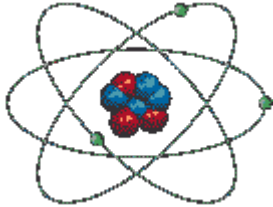




**MINISTERIO
DE ECONOMÍA
Y COMPETITIVIDAD**



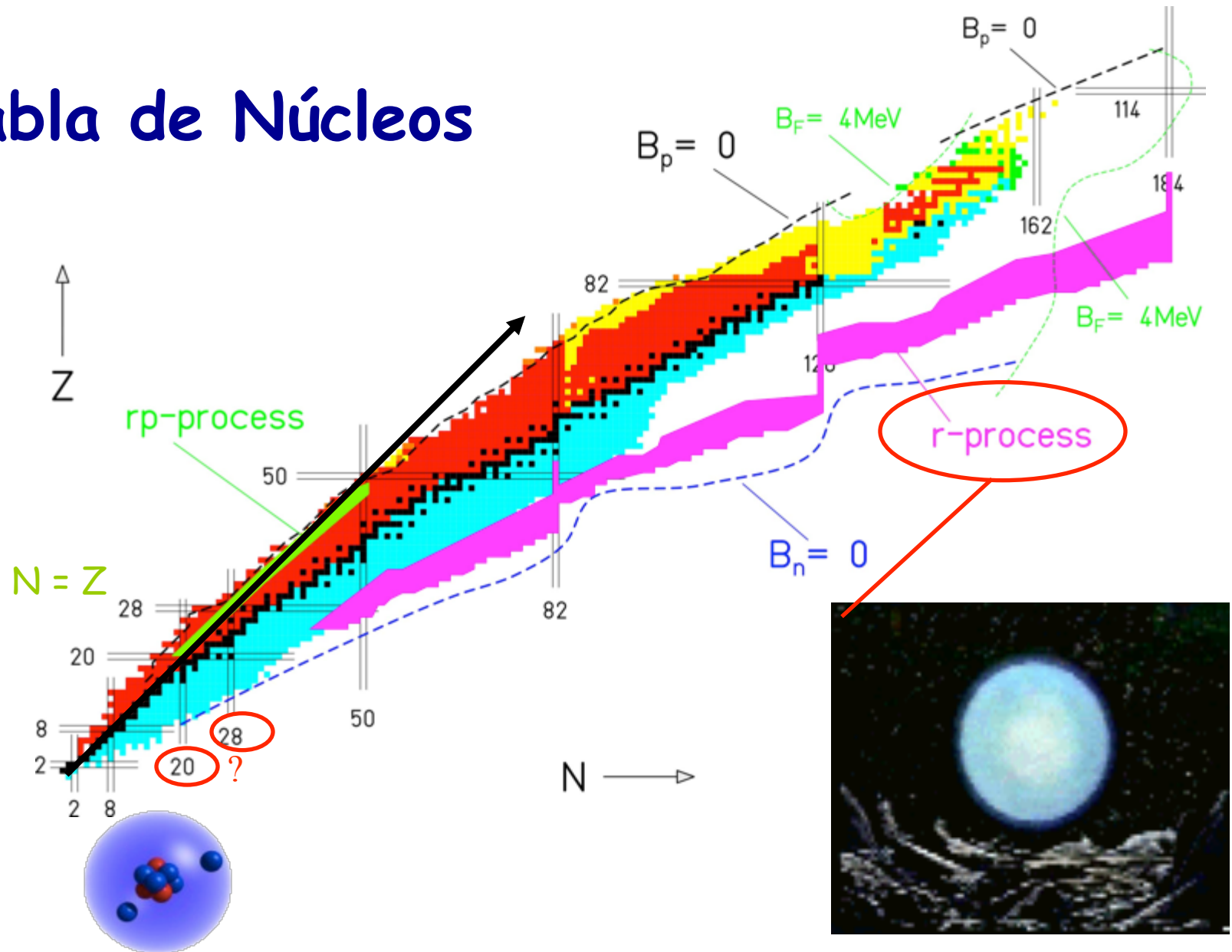
Estudios de Núcleos Exóticos Detectando partículas cargadas

**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.

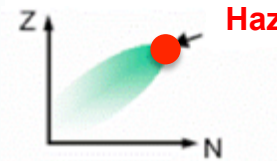
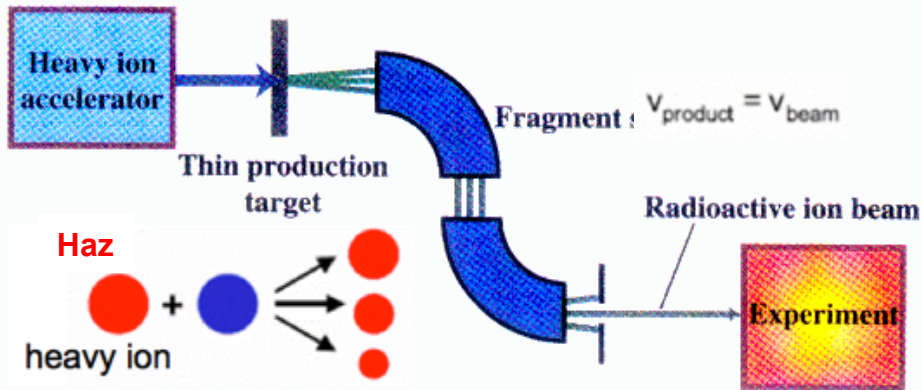
Olof Tengblad
Instituto de Estructura de la Materia - CSIC

Tabla de Núcleos



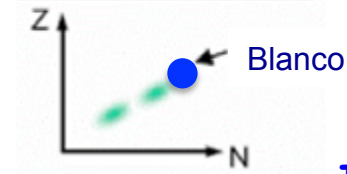
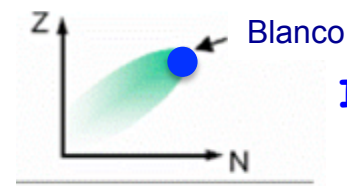
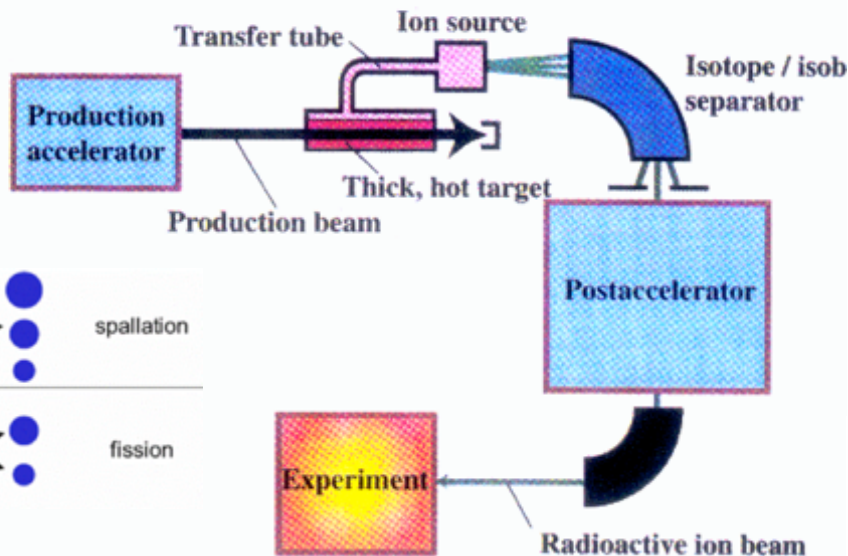
Producción de Haces Radioactivas

Projectile Fragmentation



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

ISOL



Variable energy, high intensity, good beam qualities

FAIR 1 GeV

GSI 700 MeV

GANIL 50 MeV

HIE - ISOLDE 10 MeV

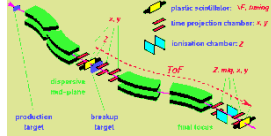
ISOLDE 0

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

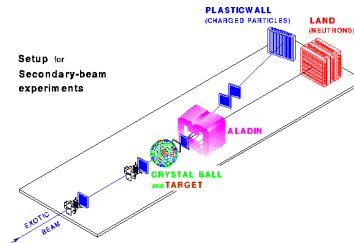
GSI

Reacciones a
 $E_r = 700 \text{ MeV/u}$

Reaction
Cross Sections



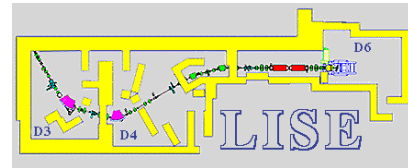
Momentum
Distributions



Unbound
Nuclei

GANIL

Reacciones a
 $E_r = 30-60 \text{ MeV/u}$



Elastic
Scattering

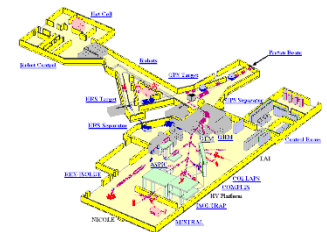
Spins
Moments

ISOLDE

Desintegración
beta $E_r = 0$

Masses

Beta
Decay



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

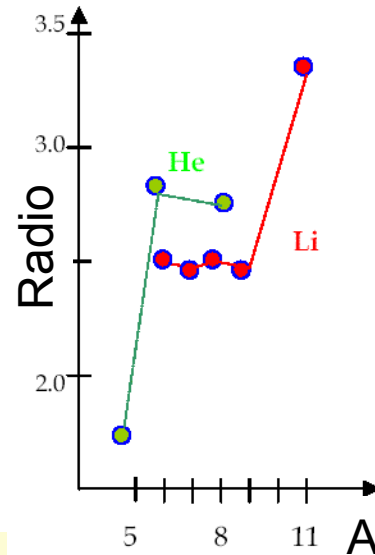
Experimento inicial

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

Li / He
790 MeV/u

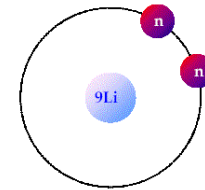


Be
C
Al

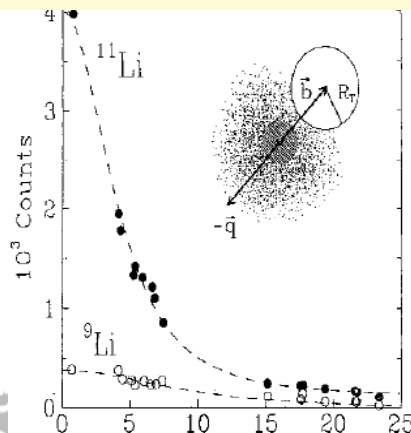


Modelo

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



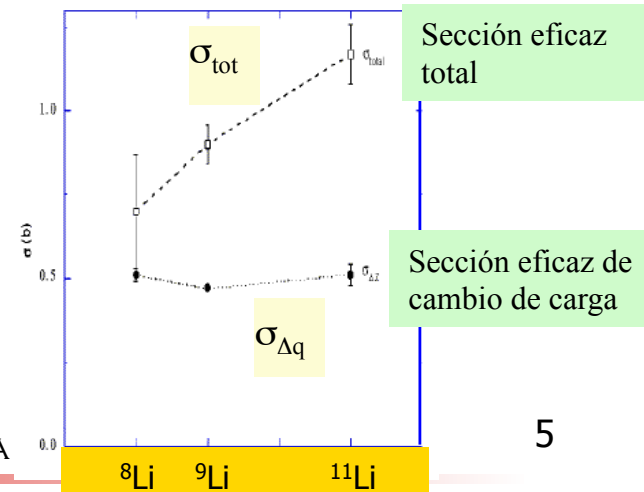
R. Anne et.al.
Phys.Lett B250(1990)19



distribución Angular del Neutron

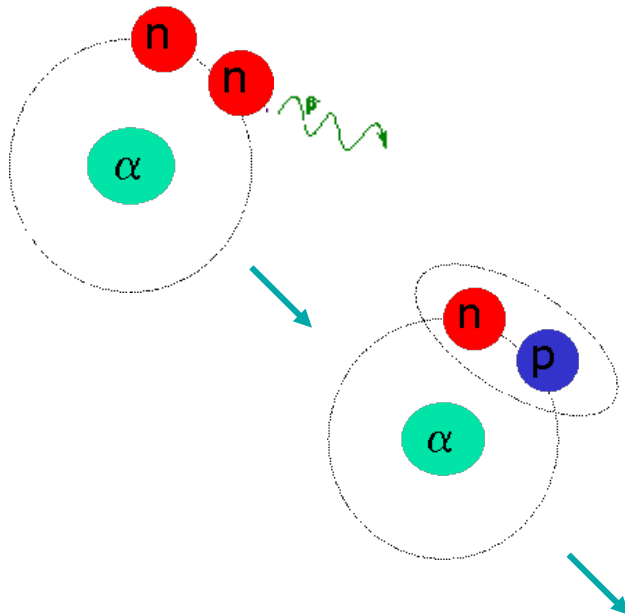
Verificación del modelo

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

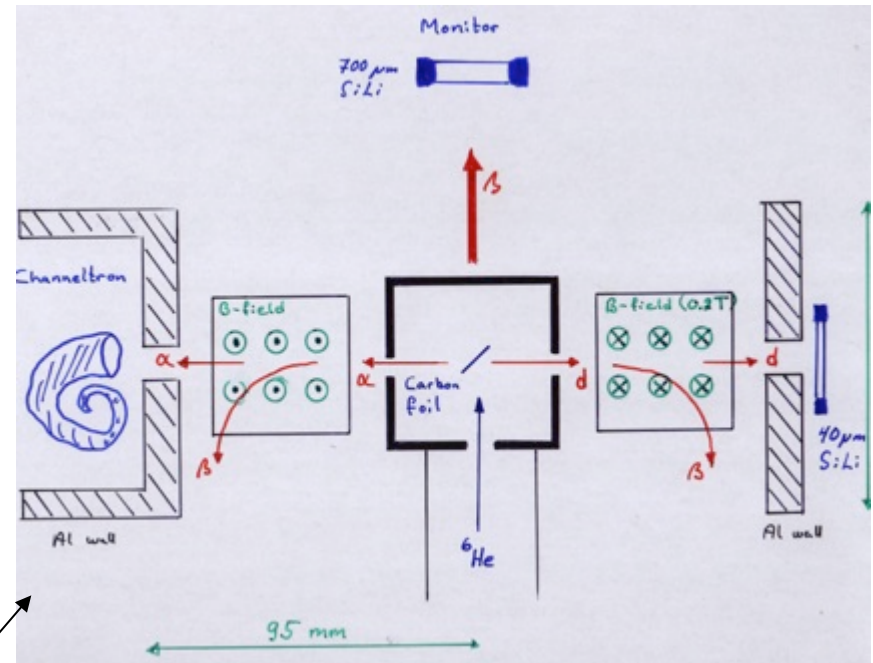


INSTITUTO DE ESTRUCTURA

También podemos estudiar este fenómeno en
reposito - en desintegración beta



${}^6\text{He}$: α -core con un halo de $2n$



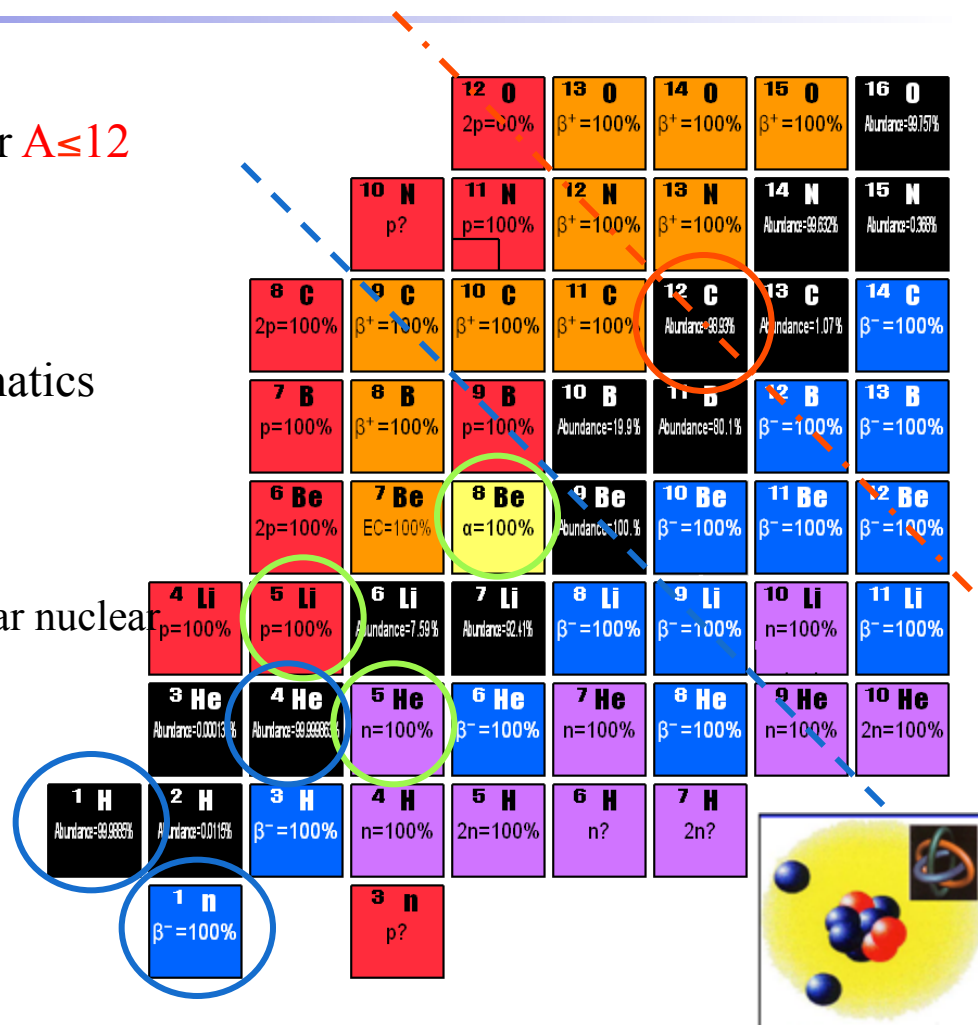
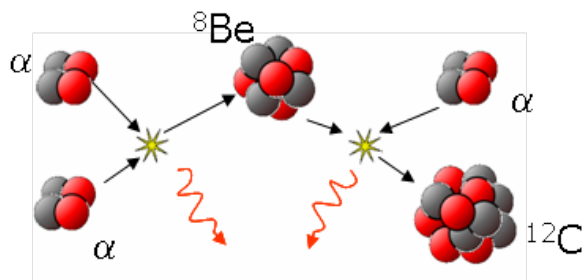
First observation of beta-delayed deuteron emission
Phys Let B235 (1990) 30

24h para 147 coincidencias $\rightarrow$ rama de desintegración $2.8 \cdot 10^{-6}$

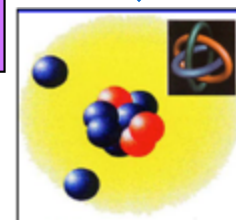
Light exotic Nuclei

- “Exact” A-body calculations possible for $A \leq 12$
 - 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
 $4\text{He} + 4\text{He} \leftrightarrow {}^8\text{Be}$
 ${}^8\text{Be} + 4\text{He} \leftrightarrow {}^{12}\text{C} + \gamma + 7.367 \text{ MeV}$

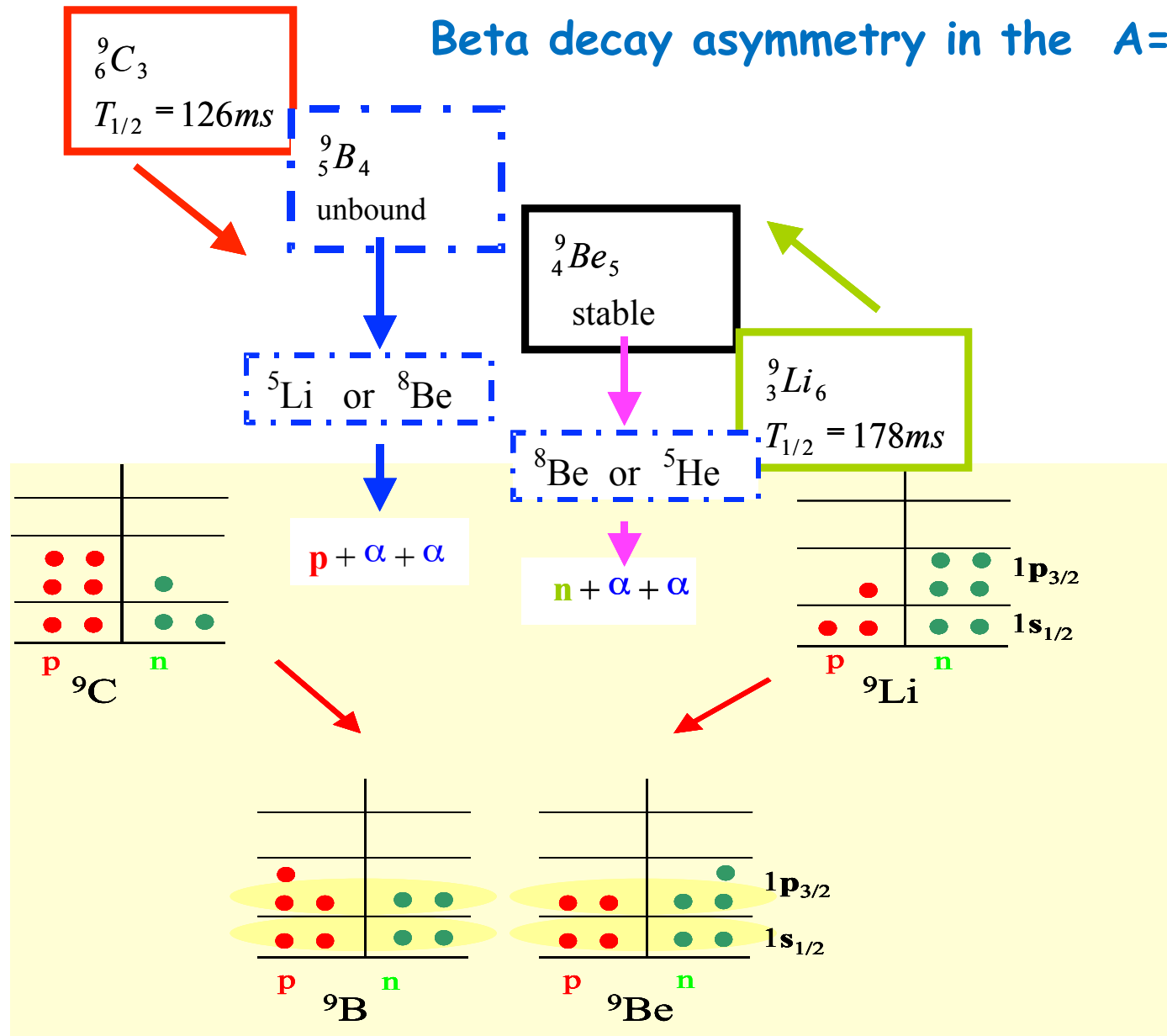


clustering

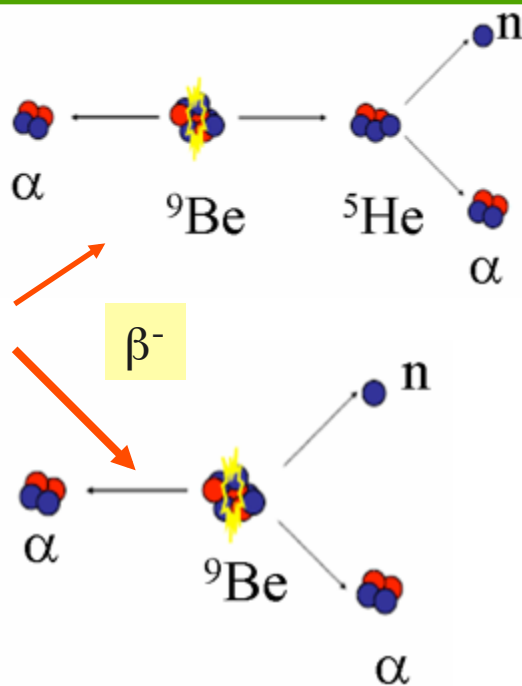
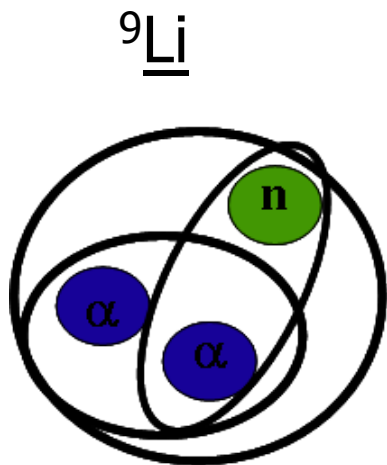
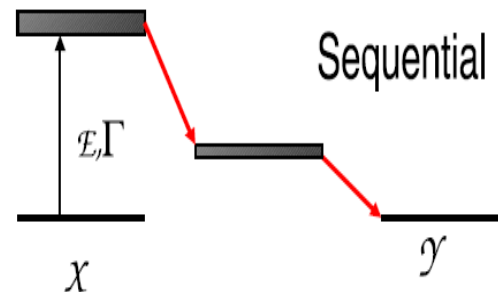
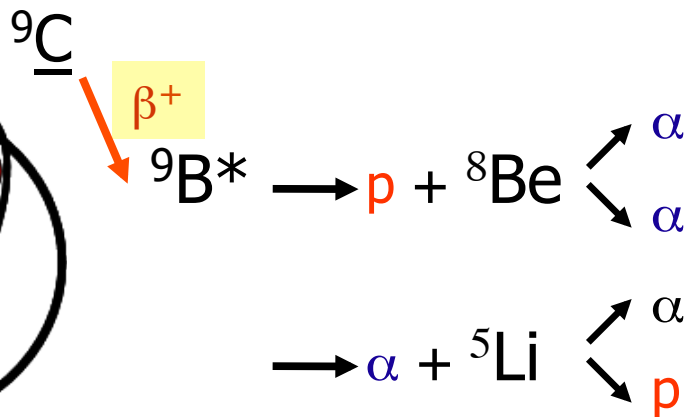
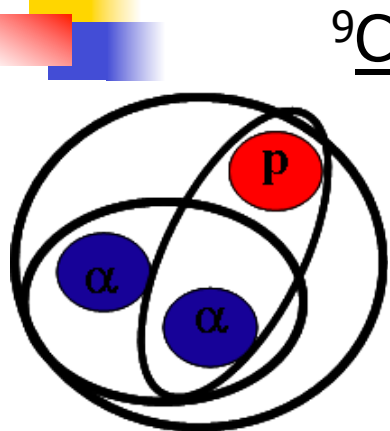


$^{11}\text{Li} \rightarrow$
 Borromean
 Halo

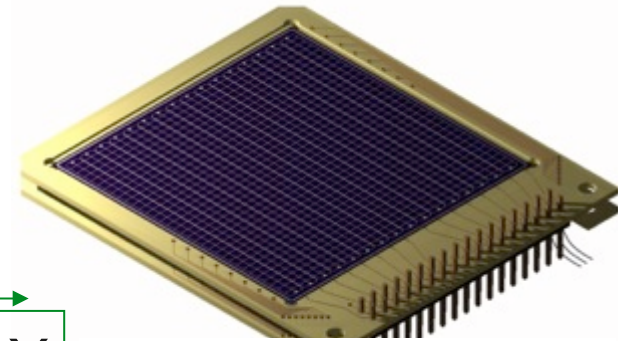
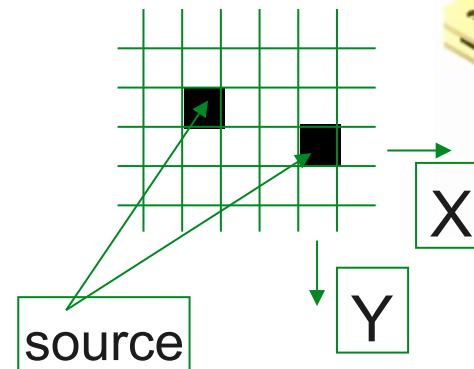
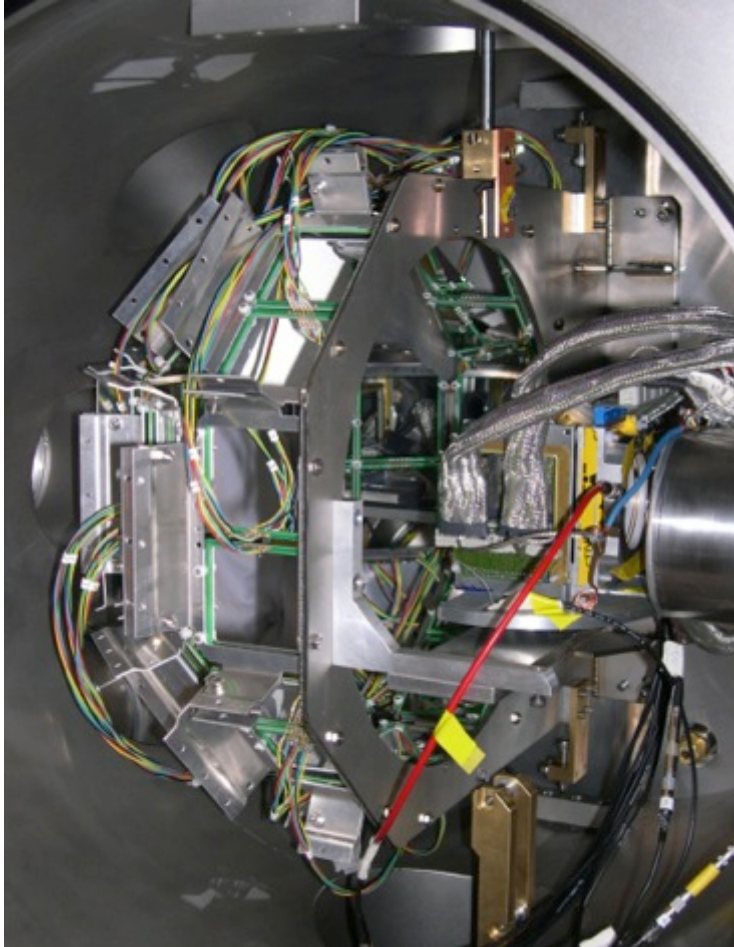
Beta decay asymmetry in the $A=9$ isobar



break-up mechanism: α -clustering?

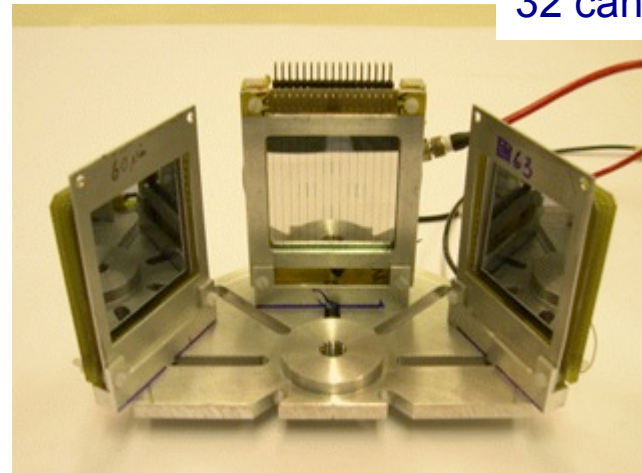


Dispositivo experimental @ ISOLDE



50x50 mm²
16x16 tiras de 3x50mm²

256 pixeles de 9 mm²
32 canales de electrónica



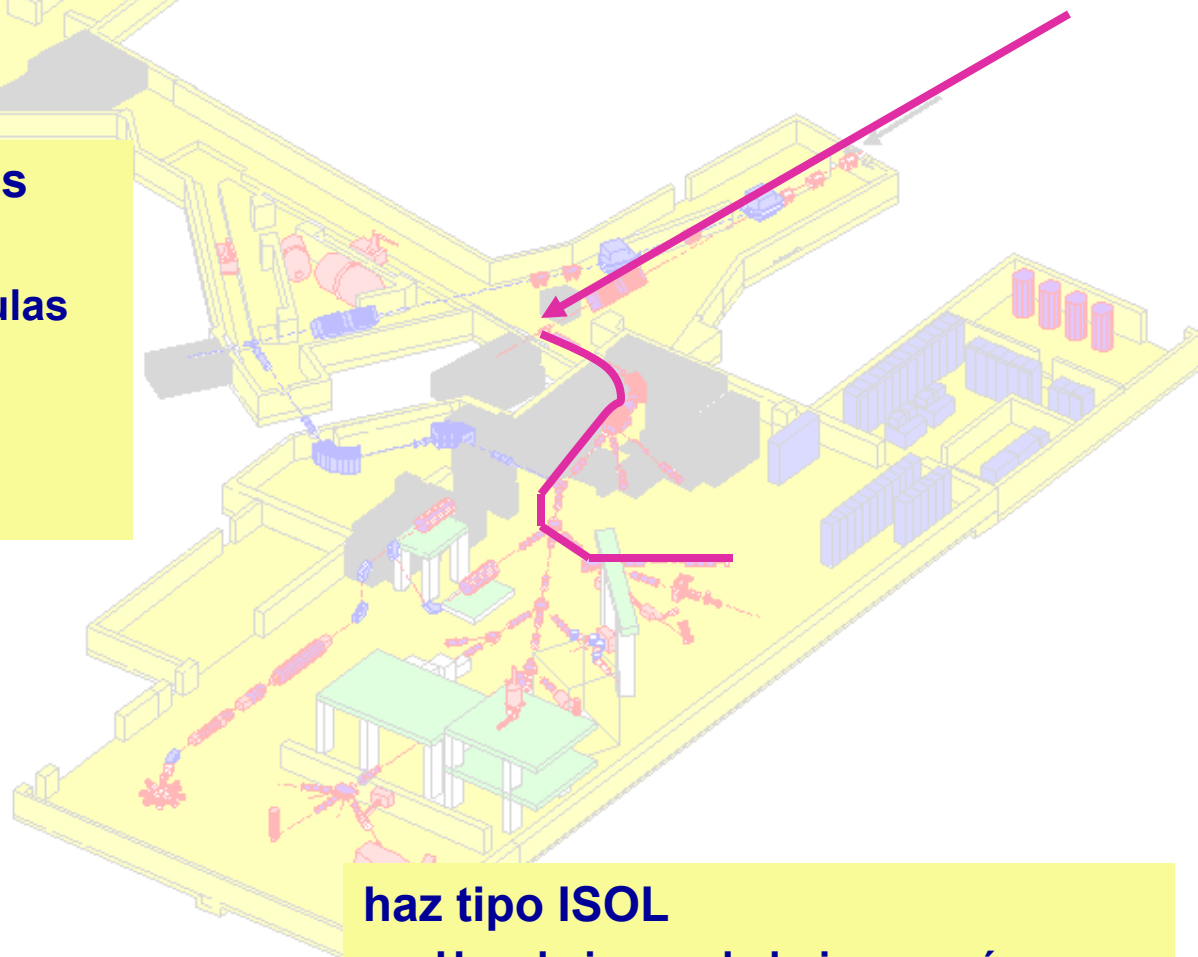
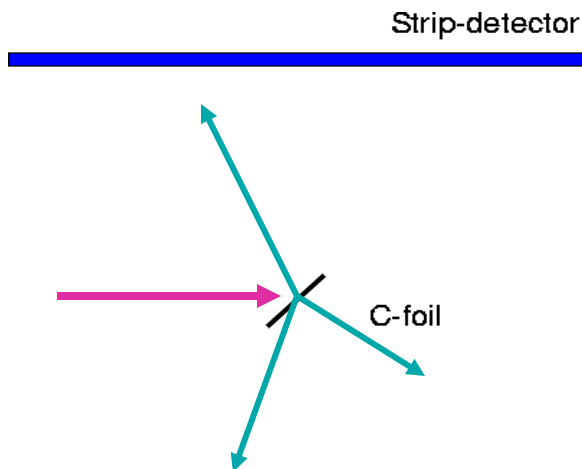
ISOLDE Si-Ball: 36x4 quadrants of 1000 micron Si
L.M. Fraile, NIMA513 (2003) 287.

3 DSSSD telescopes
60 + 1500 micron Si

Experimentos de desintegración β @ ISOLDE

Detectors de Si Segmentadas

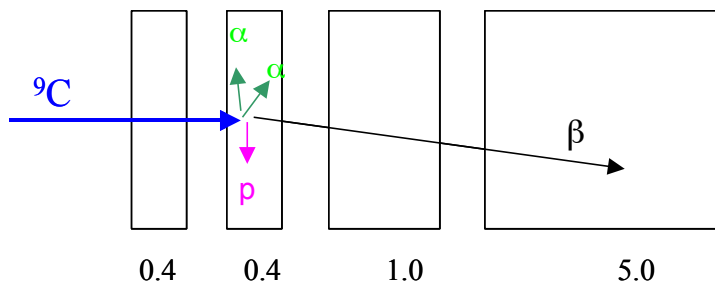
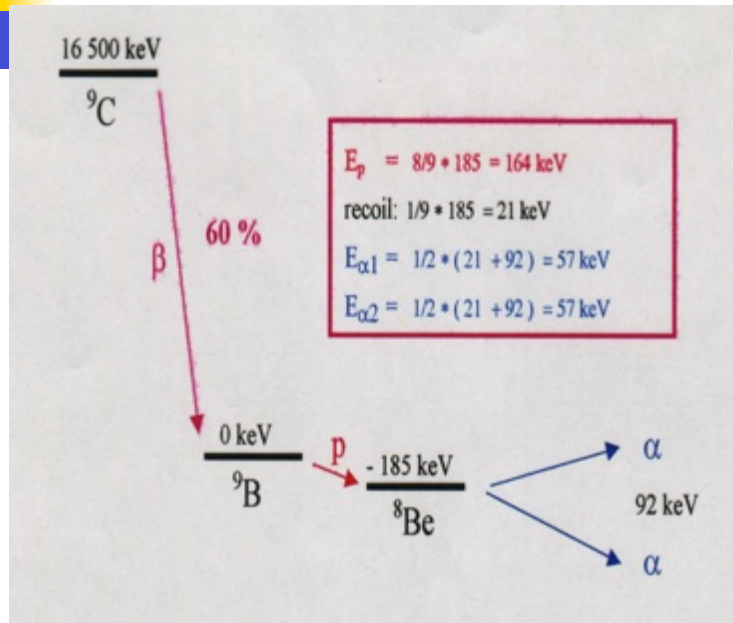
- Angulo solido grande
 - detecta todas las partículas
- Alta Segmentación
 - Eventos separados
NO sumadas



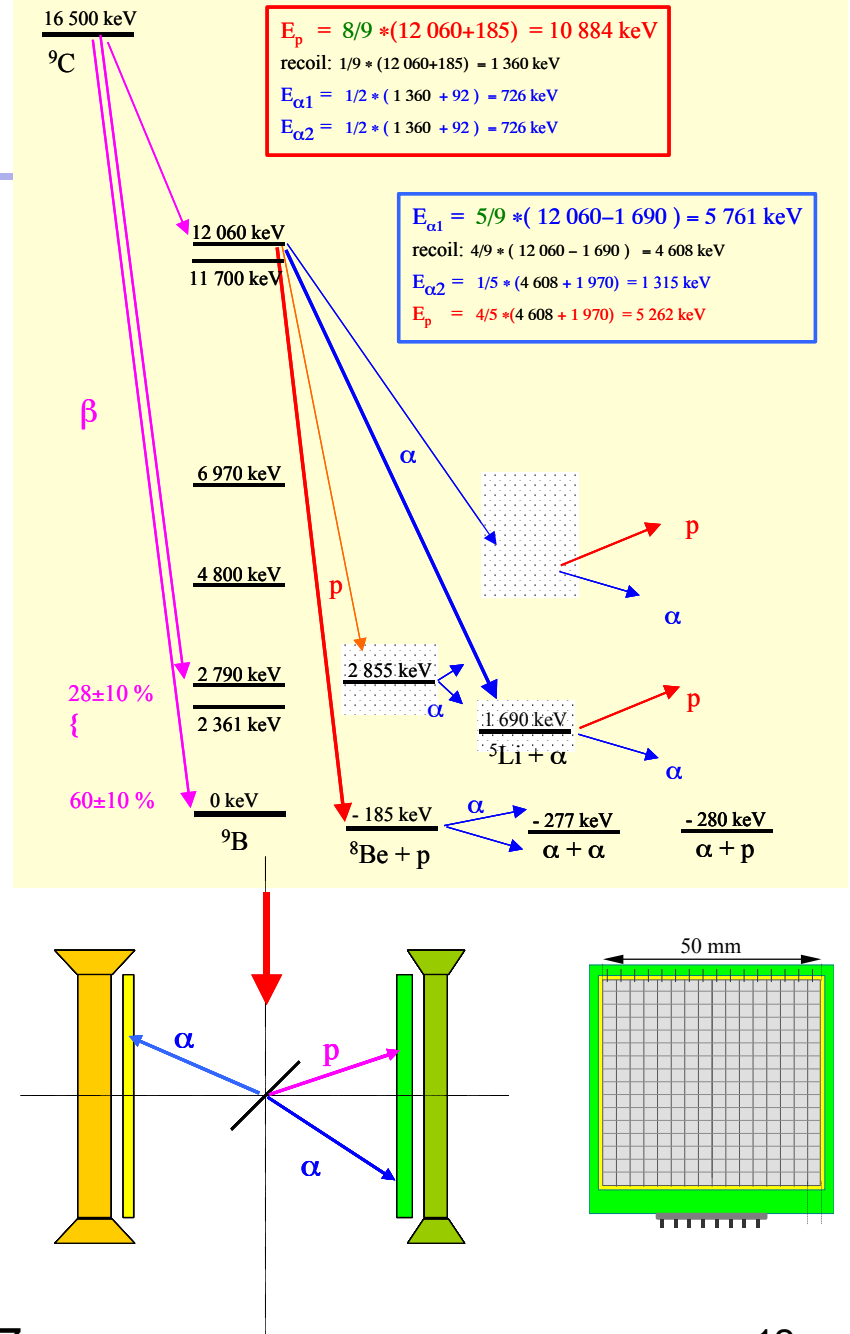
haz tipo ISOL

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

ISOBAR A=9



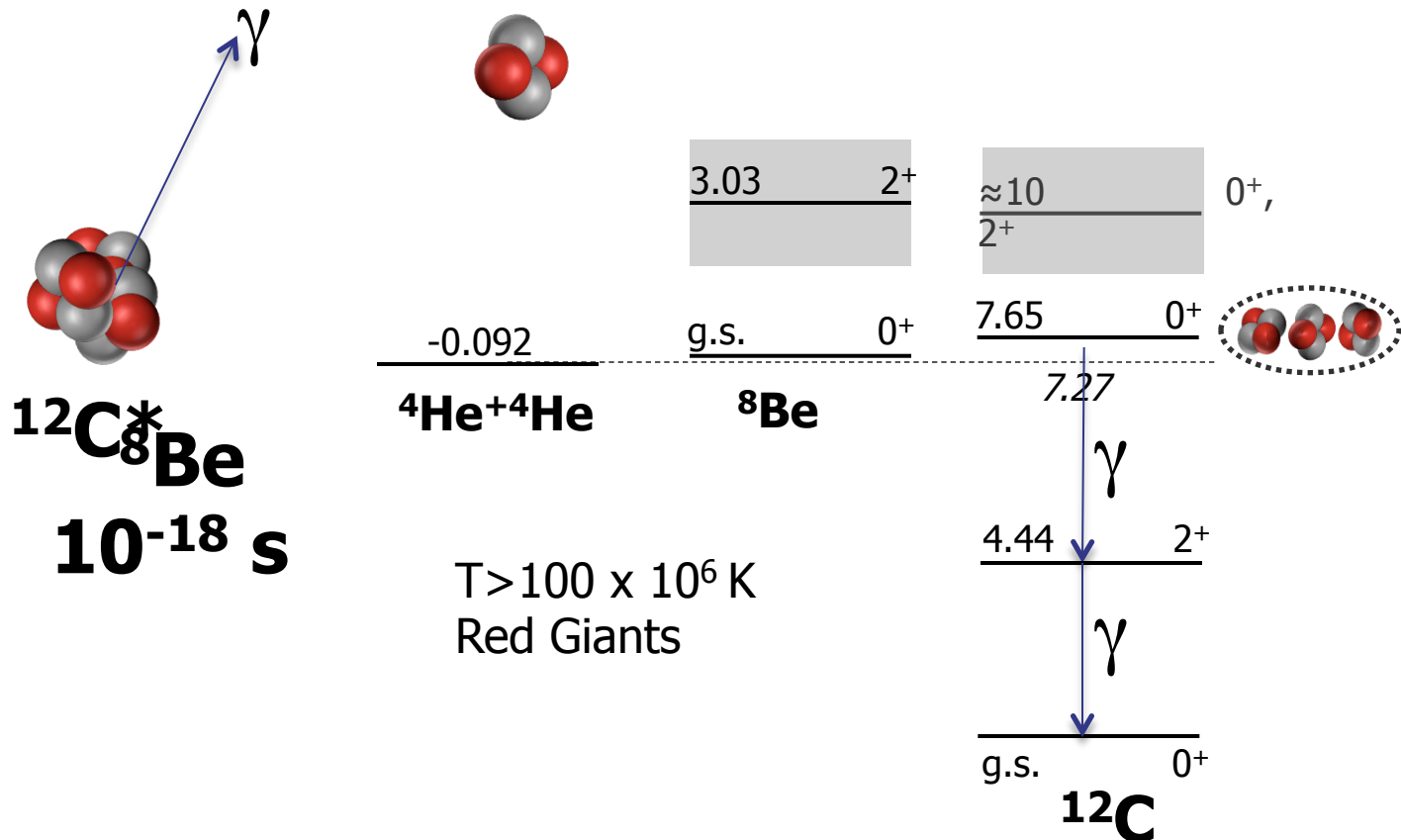
D. Mikolas et.al. Phys. Rev C37(1988)766



Triple- α Process



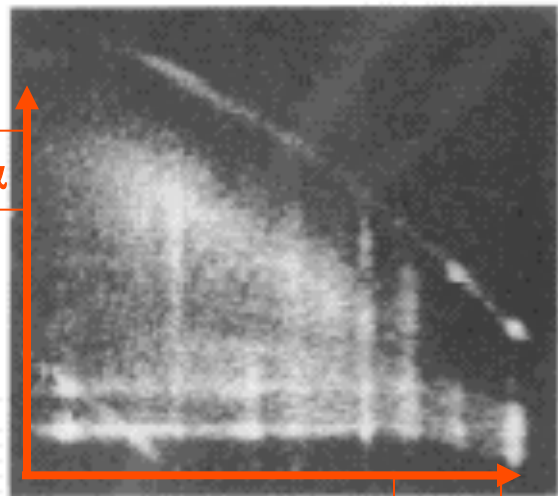
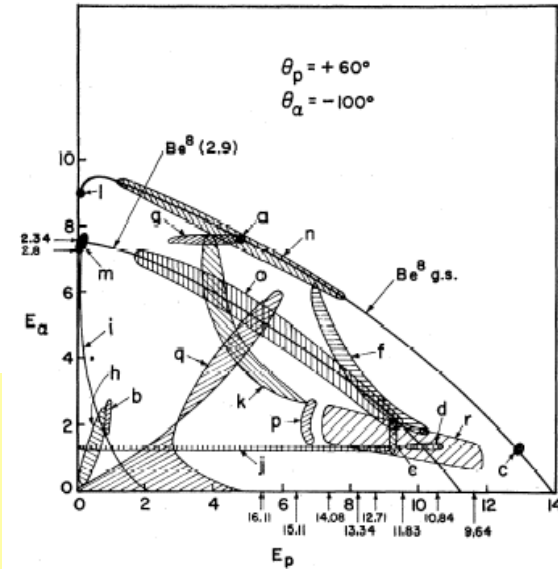
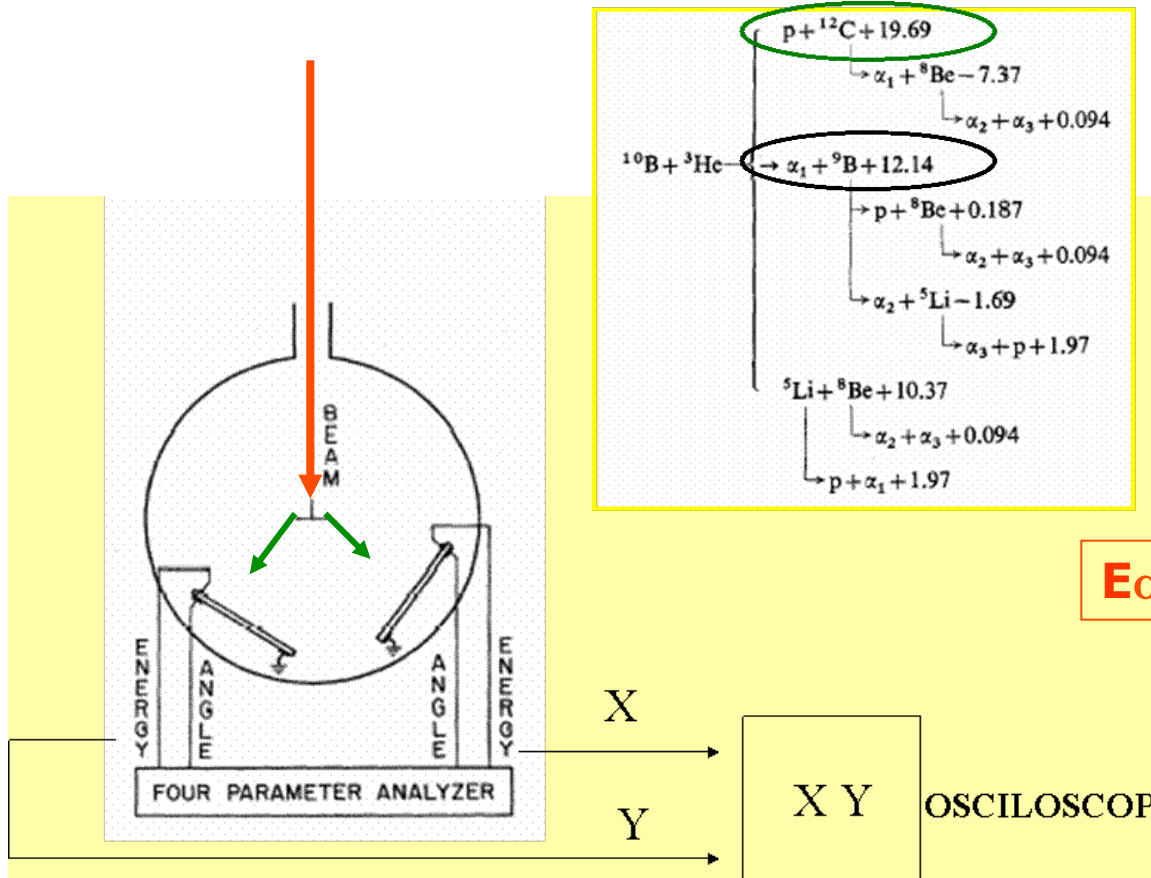
N6. A State in C^{12} Predicted from Astrophysical Evidence.* F. HOYLE, *Cambridge University* AND D. N. F. DUNBAR, W. A. WENZEL, AND W. WHALING, *Kellogg Radiation Laboratory, California Institute of Technology*.—It is
 Phys. Rev. 92:1095 (1953)



Reaction studies in the 60ies



Waggoner et al., NPA 88(1966)81



E_p

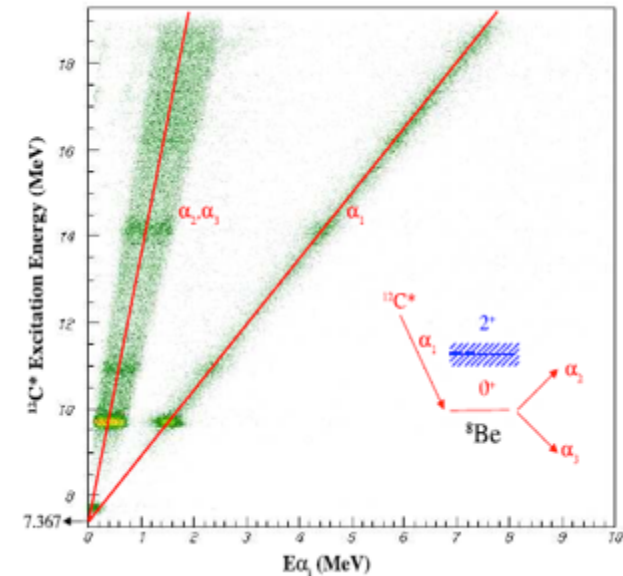
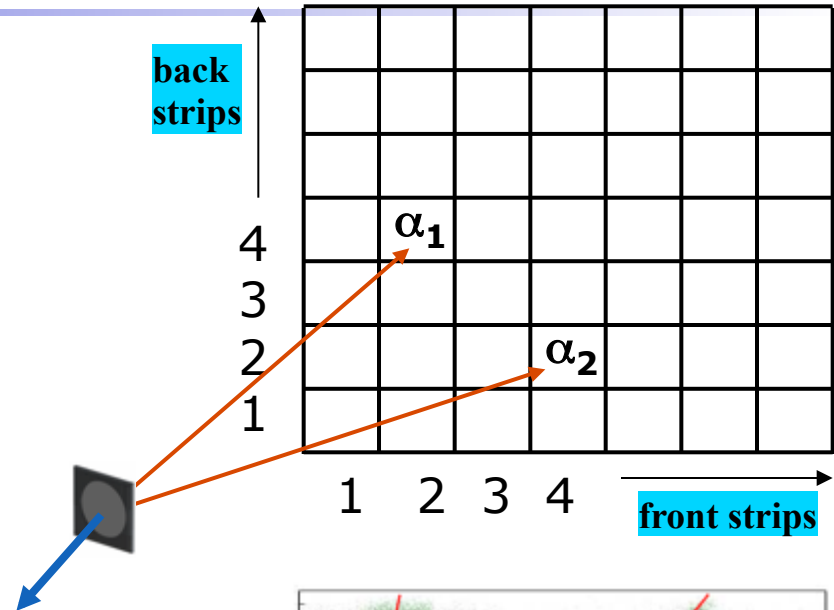
Podemos mejorar estas medidas hoy?

■ 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.

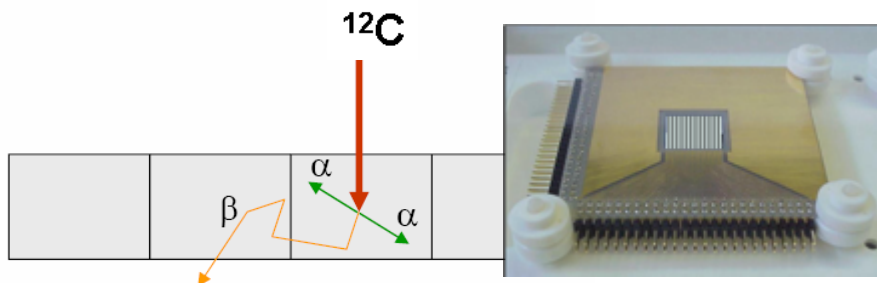
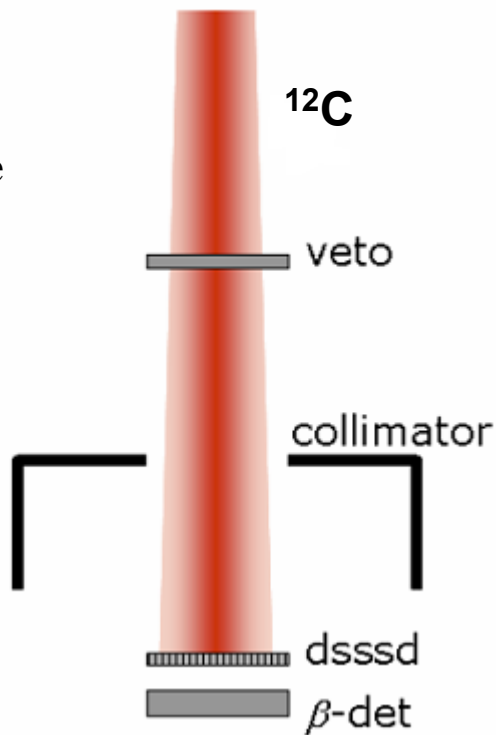


$^{12}\text{C}^*$

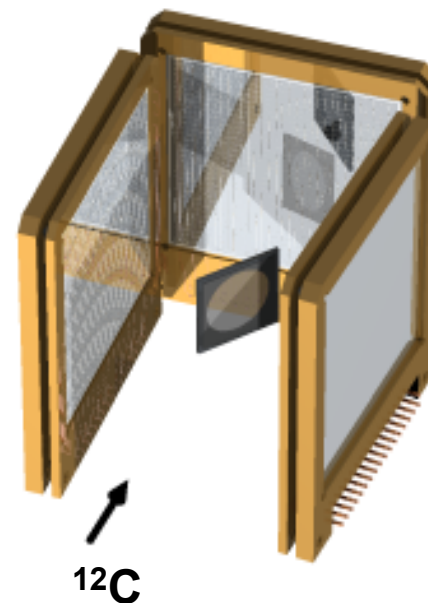
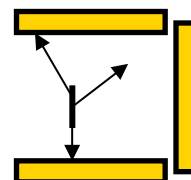
estudios en instalaciones diferentes y con métodos distintos



R. Raabe

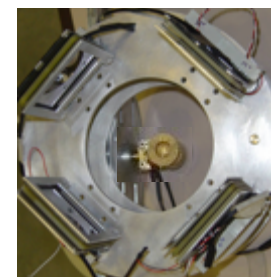


H. Fynbo



Reaction studies @ CMAM tandem
 $^3\text{He} + ^{10}\text{B} \rightarrow ^{12}\text{C}^* \rightarrow \text{p} + \alpha + \alpha + \alpha$

O. Tengblad

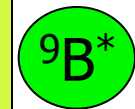
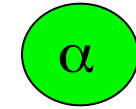
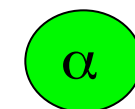
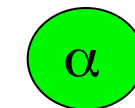
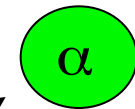
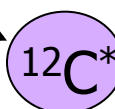
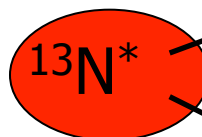
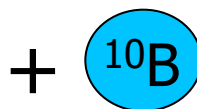


Low energy reaction study @ Madrid Tandem accelerator – how to produce the $^{12}\text{C}^*$ states



^3He @ 2.5-8.5 MeV

17 mg/cm²



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 $^3\text{He} + ^{10}\text{B}$ 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 |

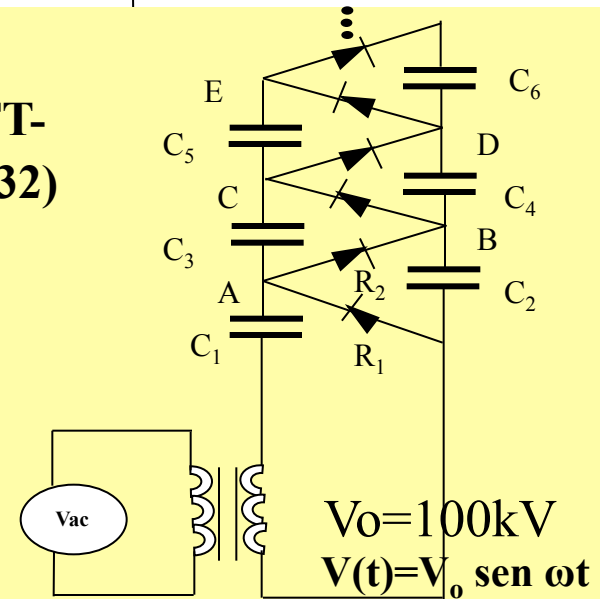
2003

- | | |
|-------------|--|
| Mar. | Official opening ceremony of the CMAM |
|-------------|--|

THE MADRID 5MV TANDETRON



COCKCROFT-WALTON(1932)



- ▶ **Electrostatic Ion Accelerator** $V_{\max} = 5 \text{ MV}$
- ▶ **Tandem type** $E_{\max} = 5 \cdot (Z+1) \text{ MeV}$
- ▶ 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

$$E = V * (q + 1) \text{ MeV}$$

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 Si^{6+} : 3 μA

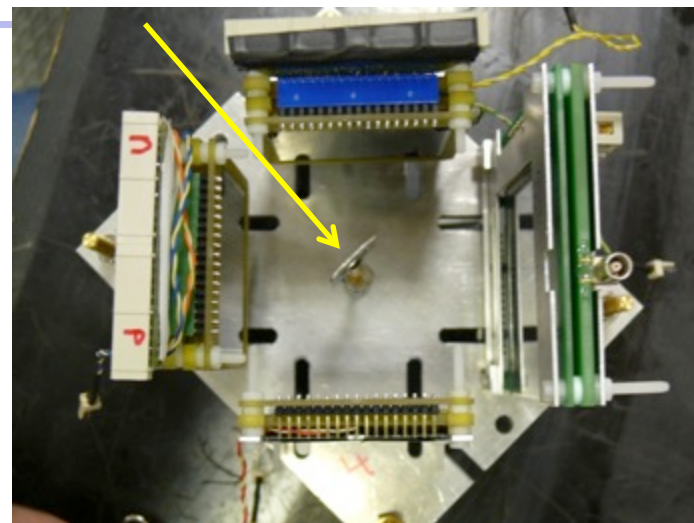
15 MeV Au^{2+} : 16 μA

20 MeV Au^{3+} : 21 μA

55 MeV Au^{10+} : 50 nA



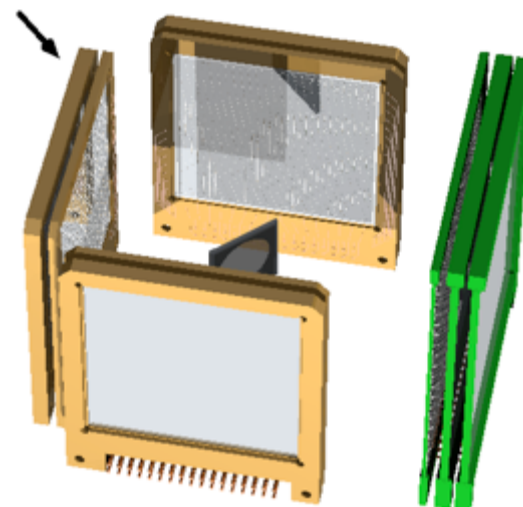
$^{10}\text{B}(^3\text{He},p)\alpha\alpha\alpha$ $^{11}\text{B}(^3\text{He},d)\alpha\alpha\alpha$ ^3He @ 4.9 and 8.5 MeV from 5 MV Tandetron



Targets:

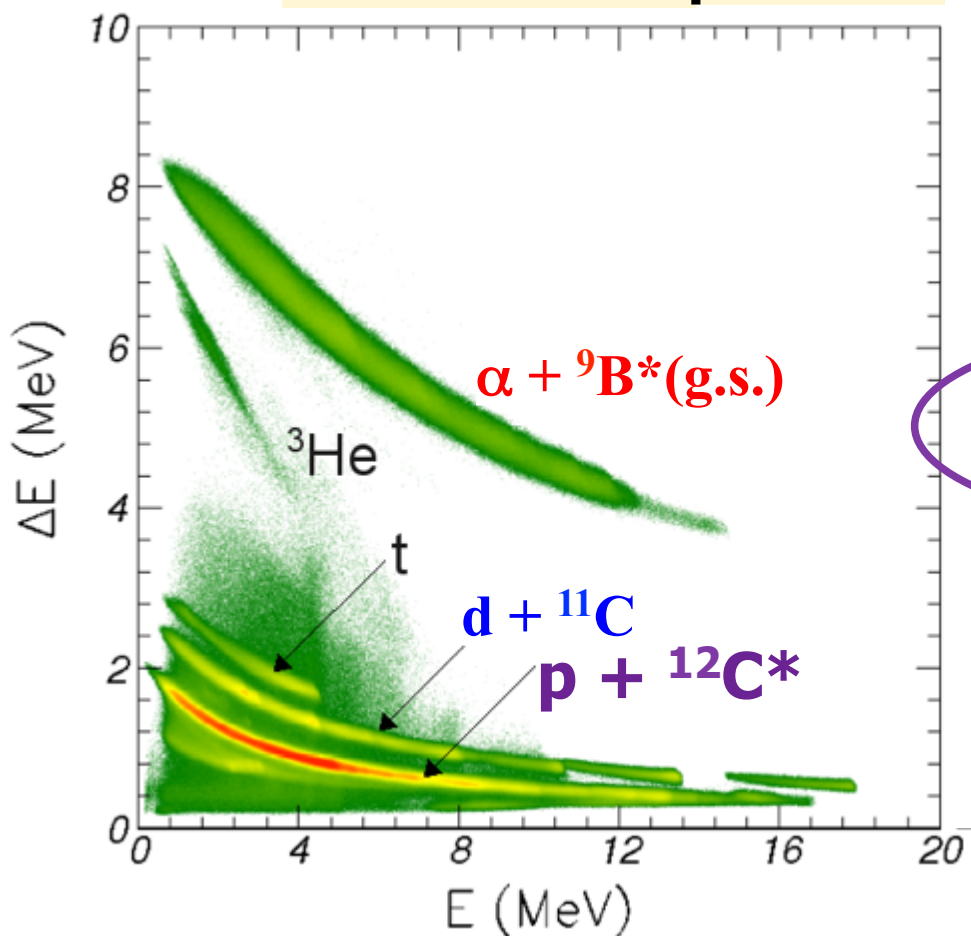
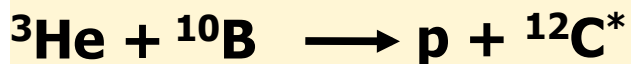
18.9 $\mu\text{g}/\text{cm}^2$	^{10}B	4 $\mu\text{g}/\text{cm}^2$ C-backing
22.0 $\mu\text{g}/\text{cm}^2$	^{11}B	4 $\mu\text{g}/\text{cm}^2$ C-backing

DSSD + PAD



$\Omega = 38\% \text{ of } 4\pi$

Identificación del canal de reacción



α

p

ΔE

E

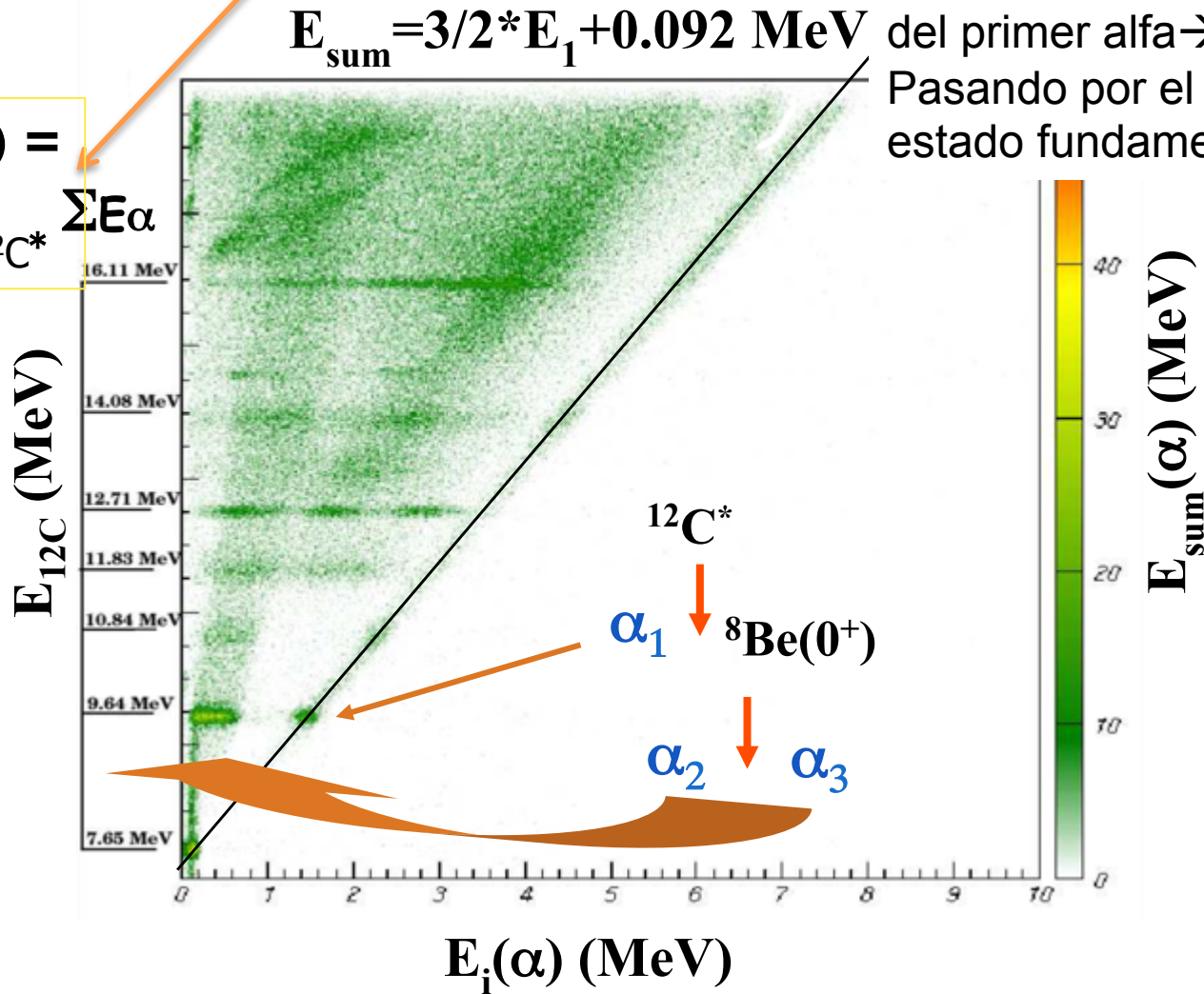
Reaction products	Q-Value (MeV)
${}^{13}\text{N} + \gamma$	21.63668
${}^{12}\text{C} + p$	19.69315
$p + 3\alpha$	12.41836
${}^8\text{Be} + p + \alpha$	12.32652
${}^9\text{B} + \alpha$	12.14145
${}^5\text{Li} + 2\alpha$	10.45334
${}^{11}\text{B} + 2p$	3.73607
${}^{11}\text{C} + d$	3.19574
${}^{12}\text{N}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

Seleccionando el canal de protón: $p + \alpha + \alpha + \alpha$ 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

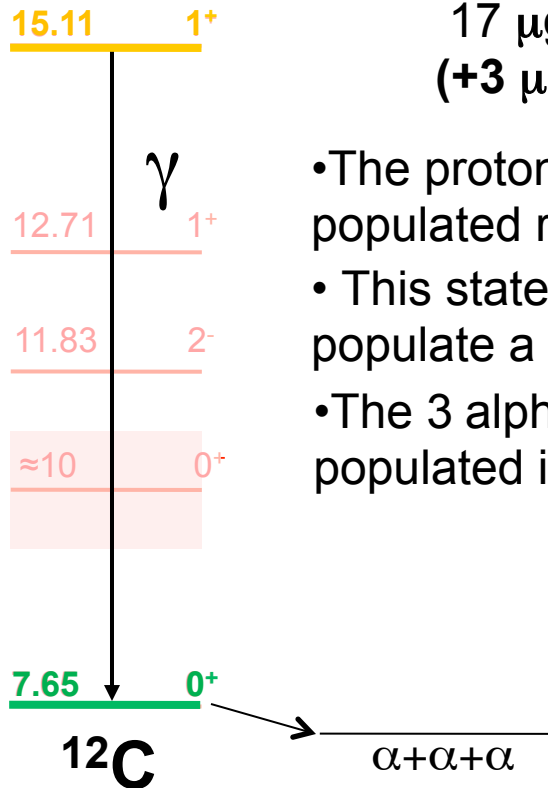
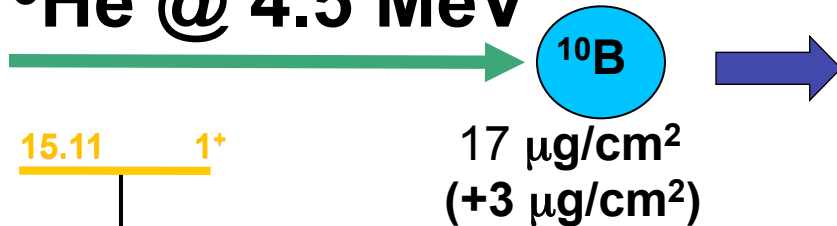
La linea indica la energia
del primer alfa → **Secuencial**
Pasando por el
estado fundamental de ^8Be

SUMA($3E_\alpha$) =
el estado
de excitación $^{12}\text{C}^*$

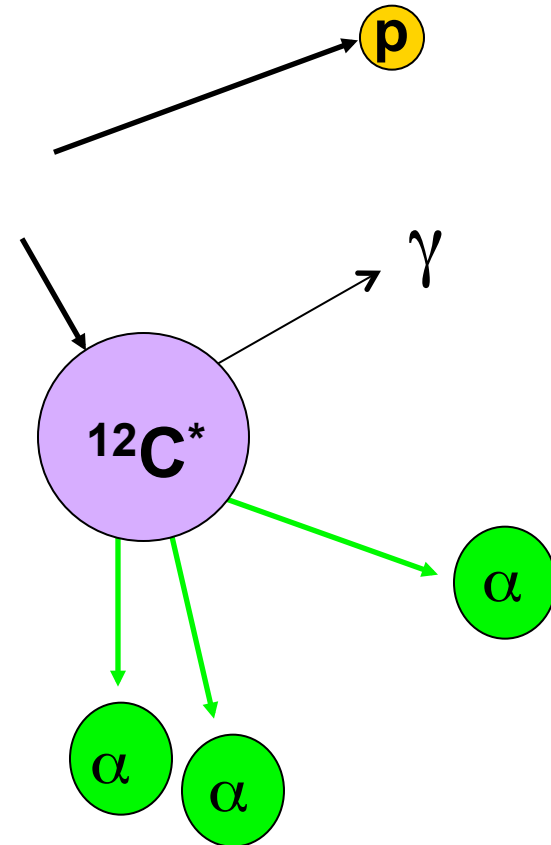


Indirect Detection of γ -decay

^3He @ 4.5 MeV

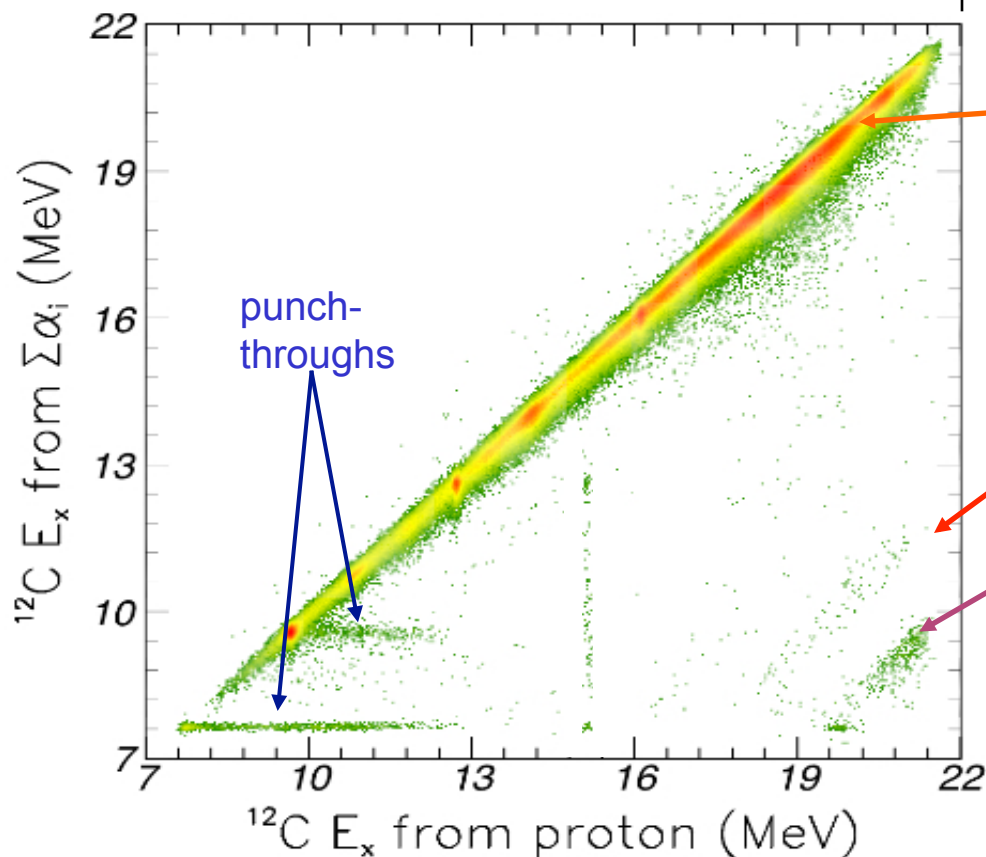


- The proton gives initial populated resonance in ^{12}C
- This state can emit γ and populate a lower excited state
- The 3 alphas give resonance populated in ^{12}C *after* γ -decay



γ -decay of the T=1 level @ 15.11 MeV

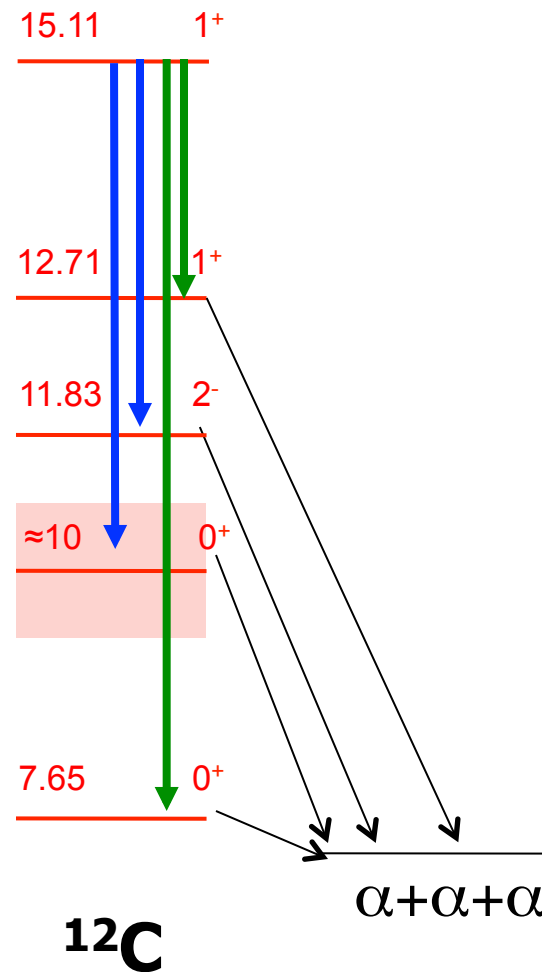
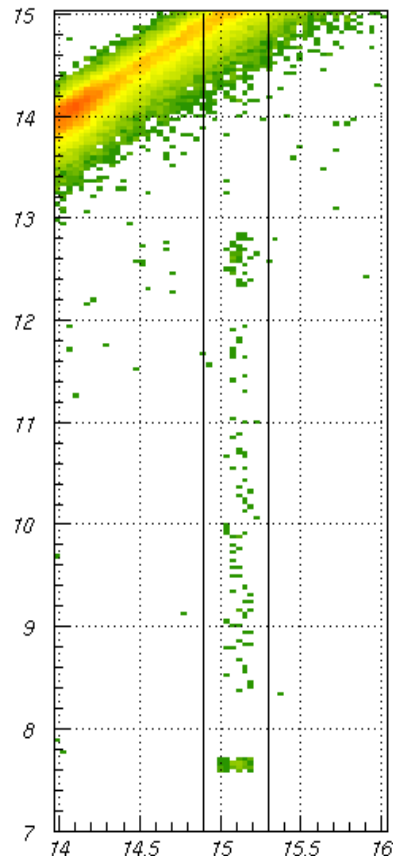
12C excitation Summing 3 α



12C excitation energy from proton



γ -decay of the T=1 @ 15.11 MeV



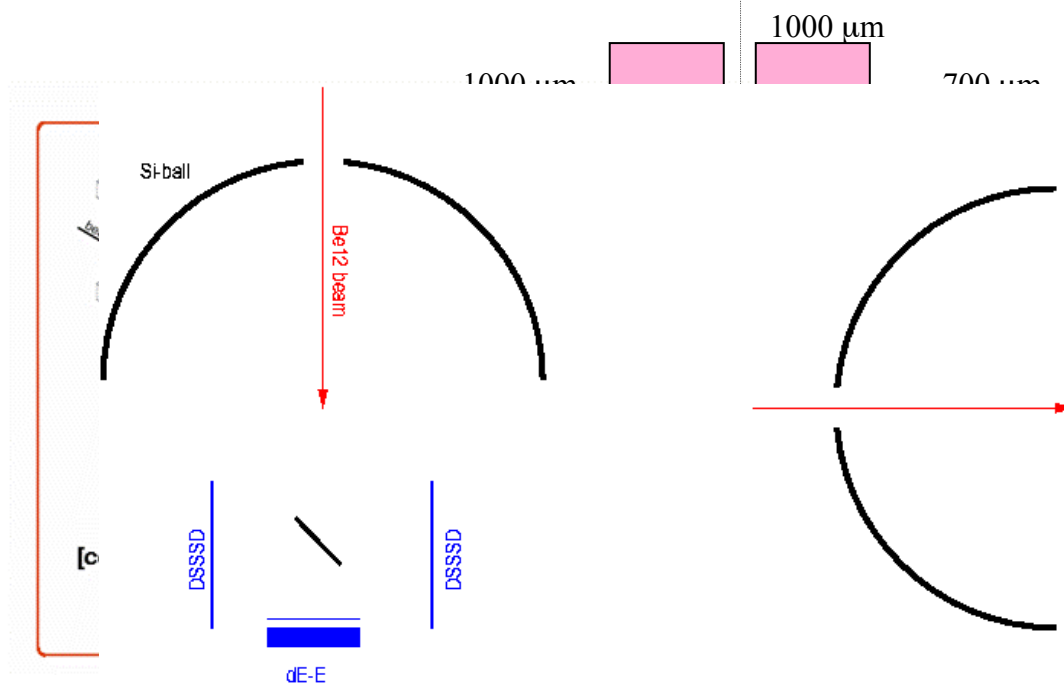
M. Alcorta et al, NIM A605, 318-325 (2009)

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

Desarrollo para experimentos a baja energía

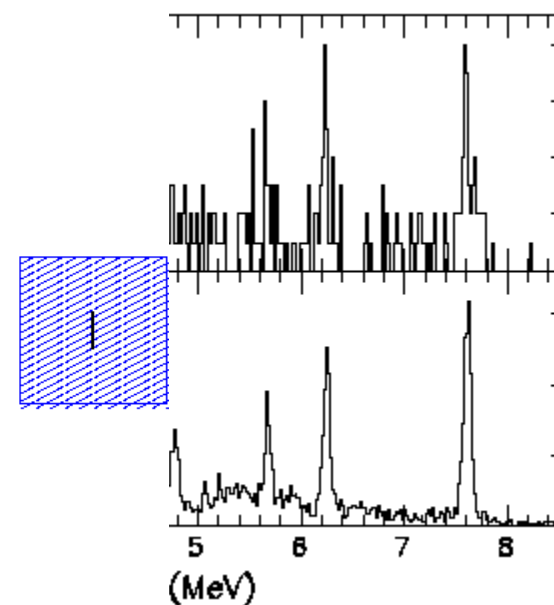
Electronic evolution in order to manage the β -decay experiments

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	^9C	4+2	4+66	4+512		RAL
2003	^{12}C	36+3	144+99	^9C 144+768		MESYTEC

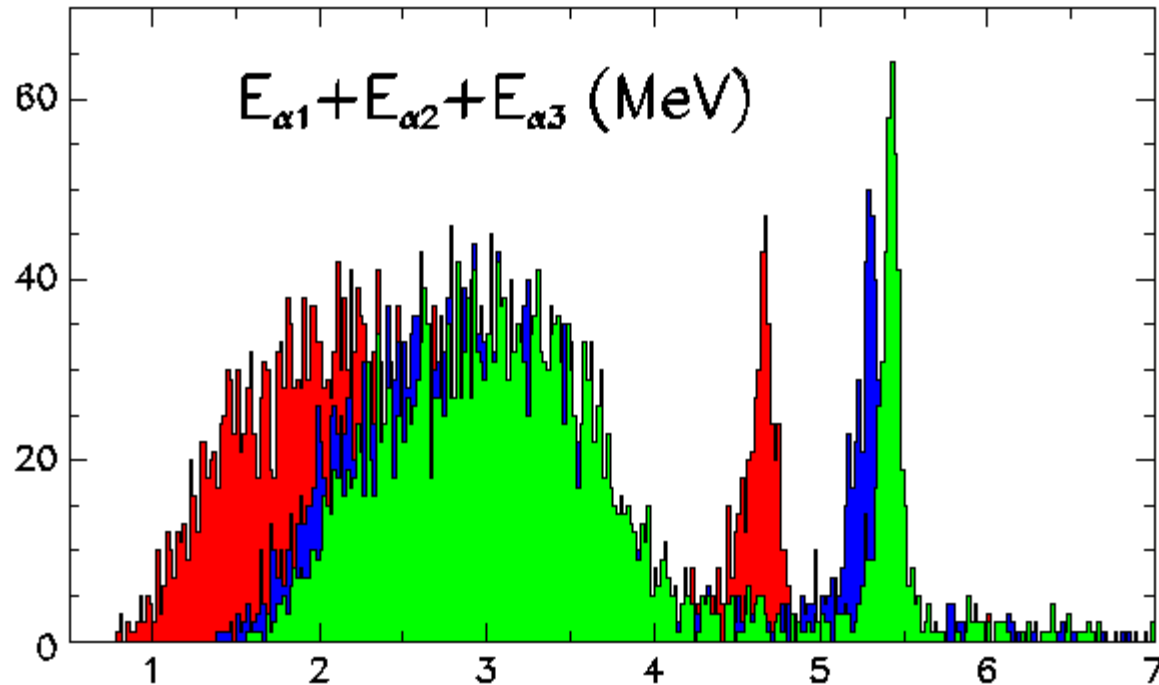


Top view

Side view



Energy loss effects

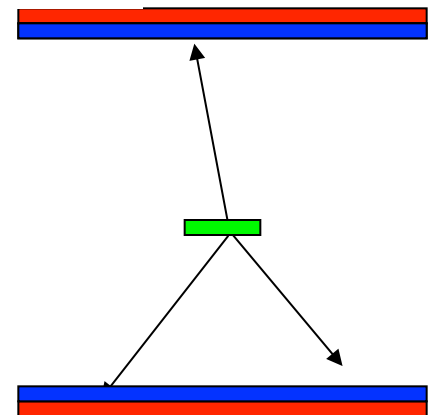


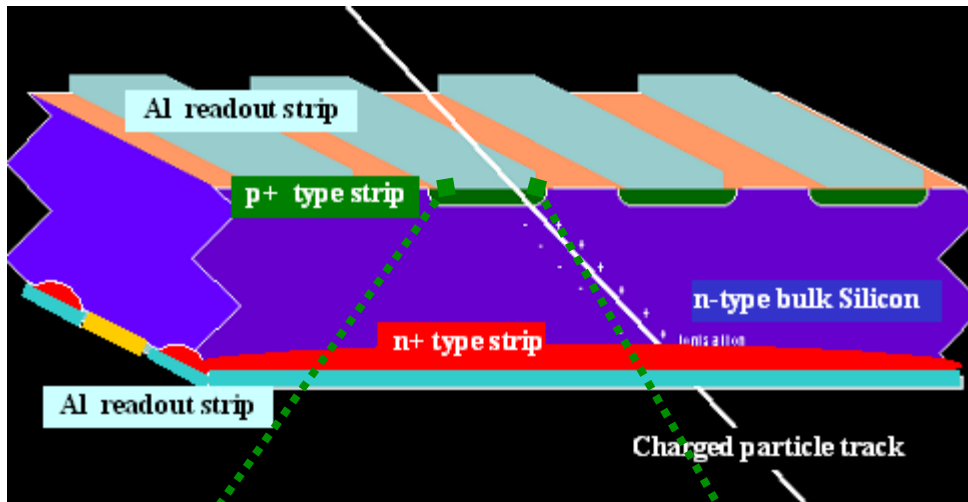
No corrections

Detector deadlayer

Carbon foil

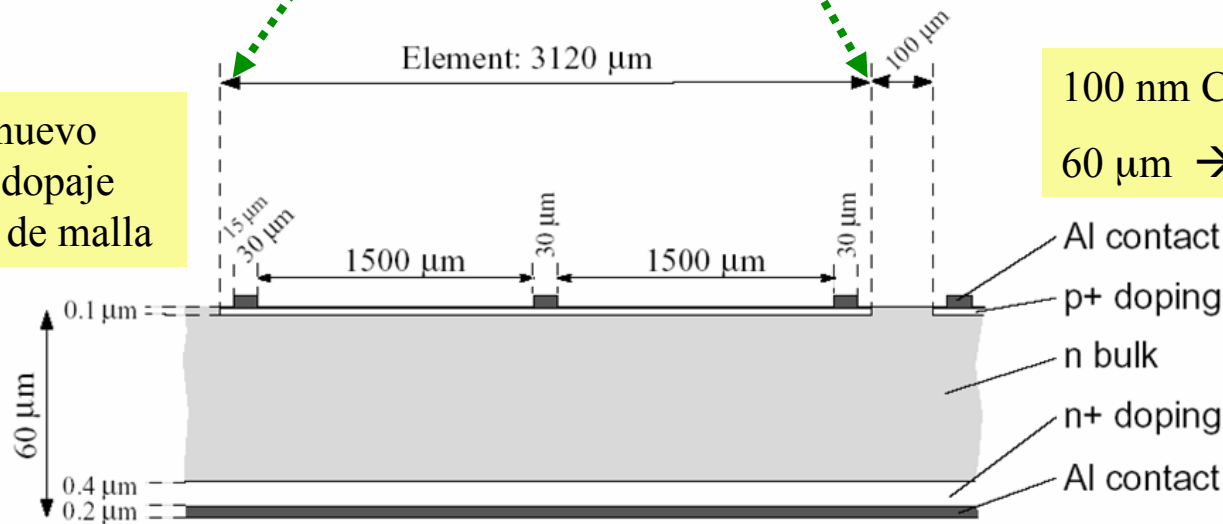
Bergmann, Fynbo & Tengblad,
NIMA515 (2003) 657.





} 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

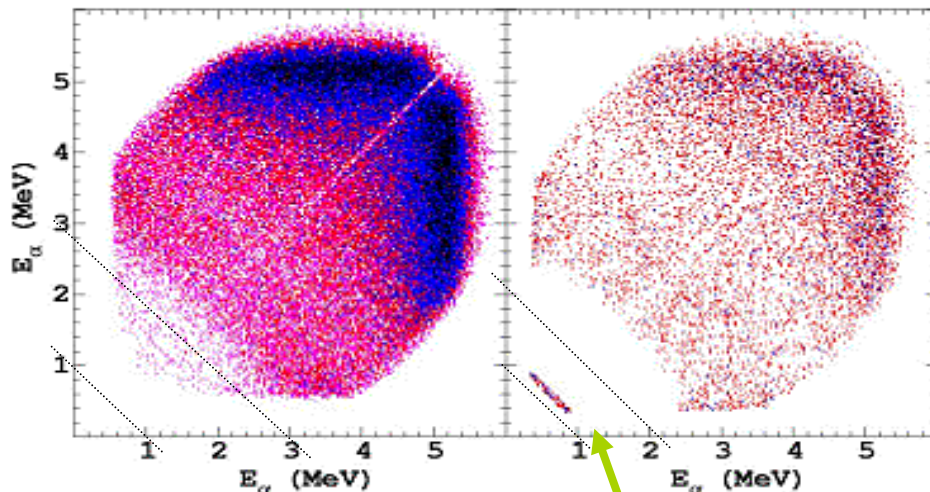
$\alpha\alpha$ distribution

$$9.7 < E_{\text{sum}} < 11.7 \text{ MeV}$$

Experiment

2001

2002

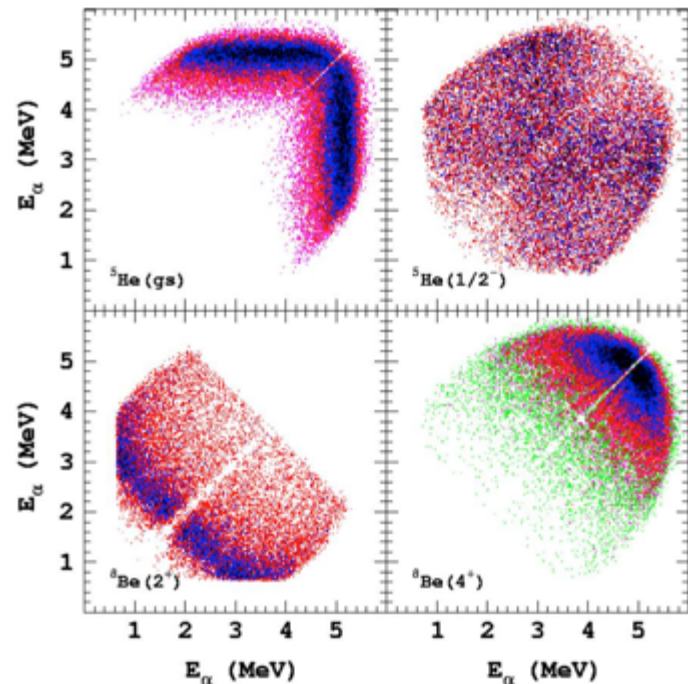


Effect of using the new DSSSD

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

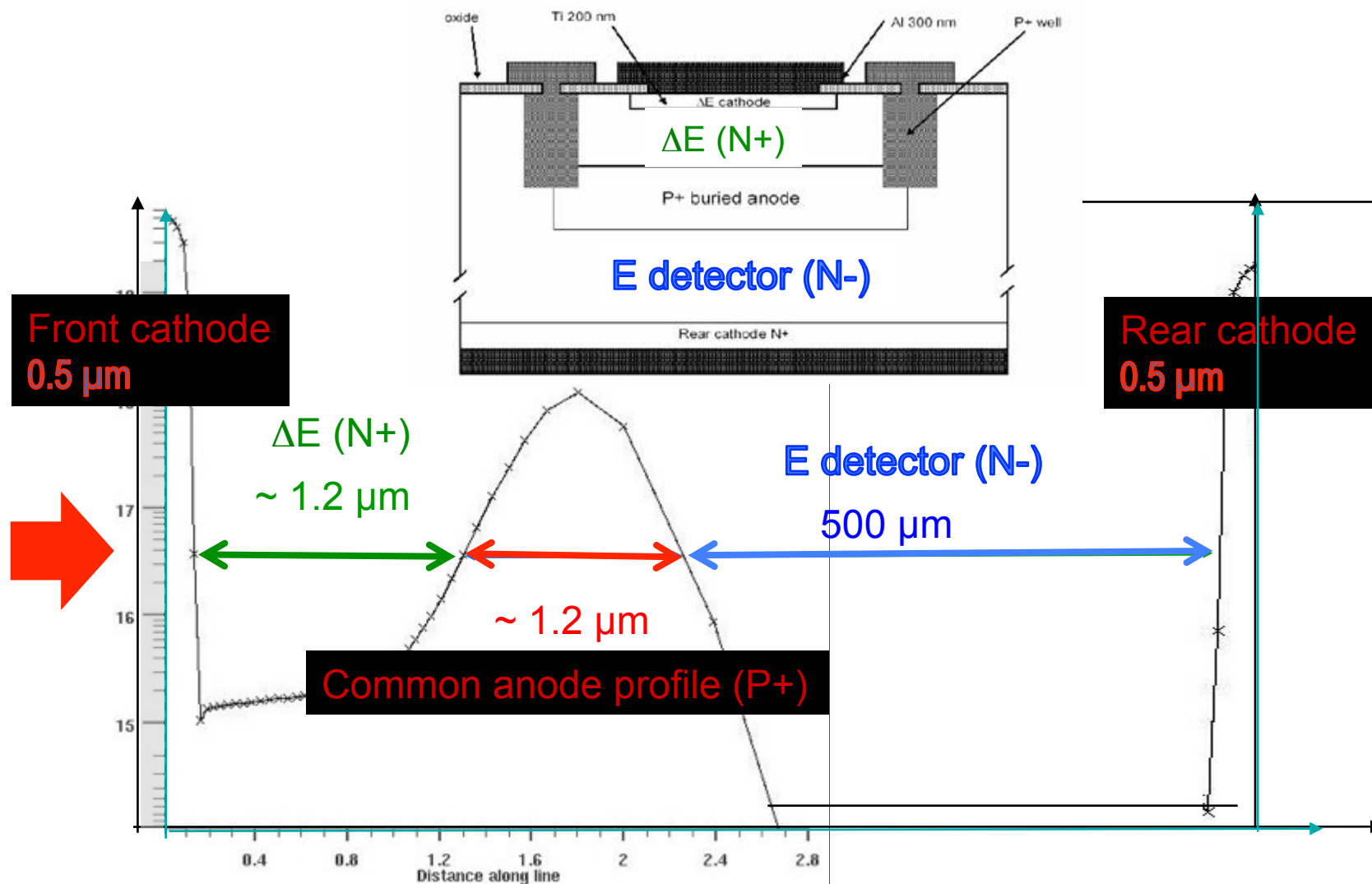
$^8\text{Be}(\text{gs})$

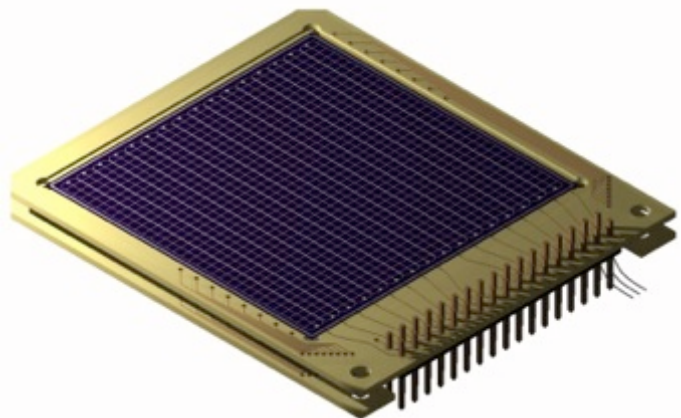
$^5\text{He}(\text{gs})$ dominate



Simulation of the $\alpha\alpha$ distribution
As function of decay channel

Monolithic Si telescope depth profile

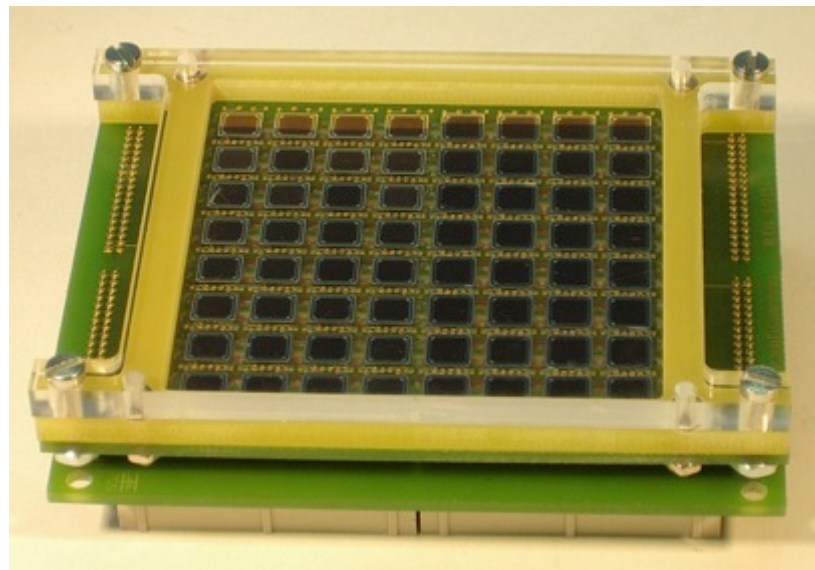
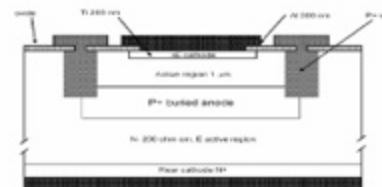




5x5 cm² 16x16 tiras de 3mm

256 pixeles de 9 mm²

32 canales de electrónica



Detector área: 5x5 cm²

64 detectores de 9 mm²

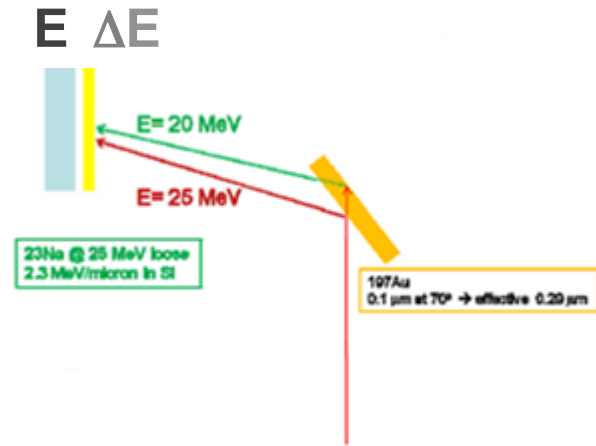
128 canales de electrónica

Angulo sólido de 20% del DSSSD

4 veces mas de electrónica

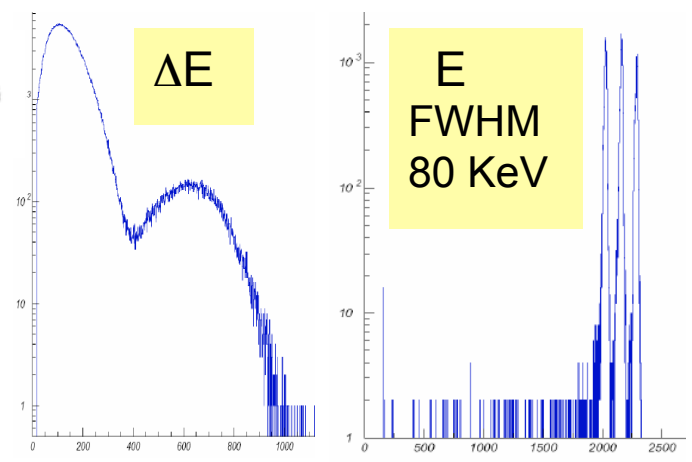
Espectros con el Monolito

MONOLITHIC
EXPERIMENT AT CMAM RUTHERFORD SCATTERING
OF ^{23}Na & ^{25}Al ON $0.1\ \mu\text{M}$ ^{197}Au



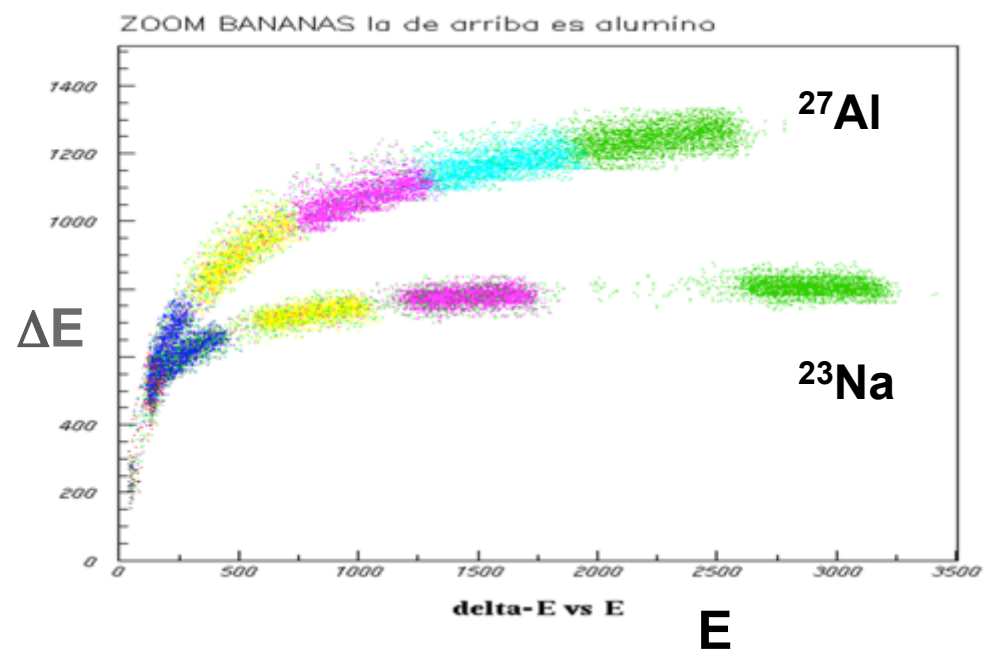
Haces de ^{27}Al y ^{23}Na @ CMAM

- verde $\rightarrow 30\ \text{MeV}$
- azul claro $\rightarrow 25\ \text{MeV}$
- rojo $\rightarrow 20\ \text{MeV}$
- amarillo $\rightarrow 15\ \text{MeV}$
- azul oscuro $\rightarrow 10\ \text{MeV}$



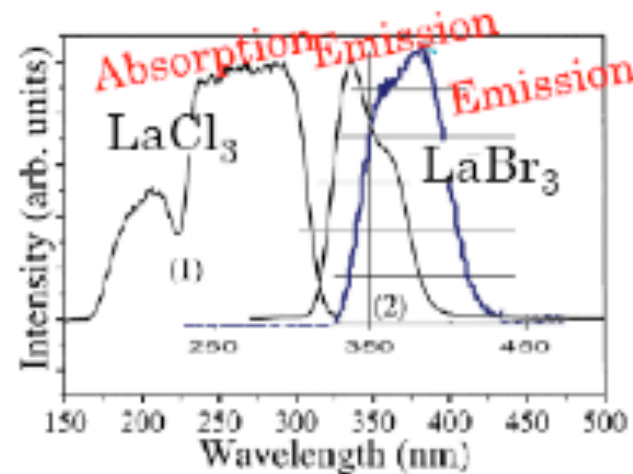
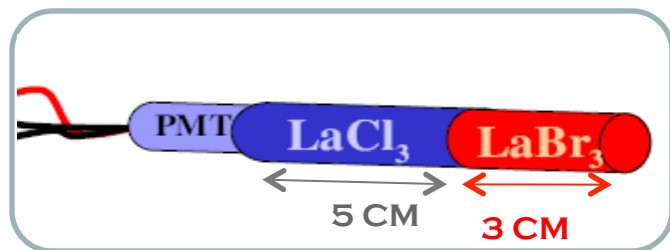
Espectros individuales del ΔE y E

Fuente triple alfa



CALIFA Forward end-cap

I+D de un centellador con dos cristales distintos con una única salida electrónico → Phoswich de $\text{LaBr}_3(\text{Ce})$ + $\text{LaCl}_3(\text{Ce})$



Segundo cristal transparente para la luz del primero

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

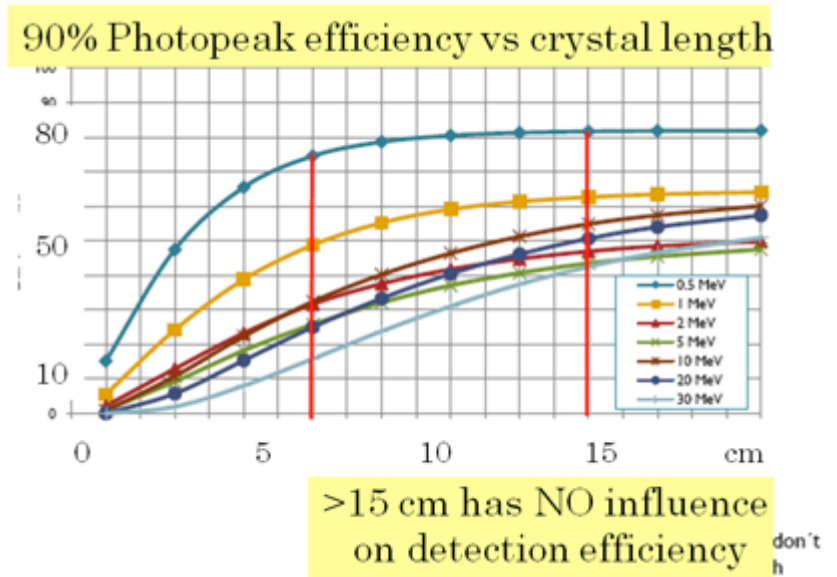
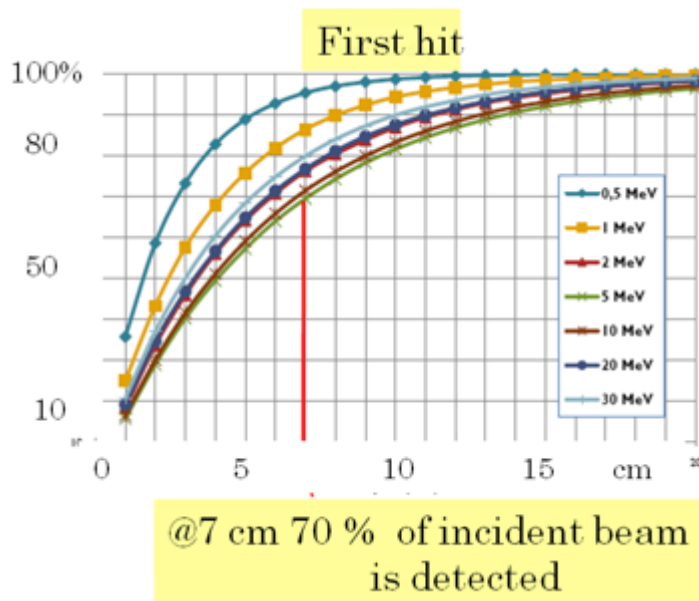
Simulations

QUESTION TO BE ANSWERED:

- DEPTH OF FIRST INTERACTION
- DEPTH @ 90% PHOTOPEAK EFFICIENCY
- HOW MANY NEIGHBOURING CRYSTALS ARE BEING HIT?

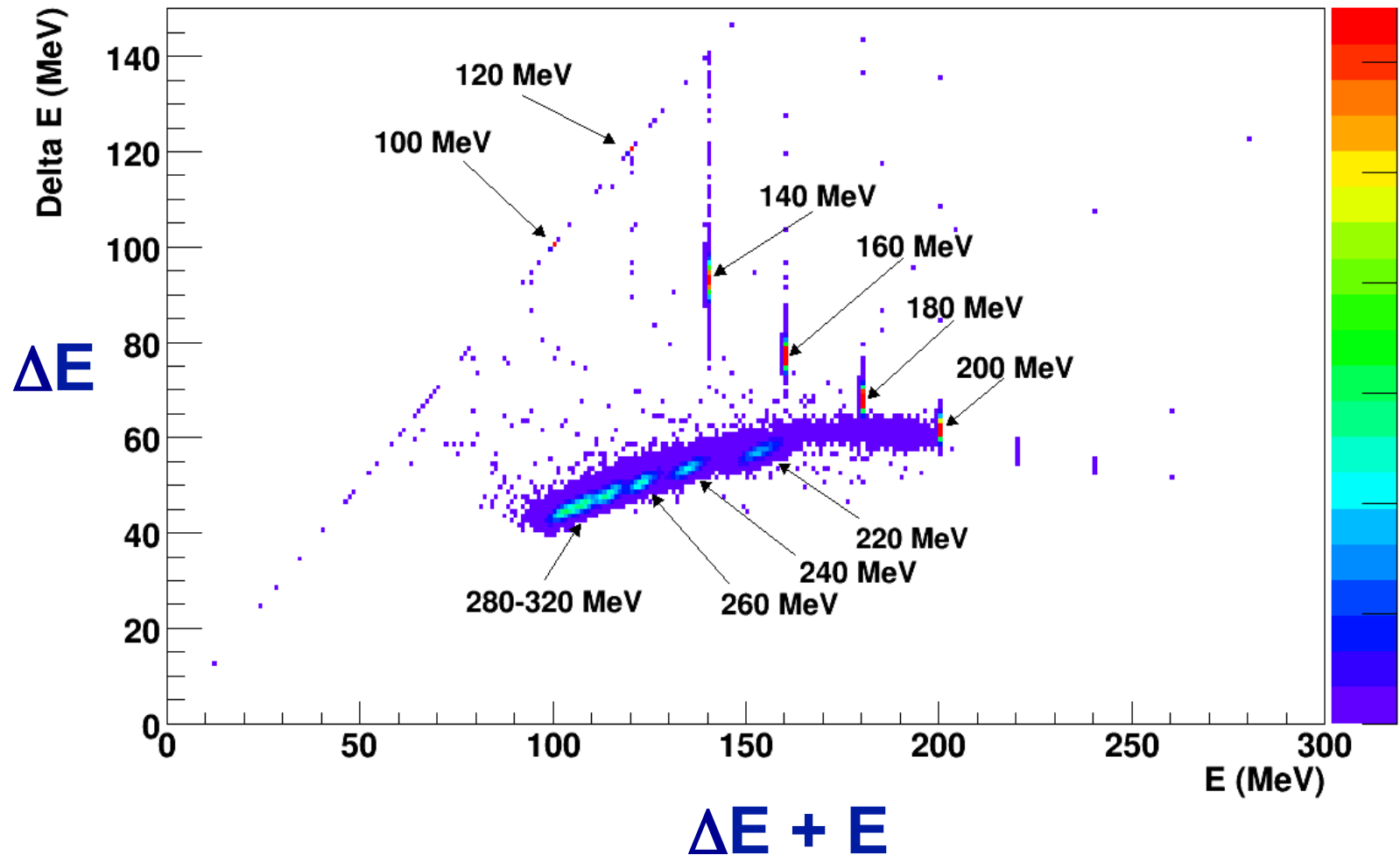
SIMULATION CODES

- SRIM – GEANT4 – MCNPX MONTE CARLO N-PARTICLE EXTENDED CODE

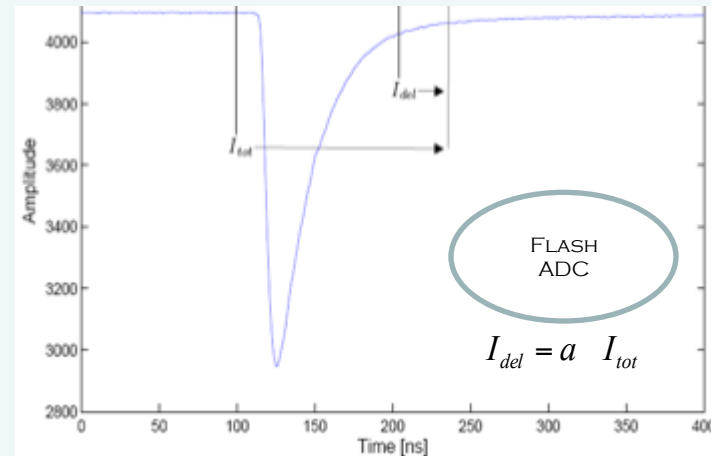
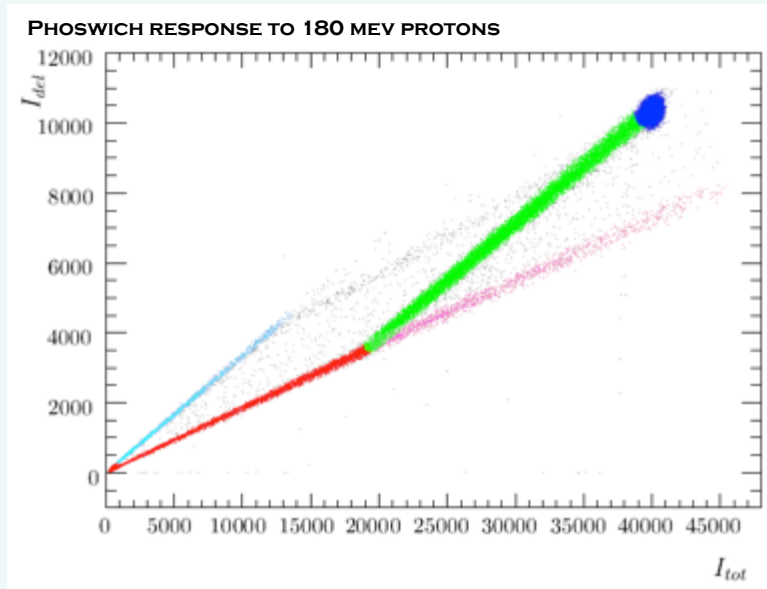


PROTONS in Phoswich: ΔE vs $\Delta E + E$

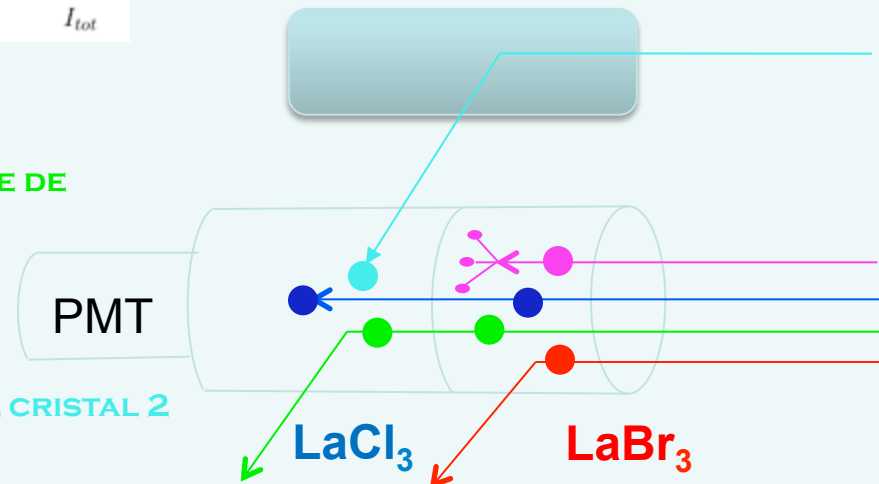
DE(1st block) vs E(total)



Phoswich: respuesta 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



CSIC

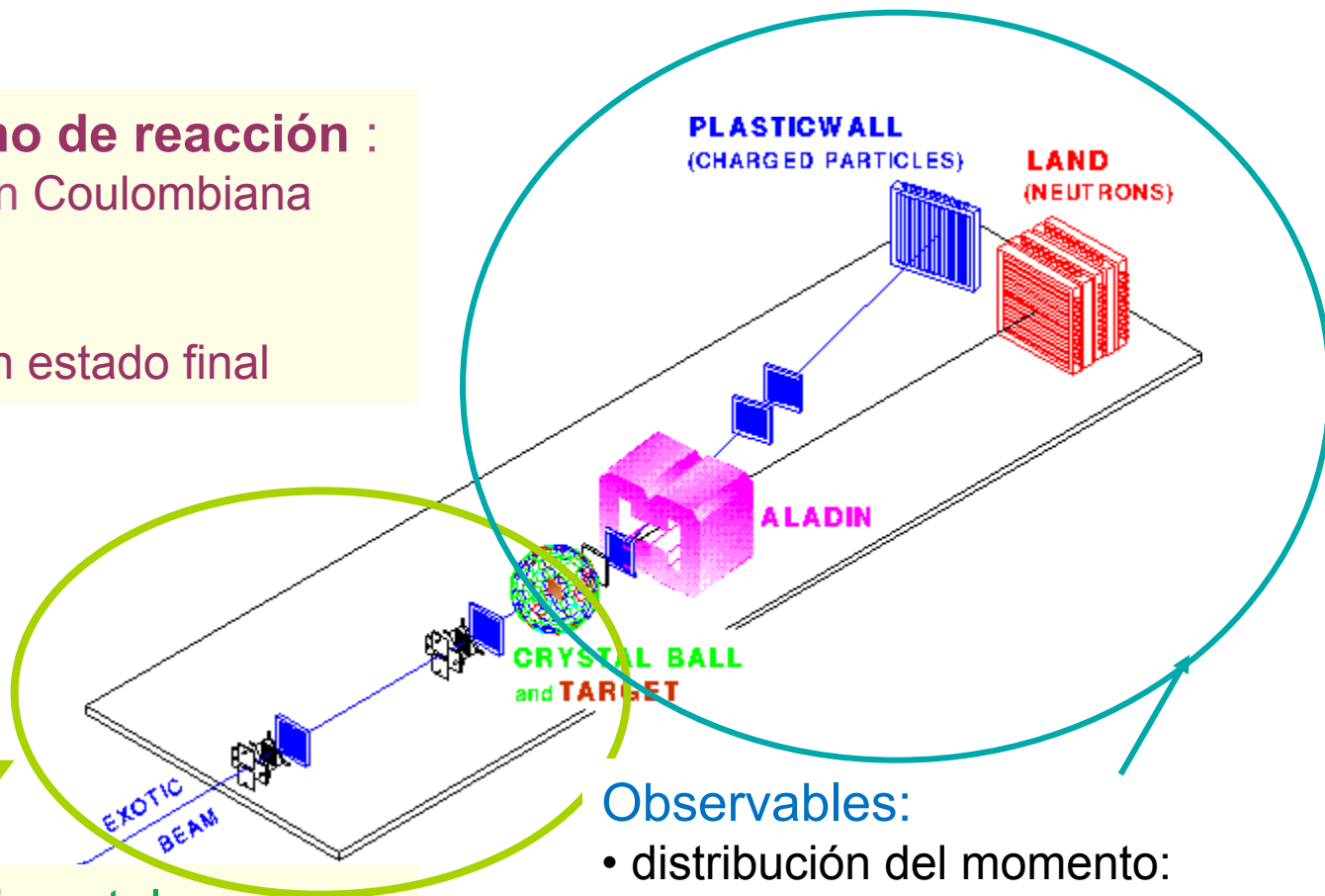
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

INSTITUTO DE ESTRUCTURA DE LA MATERIA

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

Mecanismo de reacción :

- disociación Coulombiana
- Difracción
- Absorción
- interacción estado final



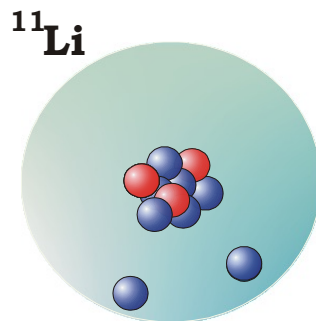
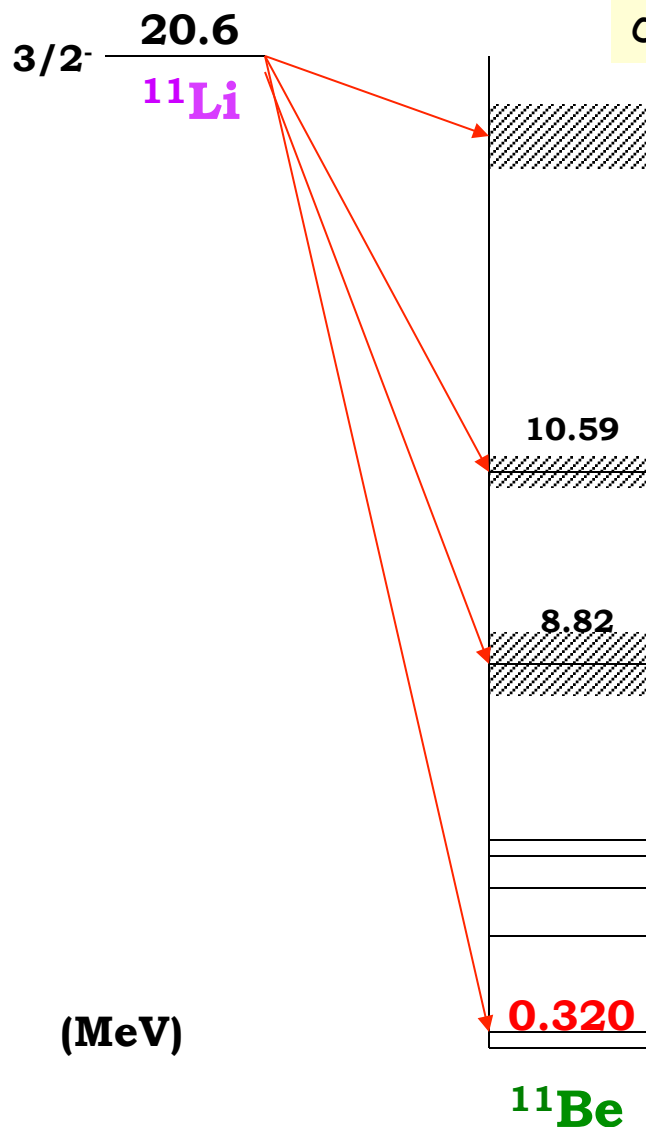
Variables experimentales:

- Energía del haz 30 → 700 MeV/A
- Target material del blanco C → Pb
- Proyectoil ${}^6\text{He} \rightarrow {}^{19}\text{C}$

Observables:

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

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



e^-

17.916

$^9\text{Li} + d$

15.721

$^8\text{Li} + t$

ν

8.982

$^8\text{Be} + 3n$

7.315

$^9\text{Be} + 2n$

0.504

$^{10}\text{Be} + n$

0.320

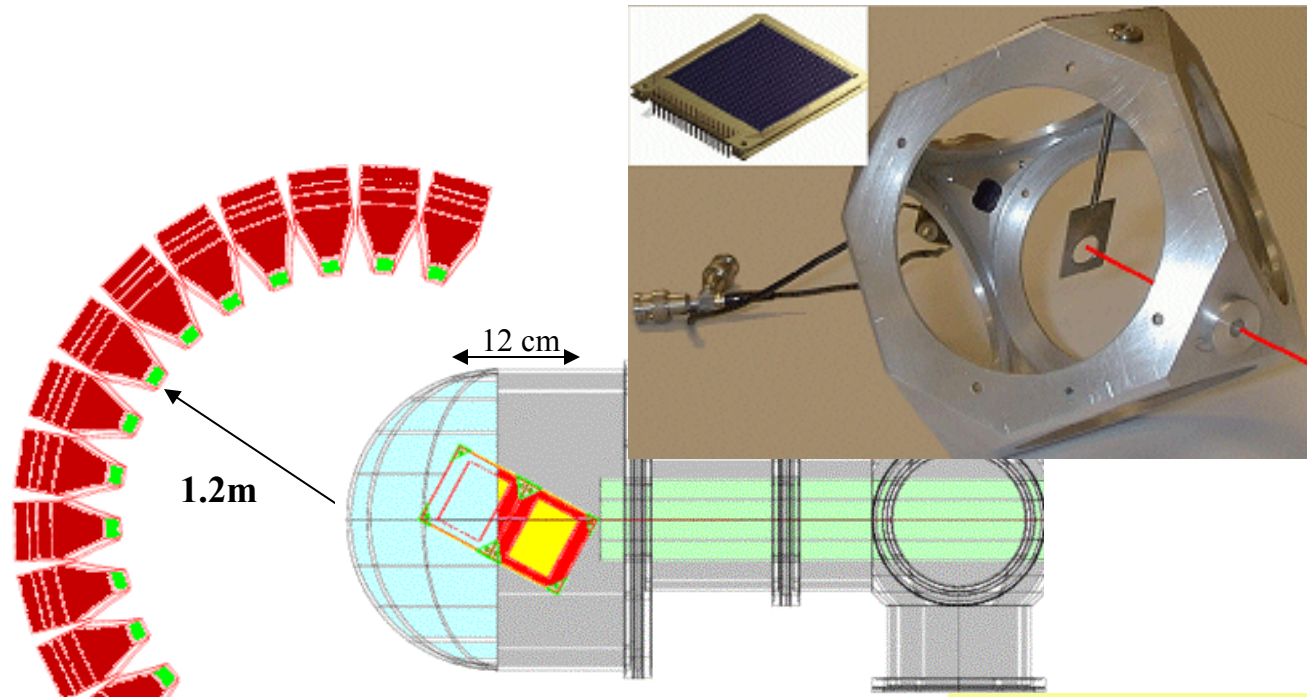
$\frac{1}{2}^-$

γ

$\frac{1}{2}^+$

^{11}Be

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

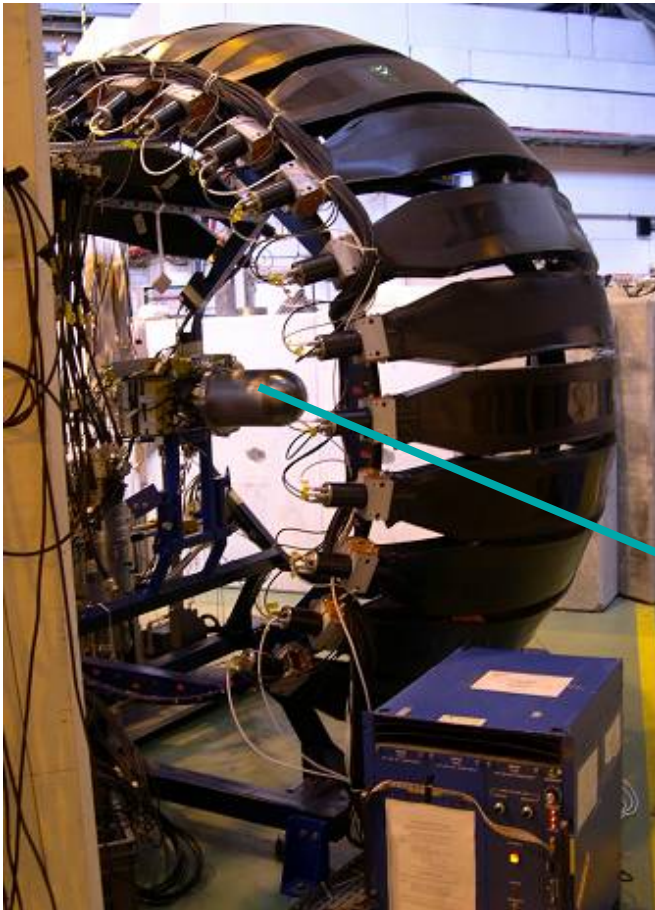
3 E-detector (Si)

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.

