# My Vision of the Future
# Nuclear Astrophysics in China



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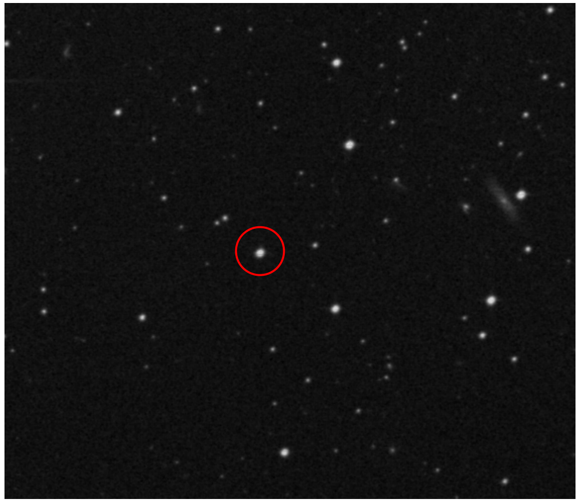
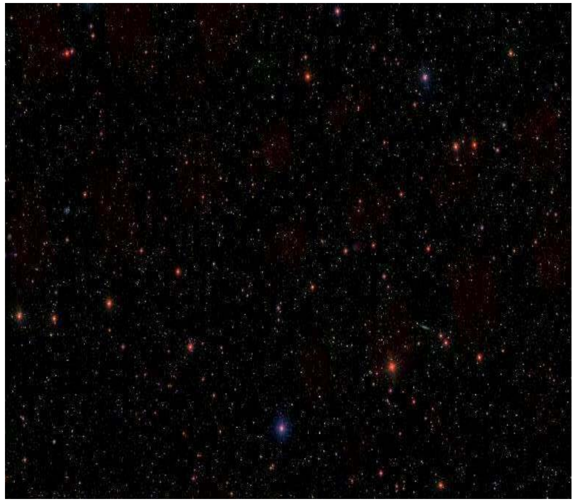
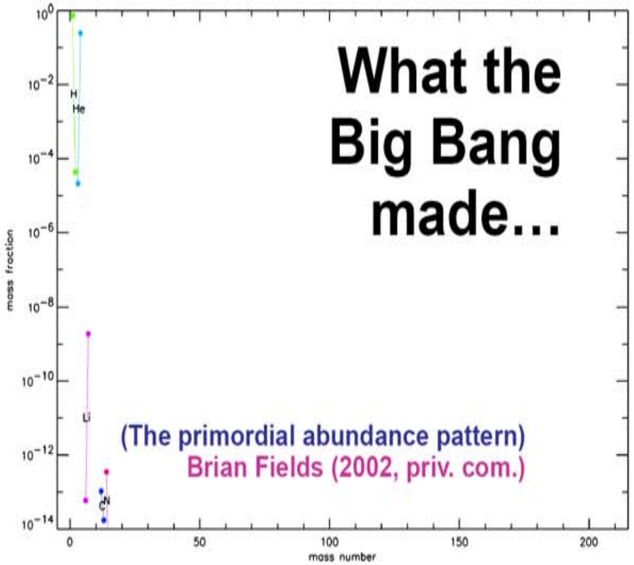
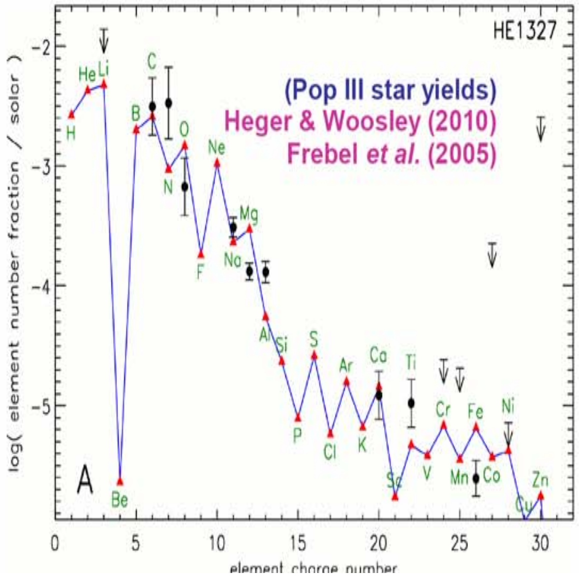
University of Notre Dame

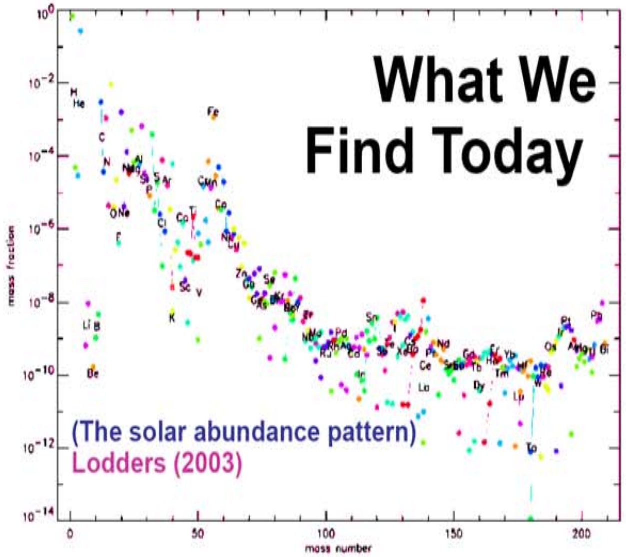


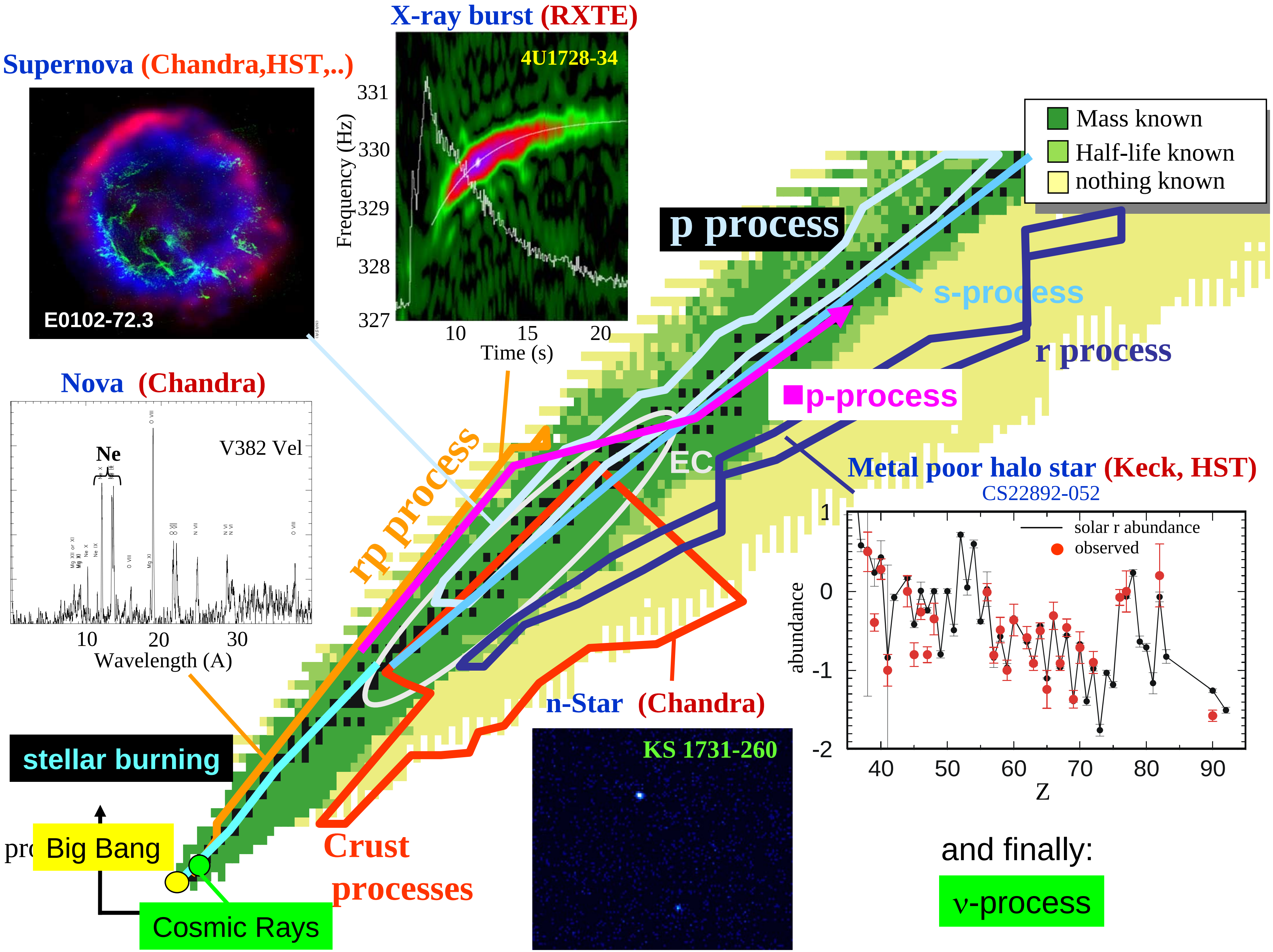


# Nucleosynthesis History



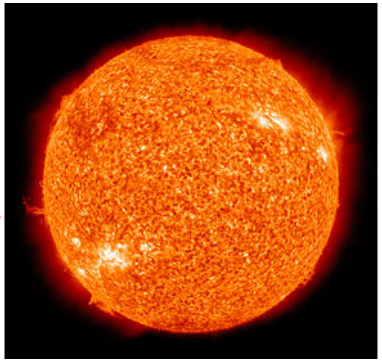



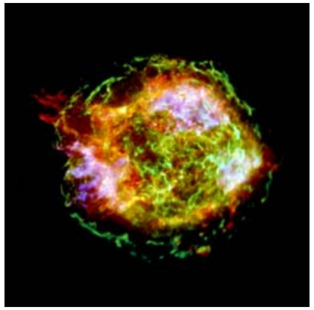





X-ray burst (RXTE)
4U1728-34
Frequency (Hz)
Time (s)
Supernova (Chandra,HST,..)
E0102-72.3
Nova (Chandra)
V382 Vel
Ne
Wavelength (A)
Mass known
Half-life known
nothing known
p process
s-process
r process
rp process
p-process
EC
Metal poor halo star (Keck, HST)
CS22892-052
solar r abundance
observed
abundance
Z
n-Star (Chandra)
KS 1731-260
stellar burning
Big Bang
Cosmic Rays
Crust processes
and finally:
ν-process

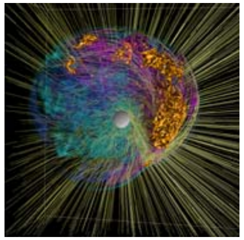
Hydrostatic burning in stars
High intensity, low energy, stable beam facility





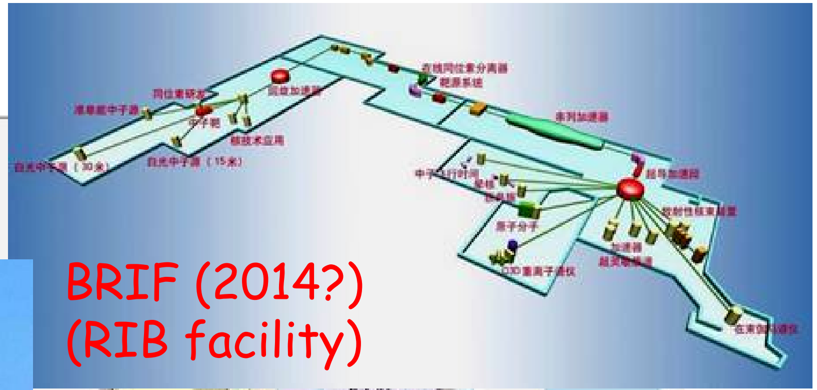
Explosive nucleosynthesis (supernova, X-ray burst)
Radioactive ion beam facility

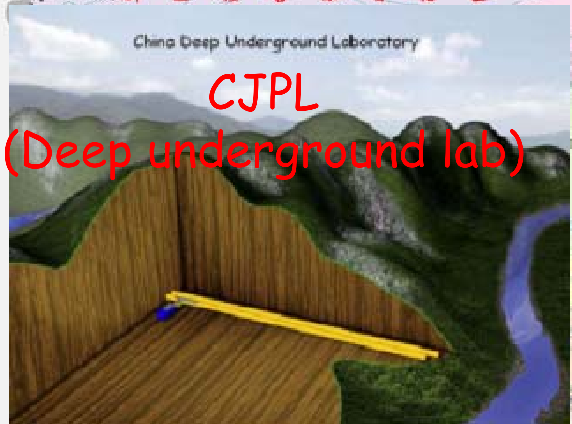
S-process in AGB stars and massive stars
Neutron facility



Stellar Neutrino (hydrostatic and explosive)
Neutrino facility


Lanzhou Heavy Ion facility
(RIB facility)


BRIF (2014?)
(RIB facility)


China Deep Underground Laboratory
CJPL
(Deep underground lab)


PKU
4.5 MV
accelerator


ICF facility
(Supernova shockwave,
High temp, high den plasma)

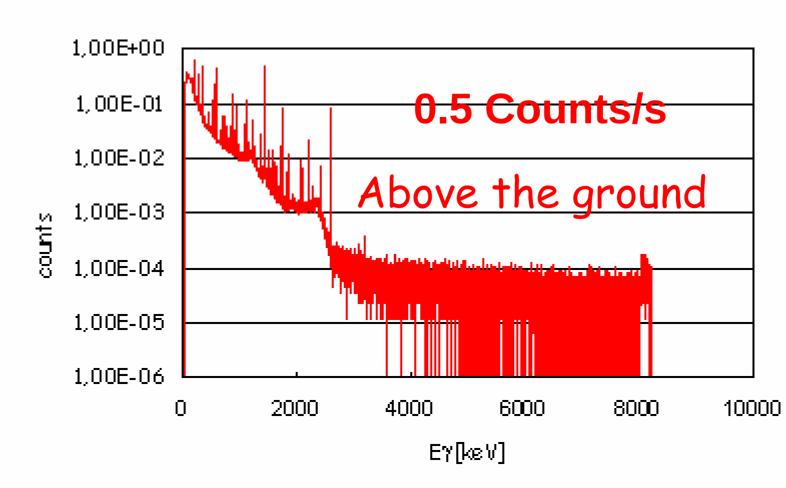

SLEGS
(photonuclear reaction)

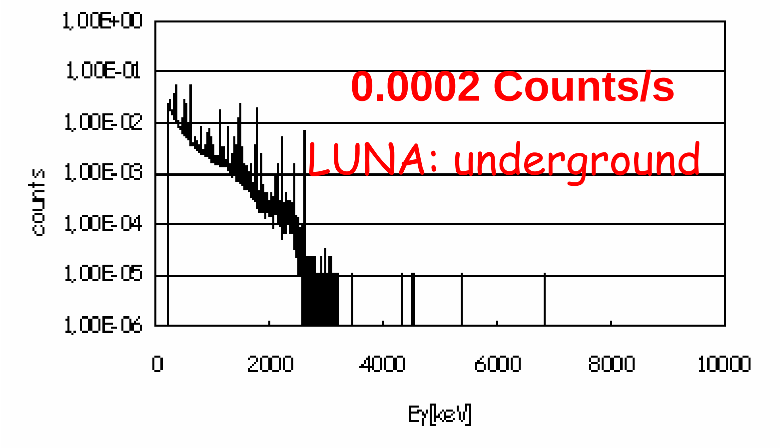

CSNS (2018)
(White neutron source,
neutrino source)

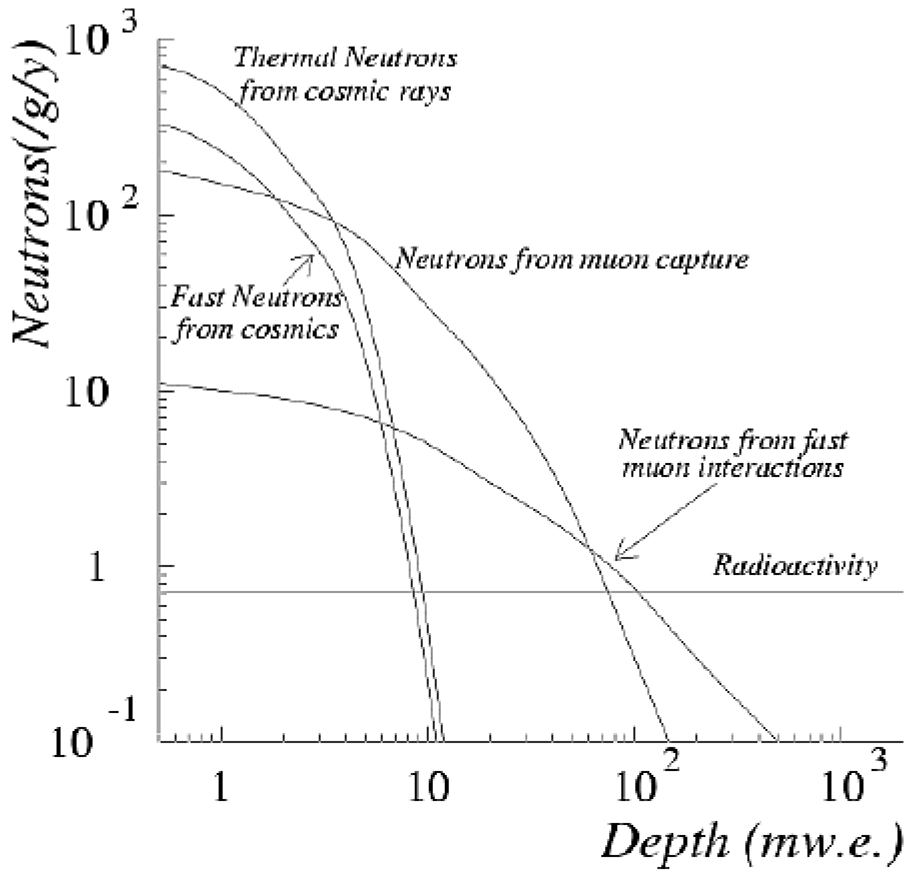
# Underground stable beam facility

# Go underground !

**Cosmic and Room Background**
**3 MeV < $E_\gamma$ < 8 MeV:**

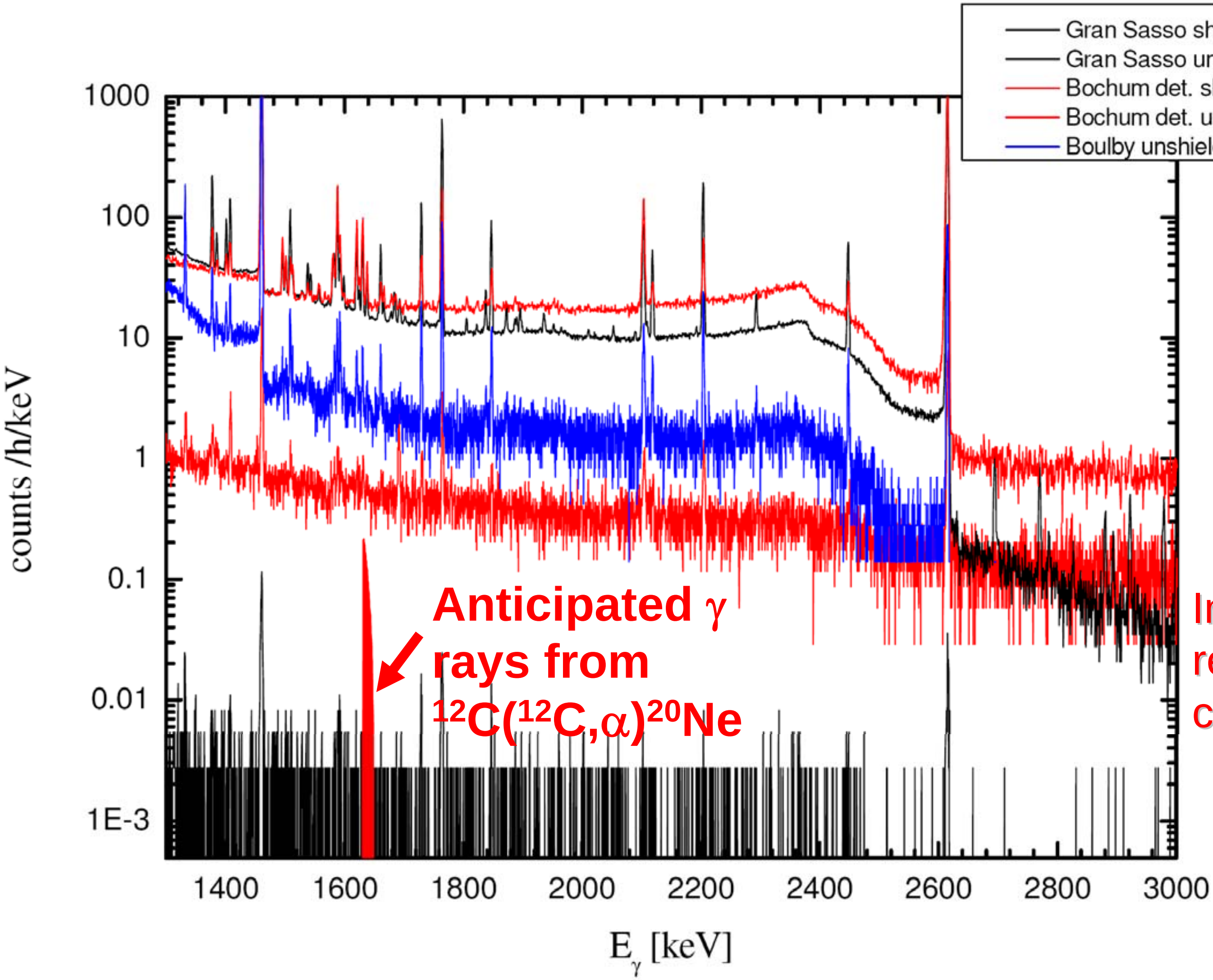



S. Eichblatt, CDMS 97-01-25 (1997)

# Background conditions in a natural salt mine environment

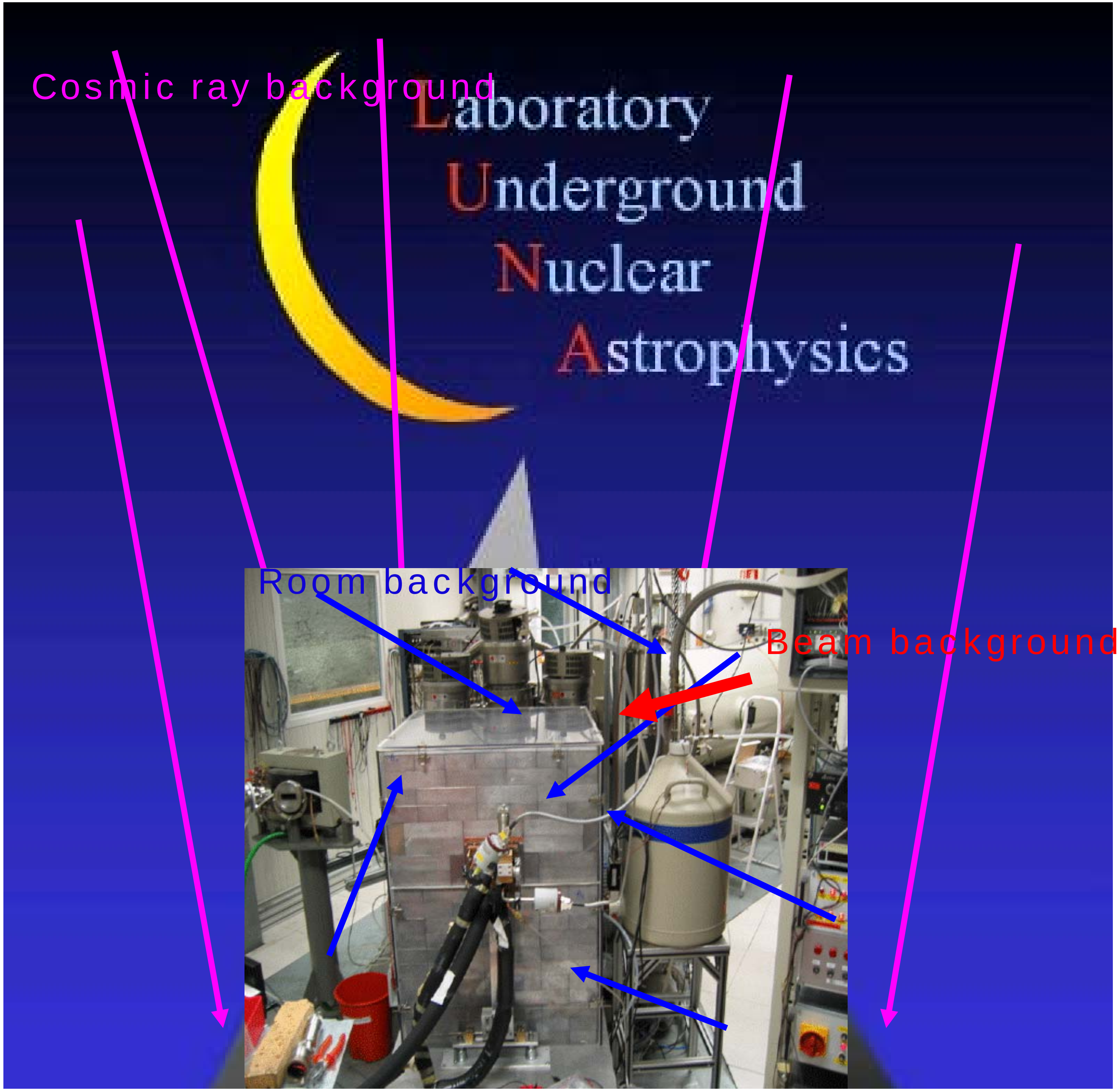



Proposals

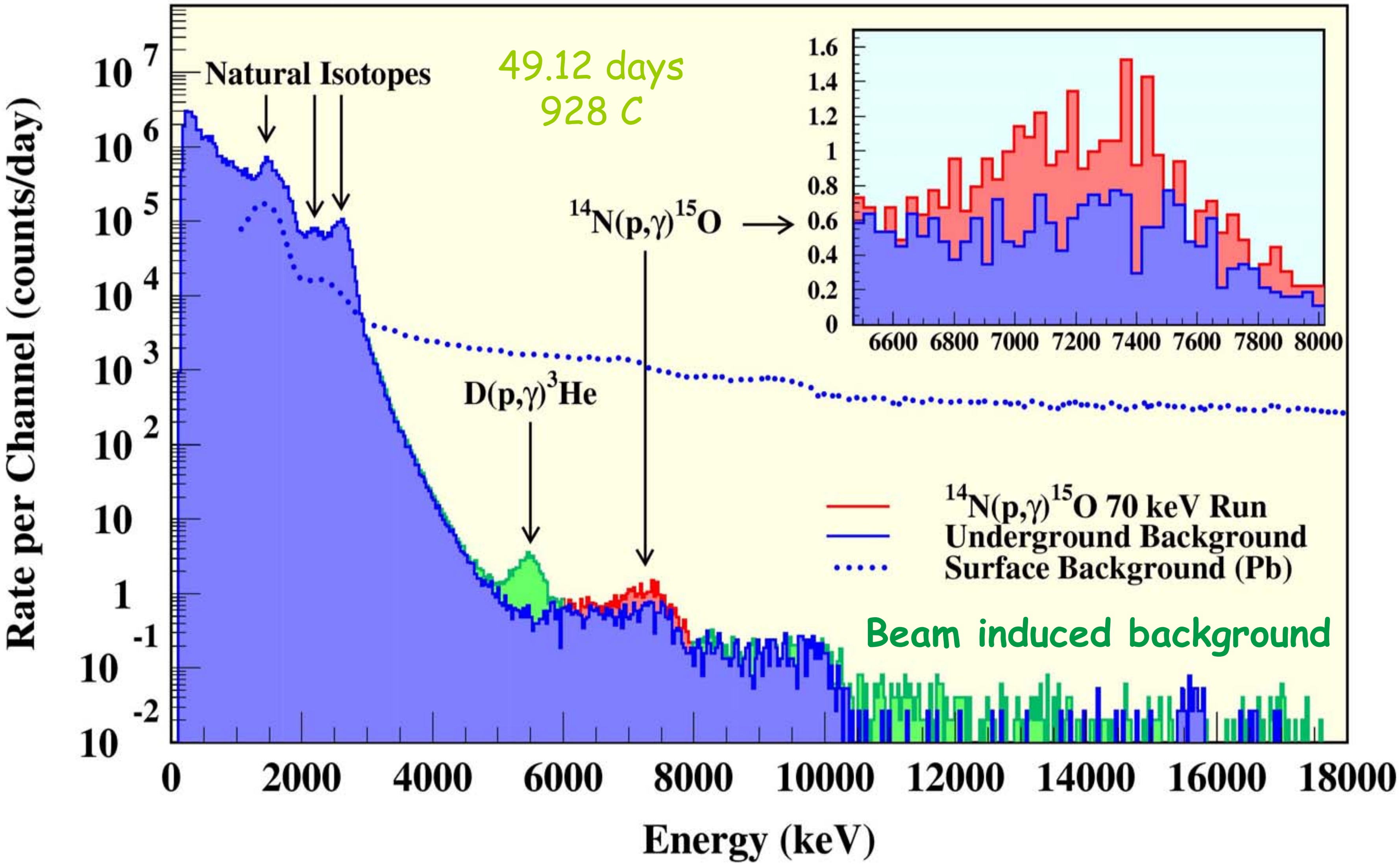
Praid, Ro, (200m)
Boulby, UK (1km)
WIPP, USA (1km)

Important for low Q-value reactions with low energy characteristic $\gamma$-transitions.

Courtesy: Marialuisa Alliota

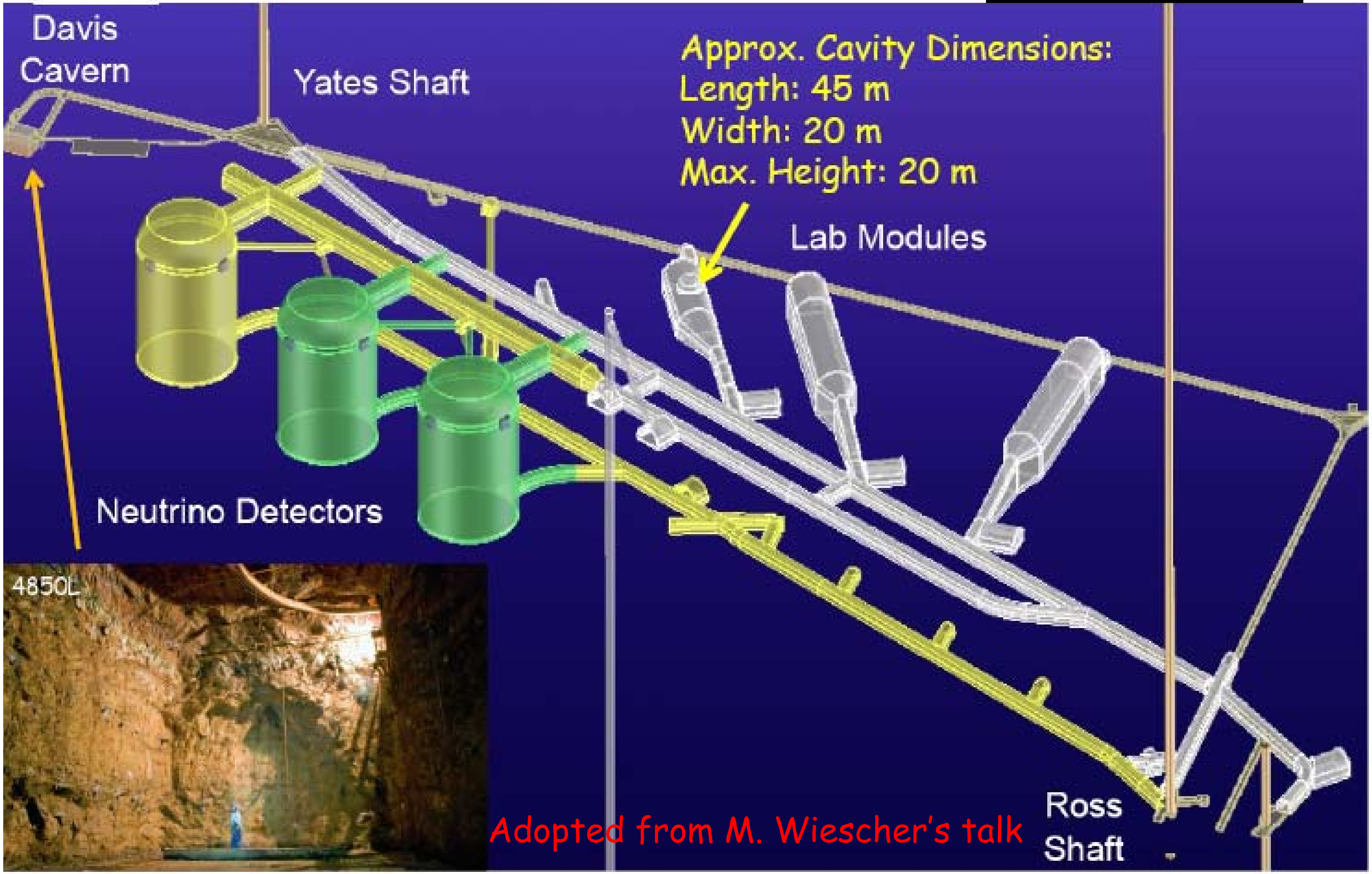

Cosmic ray background
Laboratory
Underground
Nuclear
Astrophysics
Room background
Beam background

# Backgrounds at the lowest energy




*LUNA Collaboration / Nuclear Physics A 779 (2006) 297-317*

# Proposed location in DUSEL




Adopted from M. Wiescher's talk

# DIANA design

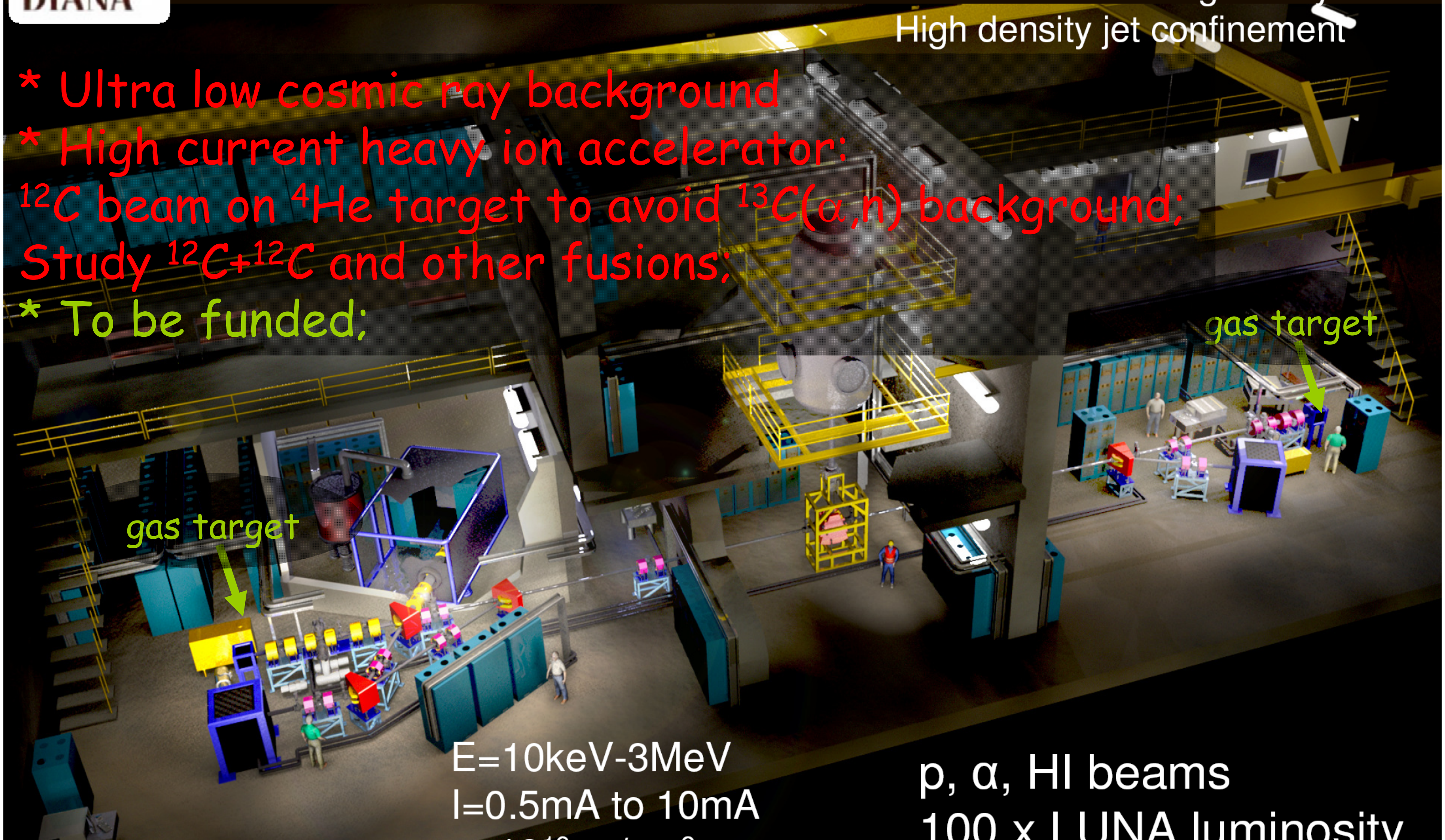
Technical achievements:

New acceleration tube design
SC solenoid beam guide system
High density jet confinement

* Ultra low cosmic ray background
* High current heavy ion accelerator:

$^{12}C$ beam on $^{4}He$ target to avoid $^{13}C(\alpha,n)$ background;
Study $^{12}C+^{12}C$ and other fusions;

* To be funded;




E=10keV-3MeV
I=0.5mA to 10mA
$\rho=10^{19}$prt/cm$^{2}$

p, α, HI beams
100 x LUNA luminosity

TABLE XIII. Attributes of proposed second-generation underground facilities for nuclear astrophysics.

| Facility | LUNA<br>Laboratory Underground<br>for Nuclear Astrophysics | DIANA<br>Dakota Ion Accelerators<br>for Nuclear Astrophysics | ELENA<br>Experimental<br>Low-Energy Nuclear Astrophysics | CUNA<br>Canfranc Nuclear<br>Astrophysics Facility |
|---|---|---|---|---|
| Location | Gran Sasso, Italy | Homestake Mine, USA | Boulby Mine, UK | Canfranc, Spain |
| Rock type | Hard limestone | Metamorphic rock | Salt | Hard limestone |
| Depth<br>(km.w.e, flat site) | 3.1 | 4.3 | 2.8 | $\sim$2.0 |
| Low-energy accelerator | 50–400 keV; 0.5–1.0 mA; rf ion source ($p$, $He^+$) | 50–400 kV high voltage platform; $\gtrsim$ 10 mA ECR i on sources, single, multiply charged | None | None |
| High-energy accelerator | 0.4–3.5 MeV electrostatic up to 0.3 mA ECR ion source | 0.35–3.0 MeV electrostatic up to 10 mA ECR ion sources single, multiply charged | 3.0 MeV accelerator electrostatic 0.5 mA ECR ion source | Up to 5.0 MeV electrostatic |

# Nuclear Astrophysics at Chinese JingPin Laboratory (CJPL)

# Neutron facilities

# Isotopic abundances from Cosmo-Chemistry provide:

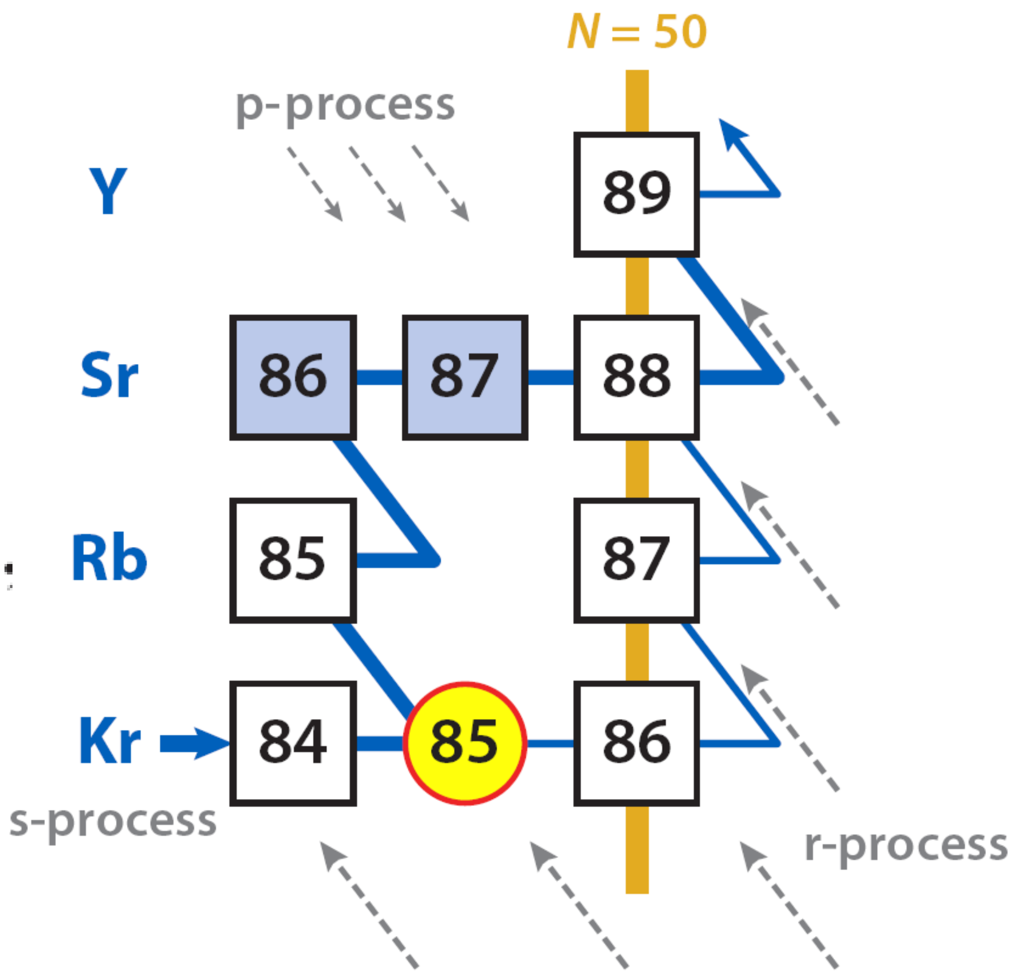
- Measure for neutron flux
- Temperature & density
- Convective conditions
- Shock front environment

$$f_\beta = \lambda_\beta / (\lambda_\beta + \lambda_n),$$

$$\lambda_n = n_n \sigma v_T$$

$n_n < 10^7$ cm$^{-3}$: $^{85}$Kr decay

$n_n > 10^7$ cm$^{-3}$, $^{85}$Kr(n,$\gamma$)



# spallation sources for TOF measurements of stellar $(n,\gamma)$ rates

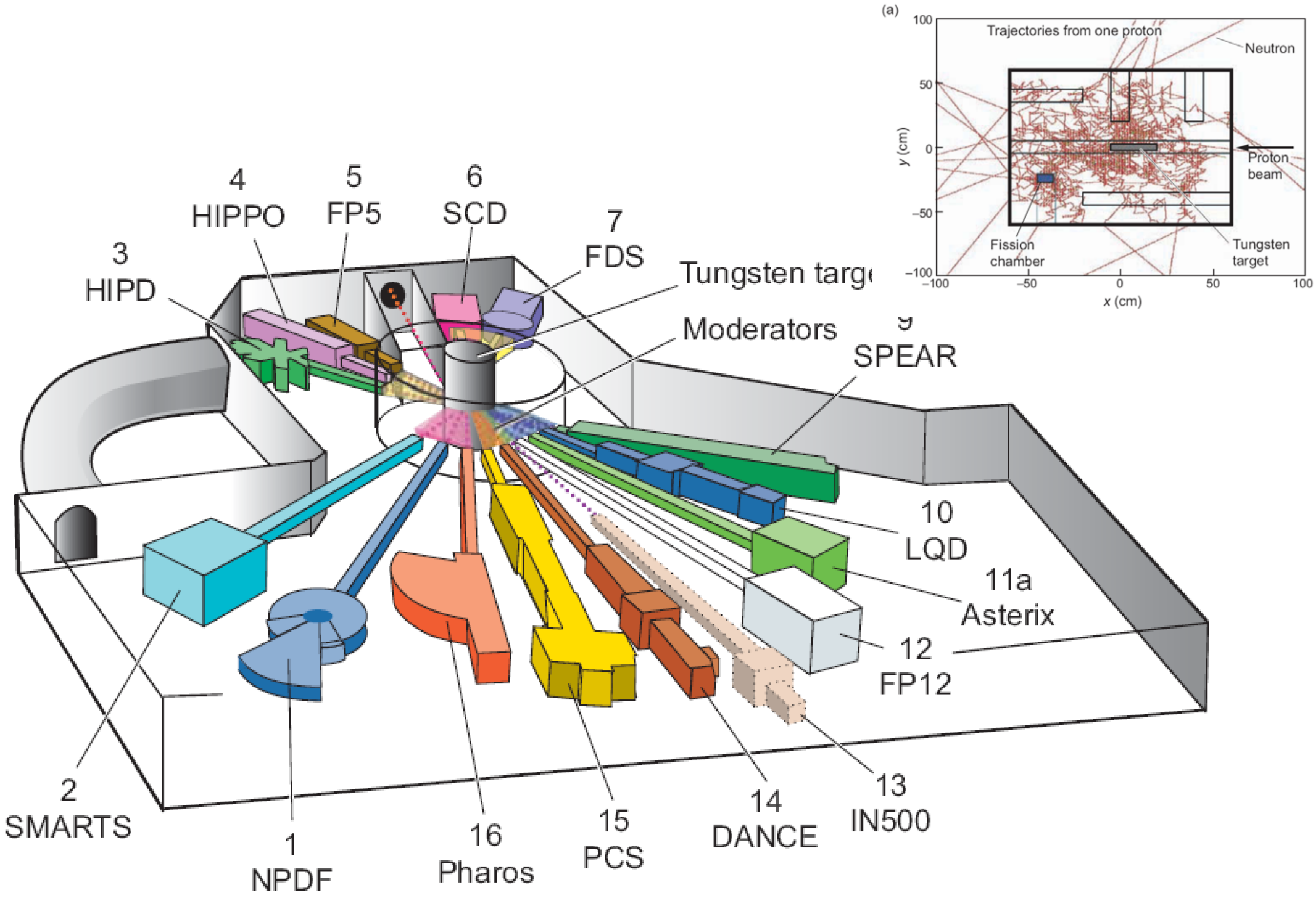
Los Alamos
NATIONAL LABORATORY
LANSCE
Los Alamos Neutron Science Center

PS213
n_TOF Collaboration

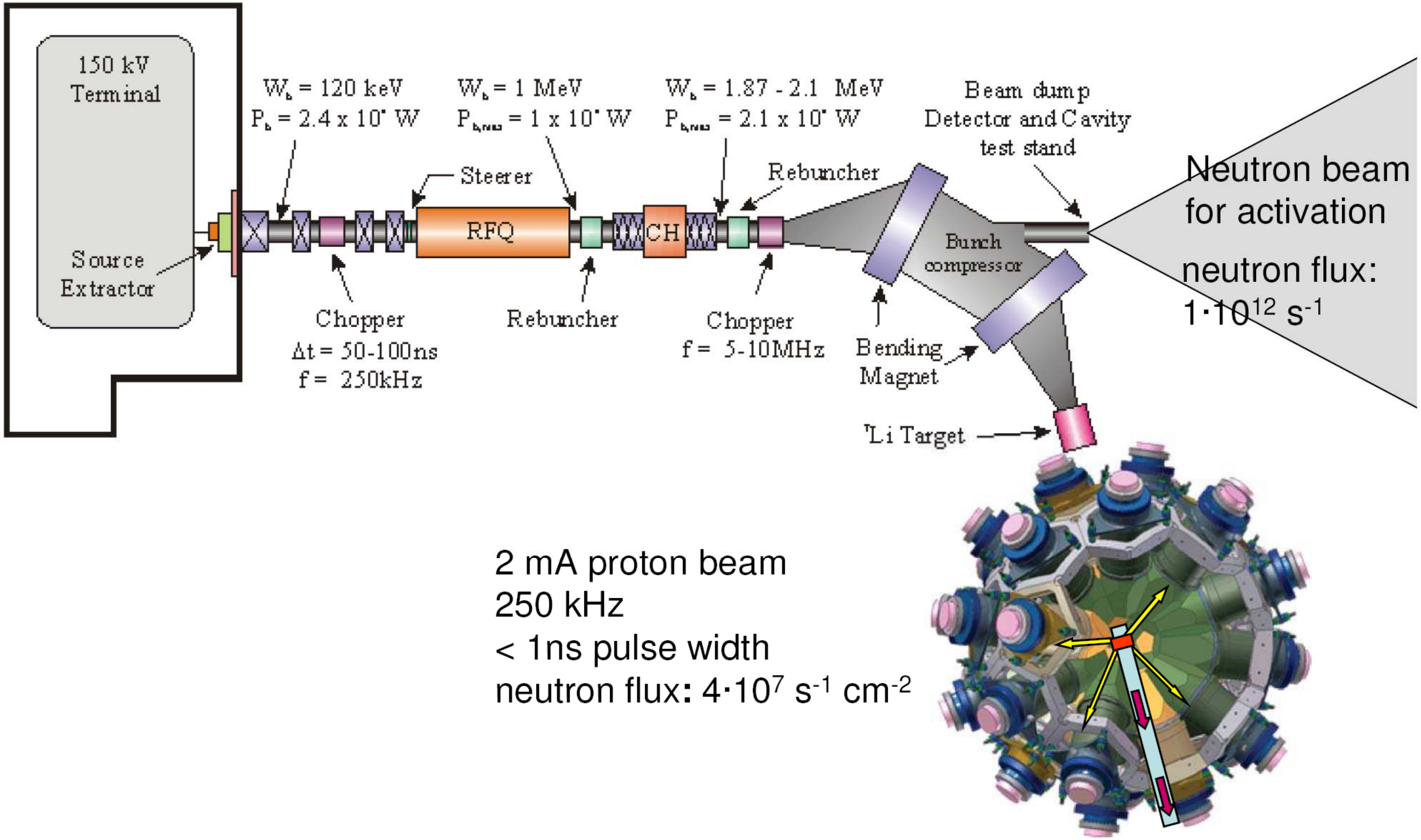
| | | |
|---|---|---|
| 0.8 | proton energy (GeV) | 24 |
| 20 | repetition rate (Hz) | 0.4 |
| 250 | pulse width (ns) | 5 |
| 20 | flight path (m) | 185 |
| 200 | average proton current ($\mu$A) | 2 |
| 20 | neutrons per proton | 760 |

Adopted from Kappler's talk

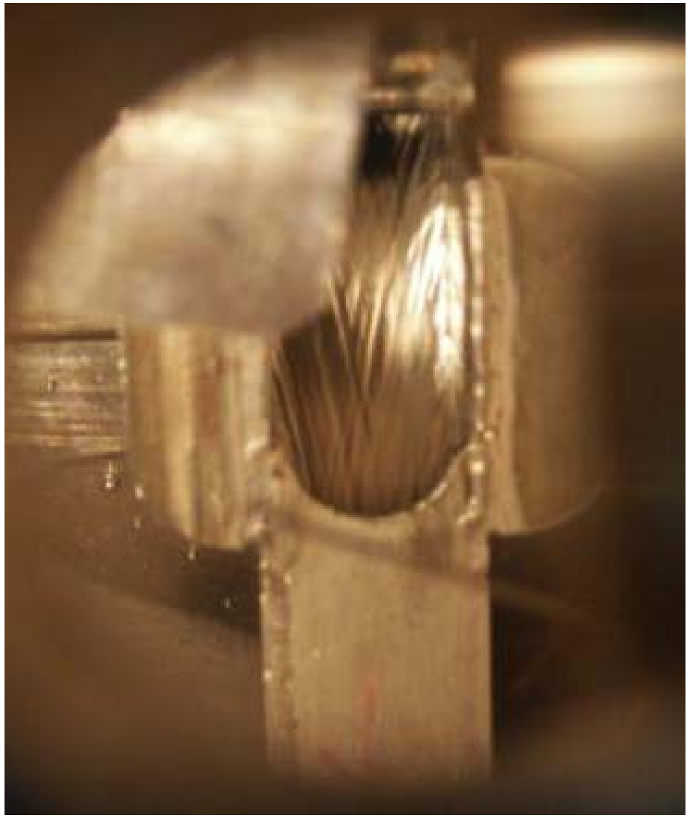
# Los Alamos Neutron Science Center (LANSCE)



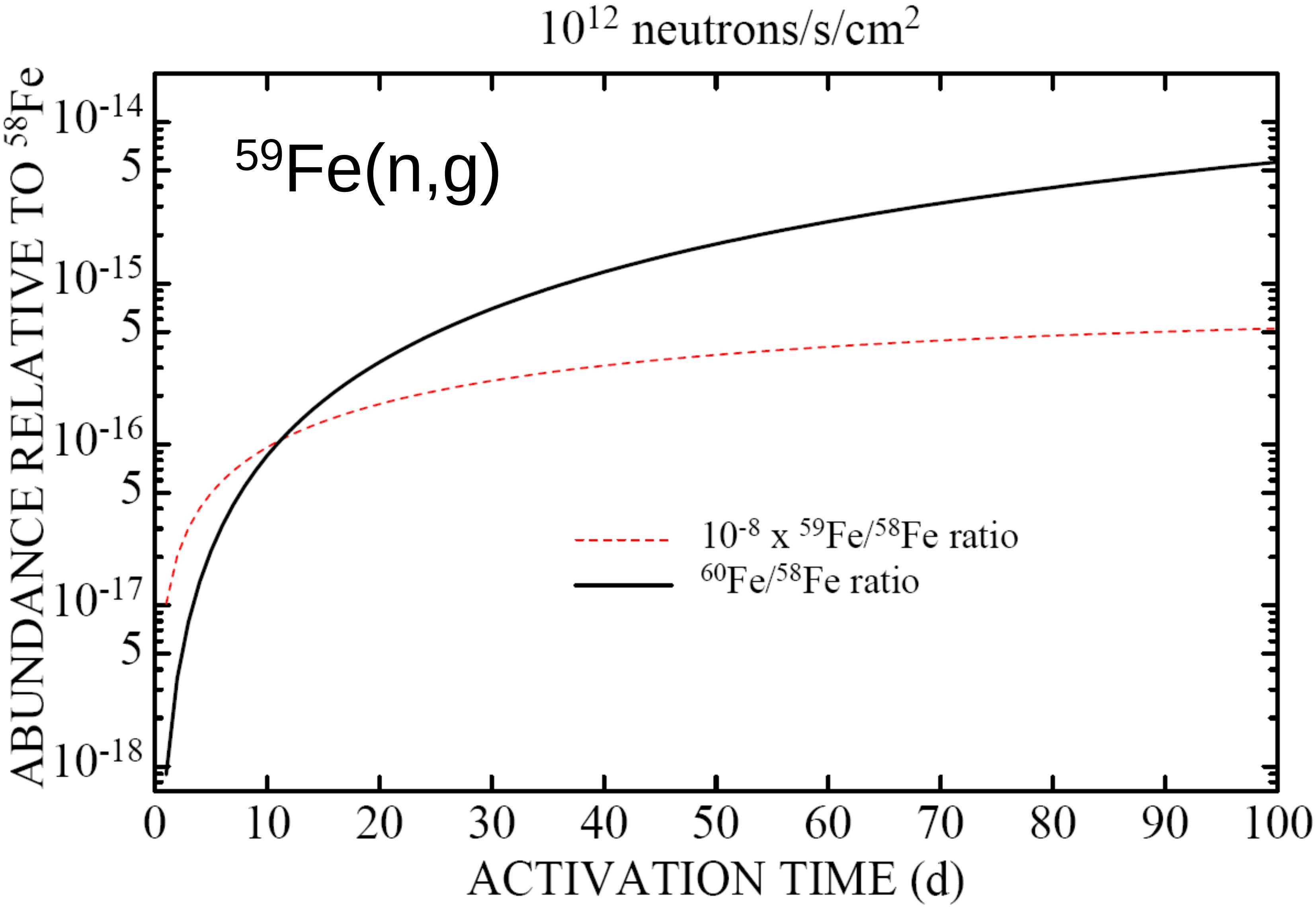
(a)
Trajectories from one proton
Neutron
Proton
beam
Fission
chamber
Tungsten
target
y (cm)
x (cm)
100
50
0
−50
−100
−100
−50
0
50
100
4
HIPPO
5
FP5
6
SCD
7
FDS
3
HIPD
Tungsten targ
Moderators
SPEAR
10
LQD
11a
Asterix
12
FP12
2
SMARTS
1
NPDF
16
Pharos
15
PCS
14
DANCE
13
IN500



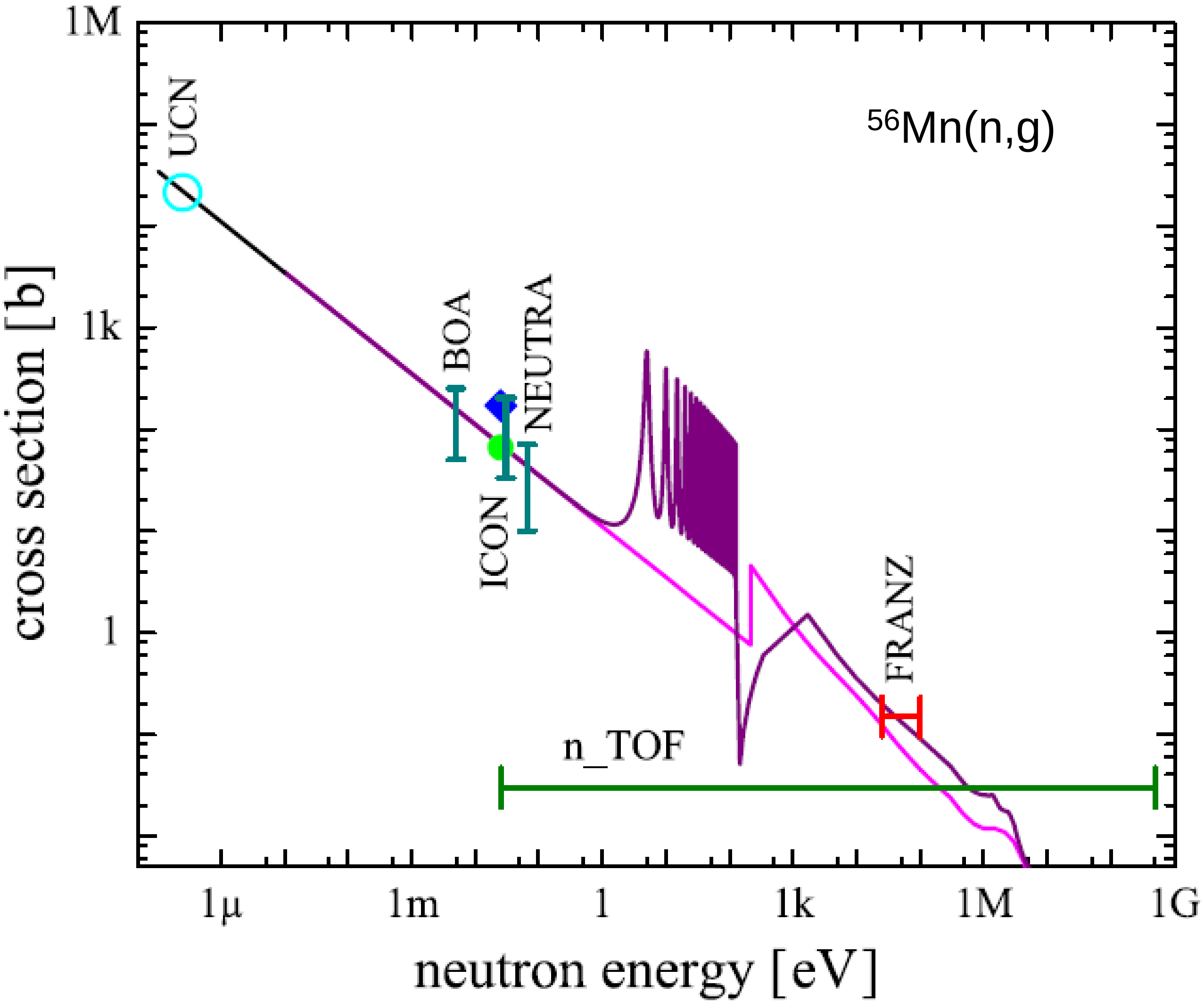

If the target is able to handle the above mentioned 60 mA proton beam, neutron fluxes of about $10^{12}$ $n/s/cm^2$ were available.



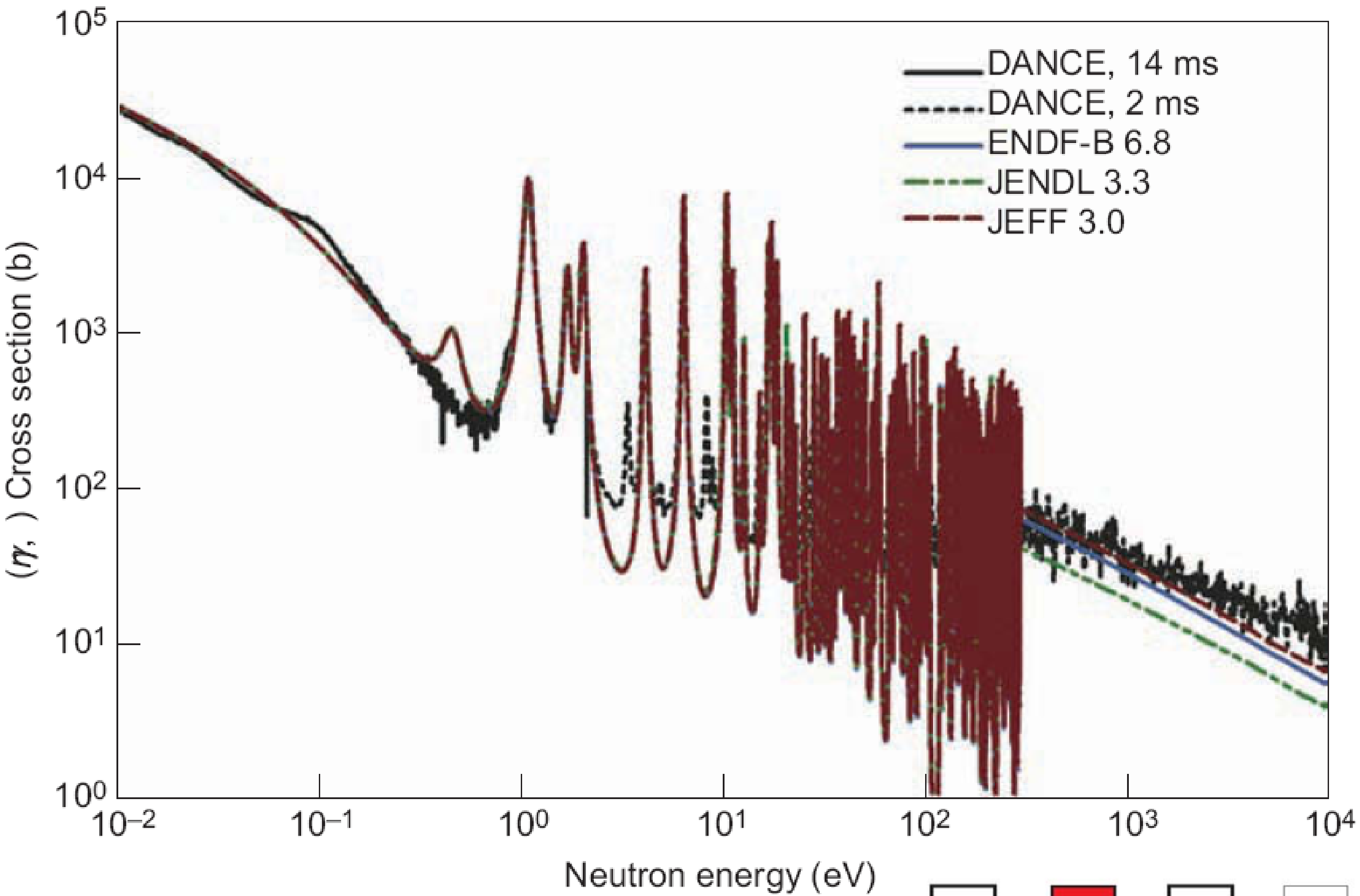

**Gitai Feinberg 2010**




How about PKU 2 MeV LINAC?

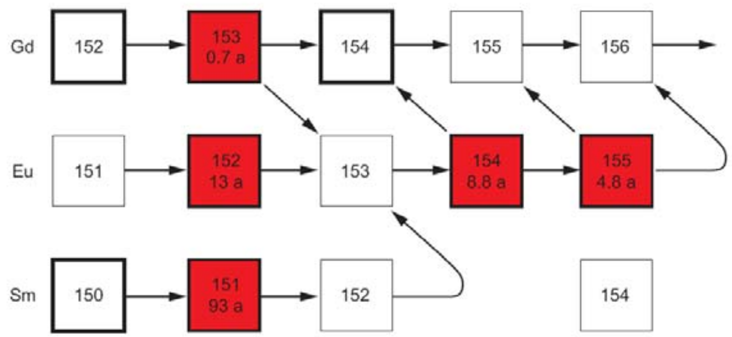


56Mn(n,g)
cross section [b]
1M
1k
1
neutron energy [eV]
1μ
1m
1
1k
1M
1G
UCN
BOA
NEUTRA
ICON
FRANZ
n_TOF



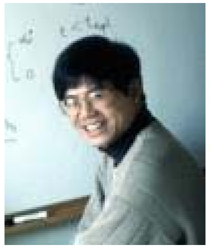
DANCE, 14 ms
DANCE, 2 ms
ENDF-B 6.8
JENDL 3.3
JEFF 3.0
(η, ) Cross section (b)
Neutron energy (eV)


$^{151}Sm(n,g)$

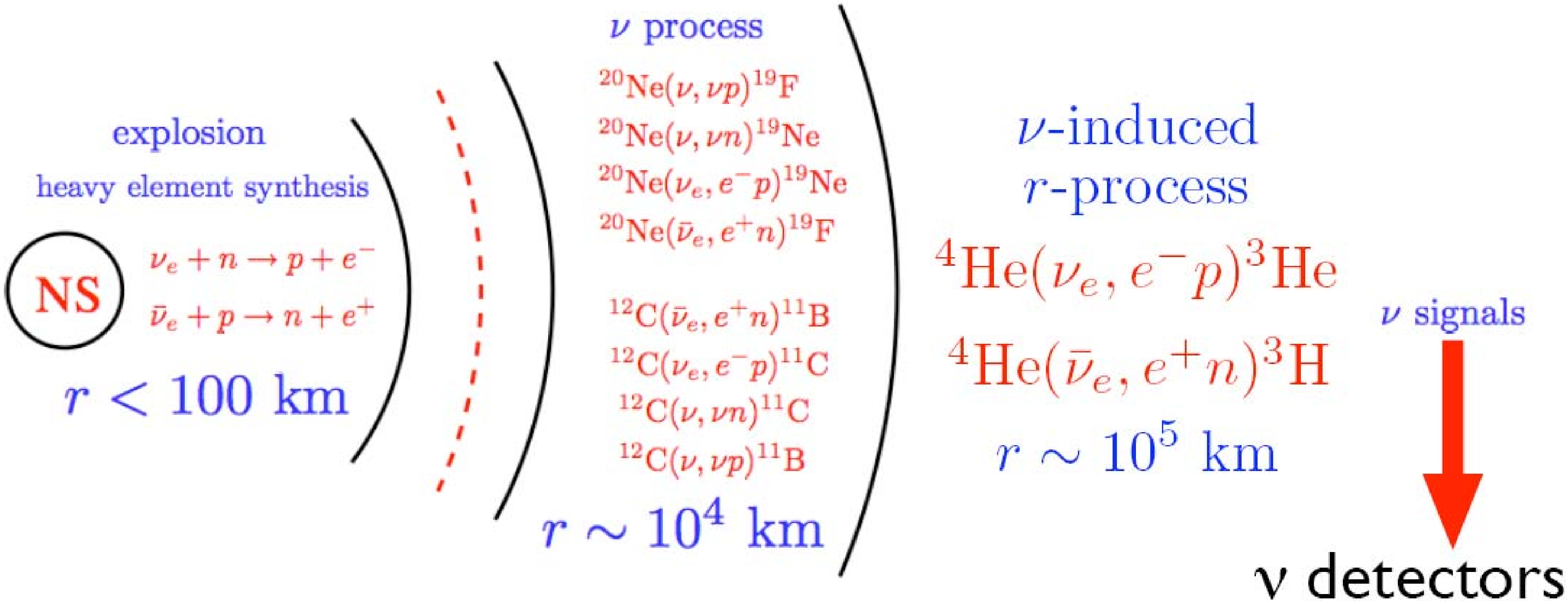


Gd
152
153
0.7 a
154
155
156
Eu
151
152
13 a
153
154
8.8 a
155
4.8 a
Sm
150
151
93 a
152
154

# Neutrino facility

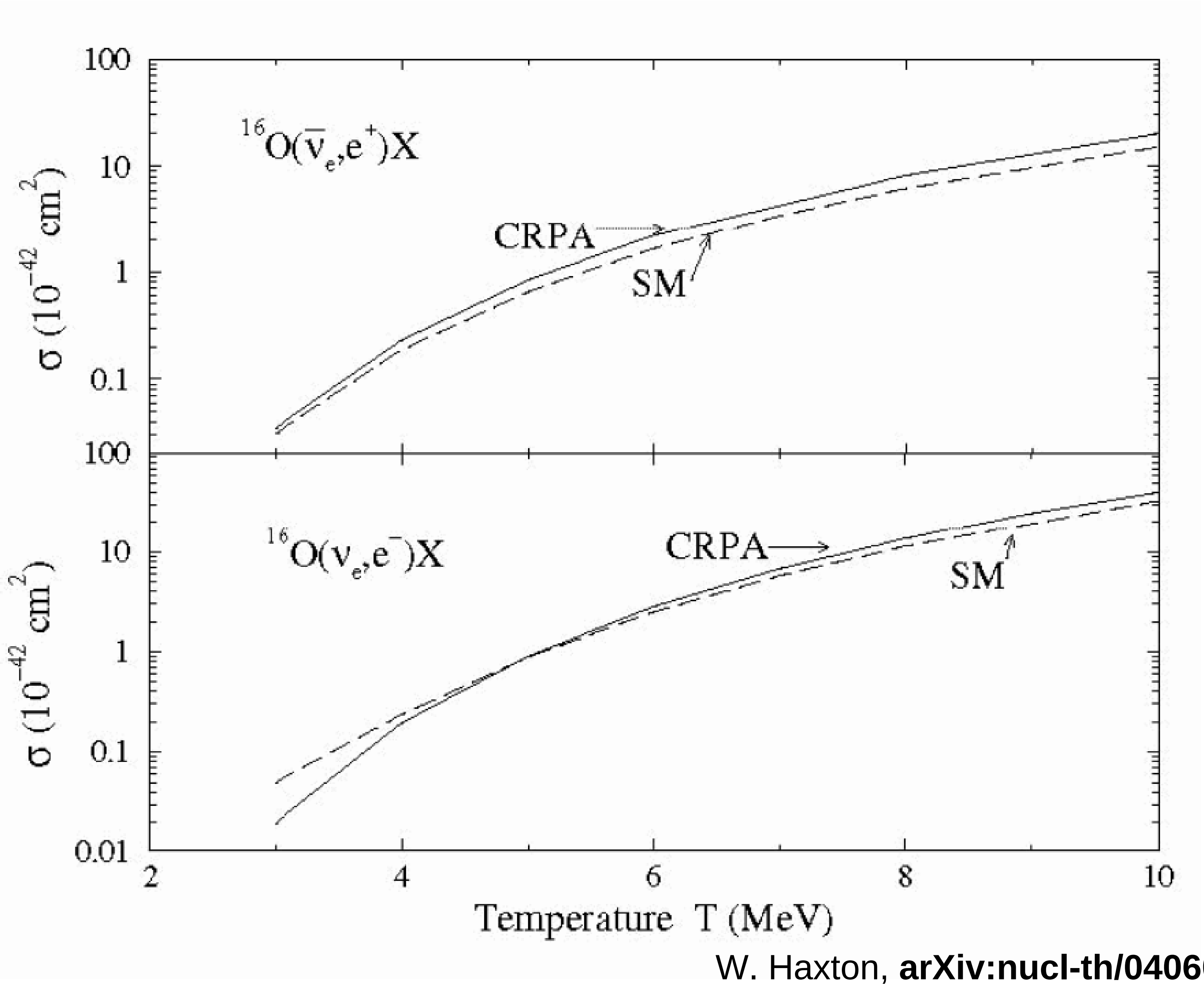


# Interplay between CCSN and Neutrino Physics



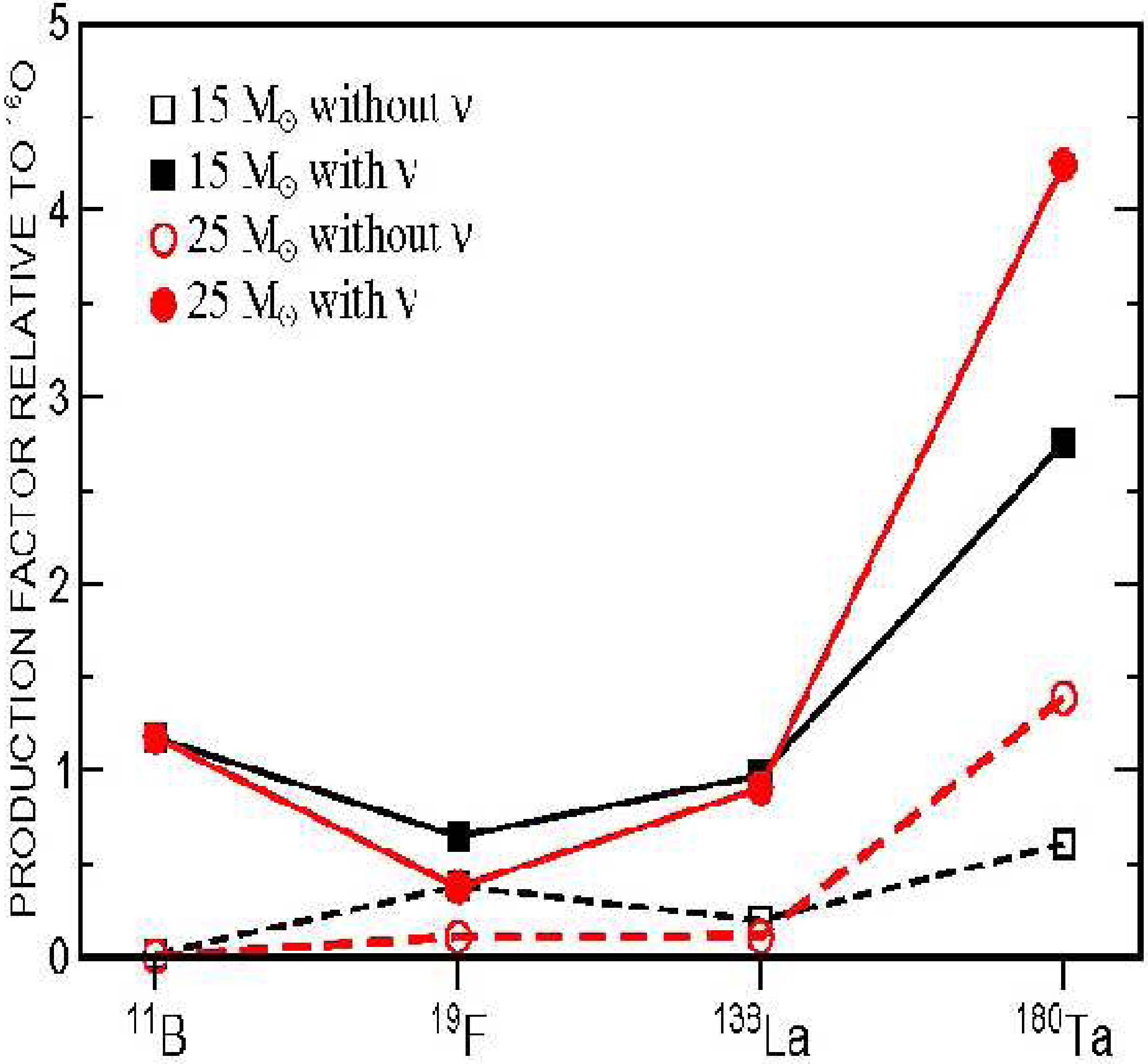

exact quantum transport of neutrinos is a hard problem,
but approximate treatments are manageable,
& the payoff is potentially huge!

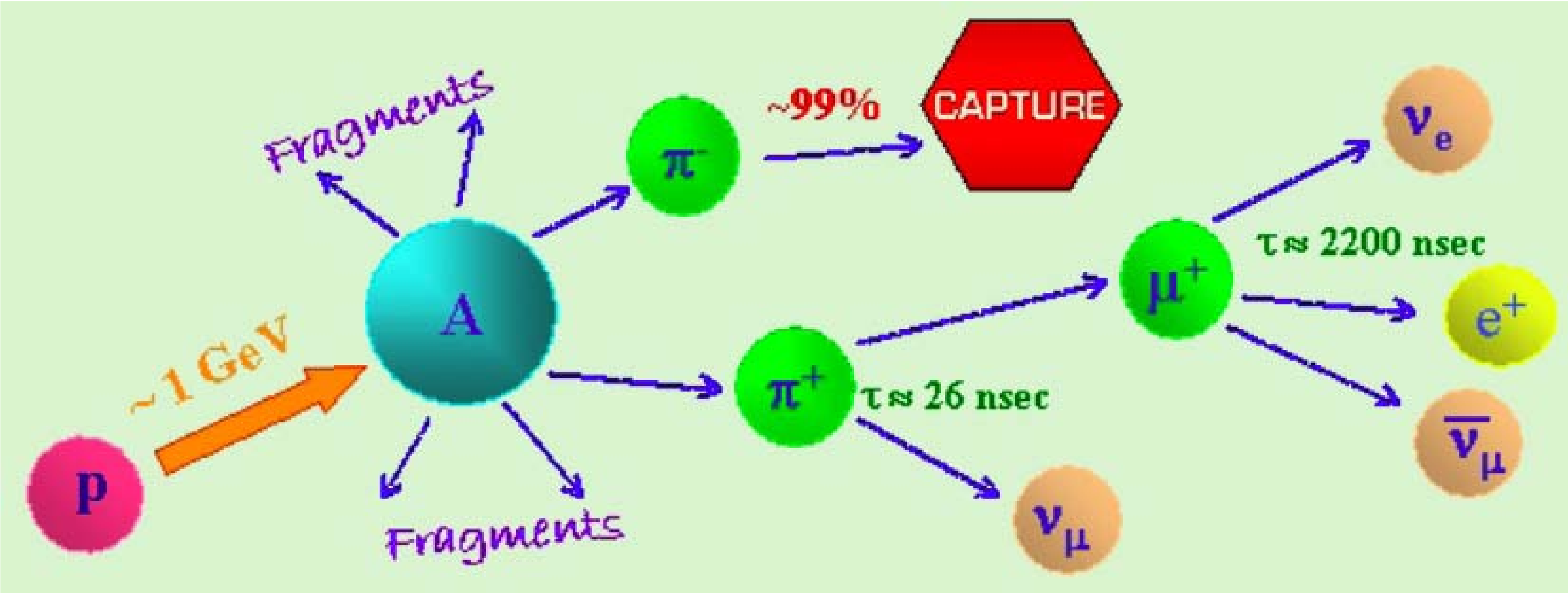
Yongzhong Qian



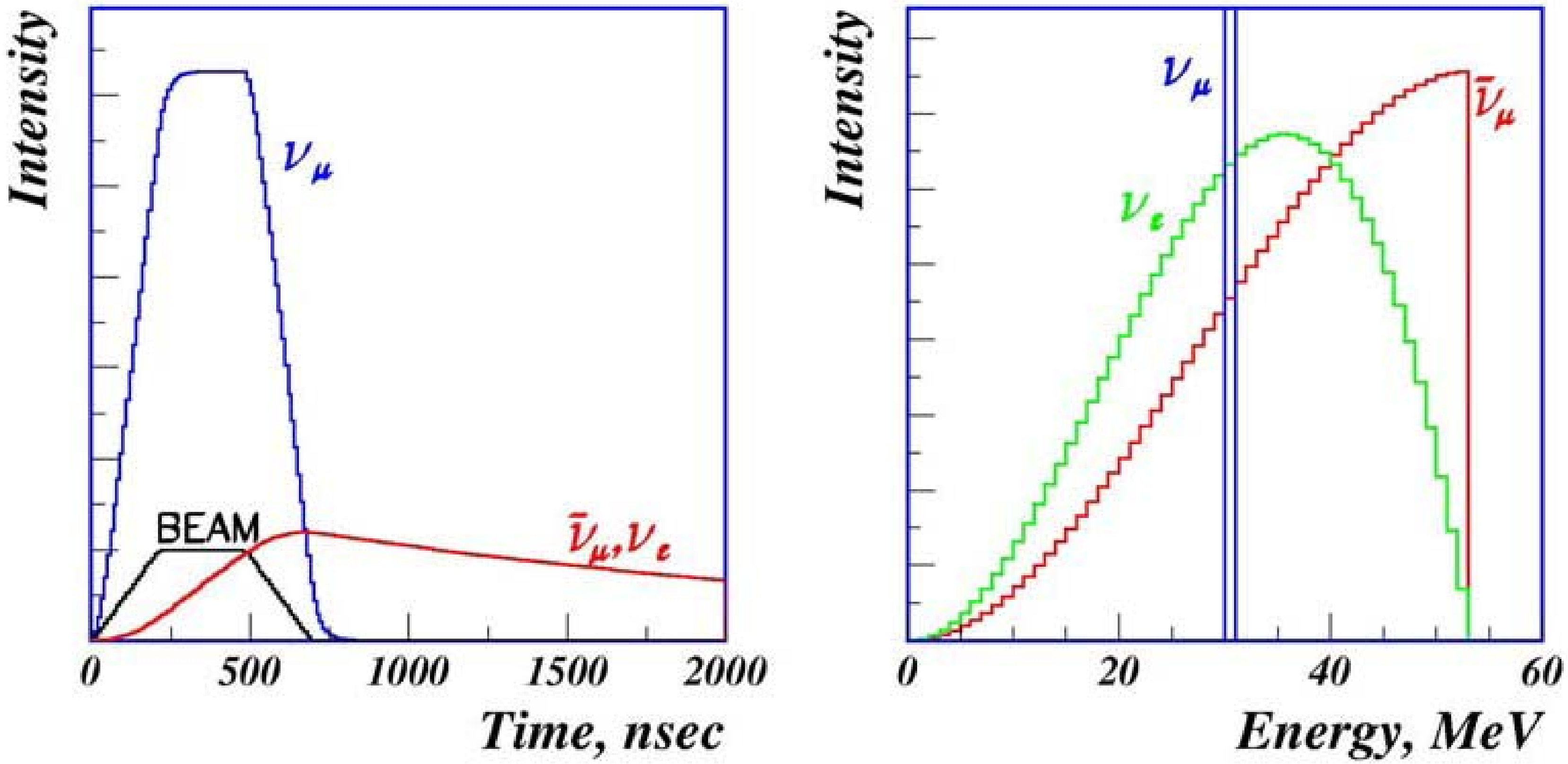

W. Haxton, **arXiv:nucl-th/0406012v1**

# Impact to nucleosynthesis






Neutrino production in SNS




Pulsed neutrino

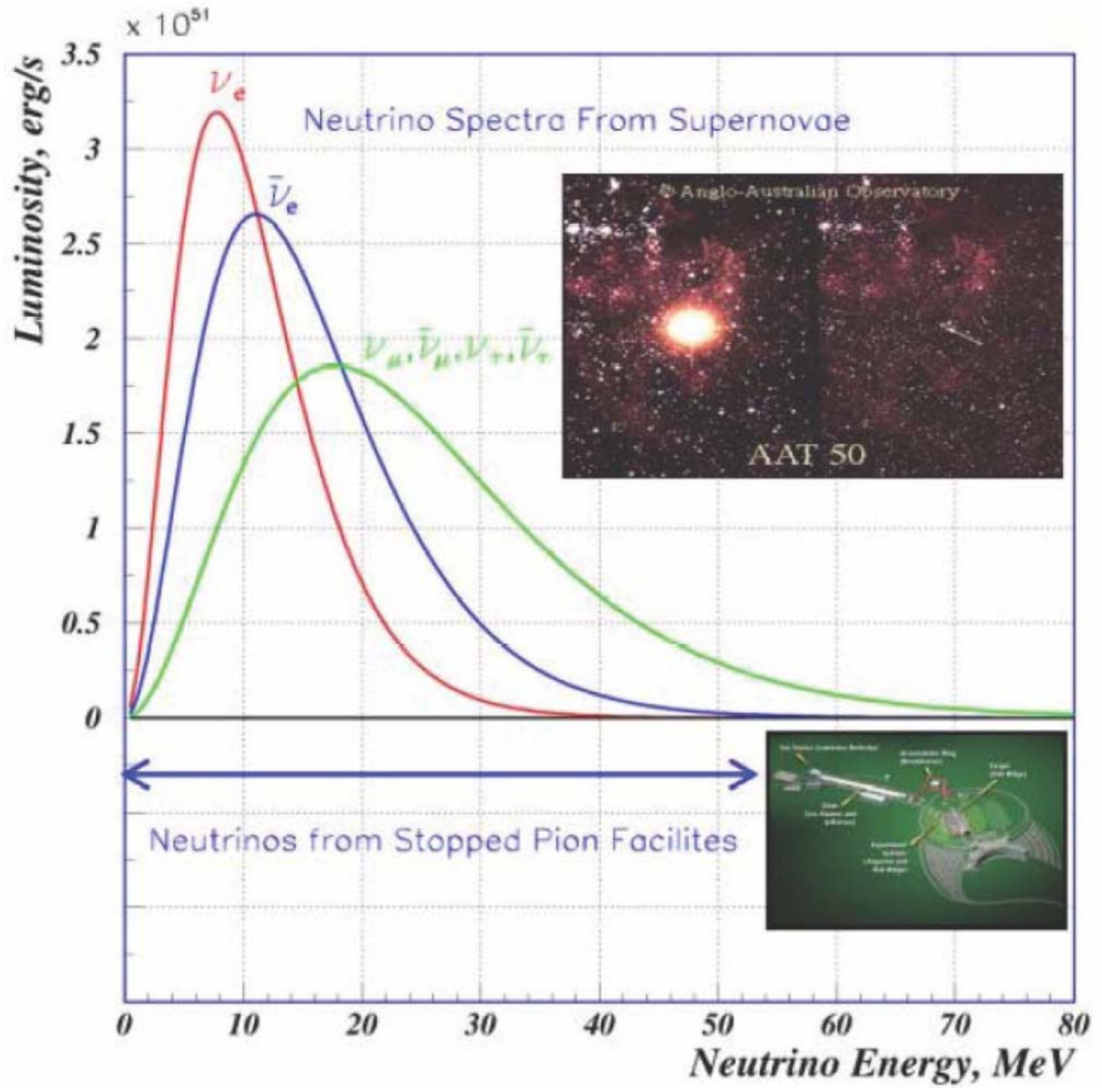



**Figure 2.4** Supernova neutrino spectra compared to the neutrino energy range at stopped-pion facilities.

Observations of supernova neutrino luminosities are only as accurate as knowledge of neutrino interaction rates.