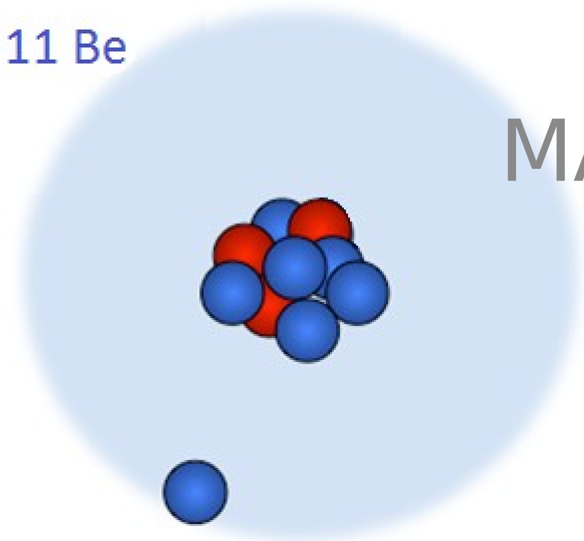
^{11}Be halo nucleus reaction on heavy targets at energies around the Coulomb barrier



MAGISOL Meeting

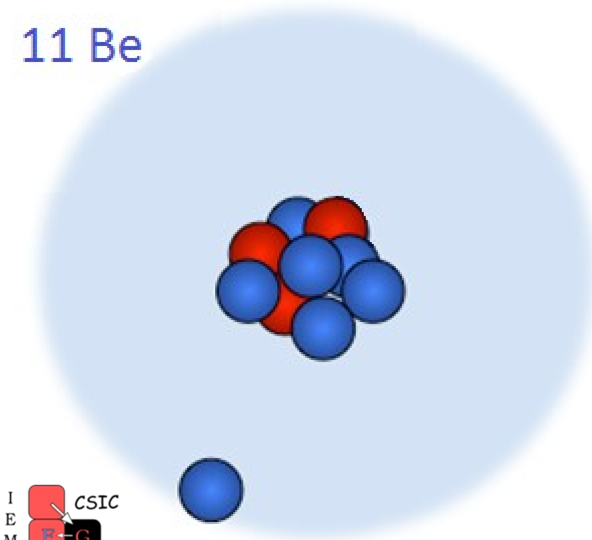
ISOLDE

April 2014

Vicente Pesudo, IEM-CSIC

Grupo de Física Nuclear Experimental

Outline



Motivation:
- Halo nuclei.
- What is new.

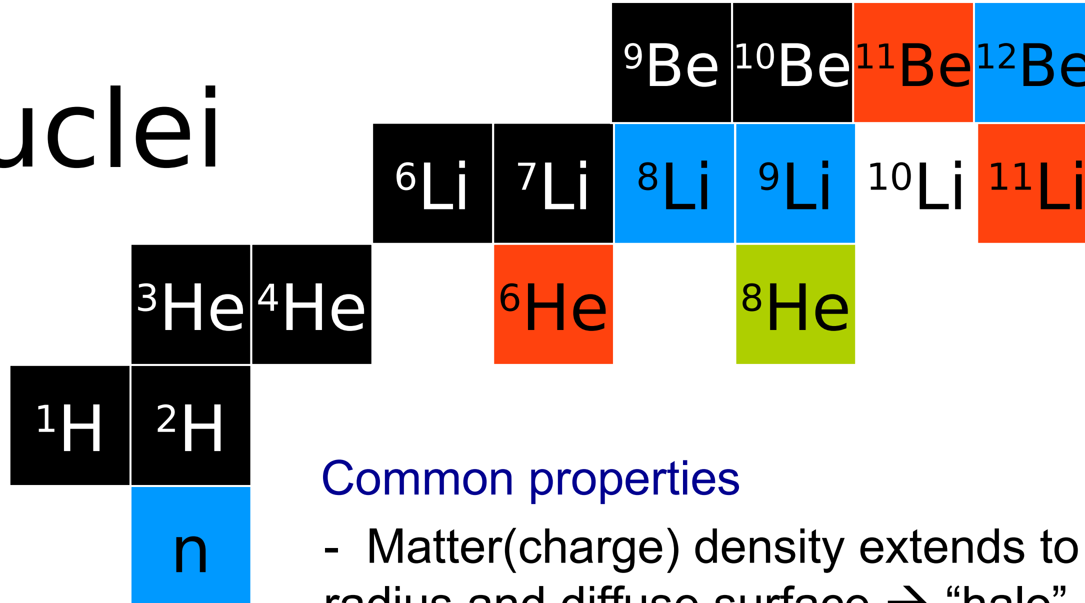
Experimental setup:
- TRIUMF and TIGRESS.
- Charged particles and gamma radiation detection.
- Fragment identification. 2D plots.

CDCC explanation temptative

Experimental results:
- Break up probability.
- Gamma-particle coincidence.
- Inelastic scattering probability.

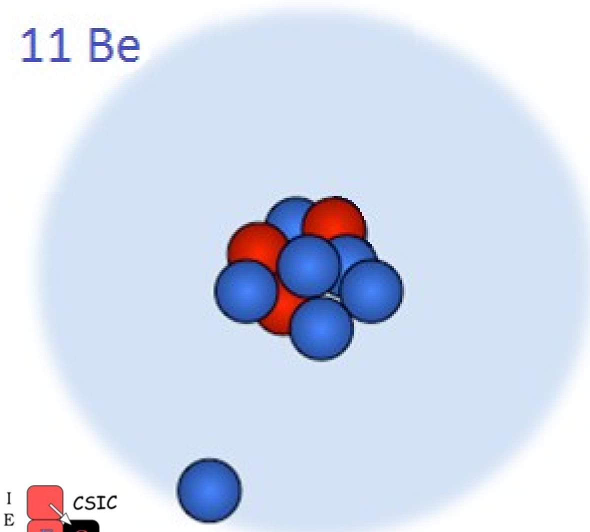
Conclusions and outlook

Halo nuclei



Common properties

- Matter(charge) density extends to large radius and diffuse surface → "halo".
- Compact and almost inert core + one or two weakly bound nucleons.
- Few excited states (if any).



→ Important absorption in the elastic channel.

→ Large fragmentation cross section.

→ **Easily polarizable.**

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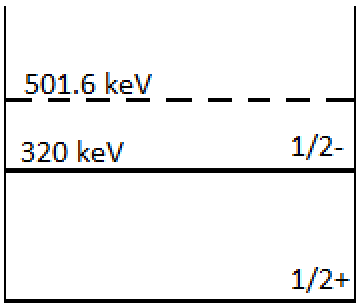
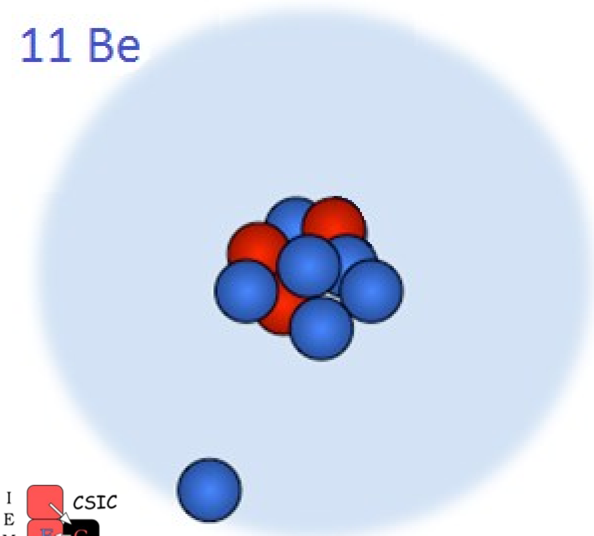
Halo nuclei

^{11}Be

^{11}Li

^{6}He





^{6}He & ^{11}Li

-Two-neutron haloes, borromean systems.

-Theoretical challenge. 4 body calculations.

^{11}Be

- One neutron halo.

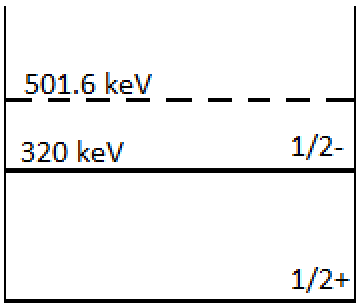
-Break up threshold Sn = 501.6 keV.

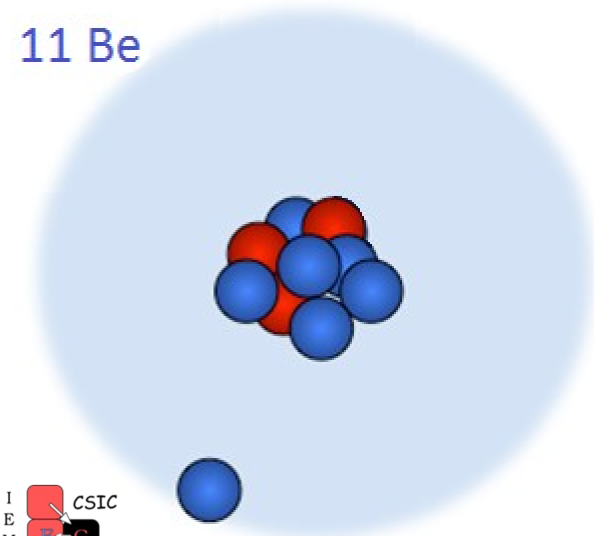
Halo nuclei

^{11}Be

^{11}Li

^{6}He





^{6}He & ^{11}Li

-Two-neutron haloes, borromean systems.

-Theoretical challenge. 4 body calculations.

^{11}Be

- One neutron halo.

-Break up threshold Sn = 501.6 keV.

- Bound excited state at 320 keV. B(E1)=0.112(4) e^{2}fm^{2} (E. Kwan, not published yet)

- Less mass difference after break up.

- Experimental challenge. Fragment identification + angular resolution + gamma detection in coincidence.

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TRIUMF & TIGRESS

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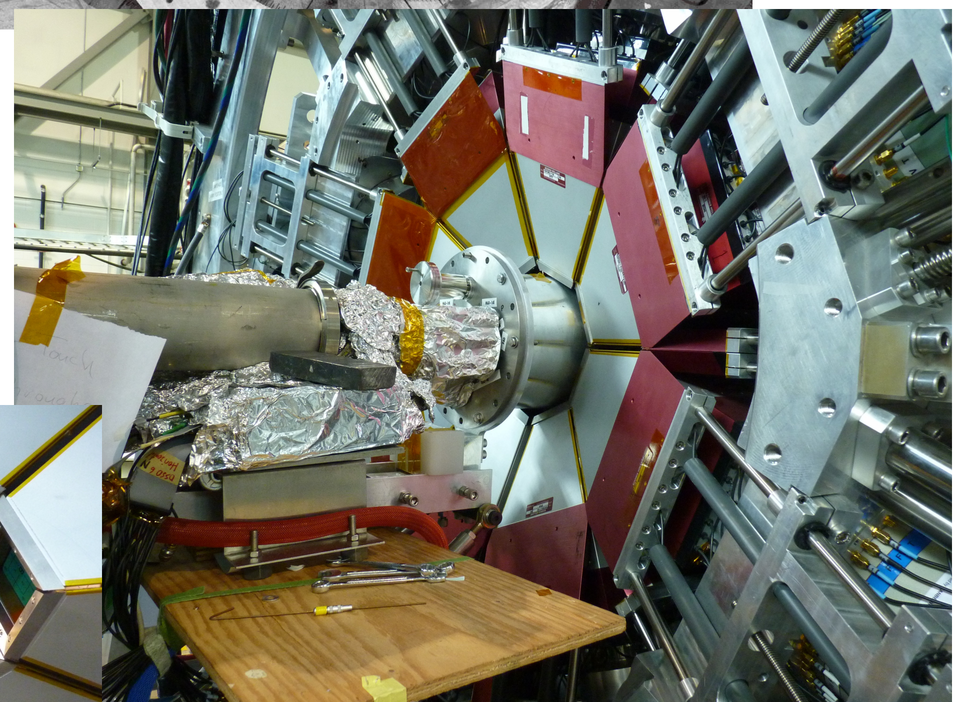
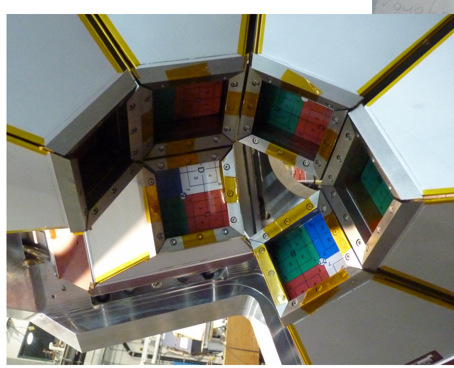
TRIUMF

- Cyclotron.
- Continuous beam accelerator.
- ISOL method.
    - Exotic nuclei at 2.9 MeV/u



TIGRESS

- HPGe Detector array.
- 16 clovers, 8 at 90º y 4 at 135º (+ 4 not used).
- 4 crystals per clover.
- 8 segments (4 + 4) per crystal.
- Compton supression with BGOs.



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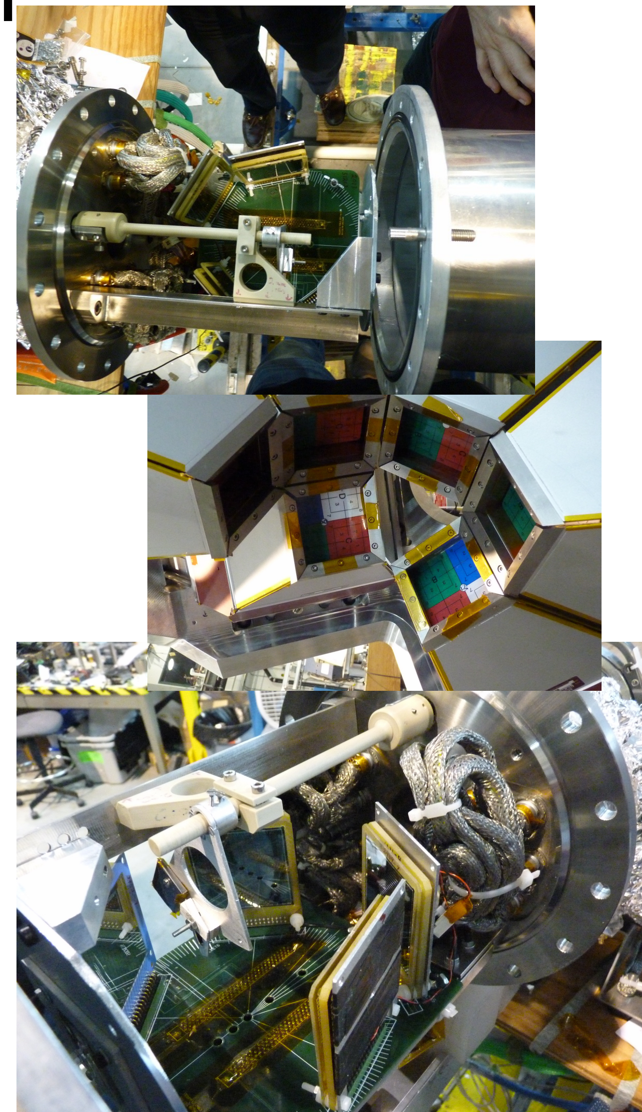
Charged particles and gamma radiation detection



Charged particles:

- 3 telescopes DSSSD 16x16 (40μm) + PAD.
- 1 telescope SSSD 16 (20 μm) + DSSSD 16x16 (300 μm).
- Covering theta range 13º - 150º

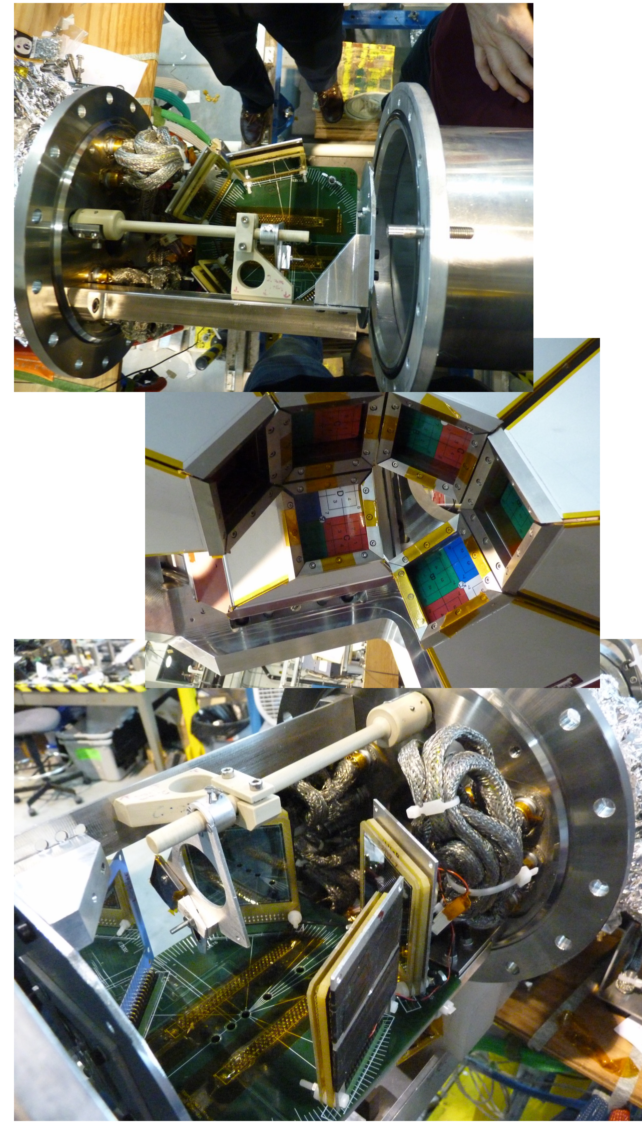
TIGRESS:

- Low efficiency configuration.
- More Compton supression.
  - Espectra at 320 keV cleaner.

Digital electronics:

- Advantage: remote manipulation of parameters:
  gains, thresholds…
- Disadvantage: Less accessibility. We had CrossTalk problems that couldn't afford stop to fix.

The experiment



2012 on ^{208}Pb (1.45mg/cm2):

- 11Be @ 3.6 MeV/u.
- 10Be @ 3.6 MeV/u.
- 11Be @ 3.1 MeV/u.
- 11Be @ 2.9 MeV/u.

2013 on ^{197}Au (1.9mg/cm2):

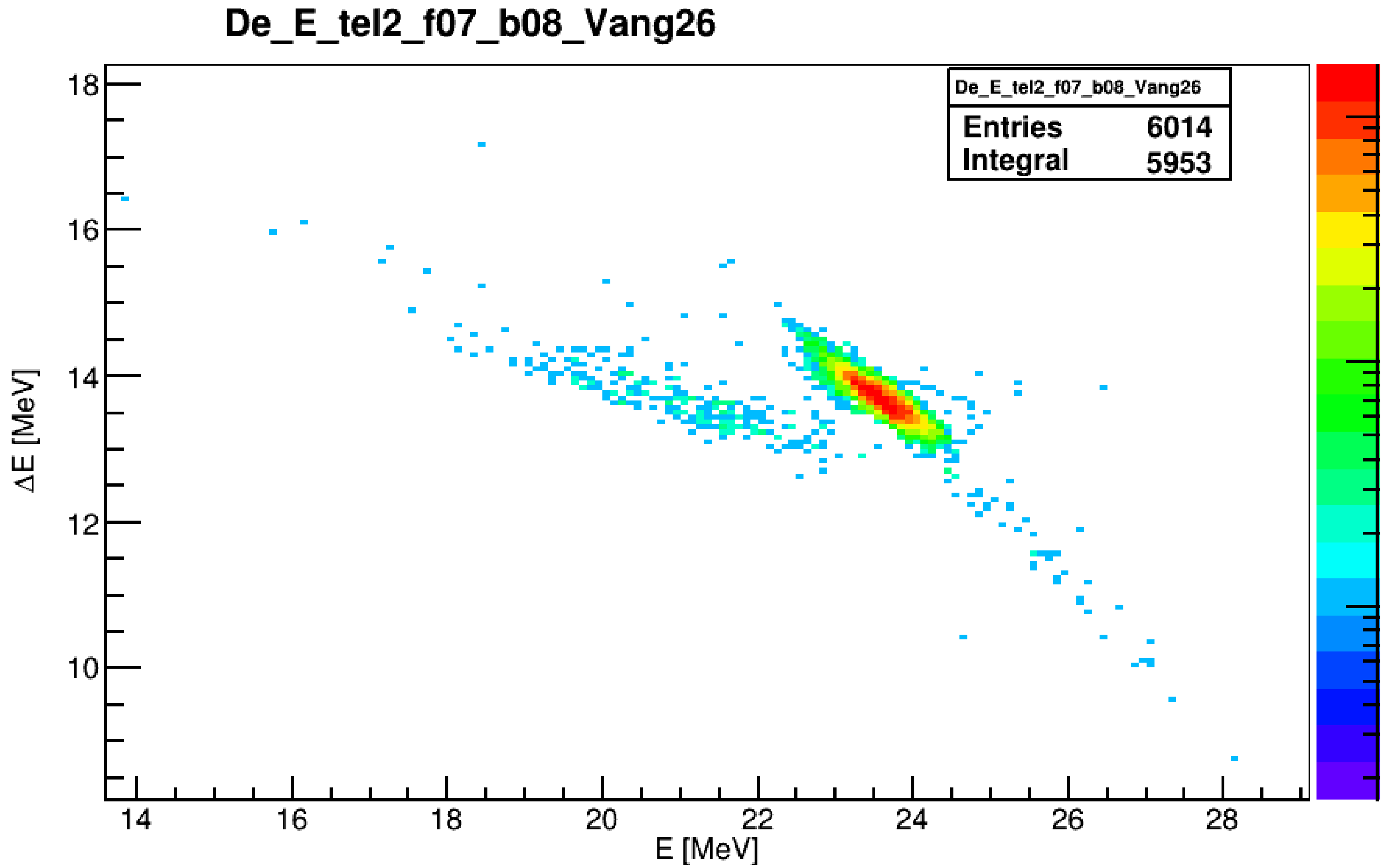
- 12C @ 5.0 MeV/u.
- 11Be @ 3.6 MeV/u. ⟵
- 11Be @ 2.9 MeV/u. ⟵

Charged particles and gamma radiation detection

Charged particles

- ΔE vs Eback.

^{11}Be@3.6MeV/u
on ^{197}Au.
1pixel.



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Analysis conditions

-Conditions for events:

P hits >0 && N hits && Pad hits > 0

if (threshold < Channel && channel < pulsed channel){

Calibrate the hit with higher energy

if |Ep-En| < 200 keV

// For identifying the physical process we are more interested in bunching the events in bananas, better than knowing their actual energy deposition.

$\Delta E = \Delta E \cos\theta$

$Epad = E\ pad + (1- \cos\theta)\ \Delta E$

Conditions for gammas coincidences:

EnerSum > threshold && EnSupressor < threshold

If EnerSum >282 keV && 310 keV < Edoppler < 337 keV

Charged particles and gamma radiation detection

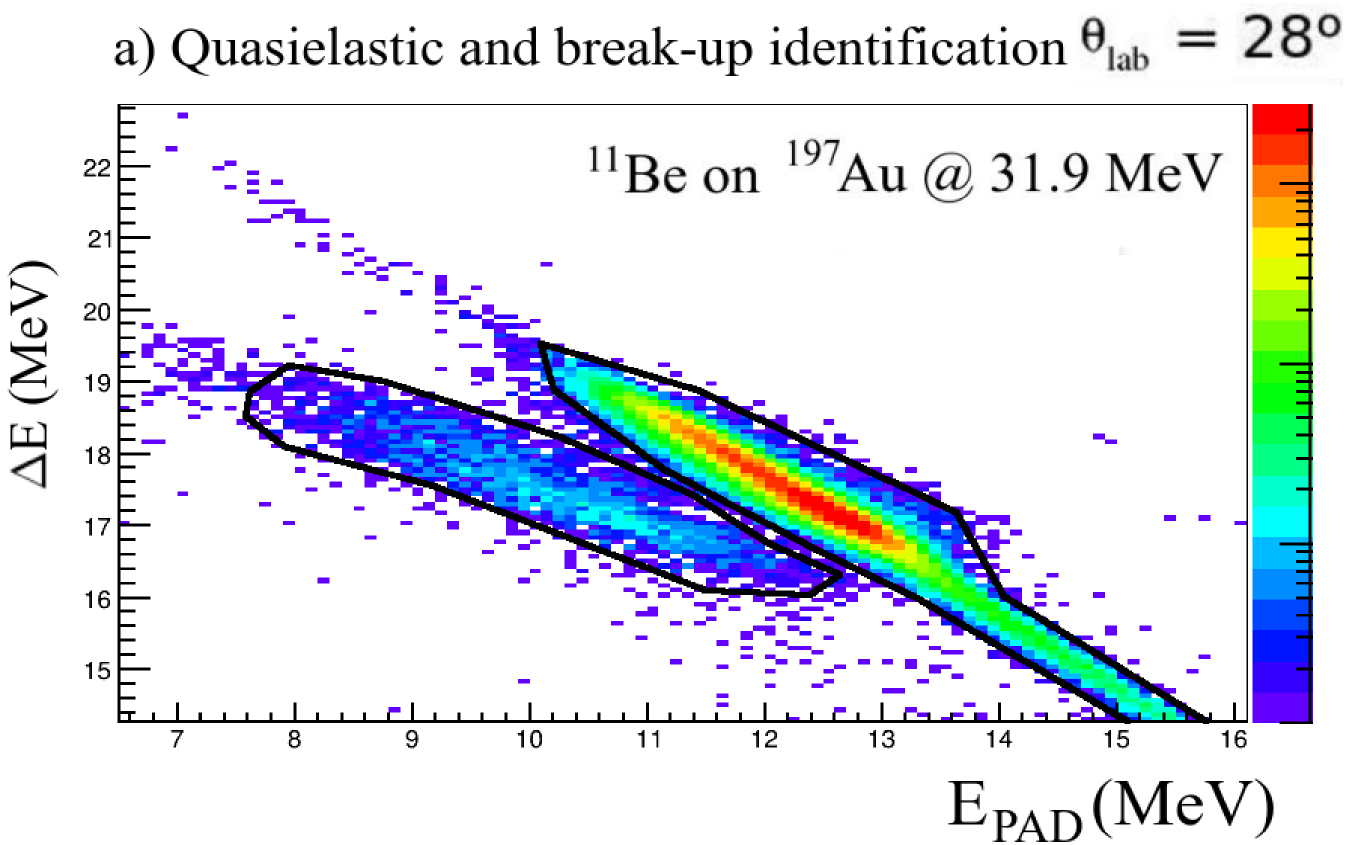
Charged particles

- ΔE vs Eback.

^{11}Be@3.6MeV/u on ^{197}Au.

Bin containing every pixel with centroid between 27 y 30º

$$Pbu = \frac{Nbu}{Nbu + Nel}$$



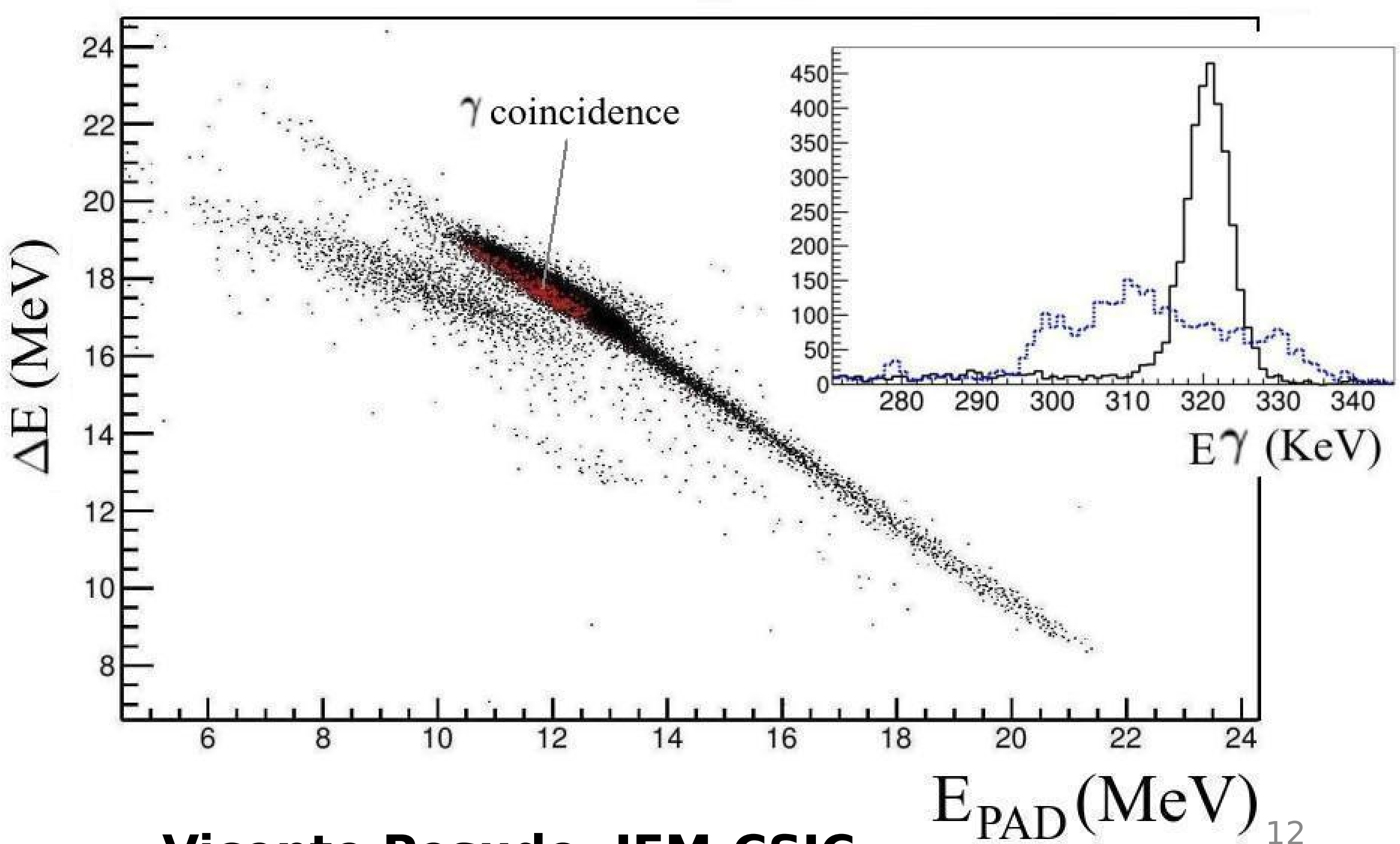
Charged particles and gamma radiation detection

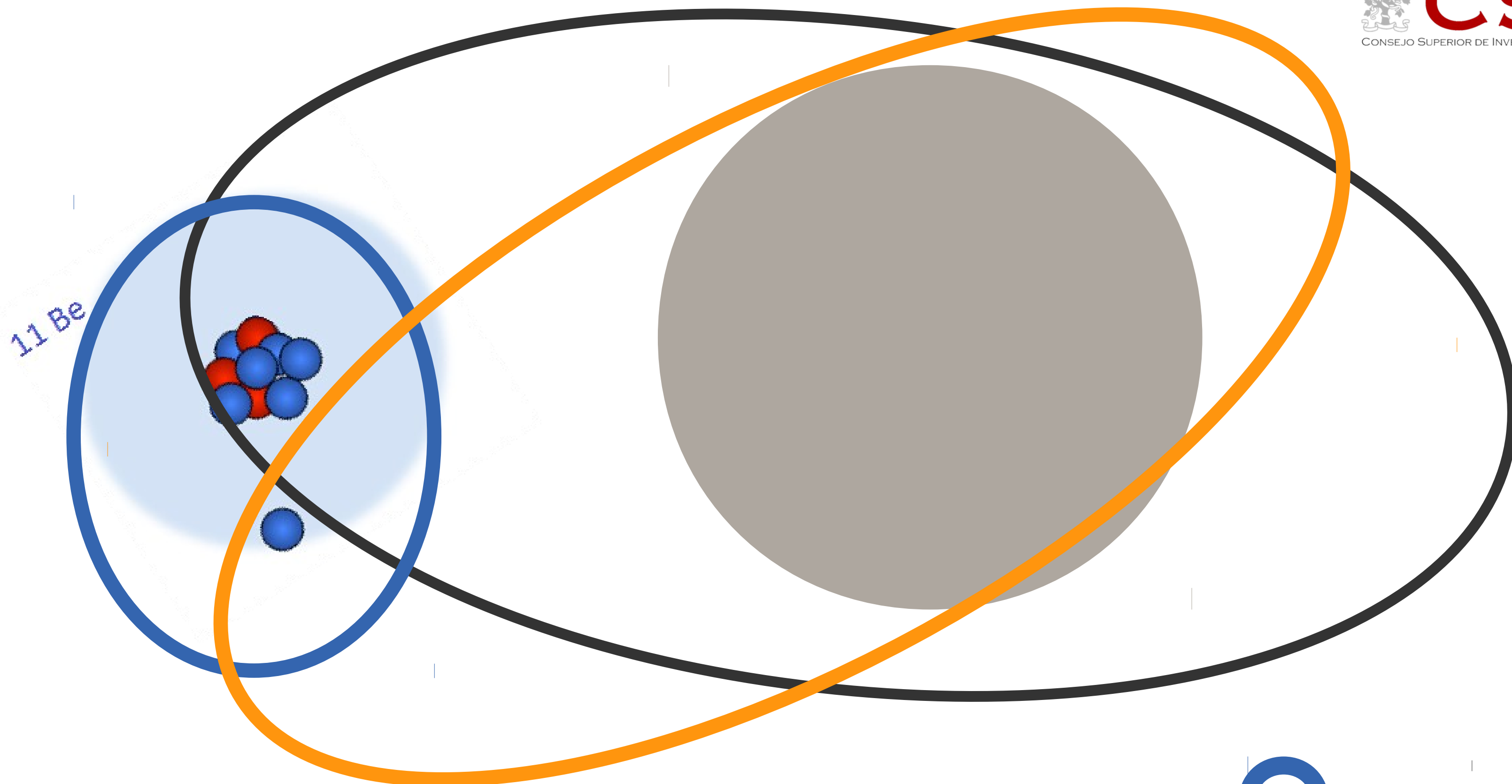
Charged particles + TIGRESS

- Gamma rays in coincidence with particles.

^{11}Be@2.9MeV/u
on ^{197}Au.
1pixel.

b) Inelastic scattering at $\theta_{lab} = 28°$





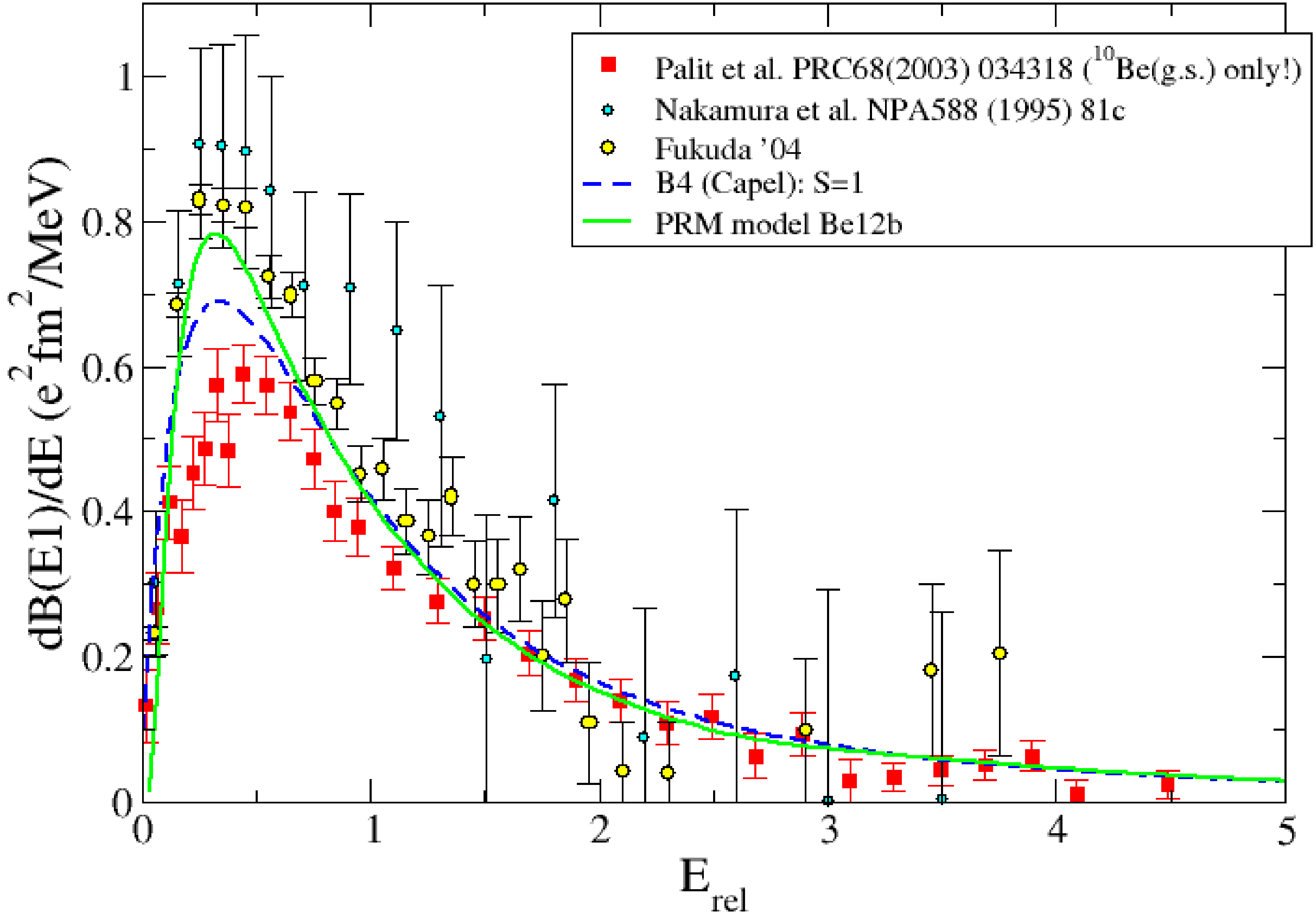
^{10}Be-n: P. Capel *et al.*, *Phys. Rev.* **C70**, 064605 (2004).

^{10}Be- "^{197}Au": J.J. Kolata *et al.*, *Phys. Rev.* **C69**, 047601 (2007).

^{197}Au-n: A.J. Koning, J.P. Delaroche, *Nucl. Phys.* **A713**, 231 (2003).

^{11}Be

Courtesy of A. Moro. U. Sevilla.



d 5/2

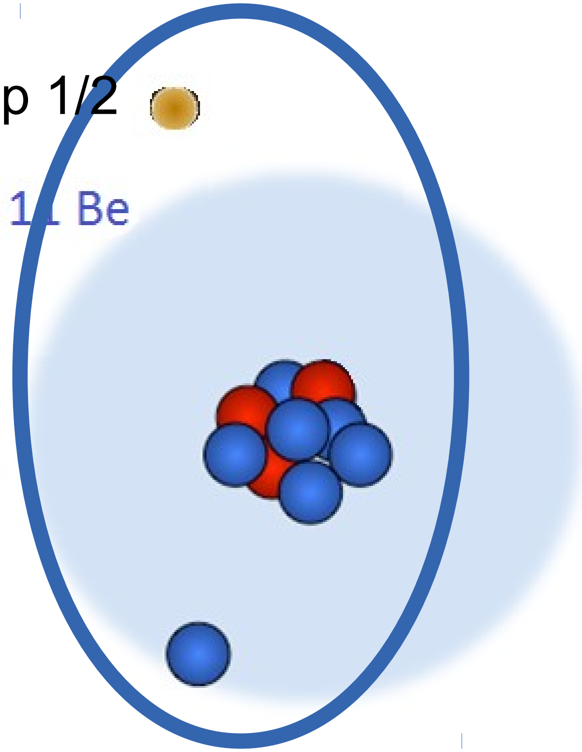
d 3/2

p 3/2

p 1/2

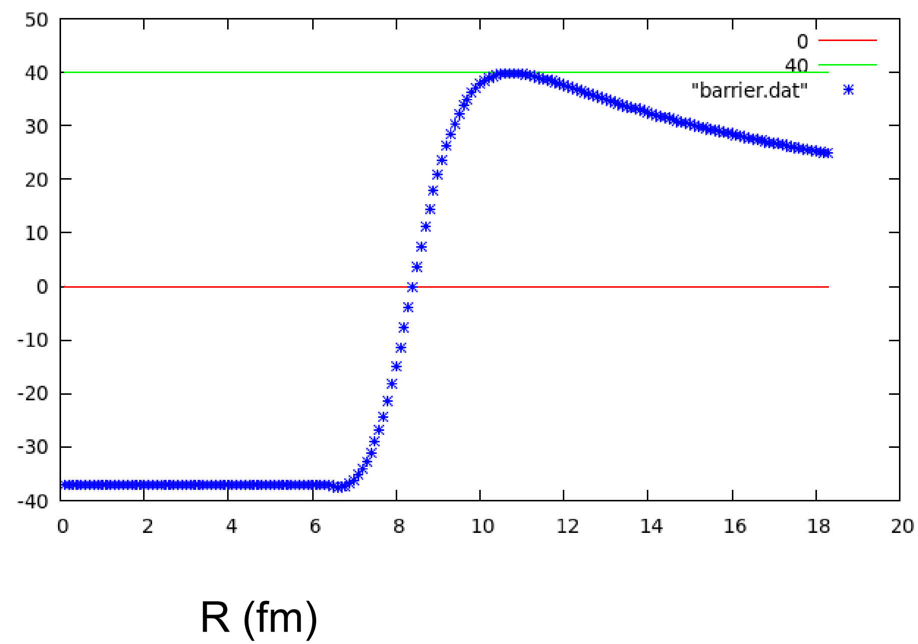
s 1/2

p 1/2

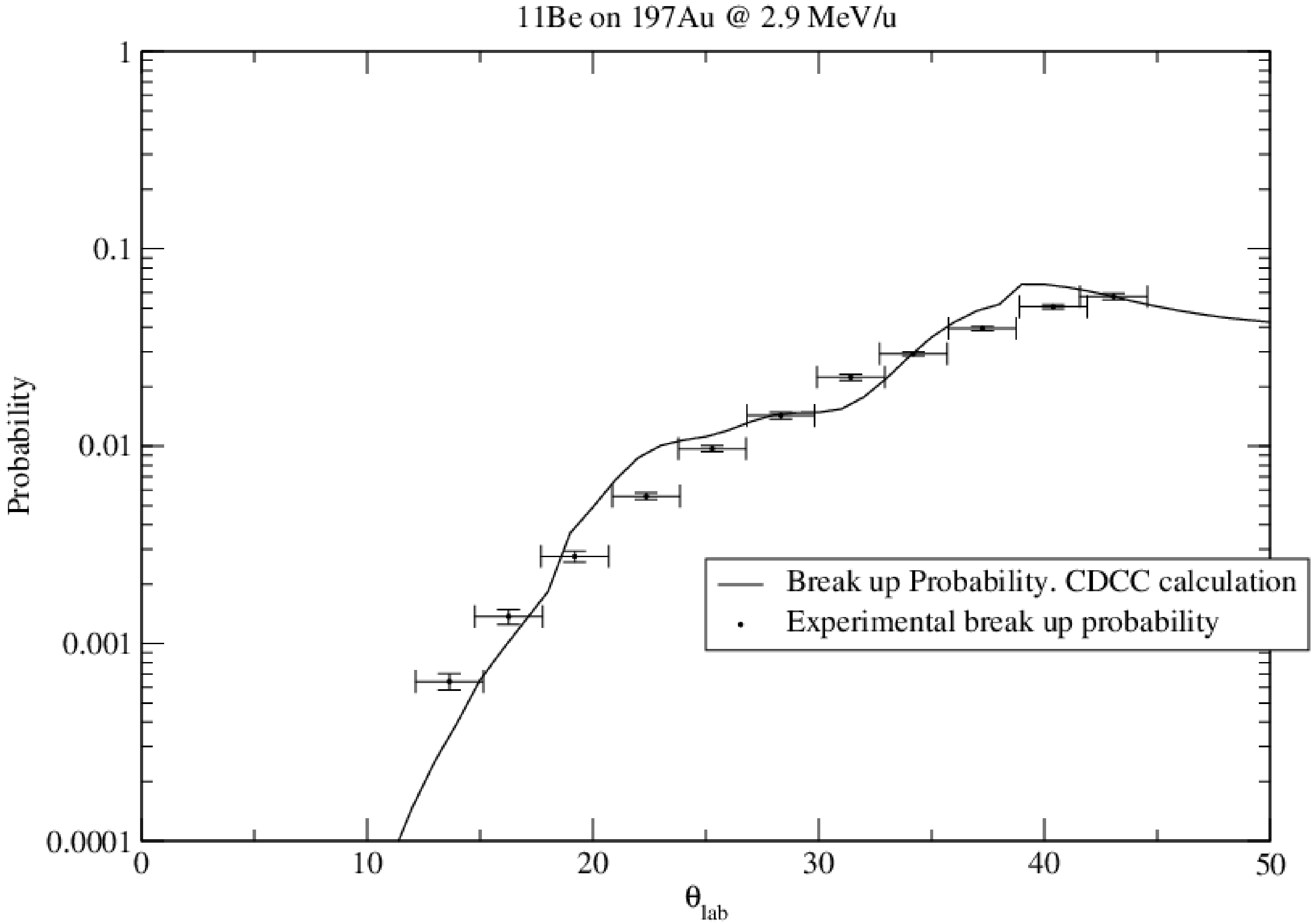


Erel < 5 MeV

Vb ≈ 40 MeV



Break up and inelastic scattering probabilities



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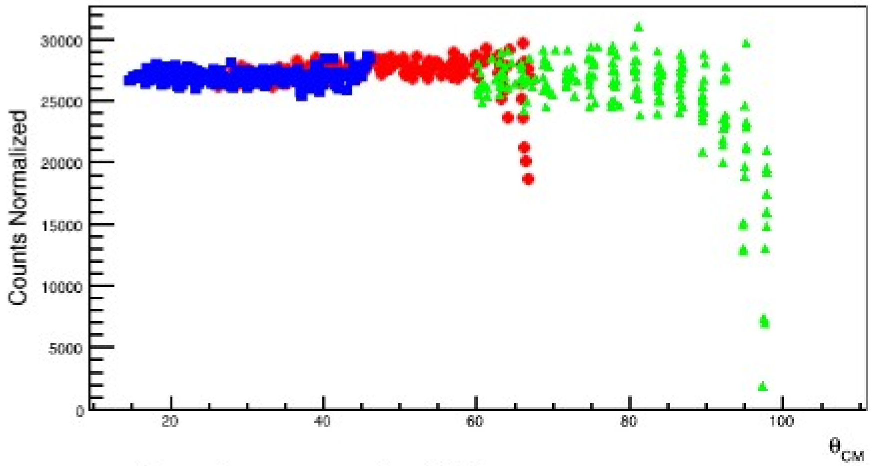
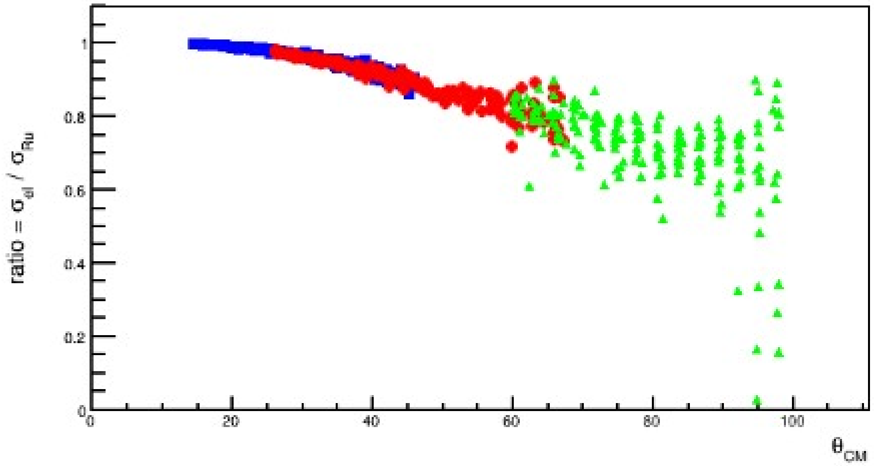
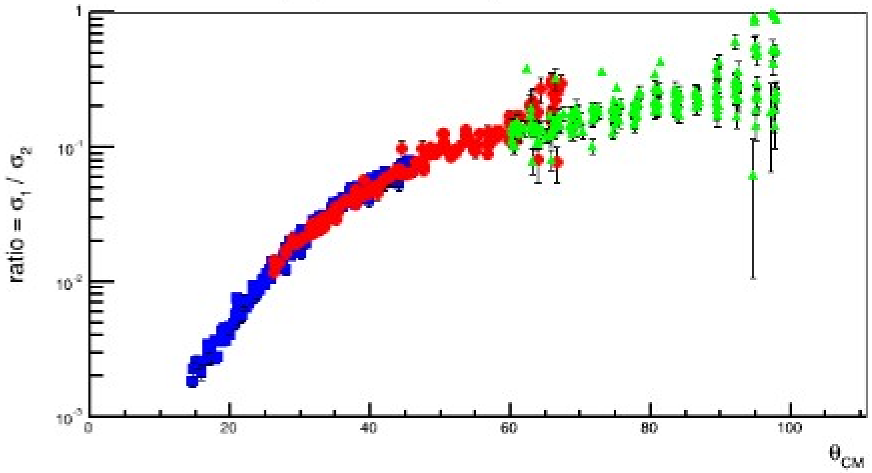
Total cross section



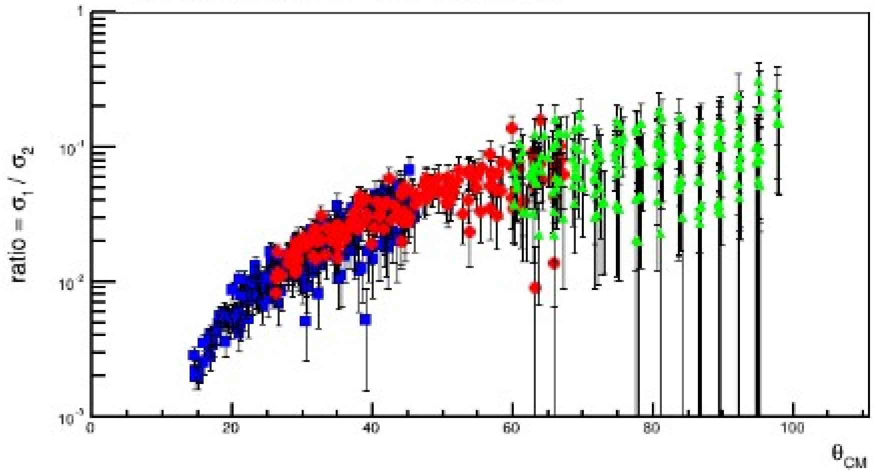
Elastic cross section



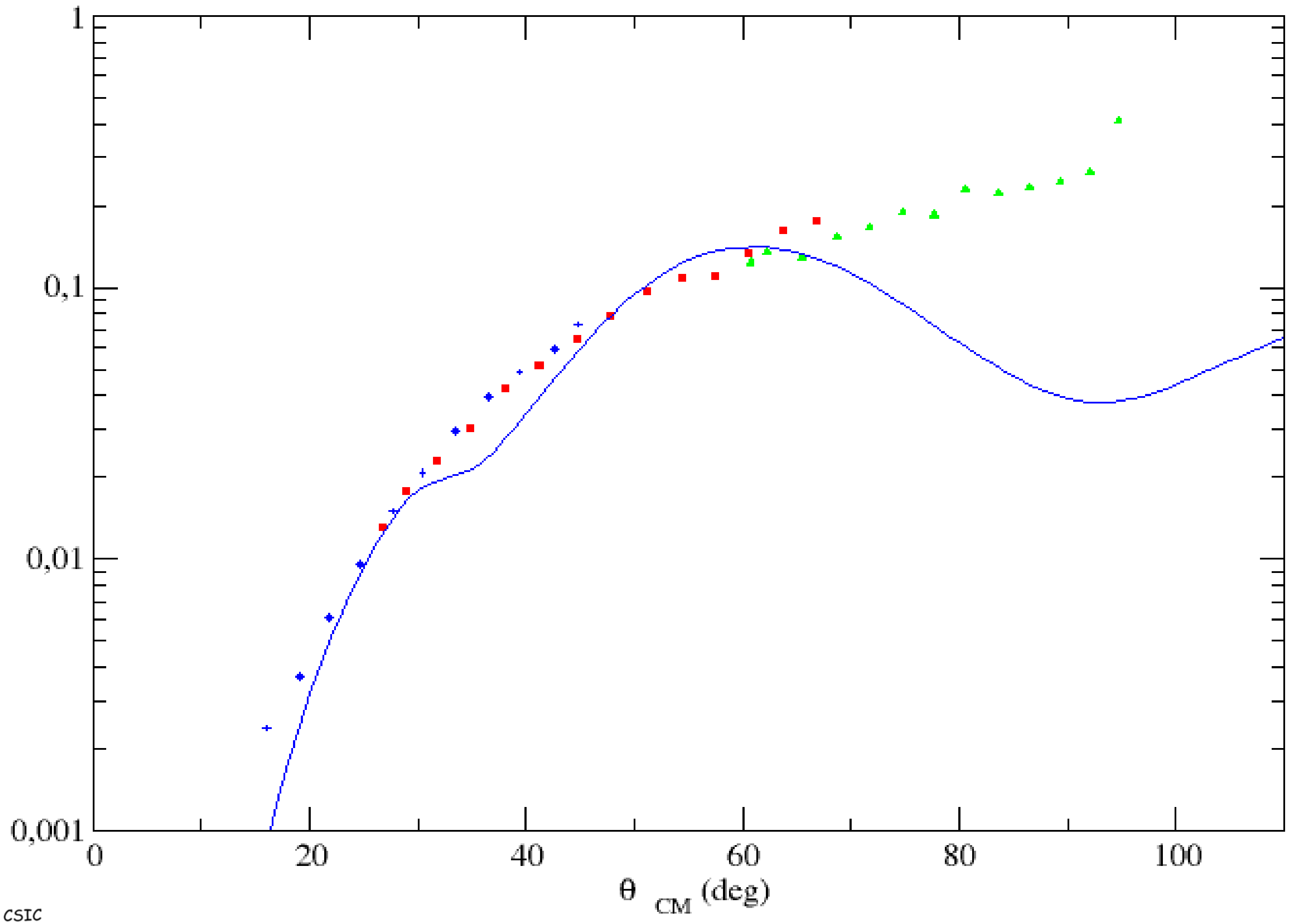
Break up probability

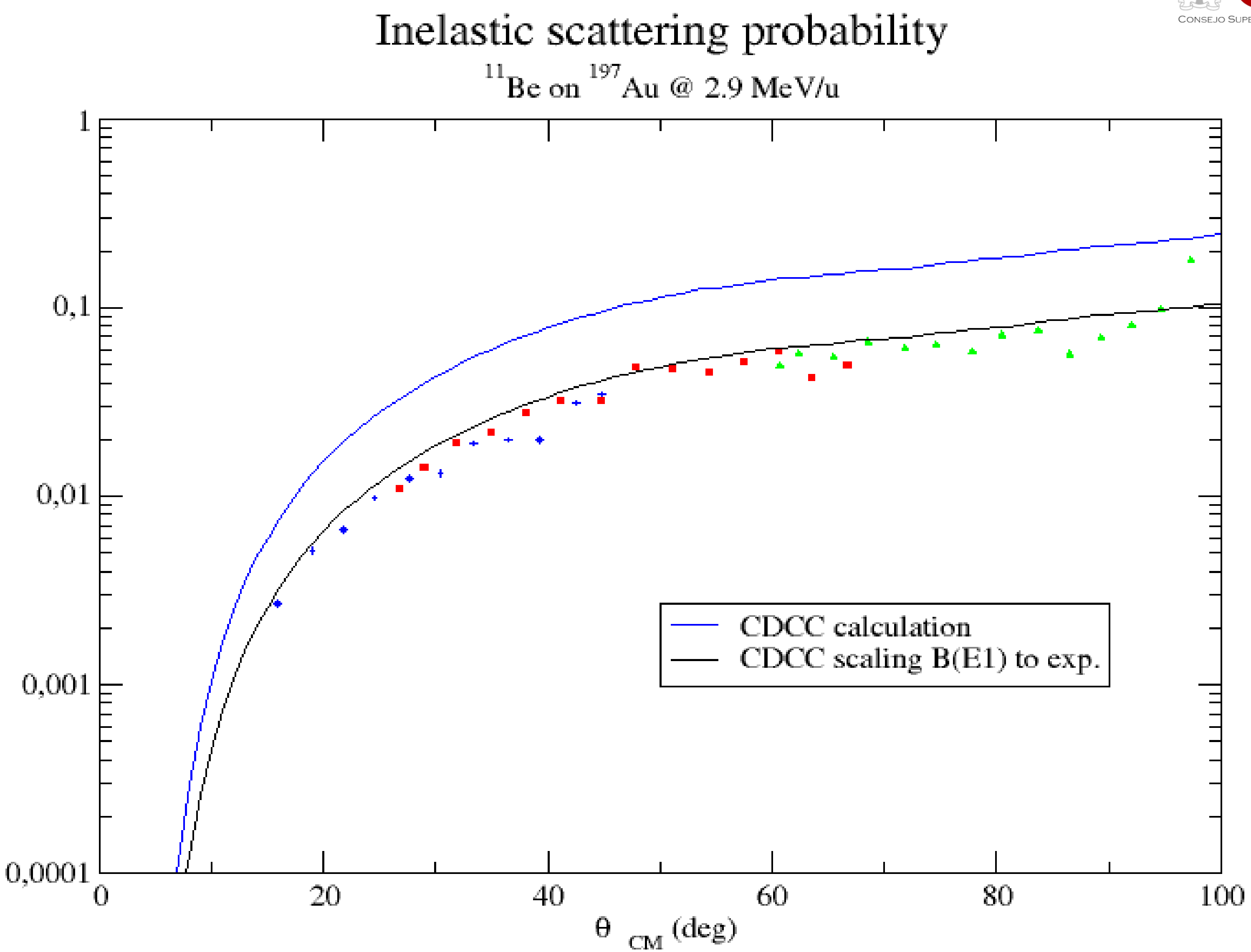


inelastic sc. probability



Break Up ^{11}Be on ^{197}Au @ 2.9 MeV/u





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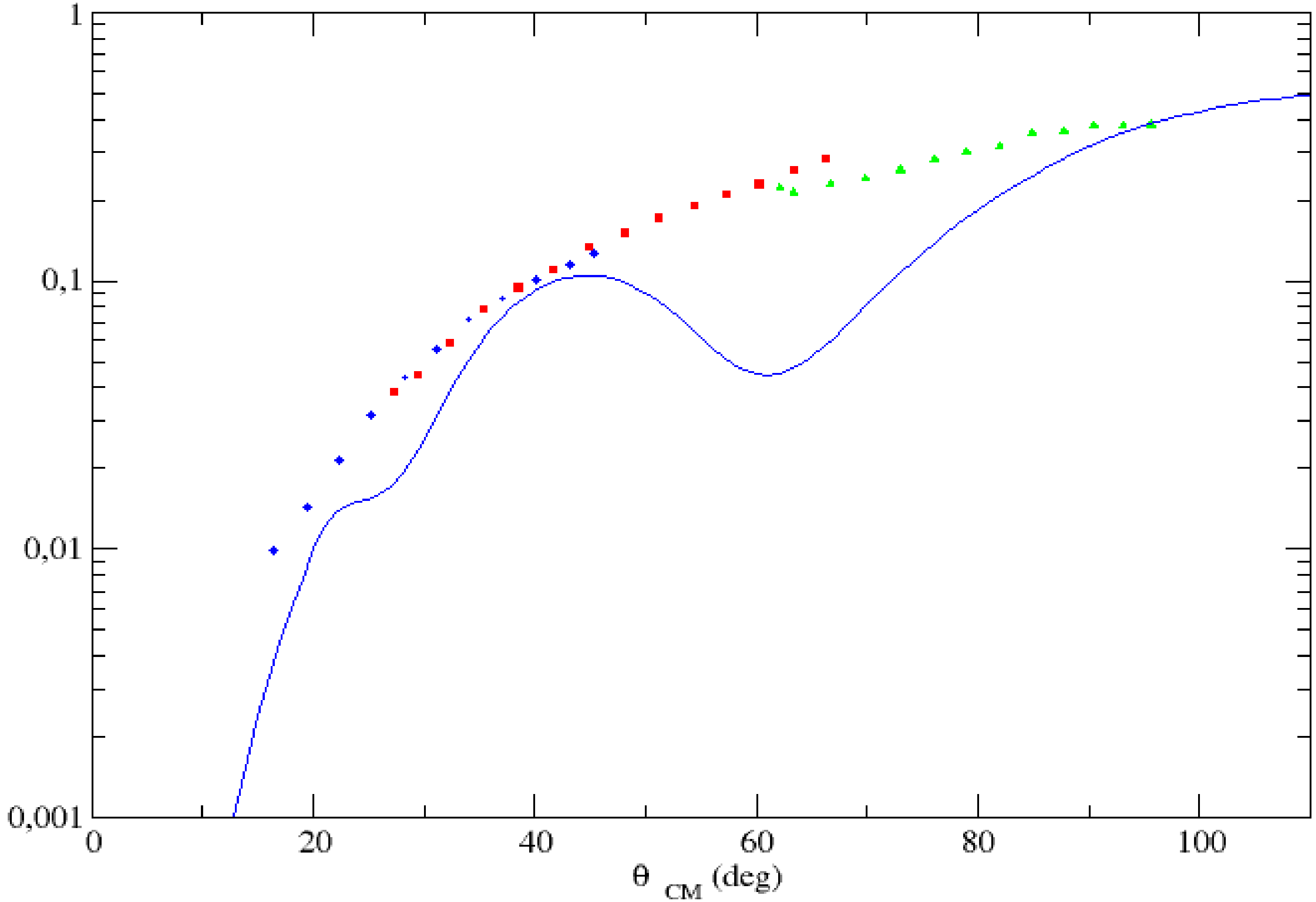
Break up ^{11}Be on ^{197}Au @ 3.6 MeV/u



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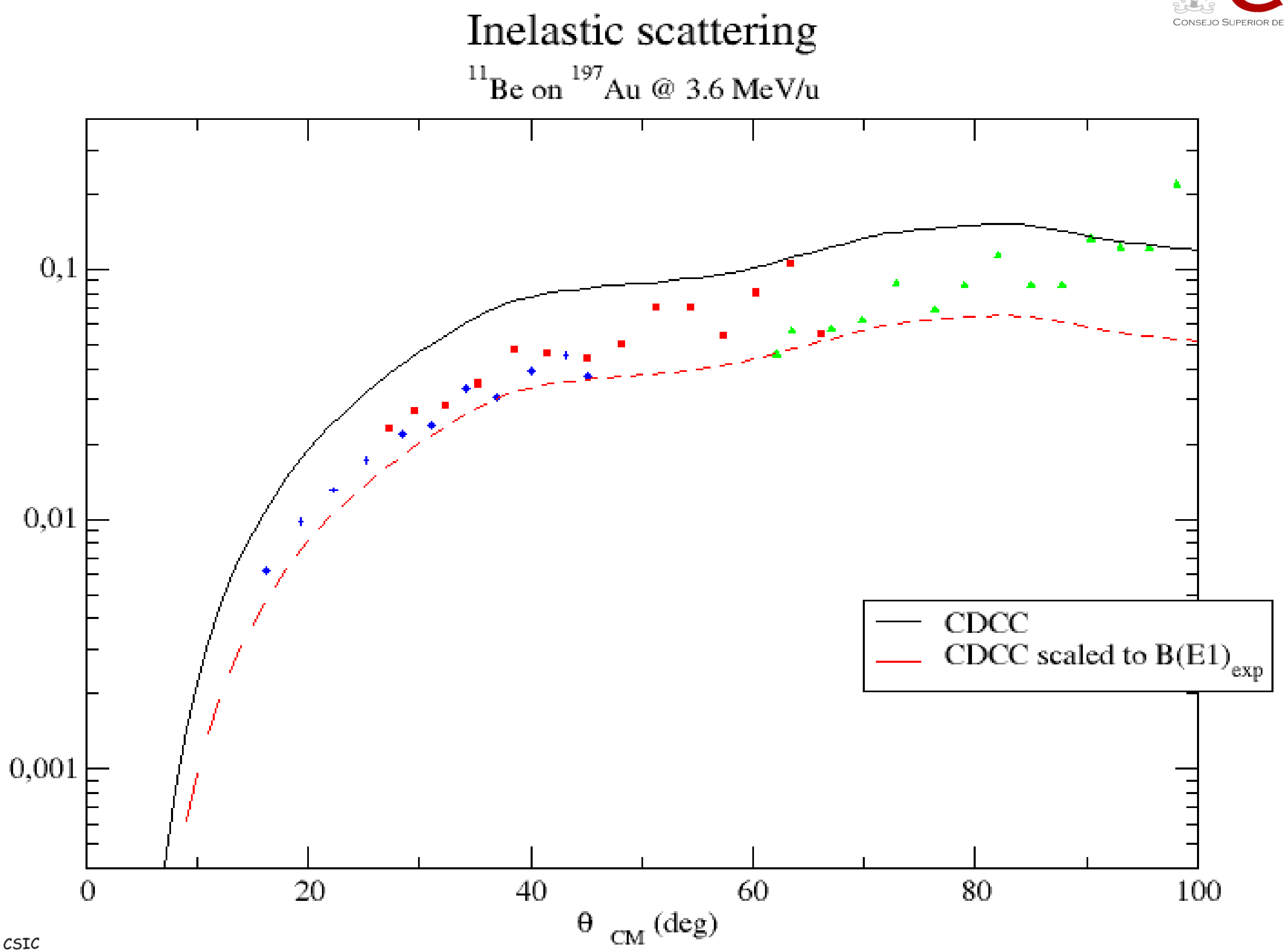

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Conclusions

-Calculations have convergence problems.

-Independent particle model predicts well the B(E1) to the continuum but overestimates B(E1) to the bound excited state ($0.26 e^2 fm^2$, factor of 2 over exp.).

Expected overestimation of P_{inel}.

-May be caused by a not-so-inert core.
Necessity including core excitations in the calculations.

$$|11Be^*\rangle_{1/2^-} = a\,|10Be(0+) \otimes p1/2\rangle_{1/2^-} + b\,|10Be(2+) \otimes \ldots + \ldots$$

$$|11Be\rangle_{1/2^+} = a'\,|10Be(0+) \otimes 2s1/2\rangle_{1/2^+} + b'\,|10Be(2+) \otimes 1d\,5/2\rangle_{1/2^+}$$

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Conclusions and outlook

-An experiment of 11Be on heavy targets at energies around the Coulomb barrier observing BU and inelastic scattering has been undertaken for first time:

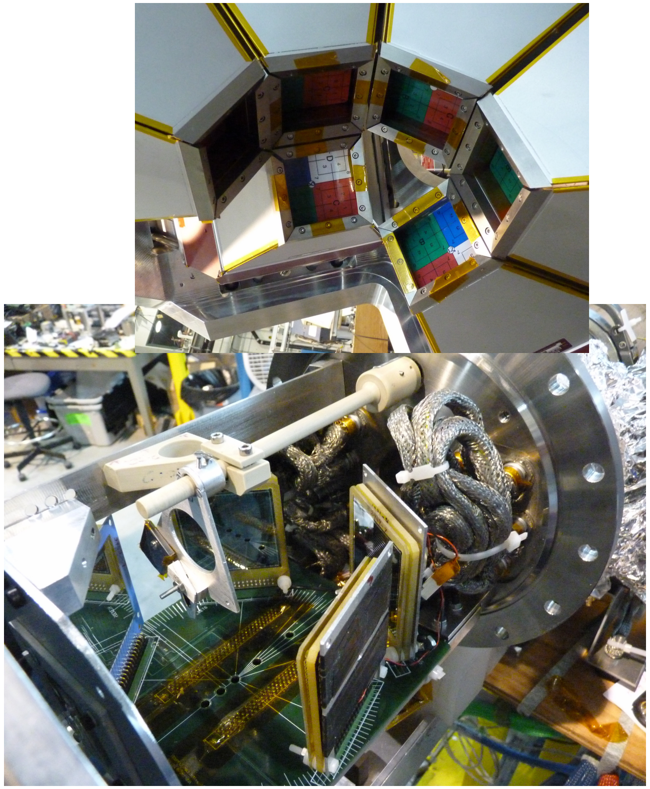
- -with high granularity.
- -at angles as low as 14º.

-Enough resolution for separation of break up and elastic events below the barrier: **Halo.**

- -Even with a mass difference between fragments of 1/11.

- Break up probability matches with CDCC calculations in the range they are reliable.

- Work on progress:
  - Exp: Fine positioning, add tel 4.
  - Th: Focusing the reaction from a n-transfer approach



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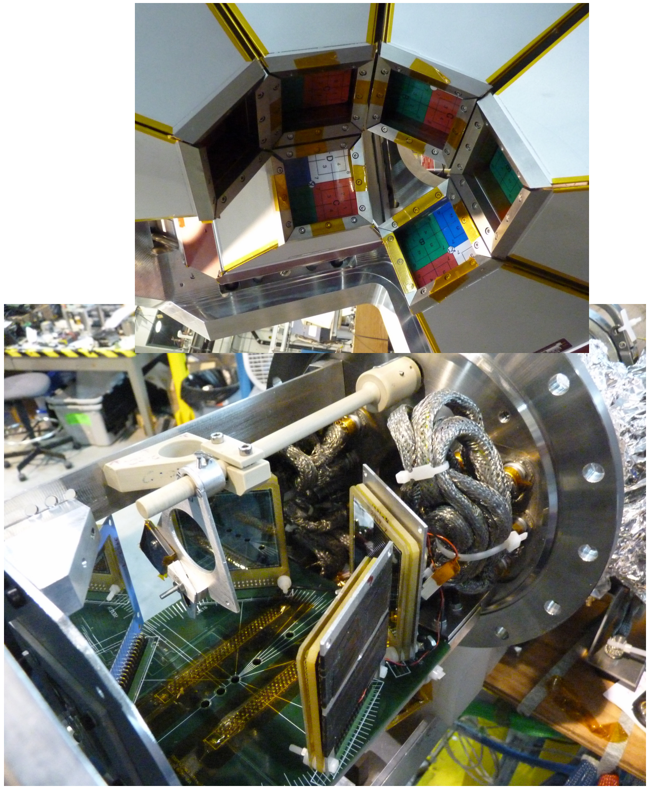
tak for din opmærksomhed
tack för din uppmärksamhet



Gracias por vuestra atención

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Probabilidad reducida de ruptura: Caso de ^{11}Li

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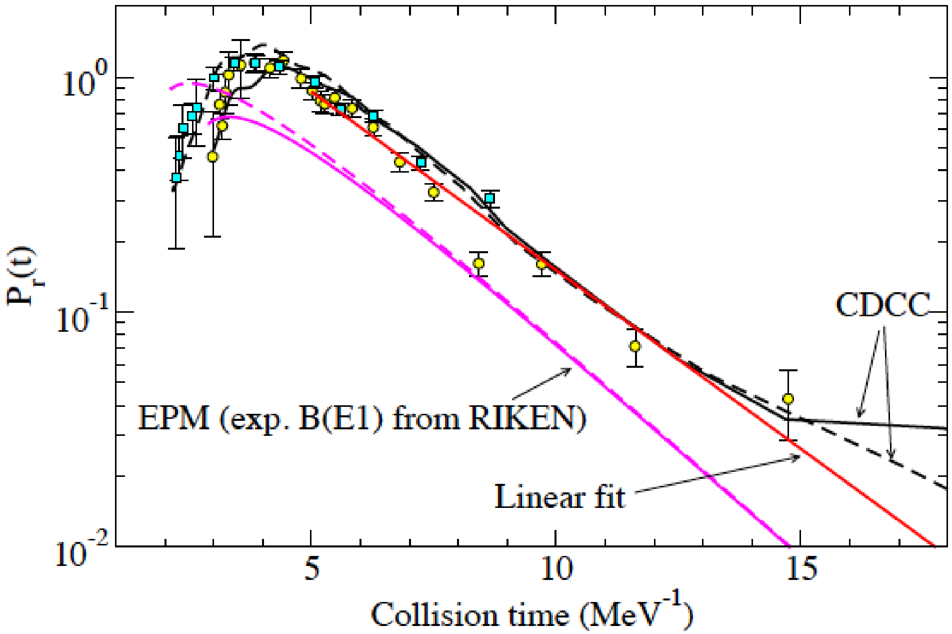
$$B(t) \equiv \frac{P_{\rm bu}(t)}{\frac{16\pi^2}{9}\frac{(Ze)^2}{(\hbar v)^4\left(t-\frac{\pi a_0}{\hbar v}\right)}} = \int d\varepsilon \frac{dB(E1;\varepsilon)}{d\varepsilon}\varepsilon e^{-t\varepsilon}$$



J.P. Fernandez-Garcia et el., Phys.Rev.Lett. 110, 142701 (2013)
Nakamura et al., PRL96 252502 (2006)

- Para las reacciones dominadas por Coulomb, la Pr. red de ruptura es la transformada de Laplace de la B(E1).

- Haciendo el cambio de variable se concentra la dependencia en energía, ángulo y blanco en un solo parámetro:

- **El tiempo de colisión.** **Scaling!**

$$t = \left(\pi + \frac{2}{\sin(\theta/2)}\right)\frac{a_0}{\hbar v}$$

- En la región donde la aproximación coulombiana es buena (ángulos pequeños o tiempos de colisión grandes) la derivada logaritmica de la Pr. Red. es la energía efectiva de ruptura

0.35 MeV for ^{11}Li.

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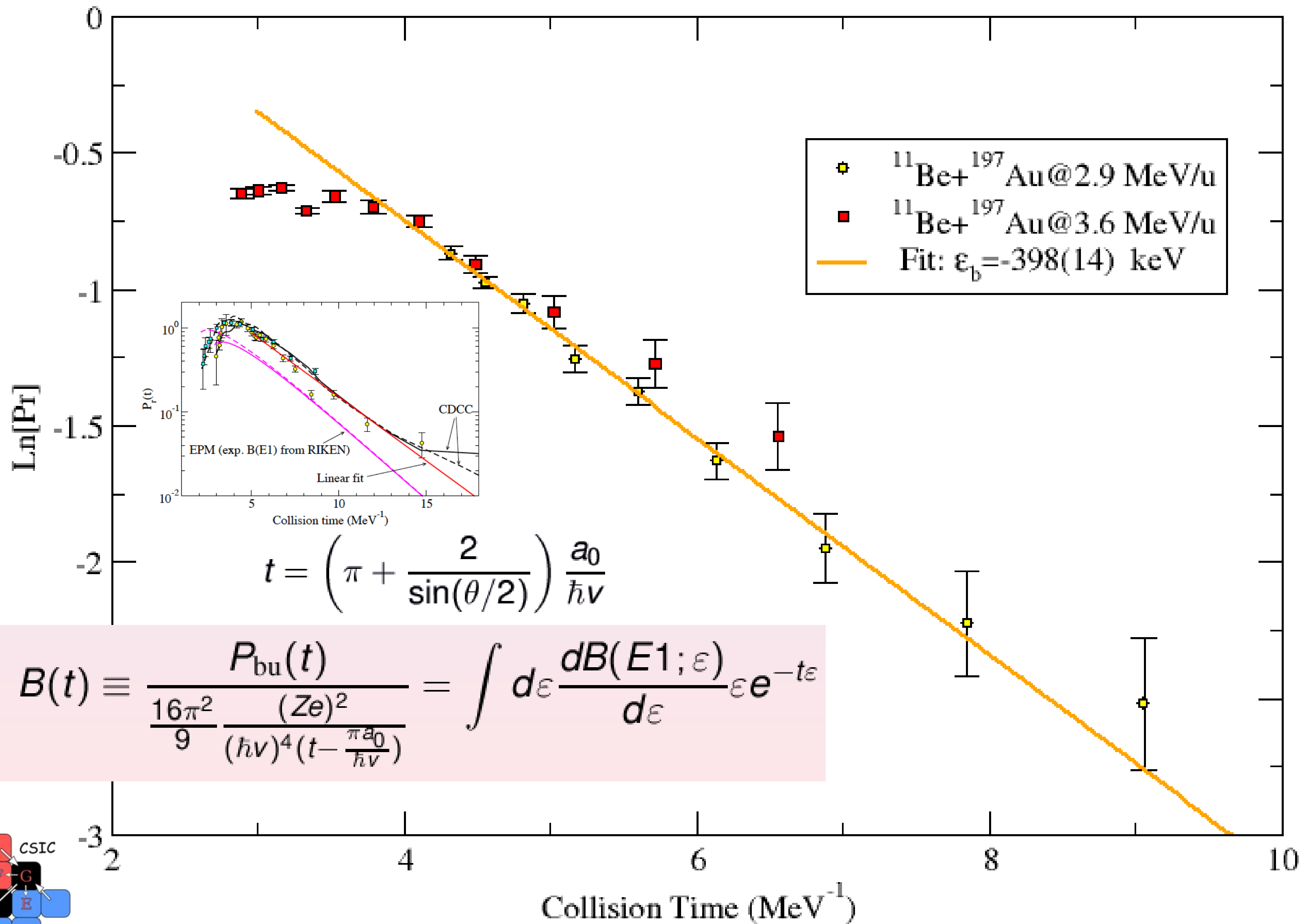
Prob. Reducida de ruptura



$$t = \left(\pi + \frac{2}{\sin(\theta/2)}\right)\frac{a_0}{\hbar v}$$

$$B(t) \equiv \frac{P_{\rm bu}(t)}{\frac{16\pi^2}{9}\frac{(Ze)^2}{(\hbar v)^4 (t - \frac{\pi a_0}{\hbar v})}} = \int d\varepsilon \frac{dB(E1;\varepsilon)}{d\varepsilon}\varepsilon e^{-t\varepsilon}$$