Nuclear Recoil Calibration Facility at TUNL

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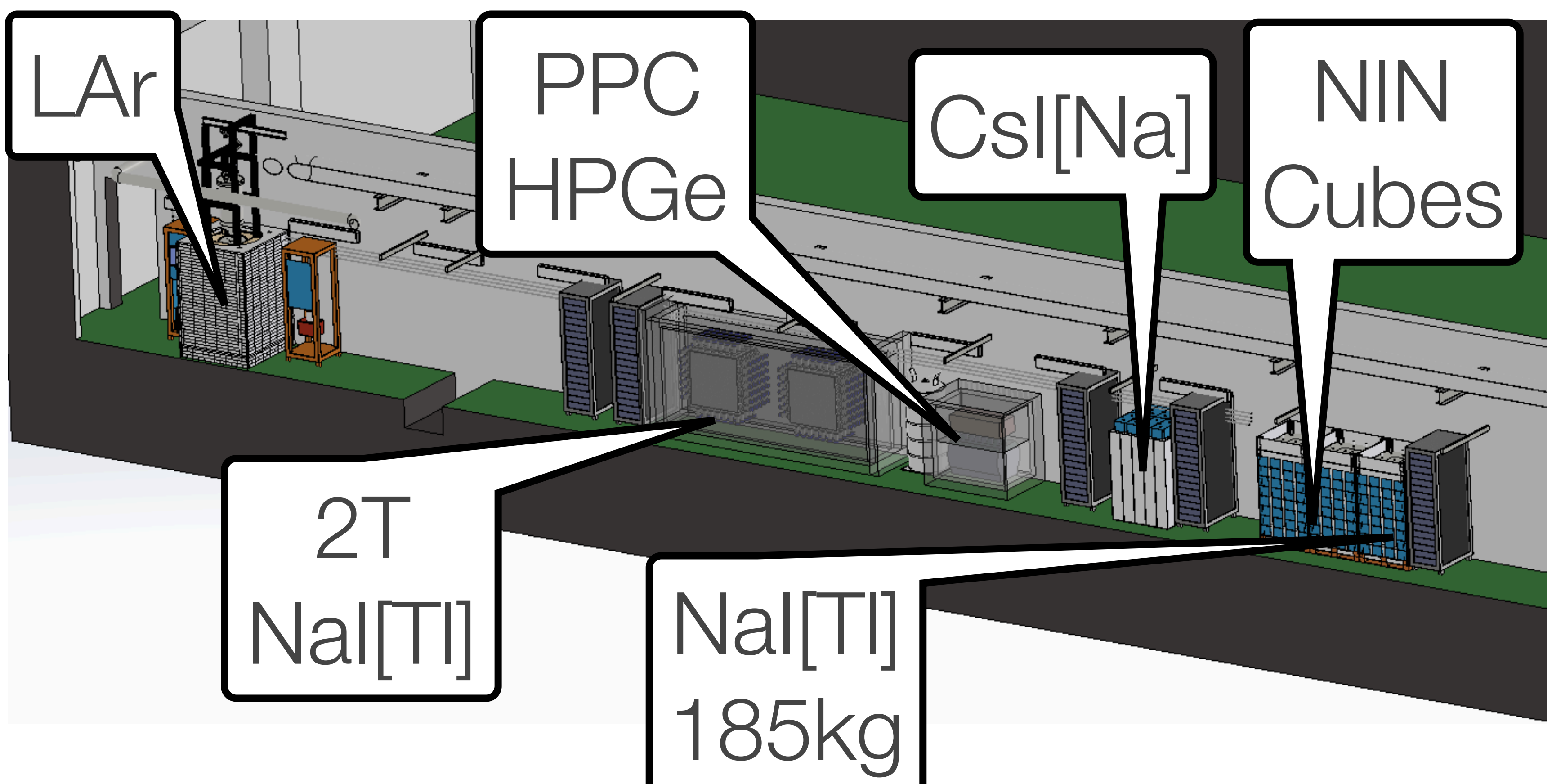
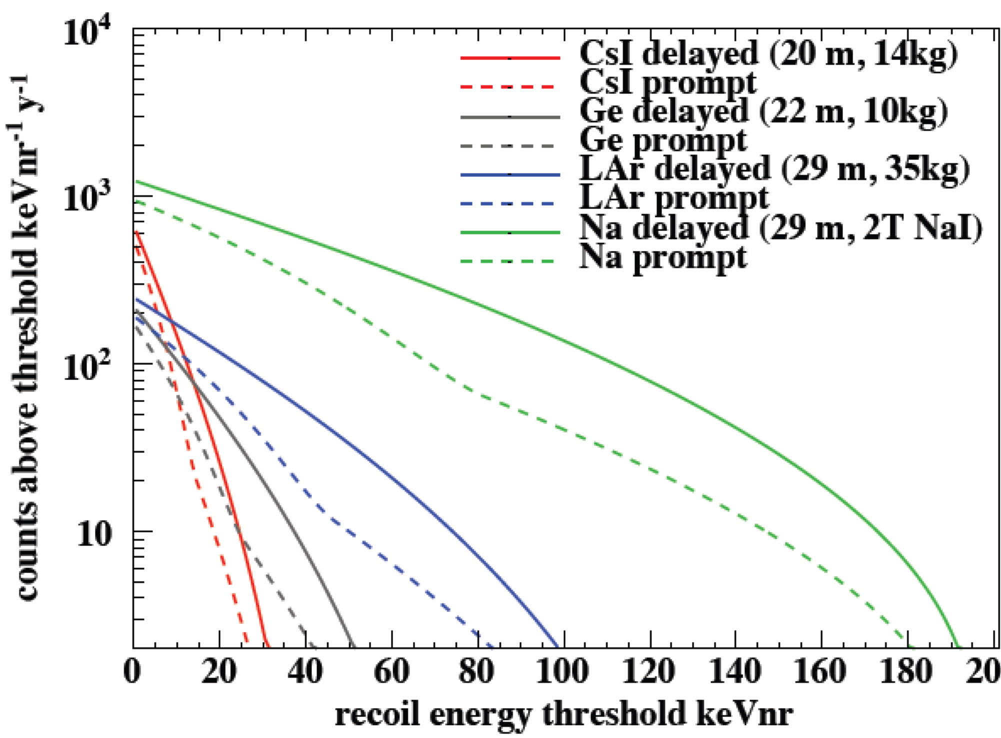
Our Interest is driven by COHERENT —But we are open to working with everyone

- COHERENT needs precision measurements of the Quenching Factor for nuclear recoils for several detector technologies in order to 1) discover Coherent Neutrino Scattering and 2) search for BSM physics that could impact the cross section measurement.
- We need much better than 30-80% uncertainty at the lowest energies; and we need detailed understanding of systematic uncertainties.

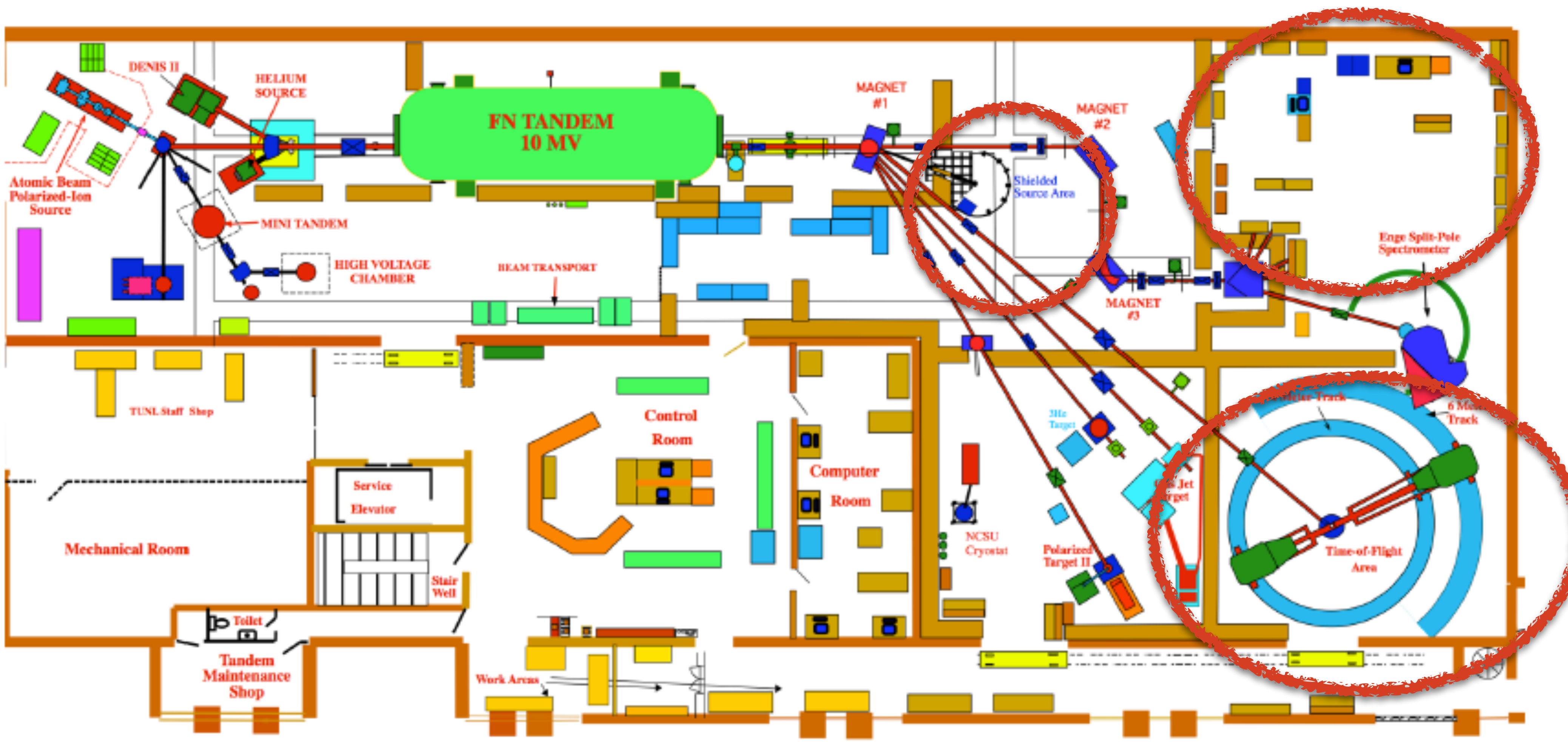
Nuclear Target	Technology	Mass (kg)	Distance from source (m)	Recoil threshold (keVr)	Data-taking start date; CEvNS detection goal
CsI[Na]	Scintillating crystal	14	20	6.5	9/2015; 3σ in 2 yr
Ge	HPGe PPC	10	22	5	Fall 2016
LAr	Single-phase	35	29	20	Fall 2016
NaI	Scintillating crystal	185*/ 2000	22	13	July 2016





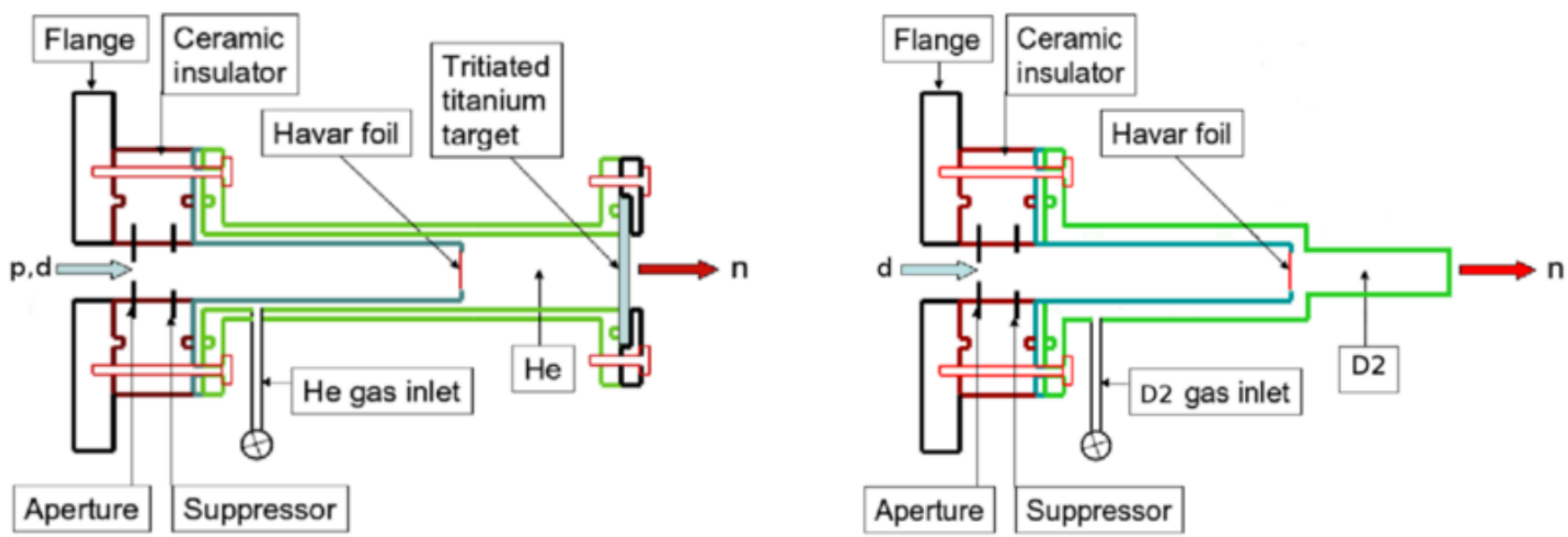
The TUNL Facility

- TUNL can produce pulsed, tunable, quasi-monoenergetic neutron beams
  - not limited to QF Measurements
  - Very flexible beam energies and configurations
  - long-term setups are possible
  - 3+ target areas are usable
  - Lots of TUNL activities and experience using neutron beams



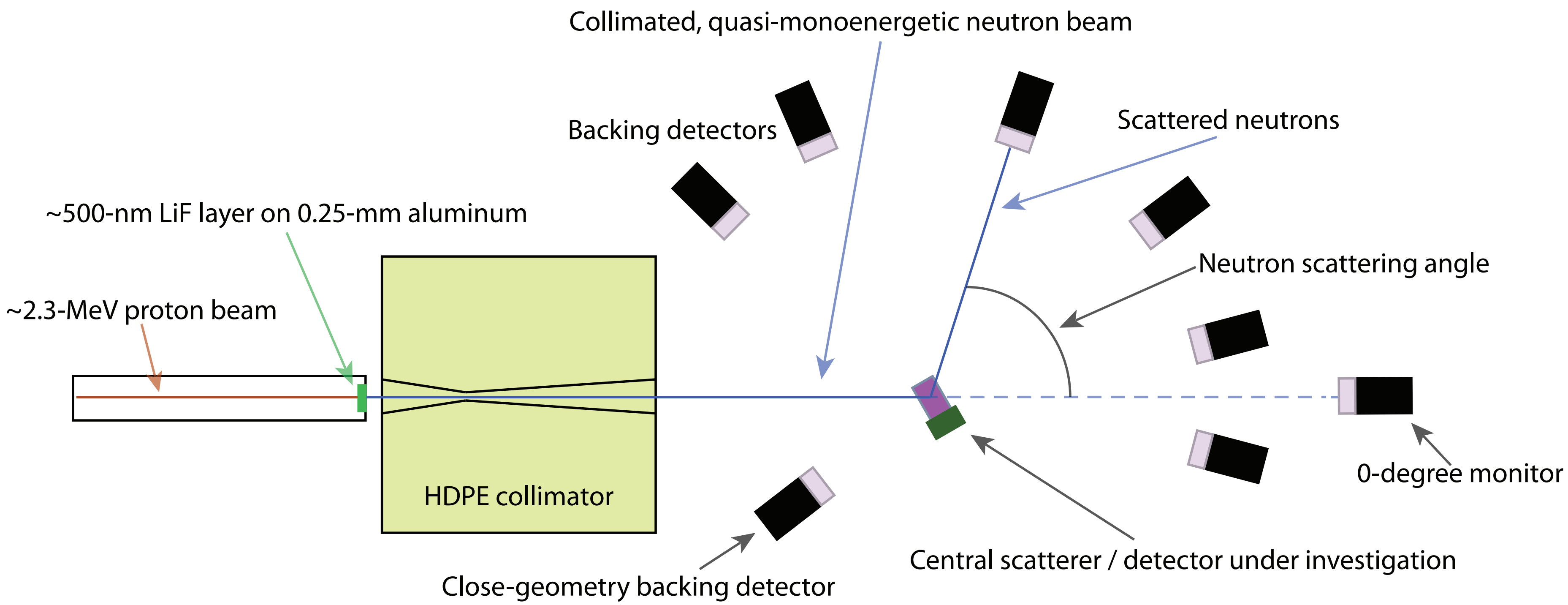
The TUNL Facility

- Many ion sources available (^{1}H, ^{2}H, ^{3}He, ^{4}He)
- 10 MV Tandem
- Capability to bunch and chop (2 ns pulsing at N x 400 ns, N >=1)
    - This also allows us extremely precise, in situ measurements of the neutron energies
- ~1 uA currents on target are the max when pulsed. This is dependent on the beam line (e.g. the 90-90 leg maxes out at ~ 800 nA).
- Wide Range of neutron energies possible (70 keV - 15 MeV)

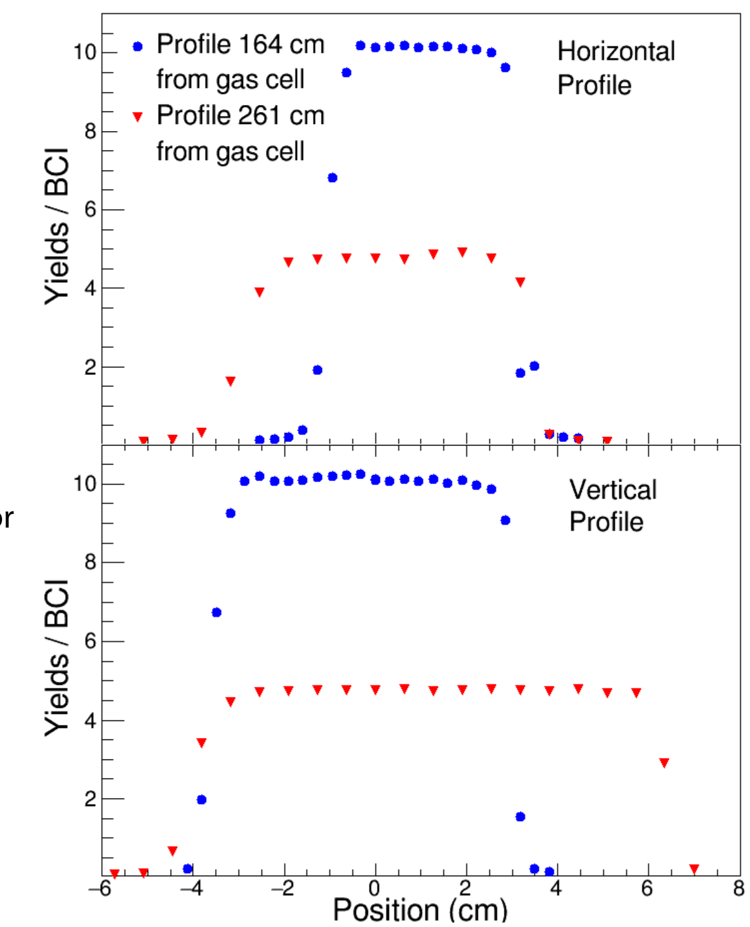


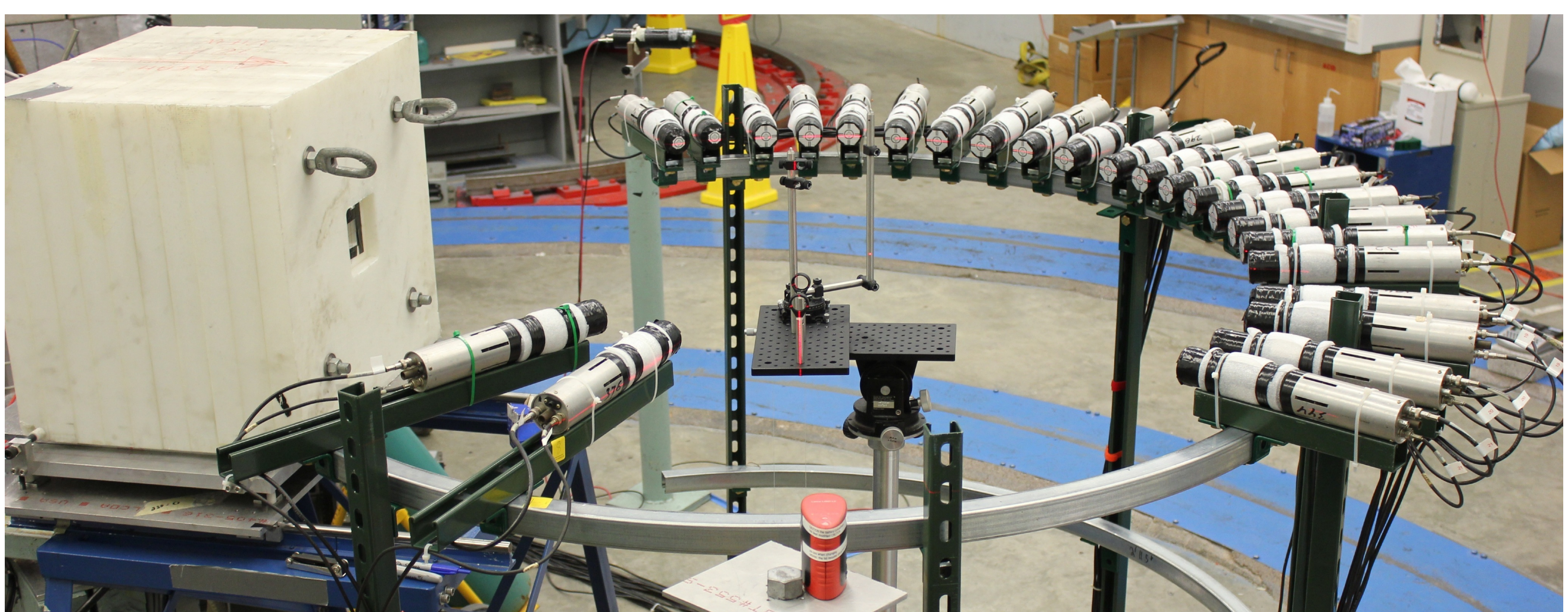
Reaction	Q-value (MeV)	Mono-energetic neutron energy range (MeV)	Off-energy reactions	Threshold (MeV)
$^{7}Li(p,n)^{7}Be$	−1.644	0.1–0.65	$^{7}Li(p,n)^{7}Be*$	2.372
$^{3}H(p,n)^{3}He$	−0.763	0.5–7.7	$^{3}H(p,np)^{2}H$	8.348
$^{2}H(d,n)^{3}He$	+3.269	4.0–7.7	$^{2}H(d,np)^{2}H$	4.449
		4.0–5.5	X(d,np)X	2.249
	+17.589	14.8–20.5	$^{3}H(d,np)^{3}H$	3.710
$^{3}H(d,n)^{4}He$	+17.589	14.8–21.9	$^{3}H(d,2n)^{3}He$	4.984
	+17.589	14.8–18.6	X(d,np)X	2.249

Experimental configuration



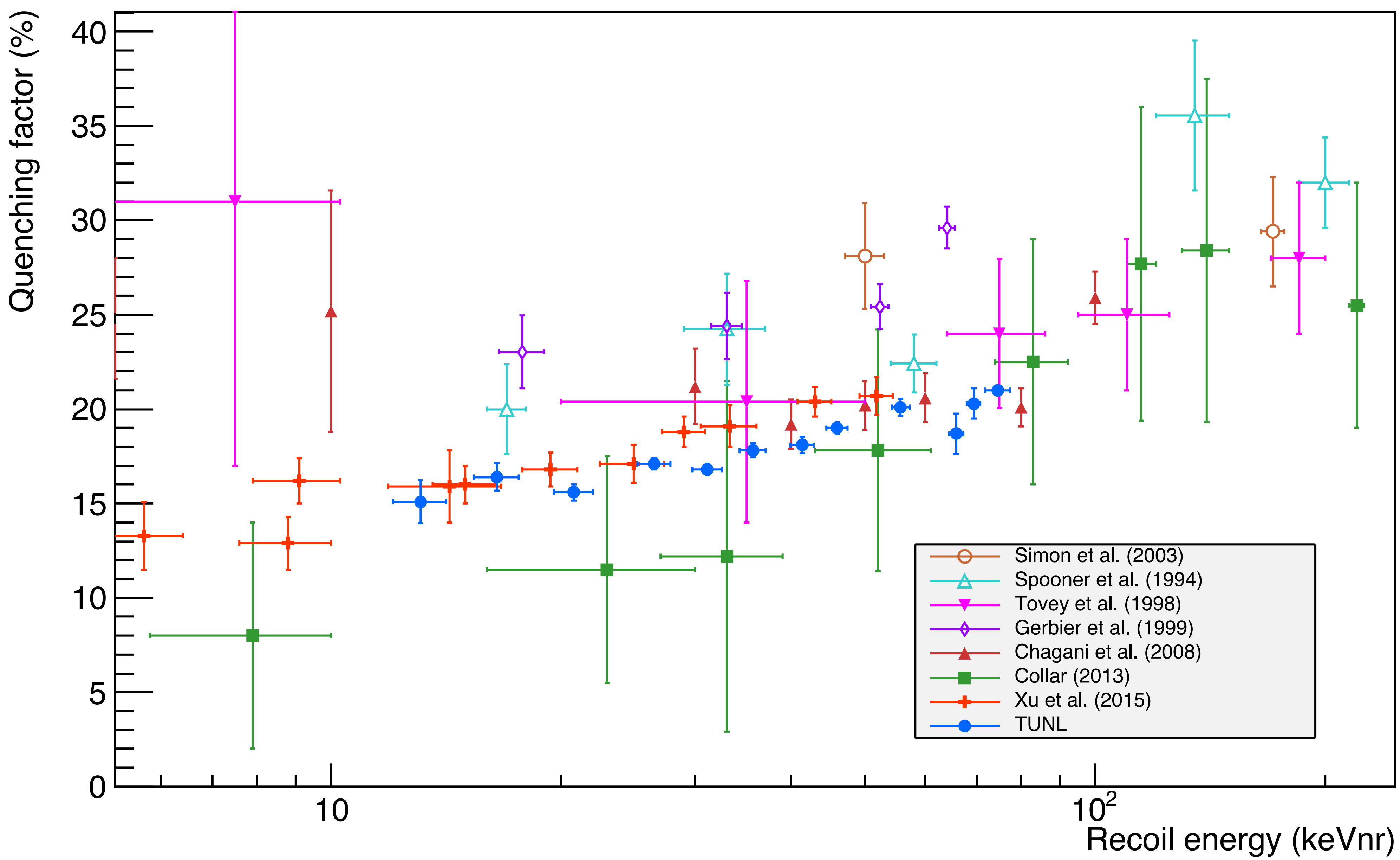
neutron collimation





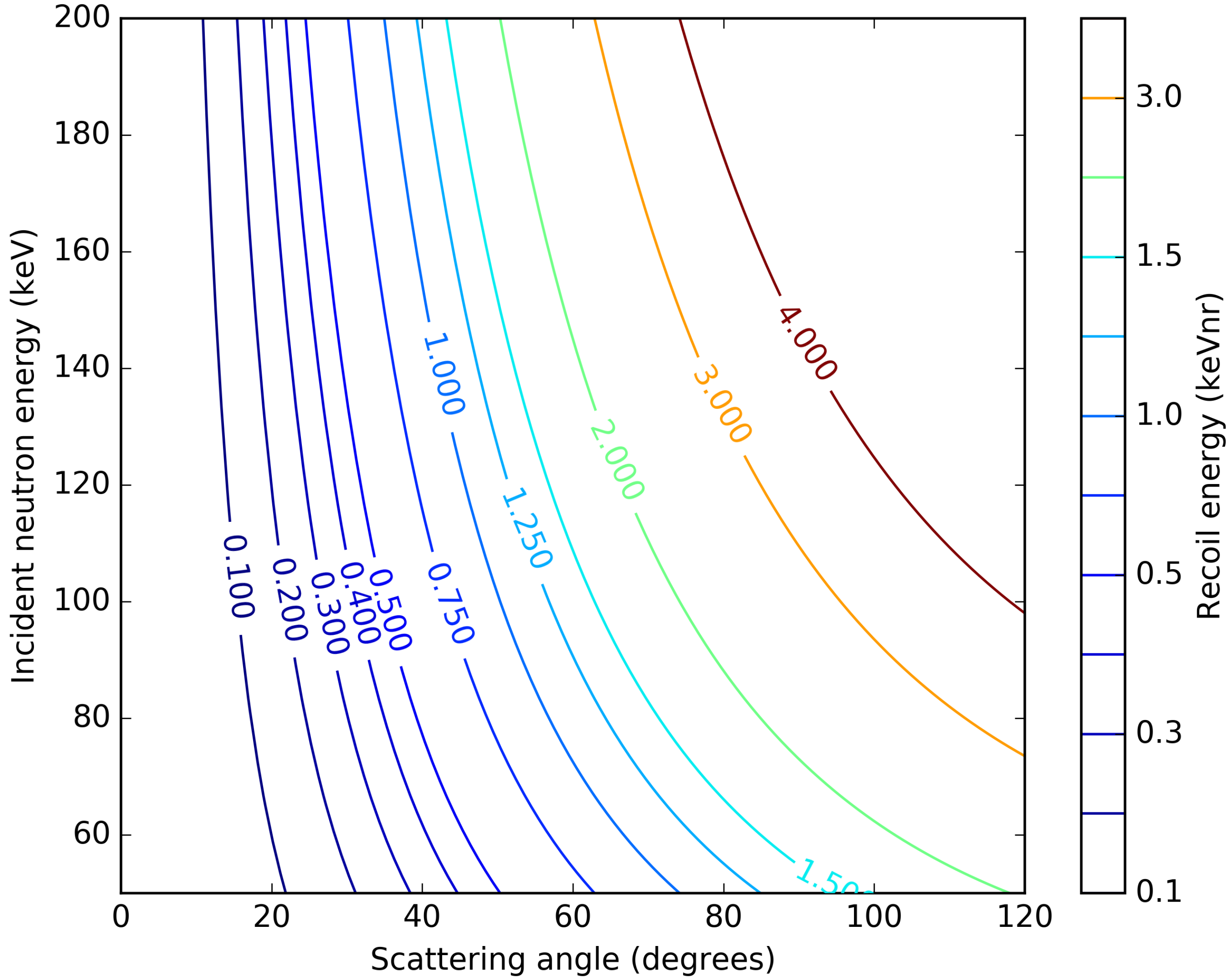
NaI[Tl]: the first precision measurement for us

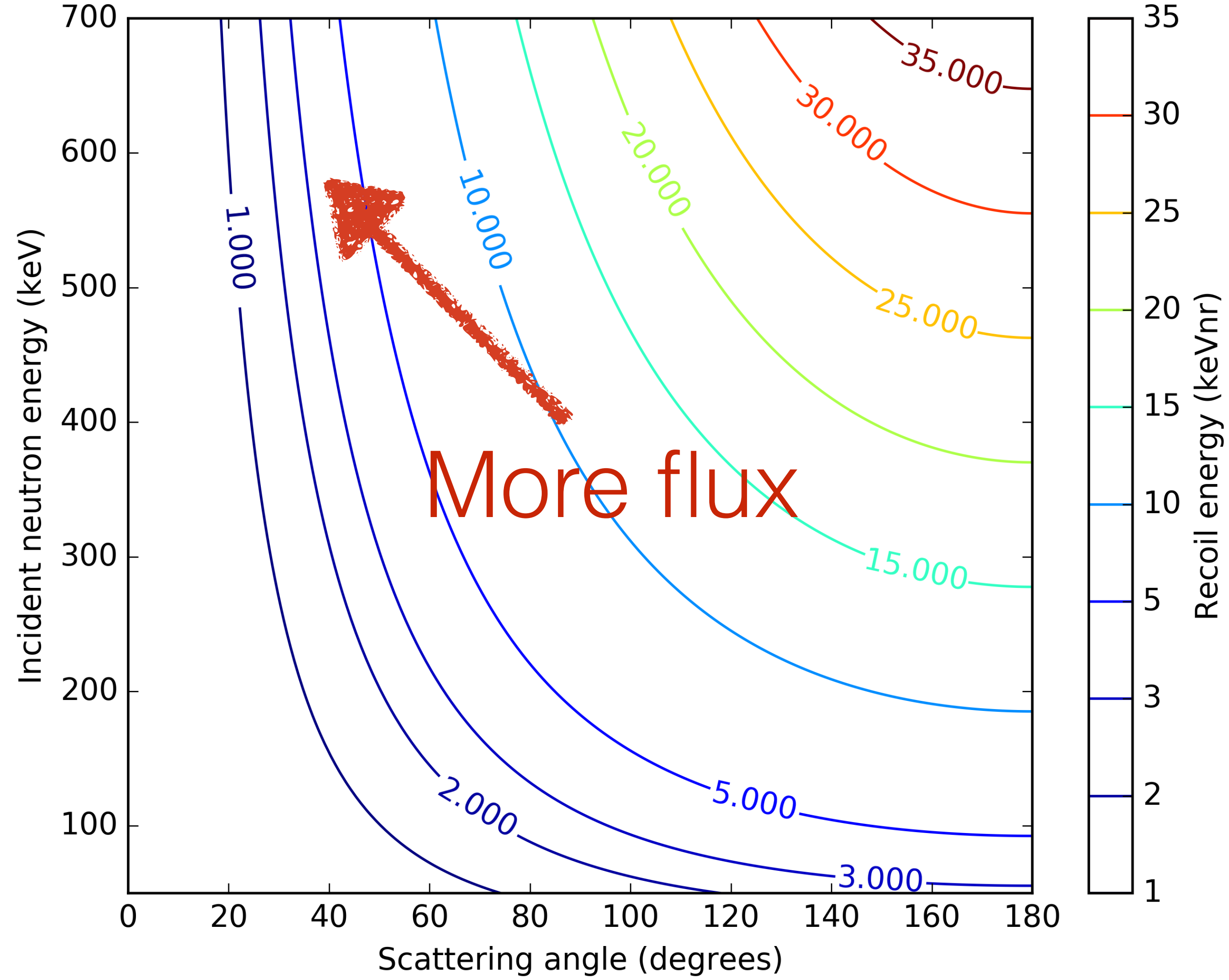
- 24 non-PSD capable backing detectors used for this run
- Backgrounds reduced with timing, but had to deal with accidental gammas, which limited the lowest energy recoils (have since moved to Ta targets, instead of Al)



Getting started: Tradeoffs — example Ge (beginning in 2 weeks)

- In this case, the aim is to look for 100 eV to 5 keV recoils
- Using these plots, we decide whether to collimate for angular resolution, or get close for more flux
- Pick out neutron source, energy. and energy resolution (100 nm-10 um LiF, D_2-Gas cell…)
- Also the number of backing detectors, angles, standoff distance (0.5-3m), pulsed or DC
- The type of backing detectors have to be selected also (**18–5” LS, 32–2” LS, 240–2” plastic, 1” LiI[Eu], …**).
- Neutron flux increases with energy (for LiF targets) and for shallower angles
- Recoil energy resolution must also be taken into account.

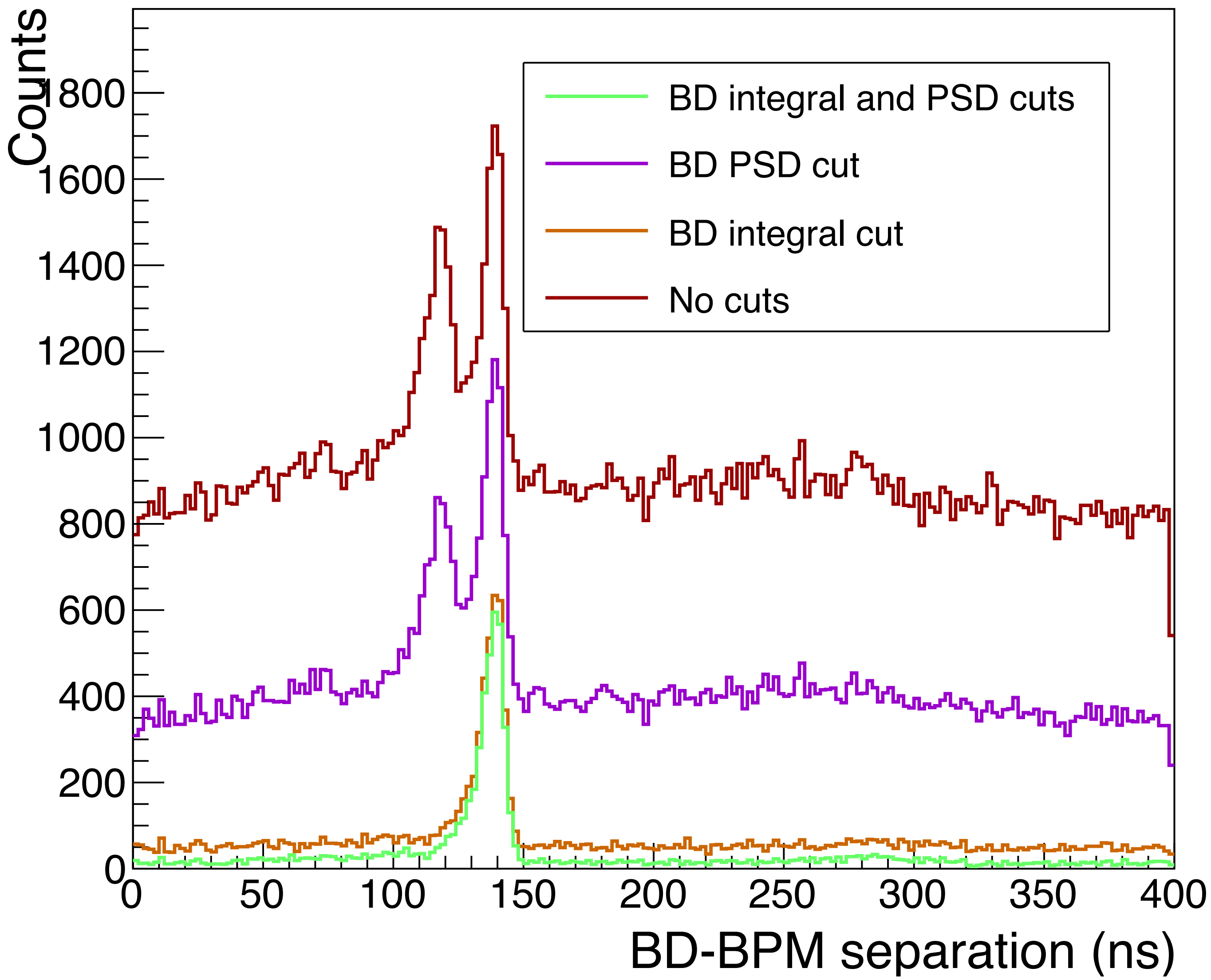


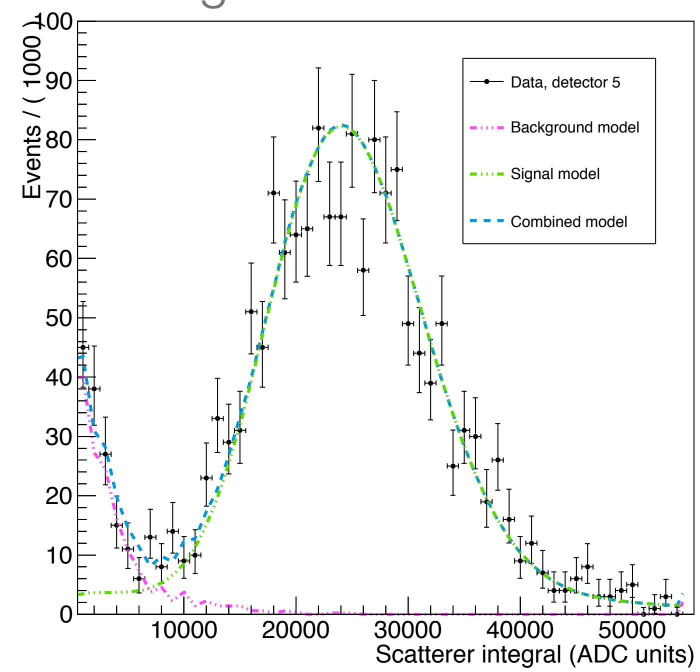


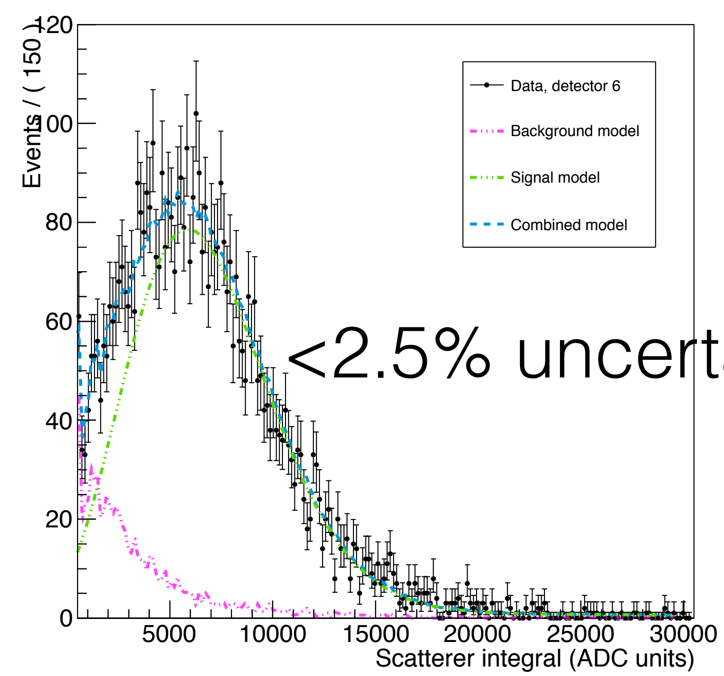
Pulsed Beams & PSD allow excellent BG rejection

- Backgrounds from accidental neutrons, gammas, inelastic scattering, and scatters off the wrong material can all be dramatically reduced with PSD, Timing and Energy cuts in the backing detectors.
- It is important to note that our most common configuration does not put a threshold on the detector of interest. We require only a coincidence between the beam pulse and the backing detector to decide when to look at the scatterer.

CsI[Na]

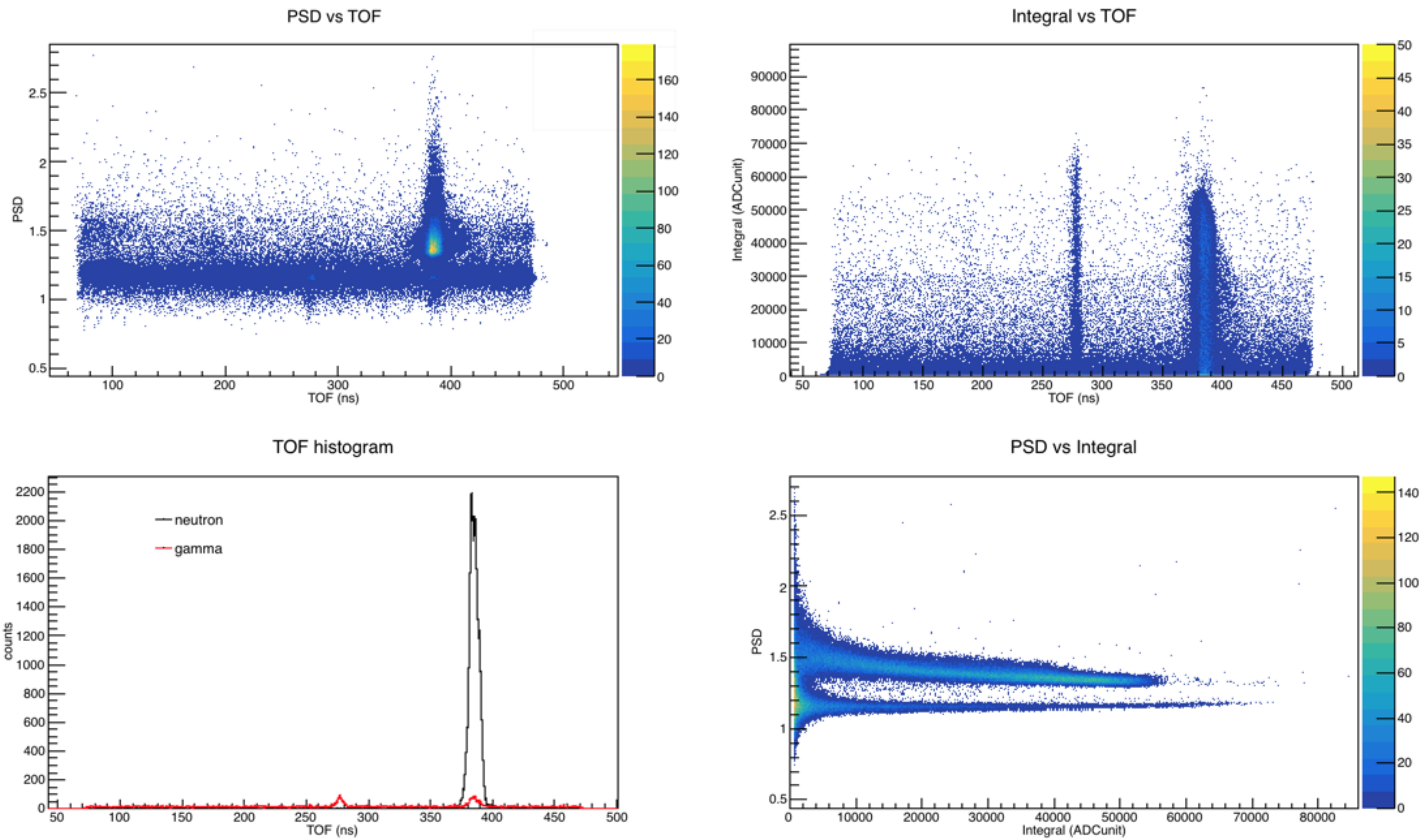






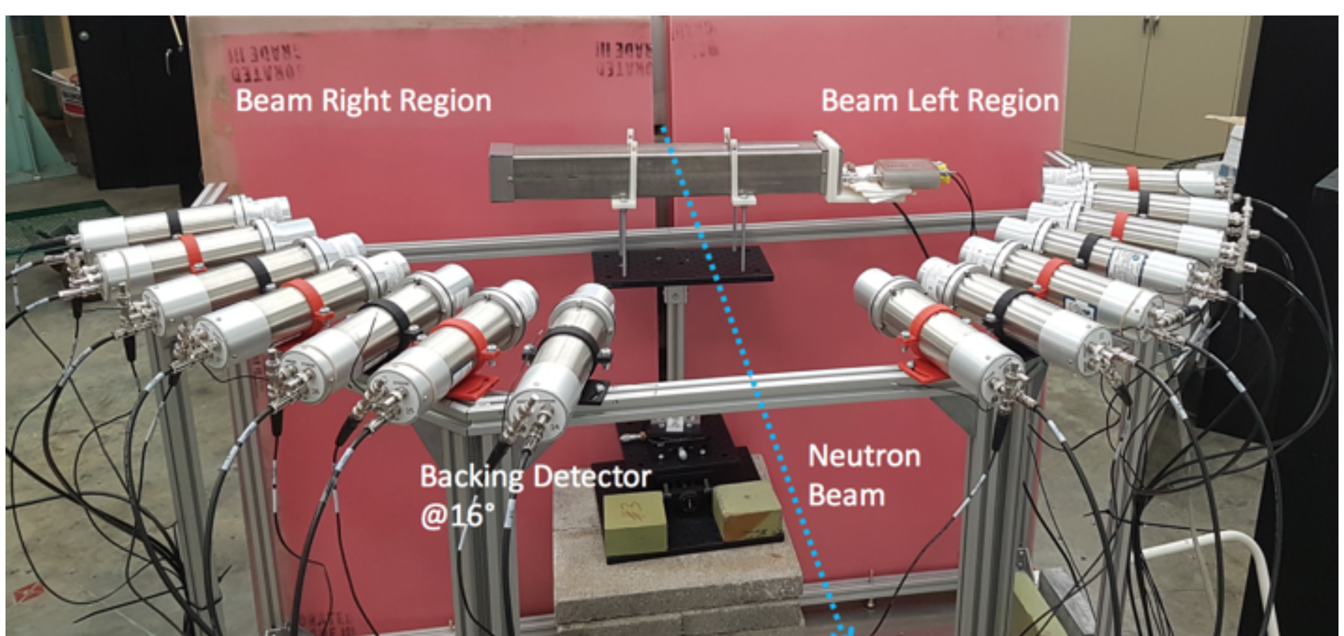
<2.5% uncertainties

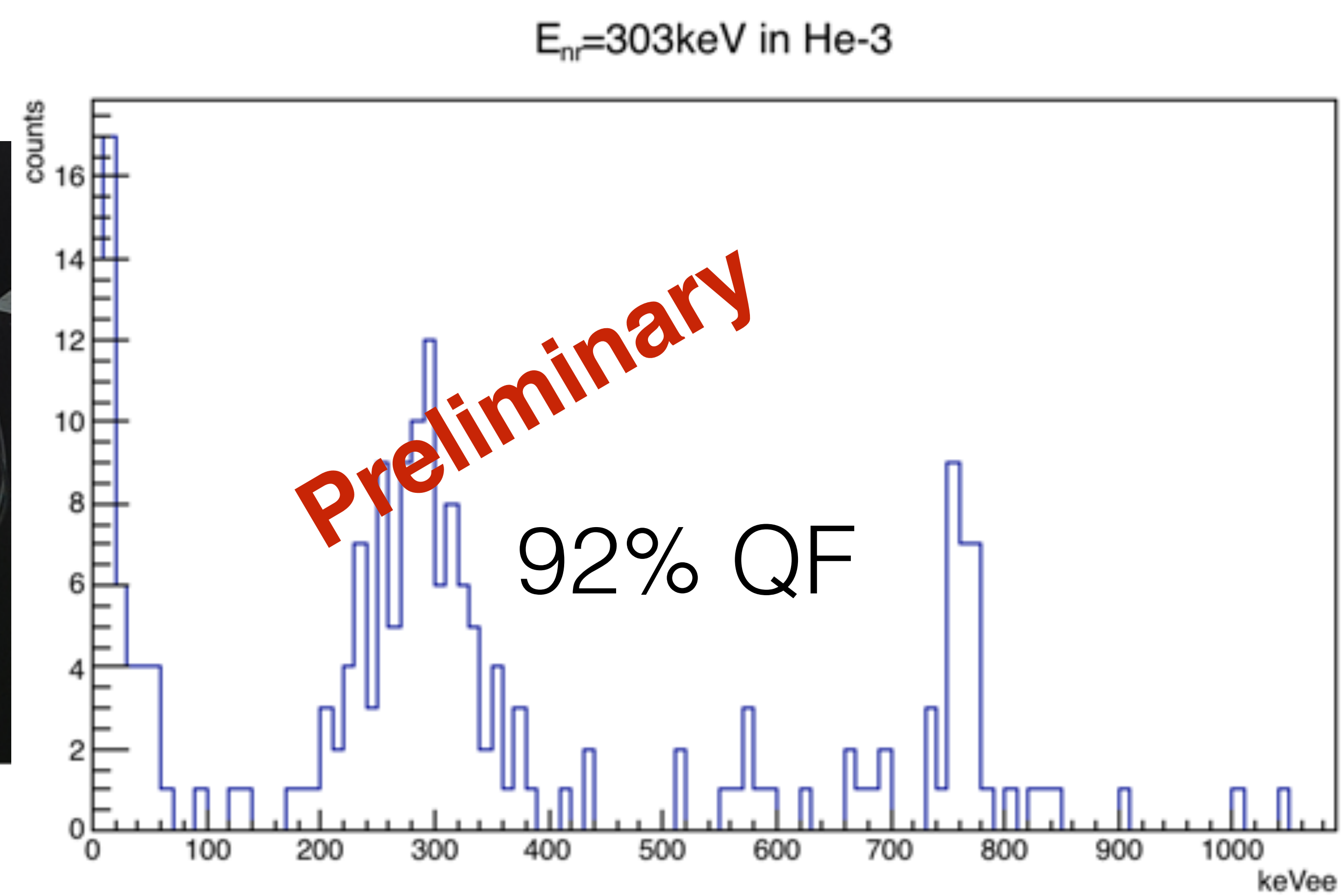
Pulsed Beams allow excellent BG rejection



Very quiet environment

- Any neutron detector that is off-axis to the collimation does not see the beam.
  - That is, the trigger rate does not change when the tandem is turned on, unless there is a detector in the neutron beam
  - Facilities all at 6 m.w.e.
- As a proof of principle, we recently performed a QF measurement on the most challenging (warm) target we could think of: He-3 gas detector.
  - Low density, lots of excess material, slow detector, swamped by thermal neutrons…





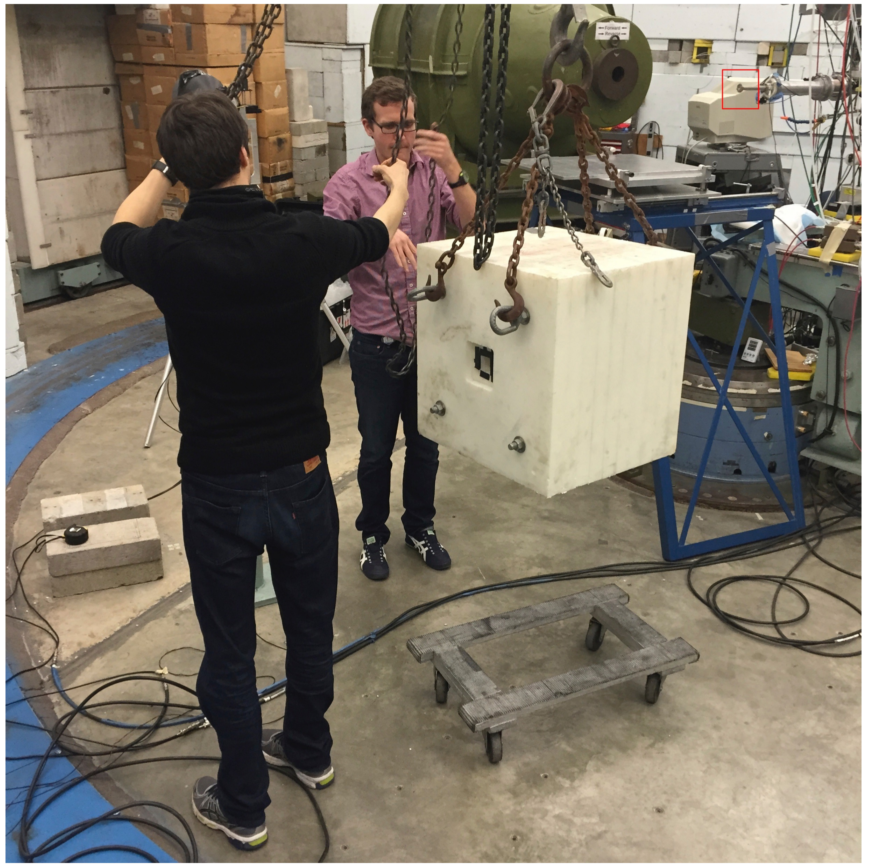
Several experiments are already planning on coming to TUNL

- Planning a campaign can be straightforward
  - Usually we will run 7-10 days at a time
  - Scheduled ~ 2 months in advance
  - More involved deployments have required more coordination
  - Typically schedule 1.5-2 months per year for these activities, but this could be increased.

- A number of groups have plans for QF measurements at TUNL, have measured in the past, or have plans to be visiting soon to investigate firsthand. (visits can be arranged with Seminars to defer costs)
  - LXe measurement for Dark Matter (Luca Grandi—UofC)
  - Si recoils for DAMIC and CONNIE (Juan Estrada—FNAL & Paolo Privatera—UofC)
  - LAr and LXe for Dark Matter and Coherent Neutrino Scattering (Adam Bernstein & Jingke Xu—LLNL)
  - Stilbene channeling (John Mattingly—NCSU & CNEC)
  - SuperCDMS (Tali Figueroa— NWU and Tarek Saab—UFL)
  - ANAIS Dark Matter (Clara Cuesta—U Madrid)
  - HPGe (Juan Collar—UofC, Dave Reyna—Sandia)
  - Stockpile Stewardship Program (Alex Glaser—Princeton)
  - Micro-Chandler (John Link—VaTech)
  - Pure NaI cooled (Liu Jing—USD)
  - Water Bubble chambers (Matt Szydagis—SUNY Albany)
  - Gas detectors (Sven…I'm looking at you!)
  - + Barbeau Group: isobutane, He, CO_2, CF_4, N_2, CaF2, NaI[Tl] channeling, BGO, CeBr3…

There ain't no such thing as a free lunch… …it's just cheap

- TUNL provides the beam-time at no cost
- There is an $80 setup fee for technical support on the front end.
- The graduate students operate the beam. If they collaborate on the effort (and if they are interested in the project, or it aligns well with already funded effort) then the time they spend on the beam is free.
  - All of them have experience measuring these parameters
- If the students are just acting as operators then the cost is ~$3k per week per 8 hour shift when the beam is running.
  - so 24 hour per day runs are ~$9k/week.
  - No setup/takedown costs

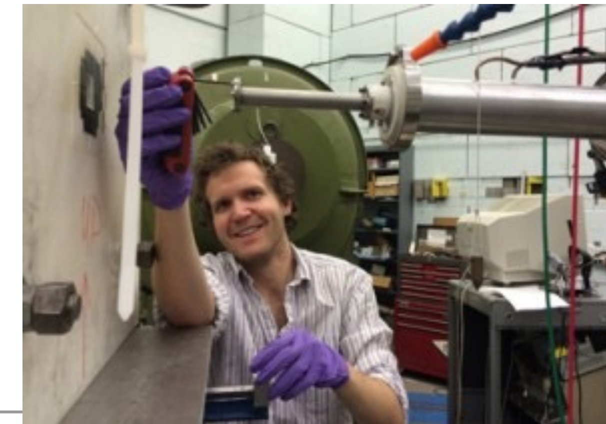


Upgrades/improvements

- DAQ, HV, PMTs, Backing detectors, shields, digitizers, etc…already exist.
- We can improve the backgrounds when using the 240 backing detector array by recording more than just the hit pattern.
  - $135-285k for electronics
- We can improve the timing resolution of the beam by ~40% by increasing the injection energy of the beam.
  - ~$100k for the transformer
- We can dramatically increase our backgrounds for low energy neutrons by using LiI[Eu] scintillators (fast capture on Li-6 results in an alpha for PSD).
  - An array of these for shallow angles will cost $150k.

The Barbeau group is there to help

https://sites.duke.edu/barbeaugroup/
https://twitter.com/NaIvE_SNS
https://twitter.com/theLeadNube
https://twitter.com/TheRealFeNube




- Graduate Students - **Grayson Rich** (UNC, Duke); **Justin Raybern** (Duke); **Long Li** (Duke, ECA); **Sam Hedges** (Duke), **Connor Awe** (Duke), **Peibo An** (Duke)
- Other DUKE/TUNL GS help - **Colin Malone, Ron Malone, Forrest Frieson**
- Undergraduate Students that have helped (**current**)
  - Year-Round - **Ben Suh** (Physics - Duke), **Katrina Miller** (Physics/Math - Duke), **Darshana Jaint** (EE/Physics - Duke), **Anna Torre** (BioPhysics - Duke), **Stuart Ki** (Physics - Duke), **Megan Conway** (Physics-Duke), **Sikunder Hanif** (Physics-Duke), **Matthew Dickson** (EE/Physics-Duke)
  - Summer - **Claire Leadbetter** (UNC - Biology)
  - Summer TUNL REU - **Aaron Manger** (IUFW - Physics), **Shaquann Siedrow** (HSC - Physics), **Kirollos Masood** (UF - Physics), **Adele Zawada** (Case Western - Physics, ME)
- High School - Max Kramer (NCSSM) + 3 more this summer