
# Contributions to the final report

Arjan Plompen

# Contents

*IRMM contributions to the final report*
- *Re-analysis Na elastic scattering (Märten, Kopecky)*
- *n-D scattering (to be finalised end August)*

*Interests*
- *Issues for HPRL*
- *Illustrative examples of impact a.d. on k, crit-mass*
- *PhD work*

*CHANDA*

# Na elastic and inelastic scattering with eight liquid scintillators (recap, shortened 2012)


*H. Märten, J. Wartena and H. Weigmann, Simultaneous high resolution measurement of the differential elastic and inelastic neutron scattering cross secftion on selected light nuclei, GE/R/ND/02/1994 (1994), unpublished*

*S. Kopecky, H. Märten, J. Wartena and H. Weigmann NDST, Triëste and EXFOR entry (1997), unpublished*

- *S. Kopecky and A. Plompen "R-matrix analysis of the total and inelastic scattering cross sections" EUR 25067 EN, LANA-25067-EN-N.pdf (2011)*

# Overview

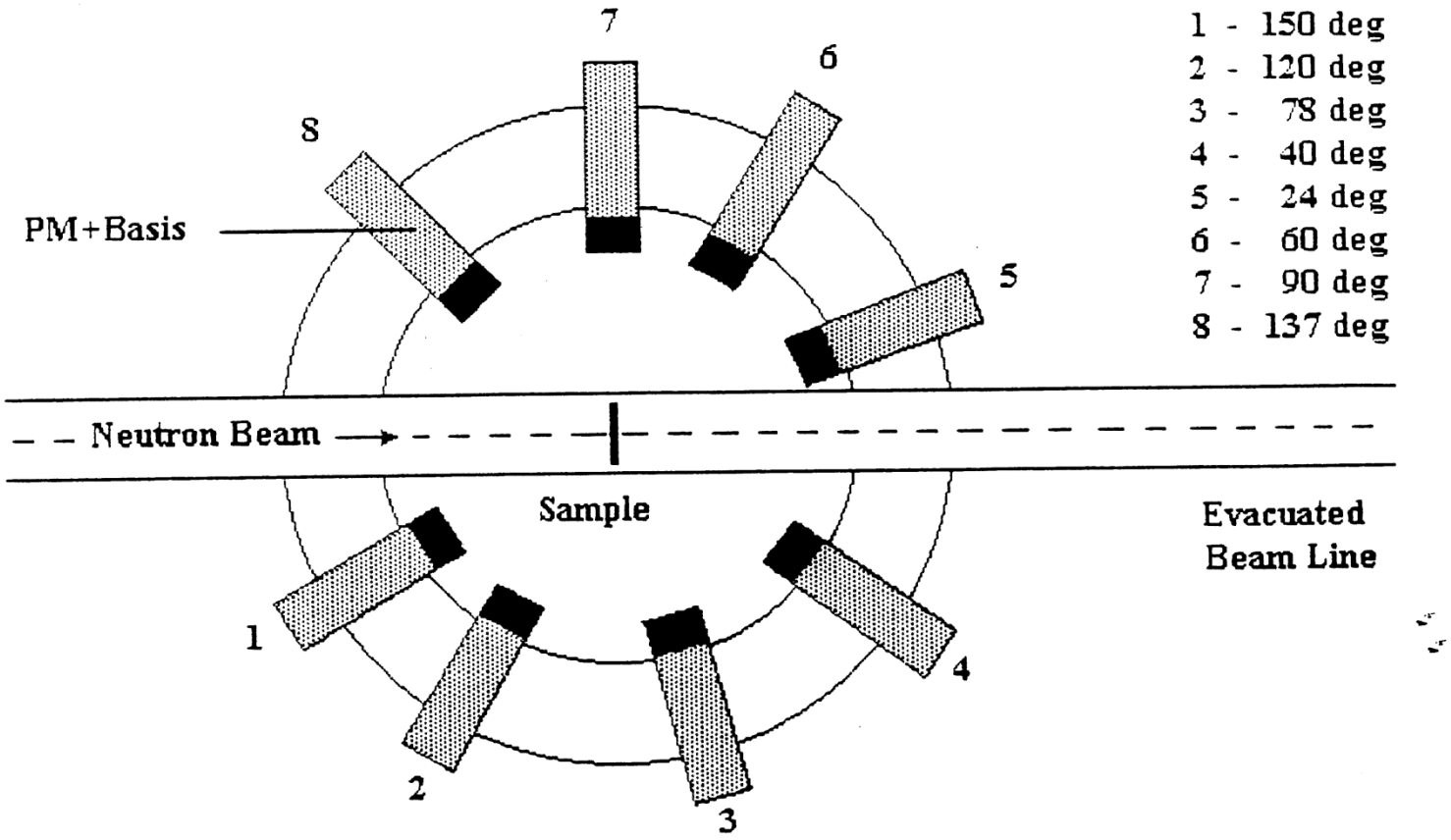
*Measurements at GELINA in 1994, C, Na, Al, Fe*
*Analysis using Blatt-Biedenharn and Multi-code*
*Re-analysis S. Kopecky in 1994-1997 using SAMMY and compilation in EXFOR*
*Provision of R-matrix parameters to CEA (2011)*
*Analysis of the consistency of the combined elastic differential and inelastic data sets*

Angle integration and comparison with total xs

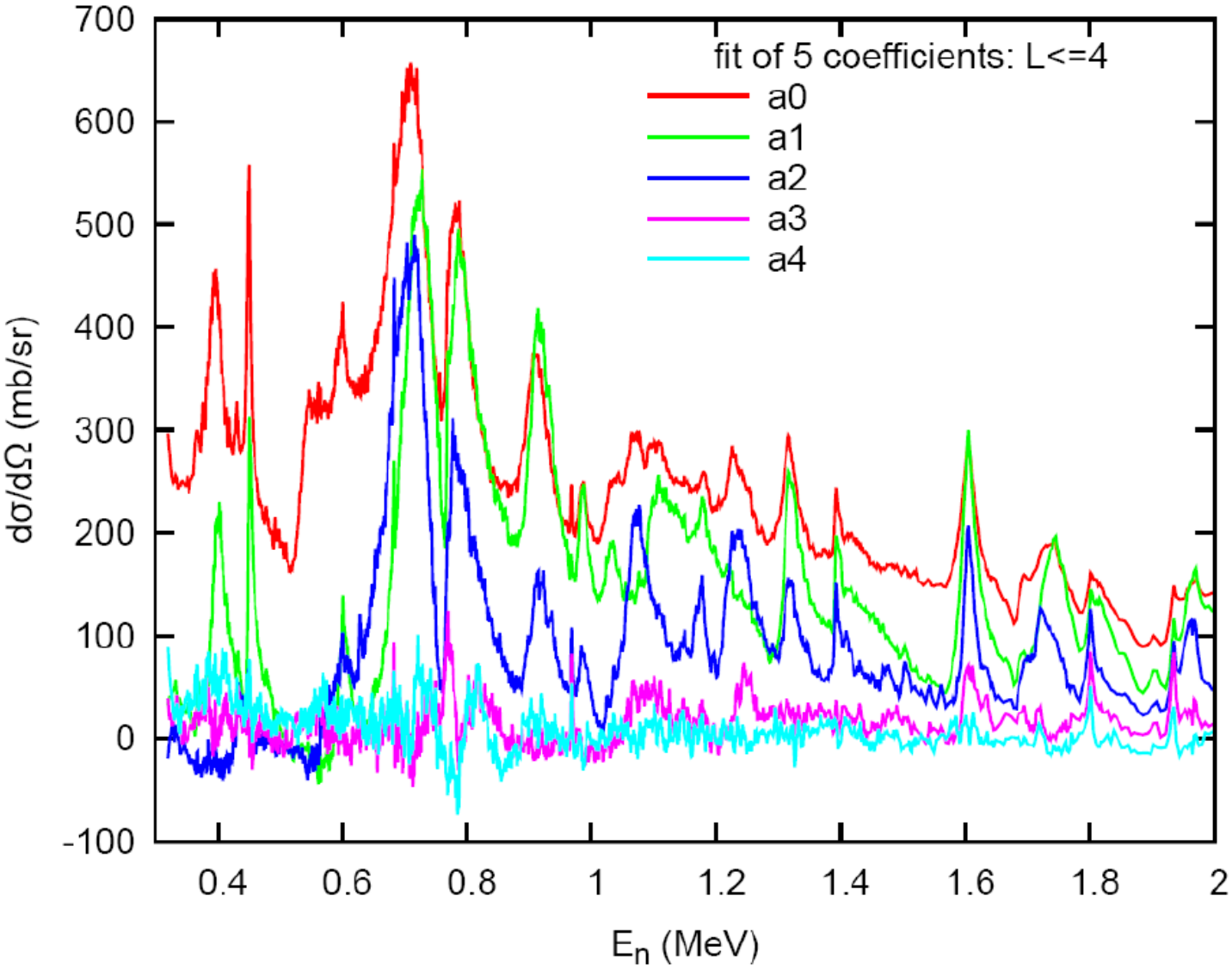
(2011)

*8x NE213*
*2”x2”ø*
*Metal. Na*
*v.s. $^{10}B(n,ag)$*

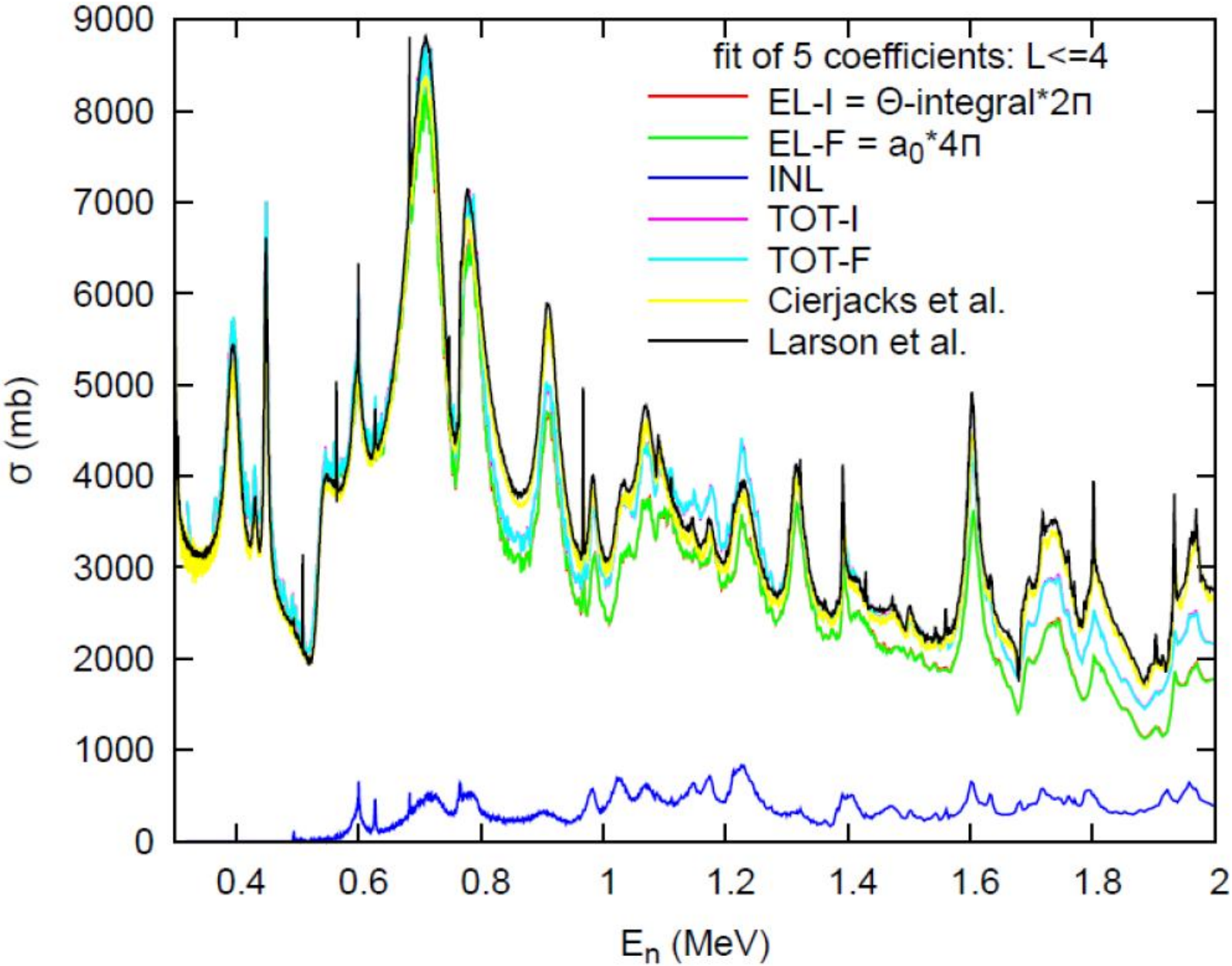
# Setup



# Legendre-fit to diff. xs.



# Consistency check



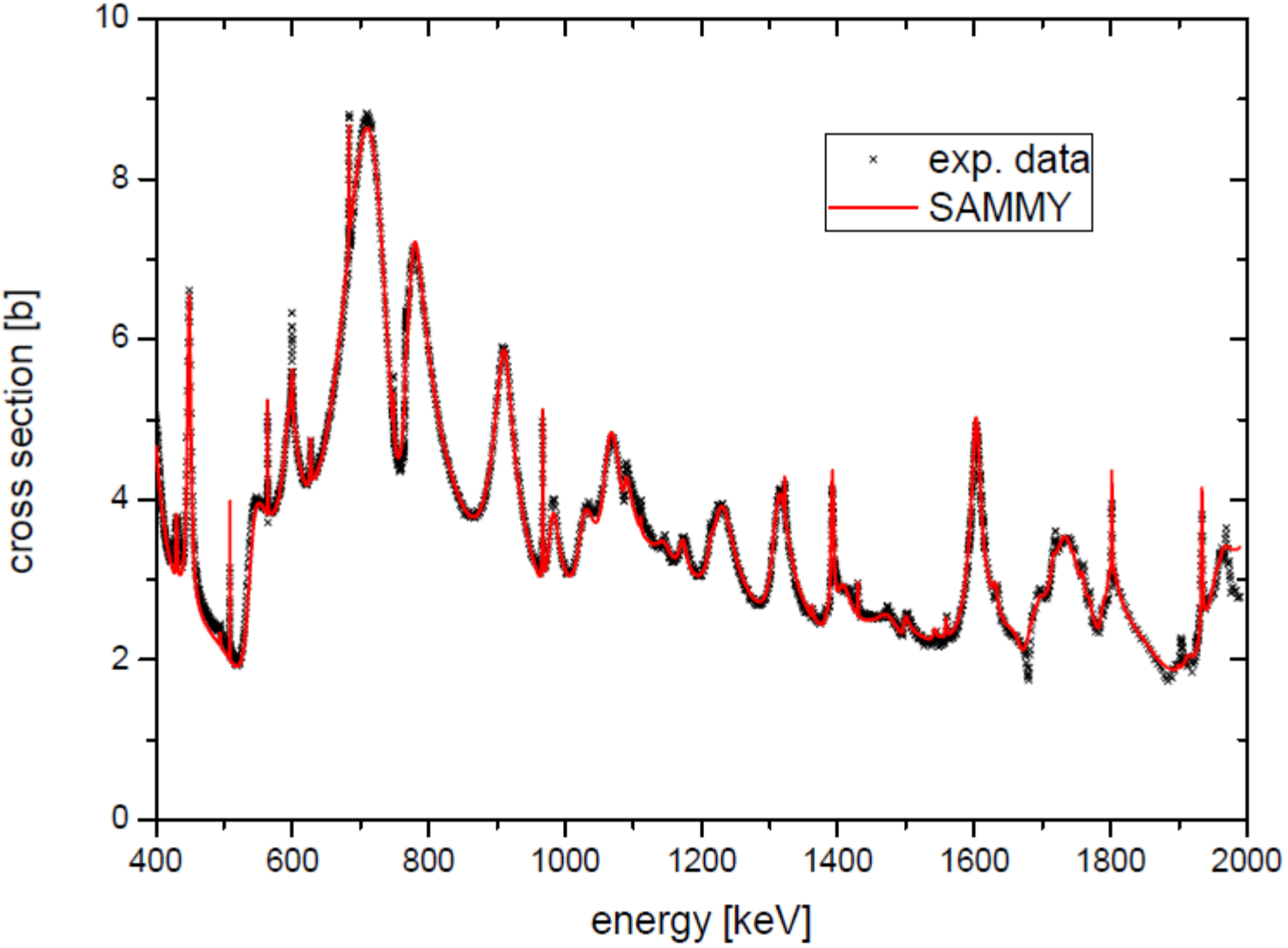



**Fig 3: Comparison of experimental total cross section data of Larson et al. with calculation**

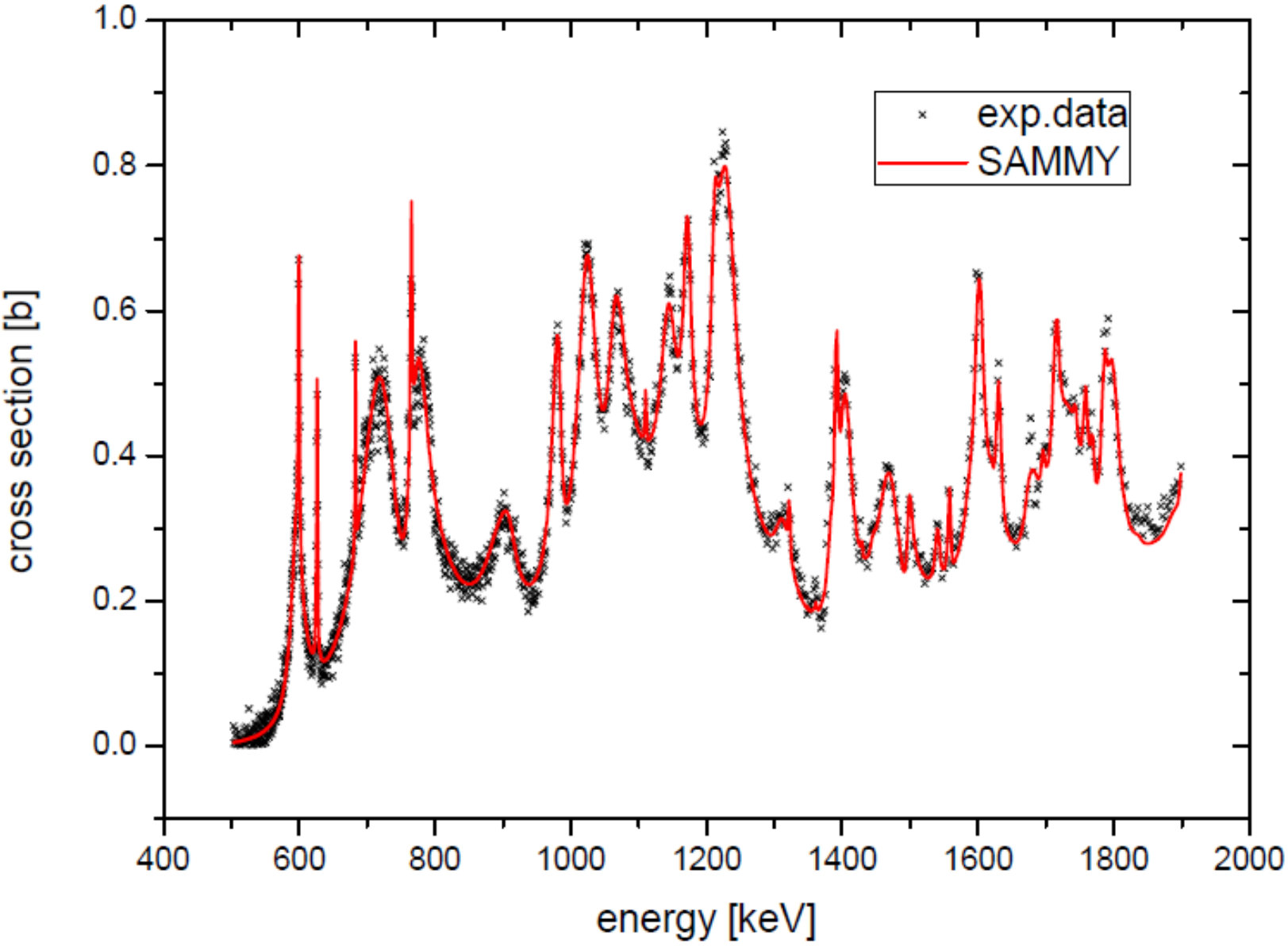



**Fig 4: Comparison of experimental inelastic cross section data with calculation**

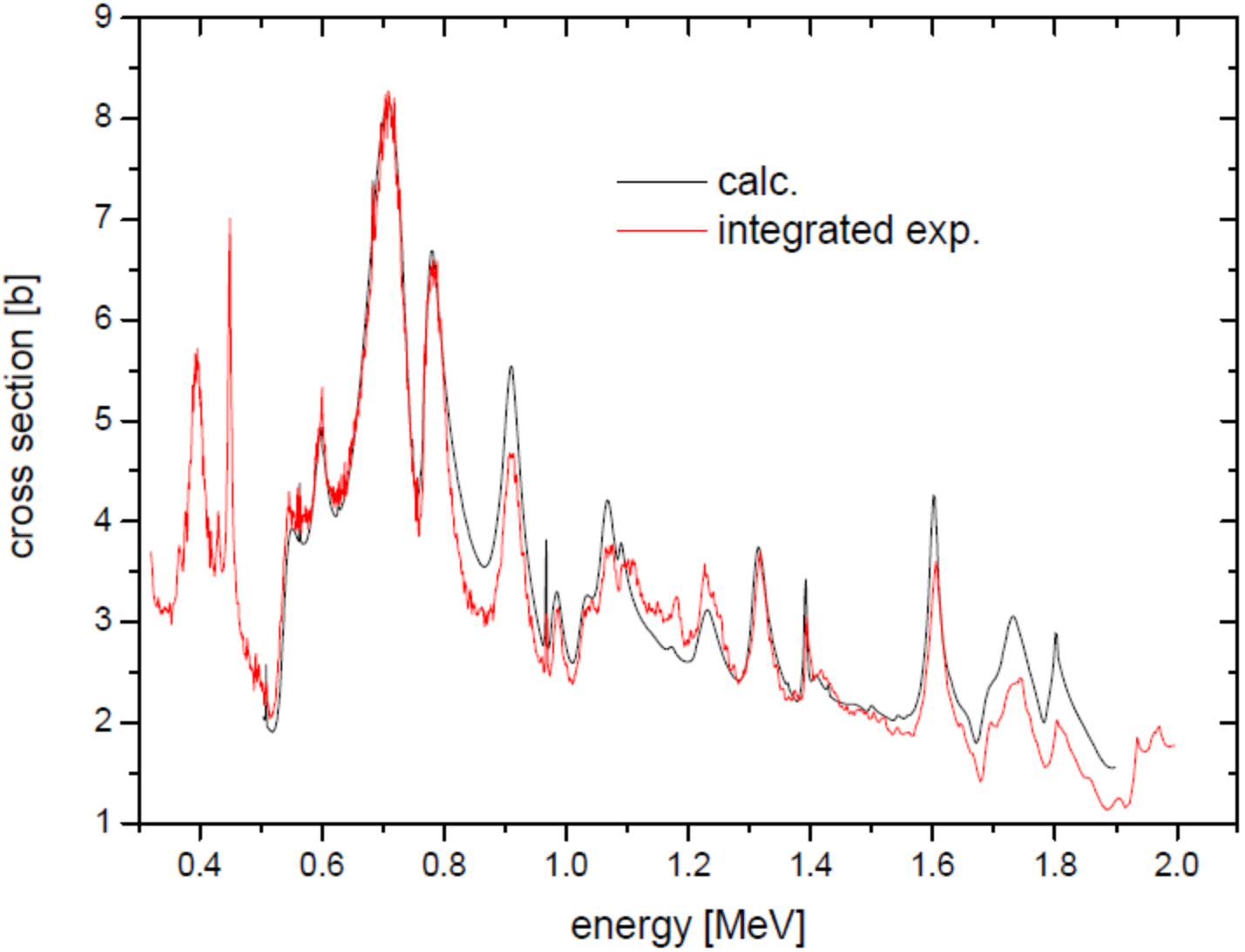



**Fig 13: The elastic scattering cross section from the R-matrix calculation (calc.) and the Legendre fit to the experimental data (Integrated exp.).**

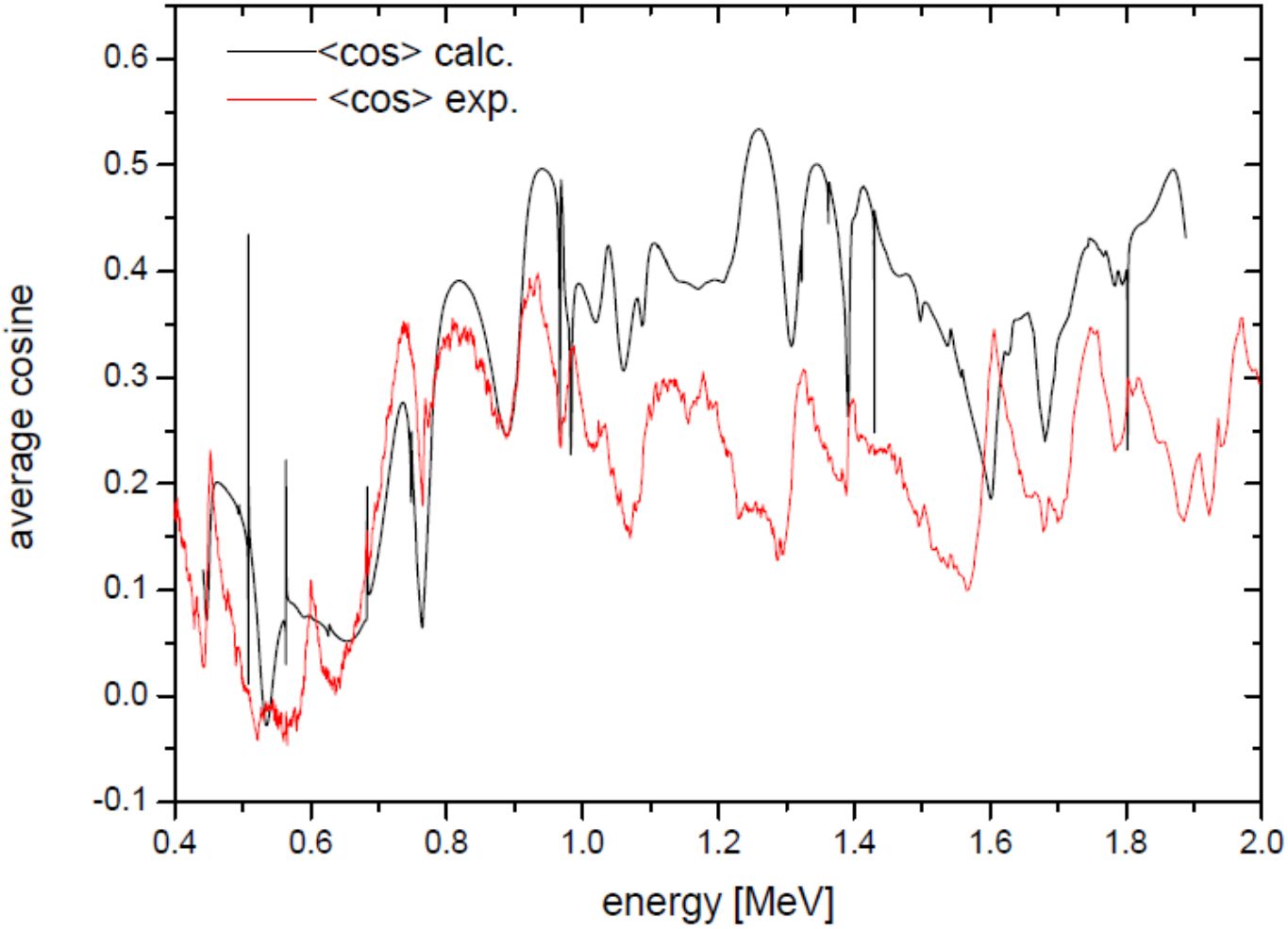



**Fig 14: The centre of mass average cosine from the R-matrix calculation (calc.) and the Legendre fit to the experimental data (exp.).**

# Summary liq.scint.meas. Na

*Expt. elastic+inelastic not equal total of Larson and Cierjacks*
*May be due to response modeling of detectors and the very low thresholds for some energies and angles*
*Need for further investigation*

*R-matrix describes total and inelastic*
*Parameters available (report, file)*
*Elastic data not well described*

# n+D scattering Collaboration

*EC-JRC-IRMM Geel*
*CENBG Bordeaux*
*HZDR Dresden-Rossendorf*
*PTB Braunschweig*
*AECL*
*U. Manitoba*
*INFN Padova*

*N. Nankov, A. Plompen, M. Stanoiu, B. Blank ++, R. Beyer, E. Grosse, R. Hanaske, A. Junghans, A. Krása, M. Massarczyk, R. Nolte, S. Röttger, R. Schwengner, D. Yakorev, A. Wagner, K. Kozier, D. Roubtsov, R. Rao, J. Svenne, L. Canton*

# Contents

*ERINDA experiment HZDR scattered neutrons*

*ERINDA experiment PTB recoil detection*

*Motivation*

*Need for angular distributions of n+D scattering identified by Ken Kozier and collaborators*

# nELBE experiment

*D(n,n)D*

*nELBE neutron source $\gamma$+Pb, Pb($\gamma$,xn)*

*6.2 m flight path*

*AECL $CD_2$ target*

*IRMM $^6$Li-glass setup*

*Focus on the problem area  $E_n$ = 0.1-1.0 MeV*

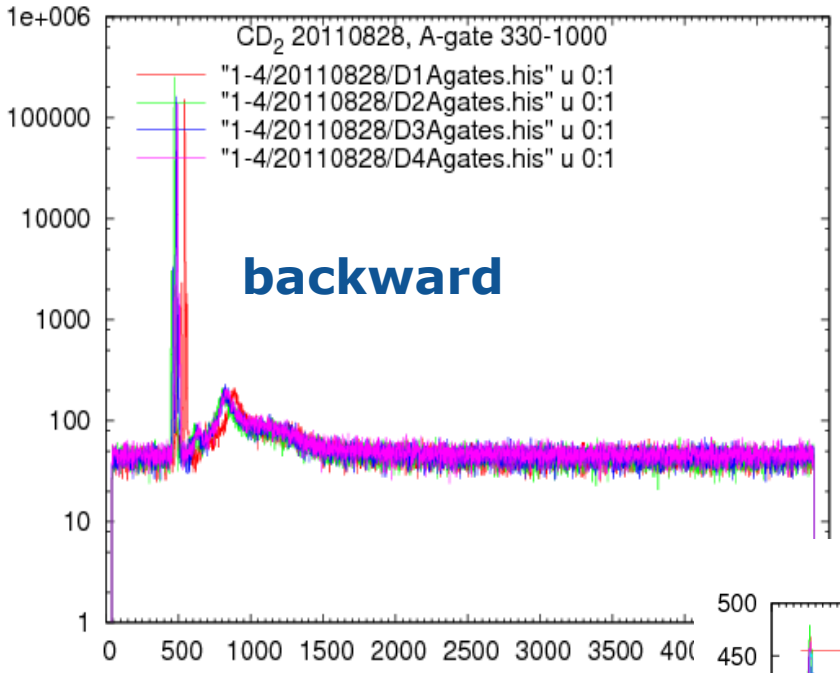
# Li-glass setup

*Eight Li-glass detectors*
*95% enriched in $^{6}Li$*
*51 mm Ø x 12.7 mm thick*
*Scionix, Netherlands*

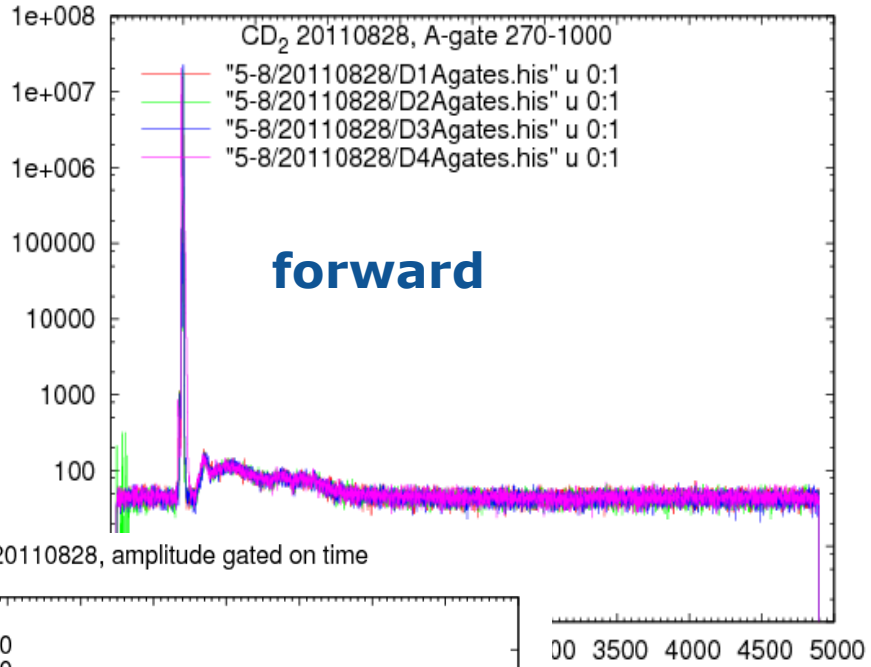
*$15^{o}$ Four detectors*
*$165^{o}$ Four detectors*
*Ratio 15/165 by detector*

*CD2 (AECL)*
*C (Goodfellow)*
*Blank*
*Natural background*

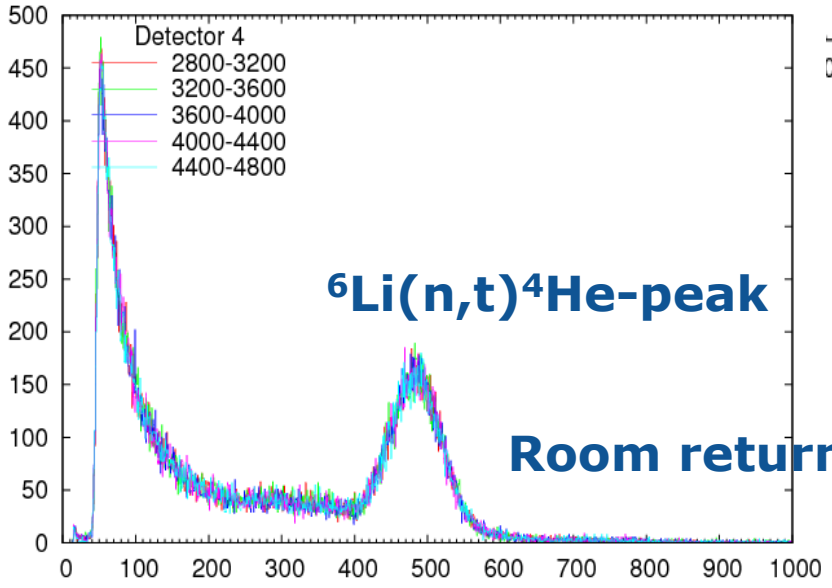
# Time-of-flight, pulse height




backward




forward

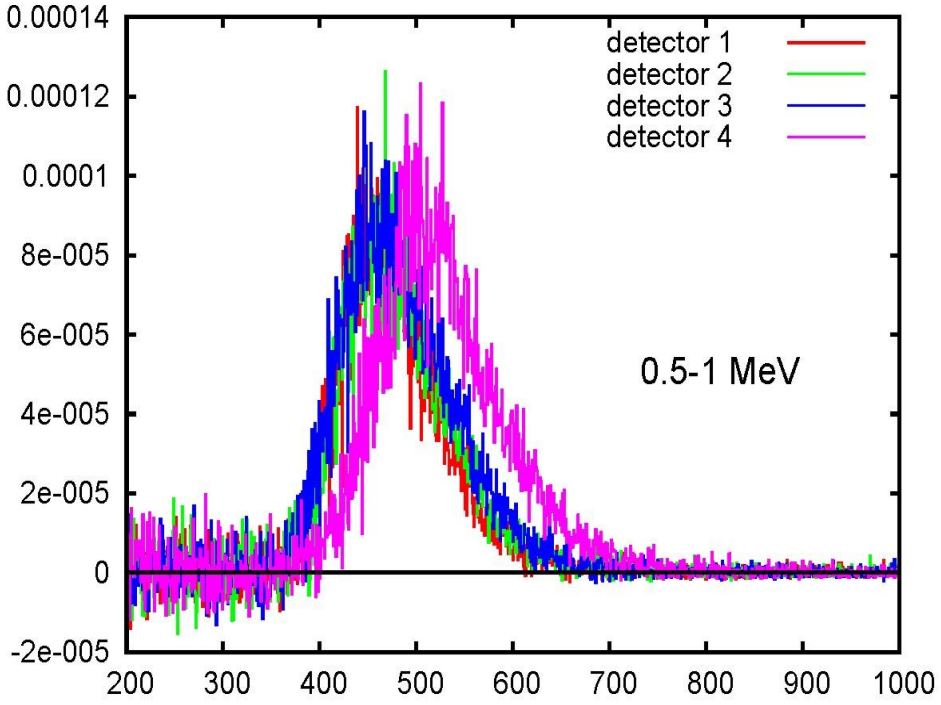


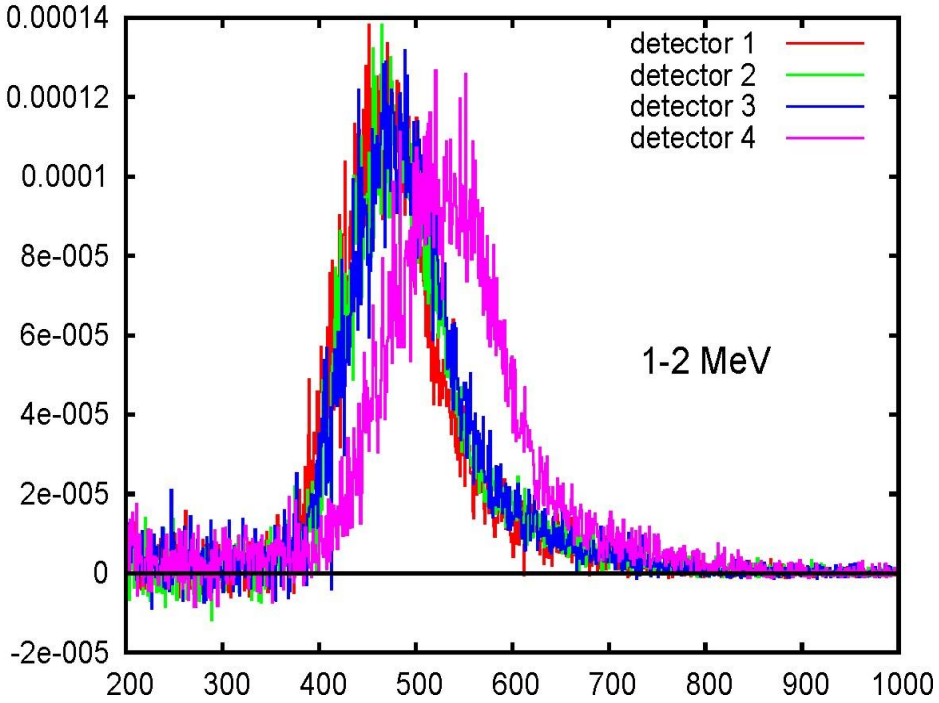

$^{6}Li(n,t)^{4}He$-peak

Pulse height spectrum
Long times

Room return neutrons

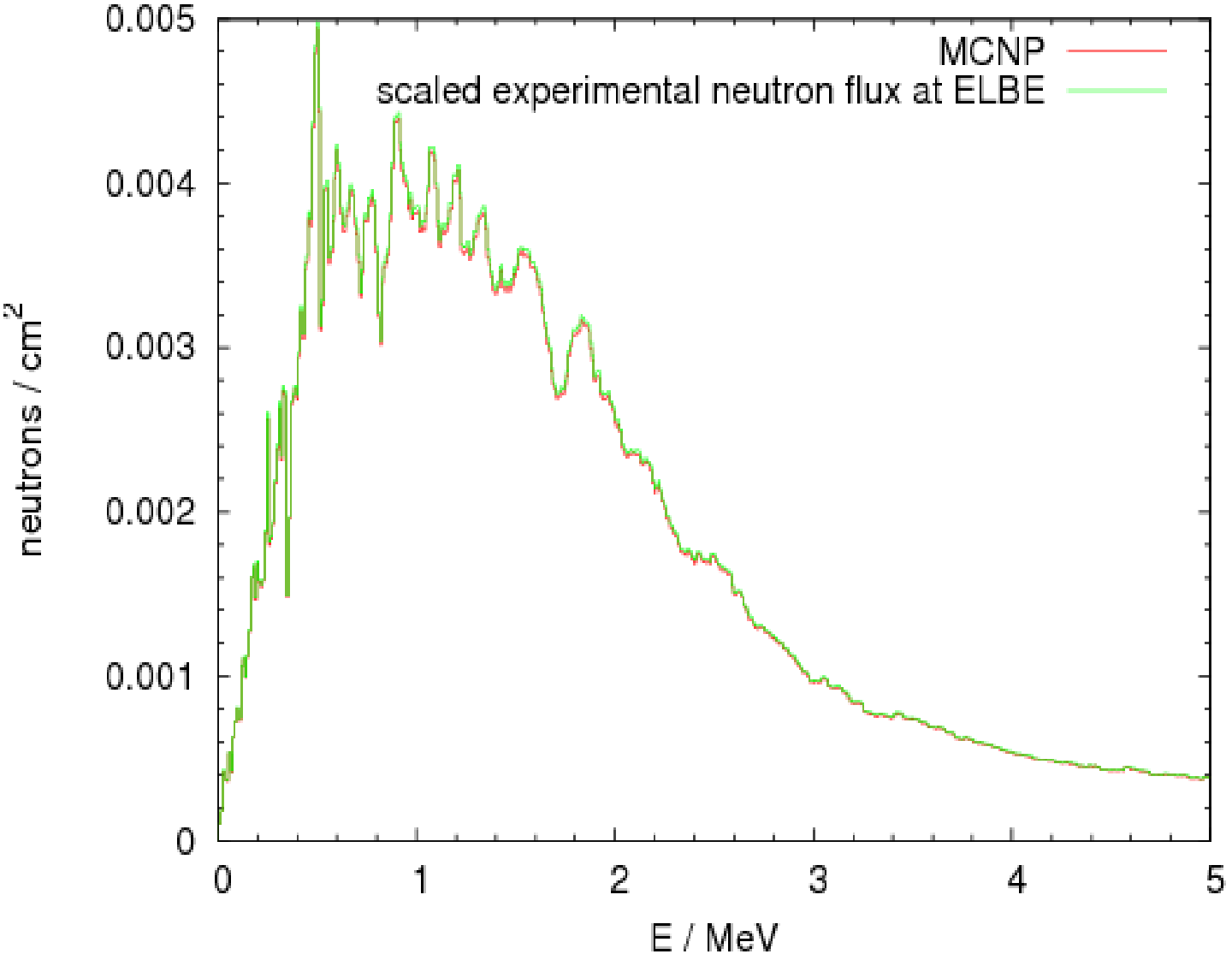
# Pulse heights, room return subtracted



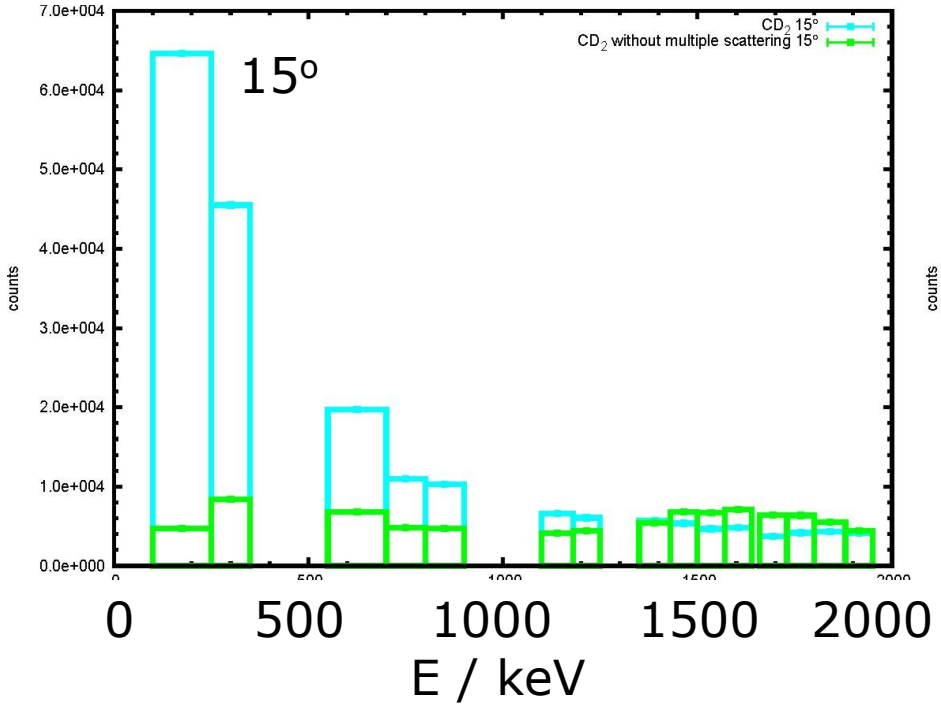



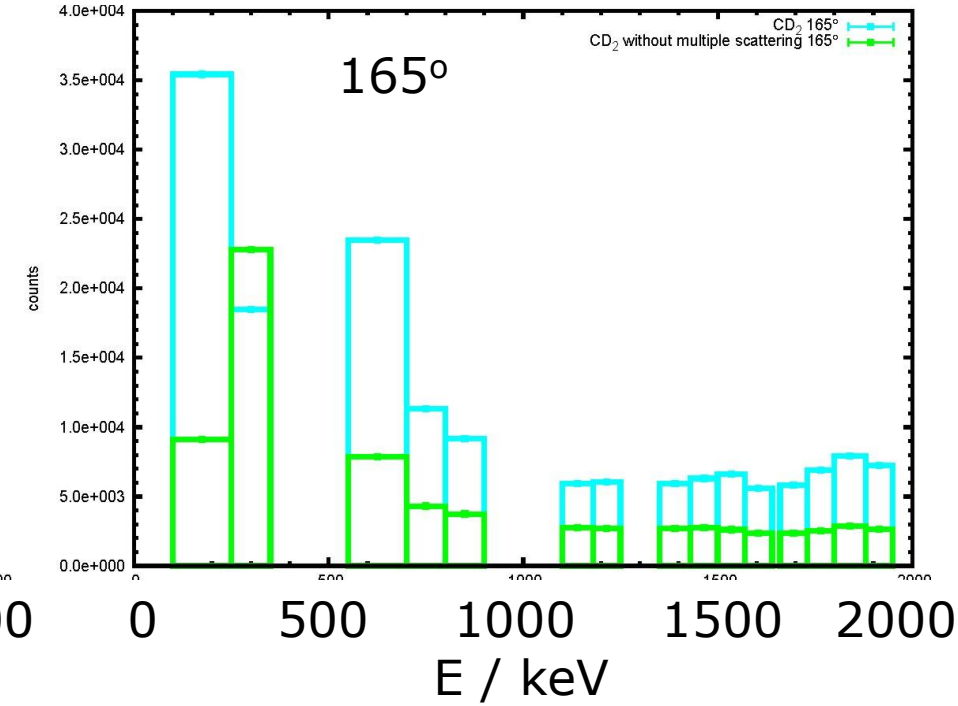

**$CD_2$ sample**
**Rough time windows**
**Normalised to the number of fissions**
**Integrals needed over finer time windows**

# Flux: PTB U-235 Fission chamber

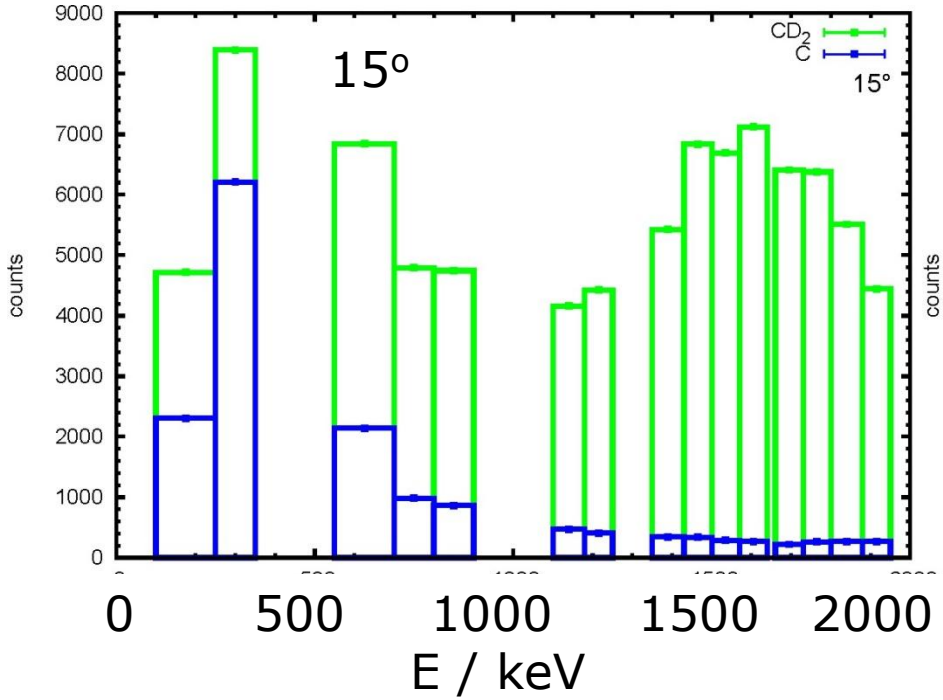


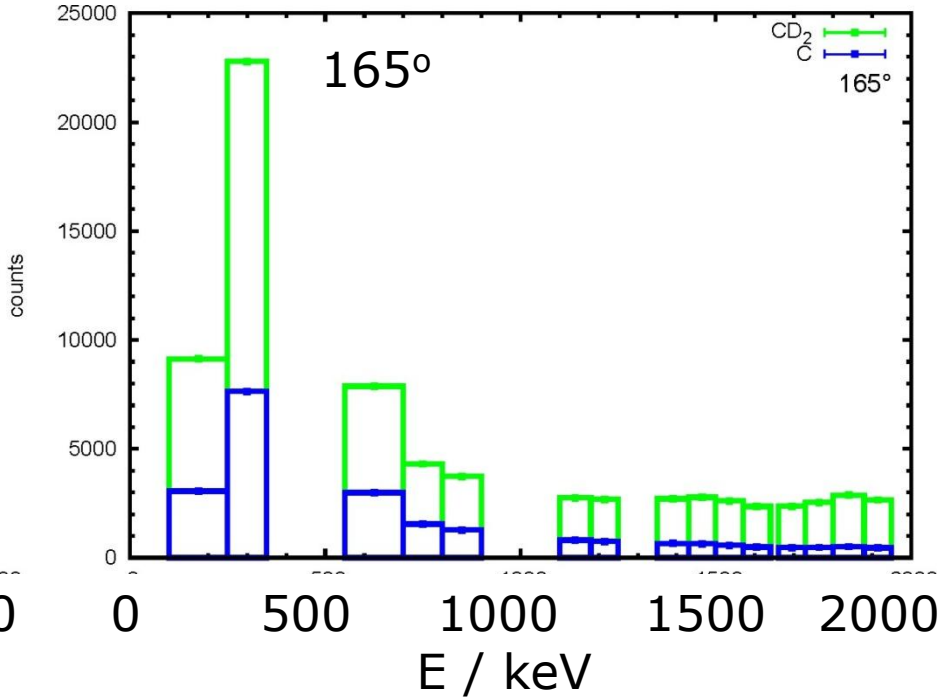
# Effect of multiple scattering in CD2
# blue=with, green=without
# Counts per bin



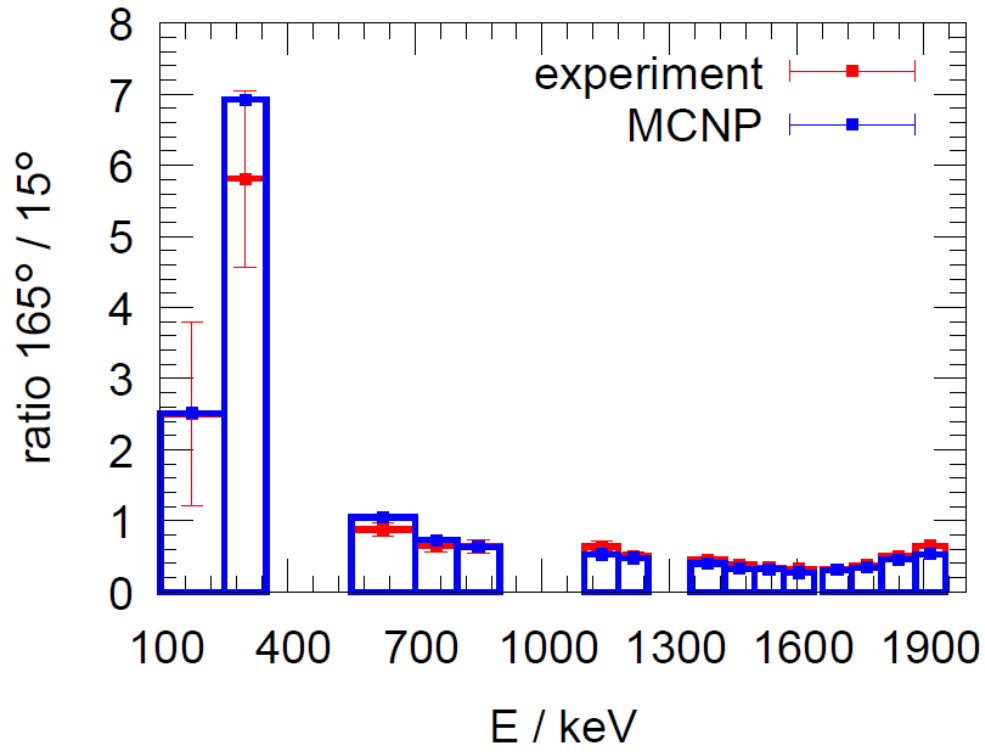



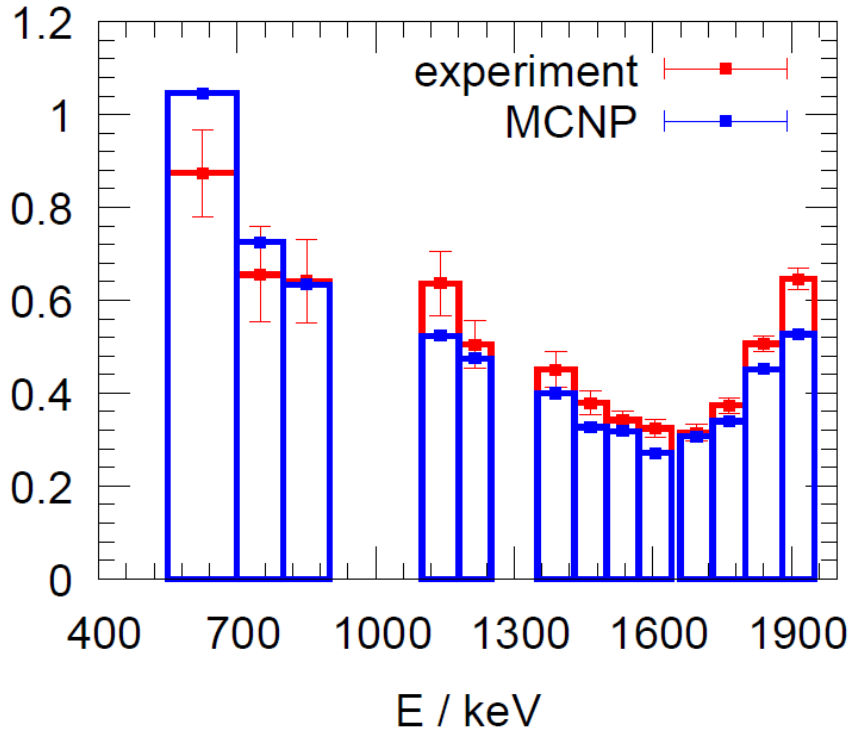
# Contribution of carbon in CD2
# blue=C, green=CD2
# Counts per bin



# Results compared with MCNP & ENDF/B-VII (ongoing: Bonn-B and ds/do)



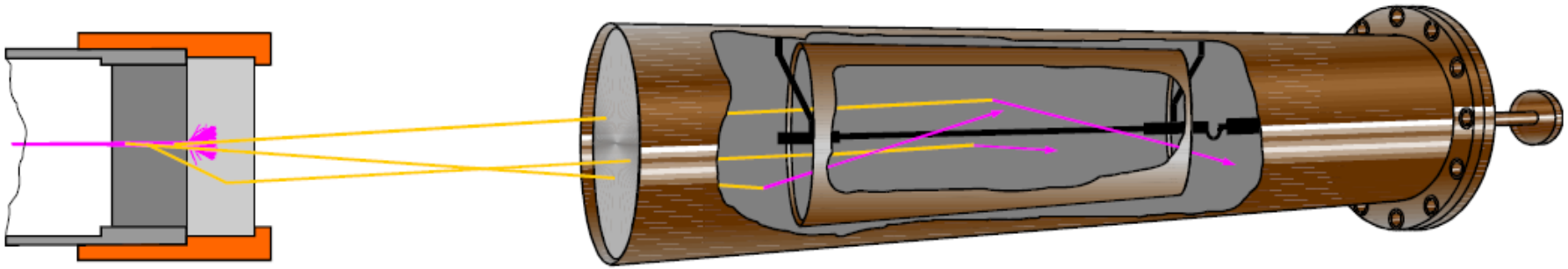
# PTB experiment

*D(n,d)n*

*deuterium recoil*
*proportional counter PTB (primary standard)*
*$D_2$+3.5%$CD_4$ vs $H_2$+3.5%$CH_4$, $H_2$, and $C_3H_8$*
*150, 200, 250, 300, 500 keV*
*8-15 keV resolution.*

*Revisit the early measurements of Adair, Tunnicliffe and Allen*
*20-24 August 2012*

# Recoil Proton Proportional Counters



Cylindrical Proportional Counter for $E_n \leq 1.2$ MeV

Counting gas

- $H_2/CH_4$ (965 / 35 hPa)
  24 keV $\leq E_n \leq$ 250 keV
- $C_3H_8$ (600 hPa)
  250 keV $< E_n \leq$ 1.2 MeV

Efficiency: MCWALL (tracking of recoil protons) + MCNP (neutron transport)

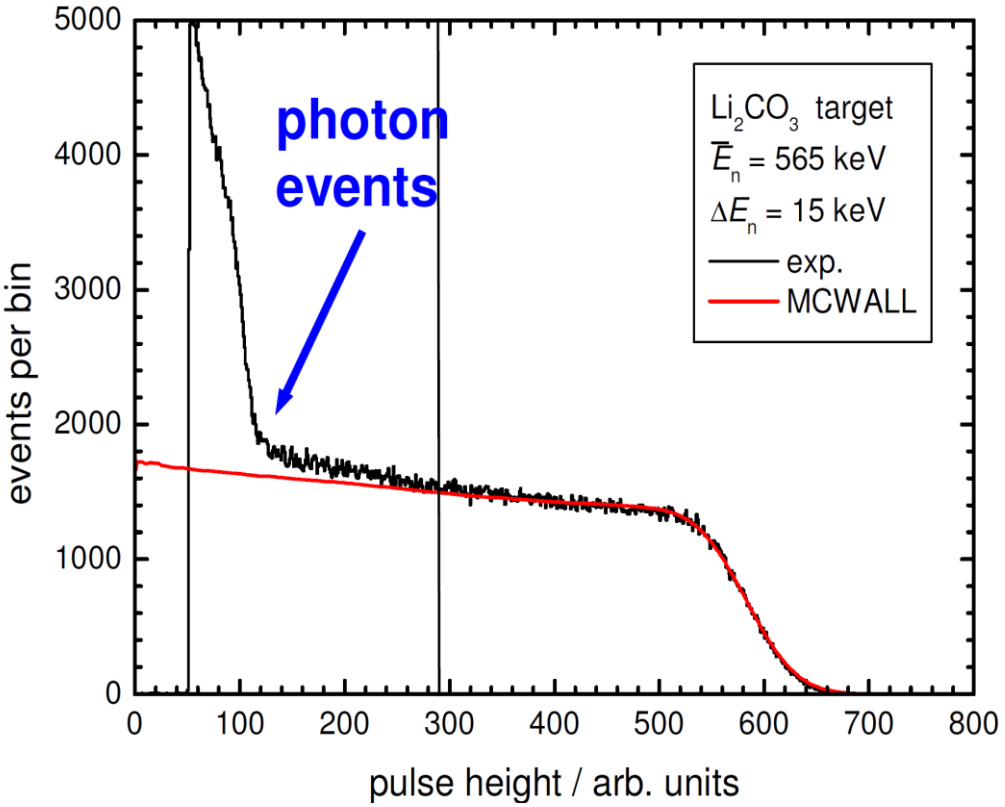
Subtraction of room scatter with shadow cone method

Photon sensitivity becomes a problem below 24 keV

# Principle and important effects

$$E_R = \frac{1}{2} E_R^{max} \left(1 - \cos\theta'_n\right), \quad E_R^{max} = \frac{4 m_n m_T}{(m_n + m_T)^2} E_n$$

$$\frac{d\sigma_{el}}{dE_R} = \frac{4\pi}{E_R^{max}} \frac{d\sigma_{el}}{d\Omega'_n}\left(\cos\theta'_n\right), \quad \cos\theta'_n = 1 - 2\frac{E_R}{E_R^{max}}$$




*Wall effect (modeled)*
- *pressure*
- *gas mixture*

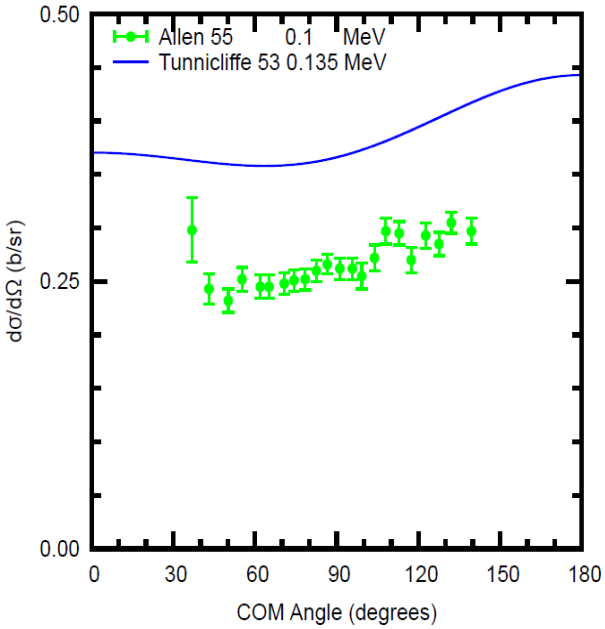
*Carbon recoils*
- *1.7% for 3.5% $CD_4$*
- *0.3% for 3.5% $CH_4$*

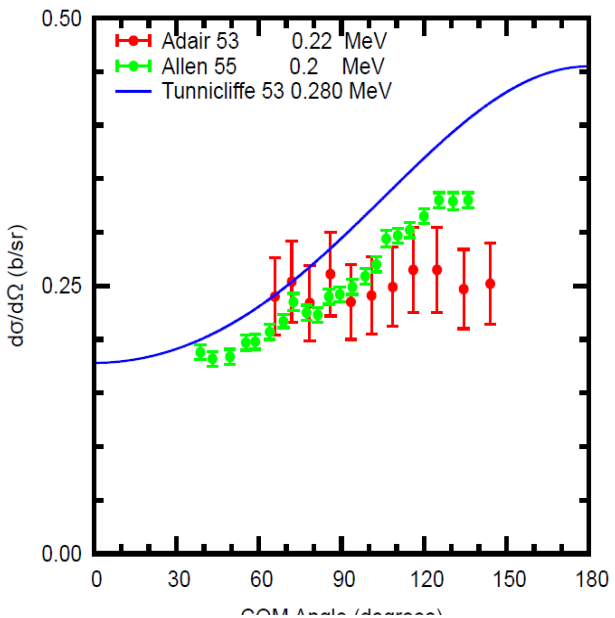
*Gamma sensitivity*
- *studies w/w.o. 2 cm Pb*

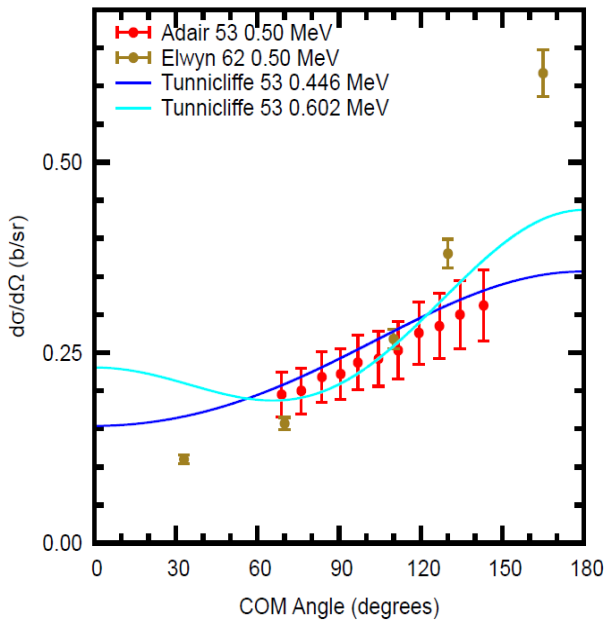
*Neutron background*
- *w/w.o. shadow bar*

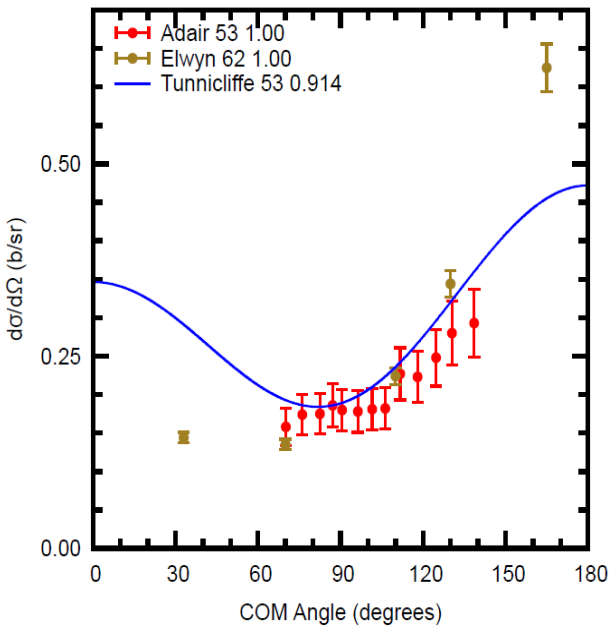
*Neutron energy (~1%)*
- *$^3$He prop. counter*

# Earlier work



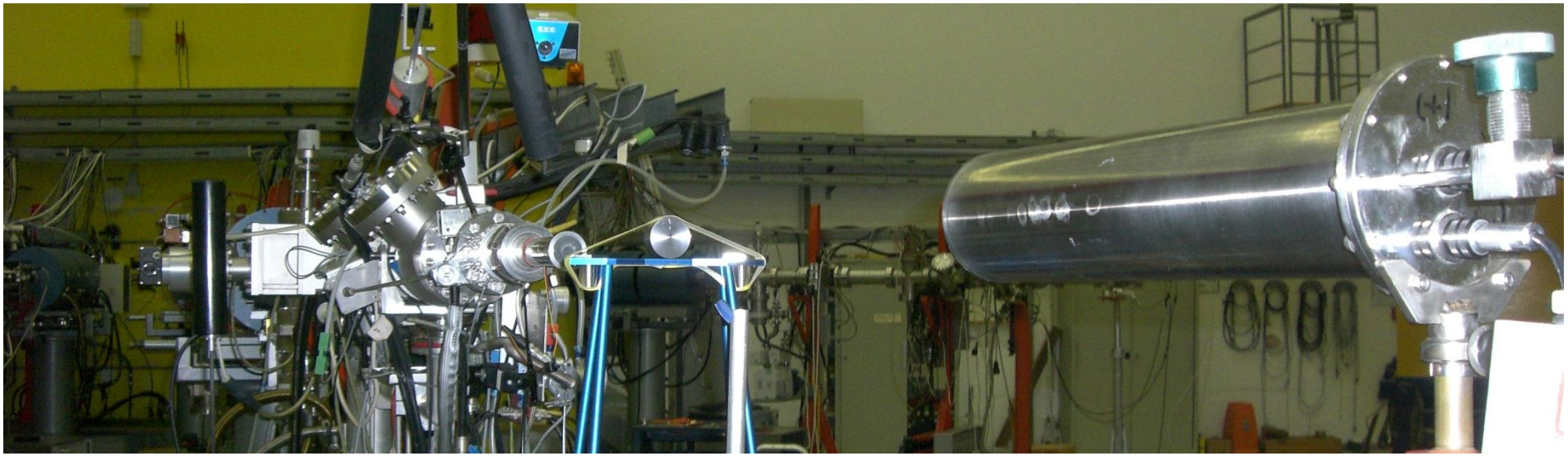

*R.K. Adair, A. Okazaki, and M.Walt,, Phys. Rev., Vol. 89, No. 6, (1952) ; R.K. Adair,, ibid. 86 (1951) 155*

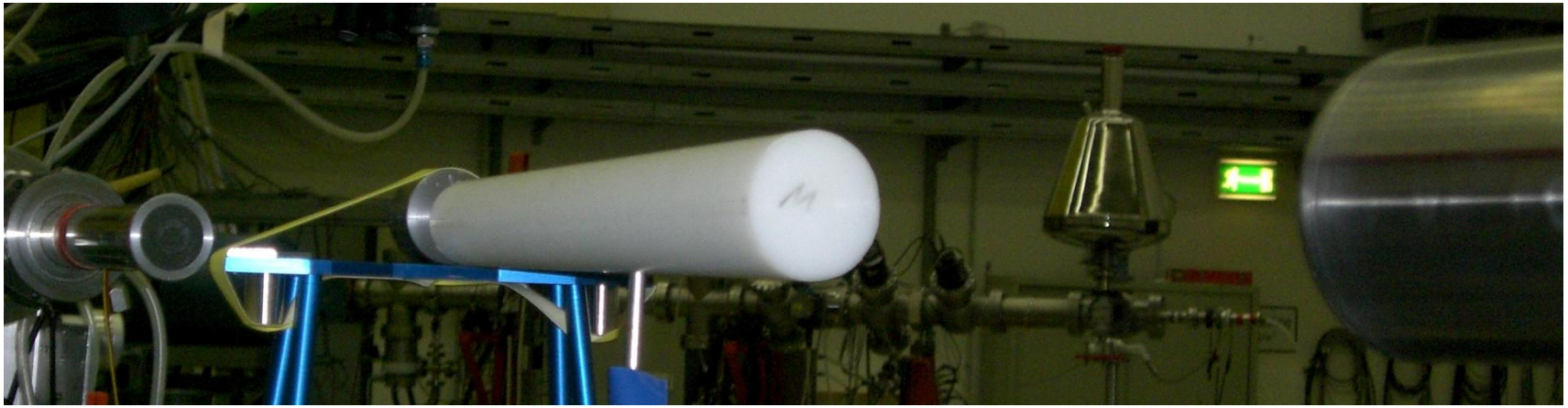
*P.R. Tunnicliffe, Phys. Rev. 89 (1953) 1247*

*W.D. Allen, A.T.G. Ferguson, and J. Roberts, Proc. Phys. Soc. (London) A68 (1955) 650*

*A.J. Elwyn, R.O. Lane, and A. Langsdorf, Jr., Phys. Rev. 128 (1962) 779*

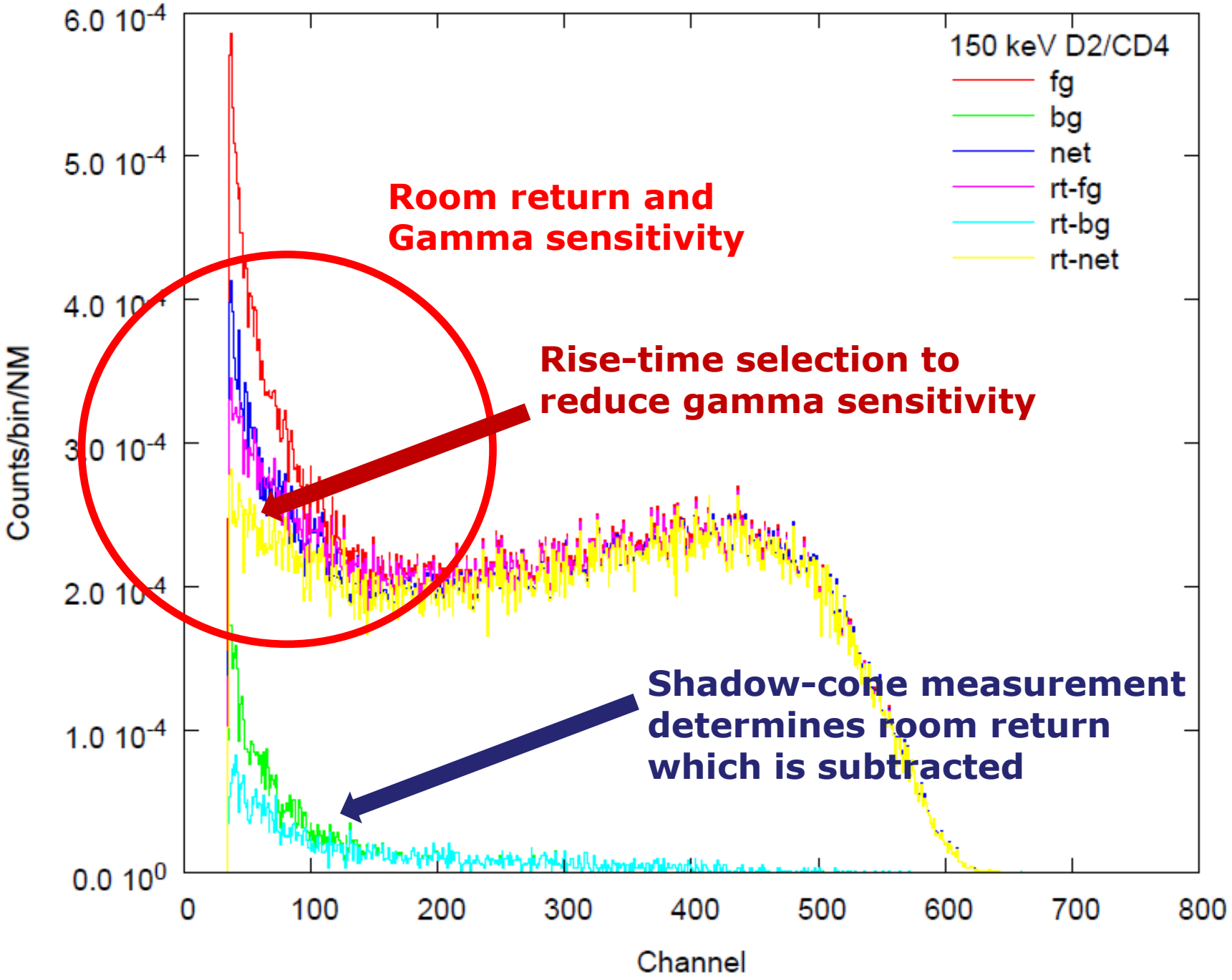
# This work 20-24 August 2012

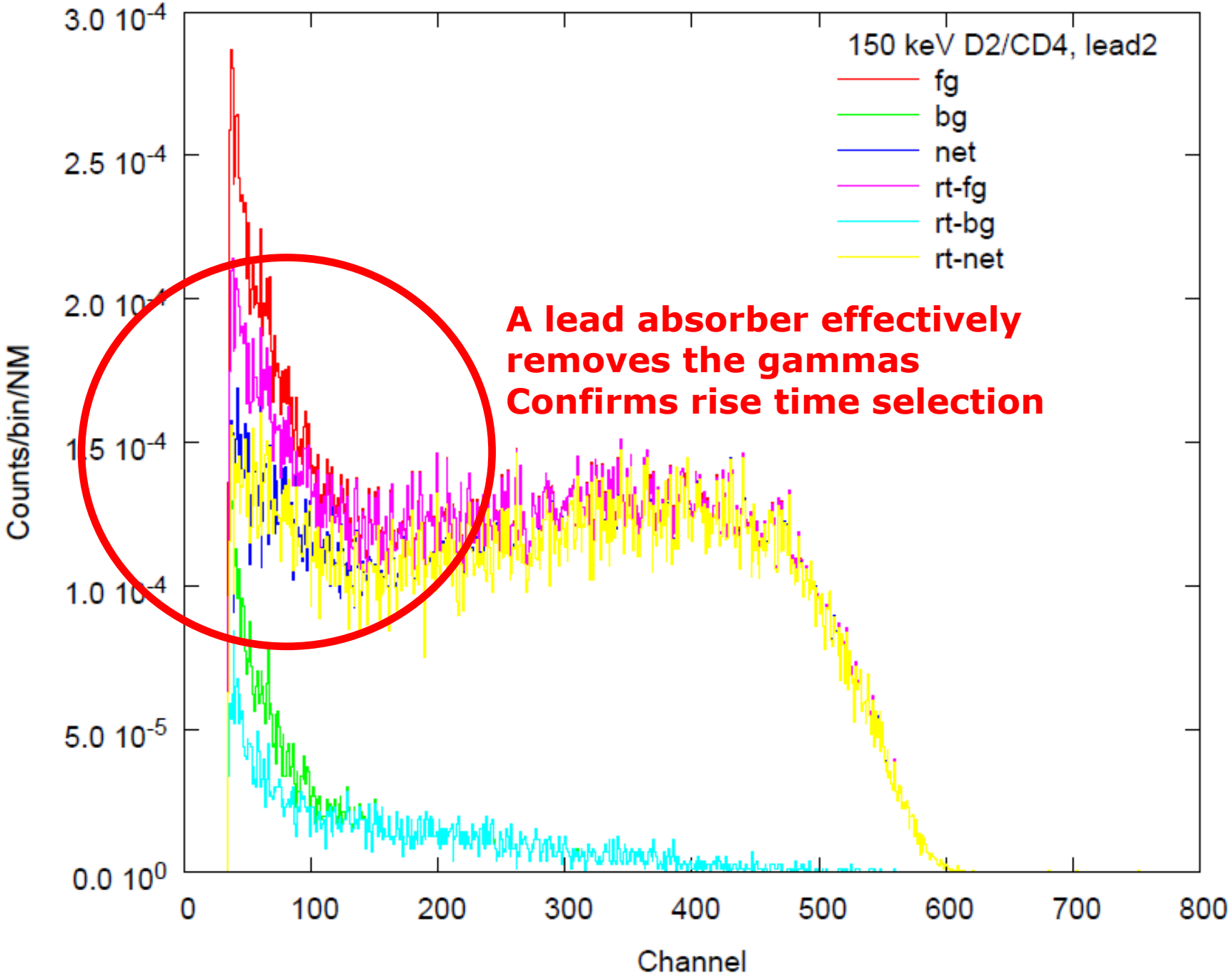


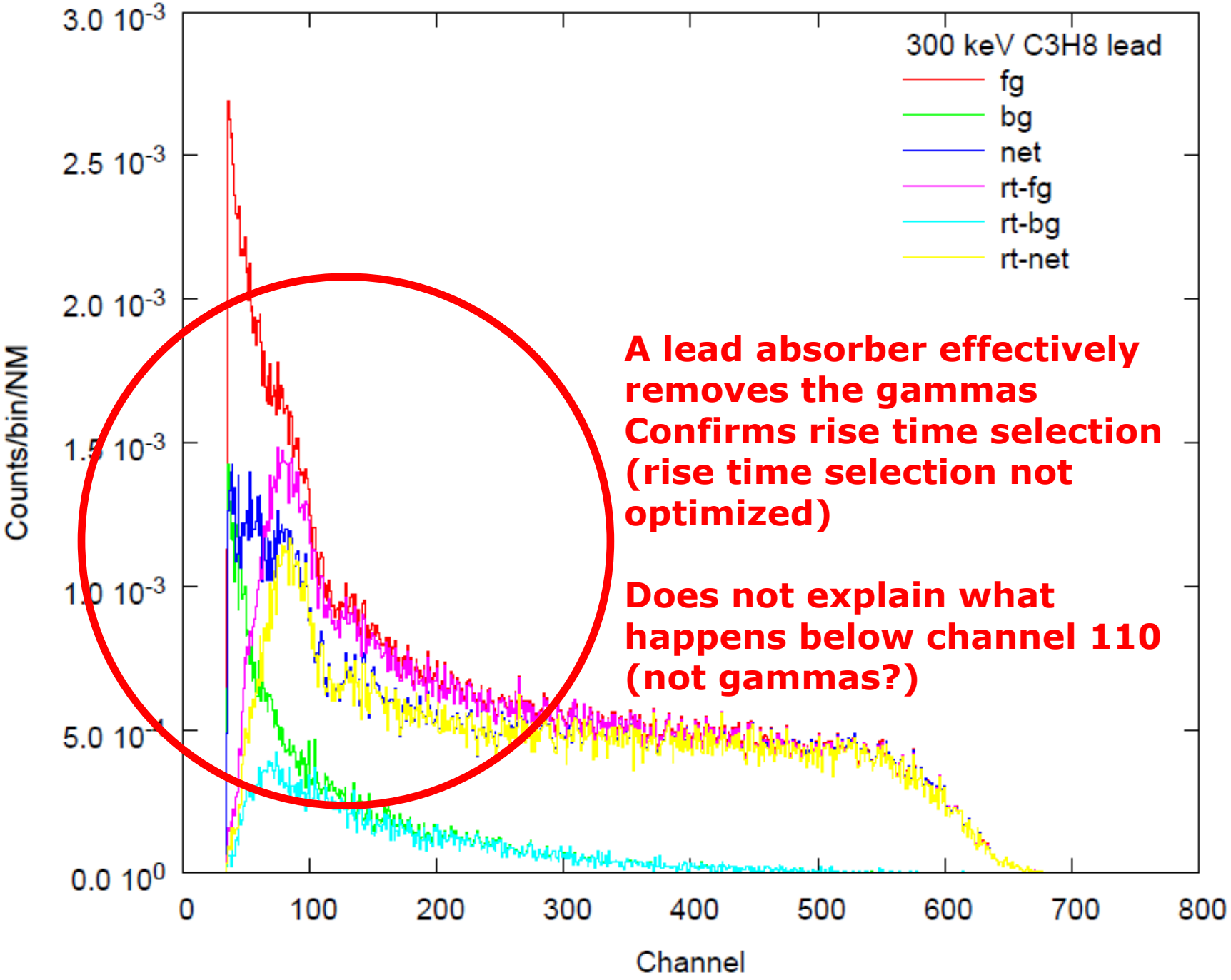


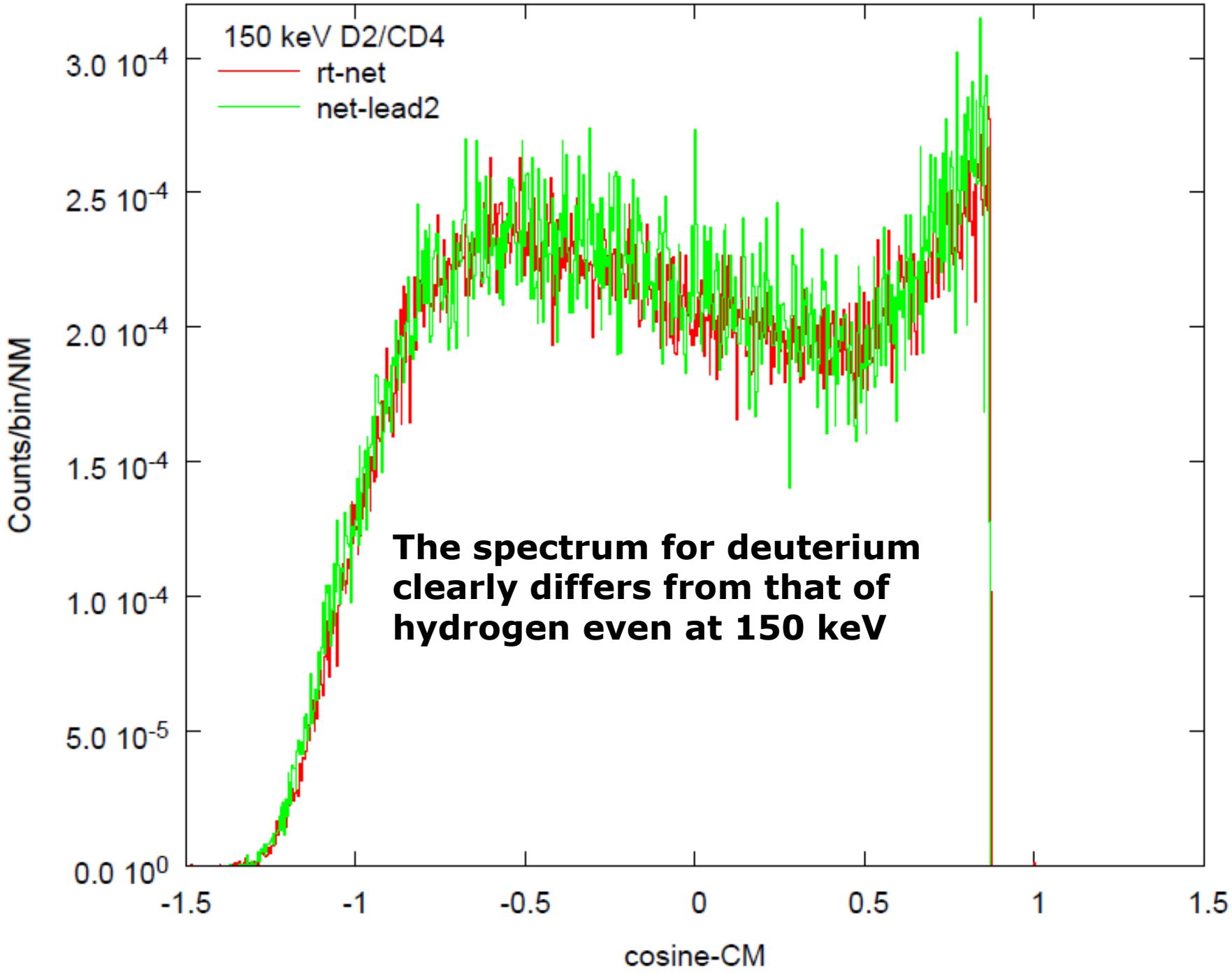
# Gas mixtures

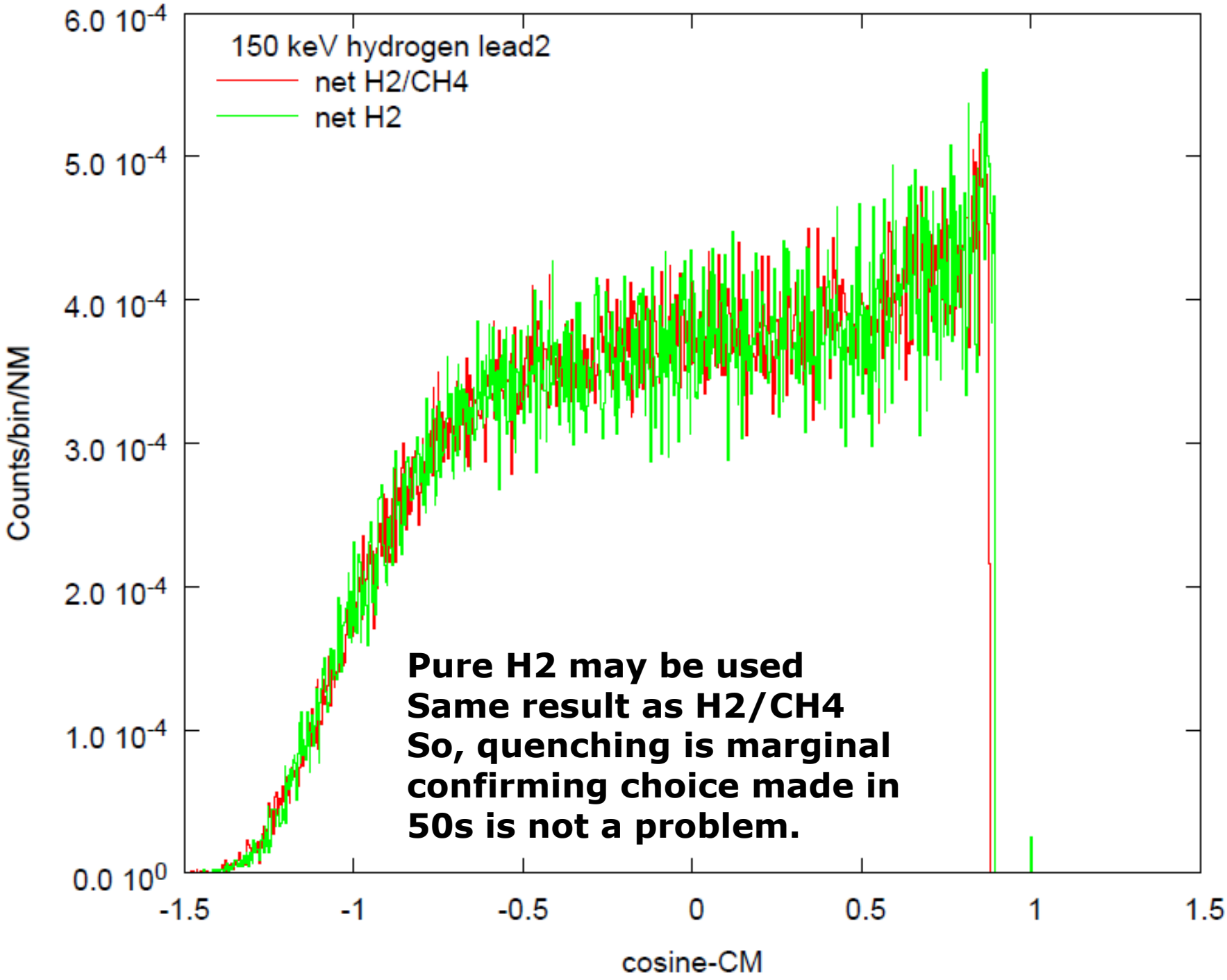
D2/CD4 965/35 mbar
H2/CH4 965/35 mbar
C3H8 600 mbar
H2 1000 mbar

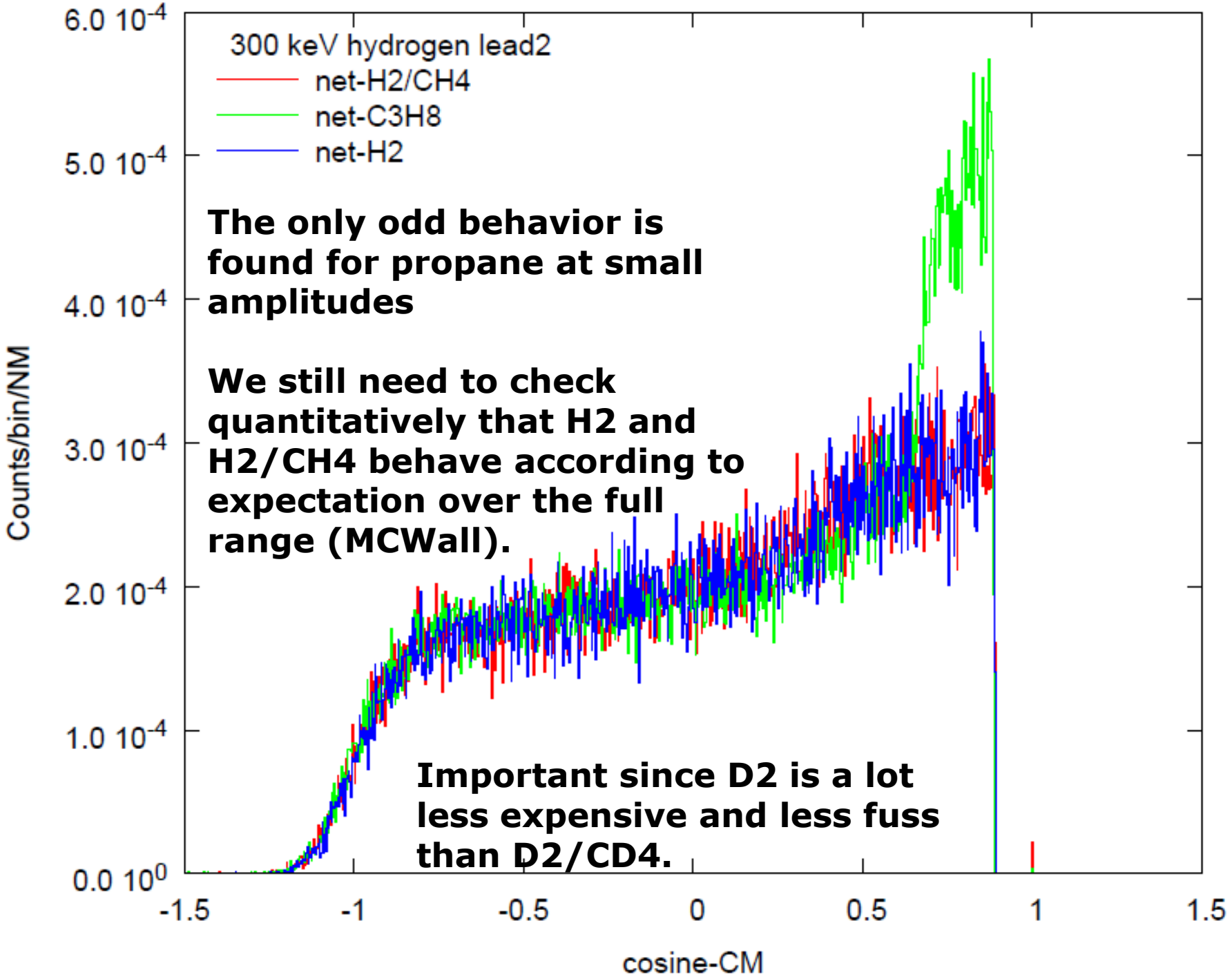

150 keV D2/CD4
fg
bg
net
rt-fg
rt-bg
rt-net
Room return and
Gamma sensitivity
Rise-time selection to
reduce gamma sensitivity
Shadow-cone measurement
determines room return
which is subtracted
Counts/bin/NM
Channel
6.0 10-4
5.0 10-4
4.0 10-4
3.0 10-4
2.0 10-4
1.0 10-4
0.0 100
0
100
200
300
400
500
600
700
800

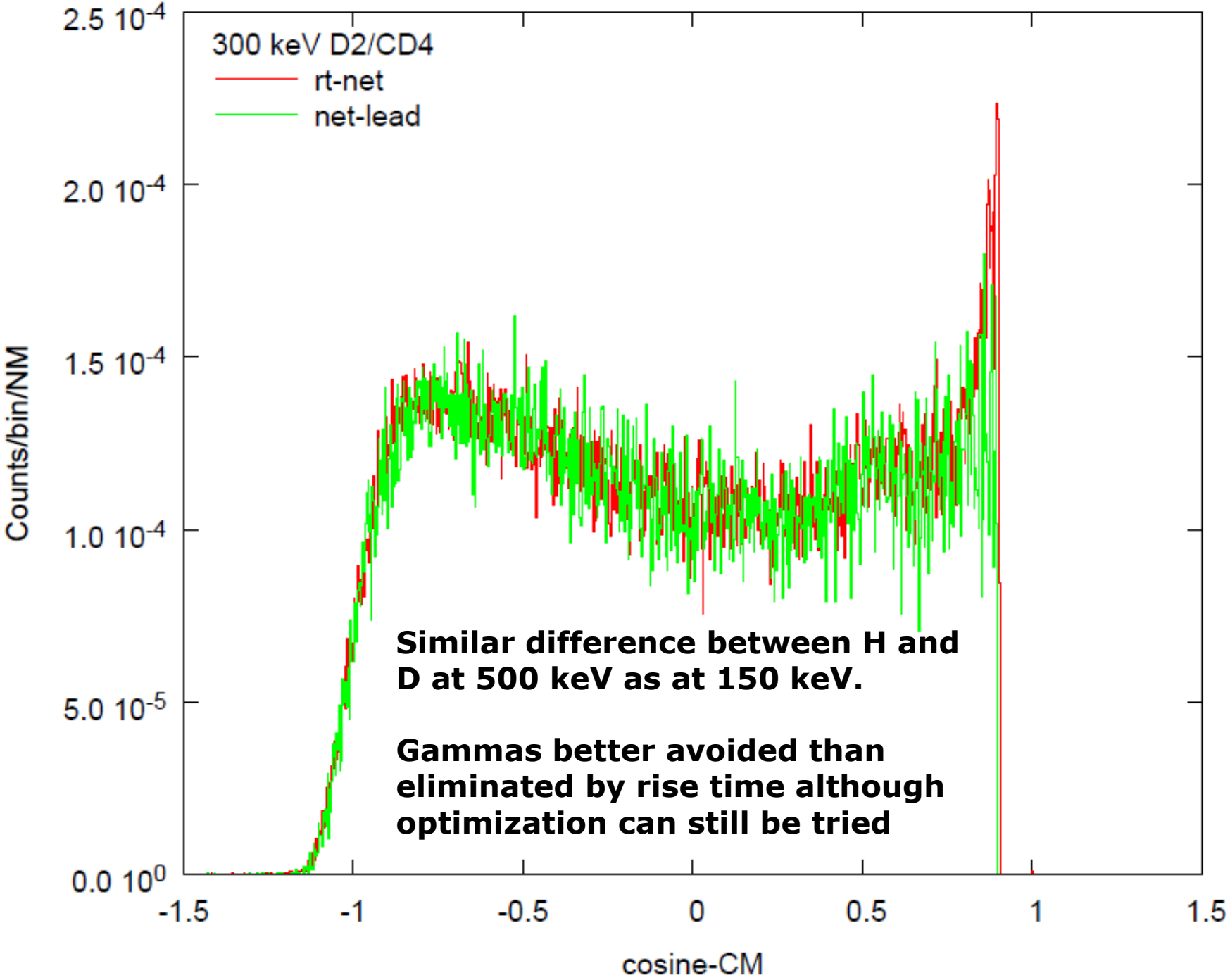

150 keV D2/CD4, lead2
fg
bg
net
rt-fg
rt-bg
rt-net
A lead absorber effectively removes the gammas
Confirms rise time selection
Counts/bin/NM
Channel
3.0 10-4
2.5 10-4
2.0 10-4
1.5 10-4
1.0 10-4
5.0 10-5
0.0 100
0
100
200
300
400
500
600
700
800


300 keV C3H8 lead
fg
bg
net
rt-fg
rt-bg
rt-net
Counts/bin/NM
Channel
3.0 10-3
2.5 10-3
2.0 10-3
1.5 10-3
1.0 10-3
5.0 10-4
0.0 100
0
100
200
300
400
500
600
700
800
A lead absorber effectively removes the gammas
Confirms rise time selection (rise time selection not optimized)
Does not explain what happens below channel 110 (not gammas?)


150 keV D2/CD4
rt-net
net-lead2
3.0 10-4
2.5 10-4
2.0 10-4
1.5 10-4
1.0 10-4
5.0 10-5
0.0 100
Counts/bin/NM
-1.5
-1
-0.5
0
0.5
1
1.5
cosine-CM
The spectrum for deuterium clearly differs from that of hydrogen even at 150 keV


150 keV hydrogen lead2
net H2/CH4
net H2
Counts/bin/NM
6.0 10-4
5.0 10-4
4.0 10-4
3.0 10-4
2.0 10-4
1.0 10-4
0.0 100
-1.5
-1
-0.5
0
0.5
1
1.5
cosine-CM
Pure H2 may be used
Same result as H2/CH4
So, quenching is marginal
confirming choice made in
50s is not a problem.


300 keV hydrogen lead2
net-H2/CH4
net-C3H8
net-H2
The only odd behavior is found for propane at small amplitudes
We still need to check quantitatively that H2 and H2/CH4 behave according to expectation over the full range (MCWall).
Important since D2 is a lot less expensive and less fuss than D2/CD4.
Counts/bin/NM
cosine-CM
6.0 10-4
5.0 10-4
4.0 10-4
3.0 10-4
2.0 10-4
1.0 10-4
0.0 100
-1.5
-1
-0.5
0
0.5
1
1.5


300 keV D2/CD4
rt-net
net-lead
2.5 10-4
2.0 10-4
1.5 10-4
1.0 10-4
5.0 10-5
0.0 100
Counts/bin/NM
-1.5
-1
-0.5
0
0.5
1
1.5
cosine-CM
Similar difference between H and D at 500 keV as at 150 keV.
Gammas better avoided than eliminated by rise time although optimization can still be tried

# Summary

*Need for n+D angular distribution 0.1 – 1.0 MeV*
*Reactor physics (HPRL, CVR)*

*Basic science: 3NF (NN-interaction, Fadeev)*
*(asymmetry, break-up)*

*Long since last measurement in this range*
*Limited selectivity*
*Important experimental corrections*
*Limited statistics*

*ERINDA support is much appreciated*
*Good progress for the nELBE experiment*
*New PTB experiment just carried out*
*promising results*

# Interests

*High priority request list*

*Will SG-35 come up with requests?*
*If so*
*Nuclides, energy range*
*Sensitivity analysis*

*Illustrative examples*
*1) What is Godiva k if all a.d. isotropic?*
*2) What is U-235 crit.mass if all a.d. isotropic?*
*3) What is flattop k & crit.mass if a.d. reflector isotropic*
*4) I have the same questions for inelastic switched off (transfer matrix equal to elastic).*

# Interests

*PhD work on scattering*

*New "Märten-setup"*
*8-32 detectors, 8 angles, zeroes P8 for angle integral*
*Check for consistency elastic and total*
*Test case: C (no INL)*
*Second test case: Na (1-2 MeV, competition with INL)*
*Support welcome*

# CHANDA

*WP8.3 Concerns scattering*

- *Inelastic by (n,n'g): Improving decay data for U-238*
- *Angular distributions of scattered neutrons*
- *DA and DE/DX*
- *nELBE, IRMM, IPHC, IFIN-HH, CEA, possibly NFS@SPIRAL2*
- *Start: 1 December 2013*
- *Duration: 4 years*
- *IRMM PhD will work in this context*

# Summary

*Two contributions to SG-35 report*
- *Na scattering (Märten/Kopecky, Rouki)*
- *Deuterium scattering*
  - *scattered neutrons > 0.5 MeV*
  - *recoils (n<0.5 MeV)*
  - *Finalised end of August 2013*

*Will SG-35 contribute to HPRL?*

*PhD work on scattering coming up.*

*CHANDA project will contribute in this domain*