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Measurements at the 175 MeV neutron beam at TSL

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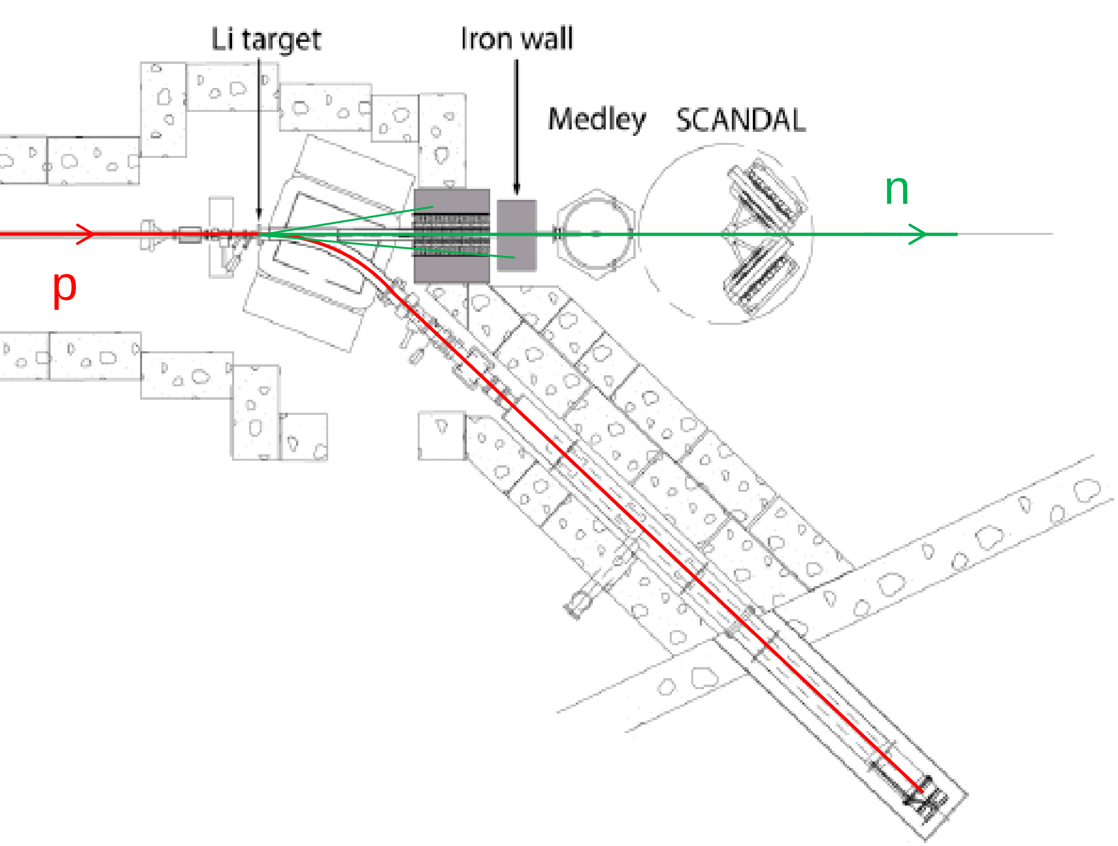
Outline

- The neutron beam facility at TSL
  - Quasi-mononenergetic neutrons
  - White spectrum
- Research activities at TSL within EFNUDAT
- The Medley setup
  - Overview of the detector
  - Some results on charged particle production
- The SCANDAL detector
  - Overview of the detector
  - Status of data analysis
- Summary and outlook

The neutron beam facility at TSL

The new neutron facility at TSL has been in operation since 2004 and was upgraded in 2007.



The quasi-monoenergetic neutron beam @ TSL:

- Neutron production reaction: $^{7}Li(p,n)$ enriched to 99.99%,
- Li targets: 1-24 mm thick.
- Available neutron energy: 11 - 175 MeV.
- Neutron flux up to $5 \cdot 10^{5}$ cm^{-2} s^{-1}.
- Flexible beam size 1 cm - 1 m in diameter.
- Beam shape: circular, square or any other shape upon request.
- User's control of the neutron flux: within a factor of 1000 .

More at www.tsl.uu.se

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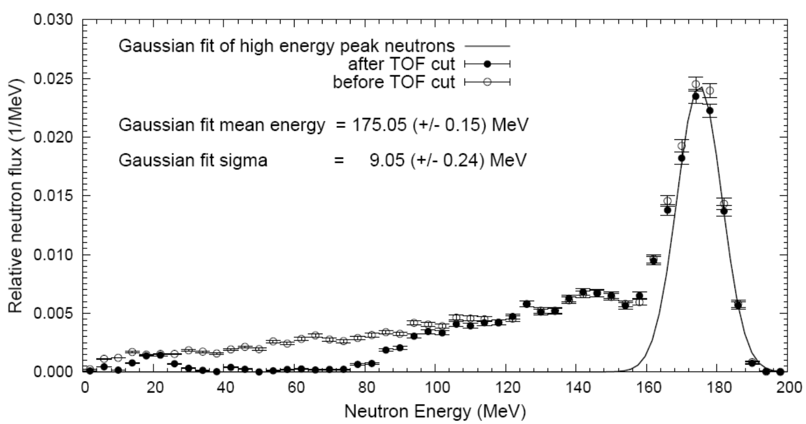
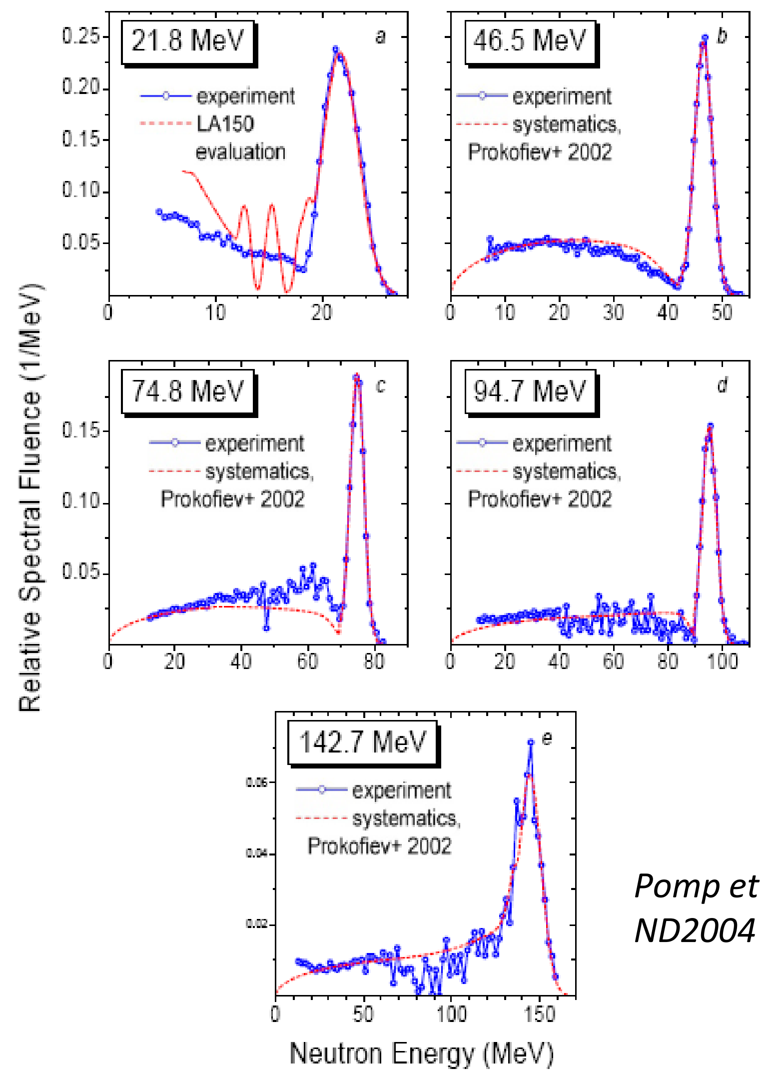
The neutron beam facility at TSL

Quasi-monoenergetic neutron spectra measured with the Medely setup.
Measured by elastic *np* scattering from CH_2 target.



Neutron spectrum at 175 MeV showing the effect of the TOF cut.
Hirayama et al. ND2010



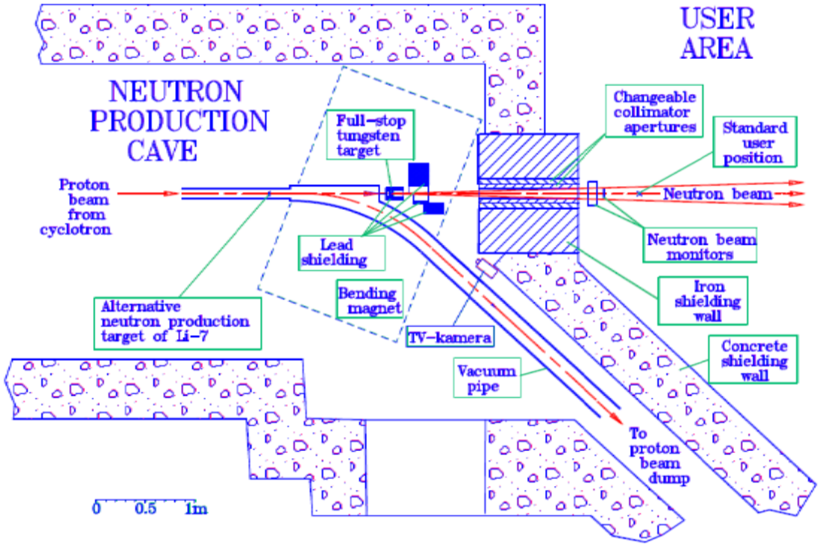
Pomp et al. ND2004

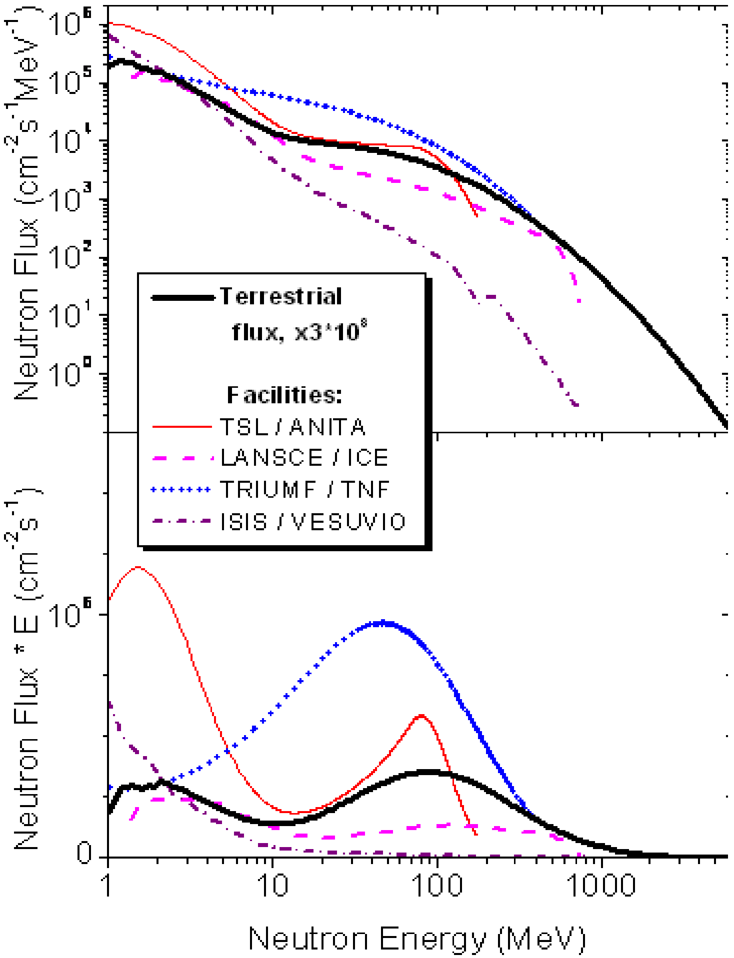
The neutron beam facility at TSL

The white neutron source (ANITA) @ TSL:

("**A**tmospheric-like **N**eutrons from th**I**ck **TA**rget")

- Tungsten target (full stop): 2.4 cm
- Neutron spectrum: atmospheric-like up to 150 MeV.
- Neutron flux >10 MeV: approx. 10^6 cm^{-2} s^{-1} corresponding to the acceleration factor of approx. 300 million at standard user position.
- User flux control within the range 5 - 10^6 cm^{-2} s^{-1}
- Neutron beam spot size: controllable 1 cm - 120 cm



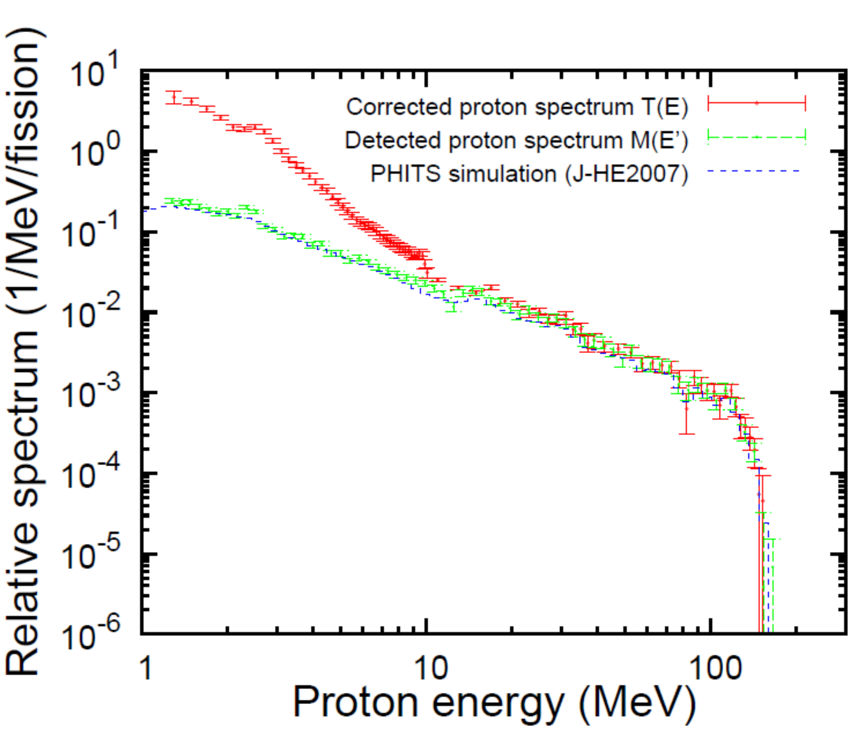


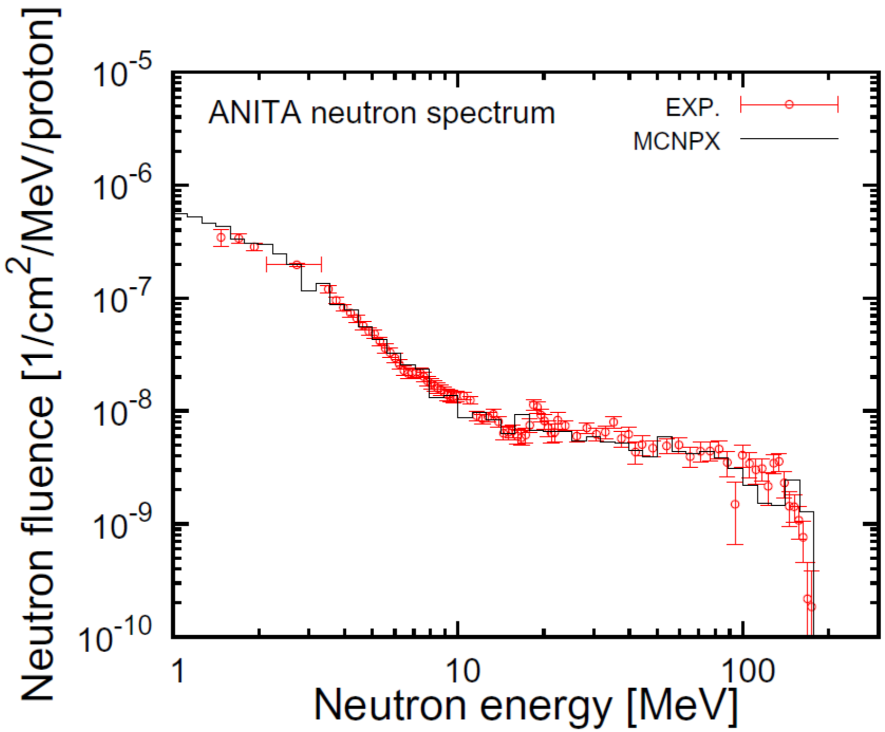
From www.tsl.uu.se

The neutron beam facility at TSL

Characterization of the ANITA neutron spectrum measured via H(n,p) at 20 degrees using Medely Measurement from 1.5 – 175 MeV.

Y.Naitou, ND2010





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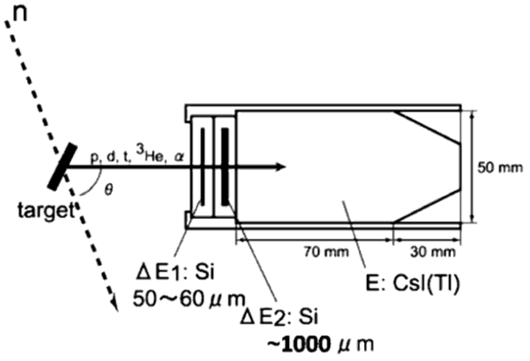
Research activities at TSL within EFNUDAT

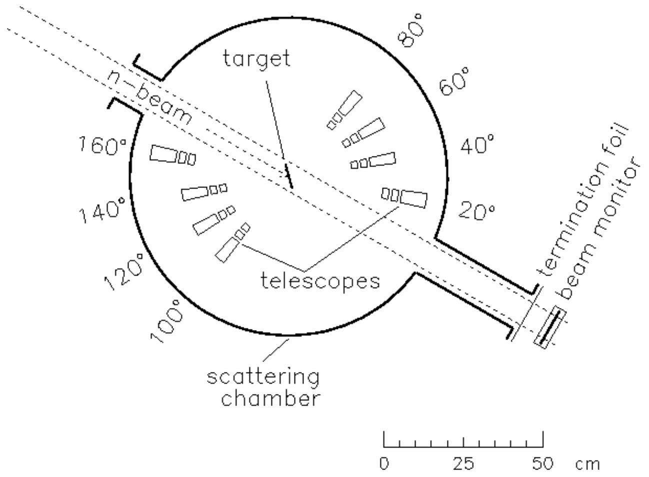
PAC	Spokesperson	Institute	Titel	Beam hours
2/2	R. Nolte	PTB, Germany	Spectral distribution of the ANITA white neutron beam facility at TSL	18 (27)
2/5	V. Wagner	NPI, Slovakia	High-energy Neutron Cross-section Measurements at TSL in Uppsala	24 (49)
4/11	F.-R. Lecolley	LPC CAEN, France	Neutron data for ADS at 175 MeV	158 (162)
5/1	D. Bemmerer	FZD, Germany	Efficiency measurements for multigap resistive plate chamber based detectors for high energy neutrons	96 (96)
5/2	L. Tassan-Got	IPNO, France	Irradiation for geological thermochronology, application to nuclear data	35 (50)
5/5	F.-R. Lecolley	LPC CAEN, France	Data for ADS at 175 MeV	100 (100)
5/7	R. Bedogni	INFN-LNF, Italy	Validating the response matrix of the INFN-LNF extended range Bonner sphere spectrometers in quasi mono-energetic high-energy neutron field.	35 (39)
6/7	V. Wagner	NPI, Slovakia	Continuation of Neutron Cross Section measurements at TSL in Uppsala.	48 (44)

Total approved: 514 hours **Total delivered: 567 hours** **Total payed for: 418 hours**

Medley = DE - DE - E + angles -> ddx

- Detect and identify light ions: *p, d, t, ^{3}He* and *a*
  - but may also detect heavier ions and even fission products
- Use the DE-DE-E technique
  - Each consisting of 2 Si detectors and 1 CsI scintillator
- 8 telescopes, typically in 20 degree interval
  - e.g. -70, -50, -30, -10, +30, +50, +70 and +90 degrees
- Low threshold for PID:
  - 2,5 MeV for protons
  - 4 MeV for alpha particles (without He-3 separation)
- Use of thin targets (now well established correction procedure for target thickness)
  - ~100 - 200 mg/cm^2 (light ions); ~1 mg/cm^2 (fission)





$\Rightarrow$ ddx data for *X(n,light ions)* and
σ, $d\sigma/d\Omega$ for *X(n,fisssion)* etc.

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ddx data from Medley at 175 MeV

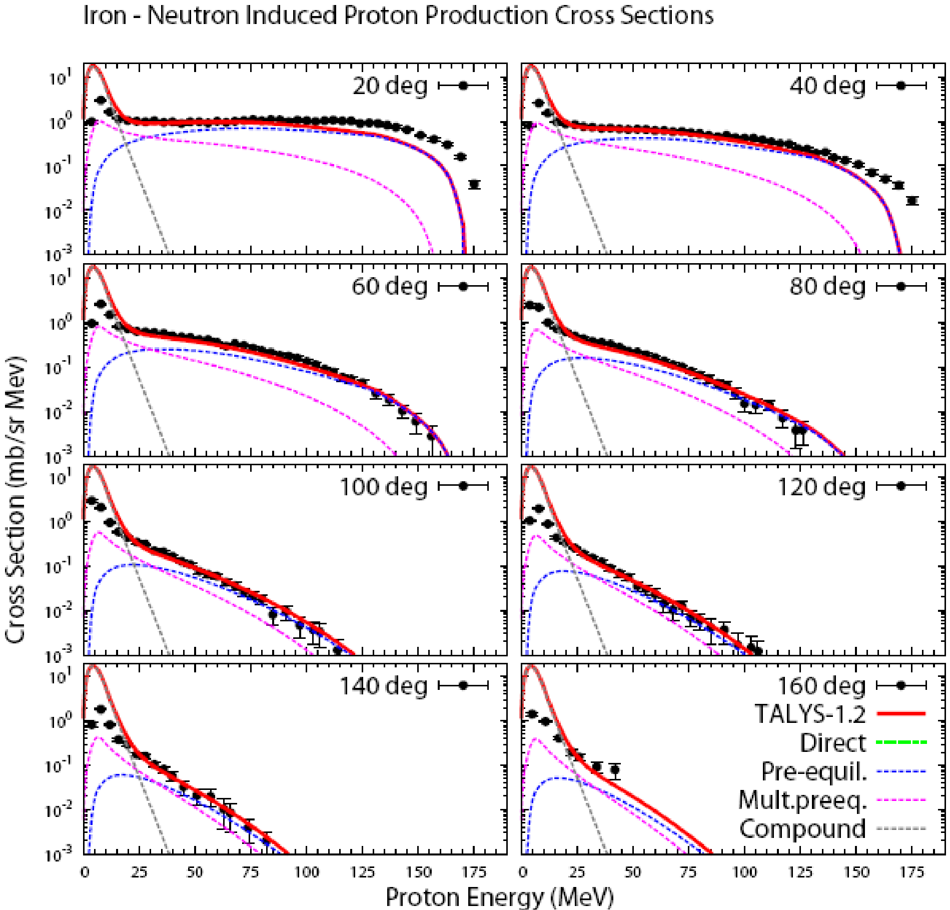
Light ion production (p,d,t,^{3}He and α) have been measured from several nuclei and analysis is underway:

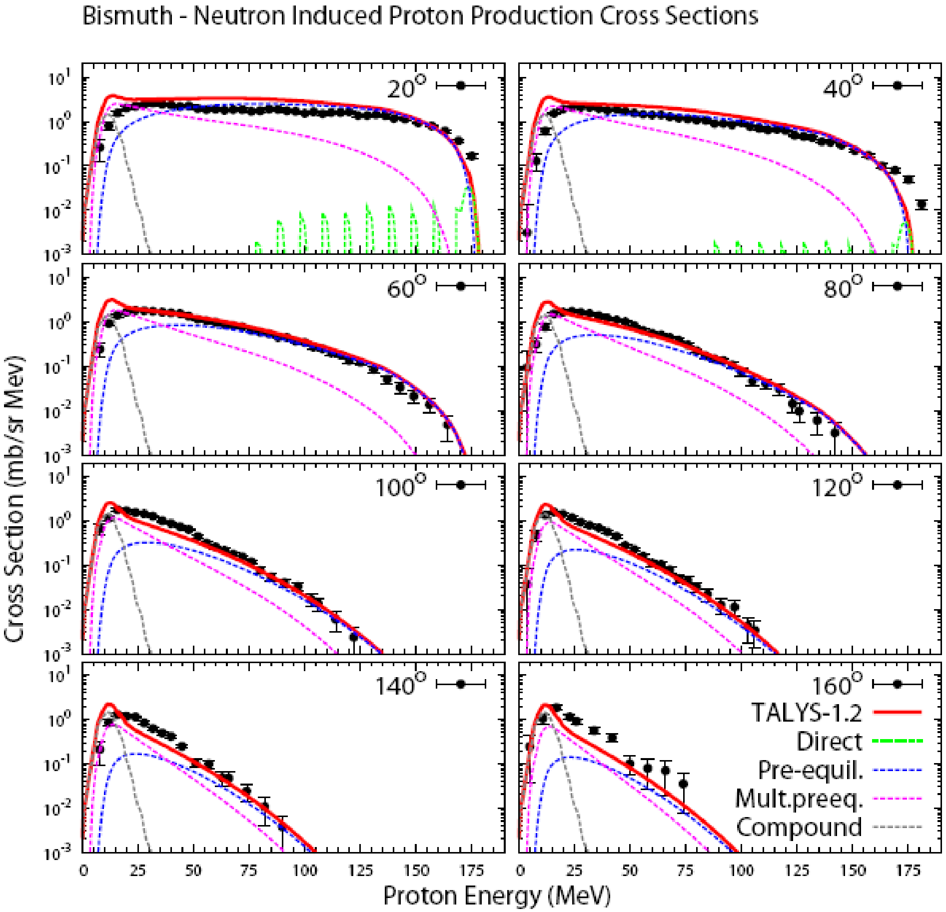
• Bi – Uppsala University, Sweden	energy applications
• Fe – Uppsala University, Sweden	energy applications
• C – Kuyshu University, Japan	medicine applications
• O – Chiang Mai University, Thailand	medicine/electronics application
• Si – Kuyshu University, Japan	electronics application
• U – LPC Caen, France	energy applications

Medley campaign at 96 MeV resulted in data for:
C, O, Ca, Si, O , Fe, Pb, U + np and nd scattering

Lower energies next? NFS Caen...

(n,px) from Fe and Bi @ 175 MeV





Target corrections still need to be done

R. Bevilacqua et al., ND2010

The SCANDAL detector

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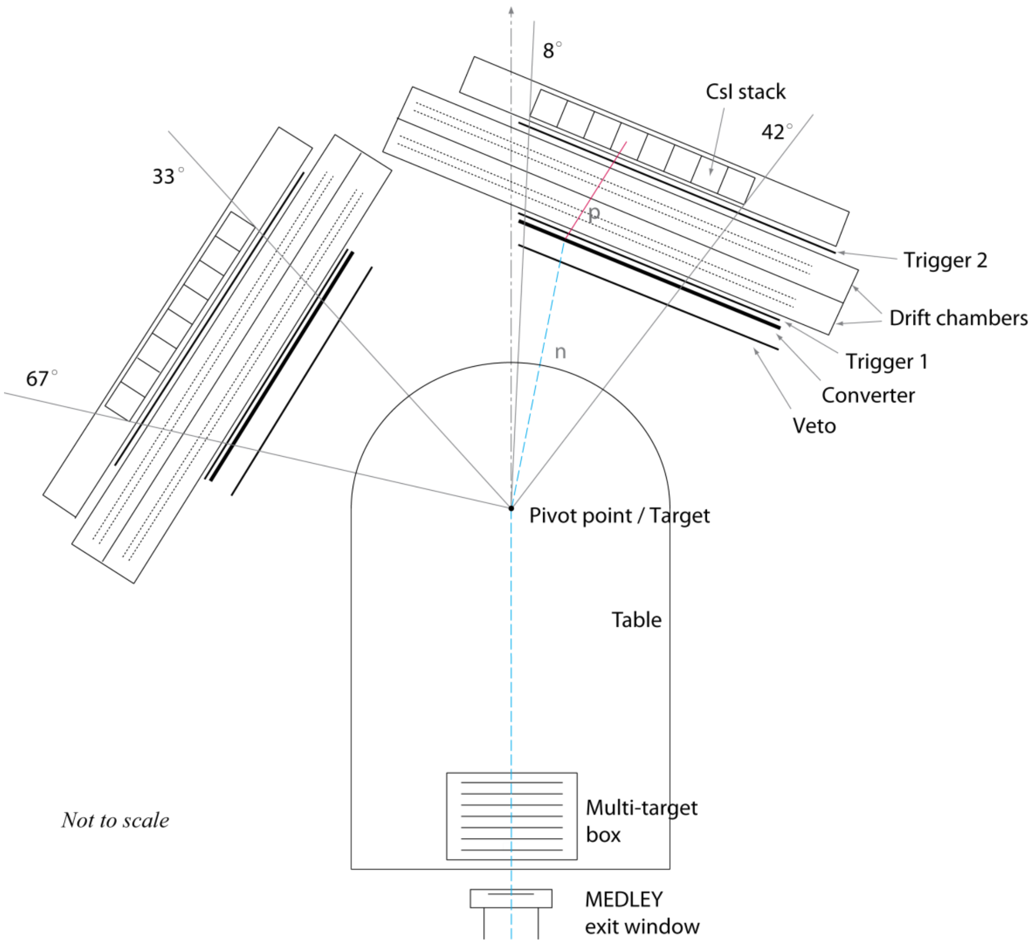
SCANDAL – SCattered Nucleon Detection AssembLy

The SCANDAL detector

- Placed after Medley in the TSL neutron beam line.
- In use since 2000.
- Have been used to measure:
  - Elastic neutron scattering (n,n).
  - *np* scattering (n,p) for calibration
  - Inelastic neutron scattering (n,xn).
  - Proton content in the ANITA beam.
- Was recently upgraded with larger CsI crystals to enable measurements up to 175 MeV.
- Problems in the new background situation at TSL after the new facility was built in 2004…

The SCANDAL detector

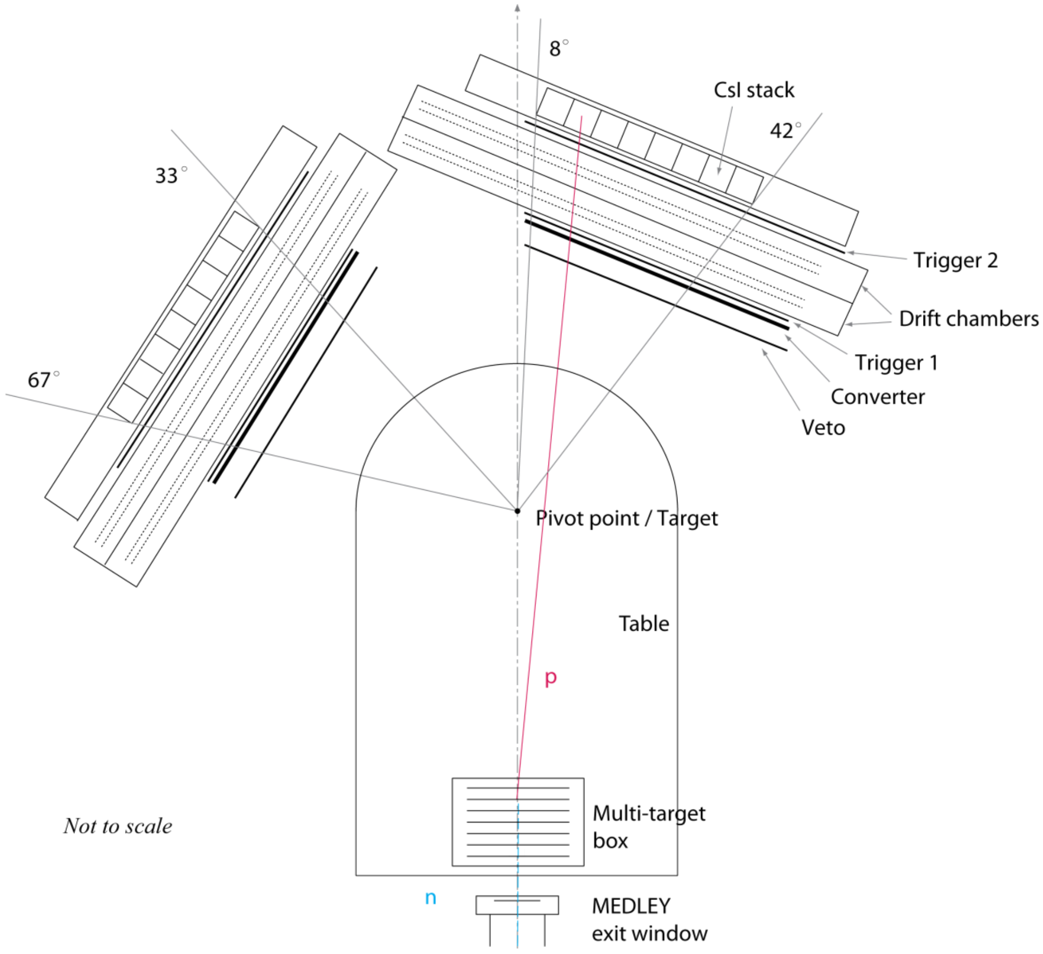
SCANDAL – SCattered Nucleon Detection AssembLy



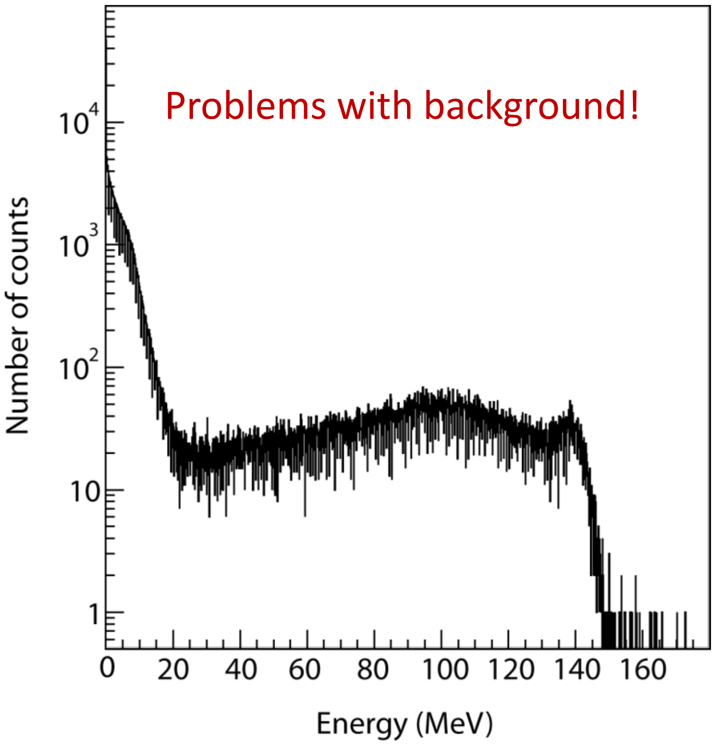
- Two identical arms typically cover 10-70 in lab system.
- The arms can be rotated around the pivot point.
- Detection of neutrons is based on:
  - neutron-to-proton conversion in an active CH_2 scintillator.
  - full energy measurement of the protons in CsI crystals.
- Data sets for (n,n) at 175 MeV, to be analysed:
  - Bi
  - Fe
  - Si
- Data sets at 96 MeV:
  - H, D, C, O, Fe, Y, Pb (n,n) – published e.g. PRC **68** 064605 (2003)
  - C, Fe, Y, Pb (n,xn) – to be published

The SCANDAL detector – calibration

SCANDAL – proton mode for calibration



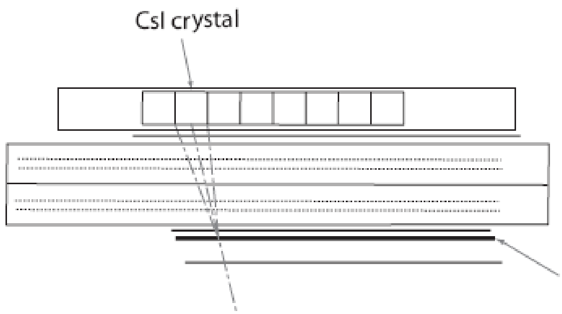
- Energy calibration is performed by using the multi-target box filled with CH_2 and C targets and identifying the hydrogen peak.



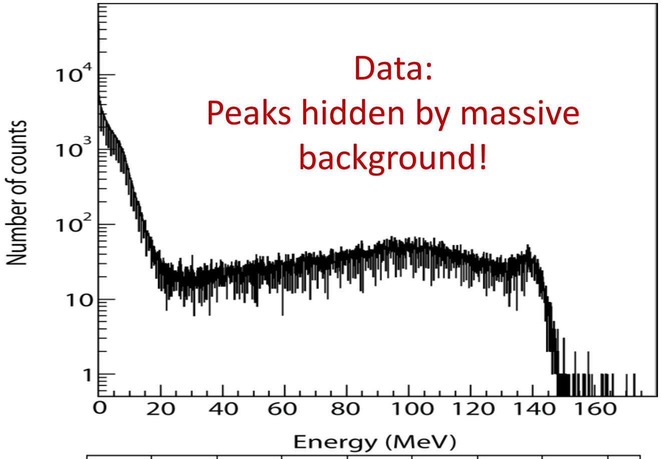
The SCANDAL detector – simulations

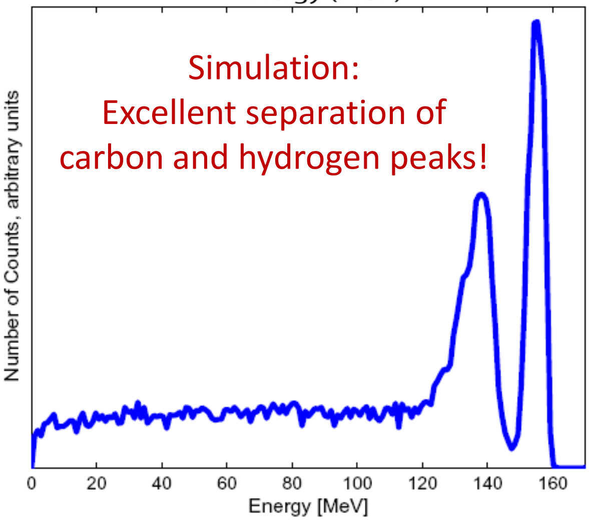
MCNPX has been used for support of the SCANDAL data analysis.
Features investigated:

- Calibrations spectra.
- The effect of the converter scintillator.
- Positions gates on the fronts of the CsI crystals.



Apart from simulations we have carefully investigated data on file; i.e. how raw data are stored from the DAQ. No errors have been found – but SCANDAL detects lots of background!





Simulation of calibration spectra by Milan Tesinsky.
See Tesisky et al. Phys. Script **81** (2010) 065202

Future SCANDAL analysis

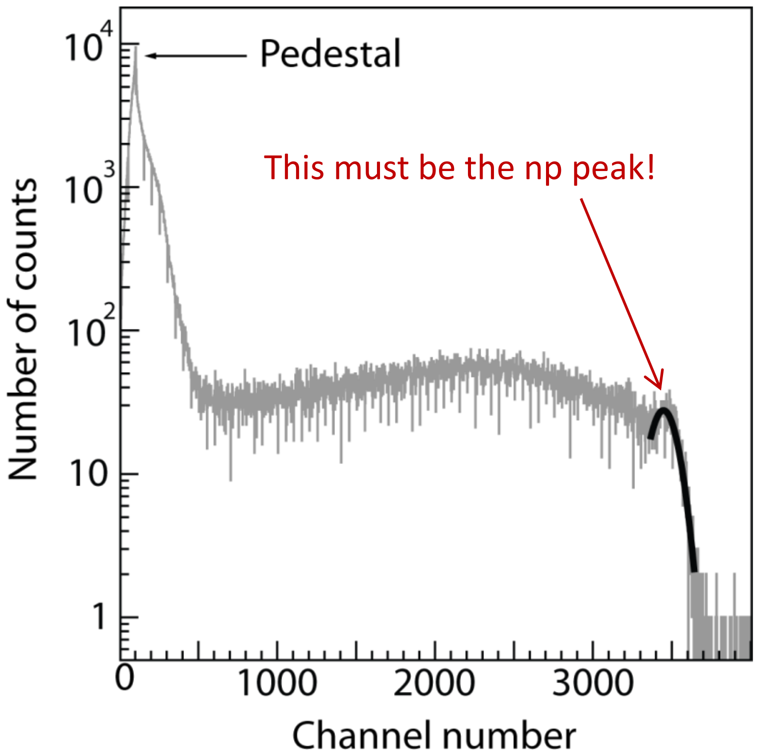
At present there are no PhD students working with the SCANDAL analysis! The results from initial calibration, simulations and raw data suggest that data have severe background problems.

The CsI crystals can be calibrated by simply assuming that the highest energies are from np scattering in CH_2 target.

But analysing the neutron scattering events is much more difficult and much more sensitive to background.

The new neutron beam facility emits more background than before, and SCANDAL (e.g. only two DCH:s on each arm) cannot efficiently distinguish between background and real events in its DAQ.

Analysing SCANDAL data is a high-risk project!



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Summary and outlook

- The two neutron beams at TSL have been presented:
  - The quasi-mono-energetic beam.
  - The ANITA (“**A**tmospheric-like **N**eutrons from th**I**ck **TA**rget”).

- Within EFNUDAT: 8 experiments have taken place at TSL: in total 567 hours of beam time.

- The Medley setup works well and has delivered beam characterization data and charged particle production data is underway for several targets.

- The SCANDAL setup has severe background problems and has not yet delivered any data from the new TSL facility. SCANDAL is now considered a high-risk project and no PhD students are involved with analysis.

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Over the years support has been given by (incomplete list …)

- The Swedish Research Council
- The Swedish Cancer Foundation
- Swedish Nuclear Fuel and Waste Management Company
- Swedish Nuclear Power Inspectorate
- Swedish Nuclear Safety Authority
- Vattenfall AB
- Barsebäck Power AB
- the Swedish Defence Research Agency
- the Thailand Research Fund
- the EU Council through HINDAS …
- … and (last not least) EFNUDAT