UNIVERSITÀ DEGLI STUDI FIRENZE

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First advanced isospin studies with the FAZIA detector

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Scientific GOAL

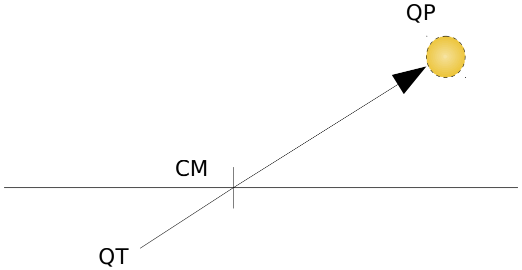
Investigation of the isospin dynamics, focusing on the isospin diffusion:

1. In a binary channel
2. In the QP break up channel

Aiming at:

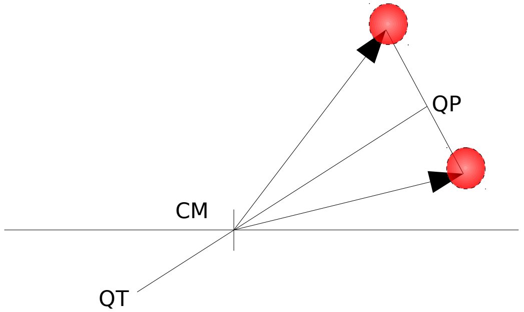
1. experimentally compare the reaction channels
2. extract information on the parameters of the nuclear Equation of State

Binary Channel



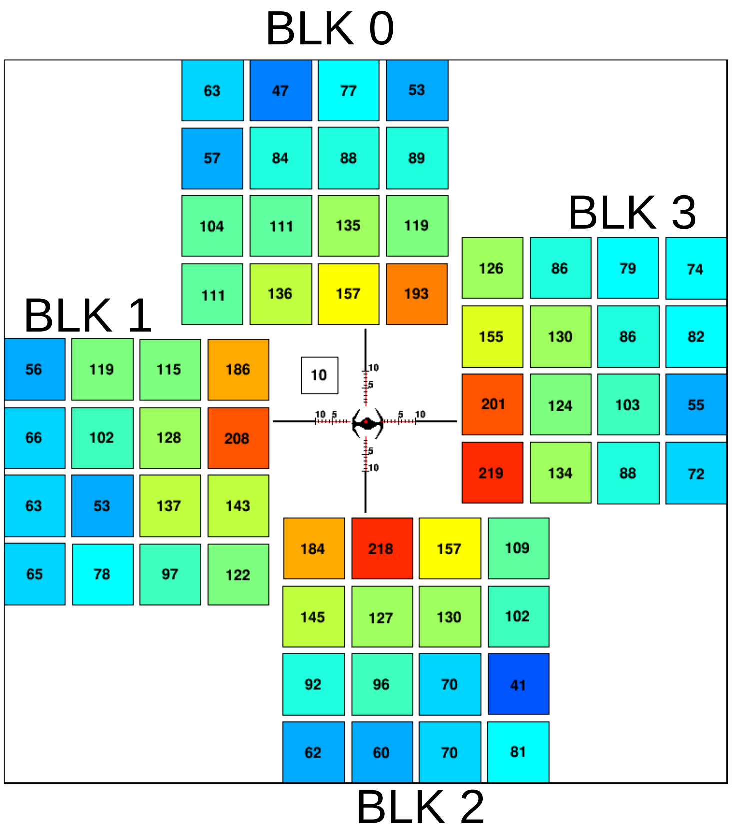
QP decays trough the emission of IMF and/or LCP

Break up channel



QP splits in two fragments

FAZIA-SYM experiment



At the Laboratori Nazionali del Sud:

- **$^{40}Ca+^{40}Ca$**
- **$^{48}Ca+^{40}Ca$**
- **$^{48}Ca+^{48}Ca$**

@ 35 MeV/u

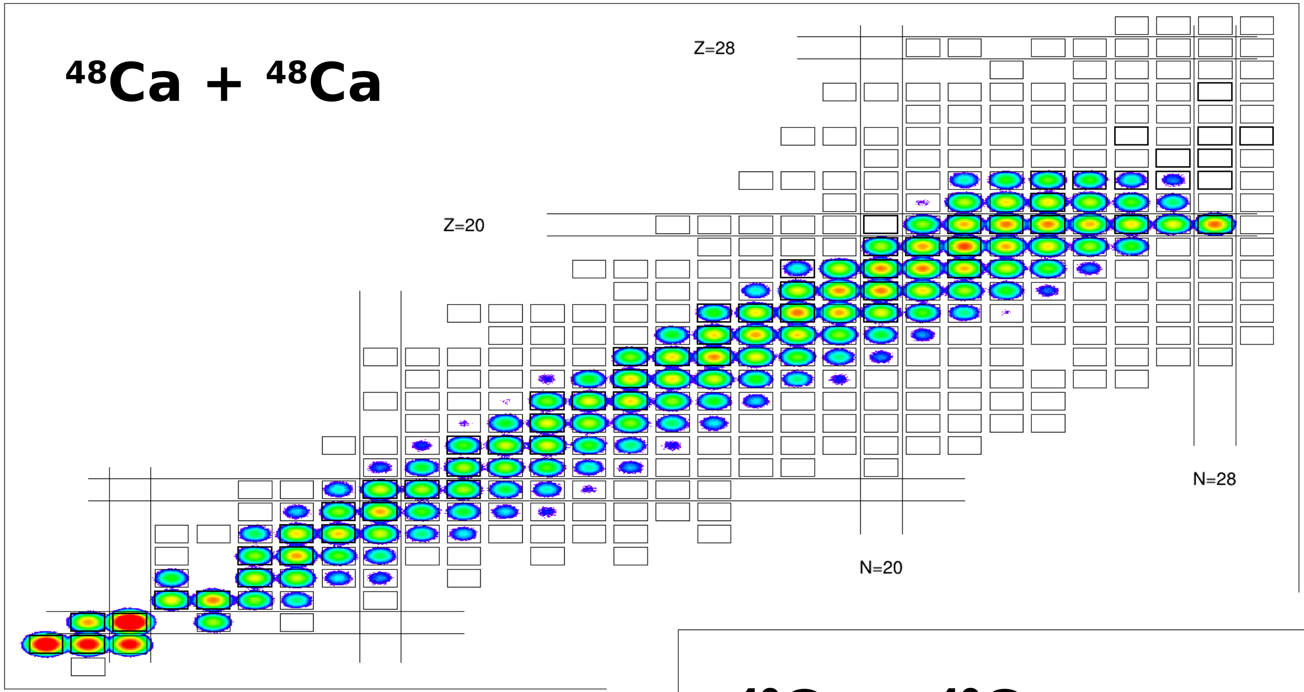
Geometry:

- 4 blocks located around the beam axis and 80cm far from the target
- Covered polar angle in the laboratory frame:
  - $\Theta_{min} = 2°$
  - $\Theta_{max} = 8°$

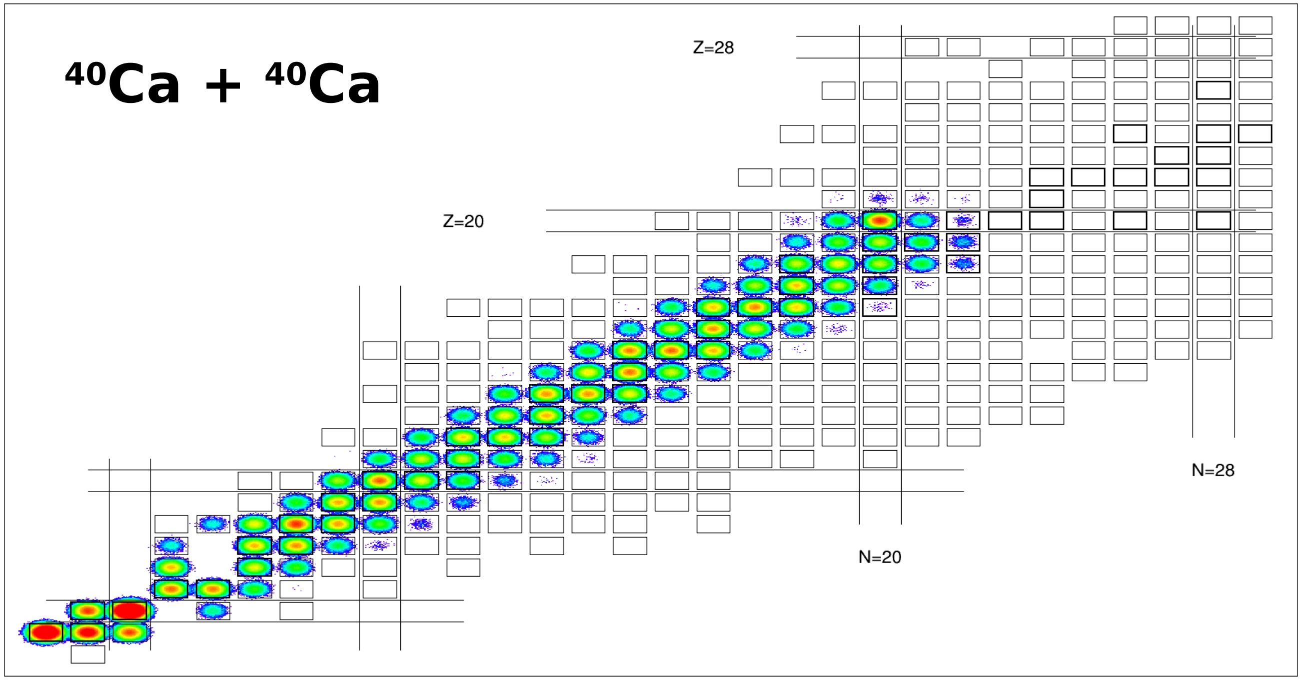
GOAL:

Investigation of isospin diffusion in the $^{48}Ca+^{40}Ca$, as a function of the reaction centrality, both in the binary and in the break up channel

FAZIA-SYM nuclide chart



We identify both in Z and A fragments up to projectile charge (Z=20), and even more..



... allowing to **isotopically resolve the QP remnant** in the binary channel

and **isotopically reconstruct the QP in the break up channel**

AMD: Antisymmetrized Molecular Dynamics

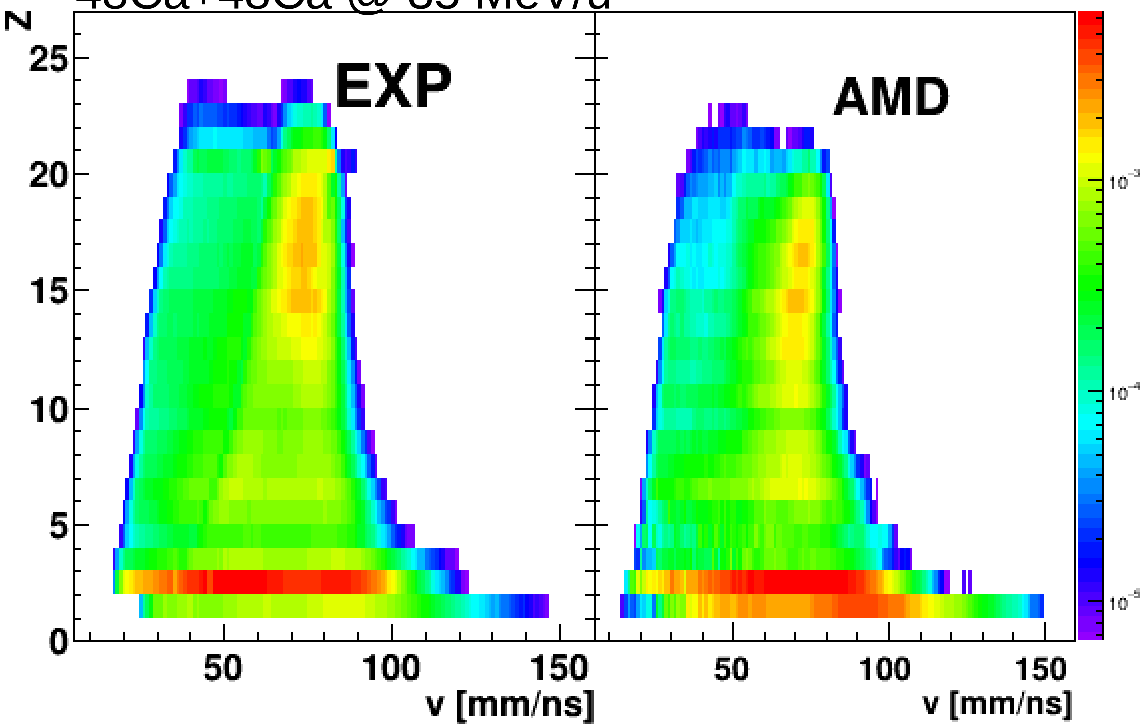
Montecarlo code: transport model.

AMD: developed by Akira Ono, Phys. Rev. C 59, 853 (1999).

Nuclear interaction: **Skyrme potential**
with **stiff (L=108MeV)** and **soft (L=46MeV)** parametrization

Dynamic calculation stopped at 500 fm/c and the **GEMINI++** as afterburner:
statistical fission and evaporation of the fragments produced by AMD

48Ca+48Ca @ 35 MeV/u



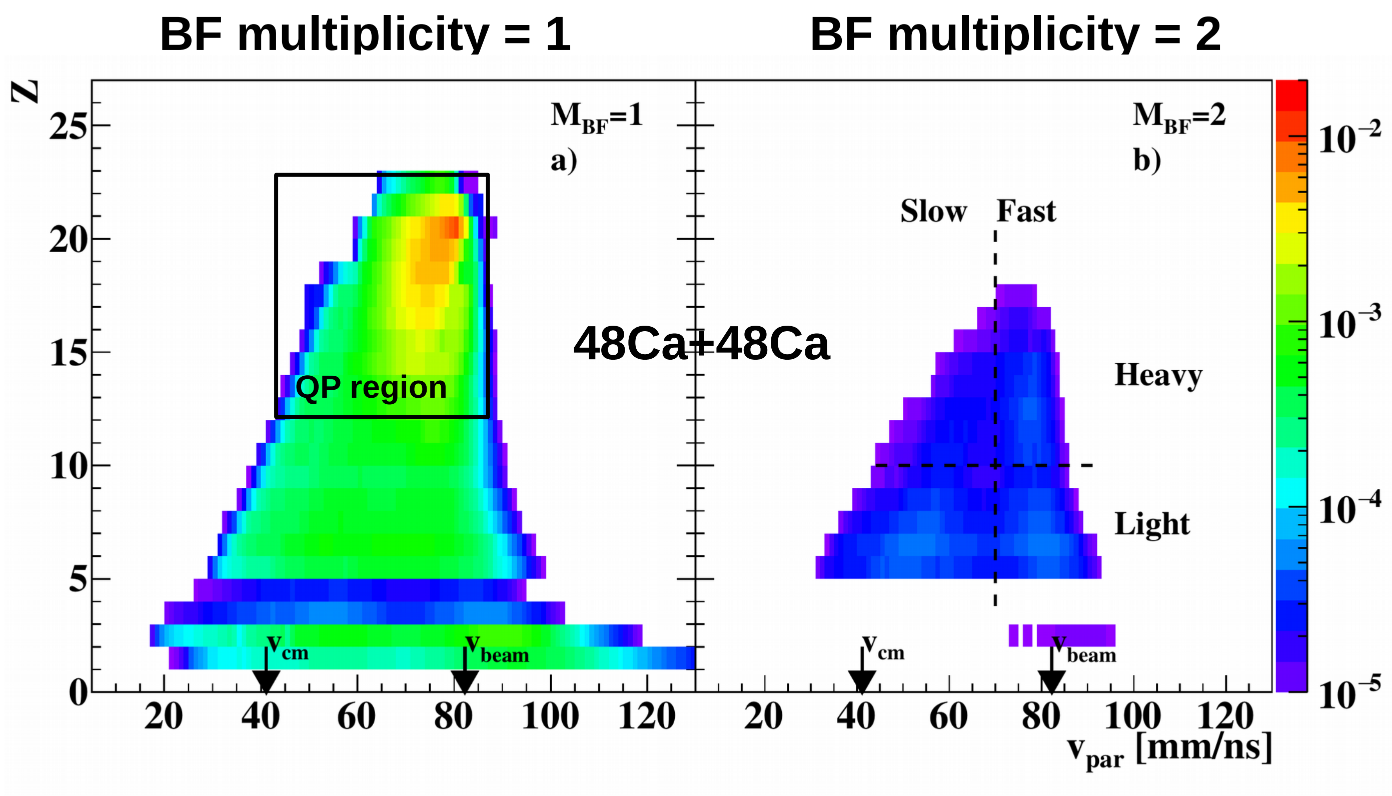
AMD+GEMINI events are filtered via software :

- **Geometrical acceptance**
- **Identification thresholds**
- **Detector energy resolution**

AMD := AMD + GEMINI

Event Selection

Only Big Fragments isotopically identified are considered:



Vocabulary:

- LCP → Z=1 & Z=2
- IMF → Z= 3 & Z=4
- Big Fragment → Z≥5

We define QP remnant
a BF with :

- $12 \leq Z^{QP} \leq 22$
- $v_{par} > v_{cm}$

We define
a reconstructed QP :

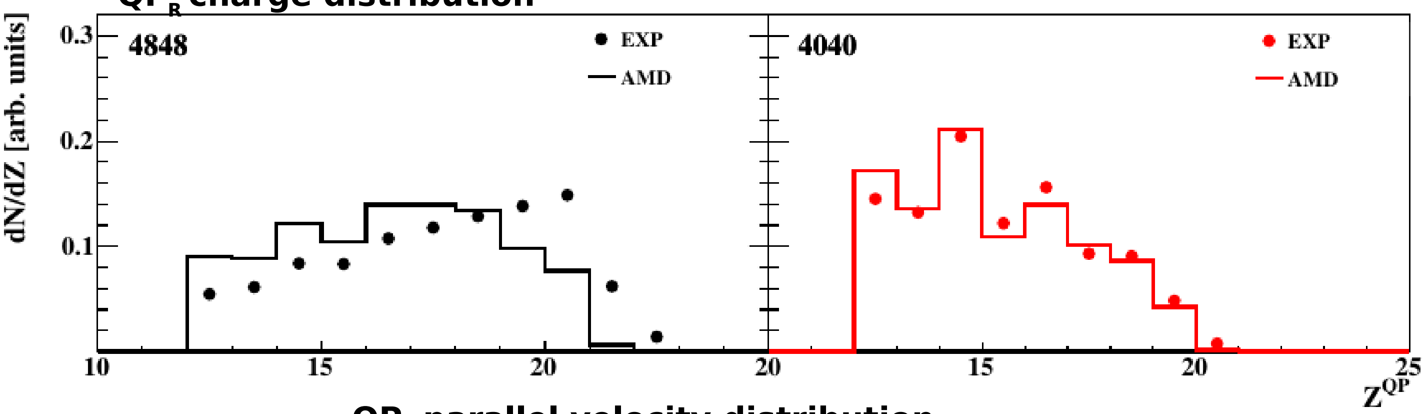
- $12 \leq Z^{rec} = Z^{H} + Z^{L} \leq 22$
- $v^{H}_{par} > v_{cm}$ & $v^{L}_{par} > v_{cm}$

QP Remnant channel (QP_R)

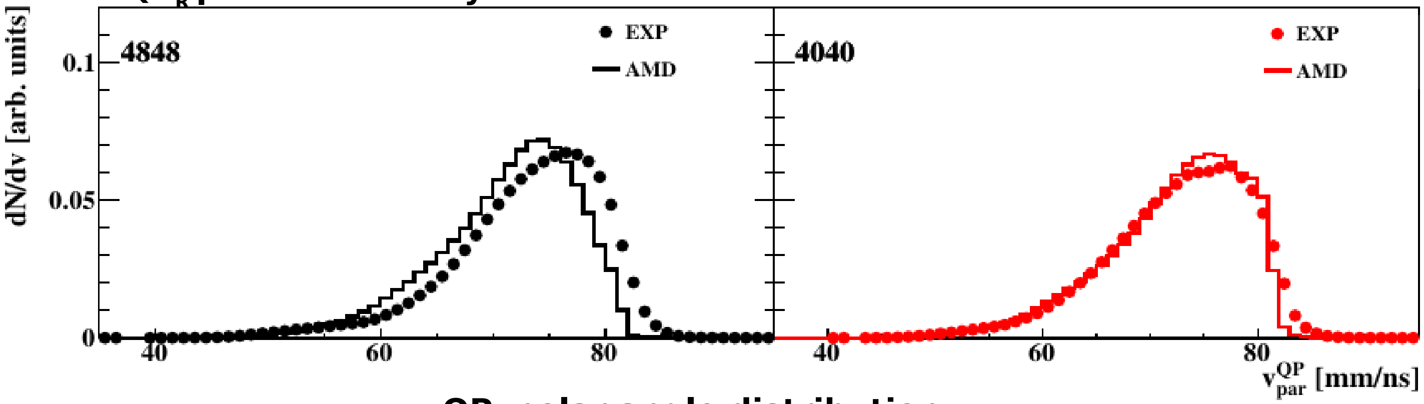
QP break up channel (QP_B)

QP_R characterization

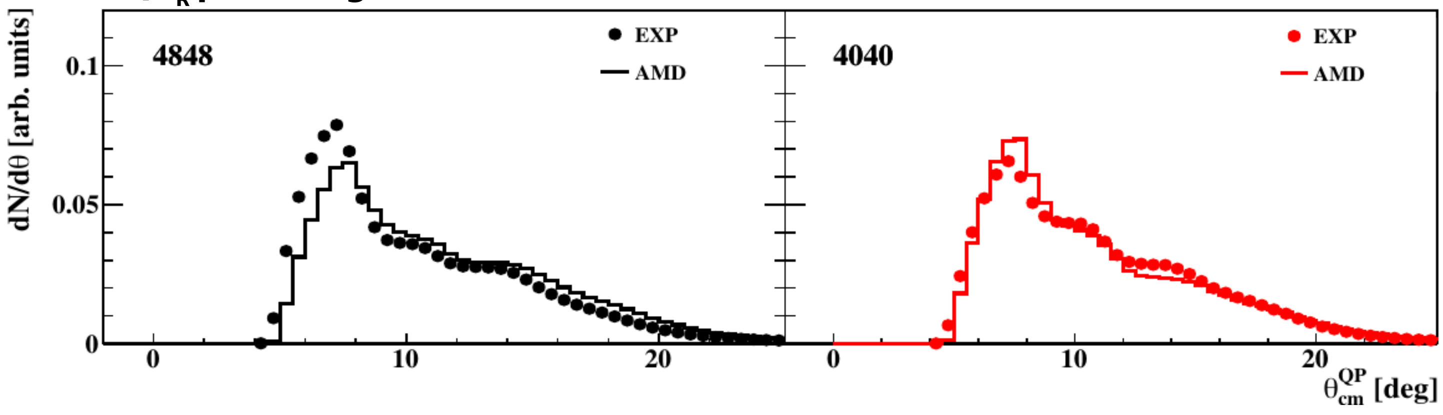
QP_R charge distribution



QP_R parallel velocity distribution



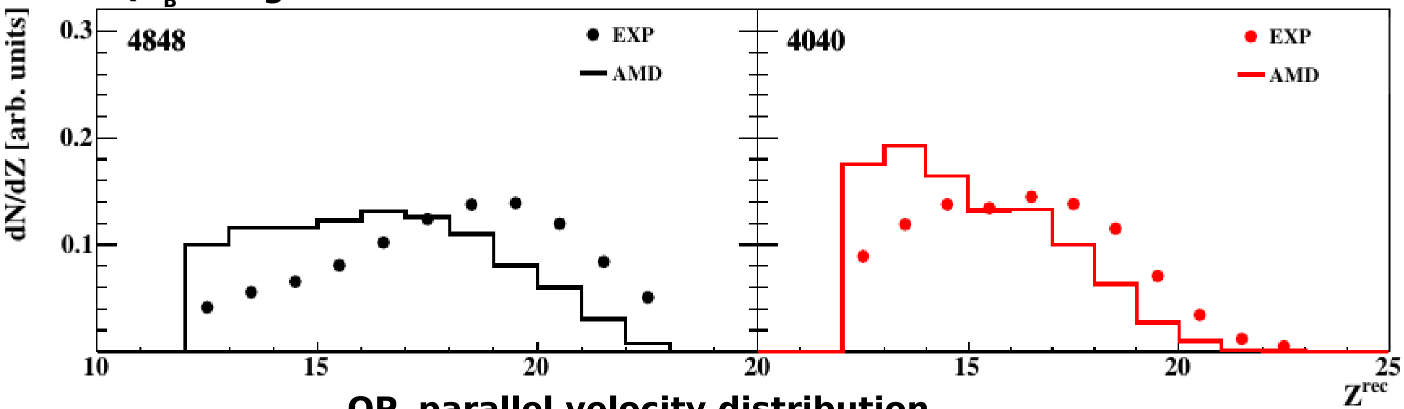
QP_R polar angle distribution



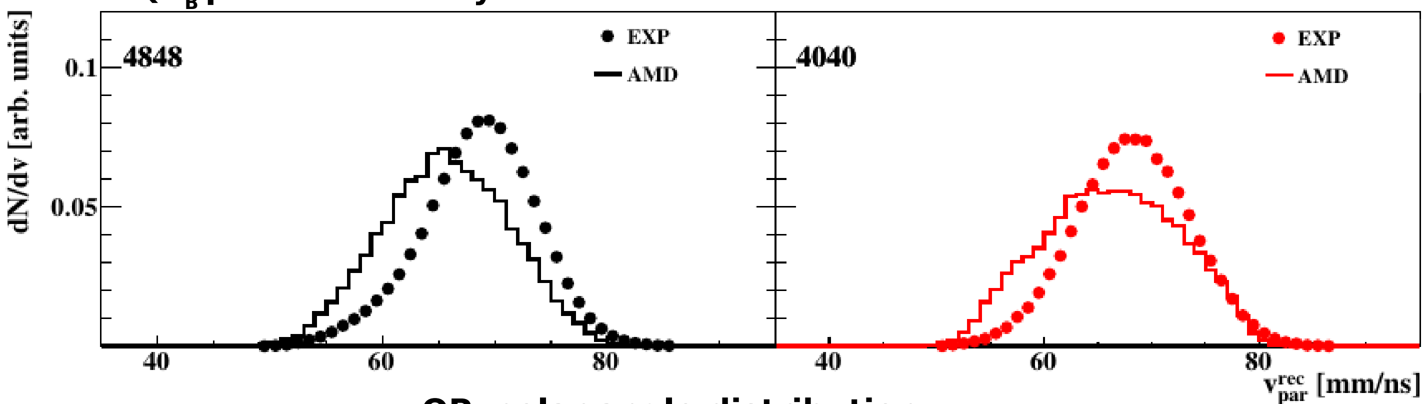
The gross properties of the QP_R channel are globally well described by AMD

QP_B characterization

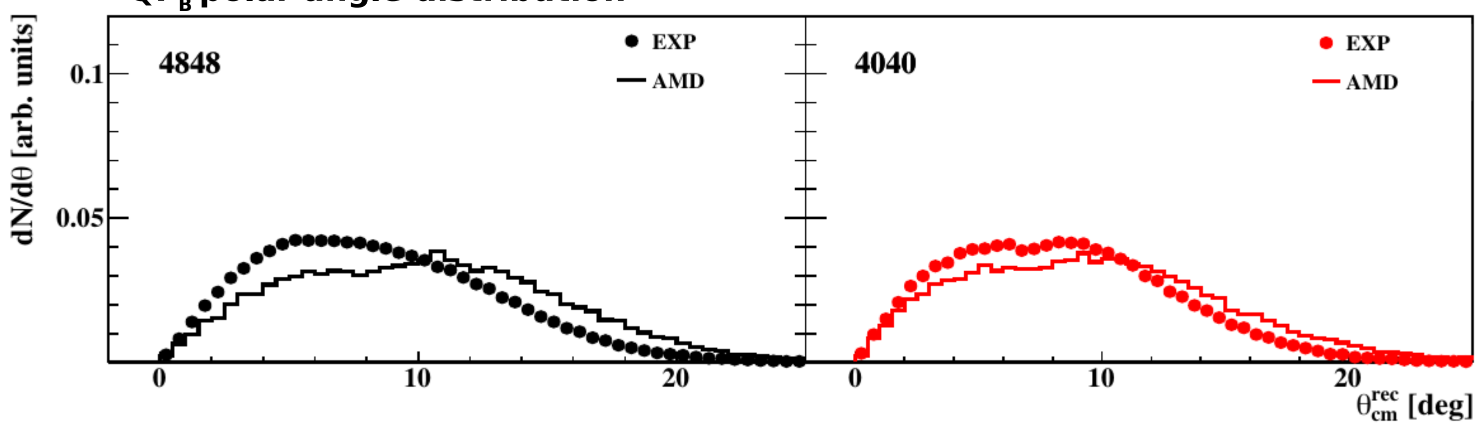
QP_B charge distribution



QP_B parallel velocity distribution



QP_B polar angle distribution

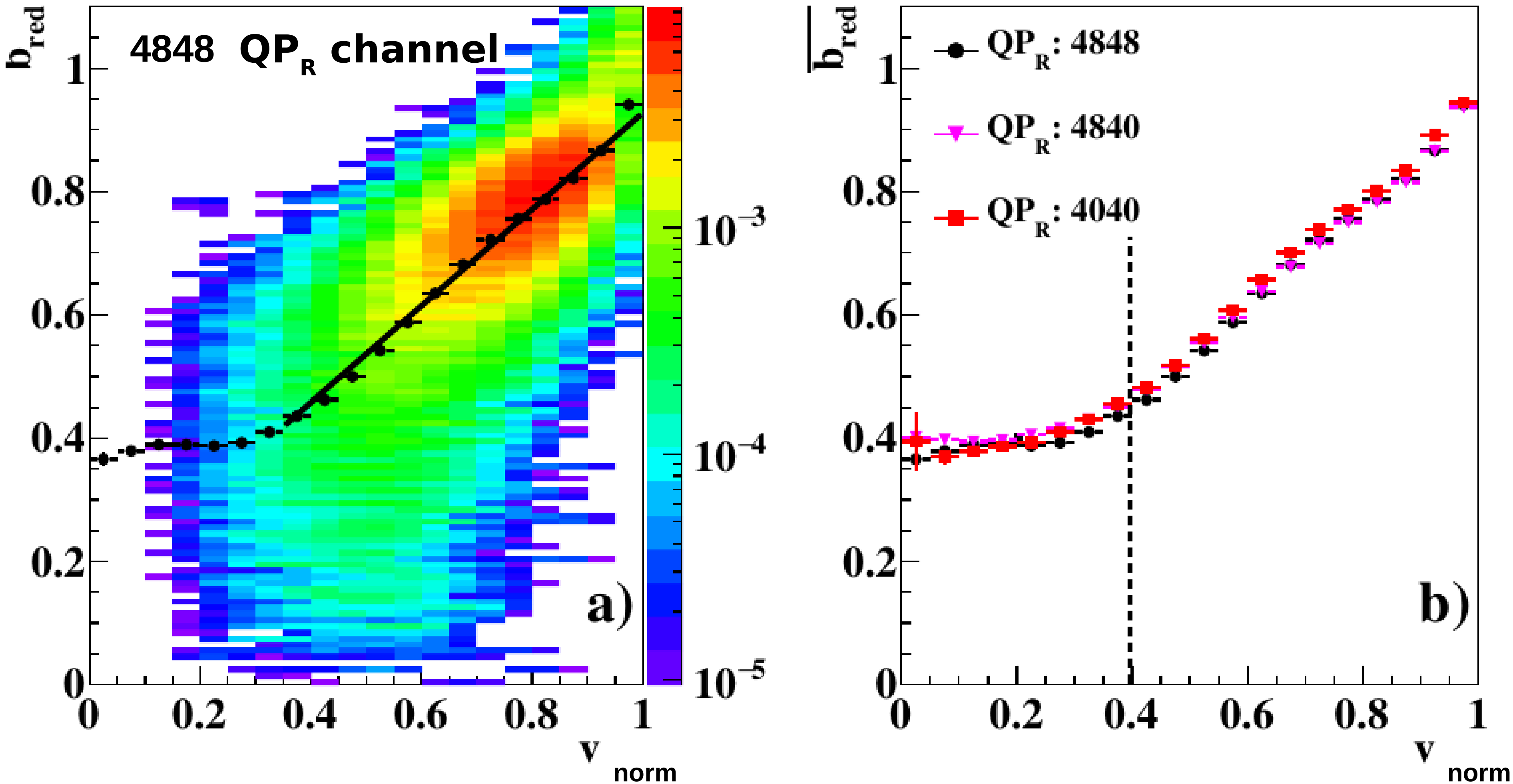


..as well as the QP_B characteristics, even if with less accuracy

Impact parameter estimation

By means of the AMD simulation we can extract information on the reduced impact parameter b_{red}:

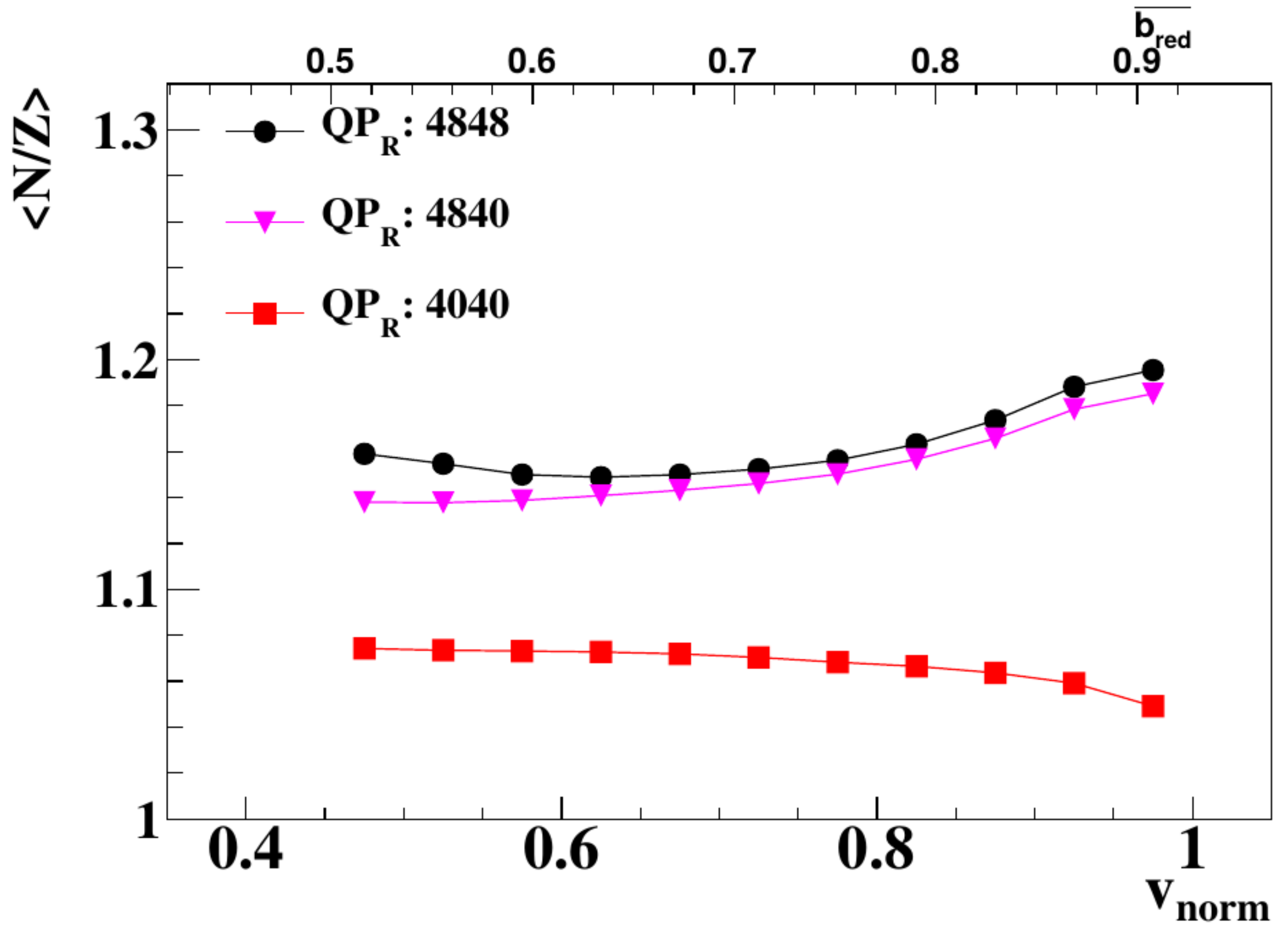
$$v_{norm} = \frac{v_{cm}^{QP}}{v_{cm}^{proj}}$$



A linear correlation between v_{red} and b_{red} is observed in the reduced velocity range of 0.4 - 1

<N/Z> of the QP_R

We can look at the average neutron to proton ration <N/Z> as a function of v_{red} combining the information of the three systems:



- In the 4840 system, the QP_R are neutron poorer than those in the 4848 system

ISOSPIN DIFFUSION

E. de Filippo et al, Phys. Rev. C 86, 014610 (2012)

- <N/Z> decreases as the reaction centrality increases

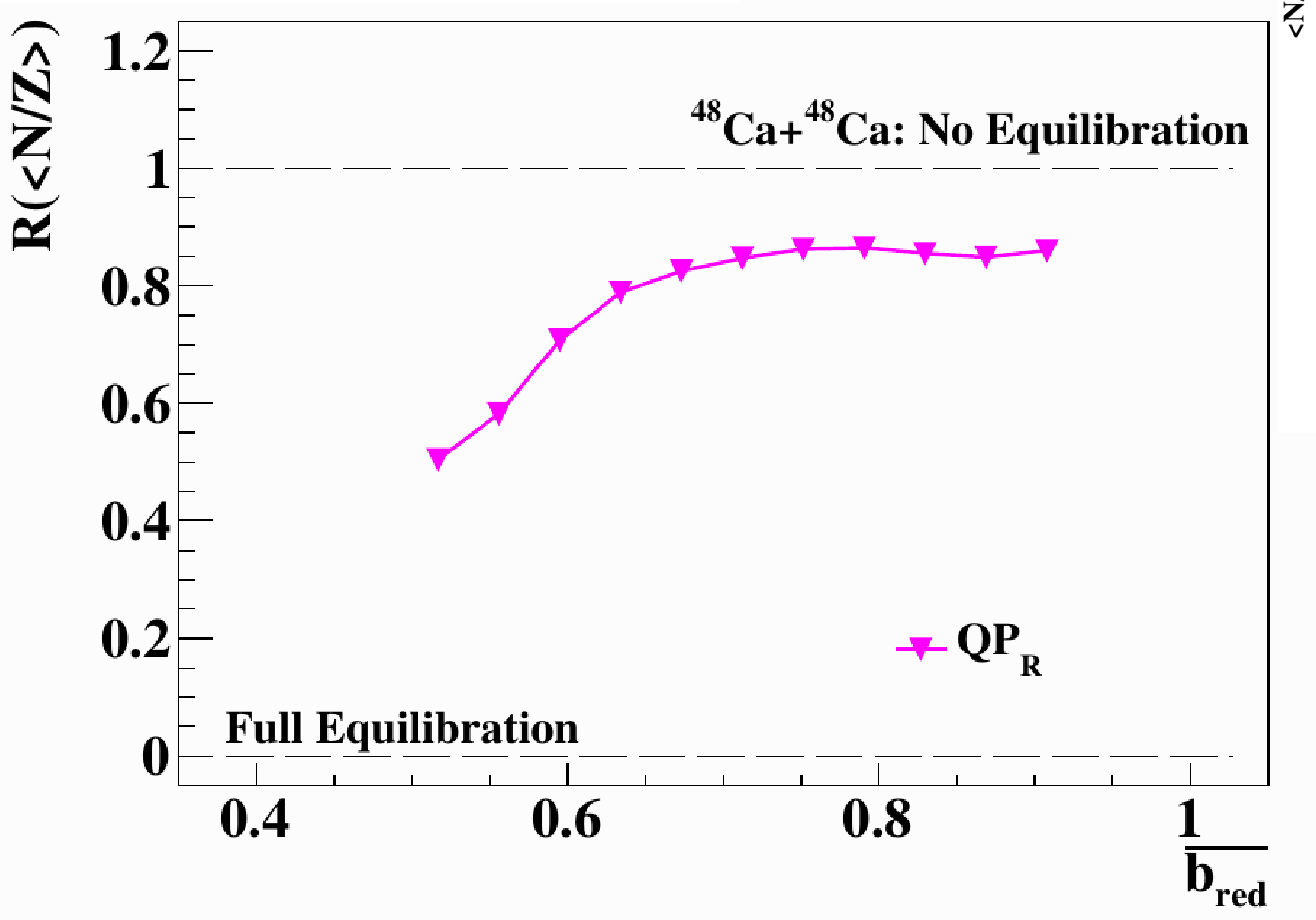
- In the 4840 system, the more damped the collision, the more n-poor the QP remnants with respect to the n-rich system

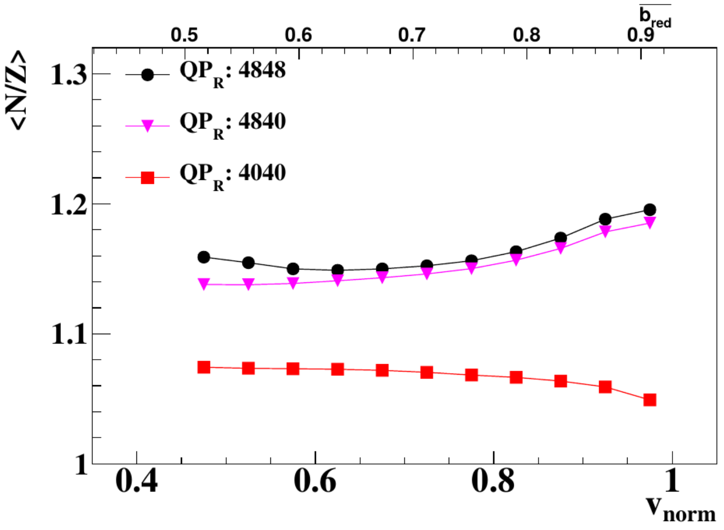
Equilibration in the QP_R channel

By mean of the Imbalance ratio we can enhance the equilibration due to the isospin diffusion:

F. Rami et al., Phys. Rev. Lett. 84, 1120 (2000)
M. B. Tsang et al, Phys. Rev. Lett. 92, 062701 (2004)

$$R(x) = \frac{2x^{4840} - x^{4848} - x^{4040}}{x^{4848} - x^{4040}} \qquad x = < \frac{N}{Z} >$$

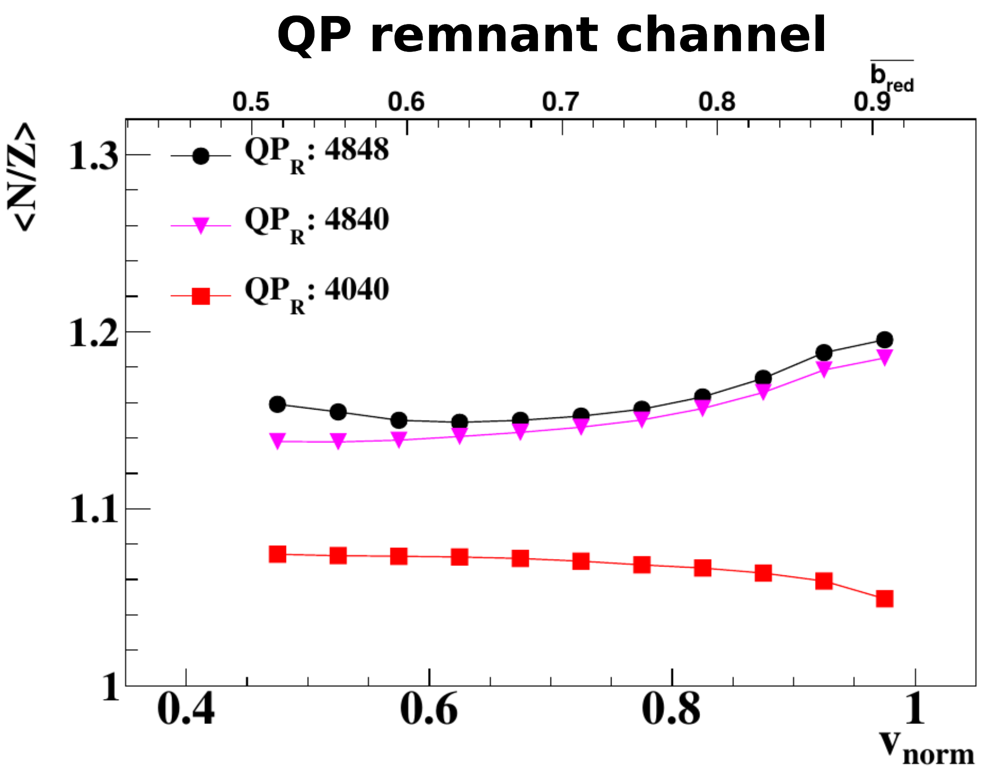


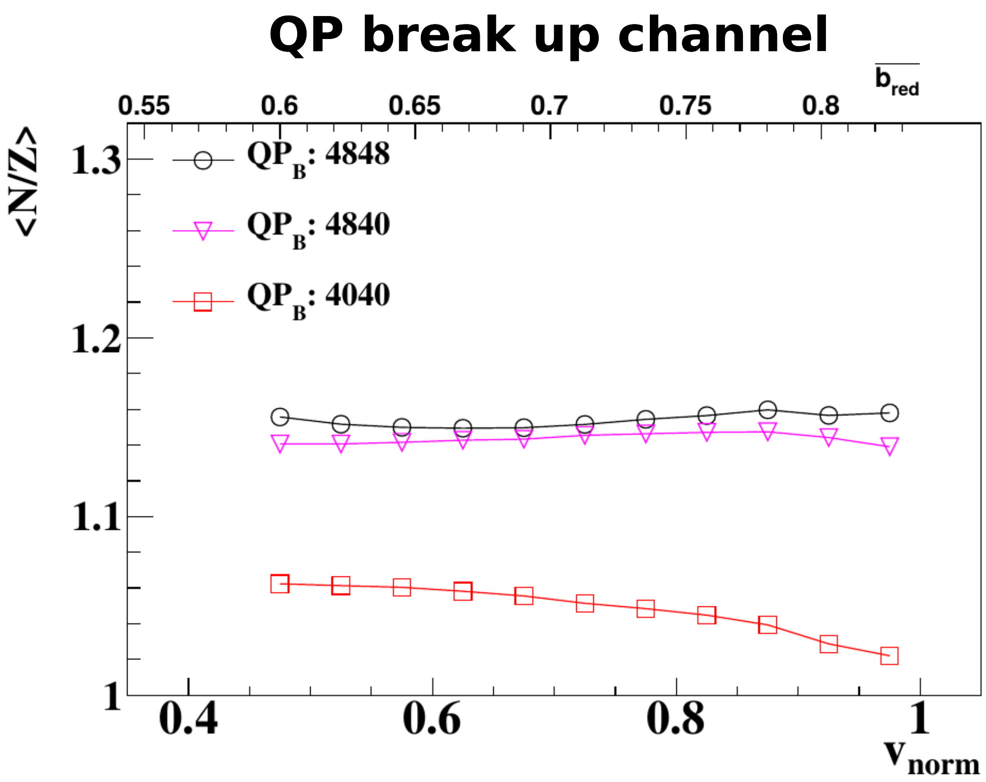


The more damped the collision, the more equilibrated the isospin

<N/Z> of the QP_R v.s. the QP_B

We can compare the QP break up channel with the QP remnant channel:



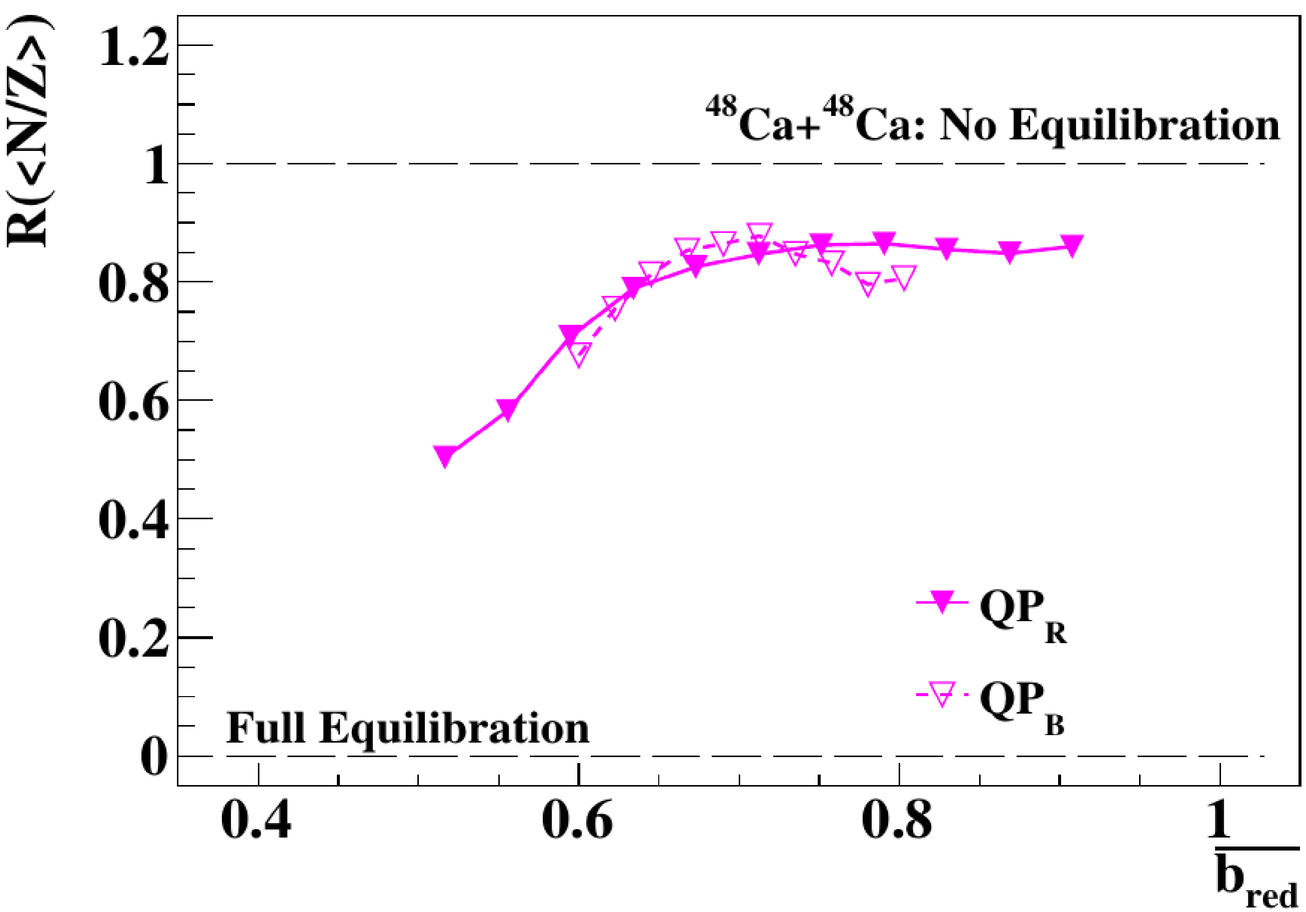


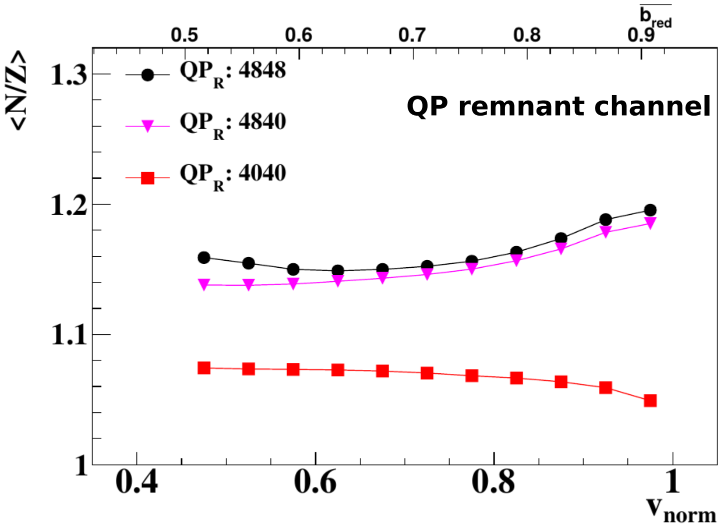
- Flatter distribution in the QP_B channel as function of the centrality

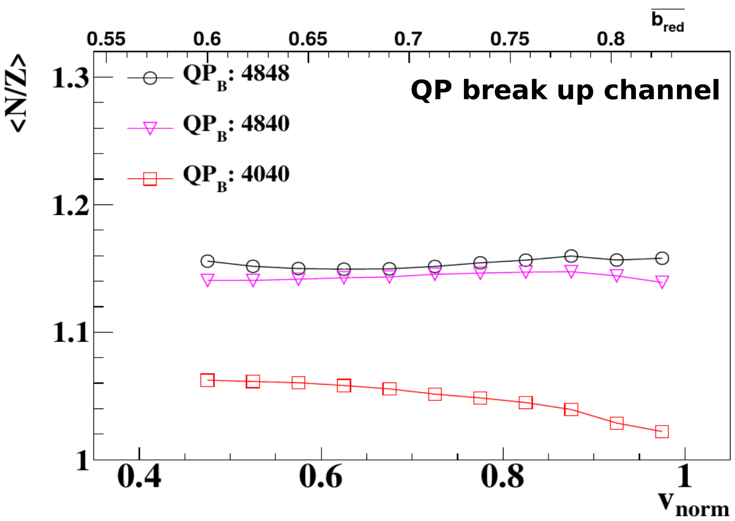
- **The hierarchy of the three systems is still preserved, pointing out the isospin diffusion in the QP_B channel**

Equilibration in the QP_B channel

By mean of the Imbalance ratio we can enhance the equilibration due to the isospin diffusion:







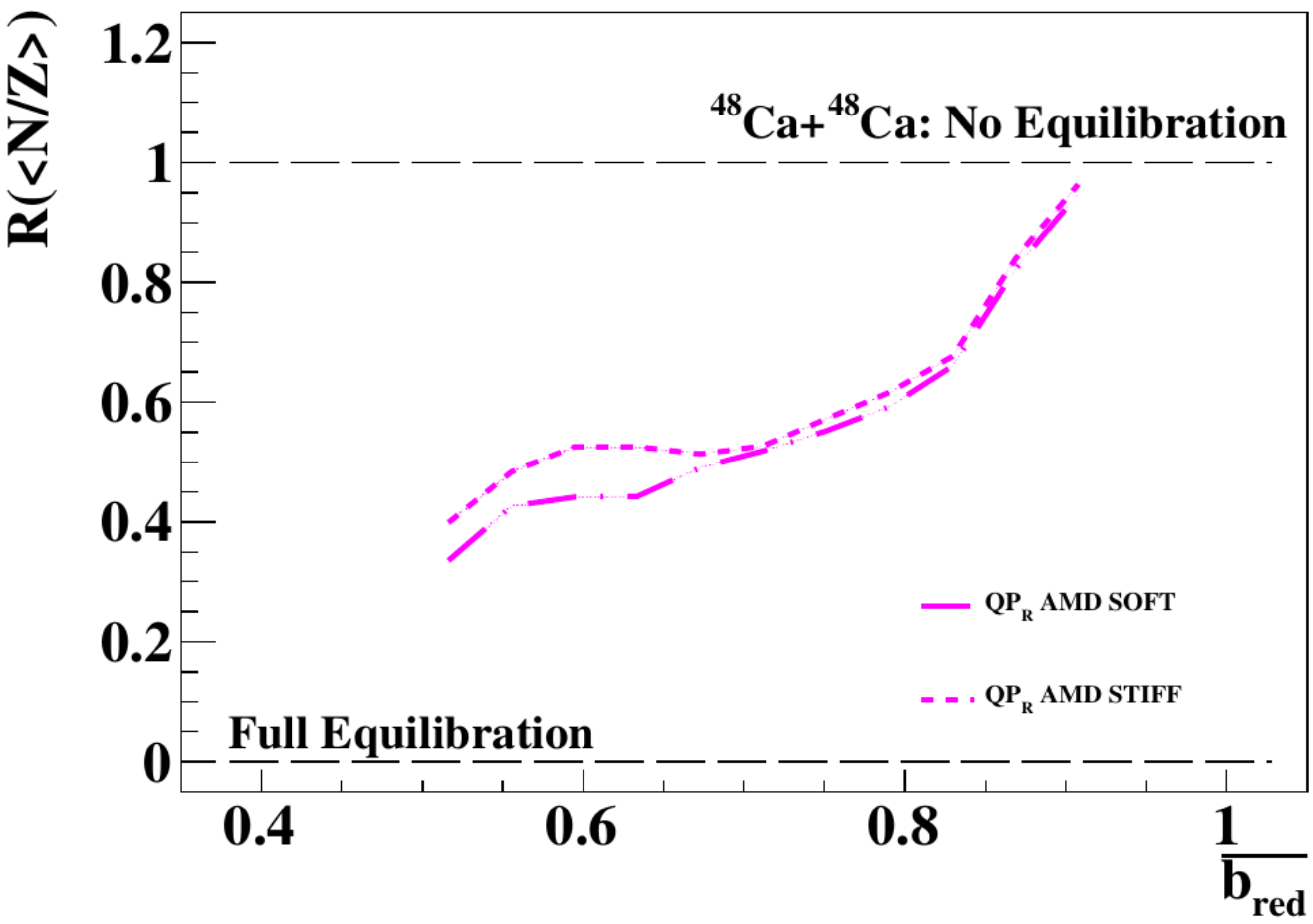
The equilibration degree seems similar in both channels, compatible with a QP break up after the separation between projectile and target

AMD STIFF v.s. AMD SOFT

The imbalance ratio is an observable sensitive to the stiffness of the EoS

P. Napolitani, Phys. Rev C 81, 044619 (2010)

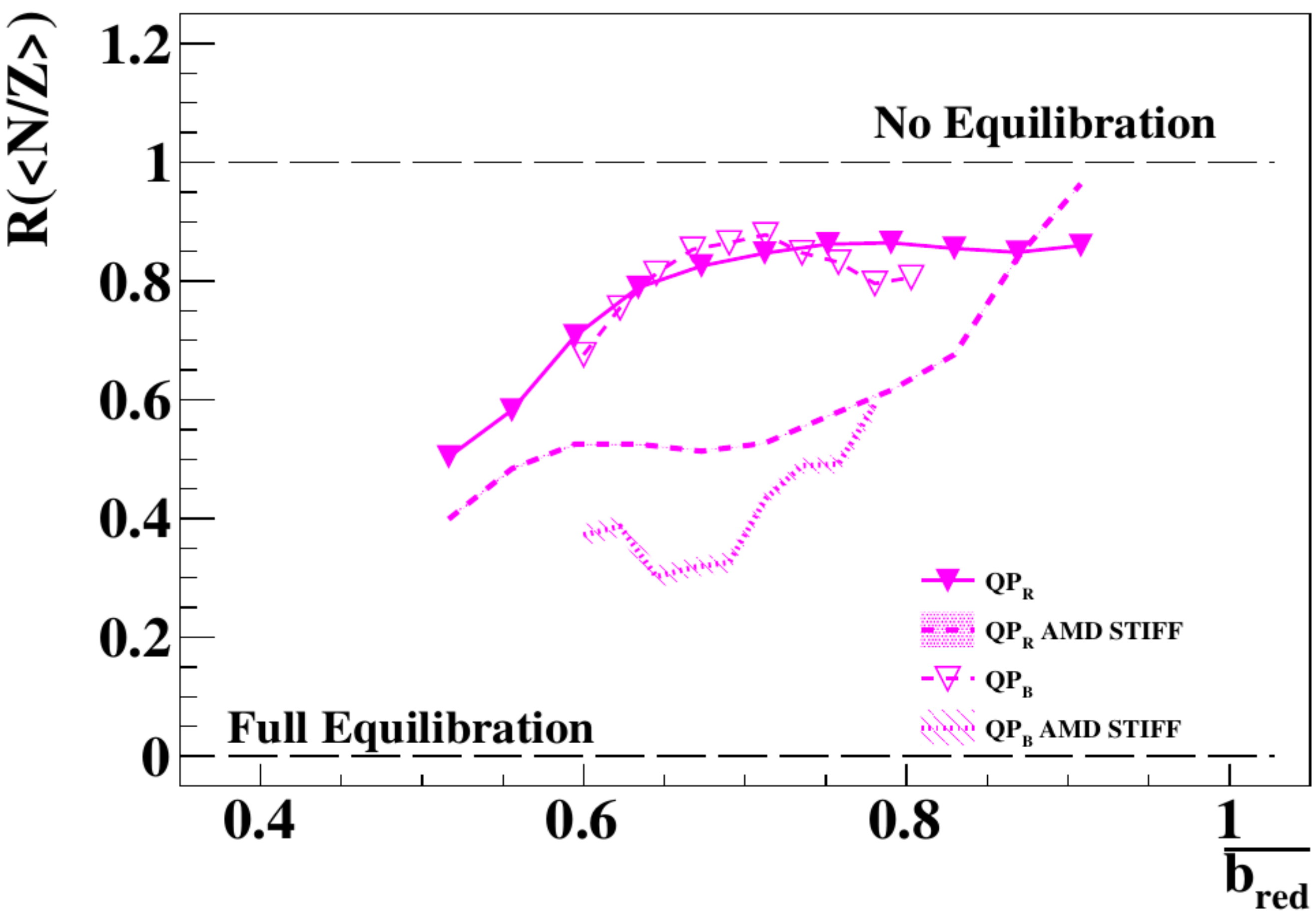
QP remnant channel

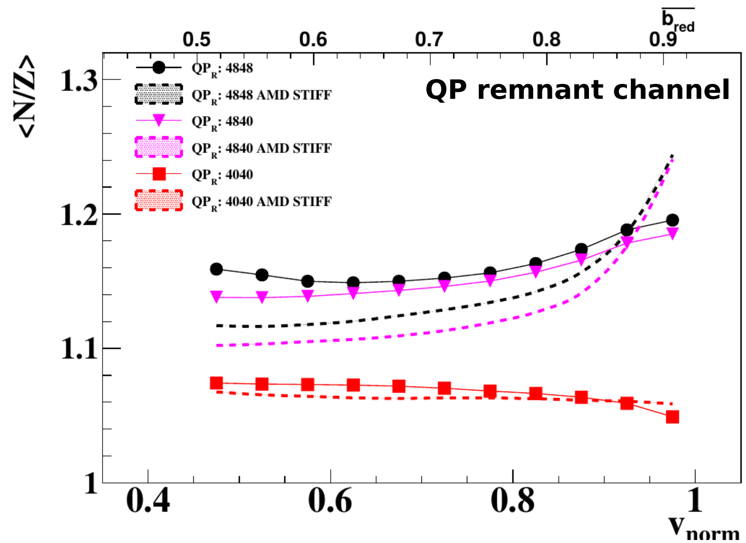


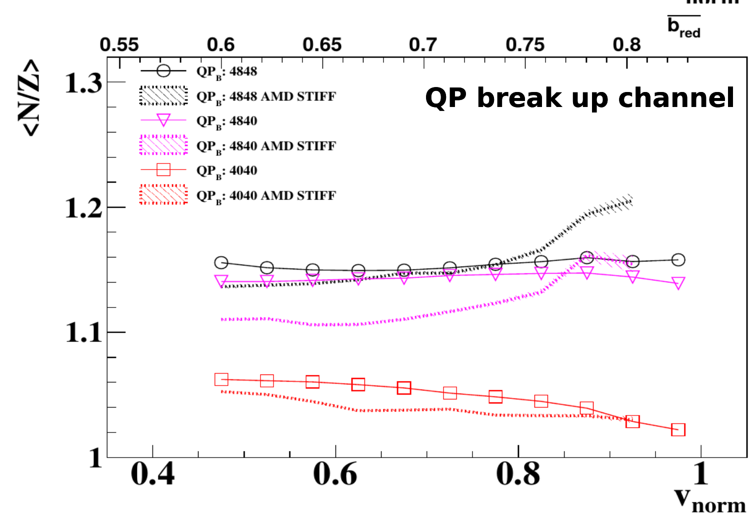
With the FAZIASYM setup, at 35 MeV/u, according to the AMD model, we cannot discriminate between the STIFF and the SOFT parametrization

AMD STIFF predictions

By mean of the Imbalance ratio we can enhance the equilibration due to the isospin diffusion:







Both in QP_R and QP_B channel,
the predicted isospin equilibration is too strong with respect to the experimental data

Summary and Conclusions

We **investigated the isospin diffusion in Ca reactions** by means of 4 FAZIA blocks. In particular we compared the **QP remnant with the reconstructed QP** in the break up channel, **both isotopically resolved**.

We experimentally observed that:

- The QP remnant in the ^{48}Ca+^{40}Ca reaction manifests the typical characteristic due to the presence of isospin diffusion
- The more damped the collision the more equilibrated the isospin
- In the break up channel, once we reconstruct the QP, the same degree of equilibration is observed

Concerning the AMD model:

- It globally well reproduces the gross properties of the reactions but..
- It does not reproduce the experimentally observed <N/Z>, neither the absolute values, nor the equilibration as a function of the centrality
- No discrimination between STIFF and SOFT parametrization at 35MeV/u of bombarding energy

First advanced isospin studies with the FAZIA detector

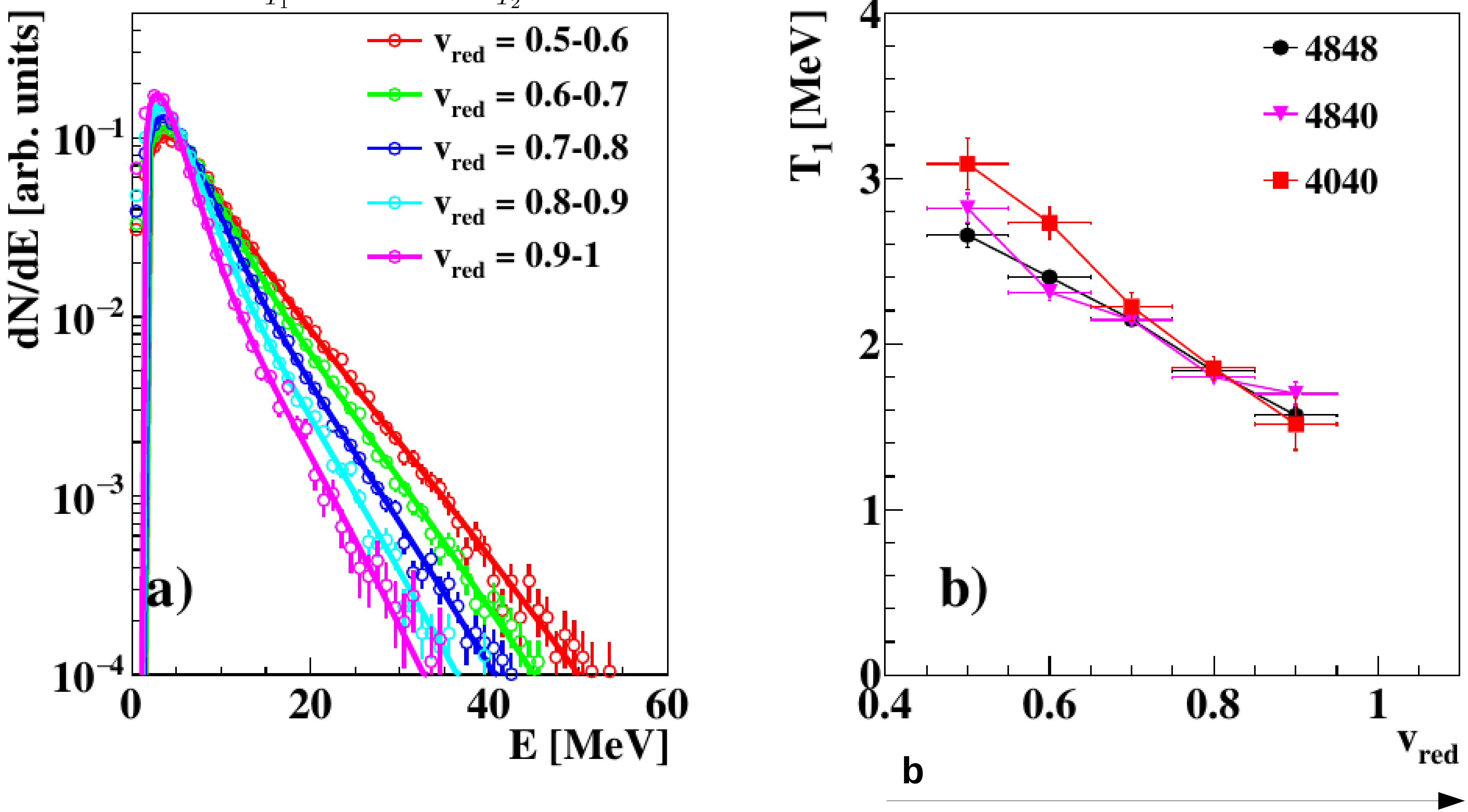
Thank you
for the attention

A. Camaiani

Impact parameter estimation

Considering the LCP forward (i.e. statistically) emitted with respect the QP:

$$f = N_1 \frac{E - B_1}{T_1} e^{-\frac{E-B_1}{T_1^2}} + N_2 \frac{E - B_2}{T_2} e^{-\frac{E-B_2}{T_2^2}}$$



The more damped the collision, the more excited the QP, thus confirming the scaling of v_{red} as a function of b_{red}