Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

# The TREND update and Nuclear Data Needs for BNL

Presenter: Dmitri G. Medvedev

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# TREND: TRi-lab Effort on Nuclear Data

## Co-authors and collaborators

Brookhaven National Laboratory (BNL):

- Michael Skulski (postdoctoral), Cathy S. Cutler

Los Alamos National Laboratory (LANL):

- Ellen O'Brien, Christiaan E. Vermeulen, Eva Birnbaum (alumni), Jonathan Morrell (postdoctoral), Francois M. Nortier (alumni, retired)

Lawrence Berkeley National Laboratory (LBNL)/UC Berkeley:

- Catherine Apgar (graduate student), Morgan Fox (alumni), Andrew Voyles, Lee A. Bernstein

# Rationale

Knowledge energy dependent cross section is critical for:

- Accurate prediction of the yield of the isotope of interest
- Accurate prediction of radioisotopic impurities
- Defining the energy windows for optimum, cost-effective production of isotopes

It facilitates:

- Production planning
- Defining shielding requirements
- Transportation and shipment constraints

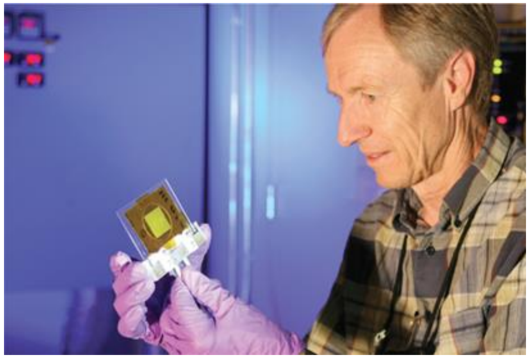
<u>Bonus</u>: comprehensive cross section data sets help constrain nuclear reaction models

# Current state of the field

- Most of the data sets are limited to proton energy range up to 30 MeV
- A few more data sets are available up to 160 MeV
- Limited number of data sets are available up to 200 MeV

# Approach

A tri-lab collaboration was formed to address the needs and cover proton energy range up to 200 MeV



- LBNL/UC Berkeley – 0 - 55 MeV
- LANL – 55 - 100 MeV
- BNL – 100 - 200 MeV

Seeks to measure nuclear reaction cross sections for production of medically relevant (and other) isotopes and for beam monitor reactions

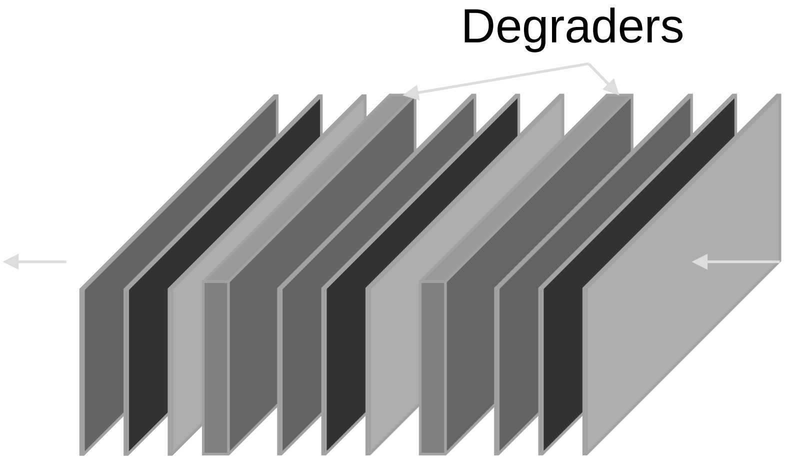
A comprehensive list of reactions was captured by Dr. François M. Nortier (Meiring) in 2017

# Data sets of the primary focus

| Priority | Isotope | Target | Incident particle | Measurement focus | Energy range | Years |
|---|---|---|---|---|---|---|
| **1** | $^{72}$Se, $^{68}$Ge | $^{75}$As | p | Primary: $^{72}$Se, $^{68}$Ge<br>Impurities: $^{70,71,73,75}$Se, $^{66,67,69,71}$Ge | Up to 200 MeV | 2019 |
| **2** | $^{119}$Te, $^{117m}$Sn | $^{nat}$Sb | p | Primary: $^{119m,119g}$Te, $^{117m}$Sn<br>Impurities: $^{116,117,118,121m,121g,123m}$Te, $^{113,119m,121m,121g}$Sn | Up to 200 MeV | 2020-21 |
| **3** | $^{202}$Pb | $^{nat}$Tl | p | Primary: $^{202m,202g}$Pb<br>Impurities: $^{198,199,200,201,203,204,205}$Pb | Up to 200 MeV | 2022 |
| **4** | $^{134}$Ce | $^{nat}$La | p | Primary: $^{134}$Ce<br>Impurities: $^{132,133,133,137,139}$Ce | 50-200 MeV | 2023 |

# Experimental: stacked foil technique

- Irradiate array of target and monitor foils with known thickness/areal density intermixed with degraders
  - Very low current 100-200 nA
- Use gamma spectroscopy to count each foil individually
  - Multiple spectra collection allows for accurate error characterization
- Determine activity of <u>all</u> produced radionuclides
- Use activation equation to solve for $\sigma$ for each individual foil




Dr. Jonathan Morrell developed Python based code (Curie)* which performs gamma spectra fitting and decay routine that is used for data analysis

*J. T. Morrell, Curie: Python Toolkit for Experimental Nuclear Data (2020).

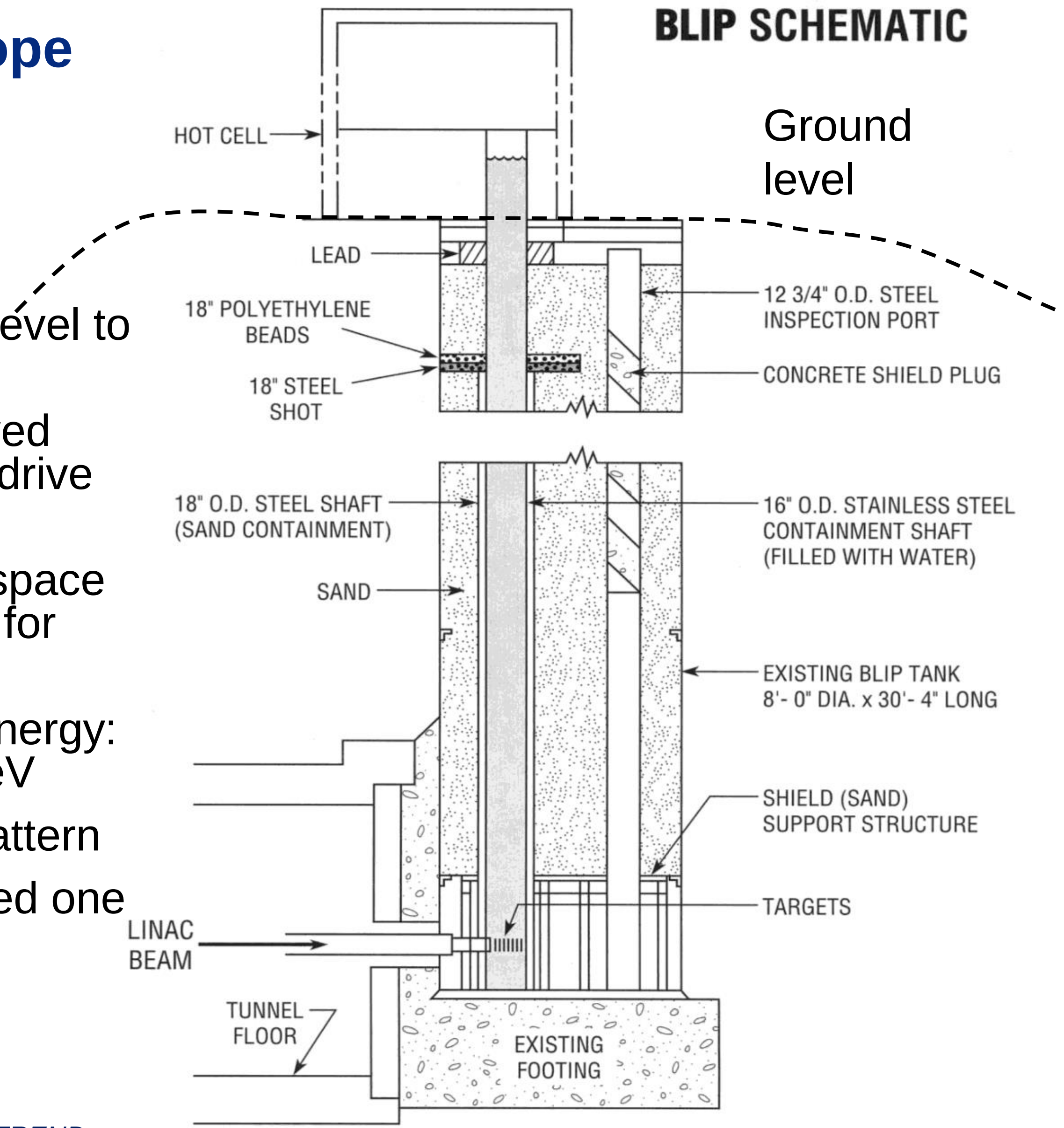
# Facilities

- LBNL operates 88-inch cyclotron
  - Both light- and heavy-ion capabilities.
  - Protons and other light-ions are available at intensities (10-20 pA)
  - Maximum energies of 60 MeV (protons), 65 MeV (deuterons), 170 MeV ($^{3}He$), and 130 MeV ($^{4}He$).

- BLIP (BNL) and IPF (LANL) share conceptually similar design
  - Operate of LINACs
    - IPF max accepted proton energy 100 MeV, max current 350 μA
    - BLIP max energy 200 MeV, incrementally tunable, max current 200 μA
  - Designed for large scale isotope production

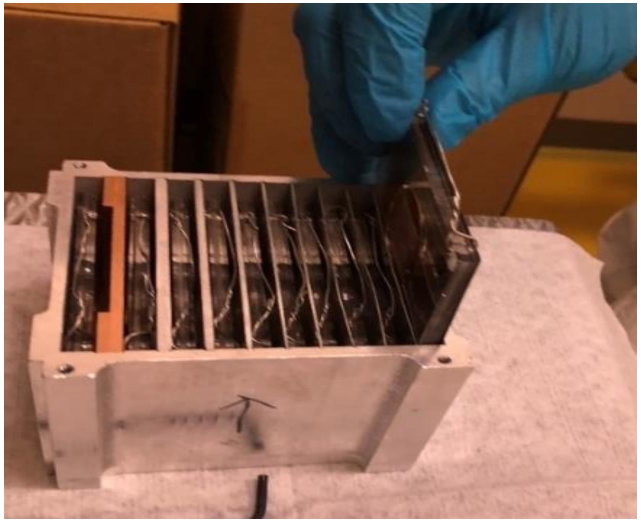
# Brookhaven Linac Isotope Producer (BLIP) target station

- Located 30 feet below ground level to the bottom of the water shaft
- Targets delivered to and retrieved from the beamline using chain drive system
- About 6 inches (152.4 mm) of space available along the beam pass for target positioning
- Incrementally tunable LINAC energy: 200, 180, 160, 140, 117, 66 MeV
- Rastered and focused beam pattern
- Multiple targets arranger stacked one after another



# Experimental: stacked foils for irradiation

IPF



BLIP

LBNL

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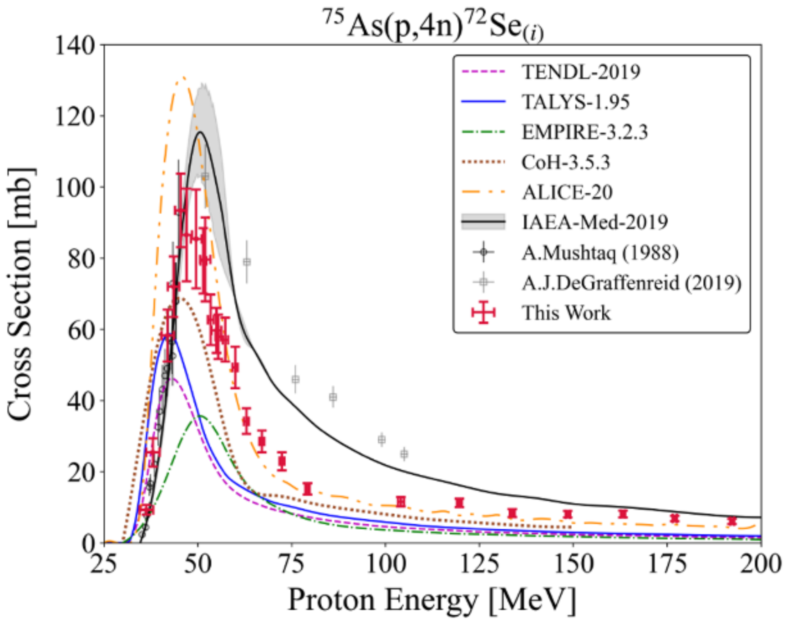
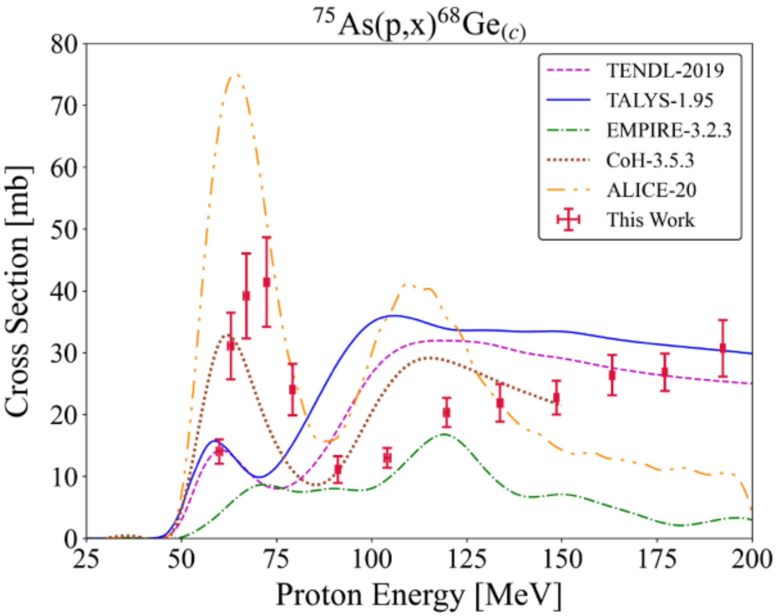
Morgan Fox
LBNL



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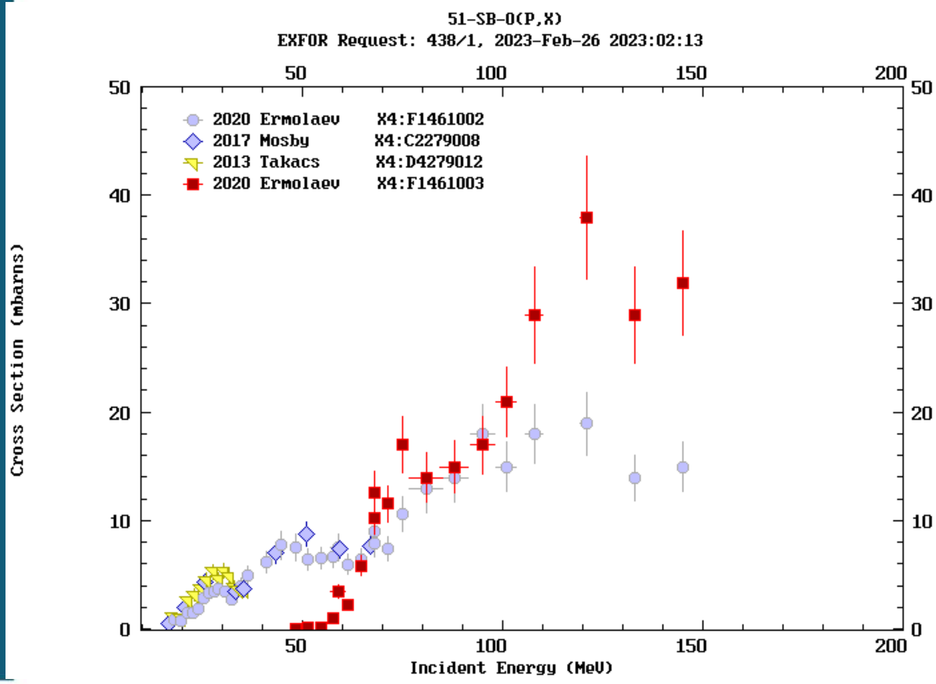
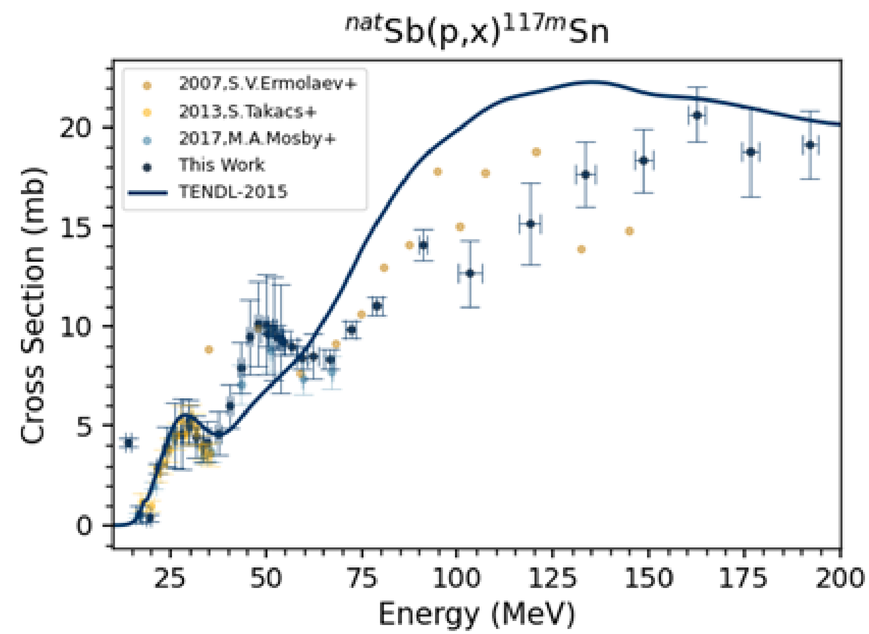
Catherine Apgar
LBNL



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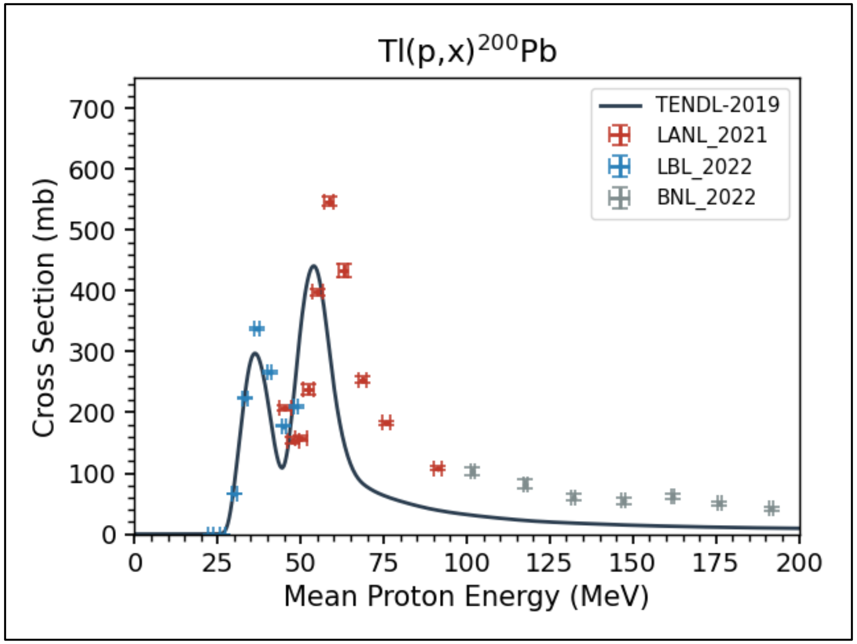
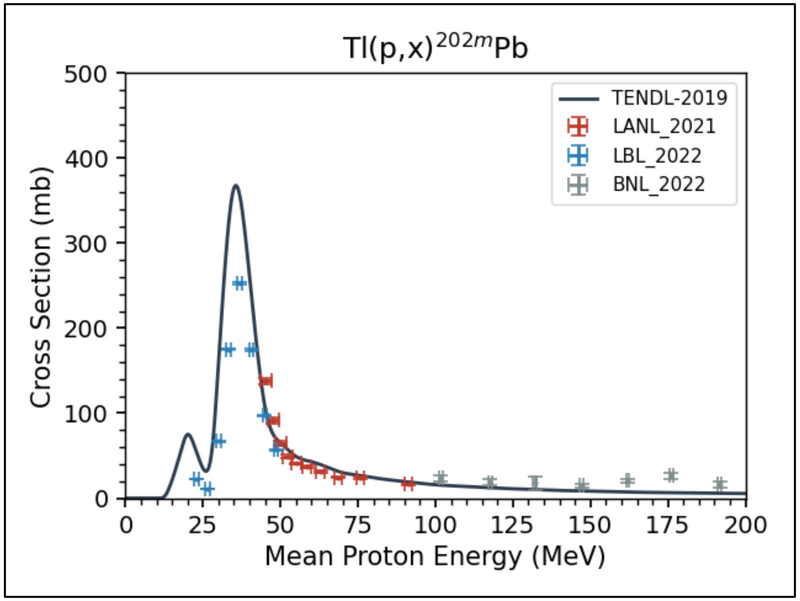
Michael Skulski
BNL




*D. Medvedev. The TREND progress and Data Needs for BNL. WANDA 2023*

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Jonathan Morrell
LBNL→LANL

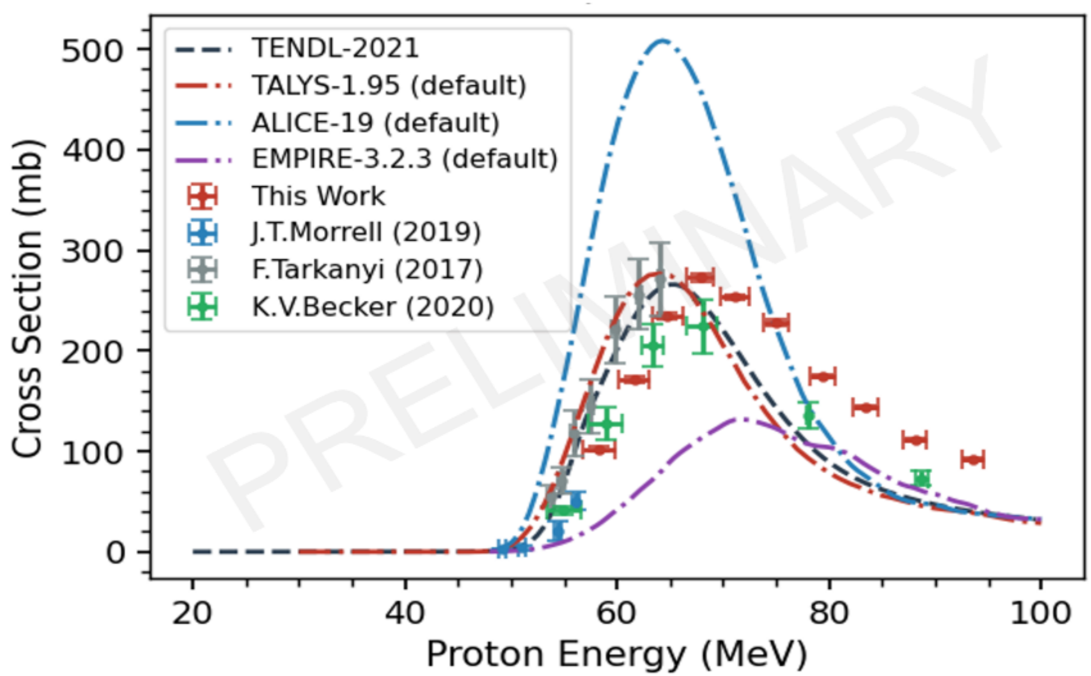
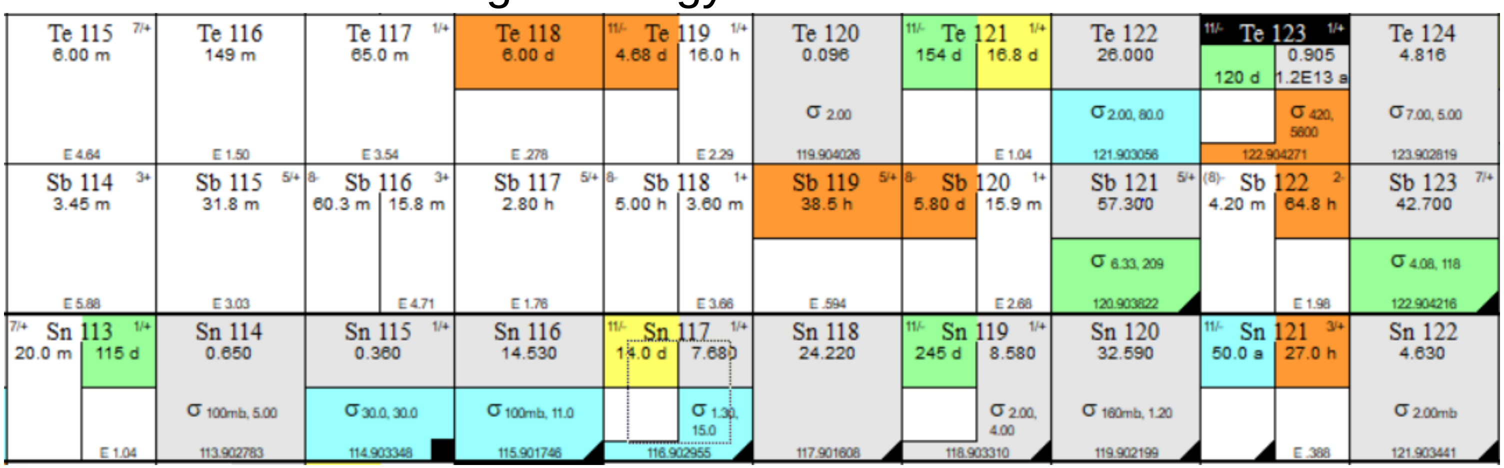



Figure 1. Preliminary measurement of the $^{139}$La(p,x)$^{134}$Ce reaction cross section, from the Sep. 22 experiment at LANL IPF, plotted against existing measurements and several modeling codes (using default parameters).

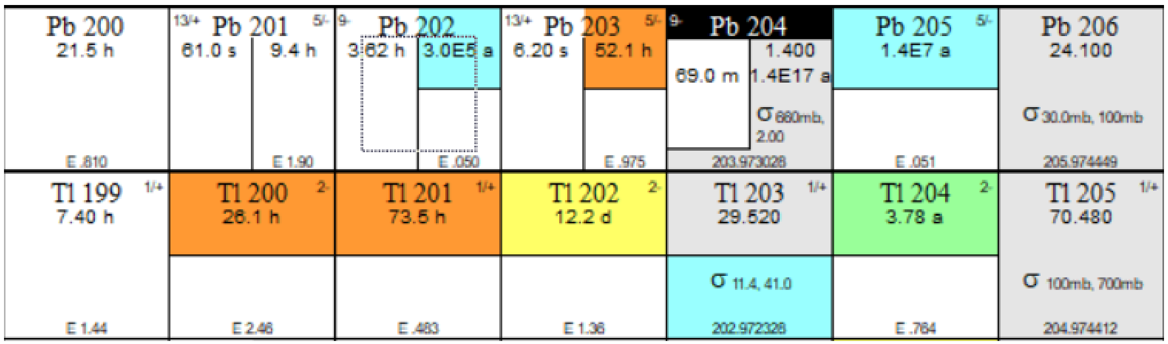
# Implications for isotope production

- **Reactions on arsenic:** first data set for $^{nat}As(p,x)\,^{68}Ge$ reaction up to 200 MeV revealed opportunities for Ge-68 production with medium to high energy protons
  - Lower thermal load on the target at higher energy
  - No interference with medium energy production targets at BLIP
- **Reactions on antimony**:
  - Control of co-production of long-lived Sn-113 impurity
  - Better understanding of energy resolution for Te-118 and Te-119

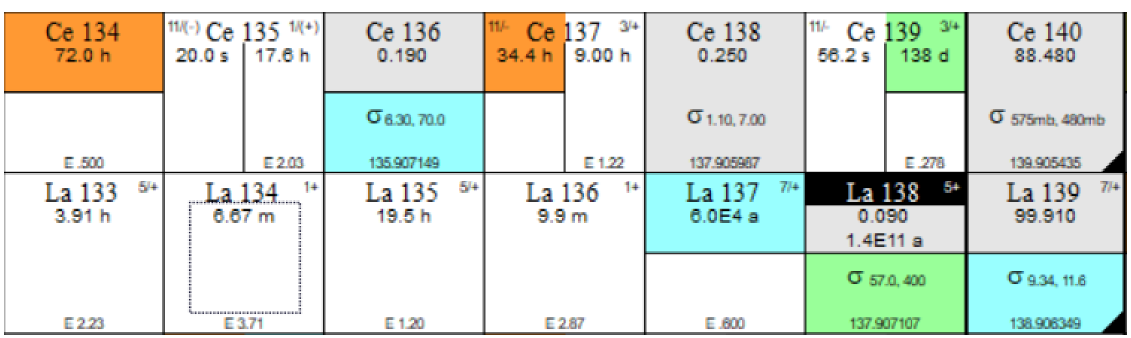


# Implications for isotope production

- **Reactions of thallium**: comprehensive data sets on thallium will constrain Talys prediction of difficult to measure Pb-202 and Pb-205




- **Reactions on lanthanum:** control of the impurities in production of Ce-134



# BLIP nuclear data needs

- BLIP receives 200 MeV protons: this energy has to be absorbed either by degraders or production targets
- Cross section data sets with improved uncertainties are necessary for design of both targets and degraders
- Data sets for production for energies from 100-200 MeV are of particular importance at BLIP to improve economics of production
- Cross section data sets for fast neutrons are of importance due to substantial flux of secondary neutrons

# Acknowledgement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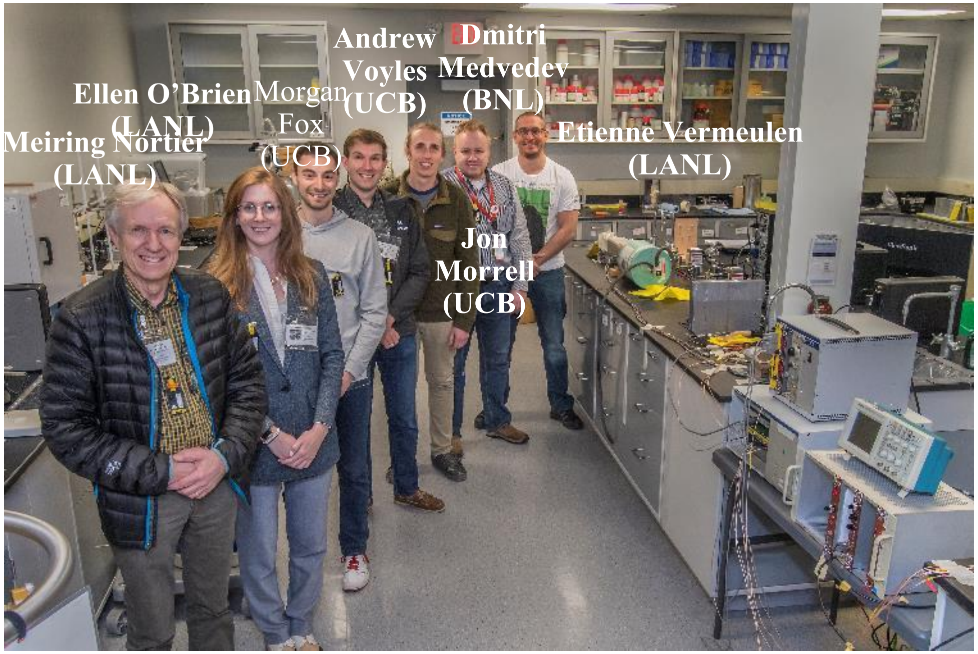
- LBNL is managed by University of California for US DOE Office of Science

# The Tri-lab Nuclear Data Collaboration




Not Pictured:

Lee Bernstein (LBNL)

Eva Birnbaum (LANL)

Cathy Cutler (BNL)