Recent results at nTOF: ^{7}Be(n,α)α cross section measurement does it solve the Cosmological Lithium Problem?
(not yet!)

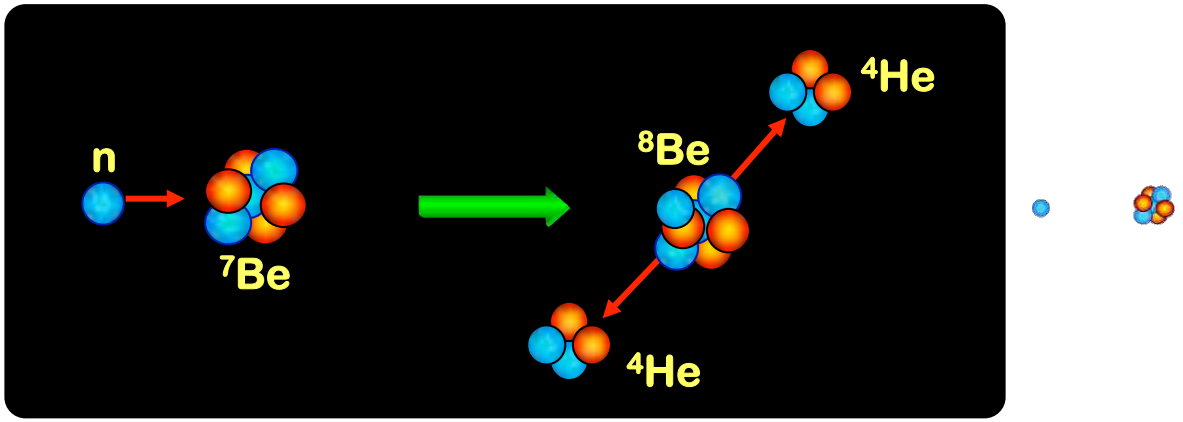
L. Cosentino, P. Finocchiaro, INFN-LNS Catania

A. Pappalardo, ELI-NP Bucharest

A. Musumarra, INFN-LNS & Dip. Fis. Astr. Catania

M. Barbagallo, N. Colonna, INFN Bari

and the n_TOF collaboration @CERN

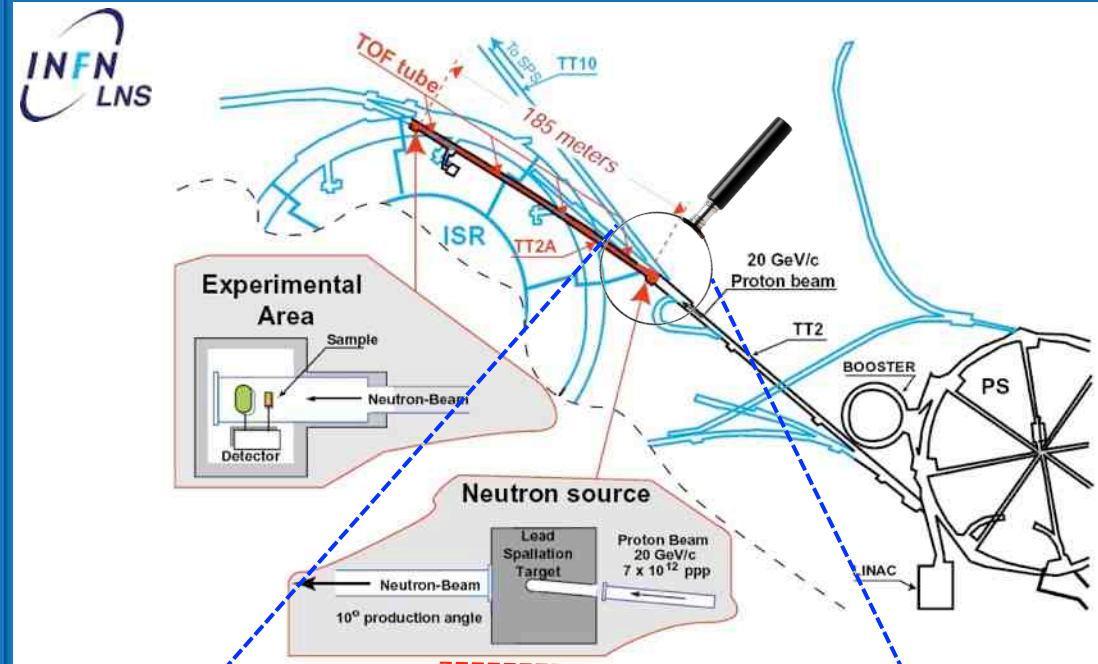


...subtitle
^{7}Be(n,α)α: a 50-year wait for an "*impossible*" measurement

Summary

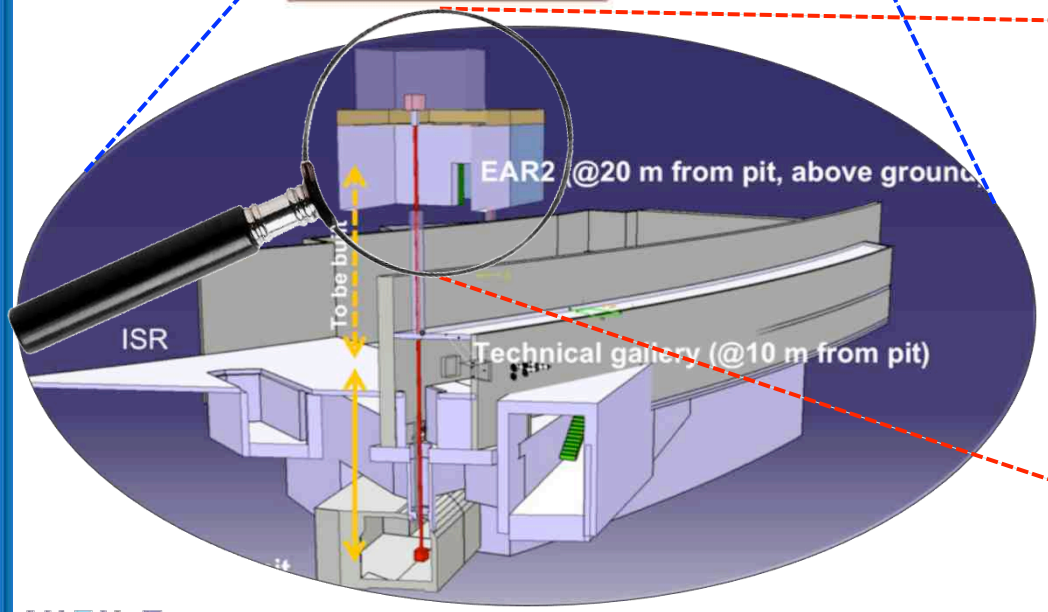
- few words and a short movie about n_TOF
- semiconductor detectors for neutrons (SiLiF)
- the challenging ^{7}Be(n,α)α reaction: preparation and experiment

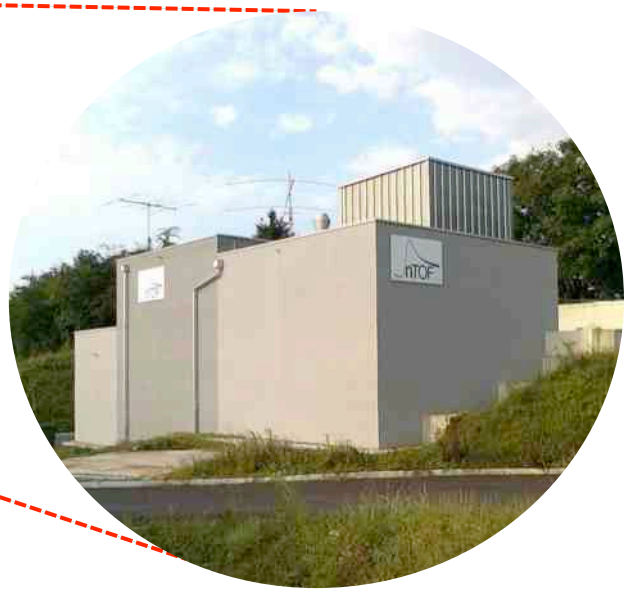
the n_TOF collaboration in Europe

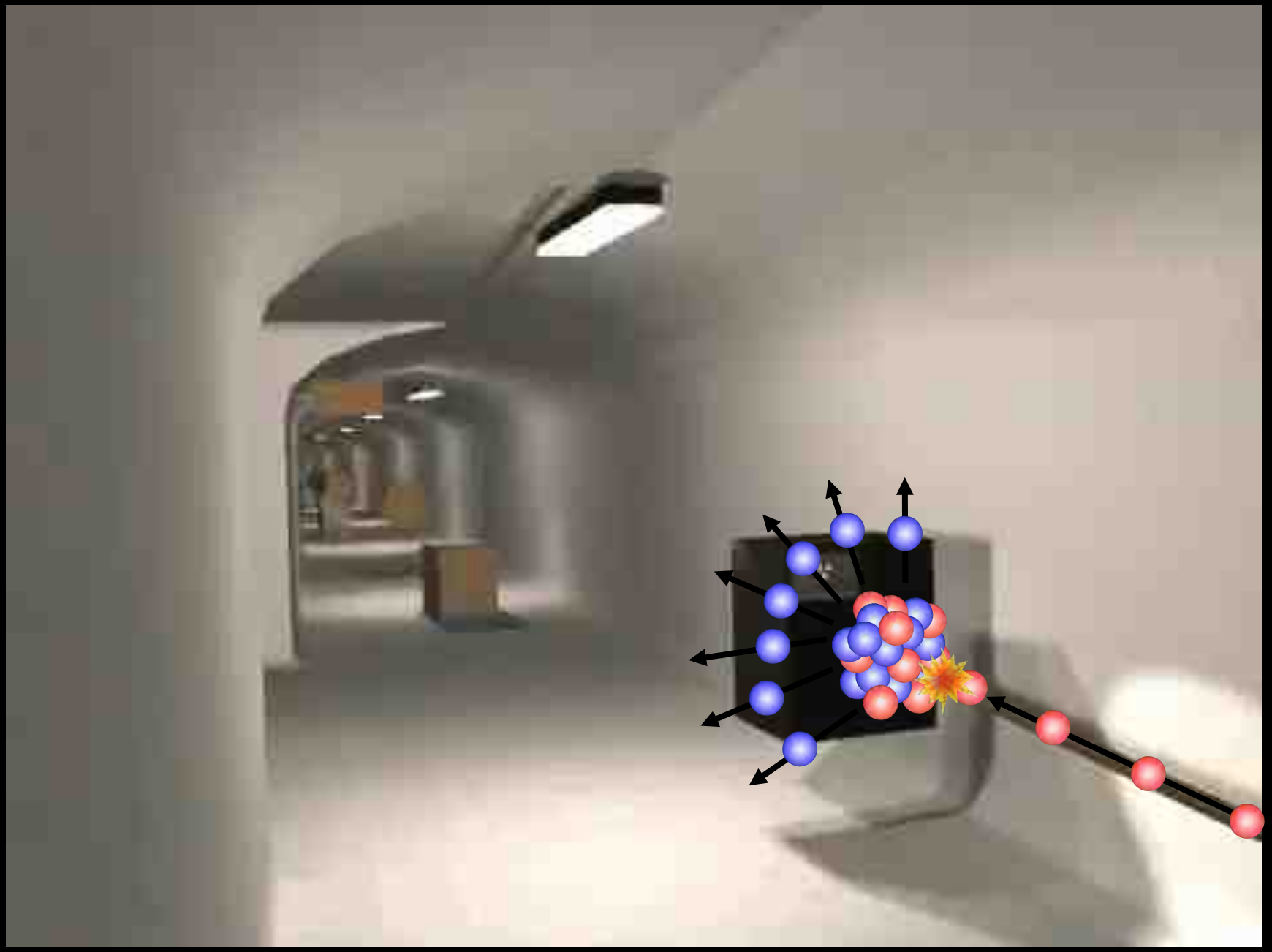


the n_TOF facility at CERN

≈ 10^7 n/pulse







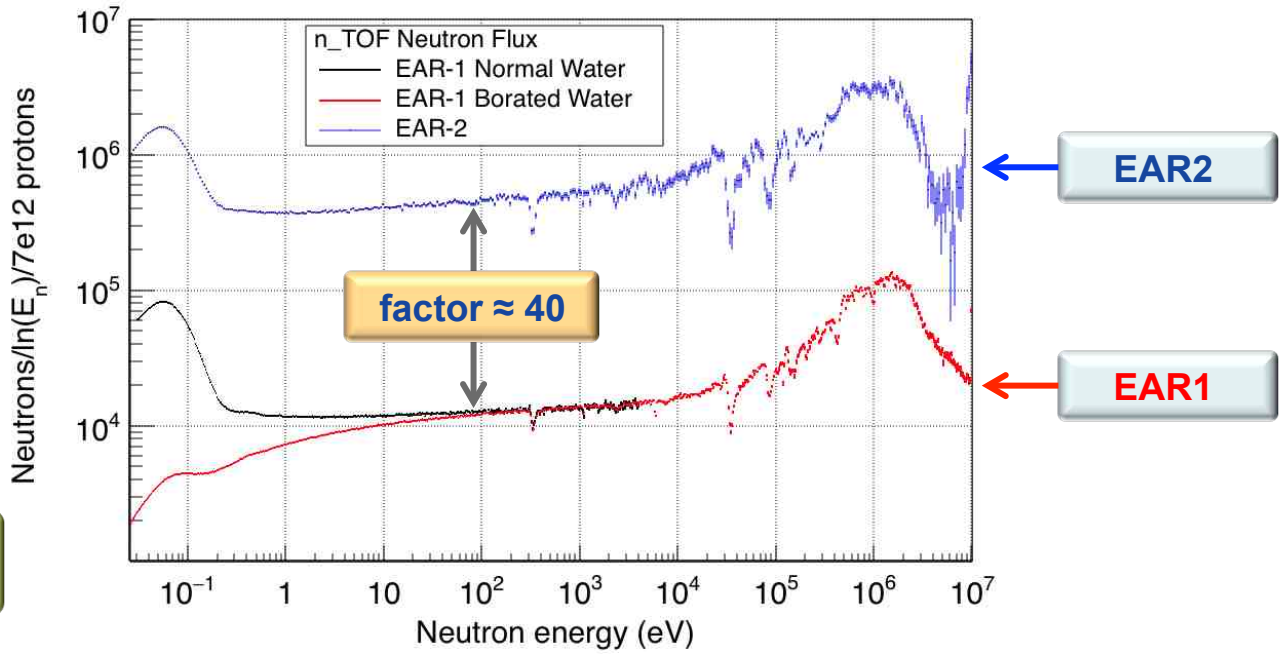
n_TOF main features

	EAR-1	EAR-2
Wide energy spectrum	25 meV<E_n<1 GeV	25 meV<E_n<300 MeV
High instant flux	10^5 n/cm^2/pulse	10^6 n/cm^2/pulse
Low repetition rate	<0.8 Hz (1 pulse/2.4 s maximum)	
High energy resolution	$\Delta E/E=10^{-4}$ (E_n < 10 keV)	$\Delta E/E=10^{-3}$ (E_n < 10 keV)

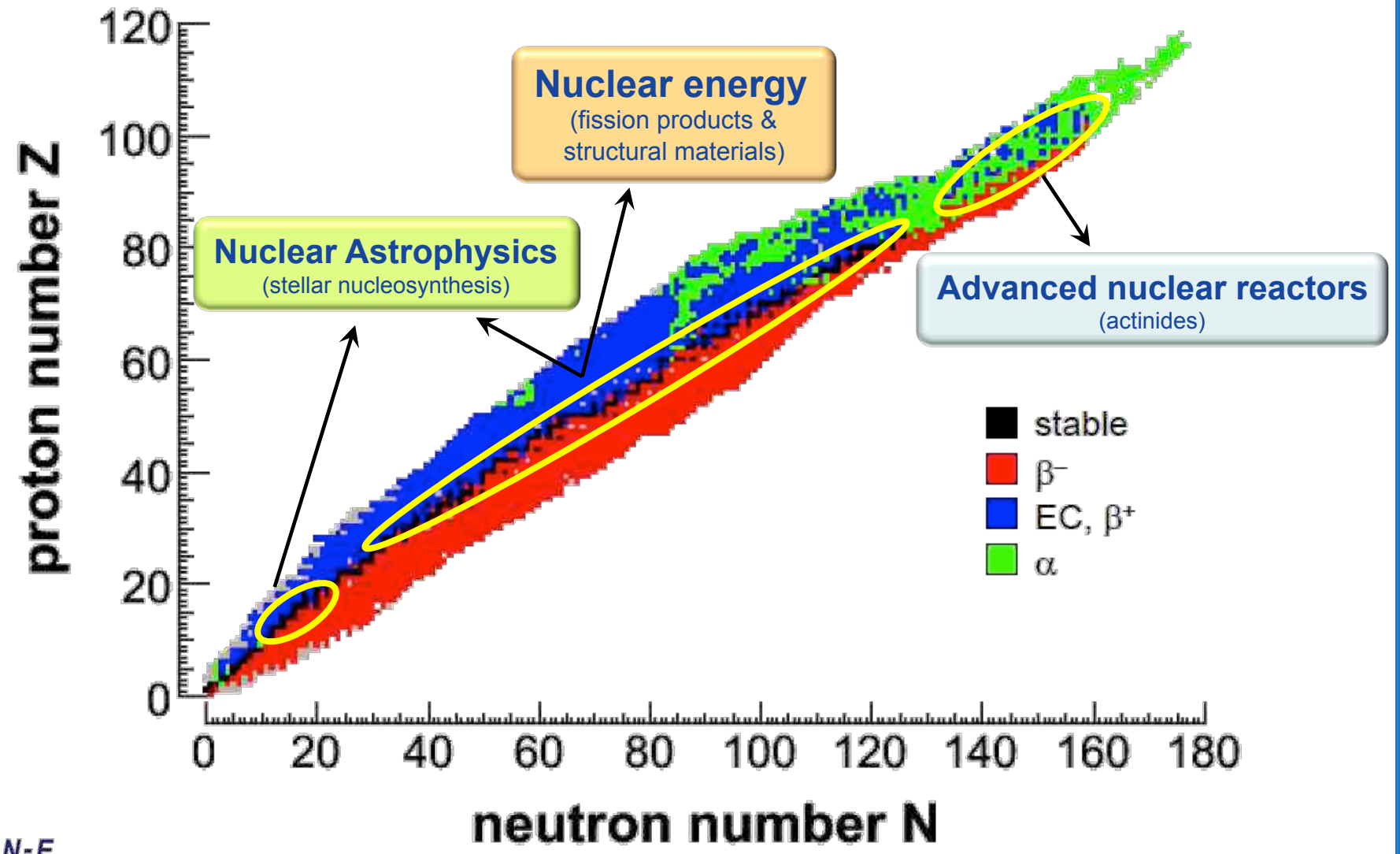
neutron flux

S/B improved by ≈ 400

highly radioactive targets and/or low cross sections



Neutron cross sections
are needed for...



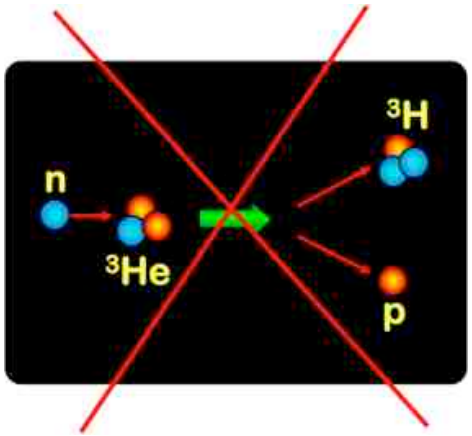
semiconductor detectors for neutrons: SiLiF

materials for thermal neutron conversion

^{3}He

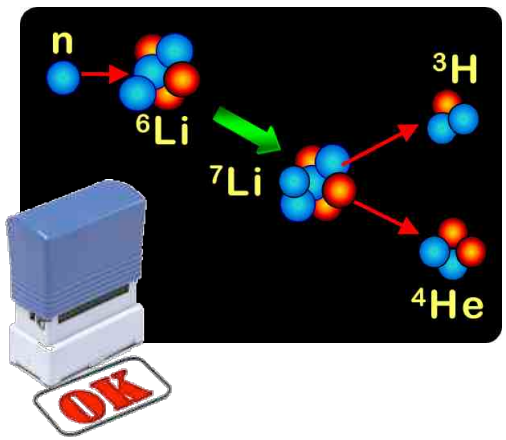
$\sigma(0.025)$
$\approx$ 5330 b

available energy
0.76 MeV
no gamma rays



**perfect gas detector but...
worldwide lack of ^{3}He**

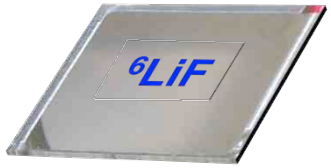
^{6}Li

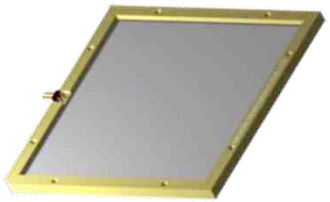


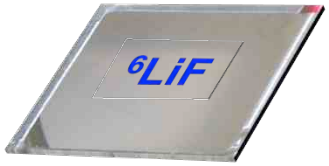
$\sigma(0.025)$
$\approx$ 940 b

available E
4.78 MeV

SiLiF: how?


6LiF

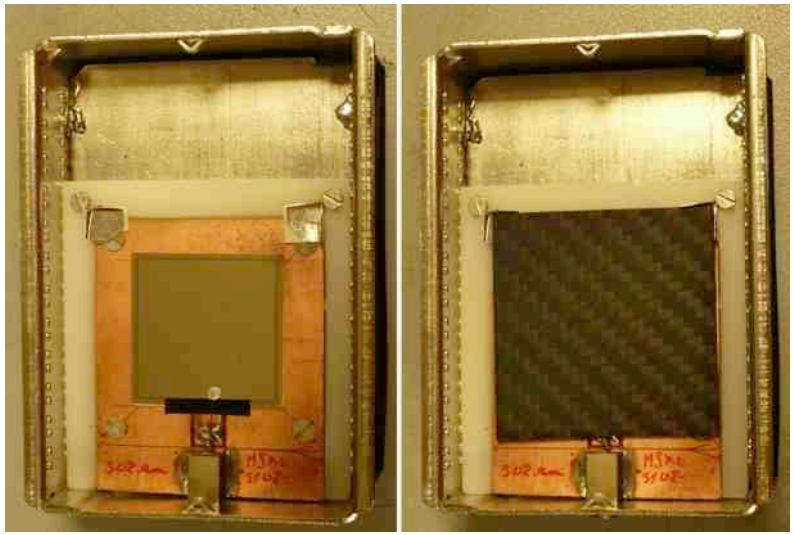



6LiF

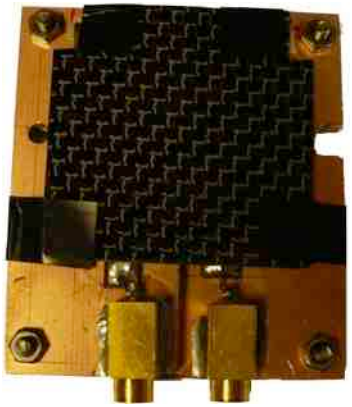
4He
n
7Li
6Li
6LiF converter
3H
Triton detected
double-side Silicon detector
Alpha detected
4He
6LiF converter
7Li
n
6Li
3H

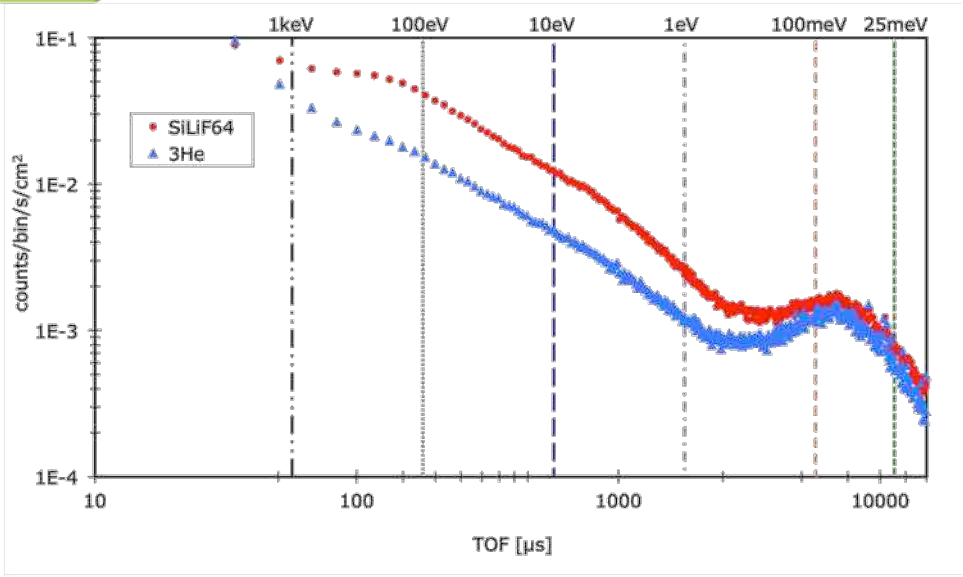
SiLiF detectors

- low cost, technology cheaper than ^{3}He
- low voltage (20-30 V)
- flat detectors, compact, robust, simple to use, easily handled
- efficiency evaluated analytically
- fine position sensitivity (mm) easily achieved
- coarse position sensitivity (cm) with pads
- this sample 3cm x 3cm active area
- 10^{-6} neutron/gamma discrimination

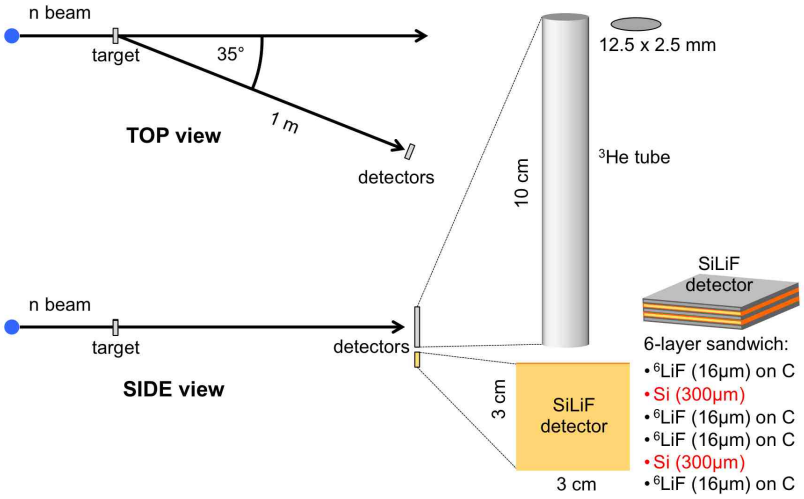


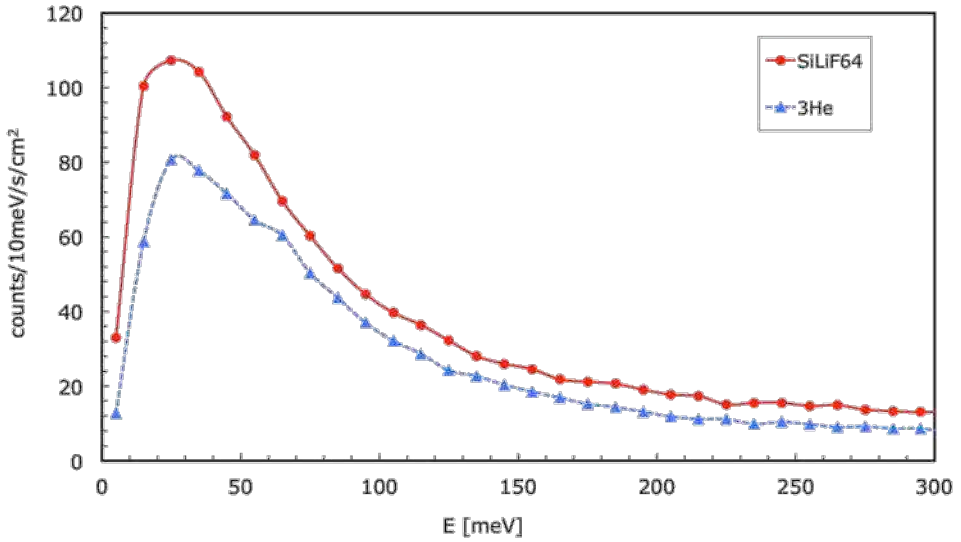
SiLiF detectors





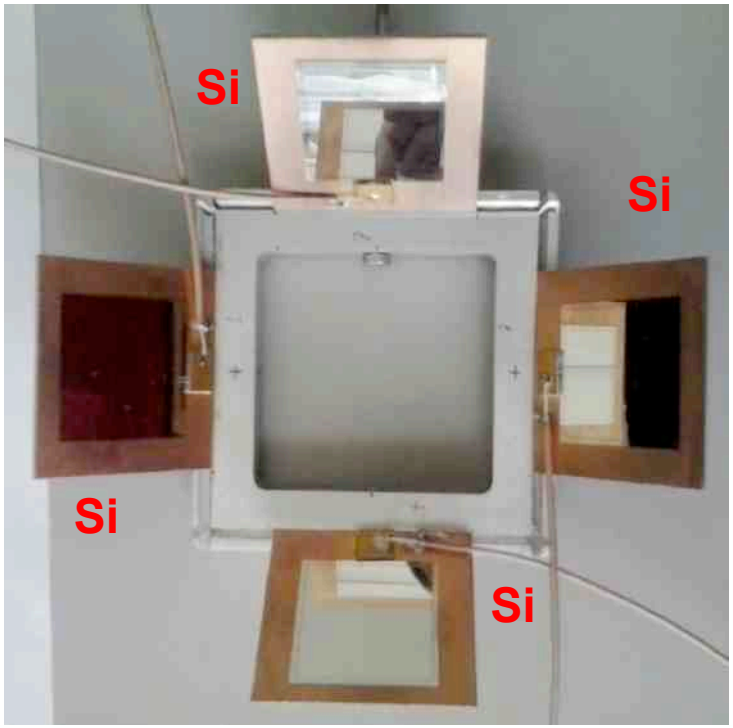
comparison with ^{3}He tube at INES/ISIS

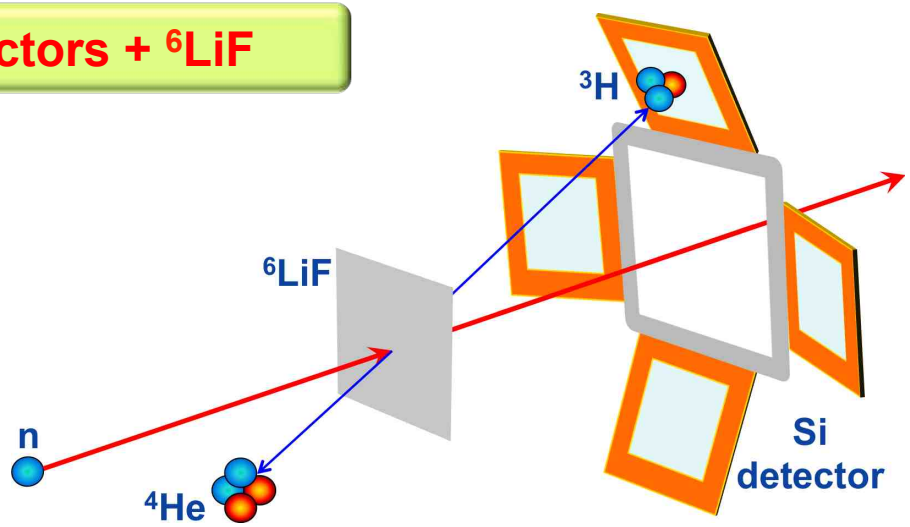


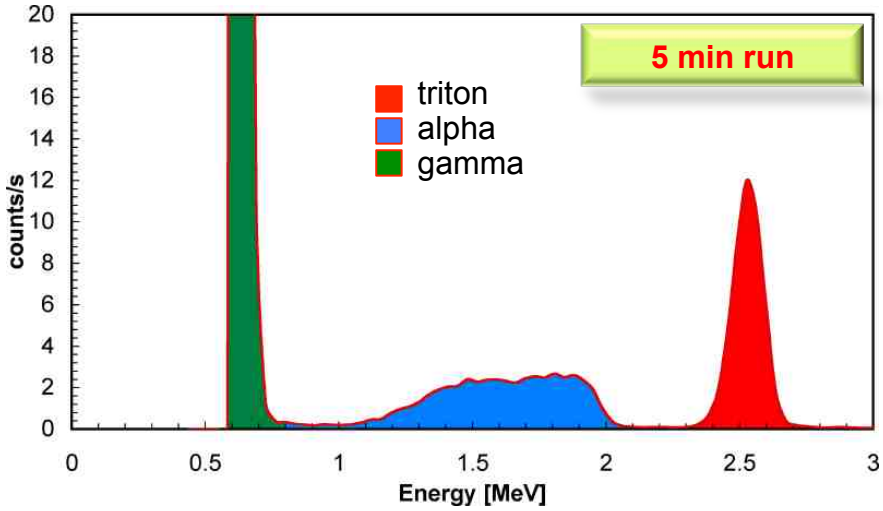


SiMon2 @ n_TOF
neutron beam monitor for flux normalization

Si detectors + ^{6}LiF

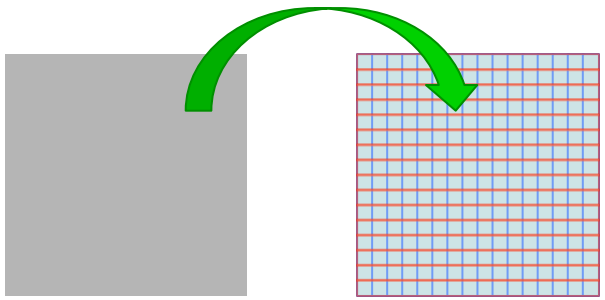




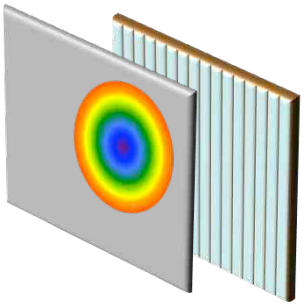


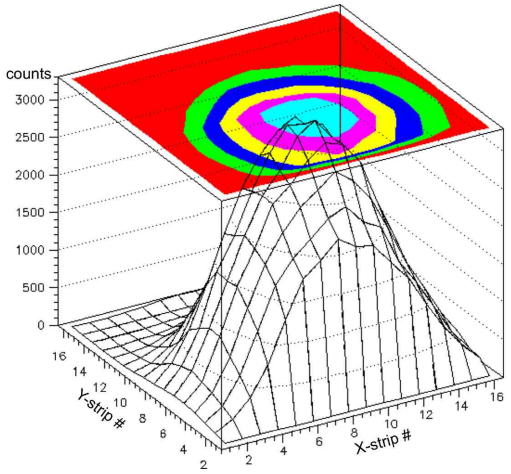
BeaMon @ n_TOF: neutron beam characterization

SiLiF



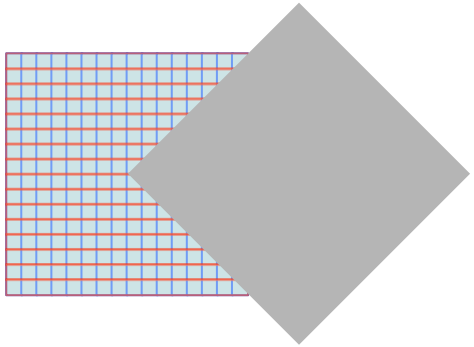
^{6}LiF foil 25+25 strip Si

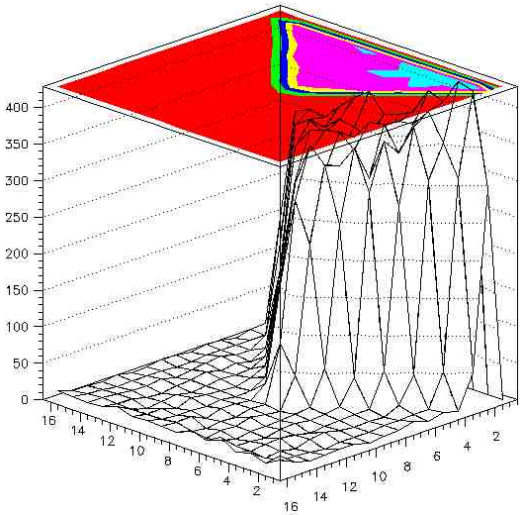




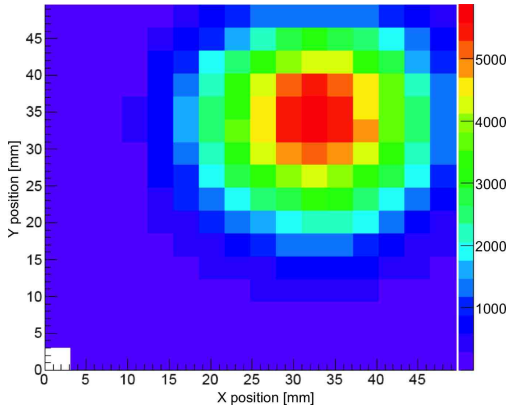
the idea

the test

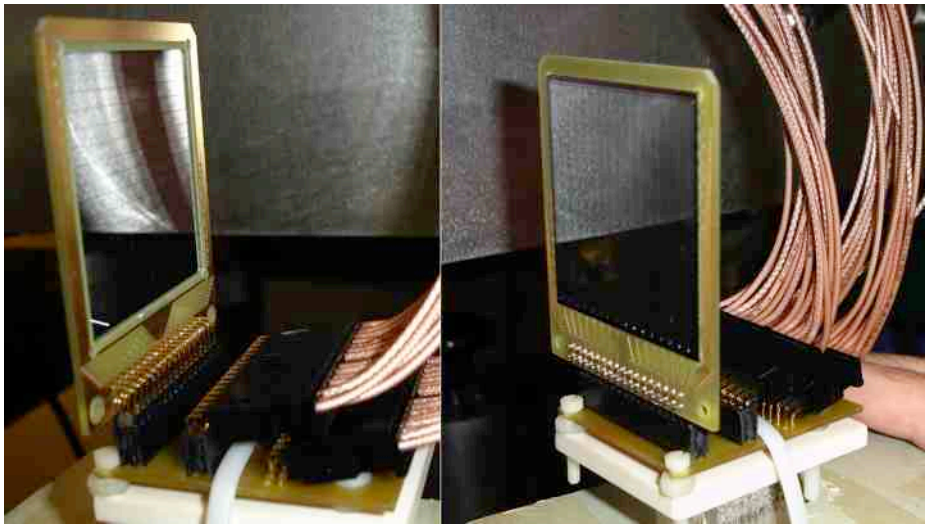


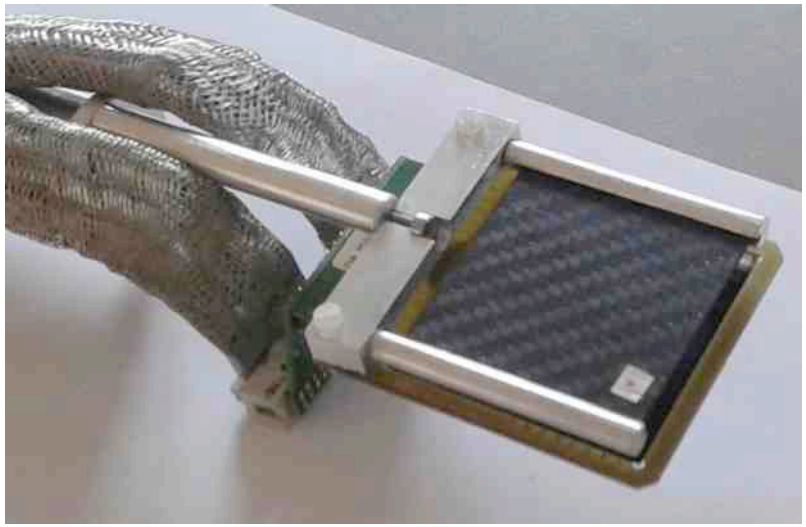


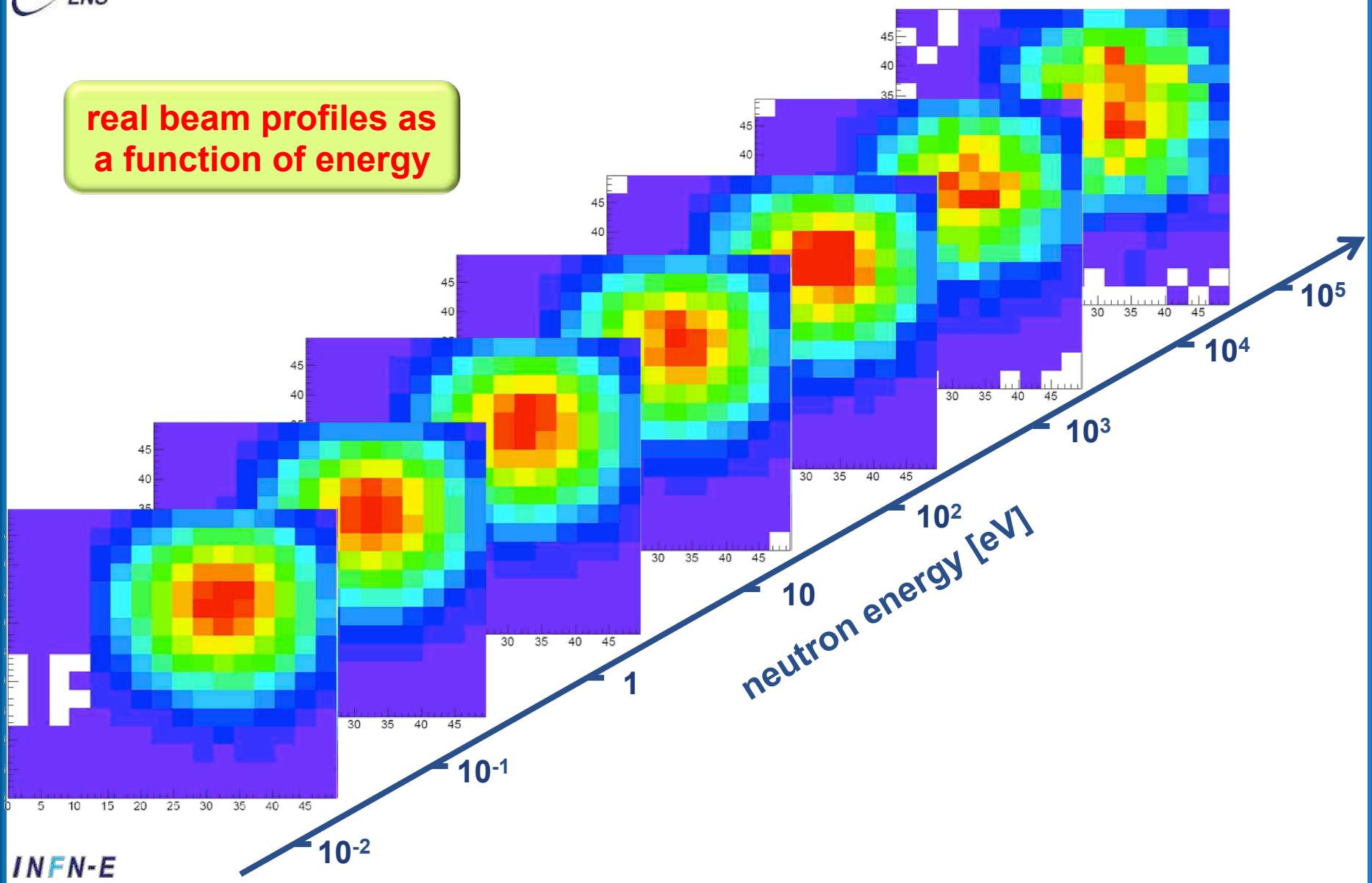
5cm x 5cm strip SiLiF detector
25 strips, 2mm x 5cm



real beam profile

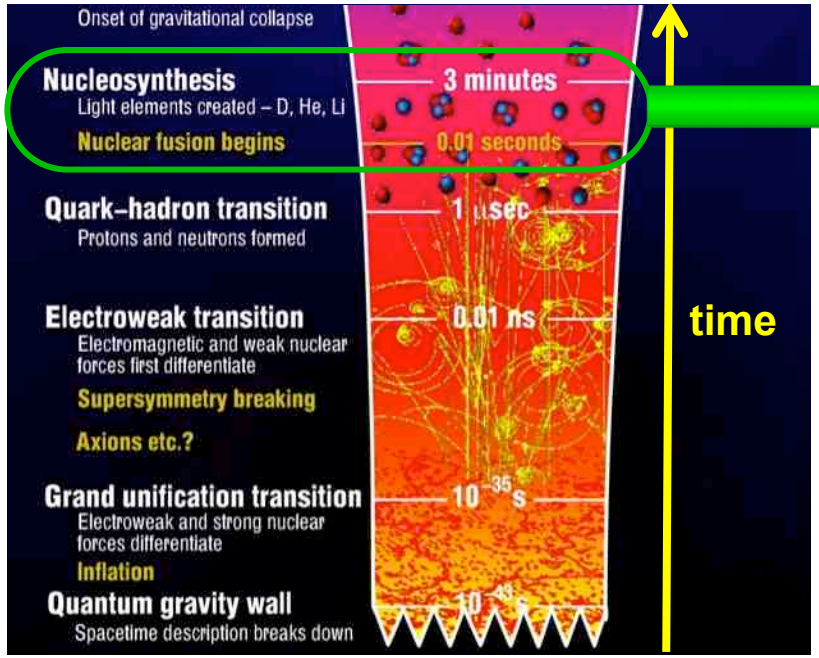





real beam profiles as a function of energy
neutron energy [eV]
10-2
10-1
1
10
10²
10³
10⁴
10⁵
INFN LNS
nTOF
INFN-E

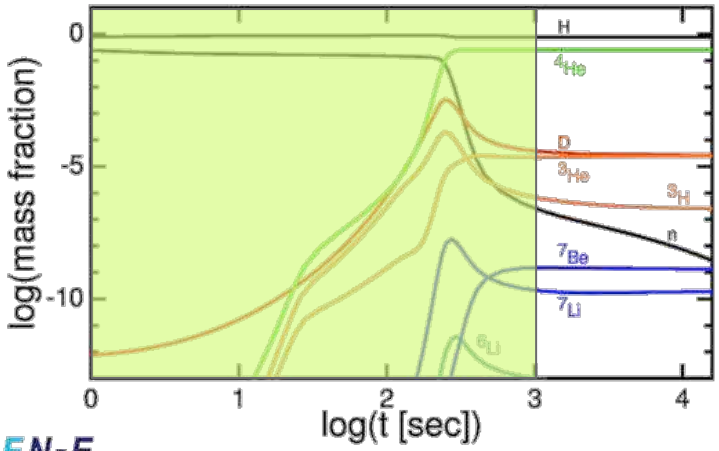
the challenging ^{7}Be(n,α)α reaction: preparation and experiment

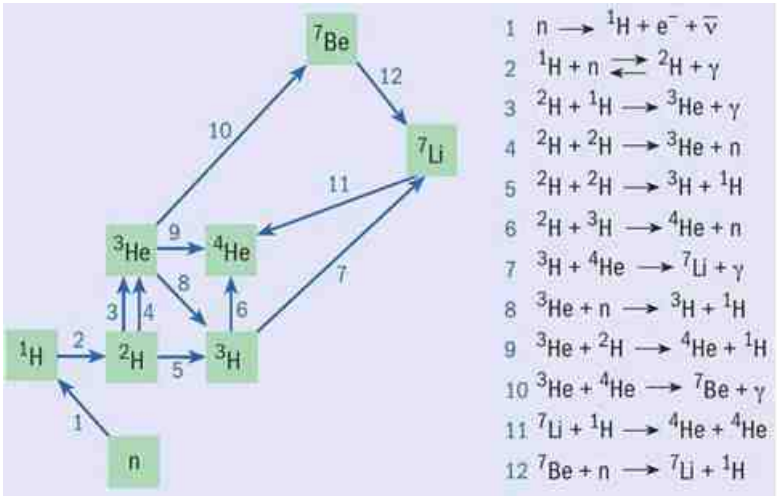
Big Bang Nucleosynthesis (BBN)



theory without free parameters
only depends on cross sections

sequence of nuclear reactions
leading to the synthesis of the
light elements (0.01 ÷ 1000 s)

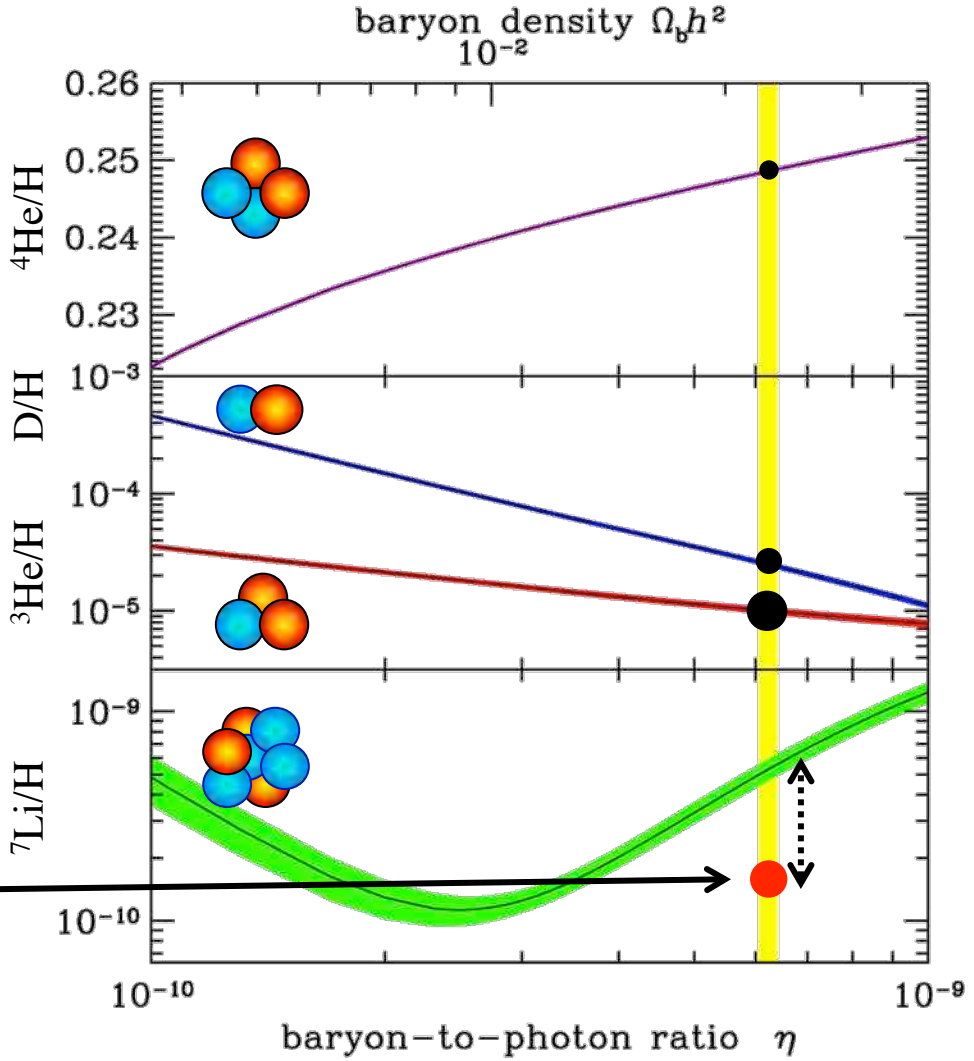




the Cosmological Lithium Problem (CLIP)

BBN successfully predicts the abundance of primordial elements (^{4}He, D, ^{3}He)

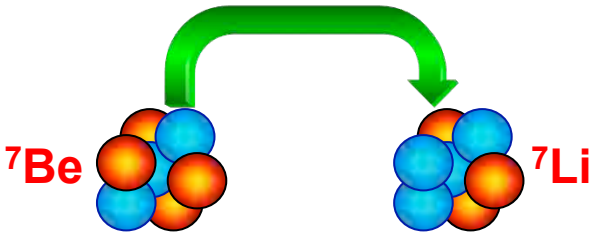
serious discrepancy for ^{7}Li theory/observation ≈ 2 ÷ 4

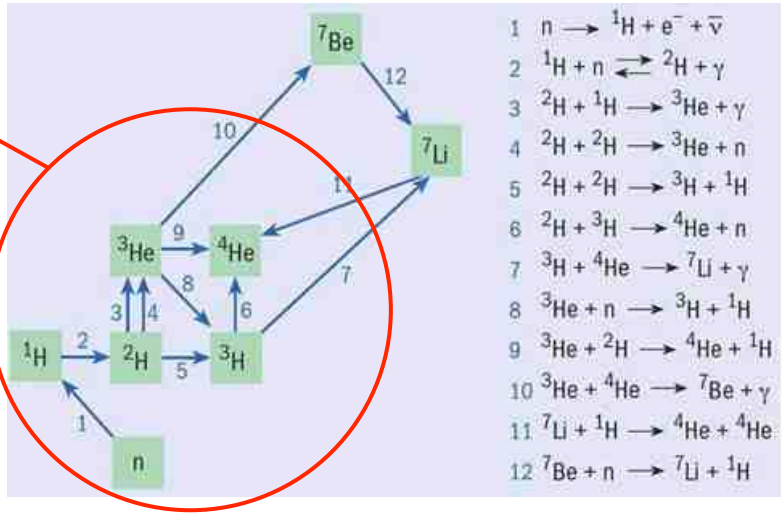


the Cosmological Lithium Problem (CLIP)

a few minutes after the Big Bang this cycle stops

≈ 95% of primordial ^{7}Li produced by EC of ^{7}Be
$t_{1/2}$ = 53.2d

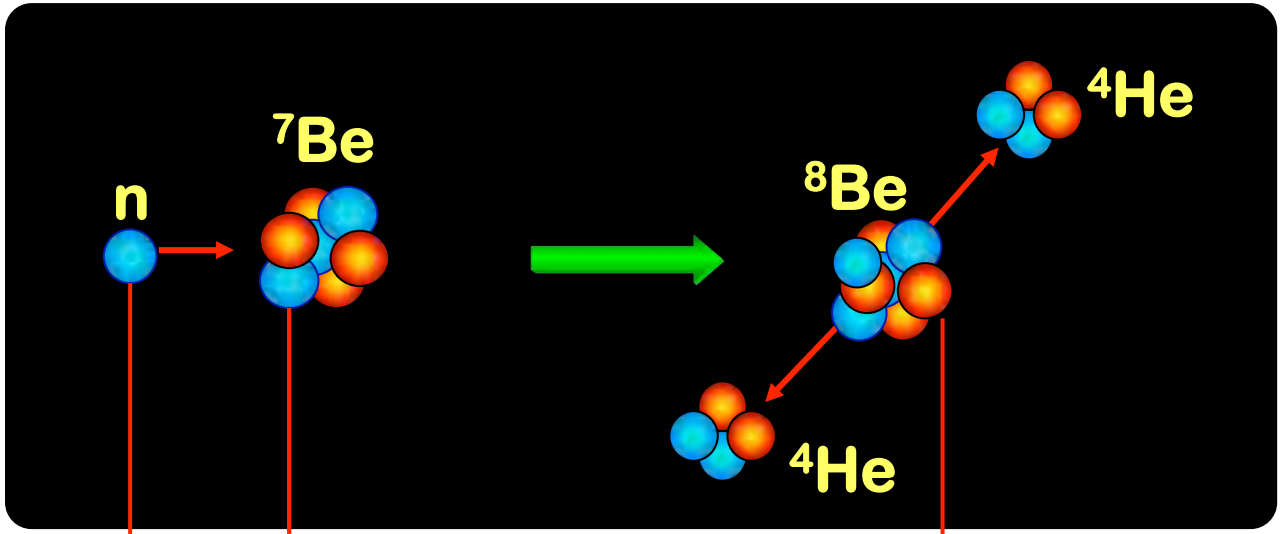




if ^{7}Be has been somehow destroyed less ^{7}Li would be produced → solution to CLIP?

remaining nuclear processes to be investigated:
^{7}Be(n,α)α ^{7}Be(n,p)^{7}Li

$^{7}Be(n,\alpha)\alpha$: why *impossible*?



huge background
(n and gamma)

^{7}Be production << 1 μg

^{7}Be target highly radioactive (13 GBq/μg),
478 keV gamma rays, $T_{1/2} \approx 53d$

intensity of available n-beams not enough

^{7}Be(n,α)α the only existing data is at 25 meV (Bassi et al., 1963)

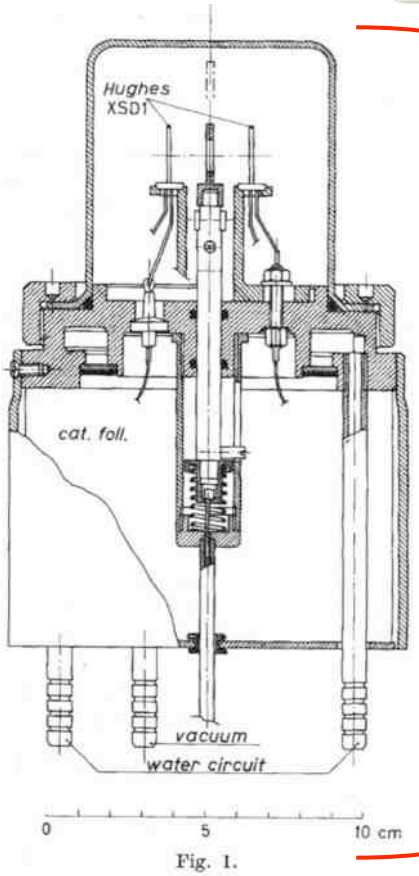
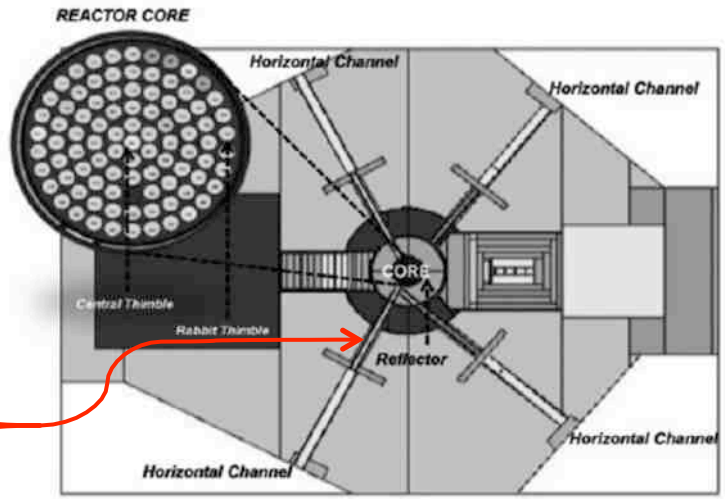
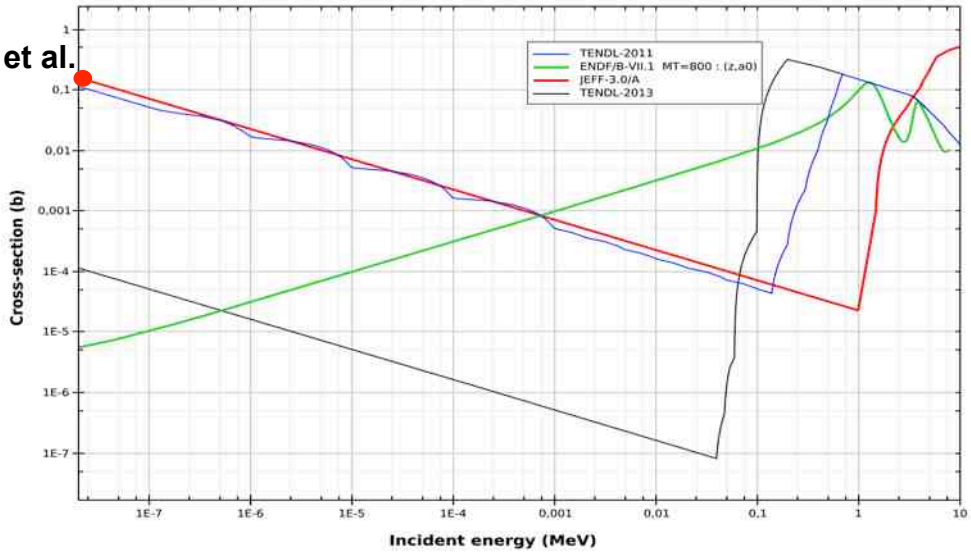


Fig. 1.



measured with thermal neutrons inside a reactor (Ispra, Italy)

Bassi et al.



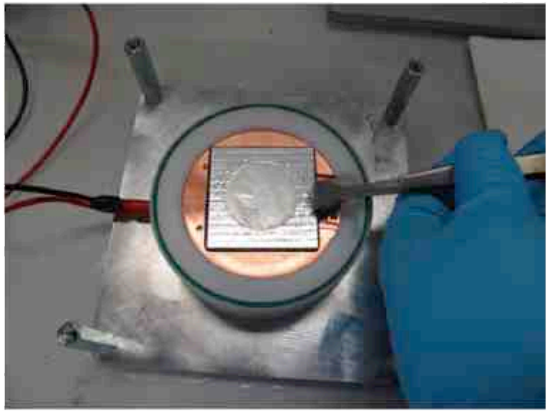
^{7}Be(n,α)α: how?

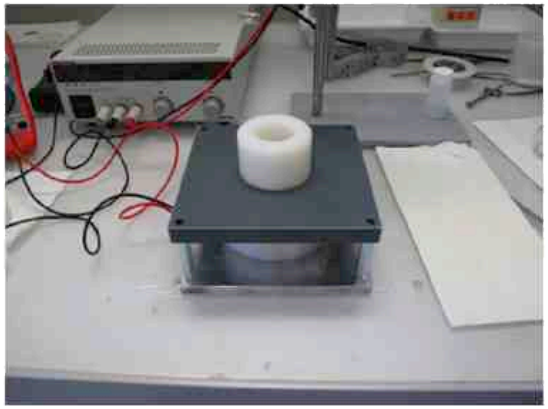
beam intensity not enough	→	n_TOF beam @ EAR2
^{7}Be production << 1 μg	→	PSI Zurich: extraction and purification of cooling water from SINQ
highly radioactive target	→	
huge background	→	

Deposition techniques

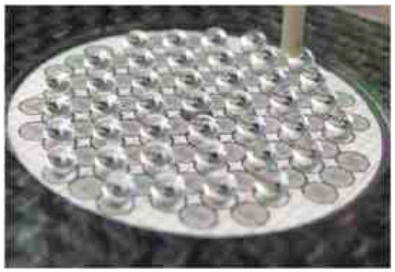
2 targets produced in a hot cell

Molecular plating

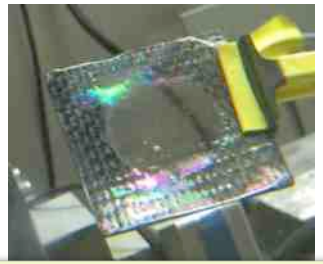




Vaporization of droplets



molecular plating
18 GBq

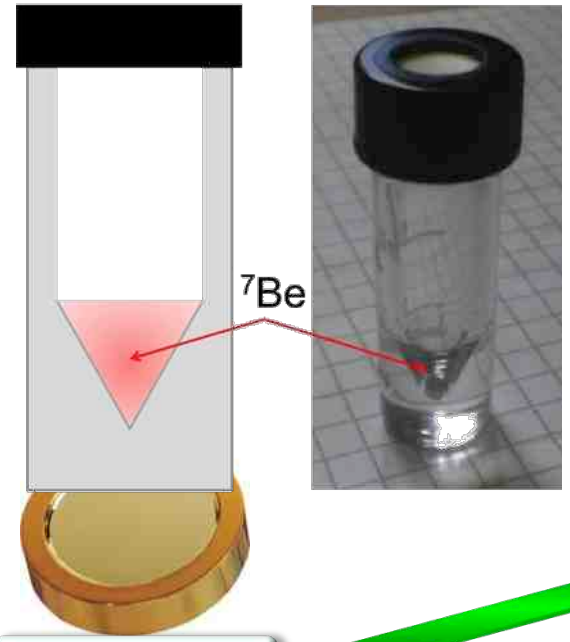


vaporization
17 GBq

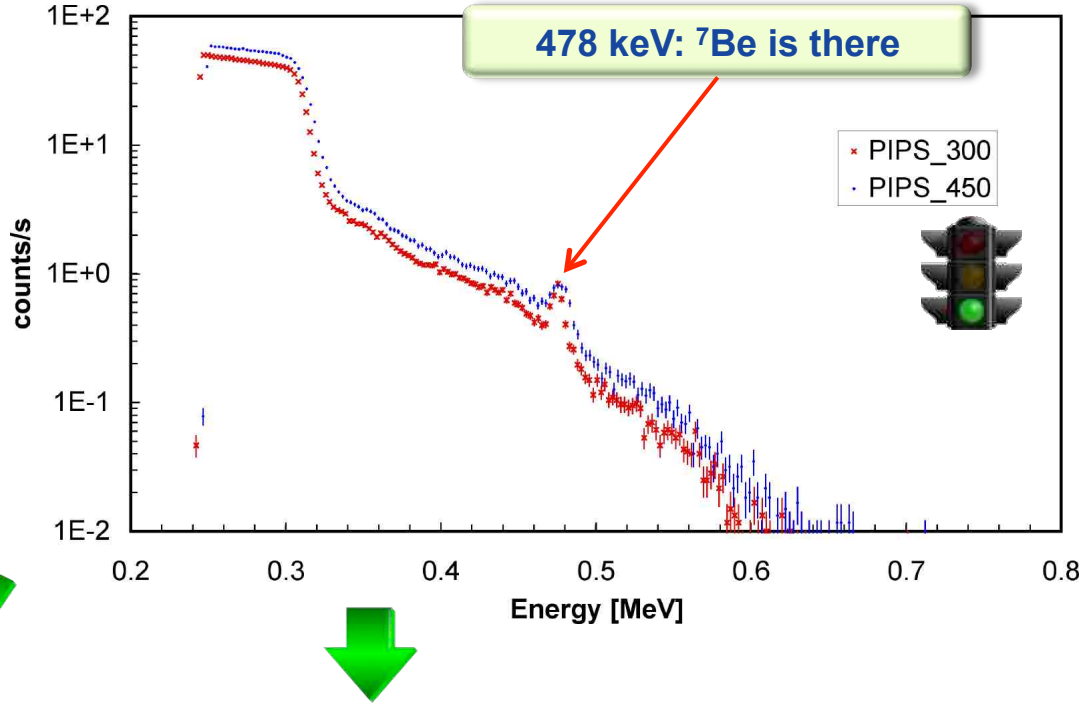
PSI 23-25.11.2015 CHANDA – workshop on target preparation – the needs and the possibilities

previously tested and checked with (^{9}Be + trace quantity of ^{7}Be)

(^{9}Be + trace quantity of ^{7}Be): check ^{7}Be presence



detector

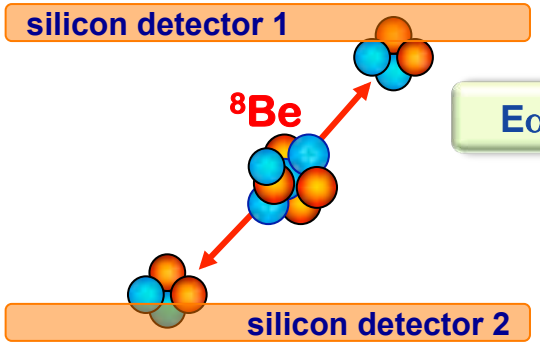


produced a test target
^{9}Be + trace quantity of ^{7}Be

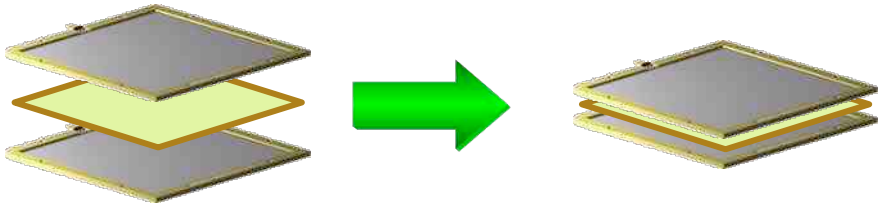
check the transferred Be: > 99.5%
(activity measurement)

^{7}Be(n,α)α: detection technique

α-α coincidence for background suppression (n and gamma)

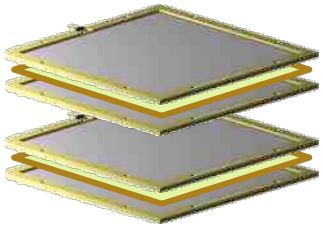


Eα ≈ 8 MeV



large solid angle

redundancy (to evaluate systematic errors and spurious counts)



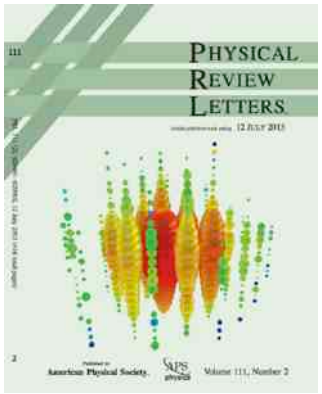
home-made detection system: no wizardry

hands-on work

data acquisition

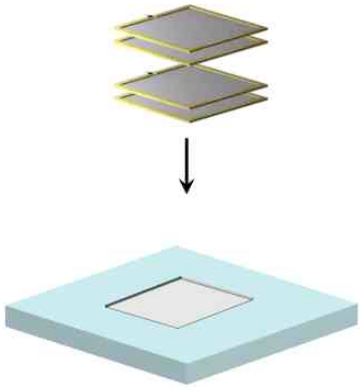
data analysis

publication

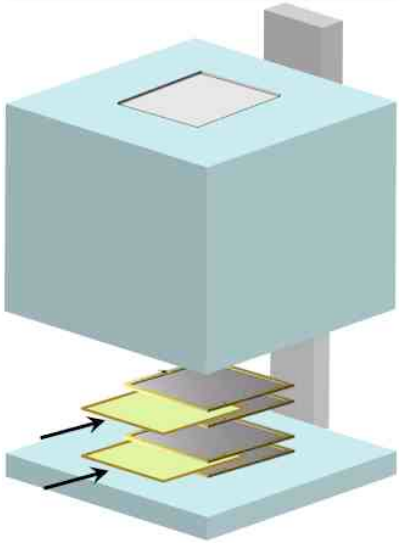


^{7}Be(n,α)α: shielding and mechanics

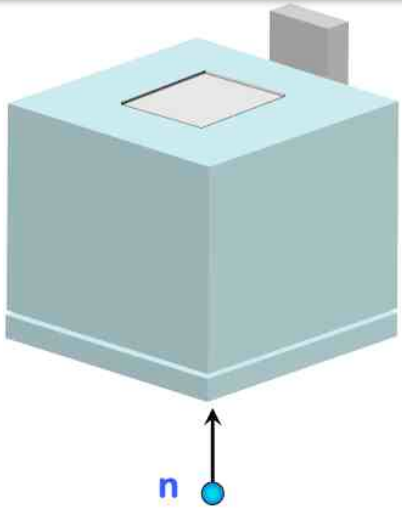
detector installation

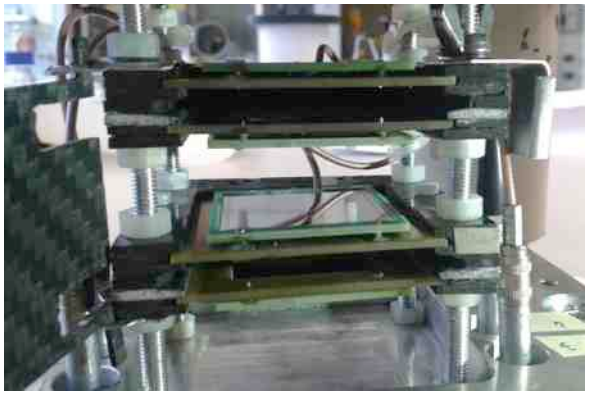


target insertion

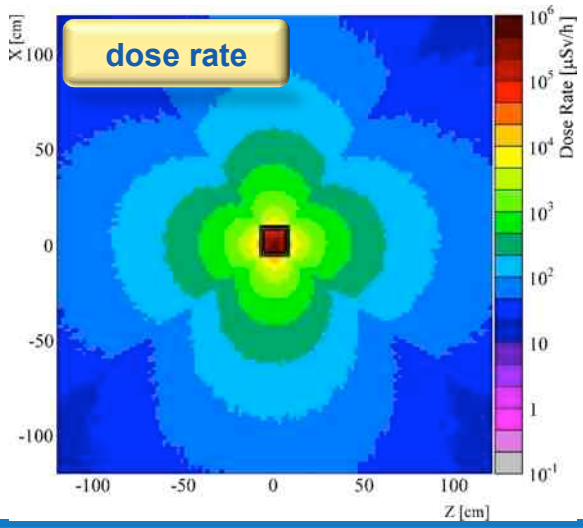


pneumatic closure





dose rate



INFN-E

target insertion (inside a hot cell)

chamber extraction

transport PSI - CERN

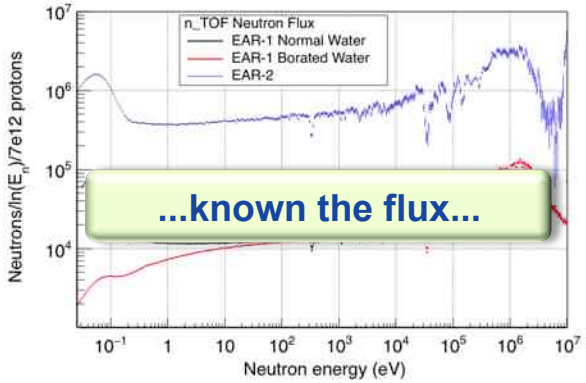
installation at EAR2 n_TOF

^{7}Be(n,α)α: the measurement?

1 “burst” of neutrons per second, duration ≈ 10ms

incident neutron energy for each α−α coincidence

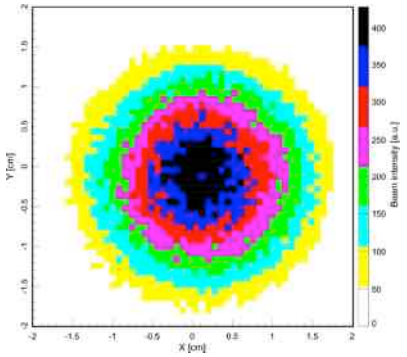
from the number of coincidence events one can deduce σ(E)...

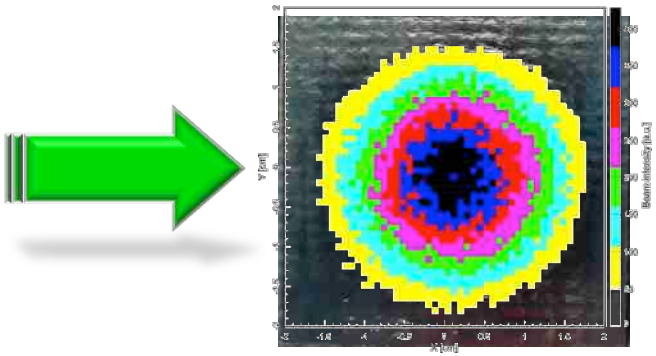


...known the flux...

...the spatial distribution of the beam...

...and the target features





INFN-E

incident neutron energy: the Time-Of-Flight technique

(invented long time ago: Orazi and Curiazi legend)

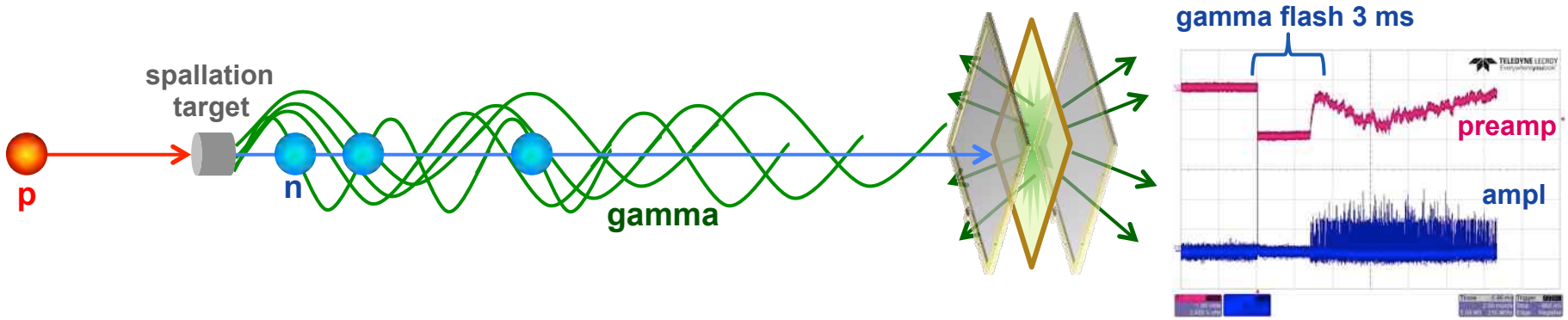
start

finish

run time (flight) proportional to 1/v

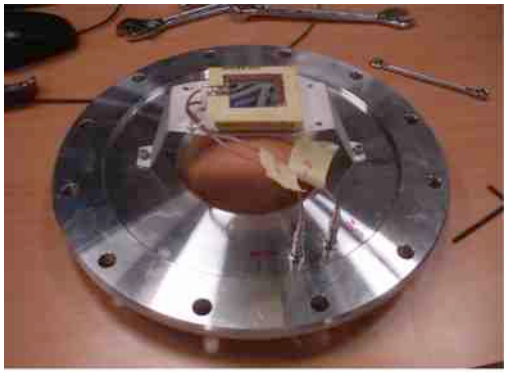
measured t (TOF) → $v = s/t$ → compute v → $E = \frac{1}{2} mv^2$ → compute E

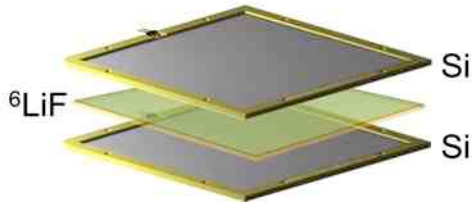
^{7}Be(n,α)α: 4 crucial questions



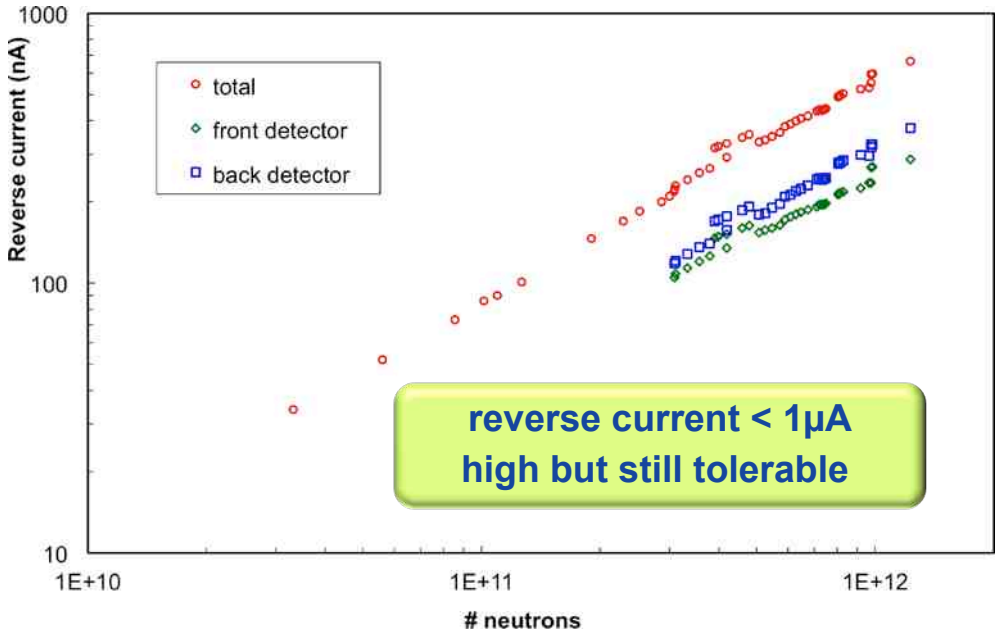
Q1: damage from neutrons	→	will the detectors survive?
Q2: energy resolution	→	worsens, is it enough to select α's?
Q3: gamma flash	→	fast electronics to recover after blinding?
Q4: gammas from ^{7}Be	→	will the system work under 1GHz gammas?

Q1: damage from neutrons → **will the detectors survive?**





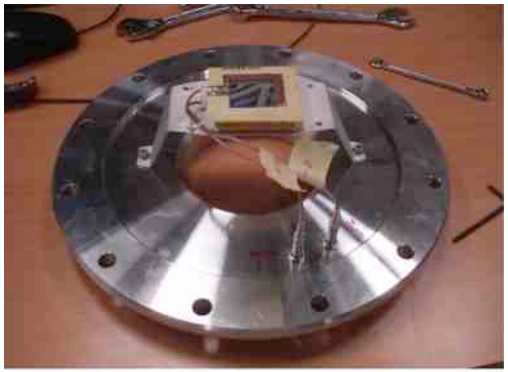
produced a sandwich Si-^{6}LiF-Si
installed in EAR2 near the beam dump
45 days irradiation, ≈ 10^{12} neutrons



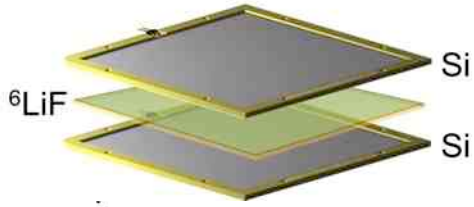
reverse current < 1μA
high but still tolerable

Q1: OK

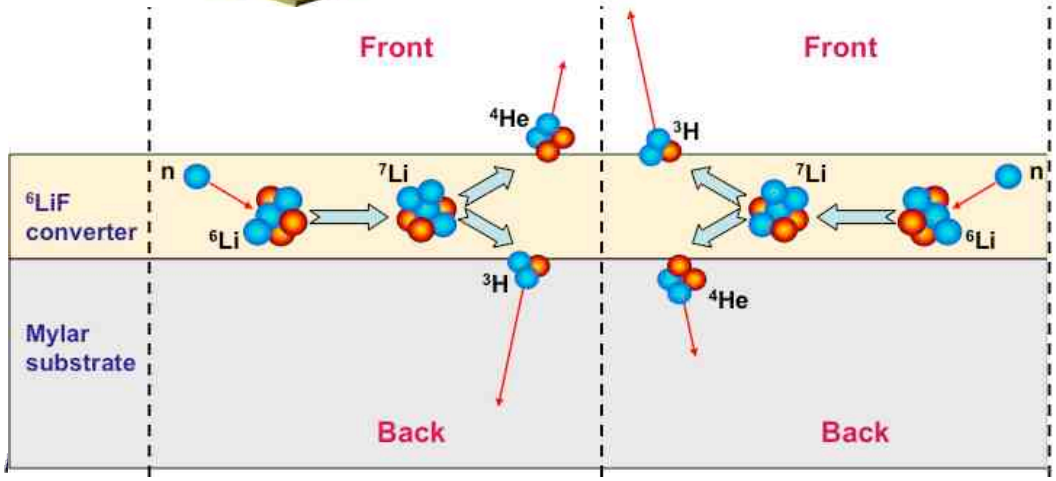
Q2: energy resolution → **worsens, is it enough to select α's?**

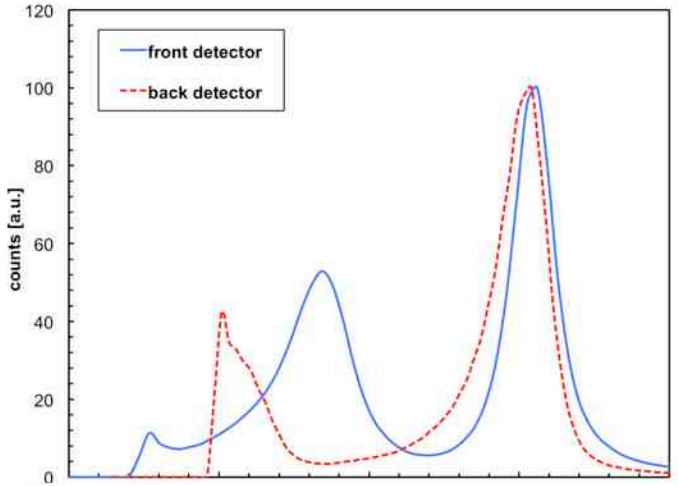


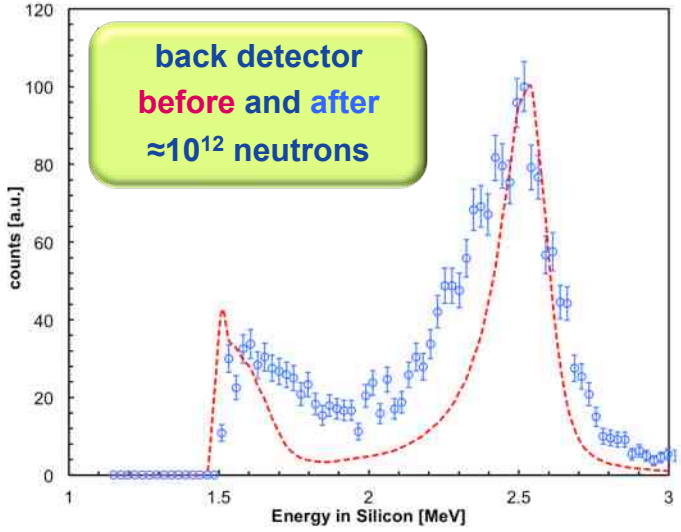
Q2: OK



^{6}Li(n,α)t

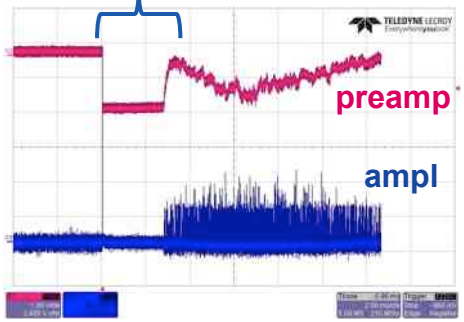






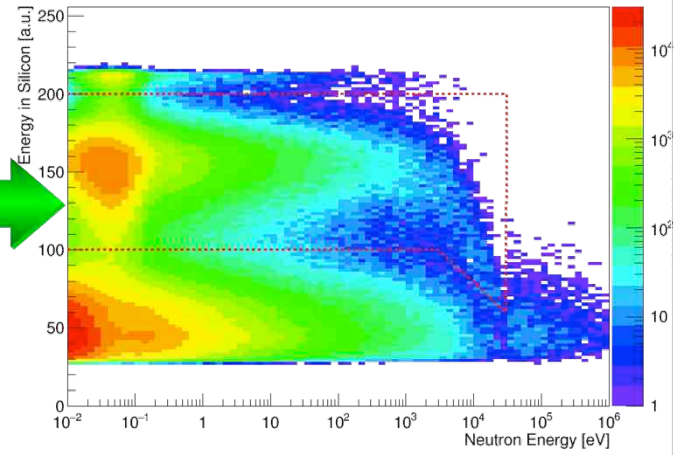
Q3: gamma flash → **fast electronics to recover after blinding?**

traditional preamp → gamma flash 3 ms

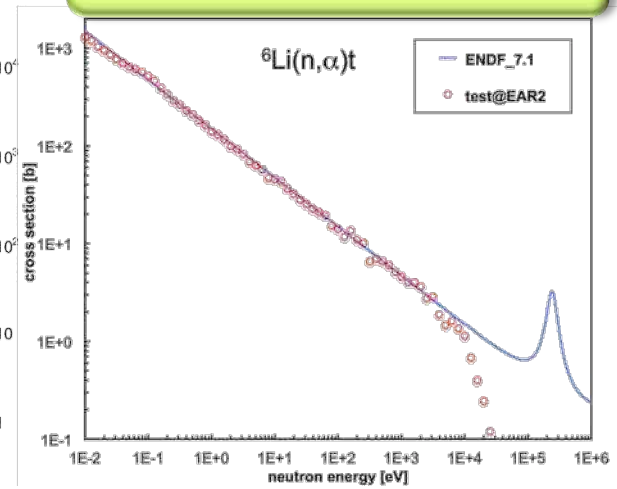


→ **limit 0.1 ÷ 1 eV**

Mesytec MPR-16
lin-log preamp

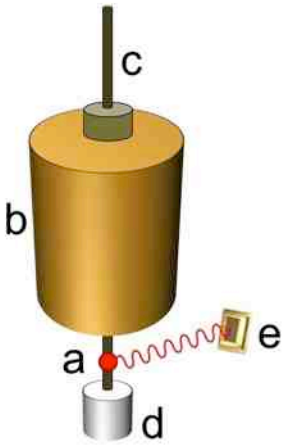


sigma ^{6}Li(n,α)t
reconstructed up to 1 ÷ 10 keV



Q3: OK

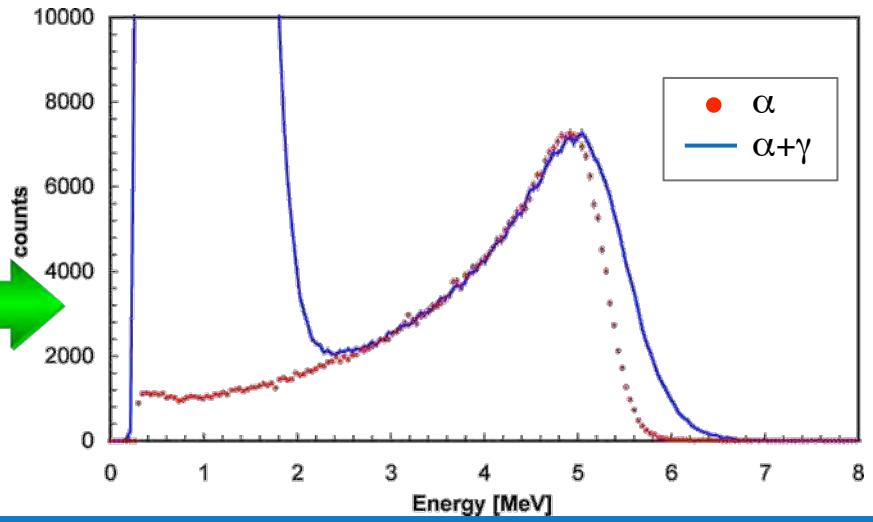
Q4: gammas from ^{7}Be → will the system work under 1GHz gammas?



^{137}Cs gamma source at LNS (39 GBq)
reference Geiger: 10^{9} γ/s on the detector
➔ $10^{6} \div 10^{7}$ signals/s from the detector

traditional preamp → saturation: no signal!

Mesytec MPR-16
lin-log preamp



Q4: OK

Conclusion 1

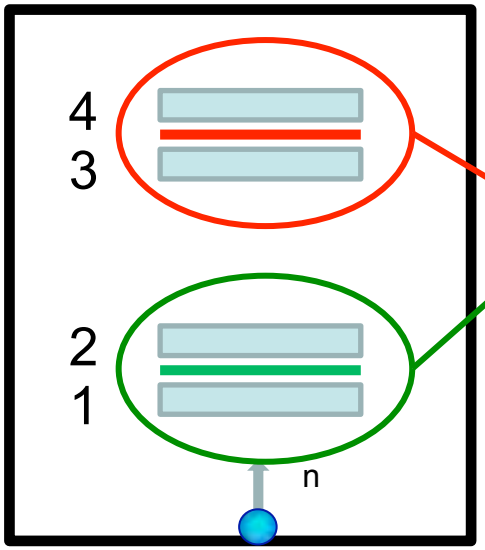
neutron beam intensity → EAR2 n_TOF @ CERN

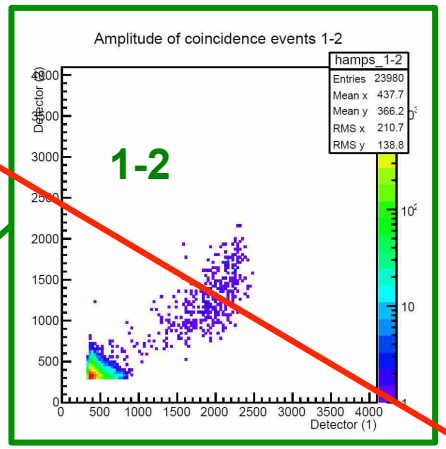
production of ^{7}Be targets → PSI @ Zurich

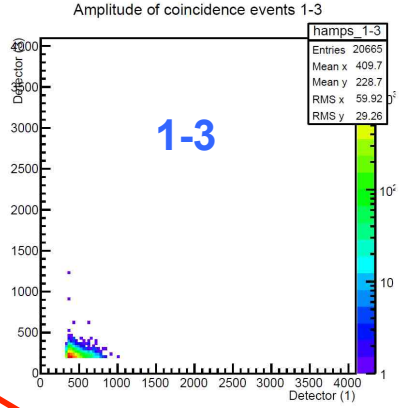
Q1: damage from neutrons
Q2: energy resolution
Q3: gamma flash
Q4: gammas from ^{7}Be
→ LNS @ Catania

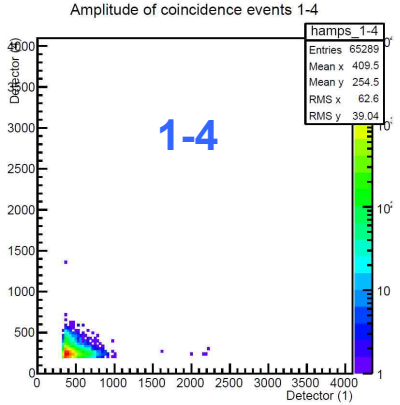
"*impossibile*" measurement? → possible measurement !!!

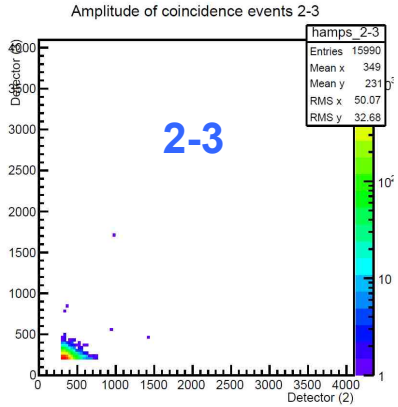
measurement results

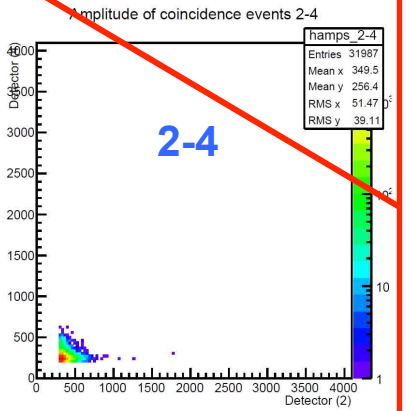


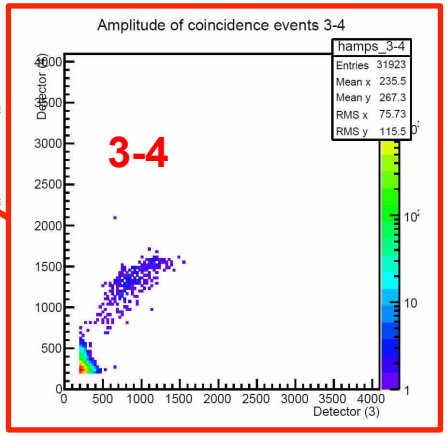


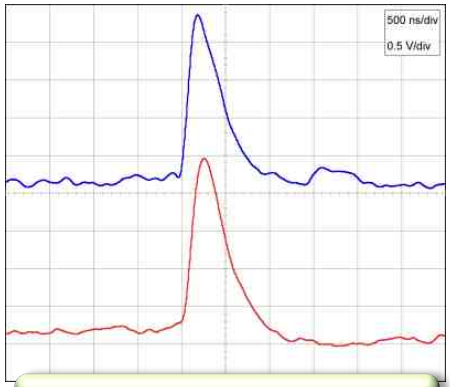










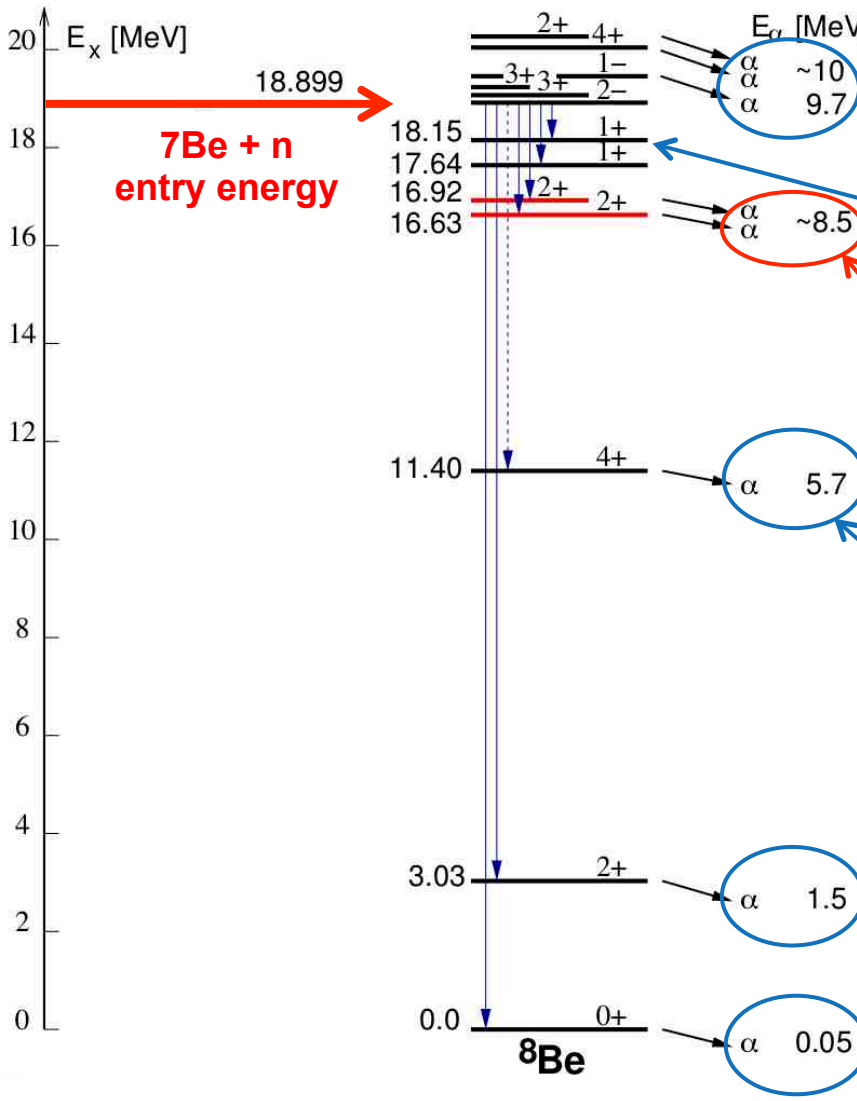


α–α coincidence

lower energy threshold at 2 MeV

^{8}Be level scheme and decay channels

by A. Mengoni



Possible 2α channels not observed due to experimental *n*-energy cutoff

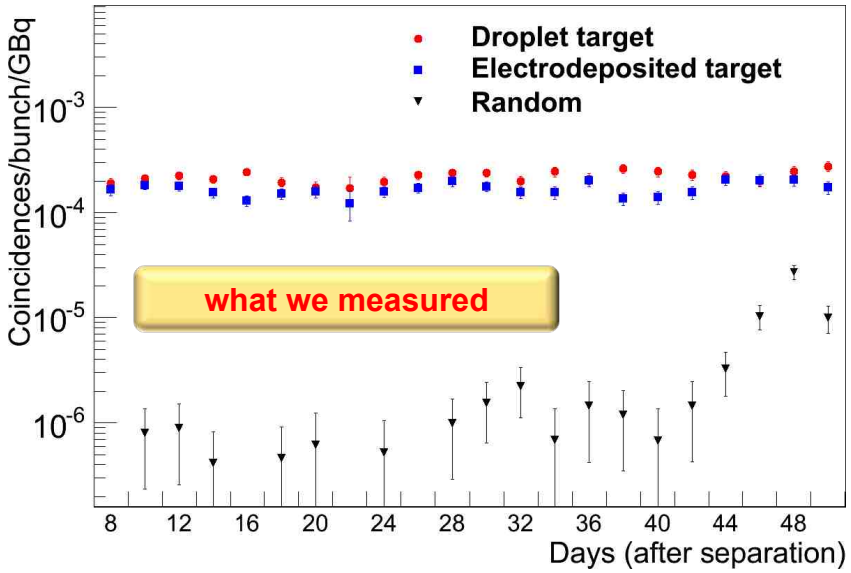
Forbidden (selection rules)

Observed γ-2α channels

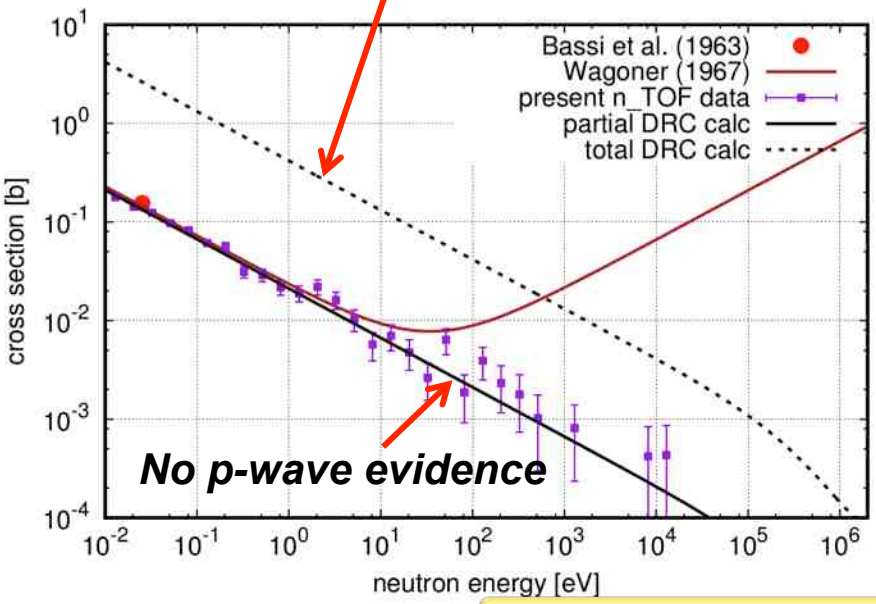
Suppressed γ−2α channel (negligible, not observed)

Predicted relevant γ-2α channels not observed due to experimental apparatus energy threshold

Impact on Cosmological Lithium Problem



Total Direct Radiative Capture

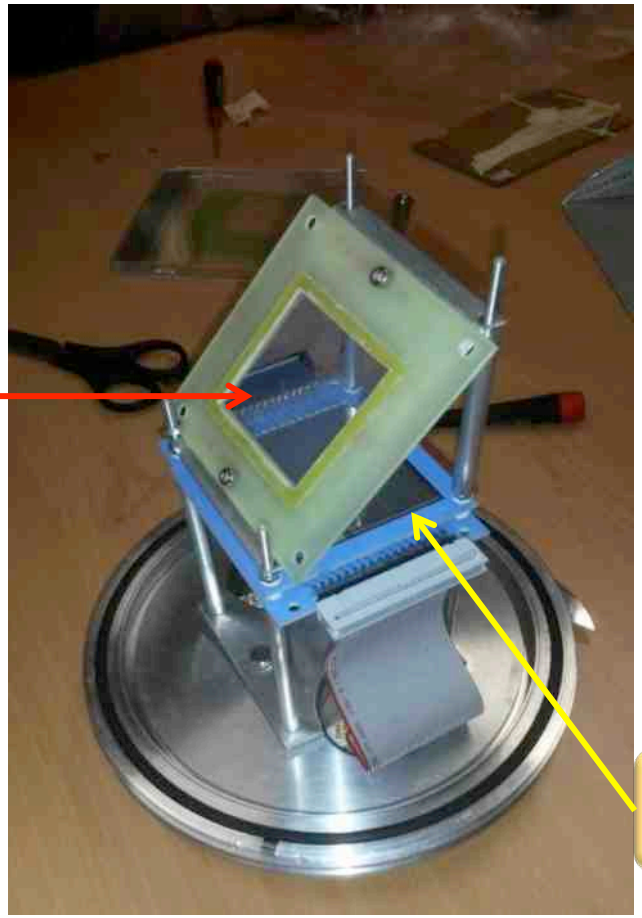


Article submitted to PRL

the n TOF results hint to a minor role of this reaction in BBN, leaving the long-standing Cosmological Lithium problem unsolved

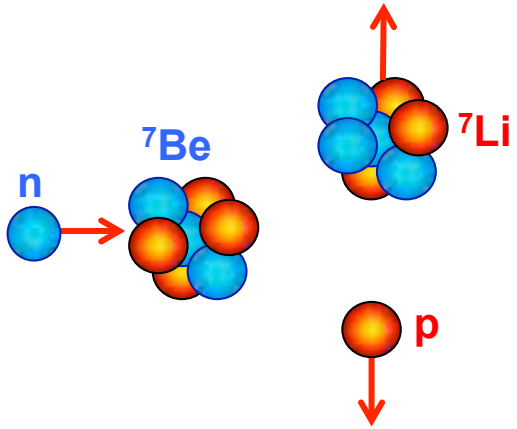
the reaction rate currently used in BBN calculations requires substantial revision

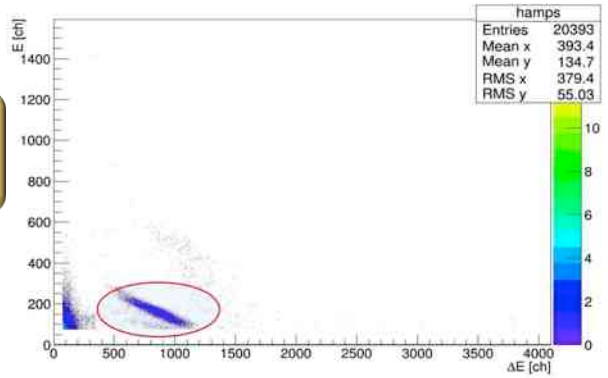
$^{7}Be(n,p)^{7}Li$



silicon strip telescope

experiment just completed





Conclusion 2

the past

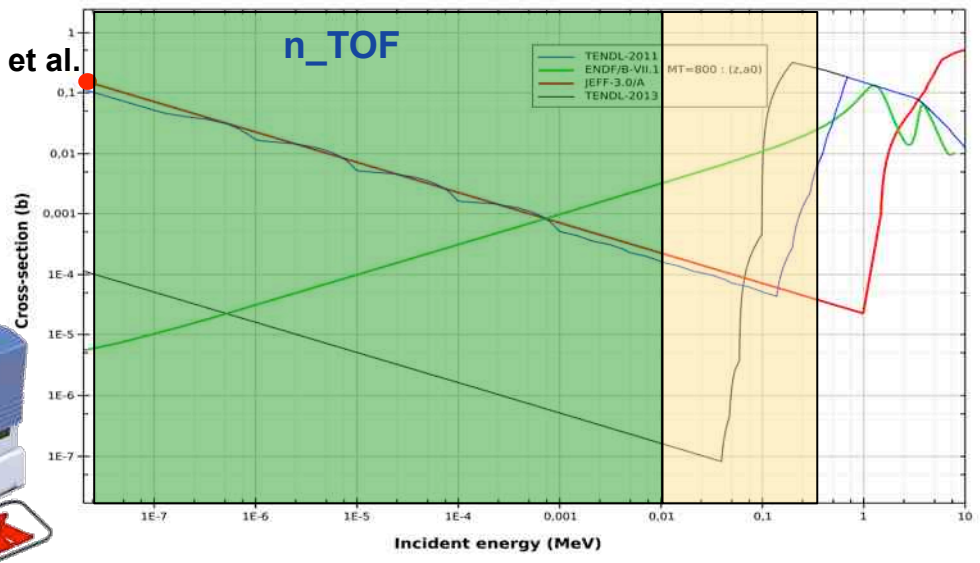
^{7}Be(n,α)α only existing data at 25 meV (Bassi et al., 1963)

the present

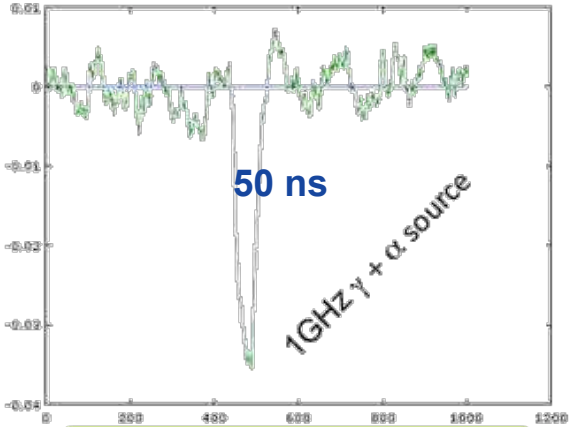
August-October 2015: just measured ^{7}Be(n,α)α

article submitted to Physical Review Letters

Bassi et al.



the future?



new preamp @ LNS ?

main characters


A.Pappalardo


N.Colonna


M.Barbagallo

without them the experiment would not have been possible

other characters

M.Piscopo, S.Russo, Lab. Bersagli LNS, Officina LNS, Elettronica LNS,
E.Maugeri, D.Schumann, O.Aberle, B.Langhans, E.Chiaveri, F.Gunsing
and the whole n_TOF collaboration
...and I apologize if I forgot somebody !!!

THE END

thank you !!!