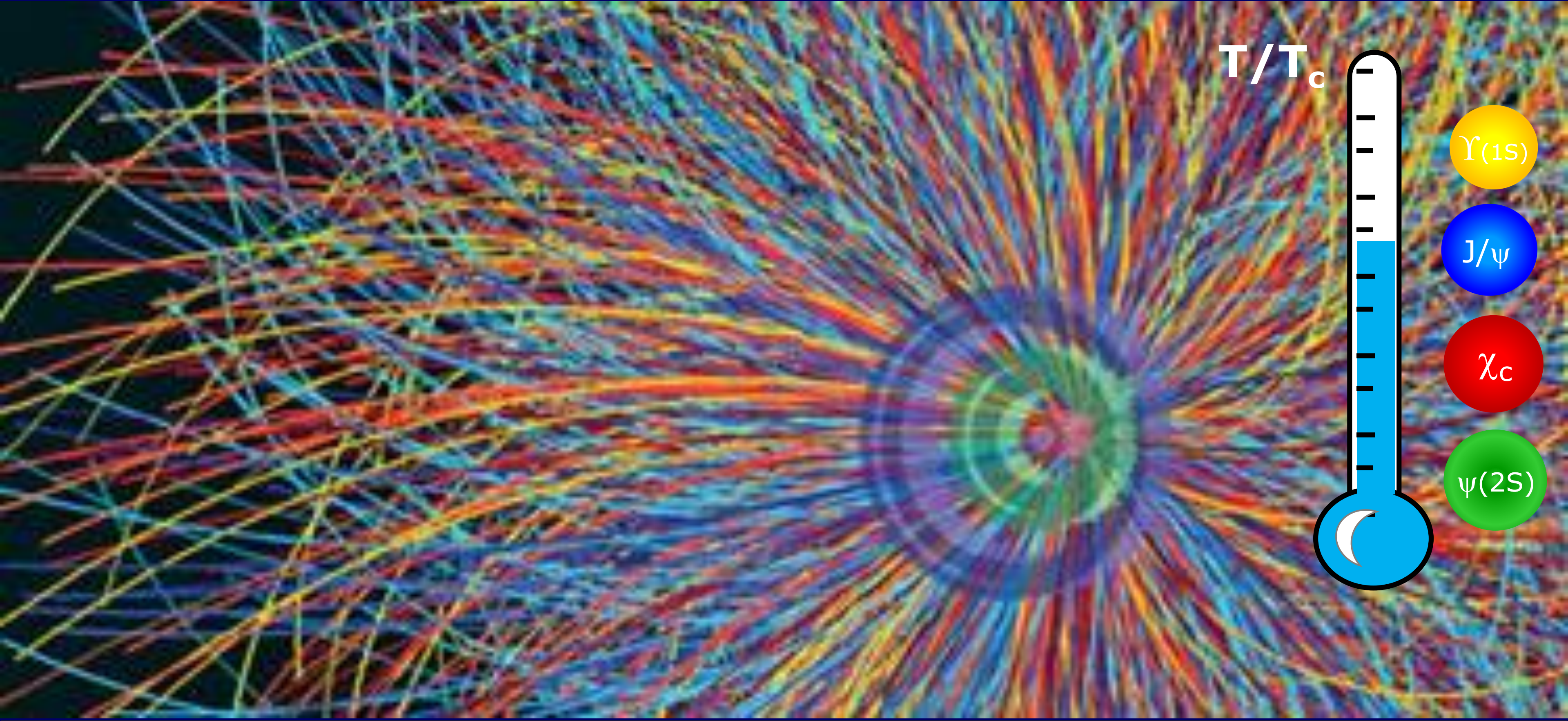


Quarkonium and Quark Gluon Plasma: introduction

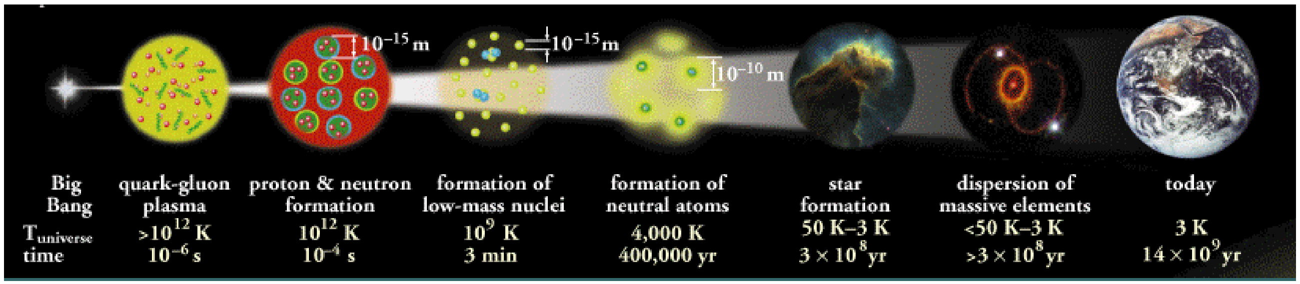
Roberta Arnaldi
INFN Torino

GSI Pre-colloquium, May 26th 2015

HEAVY-ION PHYSICS

- QCD predicts a phase transition from hadronic matter to a deconfined phase (at high temperatures)

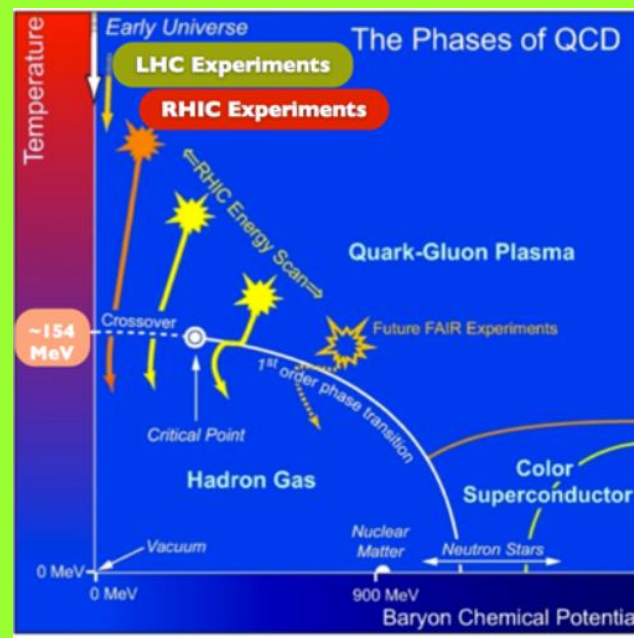
QGP at $\mu \sim 0$ similar to early Universe (~ few first μs)



- **Heavy-ion collisions provide experimental access to the QCD matter**

- First signal of QGP formation at SPS and RHIC

- LHC: detailed investigation of QGP properties



HEAVY-ION COLLISIONS

Facility	Experiment	System	$\sqrt{s_{NN}}$ (GeV)	Data taking
SPS	NA38	S-U	19	1986-1992
	NA50	Pb-Pb	17	1995-2003
		p-A	27-29	
	NA60	In-In	17	2003-2004
		p-A	17-27	
RHIC	PHENIX/STAR	Au-Au, Cu-Cu, Cu-Au, U-U	200, 193, 62, 39	2000-2015
		d-Au	200	
LHC	ALICE/ATLAS/ CMS/LHCb	Pb-Pb	2760	2010-2012
		p-Pb	5020	2013

➡ pp collision program has also been scheduled at RHIC and LHC

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~30 years long story

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More than a factor ~100 increase in energy

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Fixed target experiments

Collider experiments

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For all experiments, the AA program is followed by a pA one

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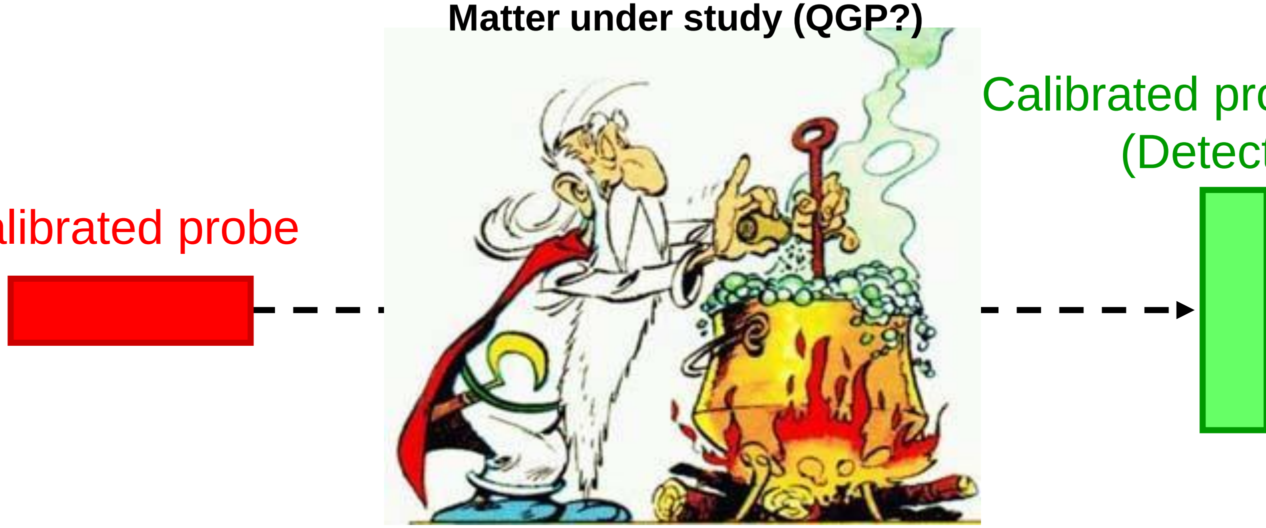
LOOKING FOR A SIGNATURE!

How can we observe the properties of the created matter?

- transient nature of the matter created in high energy collisions → external probes cannot be used to study its properties
- energetic particles, produced early in the collision, interact with the medium itself, behaving as penetrating probe

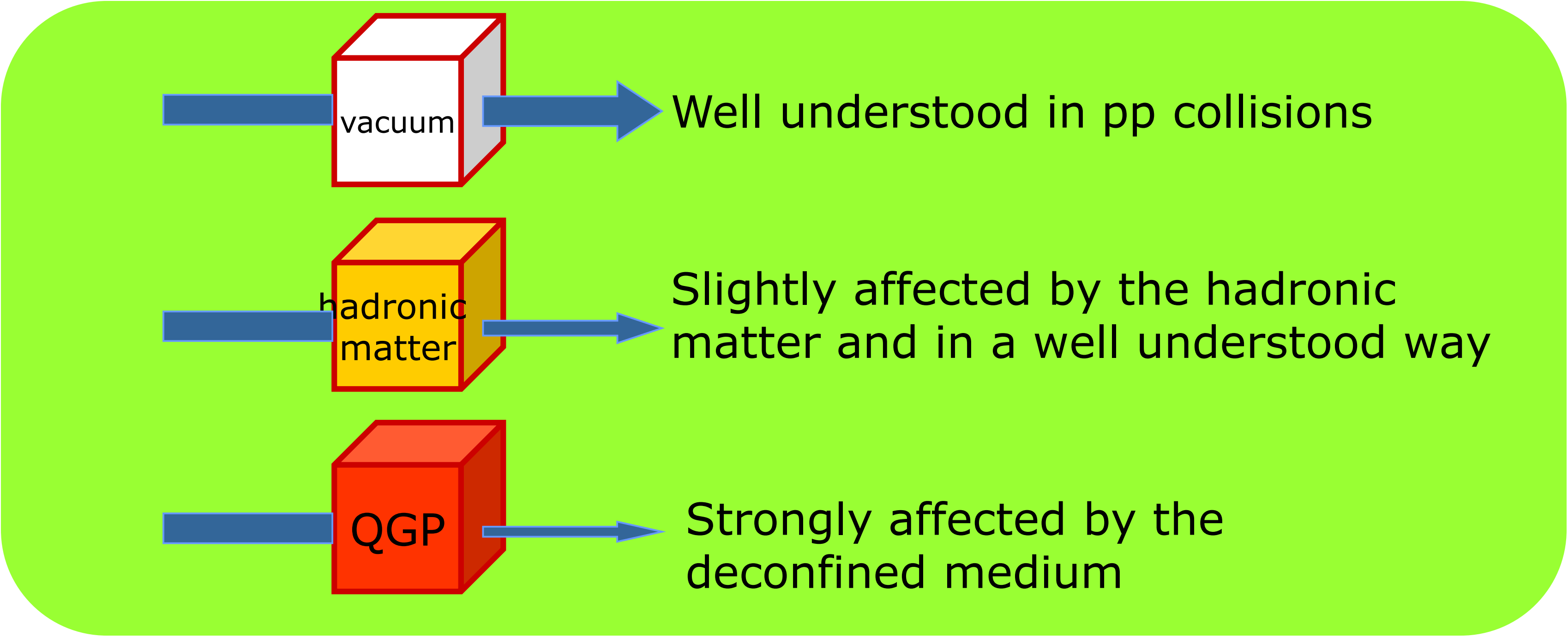
changing the temperature of the system (energy and centrality of the collisions) we study how the matter produced in the collisions affects these probes



FINDING A GOOD PROBE...

Which probe should we use to test the QCD matter?

The probe must be produced early in the collision evolution, so that it is there before the matter to be probed



The probe must be well calibrated, i.e. its behaviour in "standard" matter should be under control

AND CALIBRATE IT. . .

How can we calibrate the probe?

- Using another probe not affected by the dense QCD matter, to define a baseline reference

  → photons, Drell-Yan dimuons

- Using "trivial" collision systems, to understand how the probe behaves in absence of "new physics"

  → pp, pA, light ions collisions
  → comparison of peripheral vs. central collisions

What are the hard probes?

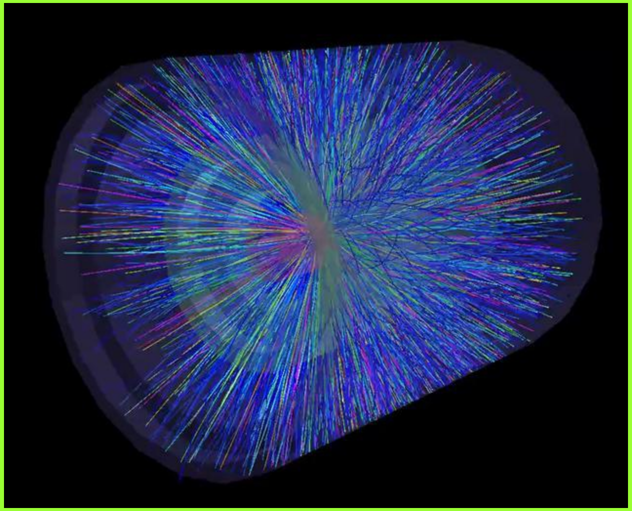
- highly penetrating observables as

  → High p_T hadrons, jets
  → Open heavy flavors (charm and beauty)
  → Quarkonia (J/ψ, ψ(2S), Υ(1S), Υ(2S), Υ(3S))

LET'S SUMMARIZE!

QGP:
deconfined state of matter made of quarks and gluon, supposed to exist in the first instants after Big Bang

Investigated, experimentally, through heavy-ion collisions (if high T and energy density reached)



Looking for QGP signals:
"unambiguous" probes for the formation of QGP

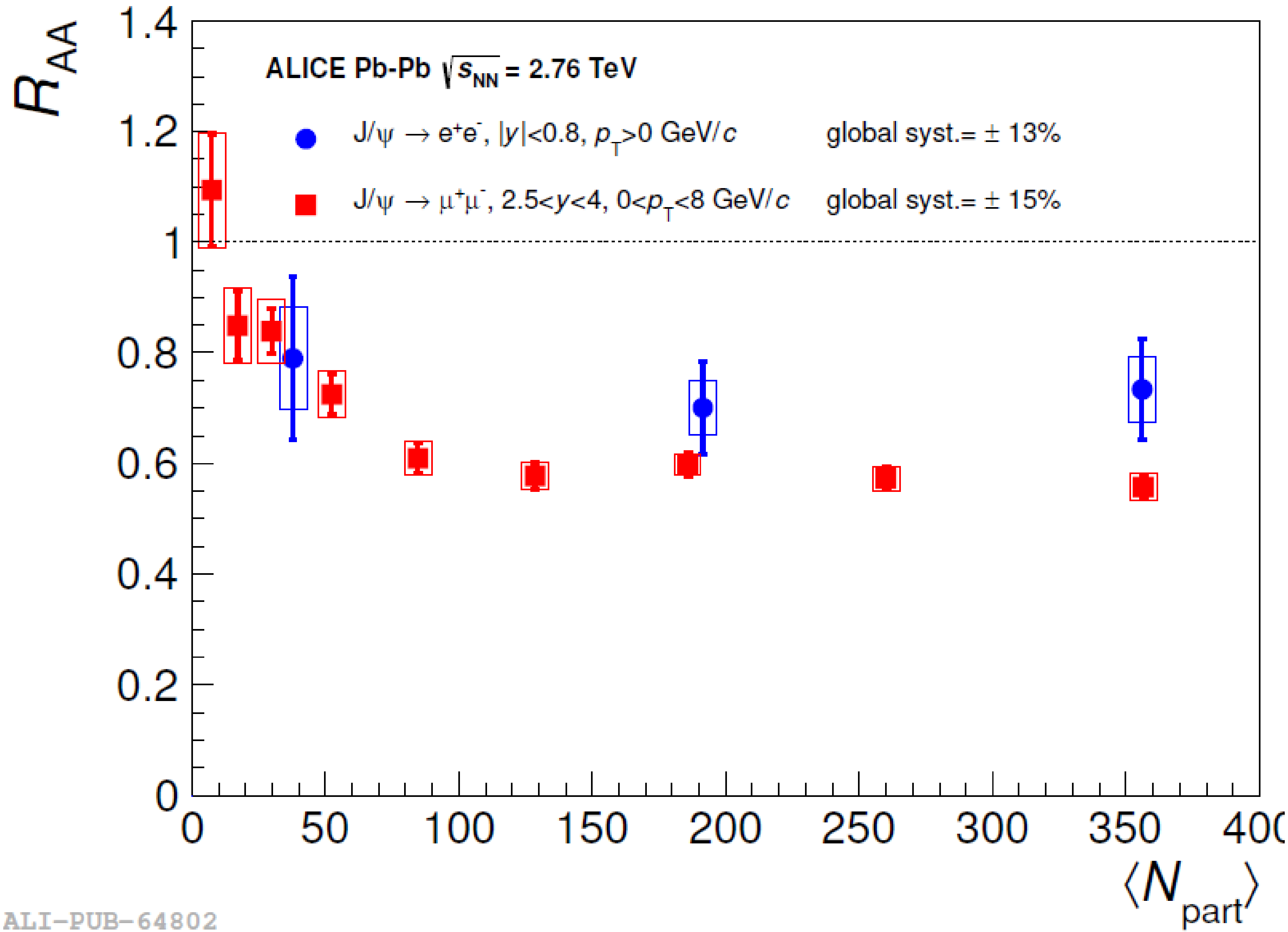
Quarkonia:
Heavy quark bound state

- J/ψ meson: bound state of a charm quark and its antiquark
- Υ meson: bound state of a bottom quark and its antiquark

Quarkonia in a QGP:
onset of quarkonia melting above a certain temperature/energy density
(Matsui and Satz, PLB 178 (1986) 416)

HOW DO WE QUANTIFY WHAT HAPPENS TO A J/ψ ?

- Quarkonium behavior in AA is investigated in terms of R_{AA} vs centrality



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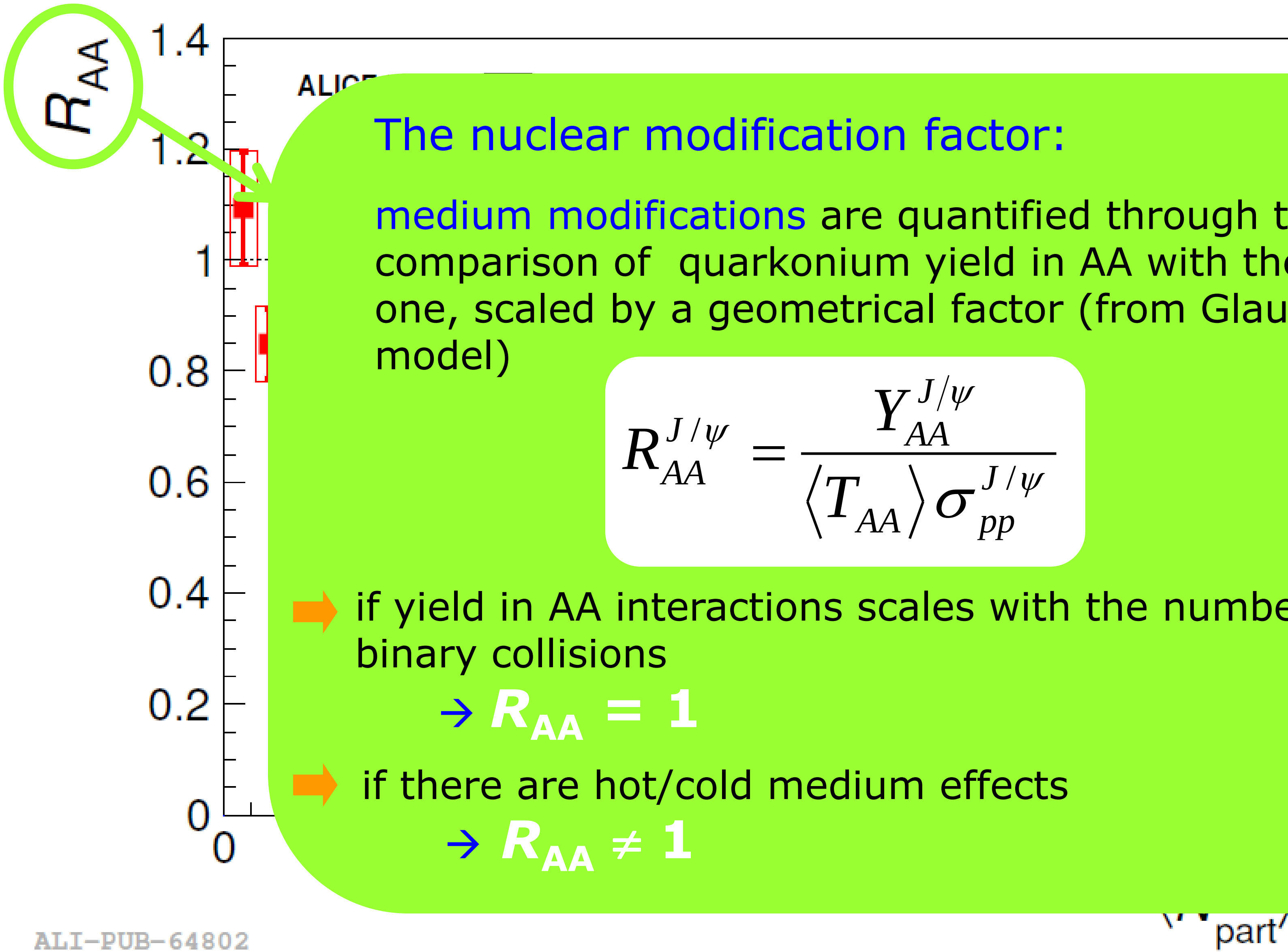

The nuclear modification factor:

medium modifications are quantified through the comparison of quarkonium yield in AA with the pp one, scaled by a geometrical factor (from Glauber model)

$$R_{AA}^{J/\psi} = \frac{Y_{AA}^{J/\psi}}{\langle T_{AA} \rangle \sigma_{pp}^{J/\psi}}$$

- if yield in AA interactions scales with the number of binary collisions
  → $R_{AA} = 1$
- if there are hot/cold medium effects
  → $R_{AA} \neq 1$

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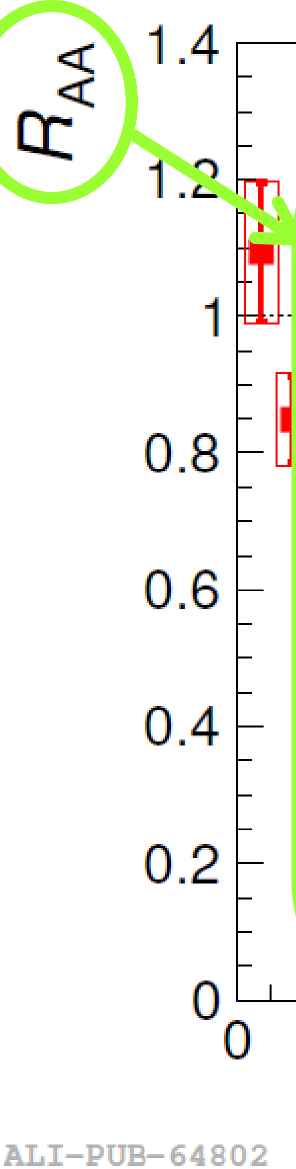
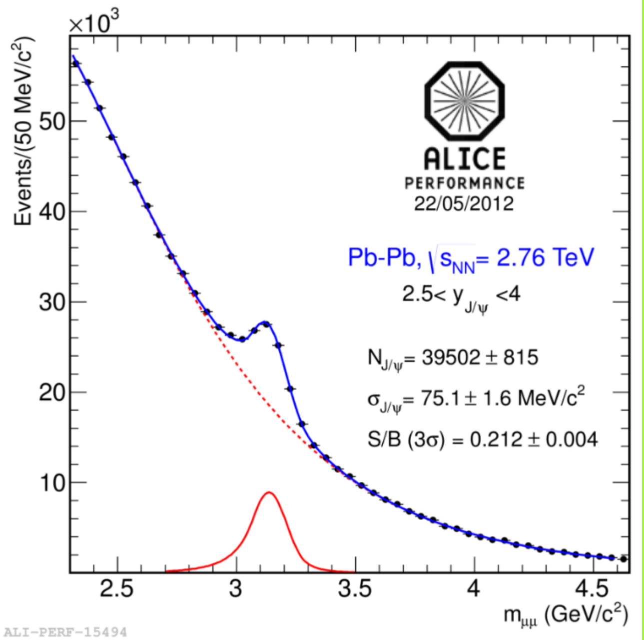


How is quarkonium detected?

Quarkonium is studied in its $\mu^+\mu^-$ or e^+e^- decay channel

How are quarkonium yields extracted?

Usually fitting the opposite sign invariant mass spectrum (signal + background shape)
or
by counting technique, after background subtraction



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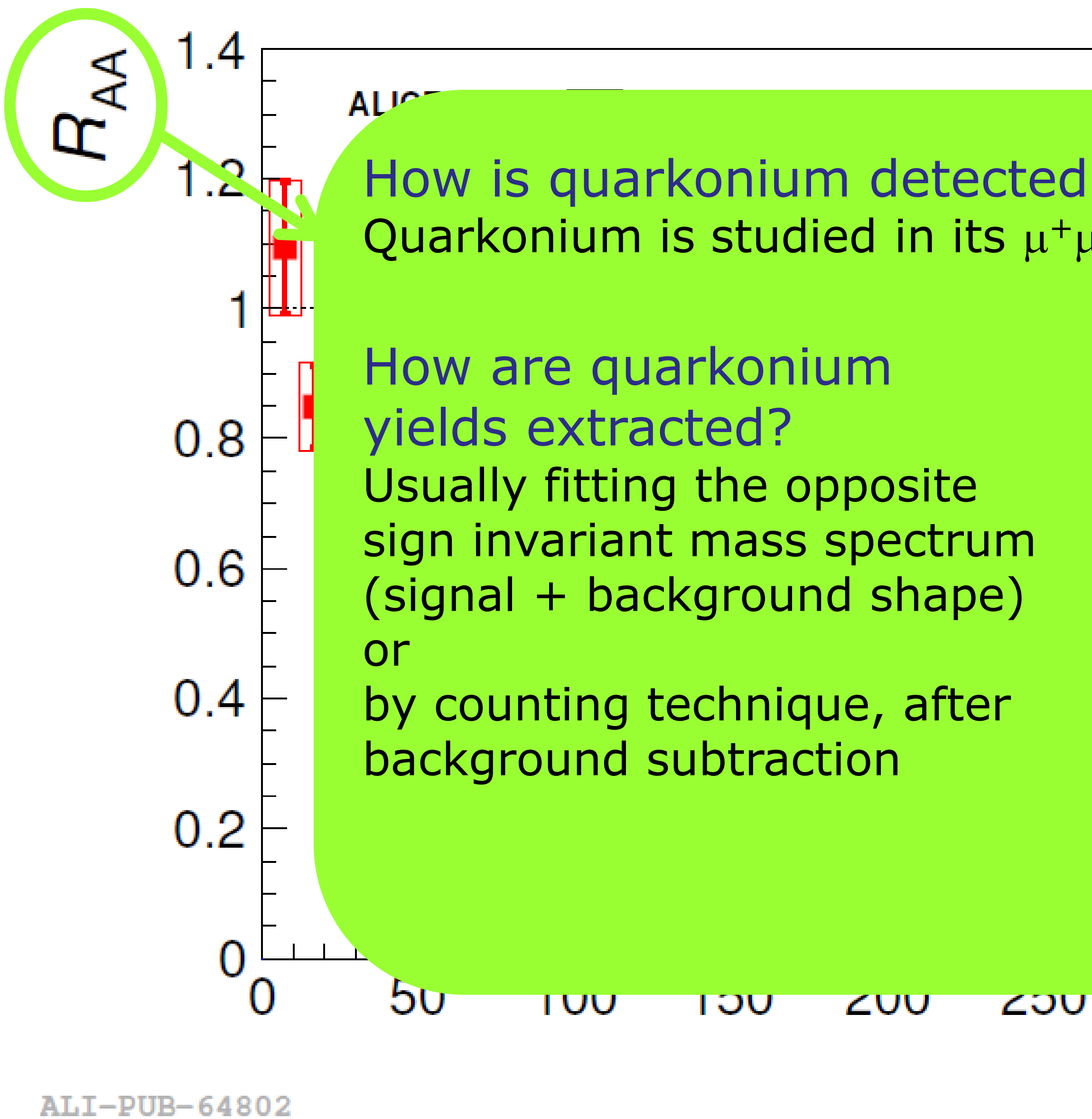

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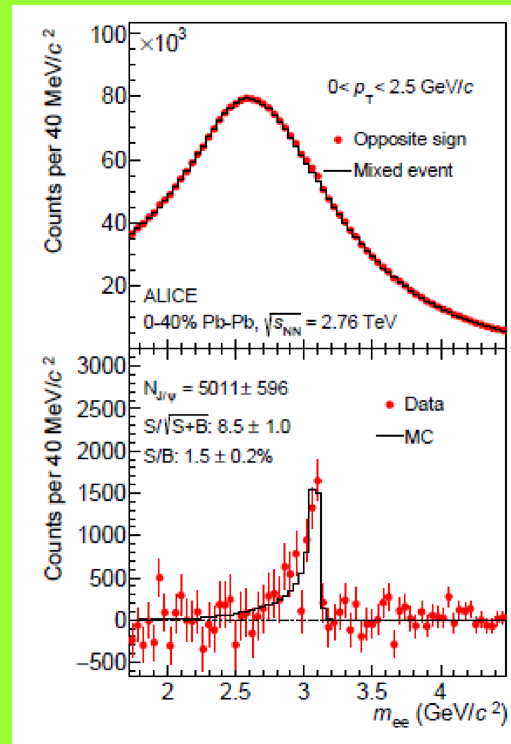

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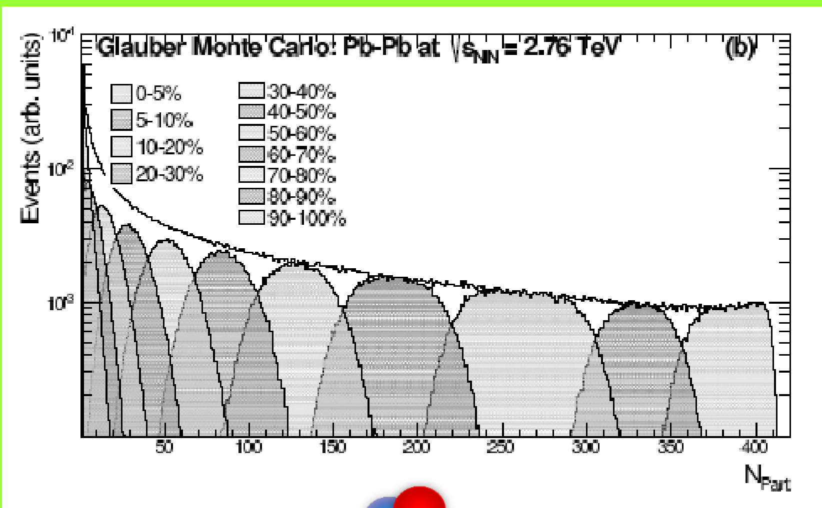
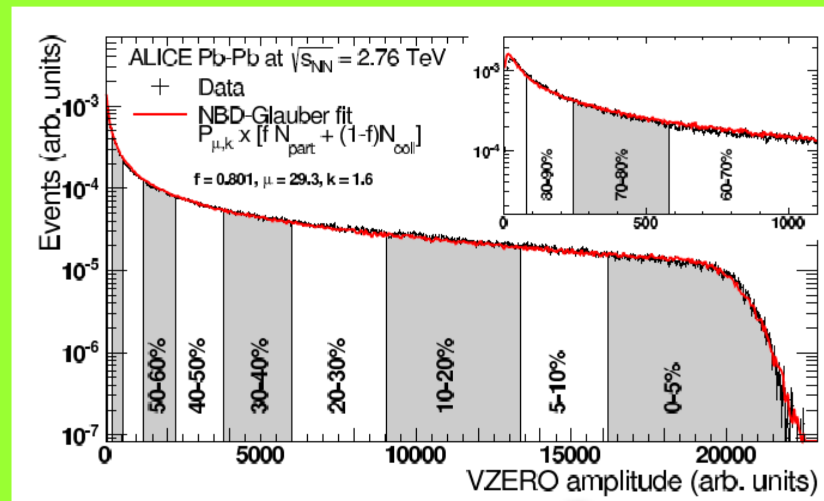
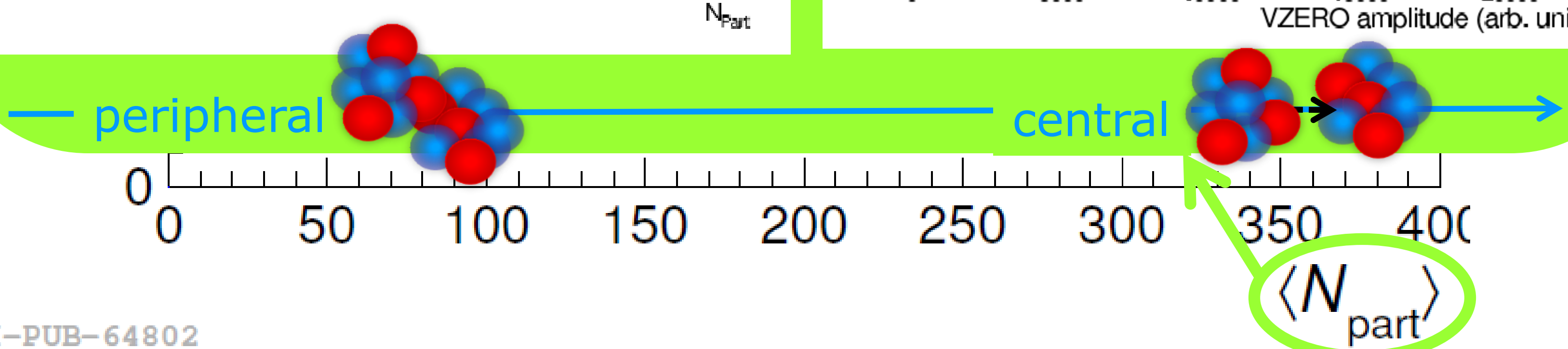
Hot matter effects should be more important in central collisions

Centrality of the collisions measured through N_{part}, i.e. nucleons which have experienced at least one collision [evaluation based on a Glauber model]







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HOW DO WE QUANTIFY WHAT HAPPENS TO A J/ψ ?

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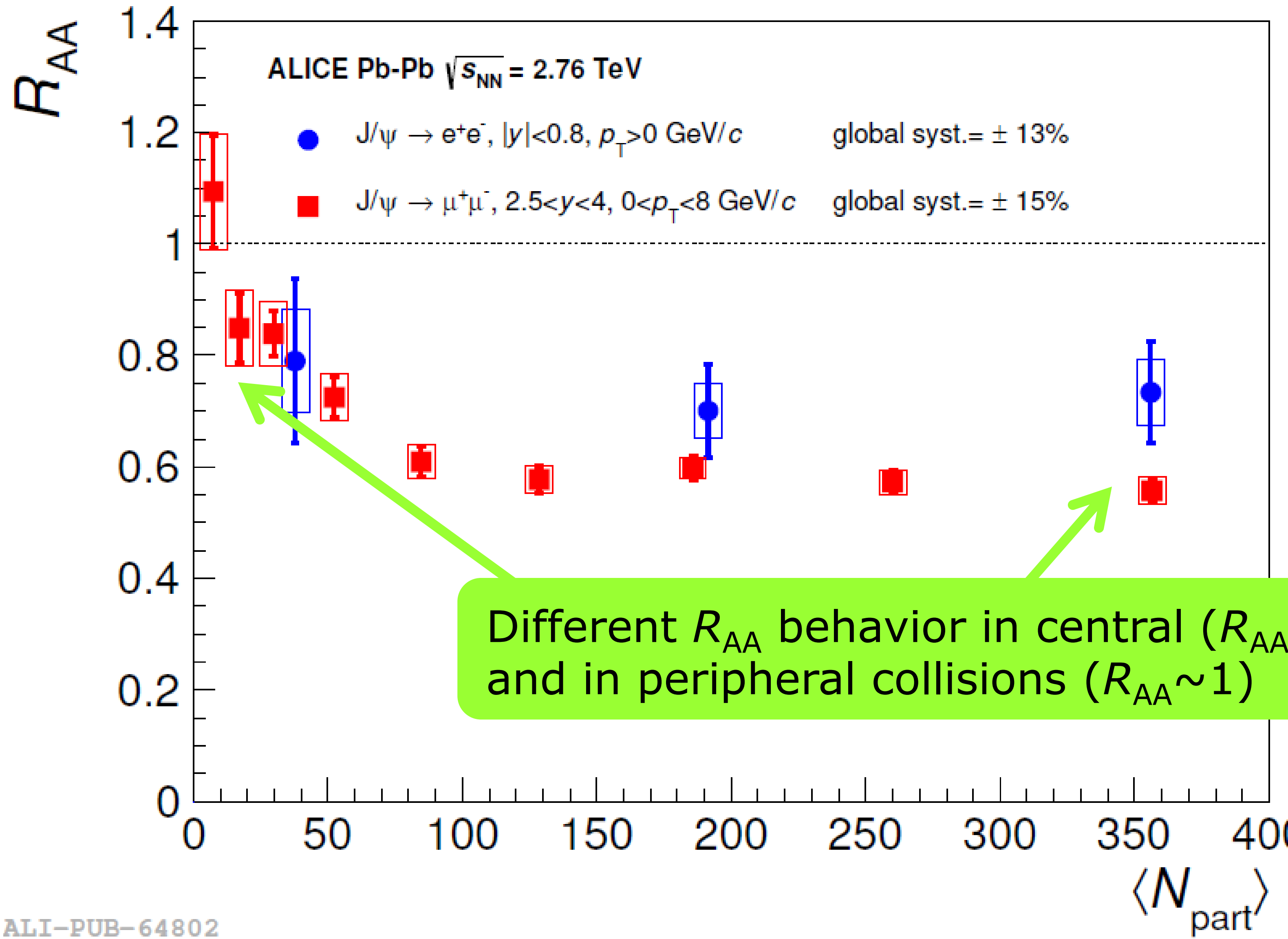

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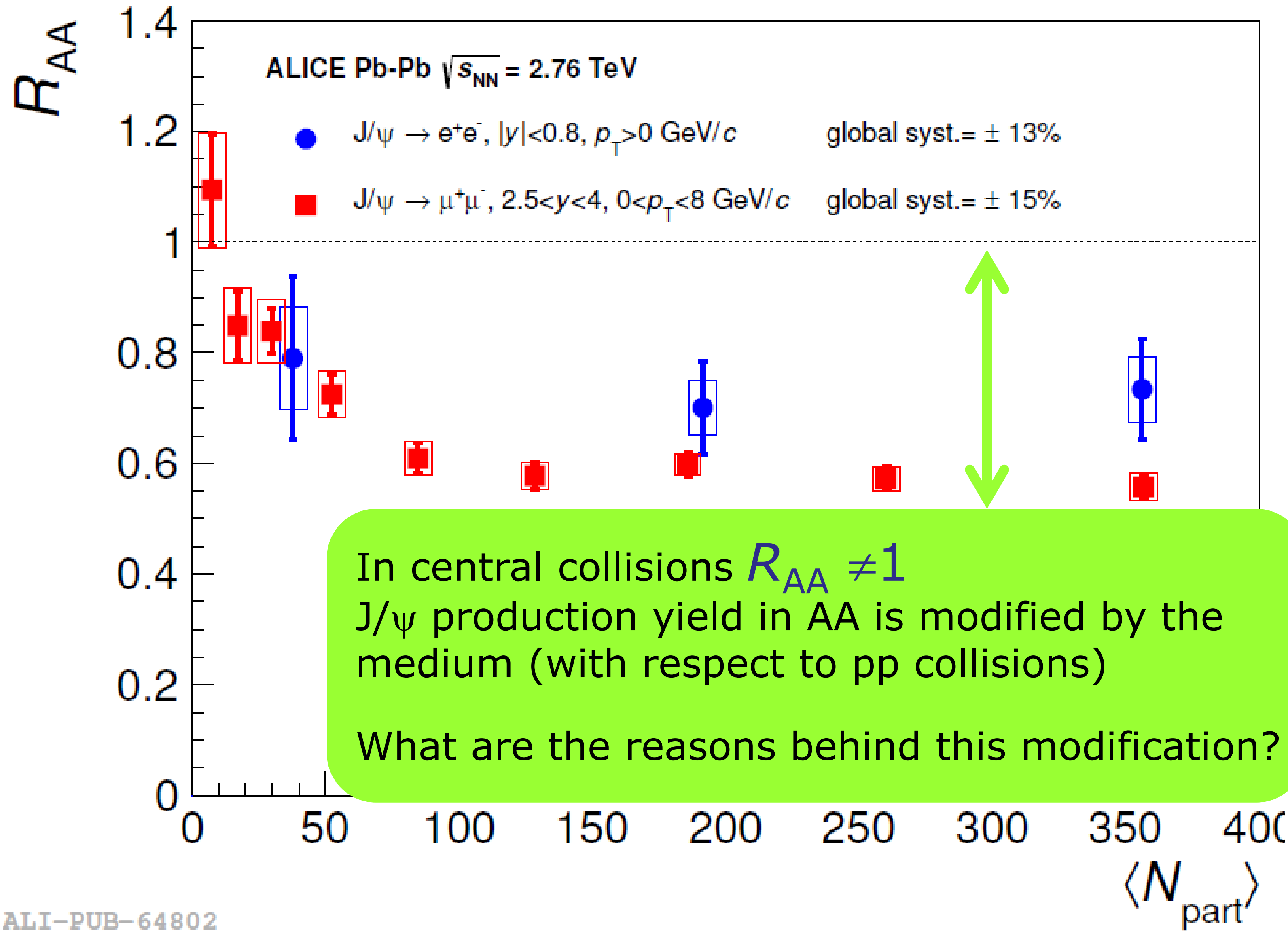

In central collisions $R_{AA} \neq 1$
J/ψ production yield in AA is modified by the medium (with respect to pp collisions)

What are the reasons behind this modification?

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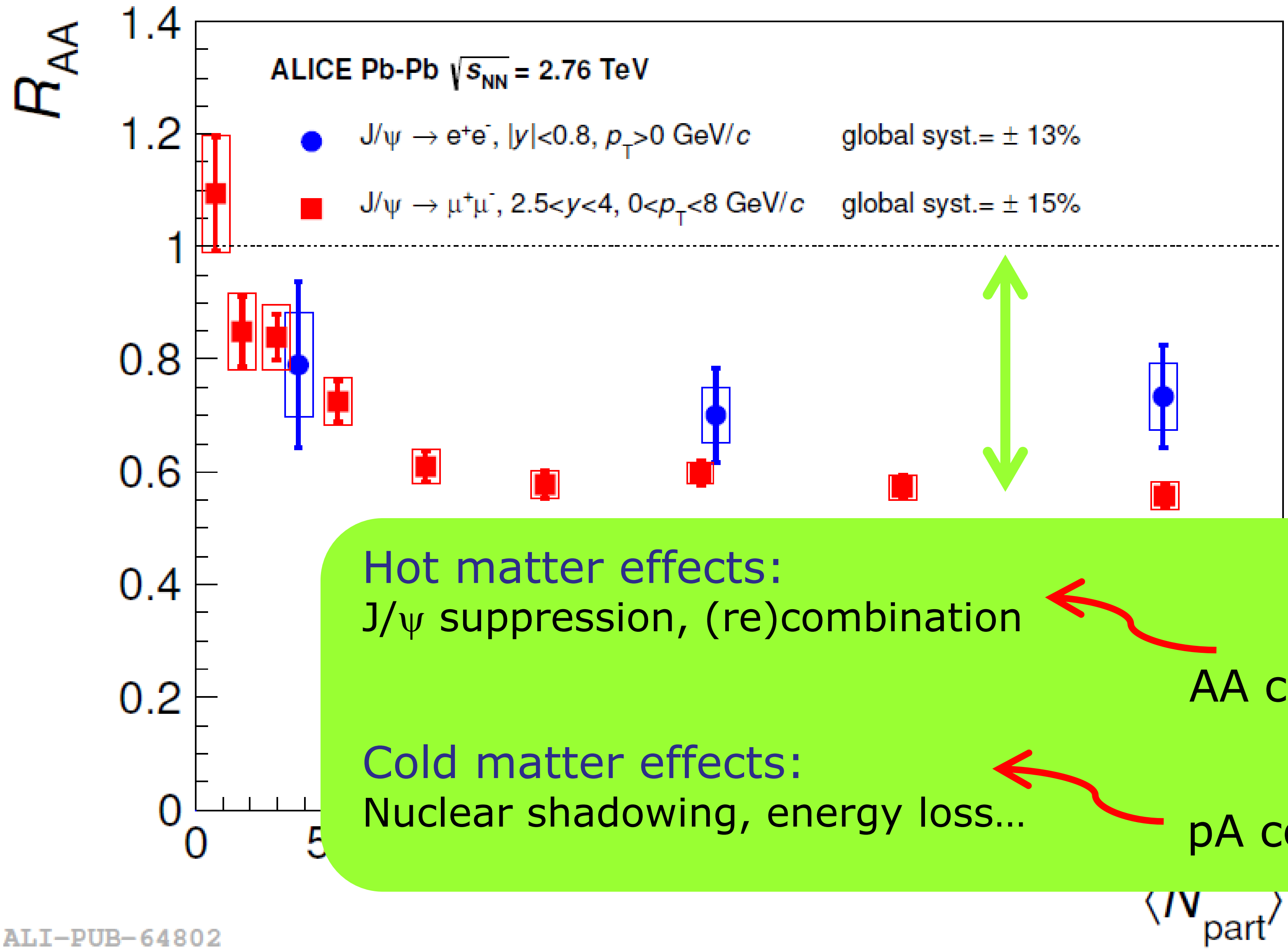

Hot matter effects:
J/ψ suppression, (re)combination ← AA collisions

Cold matter effects:
Nuclear shadowing, energy loss… ← pA collisions

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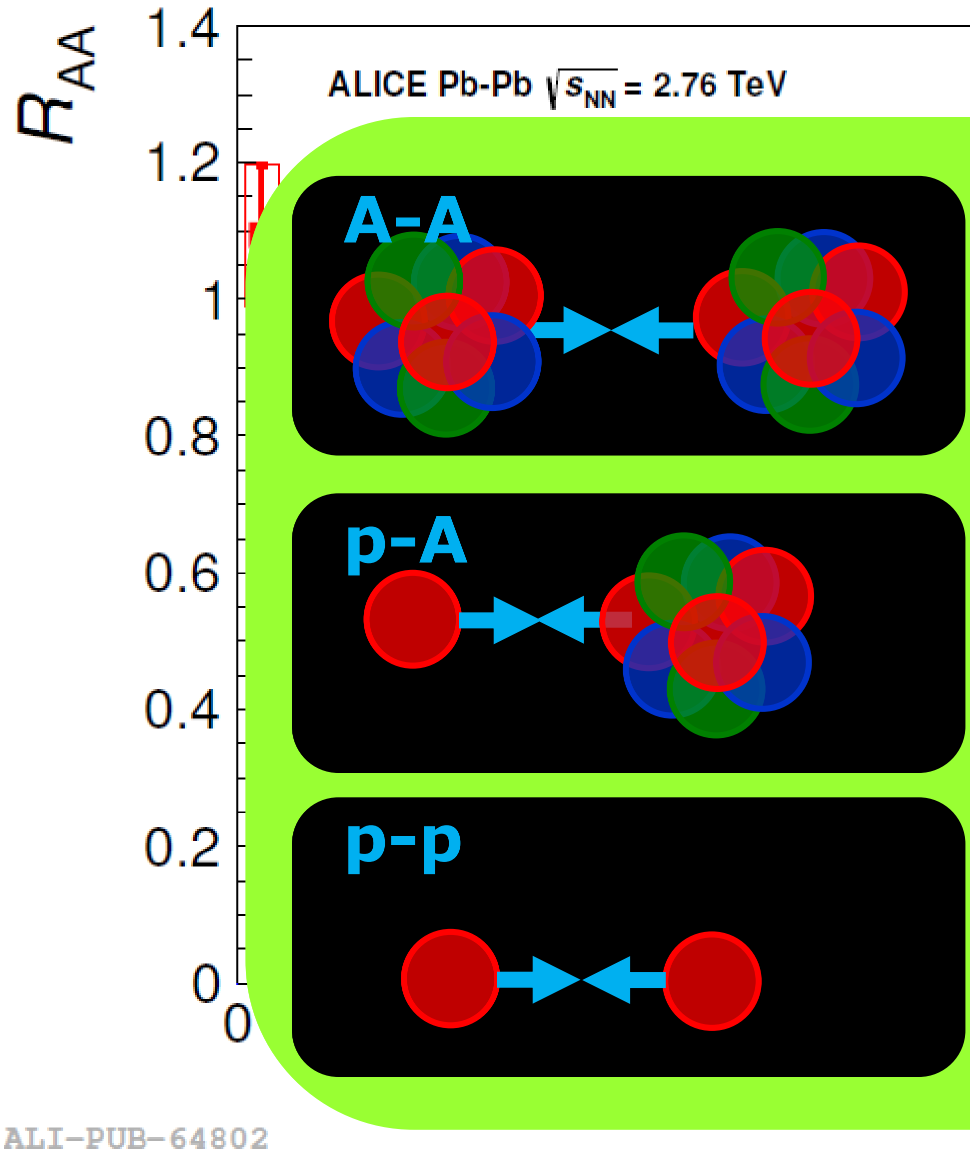

- Quarkonium as a probe of the hot medium created in the collision (QGP)
- Investigation of cold nuclear matter effects (shadowing, energy loss…)
- Reference process to understand behaviour in pA, AA collisions

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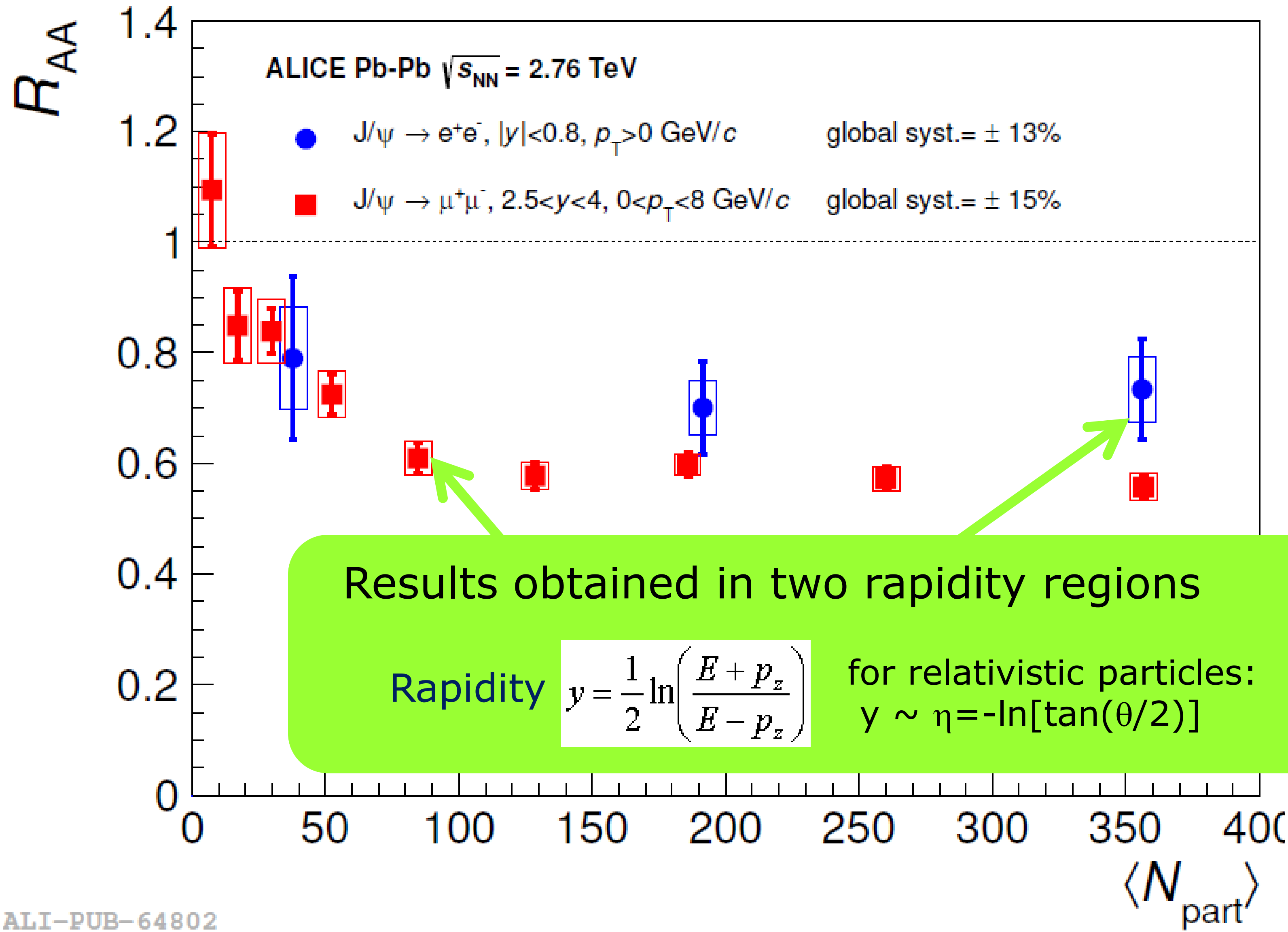

Results obtained in two rapidity regions

Rapidity $$y = \frac{1}{2}\ln\left(\frac{E+p_z}{E-p_z}\right)$$

for relativistic particles:
$y \sim \eta = -\ln[\tan(\theta/2)]$

QGP...

- QCD predicts a phase transition from hadronic matter to a deconfined phase (at high temperatures)