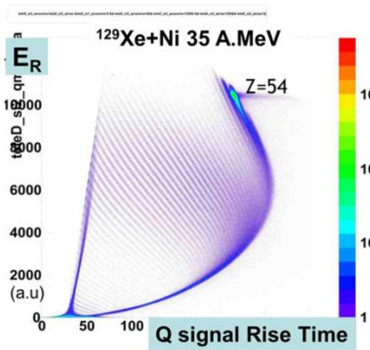
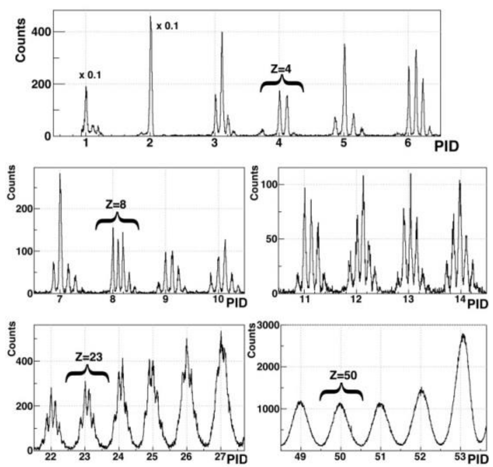
# FAZIA DEMONSTRATOR at LNS

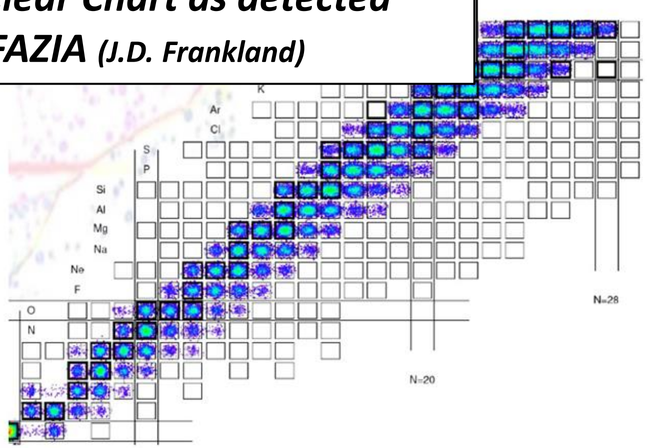
## Pulse Shape identification




## DE/E identification




***Nuclear Chart as detected by FAZIA** (J.D. Frankland)*




# Nuclear Dynamics

LIA COLL-AGAIN – COPIGAL – POLITA
workshop
Catania, April 2016

## Chemical equilibrium $^{3}He$ and $^{6}He$ production

32 A.MeV

- $^{124}Xe+^{112}Sn$
- $^{124}Xe+^{124}Sn$
- $^{136}Xe+^{112}Sn$
- $^{136}Xe+^{124}Sn$

$$E(\rho,I)=E(\rho,I=0)+\underbrace{E_{sym}(\rho)}_{SYMMETRY\ ENERGY}I^{2}+\ldots$$

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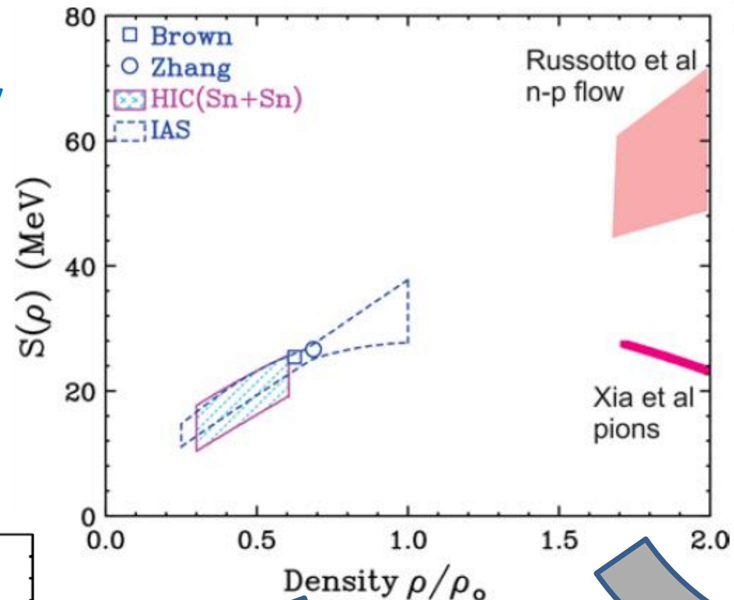
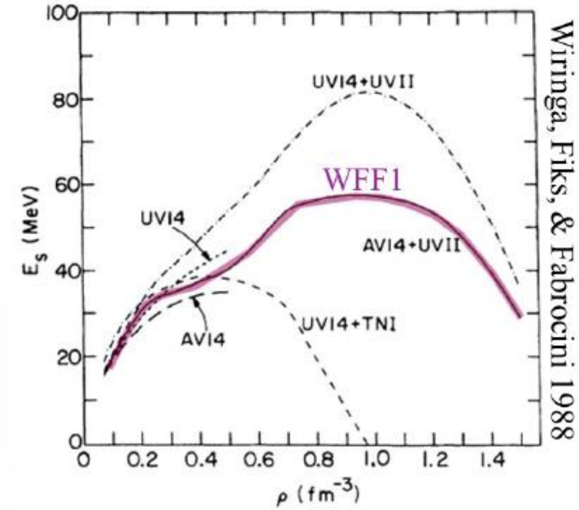
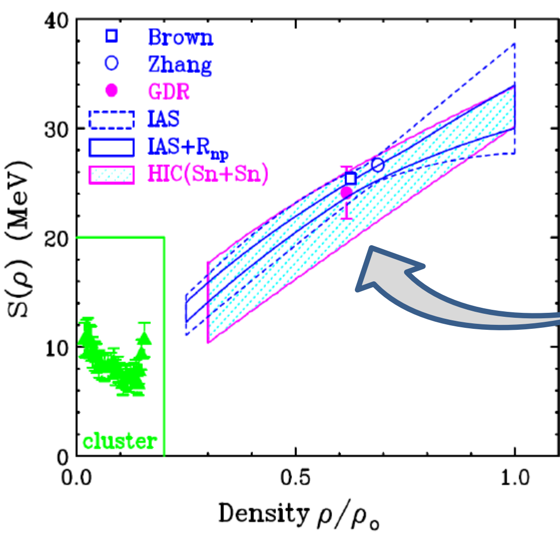
# Equation of State

## Status...

**Density dependence of the EOS Symmetry Energy**




**Function ?**

**?**

$$E_{sym}(\rho) = \frac{C_{kinetic}}{2}\left(\frac{\rho}{\rho_0}\right)^{2/3} + \frac{C_{potential}}{2}\left(\frac{\rho}{\rho_0}\right)^{\gamma}$$

**Clusters at low densities (T>0)**

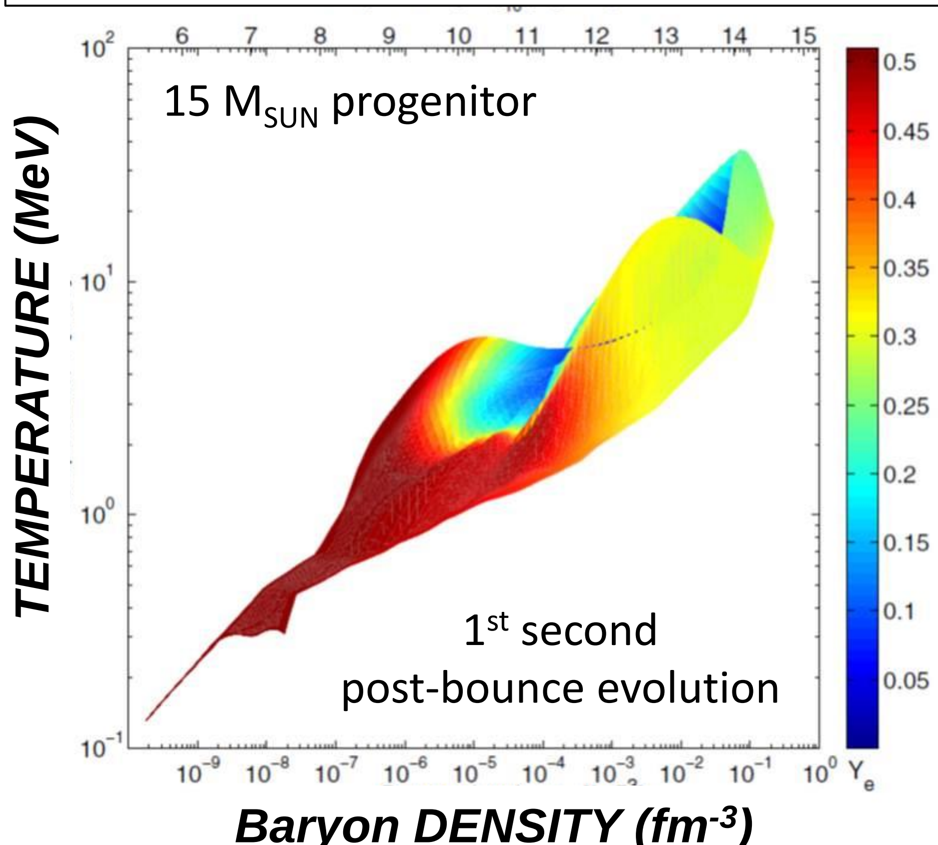
# Supernova explosion

Supernova explosion occurs via core-collapse in very massive stars ($M>8M_{sun}$)

Present best 3D hydro simulations do not produce successful explosions

- Model & progenitor dependence
- Great sensitivity to the microphysics

## Phase space covered in Core-Collapse Supervova simulations




Color: electron fraction

- From Symmetric matter (0.5) red
- To Neutron matter (0) blue

**EOS controls explosion**

**HI collisions (T, density)**

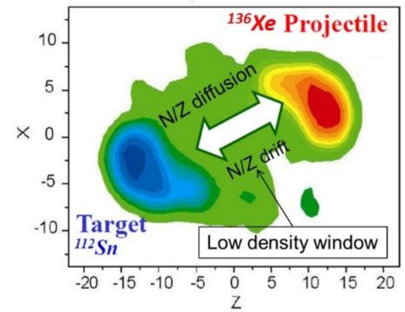
***Nuclear physics starts to constrain the complex dynamics of supernova***

T. Fischer et al. Astro. Phys. Journal 194:39 (2011)

# LCP production

$$E(\rho,I)=E(\rho,I=0)+\underbrace{E_{sym}(\rho)}_{SYMMETRY\ ENERGY}I^2+\dots$$

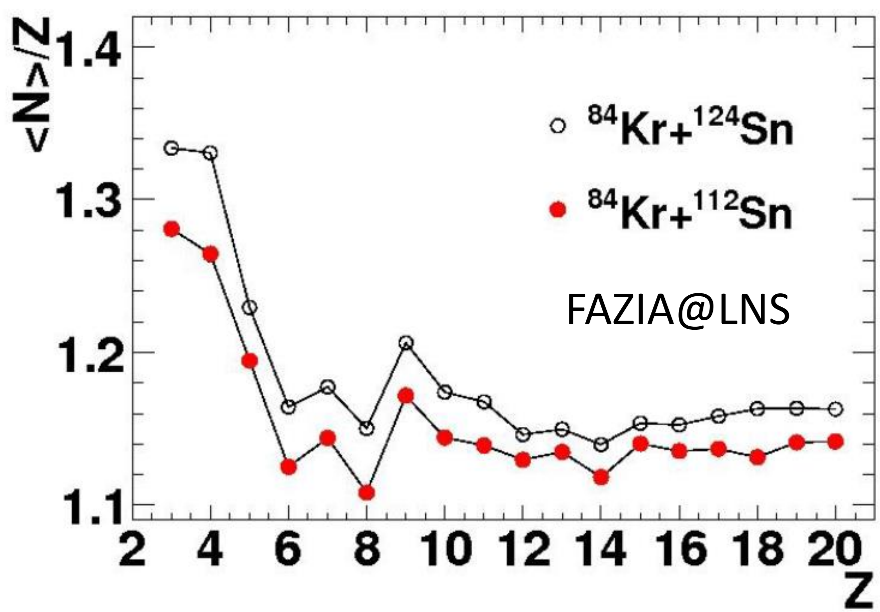
Projectile/Target nucleon exchange and mid-rapidity chemistry




are governed by drift and diffusion transport phenomena

**Diffusion**: isospin exhange projectile/target with different N/Z (tends to $N/Z_{composite}$)
**Drift**: neutron enrichment of low density zone created between projectile & target

S.Barlini et al. PRC 87, 054607 (2013)




***See also CHIMERA publications***

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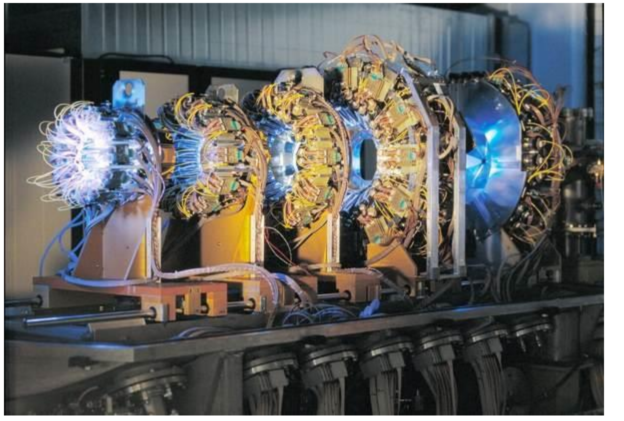
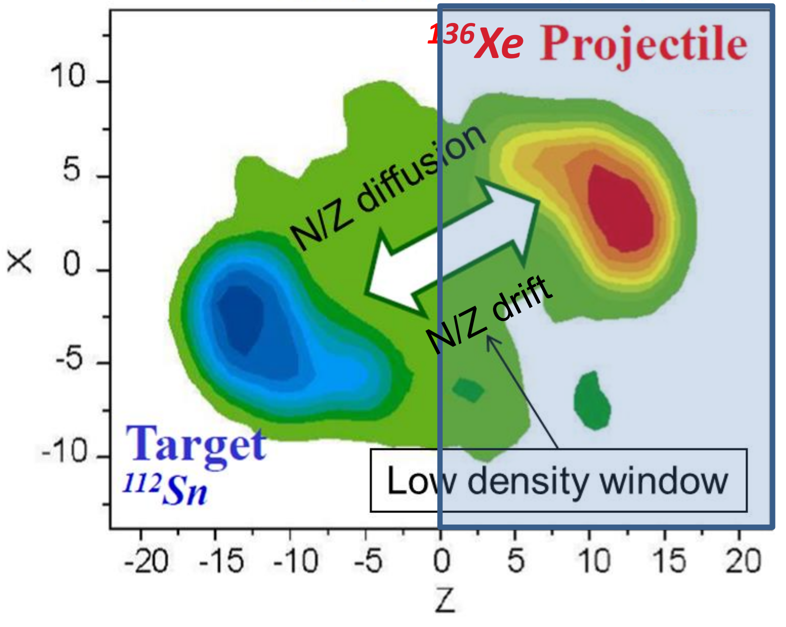
# Nuclear Dynamics

*Study of chemical equilibration between PLF & TLF*

**Light Charged Particle emitted in the forward part of the c.m (neutrons are not detected) INDRA multi-detector**






**32 A.MeV**

- $^{124}Xe+^{112}Sn$
- $^{124}Xe+^{124}Sn$
- $^{136}Xe+^{112}Sn$
- $^{136}Xe+^{124}Sn$

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# LCP production *(forward c.m)*

| mbarn | 124+112 | 124+124 | 136+112 | 136+124 |
|---|---|---|---|---|
| $^{1}H$ | 7963 | 7167 | 6621 | 6241 |
| $^{2}H$ | 2485 | 2714 | 2773 | 3092 |
| $^{3}H$ | 1342 | 1780 | 1965 | 2612 |
| $^{3}He$ | 572 | 491 | 416 | 397 |
| $^{4}He$ | 6992 | 7257 | 7005 | 7501 |
| $^{6}He$ | 109 | 147 | 163 | 239 |
| TOTAL | 19463 | 19556 | 18943 | 20083 |

No data selection/Inclusive events except elastic events are excluded

# LCP production *(forward c.m)*

| mbarn | 124+112 | 124+124 | 136+112 | 136+124 |
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| $^{1}H$ | 7963 | 7167 | 6621 | 6241 |
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**Total lcp production is system independent (within 6%)**

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| TOTAL | 19463 | 19556 | 18943 | 20083 |

**Total lcp production is system independent (within 6%) BUT THE CHEMISTRY IS!**

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# LCP production *(forward c.m)*

| mbarn | 124+112 | 124+124 | 136+112 | 136+124 |
|---|---|---|---|---|
| $^{1}H$ | 7963 | 7167 | 6621 | 6241 |
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| $^{3}H$ | **1342** | **1780** | **1965** | **2612** |
| $^{3}He$ | 572 | 491 | 416 | 397 |
| $^{4}He$ | 6992 | 7257 | 7005 | 7501 |
| $^{6}He$ | **109** | **147** | **163** | **239** |
| TOTAL | 19463 | 19556 | 18943 | 20083 |

**Increasing the system neutron richness: n-rich lcp production is doubled**

# LCP production *(forward c.m)*

| mbarn | 124+112 | 124+124 | 136+112 | 136+124 |
|---|---|---|---|---|
| $^{1}H$ | 7963 | 7167 | 6621 | 6241 |
| $^{2}H$ | 2485 | 2714 | 2773 | 3092 |
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| TOTAL | 19463 | 19556 | 18943 | 20083 |

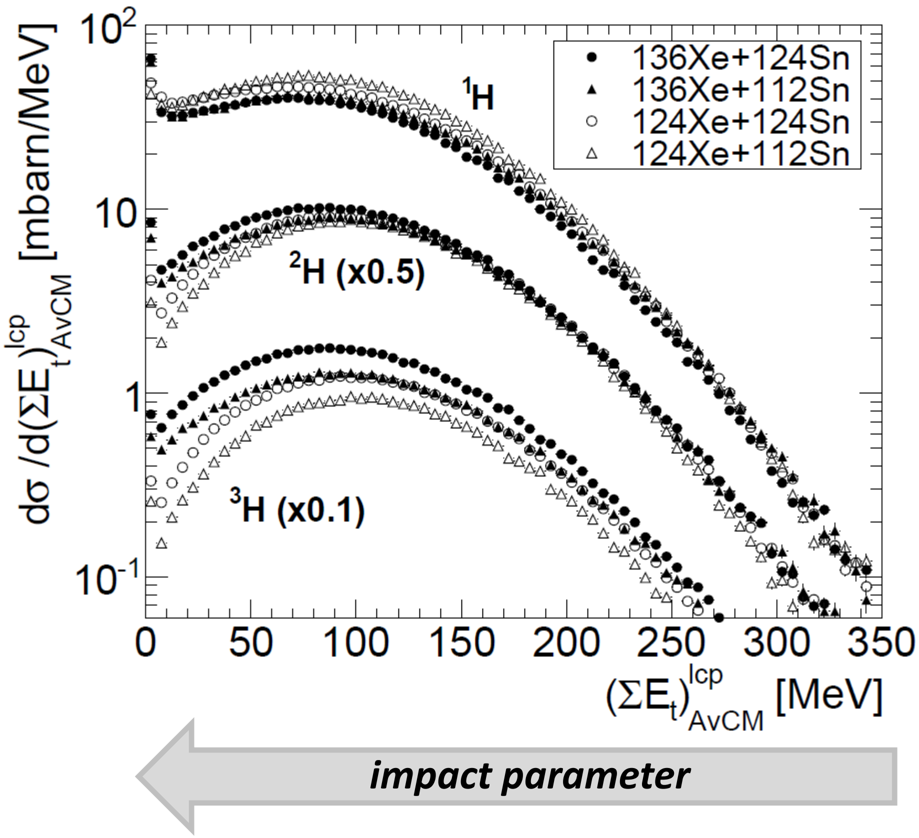
**Changing projectile & target: a lot of differences in lcp production**

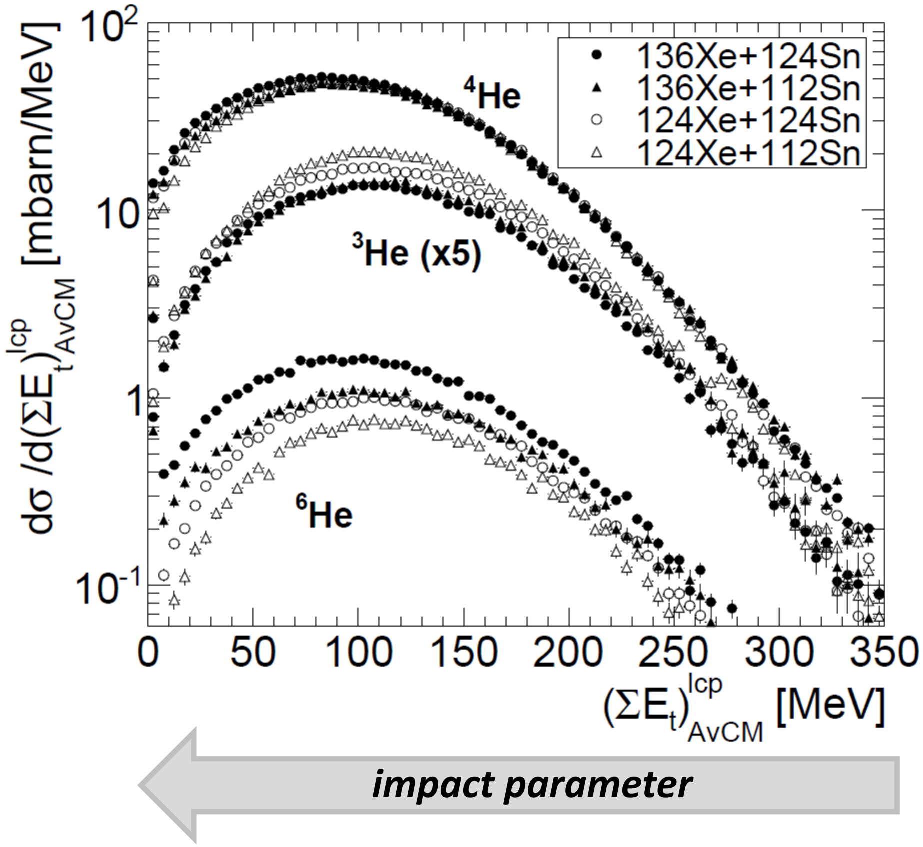
# LCP production *(forward c.m)*

| mbarn | 124+112 | 124+124 | 136+112 | 136+124 |
|---|---|---|---|---|
| $^{1}H$ | | | | |
| $^{2}H$ | | | | |
| $^{3}H$ | | | | |
| $^{3}He$ | | | | |
| $^{4}He$ | | | | |
| $^{6}He$ | | | | |
| TOTAL | | | | |

***Changing the projectile & target N/Z: isotope production cannot be summed up in solely neutron production difference***

# LCP production (forward c.m)

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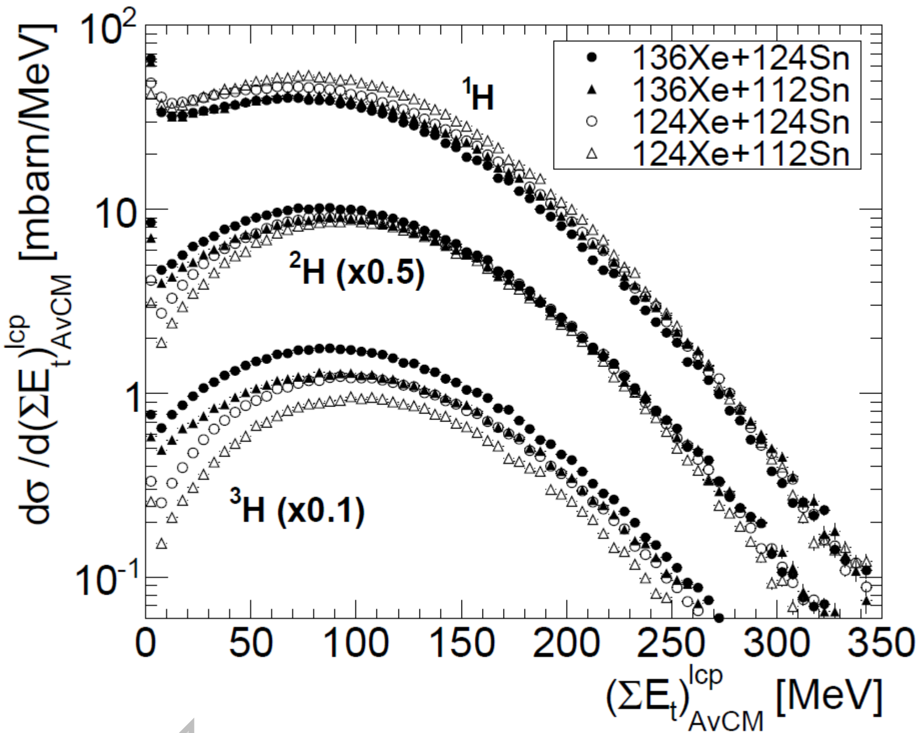
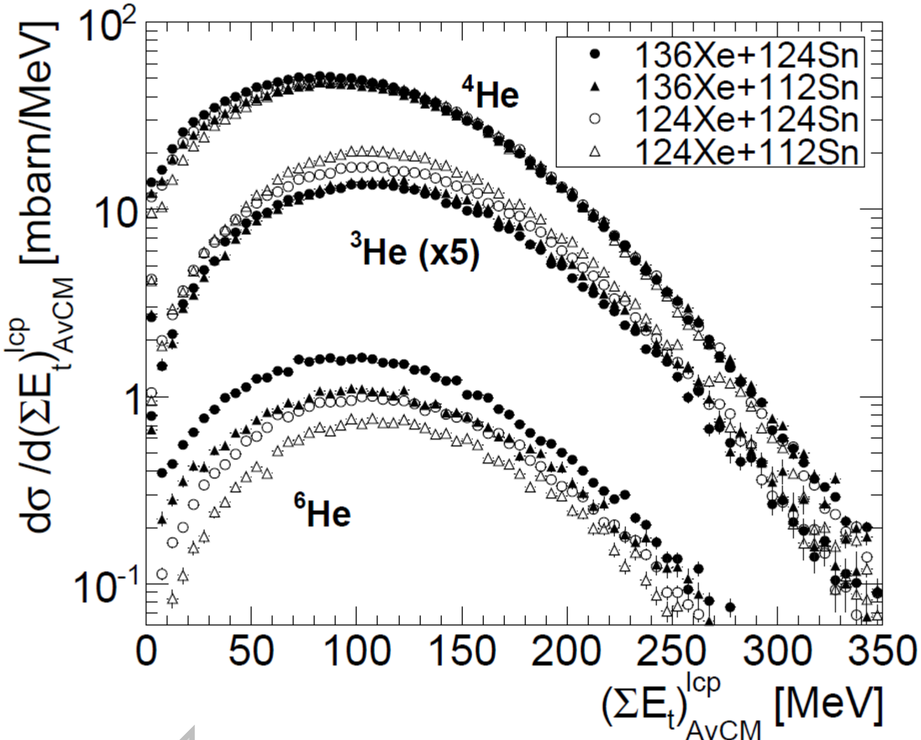
# LCP production *(forward c.m)*




*impact parameter*

*impact parameter*

**3He production is different**

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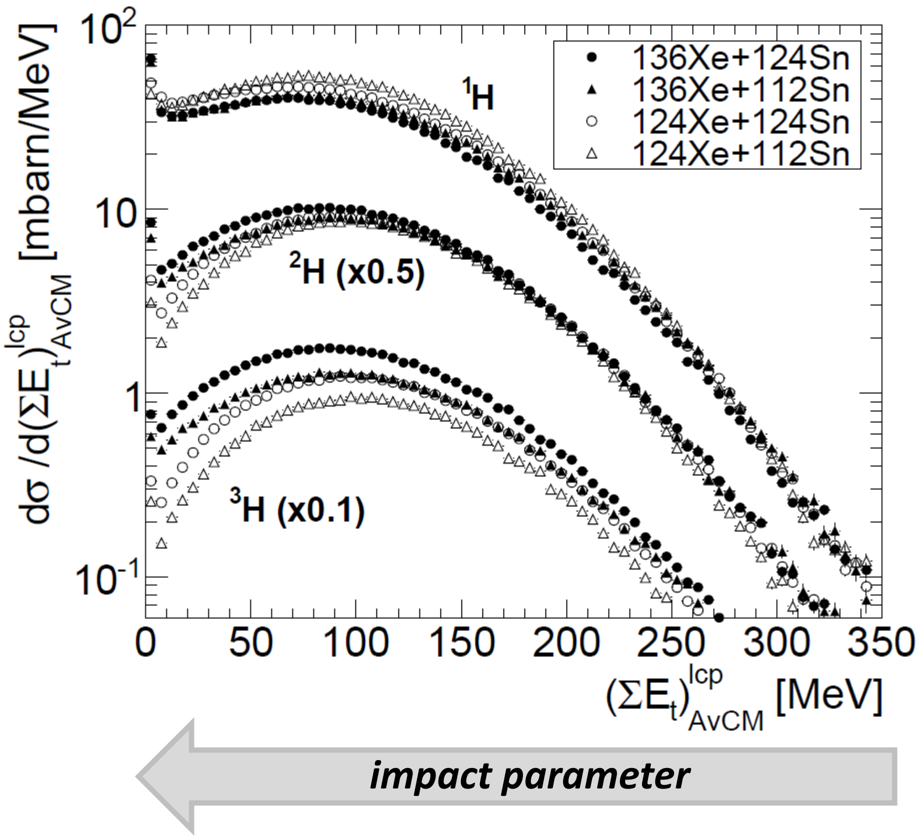
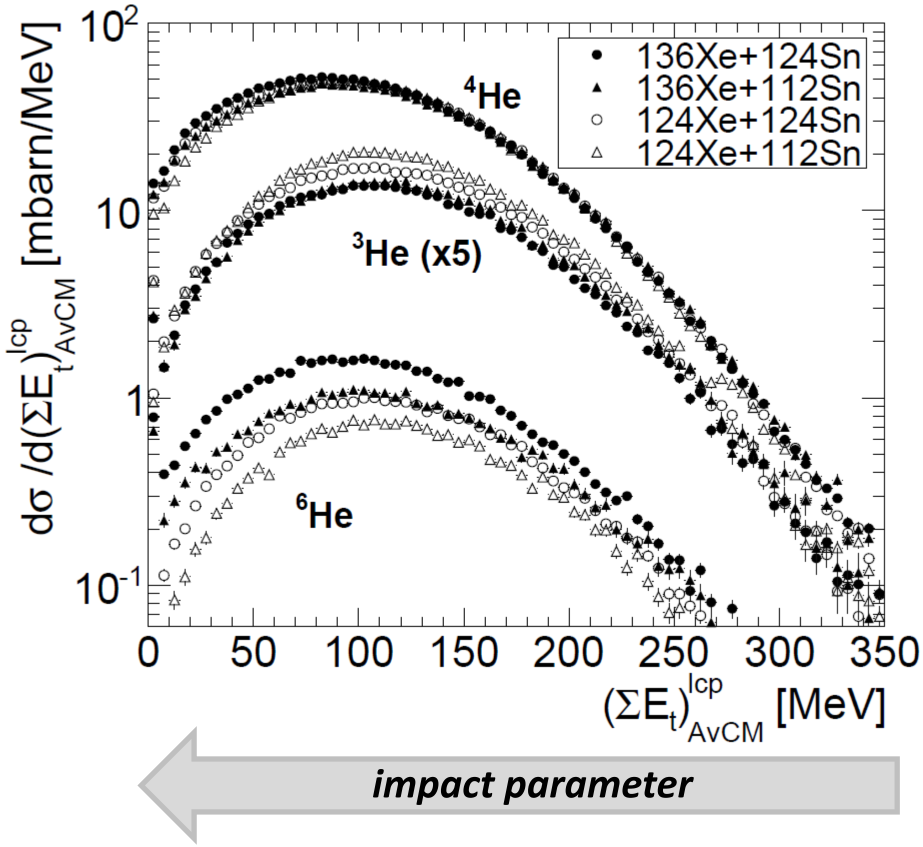
# LCP production (forward c.m)




**Lcp cross-sections: production probabilities folded by reaction cross-section**

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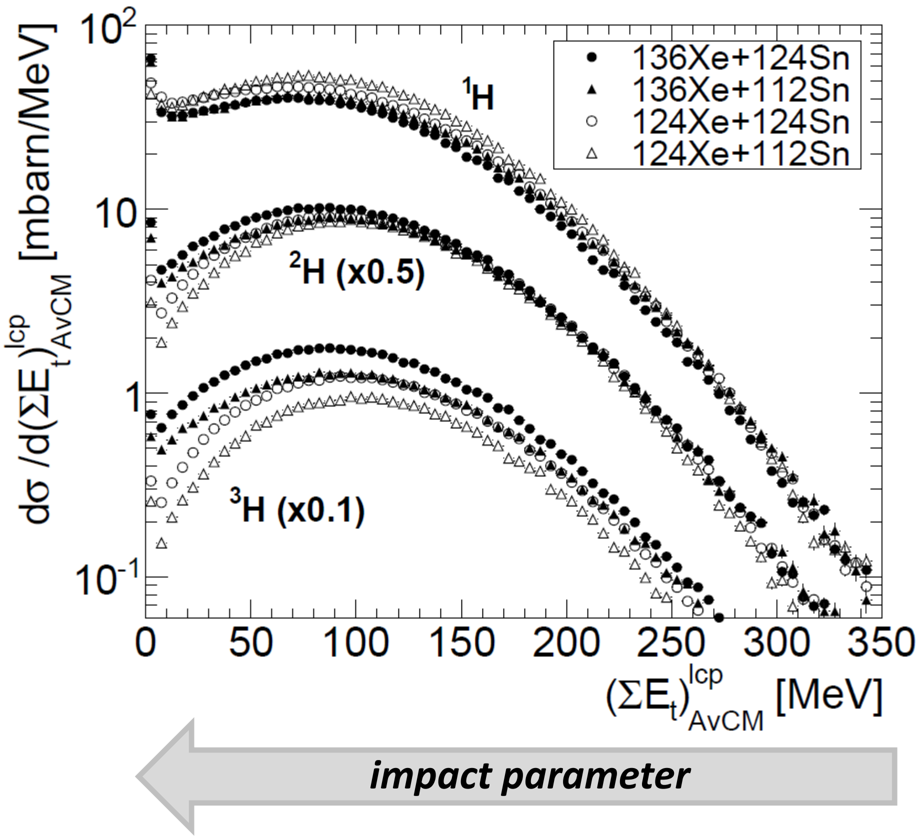
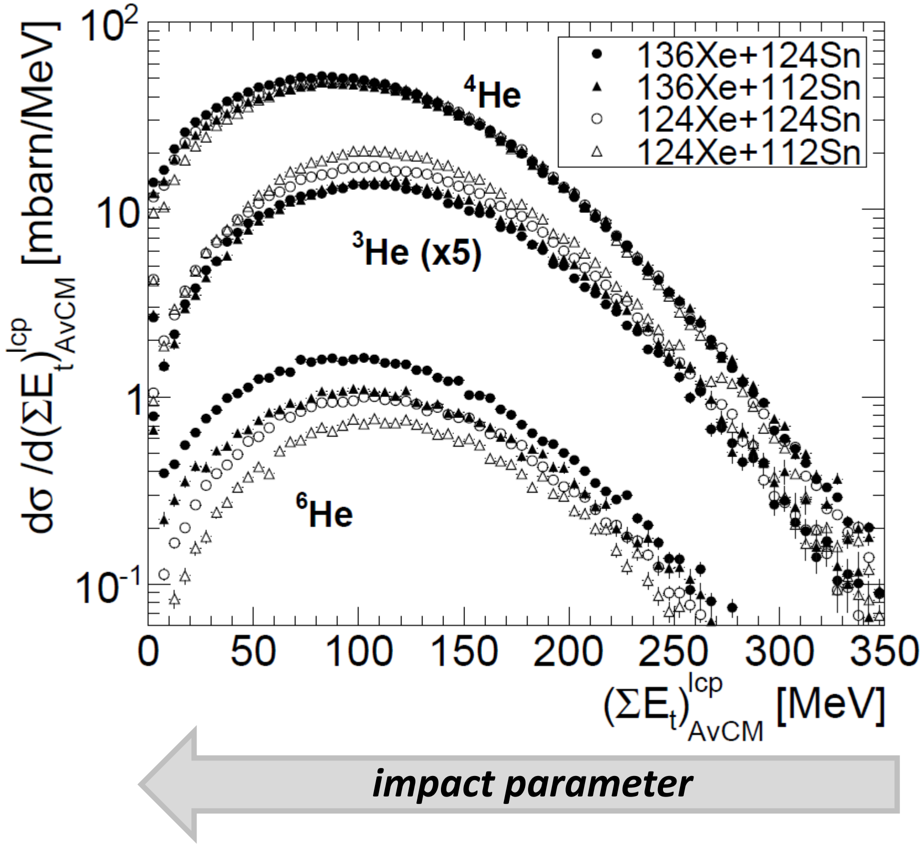
# LCP production (forward c.m)




**To study equilibrium:**
**Production probabilities (multiplicities) divided by 1H multiplicities to remove trivial size effects.**
**Chemistry related to concentrations thus Mx/Mproton (abundance ratio).**

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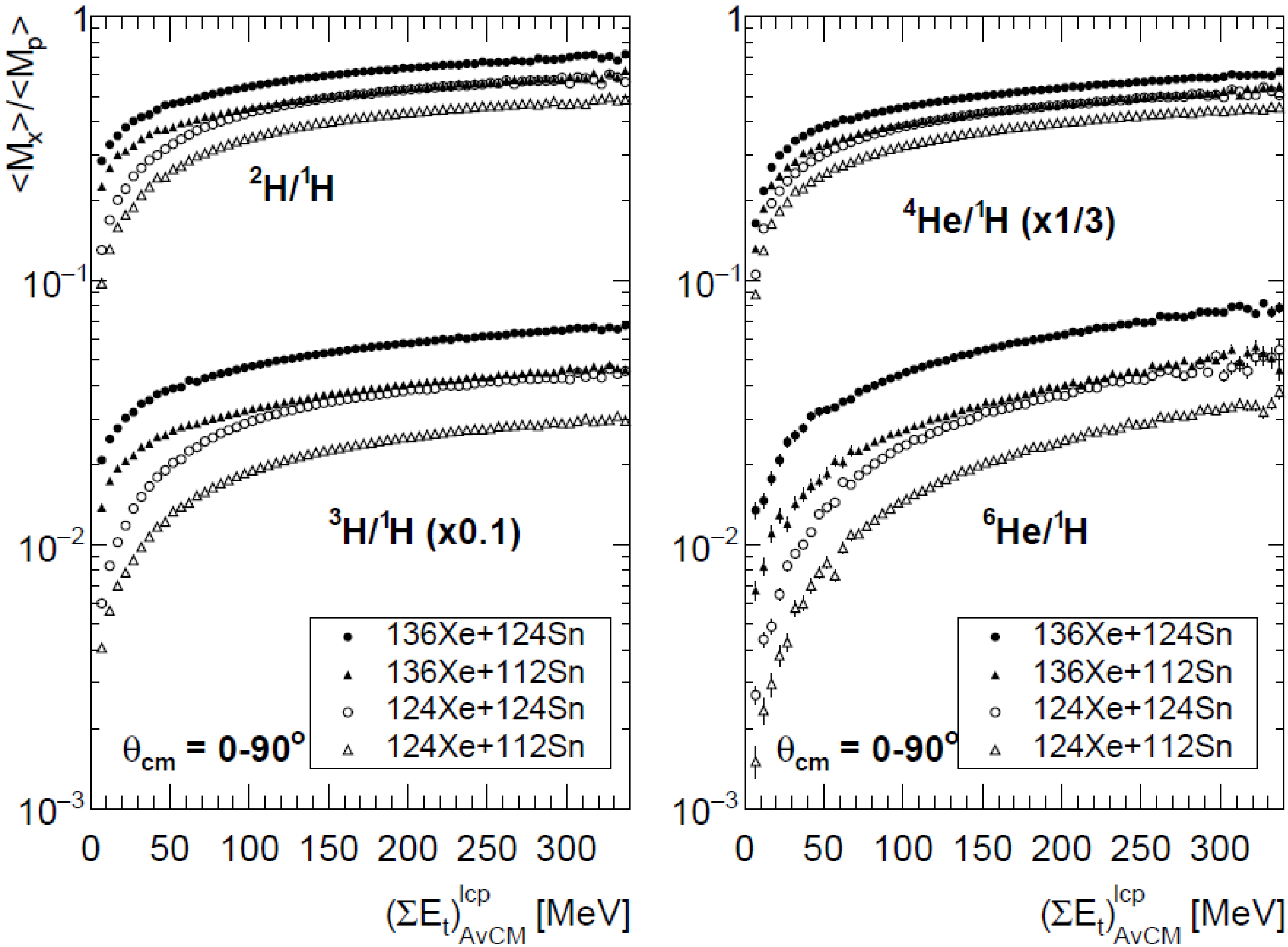
# Cluster abundance ratios

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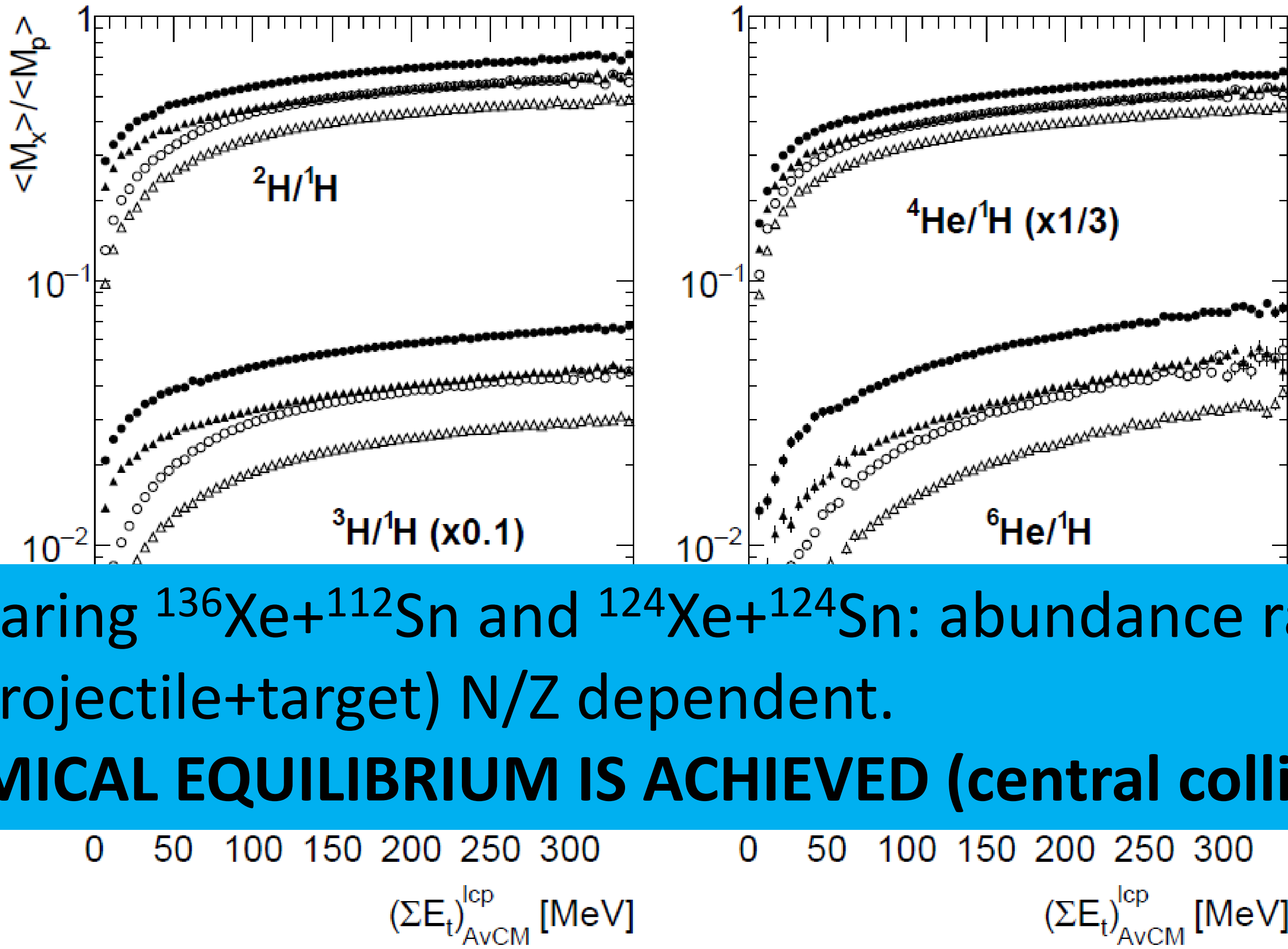


Comparing $^{136}Xe+^{112}Sn$ and $^{124}Xe+^{124}Sn$: abundance ratios are (projectile+target) N/Z dependent.

**CHEMICAL EQUILIBRIUM IS ACHIEVED (central collisions)**

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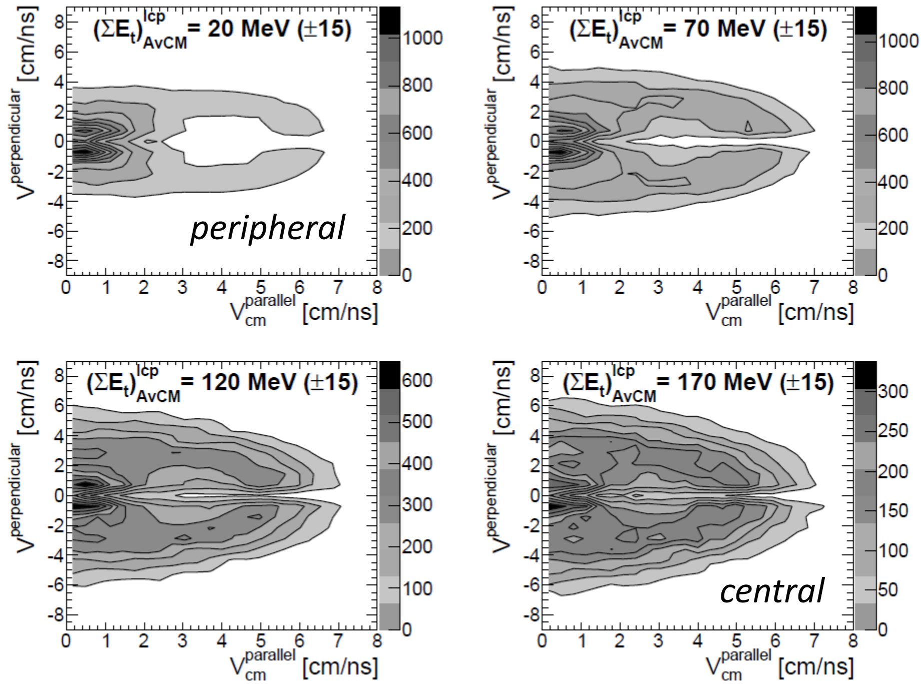
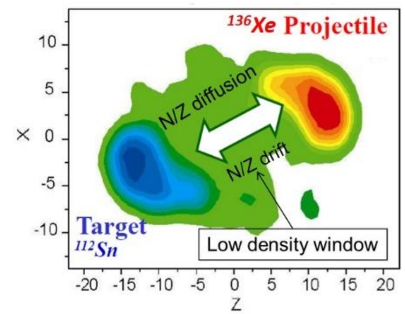
# LCP production mode (forward c.m): $^2H$




Emission from projectile-like fragment & at mid-rapidity

Projectile/Target nucleon exchange and mid-rapidity chemistry




are governed by drift and diffusion transport phenomena

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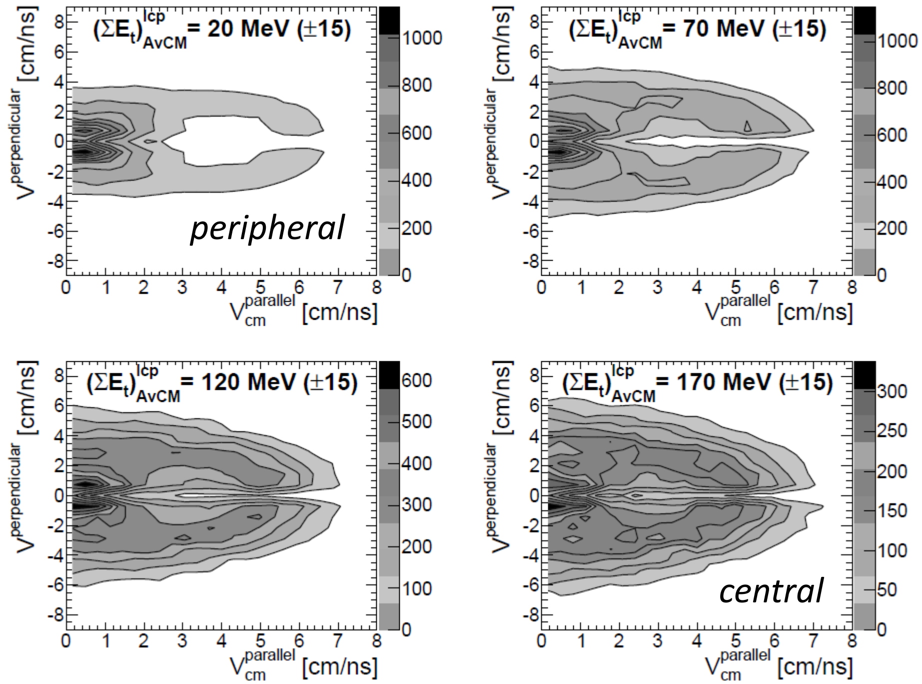
# LCP production mode (forward c.m): $^2H$




Emission from projectile-like fragment & at mid-rapidity

**Projectile-like**: 0°-30° angle selection
**½ rapidity**: 60°-90° angle selection

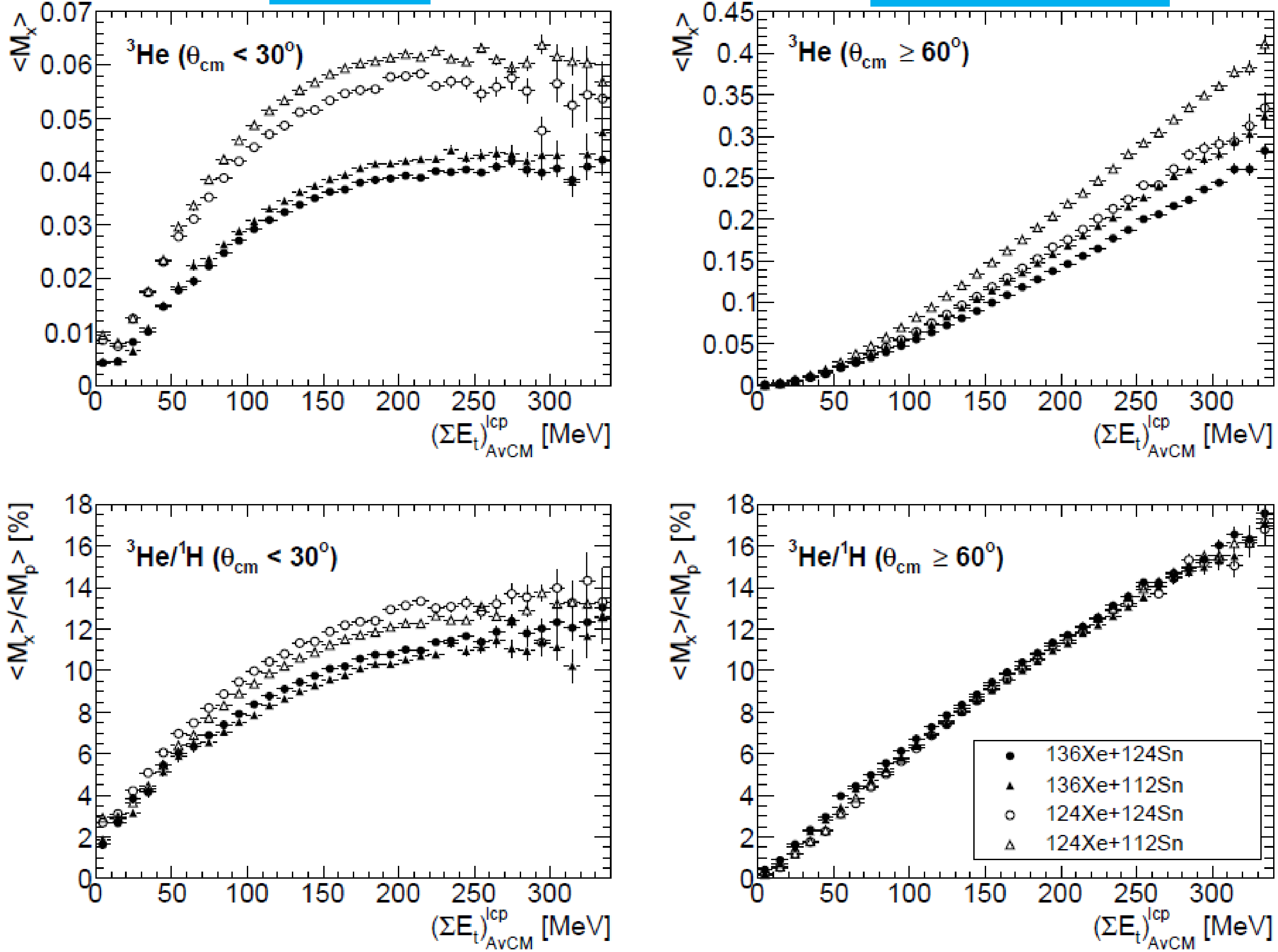
# LCP production: $^3He$

« PLF »

«1/2 rapidity »

Multiplicity

Abundance ratio

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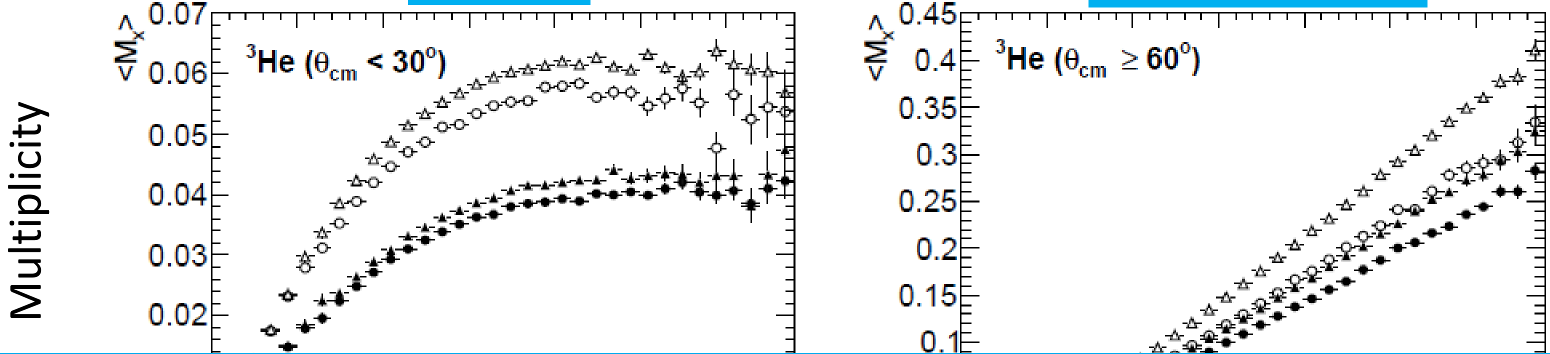
# LCP production: $^3He$

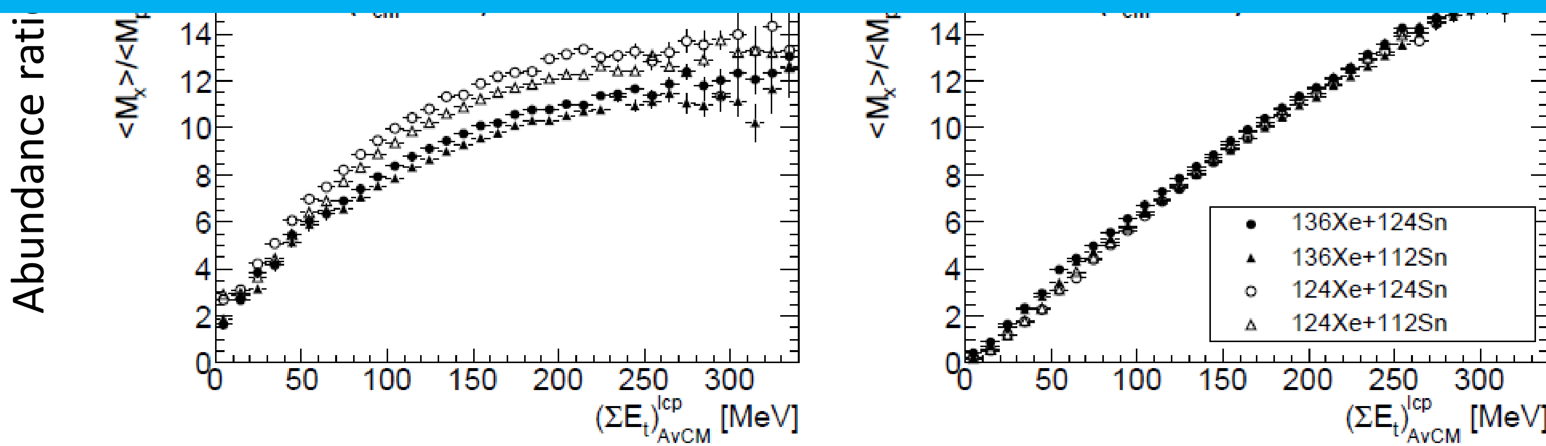
« PLF »

«1/2 rapidity »




- PLF: N/Z dependence
- ½ rapidity: total size (not N/Z) dependence

**3He produced before chemical equilibrium achievement**

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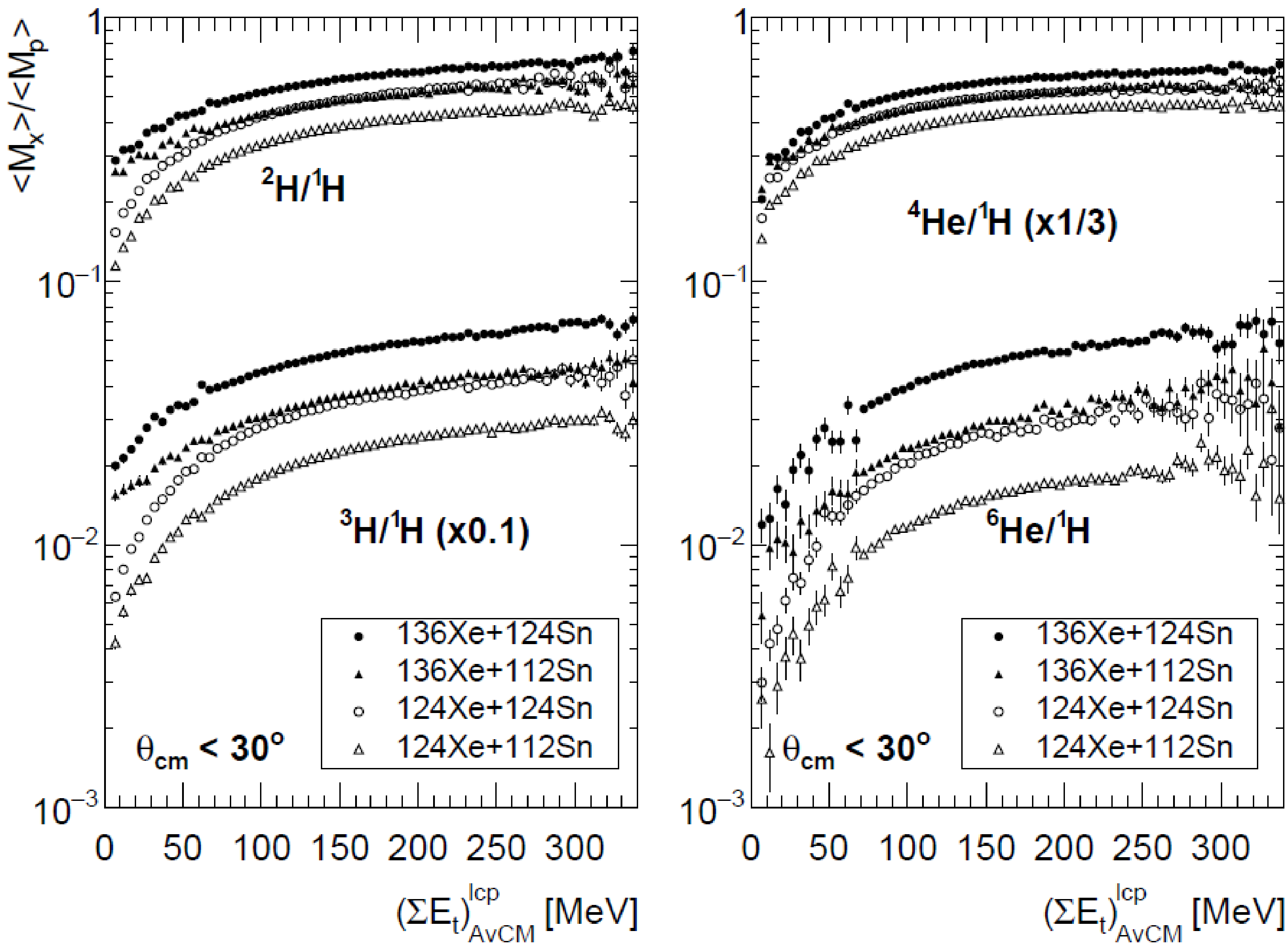
# Cluster abundance ratios ("PLF")

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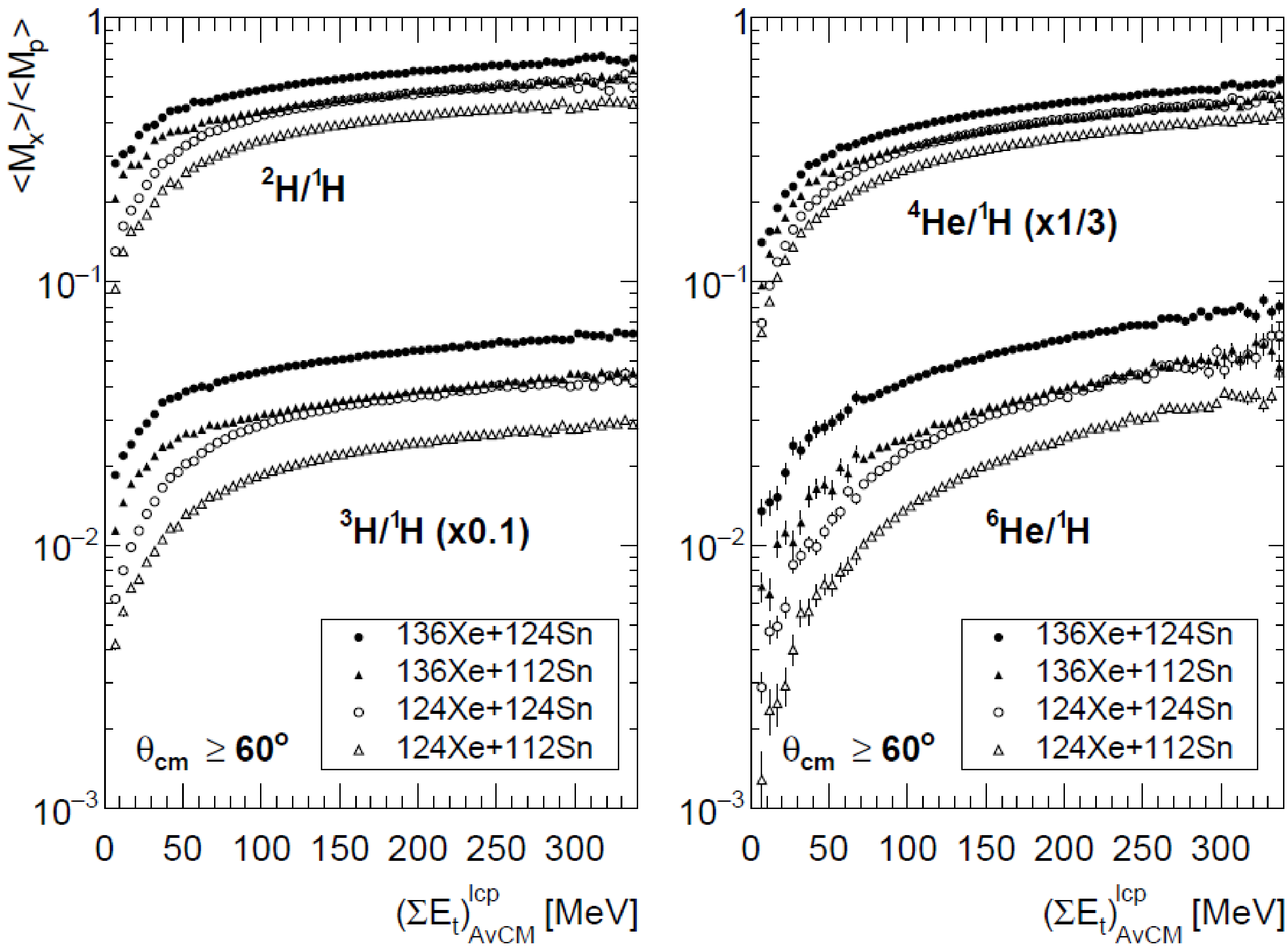
# Cluster abundance ratios ("1/2 rapidity")

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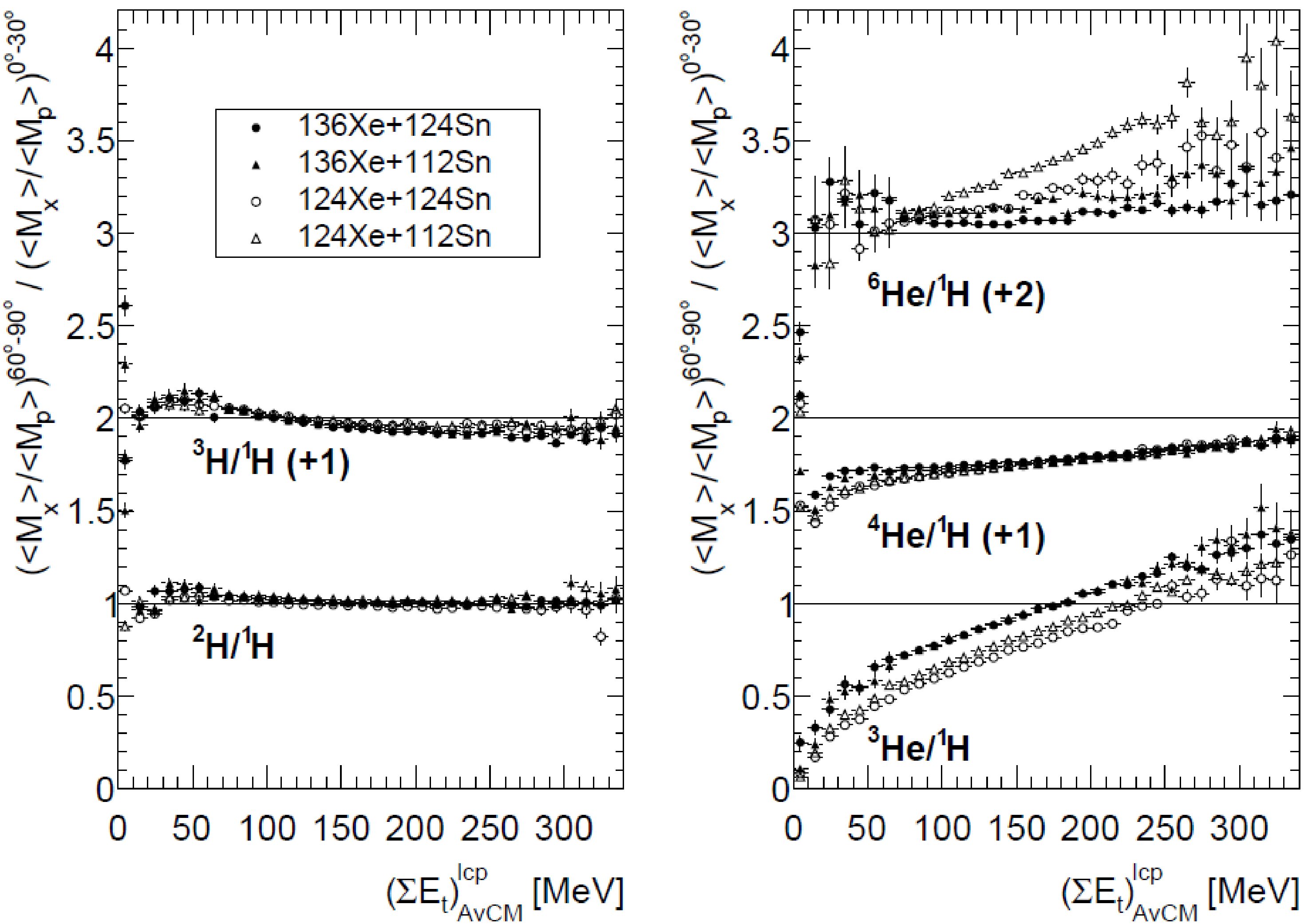
# Cluster abundance ratios

*1/2 rapidity divided by PLF*

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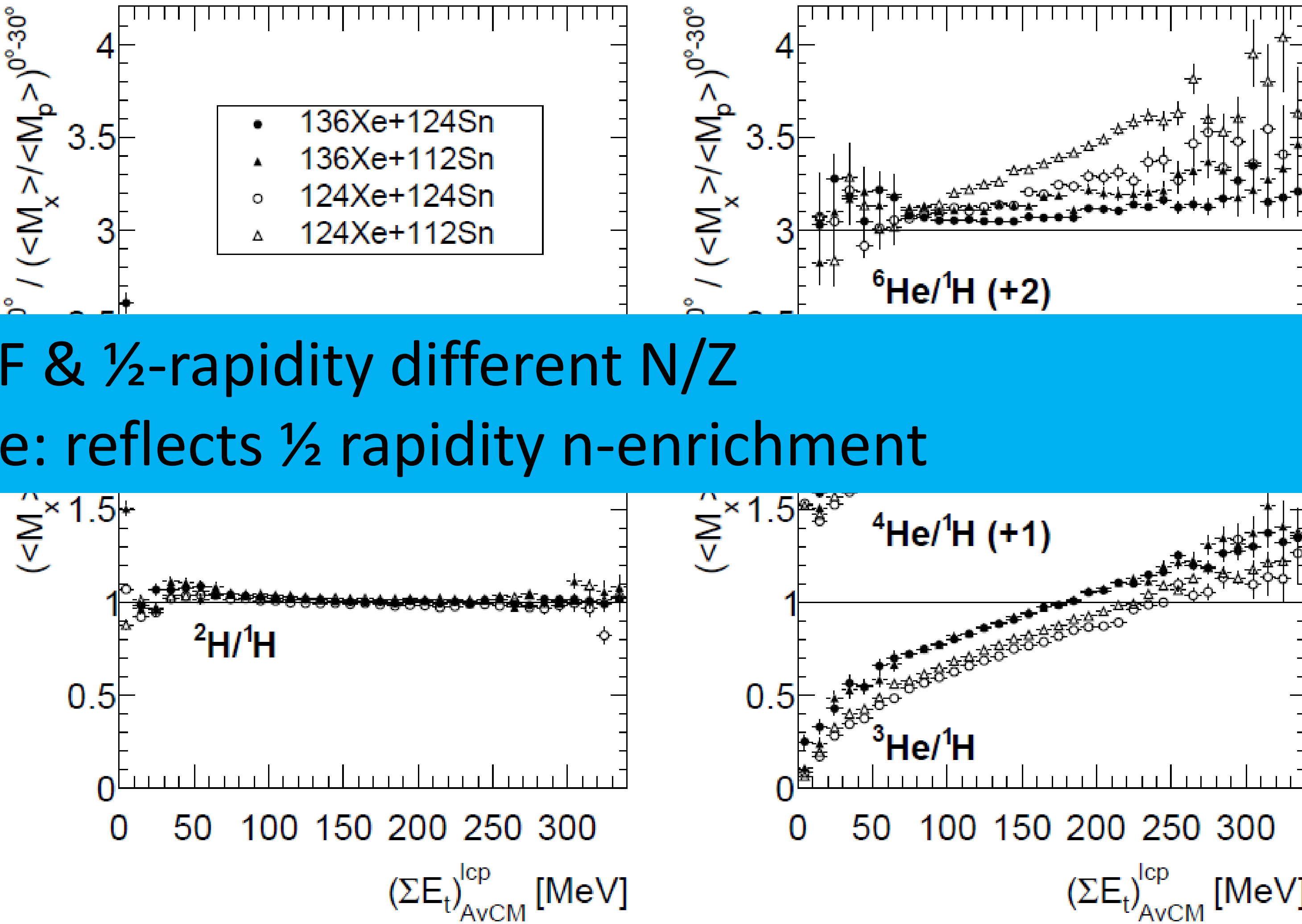
*1/2 rapidity divided by PLF*




- PLF & ½-rapidity different N/Z
- $^6$He: reflects ½ rapidity n-enrichment

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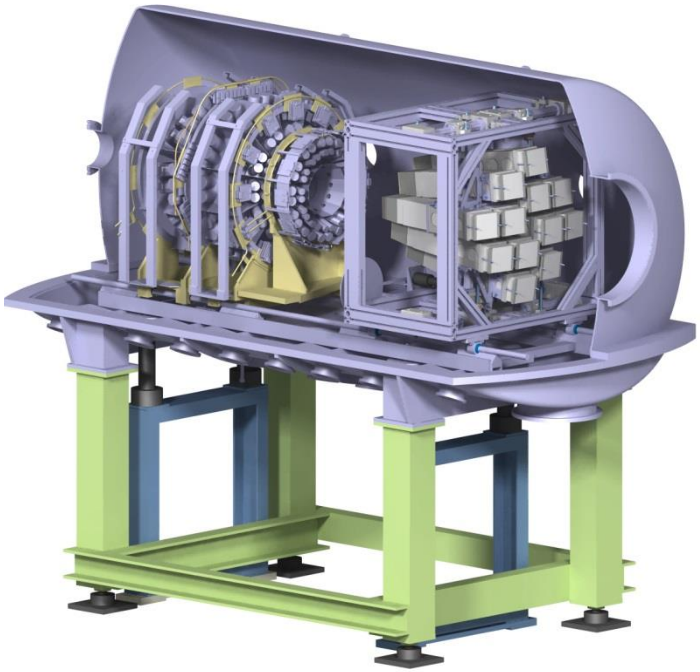
# Conclusions

- Light Charged Particle abundance ratios dependence against impact parameter: high degree of chemical equilibrium is achieved in central collisions.
- $^{3}$He mean characteristics strongly differ from other studied lcp's: helion production takes place before chemical equilibrium achievement.
- Achieved N/Z balance between PLF & TLF does not imply a pure 2-body mechanism: mid-rapidity source does exist with N/Z different as compared to PLF (n-enrichment).
- $^{6}$He production is favored by the drift phenomena.
- Results obtained with INCLUSIVE DATA

- **Importance of clusters.**
- **$^{3}$He & $^{6}$He should be used to compared data/transport models (stiff/soft Esym)**
- **Analysis will be extended (higher elements) using FAZIA@INDRA at GANIL**



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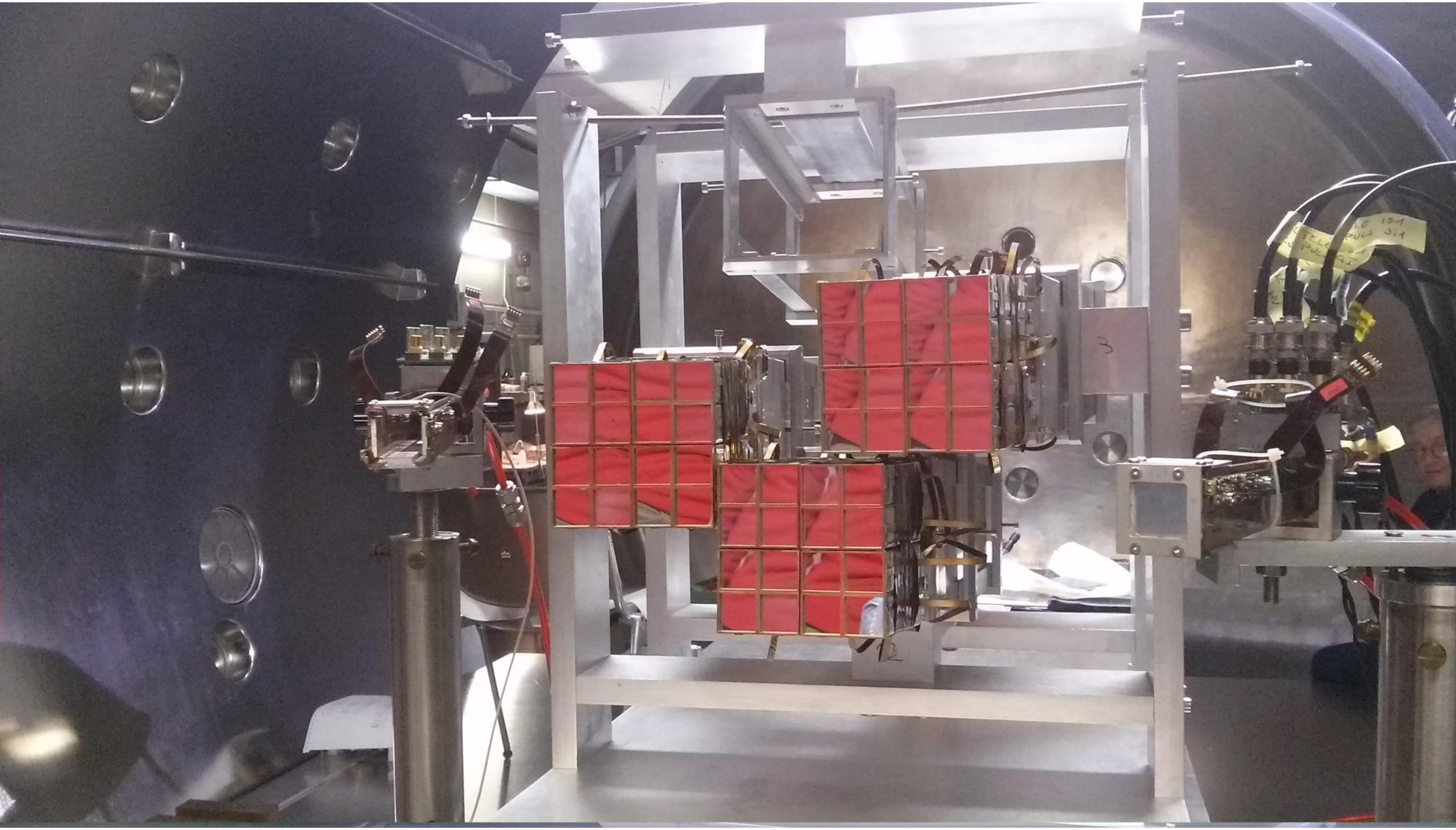
# FAZIA DEMONSTRATOR at LNS



THANKS A LOT LNS (beam, support, all…): LNS IS A GREAT Lab.!