Open Heavy Flavor in ALICE

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(European Organization for Nuclear Research,
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on behalf of the ALICE Collaboration

– Fall Meeting of the GDR PH-QCD (Oct 2011) –

Introduction and Outline

Introduction:

- Heavy flavor production is a tool to test pQCD calculations (pp coll.)
- Heavy flavor particles are suppressed at RHIC (AA coll.)
- We expect (based on theoretical grounds) a mass hierarchy on the energy loss : $R_{AA}(h) < R_{AA}(D) < R_{AA}(B)$

$$R_{AA} = \frac{Y_{AA}}{\langle N_{coll}\rangle_{AA} \times Y_{pp}} = \frac{Y_{AA}}{\langle T_{AA}\rangle_{AA} \times \sigma_{pp}}$$

[Dokshitzer and Kharzeev, PLB 519 (2001) 199.
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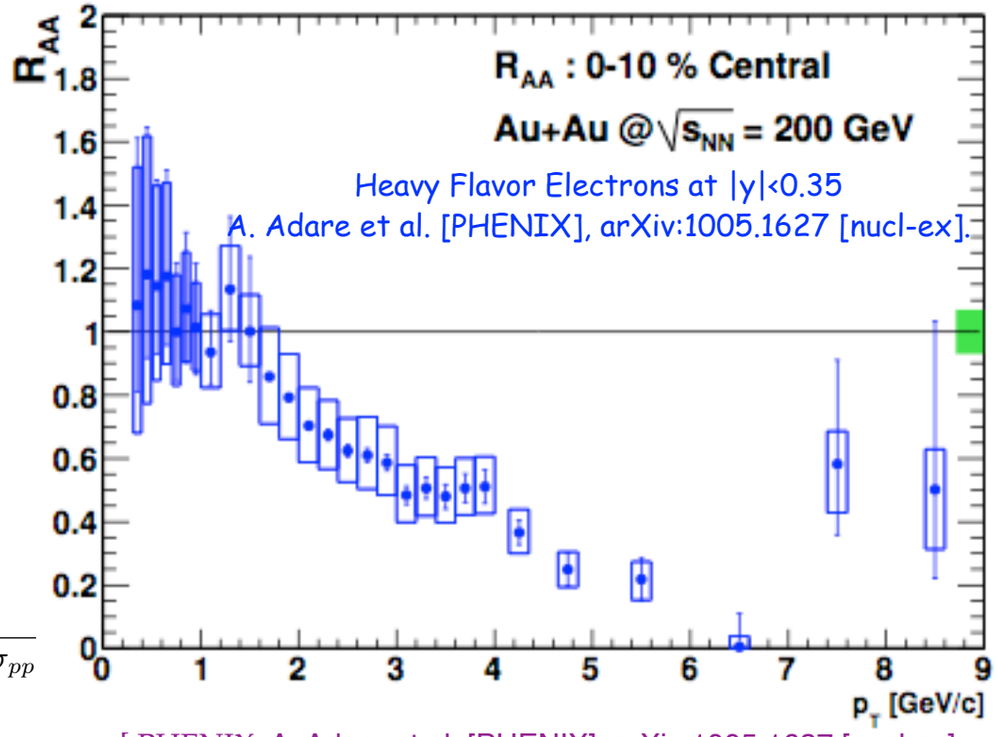

[PHENIX: A. Adare et al. [PHENIX], arXiv:1005.1627 [nucl-ex].
+ M. Durham QM2011 talk
STAR: Phys. Rev. Lett. **98** (2007) 192301]

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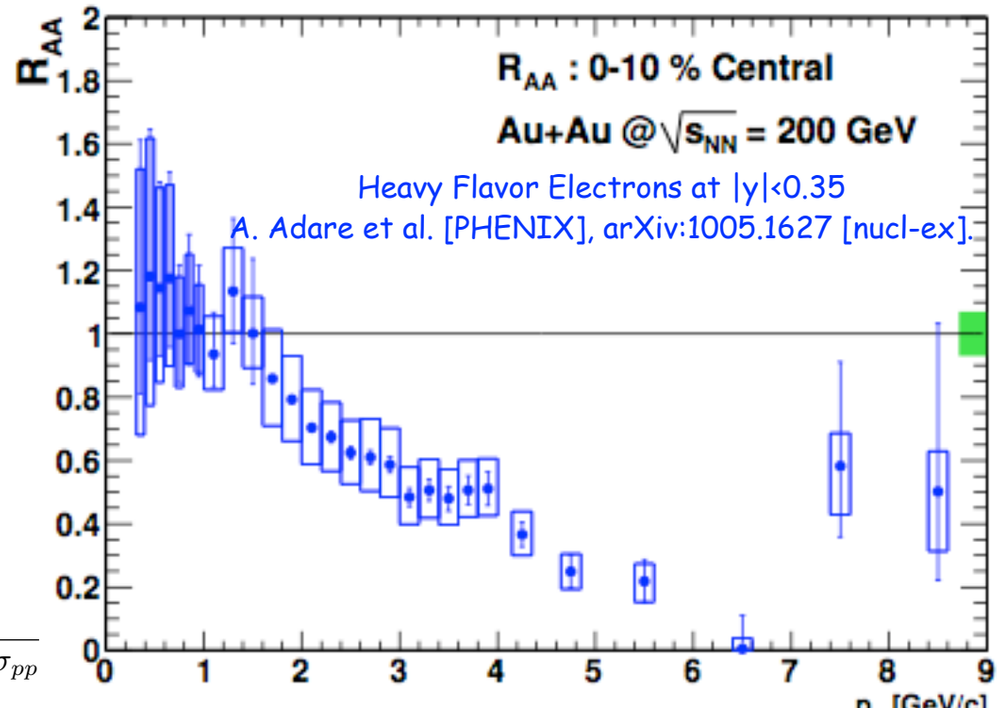

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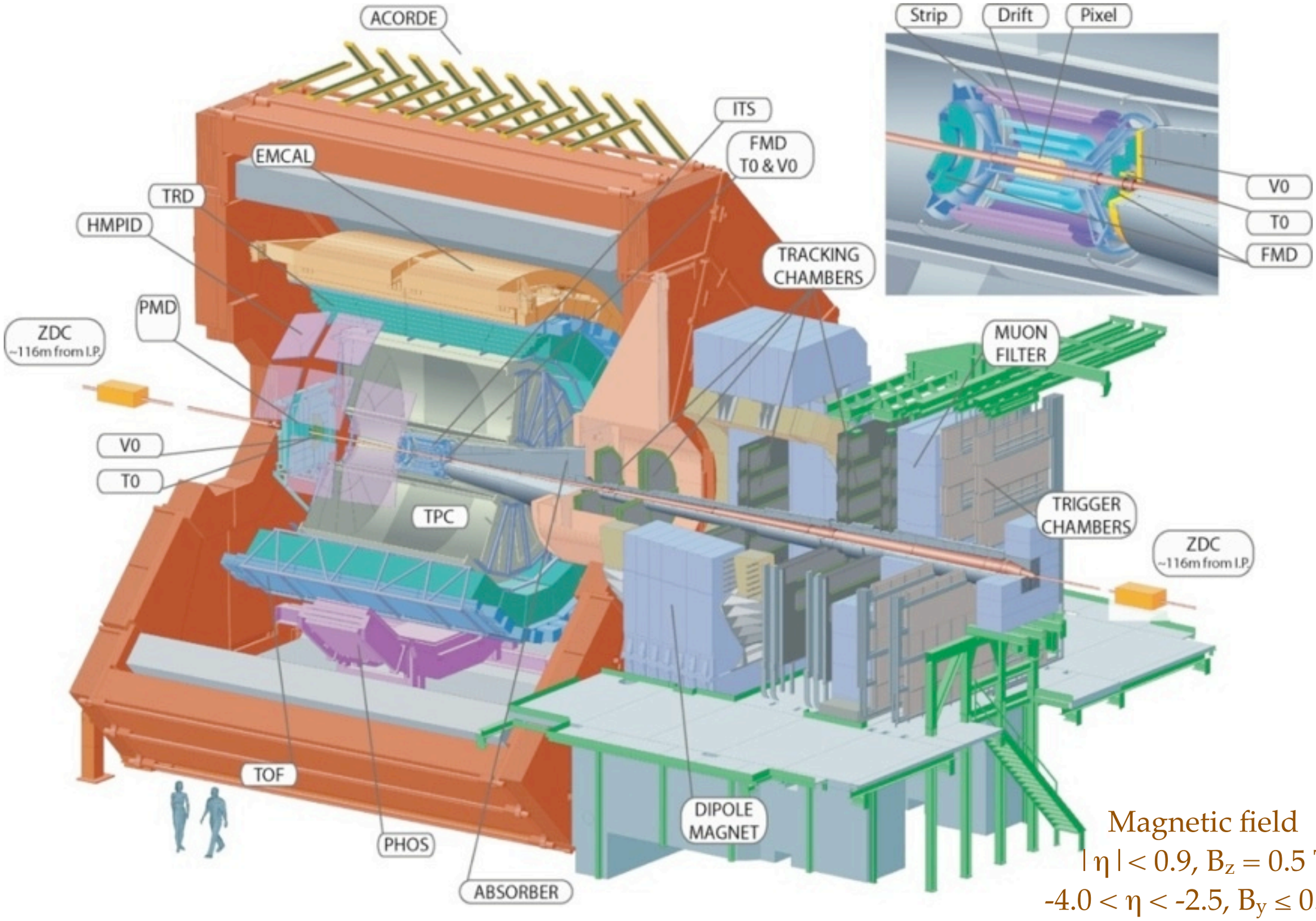
Outline:

- Open heavy flavor measurements in proton-proton interactions at $\sqrt{s}$ = 7 & 2.76 TeV
  - Results ($d\sigma/dp_t$, $d\sigma/dy$): D mesons, single electrons, single muons
- Open heavy flavor results in PbPb collisions at $\sqrt{s}$ = 2.76 TeV
  - Results (R_{AA}, R_{CP}): D mesons, single electrons, single muons
  - D^0 elliptic flow
- Conclusions

The ALICE Experiment



Magnetic field

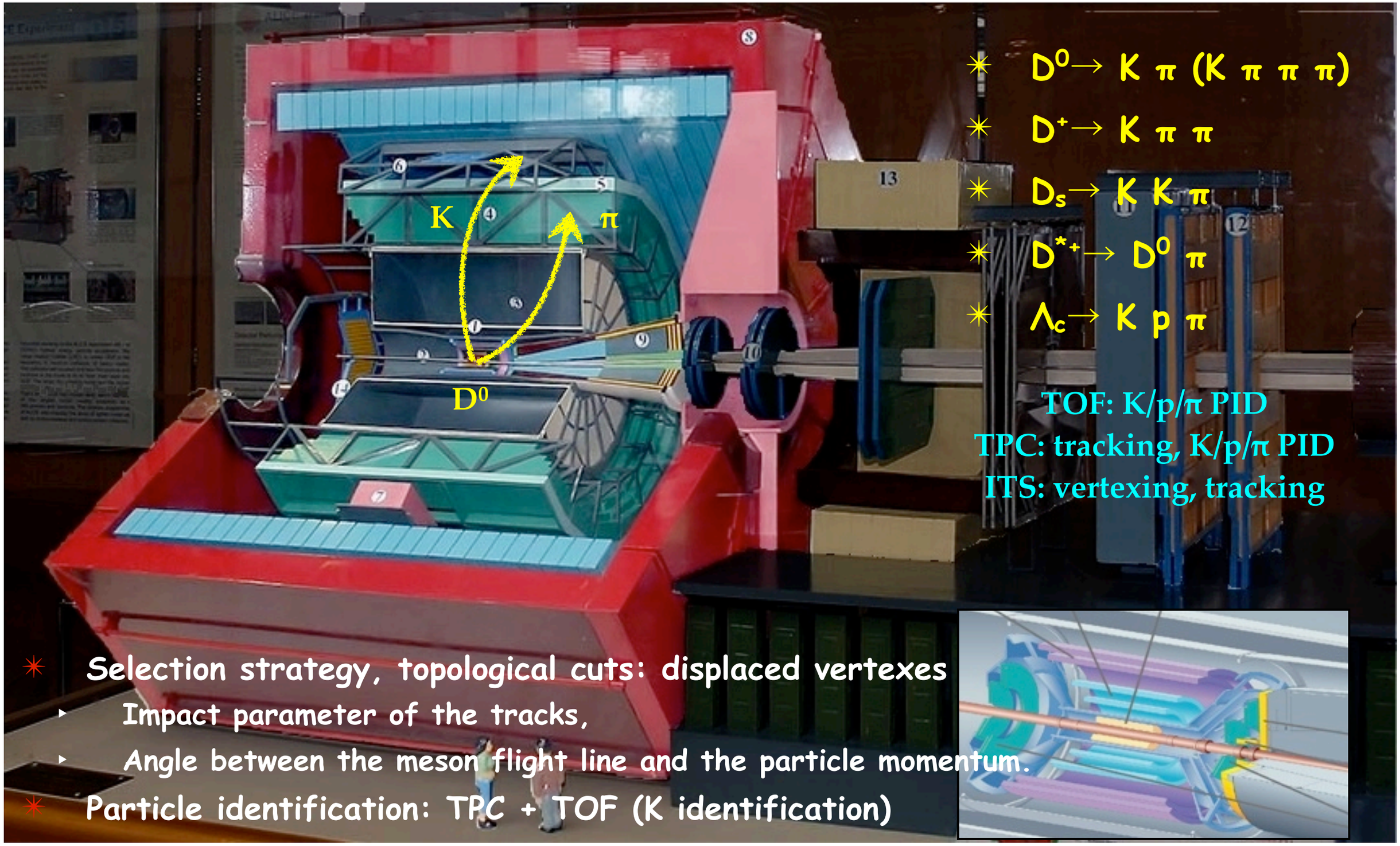
$|\eta| < 0.9$, $B_z = 0.5$ T

$-4.0 < \eta < -2.5$, $B_y \leq 0.7$ T

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	μ-trigger	MB	μ-trigger	MB
Data-taking	April-Aug 2010	April-Sept 2010	March 2011	March 2011	Nov 2010
N_{events}	100-180 (300) M	130 M	65 M	~9 M	17 M
<L> [nb^{-1}]	1.6 (5)	16	1.1	20	2.7 μb^{-1}

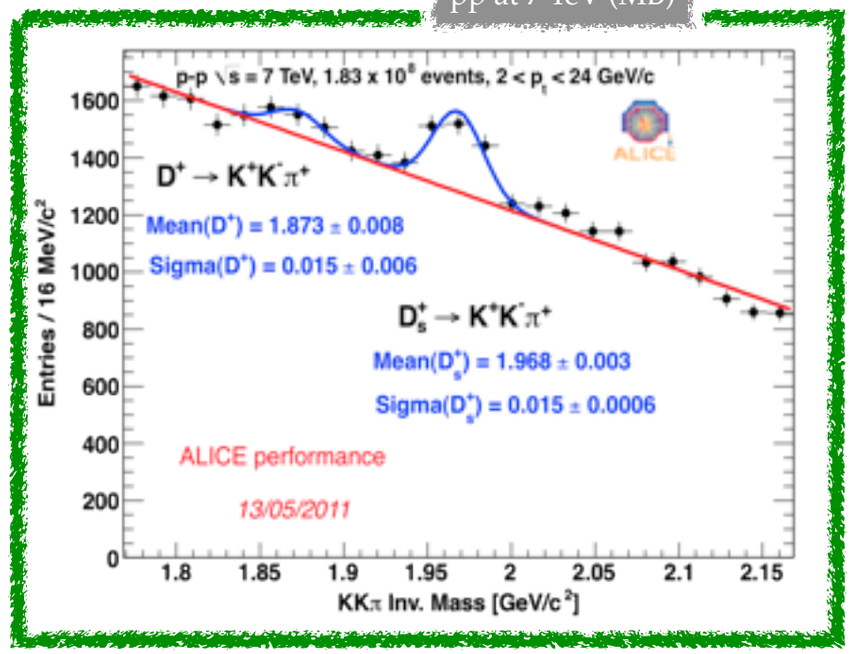
D mesons at |y|<0.8



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 cross section measured…
- Rare Λ_c starting to show up…
- Work in progress…

pp at 7 TeV (MB)



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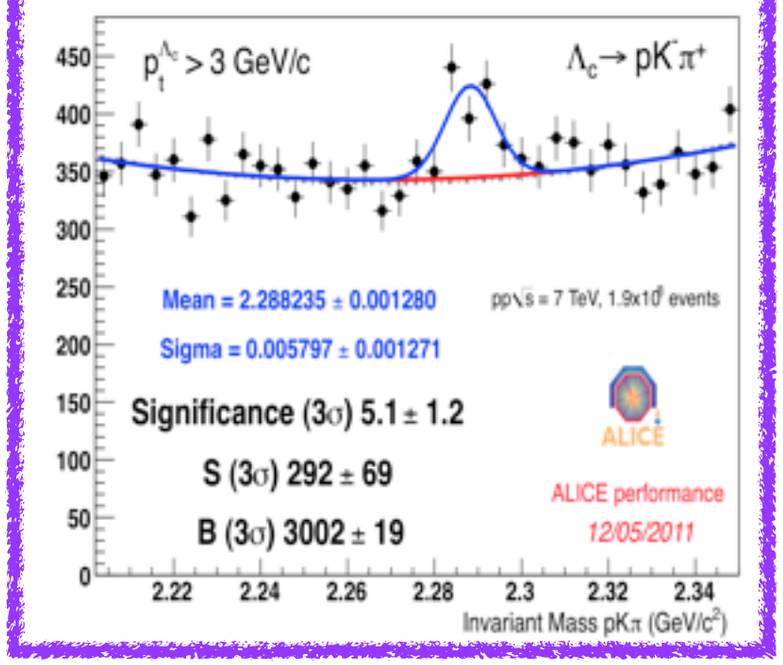
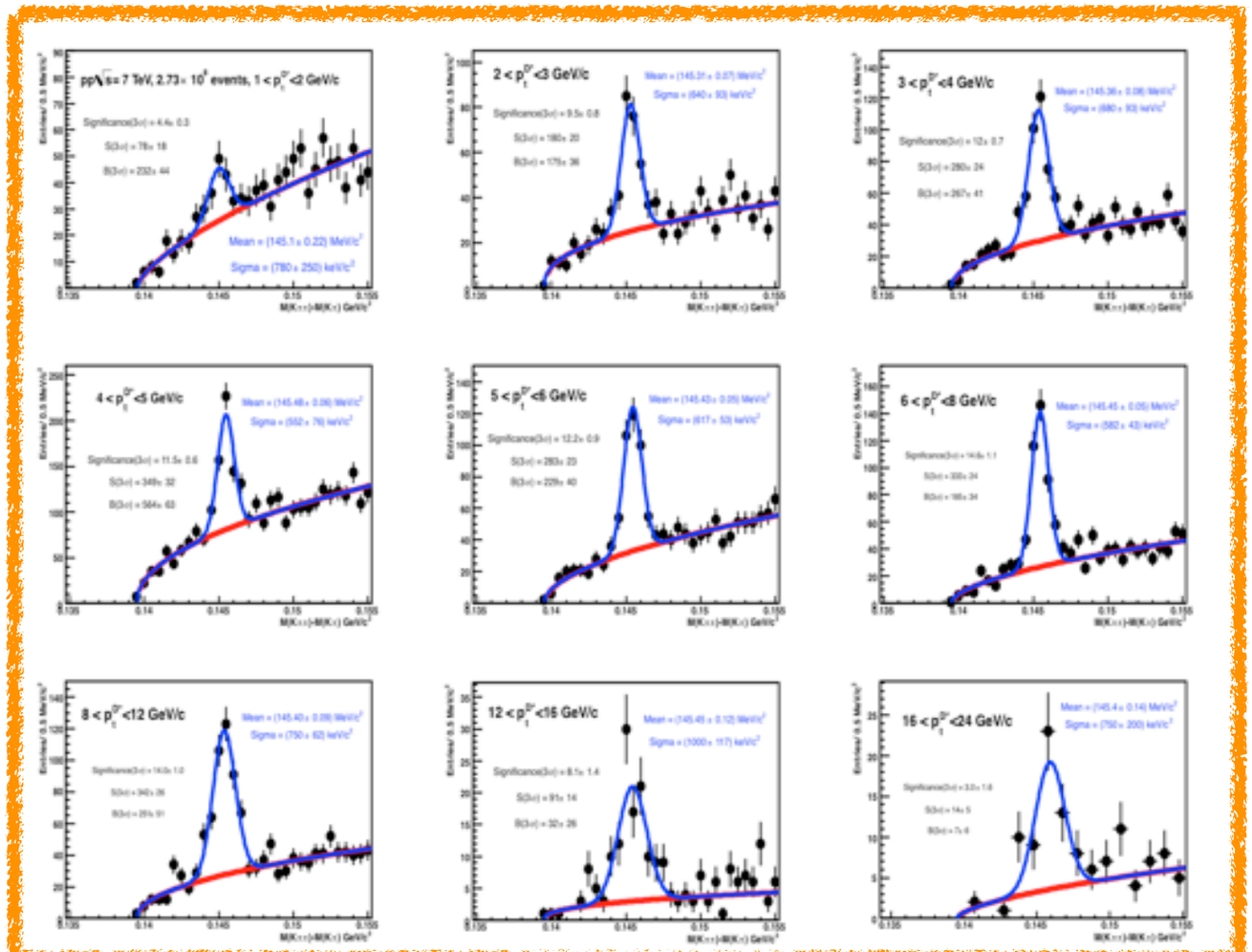
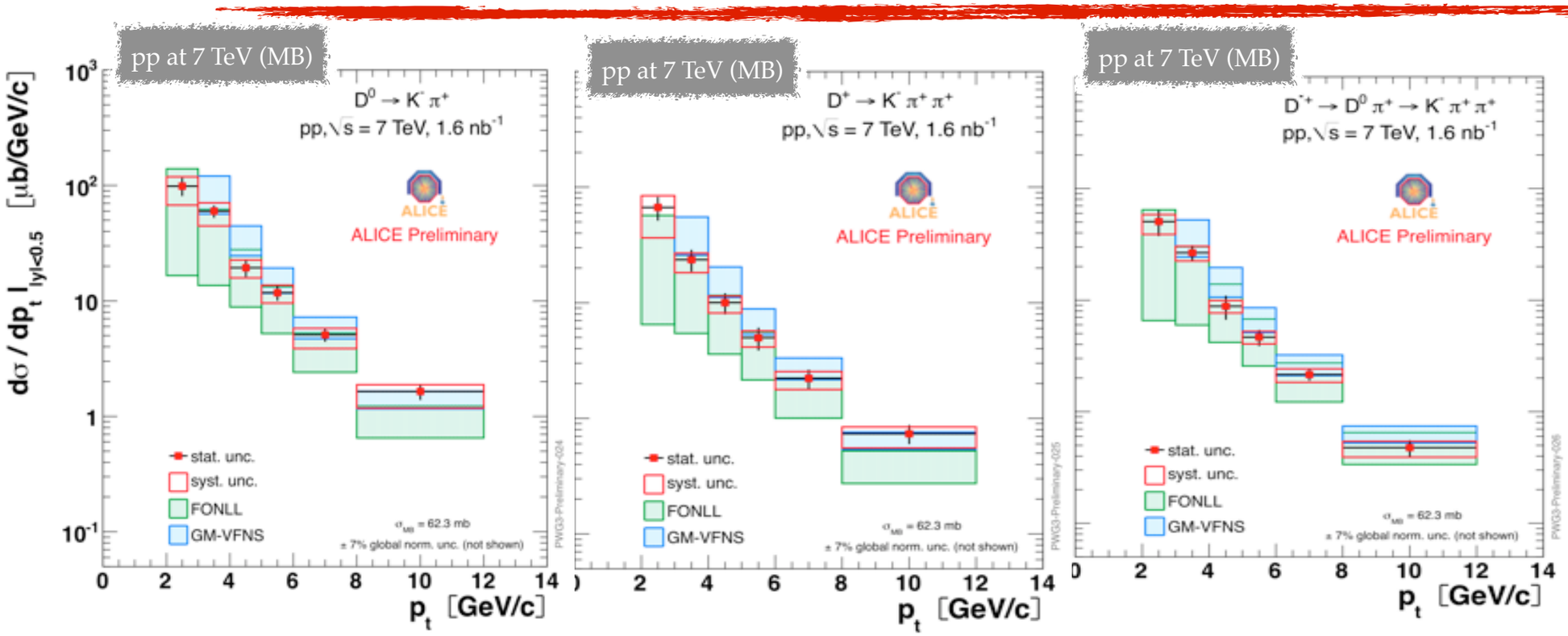




pp at 7 TeV (MB)

D meson cross-sections



G.M.Innocenti, talk at SQM 2011.

- At 7 TeV: $2 < p_t < 12$ GeV/c, with 1.6 nb^{-1} (~20% of 2010 statistics)
- At 2.76 TeV: $2 < p_t < 8$ GeV/c, with 1.1 nb^{-1} (3 days of data-taking)
- pQCD (FONLL) driven feed-down subtraction for the moment.
- well described by pQCD predictions (FONLL and GM-VFNS)

FONLL: Cacciari et al., private comm.
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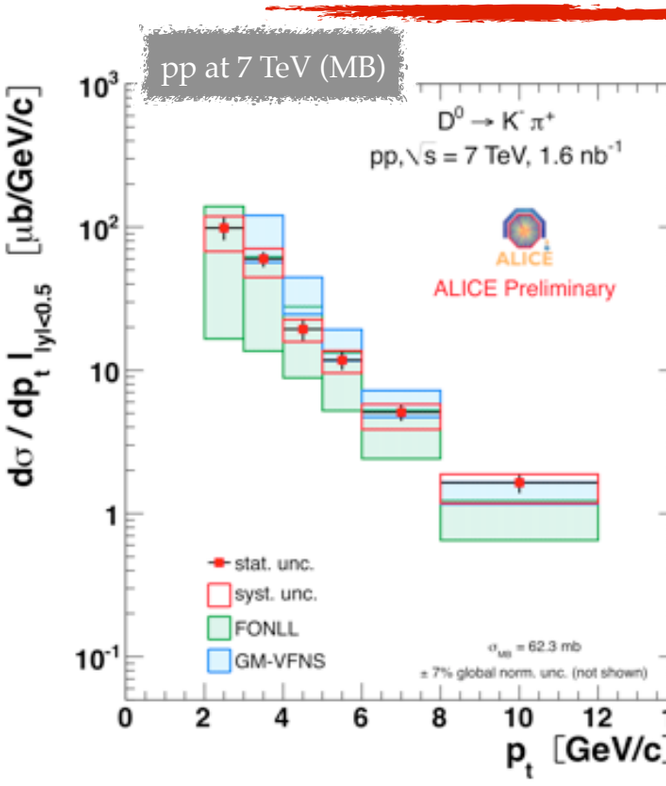

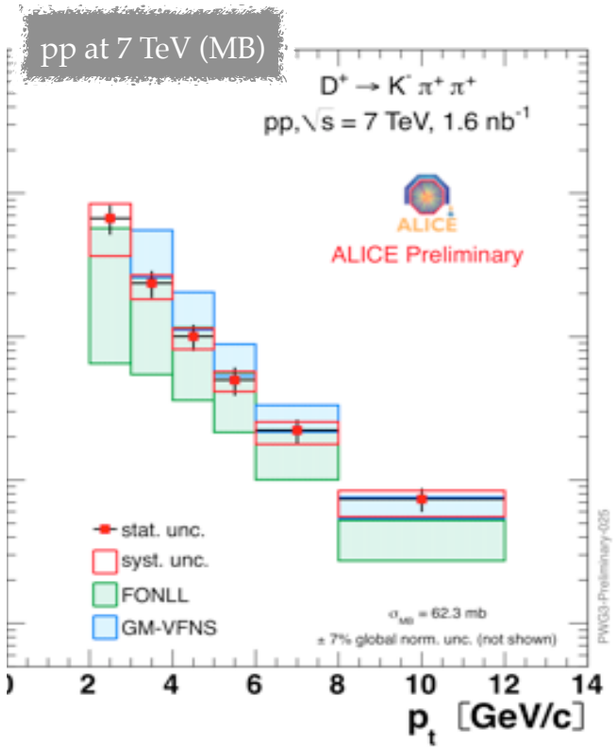

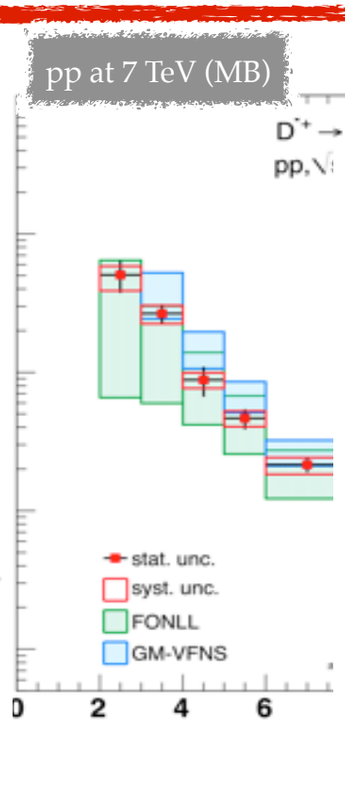

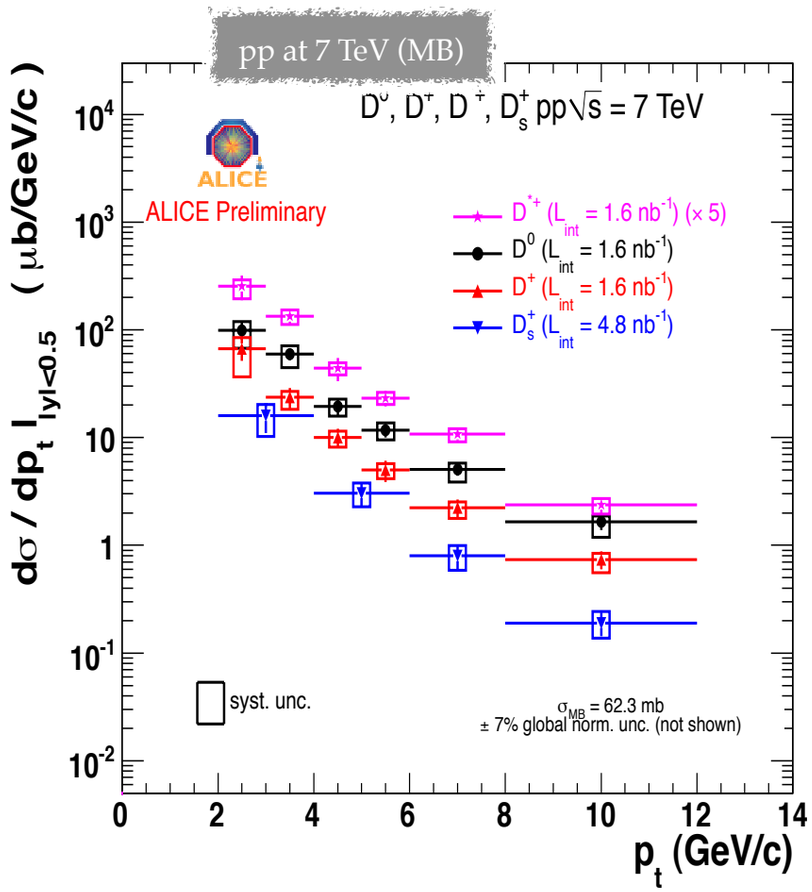

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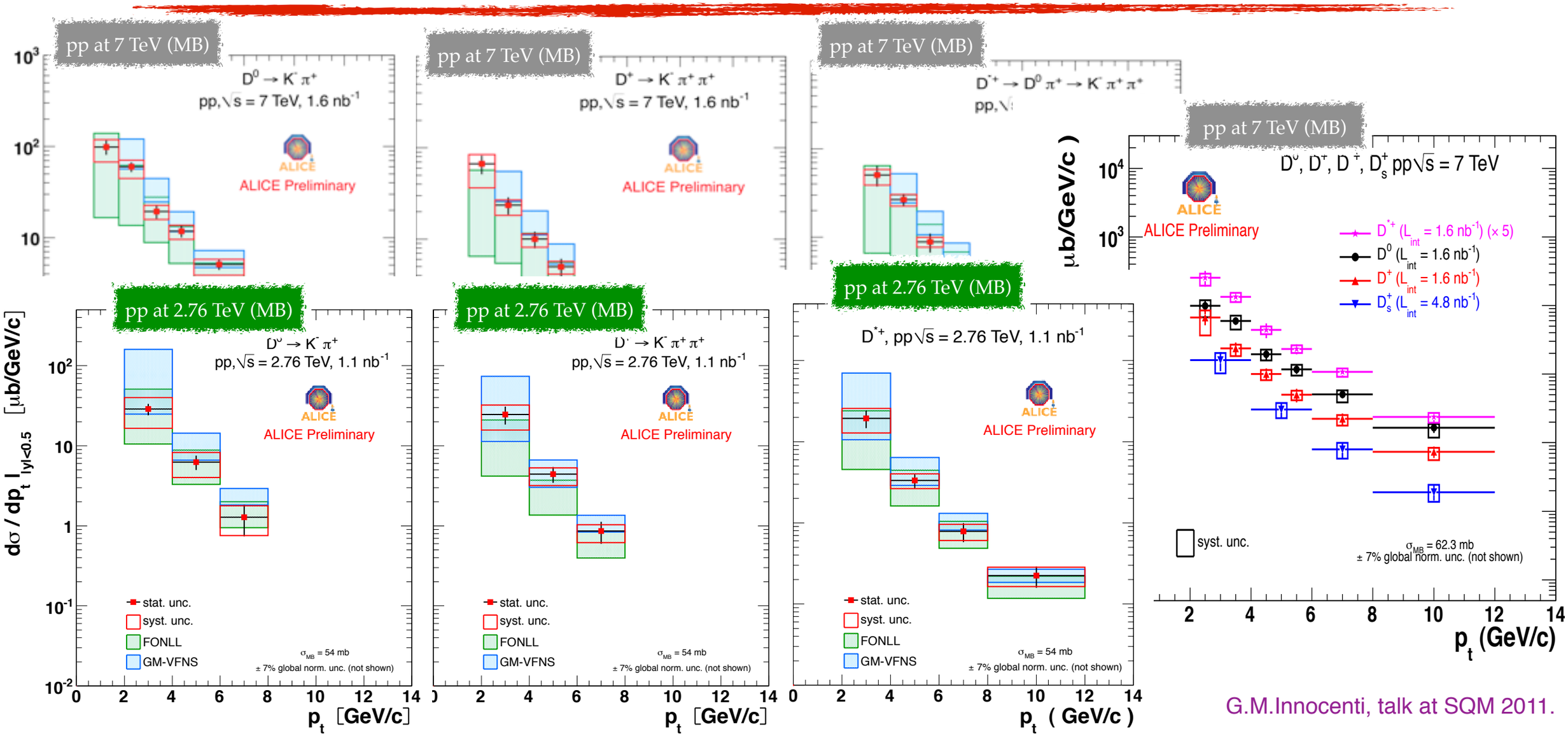

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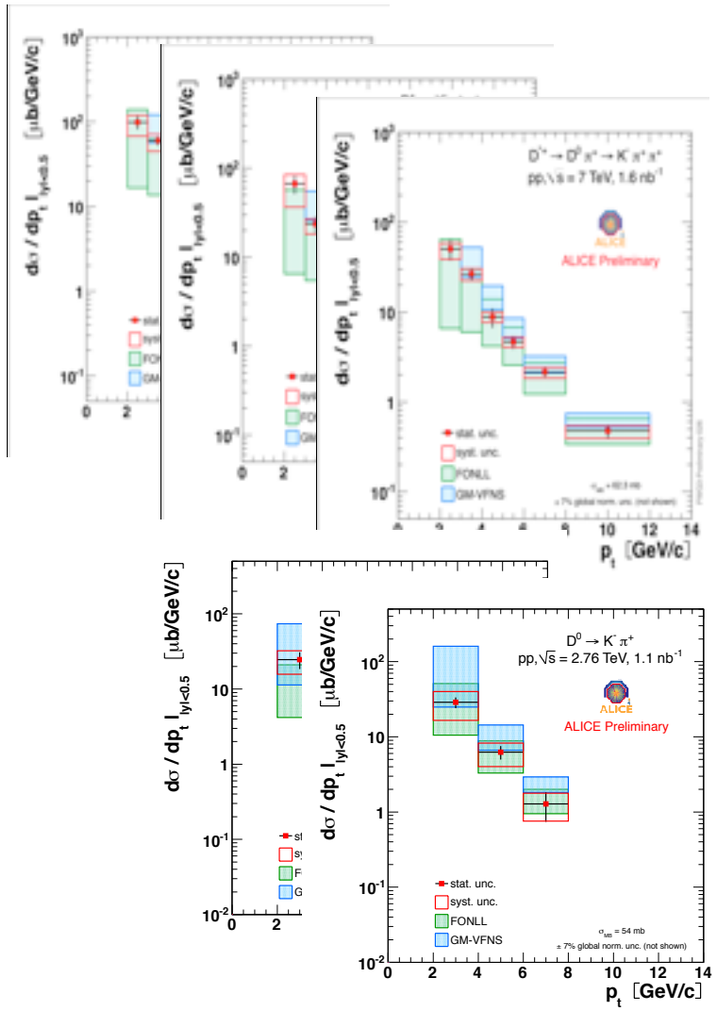
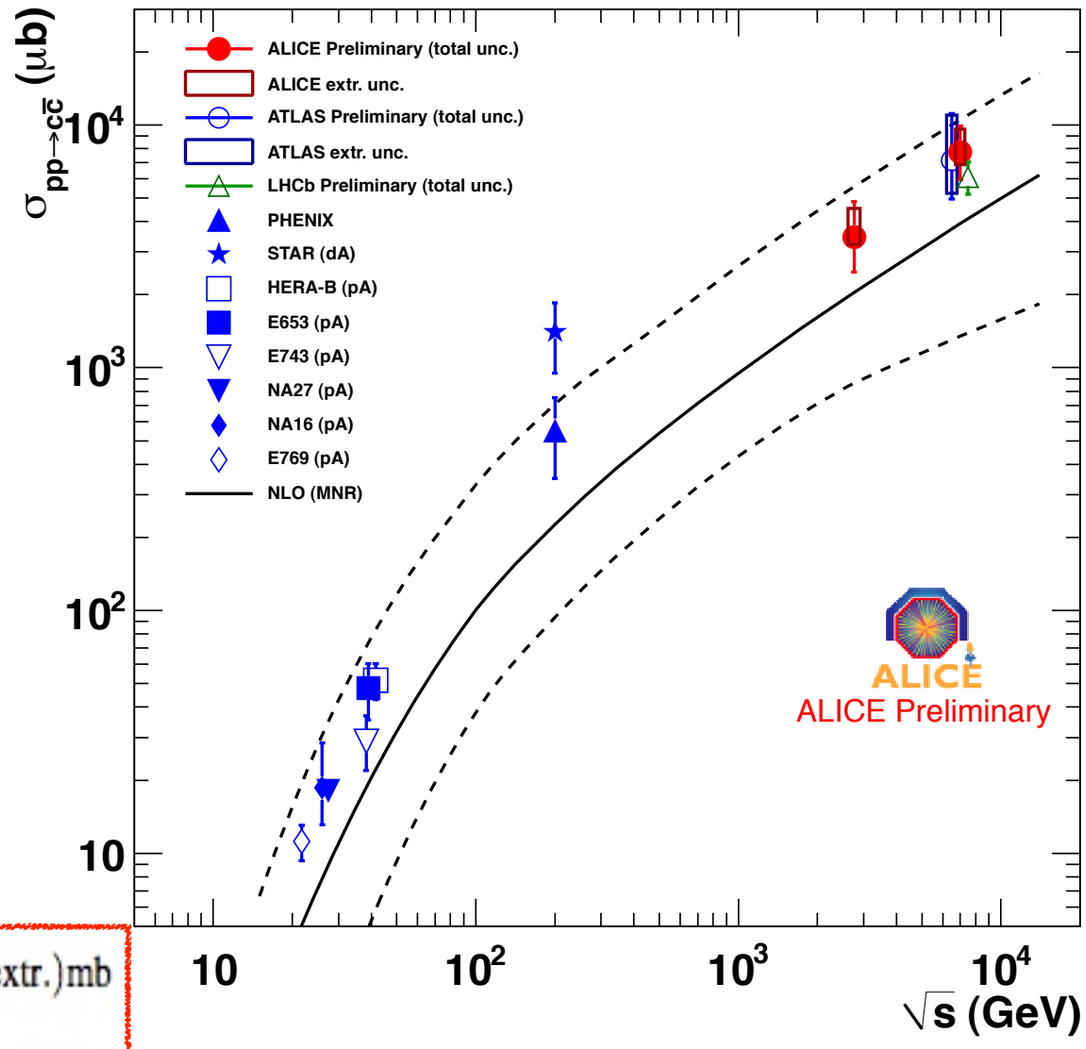
Charm cross section vs $\sqrt{s_{NN}}$



pp at 7 TeV (MB) pp at 2.76 TeV (MB)



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

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

K.Schweda, arXiv:1109.4607

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

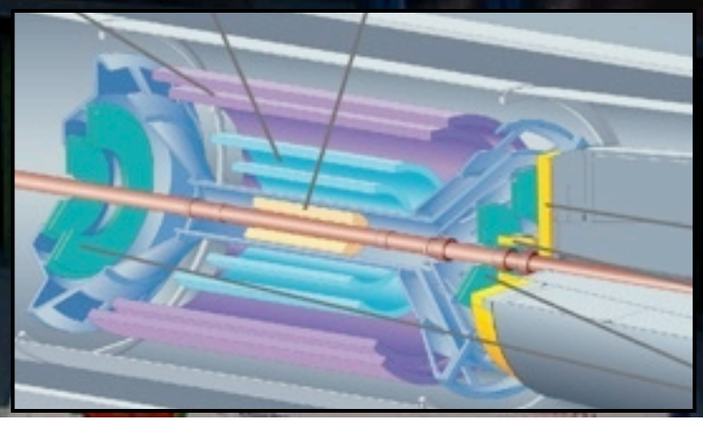
HF Electrons at $|\eta|<0.8$

- $B + D \rightarrow e^{\pm} + X$
- $B\ (\text{tagging}) \rightarrow e^{\pm} + X$

$e^{\pm}$

D, B

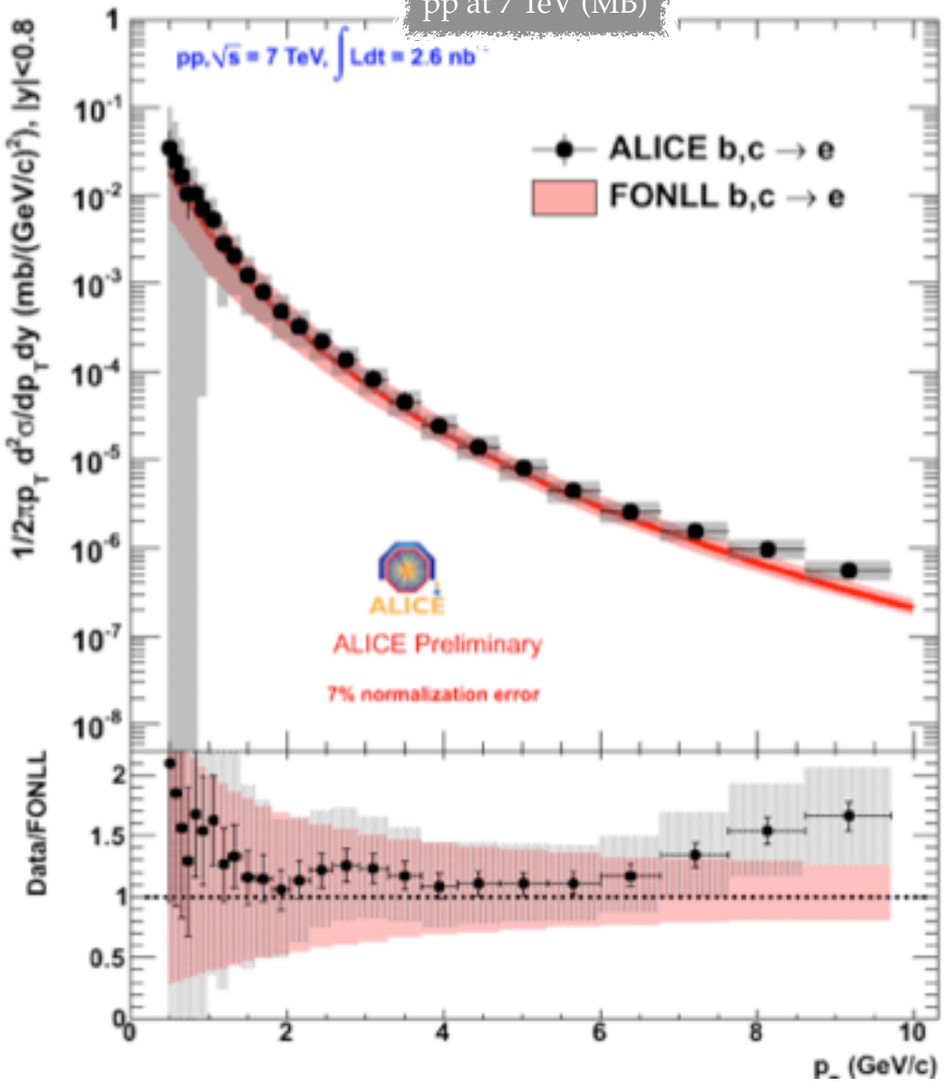
EMCAL, TOF, TRD, TPC: e/π PID
TPC, ITS: tracking
ITS: vertexing



- High quality tracks
- Electron identification: TPC+TOF (pp, PbPb), + TRD+EMCAL (pp for now)

Heavy Flavor Electrons

pp at 7 TeV (MB)



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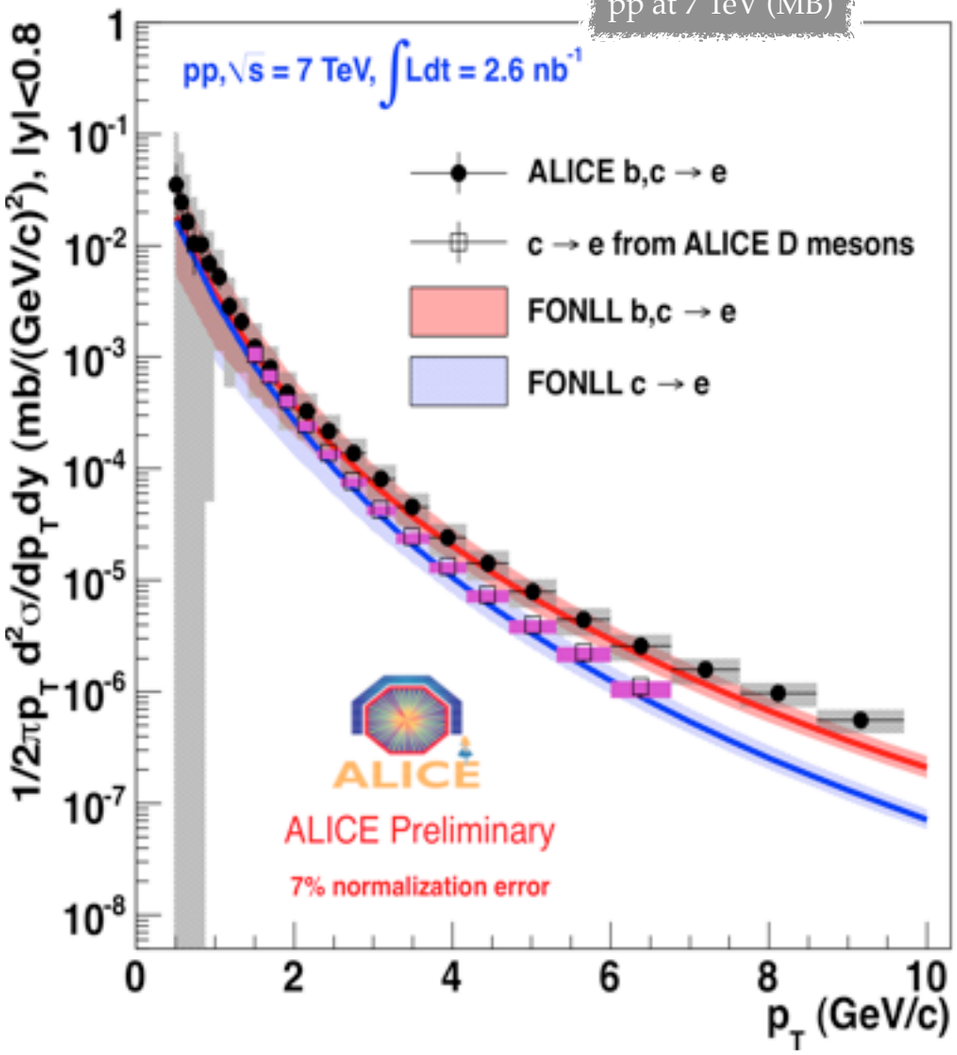
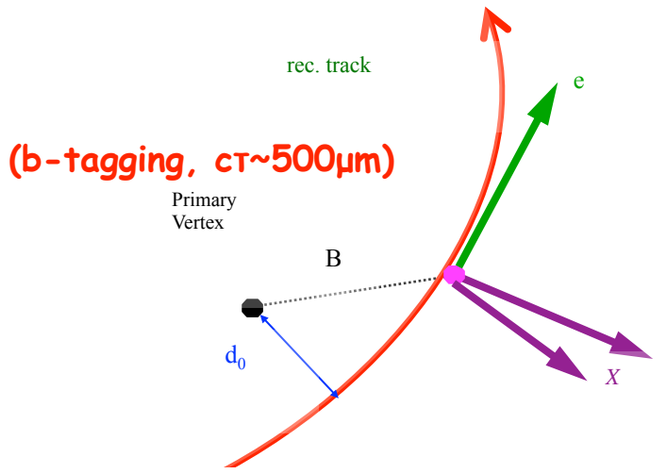


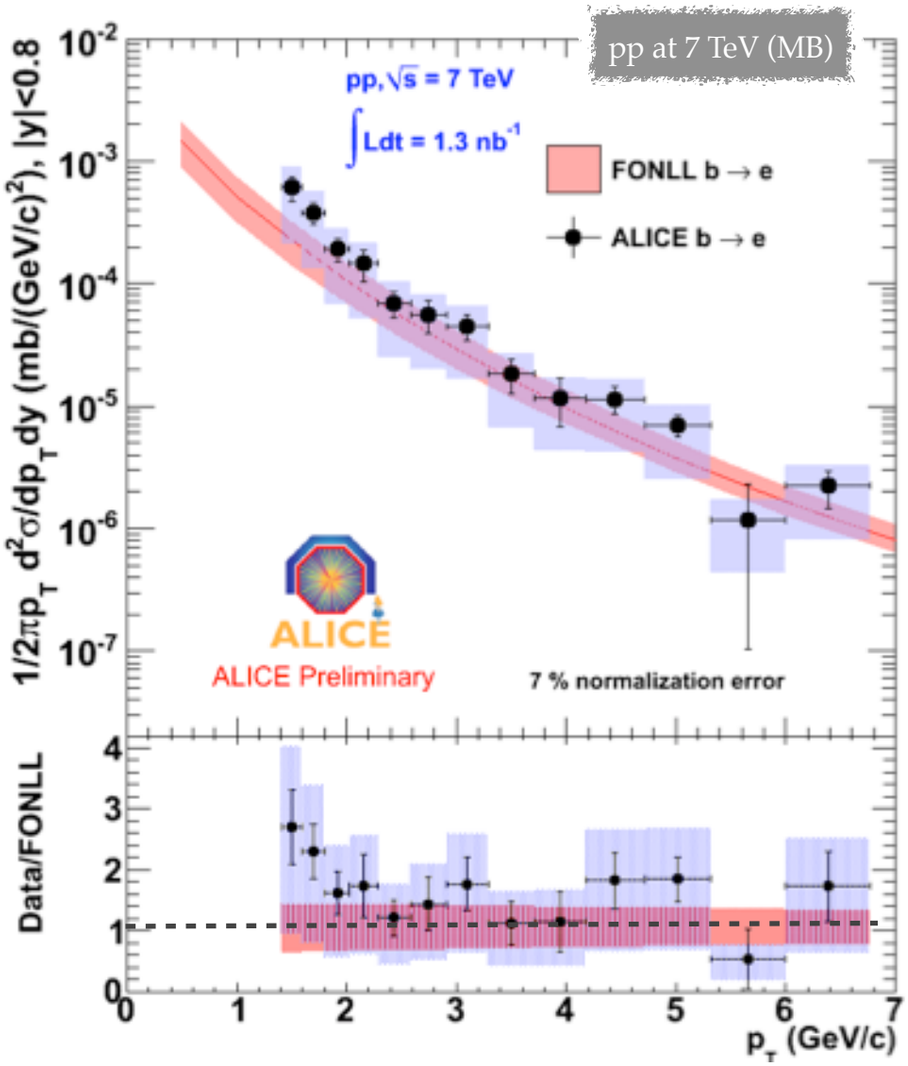
S. Masciocchi, arXiv: 1109.6436

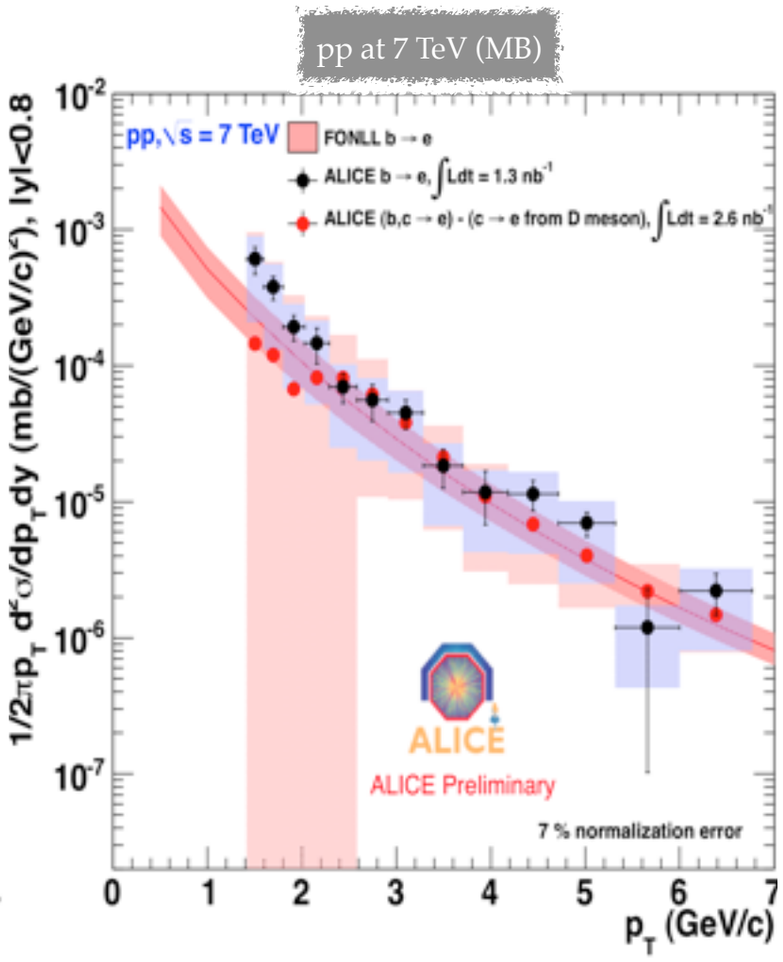
- Subtracted cocktail of electron background based on the measured π^0 (+J/ψ +Υ) spectrum + m_t-scaling + pQCD direct photons.
- Good agreement with FONLL b+c over the full p_t range
- Consistent with the prompt charm measurement from D mesons

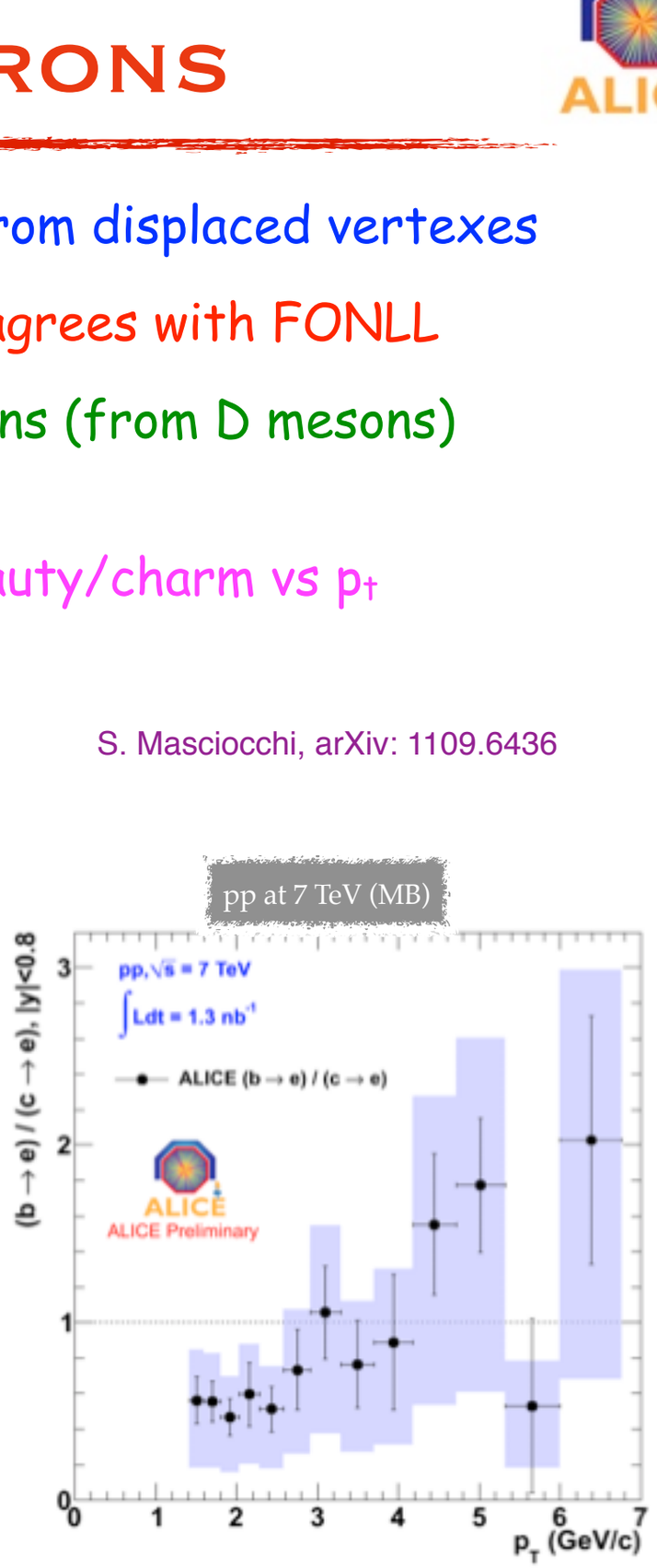
Beauty decay Electrons



- 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 p_t







S. Masciocchi, arXiv: 1109.6436

HF MUONS AT -4.0<η<-2.5

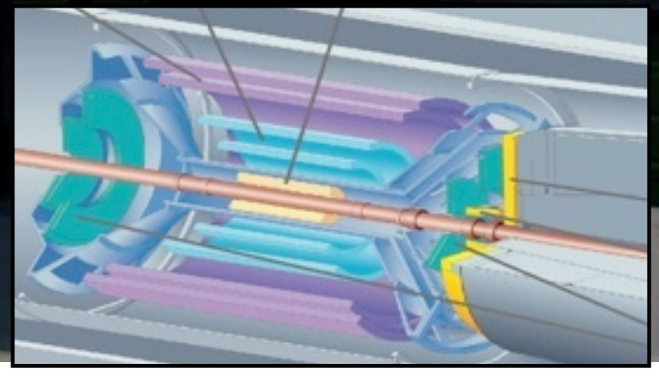
✳ B + D→ μ± + X

MUON tracker, MUON trigger:
μ - identification, tracking
ITS: vertexing

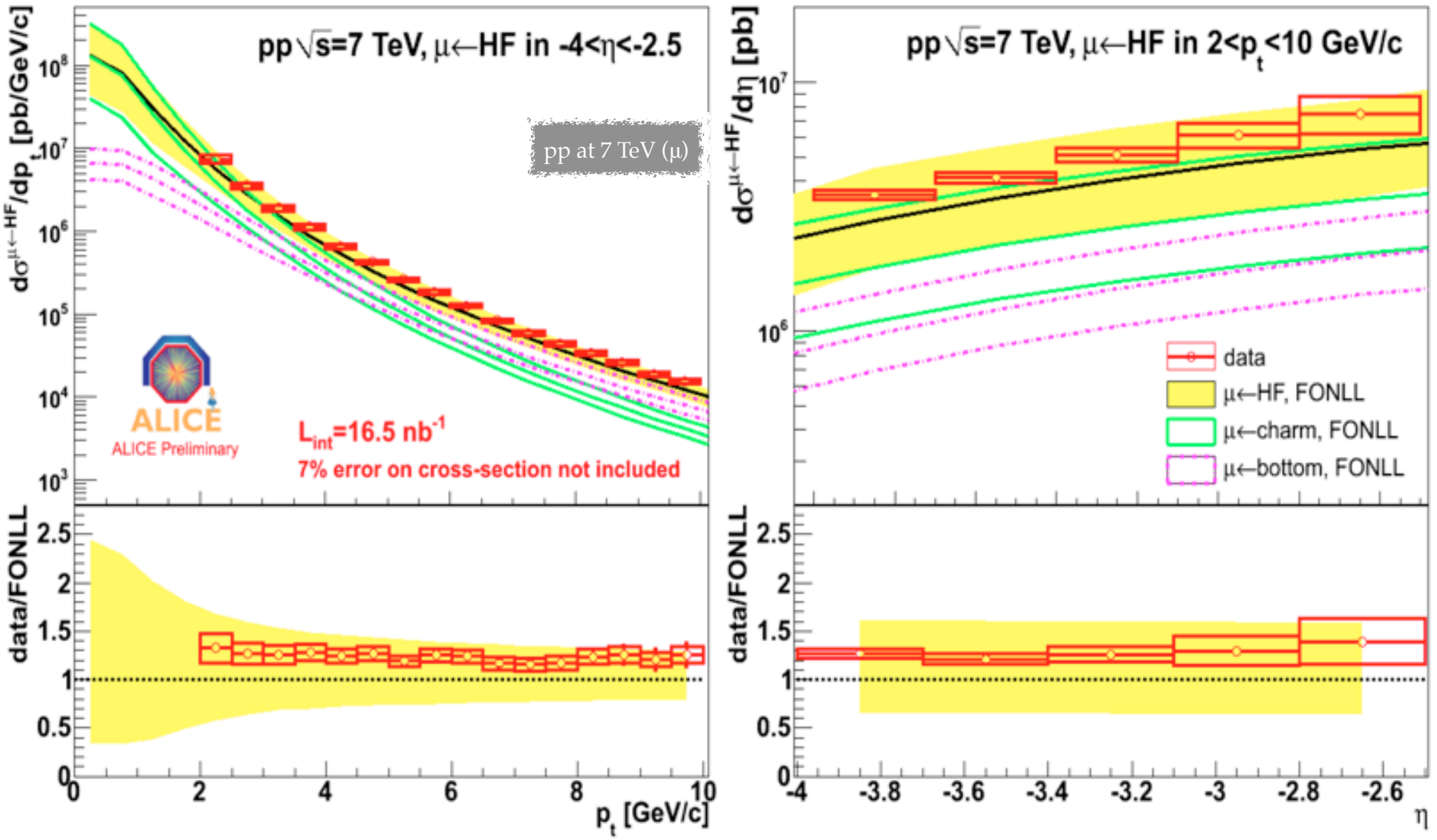
D, B

μ±

✳ Remove hadrons and low p_t secondary muons by requiring a muon trigger signal plus a cut on the DCA.



HF MUON CROSS SECTION



- Subtract decay muons by subtracting MC dN/dp_t normalized to data at low p_t
- Transverse momentum and pseudo-rapidity distributions well described by pQCD (FONLL) calculations

X. Zhang, QM talk

- FONLL suggests that beauty predominates for p_t > 6 GeV/c
  [for p_t ~ 10 (6) GeV/c prompt charm contribution is expected to be ~30% (40%)]

Measurements in PbPb collisions

System	pp	pp	pp	pp	PbPb
$\sqrt{s_{NN}}$ [TeV]	7	7	2.76	2.76	2.76
trigger	MB	μ-trigger	MB	μ-trigger	MB
Data-taking	April-Aug 2010	April-Sept 2010	March 2011	March 2011	Nov 2010
N_{events}	100-180 (300) M	130 M	65 M	~9 M	17 M
$\langle L \rangle$ [nb^{-1}]	1.6 (5)	16	1.1	20	2.7 μb^{-1}

Prompt D meson R_{AA}

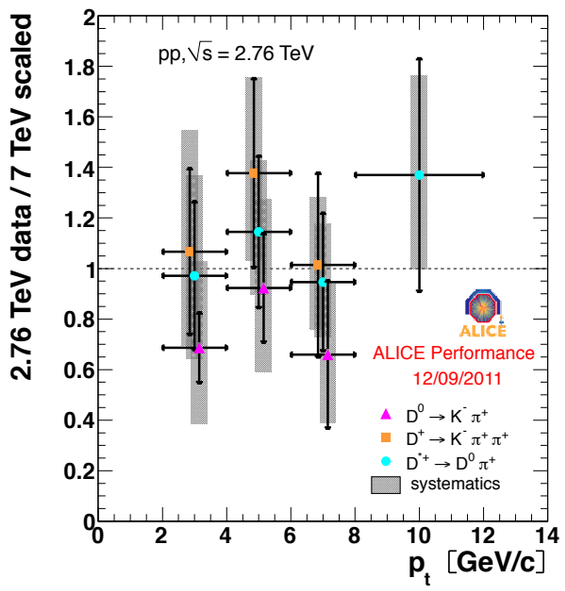
- Analysis details:
  - No reconstruction efficiency (1-10%) centrality dependence found
  - Feed-down subtraction (10-15%) based on pQCD
  - Reference spectra build from an extrapolation of the 7 TeV measurements
  - Centrality determination: Glauber model analysis of large-η V0 scintillator amplitudes (V0A : $2.8 < \eta < 5.1$, V0C : $-3.7 < \eta < -1.7$)

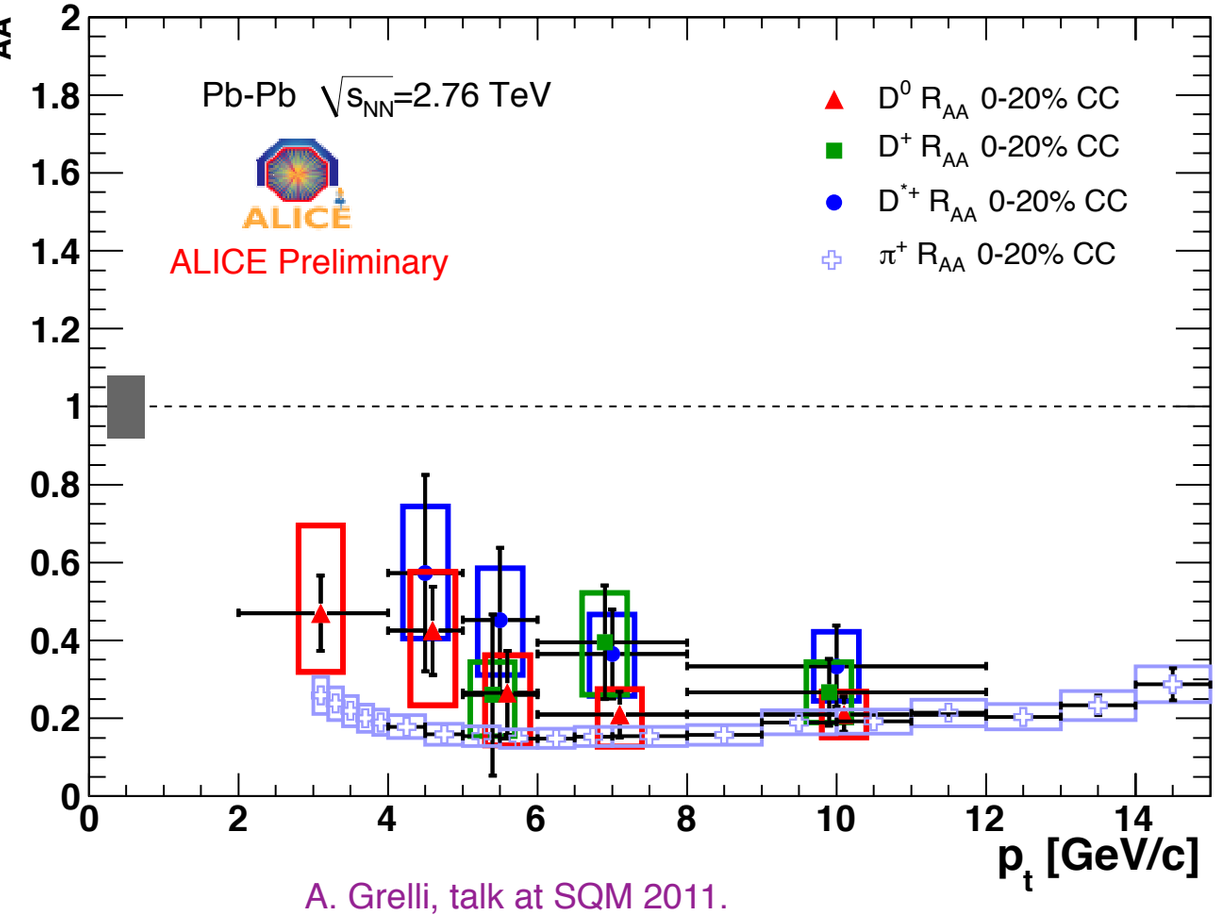
PbPb at 2.76 TeV (MB)

R. Averbeck et al, arXiv:1107.3243 [hep-ph].

pp at 7 TeV (MB)

- R_{AA} (0-20%) shows a suppression of about a factor of 2-5 for $p_t > 5$ GeV/c
- Prompt D meson and $\pi^{\pm}$ R_{AA} are compatible.





A. Grelli, talk at SQM 2011.

ELECTRON R_{AA}

- Consider: Inclusive electrons - cocktail

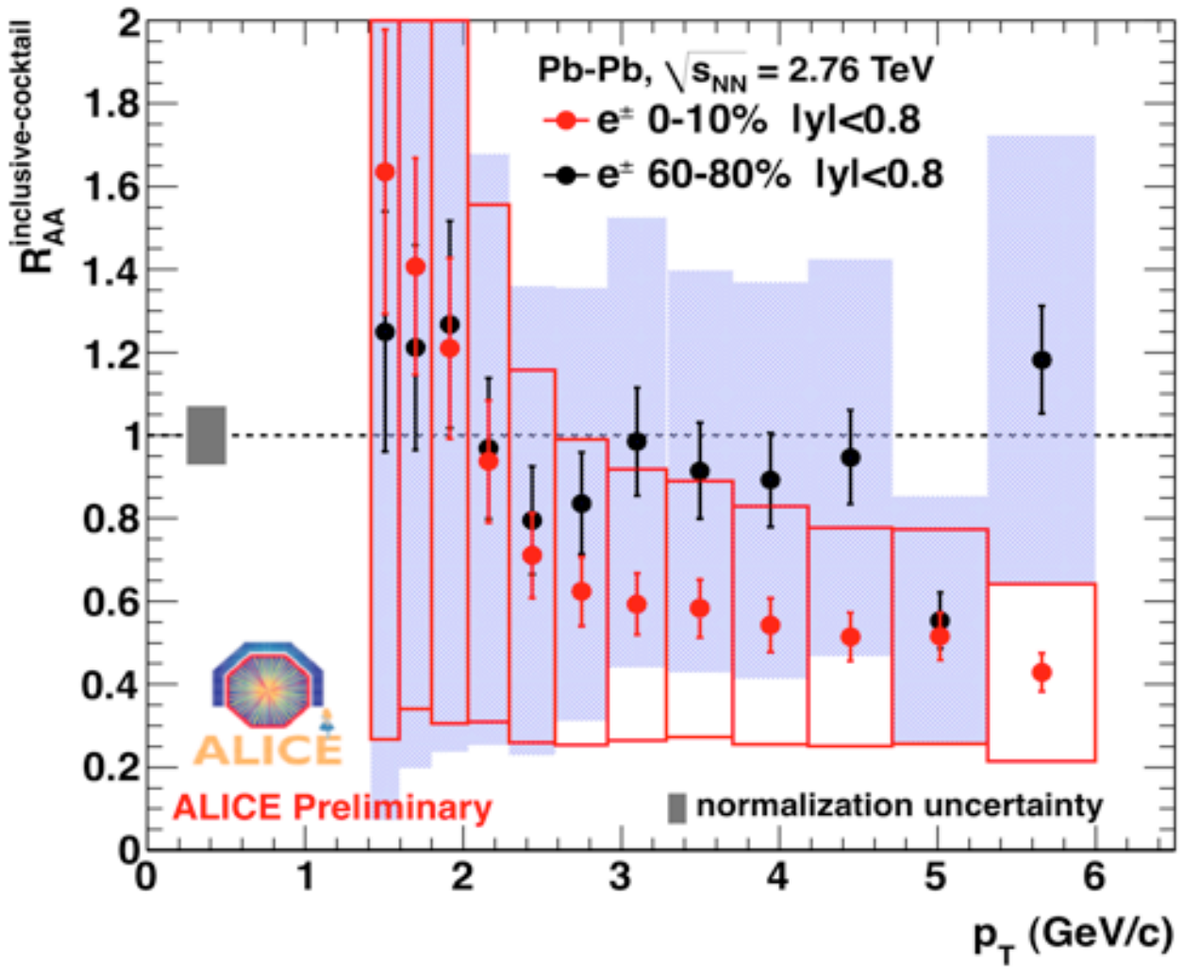
PbPb at 2.76 TeV (MB)

  - Large systematics from the PID, cocktail and the reference spectrum.
  - Spectra dominated by charm and beauty decays above 3-4 GeV/c.
  - Reference build from an extrapolation of the 7 TeV measurements.

pp at 7 TeV (MB)

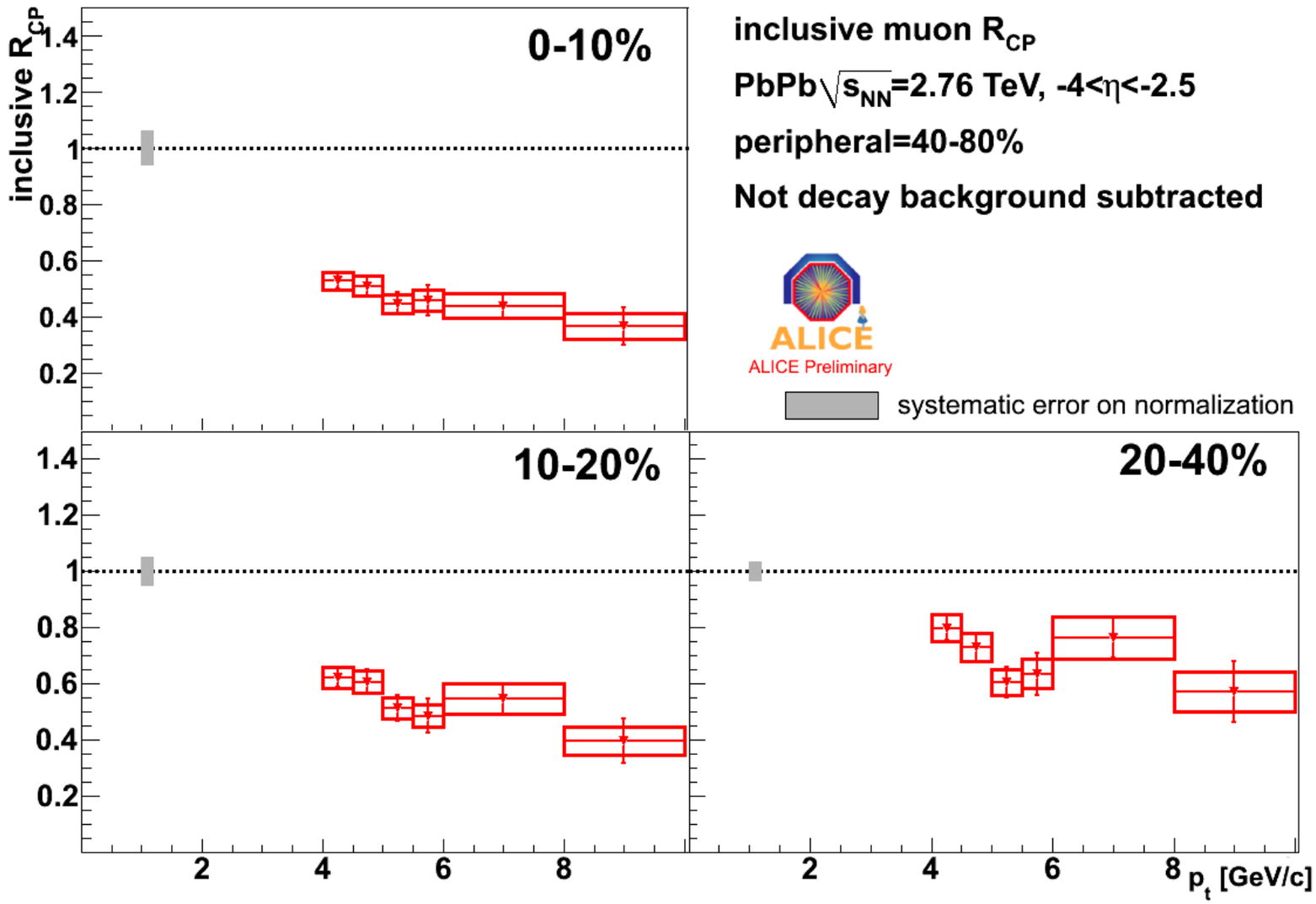
R. Averbeck et al, arXiv:1107.3243 [hep-ph].

- Suppression in central collisions by about 1.5-4.



S. Masciocchi, arXiv: 1109.6436

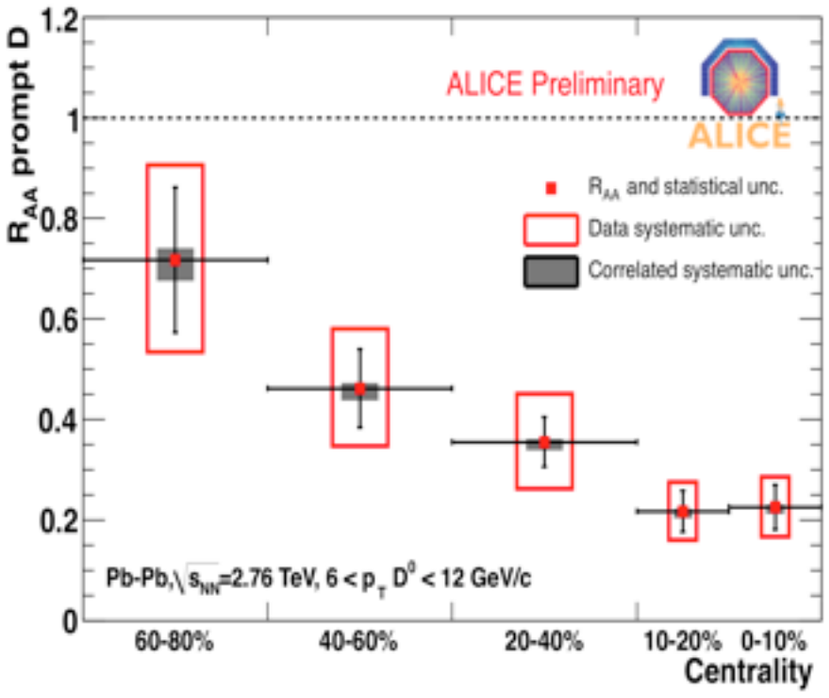
Muon R_{CP}



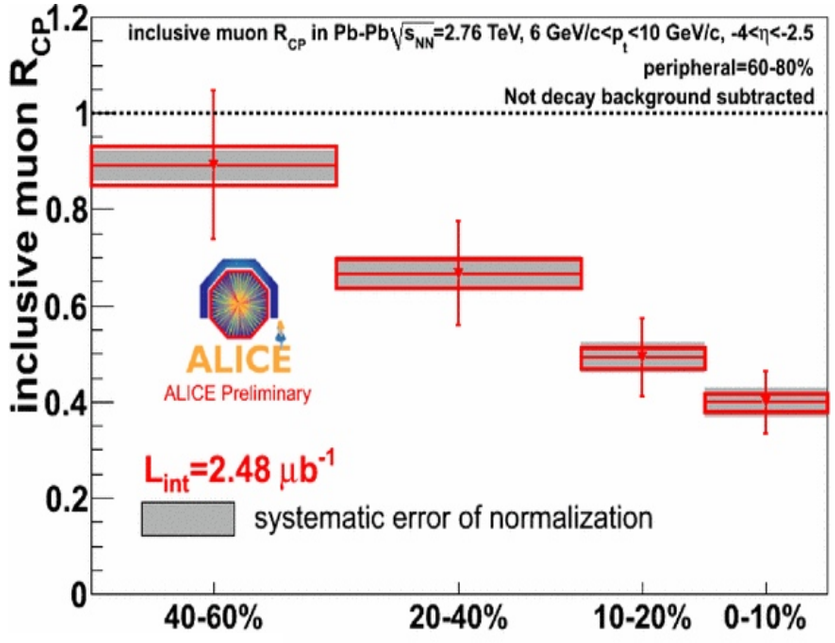
- Consider: inclusive muon spectrum — X.B. Lopez, SQM talk
  - Background from hadronic decays contribution not subtracted
  - Spectra dominated by HF decays for p_t above 4 (>85%) - 6 (>90%) GeV/c
- Suppression in central collisions by about a factor of 2.5

Open HF R_{AA} / R_{CP} Vs Centrality

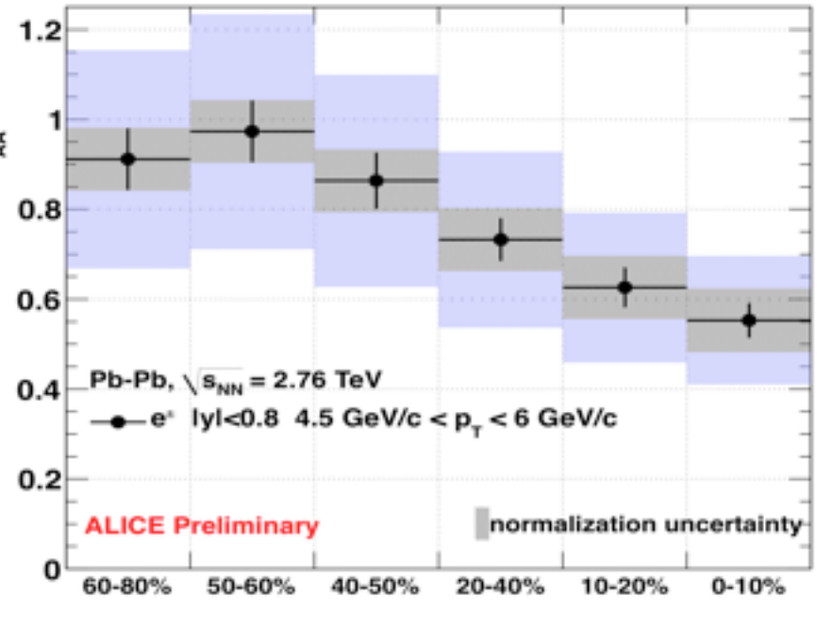
D^0 p_t > 6 GeV/*c*



μ p_t > 6 GeV/*c*



e p_t > 4.5 GeV/*c*



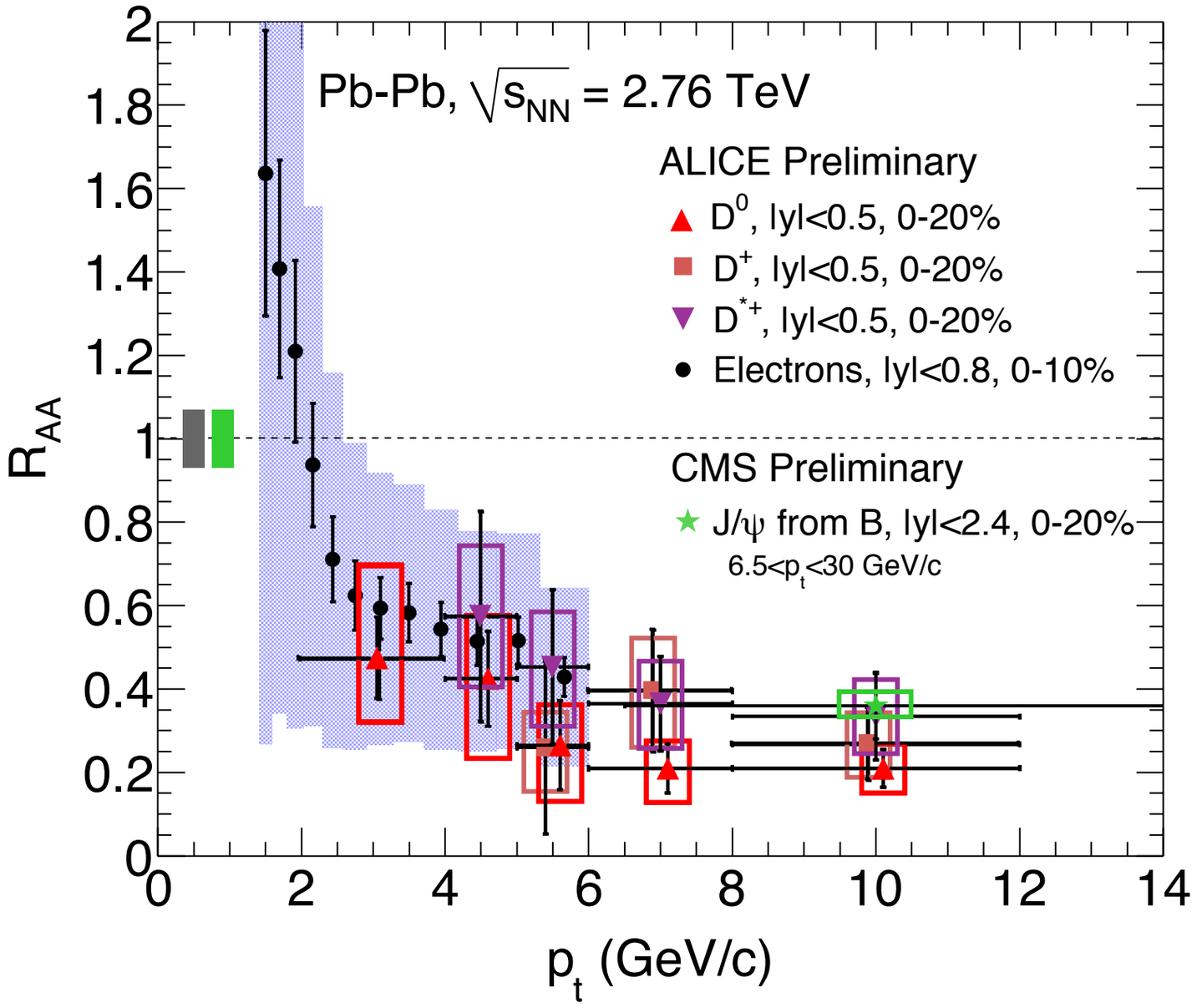
PbPb at 2.76 TeV (MB)

pp at 7 TeV (μ)

pp at 7 TeV (MB)

- Clear centrality dependence for all the probes
- Electron ($|\eta| < 0.8$) and muon ($-4.0 < \eta < -2.5$) R_{AA} / R_{CP} show a similar trend
- Prompt D mesons vs leptons (charm vs beauty?) ?

Compare Open HF R_{AA}



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A. Grelli, talk at SQM 2011.

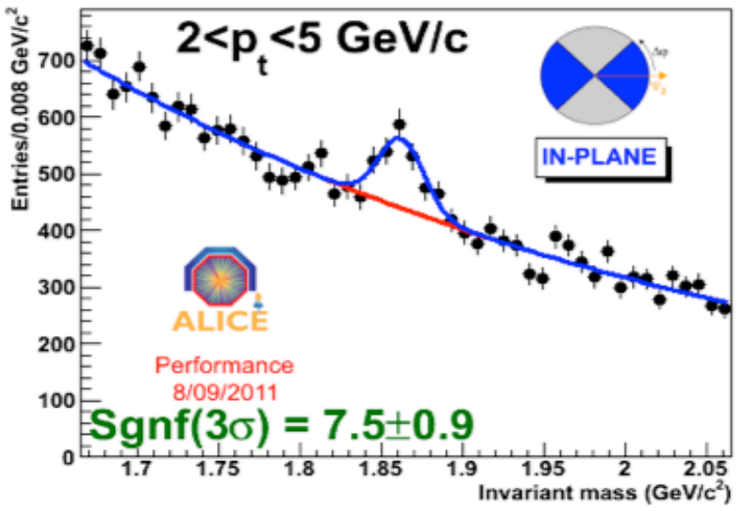
T. Dahms, talk at QM 2011.

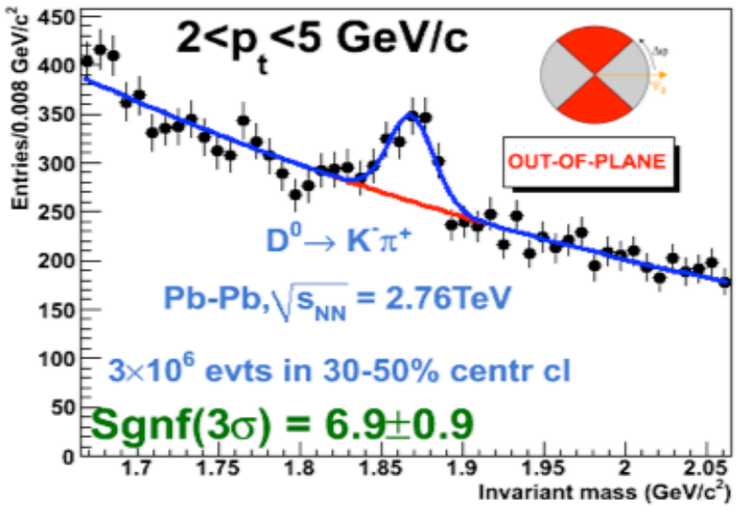
Compilation by A. Dainese

✳ The measurements of open heavy flavor production R_{AA} are consistent

D⁰ Elliptic flow

- First direct measurement of D meson flow in heavy-ion collisions
- Yield extracted from invariant mass spectra of Kπ candidates in 2 bins of azimuthal angle relative to the event plane.





$$v_2 = \frac{\pi}{4}\frac{N_{IN} - N_{OUT}}{N_{IN} + N_{OUT}}$$

C. Bianchin, talk at SQM 2011.

Summary and Outlook

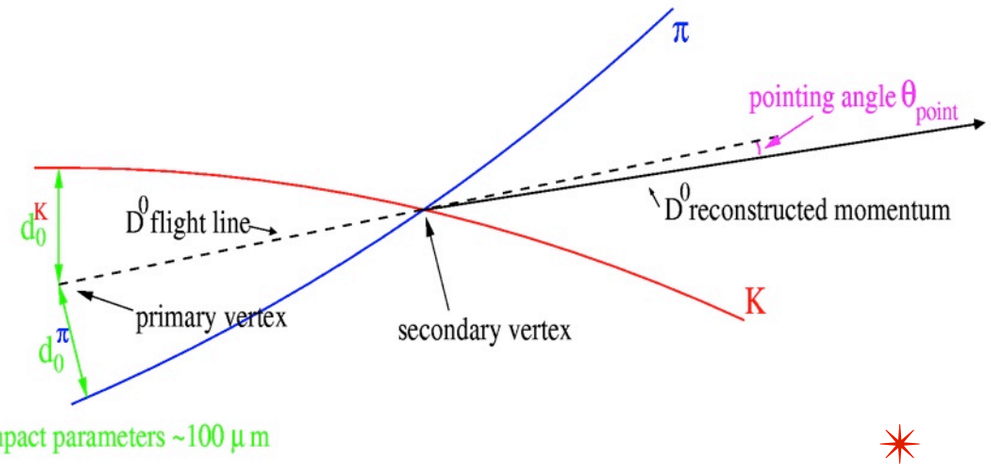
- ALICE has measured the prompt D, HF electrons, HF muon cross sections in pp collisions at 7 TeV (good progress on the 2.76TeV analysis).
- Heavy flavor nuclear modification factor in PbPb collisions at 2.76 TeV has been measured.
  - Data exhibit a clear centrality dependence.
  - HF electrons ($|\eta| < 0.8$) and muons ($-4.0 < \eta < -2.5$) show a suppression of about a factor of 2.5 in the 0-20% CC.
  - Prompt D mesons R_{AA} is suppressed by about a factor of 2-5 in the 0-20%CC.
  - The first measurement of D meson flow has been presented

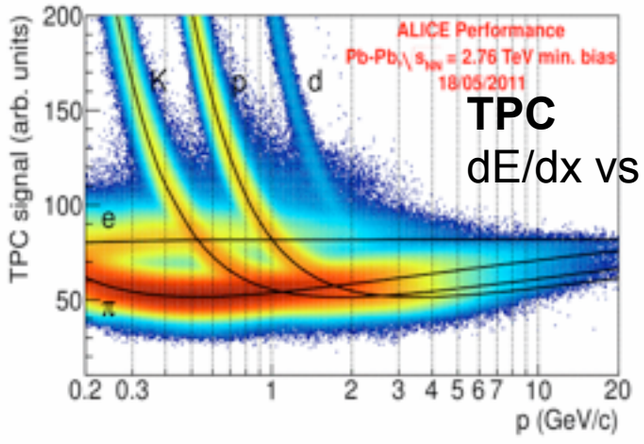
- Refined analysis with the whole statistics... (pp & PbPb)
- Ongoing comparison of particle species R_{AA}
- More data to come in 2011 (pp & PbPb) : b-tagging (?), D-zoology (?),...

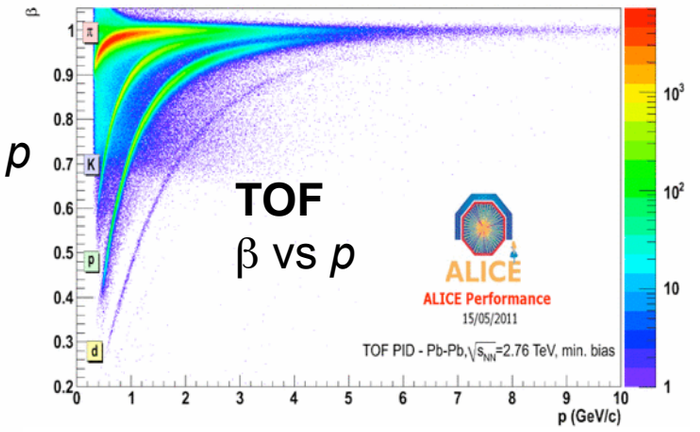
... stay tuned !

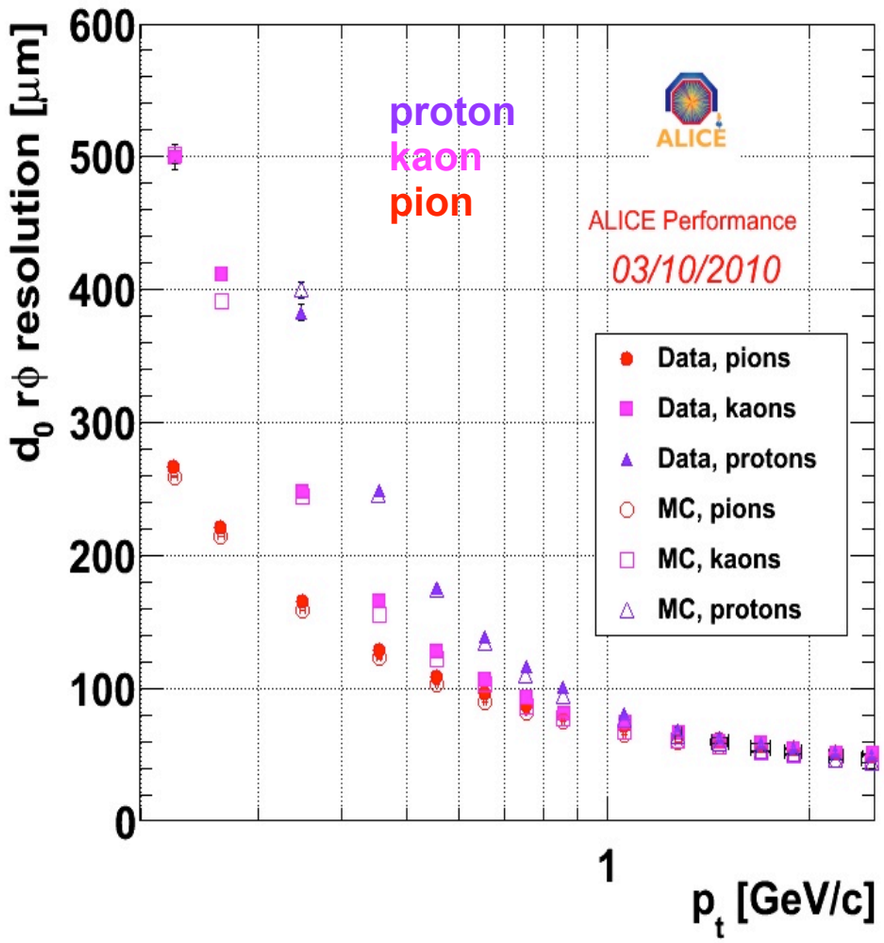
Back Up

D meson reconstruction





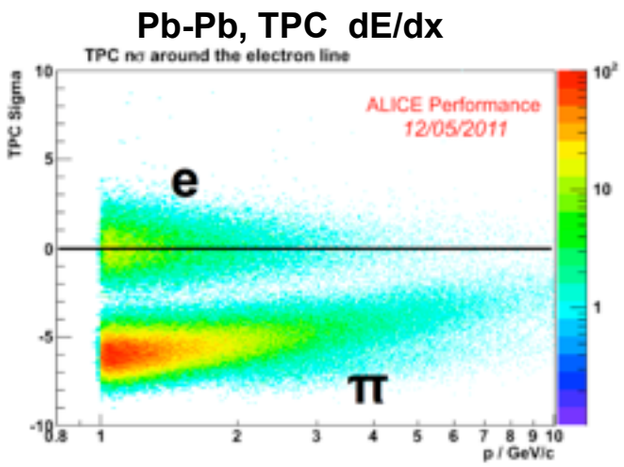


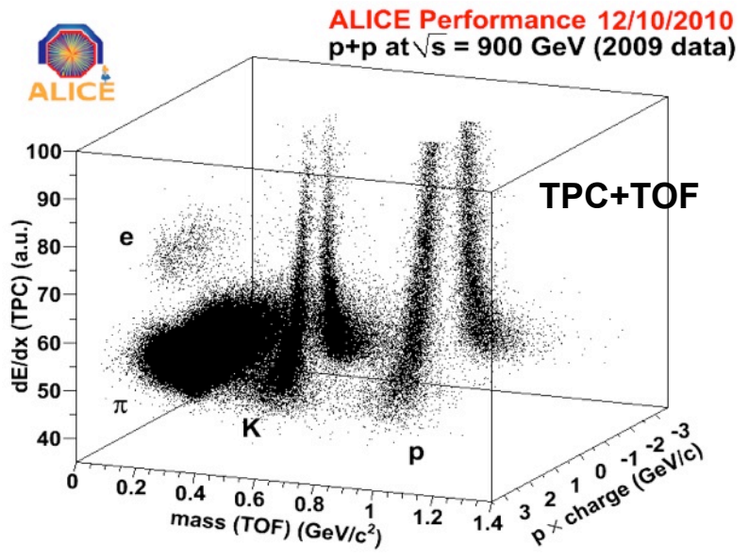


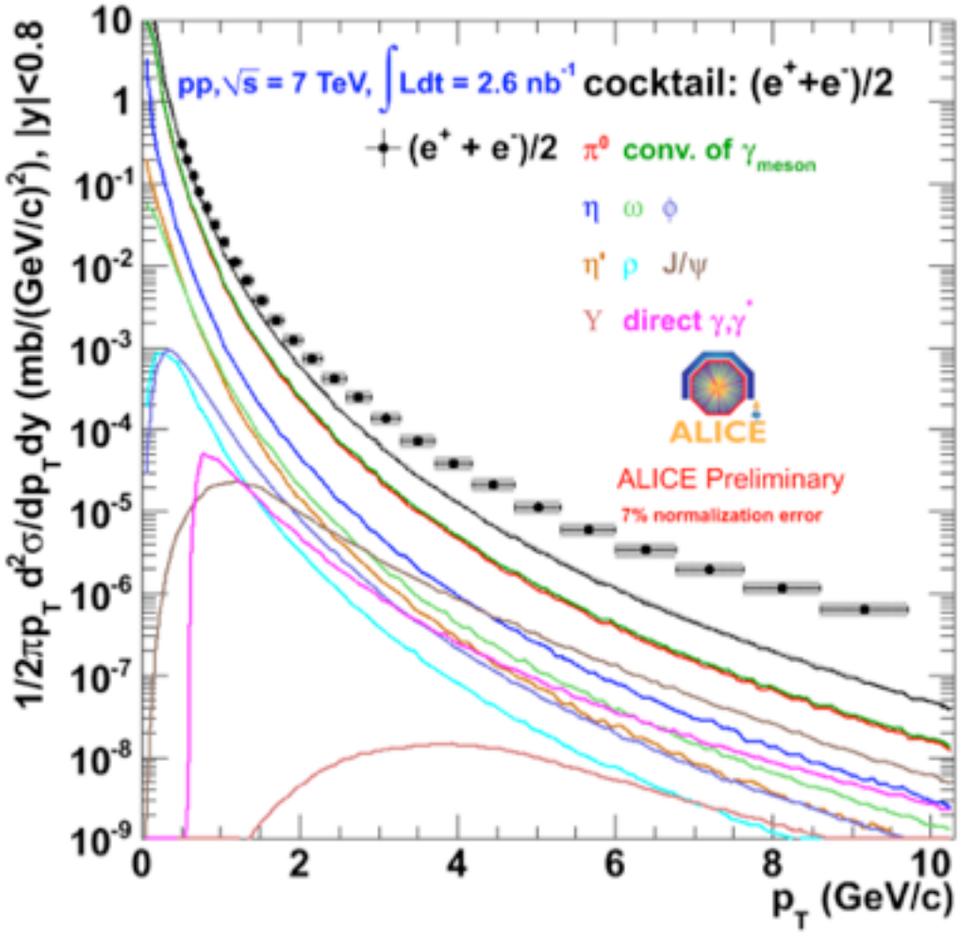
- ✳ Selection strategy: displaced vertexes
- ✳ Main topological cuts:
  - ▸ Impact parameter of the tracks,
  - ▸ Angle between the meson flight line and the particle momentum.
- ✳ Particle identification: K identification thanks to the TPC+TOF helps to reject background at low p_t
  - ▸ TPC allows K/π separation up to ~0.6 GeV/c,
  - ▸ TOF allows K/π separation up to ~2 GeV/c.
- ✳ pQCD (FONLL) driven feed-down subtraction for the moment.

Heavy flavor decay Electrons

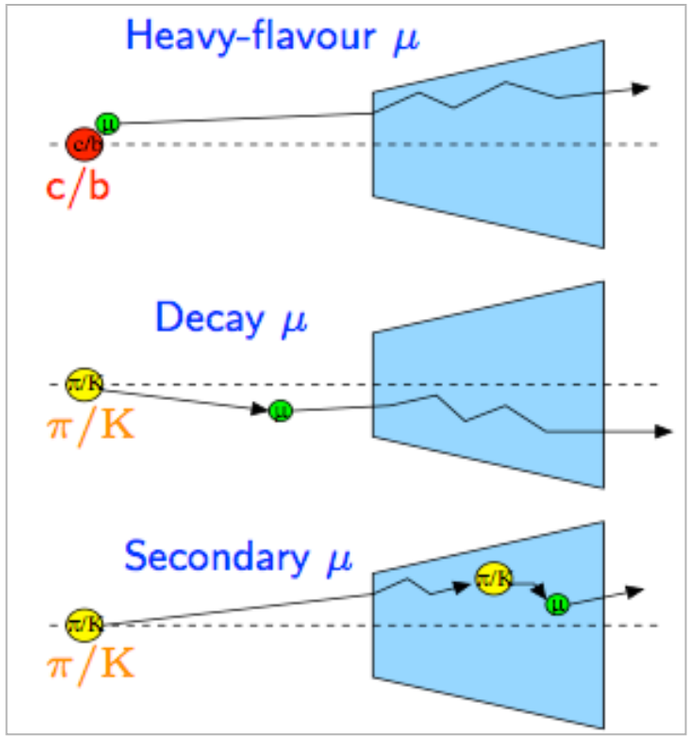
- High quality tracks
  - Hit in the innermost ITS layer to reduce the conversions
- Electron identification
  - TOF to reject K, p
  - TPC dE/dx
  - TRD (+EMCAL) in pp collisions for now.
  - hadron contamination measured fitting the TPC dE/dx in P slices
- HowTo disentangle heavy flavor
  - Cocktail of the non-heavy flavor sources.
  - Select displaced electrons (b-tagging, cτ~500μm) in pp collisions for the moment.

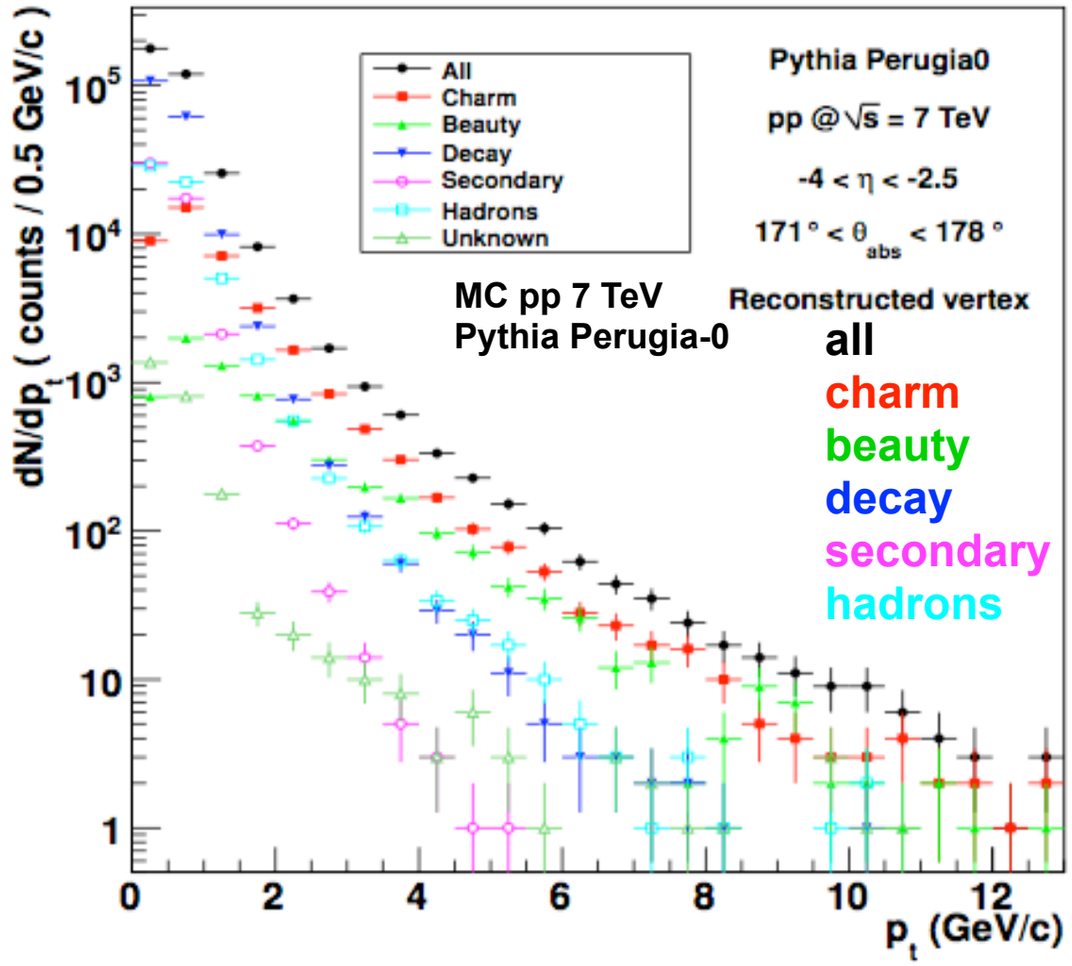






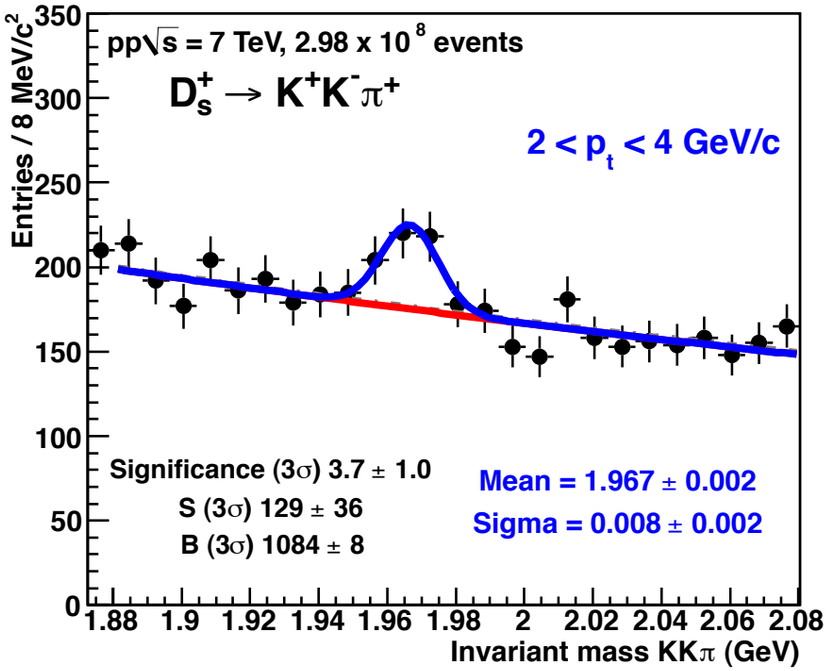
Heavy flavor decay Muons

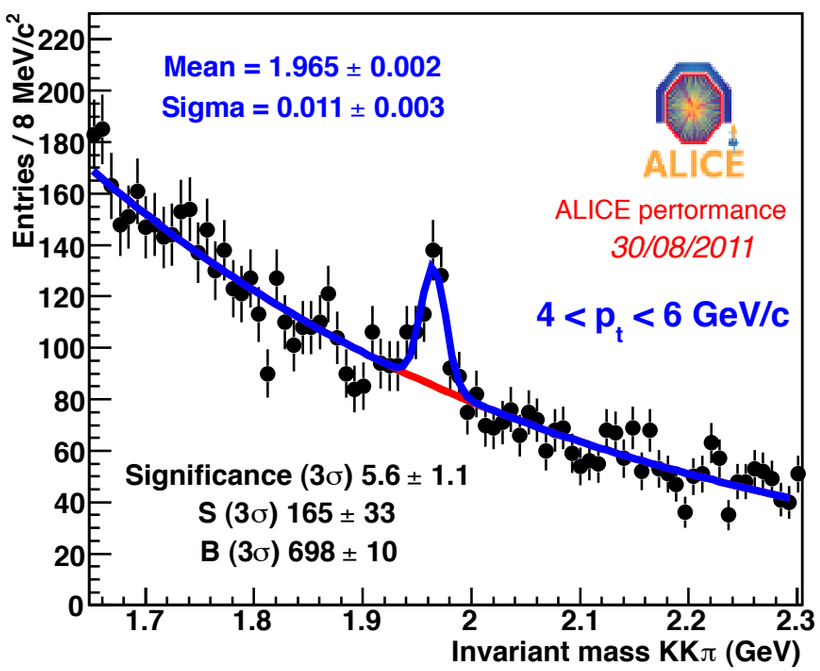


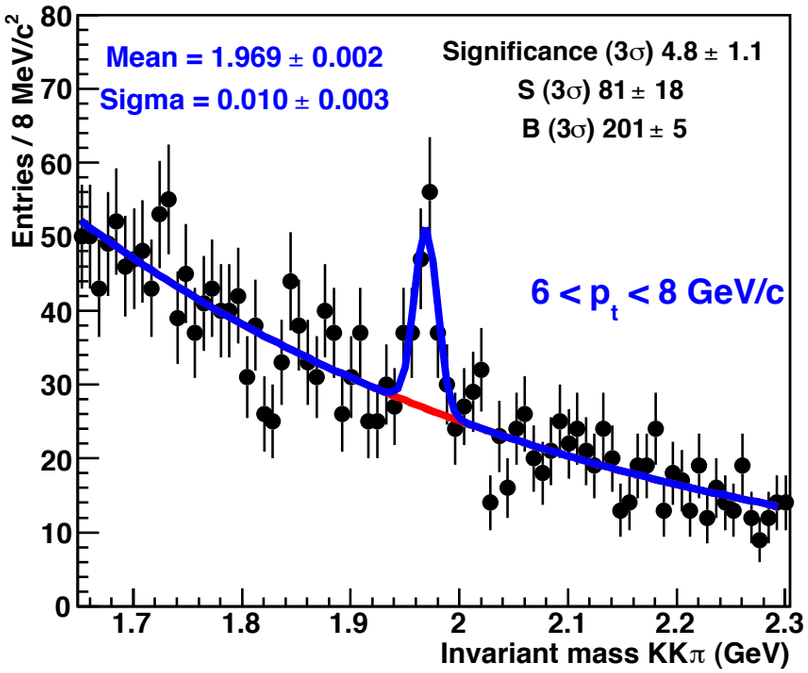


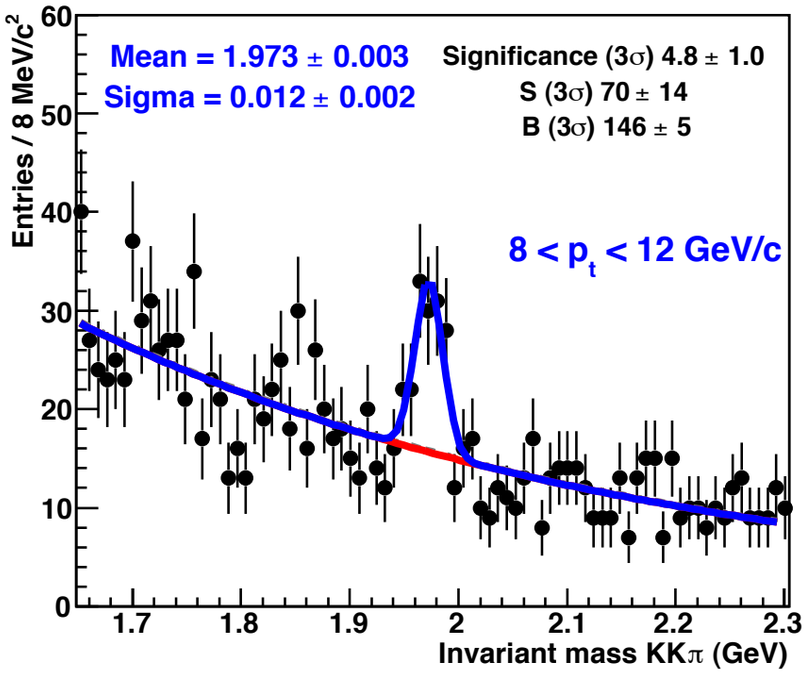
- Remove hadrons and low pt secondary muons by requiring a muon trigger signal plus a cut on the DCA
- Subtract decay muons by subtracting MC dN/dp_t normalized to data at low p_t
- In Pb-Pb, we don't subtract the decay muons for now, but restrict the analysis to the high p_t region where the background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

Ex: D_s invariant mass in pp

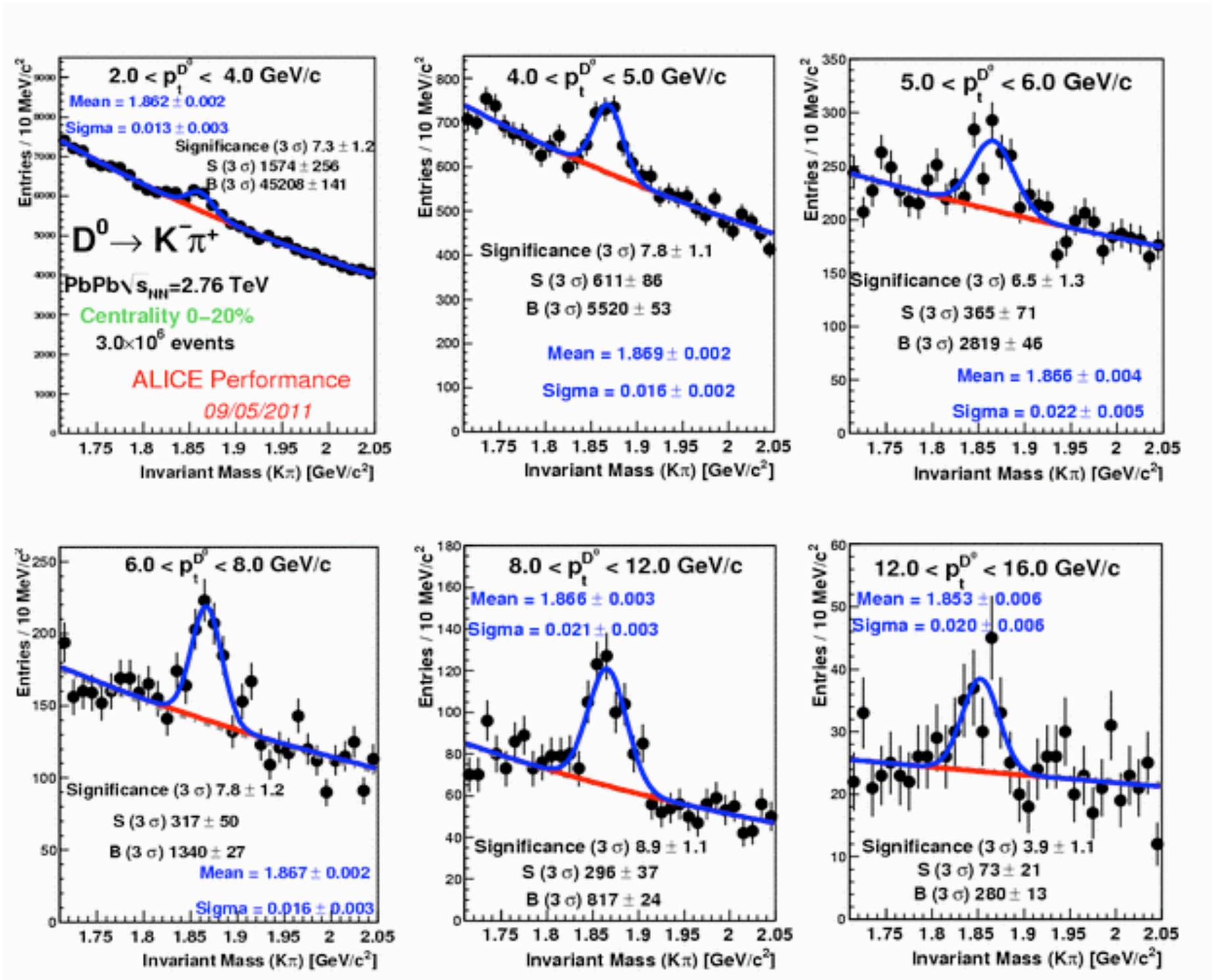








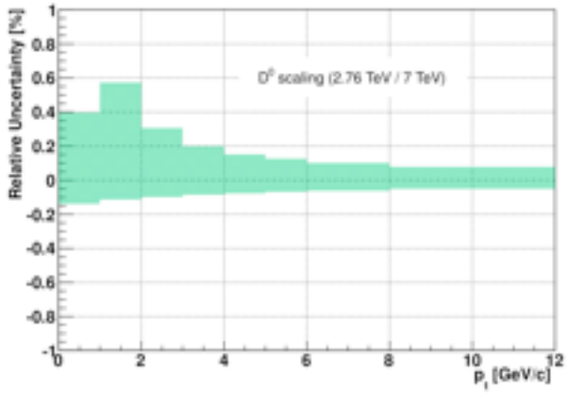
Ex: D^0 invariant mass 0-20%CC



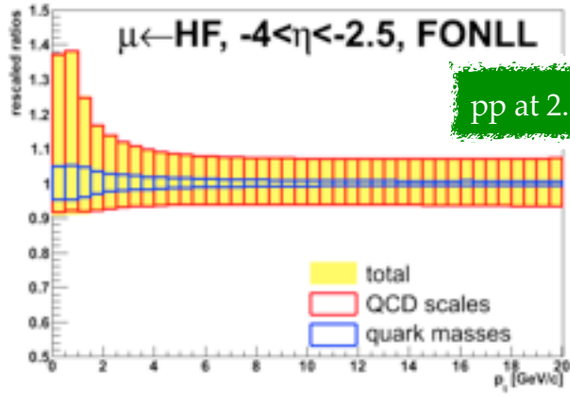
The Reference at 2.76 TeV

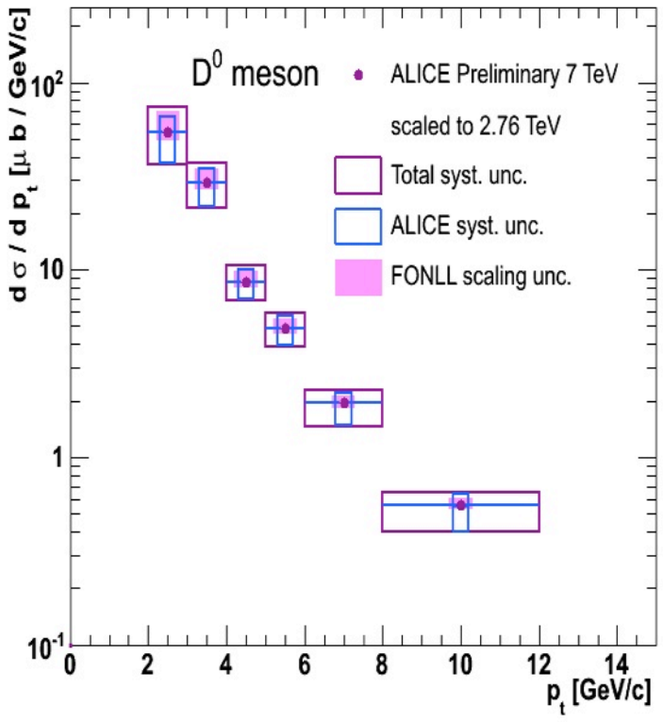
- Scale the 7 TeV measurements with the pQCD (FONLL) 2.76/7 factor
  - Consider that the calculation scales don't evolve with $\sqrt{s}$
  - Uncertainties range from 25% (low-p_t) to 10% (high-p_t)

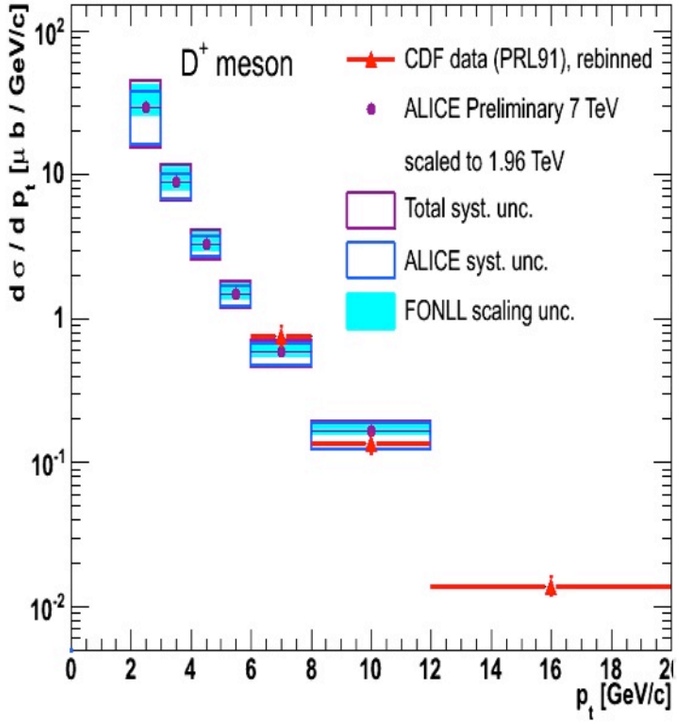
R. Averbeck et al, arXiv:1107.3243 [hep-ph].

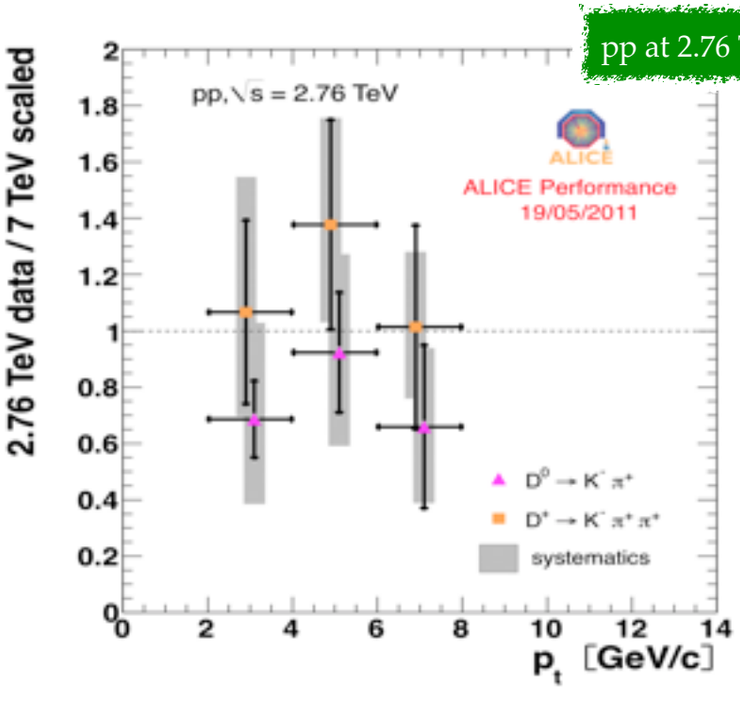


- Scaling procedure validation:
  - Compare different calculations (MNR, GM-VFNS,...)
  - CDF measurements at 1.96 TeV
  - ALICE data at 2.76 TeV for 2 < p_t < 8 GeV/c







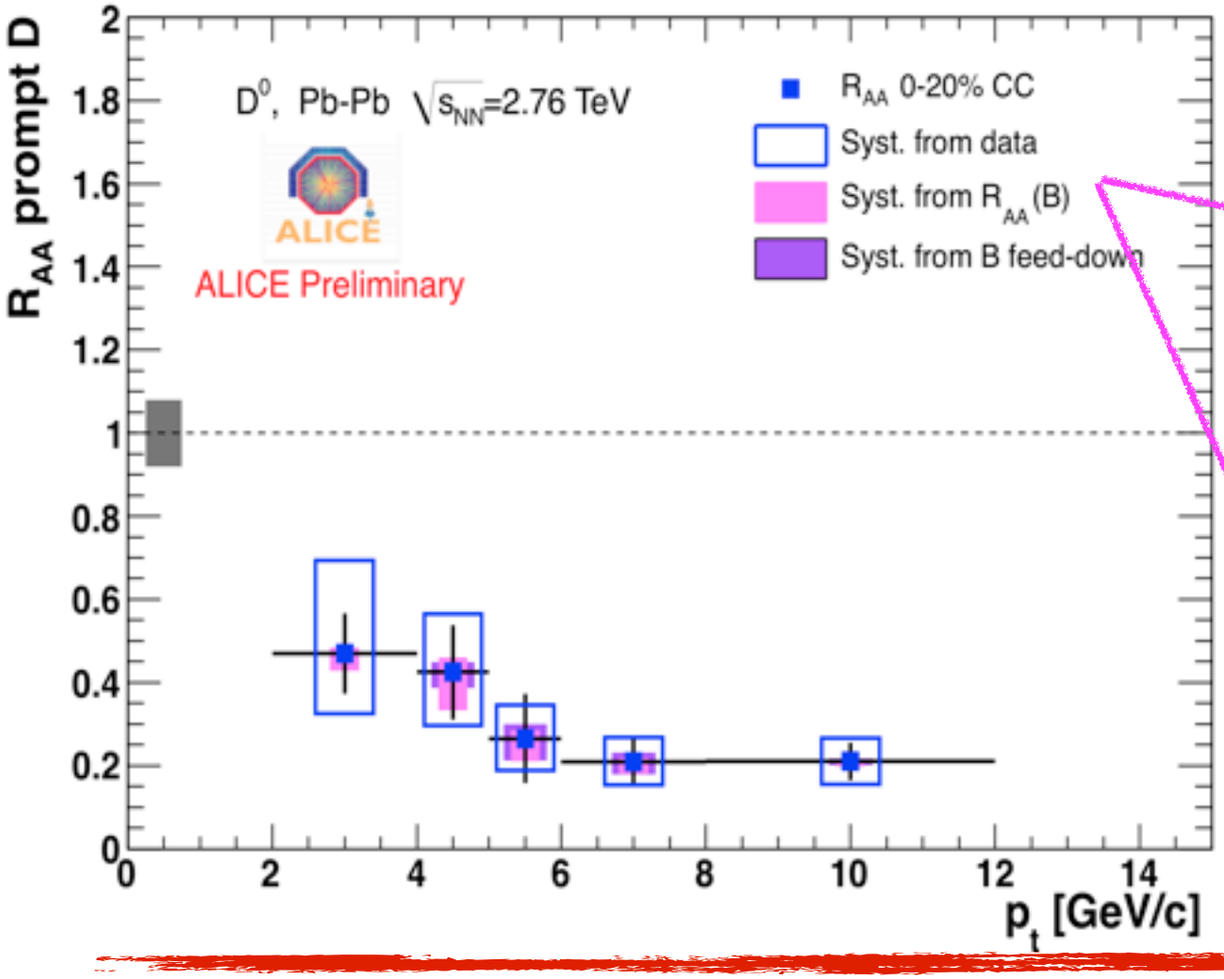


Insight: Uncertainties on Prompt D

- **Data systematics:**
  - signal extraction, reconstruction and cuts efficiency,...
- **Feed-down subtraction in PbPb:**

$$-\left\langle T_{AA} \right\rangle \times \varepsilon^{MC}_{DfromB} \times \frac{d\sigma^{FONLL}_{DfromB}}{dp_t} \times R^{B}_{AA}$$

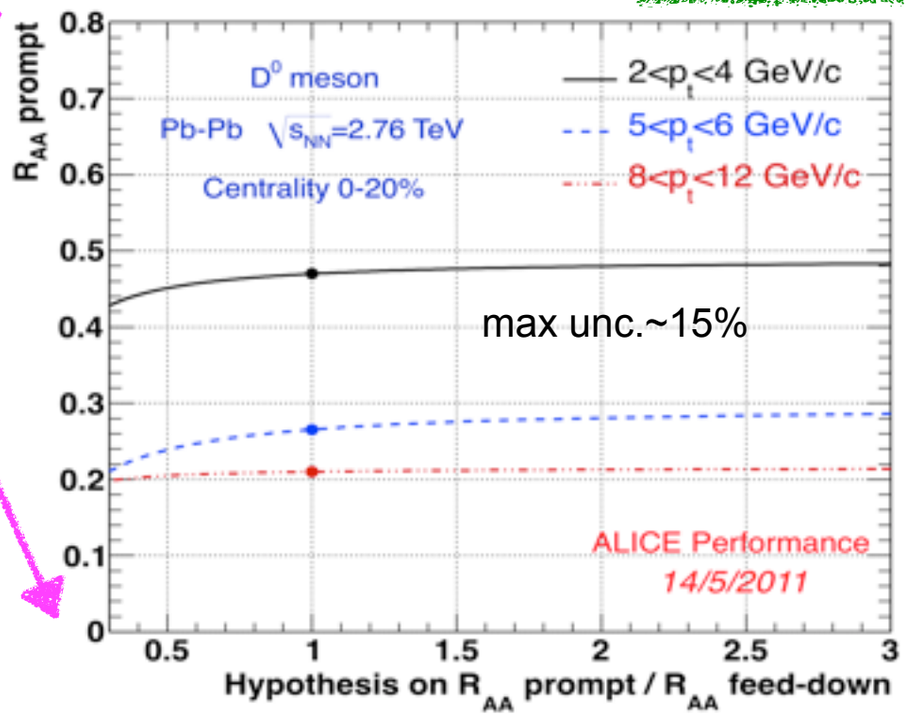
  - Based on the FONLL B predictions corrected by the efficiencies
  - Systematics from FONLL uncertainties partly cancel on the R_{AA}
  - Hypothesis on the b → D energy loss : $0.3 < R_c(c \to D) / R_b(b \to D) < 3.0$



PbPb at 2.76 TeV (MB)

pp at 7 TeV (MB)

pp at 2.76 TeV (μ)



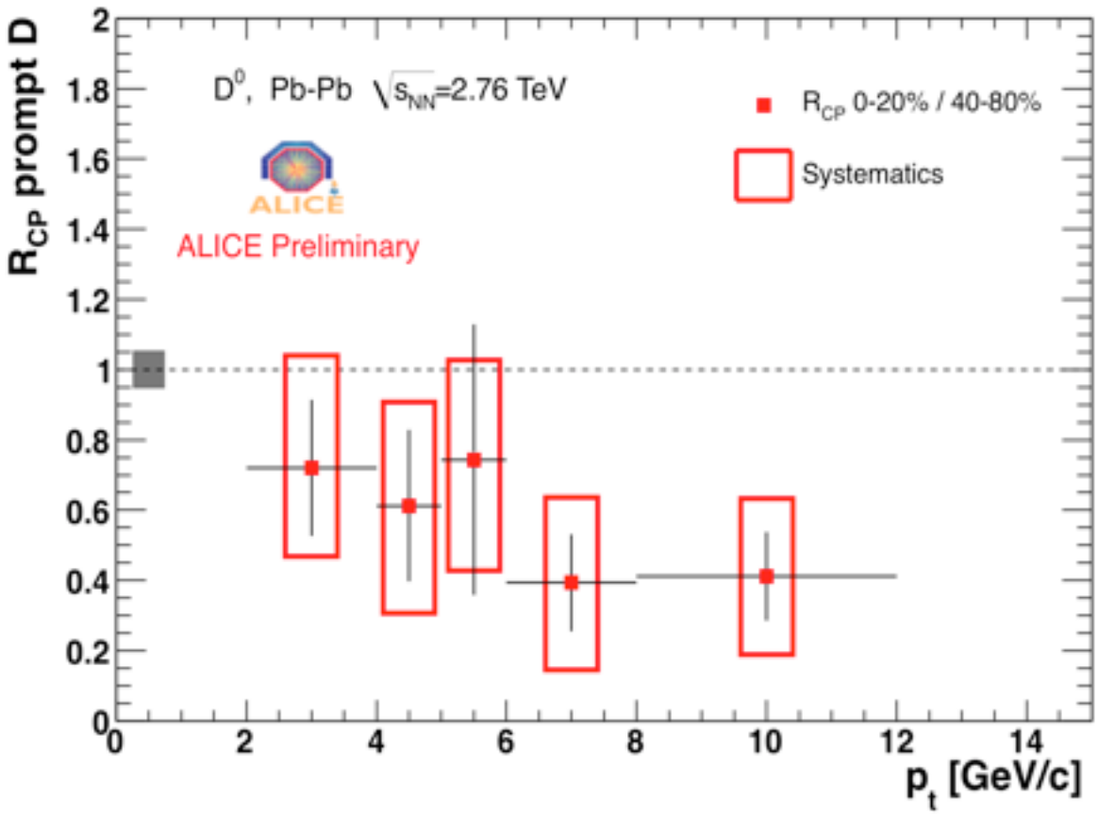
Prompt D meson R_{CP}

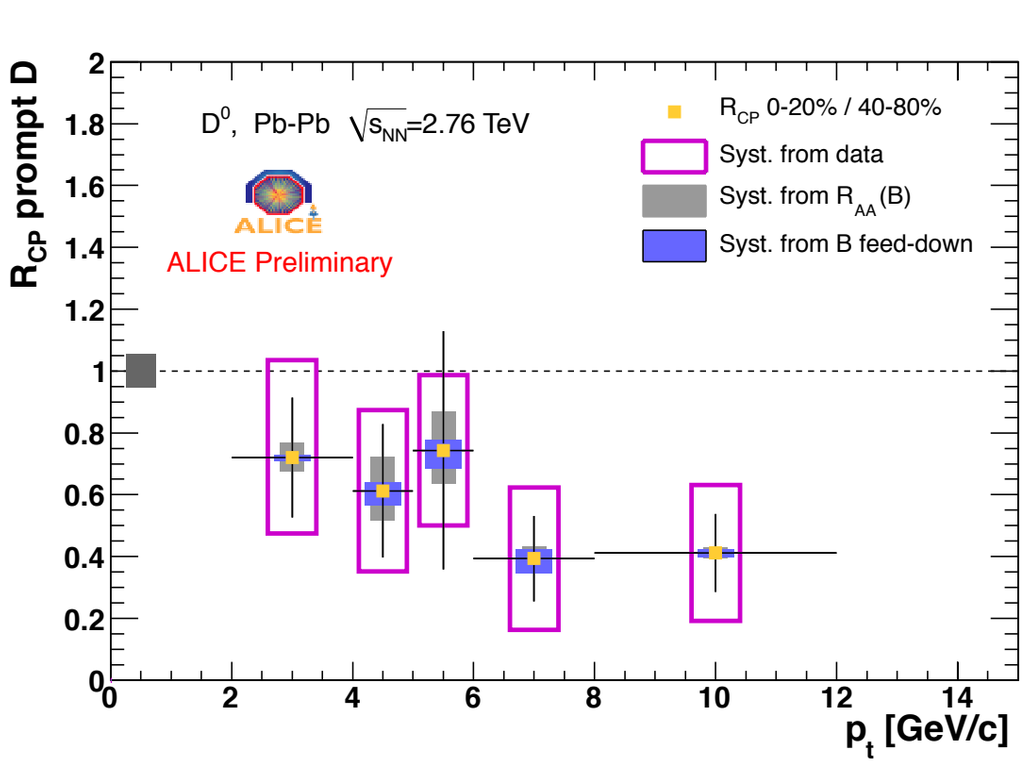
- Analysis details:
  - D^0 and D^+ spectrum in 2-12 and 5-12 GeV/c respectively
  - No reconstruction efficiency (1-10%) centrality dependence found
  - Feed-down subtraction (10-15%) based on pQCD
  - Reference spectra build from an extrapolation of the 7 TeV measurements

PbPb at 2.76 TeV (MB)

pp at 7 TeV (MB)

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



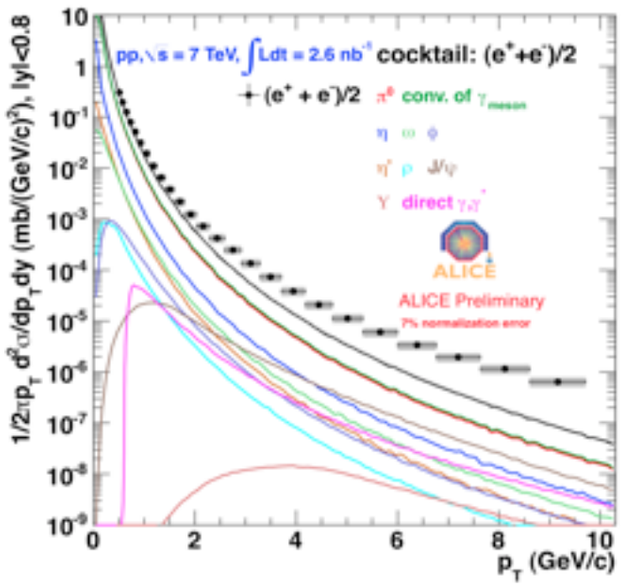


HF electrons vs Cocktail

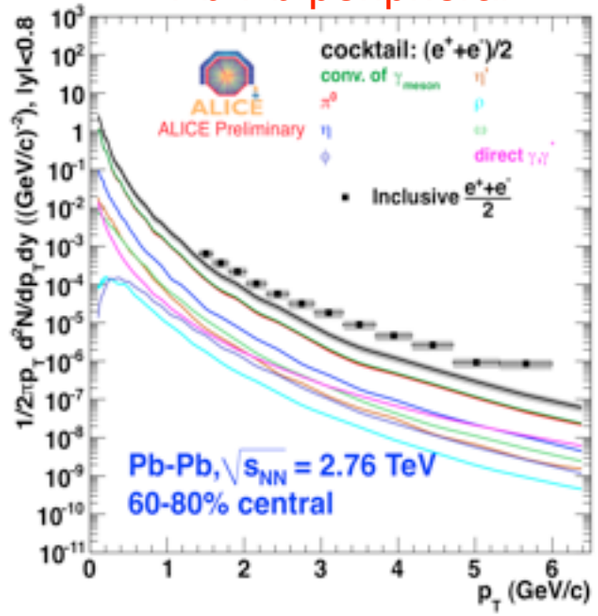
pp at 7 TeV (MB)

PbPb at 2.76 TeV (MB)

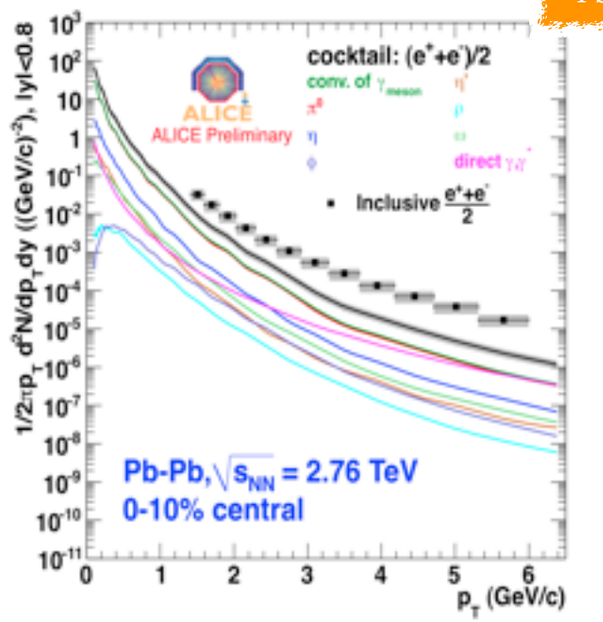
pp

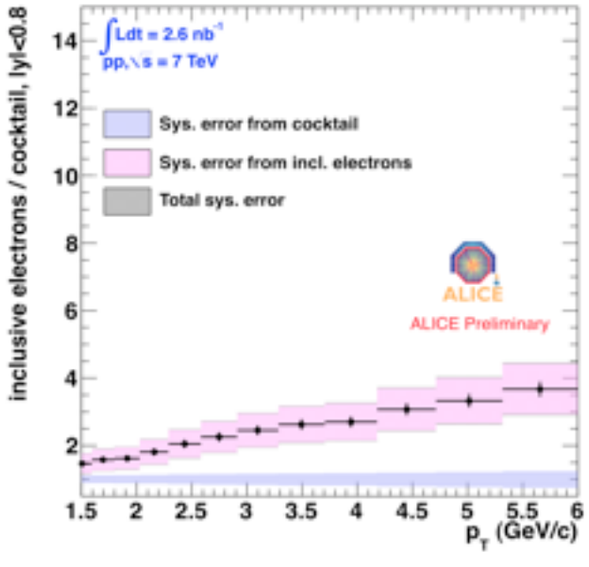


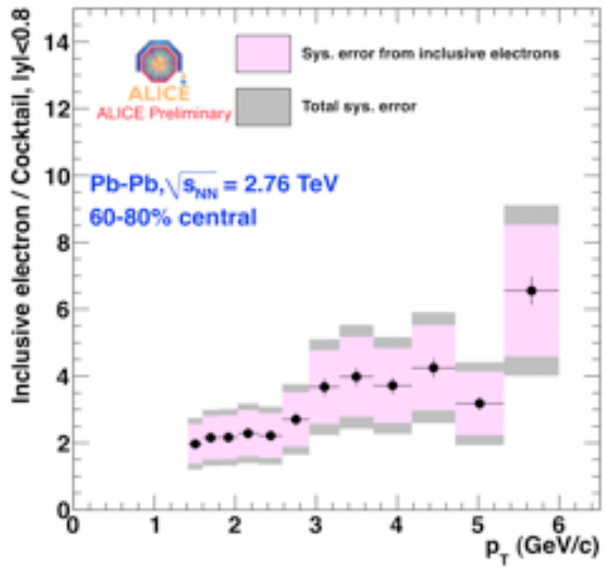
Pb-Pb peripheral

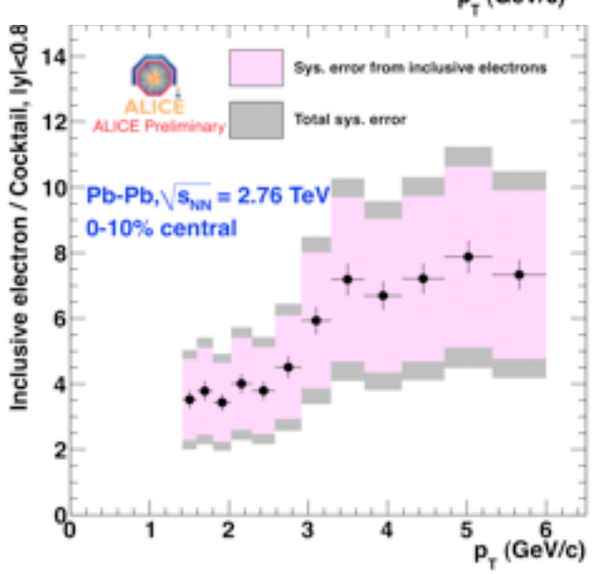


Pb-Pb central









- 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).