Towards the Gamow Peak of the $^{12}C(\alpha,\gamma)^{16}O$ reaction

a physics case for the LUNA - MV

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Round Table “LUNA - MV” at Laboratori Nazionali del Gran Sasso
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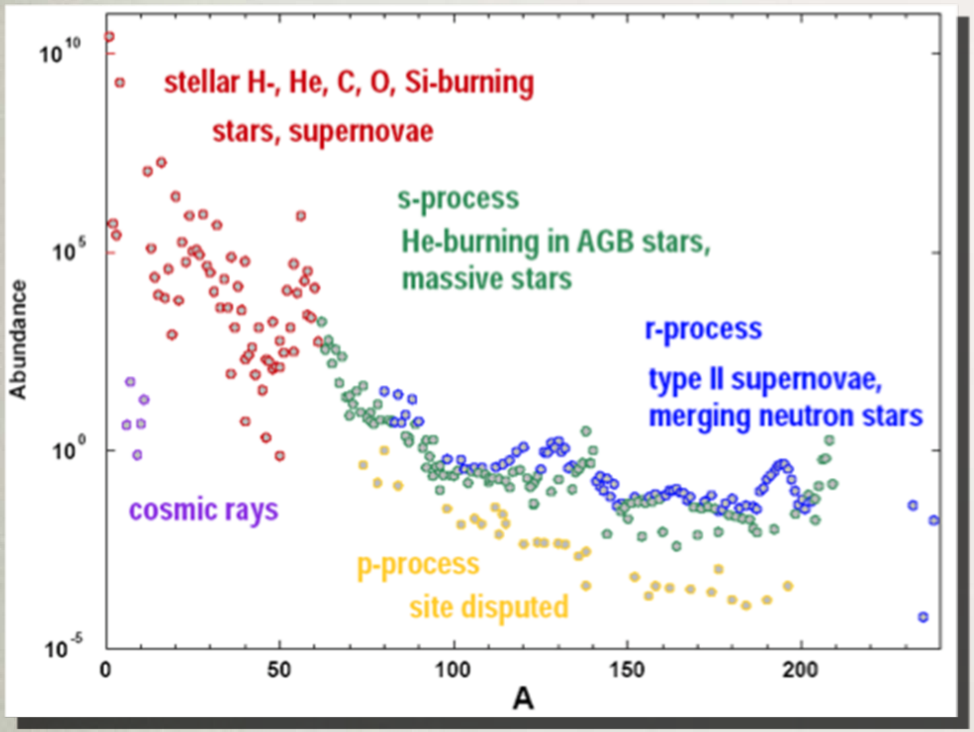
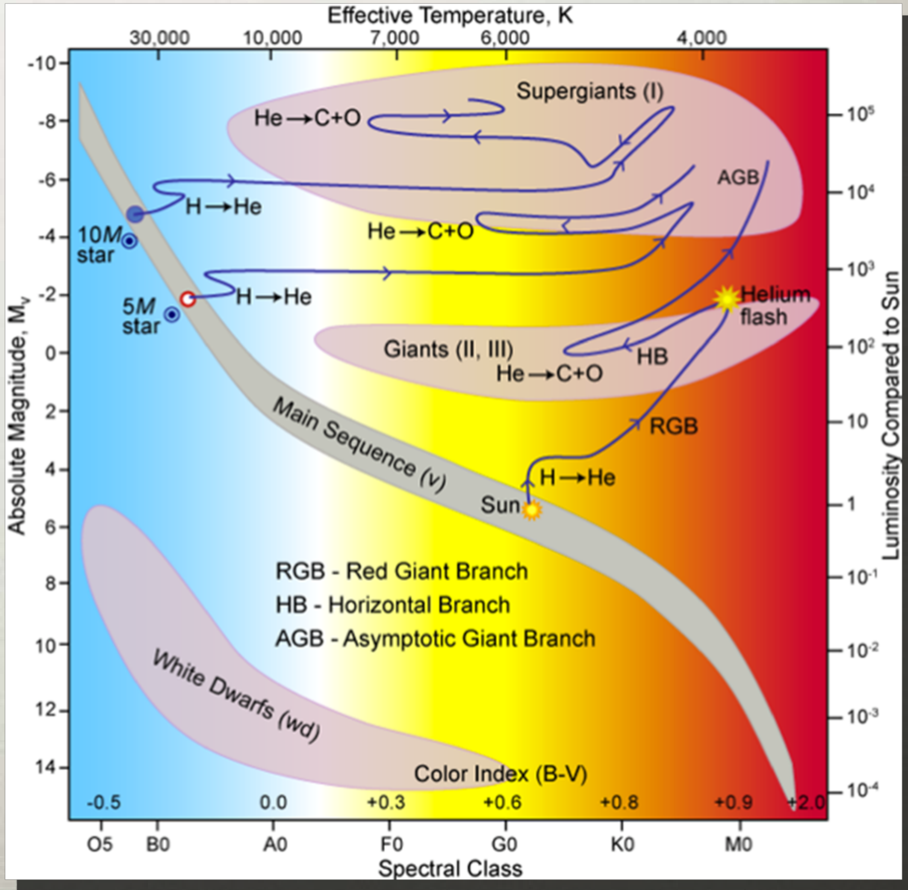
Nucleosynthesis - Origin of the Elements



He burning is ignited on the ^4He and ^{14}N ashes of the preceding hydrogen burning phase (pp and CNO)

Stellar temperture ~ 0.2 GK
(Red Giant Stars)



study energy generation processes
study nucleosynthesis of the elements
chemical evolution of the universe

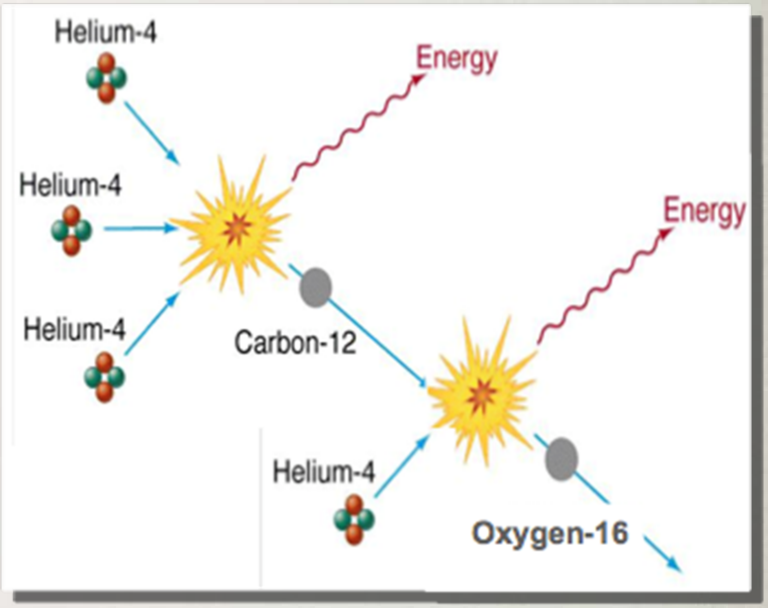
Stellar Helium burning: $^{12}C(\alpha,\gamma)^{16}O$

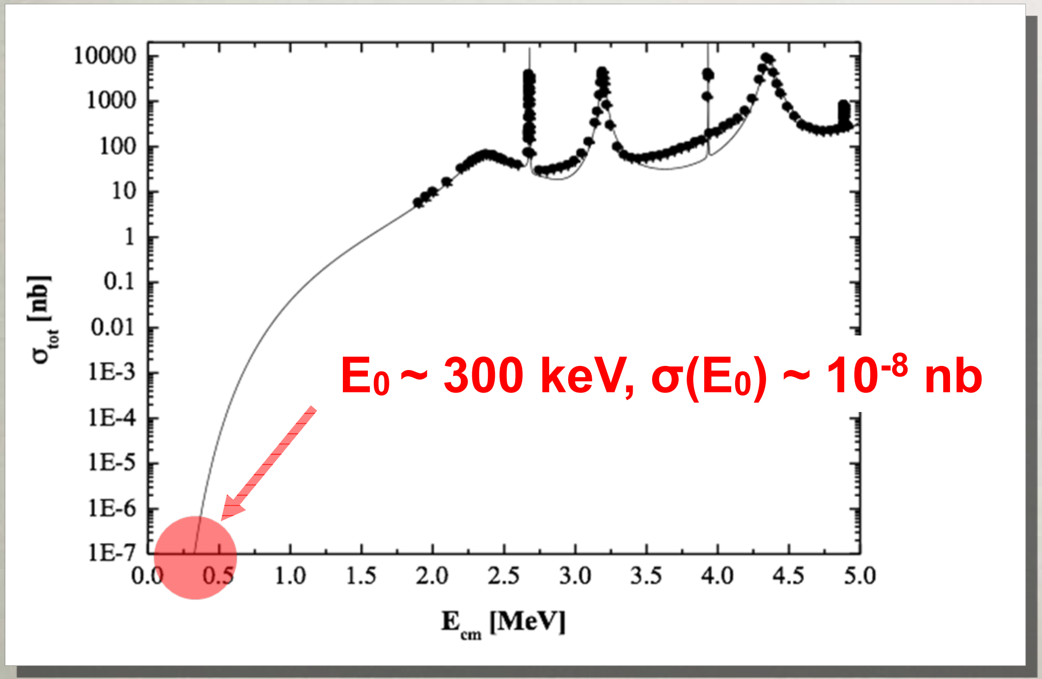
$^{12}C/^{16}O$ abundance ratio

Subsequent stellar evolution and nucleosynthesis

Composition of White Dwarfs

Mechanism of Supernovae





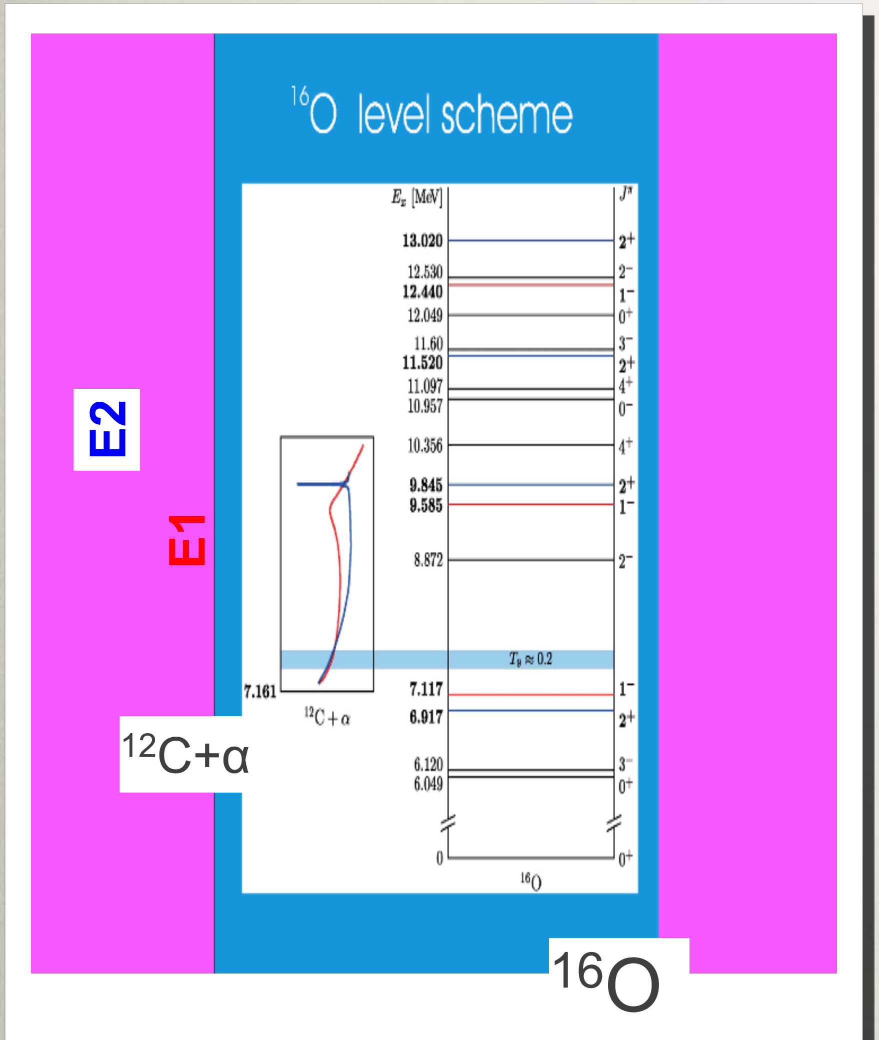
$3\alpha \rightarrow$ ^{12}C and $^{12}C(\alpha,\gamma)^{16}O$

Creation and Destruction of ^{12}C

even with
Accurate measurements at low and high energy

extrapolation to E_0 are needed

Data Relevant to $^{12}C(\alpha,\gamma)^{16}O$



- **Complex level scheme** Several 1^- and 2^+ Resonances Sub-threshold resonances dominate the S-factor at low energy
- Cascade transitions
- Direct capture

× Interference effects

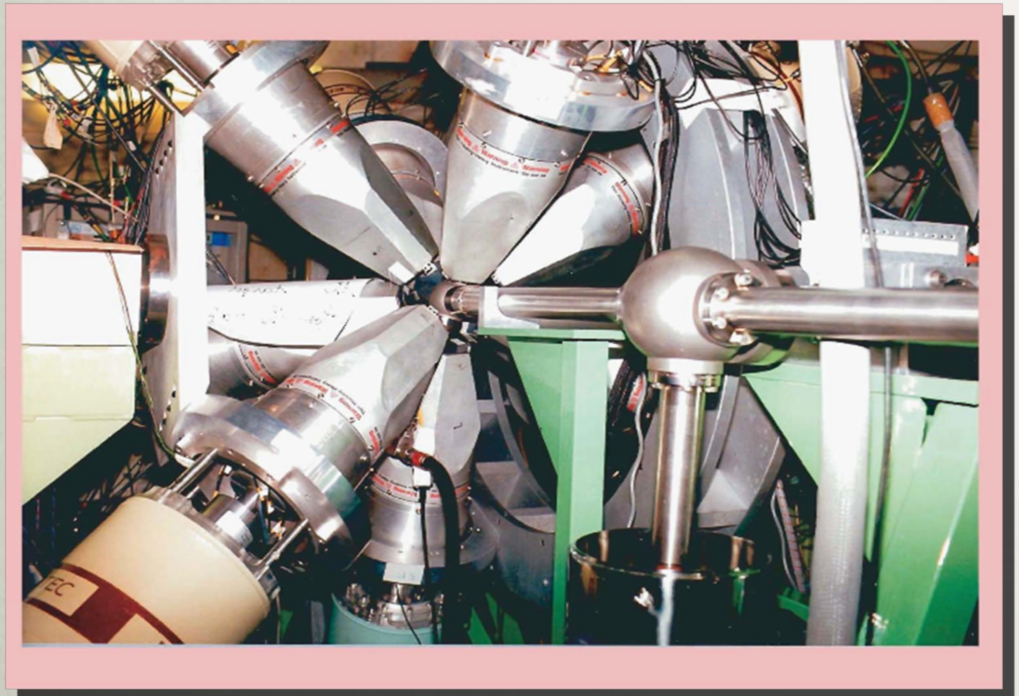
Experimental data needed

$^{12}C(\alpha,\gamma)^{16}O$ cross section dataground and excited states of ^{16}Owide range of energies$^{12}C(\alpha,\alpha)^{12}C$ elastic scattering data^{16}N β-delayed α spectrumBound-state spectroscopy (E_x, Γ_x, …)Transfer reactions

To obtain the S-factor with an uncertainty < 10%

A modern experiment
(Stuttgart Group)

R.Kunz and M.Fey PhD Thesis



EUROGAM Detectors

Efficiency

Background suppression

Granularity

GANDI

Angular distribution

but also: CalTech, Queens Univ., RUB Bochum, FZ Karlsruhe, and others

~ 12 data sets

Ion Beam

Intensity 0.5 mA He+

Stability

Beam Induced Background

Targets

Isotope separation

Density ~ $2 \cdot 10^{18}$ atoms/cm^2

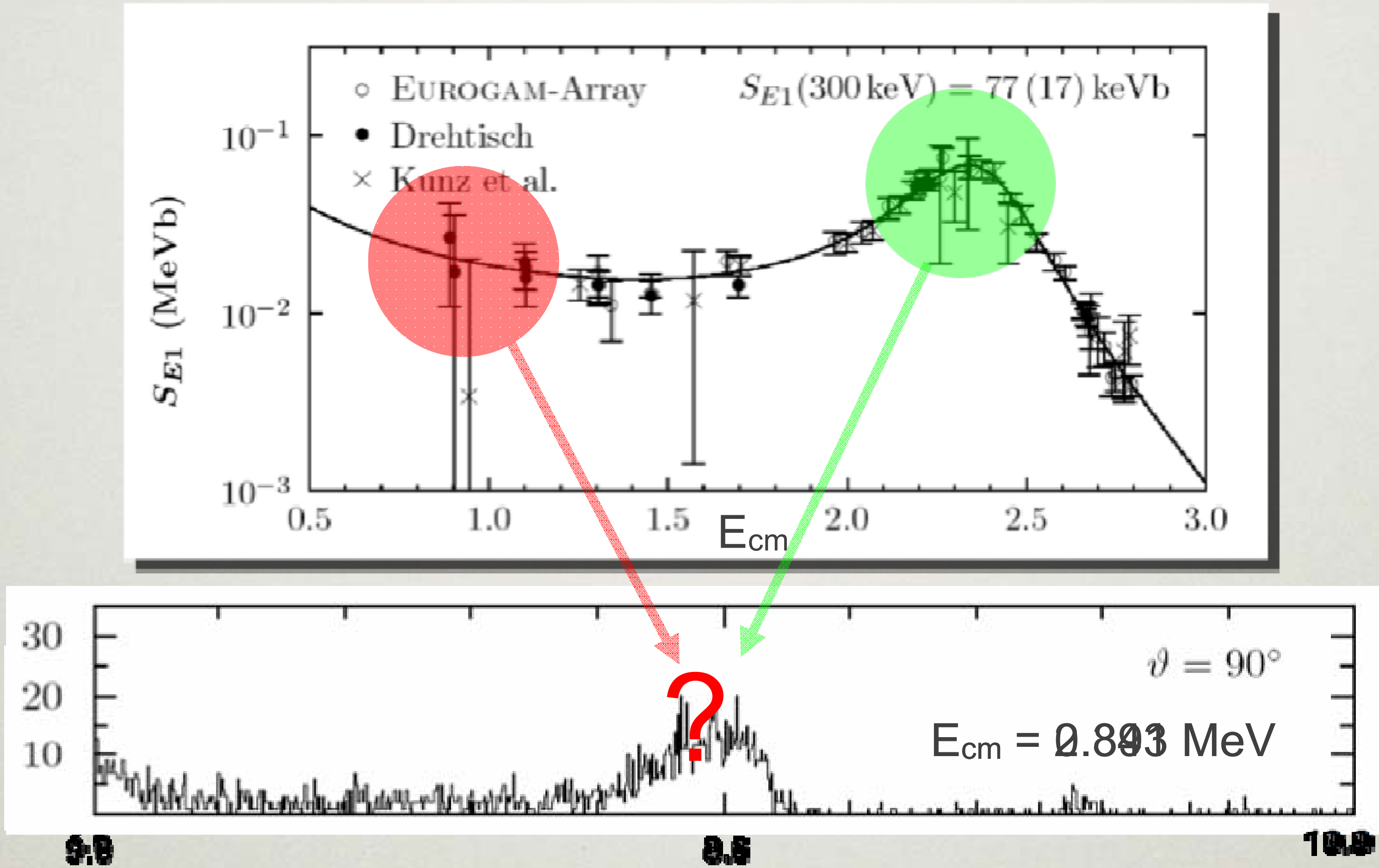
Purity ($^{12}C/^{13}C \sim 10^5$)

Omogeneity

Standing Time

A modern experiment

(some results)

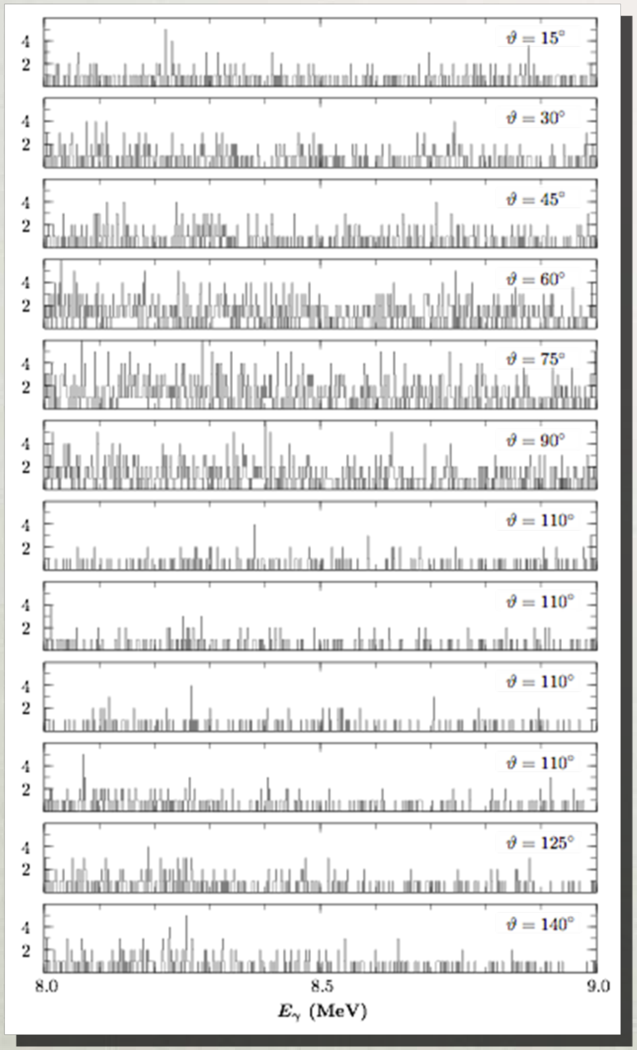


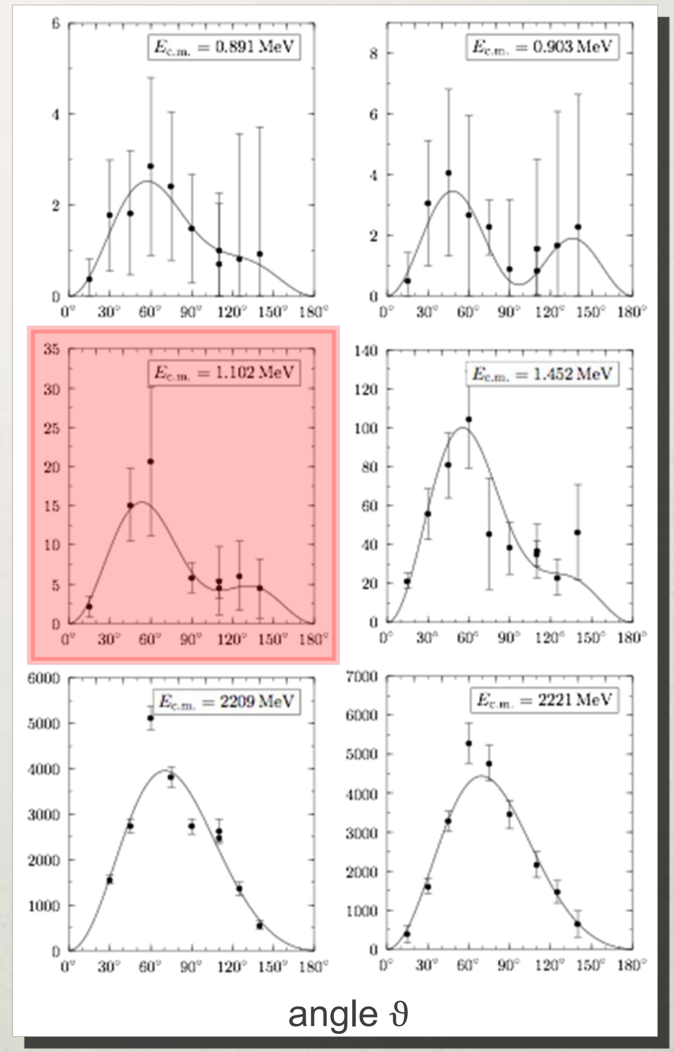
Limitation from Beam Induced or Natural Background ?

M.Fey PhD Thesis 2004

A modern experiment
(some results)

E_{cm} = 1.202 MeV

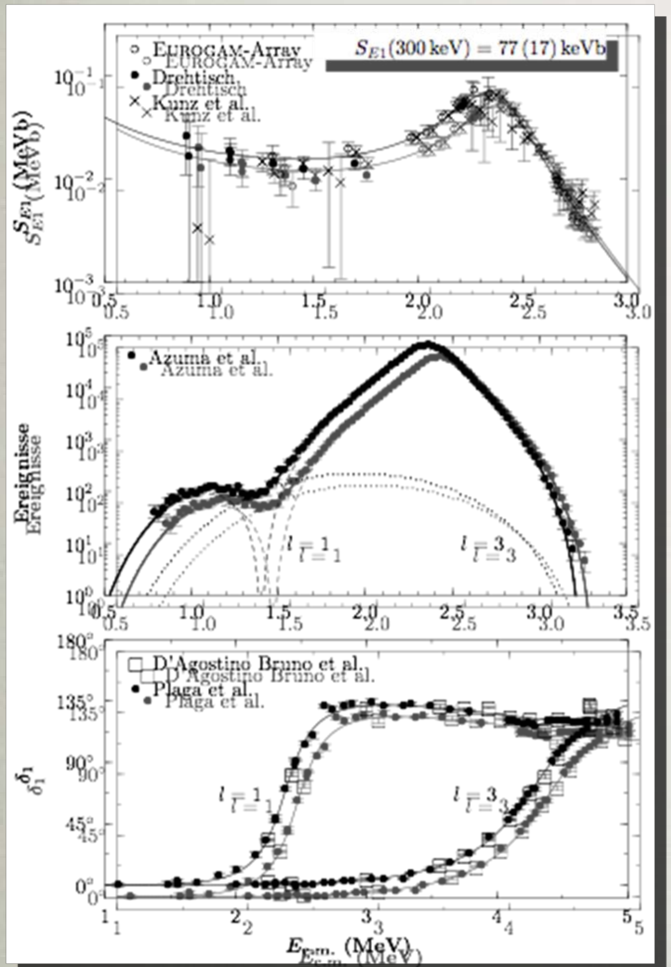




Measurements at low energies are very difficult !!

S - factor results

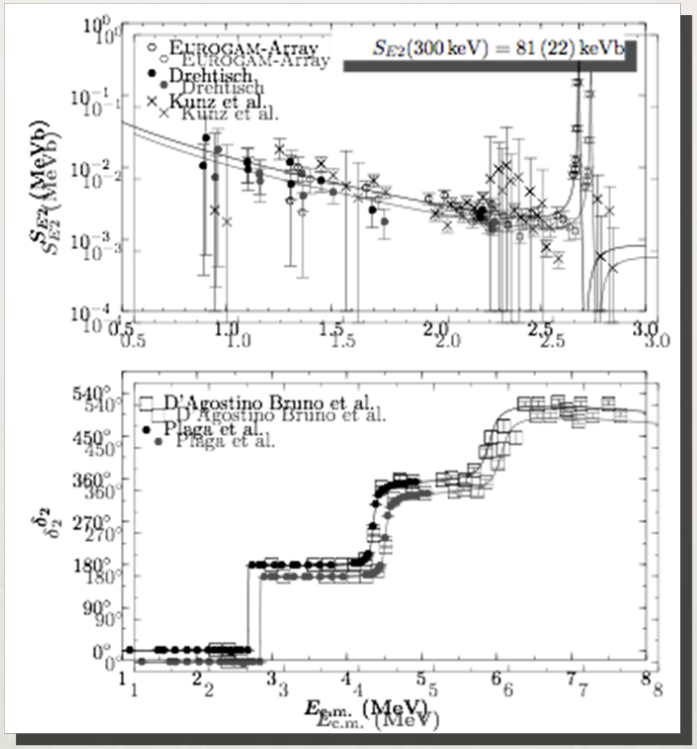
E1



Capture DAta
^{16}N data
α - scattering data

S(300)$_{E1}$ = 77 ± 17 keV b

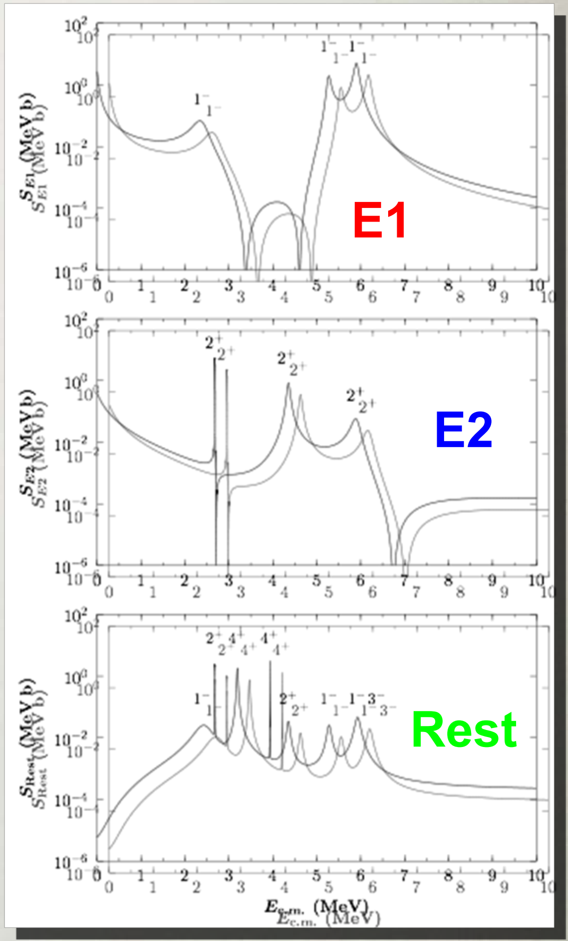
E2



Capture DAta
α - scattering data

S(300)$_{E2}$ = 81 ± 22 keV b

R - matrix fit



S(300)$_{rest}$ = 4 ± 4 keV b

S(300)$_{tot}$ = 162 ± 39 keV b

25% Uncertainty

M.Fey PhD Thesis 2004

A new measurement

(wish list)

- Beam current I_{beam} ~ 1 mA (pulsed ?)
- Ultraclean Vacuum < 10^{-8} mbar
- BIB monitors (neutron and high resolution γ)
- Detection Efficiency 100 times higher (HPGe or Scintillator ball + GE monitor)
- Improved targets $^{13}C/^{12}C < 10^{-6}$
- Better R-matrix and/or fitting codes

Detectors: main features

$R_{lab} = \sigma \cdot \varepsilon \cdot I_p \cdot \rho \cdot N_{av}/A$ → **High efficiency**

$R_{lab} > B_{nat} + B_{beam\ induced}$

$= B_{cosm} + B_{env}$

→ Enviromental radioactivity has to be considered underground

→ Low beam induced background (pure beam & targets)

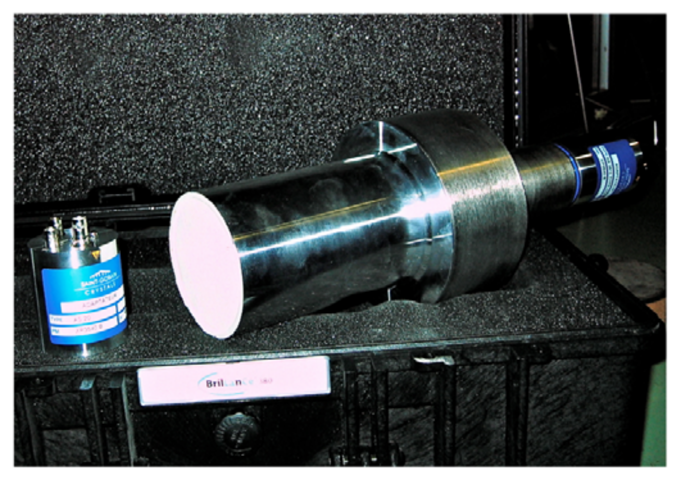
→ **High resolution**

Angular Distribution → **Granularity**

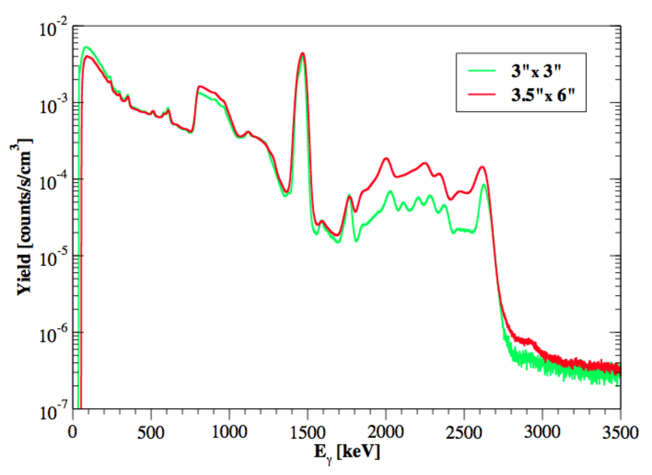
Summing → **Granularity**

Detectors for new γ-ray measurements ?

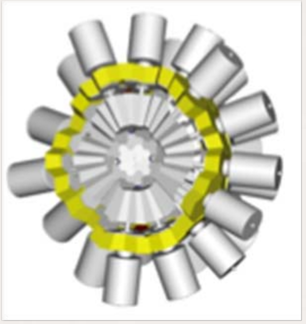
Large volume
LaBr3 detectors



FWHM @ 1333 keV: **Measured 2.27%**
ε_{ph} @ 1333 keV: **1.70 x NaI (3" x 3")**

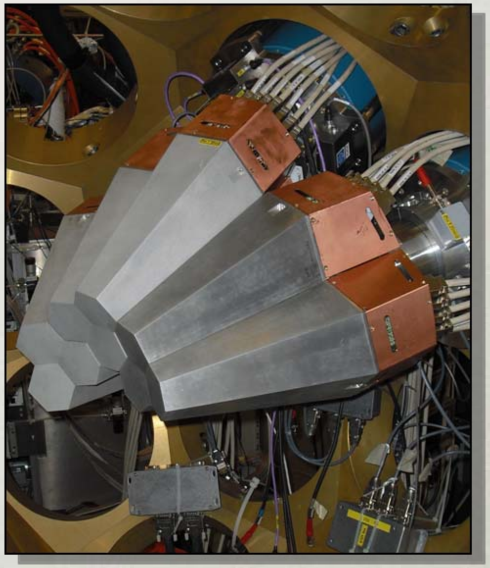


Intrinsic Background



A detector Array is needed

Segmented HPGE detectors



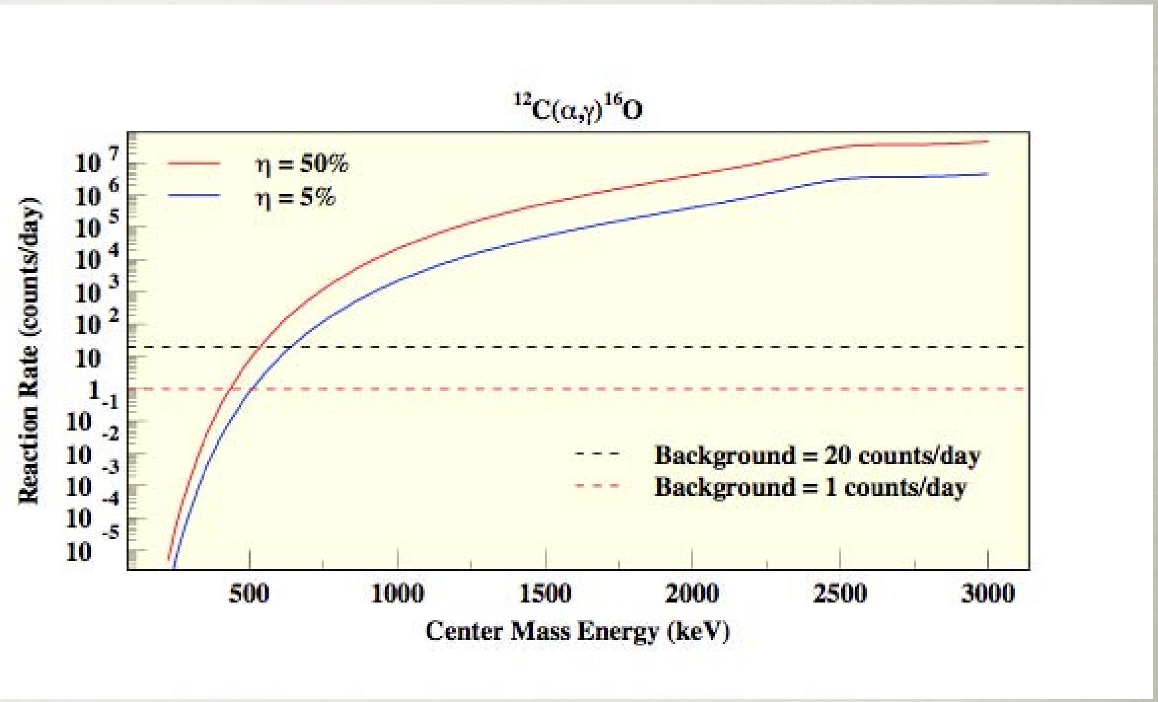
Tracking capabilities

position resolution 5 mm

continuous angular distribution !

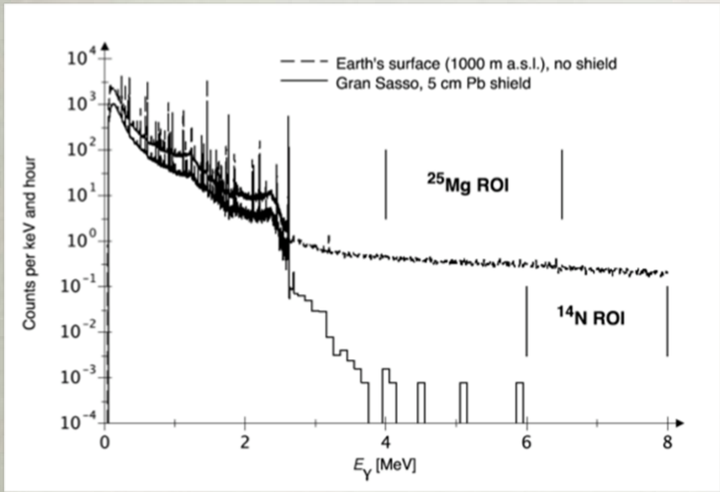
Reaction Rate

(estimated)



If we had

- MV - accelerator
- ^{12}C - enriched targets
- High Beam intensity: **500 μA**
- Detection efficiency: 50% total, 2.5% single segment (**angular distributions**)
- Detection set-up: scintillator - crystal ball

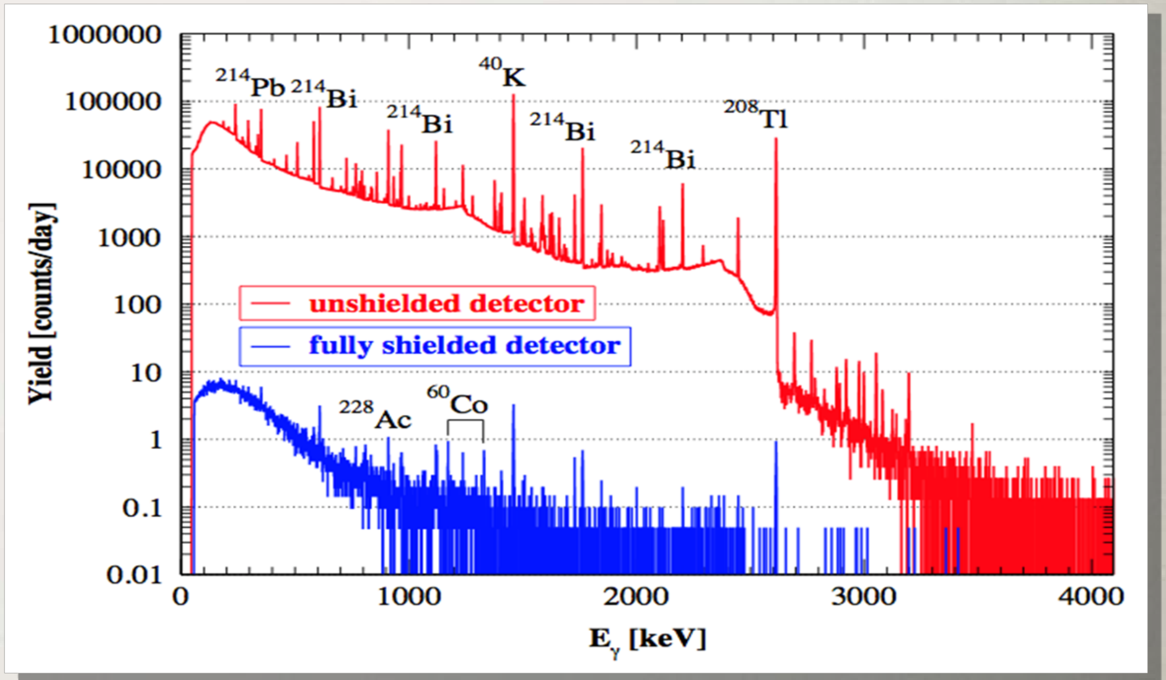


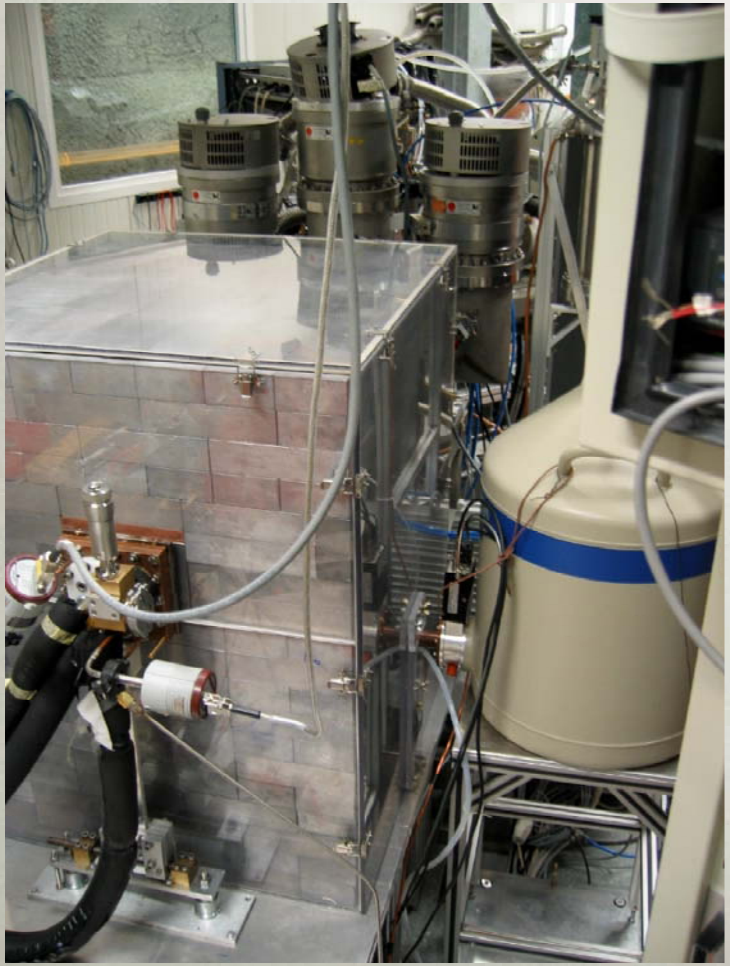
HPGe detector 3 MeV < E_γ < 8 MeV
earth surface 0.5 counts/s
LNGS underground 0.0002 counts/s

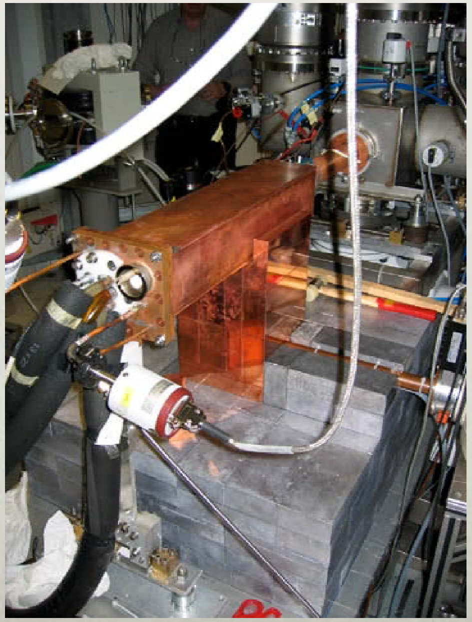
- angular distributions down to 600 keV and **total S-factor** down to **500 keV** with **10% accuracy**Theoreticians ask for 10% uncertainty on S_{tot}(300)**Great step forward**: so far, 10% accuracy only over 1.5 MeV

Shielding the detector

Measured background attenuation factor for the $^{3}He(\alpha,\gamma)^{7}Be$ setup is **~ 10^{-5} !!!** (i.e. **1.9** and **0.8 counts/day** with ΔE = 20 keV)

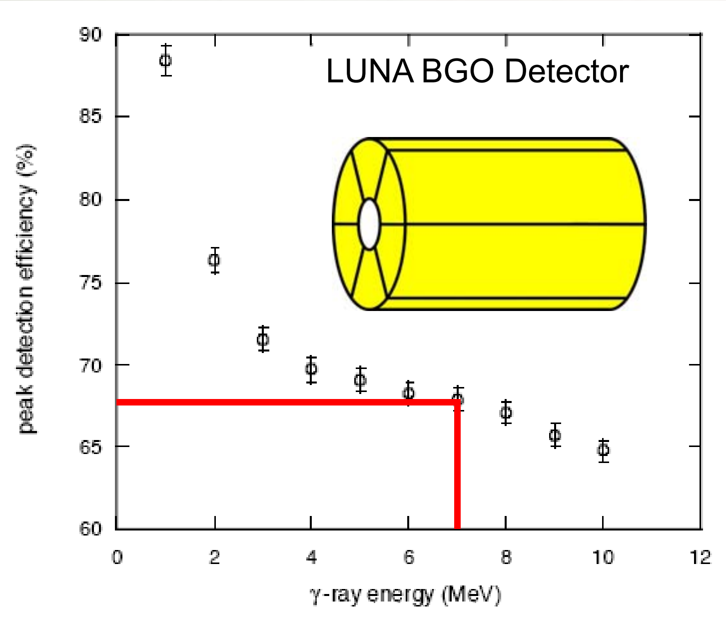


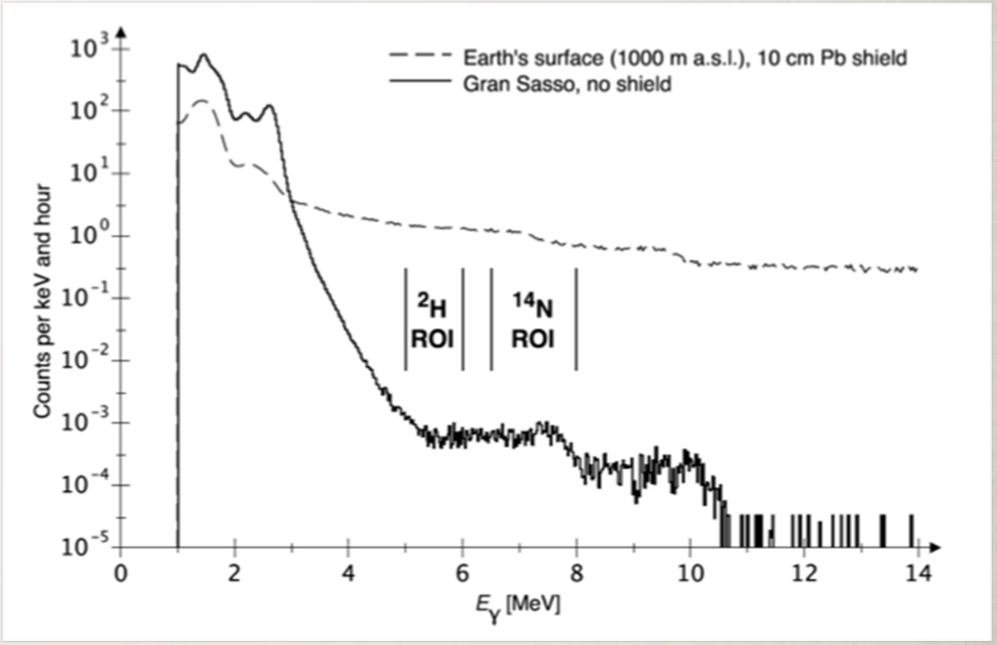




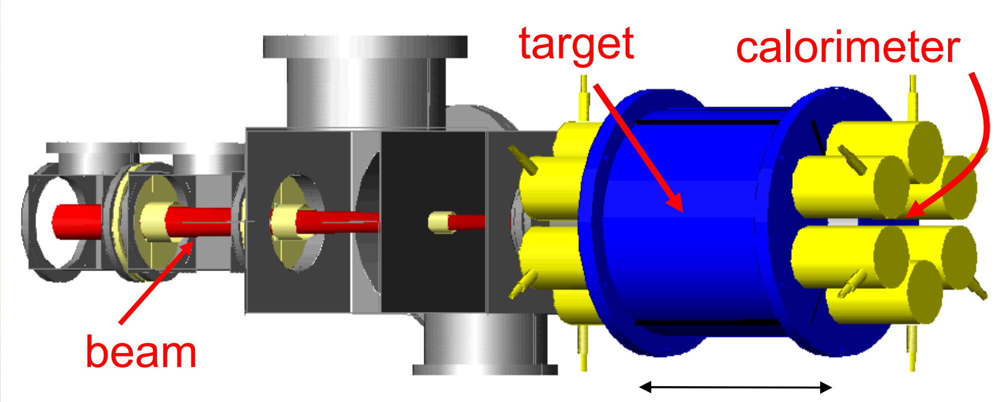
The layout includes additional Lead Shields outside the Radon Box

The old BGO





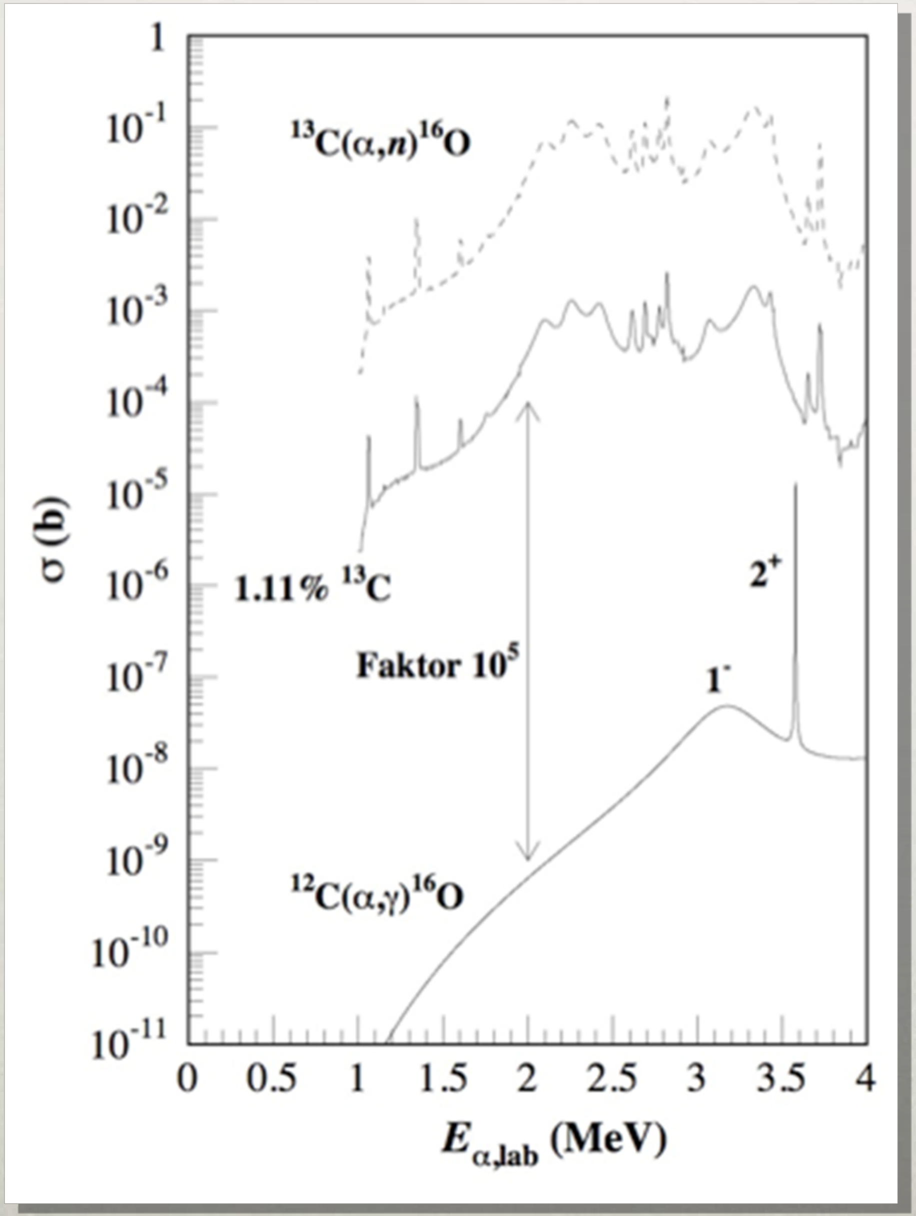
Excellent detection efficiency



4 BGO summing detector

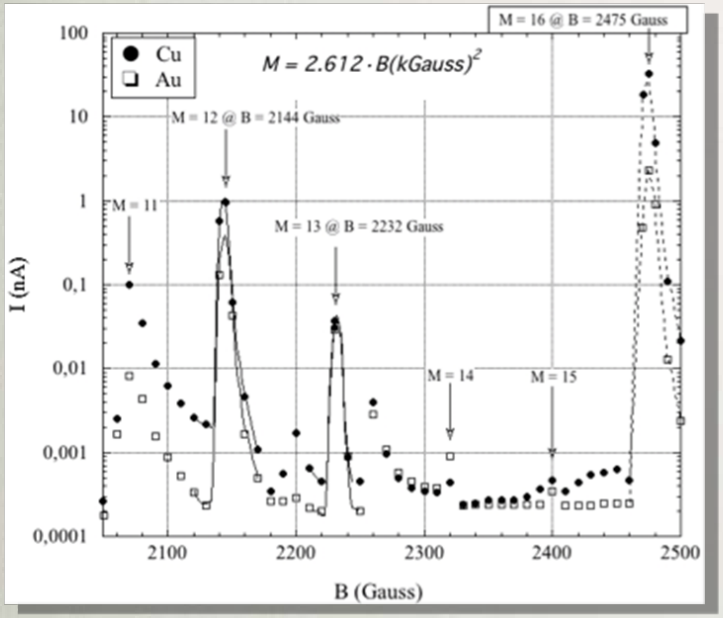
28 cm

A BIG Problem



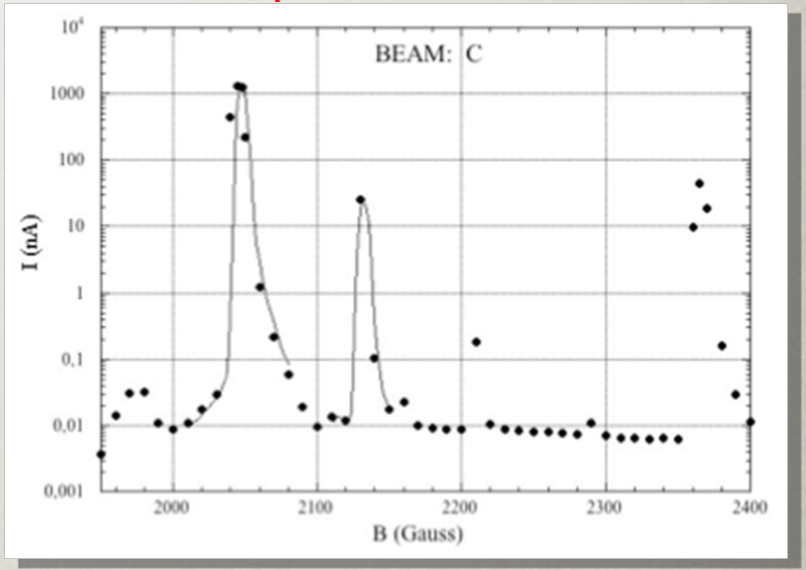
Target preparation and analysis

Cu and Au blanks



natural ^{13}C abundance 1.1%
$^{13}C/^{12}C$ in Au backing < 10^{-6}
^{12}CH (75%) in the ^{13}C peak
^{13}C implanted in Au from irradiation **< 10^{-7}**

Nuclear Graphite

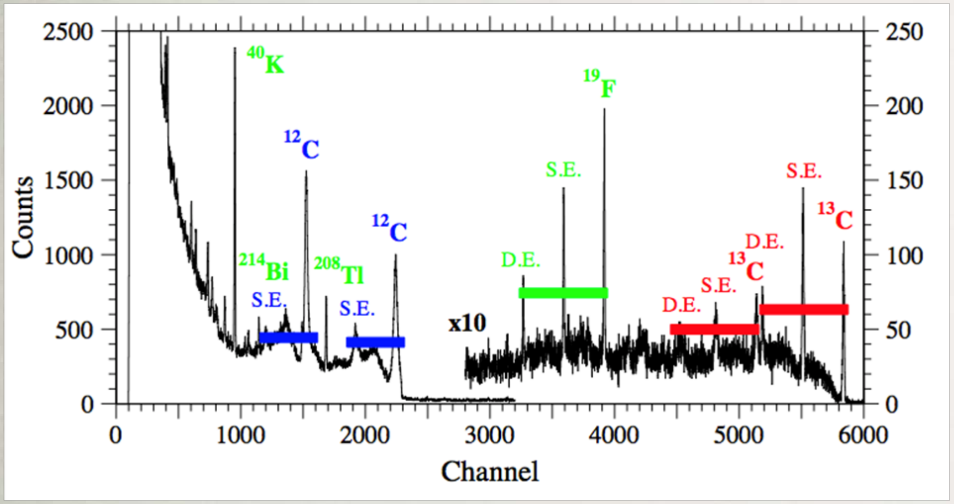


sharp line shape on the left side, no overlap between M = 12 and M = 13 peaks
$^{13}C/^{12}C$ (upper limit) = $3 \cdot 10^{-7}$

Test performed @ Ion Source test bench (LNL)

Target analysis

(first attempt)



Ep [MeV]	Γ [keV]	ωγ [eV]	σ_R [mb]	γ_0/γ
0.551	23	9.2	5.9	0.8
1.152	3.8	1.3	2.4	0.23
1.320	410	12.8	0.06	0.9
1.748	**0.135**	**14.8**	**163.5**	**0.86**

$^{13}C(p,\gamma)^{14}N$

Ep = 1.8 MeV

Q = 7.5506 MeV

Detectors

HPGe $\varepsilon_{tot} \sim 6.7 \cdot 10^{-3}$

Signal/Background ~ 150

NaI $\varepsilon_{tot} \sim 9.4 \cdot 10^{-2}$

Signal/Background ~ 200

Current sensitivity

$^{13}C/^{12}C \sim 1/20000$

(no beam induced contamination

natural background rate ~ 0.4 counts/s)

6 hours to collect 100 events if $^{13}C/^{12}C \sim 10^{-7}$

Improvements

Efficiency x 2

beam current x 10

background with pulsed beam x 0.01

Underground measurement ?

Test performed @ CN Accelerator (LNL)