Measurement of χ_{c2}/χ_{c1} production ratio in PbPb collisions with LHCb

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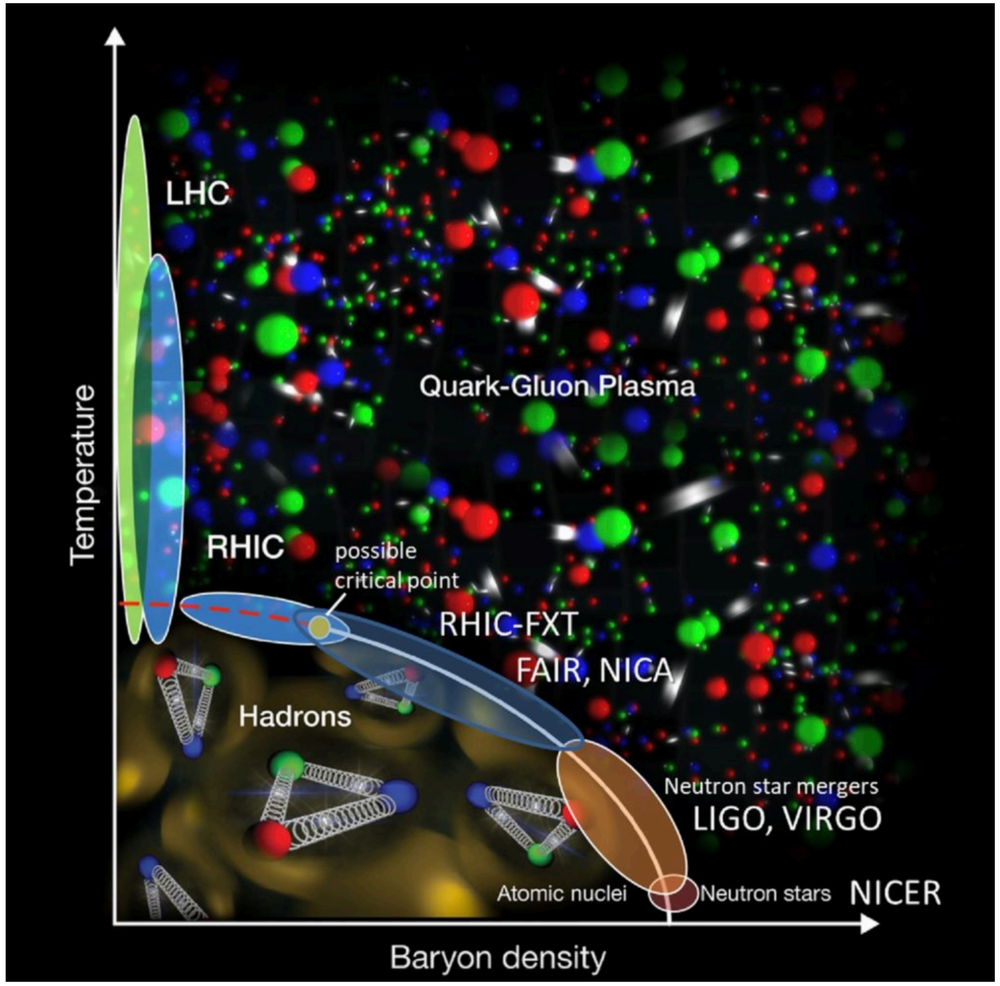
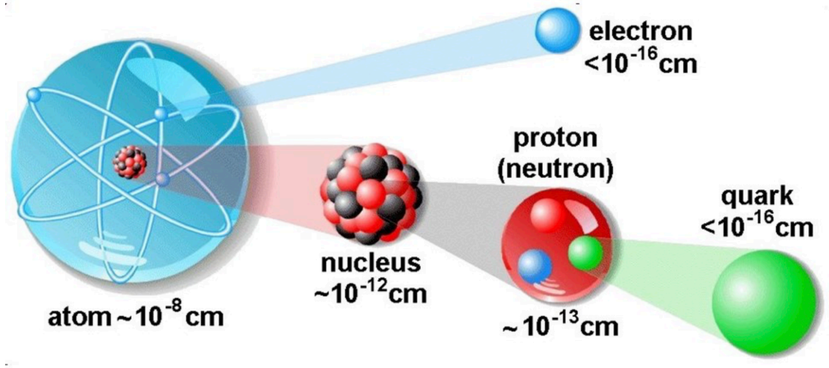
Motivation

The Quark Gluon Plasma (QGP)



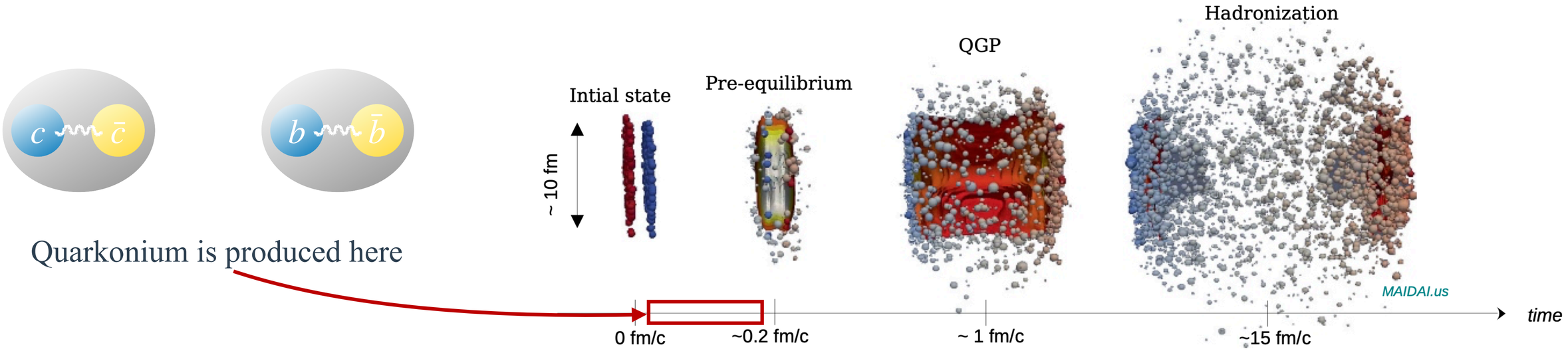


- **QGP** is an exotic **state of matter** where **quarks and gluons** are **no longer confined** inside hadrons (like protons and neutrons), but **move freely** in a hot, dense medium.
- This state of matter was present in the **"baby" universe**, just microseconds after the **Big Bang**.
- Extreme conditions of **Temperature** and **Energy Density** are needed for the QGP to form.
- **Heavy-ion collisions** at very high energies (LHC, RHIC) are the ideal scenario to study QGP.

Quarkonium in Heavy-ions collisions

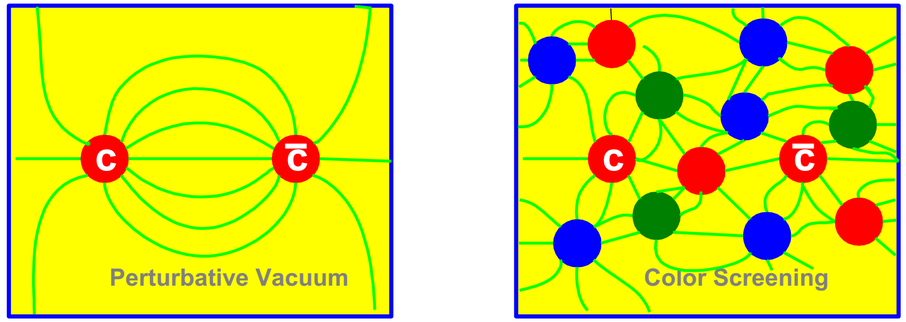
- **Quarkonium** is a bound state of a **heavy quark** and its **own antiquark**: Charmonia ($c - \bar{c}$) and Bottomonia ($b - \bar{b}$)

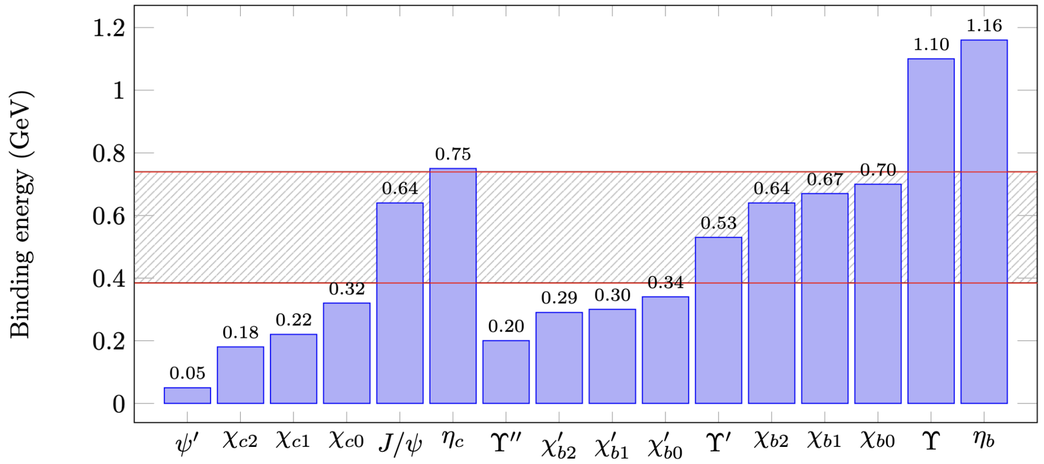
- Quarkonia are primarily produced in the **initial stages** of heavy-ion collisions via **hard parton-parton scatterings**. This occurs on a very short timescale (~0.1 fm/c), **before** the QGP forms.



Quarkonium as probe of QGP: Dissociation

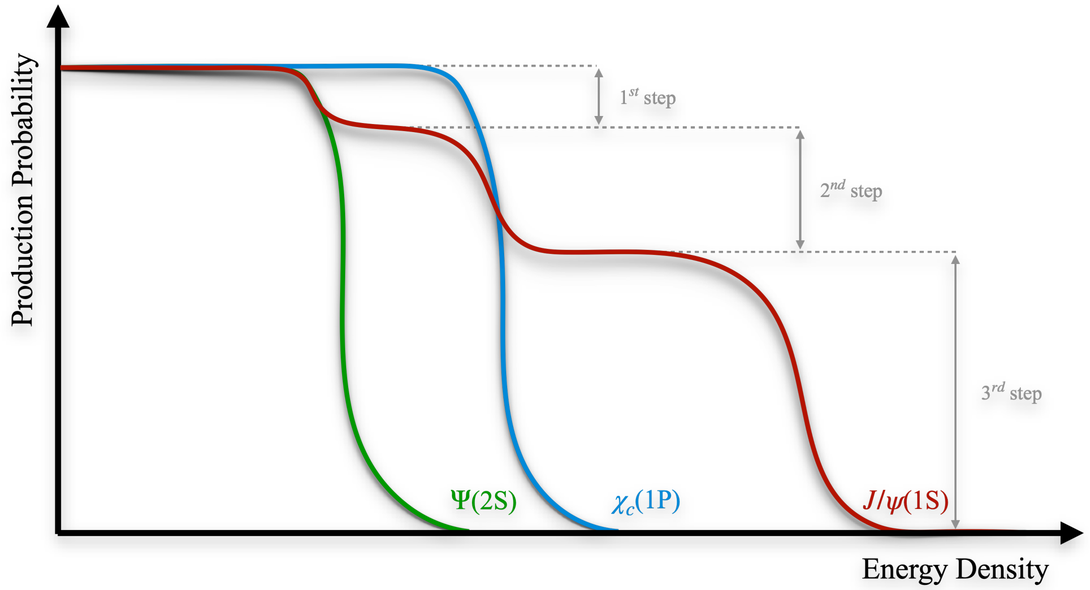
- In the QGP, free color charges (quarks and gluons) **screen the QCD potential** between the quark and antiquark. When the screening becomes stronger than the binding energy → **dissociation** occurs.
- States with **low binding energy** (e.g., $\Psi(2S)$, χ_c) dissociate at **lower temperatures**.
- **More tightly bound** states (e.g., J/ψ, $\Upsilon(1S)$) can **survive longer** in the QGP.

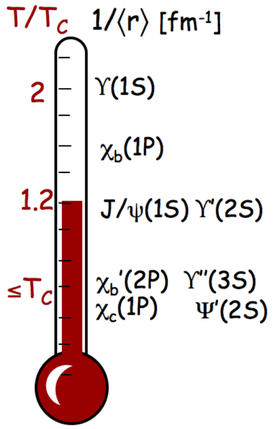




Sequential suppression

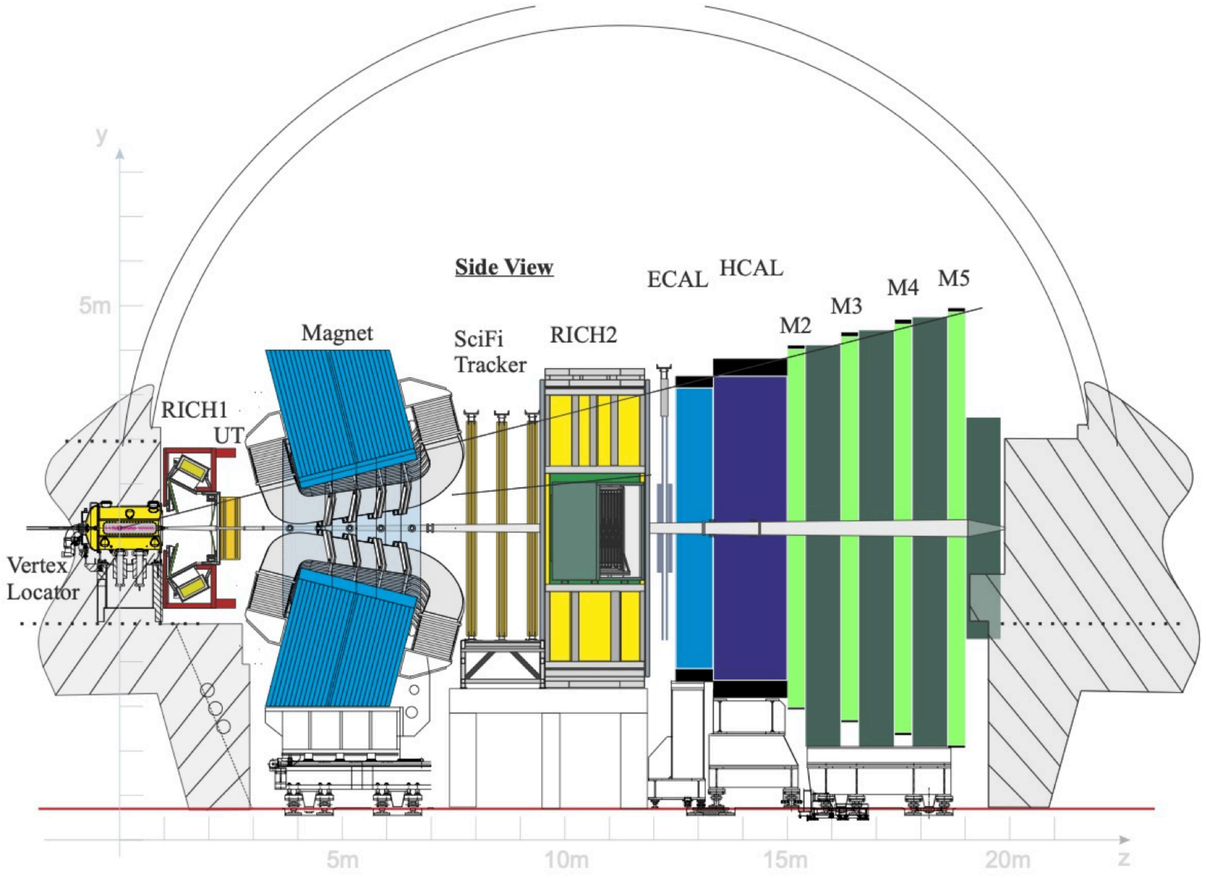
- This dissociation leads to a **step-by-step suppression** of quarkonium states as the temperature of the medium increases.
- Quarkonia ground states yields are **affected by higher states decays**: 60% direct J/ψ, 30% from χ_c decays and 10% from Ψ(2S) decays for charmonia.
- Suppression of these higher states leads to an indirect suppression of the ground state.





- Quarkonia act as a **QGP thermometer**—the pattern of suppression reveals the temperature of the medium.
- Measurement of χ_c states is a crucial piece to fully understand the sequential suppression mechanism.

The LHCb detector



- Single arm spectrometer fully instrumented in pseudorapidity range $2 < \eta < 5$.
- Tracking system with excellent **momentum resolution**.
- Excellent hadron and muon **ID**
- Precise **vertex reconstruction**, for primary and secondary vertices
- These characteristics make LHCb ideal for the study of **heavy-flavour**.

Analysis overview

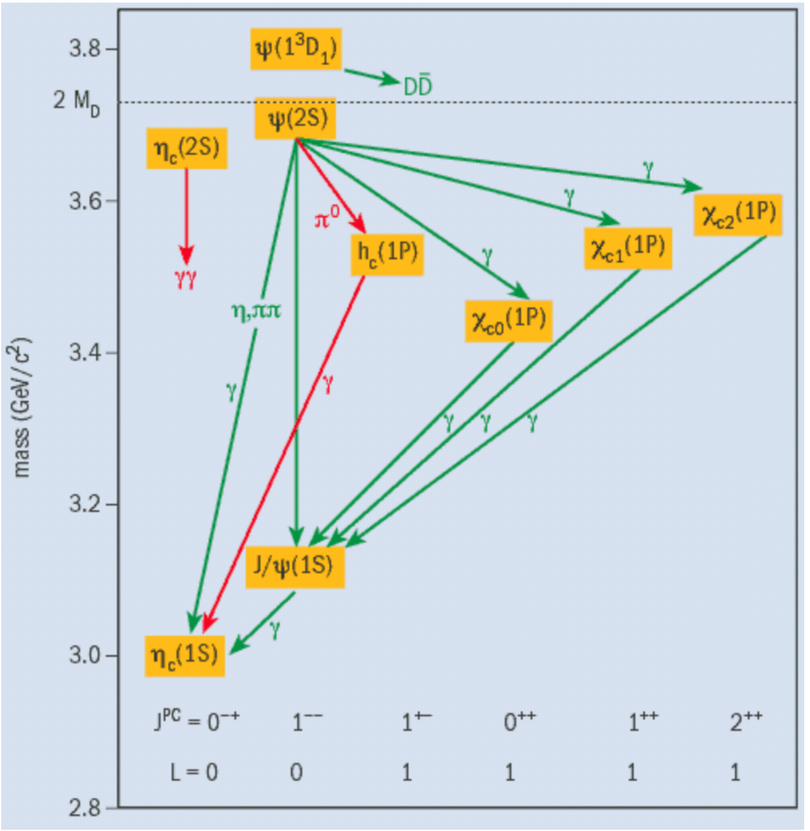
The Goal of this analysis

- Measure the χ_{c2}/χ_{c1} production ratio in PbPb collisions in the decay channel:

$$\chi_{c1,2} \rightarrow J/\psi(\mu^+\mu^-)\gamma$$

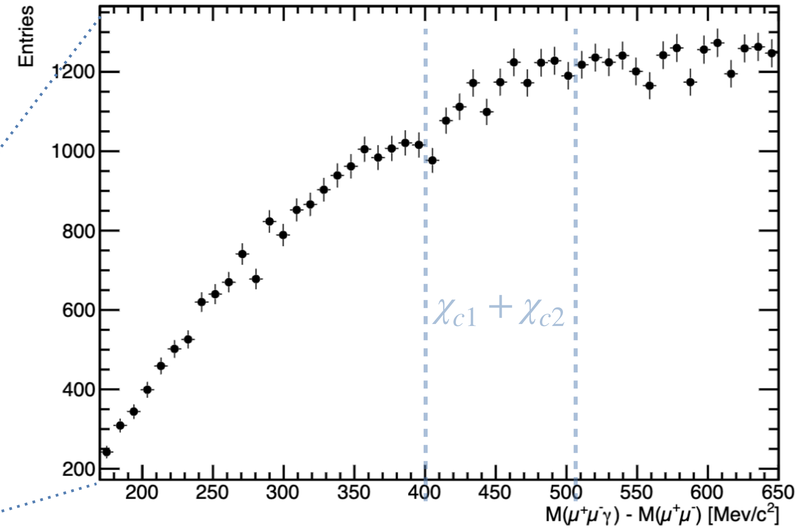
- The photons can be reconstructed as converted ($\gamma \rightarrow e^+e^-$) or as calorimetric. We focus in calorimetric ones (more abundant).

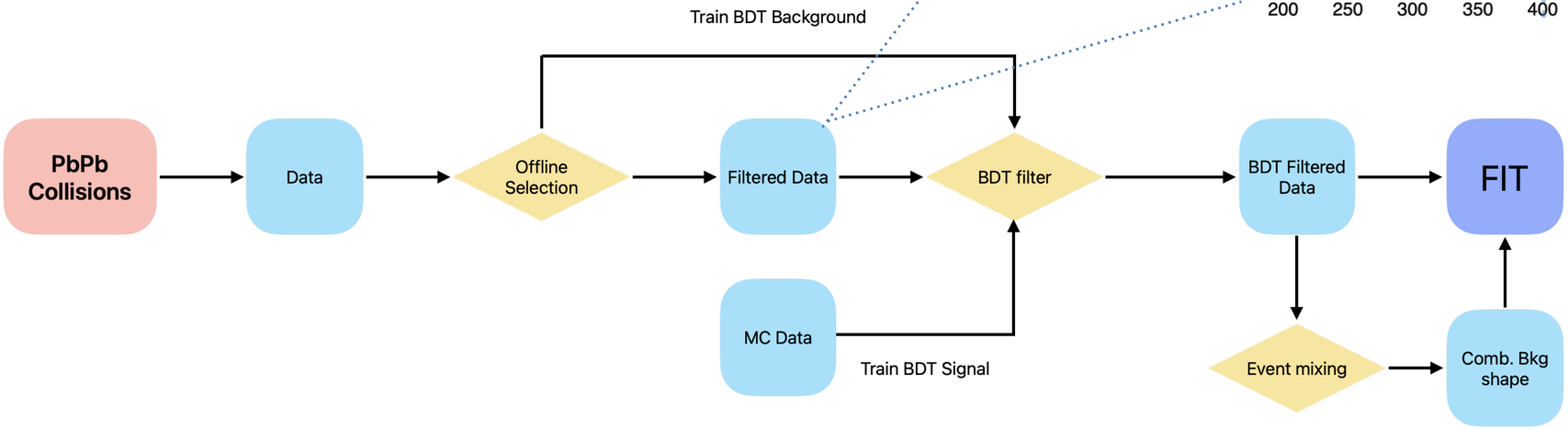
- This analysis has been performed in other collision systems (pp, pPb and Pbp) but never in PbPb.



General Strategy

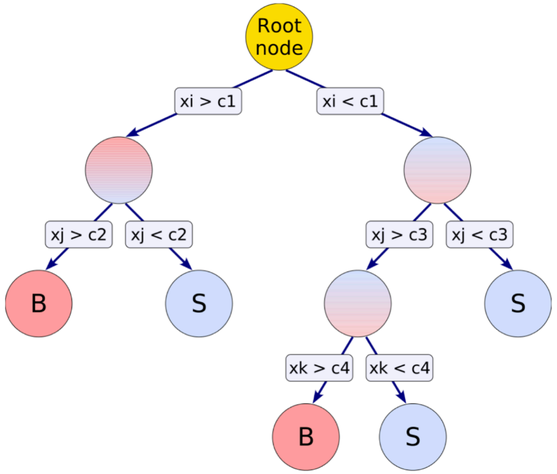
- Apply a selection on the recorded PbPb collisions data in order to increase the **signal/background**.
- Invariant mass spectrum is completely **dominated by the combinatorial background**.
- No resonance is clearly visible in the mass after the offline selection.
- Further selection: **Machine Learning** based selection.

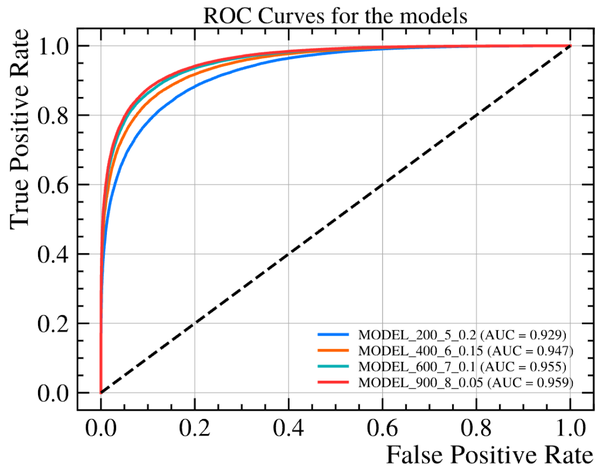


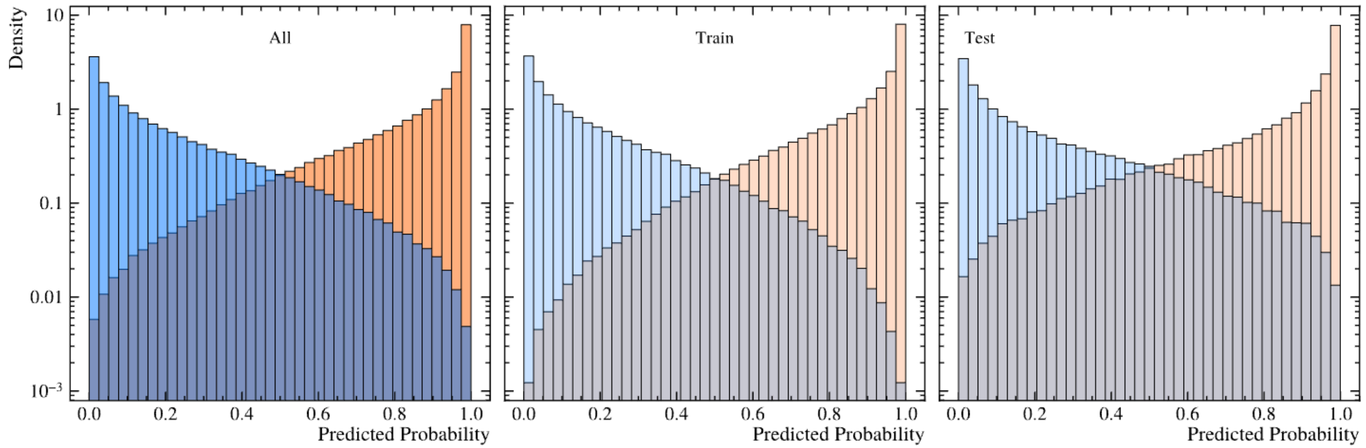


Boosted Decision Tree (BDT) selection

- A BDT is a machine learning algorithm that combines multiple decision trees to improve classification performance.
- The BDT learns how to separate **signal** from **background** by identifying complex correlations between input variables that simple cut-based or linear methods miss.
- It is **interpretable** and **tunable:** You can evaluate variable importance, control overtraining, and tune hyperparameters for optimal results.

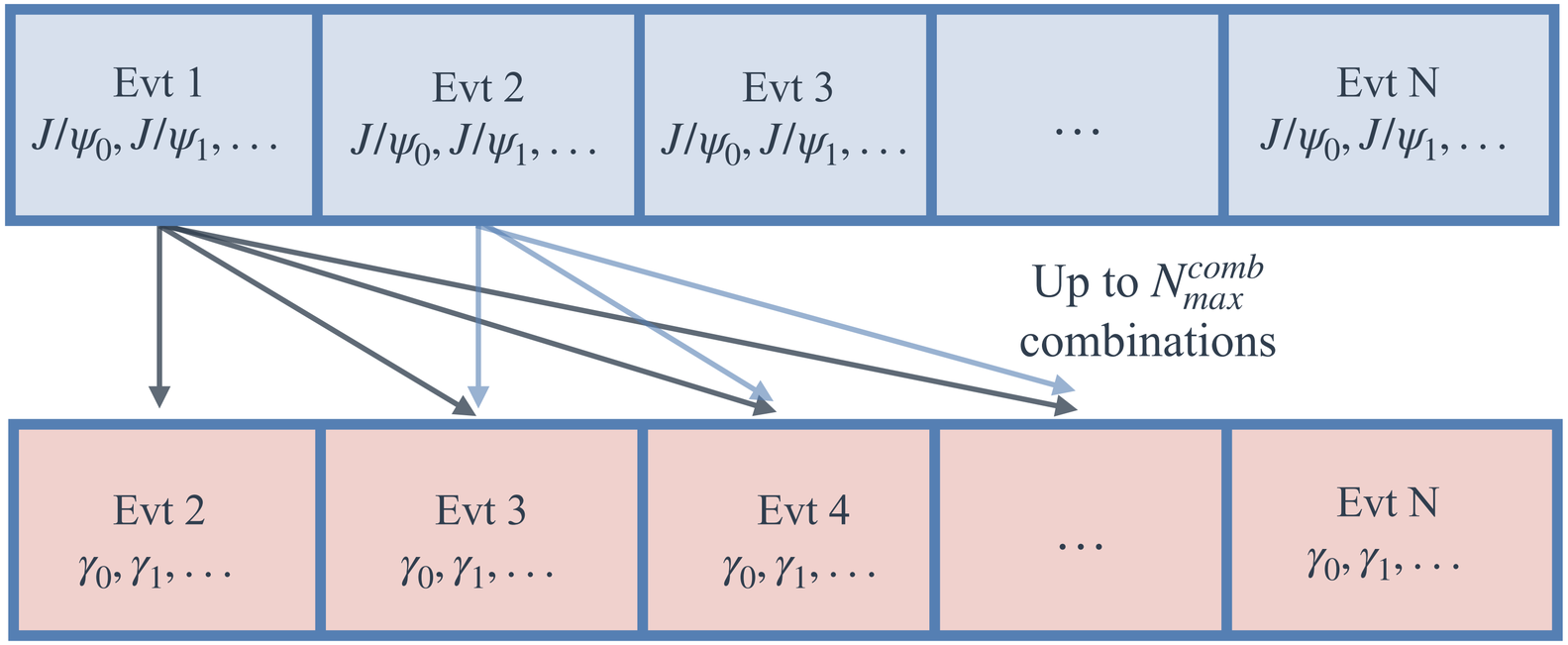






Combinatorial Background

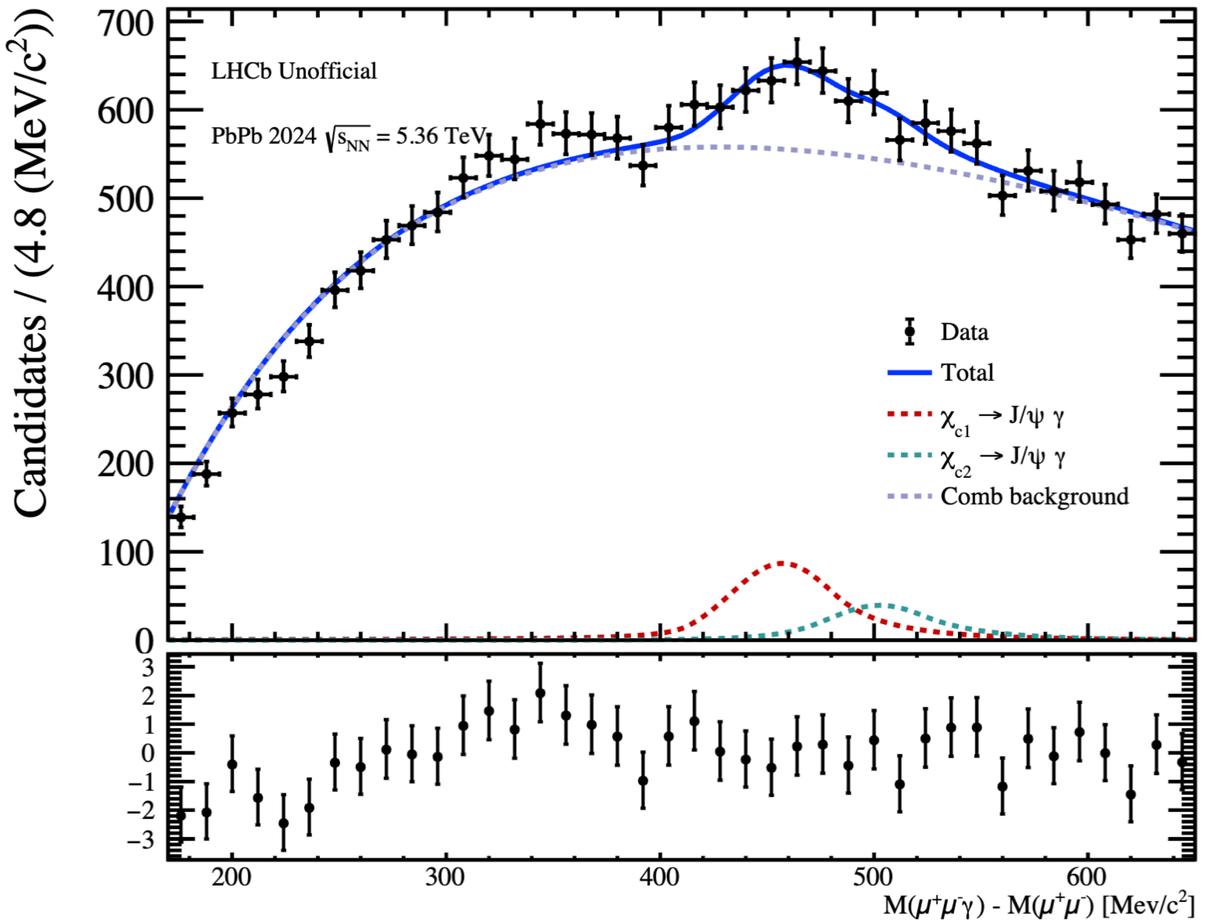
- Reproduce the background shape in the invariant mass spectrum making combinations of J/ψ and γ in different events.
- One event is mixed up to N_{max}^{comb} different events.
- Only events with similar collision conditions are mixed.



Signal extraction

A little preview: Invariant mass fit

- Data selection with BDT. ✅
- Combinatorial background shape ✅ fixed with mixing events technique.
- Perform the fit in the invariant mas 🚀

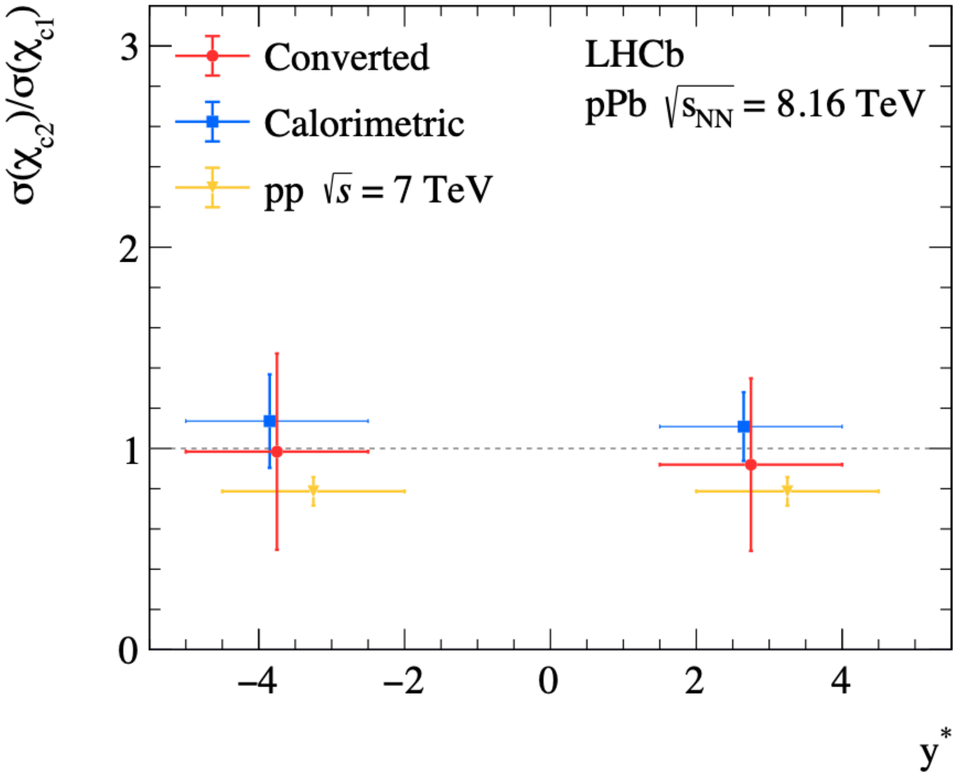


Next Steps

- Computation of the **cross-section ratio** $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ as:

$$\frac{\sigma(\chi_{c2})}{\sigma(\chi_{c1})} = \frac{N(\chi_{c2})}{N(\chi_{c1})} \cdot \frac{\varepsilon(\chi_{c2})}{\varepsilon(\chi_{c1})} \cdot \frac{BR(\chi_{c1} \to J/\psi\gamma)}{BR(\chi_{c2} \to J/\psi\gamma)}$$

- **Compare** this cross-section ratio with the **results in pp collisions** to see if there is **suppression due to QGP**.



Summary

- **QGP** is the state of matter that was present in the **early universe**, where quarks and gluons are **deconfined** from hadrons. It is created in **Heavy-ion collisions** at very high energies.
- **Charmonia** act as a **thermometer** for the QGP: by observing which states are suppressed, we can learn how hot the medium is.
- The study of χ_c states suppression is crucial to understand the **sequential suppression**: χ_c states are one of the **first states to "melt"** in QGP.
- **First time** this analysis is performed in **PbPb collisions**.
- Study of χ_c states is specially difficult due to the **large combinatorial background**. Use of **machine learning** methods to identify **signal** and **background**.
- Very exciting results coming soon!

Thank you for your attention!