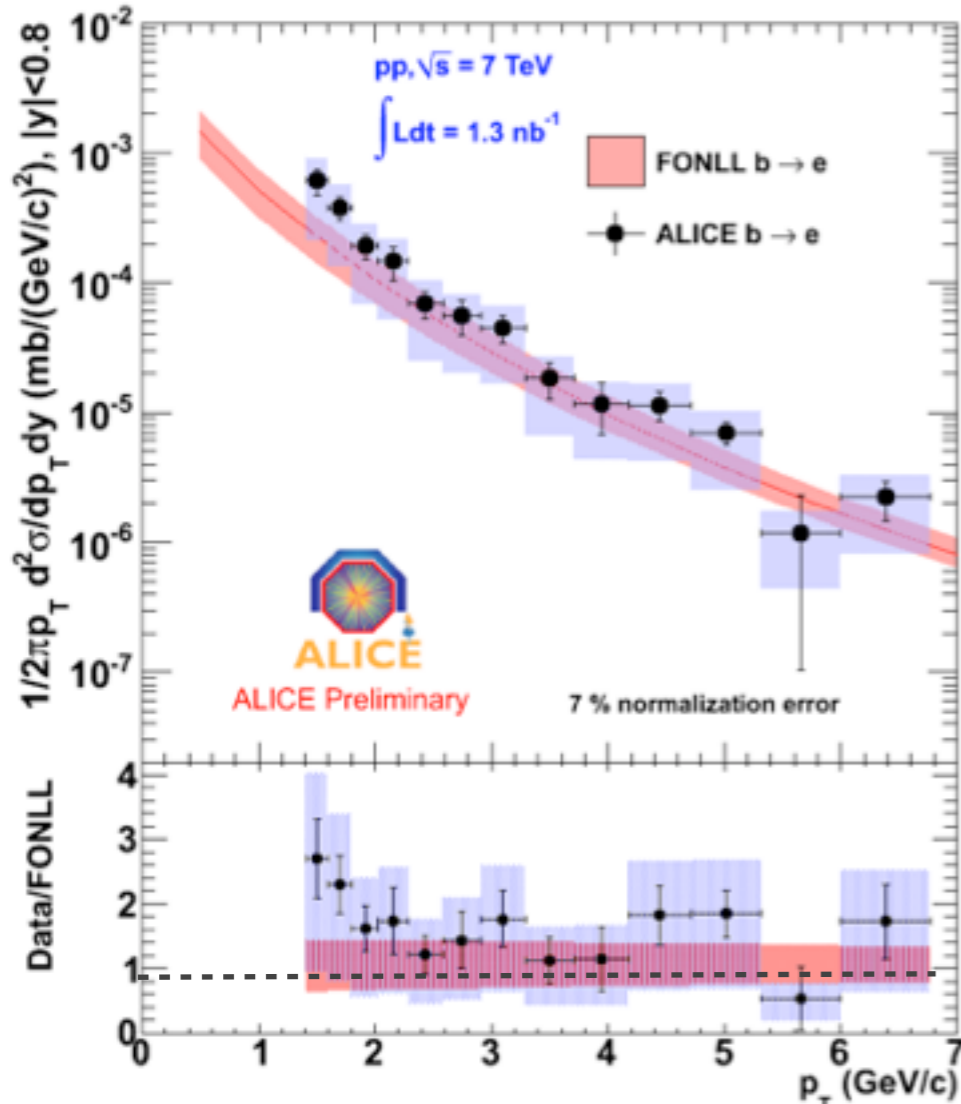


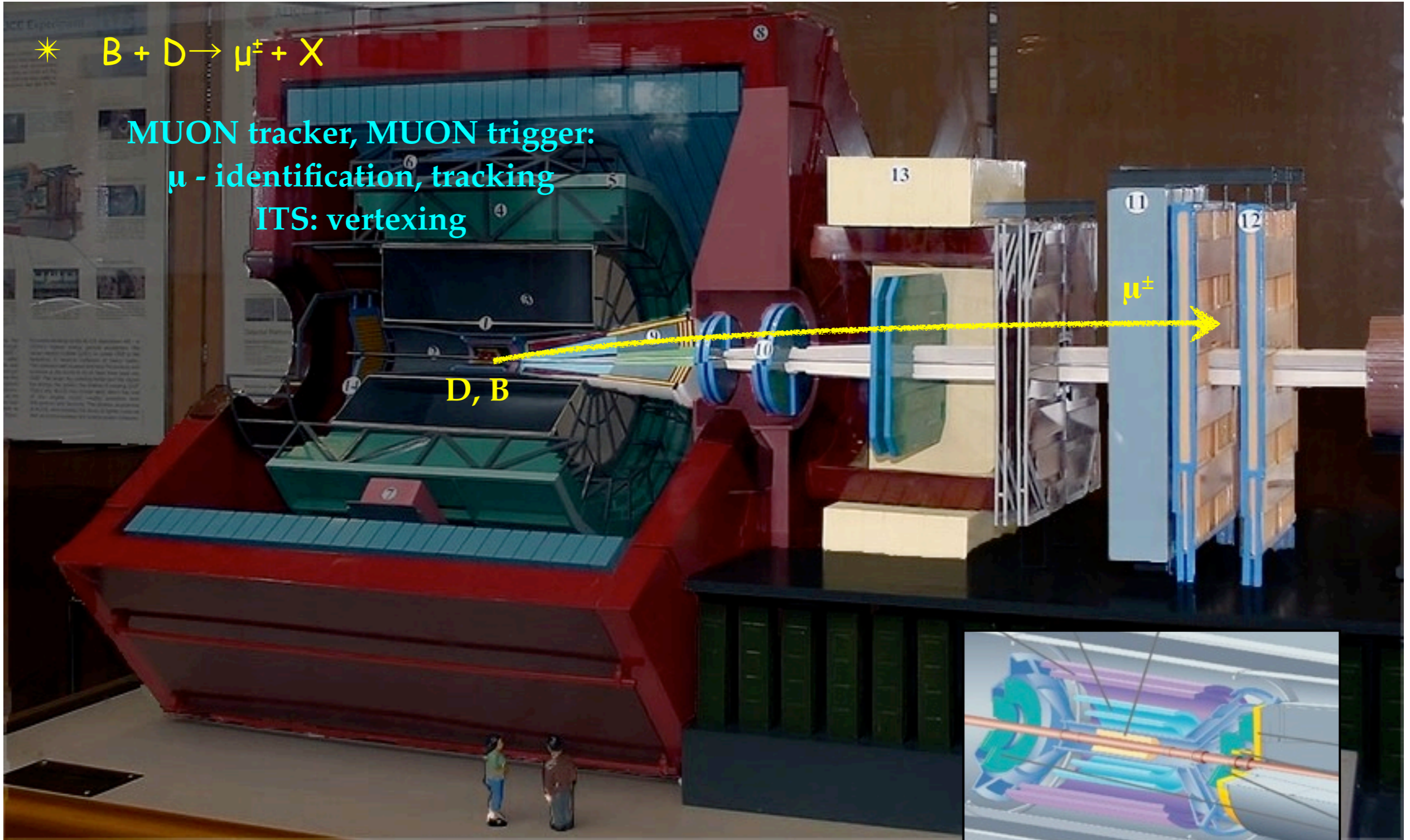
- \* Subtracted cocktail of electron background based on the measured  $\pi^0$  spectrum
- \* Good agreement with FONLL b+c over the full pt range
- \* Consistent with the prompt charm measurement from D mesons

# BEAUTY DECAY ELECTRONS

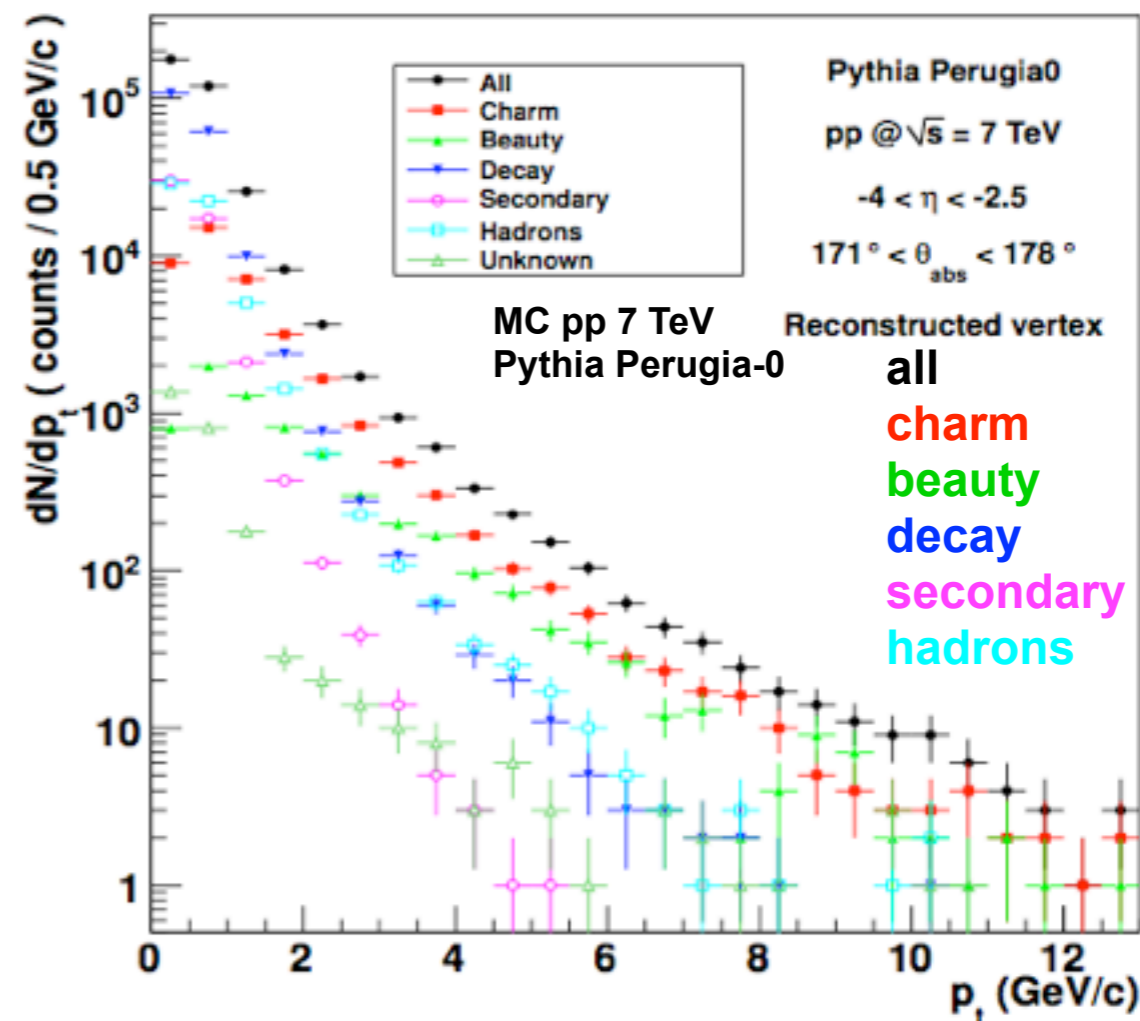
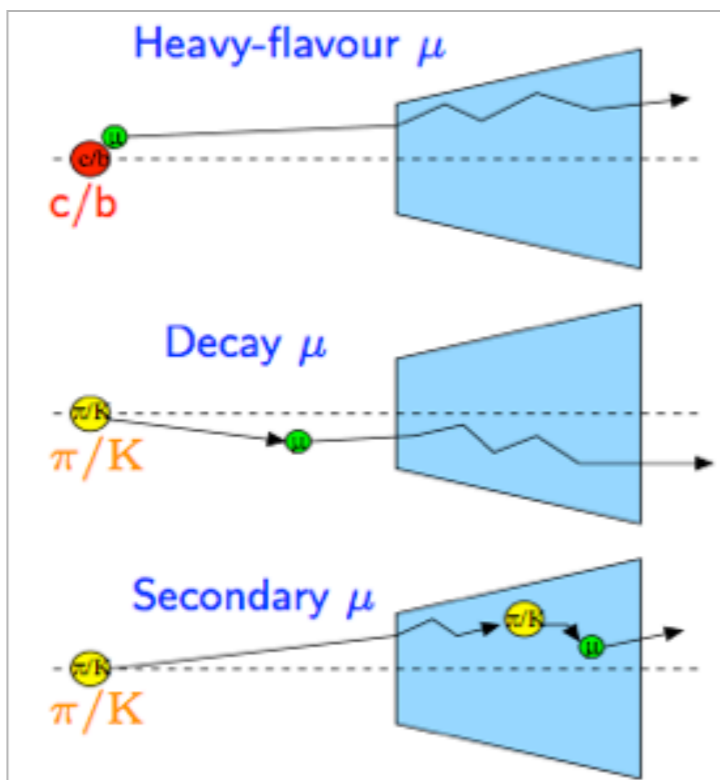


- \* Strategy : select electrons from displaced vertexes
- \* B-tagged electron spectrum agrees with FONLL
- \* HF electrons - Charm electrons (from D mesons) = B-tagged electrons
- \* Measured the fraction of beauty/charm vs pt



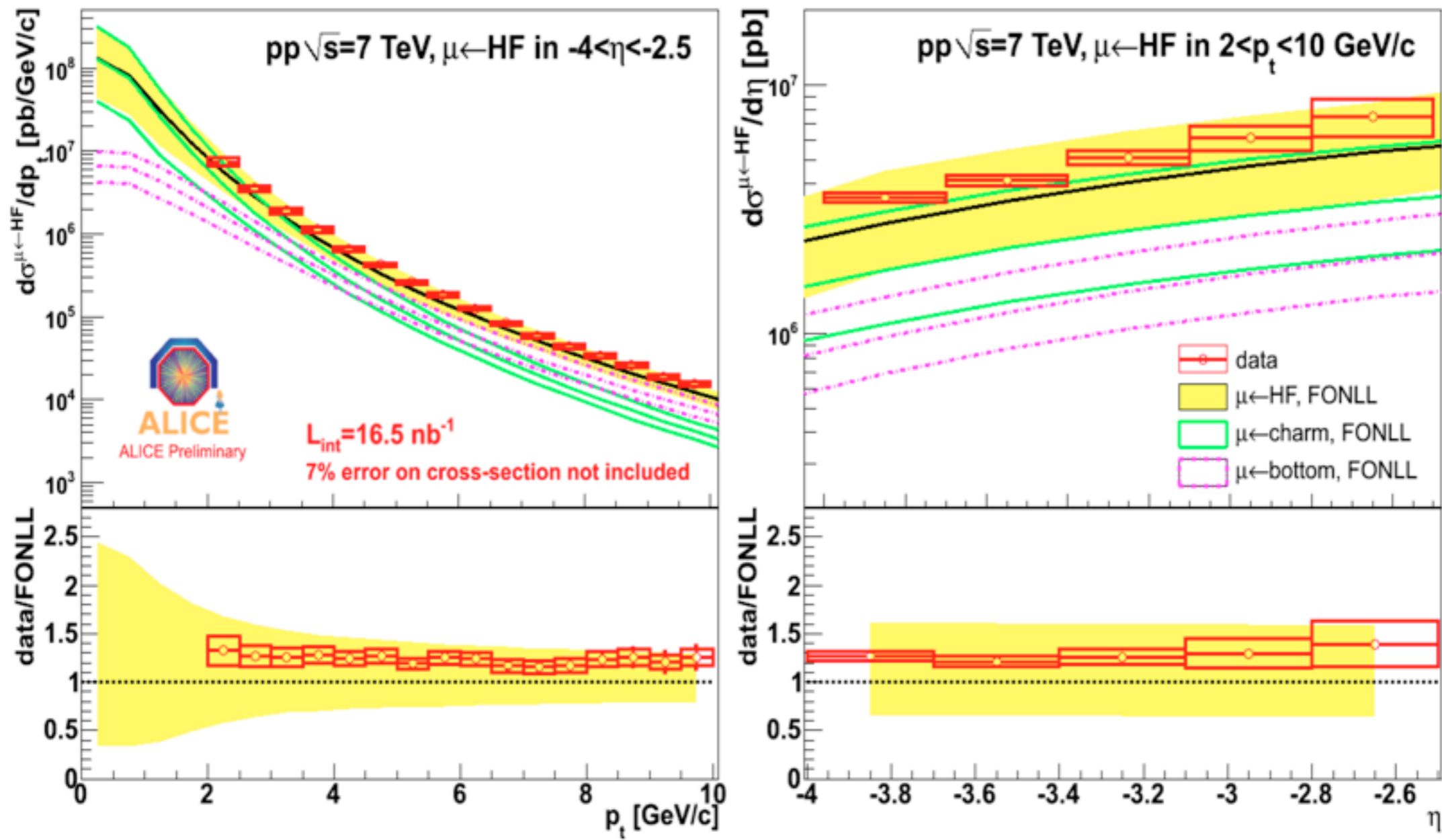






- \* Remove **hadrons** and low  $p_T$  **secondary** muons by requiring a muon trigger signal plus a cut on the DCA
- \* Subtract **decay** muons by subtracting MC  $dN/dp_T$  normalized to data at low  $p_T$
- \* In Pb-Pb, we don't subtract the decay muons for now, but restrict the analysis to the high  $p_T$  region where the background is small.

# HF MUON CROSS SECTION



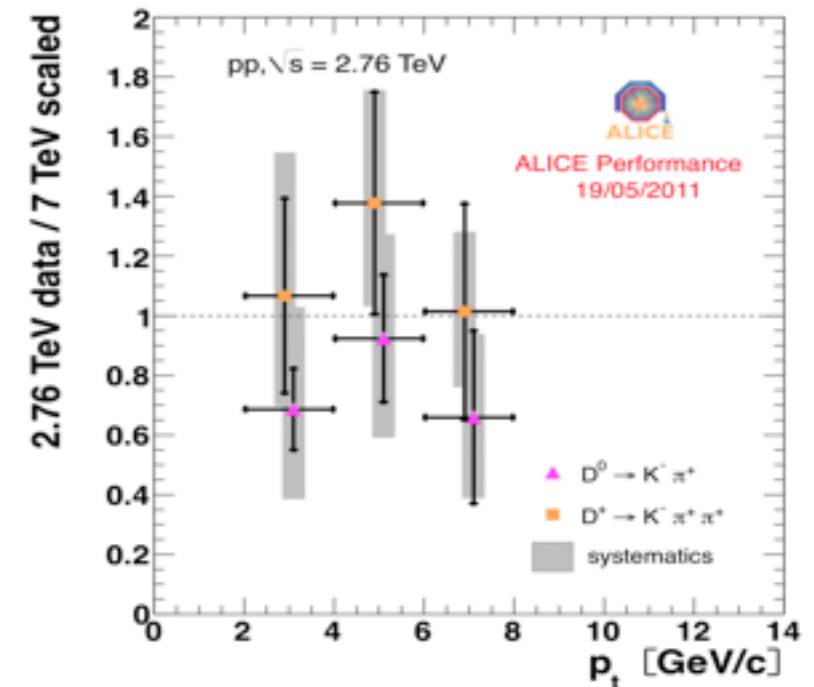
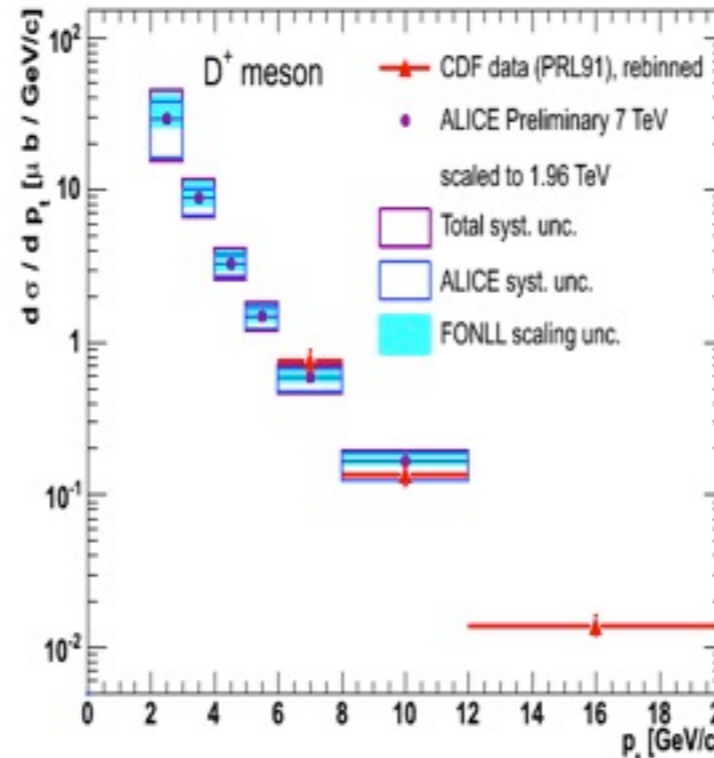
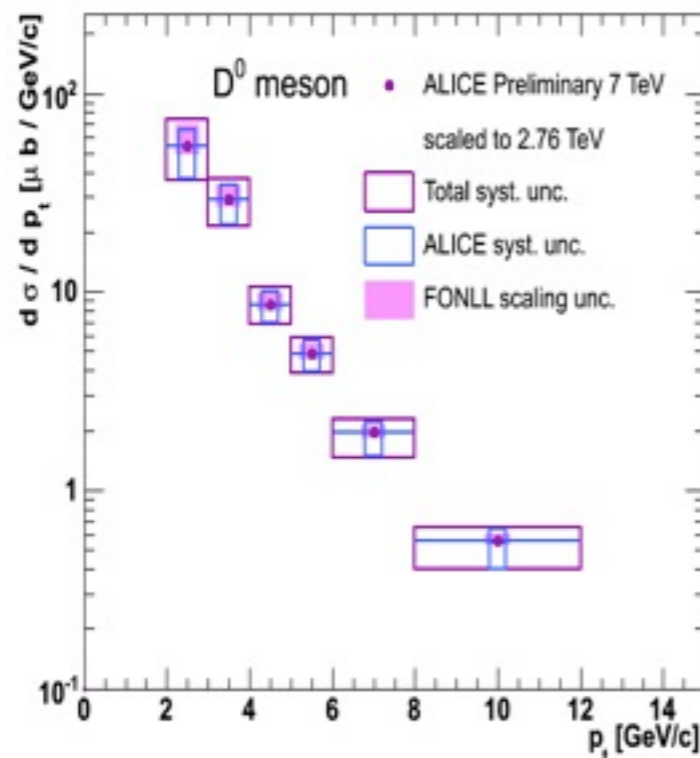
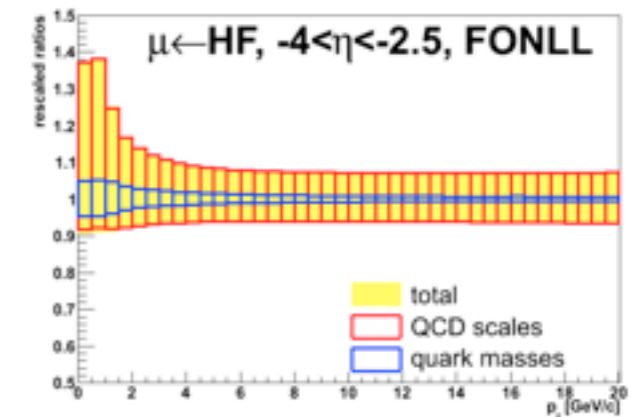
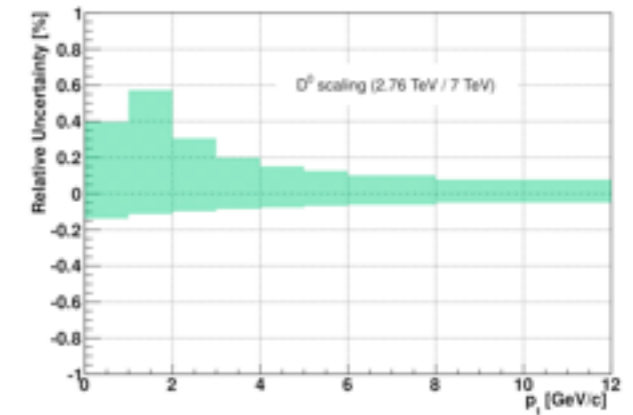
- \* Transverse momentum and pseudo-rapidity distributions well described by pQCD (FONLL) calculations
- \* FONLL suggests beauty predominates for  $p_t > 6$  GeV/c

# MEASUREMENTS IN PbPb COLLISIONS

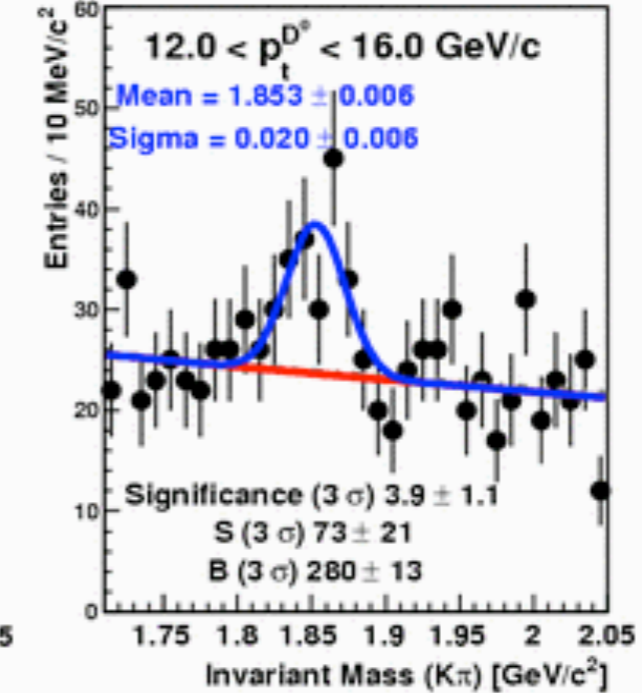
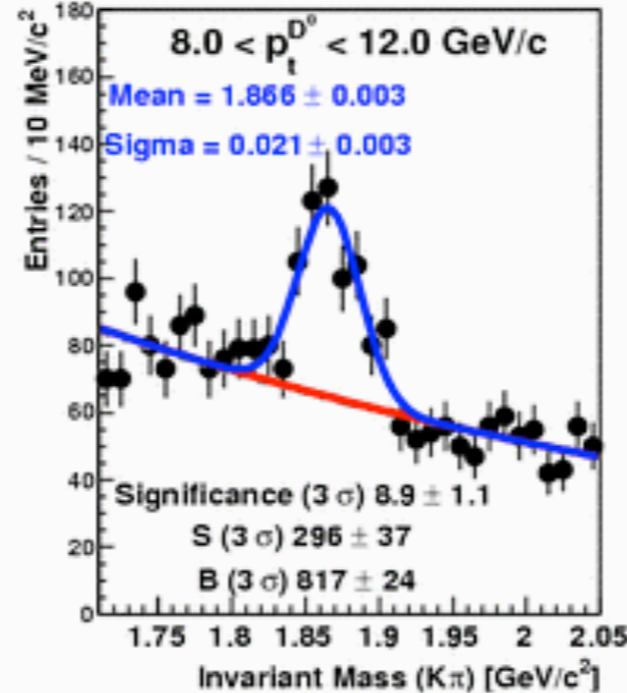
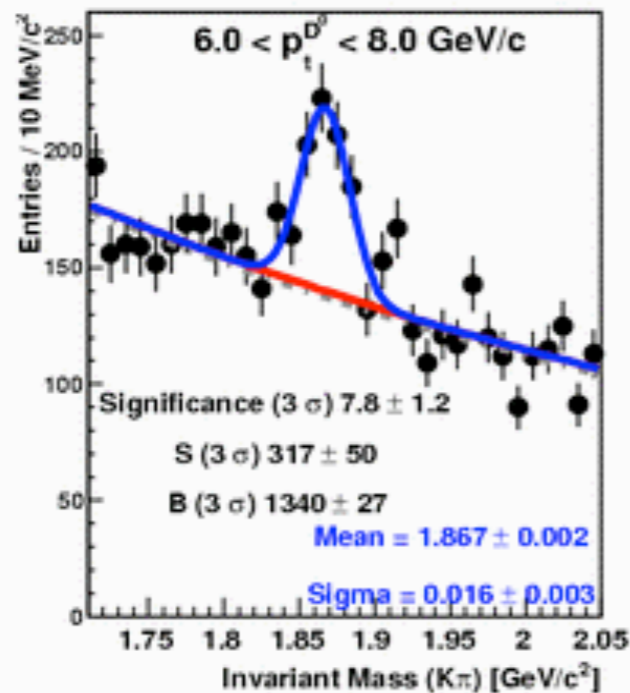
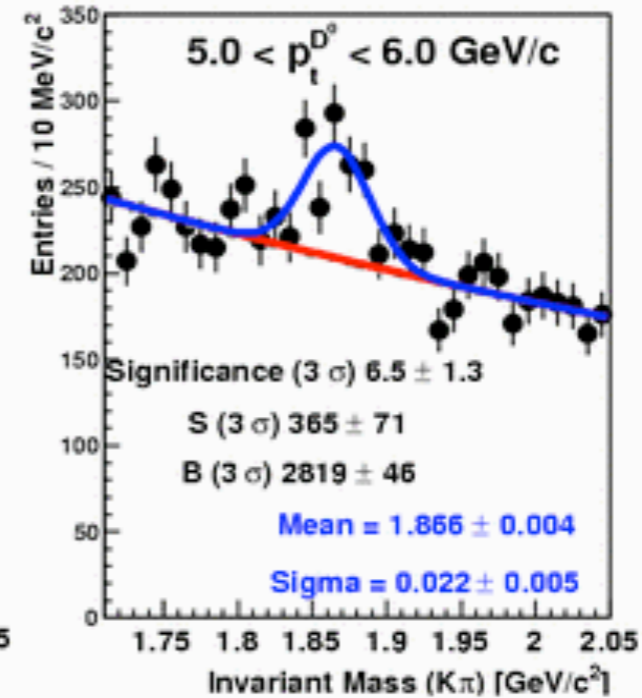
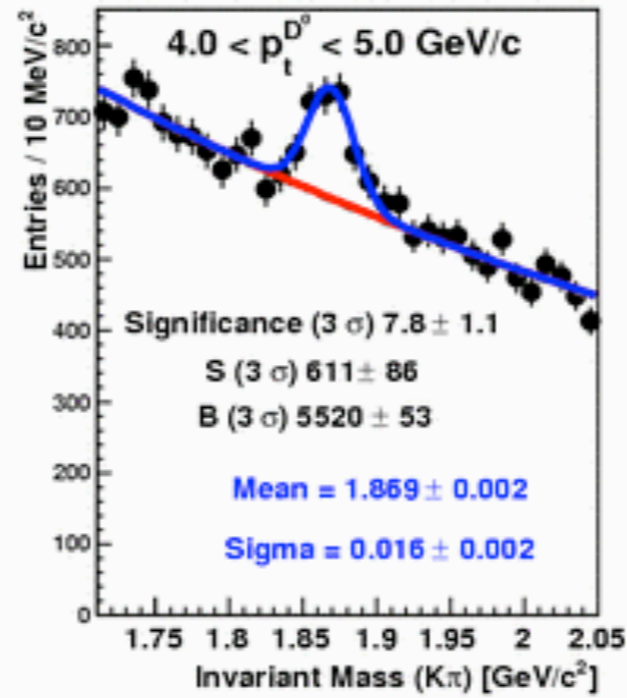
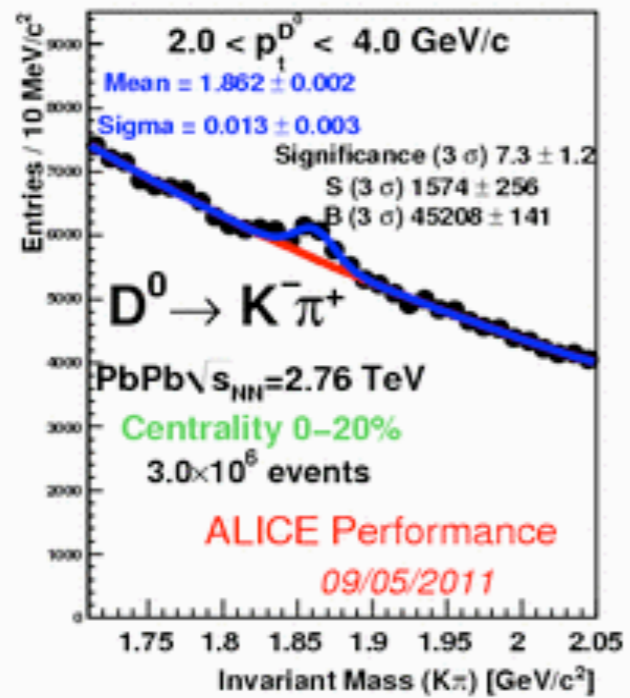
System	pp	pp	pp	pp	PbPb
$\sqrt{s_{NN}}$ [TeV]	7	7	2.76	2.76	2.76
trigger	MB	$\mu$ -trigger	MB	$\mu$ -trigger	MB
Data-taking	April-Aug 2010	April-Sept 2010	March 2011	March 2011	Nov 2010
$N_{\text{events}}$	100-180 M		65 M		17 M
$\langle L \rangle$ [ $\text{nb}^{-1}$ ]	1.6 (out of 3.9)	16	1.1	20	$2.7 \mu\text{b}^{-1}$

# THE REFERENCE AT 2.76 TeV

- \* Scale the 7 TeV measurements with the pQCD (FONLL) 2.76/7 factor
  - ▶ Consider that the calculation scales don't evolve with  $\sqrt{s}$
  - ▶ Uncertainties range from 25% (low- $p_t$ ) to 10% (high- $p_t$ )
- \* Scaling procedure validation:
  - ▶ Compare different calculations (MNR, GM-VFNS,...)
  - ▶ CDF measurements at 1.96 TeV
  - ▶ ALICE data at 2.76 TeV for  $2 < p_t < 8 \text{ GeV}/c$



# EX: $D^0$ INVARIANT MASS 0-20% CC

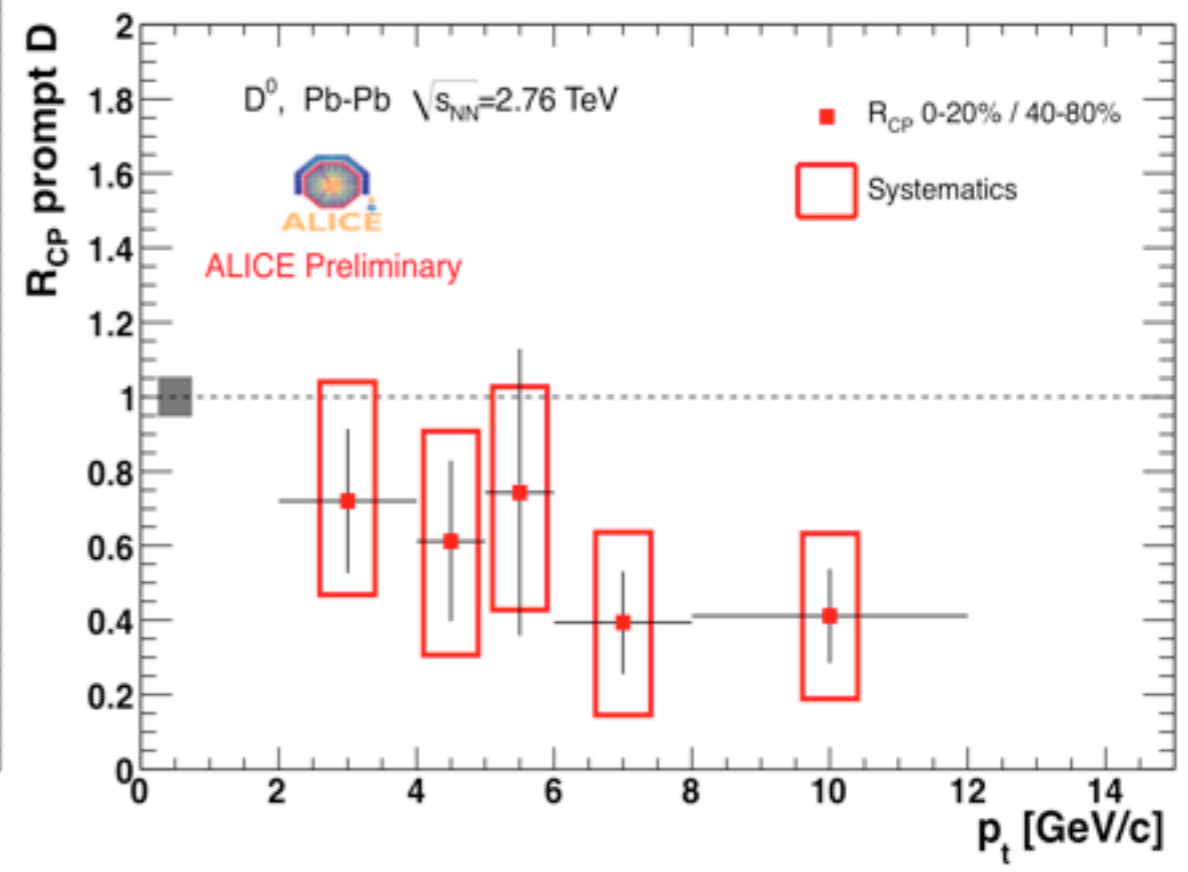
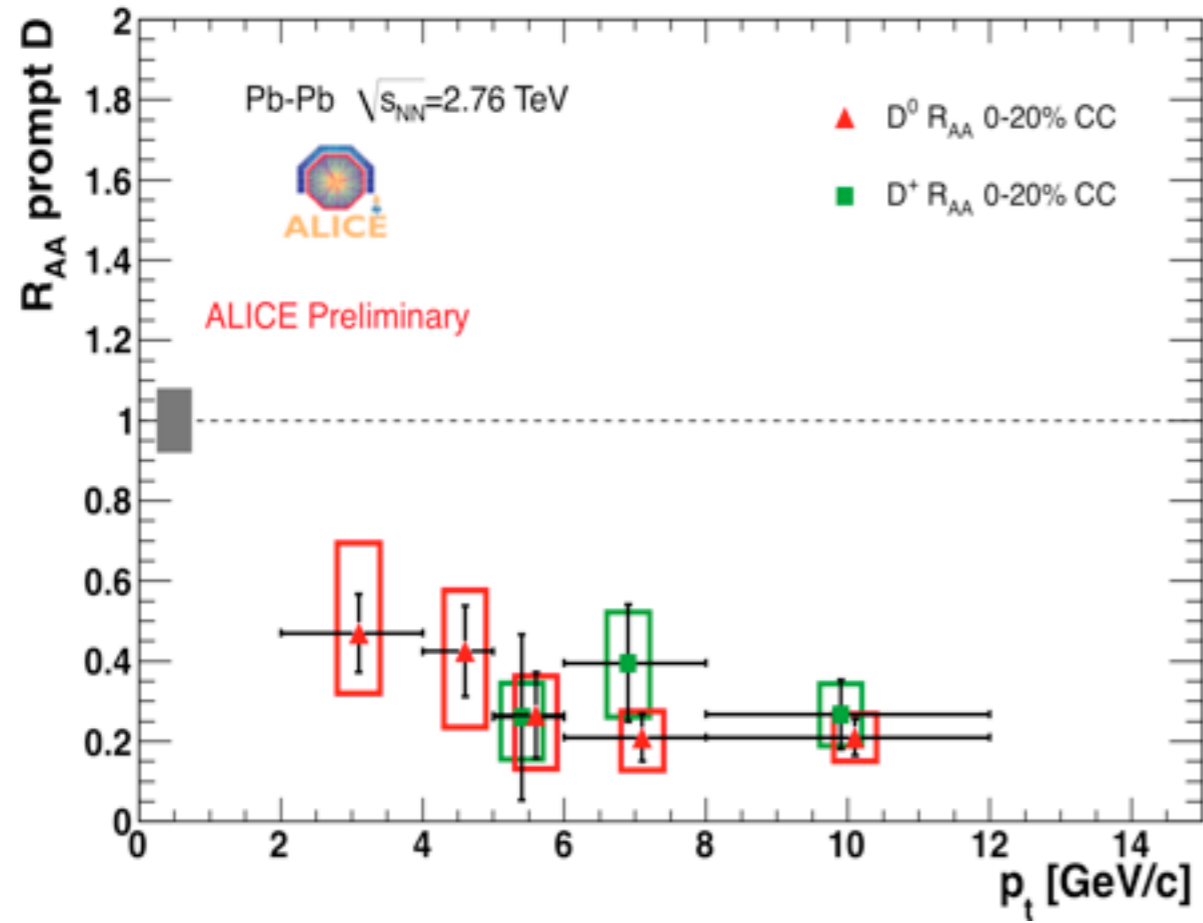


ALI-PERF-1754

# PROMPT D MESON $R_{AA}$ & $R_{CP}$

\* Analysis details:

- ▶  $D^0$  and  $D^+$  spectrum in 2-12 and 5-12 GeV/c respectively
- ▶ No reconstruction efficiency (1-10%) centrality dependence found
- ▶ Feed-down subtraction (10-15%) based on pQCD (more on next slide)



- \*  $R_{AA}$  (0-20%) shows a suppression of about a factor of 4-5 for  $p_t > 5$  GeV/c
- \*  $R_{CP}$  (0-20%/40-80%) confirms the suppression, exhibiting a reduction of a factor of 2-3 for  $p_t > 5$  GeV/c

# INSIGHT: UNCERTAINTIES ON PROMPT D

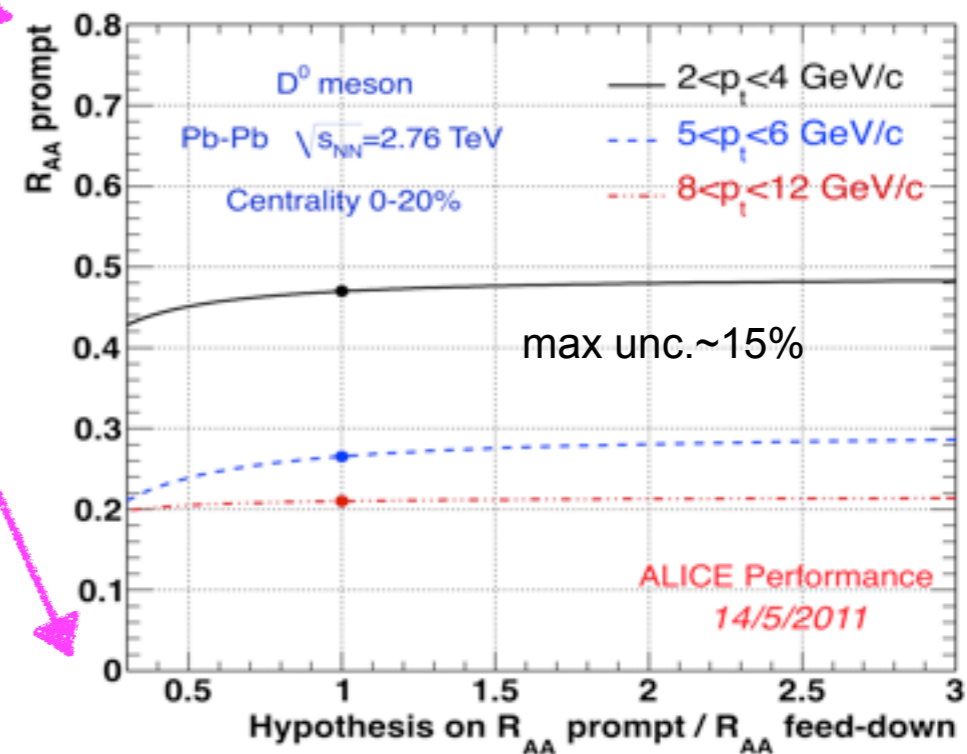
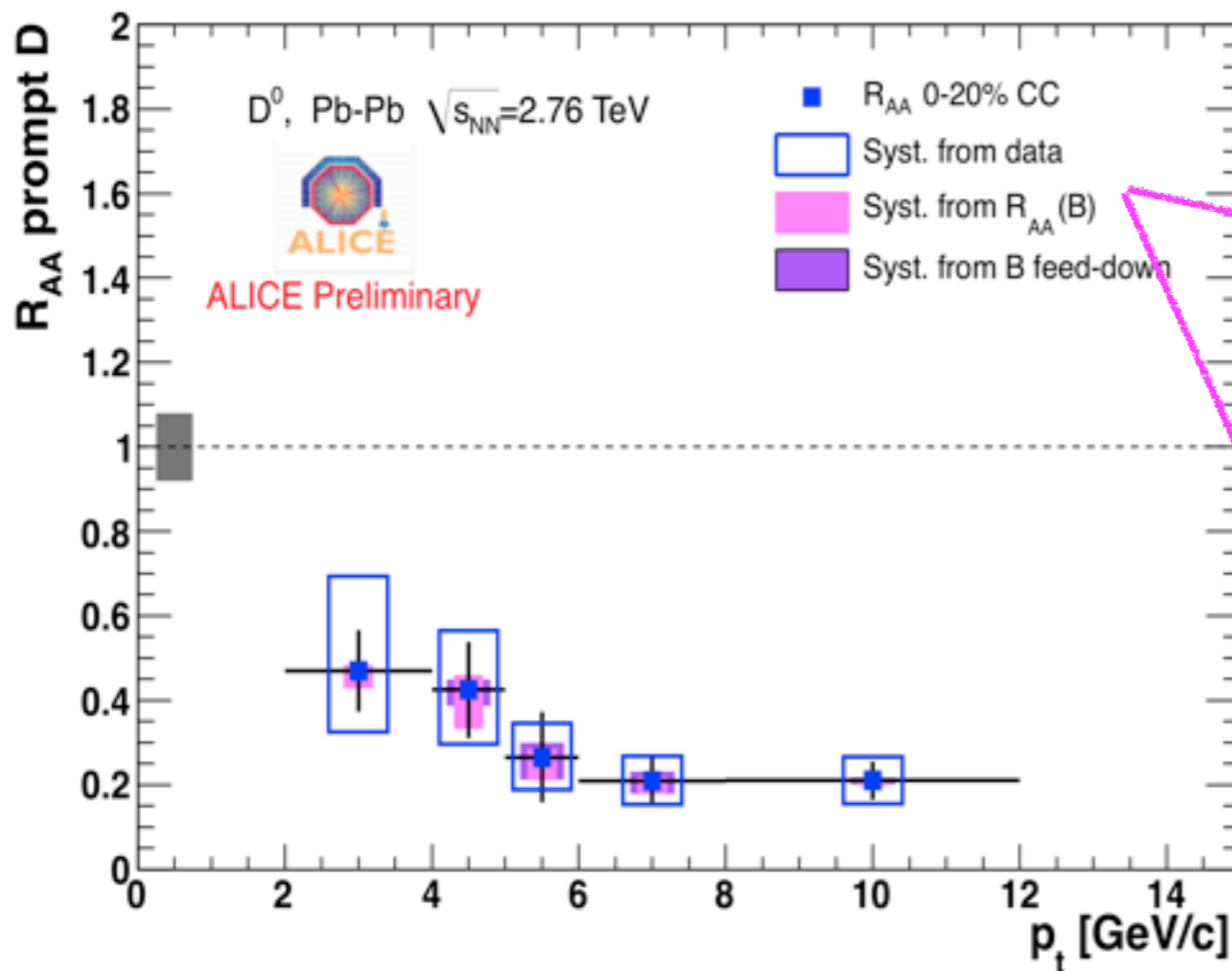
\* Data systematics:

- ▶ signal extraction, reconstruction and cuts efficiency,...

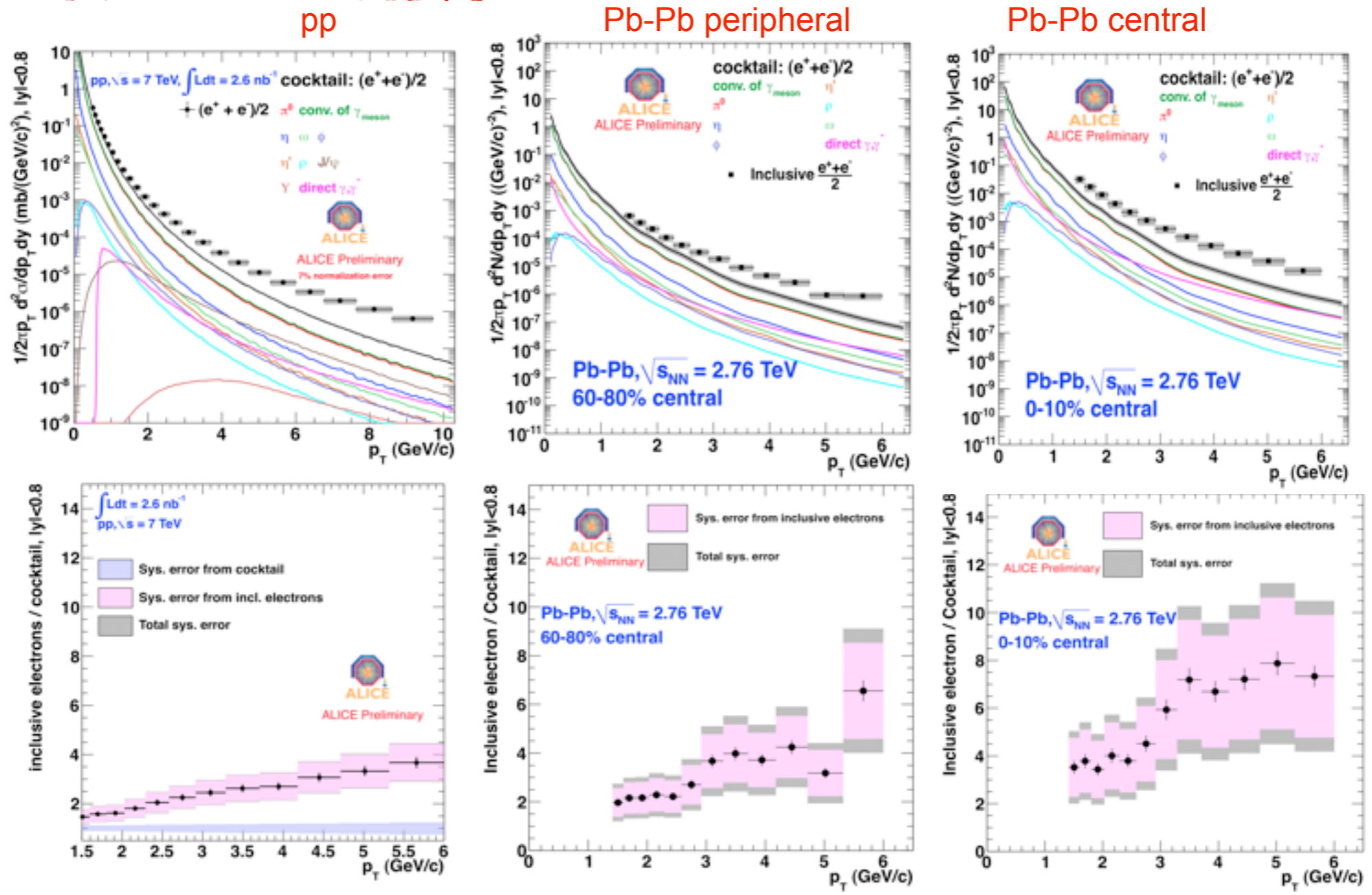
\* Feed-down subtraction in PbPb:

- ▶ Based on the FONLL B predictions corrected by the efficiencies
- ▶ Systematics from FONLL uncertainties partly cancel on the  $R_{AA}$
- ▶ Hypothesis on the  $b \rightarrow D$  energy loss :  $0.3 < R_c(c \rightarrow D) / R_b(b \rightarrow D) < 3.0$

$$-\langle T_{AA} \rangle \times \epsilon_{DfromB}^{MC} \times \frac{d\sigma_{DfromB}^{FONLL}}{dp_t} \times R_{AA}^B$$



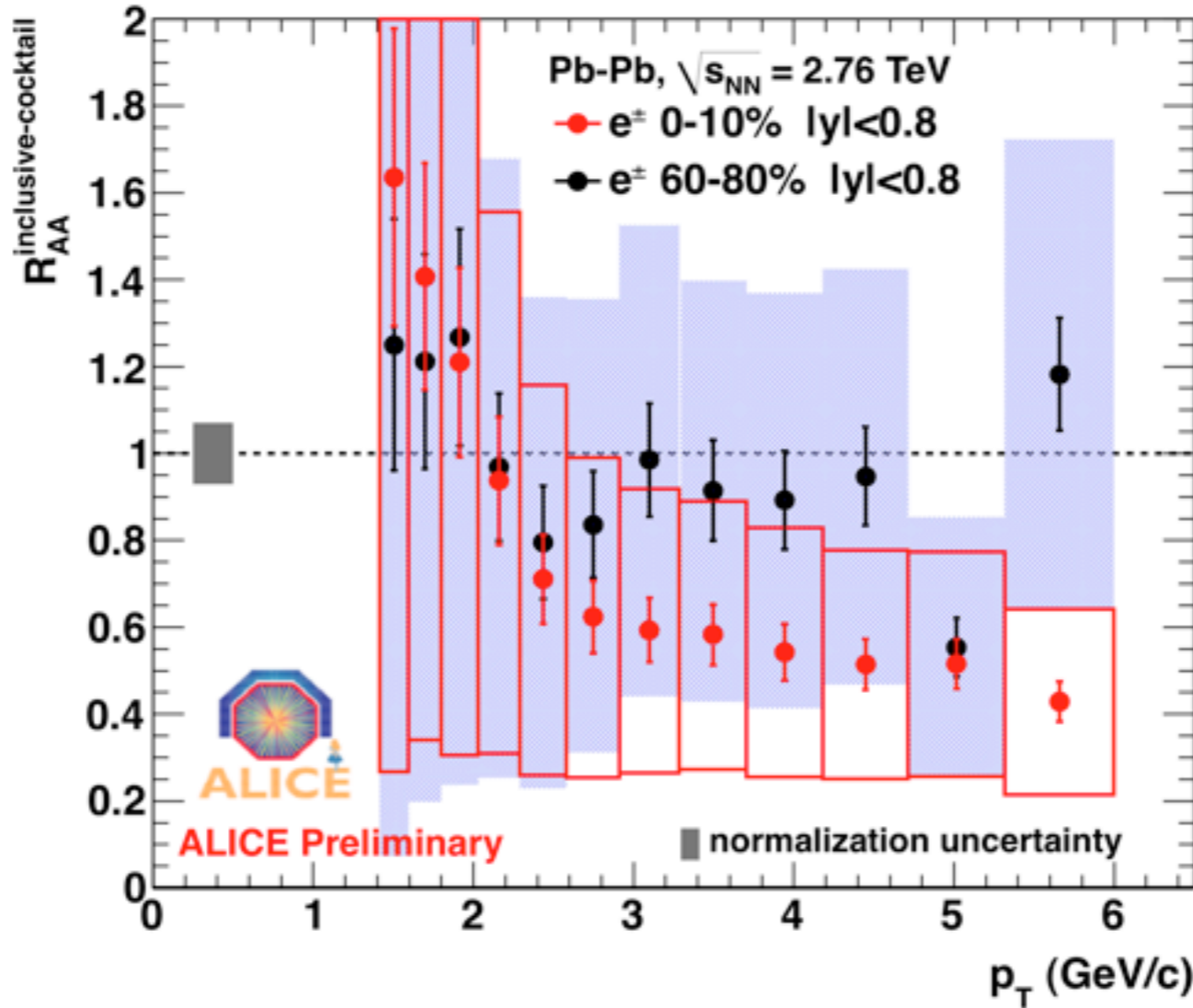
# HF ELECTRONS VS COCKTAIL



- \* Cocktail based on  $\pi^\pm$  spectra +  $m_T$ -scaling + pQCD direct photons.
- \* Contamination <10% for  $p_T < 6$  GeV/c.
- \* **Hint of electron excess at low  $p_T$  that increases with centrality.** Might be explained by thermal photons (cf. PHENIX, PRL104 and QM2011).

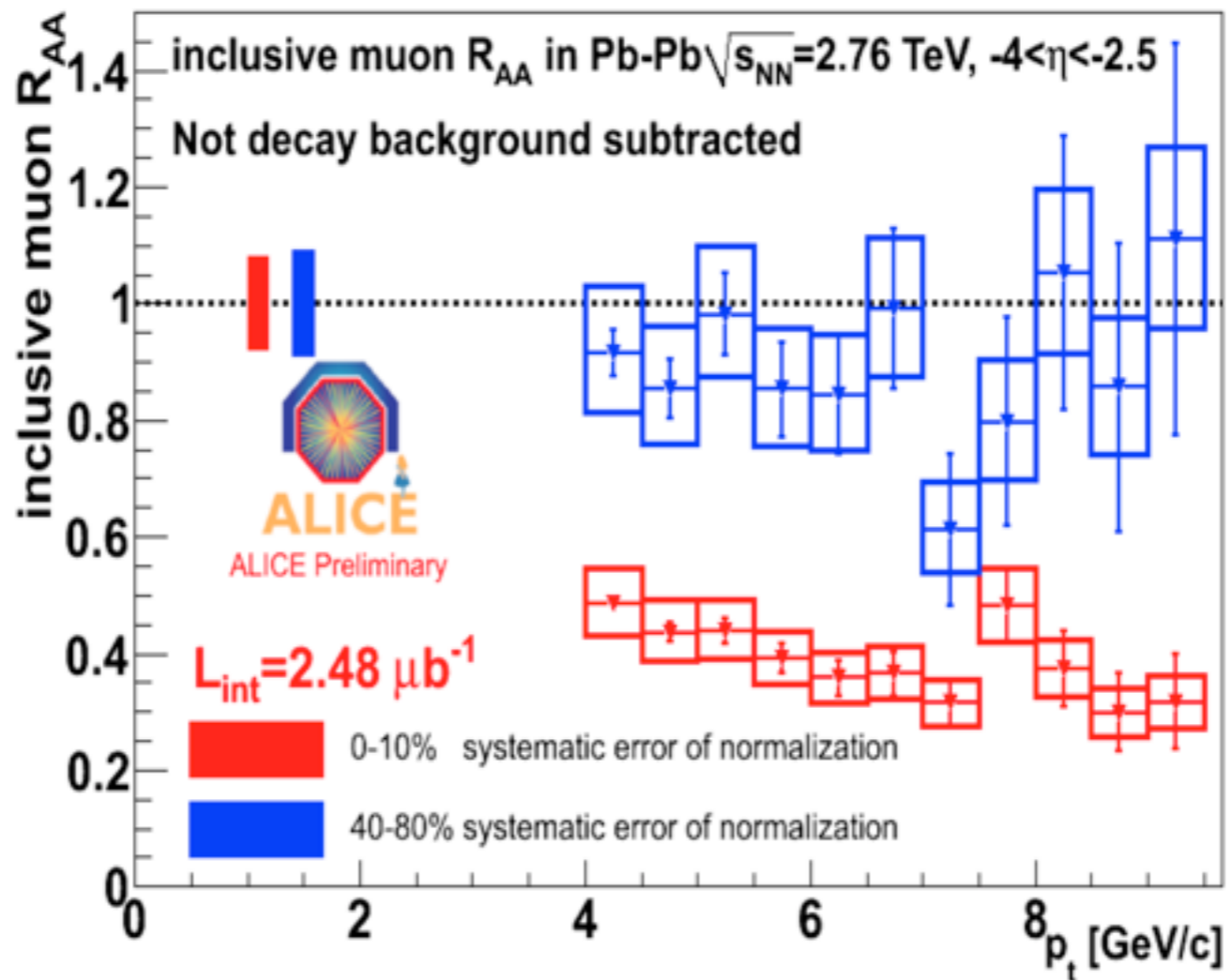


# ELECTRON $R_{AA}$



- \* Consider: **Inclusive electrons - cocktail**
  - ▶ Large systematics from the PID, cocktail and the reference spectrum.
  - ▶ Spectra **dominated by charm and beauty decays above 3-4 GeV/c.**
- \* **Suppression in central collisions by about 1.5-4.**

# MUON $R_{AA}$

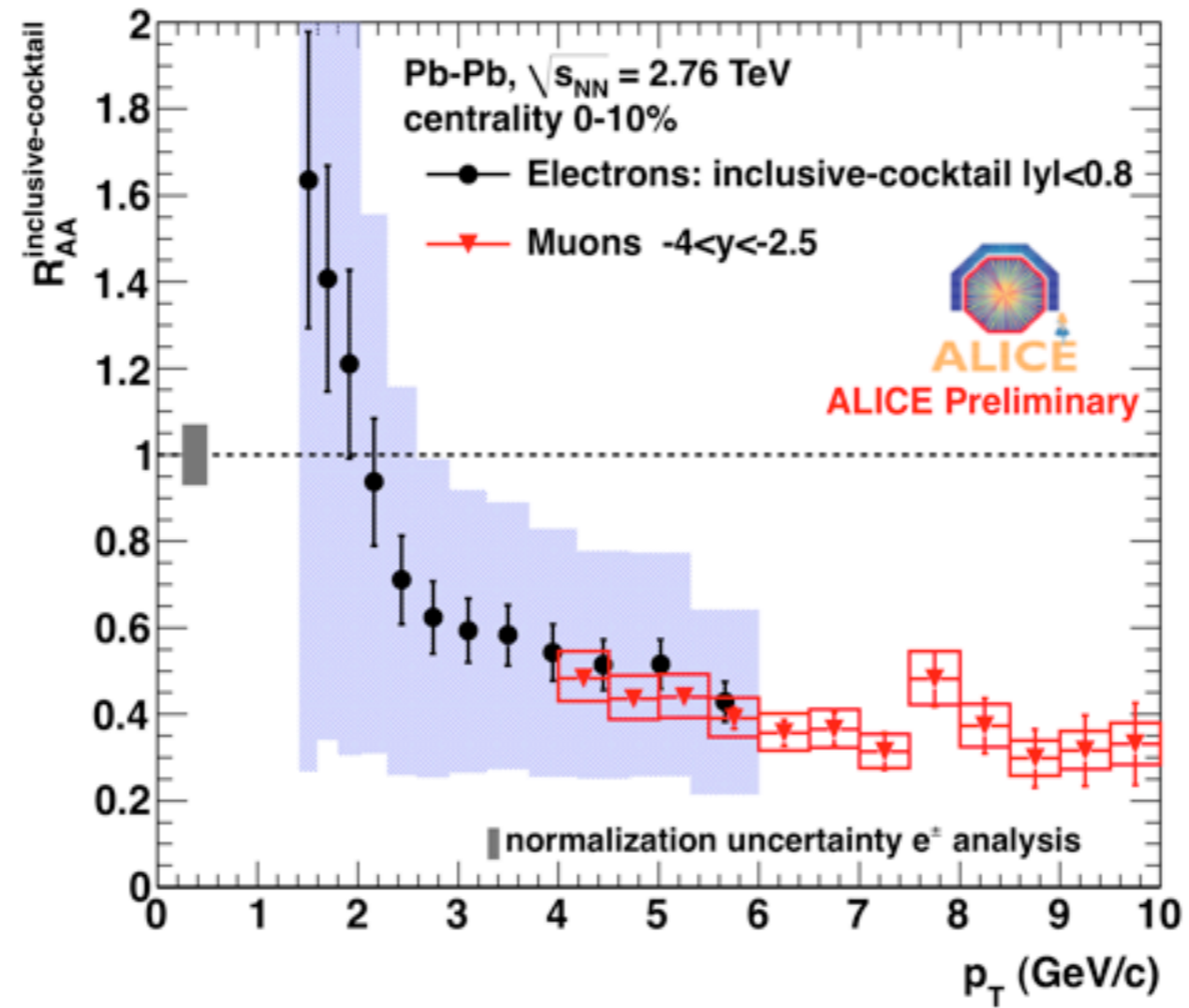


\* Consider: **inclusive muon spectrum**

- ▶ Restrict to tracks pointing to the vertex (remove background)
- ▶ Background from hadronic decays contribution not subtracted
- ▶ Spectra dominated by HF decays for  $p_t$  above 4 (>85%) - 6 (>90%) GeV/c

\* **Suppression in central collisions by about a factor of 3**

# COMPARE LEPTON $R_{AA}$



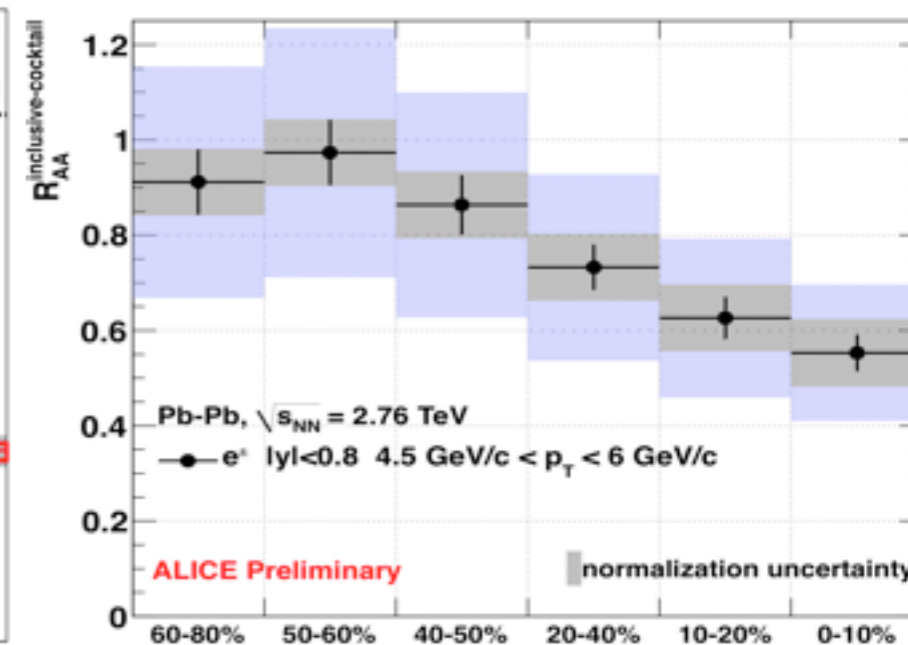
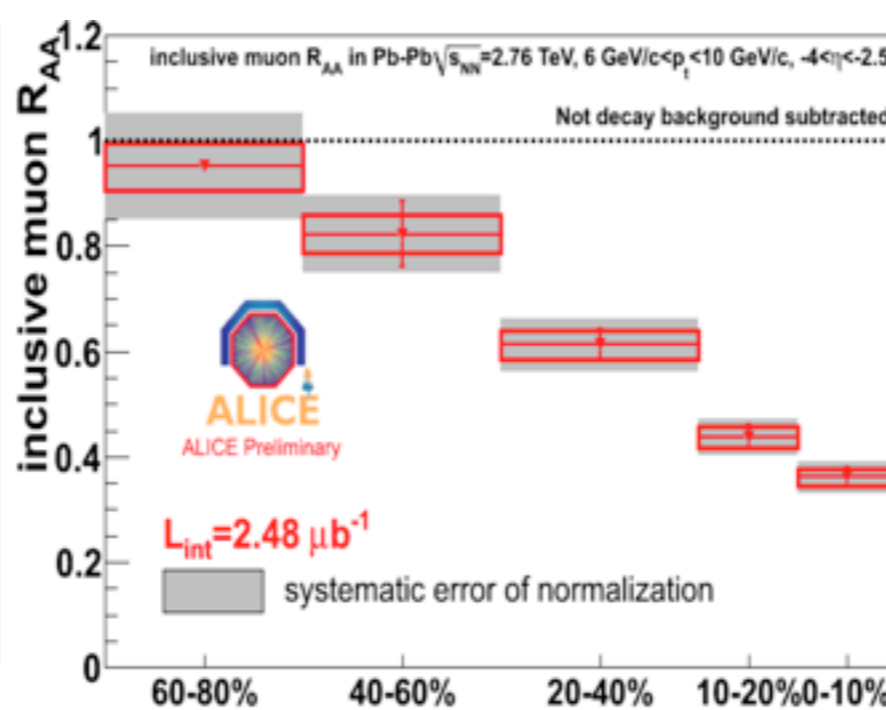
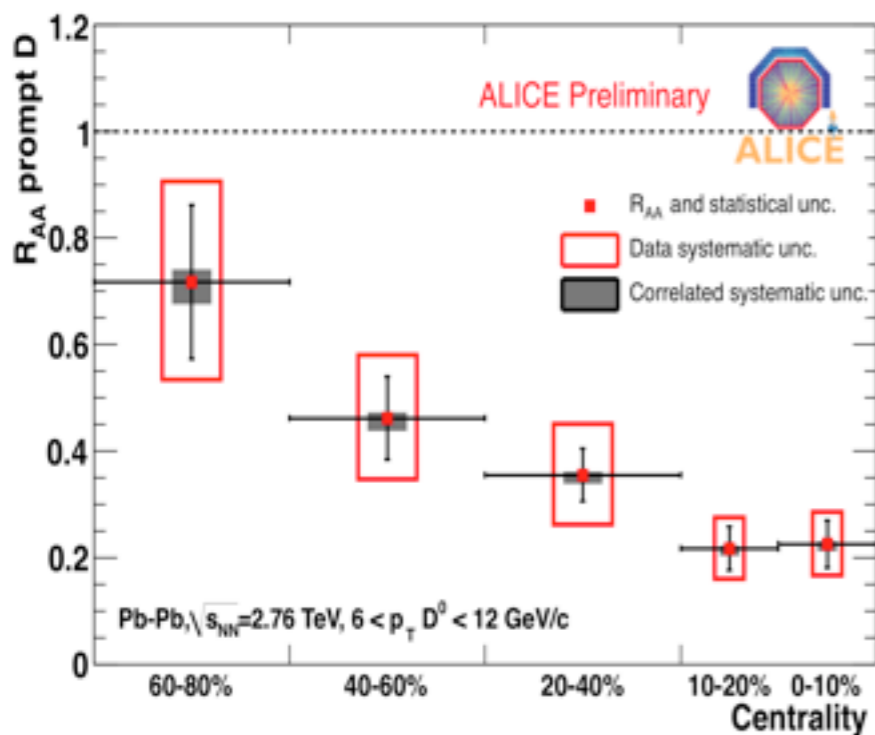
\* HF electron ( $|\eta| < 0.9$ ) and muon ( $-4.0 < \eta < -2.5$ )  $R_{AA}$  are consistent

# OPEN HF $R_{AA}$ VS CENTRALITY

$D^0$   $p_t > 6$  GeV/c

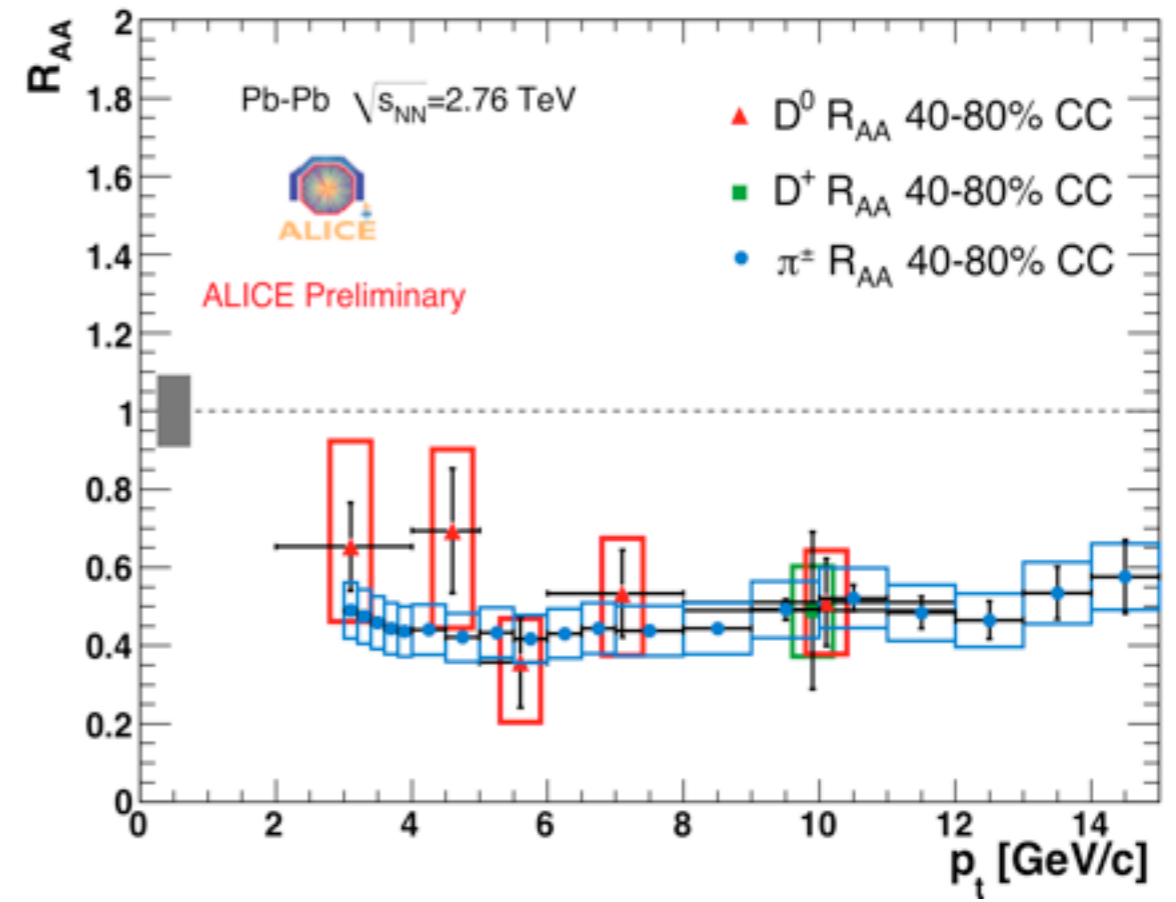
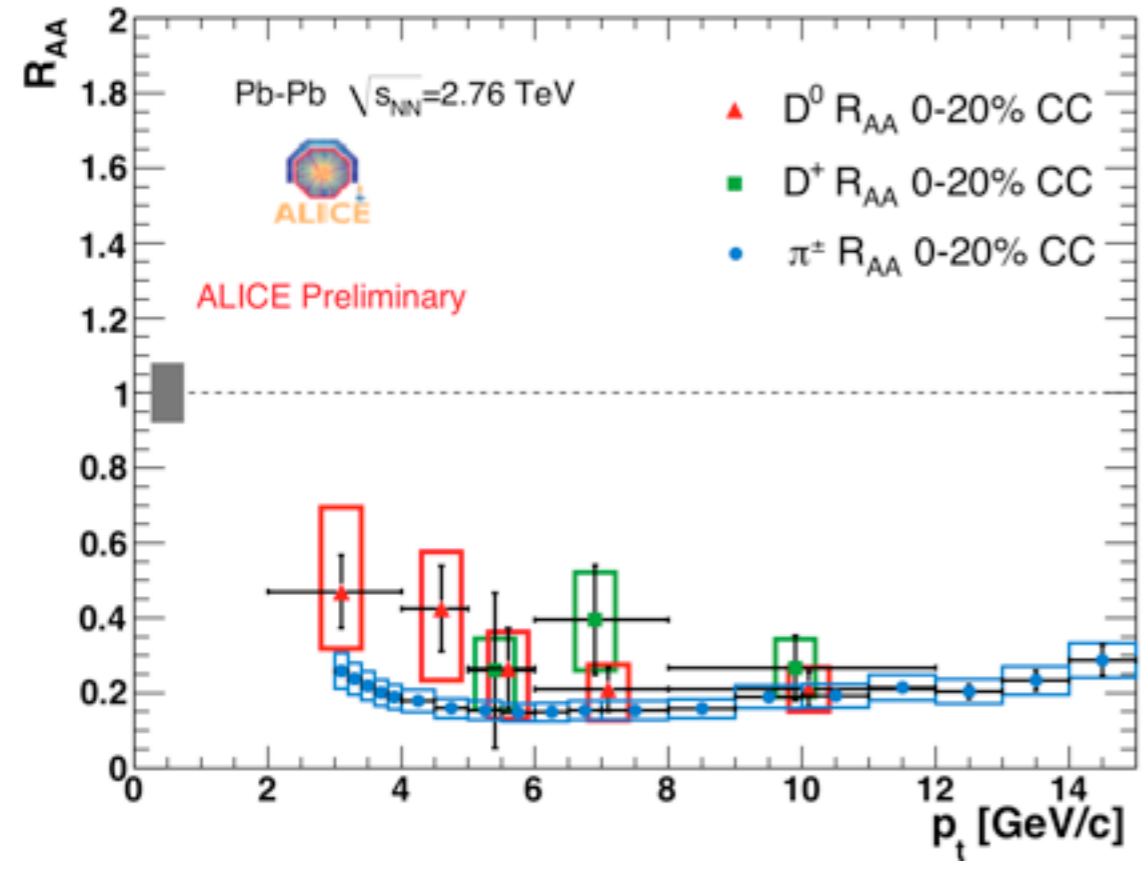
$\mu$   $p_t > 6$  GeV/c

$e$   $p_t > 4.5$  GeV/c



- \* Clear centrality dependence for all the probes
- \* Electron ( $|\eta| < 0.9$ ) and muon ( $-4.0 < \eta < -2.5$ )  $R_{AA}$  show a similar trend
- \* Prompt D mesons seem more suppressed than leptons (charm vs beauty?)

# CHARM VS PION $R_{AA}$



- \* Prompt D meson and  $\pi^\pm R_{AA}$  are compatible.
- \* Though there seem to be a deviation at low  $p_t$ . Might this be a hint of a flavor dependence?



# SUMMARY AND OUTLOOK

- \* ALICE has measured the prompt D, HF electrons, HF muon cross sections in pp collisions at 7 TeV.
- \* Heavy flavor nuclear modification factor in PbPb collisions at 2.76 TeV has been measured.
  - ▶ Data exhibit a clear centrality dependence.
  - ▶ HF electrons ( $|\eta| < 0.9$ ) and muons ( $-4.0 < \eta < -2.5$ ) show a suppression of about a factor of 3 in the 0-20% CC.
  - ▶ Prompt D mesons  $R_{AA}$  is suppressed by about a factor of 4 in the 0-20%CC.
- \* Refined analysis with the whole statistics... (pp & PbPb)
- \* Ongoing comparison of particle species  $R_{AA}$
- \* Dependence on the reaction plane : flow (PbPb)
- \* More data to come in 2011 (pp & PbPb) : b-tagging (?), D-zoology (?),...

... stay tuned !