ψ' and χ_c decays as feed-down sources of J/ψ hadro-production

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Motivation

- A considerable fraction of the J/ψ yield observed in hadronic collisions results from ψ' and χ_c decays

- The knowledge of these fractions in *p-p* and *p-A* collisions is essential to understand results in *A-A* collisions and assess the magnitude of a possible melting of quarkonium states.

- Values like **R(ψ') = 10%** and **R(χ_c) = 30%** are often quoted, without referring to specific measurements or kinematical conditions.

- The current experimental situation, while rather well defined for the ψ', is much less clear in the χ_c case.

R(ψ') and R(χ_c) : definitions

We want to answer the question
what is the J/ψ feed-down fraction from ψ' decays ?
The relevant quantity,

$$R(\psi') = \frac{J/\psi\text{'s from } \psi'}{ALL\ J/\psi\text{'s}} \ ,$$

is deduced from measurements of

$$\rho(\psi') = \frac{\sigma(\psi')\ B(\psi' \to \ell\ell)}{\sigma_{incl}(J/\psi)\ B(J/\psi \to \ell\ell)}$$

$$\frac{B(J/\psi \to \ell\ell)}{B(\psi' \to \ell\ell)}\ B(\psi' \to J/\psi\ X) = 4.53 \pm 0.13 \quad \text{(PDG)}$$

The corresponding quantity for the χ_c case is:

$$R(\chi_c) = \frac{J/\psi\text{'s from } \chi_c}{ALL\ J/\psi\text{'s}}$$

R(ψ')

E_{lab}: 39.5 → 920 GeV
A : 1 → 207
x_F : **–0.6** → **1**

Experiment	Collision system	E_{beam} [GeV]	Phase space	$\langle x_F \rangle$
E331	p-C	225	$0 < x_F < 0.7$	$\simeq 0.3$
E444	p-C	225	$0 < x_F < 0.9$	$\simeq 0.35$
E705	p-Li	300	$-0.1 < x_F < 0.5$	$\simeq 0.2$
E288	p-Be	400	$-0.6 < x_F < 0.8$	$\simeq 0.1$
NA38	p-W/U p-C/Al/Cu/W	200 450	$-0.4 < y_{cm} < 0.6$	$\simeq 0$
NA51	p-H/D	450	$-0.4 < y_{cm} < 0.6$	$\simeq 0$
NA50 96/98	p-Be/Al/Cu/ Ag/W	450	$-0.5 < y_{cm} < 0.5$	$\simeq 0$
NA50 2000	p-Be/Al/Cu/ Ag/W/Pb	400	$-0.425 < y_{cm} < 0.575$	$\simeq 0$
E771	p-Si	800	$-0.05 < x_F < 0.25$	$\simeq 0.1$
E789	p-Au	800	$-0.03 < x_F < 0.15$	$\simeq 0.06$
E866	p-Be/Fe/W	800	$-0.1 < x_F < 0.8$	$\simeq 0.3$
HERA-B	p-C/Ti/W	920	$-0.35 < x_F < 0.1$	-0.065
WA39	$\pi^{\pm}$-W	39.5	$-0.5 < x_F < 0.8$	$\simeq 0.2$
E537	π^{-}-W	125	$0 < x_F < 1$	$\simeq 0.3$
WA11	π^{-}-Be	150	$-0.4 < x_F < 0.9$	$\simeq 0.3$
E331	π^{+}-C	225	$0 < x_F < 0.9$	$\simeq 0.35$
E444	$\pi^{\pm}$-C	225	$0 < x_F < 1$	$\simeq 0.4$
E615	π^{-}-W	253	$0.3 < x_F < 1$	$\simeq 0.6$
E705	$\pi^{\pm}$-Li	300	$-0.1 < x_F < 0.5$	$\simeq 0.2$
E672-706	π^{-}-Be	515	$0.1 < x_F < 0.8$	$\simeq 0.4$
Experiment	Collision system	$\sqrt{s}$ [GeV]	Phase space	$\langle x_F \rangle$
ISR	pp	58 (avg.)	$y_{cm} \simeq 0$	0

Data selection

General selection criteria:

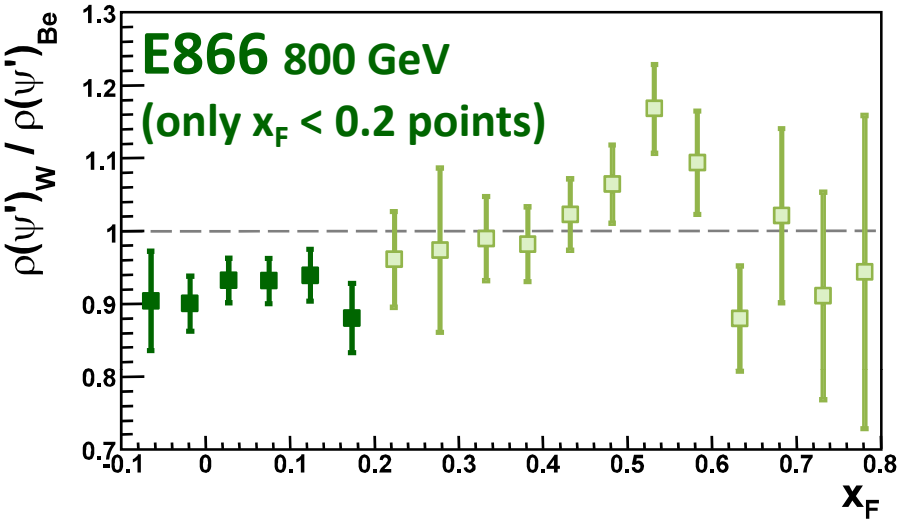
- Only mid-rapidity data are considered here
  - Quarkonium suppression measurements in *AA* collisions have been (and will be) made at mid-rapidity
  - At high-x_F there is a non-trivial cocktail of production and absorption mechanisms, not easy to disentangle

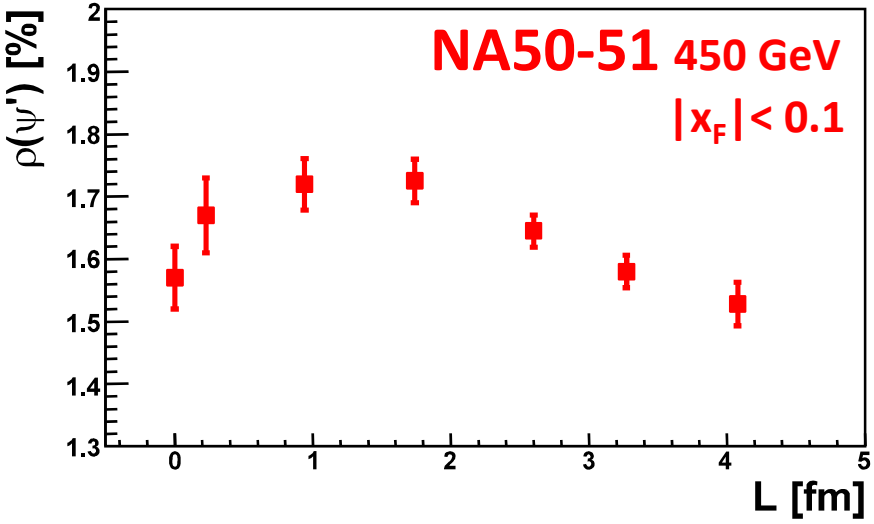
R(ψ'):

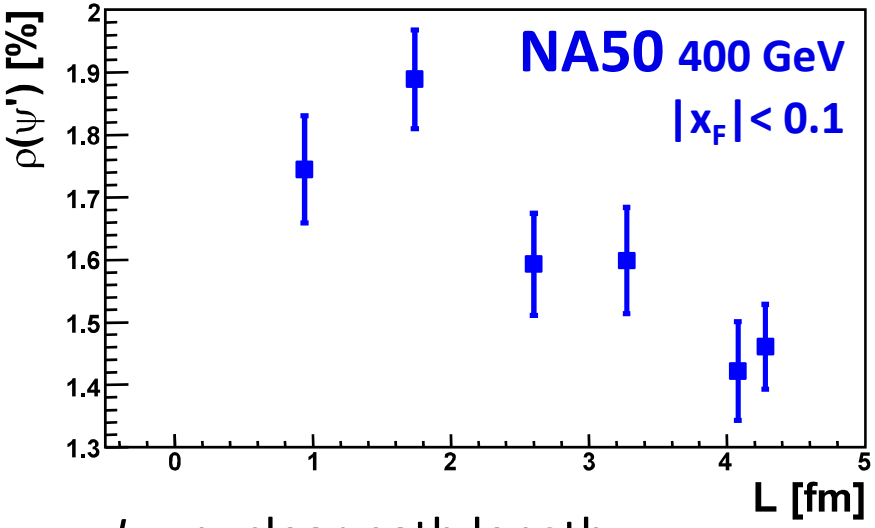
- We use the accurate nuclear-dependent measurements of
  - **NA50/NA51** : cross sections at 400-450 GeV, 8 nuclear targets
  - **E866** : p-W/p-Be ratio at 800 GeV
- Other measurements give a completely negligible contribution

Selected ρ(ψ') data

At mid rapidity, the ψ' and J/ψ are differently absorbed by the nuclear medium







L = nuclear path length

Determination of R(ψ') for L → 0

To extract from p-*nucleus* data the "elementary collisions" value, we use the Glauber model to extrapolate to $L = 0$

$$\frac{\sigma(pA \to \psi)}{A\,\sigma(pN \to \psi)} = e^{-\sigma_{abs}(\psi)\ \rho L}$$

The difference in ψ' and J/ψ absorption rates is defined as

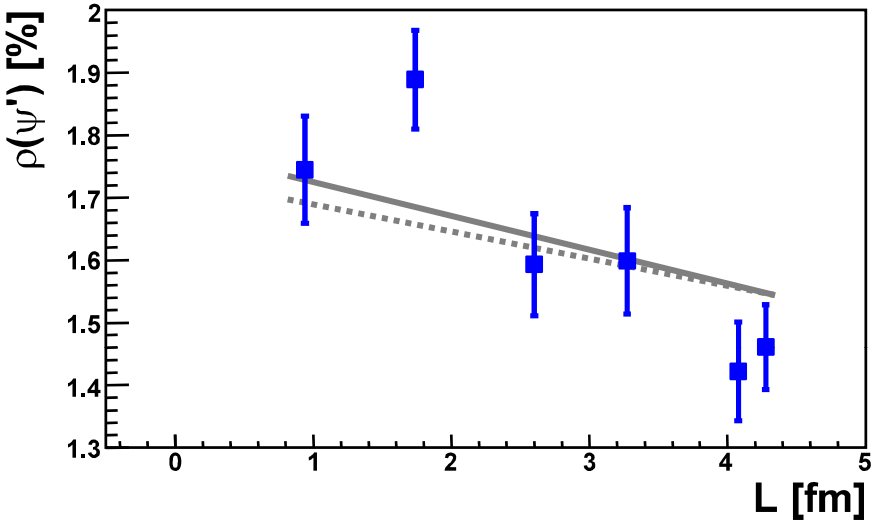
$$\Delta\sigma_{abs} = \sigma_{abs}(\psi') - \sigma_{abs}(\mathbf{J})$$

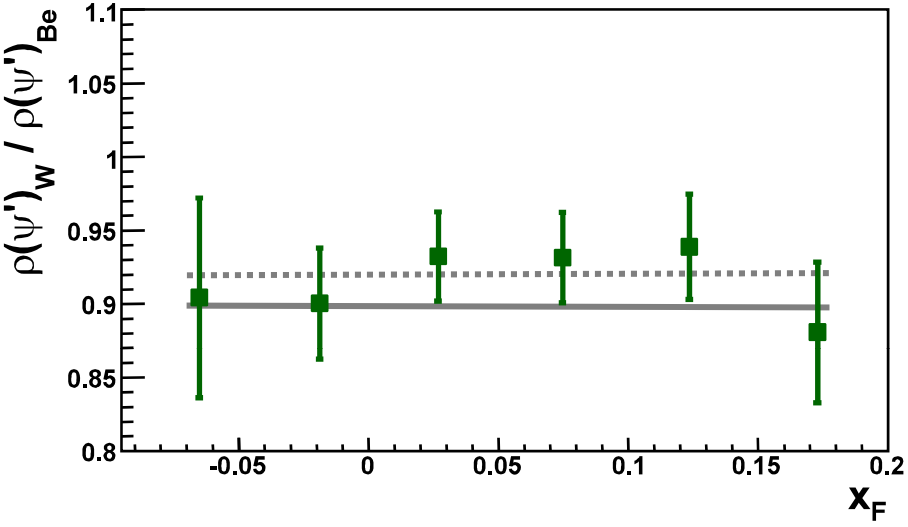
with **J** *excluding* the J/ψ's from ψ' feed down

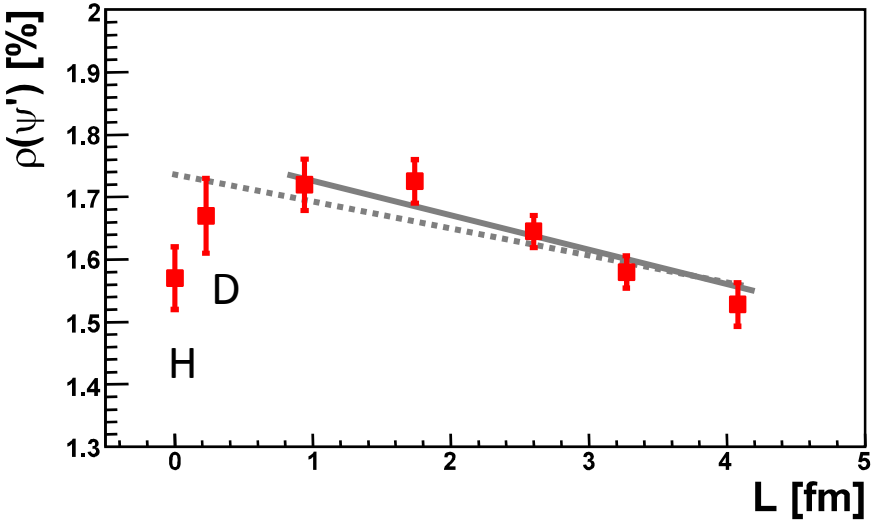
Here σ_{abs} indicates an *effective* absorption cross section, convoluting several possible effects (energy losses, nuclear modifications of PDFs, formation time effects, …)

Global fit of $R^0(\psi')$ and $\Delta\sigma_{abs}$

Two parameters, assumed independent of energy and kinematics



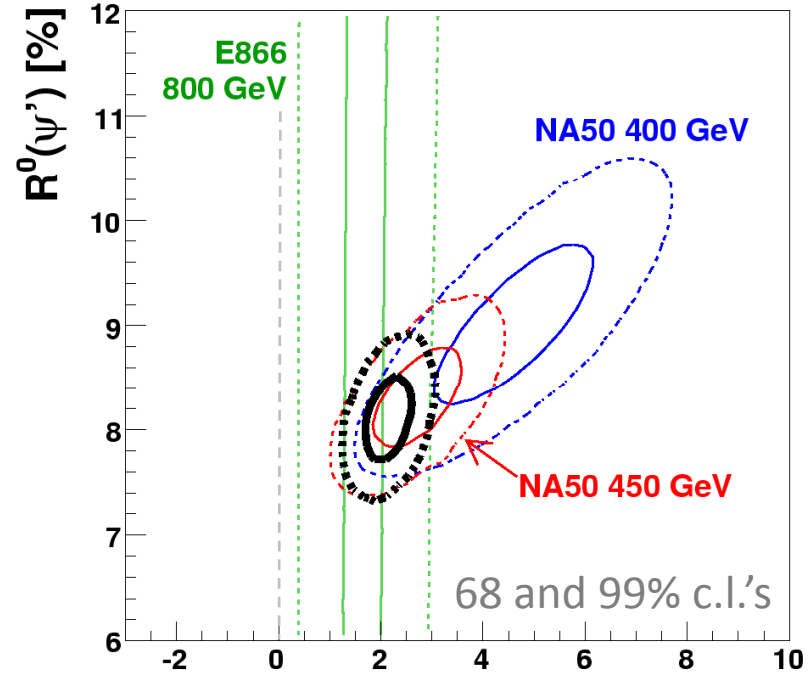


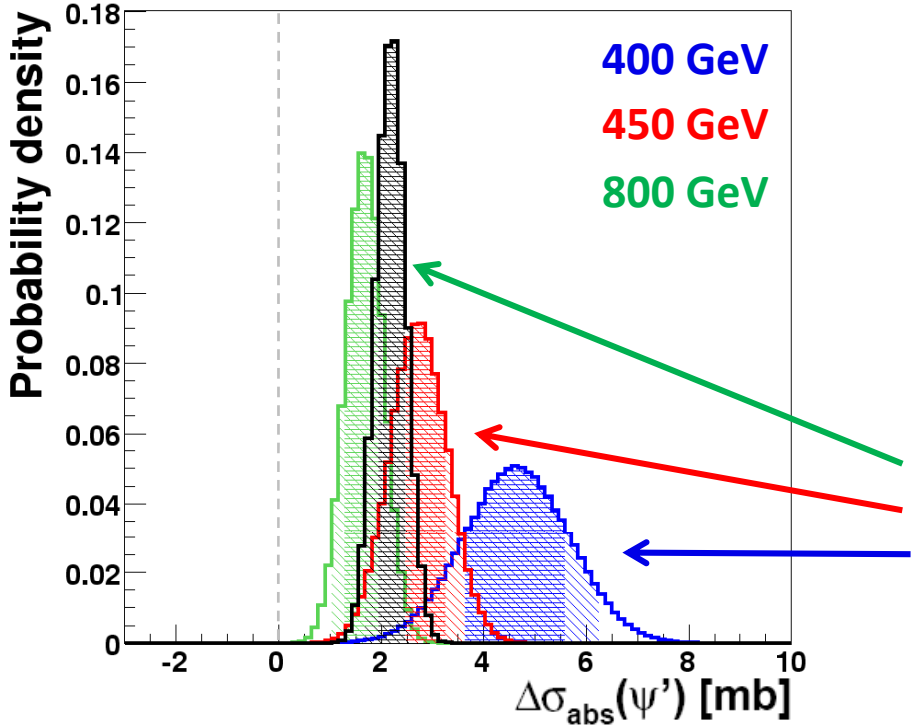


All data: $P(\chi^2) = 1\%$

Without H and D pts: $P(\chi^2) = 27\%$

- The simple model used cannot account for the H and D data points
- Are H and D nuclei not large enough to be traversed by fully formed states?
- Are Glauber calculations unreliable for such small nuclei?





ψ' results

excluding pH and pD points

NA50 400 GeV
NA50 450 GeV
E866 800 GeV

black: all combined
(→ global fits shown in the previous slide)

combined fit results

$$\mathbf{R^0(\psi') = (8.1 \pm 0.3)\ \%}$$
$$\mathbf{\Delta\sigma_{abs} = (2.2 \pm 0.3)\ mb}$$

Notes:

- The final error in $R^0(\psi')$ is essentially due to the BR's
- Even if the three values are compatible, $\Delta\sigma_{abs}$ seems to decrease with energy

R(χ_c)

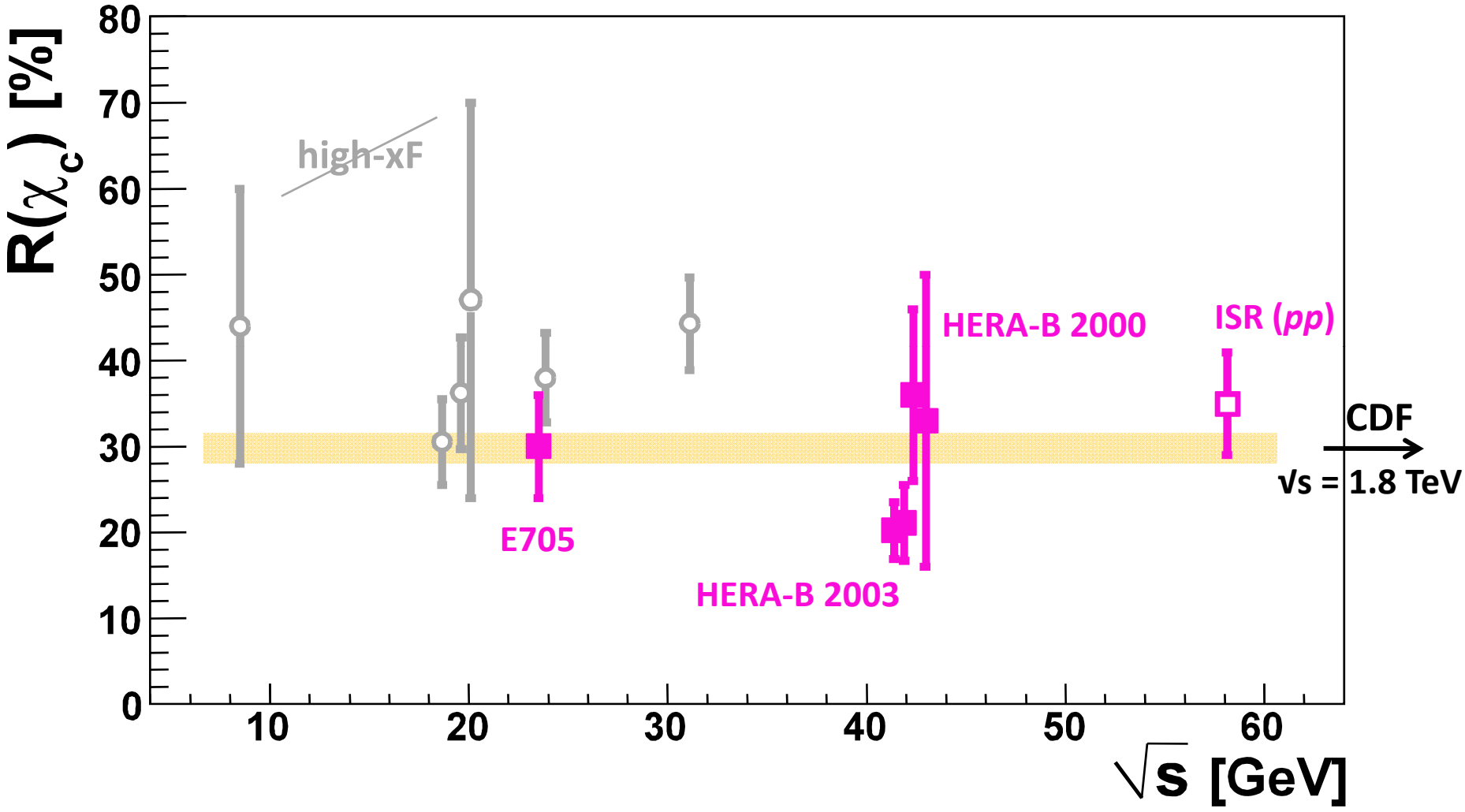
A : **1** → 184
x_F : –0.35 → **0.9**

as in the ψ' case:

- mid rapidity only
- no "exceptionally light" nuclei

Experiment	Collision system	$E_{\rm beam}$ [GeV]	Phase space	$\langle x_F \rangle$
E369-610-673	p-Be	225 (avg.)	$0.1 < x_F < 0.6$	0.32
E705	p-Li	300	$-0.1 < x_F < 0.5$	$\simeq 0.2$
E771	p-Si	800	$-0.05 < x_F < 0.25$	$\simeq 0.1$
HERA-B 2000	p-C/Ti	920	$-0.25 < x_F < 0.15$	-0.035
HERA-B 2003	p-C/W	920	$-0.35 < x_F < 0.15$	-0.065
SERPUKHOV-140	π^--H	38	$0.3 < x_F < 0.8$	$\simeq 0.5$
WA11	π^--Be	185	$-0.4 < x_F < 0.9$	$\simeq 0.3$
E369-610-673	π^--Be (mostly)	209 (avg.)	$0 < x_F < 0.8$	0.43
E705	$\pi^\pm$-Li	300	$-0.1 < x_F < 0.5$	$\simeq 0.2$
E672-706	π^--Be	515	$0.1 < x_F < 0.8$	$\simeq 0.4$
Experiment	Collision system	$\sqrt{s}$ [GeV]	Phase space	$\langle x_F \rangle$
ISR	pp	58 (avg.)	$y_{\rm cm} \simeq 0$	0
CDF	$p\bar{p}$	1800	$\lvert y_{\rm cm} \rvert < 0.6$	0

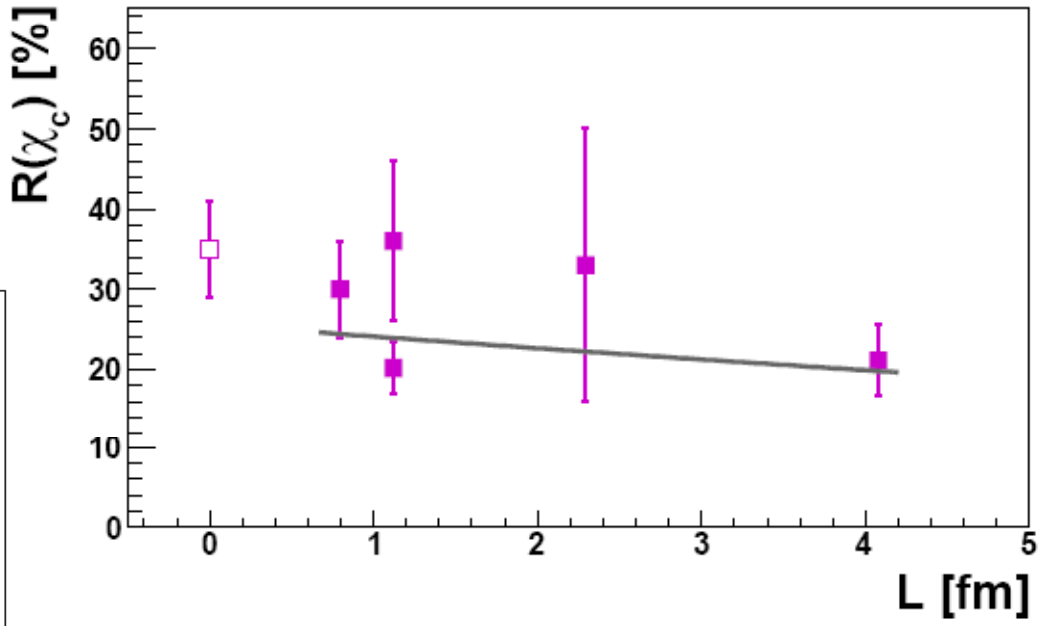
$R(\chi_c)$: selected data

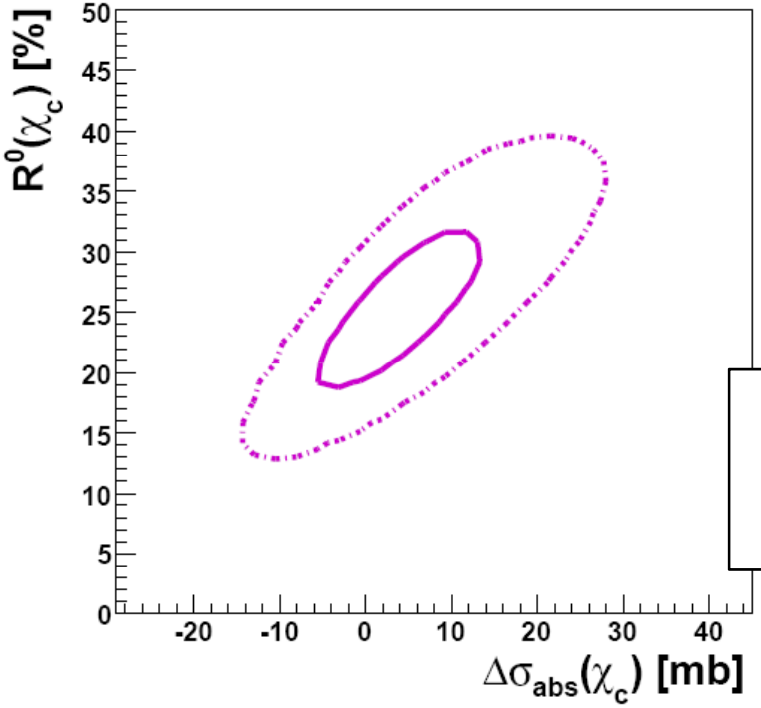


("blind" overall average: $\langle R(\chi_c)\rangle = (30 \pm 2)\%$, $P(\chi^2) < 1\%$)

$R(\chi_c)$: result

- Leaving free the difference between the J/ψ and χ_c effective absorption cross sections
- Excluding pp point





$R^0(\chi_c) = (25 \pm 5)$ %
$\Delta\sigma_{abs} > 0$ at 75% c.l.

$P(\chi^2) = 25\%$

Energy dependencies?

- From *mid-rapidity* fixed-target measurements, √s up to 40 GeV:

$\mathbf{R^0(\psi')} = \mathbf{(8.1 \pm 0.3)}$ % $\mathbf{R^0(\chi_c)} = \mathbf{(25 \pm 5)}$ %

- At much higher energies (√s = 1.8 TeV), CDF measured:
  $\mathbf{R^0(\psi')}_{p_T = 5\ \mathrm{GeV/c}} = \mathbf{(7 \pm 2)}$ % and $\mathbf{R^0(\chi_c)} = \mathbf{(30 \pm 6)}$ %

- No strong dependencies are seen with energy (or p_T ?)

  ⇨ "$dR(\psi')/d(\sqrt{s})$" = $-(0.6 \pm 1.1)$% /TeV
  "$dR(\chi_c)/d(\sqrt{s})$" = (3 ± 4)% /TeV

- We can interpolate to the RHIC energy, √s = 200 GeV:
  $\mathbf{R^0(\psi')} = \mathbf{(8.0 \pm 0.4)}$ % and $\mathbf{R^0(\chi_c)} = \mathbf{(26 \pm 5)}$ %

Current values, PHENIX preliminary:
$\mathbf{R^0(\psi')} = \mathbf{(8.6 \pm 2.5)}$ % and $\mathbf{R^0(\chi_c)} < \mathbf{42}$ % at 90% C.L.

Outlook

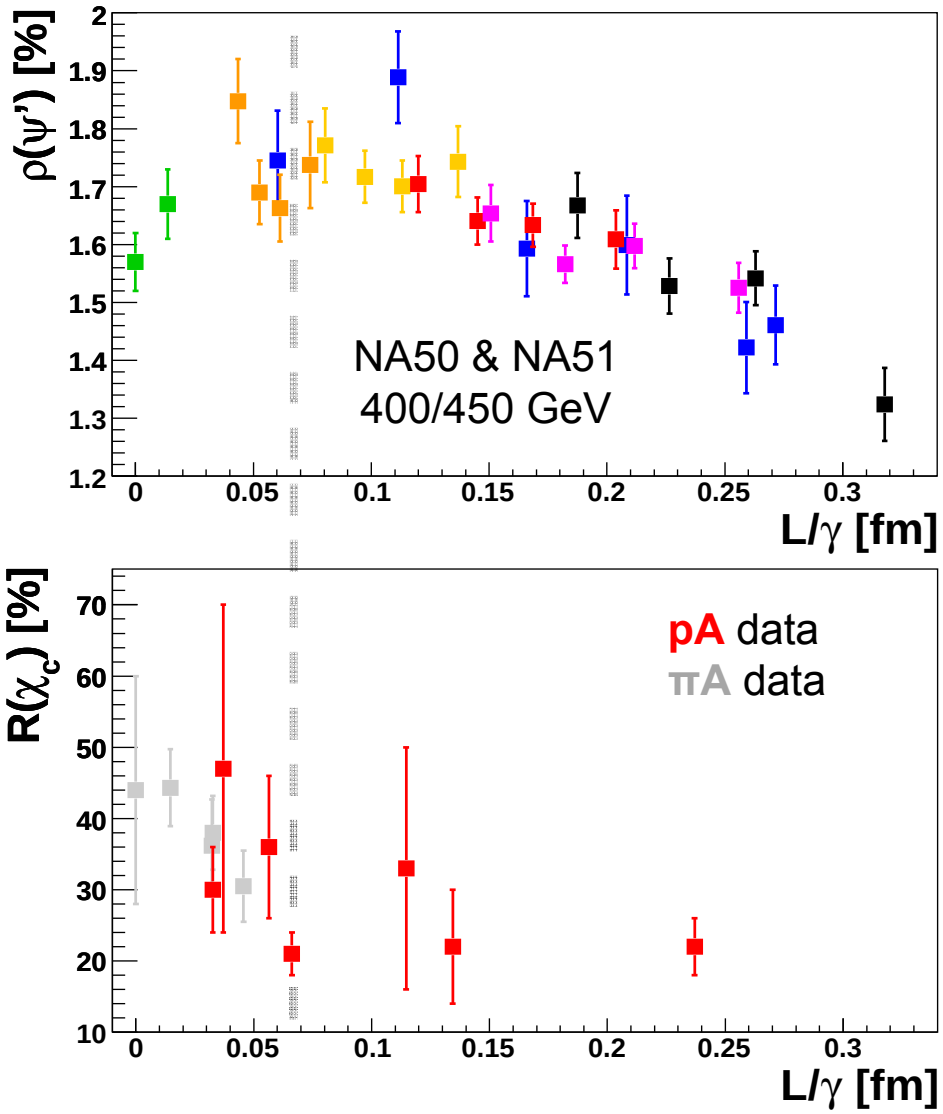
We focussed on mid-rapidity and assumed that the absorption processes do not depend on kinematics.

However,

1) the level of absorption seems to *decrease* with increasing energy or momentum
   - we saw a decreasing trend of $\Delta\sigma_{abs}(\psi')$ with energy
   - there are significant J/ψ and ψ' kinematic dependencies (see Hermine Wöhri's talk on Friday)
   - E866: $\Delta\sigma_{abs}(\psi')$ vanishes at high x_F
2) Moreover, it seems that J/ψ and ψ' are absorbed differently only in large-enough nuclei (> Be)

⇨ Less absorption for
small L and *large energy or momentum...*

A matter of time?



The ψ'-to-J/ψ and χ_c-to-J/ψ production ratios for different nuclei (***A***) and x_F values show a possible scaling with the ***proper time $L(A) / \gamma(x_F)$*** spent by the charmonium state inside the nucleus…

And something different may be happening at early times ($L/\gamma < 0.05$–0.10 fm) …

In preparation