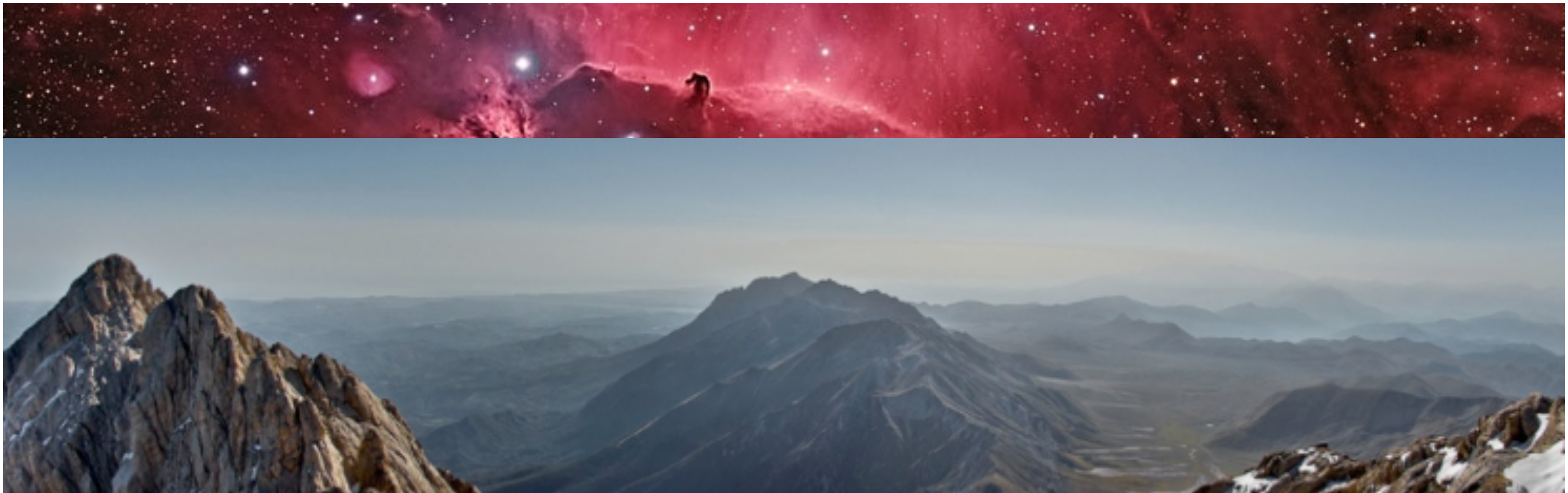


Gran Sasso Summer Institute 2014

Lecture #2: Direct Measurements

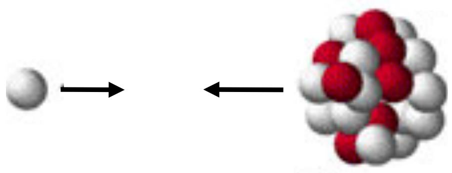
Prof. Christian Iliadis

THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL

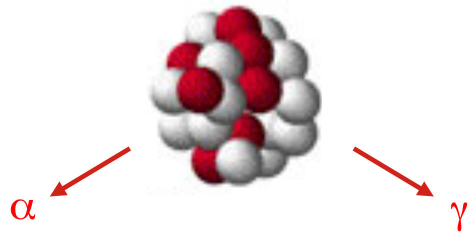
TUNL

Nuclear Astrophysics Experiments: Direct Measurements

two nuclei with kinetic energies before reaction:

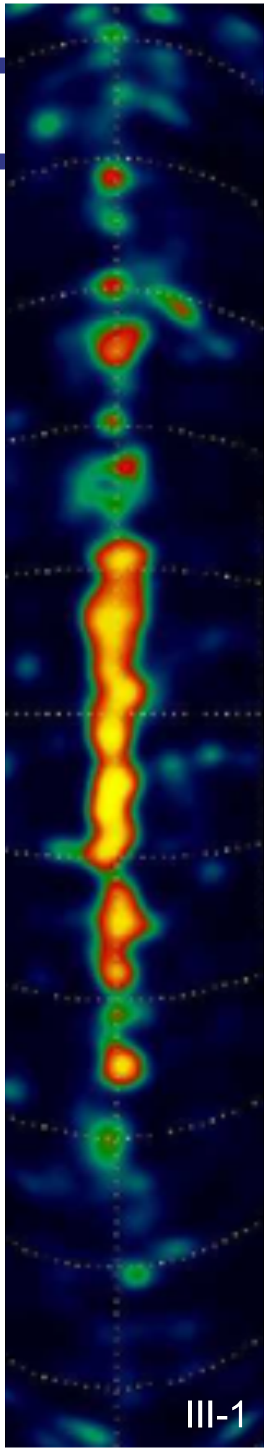


excited product nucleus after reaction:

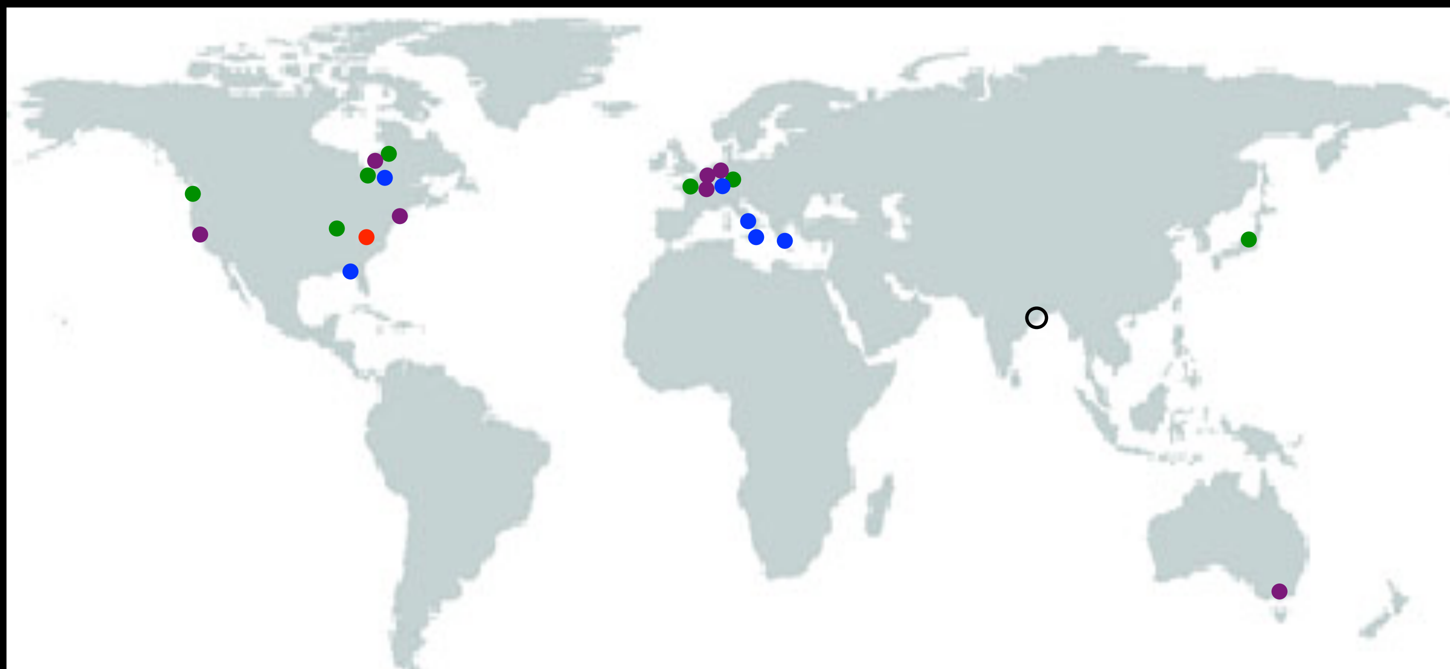


What we need:

- accelerated ion beams
- targets
- detectors



Nuclear Astrophysics Facilities Worldwide

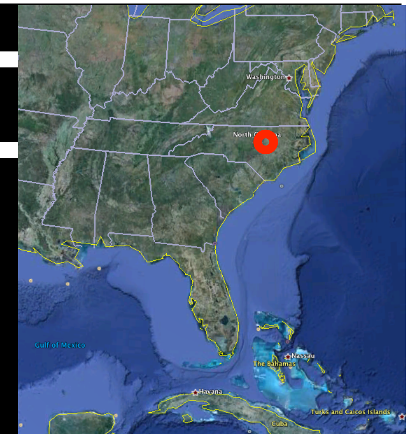


● ● present stable-ion beam facilities

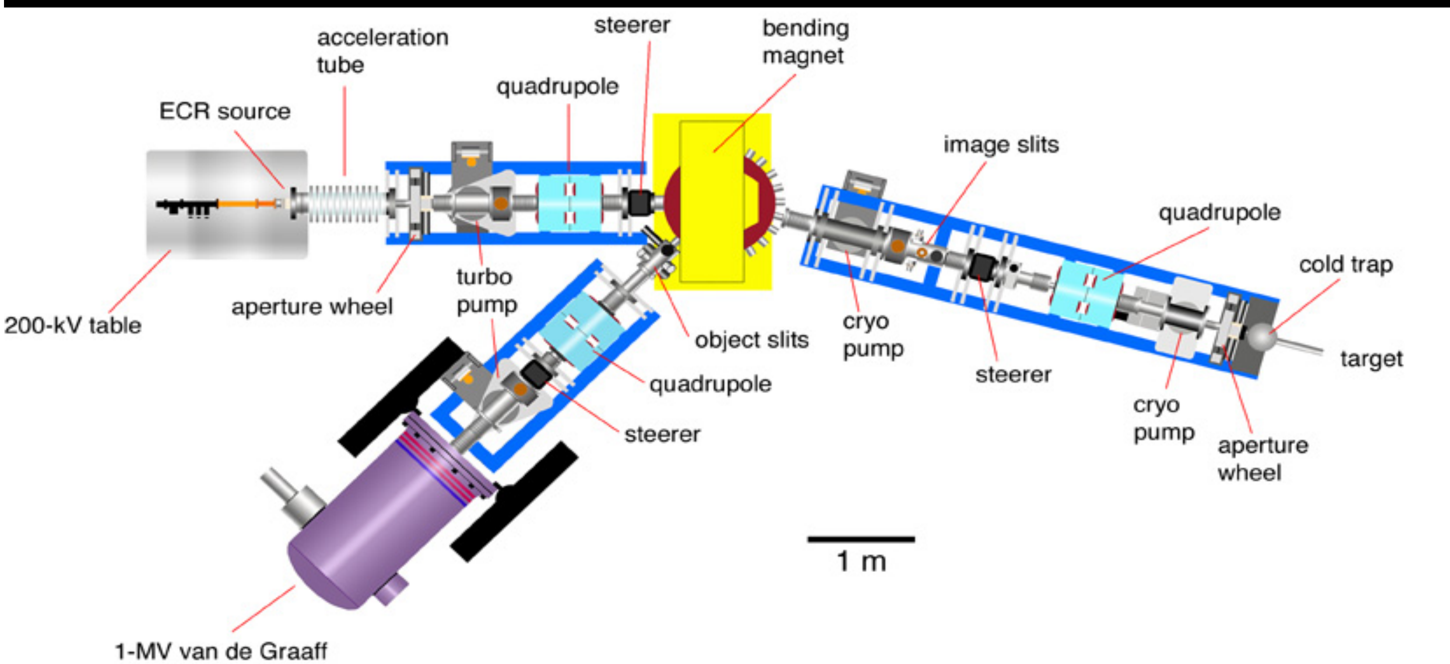
● present radioactive-ion beam facilities

● previous facilities [not operational]

Laboratory for Experimental Nuclear Astrophysics

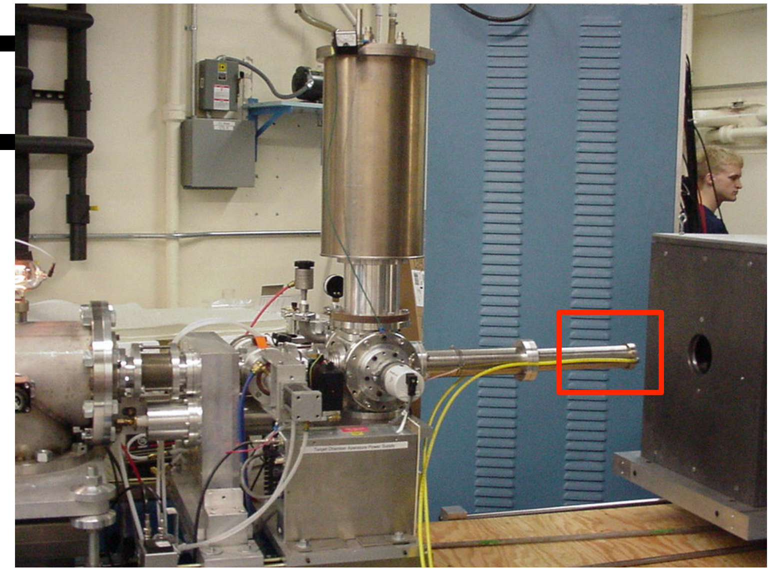


Cesaratto et al., Nucl. Instr. Meth. A623, 888 (2010)

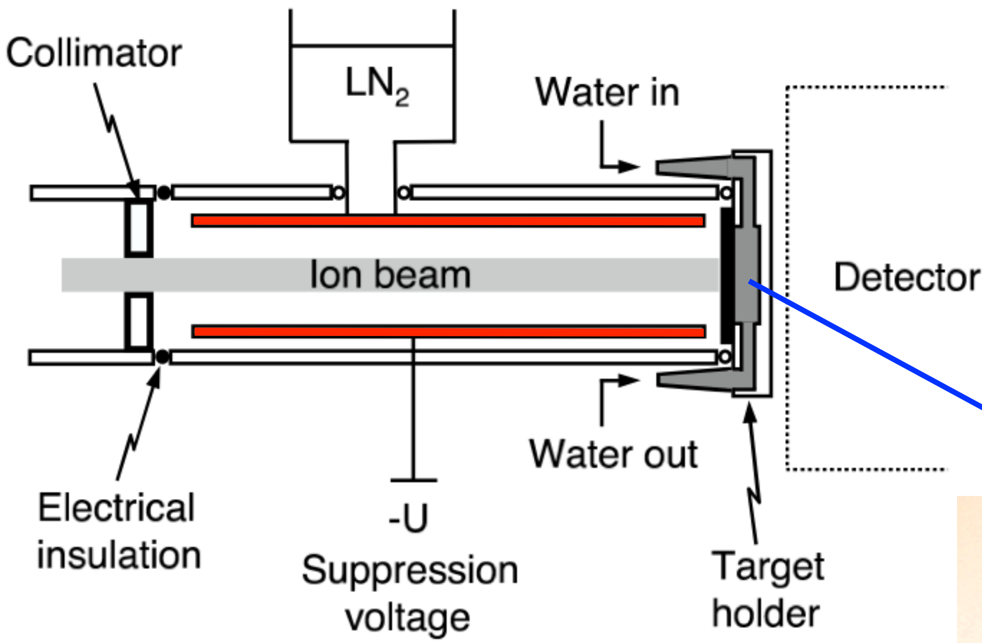


ECR:
200 kV max
2.0 mA H^+
ΔE=1 keV
JN:
1 MV max
200 μA H^+
ΔE=2 keV

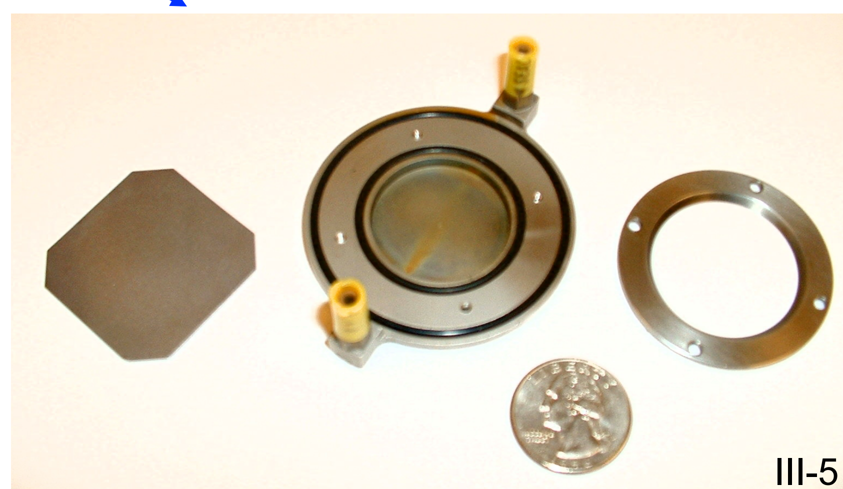
Target Chamber Design



Location where:
- reactions occur
- incident particle charge is measured



Beam power:
$P = U \cdot I = (0.1\ \text{MV})(1000\ \mu\text{A})$
$= 100\ \text{W}$

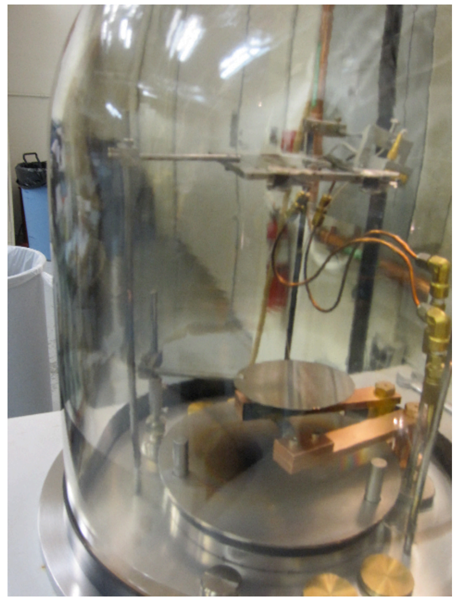


Target Material Deposited on a “Backing”

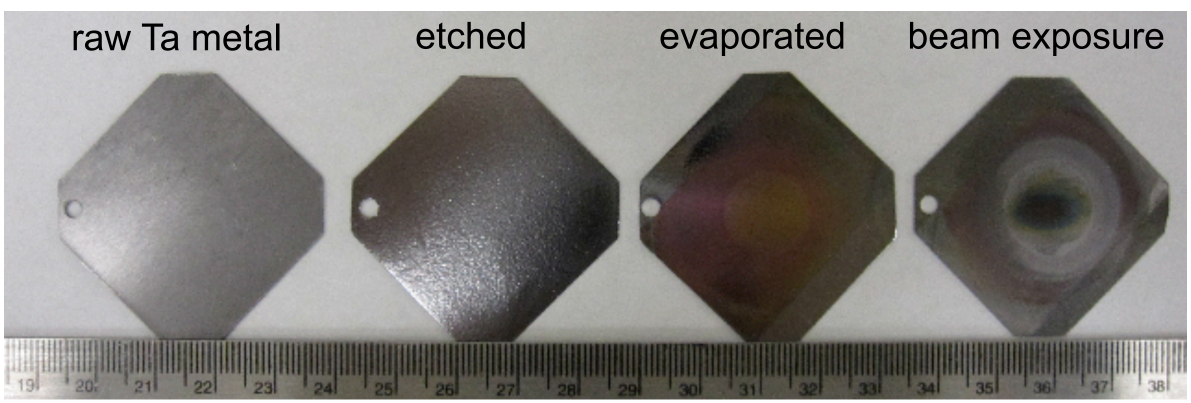
targets should: (ideally)
- have a well-known stoichiometry
- not degrade under ion bombardment
- have no contaminants

backings: Ta, Ni, Cu

contaminants: ^{11}B, ^{19}F, ^{13}C



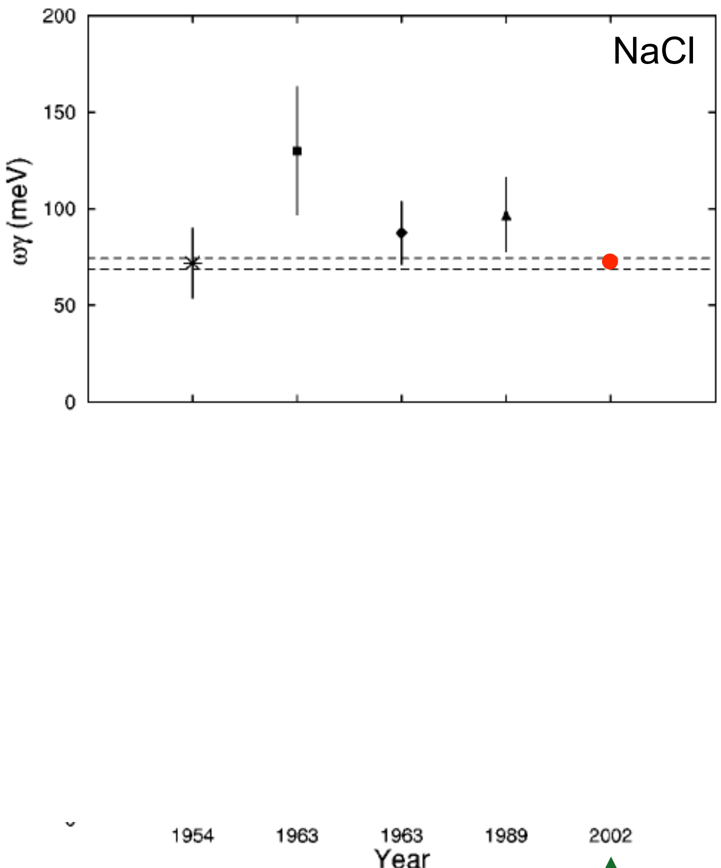
evaporation onto backing

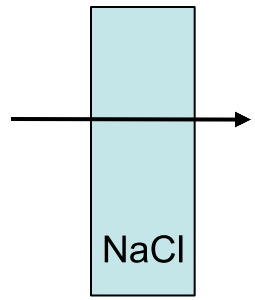


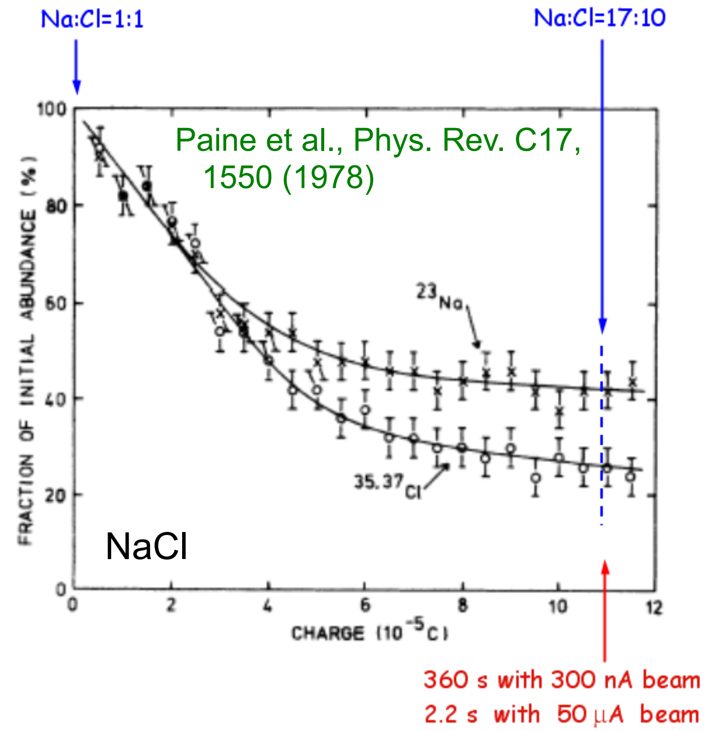
Common Mistakes…

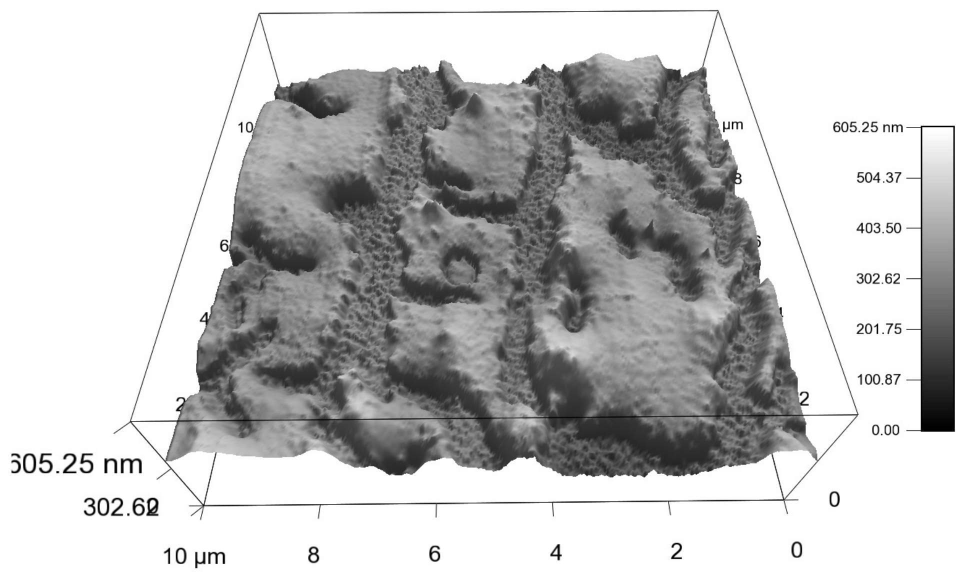
the ion beam can change the target stoichiometry!

$^{23}Na(p,\alpha)^{20}Ne$: resonance at 338 keV









Rowland, Iliadis et al., Phys. Rev. C65, 064609 (2002)

Atomic Force Microscope image of Na_2WO_4 target

Detectors: Semiconductors & Scintillators

$p + {}^{17}O \rightarrow {}^{18}F + \gamma$

$p + {}^{17}O \rightarrow {}^{14}N + \alpha$

radiation [reaction products] deposits energy in matter

Germanium [semiconductor for γ-rays]

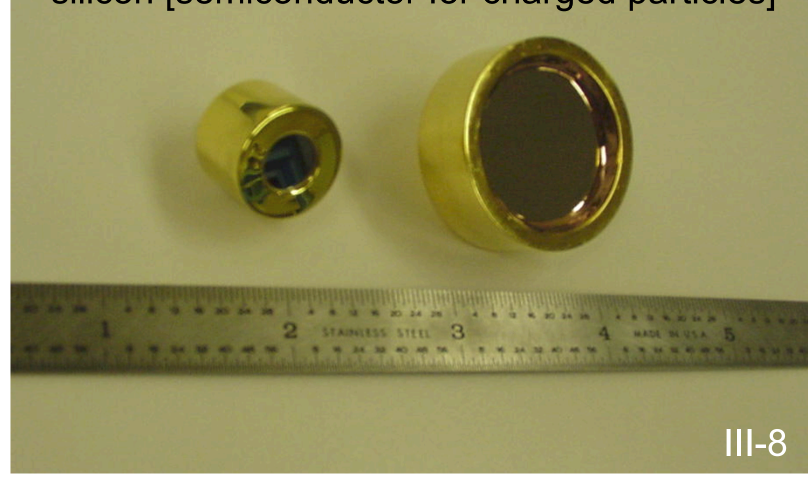
Textbook resources:

- Knoll, Radiation Detection and Measurement (Wiley, 1999)
- Gilmore, Practical γ-Ray Spectrometry (Wiley, 2011)

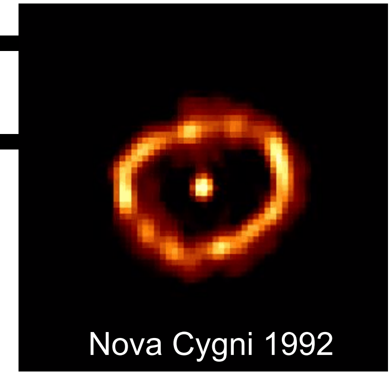
NaI(Tl) [scintillator for γ-rays]

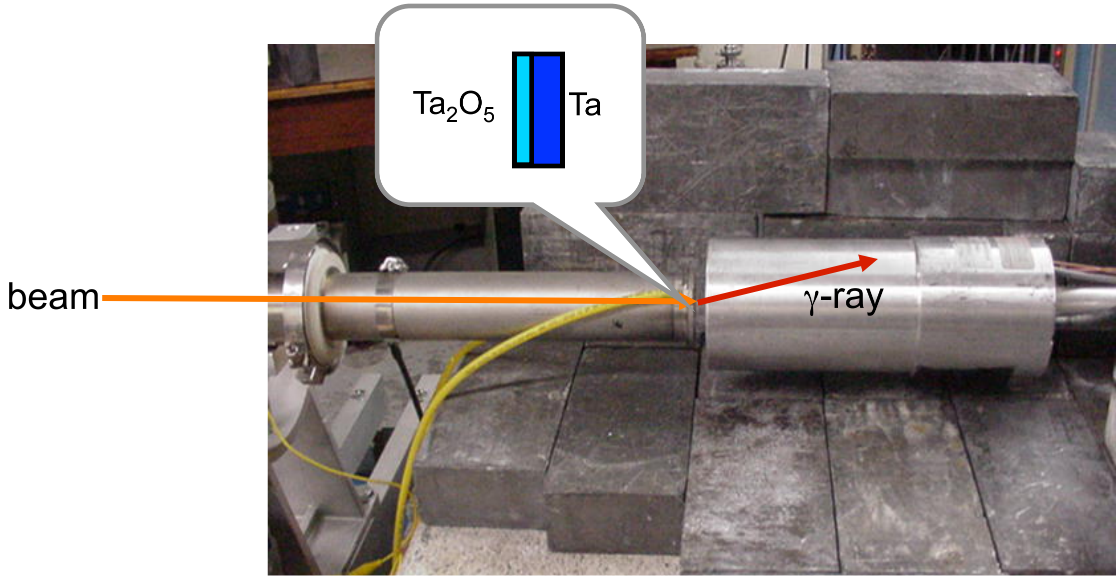
plastic [scintillator for muons]

silicon [semiconductor for charged particles]

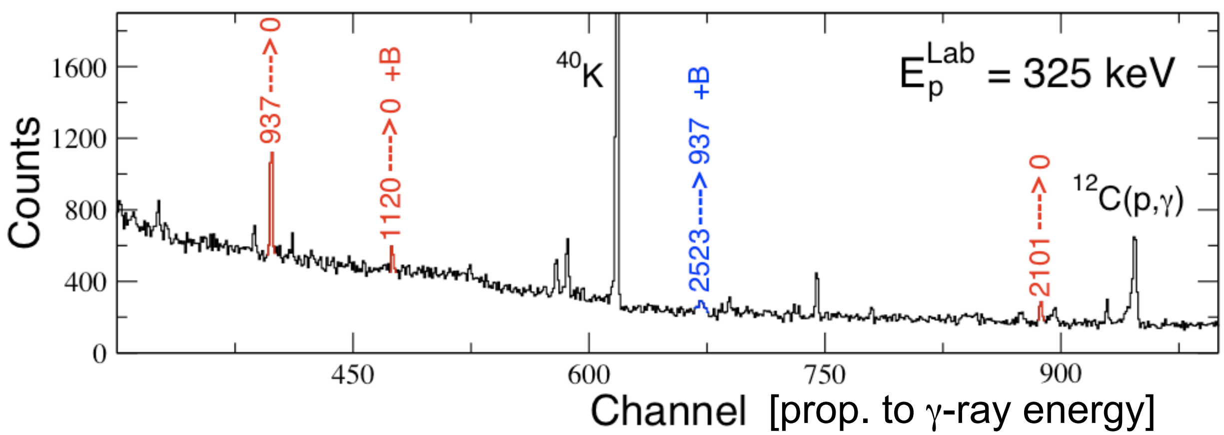


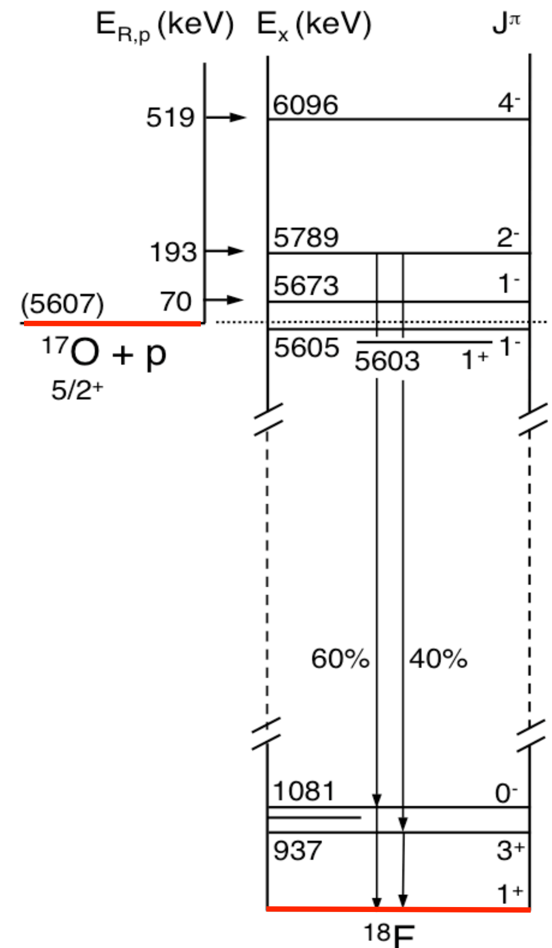
Measured Germanium Detector γ-Ray Spectrum



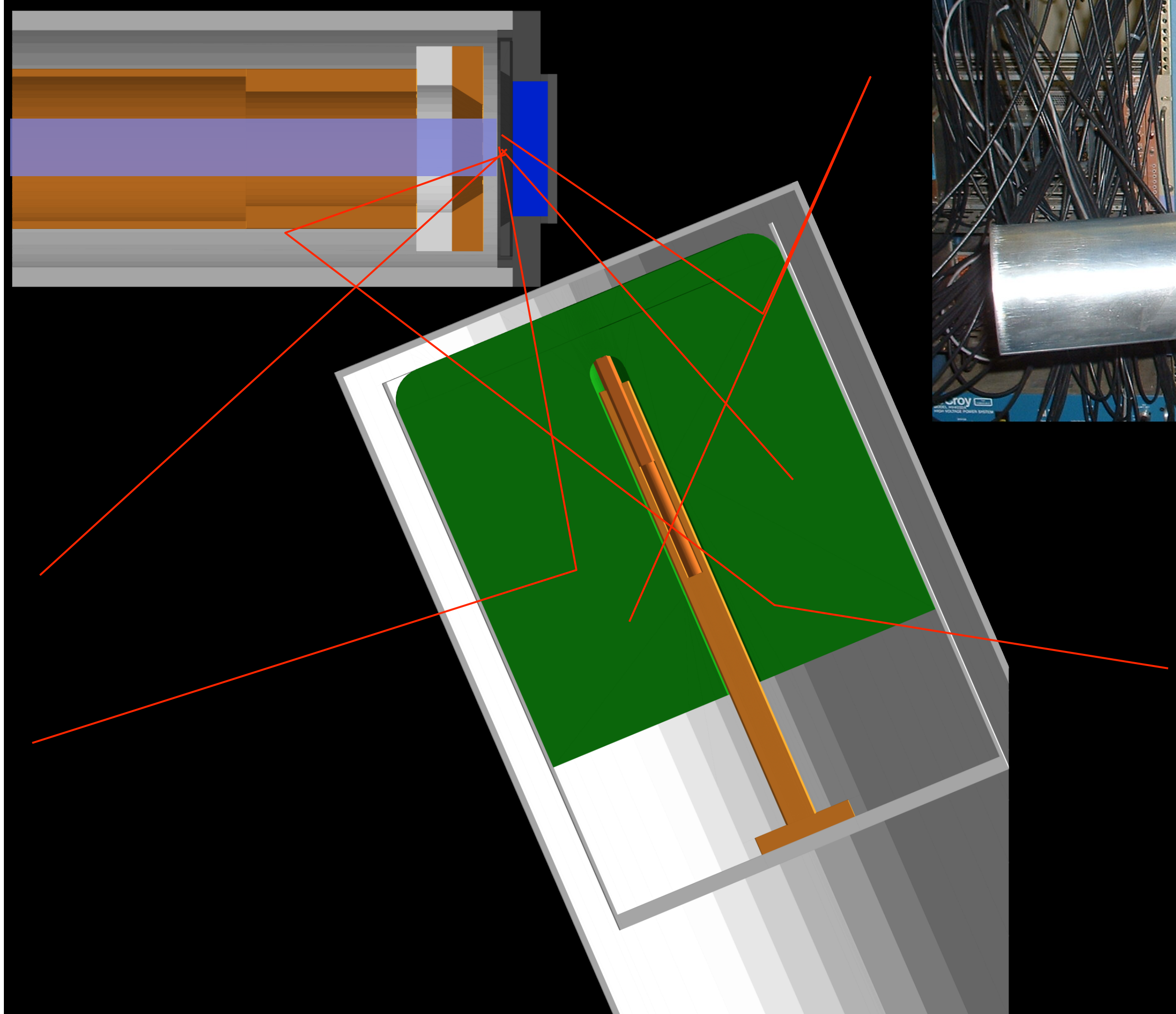


$p + {}^{17}O \rightarrow {}^{18}F + \gamma$

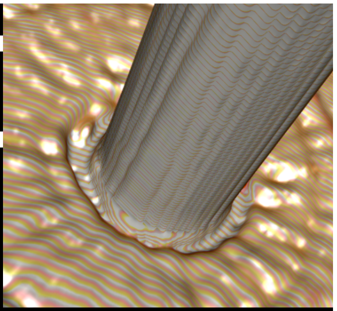




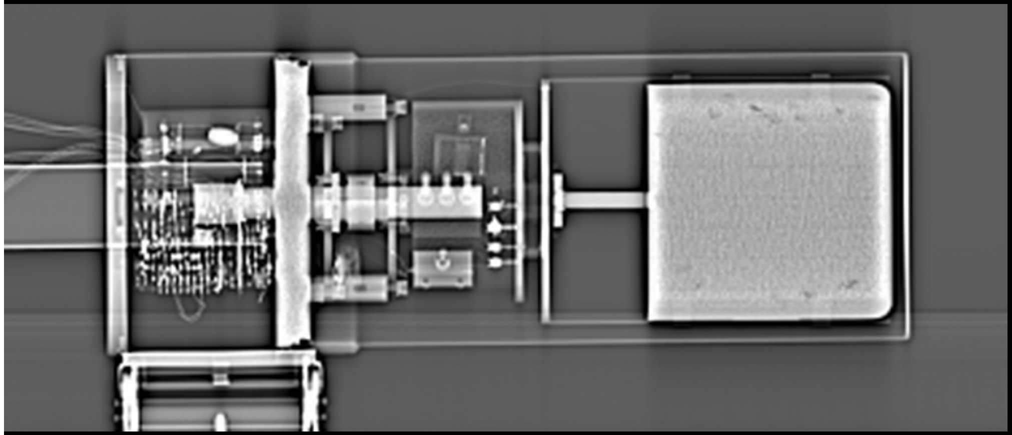
Detector Simulations: Necessity for Precision Work

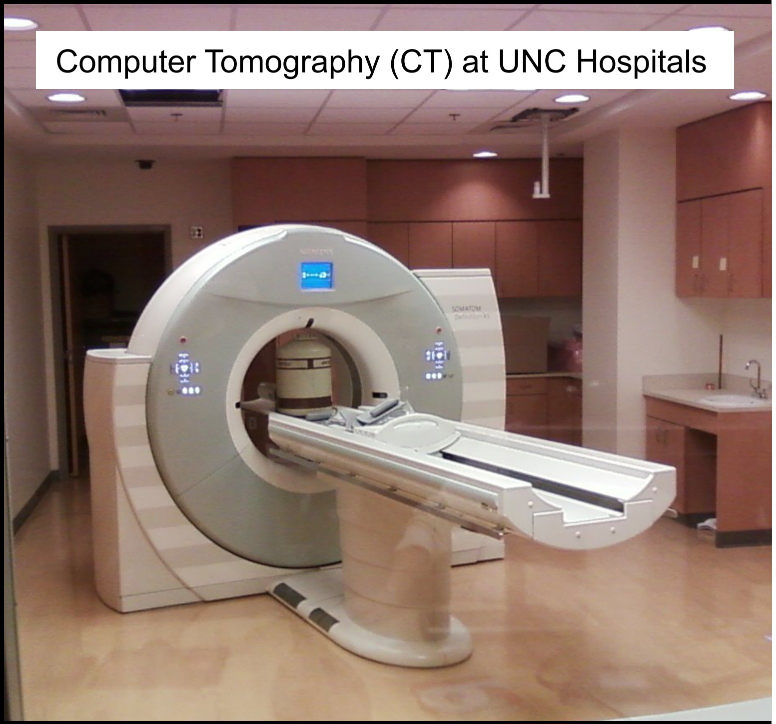


Detector Characterization



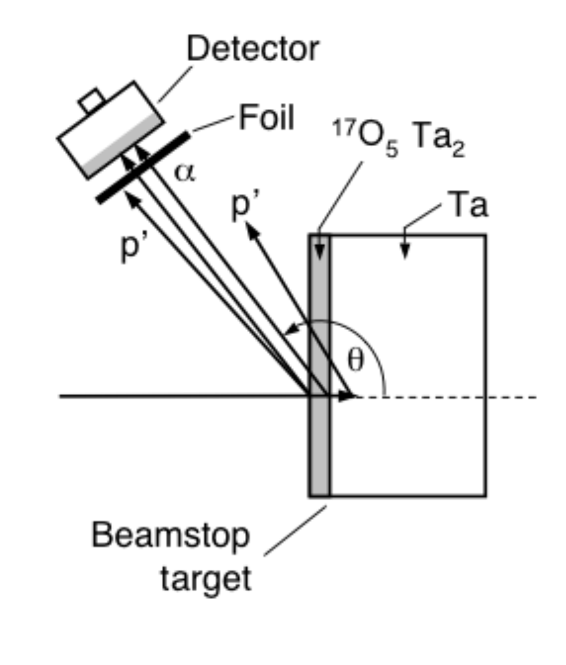
- detection efficiency
- coincidence summing corrections
- background



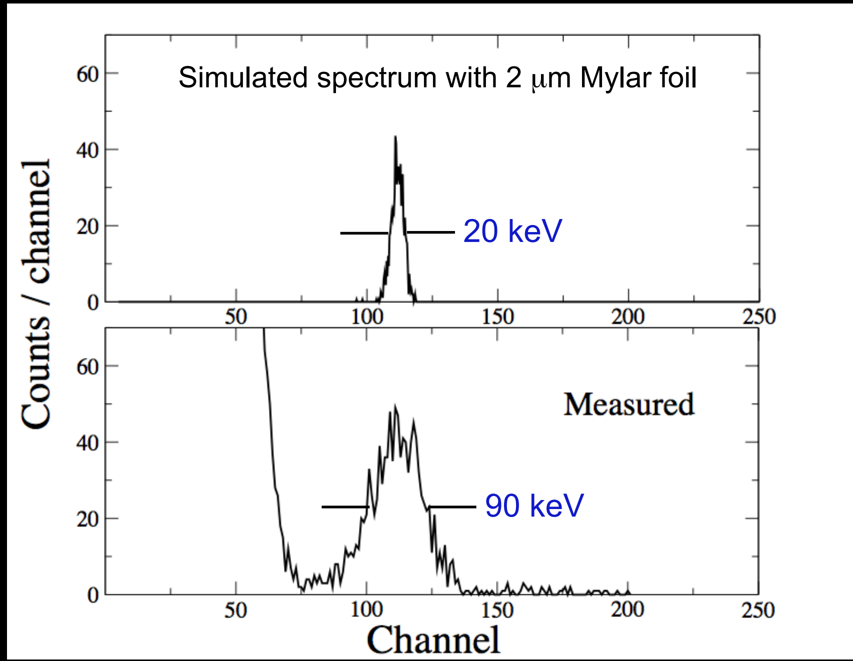


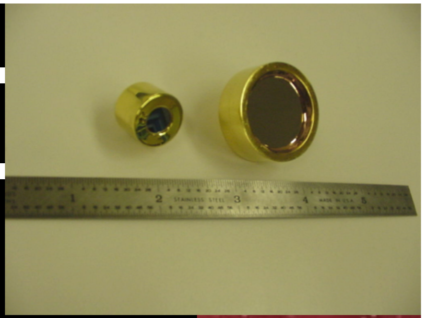
Carson, Iliadis et al., Nucl. Instr. Meth. A 618, 190 (2010)

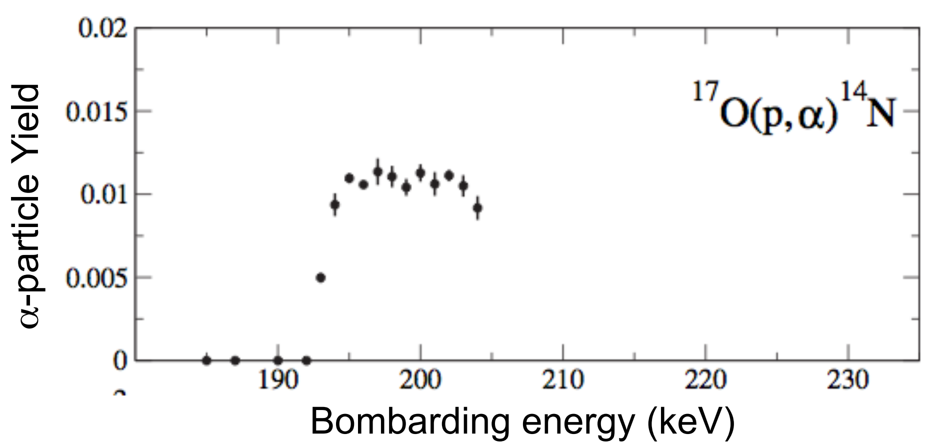
Directly Measured Resonance in $^{17}O(p,\alpha)^{14}N$ at 190 keV



Newton, Iliadis et al., PR C 75, 055808 (2007)



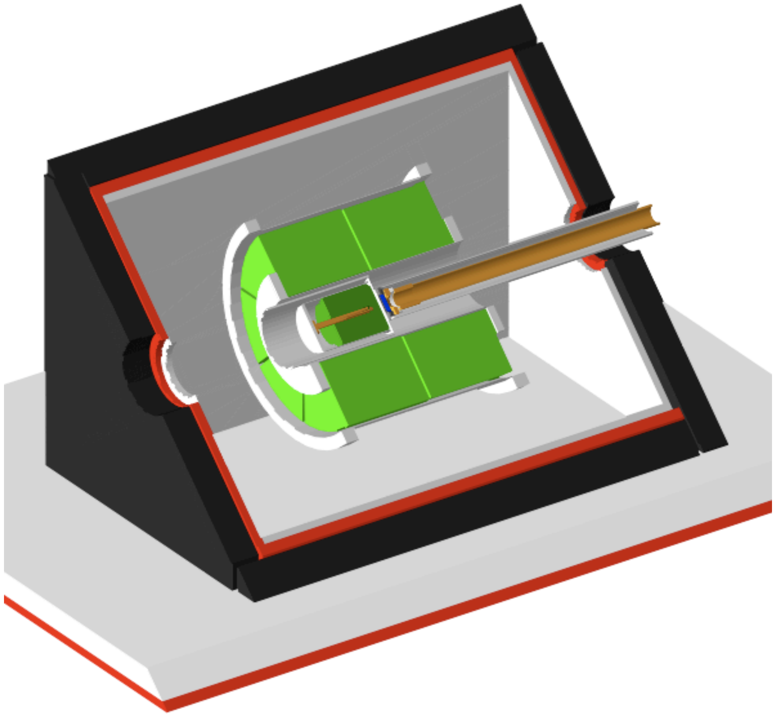


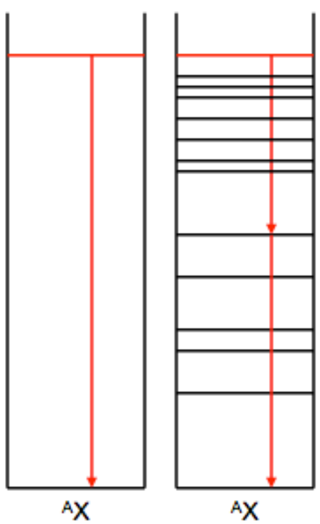


Other recent work:

Chafa et al., Phys. Rev. Lett. 95, 031101 (2005)
Moazen et al., Phys. Rev. C 75, 065801 (2007)

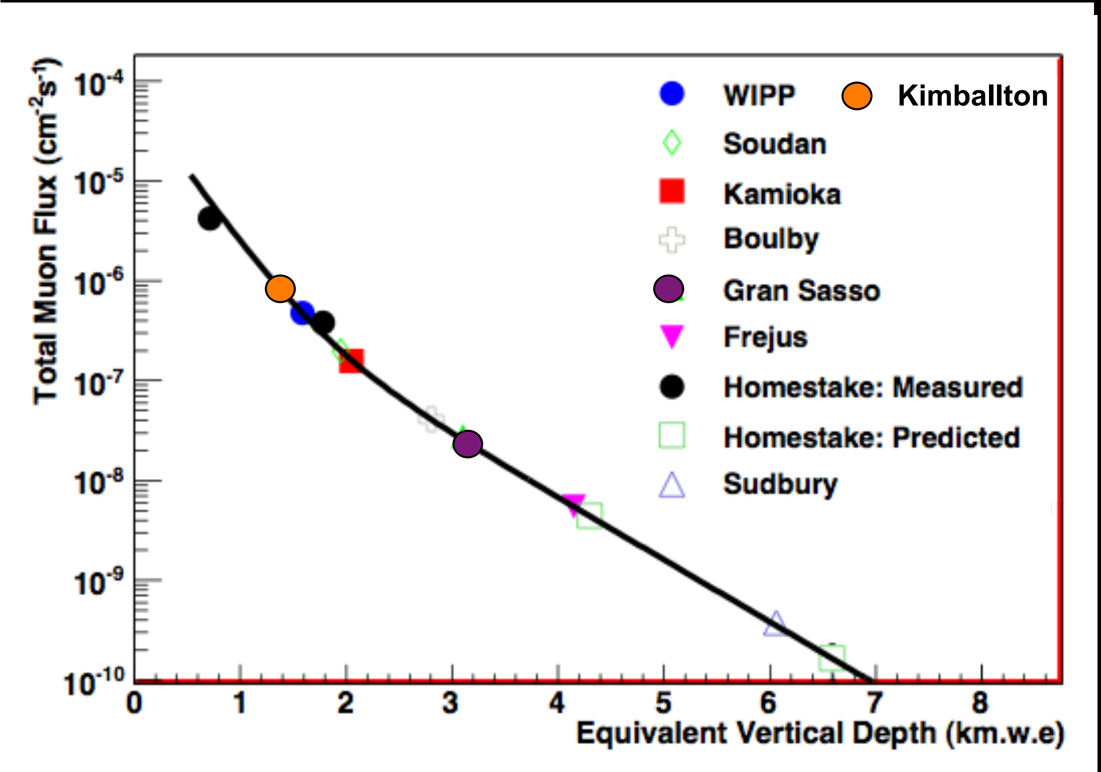
Coincidence-Anticoincidence Detection Apparatus





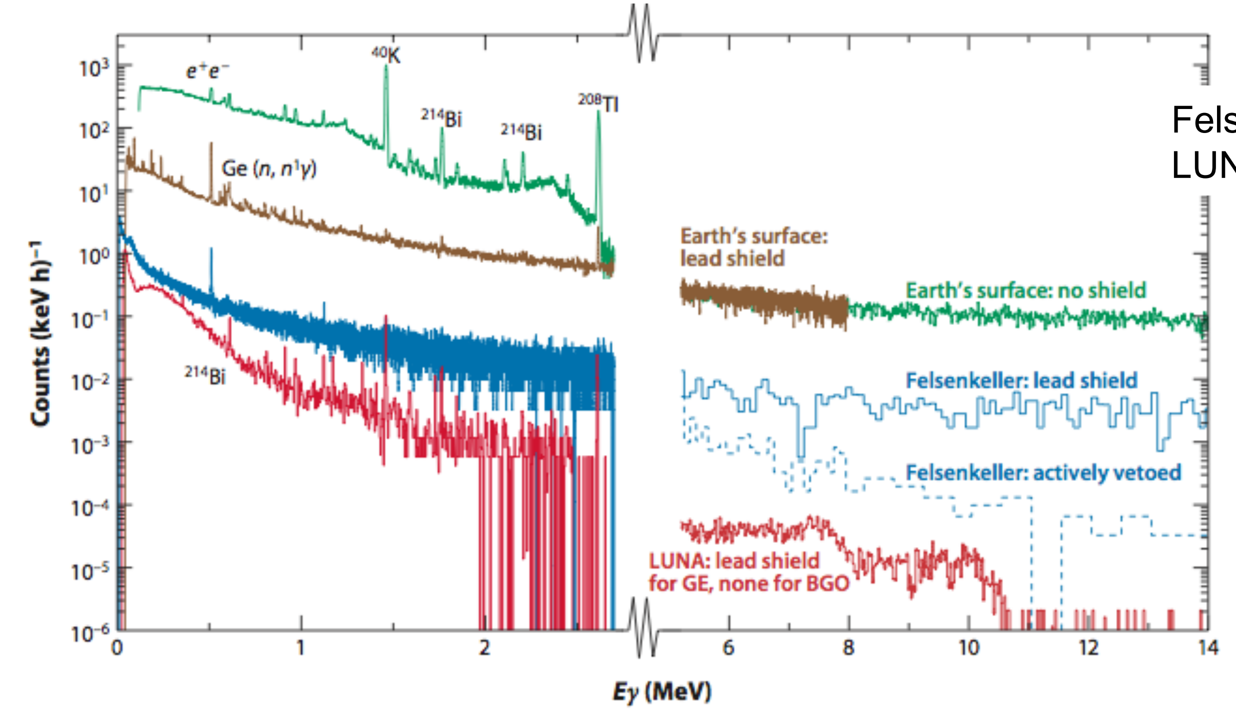
- Rowland, Iliadis et al., Nucl. Instr. Meth. A 480, 610 (2002)
- Longland, Iliadis et al., Nucl. Instr. Meth. A 566, 452 (2006)

Another Background Reduction Technique: Experiments Underground



Gray et al., arxiv: 1007.1921

Another Background Reduction Technique: Experiments Underground

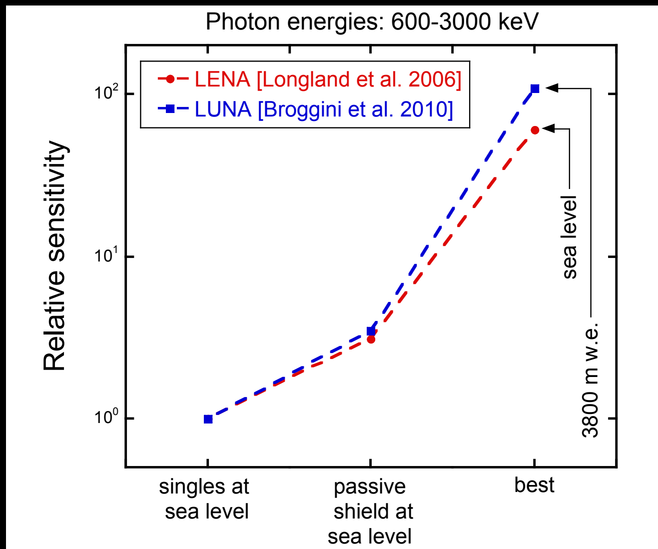


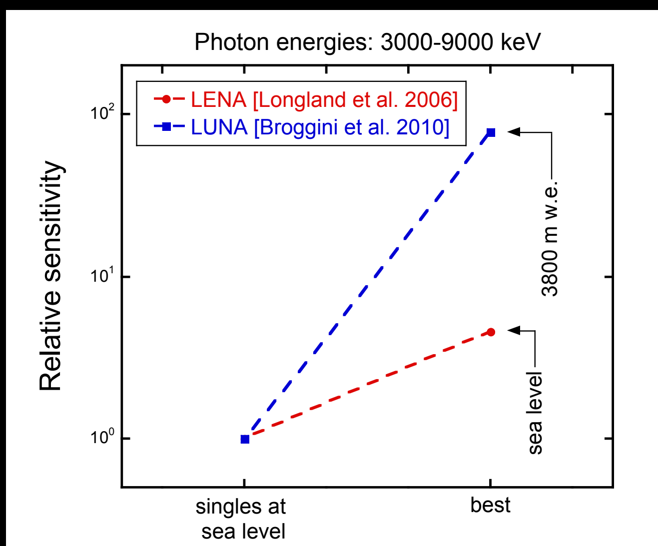
Felsenkeller: 110 m w.e.
LUNA: 3800 m w.e.

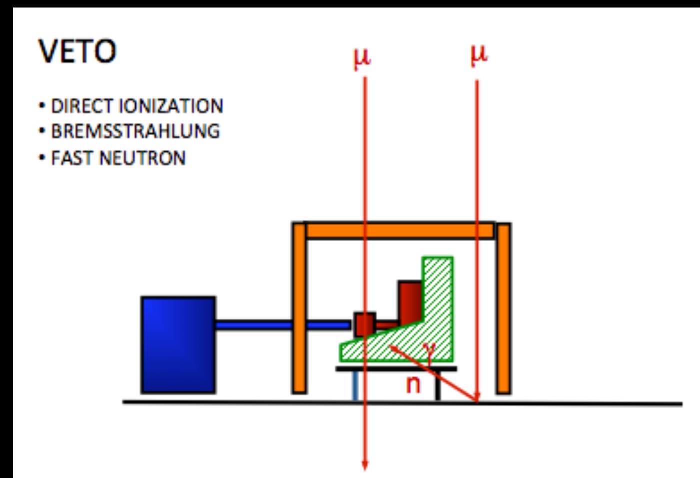
Broggini et al., Annu. Rev. Nucl. Part. Sci. 60, 53 (2010)

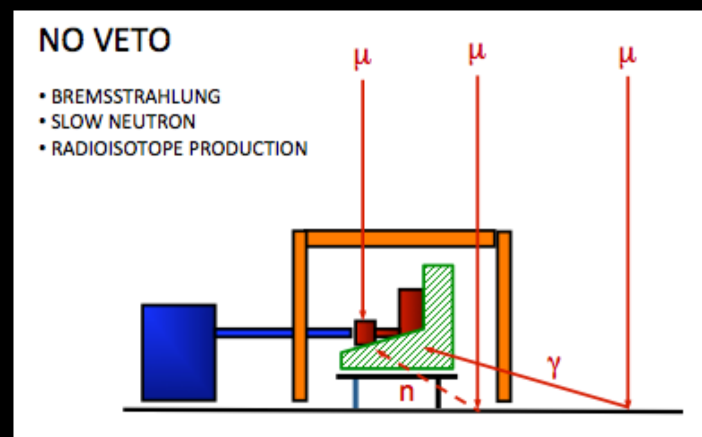
- at energies E_γ<3 MeV, specially selected materials must be used or background is not much reduced
- at energies E_γ>3 MeV, background is strongly reduced, even with conventional detectors
- beam-induced background is not reduced!

Sensitivity Comparison of SEA LEVEL versus UNDERGROUND



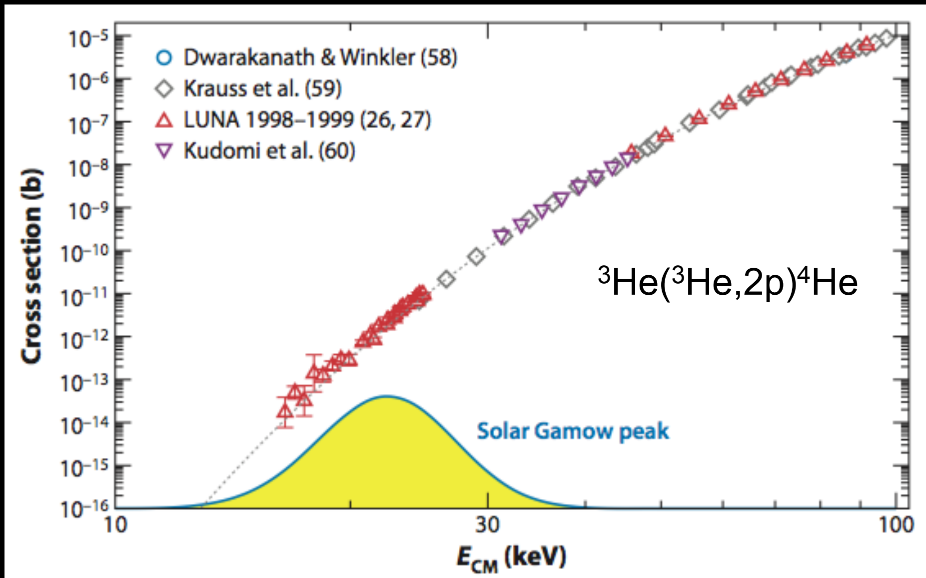


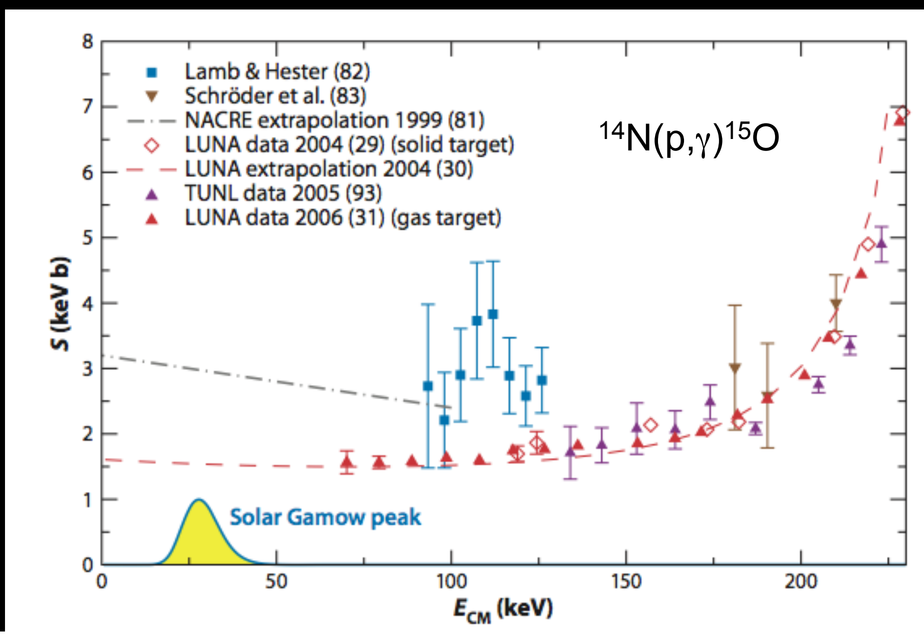


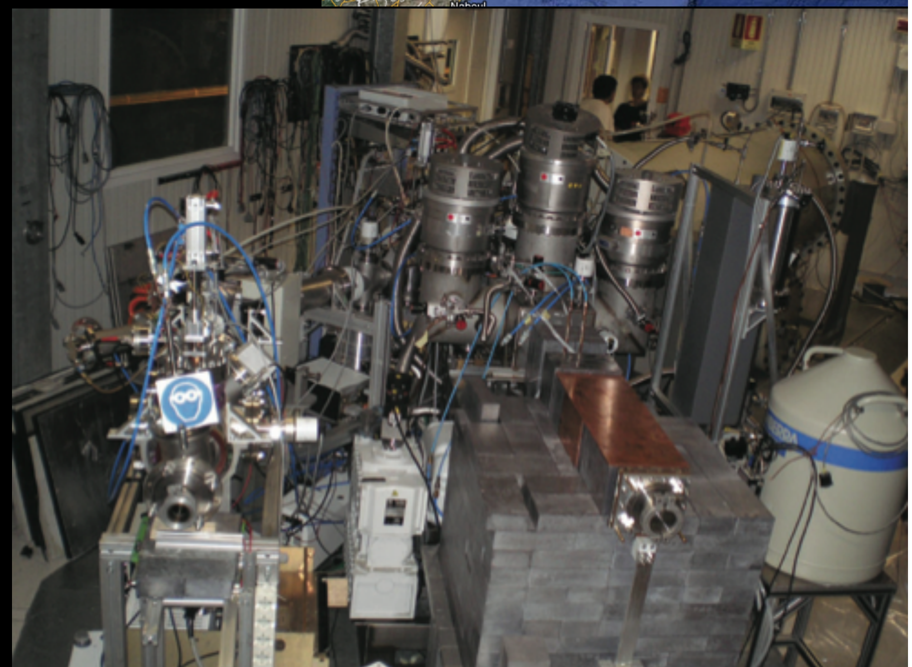


- Longland, Iliadis et al., Nucl. Instr. Meth. A 566, 452 (2006)
- Broggini et al., Annu. Rev. Nucl. Part. Sci. 60, 53 (2010)

Laboratory for Underground Nuclear Astrophysics

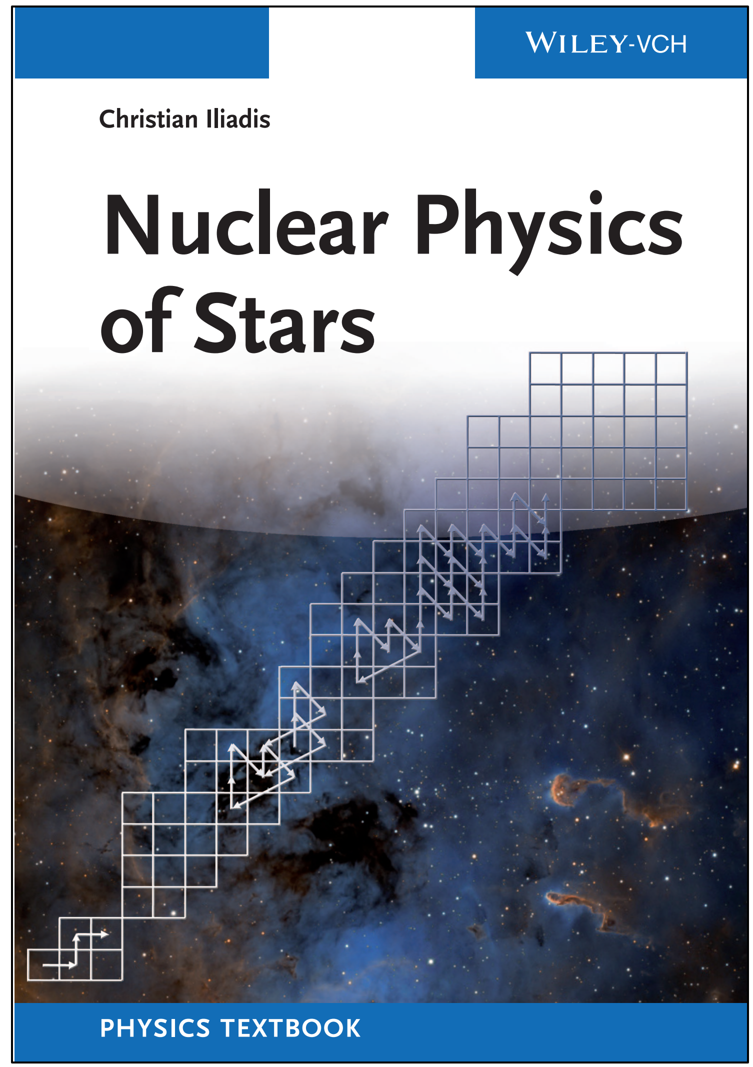






Broggini et al., Annu. Rev. Nucl. Part. Sci. 60, 53 (2010)

Further reading:



<u>Graduate student level:</u>

C. Iliadis, Nuclear Physics of Stars, 2nd edition, Wiley (2015)

J. Jose & C. Iliadis, Nuclear Astrophysics: the Unfinished Quest for the Origin of the Elements, Rep. Prog. Phys. 74, 096901 (2011) – *advanced grad student level*

<u>Other reviews:</u>

M. Wiescher, F. Kaeppeler & K. Langanke, Critical Reactions in Contemporary Nuclear Astrophysics, Annu. Rev. Astron. Astrophys. 50 (2012)