Centrality detector concept

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The centrality problem

Model-dependent. Results & systematics are only good within model assumptions.

What is the best model? pPb data showed: MCG is not good as we need it to be.

Centrality Association. Many tweaks and assumptions on the way. As a result large systematic in peripheral, inability to accurately compare A-A to (p/d)-A.

Centrality bias. Just at the beginning of understanding what we deal with.

Just an observation (Dec 2014):

Time since the first LHC pPb data:	26 months
Published centrality pPb results:	0 papers

The Concept

The only measurable centrality observable is $N_{spectator} = 2A - N_{participants}$.

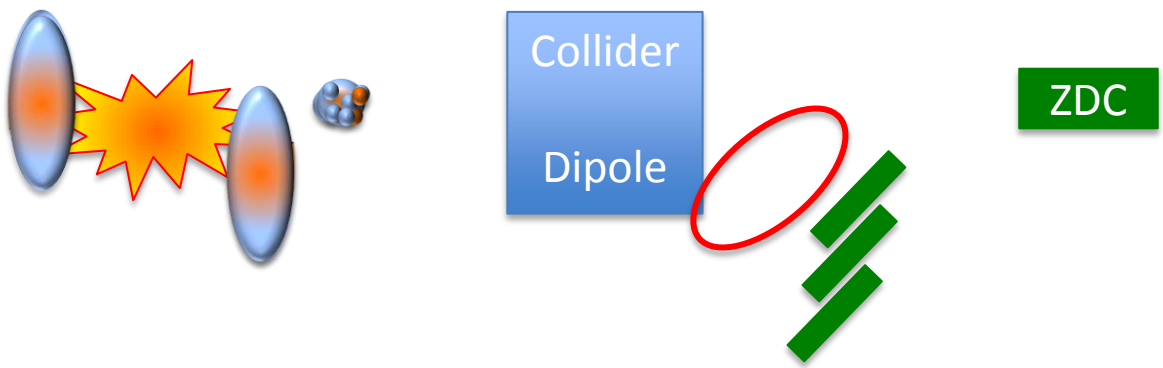
All RHIC and LHC experiments measure spectator neutrons, but ignore the rest.

Law of nature: Heavier species are more neutron rich

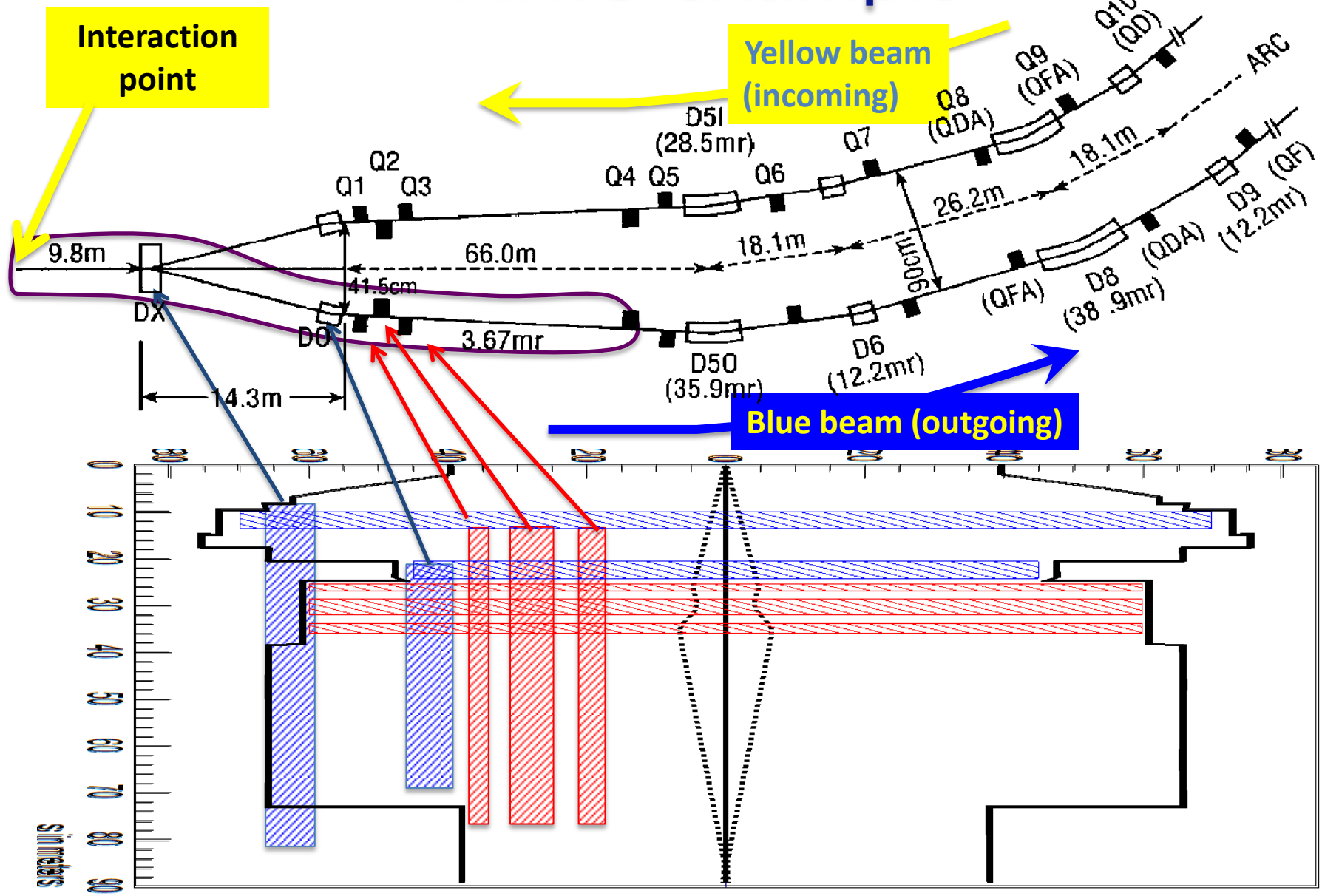
Spectator fragments MUST have less smaller mass to charge ratio.

Mass spectroscopy!

Collider magnetic system is a nearly perfect mass separator for spectator fragments according to their mass-to-charge ratio ~A/Z.



RHIC example



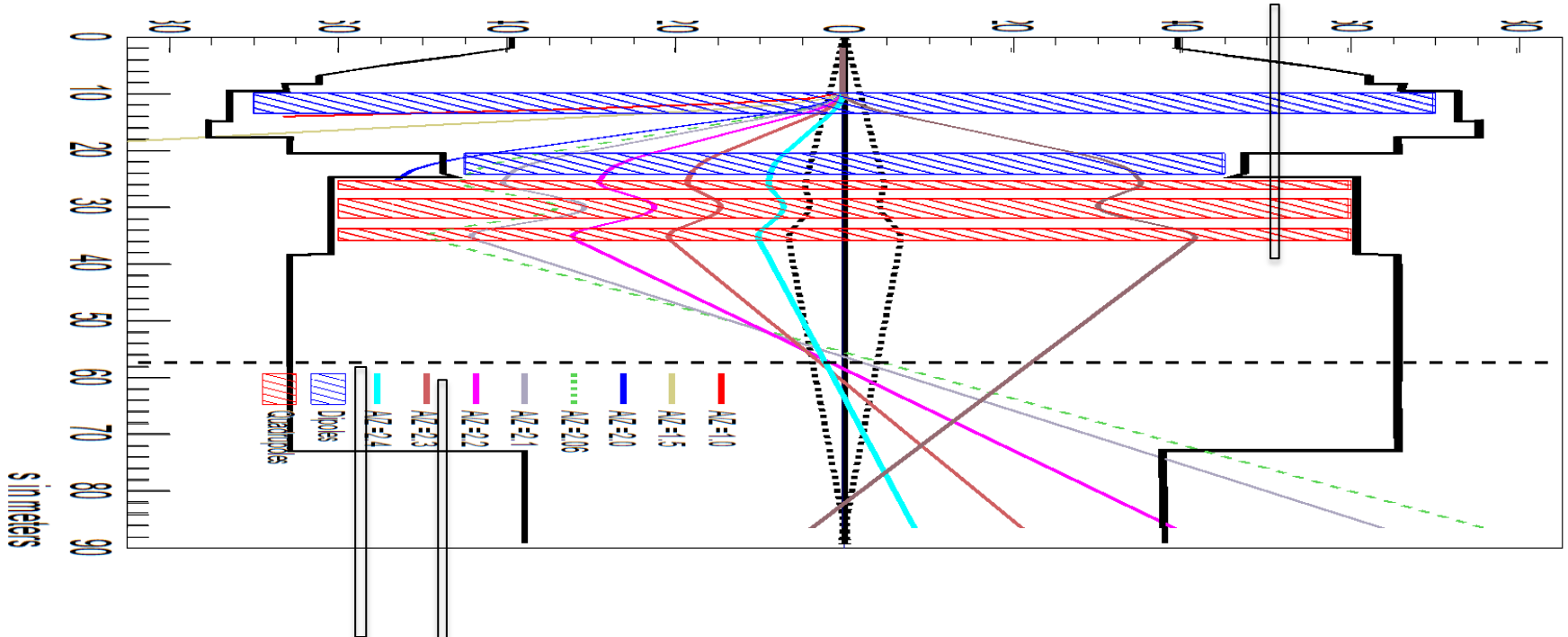
Detector stations

The third station is for the heaviest particles. It shall be around the IP reflection focus spot to get closer to the beam. This station defines the detector efficiency.

The first station is for the protons. This station shall be as close to the first dipole as possible, as protons depart early. This station defines the detector resolution

The second station shall be in between, providing to bridge the acceptances of the 1st and 3rd stations.

And one needs the ZDC!



Fragmentation

Ideally, the detector performance does not depend on how spectators fragment

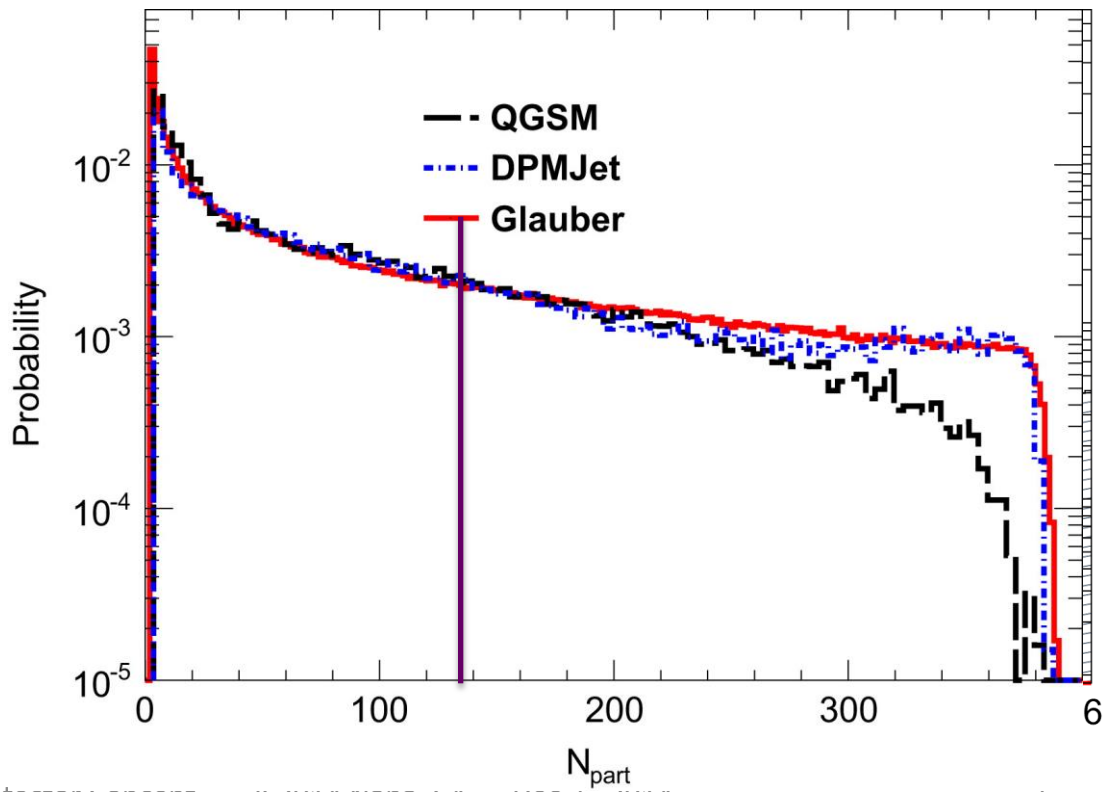
$$N_{part} = 2A_{ion} - \sum_{fragments} A_{fragment}$$

Practically, the detector performance strongly depends on fragmentation

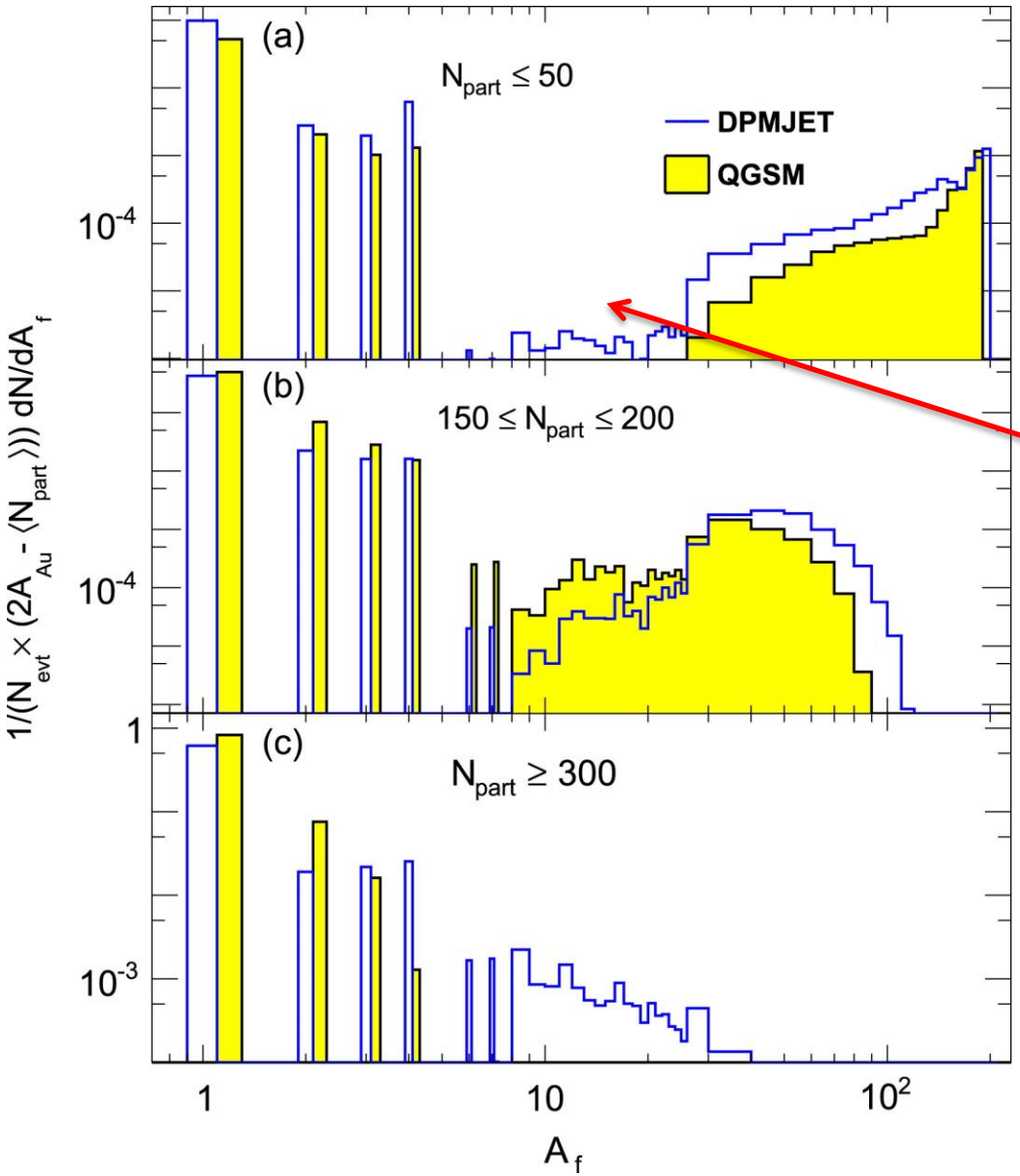
To understand performance one needs models: we used DPMJet and QGSM event generators.

Question: what is a spectator?

Final state particles with non-zero baryonic number and $|y|<5$ ($y_{beam} = 5.36$ @ RHIC), generated in a physics process that involves only one of the colliding ions.



Different scenarios



In peripheral DPMJet tends to fragment spectators into smaller pieces compared to QGSM

In central the trend flips over.

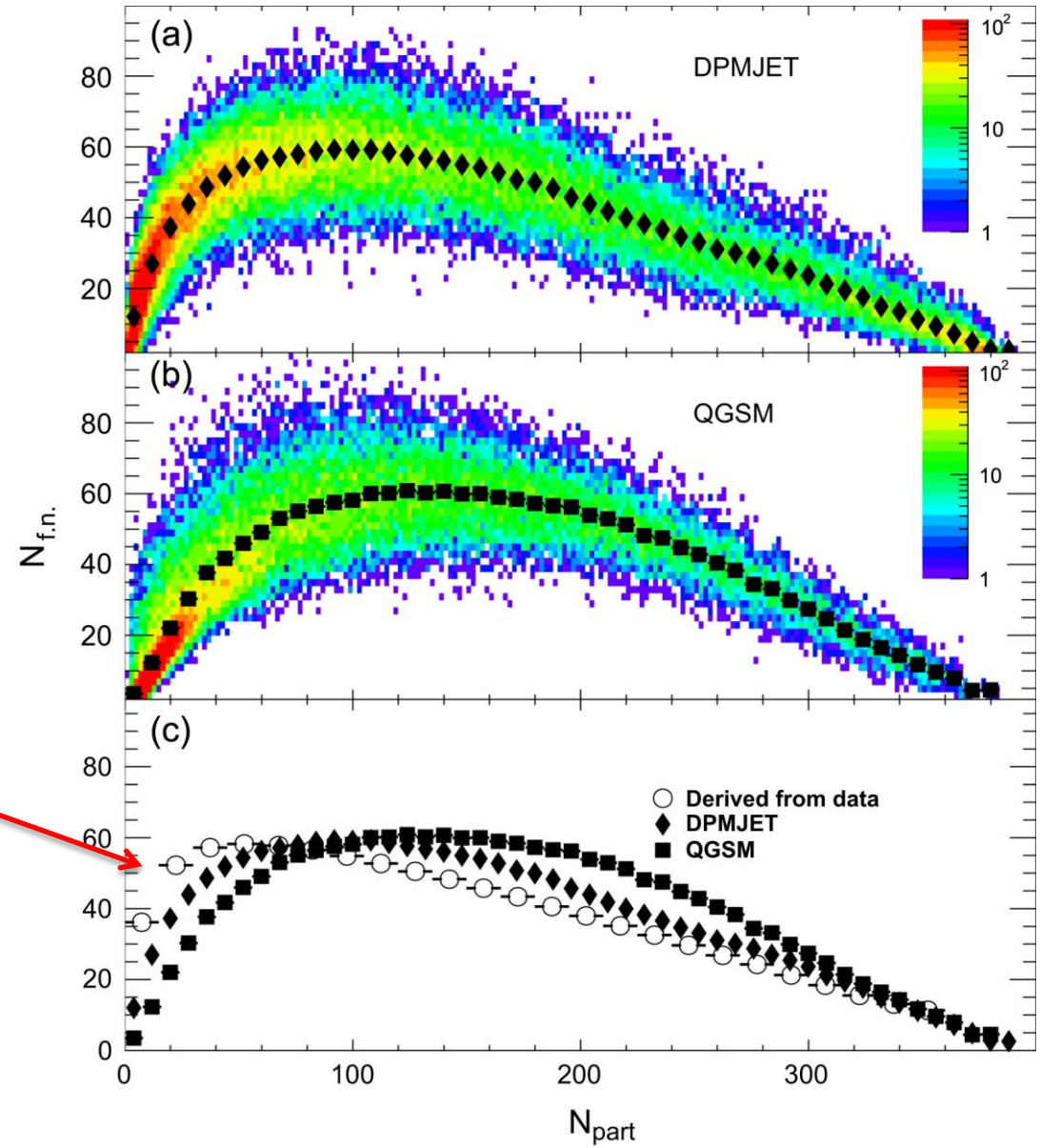
For centrality, peripheral collisions are much bigger problem than central.

… and how much one can trust them

No centrality differential data exists on fragmentation [NA49] and some old low energy experiments.

Only meaningful comparison can be done is with free neutrons measured by the ZDC.

Not ideal, DPMJet closer to data



Fragment deflection in stations

Collider effects:

Beam spreads in x and x'
Beam energy spread (*small*)
Vertex spread (*correct by event vertex*)

Collision effects (Fermi motion):

$$\langle x' \rangle \approx \frac{1}{\sqrt{3A_f}} \frac{p_F}{p_z}$$

$$\left\langle \frac{\Delta p_Z}{p_z} \right\rangle \approx \frac{1}{\sqrt{3A_f}} \frac{p_F}{m_N}$$

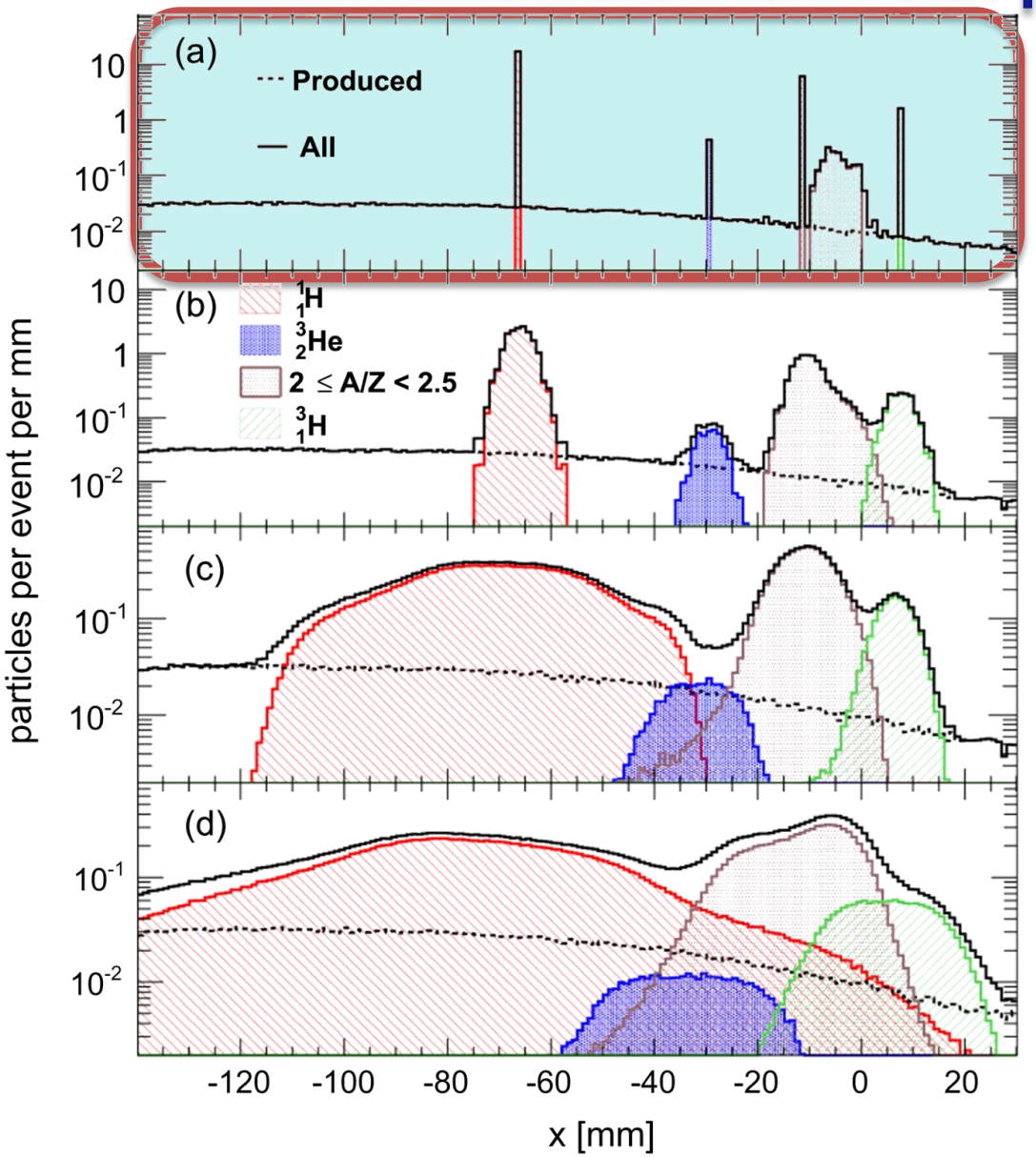
Depends on the collider energy,

$$p_z \approx \frac{\sqrt{s_{NN}}}{2}$$

Much more significant at RHIC than at LHC

Does not depend on collider energy.
Same at RHIC and LHC.

Deflection step by step



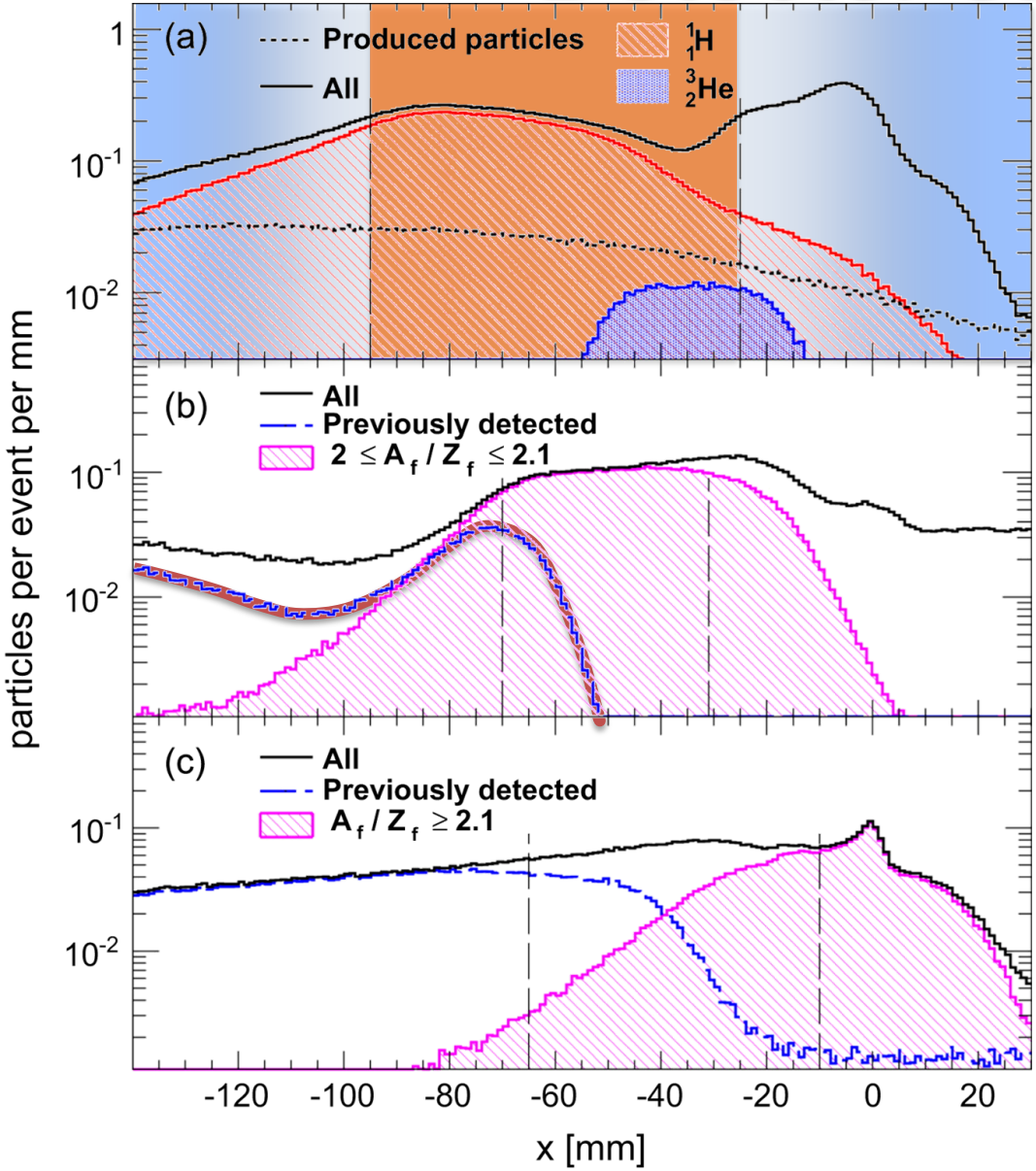
Ideal case: no smearing effects. Dashed line are particles coming from collision

Collider effects:
positional and angular spreads

+ Longitudinal Fermi motion

+ Transverse Fermi motion

Detector stations



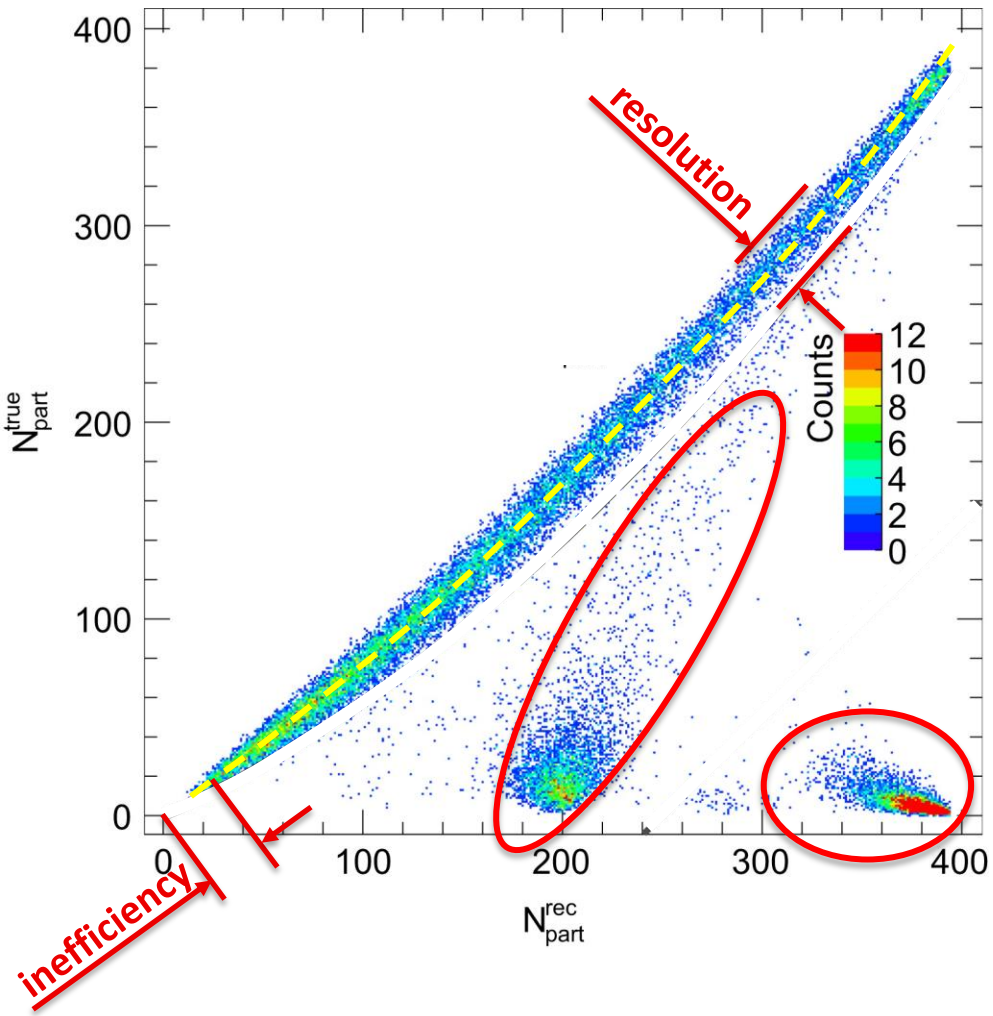
1st station works mainly for protons

Acceptance is:
magnet aperture on outside
beam size on inside.

2nd station is for fragments with $2<A_f/Z_f<2.1$

3rd station is for $A_f/Z_f>2.1$
The closer it gets to beam the better

N_{part} reconstruction



Heavy fragments missing the 3rd station on both sides.

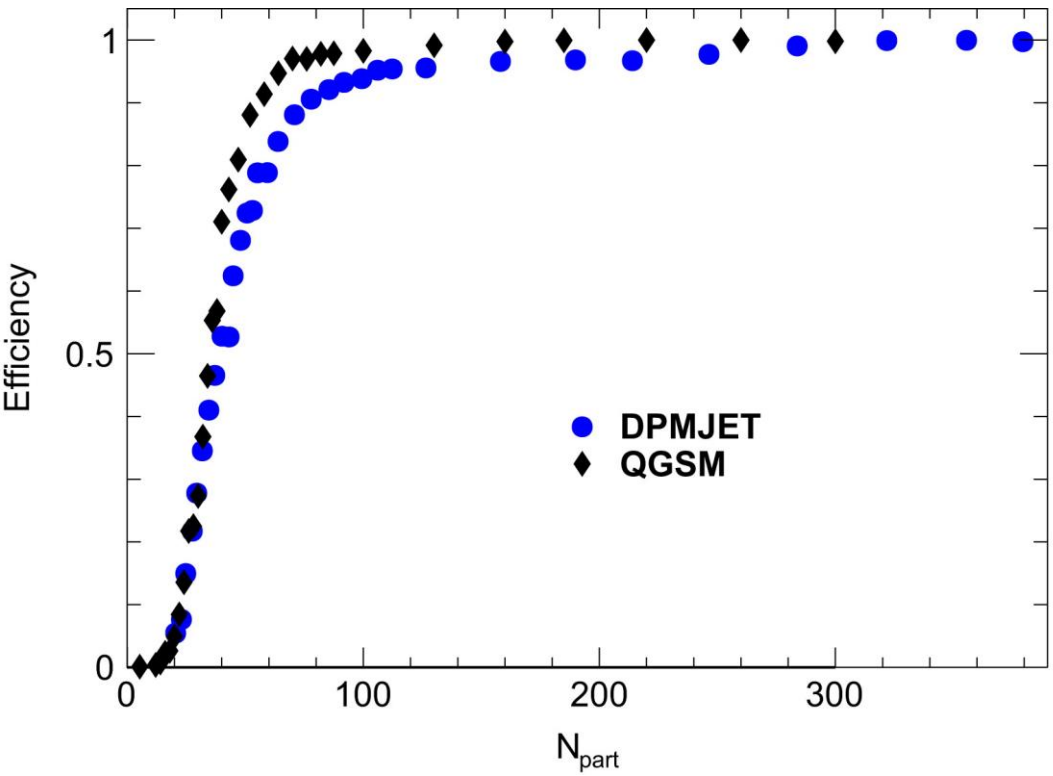
Comparing central detector response to centrality detector rejects such events

Heavy fragment missing 3rd station on one side.

Comparing two side rejects such events

Distribution is not linear → needs correction. Not a model based correction

Efficiency

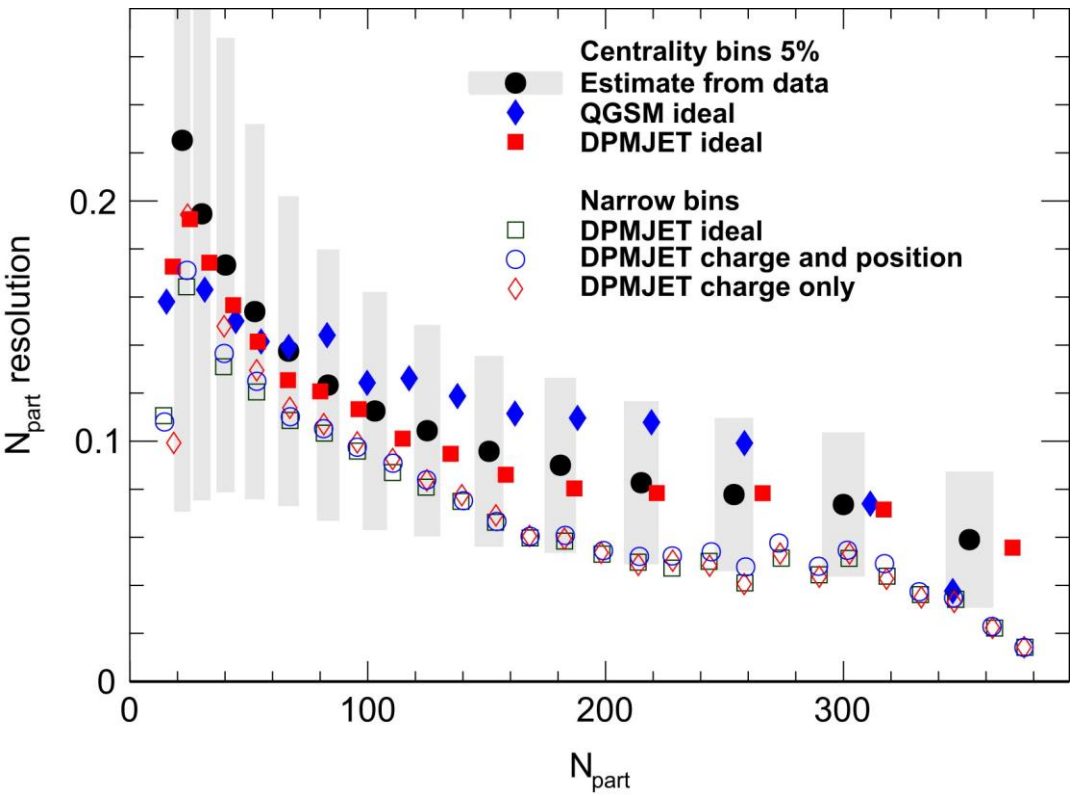


Depends on fragmentation

Starts above N_{part} = 10

Gets close to 100% at N_{part} = 50

Resolution



Vertical scale: Centrality bin width
Vertical bars: Uncertainty

Black points: From data

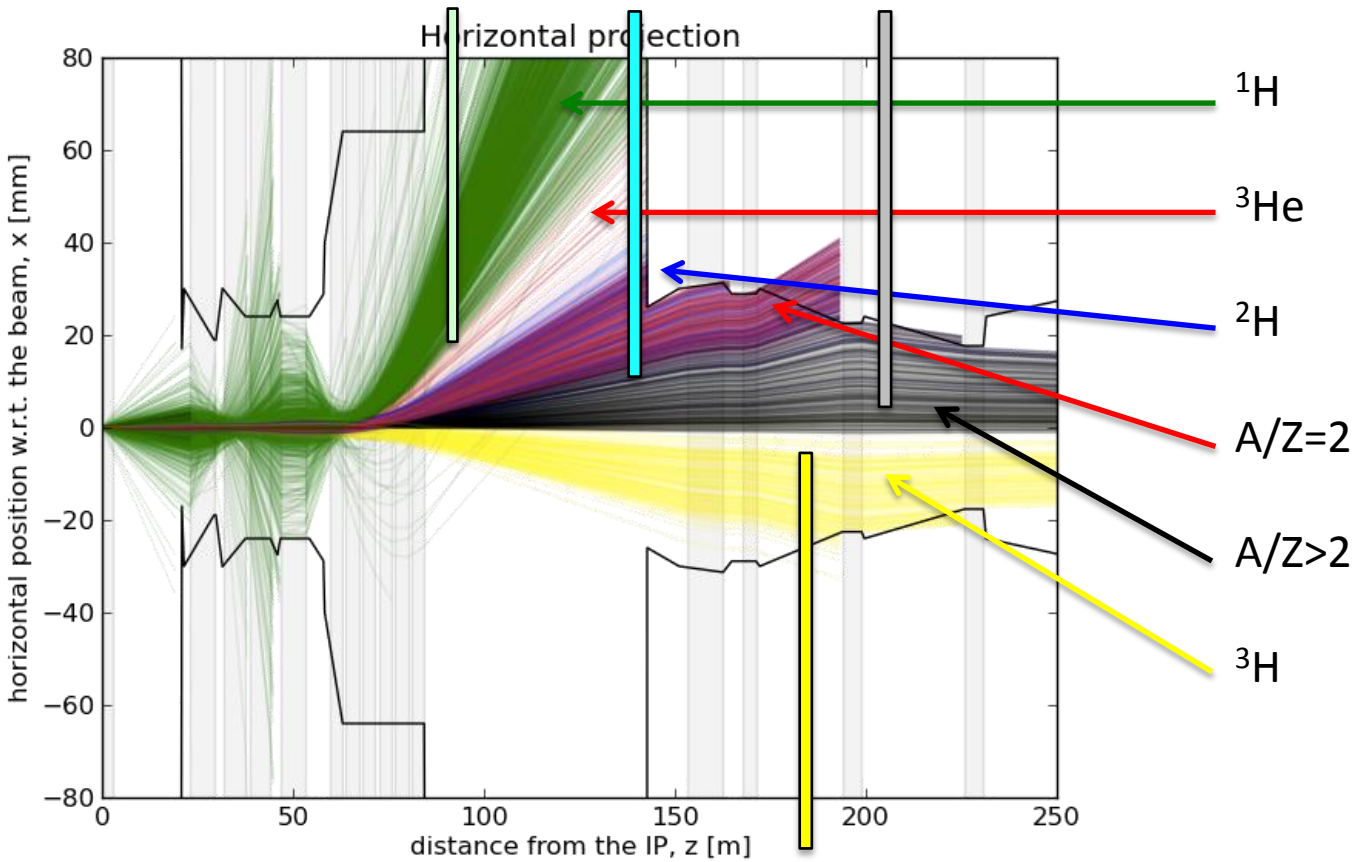
Closed symbols: same bins
0-5%, 5-10%, 10-20% etc…

Open symbols: intrinsic resolution

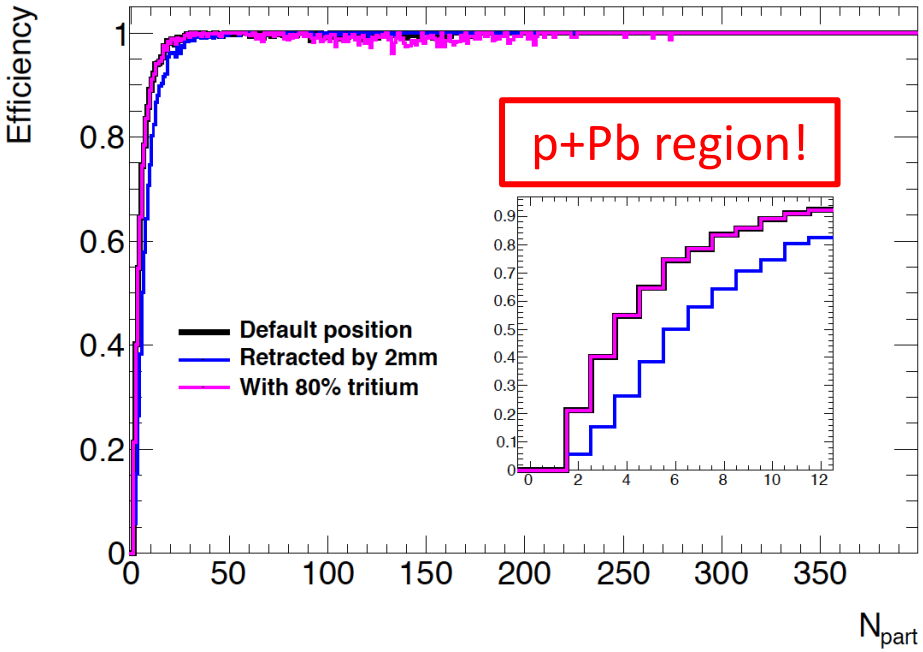
Centrality detector has resolution comparable to present techniques.

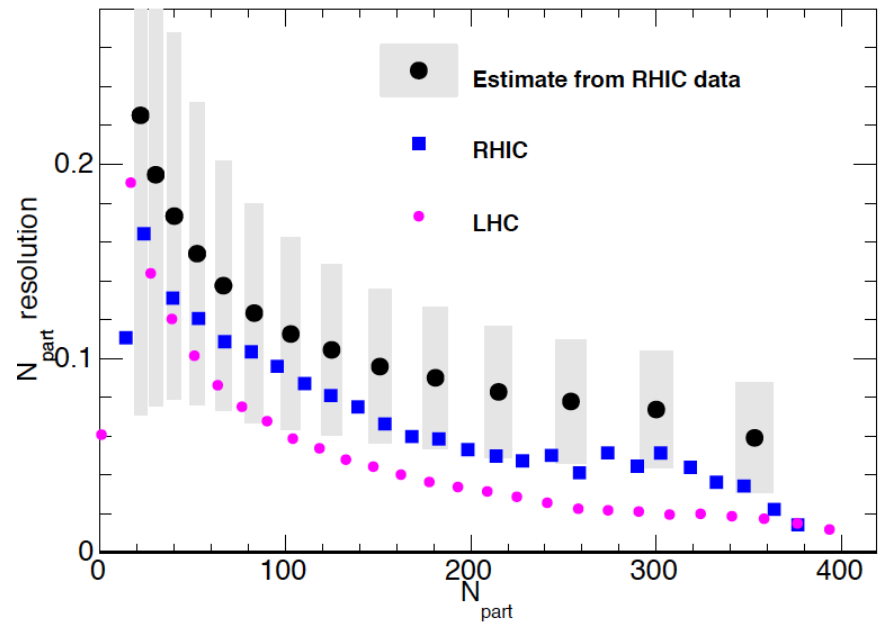
LHC

First calculations made with help of the AFP group.



LHC





Better efficiency, overlapping with p+Pb region.

Higher resolution

Both observations strongly depend on detector implementation

Summary

Centrality can be measured in experiment!

Expected performance is comparable to present techniques and is:

- model independent
- does not require assumptions about particle production mechanisms
- has no process-related biases

Many additional measurements:

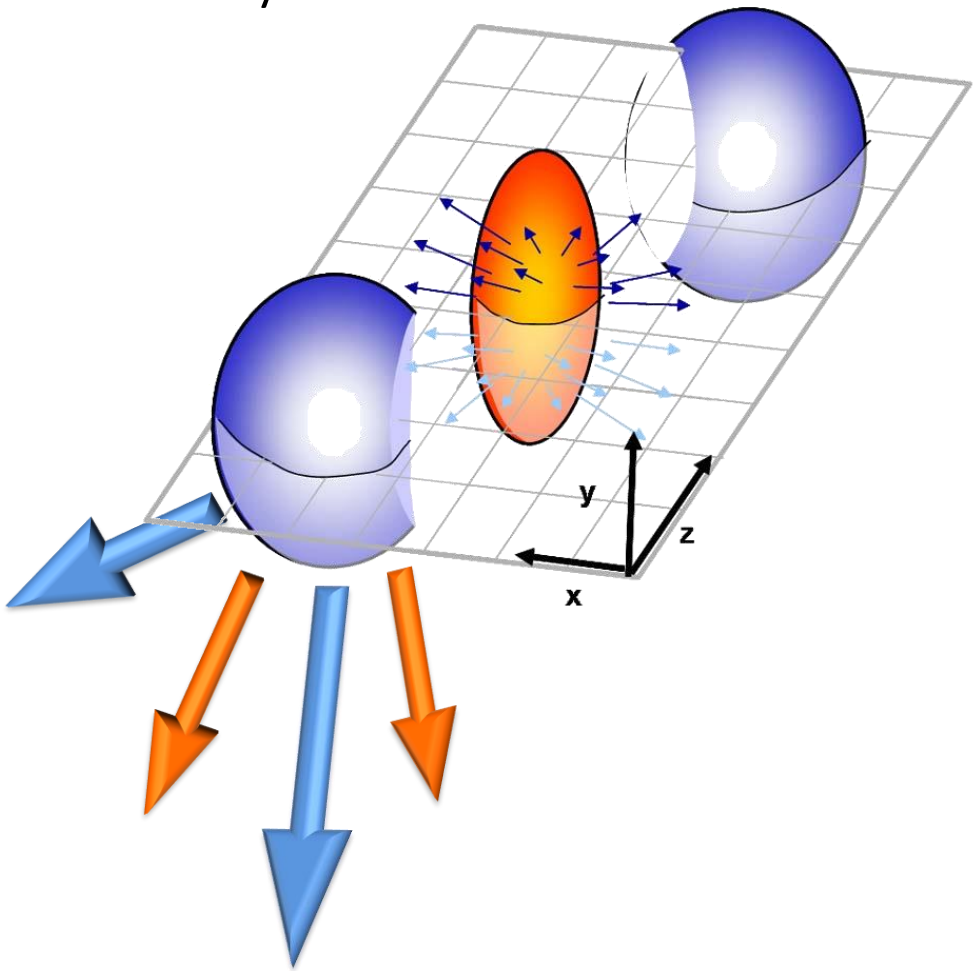
- It's a forward physics detector: whole new field.
- 1st reaction plane.
- event engineering symmetric – asymmetric, charged – neutral, etc.
- Measure fragmentation itself, Fermi motion.

Work continues to understand different system, backgrounds, performance.
Detector choice is not very challenging, can be based on currently used technology.

Building a detector integrated in the structure of a collider requires detector and accelerator people working closely together.

What else can be measured?

"Ironically" a very high energy experiment can be a perfect playground to study very low energy physics: the fragmentation of a deformed nuclei. There might be physics interest to study these effects.



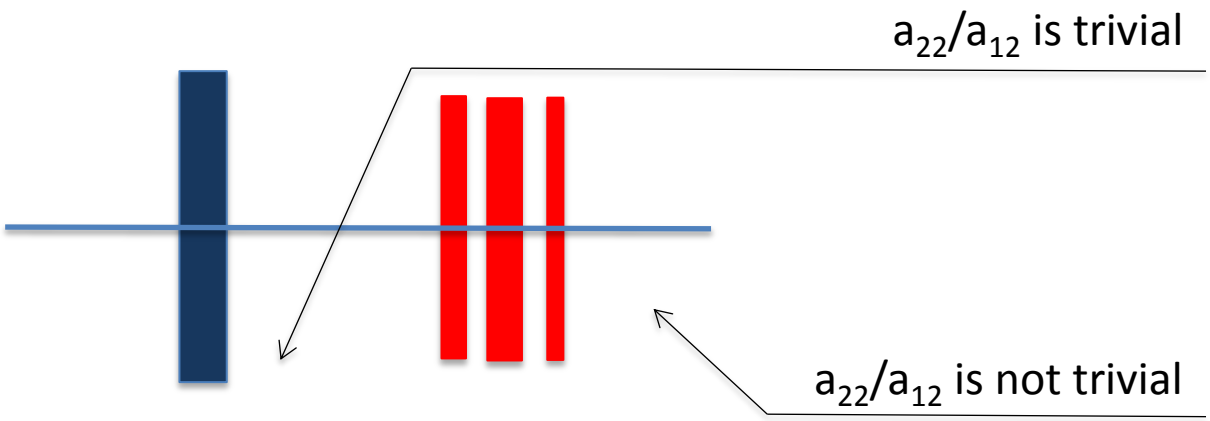
Measuring Fermi motion.

Measuring p_Z-distribution. Looking at y-coordinates and assuming that $y_{IR}=0$, or it can be independently measured, one gets $(y'/y)_{station} = a_{22}/a_{12}$

$$\begin{pmatrix} y \\ y' \end{pmatrix}_{station} = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \begin{pmatrix} y \\ y' \end{pmatrix}_{IR}$$

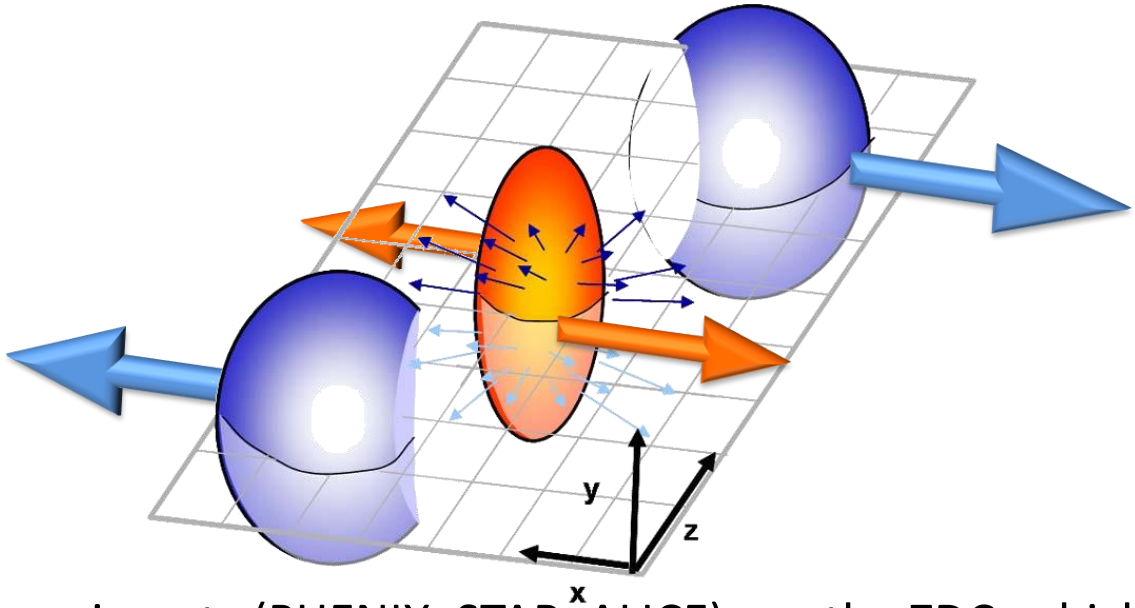
In this ratio y'_{IR} drops out. All $a_{nn}=f(p_z)$ so is the ratio of a_{22}/a_{12}.

Measuring y-coordinates can allow to measure p_z for each fragment. Measuring station must be located behind a quadruple.



Directed Flow, v_1, Measurement?

Directed flow reaction plane orientation Ψ_1. All v_1 measurements are done using spectator deflection.



Currently all experiments (PHENIX, STAR, ALICE) use the ZDC, which has poor coordinate resolution. Since the transition matrices are known for all stations a much better measurement can be done with tracking.

Event engineering?

One can select subsamples within the measures sample for fixed overall N_{part}:

- Events with more participants on one side, than on another. That can be interested to study rapidity fluctuations and rapidity shifts.

- Events with different protons-to-neutron ratio (mass reconstruction is required, of course). Particularly interesting to understand CP violation effects measured at RHIC and LHC, where the spectator charges create the magnetic field separating charges of produced particles.

Summary

- Impact of such detector on the HI field is hard to overestimate. It improves on the most important systematic uncertainty in the majority of HI results.
- It allows measuring centrality decoupled from the mid-rapidity region in the most unbiased way. We know that the FCAL in ATLAS is not really “forward enough” detector therefore we had to deal with the centrality bias effect.
- It can allow making direct comparison of Pb+Pb to p+Pb, which thus far is still challenging.
- It comes with many bonuses: learning about the physics of nuclear fragmentation; measuring the v_1 EP; testing the CP violation with different parameter, choosing asymmetric events, learning about diffraction on nuclei and probably more.
- Additional stations can be very real, because such detector are already built, it widens the region where AFP group can do their measurement.

Plans and Questions (LHC)

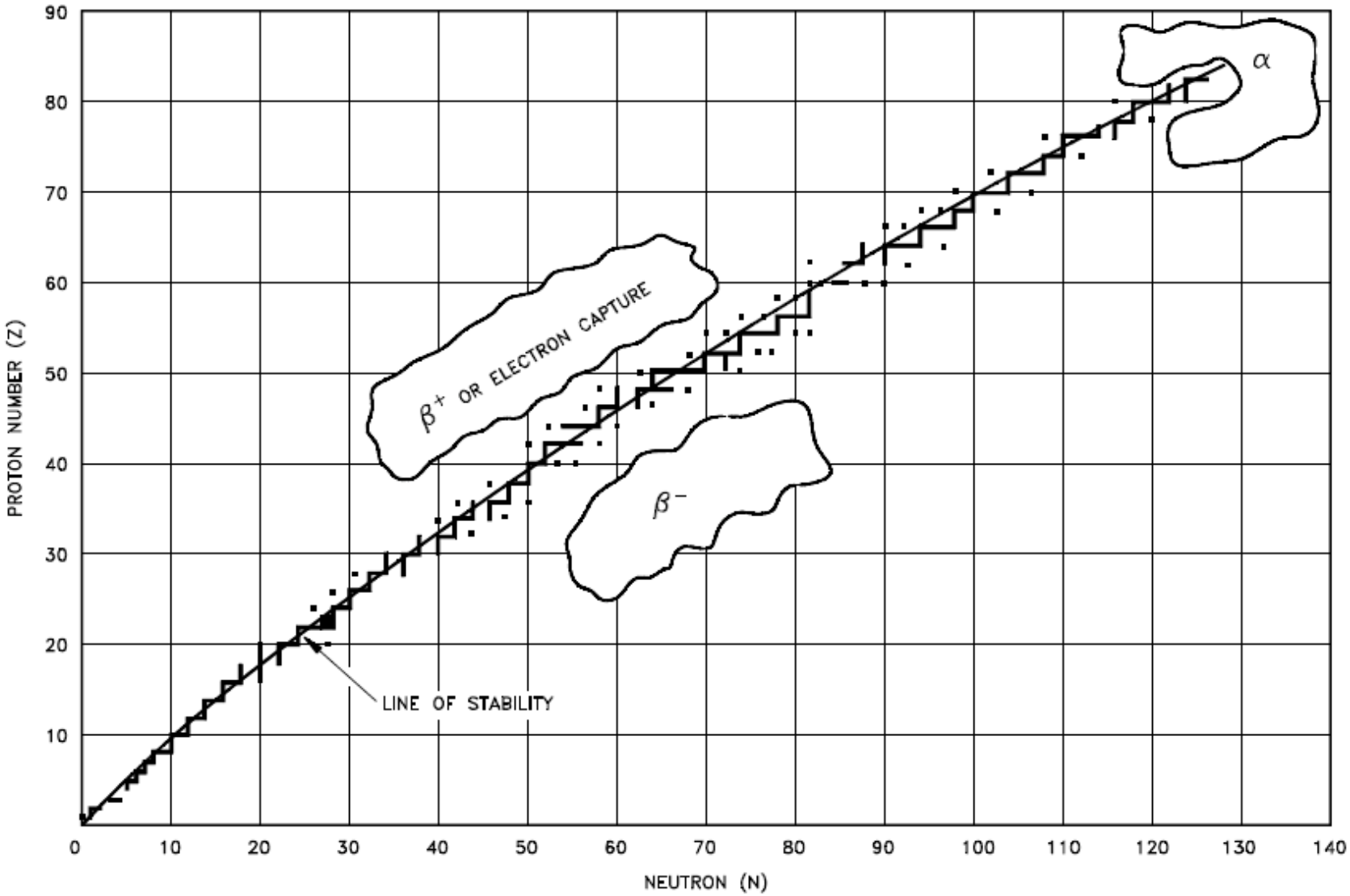
- The WIS group continues working to make calculations more realistic:
  - Pb+Pb collider structure
  - p+Pb collider structure
  - Beam dispersion effects
  - Learning about the AFP detectors

- Needed input:
  - It would be very useful to have another fragment generator.
  - Need a way to estimate the backgrounds at all stations.

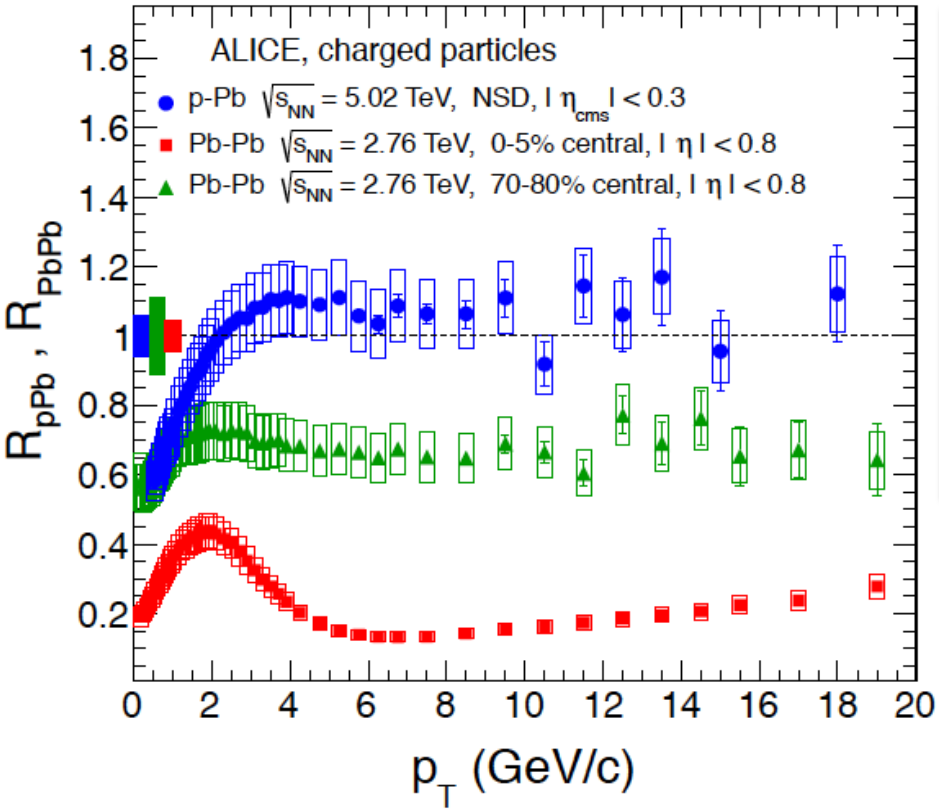
- **Questions to AFP WG.**
  - **What are our ways of cooperating with the AFP group?**
  - **What is the AFP group gaining by having closer stations?**
  - **What are the detectors and what is the timescale?**
  - **Are you interested also in the ZDC?**

Backups

Stability chart



Crazy plot



System	N_{coll}	R_{AA}	
p+p	1	--	
p+Pb	1-20	1	x15 coll – no effect
Pb+Pb	15	0.7	x15 coll – 30% effect
Pb+Pb	1600	0.2	x100 coll – 70% effect

We can learn much more if we could directly compare p+Pb to Pb+Pb, but current systematics are the limiting factor:

- large
- model dependent
- too different between p+Pb and Pb+Pb

History…

Similar concept used in the e^+e^- machines

Detector KEDR tagging system for two-photon physics

V.M. Aulchenko, B.O. Baibusinov, S.E. Baru, A.E. Bondar, G.S. Filimonov, G.Ya. Kezerashvili, G.M. Kolachev, A.M. Milov, N.Yu. Muchnoj, Yu. Pogorelov, T.A. Purlatz, L.V. Romanov *, N.I. Root, B.A. Shwartz, V.A. Sidorov, V.M. Titov, D. Zaitsev, V.N. Zhilich

Budker Institute of Nuclear Physics, Novosibirsk 630090, Russia

V.M. Aulchenko et al. / Nucl. Instr. and Meth. in Phys. Res. A 379 (1996) 360–362

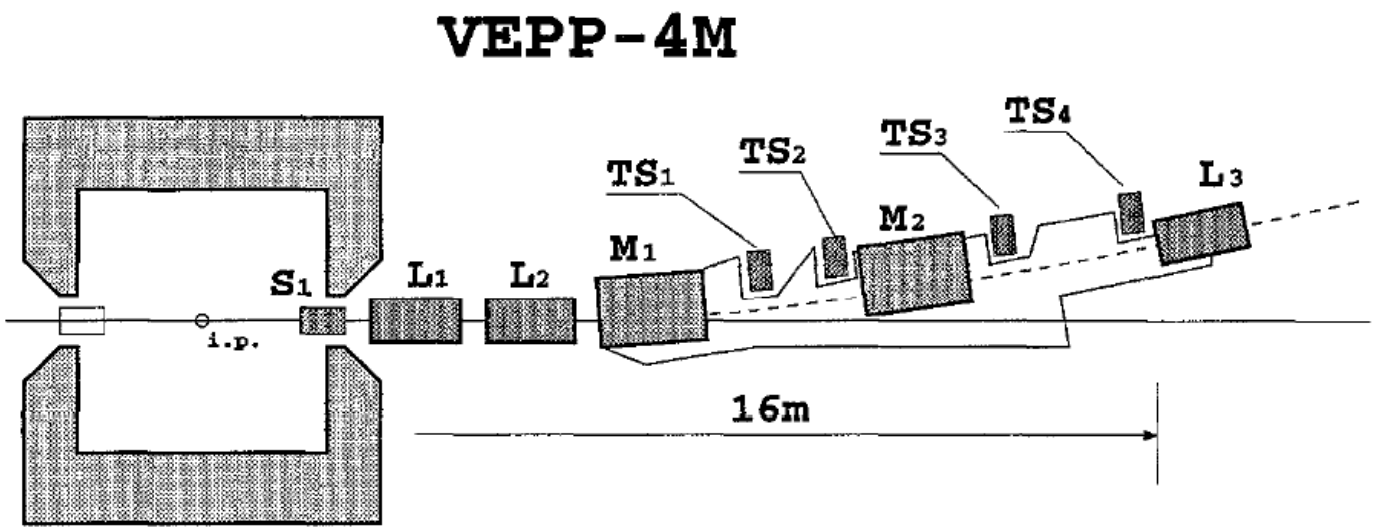
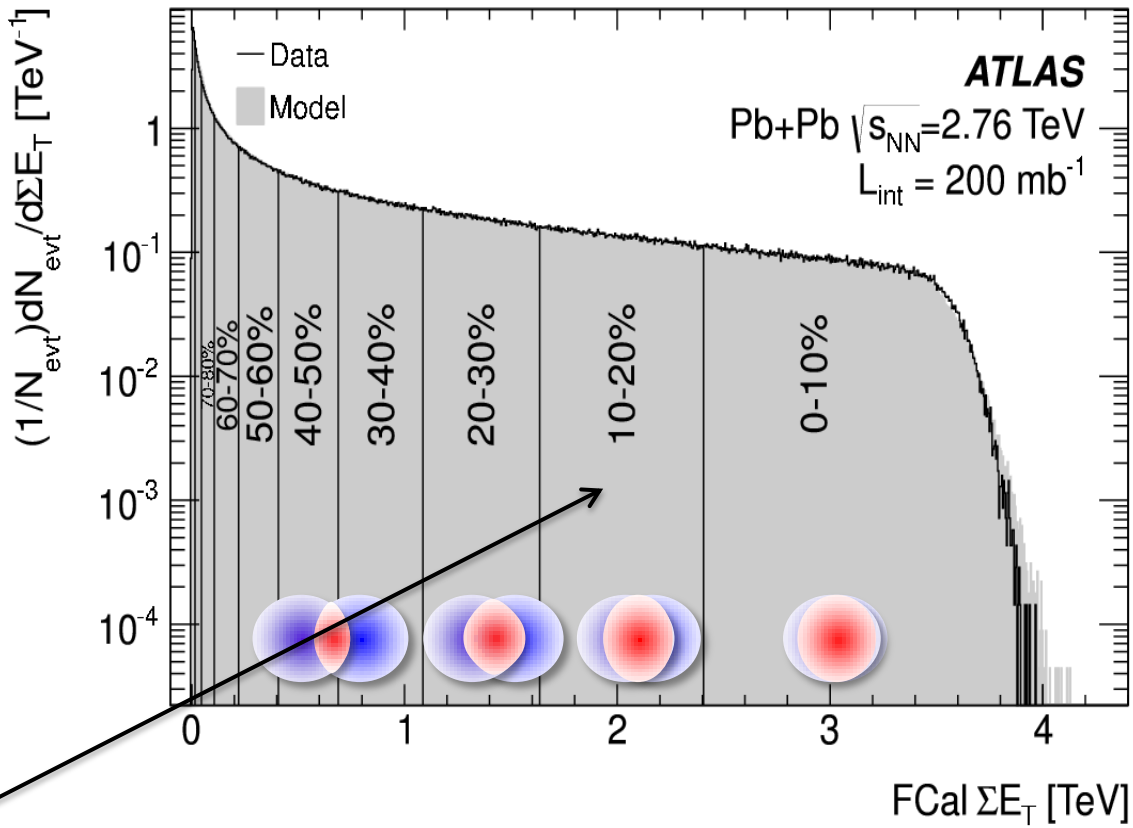


Fig. 1. Layout of VEPP-4M experimental region with the KEDR tagging system. L_1, L_2 are quadrupoles, M_1, M_2 are bending magnets.

Centrality determination

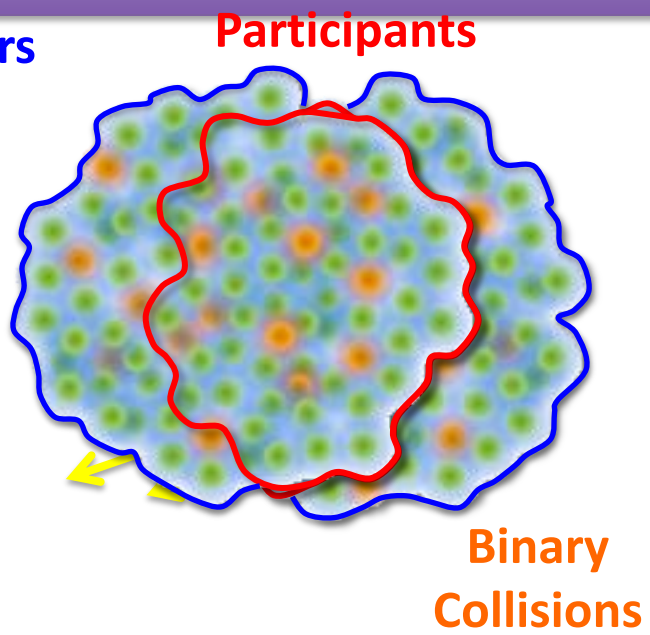


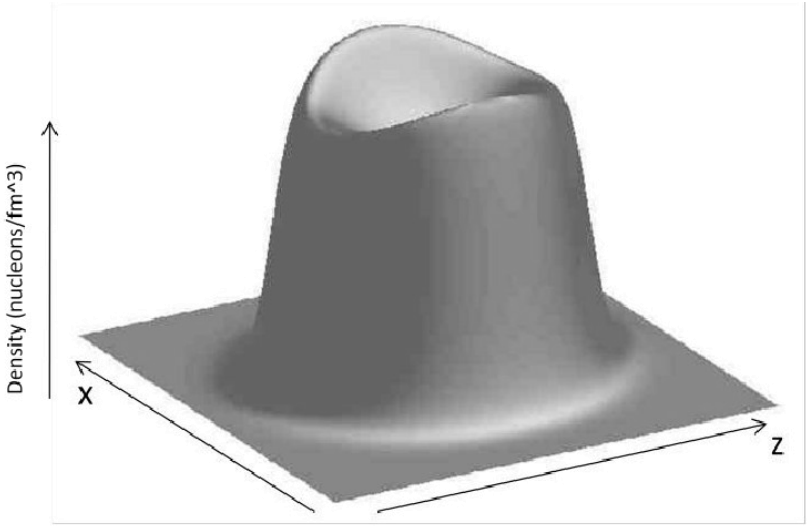
Measured distribution ← Detector response (well known) ← Particle production (approximately known) ← Collision geometry (model)

Glauber model

Nucleons in nuclei are modeled using the Woods-Saxon distribution of the form:

$$\rho(r,\theta) = \begin{cases} \rho_0\left(\frac{1+w(\frac{r}{c})^2}{1+e^x}\right) & \text{if } r < c \\ \rho_0\left(\frac{1+w}{1+e^x}\right) & \text{if } r \geq c \end{cases}$$





	$\langle N_{part} \rangle$	$\langle N_{coll} \rangle$
0-5%	382 ± 1%	1683 ± 8%
5-10%	330 ± 1%	1318 ± 8%
10-20%	261 ± 2%	923 ± 7%
20-40%	158 ± 3%	441 ± 7%
40-80%	46 ± 6%	78 ± 9%

Centrality determination