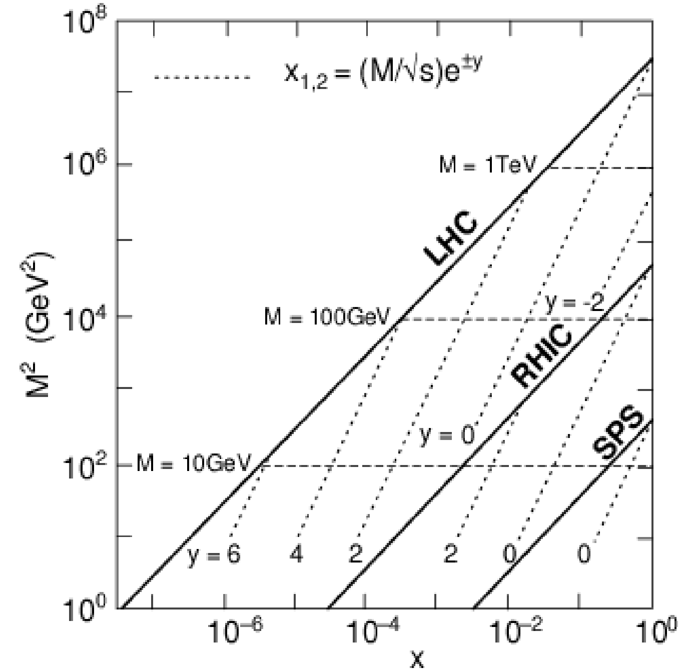
«Day-one» pp @ 14 TeV physics with the ALICE Muon Spectrometer

Outline:

- "Day-one" scenario of data taking
- Physics topics with pp collisions
- Results on selected physics channels
- Conclusion

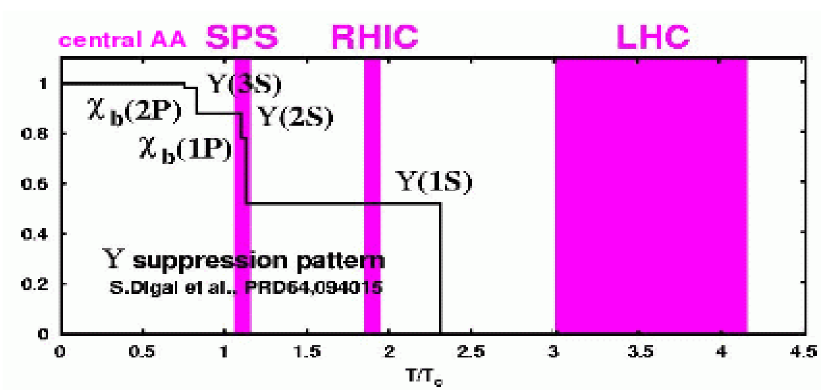
Specificities of the LHC energy range

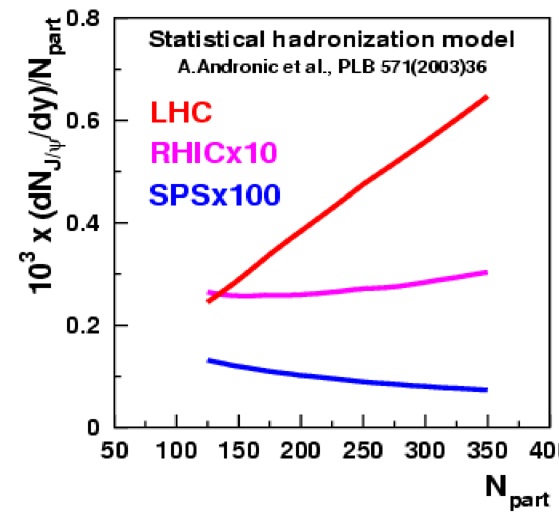
Pb/Au+Pb/Au (b = 0)	SPS	RHIC	LHC
$\sqrt{s}(GeV)$	17	200	5500
$(dN_{ch}/dy)_{y=0}$	500	850	2000-4000
$\tau^0_{QGP}(fm/c)$	1	0.2	0.1
T_{QGP}/T_c	1.1	1.9	3.0-4.2
$\epsilon(GeV/fm^3)$	3	5	15-60
$\tau_{QGP}(fm/c)$	≤ 2	2-4	≥ 10
$\tau_f(fm/c)$	~ 10	20-30	30-40
$V_f(fm^3)$	$\sim 10^3$	$\sim 10^4$	$\sim 10^5$
$N_{c\bar{c}}/event$	0.2	10	115
$N_{b\bar{b}}/event$		0.05	5



CERN/LHCC 2003-049

- New kinematical region: x down to 10^{-5}
- Large primary production
- Large secondary production of charmonia
- Υ(1S) melts only at LHC
- Large production of $W^{\pm}$ bosons





pp @ 14 TeV: scenario of data taking with the ALICE Muon Spectrometer

- "Nominal" scenario: $L = 3.10^{30}$ cm^{-2} s^{-1}, $T = 10^{7}$ s (7 months), $L_{int} = 30$ pb^{-1}
- "Day-one" scenario: $L = 1.10^{30}$ cm^{-2} s^{-1}, $T = 7.2.10^{5}$ s (20×10h), $L_{int} = 0.72$ pb^{-1}

→ 70000 Hz, ~5.10^{10} collisions

Trigger	Rate (Hz)	Collisions
Single μ	650	$5 \cdot 10^{8}$
Dimuon	9.5	$7 \cdot 10^{6}$
Low Single μ ($p_t > 1$ GeV/c)	175	$1.5 \cdot 10^{8}$
Low Dimuon ($p_t > 1$ GeV/c)	3.6	$3 \cdot 10^{6}$
High Single μ ($p_t > 2$ GeV/c)	80	$6 \cdot 10^{7}$
High Dimuon ($p_t > 2$ GeV/c)	1.8	$1.5 \cdot 10^{6}$

Readout detectors:

MUON+ITS (Vertex)+V0 (Luminosity)+T0+TOF+FMD+PMD+ZDC+PHOS

pp trigger inputs

Physics topics with pp data

- Heavy flavors
  - ✓ Open charm via single muons & dimuons
  - ✓ Open beauty via:
    - ✗ Single muons
    - ✗ US muon pairs
    - ✗ LS muon pairs
    - ✗ B $\rightarrow$ J/Ψ in tri-muon events
  - ✓ Charm & beauty via electron-muon coincidences
  - ✓ Charmonia & bottomonia: yields & polarization

- Low mass resonances
  - ✓ ρ, ω, ϕ via US muon pairs

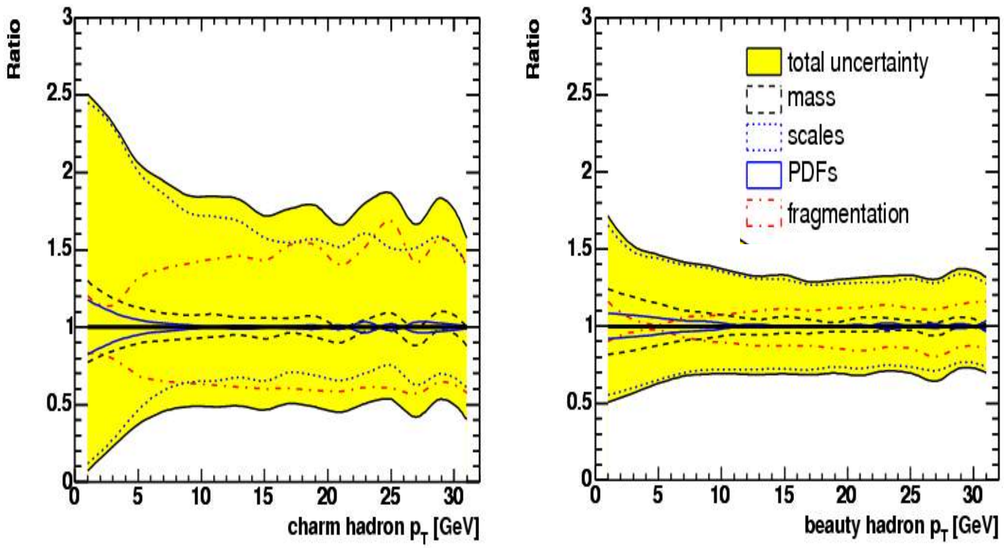
- Vector bosons
  - ✓ W yield via single muons
  - ✓ Z yield via US muon pairs

— "day-one"
— "day-one" (to be confirmed)
— "nominal"

Open heavy flavors in pp @ 14 TeV: motivations

NLO predictions for pp @ 14 TeV (ALICE baseline)

	Charm	Beauty
$\sigma_{pp}^{Q\bar{Q}}$ (mb)	11.2	0.51
$N_{pp}^{Q\bar{Q}}$	0.16	0.0072



Theoretical uncertainties on absolute values: a factor 2-3

CERN/LHCC 2005-014 & CERN/LHCC 2005-030

Heavy flavor measurement in pp @ 14 TeV: important test of pQCD in a region of large Q^2 & small Bjorken-x values (down to x ~ 10^{-5})

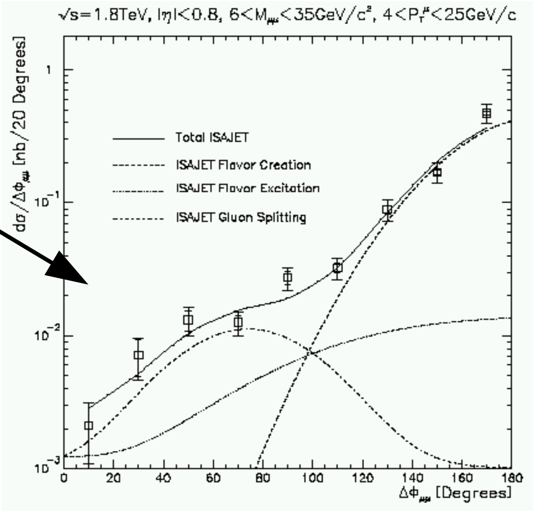
➔ measuring $\sigma(b\bar{b}, c\bar{c})$ in pp @ 14 TeV is top priority

Theoretical uncertainties on σ(5.5 TeV)/σ(14 TeV) ratio are a few %

Relevance of measuring σ(b) in pp collisions in the first days

- Measurement of σ(b) in pp collisions mandatory for understanding:
  - ✓ σ(b) in pA & AA (shadowing, quenching)
  - ✓ σ(ϒ) in pp, pA & AA (production, absorption, suppression?)
    → most natural normalization for ϒ production
  - ✓ σ(J/Ψ) in pp & (pA, AA): N(b→J/Ψ)/N(direct J/Ψ) ~ 22% in 4π

- Open beauty allows to unravel production processes via correlations



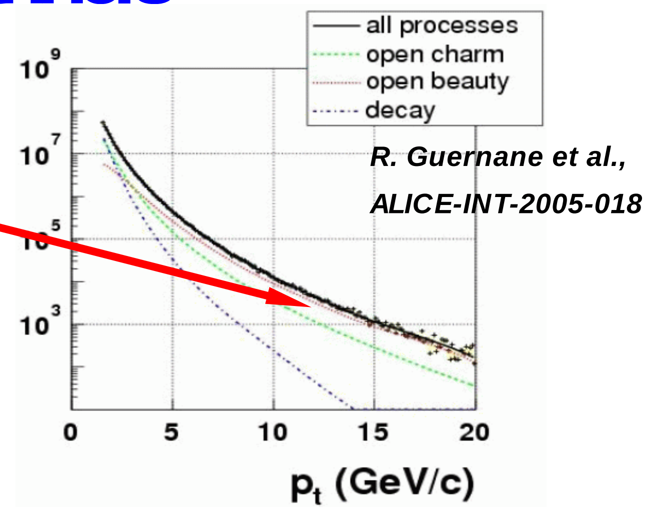
- Open heavy flavor statistics much larger than quarkonia statistics:

$$\frac{N(\Upsilon)\to l^+l^-}{N(b\bar{b})\to l^\pm} \simeq \frac{1}{570} \times \frac{2.4\%}{20\%} \simeq \frac{1}{4700}$$

➔ σ(b) = "day-one" physics in pp collisions at LHC

Open beauty measurement in the semi-muonic channels

- **Single muons (à la UA1, CDF & D0): semimuonic decays $B \to \mu$ & $B \to D \to \mu$**



- **Unlike-sign dimuons**

B-chain:

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

$\hookrightarrow \mu^+ + X$

BB-diff:

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

- **Like-sign dimuons**

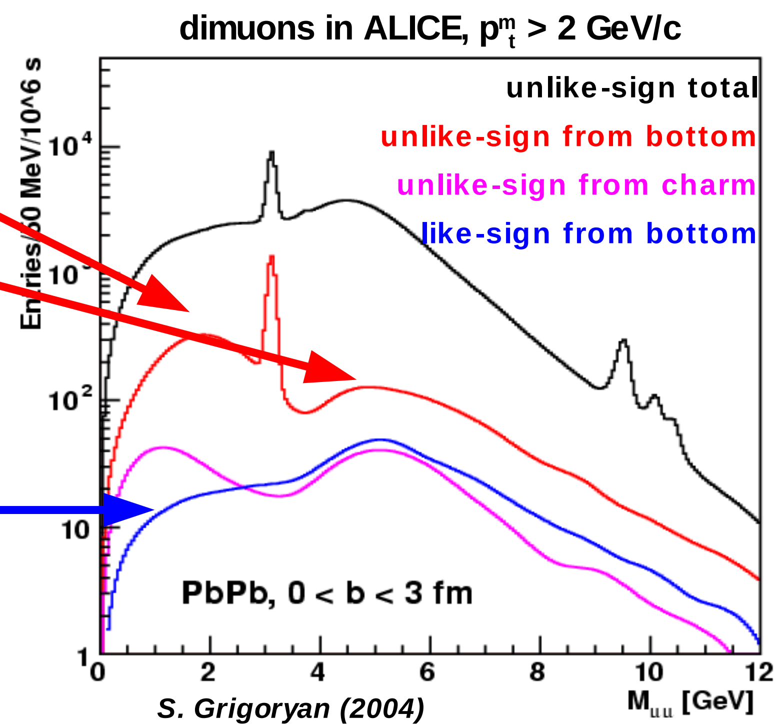
$B \to D$ decay:

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

$\hookrightarrow \mu^- + X$

B^0 oscillations:

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



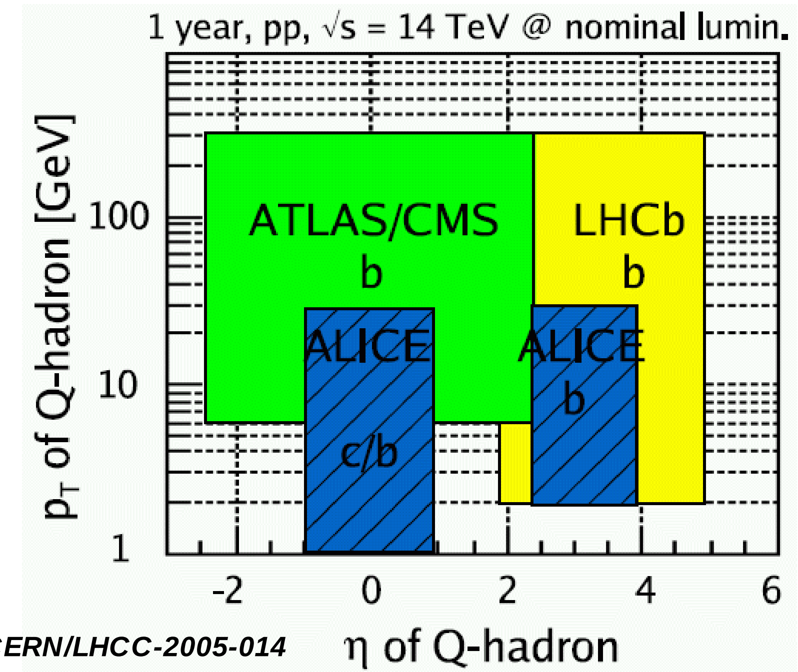
- **$B \to J/\Psi$ in 3-muon p+p events**

Open beauty production in pp @ 14 TeV

Method developed by UA1, used by CDF & D0 and should work in Pb+Pb (5%) @ 5.5 TeV

C. Albajar et al., Phys. Lett. B 213 (1988) 405

R. Guernane, P. Crochet, A. Morsch, E. Vercellin, ALICE-INT-2005-018; CERN/LHCC-2005-030



CERN/LHCC-2005-014

Expected statistics in MUON arm

$b \to \mu X$	Nominal	"Day-one"
1.5-3 GeV/c	$8.3 \cdot 10^7$	$2.0 \cdot 10^6$
3-6 GeV/c	$2.6 \cdot 10^7$	$6.3 \cdot 10^5$
6-9 GeV/c	$2.2 \cdot 10^7$	$5.3 \cdot 10^4$
9-20 GeV/c	$4.7 \cdot 10^5$	$1.1 \cdot 10^4$

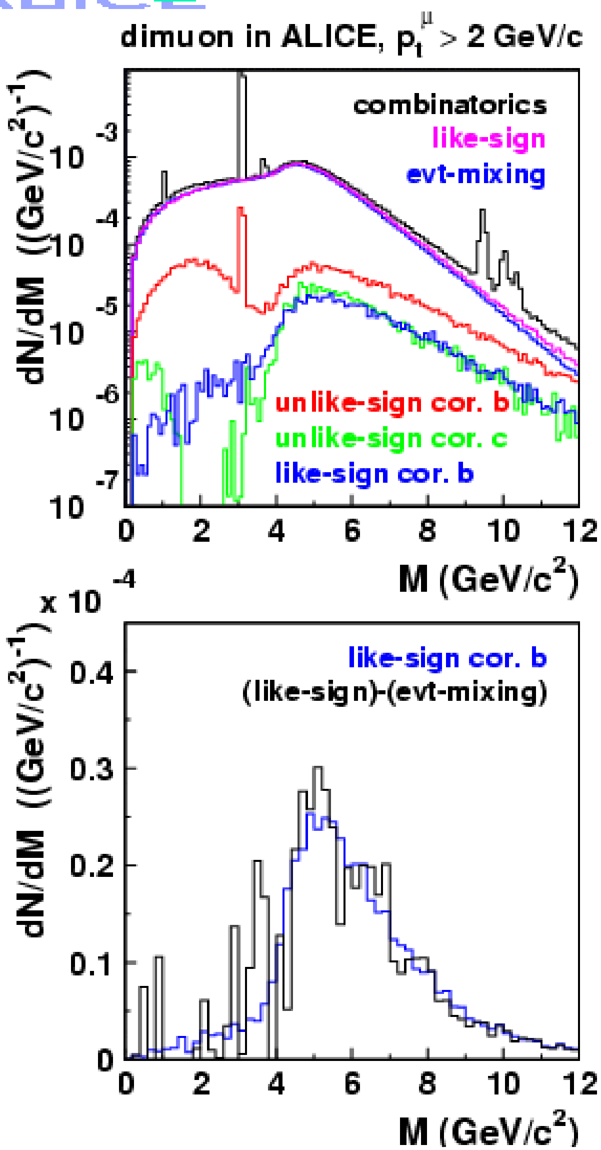
$b \bar{b} \to \mu^+ \mu^-$	Nominal	"Day-one"
0.3-5 GeV/c^2	$7.3 \cdot 10^5$	$1.8 \cdot 10^4$
5-20 GeV/c^2	$1.2 \cdot 10^5$	$3.0 \cdot 10^3$

N. Bastid & P. Crochet, PWG3 meeting, CERN, Feb. 06

- **Complementarity between LHC experiments**
- **Acceptance down to low p_t with ALICE**

Open beauty production via (di)muons is a "day-one" physics

b-hadron cross section from like-sign dimuons



B → D decay:

$$\pi^- + D^0 \longleftarrow B^- B^+ \longrightarrow \mu^+ + \bar{D}^0 + \nu_\mu$$

$$X + \mu^+ \hookleftarrow \qquad\qquad \hookrightarrow \mu^- + X$$

B^0 oscillations:

$$X + \mu^- \longleftarrow \bar{B}^0 B^0 \longrightarrow \bar{B}^0 \longrightarrow \mu^- + X$$

✓ Method relies on characteristics of combinatorial background at high invariant mass

- like-sign correlated b ~ unlike-sign correlated c
- B^0 oscillations ~ 30% of total like-sign correlated

✓ Like-sign correlated component accessible by the subtraction of event-mixing distribution from the like-sign distribution

- clean signal (D mesons do not oscillate)

P. Crochet & P. Braun-Munzinger, Nucl. Instrum. Meth. A 484 (2002) 564

Secondary J/Ψ from 3-muon events in p-p w/o secondary vertex reconstruction

- **Dimuon events**:
  - ✓ 85% of direct J/Ψ
  - ✓ 15% of J/Ψ from b decay

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

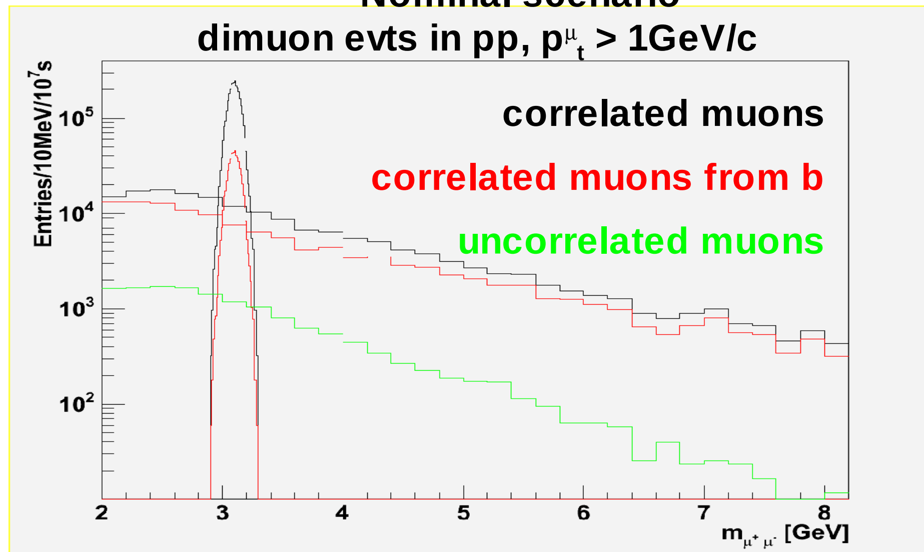
$$\mu^{\pm} + X \longleftarrow B\bar{B} \longrightarrow J/\psi + X$$
$$\hookrightarrow \mu^{+} + \mu^{-}$$

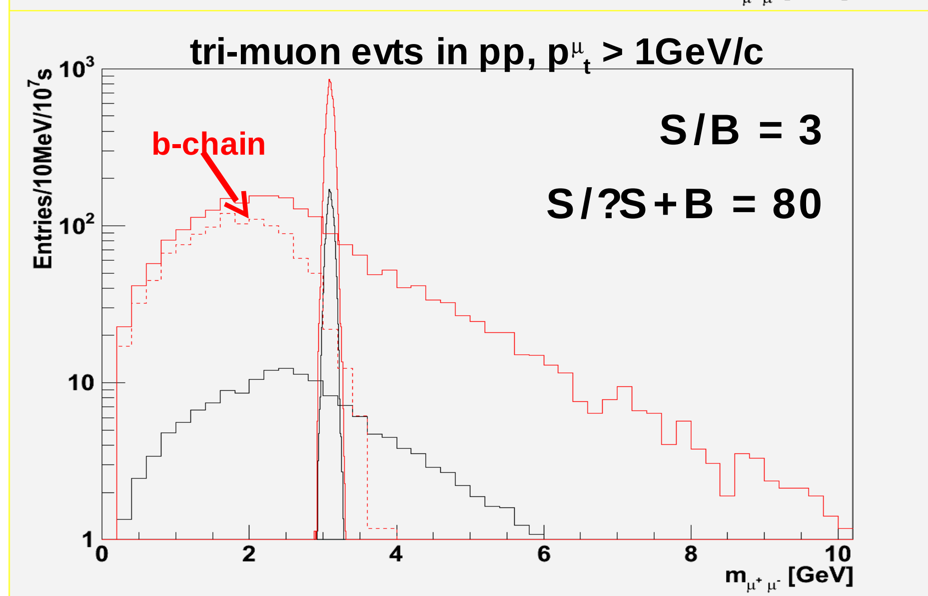
- **3-muon events:**
  - ✓ 15% of direct J/Ψ
  - ✓ 85% of J/Ψ from b decay

Expected statistics:

- ✓ Nominal scenario: ~ 8500 J/Ψ
- ✓ "Day-one" scenario: ~ 200 J/Ψ

Nominal scenario



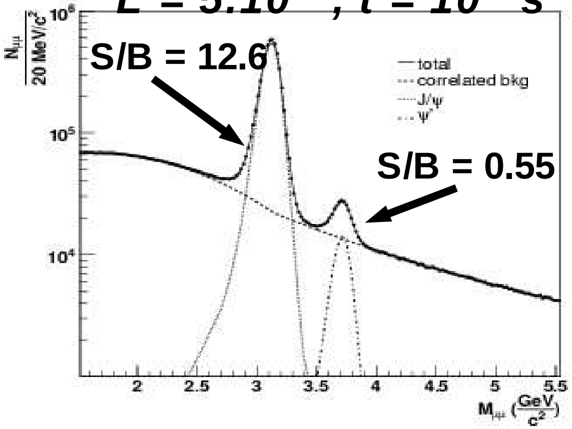


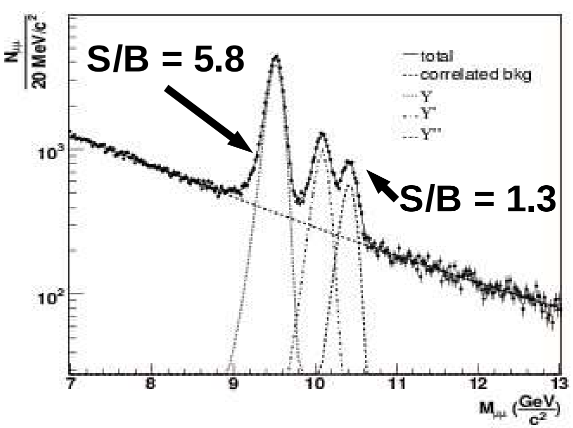
A. Morsch, Berg-en-dal , South Africa (2004) & ALICE PPR Vol. II

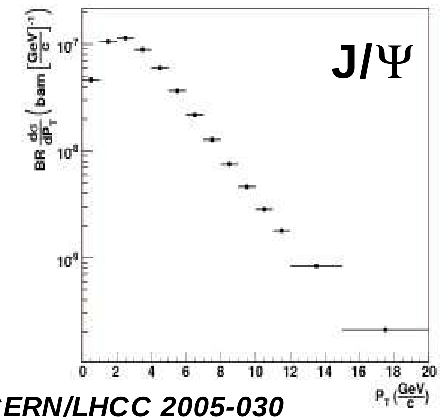
Quarkonia production in pp collisions

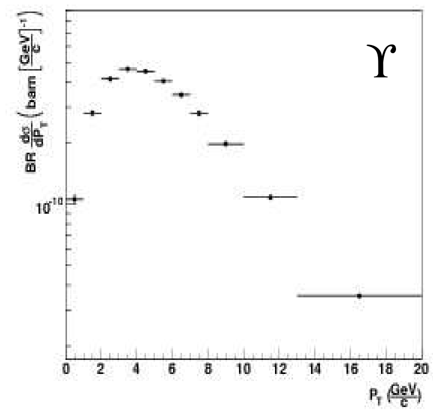
- **Sensitive probe of collision dynamics at short & long time scales**
- **In pp collisions: baseline for heavy-ion data**
  information on production mechanisms
  insight to PDF at very small x

L = 5.10 ^{30}, t = 10 ^{7} s









CERN/LHCC 2005-030

Measurement over a wide p_t range: up to ~12-14 GeV/c

Expected yields

	Nominal	Day-one
J/ψ	$4.76 \cdot 10^6$	$6.7 \cdot 10^4$
ψ'	$1.22 \cdot 10^5$	$1.76 \cdot 10^3$
Υ	$44.7 \cdot 10^3$	$6.4 \cdot 10^2$
Υ'	$11.4 \cdot 10^3$	$1.6 \cdot 10^2$
Υ''	$6.9 \cdot 10^3$	$1.0 \cdot 10^2$

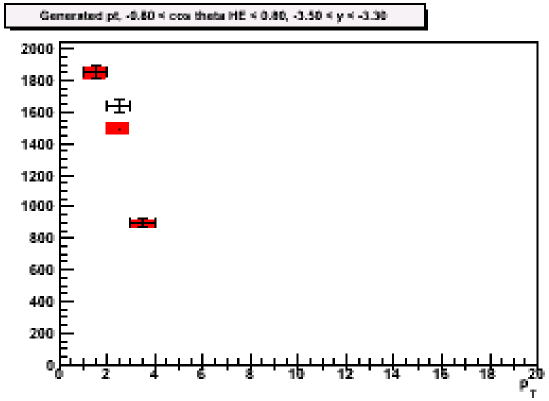
J/Ψ via US dimuons is a“day-one” physics channel

More results on Υ: talk from F. Guerin

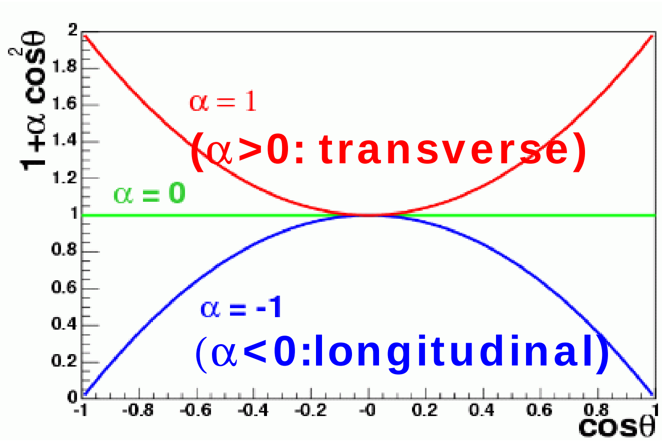
J/Ψ polarization in pp collisions

- In AA collisions: sensitive probe of QGP
- In pp collisions: test of quarkonia production mechanisms
- Not yet clear physics picture from E866, CDF, NA60, PHENIX

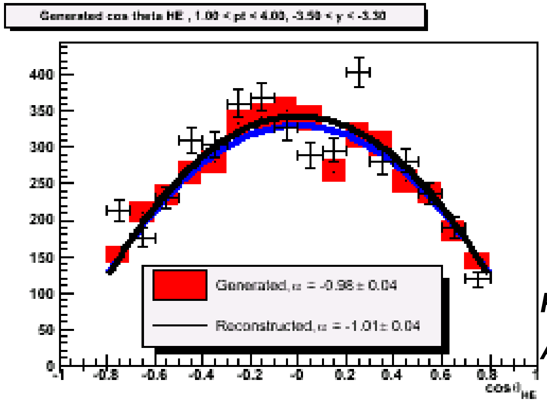
➔ ALICE should help to clarify the puzzle



J/Ψ polarization reconstructed from angular distribution of μ^+ in the rest frame of J/Ψ



$$\frac{d\sigma}{dcos\theta} \sim 1 + \alpha cos^2\theta$$



Error on α: ~5% for ~16500 J/Ψ

R. Arnaldi, E. Scomparin, ALICE Week, CERN, March 06

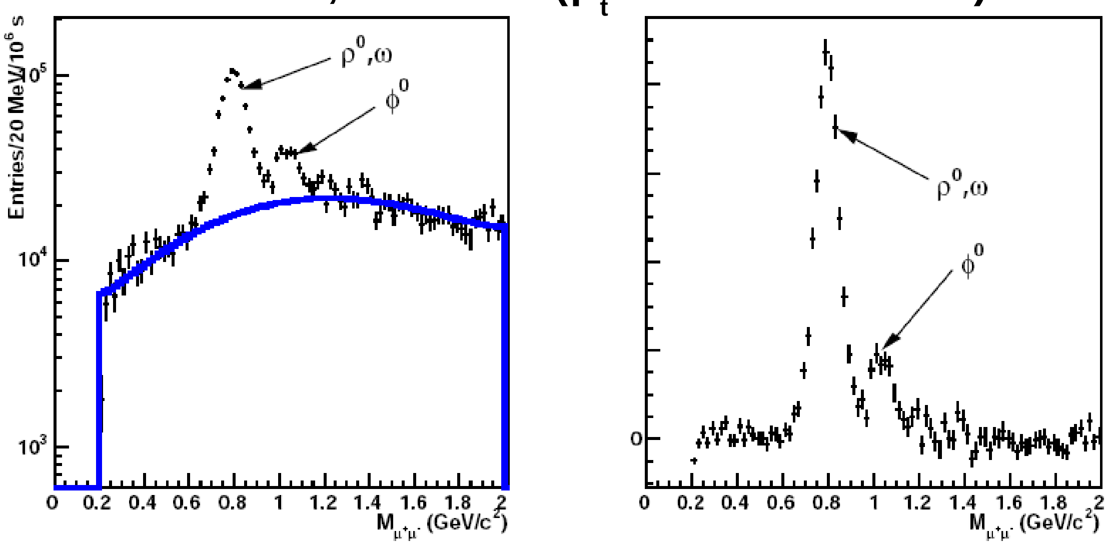
Study of J/Ψ polarization should be feasible in the "day-one" scenario

More results: talk from S. Gadrat

Low mass resonances in pp collisions

- Probe in-medium effects & chiral symmetry restoration
- In pp: baseline for AA

L = 1.10[30], t = 10[6] s (p$_t$ cut = 0.5 GeV/c)



B. Rapp, PhD thesis (2004), Univ. Claude Bernard, Lyon

Expected yields in "day-one" scenario

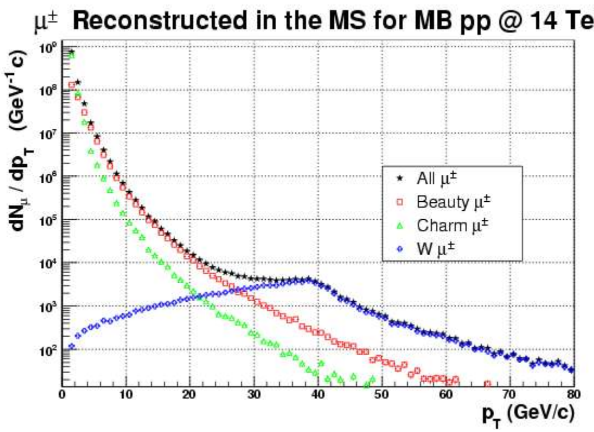
	S	S/B
ρ	$7.0 \cdot 10^4$	0.5
ω	$2.6 \cdot 10^5$	4
ϕ	$5.7 \cdot 10^4$	0.75

Production of low mass resonances = "day-one" physics channel

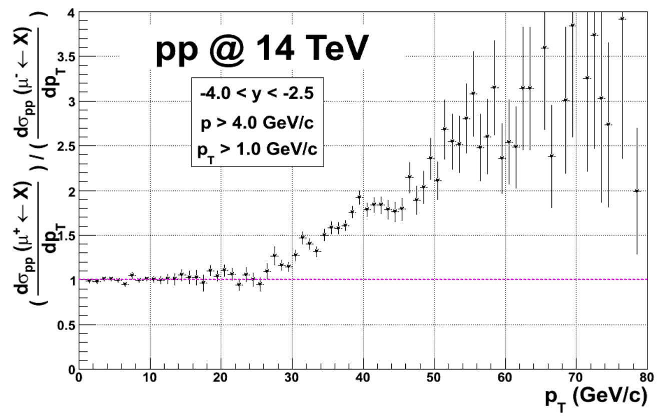
More results: talk from R. Tieulent

W± production in pp collisions

- Measurement of W± yields in pp collisions mandatory to:
  - ✓ probe PDF at $Q^2 \sim M^2_W$ in a low Bjorken-x range ($\sim 10^{-4}$-10^{-3})
  - ✓ understand yields in pA & AA collisions
- Measurement with ALICE at forward rapidities: → unique @ LHC



$W^{\pm} \rightarrow \mu^{\pm}X$ dominate the high p_t range



Promising probe of W± production

Expected muon yields

	Nominal	Day-one
All p_t's	$1.05 \cdot 10^5$	~ 2500
(30-50) GeV/c	$5.0 \cdot 10^4$	~ 1200

Z. Conessa del Valle, HQ'06 & Alice-Note;
G. Martinez & N. Blusseau, PWG3 meeting, Bologna, June 06

W± boson production = "day-one" physics channel (limited statistics for Z^0: ~ 60)

More results: talk from Z. Conesa del Valle

Conclusion

new environment, statistics important for selected physics channels, new observables, new analyses

➔ rich & exciting physics program with pp @ 14 TeV in the first days (spring 2008)

To be ready for analyses of first pp collisions:

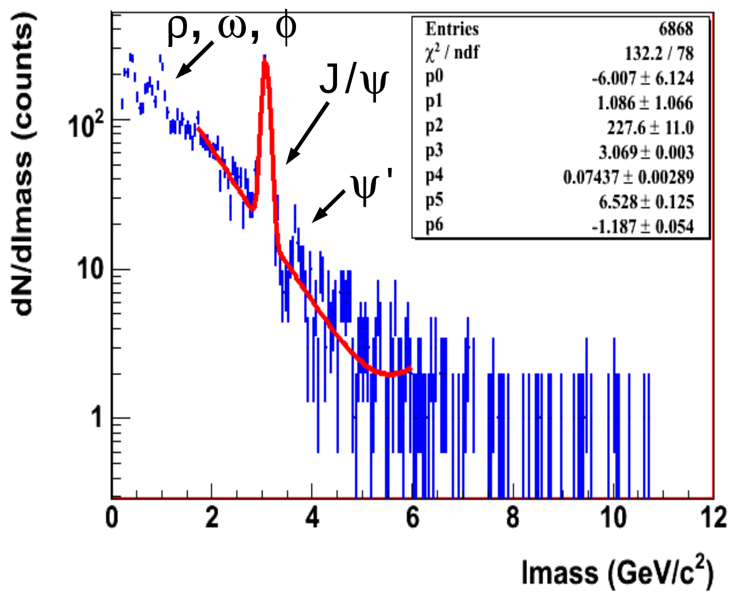
→ High statistics simulated data are going to be processed within PDC'06 via the grid

✓ 8.10^5 dimuon events

(~ 3 TB, ~5500 days of CPU-time)

✓ 10^7 single muon events

(~ 30 TB, ~14000 days of CPU-time)



Press Release on June 23th, 2006:

✓ First pp collisions expected in November 2007 at 0.9 TeV

- Physics run scenario not yet defined
- New estimates needed

Backup slides

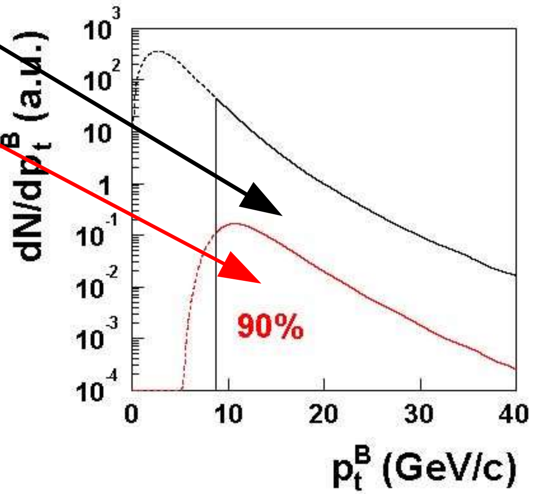
UA1 method, used by CDF & D0 and applied to Pb+Pb (5%) @ 5.5 TeV

- **Inputs: p_t disributions of single $\mu^{\pm}$ & invariant mass distributions of $\mu^{+}\mu^{-}$**
- **First steps: maximize the b signal significance (p_t cut) & get $N(b\rightarrow\mu^{\pm})$ & $N(bbar\rightarrow\mu^{+}\mu^{-})$ from fits with fixed shapes (MC) & b yield as a free parameter**
- **Extrapolation from muons to b-hadron cross section**

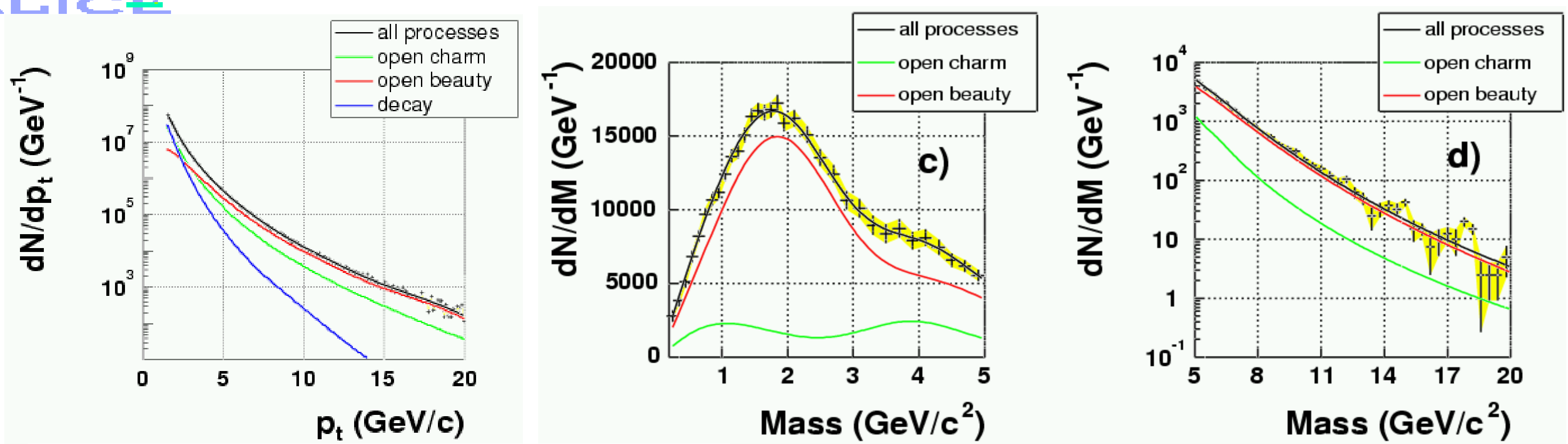
$$\sigma^B(p_t^B > p_t^{min}) = \frac{N_b(N_{b\bar{b}})}{\int L dt} \times \frac{1}{\epsilon} \times \left.\frac{\sigma^B(p_t^B > p_t^{min})}{\sigma^B(\phi^\mu)}\right]_{MC}$$

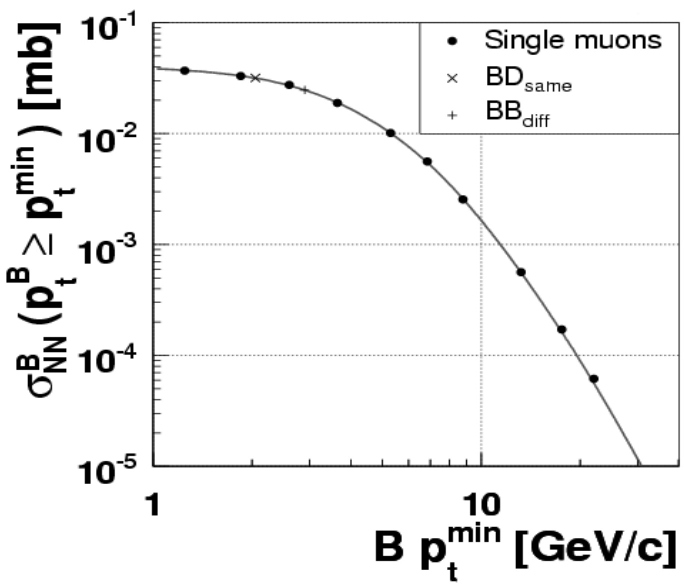
Integrated luminosity

Global detection efficiency



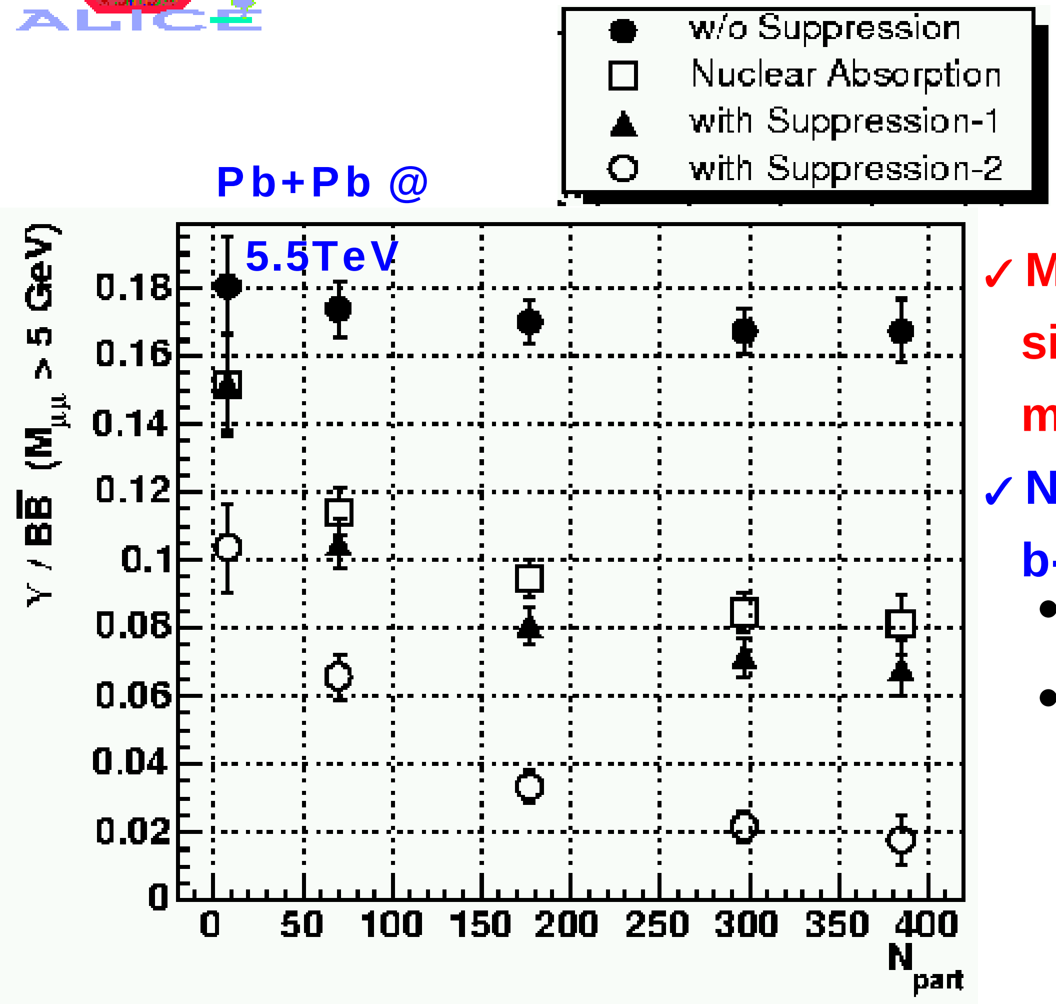
C. Albajar et al., Phys. Lett. B 213 (1988) 405





- **Input distribution well reconstructed**
- **Nice agreement between the 3 channels**

On the relevance of measuring σ(b) as a normalization for ϒ signal



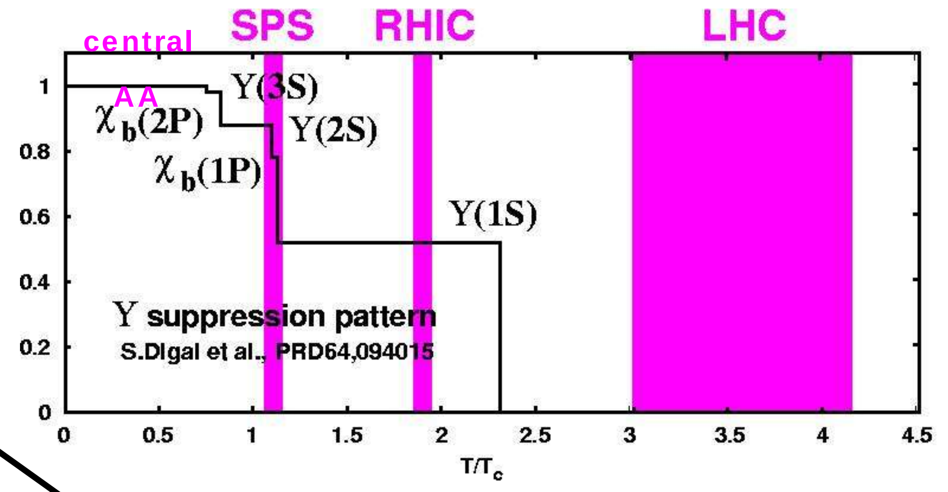
- ✓ **Most natural normalization since both signals arise from same production mechanism**
- ✓ **Normalization questionable if b-quenching**
  - **Statistics : one month Pb+Pb**
  - **Statistics of the reference is in 5<M<20GeV ~5 times larger than that of the probe (Nuclear absorption is here overestimated)**

ALICE PPR Vol. II

Dissociation temperatures: C.-Y. Wong, hep-ph/0408020 & W.M. Alberico, hep-ph/0507084

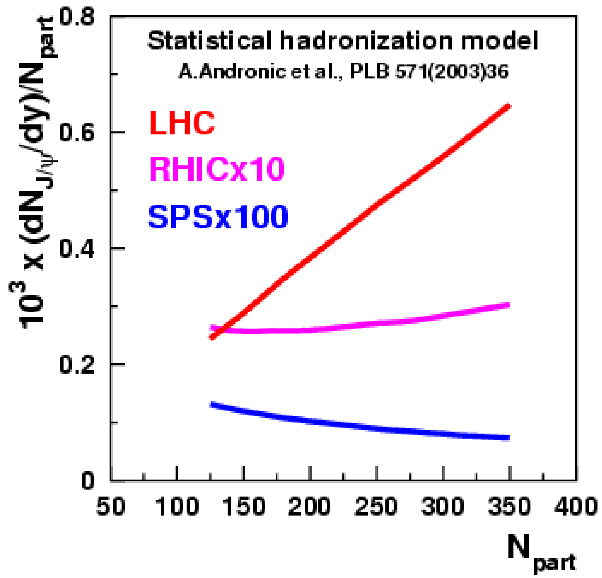
Heavy flavors:
what is different @ the LHC

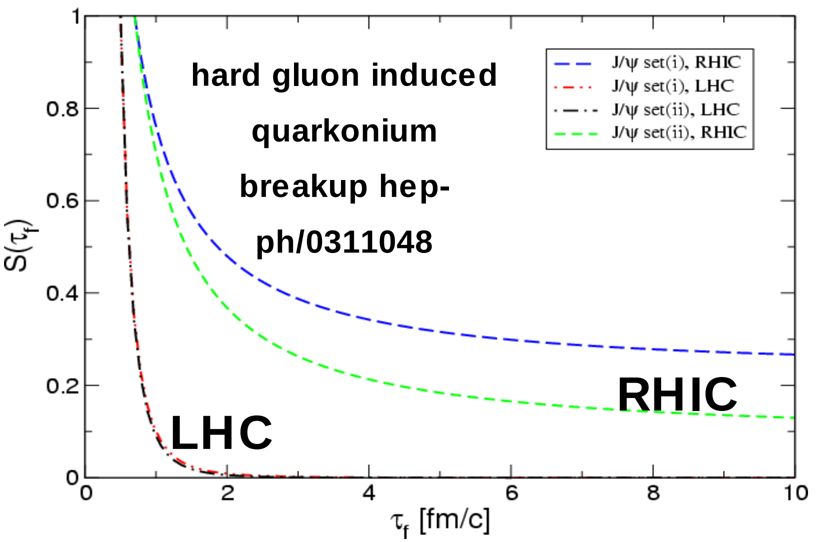
N($q\bar{q}$) per central AA (b=0)	SPS	RHIC	LHC
charm	0.2	10	130
bottom	---	0.05	5



- large primary production
- melting of Υ(1*S*) by color screening
- none of the primary J/ψ survives the (PbPb) QGP
- a lot of charmonia from b hadron decay
- large secondary

statistical hadronizat annhililation





Reality factors

There are no "unimportant details".

After we multiply the **geometric acceptance** by the **cross section** by the **delivered luminosity** by the **detector uptime**, we still have to add some **reality factors**. For example:

- Minimum bias trigger efficiency
  (0.75 in pp hard processes for PHENIX, 0.92 in AuAu for PHENIX)
- Collision vertex cut (0.8 of beam in central bucket at RHIC)
- Collision vertex cut (0.7 of central bucket for PHENIX VTX in +/- 10 cm)
- Level 1 trigger efficiency (typically 0.8)
- Pair reconstruction and PID efficiency (typically 0.8 in pp, 0.4 in AuAu).
- **Displaced vertex cut for open B (about 0.4 at 1 mm)**

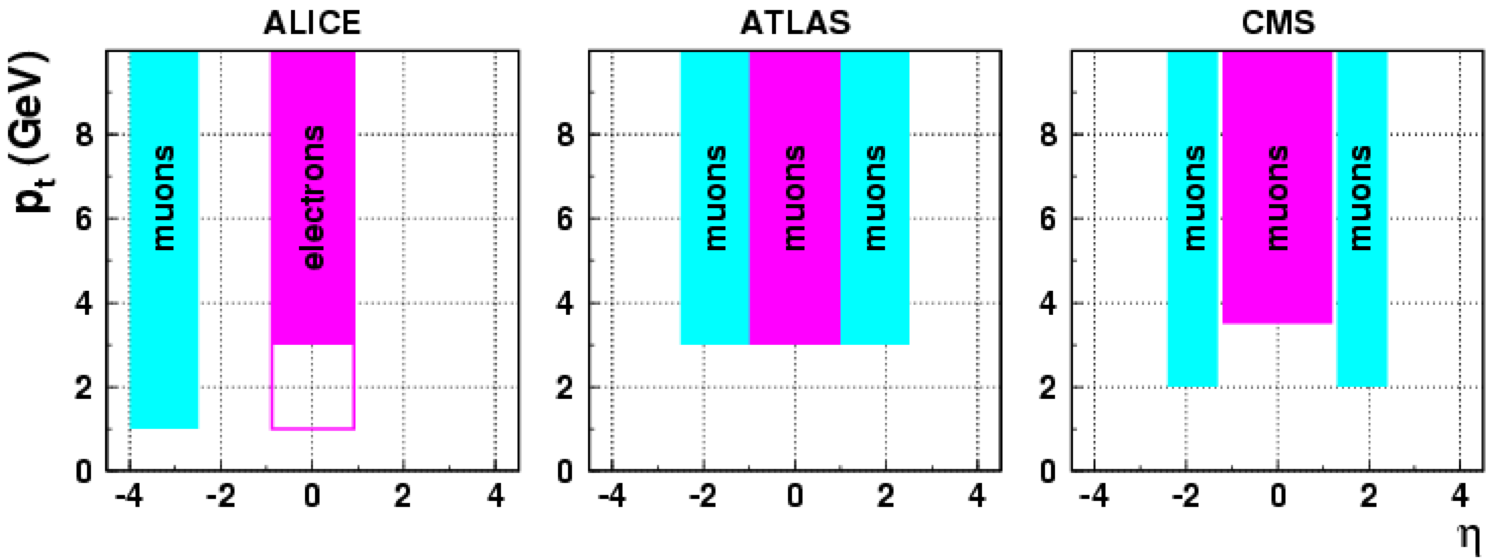
Example reality factors:

0.75 x 0.8 x 0.7 x 0.8 x 0.8 x **0.4** = **0.11** for pp B $\rightarrow J/\psi$

0.92 x 0.8 x 0.7 x 0.8 x 0.4 x **0.4** = **0.07** for AuAu B $\rightarrow J/\psi$

0.92 x 0.8 x 0.7 x 0.8 x 0.4 = **0.16** for AuAu J/ψ

T. Frawley, `http://rhicii-science.bnl.gov/heavy/doc/April05Meeting/`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8
-4
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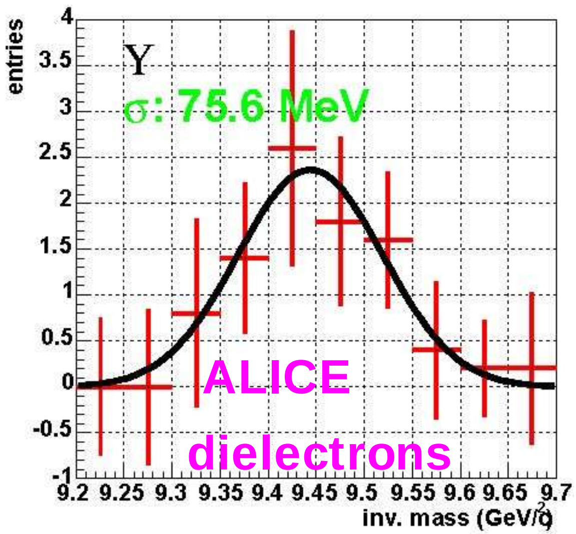
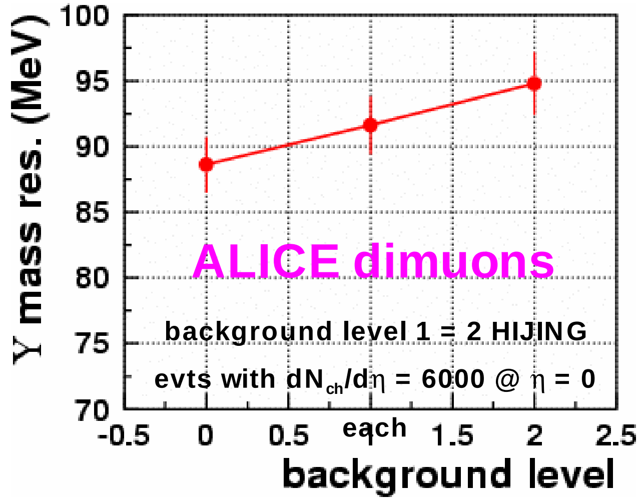
0
2
4

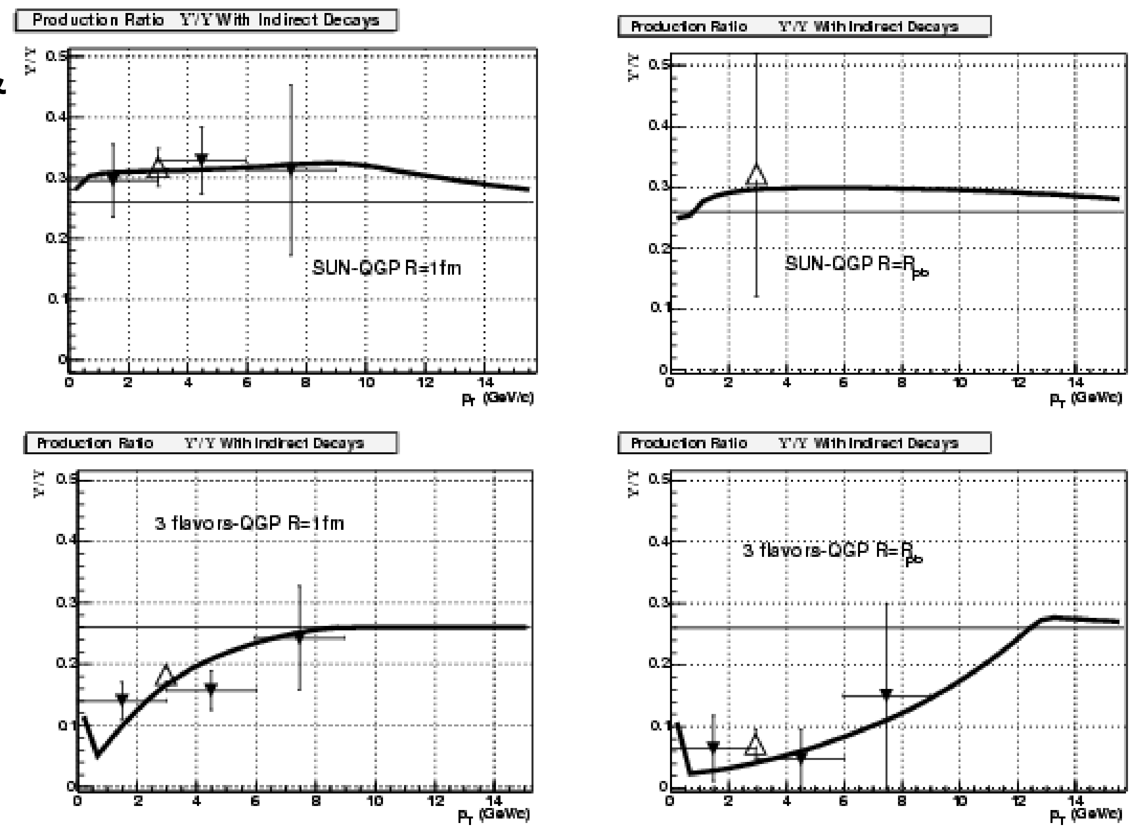

entries
Υ
σ: 75.6 MeV
ALICE
dielectrons
inv. mass (GeV/c²)

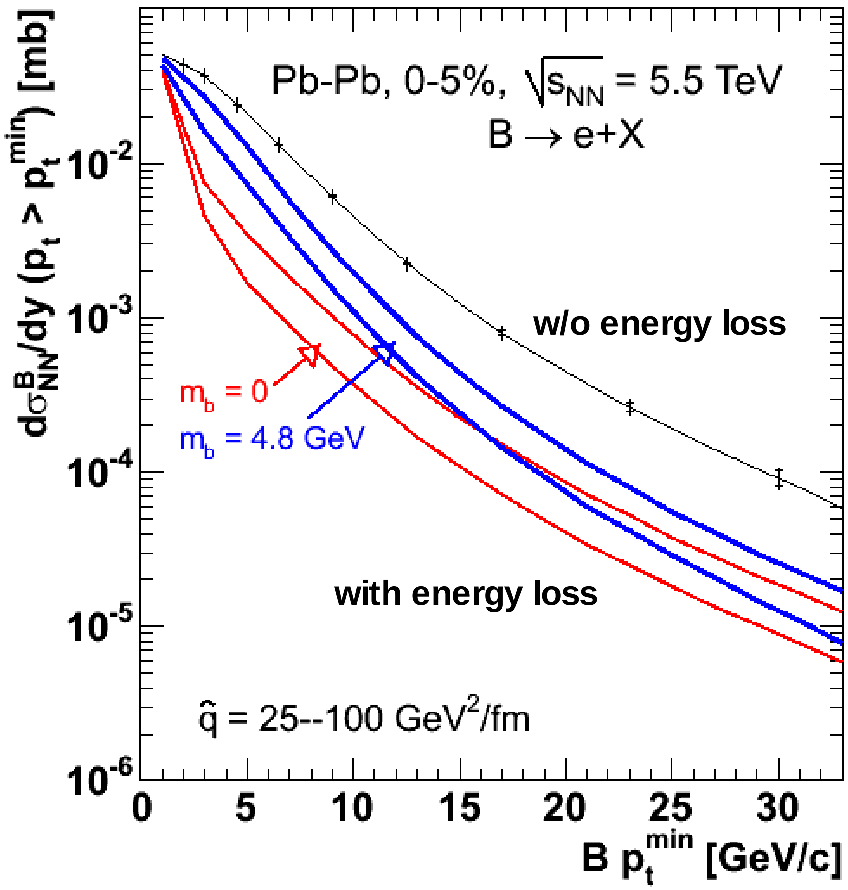

Υ mass res. (MeV)
ALICE dimuons
background level 1 = 2 HIJING
evts with dN_ch/dη = 6000 @ η = 0
each
background level

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/fm^3)	32	30	28	16	5	
J/ψ	S (x10^3)	132.6	234.6	198.2	94.75	21.66	681.4
	S/B	0.2	0.27	0.48	1.08	3.13	0.33
	S/$\sqrt{S+B}$	148	224	254	222	128	413
ψ'	S (x10^3)	3.69	6.53	5.5	2.61	0.59	18.92
	S/B	0.012	0.017	0.03	0.063	0.172	0.02
	S/$\sqrt{S+B}$	6.7	10.4	12.6	12.4	9.3	19.53
Υ	S (x10^3)	1.349	2.38	1.991	0.932	0.204	6.33
	S/B	1.66	2.31	3.6	6.06	9.12	2.46
	S/$\sqrt{S+B}$	29	40.8	39.5	28.3	13.6	67.14
Υ'	S (x10^3)	0.353	0.623	0.522	0.244	0.054	1.8
	S/B	0.65	0.9	1.36	2.25	3.46	1.03
	S/$\sqrt{S+B}$	11.8	17.2	17.3	13	6.4	30.19
Υ''	S (x10^3)	0.201	0.354	0.297	0.139	0.03	1.02
	S/B	0.48	0.63	0.99	1.57	2.22	0.74
	S/$\sqrt{S+B}$	8.1	11.7	12.2	9.2	4.6	20.85

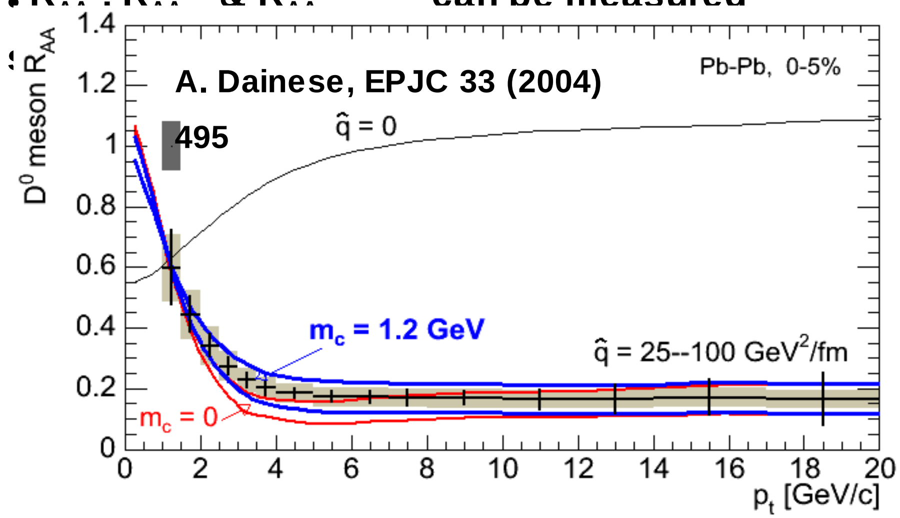
- melting depends on
  - resonance formation time, dissociation temp. & p_t
  - QGP temp., lifetime & size
- ratio is flat in ppbar (CDF)
- any deviation from the pp (pA) value is a clear evidence for the QGP (nuclear effects cancel-out)
- the p_t dependence of the ratio is sensitive to the characteristics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



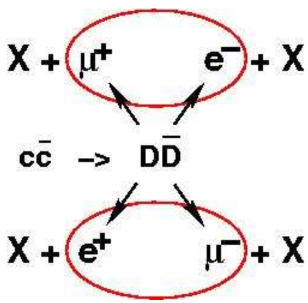


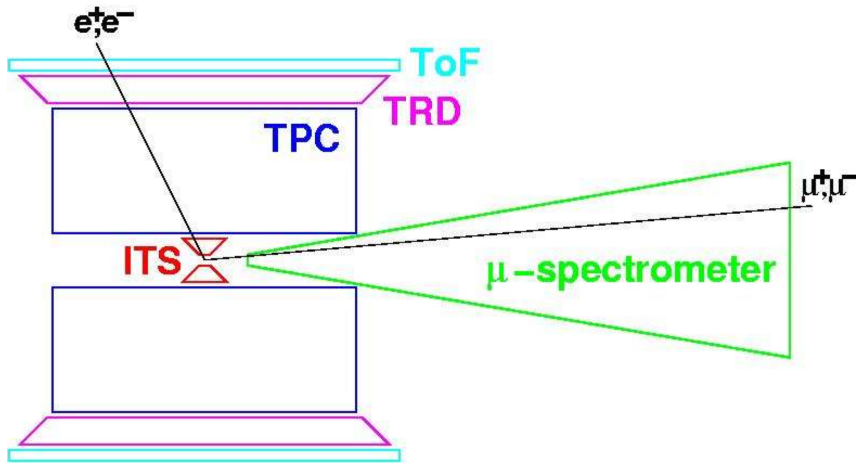
same method as the one used with muons plus scenario for b-quark energy loss

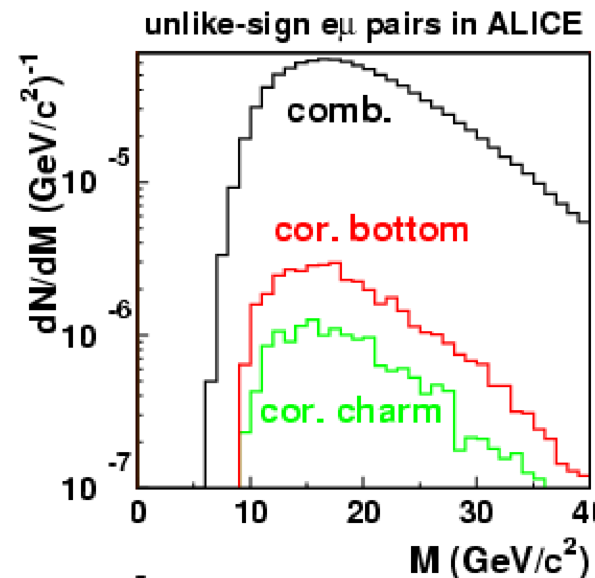
- electrons with $2 < p_t < 20$ GeV/c ®b-hadrons with $2 < p_t^{min} < 30$ GeV/c
- clear sensitivity to energy loss
- will be further used to get $R_{AA}^{b\text{-}hadrons}$
- R_{AA}^{h}, R_{AA}^{D0} & $R_{AA}^{b\text{-}hadrons}$ can be measured

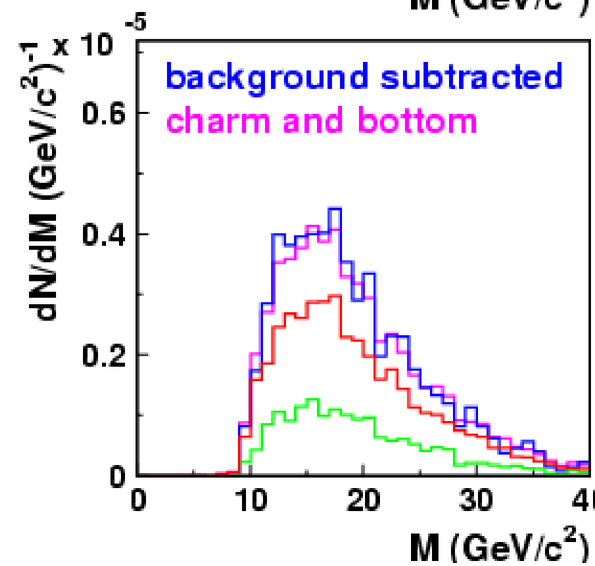


Electron-muon coincidences









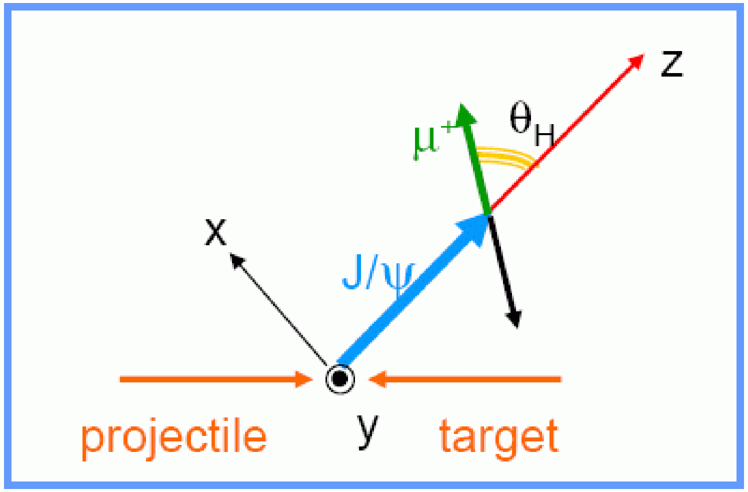
- background free signal
- covers intermediate rapidities
- successfully done in pp @ ISR (in 1979!)
- challenging in heavy ion collisions

Decay angular distribution depends on the choice of the polarization axis (z). Various possibilities exist:

- Gottfried-Jackson reference frame
- Collins-Soper – usually used in fixed target experiments
- Helicity frame – usually used in collider experiments (CDF, BaBar etc)

Helicity (recoil) reference frame:

Z axis coincides with the J/ψ direction in the target-projectile center of mass frame

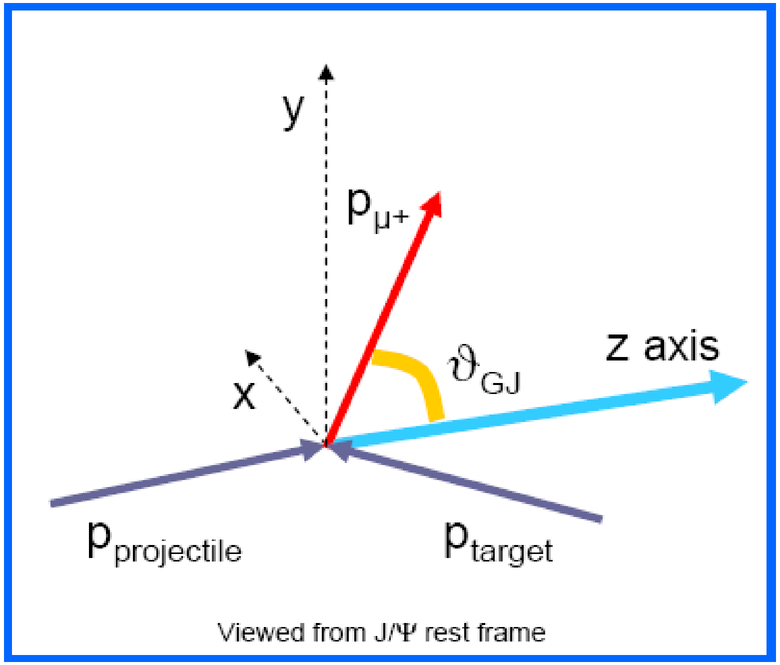


- All reference systems are equivalent for J/ψ having $p_t = 0$
- One must be careful when comparing experimental results with theoretical predictions

Decay angular distribution depends on the choice of the polarization axis (z). Various possibilities exist:

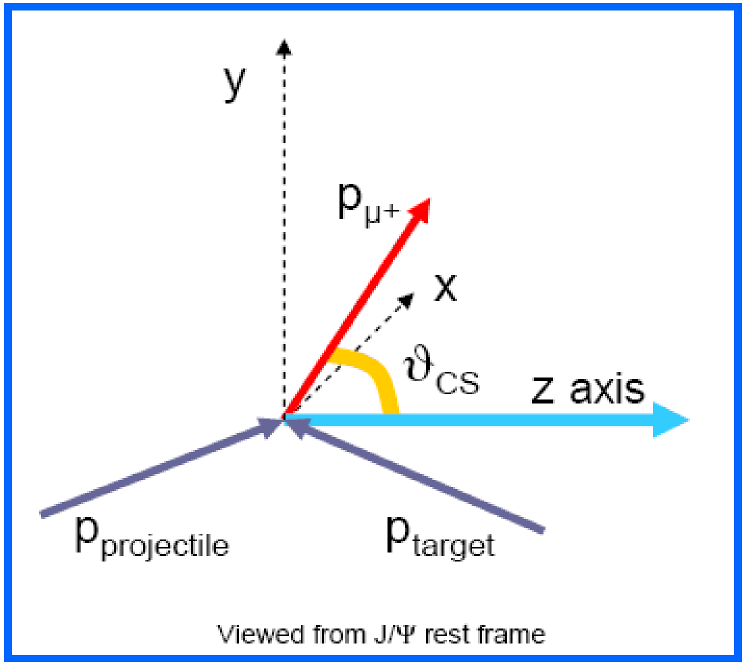
Gottfried-Jackson:

Z axis is parallel to the incoming beam axis in the quarkonium rest frame



Collins-Soper:

Z axis is parallel to the bisector of the angle between beam and target directions in the quarkonium rest frame



These reference systems are mainly used at fixed target experiments

Polarization in pp collisions - test of quarkonium production mechanisms:

CSM – Color Singlet Model:
- Perturbative QCD, underestimates quarkonium production cross-sections
- Transverse polarization

CEM - Color Evaporation Model:
- Soft gluon emission from the cc-pair during hadronization randomizes spin and color
- No polarization

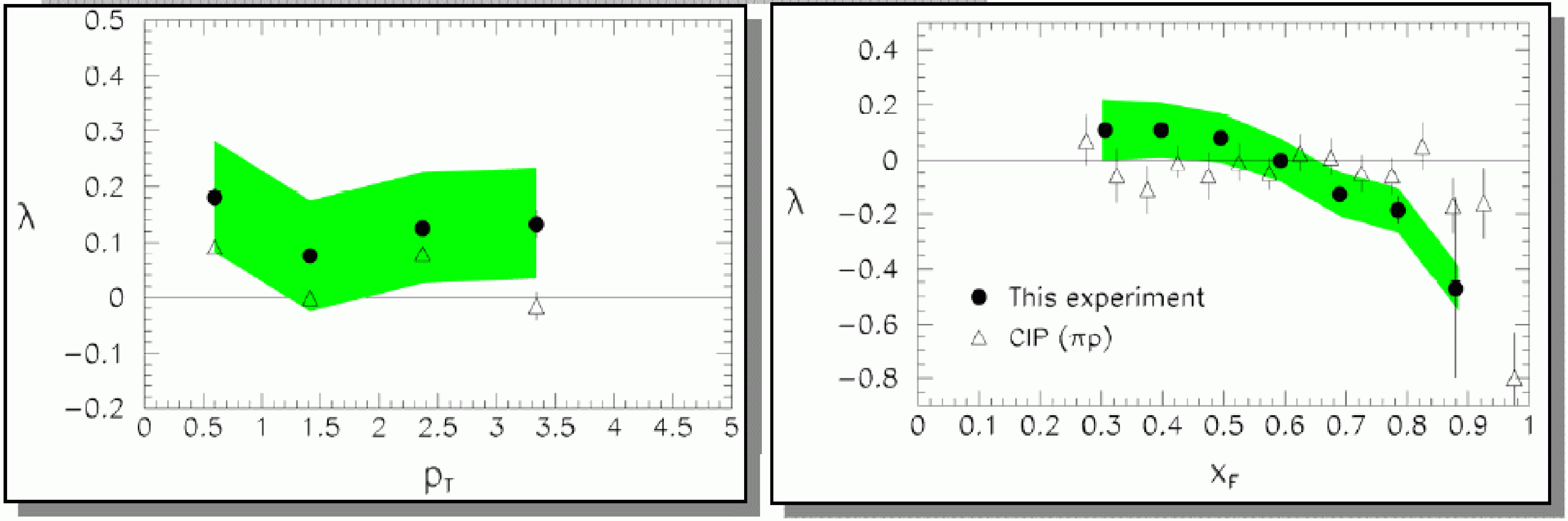
NrQCD – Non-relativistic Quantum Chromodynamics:
- Takes into account non-perturbative effects in quarkonium production
- Dominance of the gluon fragmentation mechanism for $p_t \gg M$, the fragmenting gluon is almost on-mass shell, and is therefore transversely polarized.
- The produced quarkonium inherits transverse polarization at high p_t

Khoze, Martin, Ryskin, Stirling, Eur. Phys. J., C39, 163 (2005):
- Perturbative calculations only. The basic subprocess: $g(gg)_{8s} \rightarrow J/\psi$
- Cross sections are in agreement with CDF and RHIC experiments
- Transverse polarization at small p_t, longitudinal polarization at high $p_t \gg M$.

Polarization in AA collisions: test for HIC dynamics and QGP formation

B.L. Ioffe and D.E. Kharzeev: Phys. Rev. C68 061902 (2003):
"Quarkonium Polarization in HIC as a possible signature of the QGP"
- Formation of quarkonia takes place in the plasma; changes in ratio of feed-down and direct production; non-perturbative effects are screened away
- Transverse polarization ~ 0.35 - 0.4 in the case of QGP formation

- 9 million J/ψs in p-Cu collisions @ 800 GeV
- Study vs x_F, p_T



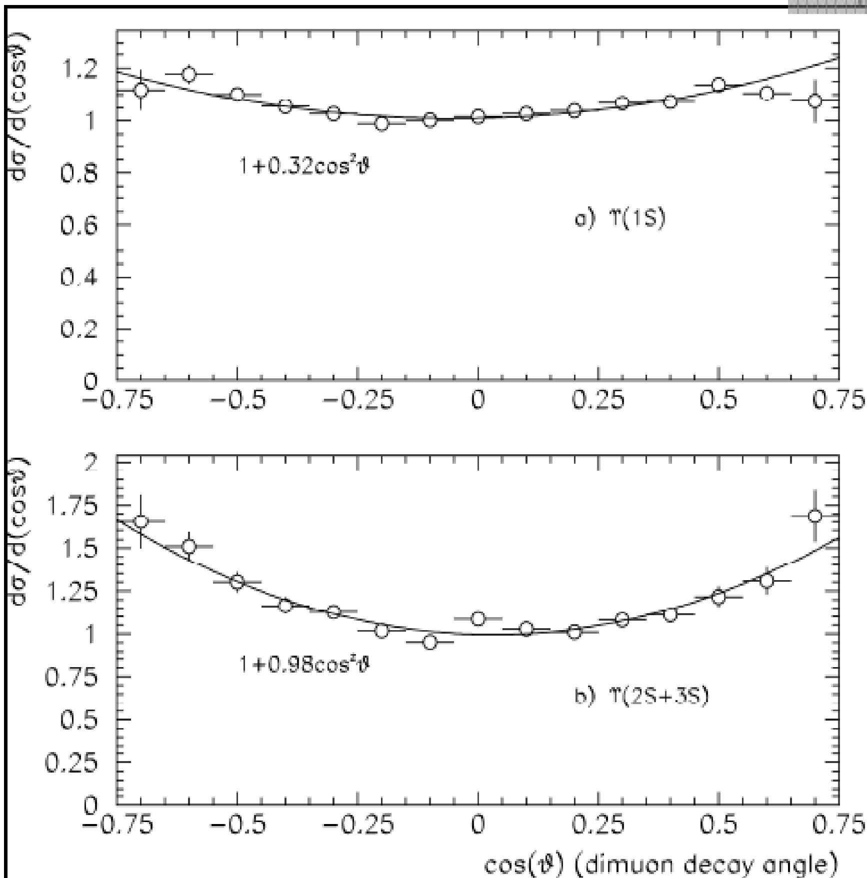
- Integrating over x_F and p_T → $\lambda = 0.069 \pm 0.004 \pm 0.08$
- NrQCD predicts $0.31 < \lambda < 0.63$

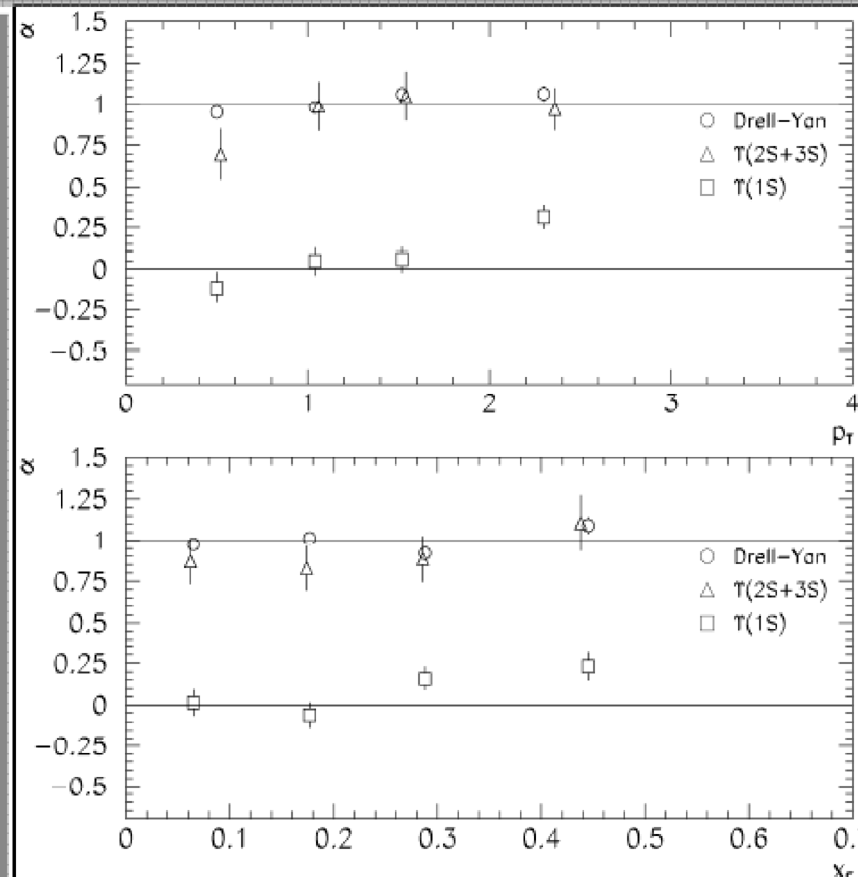
- Feed-down from χ_{c1} (longitudinal) and χ_{c2} (transverse) complicates the issue
- Nuclear effects can also play a role

Phys.Rev.Lett.,91,211801 (2003)

- p-Cu collisions @ 800 GeV (2 mln events $8.1 < M_{\mu\mu} < 15$ GeV)
- Studied vs x_F and p_t

- Υ (1S): small transverse polarization at high p_t:
  Measured value: $\alpha = 0.07 \pm 0.04$
  NRQCD predicts $\alpha = 0.28 - 0.31$
- Υ (2S) and Υ (3S): strong transverse polarization (in agreement with CSM)

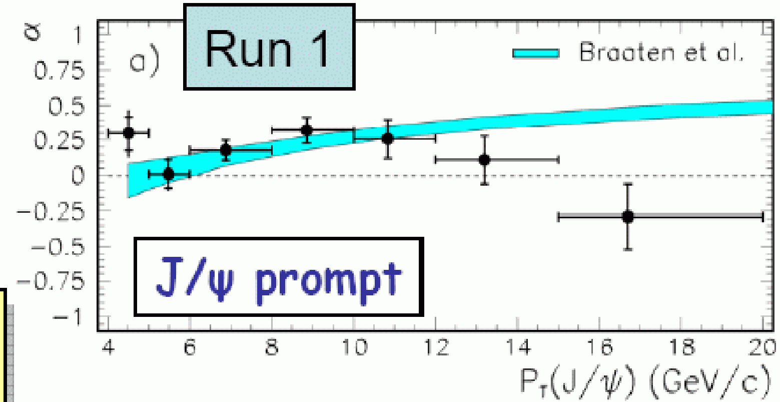


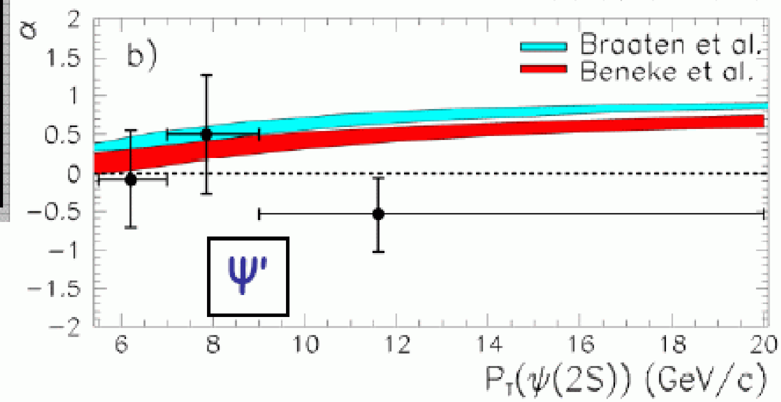


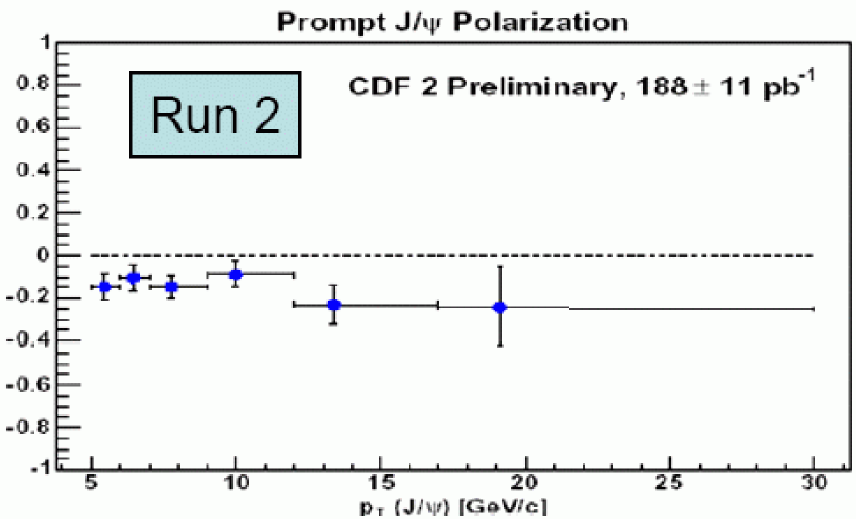
Phys.Rev.Lett.,86,2529 (2001)

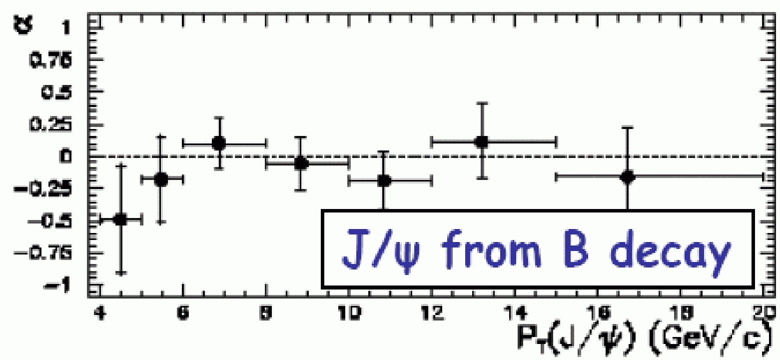
- $p - \bar{p}$ @ $\sqrt{s}$ = 1.8 TeV
- 180000 J/ψ, 1800 ψ′ (Run 1)

- Disagreement at high pt with NrQCD predictions. But in agreement with approach of Khoze et al.
- Zero polarization for J/ψ from B decays
- Inconsistency between Run1 and Run2



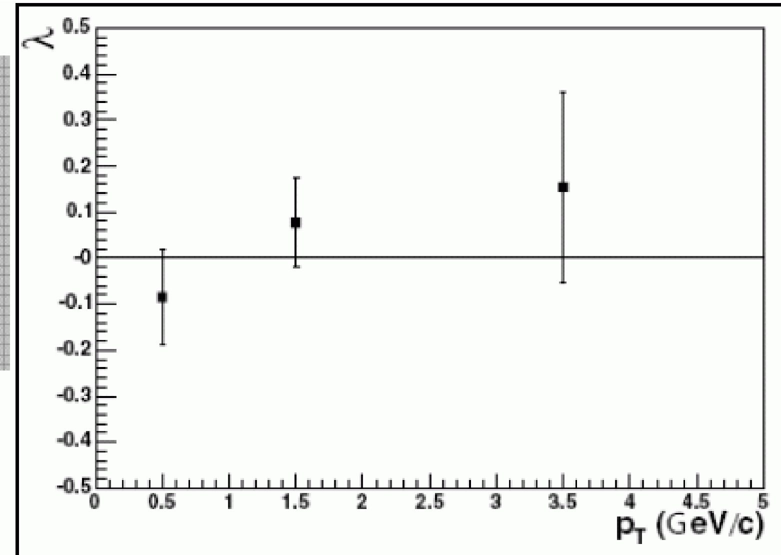


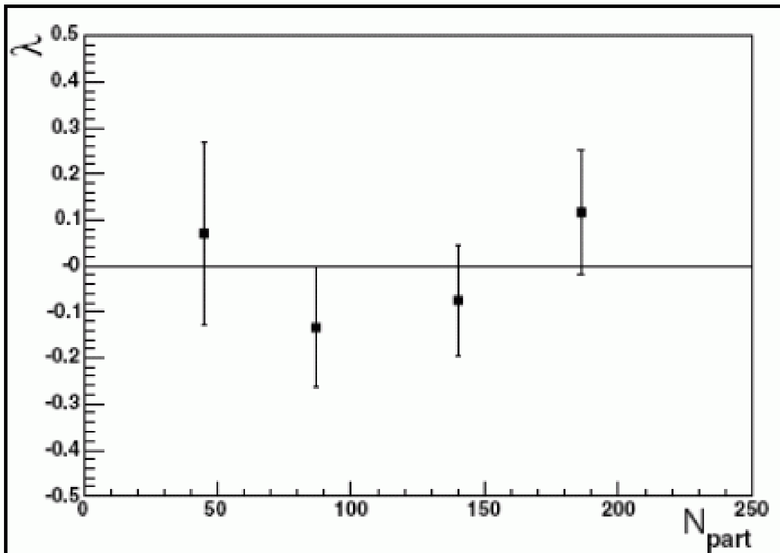


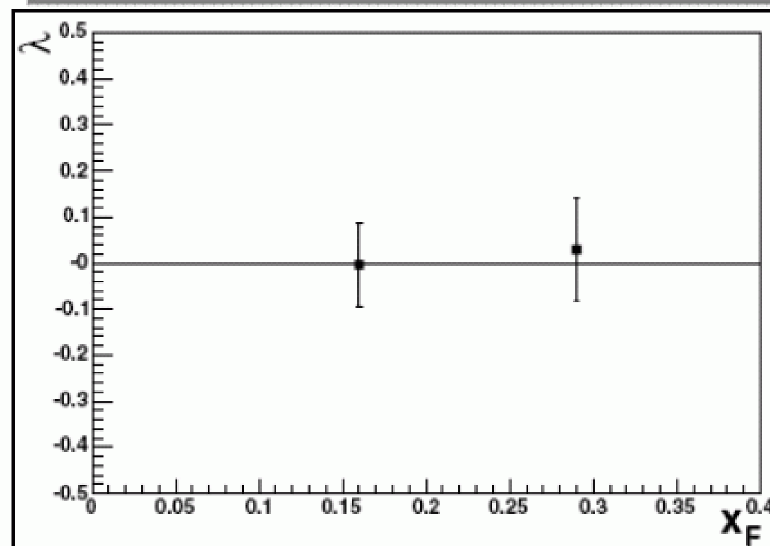


Phys.Rev.Lett.85,2886 (2000)

- In-In @ 158 AGeV
- Statistics: 30K J/ψ
- Negligible background at J/ψ mass (~2-3%)
- λ vs N_{part}, p_t, x_F measured
- Result: λ close to 0







In the case of QGP formation λ ~ 0.3-0.4 is predicted by Ioffe and Kharzeev

R. Arnaldi et al. (NA60 Coll.), Eur. Phys. J. C43, 167 (2005)

- AuAu @ 200 AGeV, dAu @200 AGeV
- $J/\psi \rightarrow e^+ e^-$
- Central arm: $|\eta|<0.35$, p > 0.2 GeV
- Low statistics
- Consistent with zero polarization
- $J/\psi \rightarrow \mu^+ \mu^-$ is under studies
- Larger statistics is expected