First Look at Beauty and Beauty-jet Tagging via Secondary Vertexing with ALICE in p+p collisions at $\sqrt{s}$ = 7 TeV

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August 14th 2010, Jets in Proton-Proton and Heavy-Ion Collisions, Prague

Outline

- **Why heavy flavour, especially b, is interesting?**
- **Open heavy flavour at LHC in theory**

- **ALICE heavy flavour measurement capability**
- **Introduction of analysis method**

- **Preliminary look of p+p@7 TeV data**

- **Summary**

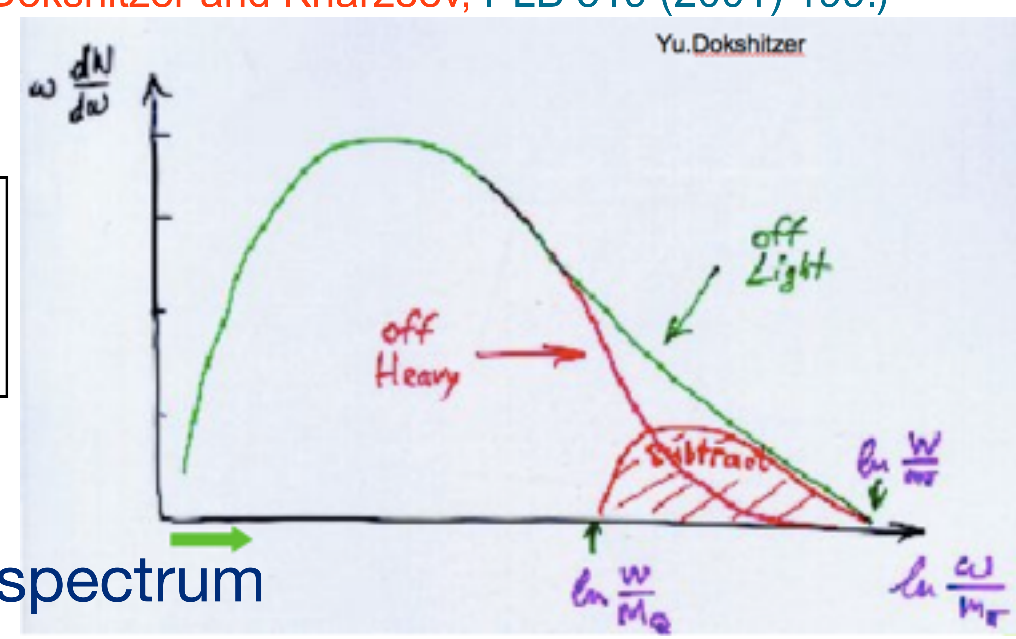
Energy loss for heavy quarks: differ from light?

- In vacuum, characteristic mass-dependent depletion of the gluon radiation at angles $\theta < m_Q/E_Q$: dead cone effect
  - distribution of gluons radiated by a heavy quark

$$dP_{HQ} = dP_0 \cdot \left(1 + \left(\frac{M_Q}{E_Q}\right)^2 \frac{1}{\theta^2}\right)^{-2} \quad \text{,where} \quad \theta \simeq \frac{k_T}{\omega}$$

- In medium, dead cone implies lower energy loss (Dokshitzer and Kharzeev, 2001)
  - angular distribution of gluons induced by the quark propagation in the medium with the size of the dead cone(Dokshitzer and Kharzeev, PLB 519 (2001) 199.)

$$\omega \frac{dI}{d\omega}\bigg|_{Heavy\ in\ Medium} = \omega \frac{dI}{d\omega}\bigg|_{Light\ in\ Medium} \cdot \left(1 + \left(\frac{M}{E}\right)^2 \frac{1}{\theta^2}\right)^{-2}$$

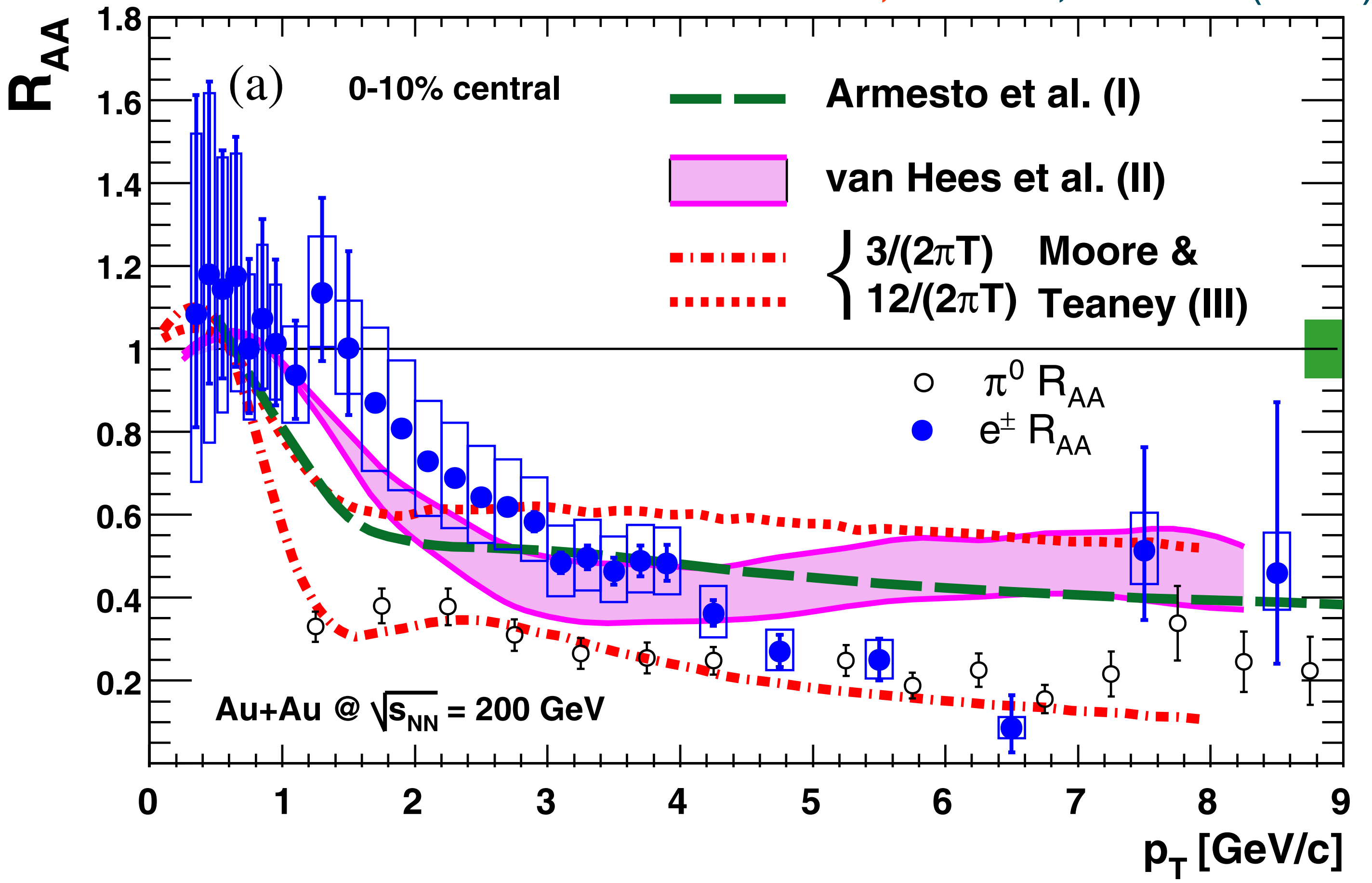


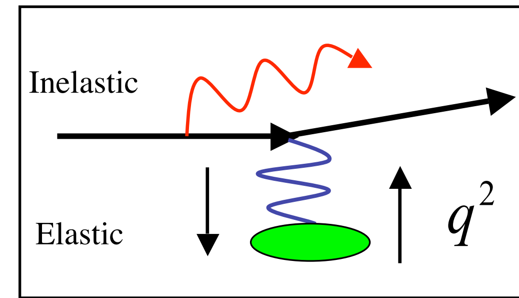
suppress high-energy tail of gluon radiation spectrum
$\Rightarrow$ sizable reduction of energy loss
$\Rightarrow$ most pronounce for bottom

Heavy quark energy loss at RHIC via heavy-flavour electron

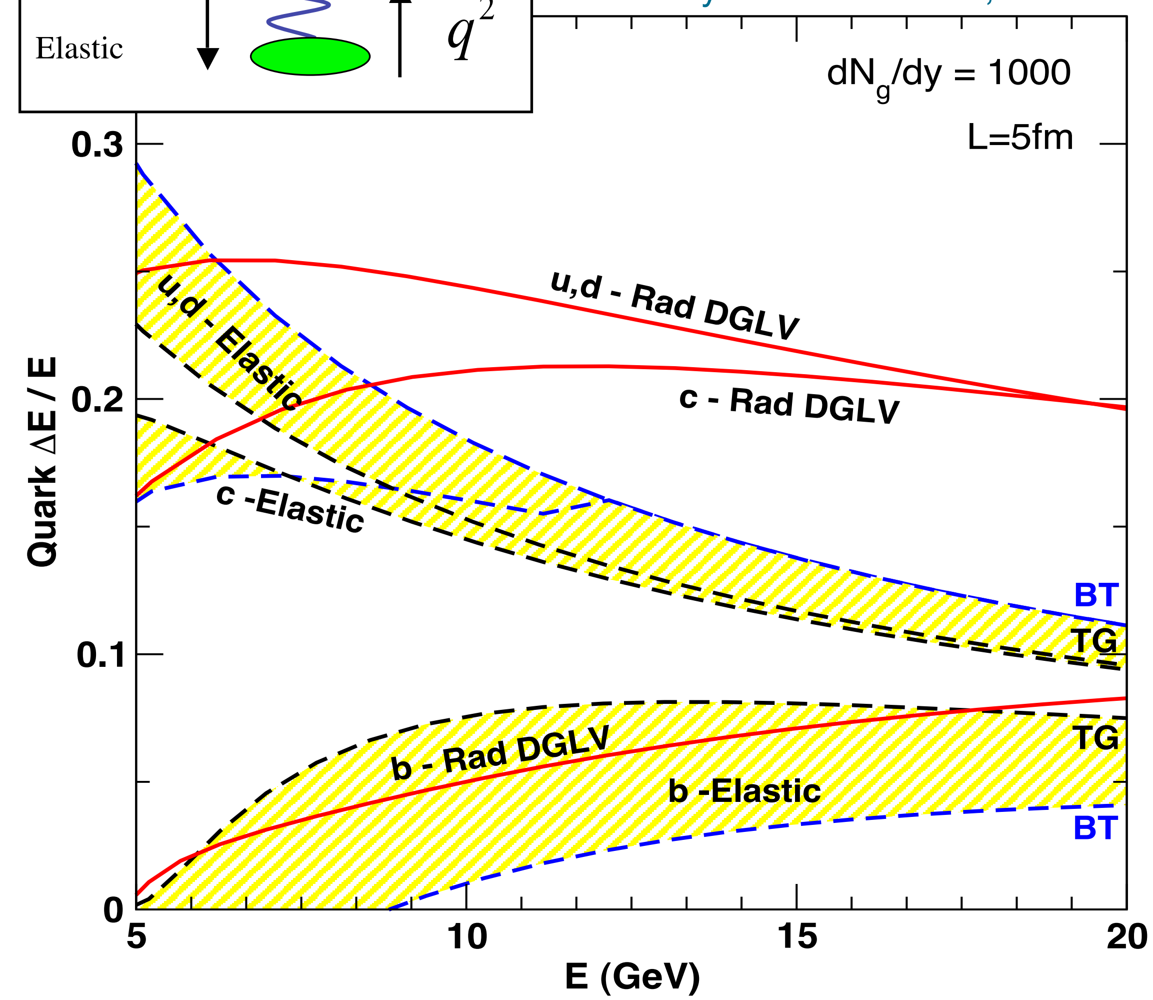
$$R_{AA}(p_T) = \frac{1}{\langle N_{coll} \rangle} \frac{dN_{AA}/dp_T}{dN_{pp}/dp_T}$$

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?

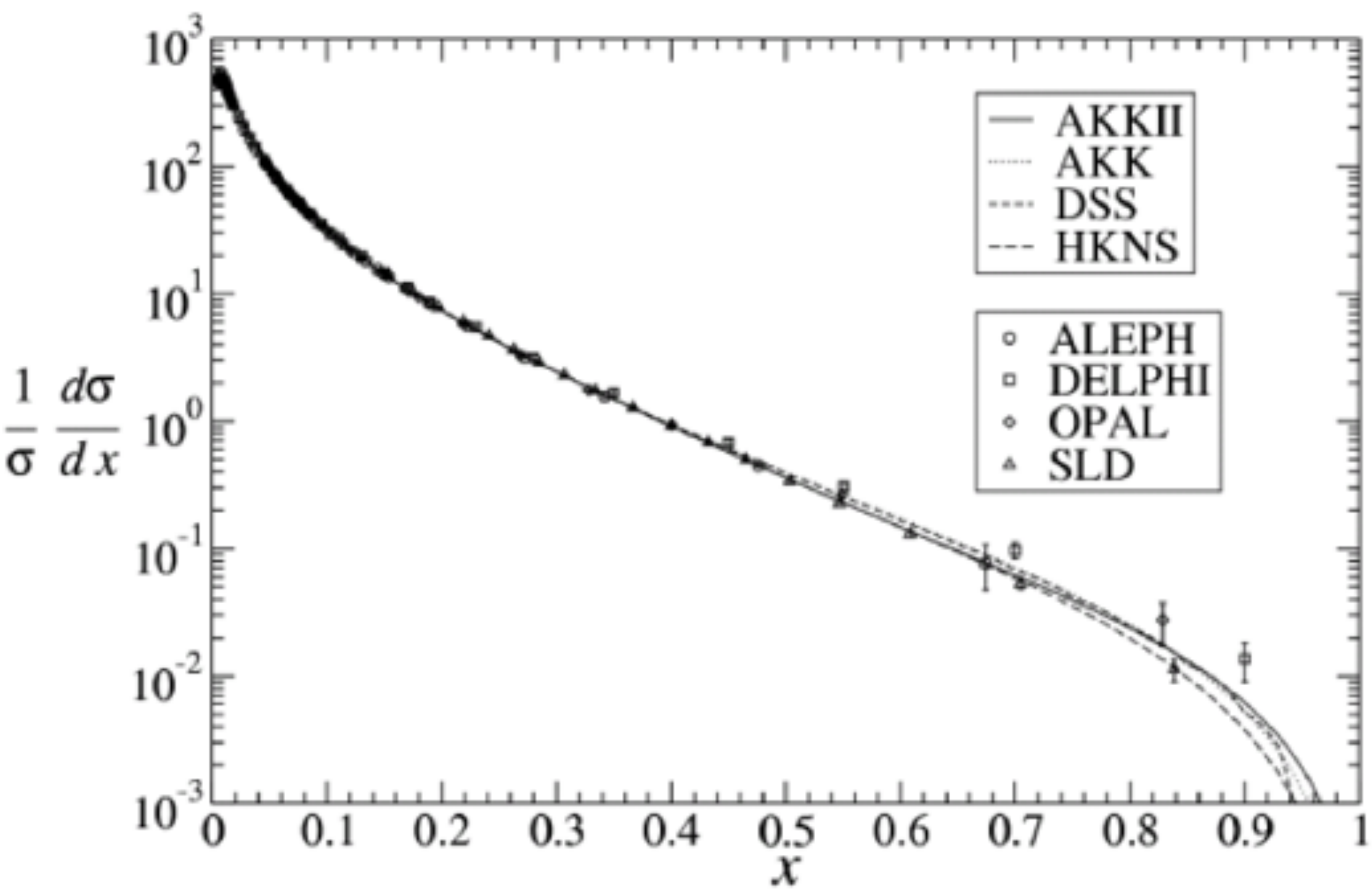
- → elastic energy lose negligible?
- → collisional dissociation probability of heavy mesons in the QGP

⇒ roll of individual D, B meson contribution?

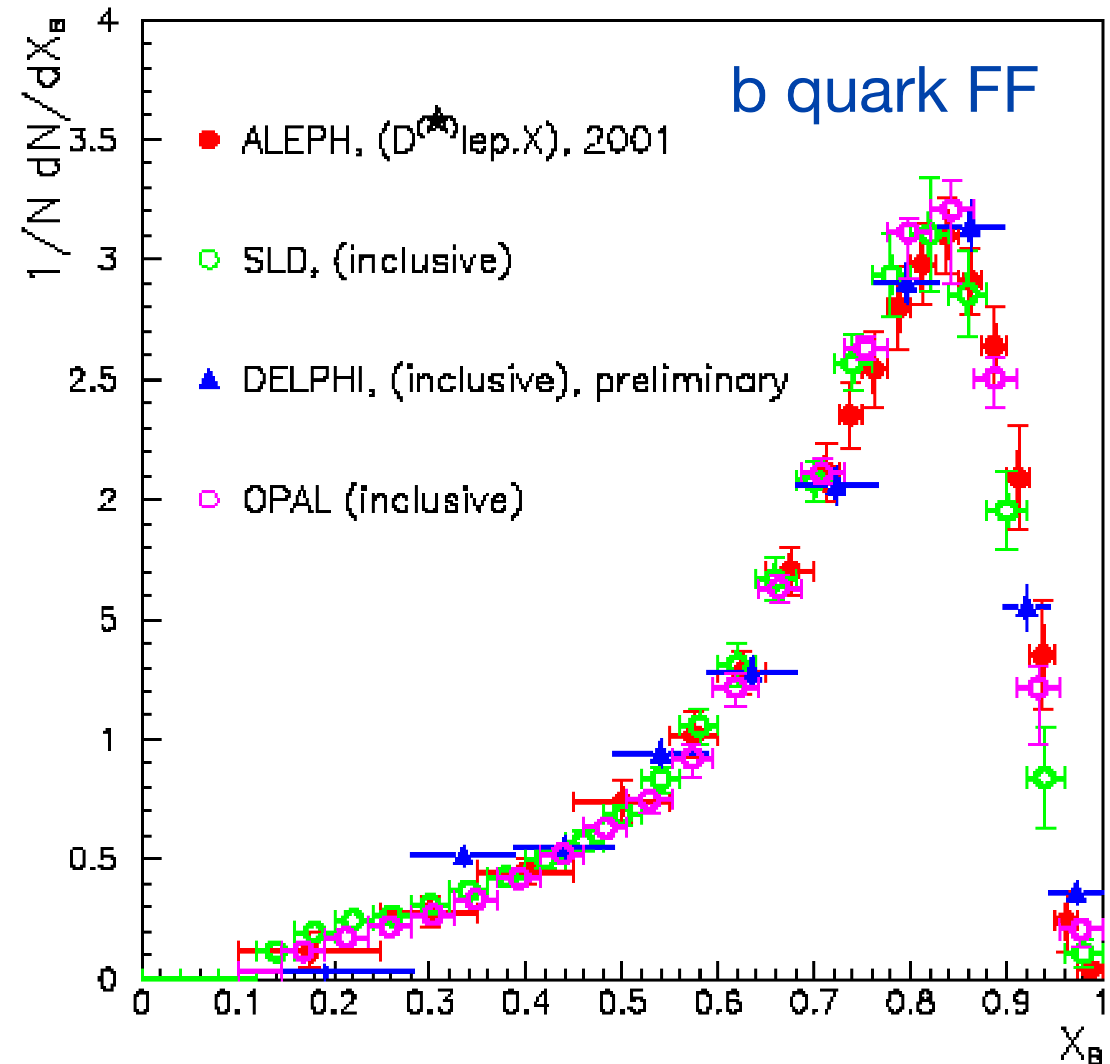
More with B-jet

b quark fragmentation function

$$e^+e^- \rightarrow \pi^\pm + X,\ \sqrt{s} = 91.2\ GeV$$



$$e^+e^- \rightarrow QX \rightarrow H_Q X$$

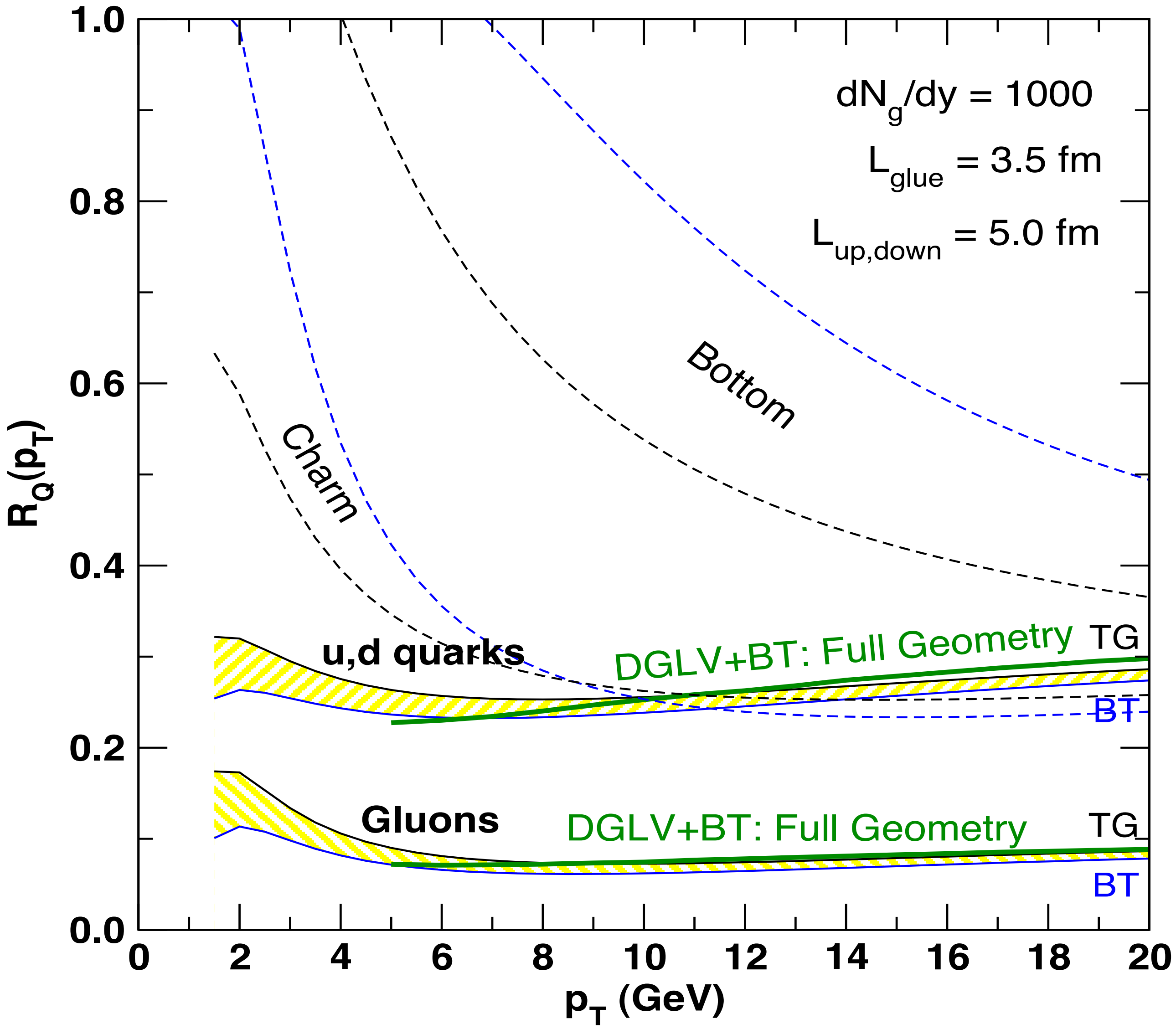


b-quark fragments much harder than light quarks

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

More with B-jet
Quark vs. gluon energy loss in the medium

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



Color charge dependence of energy loss

$$\omega \frac{dI}{d\omega} \propto \alpha_s C_R f(\omega),$$
$$C_R = 3(4/3) \;\; for\; g(q)$$

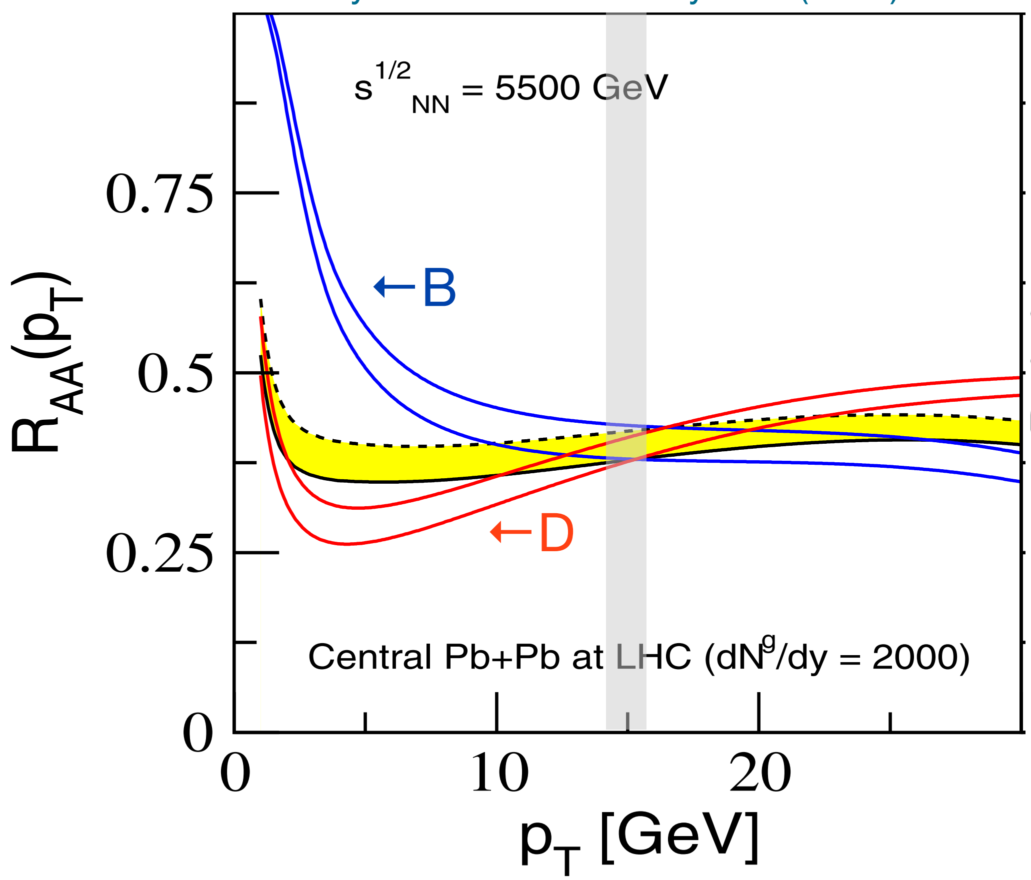
B-jets constitute a very pure samples of quark jets

here, $R_Q = d\sigma_Q^{final} / d\sigma_Q^{initial}$ (partonic modification factor before hadronization)

Open heavy flavour R_{AA} at LHC (I)

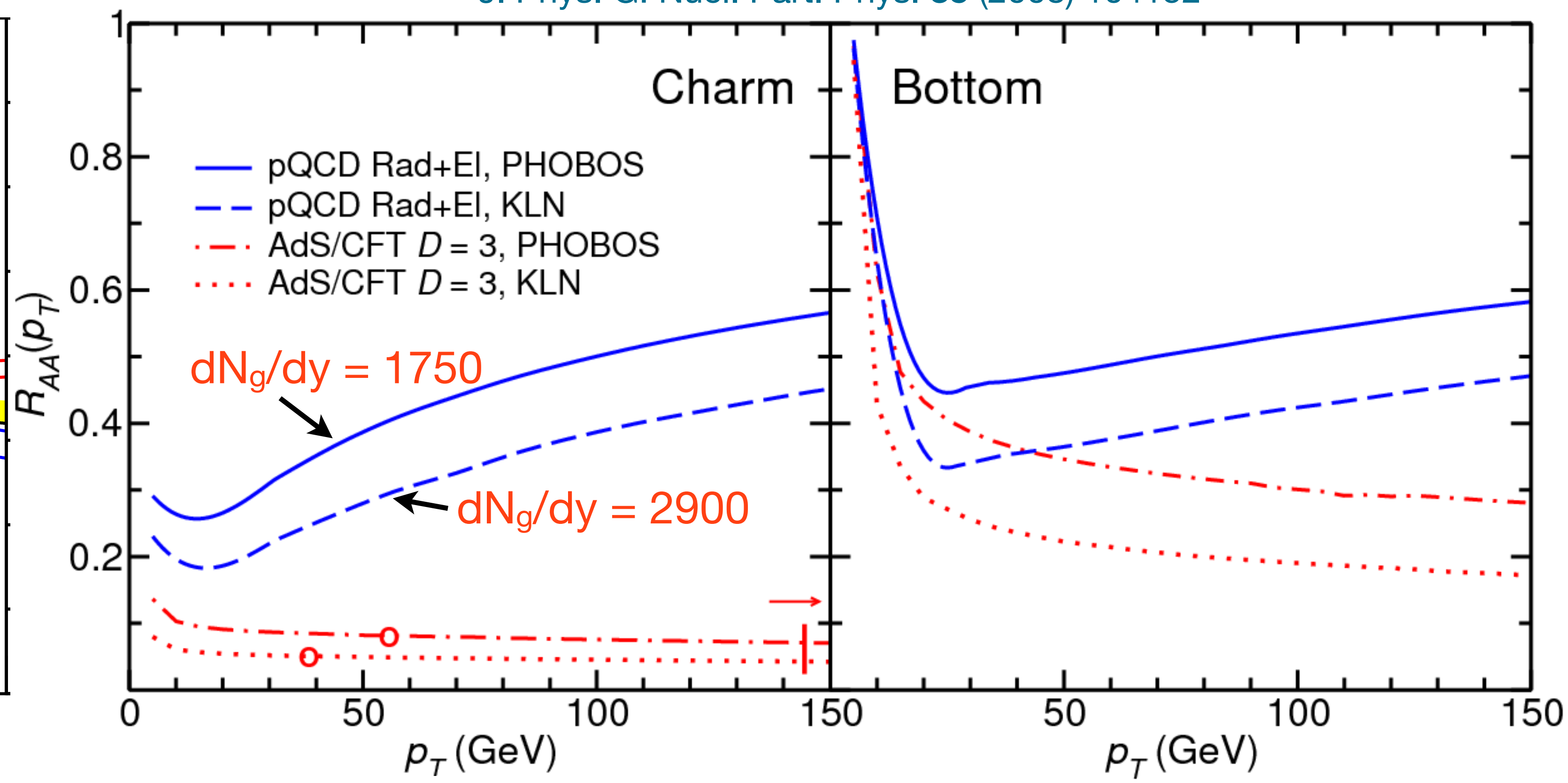
Heavy meson dissociation in QGP

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

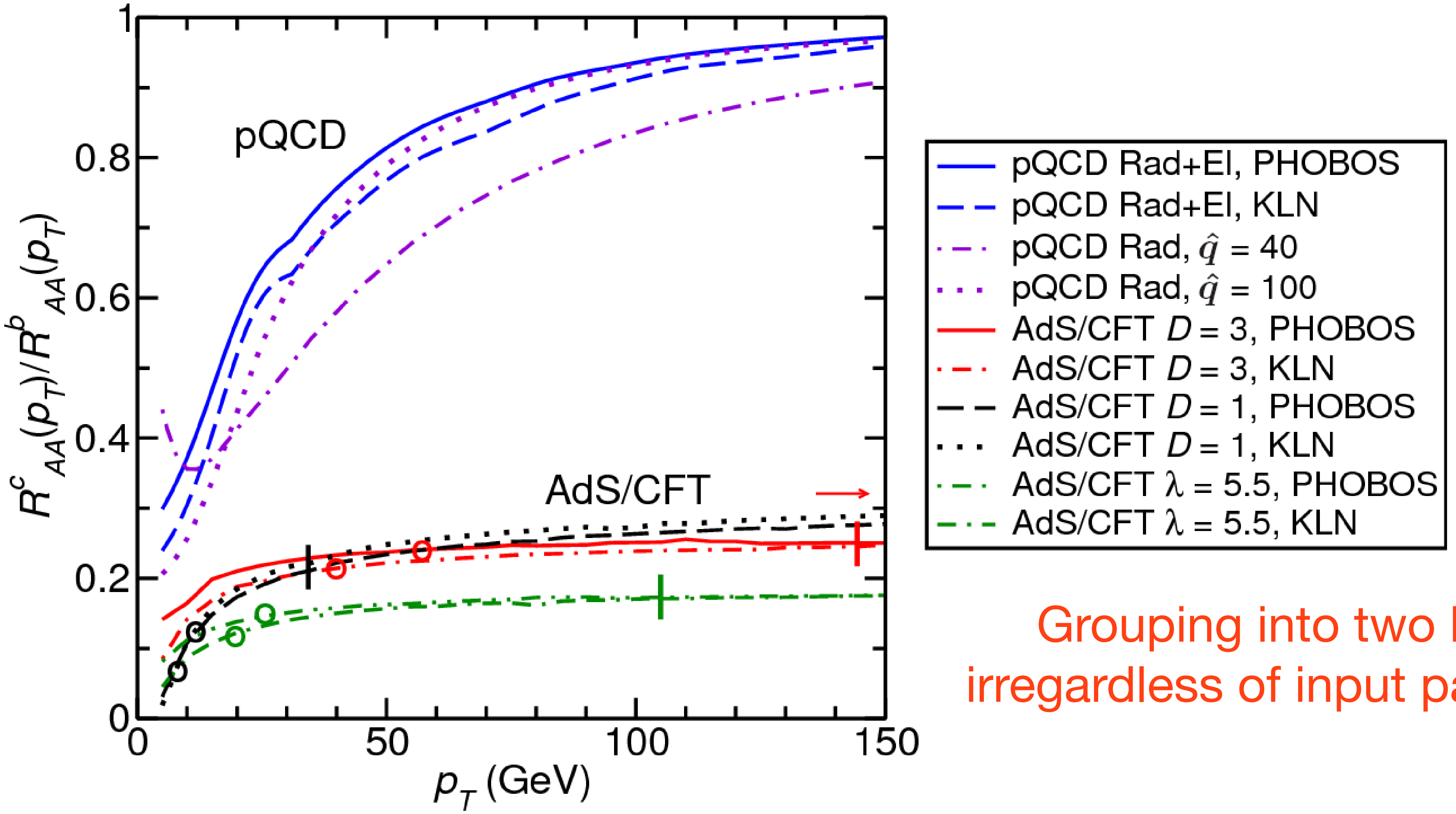


GLV + QGP dissociation shows B-meson suppression comparable to (or larger) D-meson as low as $p_T \sim 15$ GeV

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

Charm-to-Bottom ratio at LHC

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



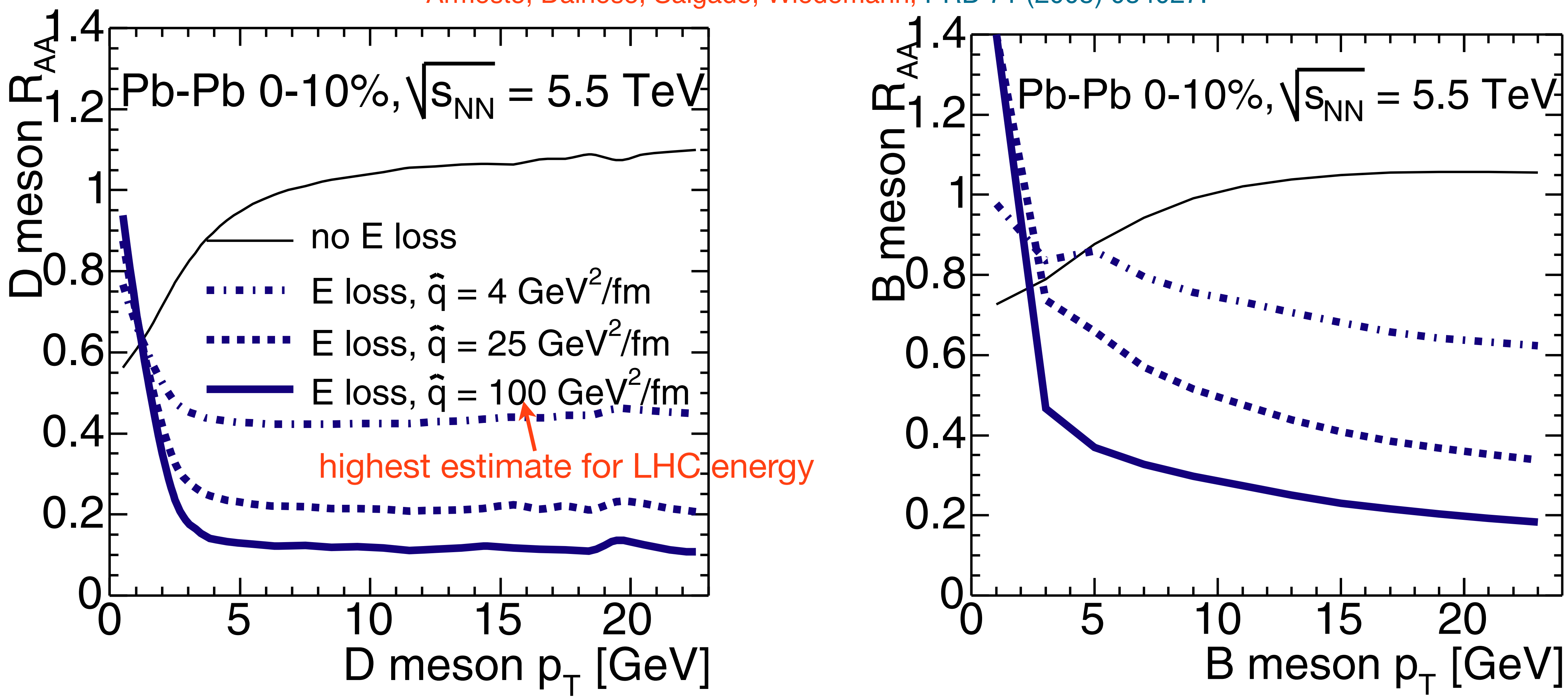
Grouping into two bands, irregardless of input parameters

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 bottom separately

Open heavy flavour R_{AA} 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.

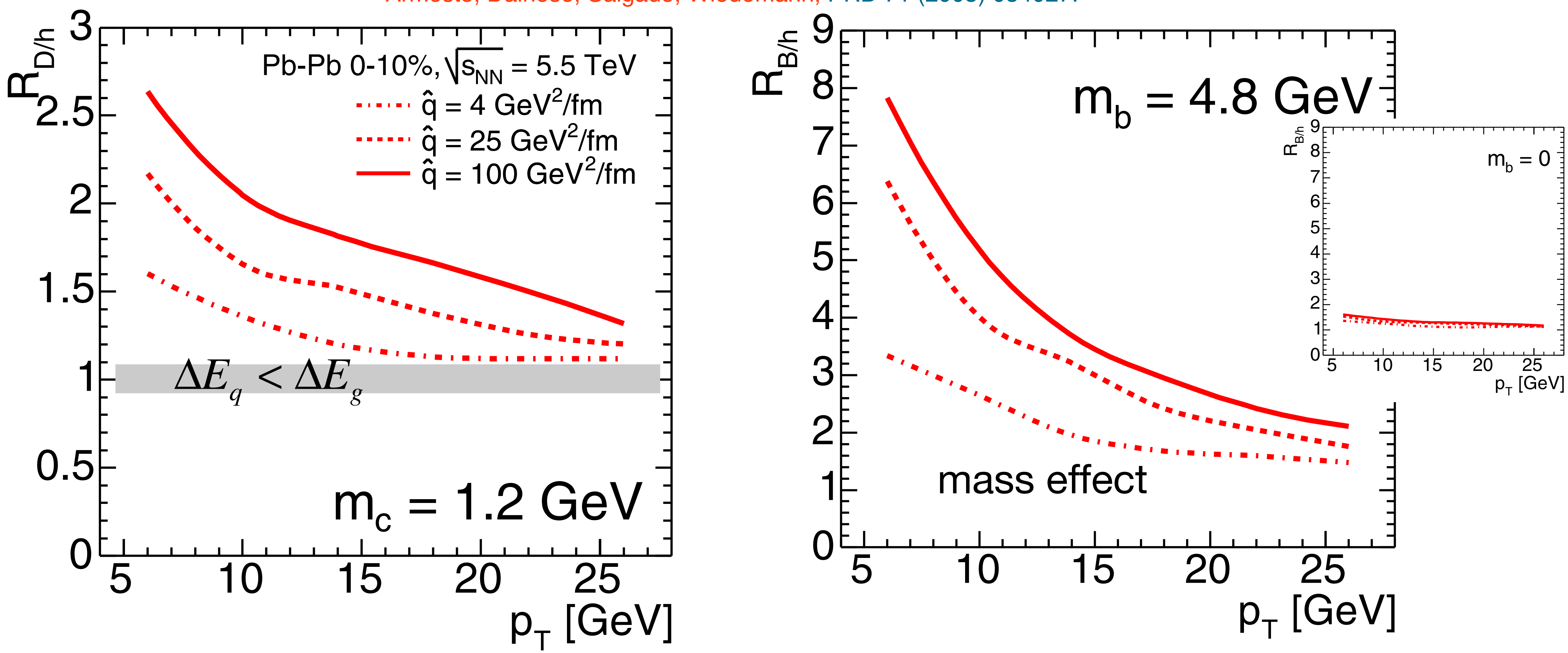
R_{AA} of D meson is less sensitive on varying $\hat{q}$ (higher $\hat{q}$ region), but can give good constraint together with R_{AA} of B meson with precise measurement

Heavy-to-Light ratios at 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

$$\omega \frac{dI}{d\omega} \propto \alpha_s C_R f(\omega),$$
$$C_R = 3 (4/3) \;\; for \; g(q)$$

Heavy quark production at LHC

MNR code (NLO): Mangano, Nason, Ridolfi, NPB373 (1992) 295

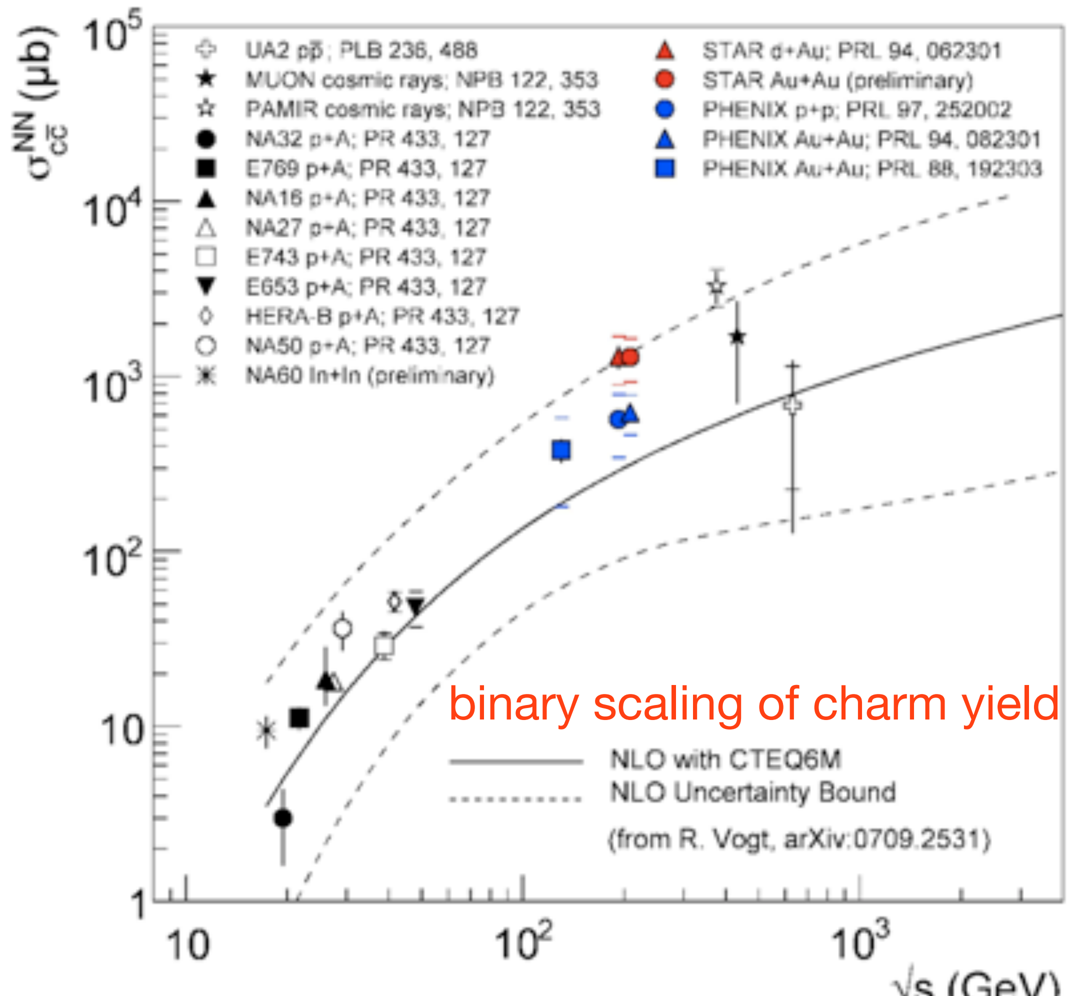
system: $\sqrt{s_{NN}}$:	Pb+Pb(0-5%) 5.5 TeV charm/beauty	Pb+Pb(0-5%) 2.75 TeV	p+p 14 TeV	p+p 7 TeV
$\sigma_{NN}^{Q\bar{Q}}[mb]$	3.4/0.14	2.1/0.075	11.2/0.5	6.9/0.23
$N_{total}^{Q\bar{Q}}$	90/3.7	56/2	0.16/0.007	0.10/0.003
$C_{shadowing}^{EKS98}$	0.58/0.77	0.60/0.85	-	-

Theoretical uncertainty of a factor 2-3

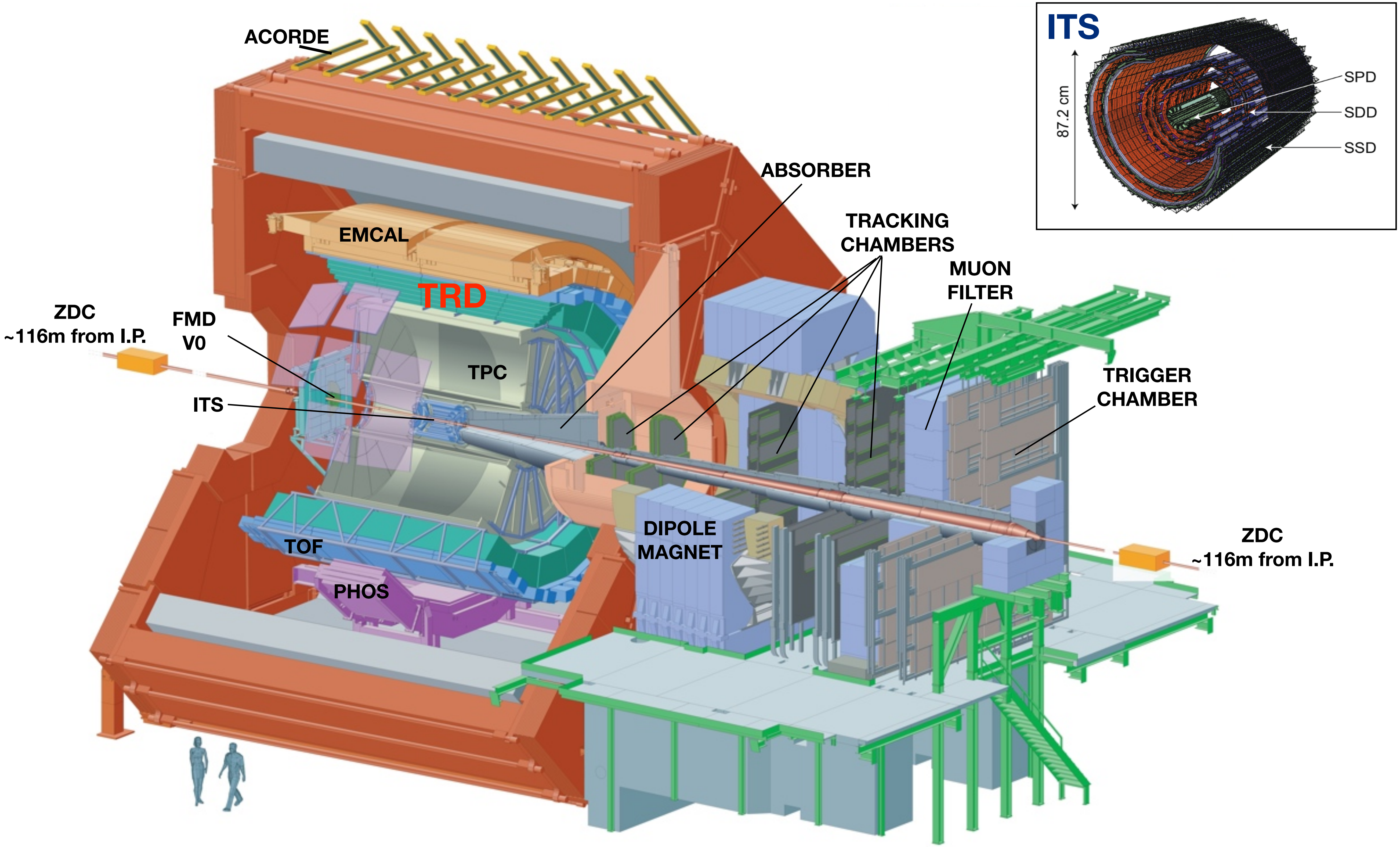
Measurement at lower energy

PHENIX 200 GeV (measured)

$\sigma_{c\bar{c}}^{NN}[\mu b] = 567 \pm 57$ (stat) ± 193 (sys)



A Large Ion Collider Experiment

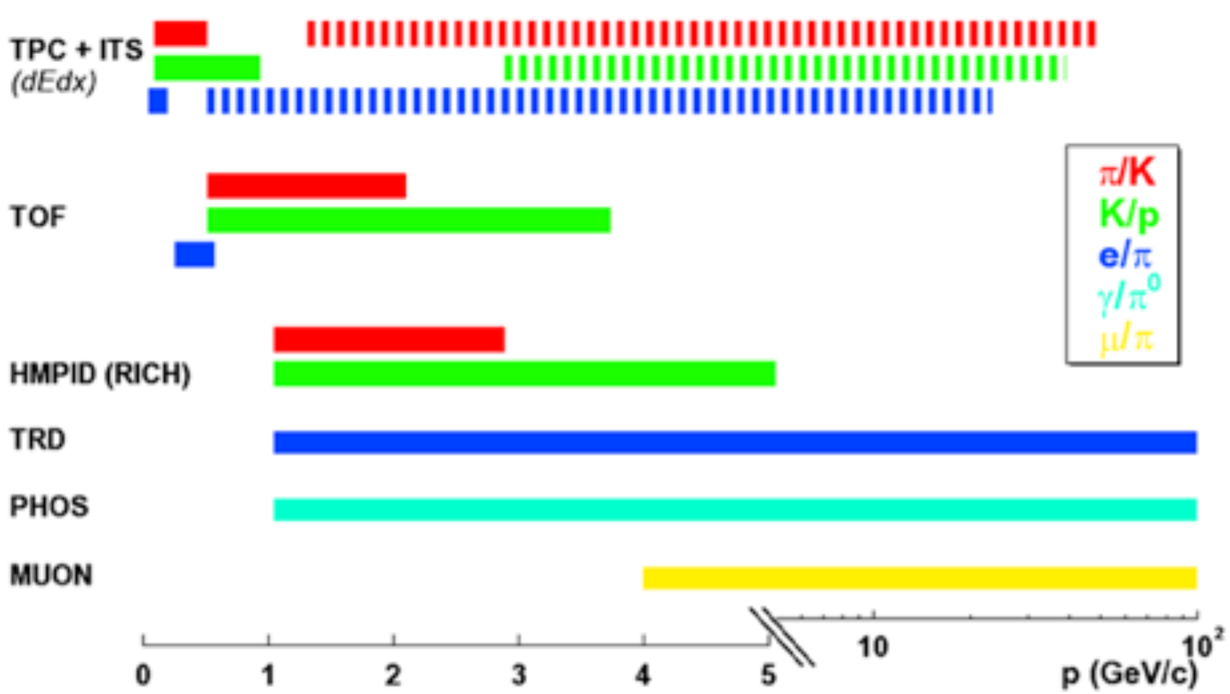


Collaboration: 31 countries, 109 institutes, > 1000 people

Heavy flavour measurement at ALICE

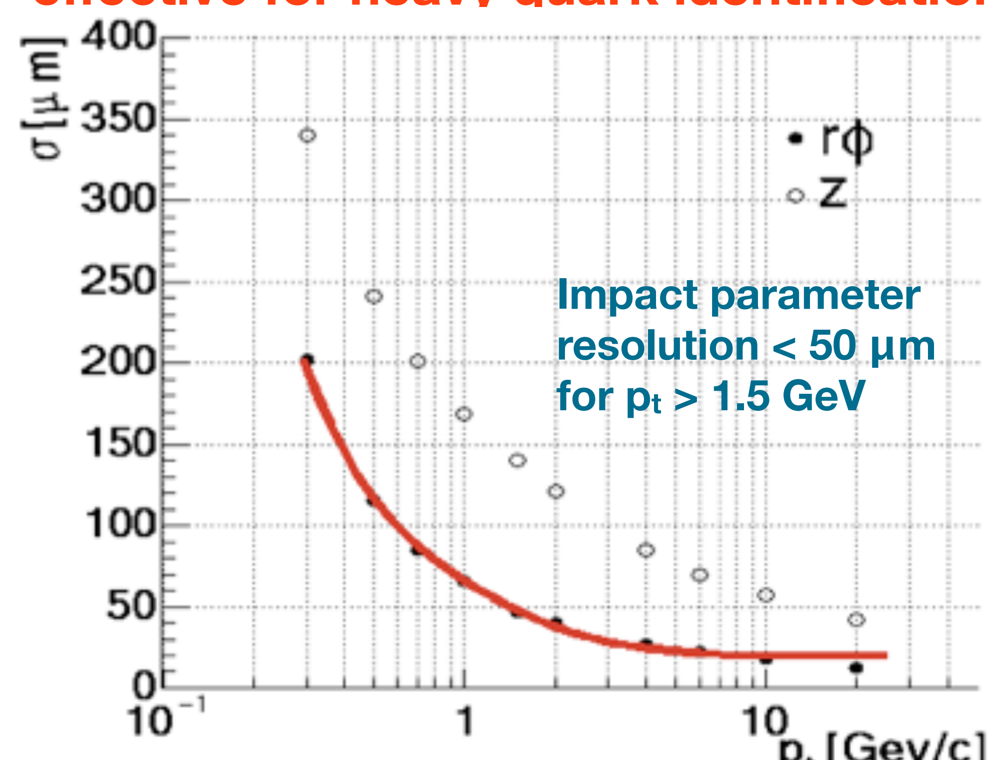
- Hadronic decays: $D^0 \rightarrow K\pi$, $D^{\pm} \rightarrow K\pi\pi$, $D_s \rightarrow K K^*$, … **(See Chiara Bianchin's Talk)**
- Leptonic decays:
  - D, B→l (e or μ) + anything
  - Invariant mass analysis of lepton pairs: J/Ψ, Ψ', ϒ family, B→J/Ψ + anything, $\chi_c \rightarrow$ J/Ψ + anything
- e-D^0 correlations
- B-Jet

PID of hadrons, electrons: -0.9<y<0.9
muons: 2.5<y<4.0



capable from ~ 100 MeV to above 50 GeV

In central barrel, vertex parameter cut effective for heavy quark identification



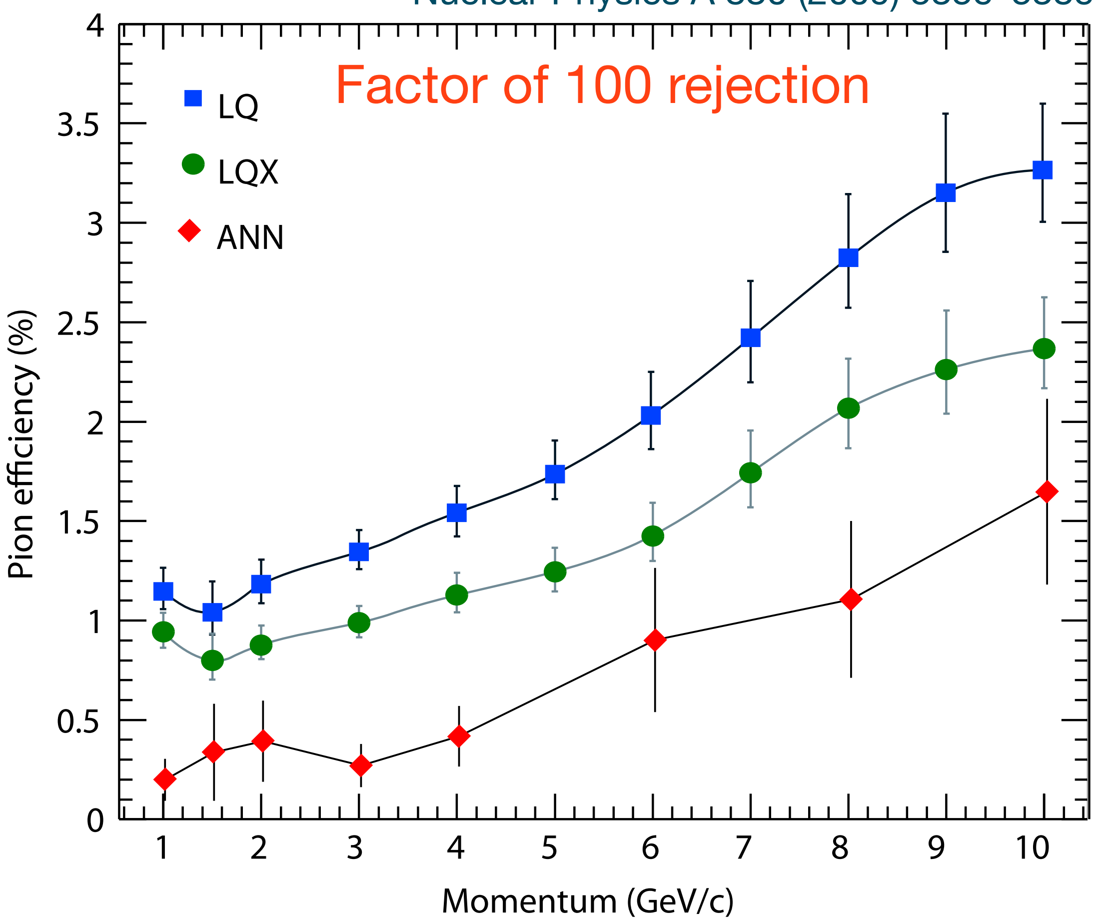
ALICE Physics Performance Report 2, J. Phys. G: Nucl. Part. Phys. 32 (2006) 1295

Electron Identification with TRD and EMCAL

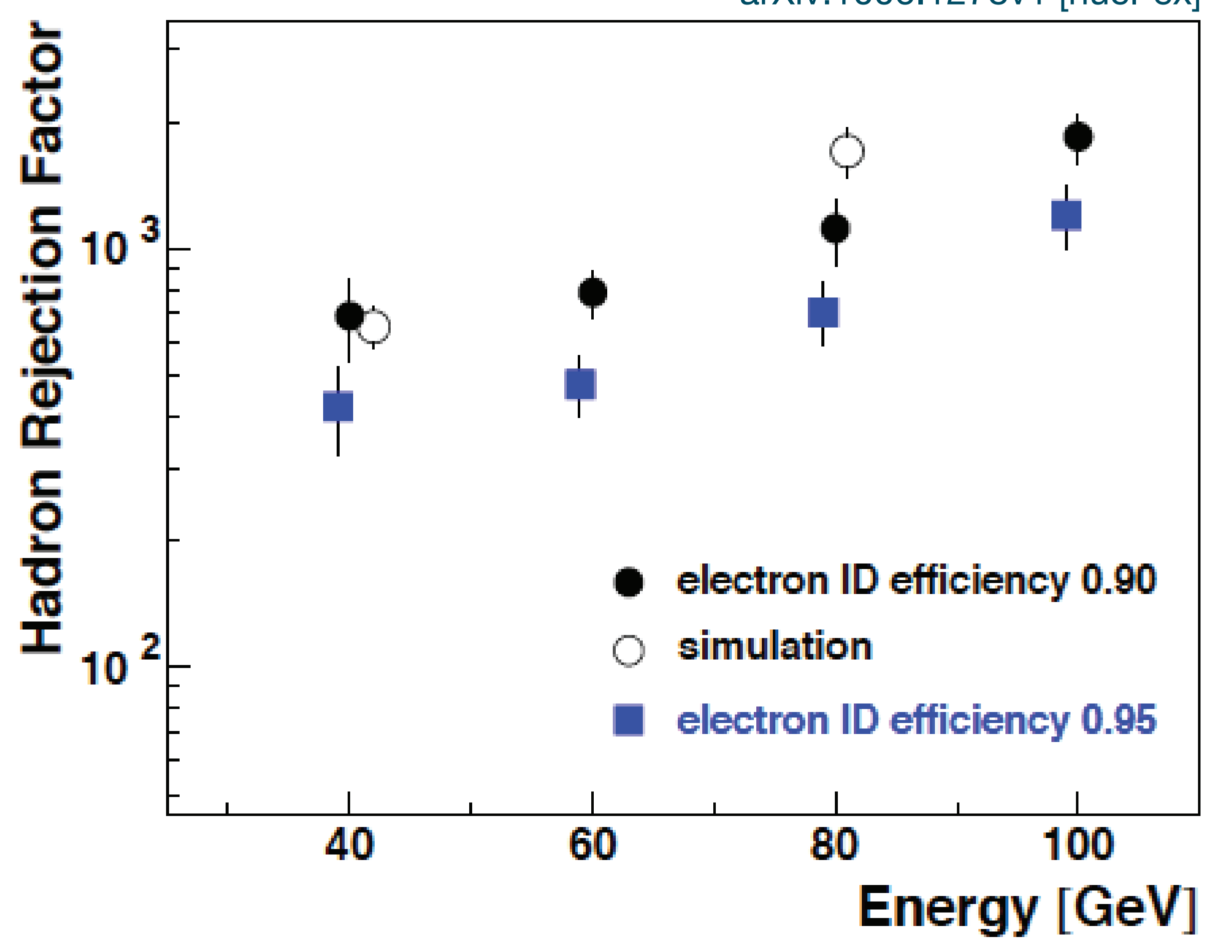
TRD: Test beam measurement at CERN PS with electron and pion beam

EMCAL: Hadron rejection factor from 2007 CERN test-beam data compared to simulation

Nuclear Physics A 830 (2009) 535c–538c



arXiv:1006.1278v1 [nucl-ex]



Allows heavy flavour electron measurement up to more than 50 GeV/c

Beauty, Beauty-Jet tagging at ALICE via electron

- High rate of lepton production from semi-leptonic decay (~11%[b→e] + 10%[b→c→e])
- Long life time (~ 500 μm)
- Large mass (~ 5 GeV/c^2)

  but, light enough to be produced copiously at LHC :)
- High decay multiplicity of B

⟹ ALICE has Good eID + vertex detectors

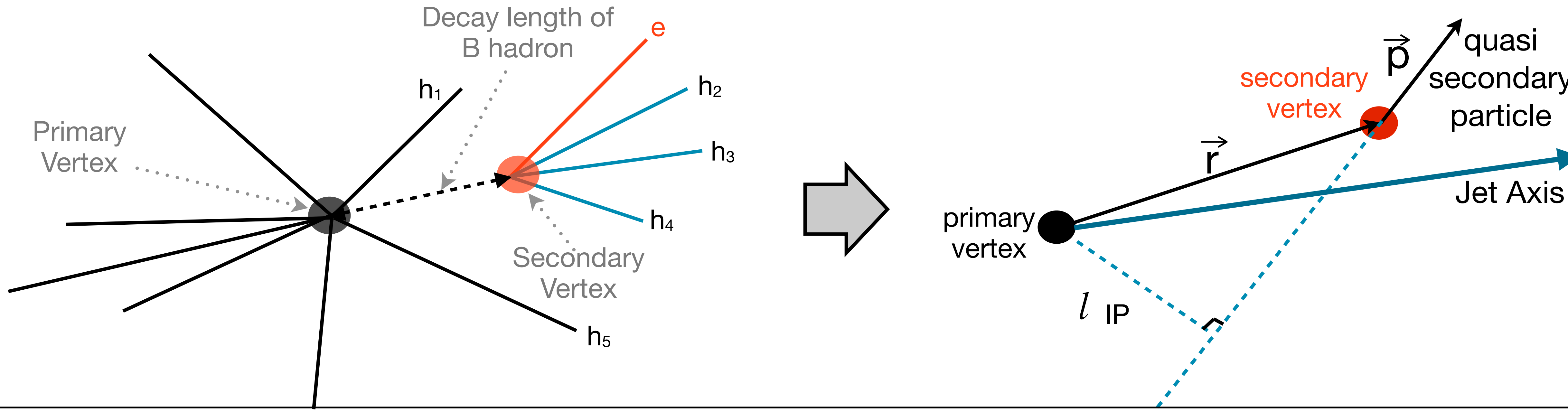
+ Jet reconstruction at ALICE (**See Christian Klein Boesing's talk**)

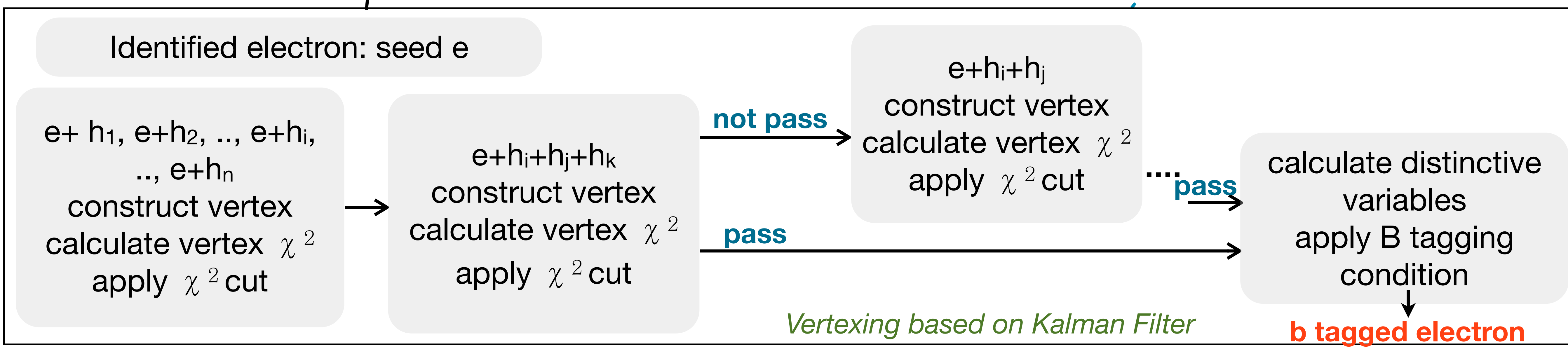
- B tagging

  ⟹ 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

B tagging algorithm(Secondary Vertexing)



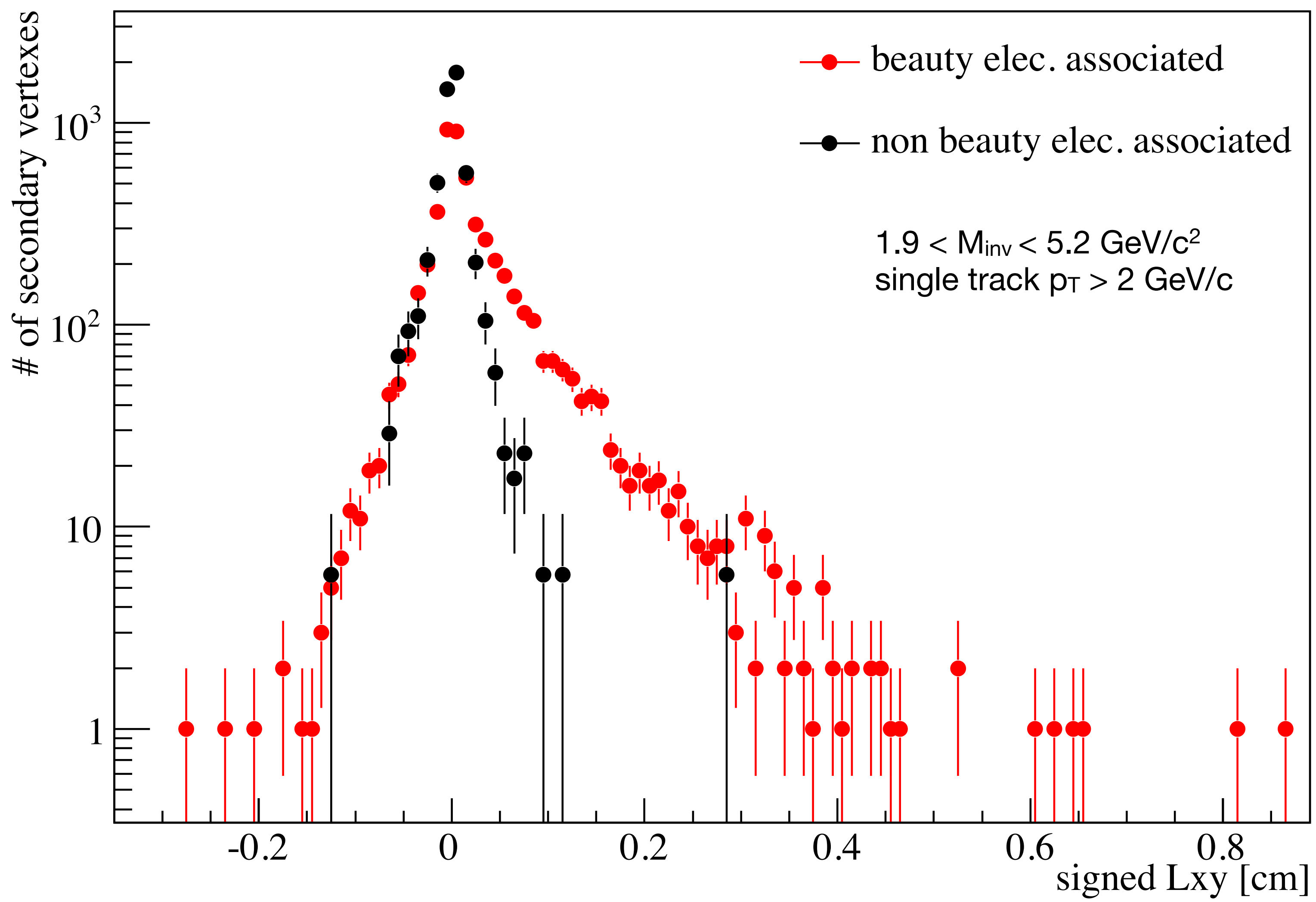


- Signed decay length $(Signed\ L_{xy}) = |\vec{r}| \frac{\vec{r} \cdot \vec{p}}{|\vec{r} \cdot \vec{p}|}$
- Invariant mass
- Secondary vertex χ^2/NDF
- Impact parameter of secondary particle(l IP)

B-Jet tagging → secondary vertexing with jet associated tracks

Similar approaches evaluated at CDF which resulted in many important physics publications

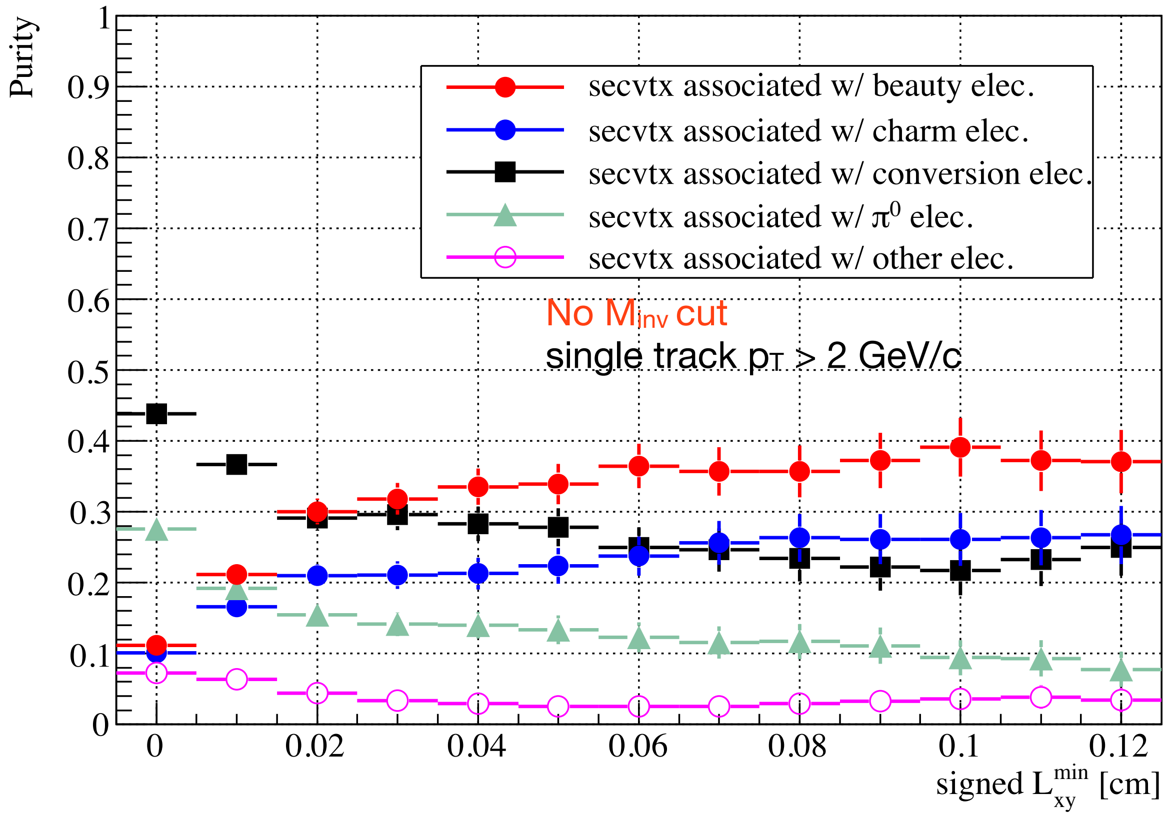
Distinctive variable (Singed decay length)

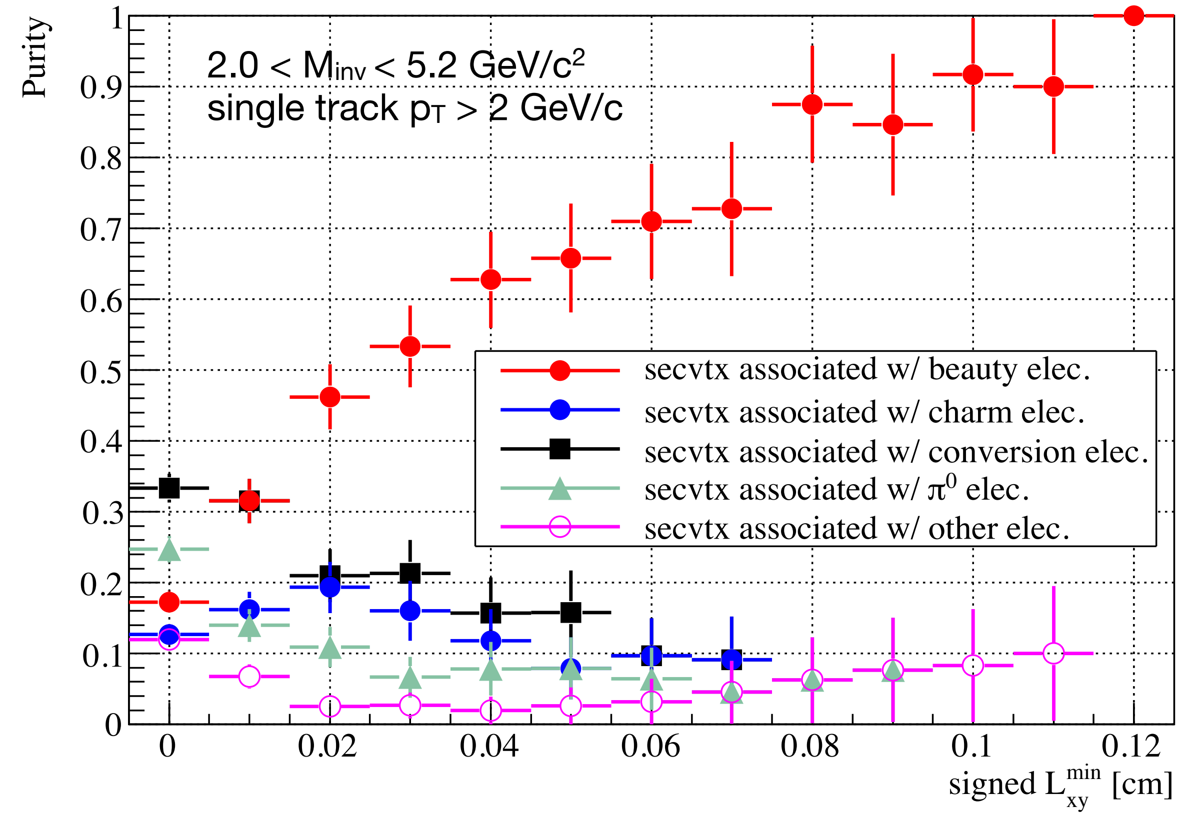


Powerful to discriminate beauty electrons from others together with invariant mass cut

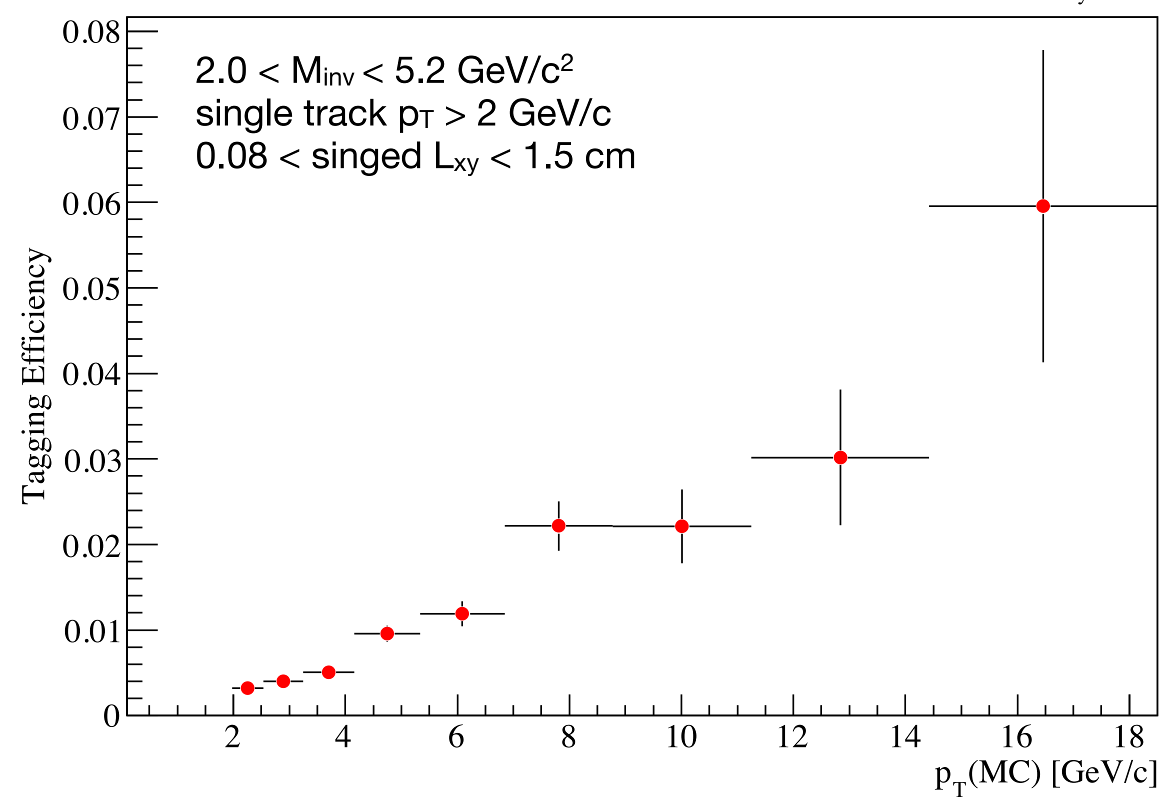
Purity and efficiency

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





~80% purity with currently optimized cuts



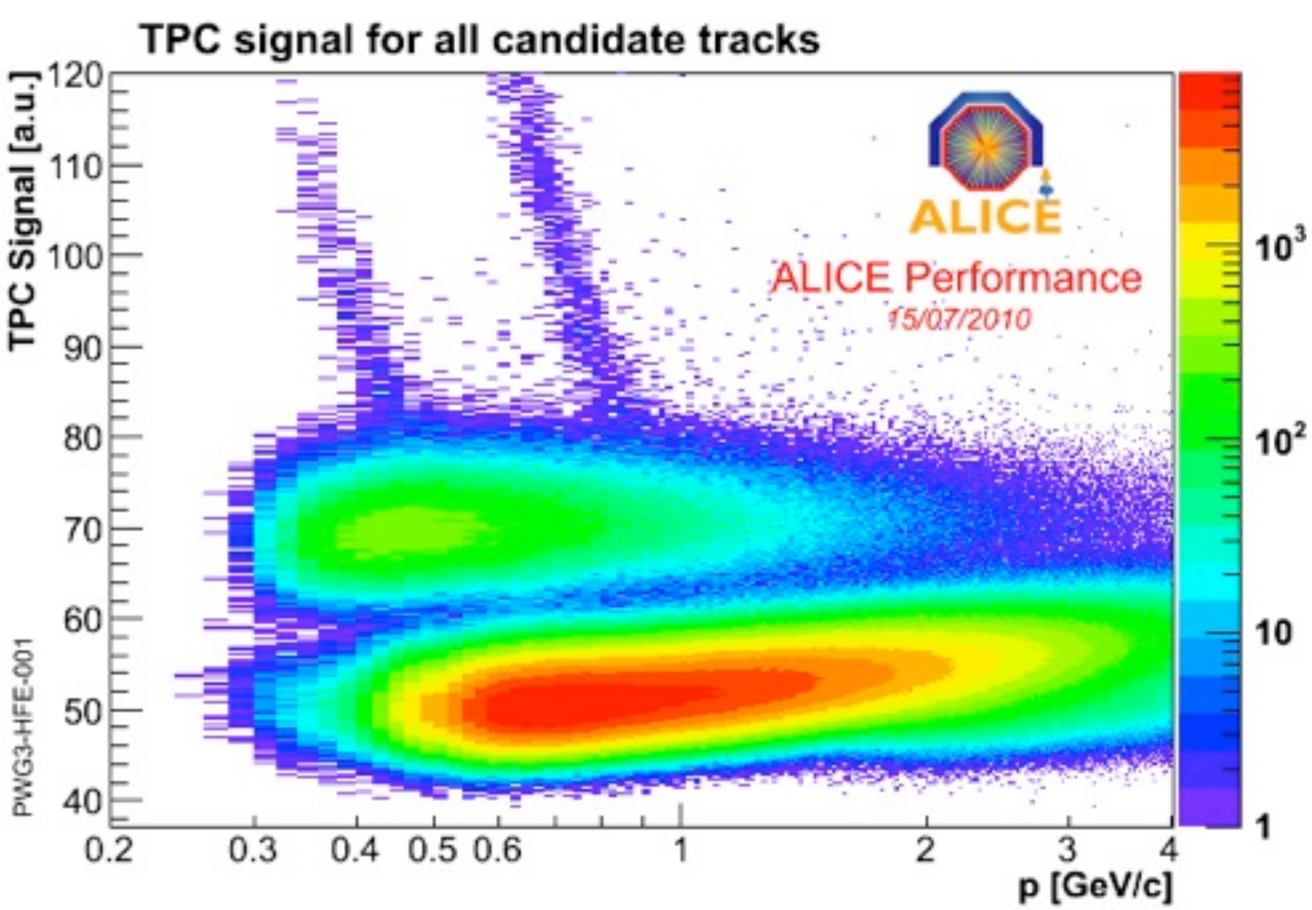
$\Rightarrow$ Require good understanding on MC

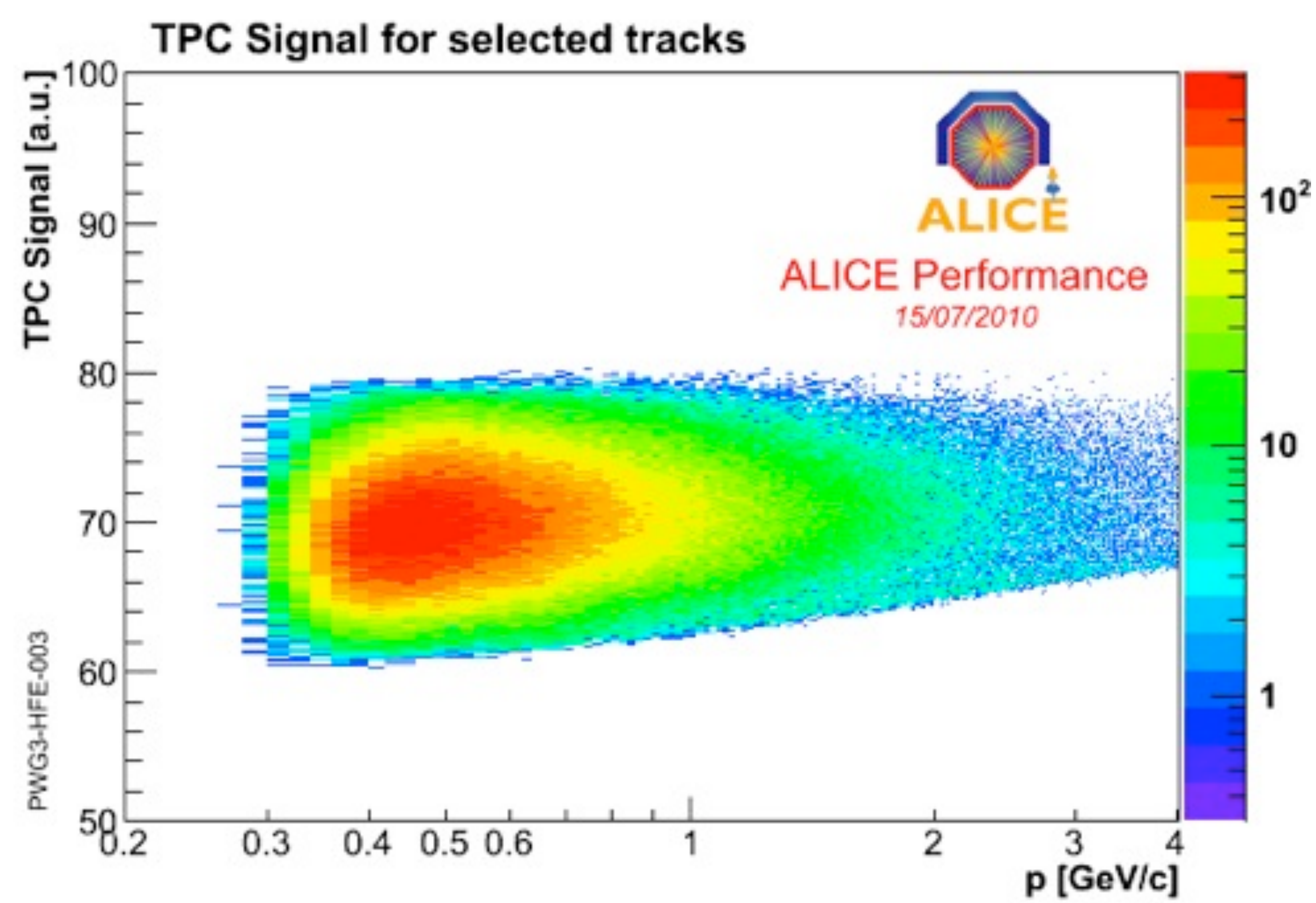
Preliminary look of p+p@7 TeV data

Electron Identification with TOF + TPC

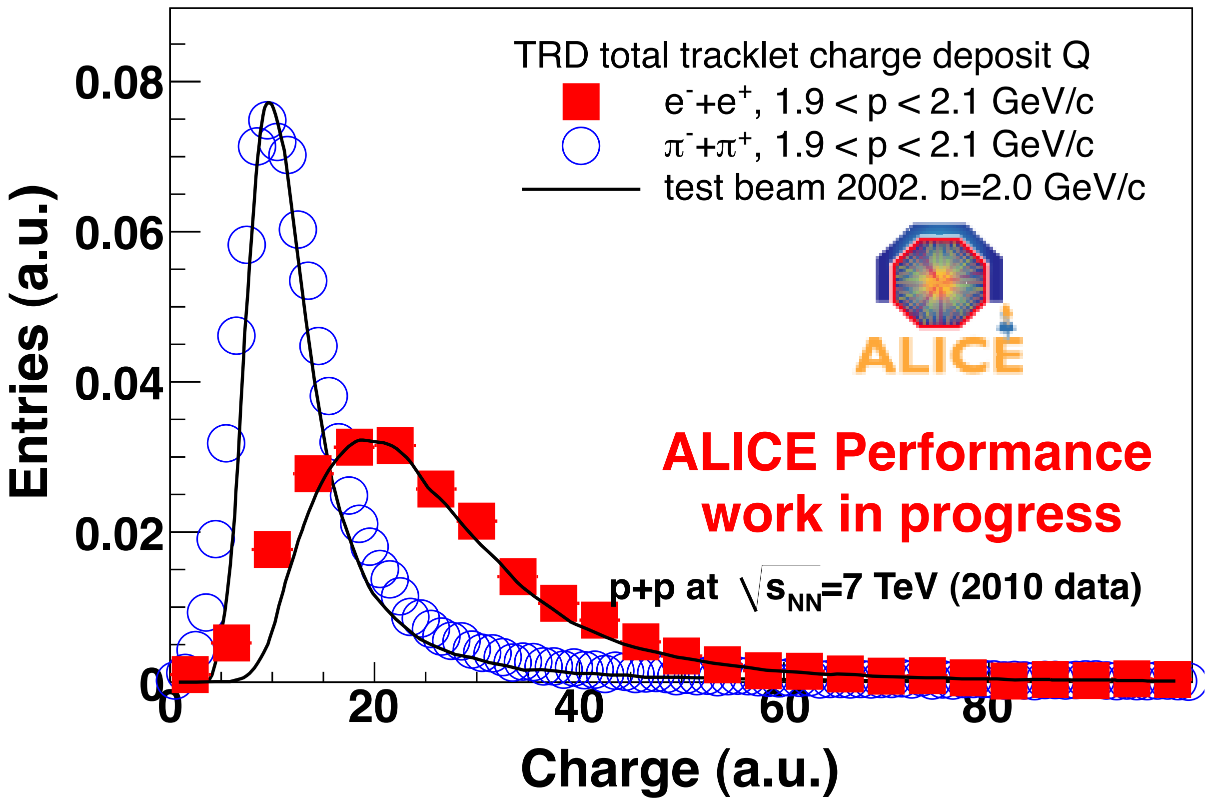
- Method to select a pure sample of electrons: TOF + TPC
  - Select tracks falling within 3σ from TOF electron line
  - Apply *n*σ cut from TPC dE/dx electron line (momentum dependent cut at lower bound to minimize π contamination)

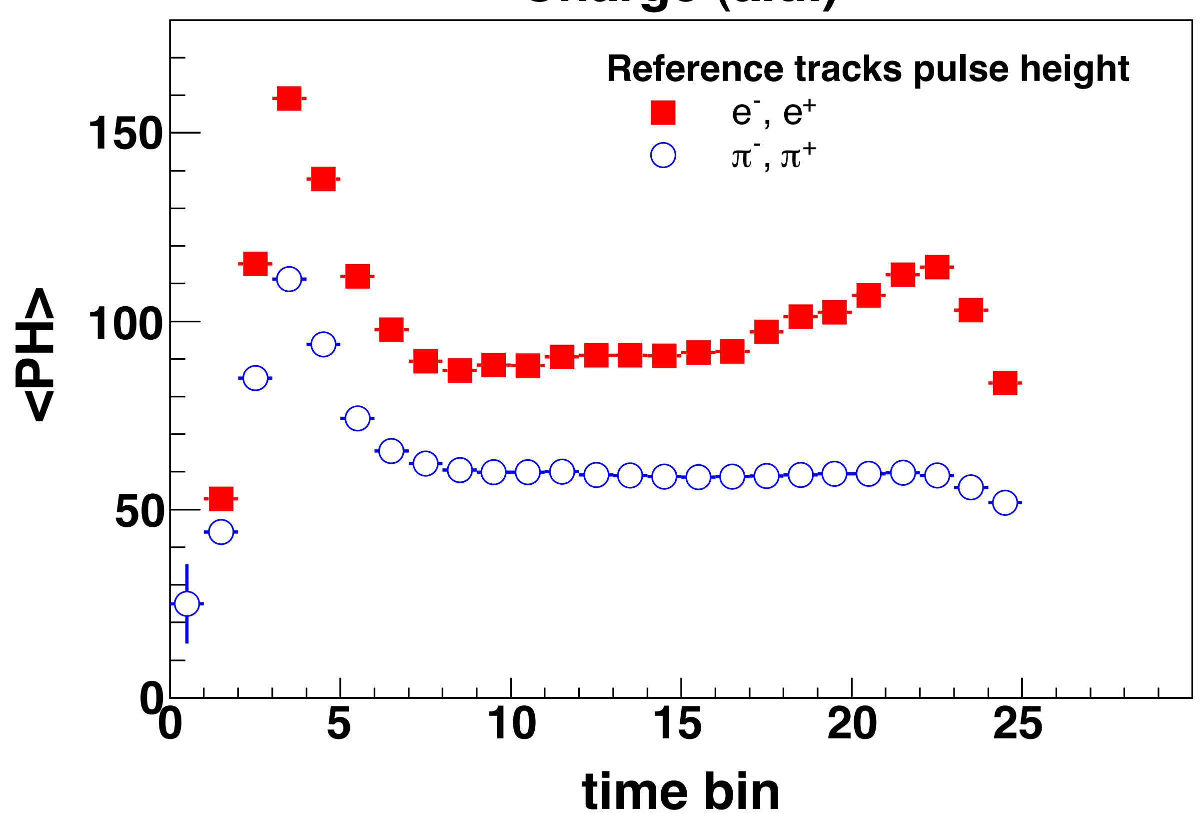
pp collisions @ √s = 7 TeV, 1.6 x 10 8 events





Electron Identification performance with TRD



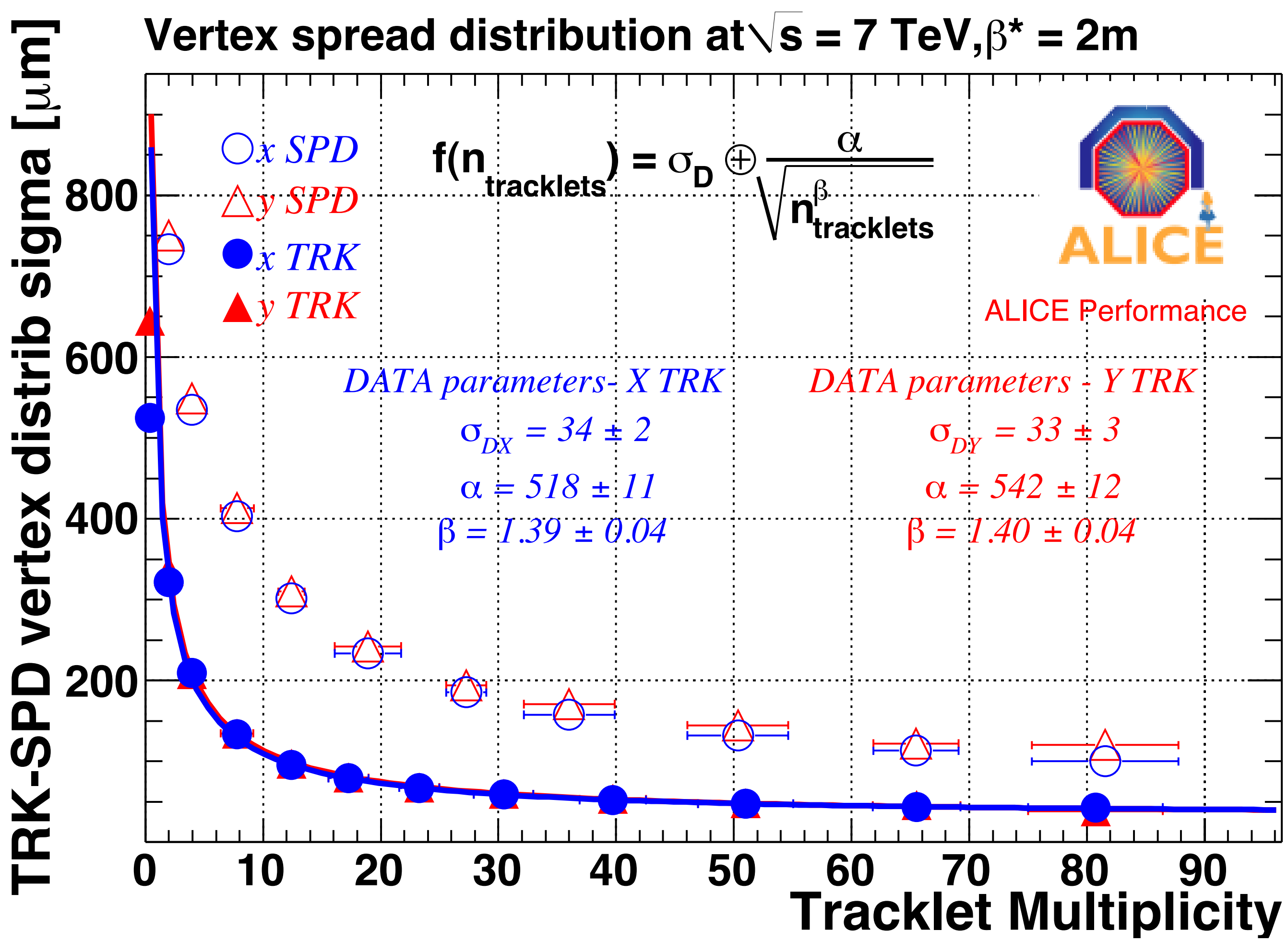


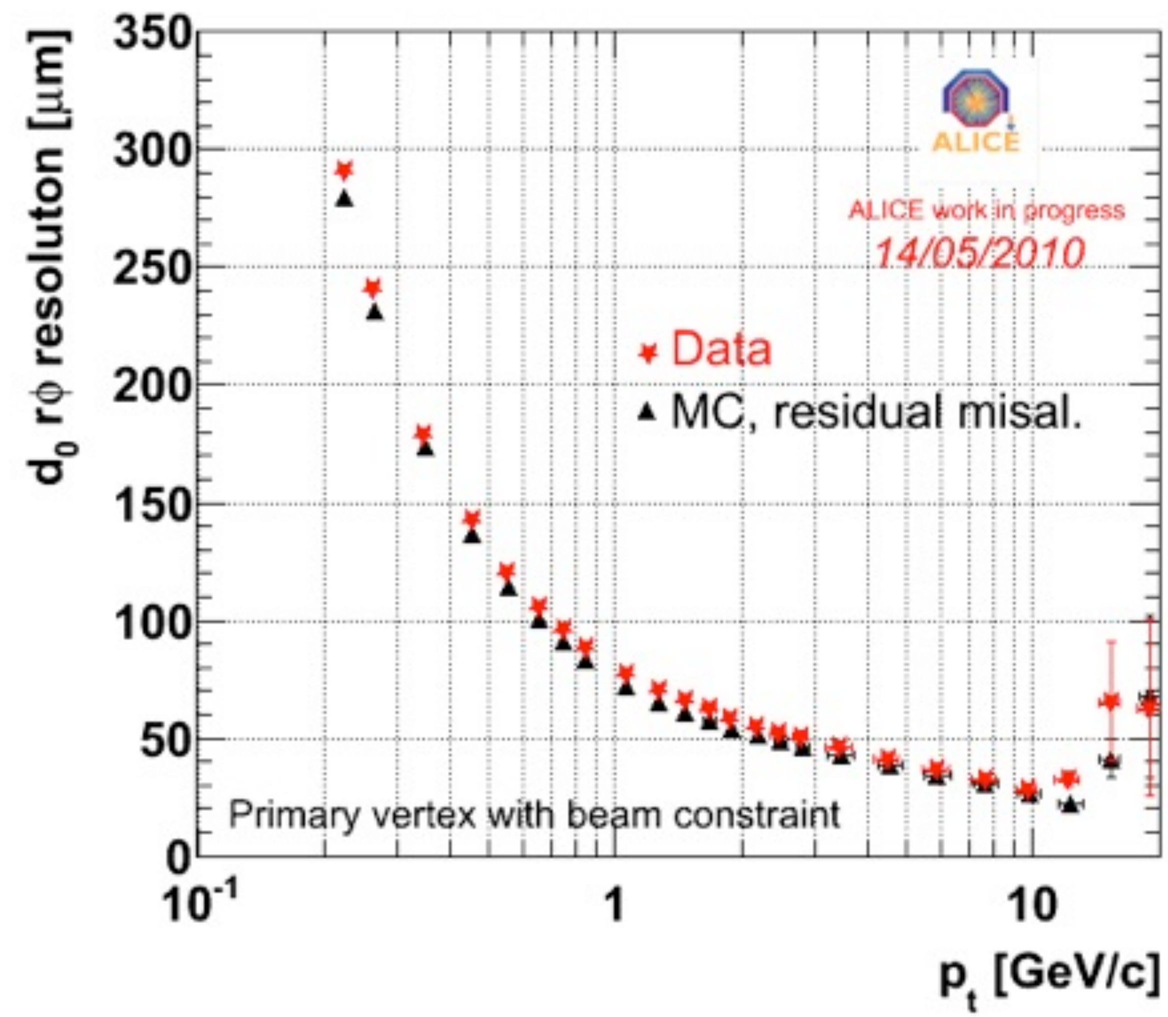
Response of the TRD to pions from K^0 decays and to electrons from Υ conversions

Remark

TRD L1 trigger on single electrons will provide high statistics on high p_T electron samples: Under being tested

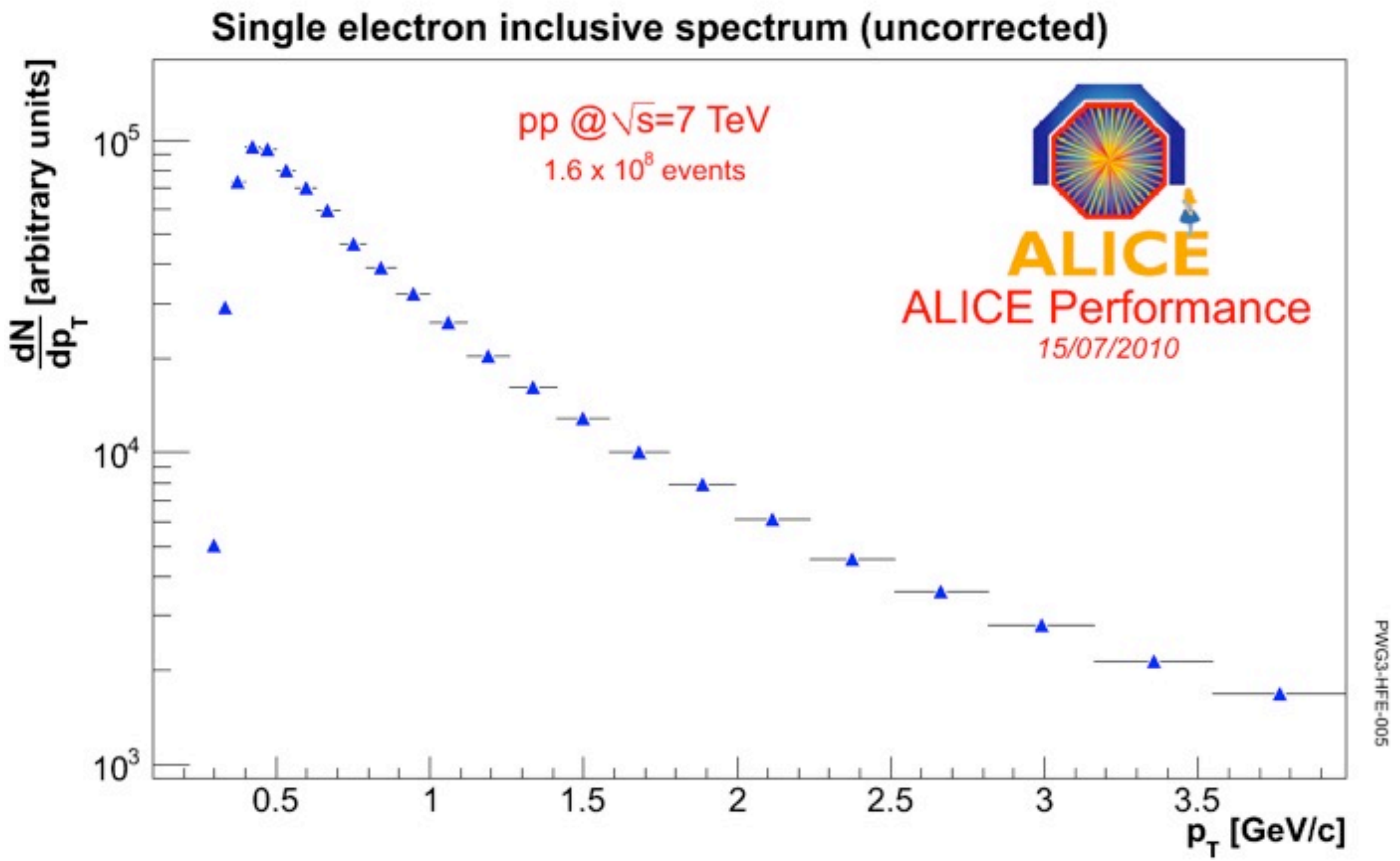
Vertexing Performance





- Impact parameter resolution is the convolution of the track position and the primary vertex resolutions
- Vertexing performance within ~10% to the MC target

Single Electron Inclusive Spectrum (eID with TPC + TOF)



Inclusive spectrum contains electrons from:

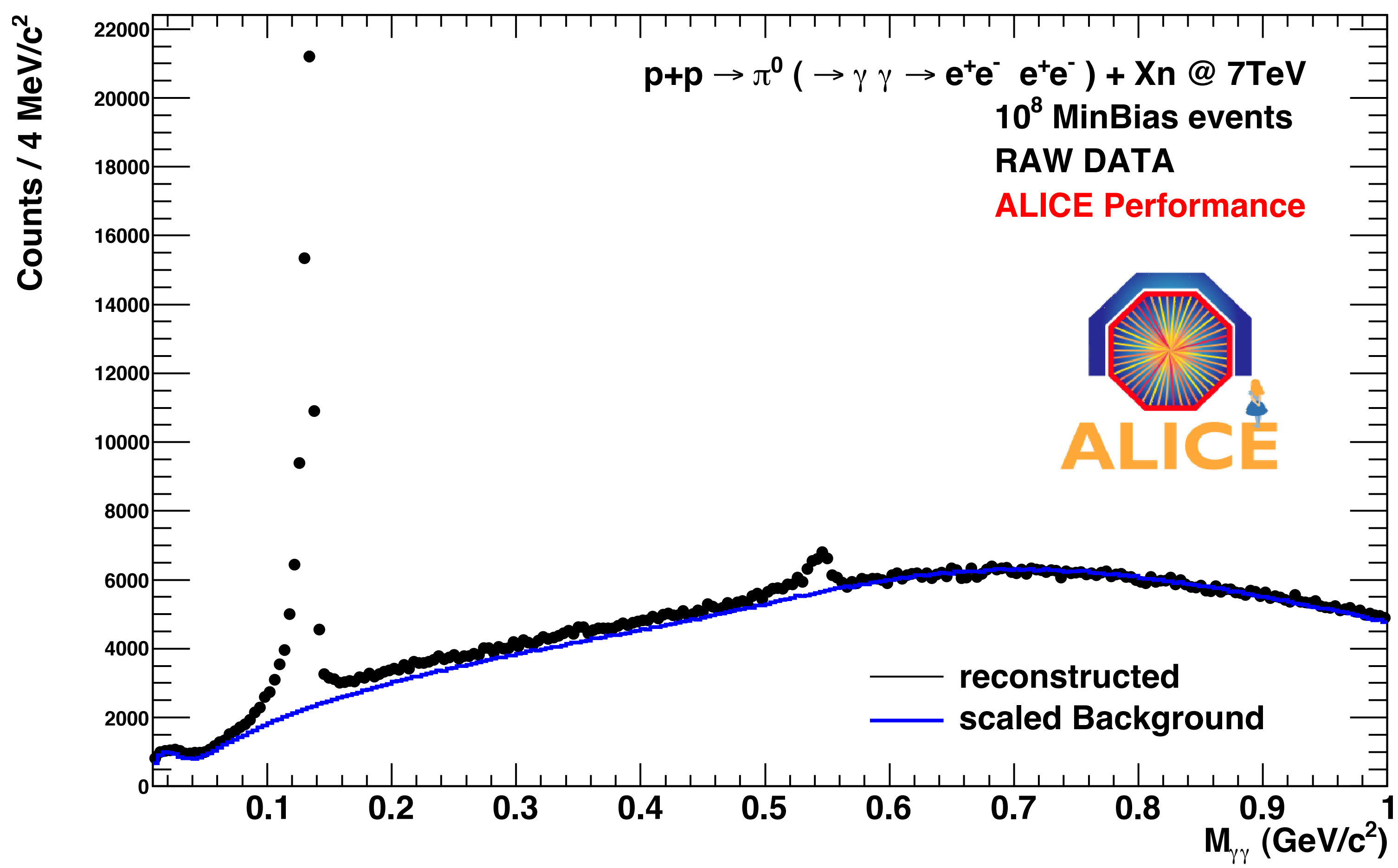
hadron decays (mainly π^0 Dalitz decay)

+ Υ conversion in the material

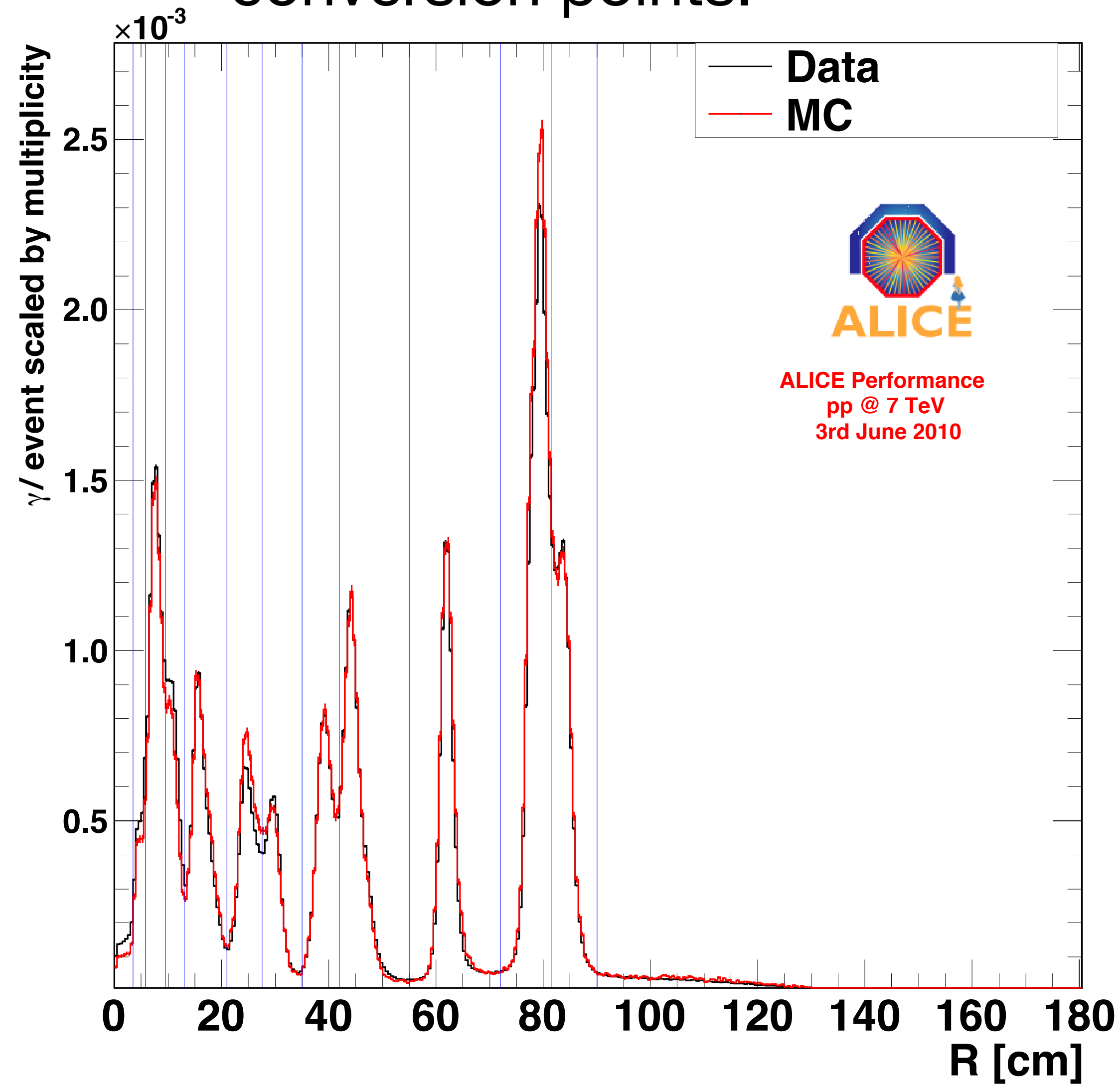
+ Charm and beauty hadrons

Background subtraction via Cocktail Method

Invariant mass distribution of two ϒ's.
π^0 and η are seen.



Radial distribution of the ϒ conversion points.

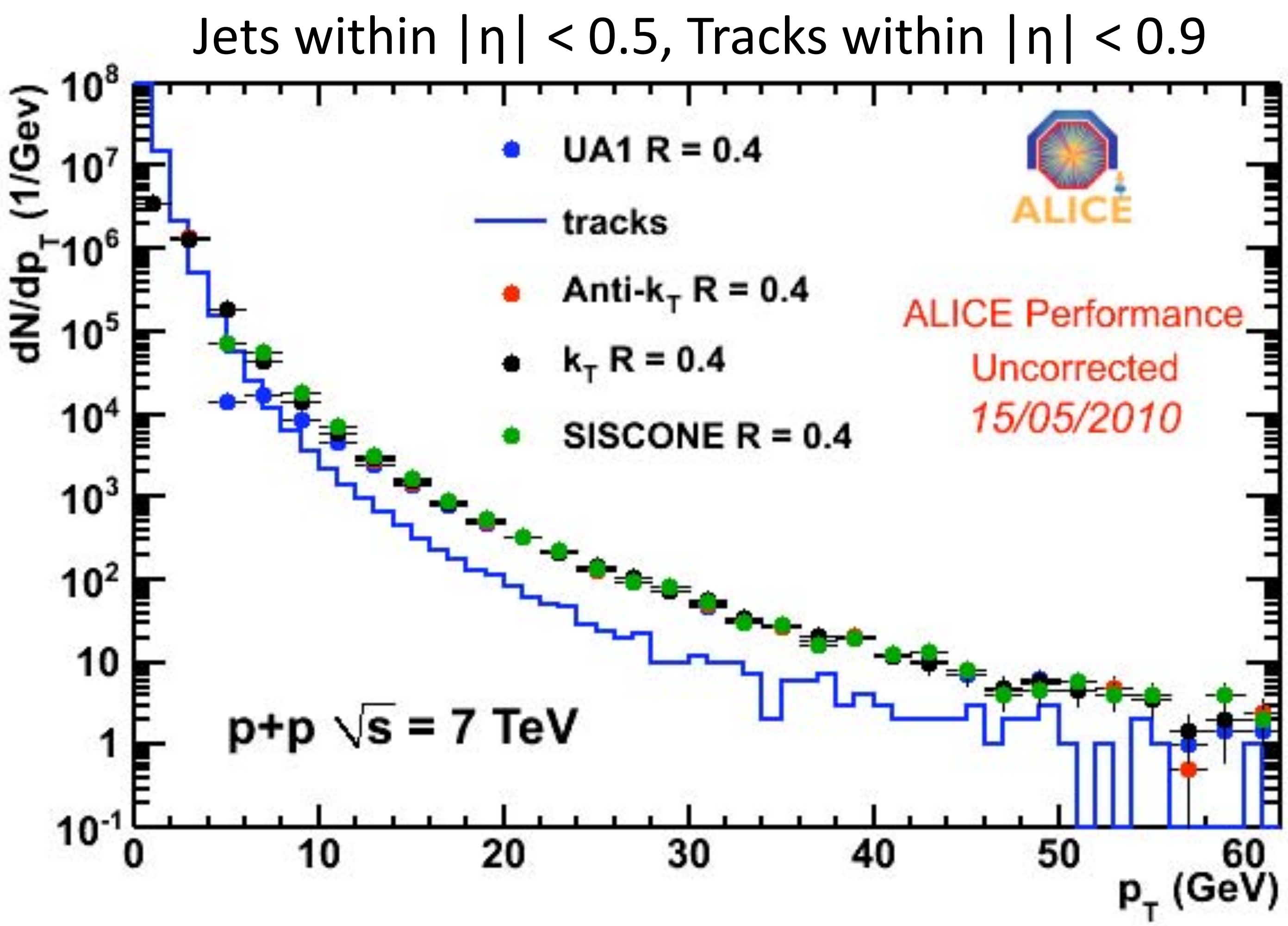


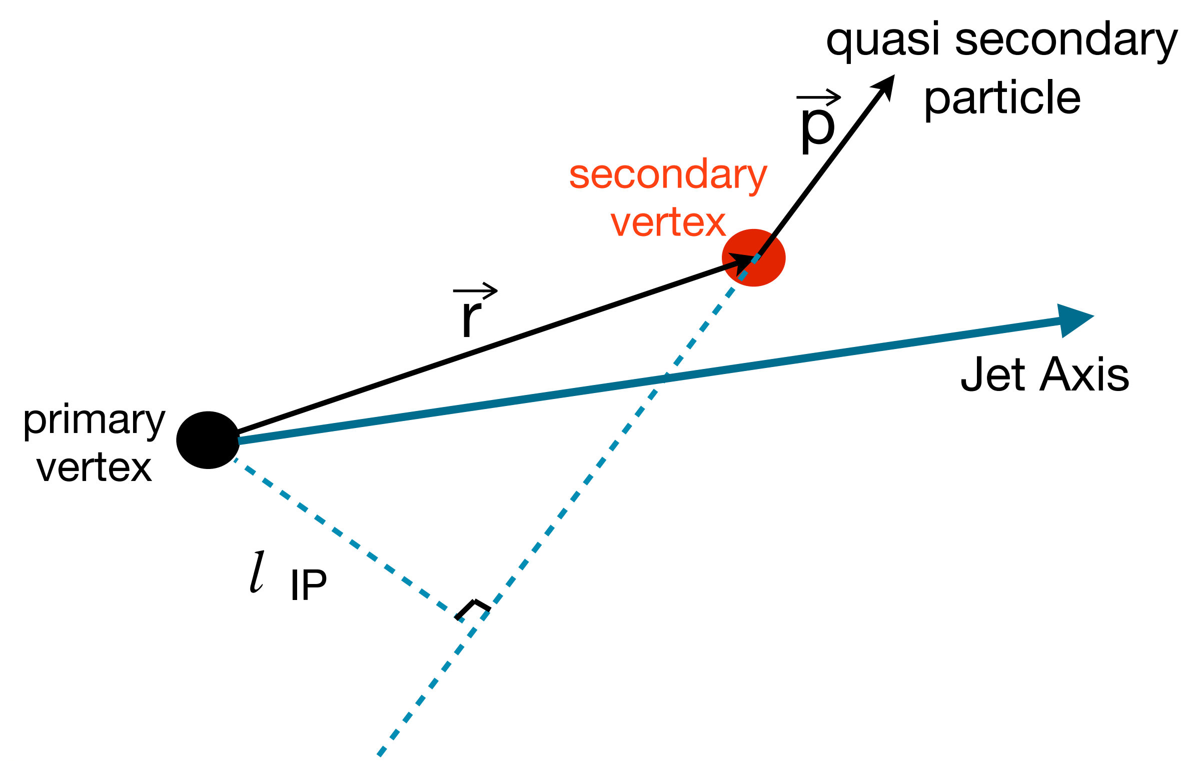
Background description via electron cocktail

- use measured hadron(π^0) spectra for the electron background from hadron decays (deduce the contributions of other sources via m_T scaling)
- use well understood material budget for describing conversion electrons (relevant material budget by requiring a hit on the most inner detector ~1.2 % X_0)

Beauty electron tagging, beauty jet tagging via associated jets

Raw jet spectrum p+p @ 7 TeV





Beauty electron tagging via secondary vertexing

Beauty Jet tagging → secondary vertexing with jet associated tracks

Analysis Ongoing

Summary

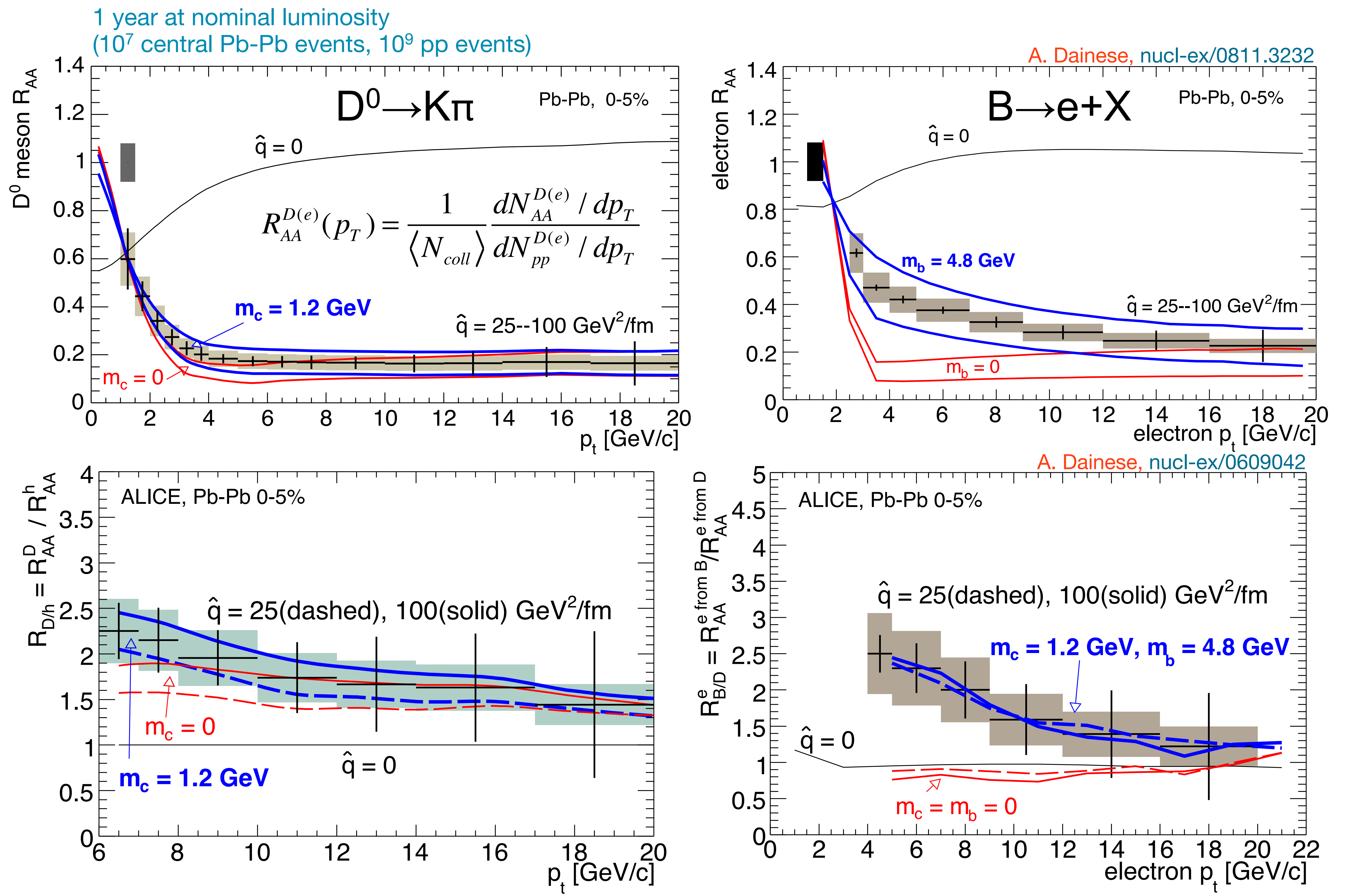
- **At LHC, charm and beauty quarks are produced copiously and this provide a tool to understand color charge and mass dependence of energy loss in the medium**
- **ALICE has excellent electron identification and vertexing capability and this allows beauty electron tagging**
- **Non-photonic elelectron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

Other ALICE talks:

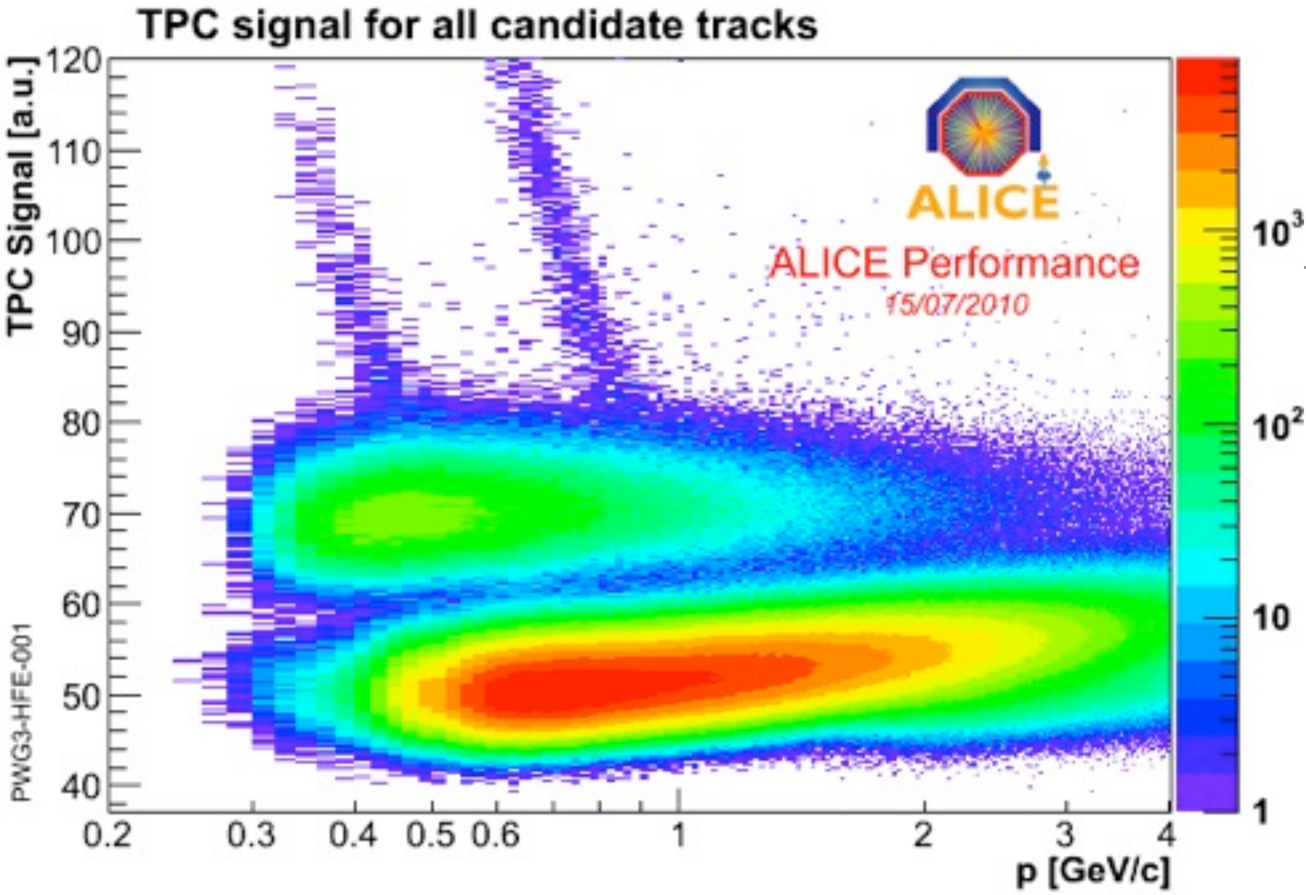
Christian Klein Boesing, Jet and high pT Measurements with the ALICE Experiment
Hermes Leon Vargas, Parton discrimination using jets with ALICE at the LHC
Chiara Bianchin, Italy Open charm analysis for energy loss studies with ALICE at LHC
Takuma Horaguchi, Japan Study of di-Jet reconstruction in p+p and Pb+Pb collisions with DCAL at LHC-ALICE

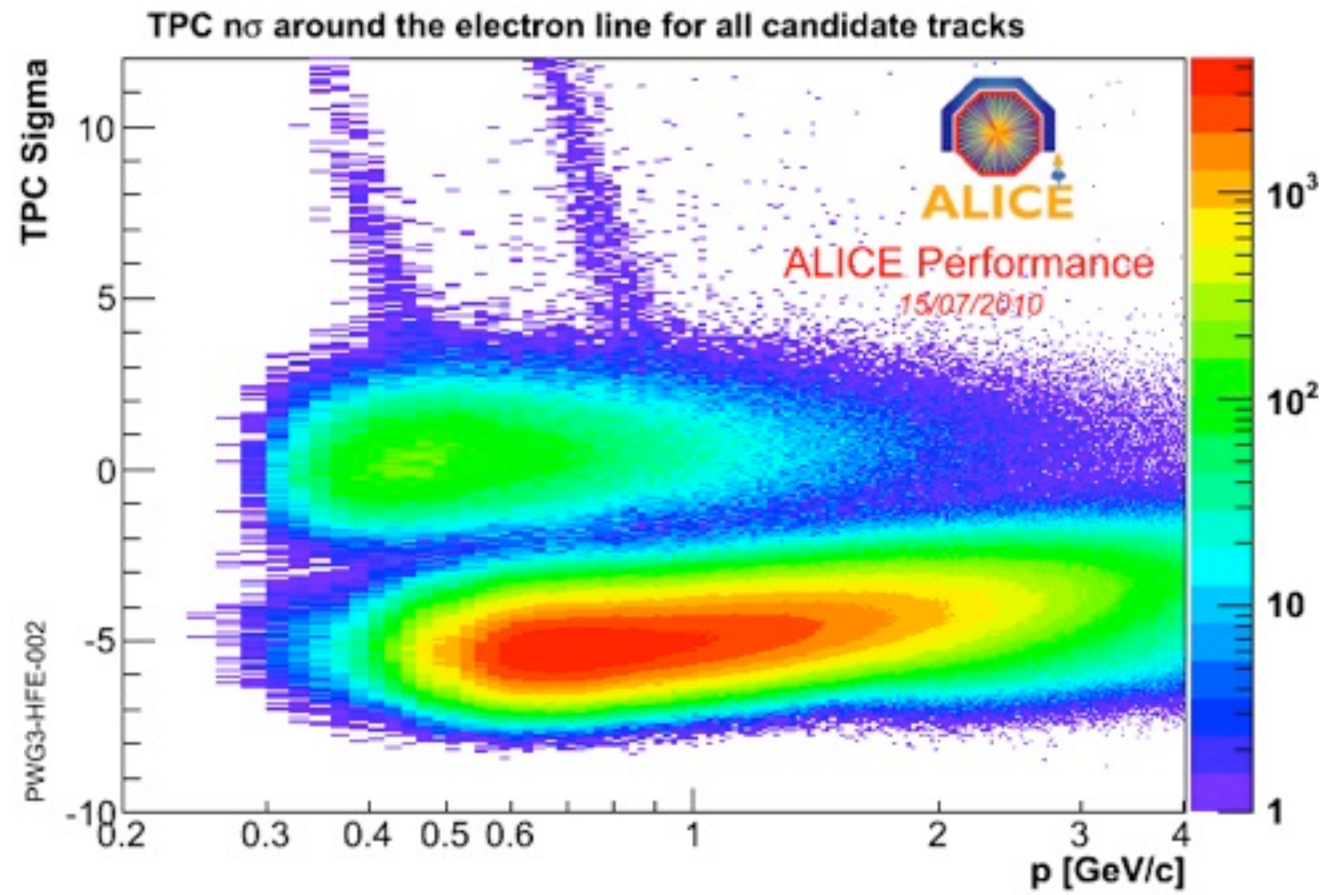
BACKUP SLIDES

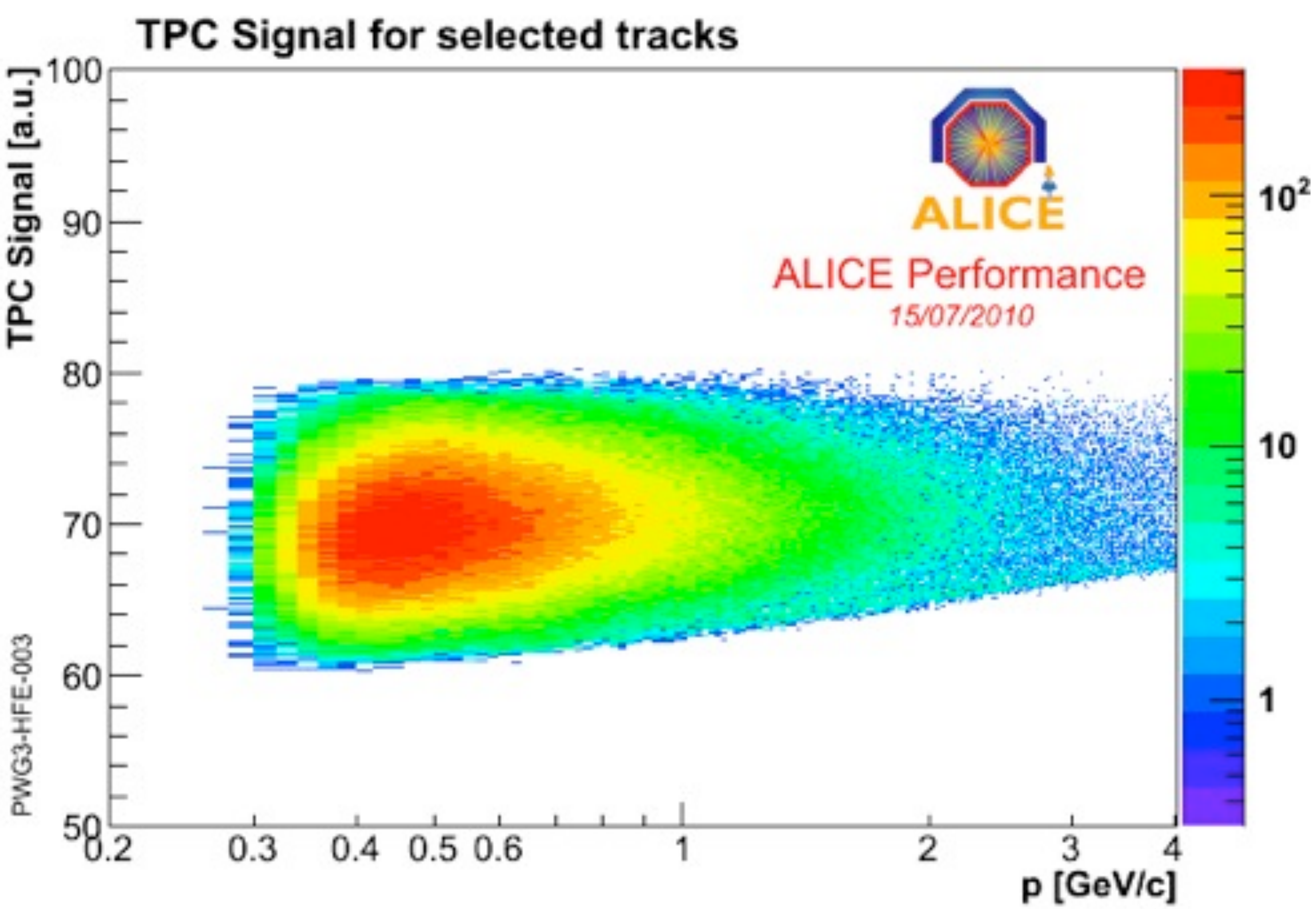
Nuclear modification for open heavy flavour

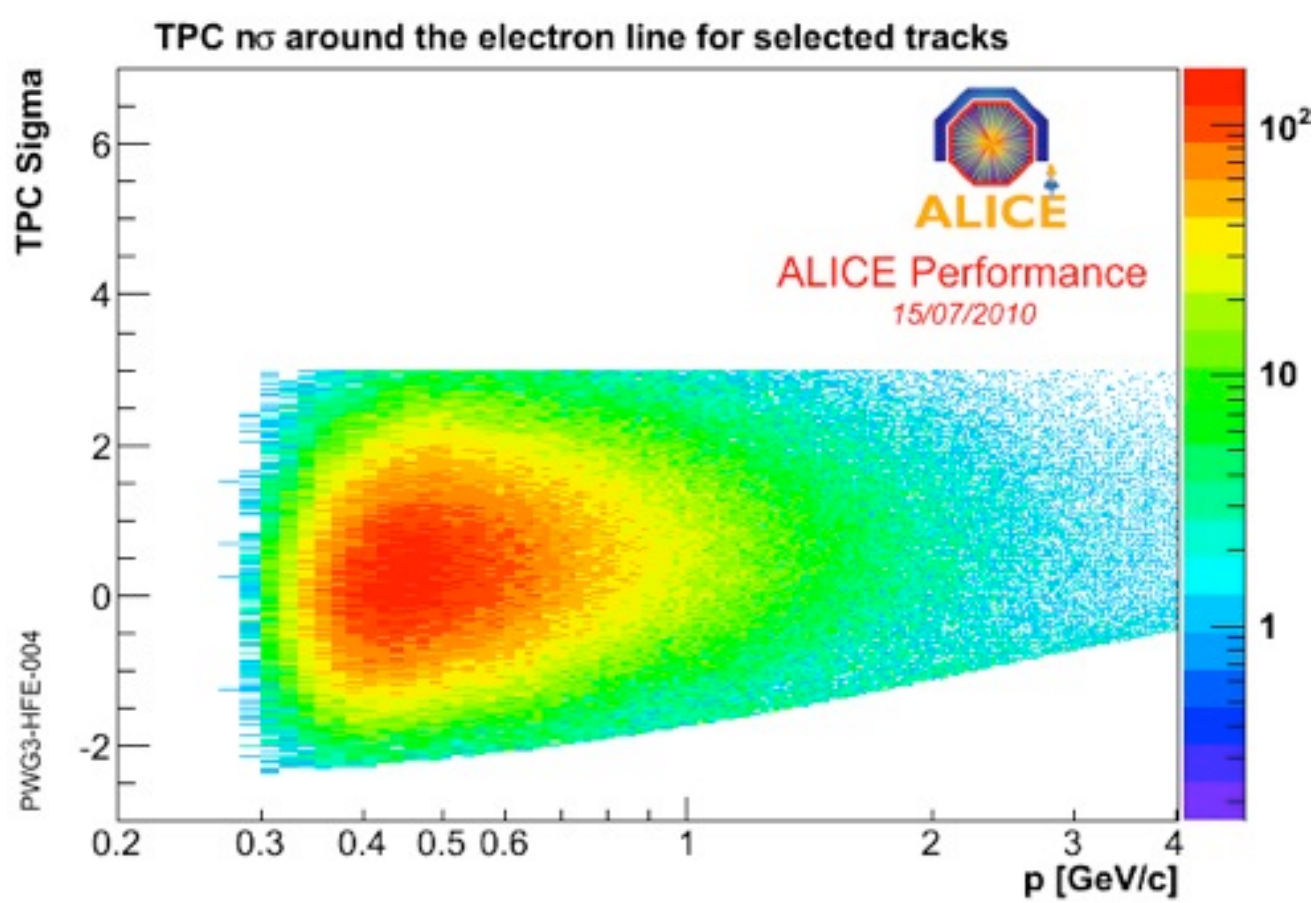


Data of one full luminosity Pb+Pb run (10^6 s) should clarify heavy flavor quenching story


TPC signal for all candidate tracks
TPC Signal [a.u.]
p [GeV/c]
ALICE
ALICE Performance
15/07/2010
PWG3-HFE-001


TPC nσ around the electron line for all candidate tracks
TPC Sigma
p [GeV/c]
ALICE
ALICE Performance
15/07/2010
PWG3-HFE-002


TPC Signal for selected tracks
TPC Signal [a.u.]
p [GeV/c]
ALICE
ALICE Performance
15/07/2010
PWG3-HFE-003

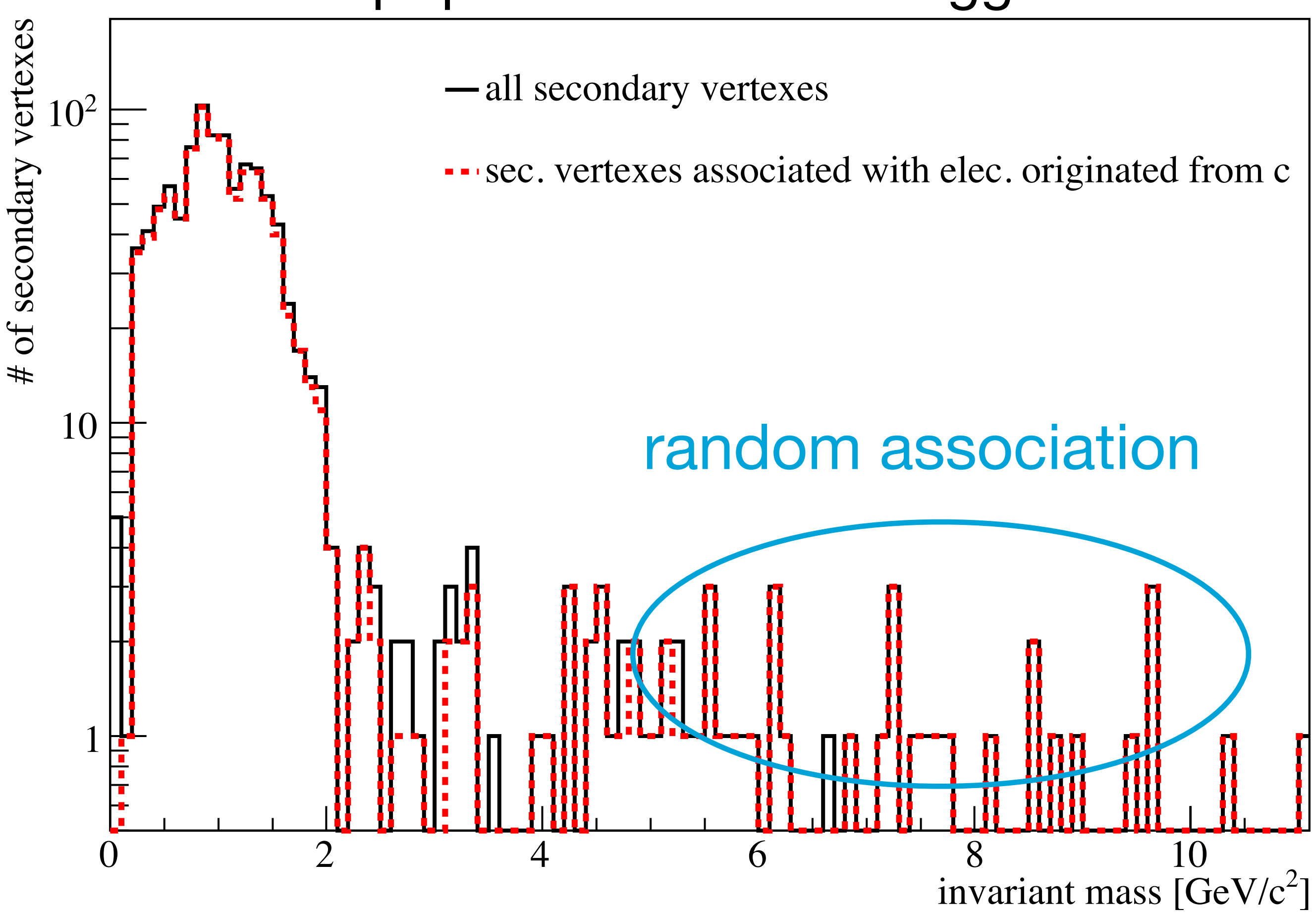

TPC nσ around the electron line for selected tracks
TPC Sigma
p [GeV/c]
ALICE
ALICE Performance
15/07/2010
PWG3-HFE-004

Powerful to reject charm background

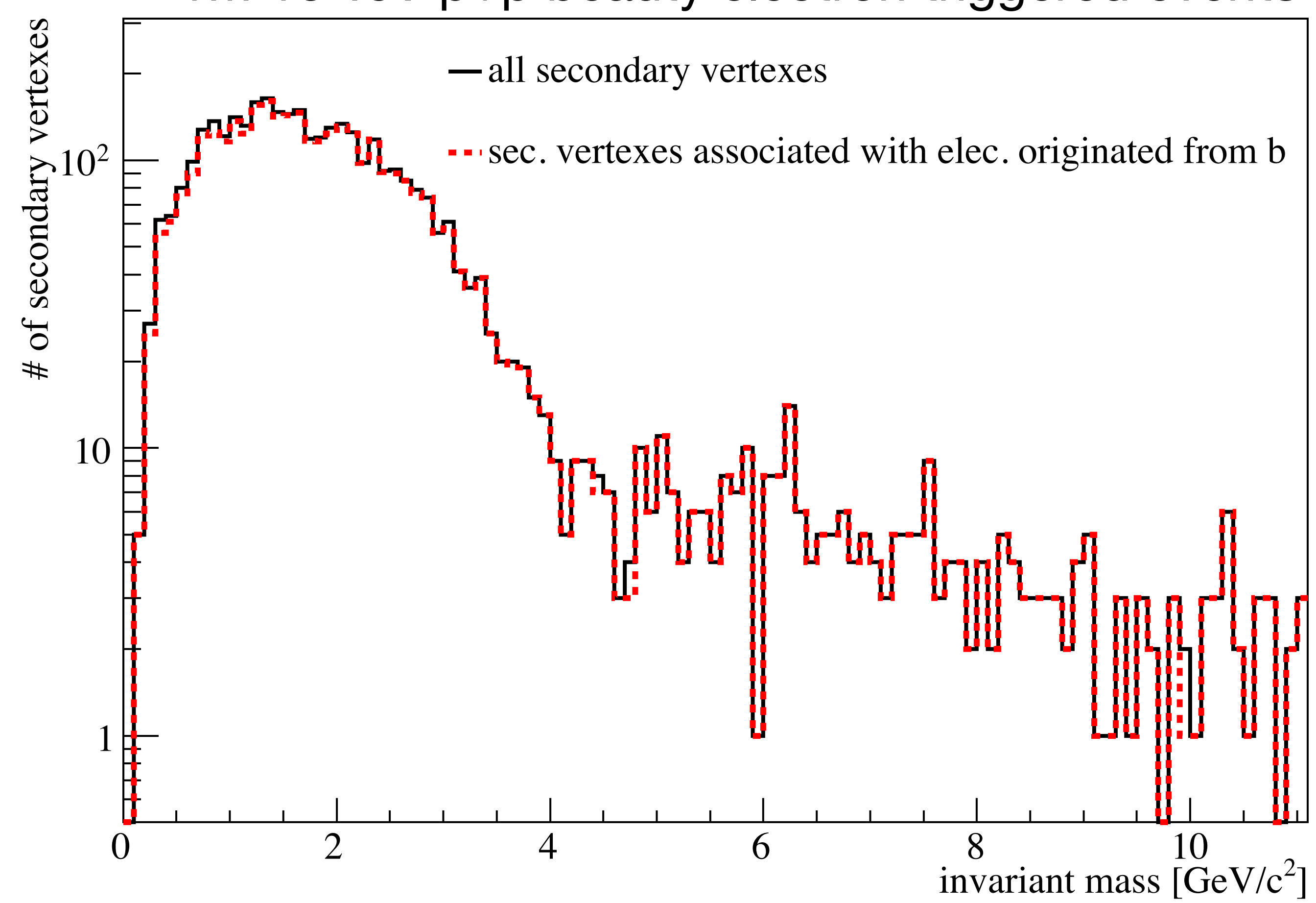
- Signed decay length $(Signed\ L_{xy}) = |\vec{r}| \frac{\vec{r} \cdot \vec{p}}{|\vec{r} \cdot \vec{p}|}$
- Invariant mass
- Secondary vertex χ^2/NDF
- Impact parameter of secondary particle(l_{IP})

MC PID for electron selection

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



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

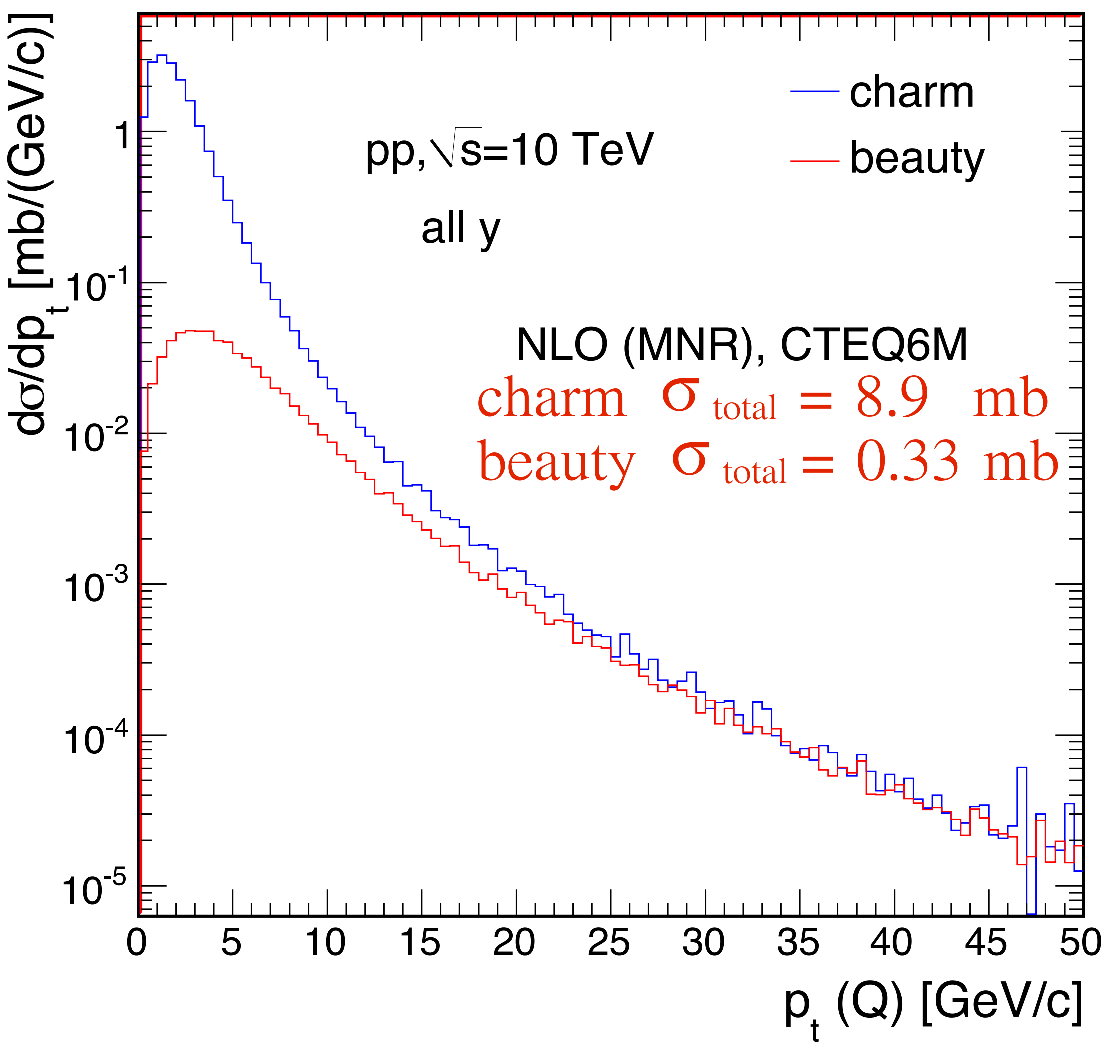


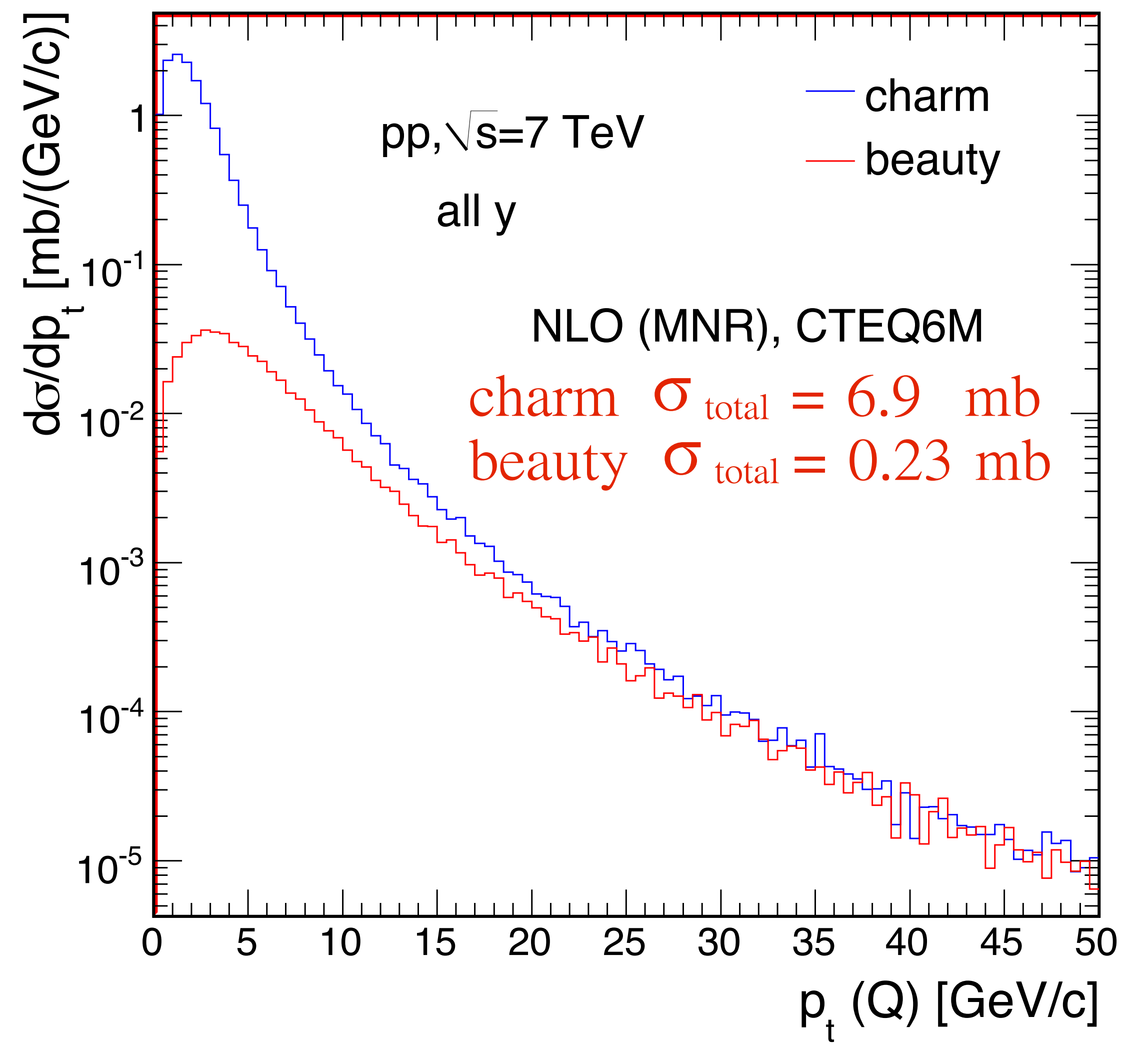
Invariant mass cut is good to suppress charm background

→ Allow to separate beauty from charm

Charm/Beauty from HVQMNR

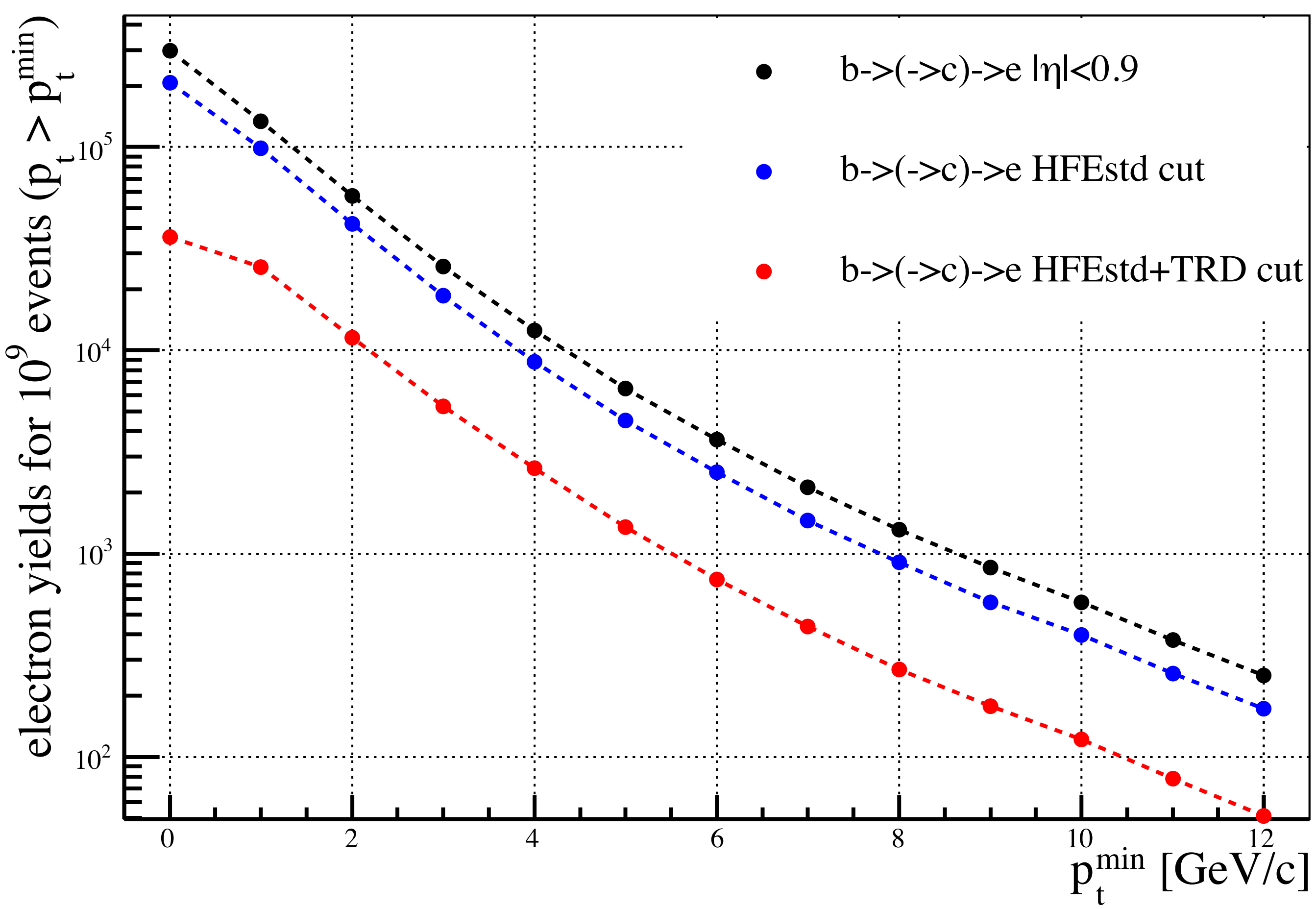
plot by Anton: http://www-alice.gsi.de/ana/results/results.html



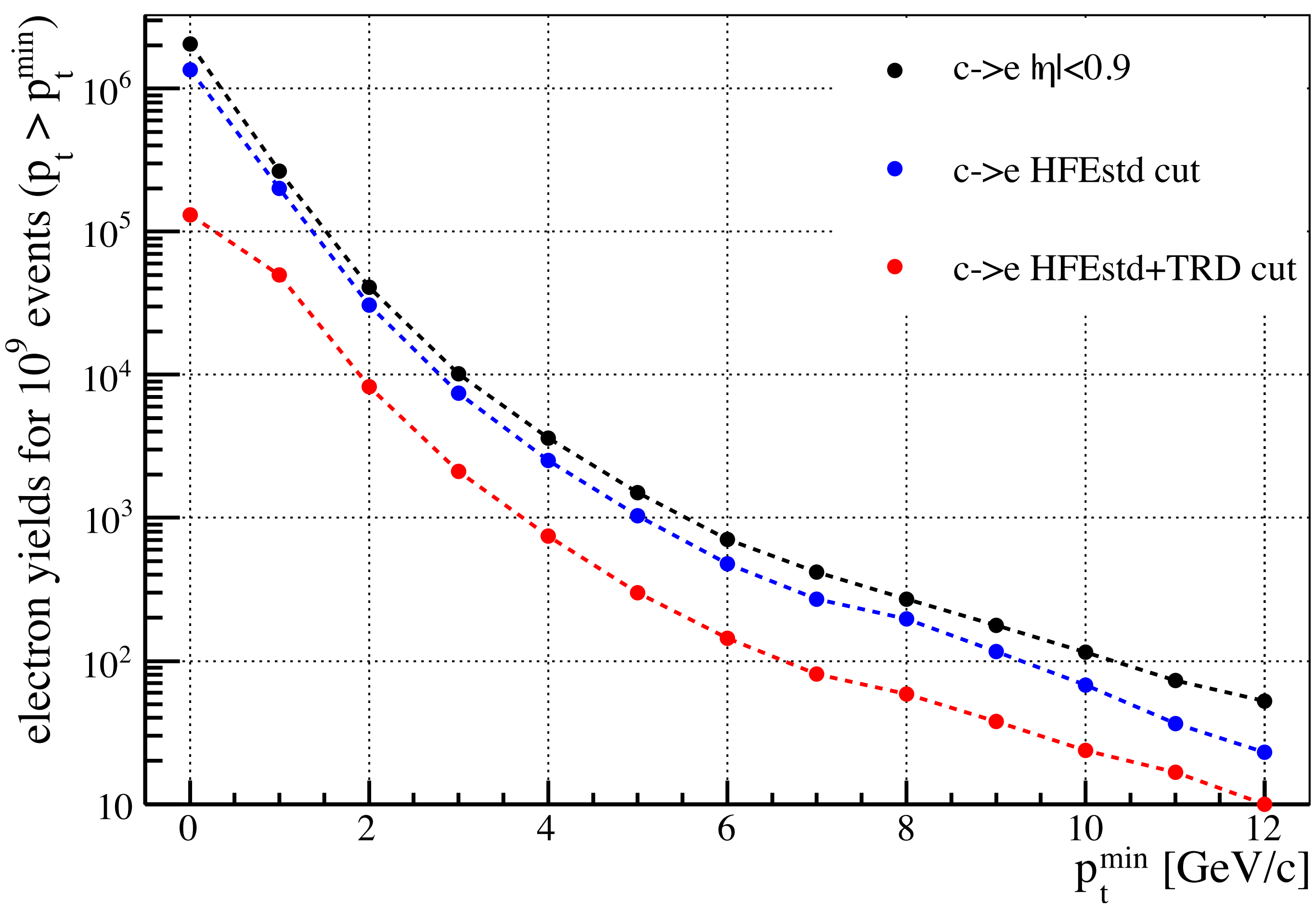


Yield

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



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

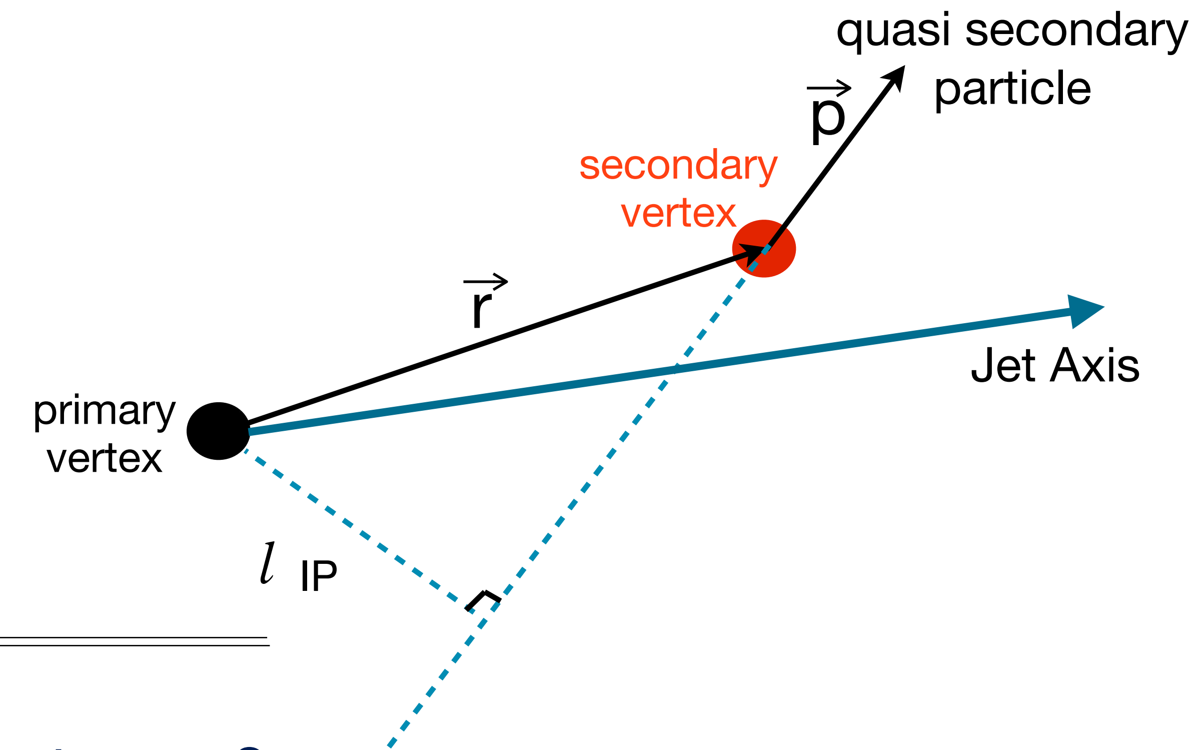


10^9 pp events leads ~190k(47k) charm and ~98k(25k) beauty electrons at p_t > 1 GeV/c

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