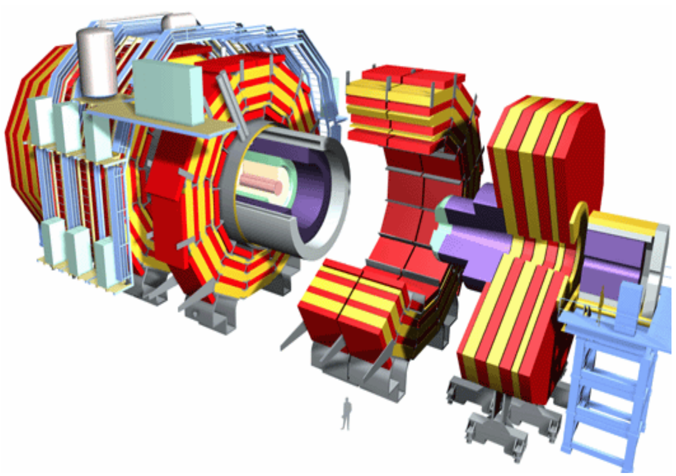
Quarkonia production in heavy-ion collisions with CMS at LHC



Bolek Wysłouch
Massachusetts Institute of Technology
for the CMS Collaboration

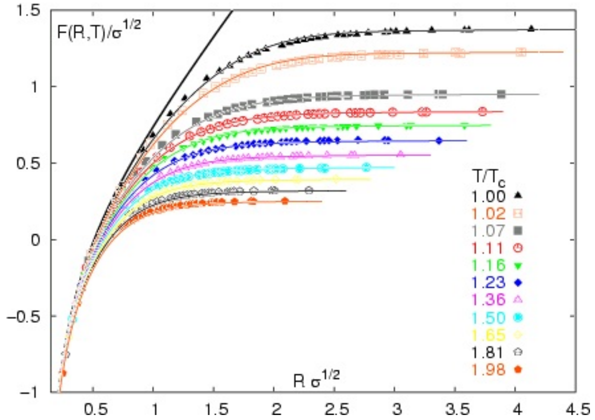
LHC Physics, Kraków 2006

CMS HI groups: Adana, Athens, Basel, Budapest, CERN, Demokritos, Dubna, Ioannina, Kiev, Krakow, Los Alamos, Lyon, MIT, Moscow, Mumbai, N. Zealand, Protvino, PSI, Rice, Sofia, Strasbourg, U Kansas, Tbilisi, UC Davis, UI Chicago, U. Iowa, U. Minnesota, Yerevan, Vanderbilt, Warsaw, Zagreb

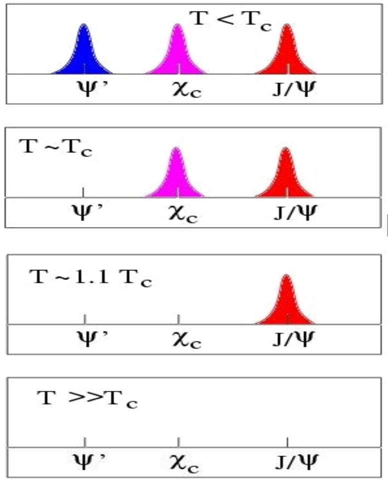
Quarkonia: probe of high-density QCD media

■ Dissociation (color screening) = hot QCD matter thermometer

Lattice $Q\bar{Q}$ free energy vs Radius for different temperatures:

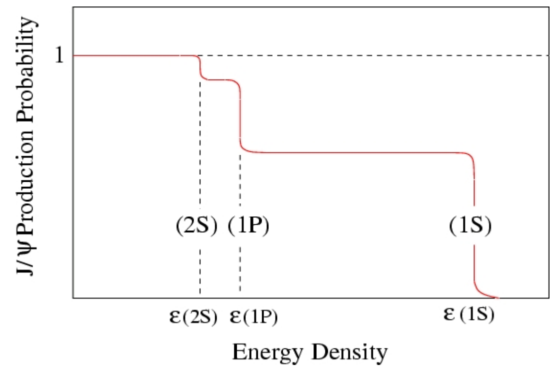


Spectral function vs T:



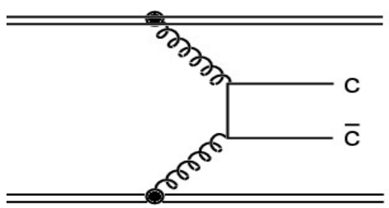
[H.Satz, hep-ph/0512217]

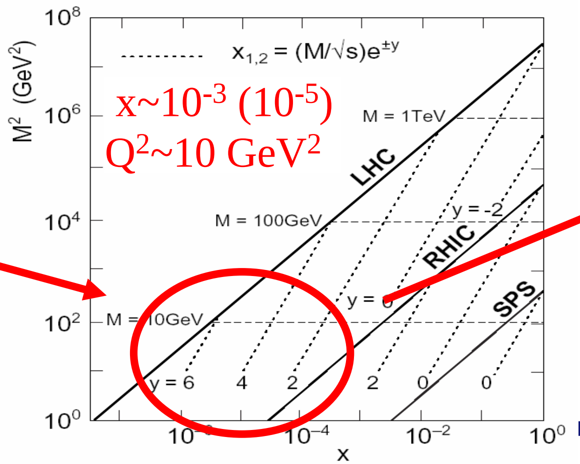
Suppression pattern vs ε :



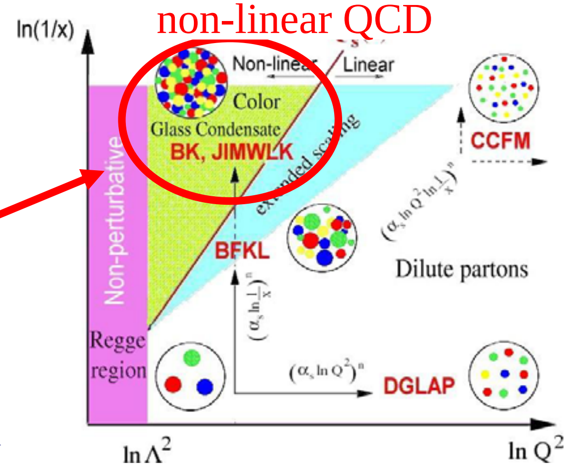
■ Probe of low-x gluon structure/evolution:

production via gg fusion:





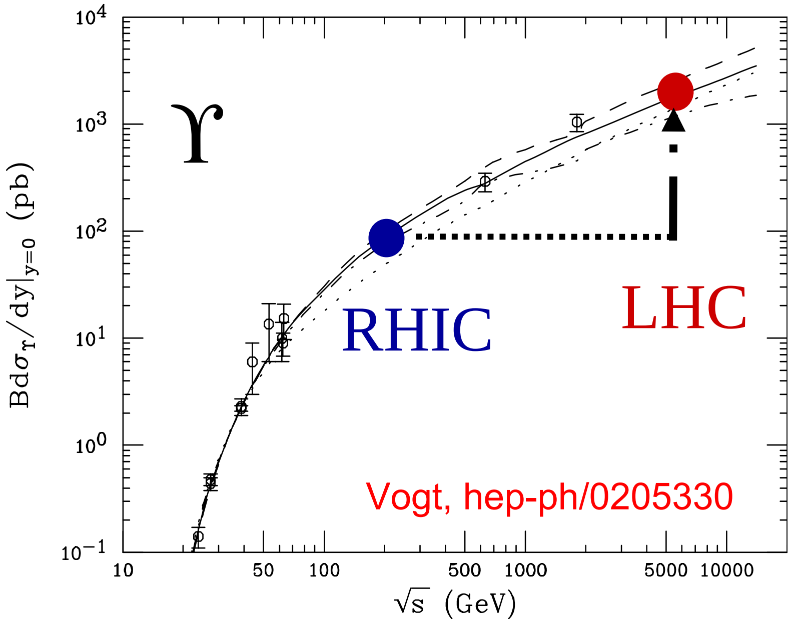
gluon saturation, non-linear QCD



e.g. K.Tuchin

Quarkonia: from SPS and RHIC to LHC

- **PbPb @ $\sqrt{s_{NN}}$=5.5 TeV, pPb @ $\sqrt{s_{NN}}$=8.8 TeV:**
  - **Factor x30-45 increase in energy compared to AuAu,dAu @ RHIC**
  - **30-45 times lower Bjorken $x=2m_T/\sqrt{s}$, ~ 10^{-3} (10^{-5})**
  - **Large perturbative cross-sections.**
  - **High luminosities (high rates).**



Heavy-ion physics at LHC:

- Plasma hotter, longer-lived than @ RHIC

- Access to lower x, higher Q^2

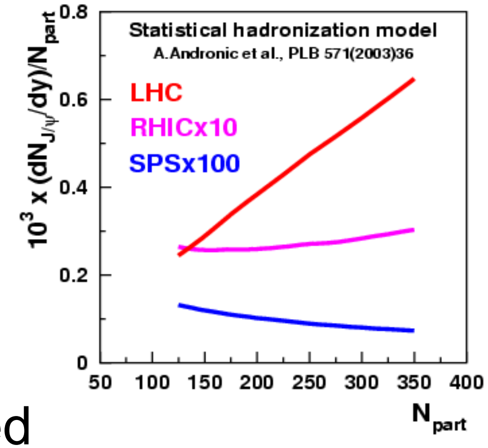
- Unprecedented gluon densities

- Availability of new probes (Y,Y',Y")

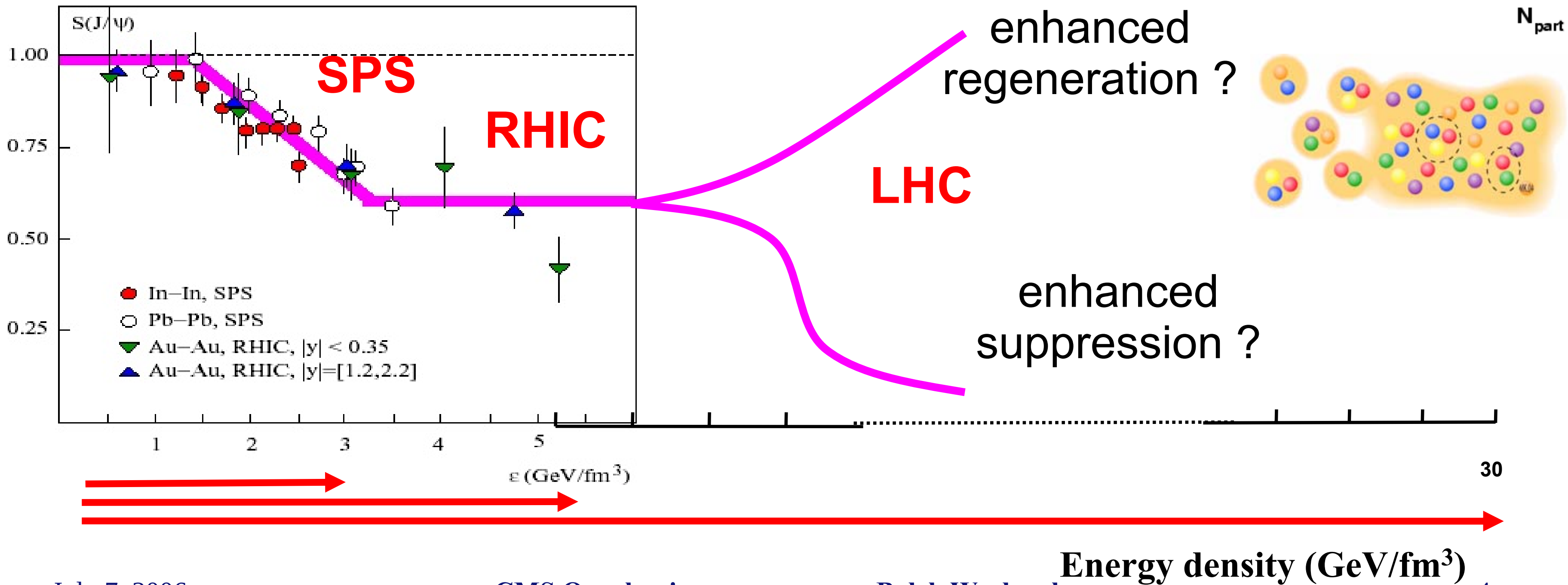
J/ψ production in AA at the LHC

■J/ψ at LHC will clarify SPS/RHIC suppression:

- Onset of direct J/ψ suppression (T_D~1.5 -2.5 T_c) ?
- Large(r) regeneration by ccbar recombination ?



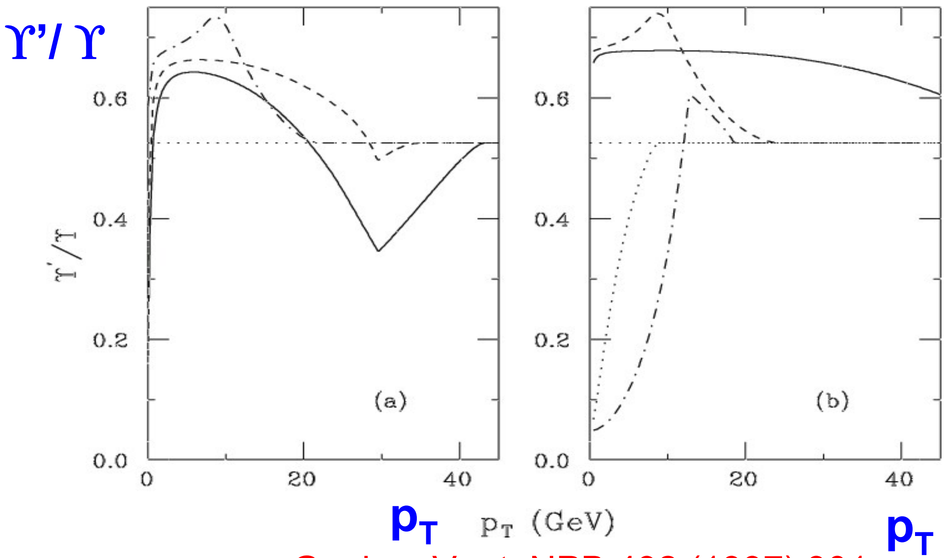
[H.Satz, hep-ph/512217]



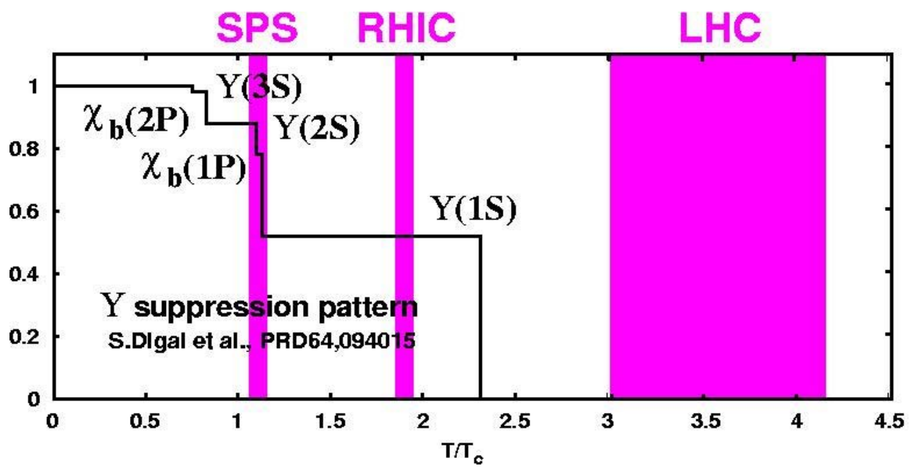
Υ production in AA at the LHC

- Large cross-sections: $d\sigma/dy$ ~ 20 x RHIC
- Υ melts only at LHC: TD~ 4 Tc
- Υ unaffected by final-state interactions:
  - Small hadronic absorption
  - Small # bbar pairs $\rightarrow$ small Υ regeneration

  } "Cleaner" probe than J/ψ
- Υ spectroscopy:
- T_D (Υ') ~ T_D (J/ψ): Υ'/Υ vs p_T very sensitive to system temperature & size



Gunion, Vogt, NPB 492 (1997) 301

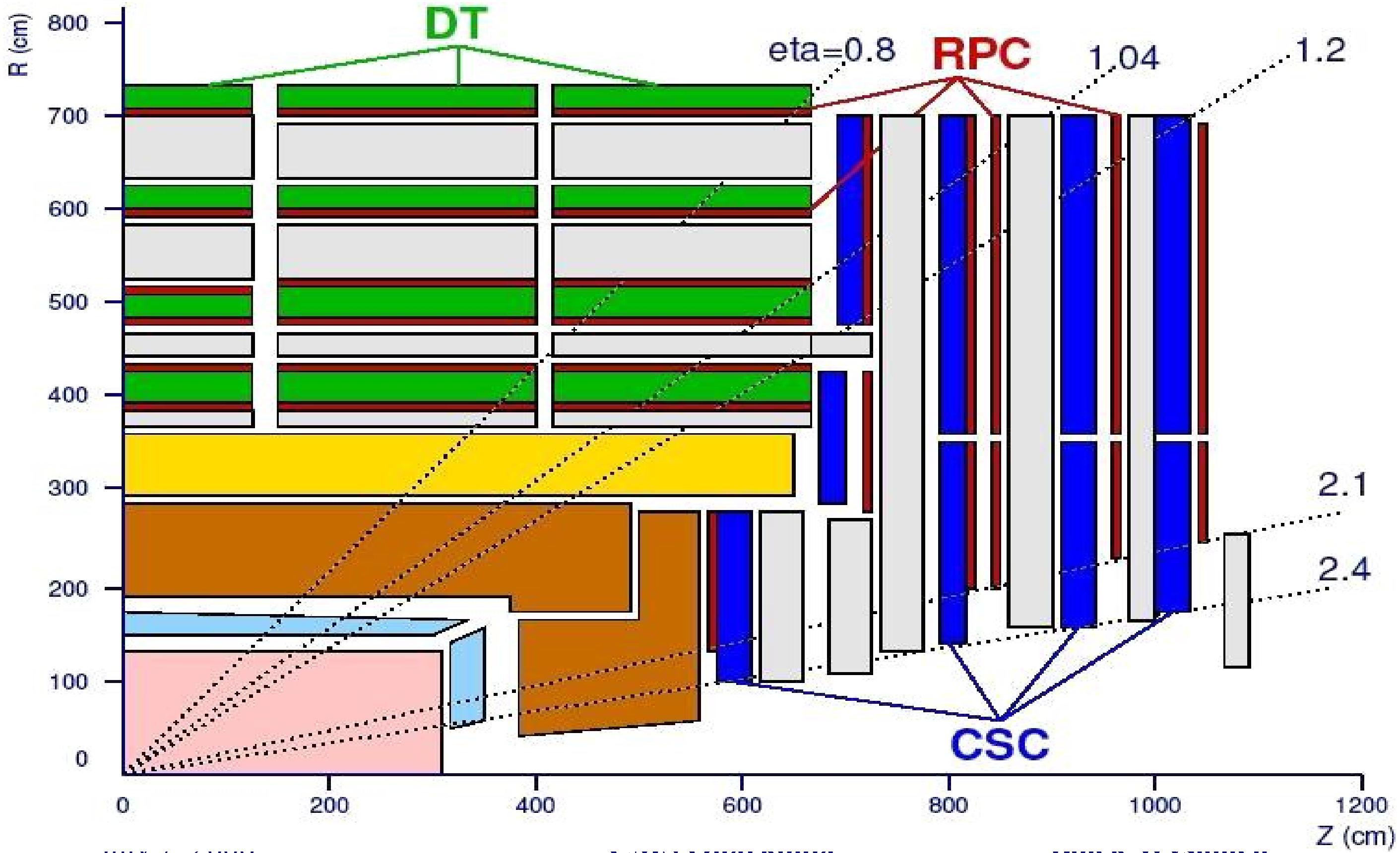


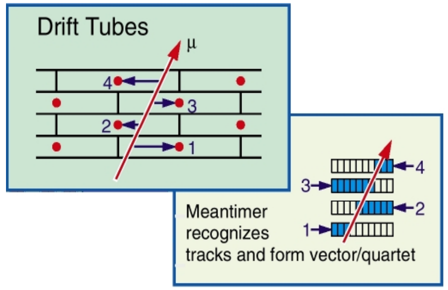
CMS Muon system

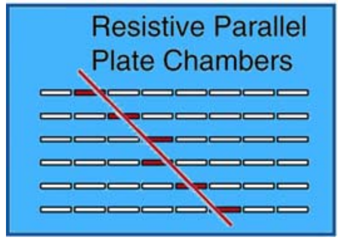
- **3 types of gaseous particle detectors for muon identification:**
  - **Drift Tubes (DT) in central barrel region**
  - **Cathode Strip Chambers (CSC) in endcap region**
  - **Resistive Plate Chambers (RPC) in barrel & endcaps**

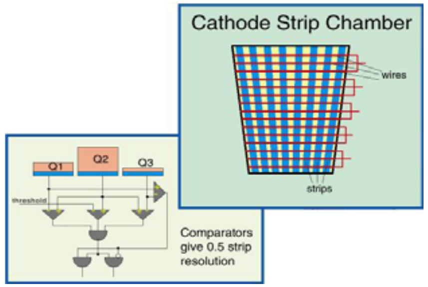
DT and CSC → precise measurement of muon position (momentum)

RPC → fast info for LVL-1 trigger





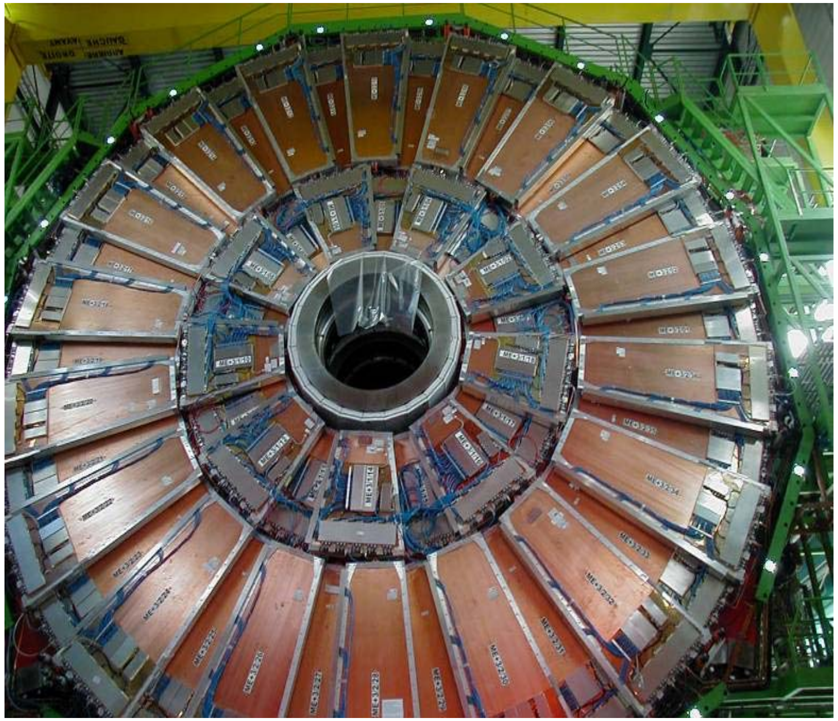




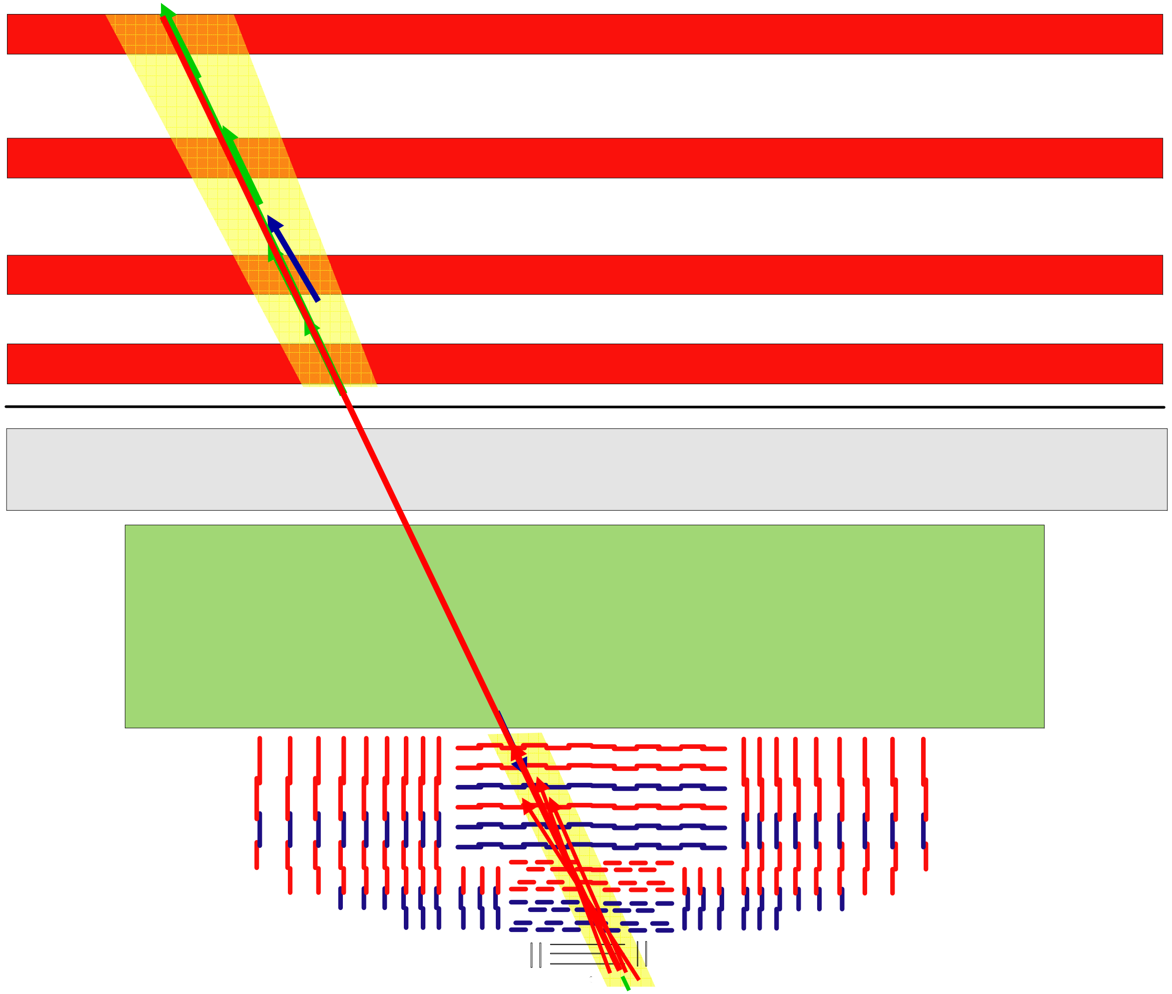
CMS Muon system

- Drift Tubes (DT) in central barrel
- Resistive Plate Chambers (RPC) in barrel and endcaps

- Cathode Strip Chambers (CSC) in endcap region



Muon reconstruction

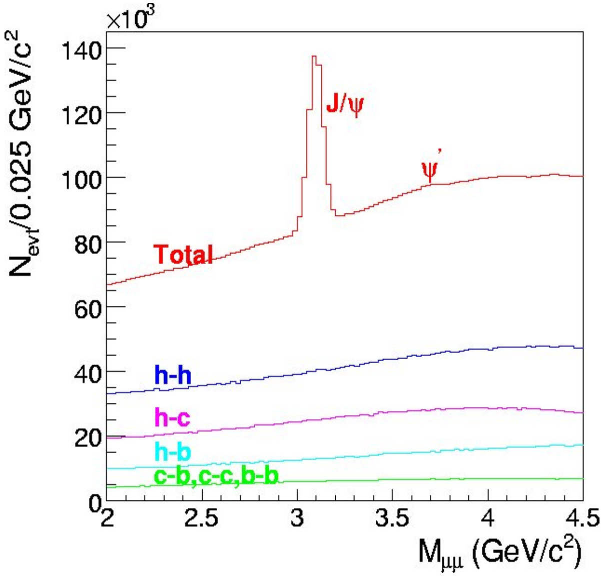


- Best muon spectrometer at LHC (CMS)
- Excellent coverage: ~5 units of rapidity and 2π
- Strongest magnetic field: 4 T, 2 T (return yoke)
- Tag from mu-chambers, momentum resolution from Silicon tracker
- Ecal + Hcal + Magnet Iron absorbs hadrons
  - Barrel: $p_T^{\mu} > 3.5$ GeV/c
  - Endcap: $p_L^{\mu} > 4.0$ GeV/c
- **Trigger at Level-1 and High Level Trigger**

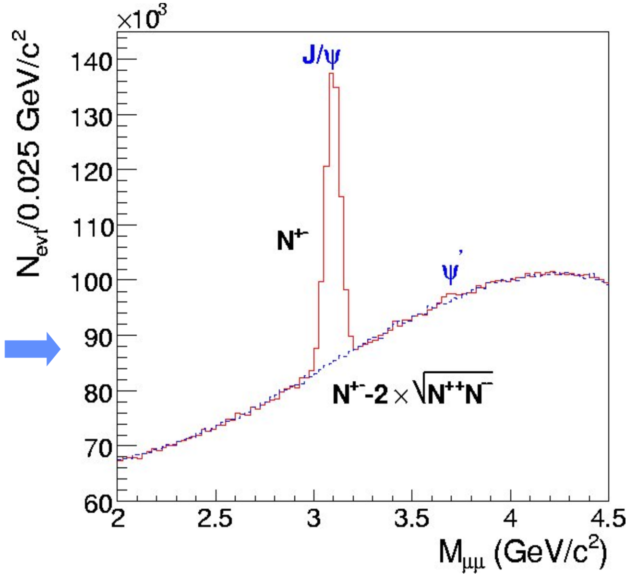
Simulation studies

Olga Kodolova, Marc Bedjidian CMS Note-2006/089

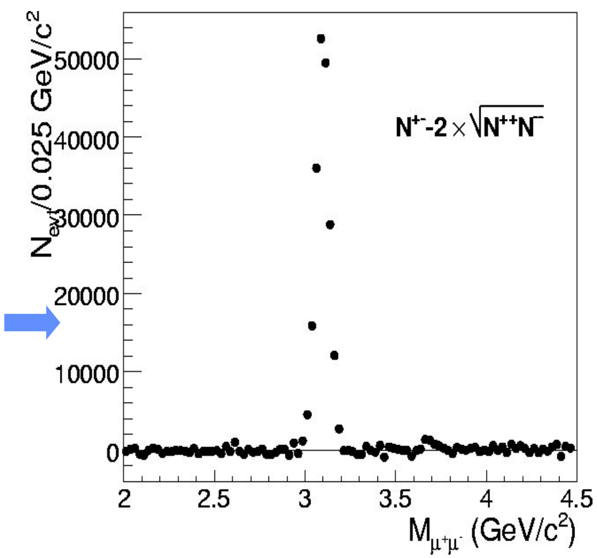
- **Signals (J/ψ,ϒ): CEM, NLO-pp, CTEQ5M+EKS98 PDF, T_{AA}-scaled**
- **Light-q background (π,K): HIJING normalized to $dN_{ch}/d\eta$=2500, 5000**
- **Heavy-Q background (c,b): NLO-pp, CTEQ5M+EKS98 PDF, TAA-scaled**



Signal+Background



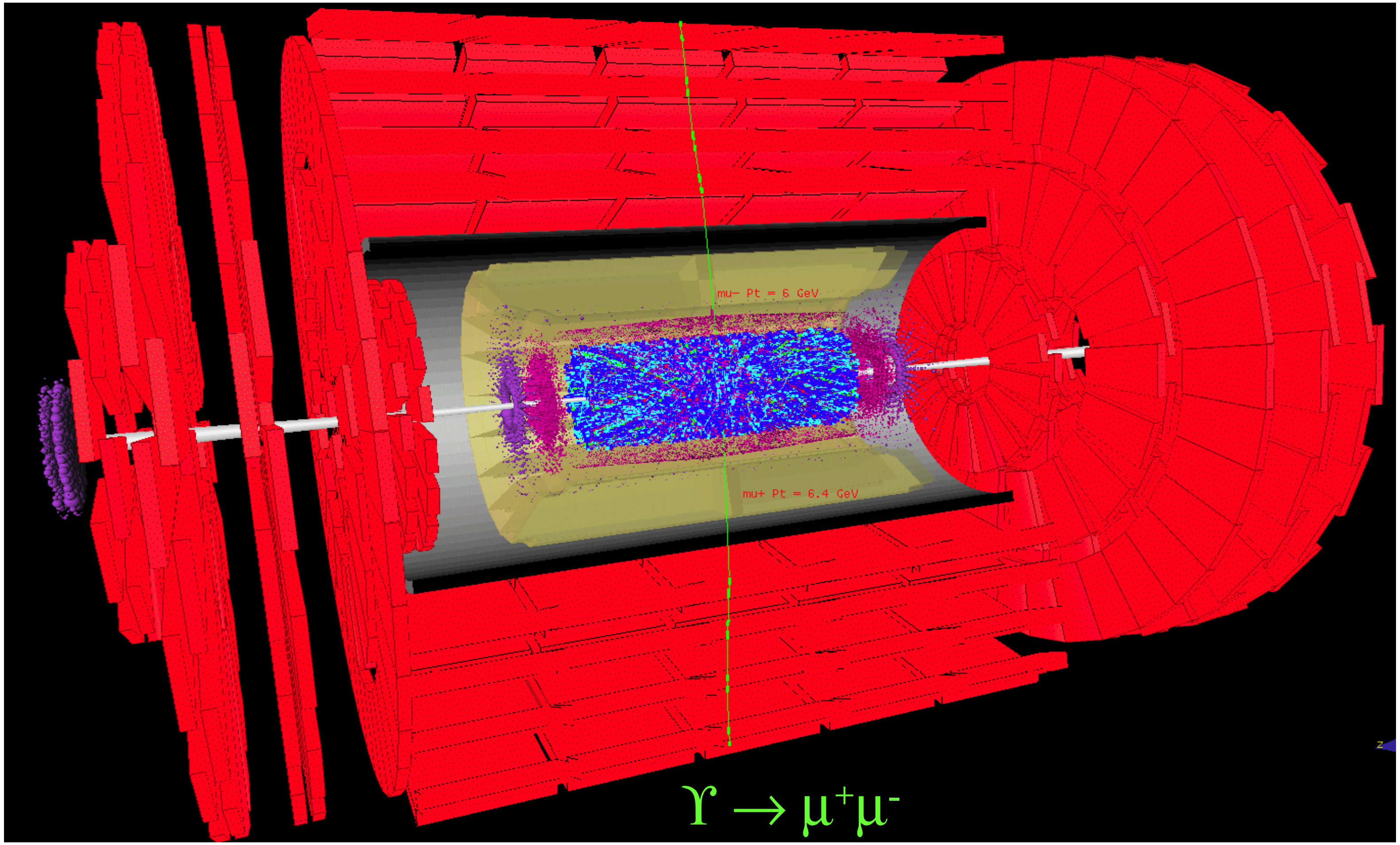
Estimate background using same sign di-muons



Subtracted background

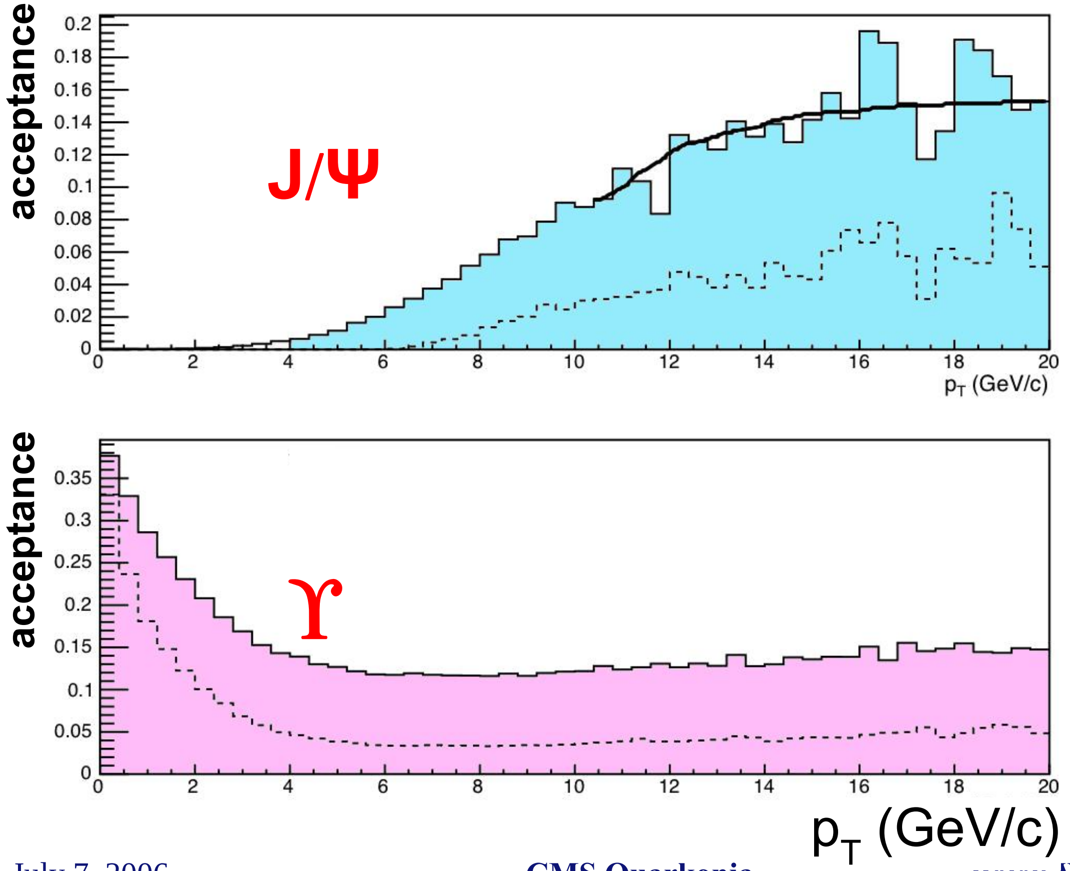
PbPb $\rightarrow \Upsilon$ + X $\rightarrow \mu^+\mu^-$ + X in CMS

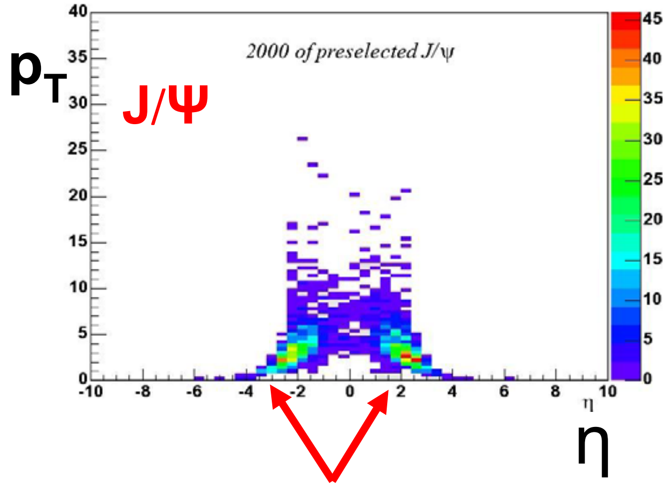
- **MC simulation & visualization of Upsilon event (PbPb, $dN/d\eta|_{\eta=0}$= 3500) using pp software framework**



J/ψ, ϒ acceptances

- J/Ψ accepted above p_T~2 GeV/c (low-p_T muons absorbed in material at y=0, but punchthrough at y~2). High-p_T acceptance ~15%
- ϒ accepted (~35%) down to p_T=0 GeV/c. High-p_T acceptance ~15%

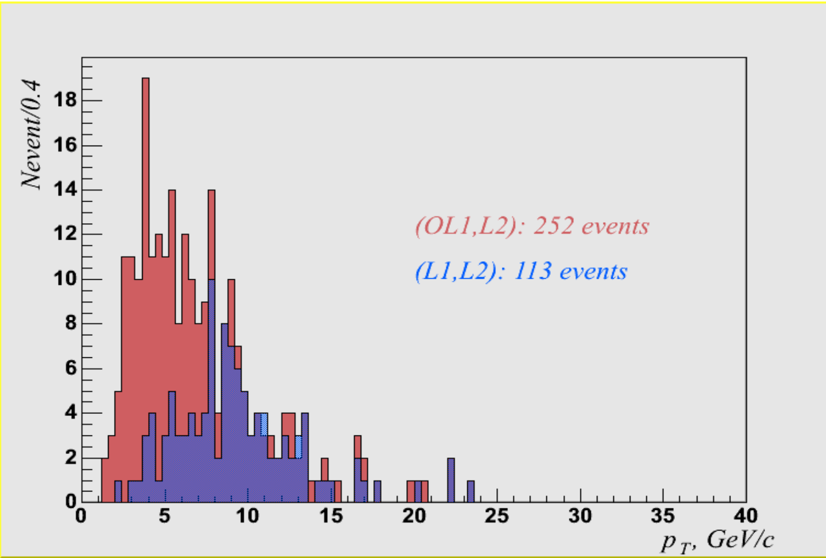


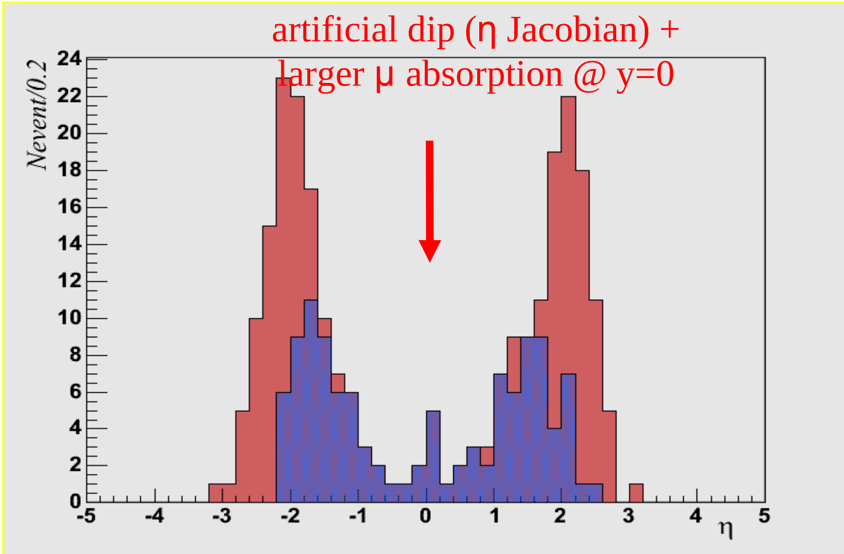


Improved low p_T
J/Ψ acceptance
at forward rapidities

J/ψ triggering (p_T-η acceptance)

- **Two different Level-1 settings:**
  - **L1 : optimized for high luminosity pp**
  - **OL1 : low quality muon candidate (used in HI)**
- **L2 and L3: run on online farm**
- **Trigger condition: two L1 or L2 opposite-sign candidates + L3 (cut on "loose" μ)**
- **26000 J/ψ generated: (OL1,L2) 252 events, (L1,L2) 113 events.**



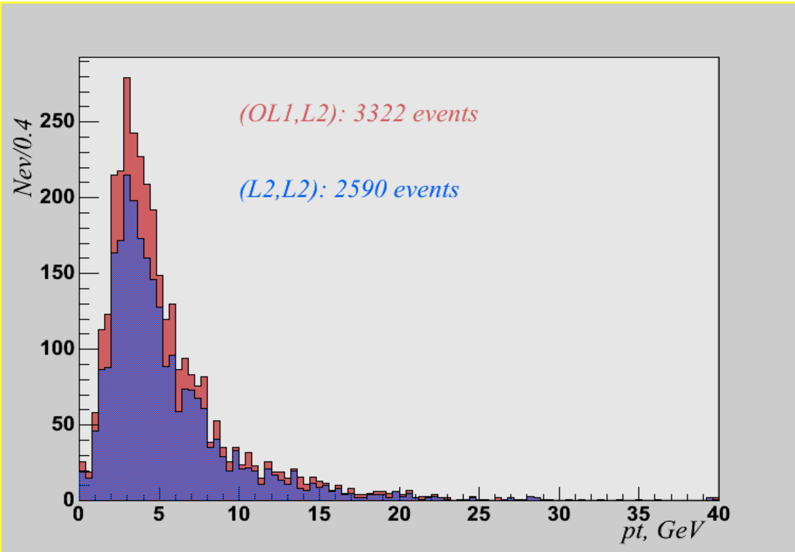


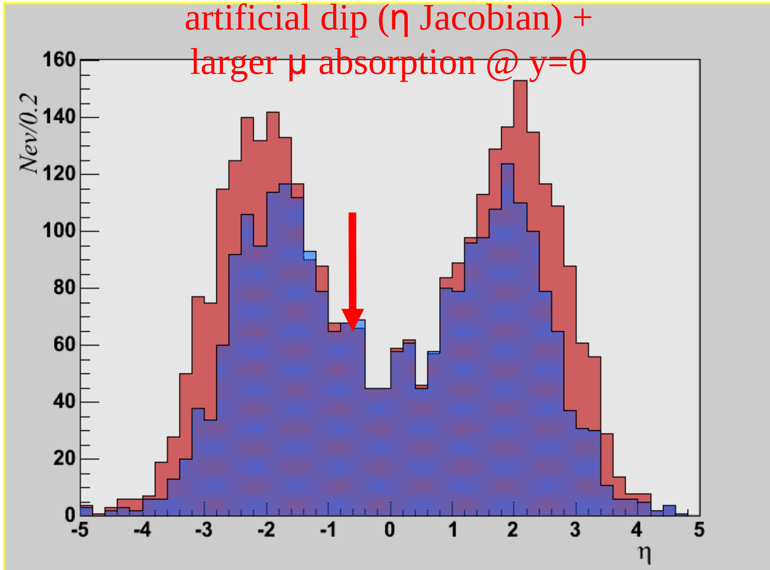
➢ **Total trigger efficiency:** 0.97% (OL1-L2 chain)

(acceptance folded in) 0.44% (L1-L2 chain)

Υ triggering (p_T-η acceptance)

- **Two different Level-1 settings:**
  - **L1 : optimized for high luminosity pp**
  - **OL1 : low quality muon candidate (used in HI)**
- **L2 and L3: run on online farm**
- **Trigger condition: two L1 or L2 opposite-sign candidates + L3 (cut on "loose" μ)**
- **15700 Υ generated: (OL1,L2) 3322 events, (L1,L2) 2590 events.**





➢ **Total trigger efficiency:** 21% (OL1-L2 chain)

(acceptance folded in) 16.5% (L1-L2 chain)

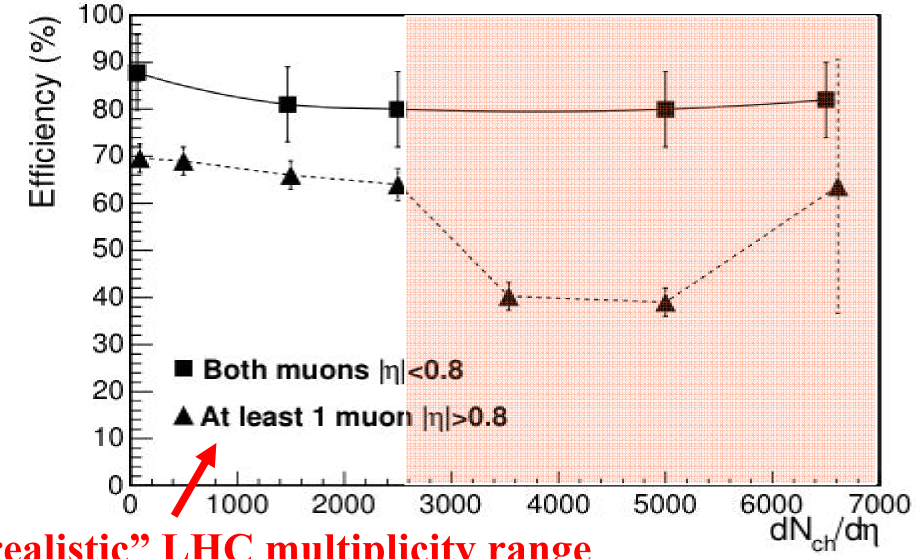
Dimuon efficiency & purity vs dNch/dη

- $\Upsilon \to \mu\mu$ embedded in PbPb event.

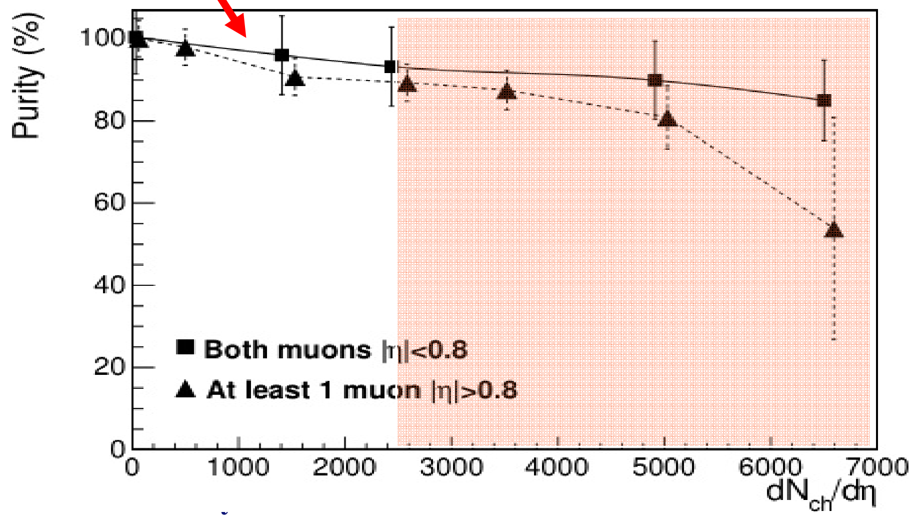
- **Efficiency:**
  - $\varepsilon(p,\eta)=\varepsilon_{track\text{-}1} \times \varepsilon_{track\text{-}2} \times \varepsilon_{vtx}$

>80% for all multiplic. (barrel)

~65% for all multiplic. (barrel+endcap)



"realistic" LHC multiplicity range



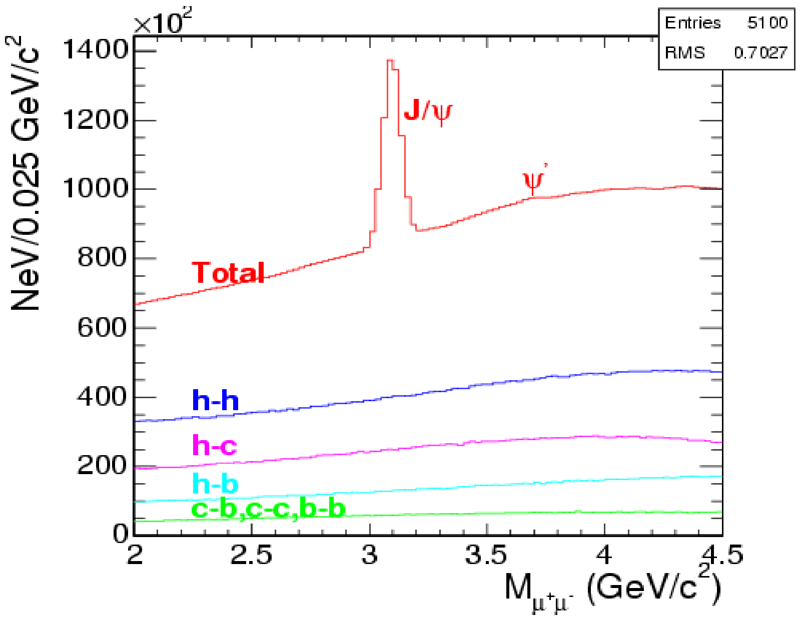
- Purity = [true Υ reco]/ [all Υ reco]

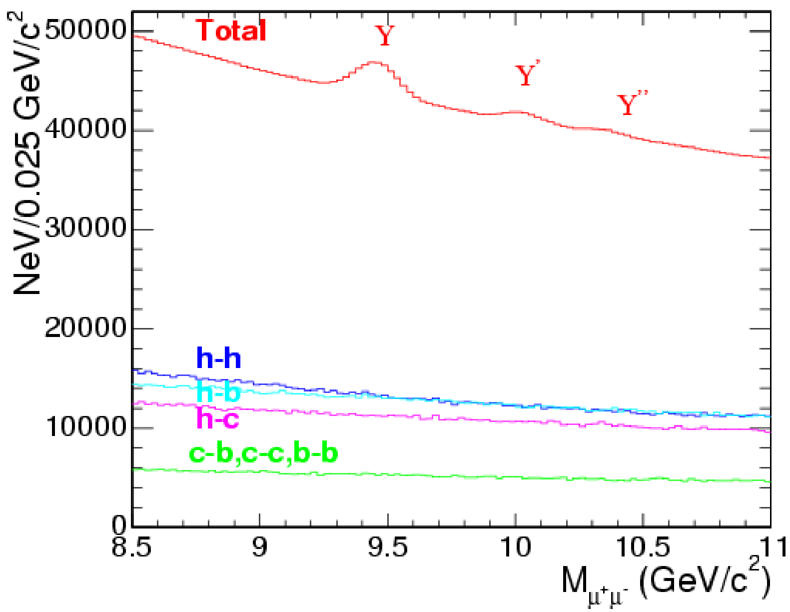
- ~90% for all multiplicities

μμ mass spectra (signal+background)

- Pb-Pb, $dN_{ch}/d\eta_{|\eta=0} = 5000$, $L = 0.5\ nb^{-1}$

- Background: π/K (90% of N_{ch}) → μμ (BR=63%)
- Background: c-,b-hadrons → μ+X ("BR"~18% ,~38%)
- Combinatorial backgd (mixed sources): 1 μ from π/K + 1 μ from J/ψ
  1 μ from b/c + 1 μ from π/K



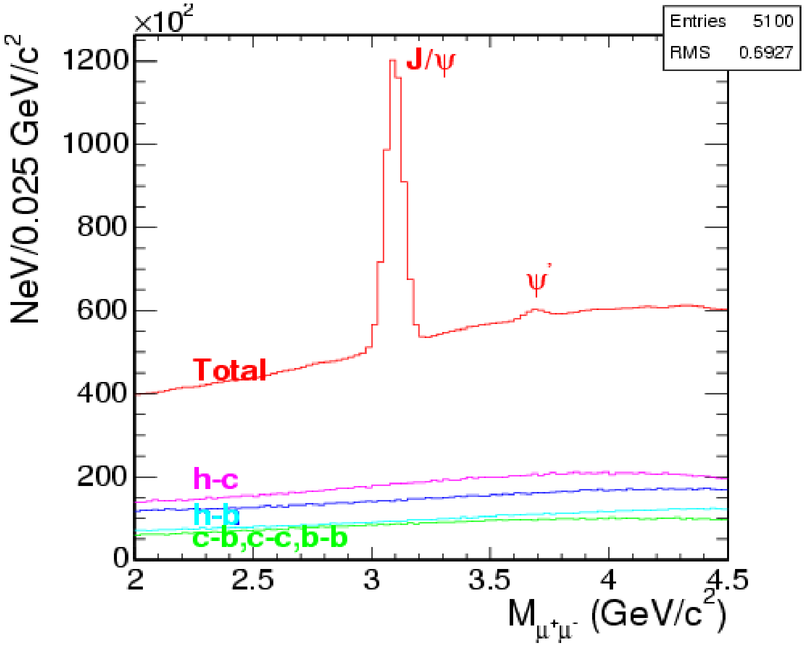


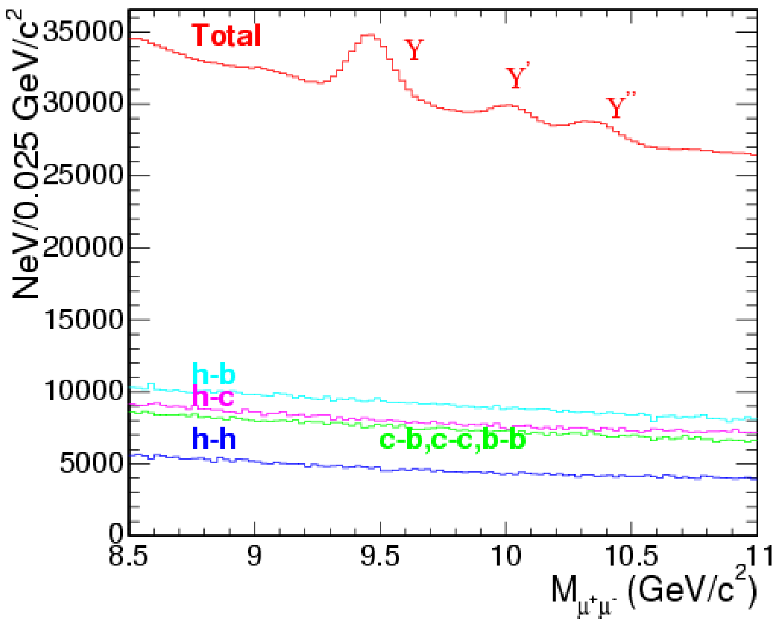
- J/ψ, ψ' peaks seen (S/B~0.6)   All 3 ϒ peaks seen (S/B~0.07)

μμ mass spectra (signal+background)

- Pb-Pb, $dN_{ch}/d\eta|_{\eta=0}$ = 2500 , L = 0.5 nb^{-1}

- Background: π/K (90% of N_{ch}) → μμ (BR=63%)
- Background: c-,b-hadrons → μ+X ("BR"~18% ,~38%)
- Combinatorial backgd (mixed sources): 1 μ from π/K + 1 μ from J/ψ
  1 μ from b/c + 1 μ from π/K





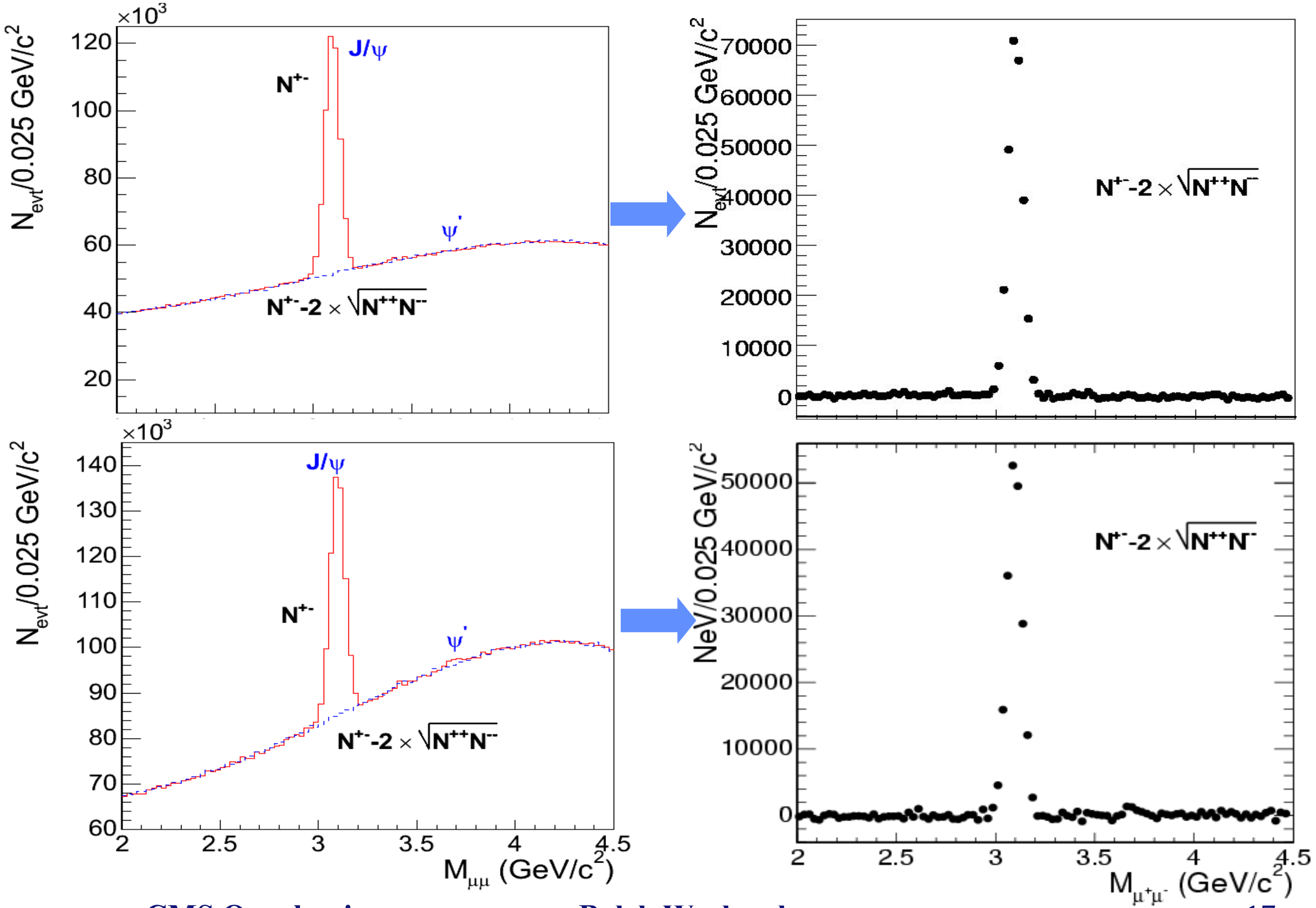
- J/ψ,ψ' peaks seen (S/B~1.2) All 3 Υ peaks seen (S/B~0.12)

J/ψ mass spectra (like-sign subtraction)

- **Best mass resolution at LHC:**
  - $\sigma_{J/\psi}$ = 35 MeV/c^2 in barrel+endcap (i.e. both muons $|\eta| < 2.4$)

"high" multiplicity
$dN_{ch}/d\eta|_{\eta=0}$ = 5000

"low" multiplicity
$dN_{ch}/d\eta|_{\eta=0}$ = 2500



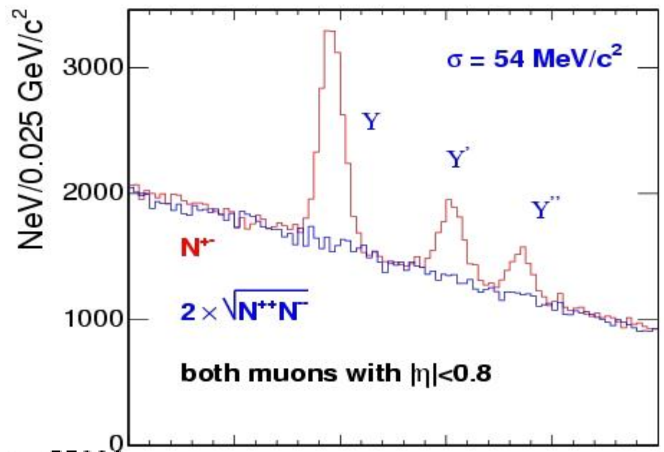
Υ mass spectra (like-sign subtraction)

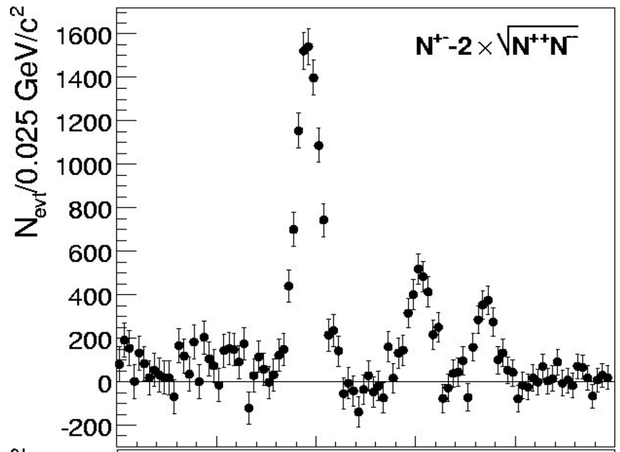
- **Best mass resolution at LHC:**

"high" multiplicity
$dN_{ch}/d\eta|_{\eta=0} = 5000$

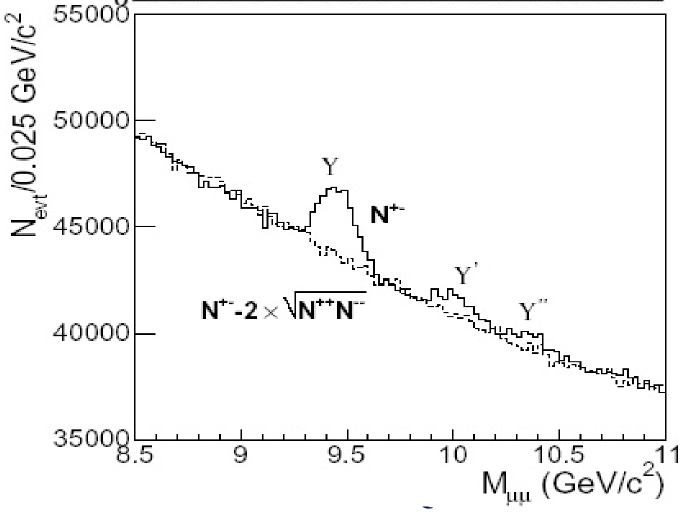
σ_{Υ}= 54 MeV/c^2 (barrel), and σ_{Υ}= 90 MeV/c^2 (barrel+endcap)

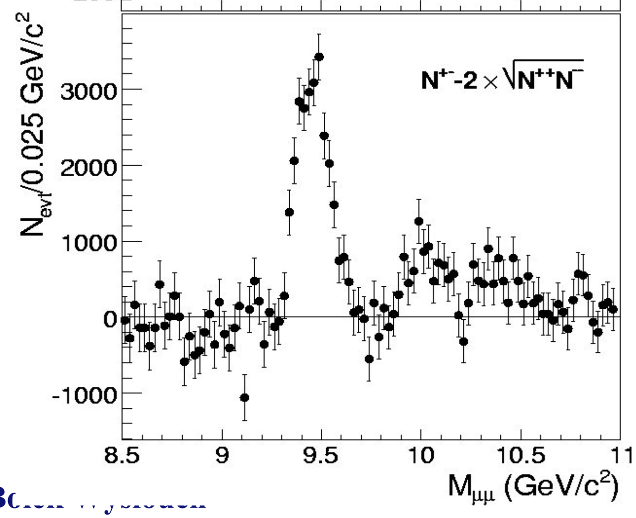
Barrel: (both muons $|\eta| < 0.8$)





Barrel+ Endcap: (both muons $|\eta| < 2.4$)





QQbar rates at CMS (1 nominal PbPb run)

- **Pb-Pb 5.5 TeV: 1-month, L = 0.5 nb^{-1}**

Table 6.1: Signal-to-background ratios and expected quarkonia yields in one month of PbPb running (0.5 nb^{-1} integrated luminosity) for two multiplicity scenarios and two η windows.

$dN_{ch}/d\eta\vert_{\eta=0}$, $\Delta\eta$	S/B	N(J/ψ)	S/B	N(Υ)	N(Υ')	N(Υ'')
2500, $\vert\eta\vert < 2.4$	1.2	180 000	0.12	25 000	7300	4400
2500, $\vert\eta\vert < 0.8$	4.5	11 600	0.97	6400		
5000, $\vert\eta\vert < 2.4$	0.6	140 000	0.07	20 000	5900	3500
5000, $\vert\eta\vert < 0.8$	2.75	12 600	0.52	6000		

- **J/ψ,Υ statistics = O(10^5),O(10^4): differential studies (dN/dp$_T$, dN/dy, centrality, ...) possible**

Summary

- **J/ψ,ϒ = excellent probes of QCD media in A+A:**
  - **Step-wise "melting" pattern = absolute QGP thermometer**
  - **Production via gg fusion = probe of low-x QCD structure&evolution (CGC)**

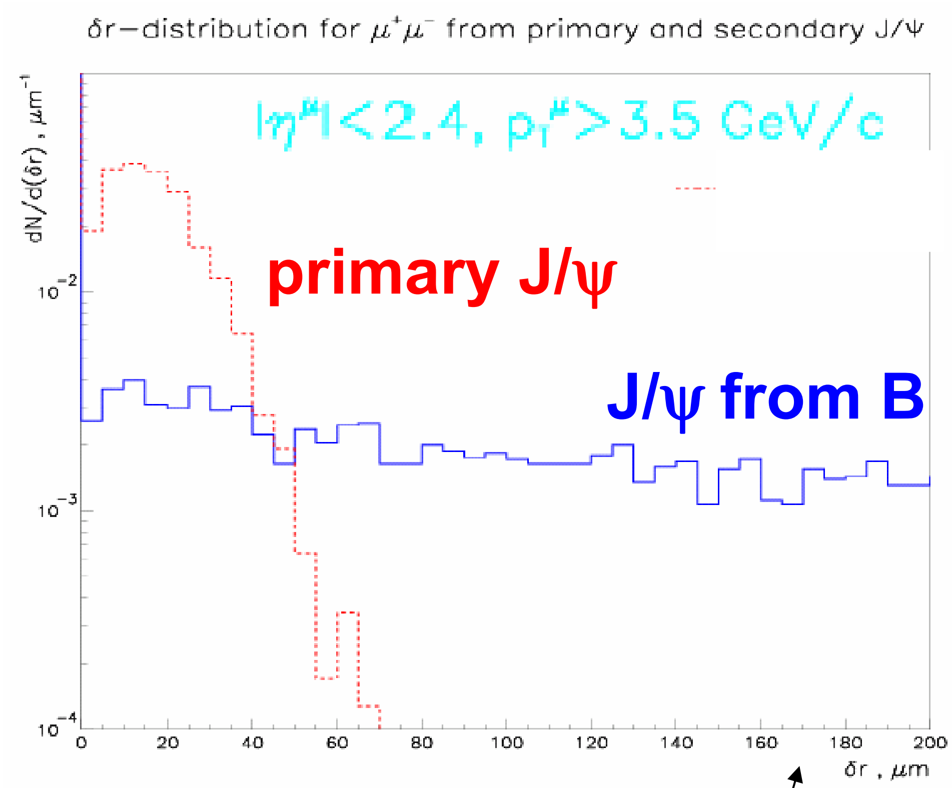
- **Simulation studies of J/ψ,ϒ→ μμ in CMS (PbPb @ $\sqrt{s_{NN}}$=5.5 TeV):**
  - **Geometrical acceptances: ~15% (at high p_T)**
  - **Dimuon efficiency ~80% and purity ~90%, for all multiplicities**
  - **Best mass resolutions at LHC: σ_{QQ} ~ 1% m_{QQ} (barrel+endcap) $\sigma_{J/\psi}$= 35 MeV/c^2 (barrel+endcap), σ_{Υ}= 54 MeV/c^2 (barrel alone)**
  - **Full separation of ϒ family: bottomonium spectroscopy**
  - **Signal/Background: ~ 5(1), ~1(0.1) for J/ψ,ϒ in barrel (+endcaps)**
  - **High rates expected (per year):**
    - J/ψ ~ 180 kevents, ϒ ~ 25 kevents, ϒ' ~ 7 kevents, ϒ'' ~ 4 kevents
- **Detailed differential studies (dN/dp_T, dN/dy, centrality, ...) of QCD matter possible !**

Thanks to many members of the (growing) CMS heavy-ion group for help in preparation of this talk

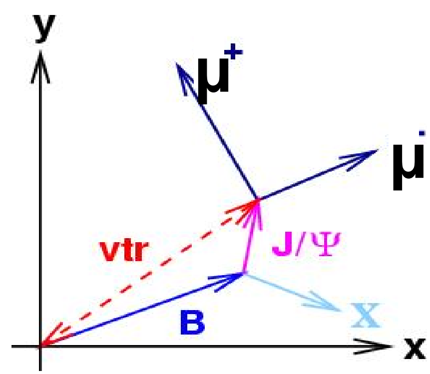
Backup Slides

Heavy-quarks decays: b,c $\rightarrow$ μ / J/ψ +X

- **J/ψ from B decays: ~20% all J/ψ at LHC**
- **Secondary vertex finding and correlated background rejection:**



I. Lokhtin, CMS-NOTE 2001/008



δr is transverse distance between the points of closest approach to the beam for two different muon tracks

Parametrized resolution
Not a full simulation