Implementation of digital DAQ system for coincidence (p,α) scattering experiment

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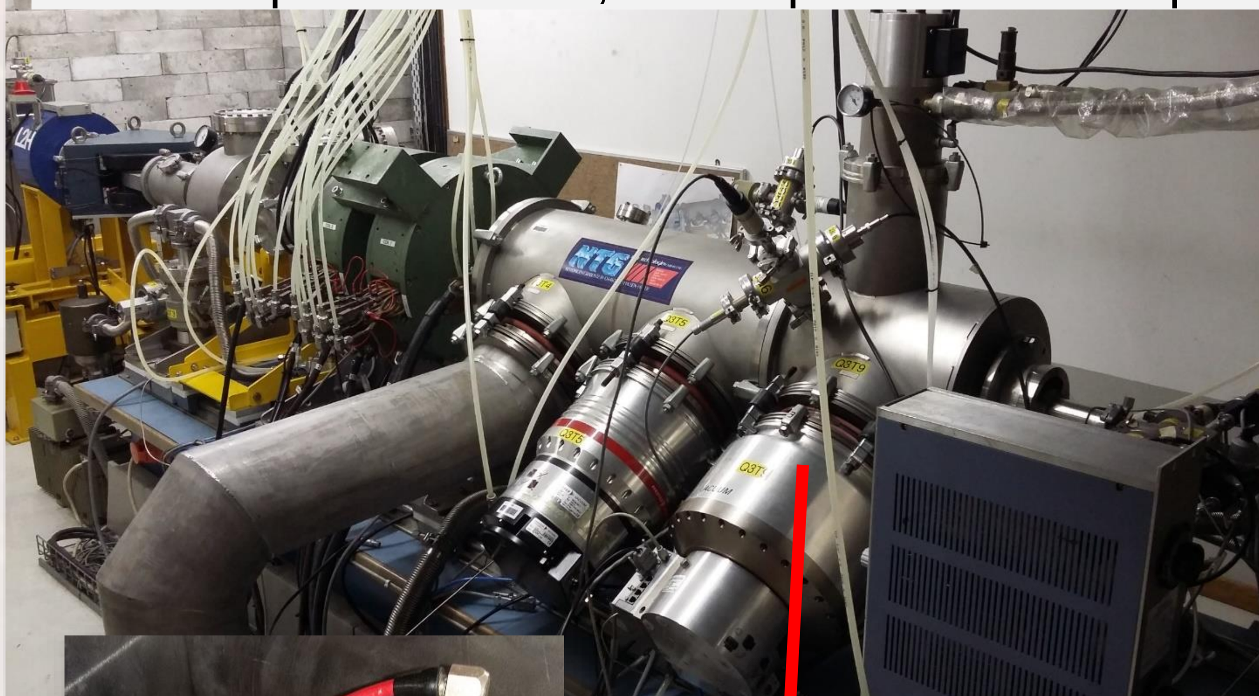
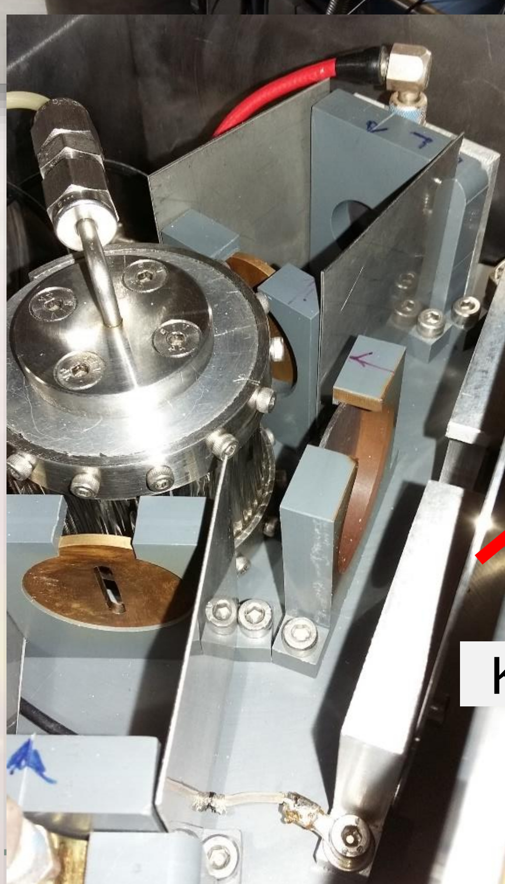
Physics

National Research Foundation
iThemba LABS
Laboratory for Accelerator Based Sciences

Sensitivity of the pre-equilibrium (*p,α*) reaction mechanism to cluster preformation in several stable isotopes of Sn

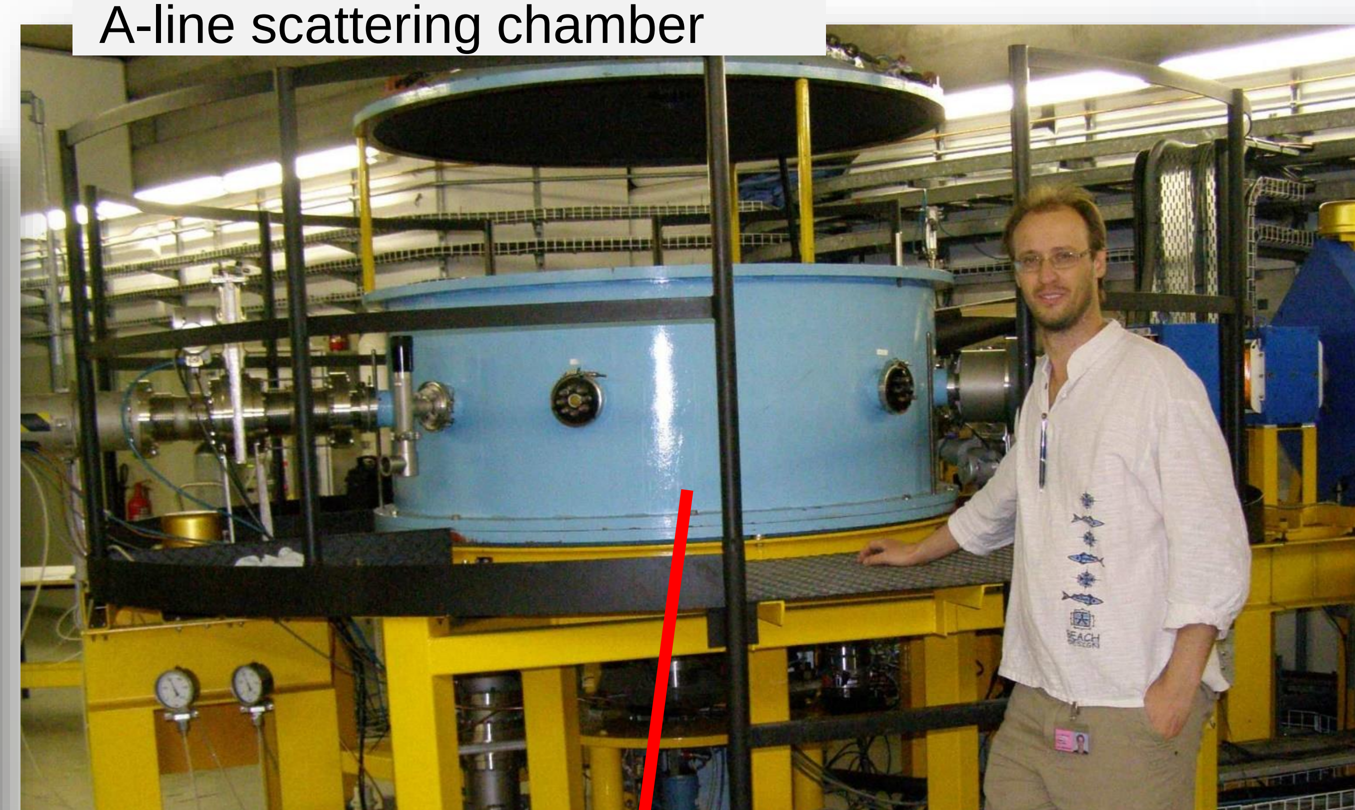
Polarised proton source, 10 s “up” and “down” flips

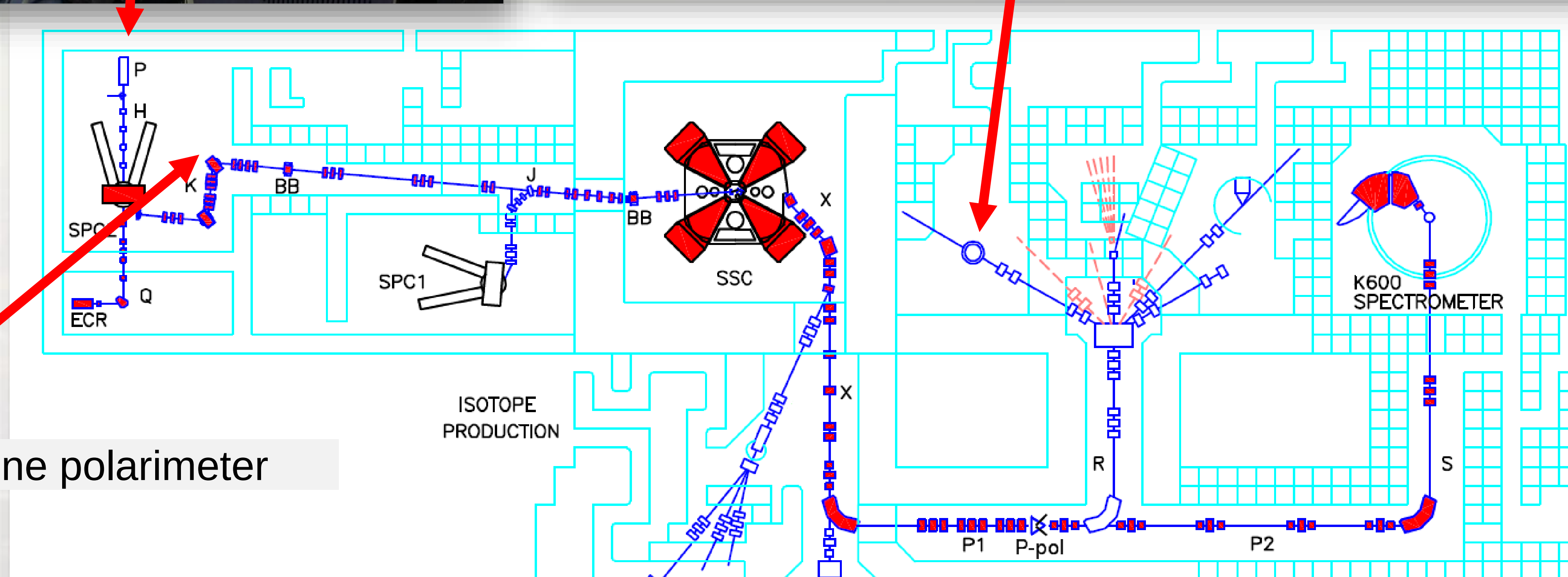




K-line polarimeter

A-line scattering chamber

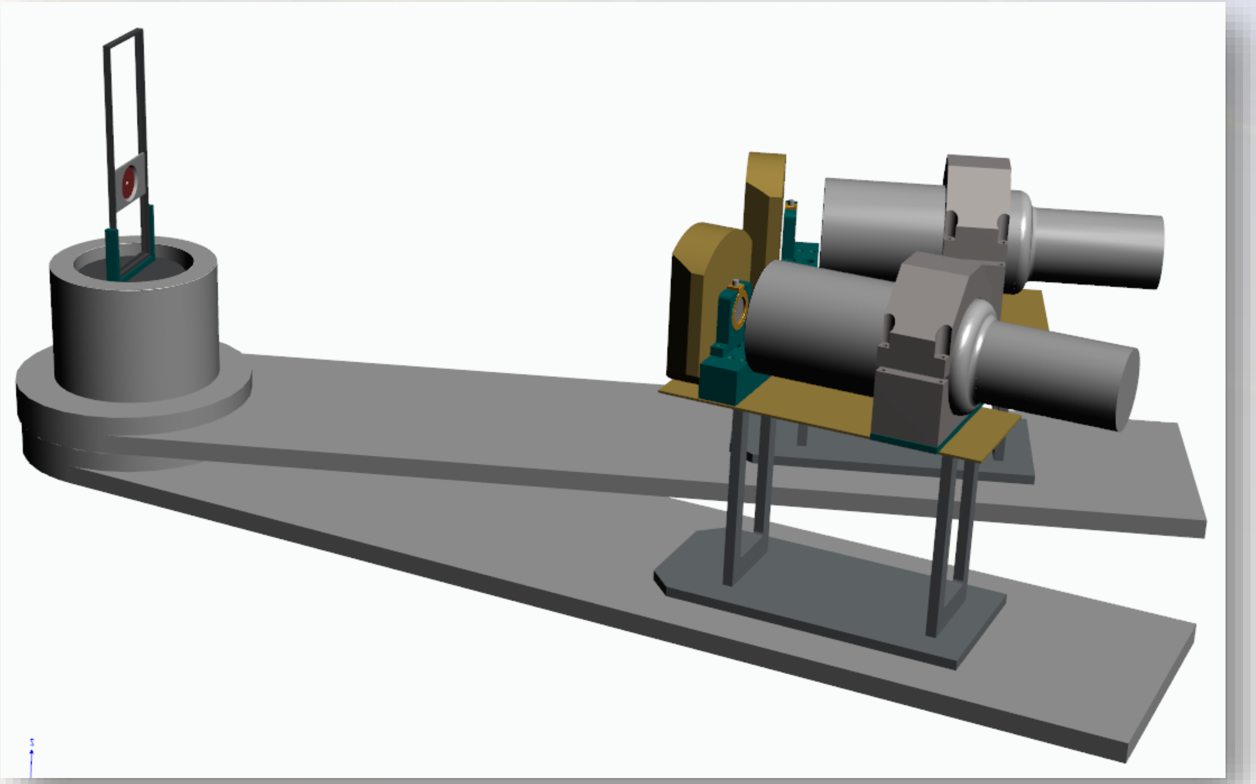




- Inclusive (p,α) measurements on $^{112,116,120,124}Sn$ targets with a 150 MeV polarised proton beam at several scattering angles from 15º to 60º

- **Two detector telescopes**, mounted coplanar on opposite sides of the beam direction in the 1.5 m diameter scattering chamber

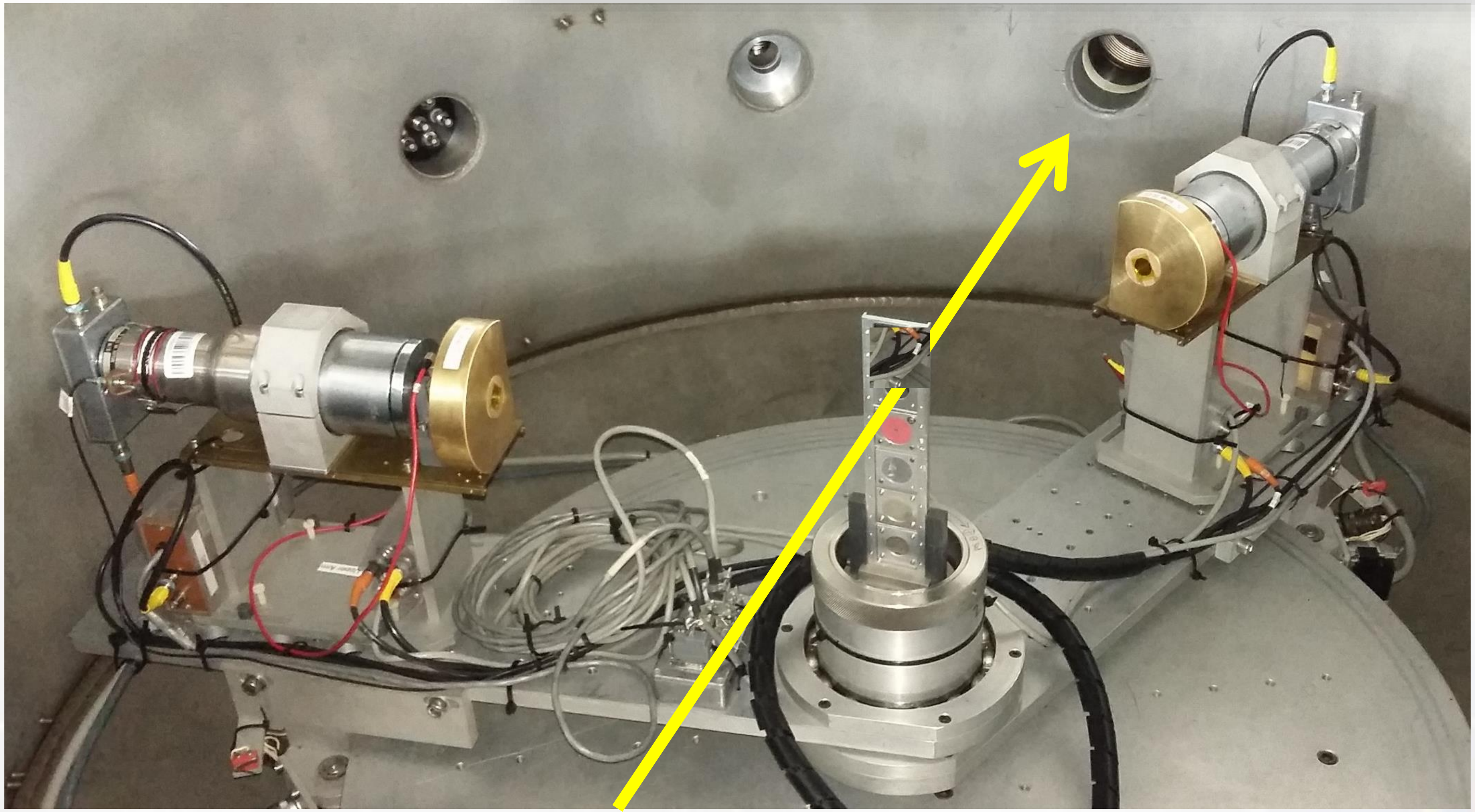
- Standard **ΔE - E detector setup** with an acceptance solid angle of about 1.1 msr.



- 500 μm Si ΔE detectors

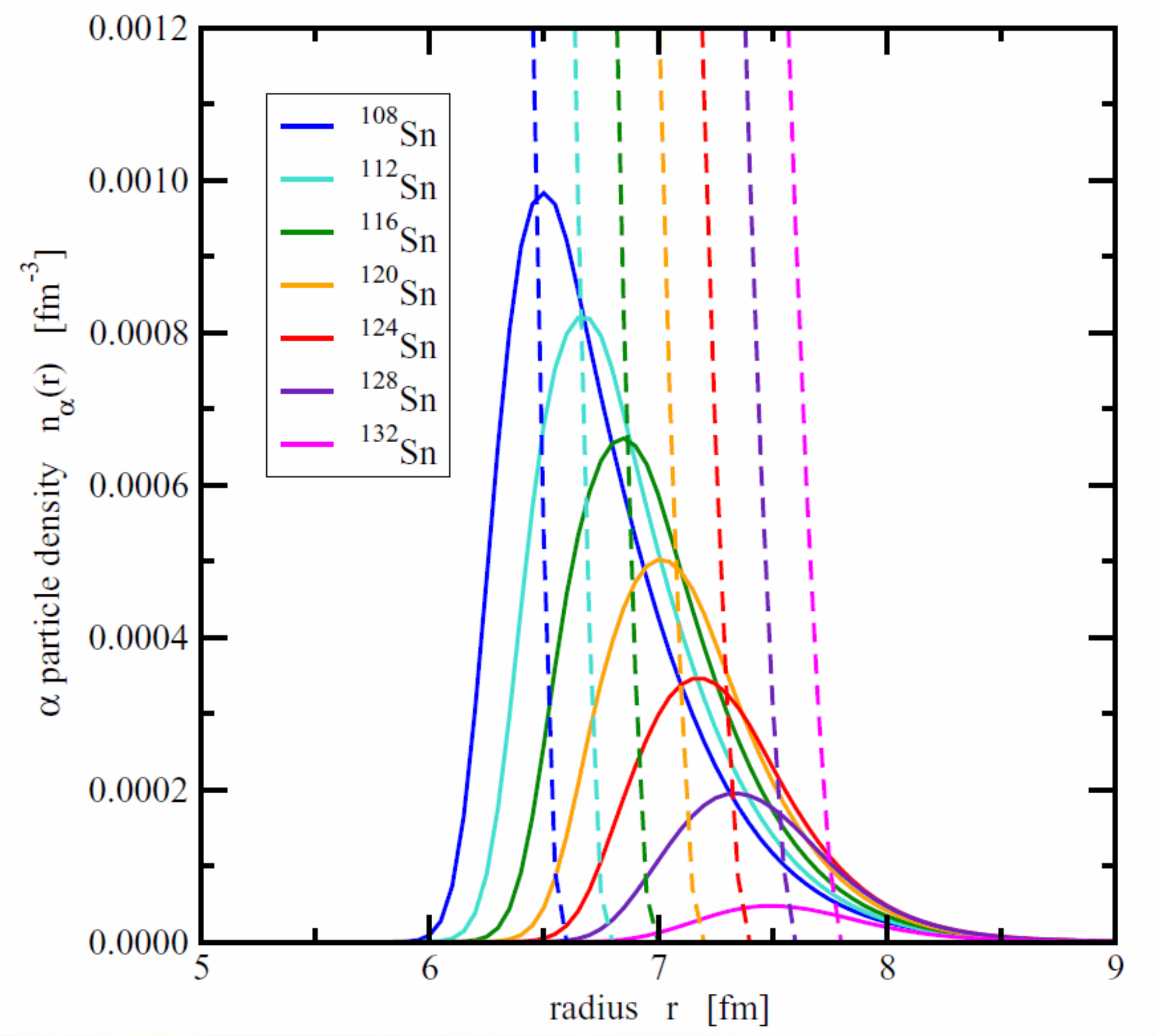
- 3" x 5" NaI E detectors

- Target foils of $^{112,116,120,124}Sn$ (1 - 10 mg cm^{-2})

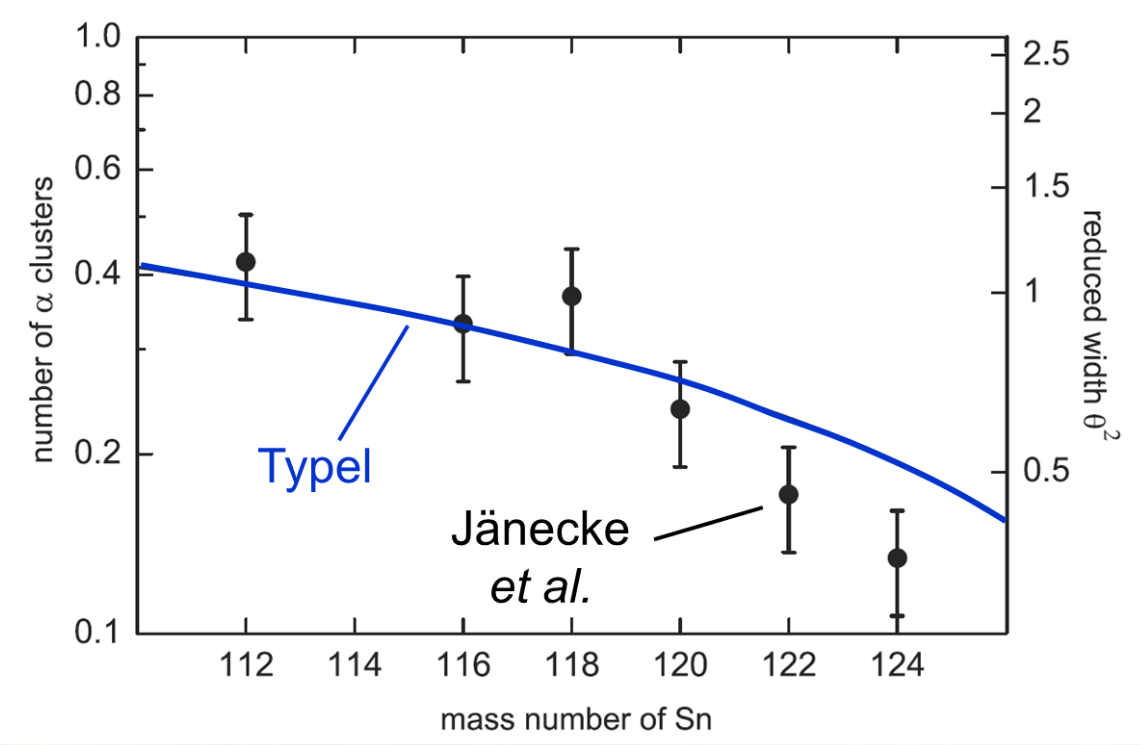


Why did we do this?

- Inclusive pre-equilibrium (p,α) studies indicate α-knockout process depends largely on α-cluster preformation probability in nuclei
- General relativistic mean-field EoS theory suggest α-cluster probability is peaked near **surface** of nuclei
- Appears **largest for lower mass** isotopes (i.e. smaller N number) – also confirmed by $^{112\text{-}124}$Sn(d,^{6}Li)$^{108\text{-}120}$Cd **α-transfer reaction studies** (Jänecke *et al.* *Nucl. Phys.* ***A325***, 337, 1979)

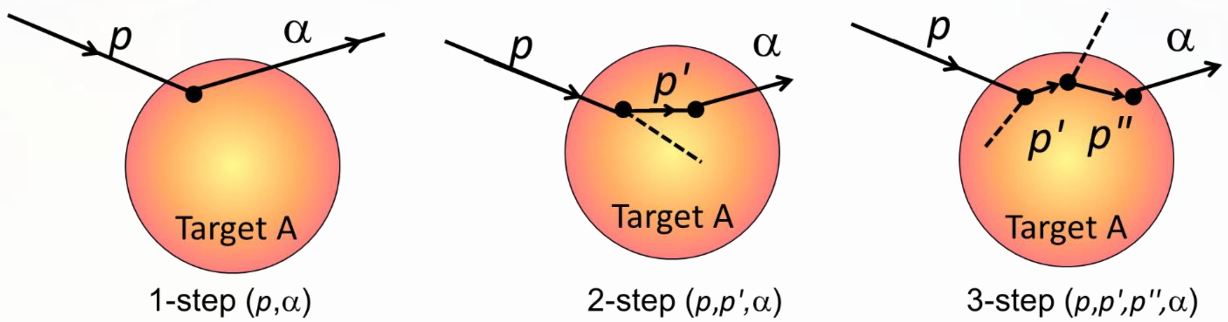


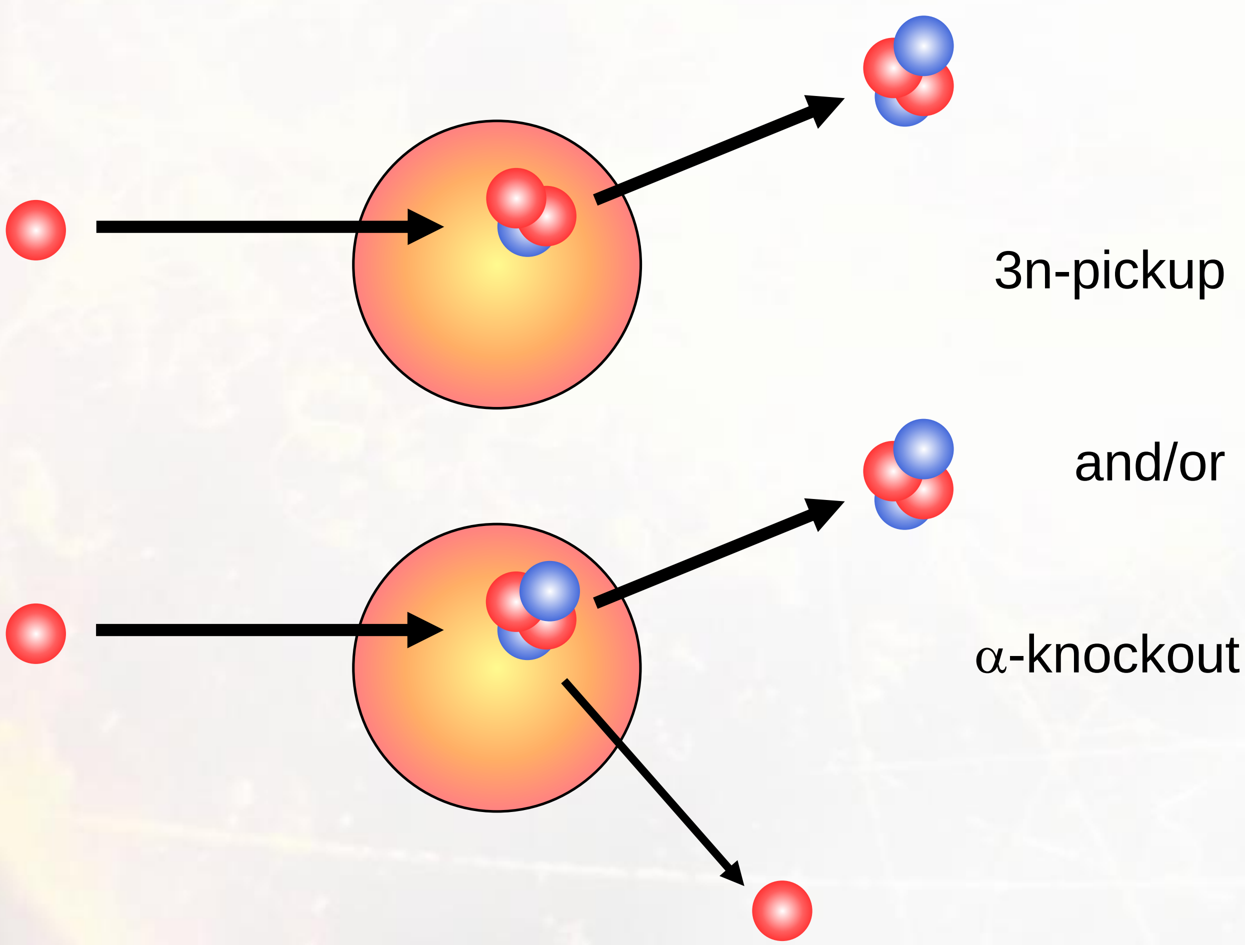
Radial density distribution of α particles (solid) and neutrons (dashed) for set of Sn isotopes.
S. Typel, *Phys. Rev. C* ***89***, 064321 (2014)



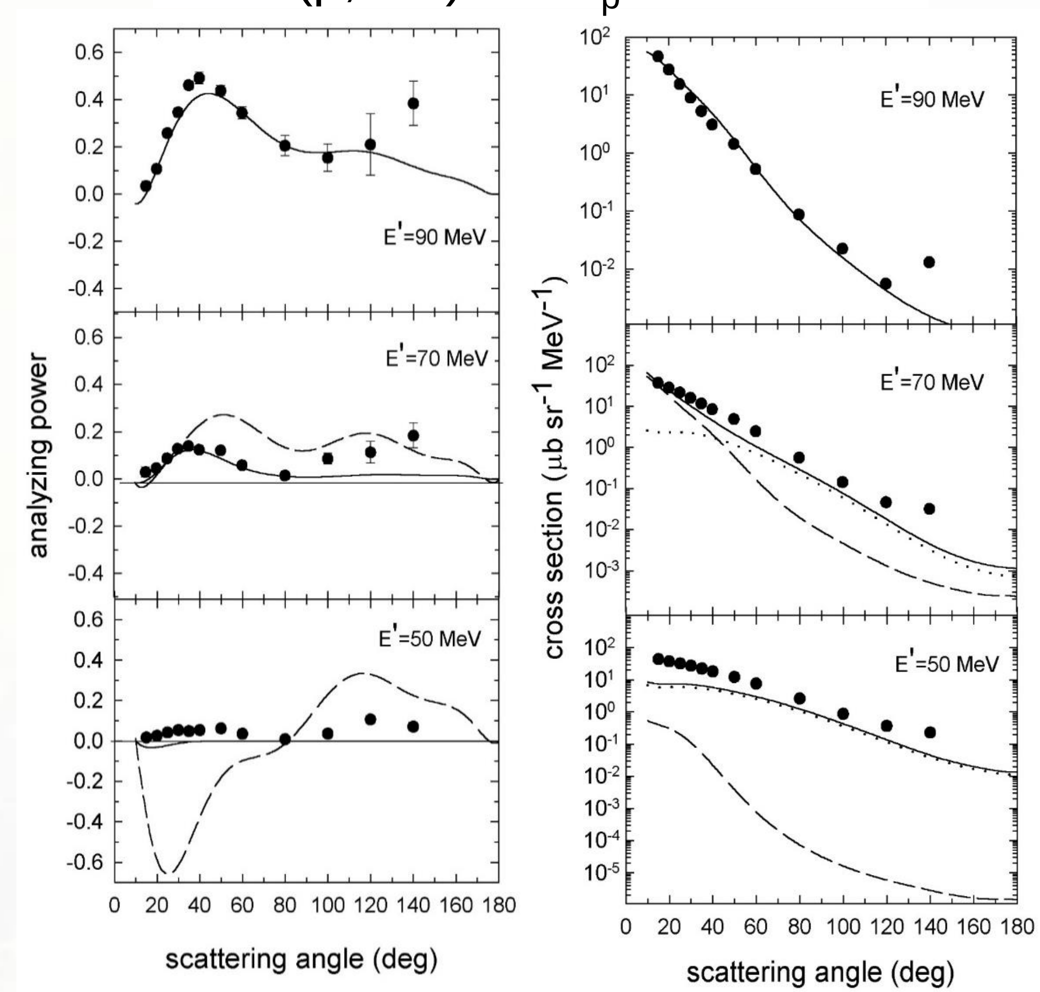
Cowley, Phys. Rev. C **93**, 054329 (2016)

- Studies of α-clustering in nuclei NB for equation of state for astrophysical properties, effect on neutron-skin thickness, and α decay.
- Also important to understand mass dependence of reaction mechanisms producing composite particle emission
- Statistical multistep direct emission (SMDE) theory of Feshbach, Kerman, and Koonin (**FKK**) well understood
- (*p*,α) reaction - two possible mechanisms



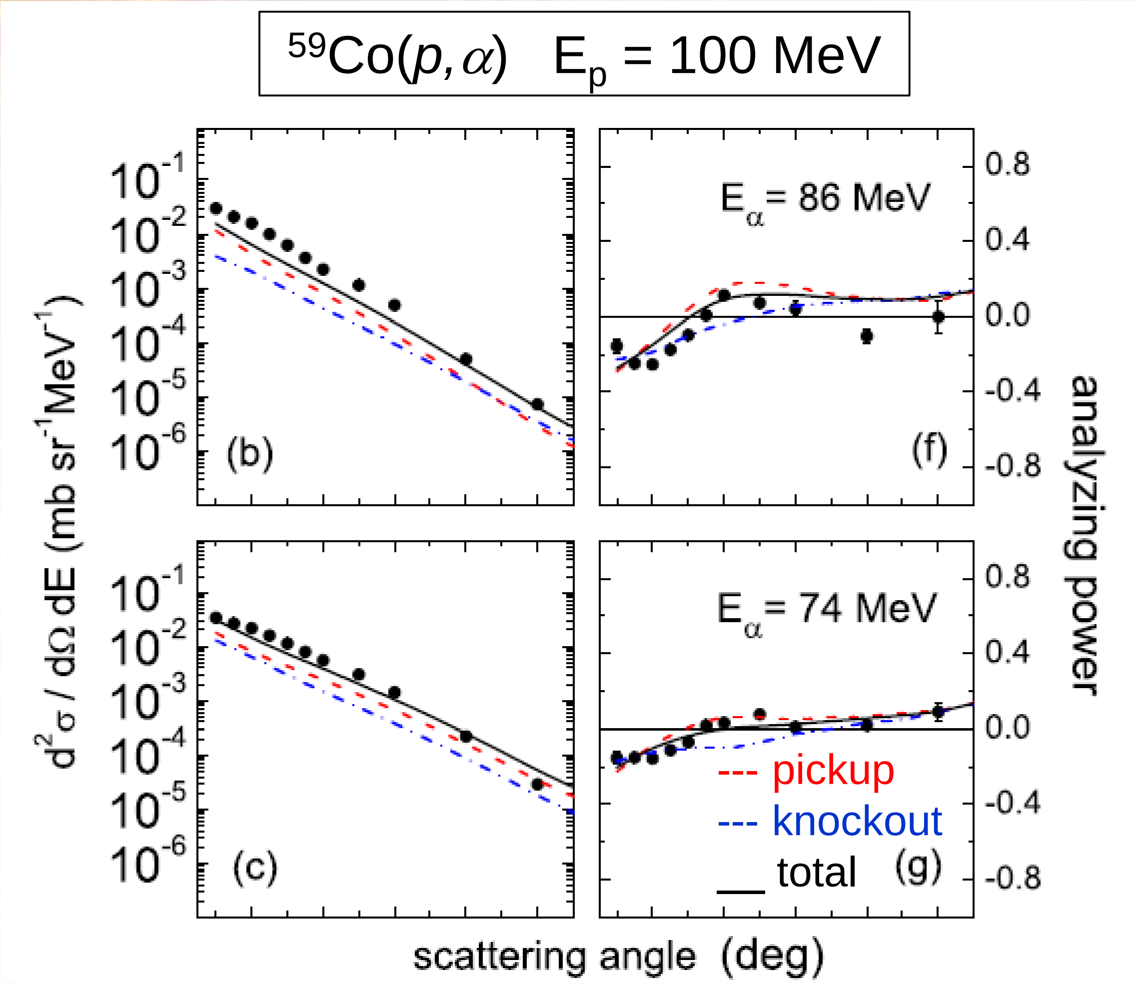


^{93}Nb(p,^{3}He) at E_p = 100 MeV

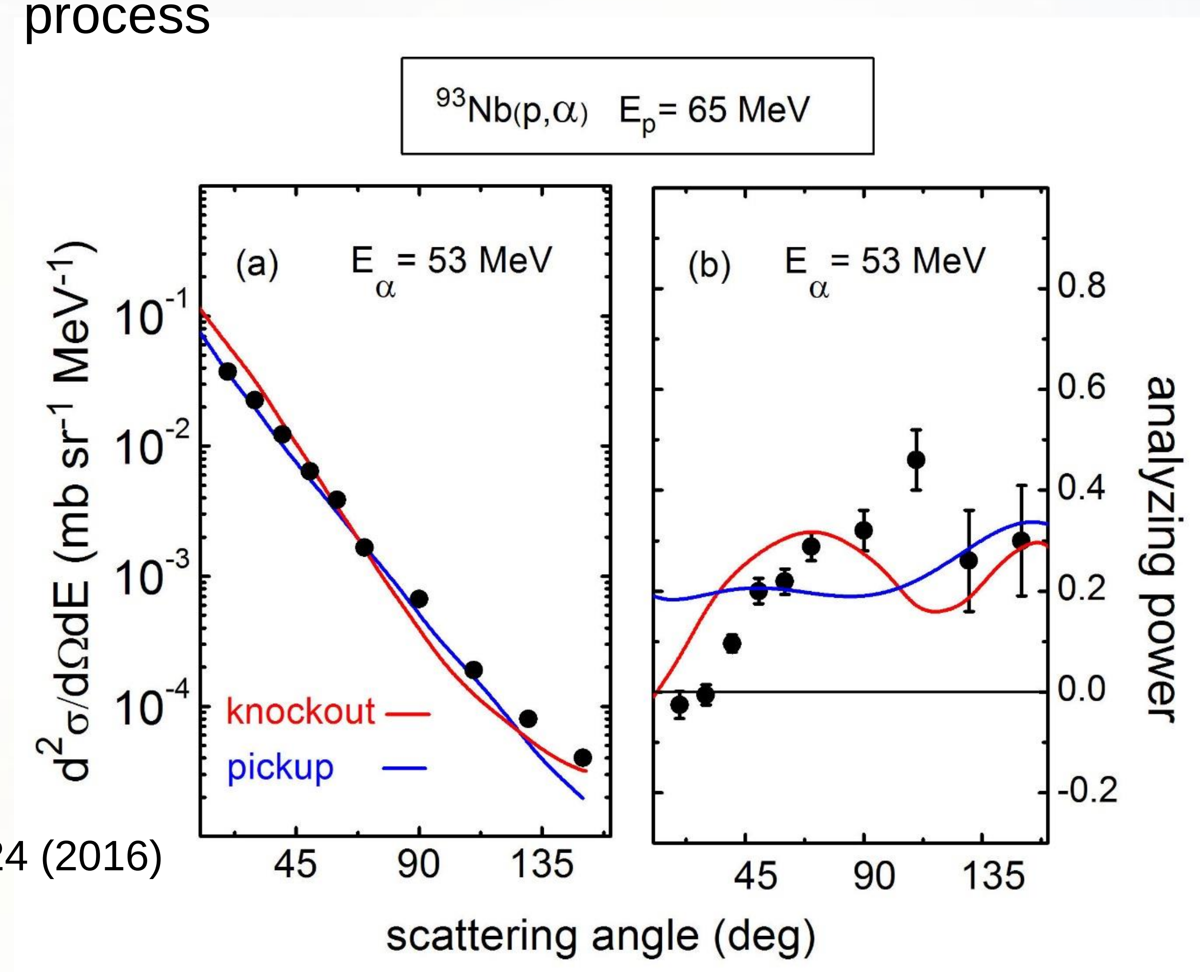


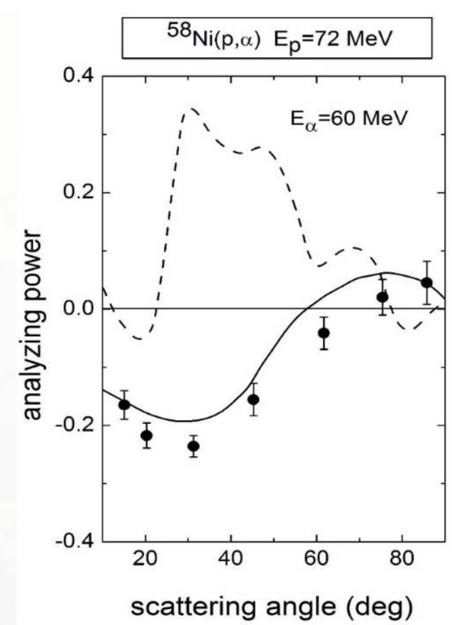
Cowley *et al.*, Phys. Rev. C **62**, (2000) 064605

- Unexpected and interesting feature of recent investigation at 100 MeV - pickup mechanism now competes strongly with a knockout process



Cowley *et al.*, Phys. Rev. C **93**, 034624 (2016)



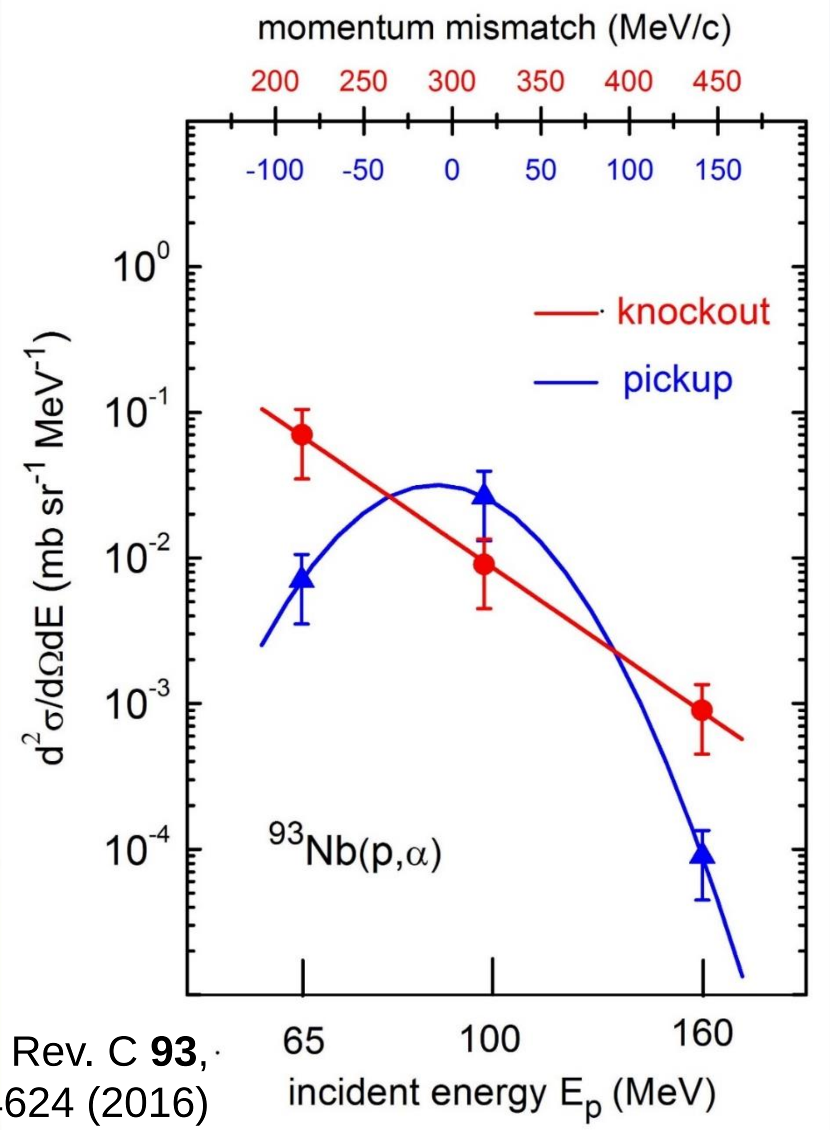


- In strong contrast with the trend at both higher (160 MeV) and lower (65 MeV) incident energies where knockout appears to dominate

- **Analysing power** as indicator of relative contributions of knockout and pickup

Bonetti *et al.* Nucl Phys **A499** (1989) 381

- **Knockout** and **pickup** contributions to the total cross section of e.g. ^{93}Nb(p,α) reaction at incident energies between 65 MeV and 160 MeV - strongly related to the **large momentum mismatch** between the momentum transfer and the orbital angular momentum

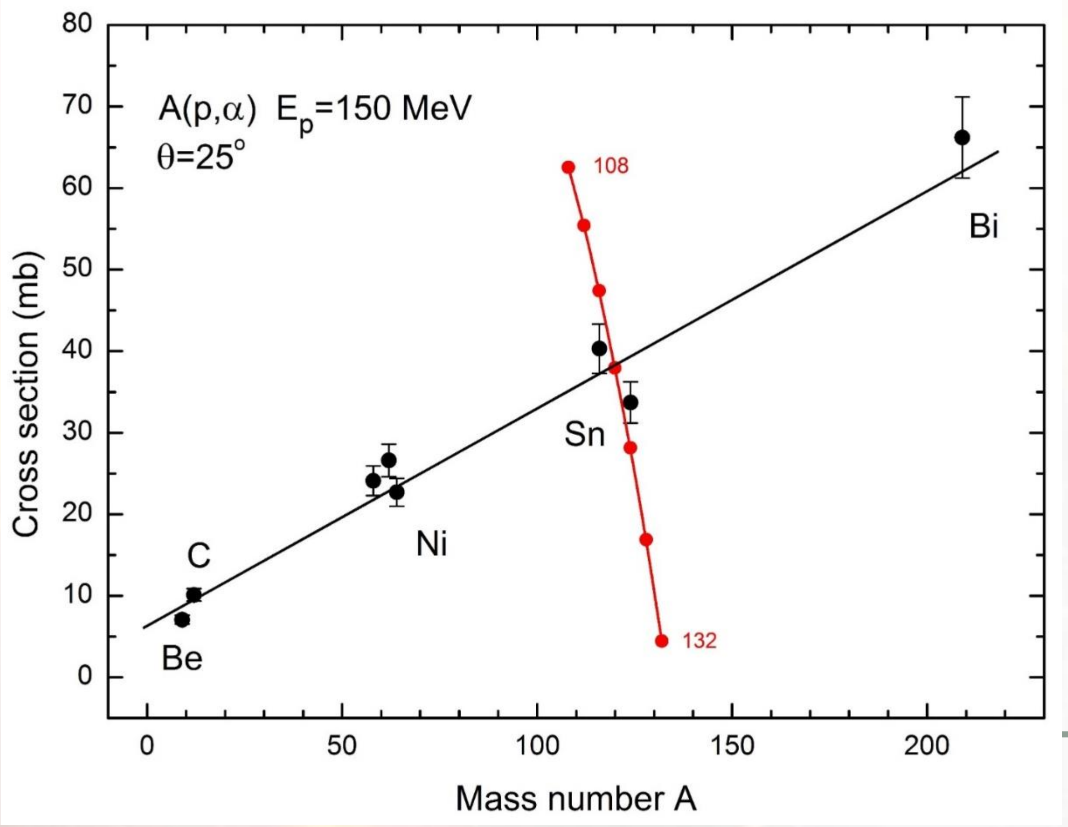


Cowley, Phys. Rev. C **93**, 034624 (2016)

- **Knockout** cross section drops of nearly exponentially with increasing incident energy - momentum difference grows with increasing incident energy

- Three-nucleon **pickup** mechanism dominates at ~100 MeV where the combination of angular-momentum transfer L and q is favourable.

- The combined effect is an enhanced contribution of the knockout mechanism at the lower 65 MeV and higher 160 MeV projectile energies and an almost equal mixture of knockout and pickup in between.

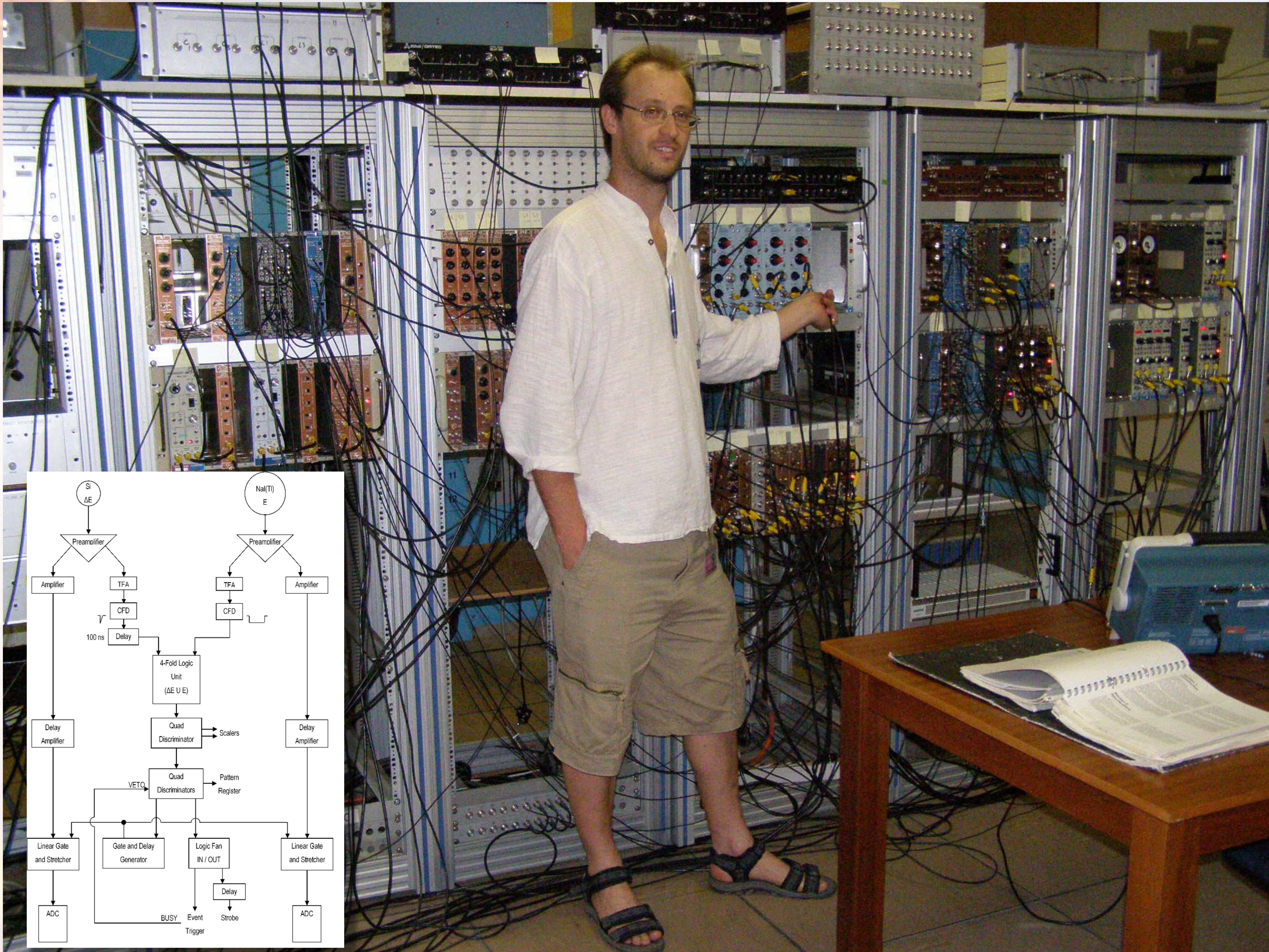


Courtesy of AA Cowley, data from Segal *et al., Phys. Rev. C* **32**, 721 (1985)

- Measure influence of isotopic mass (indicative of the **preformation probability of α clusters**) on the **pre-equilibrium α-knockout** cross section through systematic investigation on selection of Sn isotopes (^{112,116,120,124}Sn) at 150 MeV (or better, 65 MeV)

The experiment…

- All previous successful polarised pre-equilibrium (p,α) reaction studies done at only few labs including RCNP and iThemba LABS – of which only iTL may still be able to do it...?
- Simple, yet tried and tested method – many years' experience
- However, facility **constraints** have made it difficult to perform these otherwise simple experiments:
    - Old CAMAC interface, obsolete VAX-based XSYS data acquisition system – unsupported
- Expertise and support for the newer VME front-end and XIAFE/MIDAS back-end used in the K600 Spectrometer setup, or the XIA PIXIE-16 digital front-end and MIDAS back-end (time constraints).
- Ideal opportunity to initiate a suitable DAQ/setup upgrade for A-line S.C. facility – future experiments
- Maintenance of polarised ion source facility, staff training


Si
ΔE
NaI(Tl)
E
Preamplifier
Preamplifier
Amplifier
TFA
TFA
Amplifier
CFD
CFD
100 ns
Delay
4-Fold Logic
Unit
(ΔE U E)
Delay
Amplifier
Quad
Discriminator
Scalers
Delay
Amplifier
VETO
Quad
Discriminators
Pattern
Register
Linear Gate
and Stretcher
Gate and Delay
Generator
Logic Fan
IN / OUT
Linear Gate
and Stretcher
Delay
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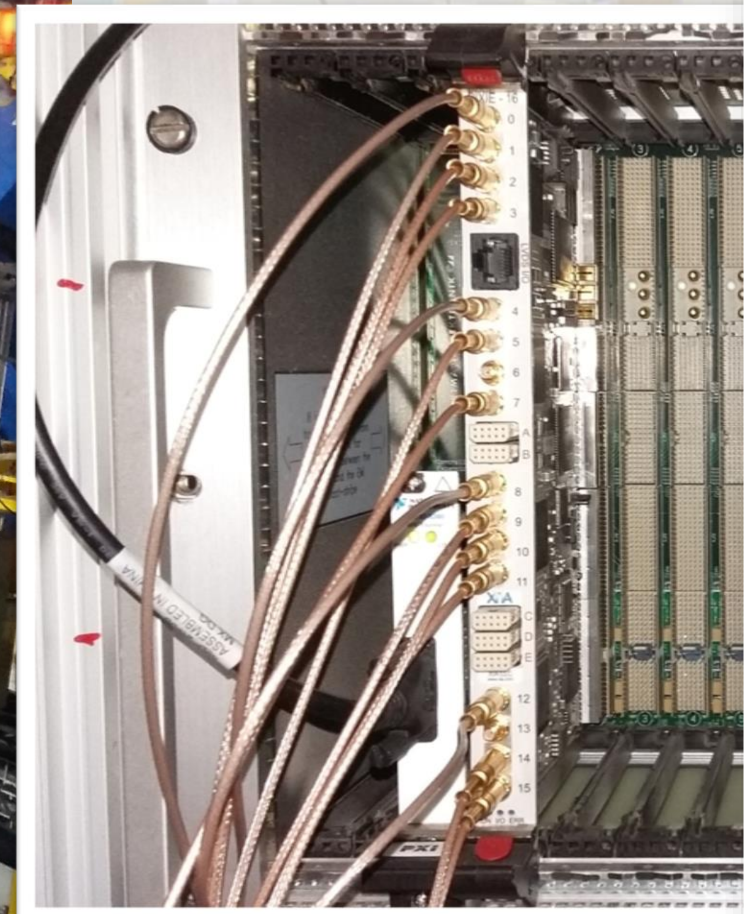
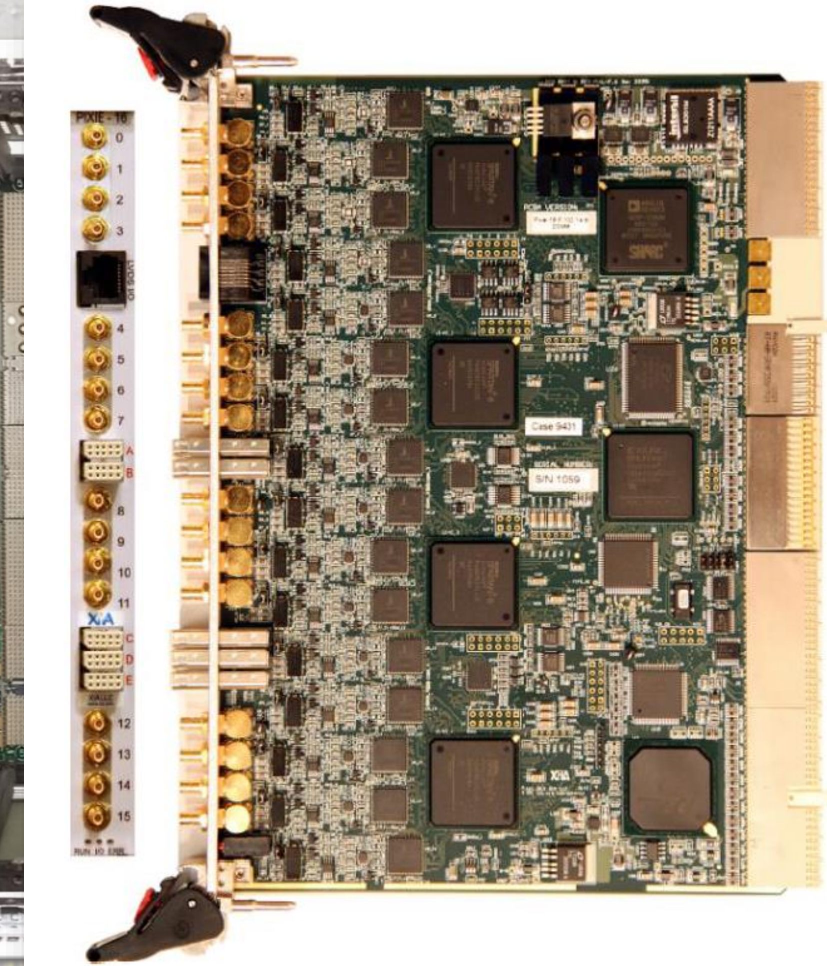
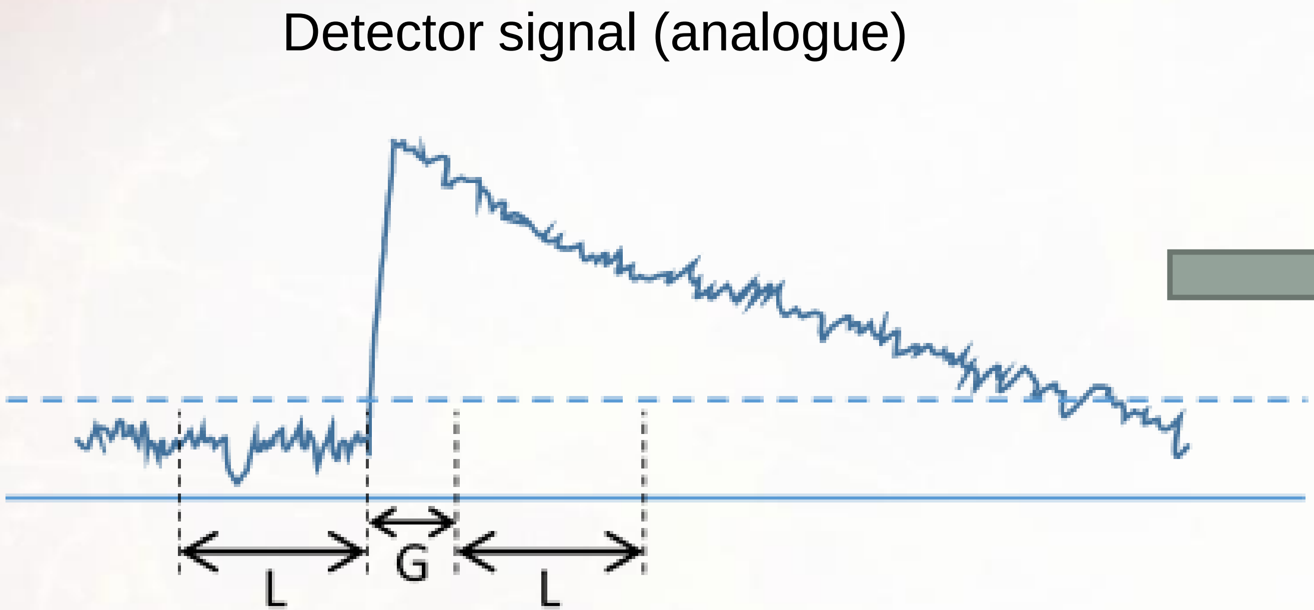
BUSY
Event
Trigger
Strobe
ADC

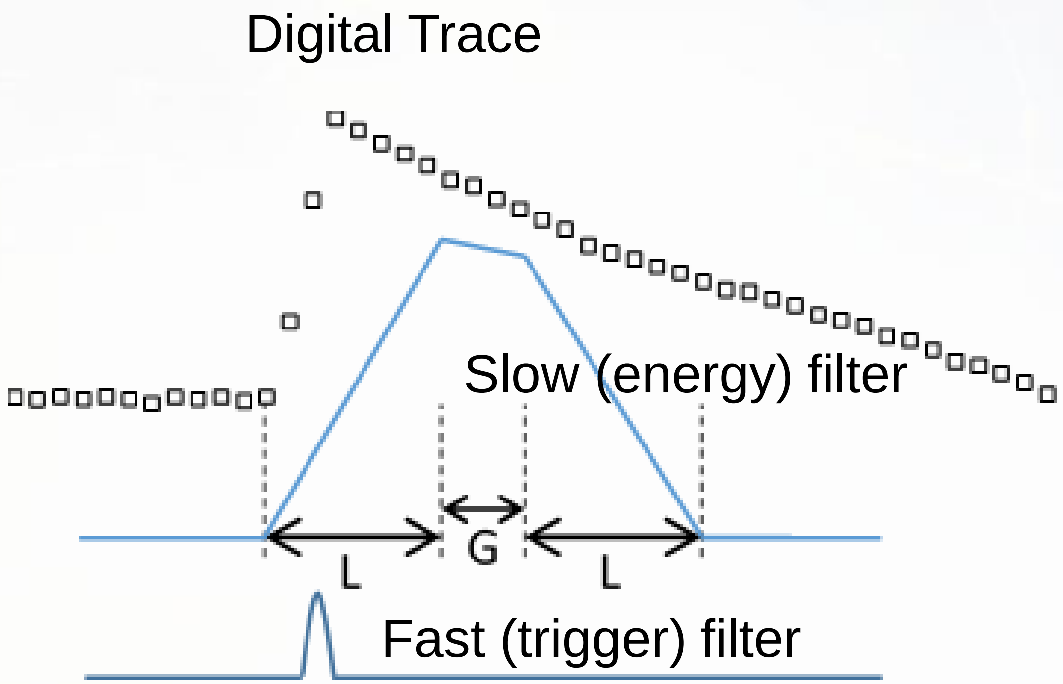




Mod	Ch	Detector		Purpose
0	0	Si	dE, Left telescope	dE
0	1	Si	K-line polarimeter, Left	E
0	4	Si	dE, Right telescope	dE
0	5	Si	K-line polarimeter, Right	E
0	7	Pulser	Copy of Pulser to LEDs	Pulser tag
0	8	NaI	E, Left telescope	E
0	9	NaI	E, Right telescope	E
0	12	Current Integrator	Beamstop	Incident Beam Current
0	14	Pol_down	Logic strong field	Pol down
0	15	Pol_up	Logic weak field	Pol up

Digital data acquisition





- Analog systems use peak sensing ADC's
- In analogue system the signal peak value must be "captured" into analogue storage device like capacitor and "kept" until digitized (permanent, requires electronic modules for proper shaping)
- Digital value stored
- During this ADC conversion system is "dead" to next events - computer dead time

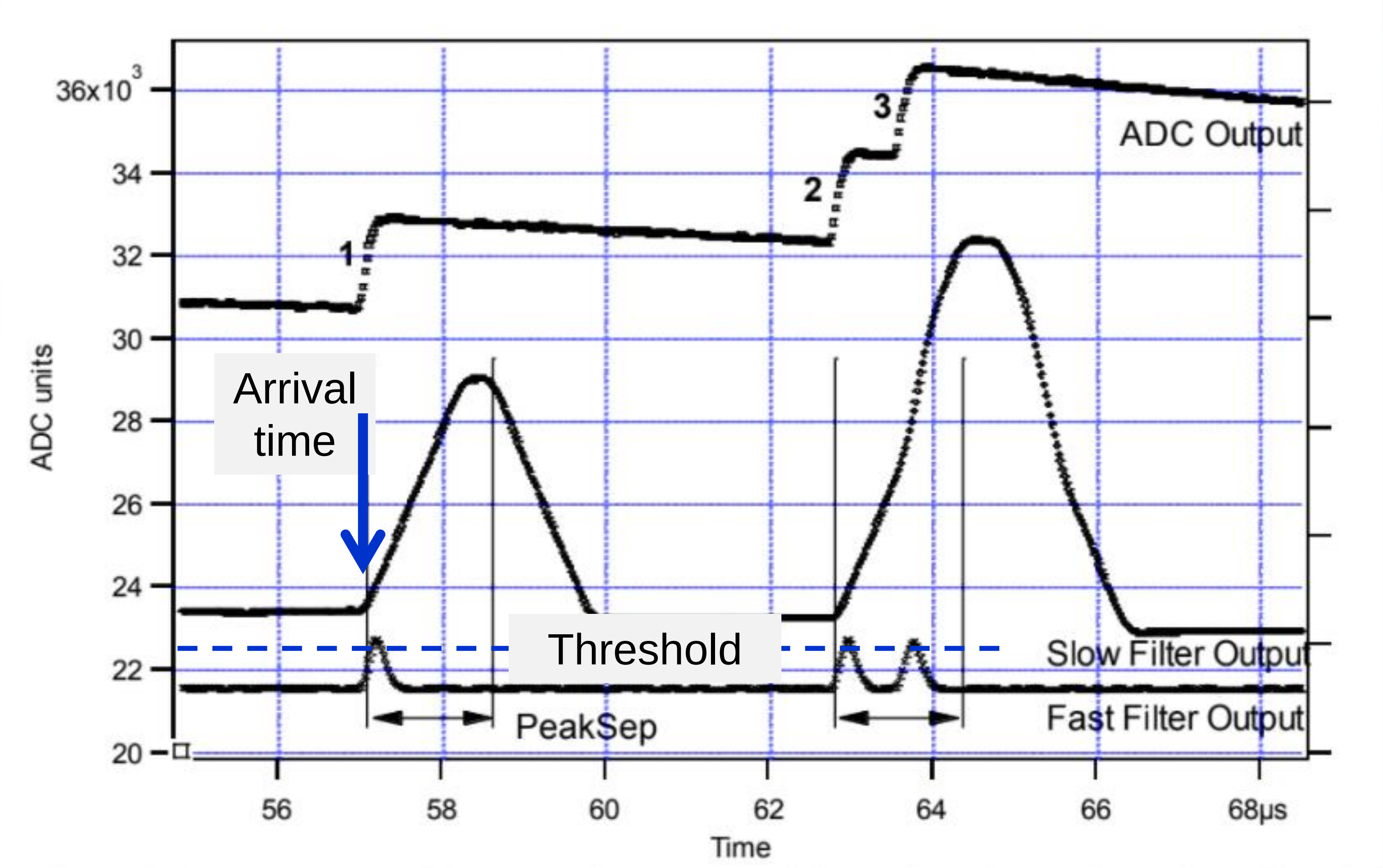
- Digital systems much more efficient - values output by energy filter already digital (waveform digitizer)
- Whole trace can be stored
- Only take filter sums (L & G) and reconstruct energy (filter amplitude)
- In Pixie-16, real time processing continuously updated in FPGA, and captured into event buffers (16 independent ch's)
- Reconstructing the energy and incrementing the spectrum is done by the DSP, so that FPGA ready for next data

Features of the digital DAQ

- 12-16 bit 100-500 MSPS digitizing on input signals (14 bit, 250 MSPS, 8 ns sample period)
- Energy and time stamp recorded in list mode - Pulse height measurement with 16-bit precision
- CFD timing resolution
- Fast 32-bit PCI data transfer interface (rates up to 100 MB/s)
- Trace capture up to 163 μs long per channel
- On-board memory for 32K MCA spectrum
- Accommodates both polarity input signal, adjustable trigger and energy filter parameters
- Coincident data acquisition across channels and modules, shared triggers and run synchronisation
- Programmable pile-up inspection

Thresholds and Pile-up inspection

- Signal processed further if fast filter condition met
- Pile-up flagged if two peaks are not sufficiently separated so that leading edge of second peak does not fall after the peak of first pulse.
- Trapezoidal filter function symmetrical, thus for no pile-up, two pulses must be separated by at least L + G
- Pile-up depends critically on rise time of the filter being used



- Pixie-16 module can test for slow channel pileup by measuring fast filter for interval “peakSep” after pulse arrival time.
- For pile-up, both signals zero energy

DAQ and analysis suite

- Decided to try Pixie Acquisition and Analysis Software Suite (**PAASS**)

- Originally developed as part of the research efforts of the Experimental Nuclear Physics Group of University of Tennessee, Knoxville and members of Oak Ridge National Laboratory for use with the Pixie-16 electronics - DAQ and analysis components of the software come from packages developed over many years by many people

- Provides acquisition and analysis frameworks for the XIA Pixie-16 modules

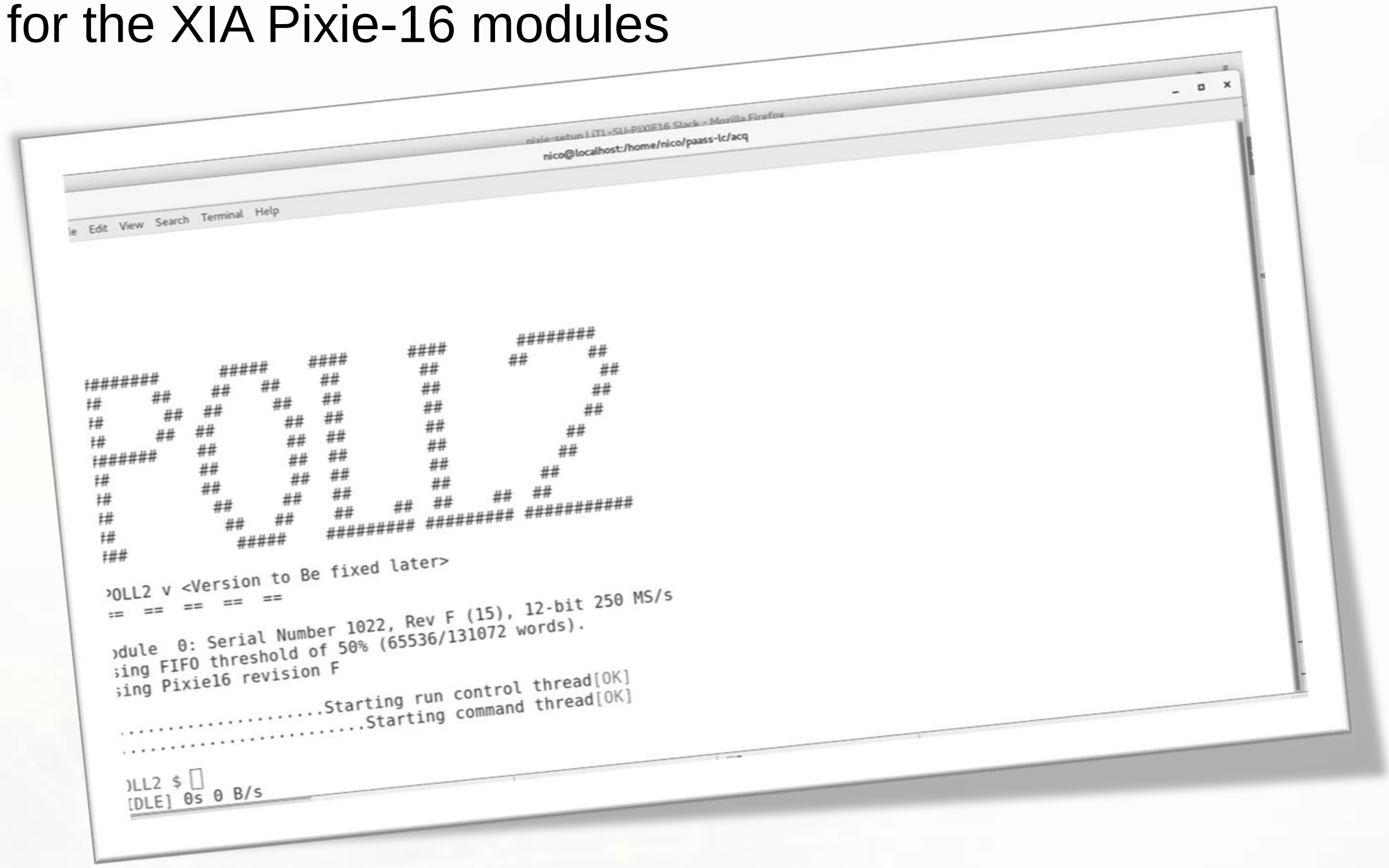
- Tested on CENTOS and UBUNTU

- Data written in PLD or LDF formats

- POLL2 run control provides stable and well debugged DAQ system

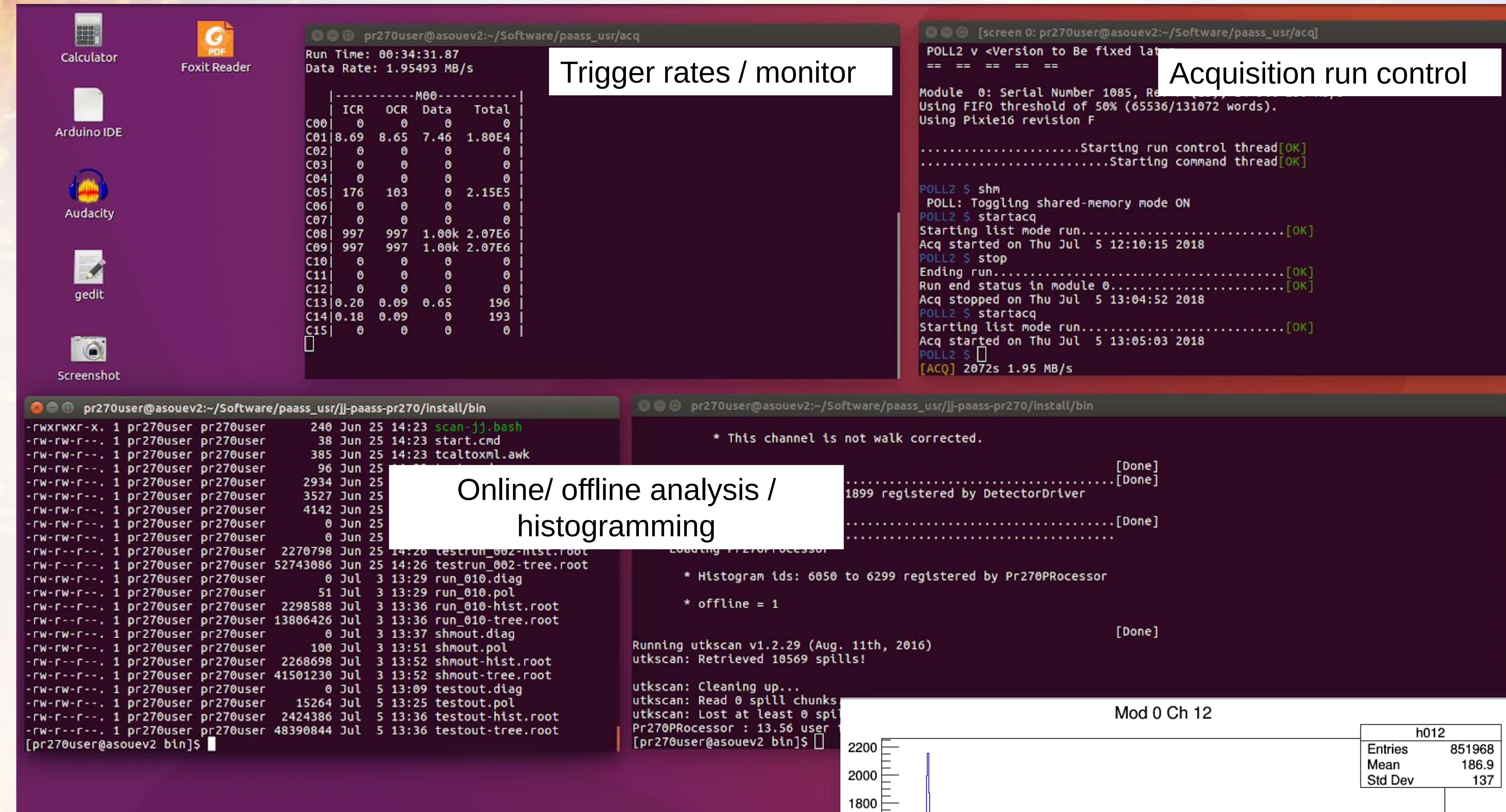
- A modern scientific software package, supported and well documented

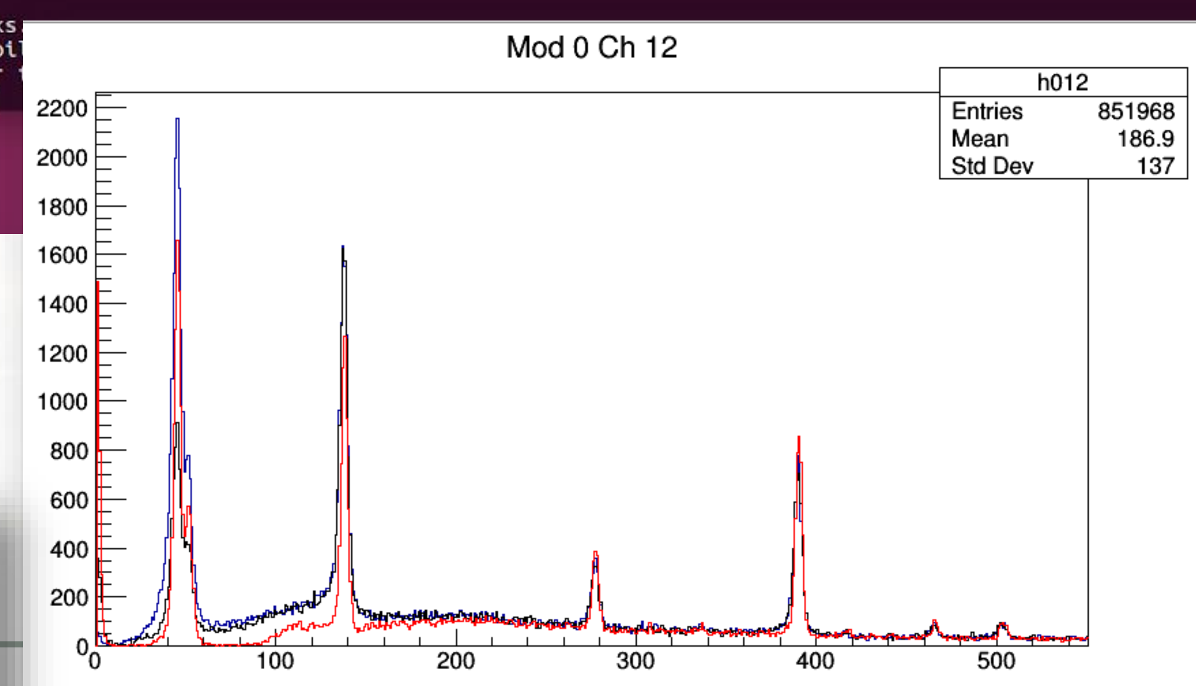
- Adapted to interface with ROOT



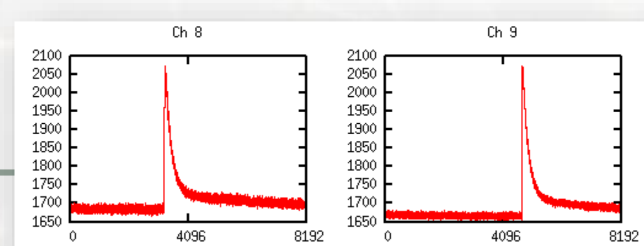
- Provide an extensible framework to run customisable experiments by creating simple experimental “processor” code written in C++

- Configuration file for channel / module setup





- Simple command line run controls
- Channel parameter control, baselines



- UTKSCAN - User-specific processor
- Much of the ROOT interfacing was developed as part of this collaboration - (https://dolosse.org/)
- Ideal software package for smaller testing labs such as the MANDELAB at UWC

```
rootname << Globals::get()->GetOutputPath() << Globals::get()->GetOutputFileName() << ".root";
cout << rootname.str() << endl;
rootfile_ = new TFile(rootname.str().c_str(), "RECREATE");
roottree_ = new TTree("DATA", "");

roottree_->Branch("dE_energy", &t_E_energy);
roottree_->Branch("dE_time", &t_E_time);
roottree_->Branch("dE_det", &t_E_det);
roottree_->Branch("E_energy", &t_E_energy);
roottree_->Branch("E_time", &t_E_time);
roottree_->Branch("E_det", &t_E_det);
roottree_->Branch("CI_energy", &t_CI_energy, "t_CI_energy/D");
roottree_->Branch("CI_time", &t_CI_time, "t_CI_time/I");
roottree_->Branch("cntrate", &t_cntrate, "t_cntrate/I");
roottree_->Branch("isEdE", &t_isEdE, "t_isEdE/B");
```

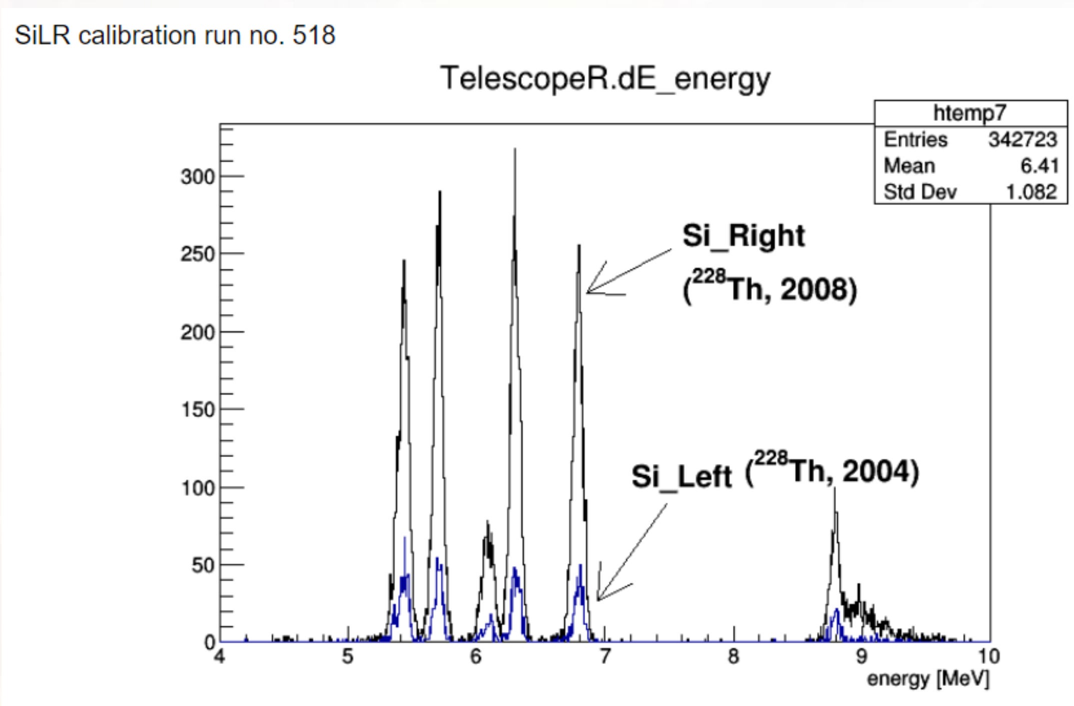
- Dolosse: Scalable and Maintainable Physics Data Acquisition (https://dolosse.org/)

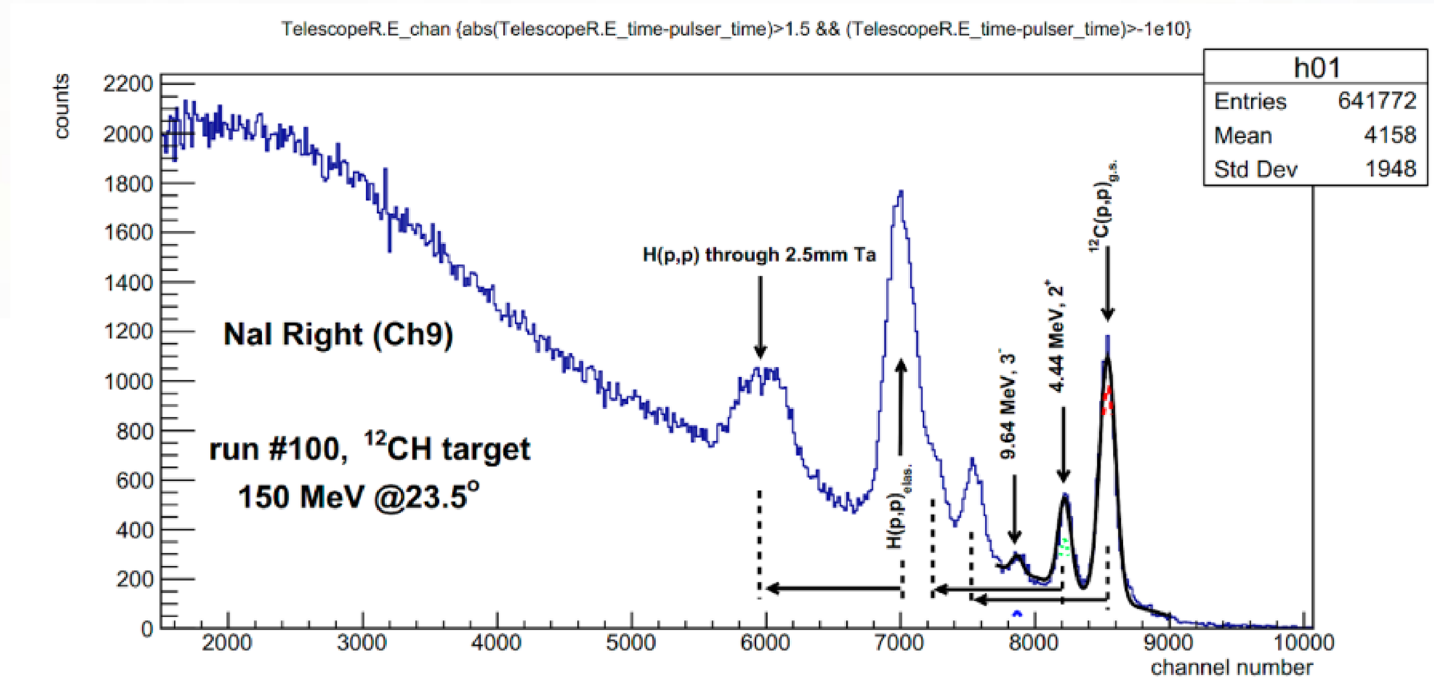
Dolosse

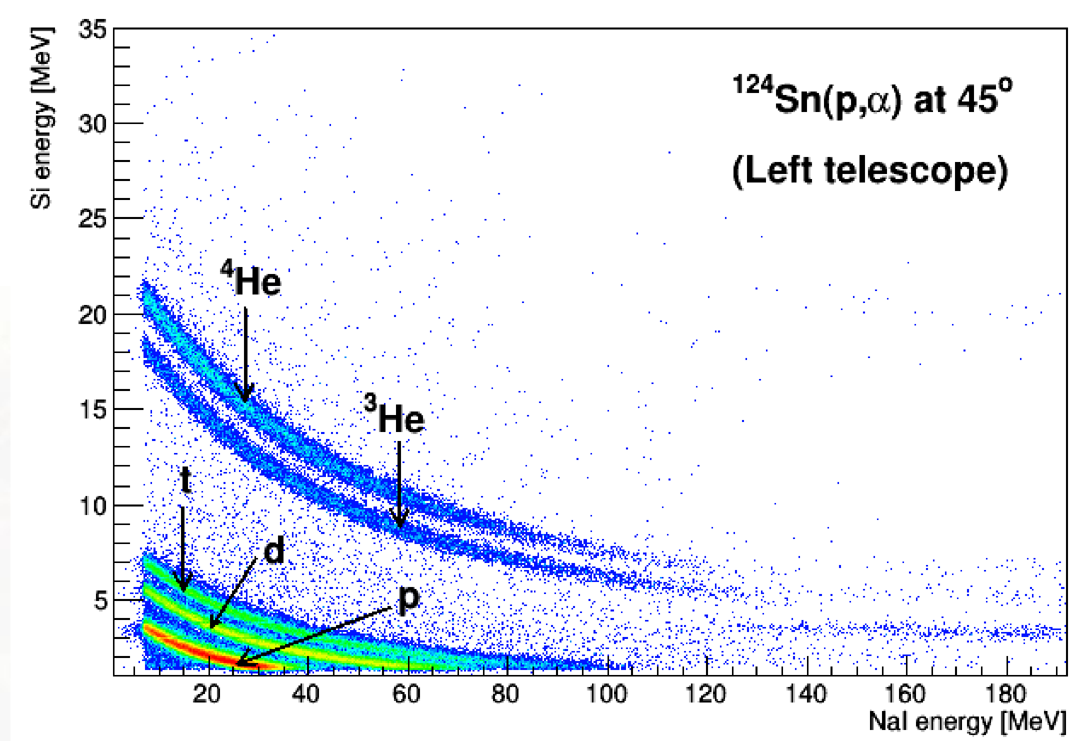
```
for (const auto &it : E_evt) {
    auto location = it->GetChanID().GetLocation();
    auto energy = it->GetCalibratedEnergy();
    auto time = it->GetWalkCorrectedTime();

if(!isFirst && (time < firsttm)) {
    firsttm=time;
            isFound=true;
}

if(PrntDiag)
    myfile<<"NaI "<<location<<", time = "<<(time-firsttm)*s2ns<<endl;

t_E_det.push_back(location);
    t_E_energy.push_back(energy);
    t_E_time.push_back((time-firsttm)*s2ns);
```

Current analysis of experiment

- Very preliminary !!
- Calibrations
- PID

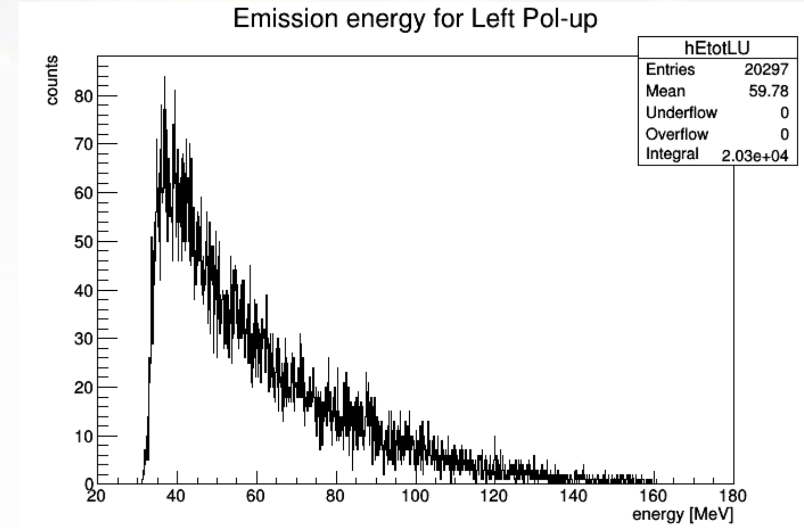




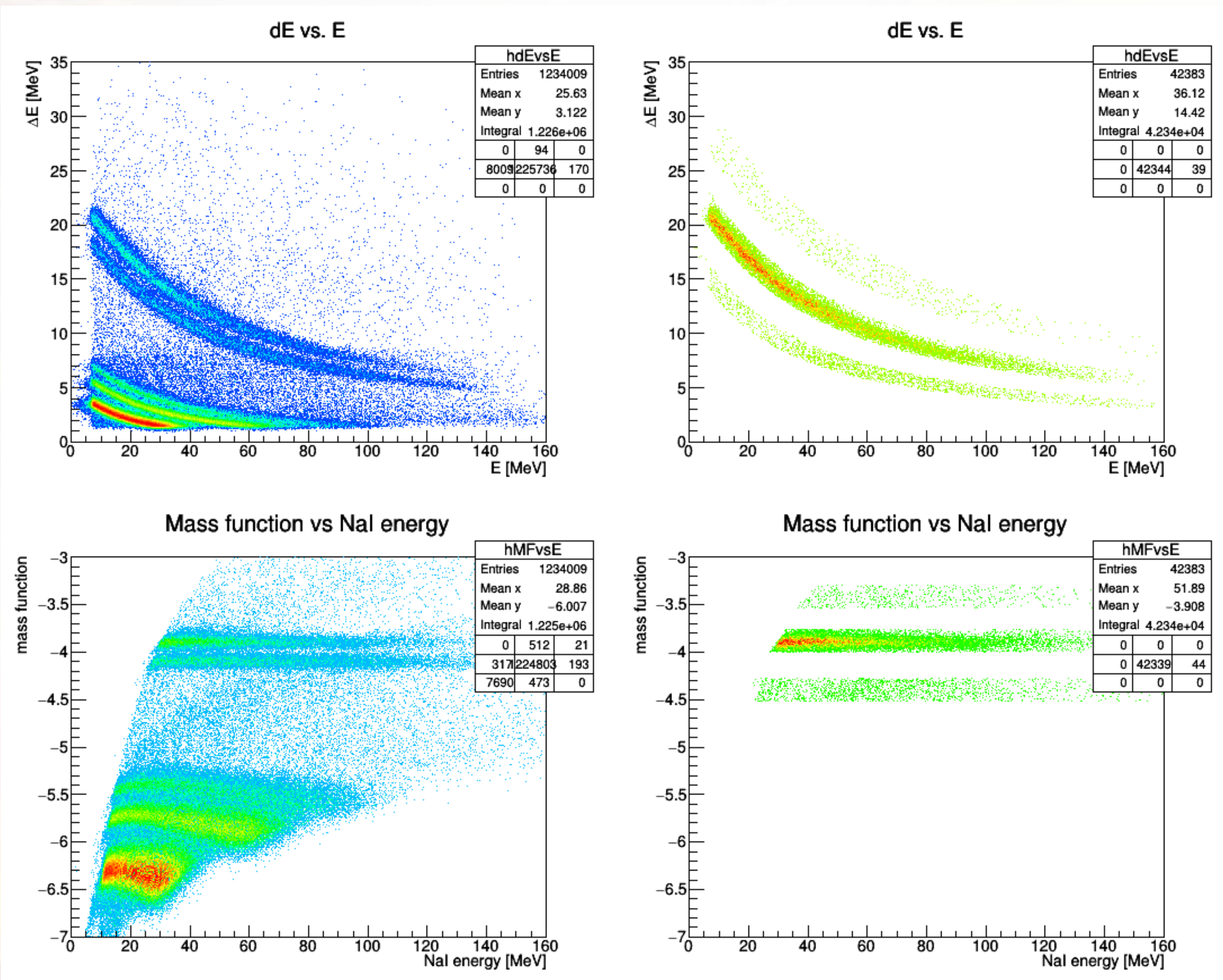


Current analysis of experiment

- Very preliminary !
- Alpha-particle yields



$$\sigma_0 = \frac{\sigma_0^L + \sigma_0^R}{2} = \frac{\sigma_L^{\uparrow} p^{\downarrow} + \sigma_L^{\downarrow} p^{\uparrow} + \sigma_R^{\uparrow} p^{\downarrow} + \sigma_R^{\downarrow} p^{\uparrow}}{2\left(p^{\uparrow} + p^{\downarrow}\right)} = \frac{\left(\sigma_L^{\uparrow} + \sigma_R^{\uparrow}\right) p^{\downarrow} + \left(\sigma_L^{\downarrow} + \sigma_R^{\downarrow}\right) p^{\uparrow}}{2\left(p^{\uparrow} + p^{\downarrow}\right)}$$



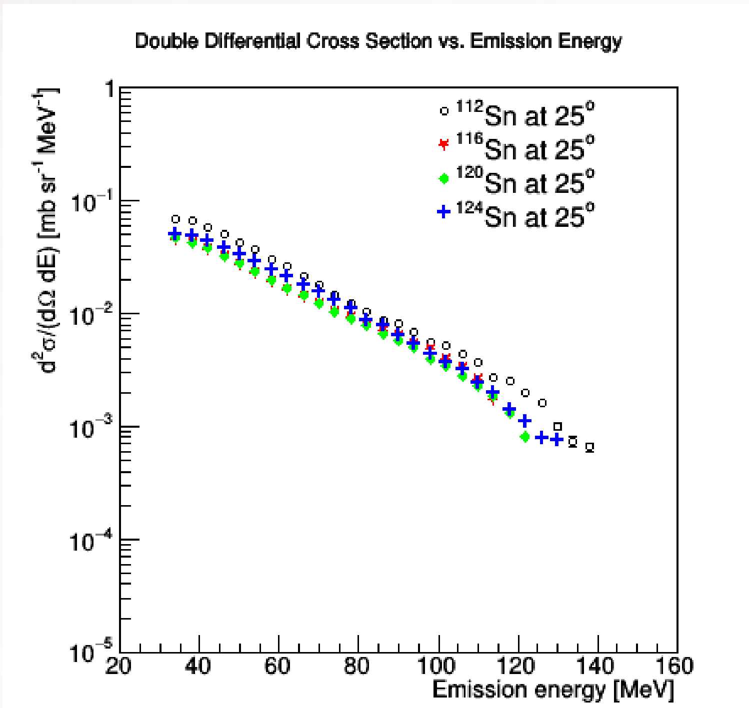
$$A_y = \frac{(R+1)(p^{\uparrow} + p^{\downarrow}) - \sqrt{\Delta}}{2p^{\uparrow}p^{\downarrow}(R-1)},$$

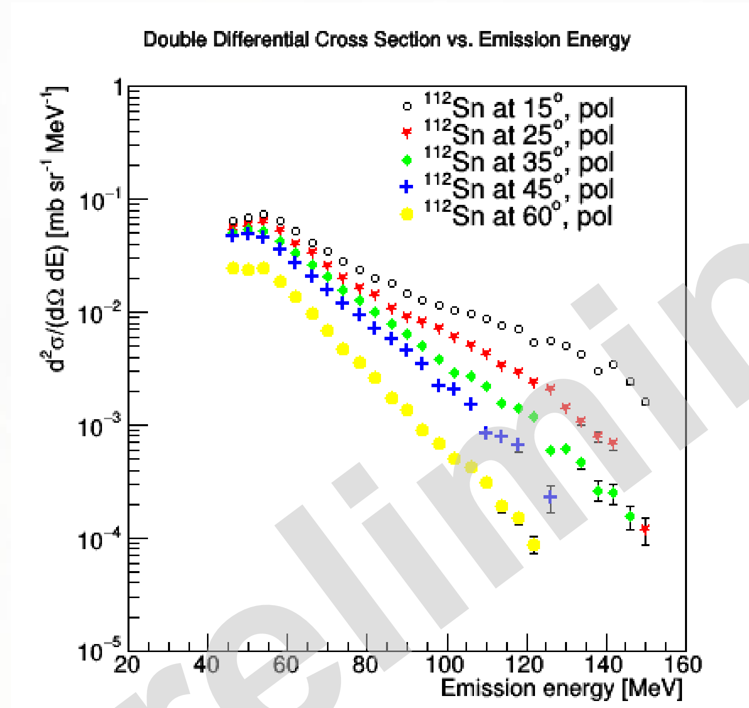
$$R = \frac{\sigma_L^{\uparrow}\sigma_R^{\downarrow}}{\sigma_L^{\downarrow}\sigma_R^{\uparrow}},$$

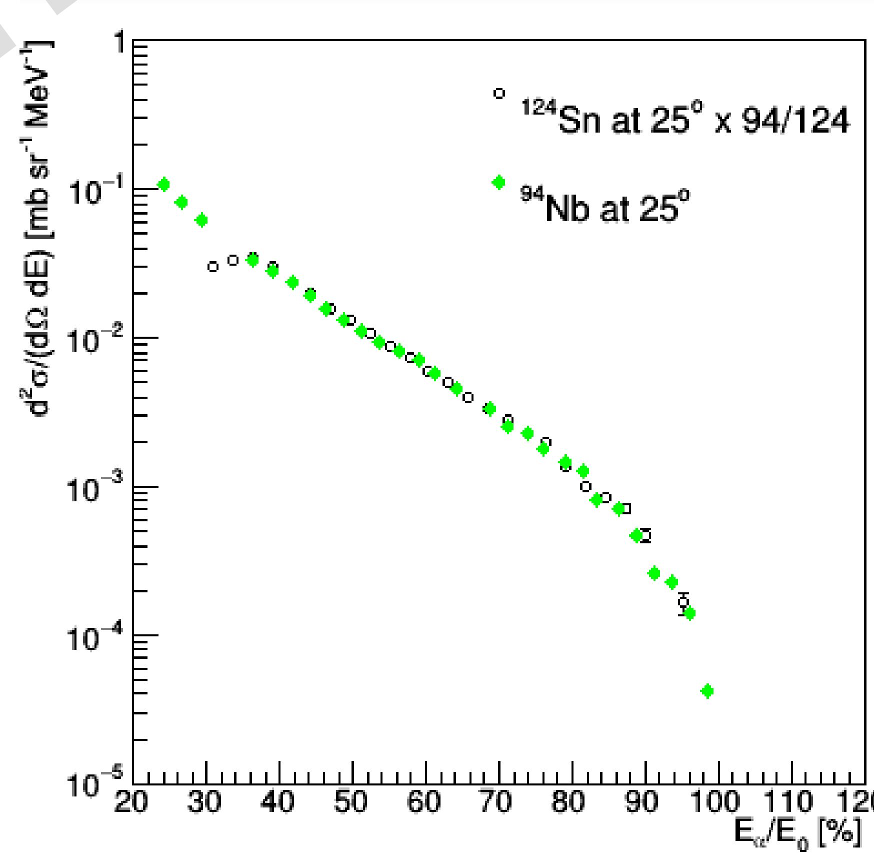
$$\Delta = \left(R^2+1\right)\left(p^{\uparrow} - p^{\downarrow}\right)^2 + 2R\left[\left(p^{\uparrow} - p^{\downarrow}\right)^2 + 8p^{\uparrow}p^{\downarrow}\right].$$

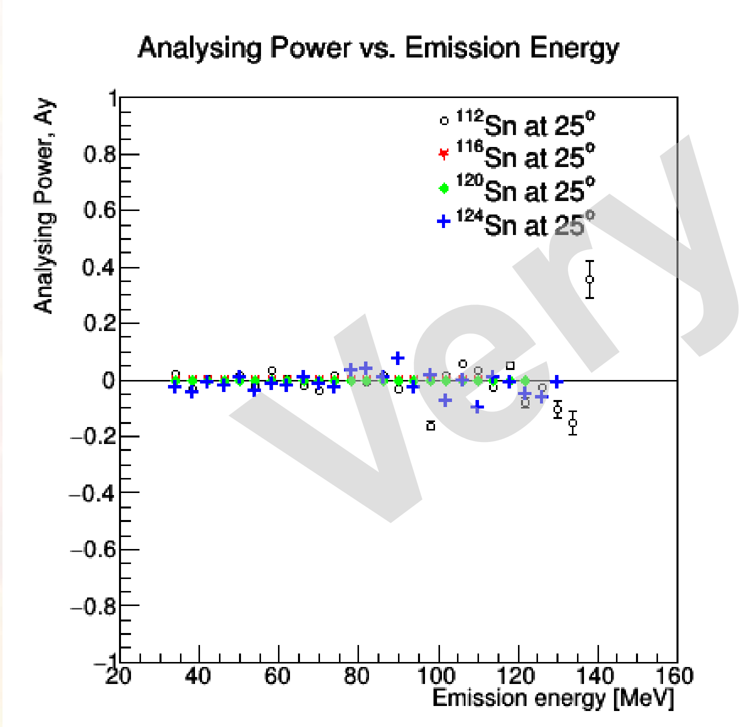
Current analysis of experiment

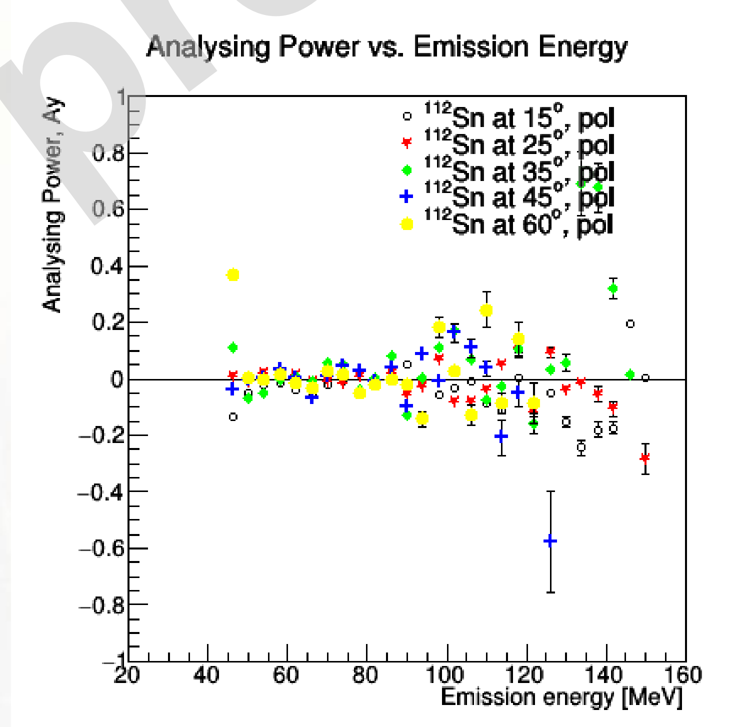
Very preliminary !











Thank you!

Pre-equilibrium studies (hot topic!)

- The **pre-equilibrium emission of ^{3}He and α particles** into the continuum induced by medium energy protons has been the topic of several studies over the past few decades.

- Several **recent** publications, mostly iTL:

  - ✓ Cowley, Dimitrova, Zemlyanaya, Lukyanov, Van Zyl, *Phys. Rev. C* ***93*** *(2016) 034624*
  - ✓ Felix S. Olise, Afis Ajala, and Hezekiah B. Olaniyi, *Nucl. Eng. Tech.* ***48*** *(2016) 482*
  - ✓ Dimitrova, Cowley, Zemlyanaya, Lukyanov, *Phys. Rev. C* ***90*** *(2014) 054604*
  - ✓ Dimitrova, Cowley, Van Zyl, Zemlyanaya, Lukyanov, *Phys. Rev. C* ***89*** *(2014) 034616*
  - ✓ Van Zyl, Cowley, Neveling, Buthelezi, Förtsch, Mabiala, Mira, Nemulodi, Smit, Steyn, Swartz, and Usman, *Phys. Rev. C* ***89*** *(2014) 034616*
  - ✓ Cowley, Van Zyl, Dimitrova, Zemlyanaya, Lukyanov, *Phys. Rev. C* ***85*** *(2012) 054622*

- All previous successful polarised pre-equilibrium (p,α) reaction studies done at only few labs including RCNP and iThemba LABS – of which only iTL may still be able to do it.

- Simplest, yet tried and tested method – many years' experience.

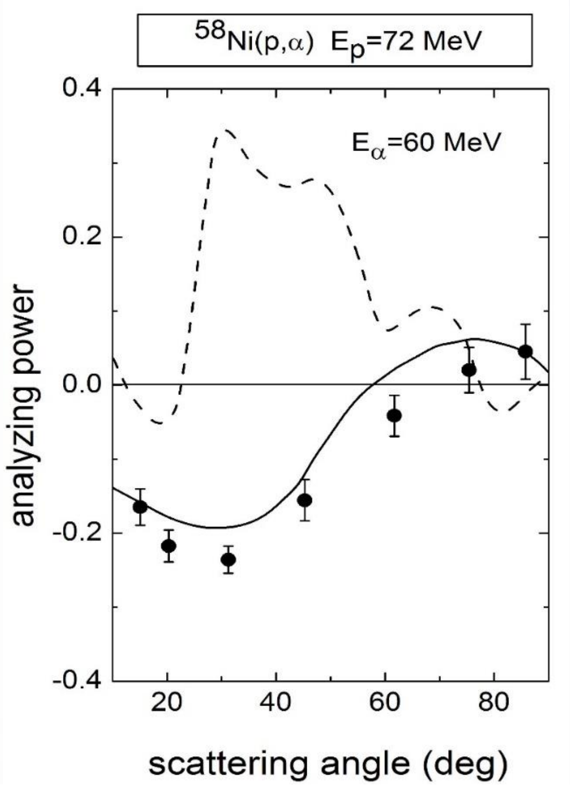
- New understanding of reaction mechanisms involved.

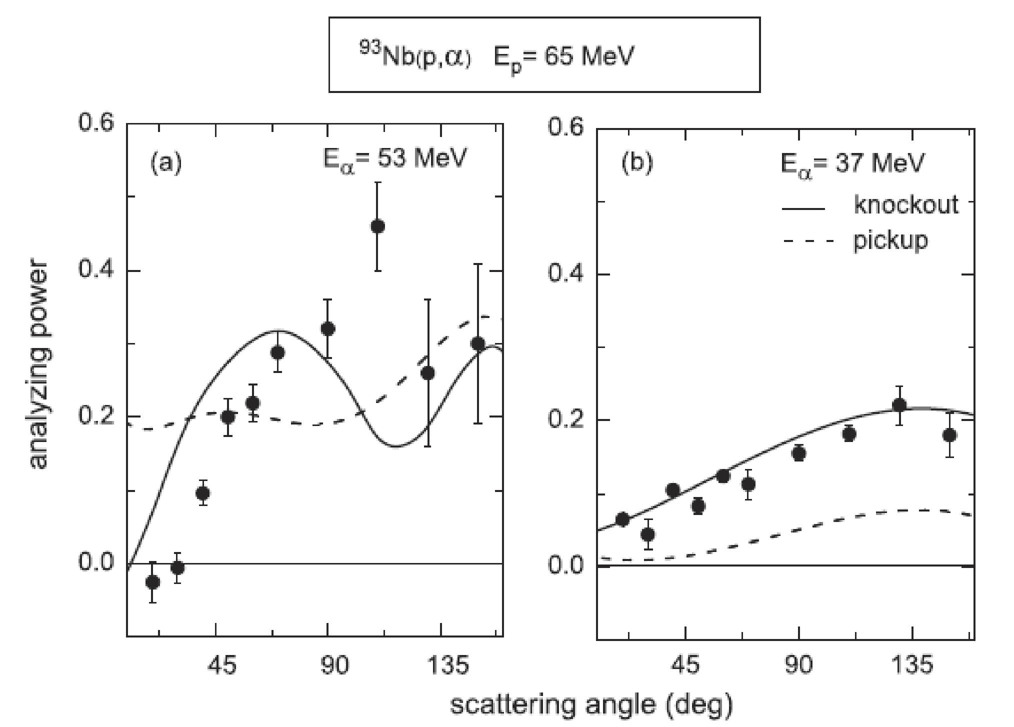
Analyzing power…

$$\text{Analyzing power} \quad A_y \propto \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$

- The measurement of the A_y as function of scattering angle is also powerful tool to examine the interplay between the two terminating processes.
- A_y much more sensitive to reaction mechanism than cross section.
- A_y insensitive to problems of DWBA with σ magnitude (ratio of cross sections)
- Sensitivity to target properties should be noticeable in A_y
- Because A_y angular distributions are more sensitive to details of reaction mechanism than σ, **polarized projectiles** proved to be especially valuable for these studies.

Bonetti *et al.* Nucl Phys **A499** (1989) 381





Cowley, Phys. Rev. C **93**, 054329 (2016)