JRJC 2023 22-28 OCTOBRE
Journées de Rencontre des Jeunes Chercheurs

J/Ψ FLOW MEASUREMENTS IN PB-PB COLLISIONS WITH THE ALICE DETECTOR AT LHC RUN 3

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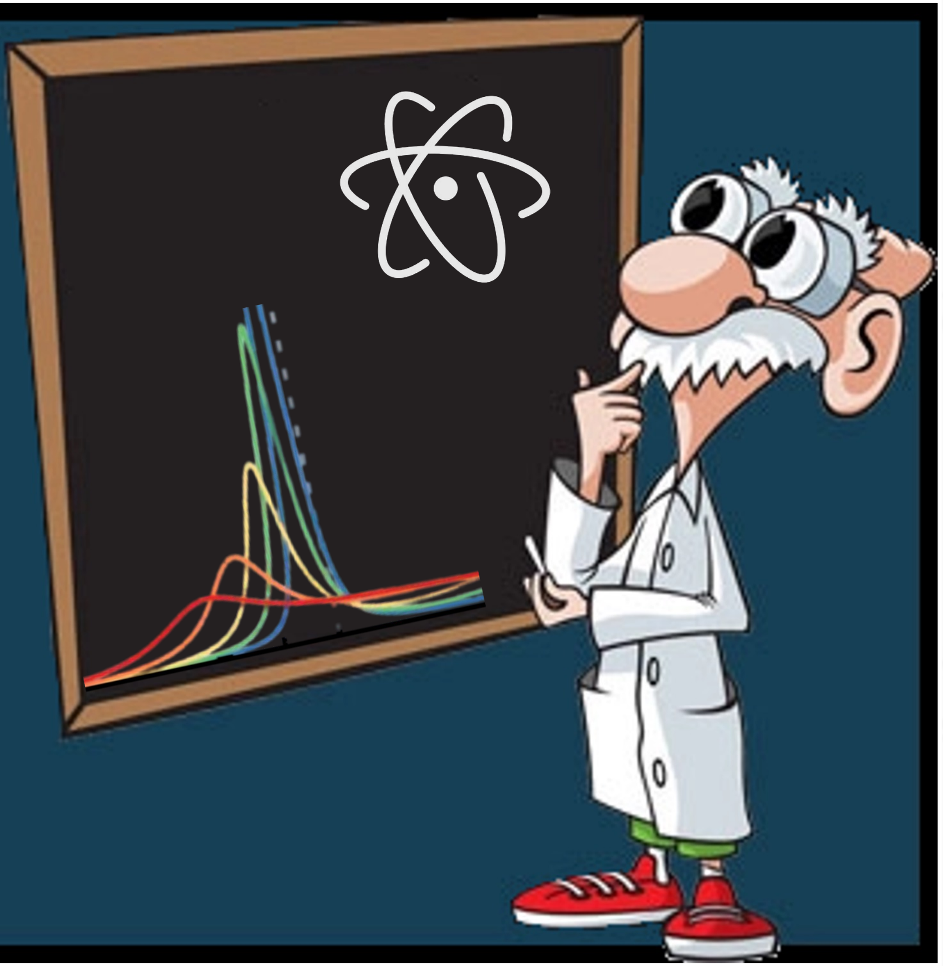
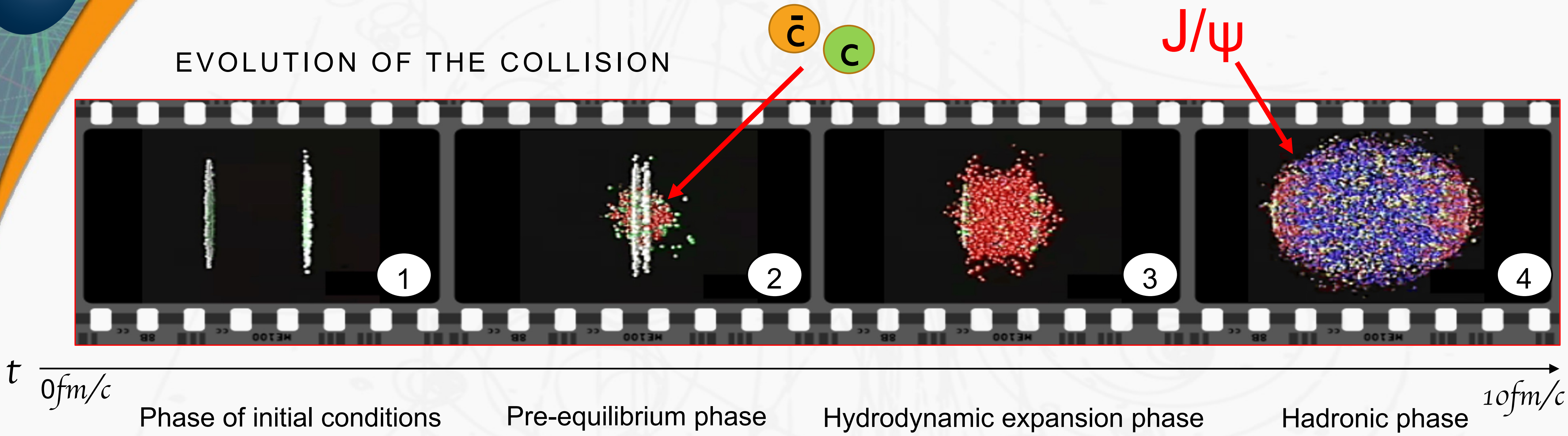


THEORETICAL CONTEXT

EVOLUTION OF THE COLLISION



QGP PROBES

- Photons, Drell-Yan dileptons, Z and W bosons.
- Jets, high PT particles et Quarkonia (Charmonium et Botonium)

THEORETICAL CONTEXT

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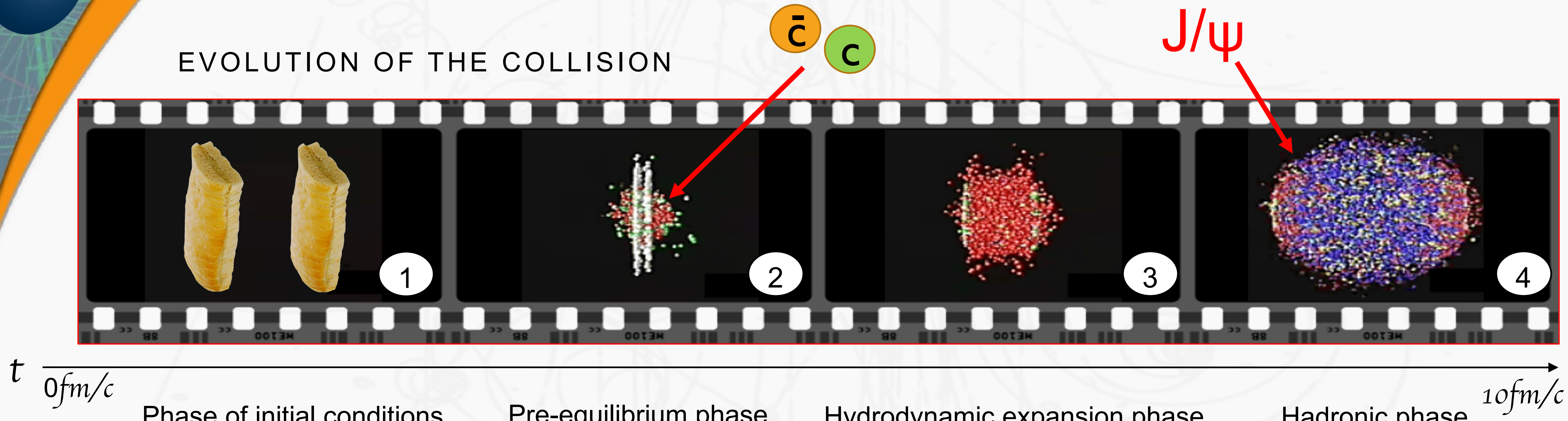

QGP PROBES

- Photons, Drell-Yan dileptons, Z and W bosons.
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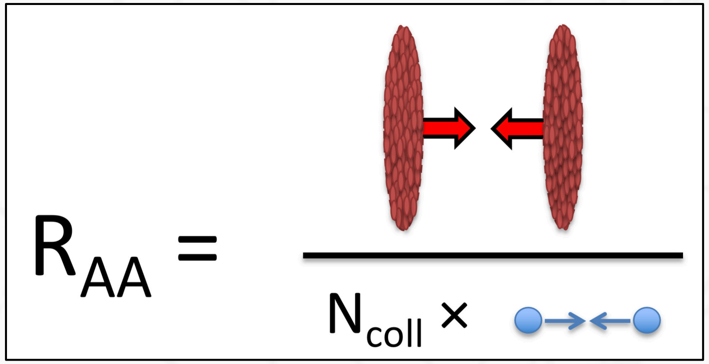
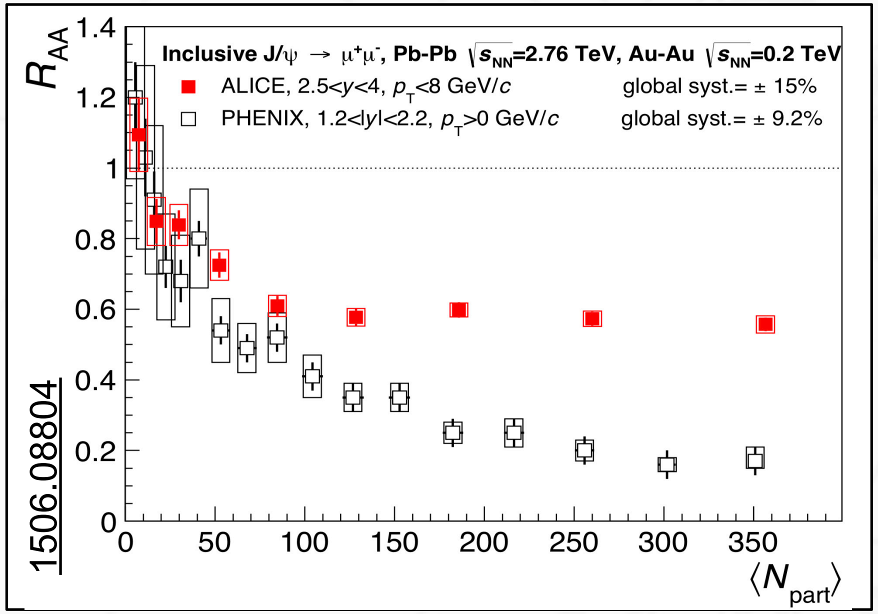
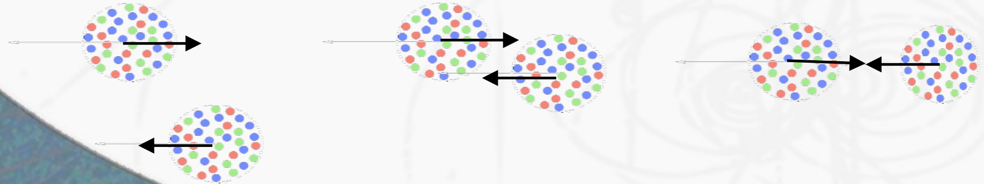
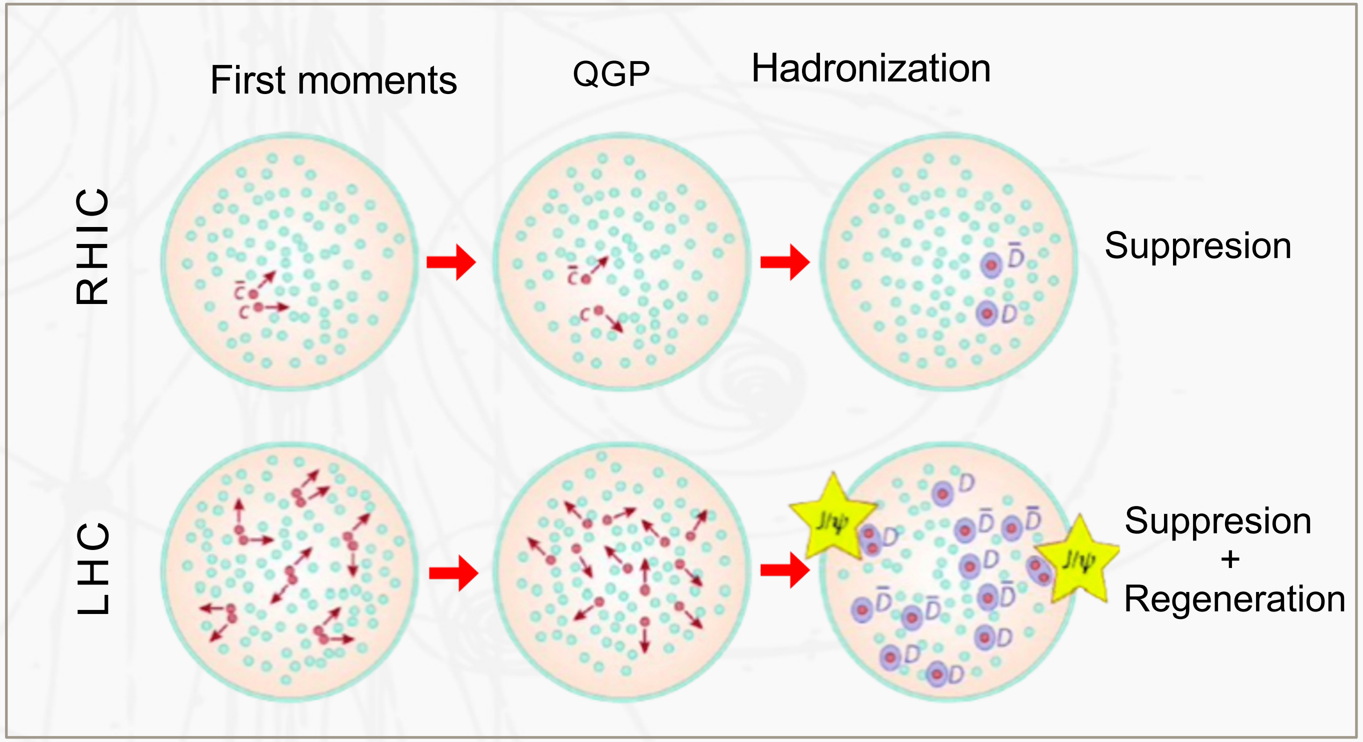
J/Ψ SUPPRESSION AND REGENERATION



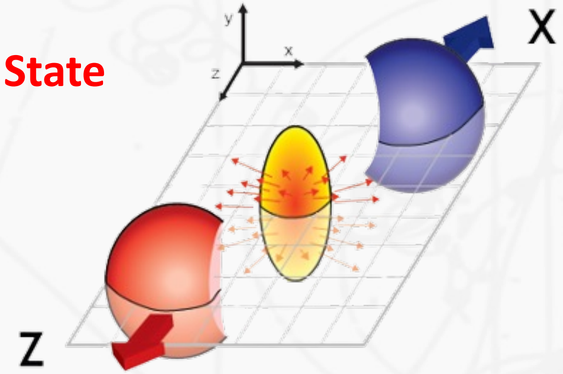






QUARK GLUON PLASMA: ALMOST A PERFECT FLUID

Initial State



$$\varepsilon(x, y, \eta^{s})$$

Coordinate space Eccentricity

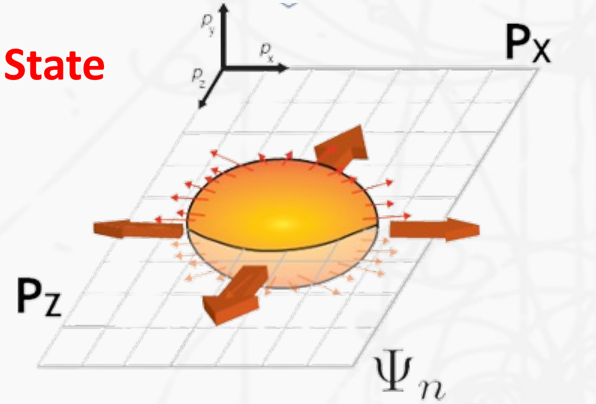
Hydrodynamics

$\delta_{\mu} T^{\mu\upsilon} = 0 + (\eta, \zeta, \ldots)$

QGP = Low viscosity fluid

System Expansion

Final State



$$f(p_T, \eta, \phi)$$

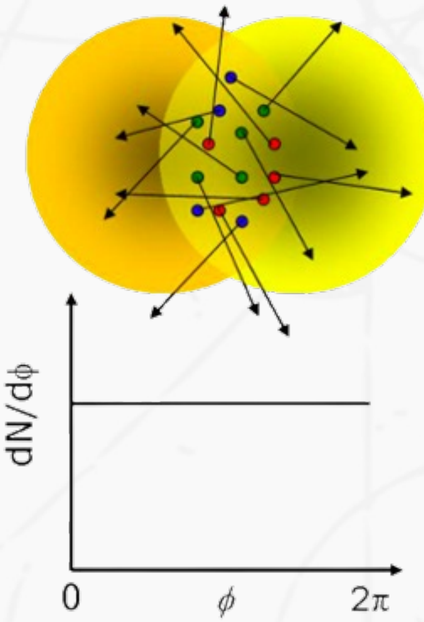
Momentum space Flow

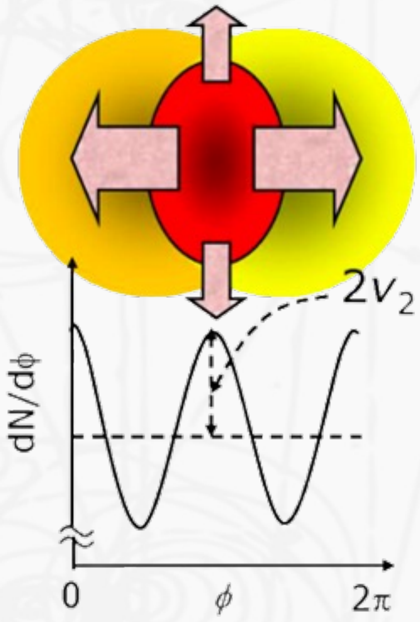
Fourier series: $f(p_T, \eta, \phi) = N(p_T, \eta) \sum_{n=-\infty}^{\infty} v_n e^{in(\psi_n - \phi)}$

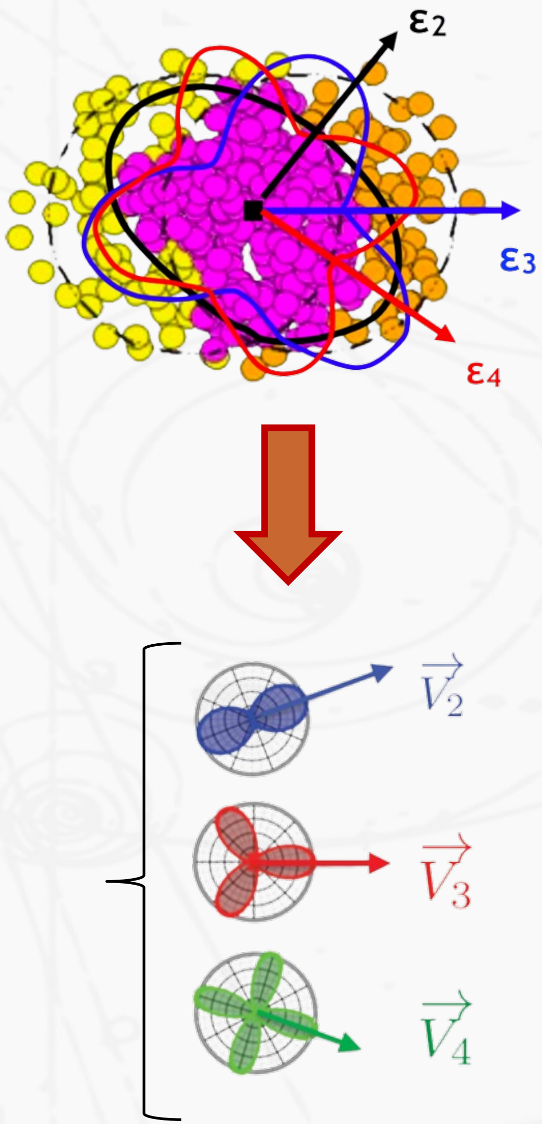
ANISOTROPY OF PARTICLE MOMENTUM DISTRIBUTION

$$\frac{dN}{d\phi} = \frac{1}{2\pi}\left[1 + \sum_{n=1}^{\infty} 2v_n \cos[n(\phi - \Psi_n)]\right]$$

$$v_n = \langle \cos[n(\phi - \Psi_n)] \rangle$$

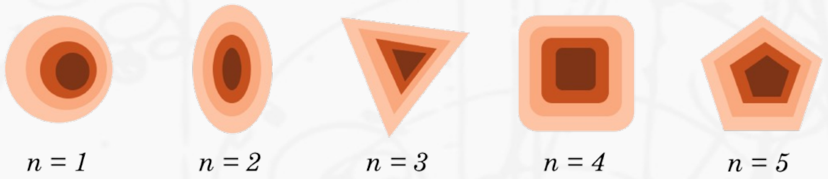






J/Ψ FLOW ANALYSIS

FLOW



$v_n = \langle \cos n(\varphi - \Psi_n) \rangle$ ⟷ Ψ_n is hardly known in experiment

2-PARTICLE AZIMUTHAL CORRELATION:

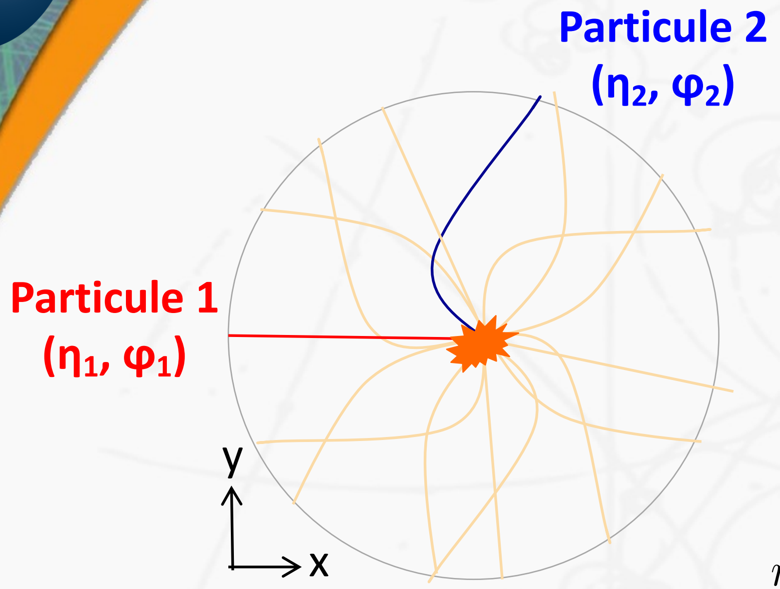
$c_n\{2\} = \langle\langle \frac{e^{in\varphi_1}}{(A \times \epsilon)_1} \cdot \frac{\bar{e}^{in\varphi_2}}{(A \times \epsilon)_2} \rangle\rangle$ ⟷ Experimentally we need to take in to account the $(A \times \epsilon)$ of the detector.

$\langle\langle\, e^{in(\varphi_1 - \varphi_2)} \rangle\rangle \propto \langle\langle \cos n(\varphi_1 - \varphi_2) \rangle\rangle = \langle v_n^2 \rangle$ ⟷ RMS value of v_N without knowing Ψ_n

IN EXPERIMENT: $\langle\langle \cos n(\varphi_1 - \varphi_2) \rangle\rangle = \langle v_n^2 + \delta_2 \rangle$ ⟷ ⚠ Nonflow (resonance decay, jets…)

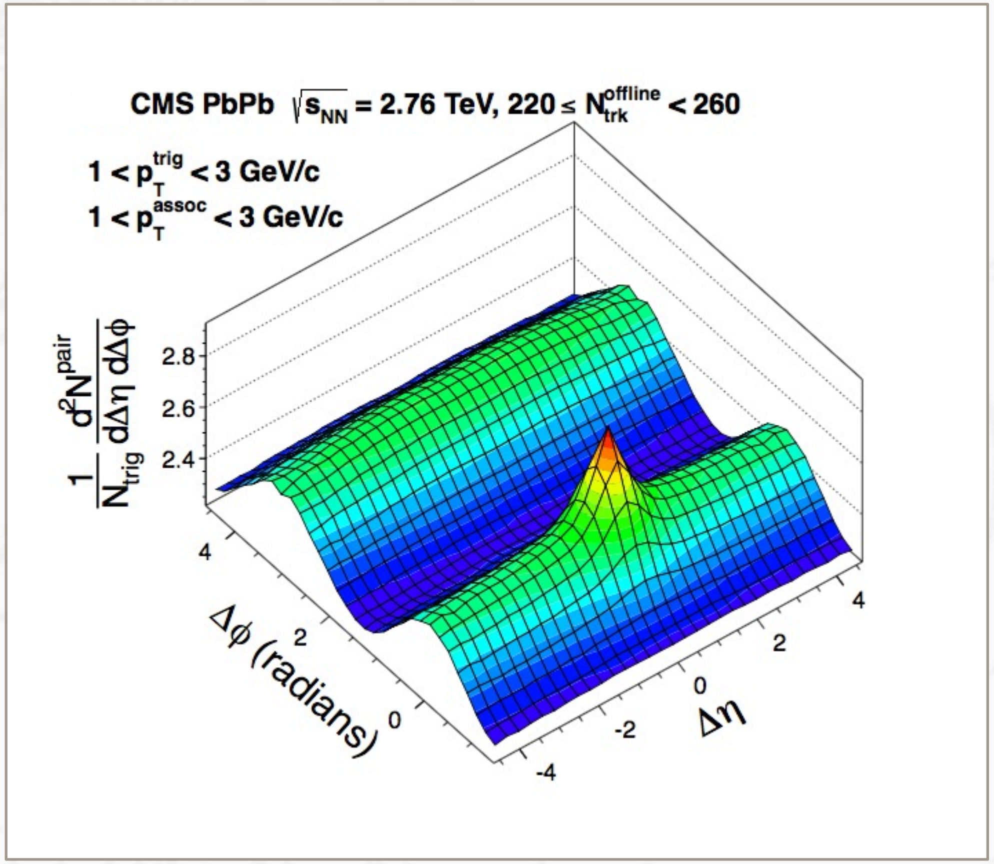
$\delta_2 \sim 1/M$

2-PARTICLE CORRELATION

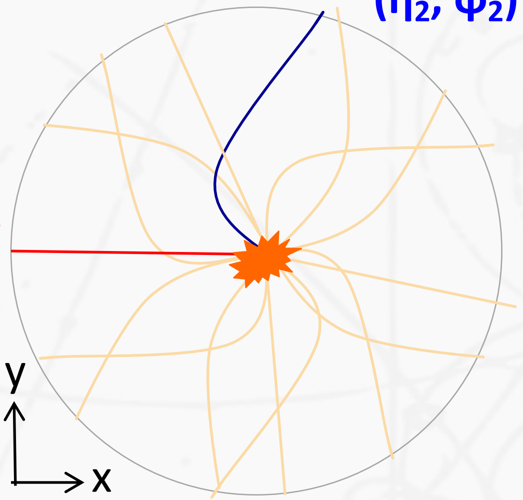


$$\boxed{\begin{array}{c}\Delta\eta = \eta_1 - \eta_2 \\ \Delta\varphi = \varphi_1 - \varphi_2\end{array}}$$

$$\eta = -ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$



2-PARTICLE CORRELATION



Particule 2
(η_2, φ_2)

Particule 1
(η_1, φ_1)

$$\boxed{\begin{array}{c}\Delta\eta = \eta_1 - \eta_2 \\ \Delta\varphi = \varphi_1 - \varphi_2\end{array}}$$

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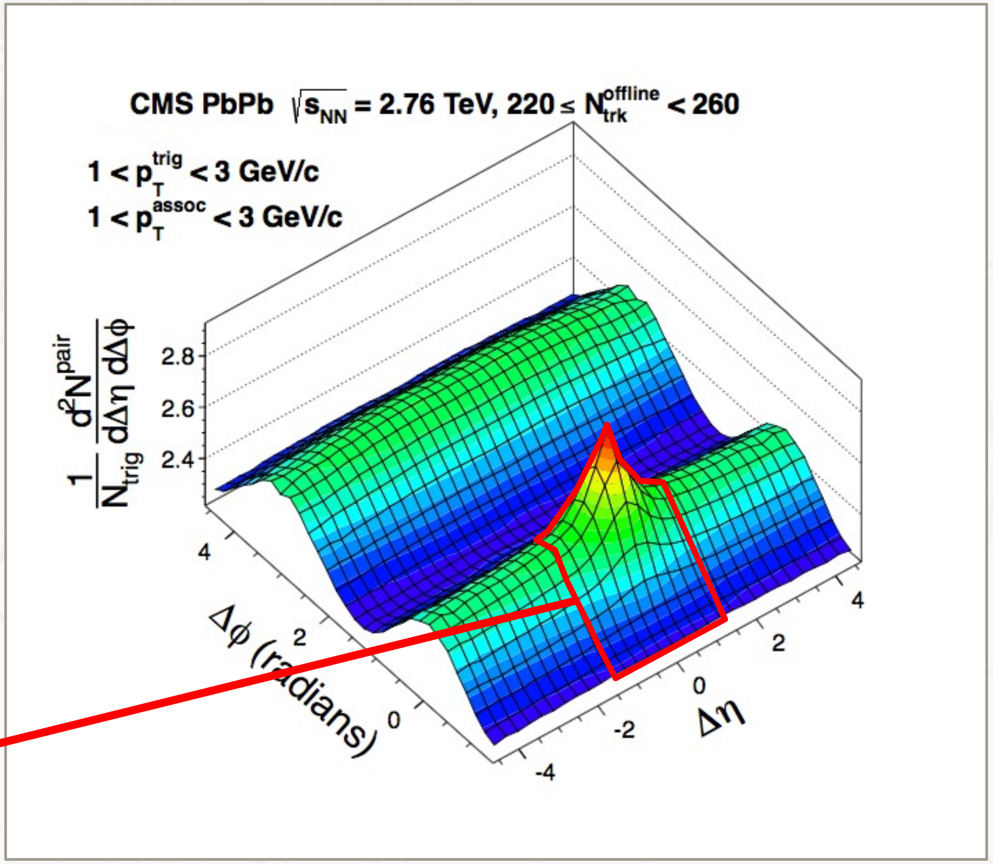
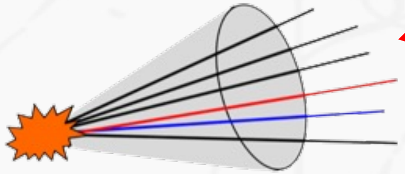
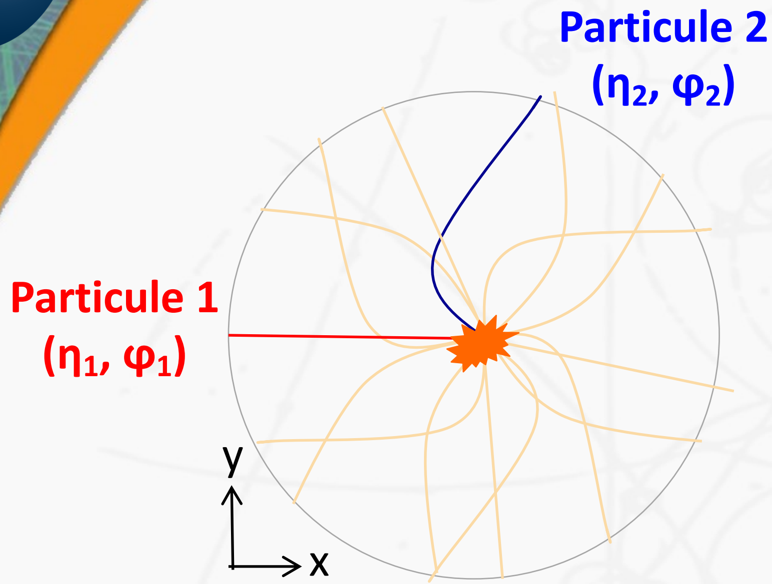




Simple Jet

2-PARTICLE CORRELATION



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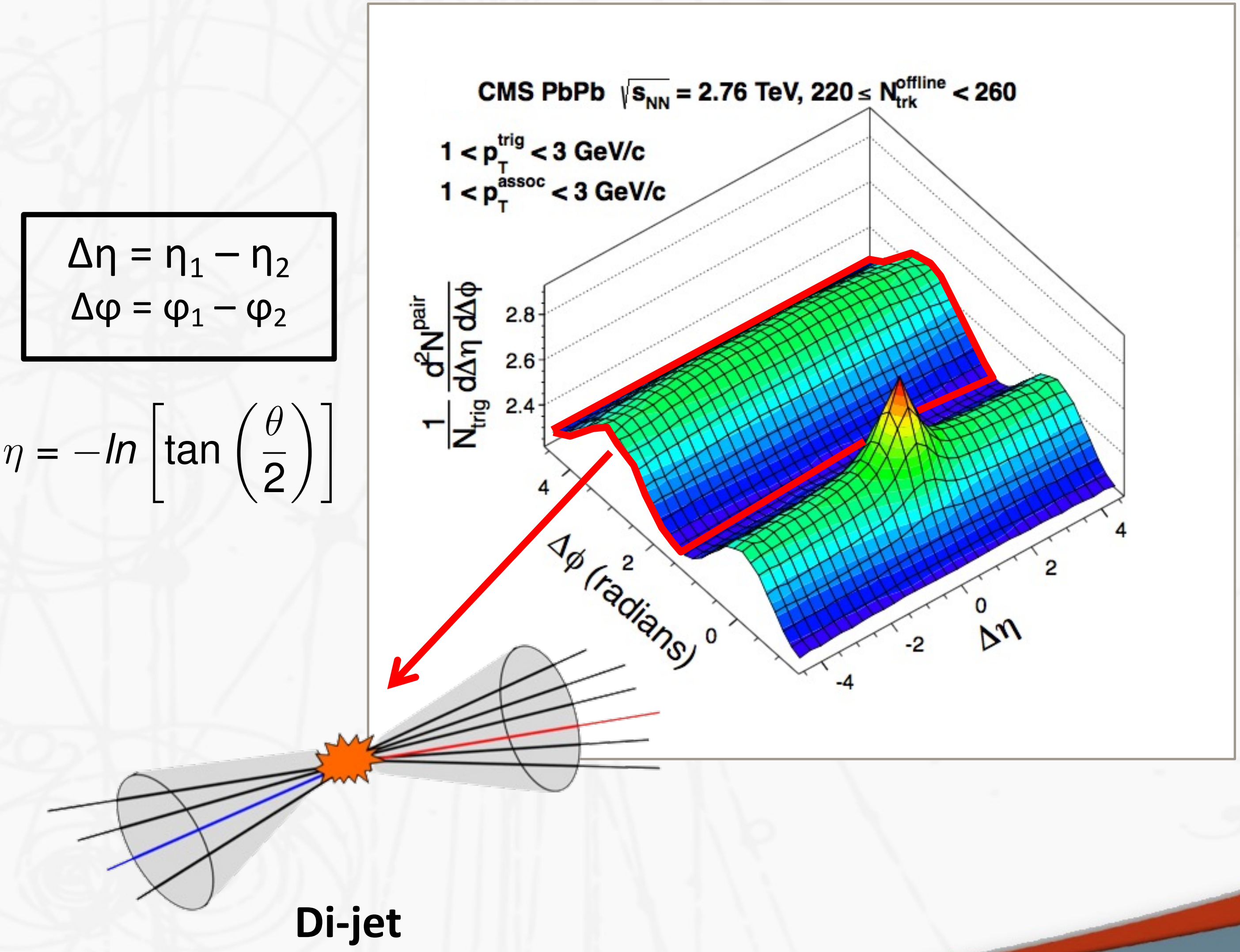
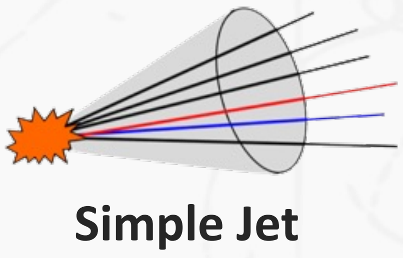
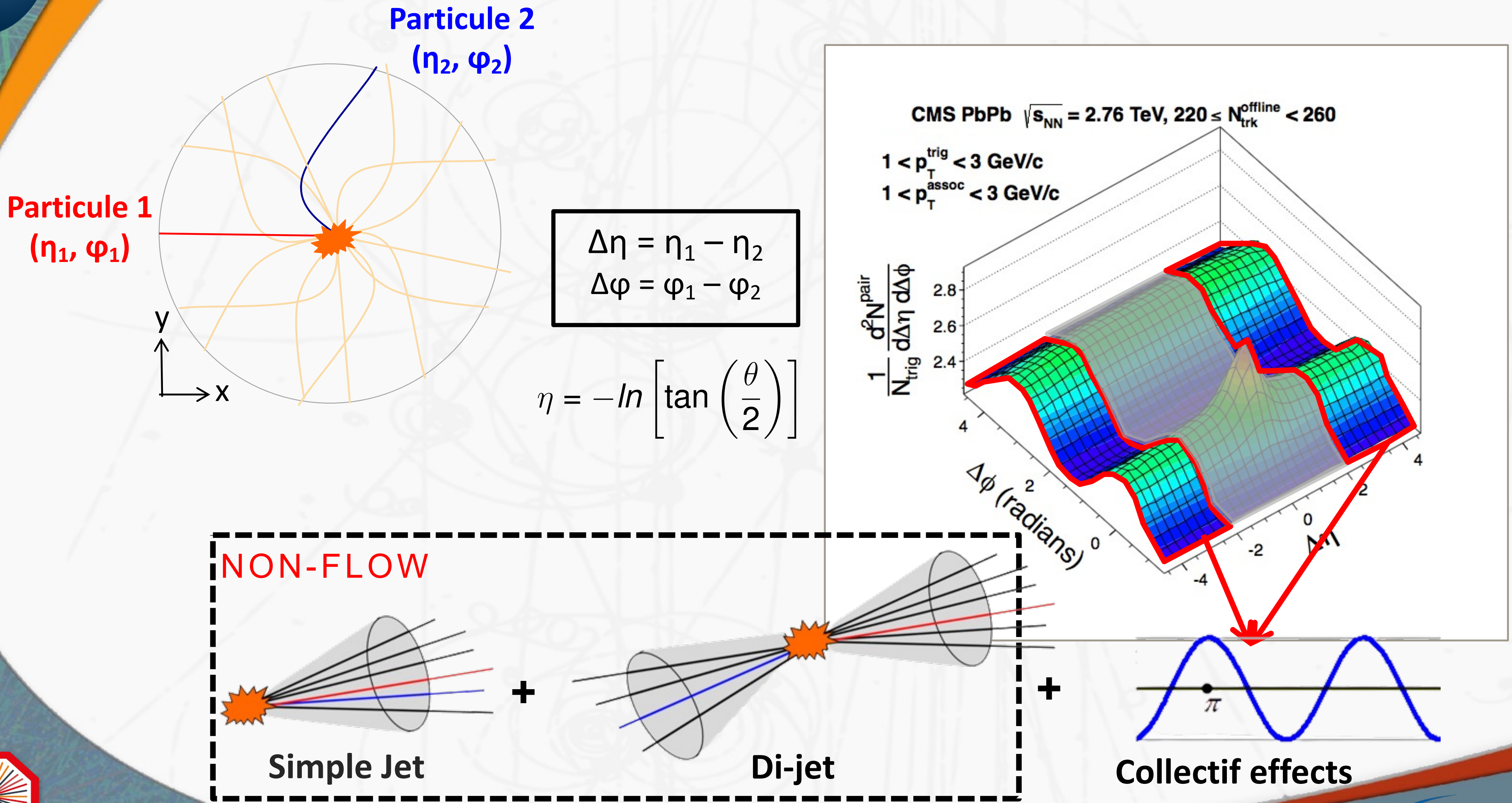




+

2-PARTICLE CORRELATION



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$$\eta = -ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$

NON-FLOW

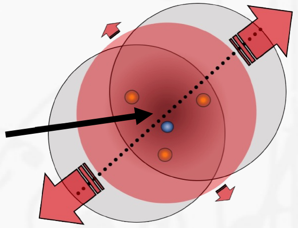
Simple Jet

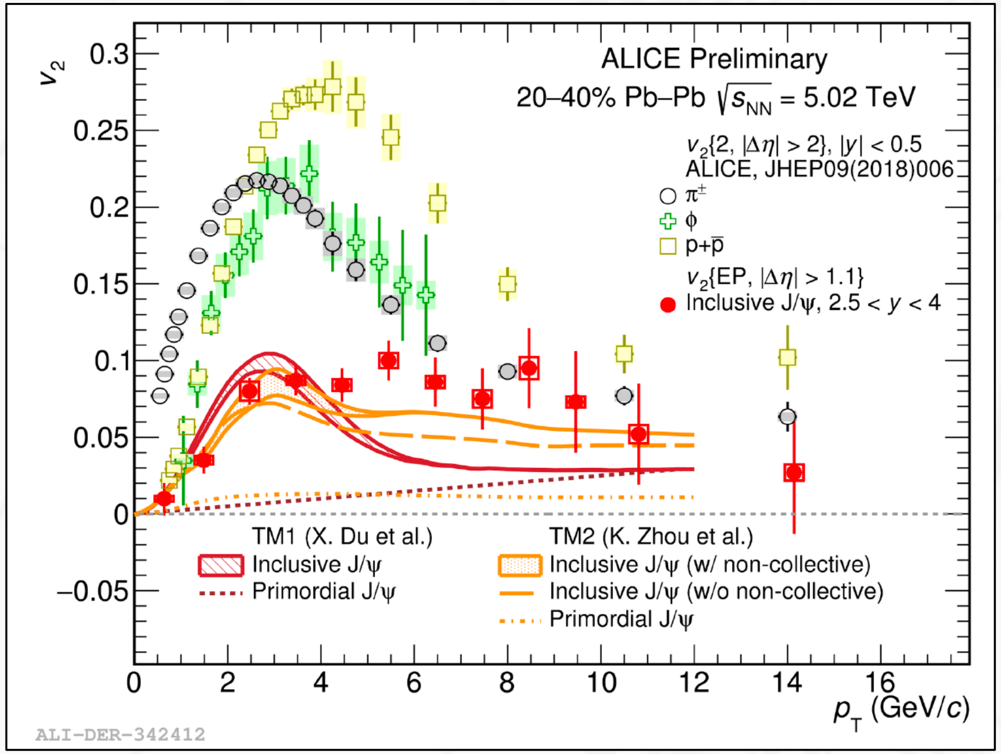
Di-jet

Collectif effects

CHARGED FLOW MEASUREMENTS AND MODELS

Elliptic flow v_2





J/Ψ VS LIGHT HADRONS

- Light Hadrons inherit their v_2 from the QGP
- Light quarks "u, d , s" thermalize with the medium.
- Partial thermalization for quark c ?
- Tension between J/Ψ measurements and transport models

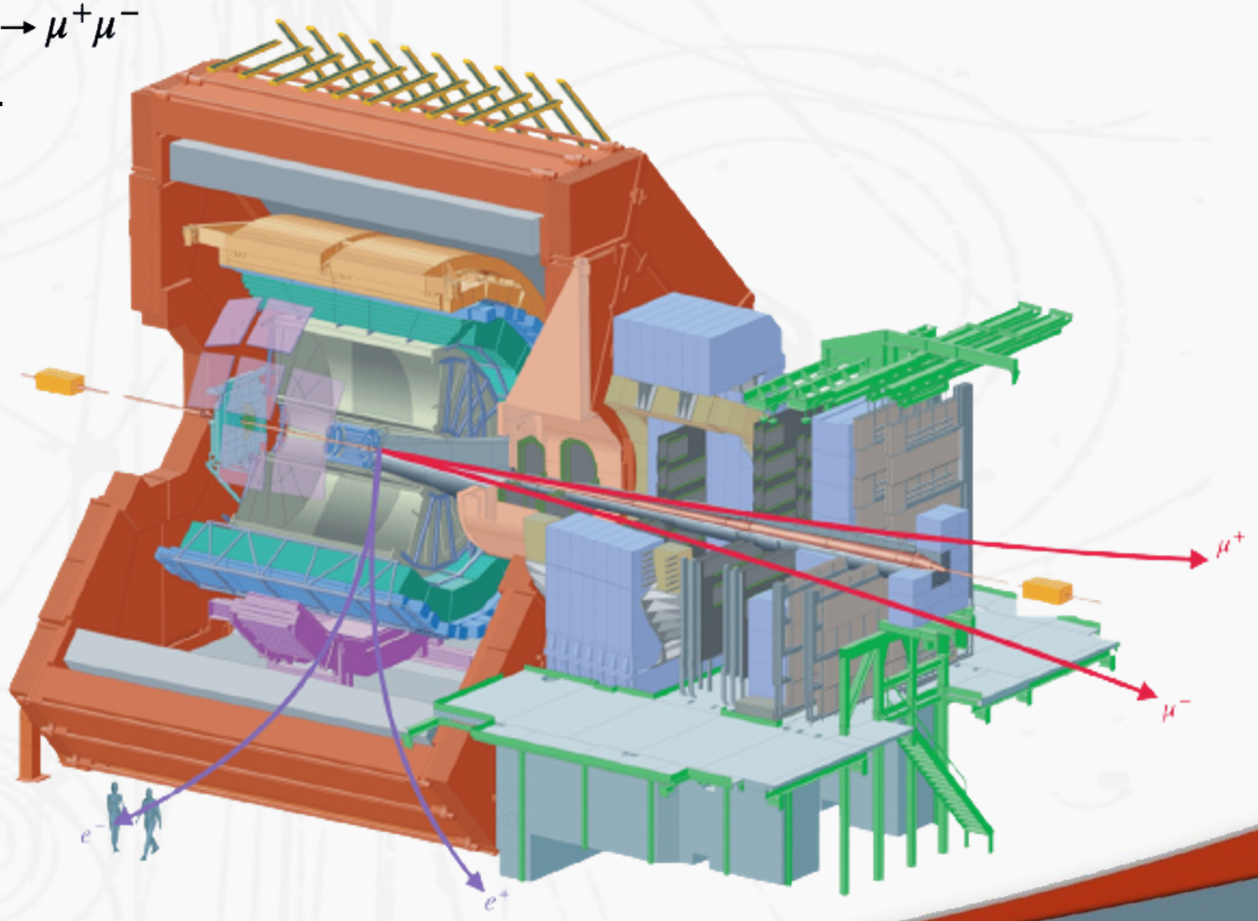
ALICE DETECTOR

Mid-rapidity
$$\begin{cases} J/\psi \rightarrow e^+e^- \\ |y_{ee}| < 0,9 \end{cases}$$

Forward-rapidity
$$\begin{cases} J/\psi, \psi(2S), \Upsilon(nS) \rightarrow \mu^+\mu^- \\ 2,5 < |y_{\mu\mu}| < 4 \end{cases}$$

A
Large
Ion
Collider
Experiment

RUN 2	→	Trigger DATA
RUN 3	→	Continuous readout



ALICE DETECTOR

Mid-rapidity $\left\{ \begin{array}{l} J/\psi \rightarrow e^+e^- \\ |y_{ee}| < 0{,}9 \end{array} \right.$

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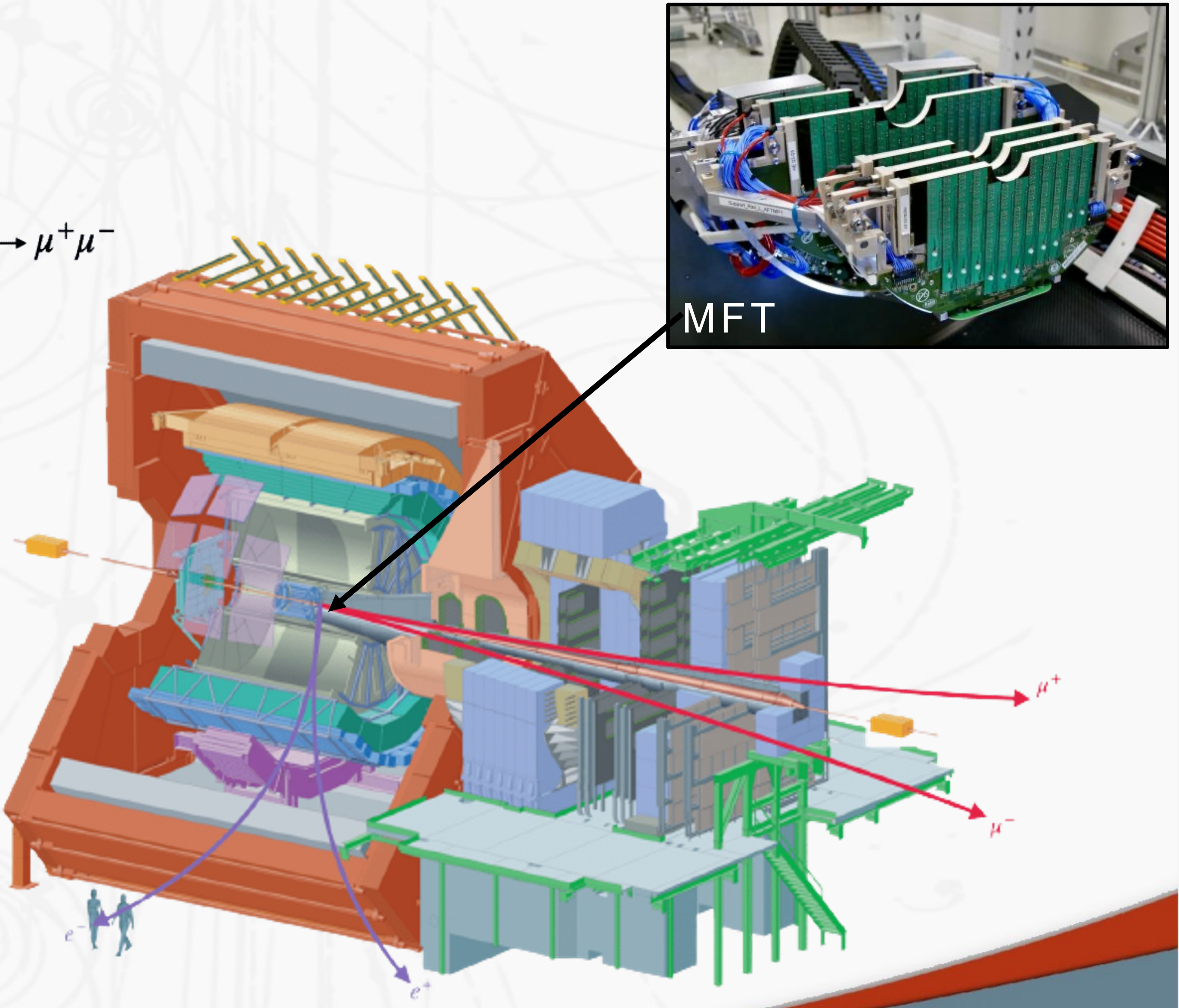
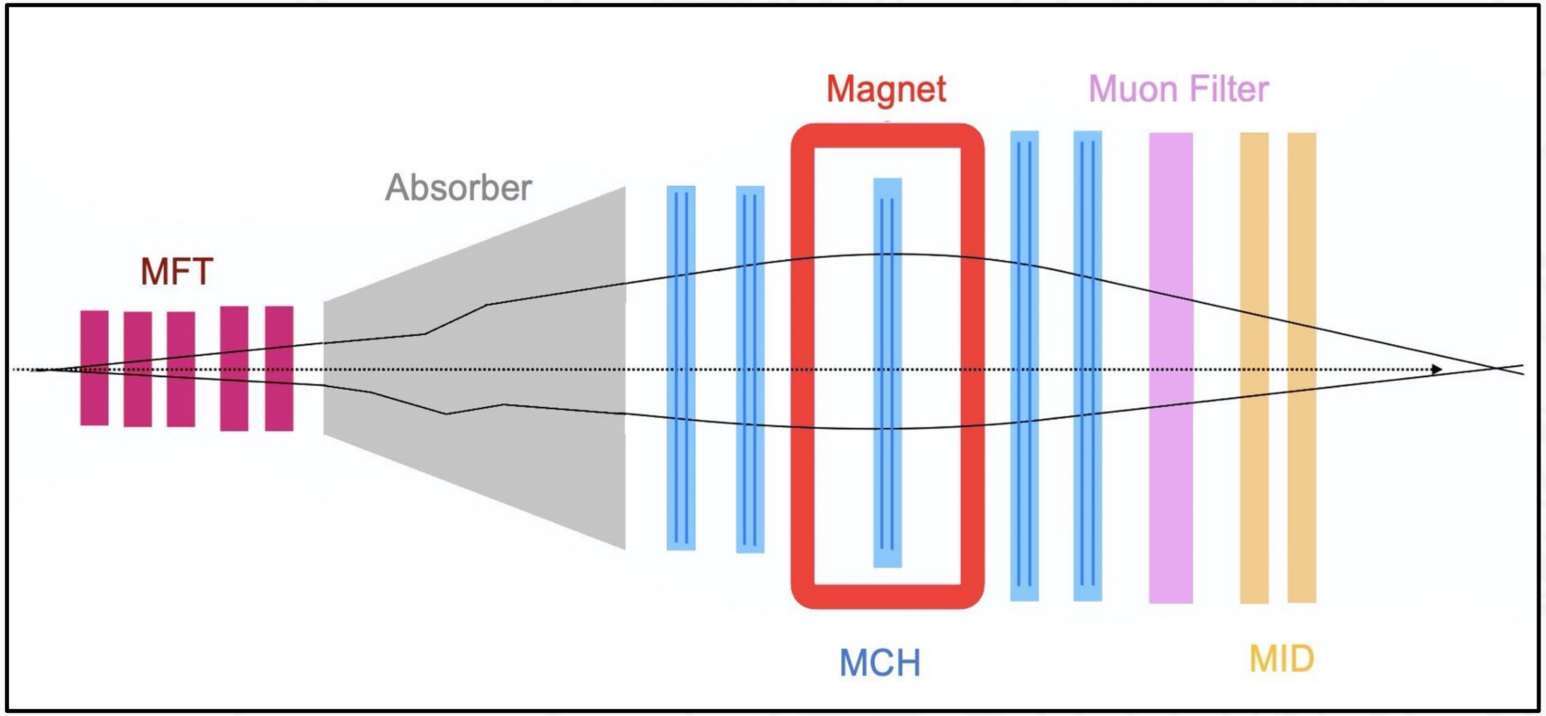


MUON SPECTROMETER OF RUN 3



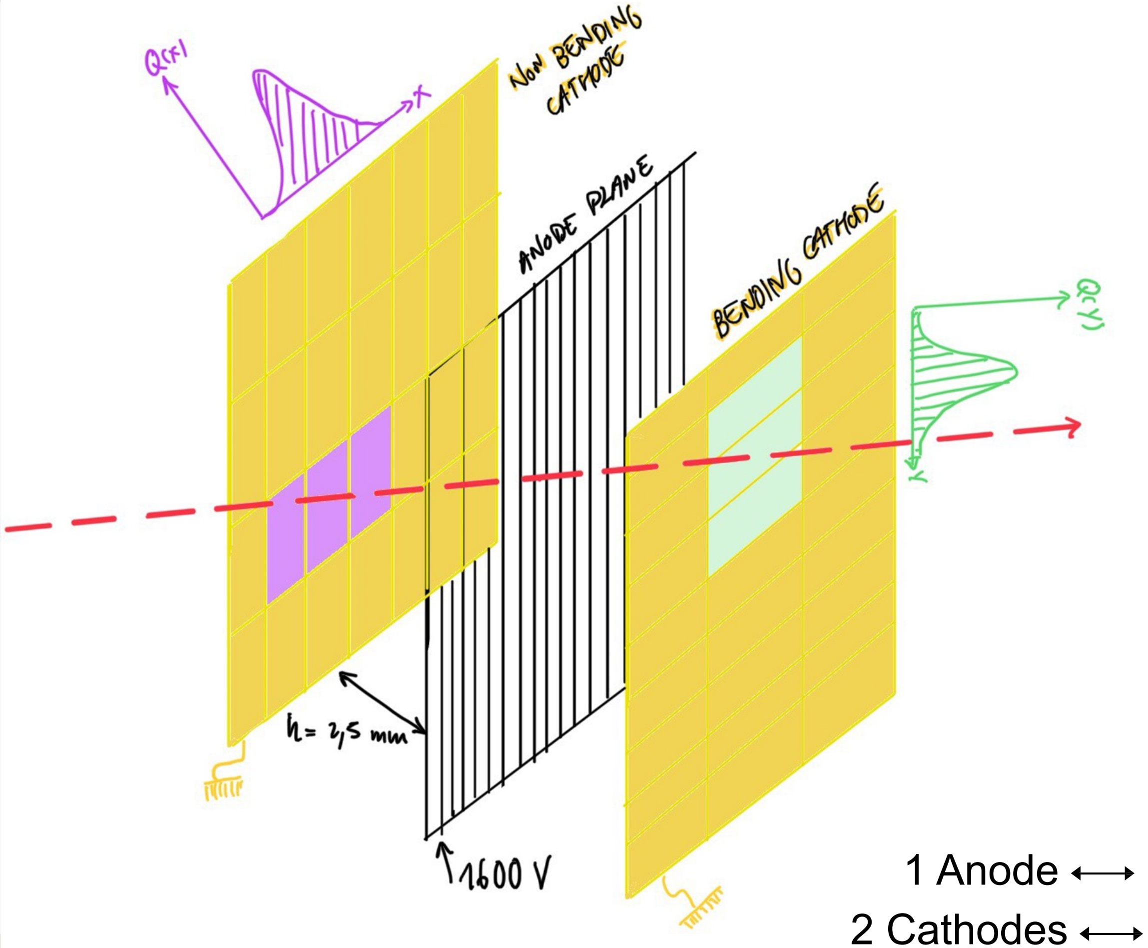
MFT: Muon Forward Tracker

MCH: Muon Chambers

MID: Muon Identifier

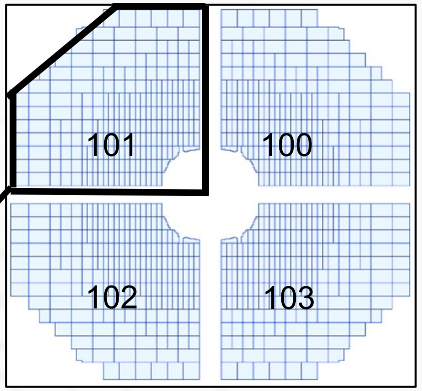
1 MCH Station = 2 Chambers

CATHODE PAD CHAMBER



1 Anode ⟷ wires
2 Cathodes ⟷ pads

1ST CHAMBER

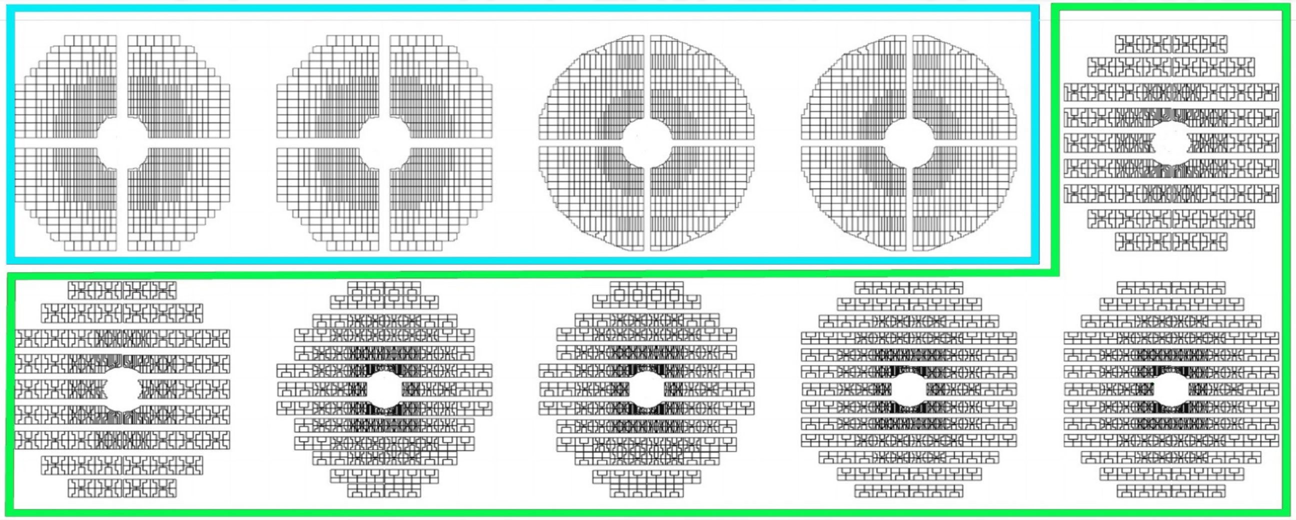


DETECTION ELEMENT DE 101

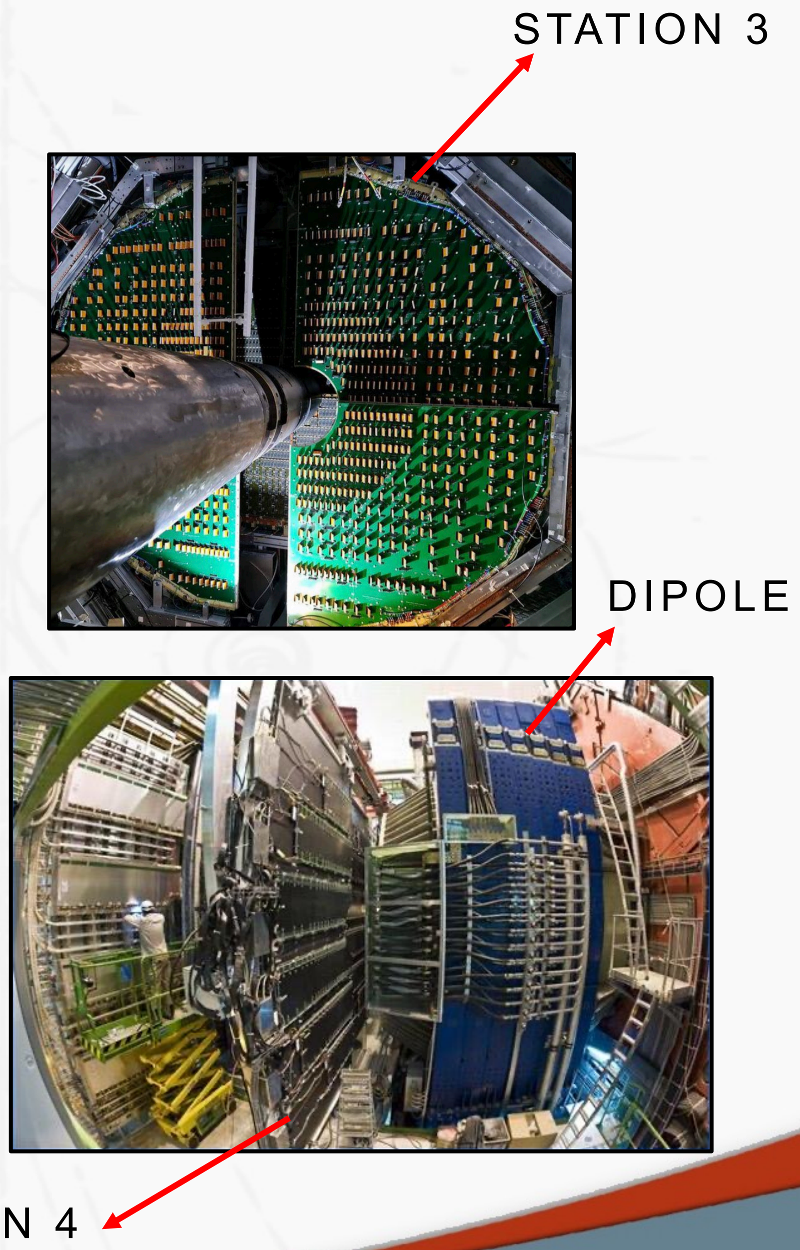
DUALSAMPA **DS 1**

CHARACTERISTICS OF MCH

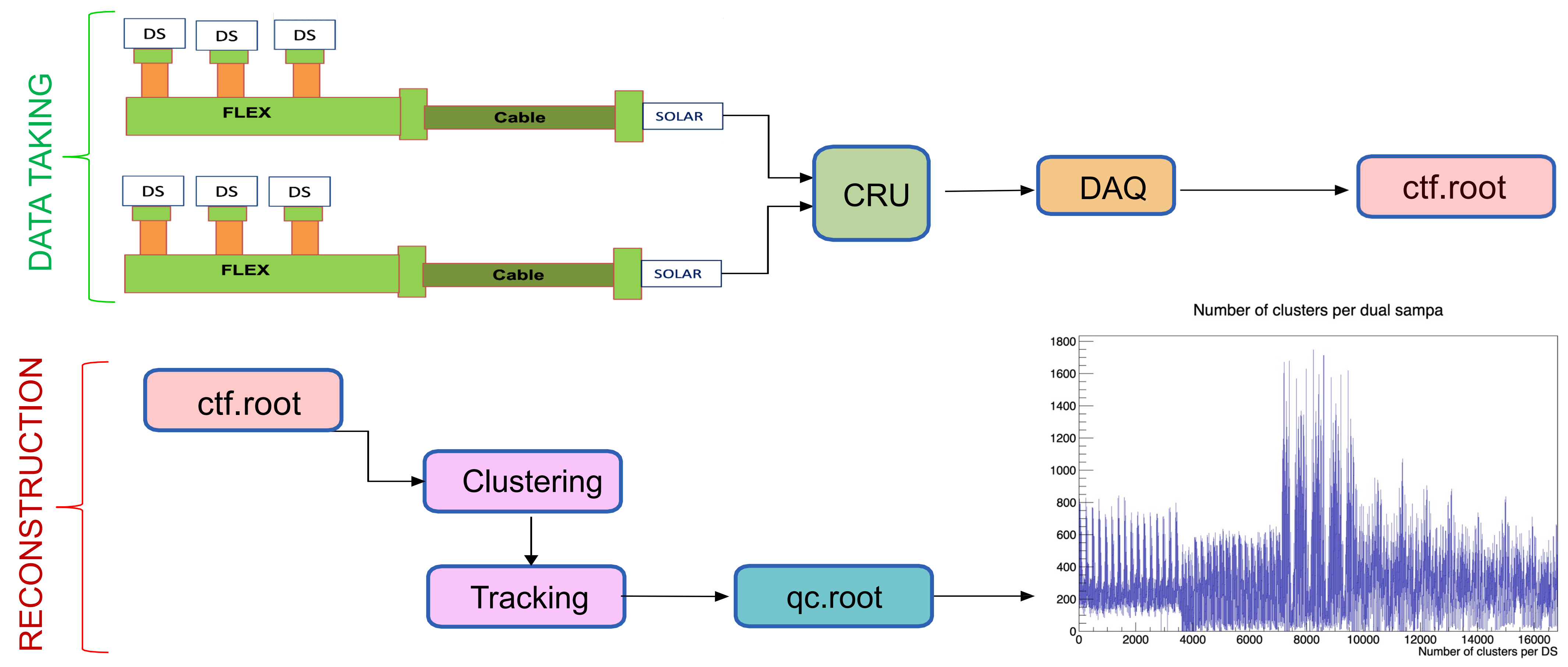
- 16 quadrants
- 140 slats



- 5 Stations = 10 Chambers
- 156 Detection Elements (DE)
- 16820 DualSampa (**DS**)



DATA TAKING + RECONSTRUCTION



DATA TAKING

DS DS DS

FLEX

Cable

SOLAR

DS DS DS

FLEX

Cable

SOLAR

CRU

DAQ

ctf.root

RECONSTRUCTION

ctf.root

Clustering

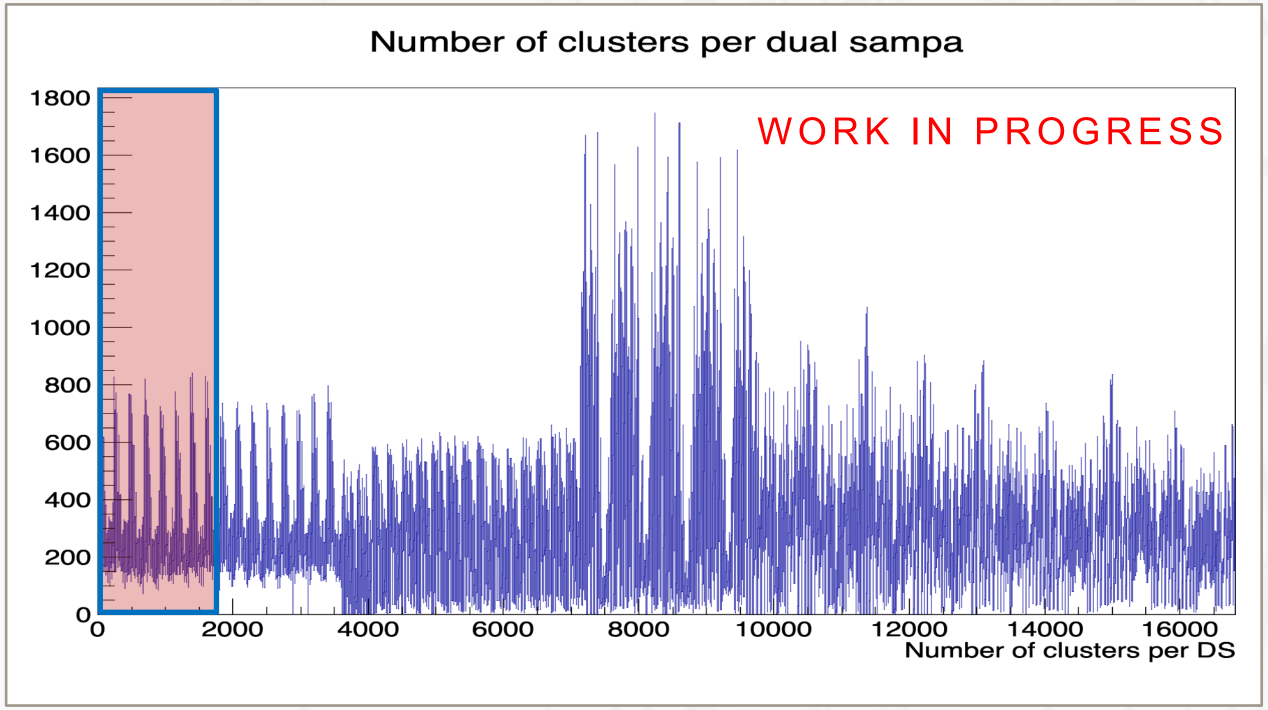
Tracking

qc.root

Number of clusters per dual sampa

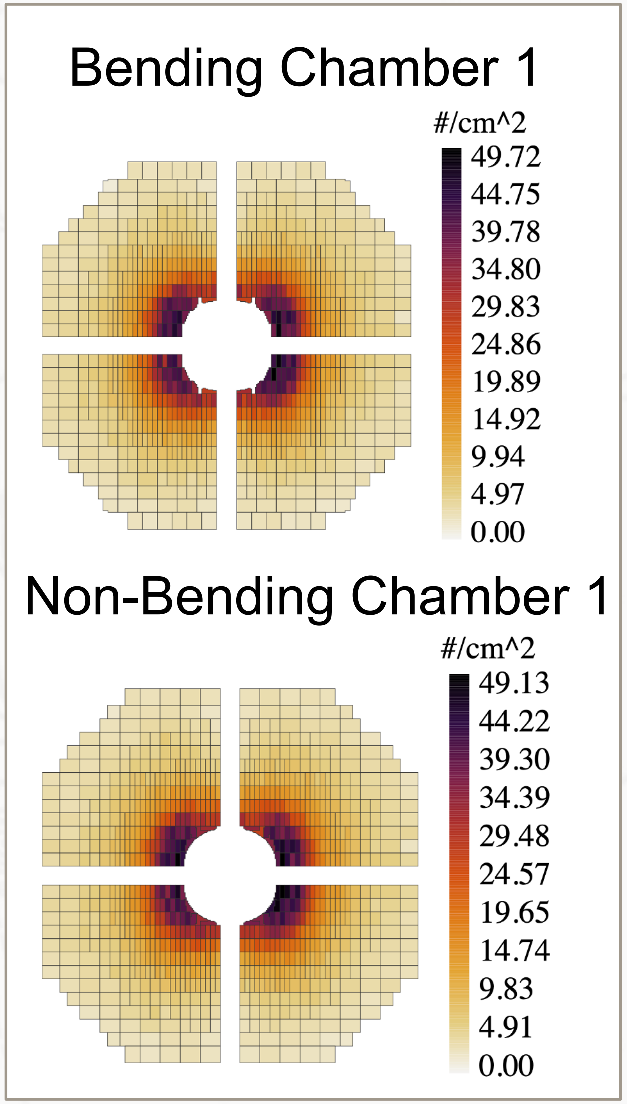
$(A \times \epsilon)$ STUDIES

LHC 2022 DATA



Number of clusters per dual sampa

WORK IN PROGRESS

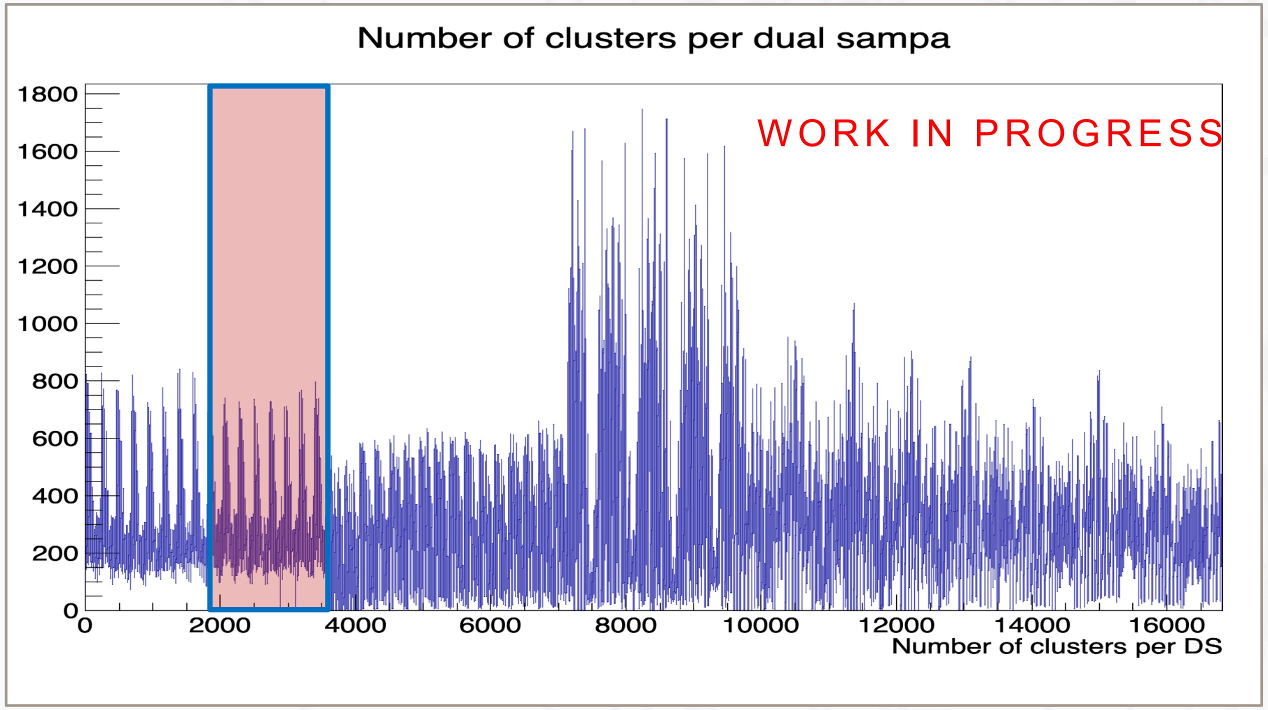


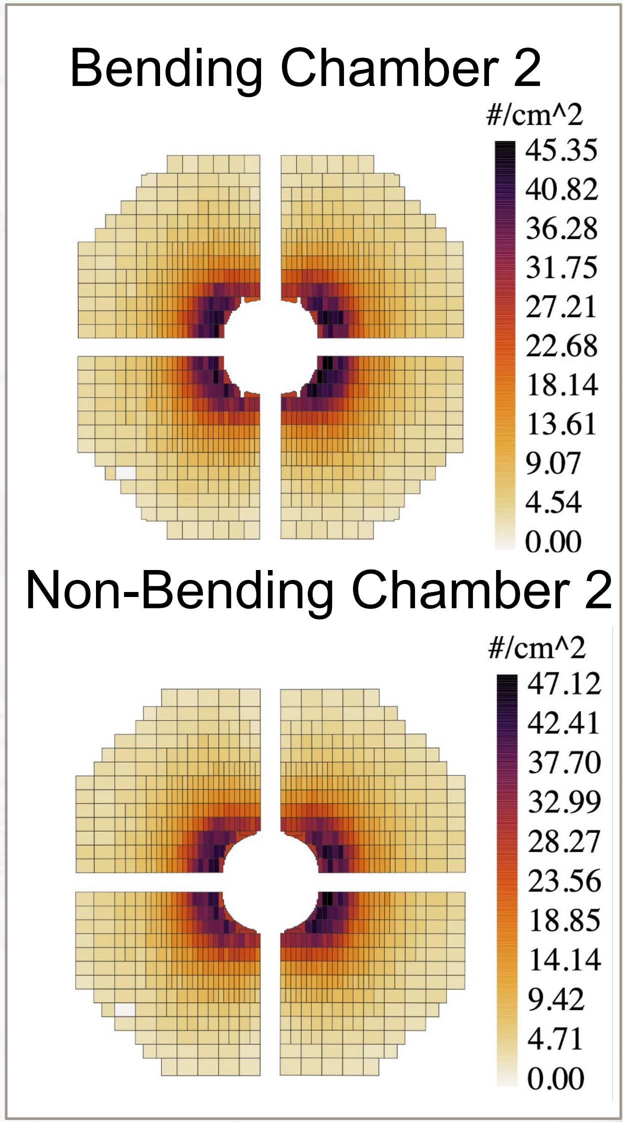
Bending Chamber 1

Non-Bending Chamber 1

$(A \times \epsilon)$ STUDIES

LHC 2022 DATA





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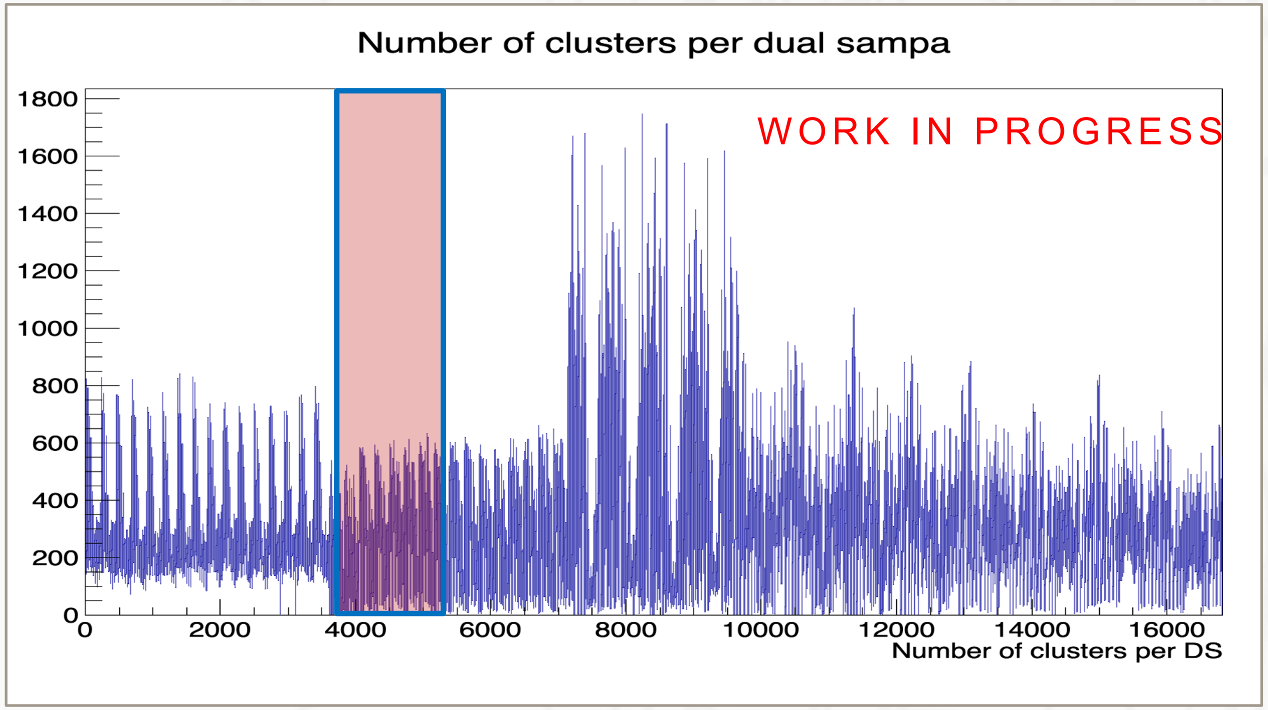
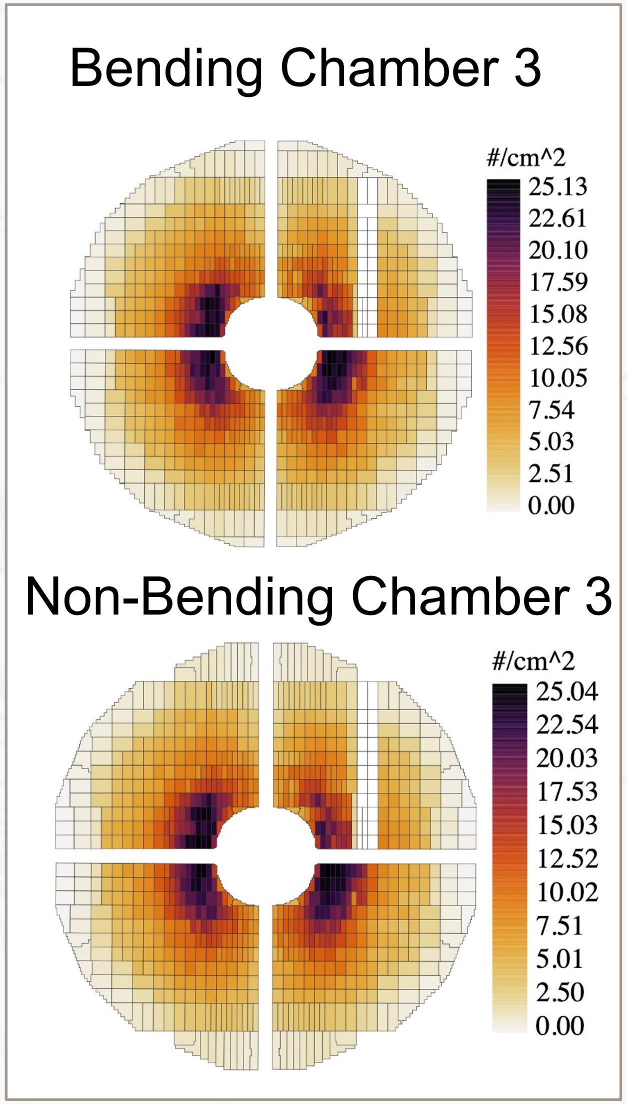
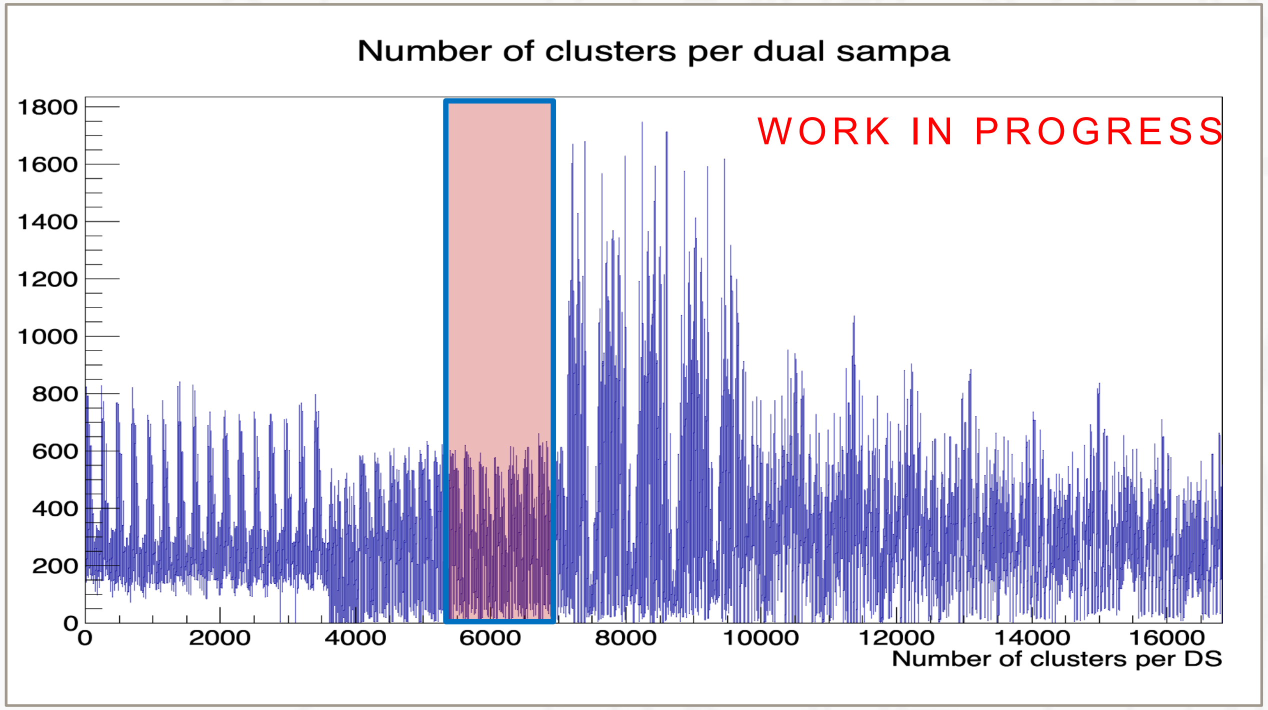

Number of clusters per dual sampa

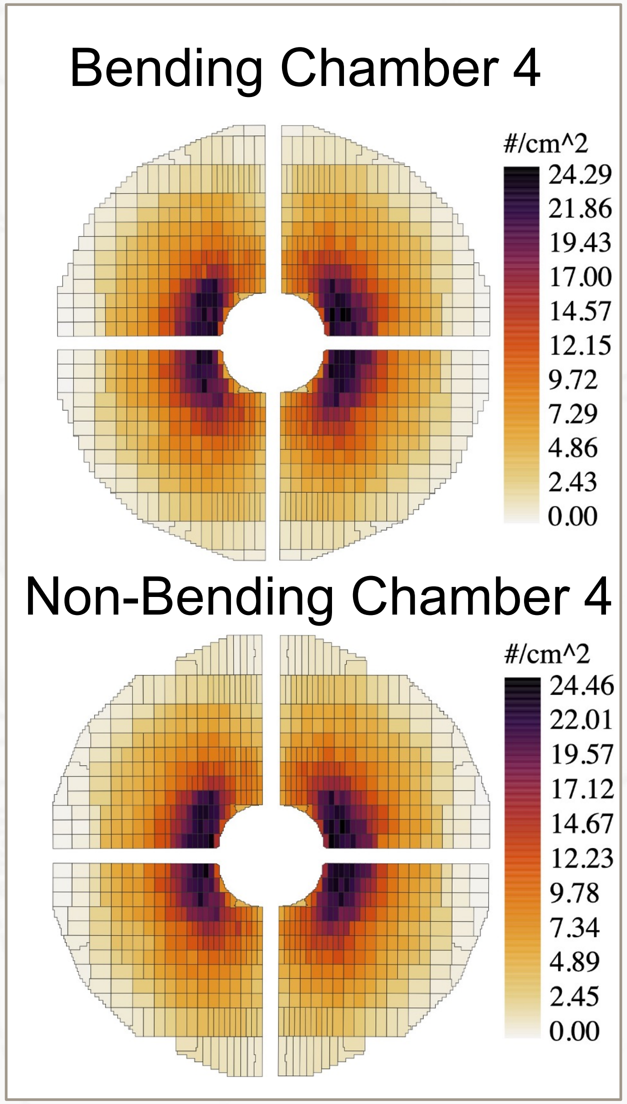

Bending Chamber 3

Non-Bending Chamber 3

$(A \times \epsilon)$ STUDIES

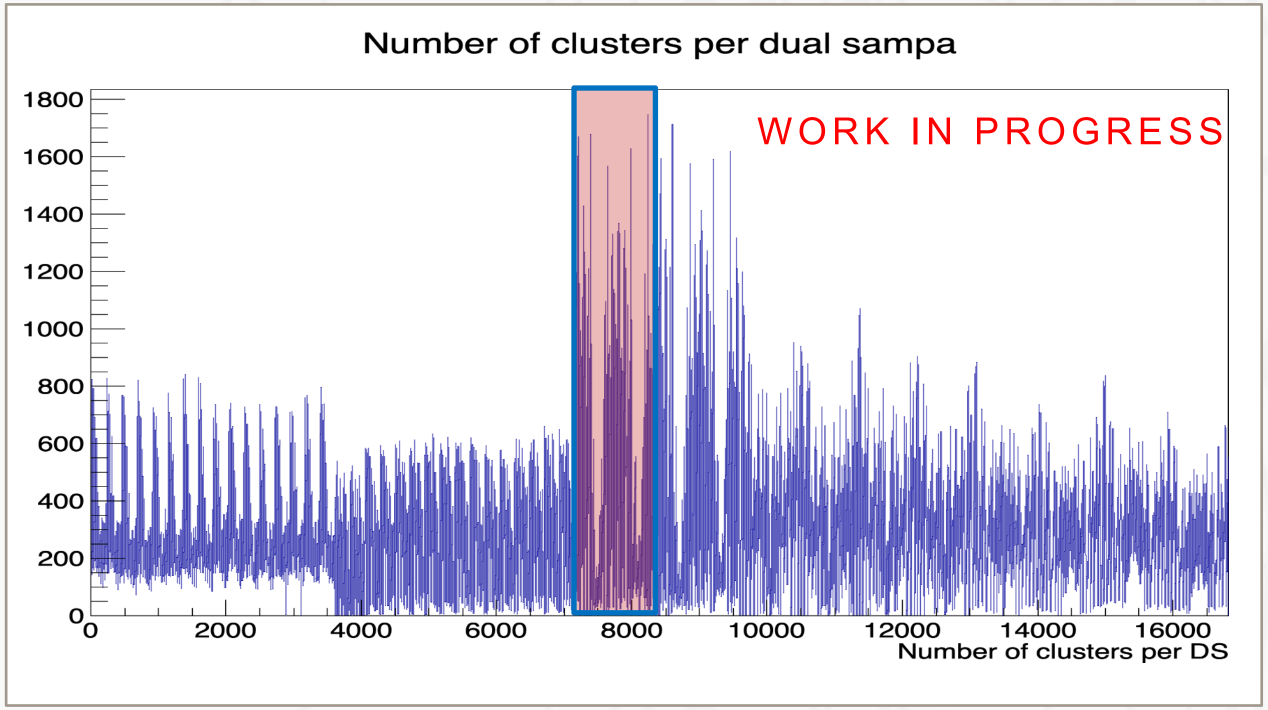
LHC 2022 DATA



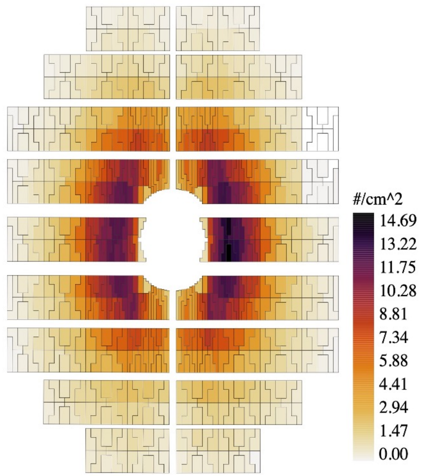


$(A \times \epsilon)$ STUDIES

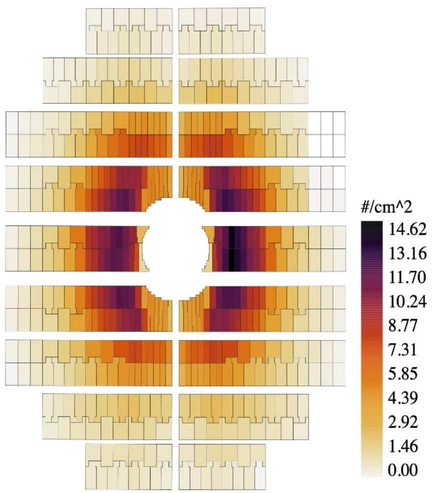
LHC 2022 DATA



Bending Chamber 5

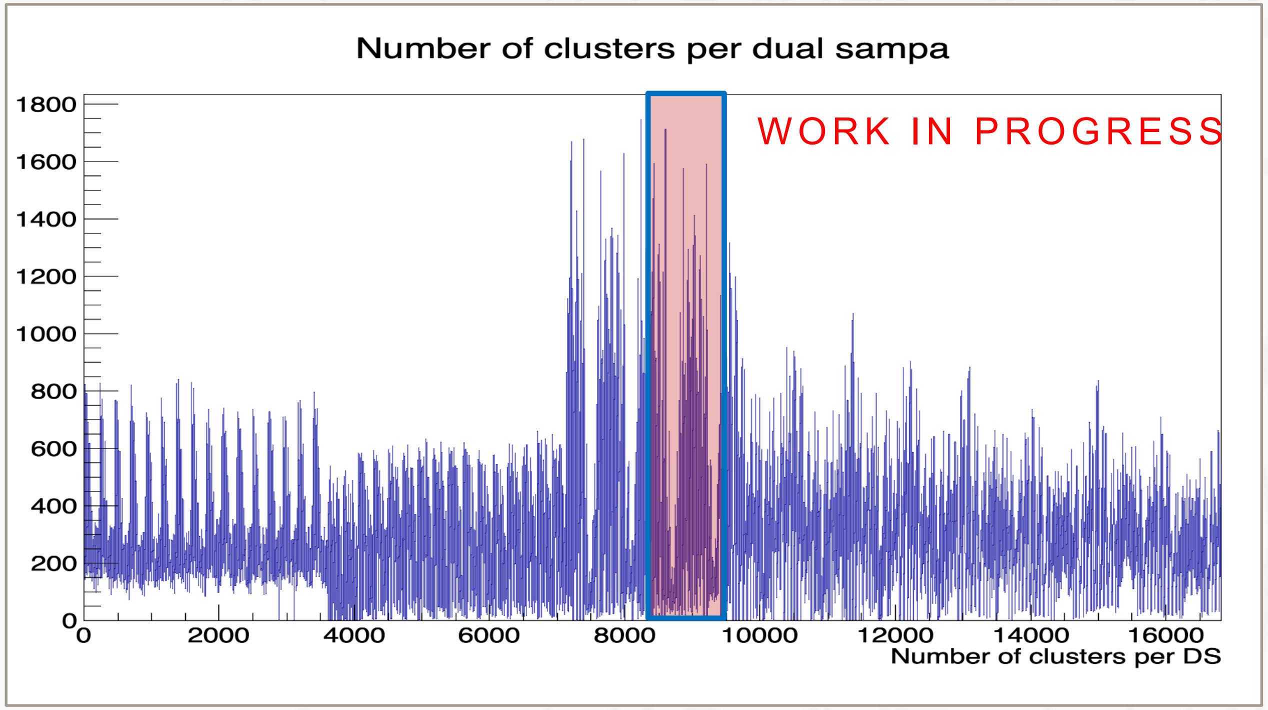


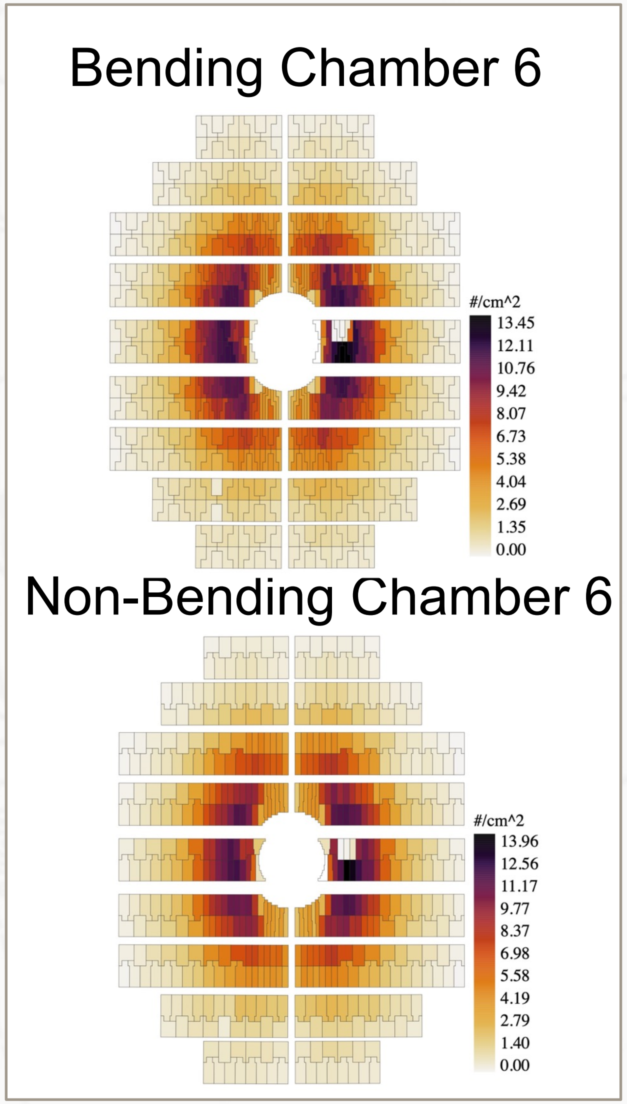
Non-Bending Chamber 5



$(A \times \epsilon)$ STUDIES

LHC 2022 DATA





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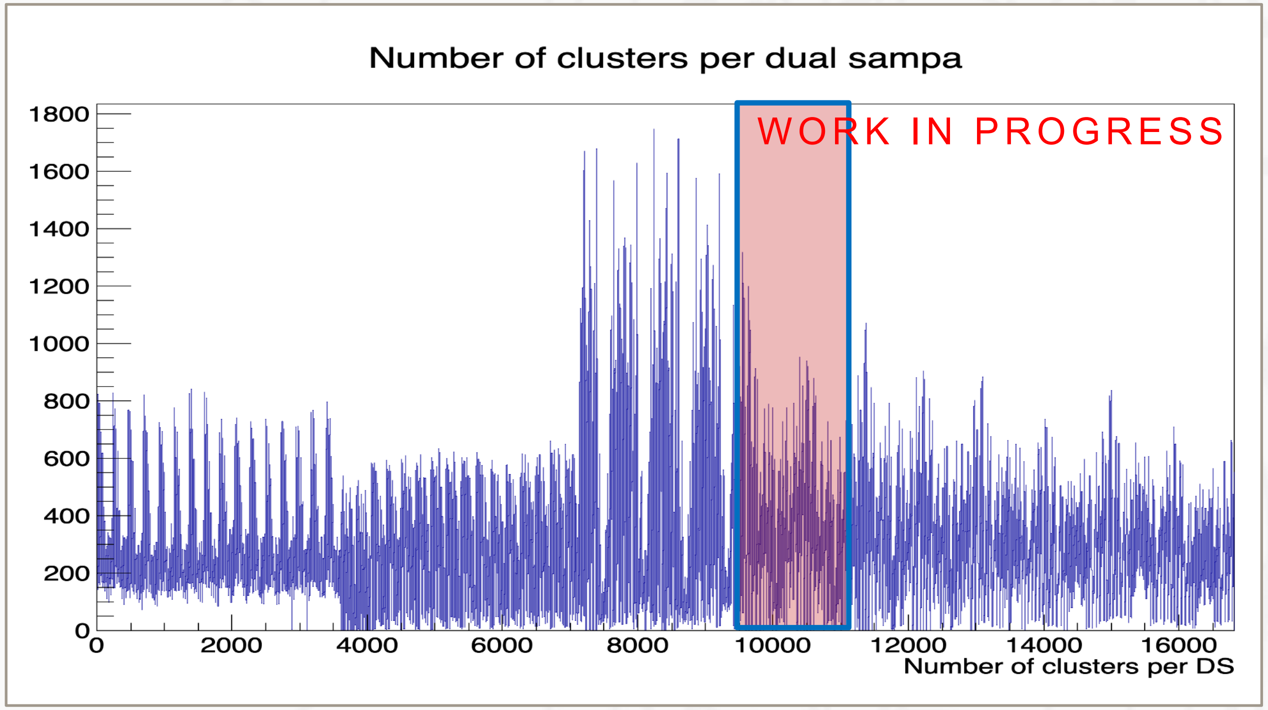
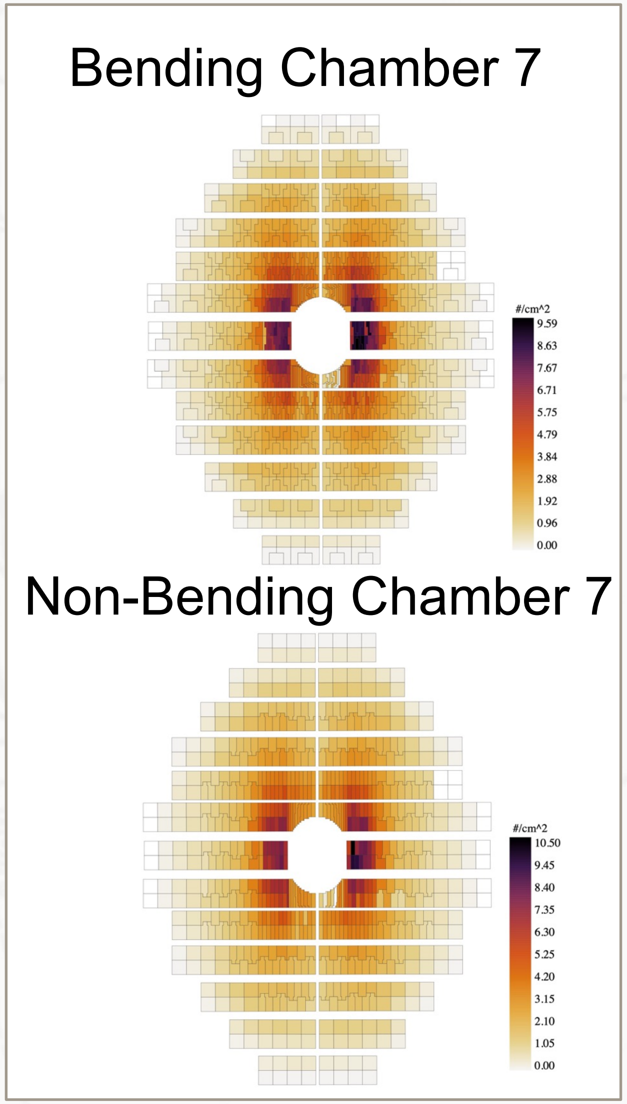

Number of clusters per dual sampa

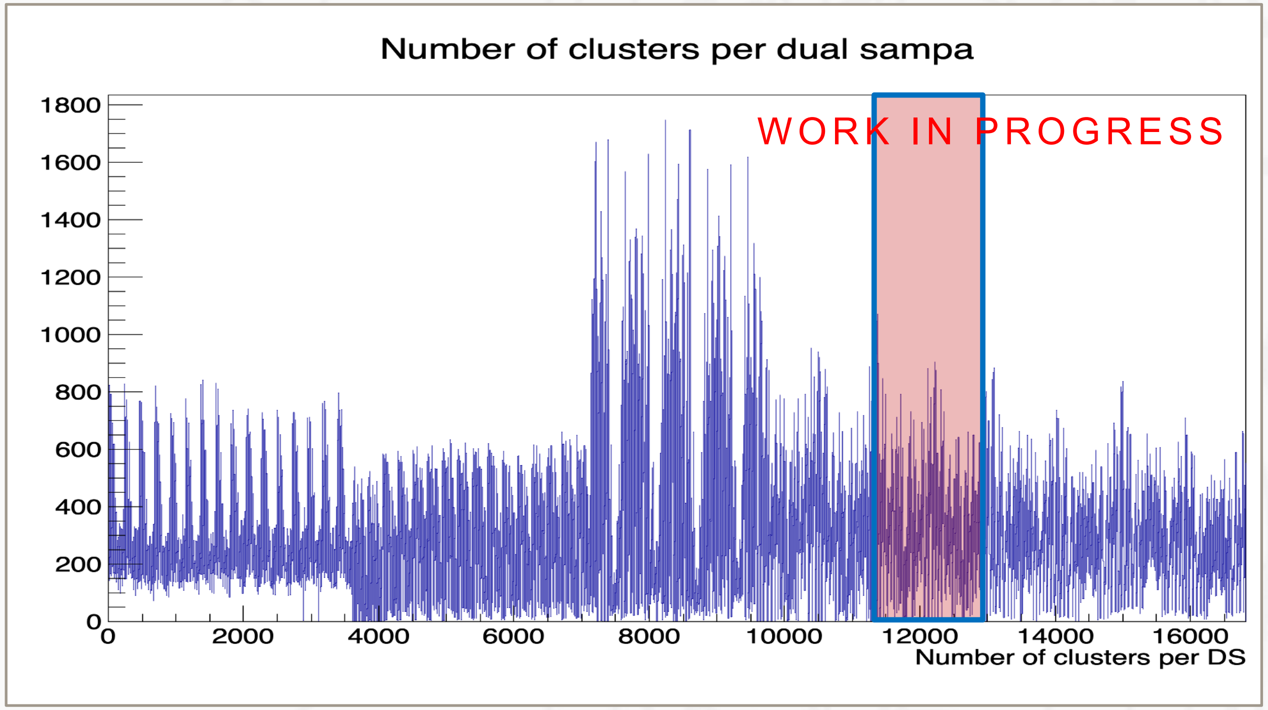
WORK IN PROGRESS


Bending Chamber 7

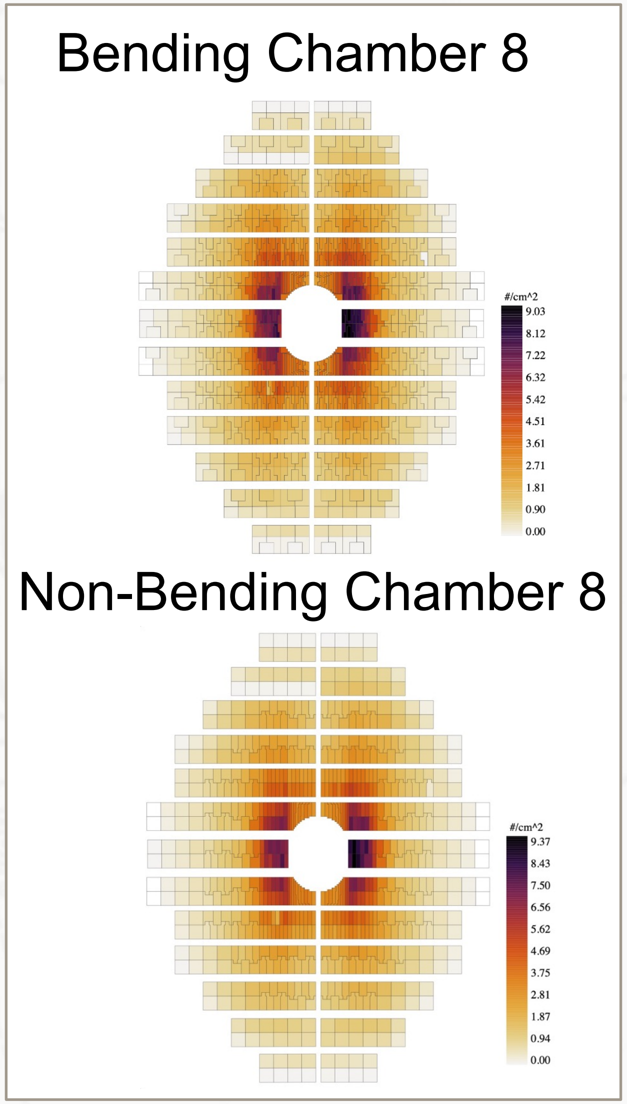
Non-Bending Chamber 7

$(A \times \epsilon)$ STUDIES

LHC 2022 DATA



Number of clusters per dual sampa

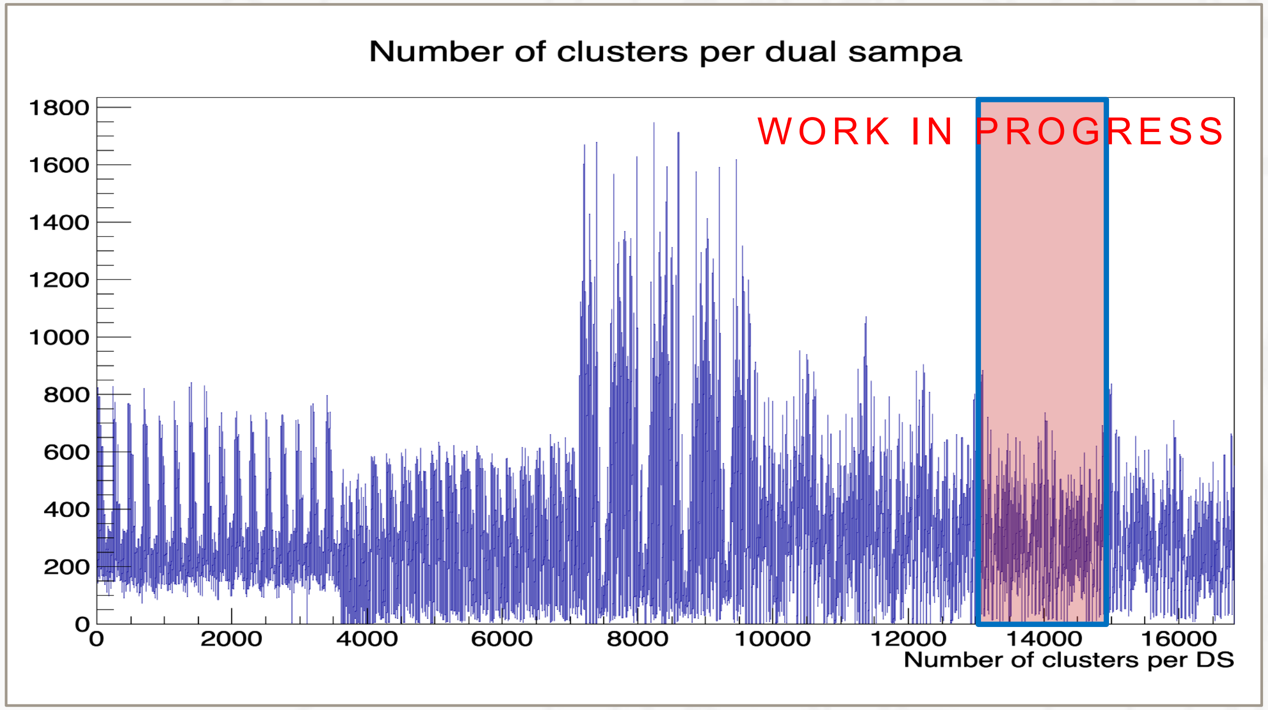


Bending Chamber 8

Non-Bending Chamber 8

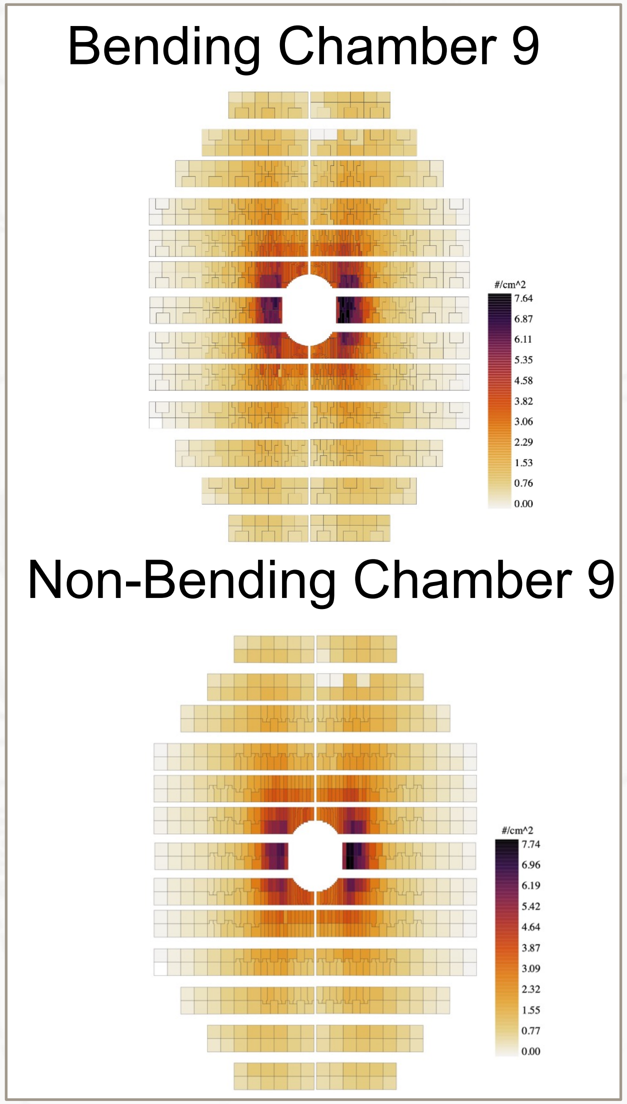
$(A \times \epsilon)$ STUDIES

LHC 2022 DATA



Number of clusters per dual sampa

WORK IN PROGRESS

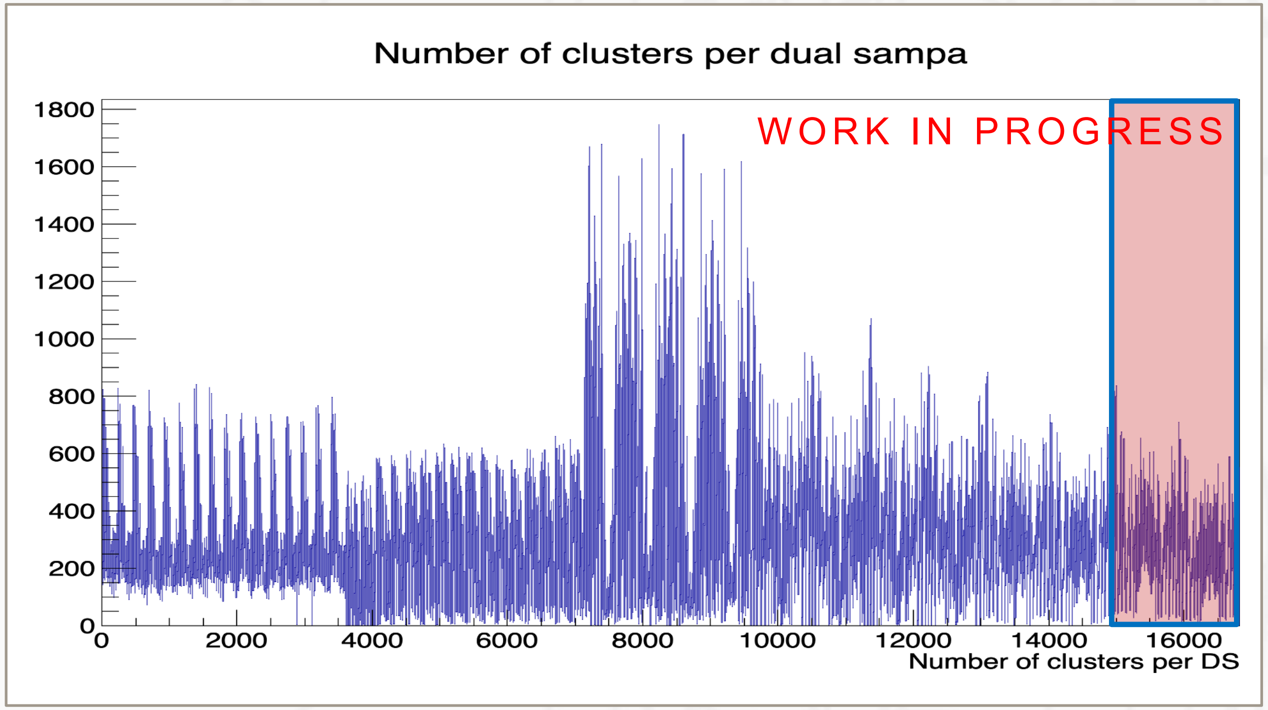


Bending Chamber 9

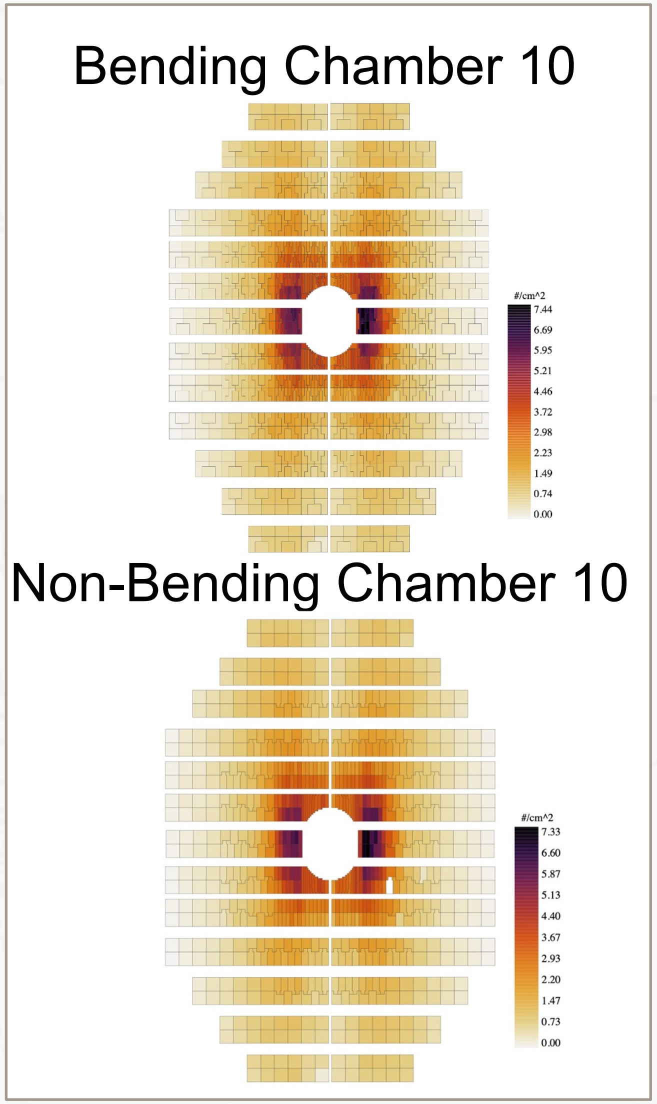
Non-Bending Chamber 9

$(A \times \epsilon)$ STUDIES

LHC 2022 DATA


Number of clusters per dual sampa

WORK IN PROGRESS

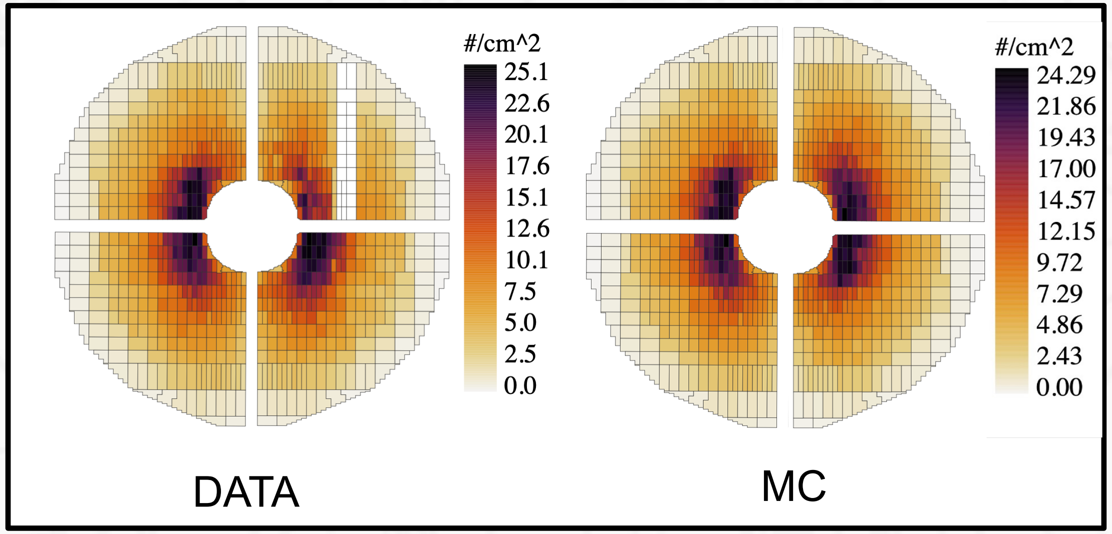

Bending Chamber 10

Non-Bending Chamber 10

$(A \times \epsilon)$ STUDIES

WORK IN PROGRESS

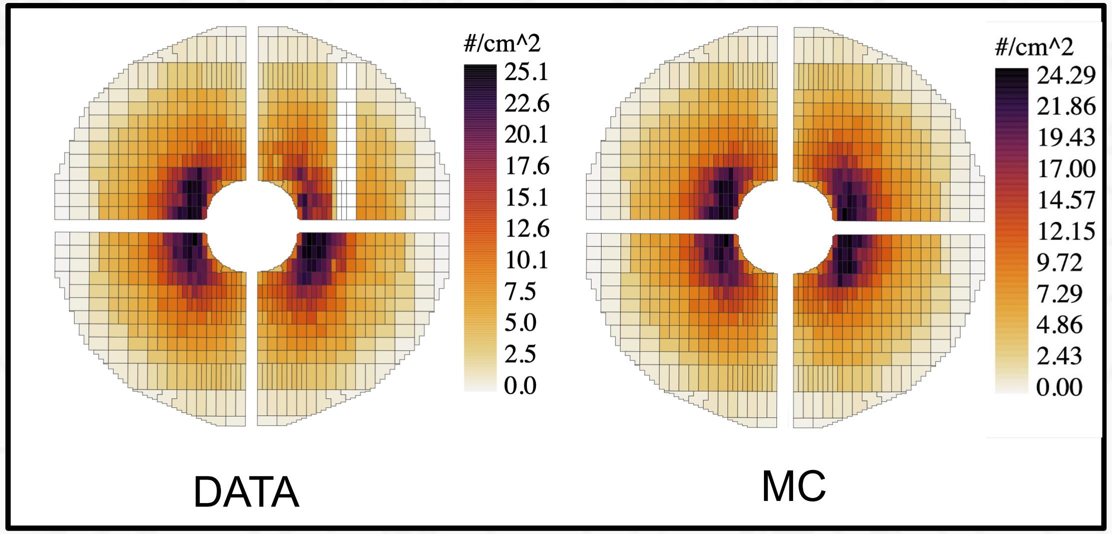
DISPLAY OF DATA VS MC

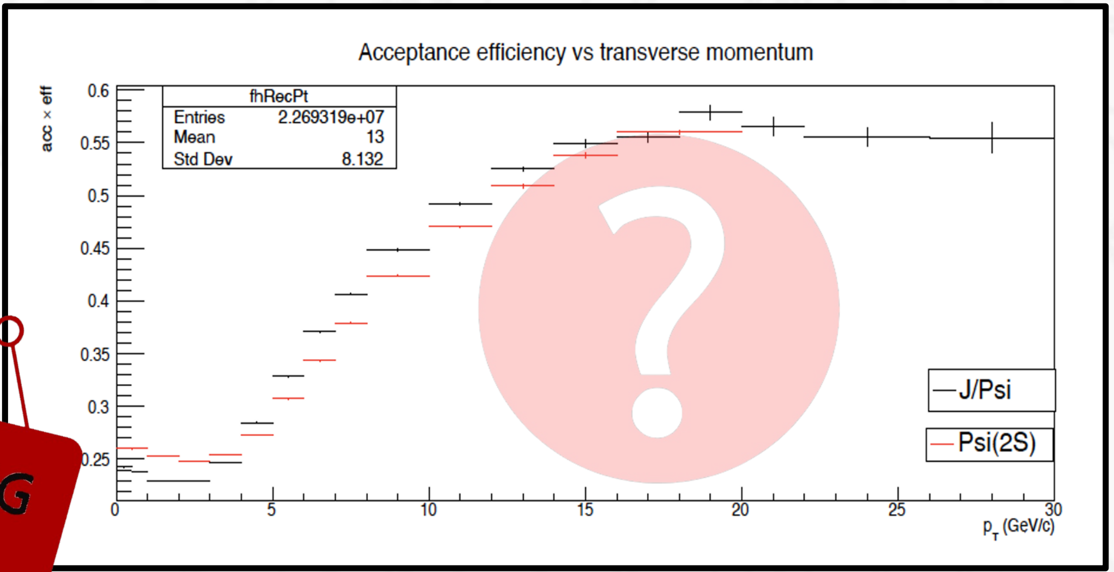


$(A \times \epsilon)$ STUDIES

WORK IN PROGRESS

DISPLAY OF DATA VS MC





$$(A \times \epsilon) = \frac{N^{reco}_{J/\psi}}{N^{gen}_{J/\psi}}$$

COMING SOON

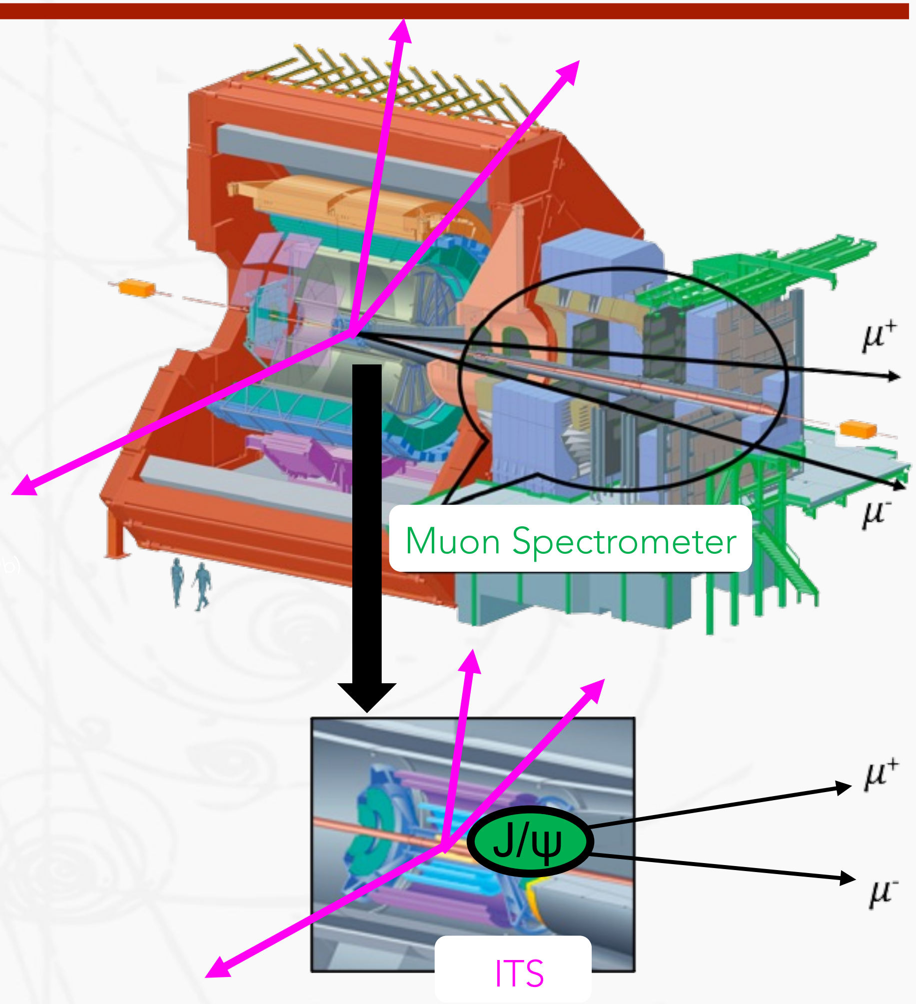
J/Ψ FLOW ANALYSIS

MUON SPECTROMETER

- J/ψ TRACK SELECTION
- J/ψ SIGNAL EXTRACTION
- $<v_2^2(J/\psi)>$

ITS

- CHARGED TRACK SELECTION
- $<v_2^2(ITS)>$



MUON SPECTROMETER + ITS:

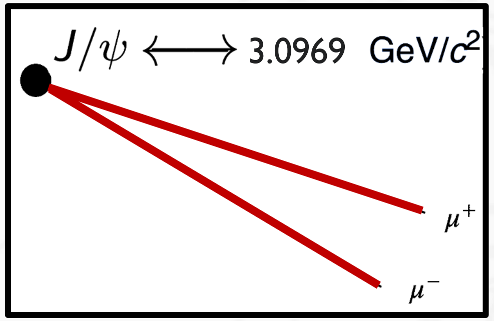
$$< v_2^2(J/\psi) > = \frac{< v_2^2(J/\psi)\cdot v_2^2(ITS) >}{< v_2^2(ITS) >}$$

J/Ψ FROM MUON SPECTROMETER IN RUN 3

LHC22 P-P DATA SAMPLE AT $\sqrt{S} = 13.6$ TeV

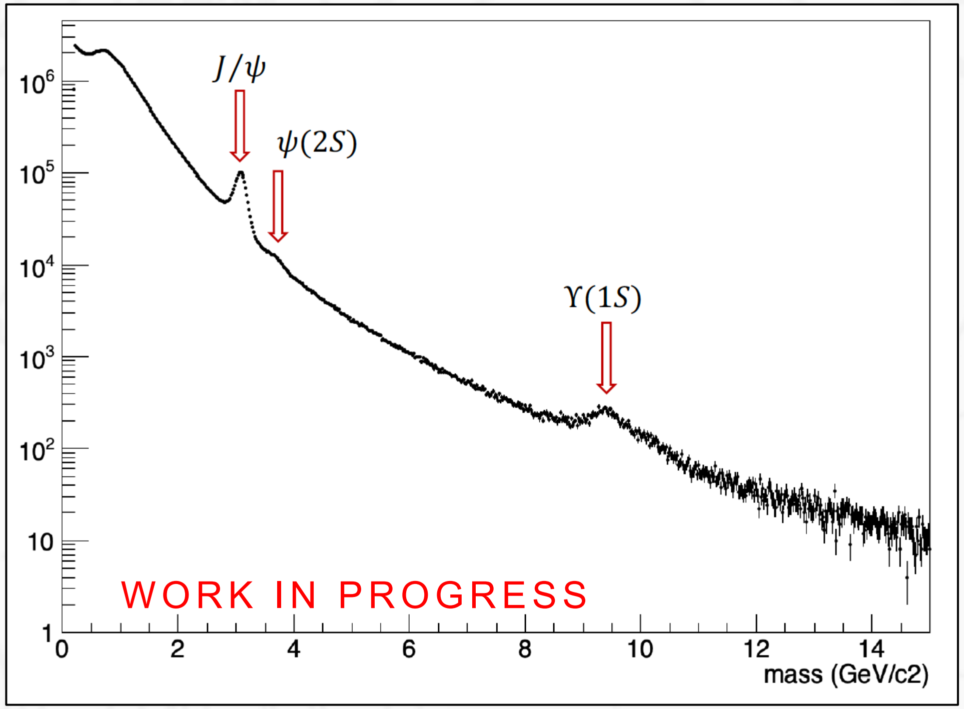
TRACK SELECTION

- Pseudorapidity $-4 < \eta < -2,5$
- Cut in the absorber $2^\circ < \theta\text{abs} < 10^\circ$
- pT > 0.5 GeV/c
- MCH-MID Tracks



INVARIANT MASS

$$m_{\mu\mu} = \sqrt{m_1^2 + m_2^2 + 2(E_1E_2 - P_1P_2\cos\theta)}$$



J/Ψ SIGNAL EXTRACTION IN RUN 3

Fit conditions

Free tails parameters

$$m_{\psi(2S)}^{\mathrm{FIT}} = m_{J/\psi}^{\mathrm{FIT}} + \Delta m^{\mathrm{PDG}}$$

$$\sigma_{\psi(2S)}^{\mathrm{FIT}} = \sigma_{J/\psi}^{\mathrm{FIT}} \cdot \frac{\sigma_{\psi(2S)}^{\mathrm{MC}}}{\sigma_{J/\psi}^{\mathrm{MC}}}$$

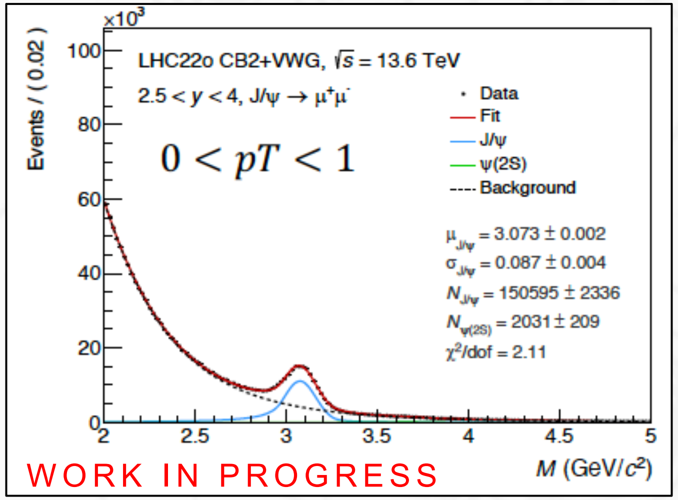
Fit functions

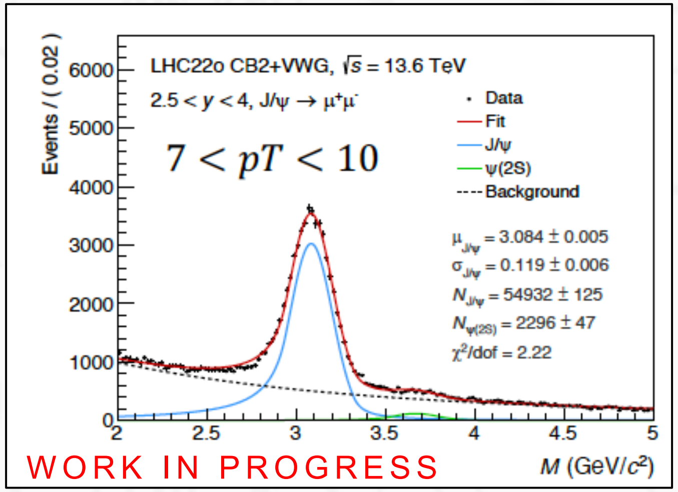
Signal:

- CB2 and NA60

Background:

- VWG and Pol4Exp





FLOW MEASUREMENTS

HISTOGRAMS WITH μμ:

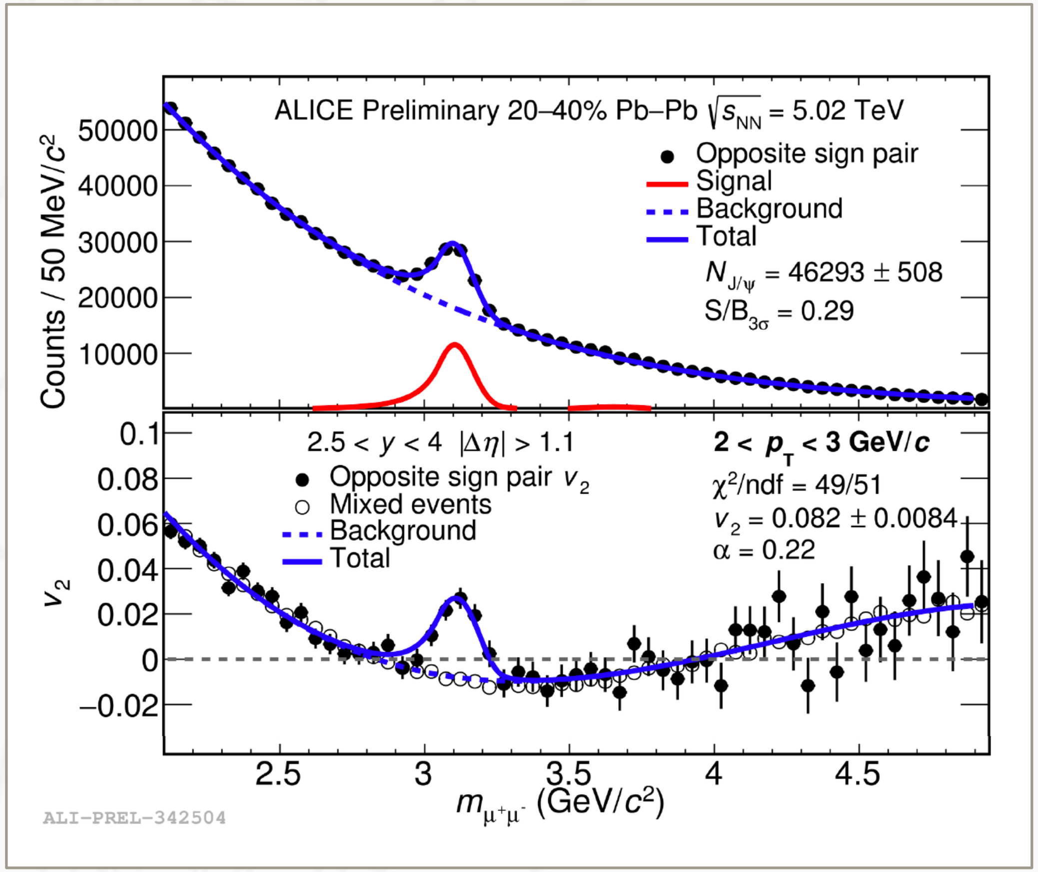
- $m_{\mu\mu}$
- $v_n = \langle \cos n(\varphi - \Psi_n) \rangle$

FITTING PROCEDURE:

$$v_n = v_n^{bkg}(1-\alpha) + v_n^{sig}\alpha$$

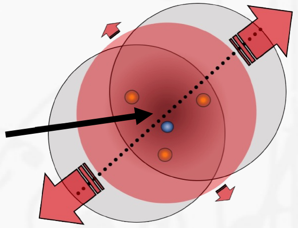
v_n^{sig}	Extracted by fitting dimuon v_N
v_n^{bkg}	Polynomial functions
$\alpha = \frac{S}{S+B}$	Signal/Background fraction

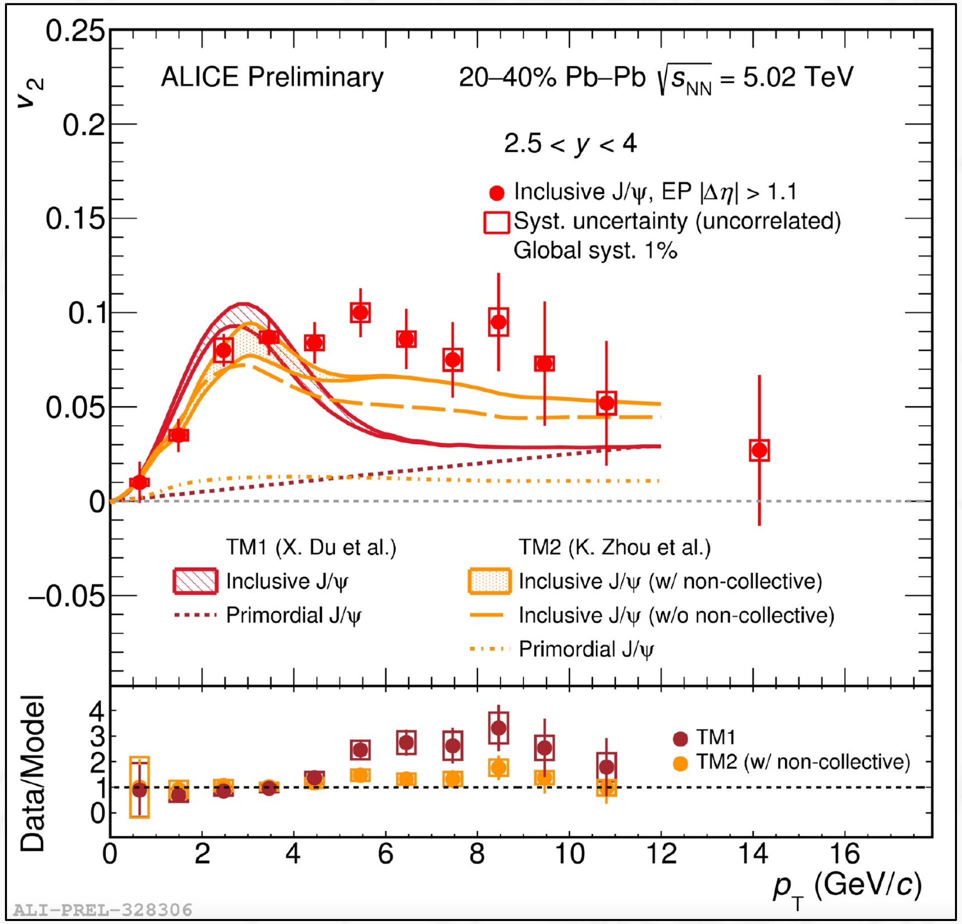
RUN 2:



FLOW MEASUREMENTS AND MODELS

Elliptic flow v_2

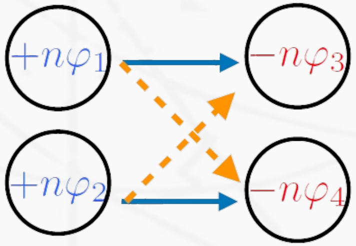




- Charm regeneration at low P_T well predicted by transport models.
- Charm energy loss at higt Pt?
- Is this effect coming from non-flow correlations?

FLOW MEASUREMENTS

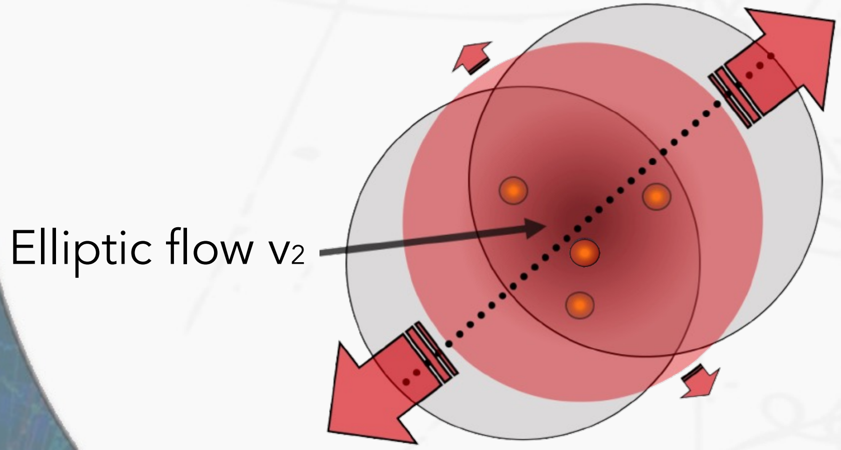
- 4-particle cumulant suppress nonflow contaminations

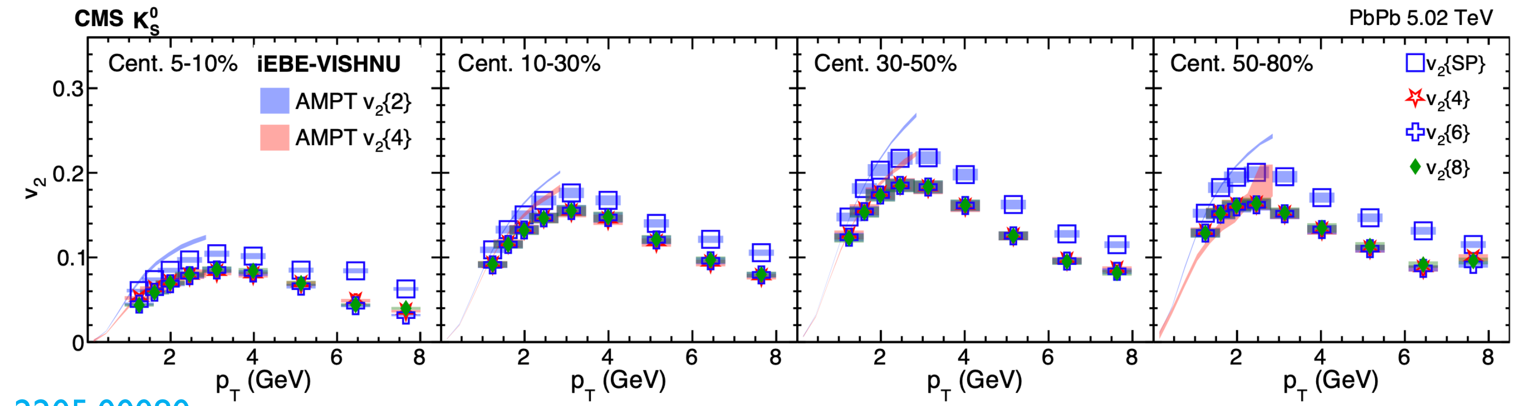


$$c_n\{4\} = \langle\langle \cos n(\varphi_1+\varphi_2-\varphi_3-\varphi_4)\rangle\rangle - \langle\langle \cos n(\varphi_1-\varphi_3)\rangle\rangle\ \langle\langle \cos n(\varphi_2-\varphi_4)\rangle\rangle - \langle\langle \cos n(\varphi_1-\varphi_4)\rangle\rangle\ \langle\langle \cos n(\varphi_2-\varphi_3)\rangle\rangle$$

$$= \langle -v_n^4 + \underbrace{\delta_4}_{} \rangle = -v_n\{4\}^4$$

Nonflow of 4-particles $\delta_4 \sim 1/M^3$





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CONCLUSION

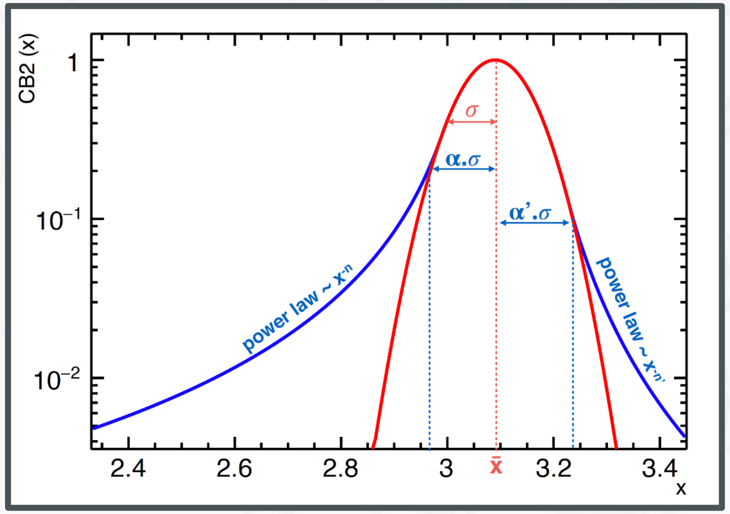
- Realistic simulations of MCH chambers
- $(A \times \epsilon)$ calculation for Pb-Pb 2023 Data
- J/ψ flow analysis by measuring multi-particle correlations

BACK UP

FIT FUNCTIONS FOR SIGNAL EXTRACTION

Signal function:

- Double Crystall Ball



$$CB2(x) = N \cdot \begin{cases} \exp\left(\frac{-(x-\bar{x})^2}{2\sigma^2}\right) & \text{for } \alpha' > \frac{x-\bar{x}}{\sigma} > -\alpha \\ A.\left(B - \frac{x-\bar{x}}{\sigma}\right)^{-n} & \text{for } \frac{x-\bar{x}}{\sigma} \leq -\alpha \\ C.\left(D + \frac{x-\bar{x}}{\sigma}\right)^{-n'} & \text{for } \frac{x-\bar{x}}{\sigma} \geq \alpha' \end{cases}$$

$$A = \left(\frac{n}{|\alpha|}\right)^{n} \cdot exp\left(-\frac{|\alpha|^2}{2}\right), B = \frac{n}{|\alpha|} - |\alpha|$$

$$C = \left(\frac{n'}{|\alpha'|}\right)^{n'} \cdot exp\left(-\frac{|\alpha'|^2}{2}\right), D = \frac{n'}{|\alpha'|} - |\alpha'|$$

Background function:

- Quadratic Variable Width Gaussian

$$qVWG(x) = N\exp\left(\frac{-(x-\bar{x})^2}{2\sigma^2}\right)$$

$$\sigma = \alpha + \beta\left(\frac{x-\bar{x}}{\bar{x}}\right) + \gamma\left(\frac{x-\bar{x}}{\bar{x}}\right)^2$$

- Ratio de Polynômes

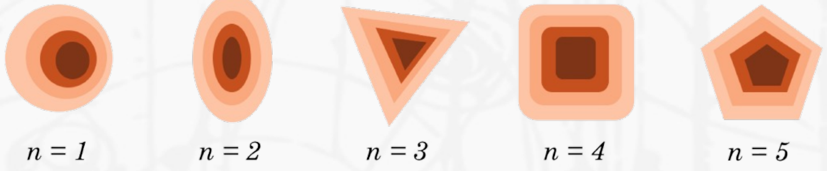
$$Pol(x) = N\frac{1 + a_1x + a_2x^2}{b_1x + b_2x^2 + +b_3x^3}$$

- Polynôme d’ordre 6

$$\gamma(x) = a + bx + cx^2 + dx^3 + ex^4 + fx^5 + gx^6$$

J/Ψ FLOW ANALYSIS

FLOW:



$v_n = \langle \cos n(\varphi - \Psi_n) \rangle$ ⟷ Ψ_n is hardly known in experiment

2-PARTICLE AZIMUTHAL CORRELATION:

$$c_n\{2\} = \langle\langle\, e^{in(\varphi_1 - \varphi_2)} \rangle\rangle = \langle\langle \cos n(\varphi_1 - \varphi_2) \rangle\rangle$$

$$\begin{aligned} \langle\langle \cos n(\varphi_1 - \varphi_2) \rangle\rangle &= \langle\langle \cos n\,[(\varphi_1 - \Psi_n) - (\varphi_2 - \Psi_n)] \rangle\rangle \\ &= \langle\langle \cos n(\varphi_1 - \Psi_n) \cdot \cos n(\varphi_2 - \Psi_n) \rangle\rangle \overset{= 0 \text{ due to symmetry } ^{\text{(Pb-Pb)}}}{\cancel{+ \langle\langle \sin n(\varphi_1 - \Psi_n) \cdot \sin n(\varphi_2 - \Psi_n) \rangle\rangle}} \\ &= \langle v_n^2 \rangle \end{aligned}$$

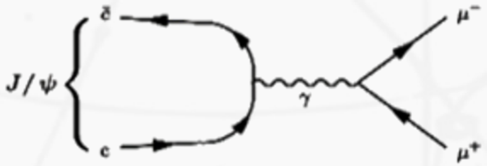
→ RMS value of v_N distribution without knowing Ψ_n

In fact in experiment we actually get: $\langle\langle \cos n(\varphi_1 - \varphi_2) \rangle\rangle = \langle v_n^2 + \delta_2 \rangle$

Nonflow (resonance decay, jets etc) ←

CHARMONIA

$J/\psi(1S)$ ⟷ $I^G(J^{PC}) = 0^-(1^{--})$

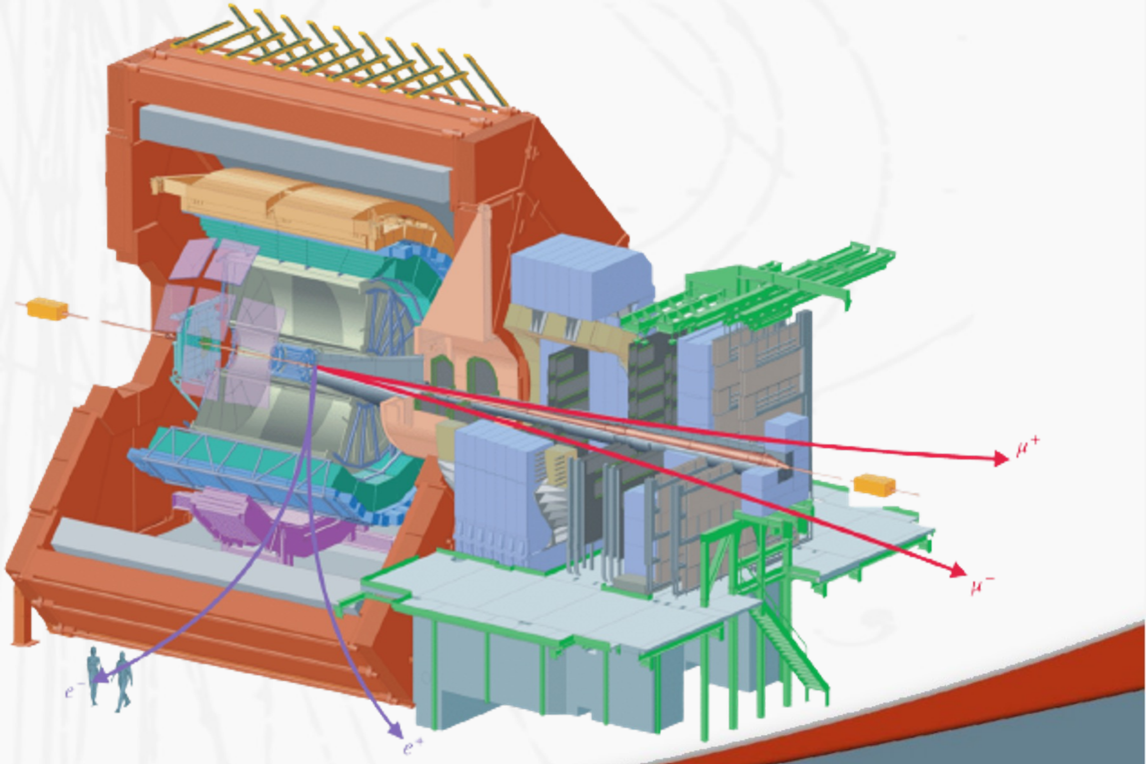


	Mode	Fraction (Γ_i/Γ)
Γ_1	hadrons	(87.7 ± 0.5) %
Γ_2	virtual $\gamma \to$ hadrons	(13.50 ± 0.30) %
Γ_3	ggg	(64.1 ± 1.0) %
Γ_4	γgg	(8.8 ± 0.5) %
Γ_5	e^+e^-	(5.94 ± 0.06) %
Γ_6	$\mu^+\mu^-$	(5.93 ± 0.06) %

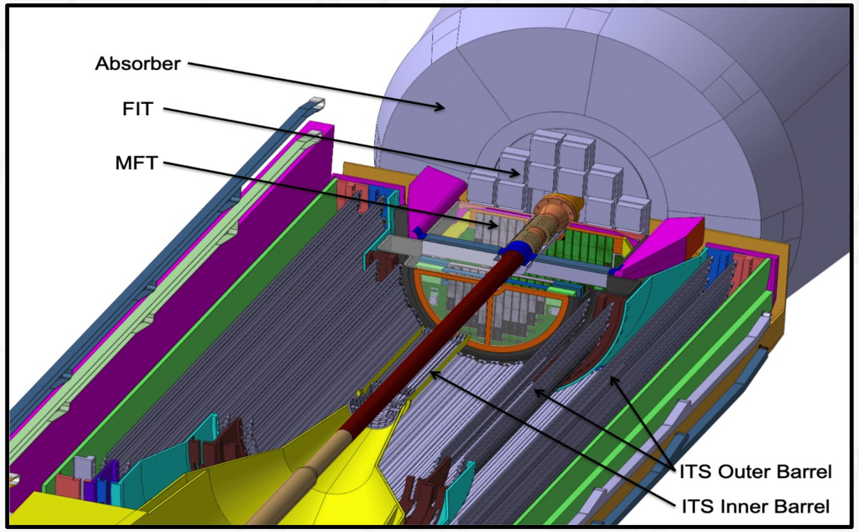
CENTRAL AND FORWARD DETECTORS

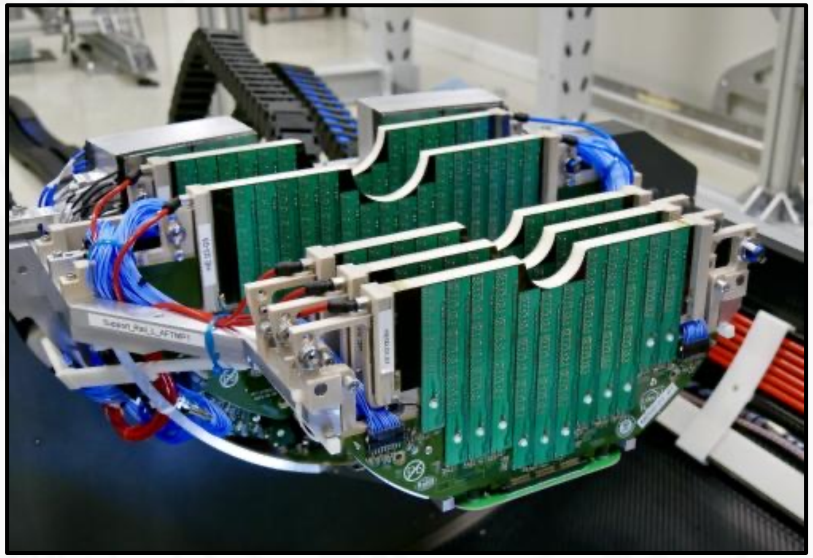
Mid-rapidity $\begin{cases} J/\psi \to e^+e^- \\ |y_{ee}| < 0{,}9 \end{cases}$

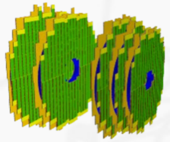
Forward-rapidity $\begin{cases} J/\psi, \psi(2S), \Upsilon(nS) \to \mu^+\mu^- \\ 2{,}5 < |y_{\mu\mu}| < 4 \end{cases}$



CHARACTERISTICS OF MFT

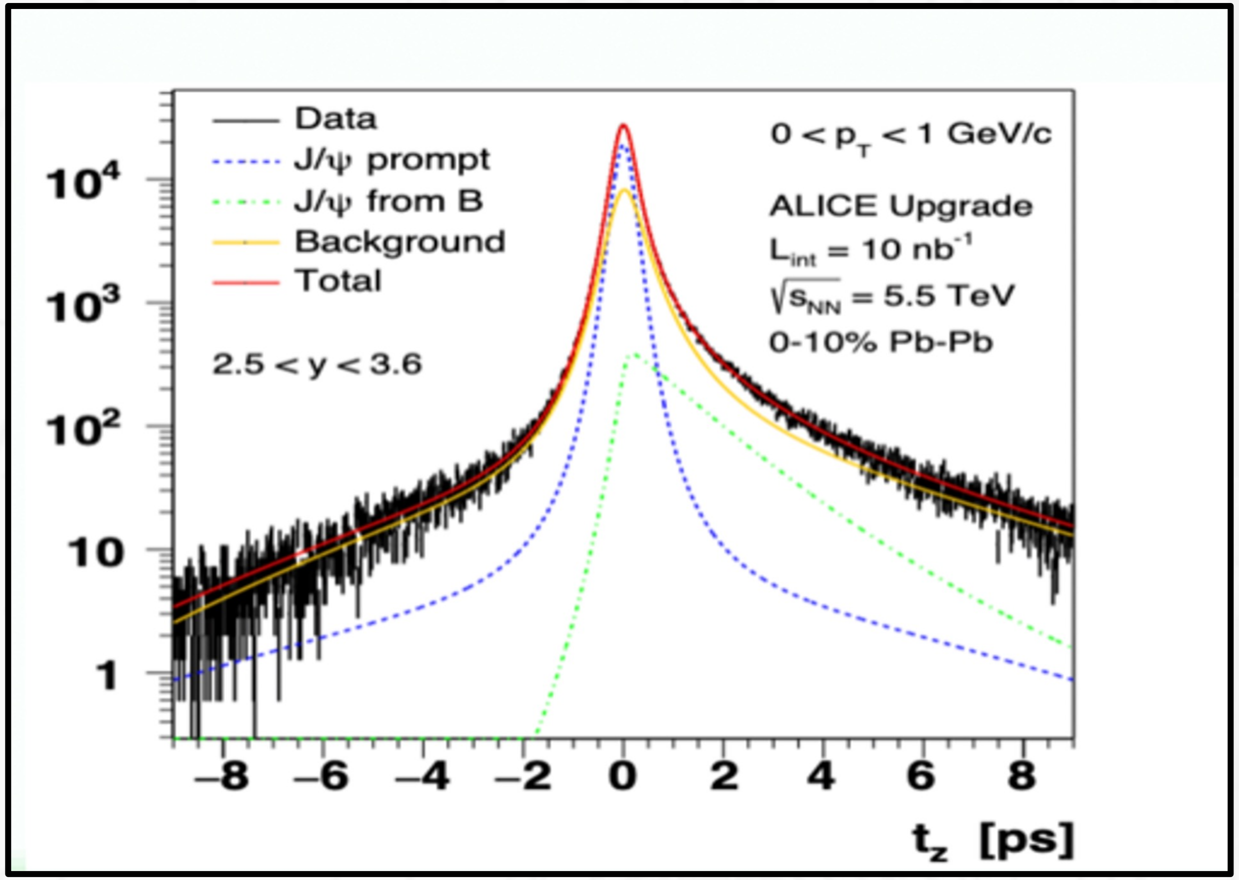






- Installed between ITS and the absorber
- Designed to obtain hig spatial resolution
- Five double sided disks composed of 936 silicon pixel sensors

Identifying Prompt and Nonprompt



Pseudo proper decay time:

$$\tau_z = \frac{(z_{J/\psi} - z_{vtx}) \cdot M_{J/\psi}}{p_z}$$