Studies of the production of neutron-rich nuclei towards zero degrees in deep-inelastic collisions

I. Stefan IPN Orsay

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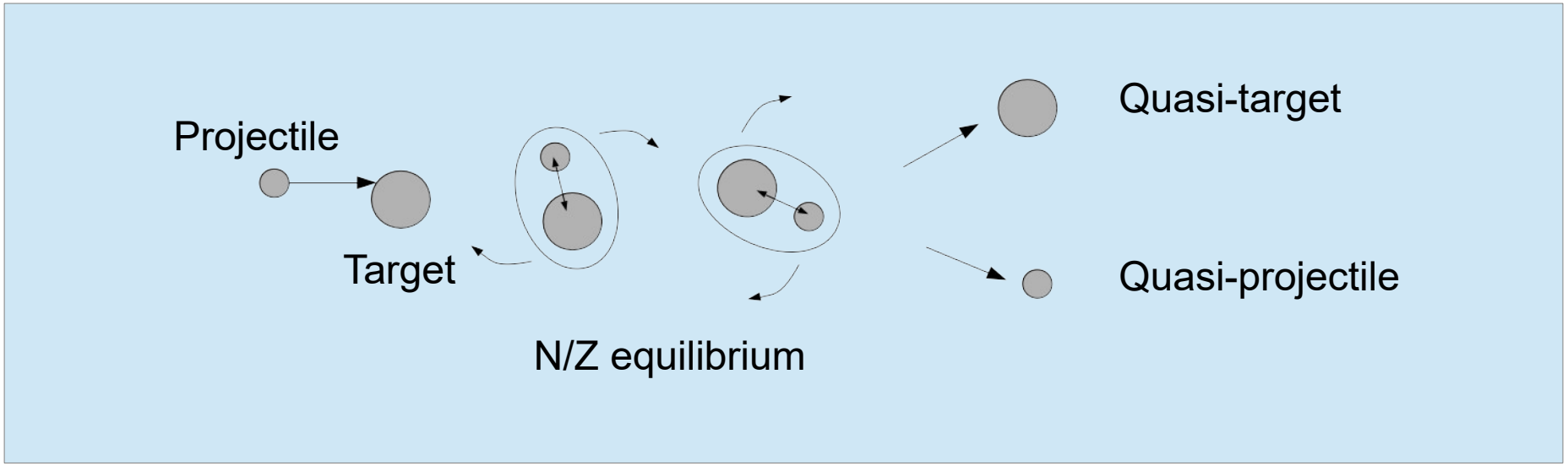
Deep-inelastic collisions

Experimental measurements

Difficulties encountered

Conclusions

Studies of the production of neutron-rich nuclei towards zero degrees in deep-inelastic collisions



Deep-inelastic collisions (*damped collisions , multi-nucleon transfer)*

First observed in 60s R. Kaufmann and R. Wolfgang, Phys. Rev. 121, 192 (1961).

70s intensives studies J. Wilczynski, Phys. Lett. B 47, 484 (1973).

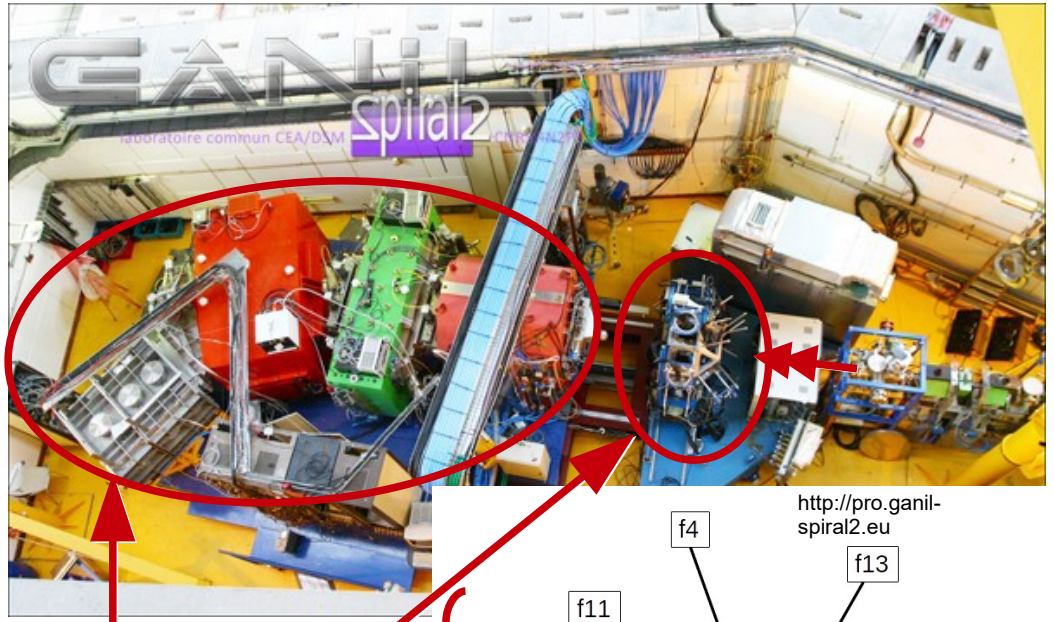
Low beam intensity (<1 nA)
Limited forward angle measurement for low energy (<8°)

Do the exotic nuclei survive at forward angles ?

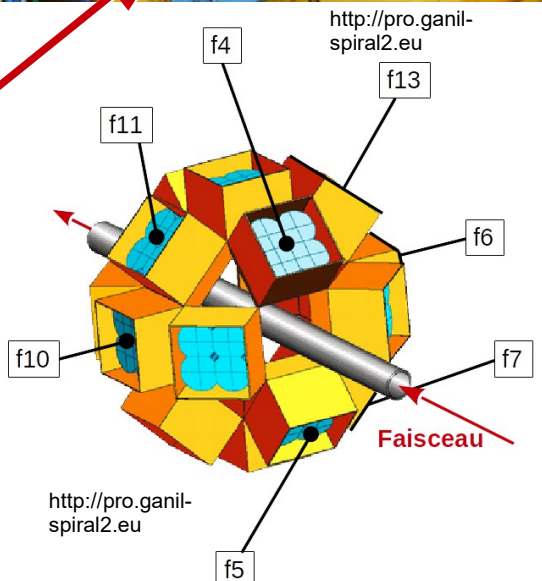
Double differential reaction cross-sections from grazing to 0 degrees for exotic nuclei
Ganil → Vamos & Lise

Vamos → I between 0.01 - 3 pnA, 10 MeV/A ^{48}Ca on 0.17 mg/cm^2 ^{238}U (0 : 35°)
Lise → I between 1-200 pnA, 12 MeV/A ^{36}S on 1 mg/cm^2 ^{238}U @ 0° (<1°)
→ I between 1-200 pnA, 8.5 MeV/A ^{18}O on 1 mg/cm^2 ^{238}U @ 0° (<1°)

Vamos



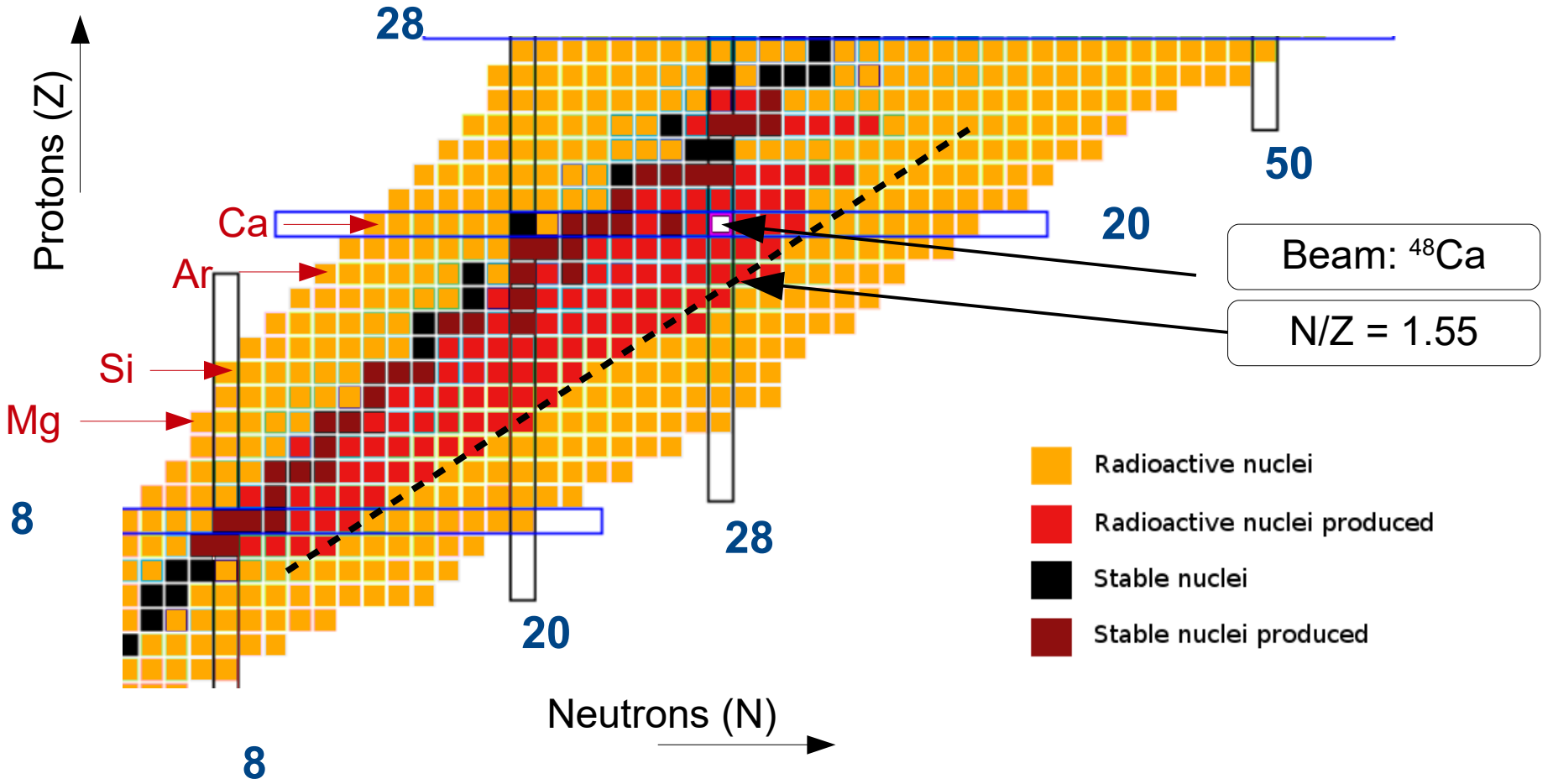
7 Exogam clovers
+
1 BaF_2,
Vamos spectrometer



http://pro.ganil-spiral2.eu

Studies of the production of neutron-rich nuclei towards zero degrees in deep-inelastic collisions

Vamos → I between 0.01 - 3 pnA, 10 MeV/A ^{48}Ca on 0.17 mg/cm^2 ^{238}U (0 : 38 degrees)



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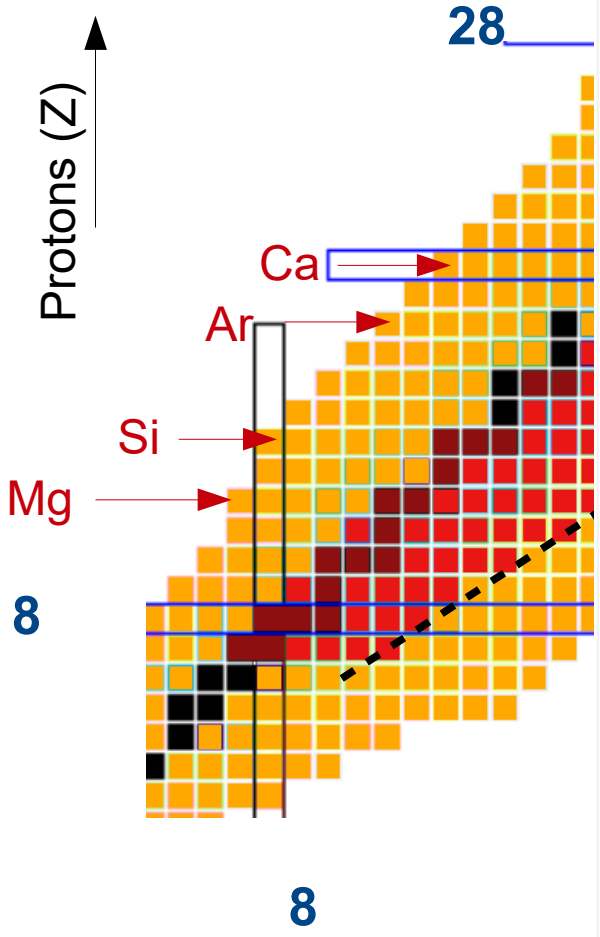

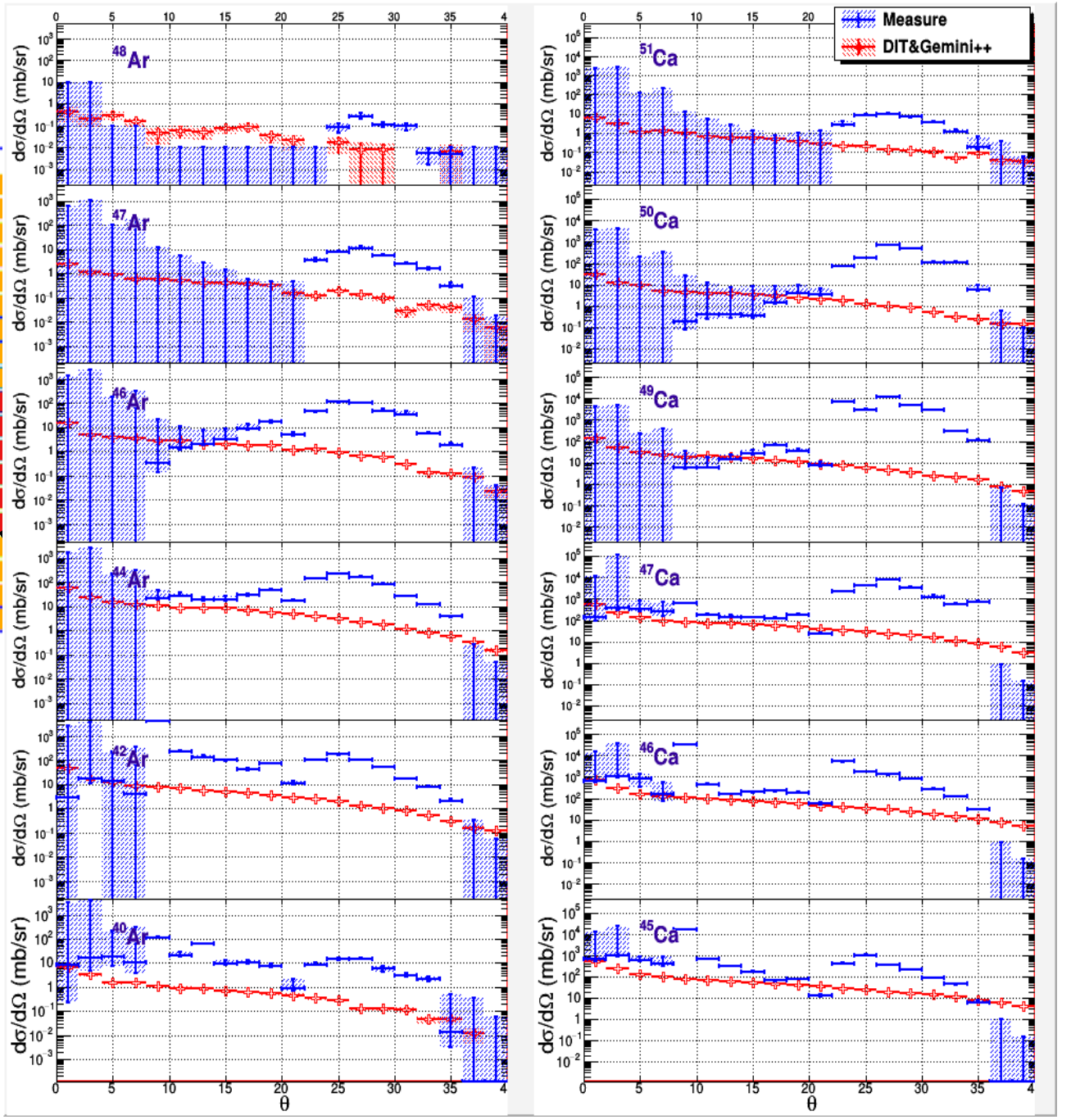

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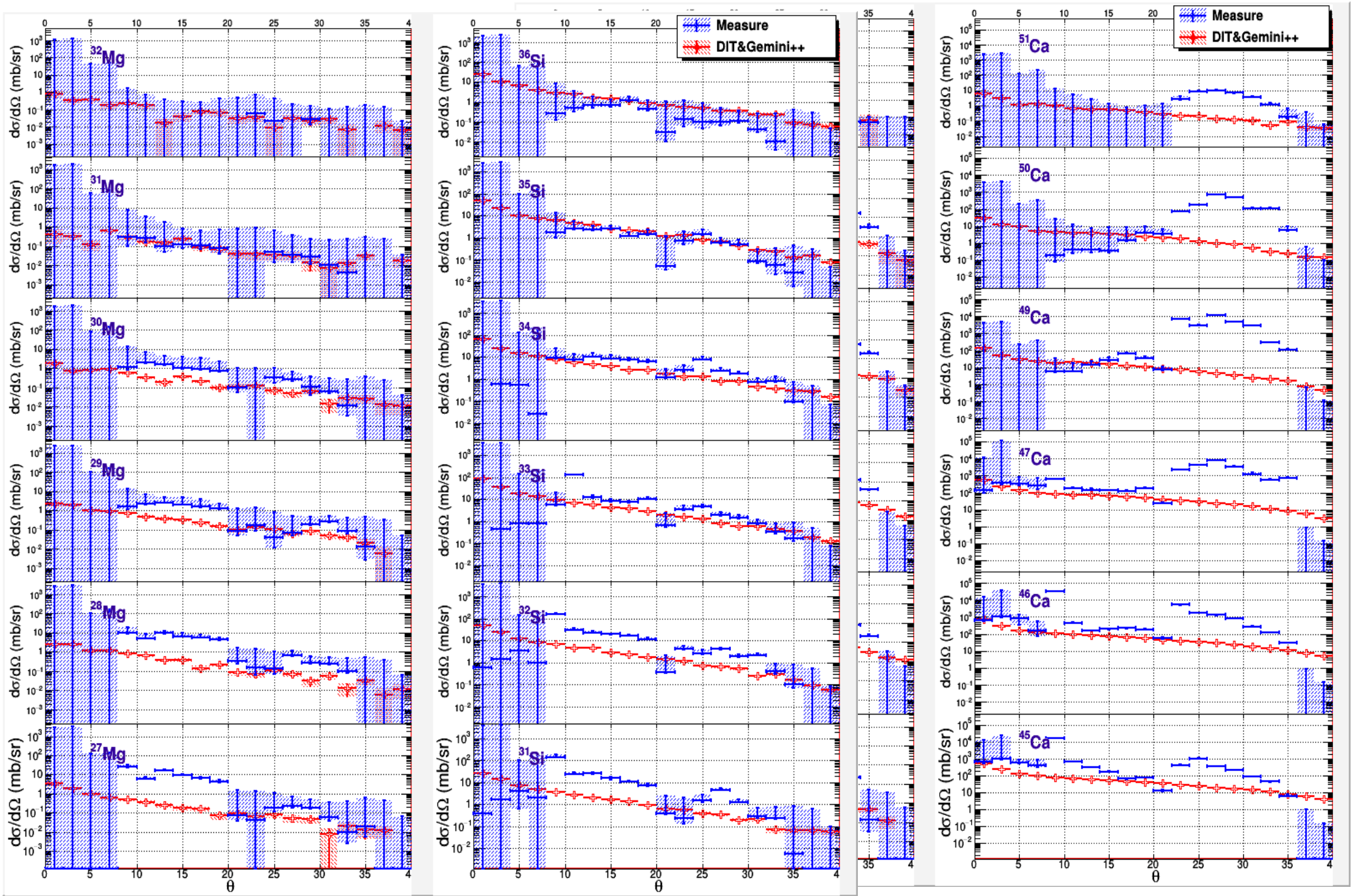

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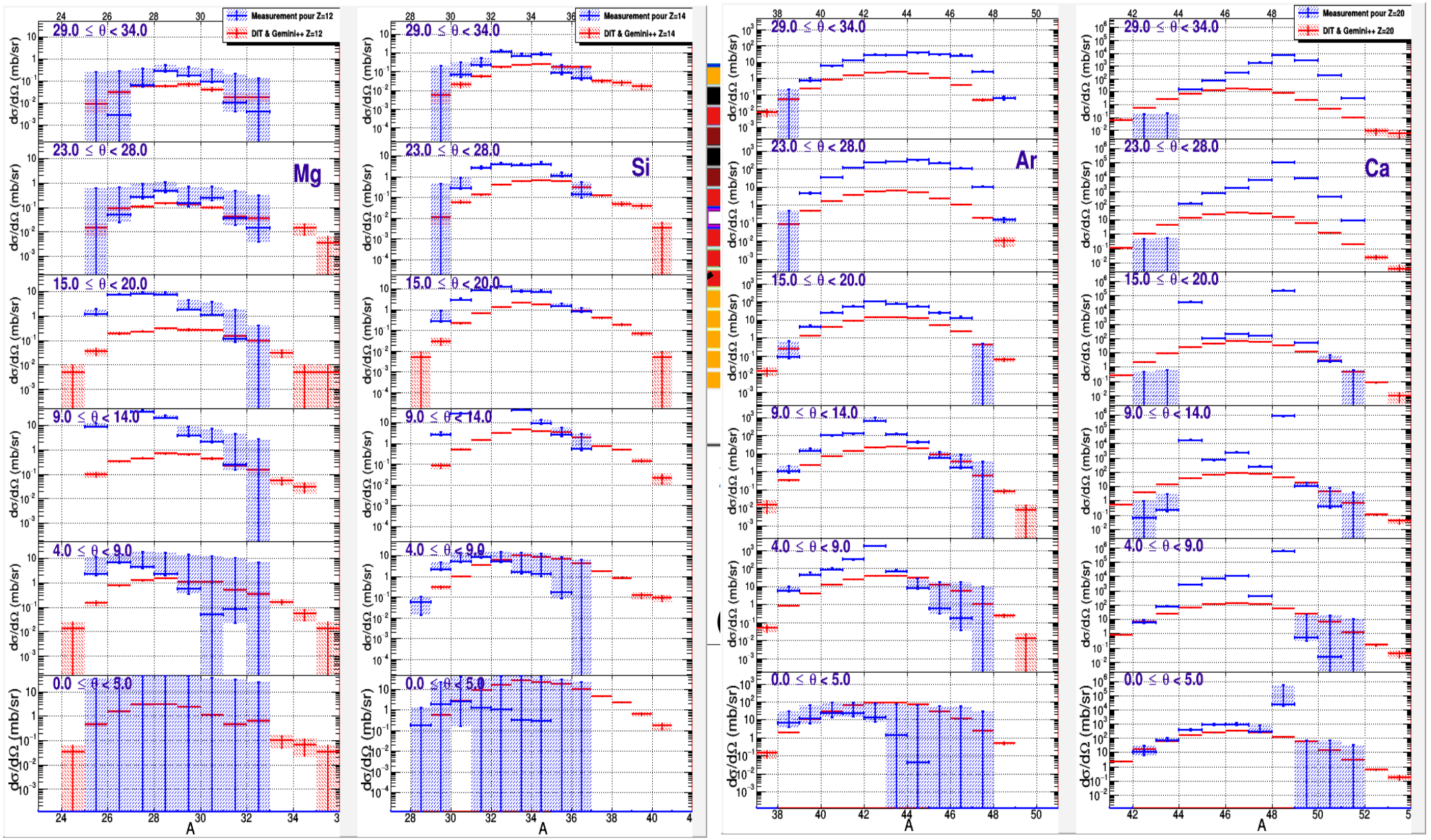

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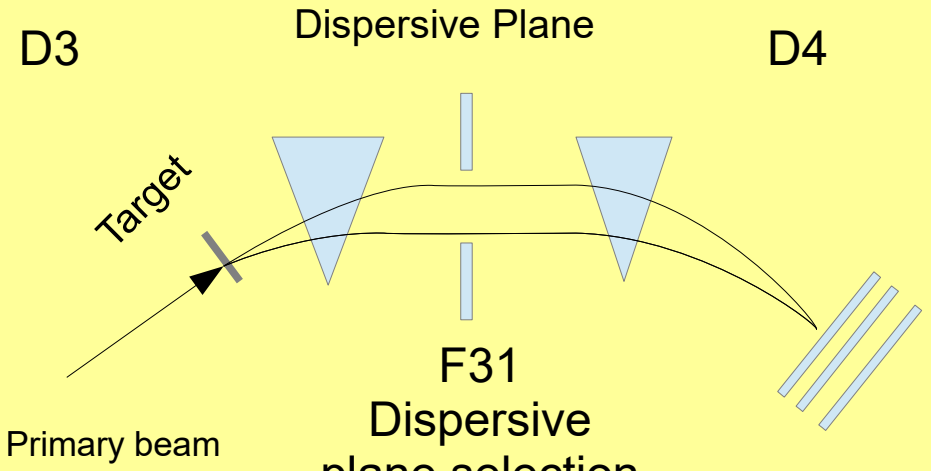
LISE



Beams :

^{36}S 12 MeV/A <=> 2.2 E/B

P. Marini & I. Stefan

^{18}O 8.5 MeV/A <=> 1.6 E/B

B. Fornal, S. Leoni & I. Stefan

Targets:

^{238}U 1 mg/cm^2

^{12}C 1 & 10 mg/cm^2

Beam intensity 1-200 pnA

Detection system

dE_1 ionization chamber

dE_2 37 um Silicium detector

Eres 300 um Silicium detector

2xTof → dE_2 start; RF stop

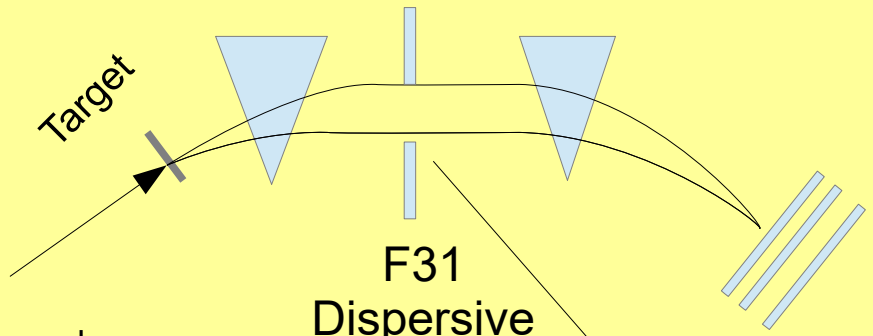
→ Eres start; RF stop

Deep inelastic measurement @ LISE in 2015
^{18}O 8.5 MeV/A beam

D3

Dispersive Plane

D4



Primary beams
^{36}S ~ 12 MeV/A

^{18}O – 8.5 MeV/A

F31
Dispersive plane selection slits (±1 mm =

Detection system

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Targets:
^{238}U 1 mg/cm^2
^{12}C 1 & 10 mg/cm^2
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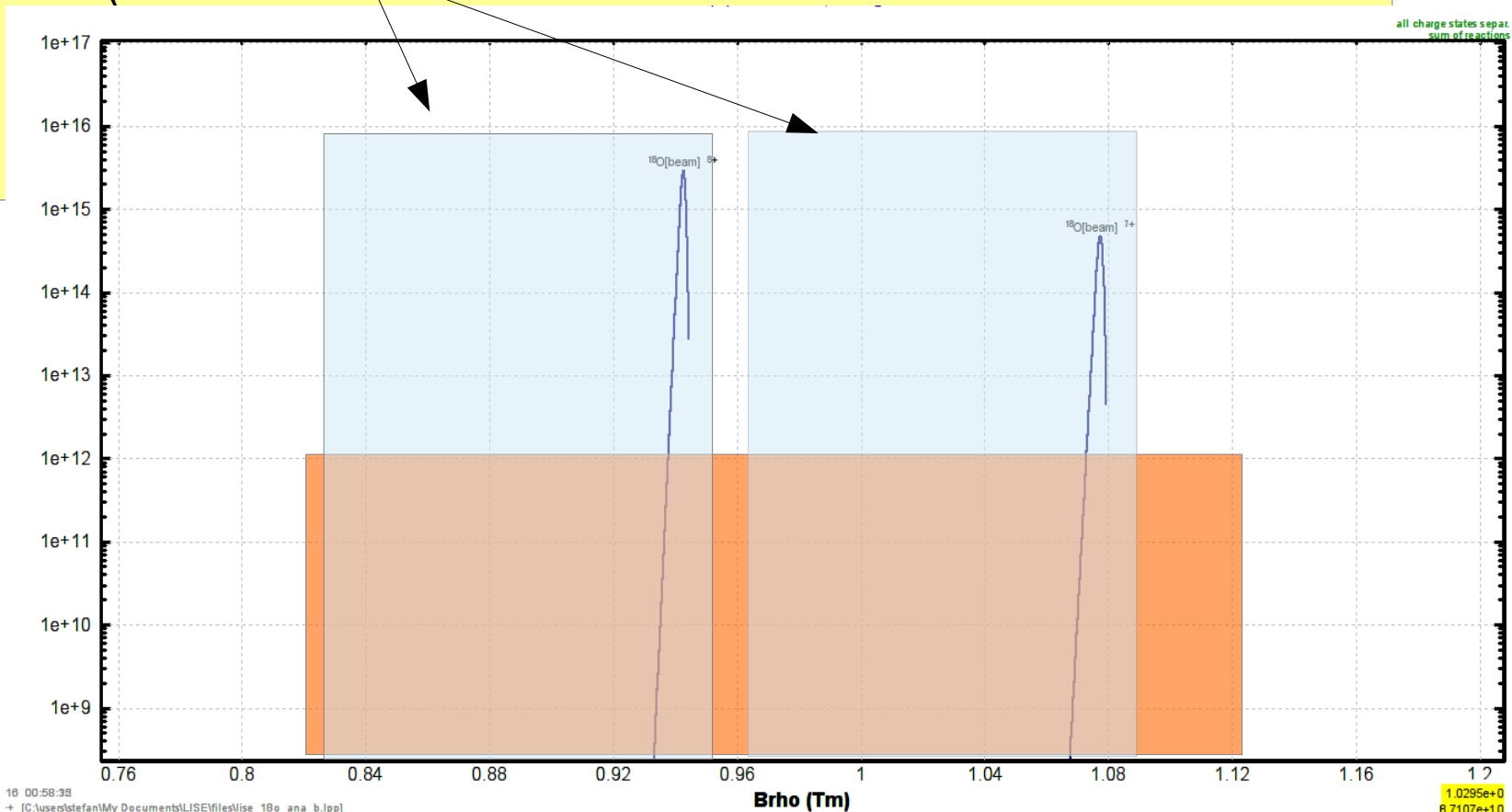

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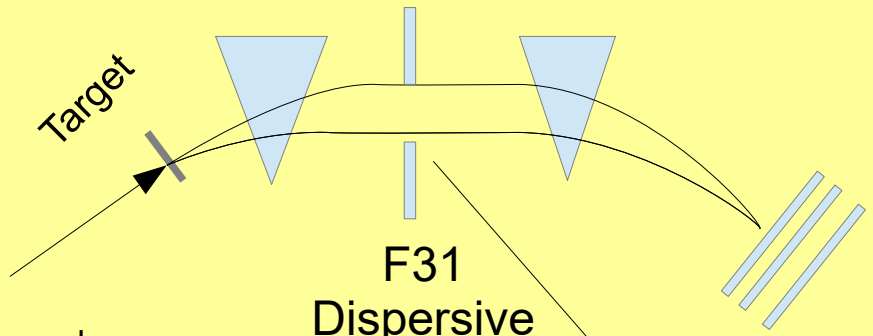

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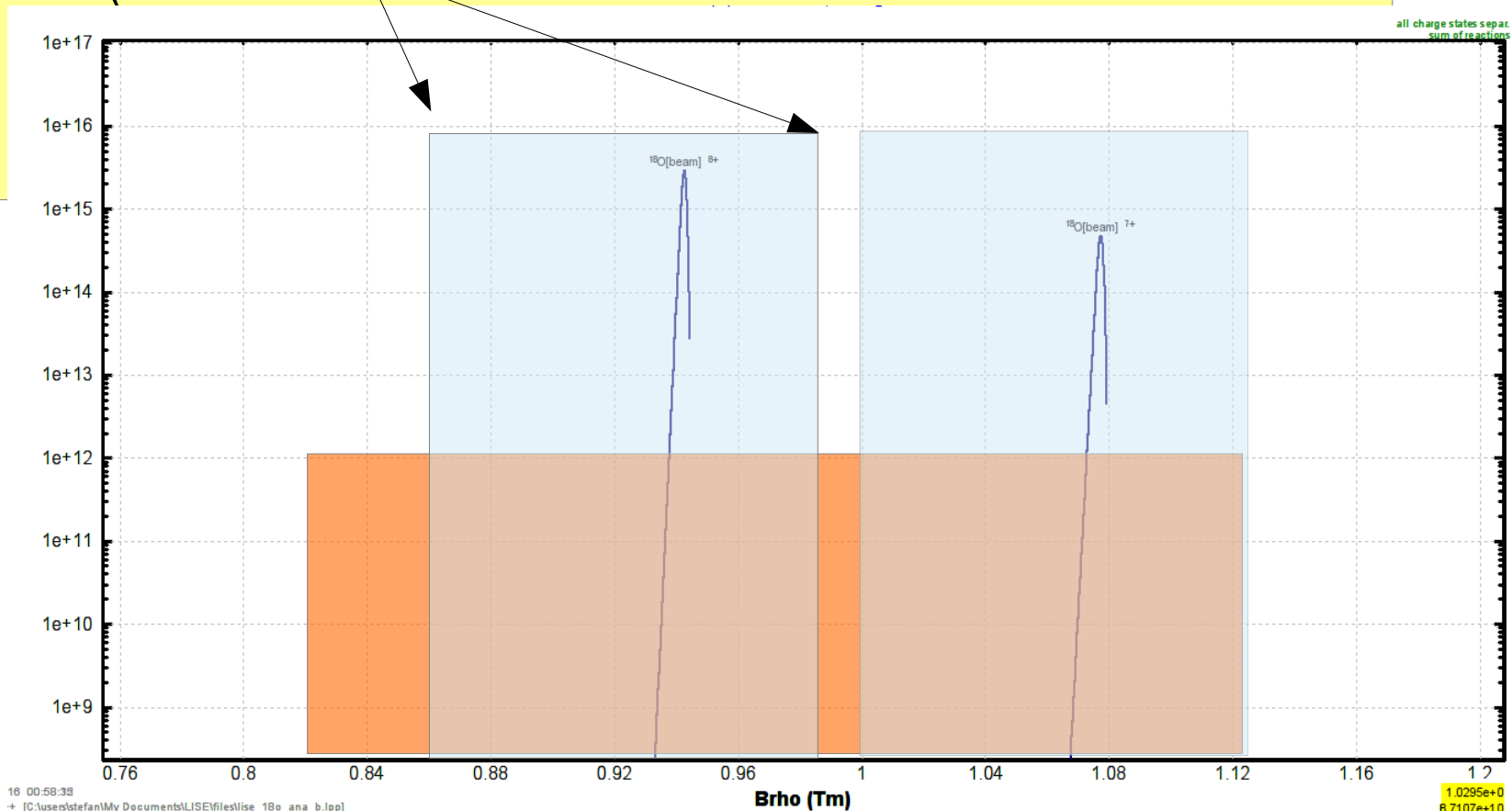

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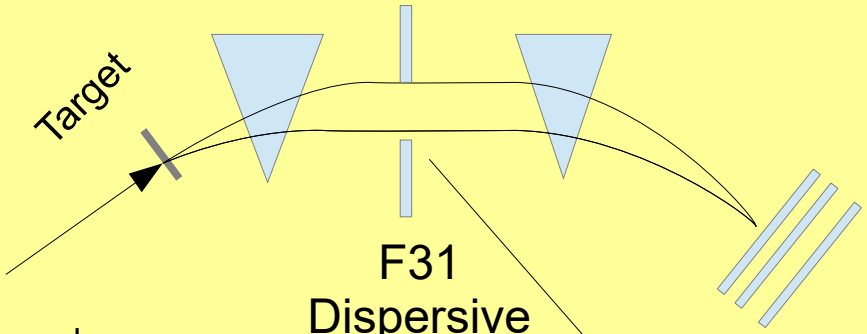

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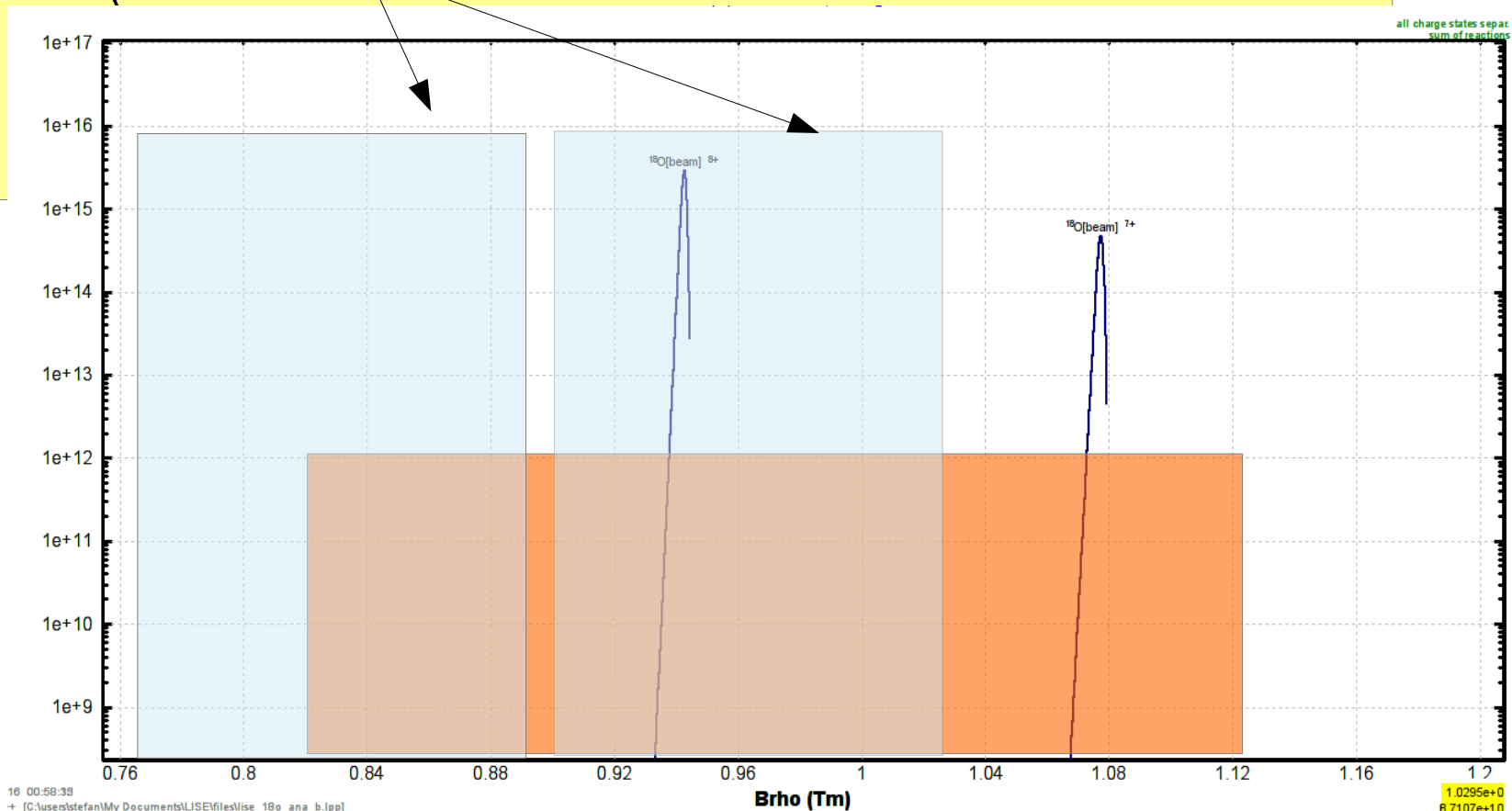

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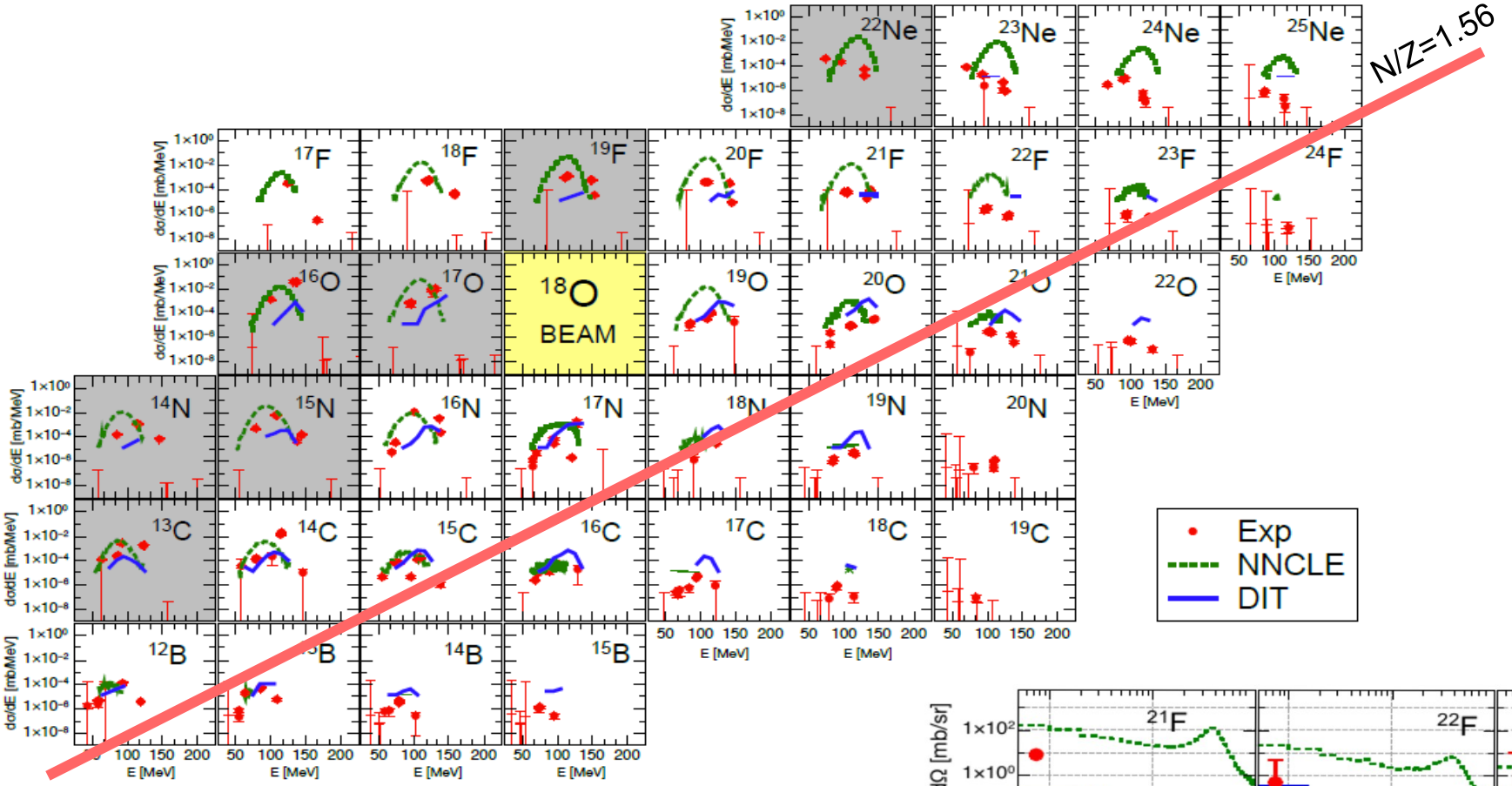
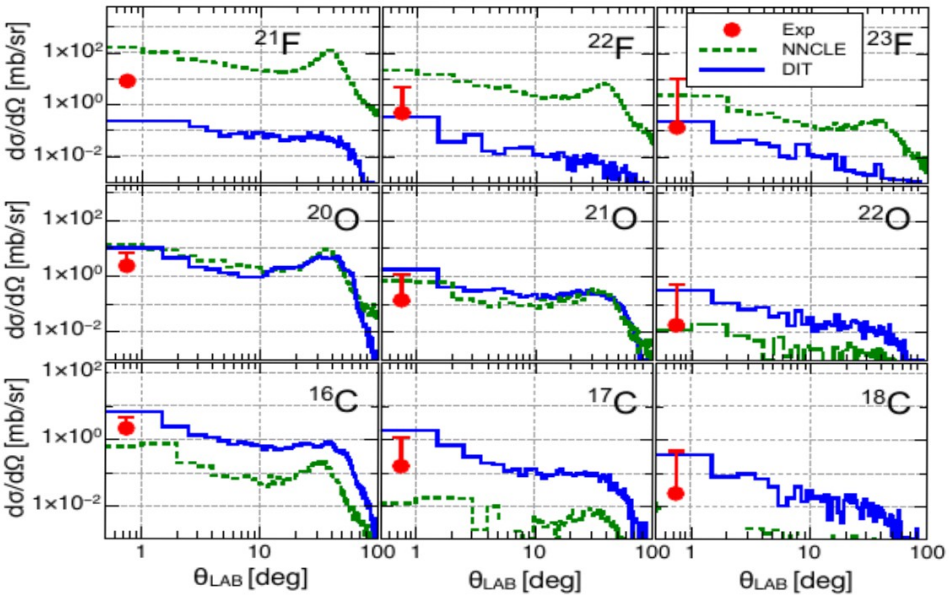
Lise → I between 1-200 pnA, 8.5 MeV/A ^{18}O on 1 mg/cm^2 ^{238}U @ 0°





Difficulties

Vamos:
→ Beam intensity measurement (BaF2 + Elastic scattering)
→ Charge states distribution correction
→ Vamos acceptance

Lise:
→ Identification (beam charge states)
→ Beam charge states rejection
→ Integrate the momentum distribution (linear interpolation)

Theoretical models used:

DIT (Deep Inelastic Transport) & Gemini++

L. Tassan-Got et al. Nucl. Phys. A, 765 (1991)

R. J. Charity, Phys. Rev. C 82, 014610 (2010)

NNCLE (Nucleus-Nucleus Collisions based on Langevin Equations)

A. V. Karpov, Phys. Rev. C 96, 024618 (2017)

Conclusions

- **Measurement:**
  - ^{48}Ca Large angular range between 0° and 35°: *Grazing angle 30.6° @C. Portail phd Thesis*
  - *^{18}O @0° I. Stefan, S. Leoni, B. Fornal et al. To be submitted*
  - *^{36}S @0°* under analysis *C. Petrone (IFIN-HH Roumanie)*
  - γ-decay data to identify nuclei, possible spectroscopy studies
- **Produced nuclei:**
  - ^{48}Ca → From C (Z=6) to Ni (Z=28)
  - ^{18}O → From B (Z=5) to Ne (Z=10)
- **Mechanism:**
  - Increasing differential reaction cross-sections with decreasing angles (for deep-inelastic)
  - Maximum differential reaction cross-section at 0° degrees (for deep-inelastic)

Thank you

DEEP INELASTIC COLLISIONS (DIC)

- Orbiting phenomenon
- N/Z equilibration
  Most neutron-rich beam and target
- Evaporation
  Need to limit the incident energy

Deep-inelastic collisions (*damped collisions , multi-nucleon transfer)*
First observed in 60s [1] R. Kaufmann and R. Wolfgang, Phys. Rev. 121, 192 (1961).

70s intensives studies J. Wilczynski, Phys. Lett. B 47, 484 (1973).

Low beam intensity (<1 nA)
Limited forward angle measurement for low energy (<8°)

How exotic can we go?
Exotic nuclei at 0° ?

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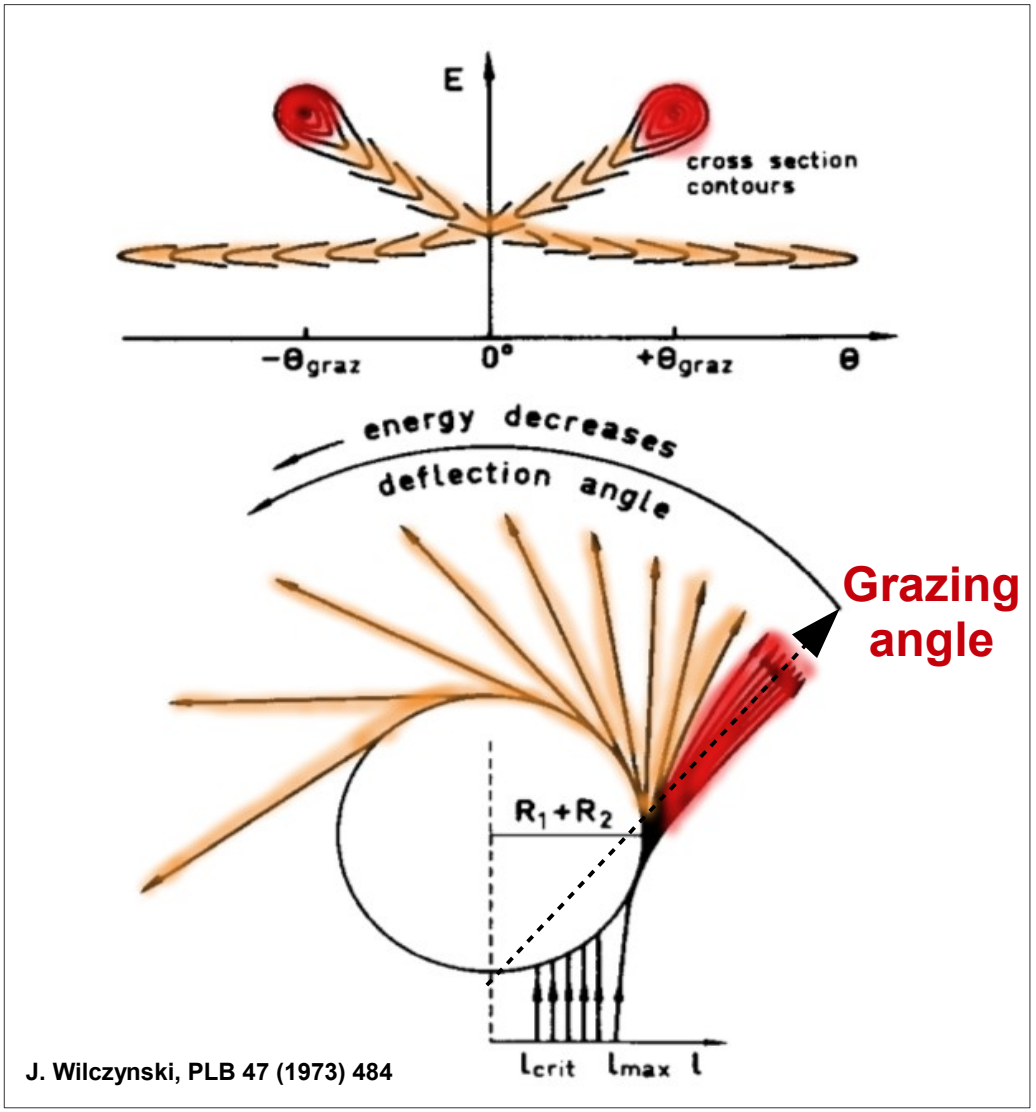
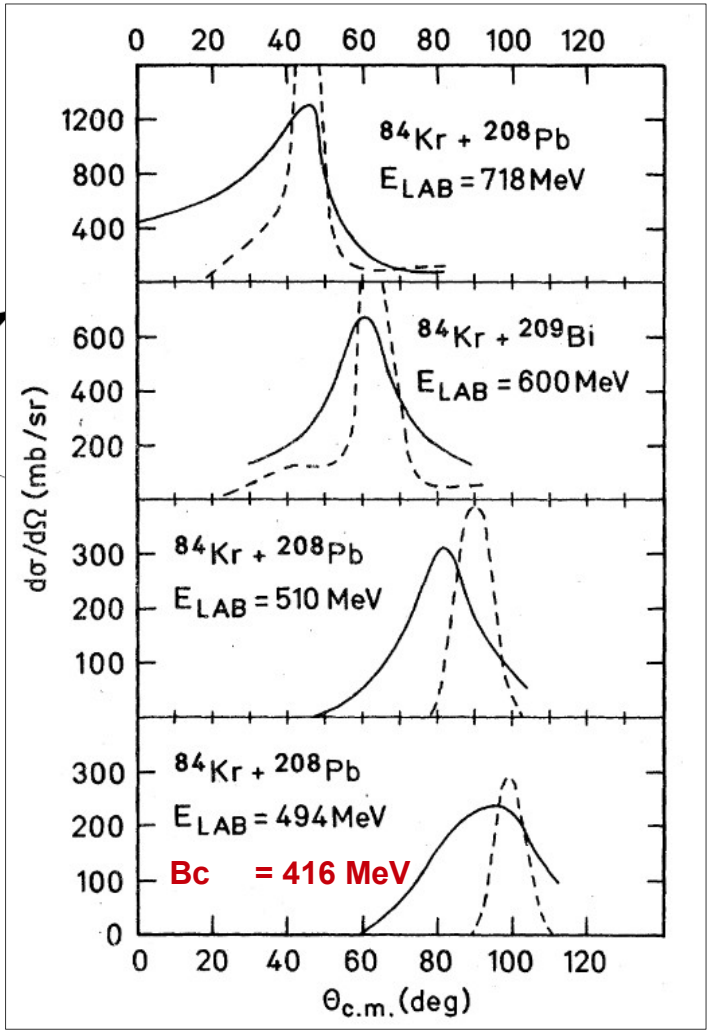


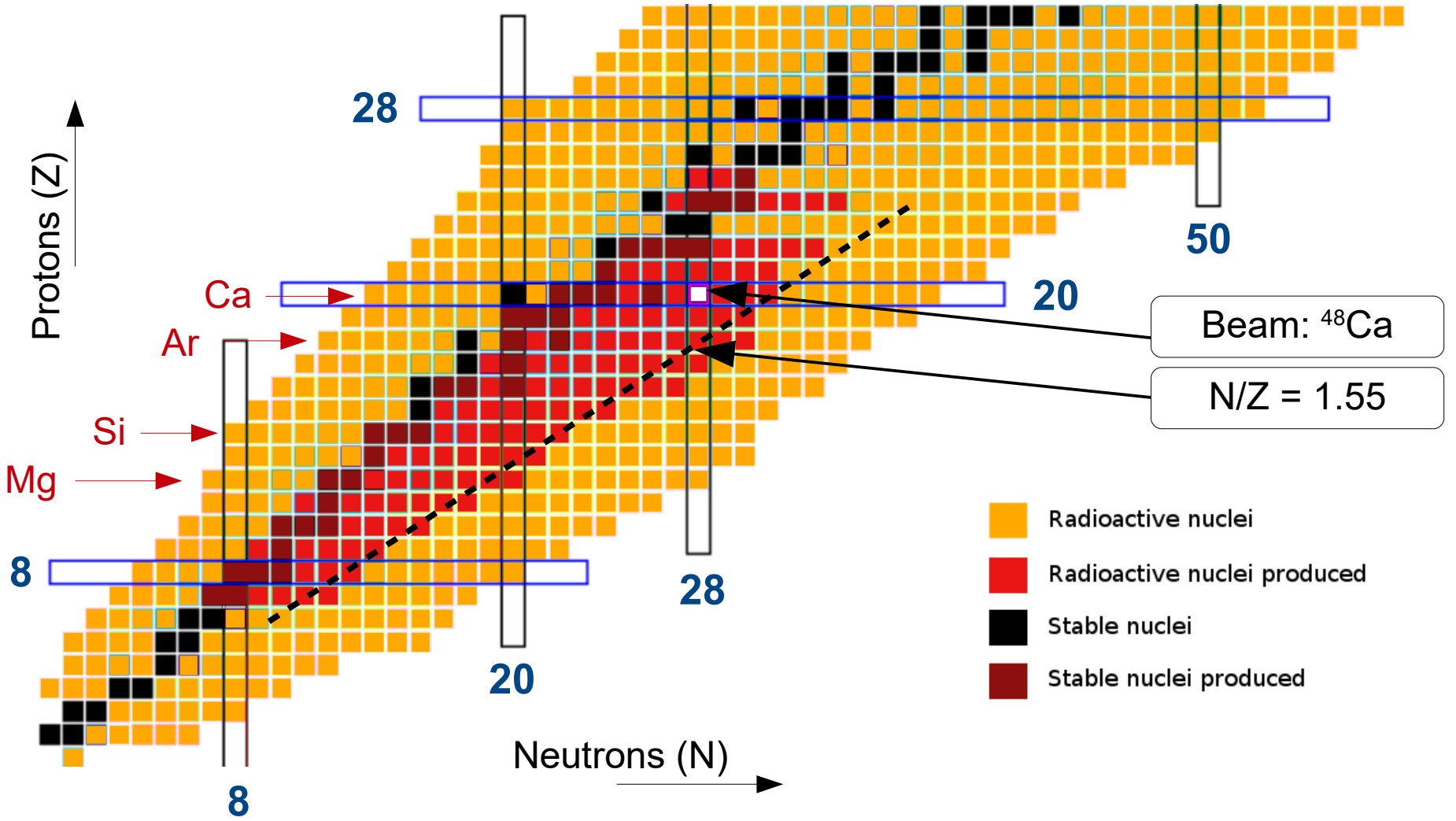
J. Wilczynski, PLB 47 (1973) 484



D. Agassi *et al*, PRC 18 (1978) 223

$^{48}Ca^{19+}$

0.1 – 50 enA beam intensities


Protons (Z)
Neutrons (N)
28
50
20
8
28
20
8
Ca
Ar
Si
Mg
Beam: ^{48}Ca
N/Z = 1.55
Radioactive nuclei
Radioactive nuclei produced
Stable nuclei
Stable nuclei produced

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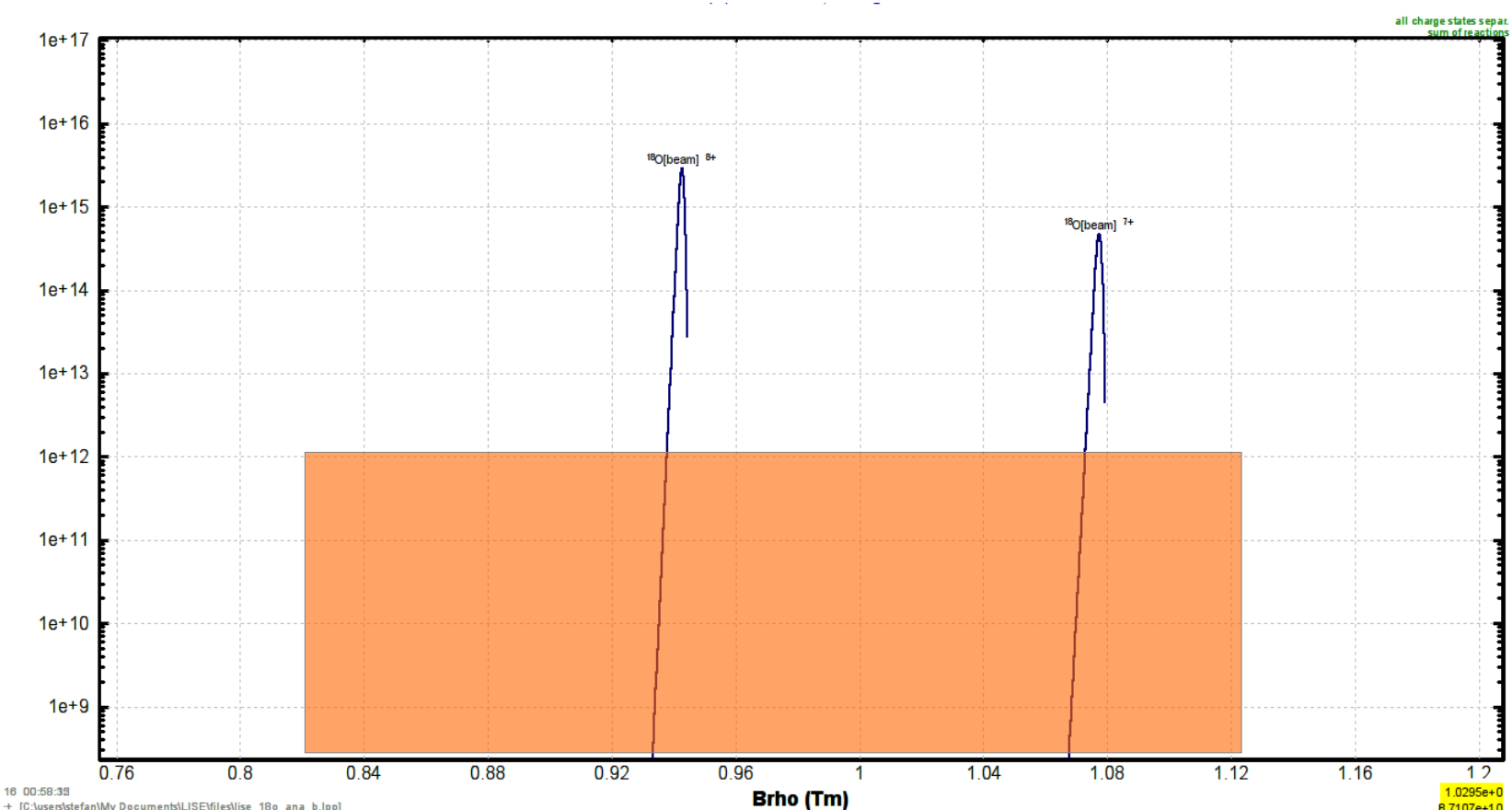

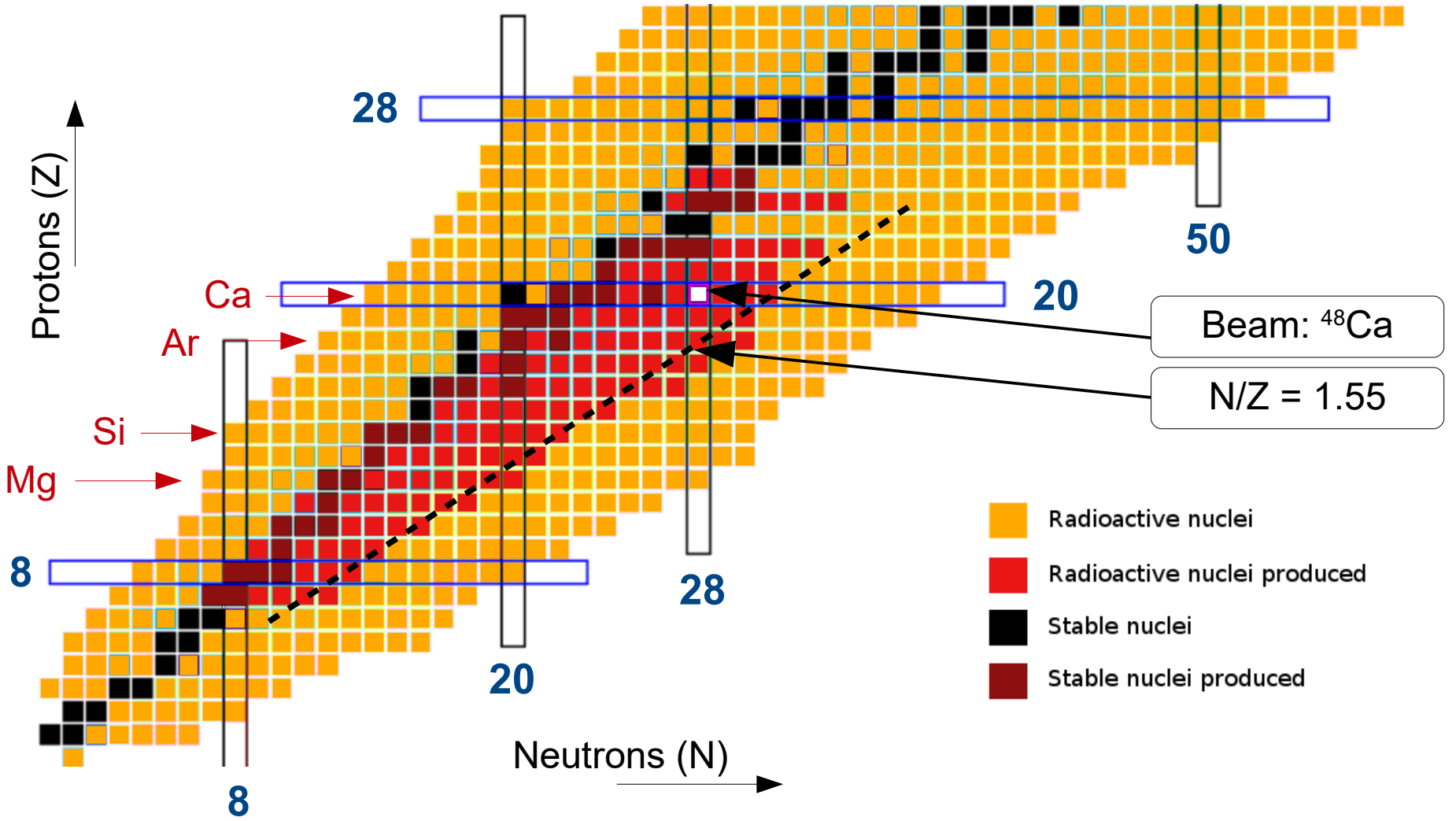
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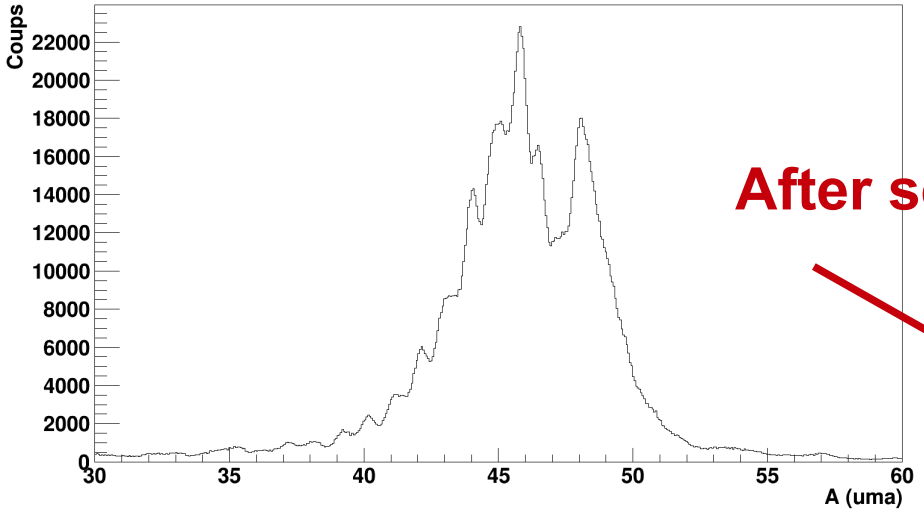
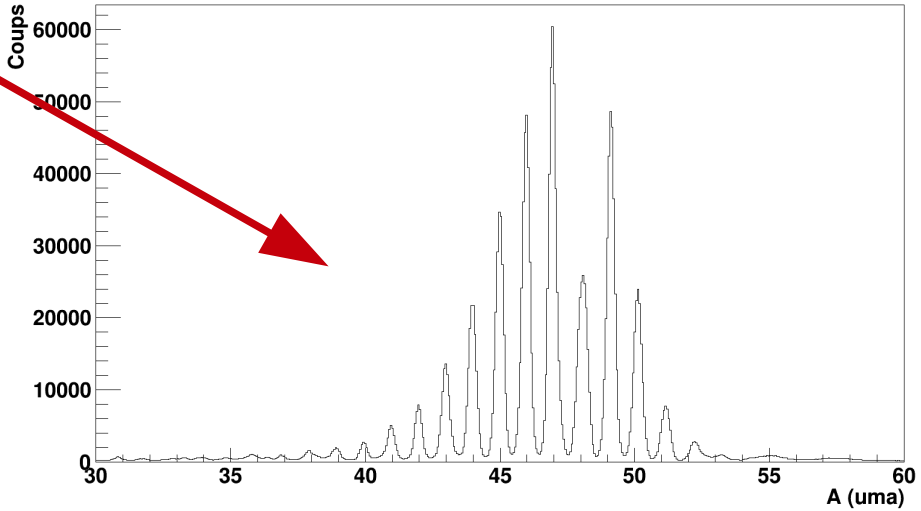
Radioactive nuclei
Radioactive nuclei produced
Stable nuclei
Stable nuclei produced

Vamos → I between 0.1 - 10 nA, 10 MeV/A ^{48}Ca on 0.17 mg/cm^2 ^{238}U (0 : 38 degrees)

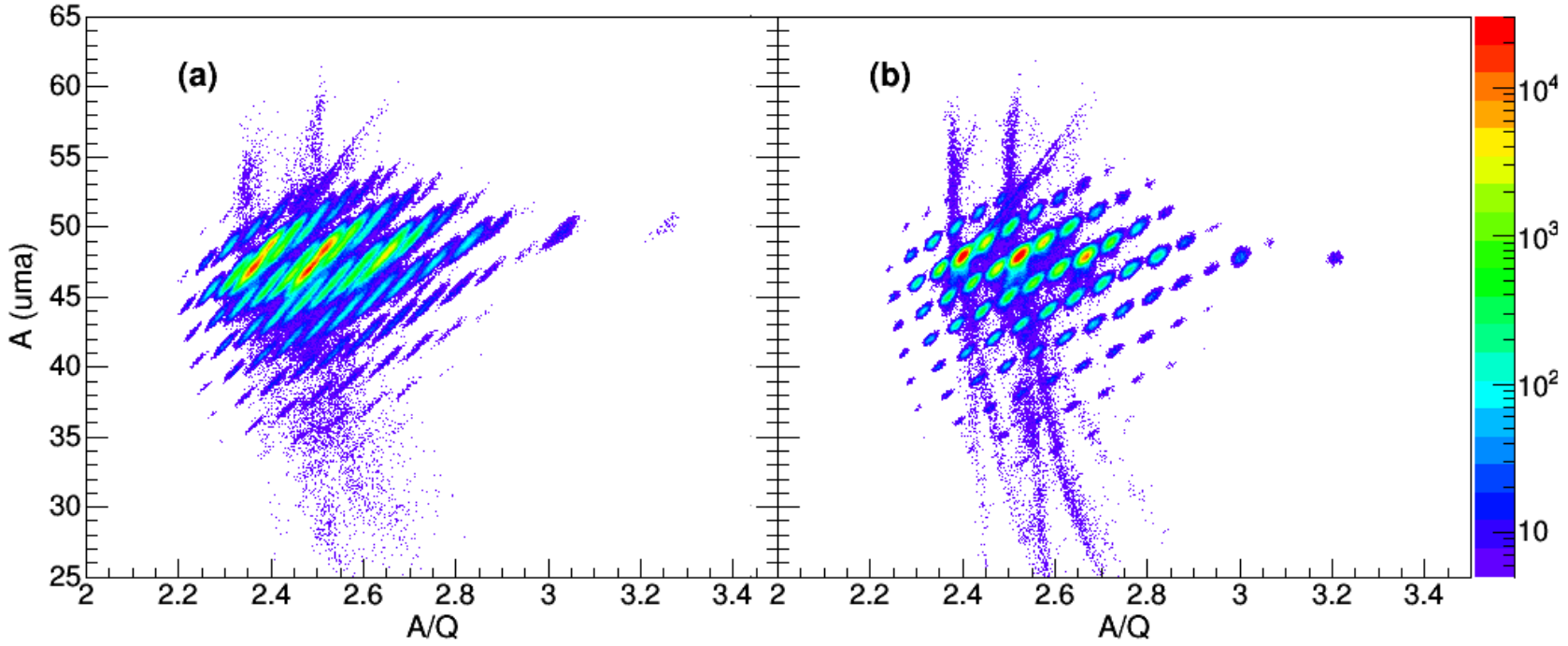


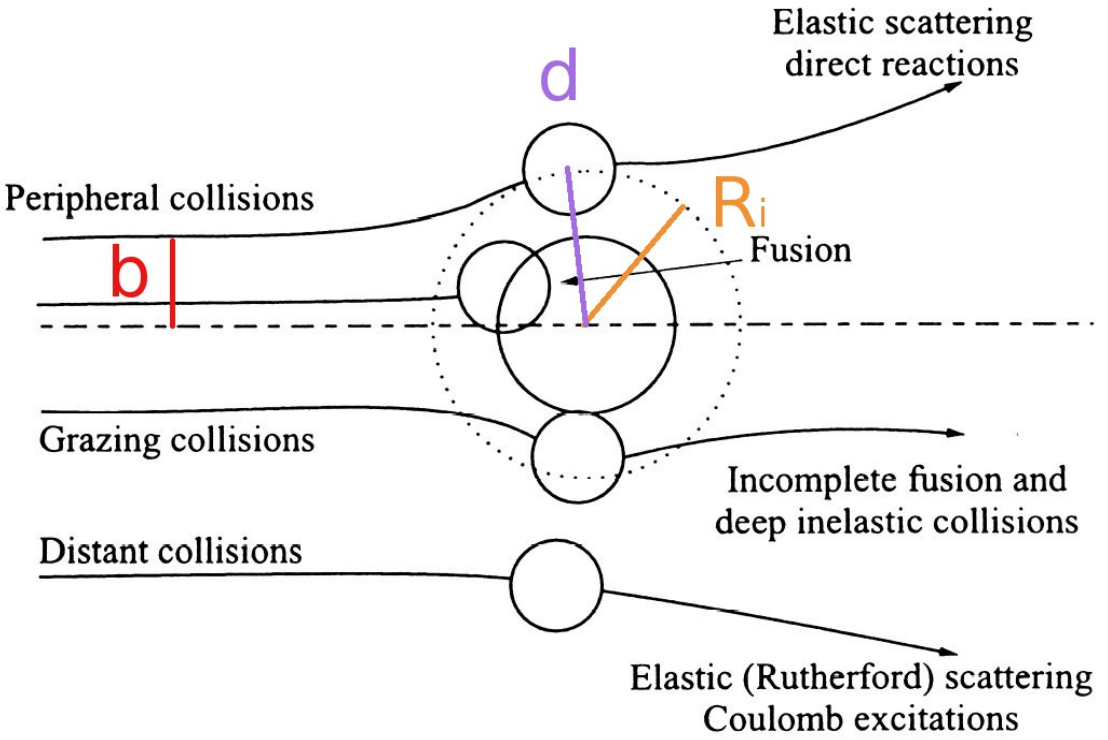
After second order step



Mass spectra for all data 30° (except Ca)

Vamos → I between 0.1 - 10 nA, 10 MeV/A ^{48}Ca on 0.17 mg/cm^2 ^{238}U (0 : 38 degrees)




Elastic scattering
direct reactions
d
Peripheral collisions
R_i
Fusion
b
Grazing collisions
Incomplete fusion and
deep inelastic collisions
Distant collisions
Elastic (Rutherford) scattering
Coulomb excitations

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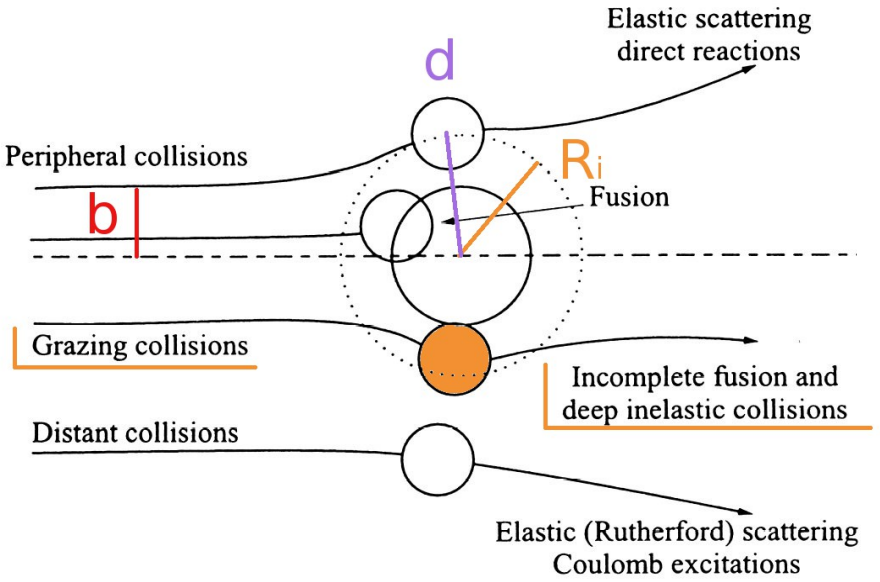
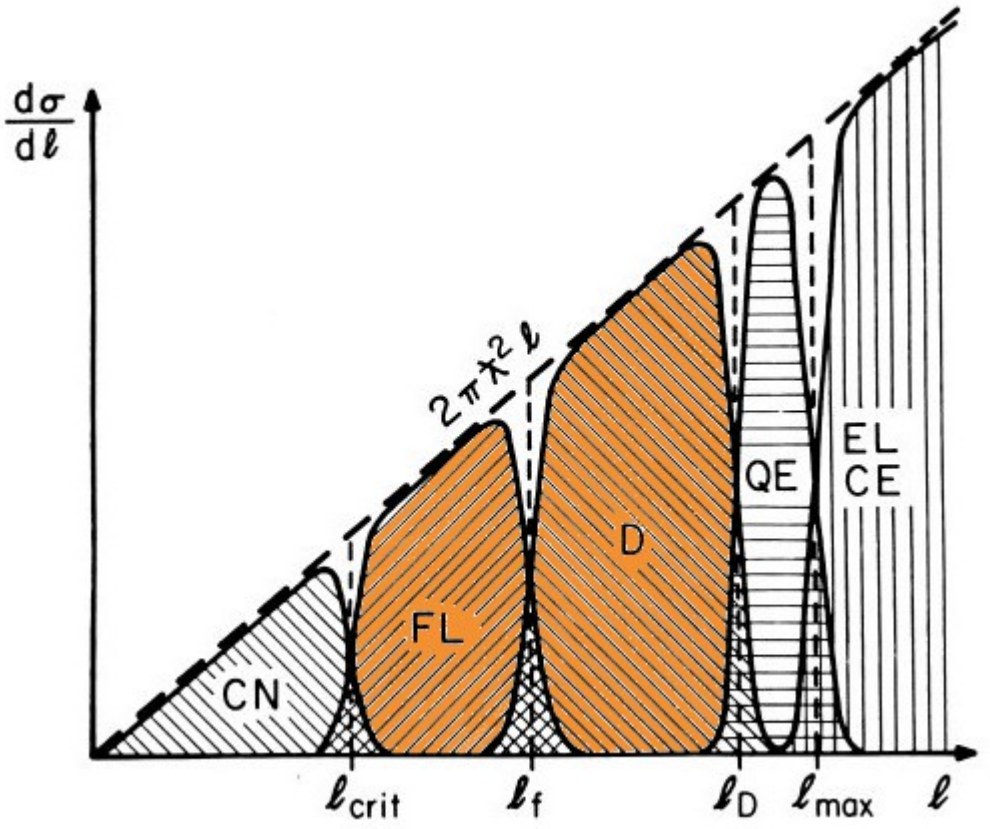
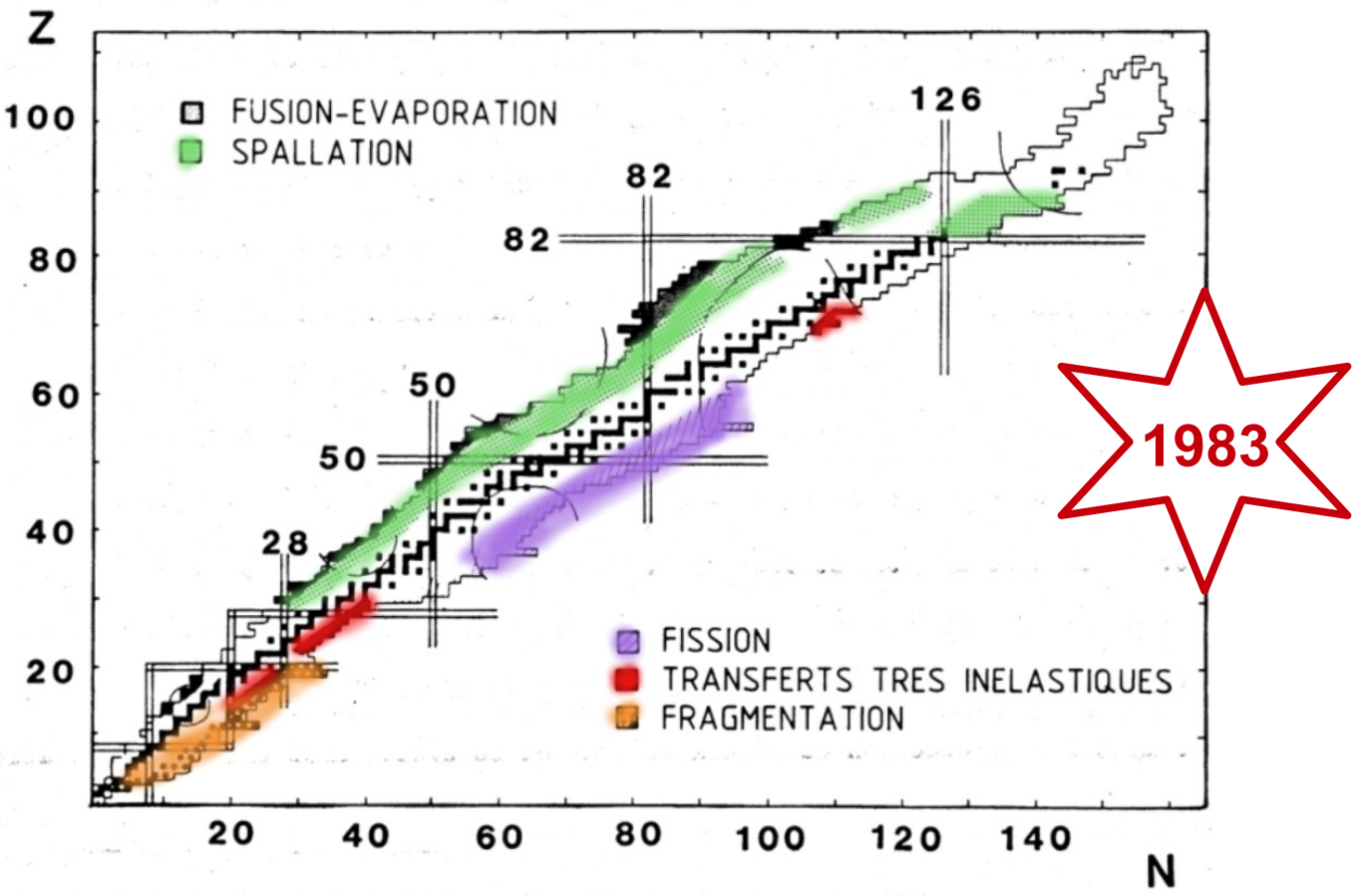




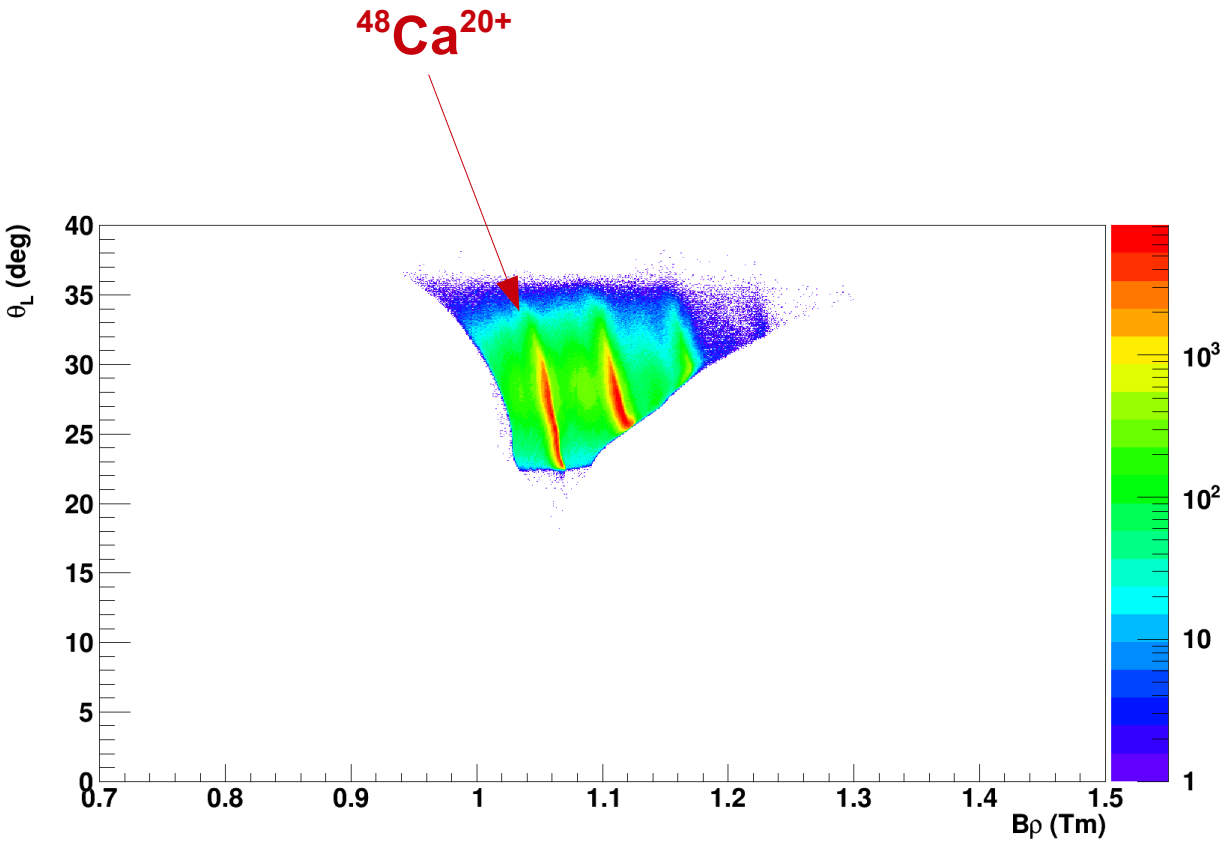
Schroeder and Huizenga (1984)

Deep-inelastic collisions also known as
damped collisions , multi-nucleon transfer reactions



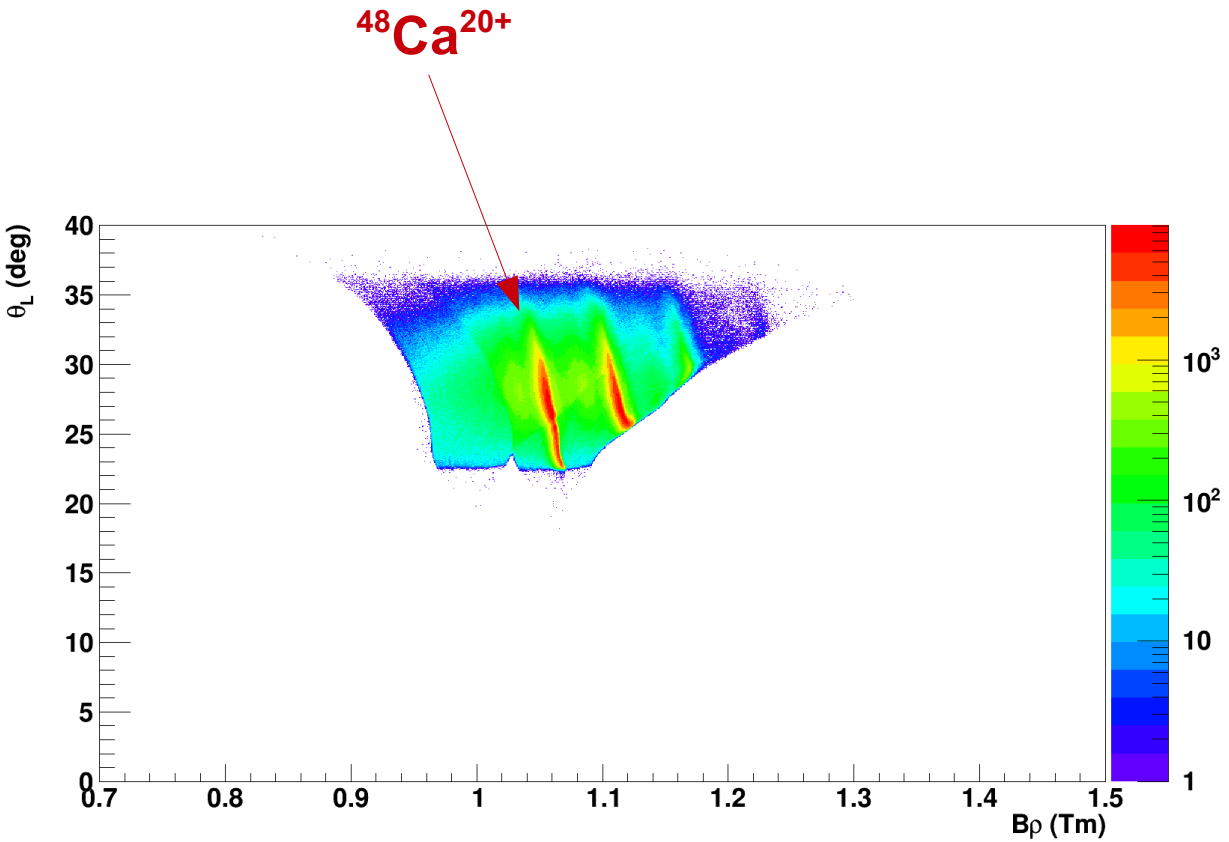
EXPERIMENTAL SETUP – *Vamos settings*

θ_{Vamos}	$B\rho_{ref}$ (Tm)
30° *(10 - 50 enA)*	1.12 *(14h)*



EXPERIMENTAL SETUP – *Vamos settings*

θ_{Vamos}	$B\rho_{ref}$ (Tm)
30° *(10 - 50 enA)*	1.12 *(14h)* 1.05 *(7h)*



EXPERIMENTAL SETUP – *Vamos settings*

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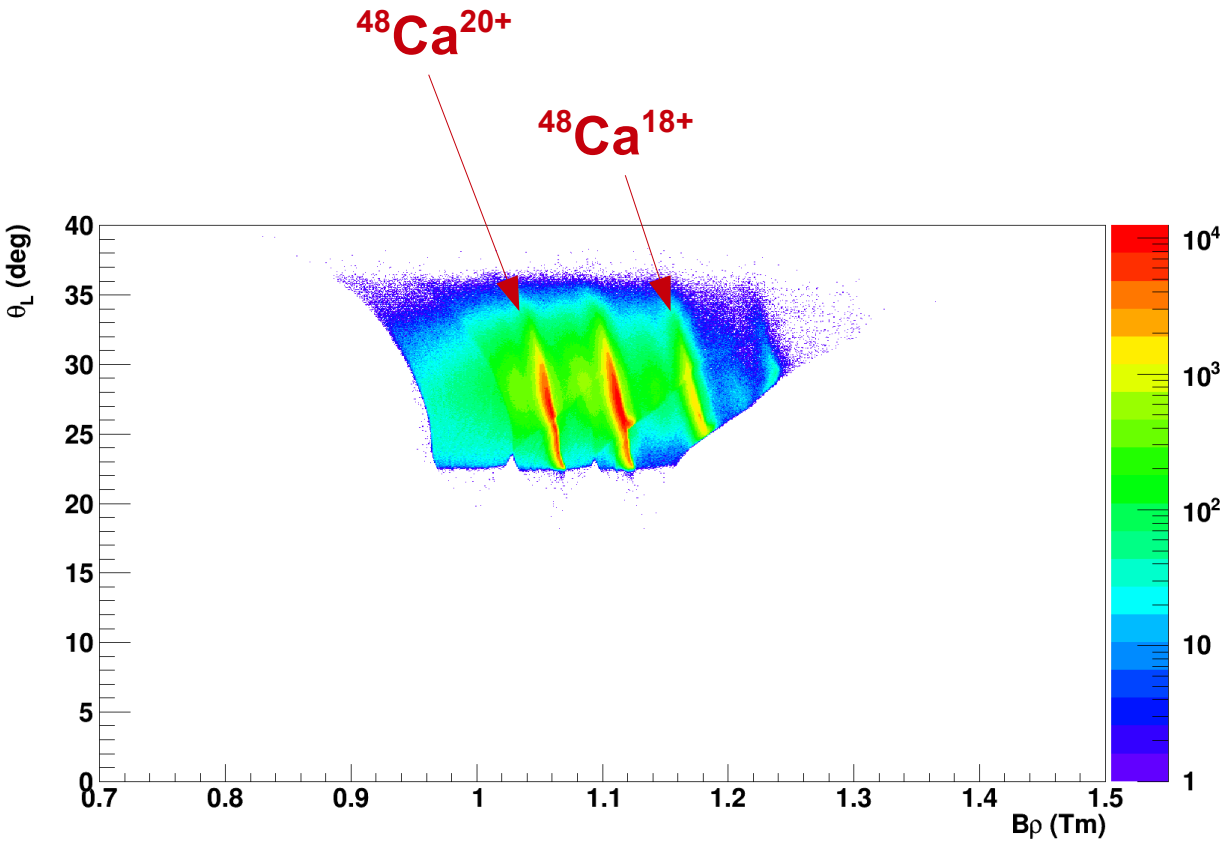
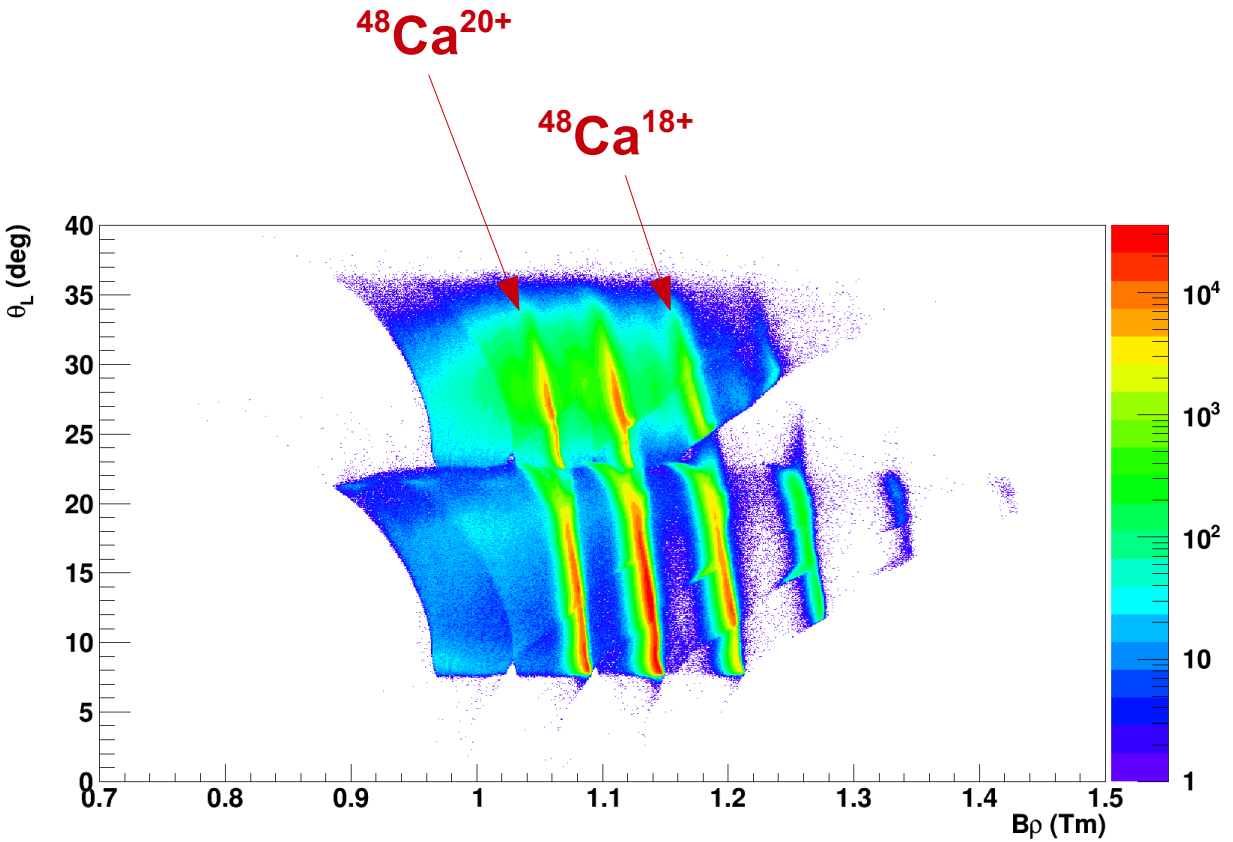


EXPERIMENTAL SETUP – *Vamos settings*

θ_{Vamos}	$B\rho_{ref}$ (Tm)
30° *(10 - 50 enA)*	1.12 *(14h)* 1.05 *(7h)* 1.19 *(8h)*
15° *(1 – 10 enA)*	1.05 *(7h)* 1.12 *(25h)* 1.19 *(20h)* 1.25 *(4h)*



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0° *(0.1 enA)*	0.96 *(10h)*