PhD Hours

Prompt/non-prompt J/Ψ production in pp collisions at 13.6 TeV at forward rapidity with ALICE experiment

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Supervisors : Maurice Coquet, Maxime Guilbaud, Marie Germain

Subatech, Nantes

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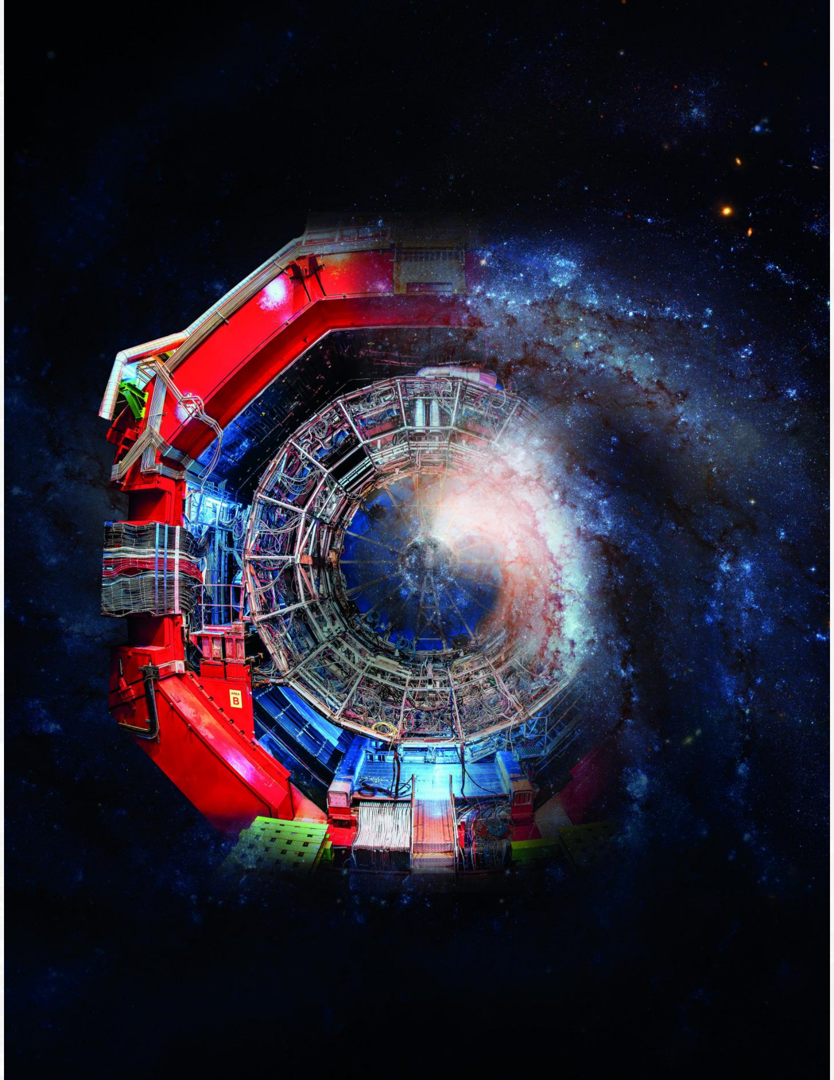
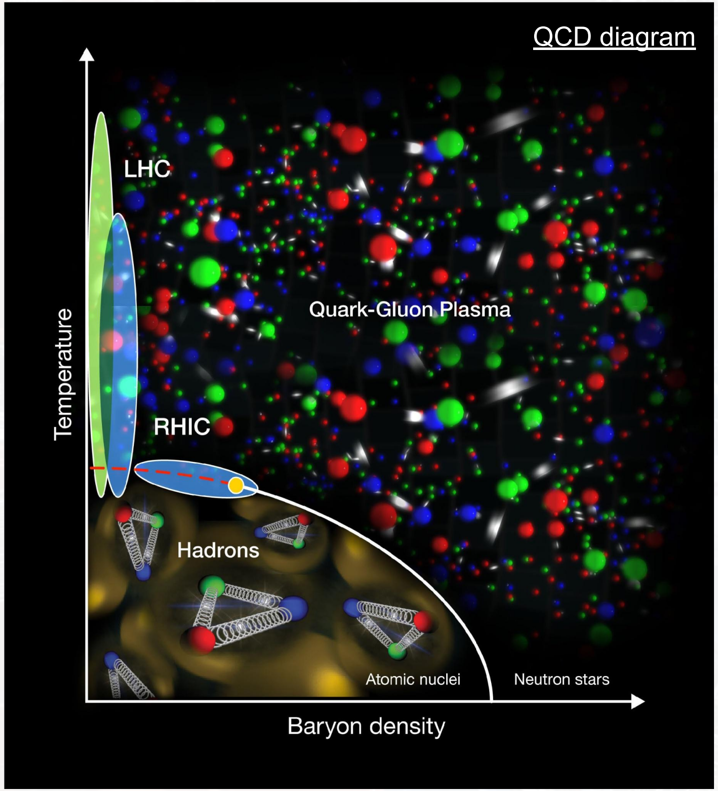


1. Context

Nuclear phase diagram



QGP properties

- Deconfined phase of matter
- Hypothetical state of the early Universe
- Predicted by Lattice QCD
- Quarks et gluons are deconfined
- High temperature and/or high baryonic density

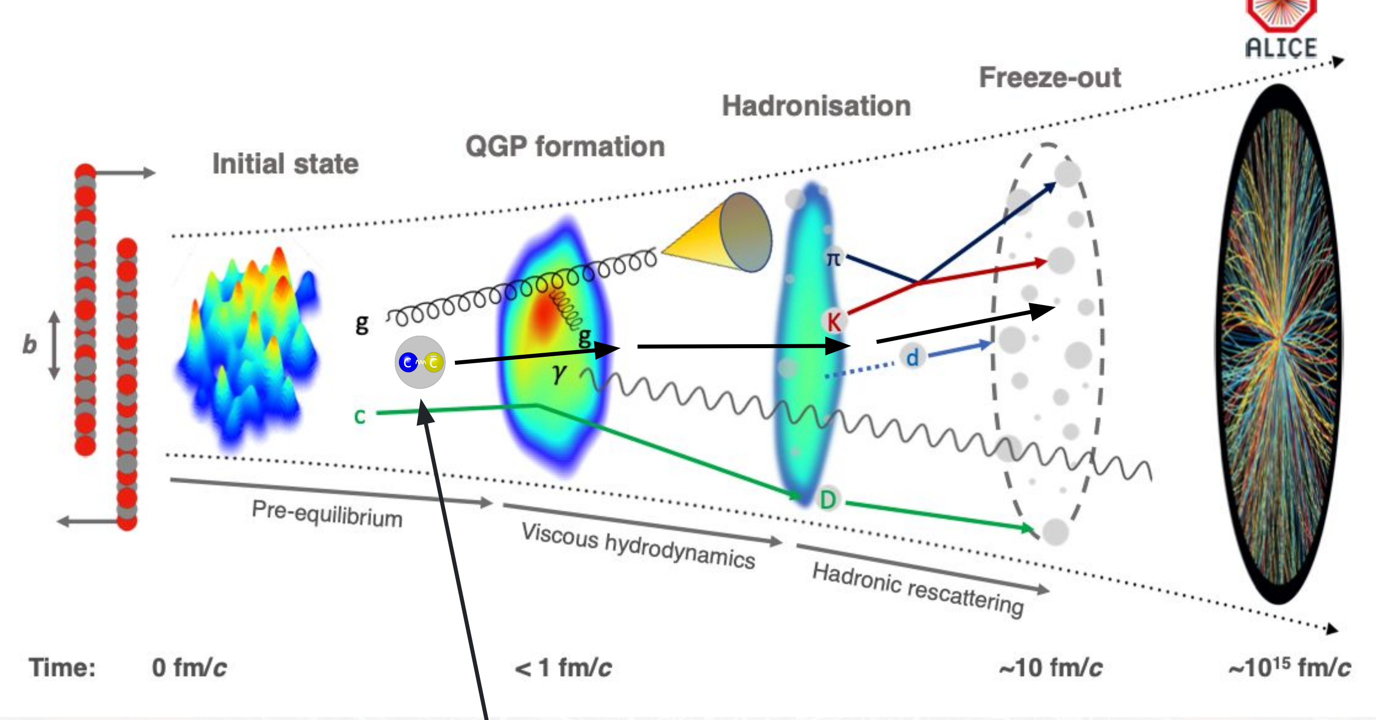
Study of this particular state of matter possible thanks to high energy colliders

↓

Production via heavy ion collisions

Heavy Ion Collision at the LHC

Eur. Phys. J. C 84 (2024) 813

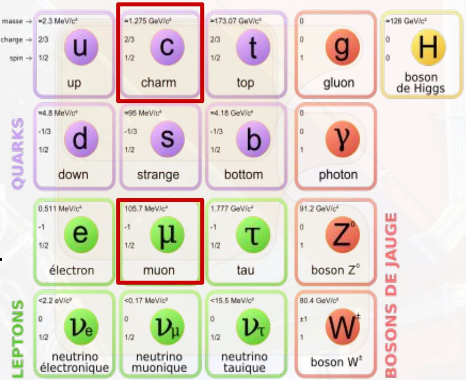


Production of the c$\bar{c}$ pair at the initial state : witnesses the whole evolution of the collision → excellent probe for QGP (among other ones)

QGP Probe : J/Ψ

- Charm-anticharm (quarkonia) meson
- Muonic channel decay study
- Sensitive to QGP : weakly bounded state

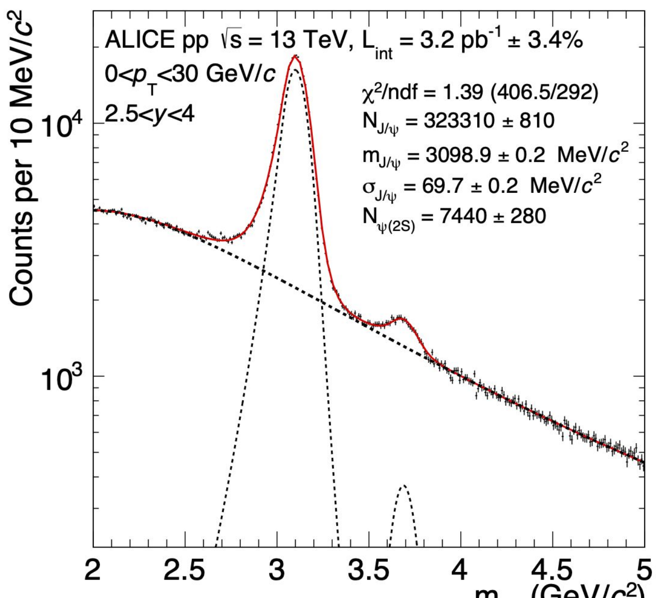
Standard Model



Particle Data Group

$J/\psi(1S)$ DECAY MODES

	Mode		Fraction (Γ_i/Γ)	Scale factor/ Confidence level
Γ_1	hadrons		(87.7 ± 0.5) %	
Γ_2	virtual $\gamma \to$ hadrons		(13.50 ± 0.30) %	
Γ_3	ggg		(64.1 ± 1.0) %	
Γ_4	γgg		(8.8 ± 1.1) %	
Γ_5	e^+e^-		(5.971 ± 0.032) %	
Γ_6	$e^+e^-\gamma$	[a]	$(8.8 \pm 1.4) \times 10^{-3}$	
Γ_7	$\mu^+\mu^-$		(5.961 ± 0.033) %	



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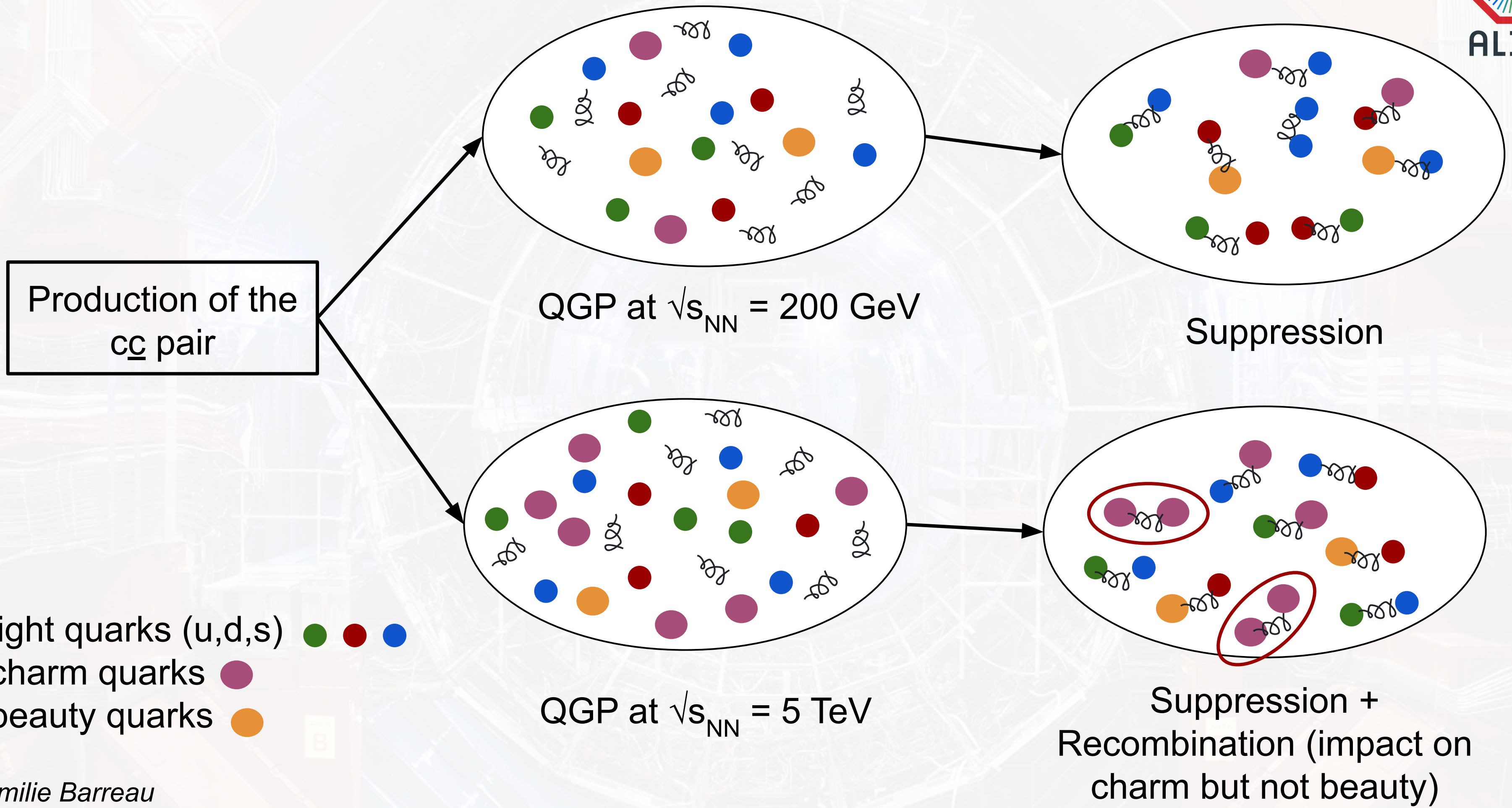
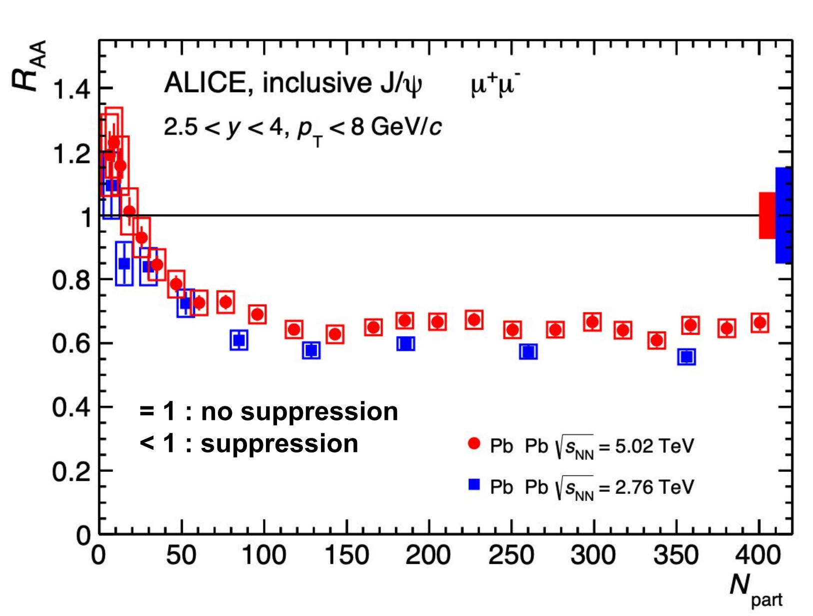
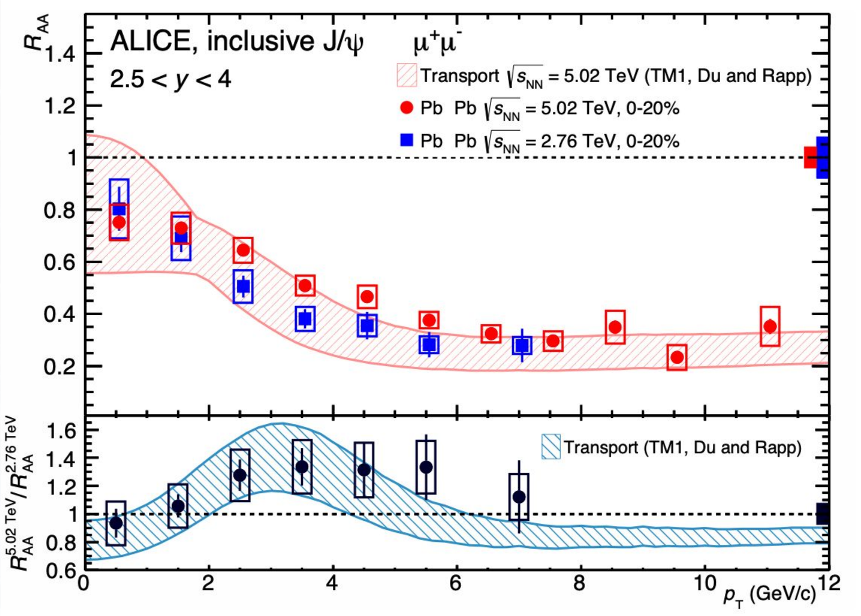
Suppression and recombination inside a QGP



Significant J/Ψ results : nuclear modification factor R_{AA}



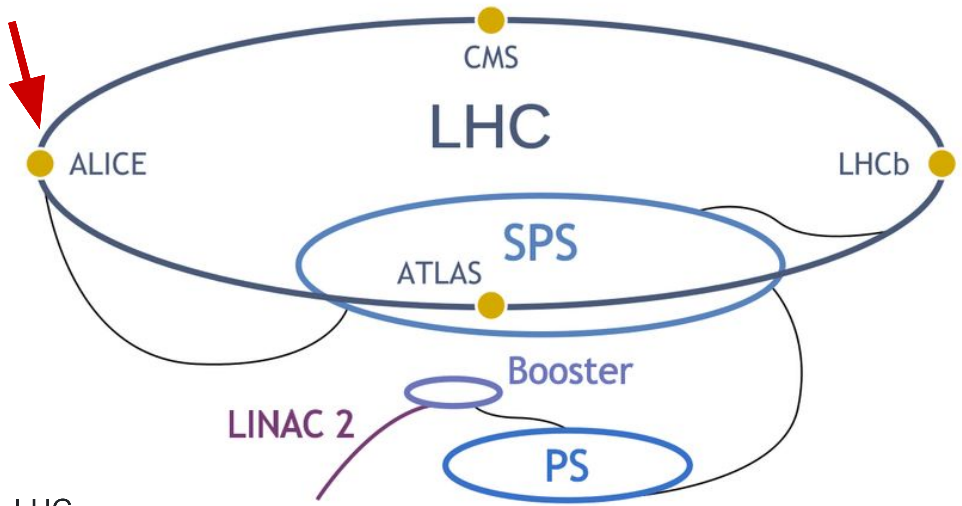


$$R^i_{AA}(\Delta p_T) = \frac{N^i_{J/\psi}(\Delta p_T)}{BR_{J/\psi\rightarrow\mu^+\mu^-} N^i_{MB} A\varepsilon^i(\Delta p_T)\langle T^i_{AA}\rangle \sigma^{pp}_{J/\psi}(\Delta p_T)}$$

$$\frac{d^2\sigma^{pp}_{J/\psi}}{dy dp_T} = \frac{N^{pp}_{J/\psi}(\Delta p_T)}{BR_{J/\psi\rightarrow\mu^+\mu^-} L^{pp}_{int} A\varepsilon_{pp}(\Delta p_T)\Delta p_T \Delta y}$$

2. The ALICE Experiment

Large Hadron Collider



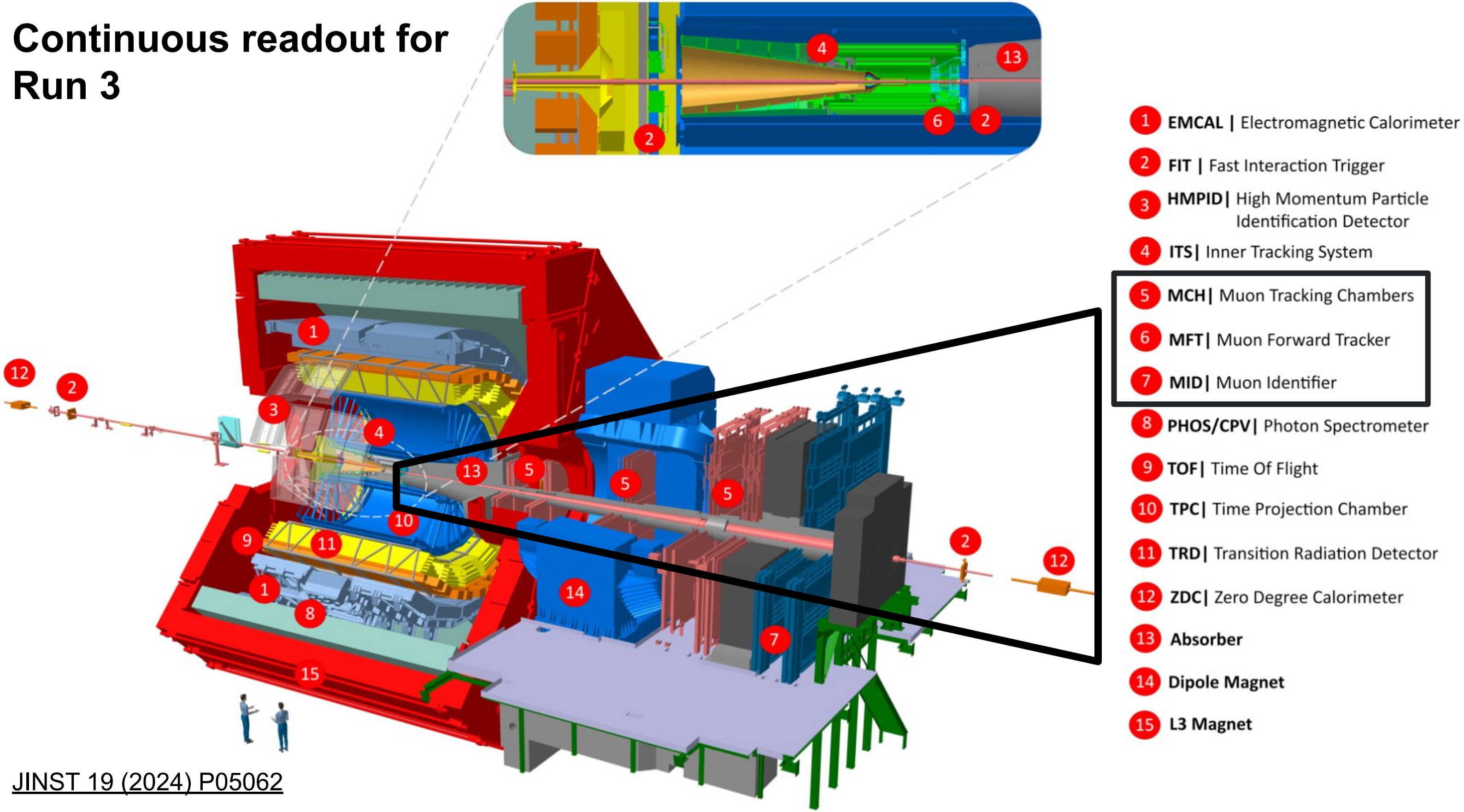
LHC

Top Energy (Run 2 : 2015 - 2018)	Top Energy (**Run 3 : 2022 - now**)
pp : 13 TeV	pp : 13.6 TeV
p-Pb : 8.16 TeV	p-Pb : not done yet
Pb-Pb : 5 TeV	Pb-Pb : 5.36 TeV

Luminosity (Run 1 + Run 2)	Luminosity (**Run 3**)
pp : 41.40 pb^{-1}	pp : 82.1 pb^{-1}
Pb-Pb : 0.875 nb^{-1}	Pb-Pb : 2.11 nb^{-1}

The ALICE Experiment

Continuous readout for Run 3



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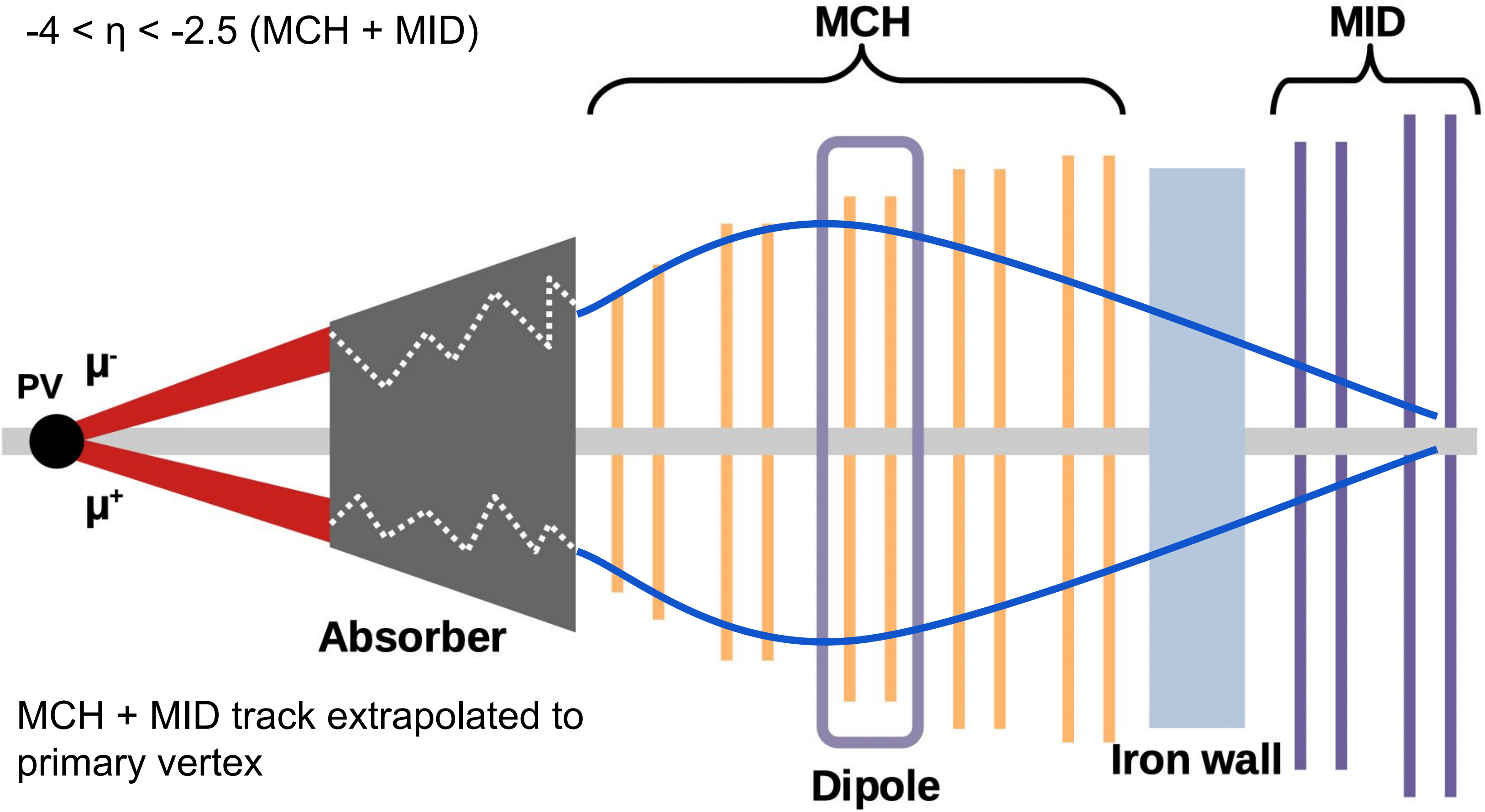
Muon tracking during Run 2

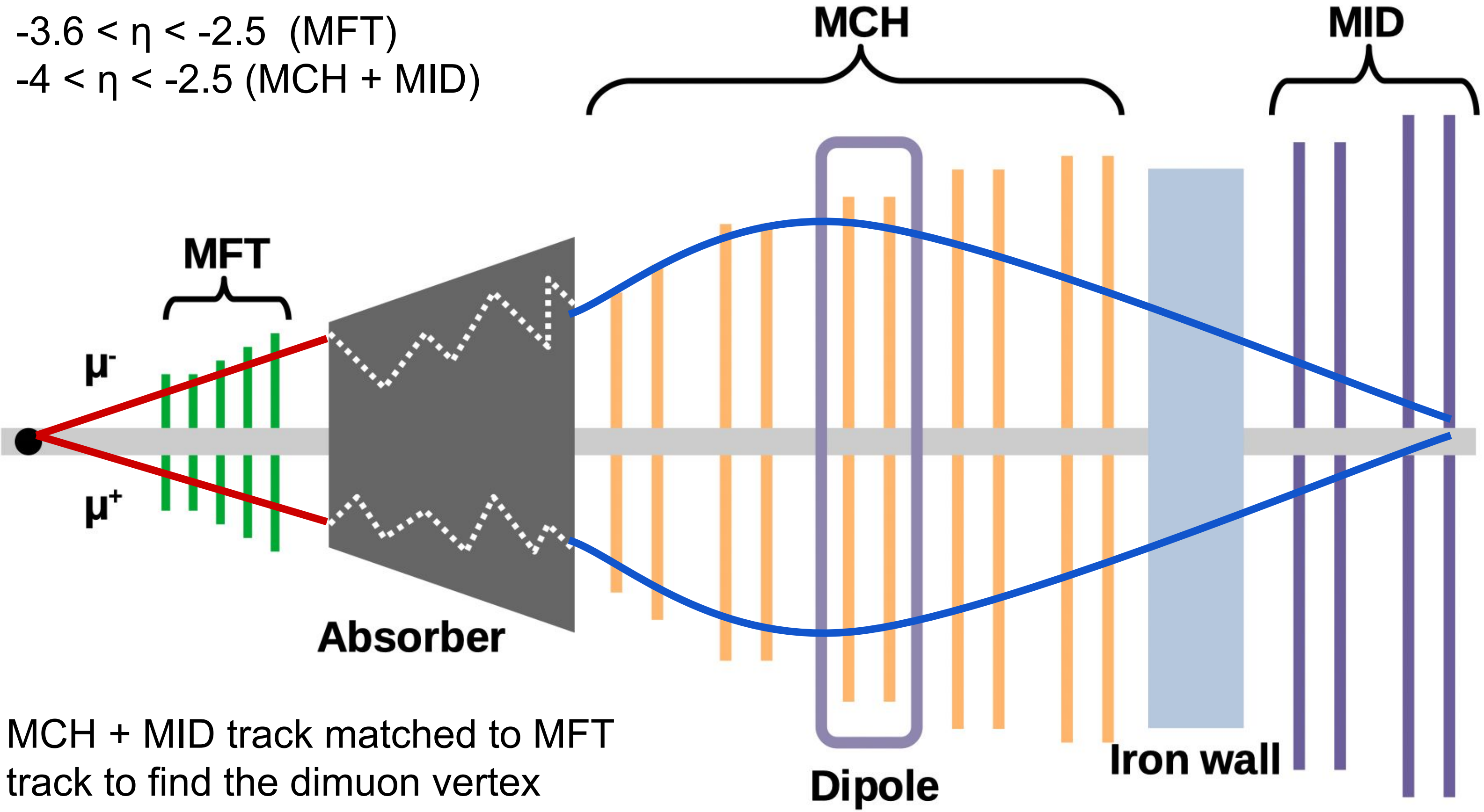
$-4 < \eta < -2.5$ (MCH + MID)



MCH + MID track extrapolated to primary vertex

Muon tracking during Run 3

-3.6 < η < -2.5 (MFT)
-4 < η < -2.5 (MCH + MID)



MCH + MID track matched to MFT track to find the dimuon vertex

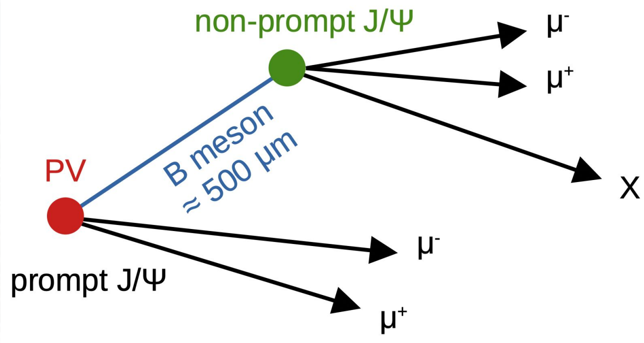
3. Prompt/non-prompt J/Ψ separation using the pseudo-proper decay time

Prompt and non-prompt contributions

- Two main contributions for J/Ψ
  - Prompt
    - produced at primary vertex or coming from charm excited state
    - made it through QGP, probe charm sector
  - Non-prompt
    - decay from hadron b
    - probe beauty sector

- Prompt/non-prompt separation : specific infos about charm and beauty productions
- Improvement of the theoretical models

Prompt and non-prompt J/Ψ separation done using secondary vertexing provided by MFT

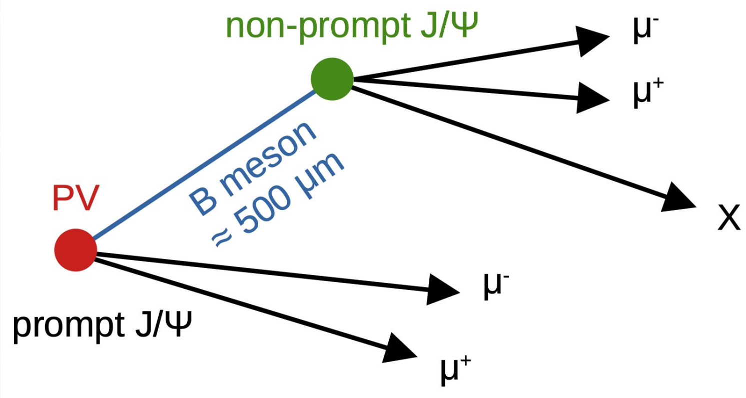


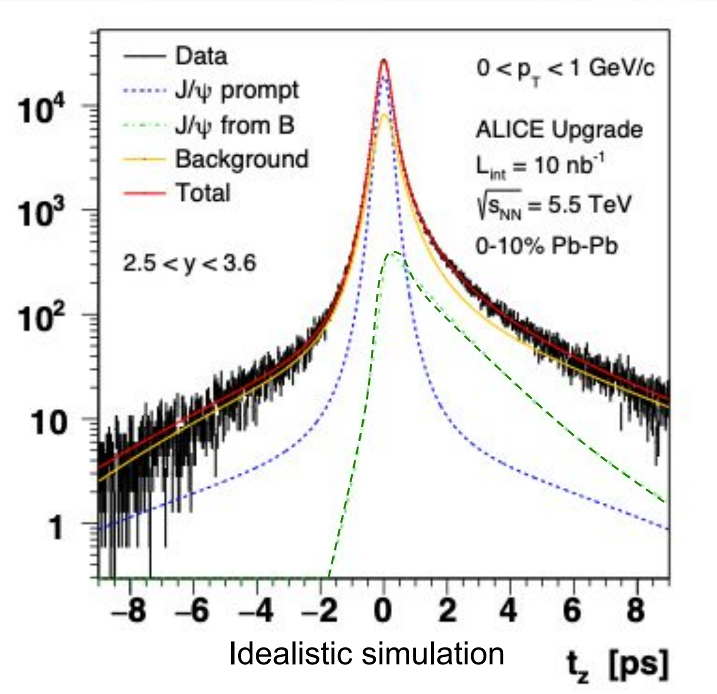
Study of the pseudo-proper decay time τ_z

- Pseudo proper decay time
  - $\tau_z = 0$ if prompt
  - $\tau_z > 0$ if non-prompt

- 2 algorithms for vertexing
  - one made by Rita Sadek

$$l_{J/\Psi} = c.\tau_z = c.\frac{(z_{J/\psi} - z_{vtx}).M_{J/\Psi}}{p_z}$$



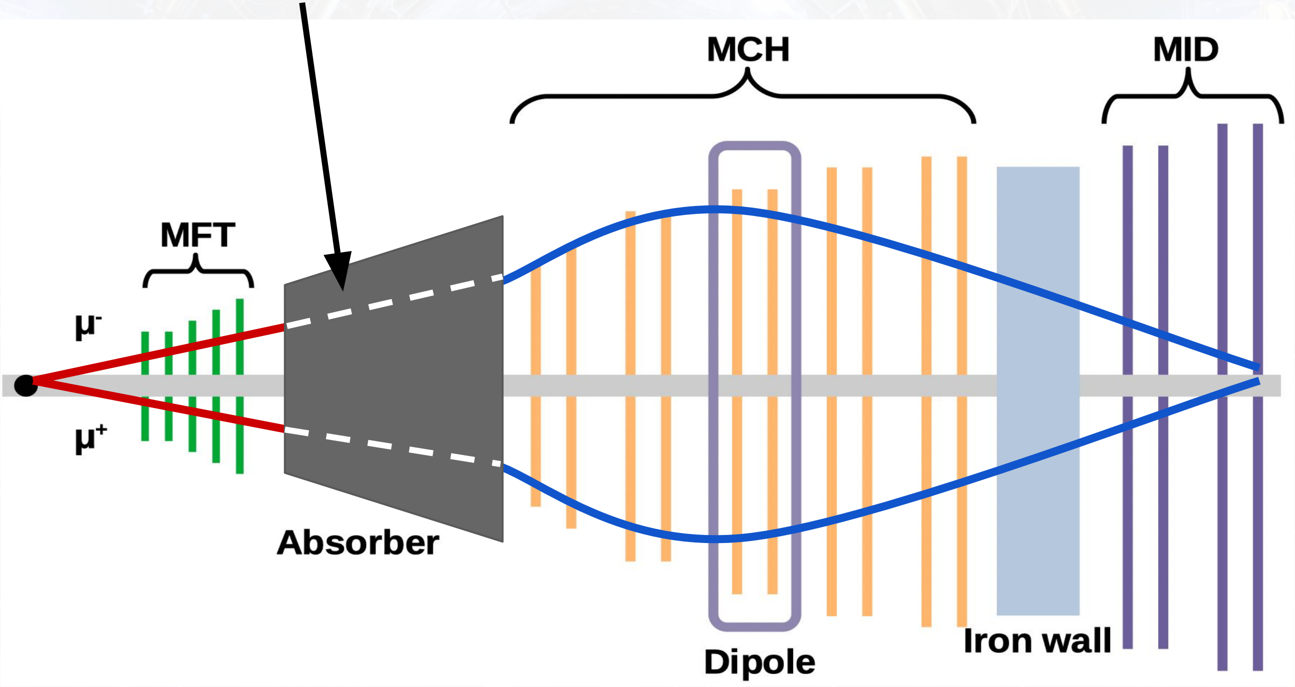


CERN-LHCC-2015-001 ; ALICE-TDR-018

4. Results

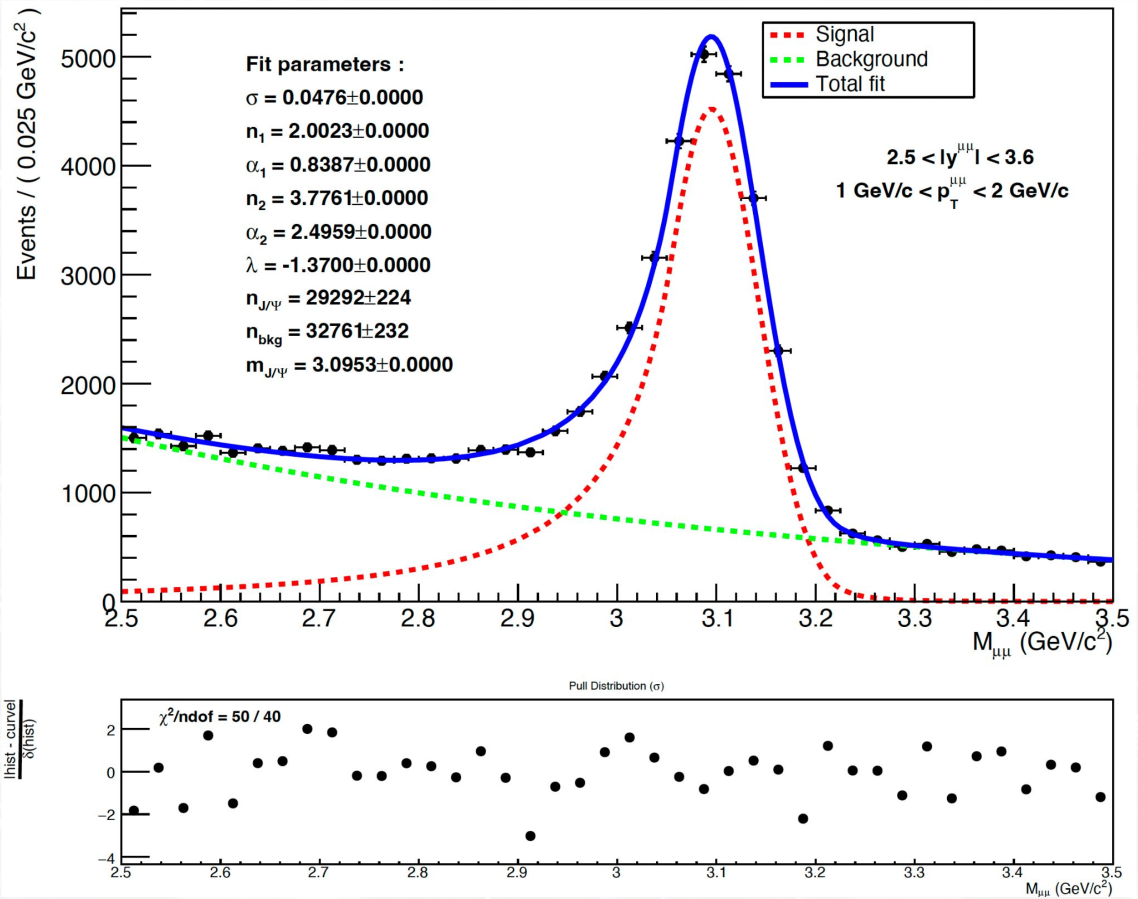
Step 0 : Study of the MFT-MCH matching

- Crucial step for the analysis
- Optimization of the MFT-MCH matching using the X^2
- Work done following the procedure made by Nicolas Bizé



Step 1 : signal/background separation

- Using the invariant mass fit
- Double Crystal Ball + exponential functions
- parameters are fixed after a free iteration (except $N_{J/\Psi}$, N_{bkg})



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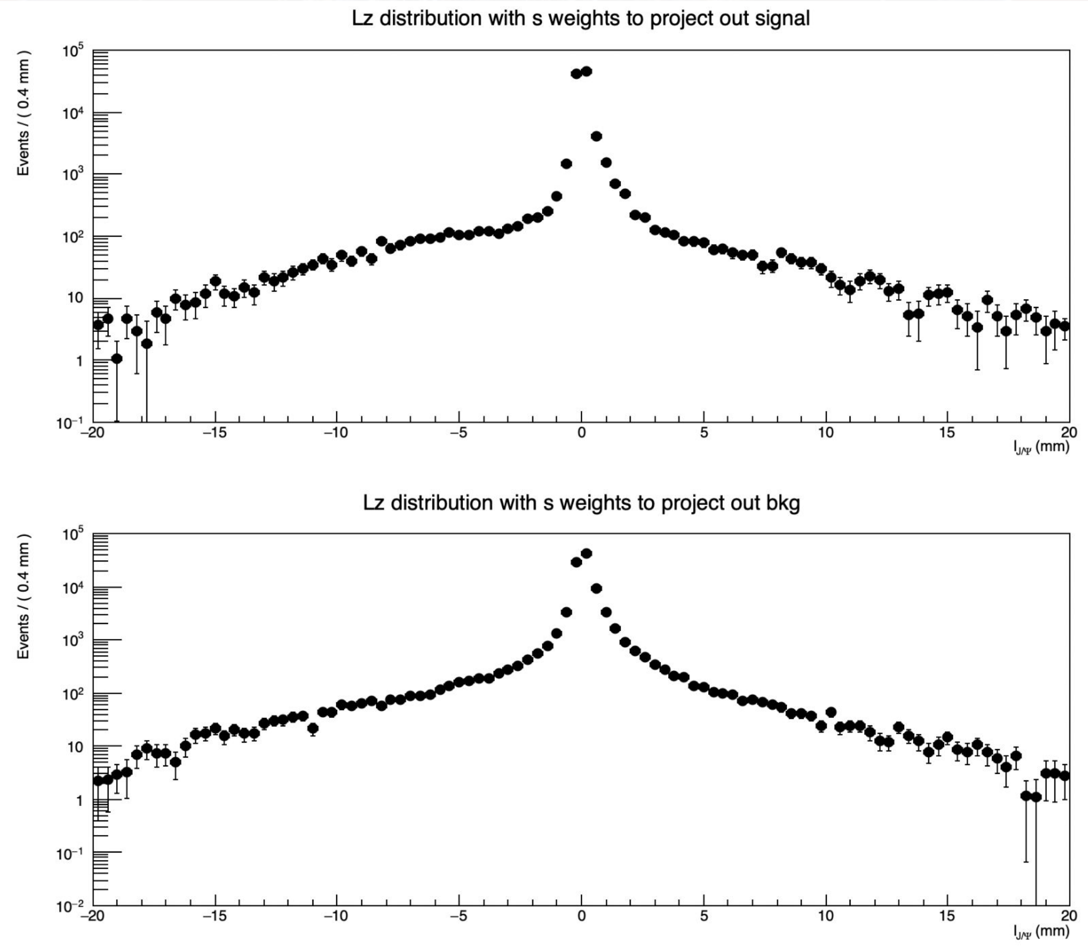
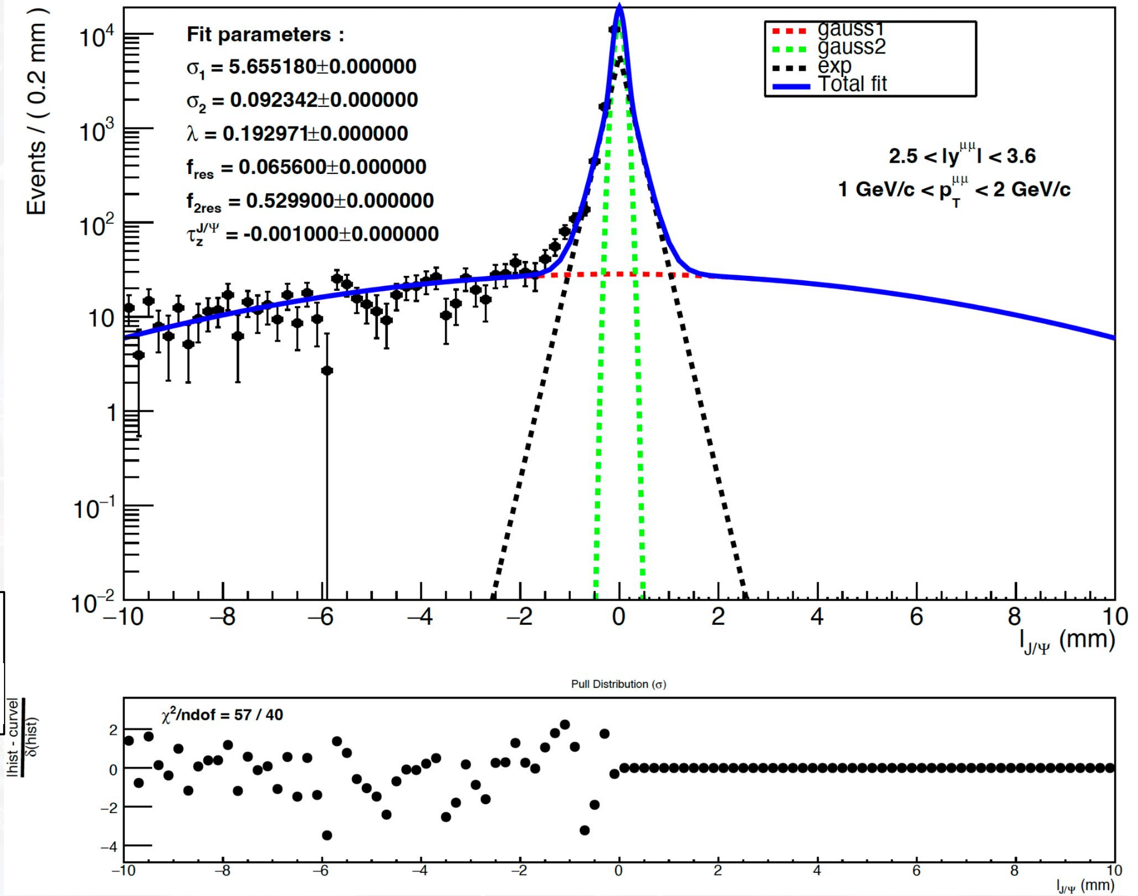
Step 1: results



Step 2 : prompt J/Ψ signal fit

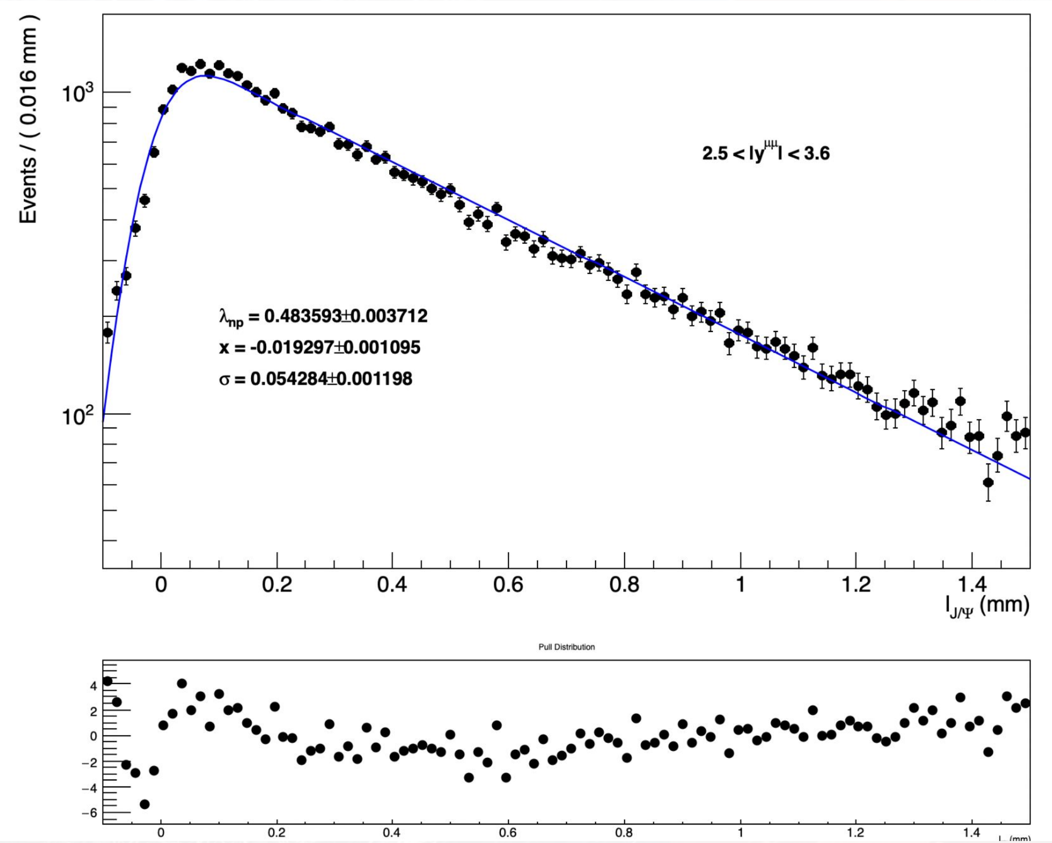
- Fitting only left side to get rid of the non-prompt contribution
- Access to the resolution
- Parameters are fixed just as the previous fit
- Done for every p_T ranges

$$F_{prompt}(l_z) = [f_{res} \cdot Gauss(l_z, \sigma_1, l_0) + (1 - f_{res}) \cdot [f2_{res} \cdot Gauss(l_z, \sigma_2, l_0) + (1 - f2_{res} \cdot exp(-\lambda|l_z - l_0|))]]$$



Step 3 : non-prompt signal initialization using MC

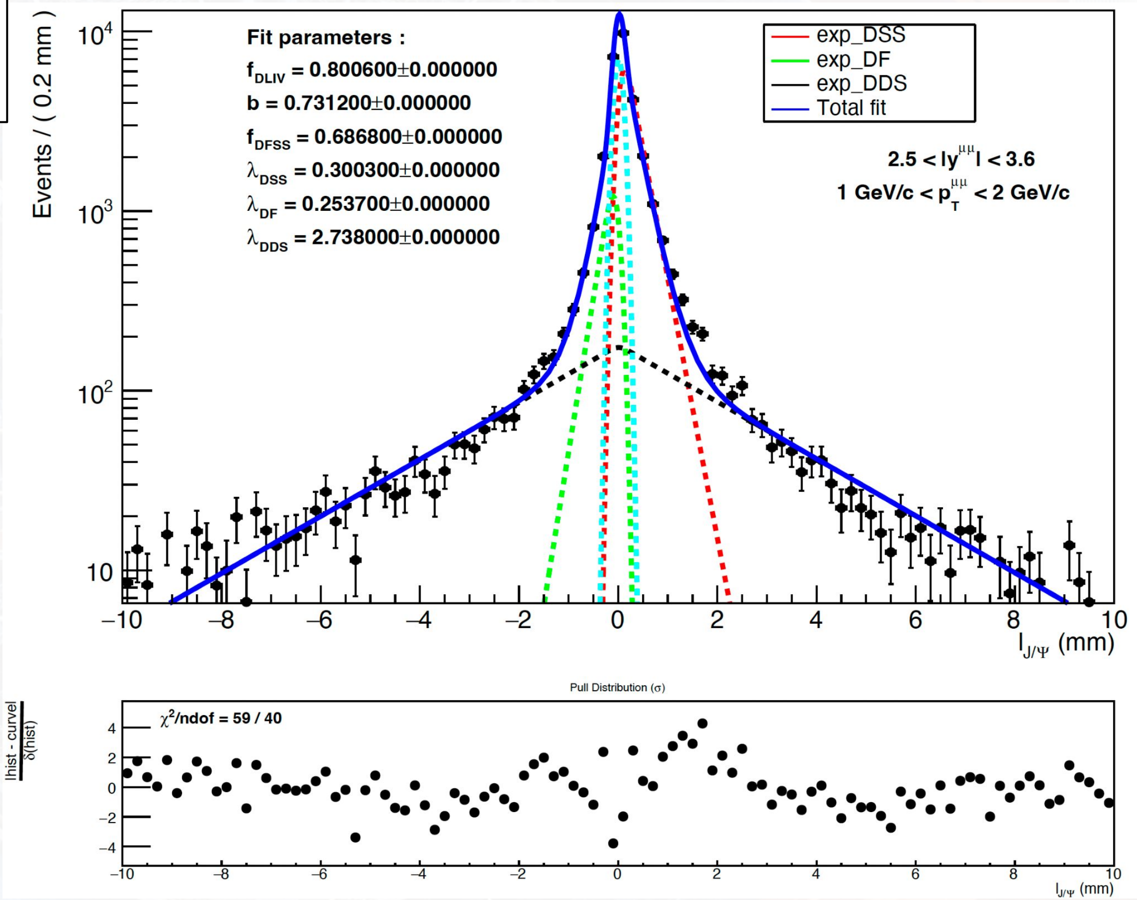
- Using a full non-prompt Monte Carlo dataset
- To initialize the slope of the exponential function
- $\exp(-l_{J/\psi}/\lambda_{np})$ with $\lambda_{np} \approx 500$ µm
- λ_{np} parameter constrained but not fixed



Step 4 : J/Ψ background fit

$$F_{bkg}(l_z) = b \cdot [f_{DLIV} \cdot (e^{-|\lambda_{DSS}|l_z} + (1 - f_{DFSS}) \cdot e^{|\lambda_{DF}|l_z}) + (1 - f_{DLIV}) \cdot e^{-|\lambda_{DDS} \cdot l_z|}] + (1 - b) \cdot \delta(l_z)$$

- DSS : Single Sided exp
- DF : Flipped exp
- DDS : Double Sided exp
- Parameters are fixed
- Complicated fit
  - difficulties to converge
  - more stat would help for the tail part



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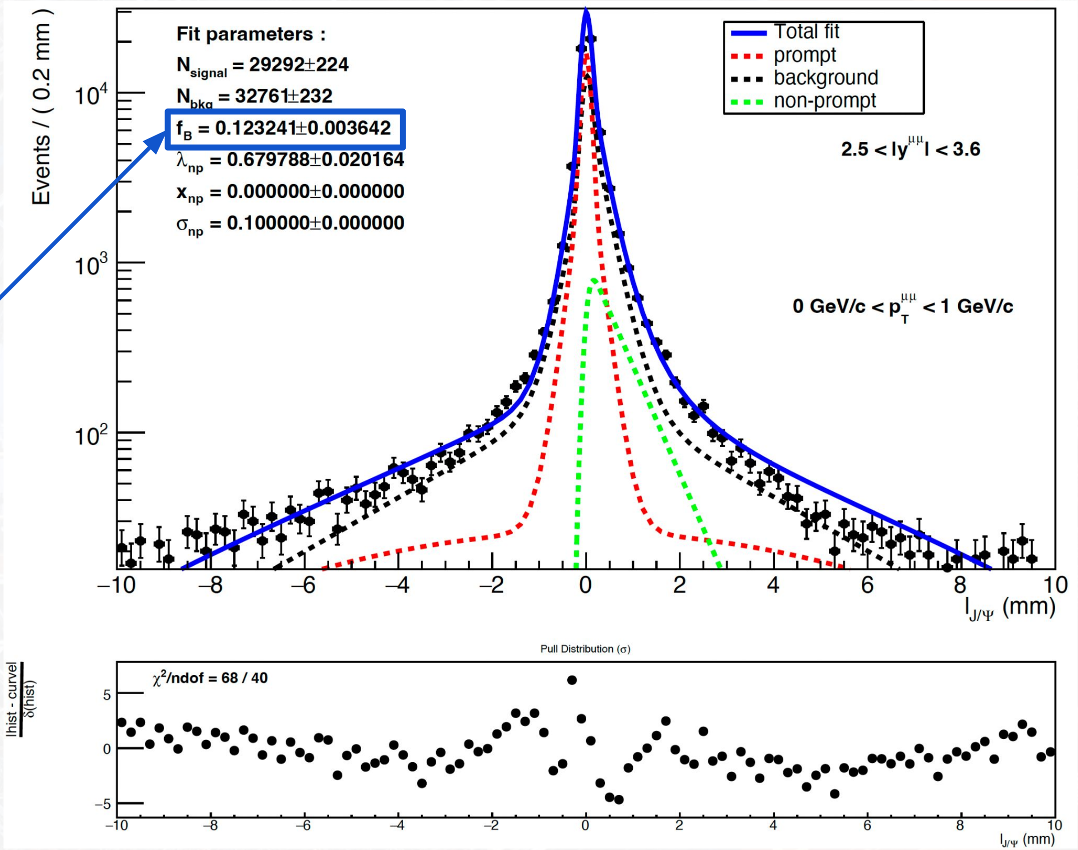
Step 5 : 2D fit projection

$$f'_B = \frac{N_{J/\Psi \leftarrow h_B}}{N_{J/\Psi \leftarrow h_B} + N_{J/\Psi}}$$

- Non-prompt prompt fraction f'_B
- Study done for each p_T bin
- Promising results but background fit could be improved



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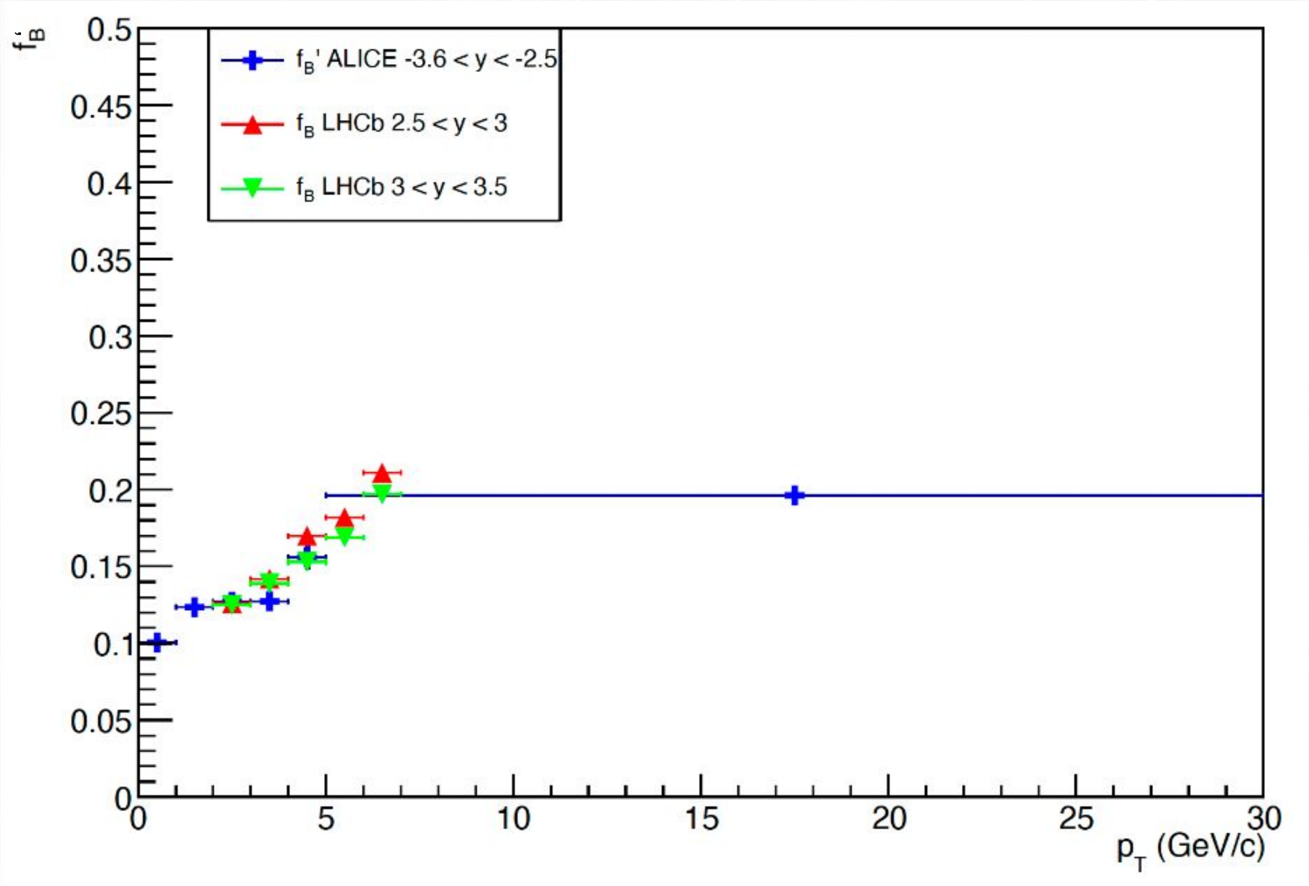
Non-prompt fraction



LHCb-PAPER-2015-037, CERN-PH-EP-2015-222, arXiv:1509.00771

Acceptance-efficiency correction using Monte Carlo

- Acceptance
  - geometric correction
  - linked to the detector

$$\langle A \cdot \varepsilon \rangle = \frac{N_{rec}}{N_{gen}}$$

- Efficiency
  - technical correction
  - linked to material, trigger, analysis etc.

- Waiting for the associated MC dataset anchored on 2023 data
- In progress

$$f_B = \left(1 + \frac{1 - f'_B}{f'_B} \frac{\langle A \cdot \varepsilon \rangle_{non-prompt}}{\langle A \cdot \varepsilon \rangle_{prompt}}\right)^{-1}$$

Systematics uncertainties

There is a lot and it is complicated so have a cupcake first

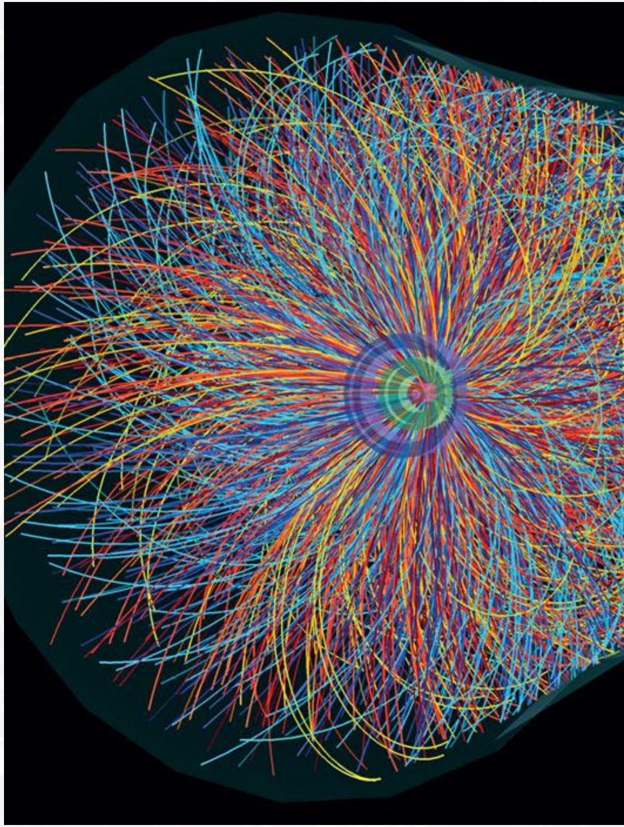
Systematics uncertainties

- Range and function of fits:
  - invariant mass fit functions
  - l_z background model, template, side bands
  - MC template for non-prompt
  - PDF resolution
  - mass pole (mean fit value and PDG value) for l_z calculation
- Signal/background separation method
- Acceptance-efficiency
- Vertexing and matching:
  - variation of matching $\chi2$ selection
  - MFT-Muon matching purity and efficiency from MC
  - MFT-MCH tracking
  - vertexing algorithm (DCAFitter or KFVertexing)
- Impact of ambiguous tracks

5. Conclusion

Conclusion

- J/Ψ is a QGP probe for charm (prompt) and beauty (non-prompt) quarks
- MFT and muon spectrometer allows us to track the dimuon starting from the J/Ψ vertex
- Both J/Ψ contribution can be separated using the pseudo-proper decay time/length
- Some corrections need to be applied (A.ε, systematics…)



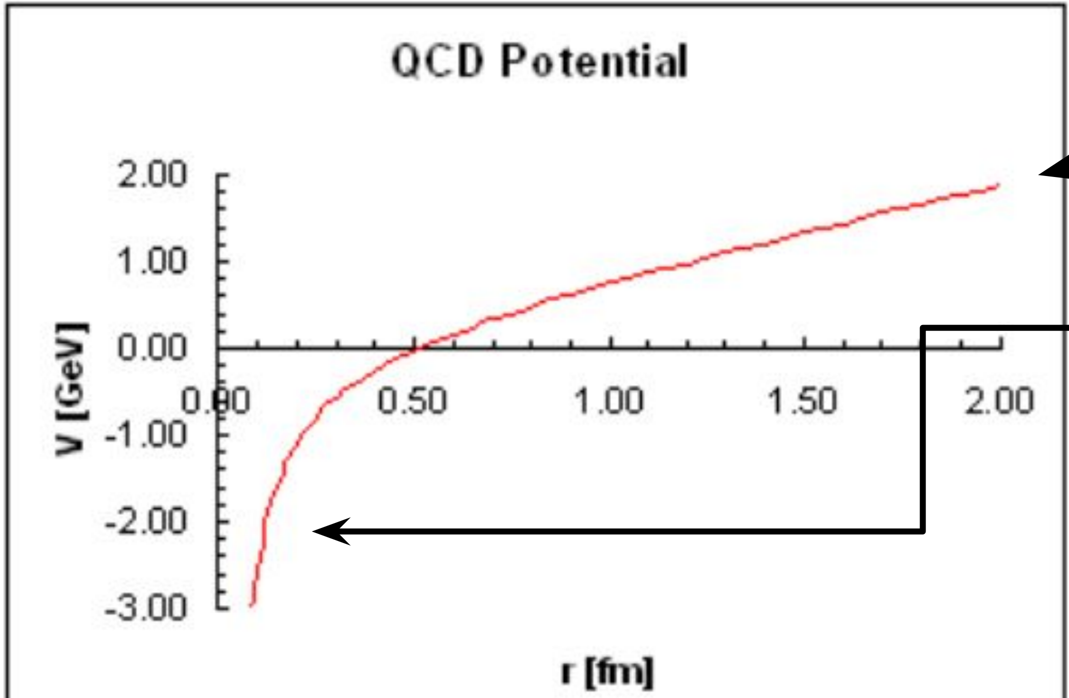
- Talks at QGP France and ALICE meetings
- Poster at Strangeness in Quark Matter 2024
- *Poster for Quark Matter 2025 (ongoing)*

Thank you for your attention !

(just clap and pretend you were not sleeping the whole time)

Backup

QCD prediction



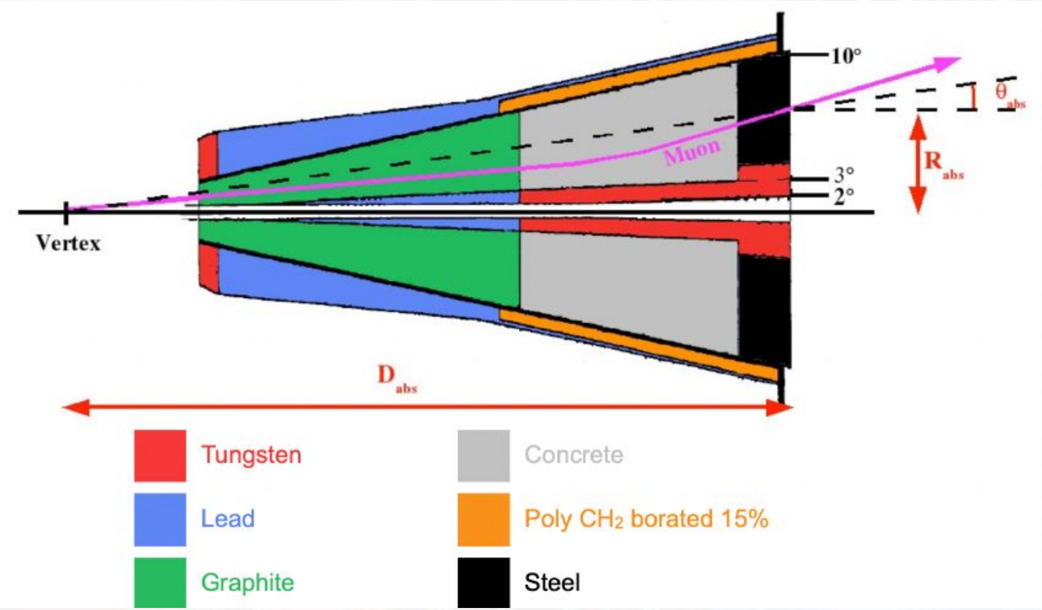
Potentiel QCD

- **Positive potential** : r >>1
  - tight spring
  - strong bond energy
  - confinement des quarks
- **Negative potentiel** : r <<1
  - slack spring
  - weak bond energy
- If T or p ↗, potential reaches a constant value
- Possible deconfinement

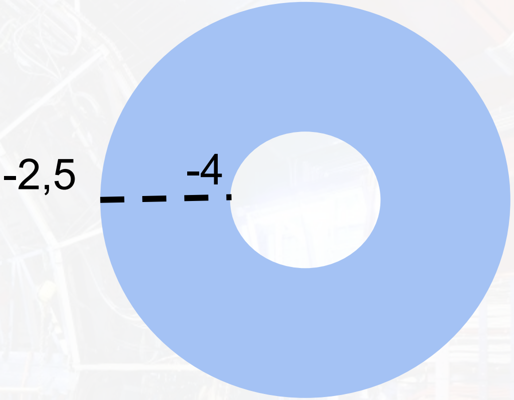
Cold Nuclear Matter effects

- Nuclear absorption = dissociation of the c-/c pair with a nucleus
- Inelastic interactions
- Coherent energy lost = quarkonium suppression in p-A interaction
- Cronin effect = interaction g-N donne impulsion transverse aux particules
  - enlargement of the pT distribution
  - increase with centrality
- Shadowing = screening of central nuclei by peripheral ones
  - A-A collision ≠ sum of p-p collisions

Specific parameters

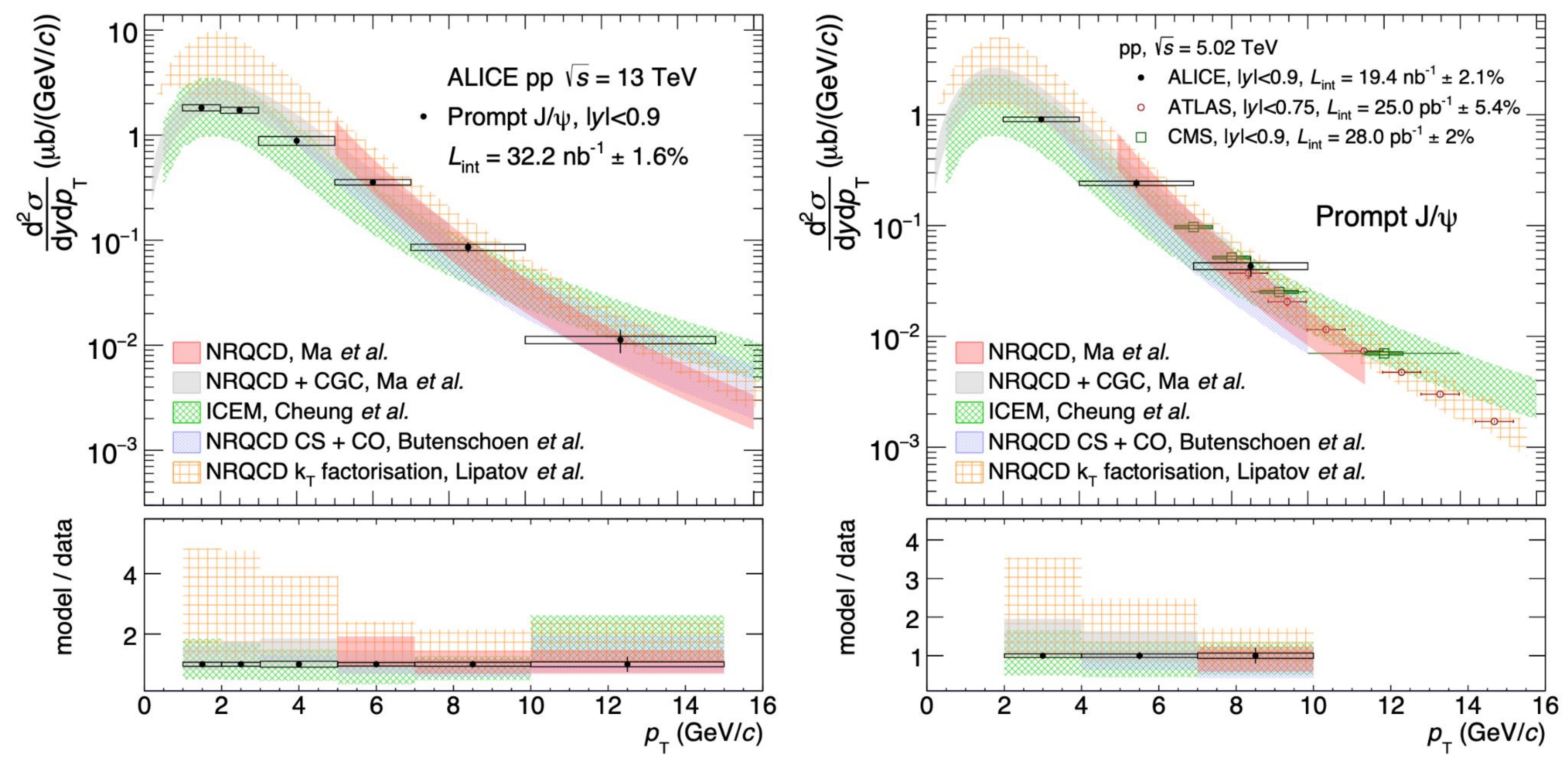


Transverse radius R_{abs}



Pseudorapidity η

Charm and beauty production models



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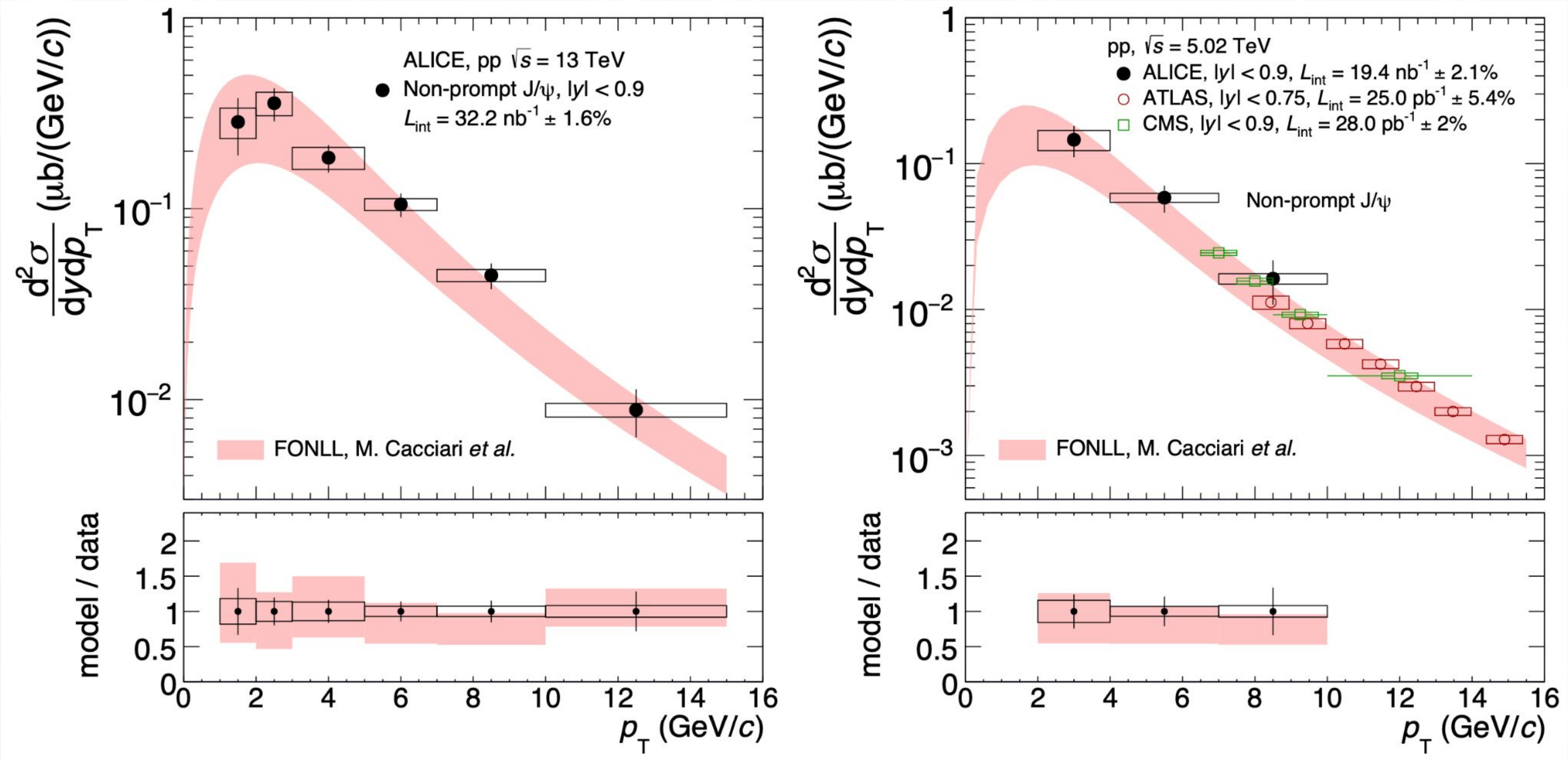
https://arxiv.org/abs/2108.02523

Charm and beauty production models



Expected shapes for 2D fit projection

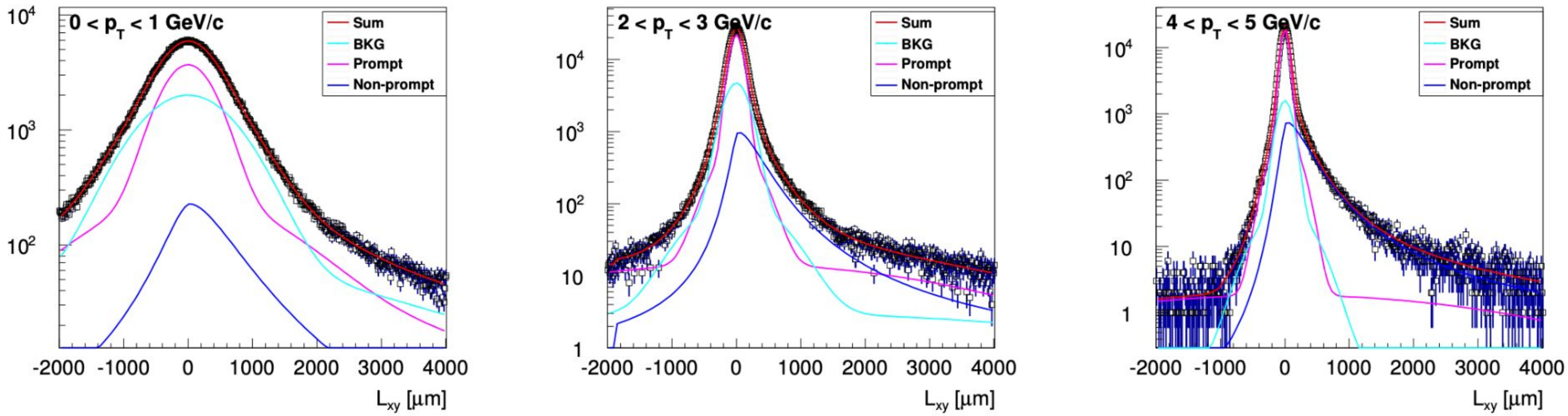


Figure 2.17: *Fit of the global pseudo-proper decay-length distributions, for 0-10 % Pb-Pb collisions at* $\sqrt{s_{NN}} = 5.5$ *TeV, with the superposition of the three expected contributions for three different* p_T *bins.*

Methods for τ_z determination

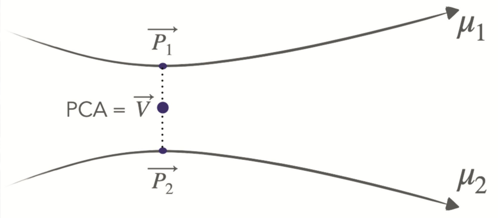
2 ways to get the secondary vertex

KFVertexing

- using Kalman filter method
- try to find the optimum estimation of an unknown vector (vertex) according to known measurements (tracks parameters)
    - first approximation of the vector, then filtering by using known parameters
    - repeat the process until reach the optimum estimation

DCAFitter

- described in R.Sadek thesis
- secondary vertex determined by finding the crossing point between the 2 muons :
    - Point of Closest Approach (PCA)
- PCA determined using χ^2 minimization



Goal : to compare both methods in τ_z determination

χ^2_{MCHMFT} optimization for 2023 data

- Study performed on integrated and differential p_T
- Method similar to the one performed on 2022 data by Nicolas Bizé
- Cut around 40 for integrated p_T
- See PAG meeting for more