Scattering of the halo nucleus ^{11}Li and its core ^{9}Li on ^{208}Pb at energies around the Coulomb barrier

Mario Cubero Campos

Instituto de Estructura de la materia, CSIC

On behalf of the E-1104 Collaboration: IEM-CSIC - U. Aarhus - U. Chalmers - U. Huelva- U. Lisboa – U. St. Marys - U. Sevilla - U. York –TRIUMF

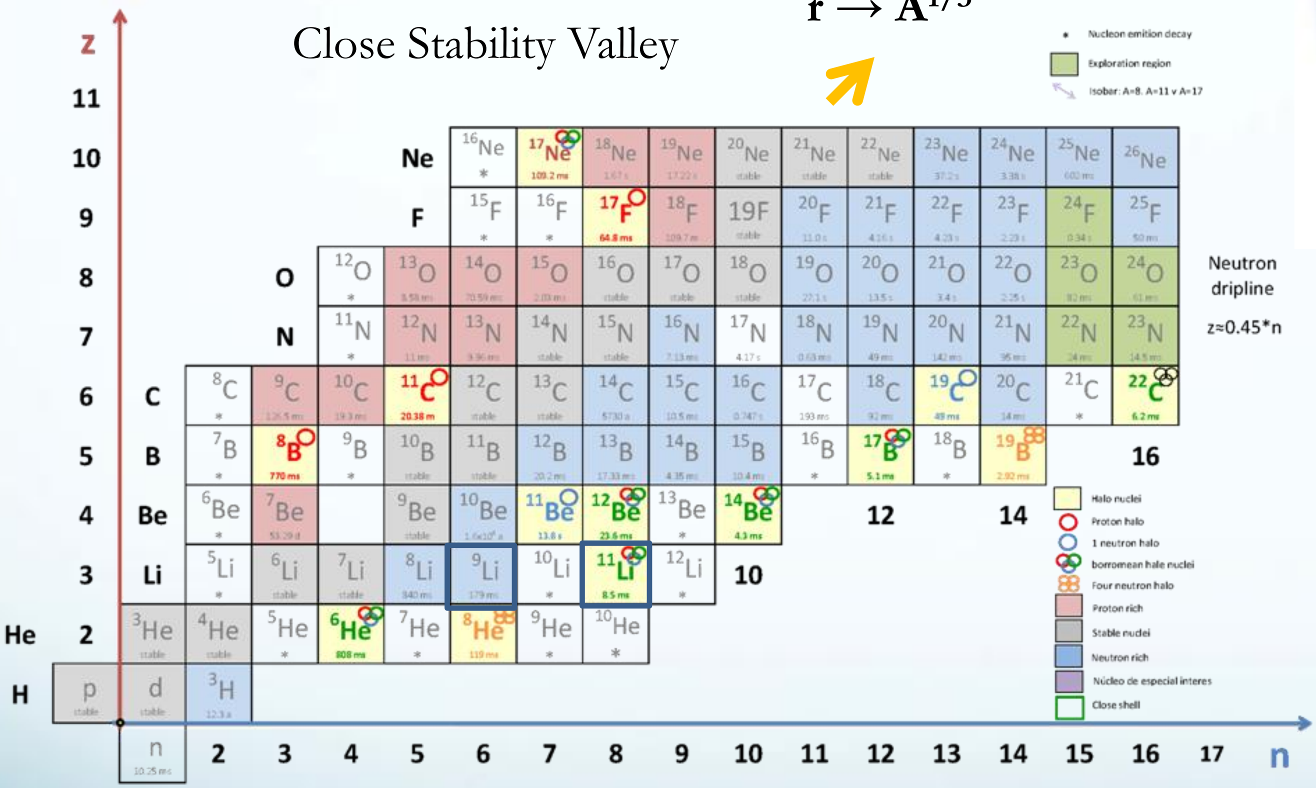
Introduction

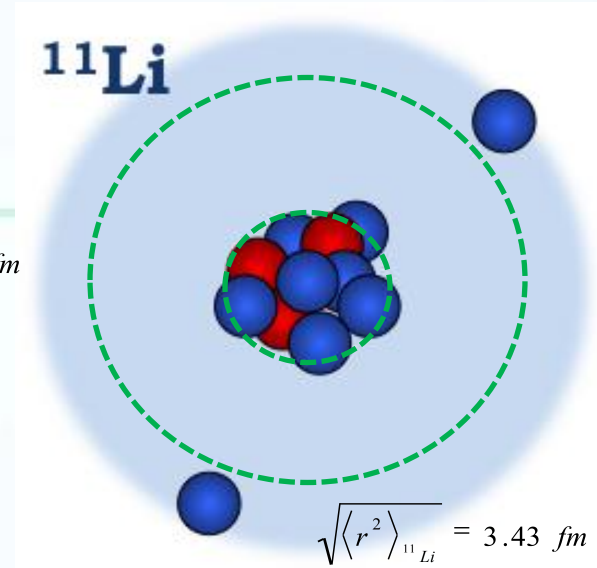
Far from Stability Valley

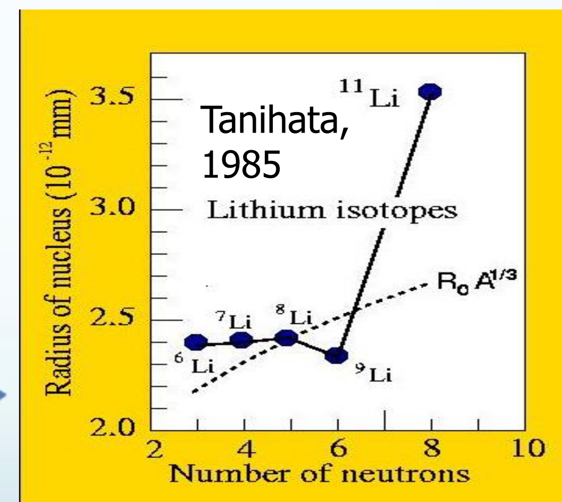
Close Stability Valley

$\mathbf{r \rightarrow A^{1/3}}$

$\sqrt{\langle r^2 \rangle_{^9Li}} = 2.44\ fm$







Borromean

^{11}Li is an example of borromean nuclei.

- n+n unbound
- n+^{9}Li unbound
- n+n+^{9}Li bound

Tanihata et al., PRL, **55** (1985)**,** 24,2676

Dobrovolsky et al, NPA766 (2006) 1

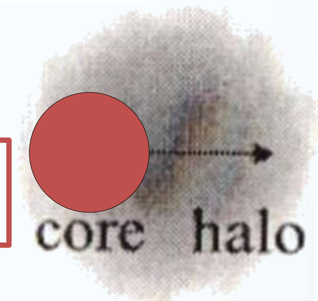
Motivation

Due to loosely bound structure of the halo nuclei, the reaction mechanism at energies close to the Coulomb barrier will be affected.

Coupling to continuum

Reaction Mechanisms

Dipole Coulomb force



Scattering of halo ^{11}Li

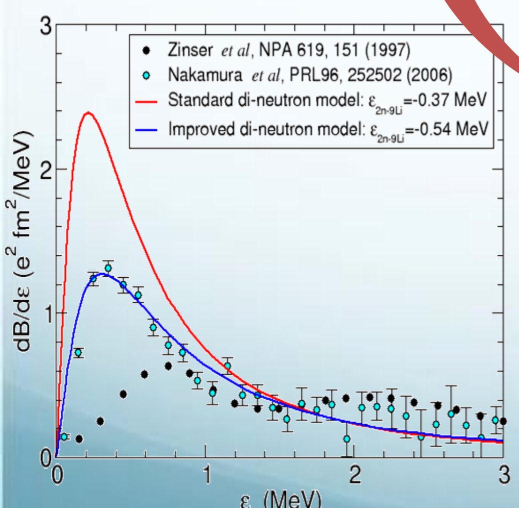
Elastic and Breakup (heavy targets)

Nuclear Effects

S_{2n}=369.15(65) keV

Smith et al., Phys. Rev. Lett. 101, 202501 (2008).

B(E1)

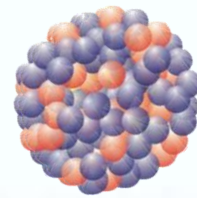


Nakamura et al., PRL 96, 252502 (2006)

Reaction Mechanisms

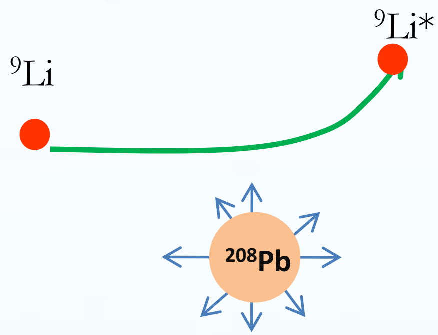
Start

^{9}Li



^{208}Pb

2-Body System



Elastic Scattering
(below the Coulomb barrier
30 MeV C.M.)

Nuclear effects
(higher energy reactions)

^{9}Li+^{208}Pb

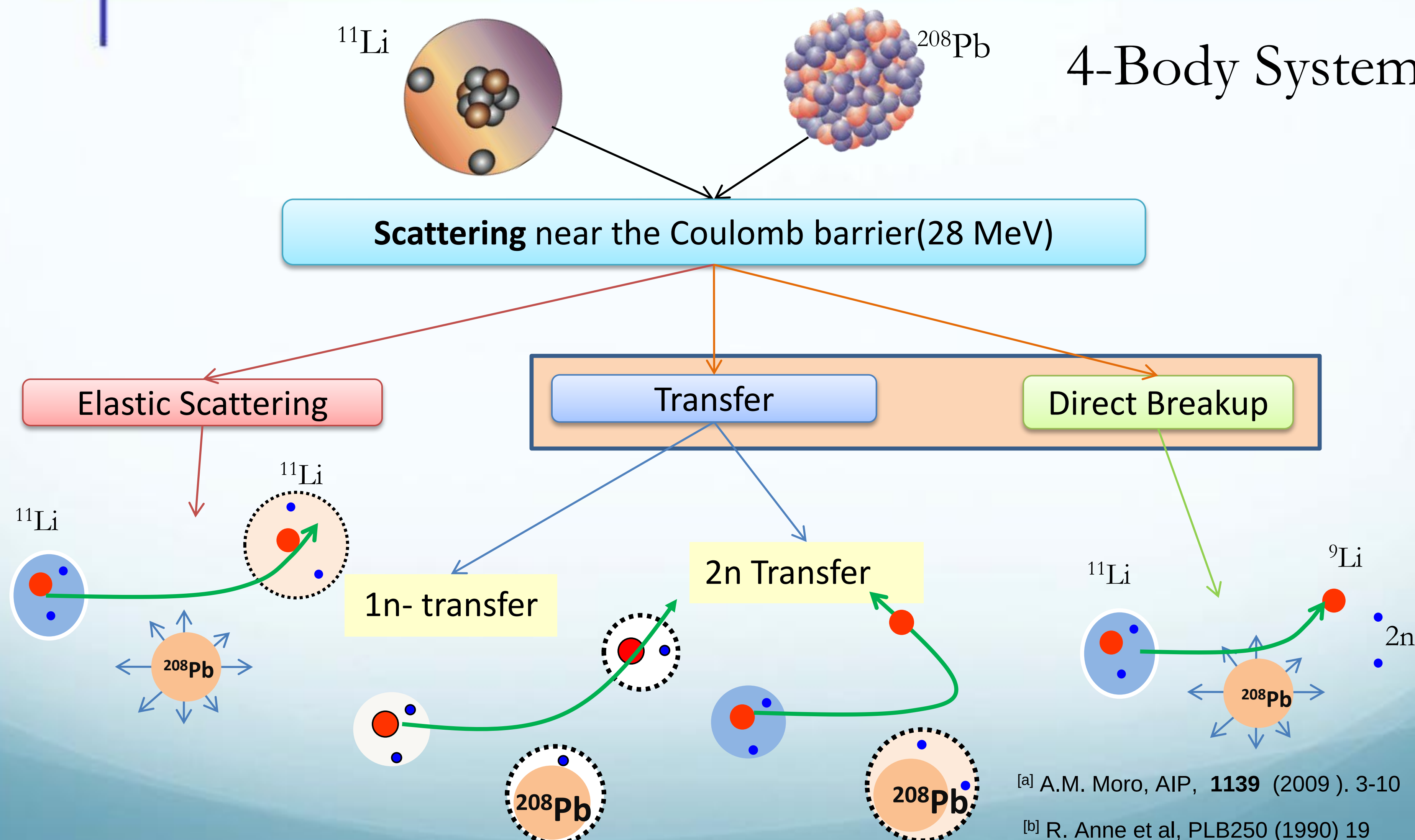
Open channels

^{7}Li + ^{210}Pb (Q = + 3 MeV)

^{8}Li + ^{209}Pb (Q = -0.1 MeV)

^{4}He+^{5}He (Q = -4.5 MeV)

Reaction Mechanisms



[a] A.M. Moro, AIP, **1139** (2009). 3-10

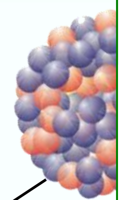
[b] R. Anne et al, PLB250 (1990) 19

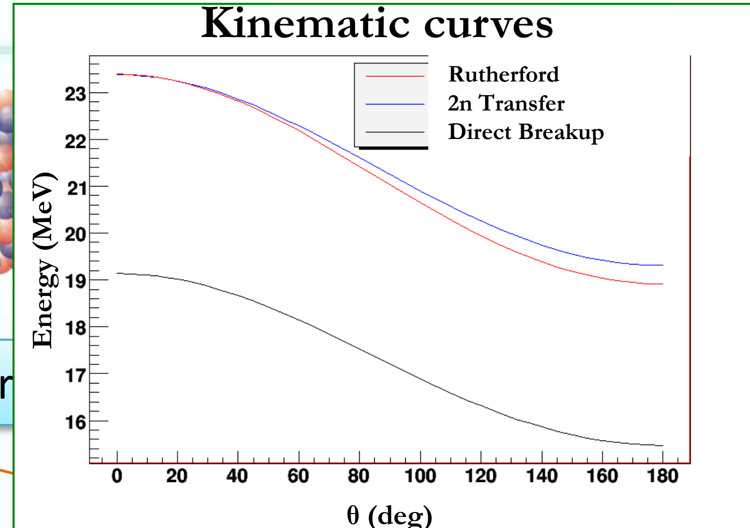
Reaction Mechanisms

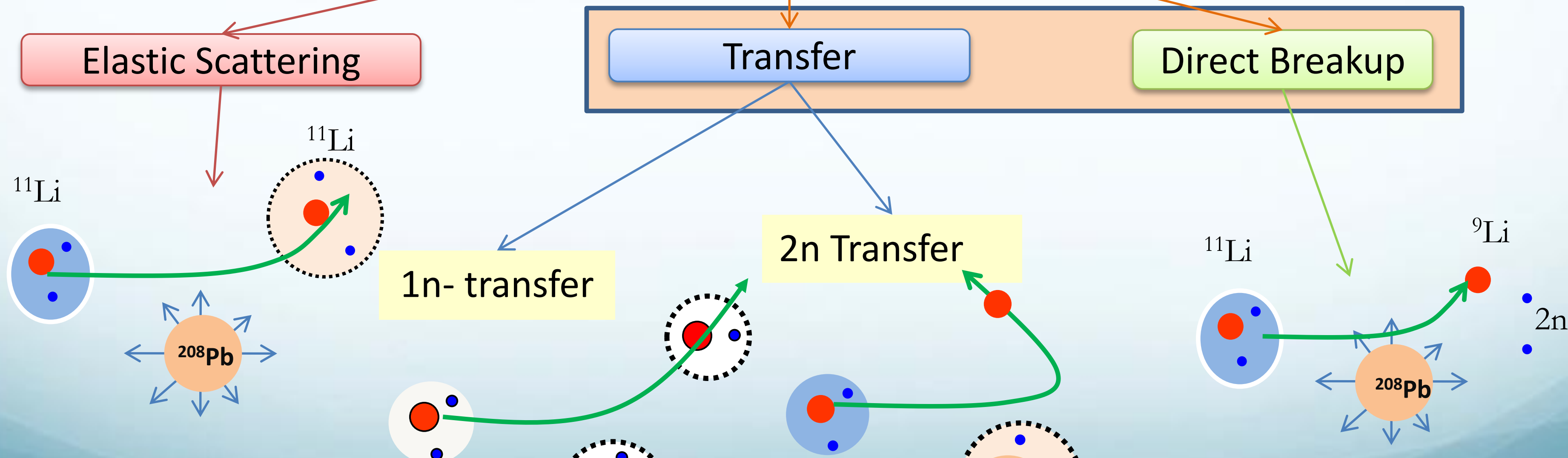
Limits:

- **Rutherford**: Ejectil=Projectil
- **2n Transfer**: $E_{frag} \approx E_{proj}$
- **Direct Breakup:** $V_{CM\ frag} = V_{CM\ proj}$.

- The energy range of those this process are describes by kinematics curves.







[a] A.M. Moro, AIP, **1139** (2009). 3-10

[b] R. Anne et al, PLB250 (1990) 19

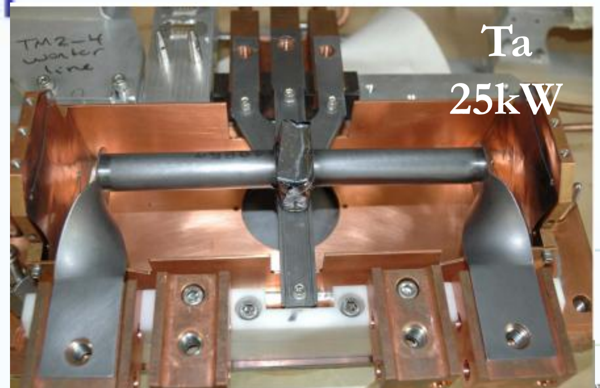
Objetives

- **To study the dynamics of ^{11}Li and ^{9}Li beams in a strong electric field at energies around the Coulomb barrier.**
  - Measured at the ISACII-TRIUMF Facility the angular distribution of elastic and inelastic scattering of $^{11}Li+^{208}Pb$ at 24.2 and 29.7 MeV and $^{9}Li+^{208}Pb$ at 24, 29.5 and 33 MeV laboratory energies.

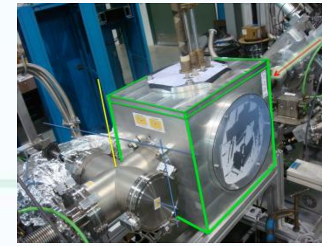
- **Compare the results with dispersion models developed for this type of nuclei.**
  - The $^{9}Li+^{208}Pb$ data was used to tune the potential using the double-folding São Paulo Potential (SPP) for the real part and for the imaginary part a Woods-Saxon potential.
  - The ^{11}Li scattering data will be compare with CDCC calculations

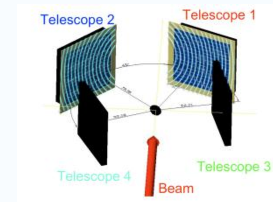
This is the first determination of the angular distribution of the cross section for $^{11}Li+^{208}Pb$ and $^{9}Li+^{208}Pb$.

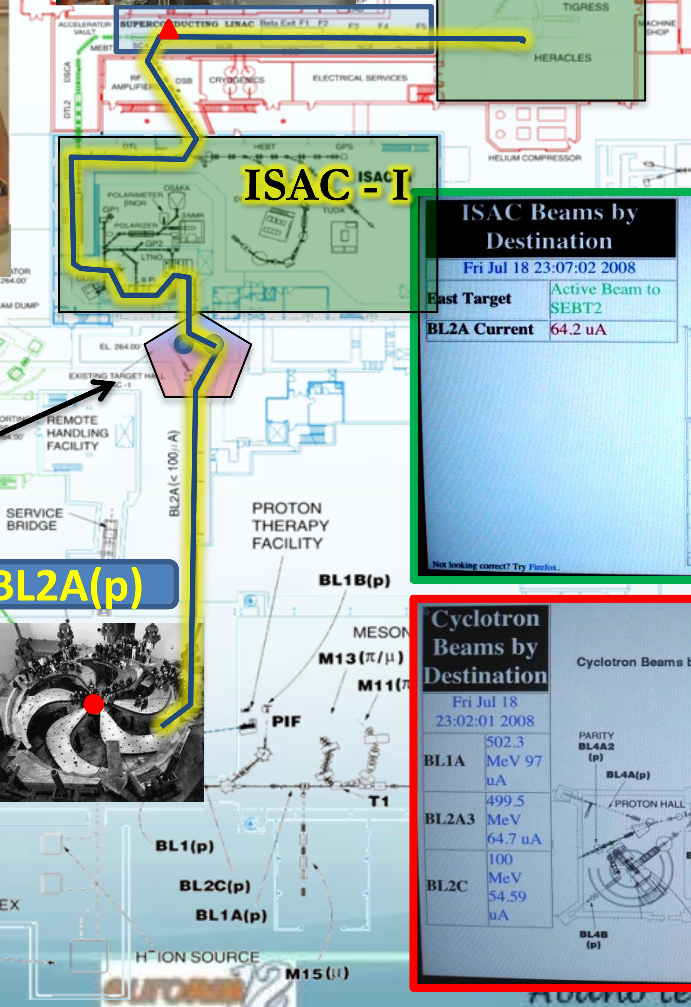
TRIUMF's Facility

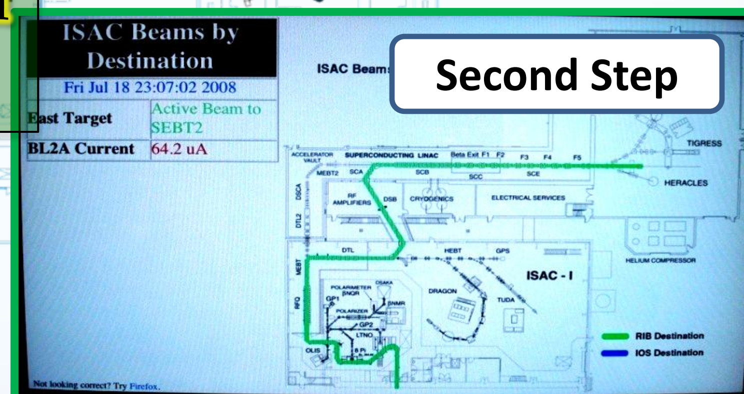


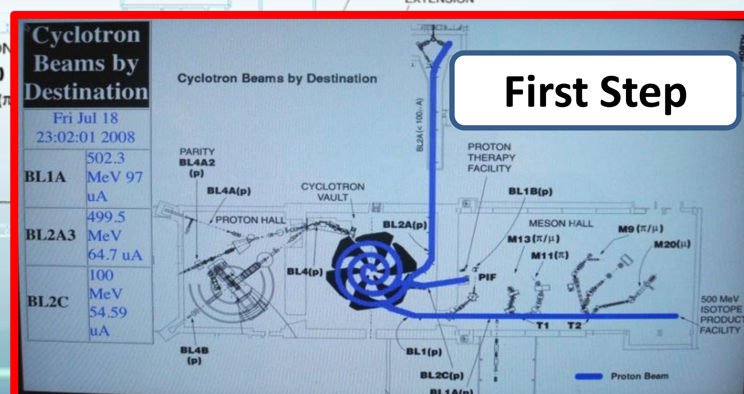
A/q=5.5 MeV/u











$^{11}Li^{2+}$

Yield: 4000 ions/s

Max: 6000 ions/s

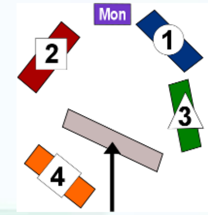
Cyclotron

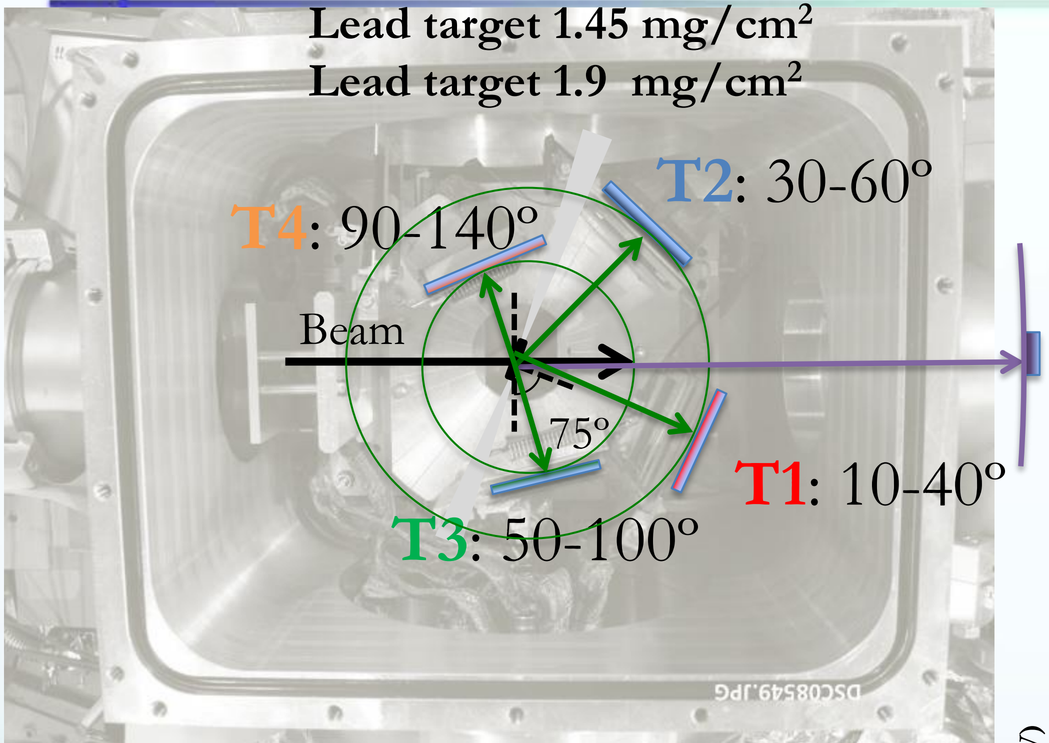
Proton beam

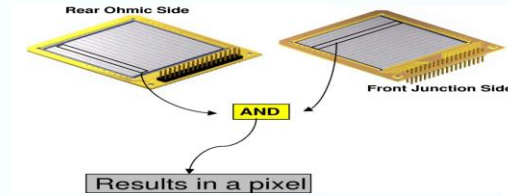
500 MeV

100 μA

Experimental Setup





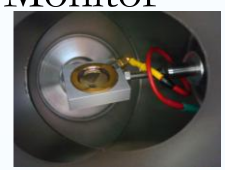


1024 pixels !

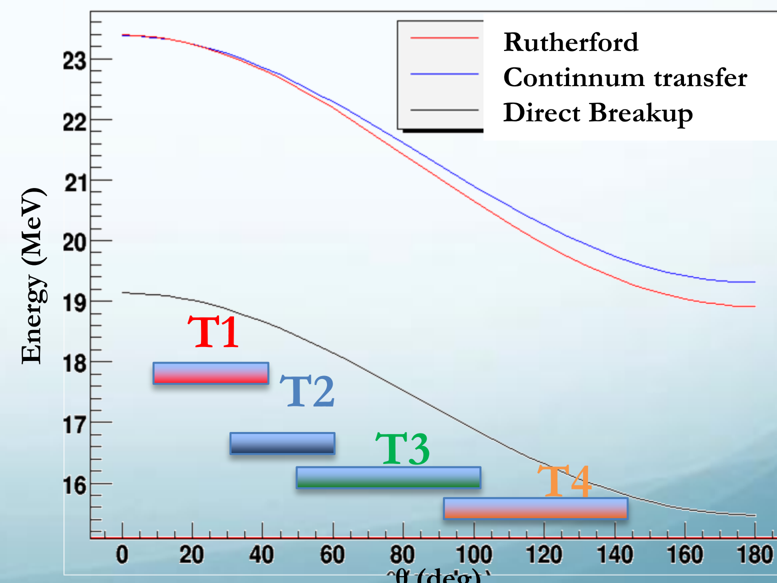
16x16 DSSSD+PAD

16 SSSD+ 16x16 DSSSD

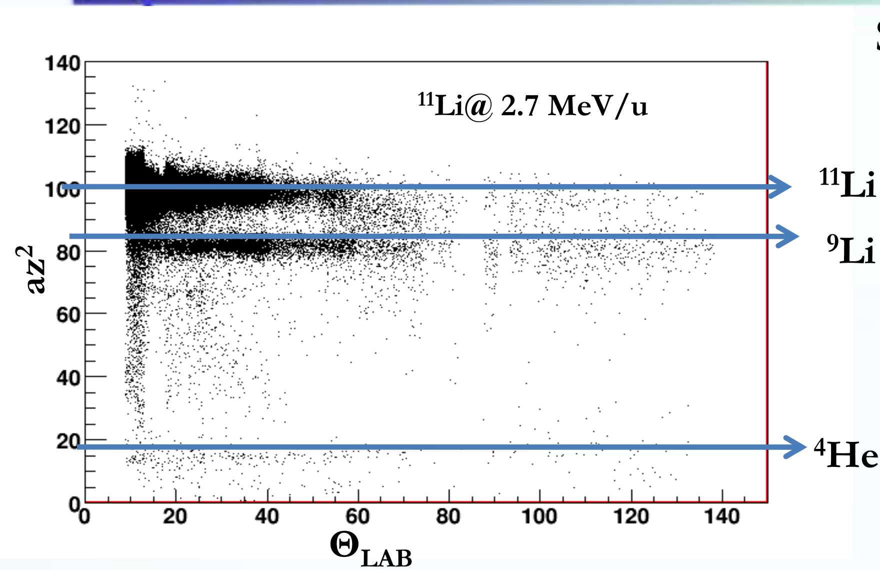
Monitor



Detector	Thickness(μm)	Angular Range	
T1	45+500	10-40º	80 mm
T2	45+500	30-60º	
T3	20+60	50-100º	55 mm
T4	20+63	90-140º	
Mon	700		28 cm

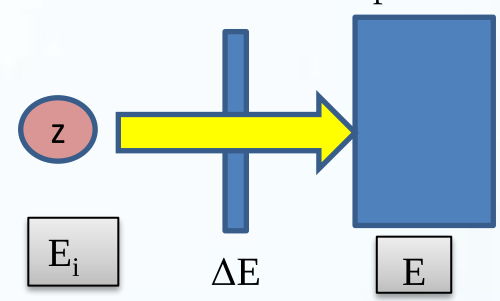


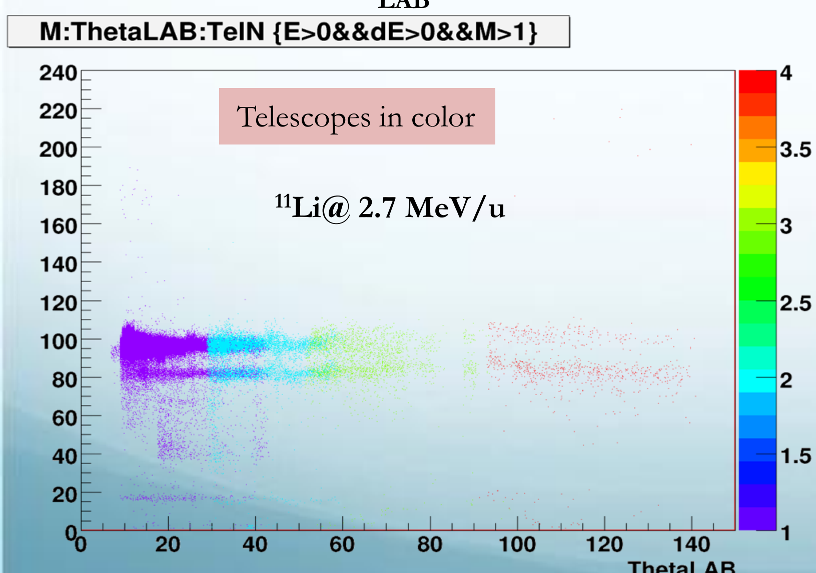
Particle Identification

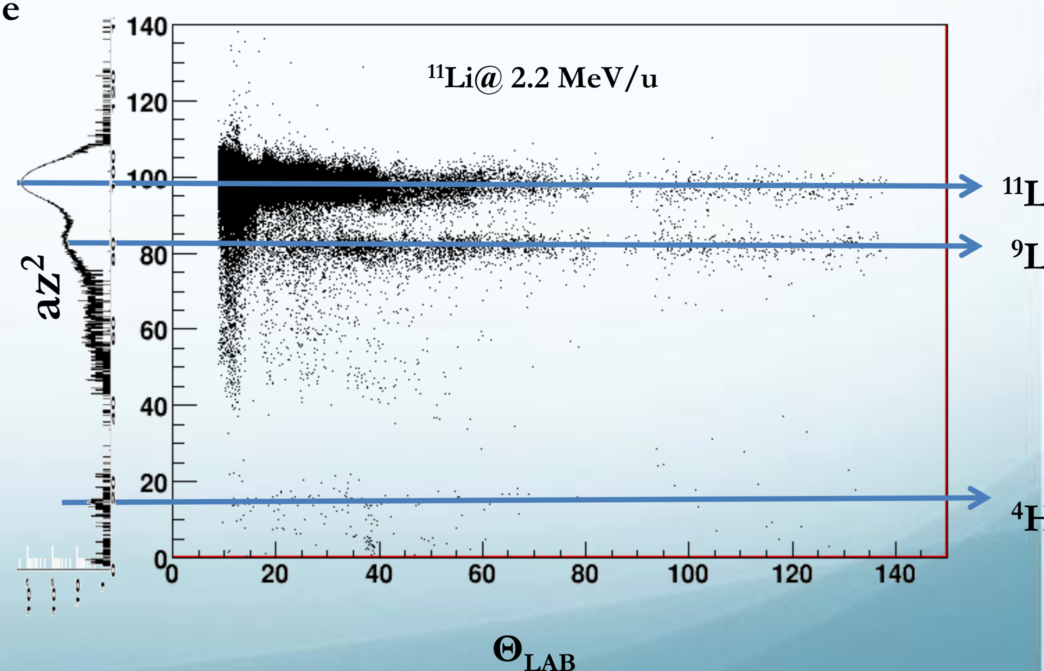


Several representation can be done using Bethe-Block.

$$az^2 = \frac{\Delta E \cdot E_i}{C}$$

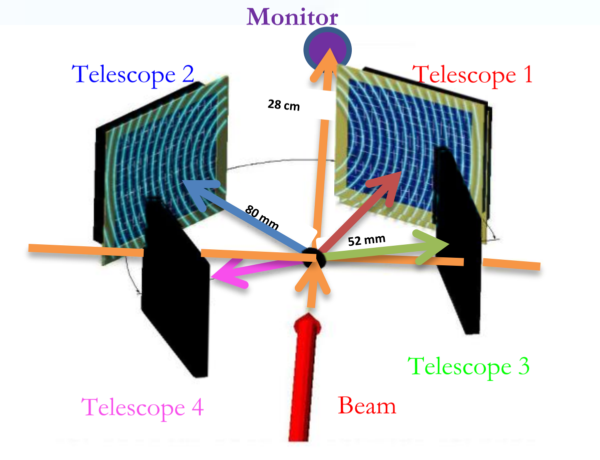




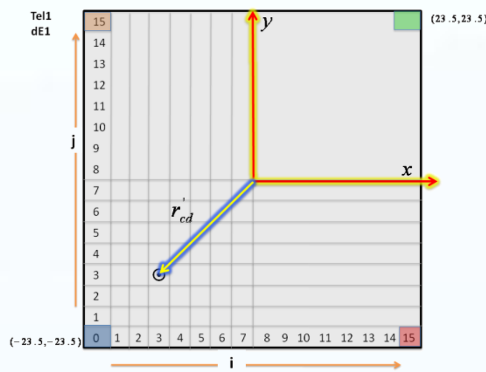


Particle Identification dEvsE

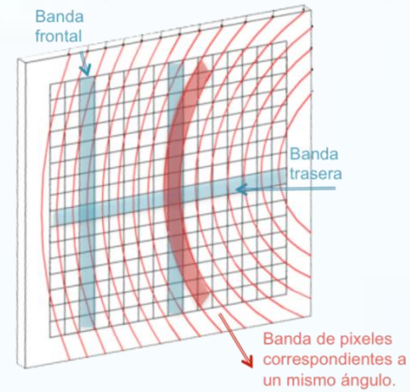
4 telelescopes



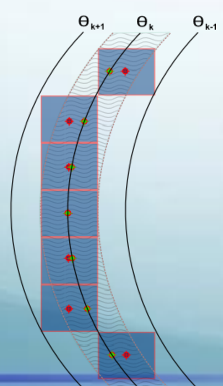
Detector Pixel data

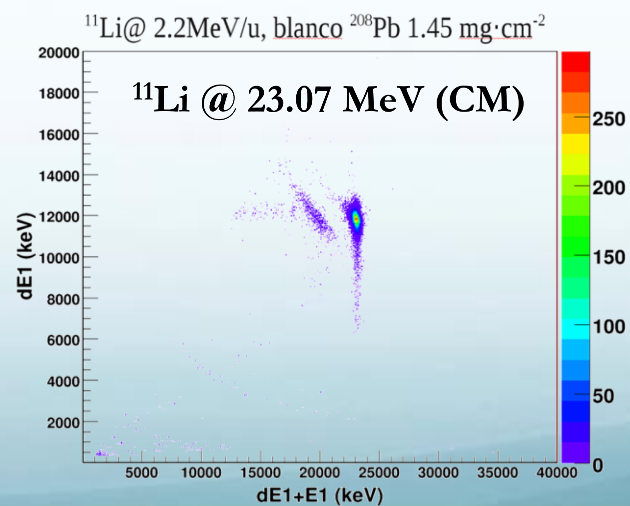


Angular and pixel data



Ring -> Sum Pixels

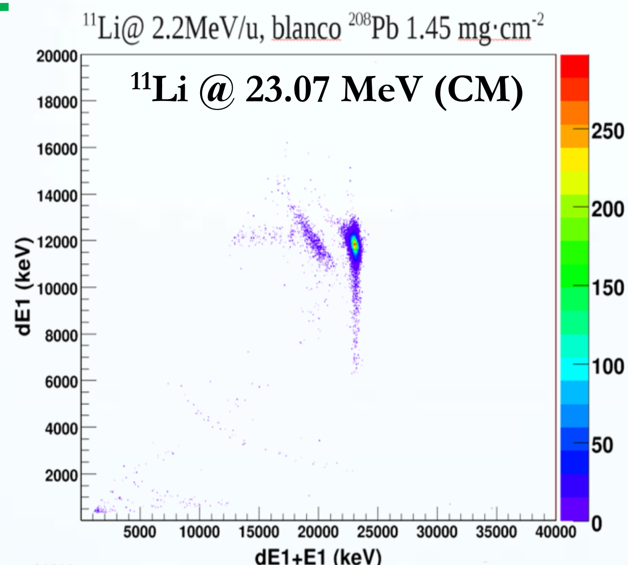


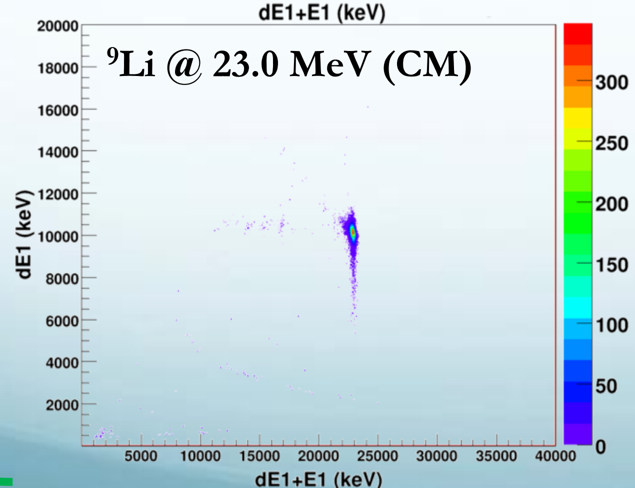


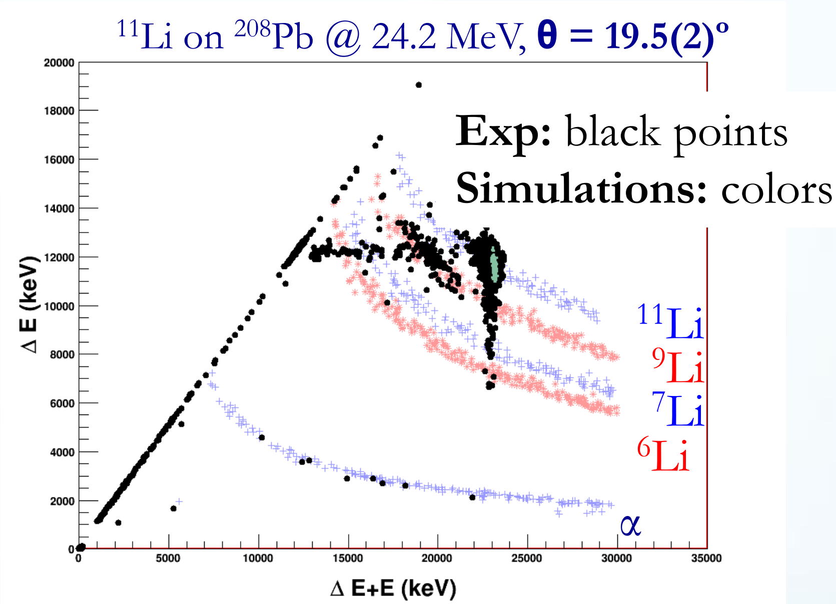
Elastic & Breakup / ^{11}Li & ^{9}Li Data @ C.M. Energy

Identification comparing by angle with simulation.

Below Coulomb Barrier

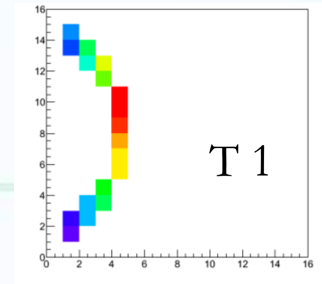


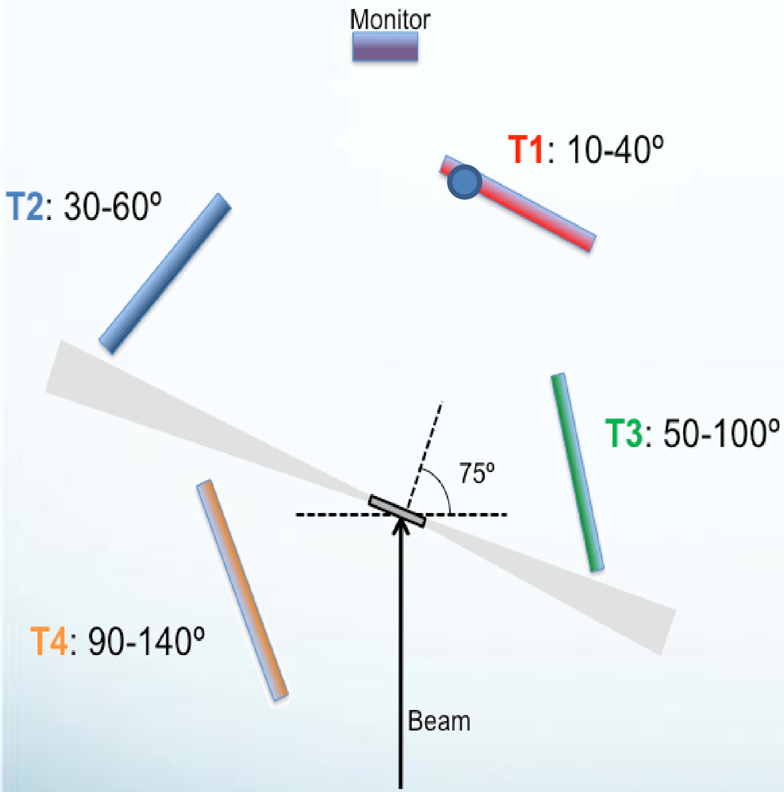


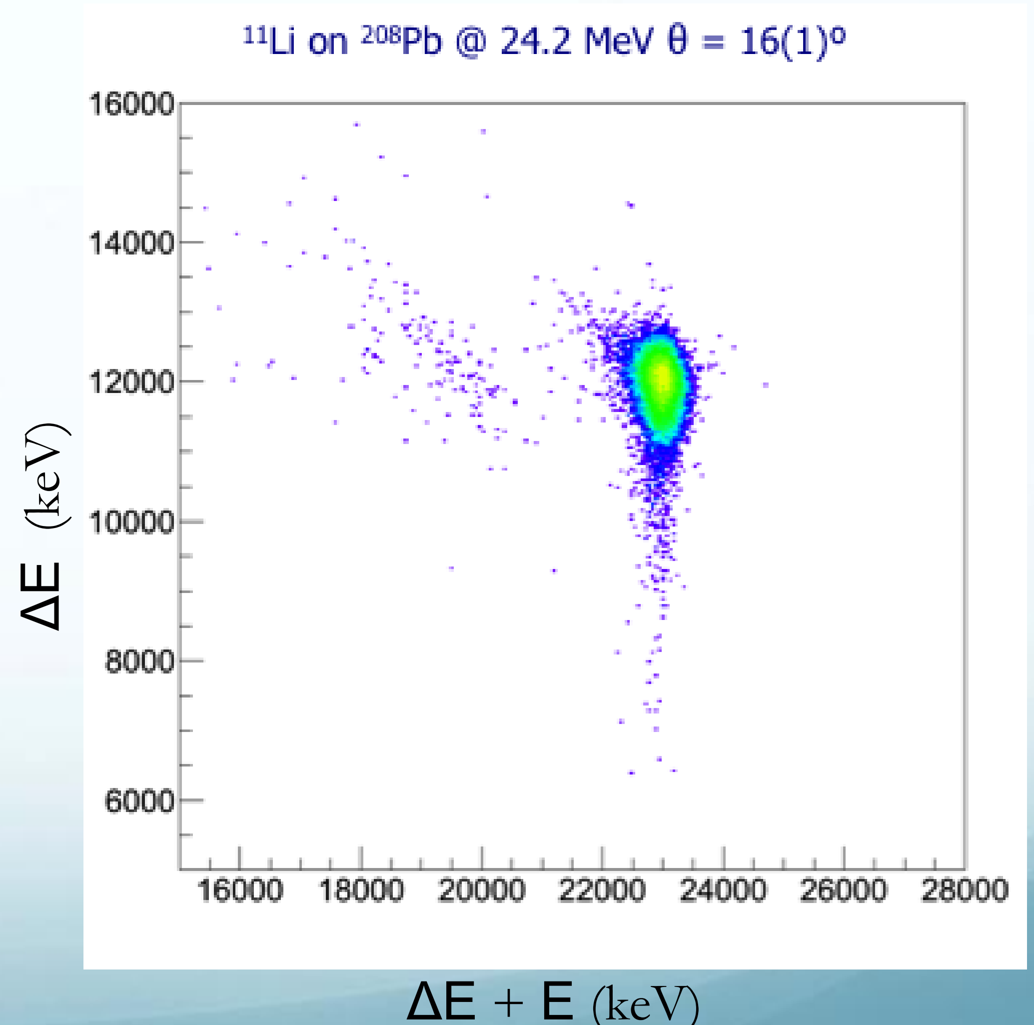


- ✓ Large breakup contribution well below the Coulomb barrier (≈28 MeV)
- ✓ MC Simulations of losses in the different sensitive and unsensitive materials.

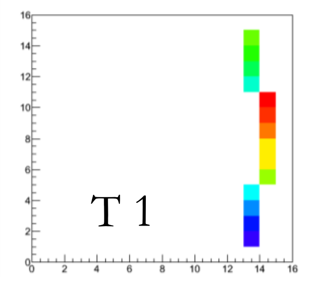
Cross section @ forward angles

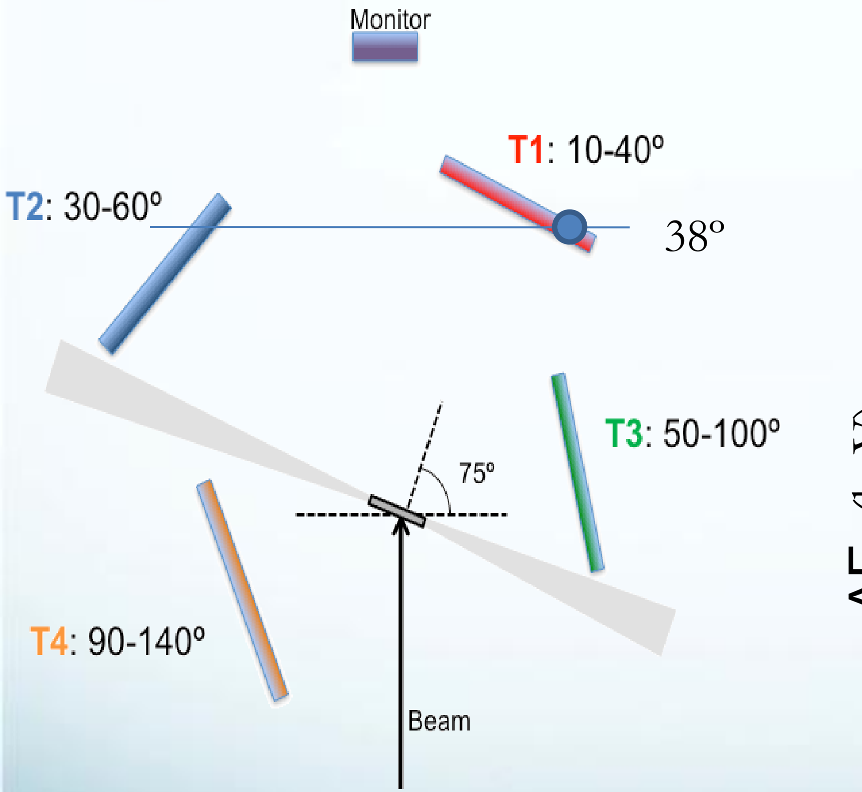


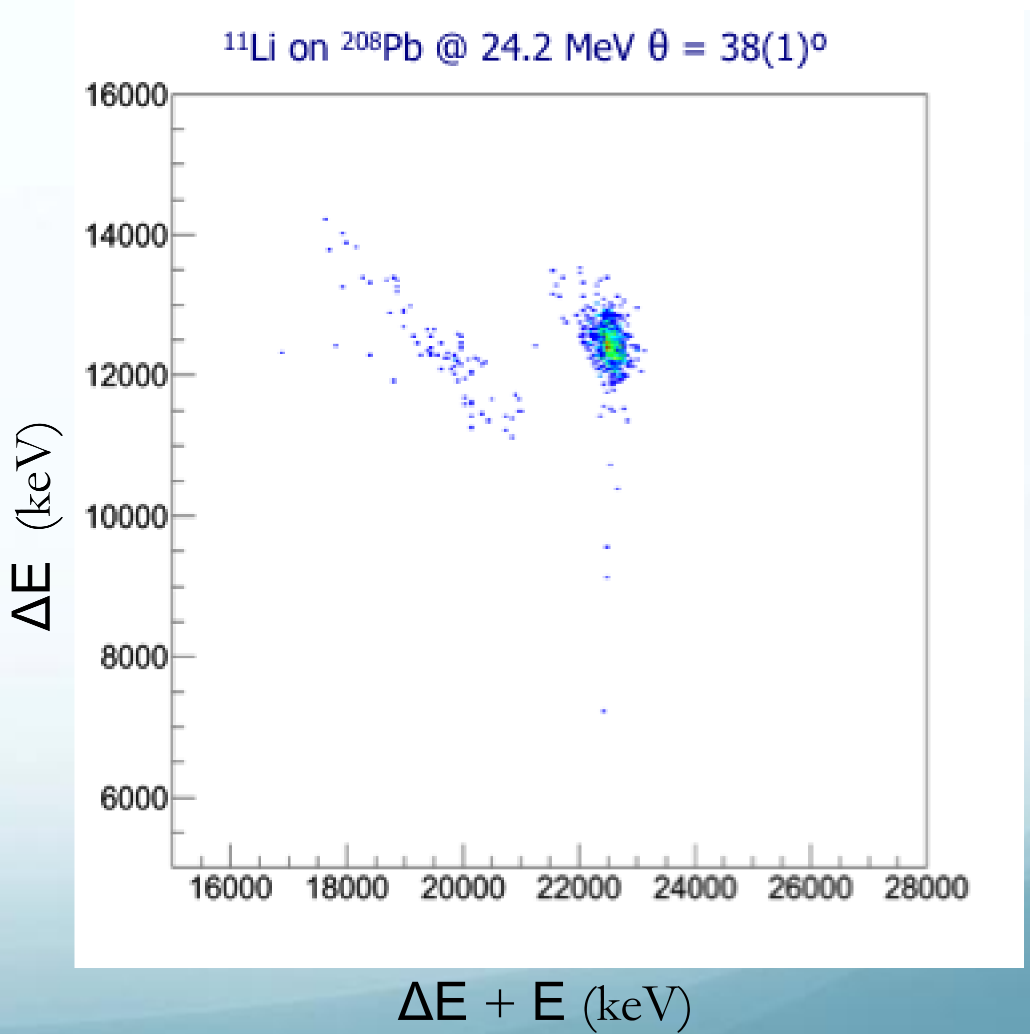




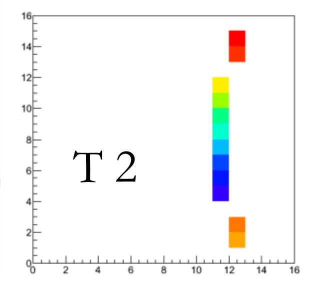
Cross section @ forward angles

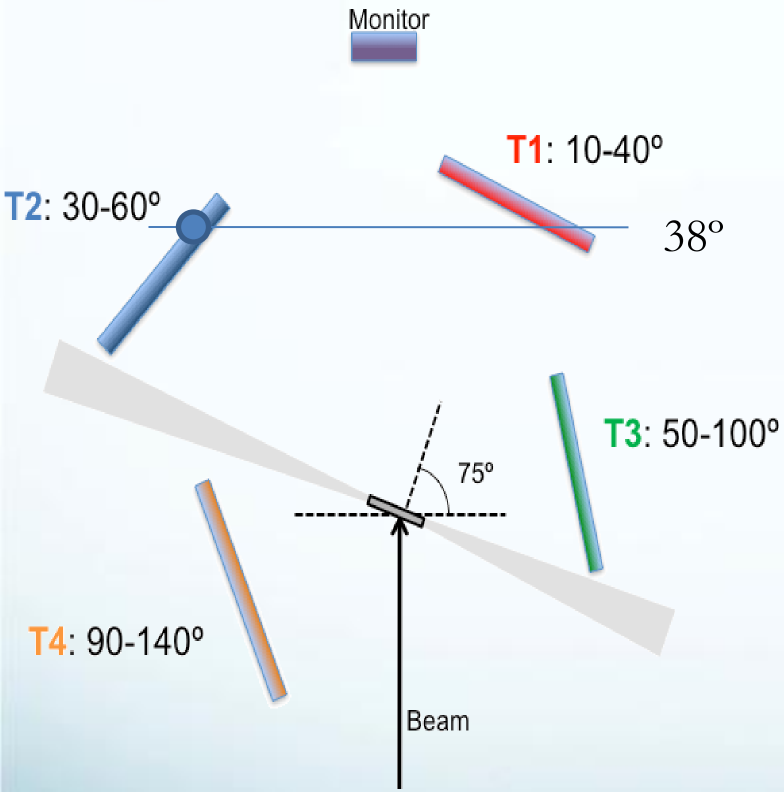


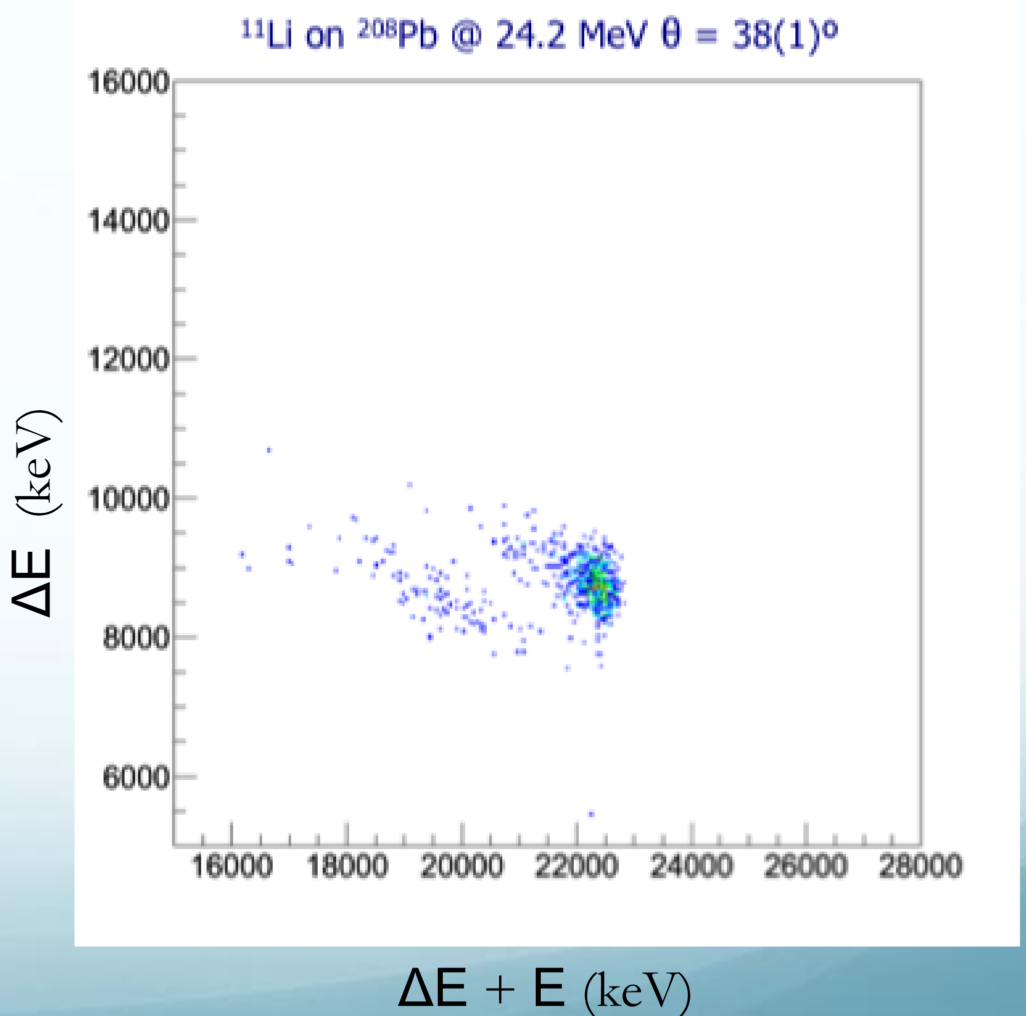




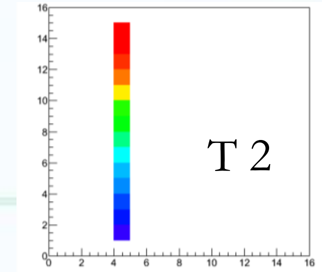
Cross section @ forward angles

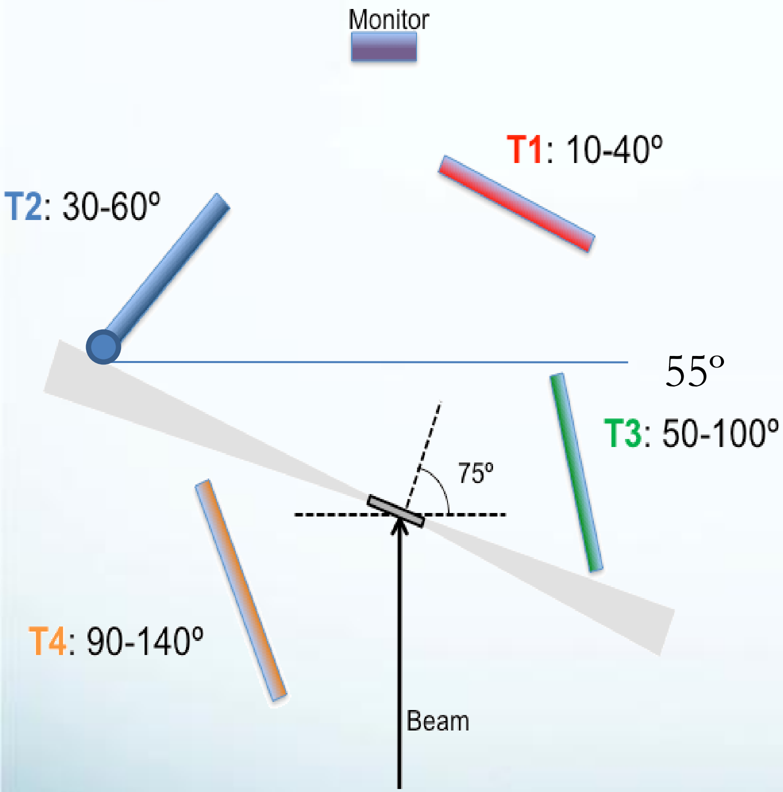


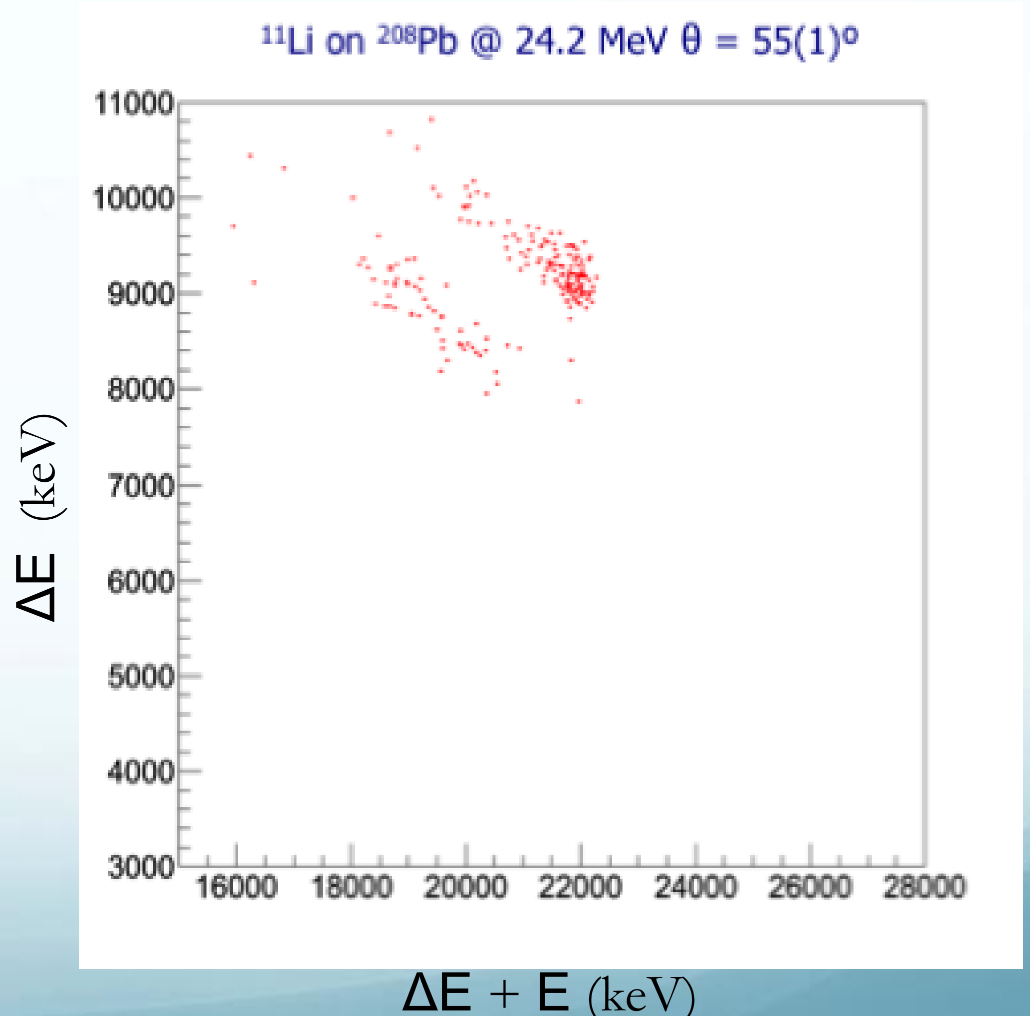




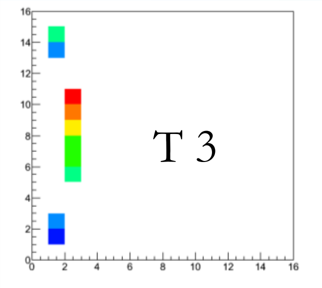
Cross section @ forward angles

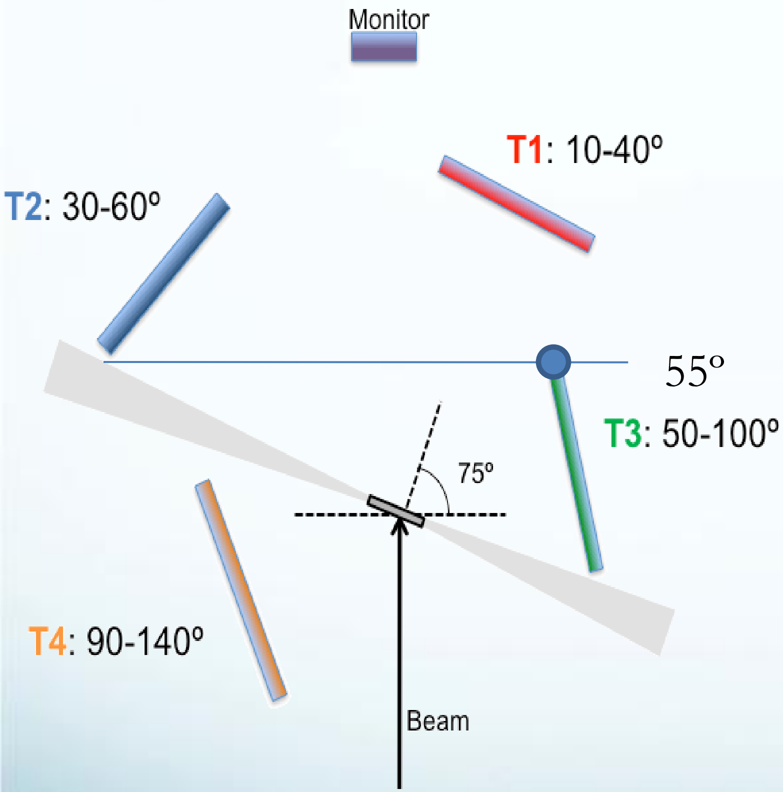


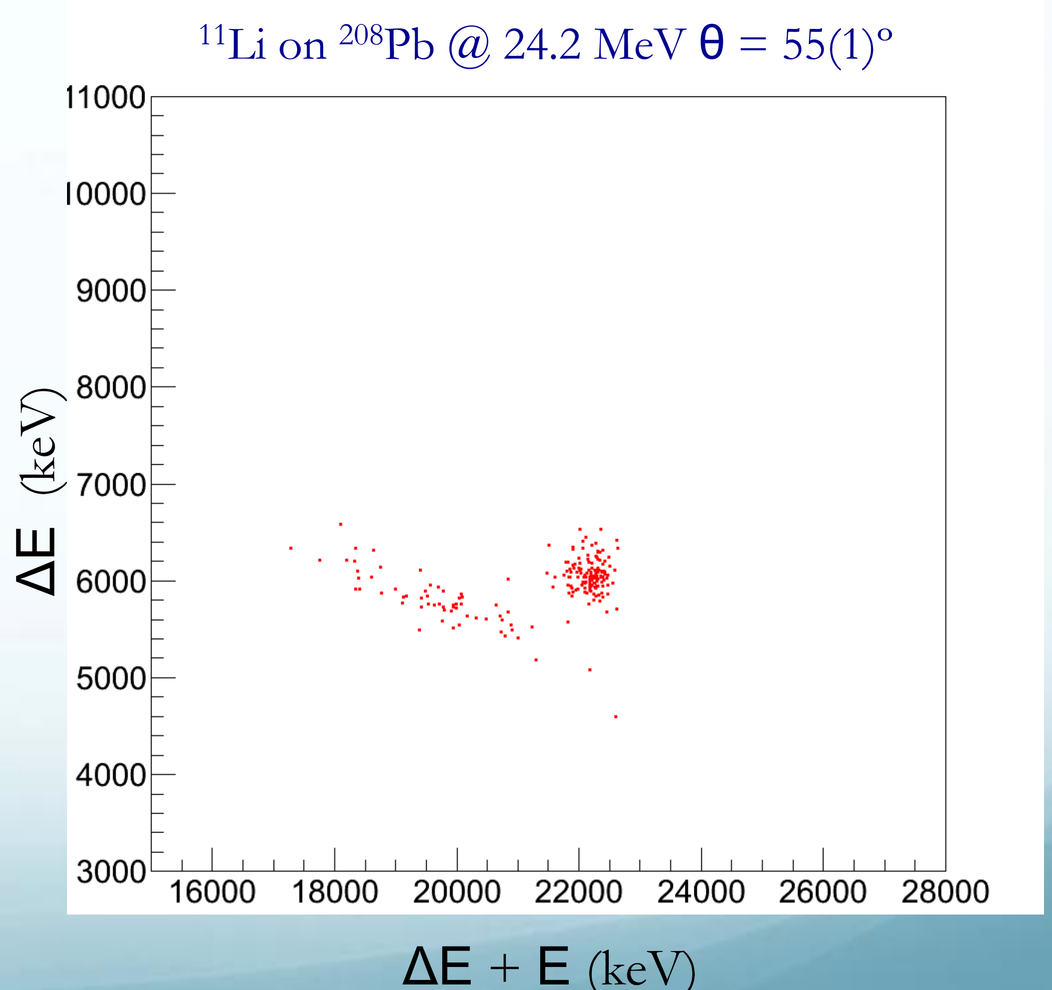




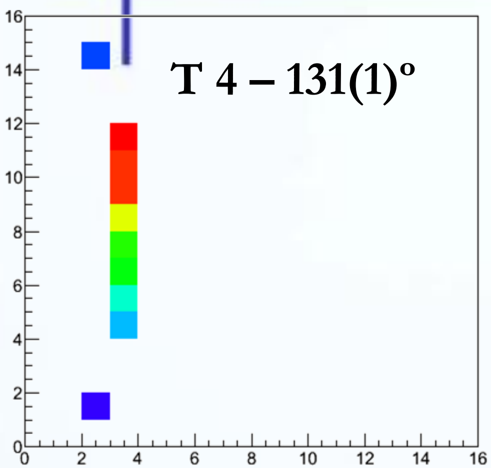
Cross section @ forward angles



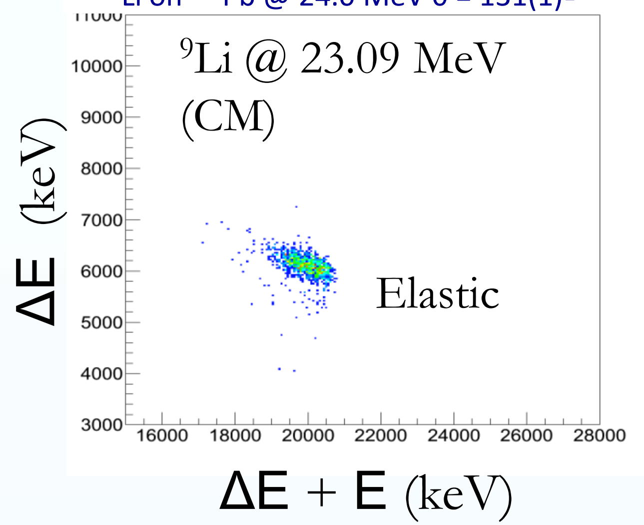




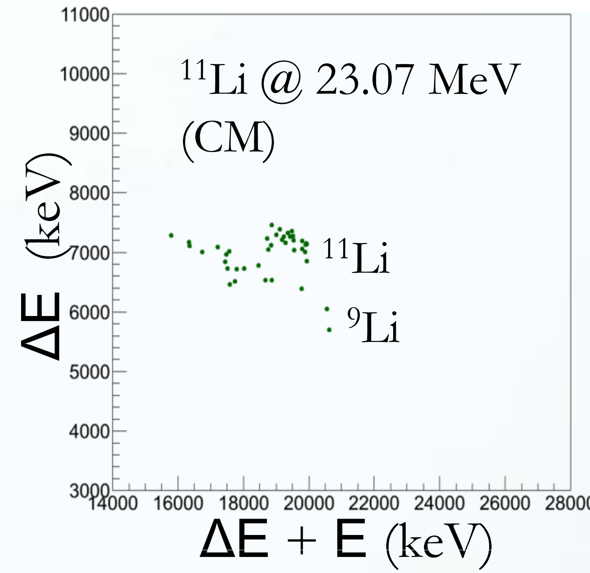
Cross section @ Backward angles

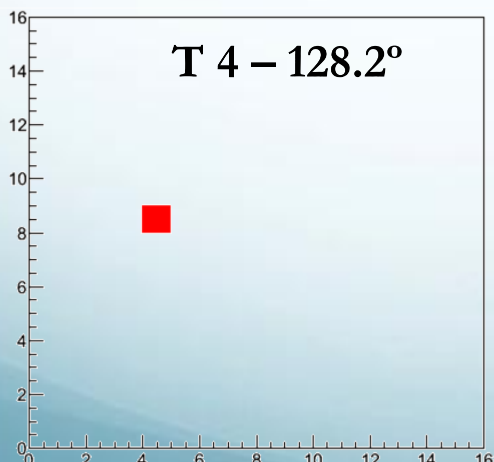


^{9}Li on ^{208}Pb @ 24.0 MeV θ = 131(1)º

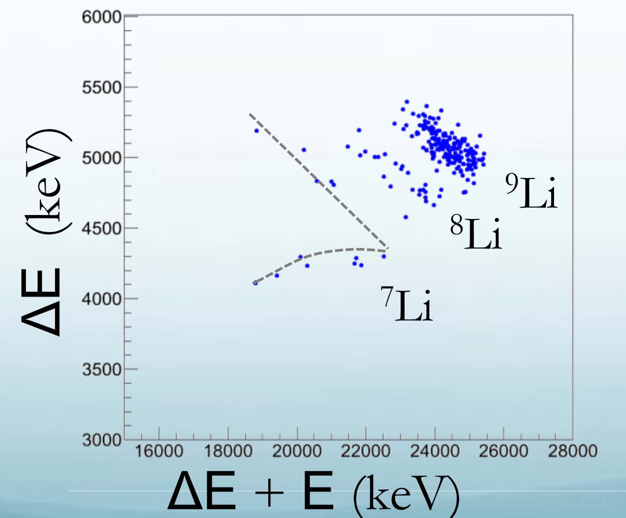


^{11}Li on ^{208}Pb @ 24.2 MeV θ = 131(1)º





^{9}Li on ^{208}Pb @ 29.7 MeV, θ = 128.2º



Open Channels:

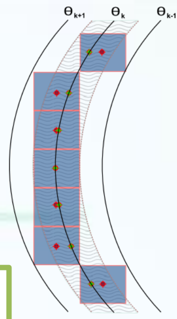
^{9}Li + ^{208}Pb

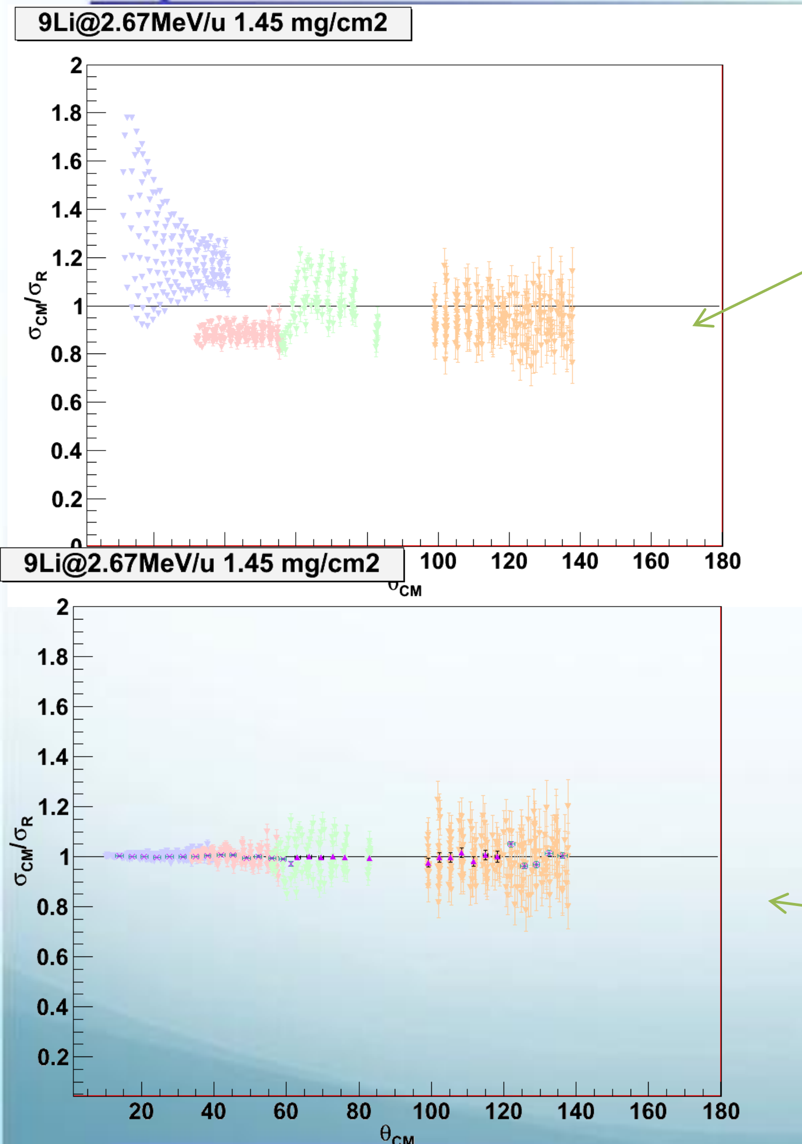
→ ^{7}Li + ^{210}Pb (Q = + 3 MeV)

→ ^{8}Li + ^{209}Pb (Q = -0.1 MeV)

→ ^{4}He + ^{5}He (Q = -4.5 MeV)

Angular Optimization with Coincidence data



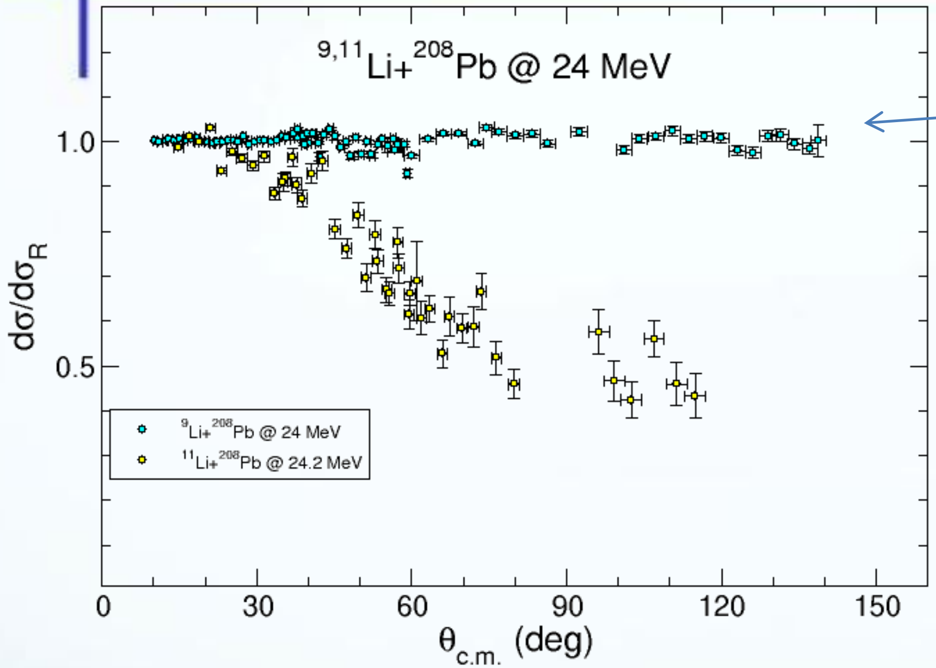


Color points represent the pixel calculation of the differential cross section divided by Rutherford.
Each color represents a detector.
Accurate position for the detector can be calculated improving ***χ2*** *minimización.*

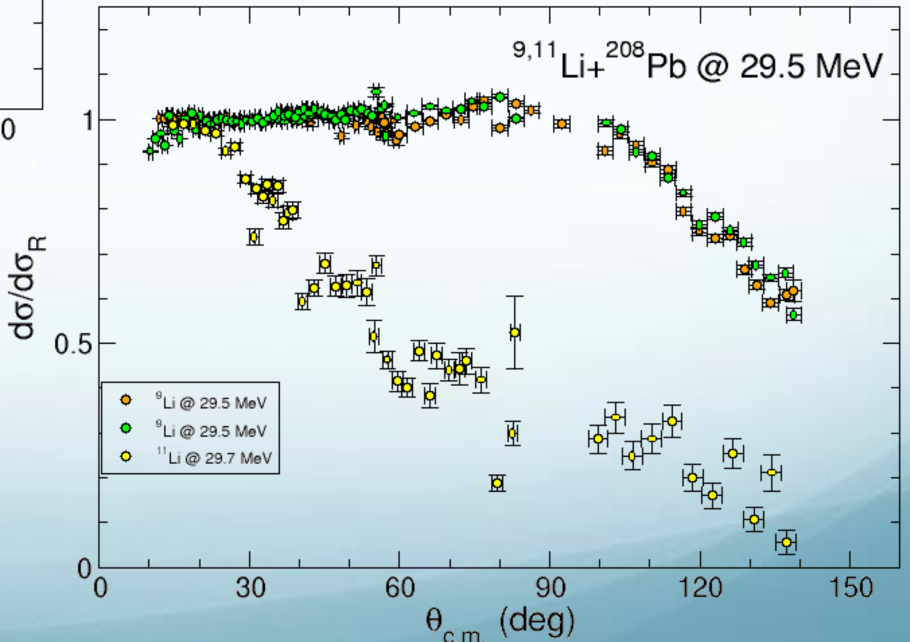
Minimization procedure:
- Calculate position and solid angle for each pixel.
- Select the pixels in the rings for each detector.
- Change between LAB to CM.
- Minimization of **χ2** of the NCountsCM/Ruth = 1

Minimized data according to Rutherford.

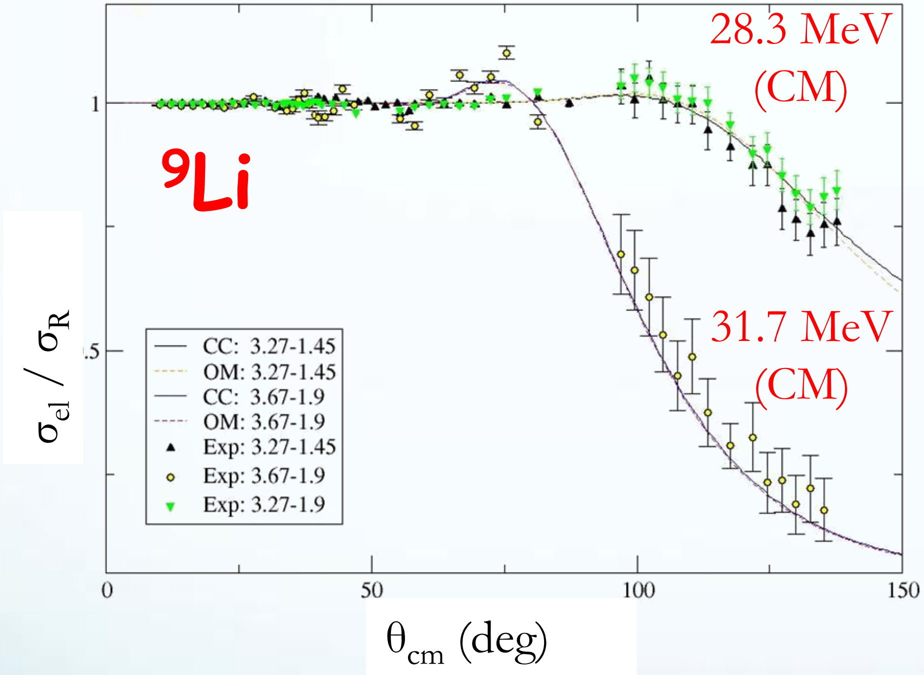
Elastic Scattering of ^{9,11}Li@24 MeV, 29.5 MeV



Rutherford



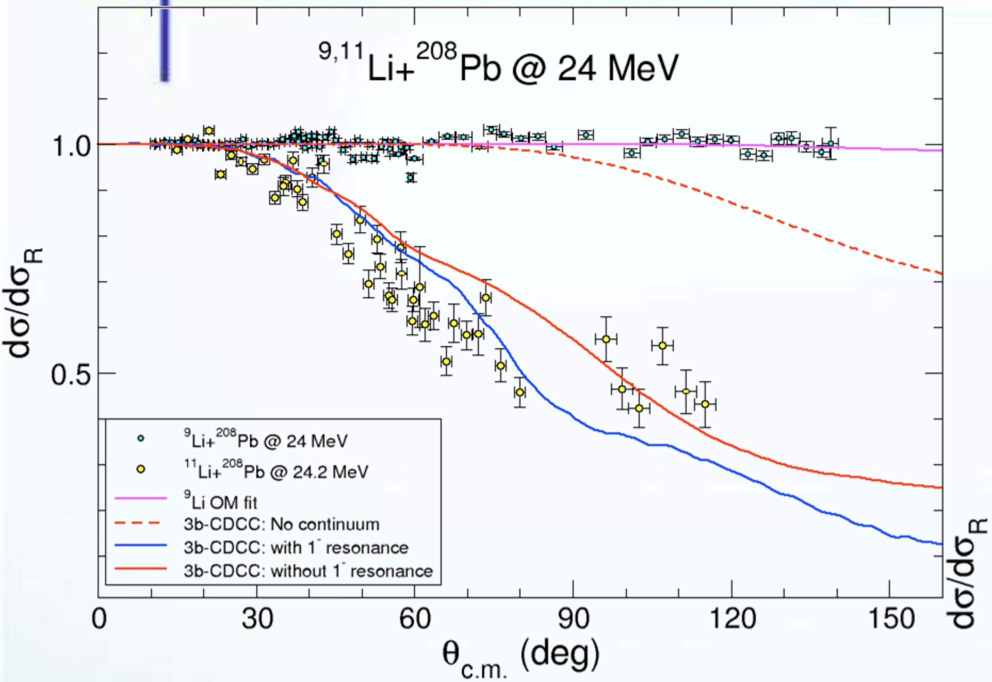
Elastic Scattering of ^{9}Li used to tune the potential



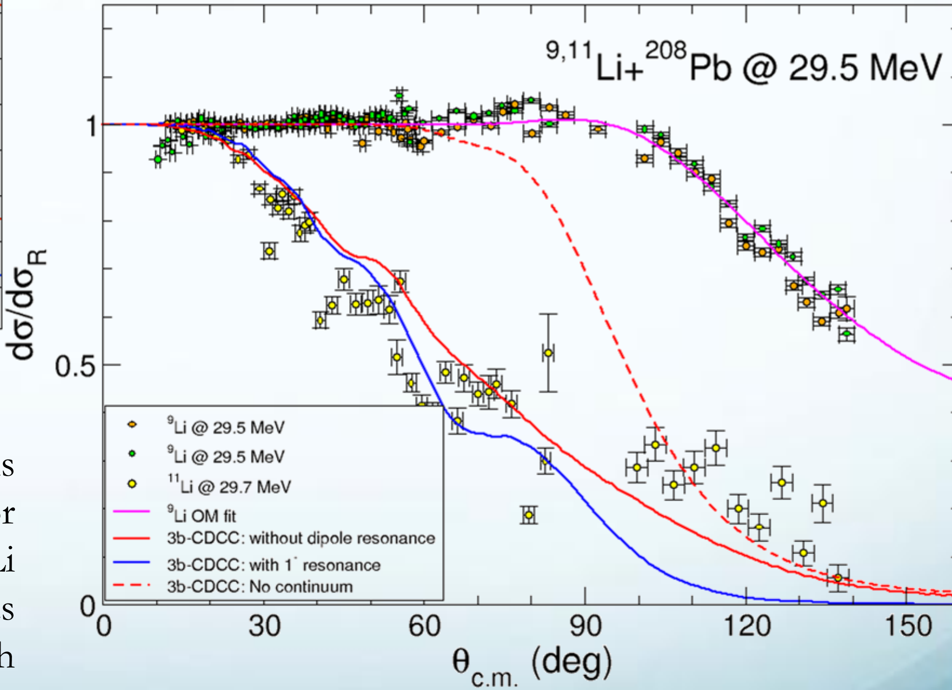
Model	Energy (MeV/u)	N_r	W_i(MeV)	χ^2/n
OM	3.27	0.883	6.01	4.1
OM	3.67	0.798	17.6	6.4
CC	3.27	0.85	6.50	4.2
CC	3.67	0.95	17.18	6.2

- Elastic scattering of ^{9}Li on ^{208}Pb @ 2.67 MeV/u follows Rutherford.
- The real part of the potential is from double folding Sao Paolo Potential (SPP) and the imaginary part from a Wood Saxon.
- It is possible to describe the data with fixed geometry, r_i = 1.35 fm , a_i = 0.51 fm
- The fact that N < 1 => Attractive polatization effect
- The contribution of 1st excited state in ^{9}Li included in CC calculation
- The OM and CC reproduce similarly well the data.

Results and Discussion



▪The experimental data for the elastic scattering of ^{11}Li + ^{208}Pb display a strong reduction with respect to Rutherford, over the whole angular range, at both energies. In contrast to the behaviour of the data for ^{9}Li, which behaves as a *normal* nucleus.



▪These data have been compared with CDCC calculations assuming a two-body model for ^{11}Li (^{9}Li+2n) and using for the ^{9}Li+^{208}Pb interaction the potential deduced from ^{9}Li data [1,2,3]. The inclusion of a 1^{-} resonance in ^{11}Li has been considered and improves greatly the agreement with the data.

▪The special behaviour of ^{11}Li is associated to the effect of Coulomb Dipole Polarizability[4] and coupling to the continuum.

[1] M. Cubero et al., Eur. Phys. J web of conf 17, 16002 (2011).
[2] L. C. Chamon, et al. Phys. Rev. C. 66, 014610 (2002).
[3] C.M. Perey and F.G. Perey Phys. Rev. 132, 755 (1963).
[4] M.V. Andres et al. Phys. Rev. Lett 82, 1387, (1999).

Summary and Outlook

- We had presented the first data of the elastic scattering of the halo nucleus ^{11}Li and its core ^{9}Li on ^{208}Pb at energies below and around the Coulomb barrier .
- The ^{9}Li + ^{208}Pb scattering data behave as expected.
- The strong reduction of the ^{11}Li + ^{208}Pb elastic cross section observed both below and around the Coulomb barrier, has been interpreted as due to the dipole coupling of the ground state to low energy continuum states.
- We are going to extended this studies to the ^{11}Be case in July 2012.
- Four body calculation to describe the dynamics of the system are in progress.

Acknowledgments

On behalf of the E-1104 Collaboration:

M.J.G. Borge[1], L. Acosta[2], M. Alcorta[1], M.A.G. Alvarez[3,4], C. Diget[5], J.P. Fernández-García[3], H.O.U. Fynbo[6], D. Galaviz[1], J. Gomez-Camacho[3,4], R. Kanungo[7], J.A. Lay[3], M. Madurga[1], I. Martel[2], A.M. Moro[3], I. Mukha[3], T. Nilsson[8], A.M. Sánchez-Benítez[2], A. Shotter[7], O. Tengblad[1], P. Walden[7].

[1] Instituto de Estructura de la Materia, CSIC, Serrano 113bis, E-28006 Madrid, Spain
[2] Departamento de Física Aplicada, Universidad de Huelva, E-21071, Huelva, Spain
[3] Departamento de FAMN, Universidad de Sevilla, E-41080 Sevilla, Spain
[4] Centro Nacional de Aceleradores, Universidad de Sevilla, Av. Thomas A. Edison, E-41092 Sevilla, Spain
[5] Department of Physics, University of York, York, UK
[6] Department of Astronomy and Physics, University of Aarhus, DK-8000, Aarhus, Denmark
[7] TRIUMF, V6T 2A3 Vancouver, British Columbia, Canada
[8] Fundamental Physics, Chalmers University of Technology, S-41296 Göteborg, Sweden

Thank you very much for you attention