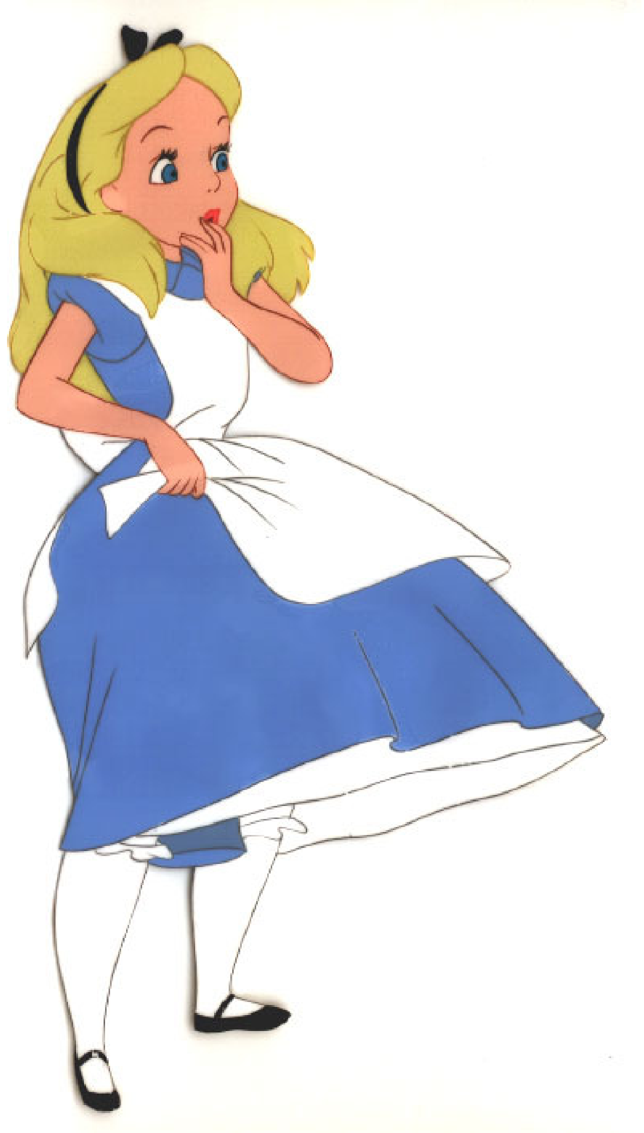
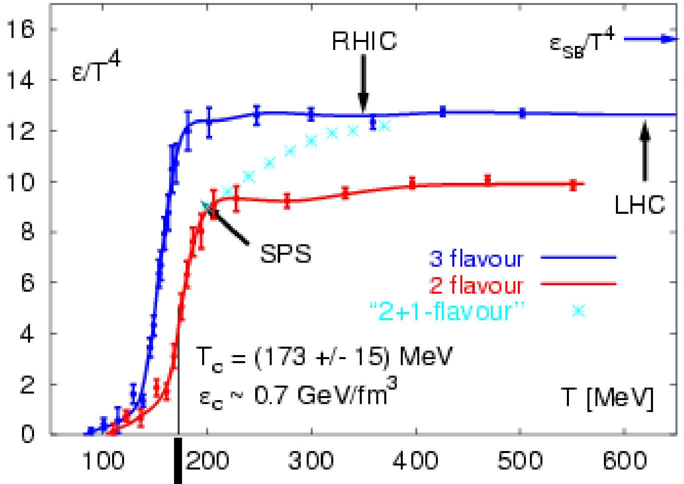
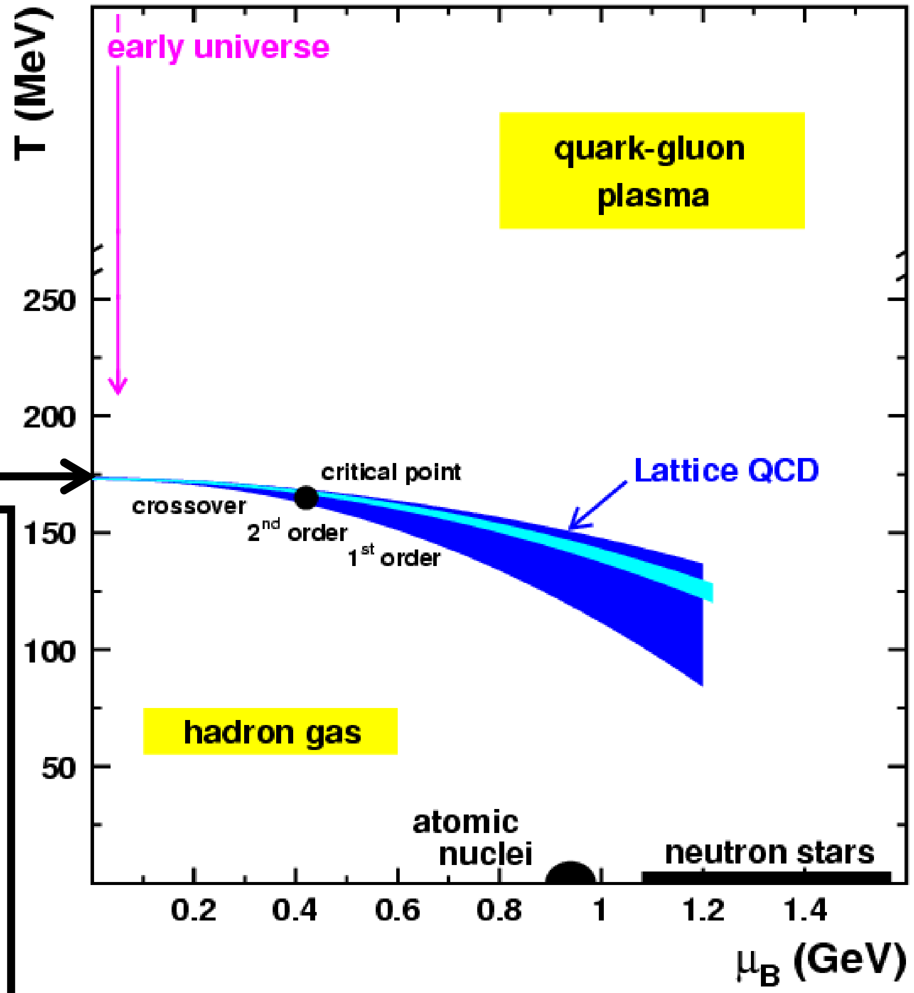
Heavy flavour measurements with ALICE



- heavy ion collisions & QGP
- heavy flavours & QGP
- ALICE detector overview
- selected physics channels

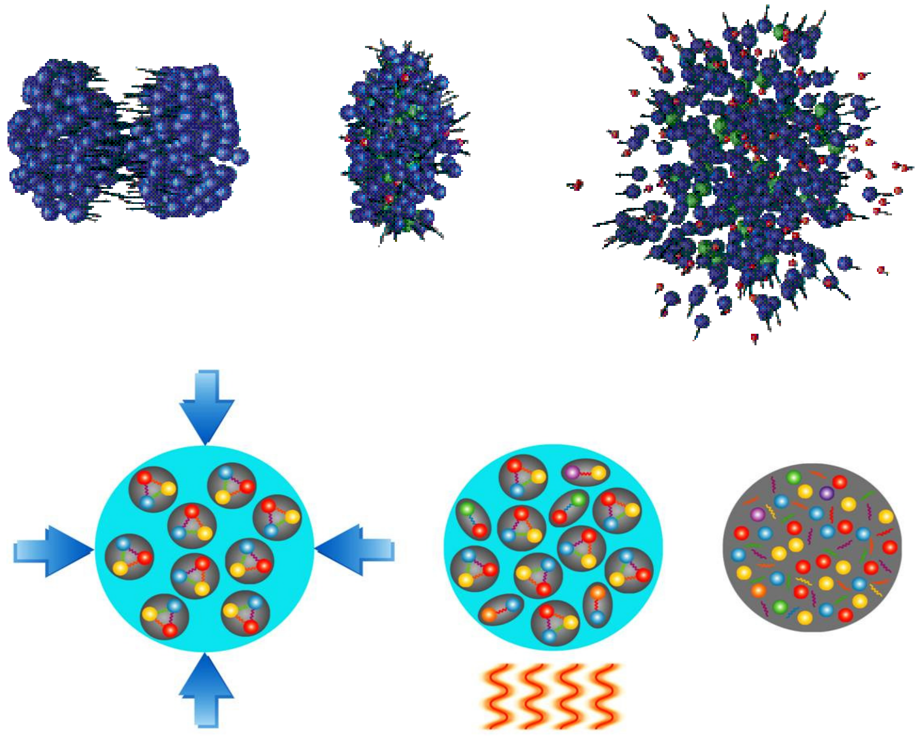
The QCD phase diagram



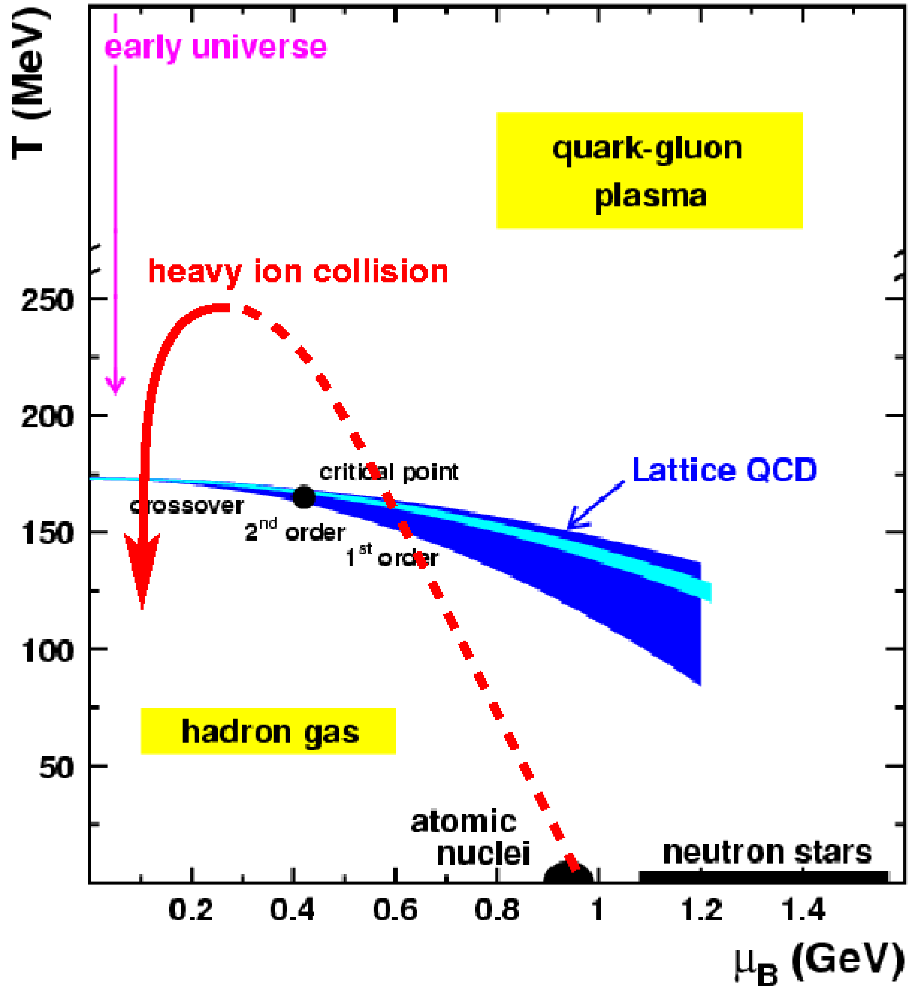


- $\mu_B = 0$:
  - $T_c = 173 \pm 15$ MeV
  - $\varepsilon_c = 0.7 \pm 0.3$ GeV/fm^3
  - "crossover"-like transition
- $\mu_B > 0$:
  - large uncertainties
  - order of transition unknown
  - existence of a critical point
- chiral sym. rest. coincides with deconf.
- the QGP is not an ideal gas
- $\mu_B >> 0$: color superconductivity (not shown)

Exploring the QCD phase diagram with heavy ion collisions

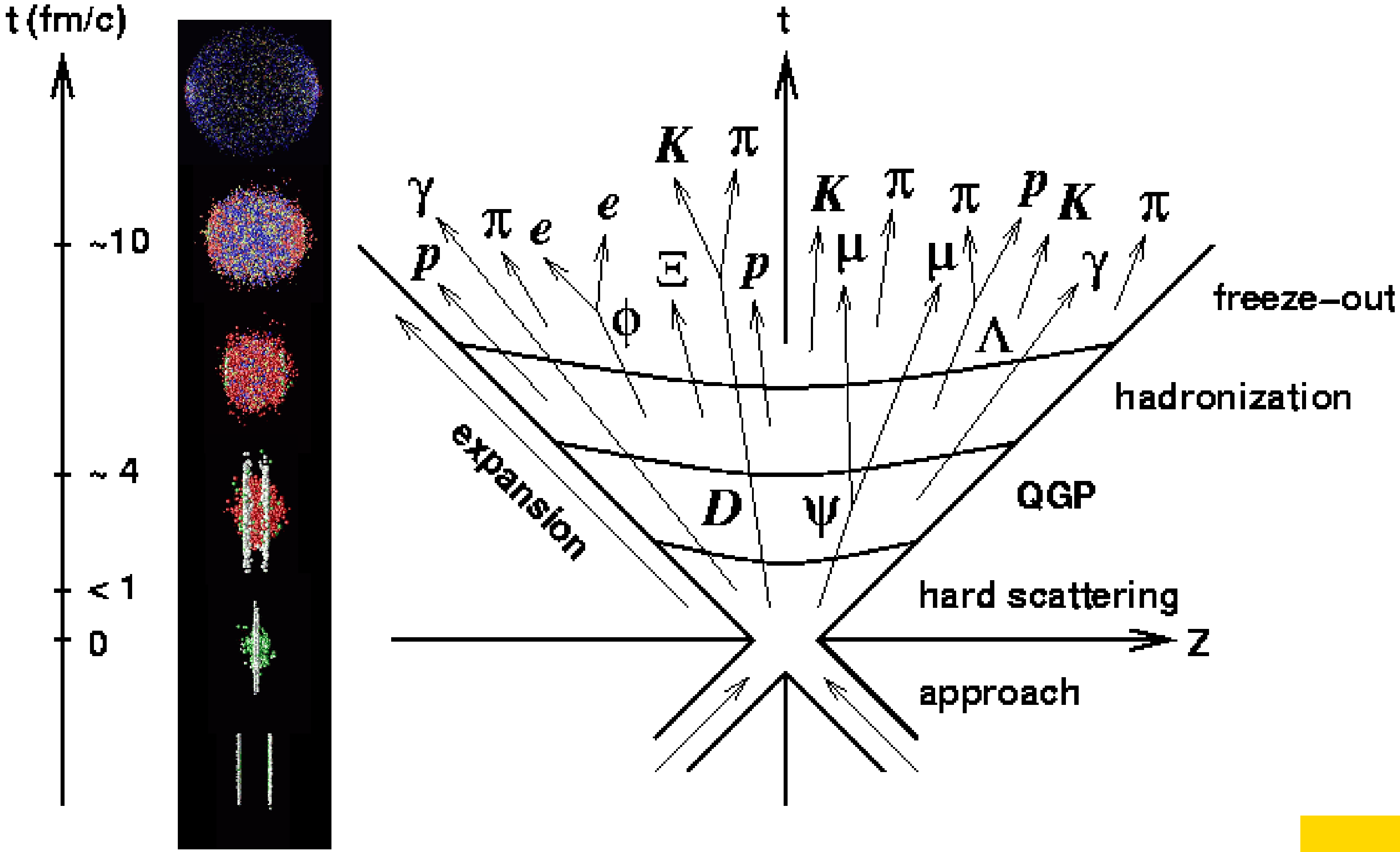


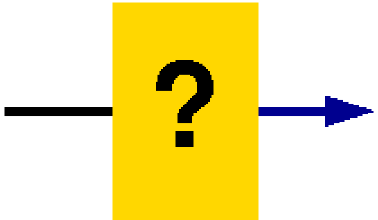
pressure + heat ⇒ QGP



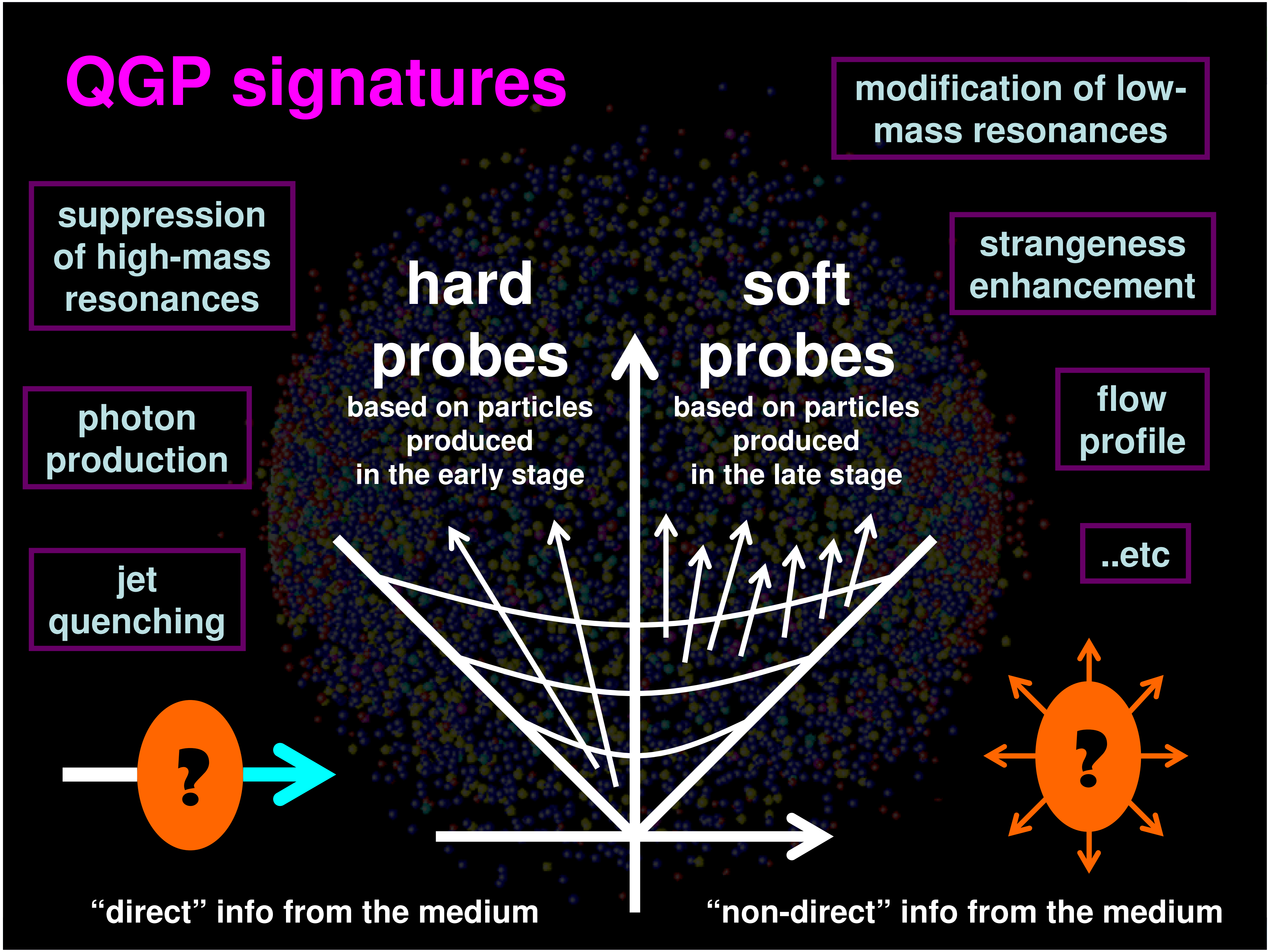
key parameters: bombarding energy, collision centrality, particle transverse momentum

Schematic space-time evolution of a heavy ion collision



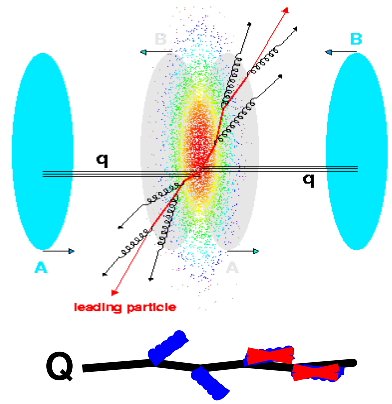


- 4 main “distinct” phases
- strategy: use produced particles as probes of the medium


QGP signatures
modification of low-mass resonances
suppression of high-mass resonances
strangeness enhancement
hard probes
based on particles produced in the early stage
soft probes
based on particles produced in the late stage
photon production
flow profile
jet quenching
..etc
?
?
“direct” info from the medium
“non-direct” info from the medium

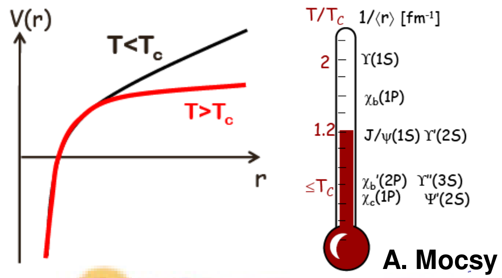
Heavy flavours in heavy ion collisions

- **open heavy flavour quenching probe medium density**



  - parton energy loss via medium-induced gluon radiation
  - proportional to ε, L & C_R with C_R = 4/3(3) for q(g)
  - and to m_Q (gluon radiation suppressed at $\Theta < m_Q/E_Q$)
    $\rightarrow \Delta E_g > \Delta E_{c \sim q} > \Delta E_b$ expected

- **quarkonia (final) yield probe medium temperature**



A. Mocsy

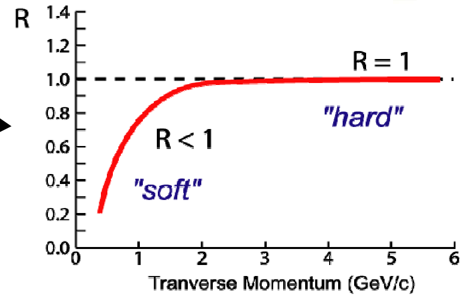
  - debye screening suppresses QQbar bound states
  - but non-correlated quarks can recombine in the QGP

- **observable: nuclear modification factor**

$$R_{AA} = \frac{Yield\ in\ AA}{Yield\ in\ pp \times N_{coll}}$$

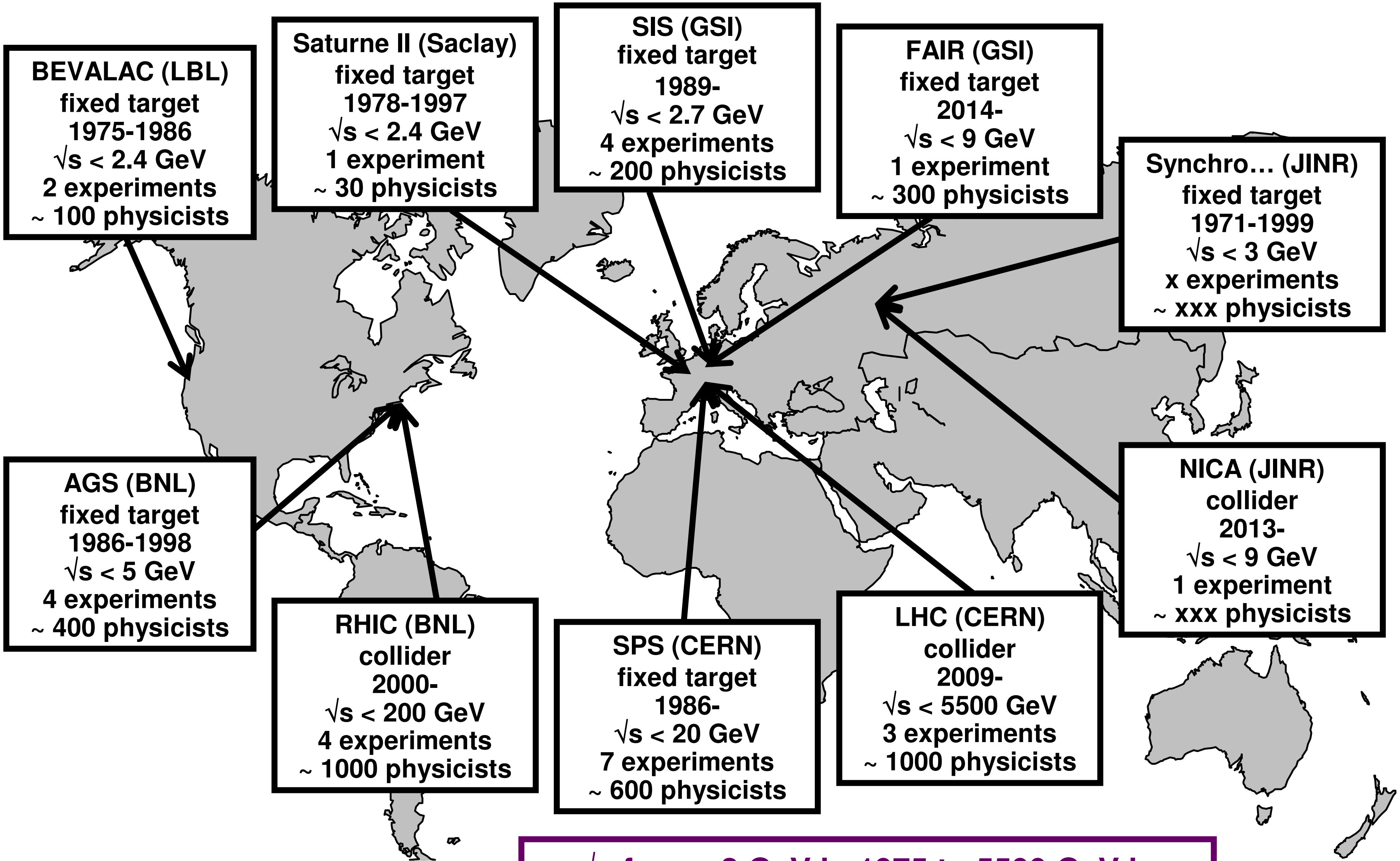
if no hot nuclear effects →

average number of NN collision in an AA collision



note: only effects in final state here, for effects in initial state, see M. Malek talk on Friday

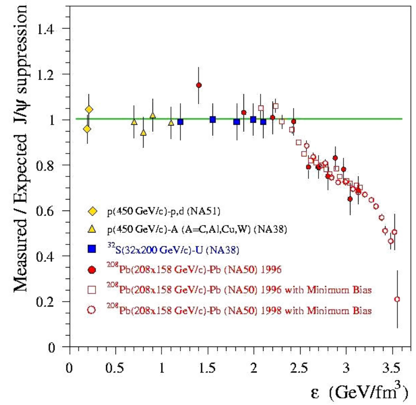
1975-2009: 34 years of heavy-ion collisions



√s from ~2 GeV in 1975 to 5500 GeV in 2009

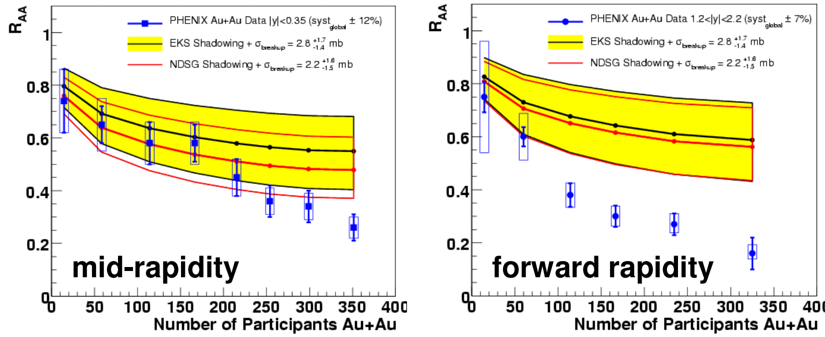
SPS & RHIC results on heavy flavours in 4 plots

- **SPS: J/ψ suppression in central PbPb**



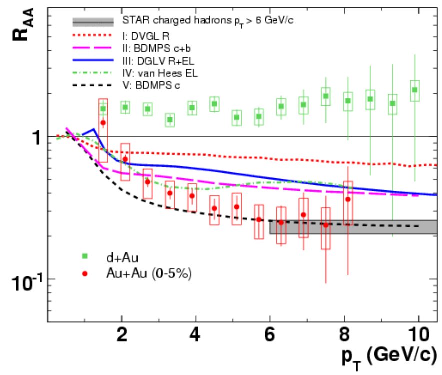
  - debye screening not a unique scenario
  - models cannot reproduce data in InIn collisions

- **RHIC: J/ψ suppression in central AuAu**



  - large uncertainties in cold nuclear effects
  - larger suppression at forward angles?

- **RHIC: charm quenching ~ light hadron quenching**



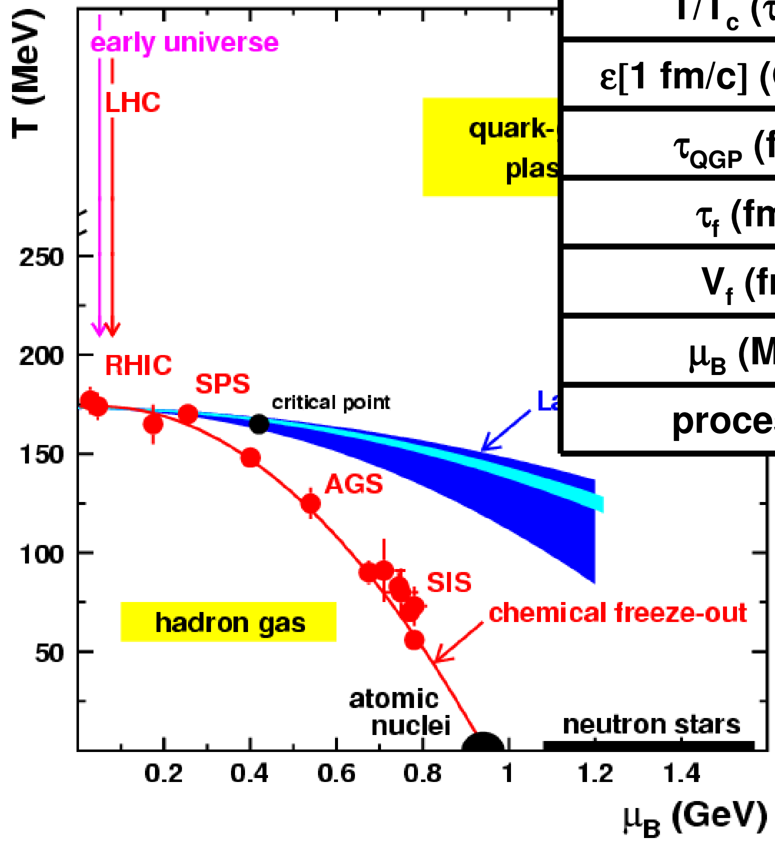
  - non-photonic electron vs. hadron R_{AA}
  - a challenge for models
  - experiments disagree on charm x-section

Phys. Lett. B477 (2000) 28, Phys. Rev. Lett. 98 (2007) 192301, Phys. Rev. C 77 (2008) 024912

Heavy ion collisions & QGP @ LHC

the biggest step in energy in the history of heavy-ion collisions

machine	SPS	RHIC	LHC	
$\sqrt{s}$ (GeV)	17	200	5500	= 0.18 mJ
N_{ch}	1000	4000	50 000	
τ^0_{QGP} (fm/c)	1	0.2	0.1	⇒ faster
T/T_c (τ^0_{QGP})	1.1	1.9	3.0-4.2	⇒ hotter
ε[1 fm/c] (GeV/fm³)	3	5	15-60	⇒ denser
τ_{QGP} (fm/c)	≤ 2	2-4	≥ 10	⇒ longer
τ_f (fm/c)	~ 10	20-30	30-40	
V_f (fm³)	~ 10^3	~ 10^4	~ 10^5	⇒ bigger
μ_B (MeV)	250	20	1	⇒ cleaner
processes	soft →	semi-hard →	hard	⇒ harder



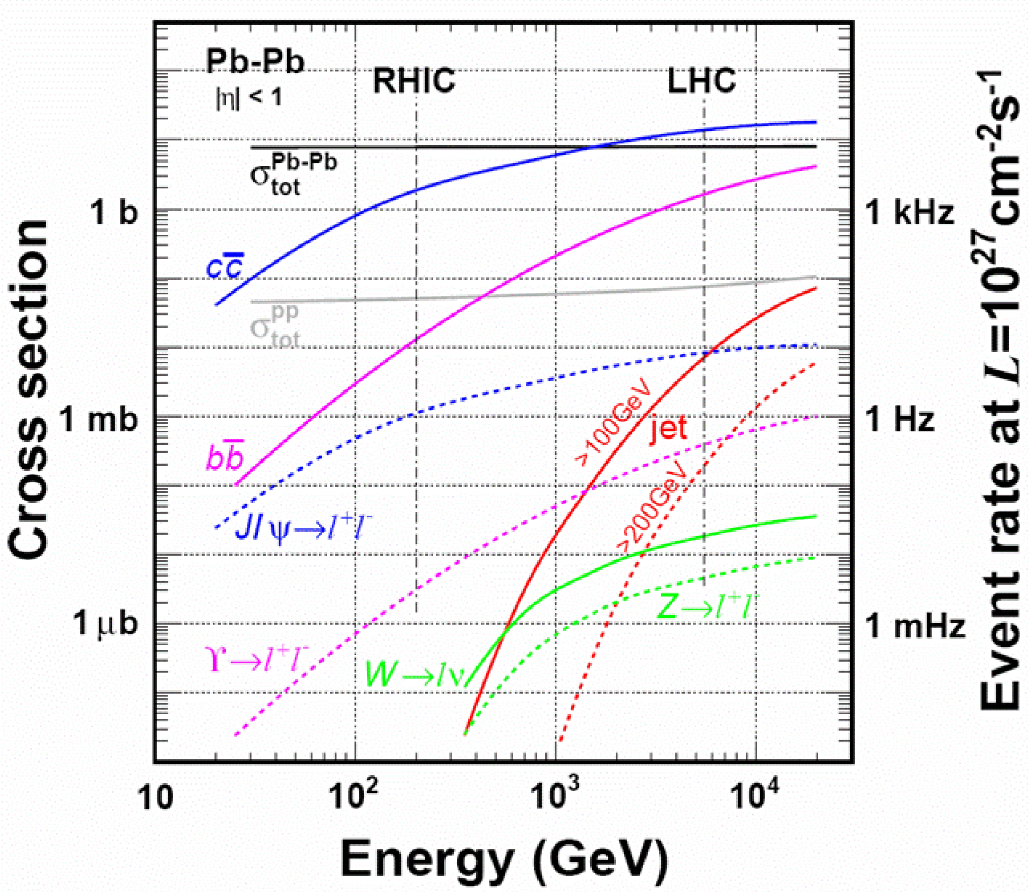
ε, vol. & τ QGP × 10(4) from SPS(RHIC) to LHC

"...the LHC will become the ideal facility for a systematic exploration and quantitative confirmation of the insights obtained at RHIC, aided by the plentiful abundance of hard probes."

B. Müller, hep-ph/0410115

J. Schukraft, Nucl. Phys. A 698 (2002) 287

Heavy-flavour x-sections @ LHC



$\sigma_c(\text{LHC}) = \sigma_c(\text{RHIC}) \times 10$

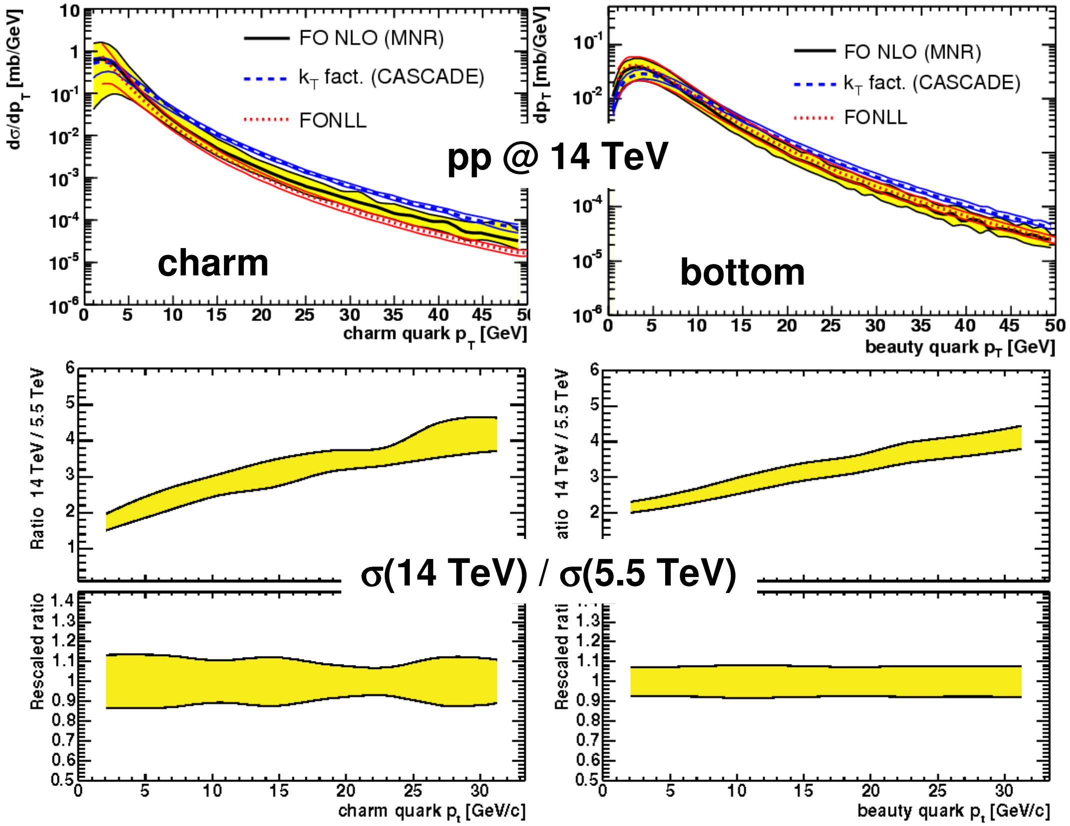
$\sigma_b(\text{LHC}) = \sigma_b(\text{RHIC}) \times 100$

$\sigma_W(\text{LHC}) = \sigma_\Upsilon(\text{RHIC}) \times 10$

$\sigma_Z(\text{LHC}) = \sigma_\Upsilon(\text{RHIC})$

K. Safarik

A closer look at heavy-quark cross-section



- **NLO predictions for pp @ LHC: a factor ~ 2 uncertainty**
- **σ(14 TeV) / σ(5.5 TeV) ~ 10%**

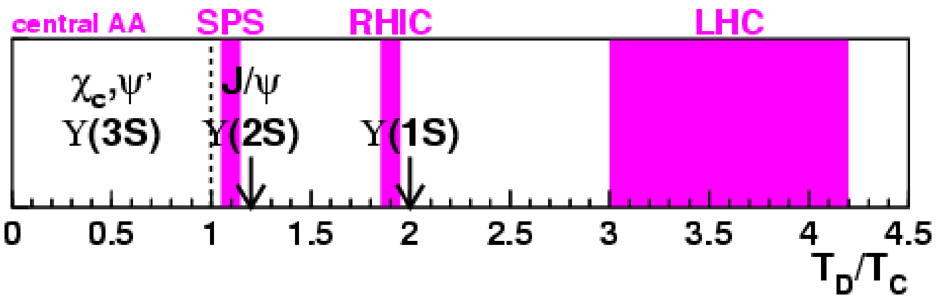
  → measuring σ(c,b) in pp @ 14TeV is top priority

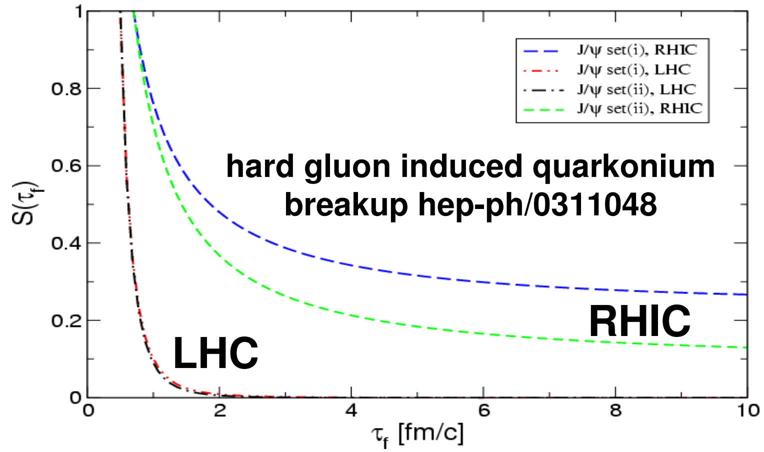
hep-ph/0601164, J. Phys. G 32 (2006) 1295

Quarkonia suppression @ LHC

quarkonium dissociation temperatures

A. Mocsy & P. Petreczky, Phys. Rev. Lett. 99 (2007) 211602





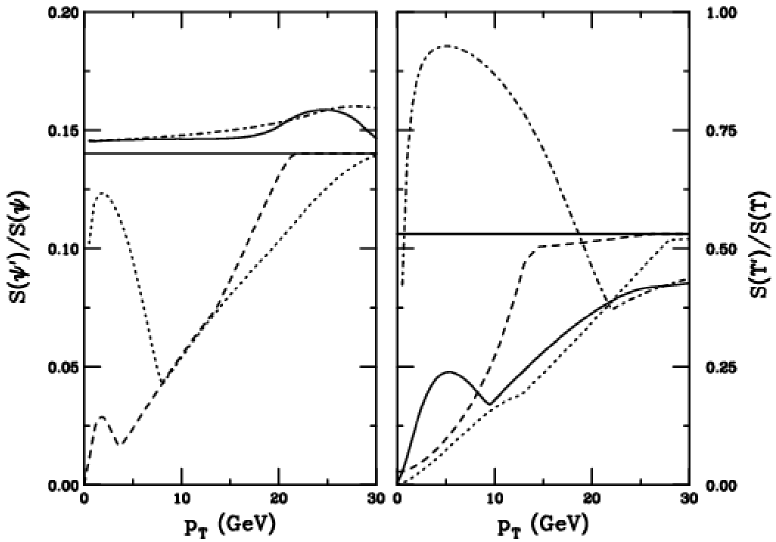
- whether J/ψ melts or not @ RHIC it will be strongly either suppressed or regenerated @ LHC
- use Υ(2S) to unravel J/ψ sup. vs. reco.

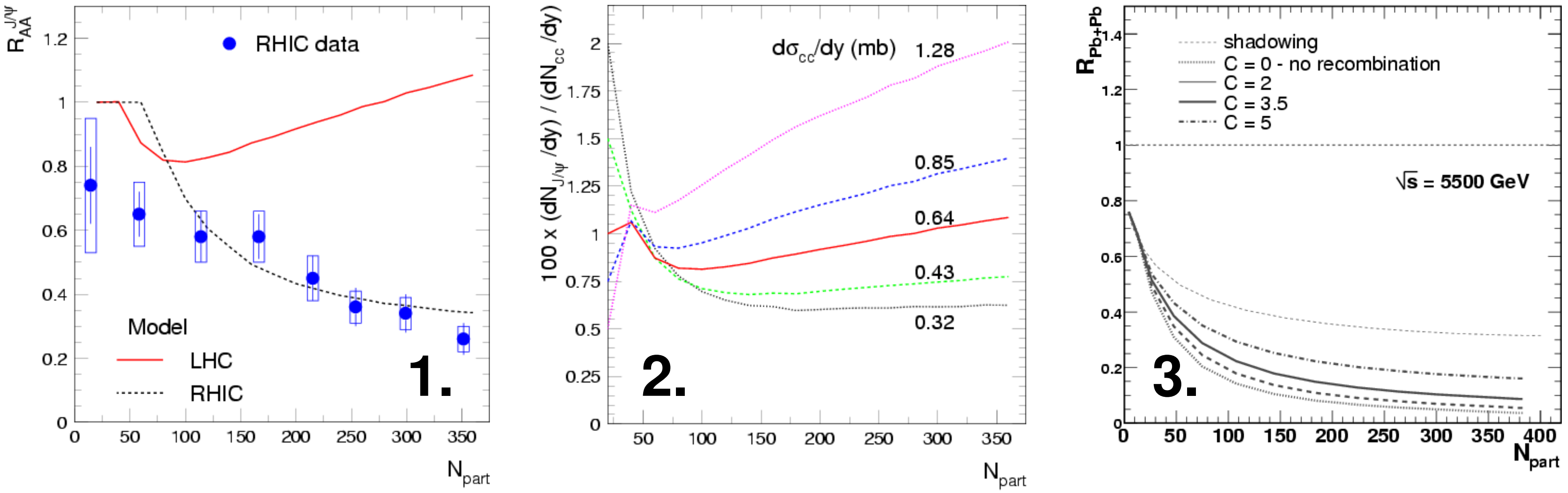
Υ reco. is small: L. Grandchamp et al., PRC 73 (2006) 064906

- Υ(1S) melts significantly only at LHC
- additional suppression by hard gluons
- relevance of quarkonium ratios vs. p_t

R. Vogt in J. Phys. G 35 (2008) 054001

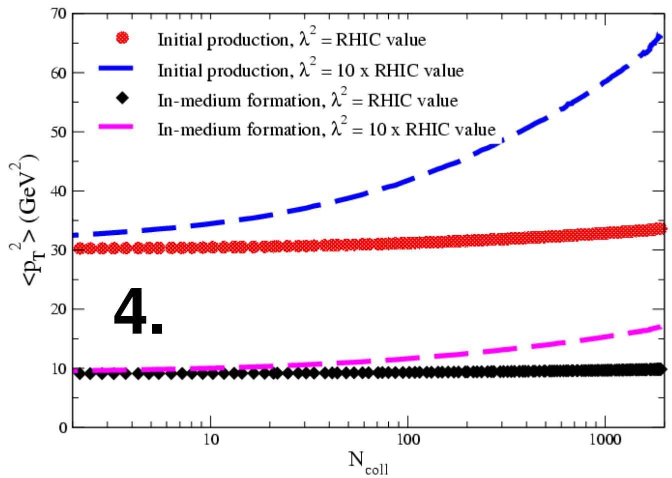
PbPb @ 5.5 TeV





1. peculiar centrality dependence
2. predictions strongly depend on σ_{cc}
3. (re-)dissociation by comovers
4. regeneration $\rightarrow$ smaller $\langle p^2_t \rangle$

note: N(B $\rightarrow$ J/ψ) / N(direct J/ψ) ~ 20% in 4π

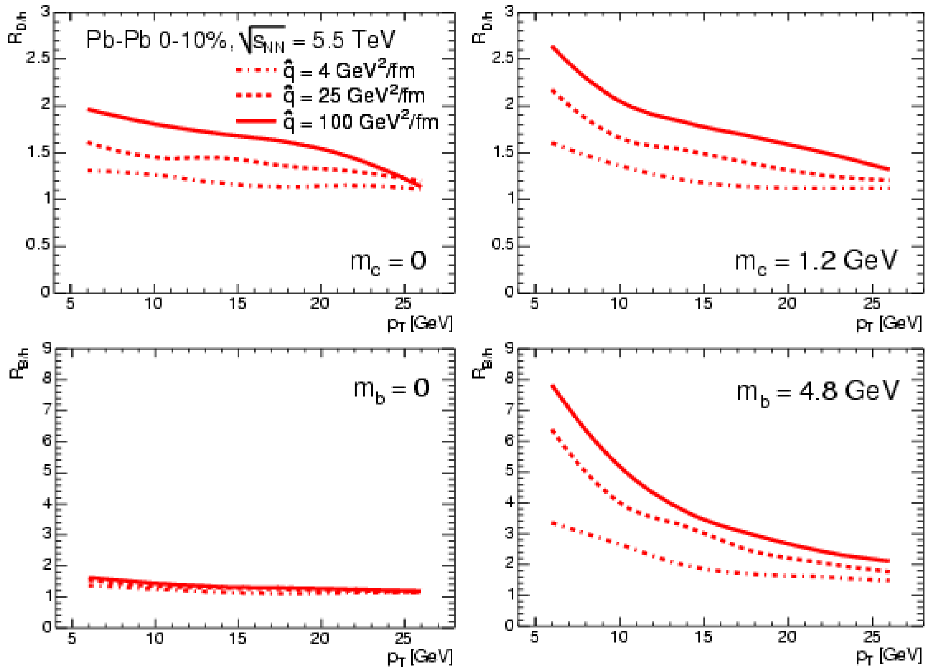


A. Andronic et al., Phys. Lett. B 652 (2007) 259, J. Phys. G 35 (2008) 054001,
A. Capella et al., Eur. Phys. J. C58 (2008) 437, R. Thews et al., J. Phys. G 35 (2008) 054001

Heavy quark quenching @ LHC: new ratios

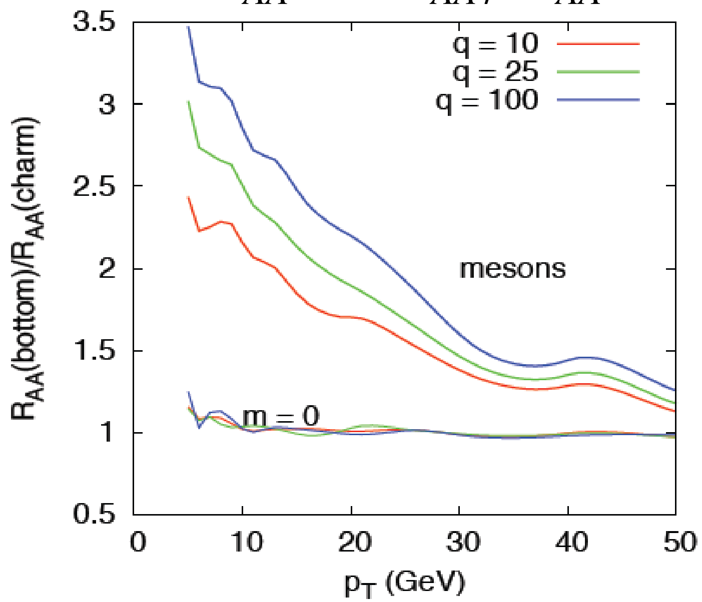
$$\Delta E_g > \Delta E_{q \approx c} > \Delta E_b \Rightarrow R_{AA}^h < R_{AA}^D < R_{AA}^B$$

$$R^{D(B)/h} = R_{AA}^{D(B)} \Big/ R_{AA}^h$$



- $R^{D/h}$ probes color charge dep. of ΔE
- $R^{B/h}$ probes mass dep. of ΔE

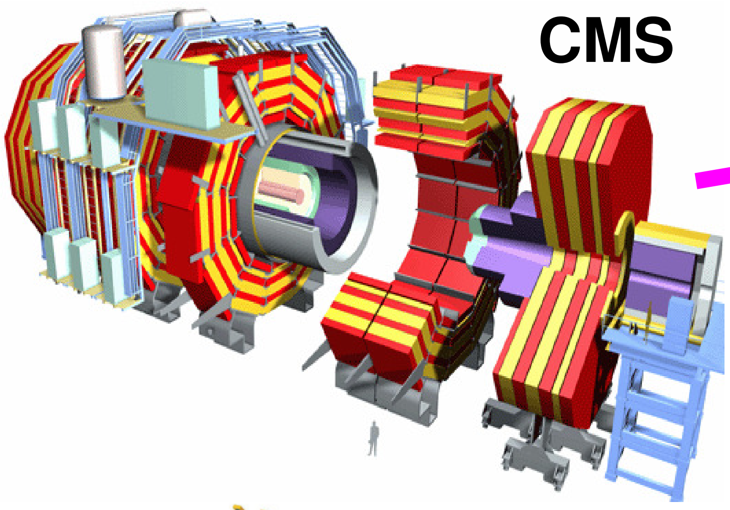
$$R_{AA}^{B/D} = R_{AA}^B \Big/ R_{AA}^D$$

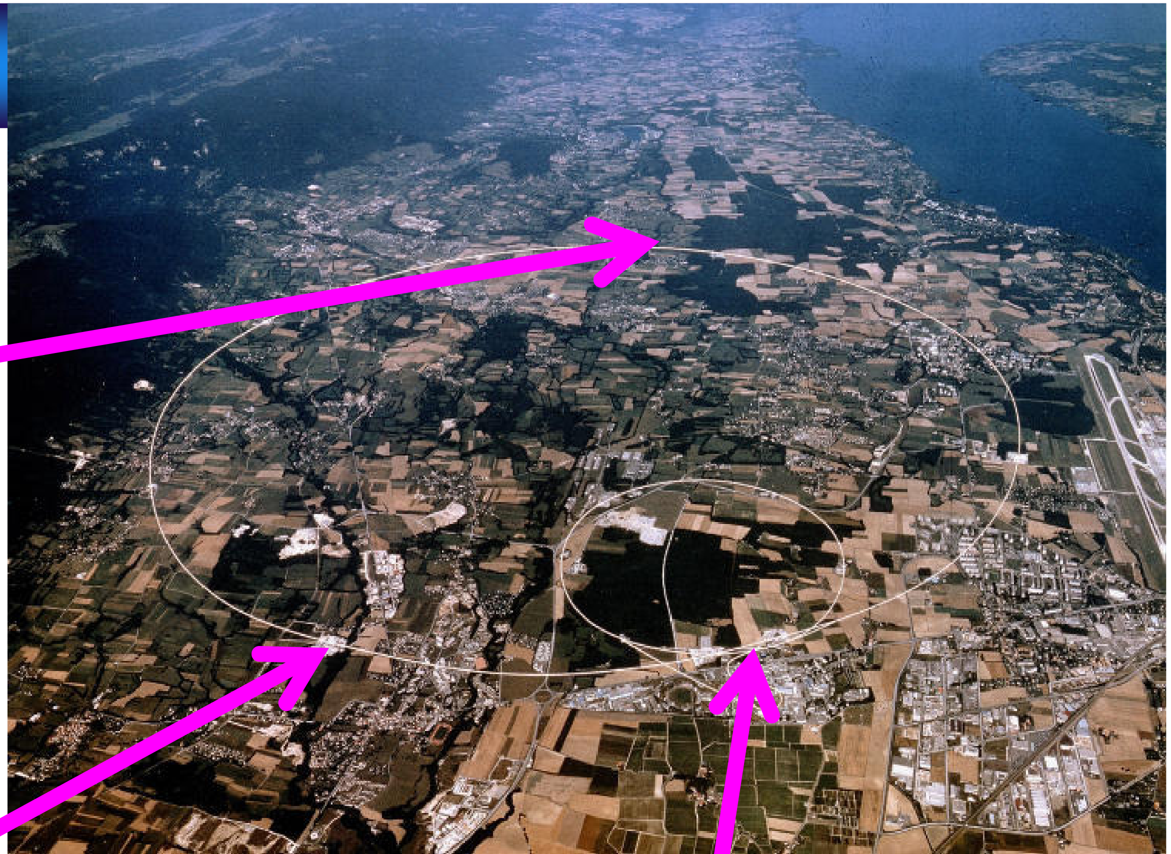


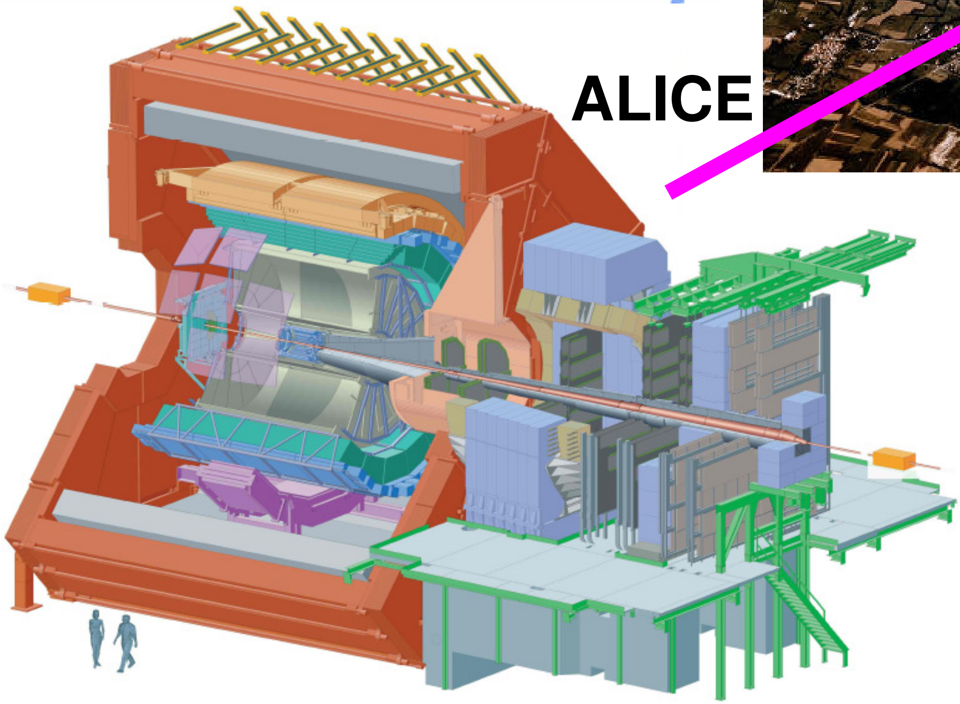
- isolate mass dep. of ΔE
- sensitivity disappears at large p_t
- lower sensitivity to qhat

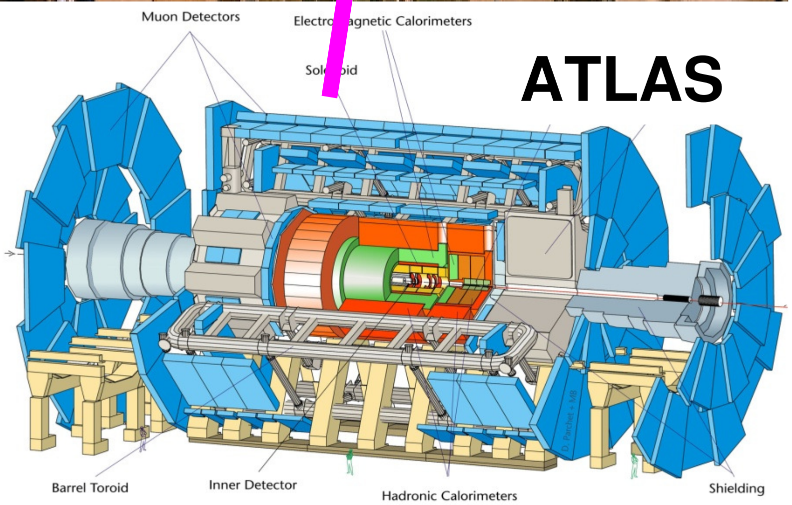
N. Armesto et al., Phys. Rev. D 71 (2005) 054027, J. Phys. G 35 (2008) 054001

Heavy ions @ LHC



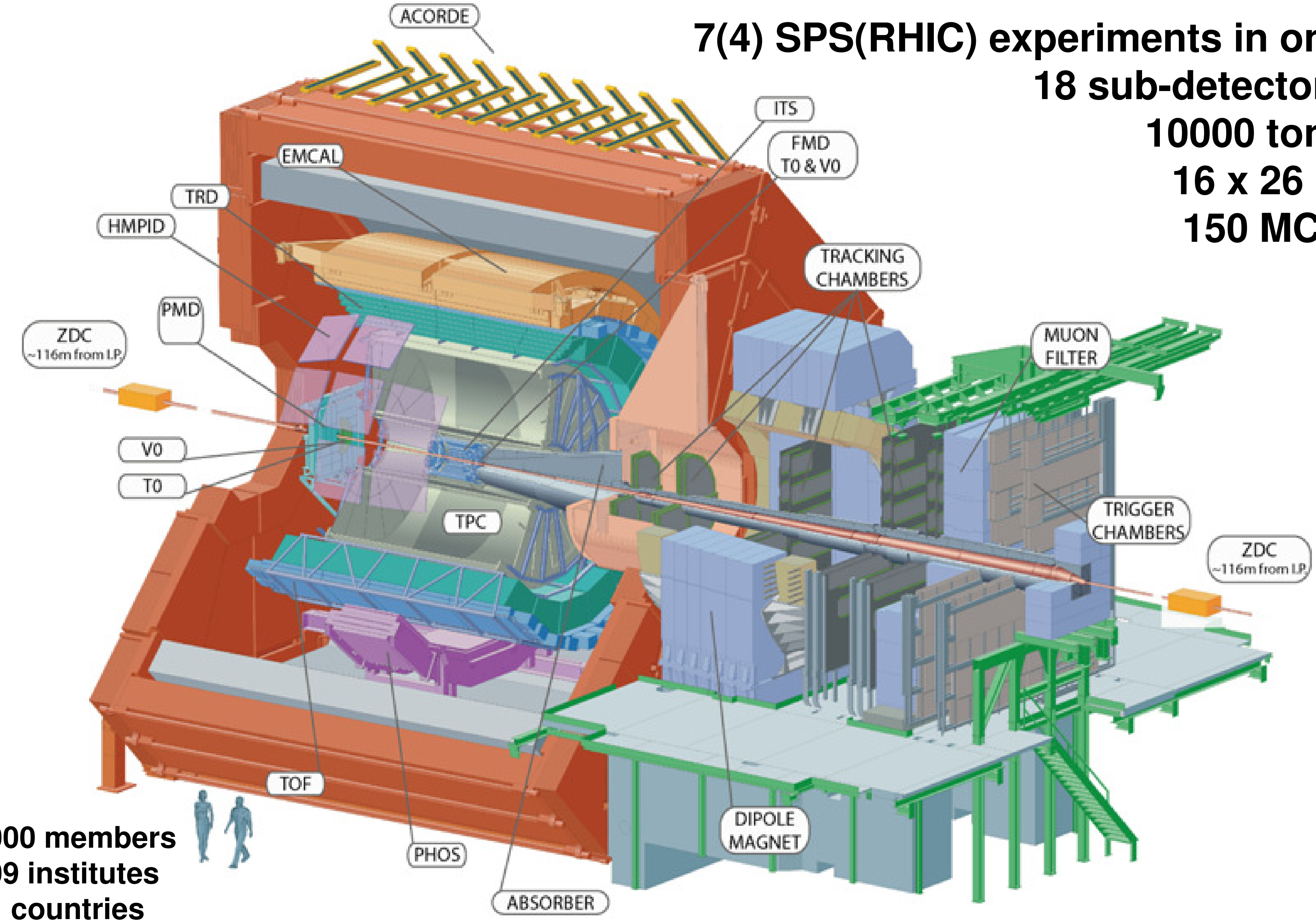






ALICE (A Large Ion Colider Experiment)

7(4) SPS(RHIC) experiments in one
18 sub-detectors
10000 tons
16 x 26 m
150 MCH



1000 members
109 institutes
31 countries

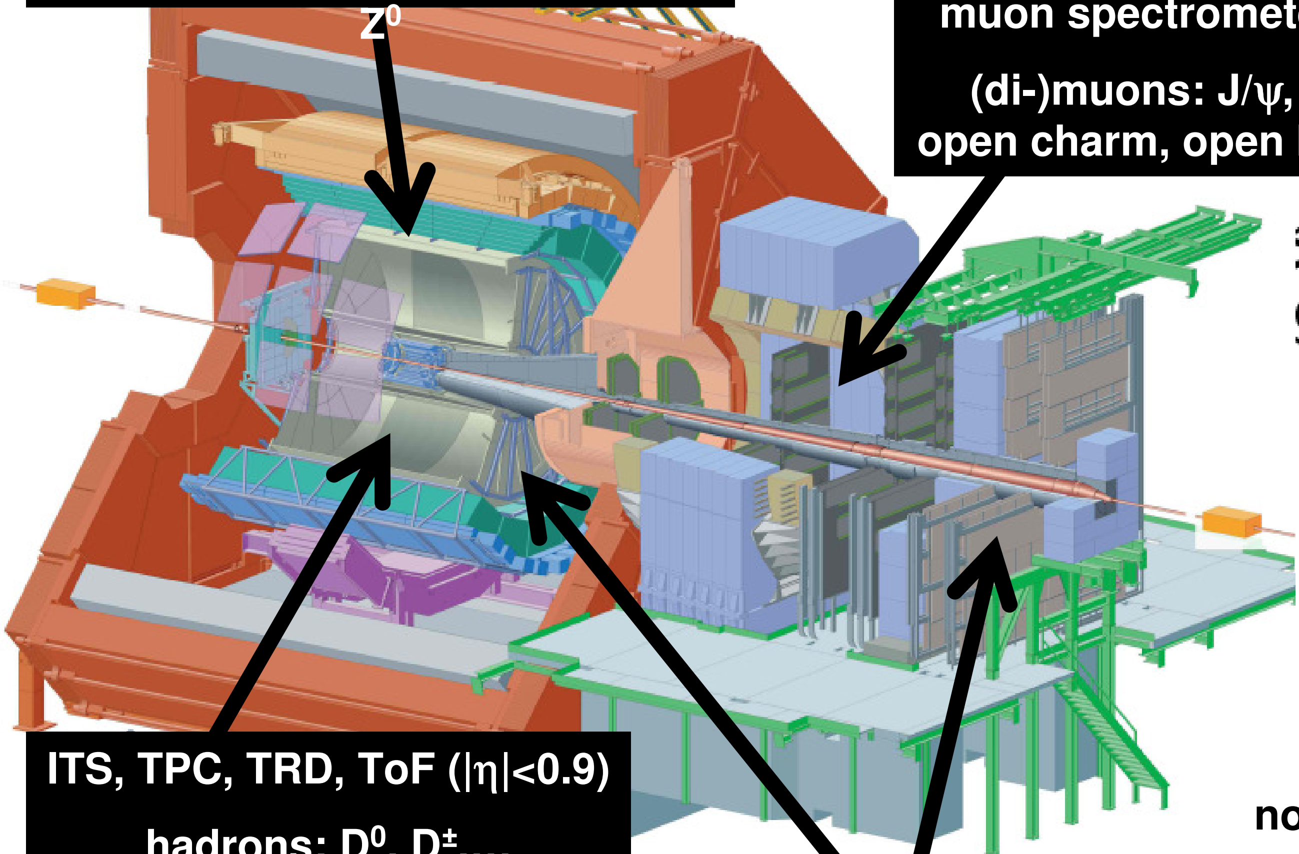
Heavy flavours with ALICE

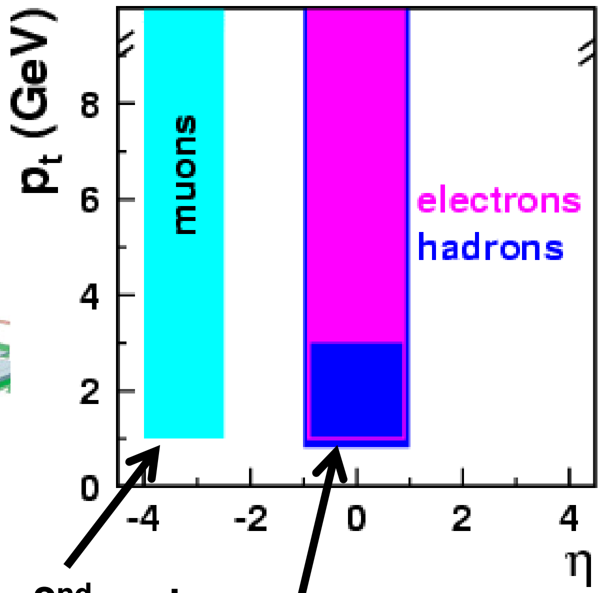
ITS, TPC, TRD, ToF ($|\eta|<0.9$)

(di-)electrons: J/ψ, ψ', Υ, Υ', Υ'', open charm, open bottom, $W^{\pm}$, Z^0

muon spectrometer ($-2.5<\eta<-4$)

(di-)muons: J/ψ, ψ', Υ, Υ', Υ'', open charm, open bottom, $W^{\pm}$, Z^0





no 2nd vertex

2nd vertex

ITS, TPC, TRD, ToF ($|\eta|<0.9$)

hadrons: D^0, $D^{\pm}$,…

electron-muon coincidences: open charm & bottom

Selected physics channels

- Quarkonia
- B from single leptons
- $D^0 \rightarrow K\pi$
- Heavy flavour quenching

"published" results only

Quarkonia: expected statistics in muon channel

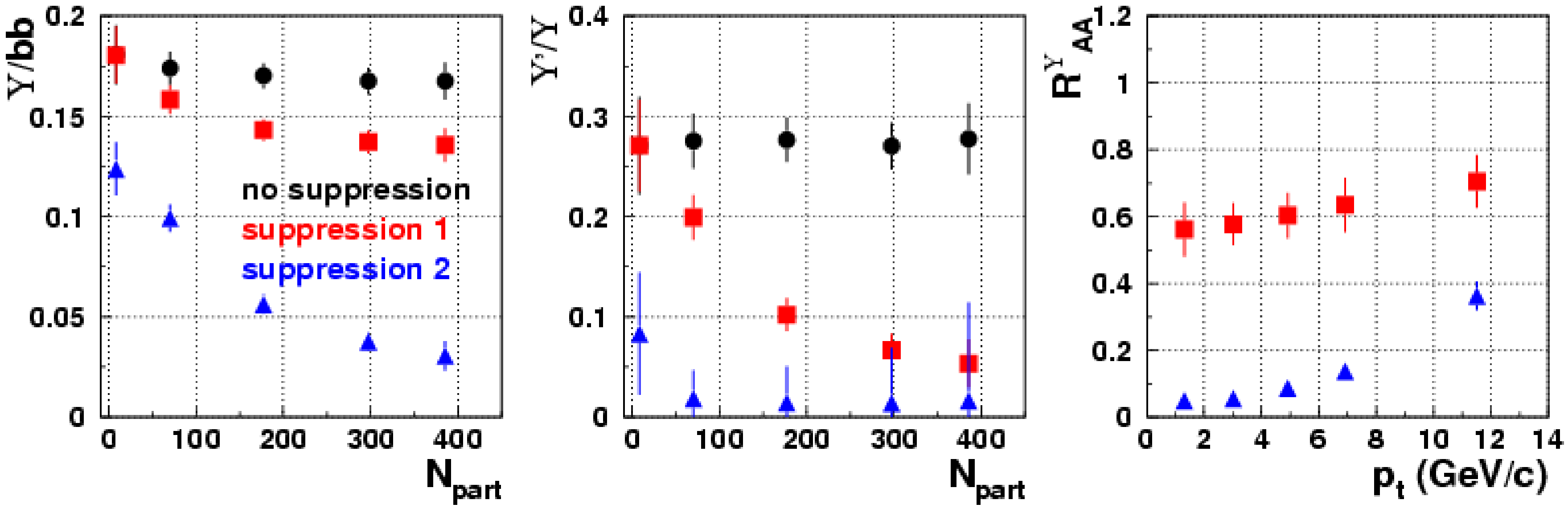
1 LHC year = 7 months pp (10^7s, $3 \cdot 10^{30}$cm^{-2}s^{-1}) + 1 month AA (10^6s, $5 \cdot 10^{26}$cm^{-2}s^{-1})

		J/ψ	ψ'	ϒ	ϒ'	ϒ''
PbPb MB 5.5 TeV	S (×10^3)	681.4	18.92	6.33	1.8	1.02
	S/B	0.33	0.02	2.46	1.03	0.74
	S/√S+B	413	19.53	67.14	30.19	20.85
pp 14 TeV	S (×10^3)	4670	122	44.7	11.4	6.9
	S/B	12.6	0.55	5.8	1.9	1.3
	S/√S+B	2081	209	195	86	62

- from PbPb MB to pp, a factor ~ 10 more stat.
  - J/ψ: large stat., good significance
  - ψ': small S/B
  - ϒ: good stat., S/B > 1, good significance
  - ϒ': good stat., S/B > 1, good significance
  - ϒ'': low statistics
- similar expected statistics in the electron channel

J. Phys. G 30 (2004) 1517, x-sections from CERN-2004-009, hep-ph/0311048, with shadowing & feed-down, w/o nuclear absorption/suppression/regeneration…

Observables with bottomonia



suppression 1: T_C = 270 MeV, T_D/T_C = 4.0 (1.4) for Υ(Υ')

suppression 2: T_C = 190 MeV, T_D/T_C = 2.9 (1.1) for Υ(Υ')

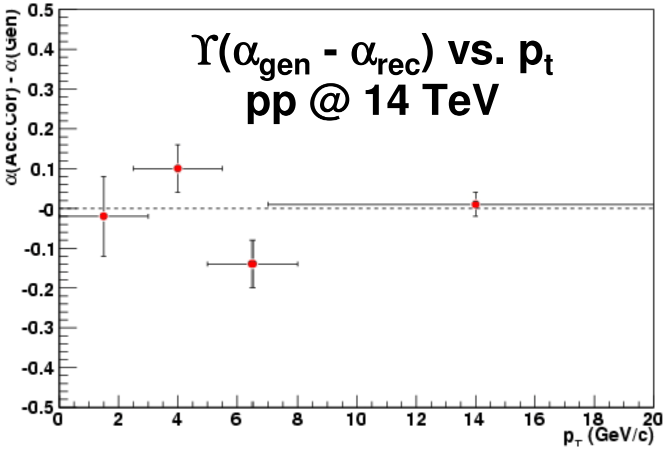
- **statistics: one month PbPb @ 5.5 TeV**
- **large sensitivity to dissociation temperatures and medium size**

ALICE: J. Phys. G 32 (2006) 1295

More with quarkonia

polarization

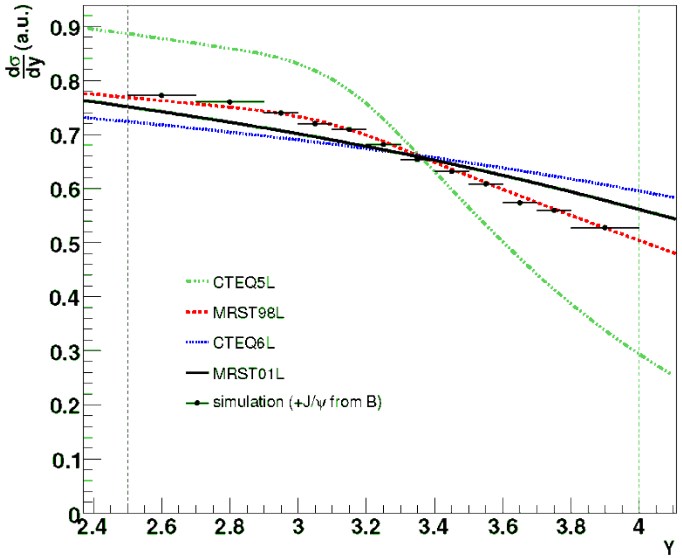
- pp: test production mechanisms
- AA: probe QGP formation



- pp @ 14 TeV: J/ψ & ϒ pol. vs. p_t
- PbPb @ 5.5TeV: J/ψ pol. vs. centrality, ϒ pol. needs 2-3 runs

dN/dy in pp

- probe gluon distribution at low x



R. Analdi, E. Scomparin, D. Stocco

Open charm & bottom: accessible channels

charm:
exclusive hadronic channels

- $D^0 \rightarrow K\pi$ (tested in pp & PbPb)
- $D^+ \rightarrow K\pi\pi$ (tested in pp & PbPb)
- $D^{\pm}_s \rightarrow KK\pi$ (under study)
- $D^* \rightarrow D^0\pi$ (under study)
- $D^0 \rightarrow K\pi\pi\pi$ (under study)
- $\Lambda_c \rightarrow pK\pi$ (under study)

charm & bottom:
semi-inclusive leptonic channels

- $c \rightarrow l + X$ (à la CDF & D0)
- $b \rightarrow l + X$ (à la CDF & D0)
- $b \rightarrow J/\psi + X$ (à la CDF & D0)
- bbbar $\rightarrow J/\psi + l$ (under study)
- bbbar $\rightarrow 3\mu$ (should work in pp)
- bbbar $\rightarrow l^+l^-, l^-l^+$ (Bchain & BBdiff)
- bbbar $\rightarrow l^-l^-, l^+l^+$ (Bchain & B osc.)

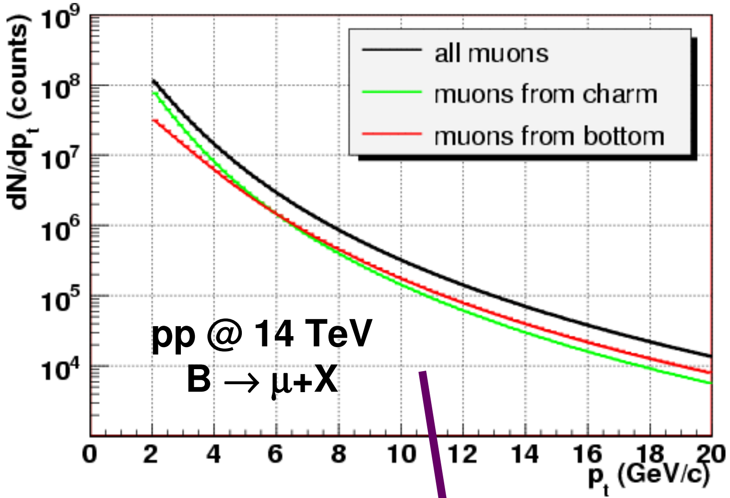
more exotic (and more challenging):
QQbar $\rightarrow e\mu$, b $\rightarrow$ > 5 prongs, $\Lambda_b \rightarrow J/\psi + X$, etc

B-hadron cross-section from single leptons

First step: extract $N_l \leftarrow B$

w/o 2nd vertex: unfold lepton dN/dp_t via combined fit

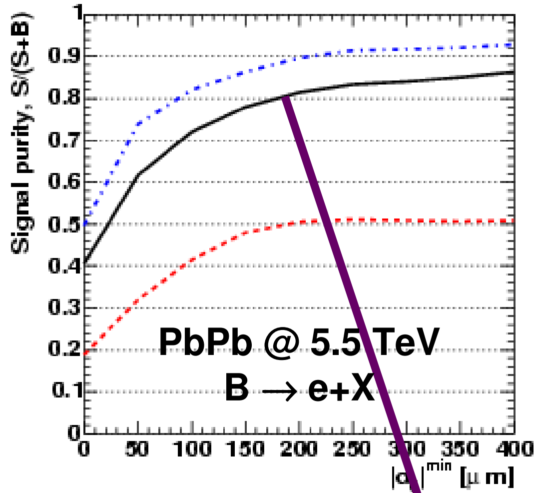
large statistics constrains fit

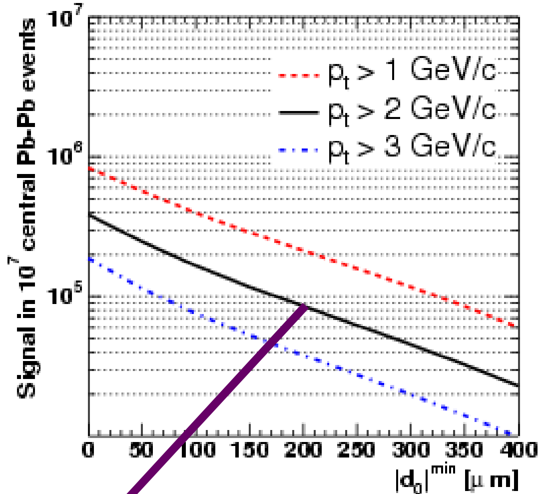


2.1·10^{12} pp evts (1 year)
p_t > 2 GeV/c
1.7·10^8 $\mu^\pm$ from B

with 2nd vertex: cut on dca & subtract remaining background

large purity of lepton sample





10^7 PbPb (5%) evts (1 month)
p_t > 2 GeV/c, 200 < d0 < 600 μm
80000 $e^\pm$ from B, S/(S+B) = 80%

J. Phys. G 32 (2006) 1295, DIMUONnet

B-hadron cross-section from single leptons

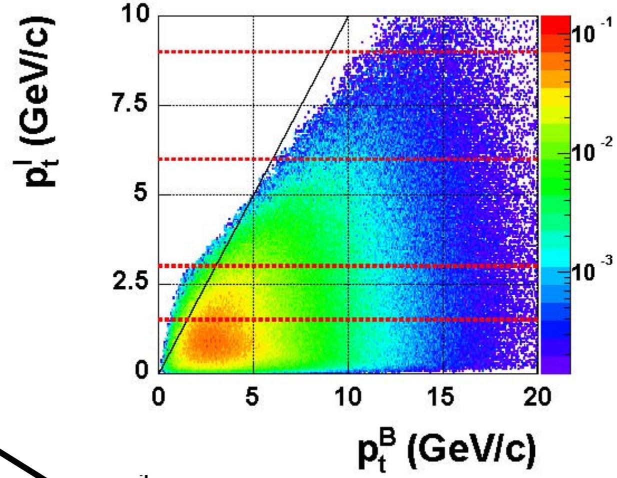
Second step: correct for efficiency, acceptance & decay kinematics

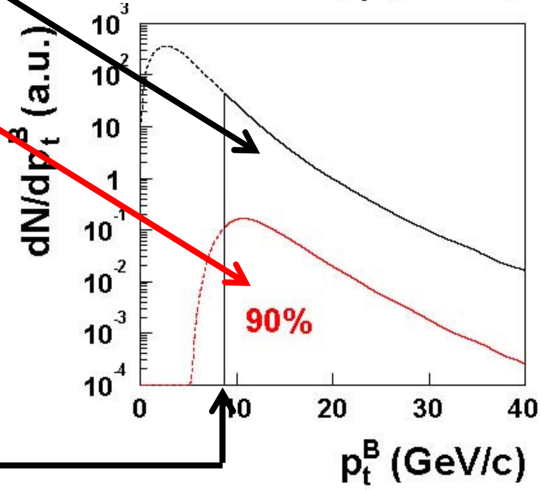
total number of l←B

$$\sigma^B(p_t^B > p_t^{\min}) = \frac{N_{l\leftarrow B}}{\int L\mathrm{d}t} \times \frac{1}{\varepsilon} \times \left.\frac{\sigma^B(p_t^B > p_t^{\min})}{\sigma^B(\Phi^l)}\right|_{MC}$$

integrated luminosity

lepton global detection efficiency



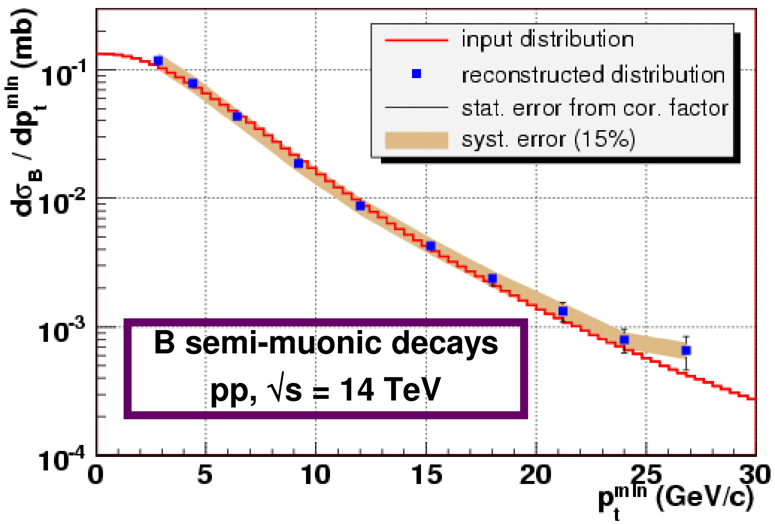


J. Phys. G 32 (2006) 1295, DIMUONnet

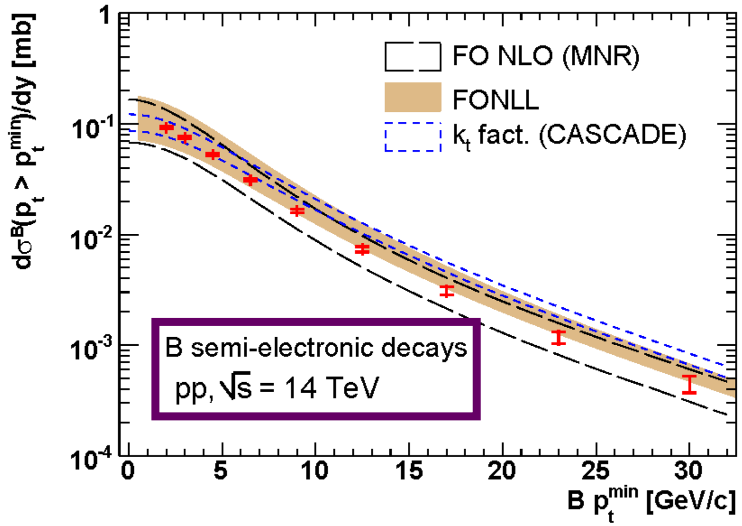
B-hadron cross-section from single leptons

Third step: the inclusive differential B-hadron cross-section

w/o 2nd vertex



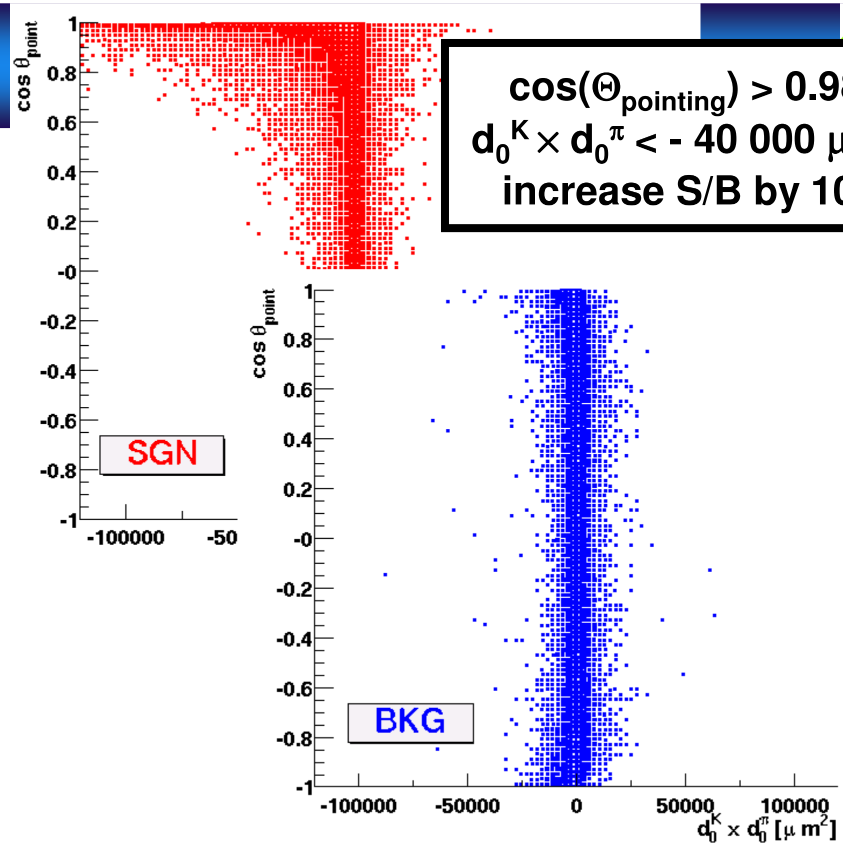
with 2nd vertex



- method widely used (UA1, CDF, D0)
- large p_t reach (~ 80% of the total cross-section is reconstructed)
- large η reach (central and forward regions)
- (very) small statistical errors, systematics ~ 10-15%
- allows to get B-hadron $R_{AA}(p_t)$ (and D-hadron $R_{AA}(p_t)$ simultaneously)

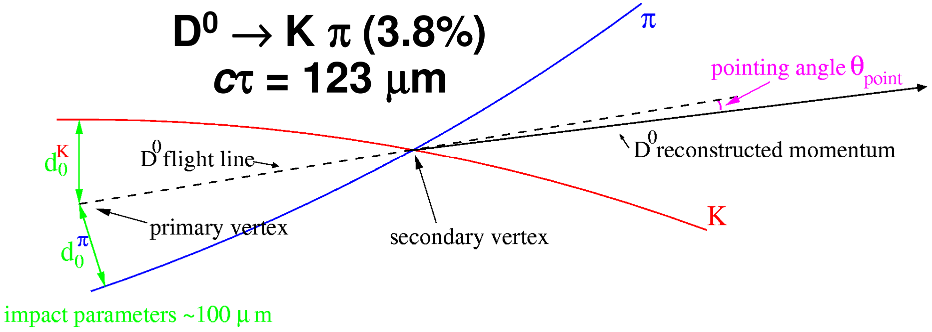
J. Phys. G 32 (2006) 1295, DIMUONnet

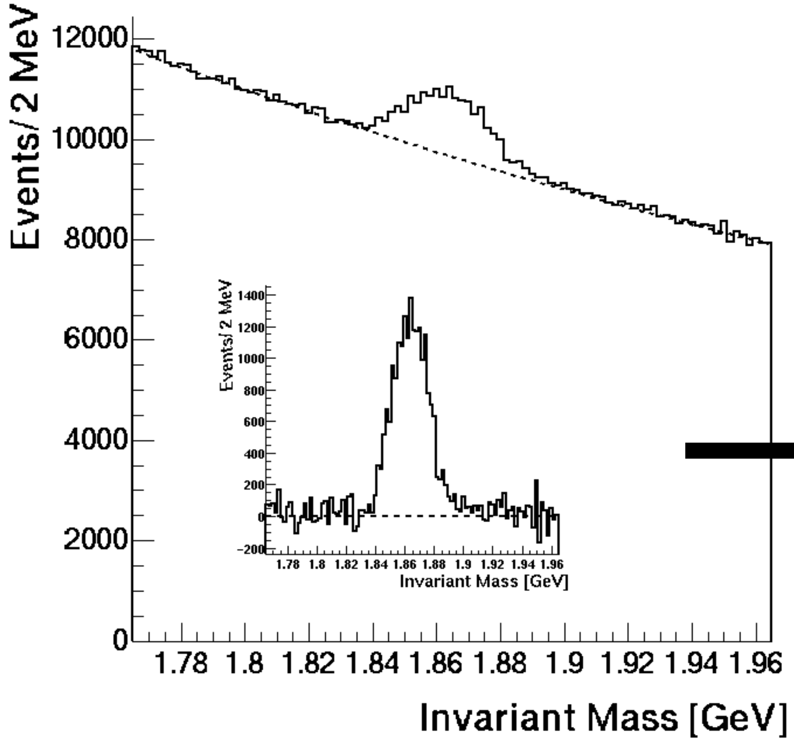
Hadronic charm



cos($\Theta_{pointing}$) > 0.98
$d_0^K \times d_0^\pi$ < - 40 000 μm²
increase S/B by 10^3

$D^0 \rightarrow K\,\pi$ (3.8%)
$c\tau$ = 123 μm





10^7 central PbPb (5%)

- **S ~ 13000**
- **S/B ~ 10 %**
- **S/√(S+B) ~ 40**

background assumes dN/dη = 6000 @ η = 0

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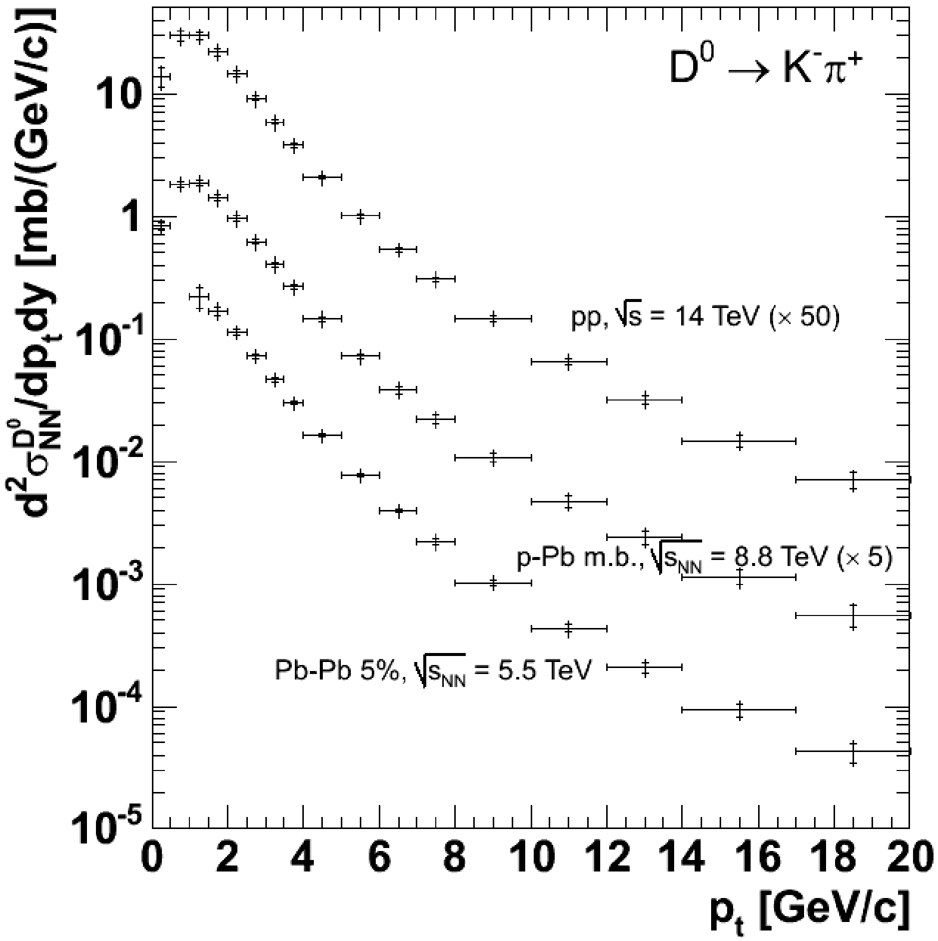
Hadronic charm differential x-section



system	pp	pPb	PbPb
$\sqrt{s}$ (TeV)	14	8.8	5.5
trig	MB	MB	CC
N_{evt}	10^9	10^8	10^7
time (months)	8	1	1
p_t^{min} (GeV/c)	0.5	0.5	1
E_{stat} (%)	3	2	7
E_{syst} (%)	14	16	17

the most precise measurement of the total charm x-section in pp collisions @ LHC

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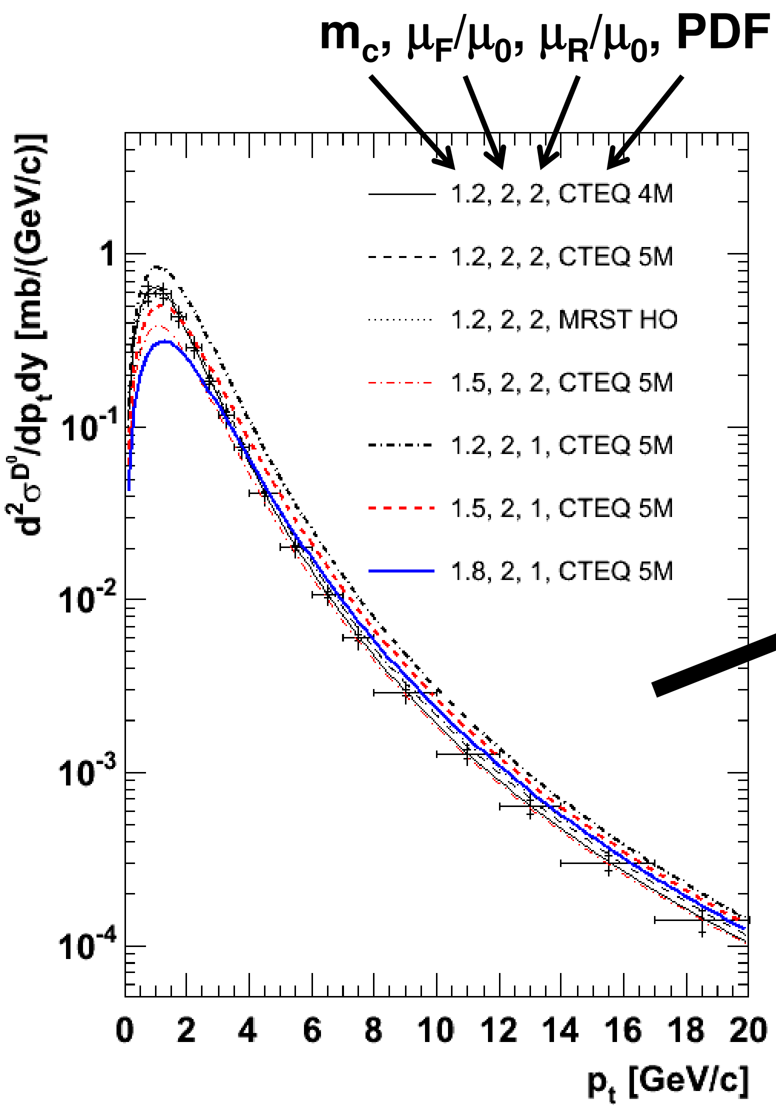
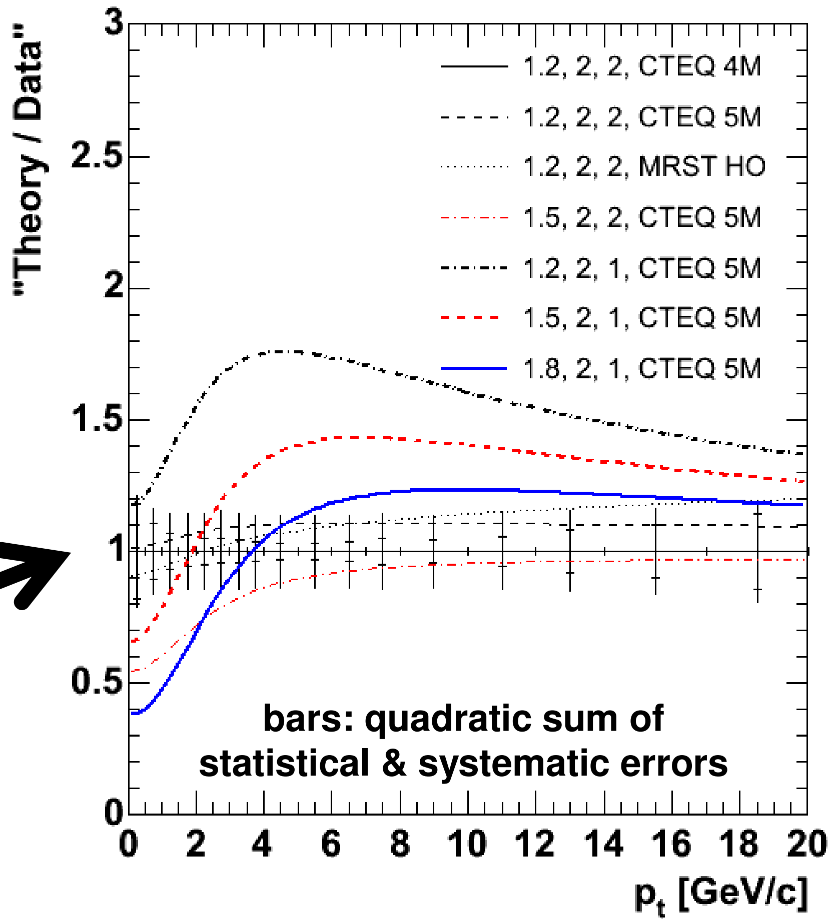
Testing QCD with hadronic charm in pp collisions @ 14 TeV





expected experimental errors are much smaller than theoretical uncertainties

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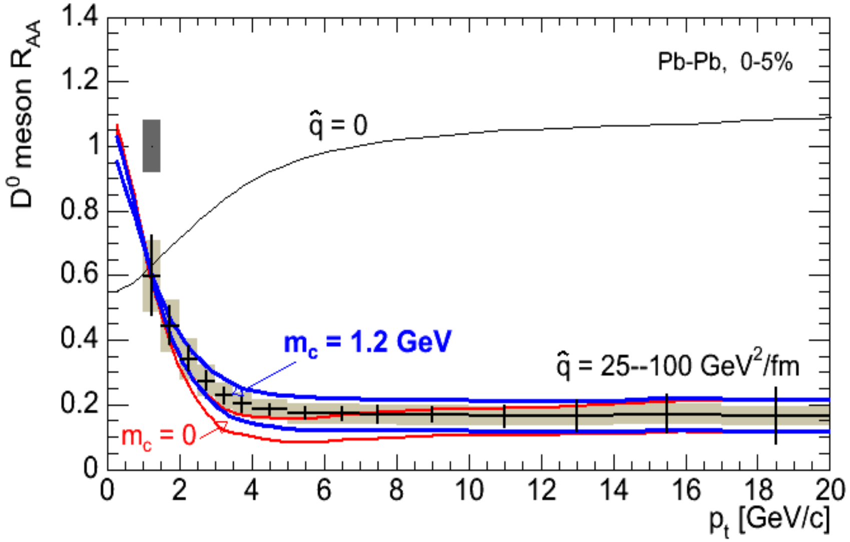
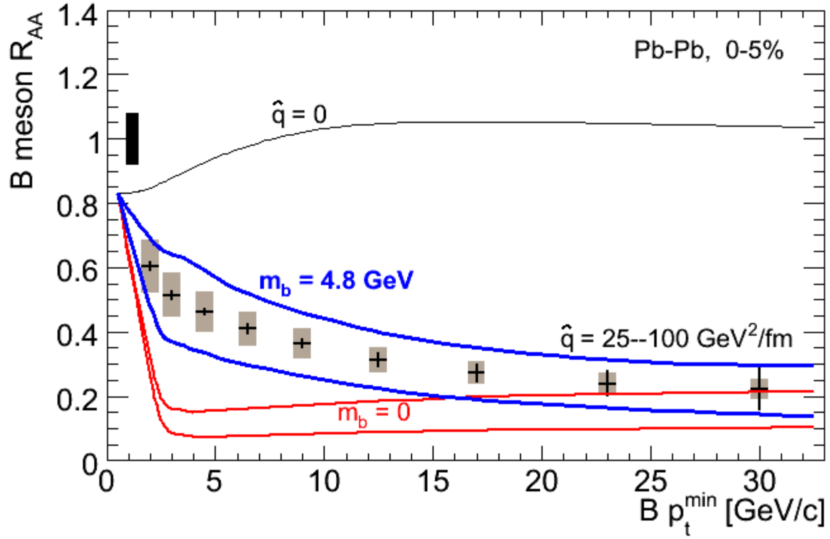
Heavy quark quenching: traditional ratios

1 nominal year: 10^7 central Pb-Pb events, 10^9 pp events
statistics: bars, systematics: bands

$$R_{AA}^{D} = \frac{1}{N_{coll}} \times \frac{dN_{AA}^{D} / dp_t}{dN_{pp}^{D} / dp_t} \qquad R_{AA}^{e} = \frac{1}{N_{coll}} \times \frac{dN_{AA}^{e} / dp_t}{dN_{pp}^{e} / dp_t}$$





sensitivity to shadowing for p_t <~ 7 GeV/c & to energy loss for p_t >~ 7GeV/c

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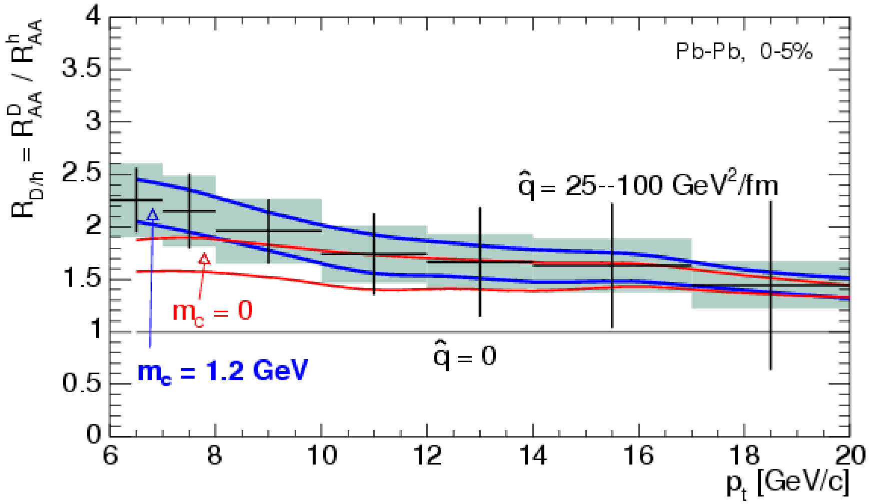
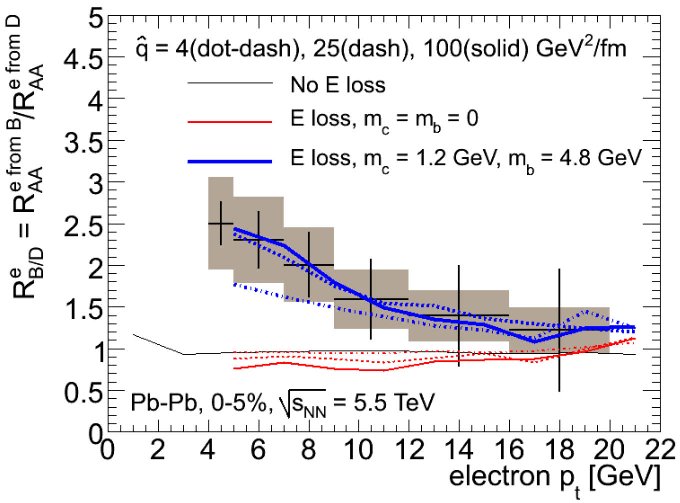
Heavy quark quenching: more ratios

1 nominal year: 10^7 central Pb-Pb events, 10^9 pp events
statistics: bars, systematics: bands

$$R_{D/h} = R_{AA}^{D} / R_{AA}^{h} \qquad R_{B/D} = R_{AA}^{\text{e from B}} \Big/ R_{AA}^{\text{e from D}}$$





sensitivity to color charge dependence

sensitivity to mass dependence

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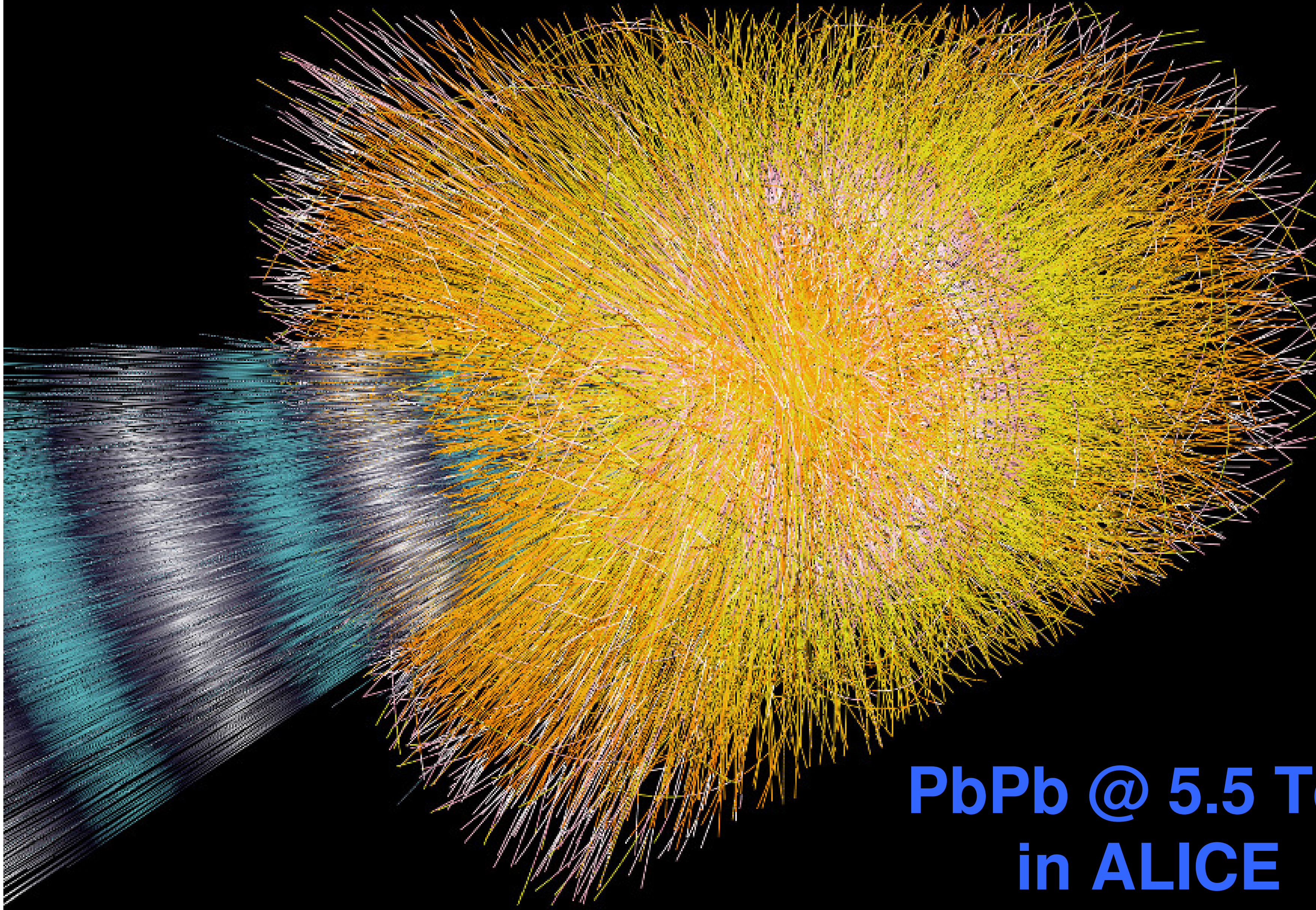
Waiting for data… first collisions expected in August 09



PbPb @ 5.5 TeV
in ALICE