Heavy Flavours and Heavy-Ion Collisions: Status and ALICE Perspectives

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Intro: Heavy Flavours as medium probes in AA collisions

Charm & beauty: ideal probes

- calculable in pQCD; calibration measurement from pp
  - → rather solid ground
    - caveat: modification of initial state effects from pp to AA
      - shadowing ~ 30 %
      - saturation?
    - pA reference fundamental!

- produced essentially in initial impact
  - → probes of high density phase

- no extra production at hadronization
  - → probes of fragmentation
    - e.g.: independent string fragmentation vs recombination

Heavy Flavour Quenching

- quenching vs colour charge
  - heavy flavour from quark (C_R = 4/3) jets
  - light flavour from (p_T-dep) mix of quark and gluon (C_R = 3) jets

- quenching vs mass
  - heavy flavour predicted to suffer less energy loss
    - gluonstrahlung: dead-cone effect
  - beauty vs charm

→ heavy flavour should provide a fundamental tool to investigate the properties of the medium formed in heavy-ion collisions

→ at LHC: high stats and fully developed jets

Heavy Flavour Decays

Some zoology…

- Lower mass heavy flavour hadrons decay weakly
  - $\tau \sim$ ps
  - $c\tau \sim 100$'s μm
- weakly decaying states from PDG 2006 summary tables:

$D^+(c\bar{d})$	$\mathrm{m} \approx 1869\ \mathrm{MeV}$	$c\tau \approx 312\ \mu\mathrm{m}$
$D^0(c\bar{u})$	$\mathrm{m} \approx 1865\ \mathrm{MeV}$	$c\tau \approx 123\ \mu\mathrm{m}$
$D_s^+(c\bar{s})$	$\mathrm{m} \approx 1968\ \mathrm{MeV}$	$c\tau \approx 147\ \mu\mathrm{m}$
$\Lambda_c^+(udc)$	$\mathrm{m} \approx 2285\ \mathrm{MeV}$	$c\tau \approx 60\ \mu\mathrm{m}$
$\Xi_c^+(usc)$	$\mathrm{m} \approx 2466\ \mathrm{MeV}$	$c\tau \approx 132\ \mu\mathrm{m}$
$\Xi_c^0(dsc)$	$\mathrm{m} \approx 2472\ \mathrm{MeV}$	$c\tau \approx 34\ \mu\mathrm{m}$
$\Omega_c^0(ssc)$	$\mathrm{m} \approx 2698\ \mathrm{MeV}$	$c\tau \approx 21\ \mu\mathrm{m}$

$B^+(u\bar{b})$	$\mathrm{m} \approx 5279\ \mathrm{MeV}$	$c\tau \approx 501\ \mu\mathrm{m}$
$B^0(d\bar{b})$	$\mathrm{m} \approx 5279\ \mathrm{MeV}$	$c\tau \approx 460\ \mu\mathrm{m}$
$B_s^0(s\bar{b})$	$\mathrm{m} \approx 5370\ \mathrm{MeV}$	$c\tau \approx 438\ \mu\mathrm{m}$
$B_c^+(c\bar{b})$	$\mathrm{m} \approx 6.4\ \mathrm{GeV}$	$c\tau \approx 100 - 200\ \mu\mathrm{m}$
$\Lambda_b^0(udb)$	$\mathrm{m} \approx 5624\ \mathrm{MeV}$	$c\tau \approx 368\ \mu\mathrm{m}$

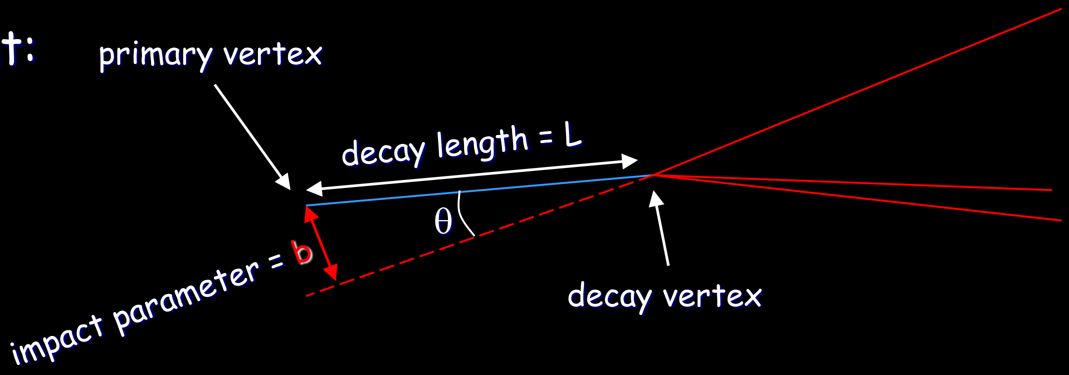
Impact parameter ~ cτ

- In UR limit *b* ~ Lorentz invariant:

$$L \approx \gamma ct \quad (t = \text{proper time})$$

$$\theta_{LAB} \approx \frac{1}{\gamma}\theta_{CM}$$

$$b \approx L\vartheta_{LAB} \approx \gamma ct\frac{\vartheta_{CM}}{\gamma} = ct\vartheta_{CM}\,,$$



... so b ~ independent of γ

- if cos θ_{CM} distribution is flat:

$$f(\theta_{CM})d\theta_{CM} = \frac{1}{2}\sin(\theta_{CM})d\theta_{CM}$$

$$\langle\theta_{CM}\rangle = \frac{1}{2}\int_0^{\pi}\theta_{CM}\sin(\theta_{CM})d\theta_{CM} = \frac{\pi}{2}$$

so, in space,

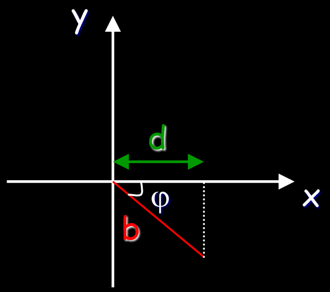
$$\langle \mathrm{b}\rangle = c\tau\langle\theta_{CM}\rangle = \frac{\pi}{2}c\tau$$

- in projection:

$$d = b\cos\varphi$$

$$f(\varphi) = \frac{1}{\pi}d\varphi;$$

$$\langle \mathrm{d}\rangle = \langle \mathrm{b}\rangle\frac{1}{\pi}\int_{-\pi/2}^{\pi/2}\cos\varphi d\varphi = \frac{2}{\pi}\langle \mathrm{b}\rangle$$

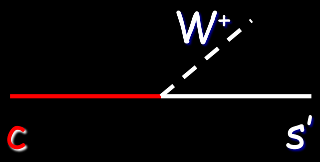


so:

$$\langle \mathrm{d}\rangle = c\tau$$

Weak decays of charm

- typically:

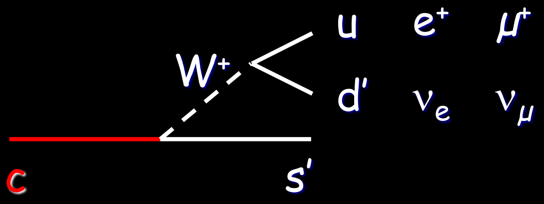


$$|s'\rangle = \cos\vartheta_C|s\rangle - \sin\vartheta_C|d\rangle \approx 0.97|s\rangle - 0.22|d\rangle$$

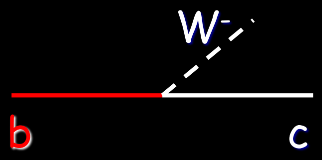
ϑ_C = "Cabibbo angle"

→ large branching ratio to kaons:
- D^+:
  - $D^+ \to K^- + X$ BR ~ 28 %
  - "golden" channel: $D^+ \to K^-\pi^+\pi^+$ BR ~ 9%
- D^0:
  - $D^0 \to K^- + X$ BR ~ 50%
  - "golden" channels: $D^0 \to K^-\pi^+$ BR ~ 4% ; $D^0 \to K^-\pi^+\pi^+\pi^-$ BR ~ 7%

- $W^\pm$ branchings:



(similarly:



)

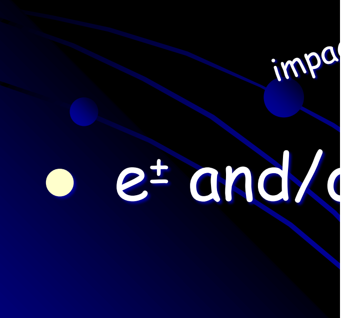
→ large semileptonic branching ratio, varies with heavy flavour particle, typical ~ 10%

~ 10% heavy flavour hadrons give in final state an $e^\pm$ (and ~ 10% a $\mu^\pm$)

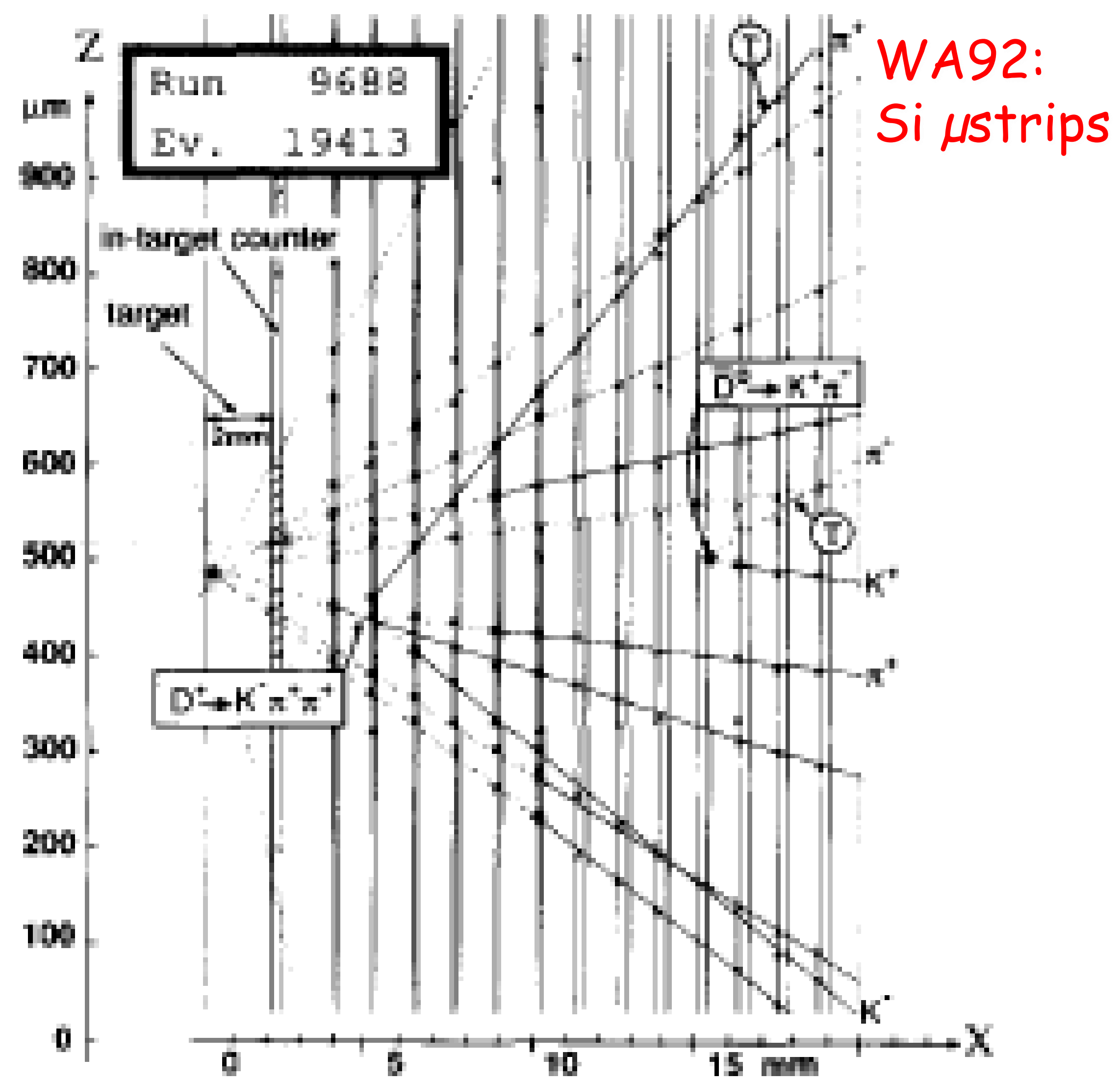
(and with a respectable p_T...)

Experimental tools

- Silicon v
  - so: tr s" primary verte
  - impac s ~ 10's μm



- e± and/c
- charged



WA92:
Si μstrips

[Adamovich et al.: NIM A 379 (1996) 252]

Heavy Flavour Production in QCD

Heavy Flavour hadro-production in pQCD

- Factorization: (at sufficiently large Q^2)

$$A + B \to D + X$$

hadron hadron

charmed hadron

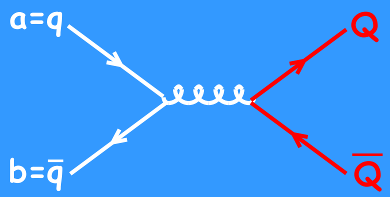
$$\int G_{a/A}(x_a)G_{b/B}(x_b)\,\hat{\sigma}_{ab\to c\bar{c}}(\hat{s}=x_a x_b s)\;D_{D/c}(z) = \sigma_{AB\to DX}$$

parton distribution functions

x_a = momentum fraction of parton a in hadron A

cross-section at parton level

e.g.:



fragmentation

z = fraction of c momentum to hadron D

cross-section at hadron level

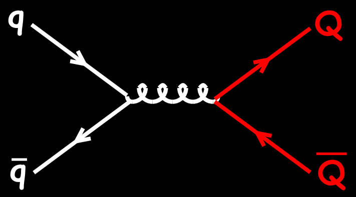
$$\int G_{a/A}(x_a) G_{b/B}(x_b)\, \hat{\sigma}_{ab\to c\bar{c}}(\hat{s}=x_a x_b s)\, D_{D/c}(z) \quad = \sigma_{AB\to DX}$$

- factorization implies:
  - PDFs can be measured with one reaction…
    - say: Drell-Yan: A+B → e^+e^- + X

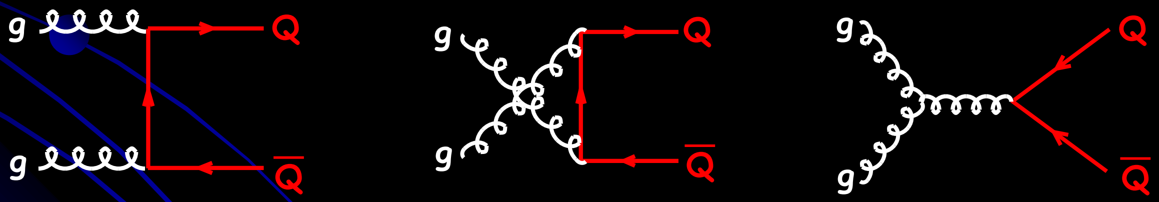
    … and used to calculate a different one
    - say: heavy-flavour production
  - fragmentation independent of the reaction (e.g.: same in pp, e^+e^-)

Leading-order (LO)

- Relevant diagrams: pair creation
  - $q\bar{q} \rightarrow Q\bar{Q}$ (quark-antiquark annihilation)



  - $gg \rightarrow Q\bar{Q}$ (gluon-gluon fusion)



A few results

- the partonic cross-section decreases with energy
  - faster for $q\bar{q}$ than for gg (which therefore is expected to dominate, except near threshold)
  - the parton luminosities near threshold increase with energy,

    the cross section increases with the energy of the hadron-hadron collision

- the pair cross section is proportional to:

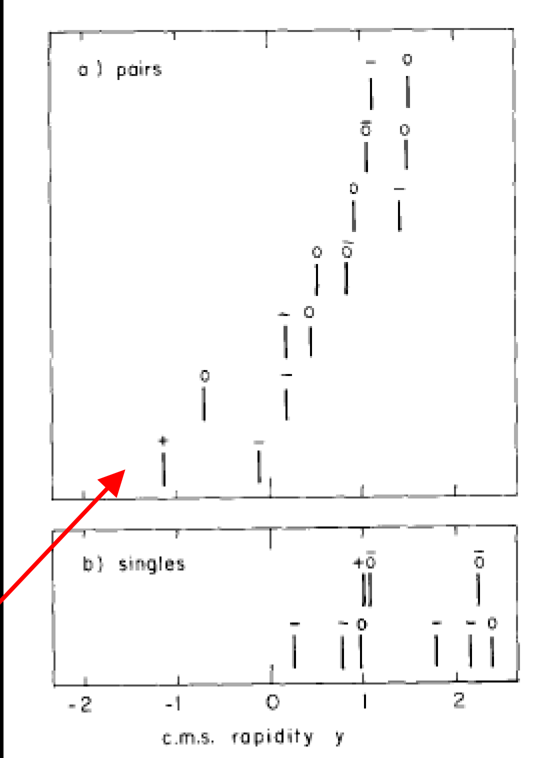
$$\frac{1}{[1+\cosh(y-\bar{y})]^2}$$

$$y = \tfrac{1}{2}\log\frac{E+p_z}{E-p_z}$$

y ($\bar{y}$): rapidity of Q ($\bar{Q}$)

→ Q and $\bar{Q}$ therefore expected to be close in y

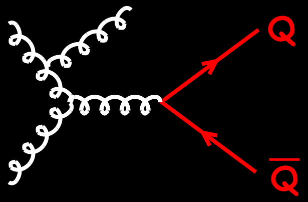
→ Experimentally: EHS, 360 GeV $\pi^- p \to D\bar{D}X$



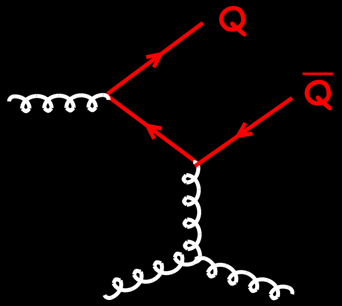
[EHS: PLB 123 (1983) 98]

Next-To-Leading-Order (NTLO)

- in absolute value, LO cross sections are typically underestimated by factor 2.5 - 3 (“K factor”)
- at NTLO: additional diagrams, such as:

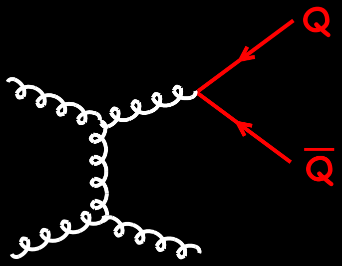


higher order corrections to pair creation

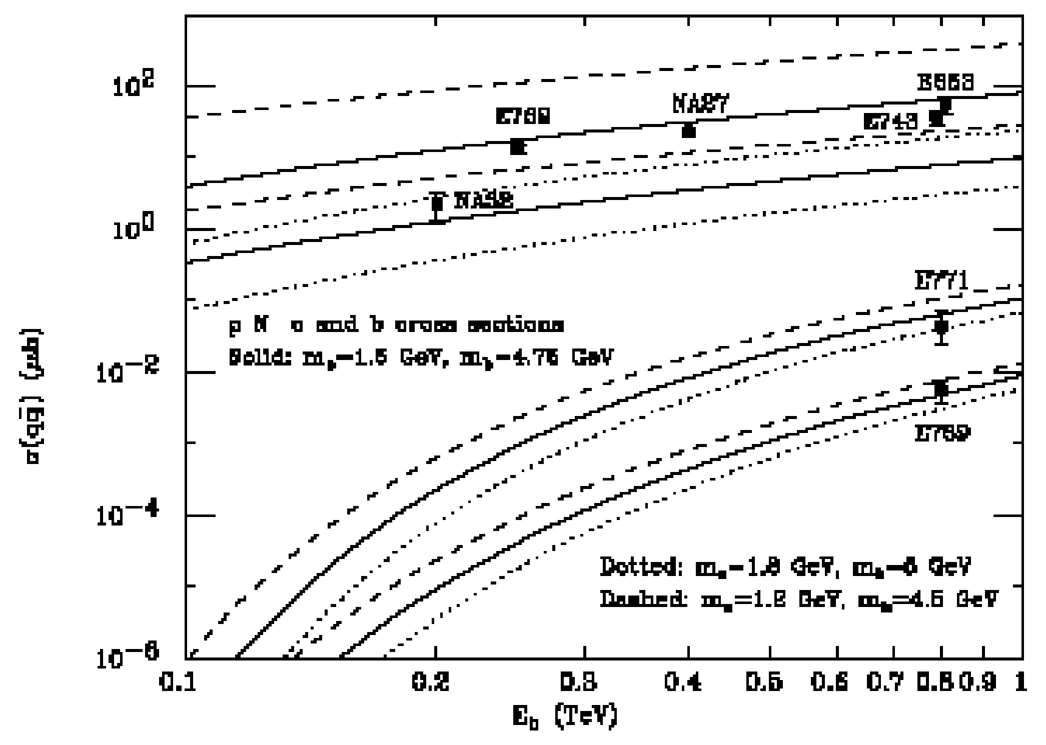


flavour excitation

gluon splitting



- the agreement with experiment for the total cross-section is good (within large bands...)
  - e.g.: charm cross section at fixed target:



[Mangano: hep-ph/9711337]

- results depend on the values of:
  - m_c, μ_R (renormalization scale), μ_F (factorization scale)

- the result of an exact calculation would be independent of the choice of the scale parameters μ_R, μ_F
  - the residual scale dependence is a measure of the accuracy of the calculation
  - e.g.: for b production at Tevatron (μ_R=μ_F=μ):

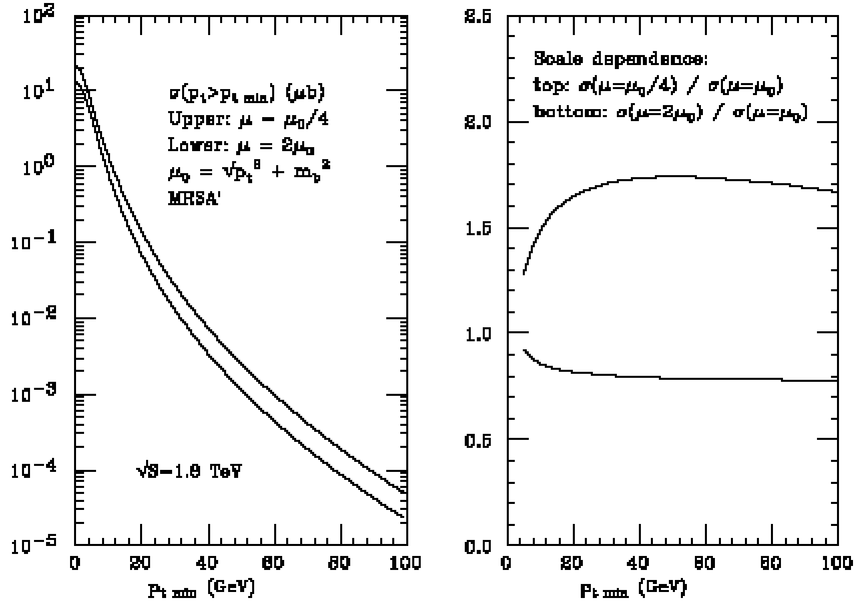
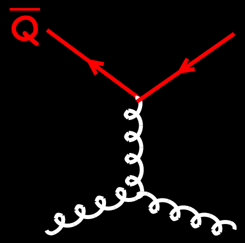


Figure 5: *Scale dependence of the inclusive p_T distributions for bottom quarks, in $p\bar{p}$ collisions at $\sqrt{S} = 1.8$ TeV. $\mu_R = \mu_F = \mu$.*

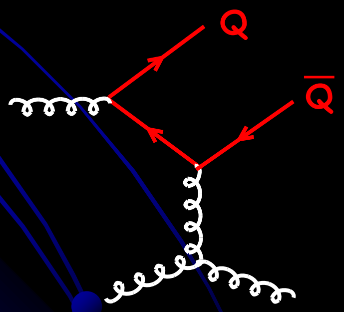
[Mangano: hep-ph/9711337]

- it is important to match the PDFs with the order of the calculation.
- e.g. one must avoid double counting:
  - at LO:



“intrinsic flavour”

  - at NTLO:



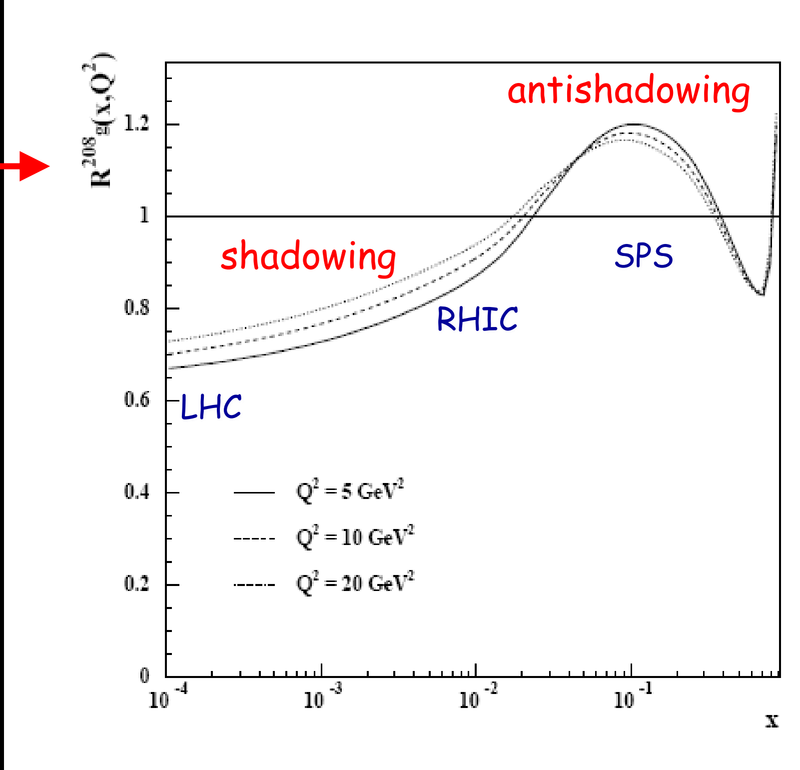
“flavour excitation”

Heavy Flavour in p/π-A

Nuclear shadowing

- PDFs in the nucleus different from PDFs in free proton
  - R = ratio of nuclear to nucleon PDFs
    - from Deep Inelastic Scattering (e^-+p; e^-+A), Drell-Yan (p+p, p+A -> $\ell^+\ell^-$+X)

e.g.:
R for gluons vs
gluon momentum fraction x
from EKS parametrization
[Eskola et al.: EPJ C9 (1999) 61]



- typical x for $c\bar{c}$ production ($y \approx 0$)
  - $x \approx 10^{-1}$ @ SPS
  - $x \approx 10^{-2}$ @ RHIC
  - $x \approx$ a few 10^{-4} @ LHC

Nuclear dependence

- From pQCD one expects the cross section for production off nuclei to increase like number of nucleon-nucleon collisions
  ("binary collision scaling")

→ proportional to number of nucleons (for min. bias collisions):

$$\sigma_A^{(Q\bar{Q})} = \sigma_0^{(Q\bar{Q})} A^\alpha$$

with α =1

  - modulo shadowing effects, expected to be small

- Experimentally: not far… e.g. WA82:
  - D production in π^-+W/Si at SPS (340 GeV beam momentum)
  - (relatively) central production

$$\alpha = 0.92 \pm 0.06$$

$$@ \langle x_F \rangle = 0.24$$

$$x_F = p_z / p_{z\max} \approx \frac{2p_z}{\sqrt{s}}$$

"Feynman's x"

Caveats...

- i) α = 1 does not work down to pp!

$$\sigma_0^{c\bar{c}} \neq \sigma_{pp}^{c\bar{c}}$$

  - e.g.: MacDermott & Reucroft [PLB 184 (1987) 108] compare pA results with earlier hydrogen data from NA27, good agreement using:

$$\sigma_{pA}^{c\bar{c}} = K_0 \sigma_{pp}^{c\bar{c}} A^{\alpha}$$

$$\alpha \approx 1, \;\; K_0 \approx 1.5$$

  - note: similar situation for light flavours!

    systematic study by Barton et al. [PRD 27 (1983) 2580], for various reactions at 100 GeV FT

    e.g.: central for production of π, K, p from p on nuclear targets:

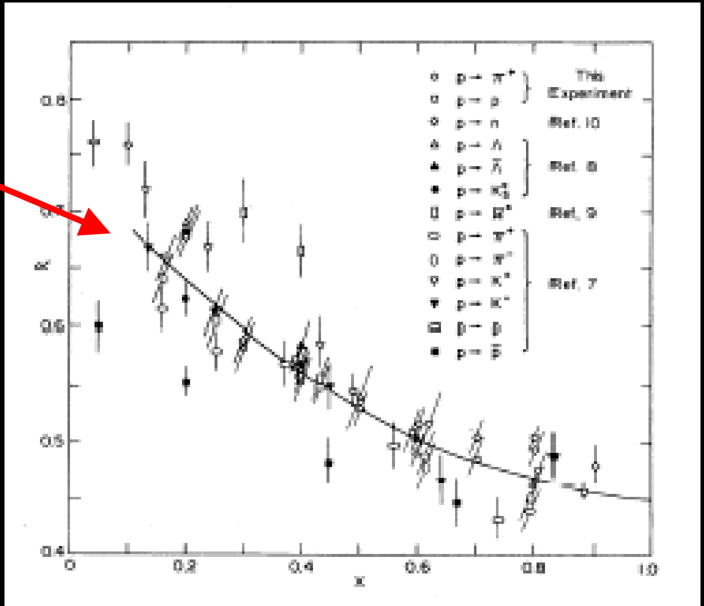
$$\alpha \approx 0.6 \quad \text{with} \quad K_0 \approx 1.5 \div 2$$

- ii) lower α at large x_F?
  - early beam dump experiments, sensitive at large x_F (max acceptance for $x_F \approx 0.5$)
    (in tracking experiments, typically max. acceptance for $x_F \approx 0.2$)
    e.g. WA78 [Cobbaert et al.: PLB 191 (1987) 456]
    α for muons escaping dump ($\pi^- A$ at 320 GeV FT):

$$\alpha(\mu^+) = 0.76 \pm 0.08$$
$$\alpha(\mu^-) = 0.83 \pm 0.06$$

$$\langle x_F \rangle \approx 0.4$$

  - note: α is known to decrease with x_F for light hadrons



[Barton et al.: PRD 27 (1983) 2580]

Heavy Flavour Fragmentation

Fragmentation function

- c → D, D takes fraction *z* of c momentum
  - fragmentation function: $D_{D/c}(z)$
  - depends only on fraction z
  - e.g.:

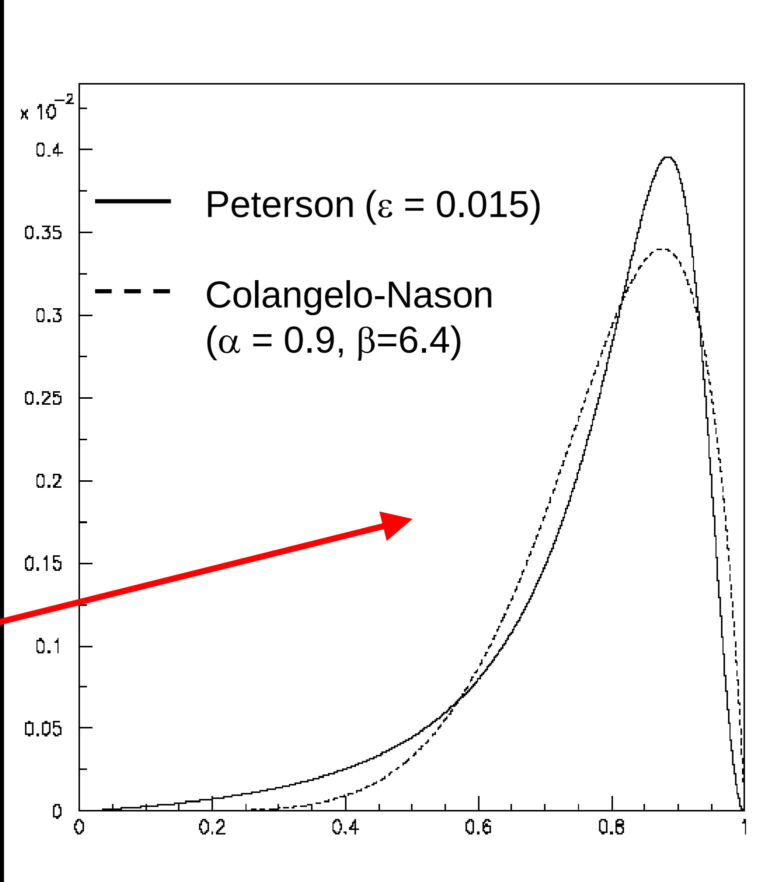
$$D_{D/c}(z) \propto \frac{1}{z[1-1/z-\varepsilon/(1-z)]^2}$$

Peterson

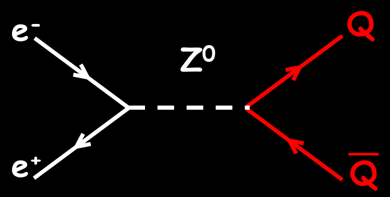
$$D_{D/c}(z) \propto (1-z)^\alpha z^\beta$$

Colangelo-Nason

e.g.:
(parameters from fits to charm production at LEP)

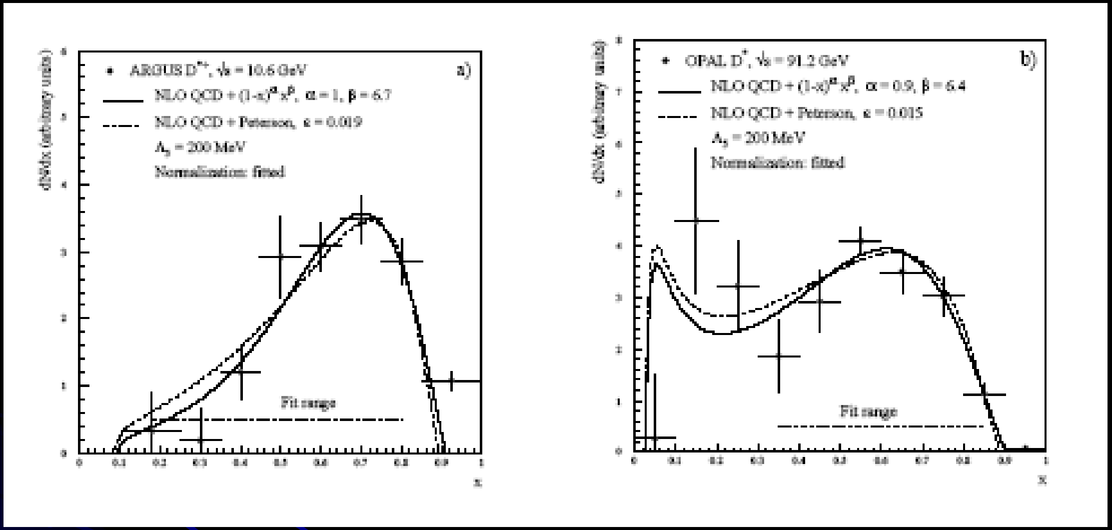


- How to measure the fragmentation function?
  - we don't measure the original Q momentum …
  - but in e^+e^- we do know the Q energy (by energy conservation!)
    - e.g.:



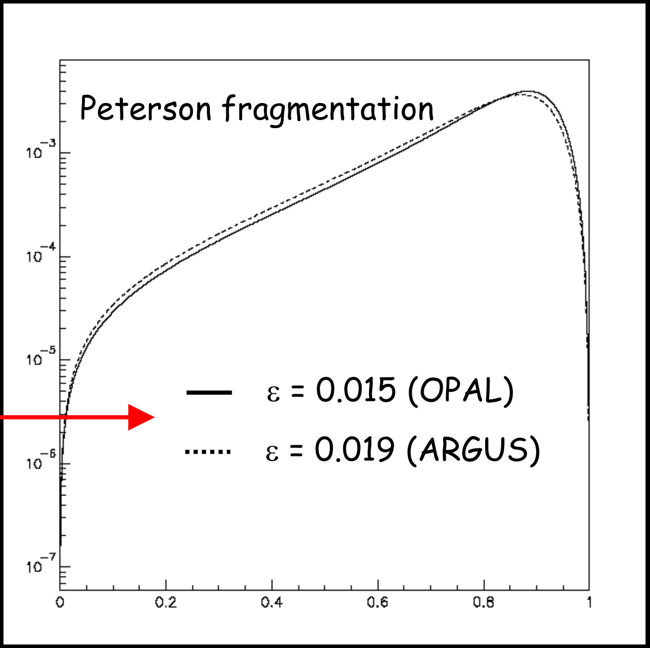
  - fragmentation functions are usually extracted from e^+e^- measurements and then used for other collisions

- e.g.: fits to charm $x = 2E/\sqrt{s}$ distributions in e^+e^-:
  [Cacciari & Greco: PRD55 (1997) 7134]

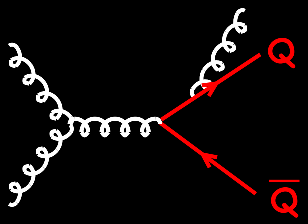


$\sqrt{s}$ = 10.6 GeV (ARGUS) $\sqrt{s}$ = 91.2 GeV (OPAL)

- very similar parameters at the two energies (as expected)



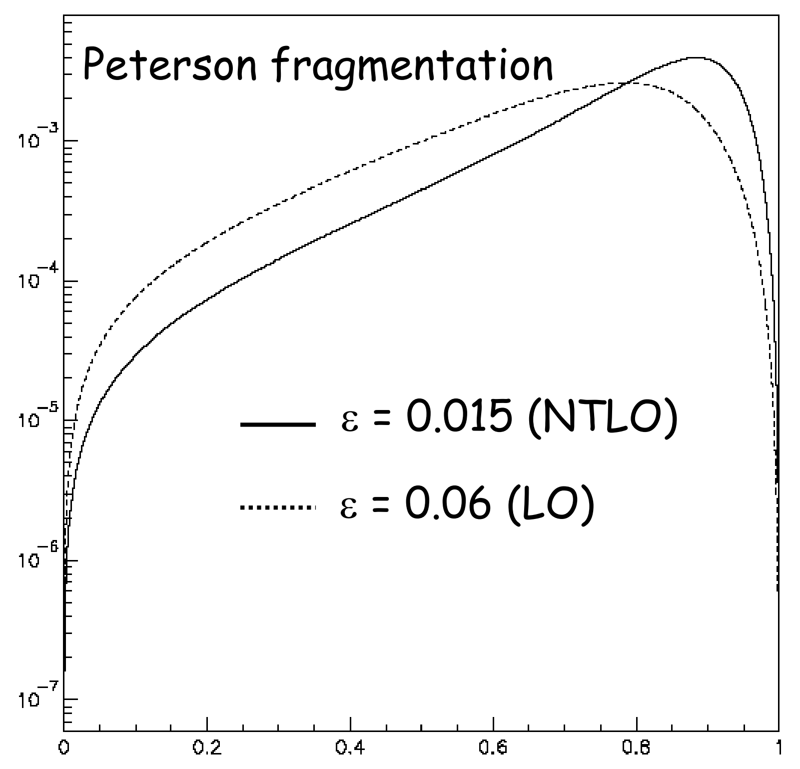
- like for the PDFs, the fragmentation function has to be matched to order of pQCD calculation
  - e.g. at NTLO the Q can radiate:



  - so final energy before non-perturbative part of fragmentation lower than at LO

→ harder fragmentation at NTLO
    - at NTLO: $\varepsilon \approx 0.015$
    - at LO: $\varepsilon \approx 0.06$

(e.g.: [Cacciari & Greco: PRD55 (1997) 7134])



Heavy Flavour at Tevatron

Beauty at Tevatron

- Discrepancy between pQCD and data seems to have disappeared…
  - from…

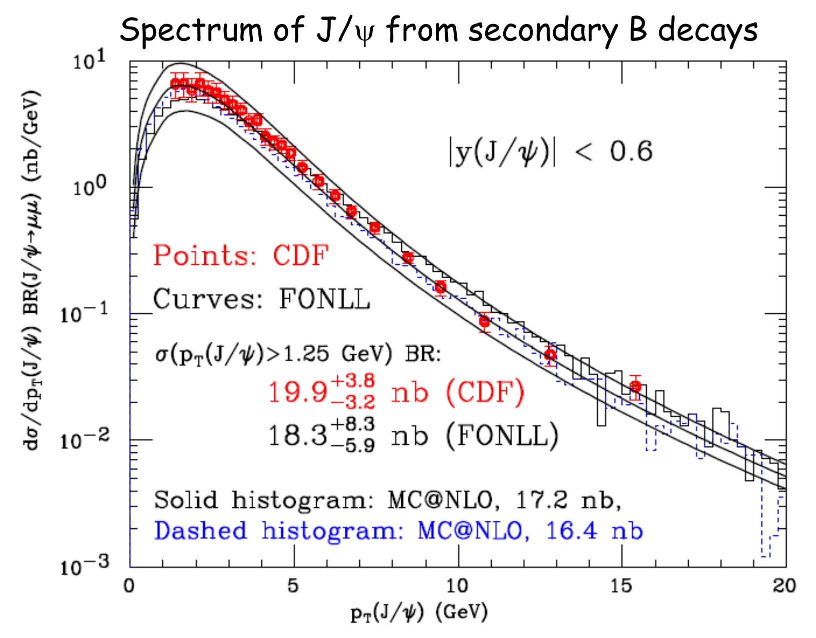
$$\sigma(p\bar{p} \rightarrow bX;\, p_T^b > 11.5\mathrm{GeV},\, |y| < 1) = \begin{array}{ll} \mathrm{CDF:} & 6.1 \pm 1.9_{stat} \pm 2.4_{syst}\,\mu\mathrm{b} \\ \mathrm{theory:} & 1.1 \pm 0.5\,\mu\mathrm{b} \end{array}$$

Run 0

a factor 5.5 (but only 1.6 σ …)

[CDF: PRL 68 (1992) 3403]

  - to…



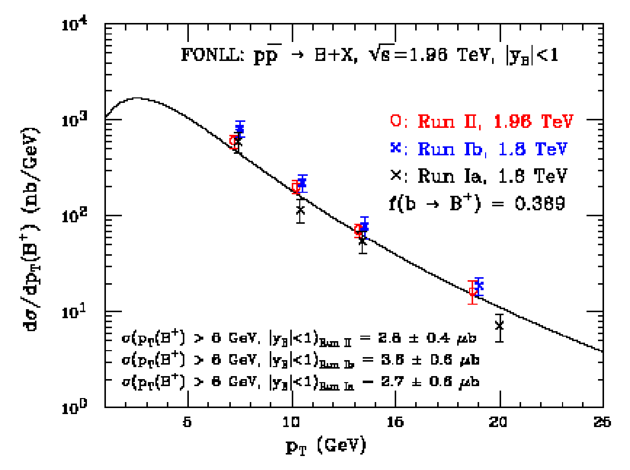
Run II

[Cacciari et al: JHEP 0407 (2004)]

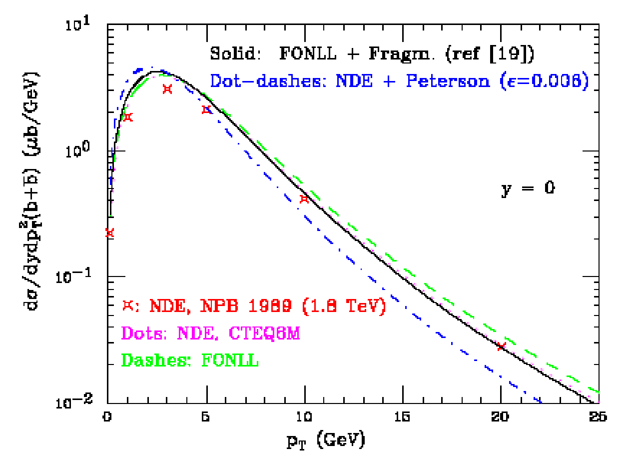
- From run I on, important improvements in accuracy:
  - experiment (vertex detectors, high statistics)
  - prediction (post-HERA PDF sets)

- Levels of stability over time:

Data



Predictions



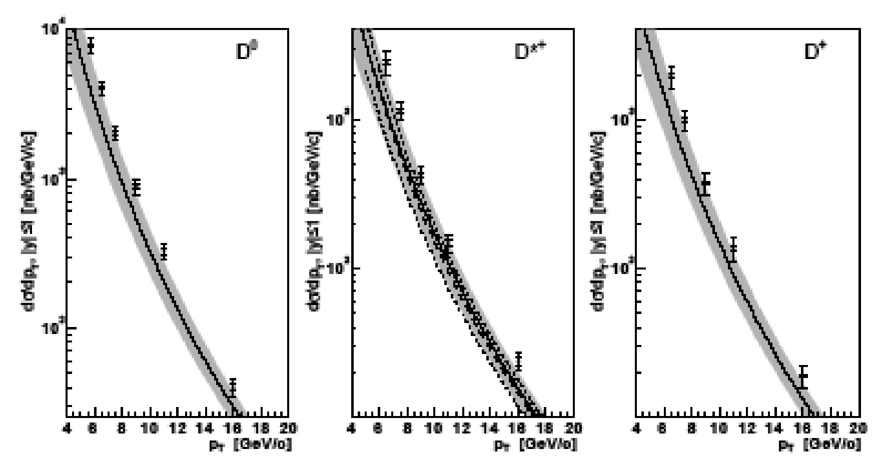
from [Cacciari et al: JHEP 0407 (2004) 033]

- no large room for new physics any more...

→ for more see, e.g.:
[Cacciari et al: JHEP 0407 (2004) 033, Cacciari: hep-ph/0407187, Mangano: hep-ph/0411020]

What about charm?

- Nice data from CDF run II



- roughly in agreement with full pQCD calculation

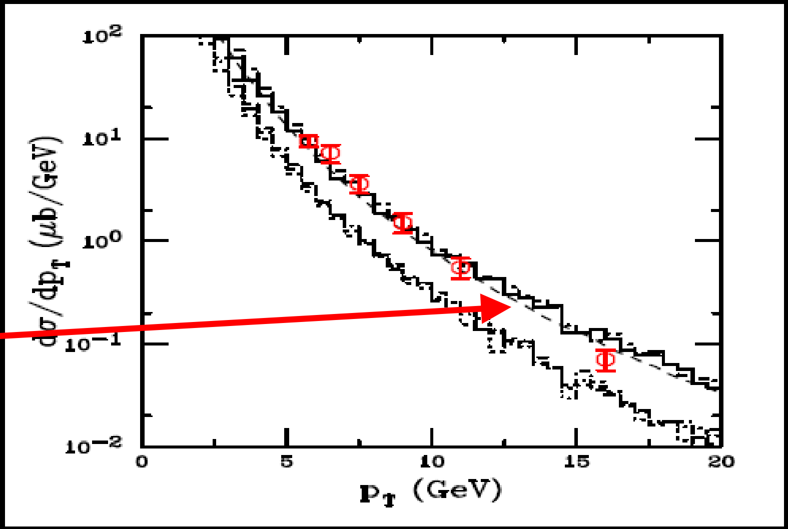
  (though prediction somewhat low)

  [CDF: Phys.Rev.Lett. 91 (2003) 241804]

- A curiosity (?):

  good agreement between data and prediction for bare quark

  [Vogt: talk at SQM 2004]



Heavy Flavour in AA

Heavy flavour production in AA

- binary scaling:

$$\boxed{d\sigma_{\mathrm{AA}} = N_{coll} \times d\sigma_{\mathrm{pp}}}$$

can be broken by:

- initial state effects (modified PDFs)
    - shadowing
    - k_T broadening
    - gluon saturation (colour glass)

(concentrated at lower p_T)

- <u>final state effects</u> (modified fragmentation)
    - parton energy loss
    - violations of independent fragmentation (e.g. quark recombination)

(at higher p_T)

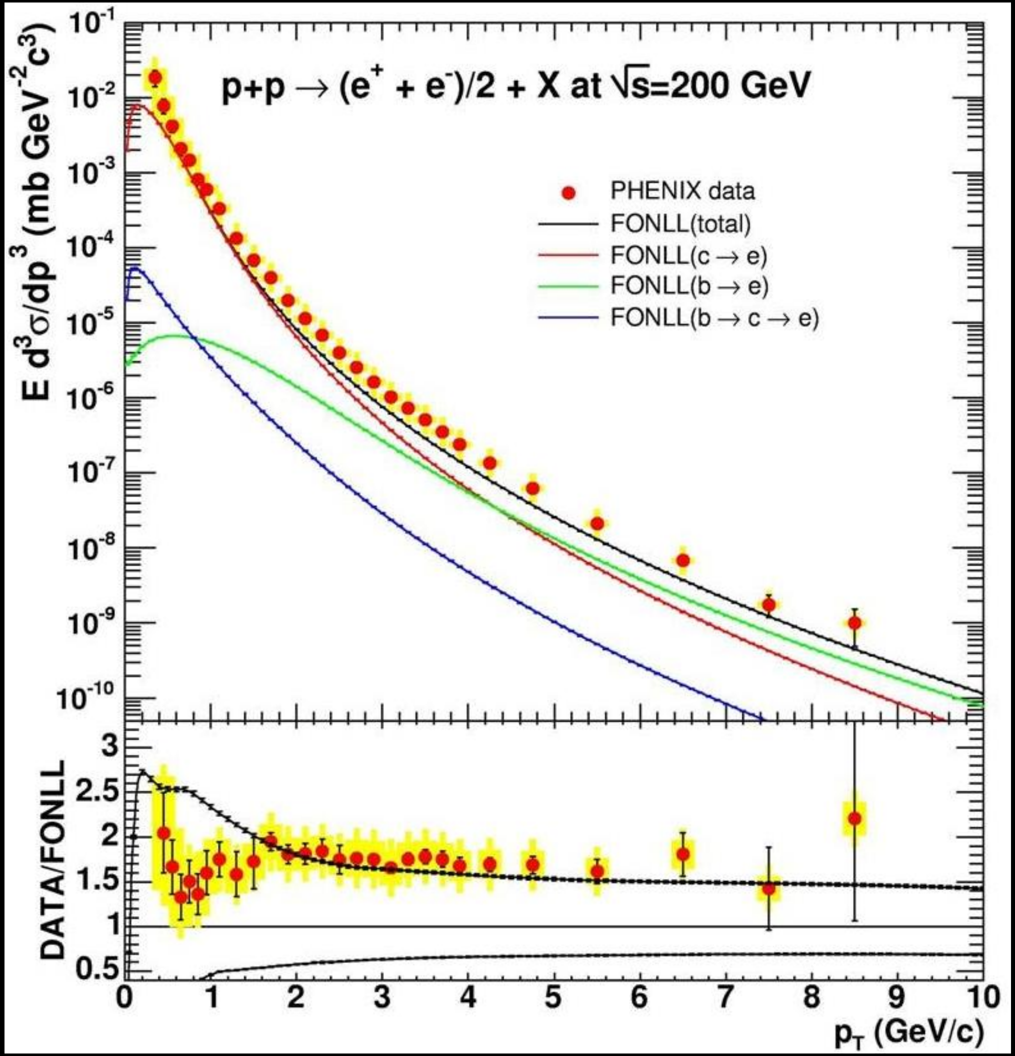
PHENIX pp

- Excess wrt FONLL:

  Ratio:

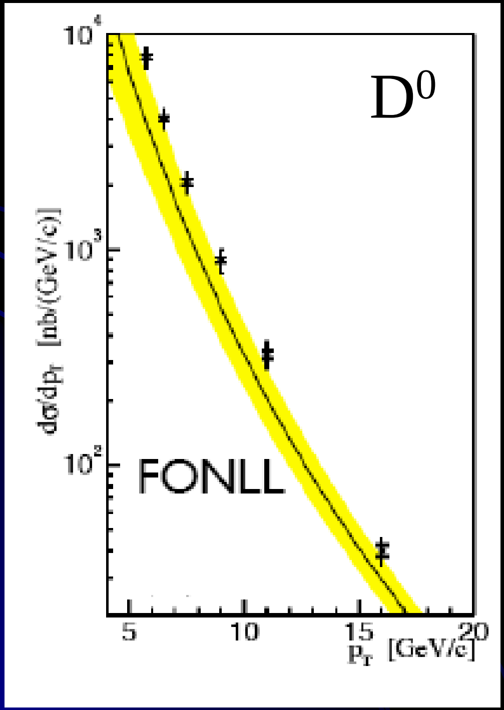
  1.72 ± 0.02 (stat) ± 0.19 (sys)

  ($0.3 < p_T < 9.0$ GeV/c)



[A. Adare et al. (PHENIX) Phys.Rev.Lett. 97 (2006) 252002]

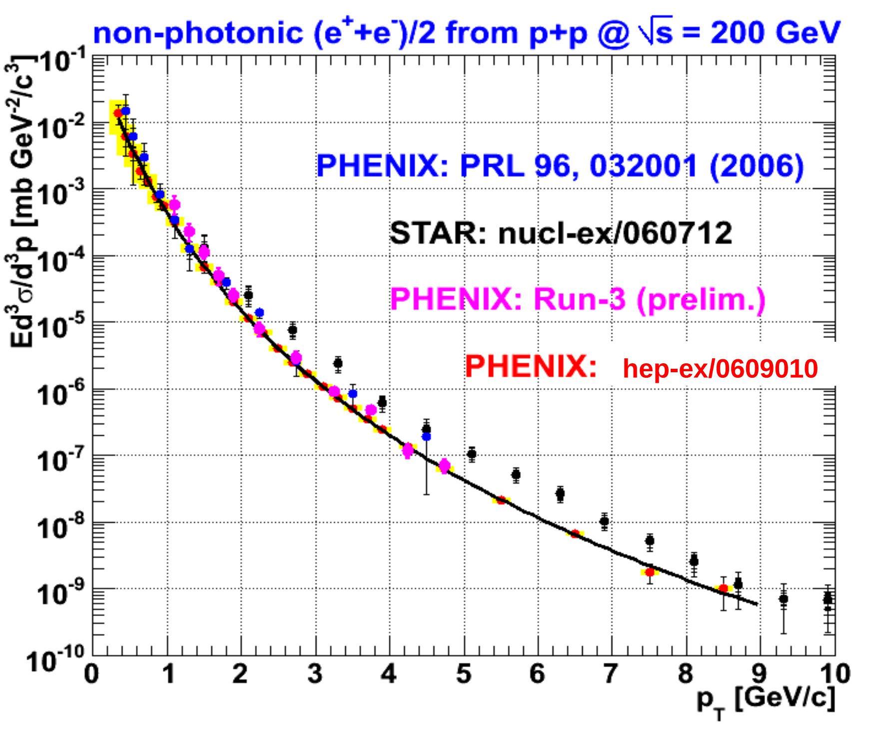
- Similar situation also in CDF:

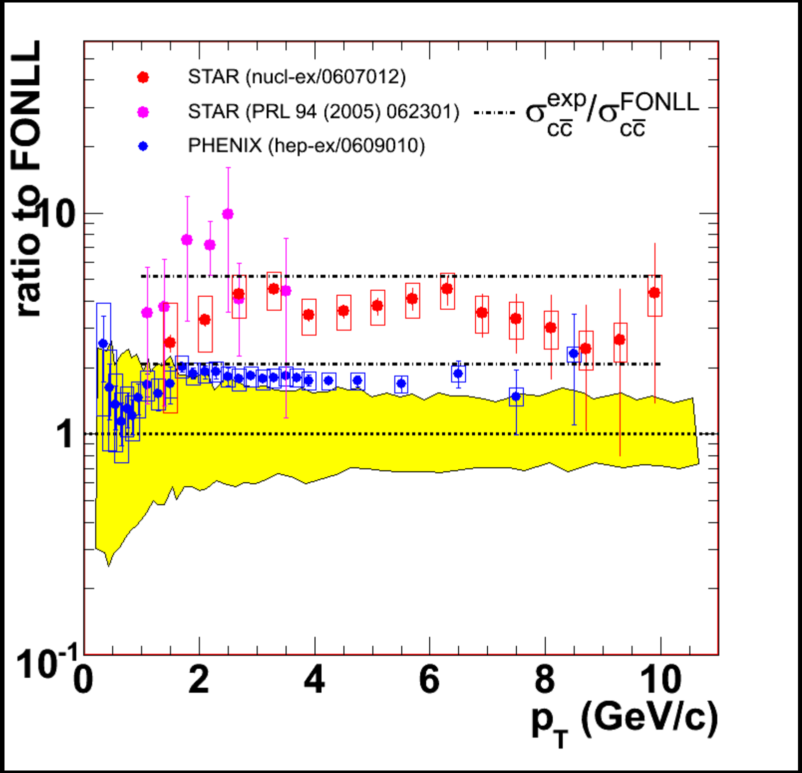


[D. Acosta et al. (CDF) PRL 91 (2003) 241804]

STAR v PHENIX pp

- ~ a factor 2 discrepancy

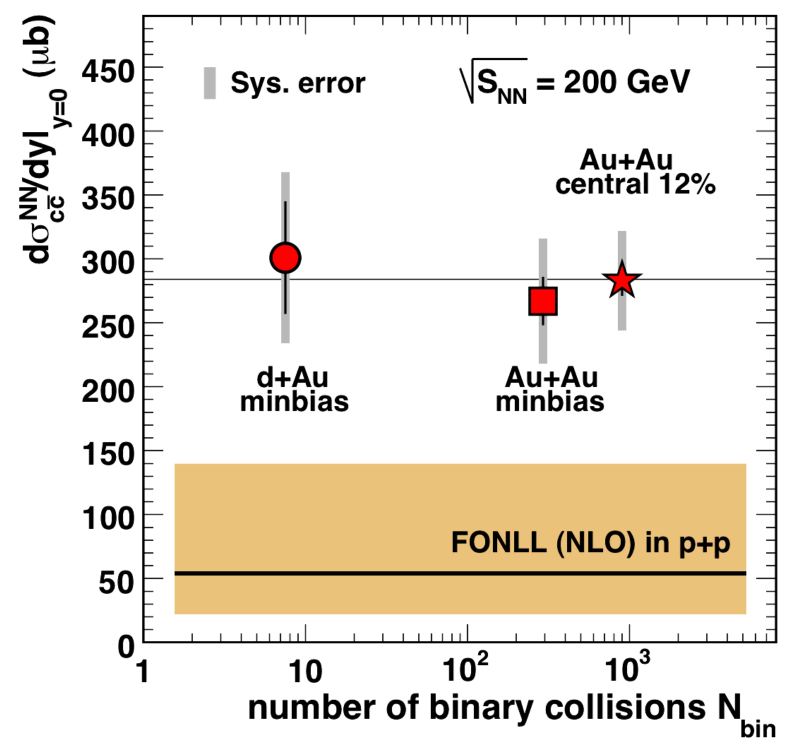


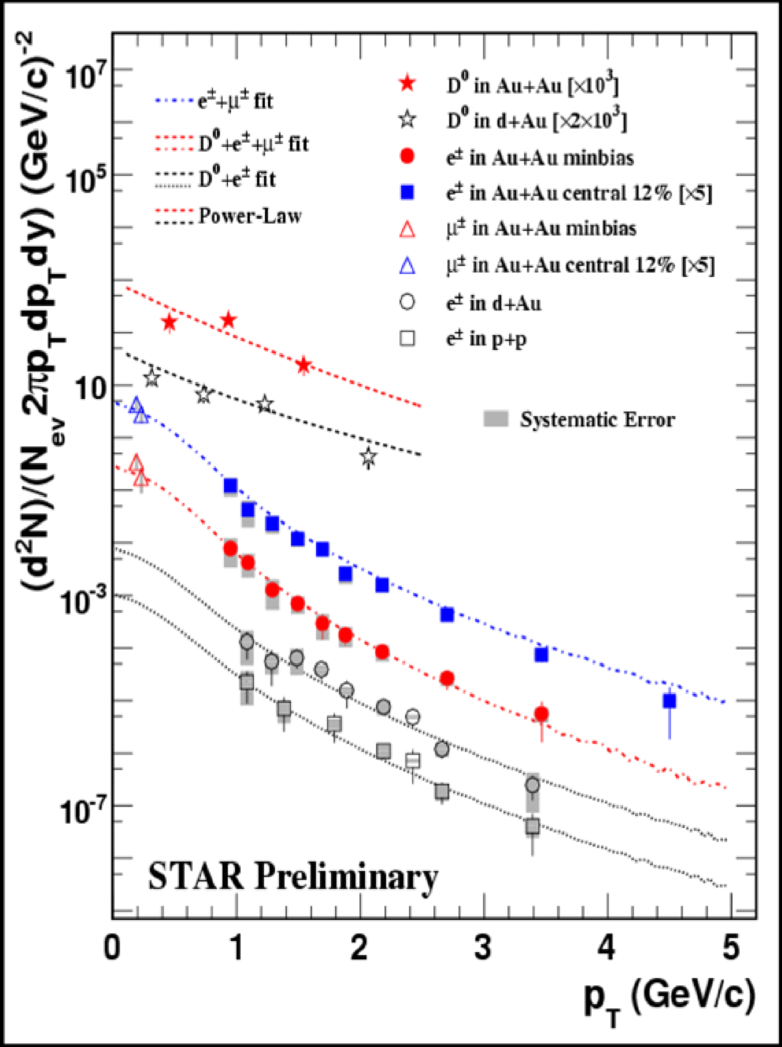


[J. Lajoie (PHENIX) QM06]

STAR dAu, AuAu

- Internal consistency

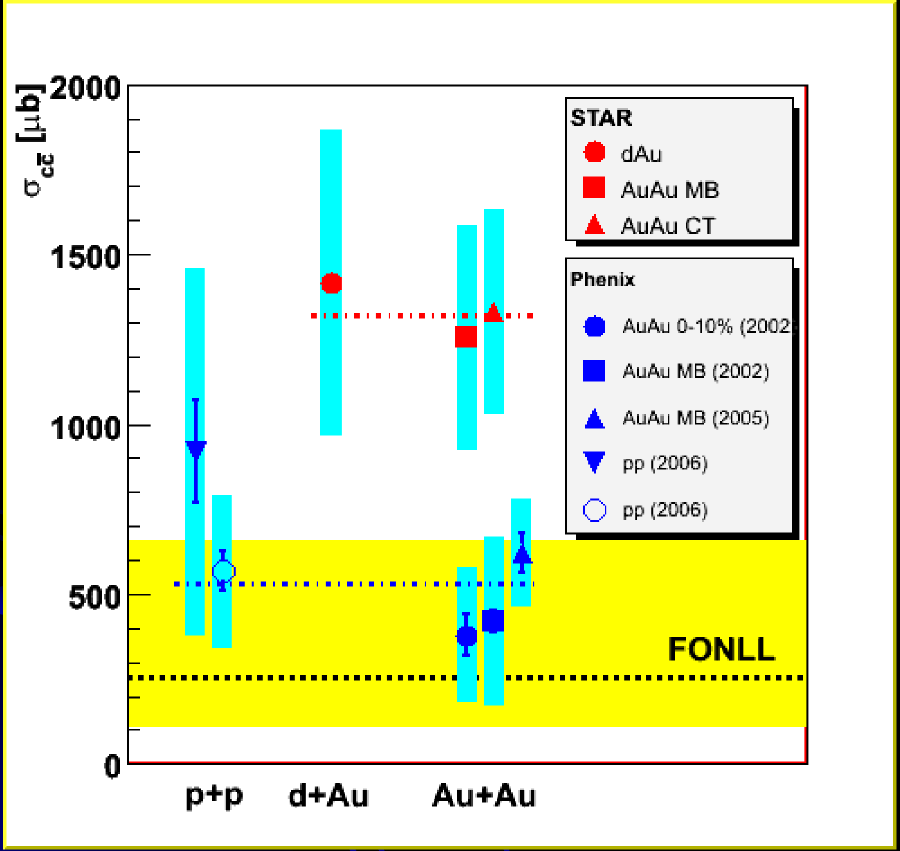


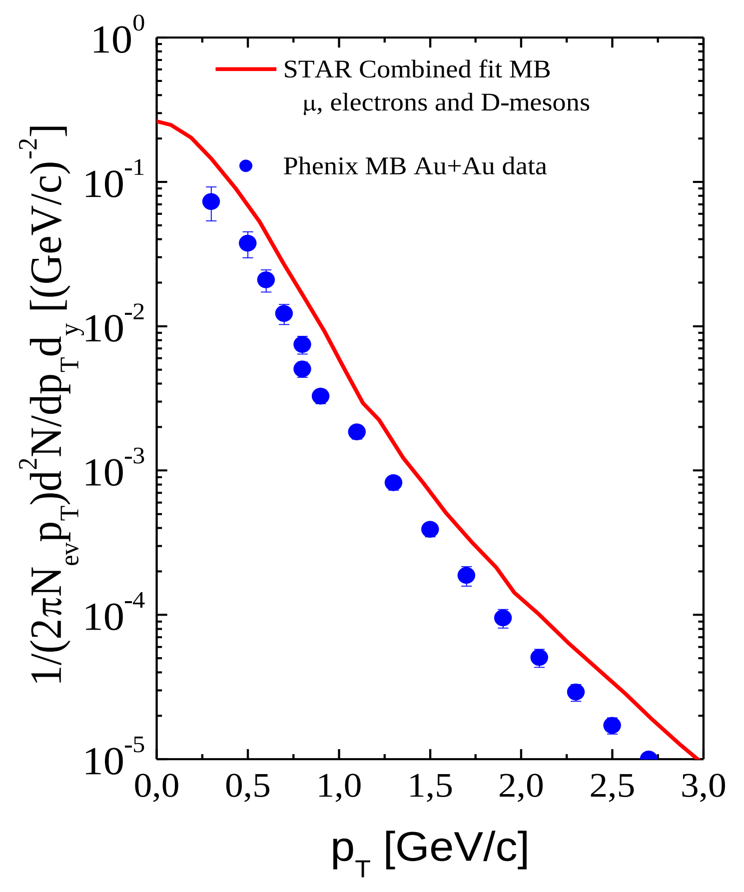


[M. Calderon (STAR) QM06]

STAR v PHENIX dAu, AuAu

- Discrepancy pretty "stable" v system, p_T



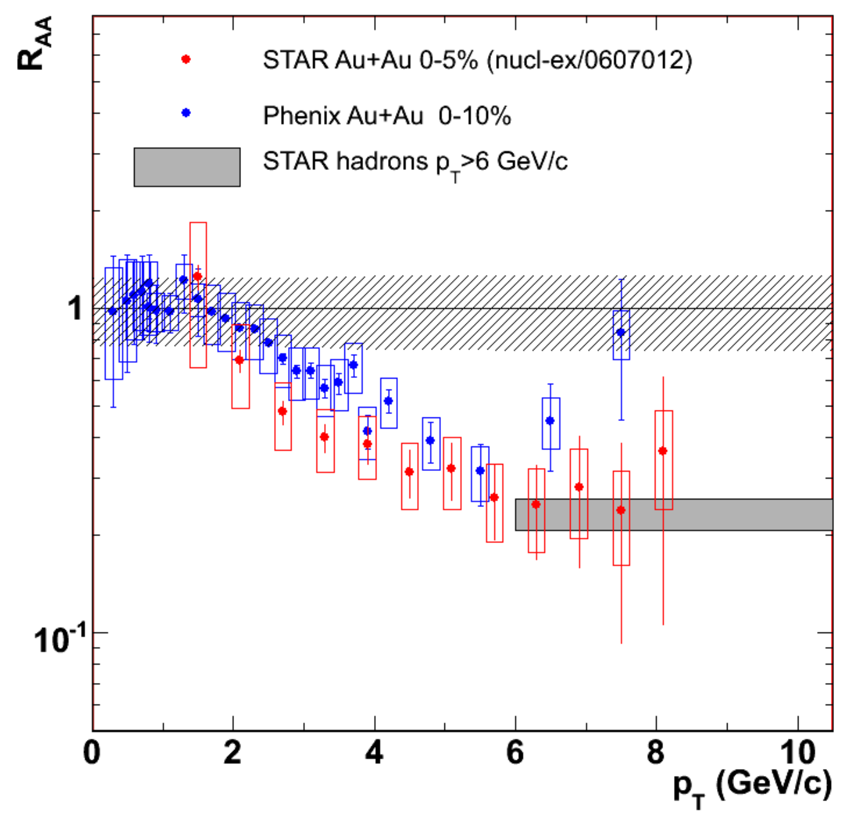


- looks like something very basic...
- of course then R_{AA} not too different...

[A. Suaide QM06]

STAR v PHENIX: R_{AA}

- R_{AA} of non-photonic electrons



[A. Suaide QM06]

→ similar picture from STAR and PHENIX

Heavy flavour energy loss?

$$\langle \Delta E \rangle \propto \alpha_s \, C_R \, \hat{q} \, L^2$$

average energy loss

Casimir coupling factor

transport coefficient of the medium

distance travelled in the medium

→ R.Baier et al., Nucl. Phys. **B483** (1997) 291 ("BDMPS")

Energy loss for heavy flavours is expected to be reduced:

i) Casimir factor

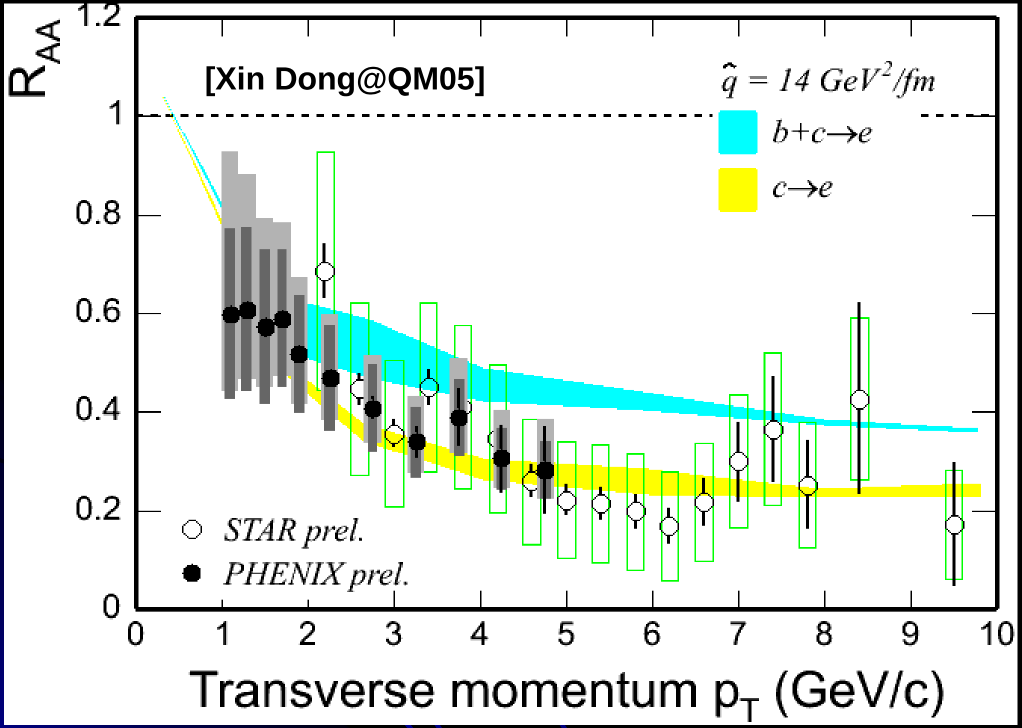
- light hadrons originate predominantly from gluon jets, heavy flavoured hadrons originate from heavy quark jets
- C_R is 4/3 for quarks, 3 for gluons

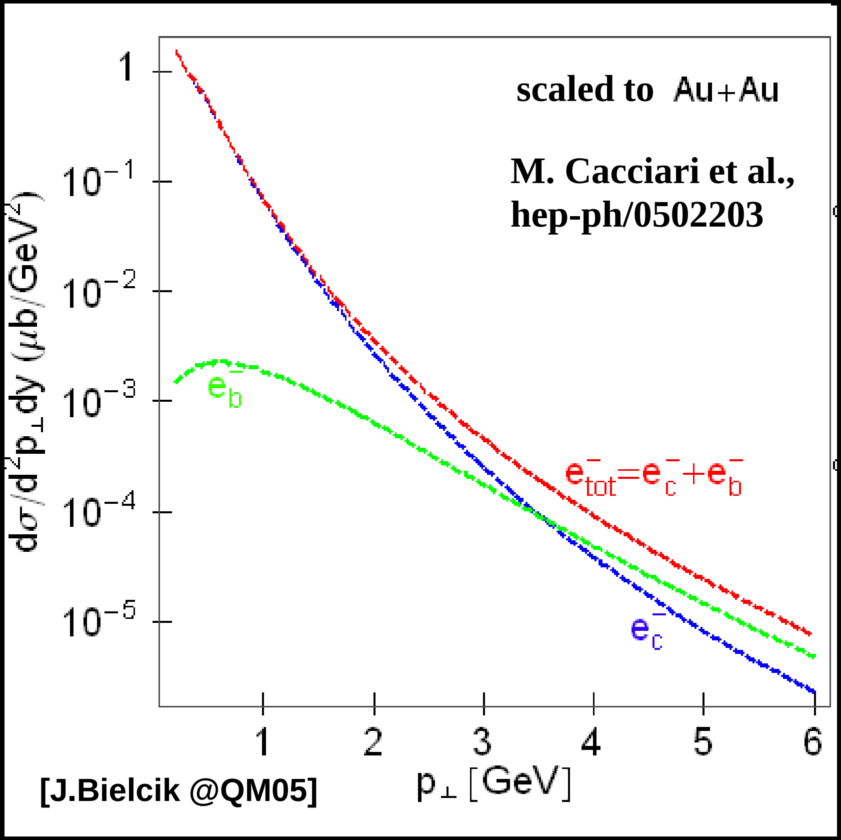
ii) dead-cone effect

- gluon radiation expected to be suppressed for $\theta < M_Q/E_Q$
  [Dokshitzer & Karzeev, Phys. Lett. **B519** (2001) 199]
  [Armesto et al., Phys. Rev. D69 (2004) 114003]

Large suppression at RHIC!

- n.p. electrons ~ as suppressed as expected for c only (no b)
- yet, region above 3-4 GeV expected to be dominated by beauty...





- disentangling c/b is a must!
  - e.g. full reconstruction of D vertices

Heavy Flavour in Alice

LHC

- Running conditions:

Collision system	$\sqrt{s_{NN}}$(TeV)	L_0 ($cm^{-2}s^{-1}$)	Run time (s/year)	σ_{geom} (b)
pp	14.0	10^{34} *	10^7	0.07
PbPb	5.5	10^{27}	10^6 **	7.7
pPb	8.8	10^{29}	10^6	1.9
ArAr	6.3	10^{29}	10^6	2.7

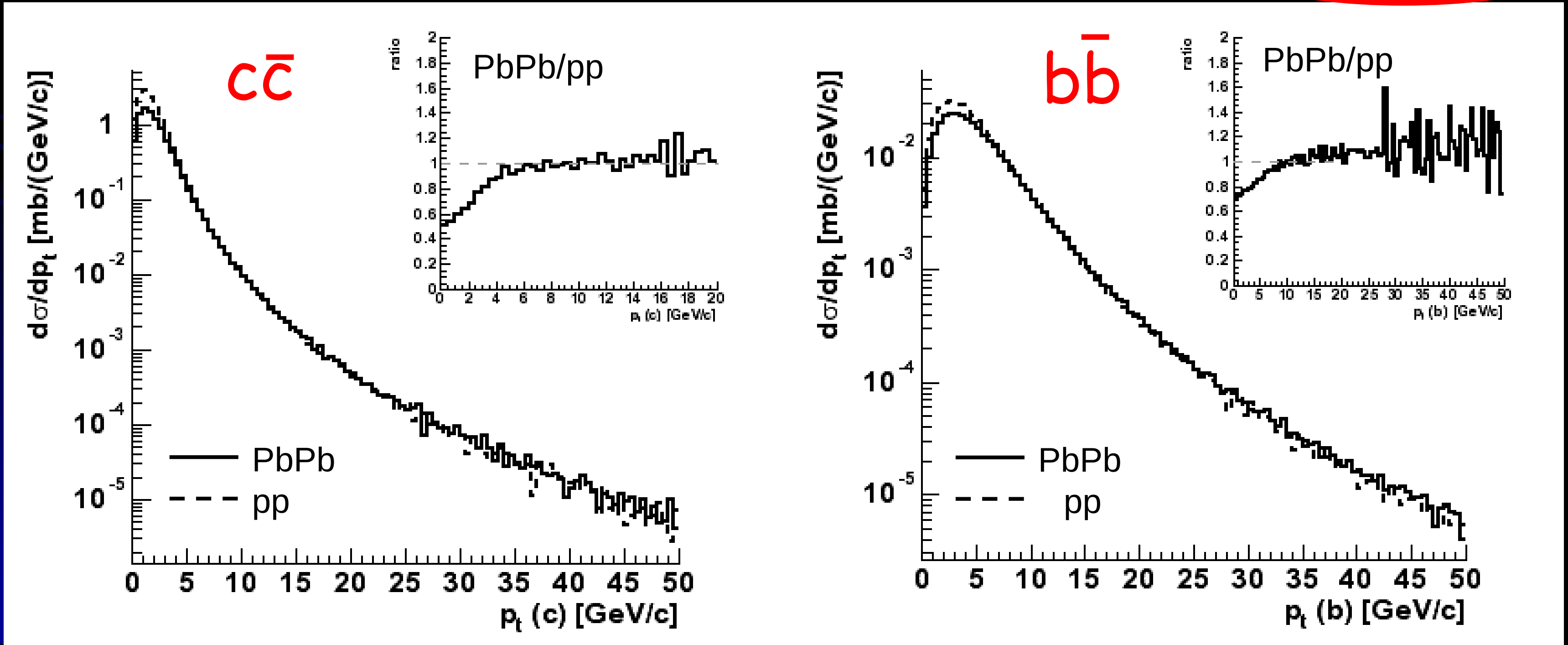
*$\mathcal{L}_{max}$ (ALICE) = 10^{31} **$\mathcal{L}_{int}$ (ALICE) ~ 0.5 nb^{-1}/year

- + other ions (Sn, Kr, O) & energies (e.g.: pp @ 5.5 TeV)

LHC is a Heavy Flavour Machine!

- $c\bar{c}$ and $b\bar{b}$ rates
  - ALICE PPR (NTLO + shadowing)

system	NN x-sect (mb)	shadowing	total multiplicity
pp 14 TeV	11.2 / 0.5	1 / 1	0.16 / 0.007
Pb-Pb 5.5 TeV (5% cent)	6.6 / 0.2	0.65 / 0.85	115 / 4.6

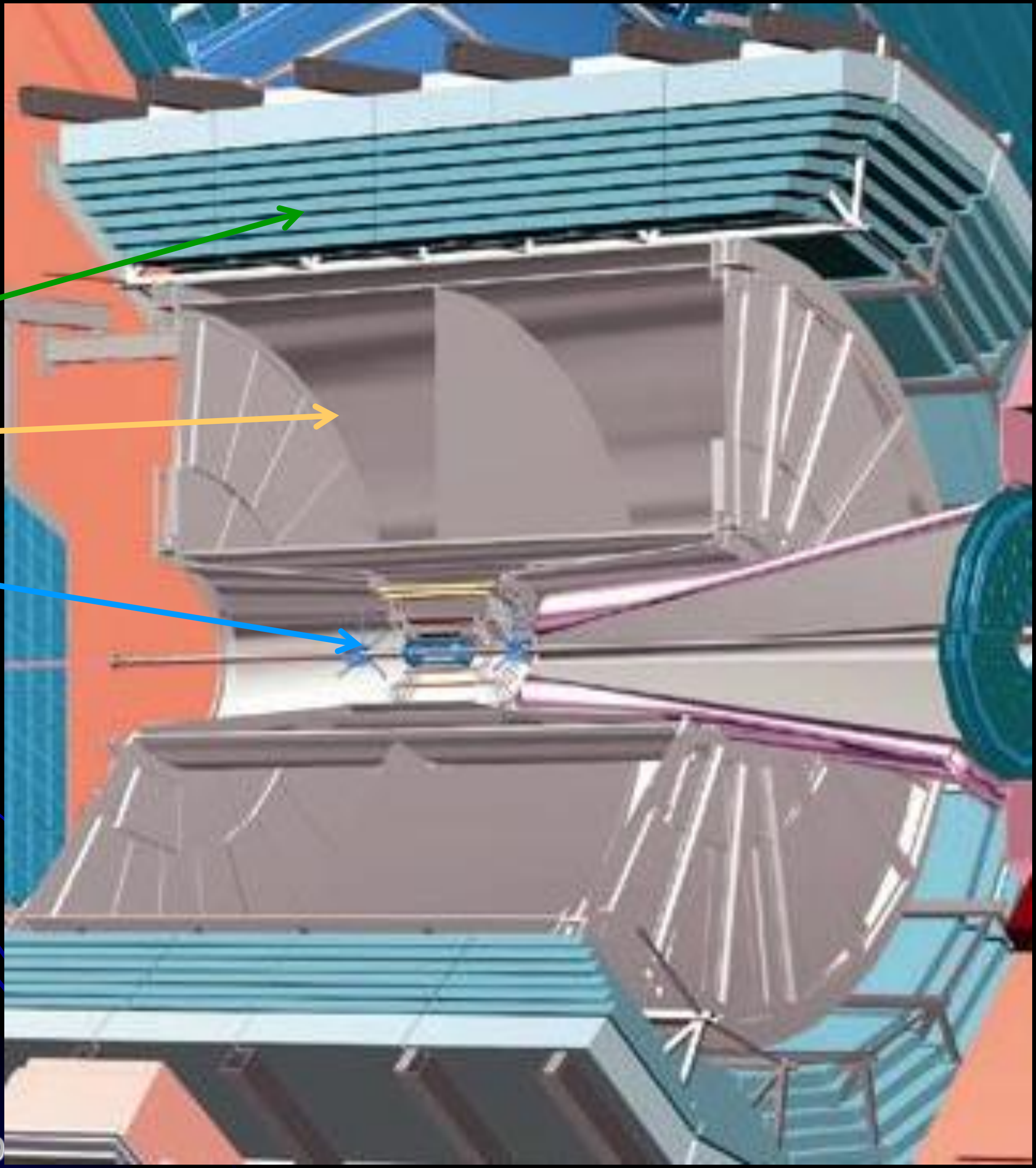


ALICE Set-up

Size: 16 x 26 meters

Weight: 10,000 tons

Tracking



|η| < 0.9:

B = 0.4 T

TRD

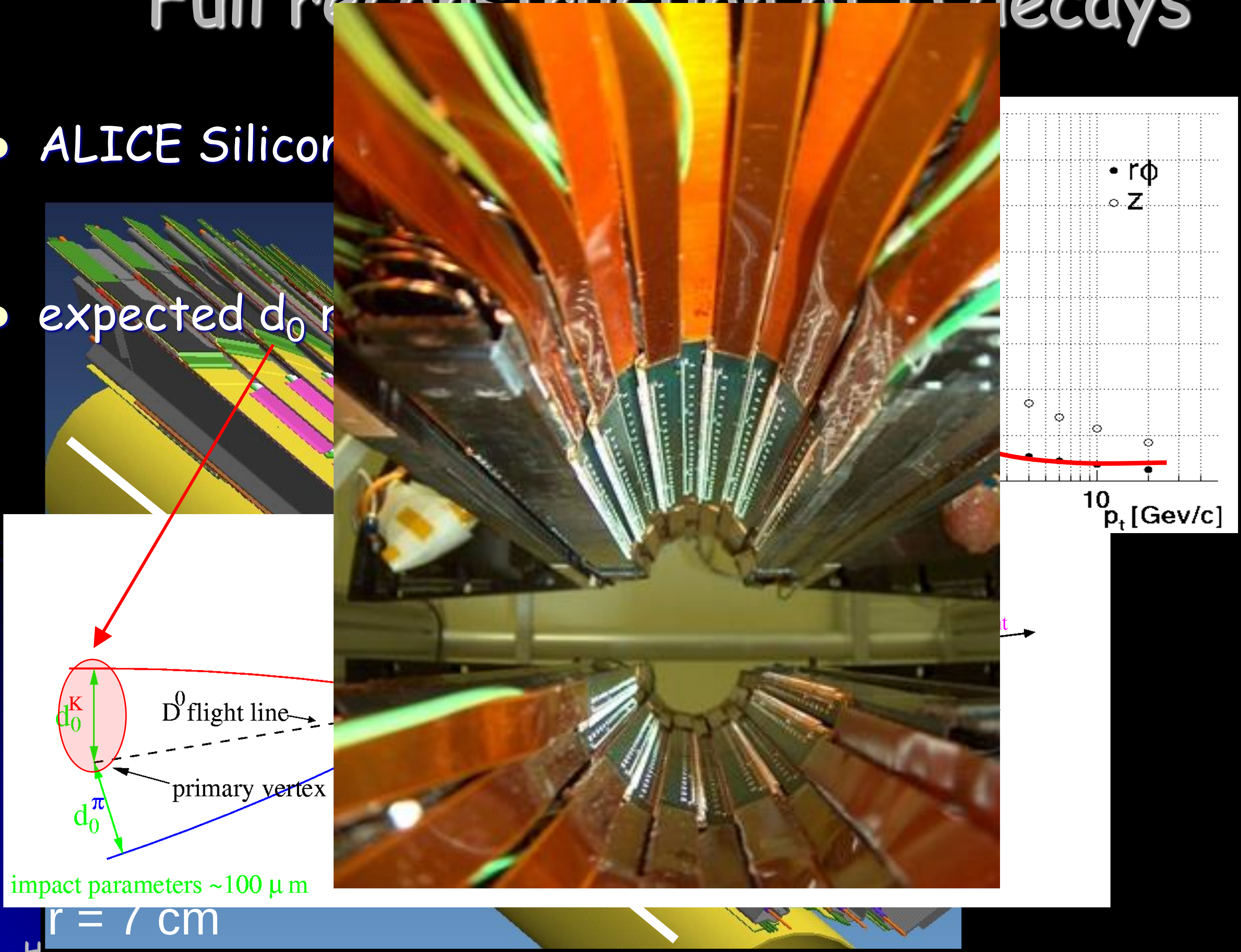
TPC

ITS with:

- Si pixel
- Si drift
- Si strip

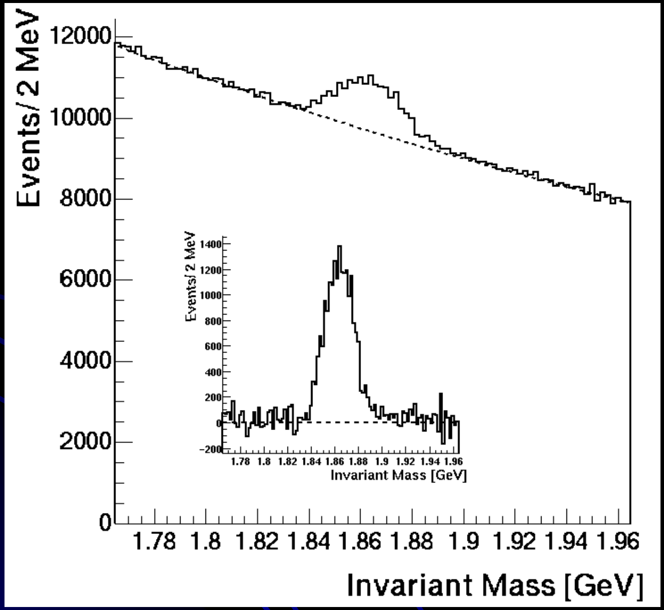
Full reconstruction of D decays

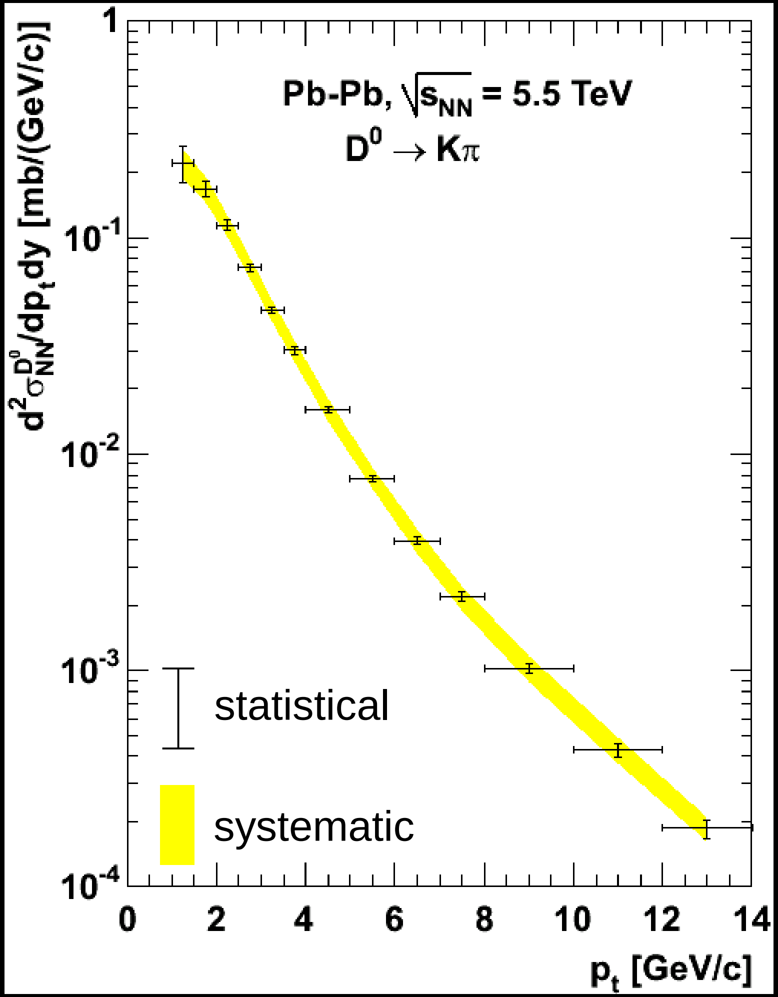
- ALICE Silico
- expected d_0 r



$D^0 \rightarrow K^- \pi^+$

- expected ALICE performance
  - S/B ≈ 10 %
  - $S/\sqrt{(S+B)} \approx 40$
    (1 month Pb-Pb running)





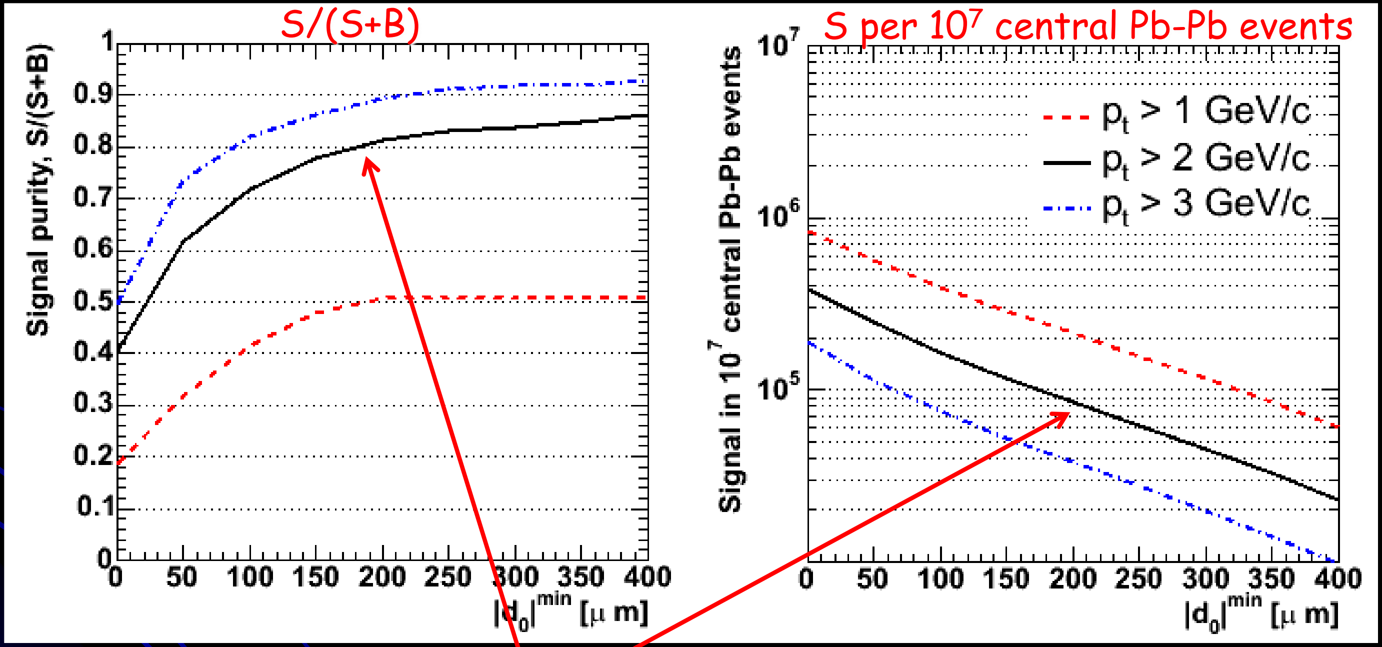
→ similar performance in pp

- (wider primary vertex spread)

p_T - differential

Beauty to electrons

- Expected ALICE performance (1 month Pb-Pb)
  - e± identification from TRD and dE/dx in TPC
  - impact parameter from ITS



p_t > 2 GeV/c , 200 < $|d_0|$ < 600 μm ⇒

80% purity
8 × 10^4 e from B

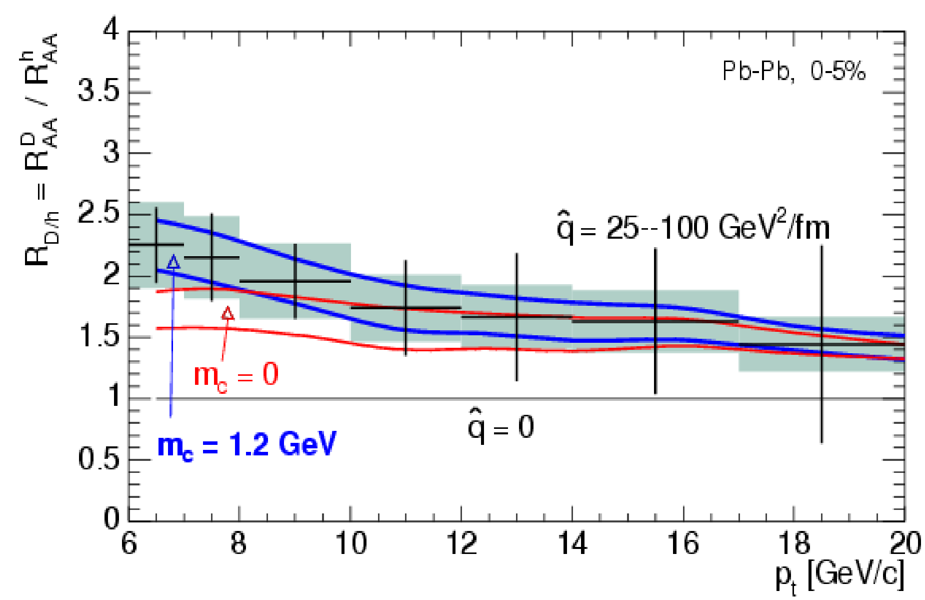
Expected performance on D, B R_{AA}

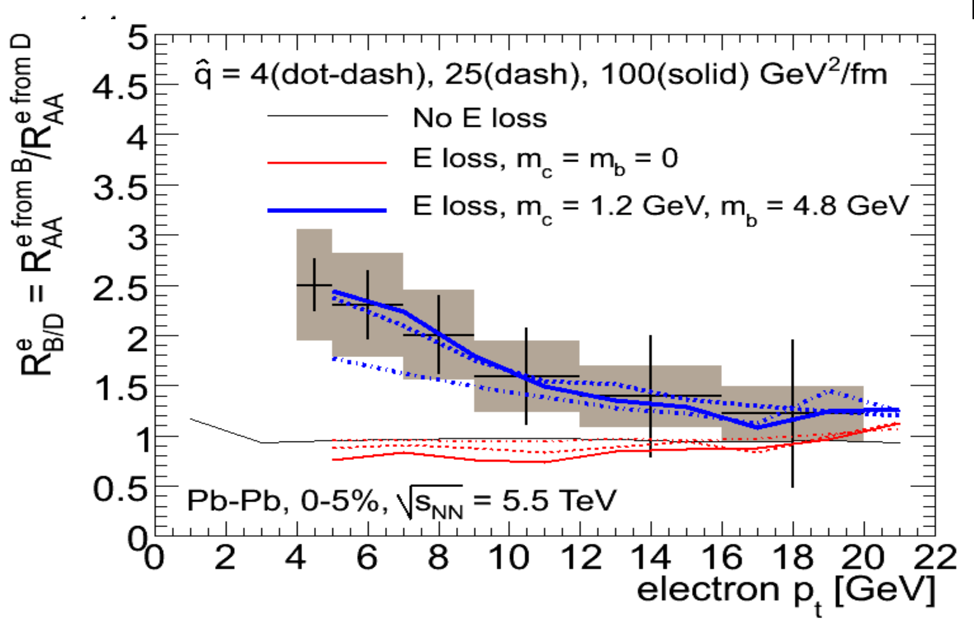
colour charge dependence

$$R_{D/h}(p_t) = R_{AA}^{D}(p_t) \big/ R_{AA}^{h}(p_t)$$

mass dependence

$$R_{B/D}(p_t) = R_{AA}^{\text{e from B}}(p_t) \big/ R_{AA}^{\text{e from D}}(p_t)$$





1 year at nominal luminosity
(10^7 central Pb-Pb events, 10^9 pp events)

- should clarify the heavy flavour quenching story

Heavy Flavour v_2

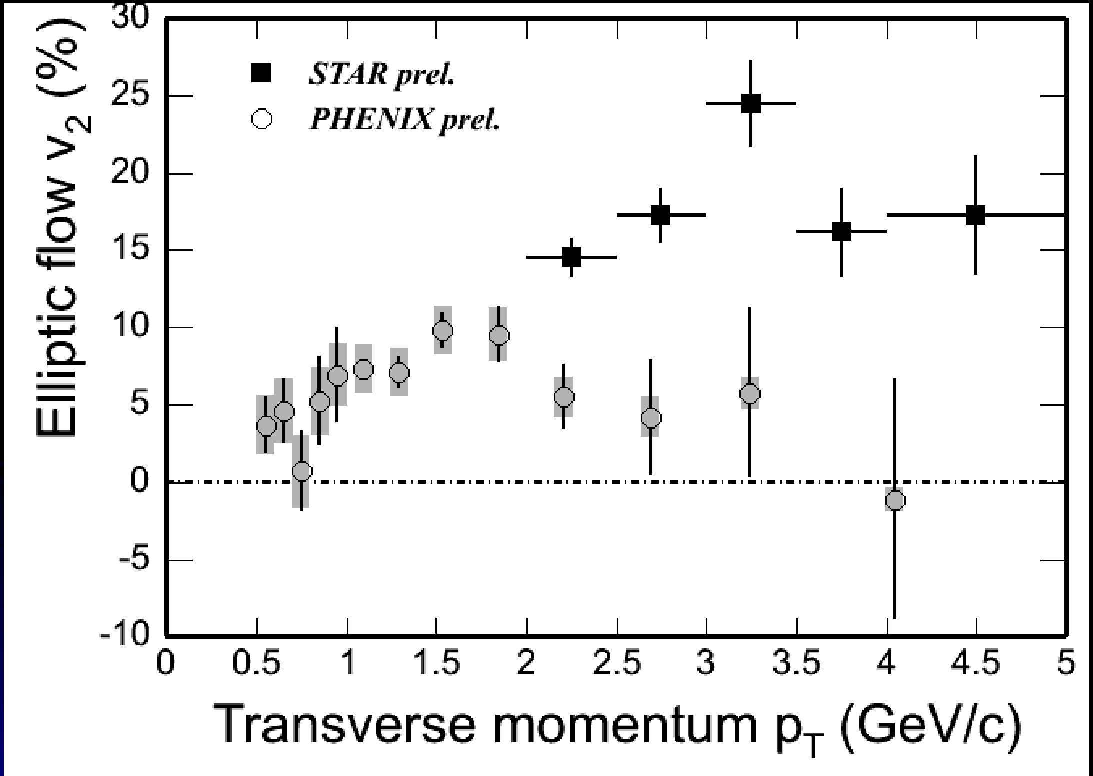
- v_2 = azimuthal anisotropy ≠ elliptic flow

- can get charm v_2 from
  - direct charm elliptic flow
  - non-flowing c recombining with flowing matter
  - azimuthally dependent energy loss
  - ...?

→ in general, $v_2 \neq 0$ if charm "strongly coupled" with azimuthally asymmetric medium...

electron v2 at RHIC

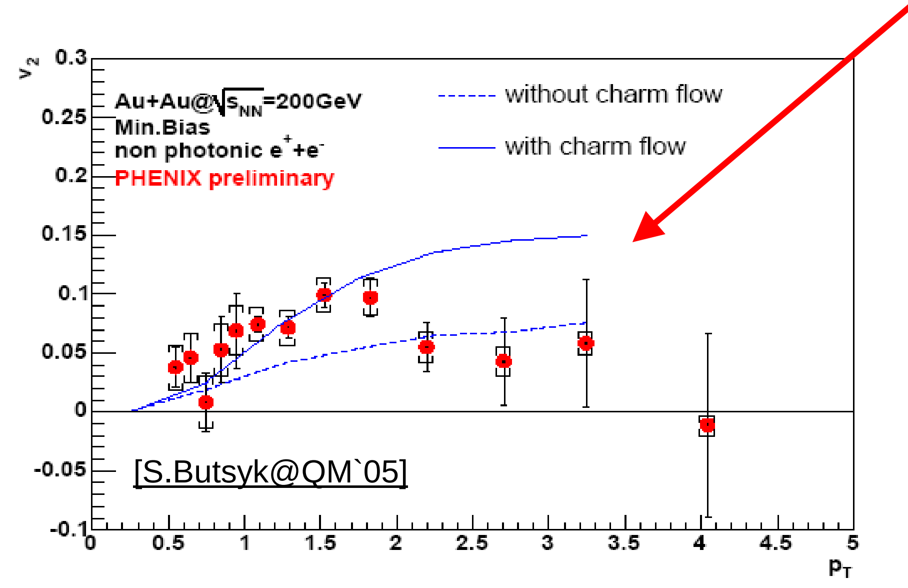
- puzzle: at QM`05 different results from PHENIX and STAR...



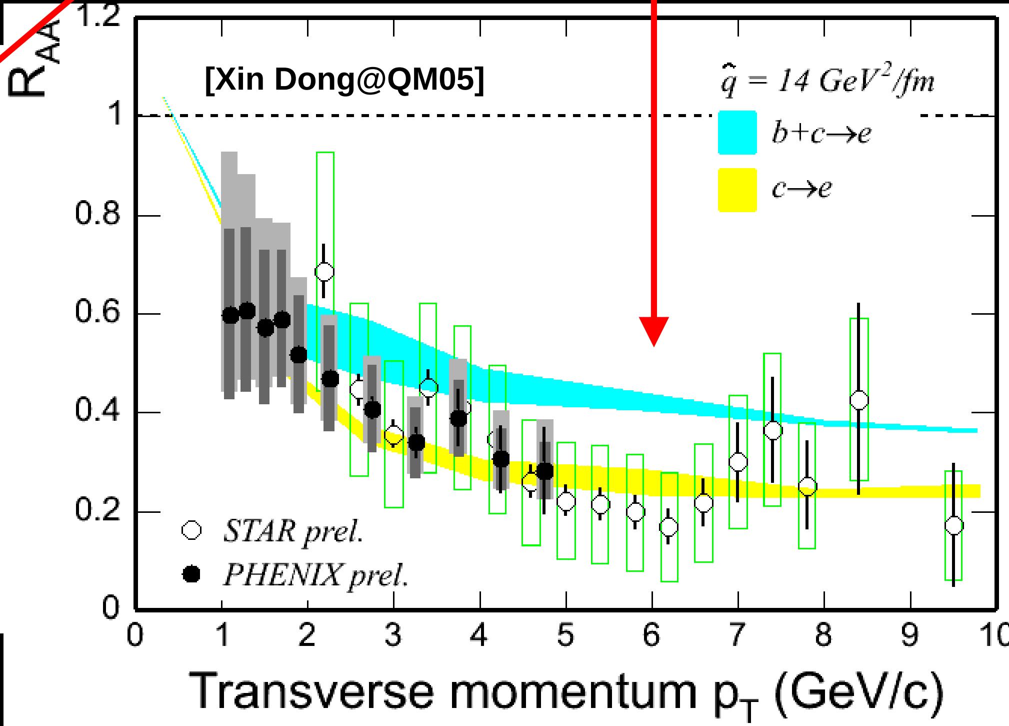
- PHENIX:
  - subtraction of conversions by converter method and cocktail
- STAR:
  - rejection of conversions by inv. mass combinations
  - @ RIKEN-BNL heavy flavour workshop in december STAR said measurement affected by "too much photonic background"

- question:

  to what extent can one accommodate small v_2 with large suppression?



[S.Butsyk@QM`05]



[Xin Dong@QM05]

Charm v_2 at LHC?

- Full reconstruction of D decays at LHC
  - qualitatively different measurement from non-photonic electrons!
  - better correlation with original heavy-quark momentum
  - b vs c

- First indications from preliminary studies in ALICE: expected error ~ few % (D v_2)

D_s^+

- D_s^+ as probe of hadronization?
- from string fragmentation: $c\bar{s}$ / $c\bar{d}$ ~ 1/3
  - after decays: D_s^+ ($c\bar{s}$) / D^+ ($c\bar{d}$) ~ 0.6
- from recombination: $c\bar{s}$ / $c\bar{d}$ ~ $N(\bar{s})$ / $N(\bar{d})$

  → how large at LHC?
- experimentally accessible?
  - D^+ ($c\tau$ ~ 310 μm) → $K^-\pi^+\pi^+$ with BR ~ 9.2 %
    - in Alice: probably similar performance as for $D^0 \rightarrow K^-\pi^+$
  - D_s^+ ($c\tau$ ~ 150 μm) → $K^-K^+\pi^+$ with BR $\underset{\sim}{}$ 4.4 %
    - but mostly resonant decays: $\Phi\pi^+$ or $\bar{K}_0^*K^+$ (non resonant only 20 %)

      → favours bkgnd rejection (for $D^+ \rightarrow K^-\pi^+\pi^+$, non-resonant ~ 96 %)

  → may be well visible (expecially if D_s^+/D^+ is large!)

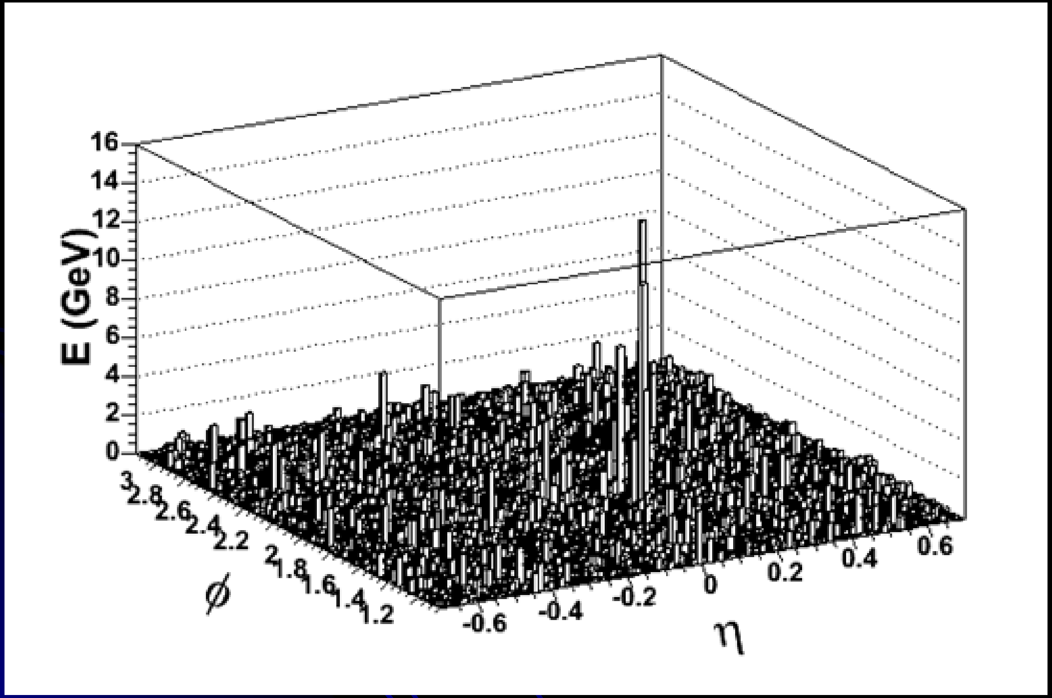
- D_s v_2 would be particularly interesting!

Heavy flavour jets?

2 GeV 20 GeV 100 GeV 200 GeV

Mini-Jets 100/event 1/event 100k/month

- Well visible event-by-event! e.g. 100 GeV jet + underlying event



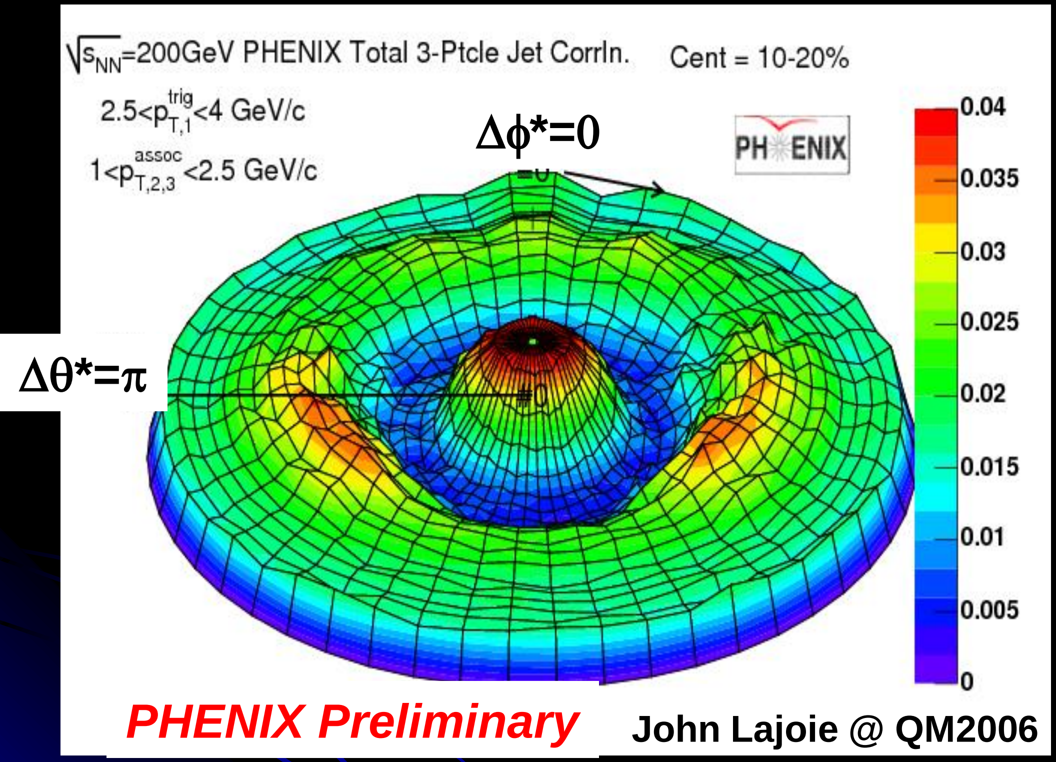
- For high energy jets: Nb ~ Nu,d

→ heavy flavour rich!

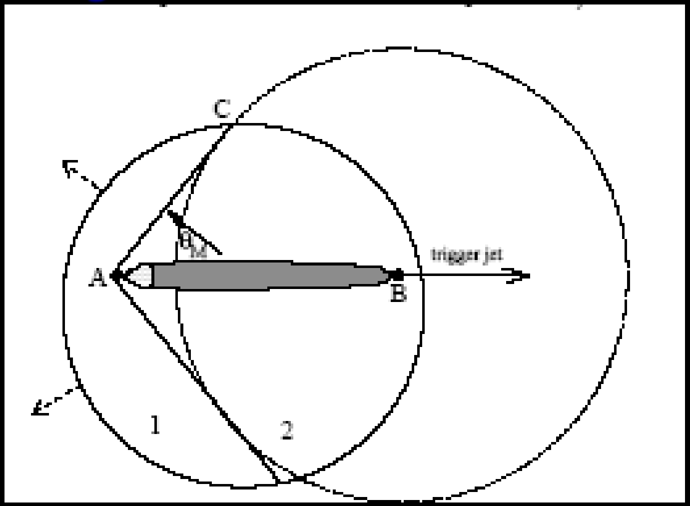
- b-tagged jets?

→ study quenching of b jets!

Away side cone?



- Collective behaviour opposite to jet?
  - eg: Mach cone



[Casalderrey-Solana, et al.: hep-ph/0411315]
[Stocker: Nucl.Phys. A750 (2005) 121])

- What happens with big-fat-heavy quark jets?

Modified Mach cone?

- Heavy quarks at moderate p_T move with substantially lower speed
- e.g.: for beauty, taking:
  - $c_S^2 = 0.2$
  - m(b) = 4.5 GeV

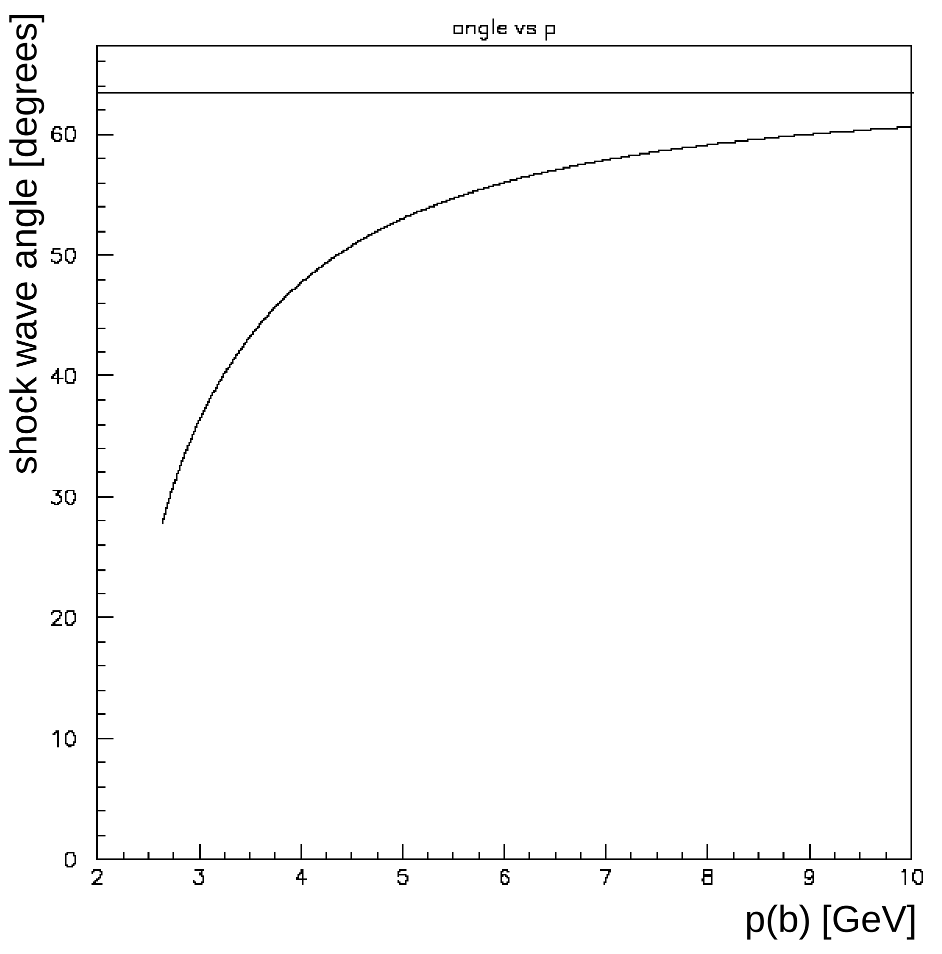
→ b quark is “subsonic”

for p < 2.25 GeV

→ for p ~ 3-4 GeV,

shock wave angle ~ 40^O

[FA, E Shuryak: J.Phys. G31 (2005) 19]



Now:
observing THAT
would be something!

Conclusion

- Heavy flavours kindly provide us with a very promising tool to study the properties of the strongly interacting medium produced in ultra-relativistic nucleus-nucleus collisions

- LHC is the place to be → very high rates
  - p_T reach
  - recombination?
  - jets?

- ALICE is well equipped for heavy flavour physics