Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin
Nationales Metrologieinstitut

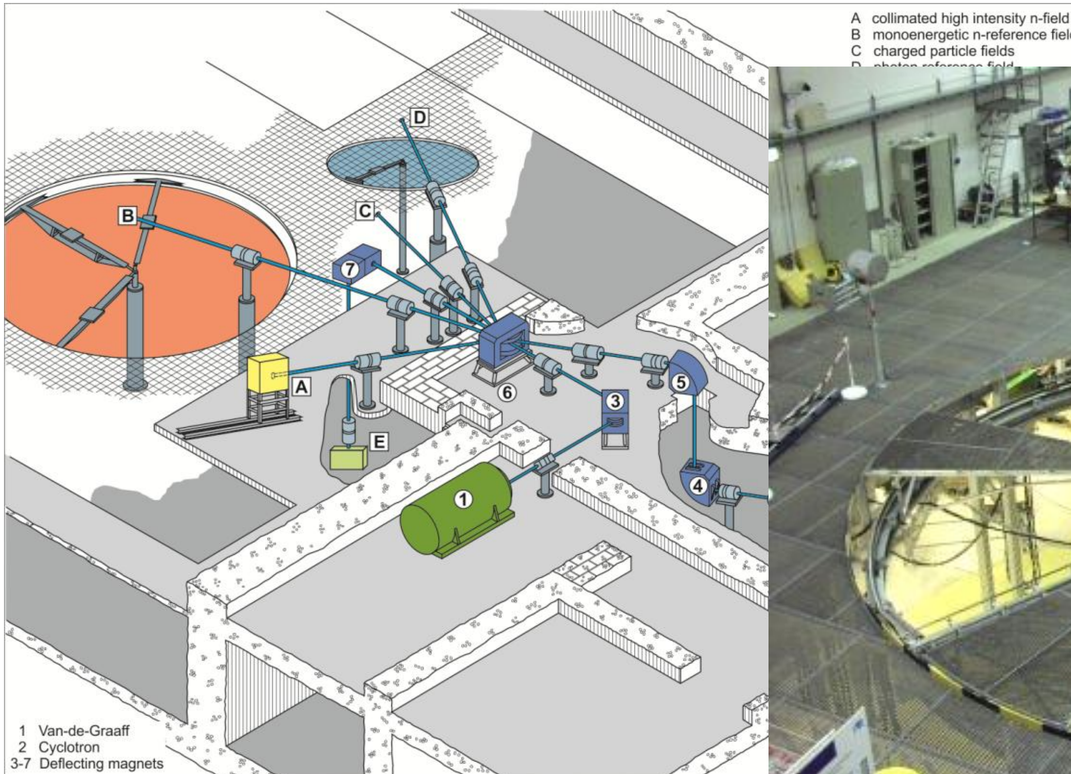
Hands-on Exercise:
Analysis of Neutron Flux Measurements using Different Detectors

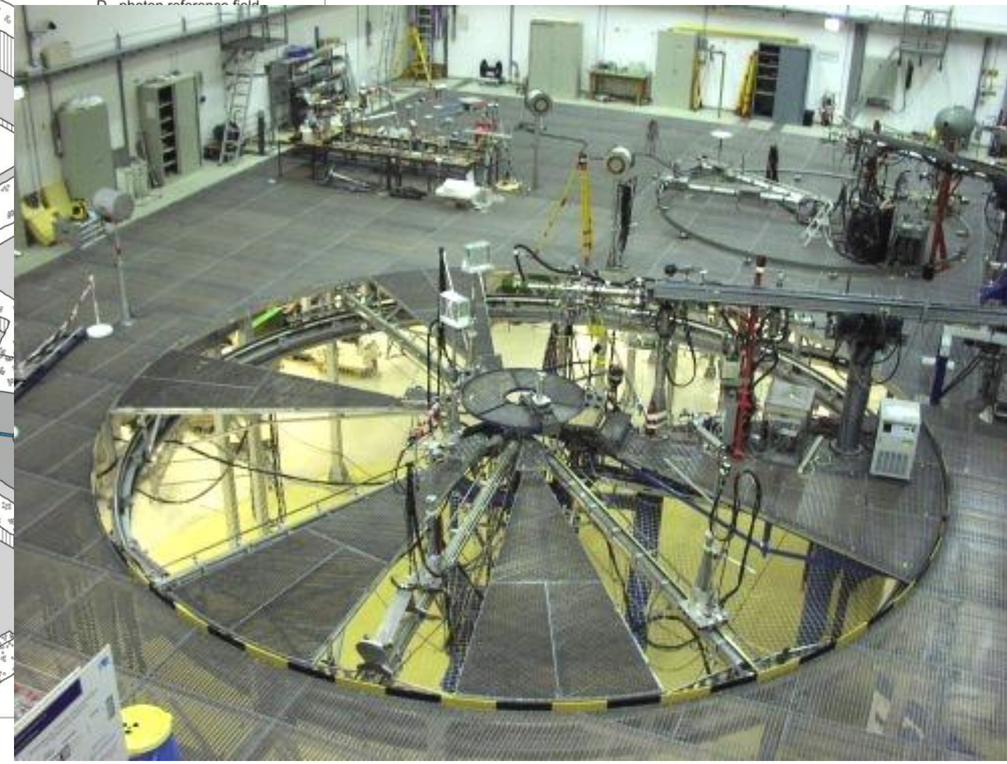
Ralf Nolte

Overview

- **Reference facility**
- **Neutron production** — **DROSG2000**, **NeuSDesc**, **TARGET**
- **Data taking:** — **MPA3 + MPANT**
- **Analysis of measurements:** — **WinSpekt**
- **Monitoring** — **EXCEL**
- **Neutron fluence standards:**
  - **Long counter** — **GUM Workbench**
  - **Recoil proton prop. counter** — **PTRAC Filter**
  - **Recoil proton telescope** — **PRTelescope**

Neutron Reference Facility

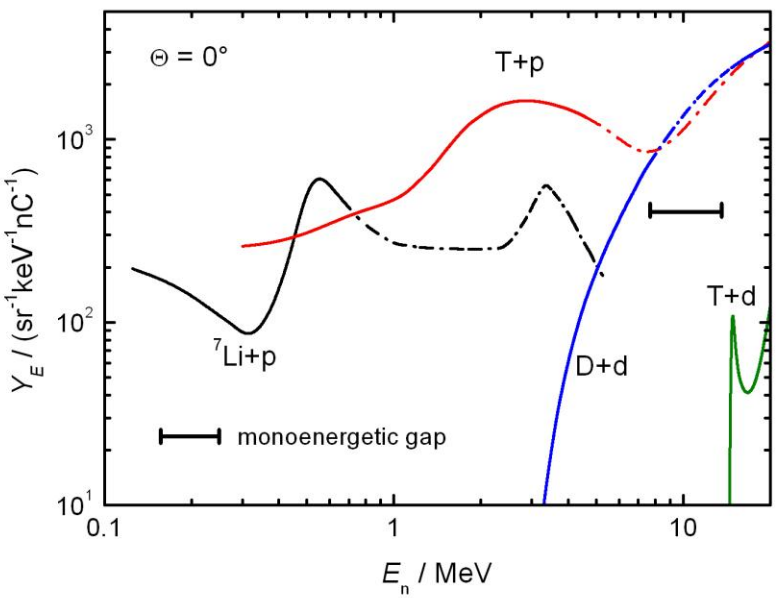




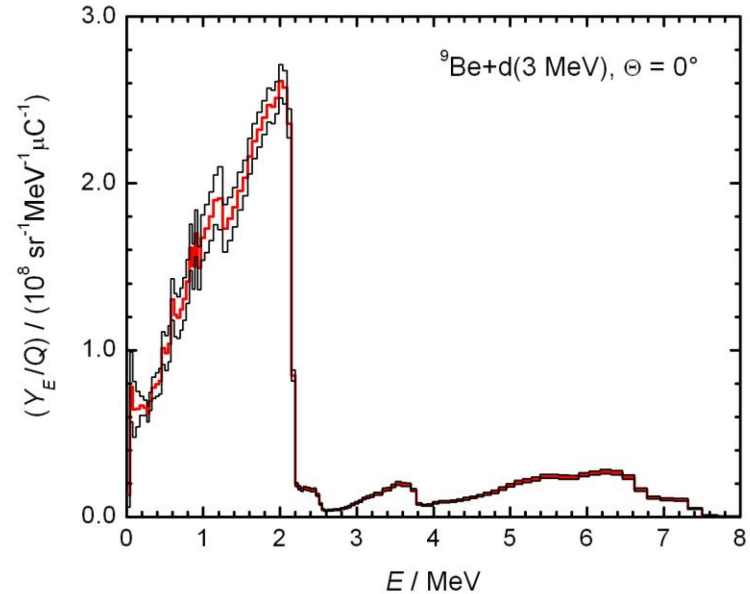
- **Monoenergetic neutrons: thin Ti(T), D_2, ^{nat}Li, ^{nat}LiF, (Sc) targets**
- **Open fields: low backscatter required**
  MC simulation of target scattering
- **Monitors: three neutron monitors + beam charge**

Neutron Production

monoenergetic neutron sources



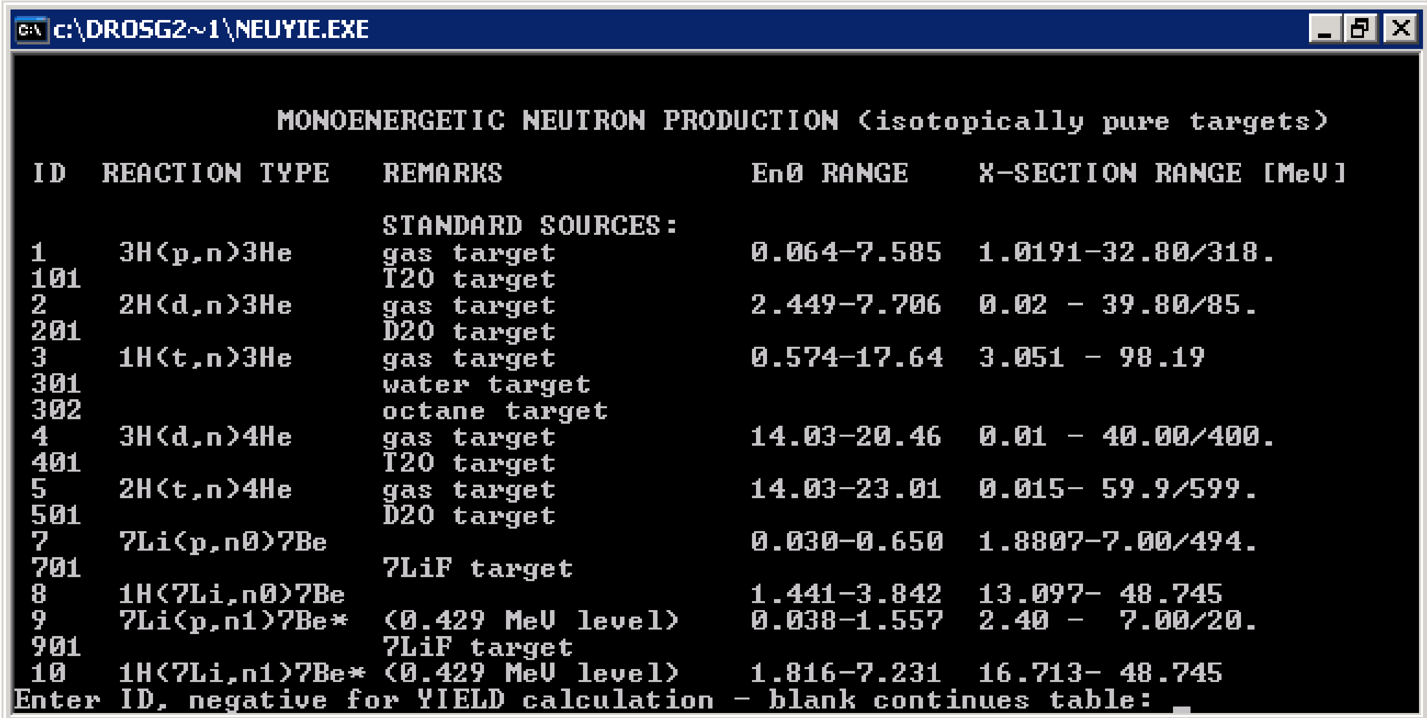
white neutron source



- **Neutron Sources have a large variety of energy and angular distribution**
- **Measurements must be planned**
  - **Energy distribution: Target scattering**
  - **Angular distribution: Monitor position**

⇒ **Reliable data needed!**

Neutron Production: DROSG2000


c:\DROSG2~1\NEUYIE.EXE

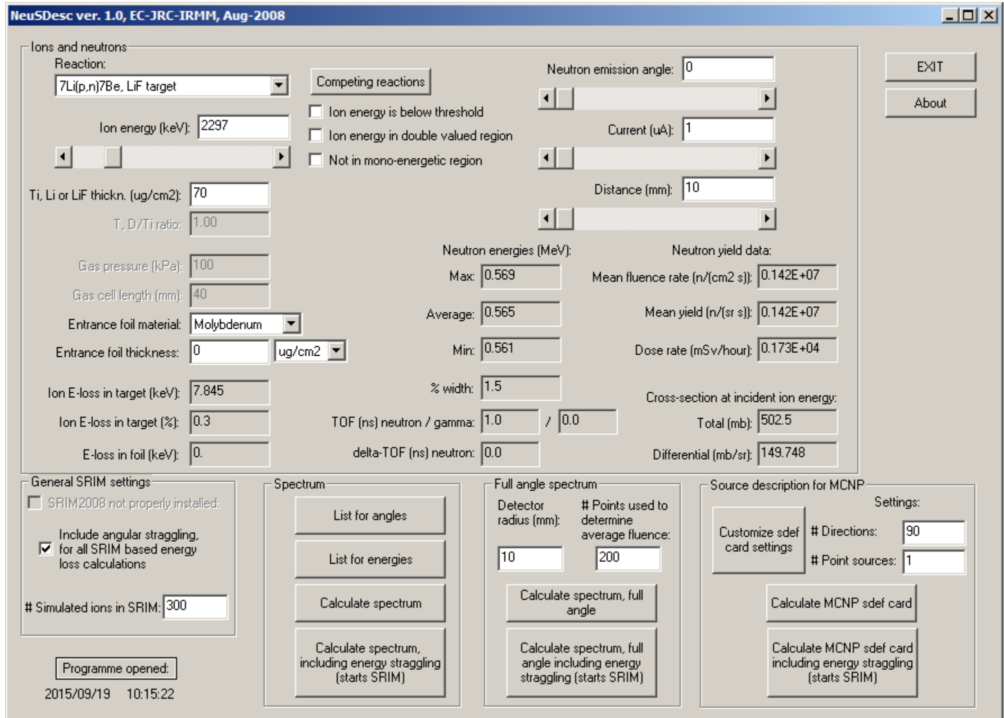
MONOENERGETIC NEUTRON PRODUCTION (isotopically pure targets)

ID	REACTION TYPE	REMARKS	En0 RANGE	X-SECTION RANGE [MeV]
		STANDARD SOURCES:		
1	3H(p,n)3He	gas target	0.064-7.585	1.0191-32.80/318.
101		T20 target		
2	2H(d,n)3He	gas target	2.449-7.706	0.02 - 39.80/85.
201		D20 target		
3	1H(t,n)3He	gas target	0.574-17.64	3.051 - 98.19
301		water target		
302		octane target		
4	3H(d,n)4He	gas target	14.03-20.46	0.01 - 40.00/400.
401		T20 target		
5	2H(t,n)4He	gas target	14.03-23.01	0.015- 59.9/599.
501		D20 target		
7	7Li(p,n0)7Be		0.030-0.650	1.8807-7.00/494.
701		7LiF target		
8	1H(7Li,n0)7Be		1.441-3.842	13.097- 48.745
9	7Li(p,n1)7Be*	(0.429 MeV level)	0.038-1.557	2.40 - 7.00/20.
901		7LiF target		
10	1H(7Li,n1)7Be*	(0.429 MeV level)	1.816-7.231	16.713- 48.745

Enter ID, negative for YIELD calculation - blank continues table: _

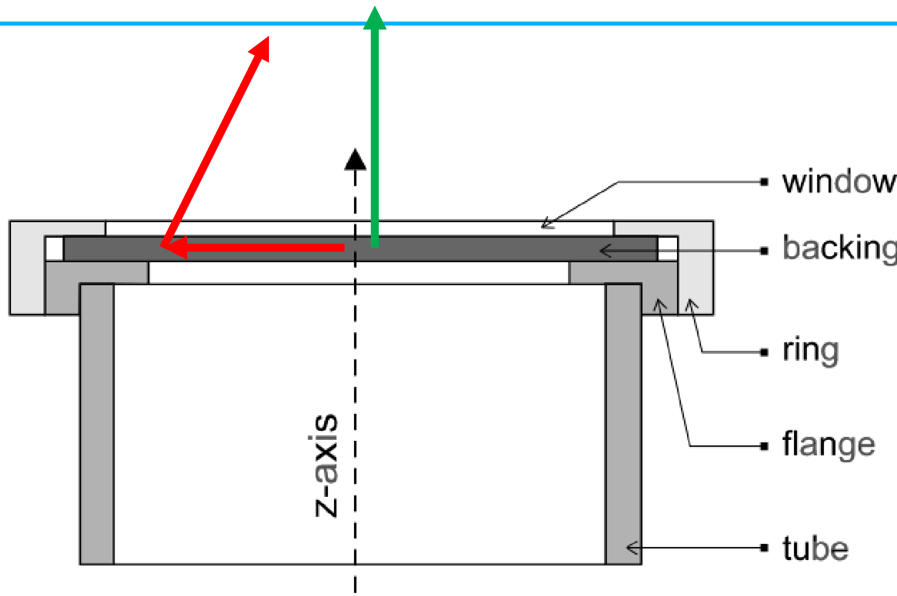
- **Data base compiled by M. Drosg (U Vienna): DROSG2000**
- **Available at https://www-nds.iaea.org/drosg2000.html (only 32 bit version)**
- **Large set of (p,n), (d,n) and (α,n) reactions, also in inverse kinematics**
- **Thick target yields (only n_0 contribution)**
- **Somewhat inconvenient to operate (only available for 32 bit OS) …**

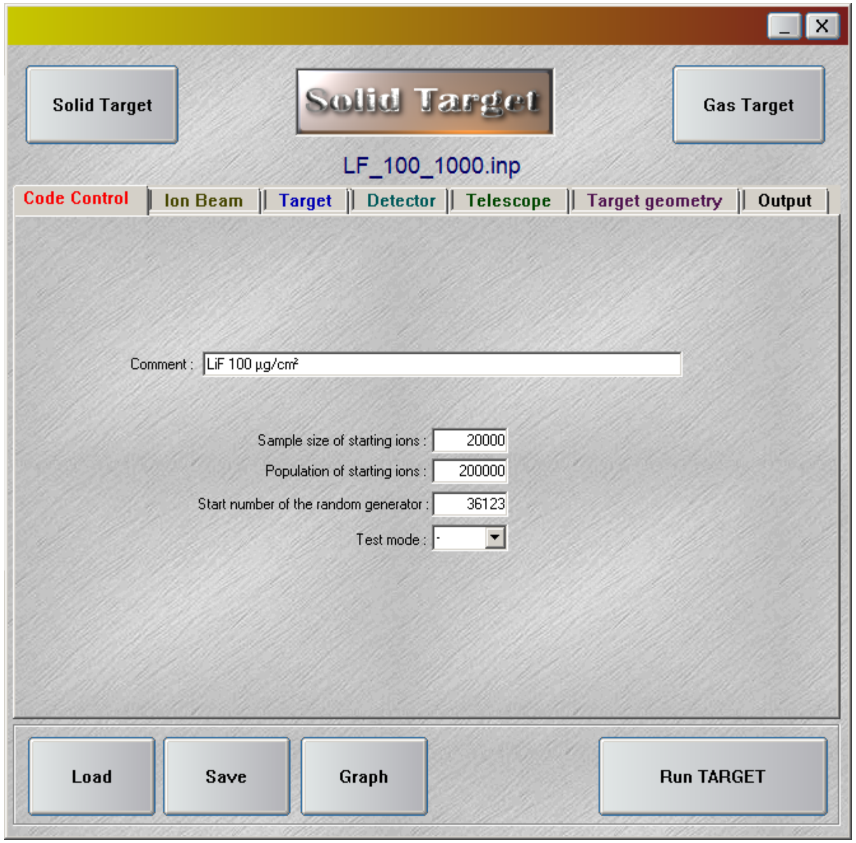
Neutron Production: NeuSDesc



- **Available from IRMM at …**
- **Calculates $Y_E(\Theta,E_p)$ for various reactions and targets**
- **Several files for plotting available in the \RESULTS folder**
- **Coupled to: SRIM201x (energy and angular straggling)**
  MCNP: SDEF card (target scattering)

TARGET

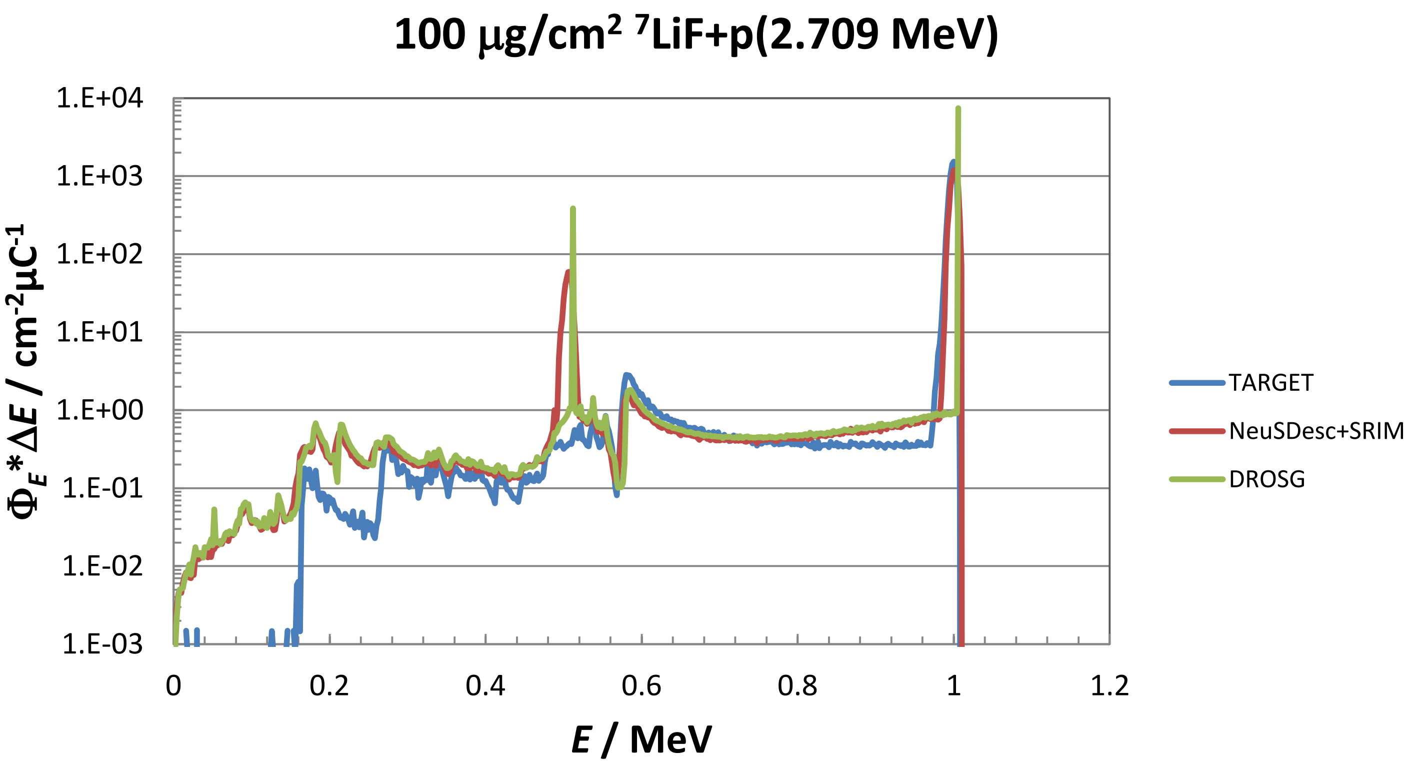




- **D. Schlegel: TARGET available from PTB on request**
- **Simulation: ion transport (energy and angular straggling), neutron scattering in the target, extended detectors**
- **Lots of PTB specific details: gas target, recoil telescope**
- **NB: TARGET has bugs (non-rel. TOF, Tritium profiles, Ta backings, …)**

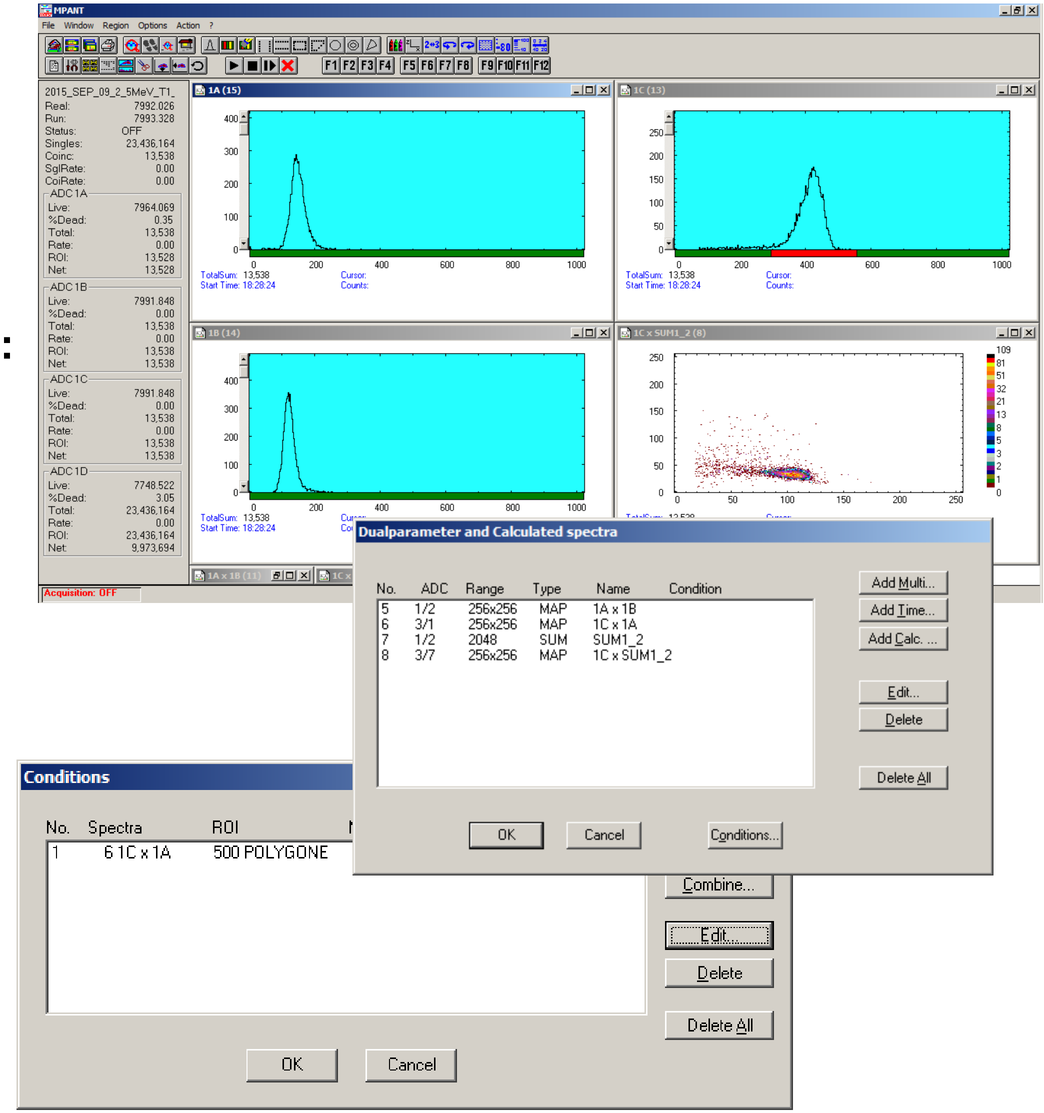
Exercise 1

Calculate spectrum for 2709 keV protons on 100 mg/cm² LiF and compare TARGET and NeuSDesc peaks: ∅10 mm det. at 100 mm dist.



Data Acquisition: MPA3 + MPANT

- **Multi-parameter DAQ required for**
  - **time-of-Flight**
  - **particle identification**
  - **coincident detectors: RPT, TCAP**
- **Simple NIM/PC-based DAQ system: Fast/ComTec MPA**
- **Up to 16 channels: PHA ADCs and TDCs**
  - **independent channels (‘singles’)**
  - **coincident groups**
  - **fast 24 bit scalers (← monitors)**
- **Display software MPANT is free**
  - **Many dialogues for definition of conditions and spectra**
  - **Listmode data in open format**
  - **Replay option ‘dongled’**
- **More: www.fastcomtec.com**

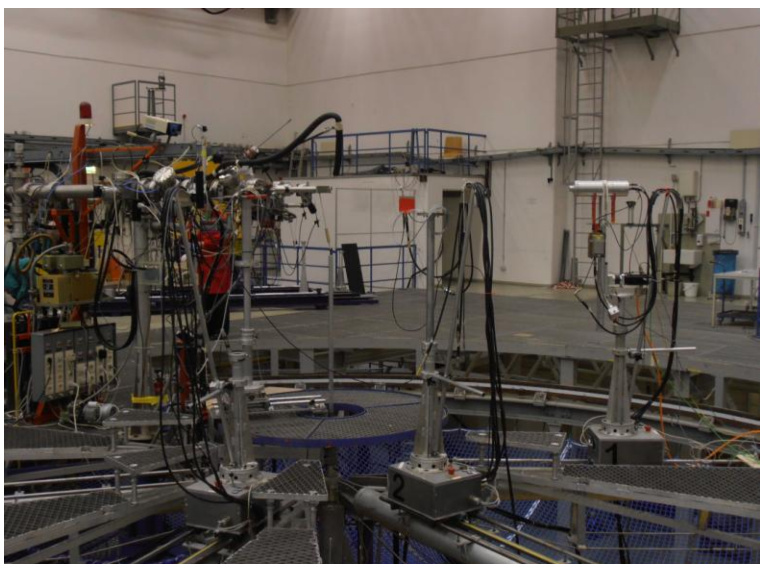


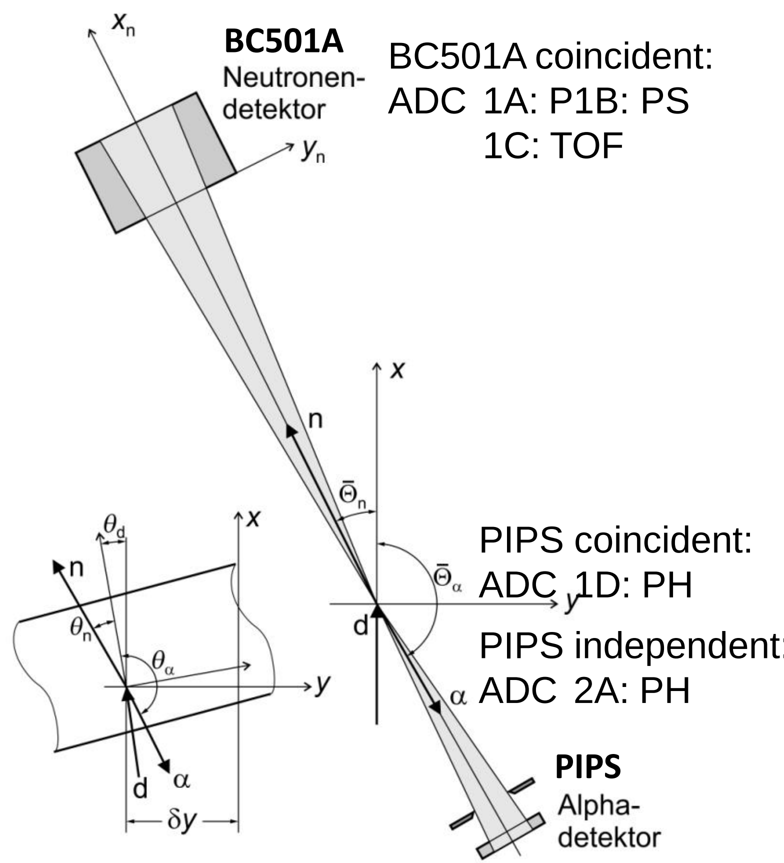
Exercise 2

Replay data from a T(d,n)^{4}He TCAP experiment at E_n = 14 MeV

- **n-induced events in BC501A (n/γ separation)**
- **α-events with full energy deposition in PIPS (PH window)**
- **α-n time correlation**

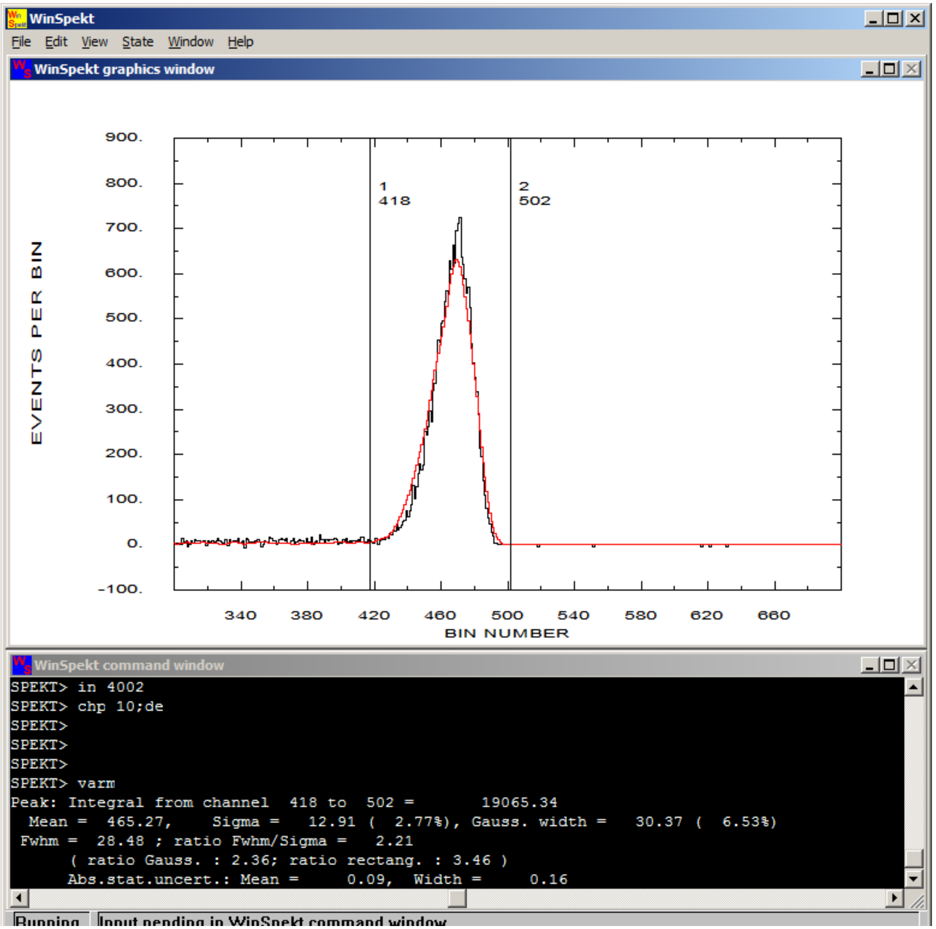
⇒ **identify 'valid' (α,n) events**





Visualization and Analysis

- **Dedicated tool: WinSpekt**
  - **Manipulation of 1-dim histograms**
  - **Error propagation**
  - **Input via command window**
  - **BASIC-style scripts, simple control structures** **`(for, if, go, sub, ret)`**
  - **Capture and propagation of numerical results `(s c=a⊗b)`**
  - **Interfaces to other 'PTB codes'**
    NRESP/NEFF
    NUMDAT
    MPA3/MPANT
    STREUER (TOF Spectrometer)

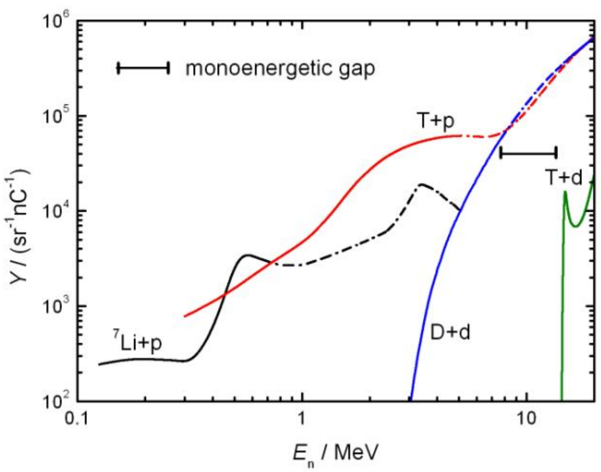


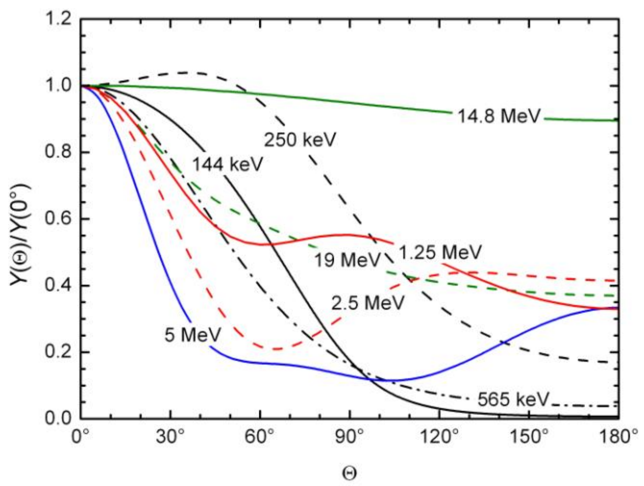
- **NB: <u>no</u> alternative to**

ROOT
An Object-Oriented Data Analysis Framework

ROOT
Data Analysis Framework

Monitoring the Source Yield

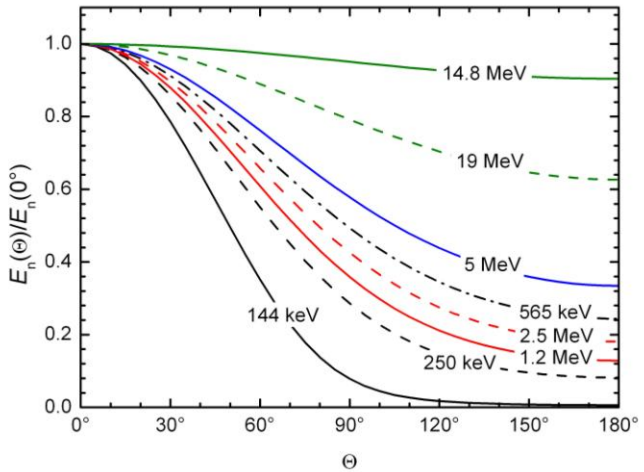




Requirements for a 'good' monitor:

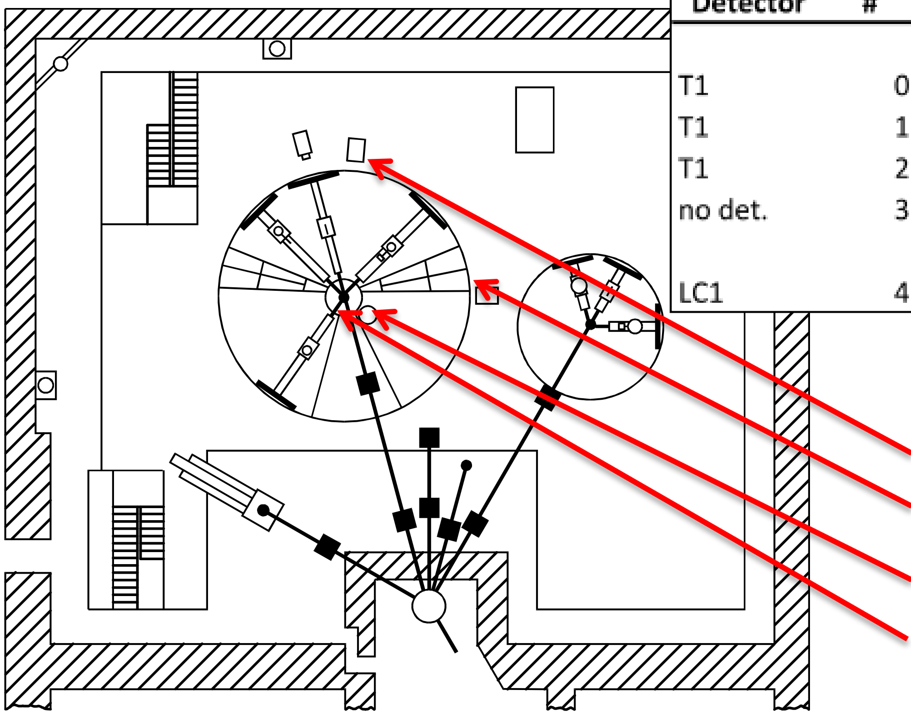
- **Proportional to 0° yield**
- **Efficiency: $R_\Phi \approx 1\ \text{cm}^2 - 10\ \text{cm}^2$**
- **Flat energy dependence**
- **Insensitivity to change of projectile angle**

⇒ a good monitor is not found easily



Exercise 3

			DT:	5.64	3.00	1.50	2.90 µs
Detector	**#**	**t / s**	**Q / mC**	**PLC**	**He-3**	**GM**	**NLC**
T1	0	4000.75	12.4160	1313427	14319829	10577	11604691
T1	1	1752.99	5.5892	591381	6438024	4721	5216267
T1	2	600.00	1.7927	190237	2068397	1541	1674446
no det.	3	600.00	2.6493	275121	3015824	2131	2418582
LC1	4	1058.61	1.5068	156240	1748432	1330	1392381



NLC: McTaggart Long Counter (^{3}He)

PLC: de Pangher Long Counter ($^{10}BF_3$)

He-3: ^{3}He prop. counter in PE moderator

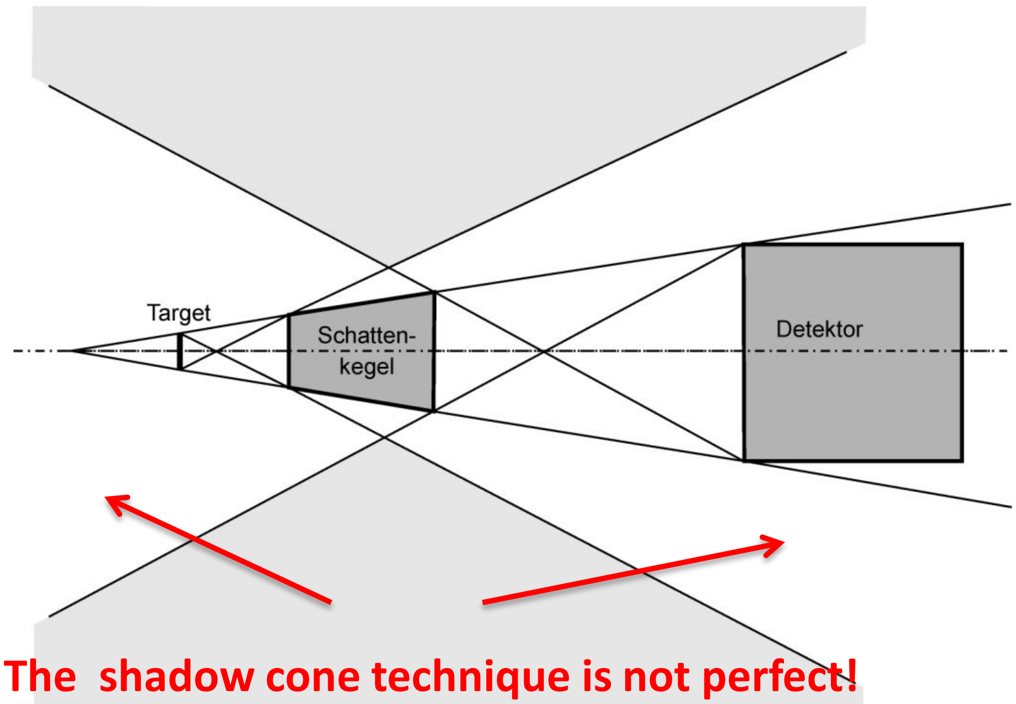
GM: compensated GM counter

- **Determine in-scatter corrections**
- **Find the most suited monitor detector**

Shadow Cone Subtracction

Suppression or subtraction of room scattering:

- **Short distance: $\Phi_{dir} >> \Phi_{sc}$**
- **Distance variation: $\Phi_{dir} \propto 1/d^2$, $\Phi_{sc} \propto 1/d^{\alpha}$, $\alpha < 2$**
- **Shadow cone method:**



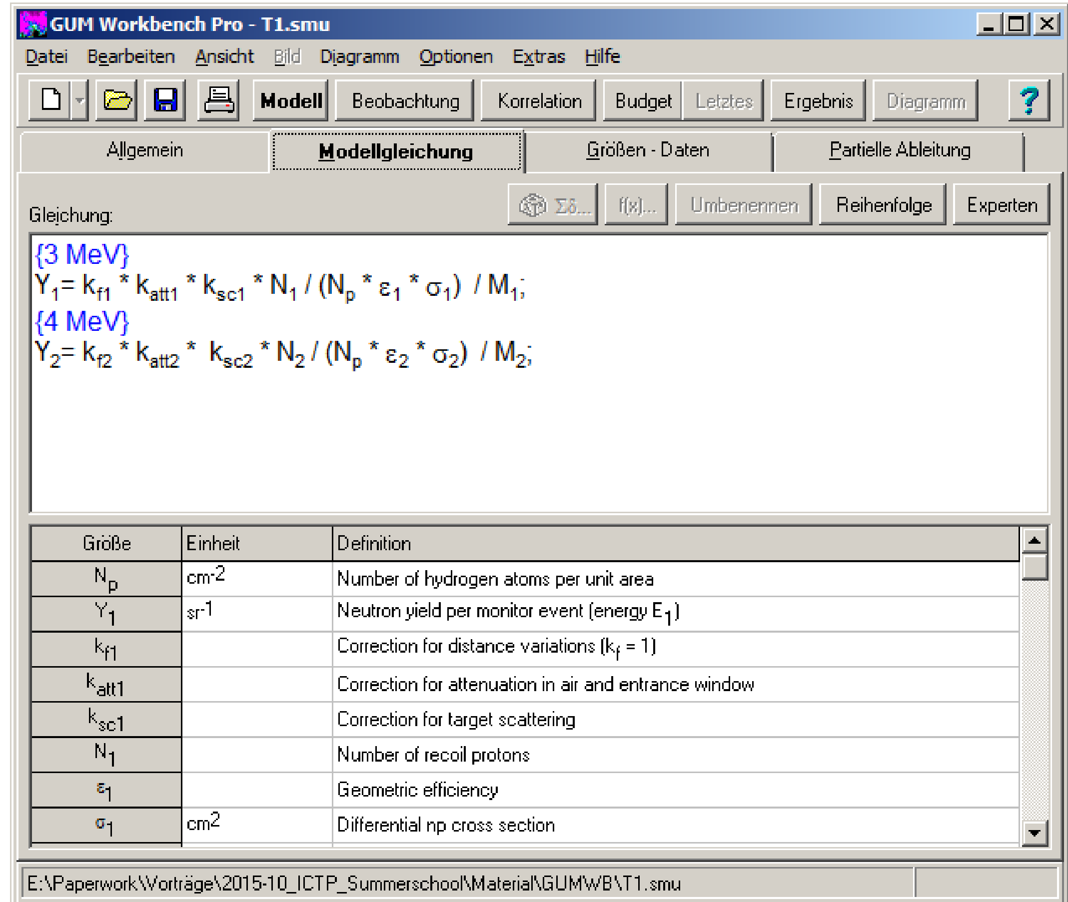
NB: The shadow cone technique is not perfect!

GUM Workbench

- **Model of the measurement**

$$\vec{Y} = f(\vec{X})$$

- **Propagation of uncertainties**
  - **Analytical formulas**
  - **MC simulation**
- **Covariance analysis**
- **Documentation of results**



Ref: Guide to the Expression of Uncertainty in Measurement 2008

Fluence Measurement using a Long Counter

- **Practical advantages of a long counter:**
  - **Very reproducible**
  - **Long term stability (with check sources)**
  - **Simple to use!**
- **Disadvantages**
  - **Bulky: pos. of ‘effective centre’ required**
  - **Therm. detector: sensitive to room scattering:**
    $\Rightarrow$ shadow cone method used for subtraction
  - **‘effective’ BF_3 pressure to be fixed**
- **NPL carried out careful modeling using MCNP5:**

$$M = \frac{K}{(d + d_{\mathrm{eff}})^2}$$

$$R_\Phi(E) = N / \Phi$$

$$d_{\mathrm{eff}}(E)$$

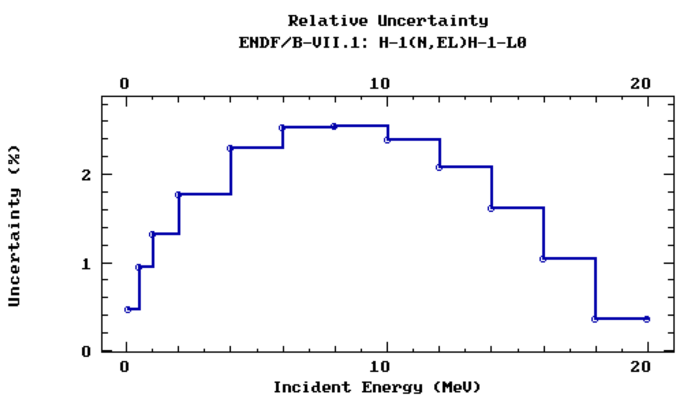
Exercise 4

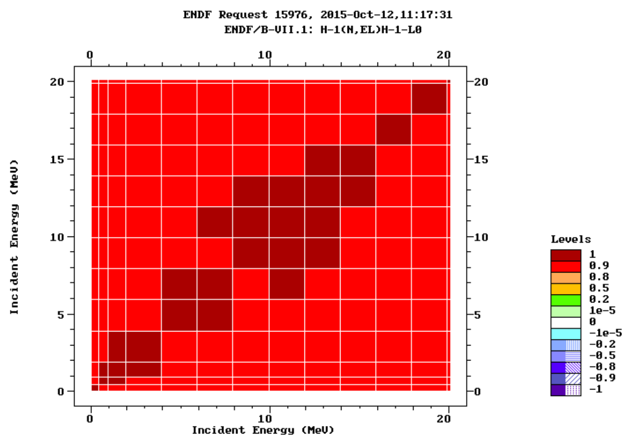
Neutron yield measurement with a long counter:
^{7}LiF + 2.824 MeV p, ^{7}LiF + 3.351 MeV p

GUM Workbench:

- **Set up a model** $$Y = \frac{N_F - (Q_F / Q_S) N_S}{k_{air} k_{sc} \overline{R}_{\Phi} Q_F} f^2$$
- **Measured count rates:** `Exercise_3.xlsx`
- **Effective centre and fluence response:** `LC1.xlsx, 2MeV.ene, 2_5MeV.ene`
- **Estimate uncertainties and correlations:** see lecture slides

⇒ **Get results with uncertainty and correlations**

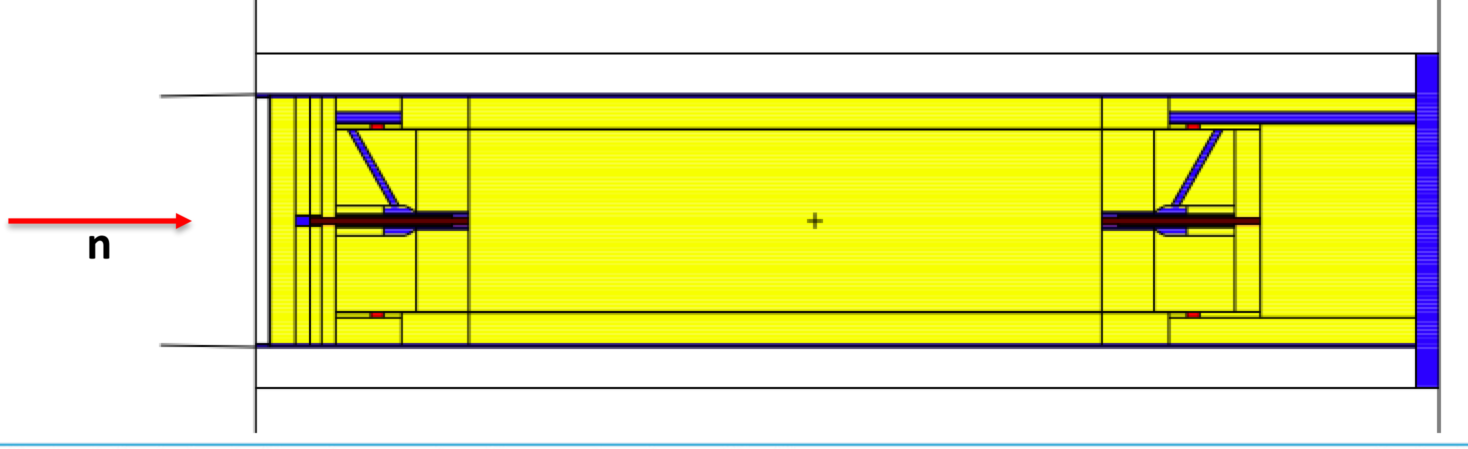




Recoil Proton Proportional Counter

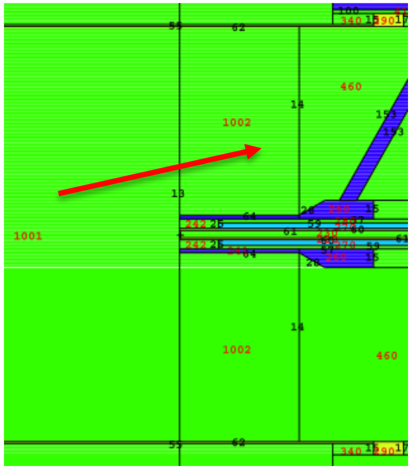
- **Reaction rate:** $N_{\mathrm{p}} = n_{\mathrm{H}} V \sigma_{\mathrm{np}} Y / d^2$
- **Corrections (see lecture):**
  - **target scattering:** $Y = Y_{\mathrm{dir}} + Y_{\mathrm{scat}}$
  - **size of the sensitive volume:** $V_{\mathrm{eff}} = V_{\mathrm{geo}} / 1.012$
  - **number of hydrogen atoms:** **real gas law**

- **Neutron and proton transport:** **MCNPX model**
  - **neutron transport:**
  - **track protons for $E_{\mathrm{p}} > 1$ keV:** **PTRAC file**



PTRAC

```
C
PHYS:N 10. 10. J J J J 1          $ neutrons: 10 MeV, analogue capture, recoil on
PHYS:H 10. 10. J J J J J J J J J $ protons: 10 MeV, analogue capture, recoil off
C
CUT:N 1E+9  1.E-04  0 0      $ cut offs: T in 10ns, E in MeV, WGT1, WGT2
CUT:H 1E+9  1.E-03  0 0      $ cut offs: T in 10ns, E in MeV, WGT1, WGT2
C
PTRAC FILE=ASC MAX=1000000 WRITE=ALL EVENT=SRC,BNK,SUR,TER
      CELL=1000,1001,1002 TYPE=H
C
```



```
  -1
mcnpx   2.7.0Mon Apr 18 08:00:00 MST 2011  04/01/15 23:04:49
RPPC detector: MCNPX version with p transport
   1.4000E+01  1.0000E+00  1.0000E+02  3.0000E+00  1.0000E+03  1.0010E+03  1.0020E+03  4.0000E+00  1.0000E+00  2.0000E+00
   3.0000E+00  5.0000E+00  1.0000E+00  1.0000E+00  0.0000E+00  1.0000E+00  1.0000E+06  0.0000E+00  0.0000E+00  0.0000E+00
   0.0000E+00  1.0000E+00  9.0000E+00  0.0000E+00  1.0000E+00  2.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
     3     7     9     8     9     8     9     8     9     8     9     0     4     0     0     0     0     0     0     0
    1    2    3    7    8    9   16   17   18   19   20   21   22   23   24   25   26   27   28    7    8   10   11   16   17   18   19   20   21   22
   23   24   25   26   27   28    7    8   12   13   16   17   18   19   20   21   22   23   24   25   26   27   28    7    8   10   11   16   17   18
   19   20   21   22   23   24   25   26   27   28    7    8   14   15   16   17   18   19   20   21   22   23   24   25   26   27   28
...
        16707       2030       1000
         3000         11       1001        -99          9       1001          3          0
   0.78154E+00  0.20779E+01  0.25705E+02 -0.23773E+00 -0.97997E-01  0.96638E+00  0.52724E+00  0.10000E+01  0.11999E+02
         5000         12         13         16          9       1002          3          6
   0.74673E+00  0.20619E+01  0.25840E+02 -0.25215E+00 -0.12470E+00  0.95962E+00  0.43763E+00  0.10000E+01  0.12013E+02
         9000         12          2          2          9       1002          3        179
   0.60849E+00  0.20211E+01  0.26299E+02 -0.49167E+00 -0.87058E+00 -0.18518E-01  0.10000E-02  0.10000E+01  0.12105E+02
...
```

Annotations: next event; part. species; cell no.; mat no.; surf. no.; $(\vec{x}, \vec{u}, E, w, t)$

… the data format is a bit complicated, but comprehensible:

- **dedicated filter used to produce a histogram**
- **normalized to one source neutron per unit solid angle**

Exercise 5

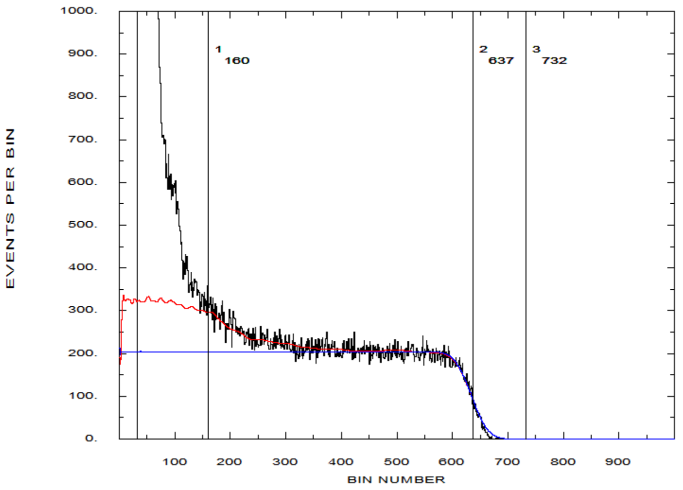
Recoil counter for pedestrians and cavaliers:
E_n = 300 keV, p = 300 hPa C_3H_8 and 1000 hPa H_2/CH_4

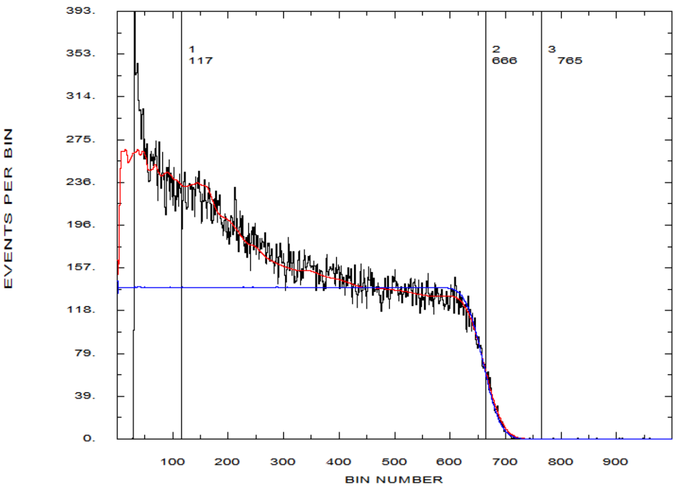
- **Inscattering subtracted with shadow cone**
- **Input data for P2:** `Input.xls`
- **WinSpekt scripts:** `P2_H.prg, P2_P.prg`

⇒ **Get *Y*/*Q* with a simple analytical and an MCNPX response:** `LM_70_300_Xppp.ASC`

How to make a simple rectangular response with Gaussian broadening:

```
SPEKT> lsh;adn 2.616E-08,0,638;mul 0,1.E6;flt 2,8.2;spe 2003
```

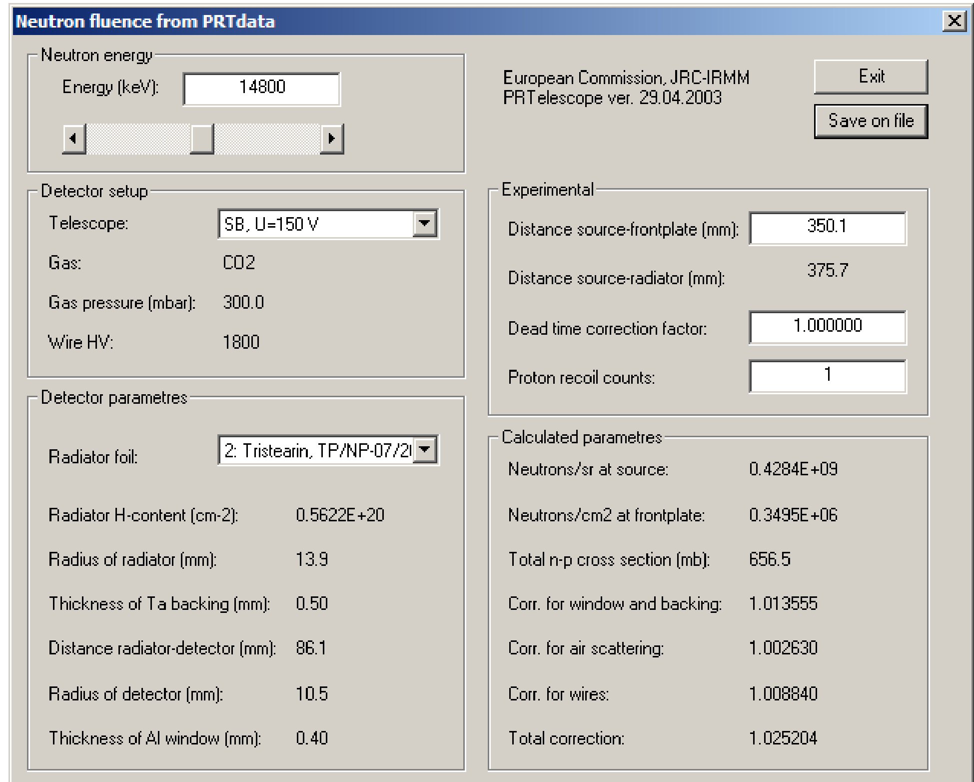




Recoil Proton Telescope

- **Experimental problems:**
  - **High single rates: > 10^4 cts/s**
  - **Low coincidence rates: < 10 cts/s**
  - **Small distance to target: ≈ 20 cm**
  - **Energy loss and straggling of recoil protons**
- **Detection Efficiency**
  - **Analytical calculation using relativistic kinematics: PRTelescope**
  - **Full MCNPX modeling**

$$Y = \frac{N_{\mathrm{p}}}{\varepsilon(d_{\mathrm{rad}}, r_{\mathrm{rad}}, d_{\mathrm{det}}, r_{\mathrm{det}})\, n_{\mathrm{H}}\, \sigma_{\mathrm{np}}}$$



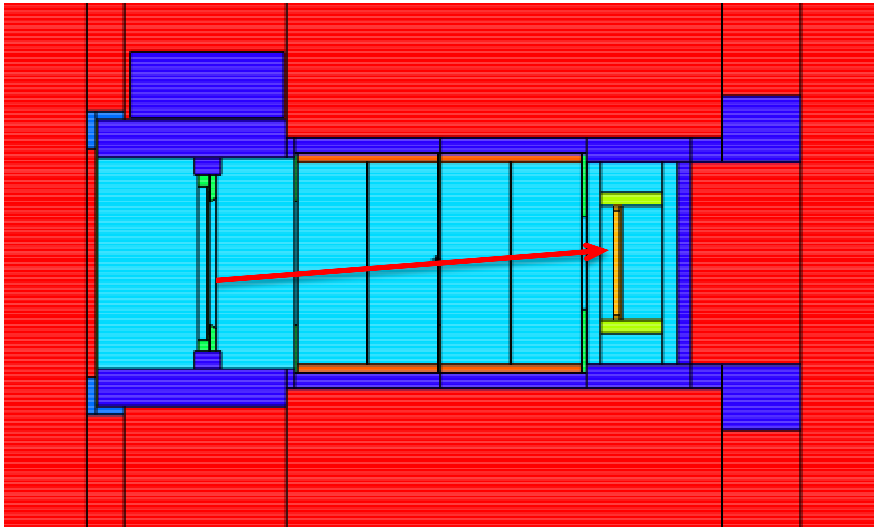
by courtesy of: G. Lövestam (IRMM/JRC)

ref: D. Sloan, J.C. Robertson, NIM198 (1982) 365-372

MCNPX Model

```
124   3   -5.404E-04 -137 131 -136 133                  IMP:N=1 IMP:H=1 IMP:A=1 $ groove in aperture
C
130   7   -0.862      -131 130 -134                     IMP:N=1 IMP:H=1 IMP:A=1 $ tristearine layer
                                                        FCL:N=-1

C
131   3   -5.404E-04 -131 130 -136 134                  IMP:N=1 IMP:H=1 IMP:A=1 $ around tristearin
C
...
C
FC11 *** Protons at detector surface per unit source yield (sr) ***
F11:H 403
FS11 -409
CF11:H 205 303
FM11 0.07734601 $ solid angle for Theta = 9°
E11 0.02 758I 15.2
C
```



- **Forced interaction (`FCL` card)**
- **Tally: proton current on the Si detector**
- **Detection of triple coincidences**
  - **cell flagging (`CF` card)**
  - **PTRAC file**
- **NB: MCNPX uses non-relativistic kinematics: correction factor $k_{rel} \approx 1.007$ at 14 MeV**

Exercise 6

Recoil telescope for galley slaves and admirals:
E_n = 2.5 MeV

- **Background with radiator in reverse position**
- **Input data for T1:** `Input.xls`
- **WinSpekt script:** `T1.prg`

⇒ **Get *Y*/*Q* with an analytical formula:** `PRTelescope`
and an MCNPX response: `T1.prg, McT1_2500.ASC`

- set three markers
- use `inm m1,m2` to get integral between markers
- extrapolate background into peak area