J/ψ suppression in Pb-Pb collisions at CERN SPS

- **Physics motivation**: look for QGP studying charmonium suppression in heavy-ion collisions

- **NA38**: p, O, S projectiles
  → Standard analysis method
  → review of p-A and light ion charmonium production

- **NA50**: Pb-Pb collisions
  → Anomalous J/ψ suppression
  → Minimum bias analysis method

- **Conclusions**: evidence for a new state of nuclear matter (QGP?) at CERN SPS
  (message of Feb. 10th 2000, CERN Press Release)

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*for the **NA50 collaboration***

ISMD2000 - Tihany, October 9-15, 2000

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Brief history of J/ψ suppression in nuclear collisions

- ***proposed*** in 1986 by **Matsui and Satz** as a signal of **colour deconfinement**
  → *Debye screening prevents $c\bar{c}$ formation in a deconfined medium*

- ***observed*** in **light ion** (O-U, S-U) reactions (NA38)

BUT :

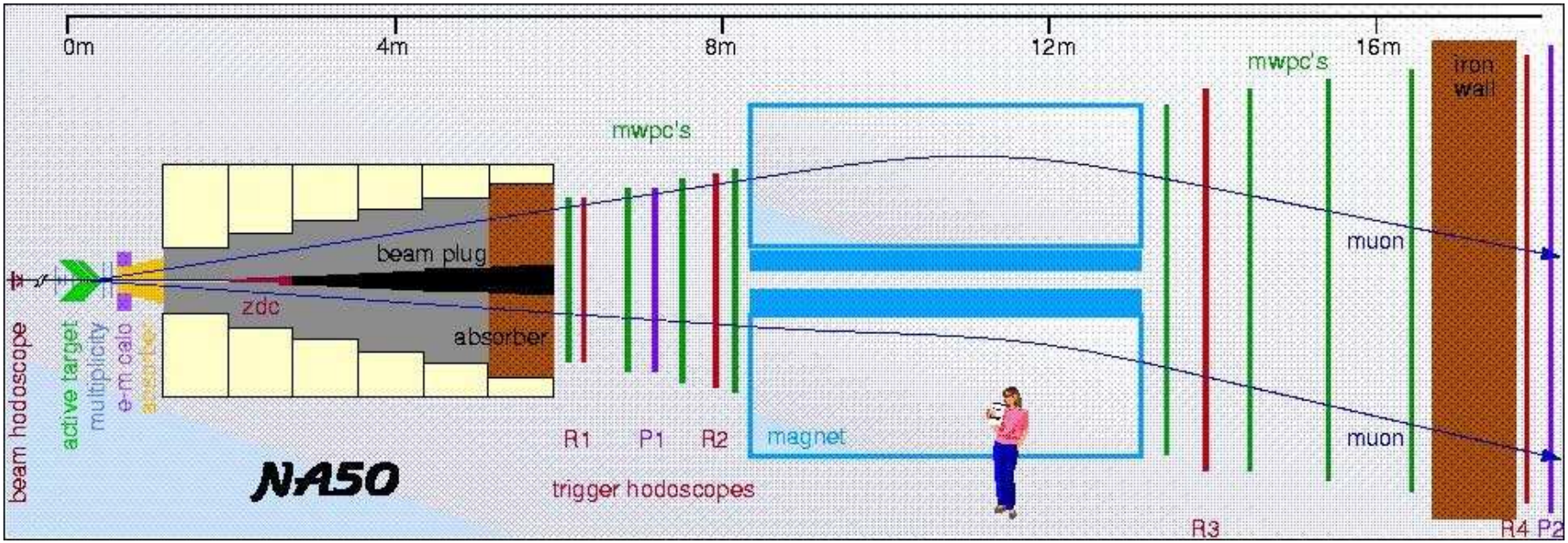
- ***observed also*** in **p-A** collisions (NA38, NA51)

→ *understood as **ordinary absorption** of pre-resonant state in a confined medium*

Onset of deconfinement → ***Additional J/ψ suppression beyond the ordinary nuclear absorption***

- ***anomalous J/ψ suppression observed*** since 1995 in **Pb-Pb** collisions by **NA50** collaboration
  → detailed pattern of J/ψ suppression vs. centrality observed by NA50 in 1996 and 1998 data

NA50 experimental setup



- **DIMUON SPECTROMETER** ($0<y_{cm}<1$)
  - Magnet + MWPC + Trigger hodoscopes
- **CENTRALITY DETECTORS**
  - **EM Calorimeter** ($1.1<\eta_{lab}<2.3$)
  - **Multiplicity detector** ($1.5<\eta_{lab}<3.5$)
  - **Zero Degree Calorimeter** ($\eta_{lab}>6.3$)

- **ACTIVE TARGET**
  - Pb target + Cherenkov counters

Year	# Subt	L(mm)	λ_{int}
1995	7	7	17%
1996	7	12	30%
1998	1	3	7%

Data taking and event selection

***BEAM*:**

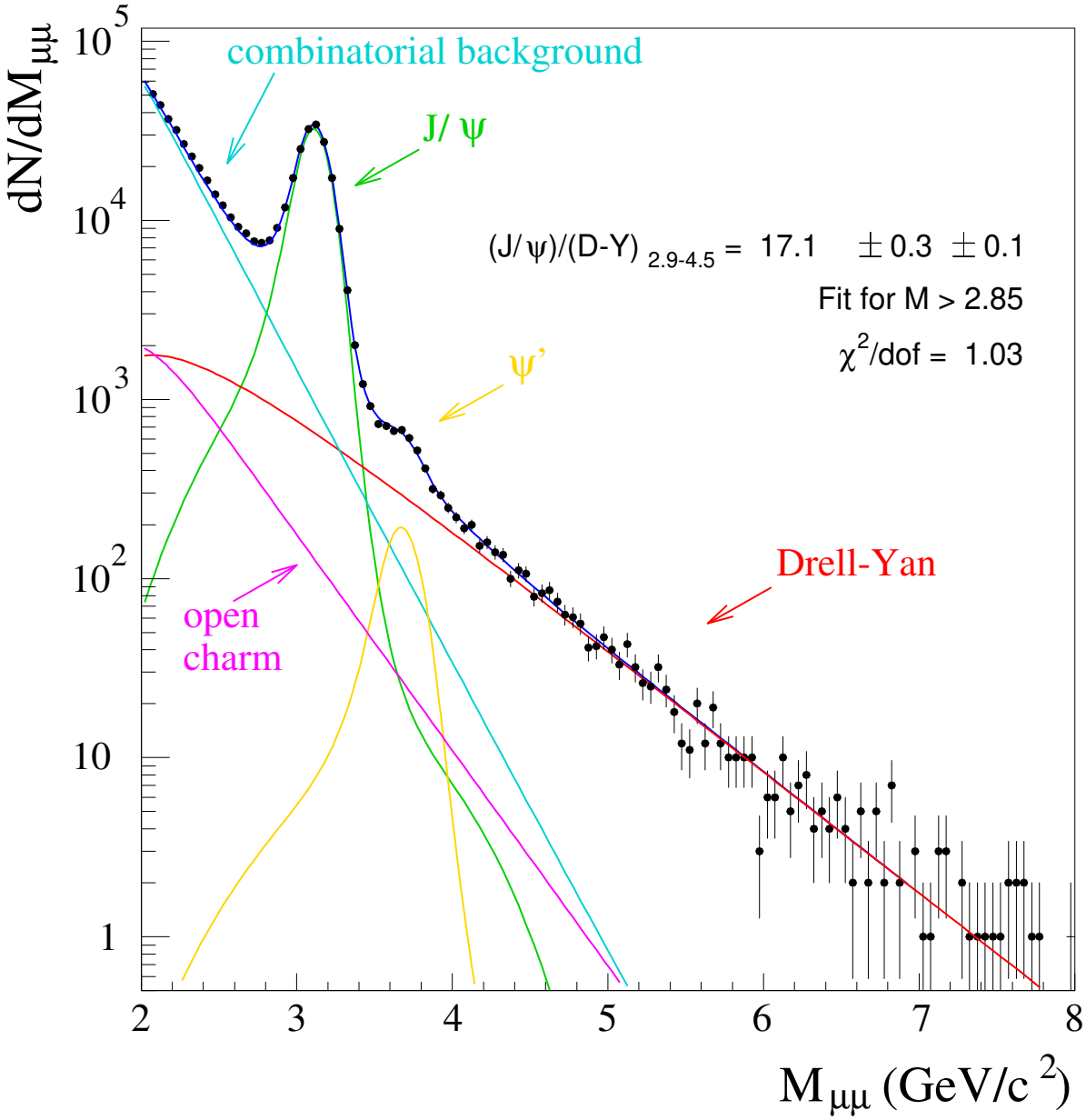
SPS 208Pb beam; momentum 158×A GeV/c => 33TeV

Year	Beam Int.	# triggers	total J/ψ	total DY
1995	$3.5*10^7$	$52*10^6$	50000	650
1996	$5.4*10^7$	$170*10^6$	190000	2100
1998	$5.5*10^7$	$80*10^6$	40000	800

***EVENT SELECTION*:**

- **Pile-up rejection** by means of the Beam Hodoscope (BH)
- **Beam halo rejection** + rejection of interaction in the BH
- Severe **cuts on the muon track quality**
- **"Image" cut** (to have same acceptance for $\mu^+\mu^+$,$\mu^-\mu^-$,$\mu^-\mu^+$)

Standard charmonium analysis



- dimuon trigger → selection of $\mu^+\mu^-$ events
- fit of $\mu^+\mu^-$ invariant mass spectrum as a superposition of:
  J/ψ, ψ', Drell-Yan, open charm and background
- combinatorial background from π and K decays
  estimated from $\mu^+\mu^+$ and $\mu^-\mu^-$ events
- analysis performed as a function of centrality estimators:
  E_T, E_{ZDC} (measured)
  b, L (calculated)

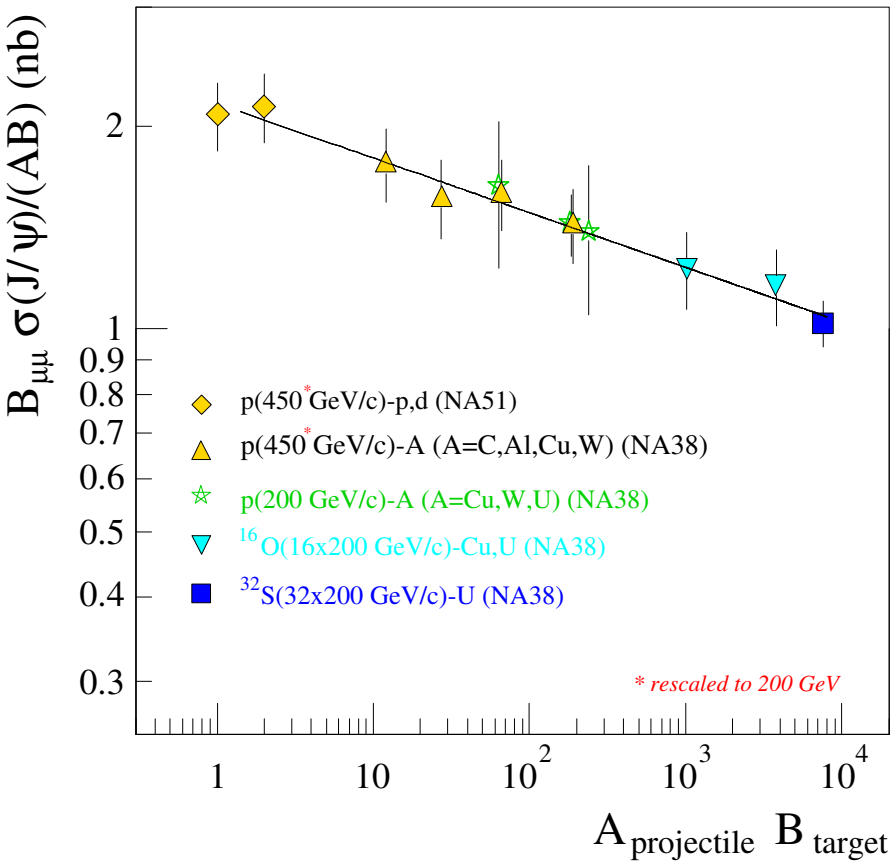
NA38
J/ψ cross section vs. AB

Charmonium production = hard process

Use ***cross section per nucleon-nucleon collision***

$$\frac{B_{\mu\mu}\sigma^{J/\psi}}{A \times B}$$

to compare charmonium production
in different colliding systems



Usual parametrization:

$$\sigma = \sigma_0 (A \times B)^{\alpha}$$

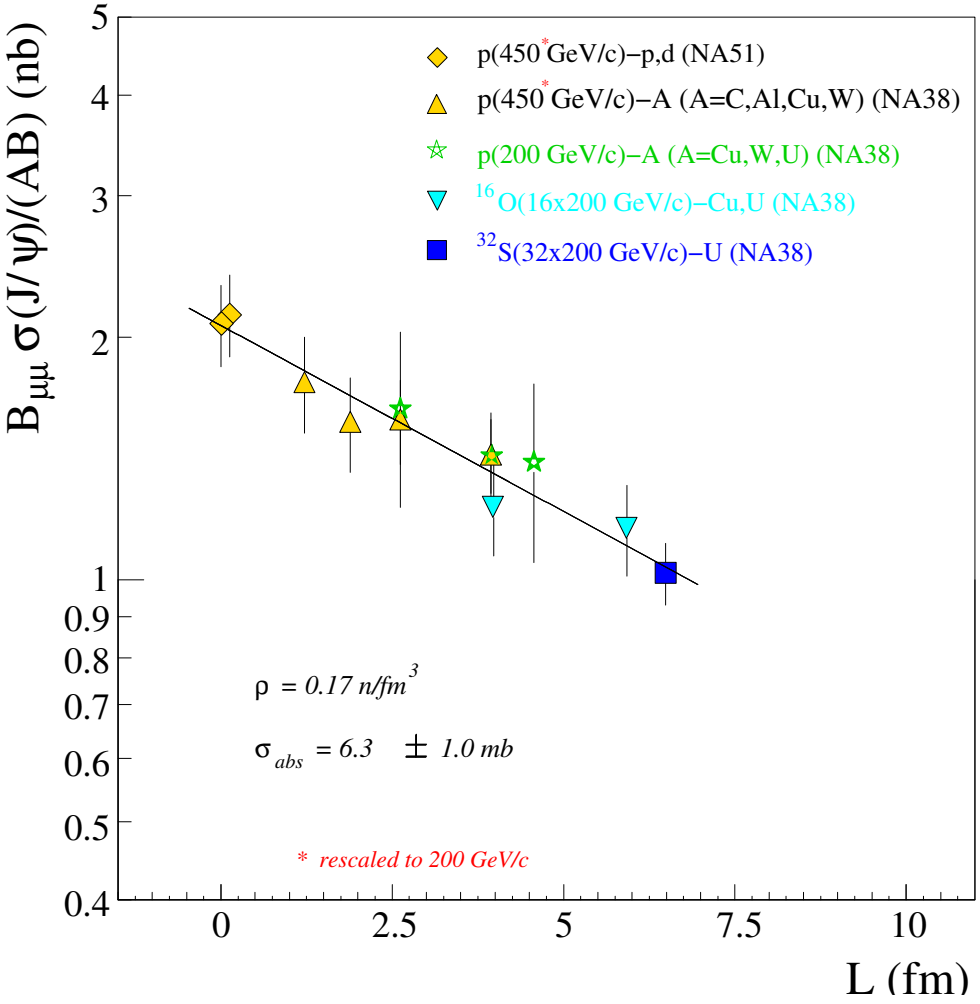
Global fit to
NA38 and NA51 data:

$$\alpha^{\psi} = 0.918 \pm 0.015$$

Less than linear scaling

NA38
J/ψ cross section vs. L

L = length of nuclear matter traversed by the $c\bar{c}$ while escaping from the interaction region



$$\sigma^{\psi}_{AB} \approx (AB)e^{-\rho_0\sigma^{\psi}_{abs}\langle L\rangle}$$

Simple fit → σ_{abs} =6.3 ± 1.0 mb
Full calculation → σ_{abs} =7.2 ± 1.2 mb

NA50: Pb-Pb collisions

NA38 RESULTS:

→ J/ψ production shows a ***continuous decreasing pattern*** from p-p to S-U

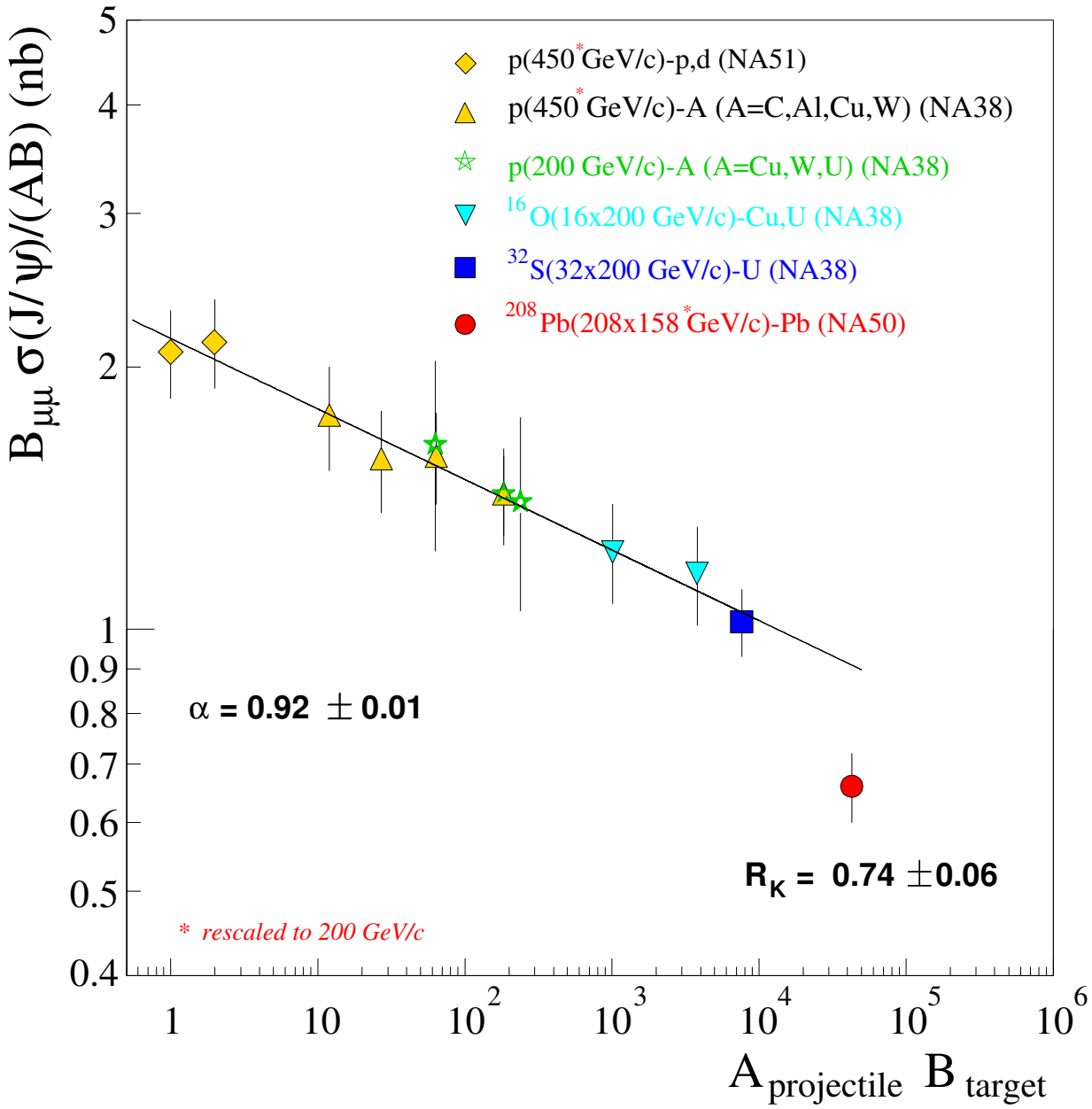
→ J/ψ production can be accounted for by ***nuclear absorption*** of pre-resonant state meant to become later on, if not destroyed, the fully formed resonant J/ψ state

Additional suppression expected in a deconfined medium

NA50 EXPERIMENT: **Pb-Pb collisions**

- larger energy density
- larger reaction volume

The anomalous J/ψ suppression (1995)

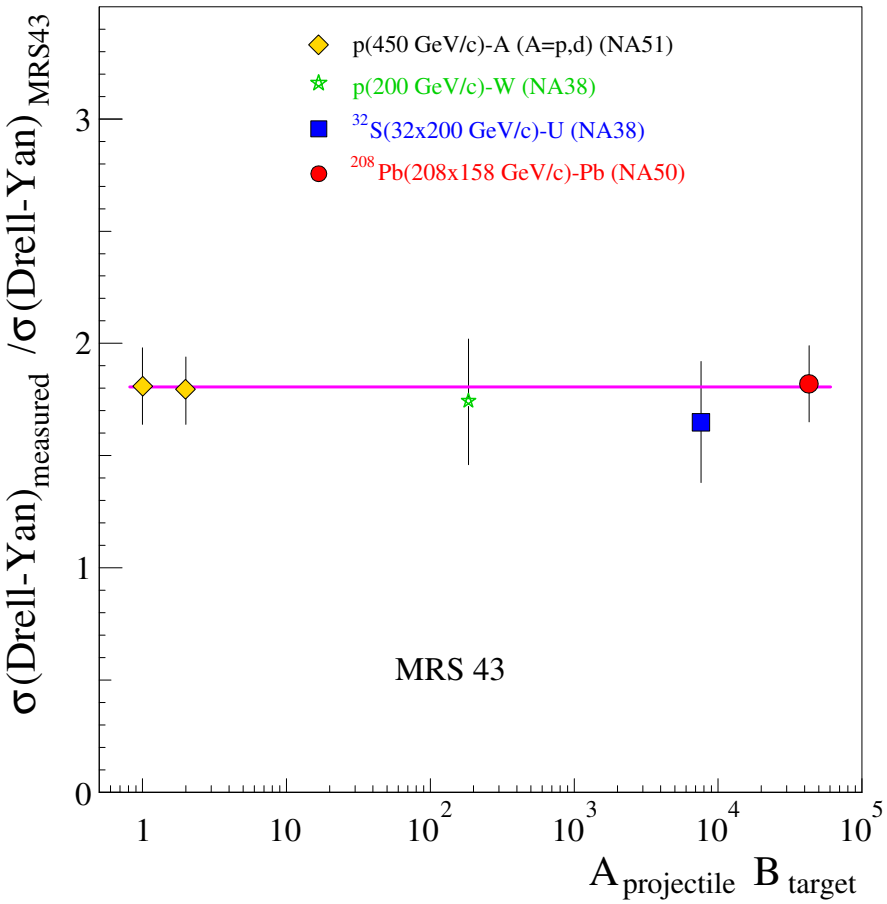


J/ψ cross section ~5 standard deviations below the expected value

→ *New suppression mechanism at work*

The Drell-Yan reference

GOAL: study the behaviour of J/ψ production as a function of the centrality of the collision



Drell-Yan cross section scales with the number of nucleon-nucleon collisions:

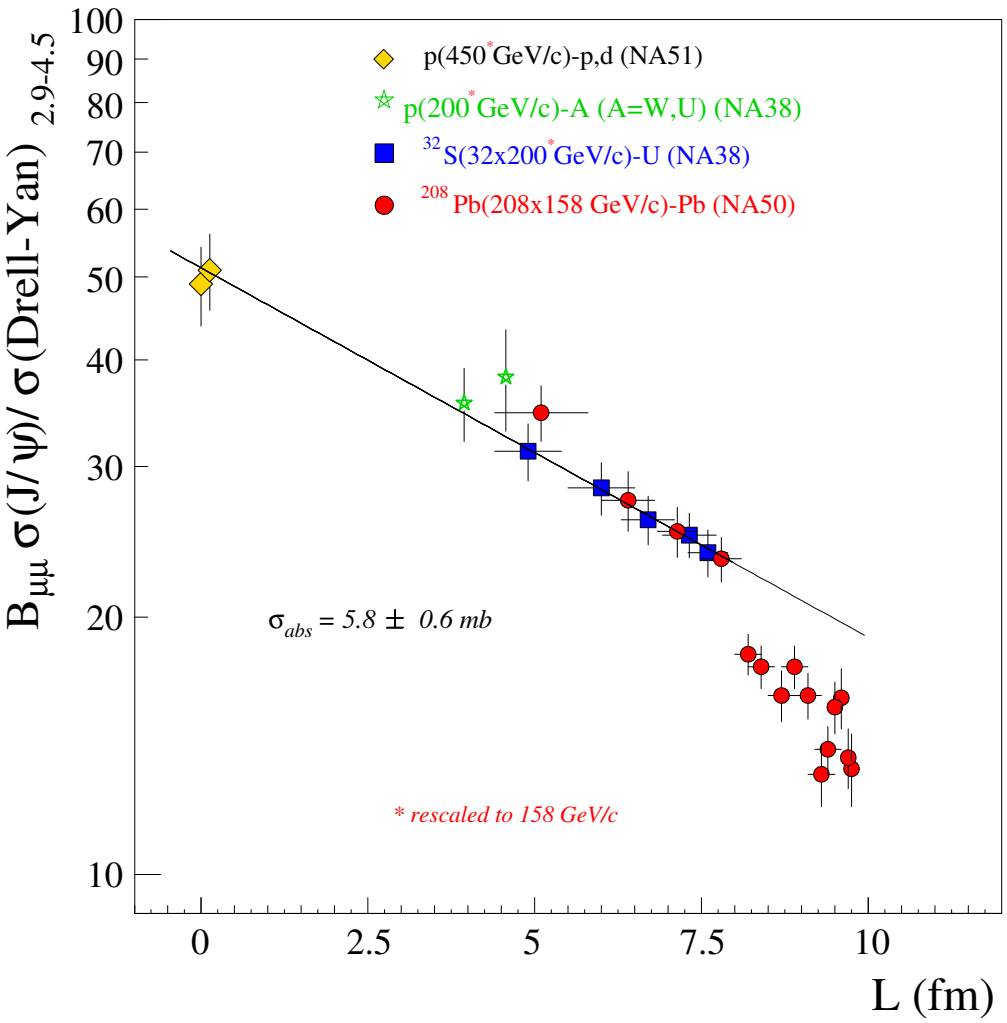
$\sigma^{DY} \sim A \times B$

⇨Instead of $B_{\mu\mu}\sigma^{J/\psi}/(A\times B)$, we can study the ratio:

$$R(E_T) = \frac{B_{\mu\mu}\sigma^{J/\psi}}{\sigma^{DY}_{2.9-4.5}}$$

Advantage: ***systematics errors*** (detector inefficiencies and flux uncertainties) (identical for J/ψ and DY) ***are cancelled in the ratio***

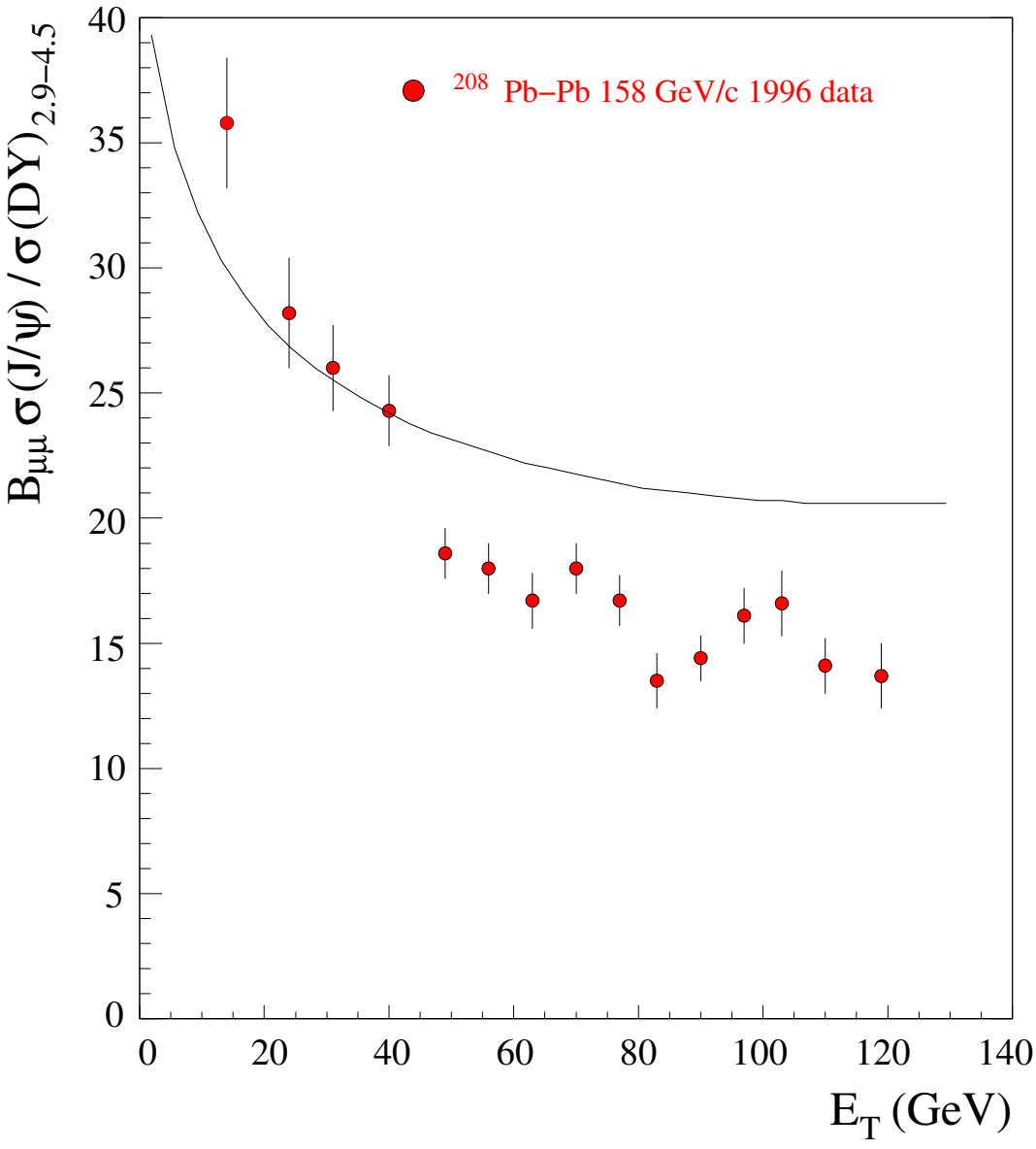
The threshold effect (1996)



An anomalous suppression pattern is seen for the first time within the same data sample

- ✓ 15 centrality (E_T) bins
- ✓ ordinary ***nuclear absorption*** accounts for p-A, S-U and ***peripheral Pb-Pb*** data
- ✓ ***threshold effect*** at L~8 fm (→ b ~8 fm)
- ✓ suppression no more governed by the L variable
- ✓ bias for central collisions (reinteraction of Pb fragments)

ψ/DY as a function of E_T



✓Threshold for anomalous J/ψ suppression at

E_T~40 GeV

✓ Significance of the result limited by

low Drell-Yan statistics

The minimum bias analysis

GOAL: Build a new estimator of σ_ψ/σ_{DY}, to overcome the problem of fluctuations in the DY sample

⇨ **MINIMUM BIAS EVENTS** defined by an incident Pb ion which interacts in the Pb target

⇨ **MINIMUM BIAS TRIGGER** = non zero energy deposit in the ZDC

1) Drell-Yan spectrum calculated from the huge sample of minimum bias events:

$$\left(\frac{dN}{dE_T}\right)_{DY^*} = \left(\frac{dN}{dE_T}\right)^{\exp}_{MB} \times \frac{\left(\frac{dN}{dE_T}\right)^{th}_{DY}}{\left(\frac{dN}{dE_T}\right)^{th}_{MB}}$$

with :

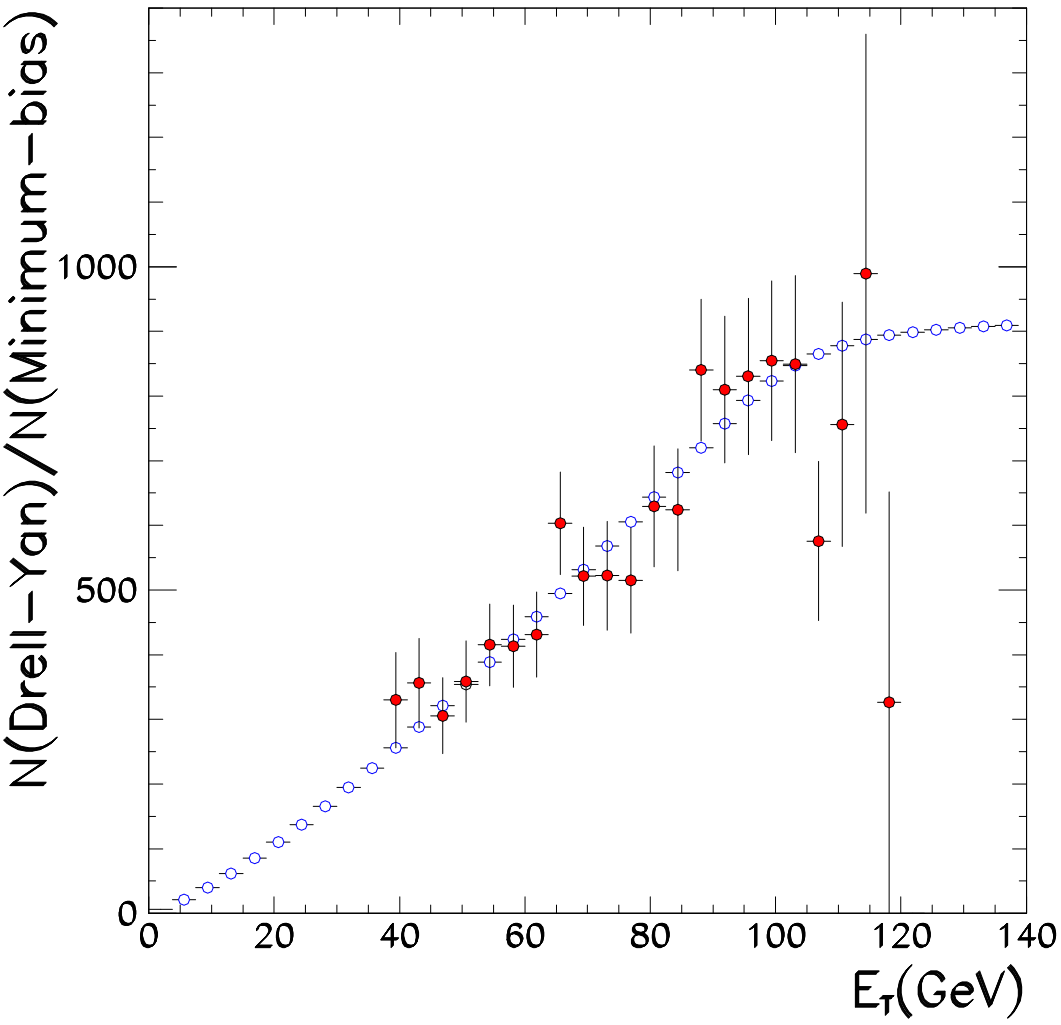
$$\left(\frac{dN}{dE_T}\right)^{th}_{MB} \propto \int P(E_T, b)\, b\, db$$

$$\left(\frac{dN}{dE_T}\right)^{th}_{DY} \propto \int N_{AB}(b) P(E_T, b)\, b\, db$$

→ $N_{AB}(b)$, $P(E_T,b)$ calculated in the frame of the Glauber model

2) $(dN/dE_T)_{J/\psi}$ obtained counting in each E_T bin (after background subtraction) the number of muon pairs with $2.9 < M_{\mu\mu} < 3.3$ GeV/c^2

The minimum bias analysis

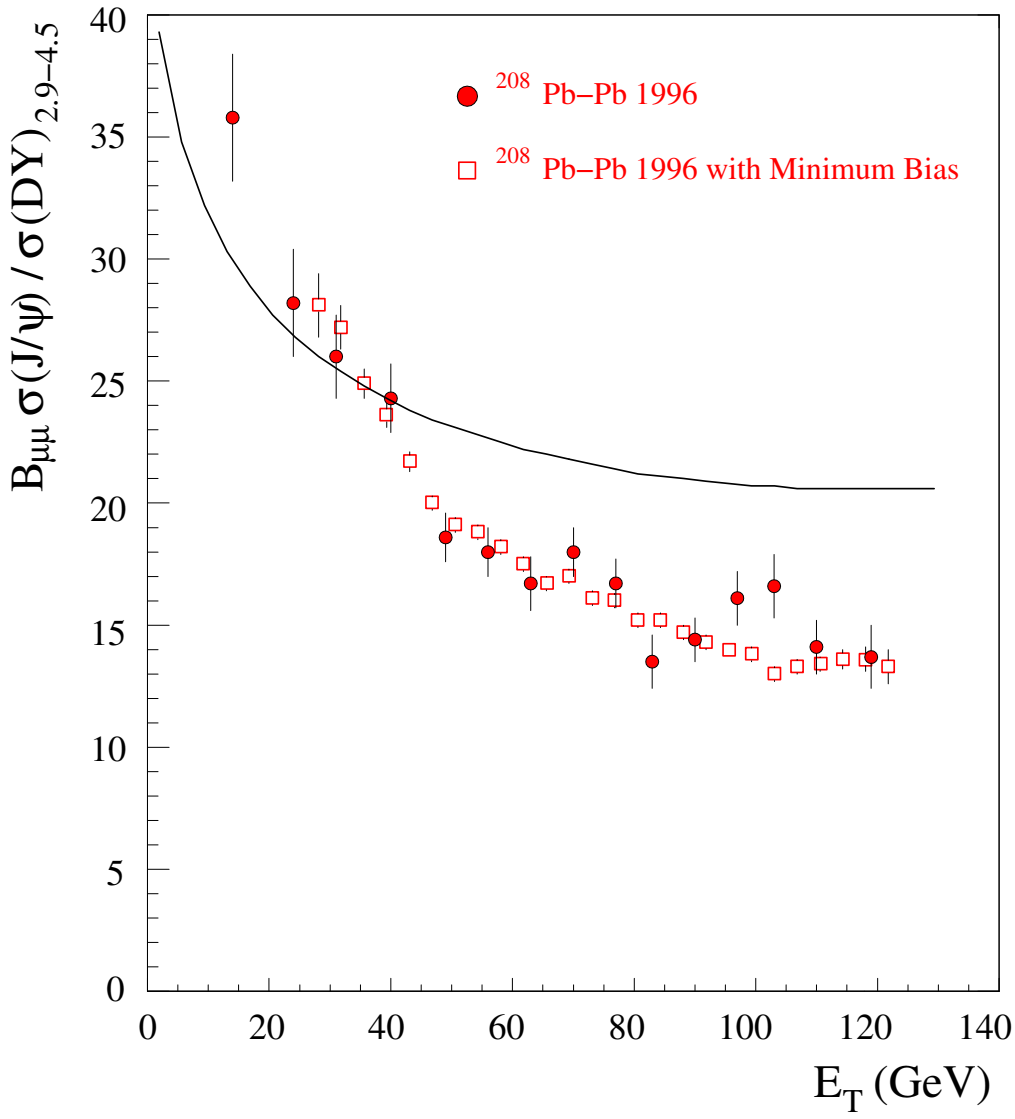


Advantages: $\sigma_{J/\psi}/\sigma_{DY*}$ free from:

- statistical fluctuations
- inefficiencies (ratio of experimental numbers)

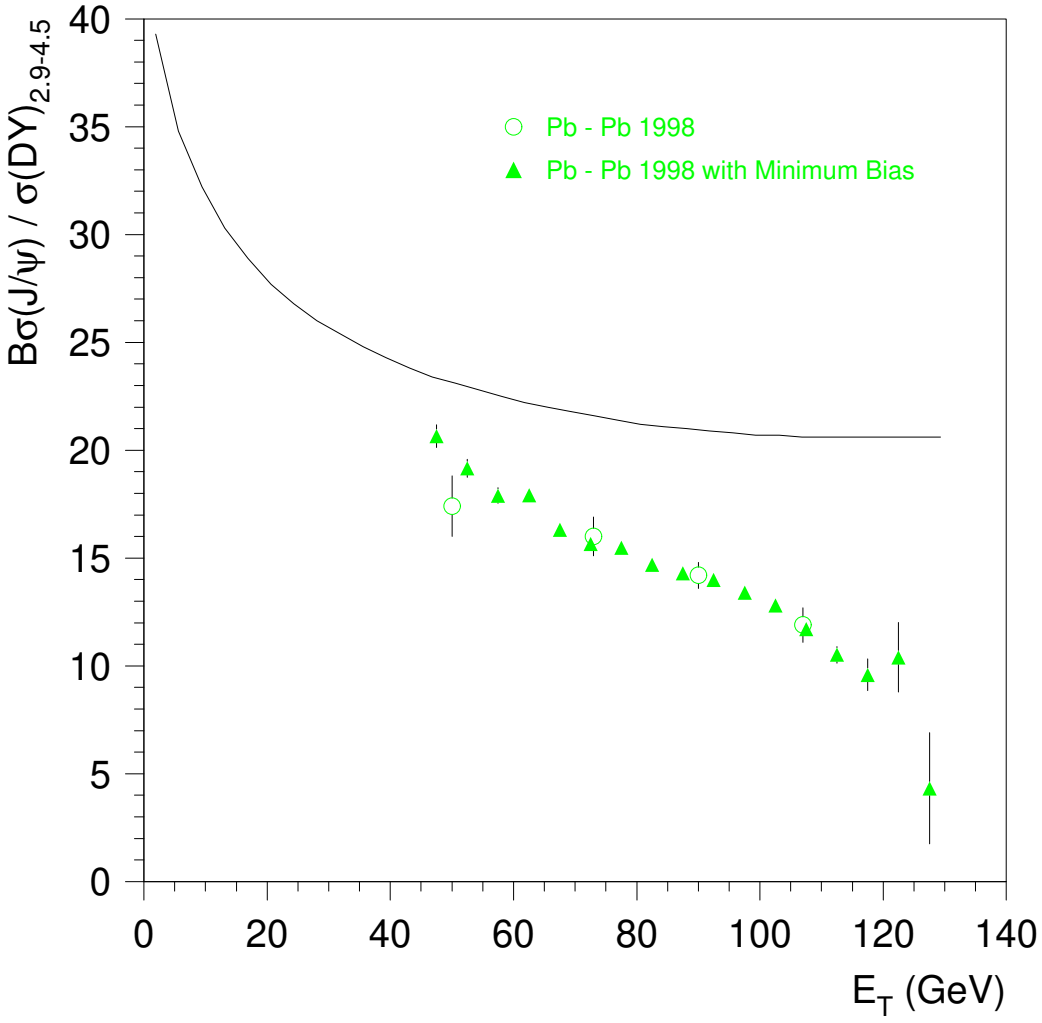
Drawback: potential new systematic effects

‘96 results with minimum bias



Excellent agreement between the two different analysis for 30 GeV<E_T<55 Gev where the drop of J/ψ yield is observed

The high E_T region (1998)



- **Thin target** (3 mm Pb): suppression ***does not saturate*** any more at high E_T

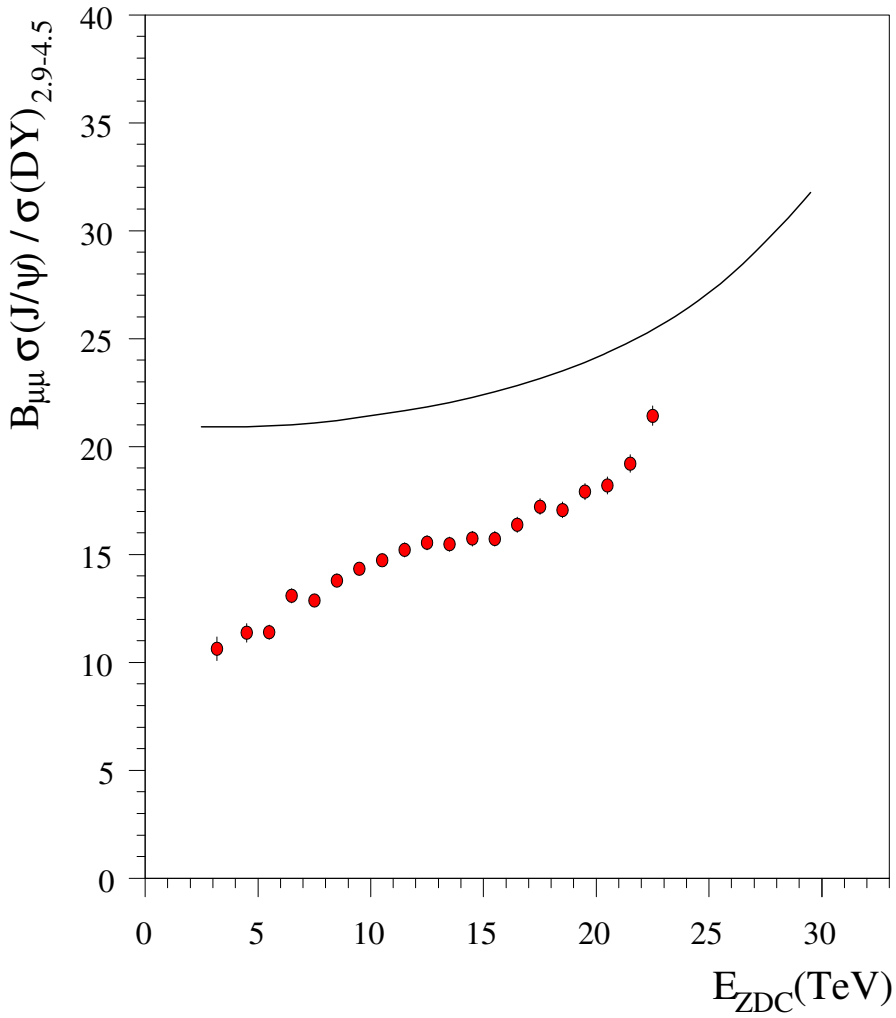
→ ***second drop at $E_T \approx 90$ GeV***

- ***Peripheral collisions***: higher contamination from off-target interactions (due to thinner target)

→ *use multiplicity detector to reconstruct interaction vertex (work in progress)*

J/ψ suppression vs. E_{ZDC}

The ***second drop in the J/ψ suppression*** pattern is crucial for the interpretation of Pb-Pb result: we use another centrality estimator (E_{ZDC}) as a further check

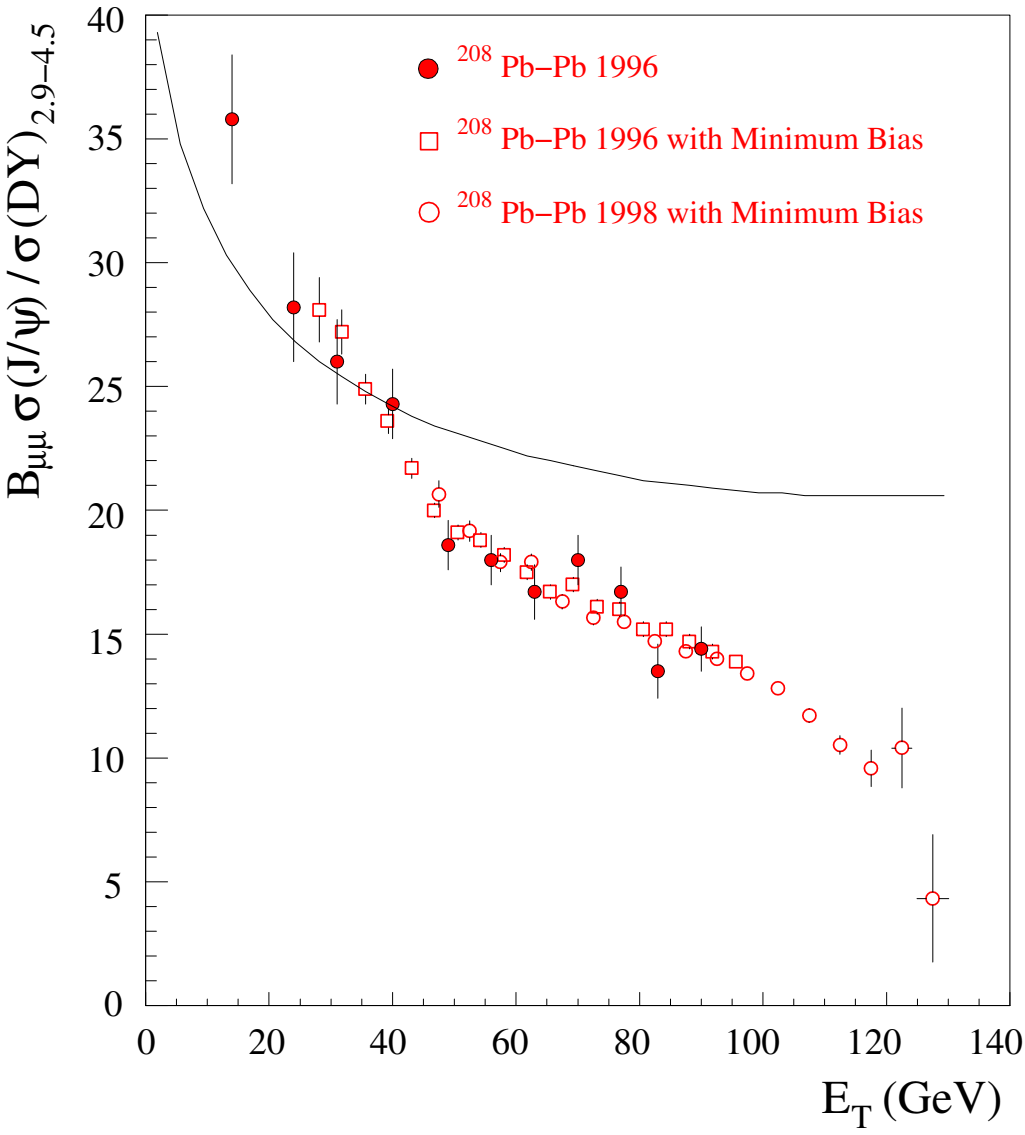


✓Suppression pattern vs. E_{ZDC} very similar to the one observed as a function of E_T

✓***No saturation for central collisions***

The complete suppression pattern

Rejected: 1996 data at E_T >90 GeV
1998 data at E_T <50 GeV



Good overall agreement!

⇨ **SHARP ONSET of the anomalous suppression**

⇨ **NO SATURATION for central events**

Hadronic absobtion models

✓ Involve ***only conventional physics***

⇨ ***no phase transition to QGP***

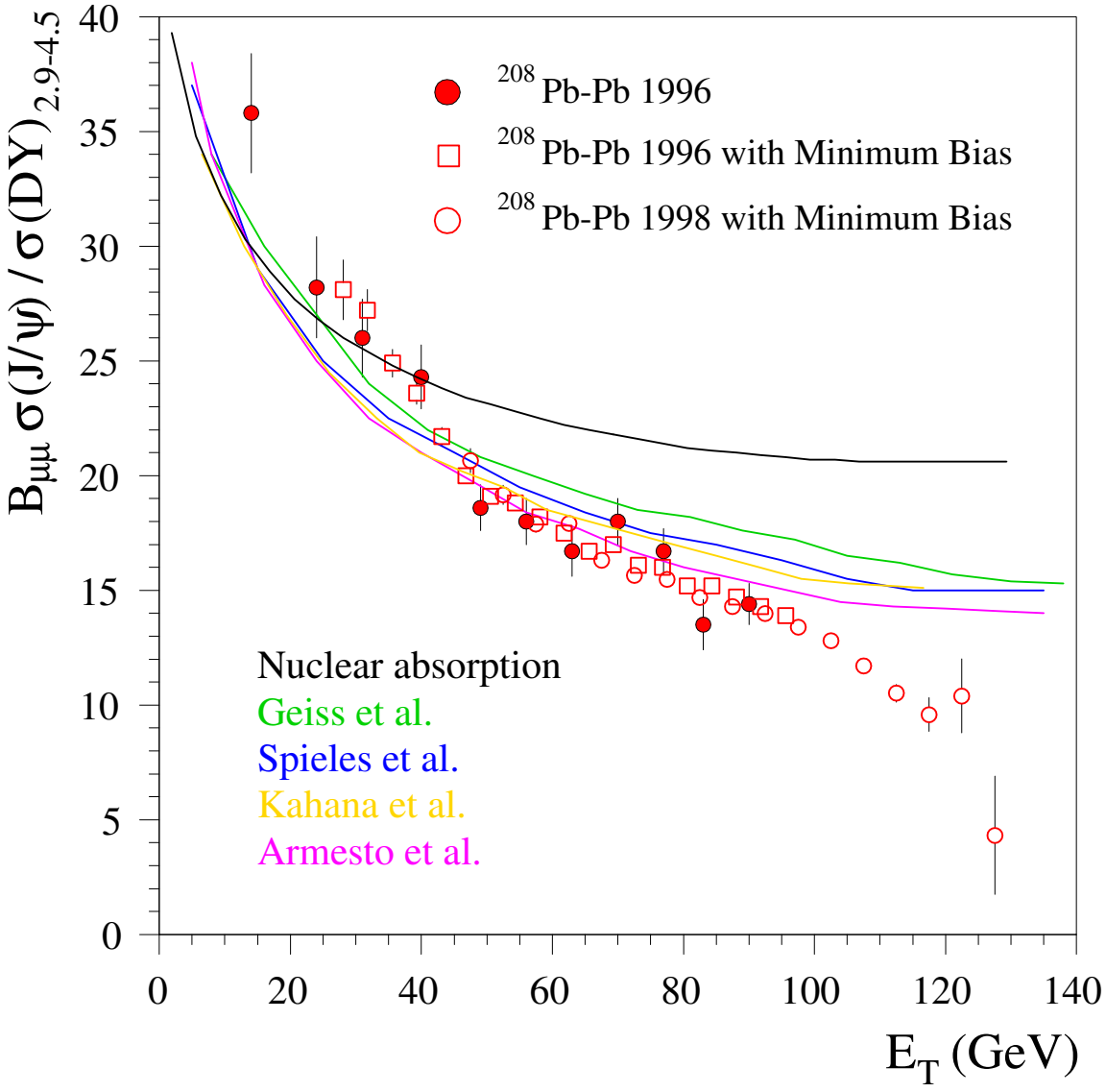
✓Consider (in addition to ordinary nuclear absorption) the effect of final-state interactions with ***comovers*** (=co-moving hadrons, mostly pions, surrounding the fully-formed J/ψ)

✓Parameters: comover density (n_{co})
nuclear absorption cross-section (σ_{nucl})
comover absorption cross-section (σ_{co})

✓Various models assuming different hypoteses on the density of comovers and their cross-section with J/ψ

⇨ ***no dicontinuity*** **of the J/ψ survival probability can be obtained with these models**

Comparison with hadronic models



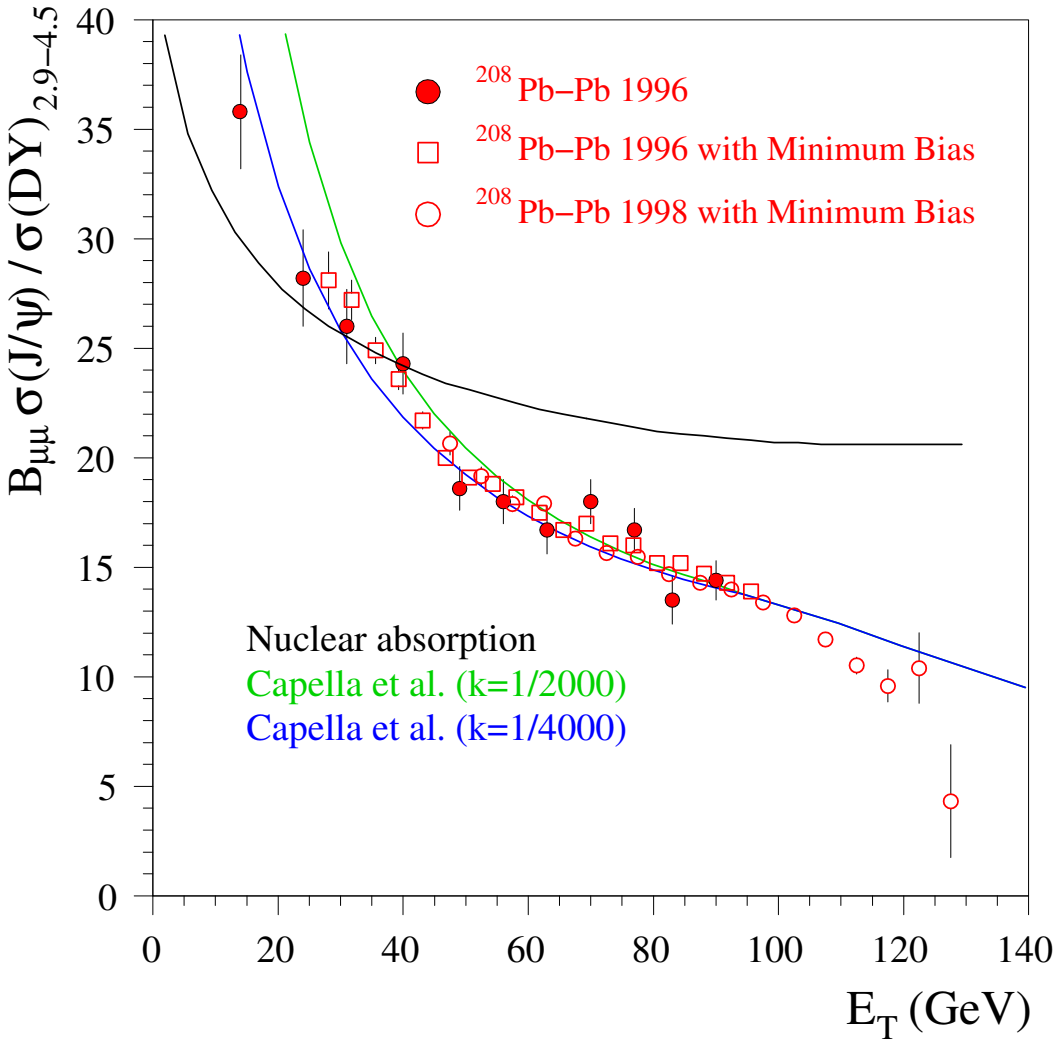
Geiss et al: cc pairs dissociation by strings

Spieles et al: Ultrarelativistic quantum molecular dynamics model

Kahana et al.: LUCIFER (Cascade theory with multiscattering formalism)

Armesto et al.: Dual Parton Model

Comparison with hadronic models



NA50 data

⇨ ***SHARP ONSET***
of the anomalous J/ψ suppression at at **E_T~40 GeV**

⇨ ***SECOND DROP***
at **E_T~90 GeV**

Hadronic models

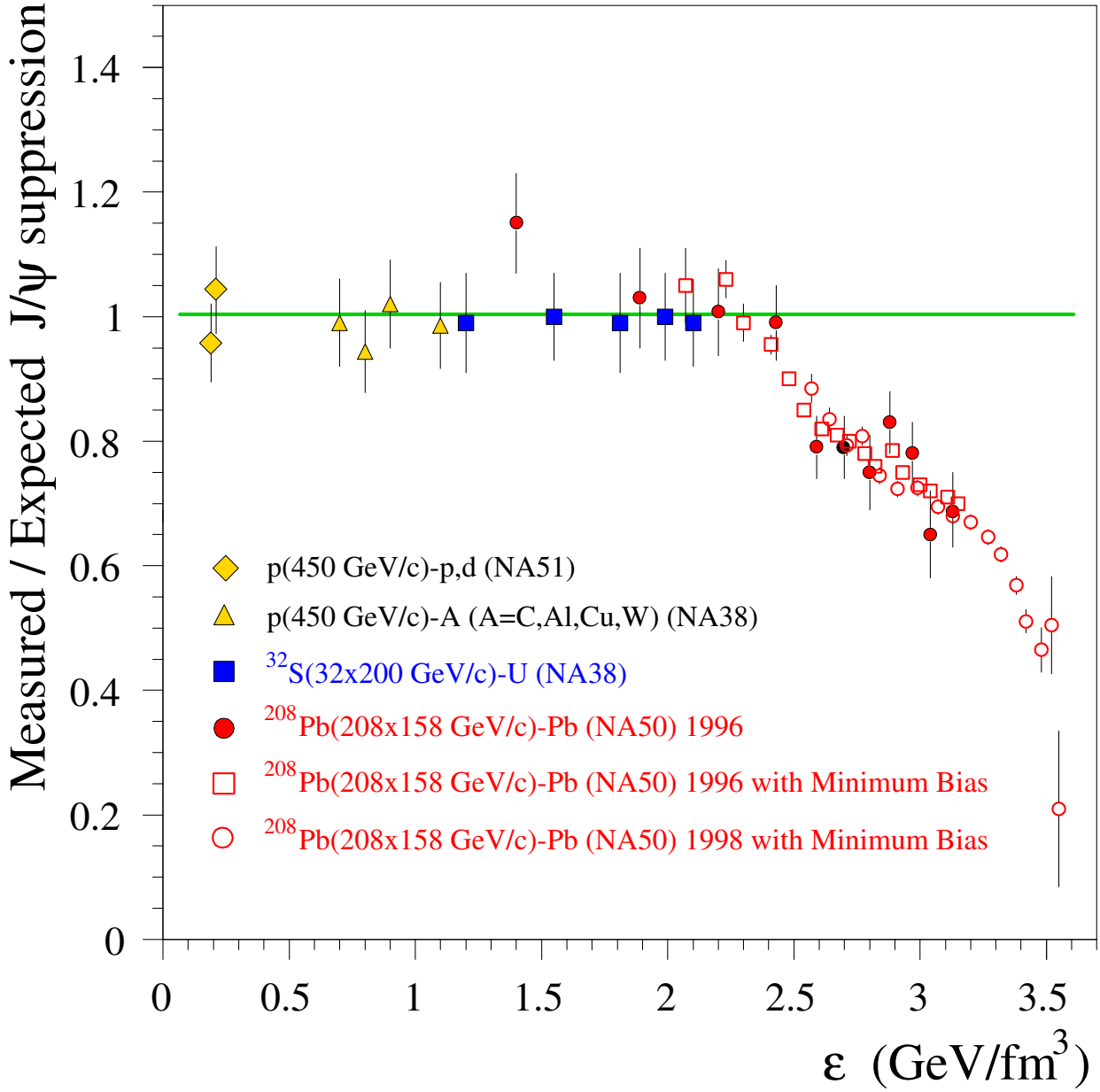
⇨ ***SMOOTH DECREASE***
of J/ψ suppression pattern

⇨ **SATURATION**
at high E_T

J/ψ suppression vs. energy density

Use Bjorken's model to compute the energy density

$$\varepsilon = \frac{\left.\frac{dE_T}{dy}\right|_{y^*=0}}{c\tau \times A_T}$$



First drop:
ε ~ 2.3 GeV/fm³

Second drop:
ε ~ 3.1 GeV/fm³

Interpretation of NA50 results assuming QGP formation

➔ ~ 40% of produced J/ψ come from χ_c decays

	χ_c	J/ψ
Radius	0.4 fm	0.2 fm
Binding energy	0.3 GeV	0.6 GeV

➔χ_c is more easily dissociated than the J/ψ

➔***2 critical values of ε:***

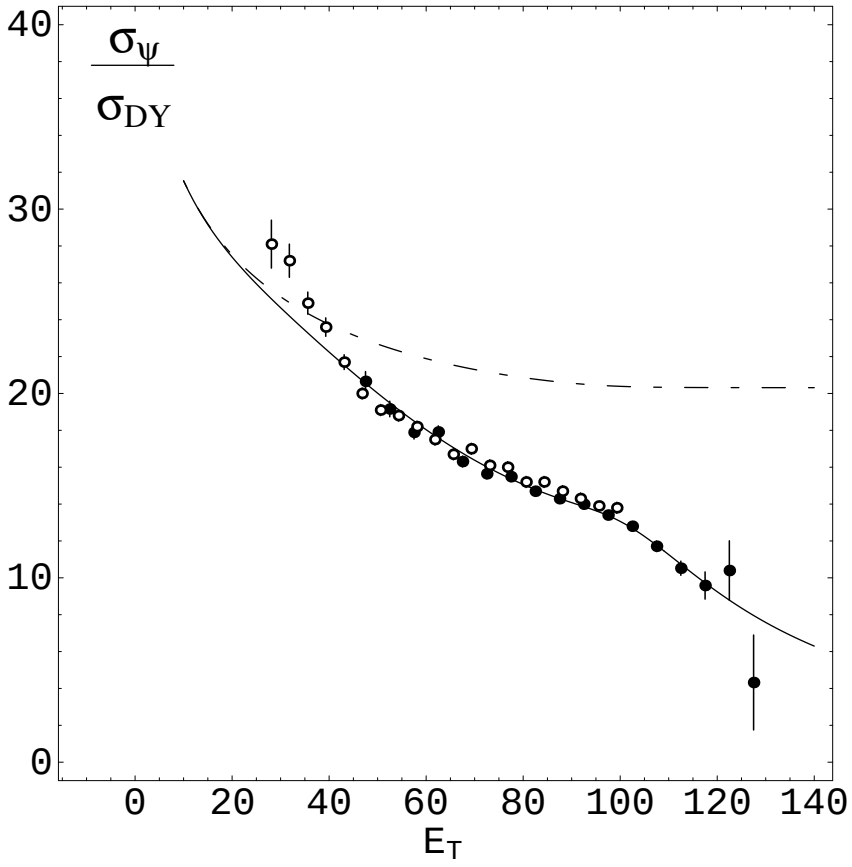
ε ~ 2.3 GeV/fm^3 dissociation of **χ_c**

ε ~ 3.1 GeV/fm^3 dissociation of **J/ψ**

Another interpretation of NA50 results

Blaizot, Dinh, Ollitrault

CERN Preprint – nucl-th/0007020 ;
Saclay-T00-098. - 10 Jul 2000



⇨ *Anomalous J/ψ suppression related to local energy density*:

$\varepsilon > \varepsilon_c$ ⇨ J/ψ disppears

⇨ ***Transverse energy fluctuations:*** for a given impact parameter, the produced transverse energy fluctuates

⇨ The largest transverse energies are achieved through fluctuations rather than by a change of the collision geometry.

Conclusions

- From **p-p** to **S-U** collisions (**NA38**) the J/ψ suppression results can be explained with ***ordinary nuclear absorption***

- **Pb-Pb** collisions (**NA50**):
  - ***Peripheral collisions*** (b≥8 fm):
    ⇨ compatible with ordinary nuclear absorption
  - ***b≈8 fm (ε≈2.3 GeV/fm^3)***:
    ⇨sharp onset of anomalous J/ψ suppression
  - ***b≈3.6 fm (ε≈3.1 GeV/fm^3)***:
    ⇨second drop in the J/ψ yield.
    ⇨No saturation for the most central collisions

- ***Conventional hadronic models*** can not explain the pattern exhibited by NA50 data
- The J/ψ suppression pattern is naturally explained in a ***deconfinement scenario***

Wait for new results from:

- ***NA50 2000 data taking*** with ***target in vacuum*** to reduce Pb-air interactions
- New experiments at **RHIC** and **LHC** which should provide further evidence of deconfinement