The beauty of quarkonium suppression

From the *charming* times of J/ψ suppression at the SPS
to the *beautiful* prospects of Upsilon studies at the LHC

Disclaimer:
*This talk is **not** given on behalf of NA38, NA50, NA51, NA60, ALICE or CMS*

Quarkonia in Deconfined Matter
Aci Trezza, September 2011

Carlos Lourenço, CERN

J/ψ suppression by quark-gluon plasma formation

1986:

J/ψ suppression in nuclear collisions: “unambiguous signature of QGP formation”

J/ψ SUPPRESSION BY QUARK–GLUON PLASMA FORMATION ☆

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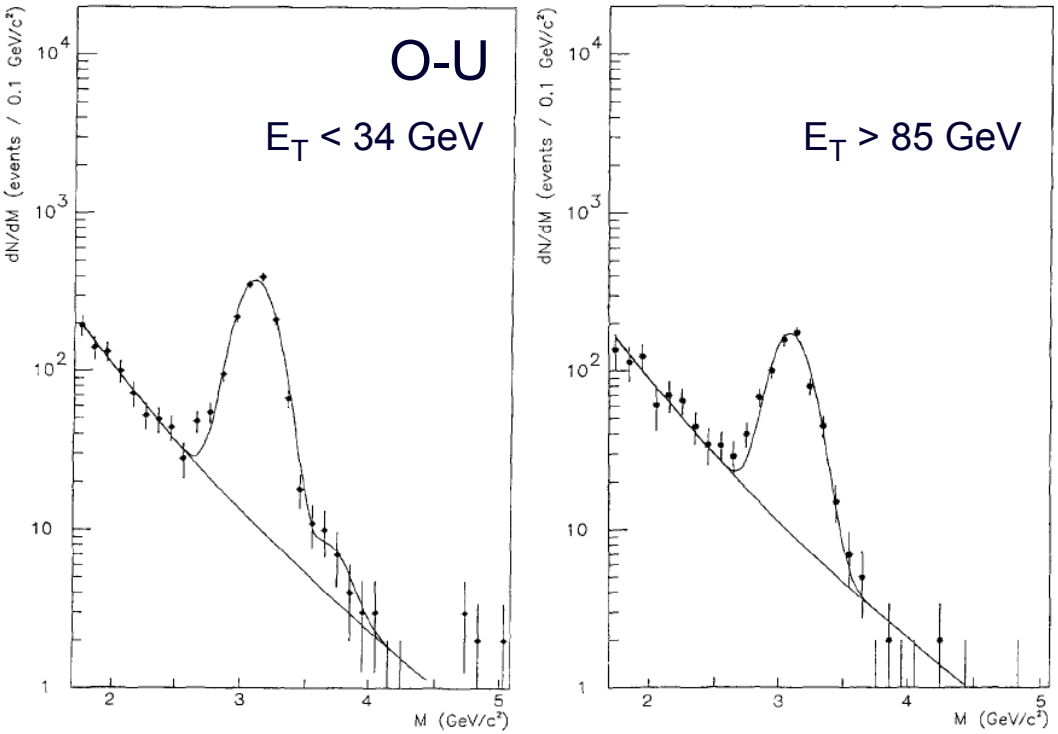
If high energy heavy ion collisions lead to the formation of a hot quark–gluon plasma, then colour screening prevents $c\bar{c}$ binding in the deconfined interior of the interaction region. To study this effect, the temperature dependence of the screening radius, as obtained from lattice QCD, is compared with the J/ψ radius calculated in charmonium models. The feasibility to detect this effect clearly in the dilepton mass spectrum is examined. It is concluded that J/ψ suppression in nuclear collisions should provide an unambiguous signature of quark–gluon plasma formation.

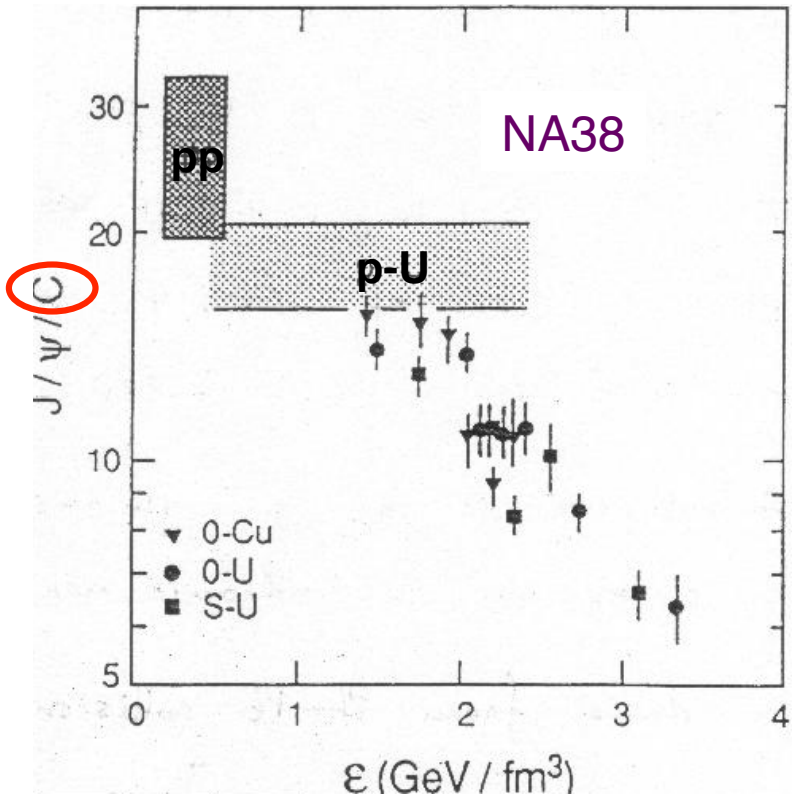
Cited 1420 times !
(and counting)

First data: the J/ψ *is* suppressed

NA38: the J/ψ is significantly suppressed with respect to the "dimuon continuum"

- from p-U to O-U and S-U
- from peripheral to central HI collisions





1987

From the empirical “C” to the physical “DY”

The anomaly got visibly reduced when the *reference* in the suppression studies changed from the “empirical” (intermediate mass) continuum, to the Drell-Yan yield, derived by fitting the data to a superposition of DY and open charm (calculated with Pythia and a detailed MC simulation reflecting the detector effects)

Because DY significantly depends on the charges of the annihilating quarks, there is a sizeable change from p-U to O-U or S-U collisions, simply because of the extra collisions involving beam neutrons

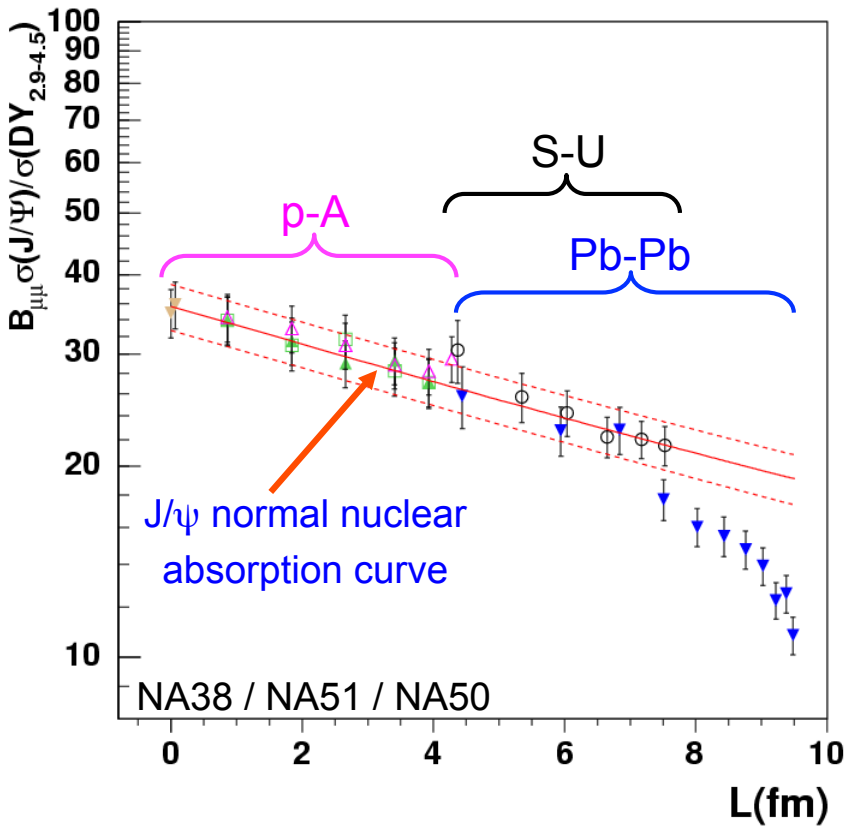
Besides, an “anomalous enhancement” of “intermediate mass region” dimuons was seen w.r.t. DY production, as a function of S-U centrality, shown by NA60 (much later) to be “thermal dimuons”

1993

The S-U J/ψ suppression decreased because we improved the continuum reference

J/ψ suppression in the NA38, NA50 and NA51 data

The S-U J/ψ suppression pattern, measured by NA38 at 200 GeV, smoothly follows the p-A trend set by NA50 at 400-450 GeV (and rescaled to 158 GeV)

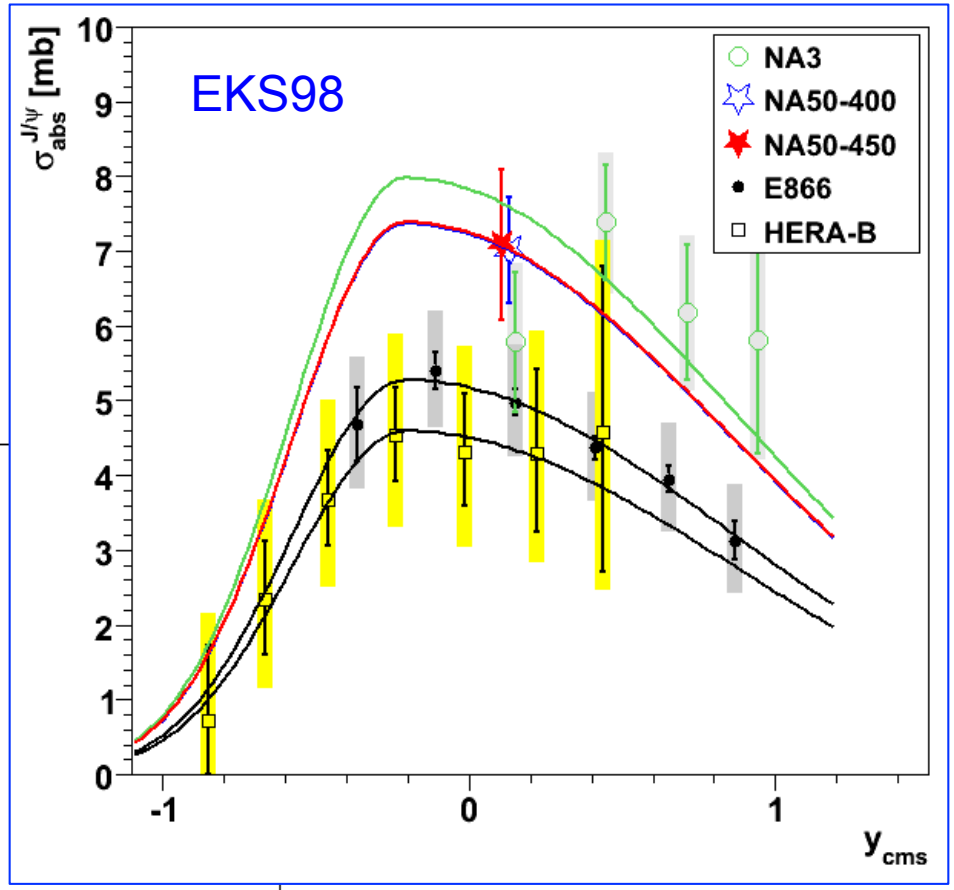


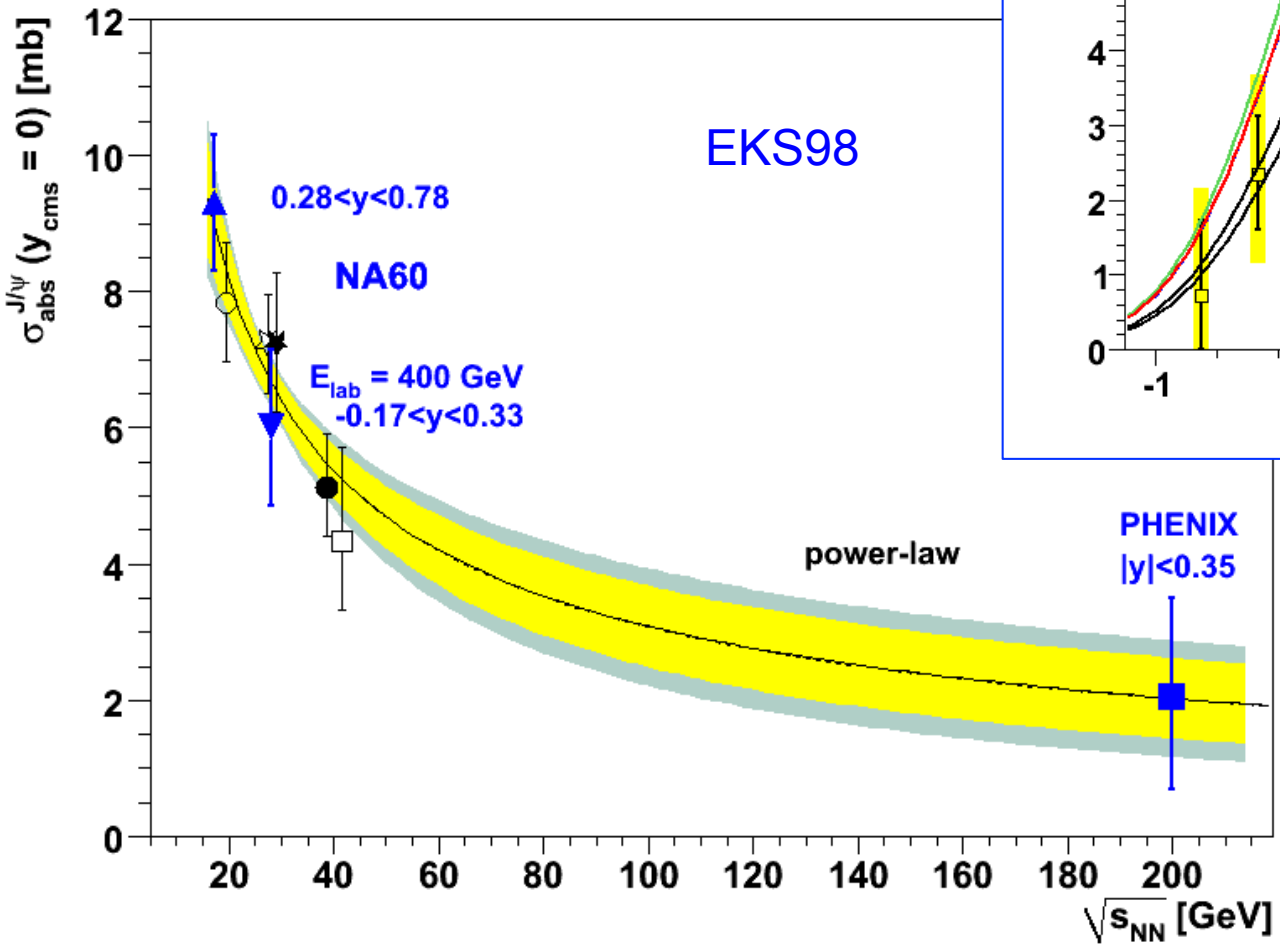
1996

The S-U J/ψ suppression disappeared because we improved the p-A reference (and a new anomaly showed up, in the Pb-Pb data)

A moving target

Convoluting all CNM effects in Glauber-like final-state charmonium absorption, the data clearly indicate that σ_{abs} changes with collision energy and J/ψ kinematics (whatever the nPDF model)



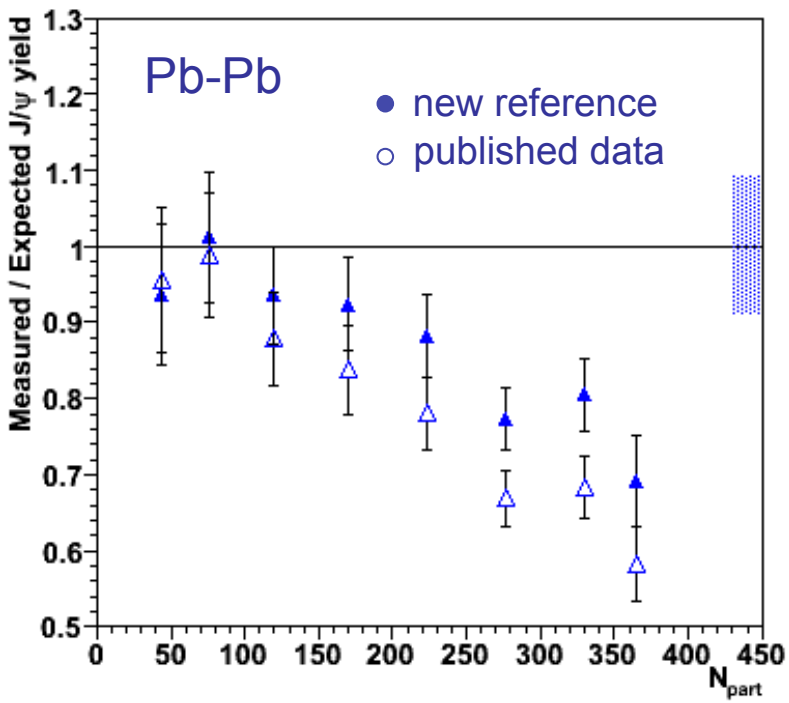


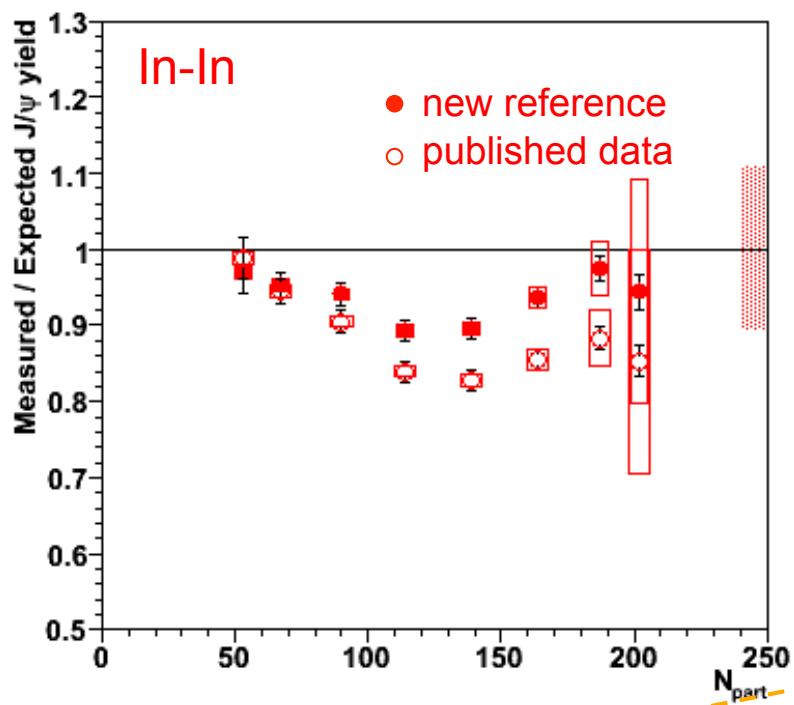
2007

NA60 and PHENIX points found to be on the top of the *previously defined* power-law (grey band)

Enters NA60 and the accuracy of silicon trackers

NA60 collected p-A data at 158 GeV and confirmed the energy dependence:
$\sigma_{abs}^{J/\psi}$ = 6.0±0.9±0.7 mb at 400 GeV and **9.3±0.7±0.7 mb at 158 GeV**, with EKS98





2009

Using such σ_{abs} values in the calculation of the "expected yields" leads to weird J/ψ suppression patterns

The heavy-ion J/ψ suppression patterns change because we changed the p-A reference
The bridge between the p-A data and the HI "reference" is really very "challenging"

Can we make our problem easier, please?

The J/ψ signal is very clean but life gets tricky when we compare it among different collisions systems and energies (p-A, Pb-Pb, etc); can we do better?

Yes: a cleaner option is to study its suppression pattern as a function of centrality in a single HI colliding system, without "reference baselines" extrapolated from p-A data

But we need a reference process to see what to expect in the absence of the QGP; "open charm" might be affected by c quark energy loss, etc; can we do better?

Yes: a cleaner option is to use the ψ', another charmonium *resonance*, and study their relative suppression patterns

But the ψ' is not easy to extract in the SPS or RHIC data; can we do better?

Yes: a cleaner option is to use LHC data, where the ψ' is easier to measure

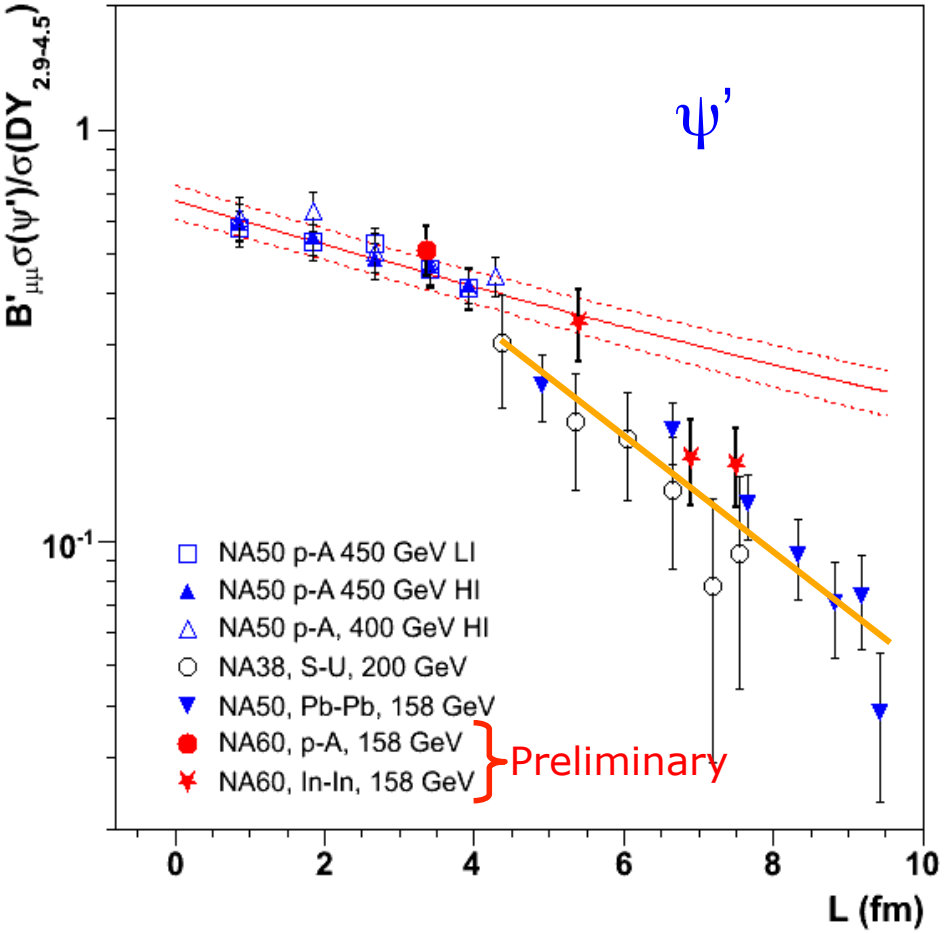
But the ψ' has a small binding energy and might be "dissolved" by hadronic matter; can we do better?

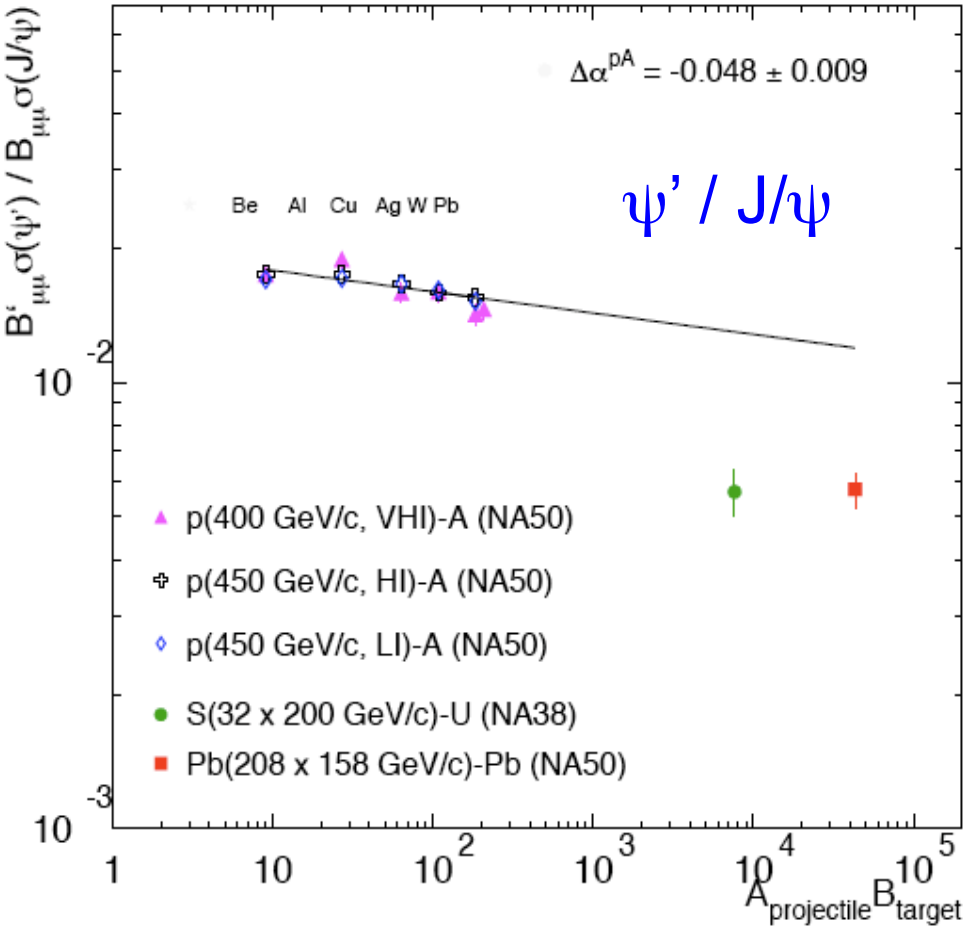
Yes: a cleaner option is to study the relative suppression patterns of the Y(nS) states

But the Upsilon production cross section is very low, even at the LHC; can we do…

ψ' suppression from p-A to S-U to Pb-Pb

The ψ' is strongly suppressed in S-U collisions with respect to the p-A pattern and there is no visible difference between the S-U and Pb-Pb trends

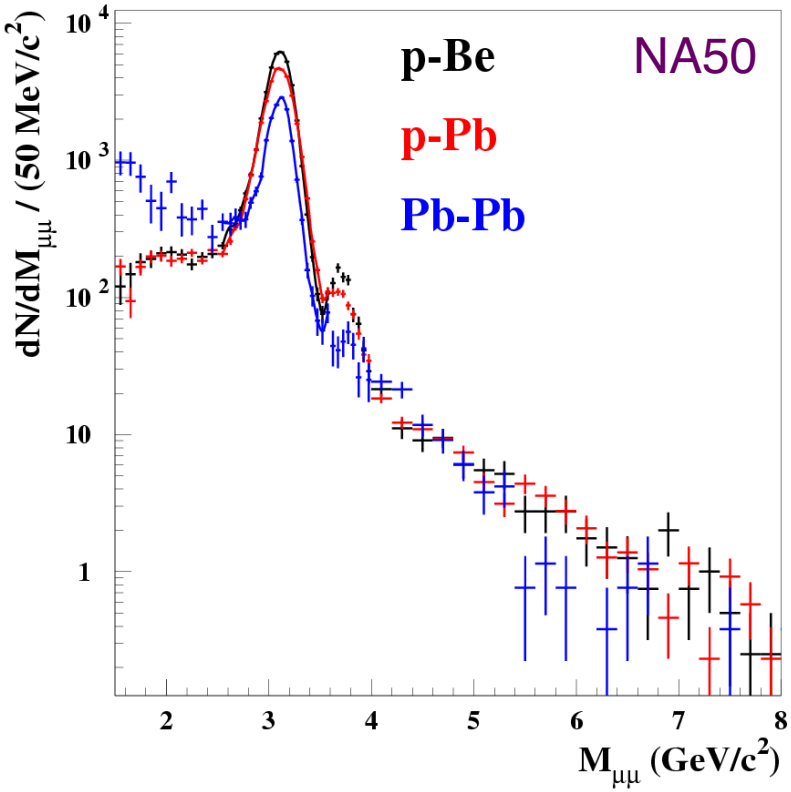


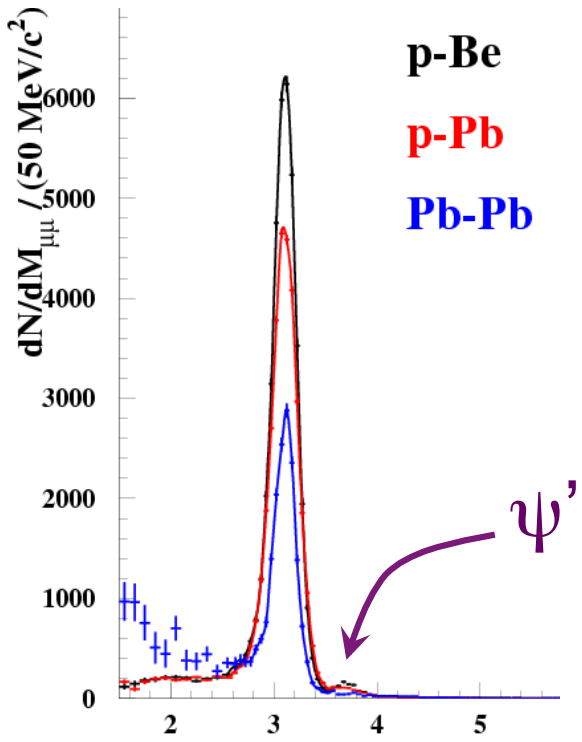


But the ψ' signal was not easy to measure at the SPS (and at RHIC)

The ψ' signal

A signal more than 50 times smaller than the J/ψ in the dimuon decay channel…





Charming, but not exactly what we can call an *outstanding* signal…

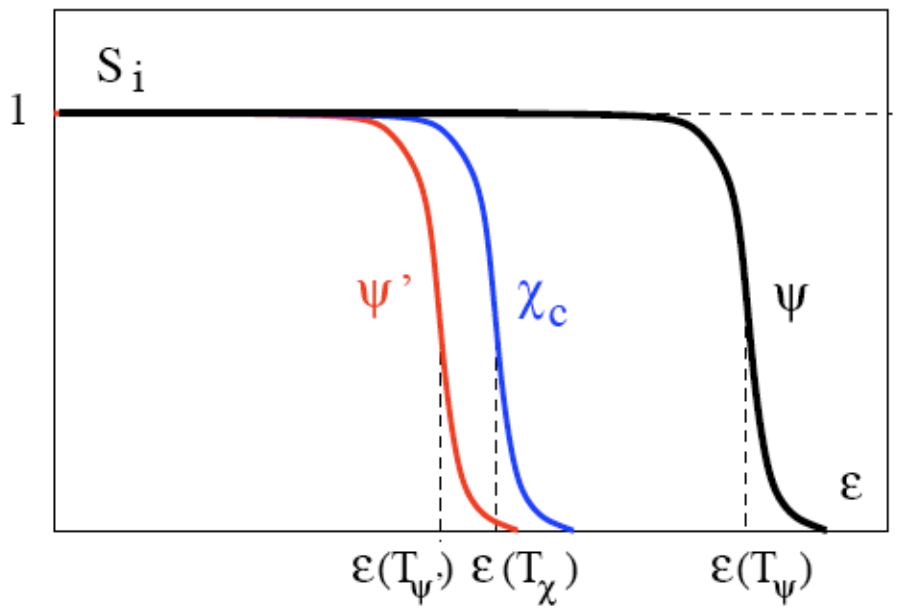
Can we do better?

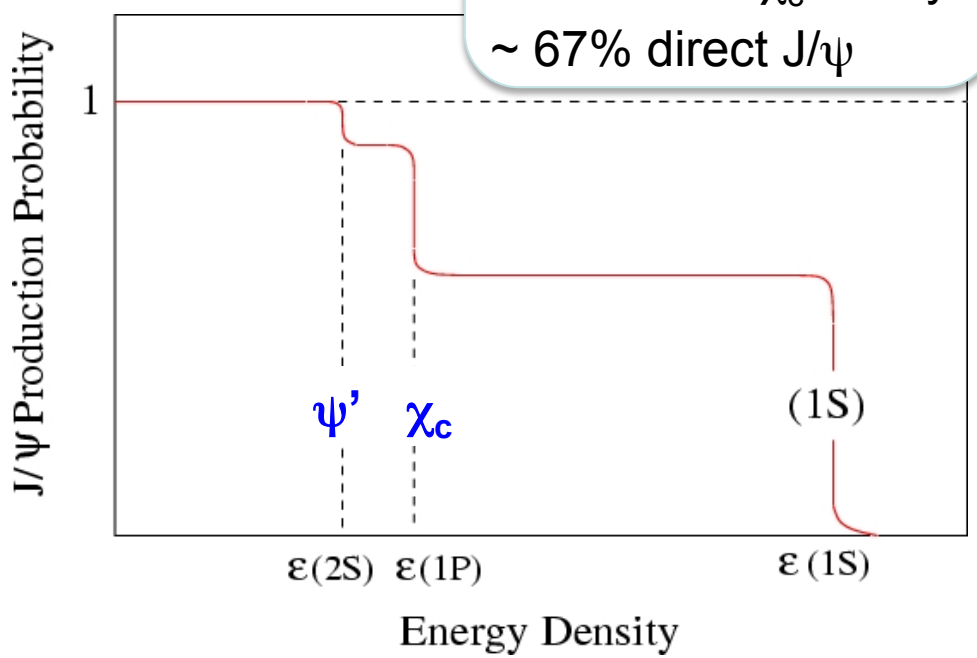
An indirect study of other charmonium states

The ψ' and χ_c feed-down decays
should induce a "step-wise" J/ψ suppression pattern

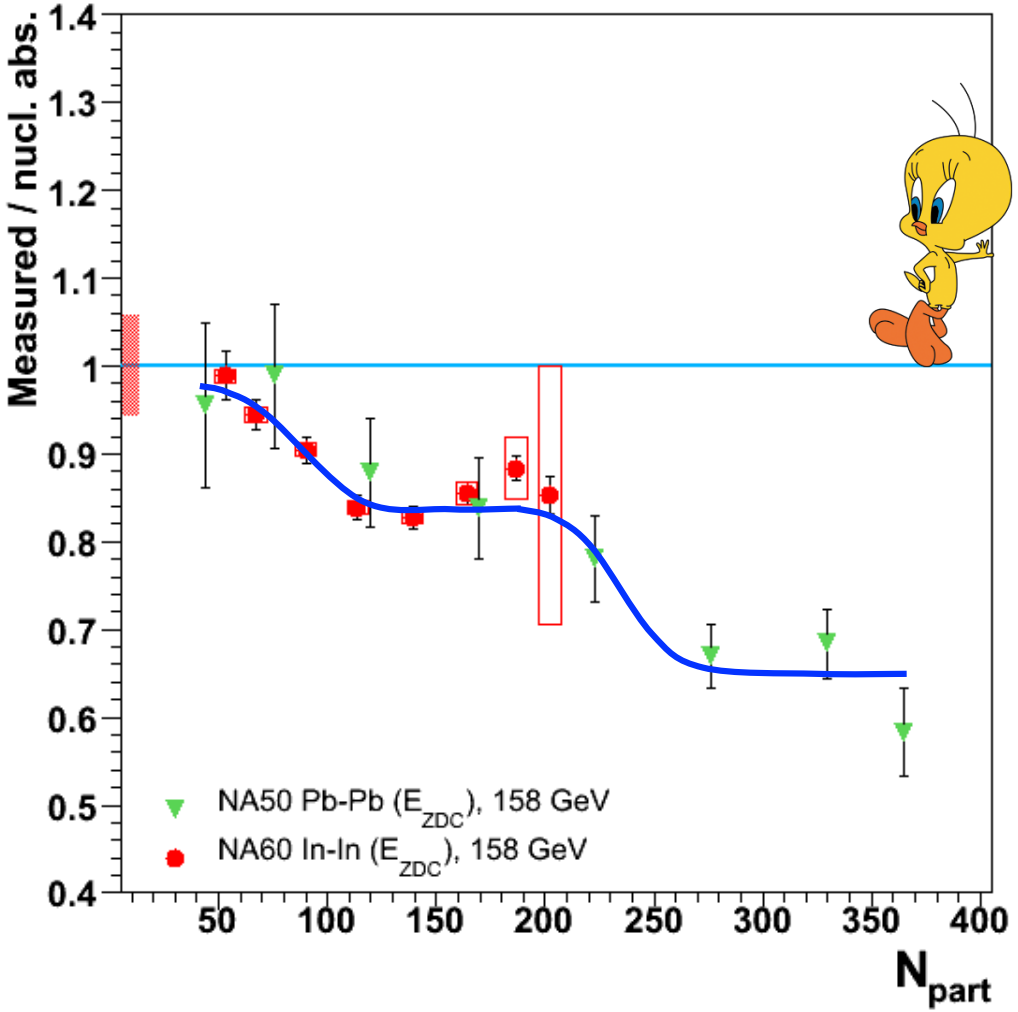
J/ψ cocktail:

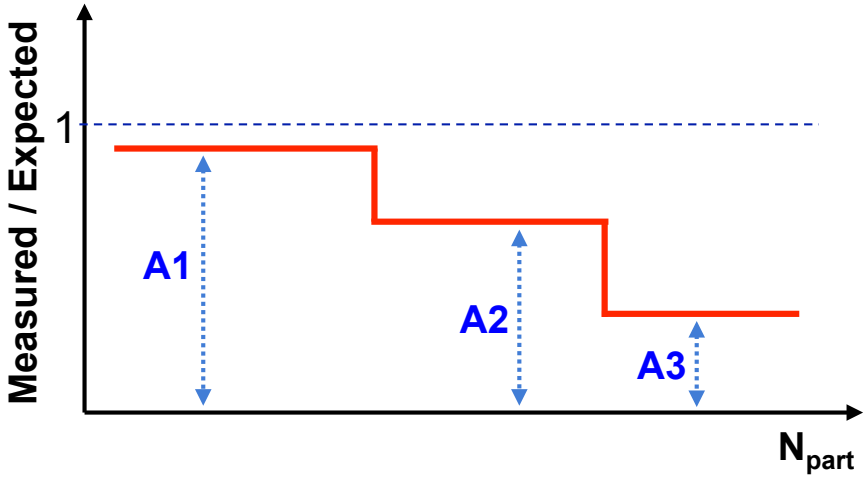
~ 8% from ψ' decays
~ 25% from χ_c decays
~ 67% direct J/ψ





I did, I did, I did see a steppy trend…





Steps: N_{part} = 90 ± 5 and 247 ± 19

A1 = 0.96 ± 0.02

A2 = 0.84 ± 0.01

A3 = 0.63 ± 0.03

ψ'

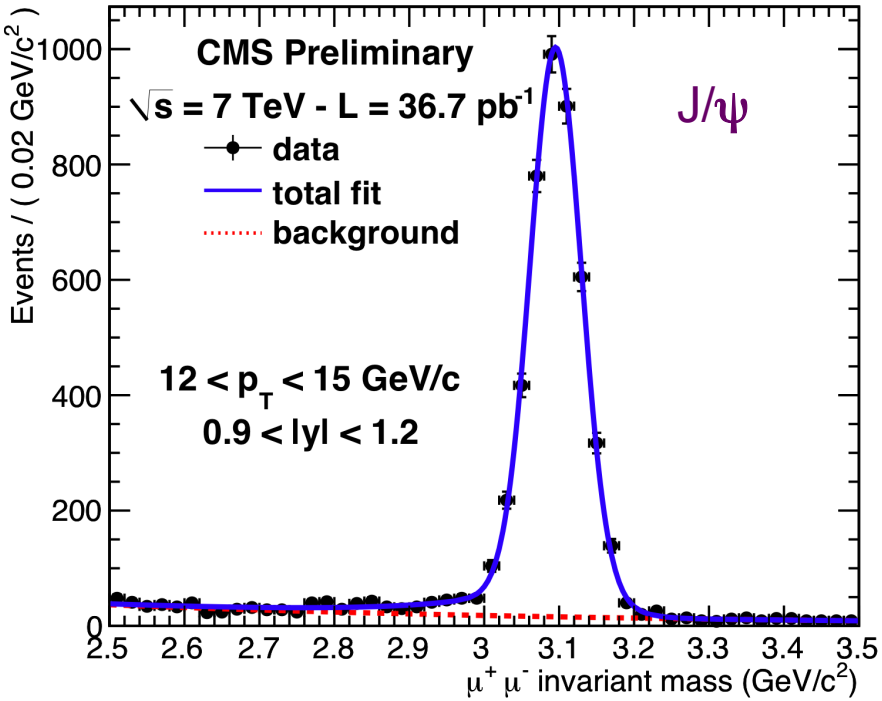
χ_c

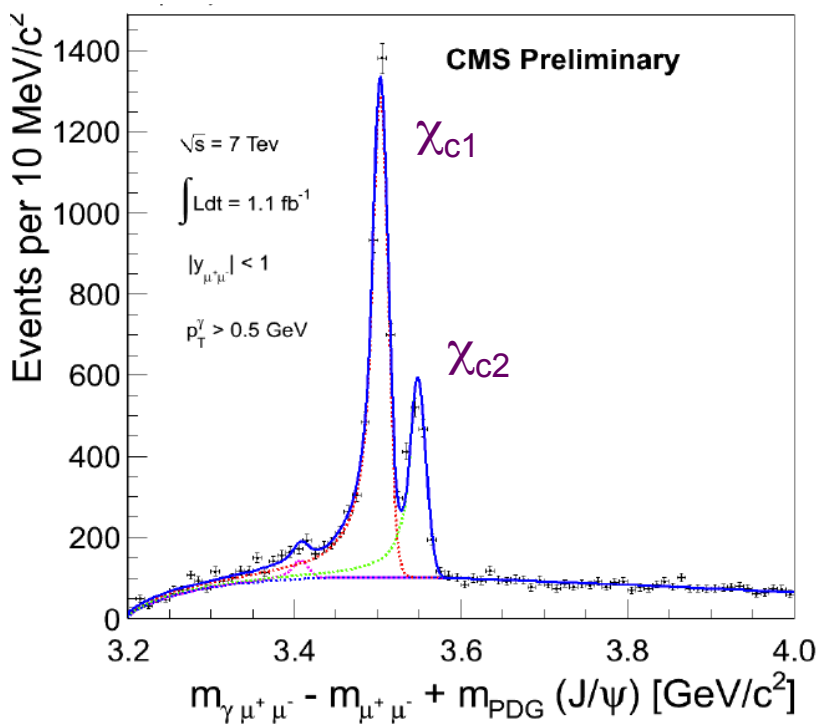
χ^2/ndf = 0.72

Charming, but (strangely enough) has not been considered a convincing signal…

Can we do better?

If better signals you want to see, come and join the LHC !

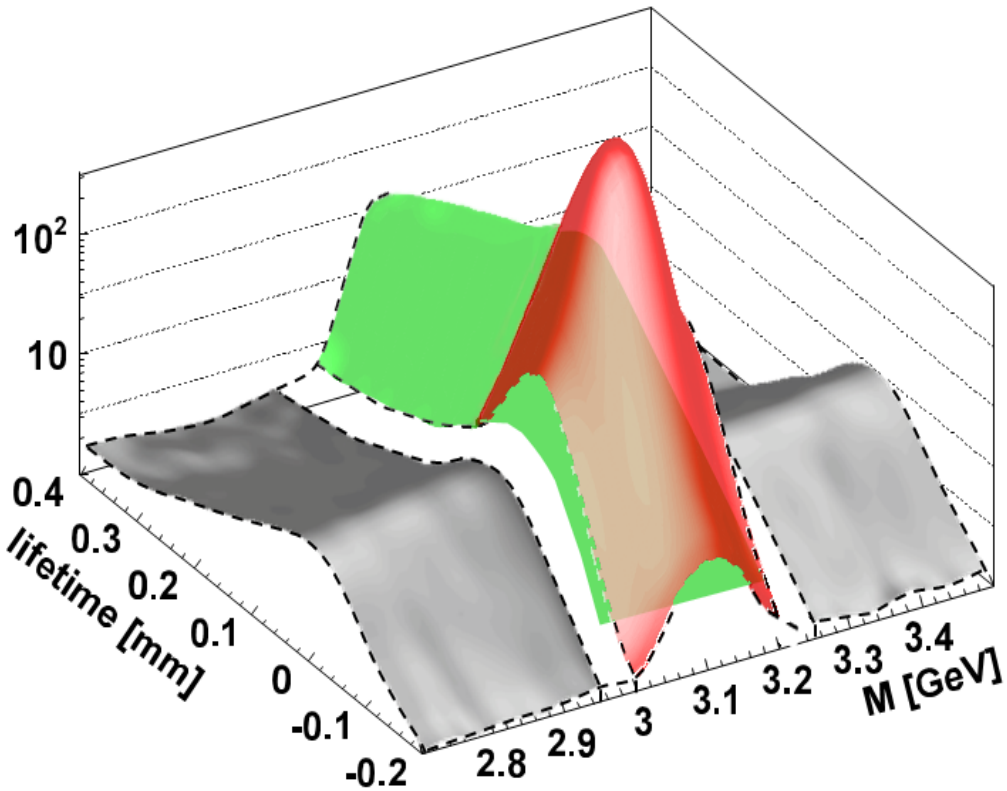


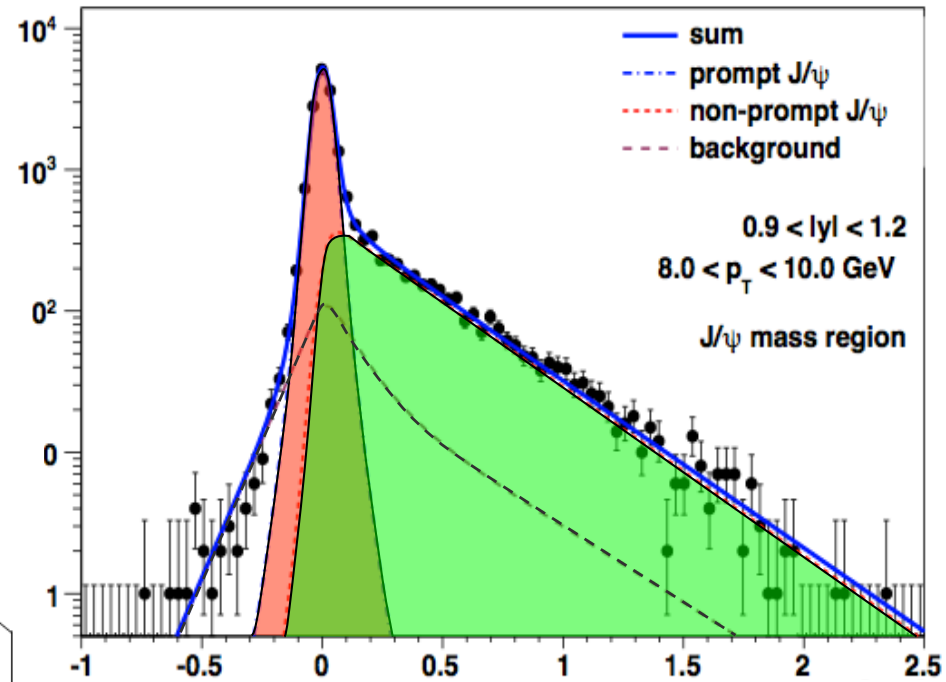


Beauty feed-down in J/ψ and ψ' production

Drawback of higher energies: B decays "background" in charmonium production

Good news:
Prompt and non-prompt J/ψ mesons
can be separated
using the "lifetime" dimension

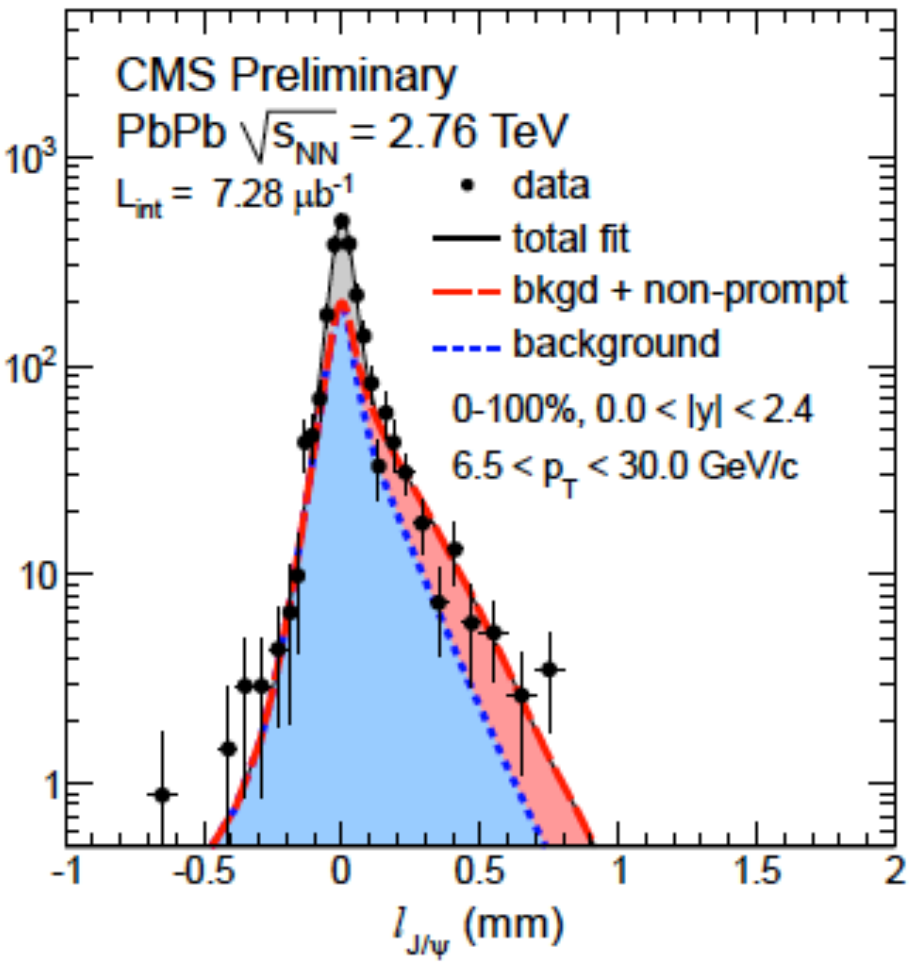


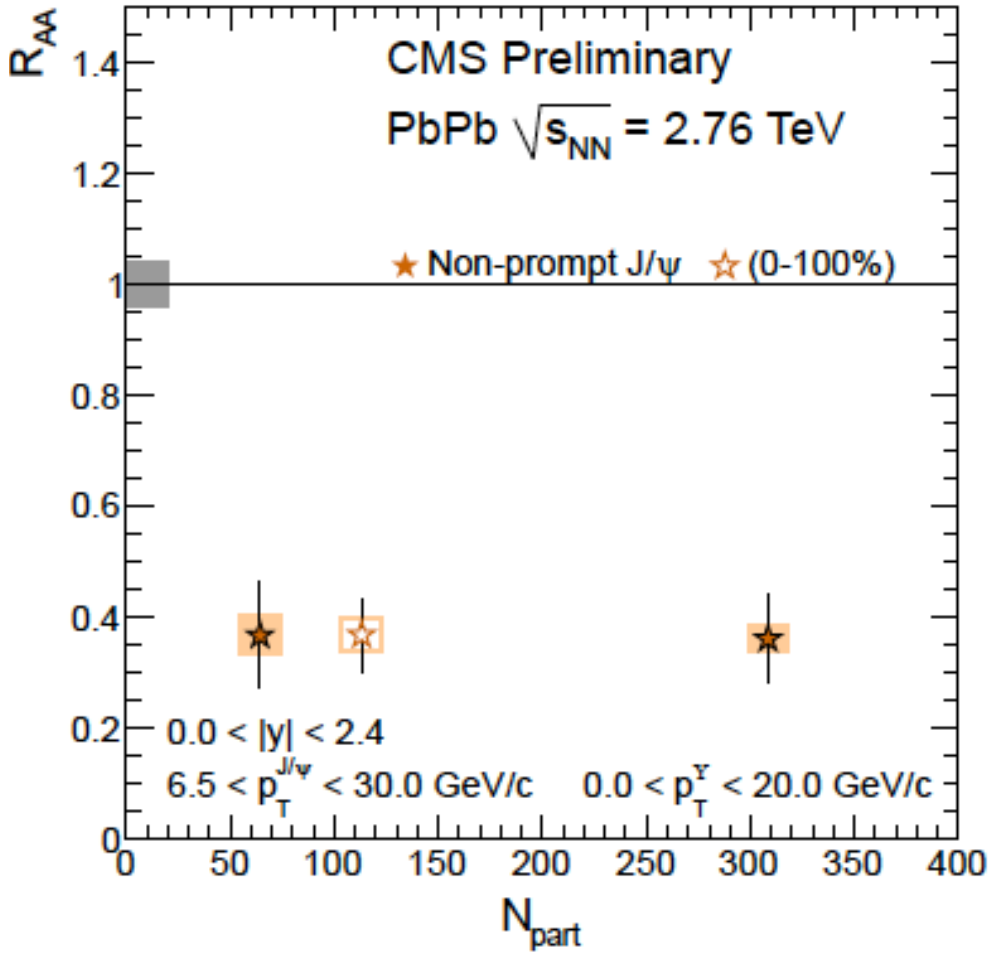


Beauty energy loss?

We can even turn the “subtracted background” into an interesting signal ☺

Non-prompt J/ψ events probe “anomalies” in beauty production as a function of collision centrality, such as those from b energy loss in the dense medium





Meet the beautiful Upsilon family

Studies of bottomonium suppression in Pb-Pb collisions are now possible, thanks to the much higher energies and luminosities provided by the LHC

We can easily detect *three* resonances, with different binding energies: we can probe the sequential quarkonium melting, the “smoking gun” QGP signature !

state	$J/\psi(1S)$	$\chi_c(1P)$	$\psi'(2S)$	$\Upsilon(1S)$	$\chi_b(1P)$	$\Upsilon(2S)$	$\chi_b(2P)$	$\Upsilon(3S)$
T_d/T_c	2.10	1.16	1.12	> 4.0	1.76	1.60	1.19	1.17

If the Y(nS) are detected with very good mass resolution and signal to background ratio, their suppression can be studied relative to each other, *without* worries about the physical composition of the underlying continuum
(and there is no beauty feed-down to complicate things)

Upsilons: are we there yet? are we there yet?

The open beauty reference is trivial to measure via non-prompt J/ψ events

The biggest challenge for the studies of Upsilon suppression in Pb-Pb collisions is… the collected event samples are very "statistically challenged"

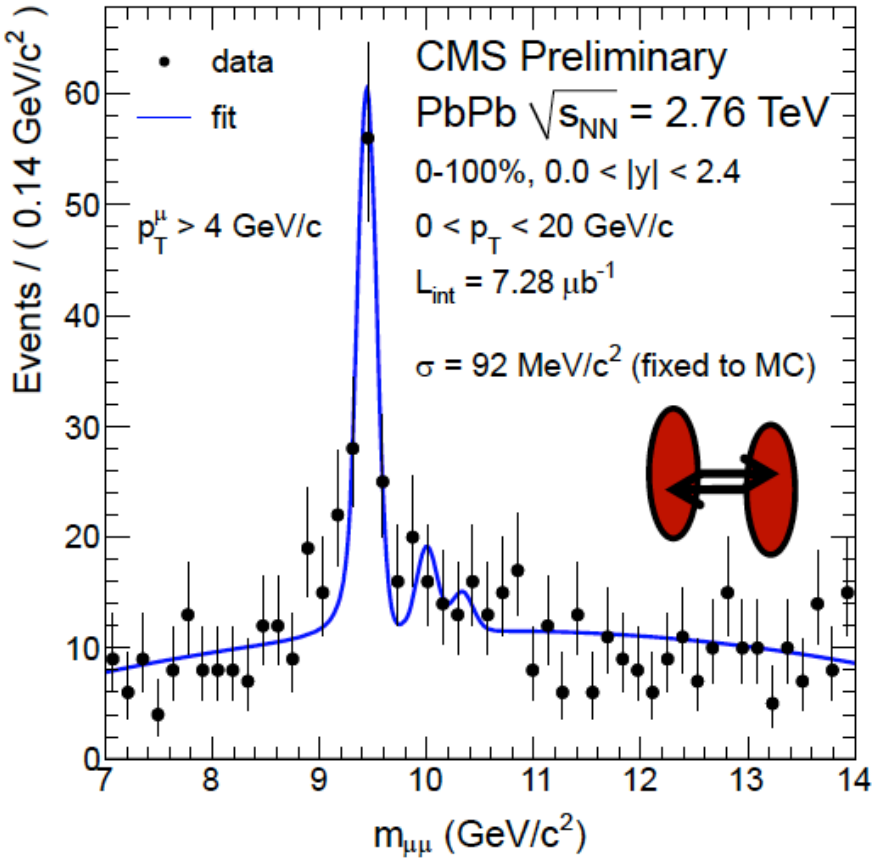
No *significant* Υ(2S) and Υ(3S) peaks have been seen in Pb-Pb collisions. Nice?

Well, would be nicer to see them disappear from peripheral to central collisions

Are there *thresholds* in the suppression patterns? Do we see that the Υ(3S) and the Υ(2S) melt *sequentially*?

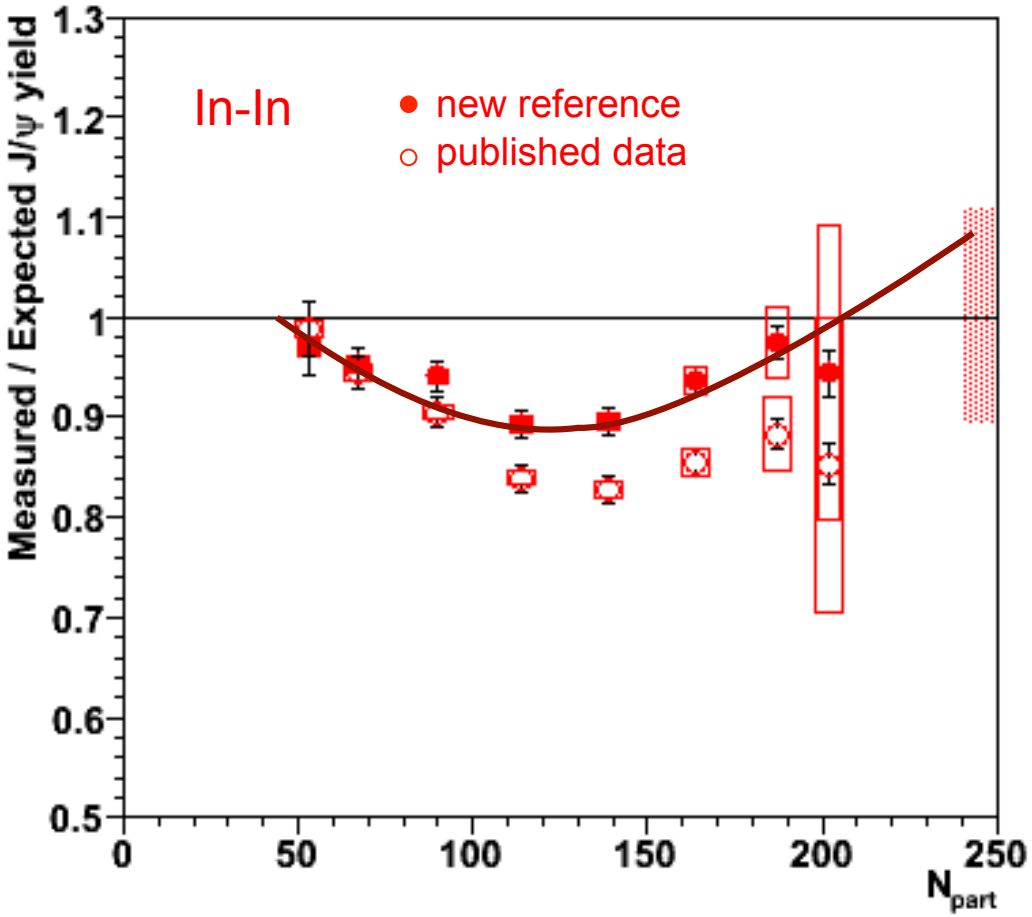
Is the Υ(1S) suppression due to the melting of the χ_b states?

We need large Pb-Pb event samples to convincingly probe sequential quarkonium suppression !



Are we on the right path?

Establishing a “normal nuclear absorption reference” in HI collisions from p-A data is highly non-trivial, even with p-A data collected with 6 nuclear targets, in the same energy and kinematical window as the HI data



Hint of *charm recombination* ?

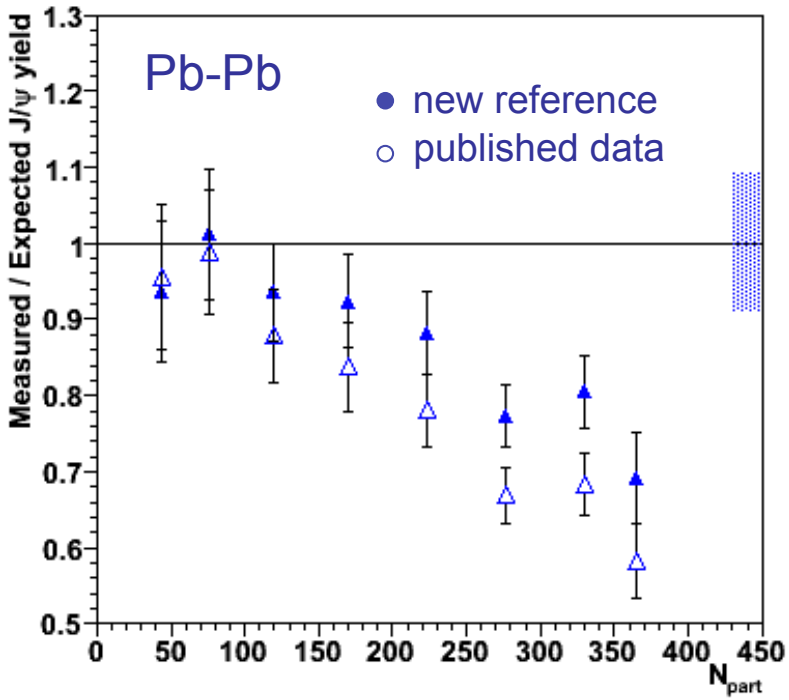
No!
Hint that Nature is complex and we have been unable, so far, to really understand quarkonium production in p-A collisions

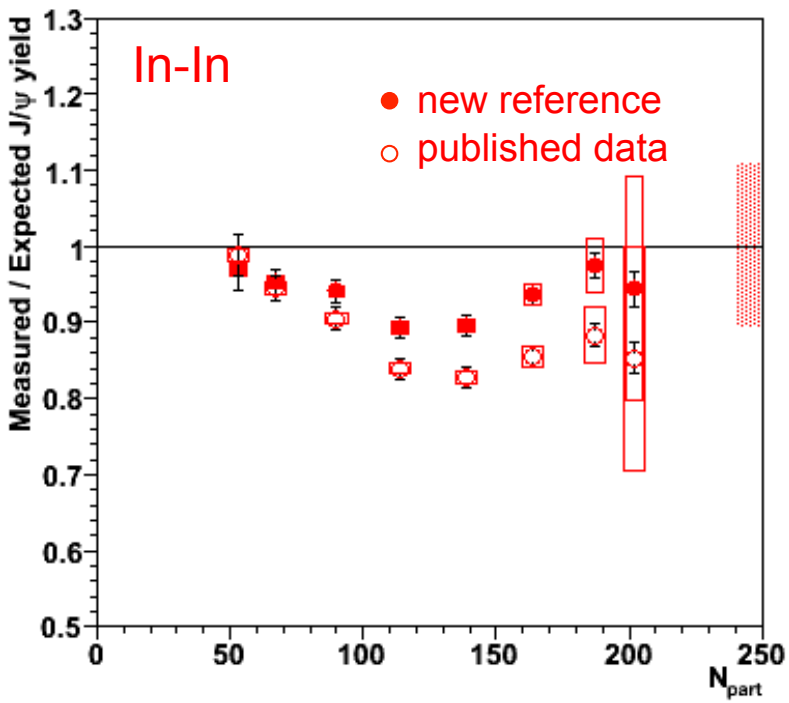
Remember: wrong references can fake “new physics” signals

When we are on the wrong path, a step backwards is a step in the right direction…

Difficult to make predictions, especially about the future

Knowing "the right σ_{abs}":
does not change the picture if the HI suppression pattern is inaccurate
does not help answering *the question* if the HI suppression pattern is accurate





*But do we **really** know what the question is?*
In which observable do we need to see a 5 sigma effect ?

Just when we were about to find the answer… we forgot the question ☹

The LHC has the *potential* of delivering the holy grail of “heavy-ion physics”: the sequential melting of 5 quarkonium S states (plus hints on the P states)

But we need to collect LOADS of high-quality Pb-Pb data !

Running p-Pb in 2012 will not solve the CNM puzzles ! Can we do better ?

Yes, we can *focus our efforts* on understanding Pb-Pb collisions at the LHC

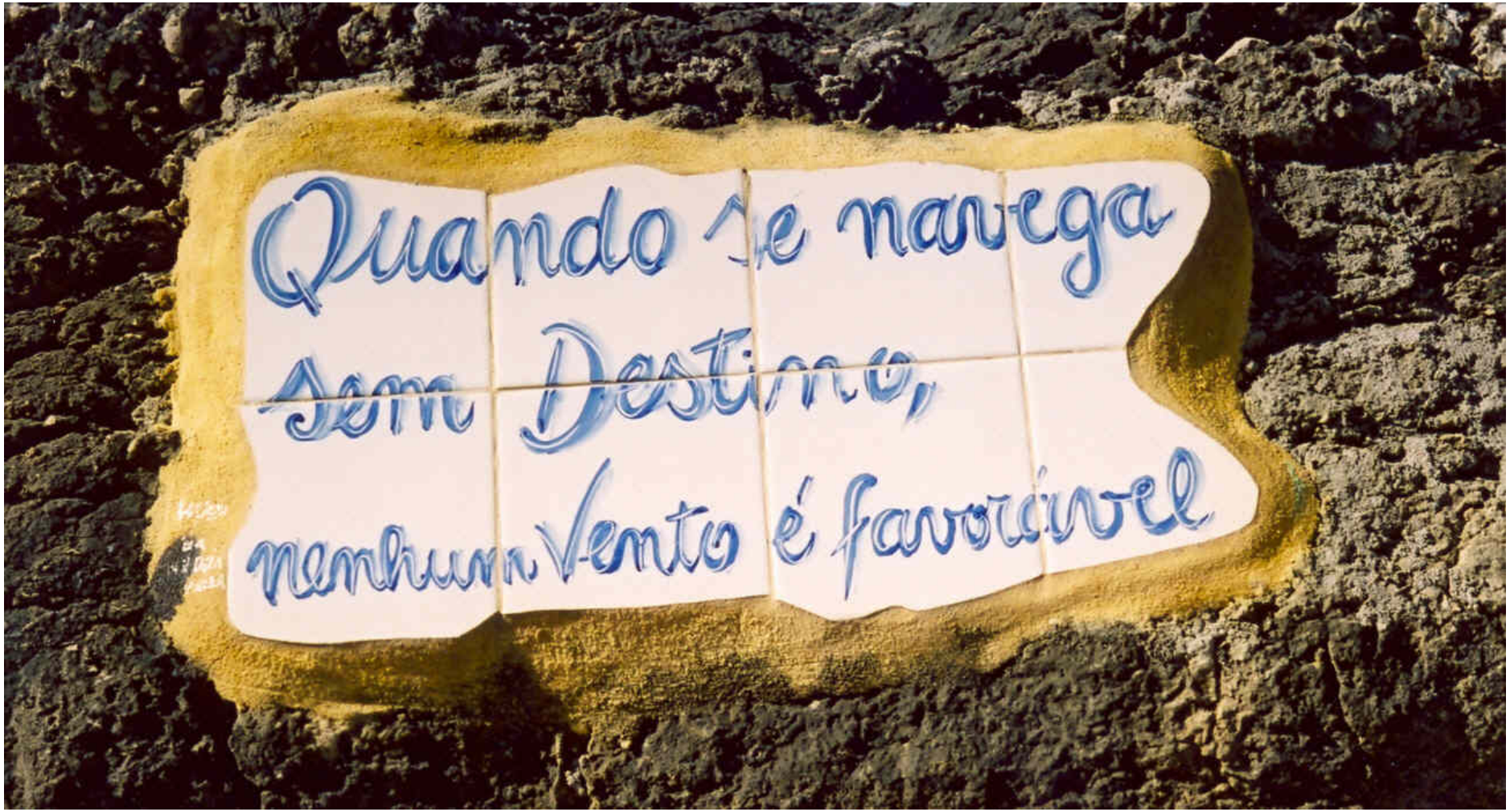
- comparing charmonium and D meson production patterns (ALICE)
- comparing bottomonium and B meson production patterns (CMS)

We should not change collision system until we see a significant Pb-Pb signal

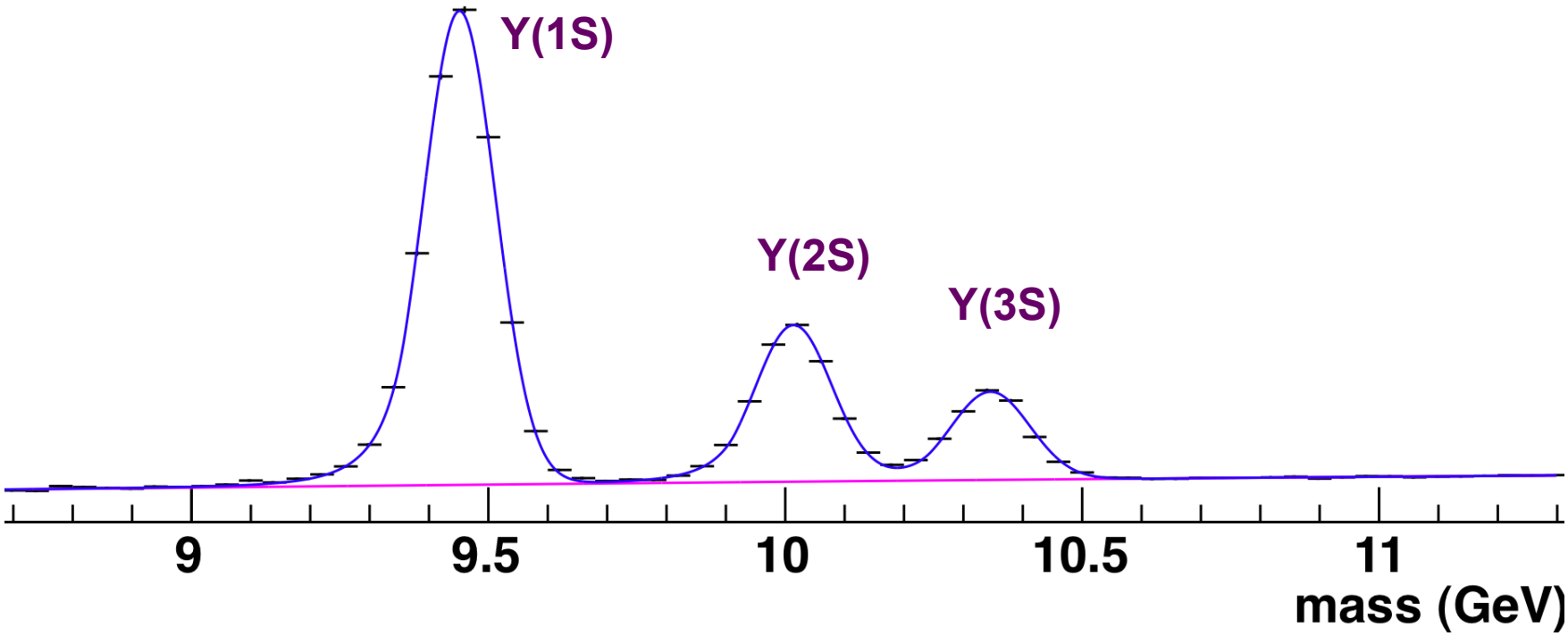
We should not look for an answer if we do not know what the question is

Sailors' wisdom

If you do not know where you are going, no wind blows in your favour



Preview of Upsilon measurement in **pp** collisions



Preview of Upsilon measurement in **peripheral Pb-Pb** collisions

Preview of Upsilon measurement in **central Pb-Pb** collisions

Thank you