Beauty and beauty-jet measurement via displaced vertices with ALICE in p+p collisions at $\sqrt{s}$ = 7 TeV

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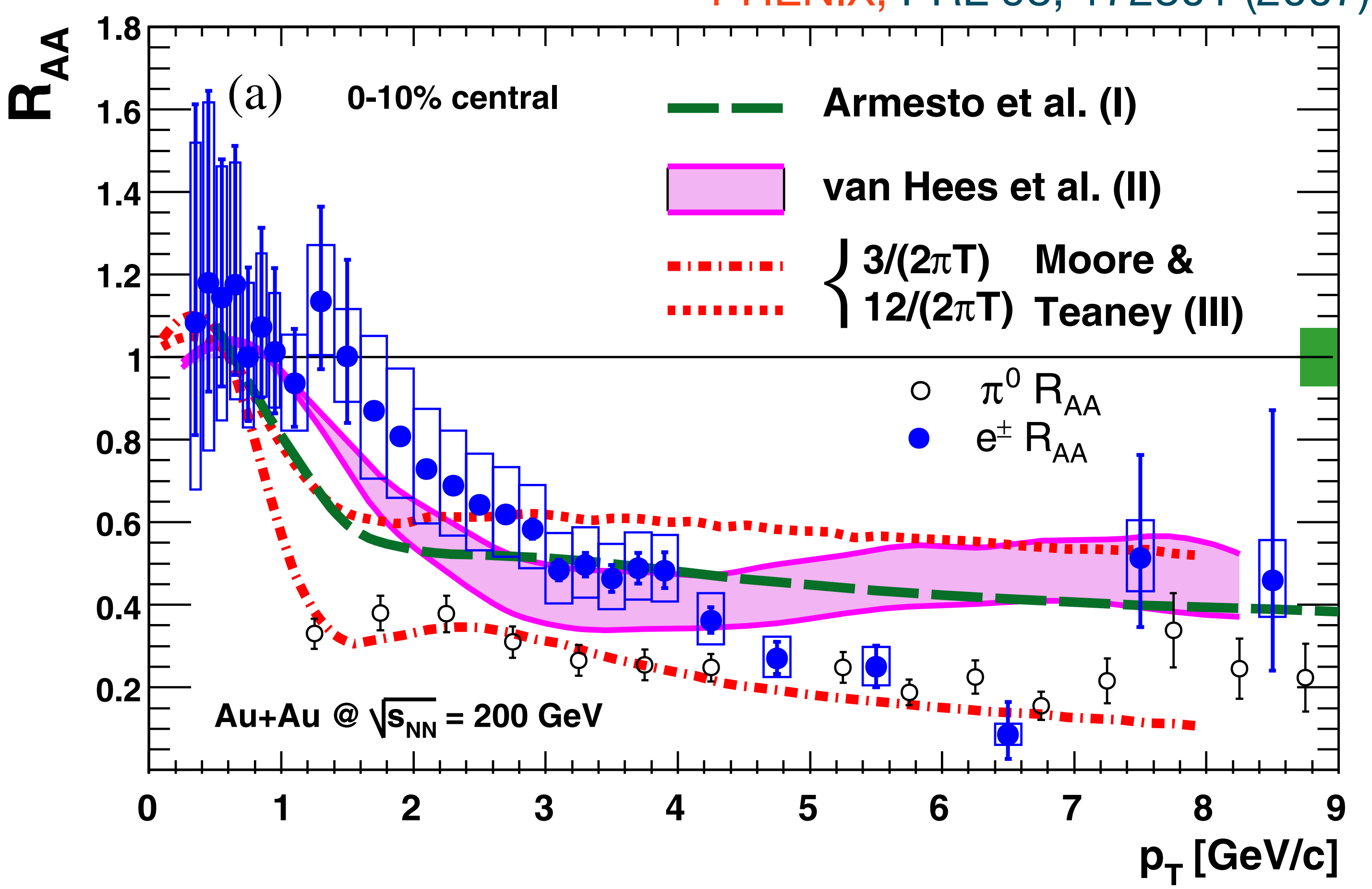
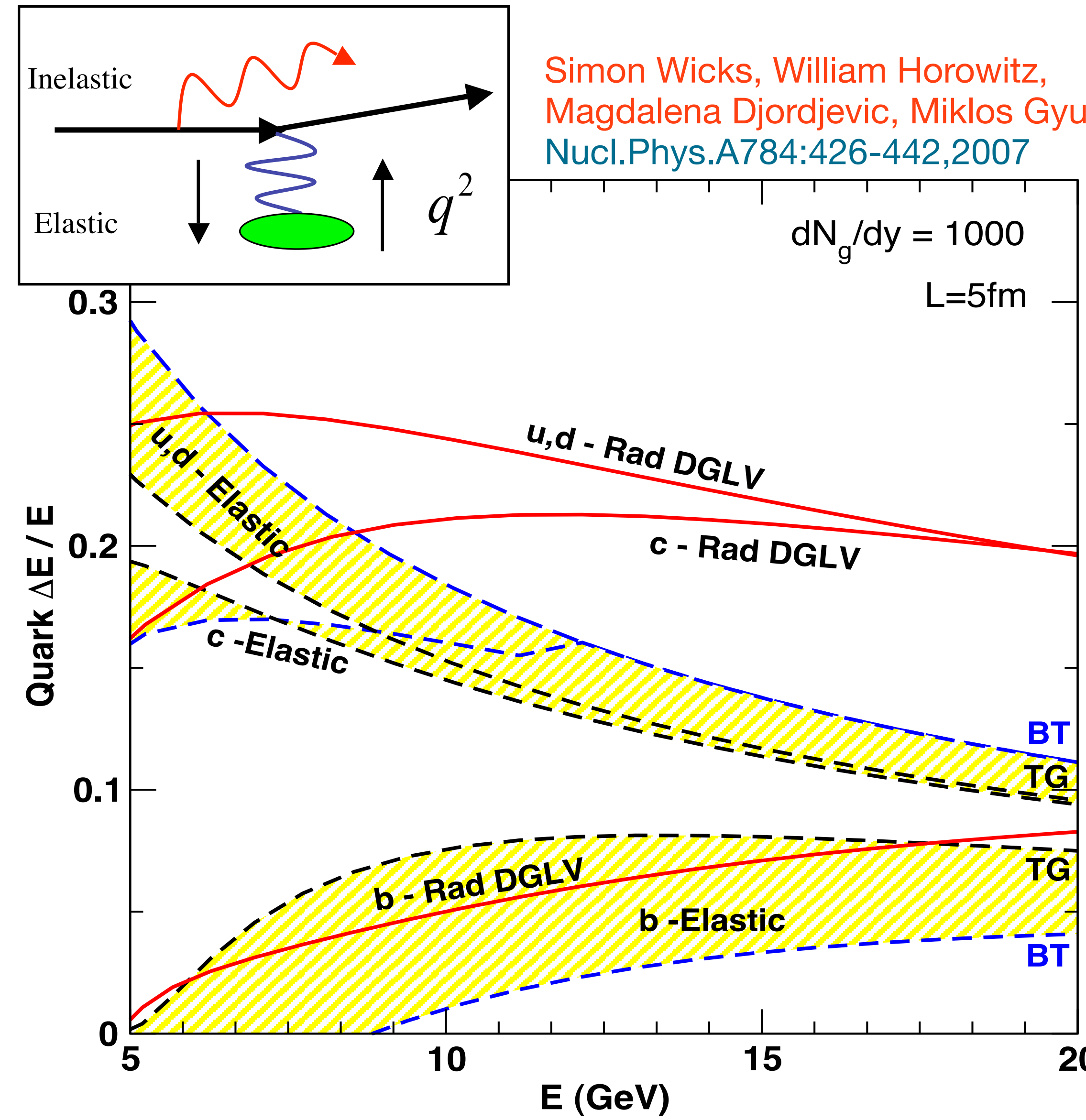
Heavy quark energy loss at RHIC via heavy-flavour electrons

$$R_{AA}(p_T) = \frac{1}{\langle N_{coll} \rangle} \frac{dN_{AA}/dp_T}{dN_{pp}/dp_T}$$

PHENIX, PRL 98, 172301 (2007)



Simon Wicks, William Horowitz, Magdalena Djordjevic, Miklos Gyulassy, Nucl.Phys.A784:426-442,2007



R_{AA} of the heavy-flavour electrons approaches the π^0 value for $p_T > 4$ GeV/c

→ Indicate strong coupling of heavy quarks to the medium (larger than expected)

⇒ additional energy loss mechanism required?

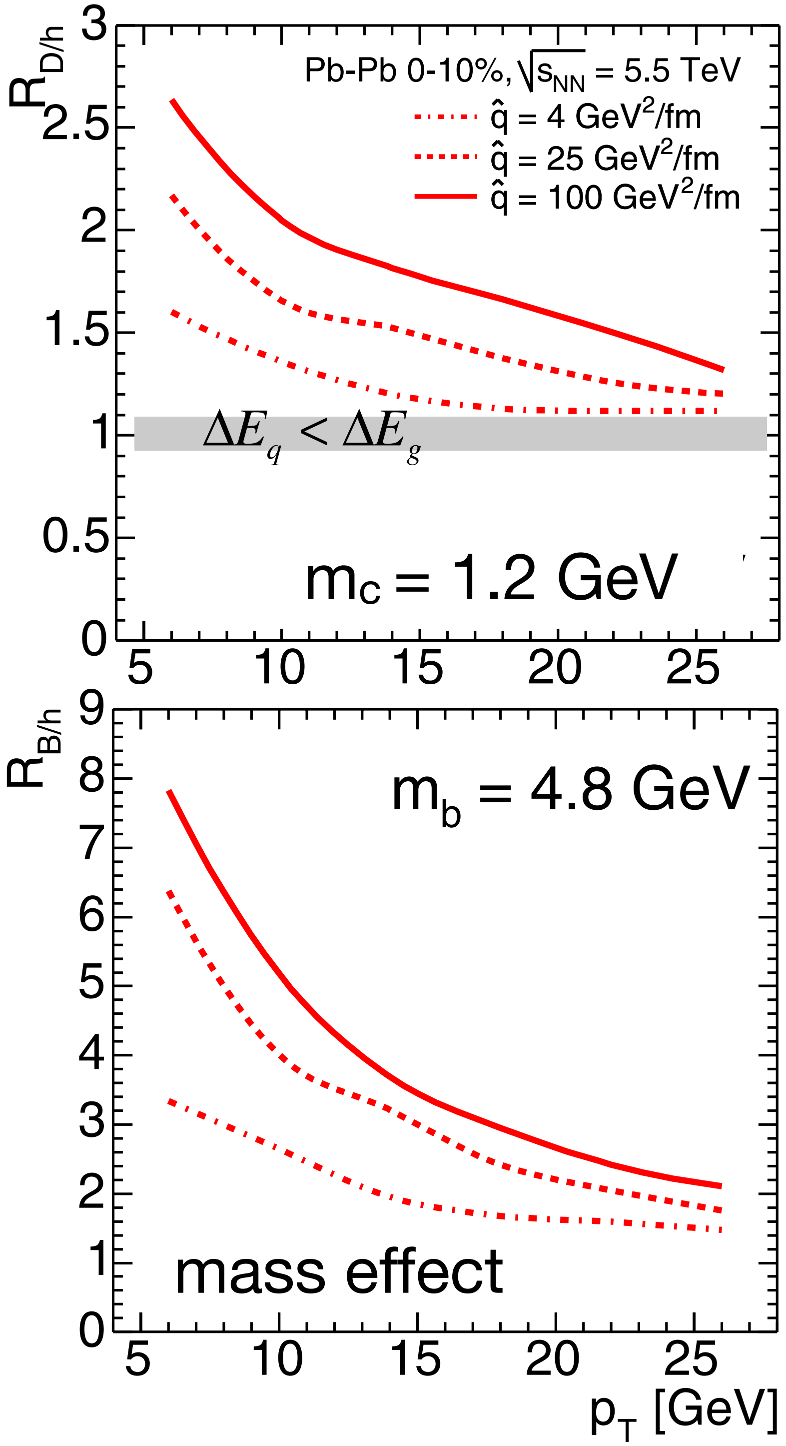
⇒ role of individual D, B meson contribution?

What do we learn more at the LHC?

Heavy-to-light ratios: $R_{D(B)/h}(p_T) = R_{AA}^{D(B)}(p_t) \,/\, R_{AA}^{h}(p_t)$

Compare g→h, c→D and b→B

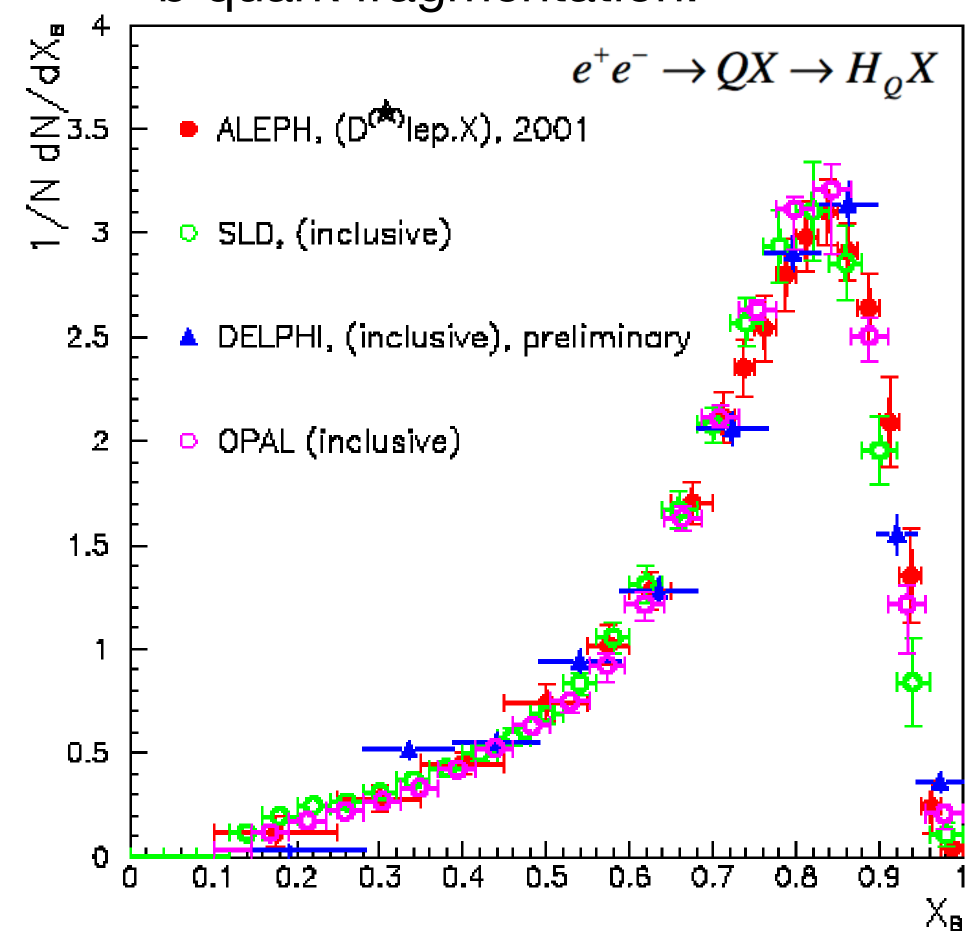
(Light flavour hadrons come mainly from gluons)



Armesto, Dainese, Salgado, Wiedemann, PRD 71 (2005) 054027.

- $R_{D/h}$ enhancement probes colour-charge dependence of energy loss
- $R_{B/h}$ enhancement probes mass dependence of energy loss

b quark fragmentation:



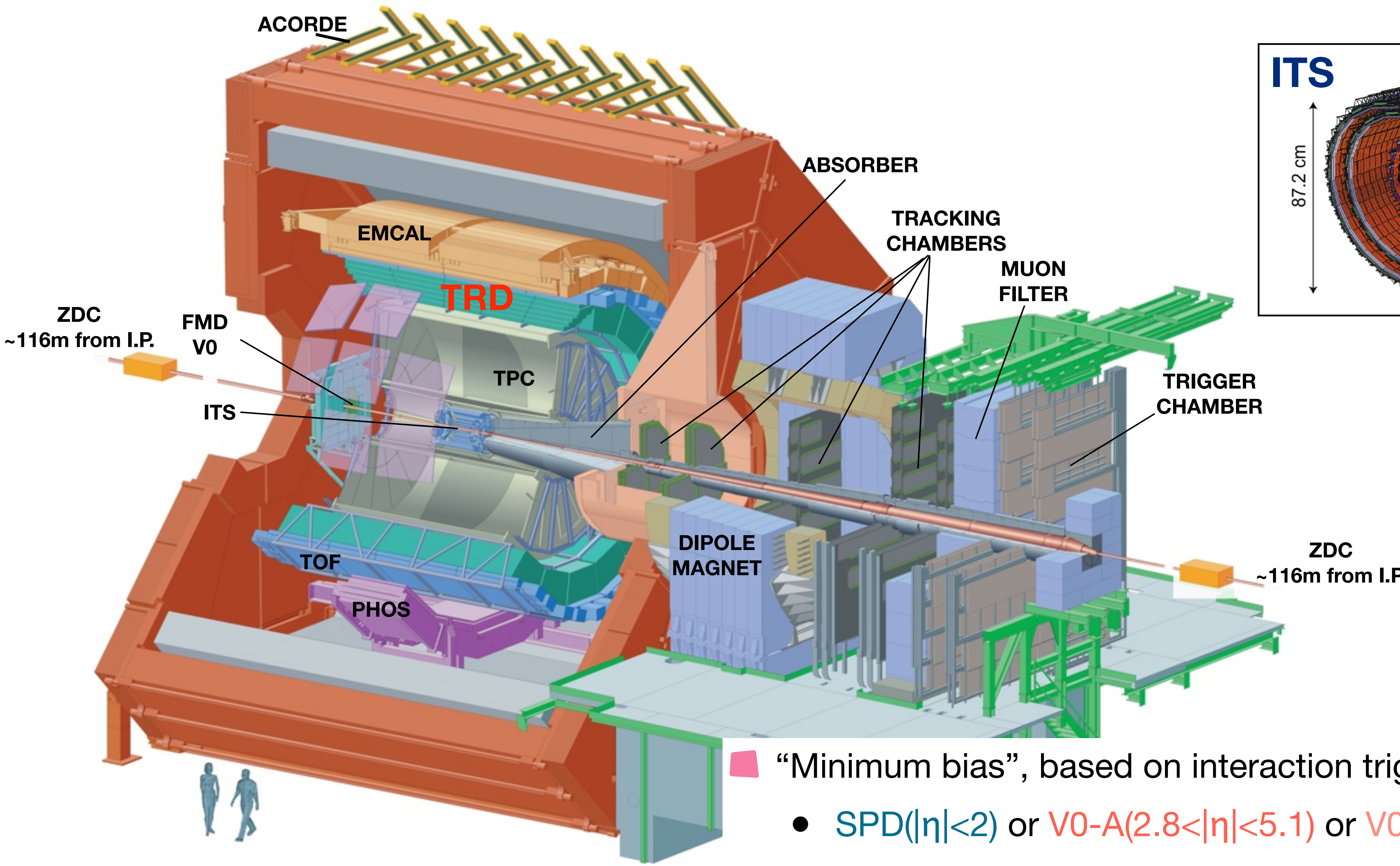
b-quark fragments much harder than light quarks(due to dead cone effect in the vacuum)

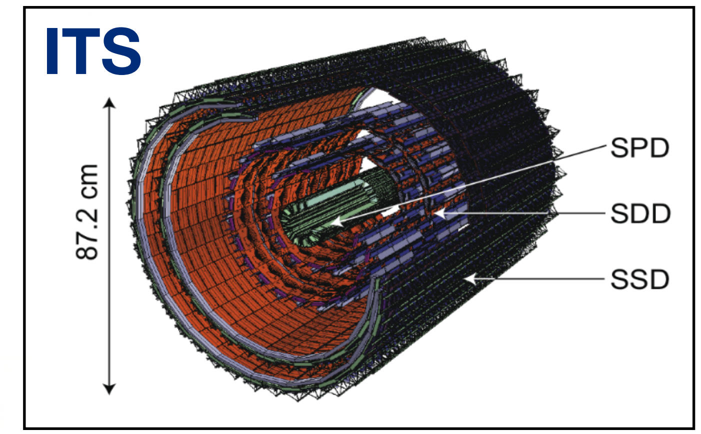
→Jet energy can be measured more precisely, so it gives better handle on the fragmentation function to extract medium modification effect

✱ Proton-proton collisions

- Measurement of heavy flavour production(charm and beauty) in p+p will provide important test of pQCD in a new energy domain and heavy ion reference

A Large Ion Collider Experiment



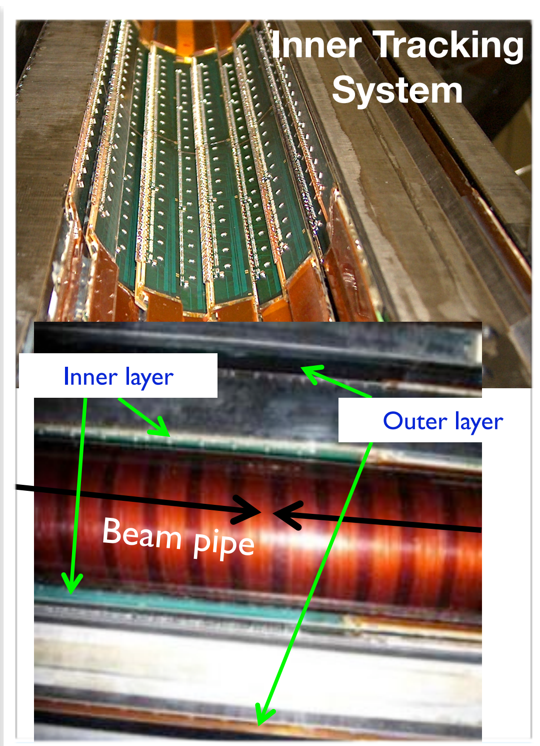


- "Minimum bias", based on interaction trigger:

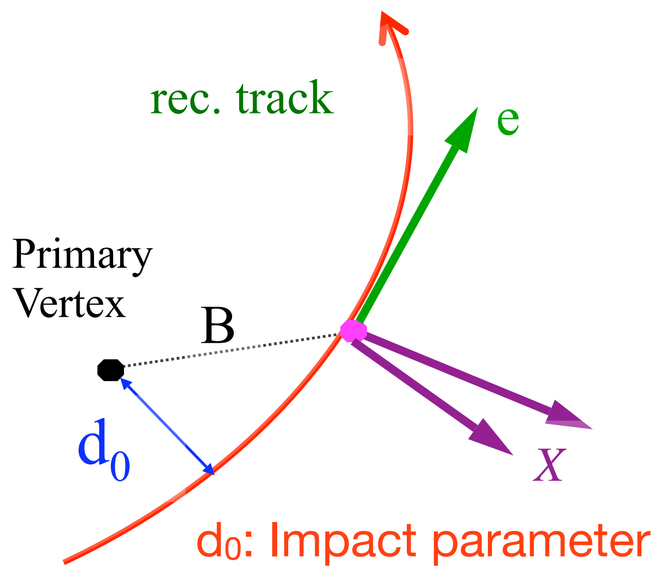
  Activated in coincidence with the BPTX beam pickups

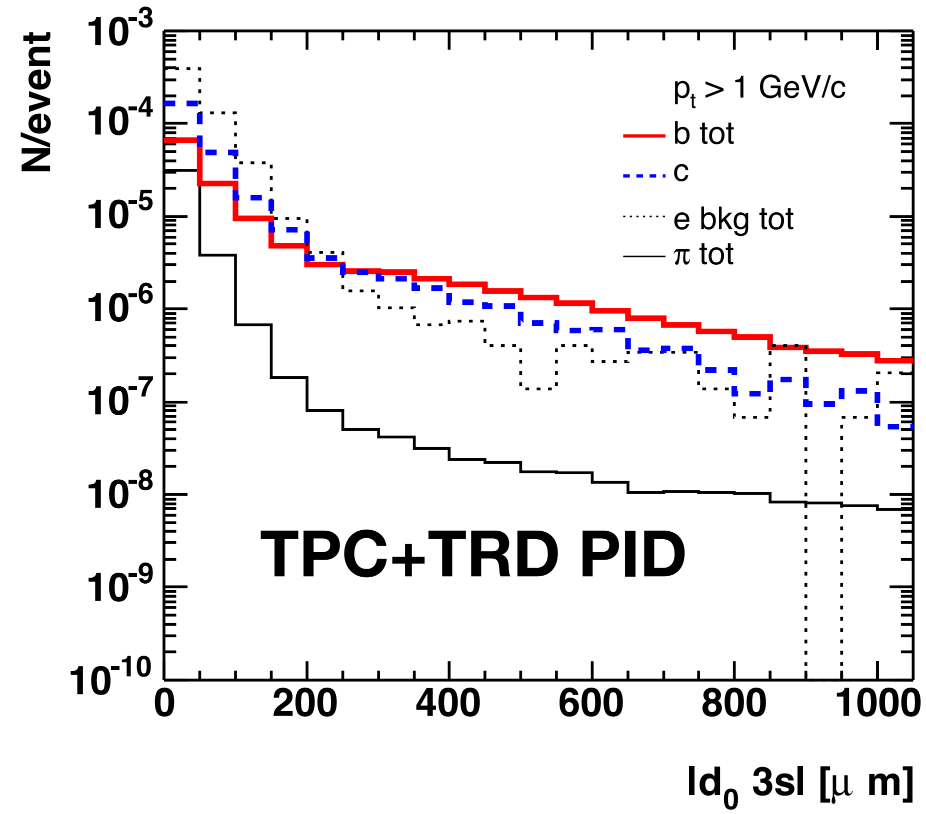
  - SPD($|\eta|<2$) or V0-A($2.8<|\eta|<5.1$) or V0-C($-3.7<|\eta|<-1.7$)
    - at least one charged particle in 8 η units
    - ~95% of σ_{inel}
- Since March 30st 2010 until PbPb collision started, collected
  - ~8.5×10^{8} minimum bias triggers
- Analysis shown here is based on
  - 2.6 nb^{-1} for electrons

Beauty Measurement via Impact Parameter



Resolution mainly provided by the 2 layers of silicon pixels -9.8 M cells 50 (rφ) x 425 (z) μm²- at 4 and 7 cm from the beam line



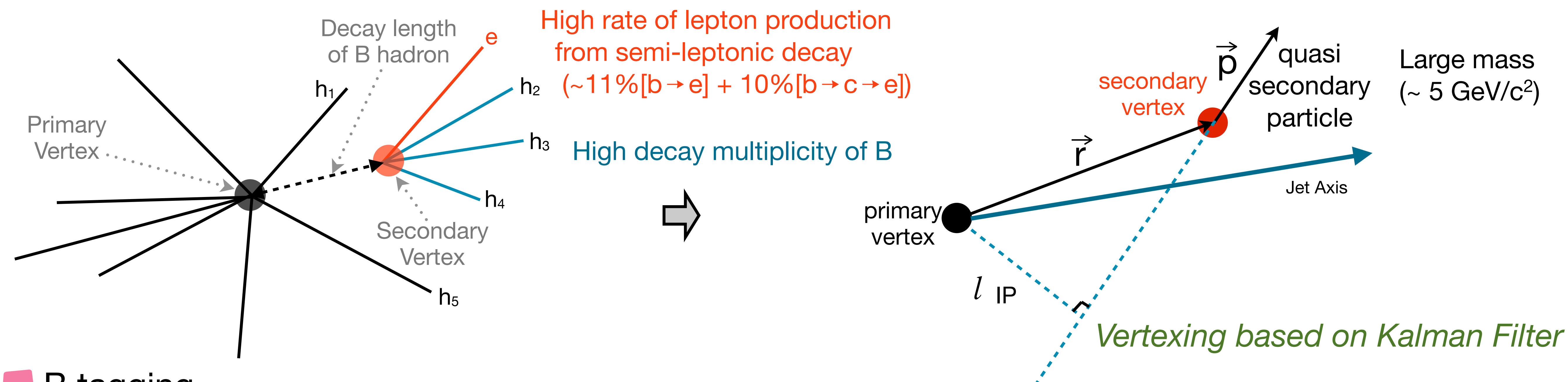


- Electrons from beauty have larger impact parameter compared to the ones from charm and hard momentum spectrum → increase S/B via impact parameter cuts
  - Electron identification with combined TPC, TOF and TRD
  - Estimate remaining charm decays via measured charm cross section
  - Estimate remaining non heavy flavor decays(e± from Dalitz decays and ϒ conversions) via background electron cocktails

ALICE has GOOD electron PID
+ vertex detectors

Beauty Tagging via Secondary Vertexing

Thanks to GOOD electron PID + vertex detectors

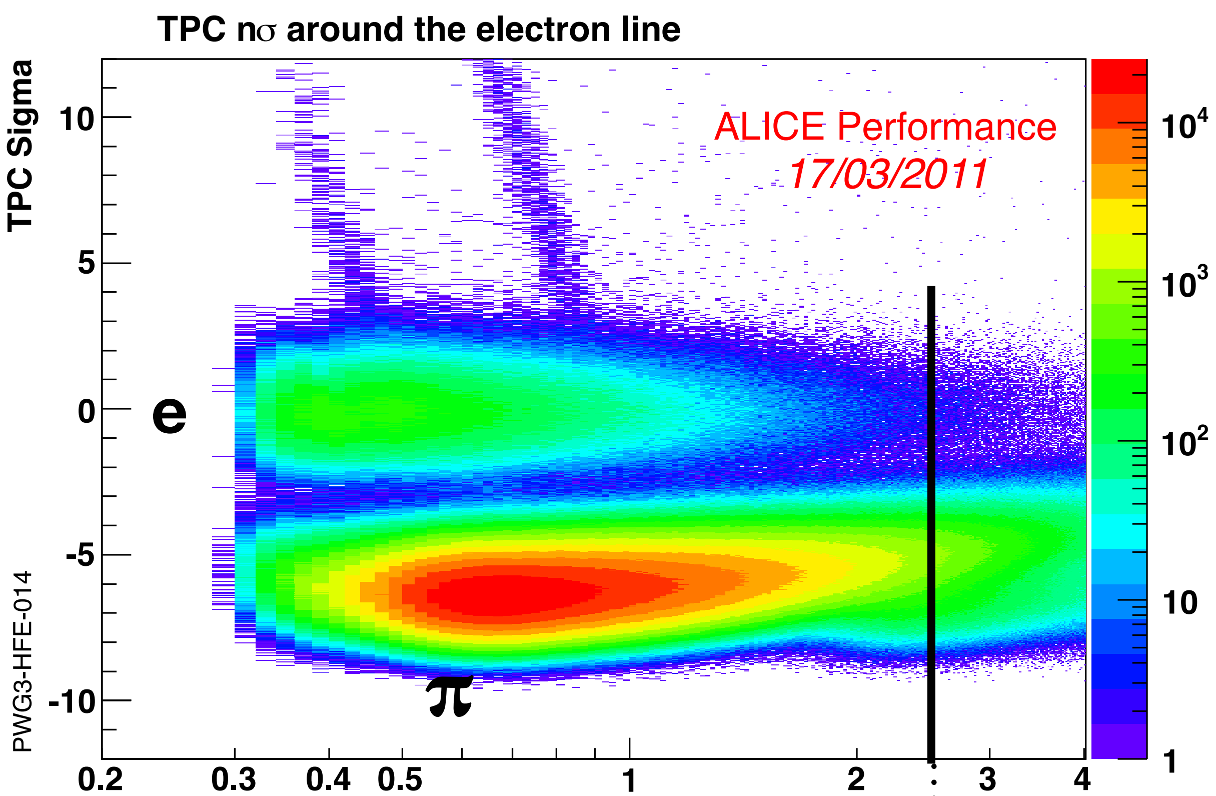


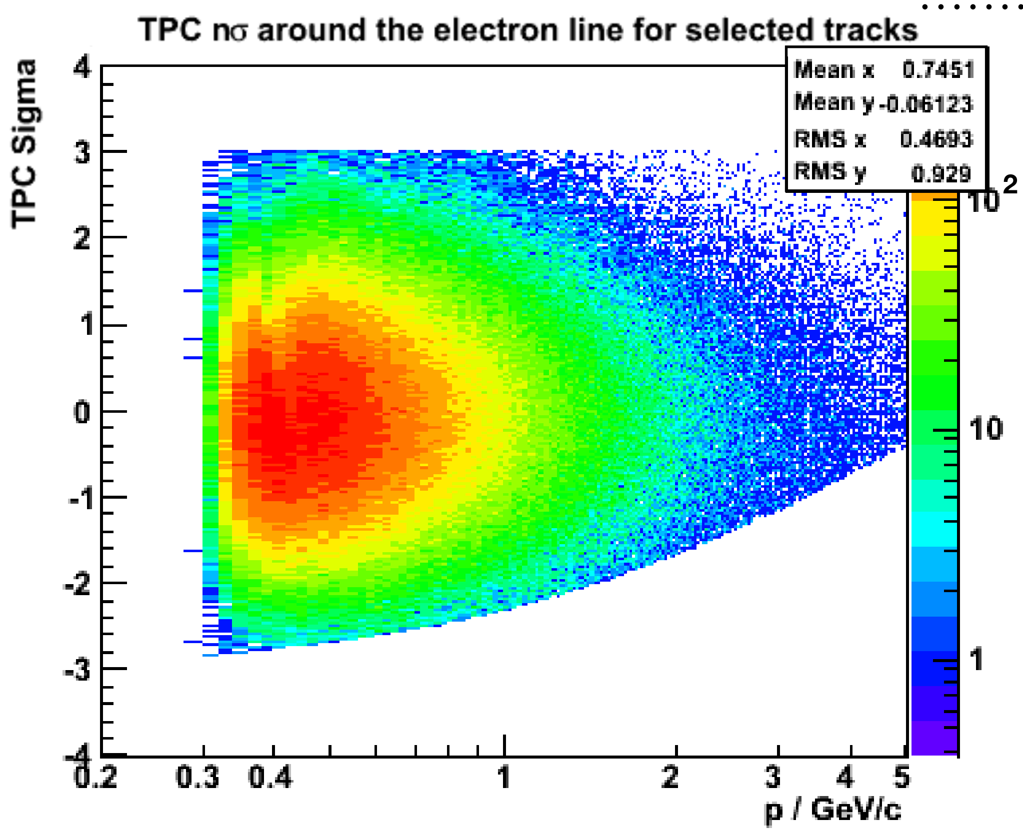
- B tagging
  - ⇒ Secondary vertex reconstruction of beauty decay through electron + hadrons
- B-jet tagging
  - ⇒ Reconstruct jets, then associated with secondary vertex tagged by above b tagging method

distinctive variables

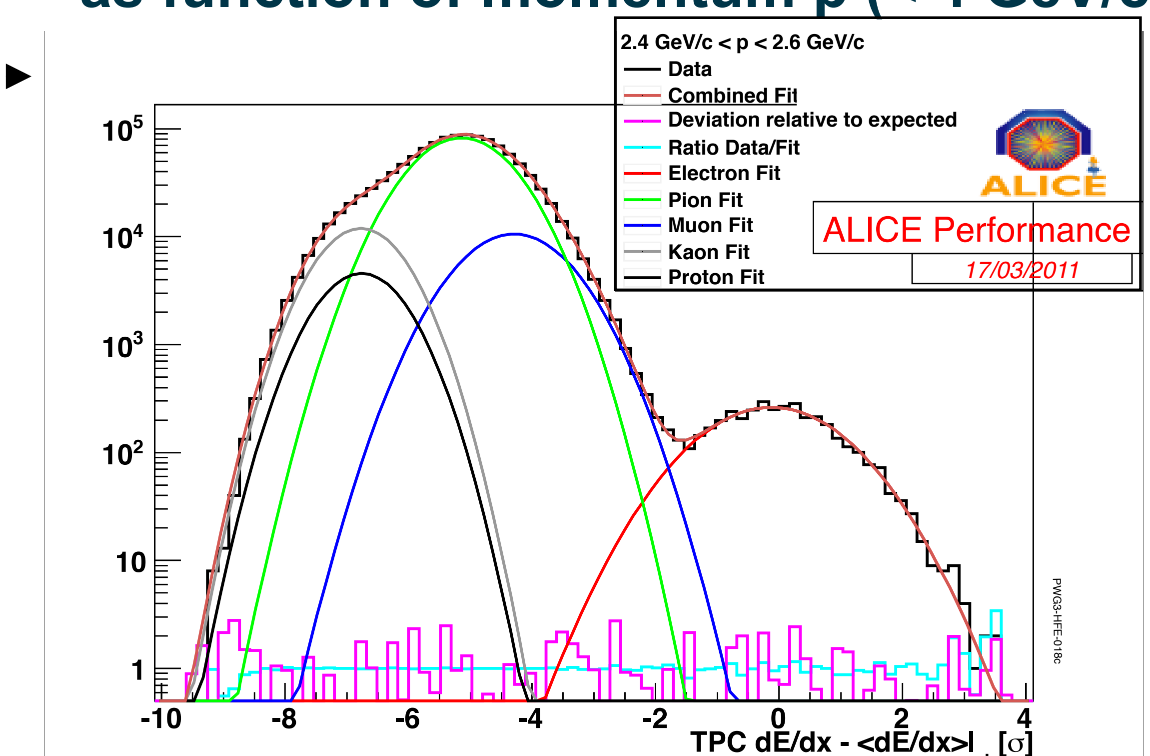
- Signed decay length $(Signed\ L_{xy}) = |\vec{r}| \frac{\vec{r} \cdot \vec{p}}{|\vec{r} \cdot \vec{p}|}$
- Invariant mass
- Secondary vertex χ^2/NDF
- Impact parameter of secondary particle(l_{IP})

Electron Identification Performance

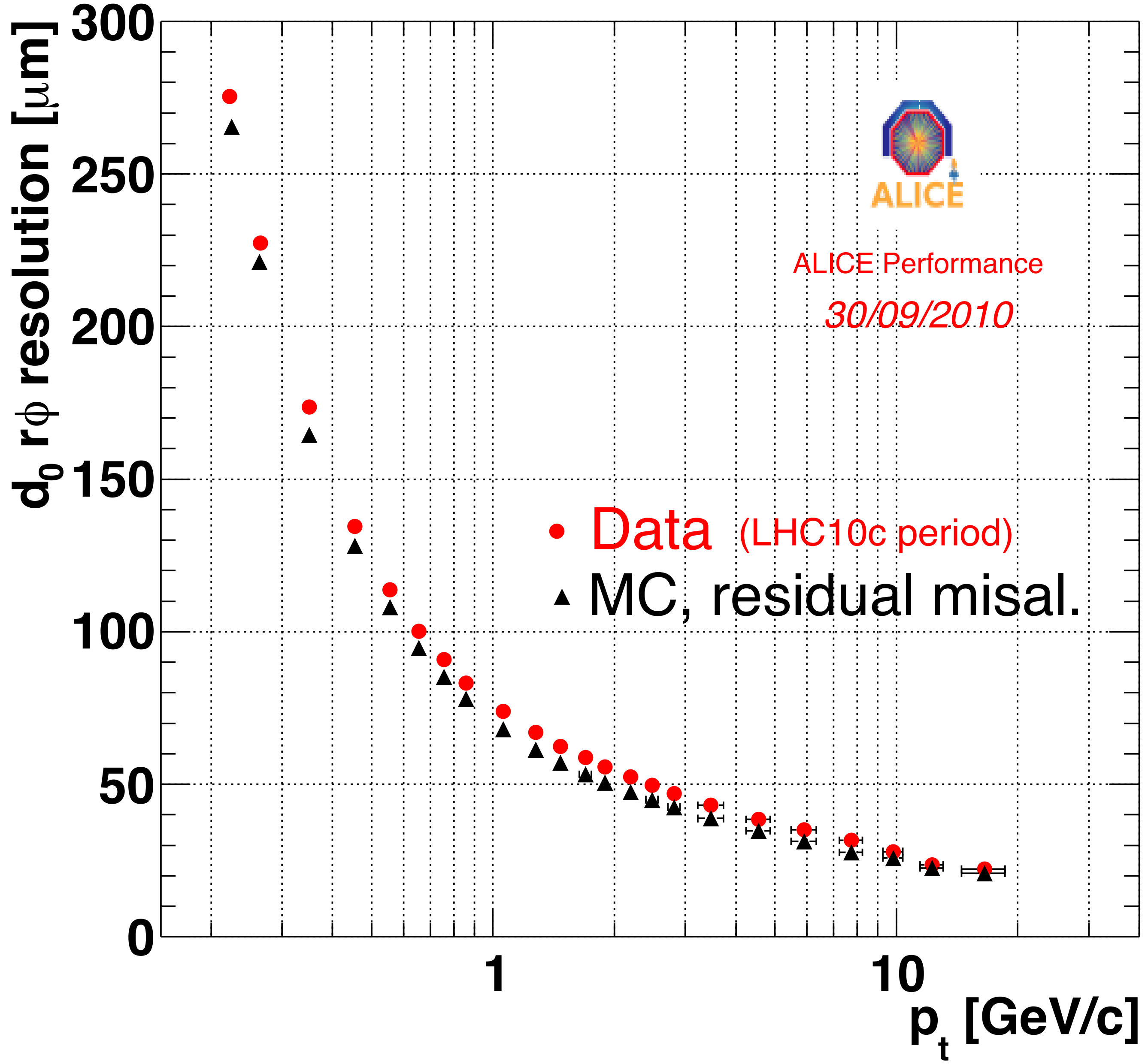




- **Kaon & Proton Rejection with TOF(3 from the electron line in TOF)**
  - Current ToF resolution: 130 ps → clean rejection of
    - K (for p < 1.5 GeV/c)
    - p (for p < 3 GeV/c)
- **Further hadron rejection with TPC**
  - Momentum dependent cut on number of sigmas from the electron line in TPC
- **Subtract remaining hadron background**
  - Gaussian fits of TPC dE/dx distributions in momentum slices → hadron contamination as function of momentum p (< 4 GeV/c)



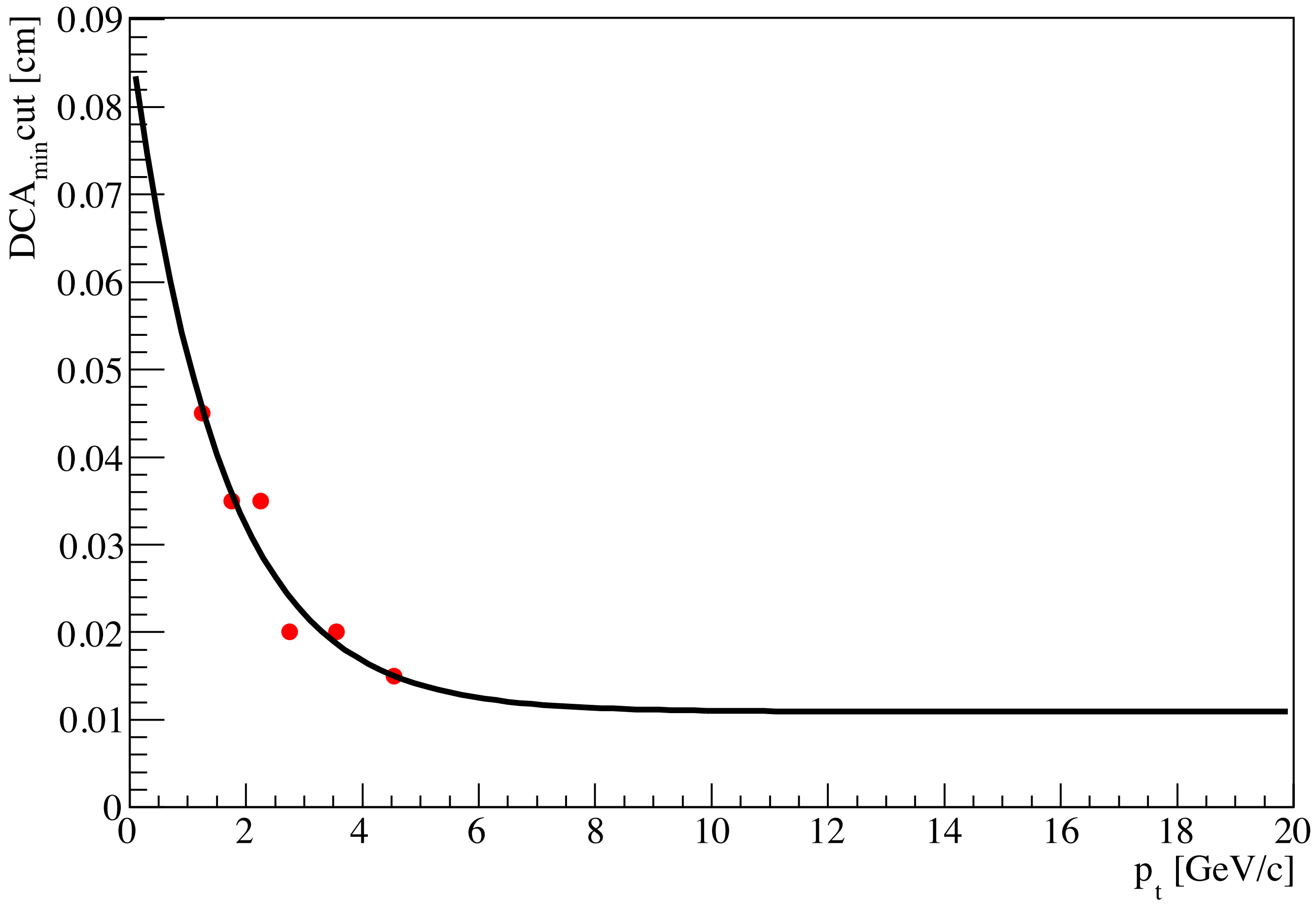
Vertexing Performance



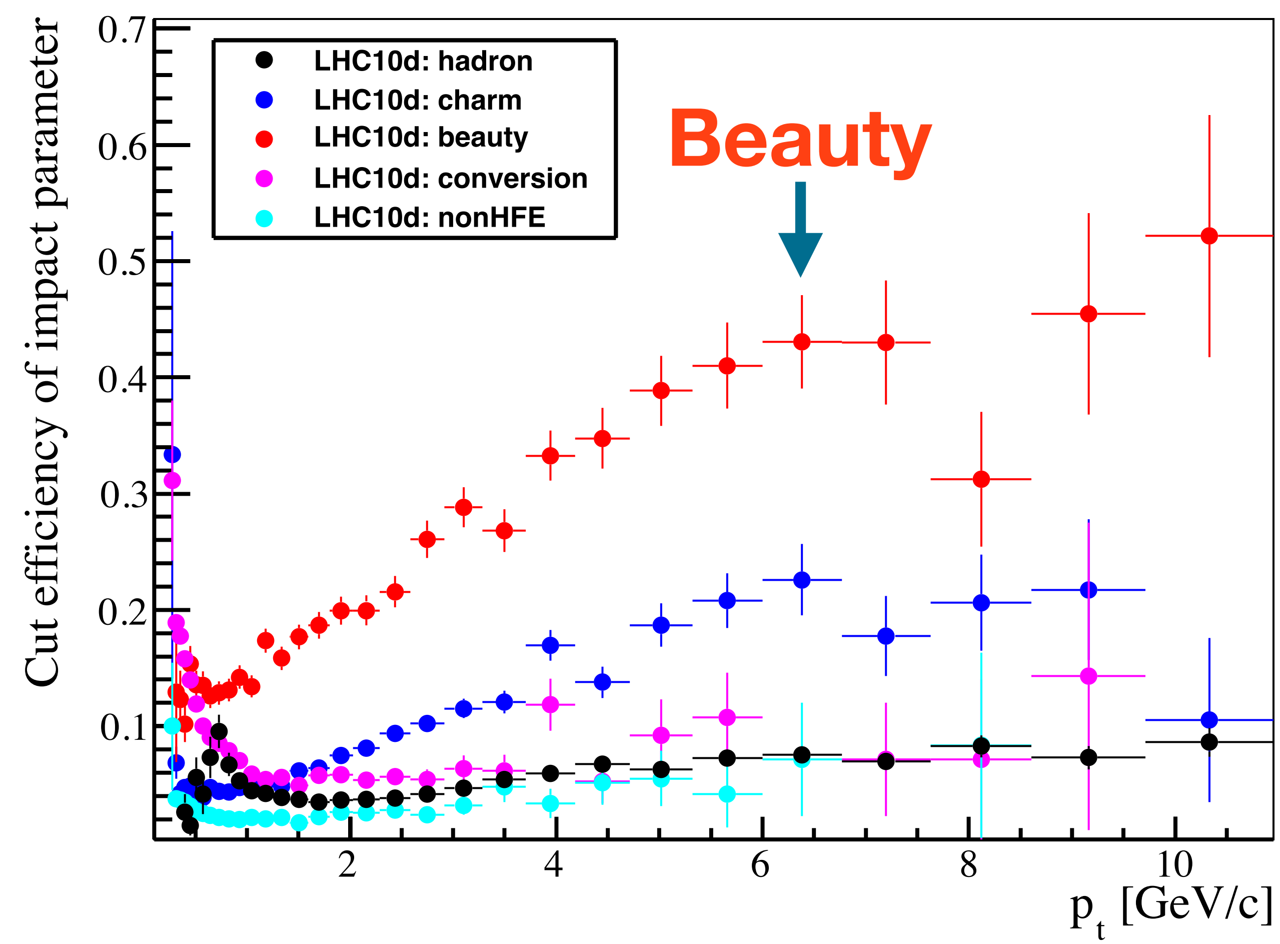
- **Excellent vertex capabilities, impact parameter resolution → (~ 75 µm at 1 GeV/c)**
- **Vertexing performance within ~10 % to the MC target**

Impact Parameter Cuts Performance

P_t dependent impact parameter cuts



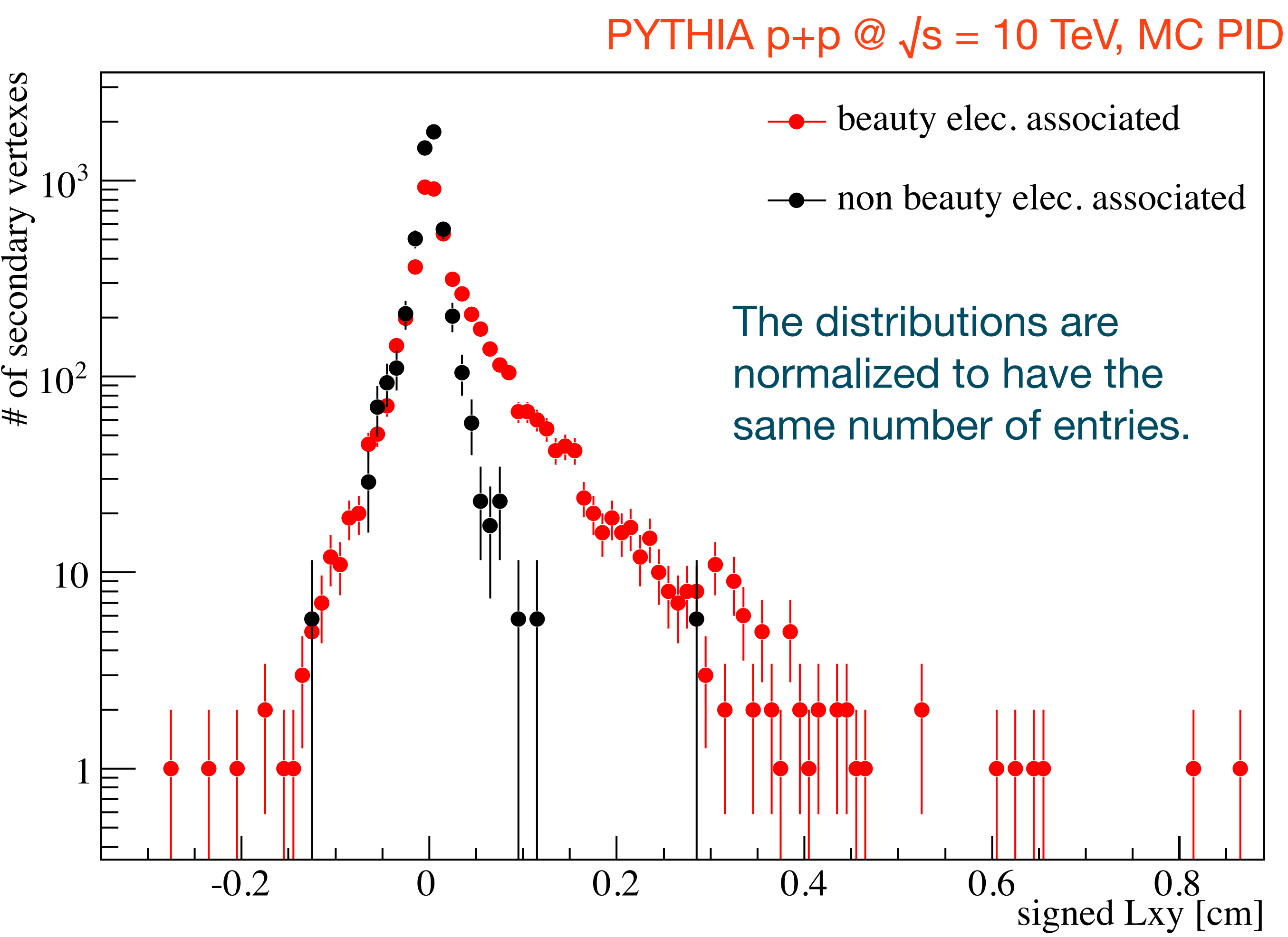
Reduction factor by impact parameter cuts for electrons from different sources



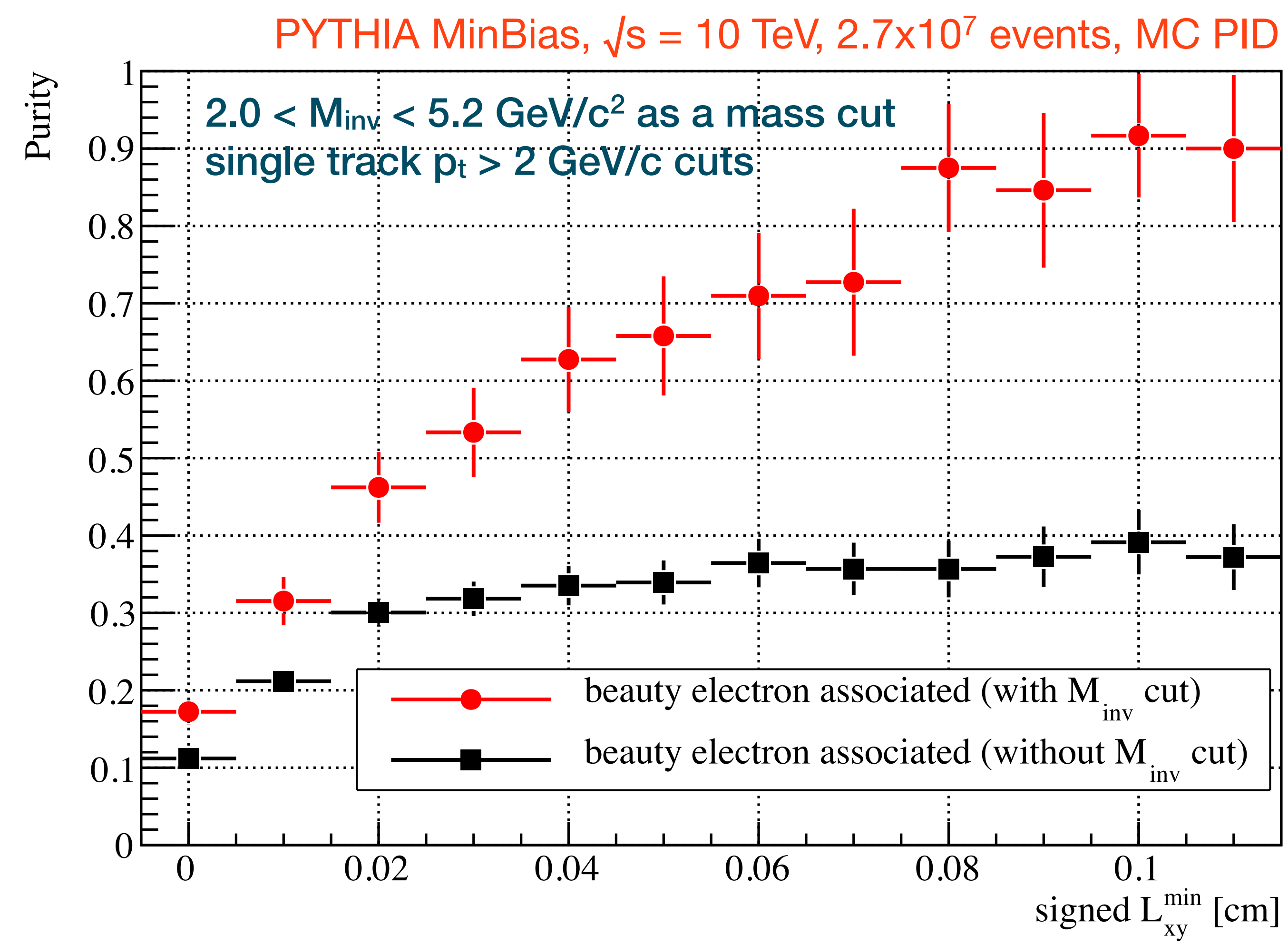
- Cuts are tuned to optimize S/B
- Impact parameter cuts → efficient to suppress backgrounds electrons than beauty electrons(~ factor 2)

B Tagging Performance

Signed decay length distribution



Purity as a function of minimum Signed L_{xy} cut

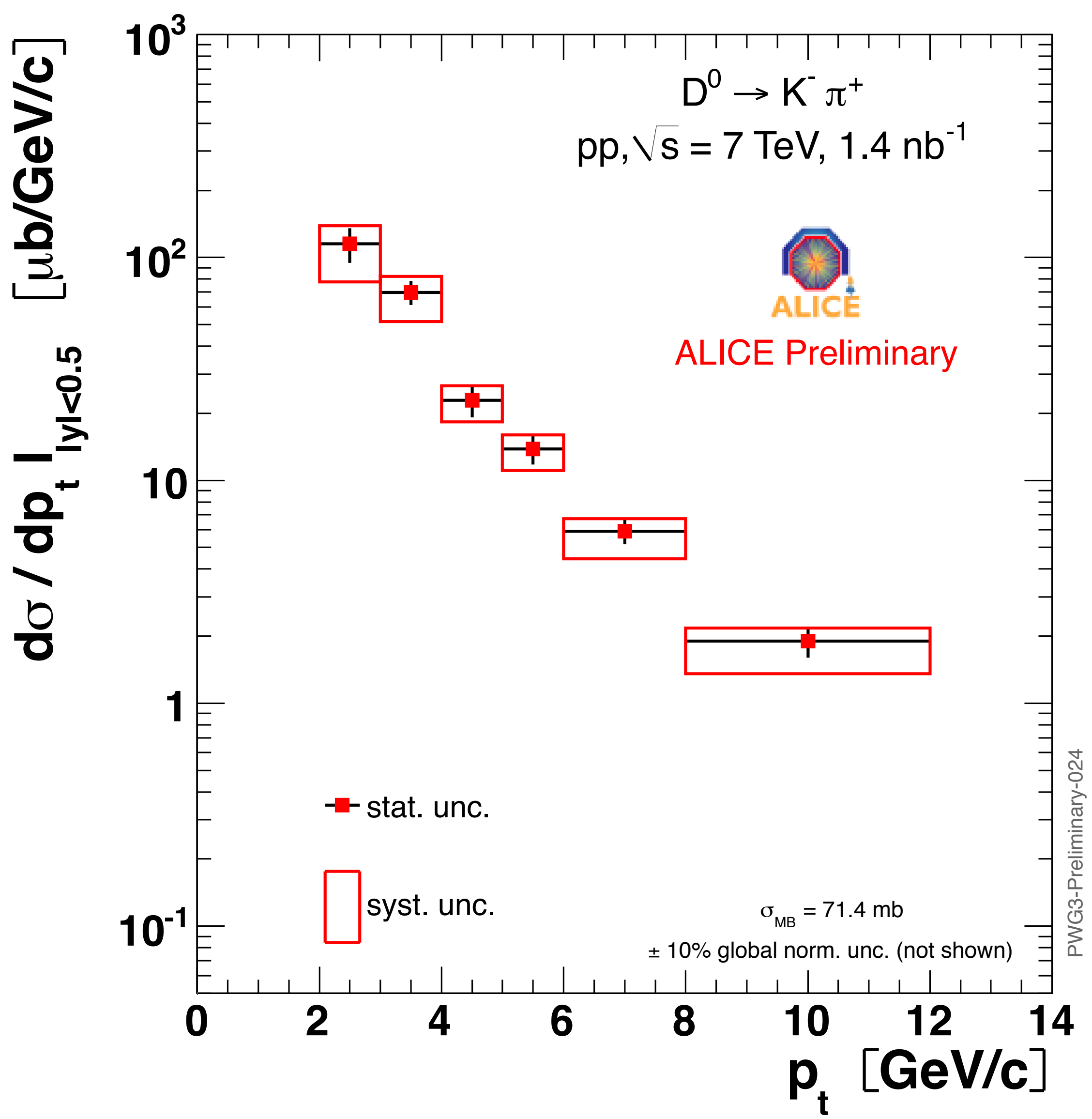


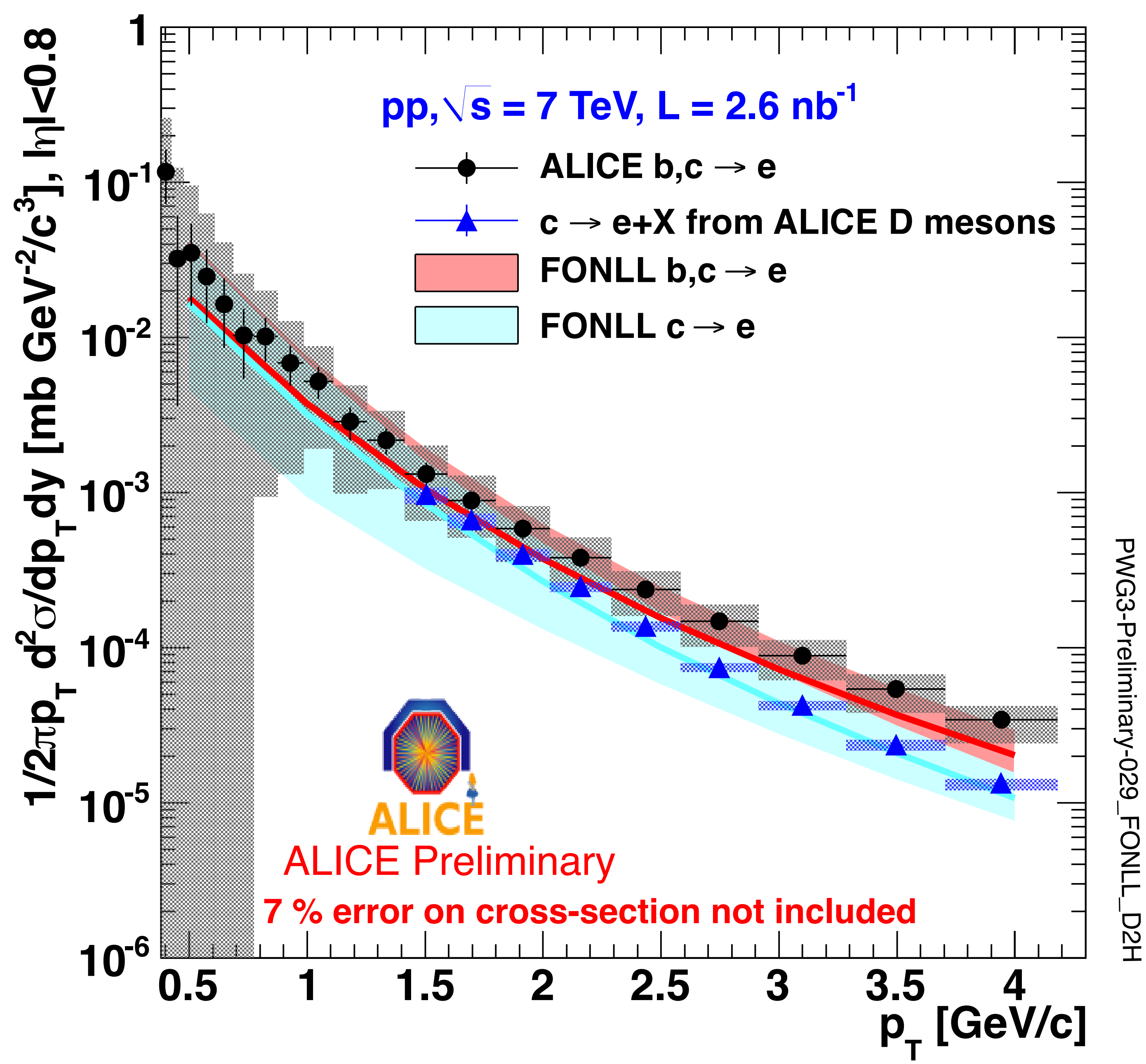
- Signal has distinctive distribution due to its larger decay length than those of backgrounds → define cuts to preferentially select electrons from b-decays

- With mass cut, obtain ~80 % purity by applying cut on 800 μm of minimum signed L_{xy}

Charm Background estimated based on Measurement

The charm cross section measured with D meson decays is used to produce electron spectrum





- ● Heavy flavor electrons from charm and beauty decay
- ▲ Heavy flavor electrons from charm

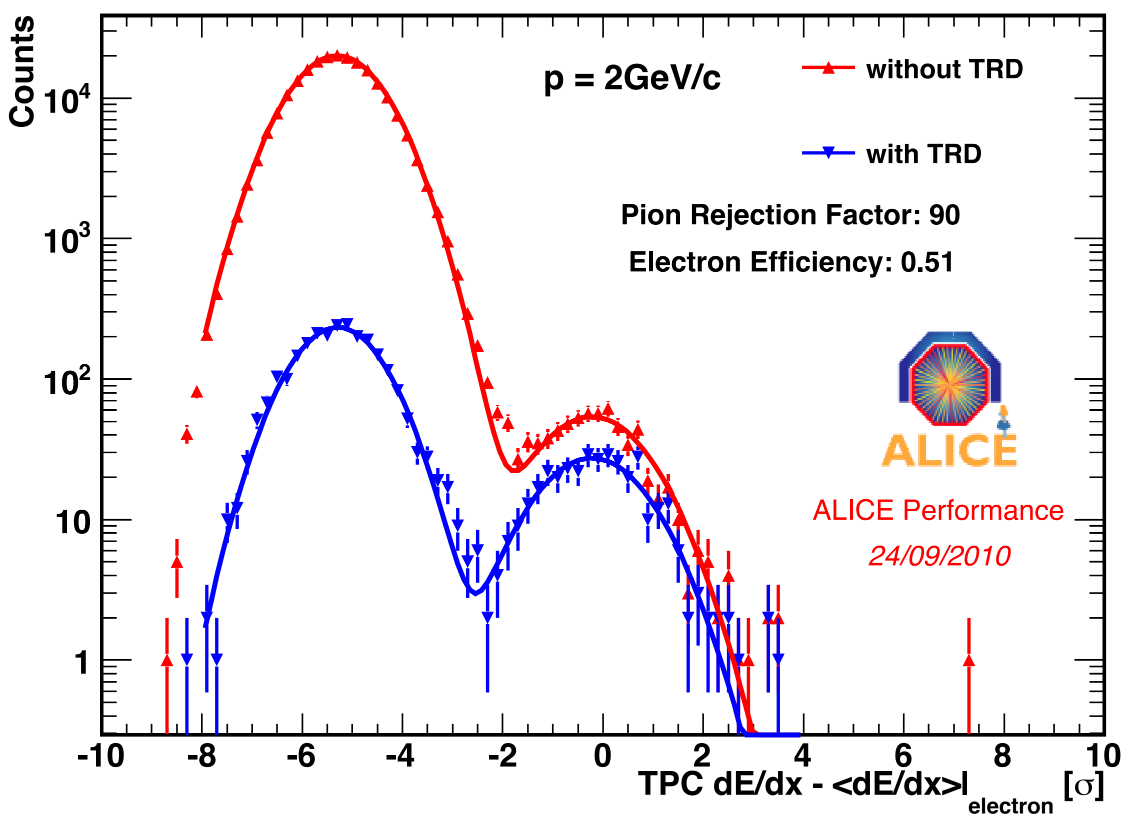
●-▲ Beauty contribution is getting large as a function of p_t

Works on subtracting remaining background after displaced vertex cuts(IP, SecVtx) are ongoing!

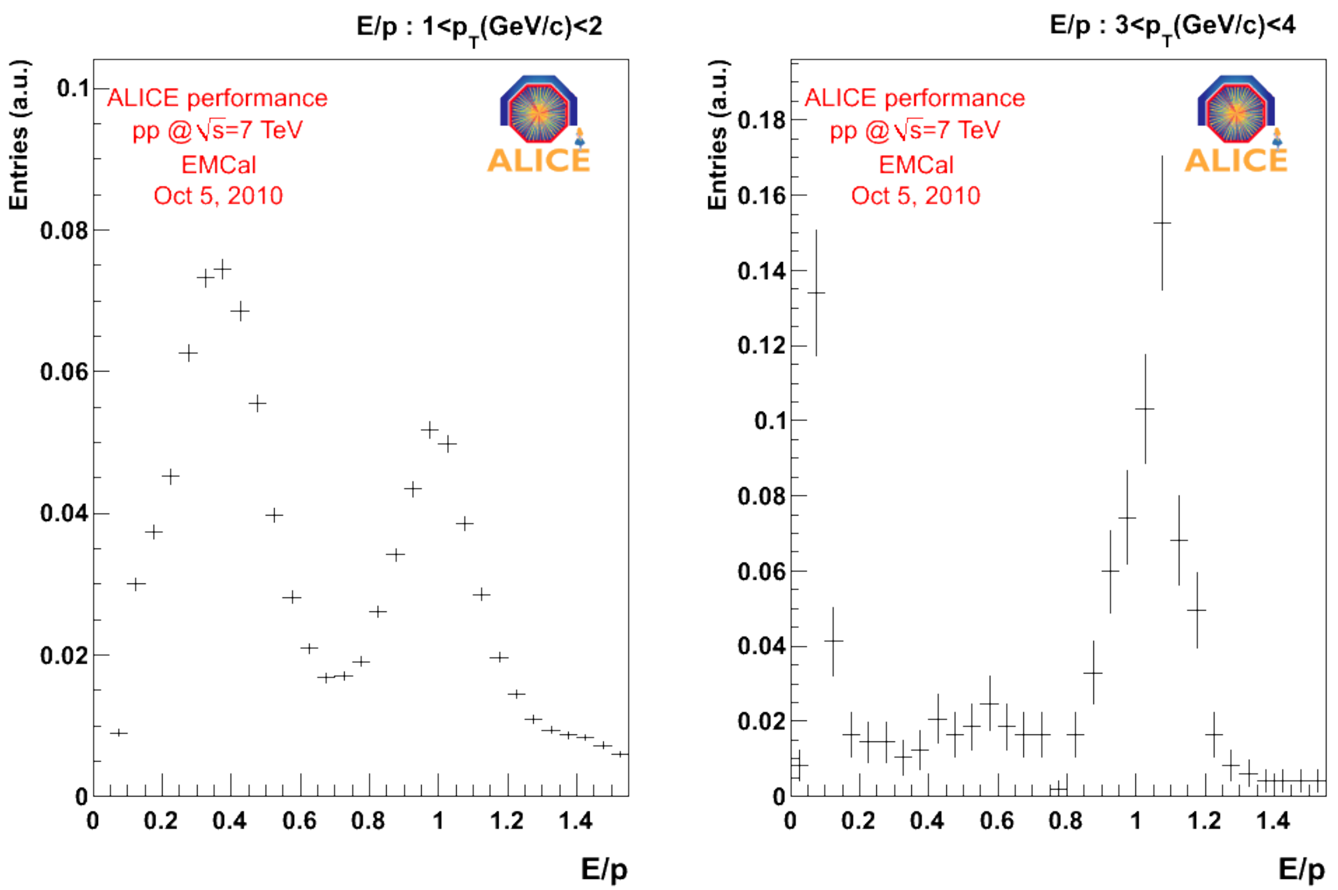
Perspectives on Electron Identification

Extend good electron identification at higher momentum with **TRD** and **EMCal**

Transition Radiation Detector
TPC dE/dx slice w/o and with TRD



ElectroMagnetic Calorimeter
E/p distributions



- Provide good e/π separation from 1 to ~15 GeV/c
- Provide possibility to trigger (L1) on high pt identified particles

Works are "actively" ongoing to extend p_t spectrum to higher momentum!

Summary and Outlook

- **At LHC, charm and beauty quarks are produced copiously and this provides a tool to understand color charge and mass dependence of energy loss in the medium**
- **ALICE has excellent electron identification and vertexing capability and this allows beauty electron tagging**
- **B, B-jet tagging analysis ongoing with $\sqrt{s}$ = 7 TeV data**
- **Pb-Pb collisions data were taken at $\sqrt{s}$ = 2.76 TeV in November 2010 and the same analysis technic will be applied**

BACKUP SLIDES

Open heavy flavour measurement via lepton channels

Theoretical uncertainty of a factor 2-3   MNR code (NLO): Mangano, Nason, Ridolfi, NPB373 (1992) 295

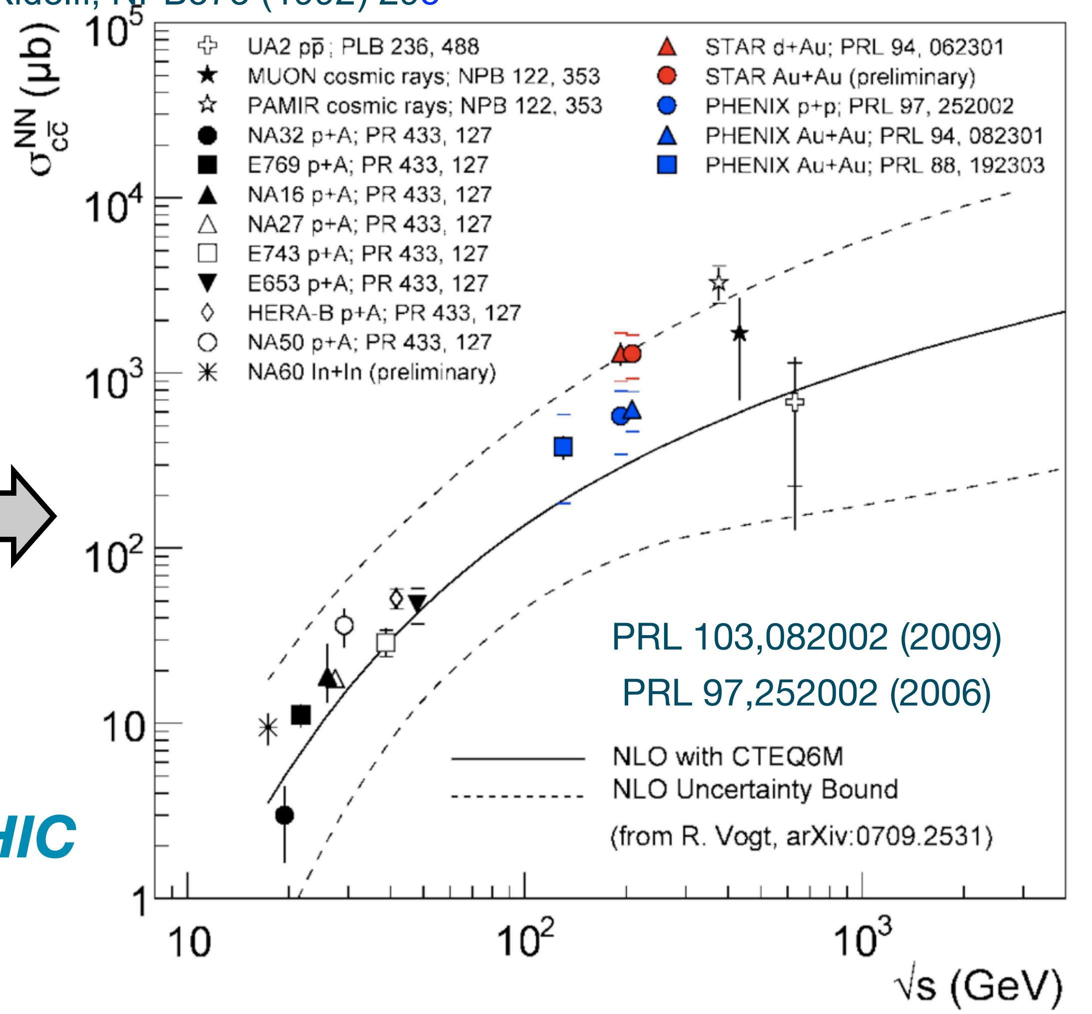
system: $\sqrt{s_{NN}}$:	p+p 14 TeV charm/beauty	p+p 7 TeV charm/beauty
$\sigma_{NN}^{Q\bar{Q}}[mb]$	11.2/0.5	6.9/0.23
$N_{total}^{Q\bar{Q}}$	0.16/0.007	0.10/0.003

Measurement at lower energy

PHENIX @200 GeV, p+p

$$\sigma_{c\bar{c}} = 567 \pm 57(stat) \pm 193(sys)\mu b$$

$$\sigma_{b\bar{b}} = 3.2^{+1.2}_{-1.1}(stat)^{+1.4}_{-1.3}(sys)\mu b$$



Cross sections cc(bb) at LHC x10(x100) larger than at RHIC

Branching Ratios:	
$c \rightarrow l + X$	9.6 %
$b \rightarrow l + X$	11 %
$b \rightarrow c \rightarrow l + X$	10 %

High rate of lepton production from semi-leptonic decay

Complementary to heavy flavor hadronic decays

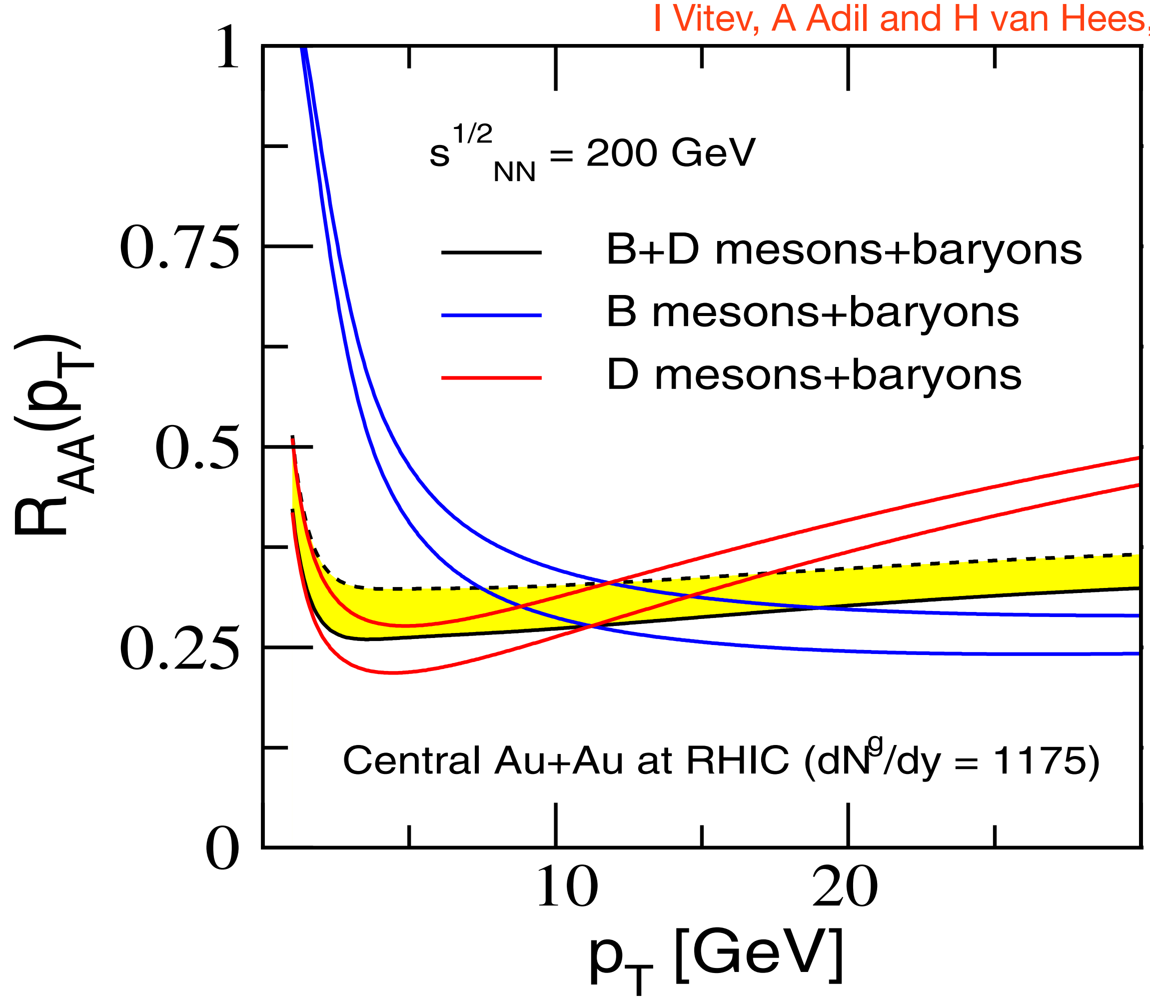
- **Proton-proton collisions**
  - Measurement of heavy flavour production(charm and beauty) in p+p will provide important test of pQCD in a new energy domain and heavy ion reference
- **Heavy-ion collisions**
  - Heavy quark energy loss in the medium

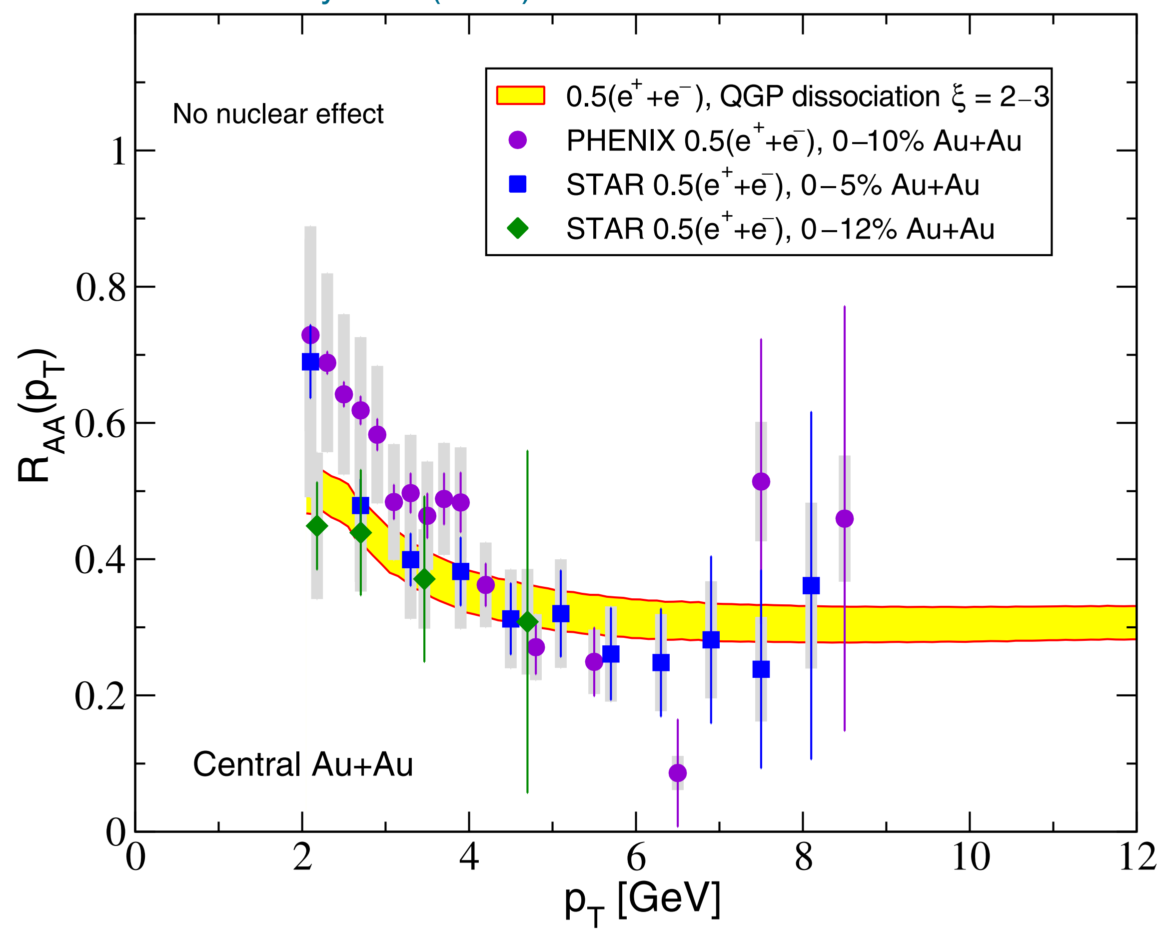
Approaches to describe non-photonic electron $R_{AA}(p_T)$

- Heavy meson dissociation in QGP

pQCD factorization approach assume hard jet hadronization in vacuum → valid for different species?

I Vitev, A Adil and H van Hees, J. Phys. G: Nucl. Part. Phys. **34** (2007) S769–S773





Shorter D- and B-meson formation time: $\tau_{\text{form}}(p_T = 10\ GeV)$

π	D	B	L_{QGP}
20 fm	**1.5 fm**	**0.4 fm**	≤ 6 fm

→ collisional dissociation probability of heavy mesons in the QGP

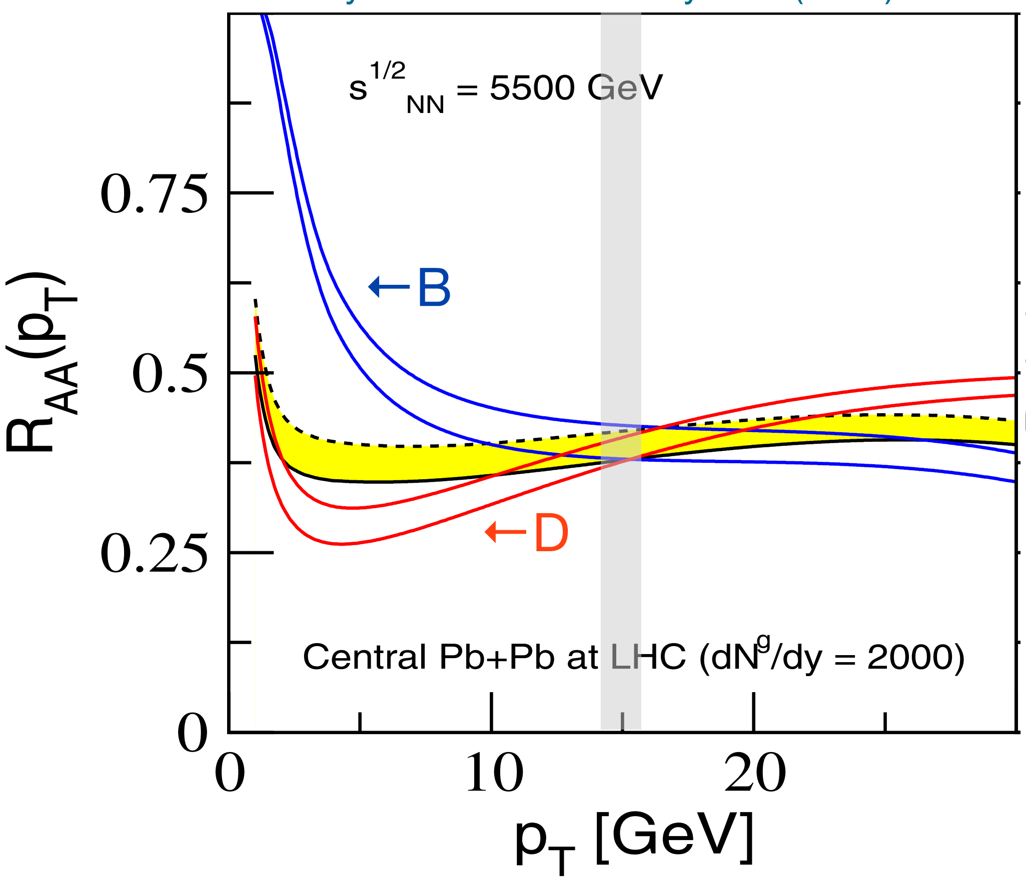
B-meson suppression comparable to D-meson as low as p_T ~10 GeV ($\tau_{B\text{-form}} < \tau_{D\text{-form}}$)

→ R_{AA}, which doesn't neglect large B-meson contribution, describes well the quenching

R_{AA} of open heavy flavour at LHC

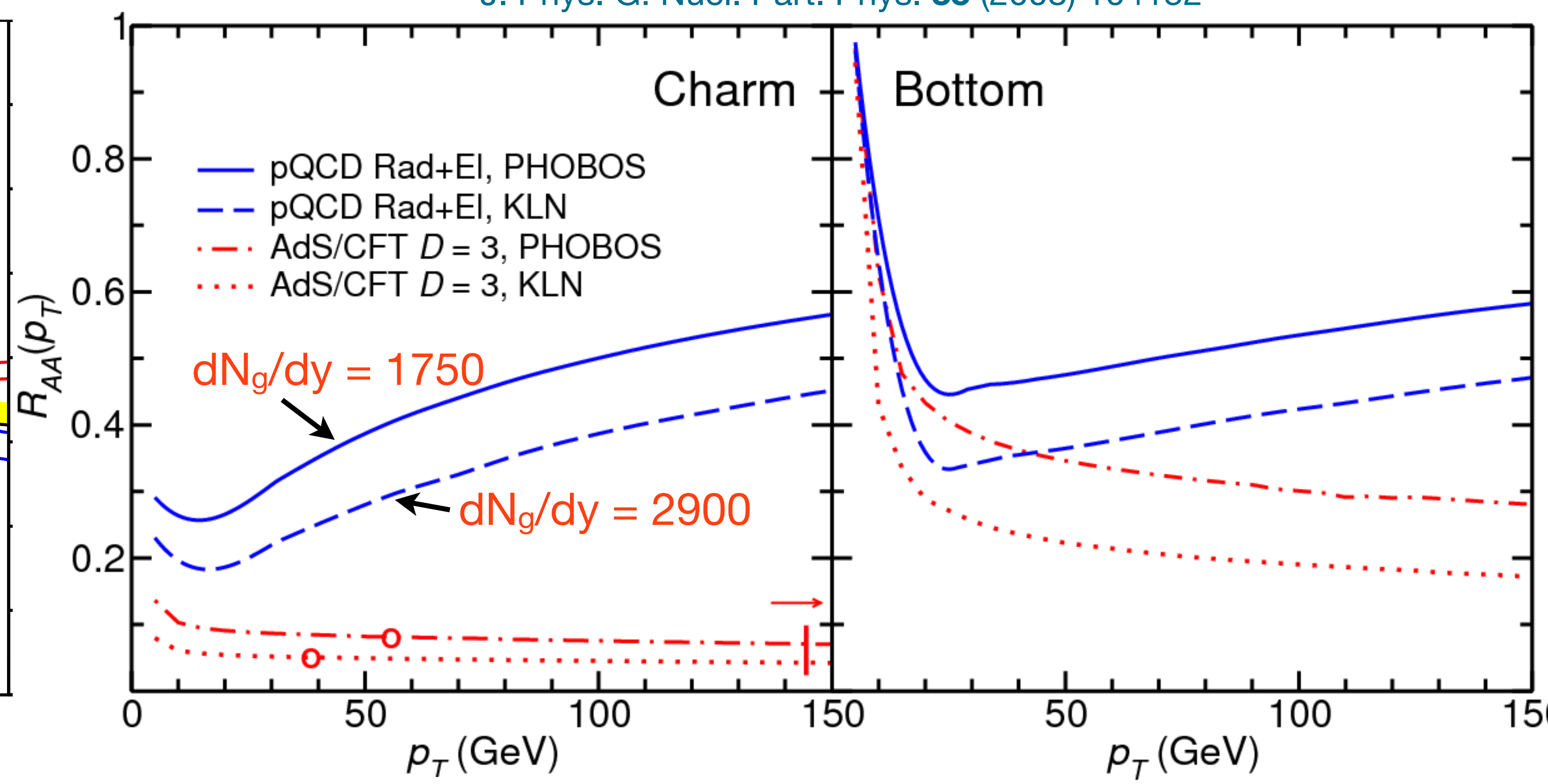
Heavy meson dissociation in QGP

I Vitev, A Adil and H van Hees,
J. Phys. G: Nucl. Part. Phys. **34** (2007) S769



AdS/CFT drag and pQCD

W A Horowitz and M Gyulassy,
J. Phys. G: Nucl. Part. Phys. **35** (2008) 104152

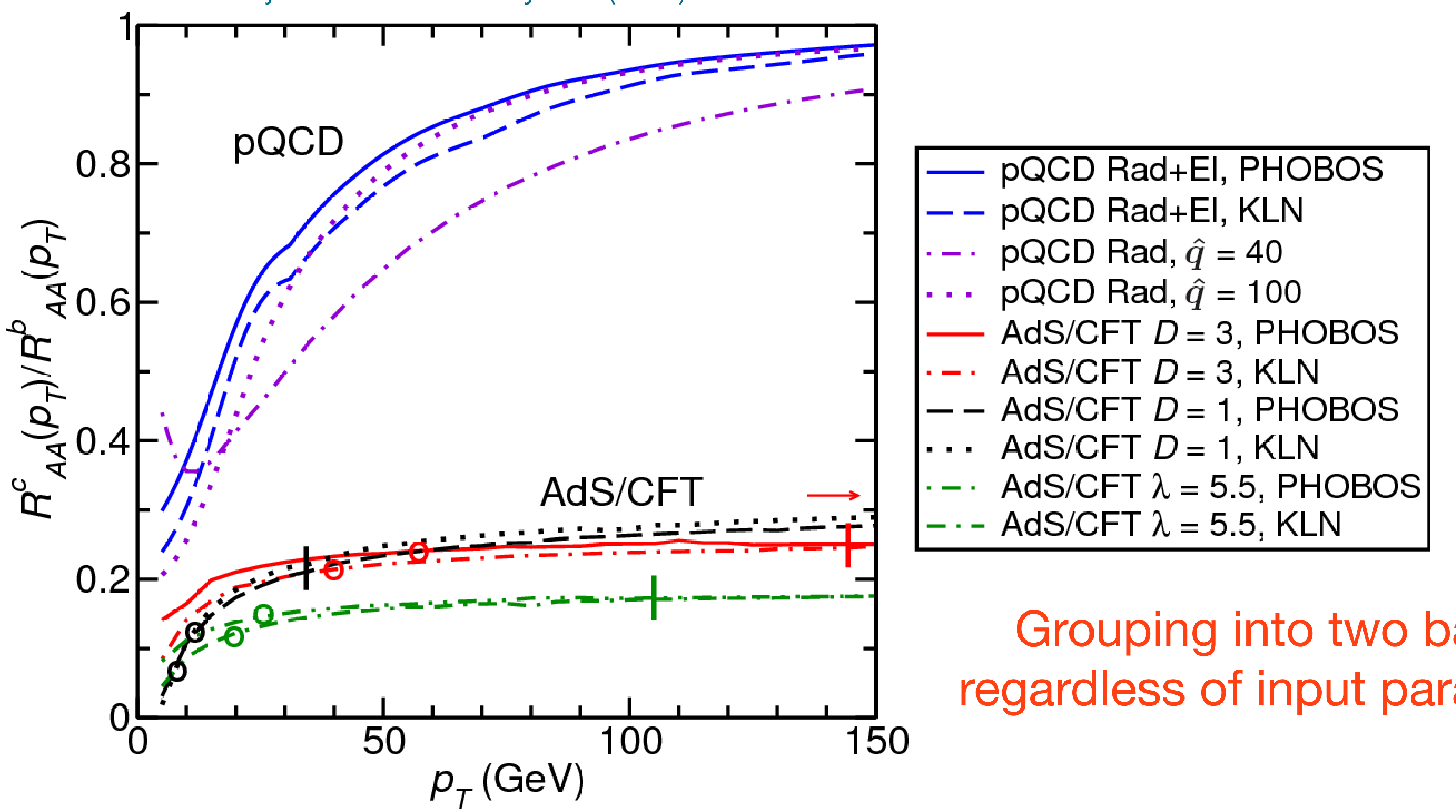


GLV + QGP dissociation shows B-meson suppression comparable to (or larger) D-meson as low as $p_T \sim$15 GeV

pQCD curves have a significant rise and the AdS/CFT curves fall with p_T

Charm-to-Beauty ratio at LHC

W A Horowitz and M Gyulassy,
J. Phys. G: Nucl. Part. Phys. **35** (2008) 104152



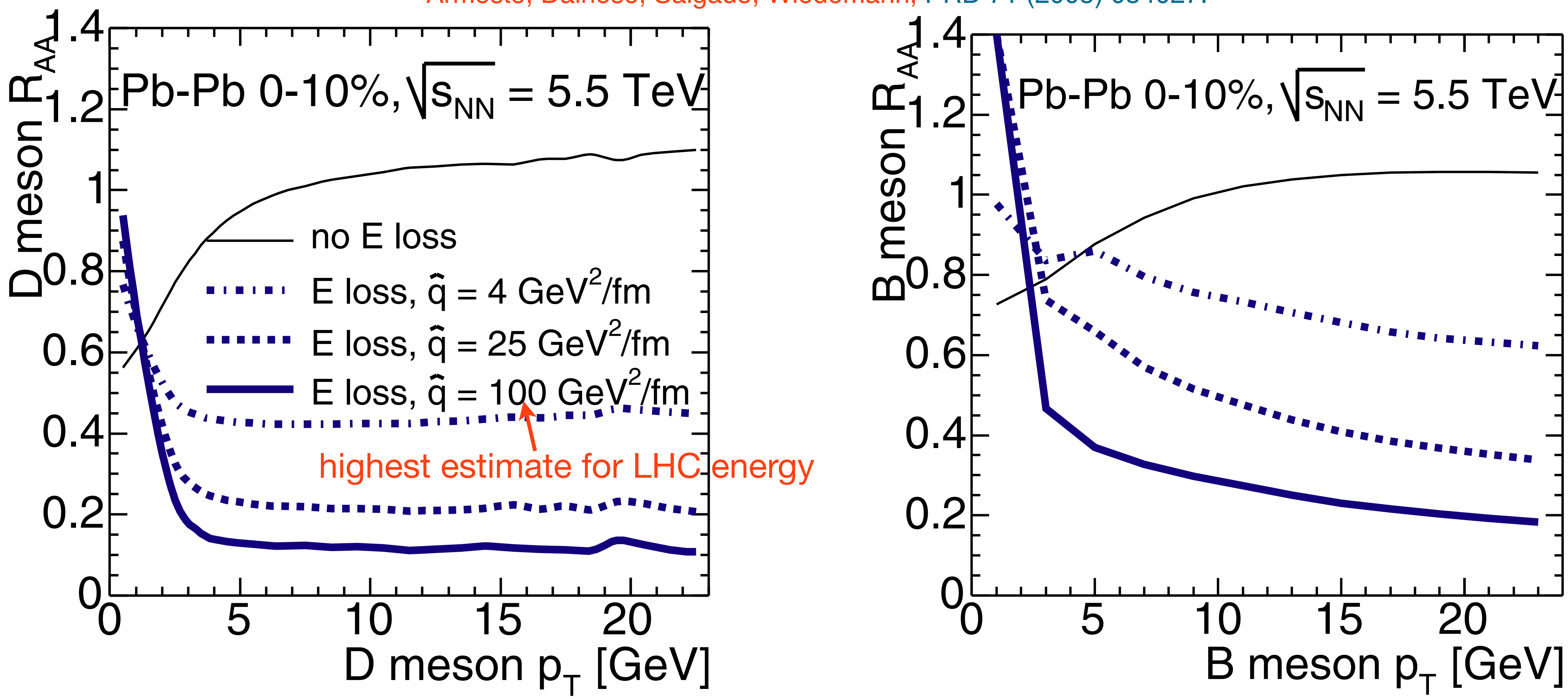
Grouping into two bands, regardless of input parameters

R_{AA}^c/R_{AA}^b vs. p_T is remarkably robust observable for finding deviations from different theoretical framework

→ Interesting to measure charm and beauty separately

R_{AA} of open heavy flavour at LHC (II)

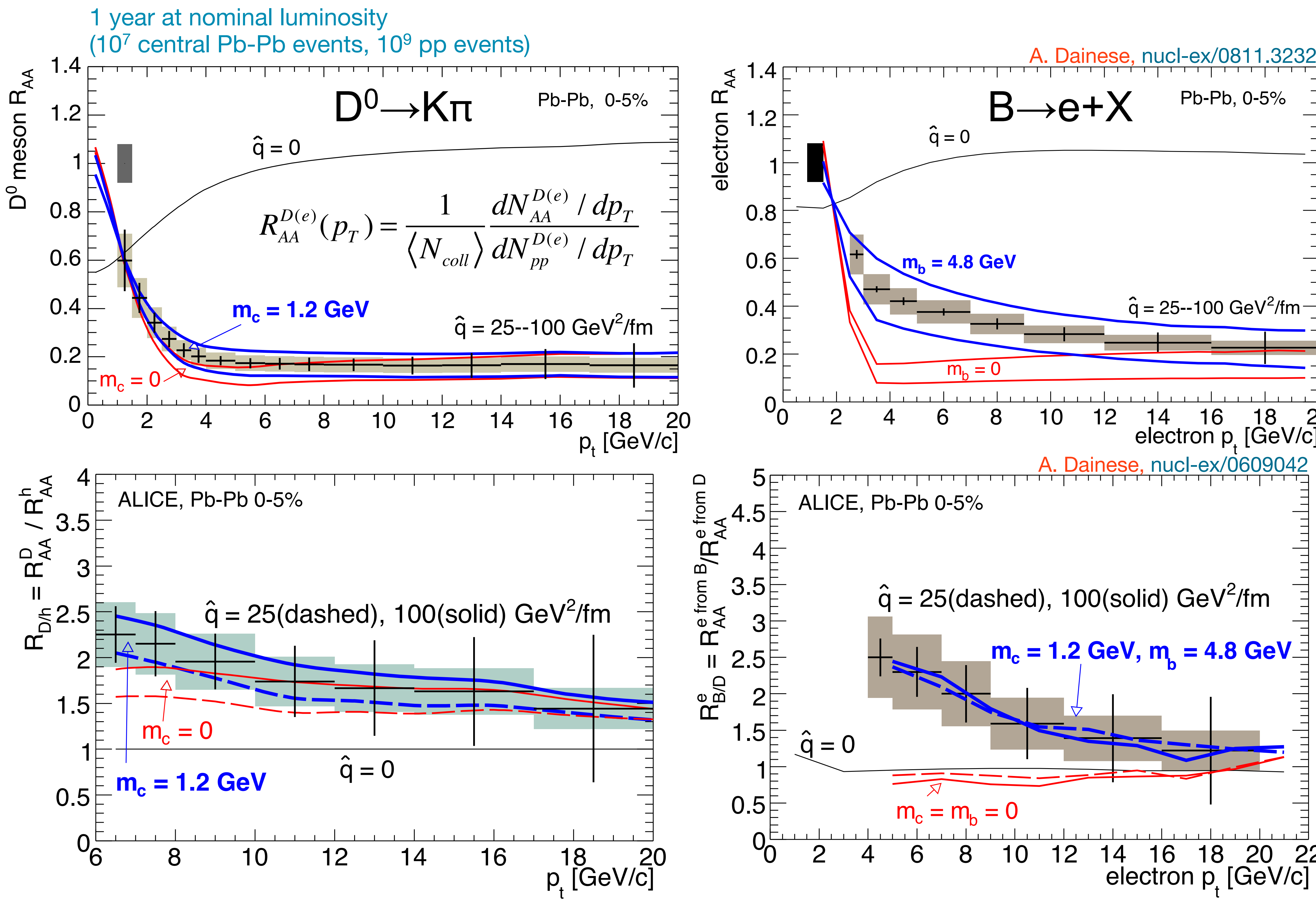
Armesto, Dainese, Salgado, Wiedemann, PRD 71 (2005) 054027.



Baseline: PYTHIA, with EKS98 shadowing, tuned to reproduce c and b p_T distributions from NLO pQCD(MNR) MNR: Mangano, Nason, Ridolfi, NPB 373 (1992) 295.

R_{AA} of D meson is less sensitive on varying $\hat{q}$ (higher $\hat{q}$ region), but can give good constraint together with R_{AA} of B meson with precise measurement

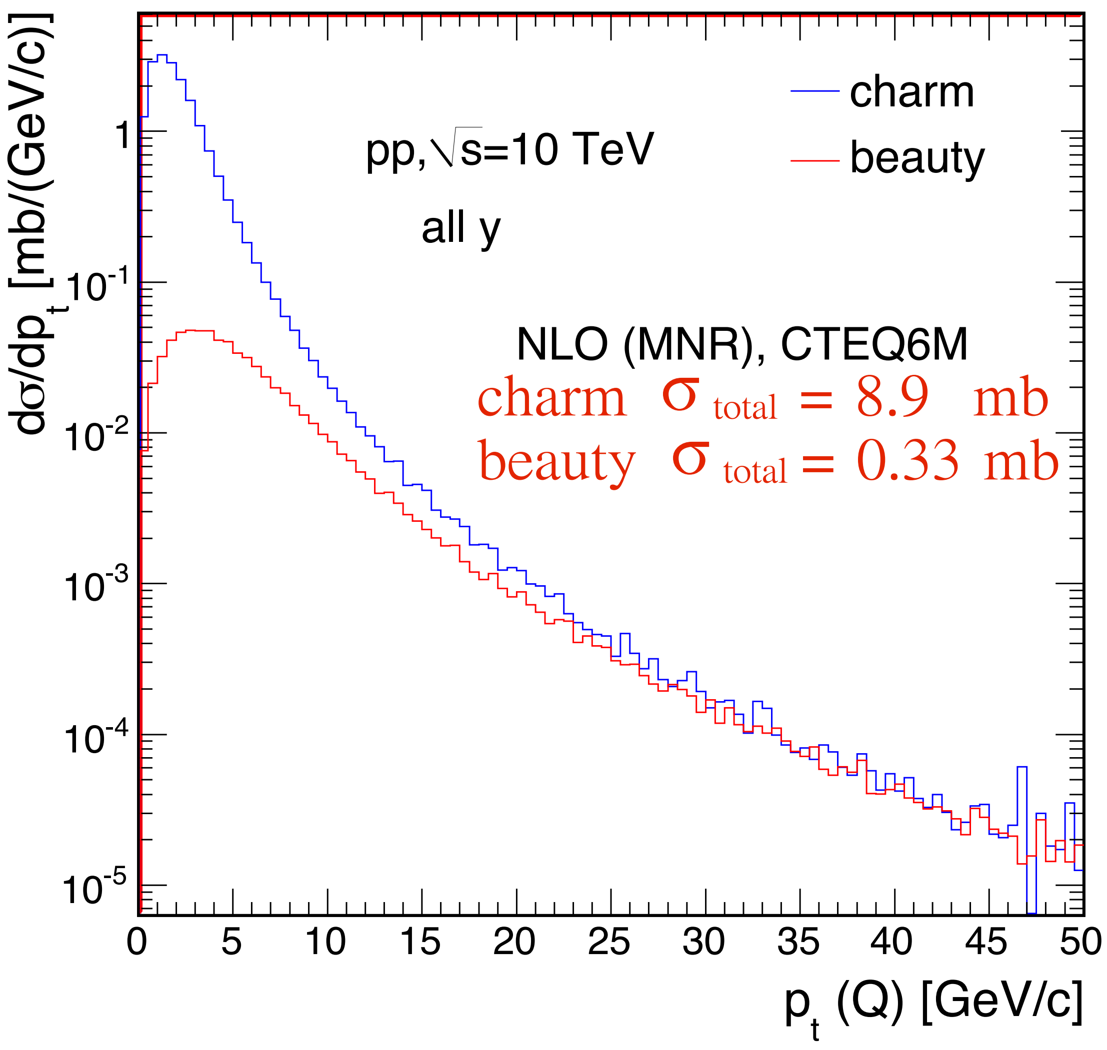
Nuclear modification for open heavy flavour

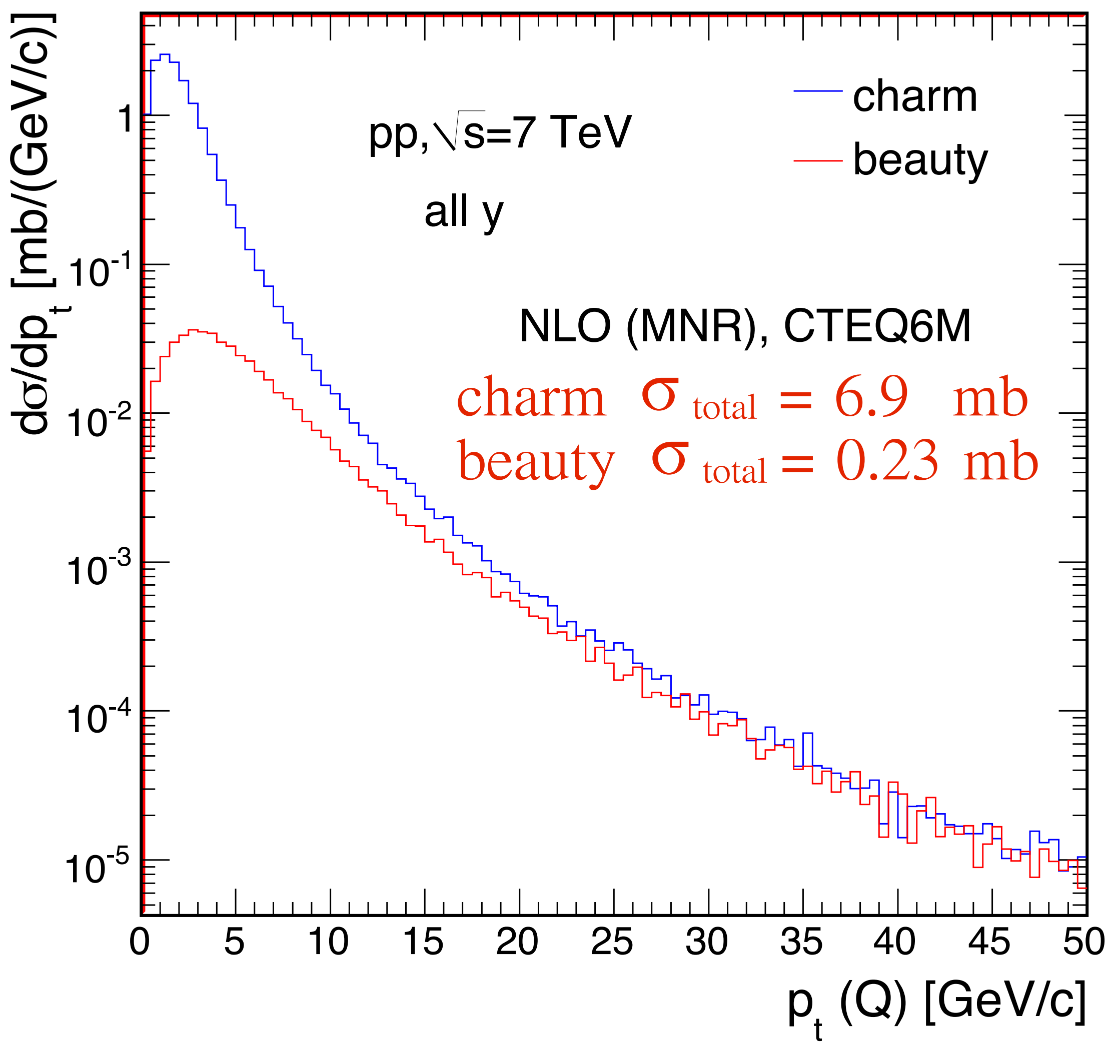


Data of one full luminosity Pb+Pb run (10^6 s) should clarify heavy flavor quenching story

Charm/Beauty from HVQMNR

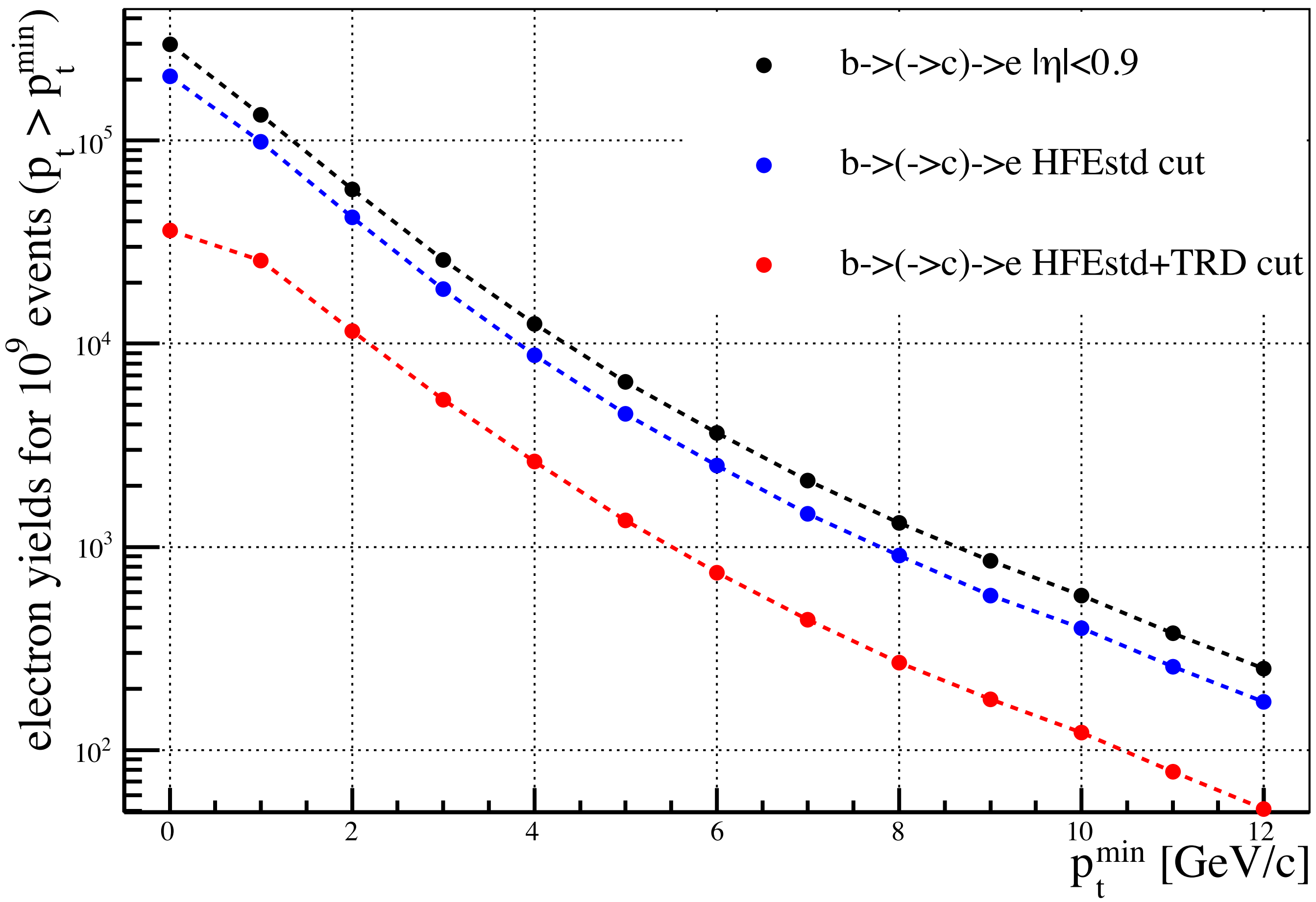
plot by Anton: http://www-alice.gsi.de/ana/results/results.html



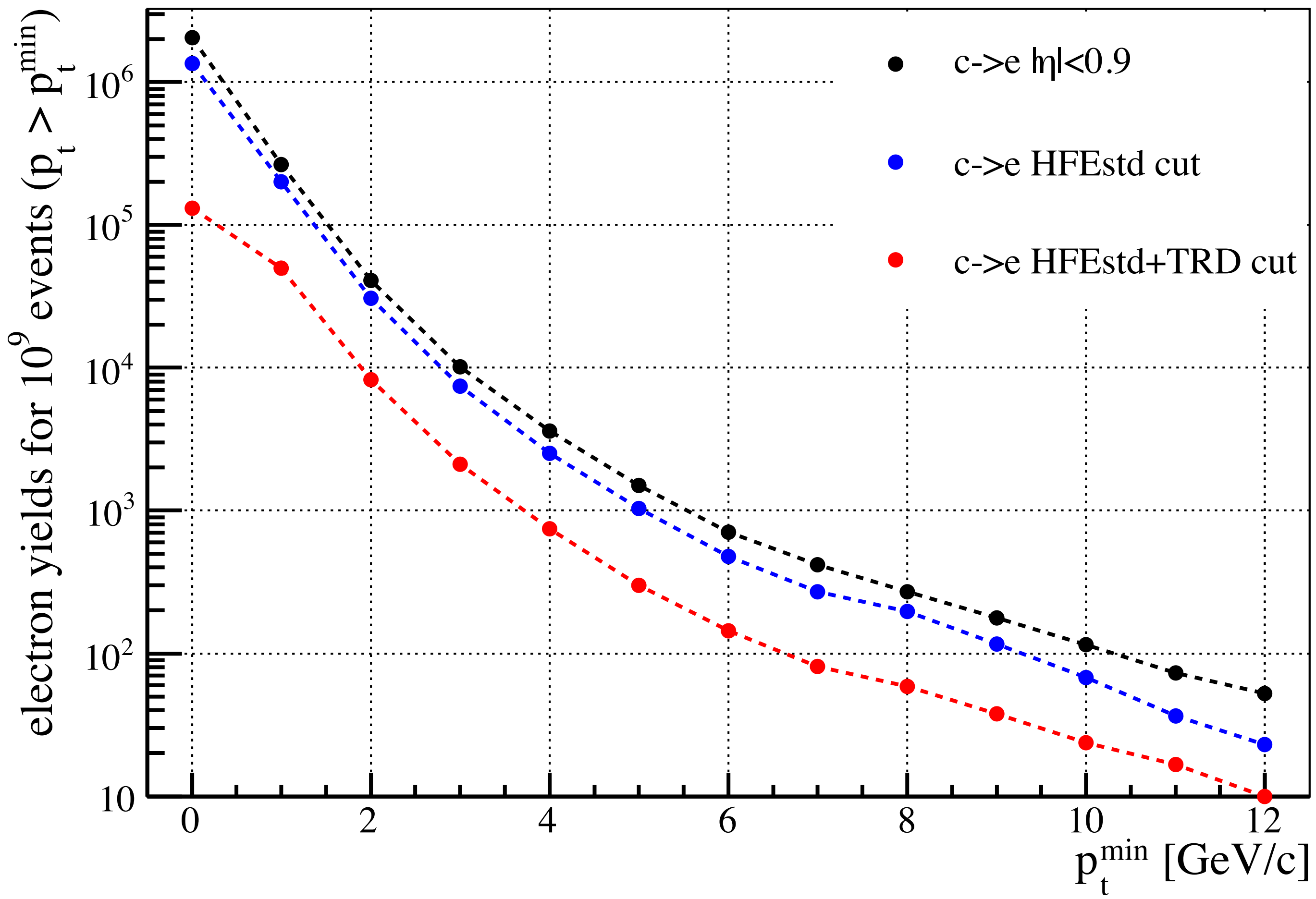


Yield

Beauty in pp @ $\sqrt{s}$ = 7 TeV



Charm in pp @ $\sqrt{s}$ = 7 TeV

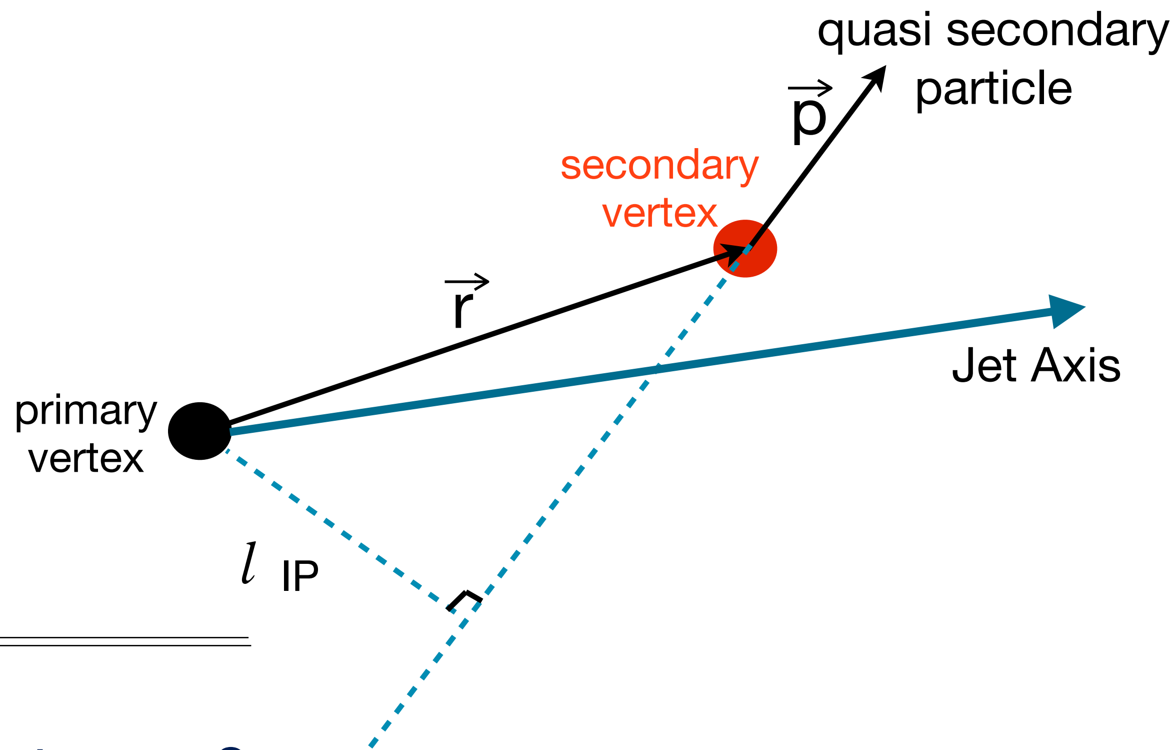


10^9 pp events leads ~190k(47k) charm and ~98k(25k) beauty electrons at $p_t > 1$ GeV/c

Distinctive variables and cuts

Secondary vertex variables

- signed decay length $(Signed\ L_{xy}) = |\vec{r}| \frac{\vec{r} \cdot \vec{p}}{|\vec{r} \cdot \vec{p}|}$
- invariant mass
- secondary vertex χ^2/NDF
- impact parameter of secondary particle(l_{IP})



Event selection cuts

- Collision event selection cuts
- Number of tracks to contribute to the primary vertex >=2 (primary vertex with beam diamond constraint)

Track & secondary vertex selection cuts

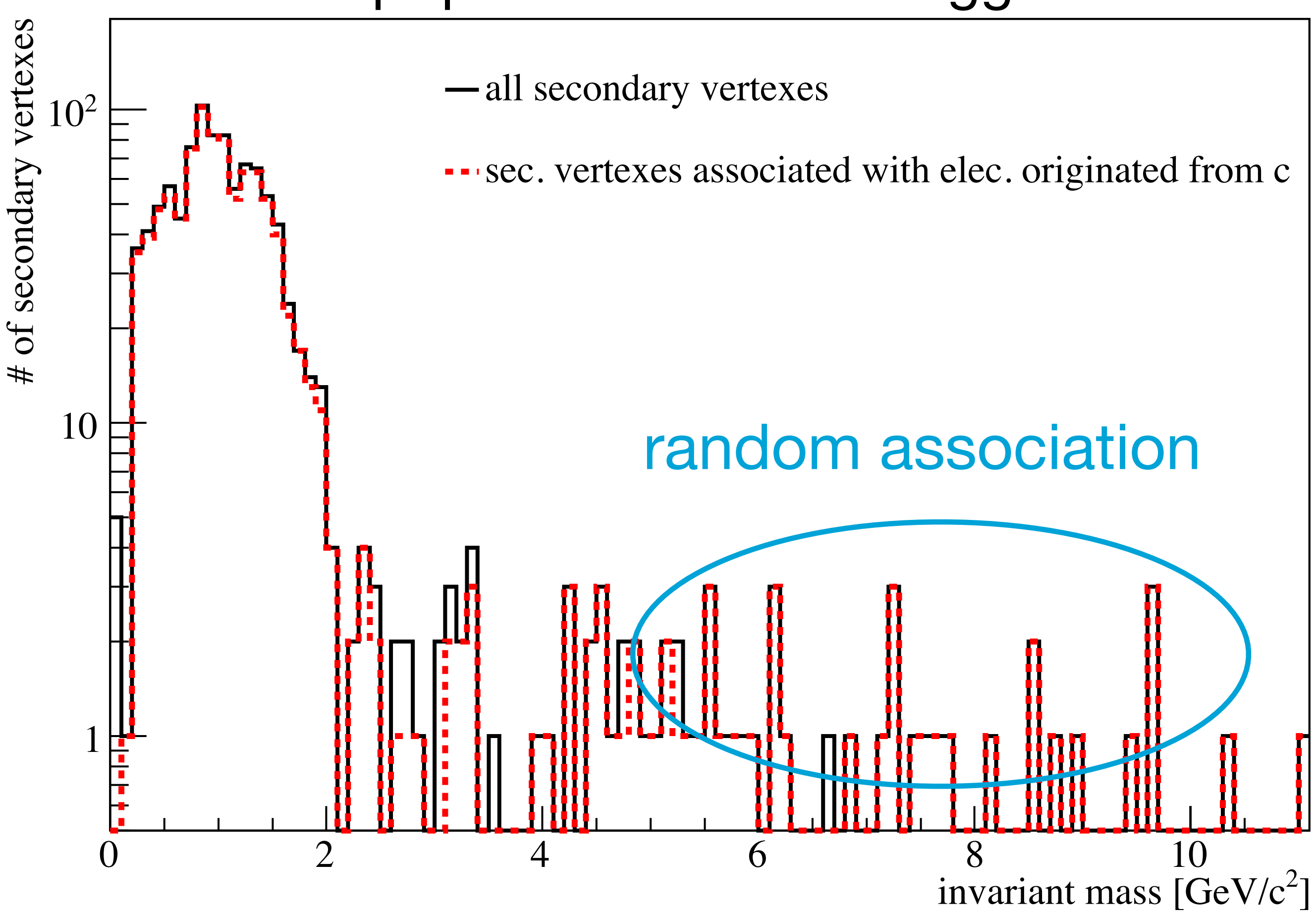
- Single track quality cuts(for electrons, hit is required on the most inner detector to reduce conversion background)
- Electron selection cuts
- Single track $p_T > 2.0$ GeV/c
- 2.0 GeV/c^2 < invariant mass < 5.2 GeV/c^2
- 0.08 cm < signed L_{xy} < 1.5 cm
- Secondary vertex χ^2/NDF <3(5), tighter cuts for 2 particle sec. vertex
- |impact parameter of secondary particle| < 0.1 cm

Powerful to reject charm background

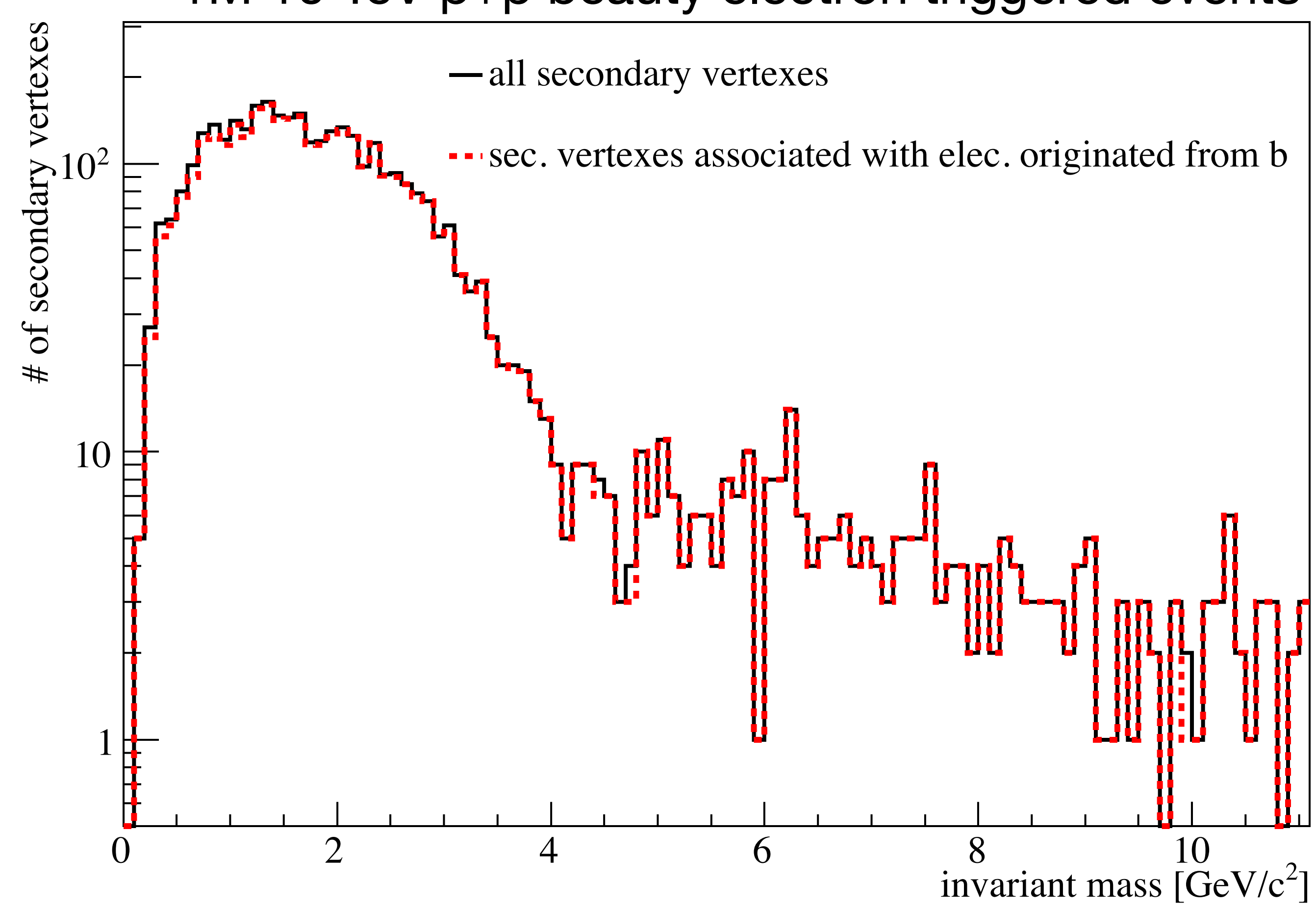
- Signed decay length $(Signed\ L_{xy}) = |\vec{r}| \frac{\vec{r} \cdot \vec{p}}{|\vec{r} \cdot \vec{p}|}$
- Invariant mass
- Secondary vertex χ^2/NDF
- Impact parameter of secondary particle($l_{\rm IP}$)

MC PID for electron selection

~ 4M 10 TeV p+p charm electron triggered events



~ 1M 10 TeV p+p beauty electron triggered events

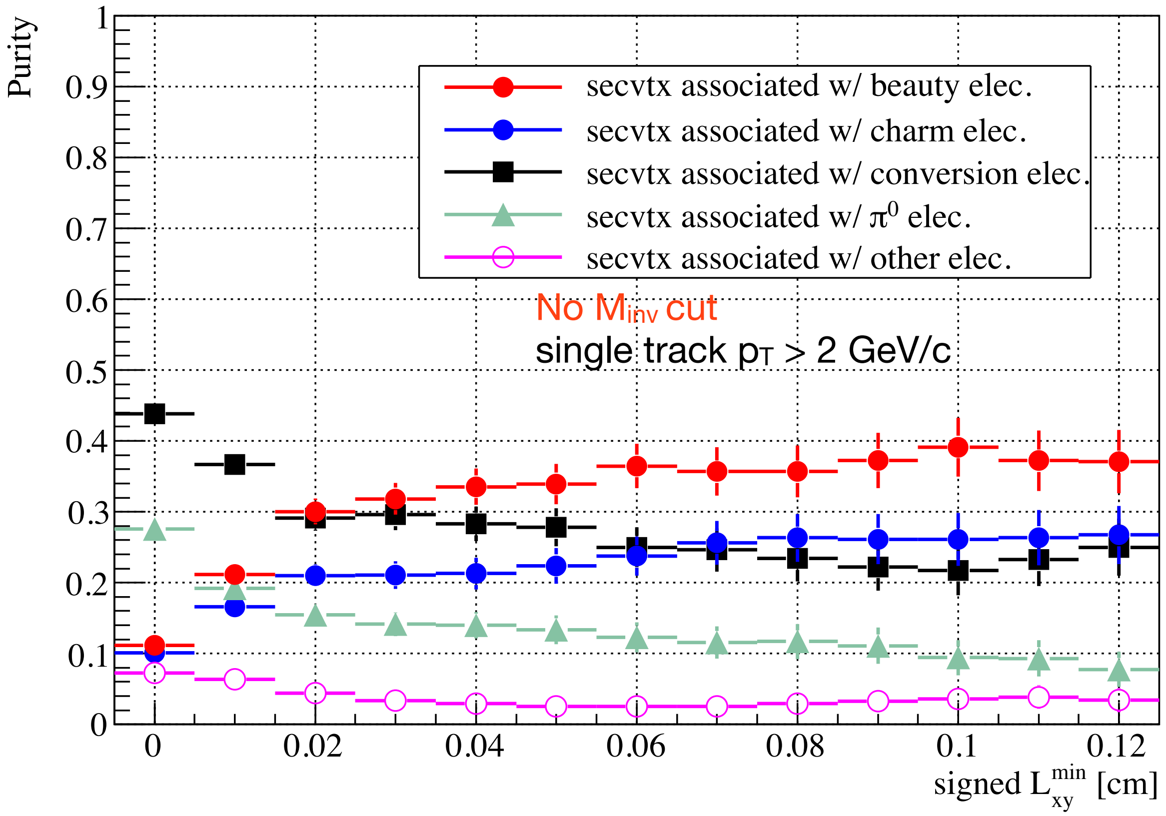


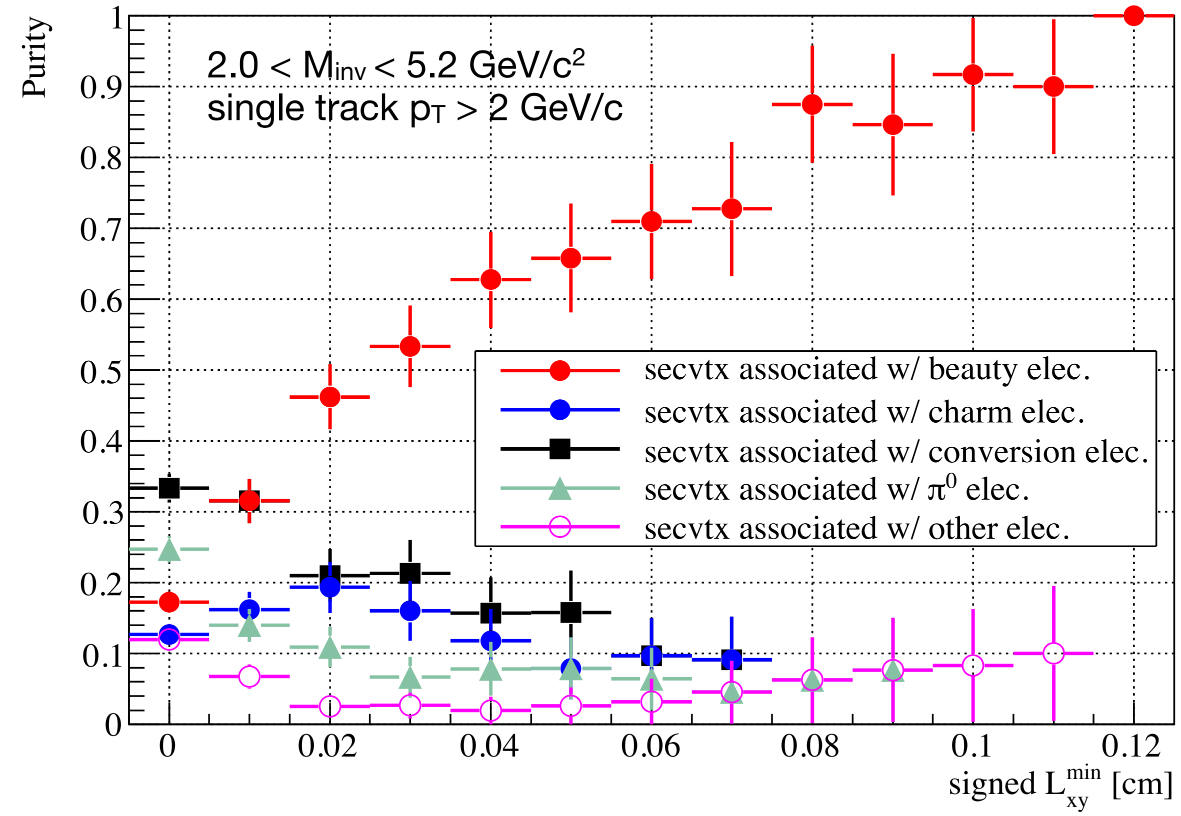
Invariant mass cut is good to suppress charm background

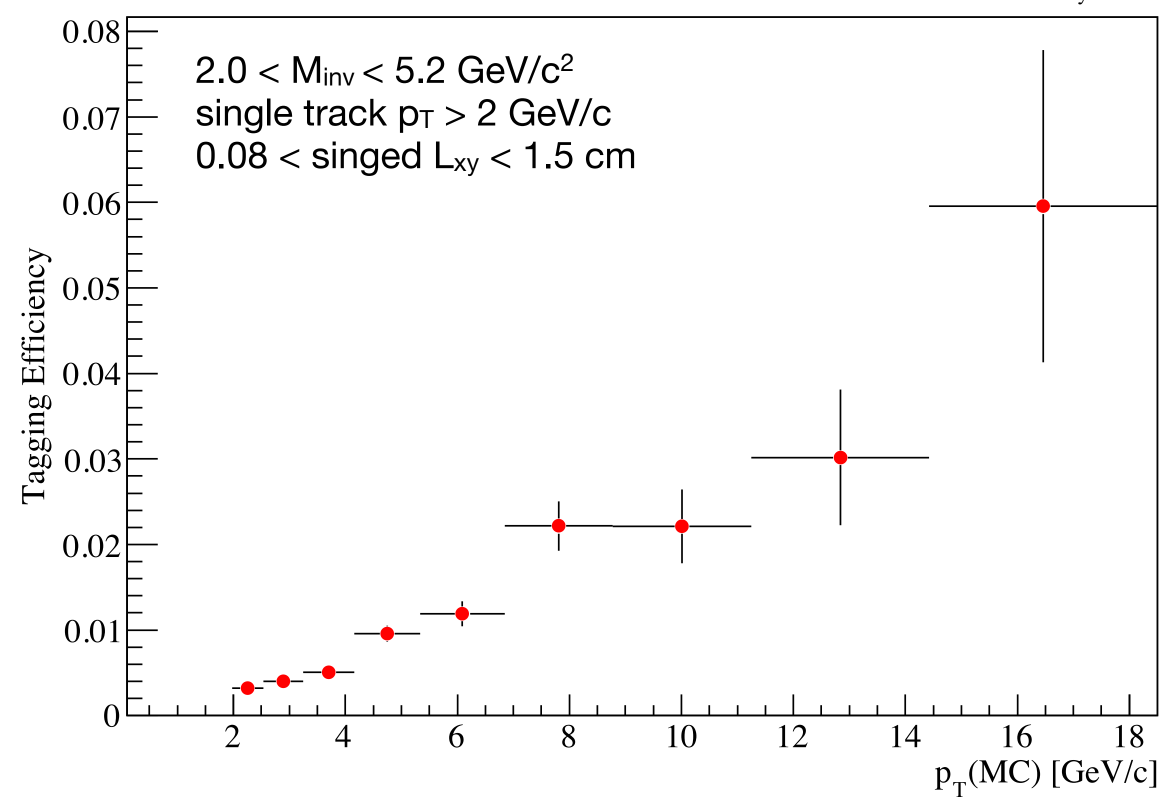
→ Allow to separate beauty from charm

Purity and efficiency

PYTHIA MinBias, $\sqrt{s}$ = 10 TeV, 2.7x10[7] events, MC PID







$\Rightarrow$ ~80% purity with currently optimized cuts with current understanding on MC

Analysis Approach via Electrons

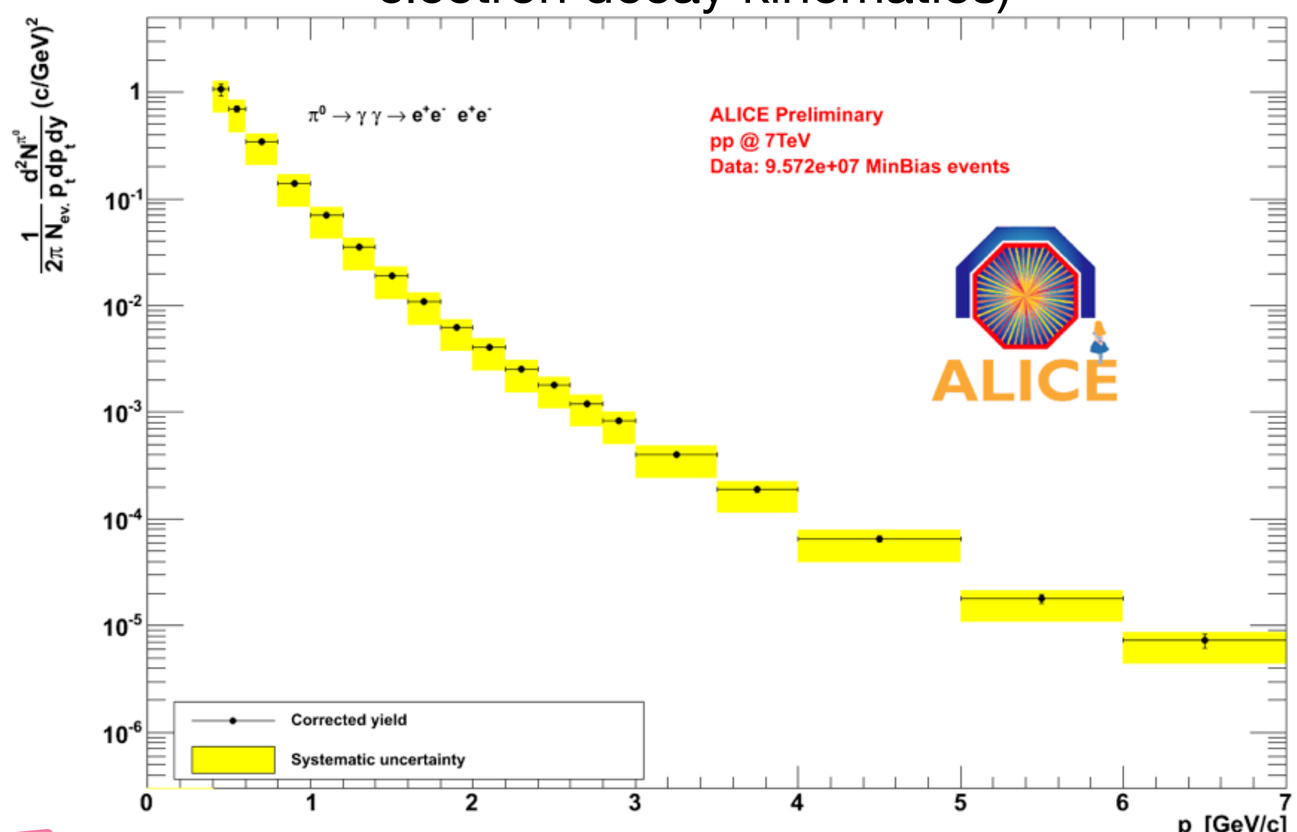
(1) Measure inclusive electron transverse momentum spectrum

(2) Build background contributions spectrum described with an electron cocktail (photonic, Dalitz/dielectron decays of mesons, weak kaon decay, direct radiation, J/ψ and ϒ)

(3) Measure heavy flavor semi-electronic decays by subtracting (2) from (1)

Electron Cocktail

- π^0 Dalitz decay sources: the π^0 measured spectrum (Fit with Hagedorn function and use PYTHIA electron decay kinematics)

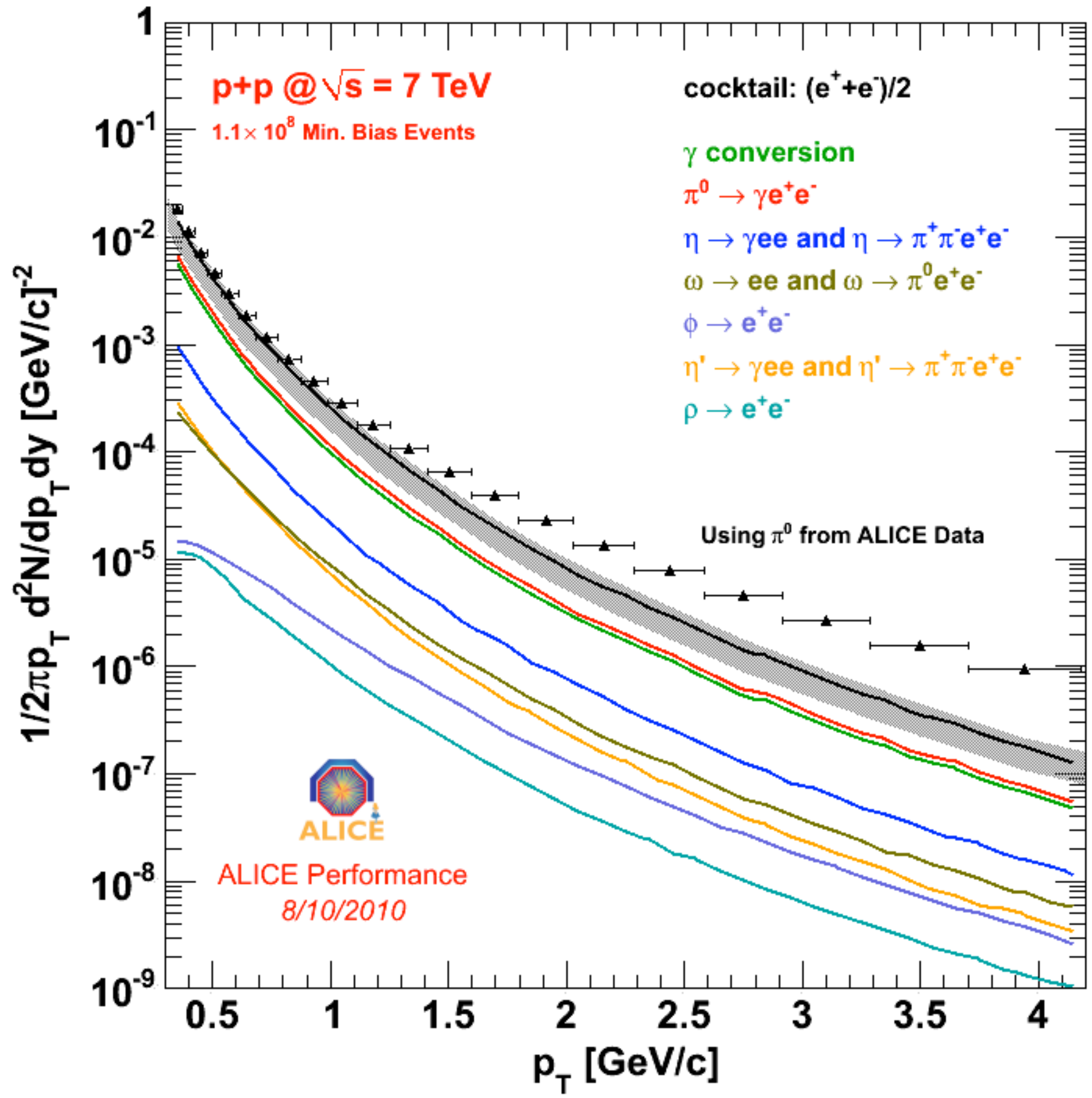


- Heavier meson sources(η, η', ρ, ω, φ): implemented via m_T scaling(verified for η)
- Photon conversion sources:
  - Calculate photon conversion in the beam pipe and 1/3 of the first pixel layer (0.5 % X_0)
  - Use the ratio of conversion to Dalitz electrons to estimate the $e^{\pm}$ contributions

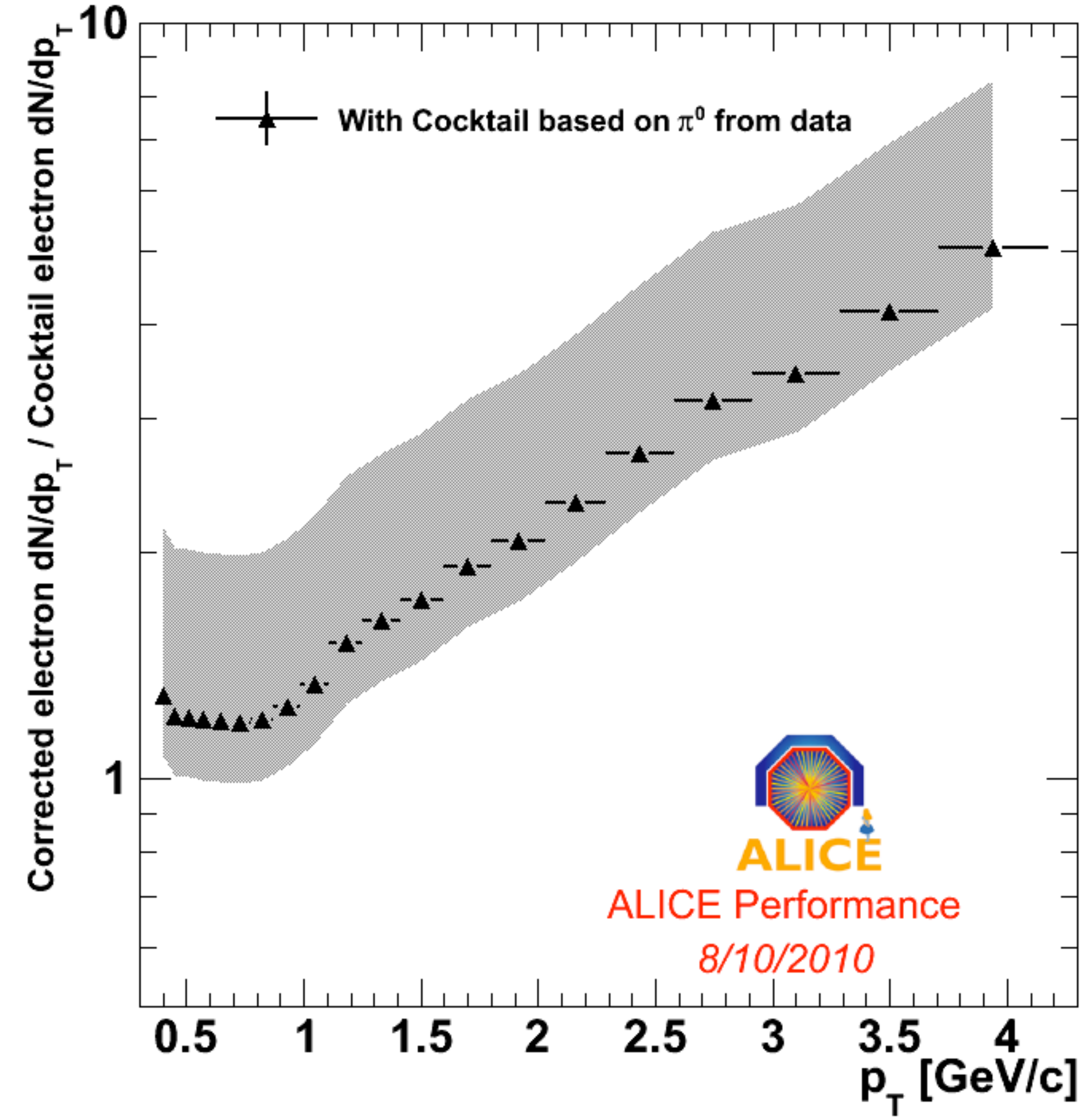
$$\frac{Conv.}{Dalitz} = \frac{BR^{\gamma\gamma} \times 2 \times \left(1 - e^{-7/9 \times X/X_0}\right) \times 2}{BR^{Dalitz} \times 2}$$

Cocktail and Corrected Inclusive Electron Spectrum

Data & Cocktail



Ratio Data/Cocktail



Excess from open heavy flavors (including J/ψ, direct radiation)

- Systematic errors on input π^0 spectrum (+20% −40%) is propagated to the cocktail
  (Will be reduced in near future!)
- No systematic errors are shown yet on the corrected inclusive electron spectrum