CIPANP 2018
Particle and Nuclear Astrophysics Highlights

Barry Davids, TRIUMF

Four Parallel Sessions

- Neutrino Astrophysics: Spencer Klein, Cosmin Deaconu Mark Paris, Kelly Patton, & Alexey Vlasenko
- Nuclear Astrophysics: Greg Christian, Frank Strieder, Dan Bardayan, Ken Nollett, & Roy Holt
- Particle Astrophysics: Francesca Giovacchini, Glennys Farrar, Andrea Albert, Feifei Huang, Qian Yue, & Murray Brightman
- Neutron Stars: Chris Fryer, Benjamin Lackey, Francois Foucart, Christian Drischler, Nicole Vassh, Alfredo Estrade

Selection Bias

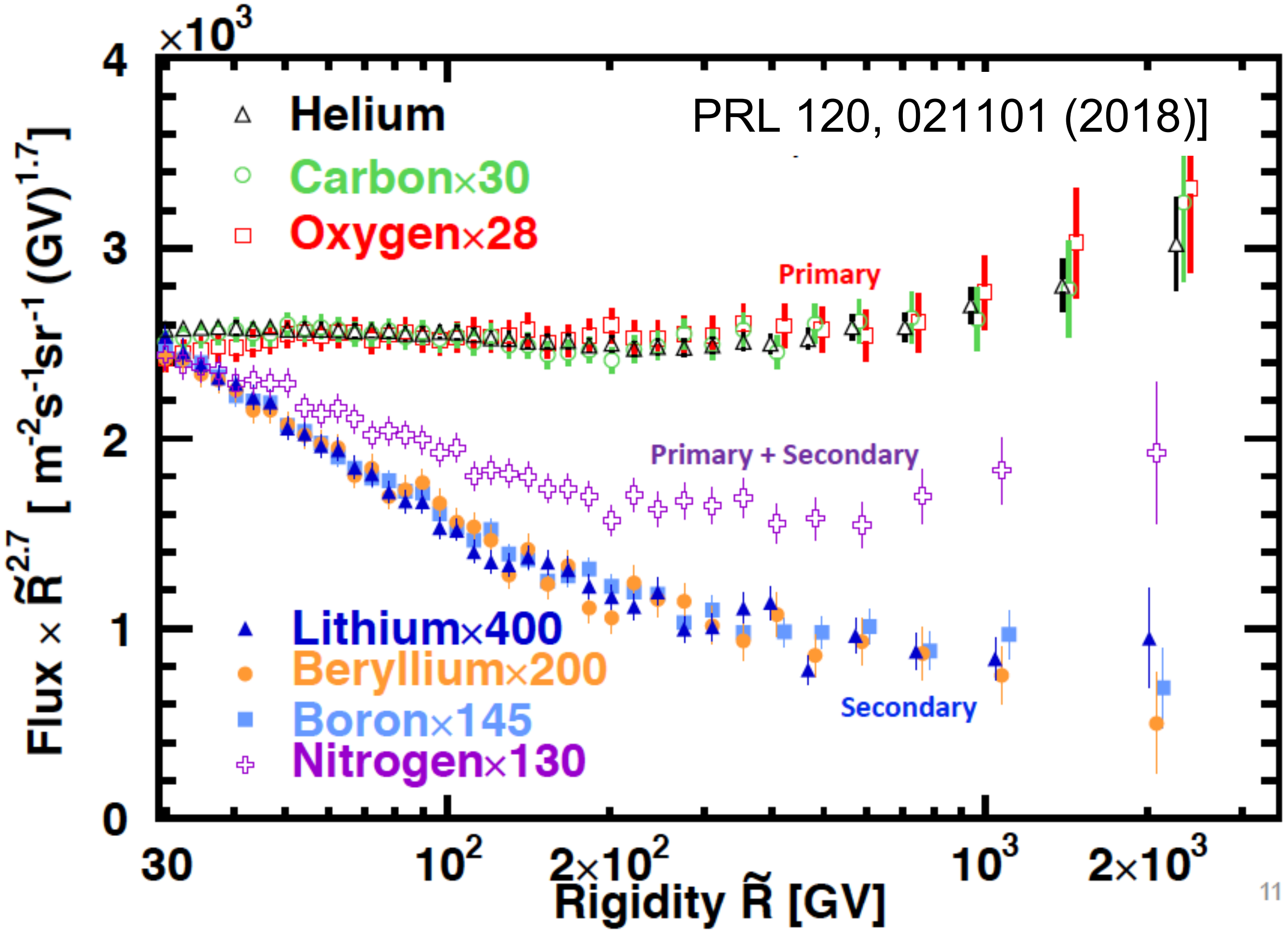
- Not an exhaustive summary
- Attempted to select highlights from topics not extensively covered in plenary sessions
- Left neutrinos to Neutrino Masses and Neutrino Mixing track
- Binary merger GW170817 discussed in plenary

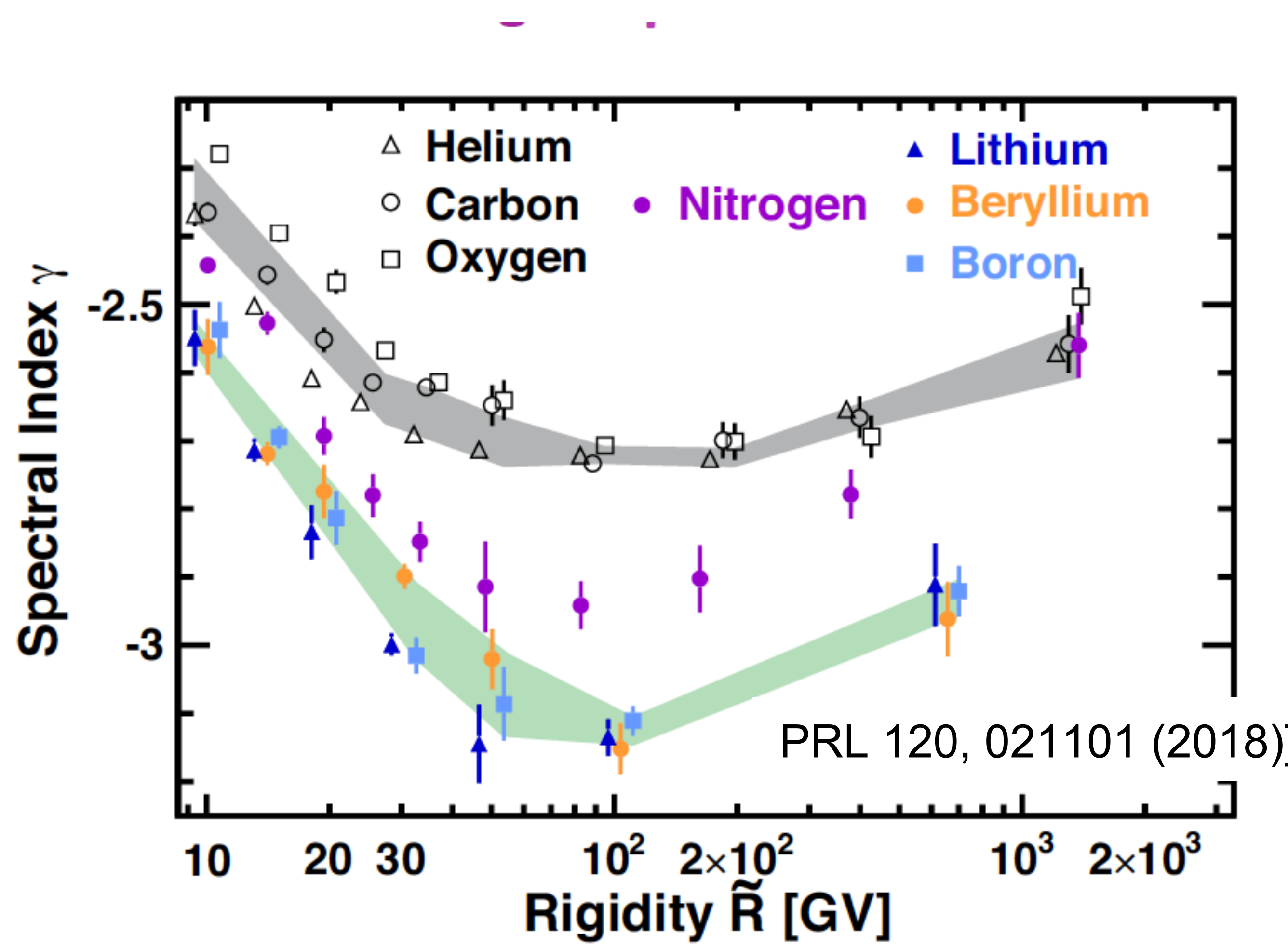
Latest Results from the Alpha Magnetic Spectrometer on the International Space Station

F. Giovacchini
on behalf of the AMS Collaboration

CIPANP 2018, Palm Spring (California)

Rigidity dependence of Primary and Secondary Cosmic Rays





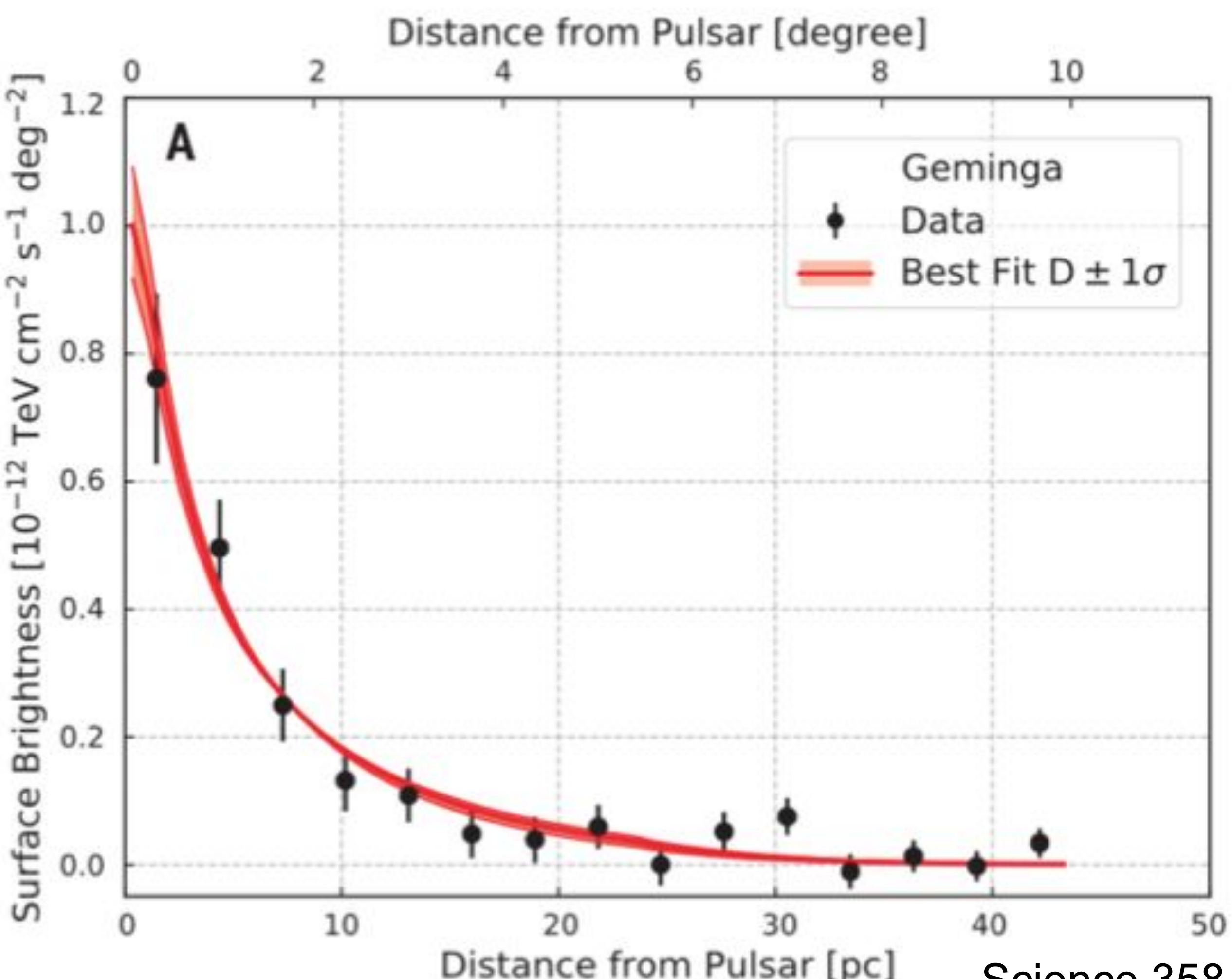
11

- Both deviate from a traditional single power law above 200 GeV.
- But their rigidity dependences are distinctly different.
- The nitrogen flux can be presented as the sum of its primary component and secondary one (secondary component ~70% @ ~GeV, <30% @TeV).

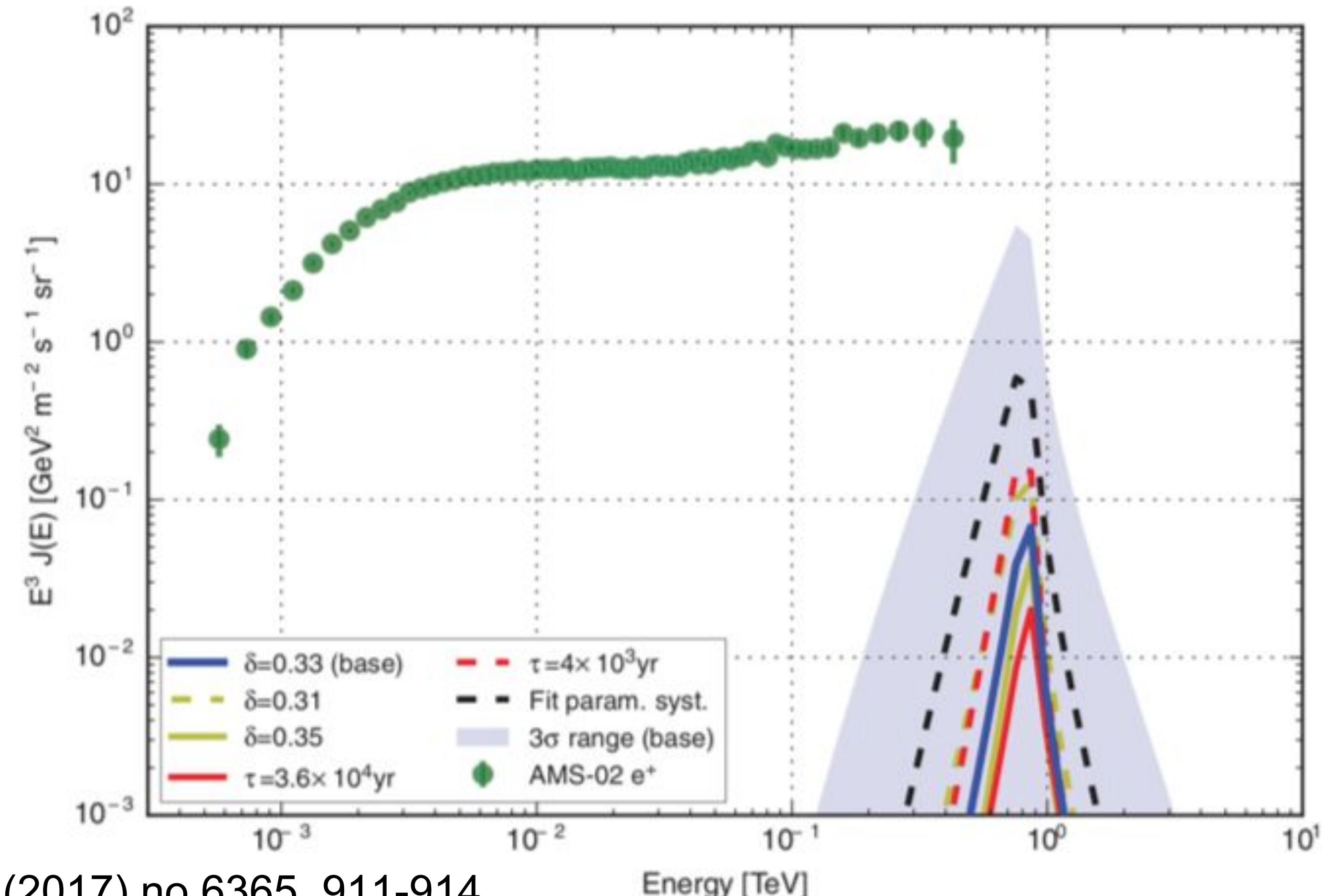
Recent Results from the HAWC Gamma-ray Observatory

Andrea Albert
Los Alamos National Lab

CIPANP 2018
May 31, 2018



Local positron flux



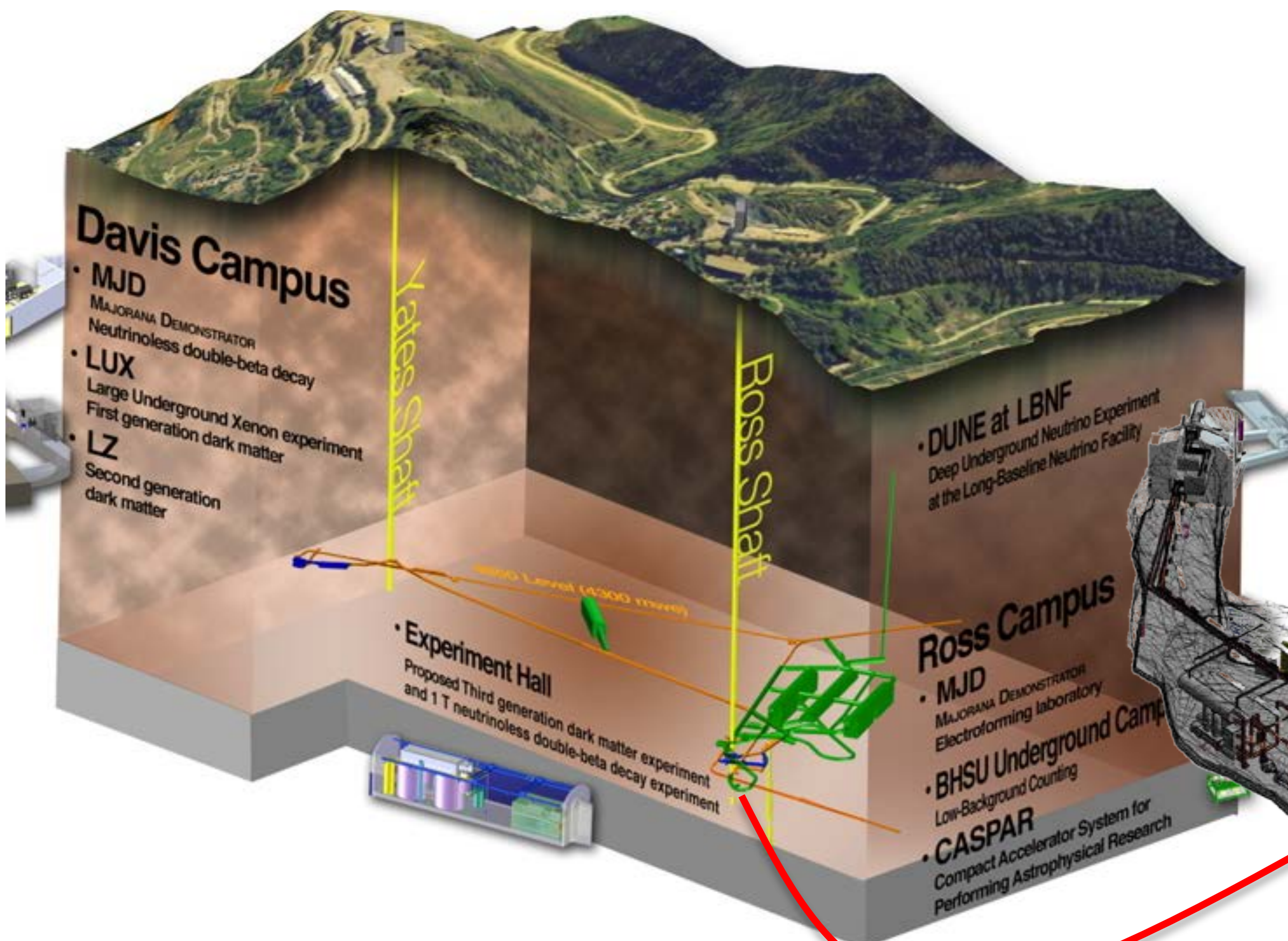
Science 358 (2017) no.6365, 911-914

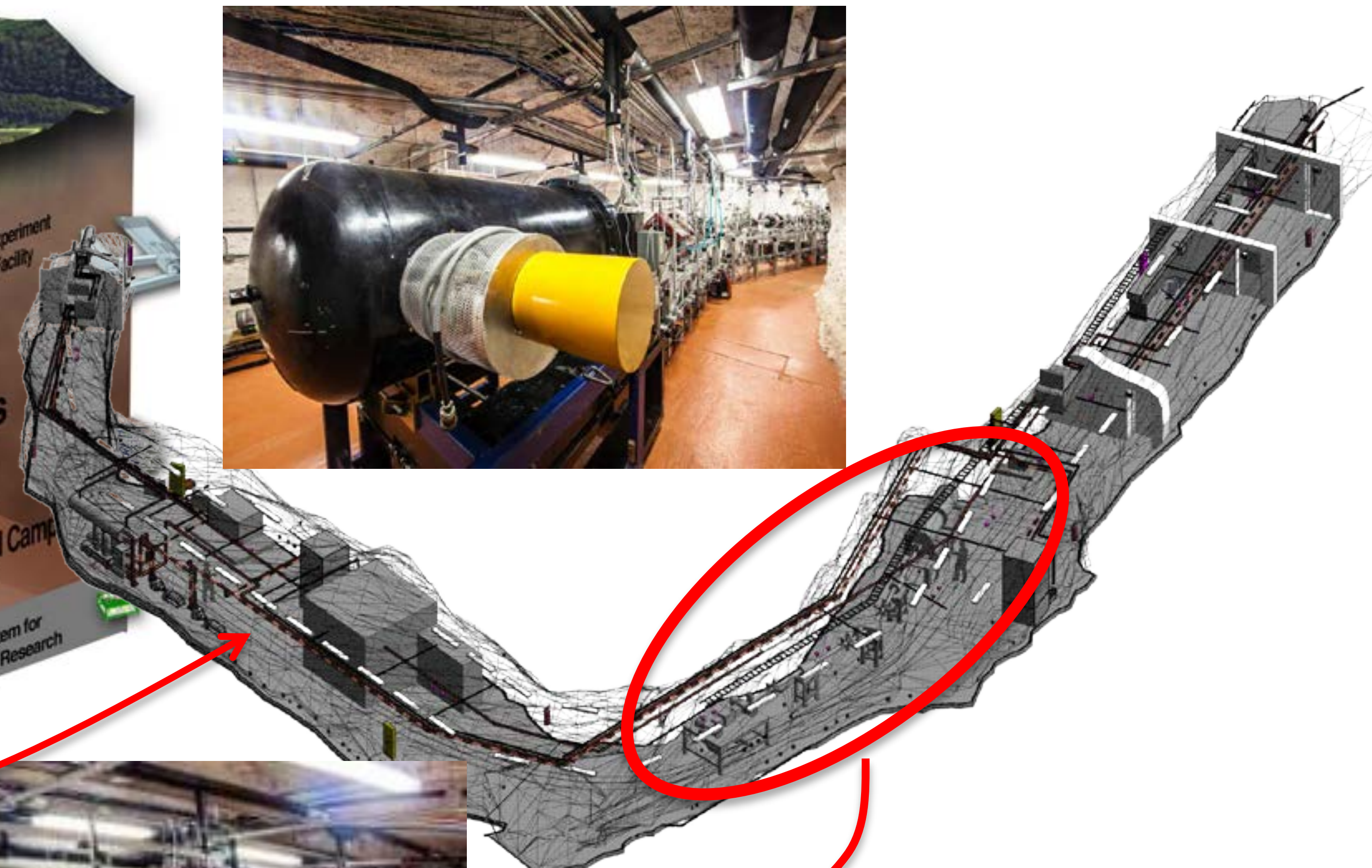
Frank Strieder, South Dakota School of Mines and Technology

Compact Accelerator System for Performing Astrophysical Research

First US Underground Accelerator

at Sanford Underground Research Facility

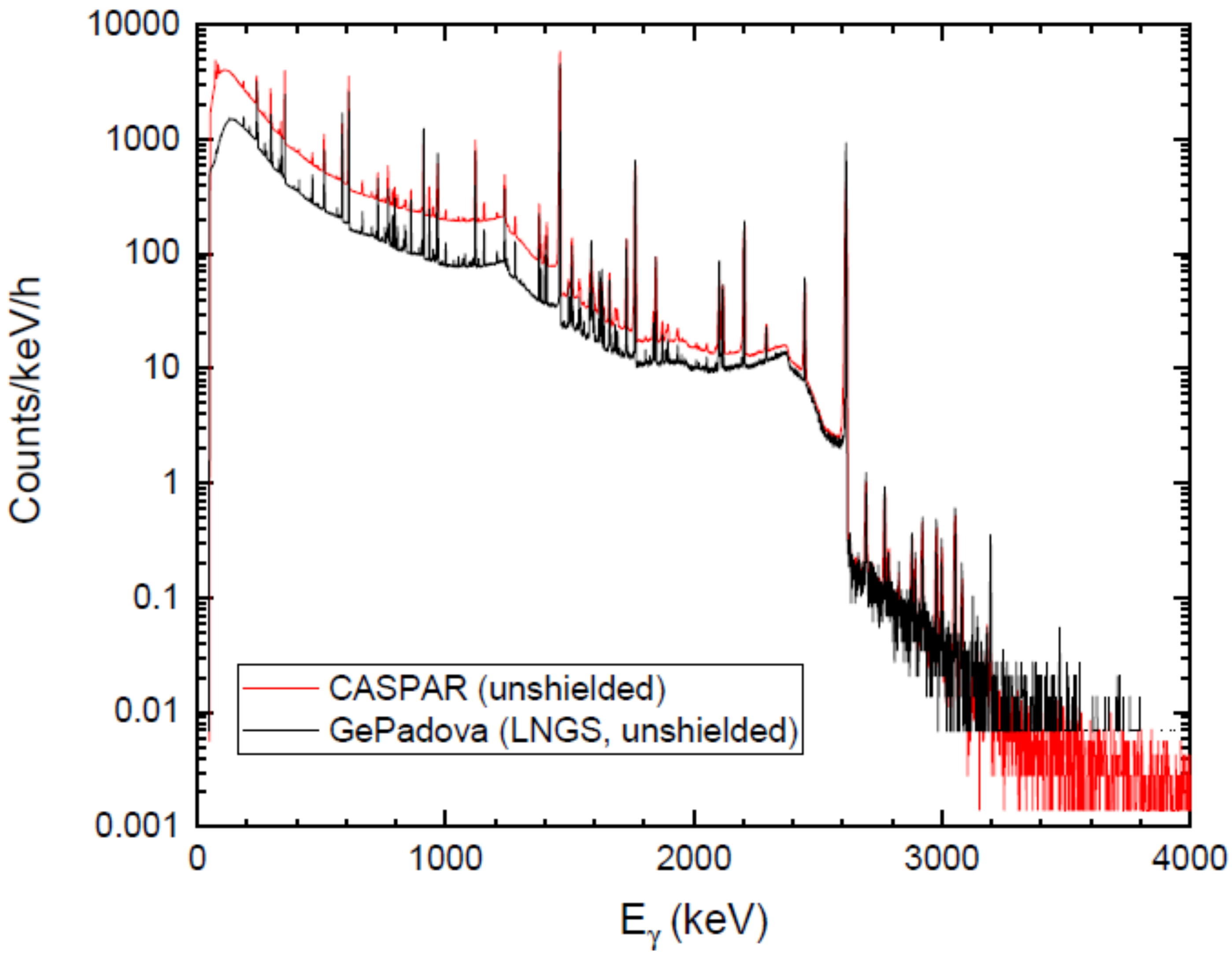




Studies of stellar neutron sources in the Laboratory
→ Understanding of Origin of the Elements

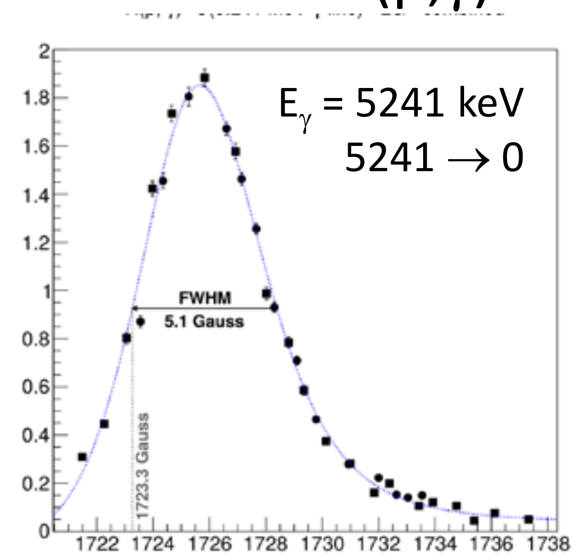
First Science at CASPAR

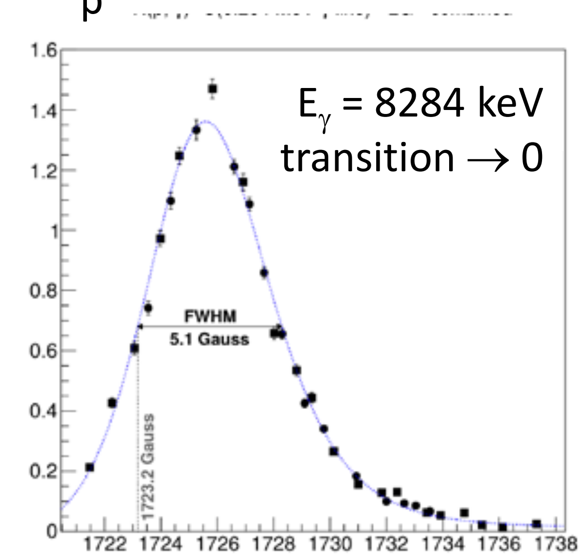
γ-ray background at CASPAR

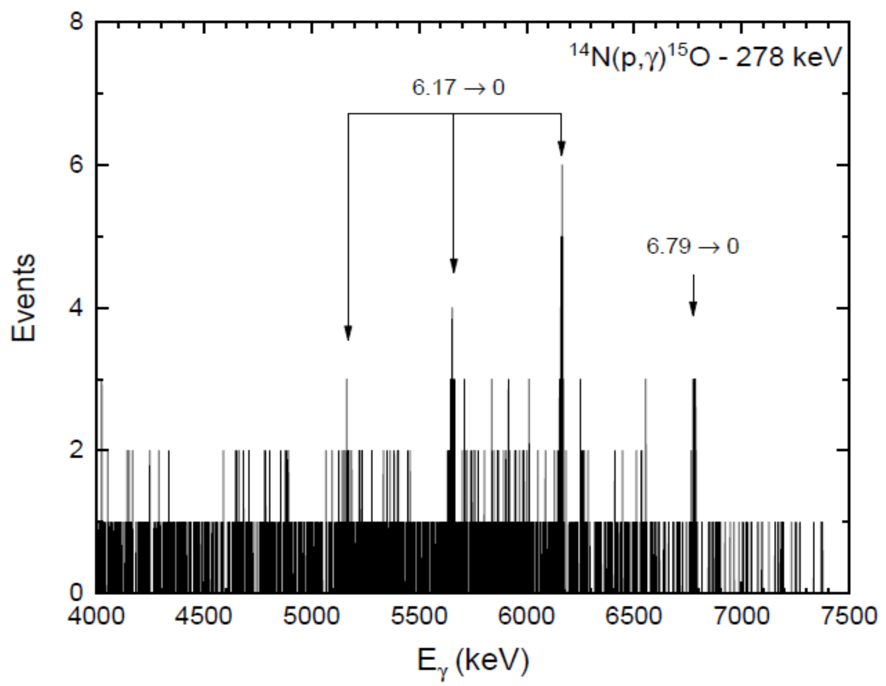


commissioning experiment

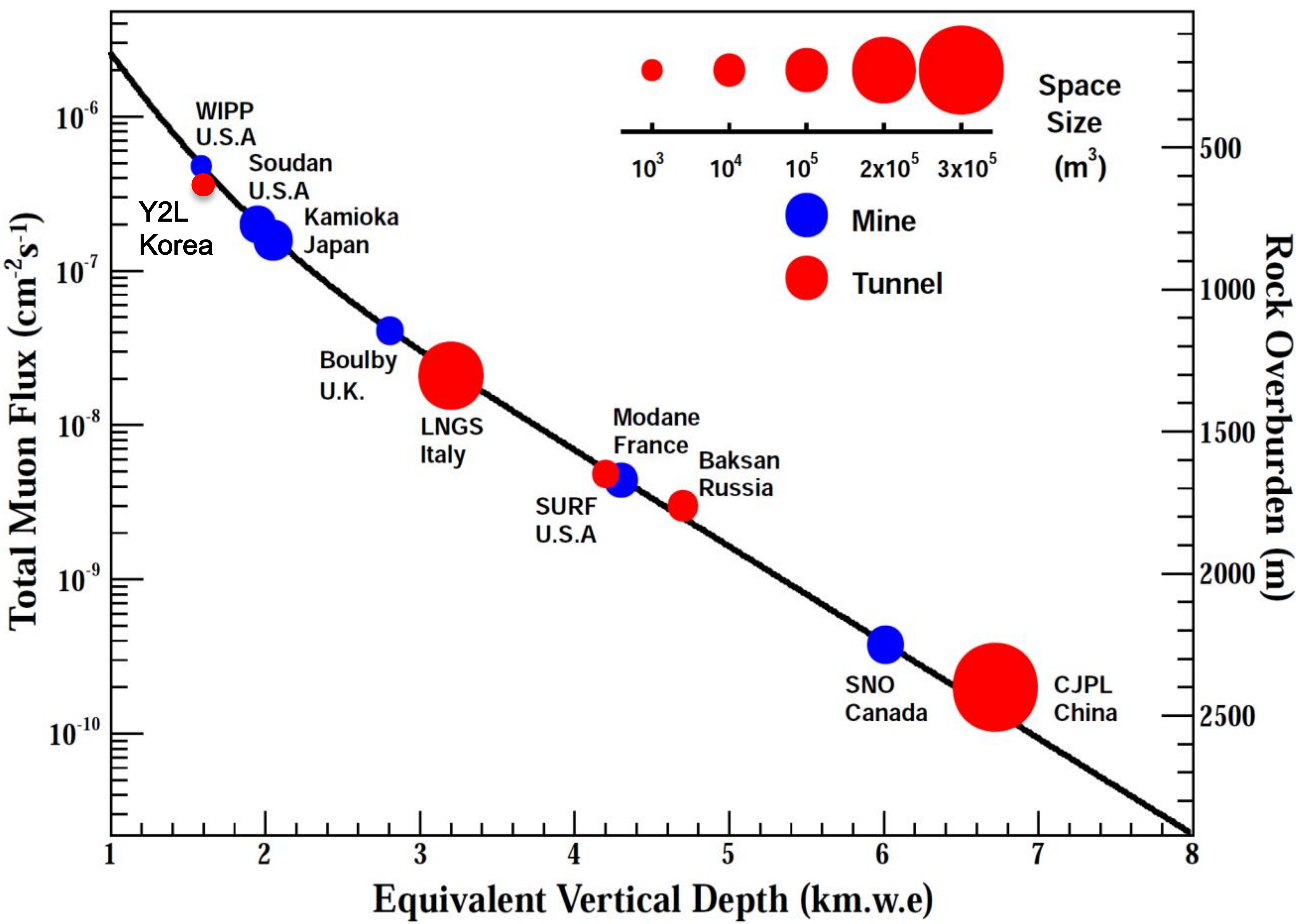
$^{14}N(p,\gamma)^{15}O$ at E_p = 1058 keV







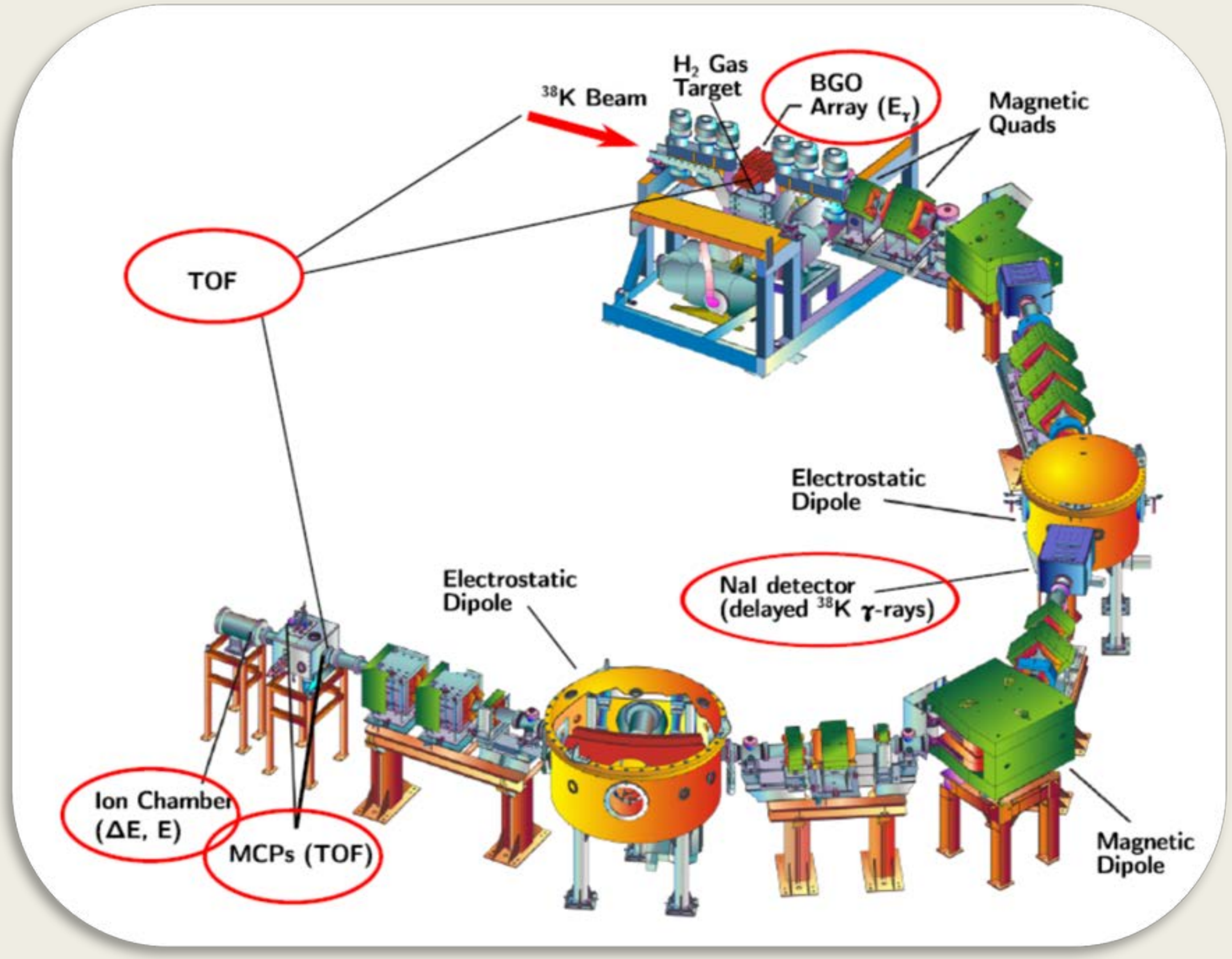
Qian Yue, Tsinghua University
China Jinping Underground Lab



Direct Measurements

- Measure yield of the reaction of interest, on-resonance
- Nowadays, inverse kinematics + recoil separators widely employed
  - *Background suppression*
  - *Measurements w/ radioactive beams*
- Sensitive to both strength (yield) and energy (position in extended target)

DRAGON Recoil Separator at TRIUMF
Vancouver, BC Canada



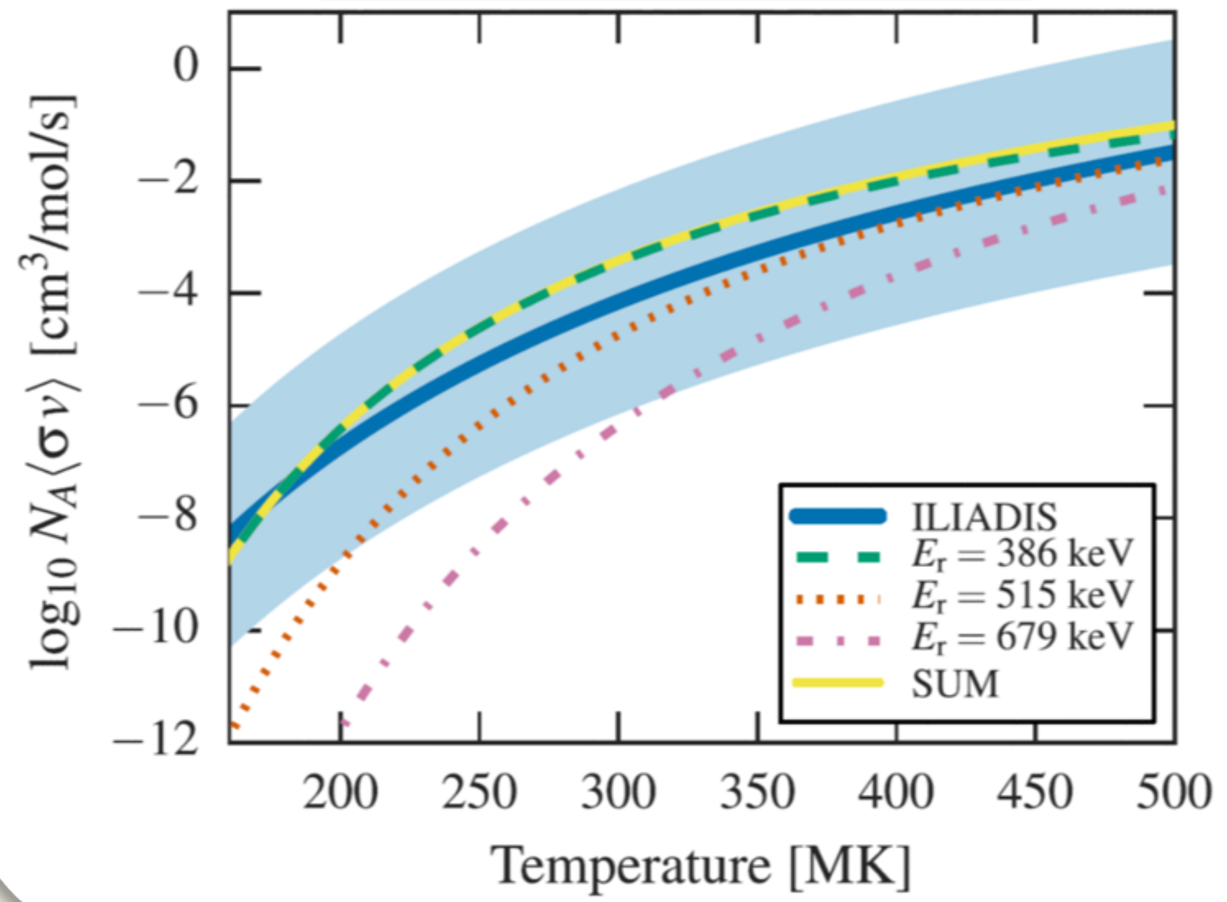
Recent Highlights (from DRAGON)

- Significant decrease on uncertainty of nucleosynthesis predictions

Element	*Uncertainty change*
Argon	25 → 2
Potassium	136 → 18
Calcium	58 → 9

First ever direct measurement of radiative capture w/ radioactive beam $A > 30$

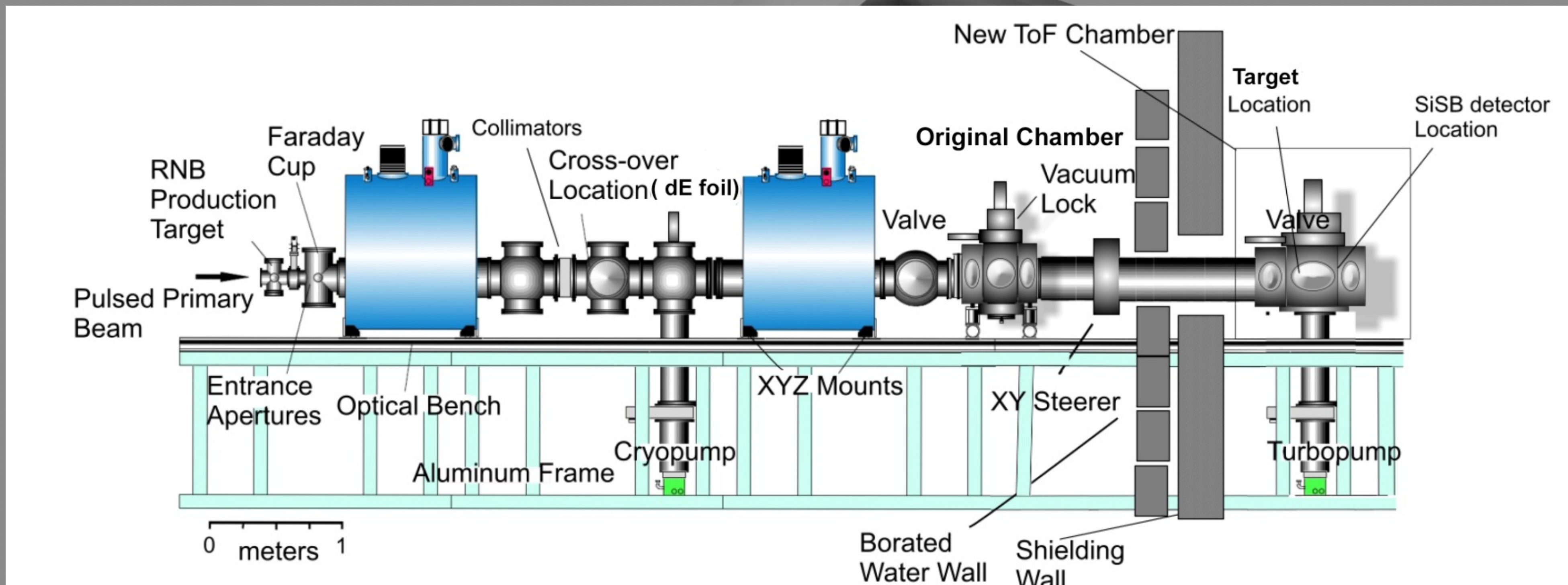
$^{38}K(p,\gamma)^{39}Ca$ rate



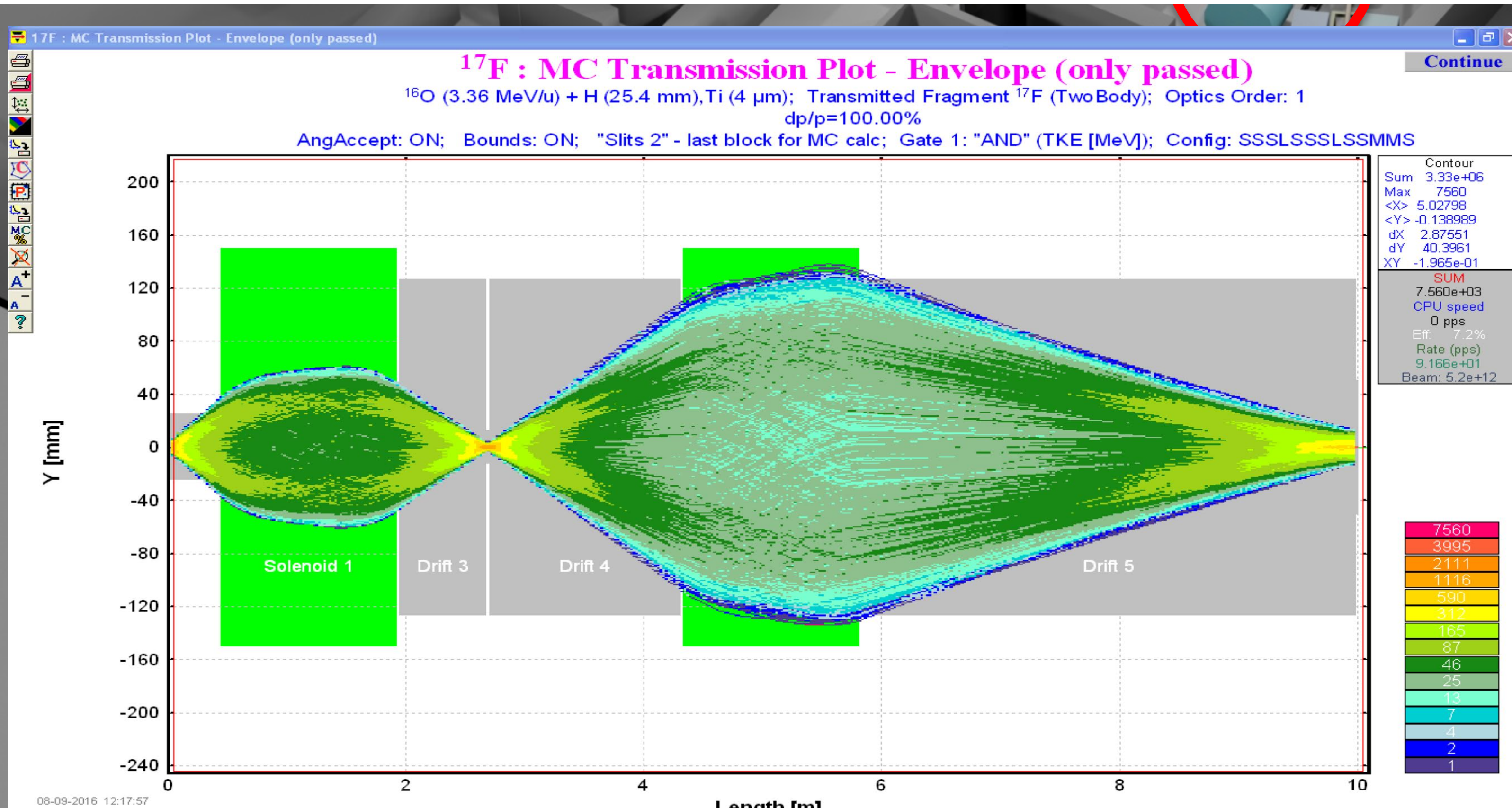
G. Lotay *et al.*, Phys. Rev. Lett., 116, 132701 (2016)
G. Christian *et al.*, Phys Rev. C 97, 025802 (2018)

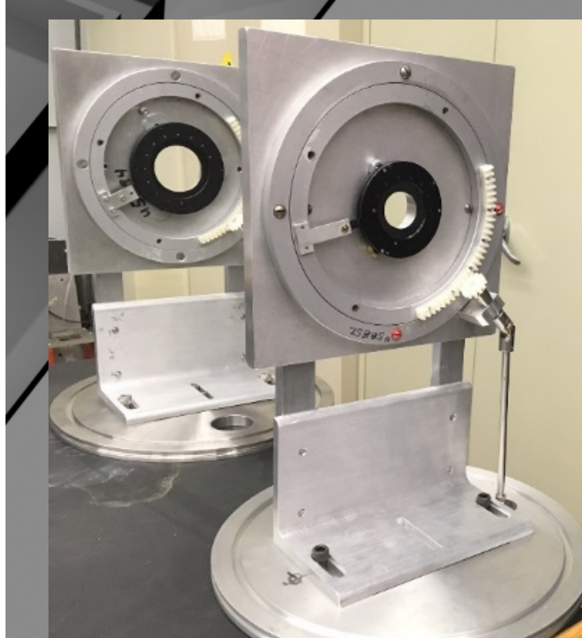
Dan Bardayan, Notre Dame University

TwinSol



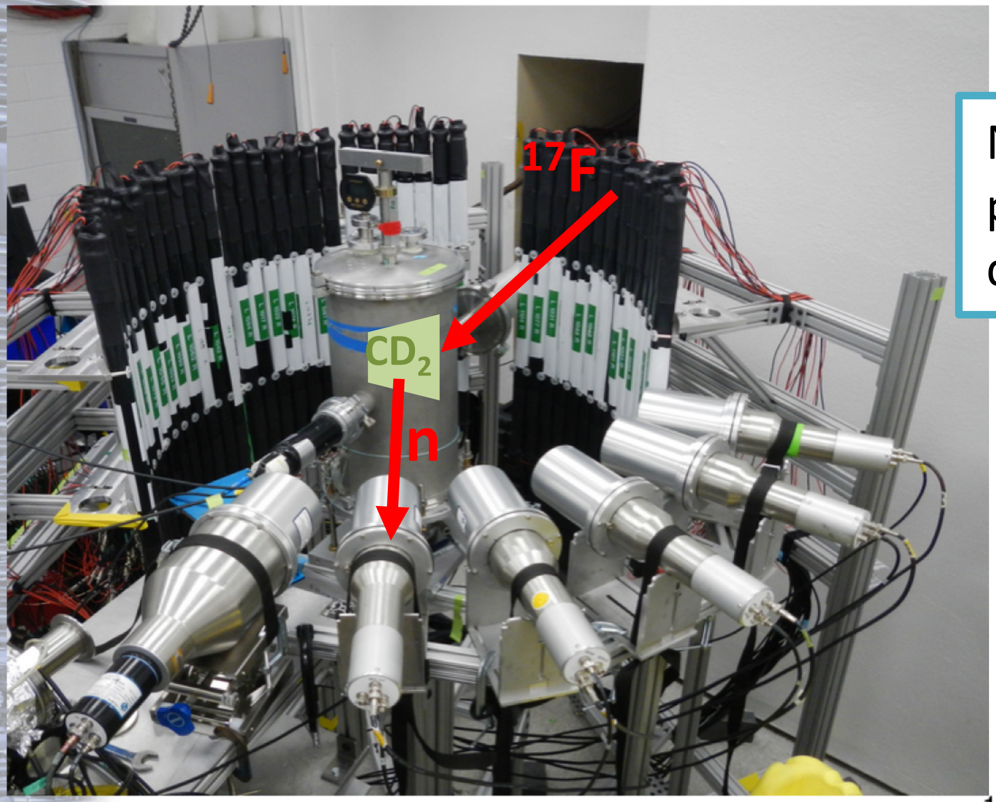
First facility dedicated to exotic beam production in the U.S.





$^{17}F(d,n)^{18}Ne$ at Notre Dame

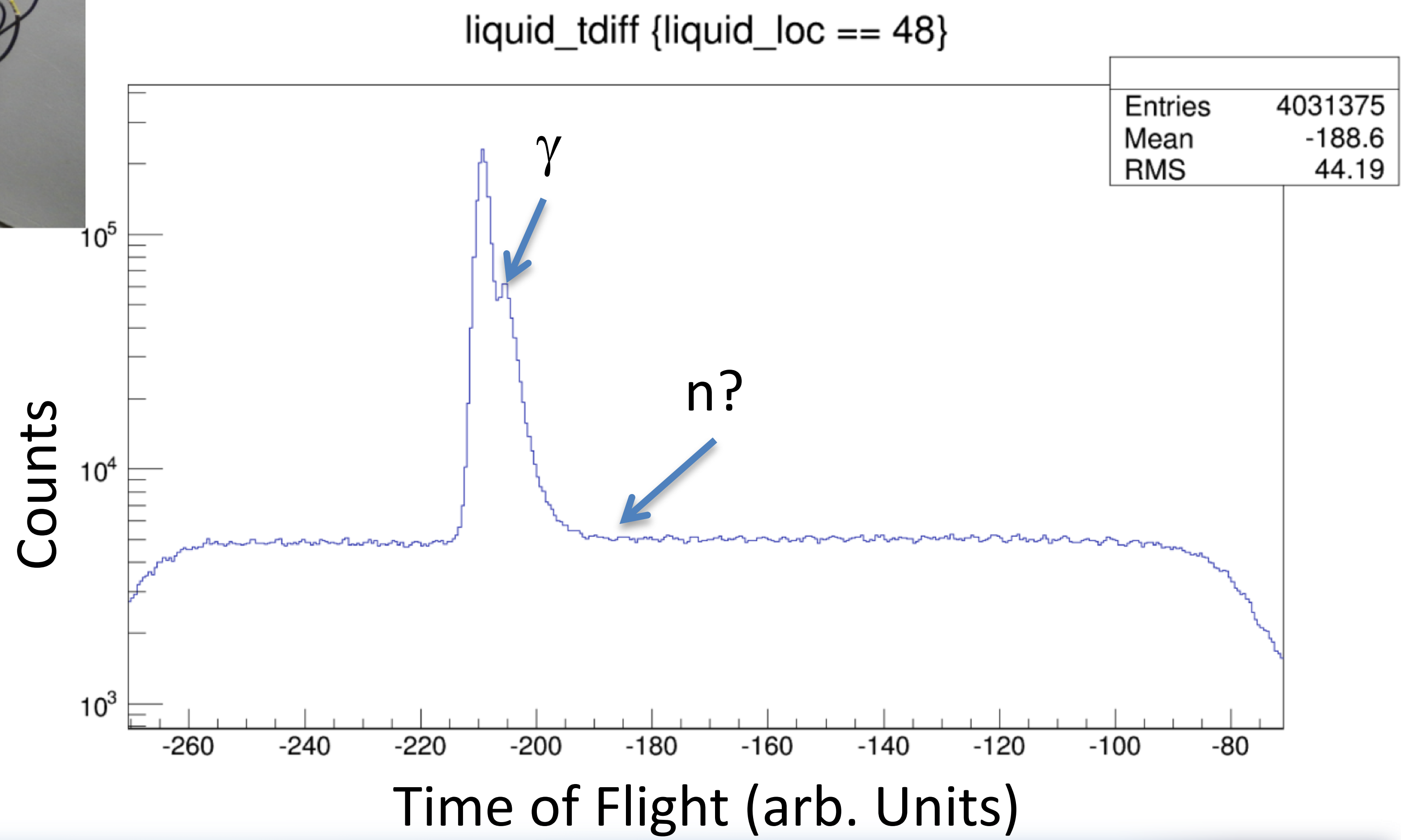
– P. O'Malley et al.



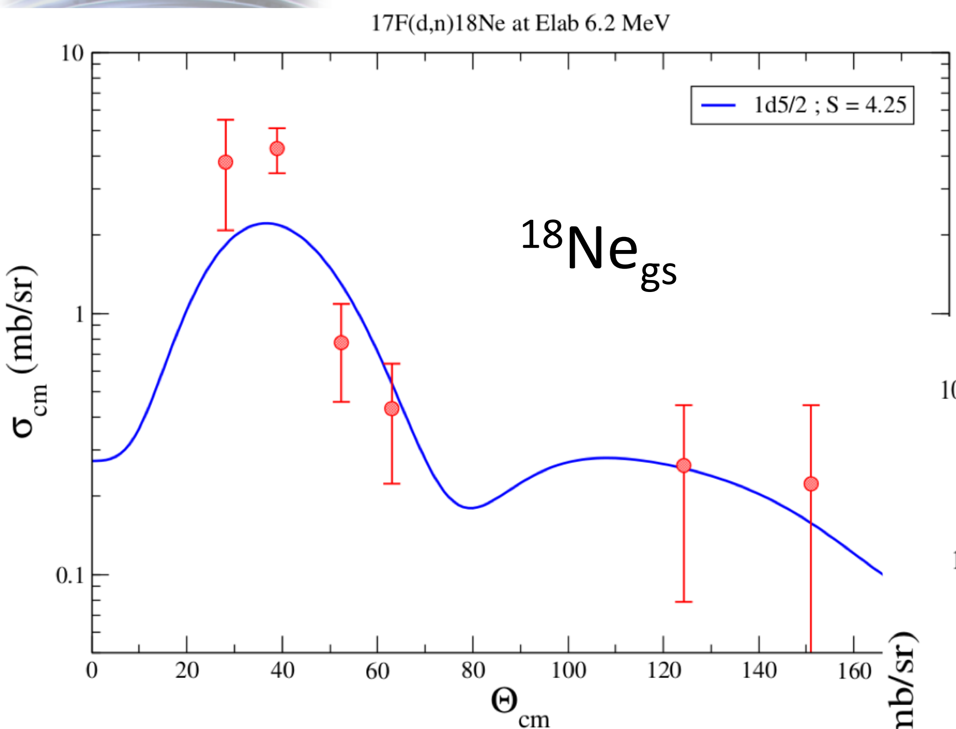
Neutrons detected in array of VANDLE plastic scintillators and U. Michigan deuterated Benzene detectors.

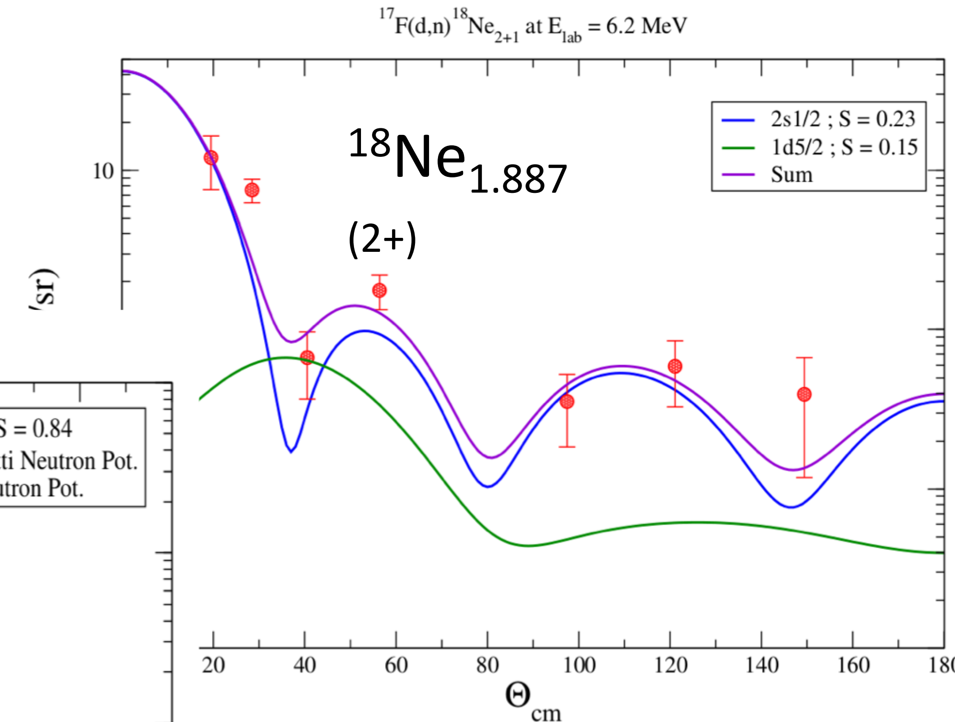
Start on n detection
Stop on delayed beam stop

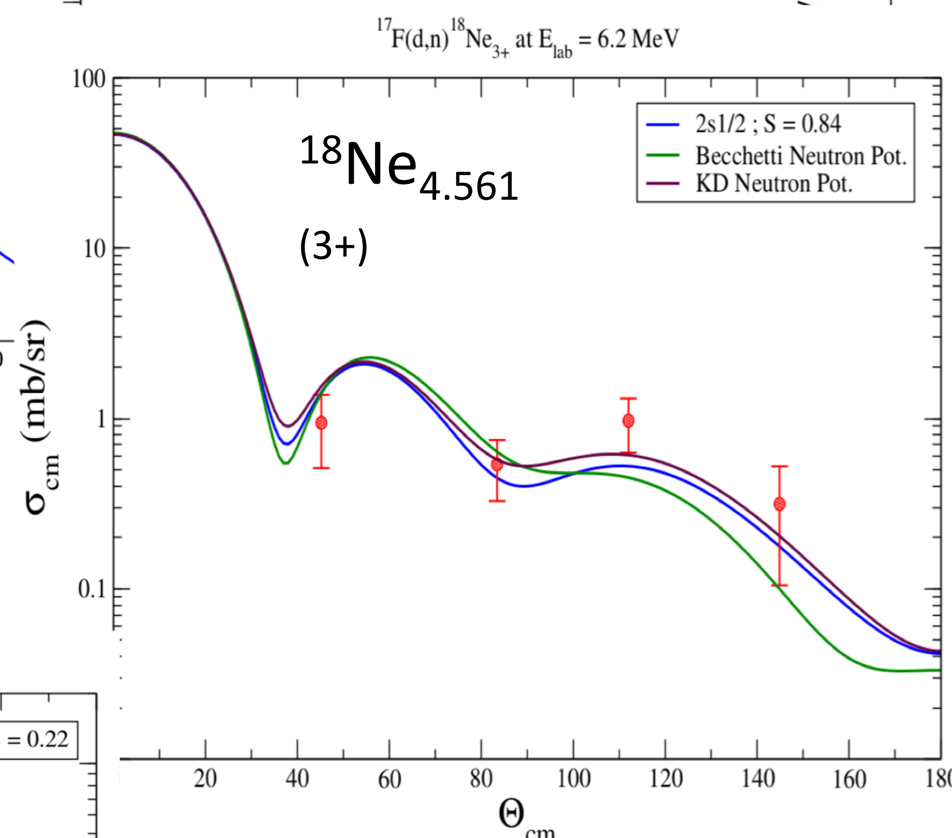
2 γ flashes from beam on target and beam stop (i.e., the scintillator).

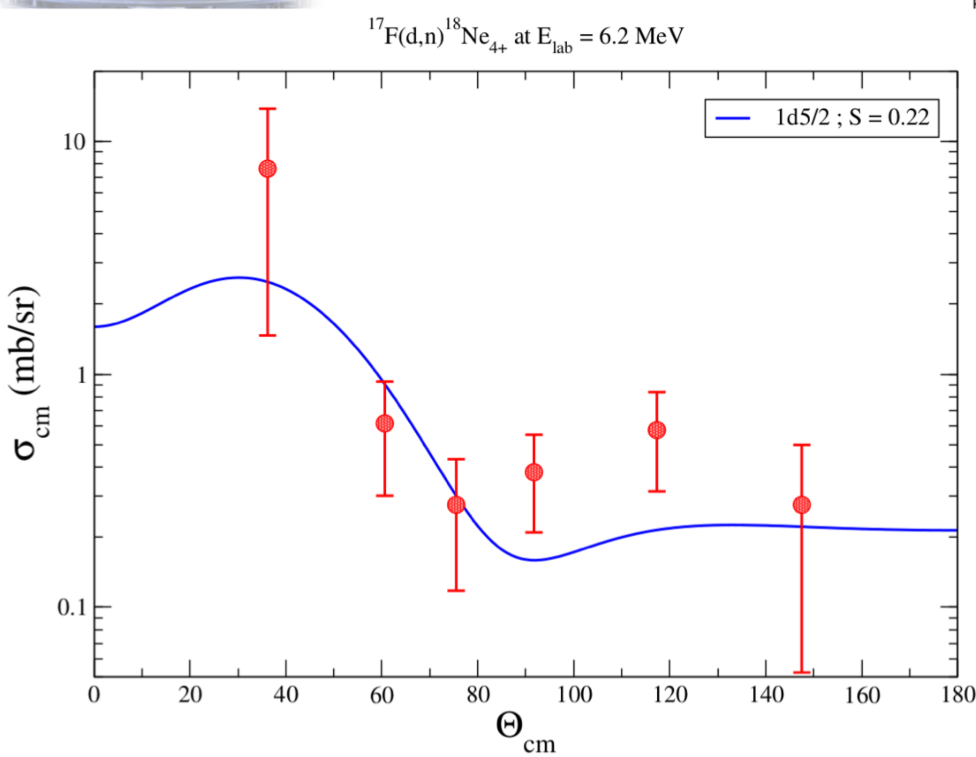


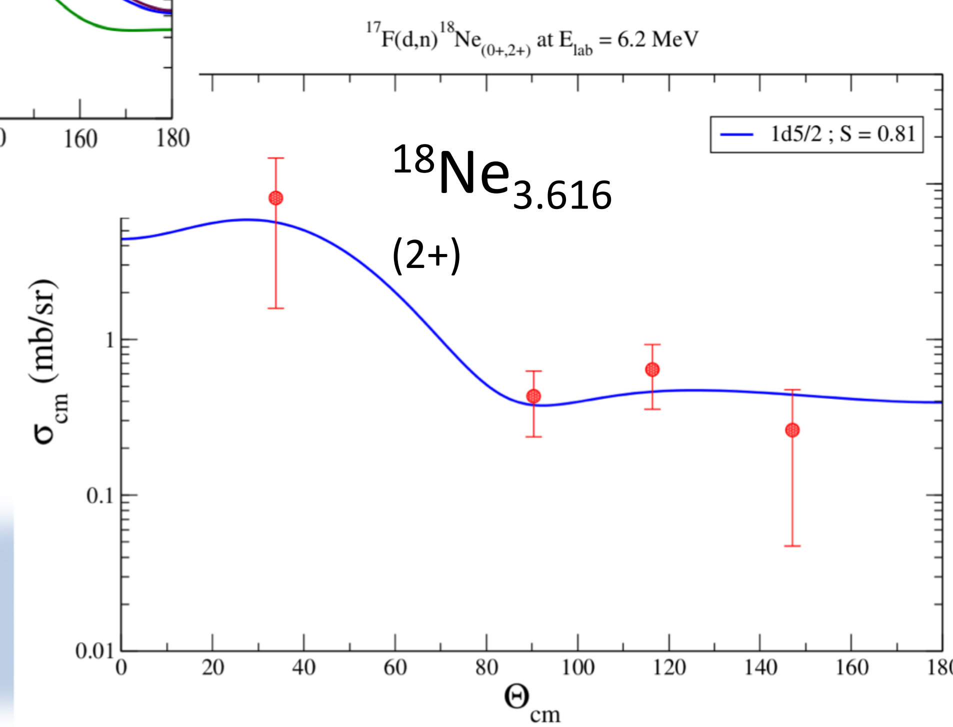
Angular Distributions







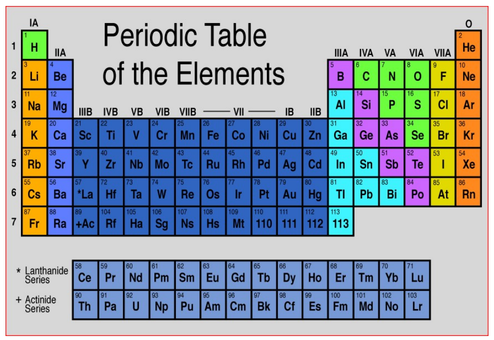




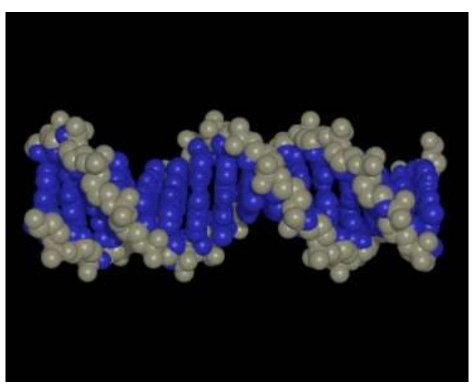
$^{12}C(\alpha,\gamma)^{16}O$ Reaction

Roy Holt, Argonne National Lab
& California Institute of Technology

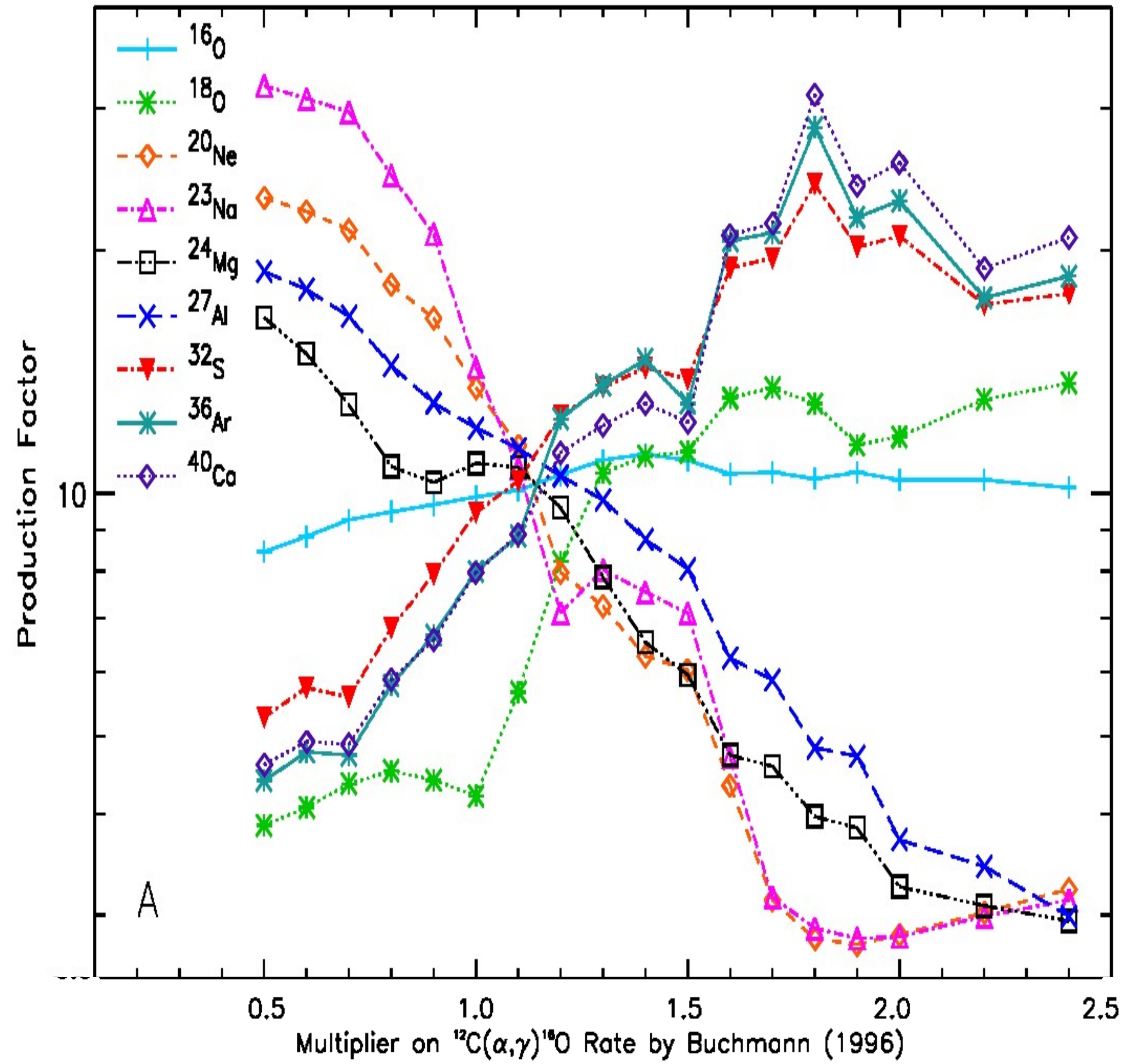
The *holy grail* of nuclear astrophysics



Affects the synthesis of most of the elements

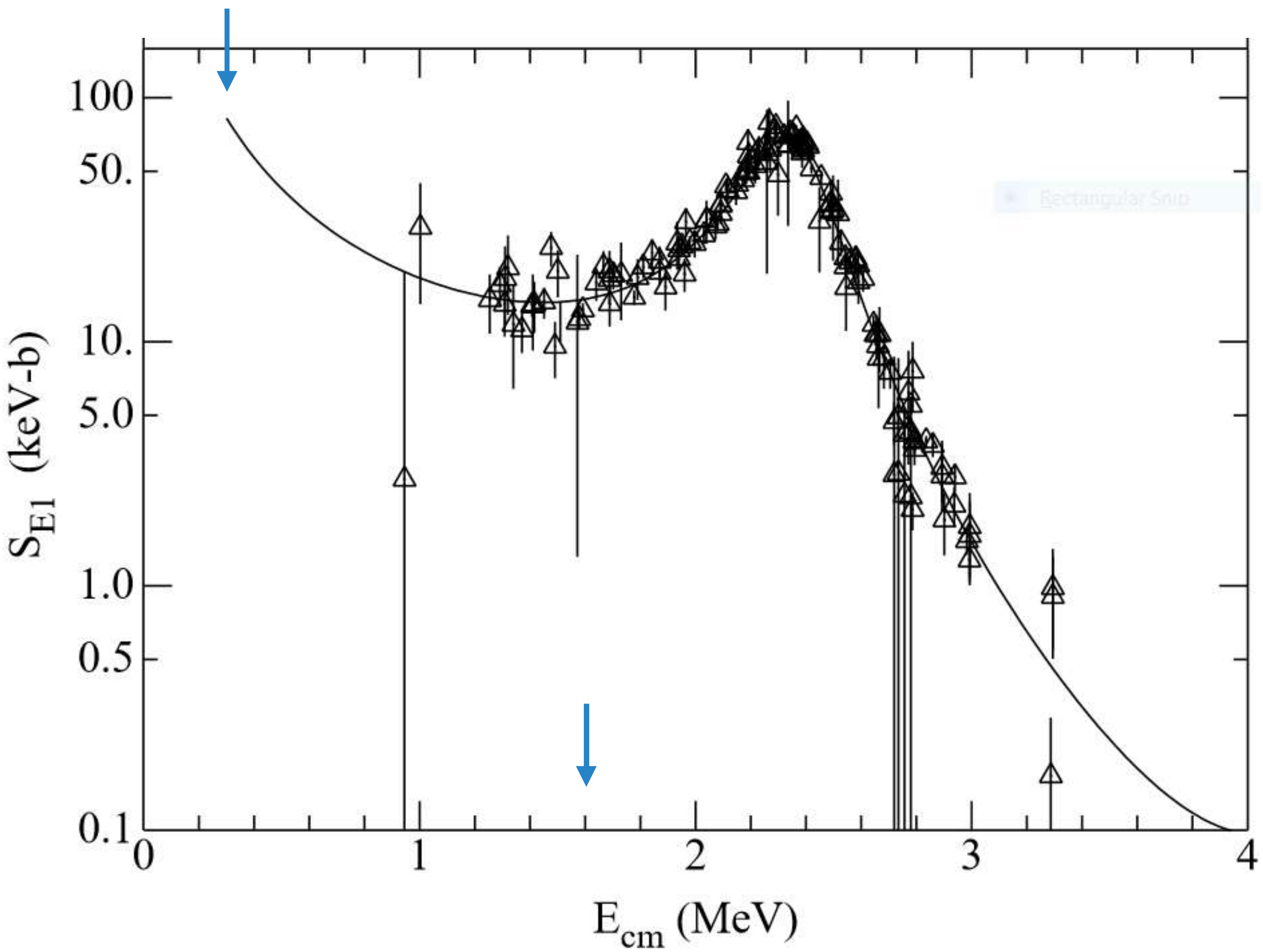


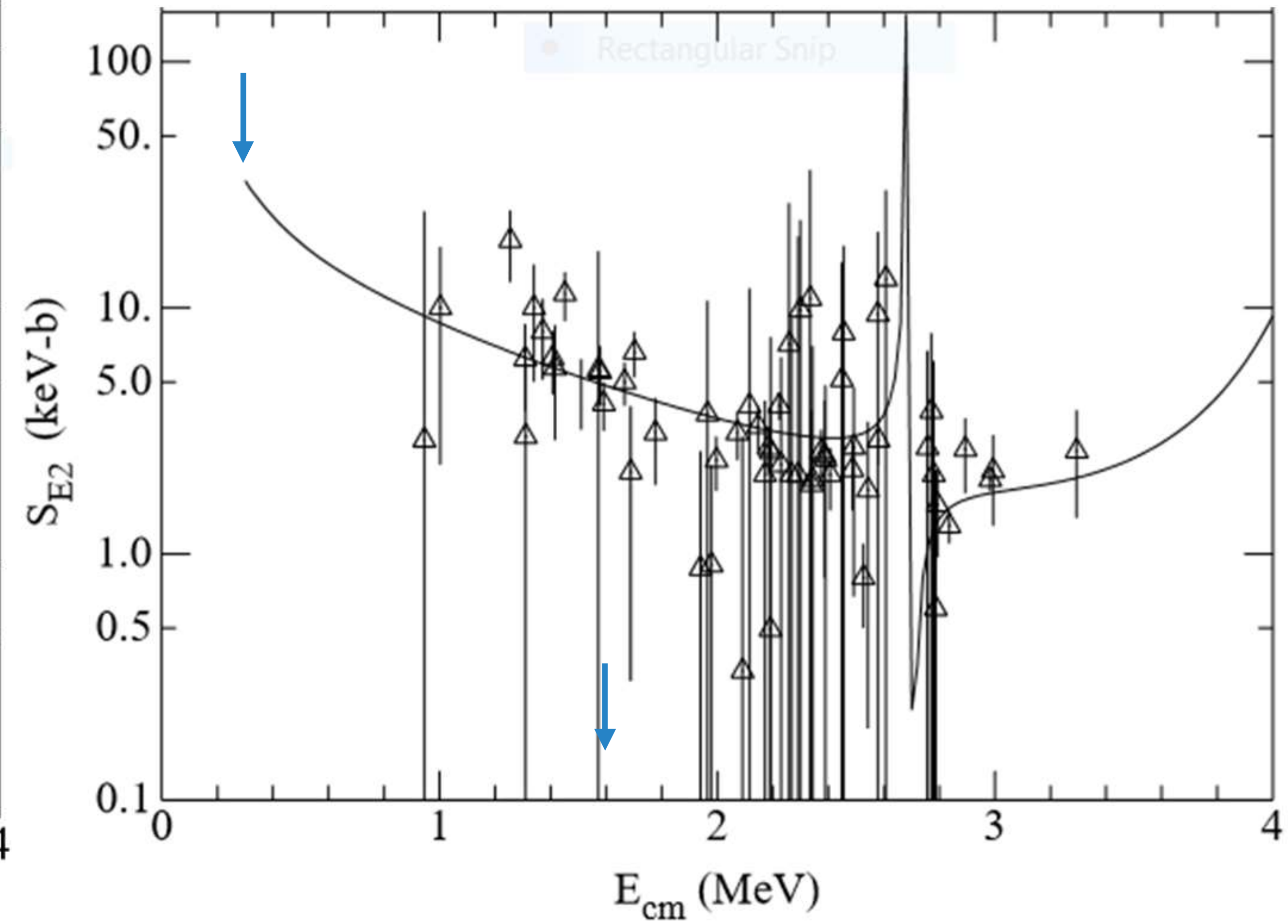
Sets the $N(^{12}C)/N(^{16}O)$ ratio in the universe



S. Woosley, A. Heger, Phys. Rep. **442** (2007) 269

E1 and E2 ground state S-factors





Method:

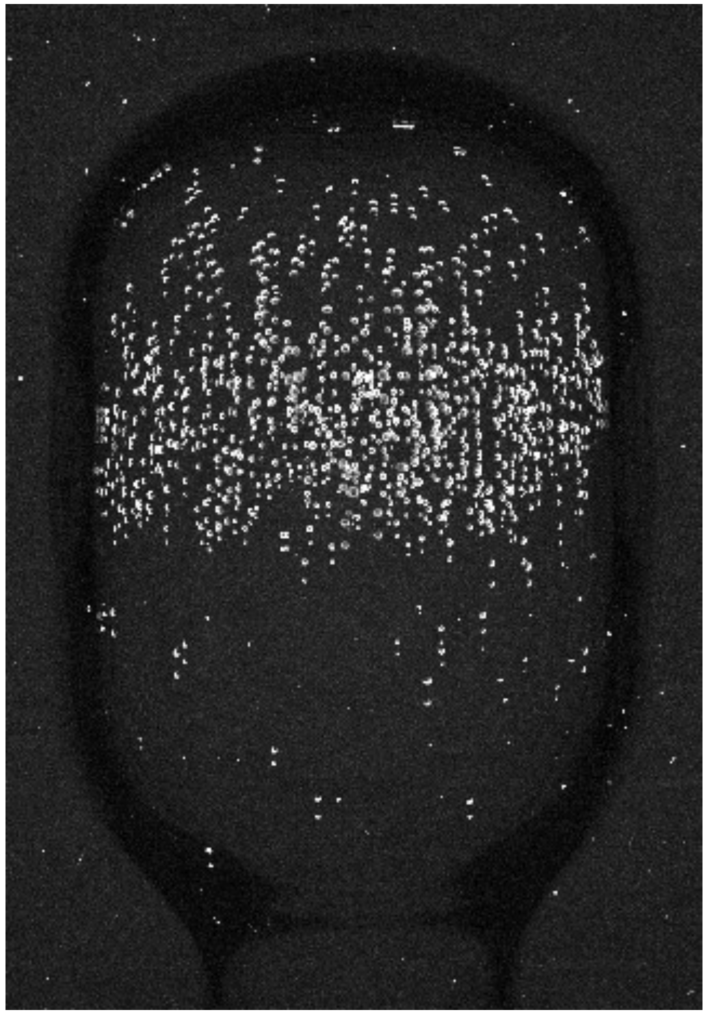
1. Fit the data, extrapolate to 300 keV
2. Generate pseudo-data from fit that is randomized according to a normal distribution within the statistical errors of data
3. Re-fit the pseudo data, extrapolate to 300 keV
4. Repeat step 2 and 3 about 100-250 times

- E2 projection is about ½ that of E1.
- Better E2 data necessary
- Or, measure total cross sections

JLab: Inverse Reaction + Bubble Chamber + Bremsstrahlung

$$\gamma + {}^{16}O \rightarrow {}^{12}C + \alpha$$

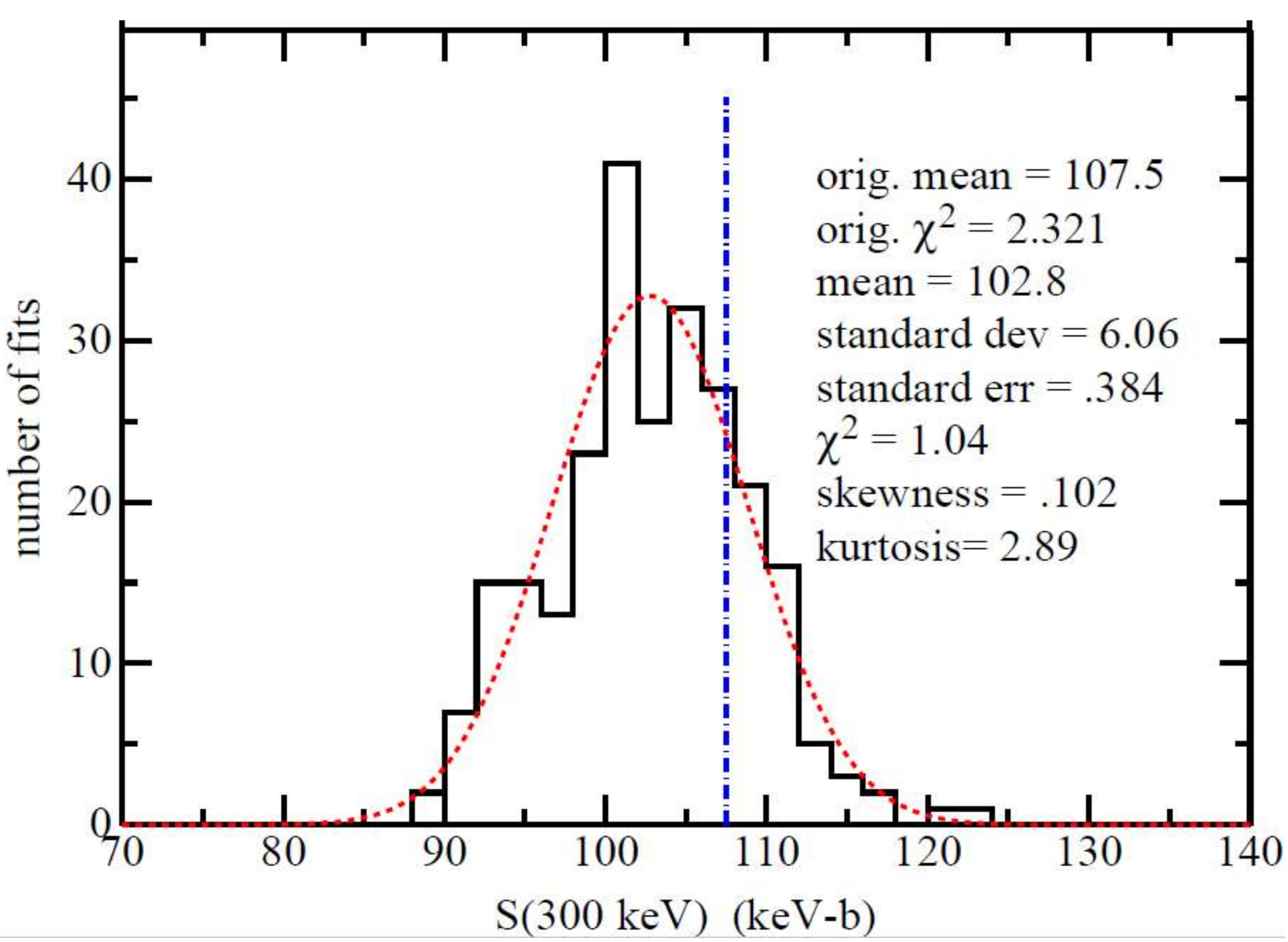
- Extra gain (>50) from inverse reaction
- Large target thickness ~ $x10^4$
- Solid Angle and Detector Efficiency = 100%
- High intensity bremsstrahlung beam
- Measures total ground state cross section



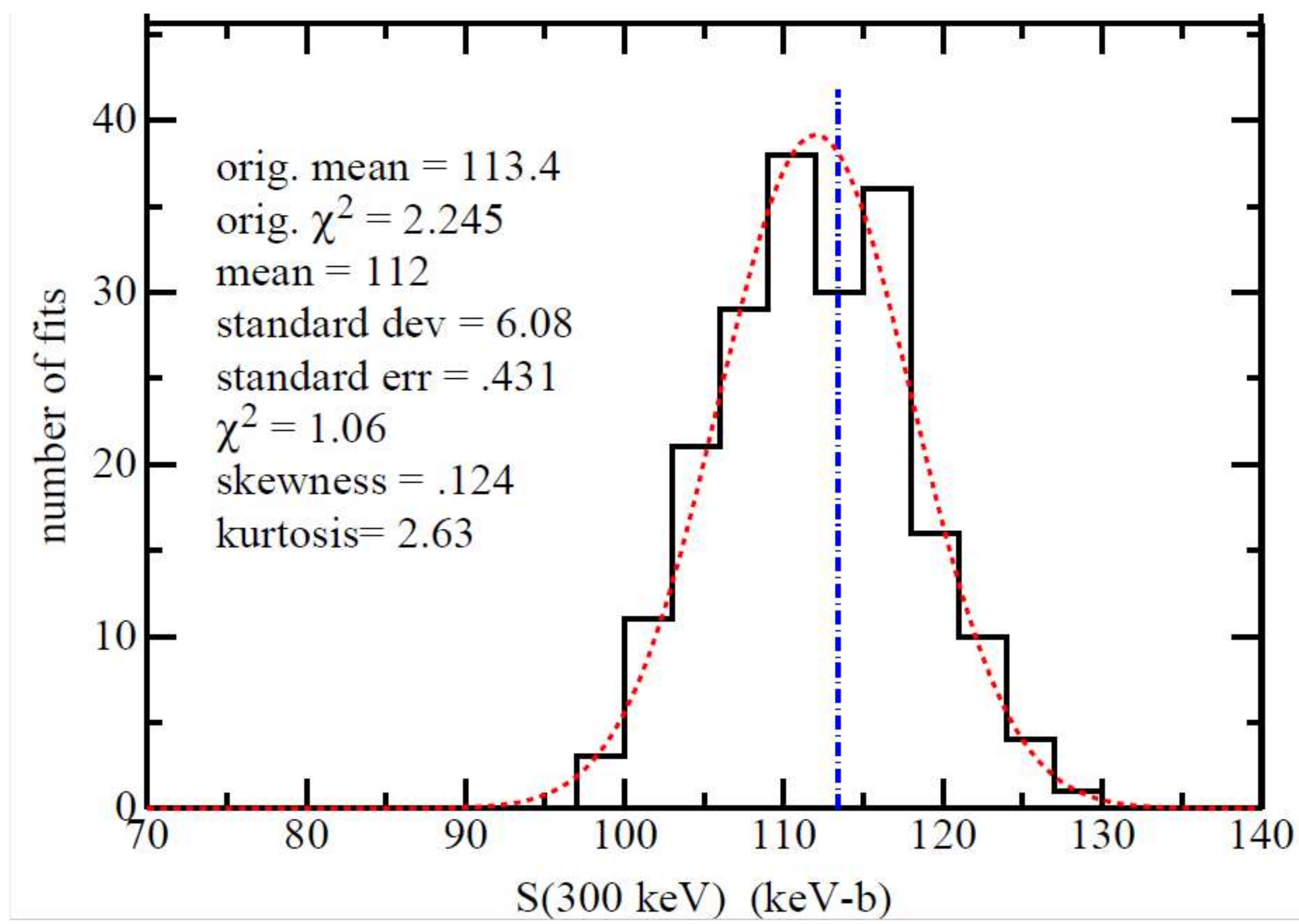
JLab experiment: R. Suleiman, E. Rehm, C. Ugalde *et al.*

Projections with and without expected JLab data

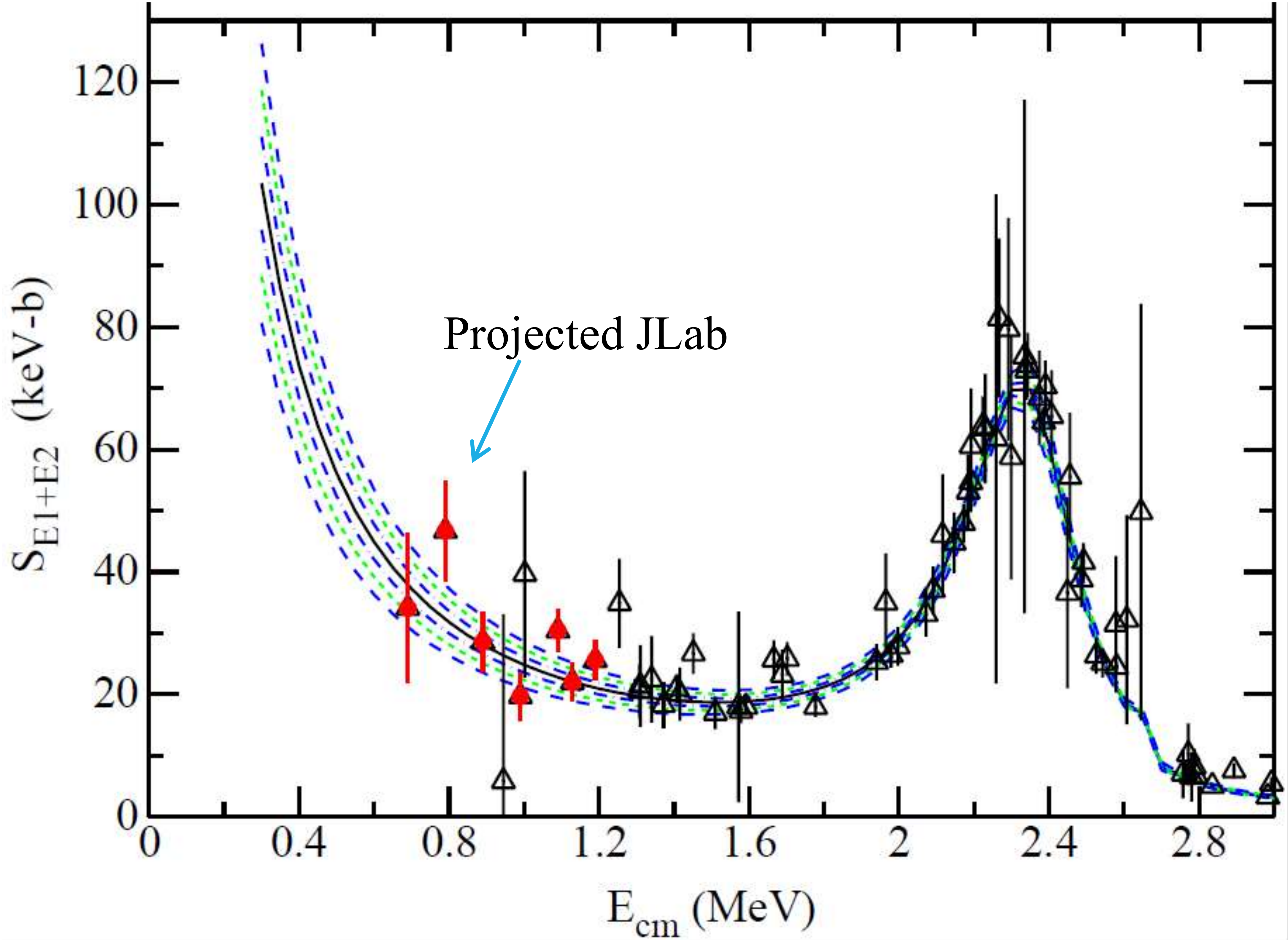
E1, E2 data



E1, E2 data + projected JLab



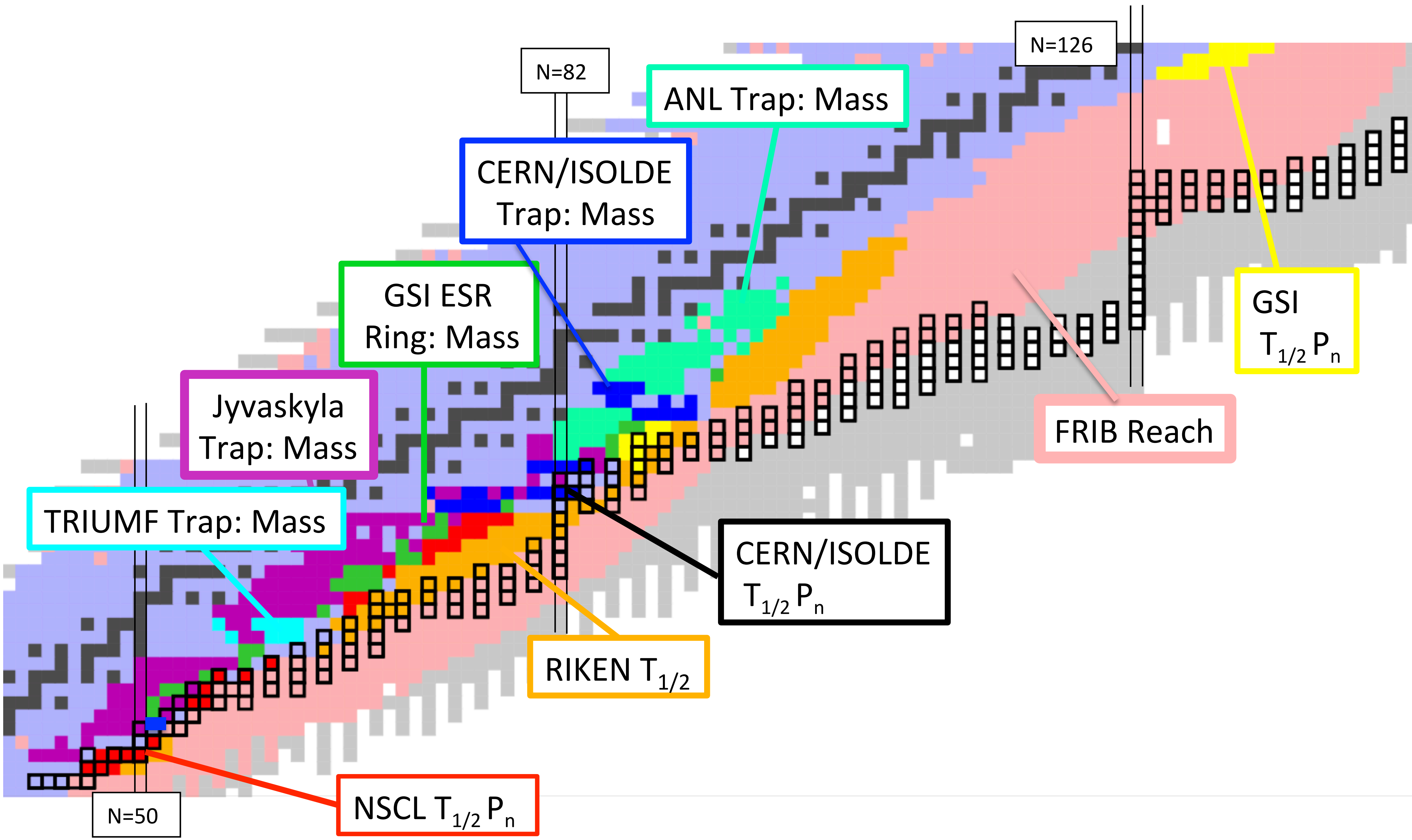
1, 2, 3 sigma bands



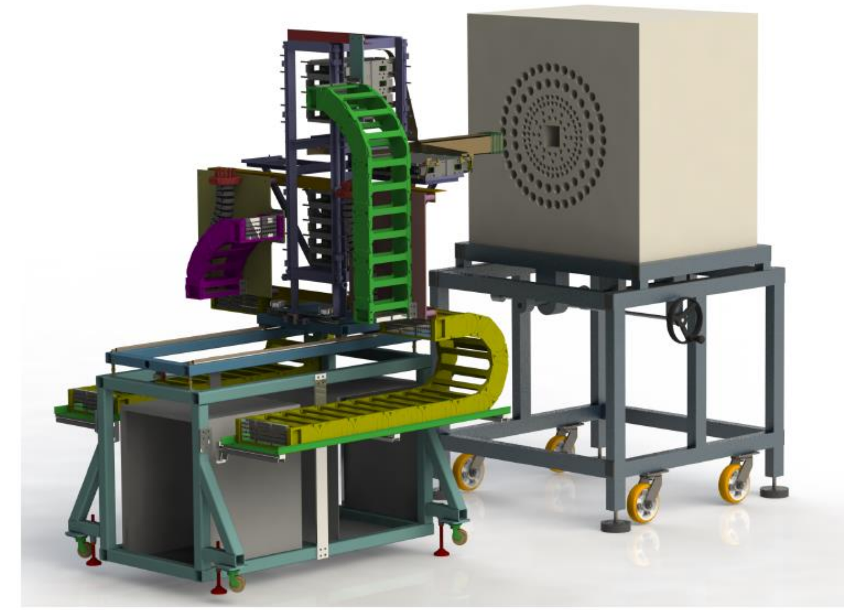
JLab data likely will not impact statistical precision of extrapolation, but could impact extrapolated value

r process path and recent measurements

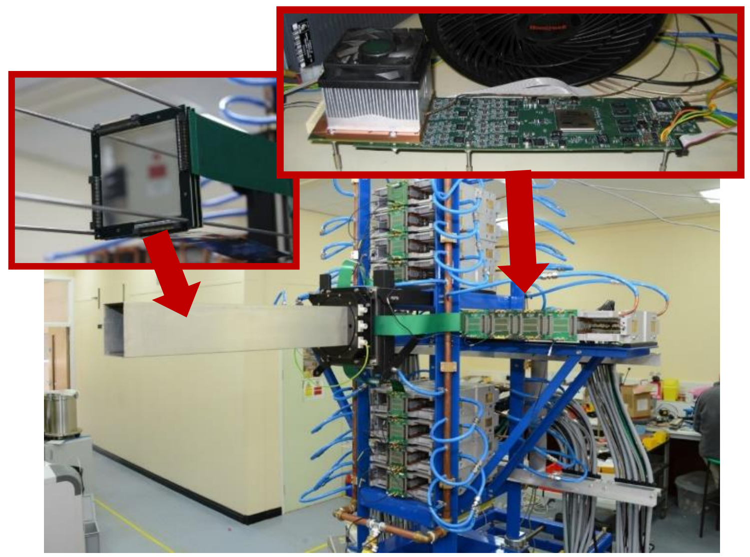
C. J. Horowitz et al. 2018



BRIKEN: β-delayed neutrons at RIKEN

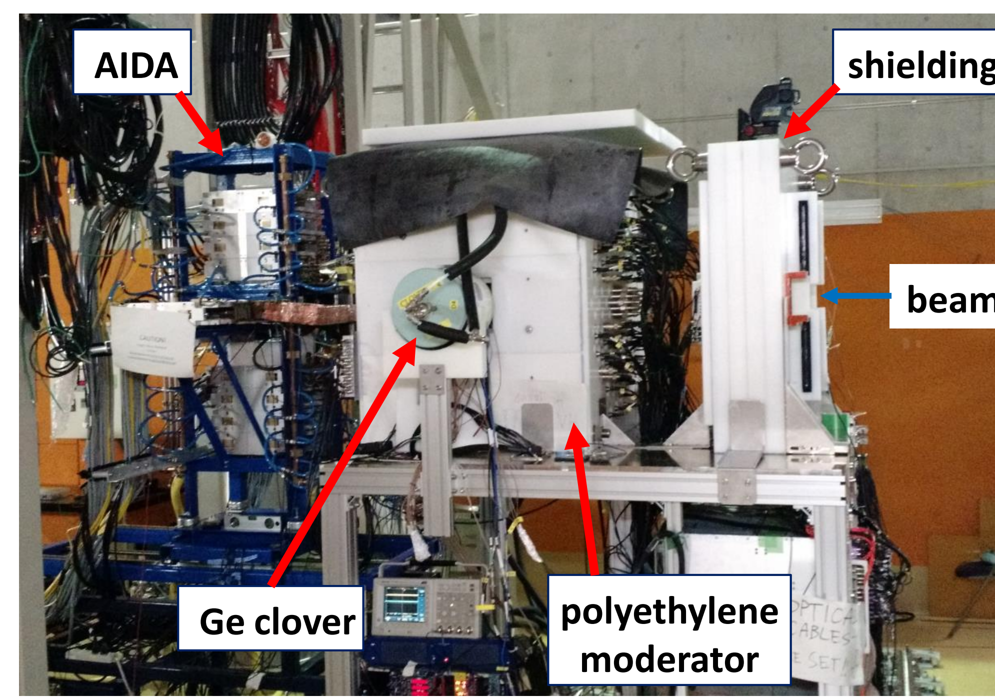


- β-decay in AIDA: Advanced Implantation Detector Array (DSSSD):



- BRIKEN neutron detector:

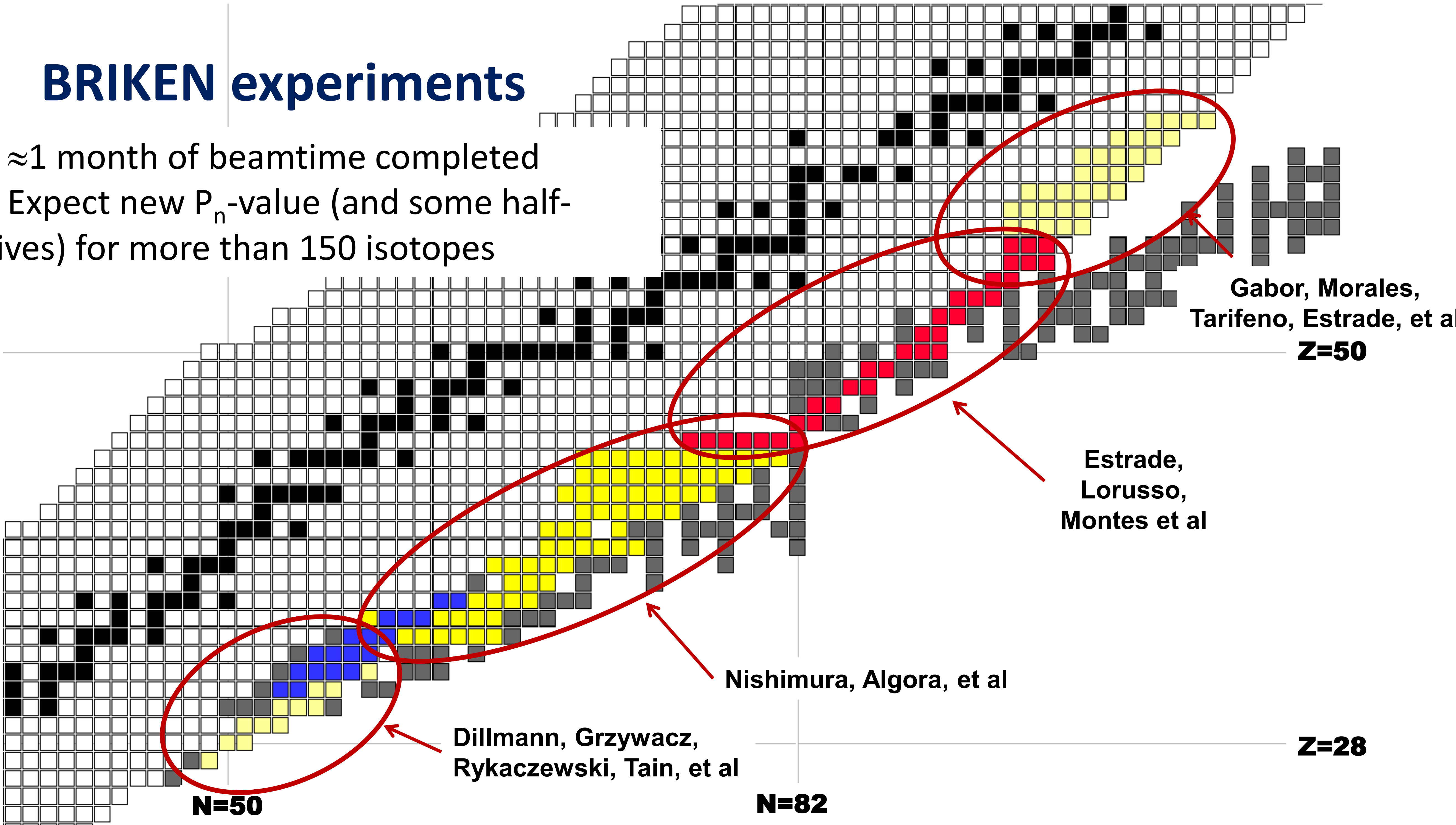
$$^{3}He + n \longrightarrow {}^{3}H + p$$



GOAL: measure P_{xn}-value, the probability for emission of *x* beta-delayed neutrons

BRIKEN experiments

- ≈1 month of beamtime completed
- Expect new P_n-value (and some half-lives) for more than 150 isotopes



Ken Nollett, San Diego State University

Quick summary of nuclear reaction theory for astrophysics

Astrophysical nuclear reaction/scattering theory is many things:

1. Direct (radiative or nonradiative) reactions – nonresonant
   ($A \lesssim 12$ & near closed shells)

2. Reactions through isolated resonances – $12 \lesssim A \lesssim 30$

3. Reactions at high level density – heavier nuclei mid-shell or far from stability

Phenomenological R-matrix is the right way to approach Case 2

Probably Case 3 will always lean on broad systematics (functions of (A, Z))

I'll talk about Case 1: Precision is needed for BBN & solar ν's

Halo EFT as a "fewer-body" framework

Halo effective field theory (EFT) can be used much like phenomenological R-matrix but might connect more simply to *ab initio* constraints

Instead of ordinary quantum mechanics, you take each nucleus as a particle in quantum field theory & develop a Lagrangian

You explicitly build in correct gauge, rotational, etc. symmetries

Lagrangian is expanded & truncated in terms of $(k/\Lambda)^n$, where Λ is breakdown scale (neglected threshold)

It's "halo" EFT because it's only useful for small binding energy – halo nuclei

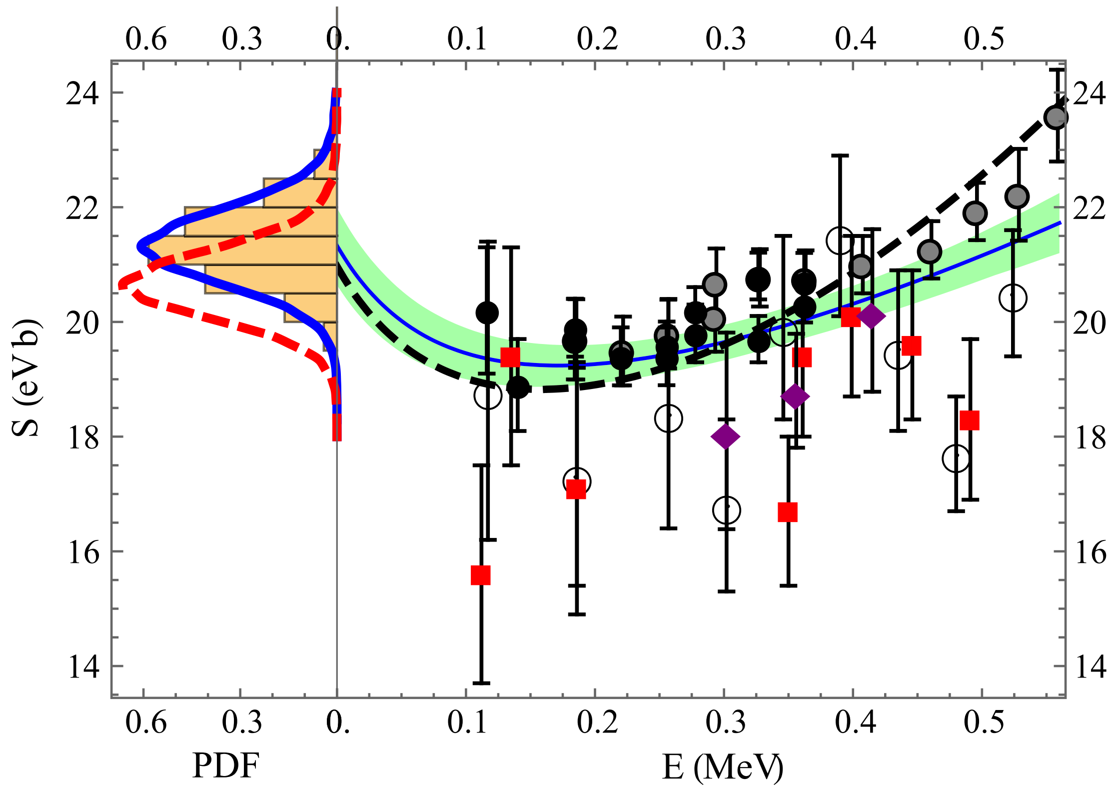
Pursued by a few groups: Rupak & Higa; Hammer & Phillips; Ryberg, Forssén, Hammer & Platter

What we really want for ^{7}Be$(p,\gamma)^8$B is $S(0)$ or $S(20\text{ keV})$

Marginalizing over all parameters, we find $S(0) = 21.3 \pm 0.7$ eV b

Solar Fusion II recommends $S(0) = 20.8 \pm 0.7\,(\text{ex}) \pm 1.4\,(\text{th})$ eV b

Navrátil et al. compute $S(0) = 19.4 \pm 0.7$ eV b *ab initio*, error from truncation



Zhang, Nollett, Phillips, PLB **751**, 535 (2015)

Full histogram: $S(0)$

Dashed histogram: $S(20\text{ keV})$

Green band: Marginalized $S(E)$

Solid curve: Parameters matching band median

Dashed curve: Keeping only LO parameters from solid curve

Some thoughts on the future

$^7\mathrm{Be}(p,\gamma)^8\mathrm{B}$ experience suggests a path toward smart use of *ab initio* information:

Construct a “fewer-body” model like R-matrix, Woods-Saxon, or halo EFT

Compute some of its parameters *ab initio* & use those and e.g. threshold energies as Bayesian priors

Then use MCMC to estimate the extrapolated cross section you care about from reaction data

Ab initio methods should eventually provide priors on more parameters than just ANCs