Heavy flavors & quarkonia @ the LHC

What is different @ the LHC

The LHC heavy ion programs

Selected physics channels

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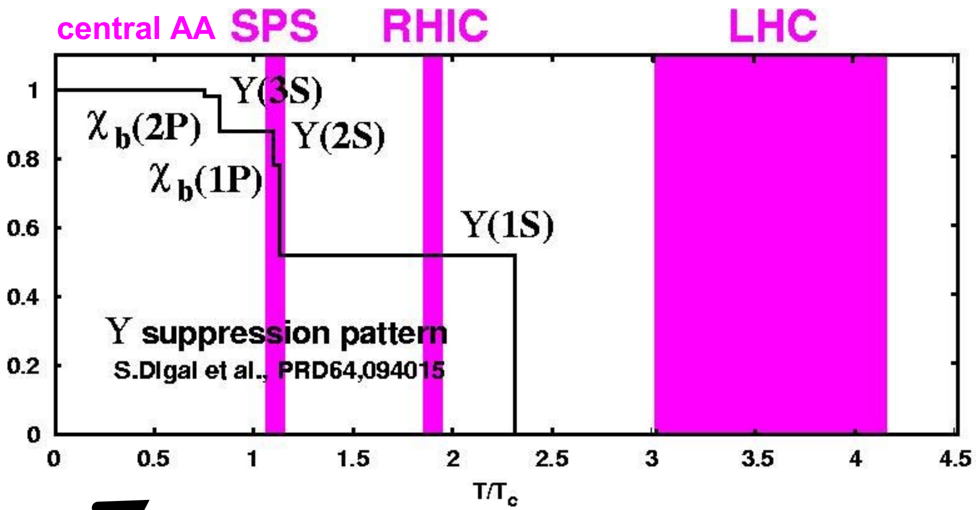
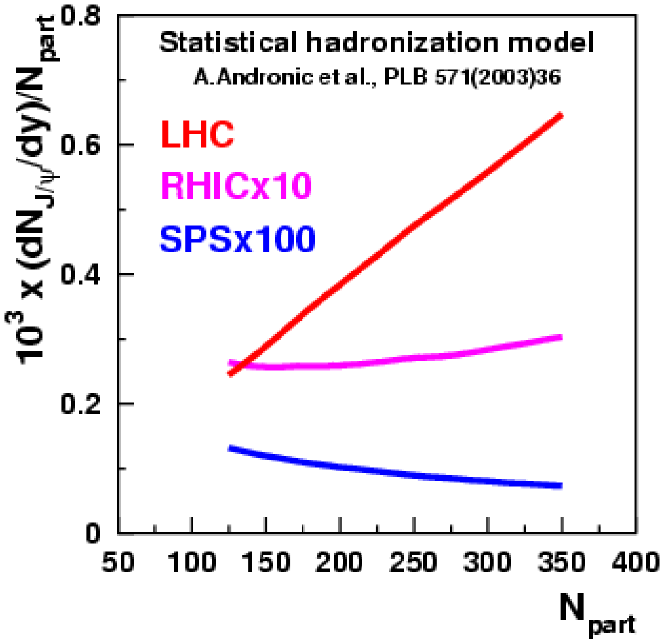
Heavy flavors @ LHC (in short)

N($q\bar{q}$) per central AA (b=0)

	SPS	RHIC	LHC
charm	0.2	10	130
bottom	---	0.05	5



- large primary production
- melting of $\Upsilon(1S)$ by color screening
- large secondary production of charmonia



new environment, new observables, new analyses

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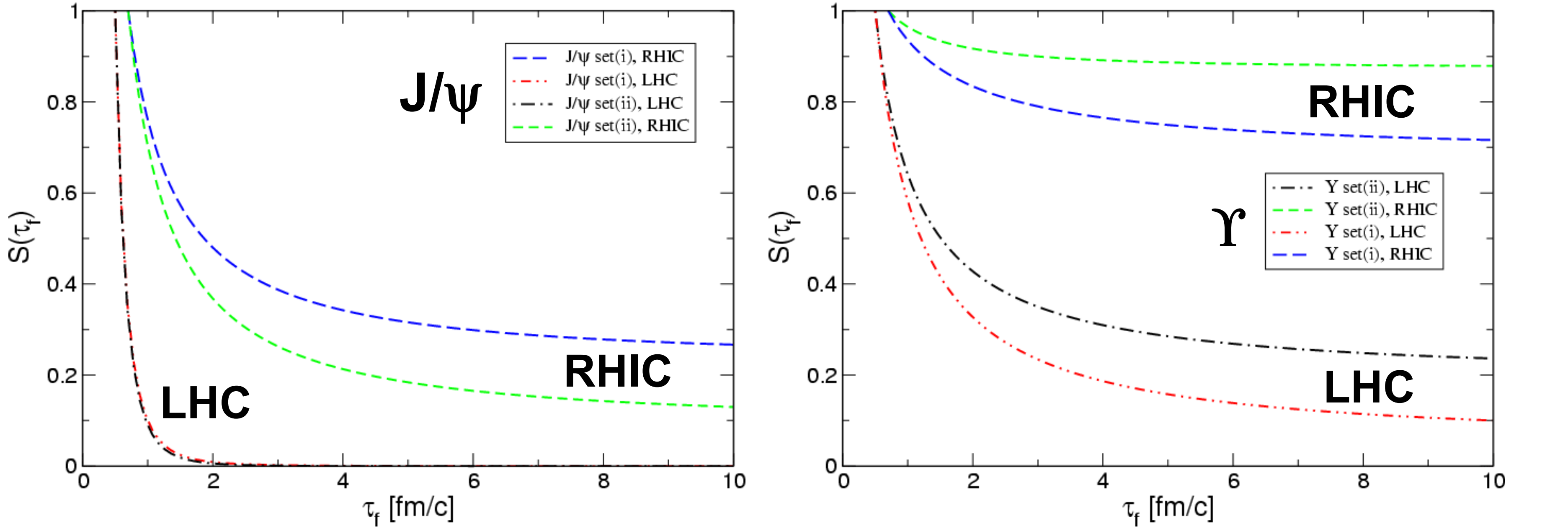
Hard gluon induced quarkonium breakup

quarkonium survival probabilities versus QGP lifetime

set(i)(ii) : lower (higher) bottomonium (charmonium) binding energy



- **none of the J/ψ survives the LHC-(PbPb)QGP!** **(importance of p_t & system size studies)**
- **ϒ probes the QGP lifetime & temperature**

X.-M.Xu, D.Kharzeev, H.Satz, X.-N.Wang, Phys. Rev. C 53(1996)3051
M.Bedjidian et al., hep-ph/0311048, D.Blaschke et al., hep/ph-0410338

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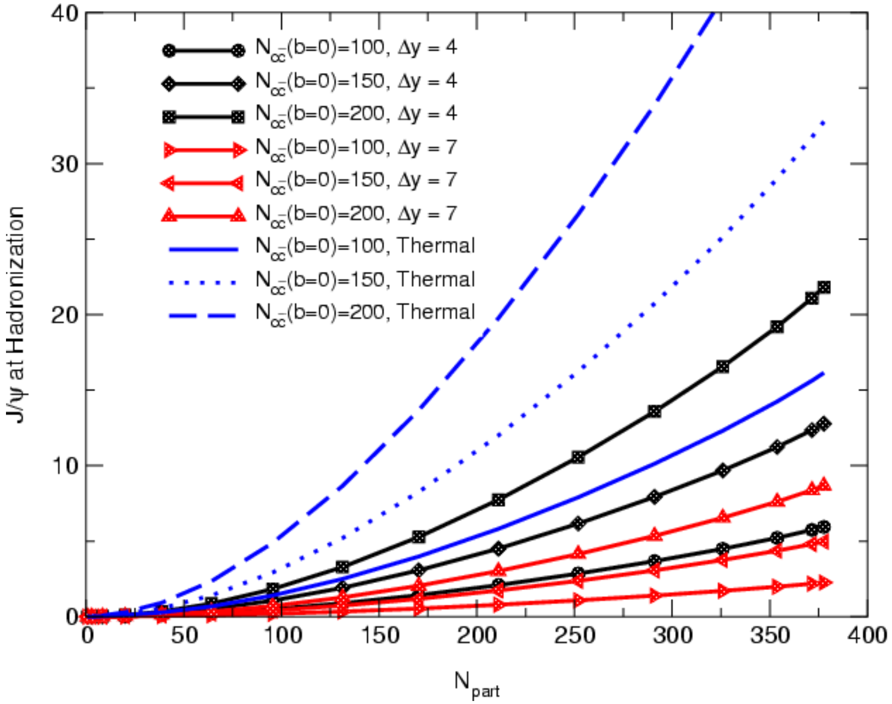
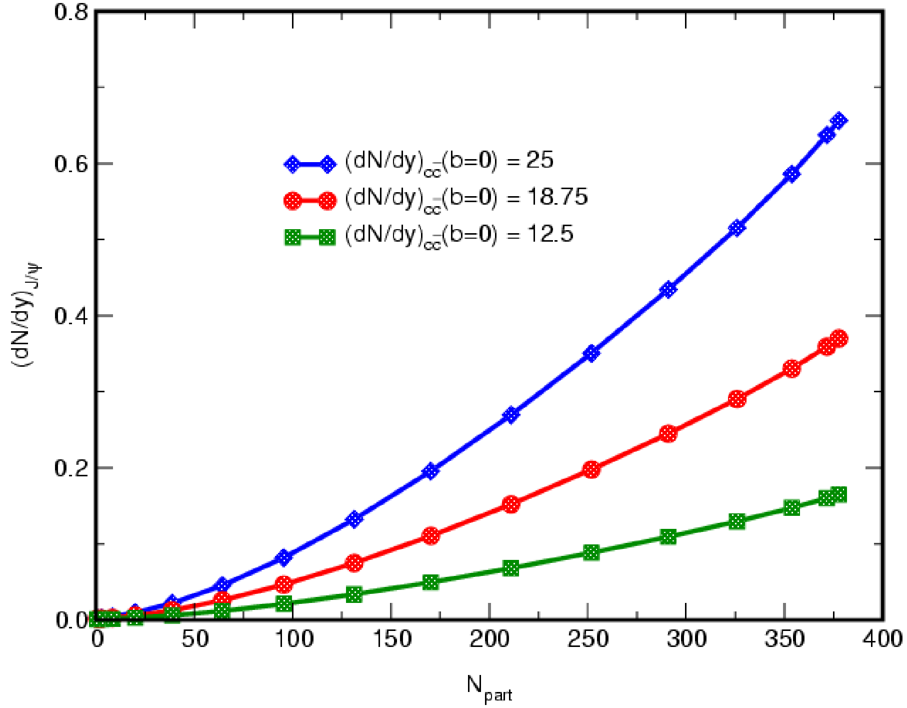
Secondary quarkonium production from kinetic recombination & statistical hadronization

J/ψ kinetic recombination @ LHC



J/ψ stat. hadronization @ LHC



N(qq̄) per central AA (b=0)

	SPS	RHIC	LHC
charm	0.2	10	130
bottom	---	0.05	5

- a (very) large J/ψ production is to be expected w.r.t. RHIC
- what about ϒ? : a b quark @ LHC is a c quark @ RHIC!

P.Braun-Munzinger, J.Stachel, Phys. Lett. B 490(2000)196

R.L.Thews, M.Schroeder, J.Rafelski, Phys. Rev. C 63(2001)054905

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The dilepton mass spectrum @ LHC

B-chain:

$$X \leftarrow B\bar{B} \rightarrow \mu^- + D + X$$
$$\hookrightarrow \mu^+ + X$$

BB-diff:

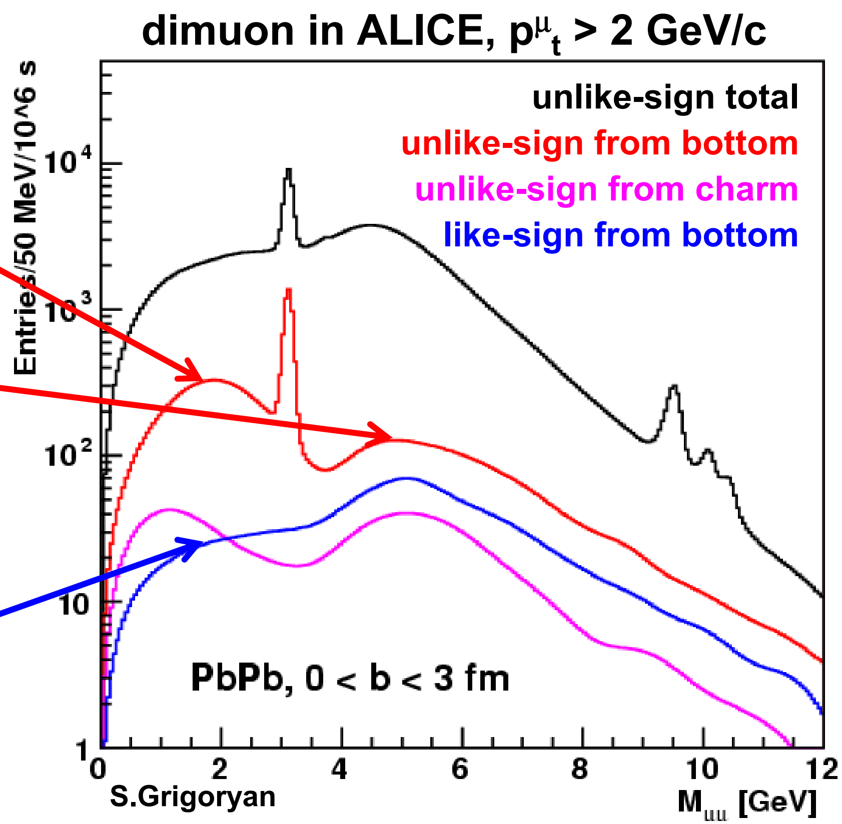
$$X + \mu^+ \leftarrow B\bar{B} \rightarrow \mu^- + X$$

$B \rightarrow D$ decay:

$$\pi^- + D^0 \leftarrow B^- B^+ \rightarrow \mu^+ + \bar{D}^0 + \nu_\mu$$
$$X + \mu^+ \hookleftarrow \qquad \hookrightarrow \mu^- + X$$

B^0 oscillations:

$$X + \mu^- \leftarrow \bar{B}^0 B^0 \rightarrow \bar{B}^0 \rightarrow \mu^- + X$$



- **dilepton from b decay dominate the spectrum below Υ & J/ψ**
- **large yield of secondary J/ψ from b decay**
- **dilepton from b decay have different origin at low & high mass**
- **sizeable yield of like-sign correlated dilepton from b decay**
- **Drell-Yan is probably out of reach (need of new normalisations)**

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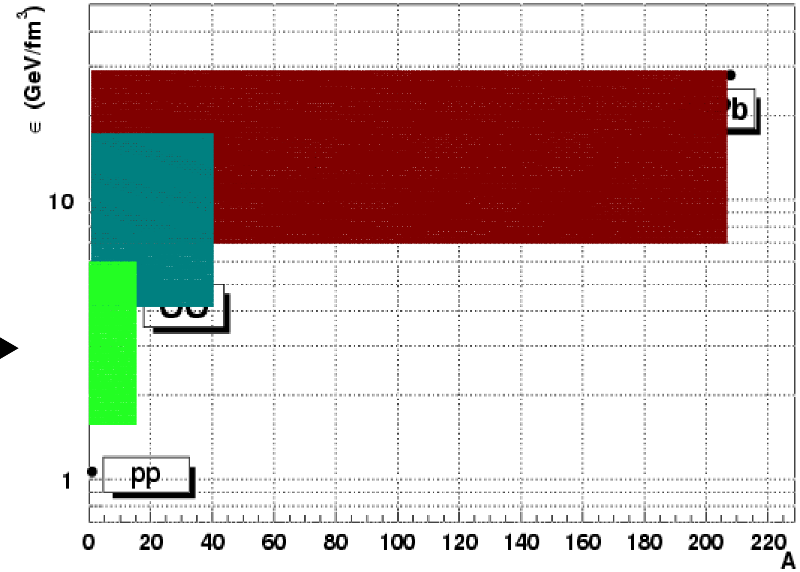
Heavy flavor physics program @ LHC
(channels investigated so far)

- **charmonia & bottomonia versus**
  - **centrality**
  - **transverse momentum**
  - **system-size** →
  - **reaction plane**



- **open bottom (inclusive)**
  - **cross-section from 2nd J/ψ, single leptons & dilepton**
  - **b quark energy loss**
- **open charm (exclusive D^0)**
  - **transverse momentum distribution**
  - **c quark energy loss**
- **electron-muon coincidences**

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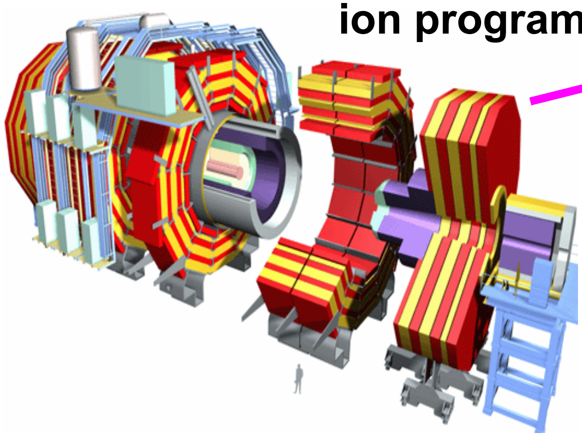
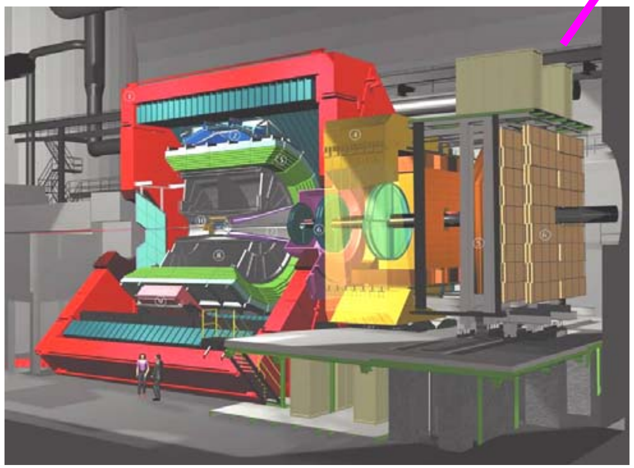
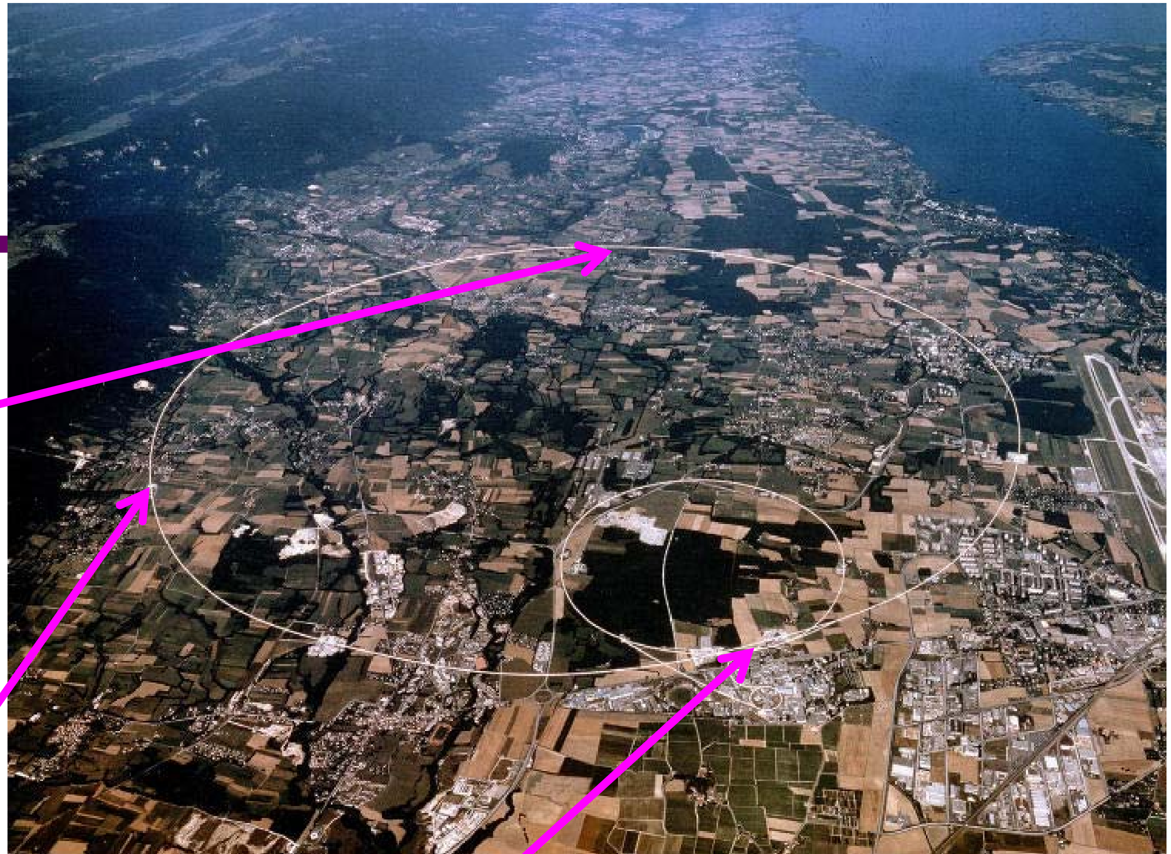
Heavy ions @ the LHC

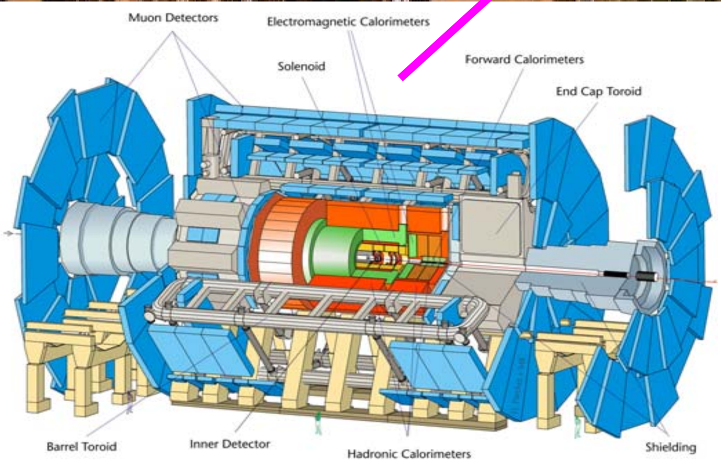
CMS: strong heavy ion program





ALICE: the dedicated heavy ion experiment





ATLAS: heavy ion LOI (2004)

one LHC year = 1 month AA (or AA-like) + 10 months pp

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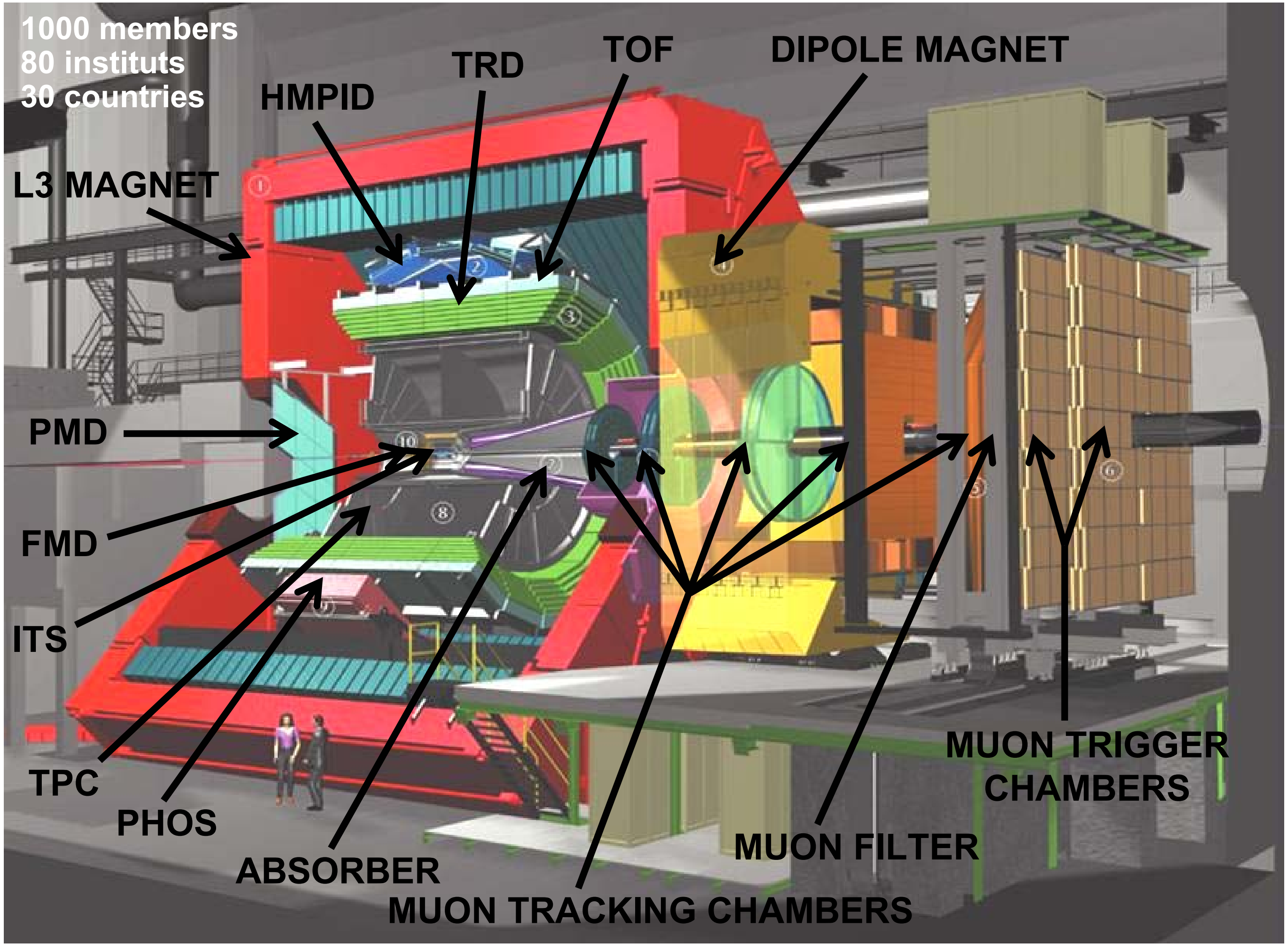
ALICE (A Large Ion Collider Experiment): 7(4) SPS(RHIC) experiments



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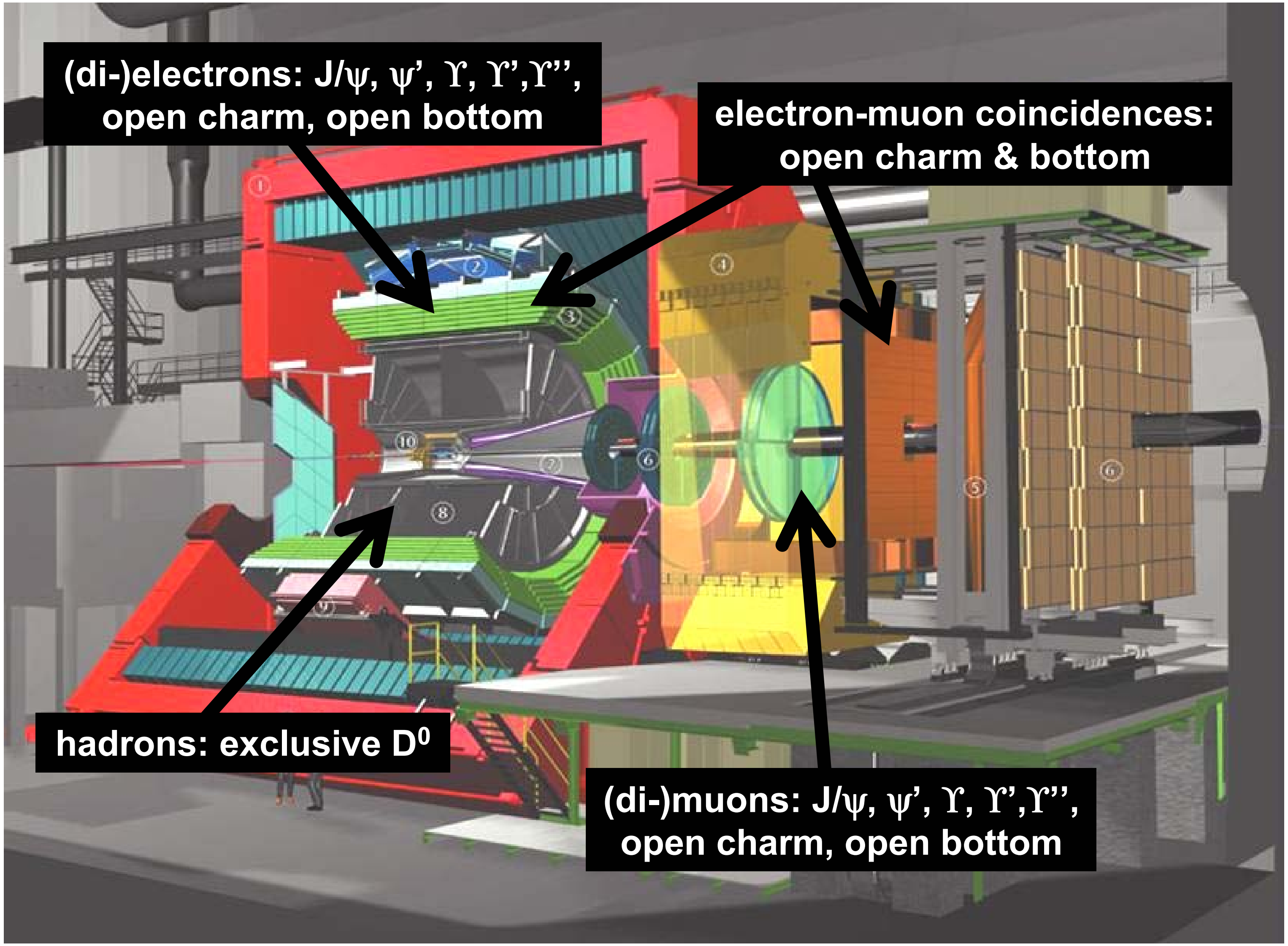
Heavy flavors with ALICE



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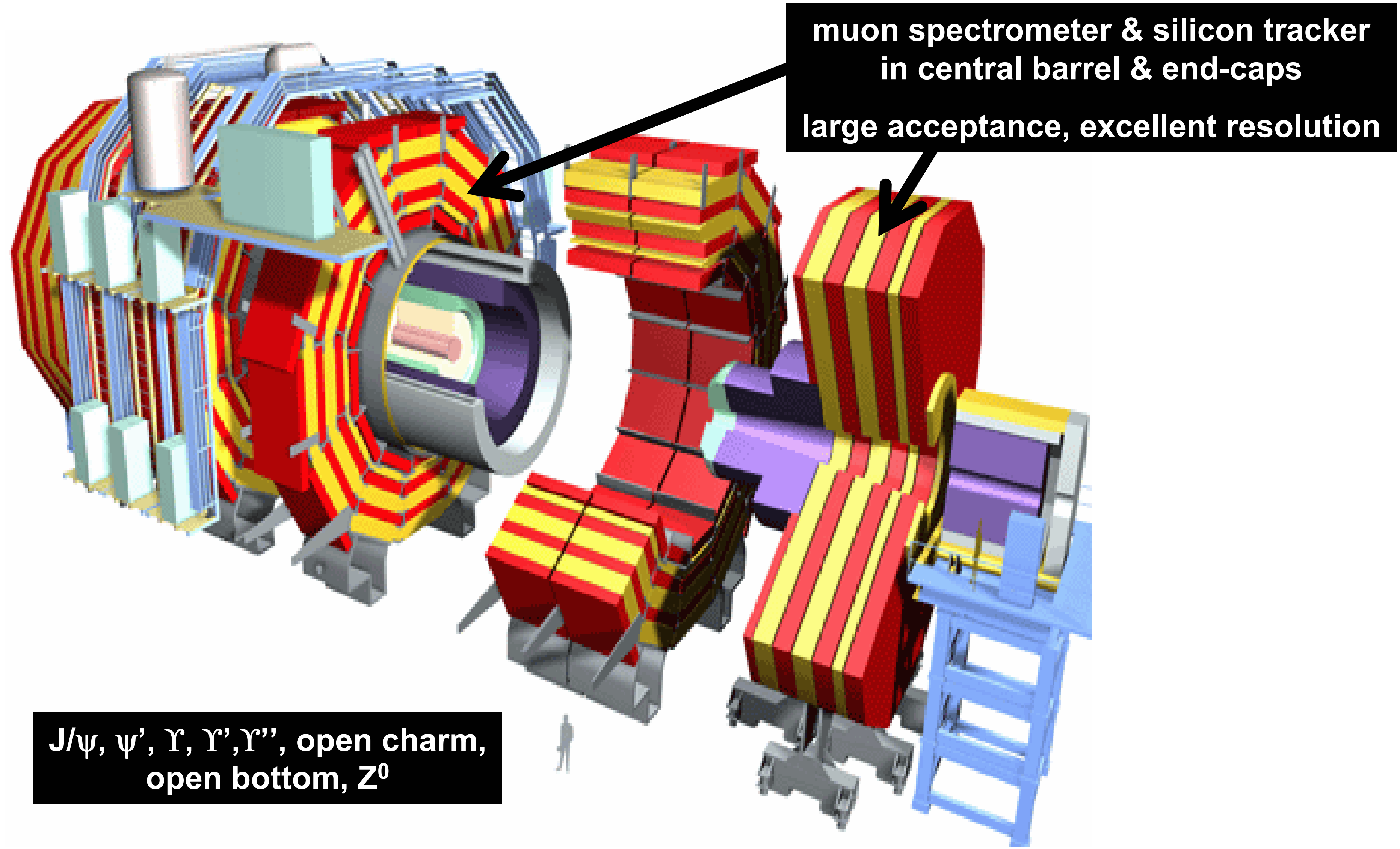
Heavy flavors with CMS



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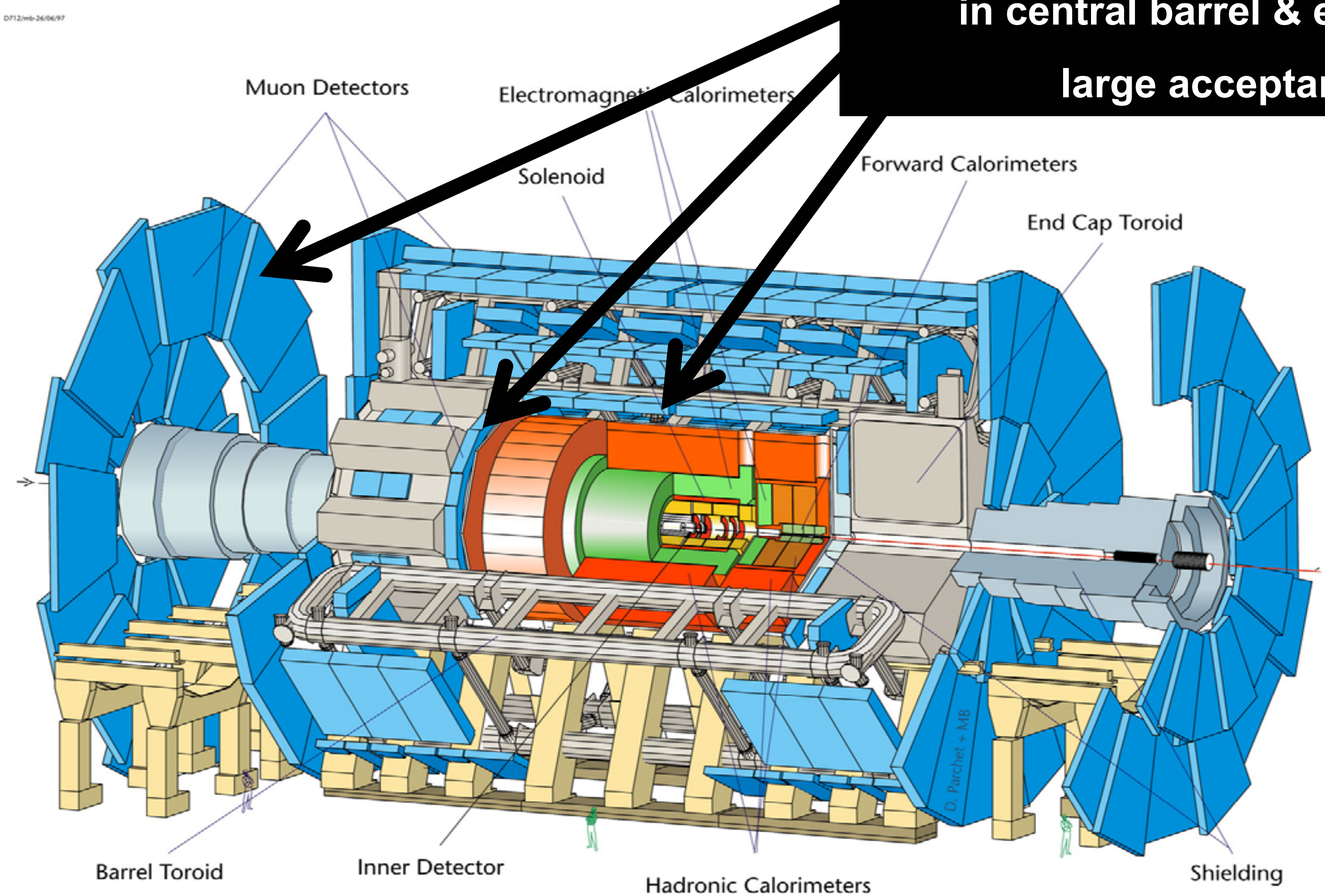
Heavy flavors with ATLAS

muon spectrometer & silicon tracker in central barrel & end-caps

large acceptance



studies limited to Υ, Υ',Υ'' reconstruction & b-jet tagging so far

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Centrality dependence of quarkonium yields in ALICE-muon

cross-sections from R.Vogt in hep-ph/0311048, assumes neither suppression nor enhancement

- J/ψ: large stat., good sign.
  (allows much narrower centrality bins)
- ψ': small S/B
- ϒ: good stat., S/B > 1, good sign.
- ϒ': good stat., S/B > 1, good sign.
- ϒ'': low statistics

PbPb, $\sqrt{s}$ = 5.5TeV, L = 5.10^{26} $cm^{-2}s^{-1}$, T=10^6s,
2σ mass-cut, ε assumes dN_{ch}/dy = 4000 @ y = 0 in central

	b (fm)	0-3	3-6	6-9	9-12	12-16	min. bias
	ε (GeV/fm³)	32	30	28	16	5	
J/ψ	S ($x10^3$)	86.48	184.6	153.3	67.68	10.46	502.4
	S/B	0.167	0.214	0.425	1.237	6.243	0.28
	S/$\sqrt{S+B}$	111.3	180.4	213.8	193.4	94.95	331.5
ψ'	S ($x10^3$)	1.989	4.229	3.547	1.565	0.24	11.57
	S/B	0.009	0.011	0.021	0.063	0.273	0.015
	S/$\sqrt{S+B}$	4.185	6.902	8.604	9.641	7.171	12.95
ϒ	S ($x10^3$)	1.11	2.376	1.974	0.83	0.118	6.408
	S/B	2.084	2.732	4.31	7.977	12.01	3.246
	S/$\sqrt{S+B}$	27.39	41.71	40.03	27.16	10.42	69.99
ϒ'	S ($x10^3$)	0.305	0.653	0.547	0.229	0.032	1.766
	S/B	0.807	1.043	1.661	2.871	4.319	1.243
	S/$\sqrt{S+B}$	11.68	18.26	18.48	13.02	5.077	31.28
ϒ''	S ($x10^3$)	0.175	0.376	0.312	0.13	0.019	1.012
	S/B	0.566	0.722	1.18	1.936	3.024	0.867
	S/$\sqrt{S+B}$	7.951	12.55	13	9.274	3.73	21.67

S.Grigoryan

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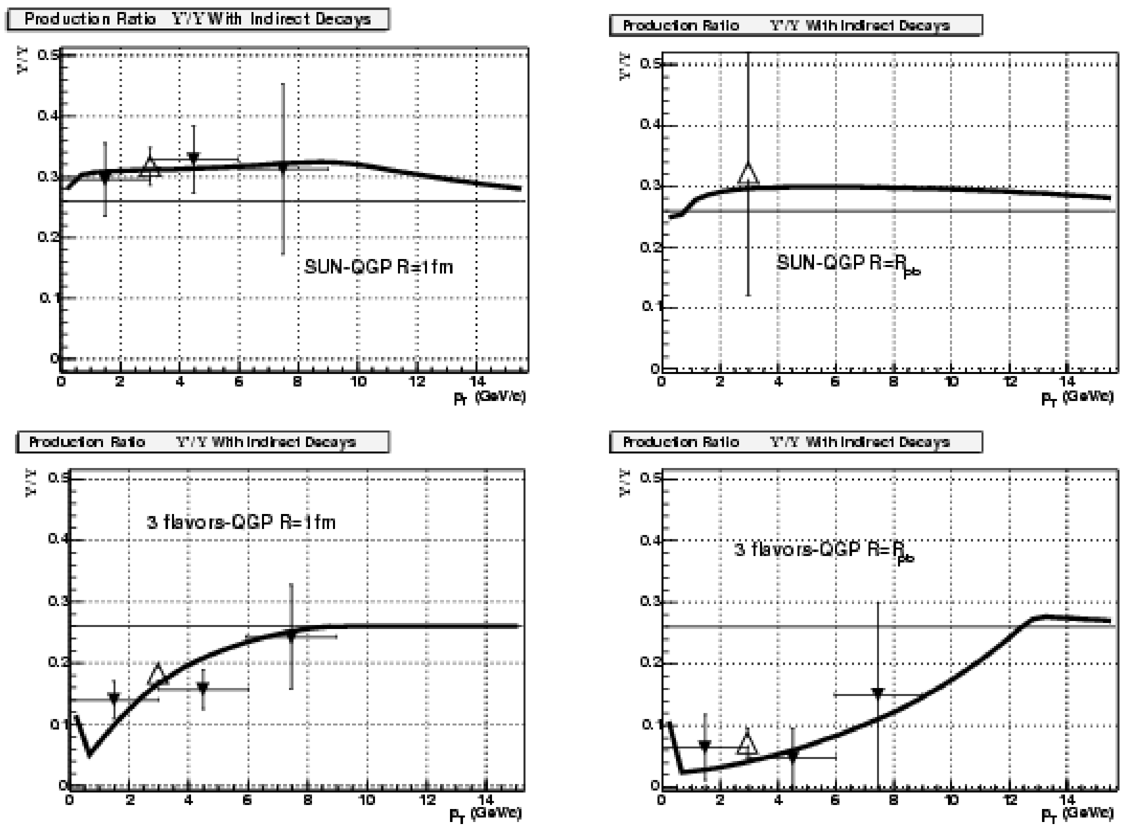
Υ'/Υ ratio versus p_t (dimuon channel)

J.P.Blaizot & J.Y.Ollitrault, Phys. Lett. B 199(1987)499; F.Karsch & H.Satz, Z. Phys. C 51(1991)209; J.F.Gunion & R.Vogt, Nucl. Phys. B 492(1997)301

- Melting depends on
  - resonance formation time, dissociation temp. & p_t
  - QGP temp., lifetime & size
- Ratio is flat in pp (CDF)
- Any deviation from the pp (pA) value is a clear evidence for the QGP (nuclear effects cancel-out)
- The p_t dependence of the ratio is sensitive to the characteristics of the QGP



- full & realistic simulation
- error bars = 1 month of central PbPb (10%)

E.Dumonteil, PhD Thesis (2004)

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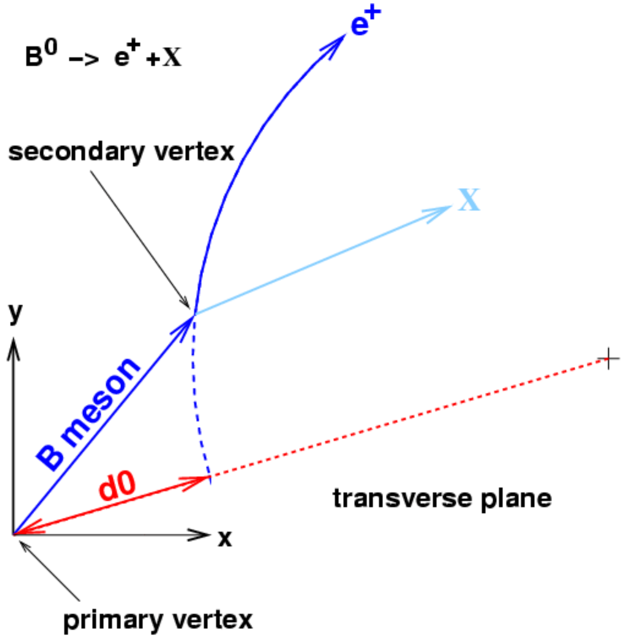
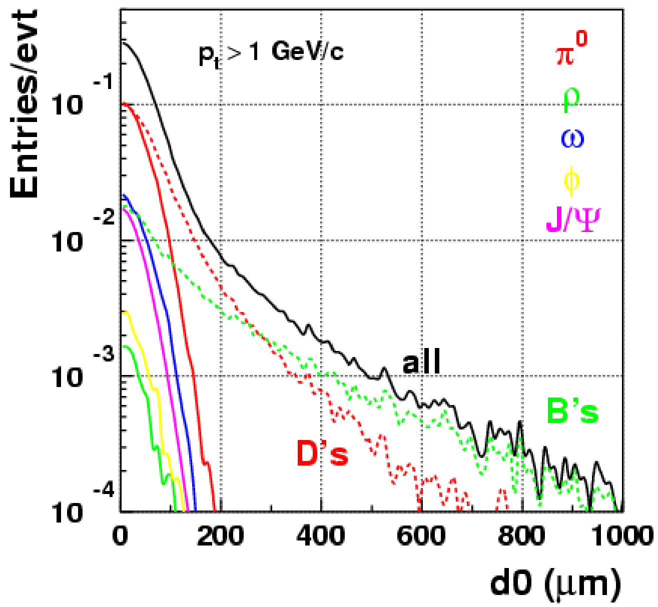
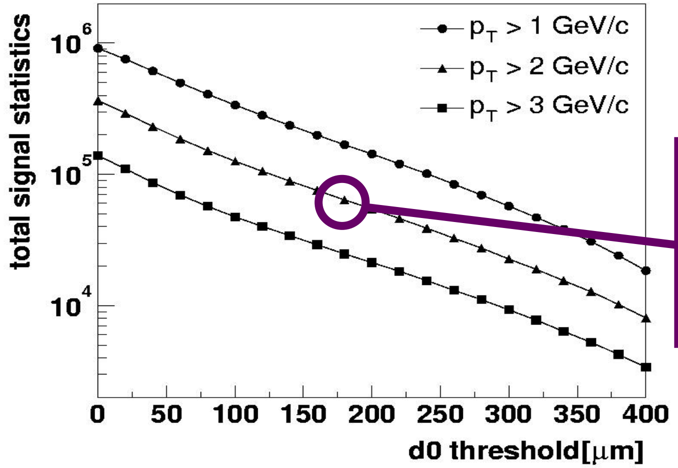
Bottom from single electrons with displaced vertices

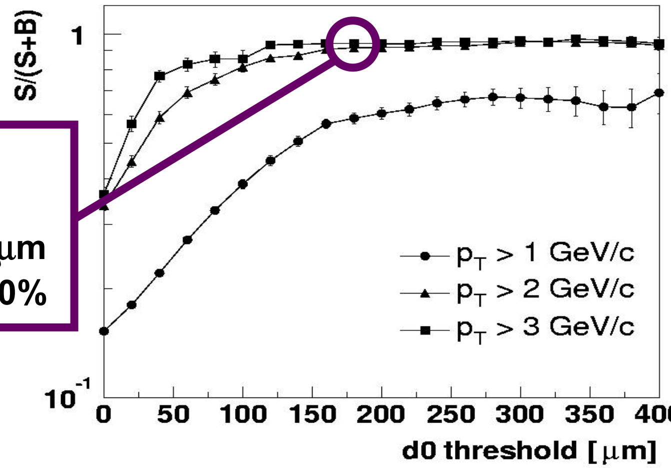




- d0 < d0cut : improve S/B for resonances
- d0 > d0cut : measure electrons from D & B



PbPb central (5%)
$B \rightarrow e^{\pm}$ in ITS/TPC/TRD
p_t > 2 GeV/c, 180 < d0 < 600 μm
50000 $e^{\pm}$ from B, S/(S+B) = 90%



CERN/LHCC 99-13, M.Lunardon & R.Turrisi

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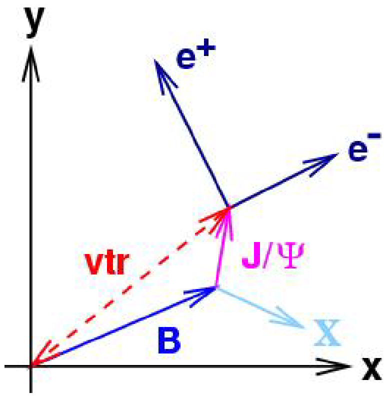
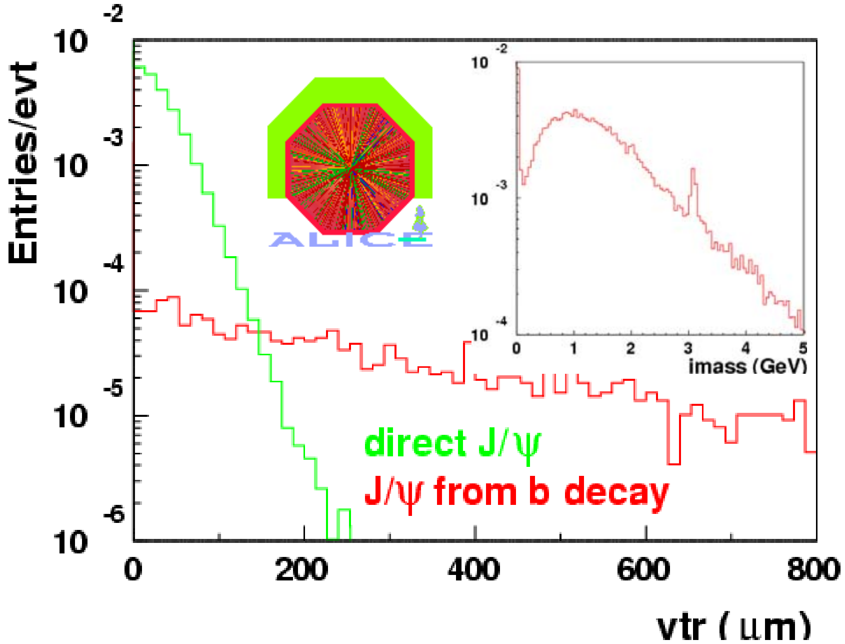
Secondary J/ψ from B decay

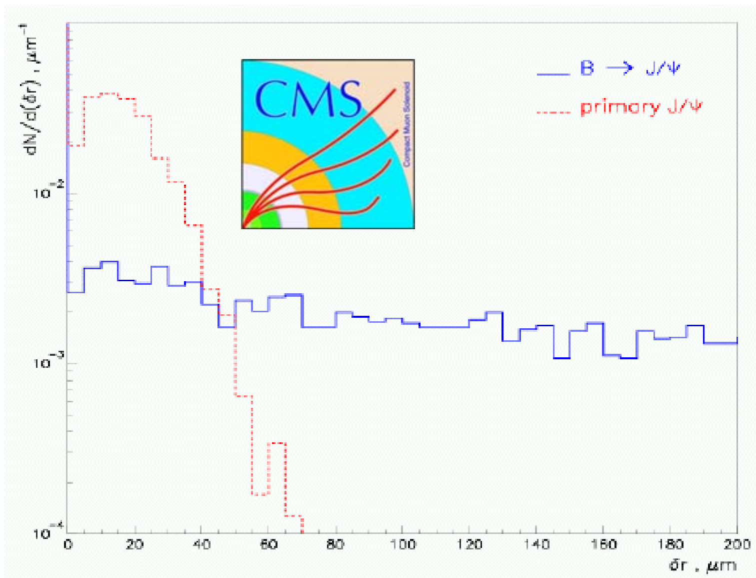
- B → J/ψ (1*S*) anything : 1.16 ± 0.10% (PDG)
- N(direct J/ψ) in central (5%) PbPb @ 5.5 TeV : 0.18
- N(bb pairs) in central (5%) PbPb @ 5.5 TeV : 4.56

⇒ N(b → J/ψ) / N(direct J/ψ) = 30% in 4π



- disentangle primary & secondary J/ψ
- measure inclusive b cross-section
- probe b quark in-medium energy loss





ALICE: CERN/LHCC 99-13, CMS: CMS/NOTE 2001/008

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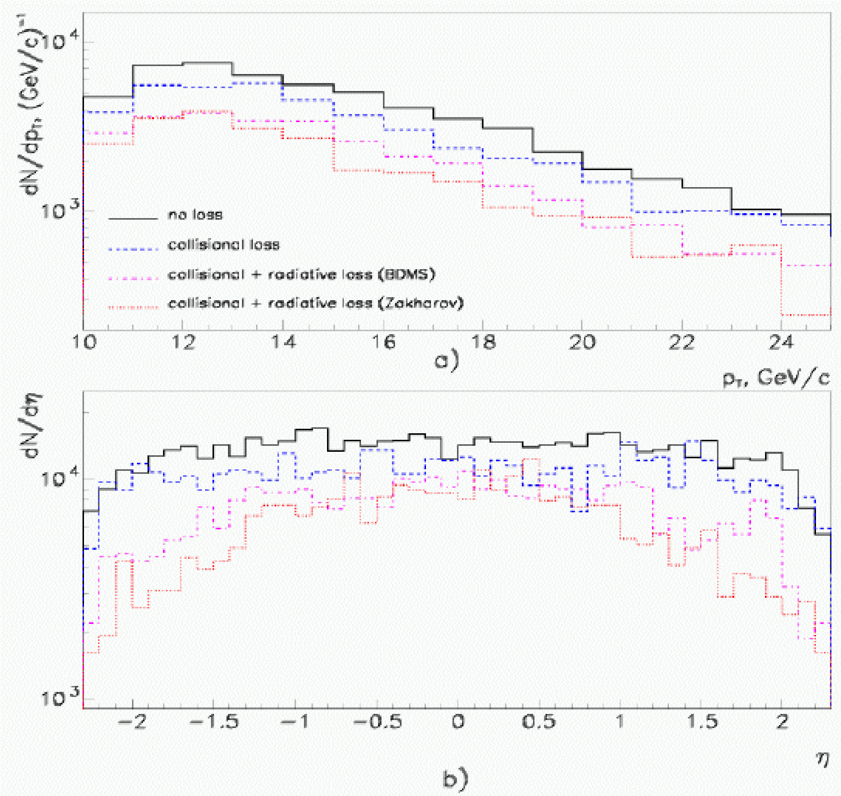
Using secondary J/ψ from B decay to probe b quark energy loss

secondary J/ψ from B decay
in CMS, p_t^μ > 5 GeV/c



energy loss is modeled in 2 extreme cases:

- collisional energy loss (minimum)
- collisional + radiative energy loss (maximum)

with energy loss:

- yield reduced by a factor ~ 4
- η distribution gets significantly narrower

interest to combine this study with dimuon from B

I.P.Lokhtin & A.M.Snigirev, Eur. Phys. J. C 21(2001)155

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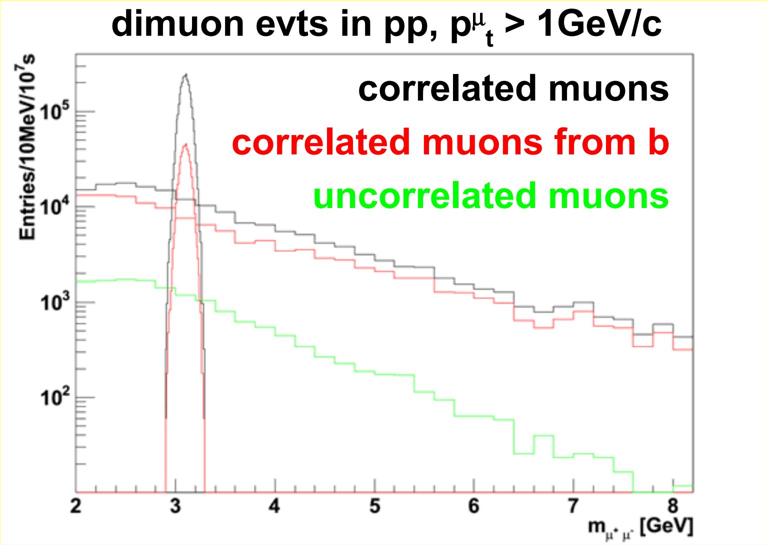
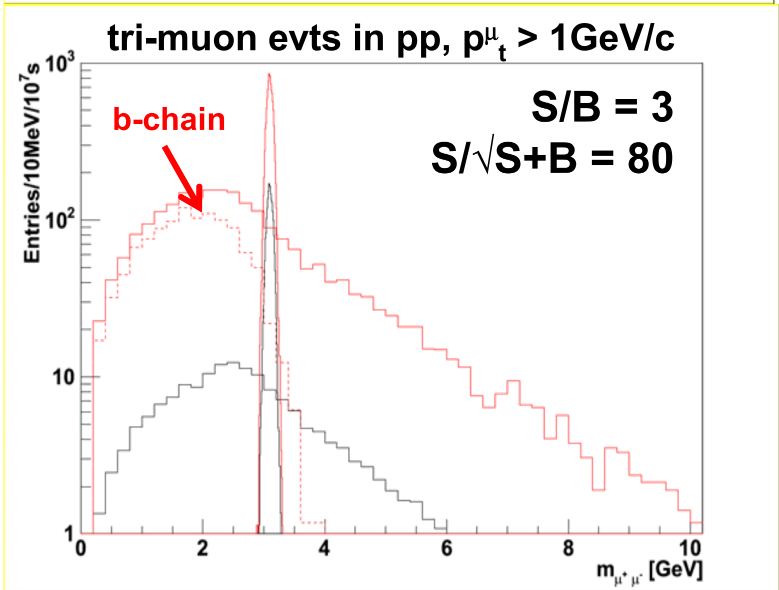
Secondary J/ψ from tri-muon events in pp w/o 2nd vertex reconstruction





- dimuon events:
  - 85% of direct J/ψ
  - 15% of J/ψ from b decay

$$\mu^{\pm} + X \longleftarrow B\bar{B} \longrightarrow \mu^{-} + D + X$$
$$\hookrightarrow \mu^{+} + X$$

$$\mu^{\pm} + X \longleftarrow B\bar{B} \longrightarrow J/\psi + X$$
$$\hookrightarrow \mu^{+} + \mu^{-}$$

- tri-muon events:
  - 15% of direct J/ψ
  - 85% of J/ψ from b decay

doable in pp & pA, very difficult in central ArAr

A.Morsch (2004)

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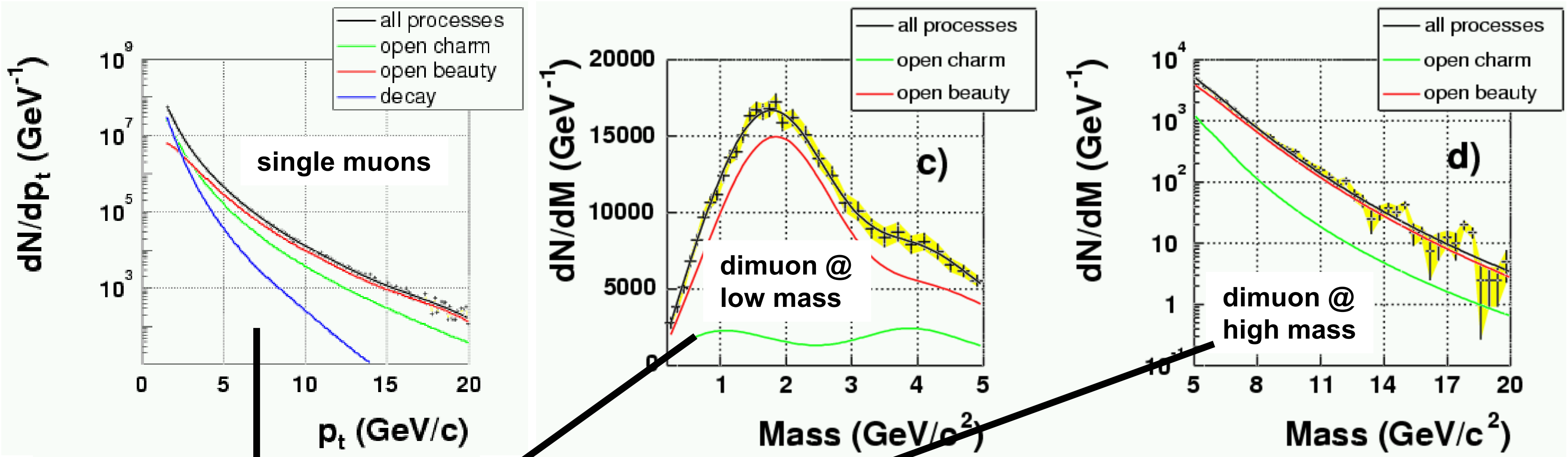
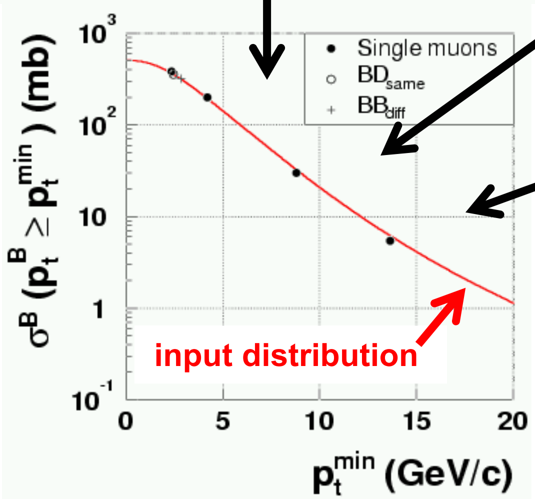
b cross-section from single muons & unlike-sign dimuon in PbPb

fits with fixed shapes (PYTHIA) & b yield as the only free parameter (central PbPb 5%)





- allows to reconstruct the differential b x-section
- uses 3 different channels
- systematical errors underway
- (very) large statistics is expected

R.Guernane (2004)

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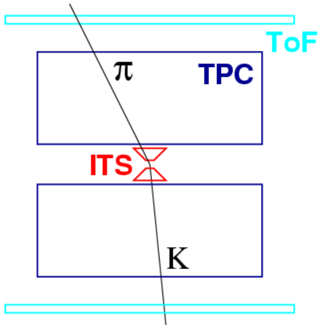
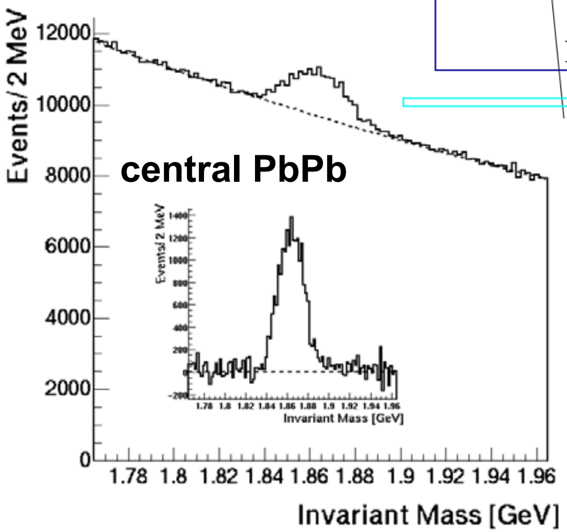
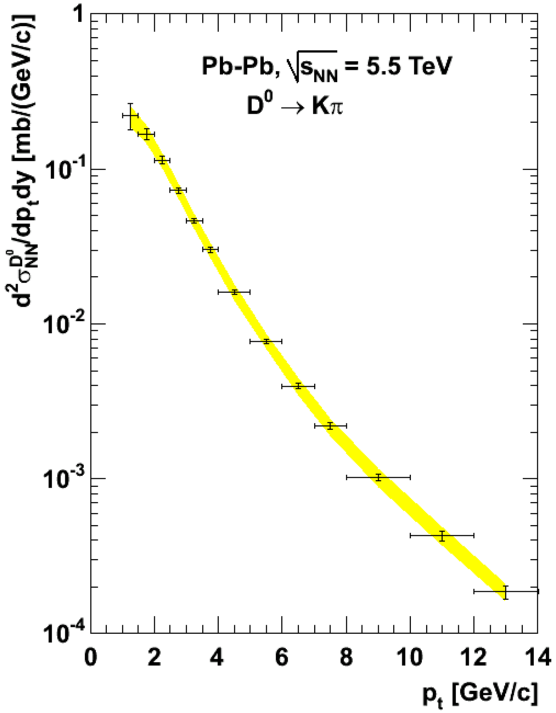
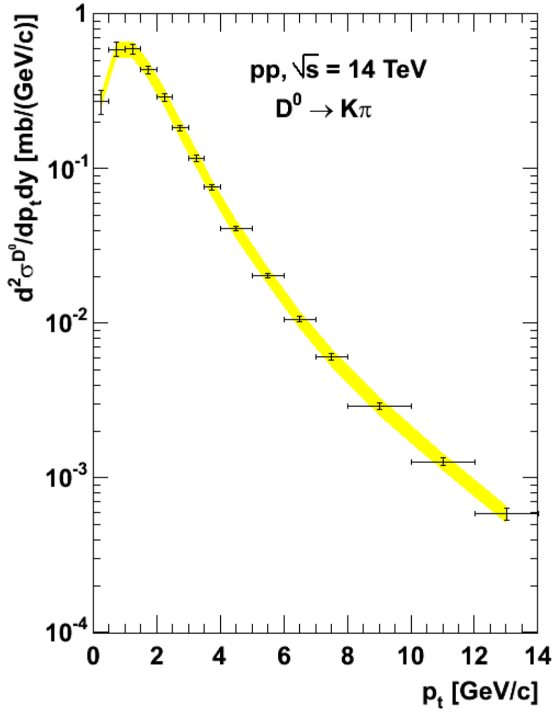
Exclusive charm measurements

$D^0 \rightarrow K\,\pi$ (3.8%)









1 LHC year, 1σ mass cut

	S	S/B (%)	S/√S+B
PbPb 5%	13000	11	37
pp	19000	11	44

- accessible p_t range down to 1(0) GeV/c in PbPb(pp)
- background assumes $dN/d\eta = 6000$ @ $\eta = 0$ in PbPb
- allows to measure $B \rightarrow D^0 \rightarrow \pi\,K$ à la CDF
- promising tool to study c quark energy loss (U.Wiedemann talk), sensitivity to gluon density (M.Djordjevic talk)

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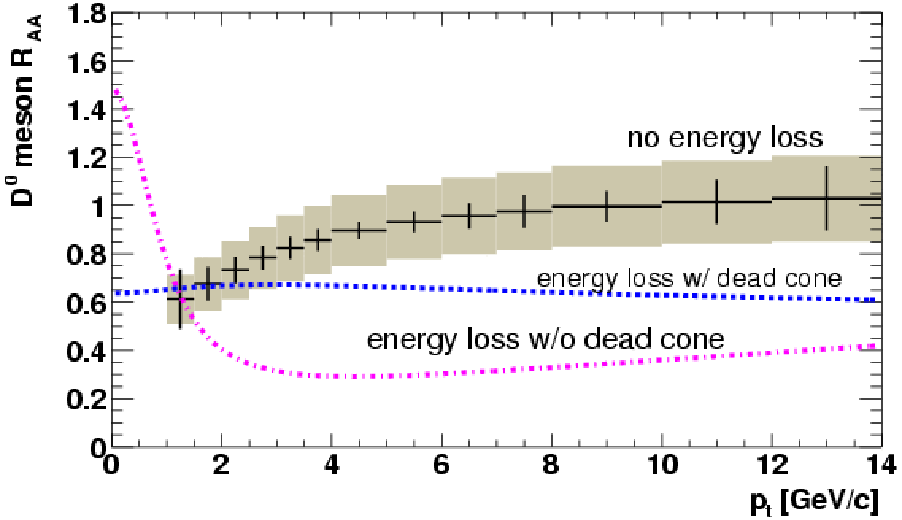
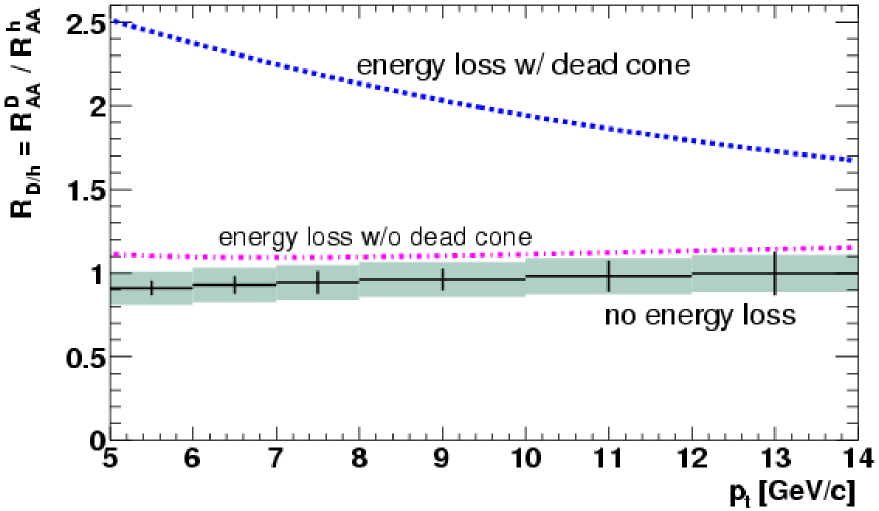
Using D^0 to probe c quark energy loss

energy loss modeled with quenching weights with and w/o dead cone

$$R_{AA}^{D}(p_t) = \frac{1}{N_{coll}} \times \frac{dN_{AA}^{D}/dp_t}{dN_{pp}^{D}/dp_t} \qquad R_{D/h}(p_t) = R_{AA}^{D}(p_t)/R_{AA}^{h}(p_t)$$





- R^{D}_{AA} sensitive to shadowing for p_t < 7 GeV/c & to energy loss for p_t > 7GeV/c
- R^{D}_{AA} behaves differently versus p_t with and w/o dead cone
- $R_{D/h}$ has small systematic uncertainties (double ratio)
- $R_{D/h}$ > 1 evidences the dead cone to some extent (see U.Wiedemann talk)

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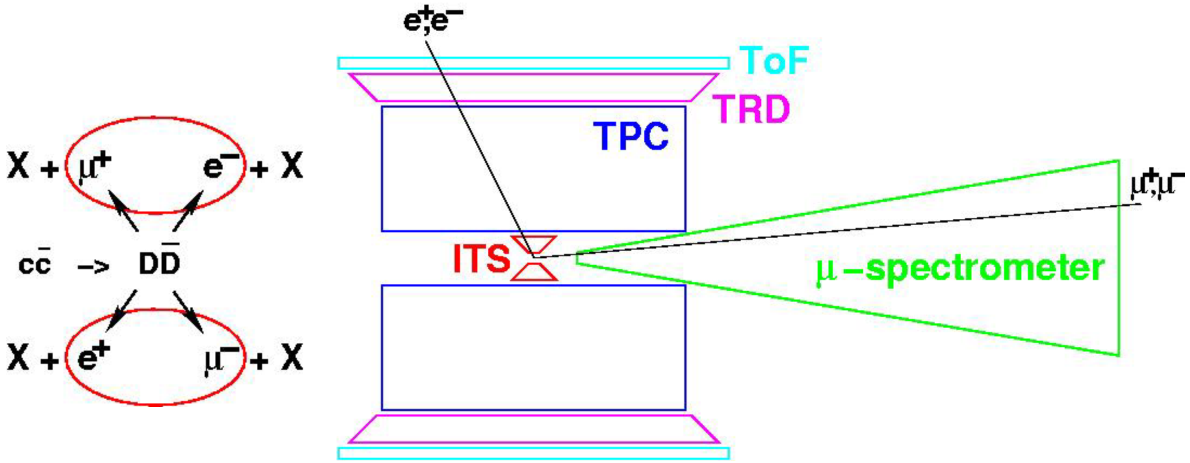
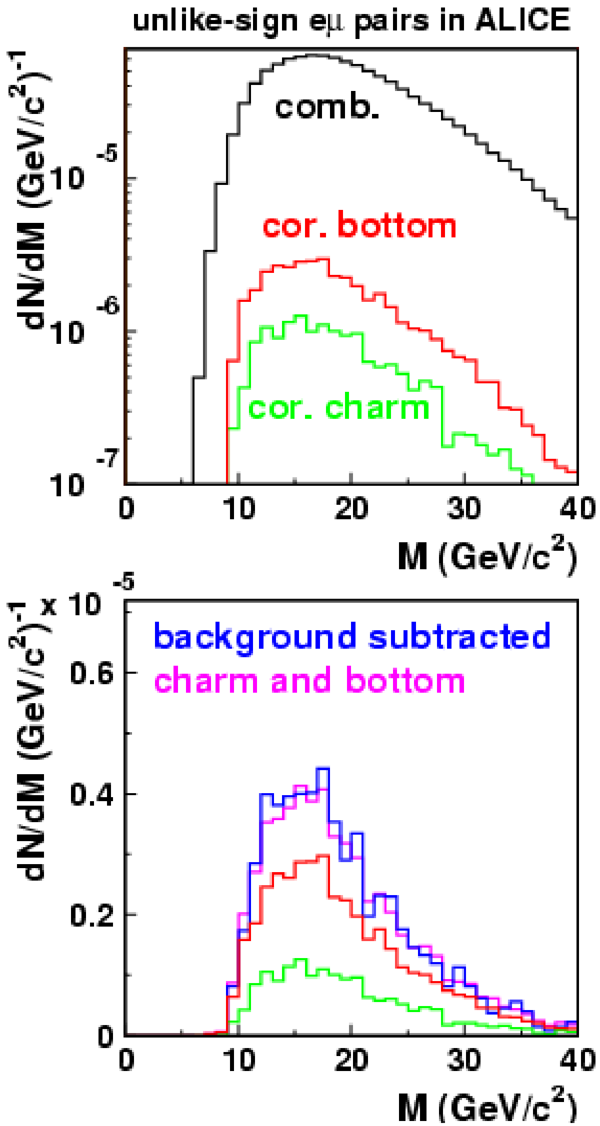
Electron-muon coincidences





- clean signal
- covers intermediate rapidities
- measurement done in pp @ ISR (1979!)
- chalenging in heavy ion collisions

ALICE-INT-2000-01

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Summary

heavy quarks will be copiously produced in HIC @ LHC

this will provide a very rich physics program with new observables & new types of analyses

first data in summer 2007

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