



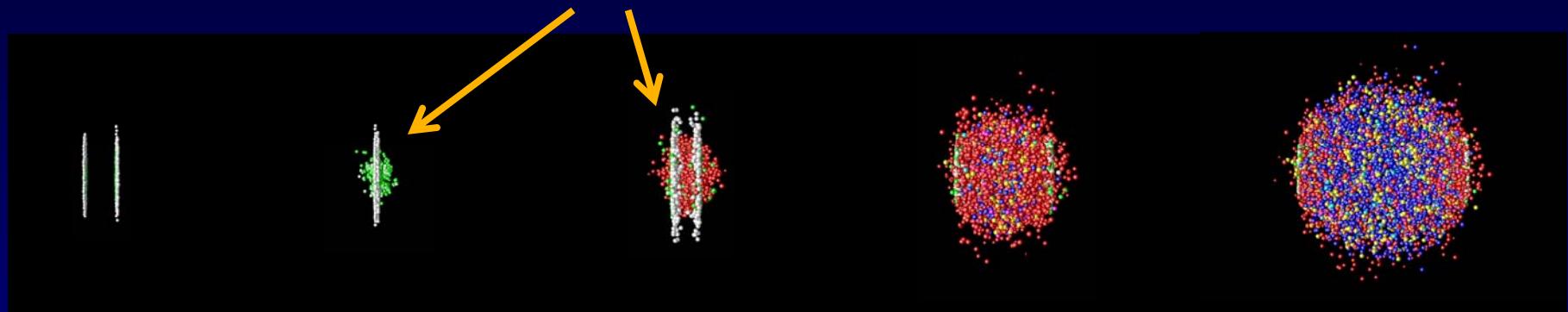
# *Heavy flavours in ALICE*

- Motivations @ LHC energies
- ALICE capabilities
- Selected physics channels

# *Heavy ion collisions at LHC*



The main goal of the ALICE experiment is to study the hot and dense medium (QGP?) formed in heavy ion collisions



Big step in energy:  $\sqrt{s}$  : (SPS  $\times$  13 = RHIC)  $\times$  28 = LHC

Central Collisions	SPS	RHIC	LHC
$s^{1/2}(\text{GeV})$	17	200	5500
$t_0(\text{fm}/c)$	$\sim 1$	$\sim 0.5$	<0.2
initial T (MeV)	200	300	600
$t_{\text{QGP}}(\text{fm}/c)$	<1	1.5-4.0	4-10

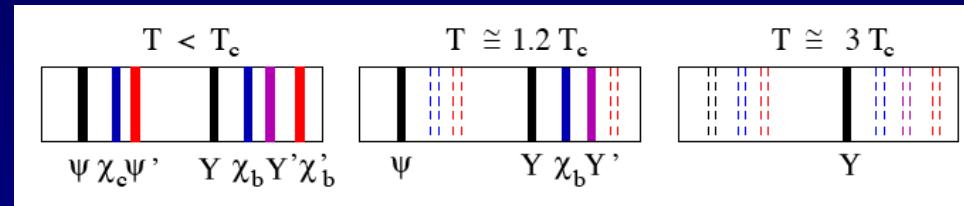
# Heavy flavours in heavy ion collisions



- Produced early in the initial collisions (hard probes)
- Experience initial stages of the collision (QGP formation/evolution)
- Weakly affected by final stages of the collision

## Quarkonia ( $J/\Psi$ , $\Upsilon$ ):

- Sequential dissociation versus T in QGP (Matsui/Satz)

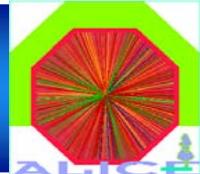


→ Can be used as thermometer of the medium

## Open heavy flavours:

- Reference for quarkonia production/suppression
  - In-medium effect (energy loss, flow, ...) compared to light hadrons
- Additional constraints on medium properties and jet quenching models

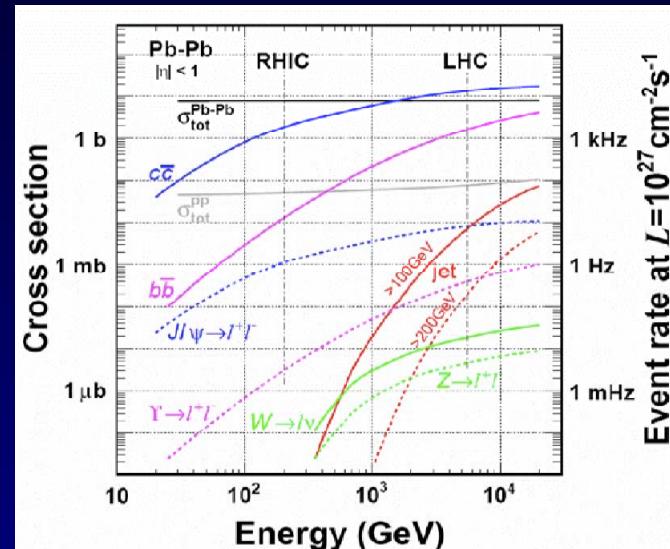
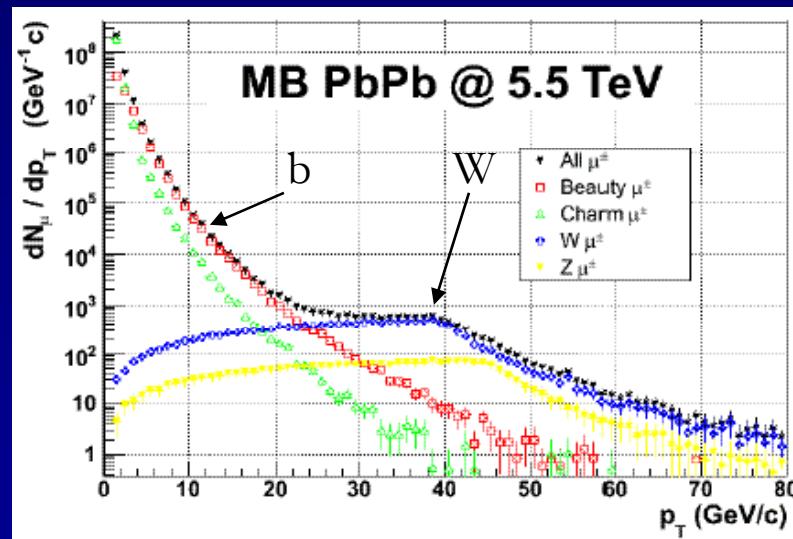
# *Heavy flavours at LHC energies*



NPB373 (1992) 295

## Big step in energy:

- Abundantly produced at LHC
  - Probe unexplored small-x regions
  - Access to higher  $p_T$



pQCD NLO + EKS98	SPS PbPb Cent	RHIC AuAu Cent	LHC <b>PbPb</b> <b>Cent</b>
cc	0.2	10	<b>115</b>
bb	-	0.05	<b>5</b>

# Physics potential of heavy flavours



p-p	p-A	A-A
<ul style="list-style-type: none"> <li>test of pQCD, PDF and fragmentation functions at small-<math>x</math> and in large <math>p_T</math> scale</li> <li>parton saturation (CGC)</li> <li>quarkonia production mechanisms</li> </ul> <p>→ reference for “cold” and “hot” nuclear matter effects</p>	<ul style="list-style-type: none"> <li>CGC / Shadowing</li> <li>multi-partonic interactions</li> <li><math>k_T</math> broadening</li> <li>quarkonia “normal” nuclear absorption</li> </ul> <p>→ reference for “hot” nuclear matter effects</p>	<ul style="list-style-type: none"> <li>test energy loss mechanisms (at high <math>p_T</math>), color / mass dependences</li> <li>thermalisation (at low <math>p_T</math>)</li> <li>thermal enhancement</li> <li>in medium hadronisation: coalescence / fragmentation</li> <li>quarkonia dissociation / regeneration mechanisms</li> <li><math>B \rightarrow J/\Psi + X</math></li> </ul> <p>→ medium characteristics (density, viscosity, temperature, ...)</p>

→ ALICE will provide measurements for all of these items and more...

# Heavy flavours in ALICE

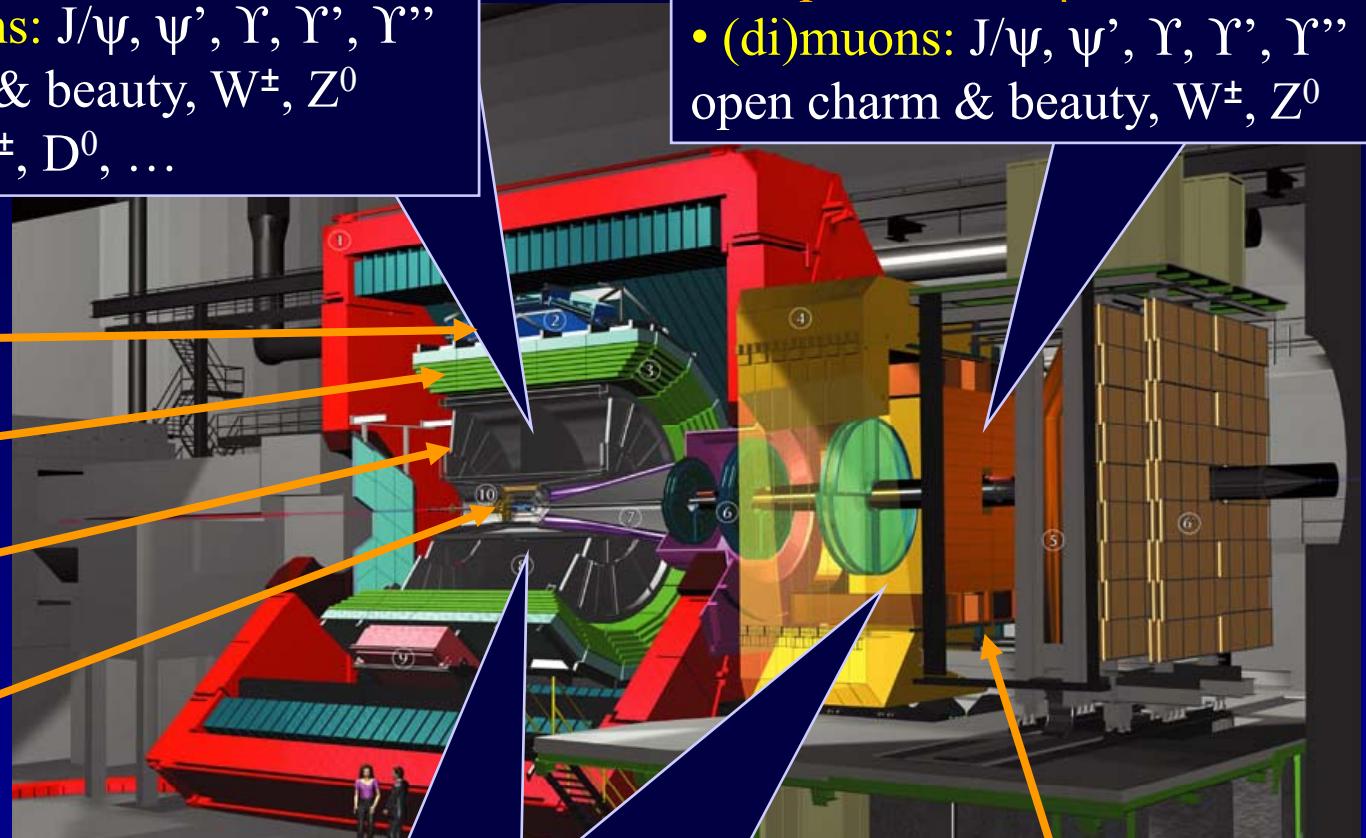


Acceptance:  $\eta < |0.9|$

- (di)electrons:  $J/\psi$ ,  $\psi'$ ,  $\Upsilon$ ,  $\Upsilon'$ ,  $\Upsilon''$   
open charm & beauty,  $W^\pm$ ,  $Z^0$
- hadrons:  $D^\pm$ ,  $D^0$ , ...

Acceptance:  $-4 < \eta < -2.5$

- (di)muons:  $J/\psi$ ,  $\psi'$ ,  $\Upsilon$ ,  $\Upsilon'$ ,  $\Upsilon''$   
open charm & beauty,  $W^\pm$ ,  $Z^0$



precise vertexing  
and particle  
identification

- electron-muon coincidences:  
open charm & beauty

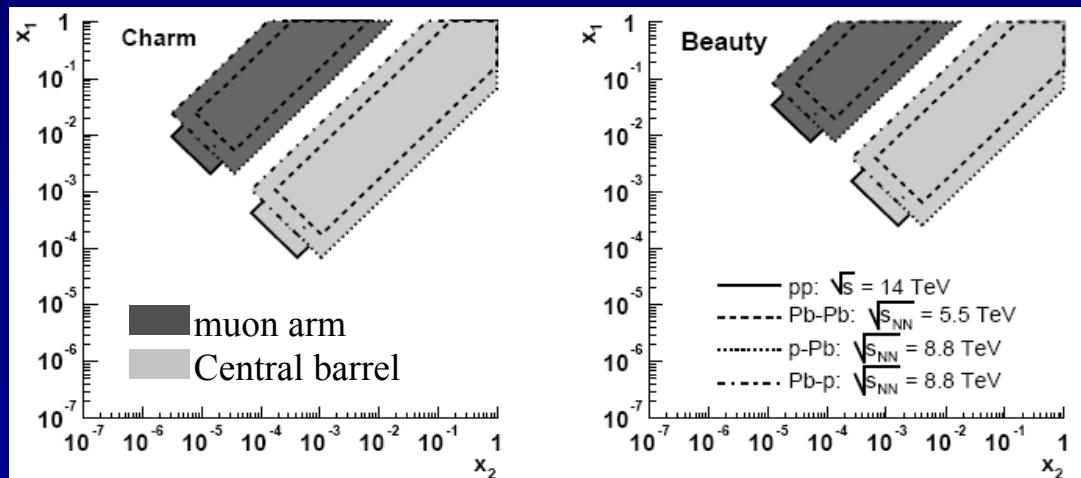
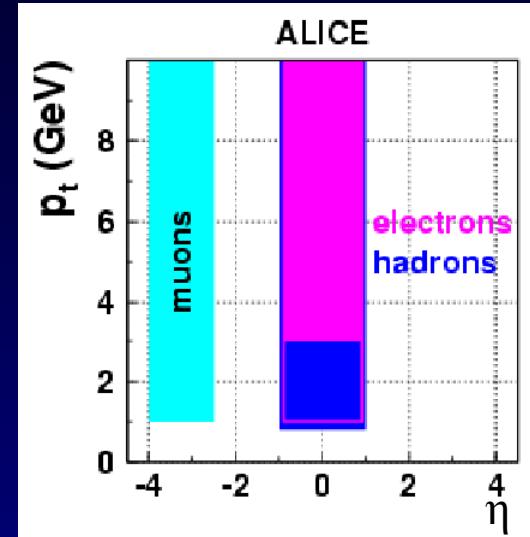
MUON Spectrometer

# Heavy flavours in ALICE



Access to low-pT region ( $< 1 \text{ GeV}/c$ ):

- At both central and forward rapidity
- In all of the 3 channels



Access to small- $x$  values:

- $\sim 10^{-4}$  in the central barrel
- $\sim 10^{-5}/10^{-6}$  in the muon arm

# *Selected physics channel*

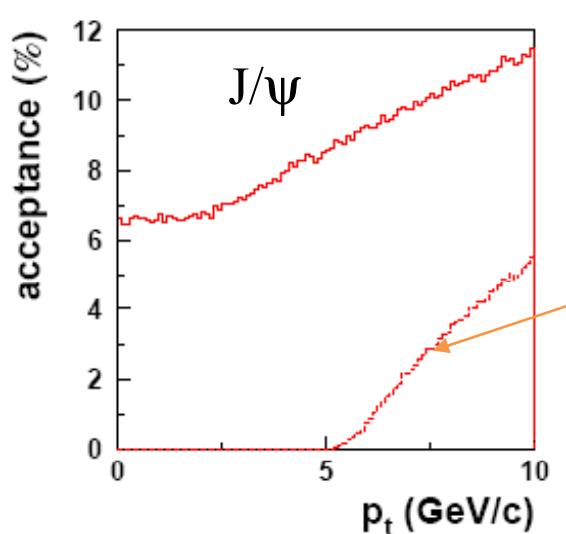


- Quarkonia in dilepton
- Open charm:  $D^0 \rightarrow K \pi$
- Open beauty:  $B \rightarrow e / \mu + X$

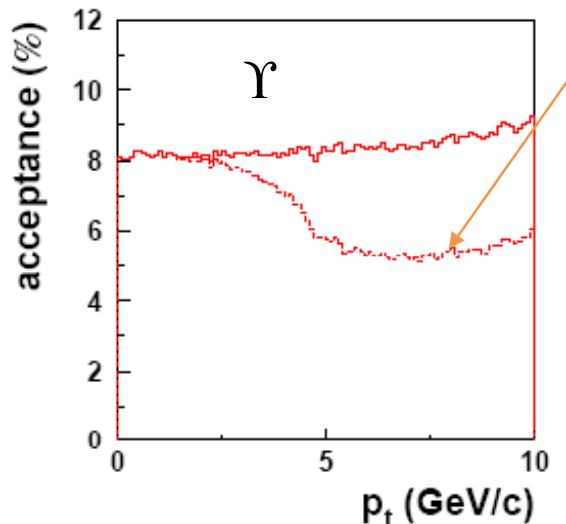
# Quarkonia acceptance



Dielectron channel

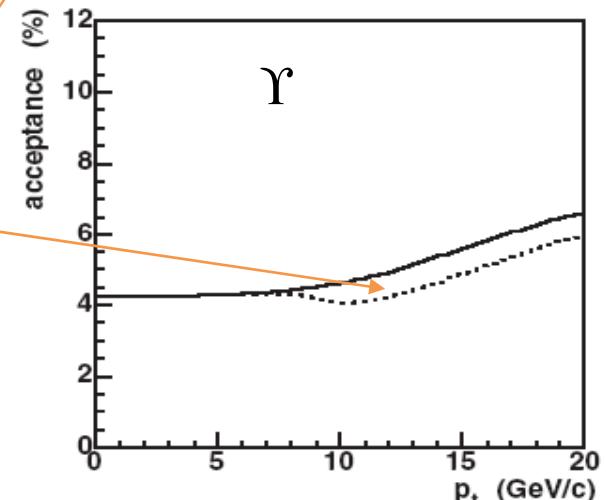
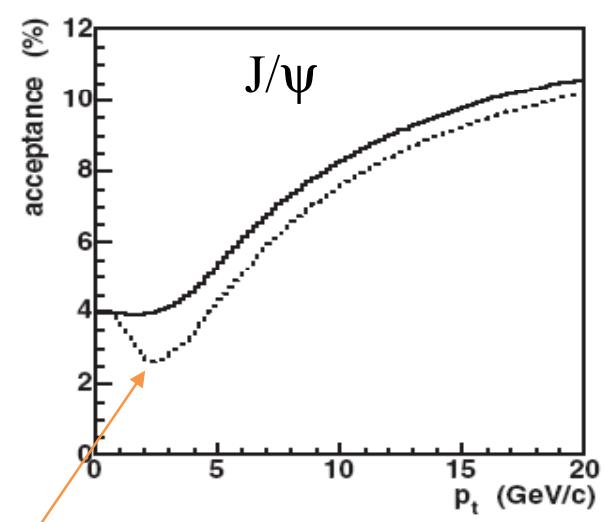


Dielectron trigger:  
 $p_T^e > 3$  GeV/c

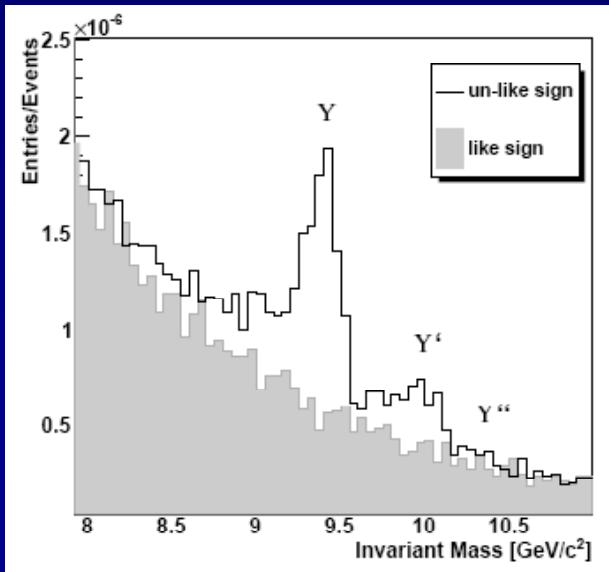
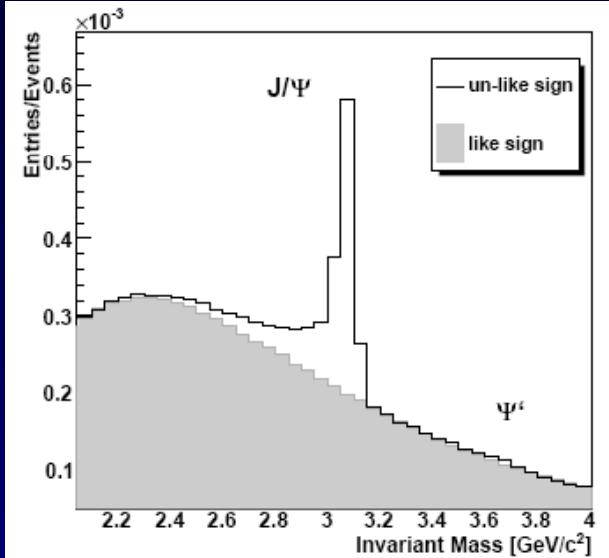


Dimuon trigger:  
 $p_T^\mu > 1$  (2) GeV/c  
for  $J/\psi$  ( $\Upsilon$ )

Dimuon channel



# Quarkonia in dielectron



- 1 month central Pb-Pb (10%)
- Luminosity of  $5 \times 10^{26} \text{ cm}^{-2}\text{s}^{-1}$
- Shadowing +  $p_T^e > 1 \text{ GeV}$

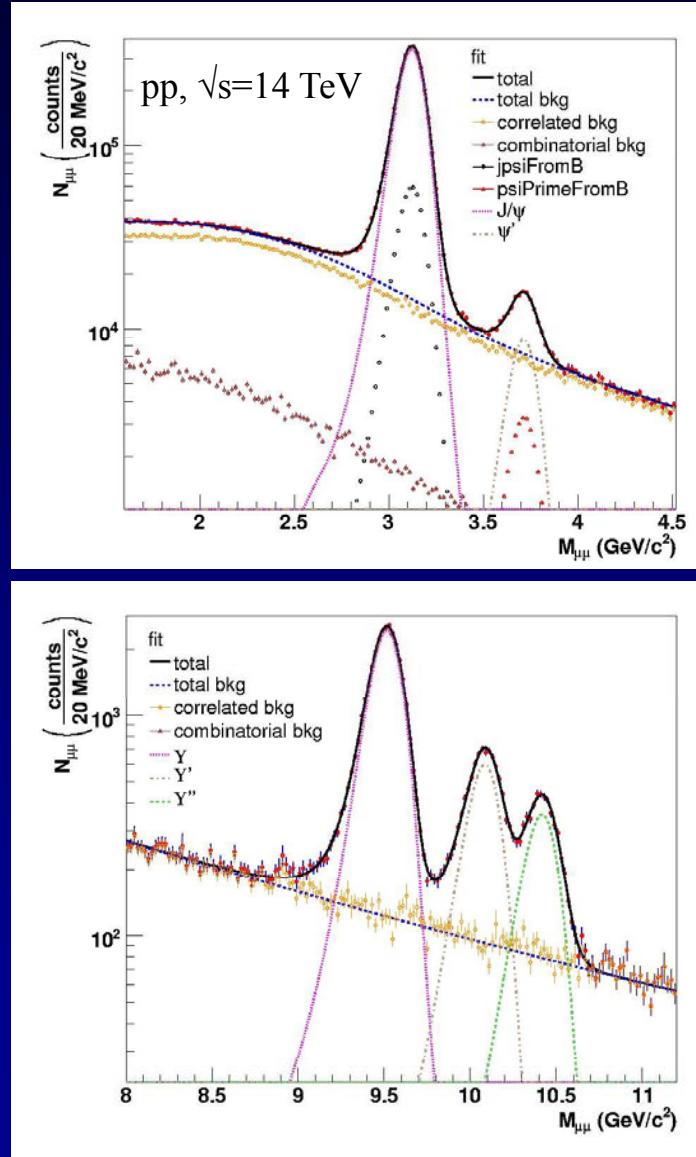
Statistics in the interval  $M \pm 1.5 \sigma$

State	S[10 <sup>3</sup> ]	B[10 <sup>3</sup> ]	S/B	S/(S+B) <sup>1/2</sup>
J/ $\Psi$	120	100	1.2	245
$\Upsilon(1S)$	0.9	0.8	1.1	21
$\Upsilon(2S)$	0.25	0.7	0.35	8

- $J/\Psi$  mass resolution  $\sim 30 \text{ MeV}/c^2$
- $Y$  mass resolution  $\sim 90 \text{ MeV}/c^2$
- No clear signal for  $\Psi'$  and  $\Upsilon(3S)$

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

# Quarkonia in dimuon



- 1 month central Pb-Pb ( $0 < b < 3$  fm)
- Luminosity of  $5 \times 10^{26} \text{ cm}^{-2}\text{s}^{-1}$
- Shadowing +  $P_T^\mu > 1 \text{ GeV}/c$

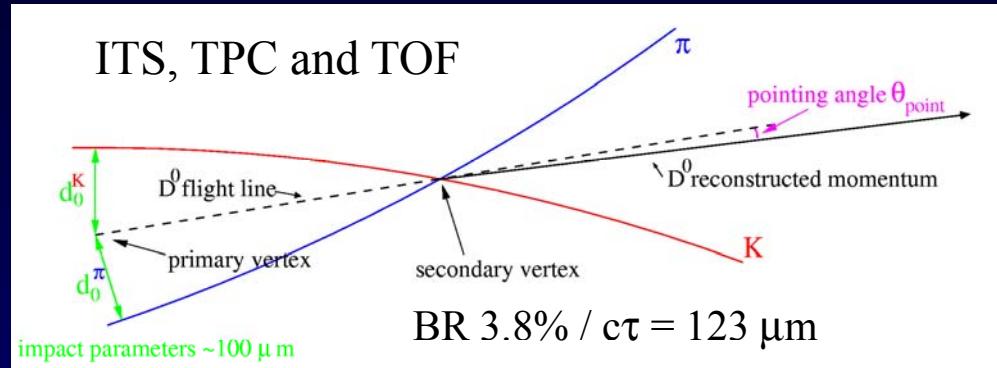
Statistics in the interval  $M \pm 2 \sigma$

State	$S[10^3]$	$B[10^3]$	S/B	$S/(S+B)^{1/2}$
$J/\Psi$	130	680	0.20	<b>150</b>
$\Psi'$	3.7	300	0.01	<b>6.7</b>
$\Upsilon(1S)$	1.3	0.8	1.7	<b>29</b>
$\Upsilon(2S)$	0.35	0.54	0.65	<b>12</b>
$\Upsilon(3S)$	0.20	0.42	0.48	<b>8.1</b>

- $J/\Psi$  mass resolution  $\sim 70 \text{ MeV}/c^2$
- $\Upsilon$  mass resolution  $\sim 100 \text{ MeV}/c^2$
- No clear signal for  $\Psi'$  and  $\Upsilon(3S)$

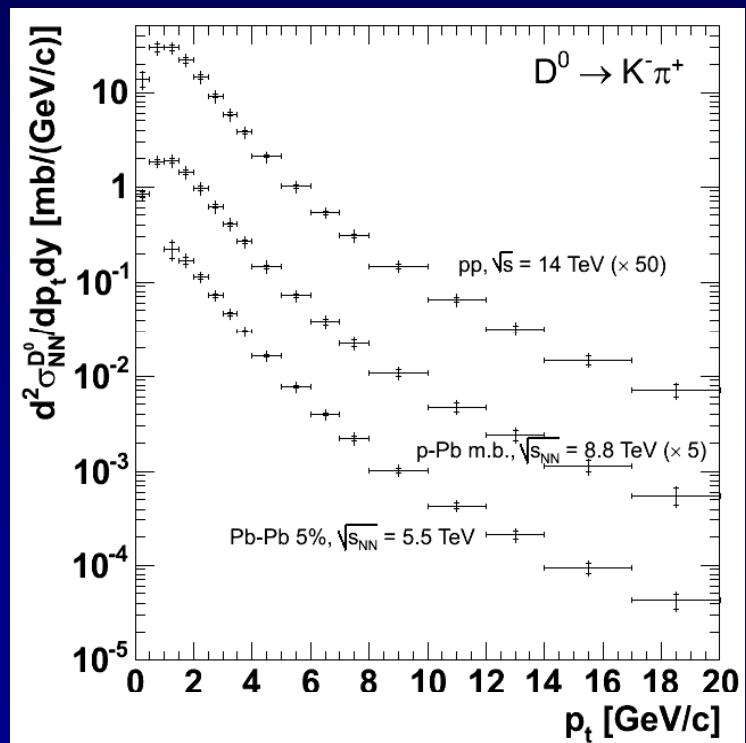
(J. Phys. G 32 (2006) 1295)

# Open charm: $D^0 \rightarrow K \pi$



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

- $\pi$ - $\pi$  pair rejection
- cut on  $d_0^{K,\pi}$ , DCA,  $\theta_{\text{point}}$ , ...
- increase S/B by  $10^5$  in central Pb-Pb (5%)



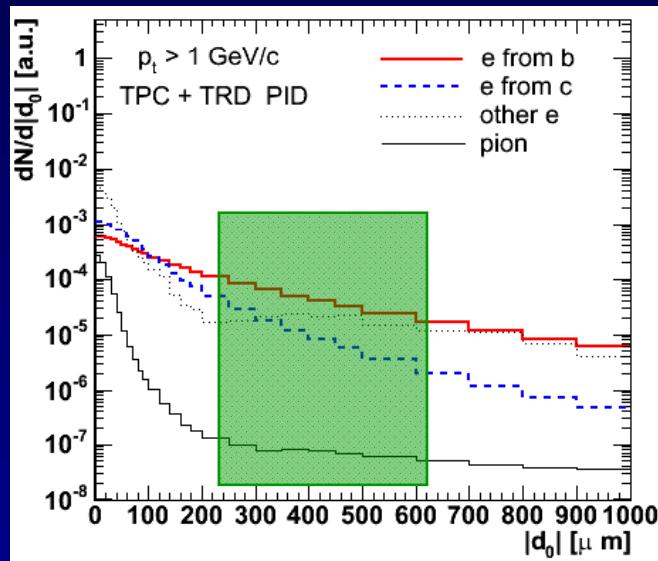
(J. Phys. G 32 (2006) 1295)

# Open beauty: $B \rightarrow e/\mu + X$



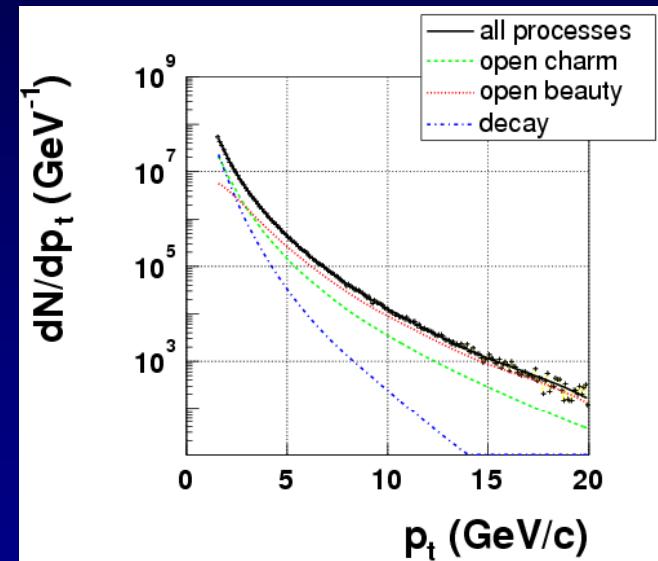
1 month ( $10^6$  s) central Pb-Pb (5%)

- ITS, TPC and TRD (with vertexing)
- $e^-$  identification +  $p_T$  cut ( $> 2$  GeV)
  - impact parameter cut



- $S = 8 \times 10^4$
- $S / \sqrt{S+B} = 80\%$
- subtract residual background  
(Pythia tuned on data +  $D^0 \rightarrow K\pi$ )

- MUON (without vertexing)
- muon  $p_T$  cut ( $> 2$  GeV)



- $S = 4 \times 10^6$
- background under study
- fit c and b contribution

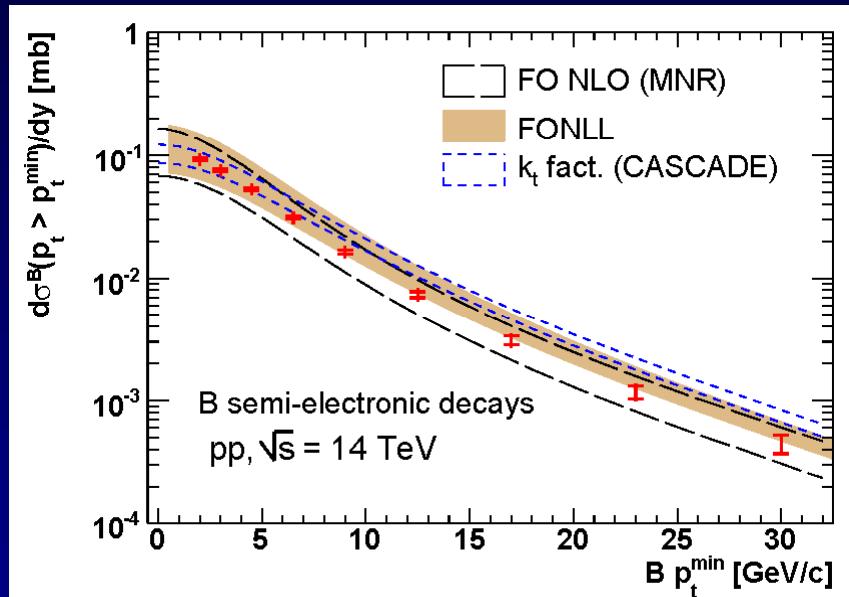
(J. Phys. G 32 (2006) 1295)

# Open beauty: $B \rightarrow e/\mu + X$

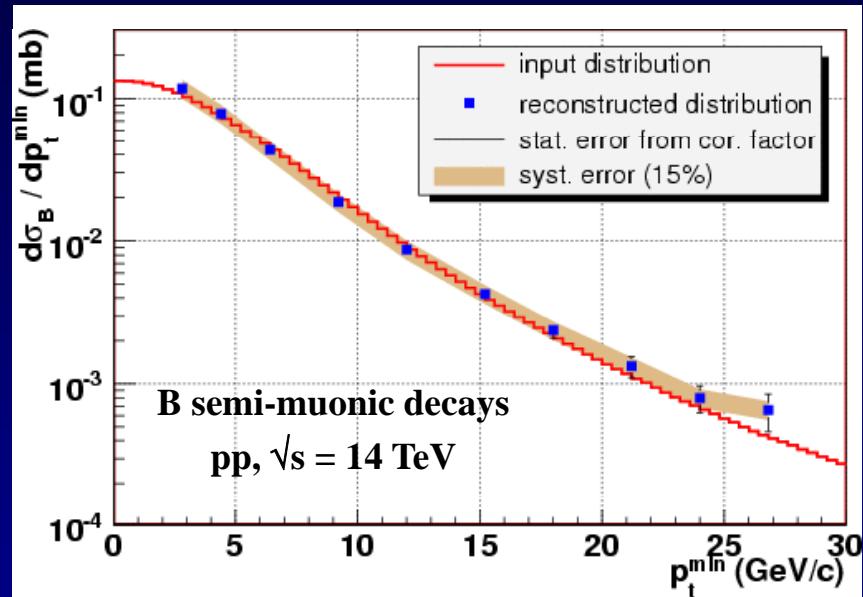


## B inclusive differential cross-section in p-p

Single e (with precise vertexing)



Single  $\mu$  (without vertexing)



- (Very) small statistical error
- Systematics  $\sim 10\%$  (15% at low  $p_T$ )

- (Very) small statistical error
- Systematics  $\sim 15\text{-}20\%$
- D-hadron cross section can be simultaneously extracted

# *Many other channels*



charm:

exclusive hadronic channels

- $D^0 \rightarrow K\pi$  (tested in pp & PbPb)
- $D^+ \rightarrow K\pi\pi$  (tested in pp & PbPb)
- $D_s^\pm \rightarrow KK\pi$  (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)
- $b\bar{b} \rightarrow J/\psi + l$  (under study)
- $b\bar{b} \rightarrow 3\mu$  (should work in pp)
- $b\bar{b} \rightarrow l^+l^-, l^+l^-$  (Bchain & BBdiff)
- $b\bar{b} \rightarrow l^+l^-, l^+l^+$  (Bchain & B osc.)

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

(Ph. Crochet @ ALICE workshop Sibiu 2008)

# Summary



- Heavy flavours are copiously produced at LHC energies and will provide essential information on the properties of the medium formed in heavy ion collisions
- ALICE is very well suited to perform these analyses:
  - exploits both electron, muon and hadronic channels
  - large rapidity coverage
  - access to low  $P_T$  region
  - excellent tracking and vertexing capabilities
  - complementary particle identification (TPC, TRD, TOF))
- Analyses presented here ( $D^0 \rightarrow K\pi$ ,  $B \rightarrow e/\mu + X$ ,  $J/\Psi$ , ...) should be feasible with the first p-p data
- More analysis (not discussed here) are under study (heavy flavours flow, quarkonia polarization,  $e-\mu$  coincidences,  $Z^0$ ,  $W^\pm$ , ...)



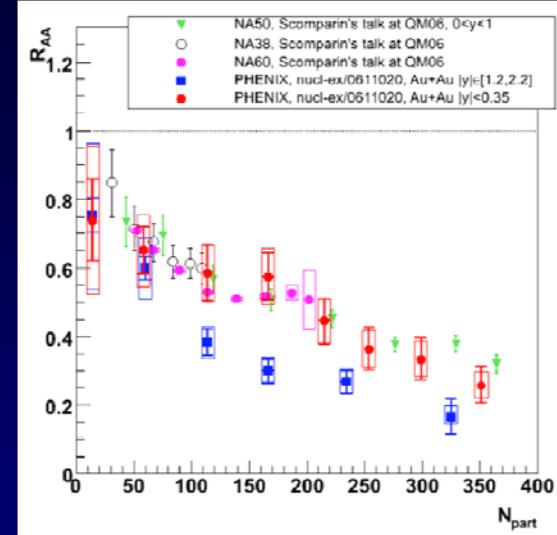
# Backup

# Heavy flavours in heavy ion collisions



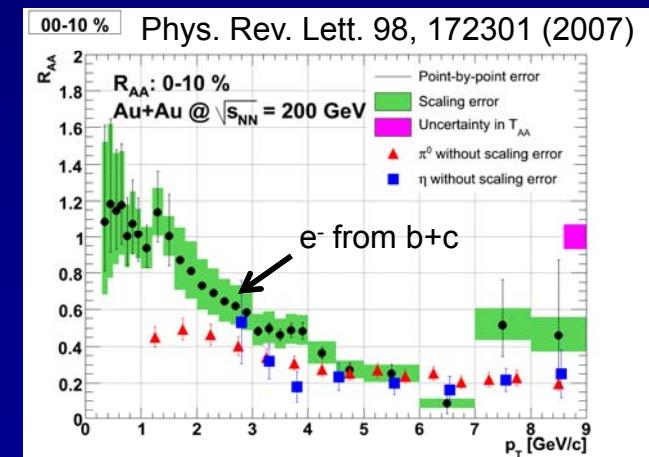
## Quarkonia:

- Abnormal  $J/\Psi$  suppression at SPS  $\rightarrow$  melting of  $\chi_c$ ?
- $J/\Psi$  not fully suppressed at RHIC
- Larger suppression at forward rapidity  
 $\rightarrow$  Regeneration? Which mechanism(s)?
- $\rightarrow$  Need better measurement of cold nuclear effects  
at RHIC (shadowing/CGC, normal absorption)
- $\rightarrow$  What about the Upsilon?



## Open heavy flavours:

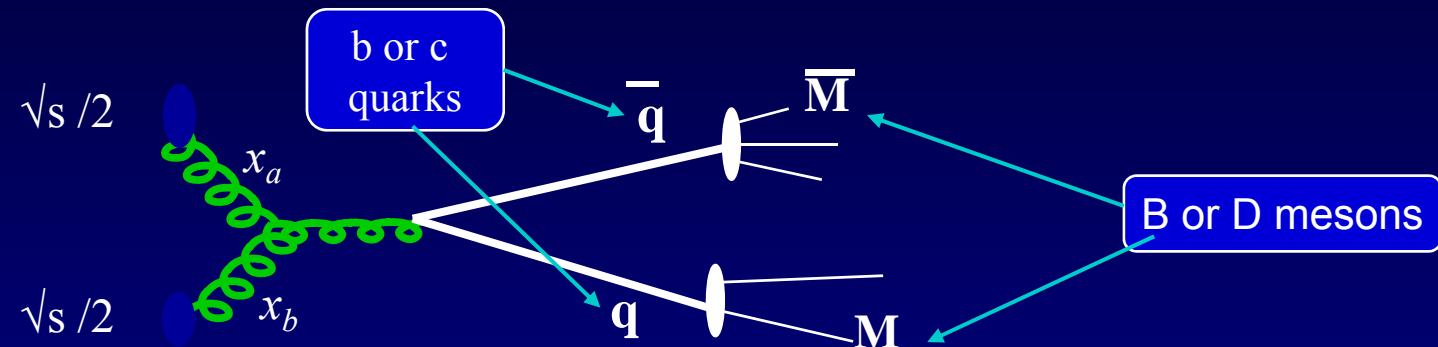
- More Eloss (and thermalisation ( $v_2$ )) than expected
- Difficult to disentangle between models
- $\rightarrow$  Need to clearly separate contribution from b and c
- $\rightarrow$  Need precise measurement of b x-section
- $\rightarrow$  Need more data at higher  $p_T$



# Baseline: $p+p$ collisions



Hard processes ( $q\bar{q}$  annihilation, gluon fusion) occurring at short space-time scale ( $\sim 1/2m_q$ )



Cross section evaluation  $\rightarrow$  factorized pQCD:

$$\frac{d\sigma_{hh \rightarrow Mx}}{dp_T} = PDF(x_a)PDF(x_b) \otimes \frac{d\sigma_{ab \rightarrow q\bar{q}}}{dp_T} \otimes D_{q \rightarrow M}(p_M/p_q)$$

Cross section  
to produce  
hadron  $M$

Parton Distribution  
Functions –  $x_a$  and  
 $x_b$  are parton  
momentum fractions  
in the colliding  
hadrons

Cross section at parton  
level: pQCD. Currently  
NLO used as a baseline  
for ALICE. FONLL  $\rightarrow$   
better description at high  
 $p_T$

Fragmentation  
function (non  
perturbative)

(M. Masera @ Quark Matter 2008)

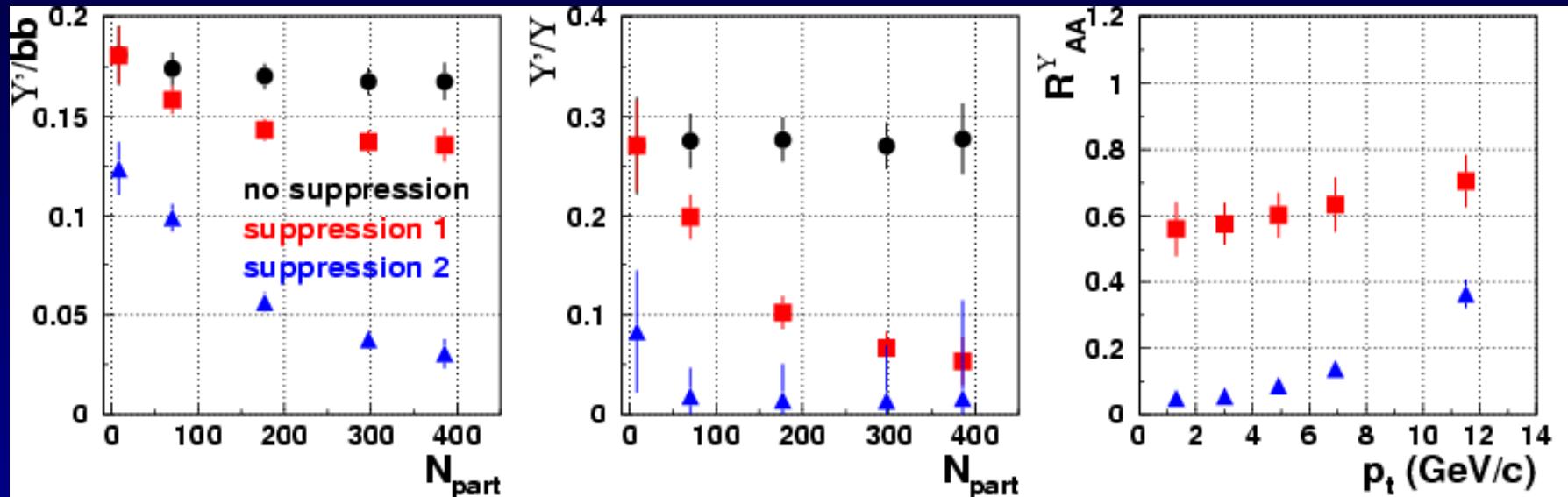
# Examples of bottomonia analyses



no suppression: Shadowing without nuclear absorption

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

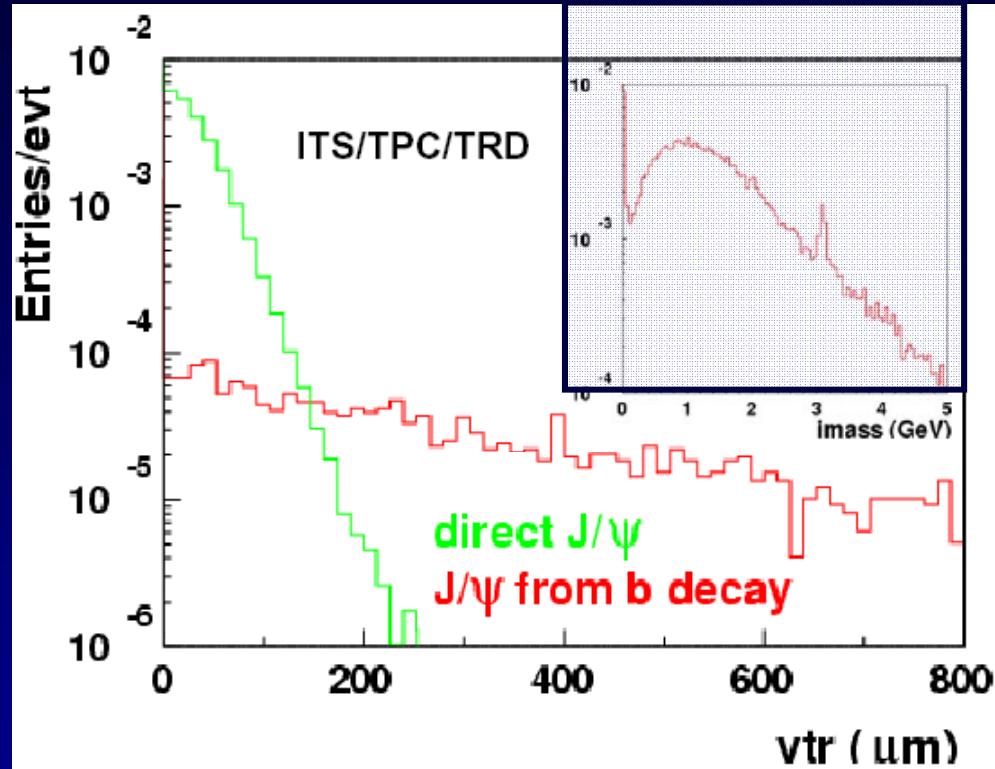
suppression 2:  $T_C = 190$  MeV,  $T_D/T_C = 2.9$  (1.1) for  $\Upsilon(\Upsilon')$



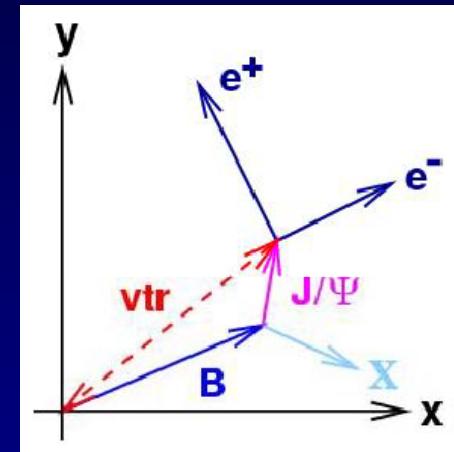
- Statistics for 1 month Pb-Pb collisions
- Perfect subtraction of combinatorial background
- Large sensitivity to in-medium effects

(J. Phys. G 32 (2006) 1295 | Ph. Crochet @ ALICE workshop Sibiu 2008)

# Secondary $J/\Psi$ from $B$



Central Pb-Pb in  $4\langle\langle$  :  
 $N(b \rightarrow J/\Psi) / N(J/\Psi \text{ directs}) \sim 20\%$

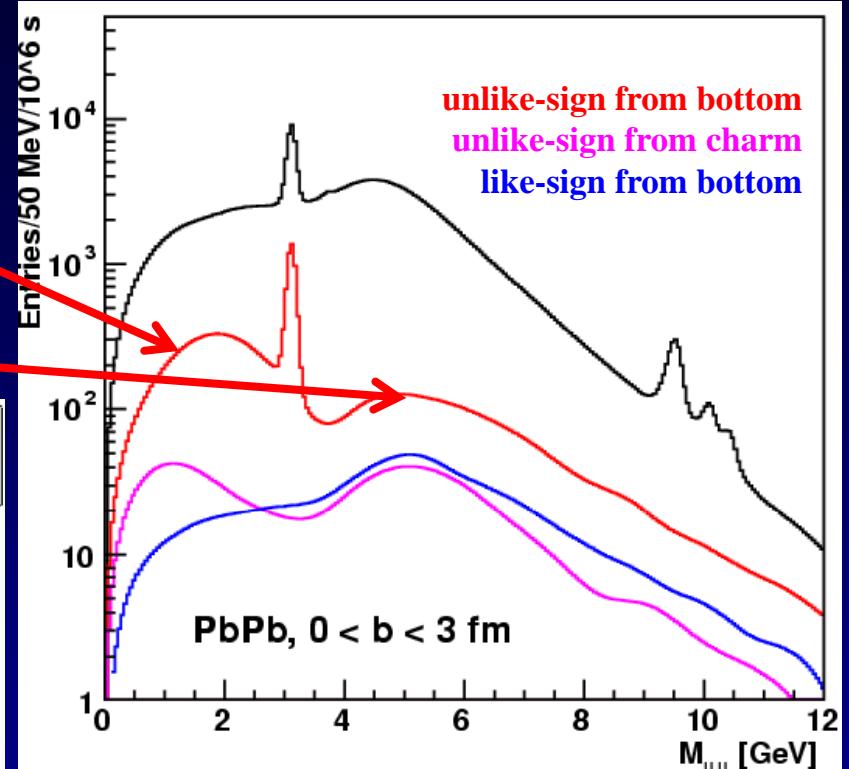
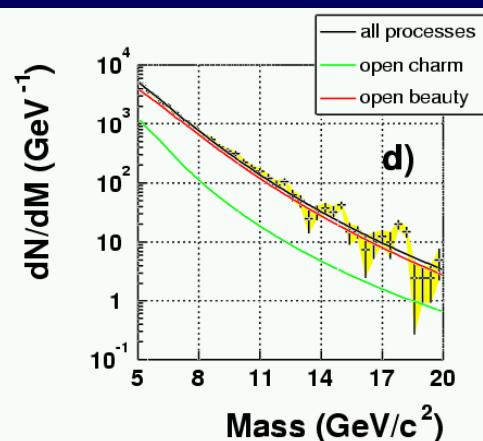
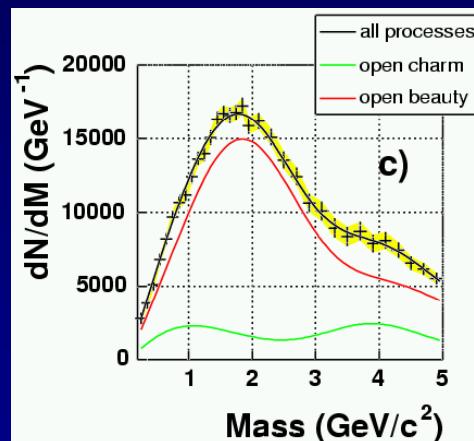
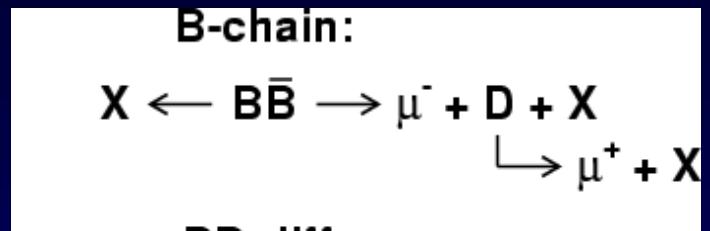


Cut on pseudoproper decay time (à la CDF) under study

- separate primary and secondary  $J/\Psi$
- inclusive measurement of the  $B$  production x-section

(ALICE TRD/TP, CERN/LHCC 99-13)

# *B signal from dimuons w/o vertexing*



central PbPb (5%), one month

Mass (GeV/c <sup>2</sup> )	0-5	5-20
N <sub>μμ</sub> from bb	41461±793	6983±130

- unfold mass continuum
- large statistics is expected
- systematics to be estimated

(J. Phys. G 32 (2006) 1295 | Ph. Crochet @ ALICE workshop Sibiu 2008)

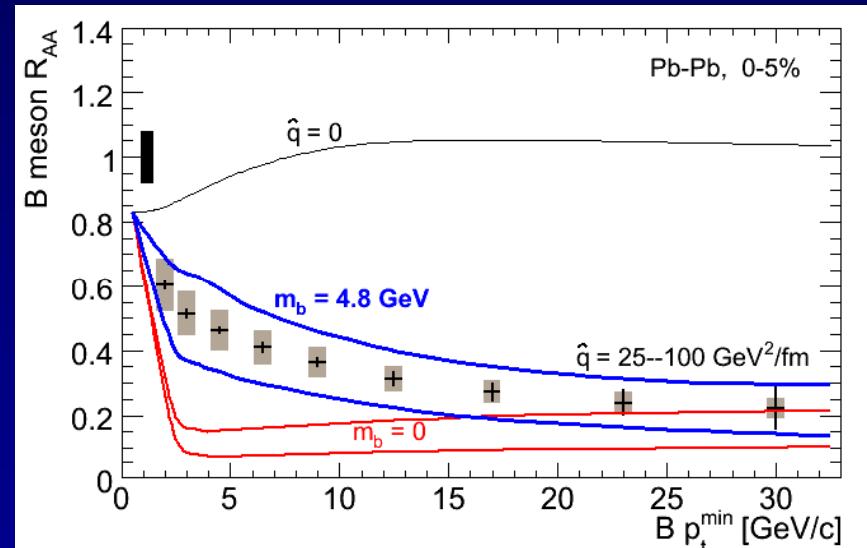
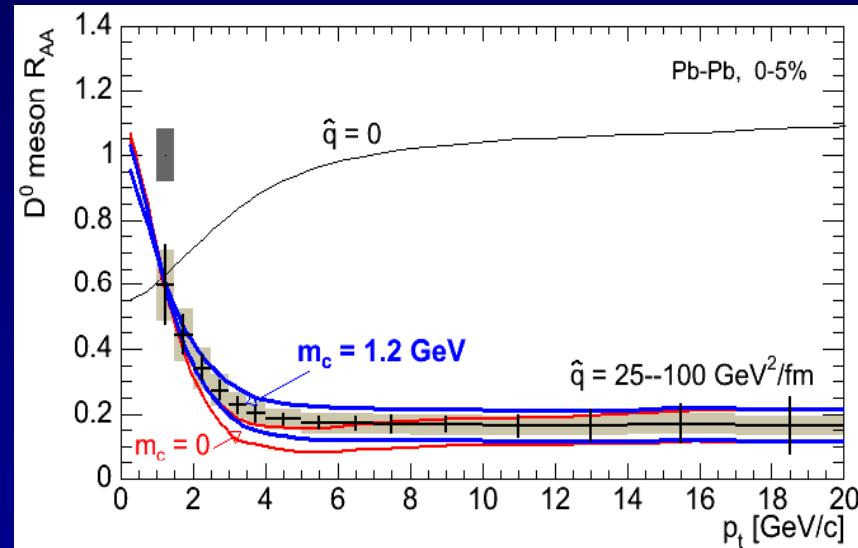
# Heavy quark quenching: traditional ratios



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

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

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



sensitivity to shadowing for  $p_t < \sim 7 \text{ GeV}/c$  & to energy loss for  $p_t > \sim 7 \text{ GeV}/c$

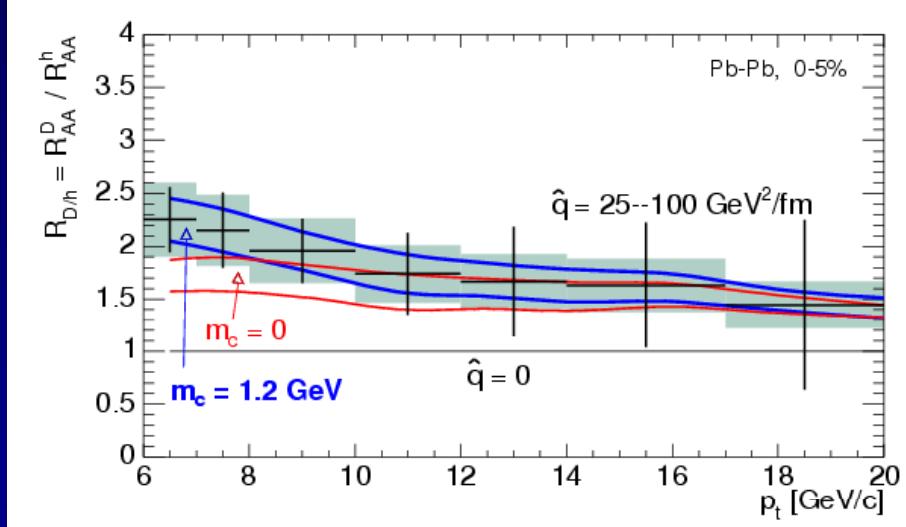
(J. Phys. G 32 (2006) 1295 | Ph. Crochet @ ALICE workshop Sibiu 2008)

# Heavy quark quenching: more ratios

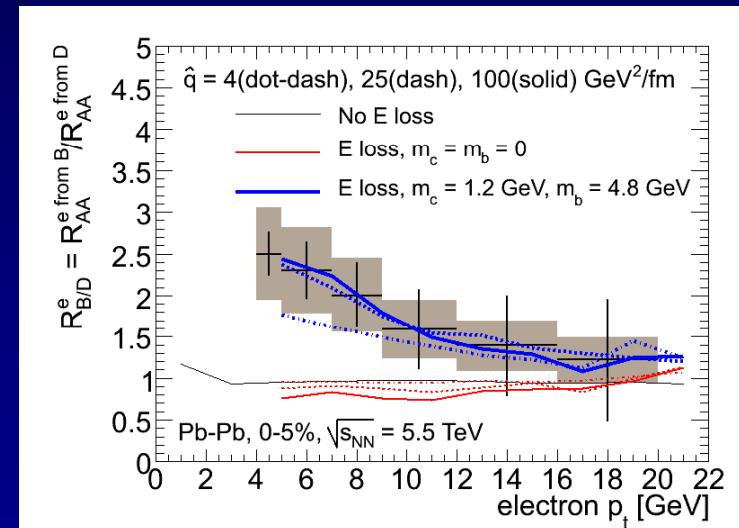


1 nominal year:  $10^7$  central Pb-Pb events,  $10^9$  pp  
 events statistics: bars, systematics: bands

$$R_{D/h} = R_{AA}^D / R_{AA}^h$$



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



sensitivity to color charge  
dependence

sensitivity to mass  
dependence

(J. Phys. G 32 (2006) 1295 | Ph. Crochet @ ALICE workshop Sibiu 2008)