Quarkonia and heavy flavour detection in CMS Detector

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From SPS and RHIC to LHC:
Increase energy $\sqrt{S}$=17-200 -> 5500 GeV

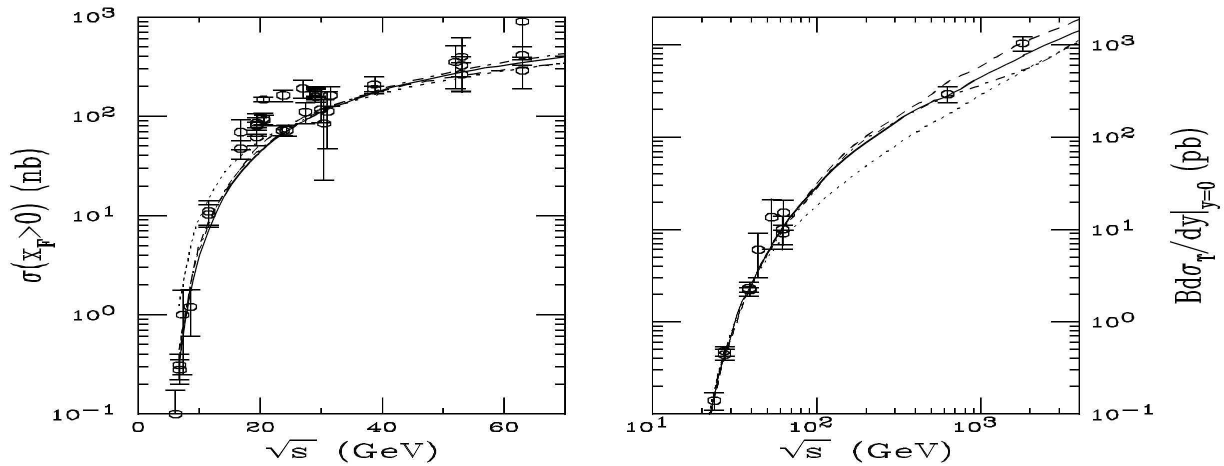
Plasma hotter and longer lived than at RHIC

Unprecedented Gluon densities

Access to lower x, higher Q^2

Availability of new probes

- Quarkonia with high statistics (J/ψ, ψ'; Y,Y',Y'')



Large cross-section for J/ψ and Y families

Different melting for Y,Y',Y''

- Z^0 with high statistics. The possibility to use E_T balance of $Z^0(\gamma^*)$+jet to observe medium induced energy loss.
- Large cross-section for heavy-quarks (b,c):
  - observation of medium induced energy loss in high mass dimuon spectrum and secondary J/ψ

CMS as a detector for Heavy Ion Physics

Muon stations cover $|\eta|<2.4$

Silicon Tracker

Wide rapidity range $|\eta|<2.4$
Excellent momentum resolution $\Delta p/p<1\%$ for p_T less than 100 GeV

4 Tesla magnetic field

The possibility to resolve Y states

DAQ and Trigger

high rate capability for AA, pA, pp
inspection of fully built events at high level trigger of the most of HI events.

Fine Grained High resolution calorimeter Hermetic coverage up to $|\eta|<5$
$|\eta|<7$ using CASTOR
Zero-degree calorimeter proposed

Determination of event centrality using calorimeters and ZDC

Signal and Background simulation

Signal:

- $\Upsilon,\Upsilon',\Upsilon'',J/\psi,\psi' \rightarrow \mu^+\mu^-$ are generated with
  - either PYTHIA or
  - R.Vogt, CERN Yelow Report on hard probes in Heavy Ion Collisions
- $Z0 \rightarrow \mu^+\mu^-$ is generated with PYTHIA
- $B \rightarrow \mu+X$, $B \rightarrow J/\psi+X$ are generated with PYTHIA

$\sigma^{AA} = A^{2a}pp$ with $\alpha=1$, for Z

$\alpha=0.95$ for $\Upsilon,\Upsilon',\Upsilon''$

$\alpha=0.9$ for J/ψ

Background events are generated with HIJING with high and low multiplicity assumptions.

High multiplicity assumption: $dN_{ch}/d\eta = 5000$ for central PbPb event

Low multiplicity assumption: $dN_{ch}/d\eta = 2500$ for central PbPb event

Signal events are combined with soft AA events.

μμ reconstruction algorithm

Primary vertex determination

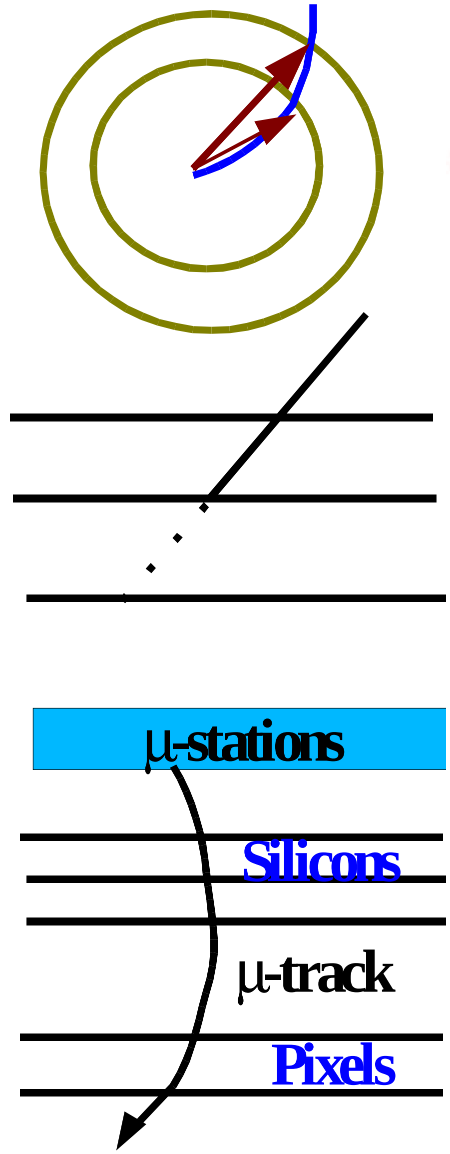
- select pairs of pixel hits with $\Delta\phi$ giving $0.5<p_T<5$ GeV
- extrapolate each pair in RZ to the beam line

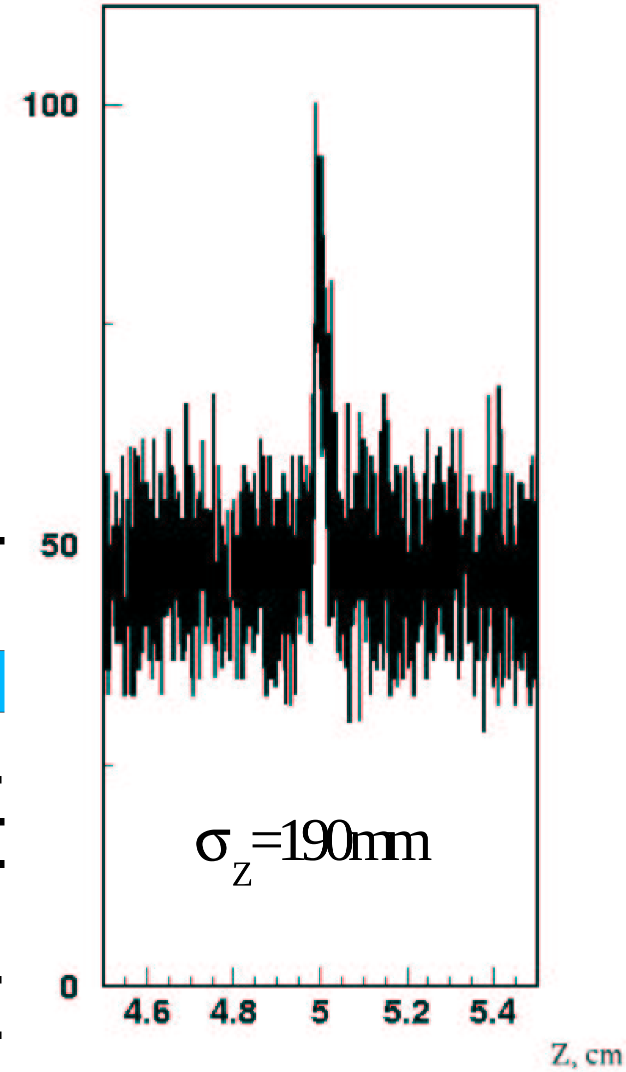
Track finding

- start from track candidate in muon stations
- extrapolate inwards from plane to plane using vertex constraints

Track selection by cuts

- fit quality (χ^2)
- vertex constraint





J/ψ spectra for different nuclei, high multiplicity assumption

For Pb-Pb at integrated luminosity 0.5 nb^{-1}

Combinatorial background:

π/K decays into μ

cc and bb production

pp cross-section

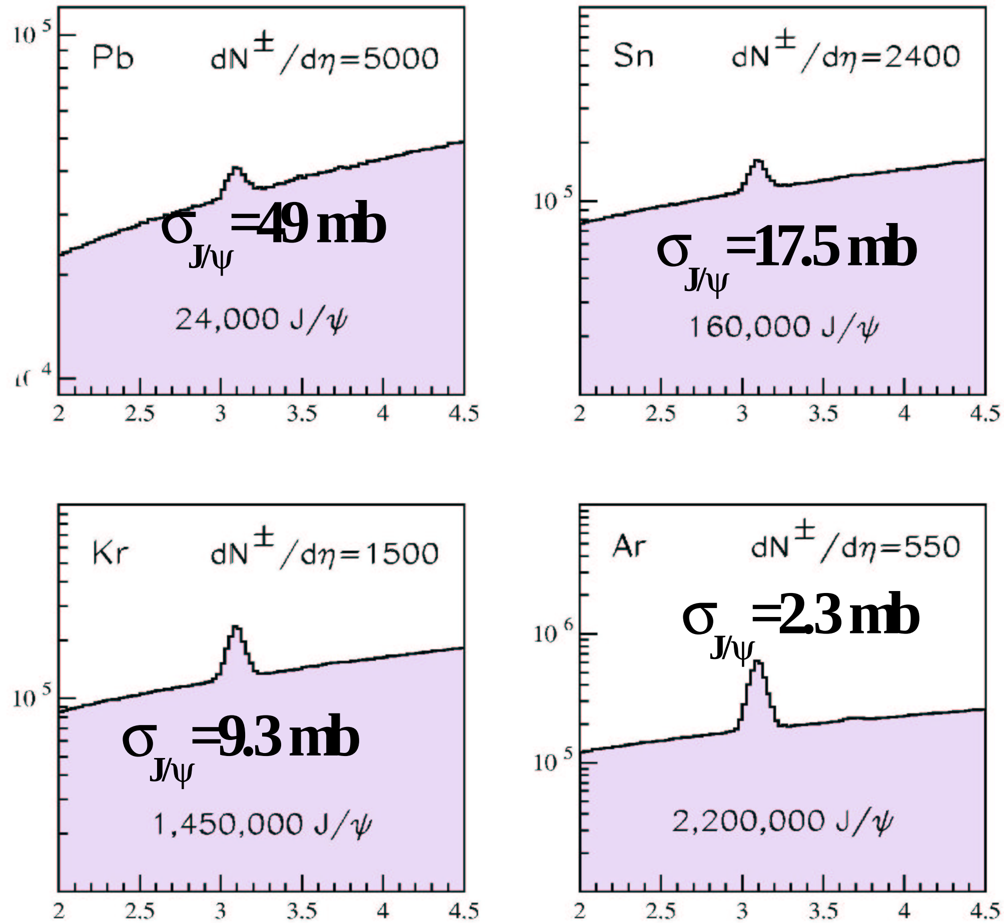
σ_{cc} = 6.3mb, σ_{bb}=0.19mb

Mixed sources, i.e.

1 μ from π/K +
1 μ from J/ψ

1 μ from b/c +
1 μ from π/K

No trigger efficiency
but P_T^{μ}>3.5 GeV/c



Opposite sign dimuon invariant mass, GeV/c^2

Full GEANT simulation for reconstruction efficiency in tracker and dimuon mass resolution. Mass resolution ~50 MeV.

J/ψ spectra for different nuclei, low multiplicity assumption

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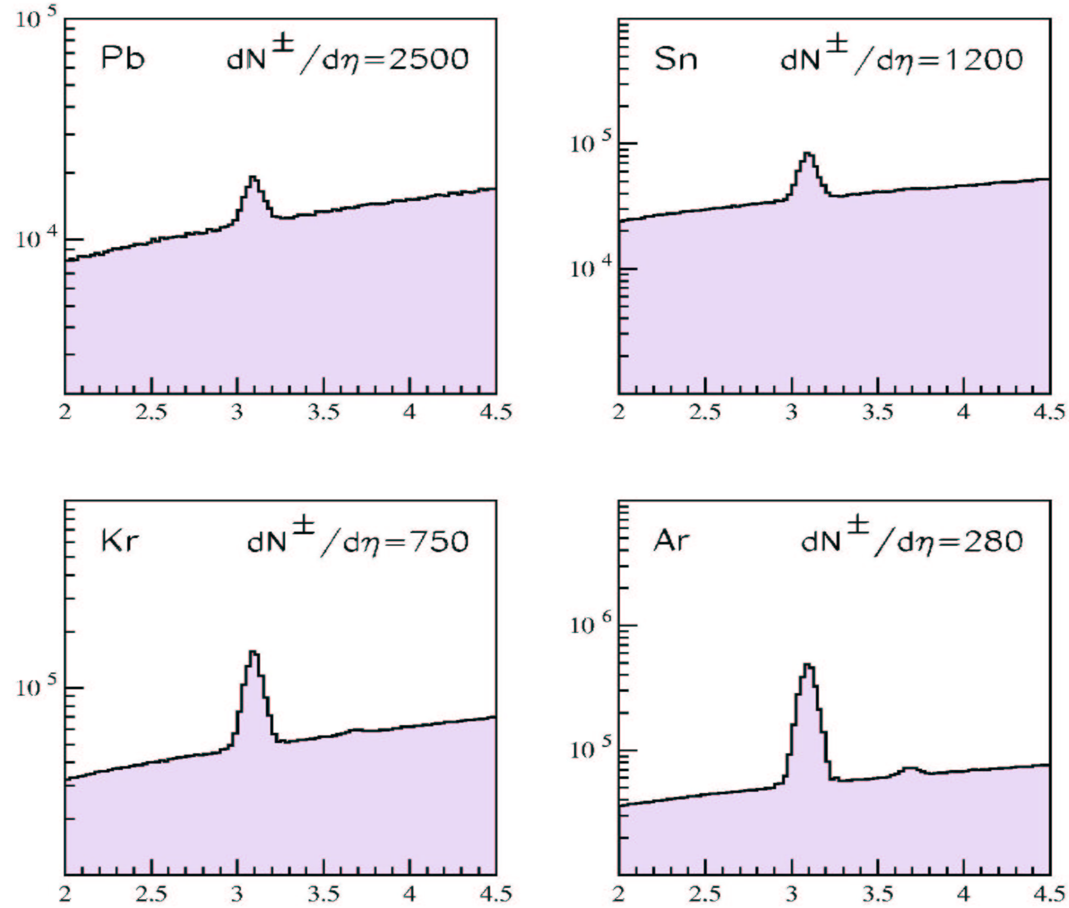
No trigger efficiency but $P_T^{\mu} > 3.5$ GeV/c



Opposite sign dimuon invariant mass, GeV/c^2

Full GEANT simulation for reconstruction efficiency in tracker and dimuon mass resolution. Mass resolution ~50 MeV.

Υ spectra for different nuclei, high multiplicity assumption

For Pb-Pb at integrated luminosity 0.5 nb^{-1}

π/K decays into μ

cc and bb production

pp cross-section

σ_{cc} = 6.3mb, σ_{bb} =0.19mb

Mixed sources, i.e.

1 μ from π/K +
1 μ from J/ψ

1 μ from b/c +
1 μ from π/K

No trigger efficiency
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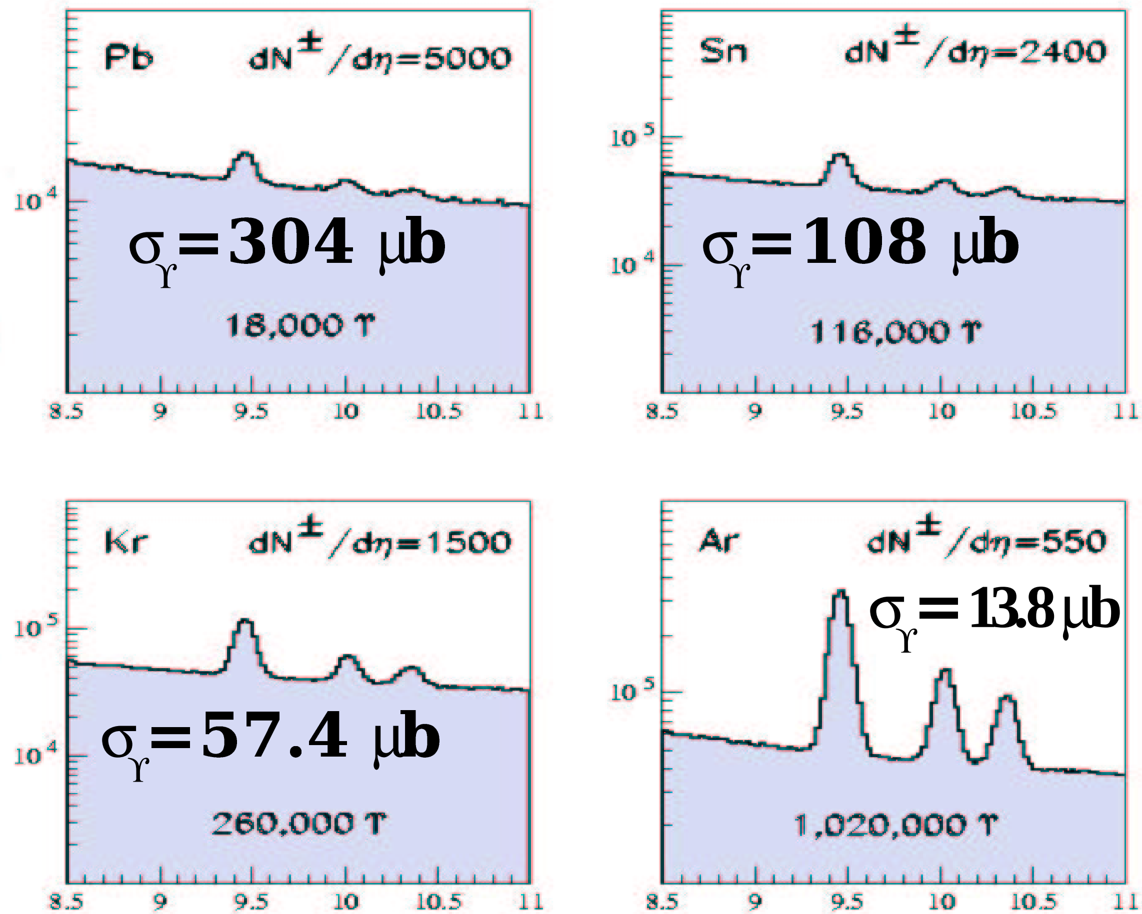

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σ_{cc} = 6.3mb, σ_{bb} =0.19mb

Mixed sources, i.e.

- **1 μ from π/K +**
- **1 μ from J/ψ**

- **1 μ from b/c +**
- **1 μ from π/K**

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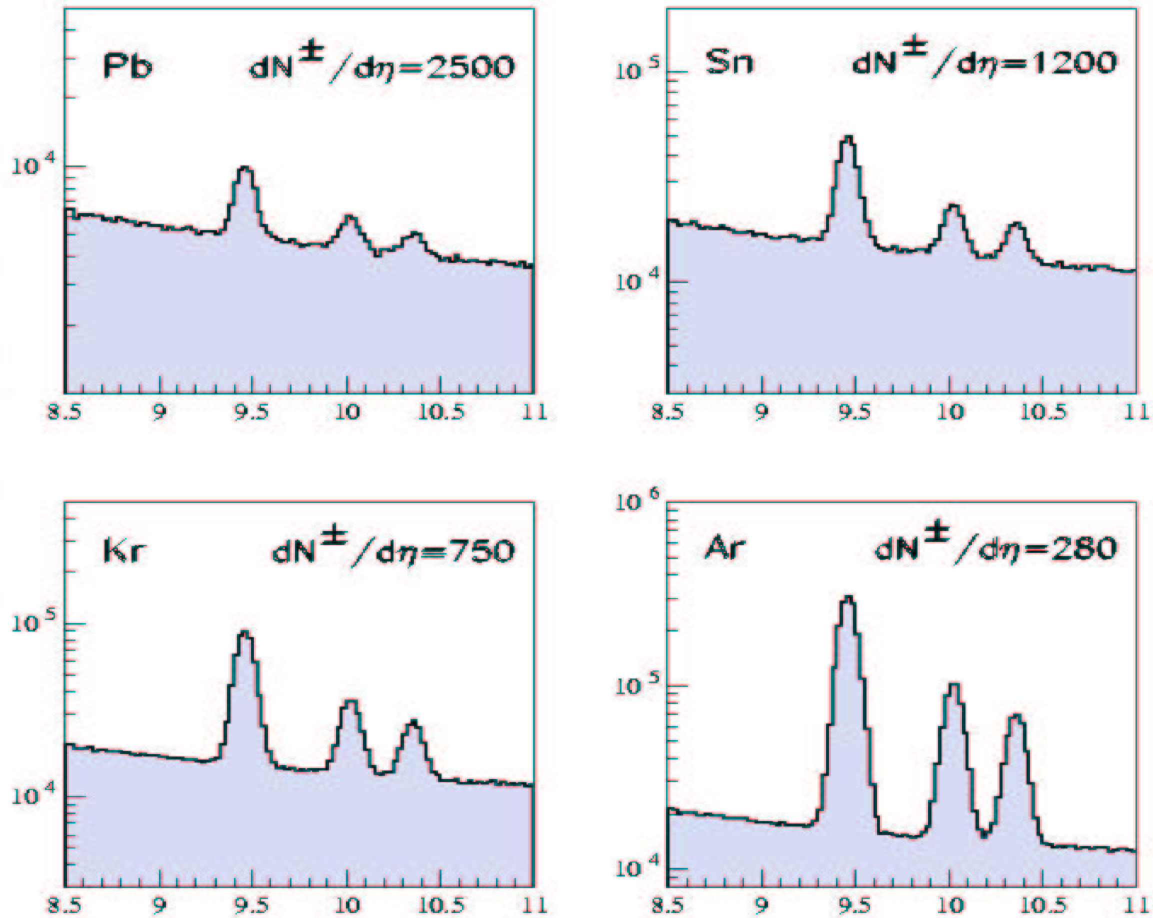


Opposite sign dimuon invariant mass, GeV/c^2

Full GEANT simulation for reconstruction efficiency in tracker and dimuon mass resolution. Mass resolution ~50 MeV.

Background composition in Υ mass range

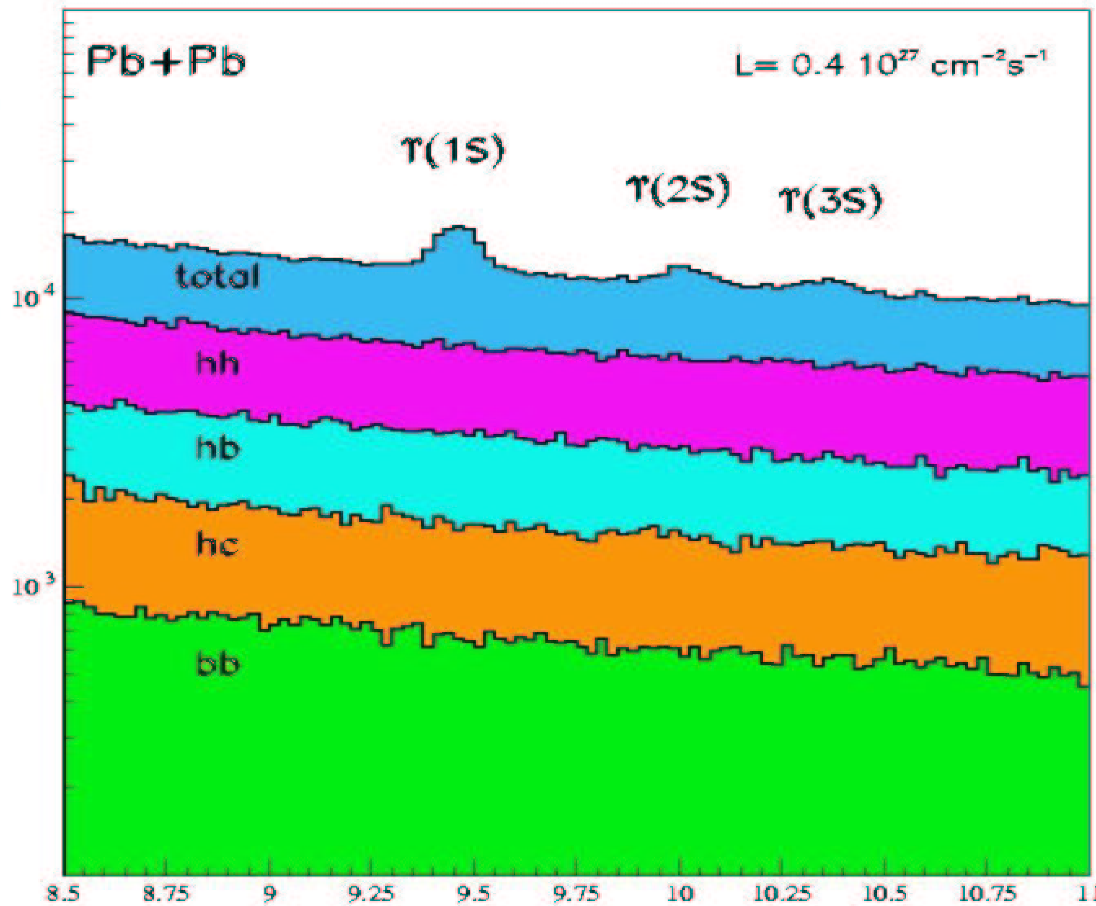
For Pb-Pb at integrated luminosity 0.5 nb^{-1}

hh **π/K decays into μ**

cc c decays into μ

bb b decays into μ

hb,hc **1 μ from b/c**
1 μ from π/K



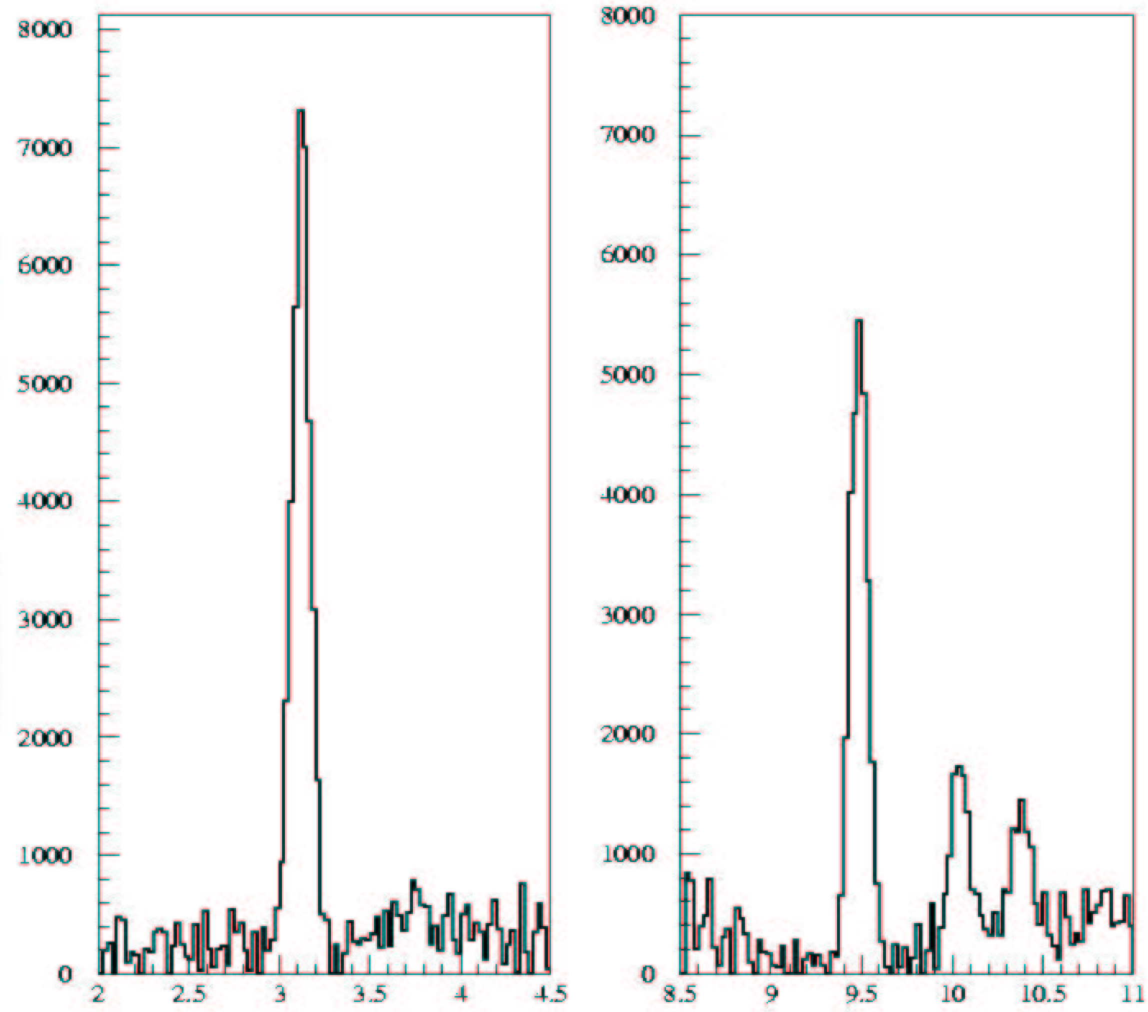
Opposite sign dimuon invariant mass, GeV/c^2

Υ spectra for PbPb after background subtraction

For Pb-Pb

After subtraction of uncorrelated background using like-sign dimuons

$$S = OS - 2\sqrt{(N^{++} N^{--})}$$



Opposite sign dimuon invariant mass, GeV/c^2

Signal/background ratios (high multiplicity-low multiplicity)

		PbPb	SnSn	KrKr	ArAr
S/B	J/ψ	0.2-0.5	0.4-1.1	0.7-1.8	2.0-6.8
	ϒ	0.4-0.9	0.7-1.9	1.5-4.3	5.3-15.6
S/sqrt(S+B)	ϒ	69-93	220-276	396-460	925-978
	ϒ'	24-38	84-123	165-218	447-512
	ϒ''	16-26	55-86	113-157	325-391

Mass window: M_{res} ***+-50 MeV***

Muon trigger for heavy ions

The heavy ion L1 muon trigger is completely a single muon with the lowest p_T cut in full region $|\eta|<2.4$.

in barrel: Ptmin = 4 GeV/c (trigger efficiency=90%)
Ptmin = 3.5 GeV/c (trigger efficiency=80%)

in endcap: Ptmin from 3.5 GeV/c to 1.5 GeV/c

The second muon is added at level 2.

This L1 baseline allows use different combination of patterns from different detectors: Drift Tube, Cathode Strip Chambers, Resistive Plate Chambers (schema OR).

Level 2 is done on the on-line farm

The relatively low luminosity of heavy ion beams allows this less restrictive L1 trigger.

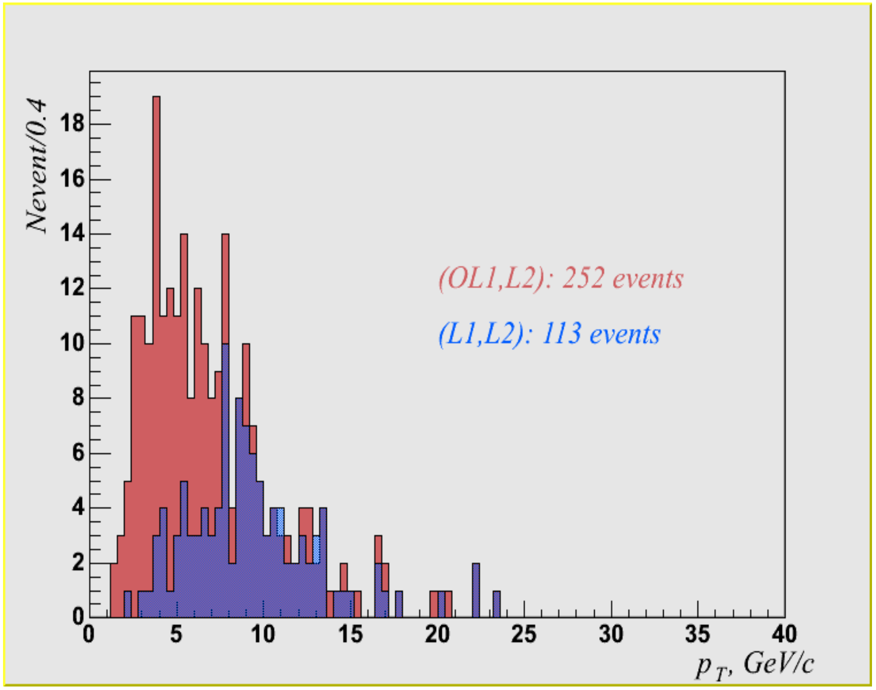
J/ψ and Y are generated according inclusive (η,p_T) distributions for central Pb+Pb and are forced to decay into m^+m^- within GEANT simulation .
(R. Vogt, CERN Yelow Report on hard probes in Heavy Ion Collisions.)

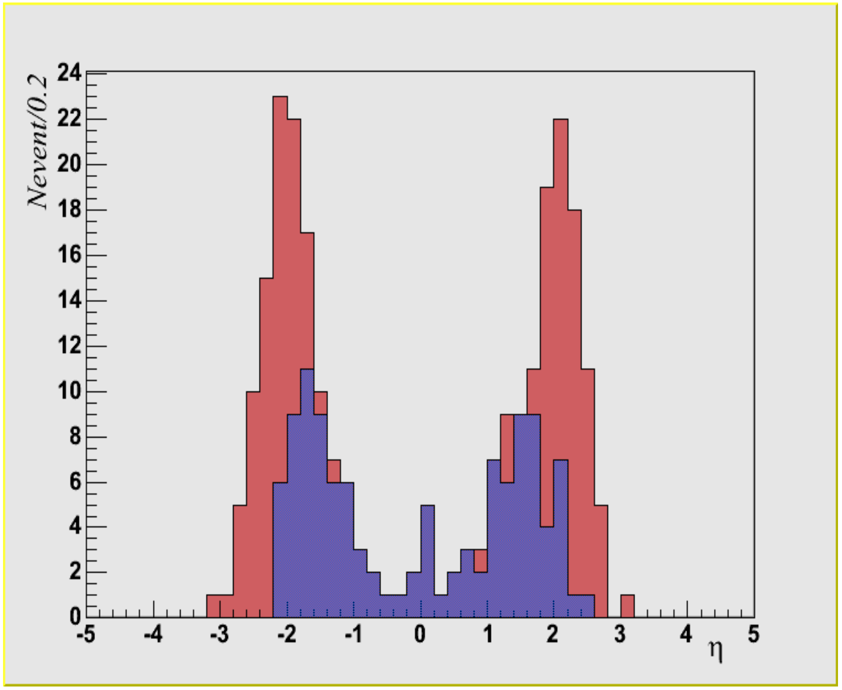
J/ψ triggerring (p_T and η dependence)

Two different optimization at level 1: L1 optimized for high luminosity pp
OL1 (low quality muon candidate) proposed for HI

Trigger condition: two opposite sign candidates at level 1 or two opposite sign candidates at level 2

(OL1,L2) 252 events, (L1,L2) 113 events.





Trigger efficiency: 0.97% (OL1-L2 chain)
0.44% (L1-L2 chain)

26000 J/ψ were generated

Y triggerring (p_T and η dependence)

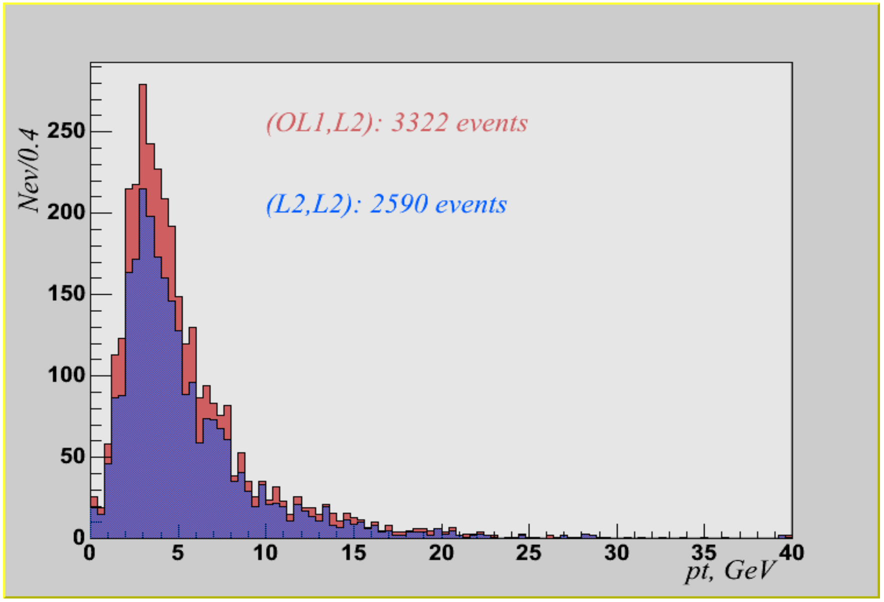
Two different optimization at level 1:

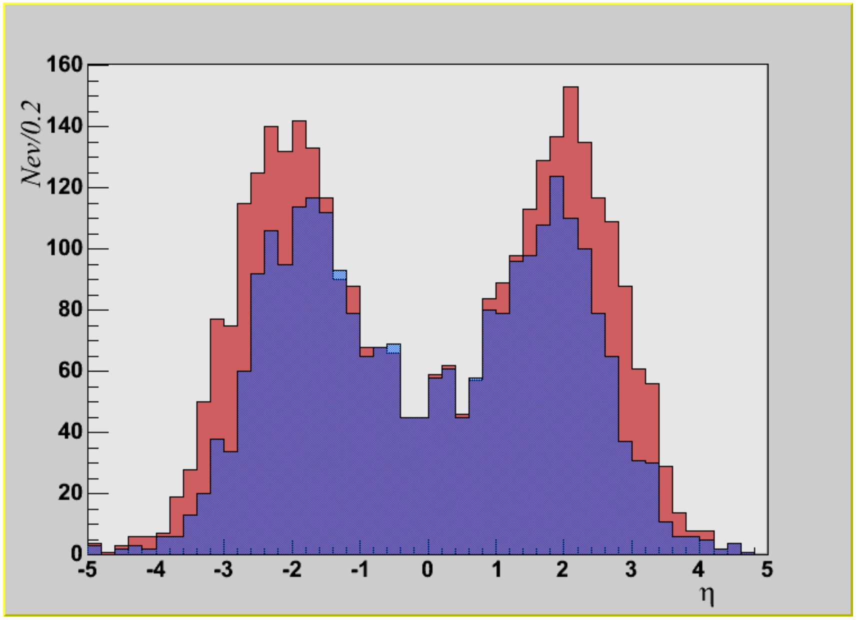
L1 optimized for high luminpsity pp

OL1 (low quality muon candidate) proposed for HI

Trigger condition: two opposite sign candidates at level 1 or two opposite sign candidates at level 2

Red (OL1,L2) 3322 events, (L1,L2) 2590 events.





Trigger efficiency: 21% (OL1-L2 chain)
16.5% % (L1-L2 chain)

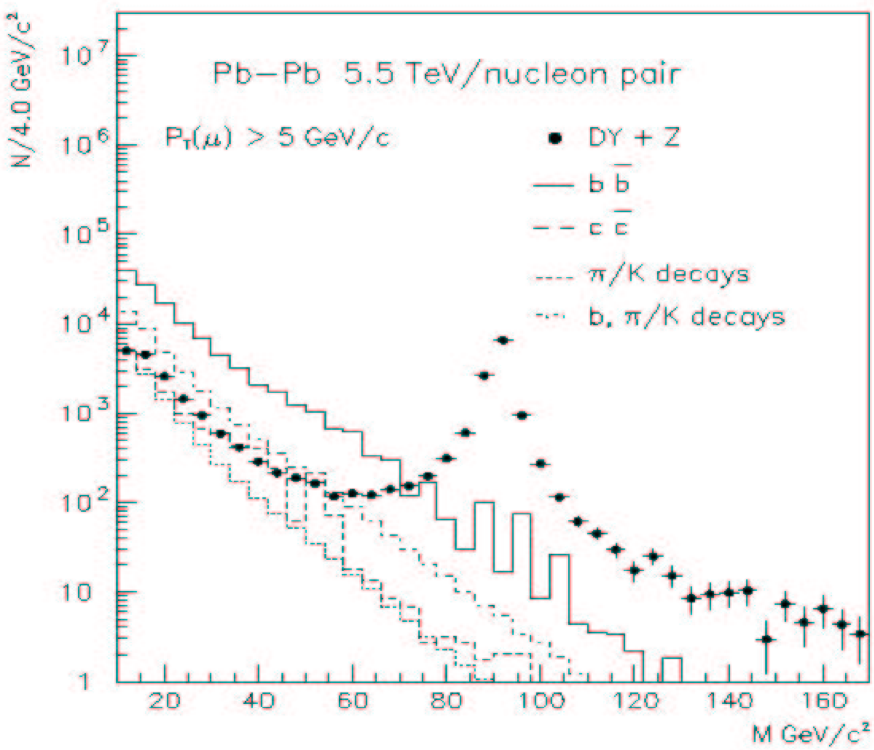
15700 Y were generated

Z->μ+μ- detection at CMS

$\sigma^{AA} = A^{2\alpha}\sigma^{pp}$ with α=1

σ^{pp} was taken from PYTHIA, correction k=2 for $c\bar{c}$ and $b\bar{b}$ and k=1.3-1.5 for Z, W, $t\bar{t}$

HIJING was used for AA event



The expected number of Z->$\mu^+\mu^-$: ~10^4/1.3x10^6 s of Pb-Pb running at L=10^{27}cm^{-2}s^{-1}.

Z can be measured with muon system alone and with muon+tracker systems.

Z+jet events

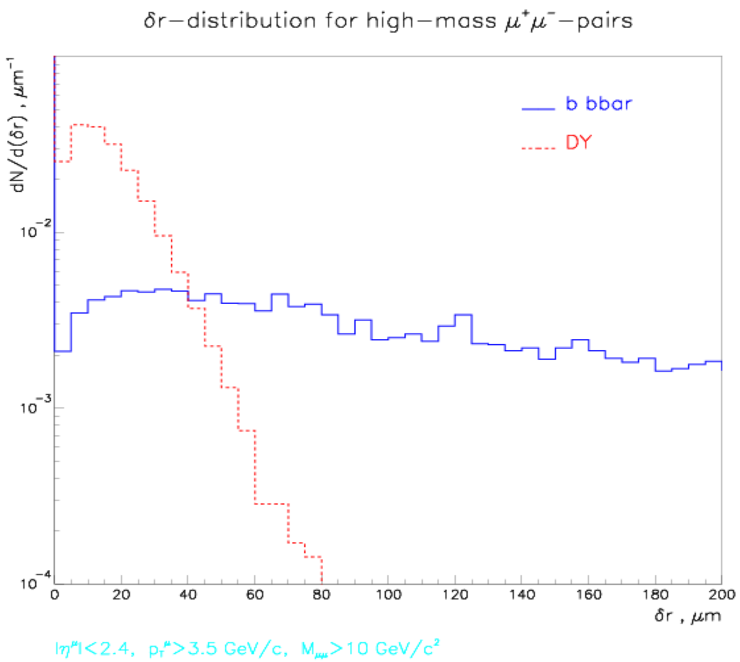
The expected number of Z+jet for jet E_T>50 GeV/c and $|\eta_{jet}|$<1.5: 900/1.3x10^6 s of Pb-Pb run at L=10^{27}cm^{-2}s^{-1}.

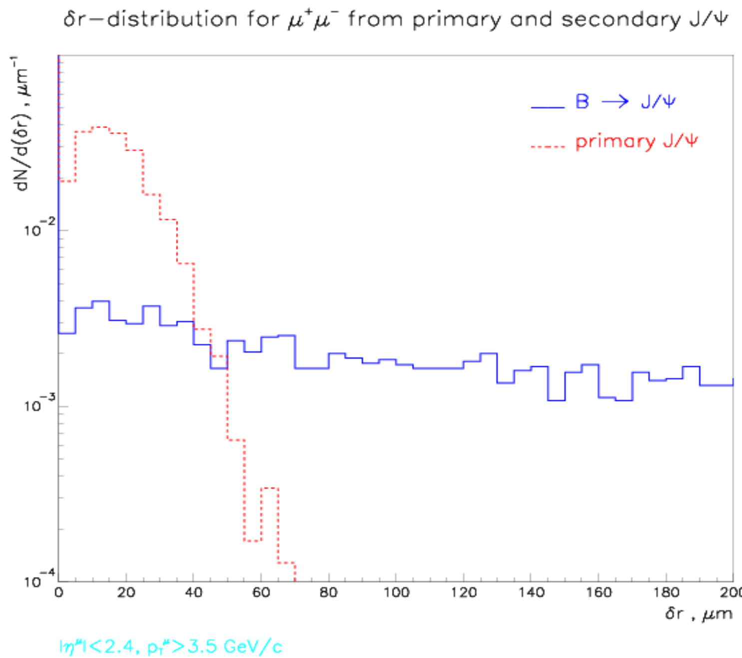
Z+jet events with P_T^Z measured from pair $\mu^+\mu^-$ should allow to study effects of jet quenching using energy balance $E_T^{jet}=P_T^Z$

Heavy-quark b,c- >μ /J/ψ +X
Secondary vertex finding and correlated background rejection

BB->$\mu^+\mu^-$

BB->J/ψ->$\mu^+\mu^-$



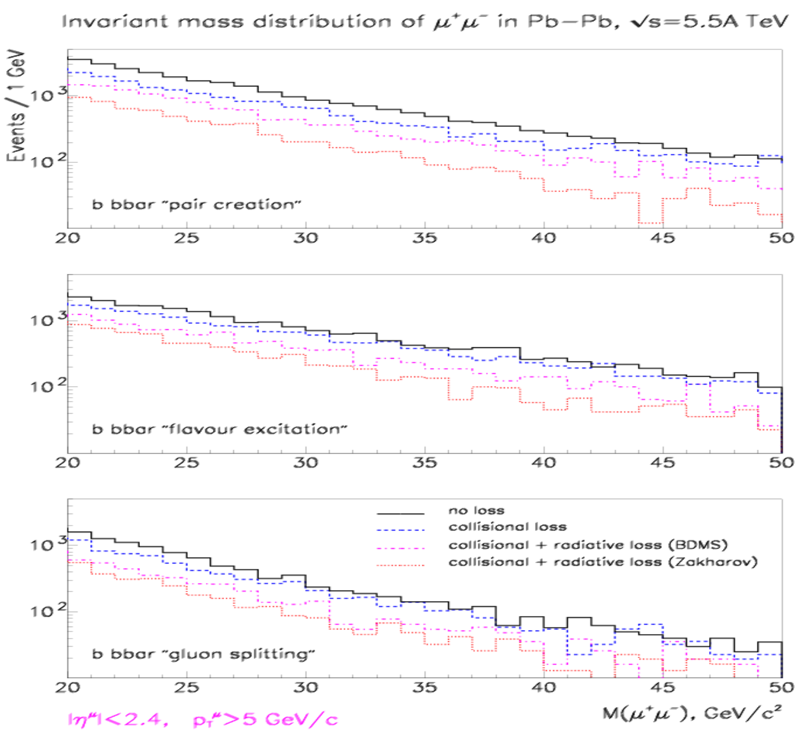


dr is transverse distance between the intersection points with the beam line (points with minimal distance to the beam axis) belonging two different muon tracks

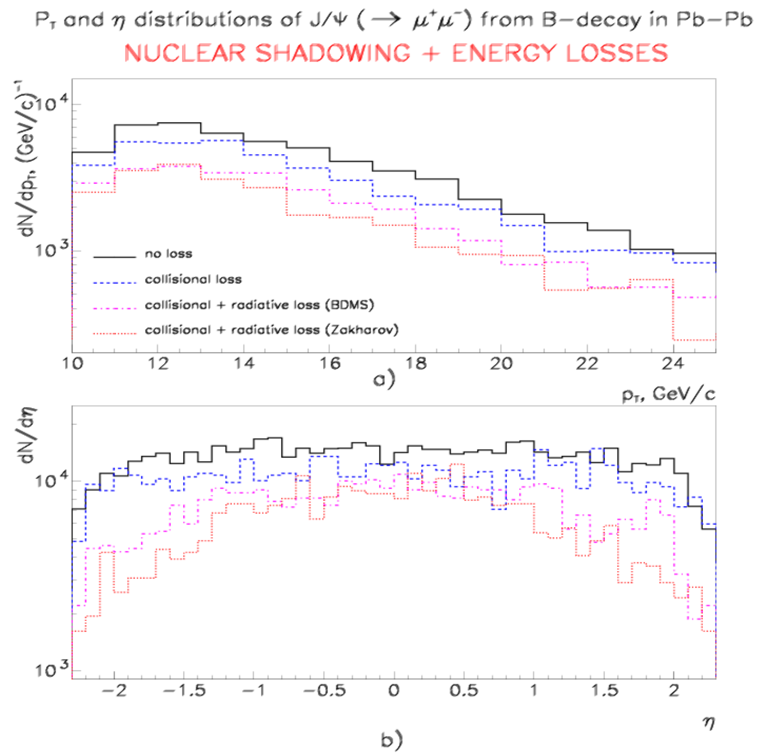
I.P.Lokhtin and A.M.Snigirev, J.Phys. C27 (2001) 2365; CMS Note 2001/008

Heavy-quark b,c- >μ /J/ψ +X (energy loss effect on dimuon spectra)

BB->$\mu^+\mu^-$



BB->J/ψ->$\mu^+\mu^-$



b-quark energy loss affects B-jet fragmentation and modification dimuon spectra depending on mechanism of heavy-quark production (for BB->$\mu^+\mu^-$) and intensity of jet quenching

I.P.Lokhtin and A.M.Snigirev, Eur. Phys. J. C21 (2001) 155; J.Phys. C27 (2001) 2365; CMS Note 2001/008; Nucl. Phys. A702 (2002) 346

Summary

1) CMS is well suited for quarkonia detection.

- states are well separated
- the number of events/month is enough to carry out correlation studies (P_T,event centrality,...).
- significances for Y are between 70 for PbPb and 1000 for ArAr

2) Dimuon spectrum from BB decay can be separated from that of Drell-Yan with secondary vertex reconstruction.

3) Z can be measured independently in muon system and in the muon + tracker system.

4) Recent work indicates that the trigger efficiency can be improved by using optimized combination of hardware and on-line muon trigger. The high level trigger also increases our acceptance for low-p_T J/ψ, which is important for heavy ion physics.