Measurements of $^{8}Li(\alpha,n)^{11}B$ and astrophysical implications

S. Cherubini, ENA VI,
Sept. 26th, 2011, S. Tecla

A BIG BANG REMINDER

LINCHPINS OF BIG BANG:

expansion,

Cosmic Microwave Background,

primordial nucleosynthesis…

BIG BANG NUCLEOSYNTHESIS SCENARIOS

depending on the phase transition from QGP to Hadronic Universe:

HOMOGENEOUS

Synthesis of elements stops with lithium

INHOMOGENEOUS

Many more elements are synthesized (up to carbon)

HOMOGENEOUS BIG BANG Nucl.Synth.

3 min after the BB the production of d starts

$$n+p \rightarrow d + \gamma$$

And hence the primordial nucleosynthesis can start

$$n + d \rightarrow t + \gamma$$

$$p+d \rightarrow {}^3He + \gamma$$

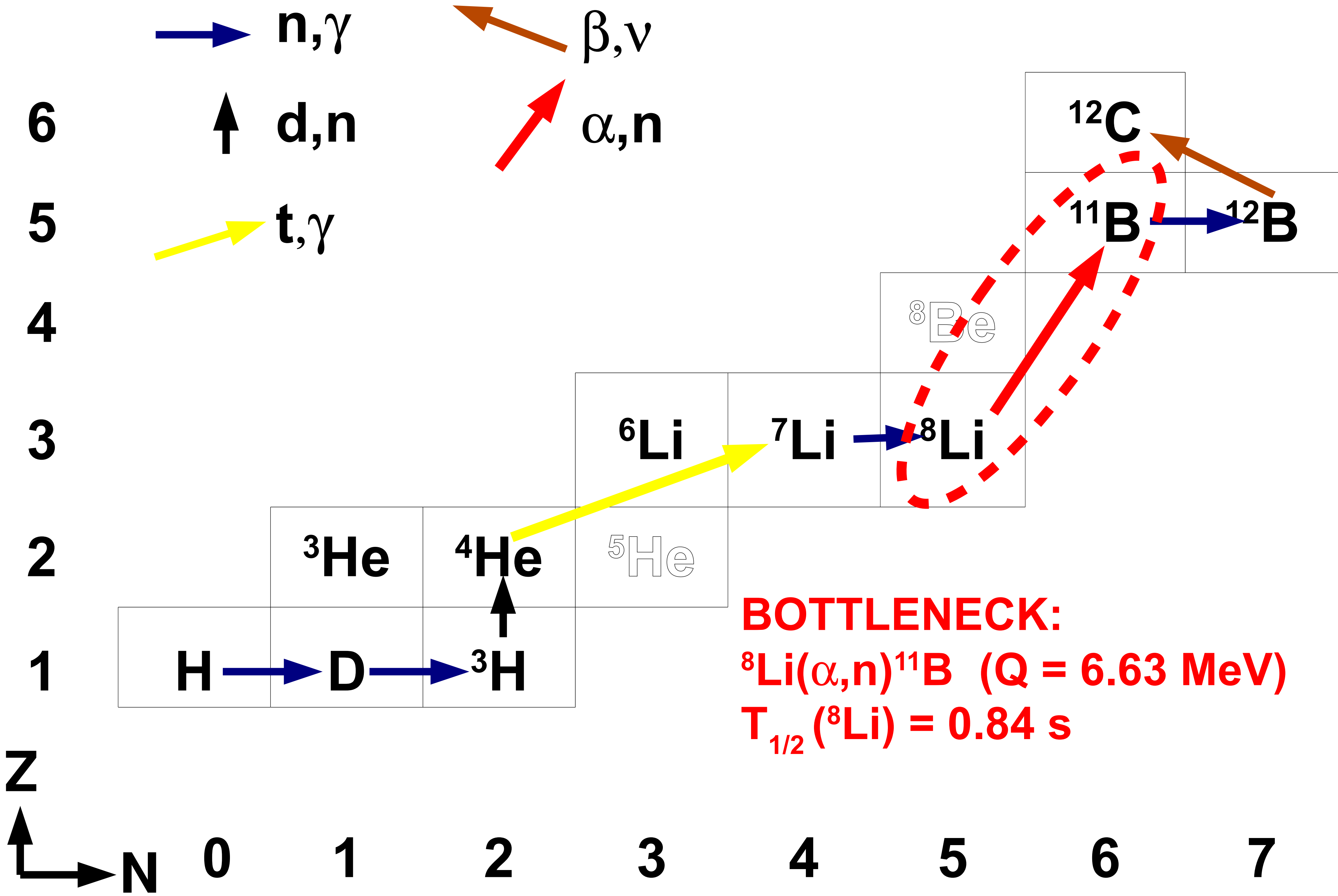
^3H and ^3He are robust against photo-disintegration so ^4He can be produced:

$$t + p \rightarrow \alpha + \gamma \qquad t + d \rightarrow \alpha + n$$

$$^3He + n \rightarrow \alpha + \gamma \qquad d + d \rightarrow \alpha + \gamma$$

$$(\alpha + t \rightarrow {}^7Li + \gamma)$$

INHOMOGENEOUS BIG BANG Nucl. Synth.



STUDIES OF THE $^{8}Li(\alpha,n)^{11}B$

Relevant energy window: 0.3 – 1.3 MeV (center of mass)

Three type of measurements

1) Indirect

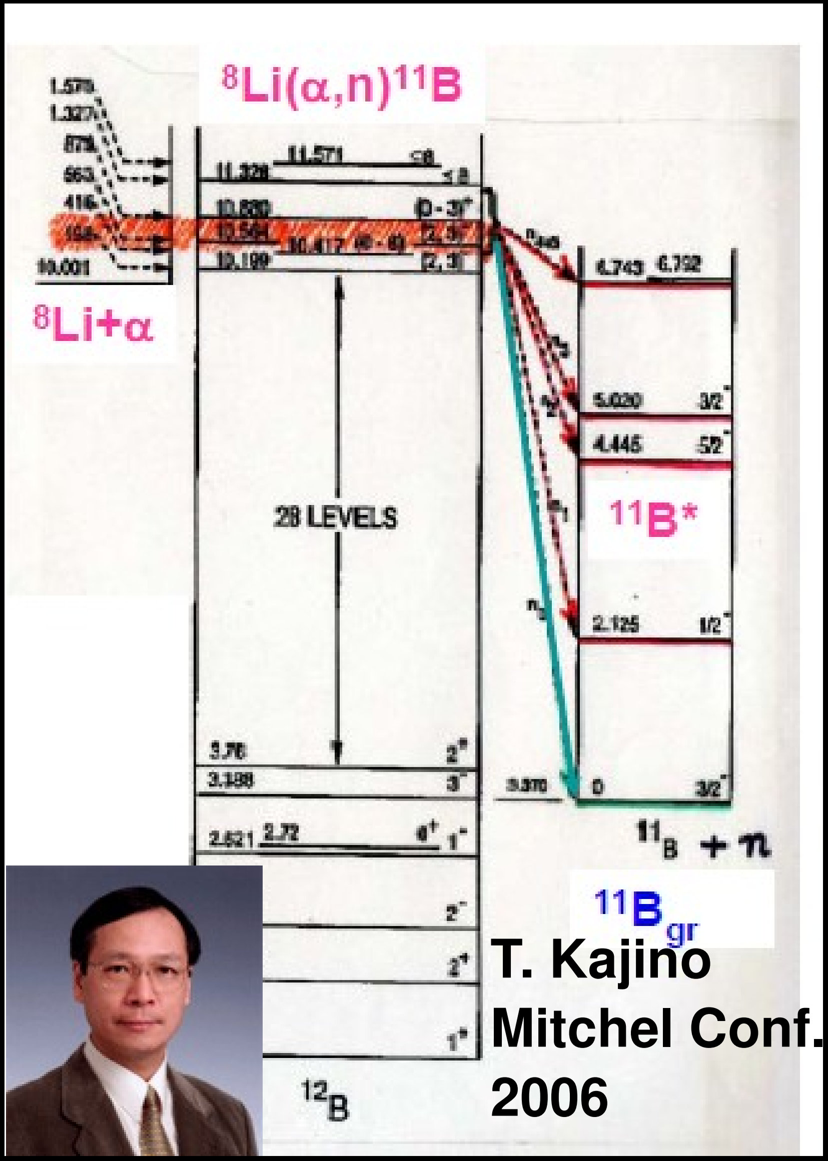
2) Direct inclusive measurements

3) Direct exclusive measurements

1) $^{11}B_{gs}(n,\alpha)^{8}Li$ E_n=7.6 to 12.6 MeV.

<u>**Major problem:**</u> **only the ^{11}B ground state contributes to the x-section**

T. Paradellis, S. Kossionides, G. Doukellis, X. Aslanoglou, P. Assimakopoulos, A. Pakou, C. Rolfs, and K. Langanke, Z. Phys. A337 (1990) 211



First measurement of this reaction, guess who...

2) $^{8}Li(\alpha,n)^{11}B$, inclusive

Two experiments: first down to 1.5 MeV (c.m.), second covering the astrophysical energy region: a factor of 5 difference with previous results

R. N. Boyd, I. Tanihata, N. Inabe, T. Kubo, T.Nakagawa, T. Suzuki, M. Yonokura, X. X. Bai, K. Kimura, S. Kubono, S. Shimoura, H. S. Xu, and D. Hirata, Phys. Rev. Lett. 68,(1992) 1283

X. Gu, R. N. Boyd, M. M. Farrell, J. D. Kalen, C. A. Mitchell, J. J. Kolata, M. Belbot, K. Lamkin, K. Ashktorab, F. D. Becchetti, J. Brown, D. Roberts, K. Kimura, Tanihata, K. Yoshida, and M. S. Islam, Phys. Lett. B 343, (1995) 31

3) $^{8}Li(\alpha,n)^{11}B$, exclusive

^{11}B tagging applied, sophisticated detector used

Y. Mizoi, T. Fukuda, Y. Matsuyama, T. Miyachi, and H. Miyatake, N.Aoi, N. Fukuda, M. Notani, Y. X. Watanabe, and K.Yoneda, M. Ishihara, H. Sakurai, Y. Watanabe, and A. Yoshida,

Phys. Rev C 62 065801

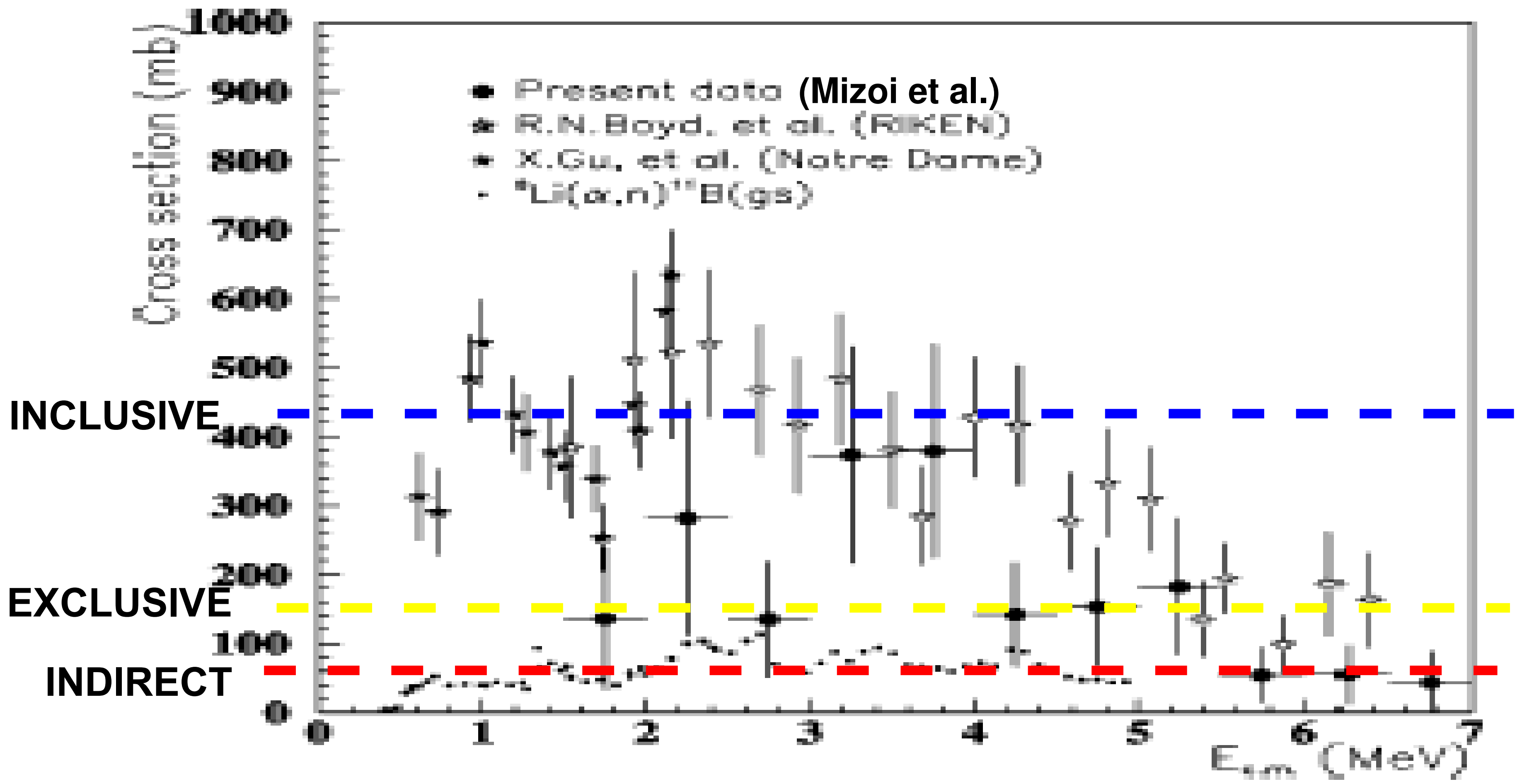


FIG. 9. Excitation functions for the $^{8}Li(\alpha,n)^{11}B$ reaction. The horizontal axis is the center-of-mass energy (MeV) and the vertical axis is the absolute cross section (mb). The filled circles indicate the present data averaged over the two mixing ratios of isobutane (Fig. 5). The small dots indicate the ground-state cross sections [13]. The open stars and filled stars indicate the data of the inclusive measurements [15,16].

"BIG BANG" at LNS

Production of a ^{8}Li beam in flight via $^{7}Li(d,p)^{8}Li$

1) Intense (300 enA) lithium primary beam
   available at LNS Tandem
2) High cross-section
3) Two kinematical solutions

Characterization of the beam

Experimental technique

A BRUTAL APPROAH

RECIPE:

Produce as much 8Li as possible

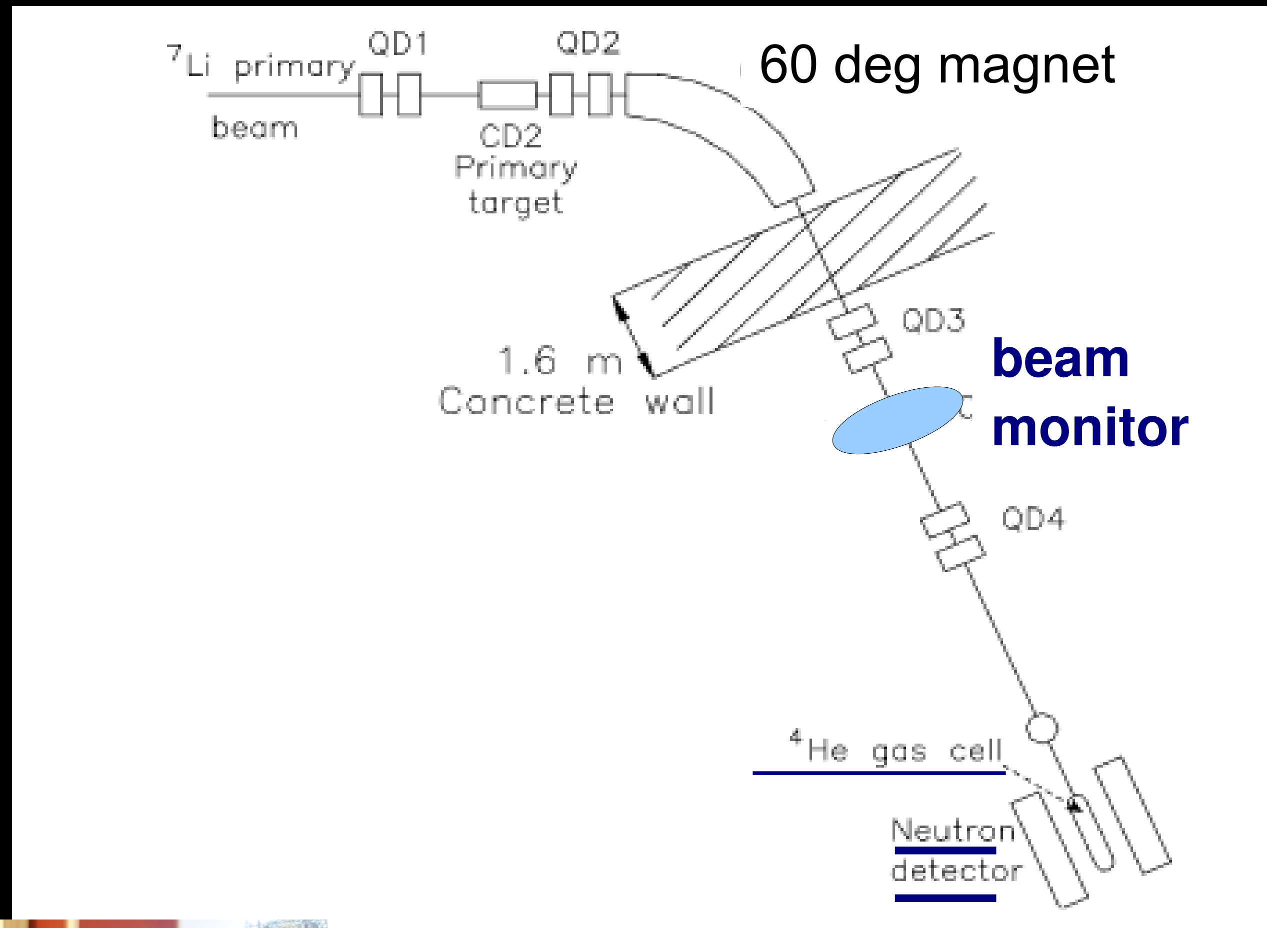
Count 8Li with a beam monitor

Send them into the ^{4}He gas cell

Count neutrons output

Publish paper

We did it (but the last point) , we were happy but.....



**Lesson #1:
double check, ALWAYS!**

Choosing the kinematical conditions for beam production

"Forward" i.e. ^{8}Li going forward in the cm ref frame

somewhat higher cross-section but magnetic rigidity of secondary beam too close to that of the primary one

→ **NO primary beam suppression**

"Backward":

lower cross-section but magnetic rigidity of secondary beam different from that of primary one

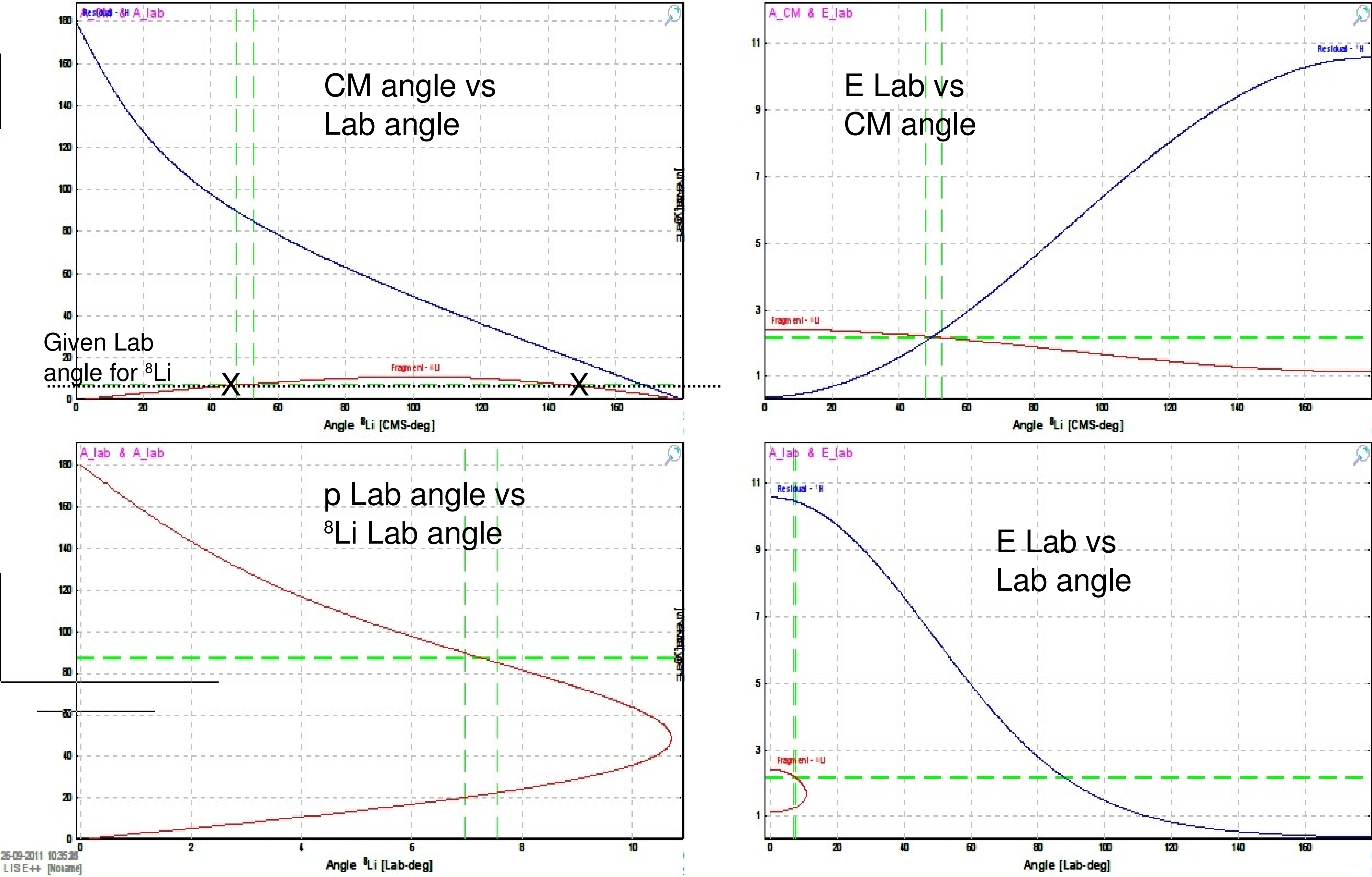
→ **YES primary beam suppression (though …)**

Reaction's Kinematics

$^{7}Li + ^{2}H \Rightarrow ^{8}Li + ^{1}H$ $^{2}H(^{7}Li, ^{8}Li)^{1}H$; Reaction at the "middle" of the target

Projectile Energy at the reaction place: 2.85 MeV/u   Grazing angle in CMS [$^{7}Li + ^{2}H$] = 9.13 deg

Q reaction: -0.19 MeV (Excitations 0.0+0.0=>0.0+0.0); Plotted Energy option is "after reaction"



EVERYTHING OK ?

Not really welcome guests…..

1) **Leaky ^{7}Li beam (no matter what you do, it is there!)**

2) **Neutrons from cyclotron and**

3) **Neutrons primary-beam induced *(really nasty ones)***

Owing to the “basicness” (thanks to NO funding from GR III....) of the setup we had bad control on the experimental conditions even using the backward solution.

Only with a beam of 10^5 ^{8}Li per second the S/N ratio would be acceptable. This was BEYOND our possibilities

So what?

1) Give up

2) THINK MORE AND FIND A EVEN BETTER SOLUTION

Lesson #2: be tough but NOT stubborn

We are left with a PROBLEM

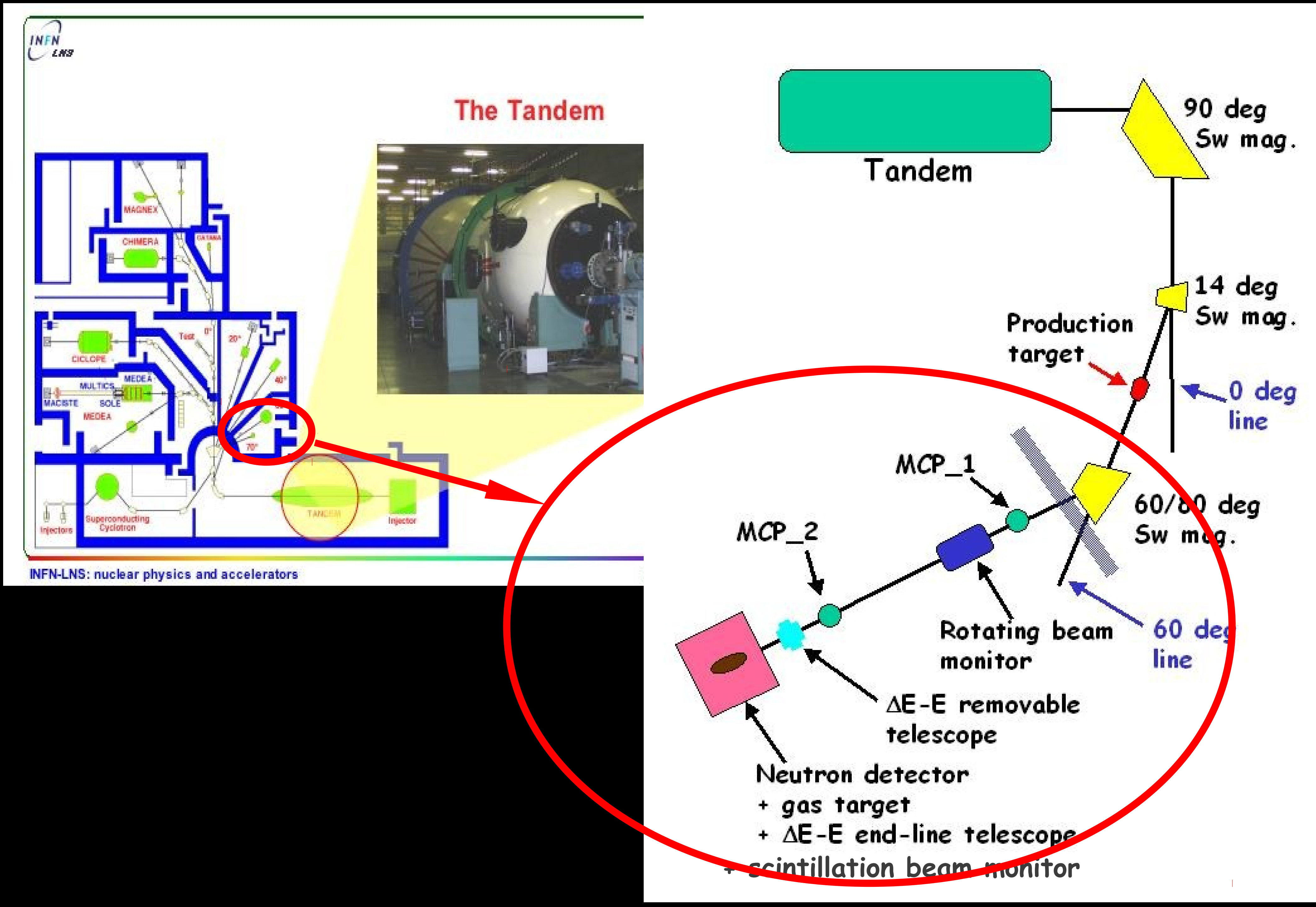
Neutron coming not from our reaction are detected by POLYCUBE

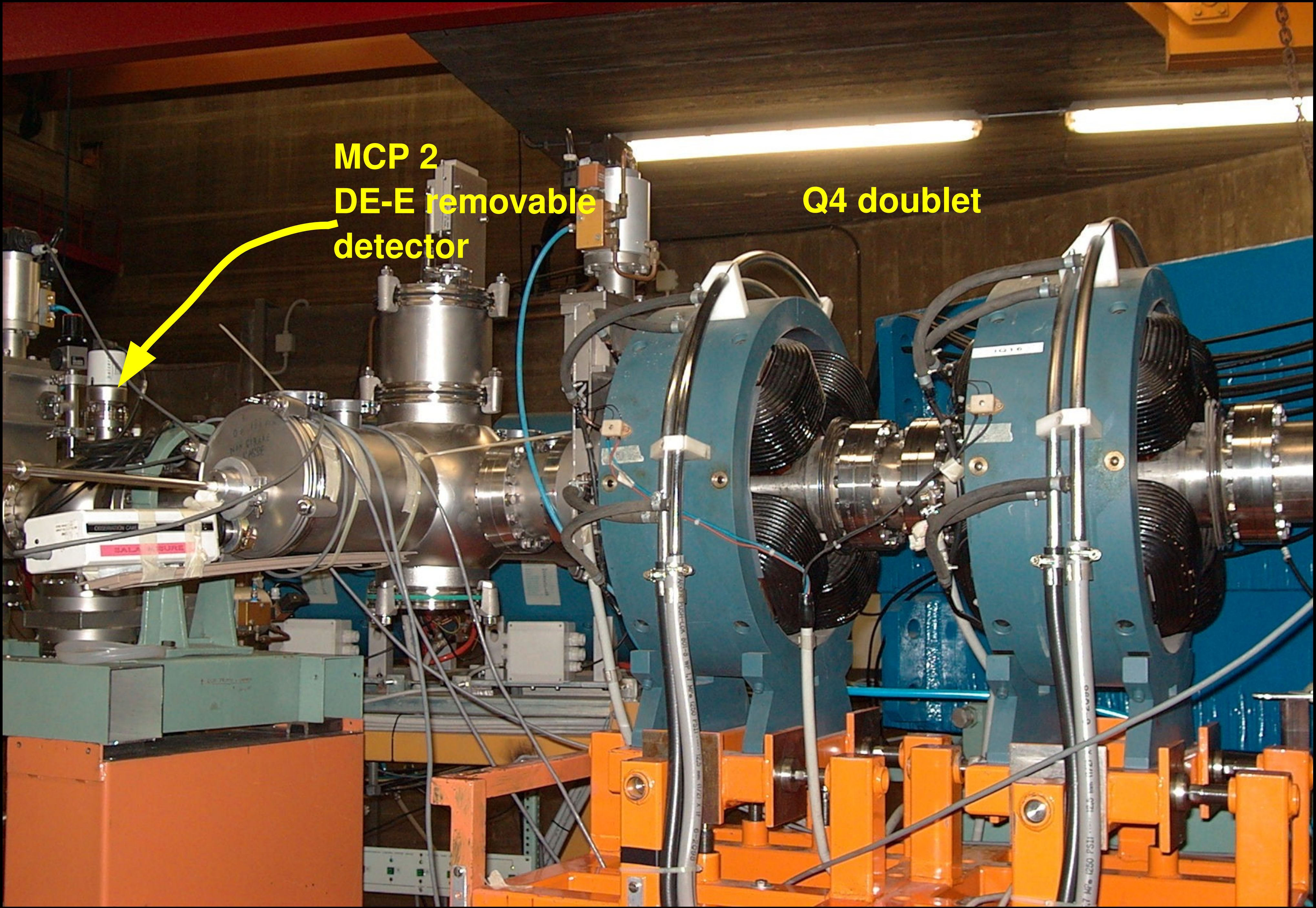
They have to be cut out.

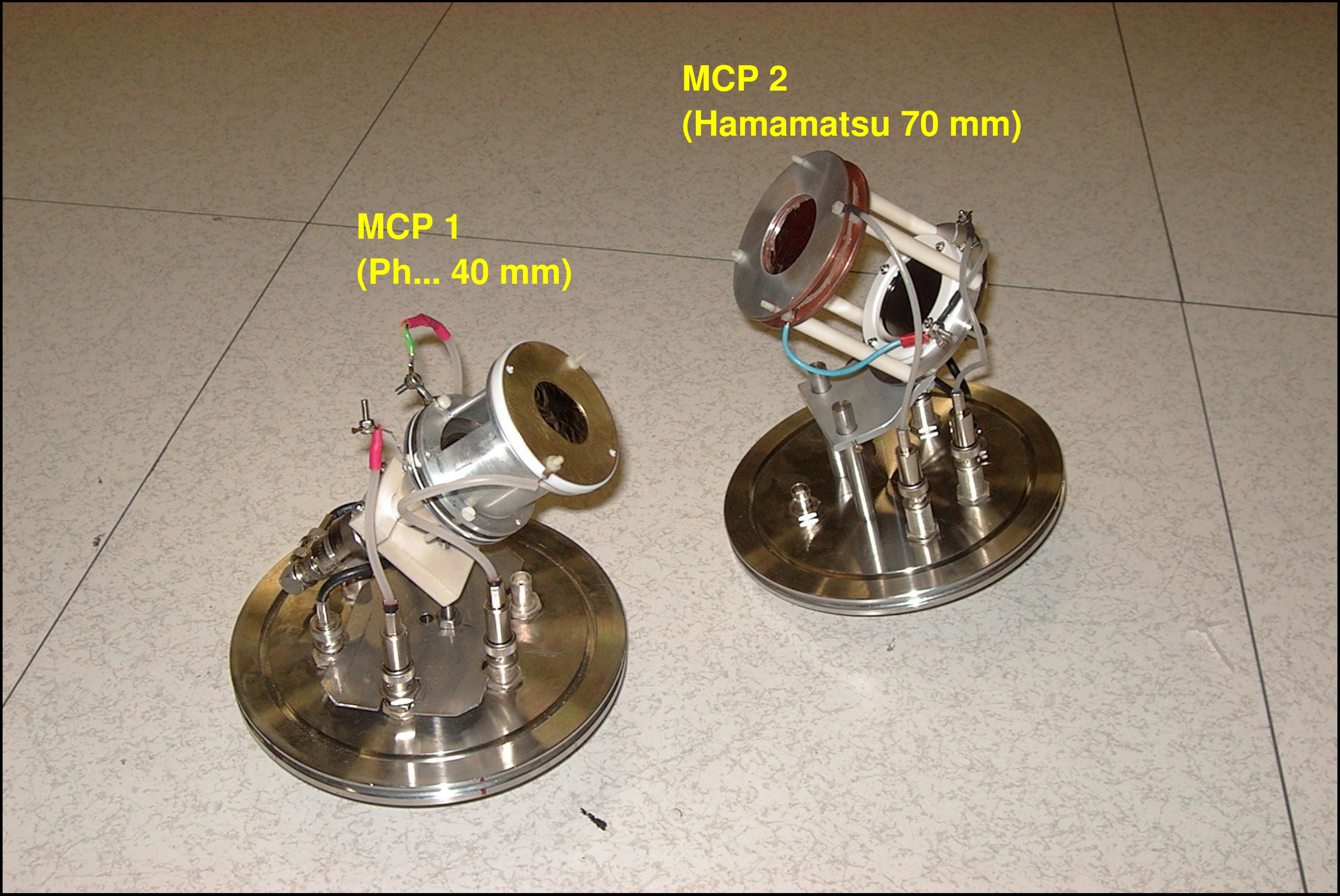
Now the question is HOW?

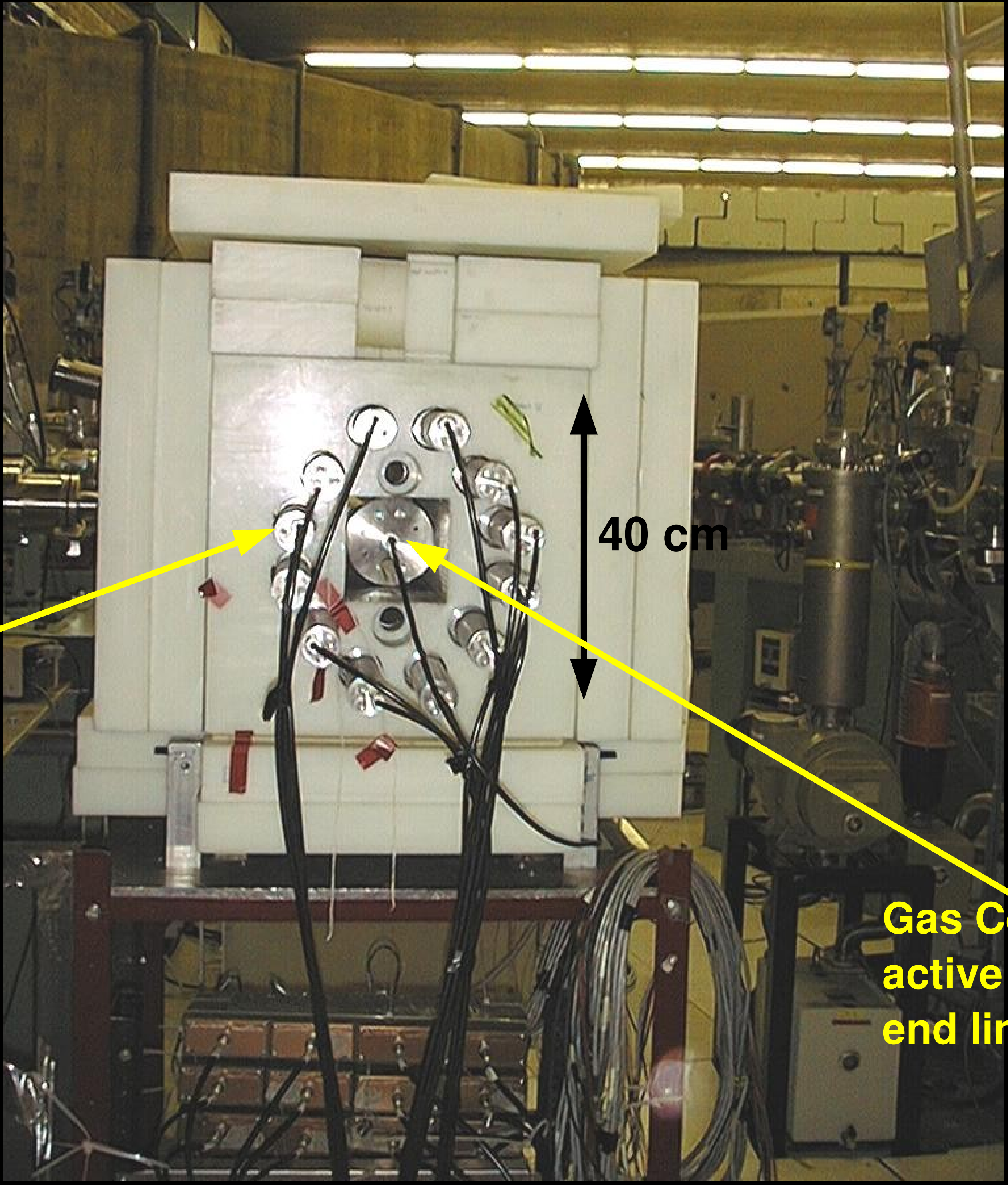
IDEA:

Turn on the neutron detector only when ^{8}Li arrived on the target i.e. beam tagging and counting


INFN LNS
The Tandem
MAGNEX
CHIMERA
CICLOPE
MEDEA
MULTICS
MACISTE
SOLE
MEDEA
Test
0°
20°
40°
70°
TANDEM
Injector
Superconducting Cyclotron
Injectors
INFN-LNS: nuclear physics and accelerators
Tandem
90 deg Sw mag.
14 deg Sw mag.
Production target
0 deg line
MCP_1
60/80 deg Sw mag.
MCP_2
Rotating beam monitor
60 deg line
ΔE-E removable telescope
Neutron detector
+ gas target
+ ΔE-E end-line telescope
+ scintillation beam monitor


MCP 2
DE-E removable
detector
Q4 doublet

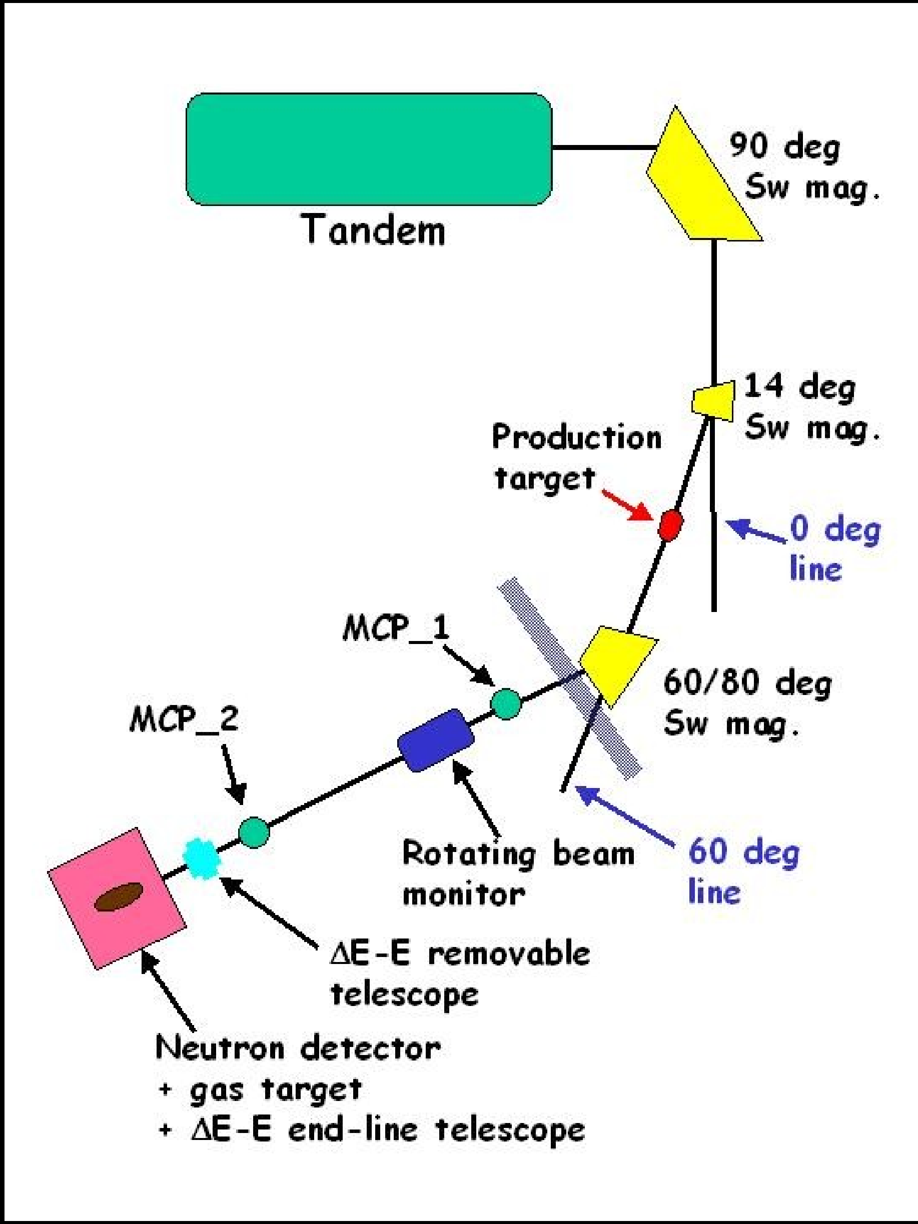

MCP 2
(Hamamatsu 70 mm)
MCP 1
(Ph... 40 mm)



3He tube
(x12)

Gas Cell target (20 cm
active length) + DE-E
end line telescope

The experimental technique



The principle:

we can suppress via "software" what was not suppressed by the "hardware" *(S. Cherubini)*

The Recipe:

1 Apply a tagging procedure to the incoming ^{8}Li ions using the MCP pair,

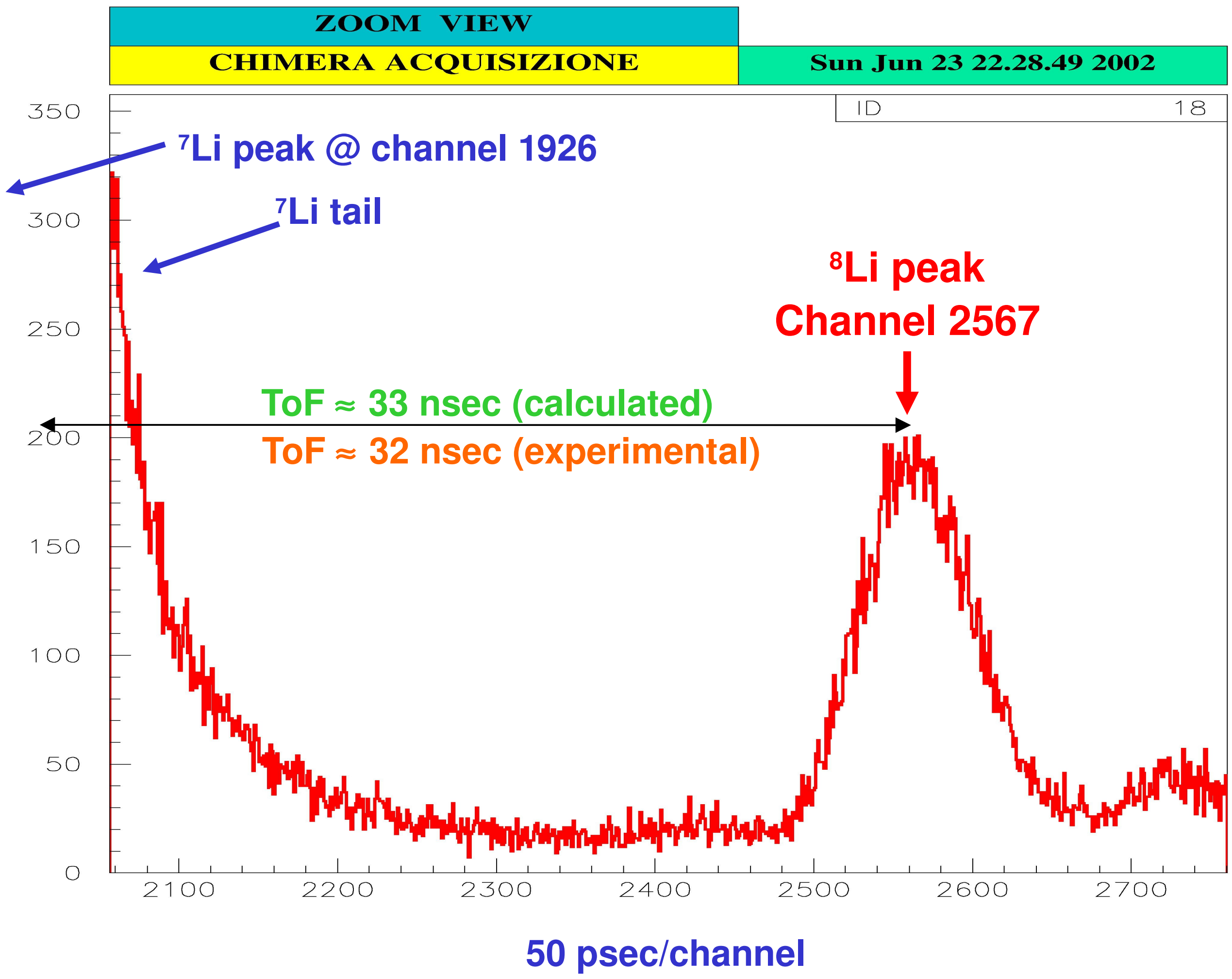
2 use this information to "switch on" the neutron detector only when a ^{8}Li has been detected.

This allow for a dramatic reduction of the background neutrons, owing to their de-correlation with the MCP trigger signal

Beam time needs (from known X-sec.)

50 ion/sec → 6 days

ToF MCP1-MCP2



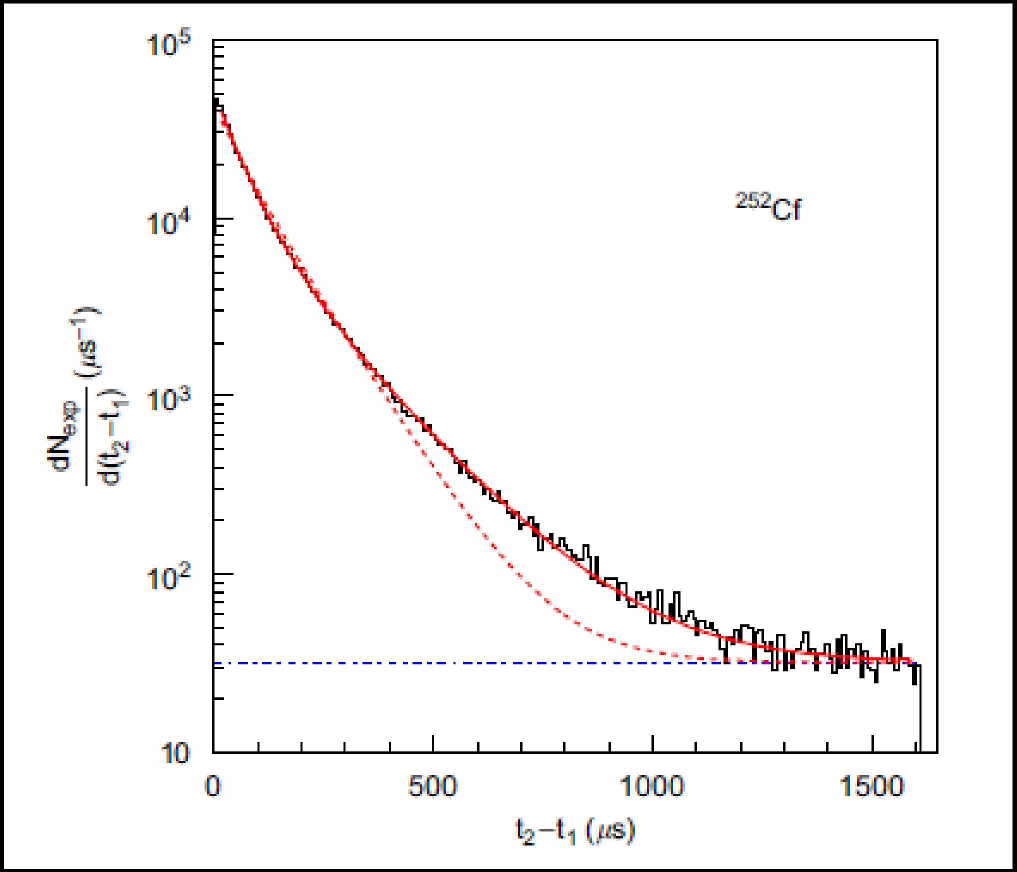
TIME RESPONSE OF THE POLYCUBE

$$\Delta N(t)/\Delta t = N_{\mathrm{BG}} + N_0 \lambda \exp(-\lambda t)$$

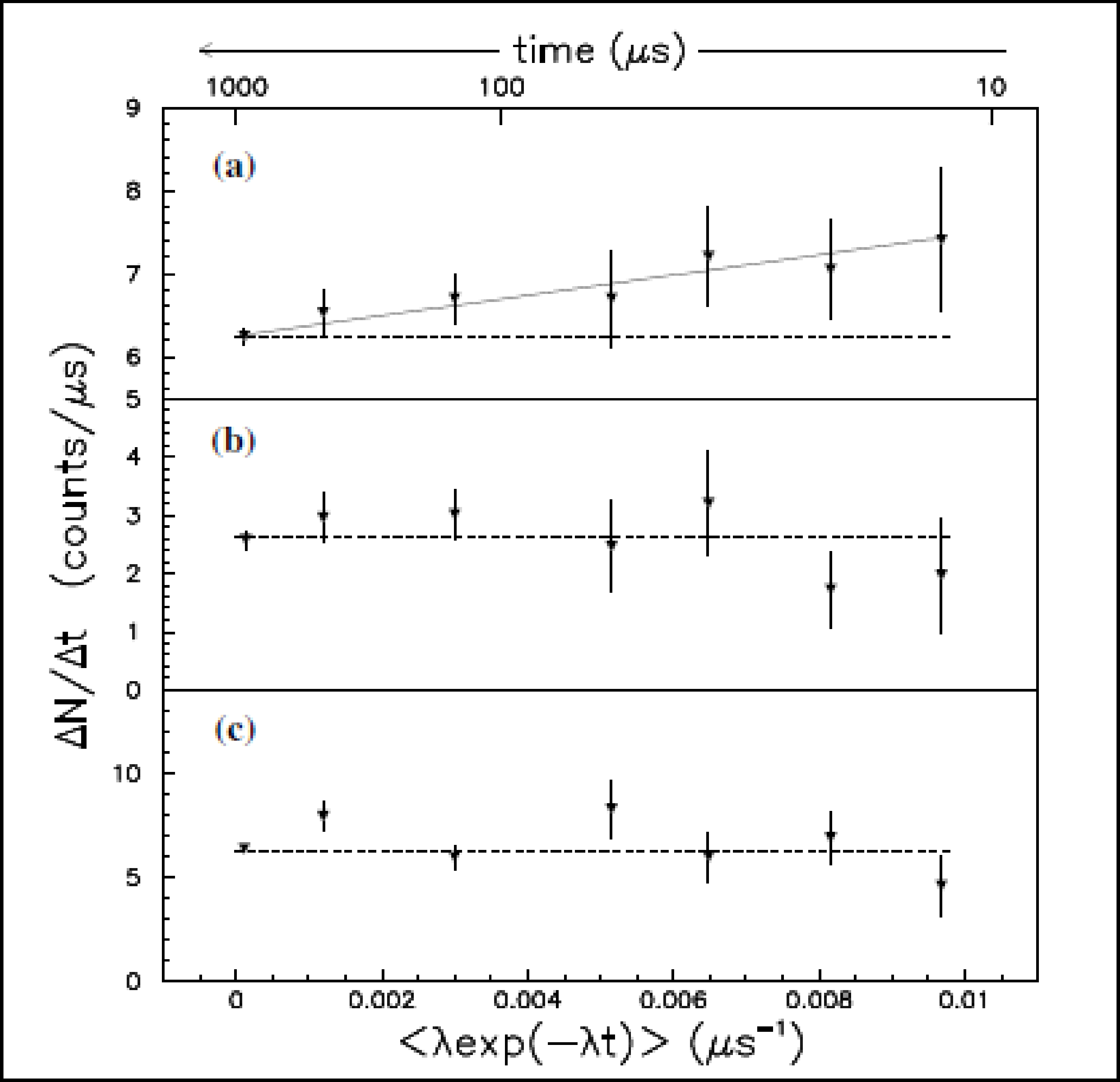
Where

λ is the inverse of die away time of polycube (supposed to be 87 μs)

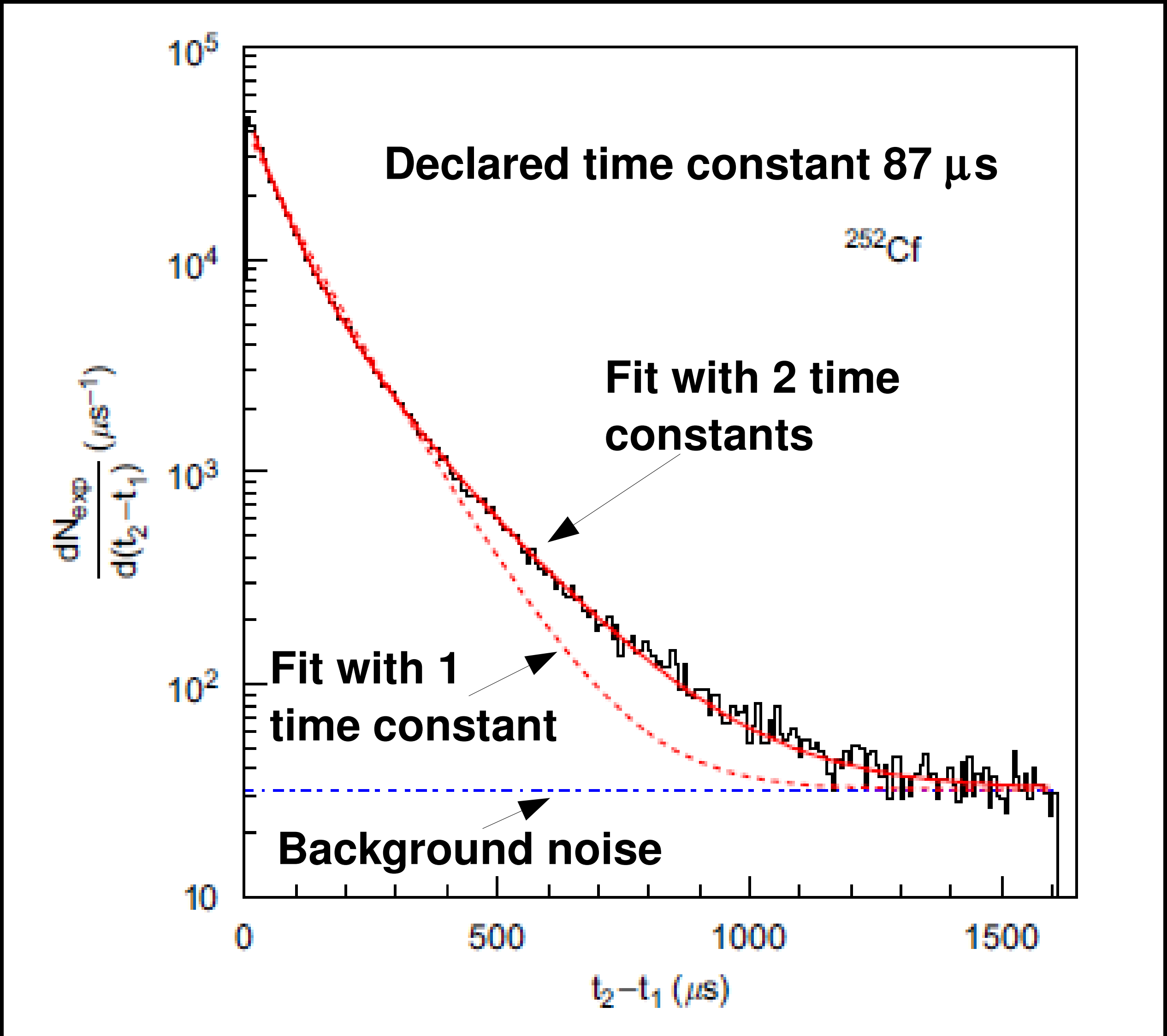
N_{BG} background

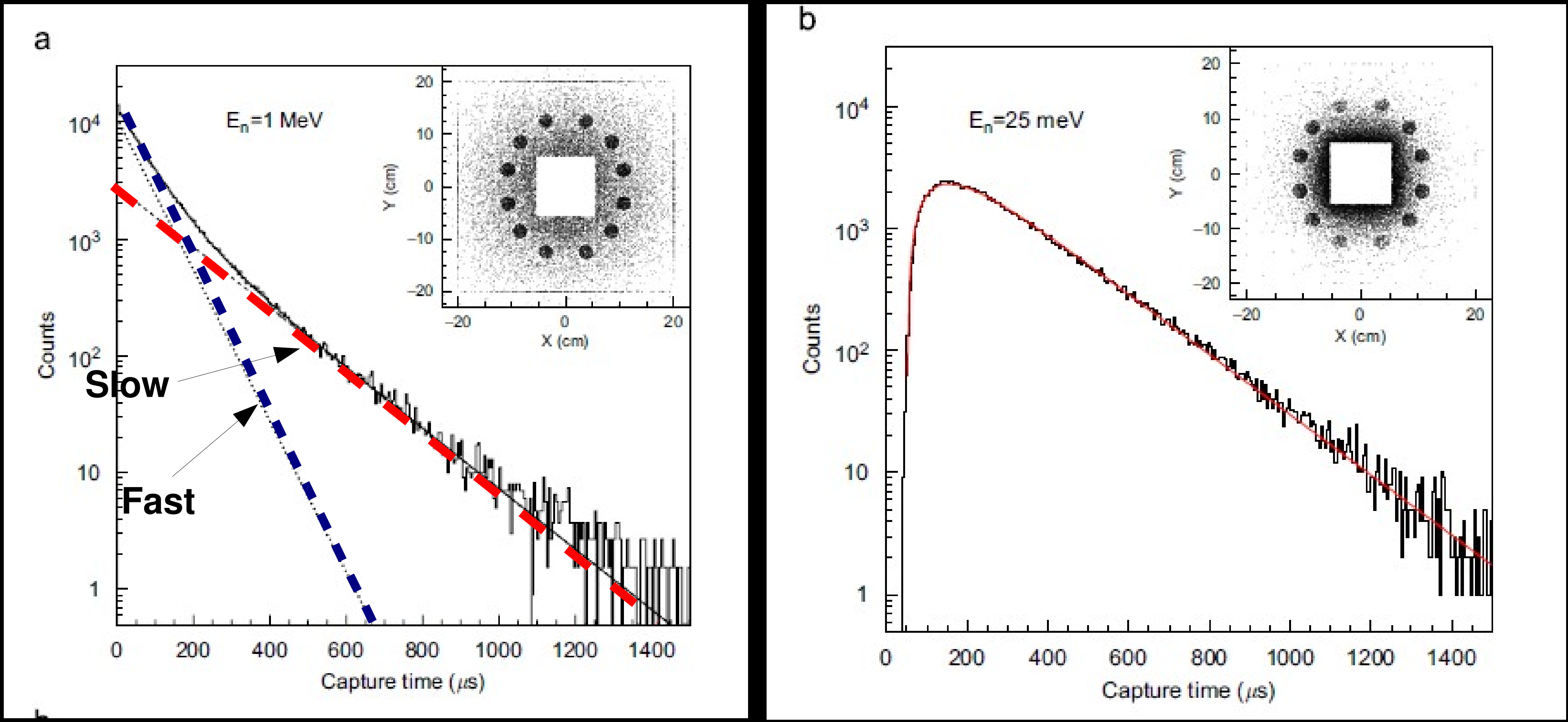


A NICE WAY TO SHOW CORRELATION



STUDY OF THE TIME CONSTANT OF POLYCUBE





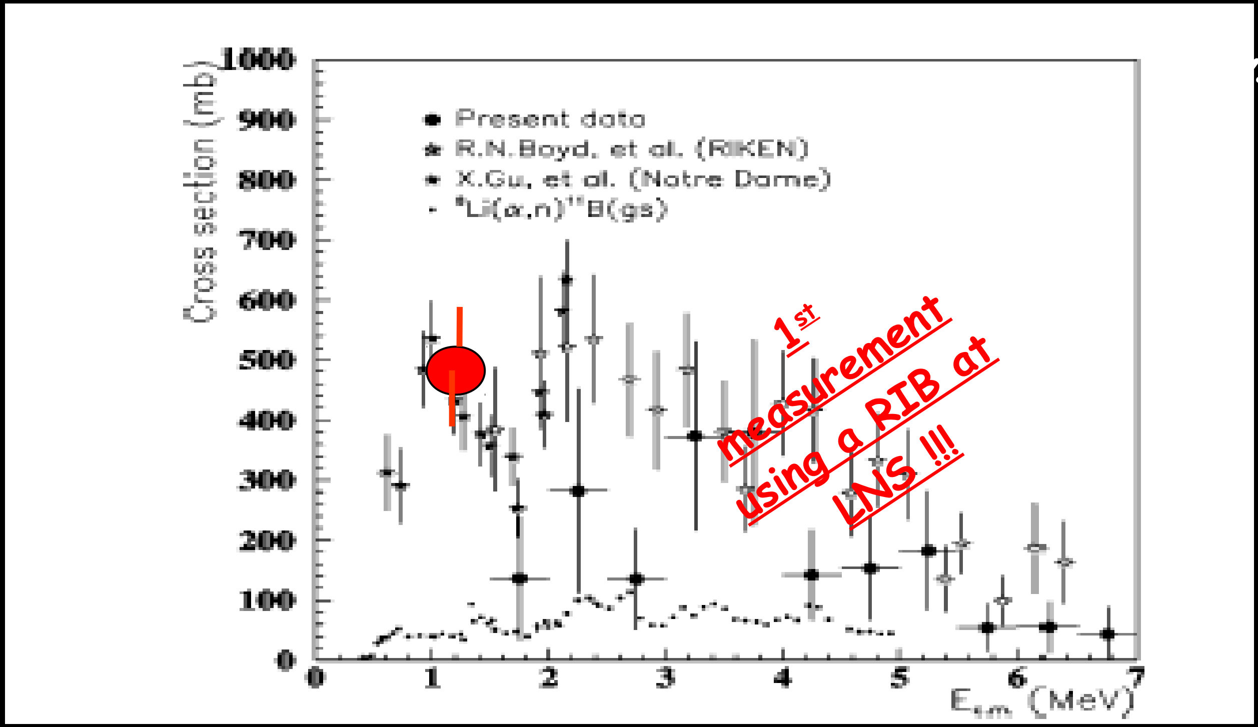
GEANT simulation of the POLYCUBE

Tslow =169 μs
Tfast = 67 μs

Direct measurements & Inhomogeneous BigBang

BIG BANG result for $^{8}Li(\alpha,n)^{11}B$ x-sec

500 mbarn +- 170 mbarn +- 70 mbarn

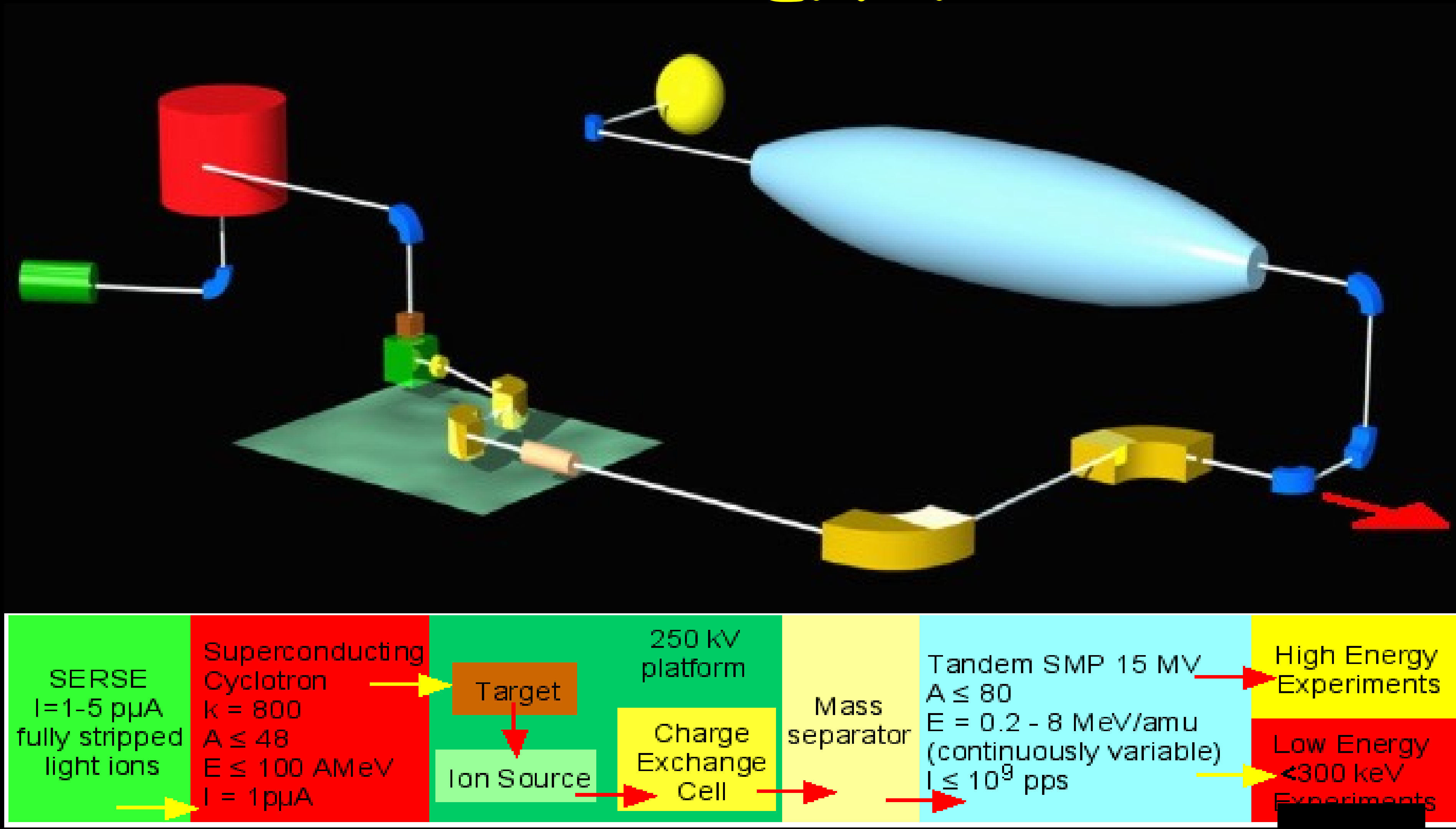


EPJ A-20, S. Cherubini et al.

+ series of papers

New runs of BIGBANG were the first experiment at

EXCYT



EXCYT de-excitation

Intensity just a bit higher

Better overall result though not as good as expected given the better beam quality (it is a tandem machine!) better focusing etc.

Reason: MANY more background neutrons

Xsection confirmed. A new point measured

BUT the X-sec puzzle remained there...

Inclusive measurements → high
Exclusive measurement → low ...

La Cognata et al.,
Phys. Lett. B, 2008
664,157

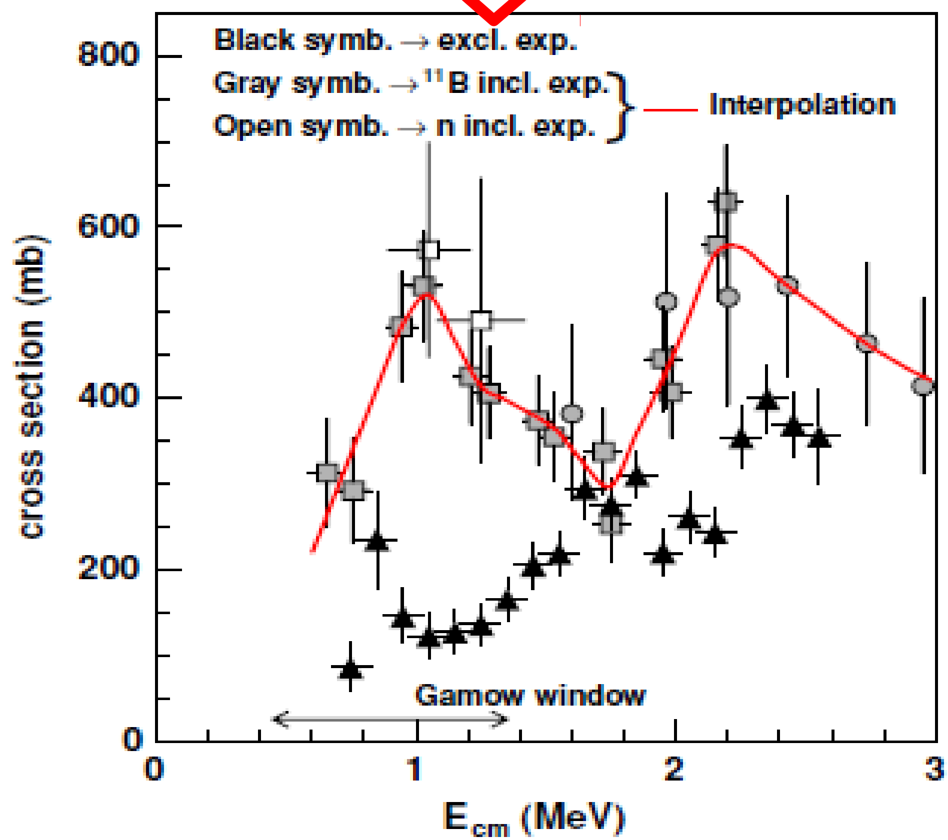
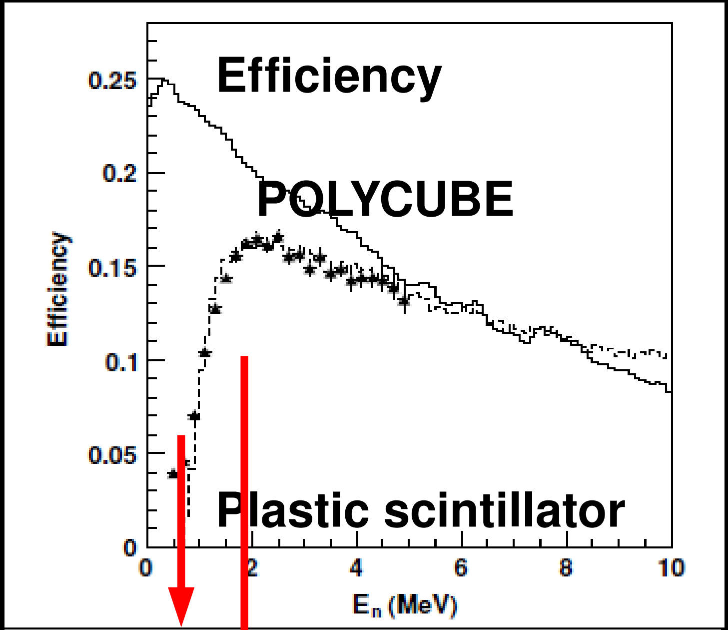
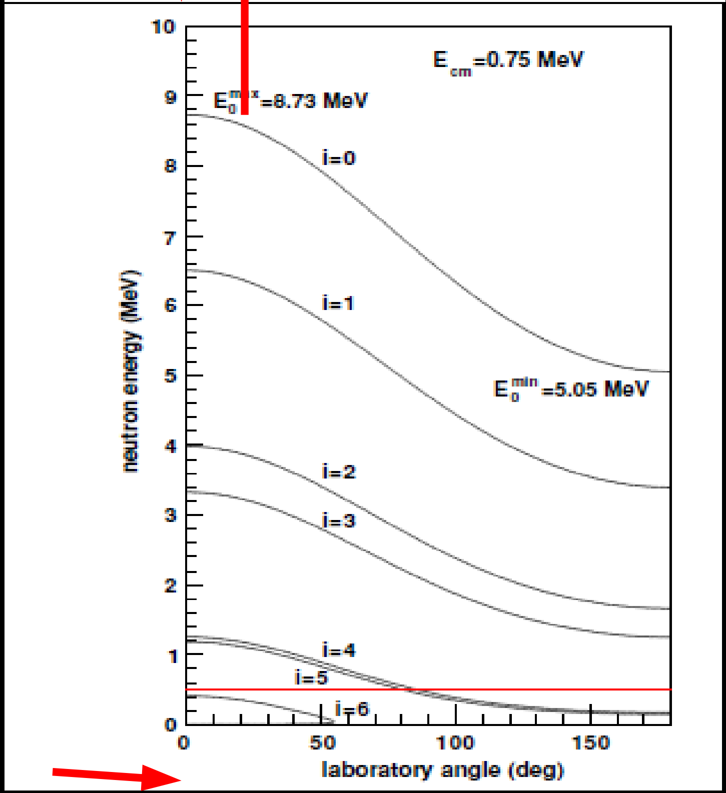
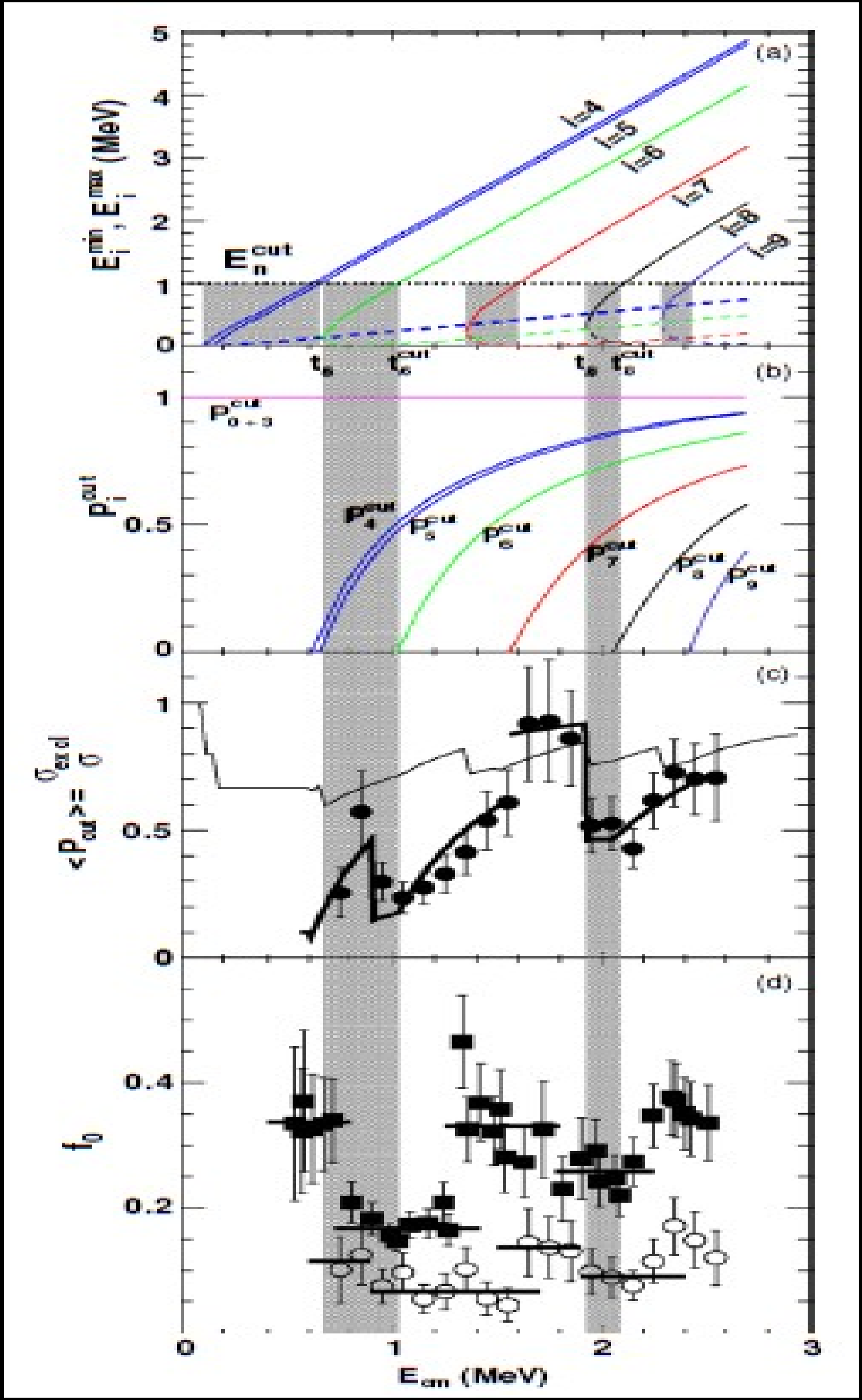


Figure 1. ^{8}Li + ^{4}He → ^{11}B + n reaction cross section data vs. E_{cm}: "□" (La Cognata et al. 2008), "●" (Boyd et al. 1992), "■" (Gu et al. 1995), and "▲" (Ishiyama et al. 2006). The curve depicts the interpolated inclusive cross section σ_{incl}. The Gamow energy region at $T = 2 \times 10^9$ K is shown.

We proposed the following solution to the puzzle







The Astrophysical Journal, 706: L251–L255, 2009 December 1

FEW WORDS MORE

Thank you all