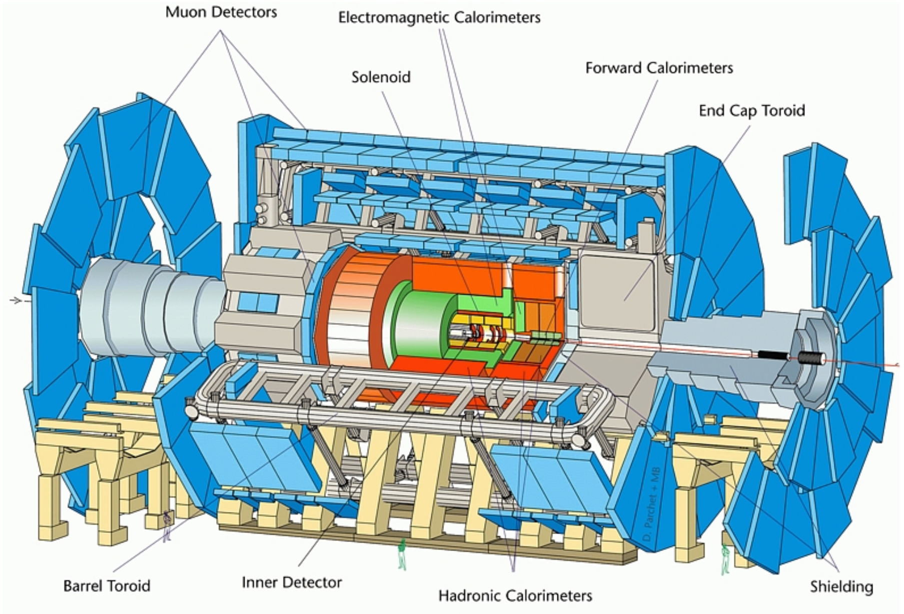
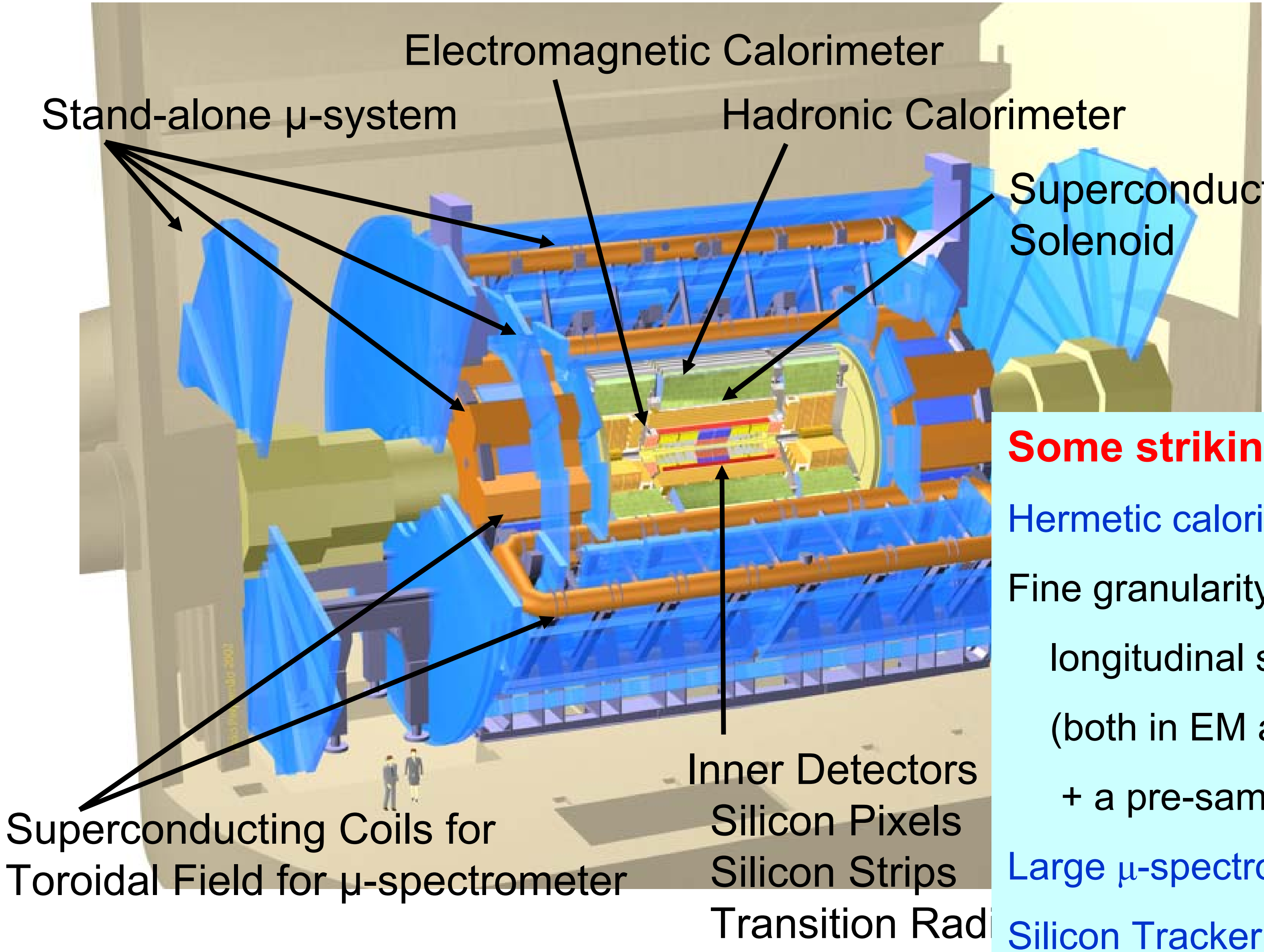
Quarkonia Physics in Heavy-Ion collisions with the ATLAS Detector



Laurent Rosselet

ECT-heavy flavor workshop, September 8th 2006

The ATLAS detector



Length 44m

Height 22m

Some striking features:

Hermetic calorimeter |η|<4.9

Fine granularity and 3 longitudinal segmentations (both in EM and hadronic) + a pre-sampler

Large µ-spectrometer |η|<2.7

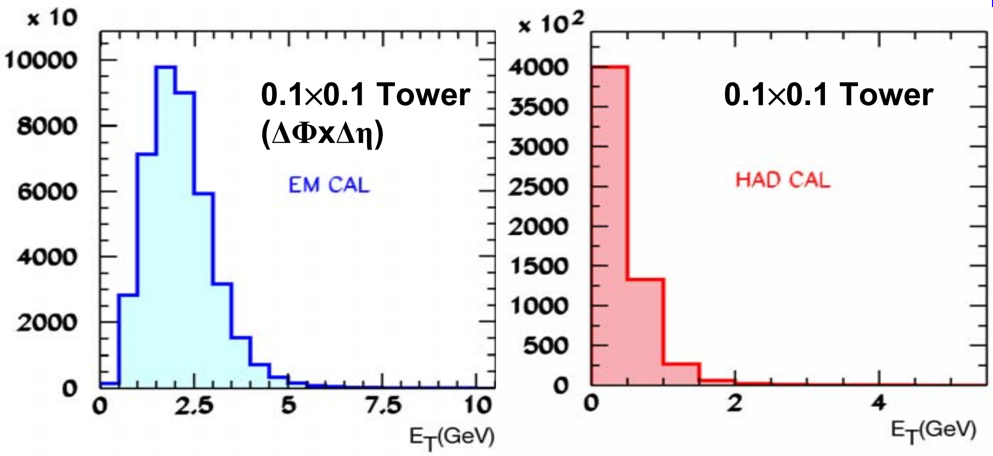
Silicon Tracker |η|<2.5

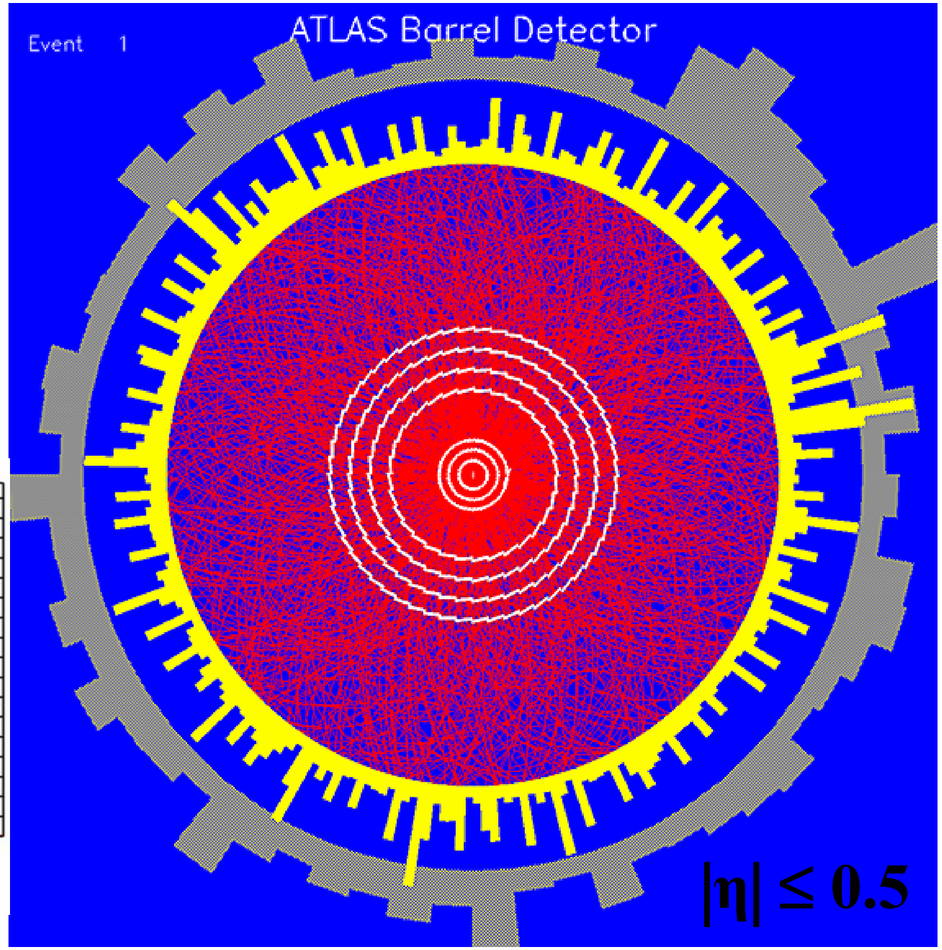
Central Pb-Pb collisions (b=0-1 fm)

- Simulation: HIJING+GEANT3

  $dN_{ch}/d\eta|_{max}$ ~ 3200 in central Pb-Pb

  c.f. 1200 from RHIC extrapolation





- Large bulk of low p_T particles is stopped in the first layer of the EM calorimeter (60% of energy)
- μ-spectrometer occupancy in Pb-Pb < high-L p-p

Track reconstruction

—Only Pixel and SCT detectors

—At least 10 hits out of 11 per track

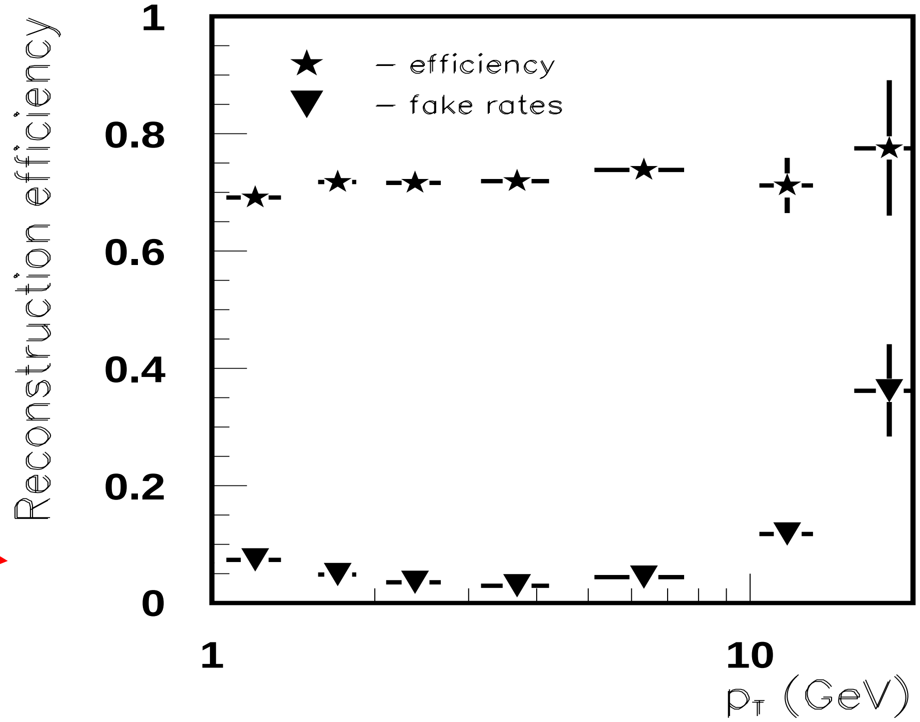
—At most 1 shared hits

—For p_T: 1 - 10 GeV/c:

efficiency > 70%

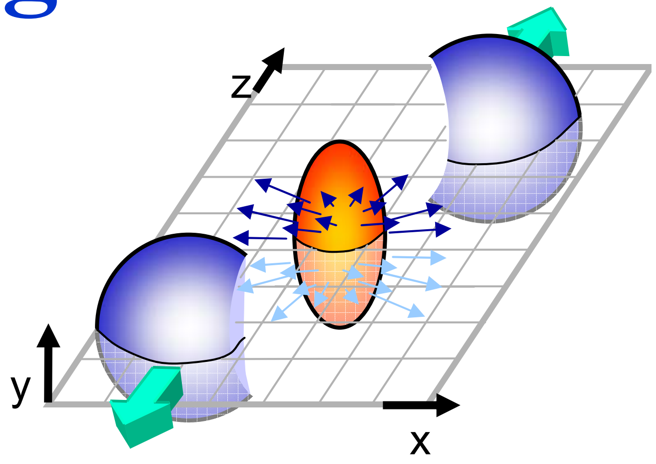
fake rate ~ 5%

p_T-resolution ~3%



- 2000 reconstructed tracks from HIJING (b=0) events with $p_T > 1$ GeV and $|\eta| < 2.5$
- Fake rate at high p_T can be reduced by matching with calorimeter data
- **TRT not considered for this study. Expected to be partially (fully) usable in central (peripheral) Pb collisions => electron identification**

Heavy ion physics program



- **Global variable measurement**

  dN/dη dE$_T$/dη elliptic flow

  azimuthal distributions

- **Jet measurement and jet quenching**
- **Quarkonia suppression**

  J/Ψ ϒ

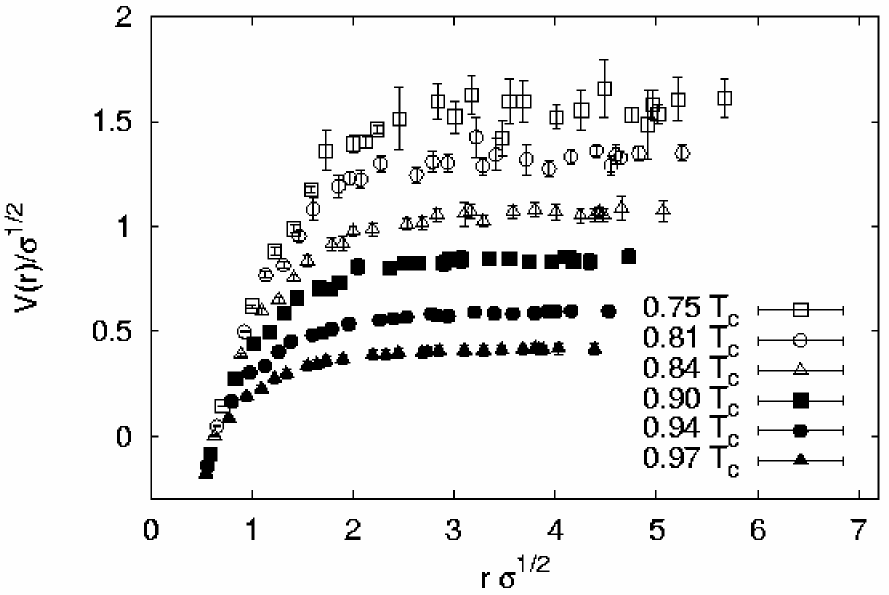
- **p-A physics**
- **Ultra-Peripheral Collisions (UPC)**

Direct information from QGP

Idea: take full advantage of the large calorimeter and μ-spectrometer

Heavy quarkonia suppression

Original idea: color screening prevents various ψ, ϒ, χ states to be formed when $T \rightarrow T_{trans}$ to QGP (color screening length < size of resonance)



Modification of the potential can be studied by a systematic measurement of heavy quarkonia states characterized by different binding energies and dissociation temperatures

~thermometer for the plasma

state	J/ψ	χ_c	ψ'	ϒ(1s)	χ_b	ϒ(2s)	χ_b'	ϒ(3s)
Mass [GeV}	3.096	3.415	3.686	9.46	9.859	10.023	10.232	10.355
B.E. [GeV]	0.64	0.2	0.05	1.1	0.67	0.54	0.31	0.2
T_d/T_c	1.10	0.74	0.15	2.31	1.13	0.93	0.83	0.74

In fact: complex interplay between suppression and regeneration

Upsilon reconstruction

Study the $\Upsilon \rightarrow \mu^+ \mu^-$ in a full simulation (GEANT3+reconstruction)

- μ-spectrometer occupancy in Pb-Pb < high-L p-p

Upsilon family	Υ(1s)	Υ(2s)	Υ(3s)
Mass (GeV)	9.460	10.023	10.355
Binding energies (GeV)	1.1	0.54	0.2
Dissociation at the temperature	$\sim 2.3T_{trans}$	$\sim 0.9T_{trans}$	$\sim 0.7T_{trans}$

=>Important to separate Υ(1s) and Υ(2s)

- $\mu^+ \mu^-$ mass resolution is 460 MeV at Υ peak in the μ-spectrometer

=> uses combined info from ID and μ-spectrometer

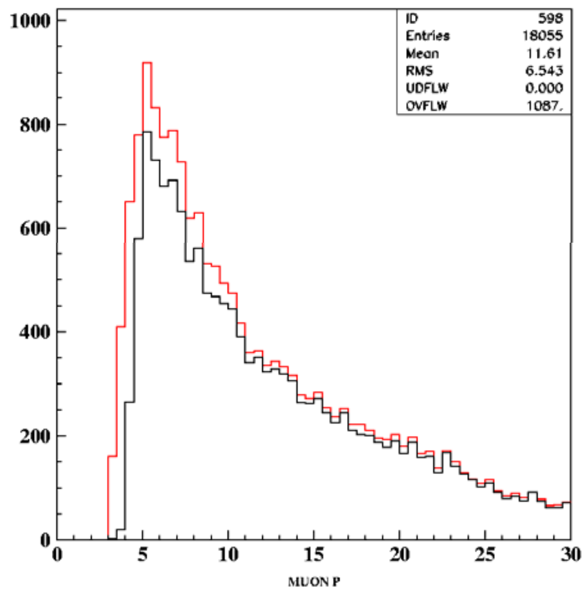
How to measure μ?

▪**Global method (A):** use tracks **fully traversing** the μ-spectrometer, which allows momentum measurement in the standalone μ-spectrometer, and associate them with ID tracks through a **global fit.**

▪**Tagging method (B):** select ID tracks whose extrapolation coincide with a **track segment** in the μ-spectrometer.

➢Advantage of A over B: better p measurement (true for Z^0,~not for J/ψ, ϒ), better purity.

➢Advantage of B over A: lower p threshold
=> larger acceptance (3 GeV instead of 4).



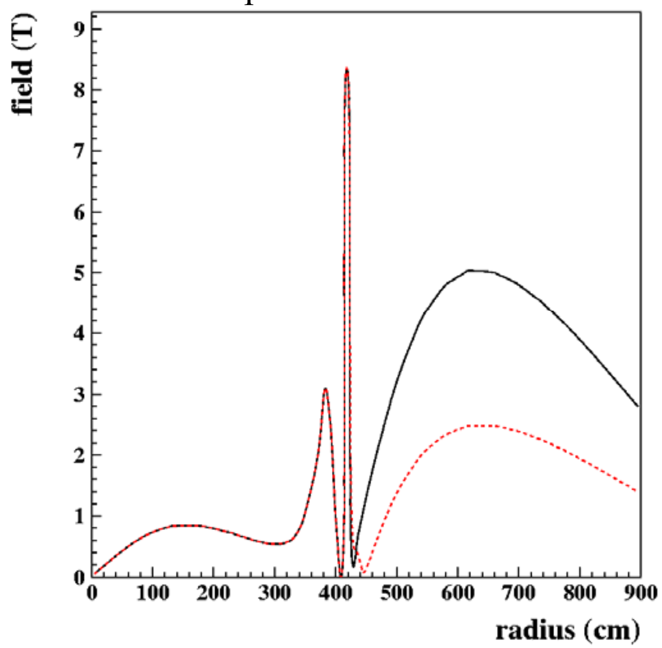
▪**Selection of di-μ pairs with two methods:**

"Global Fit" ≡ both μ's are reconstructed with A

"Global+Tag" ≡ at least one μ from method A, the other one from A or B.

Reduced toroidal field

Additional way to increase the heavy quarkonia acceptance is to reduce the toroidal field of the μ-spectrometer



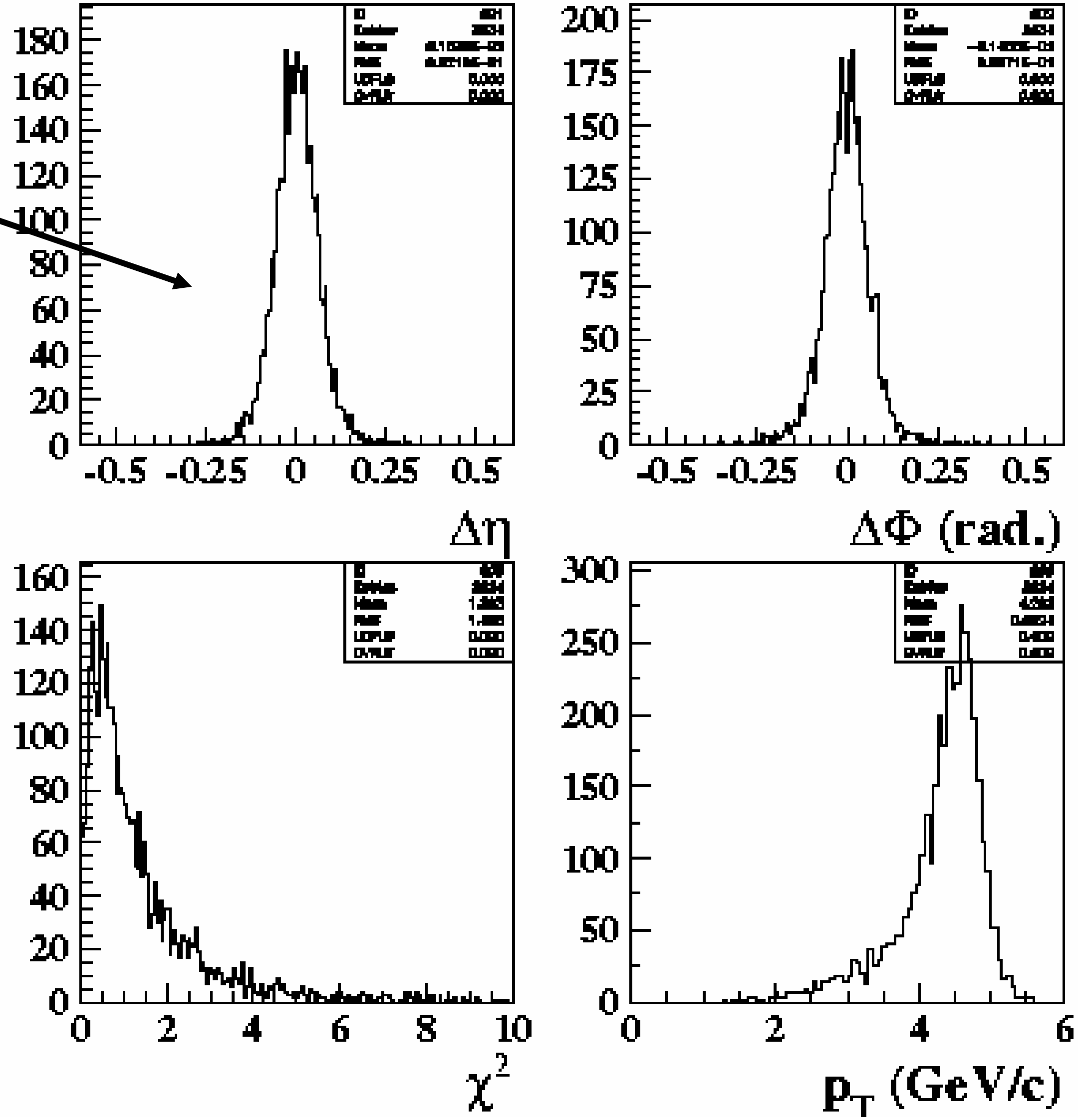
- Improves the low p_T-μ acceptance
- Makes easier a low p_T-μ trigger
- **Cost:** worse resolution & backgr.

End up with 4 studies:
"Global Fit" and "Global+Tag" ⇔ statistics vs purity
with full field (4 Tm) or half field ("B/2 mode") ⇔ statistics vs resolution

The best compromise between these different scenarios will mainly depend on the real charged multiplicity

$\Upsilon \rightarrow \mu^+ \mu^-$ using combined info from ID and μ-spectro (global fit method)

Single Upsilons



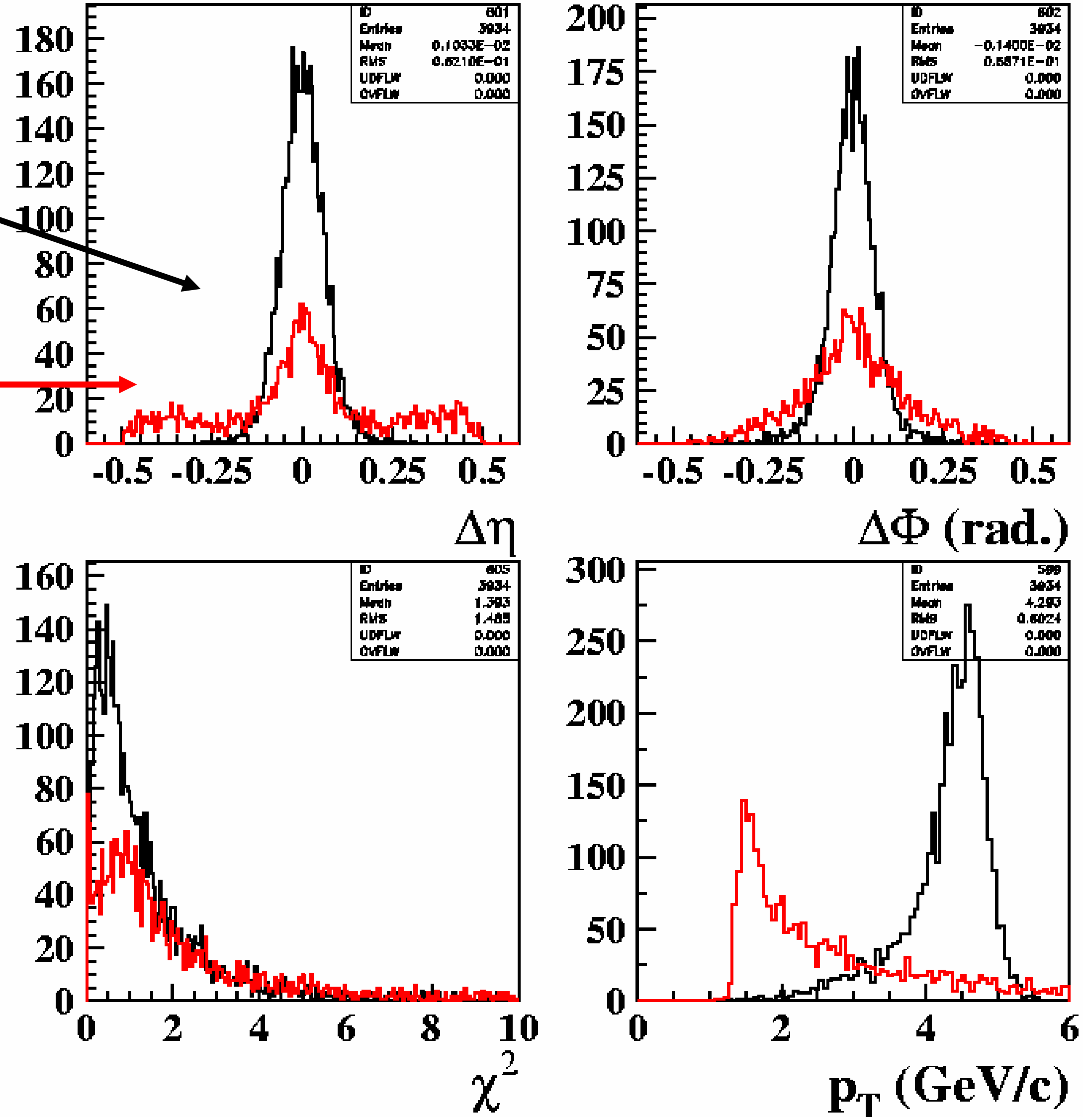
Δη, ΔΦ=difference between ID and μ-spectrometer tracks after back-extrapolation to the vertex for the best χ^2 association.

$\Upsilon \rightarrow \mu^+ \mu^-$ using combined info from ID and μ-spectro (global fit method)

Single Upsilons

HIJING background

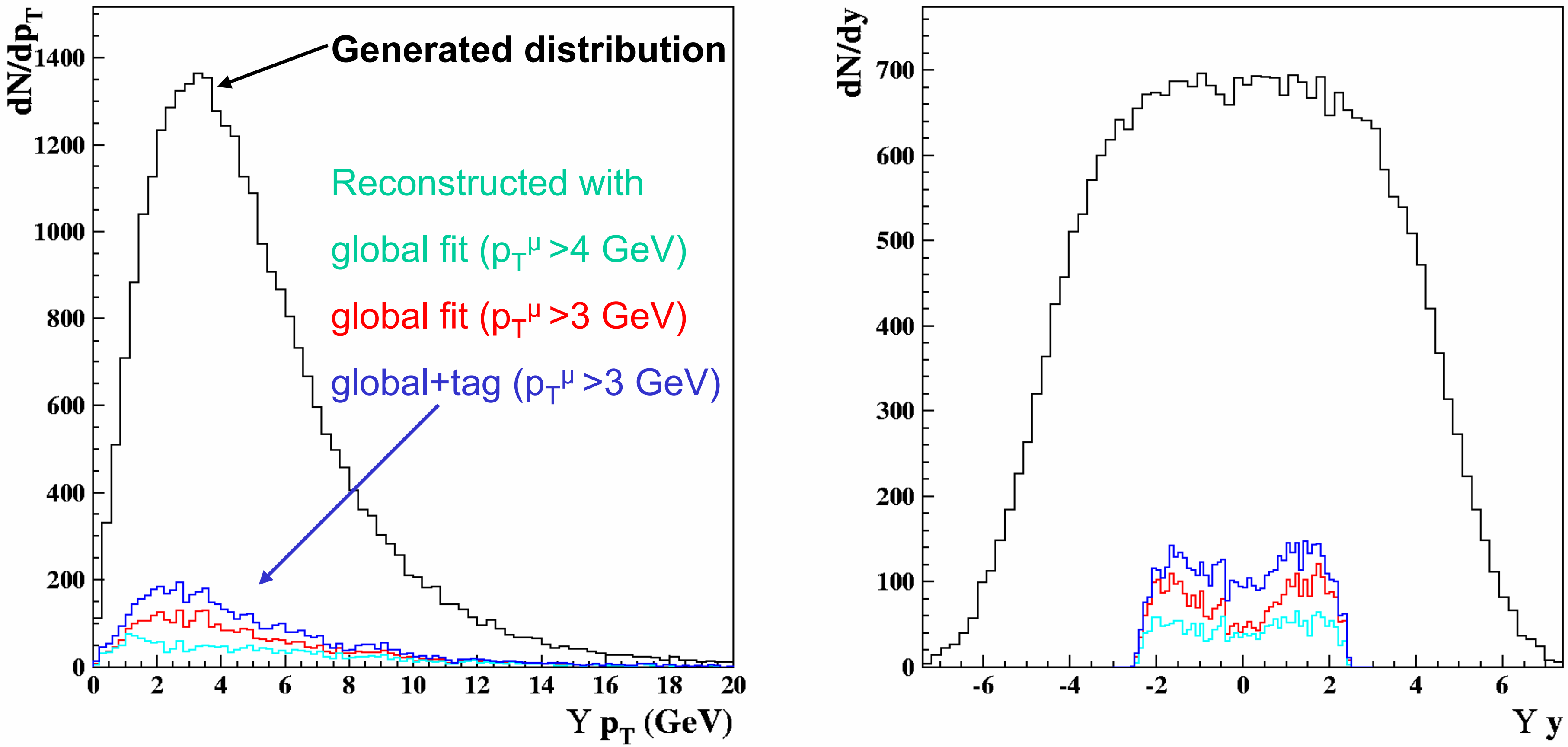
Half μ's from c, b decays, half from π, K decays for p_T>3 GeV.



Background rejection based on χ^2 cut, geometrical Δη x ΔΦ cut and p_T cut.

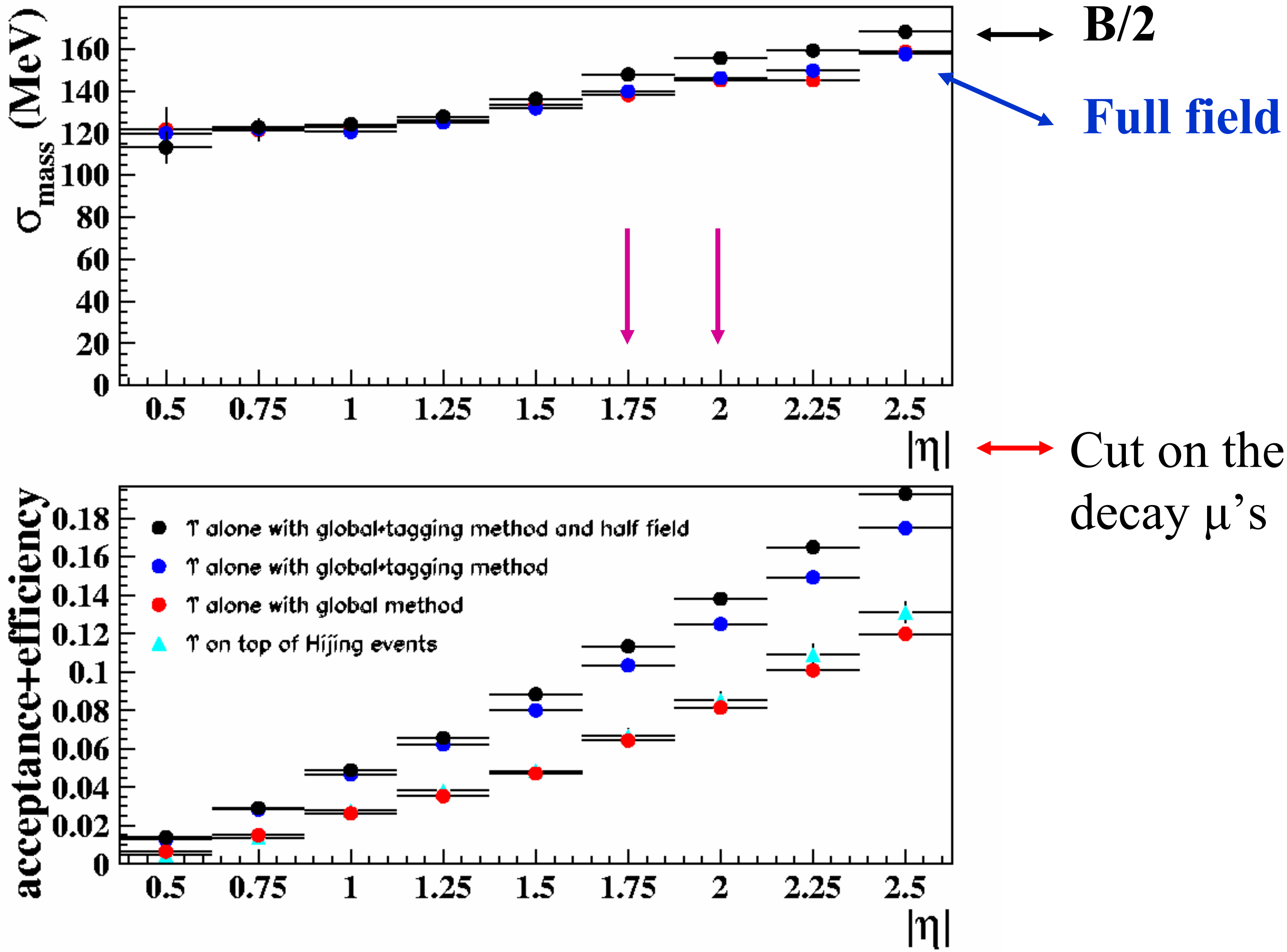
Δη, ΔΦ=difference between ID and μ-spectrometer tracks after back-extrapolation to the vertex for the best χ^2 association.

Acceptance/efficiency for the Υ



Full p_T coverage even if the p_T of the muons > 4 GeV

$\Upsilon \to \mu^+\mu^-$

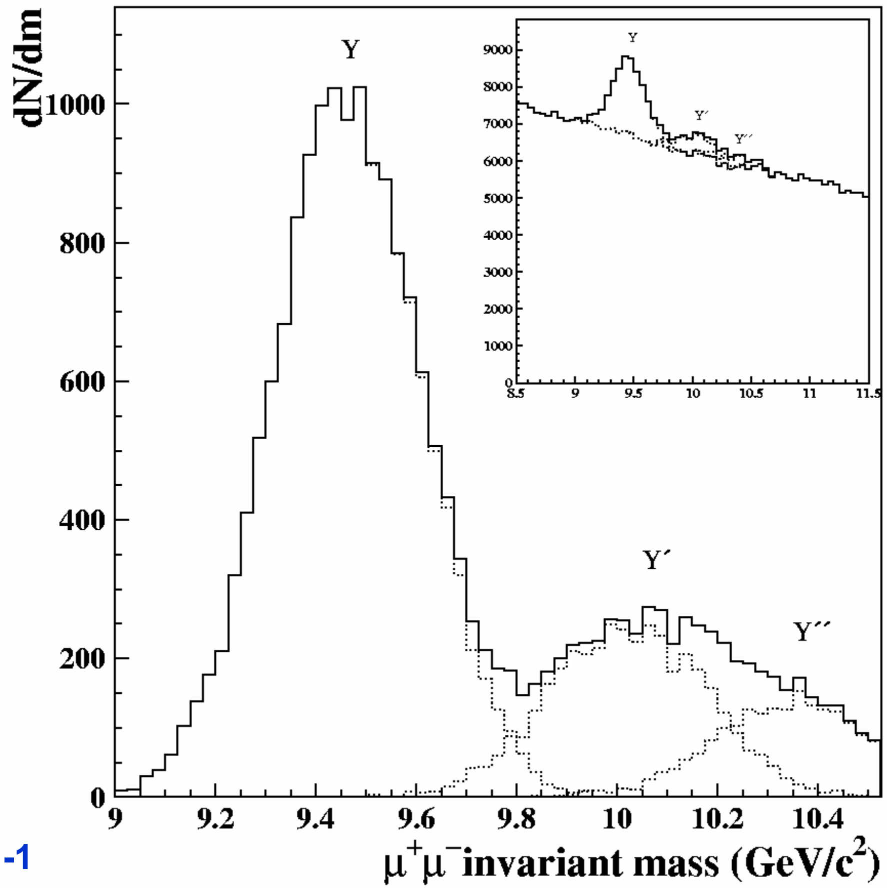


A compromise has to be found between acceptance and resolution to clearly separate ϒ states with maximum statistics (e.g. |η| < 2)

$\Upsilon \rightarrow \mu^+\mu^-$ reconstruction

global fit / global+tag	p_T^{μ} >3 GeV		
	$\lvert\eta\rvert$ <1	$\lvert\eta\rvert$ <2	$\lvert\eta\rvert$ <2.5
Acceptance +efficiency	2.6% 4.7%	8.1% 12.5%	12.0% 17.5%
Resolution	123 MeV	145 MeV	159 MeV
S/B	0.4 0.3	0.3 0.2	0.3 0.2
$S/\sqrt{S+B}$	31 37	45 46	55 55
Rate/month		10000 15000	

$\lvert\eta\rvert$ <2



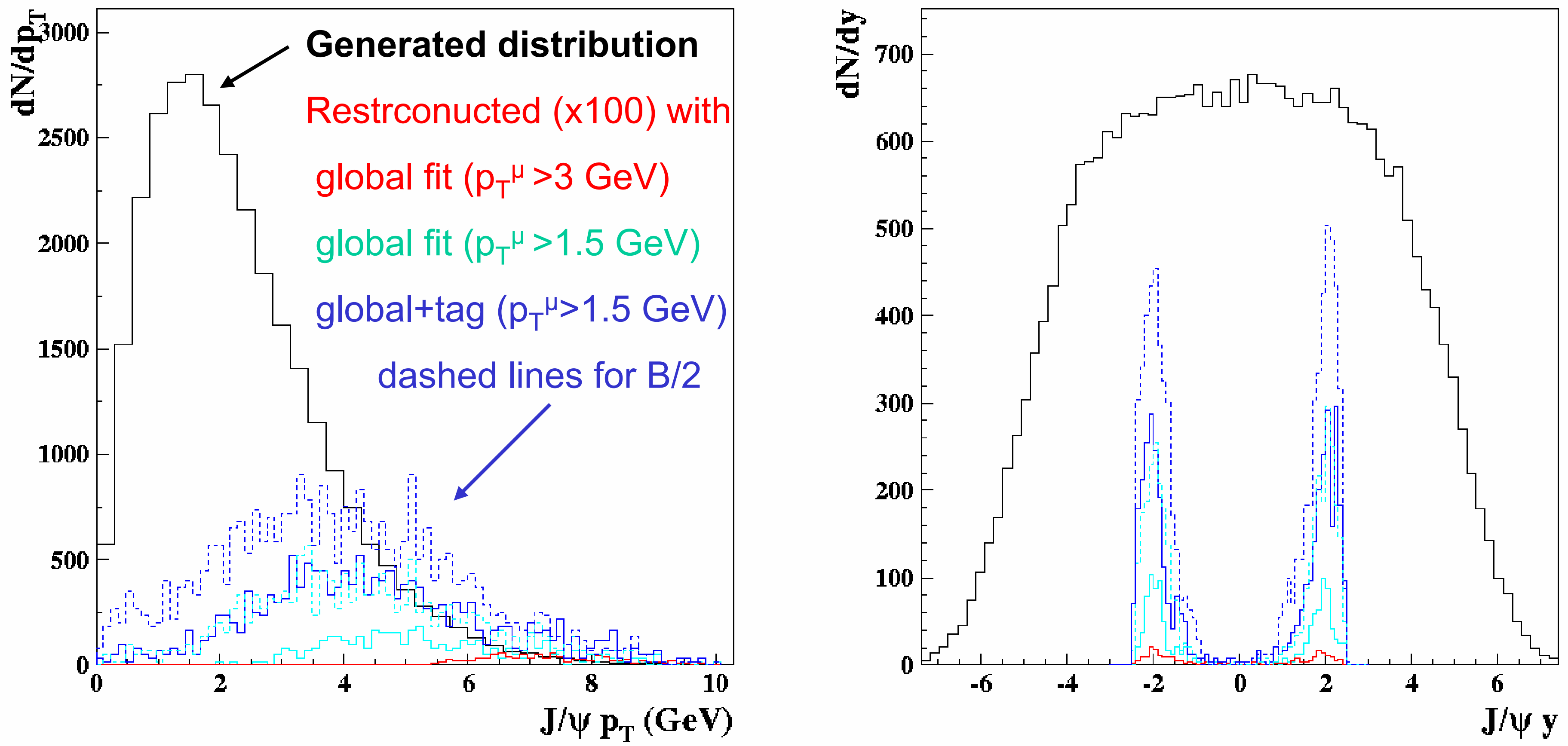
For $\lvert\eta\rvert$ < 2 (12.5% acc+eff) we expect 15K Υ/month of 10^6s at $L=4\times10^{26}$ cm^{-2} s^{-1}

No improvement with the B/2 mode: acceptance/resolution ~ cte …

The Transition Radiation Tracker has not been considered for this study. If N_{ch} allows its use, the mass resolution is improved by 25%

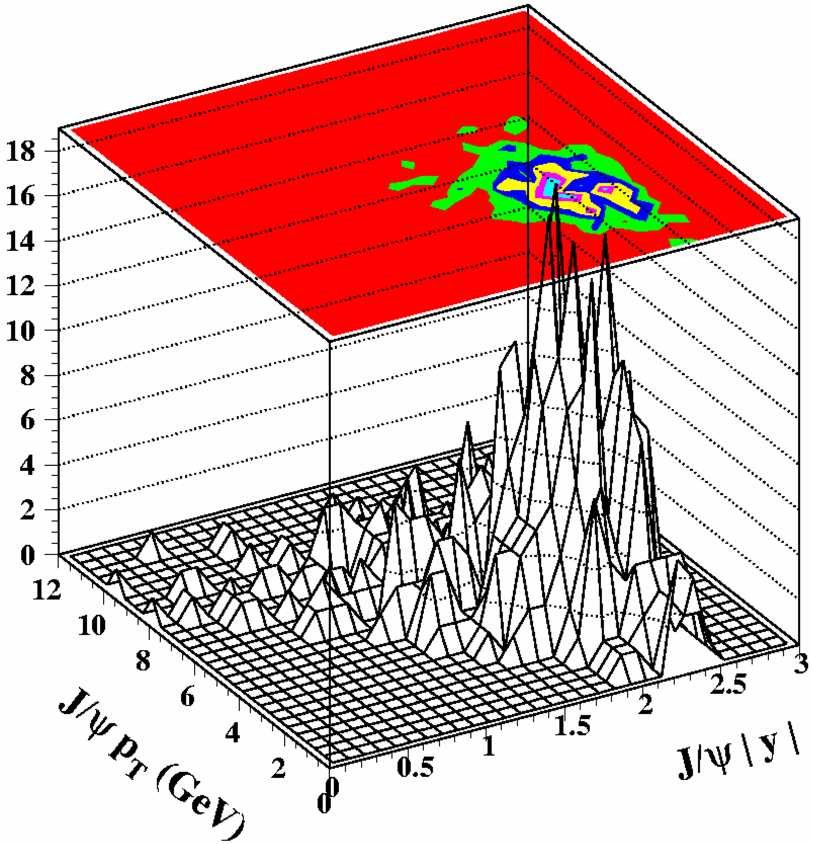
$J/\psi \rightarrow \mu^+\mu^-$

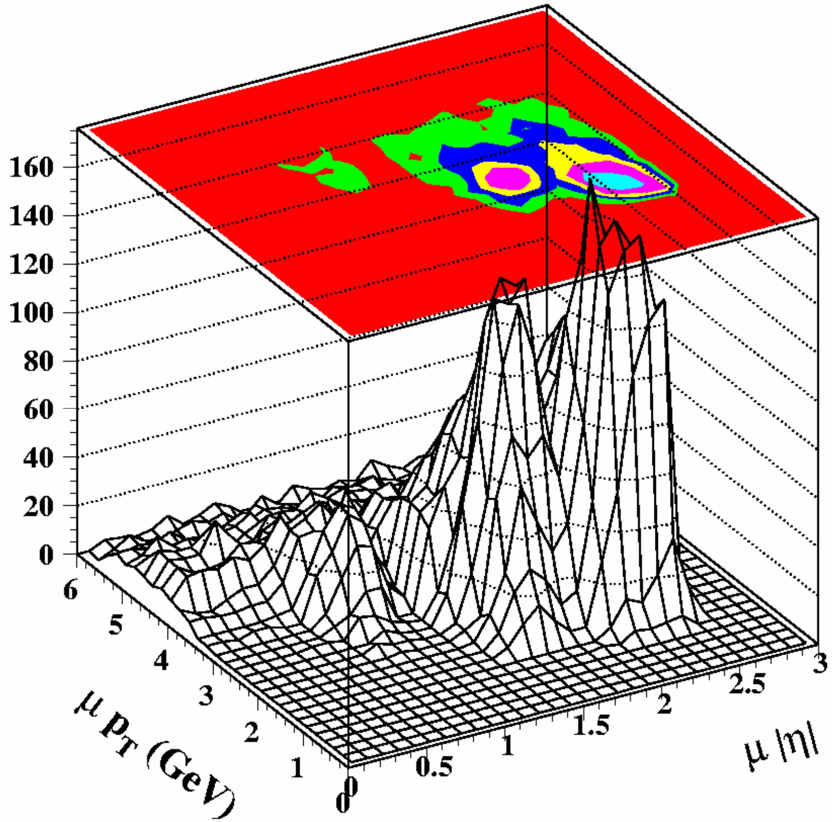
Acceptance/efficiency for the J/ψ:



The full p_T range of the J/ψ is not accessible for $p_T^{\mu} > 3$ GeV, but is accessible for $p_T^{\mu} > 1.5$ GeV. **Acceptance is forward and backward.**

Strong correlation p_T – rapidity:





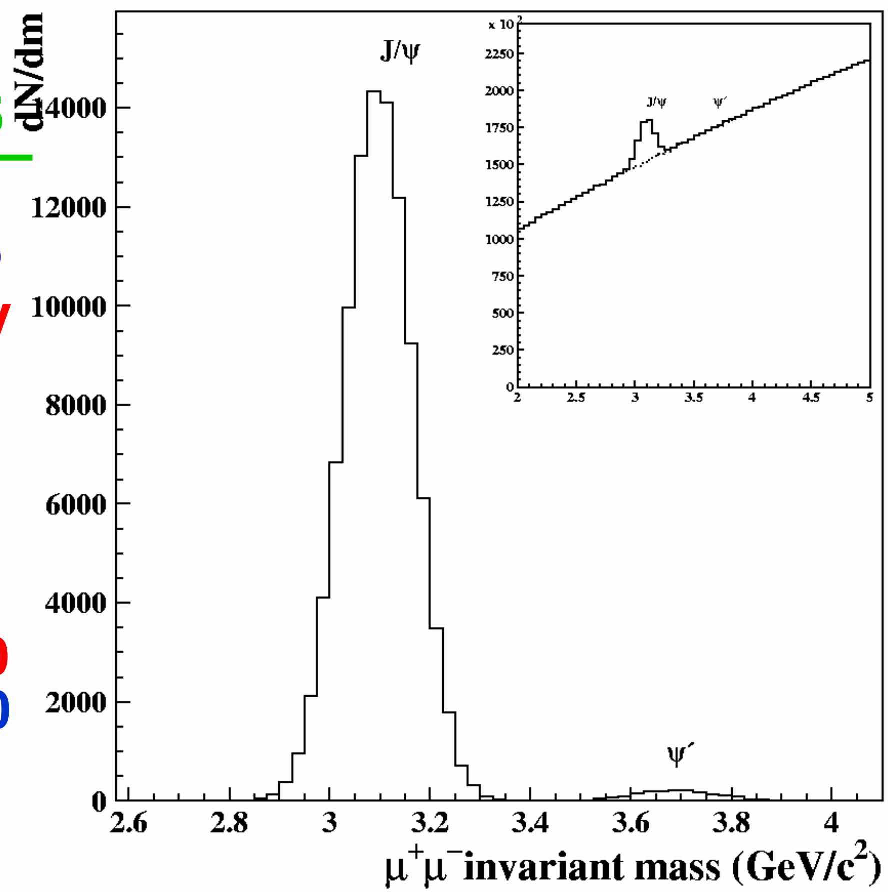
Minimum p of the μ is 3-4 GeV to be measured in the μ-spectrometer

⇔ p_T=3-4 GeV at y=0. A Lorentz-boost is needed for a p_T of 1.5 GeV

$J/\psi \to \mu^+\mu^-$ reconstruction

$|\eta| < 2.5$, $p_T^\mu > 1.5$ GeV

global fit / global+tag	$p_T^\mu > 3$	$p_T^\mu > 1.5$	B/2 $p_T^\mu > 1.5$
Acceptance +efficiency	0.039% 0.055%	0.151% 0.530%	0.529% 1.100%
Resolution	68 MeV	68 MeV	76 MeV
S/B	0.5 0.4	0.2 0.15	0.25 0.15
$S/\sqrt{S+B}$	52 56	72 113	140 164
Rate/month	8000 11000	30000 104000	104000 216000



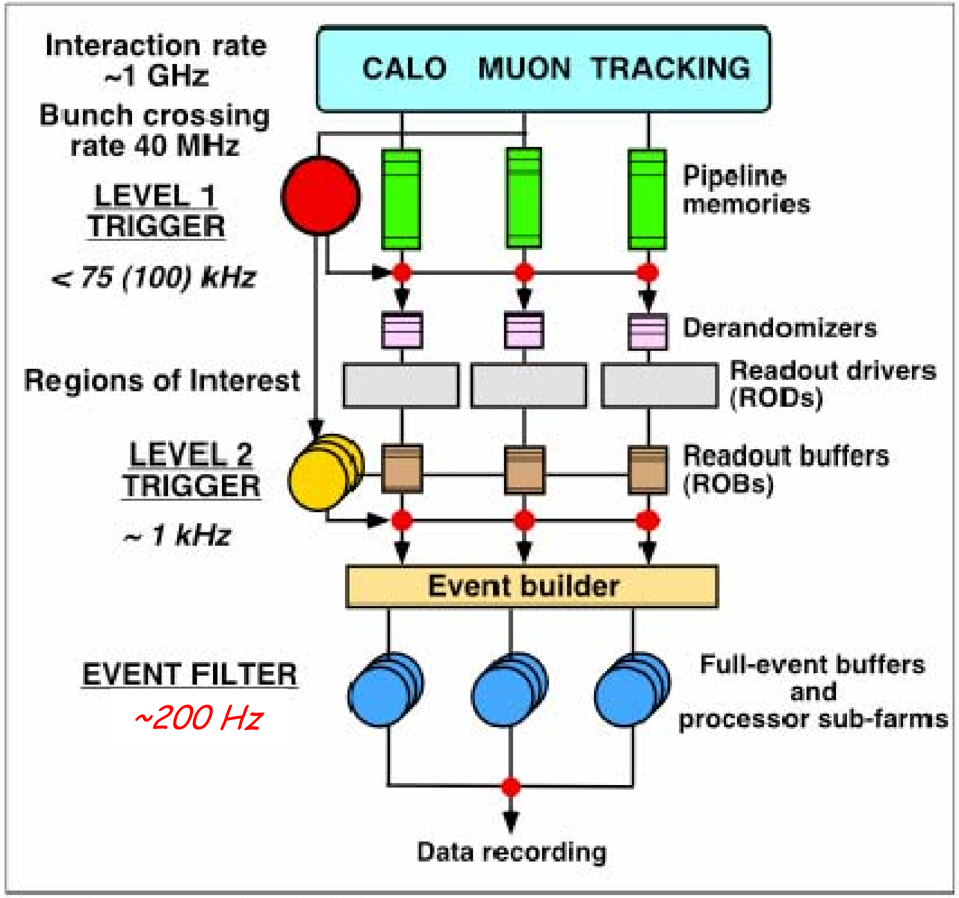
We expect 8K to 216K $J/\psi \to \mu^+\mu^-$ per month of 10^6s at $L = 4\times10^{26}$ cm^{-2} s^{-1}

Resolution is 15% worse, but acceptance is 2-3 times better with B/2. Significance is also much better.

Equivalent acceptance but better S/B and significance for the "global fit, B/2" compared to the global+tag method. Trigger is easier with global fit.

Trigger/DAQ

For Pb-Pb collisions the interaction rate is 8 kHz,
a factor of 10 smaller than LVL 1 bandwidth (75 kHz).



LVL 1 di-μ trigger is based only on ϕ information from μ-trigger chambers for a low p_T cut (toroidal B bending is in η), and defines Regions of Interest.

LVL 2 & 3 are based on reconstruction in the Regions of Interest.

Under study.

The event size for a central collision is ~ 5 Mbytes.
Similar bandwidth to storage as pp implies ~ 50 Hz data recording.

$\Upsilon \rightarrow e^+e^-$, $J/\psi \rightarrow e^+e^-$

The Transition Radiation Tracker can be used fully if N_{ch} is low enough
partially in central Pb+Pb

- **as a tracker:**

simplest strategy for central Pb+Pb: keep the 2 first time steps (out of 13) of the drift tubes

=> occupancy of 30% as in pp

=> 4 to 6 additional hits for track reconstruction

=> improves mass resolution, reduces fake tracks

- **as a transition radiation detector:**

defines a road where to look for transition radiation to identify electrons

=> the ATLAS e^+e^- trigger with p_T> 2 GeV could be used to get Υ and $J/\psi \rightarrow e^+e^-$

Scenario under evaluation

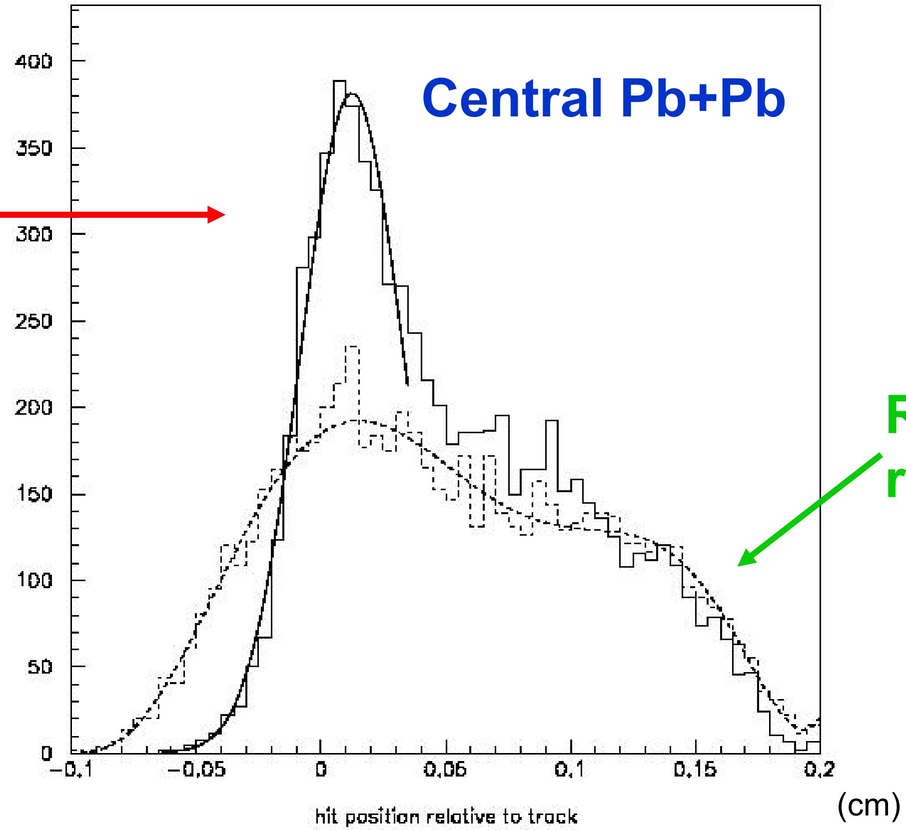
TRT as a tracker

Better strategy to optimize the usage of drift time measurements from the TRT: **select "in-time" hits for each track candidate.**

Residuals to the truth track

Still ~30% of "in-time" hits

twice better than simplest strategy



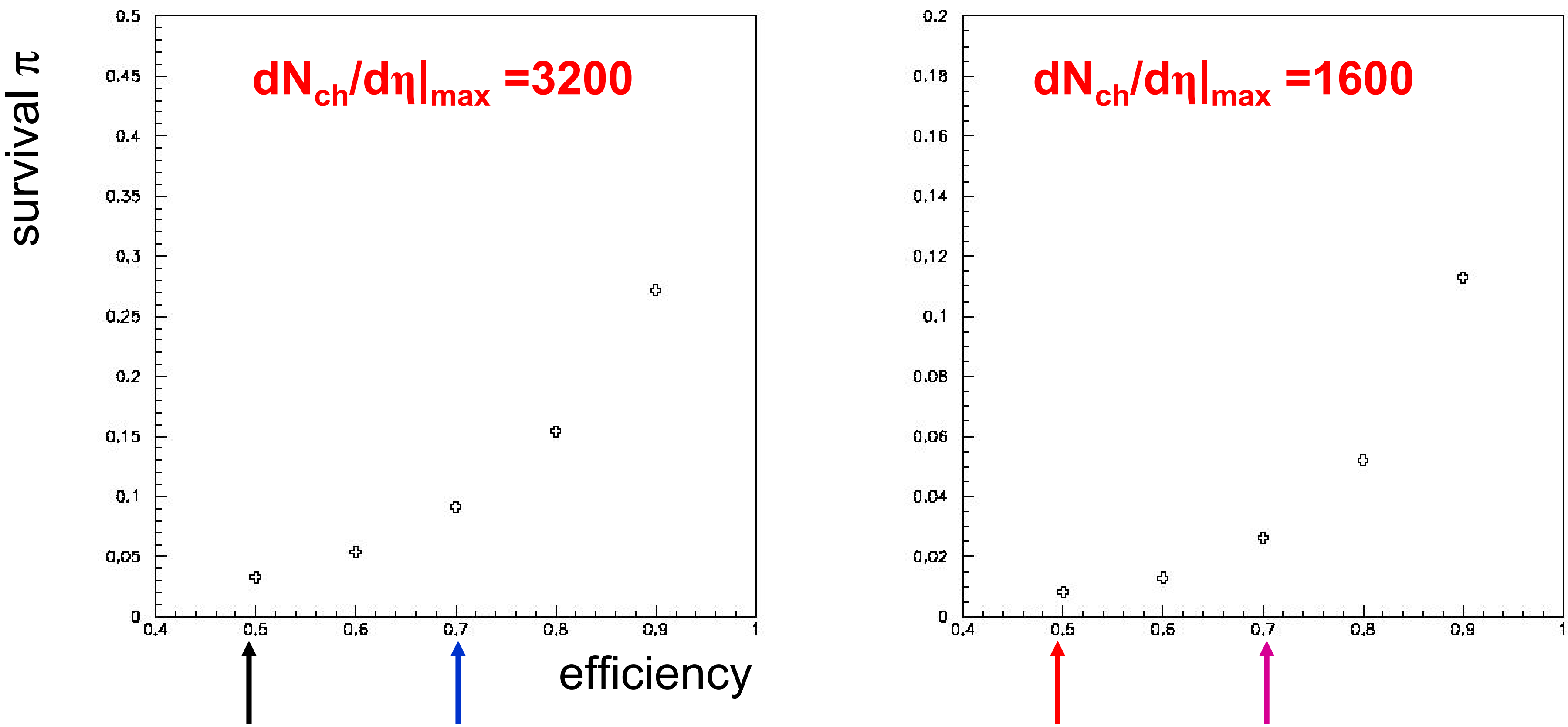
Residuals to a random track

Needs a dedicated track finding code to maximize the number of "in-time" hits and refine the trajectory.

Estimation valid for central Pb+Pb, much better otherwise

Performances of the TRT

Fraction of survival π vs electron efficiency:



A rejection factor of 20-100 against π can be achieved for an electron efficiency of 50% if $dN_{ch}/d\eta|_{max}$ =3200-1600

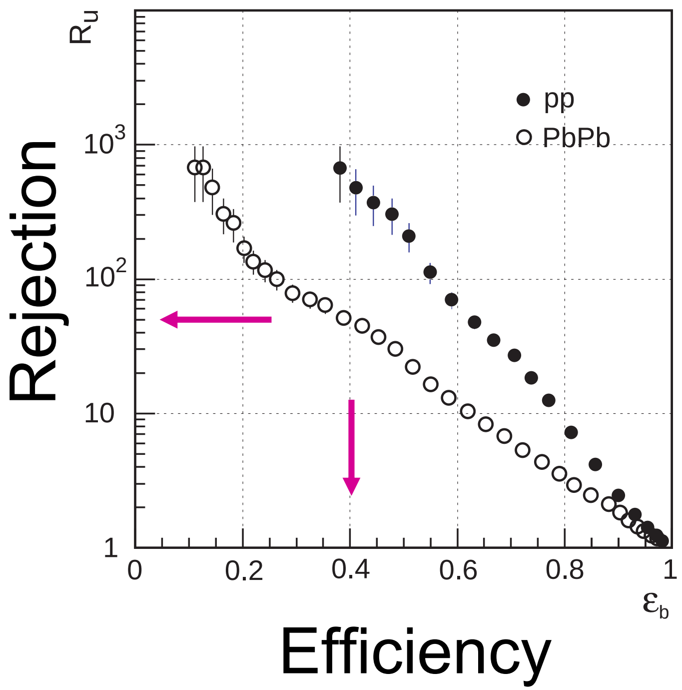
But the rejection is 100-1600 against π π for an e pair efficiency of 50%

Heavy flavors: b-tagged jets

Motivation: radiative energy loss is different for heavy/light quarks.

1st attempt based on impact parameter cuts

Rejection factors against light quarks vs b-tagging efficiency:



To evaluate b - tagging performance:

- $pp \to WH \to l\nu b\bar{b}$ and $l\nu u\bar{u}$ on top of HIJING background events.
- A displaced vertex in the Inner Detector has been searched for.

Rejection factor against u- jets ~ 50 for b-tagging efficiency of 40% in central Pb-Pb collisions

Should be improved when combined with μ tagging

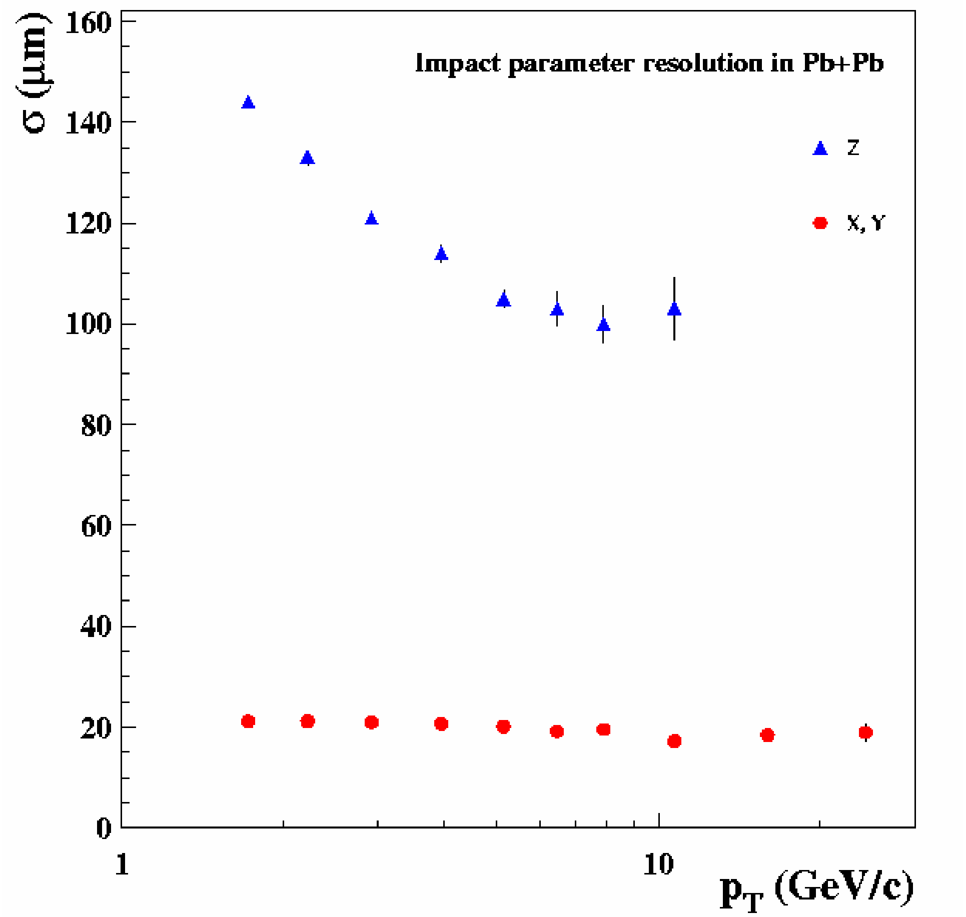
Open heavy flavors

B and D meson decays appear at secondary vertices, determined by lifetime and Lorentz boost.

Impact parameter resolution for reconstructed tracks from central Pb+Pb collisions:

=> semi-leptonic B, D decays and B-chain channel can be identified by displaced vertices via μμ, possibly μe and ee

under study



Summary

- Except for TRT, detector performances are not significantly deteriorated in central Pb-Pb compared to pp collisions.
- Heavy quarkonia physics (suppression in dense matter) well accessible,

  capability to measure and separate Υ and Υ',

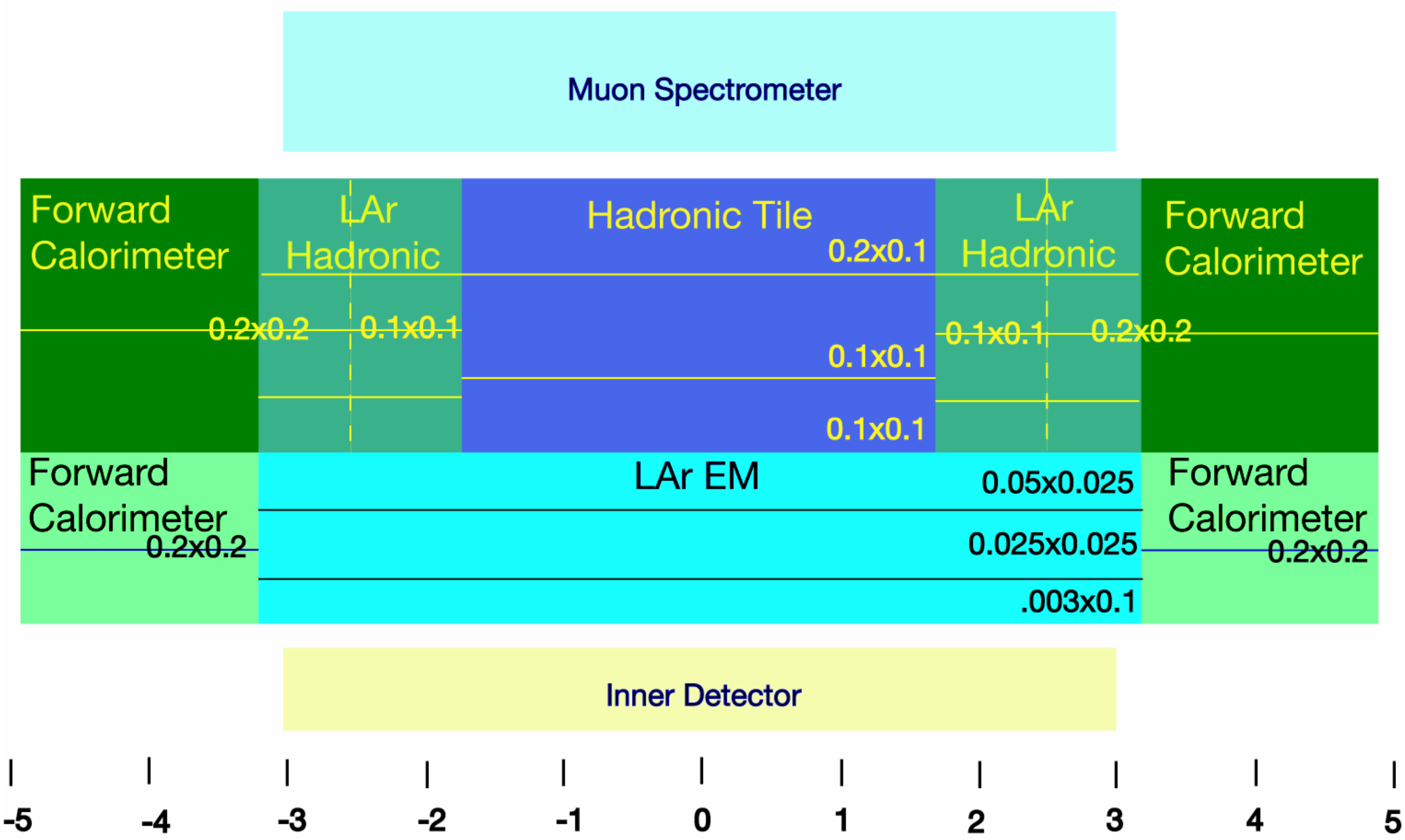
  to measure the J/ψ using a specially developed μ tagging method,

  and to reduce background from π and K to an acceptable level .
- 4 different scenarios, including μ–tagging and reduced toroidal field, are under study.

  Final choice will depend on the measured charged multiplicity.
- A study of the capability of observing Υ, $J/\psi \rightarrow e^+e^-$ and heavy flavor production is under way.

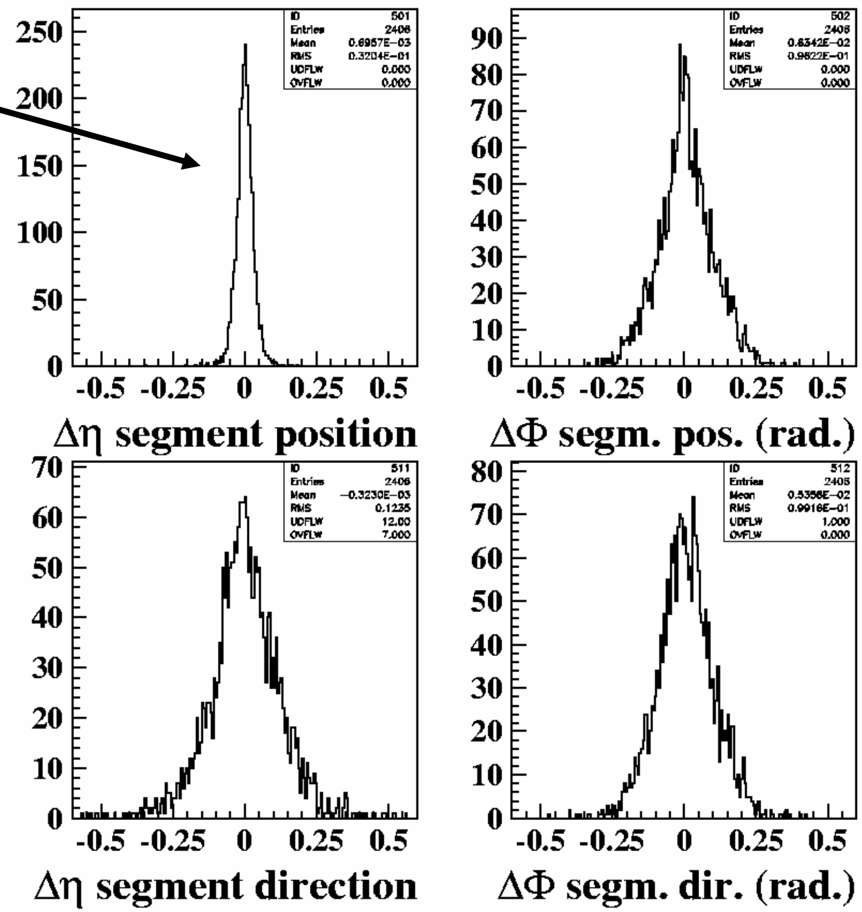
Extra slides:

ATLAS Calorimeters



Tagging method using track segments not fully traversing the μ-spectro:

Single Upsilons



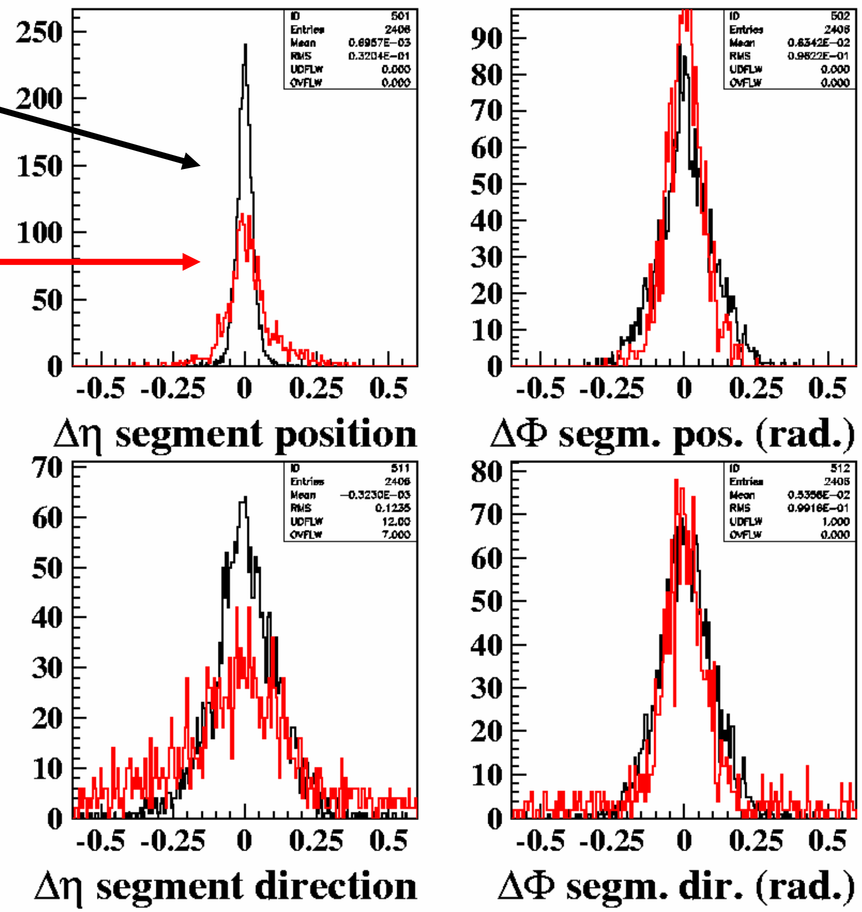
Δη, ΔΦ=difference between isolated μ-segments and ID tracks after extrapolation to the μ- spectrometer for the best spatial association.

Tagging method using track segments not fully traversing the μ-spectro:

Single Upsilons

HIJING background

Half μ's from c, b decays, half from π, K decays for p_T>3 GeV.



Background rejection based on Δη x ΔΦ segment position and direction cuts.

Δη, ΔΦ=difference between isolated μ-segments and ID tracks after extrapolation to the μ- spectrometer for the best spatial association.

$\Upsilon \rightarrow \mu^+\mu^-$ reconstruction

global fit / global+tag	p_T^μ >3 GeV $|\eta|$ <1	p_T^μ >3 GeV $|\eta|$ <2	p_T^μ >3 GeV $|\eta|$ <2.5	B/2 p_T^μ >3 GeV $|\eta|$ <1	B/2 p_T^μ >3 GeV $|\eta|$ <2	B/2 p_T^μ >3 GeV $|\eta|$ <2.5
Acceptance +efficiency	2.6% 4.7%	8.1% 12.5%	12.0% 17.5%	2.6% 4.9%	8.9% 13.8%	13.4% 19.3%
Resolution	123 MeV	145 MeV	159 MeV	126 MeV	162 MeV	176 MeV
S/B	0.4 0.3	0.3 0.2	0.3 0.2	0.55 0.3	0.3 0.2	0.3 0.2
$S/\sqrt{S+B}$	31 37	45 46	55 55	34 37	48 50	60 60
Rate/month		10000 15000			10800 16800	

S/B and significance are equivalent or slightly better with B/2

Resolution is 10% worse, acceptance 10% better,
but no difference for $|\eta| < 1$

The B/2 mode is not attractive for the Υ.