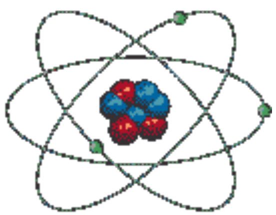
MINISTERIO
DE ECONOMÍA
Y COMPETITIVIDAD



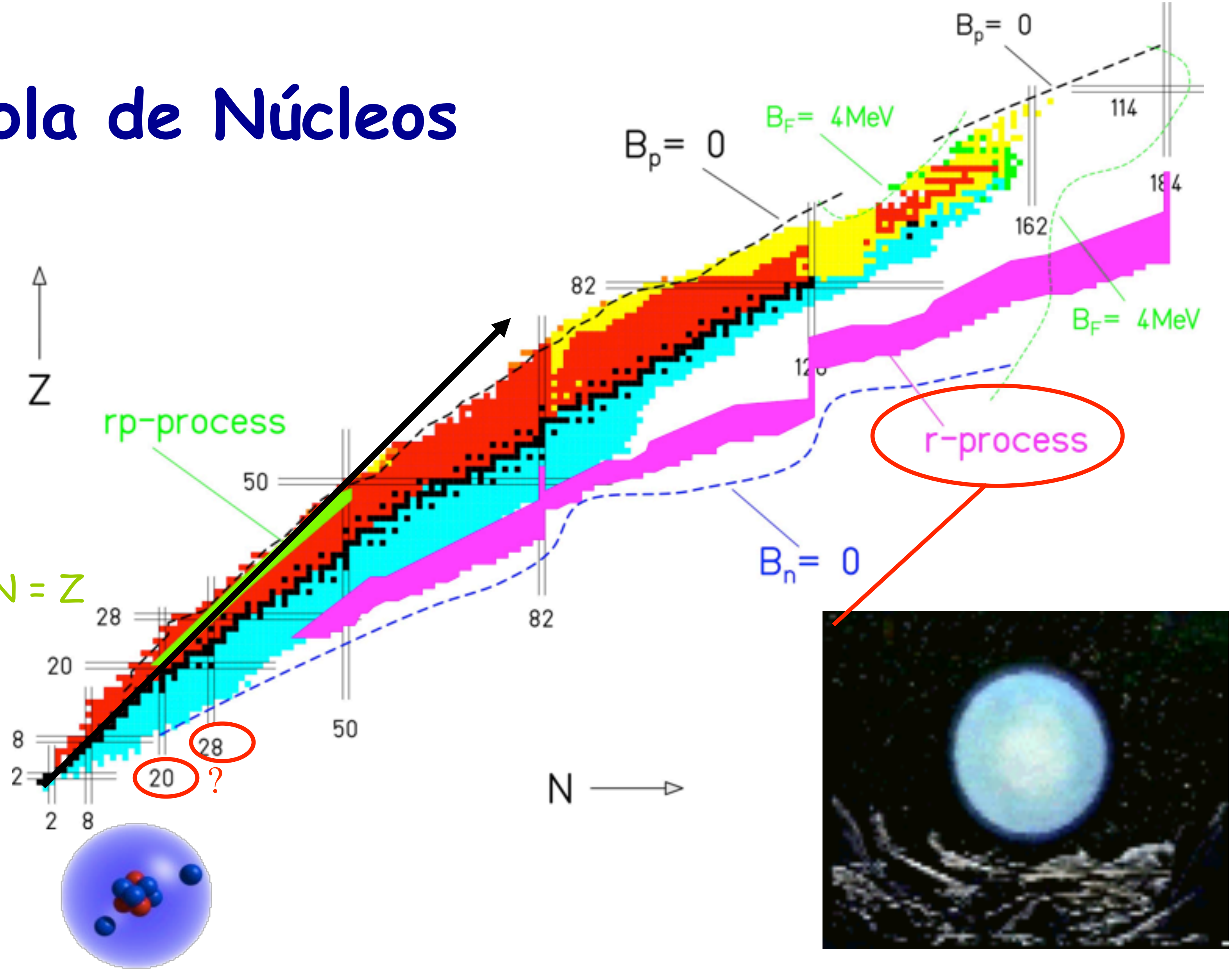
Estudios de Núcleos Exóticos
Detectando partículas cargadas

En esta charla vamos a hablar sobre estudios de Núcleos muy Exóticos;

- Que queremos estudiar, y como podemos hacerlo
- centrarnos en el I+D en detectores y electrónica necesario para poder estudiar sistemas nucleares todavía más exóticas.

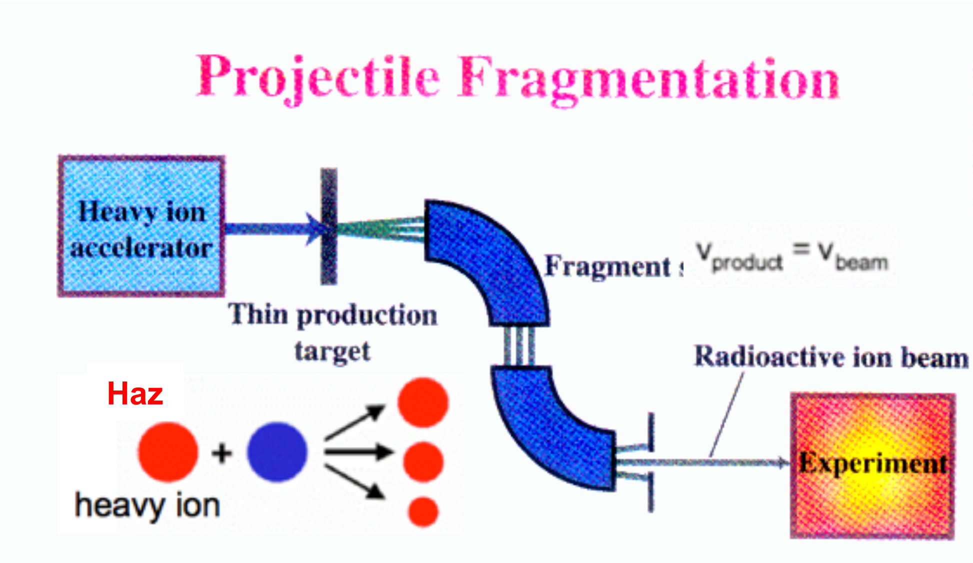
Olof Tengblad
Instituto de Estructura de la Materia - CSIC

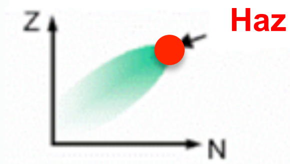
Tabla de Núcleos



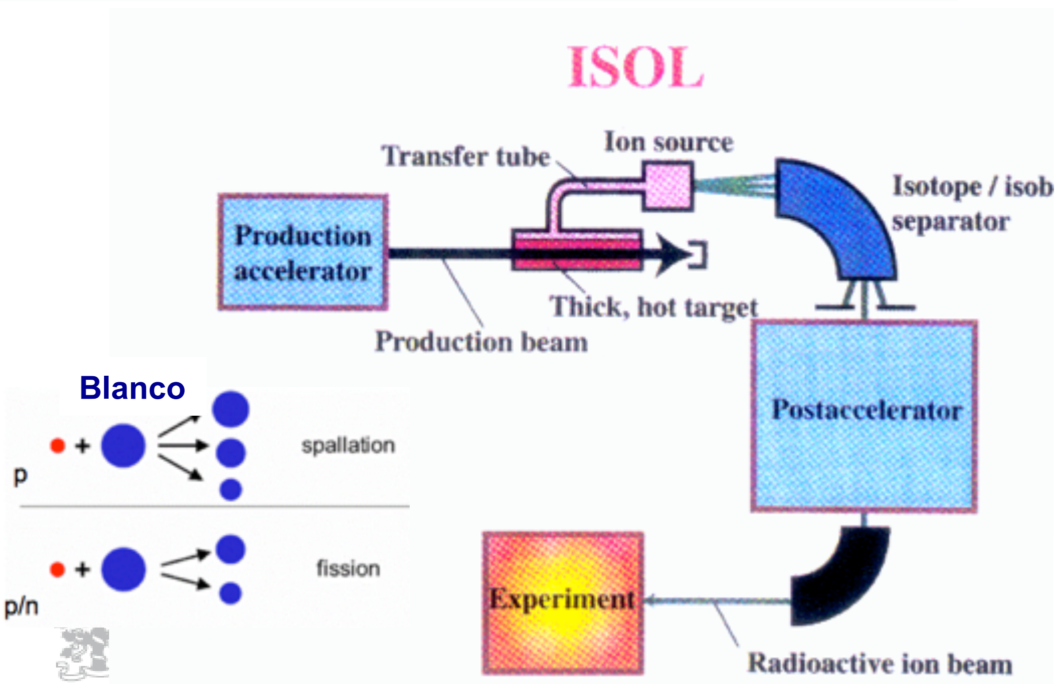
CSIC
Consejo Superior de Investigaciones Científicas

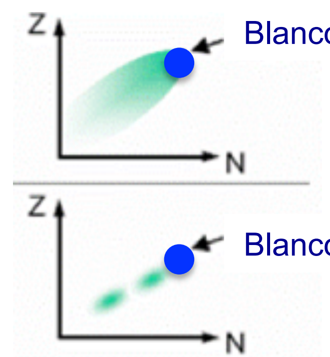
Producción de Haces Radioactivas

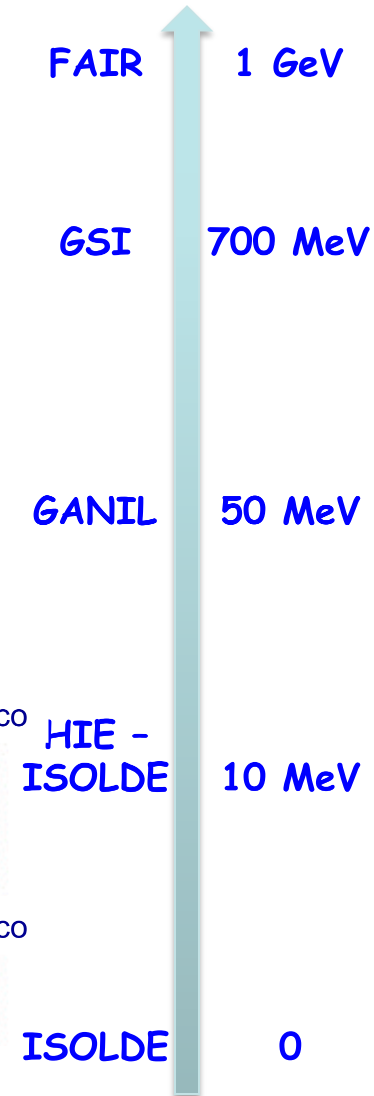




High energy, large variety of species,
Short half-lives (μs),
cocktail beam



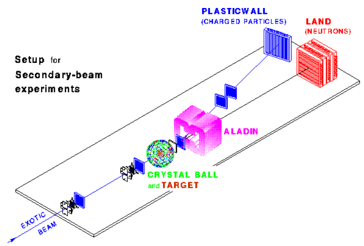




Variable energy, high intensity, good beam qualities

Para conseguir la información completa necesitamos estudiar el núcleo en reacciones a energías distintas y con métodos complementarios

GSI
Reacciones a E_r=700 MeV/u

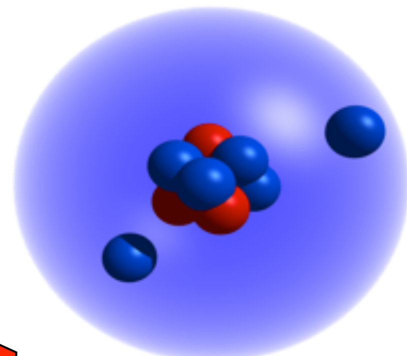


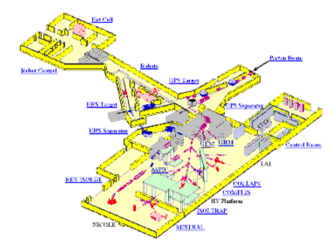
Elastic Scattering

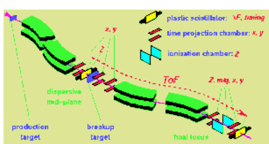
Spins Moments

ISOLDE
Desintegración beta E_r=0

Reaction Cross Sections







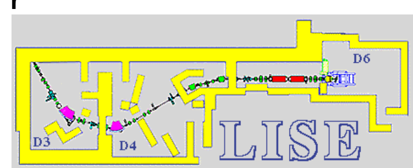
Masses

Momentum Distributions

Beta Decay

Unbound Nuclei

GANIL
Reacciones a E_r=30-60 MeV/u

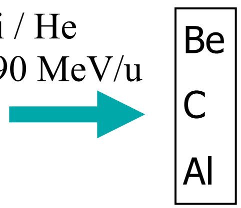


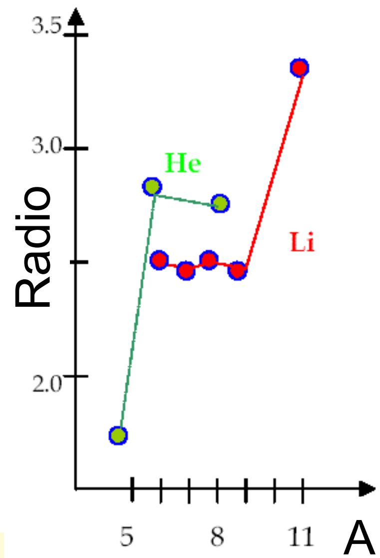
Un ejemplo: ^{11}Li y el halo de neutrones

Experimento inicial

Tanihata et.al.
Phys.Rev.Lett 55(1985)2676

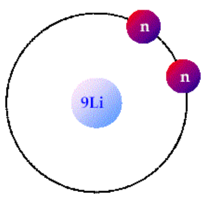
Li / He
790 MeV/u



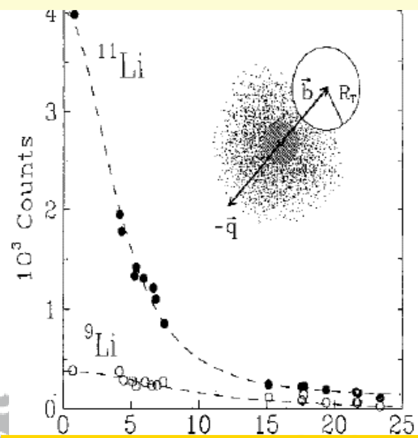


P.G. Hansen, B. Jonson
Europhys. Lett 4(1987)409

Modelo



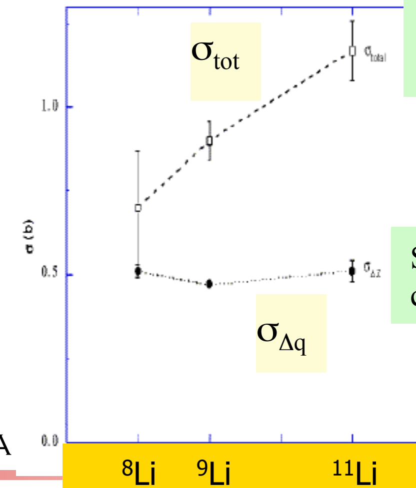
R. Anne et.al.
Phys.Lett B250(1990)19



distribución Angular del Neutron

Verificación del modelo

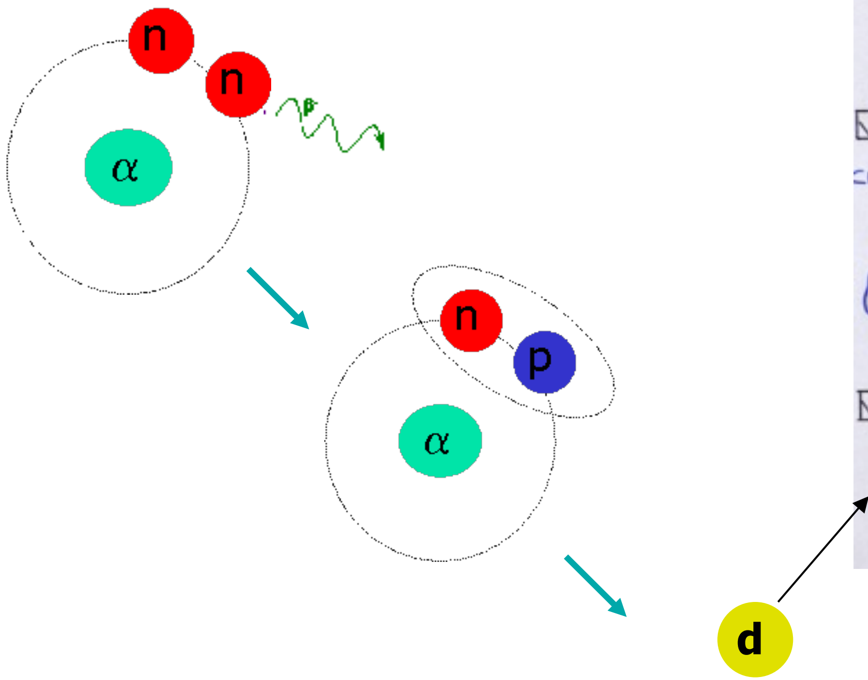
B. Blank et.al.
Z. Physik A343(1992)375

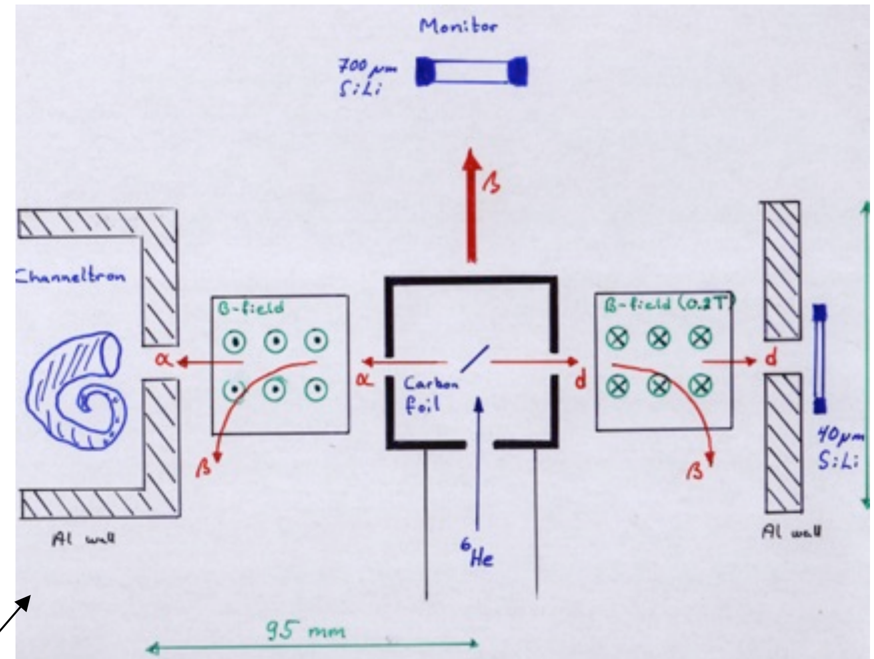


Sección eficaz total

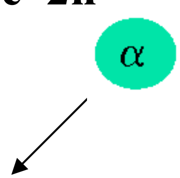
Sección eficaz de cambio de carga

También podemos estudiar este fenómeno en reposo – en desintegración beta





^{6}He: α-core con un halo de 2n



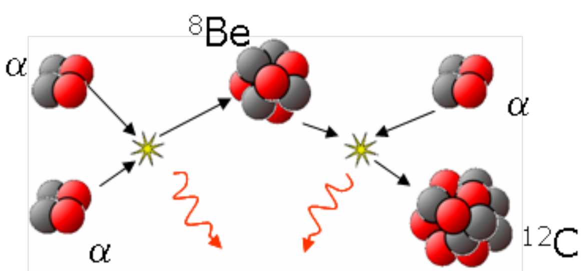
First observation of beta-delayed deuteron emission
Phys Let B235 (1990) 30

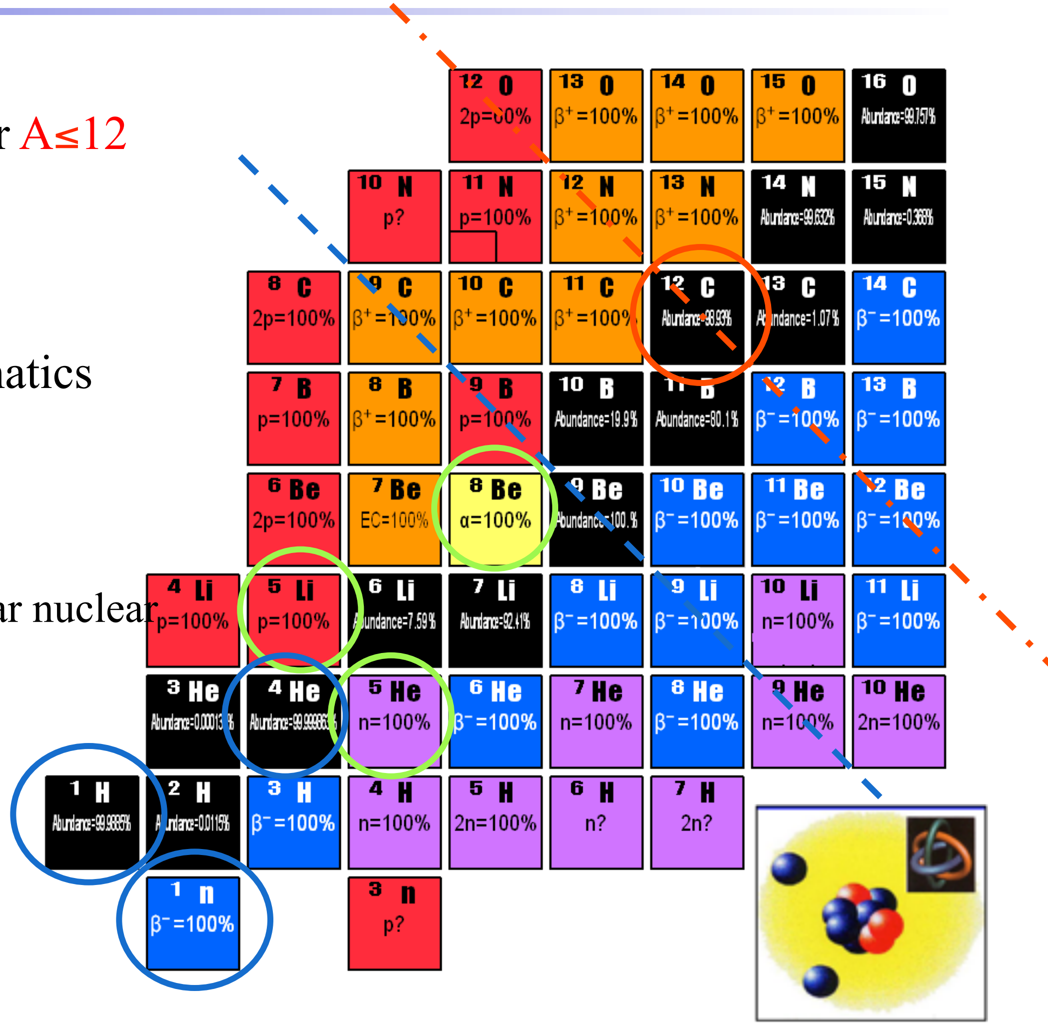
24h para 147 coincidencias → rama de desintegración 2.8 10^{-6}

Light exotic Nuclei

- “Exact” A-body calculations possible for A≤12
  - Shell-model states
  - Molecular-cluster states
- We cover from drip-line to drip-line
- Break-up mechanism not fixed by kinematics
  - Sequential?
  - Direct?
- Crucial for bridging the
  - A=5 and A=8 gaps in Big Bang and Stellar nuclear synthesis.

^{12}C & The triple alpha process
$^{4}He + {}^{4}He \leftrightarrow {}^{8}Be$
$^{8}Be + {}^{4}He \leftrightarrow {}^{12}C + \gamma + 7.367$ MeV

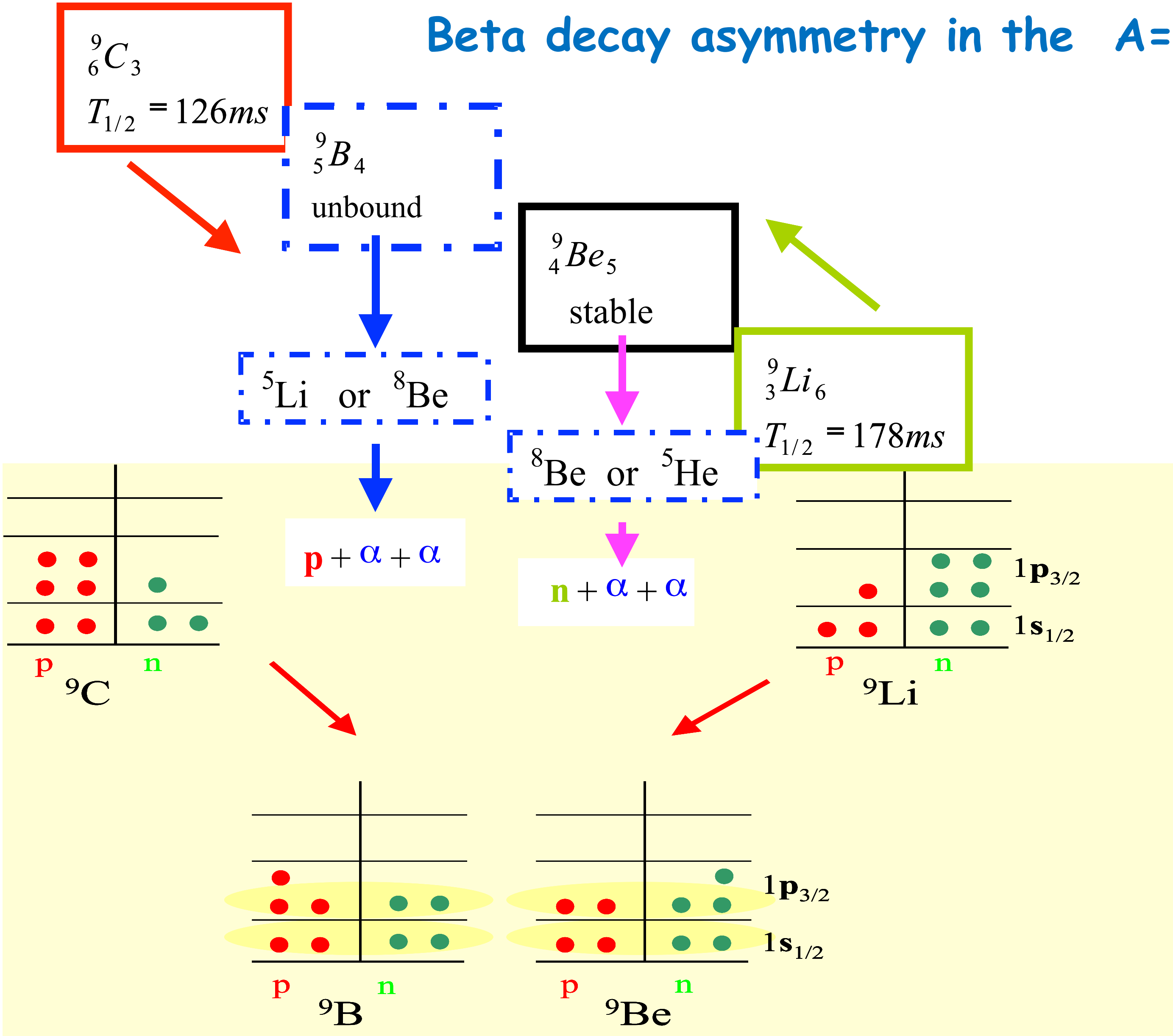




11Li → Borromean Halo

clustering

Beta decay asymmetry in the A=9 isobar



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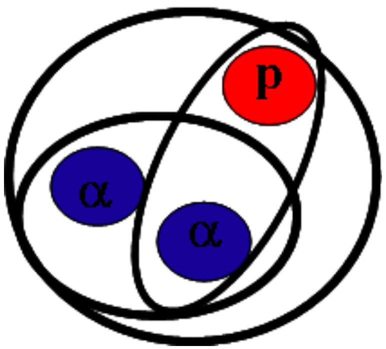
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

break-up mechanism: α-clustering?

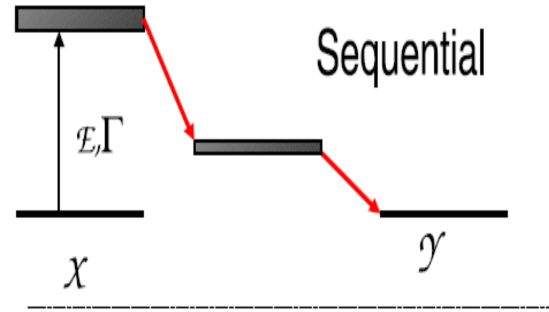
^{9}C

β^+

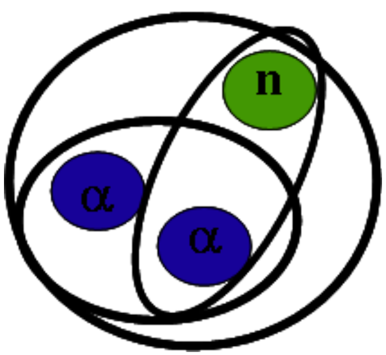


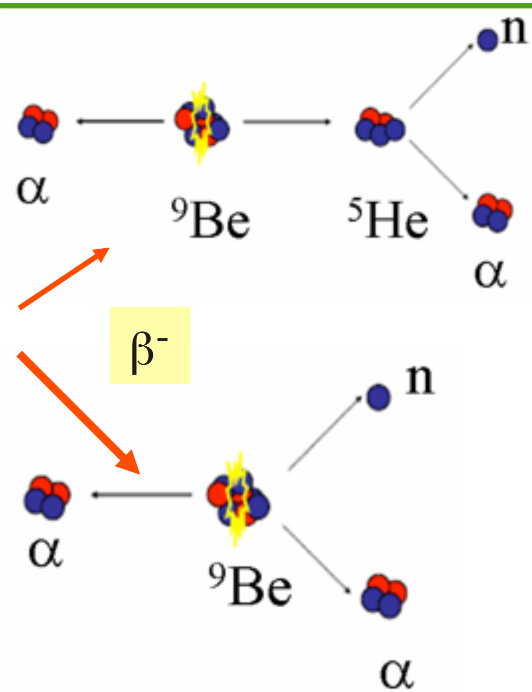
$^9B^* \rightarrow p + {}^8Be \rightarrow \alpha, \alpha$

$\rightarrow \alpha + {}^5Li \rightarrow \alpha, p$

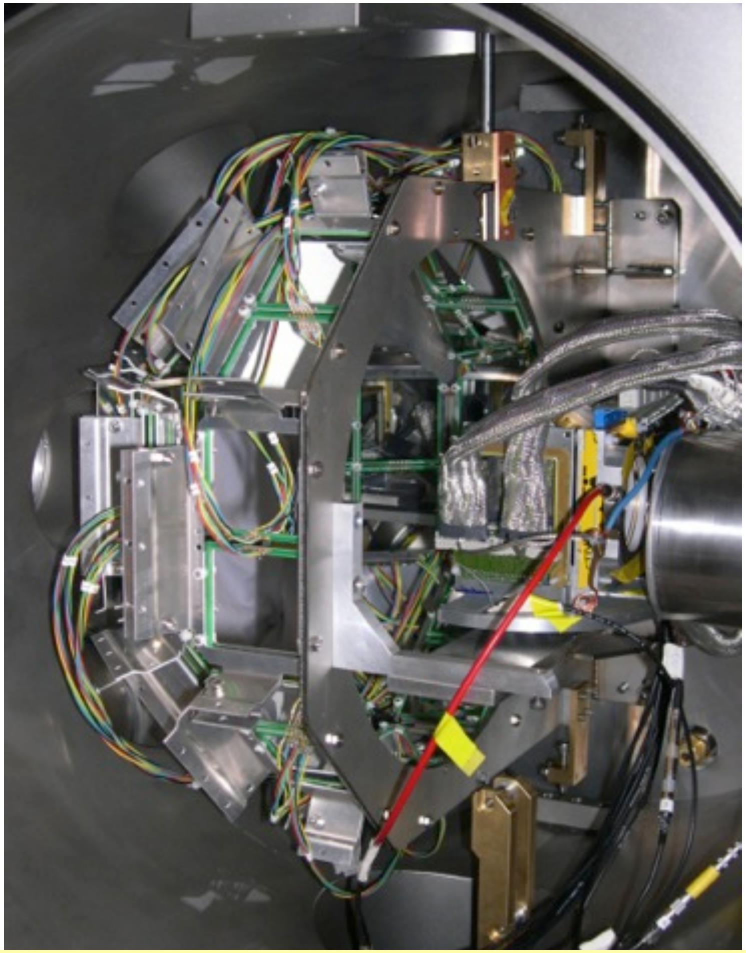


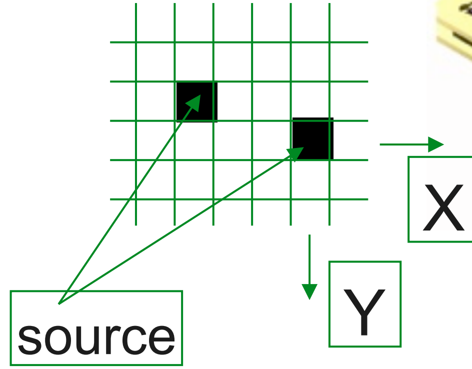
^{9}Li

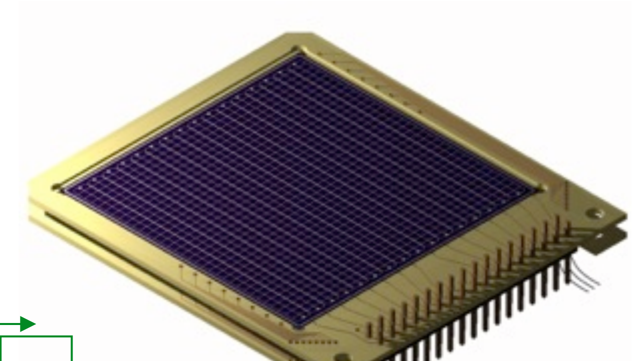




Dispositivo experimental @ ISOLDE

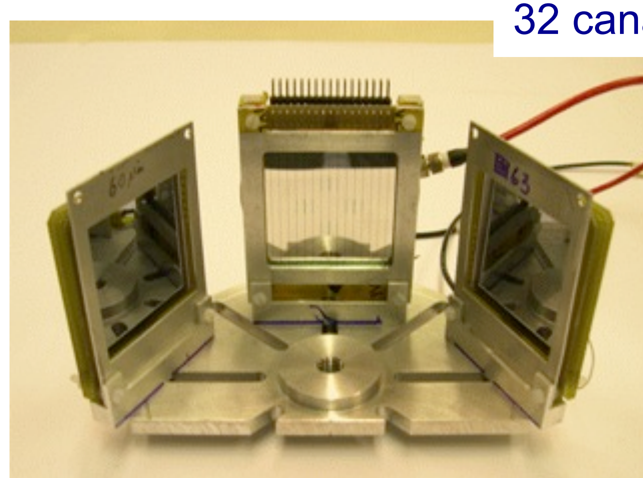






50x50 mm^2
16x16 tiras de 3x50mm^2

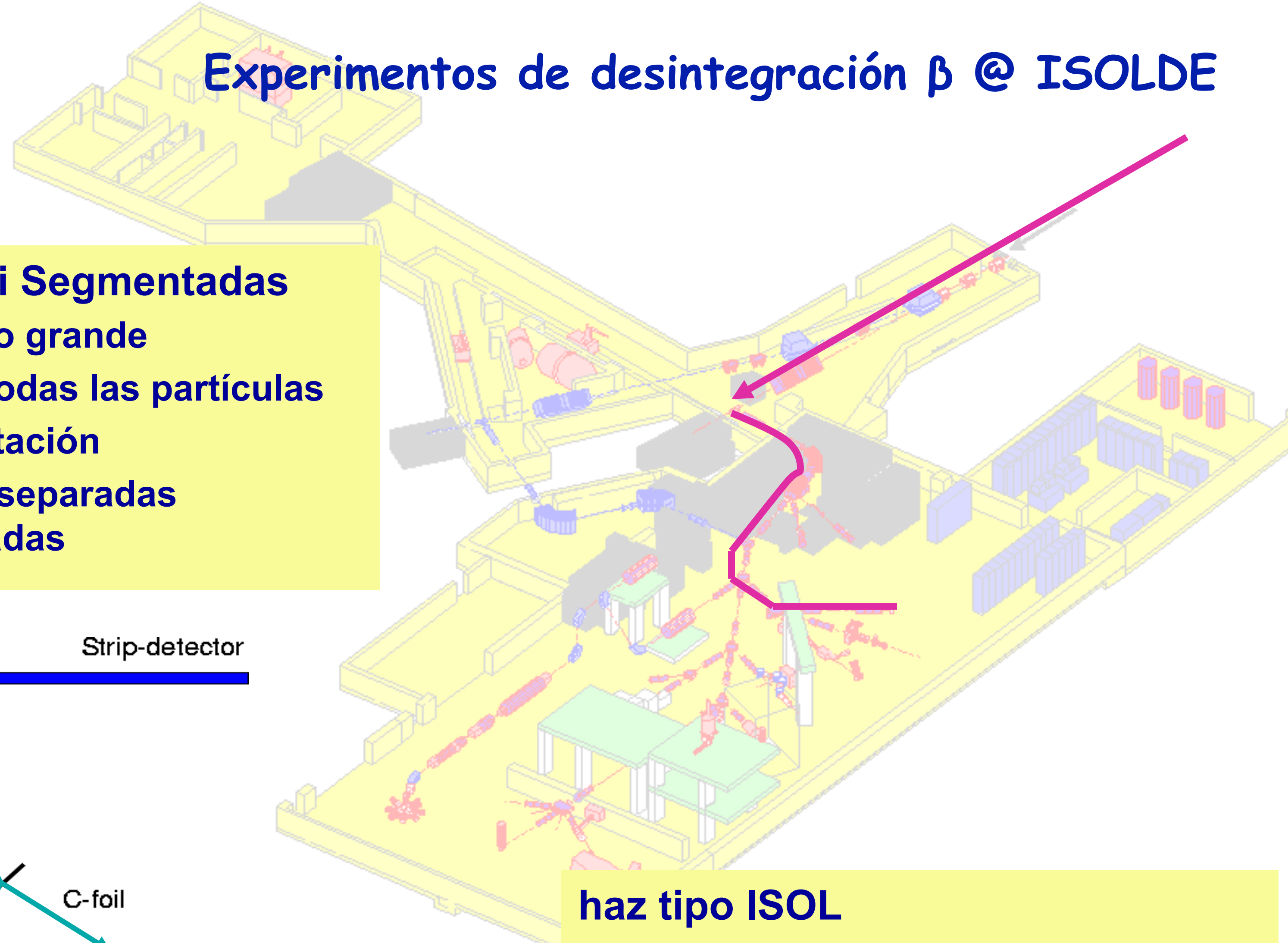
256 pixeles de 9 mm^2
32 canales de electrónica



ISOLDE Si-Ball: 36x4 quadrants of 1000 micron Si
L.M. Fraile, NIMA513 (2003) 287.

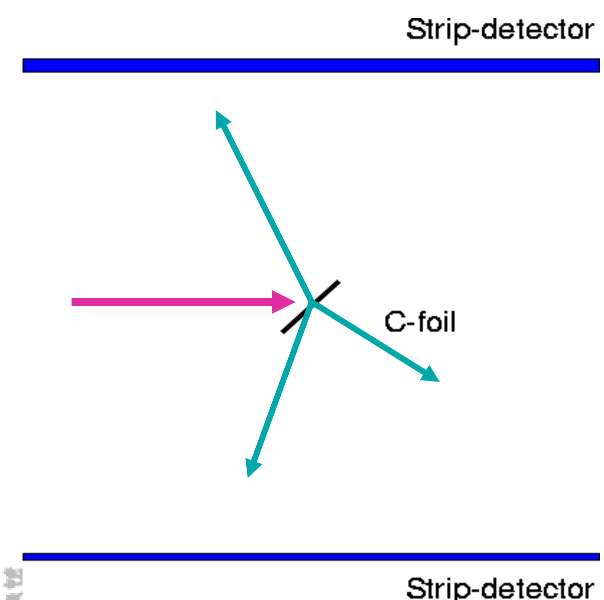
3 DSSSD telescopes
60 + 1500 micron Si

Experimentos de desintegración β @ ISOLDE



Detectors de Si Segmentadas

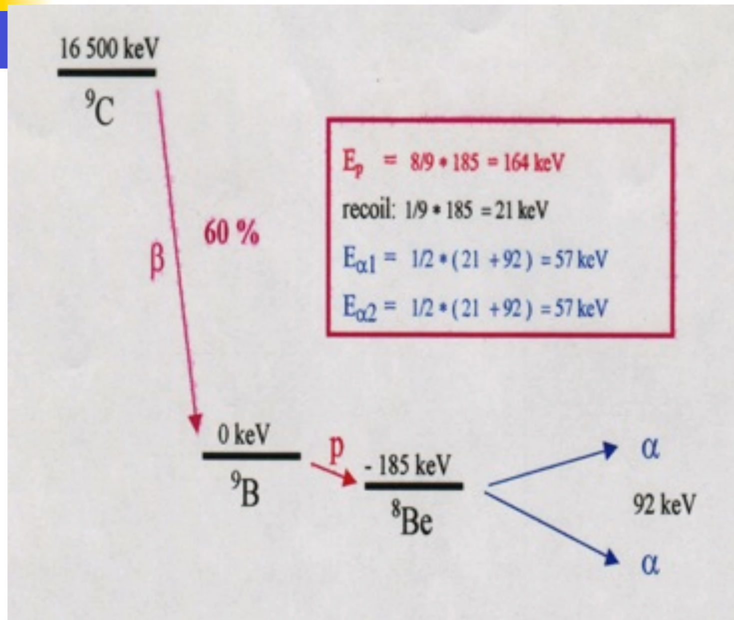
- **Angulo solido grande**
  - **detecta todas las partículas**
- **Alta Segmentación**
  - **Eventos separadas NO sumadas**

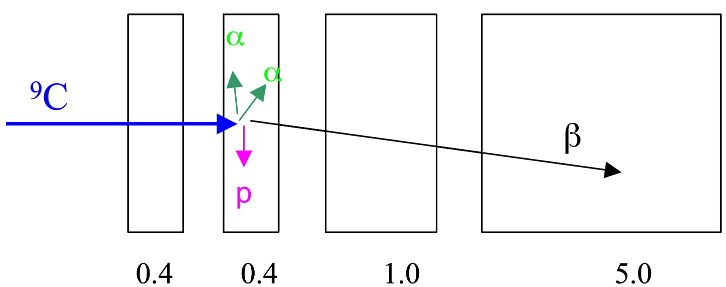


haz tipo ISOL

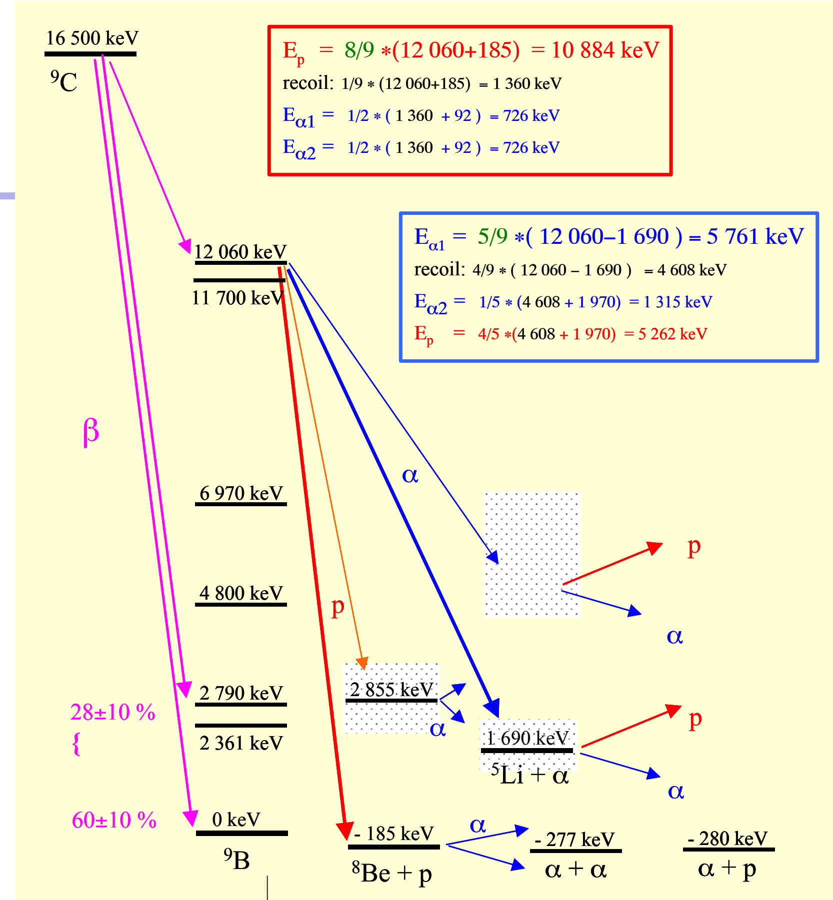
- **Haz de iones de baja energía**
- **paras en una lamina de C muy fina**
- **Fuente radiactiva de forma punto**

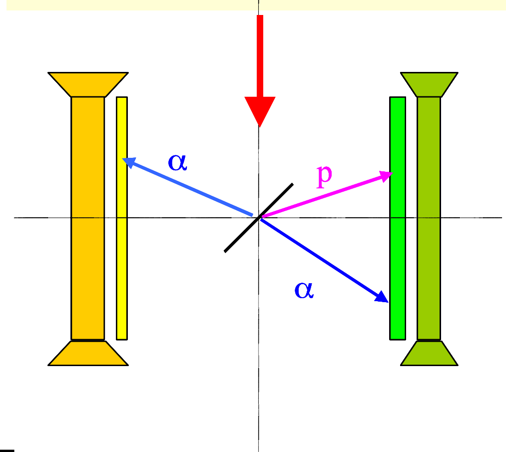
ISOBAR A=9

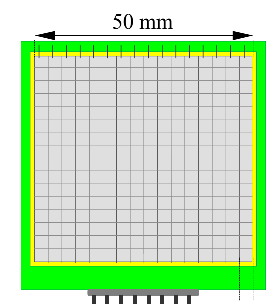




D. Mikolas et.al. Phys. Rev C37(1988)766



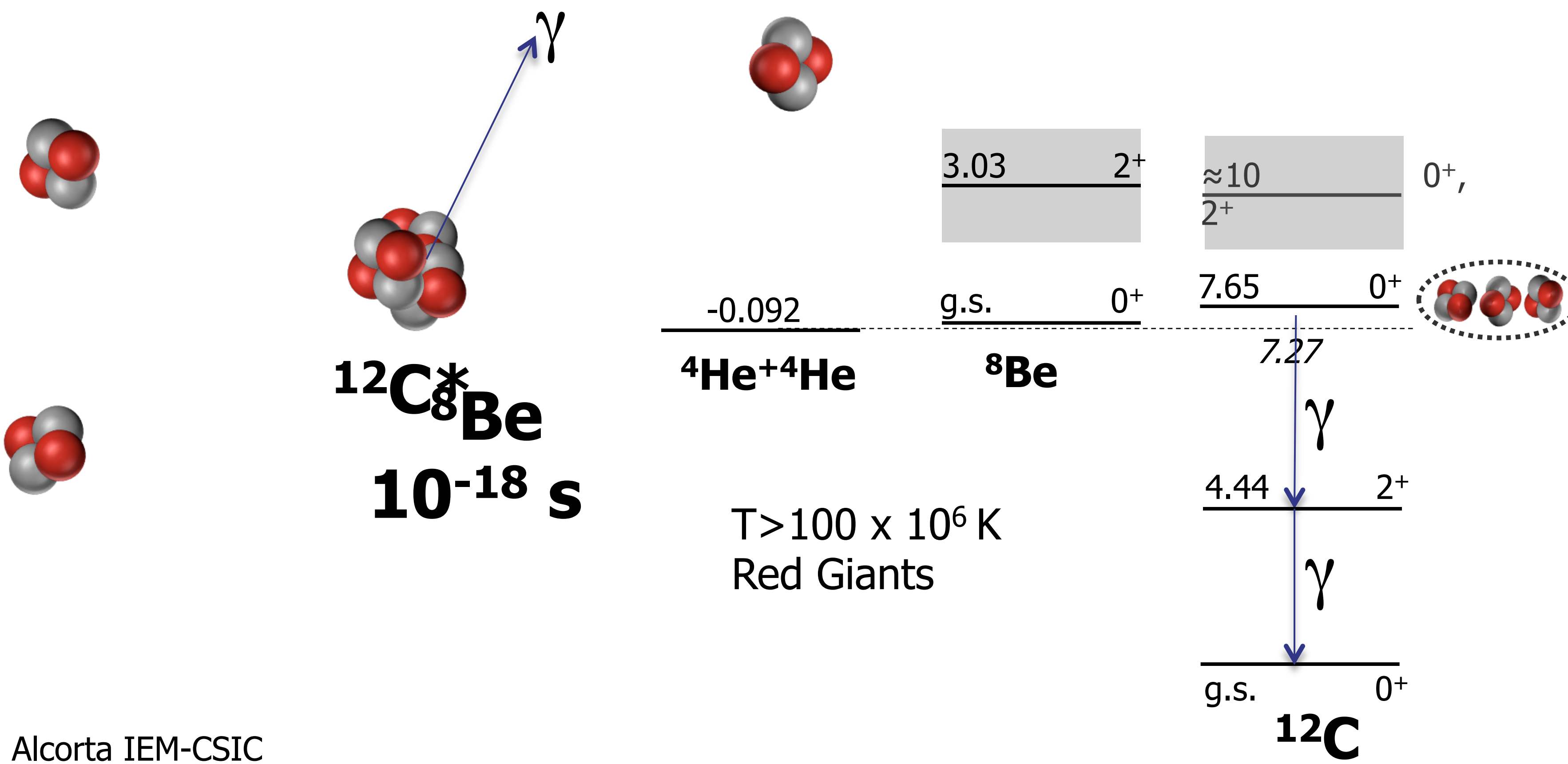




Triple-α Process

N6. A State in C¹² Predicted from Astrophysical Evidence.* F. Hoyle, *Cambridge University* and D. N. F. Dunbar, W. A. Wenzel, and W. Whaling, *Kellogg Radiation Laboratory, California Institute of Technology.*—It is

Phys. Rev. 92:1095 (1953)

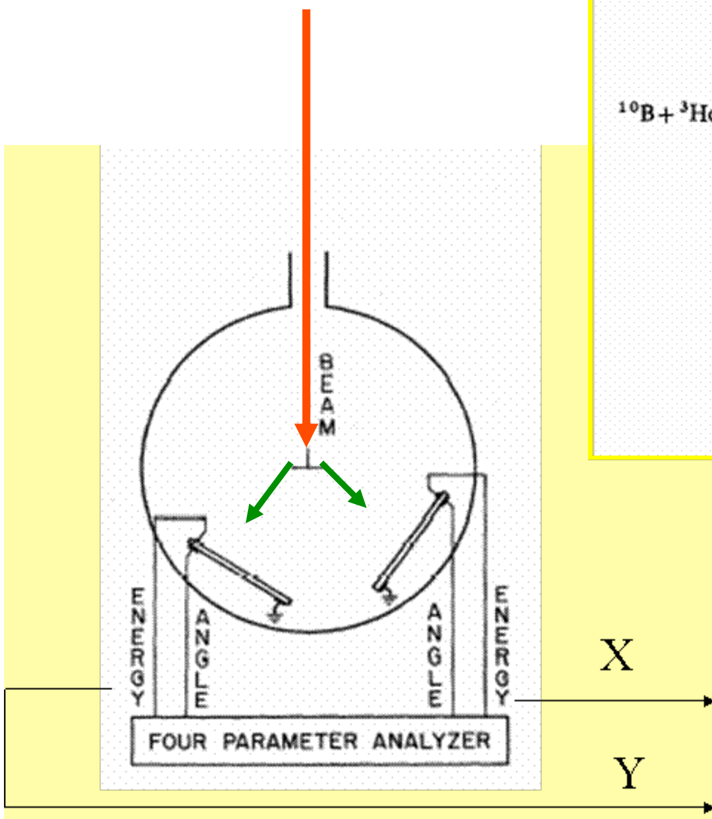


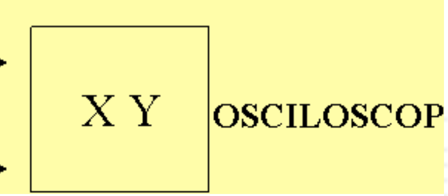
M. Alcorta IEM-CSIC

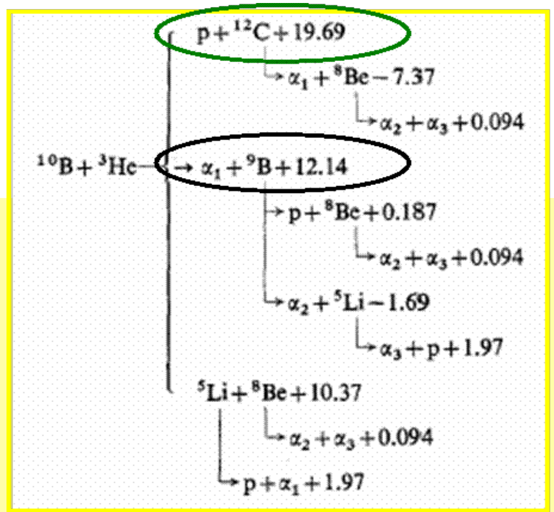
Reaction studies in the 60ies

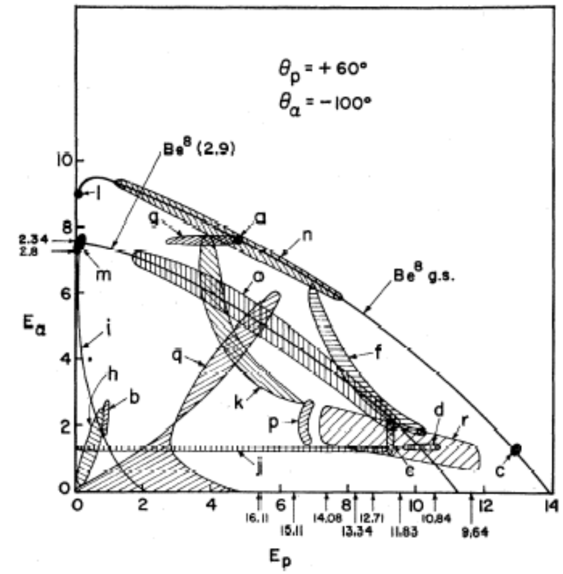
^{3}He (@ 2,45 MeV) + ^{10}B → pααα

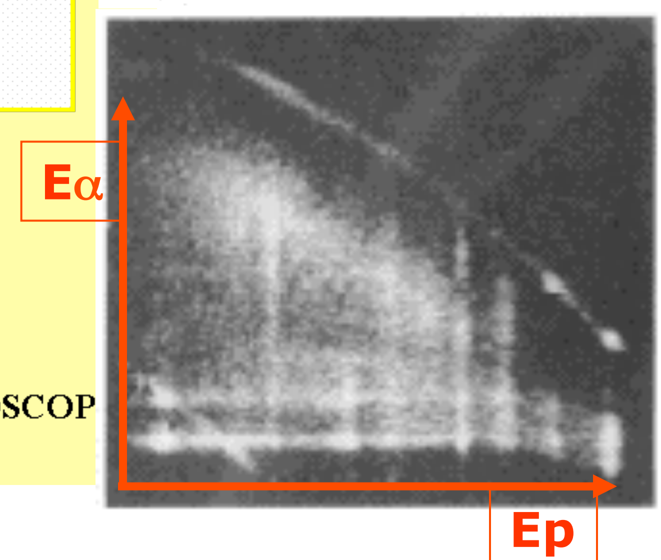
Waggoner *et al.*, NPA **88**(1966)81





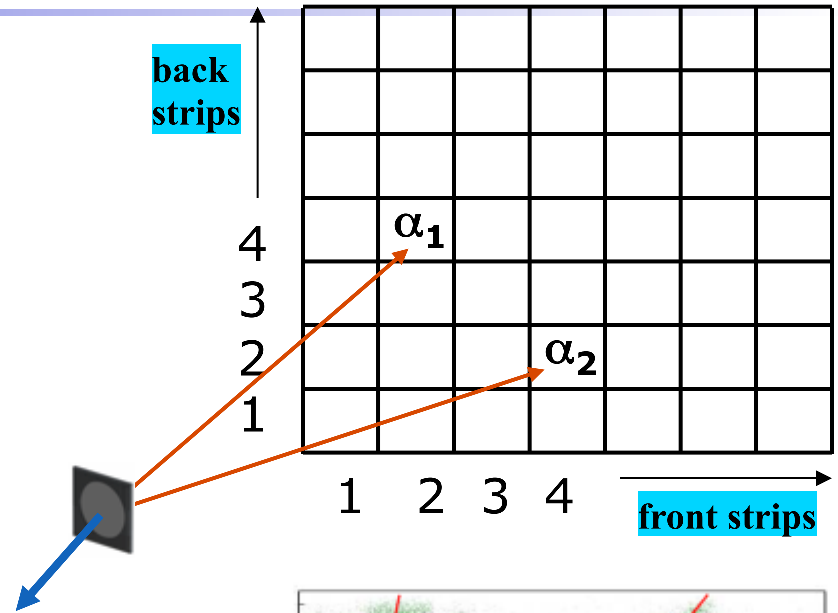




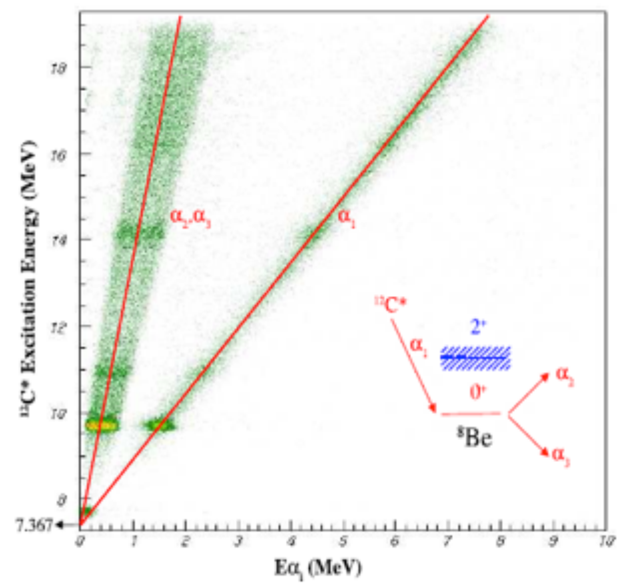


Podemos mejorar estas medidas hoy?

- **Detection system**
  - Developments in Si detectors, especially of the DSSSD the **high segmentation** of the detectors makes it possible to detect all particles, has improved tremendously the multi particle **coincidence detection probability**, and thus made possible to **kinematically reconstruct each event**.



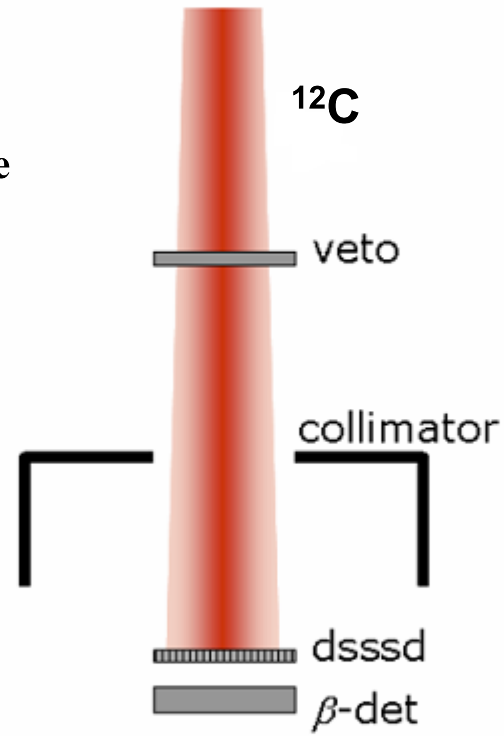
- **Computer power and analysis capability.**
  - **Event by event detection** combined with **MonteCarlo simulations** including both theory and the actual set-up makes possible to extract information about decay mode, branching ratios and other physics parameters.

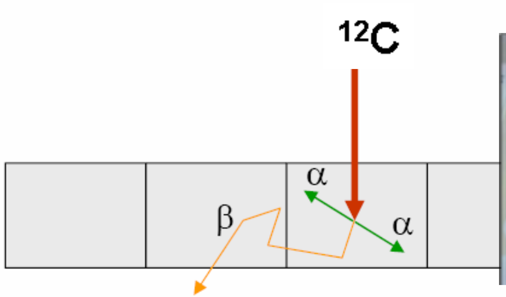


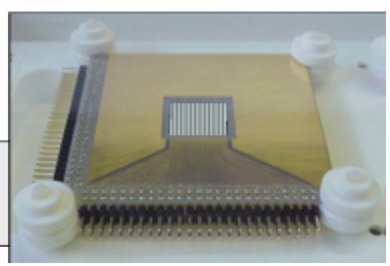
$^{12}C^*$ estudios en instalaciones diferentes y con métodos distintos

KVI

R. Raabe

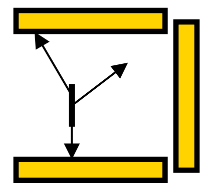


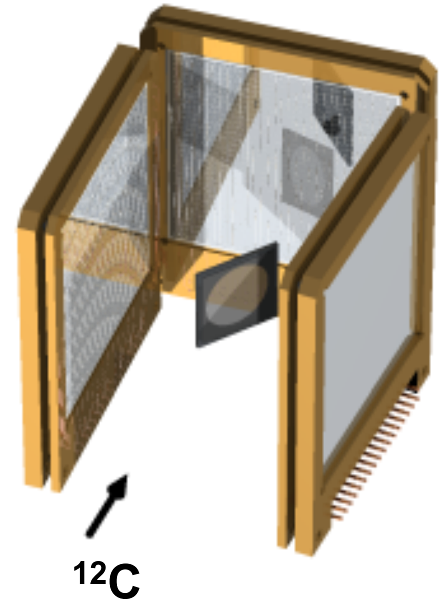




JYFL

H. Fynbo



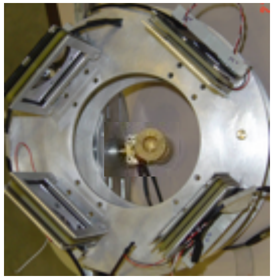


CMAM

Reaction studies @ CMAM tandem

$^{3}He + ^{10}B \rightarrow ^{12}C^* \rightarrow p + \alpha + \alpha + \alpha$

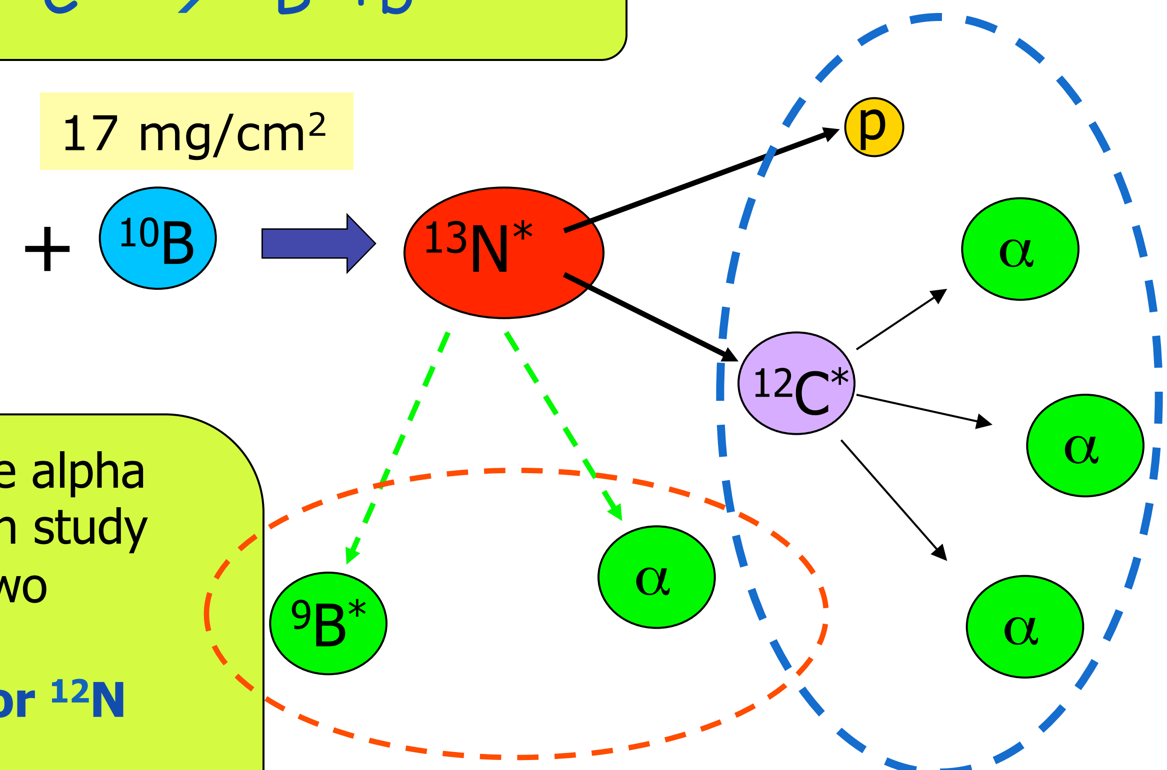
O. Tengblad



Low energy reaction study @ Madrid Tandem accelerator – how to produce the $^{12}C^*$ states

$A + a \rightarrow C^* \rightarrow B^* + b$

^{3}He @ 2.5-8.5 MeV



We cannot reproduce the triple alpha process directly, but we can study the states involved using two complementary methods;

1) In beta decay from ^{12}B or ^{12}N JYFL, ISOLDE, KVI

1) Via the $^{3}He + ^{10}B$ reaction, which allows us to gain complementary information on the ^{12}C resonances

Centro de Micro Análisis de Materiales

2002

Nov. **Delivery, and Start of installation**

Aug. **End of installation**

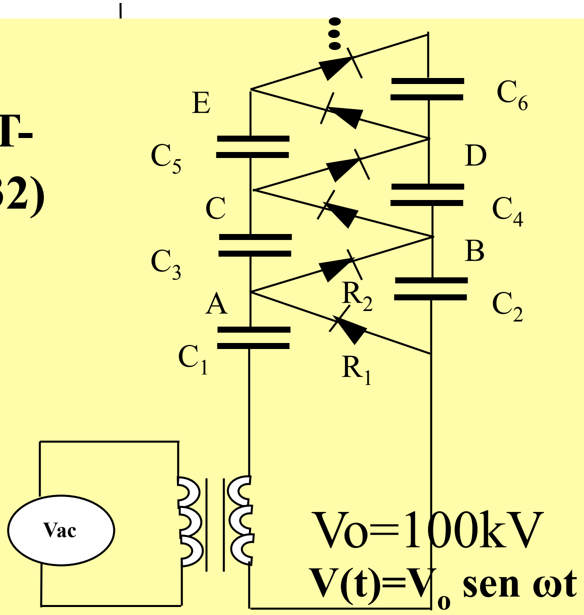
Nov. **Commissioning of the External micro-beam**

2003

Mar. **Official opening ceremony of the CMAM**

The Madrid 5MV tandetron

COCKCROFT-WALTON(1932)



- Electrostatic **Ion Accelerator** V_{max} = 5 MV
- Tandem type E_{max} = 5 ·(Z+1) MeV
- Voltage generated by a Cockroft-Walton system
  - **Remarkable stability** no moving components for the voltage generation
  - First accelerator manufactured being able to reach 5MV reliably with CW
- Manufactured by High Voltage Engineering Europa

THE BEAMS

Terminal voltage *V*
100 V – 5 MV

Energy *E*

$E = V^*(q+1)$ MeV

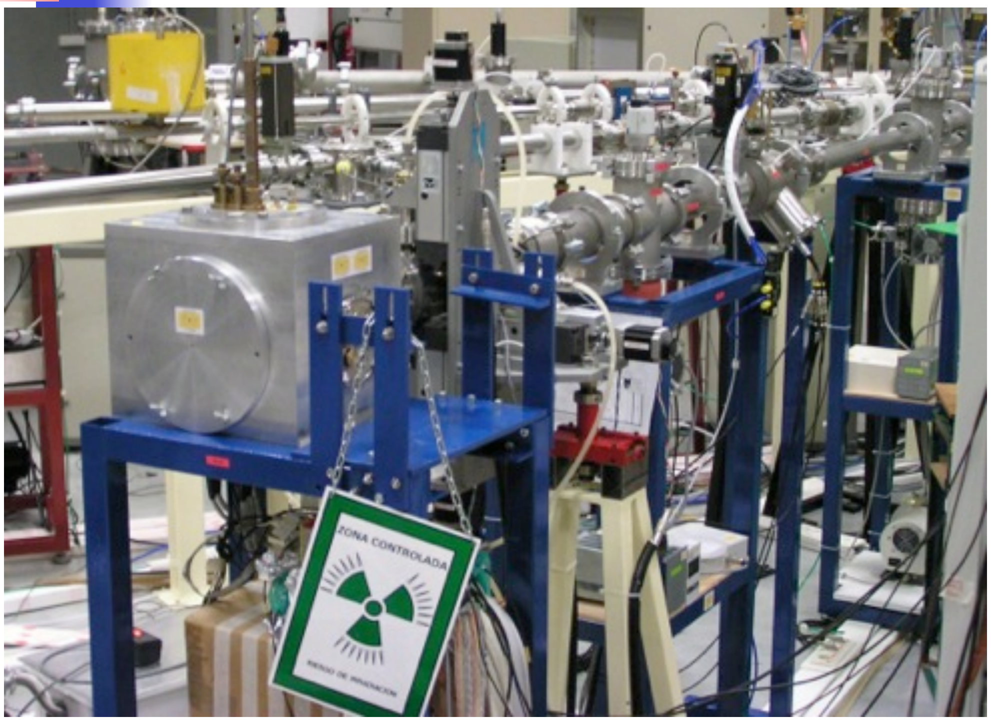
***q*=charge**

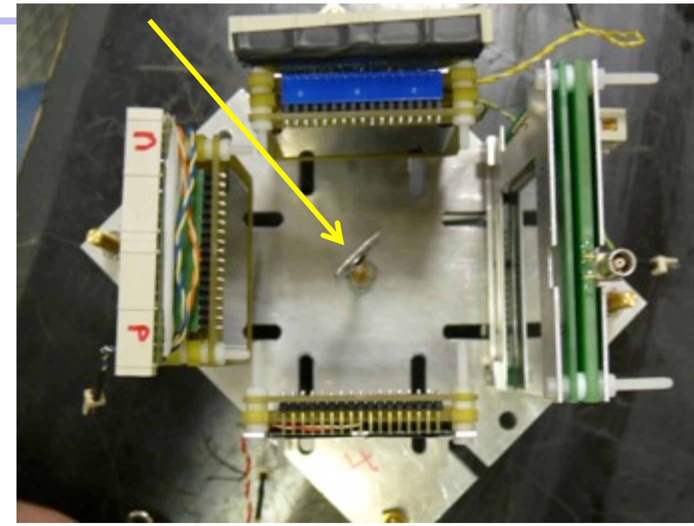
Beam current *I*

3 MeV	**H^+ :**	**15 μA**
3 MeV	**He^{2+} :**	**1 μA**
9 MeV	**Si^{2+} :**	**61 μA**
12 MeV	**Si^{3+} :**	**125 μA**
21 MeV	**Si6+ :**	**3 μA**
15 MeV	**Au2+ :**	**16 μA**
20 MeV	**Au3+ :**	**21 μA**
55 MeV	**Au10+ :**	**50 nA**

$^{10}B(^3He,p)\alpha\alpha\alpha$ $^{11}B(^3He,d)\alpha\alpha\alpha$

^{3}He @ 4.9 and 8.5 MeV from 5 MV Tandetron

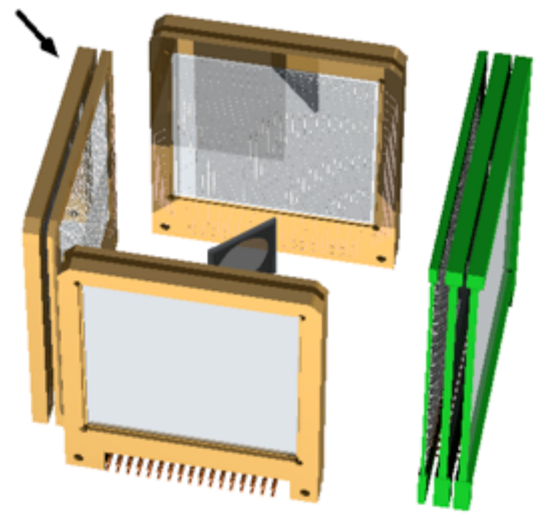




Targets:

18.9 μg/cm^2	**^{10}B**	4 μg/cm^2 C-backing
22.0 μg/cm^2	**^{11}B**	4 μg/cm^2 C-backing

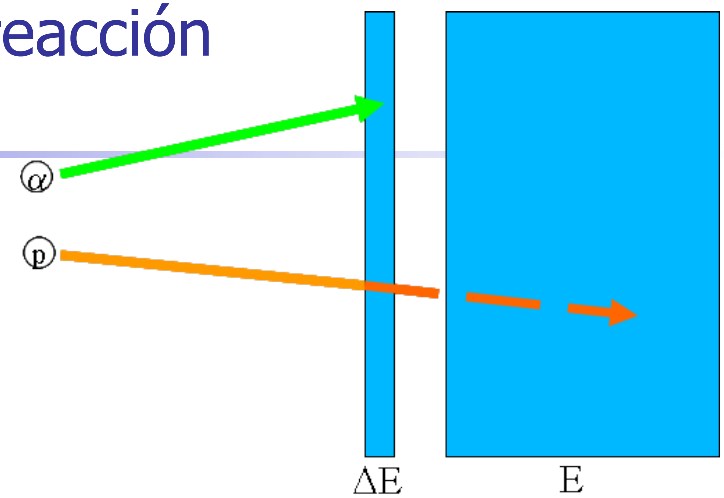
DSSD + PAD

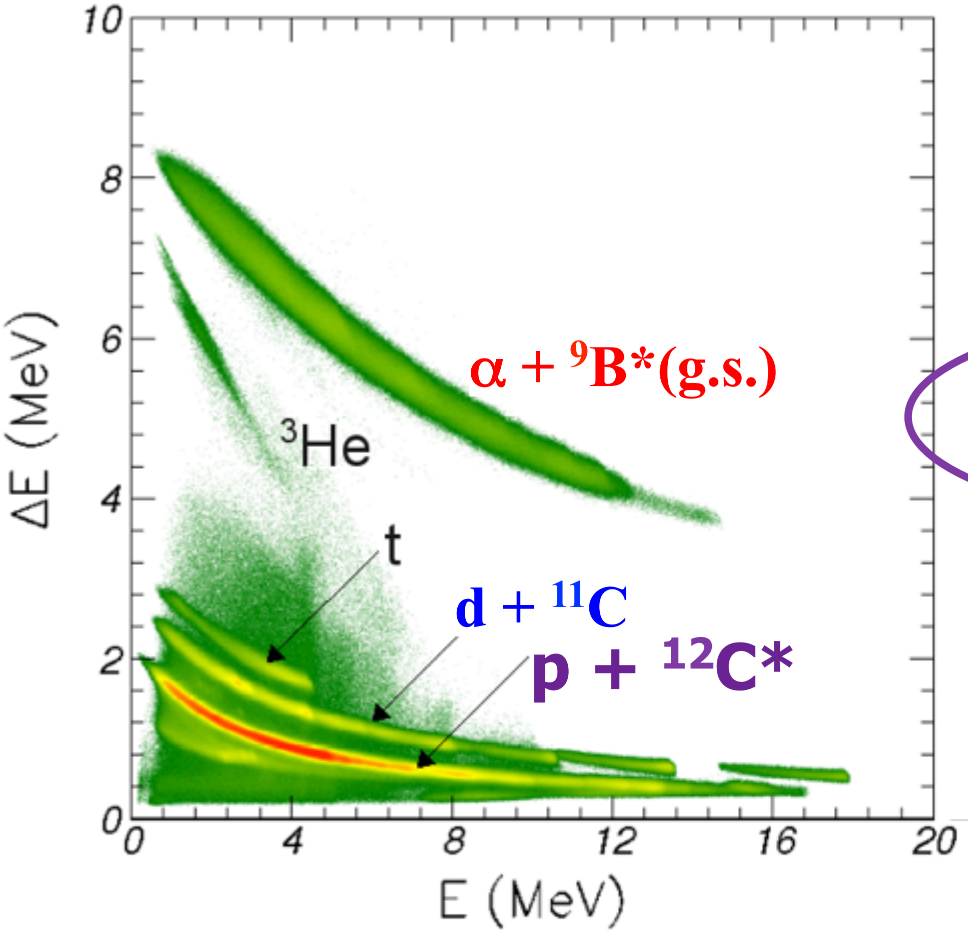


Ω = 38% of 4π

Identificación del canal de reacción

$^{3}He + ^{10}B \longrightarrow p + ^{12}C^{*}$





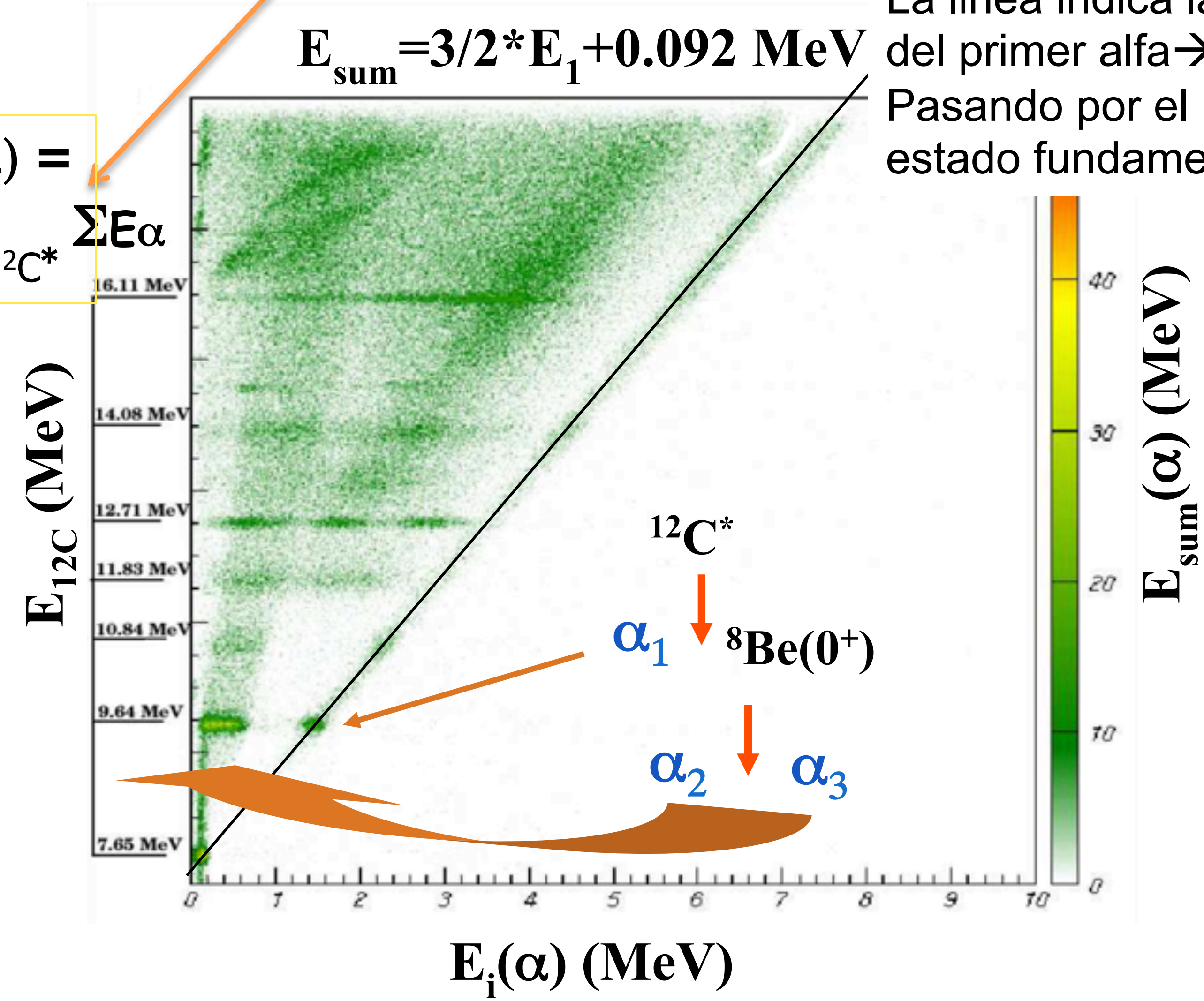
Reaction products	Q-Value (MeV)
$^{13}N + \gamma$	21.63668
$^{12}C + p$	19.69315
$p + 3\alpha$	12.41836
$^{8}Be + p + \alpha$	12.32652
$^{9}B + \alpha$	12.14145
$^{5}Li + 2\alpha$	10.45334
$^{11}B + 2p$	3.73607
$^{11}C + d$	3.19574
$^{12}N + n$	1.57257
$^{11}C + p + n$	0.97115
$^{10}B + ^{3}He$	0.00000

Seleccionando el canal de protón: p + α + α + α en coincidencias → reconstruye la Energía de Excitación en ^{12}C

Hacemos un grafico de las energías detectadas entre la SUMA de las 3 alfas vs cada alfa

La linea indica la energia del primer alfa→ **Secuencial** Pasando por el estado fundamental de ^{8}Be

SUMA(3Eα) = el estado de excitación $^{12}C^*$



Indirect Detection of γ-decay

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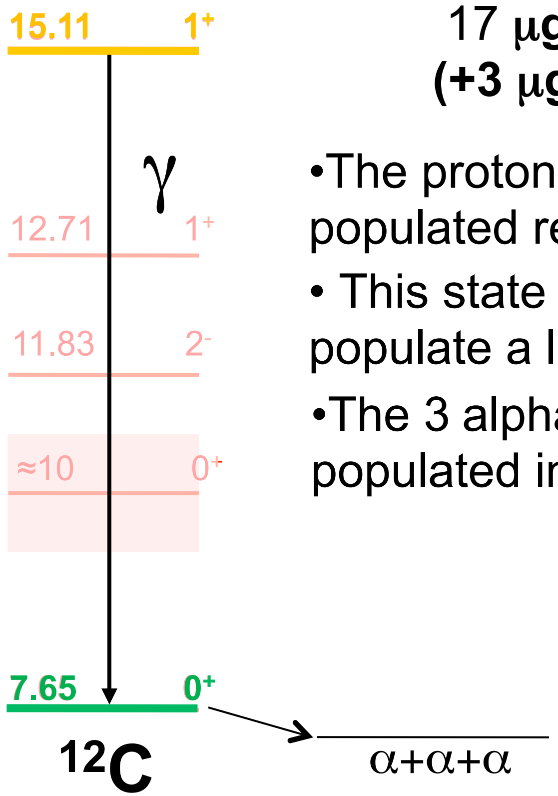
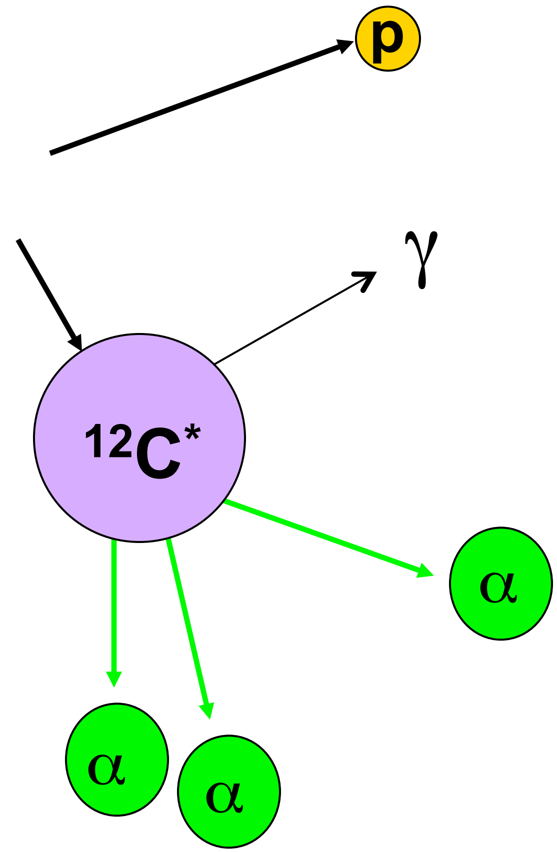
IEM CSIC
Grupo de Física Nuclear Experimental

^3He @ 4.5 MeV

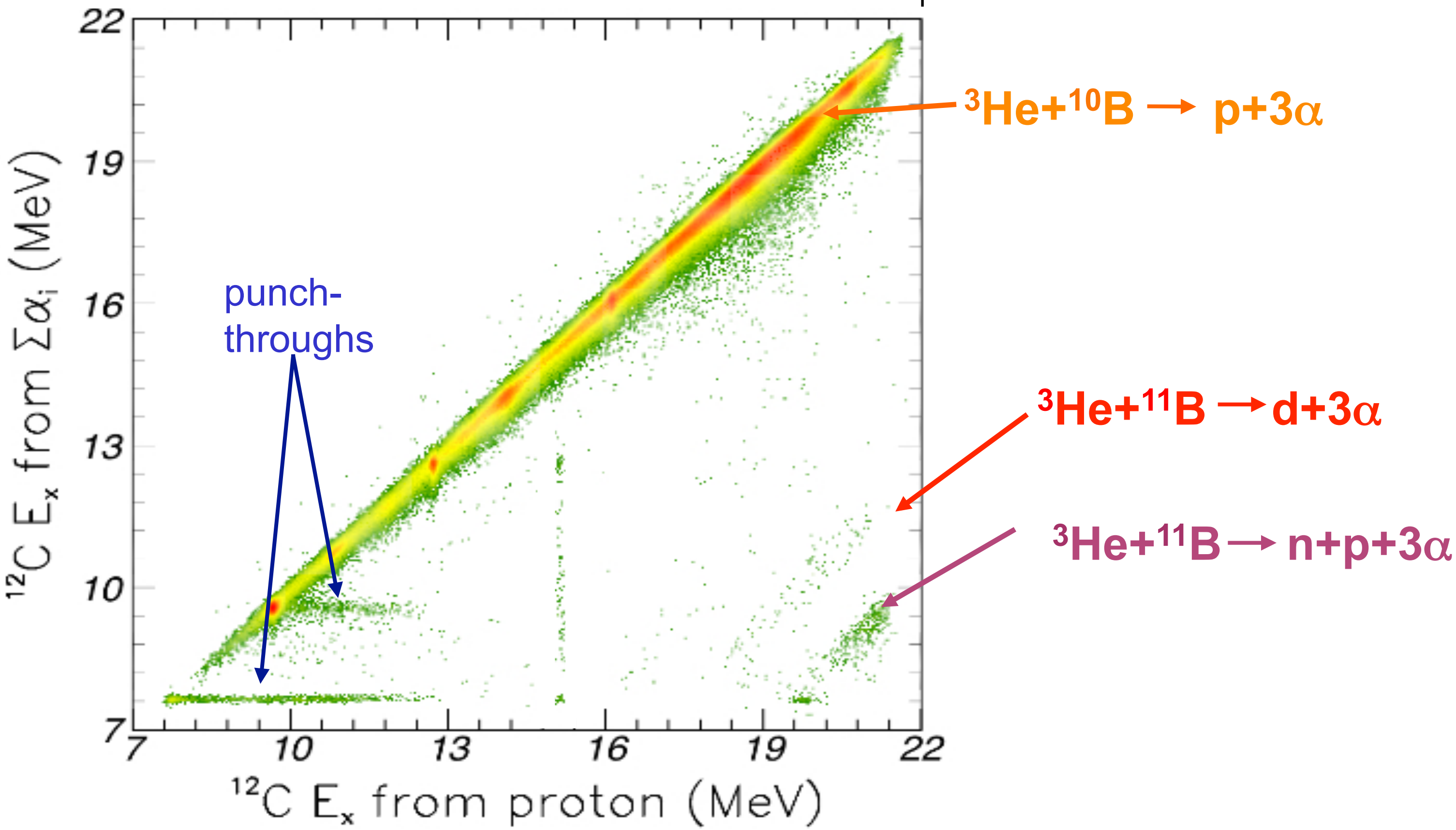
17 $\mu g/cm^2$
(+3 $\mu g/cm^2$)



- The proton gives initial populated resonance in ^{12}C
- This state can emit γ and populate a lower excited state
- The 3 alphas give resonance populated in ^{12}C *after* γ-decay



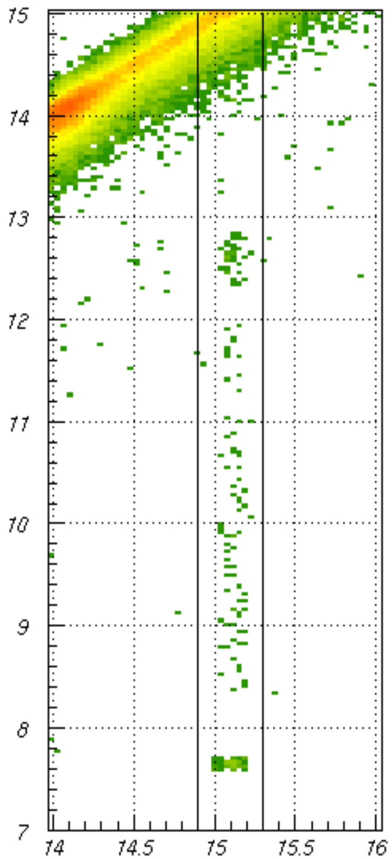
γ-decay of the T=1 level @ 15.11 MeV

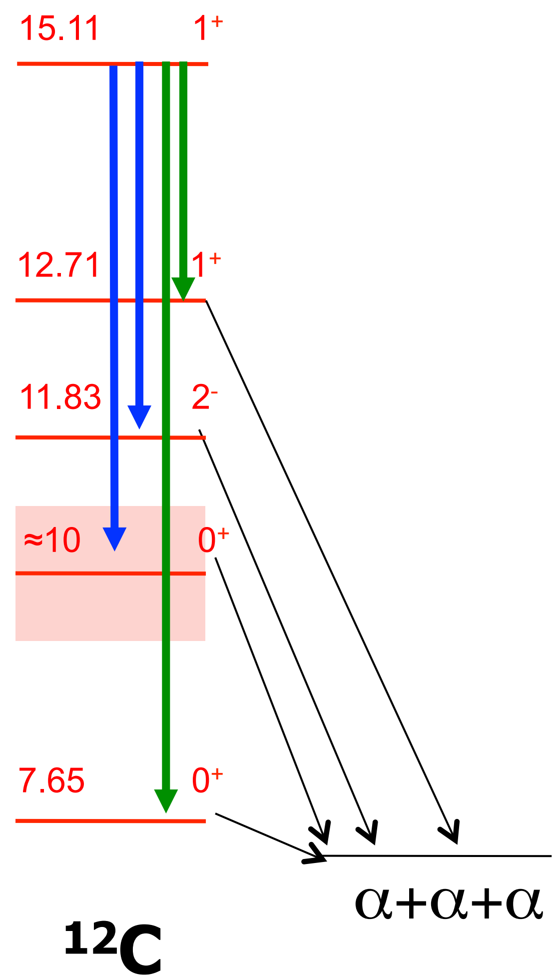


12C excitation Summing 3 α

12C excitation energy from proton

γ-decay of the T=1 @ 15.11 MeV





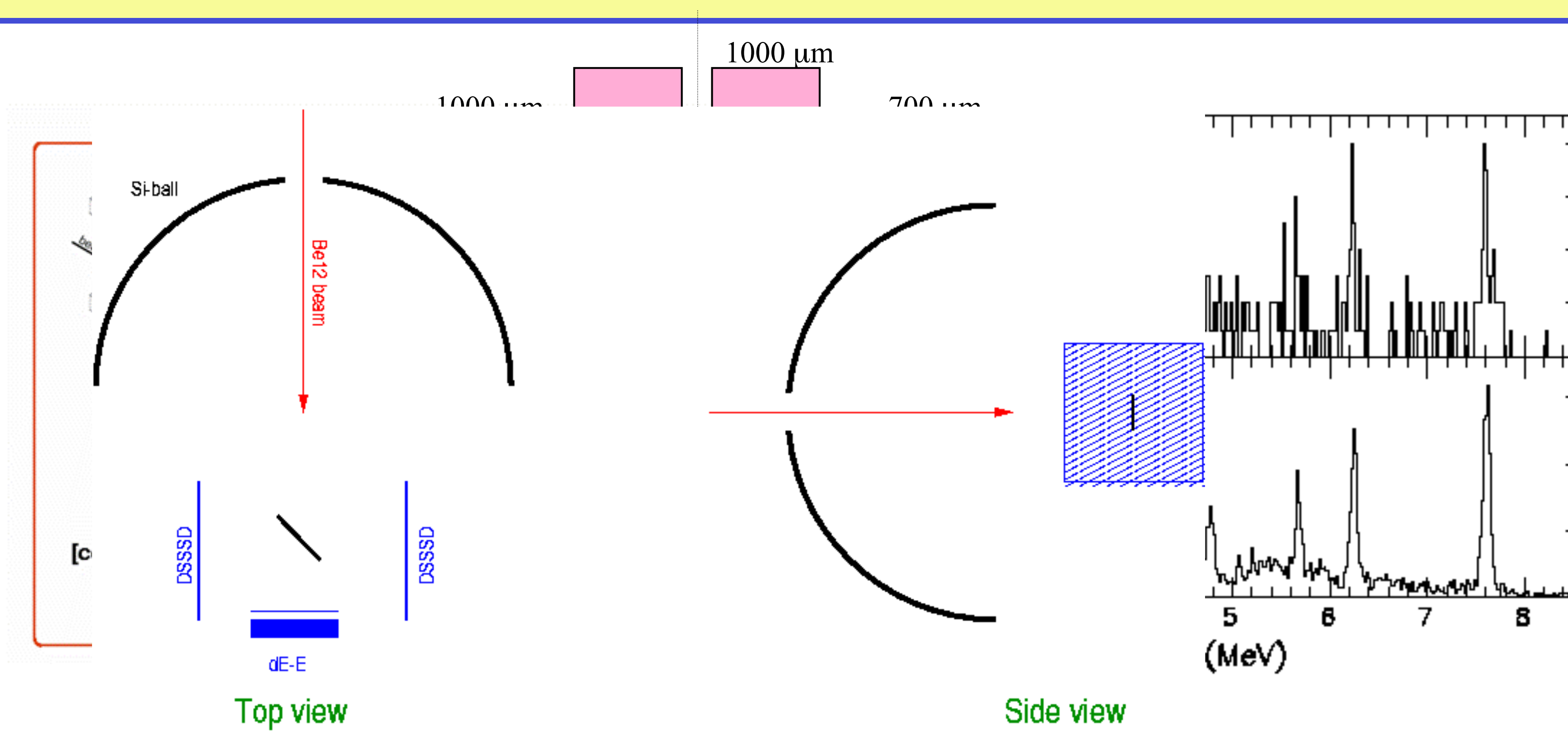
M. Alcorta et al, NIM A605, 318-325 (2009)

O.S. Kirsebom et al, Phys.Lett B680, 44-49 (2009)

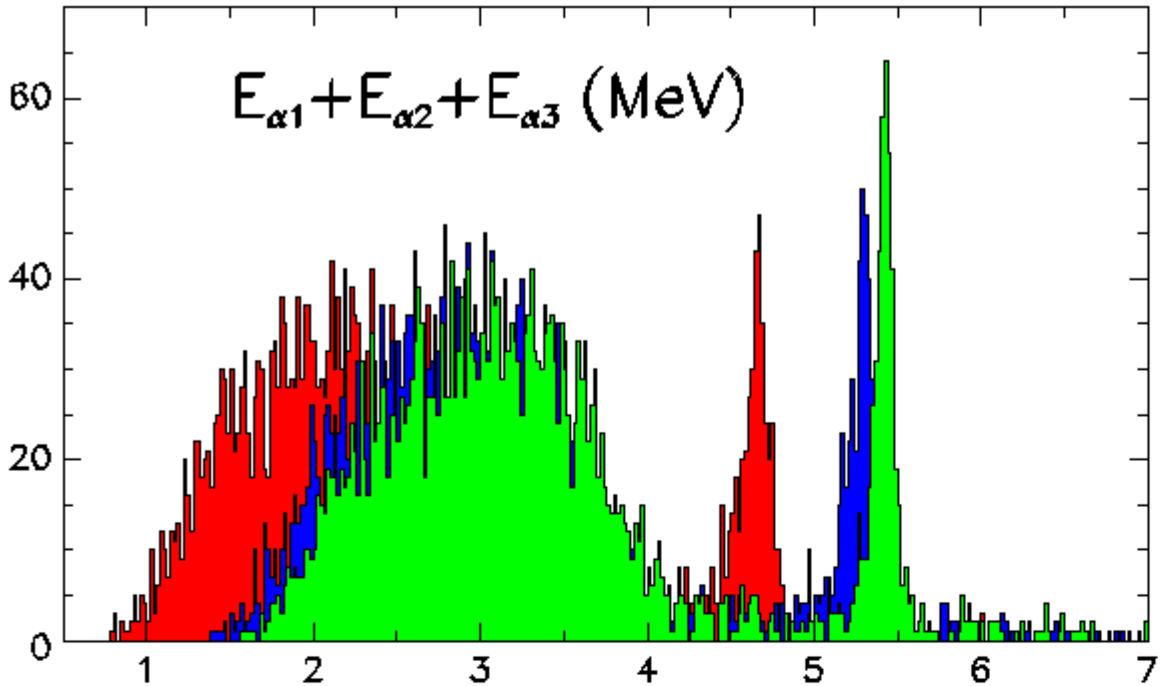
Desarrollo para experimentos a baja energía

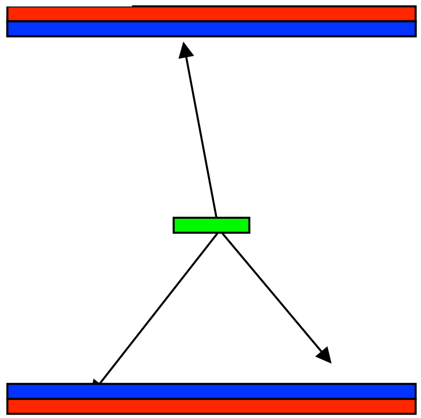
Electronic evolution in order to manage the β-decay experiments

year	exp	#det.	#el-chan.	#segments	3-co-eff		electronics
1995	^{31}Ar	5	5	5	0.0032%		ORTEC
1997	^{31}Ar	15+1	15+32	15+256	1.6%	(500)	RAL
1998	^{9}C	4+2	4+66	4+512			RAL
2003	^{12}C	36+3	144+99	144+768			MESYTEC



Energy loss effects





No corrections

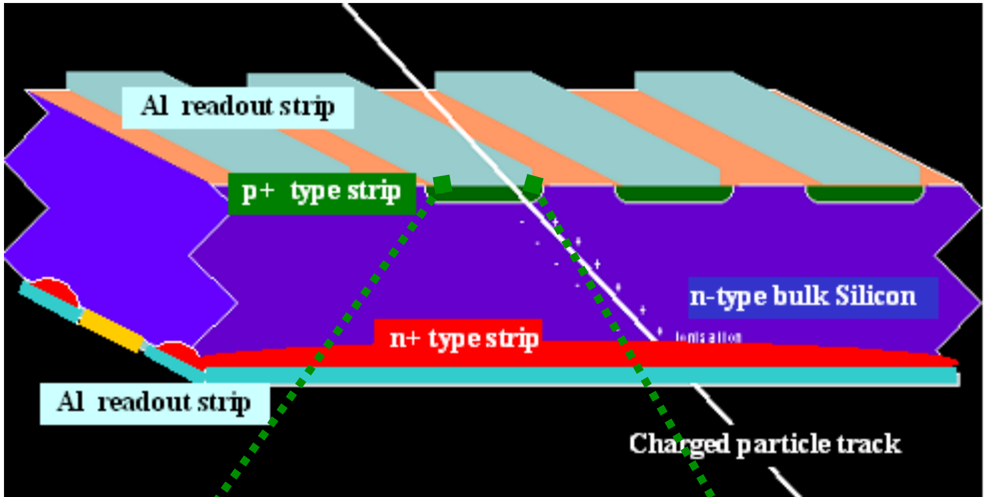
Detector deadlayer

Carbon foil

Bergmann, Fynbo & Tengblad, NIMA515 (2003) 657.

Desarrollo en Detectores

Novel thin window design for large-area Si strip detector
Nucl. Instr. Meth A525 (2004) 458



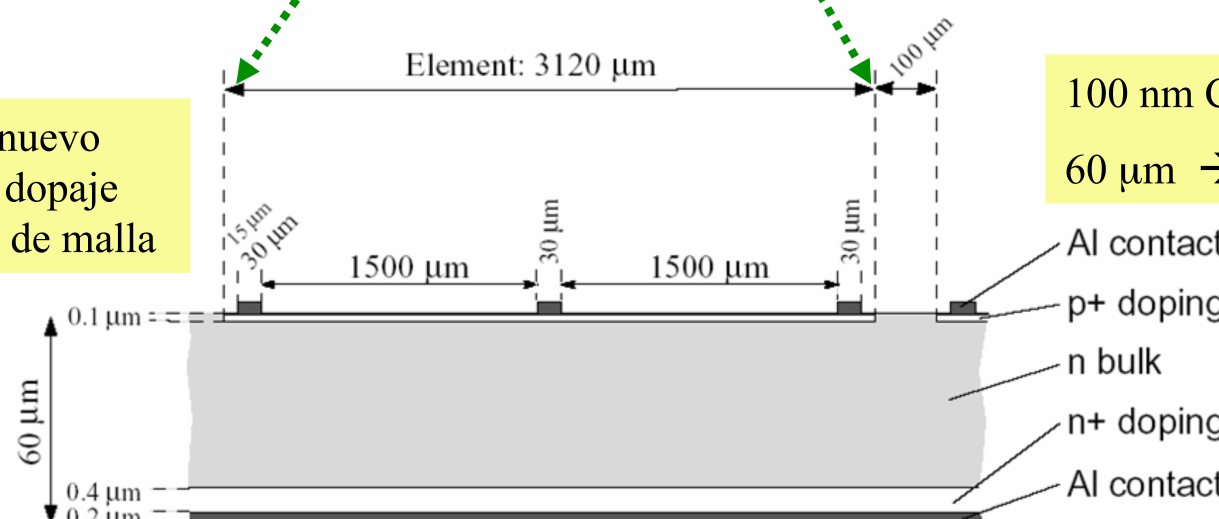
} Capa muerta

200 nm Al
400 nm doping

Diseño nuevo
100 nm dopaje
Coector de malla

100 nm Capa muerta

60 µm → poca sensibilidad a β



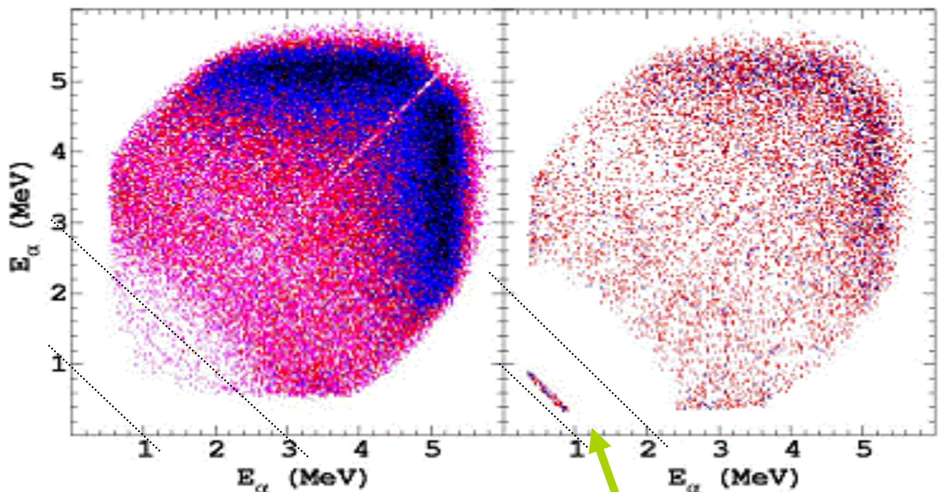
^9Li – decay channels

αα distribution

9.7 < E_{sum} < 11. 7 MeV

Experiment

2001 2002

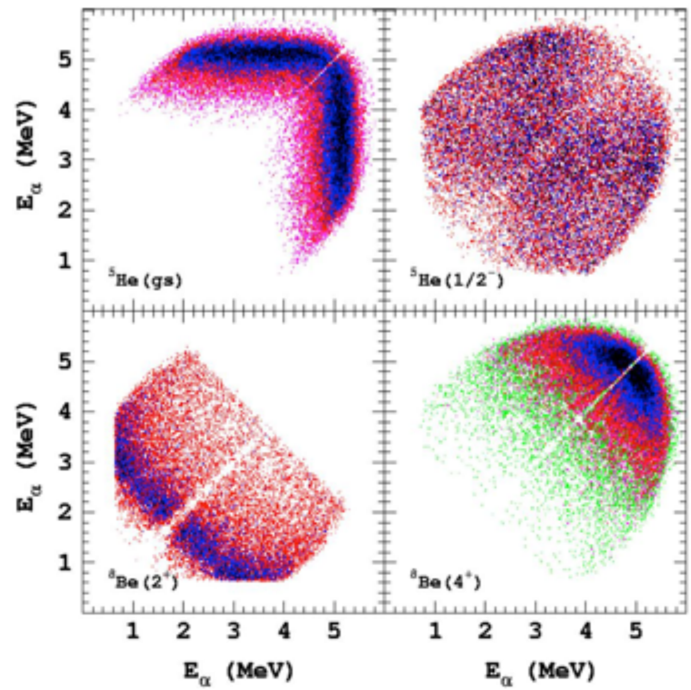


$^8Be(gs)$

Effect of using the new DSSSD

- **100 nm deadlayer**
  low cut-off threshold
- **60 μm detector**
  No β-response

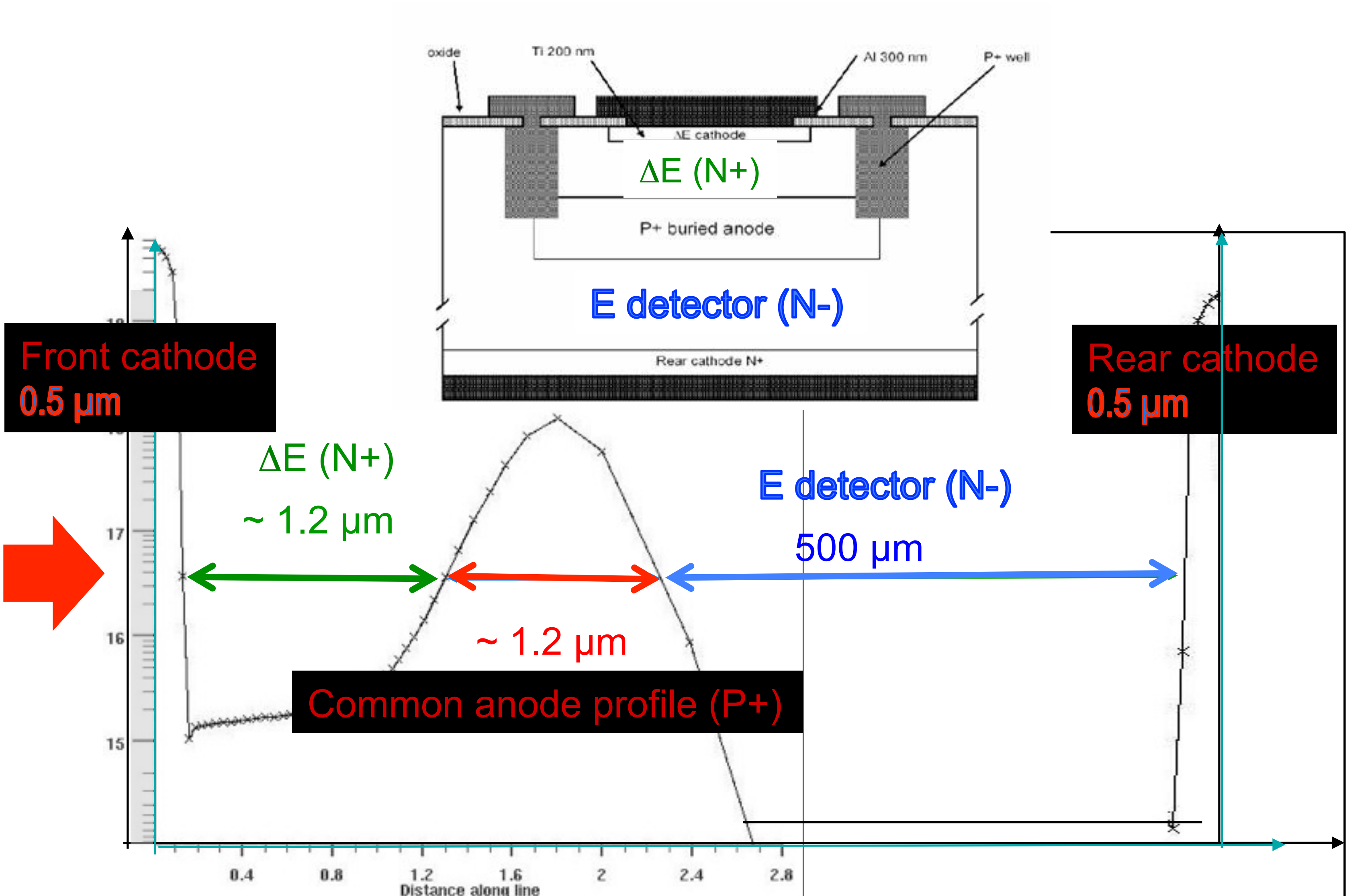
$^5He(gs)$ dominate

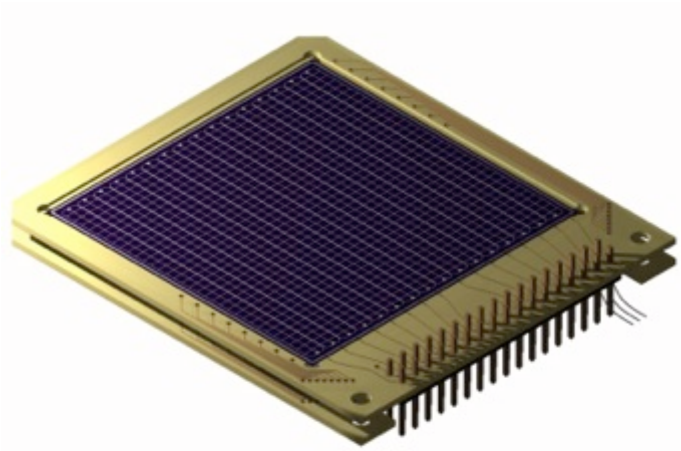


Simulation of the αα distribution

As function of decay channel

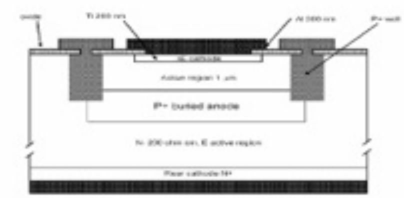
Monolithic Si telescope depth profile

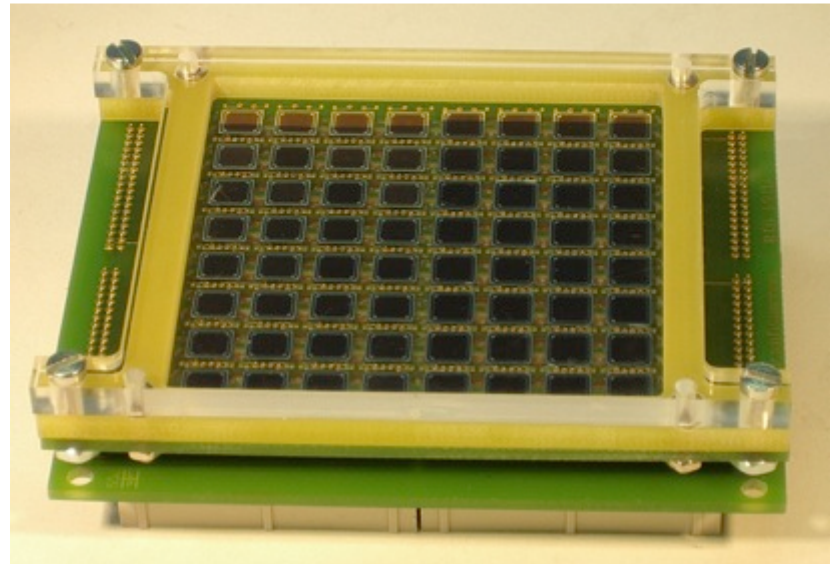




5x5 cm^2 16x16 tiras de 3mm

256 pixeles de 9 mm^2
32 canales de electrónica





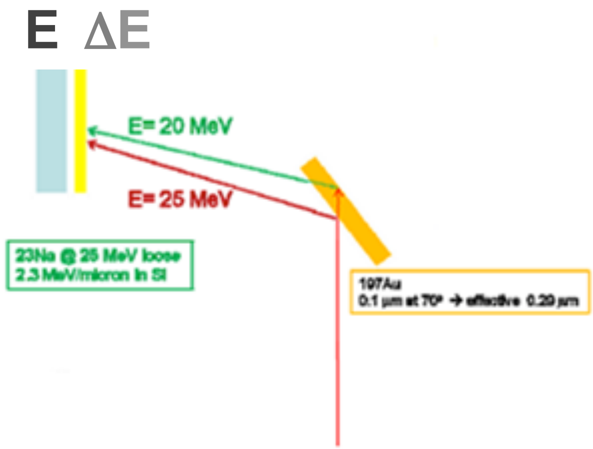
Detector área: 5x5 cm^2

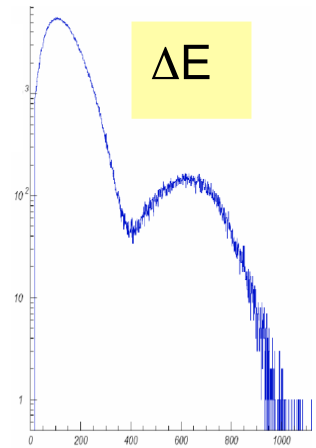
64 detectores de 9 mm^2
128 canales de electrónica

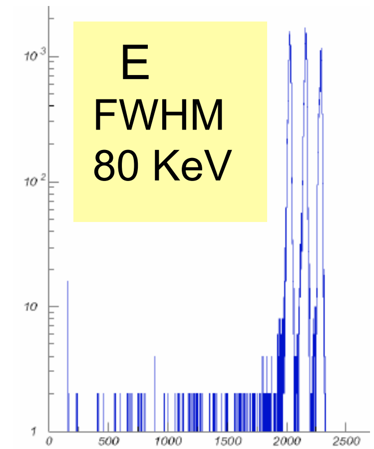
Angulo sólido de 20% del DSSSD
4 veces mas de electrónica

Espectros con el Monolito

MONOLITHIC
EXPERIMENT AT CMAM RUTHERFORD SCATTERING
OF 23NA & 25AL ON 0.1 μM 197AU





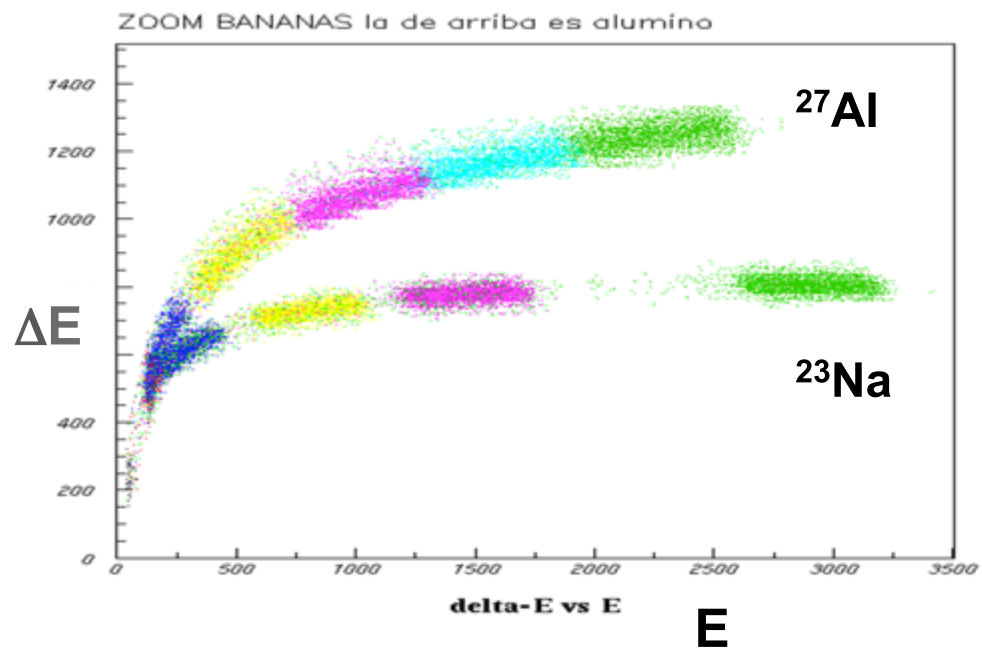


Espectros individuales del ΔE y E

Fuente triple alfa

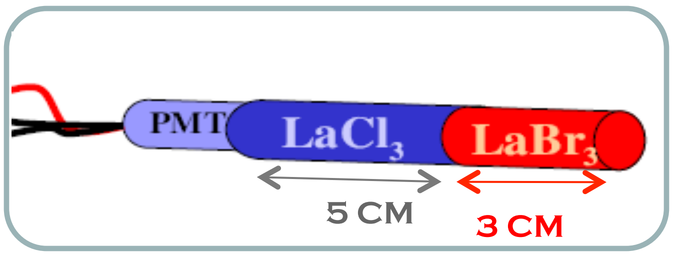
Haces de ^{27}Al y ^{23}Na @ CMAM

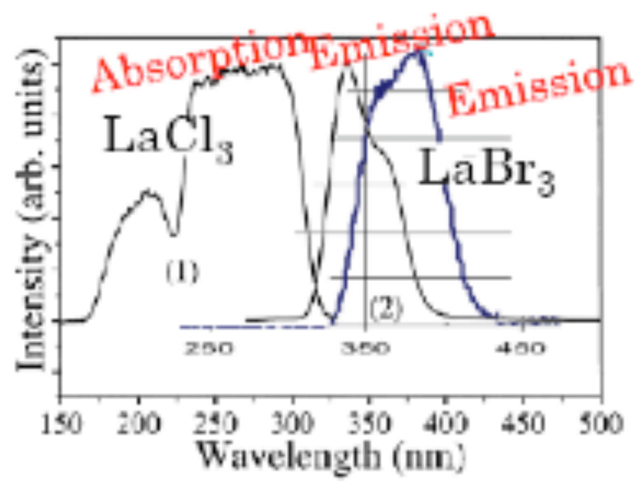
verde	→ 30 MeV
azul claro	→ 25 MeV
rojo	→ 20 MeV
amarillo	→ 15 MeV
azul oscuro	→ 10 MeV



CALIFA Forward end-cap

I+D de un centellador con dos cristales distintos con una única salida electrónico → Phoswich de $LaBr_3(Ce)$ + $LaCl_3(Ce)$





Materials	Energy Resolution (at 662 keV) (%)	Light yield (photons /keV γ)	Decay time (ns)	λ emision
$LaBr_3$	2.9	63	16	380 nm
$LaCl_3$	3.8	49	28	350 nm

Segundo cristal transparente para la luz del primero

Simulations

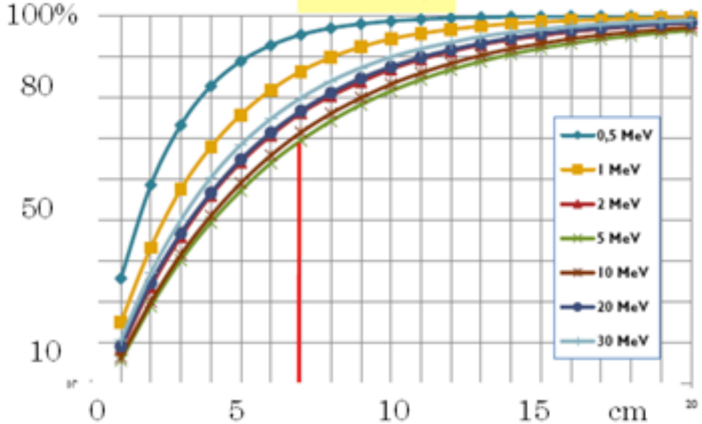
Question to be answered:

- Depth of first interaction
- Depth @ 90% photopeak efficiency
- How many neighbouring crystals are being hit?

Simulation codes

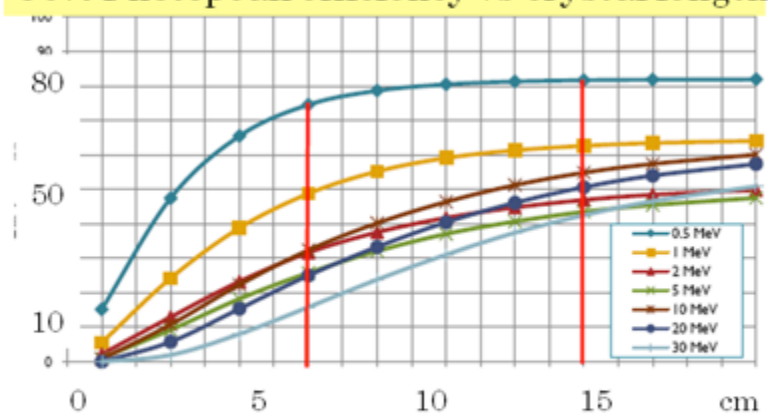
- SRIM -- GEANT4 -- MCNPX Monte Carlo N-Particle eXtended code

First hit



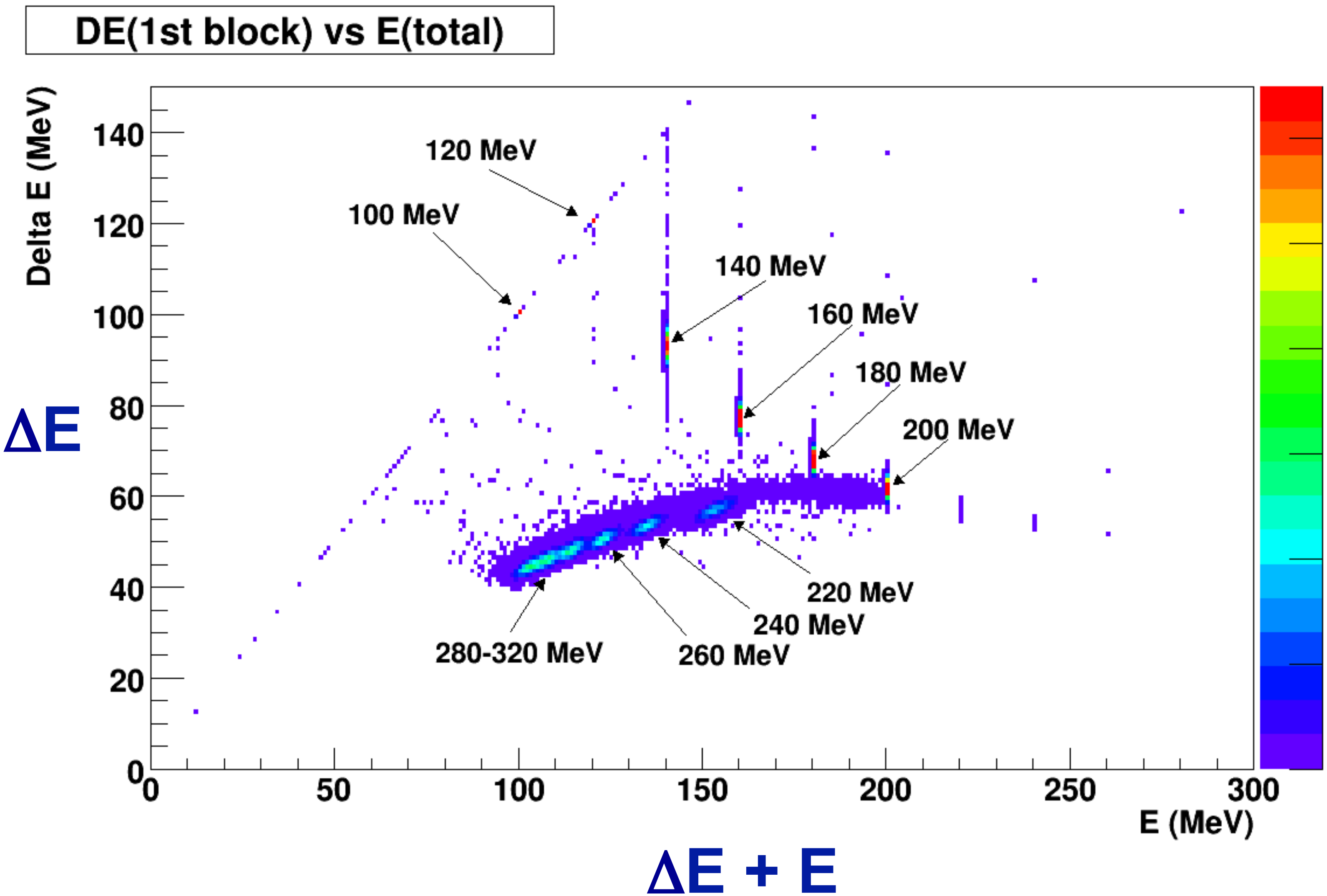
@7 cm 70 % of incident beam is detected

90% Photopeak efficiency vs crystal length

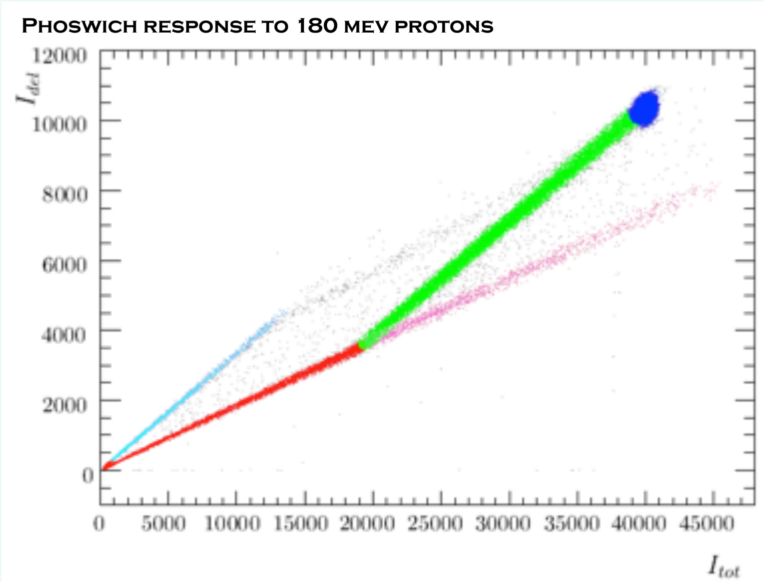


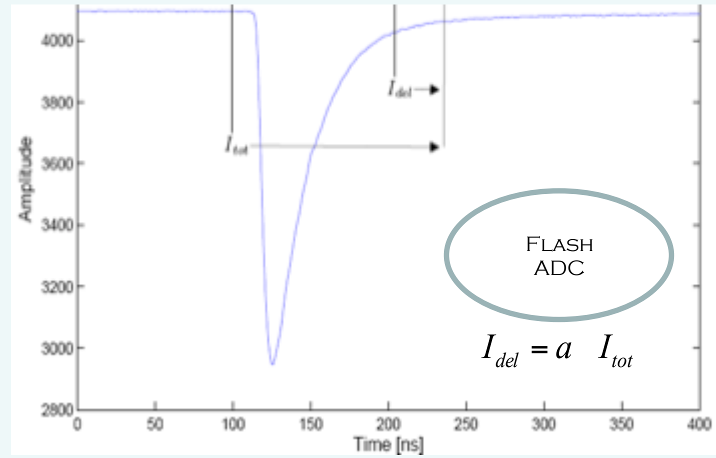
>15 cm has NO influence on detection efficiency

PROTONS in Phoswich: ΔE vs ΔE+ E

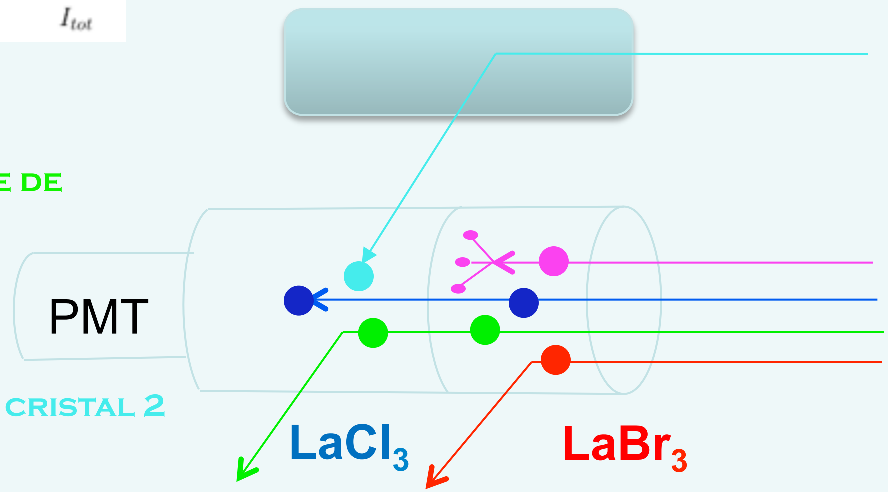


Phoswich: repuesta a PROTONES de 150 y 180 MeV





- PROTON FRENADO EN LOS DOS CRISTALES
- PROTON ESCAPANDO DEJANDO UNA PARTE DE SU ENERGIA
- PROTON SALIENDO DESDE EL LABR
- PROTON PARADO EN EL PRIMER CRISTAL
- PROTON ENTRANDO DIRECTAMENTE EN EL CRISTAL 2



Conclusiones

No hay un detector universal para todo
Tampoco hay una instalación para todos los experimentos

Es necesario Ideas novedosas en el análisis para sacar toda la información

Es necesario comparar con simulaciones de Monte Carlo

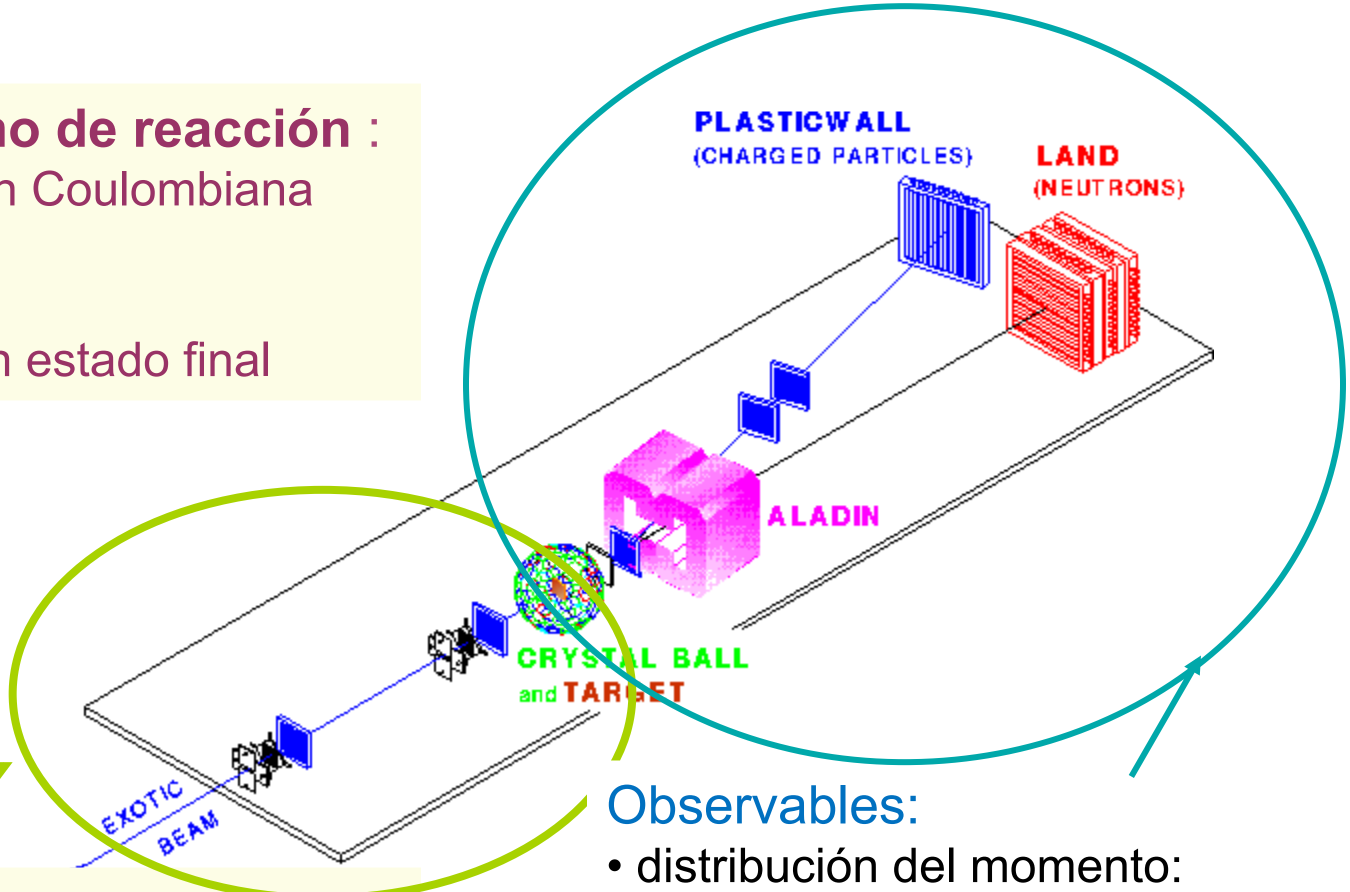
TRIUMF

Laboratorio Nacional de Canadá para la investigación de física nuclear

Picture stone 400 AC
Gotland, Suecia

Reacciones de alta energía: Cave C @GSI → R3B @ FAIR

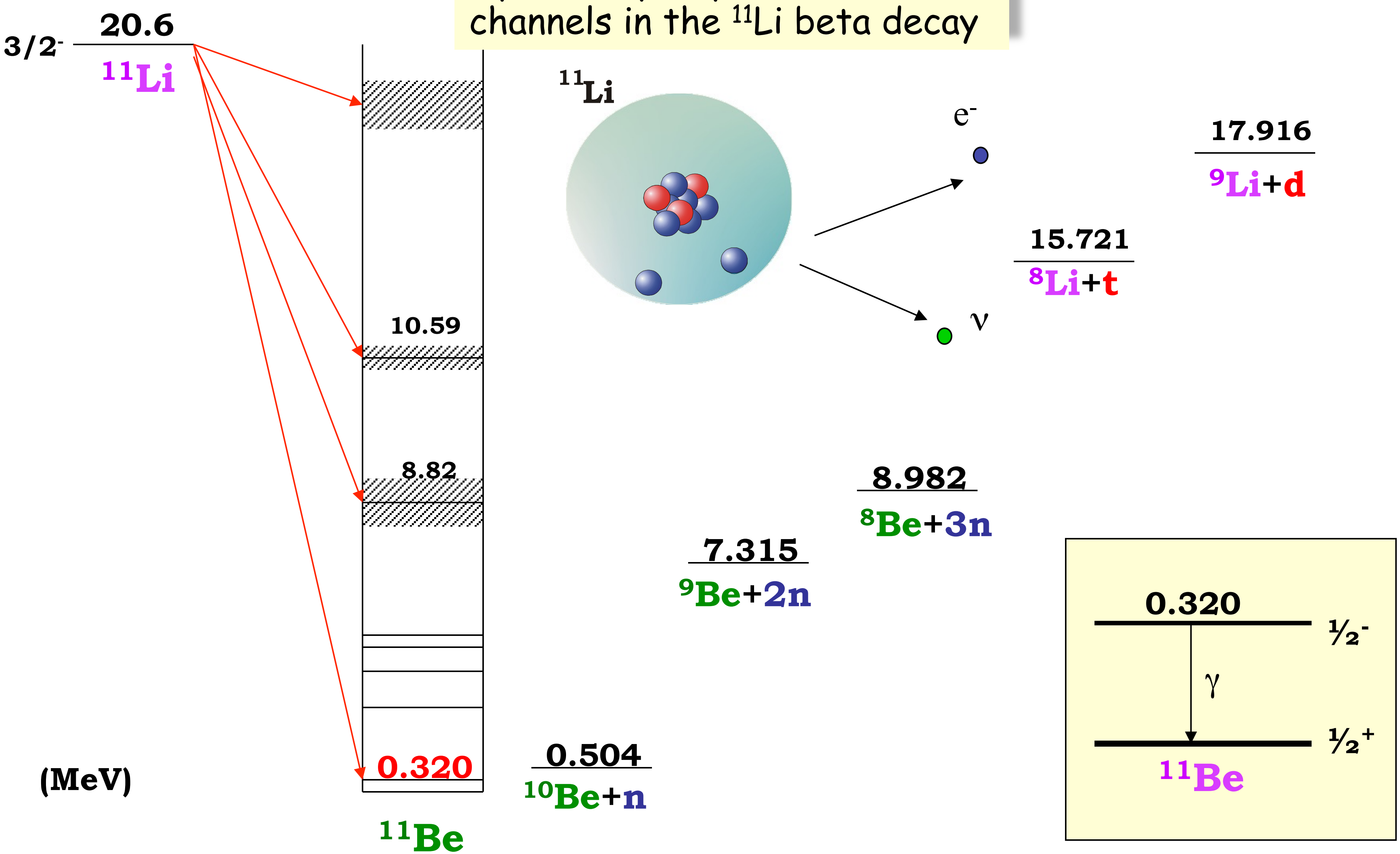
Mecanismo de reacción :
- disociación Coulombiana
- Difracción
- Absorción
- interacción estado final



Variables experimentales:
- Energía del haz 30 → 700 MeV/A
- Target material del blanco C → Pb
- Proyectil ^{6}He → ^{19}C

Observables:
- distribución del momento:
    - del n
    - del fragmento cargada
- la masa invariable
- correlaciones Angulares

Open delayed-particle channels in the ^{11}Li beta decay



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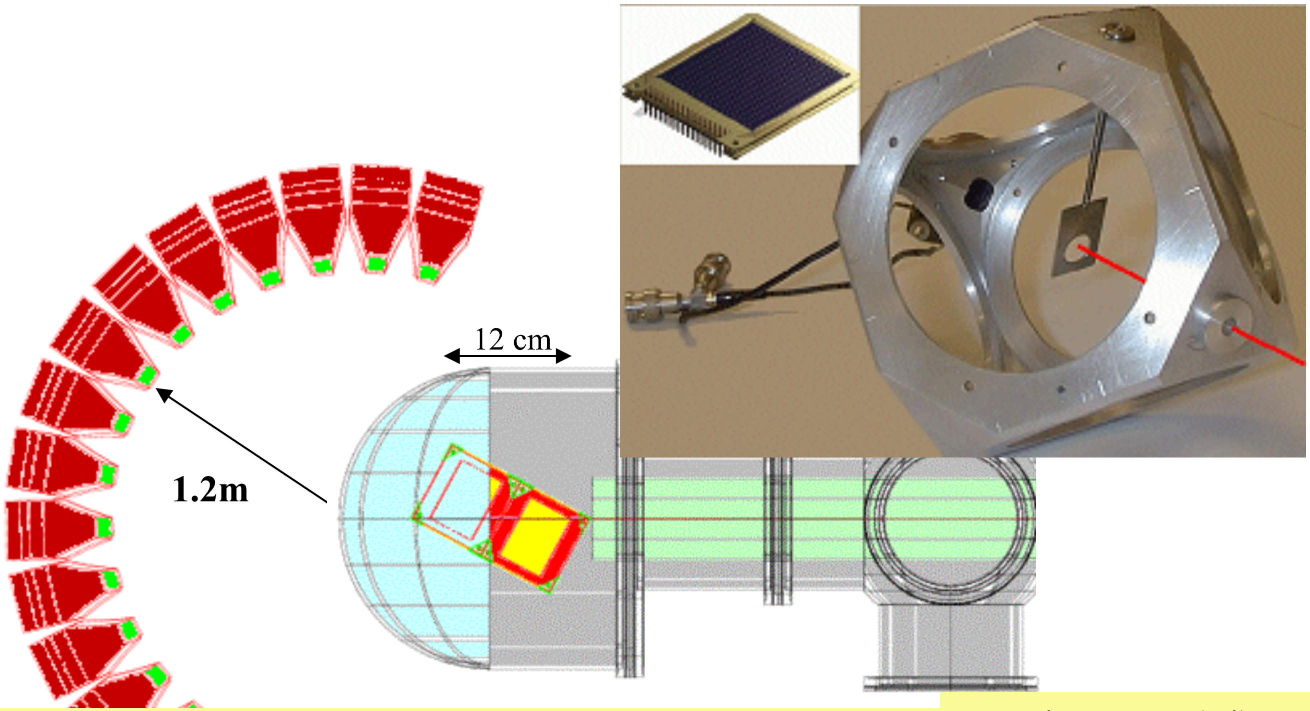
Instituto de Estructura de la Materia

Experimental set-up



Charge particle detection

- ISOCO – cube
- Particle detection efficiency 50 %
  - Double coincidence 25 %
  - Triple coincidence 12 %
- Electron detection efficiency 25 %

- 5 DSSSD (Si)
  - 2x 60 μm (deadlayer 100nm)
  - 60, 2x 300 μm (deadlayer 700 nm)
  - 5x5 cm^2
  - 256 pixels a 3x3 mm^2
  - 32 readouts

3 E-detector (Si)

5x5 cm^2

1000, 1500 μm thick

1 Monolithic (Si)

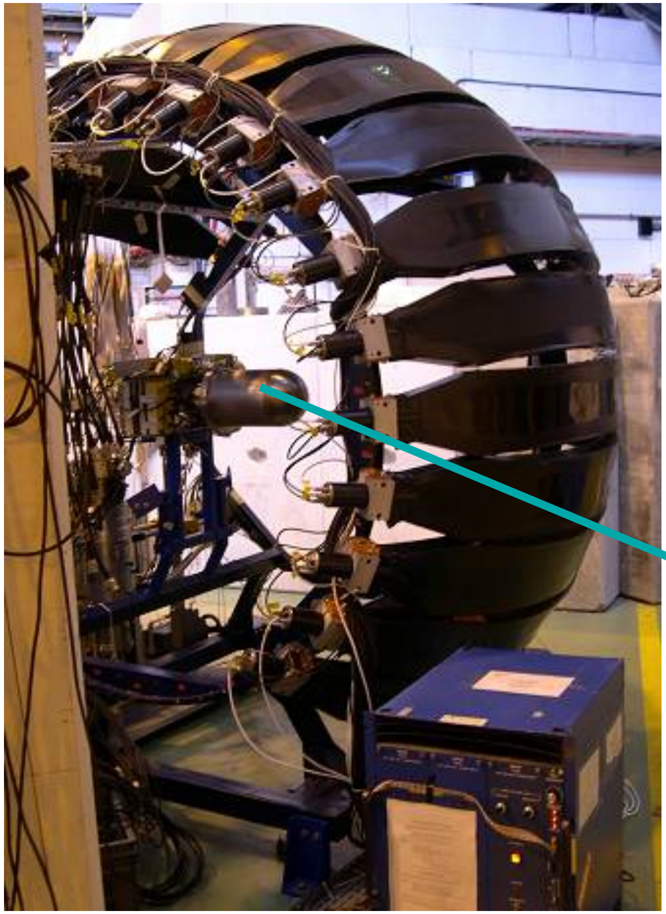
Array of 25 detectors

3x3 mm^2

ΔE: 1 μm

E: 300 μm

IS417: Study of lithium isotopes



ISOLDE experimental hall, beam line LA1, ending with a bell shaped vacuum chamber.

The black paddles in the frame surrounding the vacuum chamber are parts of the TONNERRE n-ToF detector applied here to detect delayed neutrons in coincidence with charged particles.