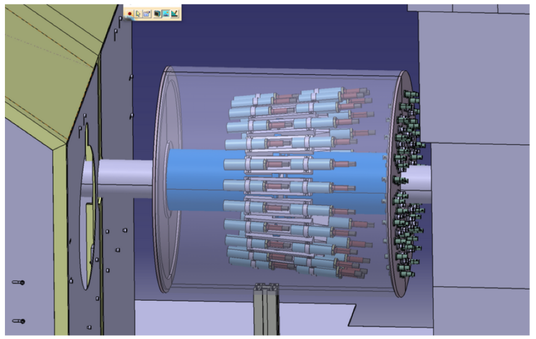
Benjamin Audurier - French-Ukranian Workshop - October 28th 2021

PLUME data for heavy-ion physics



PLUME is placed here !

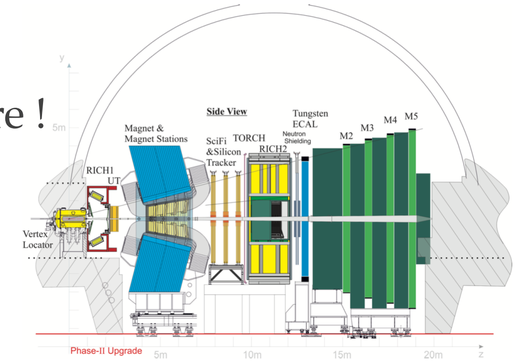


Figure 4.1: Schematic side view of the Phase-II detector.

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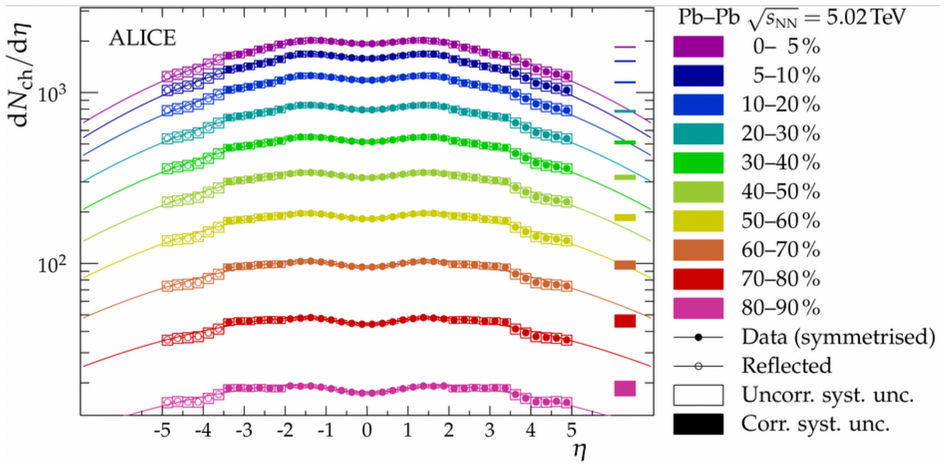
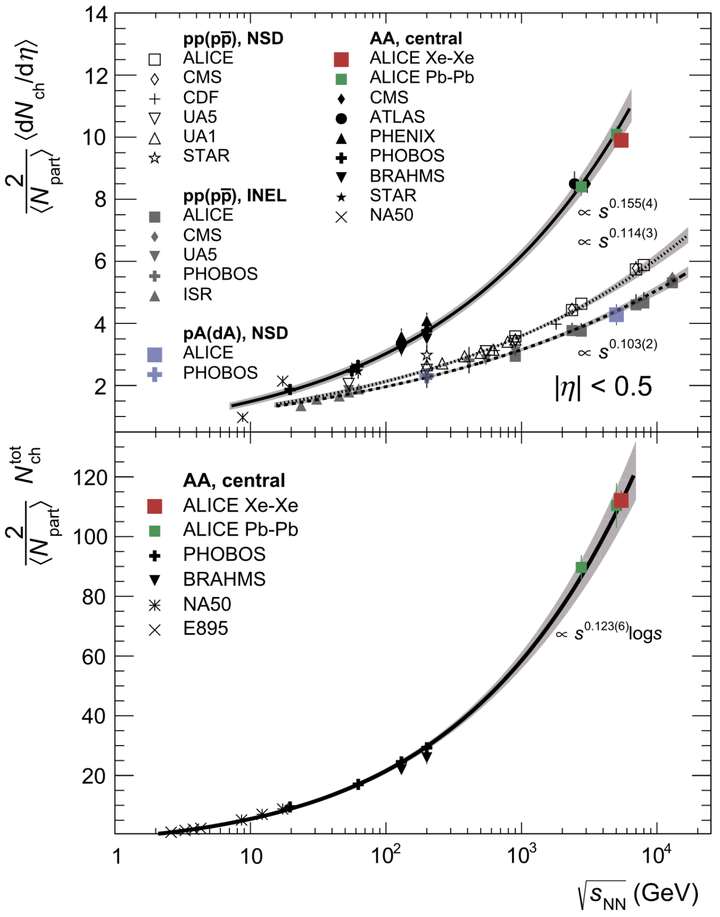
Introduction

Goals of this talk

- **This talk is not about luminosity** measurements in heavy-ion collisions !
  - Plume should work just fine, no need to discuss this topic.
- This talk is meant to trigger discussions.
  - I am not a Cherenkov detector expert, but I know a thing or two about heavy-ion physics…
- General considerations about heavy-ion collisions at the LHC (pPb and PbPb):
  - No pile-up : ~0.05 PbPb collisions per bunch crossing, not much higher in pPb.
  - Lot of tracks.

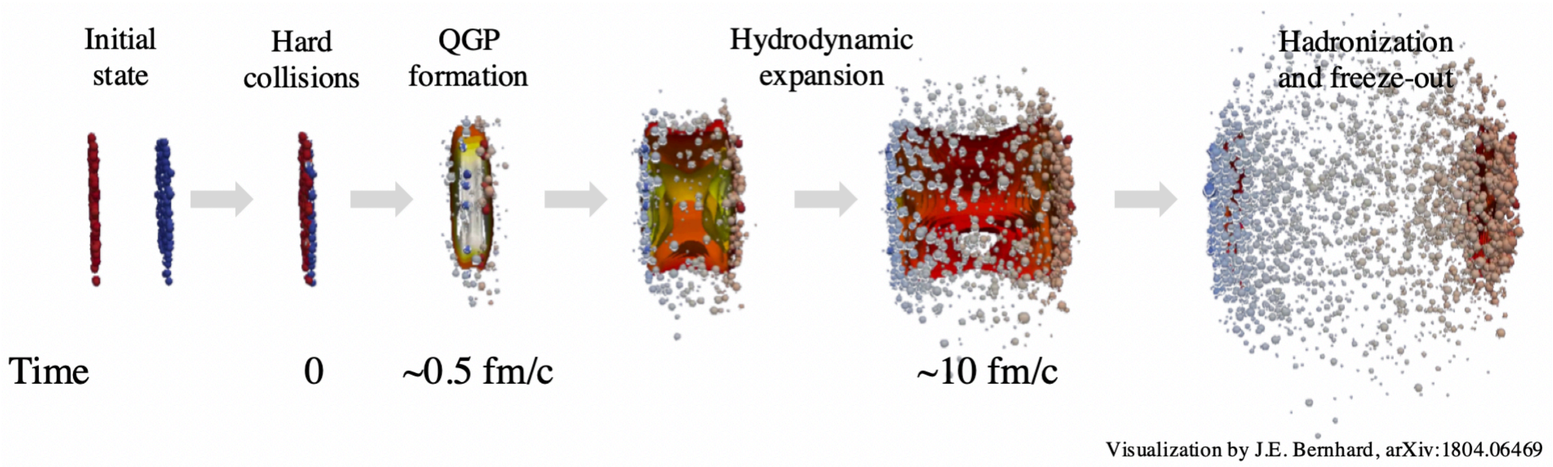


Phys. Lett. B 772 (2017)



Physics Letters B 790 (2019) 35–48

AA collision in a nutshell



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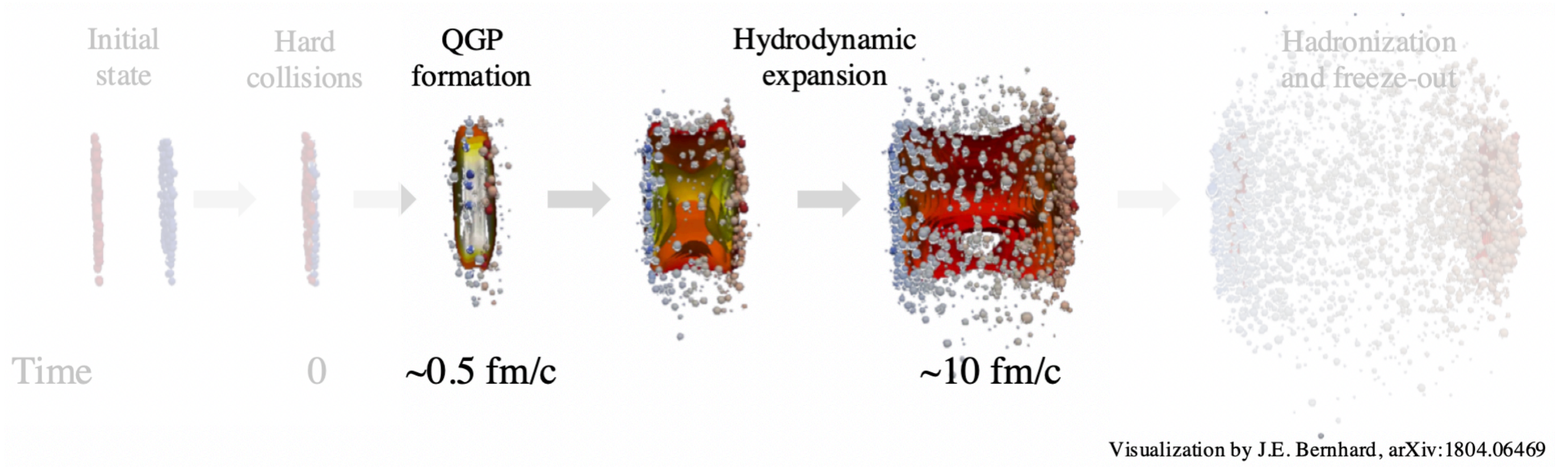

Visualization by J.E. Bernhard, arXiv:1804.06469

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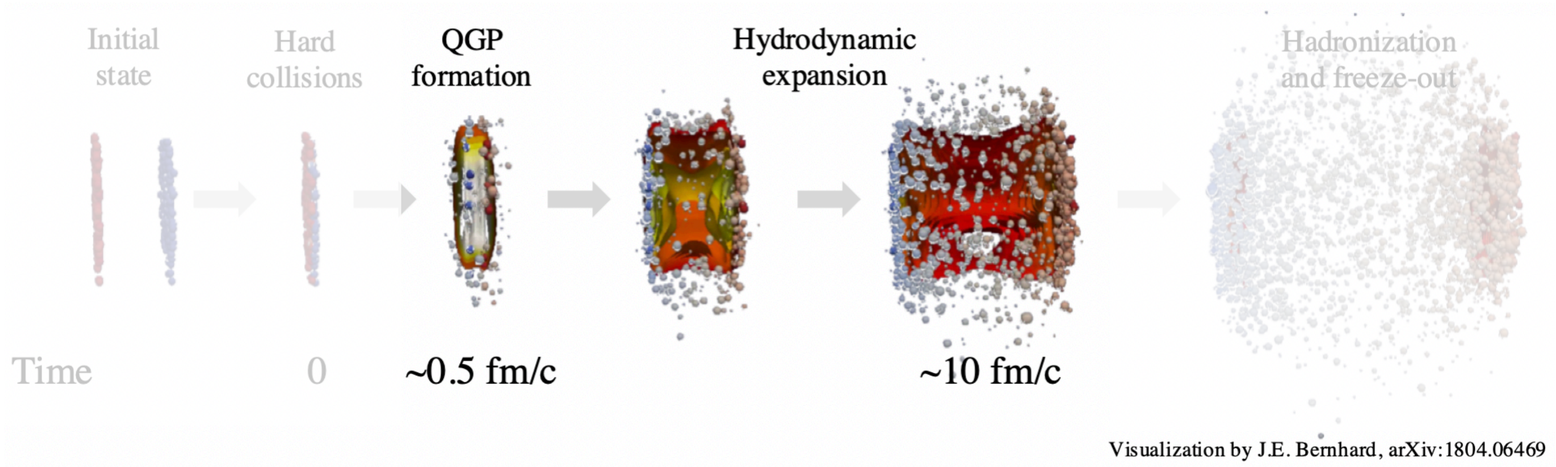

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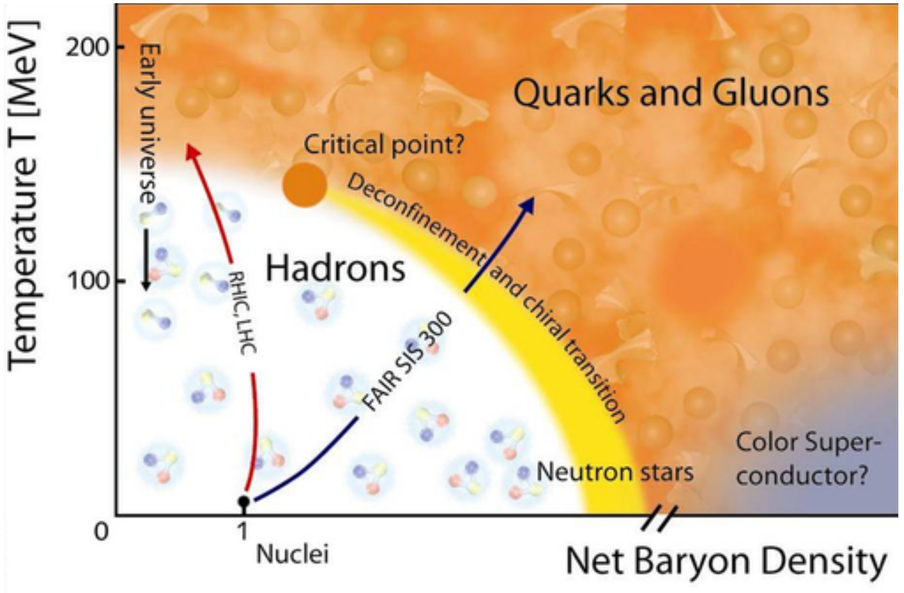

- **<u>Physics motivation to study the Quark-Gluon Plasma:</u>**

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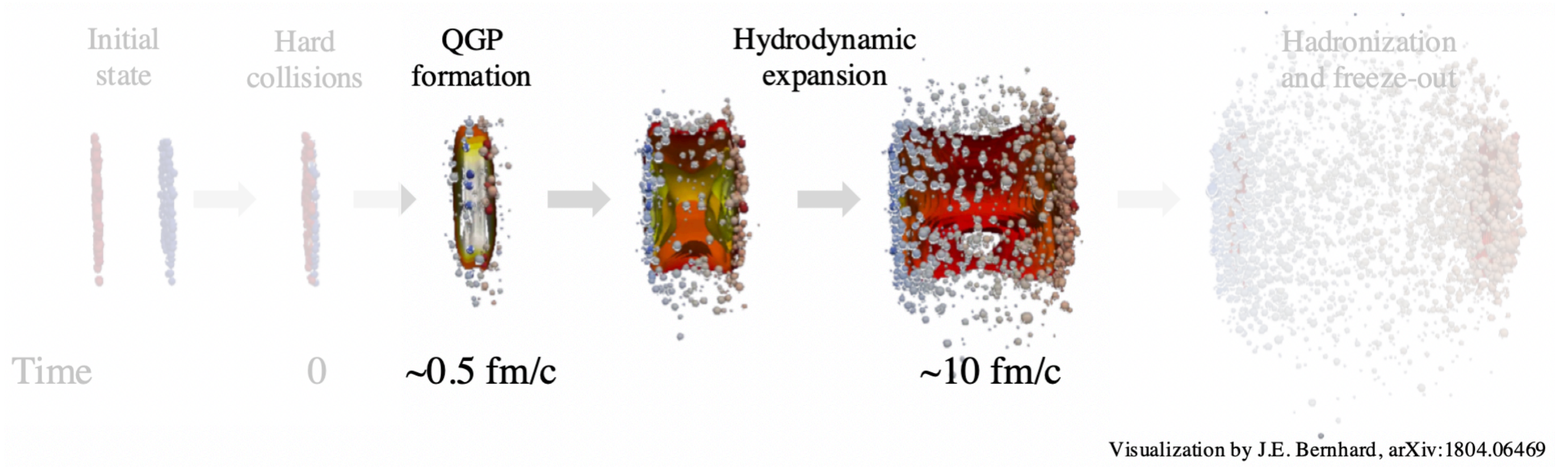

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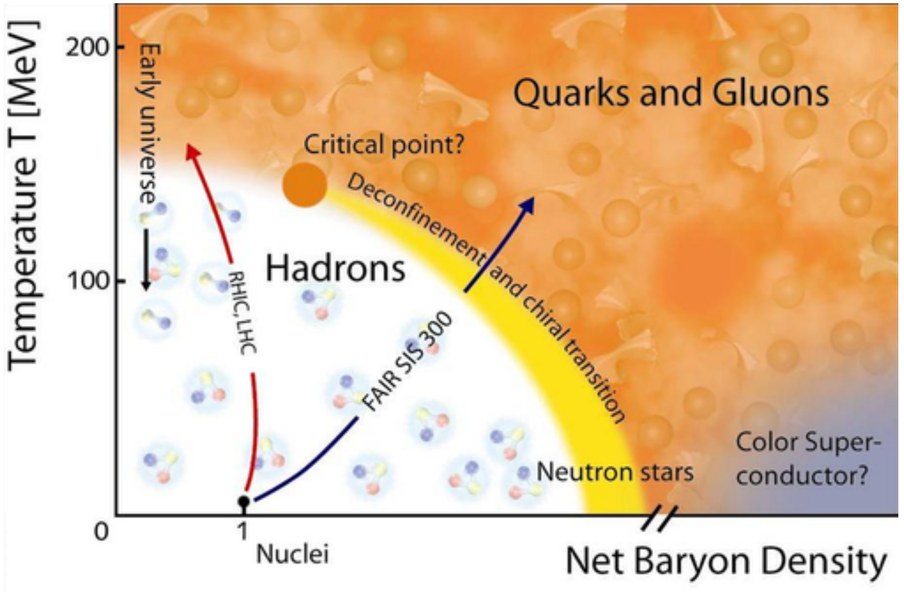

- **<u>Physics motivation to study the Quark-Gluon Plasma:</u>**
  - Phase transition between confined and deconfined matter.
    - ➡ QCD; QCD equation of state; hadronization mechanisms.

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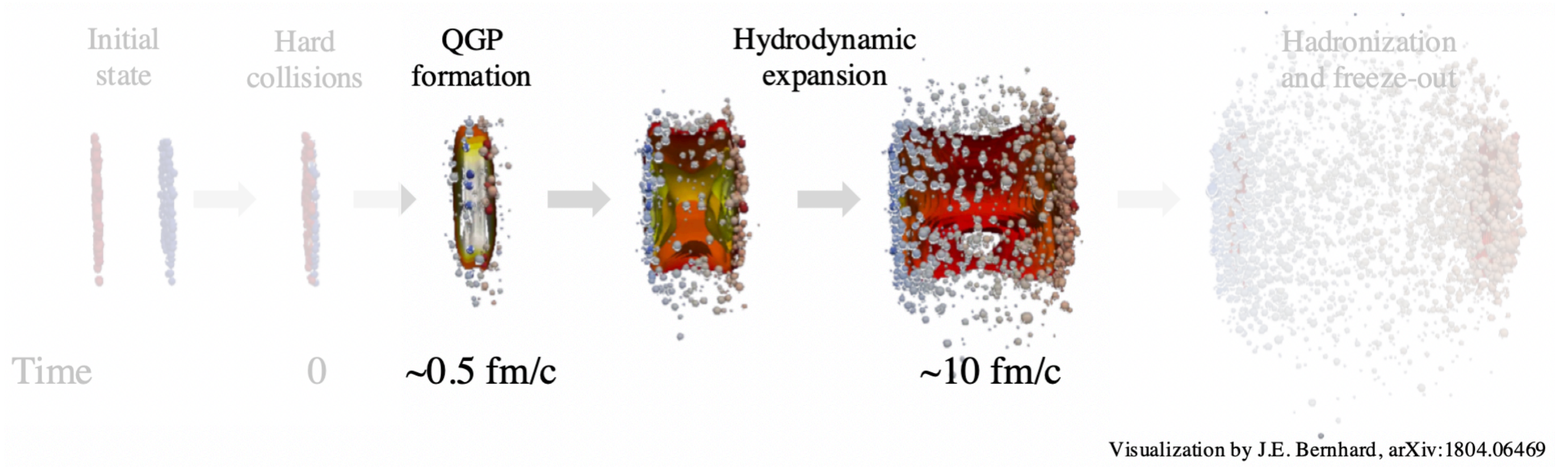
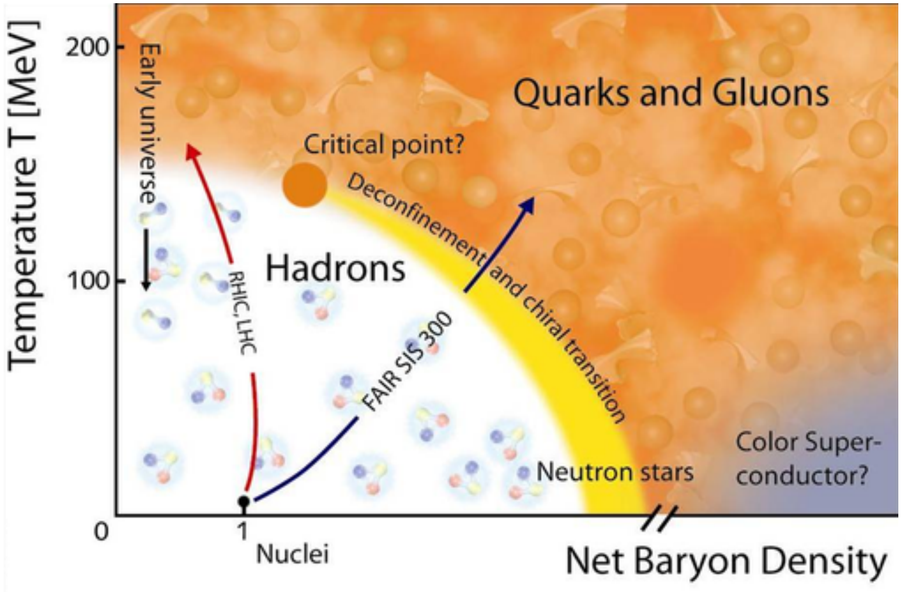
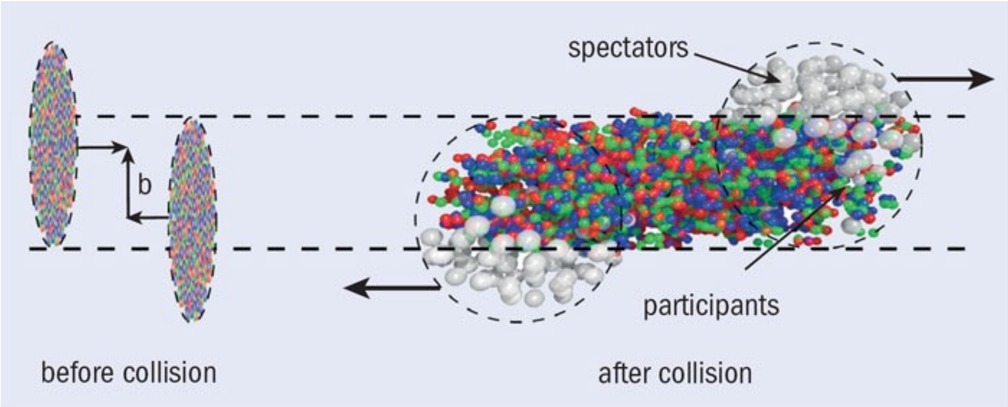




- **<u>Physics motivation to study the Quark-Gluon Plasma:</u>**
  - Phase transition between confined and deconfined matter.
    - ➡ QCD; QCD equation of state; hadronization mechanisms.
  - QGP droplet's properties and expansion.
    - ➡ Hydrodynamics.

Physics case

Case 1 : Centrality



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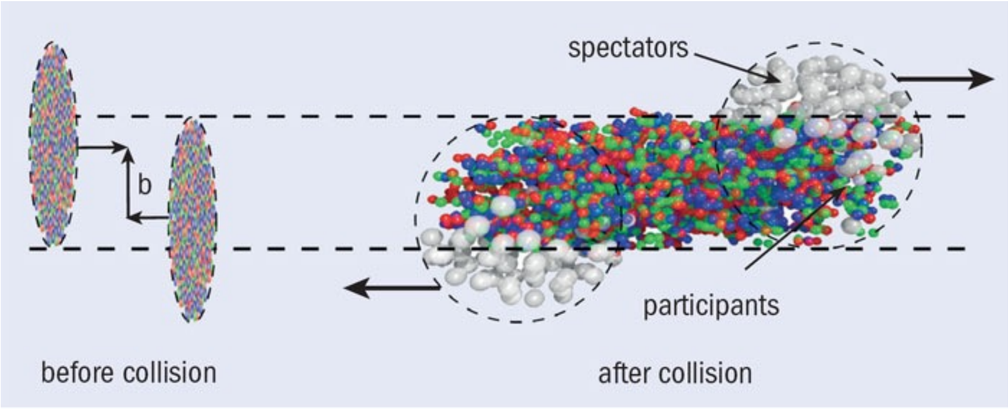

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Glauber makes the link !

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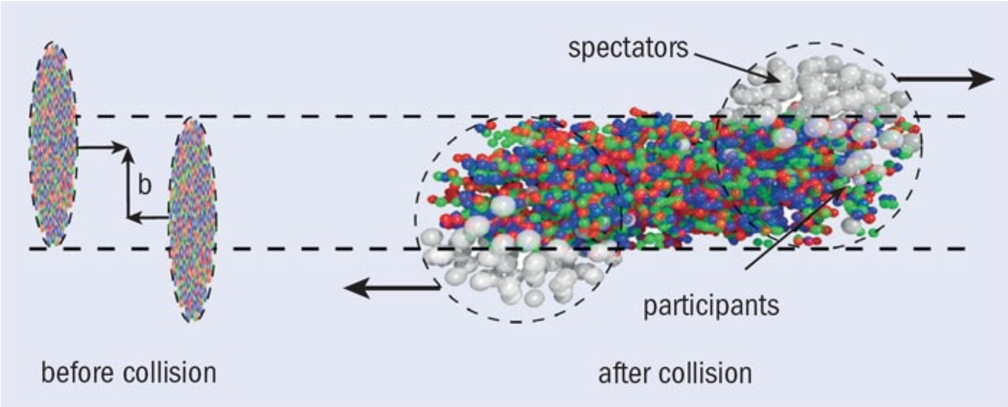

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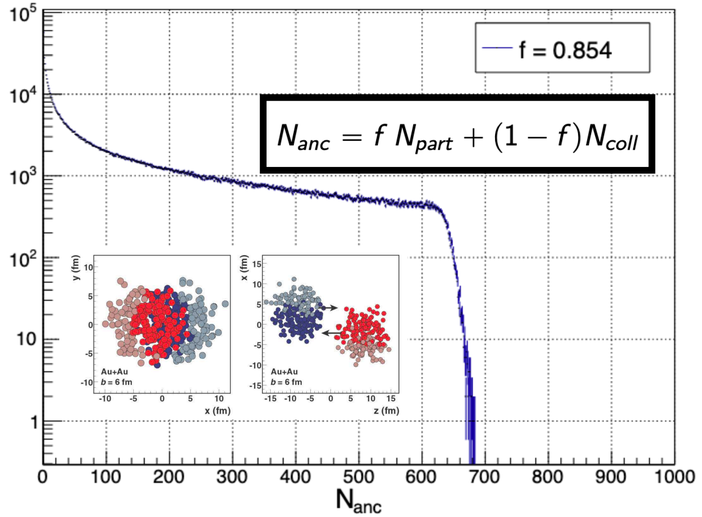
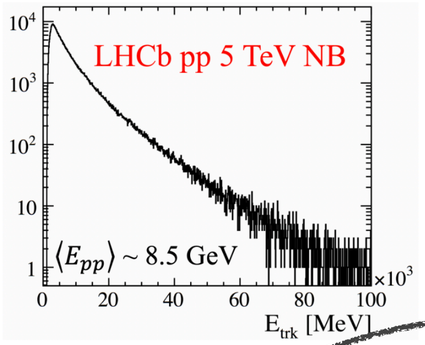
Glauber makes the link !

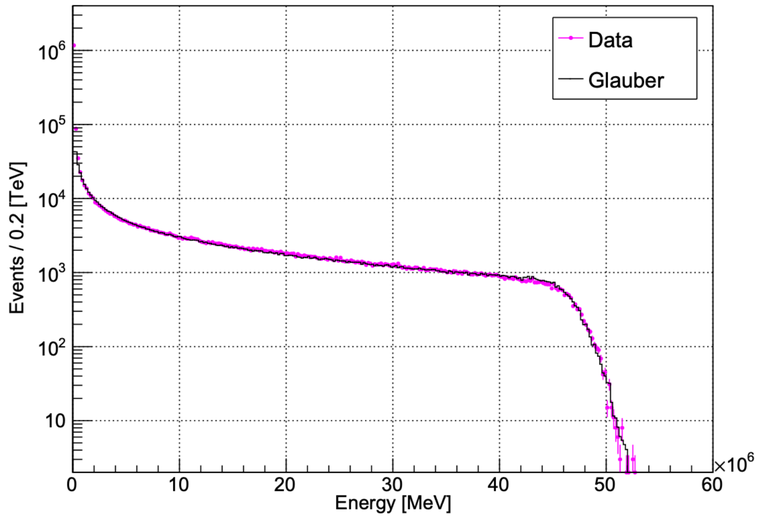
- Centrality: percentage of the total inelastic cross-section.
  - **Central** collision <=> low impact parameter b <=> **more** particles.
  - **Peripheral** collision <=> large impact parameter b <=> **less** particles.
- Centrality classification done with **two ingredients**: **a detector** and **the Glauber model.**
  - Centrality measured with ECAL in LHCb, but PLUME could do just the same !

Centrality in LHCb

Step 1 : generate AA collisions with Glauber



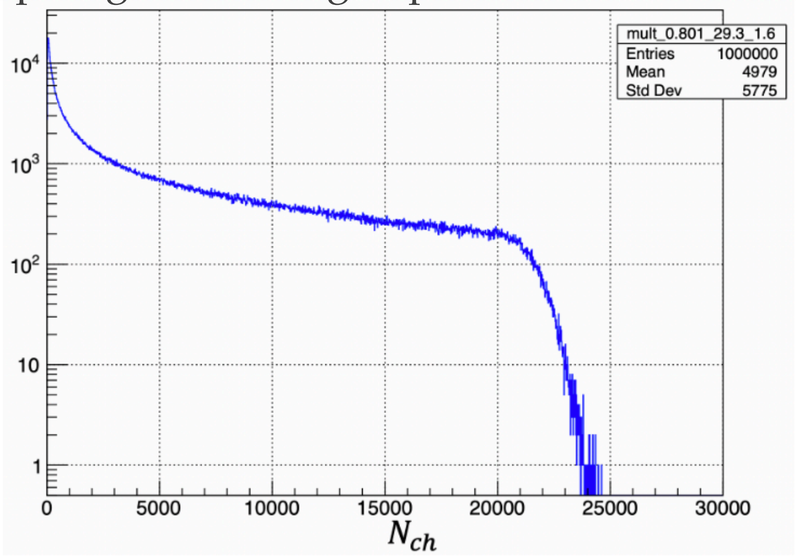


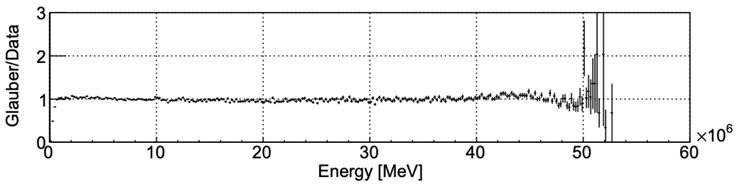


Step 2 : get the charged particles distribution

$$P_{\mu,k}(n) = \frac{\Gamma(n+k)}{\Gamma(n+1)\Gamma(k)} \frac{(\mu/k)^n}{(\mu/k+1)^{n+k}}$$

P := negative binomial distributions
:= charged particles distribution per ancestor





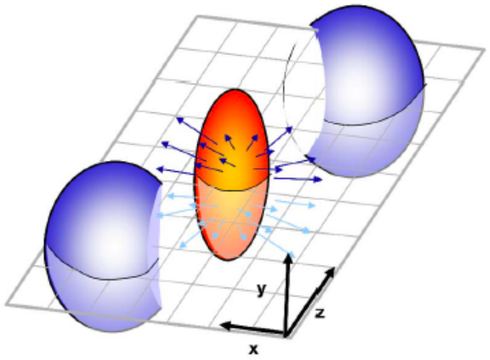
Step 3 : fit to a detector observable

Centrality measurements with PLUME

- Step 1 and step 2 are independent of the detector.
  - Only the transition between step 2 and step 3 should be adapted for PLUME.
- **Centrality is crucial** for all samples including an ion at the LHC:
  - pPb, Pb-SMOG, p-SMOG
- On a long term, PLUME could be used with/instead of ECAL for centrality estimation, especially for « small systems ».
  - Very bias sensitive measurements in pp,pA,p-SMOG collisions.

Case 2 : event plane and elliptic flow

- Semi-central AA collisions => px-py momentum asymmetry.
  - Modification of the charged particles angular distribution.
- Elliptic flow (n=2) **sensitive to collective effects**.
  - Historically, a prob for hydrodynamic phase of the collision.
- **Elliptic flow in small system: the big discovery of LHC Run 2**
  - Dozens of papers, and we still don't fully understand !



$$\mathrm{E}\frac{d^3\mathrm{N}}{d^3p} = \frac{1}{2\pi}\frac{d^2\mathrm{N}}{p_\mathrm{T}dp_\mathrm{T}dy}\{1+\sum_{n=1}^{\infty} 2v_n\cos(\mathrm{n}(\phi-\Psi_{\mathrm{RP}}))\}.$$

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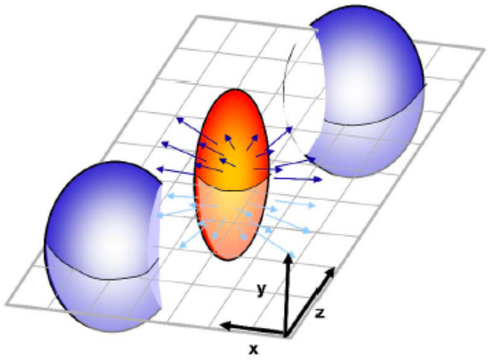

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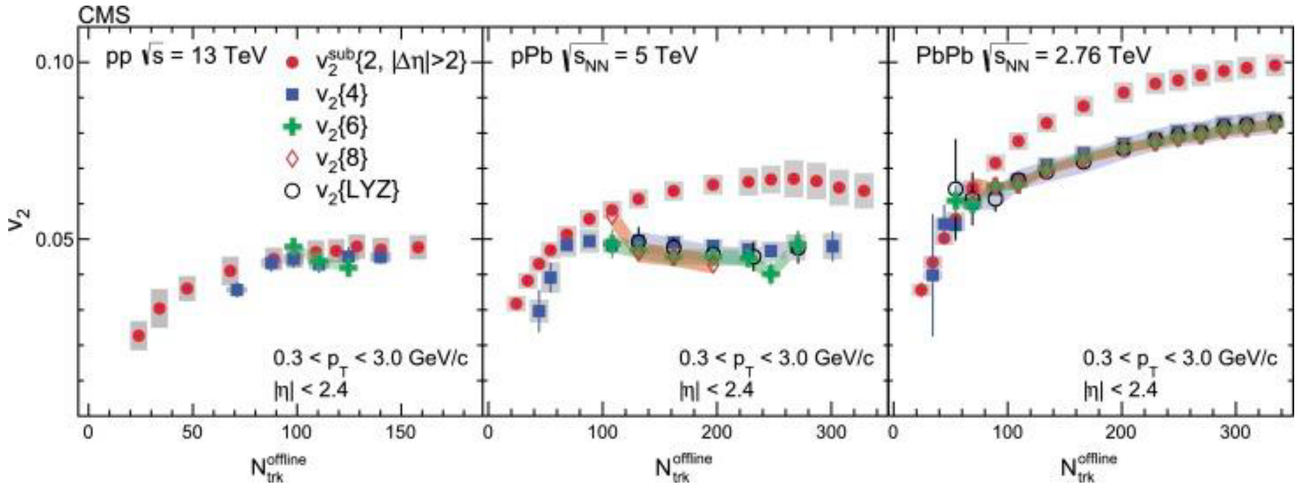

Experimentaly, how do we measure particles flow ?

Case 2 : event plane and elliptic flow

- Many different methods to compute the flow.
  - Event plane, Cumulants, scalar products ….
- The most intuitive to start with (in my opinion) is **the event plane method.**

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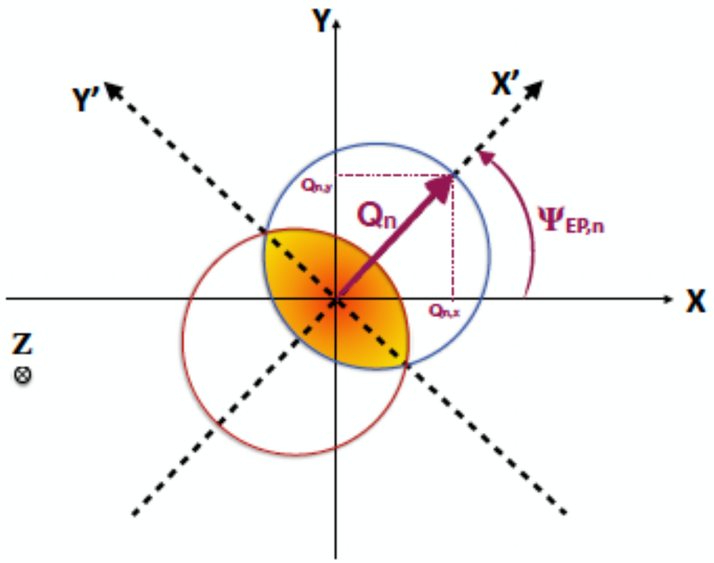


goal : Evaluate the Q vector

$$Q_n \equiv Q_{n,x} + iQ_{n,y} = |Q_n| \exp\{in\Psi_{EP,n}\}.$$

$$Q_{n,x} = \sum_{N_p} (w_i \cos n\phi_i)$$

$$Q_{n,y} = \sum_{N_p} (w_i \sin n\phi_i)$$

Flow harmonic n measured using

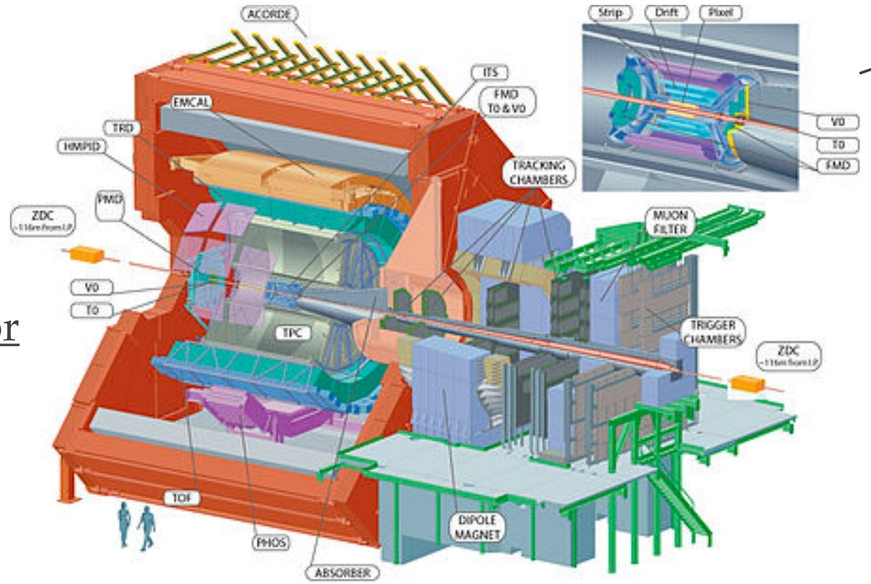
$$\Psi_{EP,n} = \frac{1}{n} \arctan \frac{Q_{n,y}}{Q_{n,x}}$$

$$v_n^{obs}(p_T, y) = \langle \cos[n(\phi_i - \Psi_{EP,n}] \rangle.$$

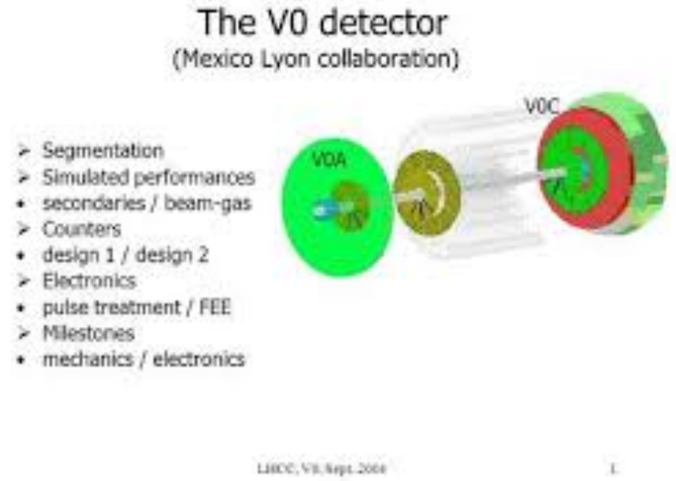
- $N_p \equiv$ total number of charged particles.
- $w_i \equiv w_i(E_p)$.
- However, $\sum_{N_p}$ can be replaced by a sum over photomultipliers.

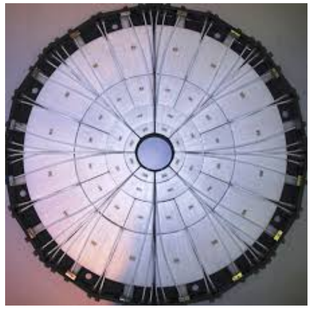
Case 2 : event plane and elliptic flow

- From the detector point of view, we need:
  - Quantity sensitive to the charged particle multiplicity (i.e energy deposit).
  - High granularity.
  - Two detectors facing each others.



ALICE Detector





- In ALICE, the V0 is the main detector for event plane measurements…

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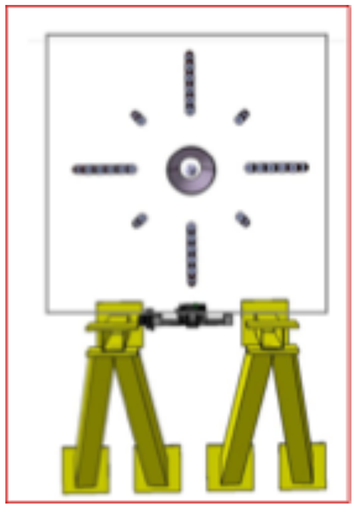

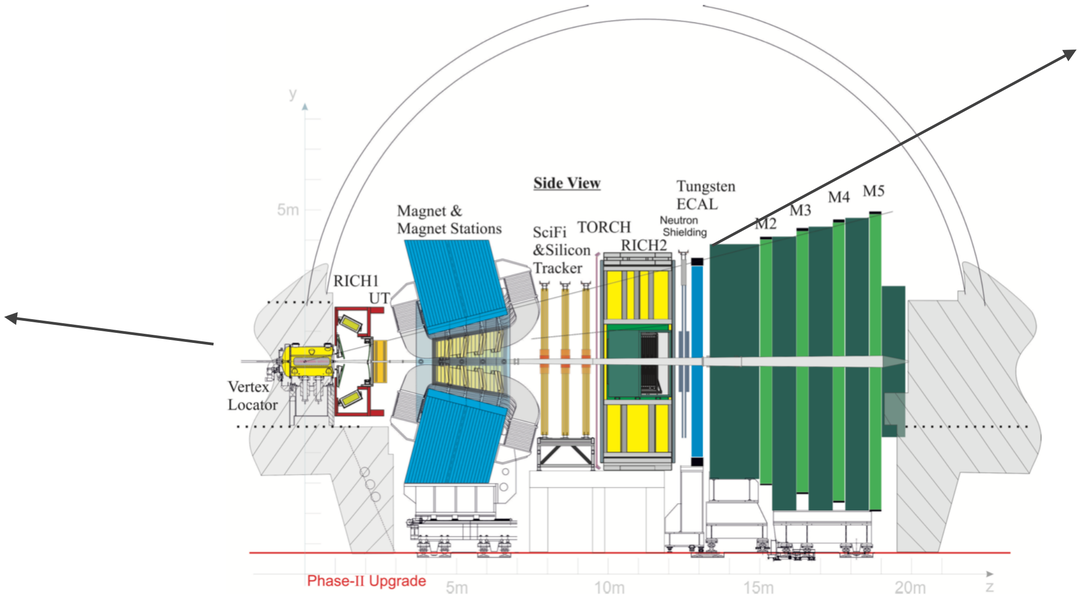

Figure 4.1: Schematic side view of the Phase-II detector.

(a) View from the LHCb cavern.

(b) Downstream view of the ECAL installation (but not completely closed) with the exception of some detector elements above the beam line.

- **But PLUME + ECAL should be the winning combo !**

Final remarks

- **Could PLUME be more than a luminosity counter for Heavy-ion physics ?**
  - Multiplicity and centrality classifier.
  - Event plane detector.
- The big question : **will PLUME cope with high multiplicities ?**
- **In any case, precise luminosity measurements in heavy-ion collisions with PLUME is extremely important, and we are looking forward to have it !**