Υ production as a function of charged-particle multiplicity in pp collisions at $\sqrt{s}$ = 13 TeV with ALICE

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1. Quarkonium production as a function of charged-particle multiplicity

- Quarkonium: bound state of heavy $Q\bar{Q}$ e.g. charmonium ($c\bar{c}$), bottomonium ($b\bar{b}$)

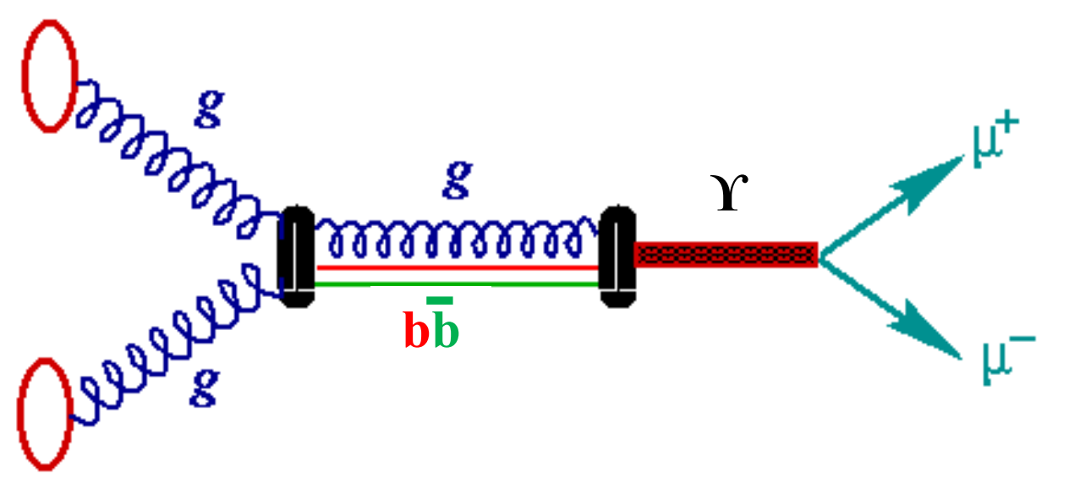
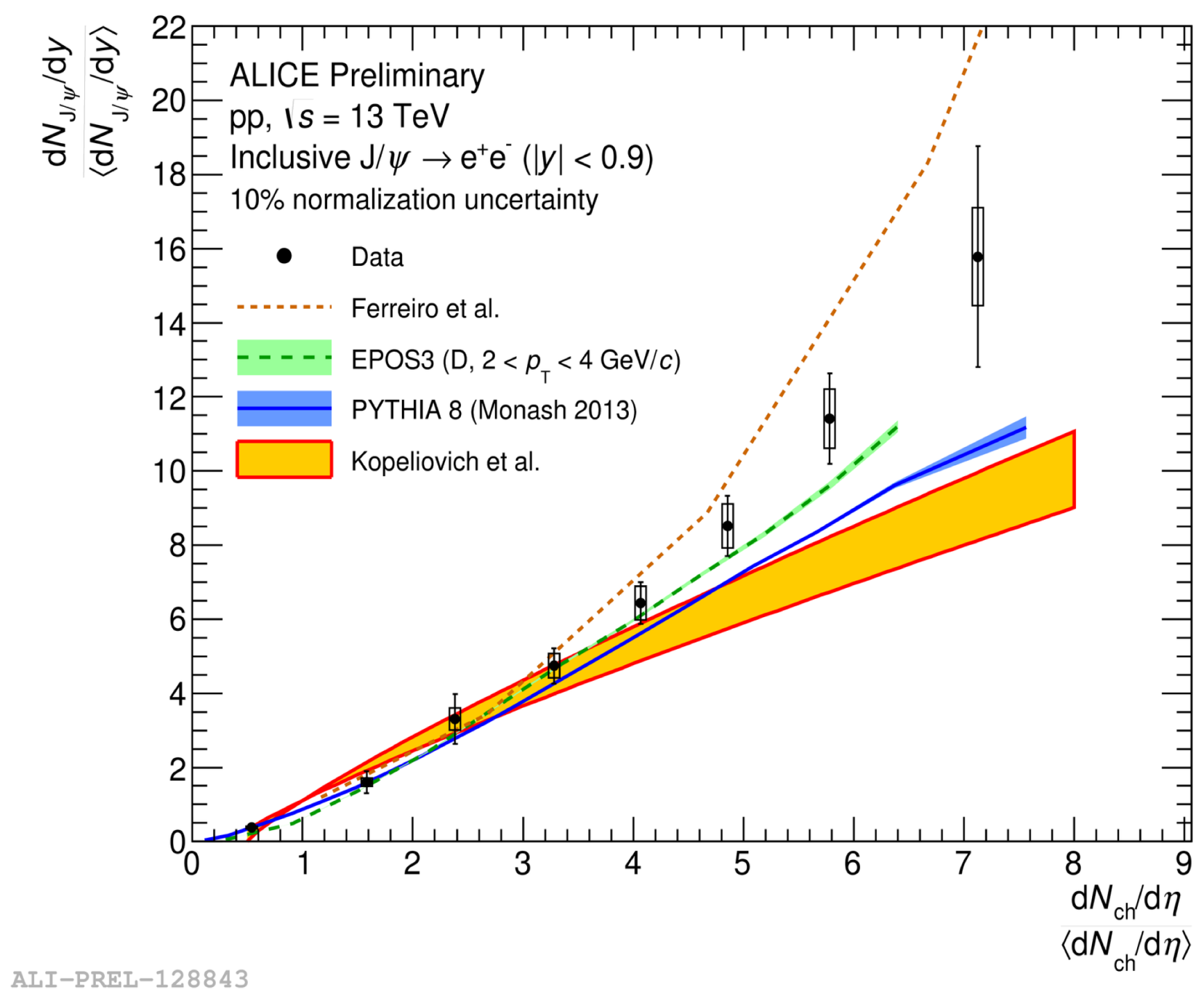


Illustration of the Υ production by gluon fusion. The formed quarkonium decays in a di-muon

- Quarkonium production in vacuum: not fully understood
- Theoretical models:
  - Colour-Evaporation Model (CEM) [1,2]
  - Colour-Singlet Model (CSM) [3]
  - Non Relativistic QCD (NRQCD) [4]



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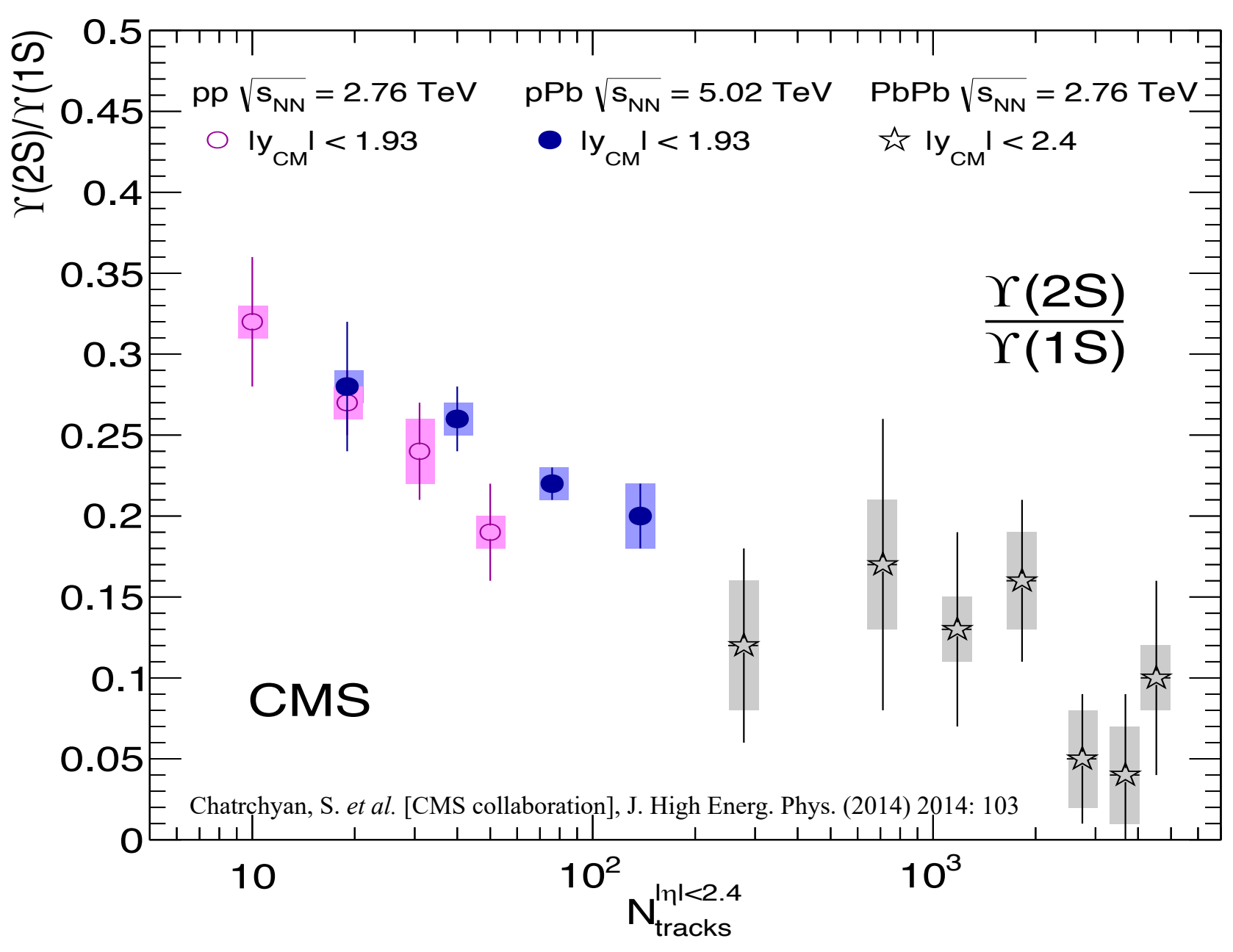
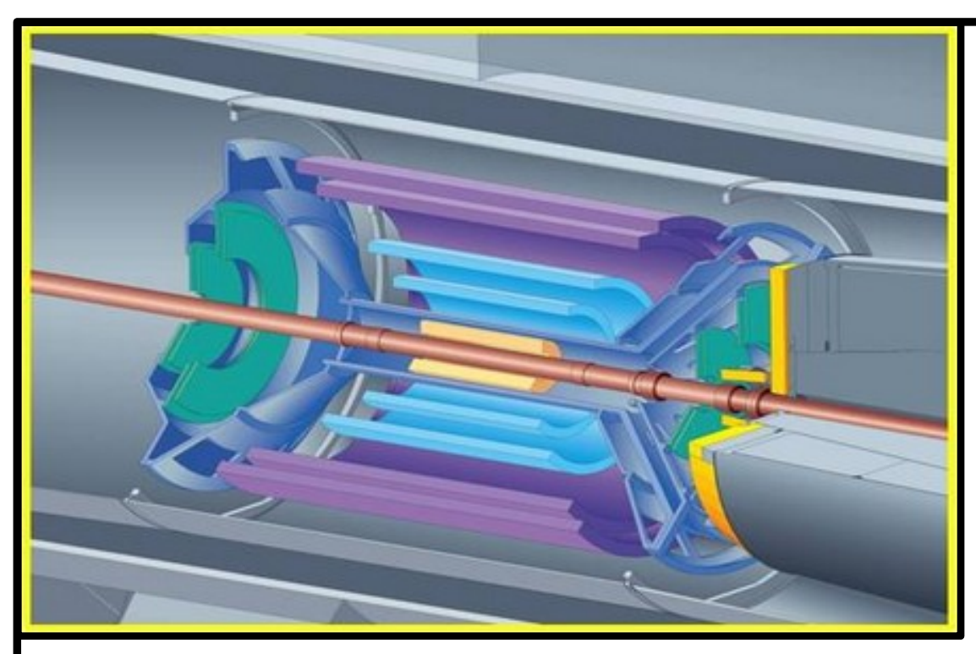


- Relative quarkonium yields increase more than linearly with increasing charged-particle multiplicity in the central rapidity region [5]
  - Linear increase: compatible with Multi-Parton Interaction (MPI) [5]
  - Non linear increase: additional effects are needed (percolation model, collectivity)[6,7]
- Υ excited-to-ground state ratio in the central rapidity region: decreasing trend with the event activity measured by CMS not well understood (initial-state vs. final-state effects) [8]
- Comparison between J/ψ and Υ(1S) at forward rapidity as a function of multiplicity at mid rapidity can help to understand this suppression

2. The ALICE detector



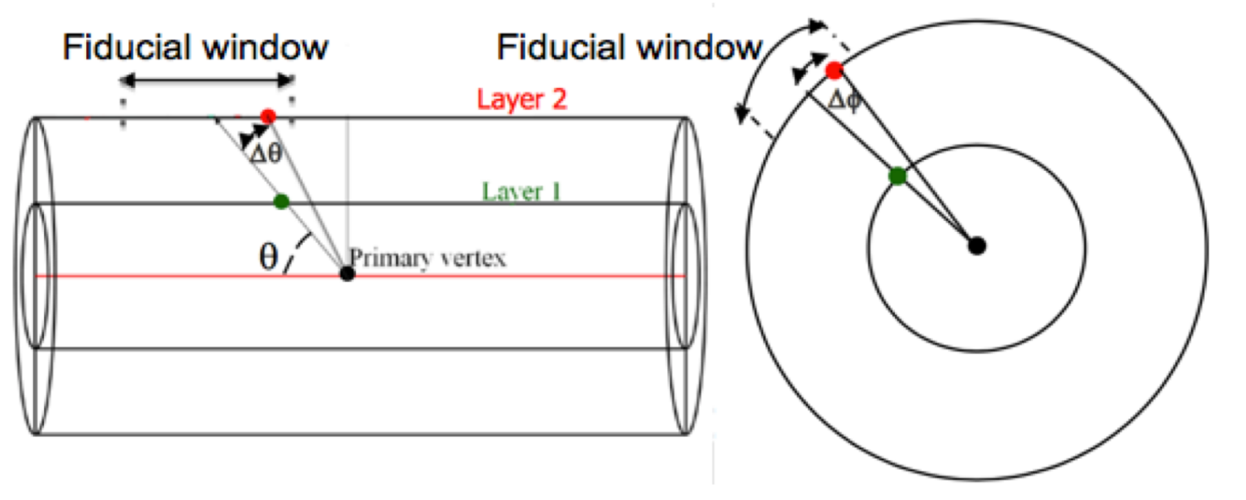
☐ Inner Tracking System

- 6 layers (2 drifts, 2 strips, 2 pixels)
- Vertex measurement

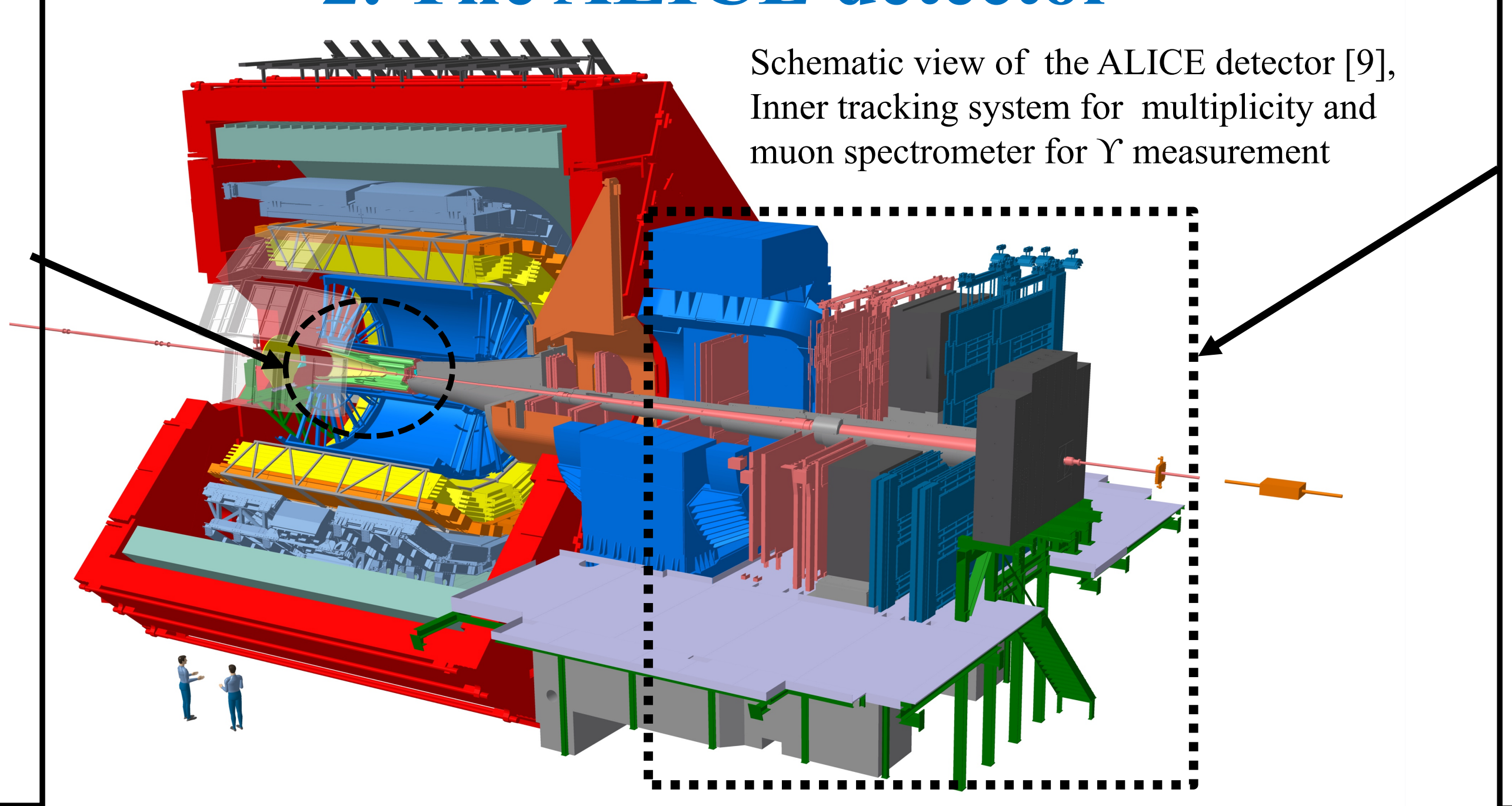
Silicon Pixel Detector (SPD)

(2 innermost ITS layers)

- Vertex determination
- **Multiplicity estimator** in $|\eta|<1$ & in $|z_{\text{vertex}}| < 10$ cm



A tracklet is a pair of hits in the two SPD layers aligned with the primary vertex within a fiducial window (θ, ϕ)



Schematic view of the ALICE detector [9], Inner tracking system for multiplicity and muon spectrometer for Υ measurement

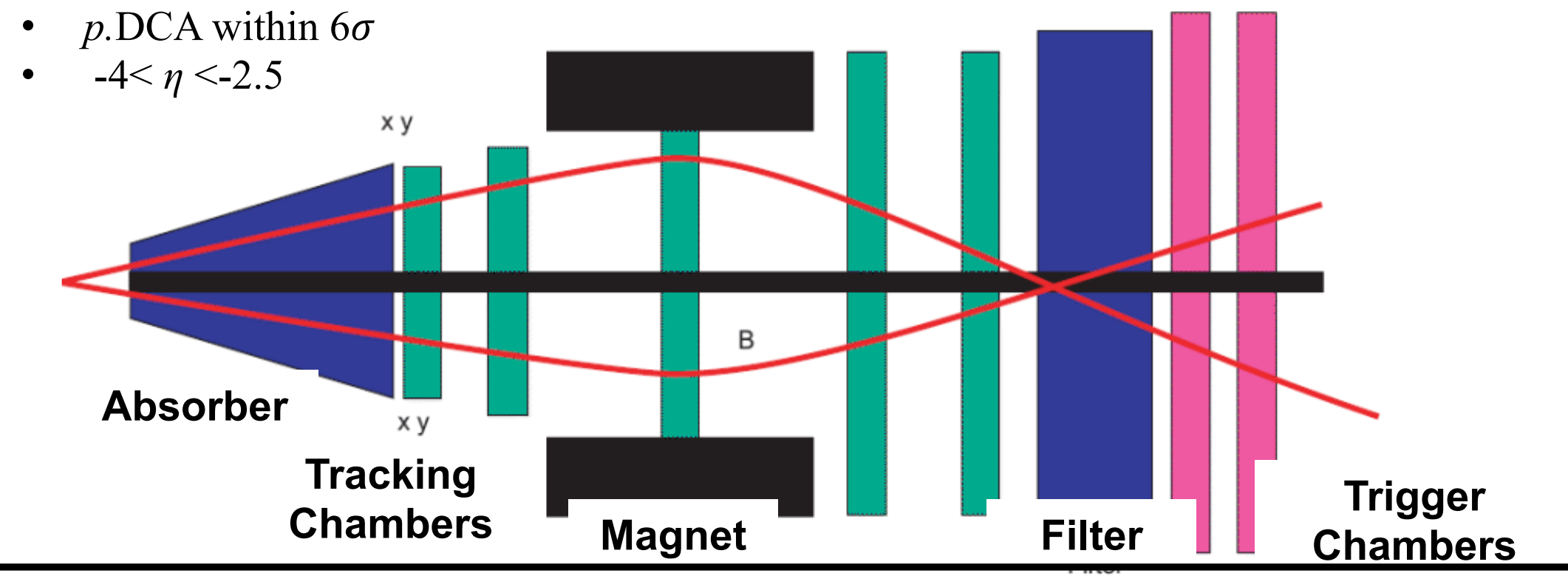
☐ Muon Spectrometer

Di-muon($\mu^+\mu^-$) reconstruction with unlike-sign dimuon triggered events at forward rapidity

Analysis cuts:

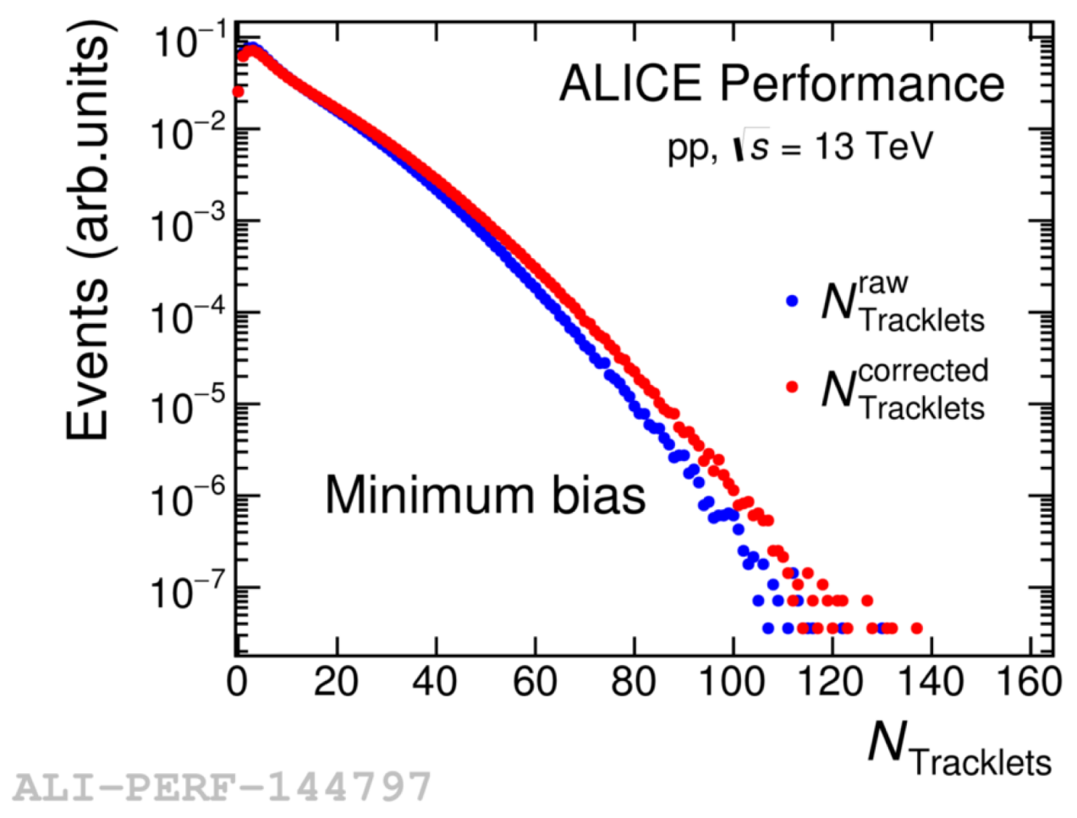
Single muons
- Tracking-trigger matching (p_T trigger threshold ~0.5 GeV/c)
- $17.6<R_{\text{abs}}<89.5$ cm
- p.DCA within 6σ
- $-4< \eta <-2.5$

Di-muons
- $2.5 < y < 4$
- Total di-muon charge = 0



3. Analysis strategy

☐ Self-normalized charged-particle density:



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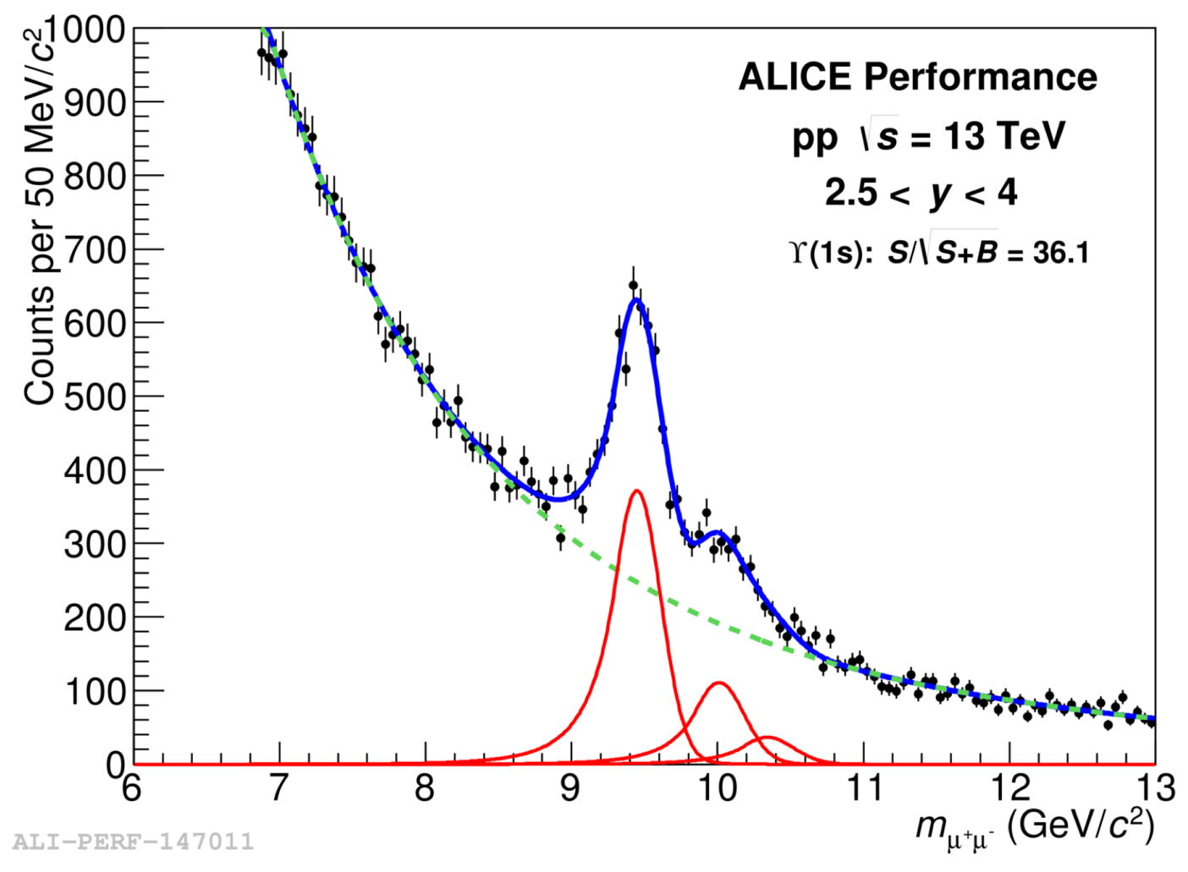
➢ **Multiplicity estimation ($|\eta|<1$):**
- Multiplicity is estimated from reconstructed SPD tracklets
- The raw tracklet ($N_{\text{tracklet}}^{\text{raw}}$) distribution (blue data points) is corrected for the SPD inefficiency ($N_{\text{tracklet}}^{\text{corrected}}$, red data points)
- Number of **tracklets** is approximately proportional to the **charged-particle multiplicity:** estimated from Monte Carlo simulations
- Only INEL>0 (having at least one charged particle in $|\eta|<1$) events are selected for multiplicity measurement

✓ **Self-normalized charged-particle density:** The average charged-particle density $\langle dN_{ch}/d\eta\rangle_i$ in multipicity bin i is normalized by the average charged-particle density from the integrated case $\langle dN_{ch}/d\eta\rangle_{\text{total}}$

✓ Systematic uncertainties for charged-particle multiplicity are computed by varying different MC inputs and vertex ranges

✓ Efficiency factors (ϵ) and corresponding systematic uncertainties are applied for trigger selection and INEL>0 selection

☐ Self-normalized Υ yields:



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➢ **Υ Signal extraction (in $2.5 < y < 4$):**

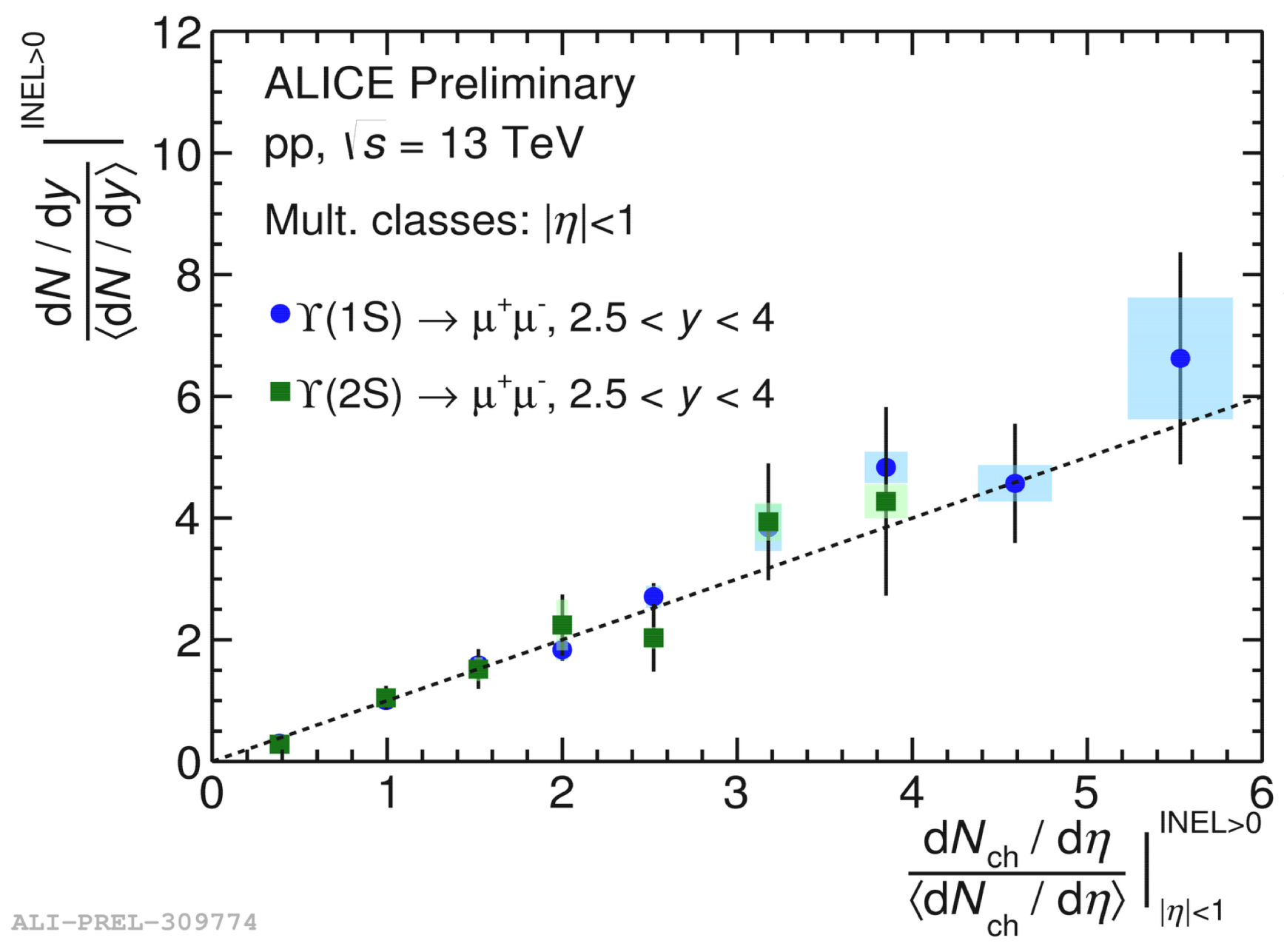
Υ yield extracted from a fit to the di-muon invariant mass spectrum combining:
- a signal function (Double Crystal Ball) for each Υ state
- a background function (variable width Gaussian/ product of two exponentials/ product of an exponential & a power law)
- Systematic uncertainties are computed by varying fit conditions

✓ The Υ yield obtained from signal extraction in each multiplicity interval is normalized by INEL>0 events in the corresponding multiplicity interval. Afterwards it is divided by multiplicity integrated Υ yield (which is also normalized by total INEL>0 events).

✓ Efficiency factors (ϵ) and corresponding systematic uncertainties are applied to account for trigger and INEL>0 selection

4. Results

☐ Self-normalized Υ(1S) & Υ(2S) yields as a function of multiplicity:



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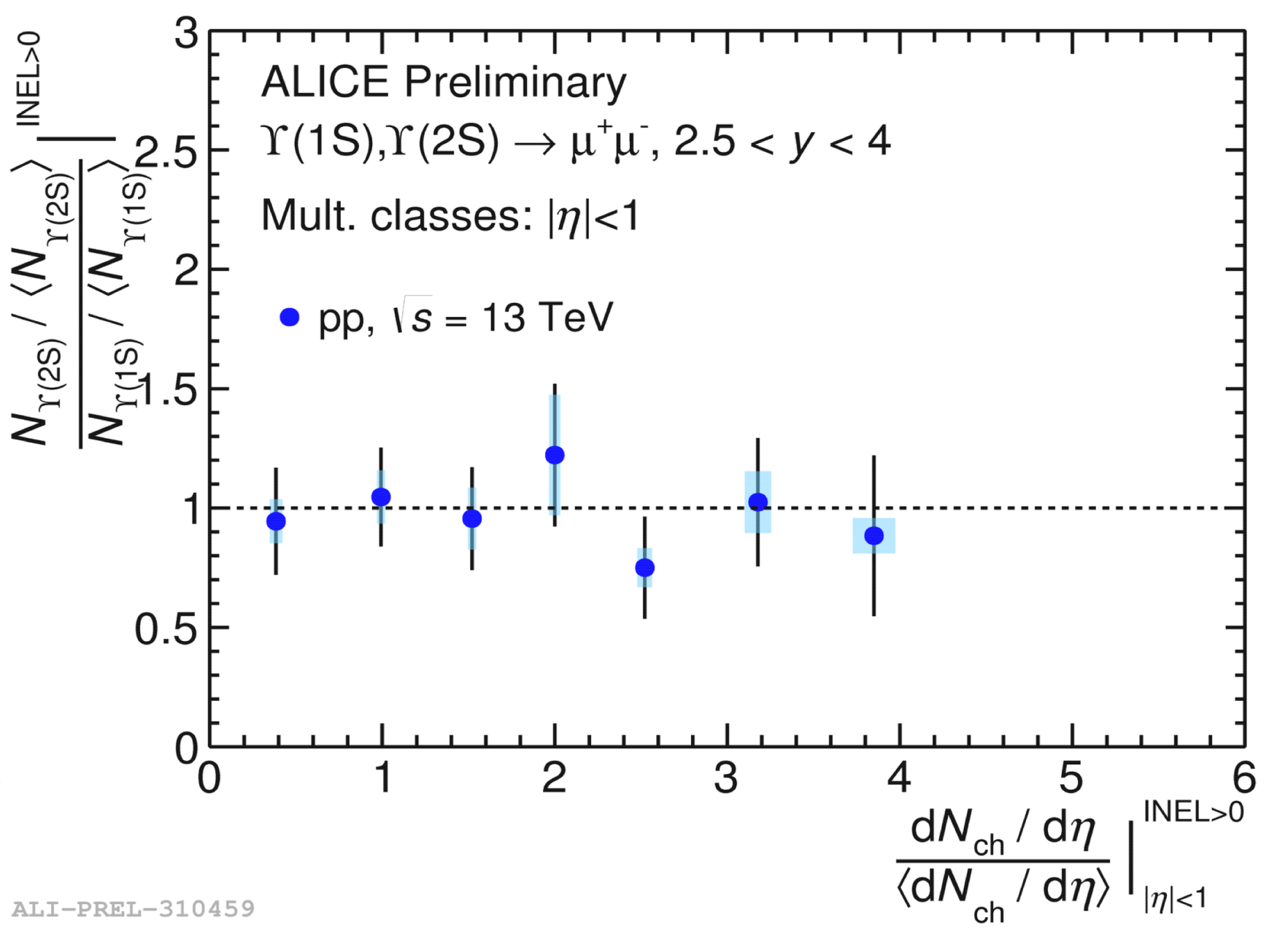
☐ Ratio between self-normalized Υ(2S) & Υ(1S) yields as a function of multiplicity:



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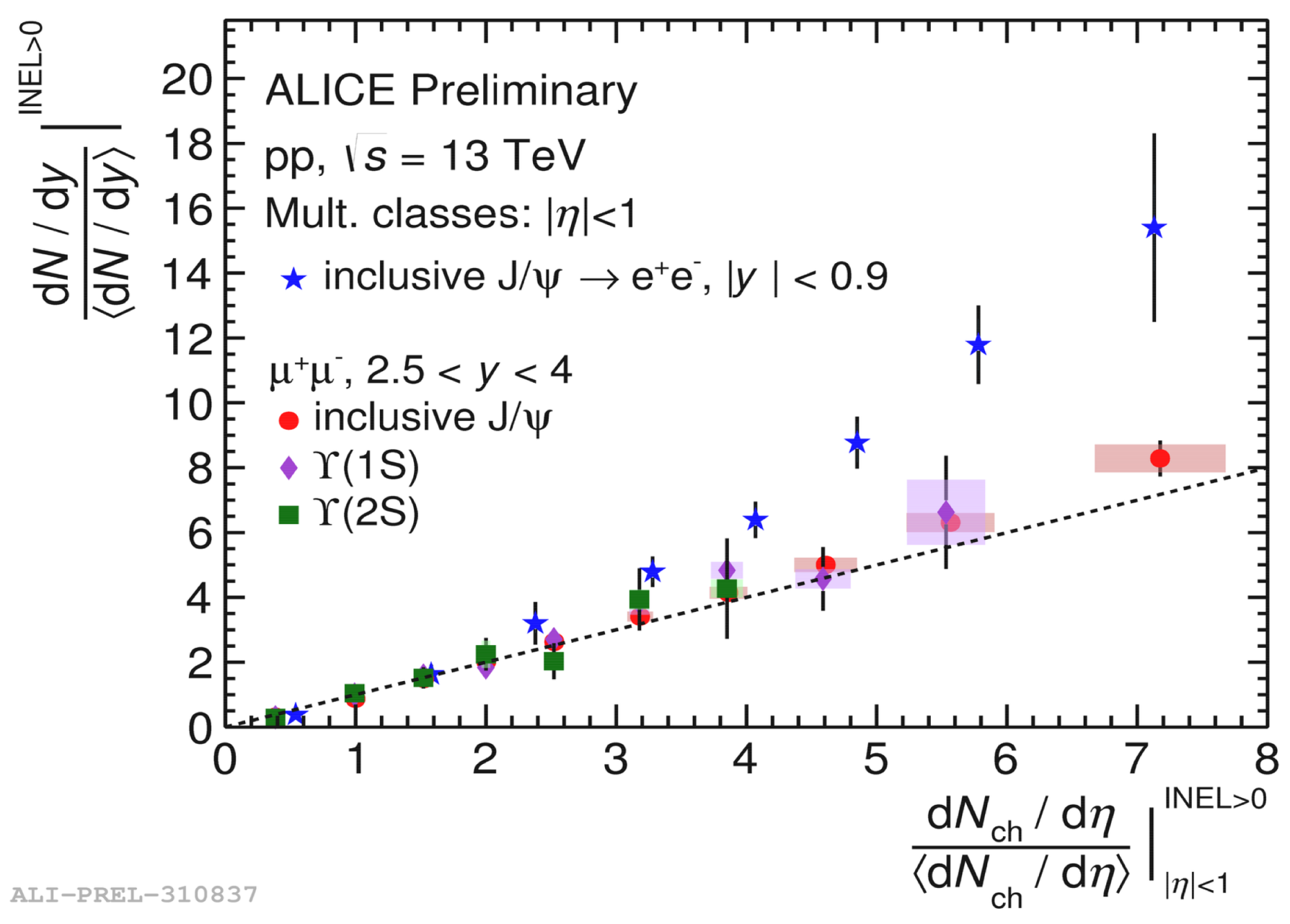
☐ Self-normalized quarkonium yields as a function of multiplicity:



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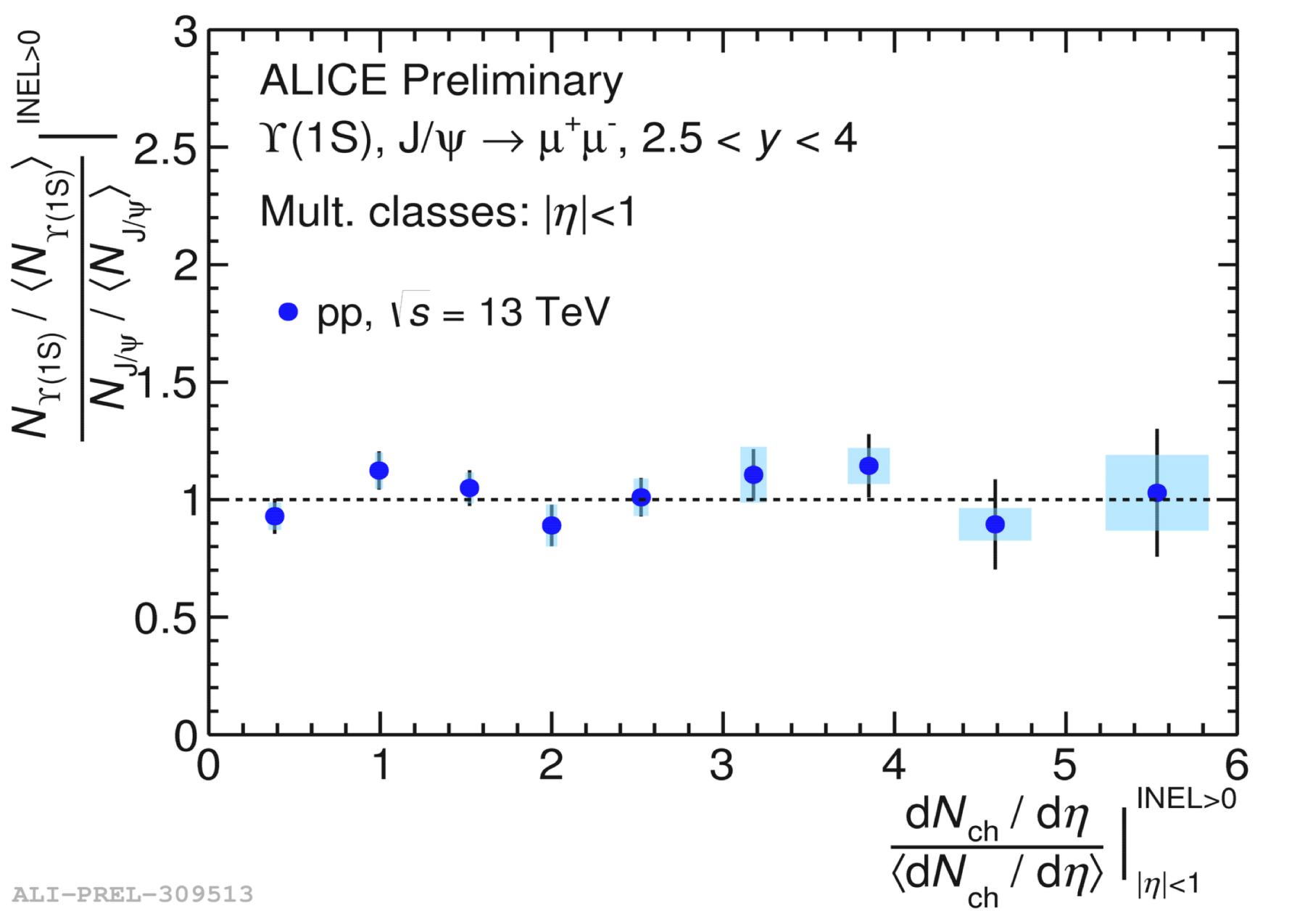
☐ Ratio between self-normalized Υ(1S) & J/ψ yields as a function of multiplicity:



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- Statistical errors are shown in bars and systematic uncertainties are represented by the boxes

✓ A linear increase is observed for both of Υ states and J/ψ measured at forward rapidity

✓ The self-normalized ratio of Υ(2S) over Υ(1S) as a function of multiplicity is constant, compatible with unity within the uncertainties, up to a relative multiplicity of about 4

✓ The self-normalized ratio of Υ(1S) over J/ψ as a function of multiplicity is constant, compatible with unity within the uncertainties, up to a relative multiplicity of about 6

✓ A faster than linear increase was observed for J/ψ measured at mid-rapidity [5]

✓ A 20% decrease in Υ(2S) / Υ(1S) as measured in the central rapidity region by CMS [8] is still compatible within current uncertainties

5. Conclusions

- ➢ First ALICE measurement for Υ(1S) & Υ(2S) as a function of charged-particle multiplicity in pp collisions at $\sqrt{s}$ = 13 TeV
- ➢ Quarkonia (J/ψ, Υ(1S), Υ(2S)) measured at forward rapidity as a function of charged-particle multiplicity measured at mid rapidity show a linear increase with increasing multiplicity
- ➢ The self-normalized ratio of the Υ(2S) over Υ(1S) and Υ(1S) over J/ψ are compatible with unity as a function of multiplicity
- ➢ No effects are seen w.r.t the resonance mass and quark content at forward rapidity
- ➢ Introducing a rapidity gap between the hard probe and the multiplicity estimator reveals a linear behavior which is different from previous observations without rapidity gap

References

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