ISS-RAD Fast Neutron Detector (FND)

ACO On-Orbit Neutron Dose Equivalent and Energy Spectrum Analysis Status

Martin Leitgab, NASA SRAG
on behalf of the ISS-RAD science team

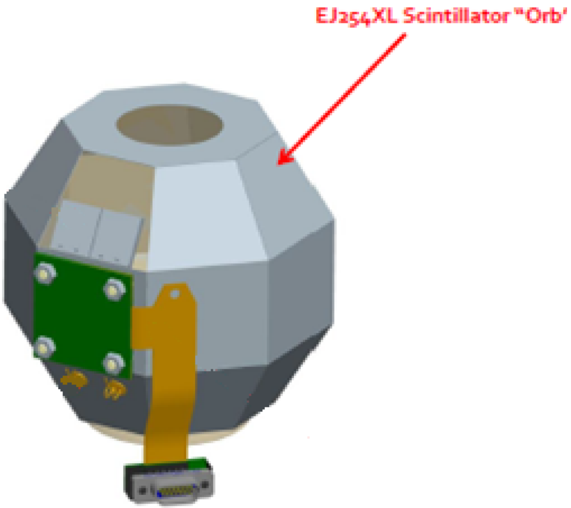
21st WRMISS 6–8 September 2016, ESTEC, Noordwijk

Ryan Rios
Edward Semones
Cary Zeitlin

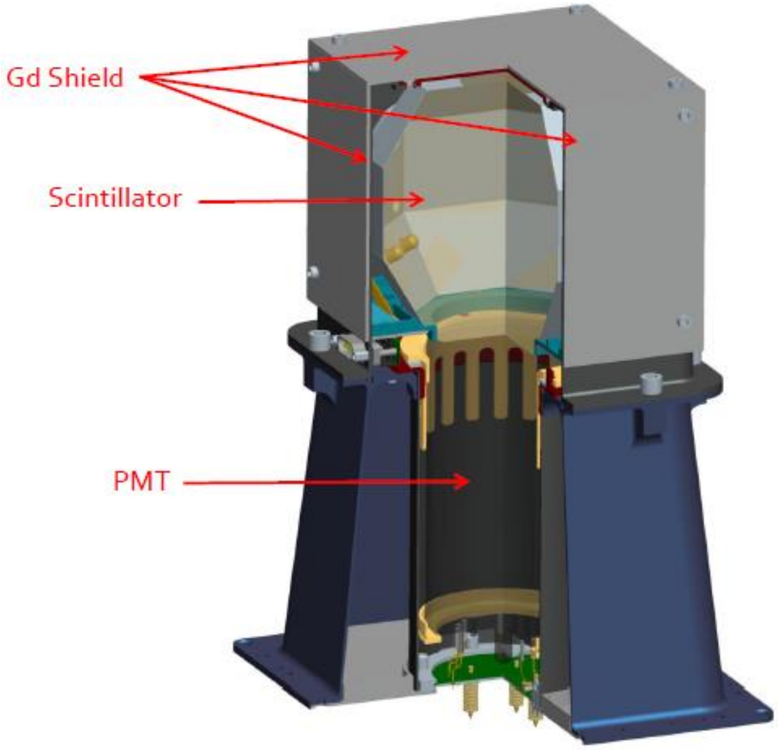
09/7/16

Outline:

1. Introduction: Basic Interpretation of FND Data
2. Orbital Data Analysis Methods (Online, Offline Light, Offline Heavy)
3. Ground Verification of Analysis Methods
4. Raw Orbital Data
5. ACO Results, Status
6. Forward Work

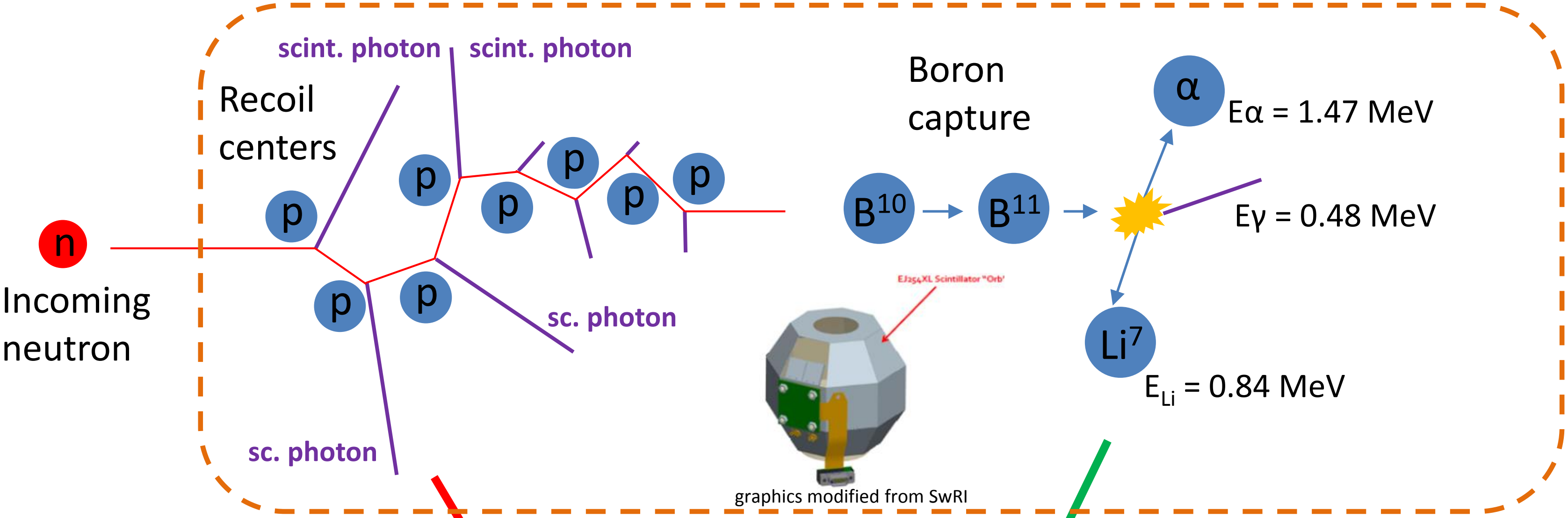


graphics modified from SwRI



1. Introduction: Detection/Selection Mechanism: Boron-loaded Scintillator

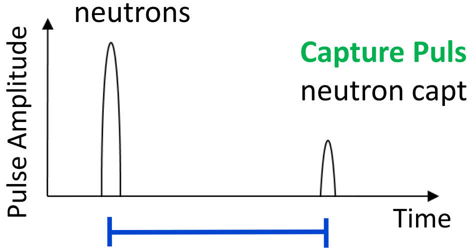
- Neutrons deposit energy in plastic scintillator, some captured by ^{10}B atoms:



graphics modified from SwRI

scintillator

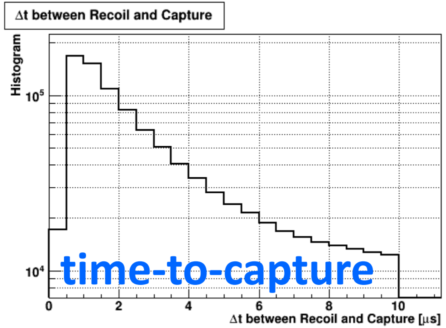
Recoil Pulse: sum of light signals produced during deceleration of neutrons



Capture Pulse: light produced by neutron capture on boron

Online: Capture Amplitude Selection

Online: Capture Time Selection



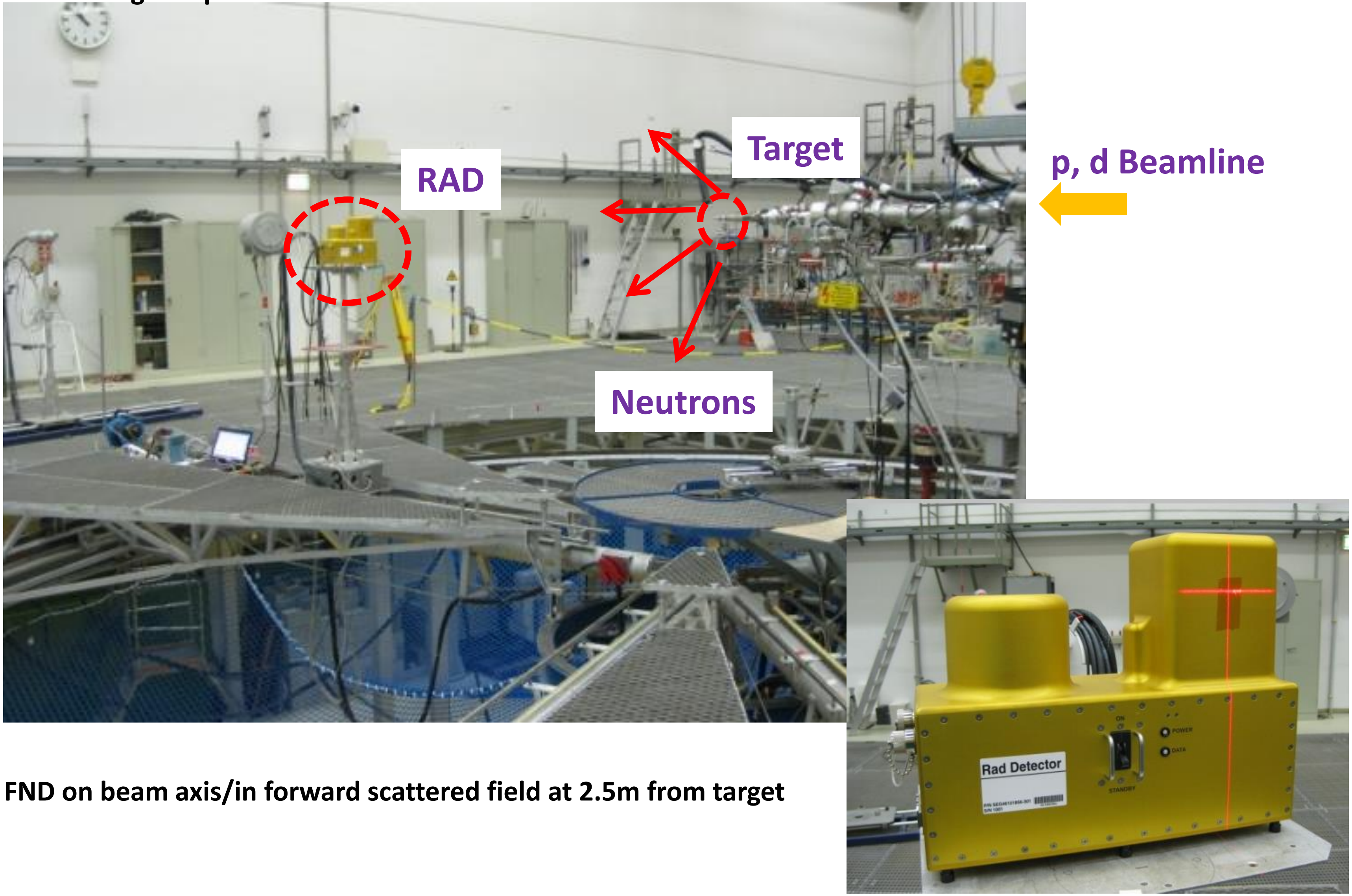
- Measurements of **recoil** and **capture** photon signals and **time-to-capture**:

time-to-capture

1. Introduction: Response Spectrum Shape

- ‘Monoenergetic’ neutron calibration ($\Delta E < 5\%$) at PTB, Germany:

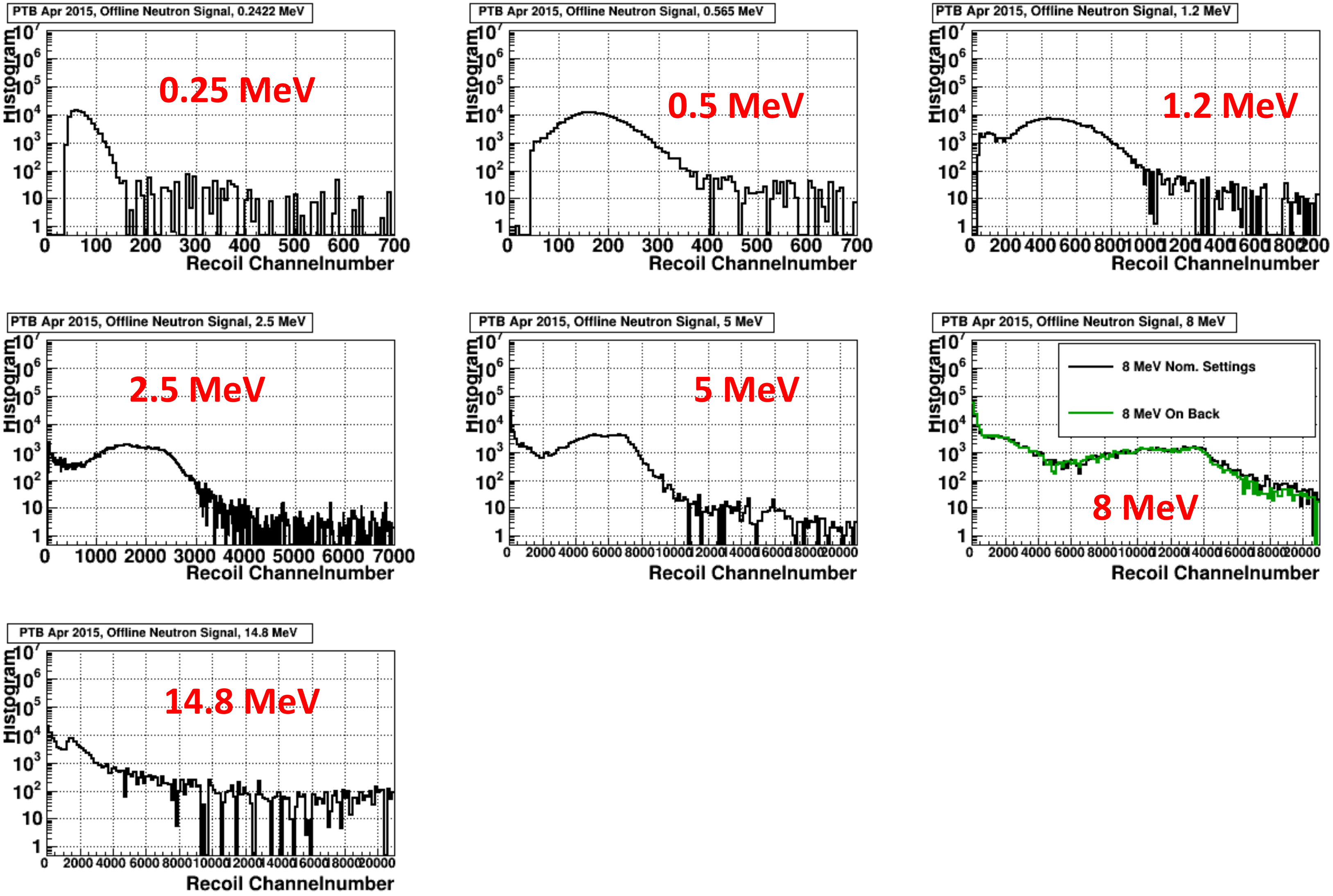
Data taking setup



FND on beam axis/in forward scattered field at 2.5m from target

1. Introduction: Response Spectrum Shape

- Filtered ADC spectrum in response to monoenergetic neutron fields (after background subtraction):



1. Introduction: Scintillation Light Creation/Propagation: Light Function Formalism

- Shape of response spectra dominated by:

a) Multiple scattering of neutron with scintillator material nuclei: multiple pulses of scintillation light per neutron

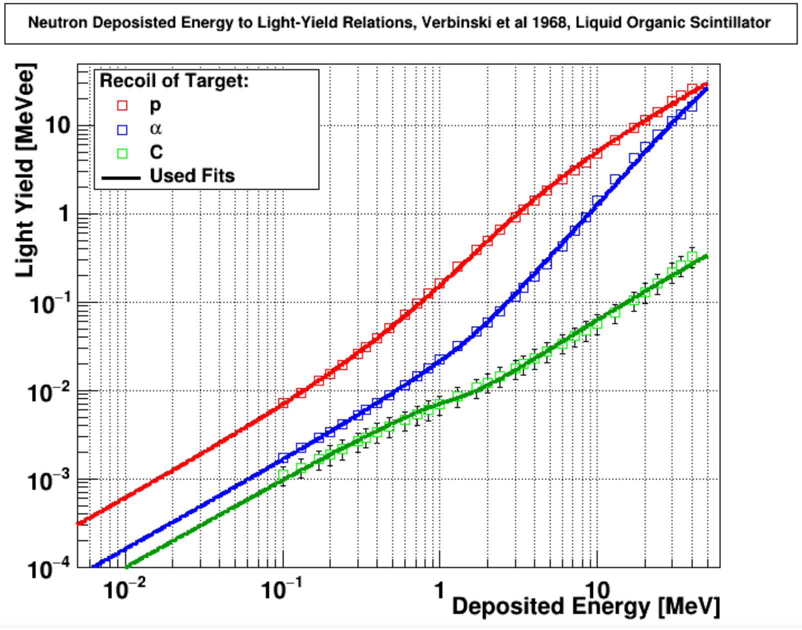
b) Scintillation light quenching (ionization quenching- Birk's law): nonlinear amount of collected scintillation light per interaction depending on energy deposit & scattering target

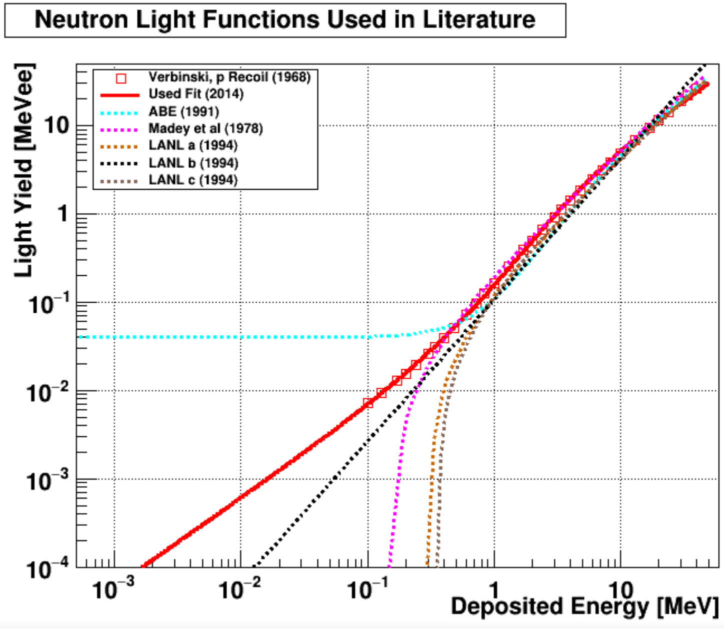
Even monoenergetic neutrons create broad distribution in light deposit/FND recoil spectra.

- Approach describing scintillation light generation in multiple scattering: Light function formalism
- Measurements/parameterization of light functions: Verbinski et al, 1968 (liquid scintillator):

Literature: Neutron recoils on...

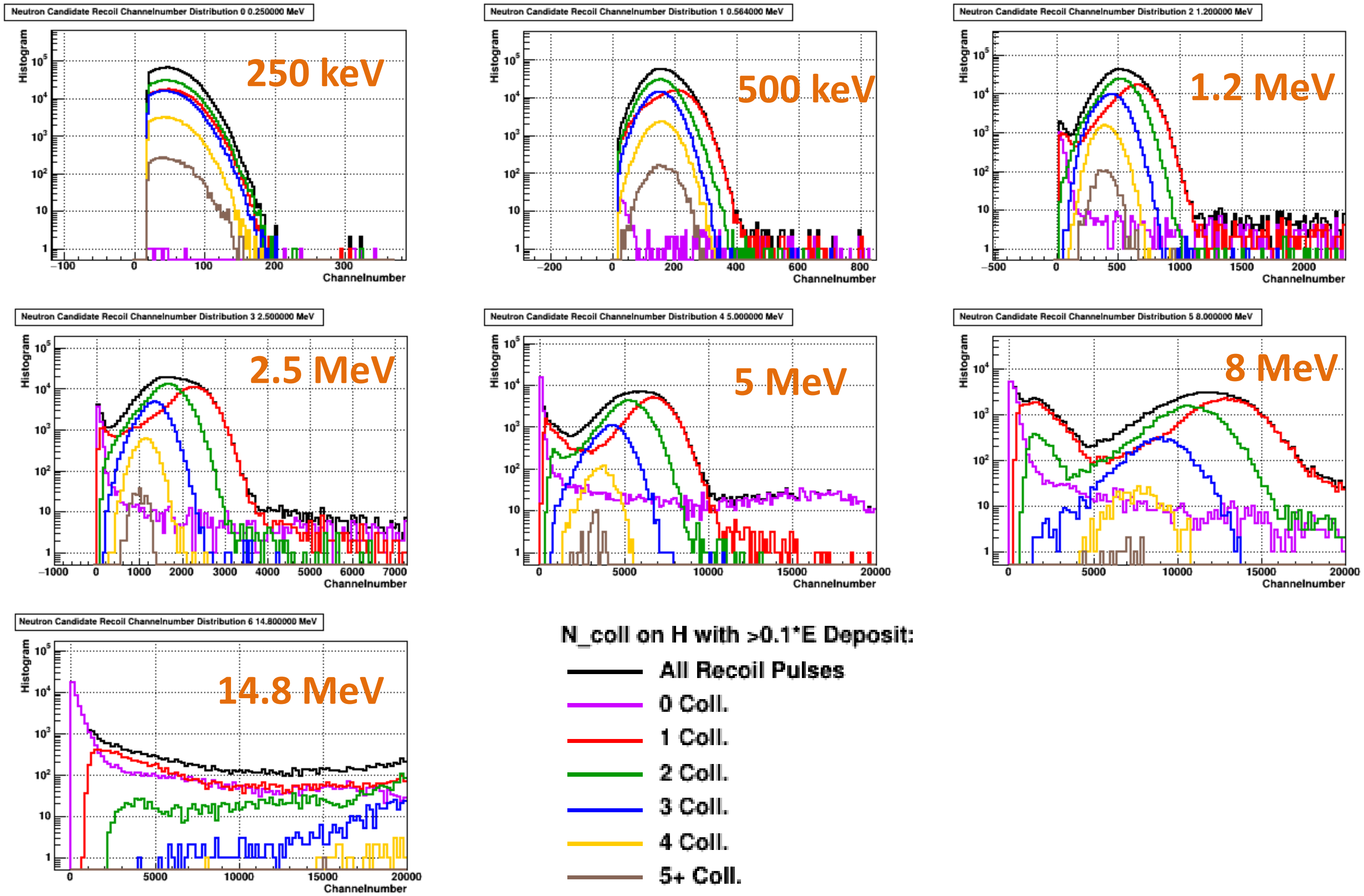
V.V. Verbinski et al, NIM 65 (1968) 8 ff


Neutron Deposisted Energy to Light-Yield Relations, Verbinski et al 1968, Liquid Organic Scintillator

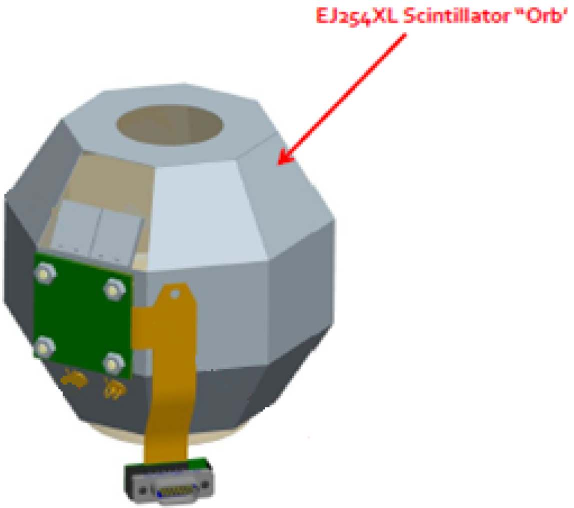

Neutron Light Functions Used in Literature

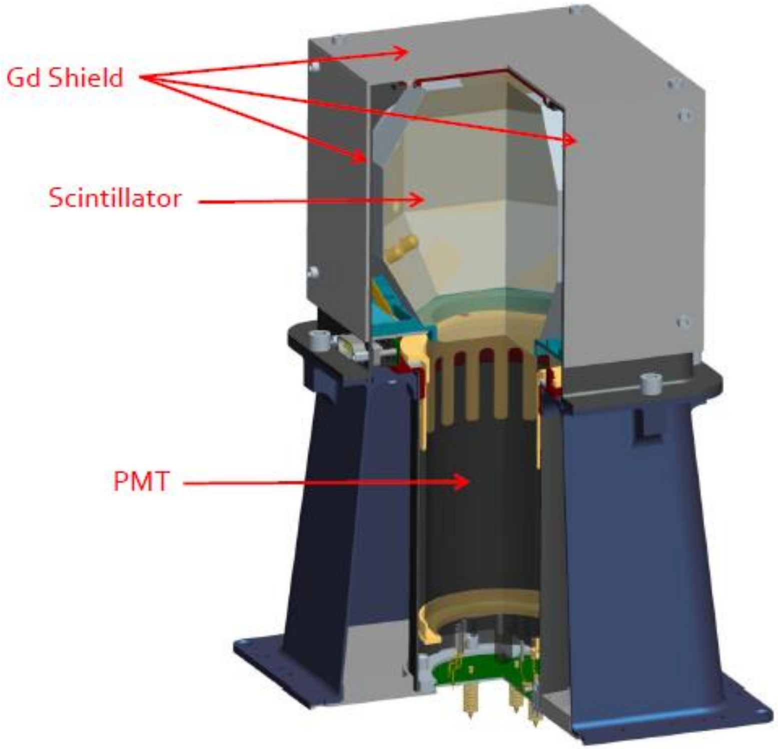
1. Introduction: Scintillation Light Creation/Propagation: Light Function Formalism

- Example: End-to-end FND simulation (MCNP-PoliMi and FND signal processing algorithms) for monoenergetic neutron fields at PTB
- Spectral shape driven by number of high energy deposit neutron collisions off hydrogen:



2. Analysis Methods





graphics modified from SwRI

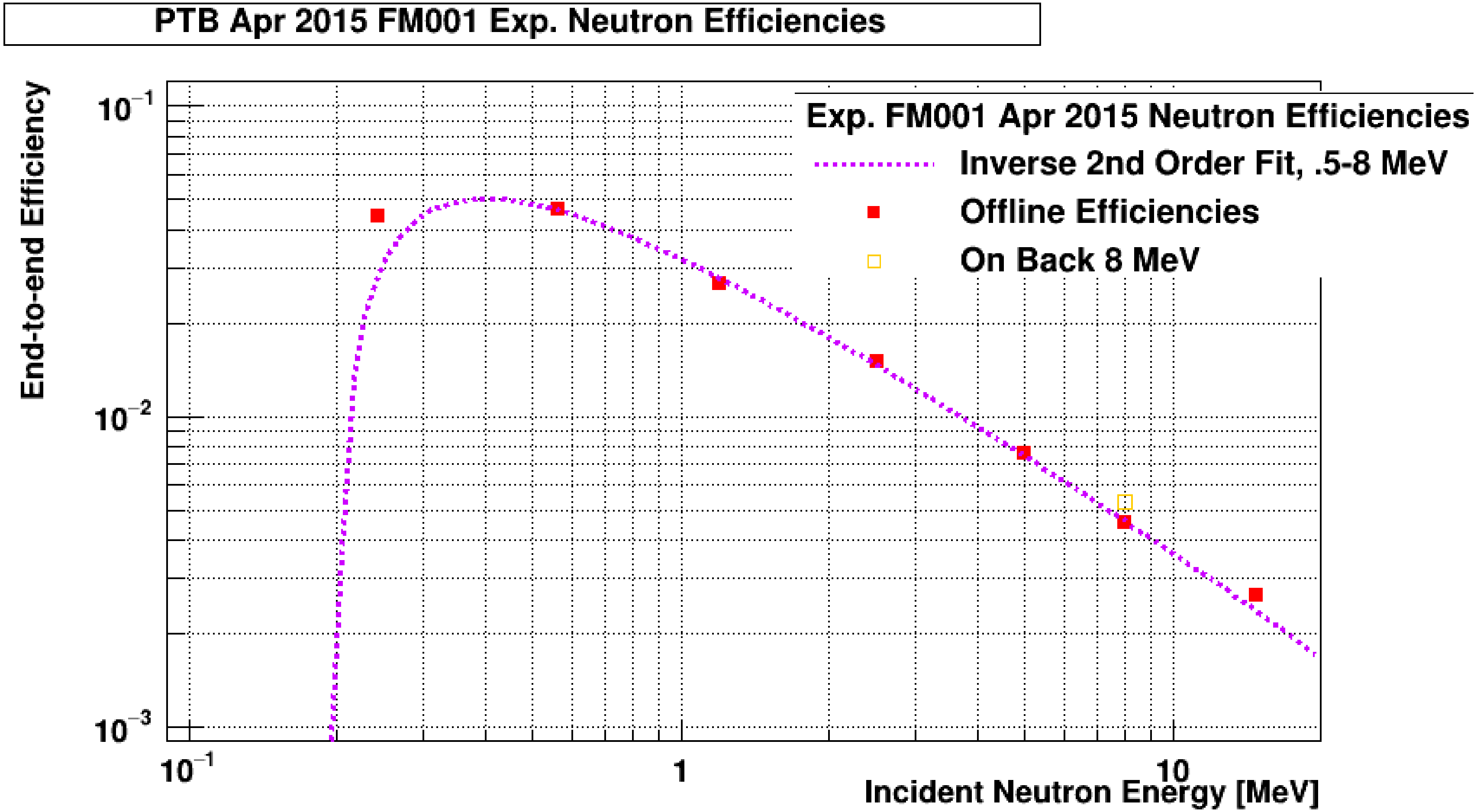
2. Analysis Variants to Extract Dose Equivalent and Neutron Energy Spectrum

- Different analysis methods depending on computational resource availability
- Dose equivalent (H*(10)) calculated with ICRP 74 conversion factors

Analysis	Computational Complexity	Output	Analysis Methods
a) On-board	**Simple**	Dose equivalent	- Conversion factors for each recoil amplitude bin
b) Ground Light	**Moderate**	Dose equivalent	- Background subtraction - Conversion factors for each recoil amplitude bin
c) Ground Heavy	**Complex**	Flux and dose equivalent energy spectra	- Background subtraction - Regularized unfolding into energy spectrum

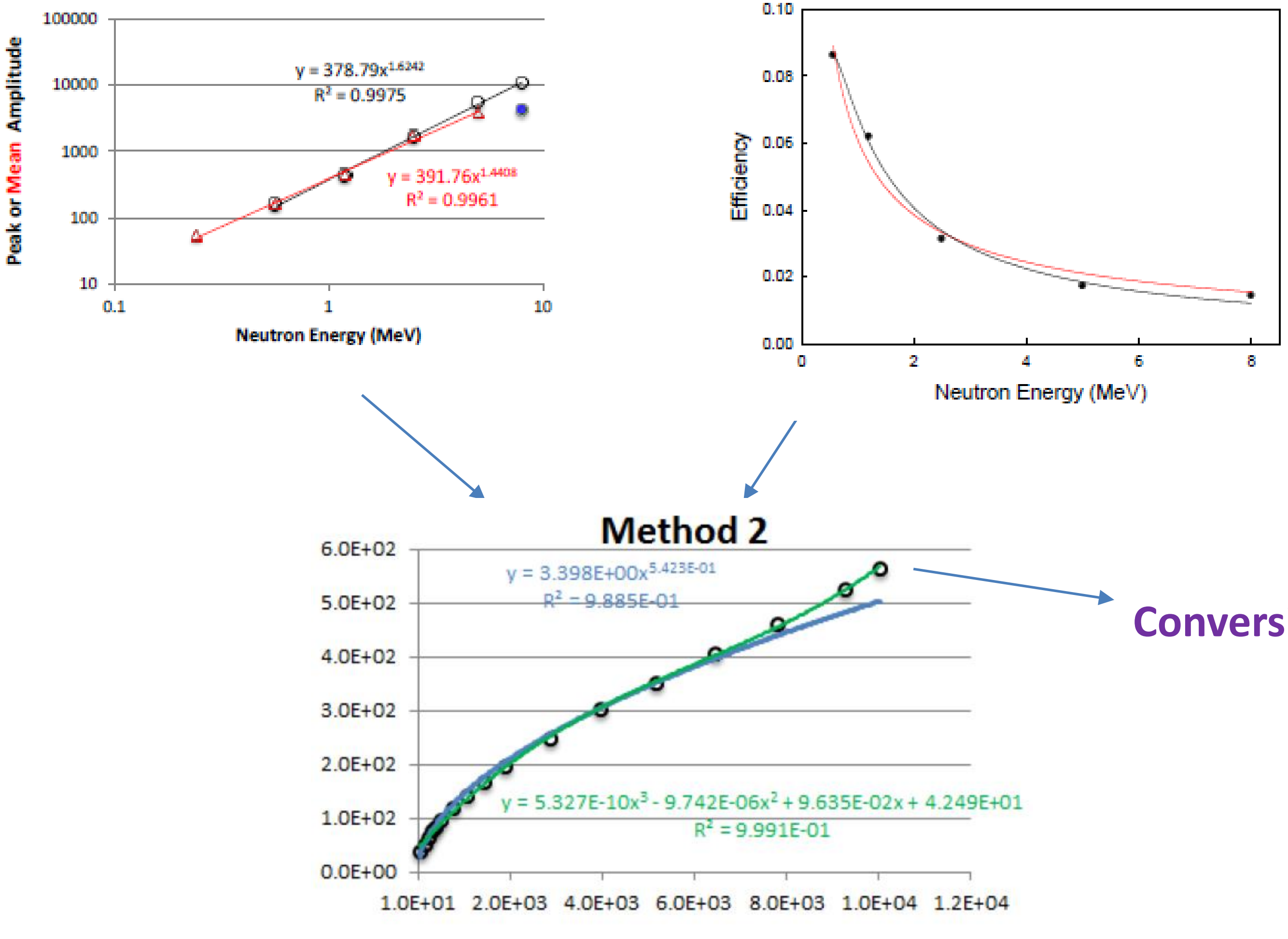
2. Efficiencies

- Use exp efficiencies directly from Apr PTB 2015 data from 0.5 to 8 MeV
- For interpolated energies, use inverse square law fit of 0.5-8 MeV data (Cary Z.)
- Values depending on cuts in background subtraction and recoil/capture spectrum



2. On-Orbit Analysis (Cary Z.)

- Conversion factors for each recoil bin amplitude to dose equivalent (H*(10))
- Factors derived from:
  - * Fit of PTB recoil spectra means with power law
  - * Fit PTB efficiency with inverse second order parameterization
  - * Multiply recoil and efficiency fit with ICRP dose conversion factors in each recoil bin

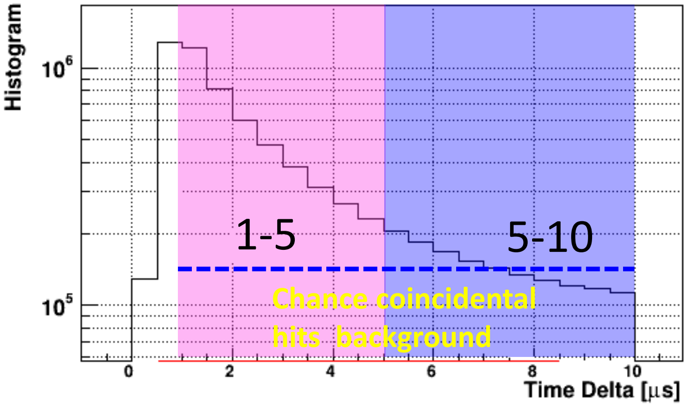


Conversion Factors

2. Background/Chance Coincidence Subtraction

- Poisson time correlation between recoil and capture pulses for B10 capture event allow to subtract backgrounds (exponential process)
- Oversubtraction ensures all backgrounds subtracted; rejected neutron pairs recovered via efficiency correction
- Performed in both offline analyses

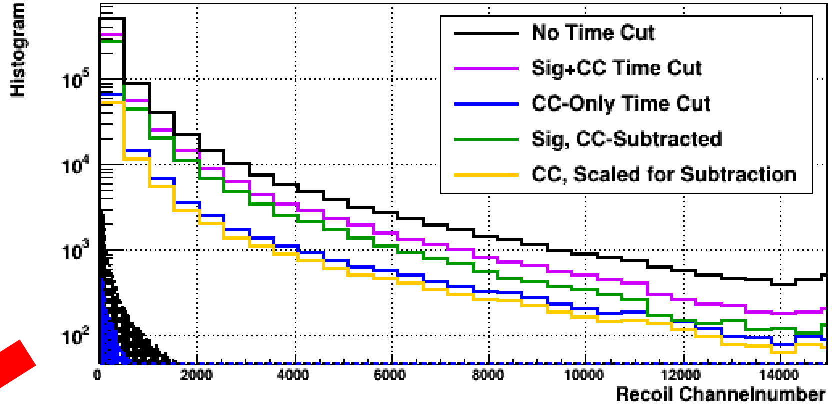
Delta T Capture



Signal + cc

cc

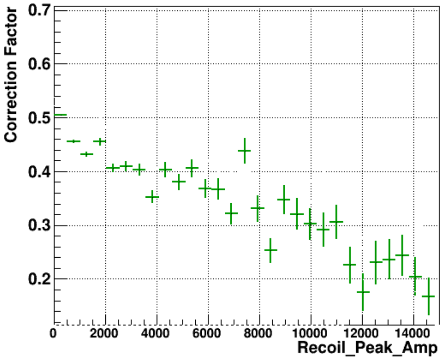
Recoil Channelnumber



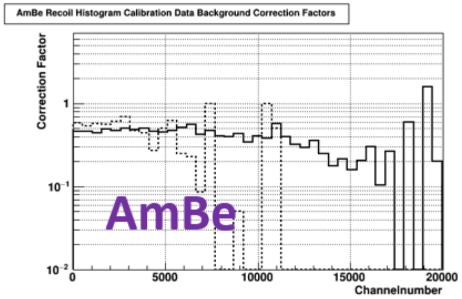
Signal

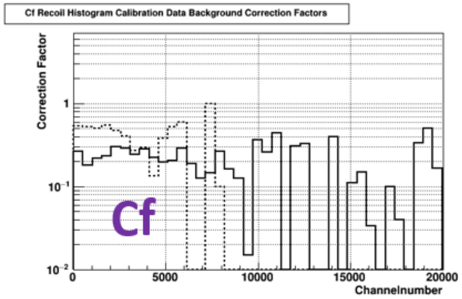
Total

Chance Coincidence Subtraction Factors



Background fractions for ground test sources:
* AmBe 40-50%
* Cf 80% (50-60% indirect radiation-only)

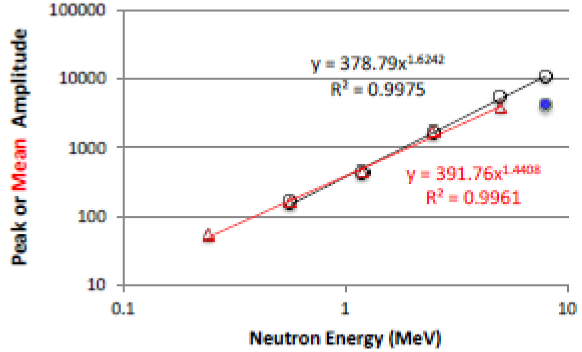


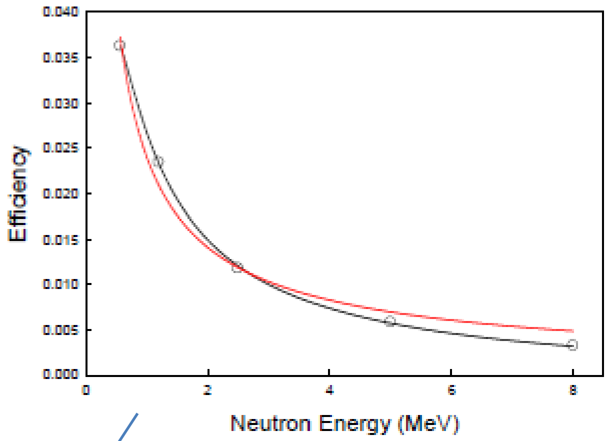


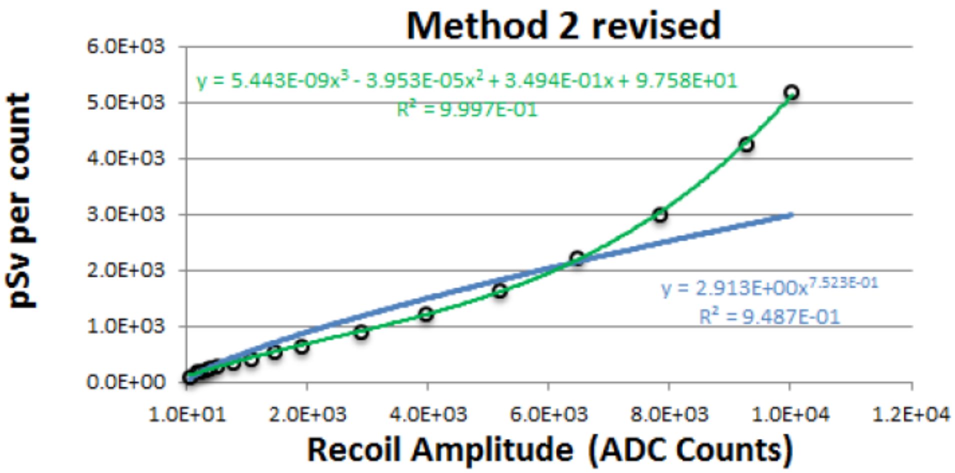
For chance coincidence subtraction of cyclic recoil histograms

2. Offline Light Analysis (Cary Z.)

- Fit of PTB background-subtracted recoil spectra means with power law
- Fit PTB efficiency with inverse second order parameterization
- Multiply recoil and efficiency fit with ICRP dose conversion factors in each recoil bin







2. Unfolding Procedure (Martin L.): Regularized SVD Unfolding

A. Hoecker, V. Kartvelishvili, NIM A372, 469 (1996)
[arxiv:hep-ph/9509307]

- Uncertainties on data distributions and response matrix
=> use regularized, singular vertex decomposition-based unfolding algorithm (ROOT: TSVDUnfold)

- **Advantages**:
* correct treatment of uncertainty-equipped input quantities (detector response matrix, input distribution)
* full uncertainty propagation; fast

- **Limitations**:
* 'strength' of regularization described by free parameter, needs to be determined from characteristics of orbit data, simulation and ground test data (systematic uncertainty)
* dependence on input distribution (not found strong)

general problem formulation:

$$\hat{A}\, x^{\text{ini}} = b^{\text{ini}}, \qquad \sum_{i=1}^{n_b}\Big(\sum_{j=1}^{n_x}\hat{A}_{ij}x_j - b_i\Big)^2 = \min$$

but: Experimental uncertainties Δb != 0

$$\sum_{i=1}^{n_b}\left(\frac{\sum_{j=1}^{n_x}\hat{A}_{ij}x_j - b_i}{\boxed{\Delta b_i}}\right)^2 = \min \qquad (\hat{A}x - b)^T \boxed{B^{-1}} (\hat{A}x - b) = \min$$

Rescaling and regularization:

$$(\tilde{A}\, w - \tilde{b})^T\, (\tilde{A}\, w - \tilde{b}) + \boxed{\tau \cdot (C\, w)^T C\, w} = \min$$

regularization parameter: chosen from rank of response matrix/problem

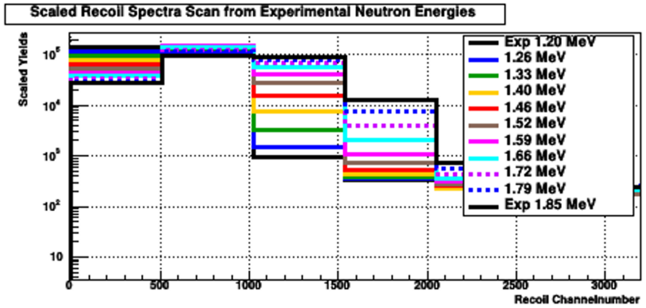
-> need response matrix for given recoil channelnumber and chosen neutron energy binning

2. Unfolding Neutron Energy Binning

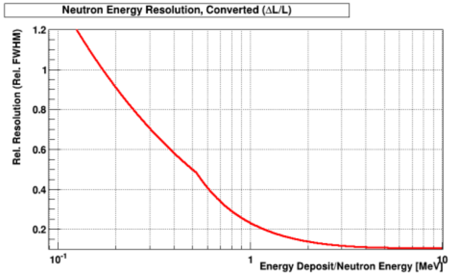
- Neutron energy binning:
  - * low and high limits: approach from detector side:
    - @ **lower limit: 200 keV** (electronics lower pulse cutoff/arming threshold)
    - @ **upper limit: 8.5 MeV** (corresponding pulses start to saturate 12-bit ADC)
  - * bin width:
    - @ FND orbit data histograms hardcoded to 512 channel width (29 bins)
    - @ Low energy challenge: light function nonlinearity: first recoil bin contains most of all < 1 MeV neutrons; 1.59 MeV centered in second bin
    - @ Unfolding requires benefits from unique response matrix rows- recoil spectrum of neighboring energy bins should 'peak' in different recoil bins
    - @ Unfolding algorithm reacts positively to similar neutron energy bin size
    - @ Choose high energy bin widths following detector resolution (determined from light function calibration), width = 2 * resolution

Lower Lim	Center	Width
0.2	0.664	0.927
1.127	1.59	0.927
2.054	2.403	0.698
2.752	3.101	0.698
3.45	3.913	0.925
4.375	5	1.375
5.75	6.5	1.5
7.25	8	1.5

recoil binning-drive

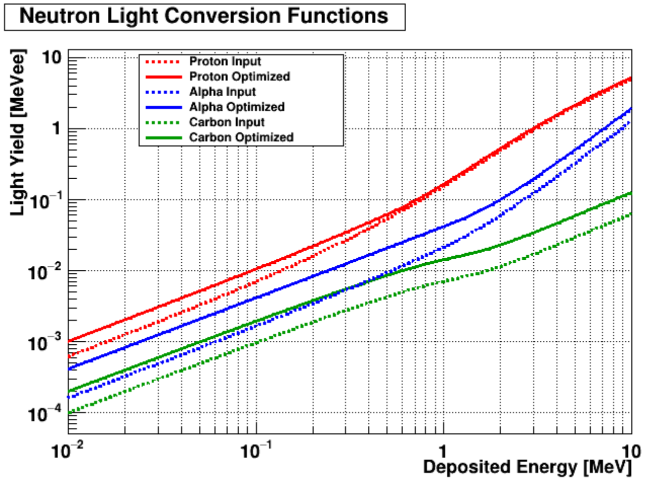


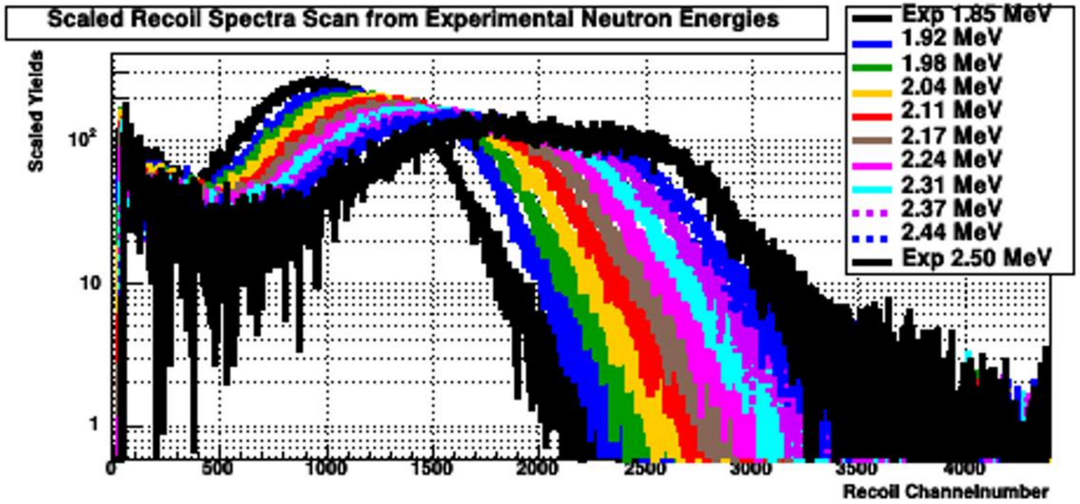
energy resolution-driven



2. Response Matrix Assembly

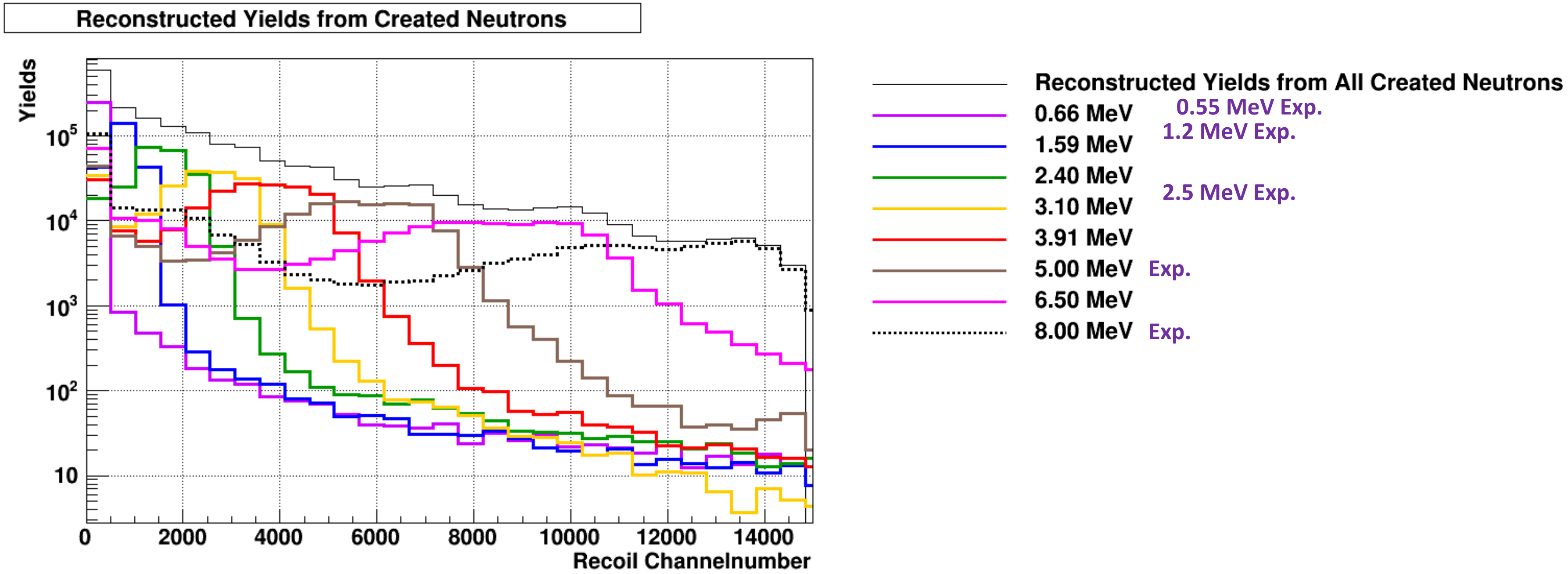
- Were unable to reproduce experimental PTB datasets with sufficient accuracy through MCNP-based simulation
- Create response matrix instead by ‘scaling’ available experimental monoenergetic distributions
- All bin centers straddled by available experimental data; assumption is that spectra change continuously with energy (supported by simulation results): Along MCNP-calibrated light function,
  a) scale down experimental distribution for **higher energy**
  b) scale up exp distribution from **lower energy**
  c) average

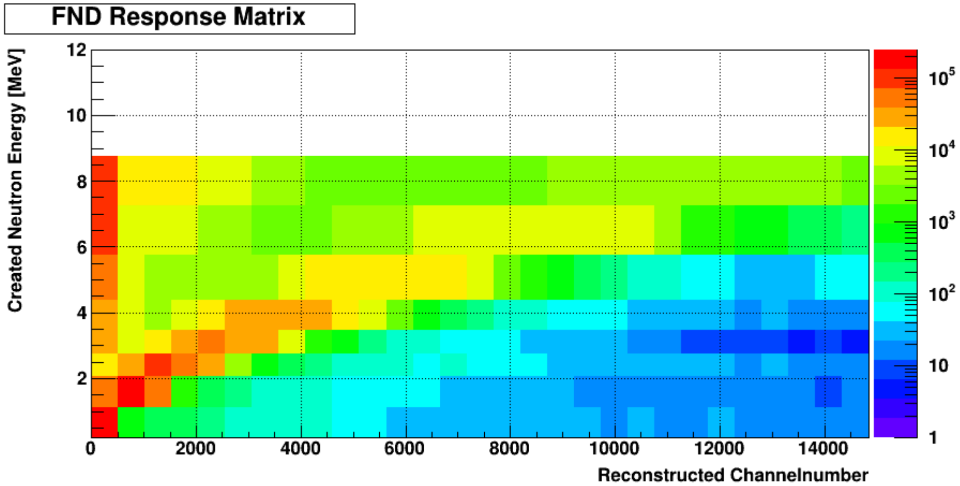


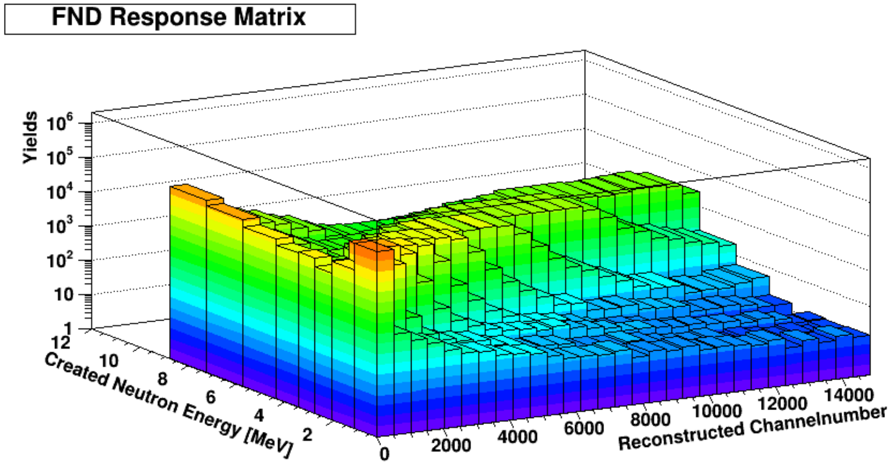


2. Response Matrix Assembly

- Response matrix and row slices from scaled experimental distributions



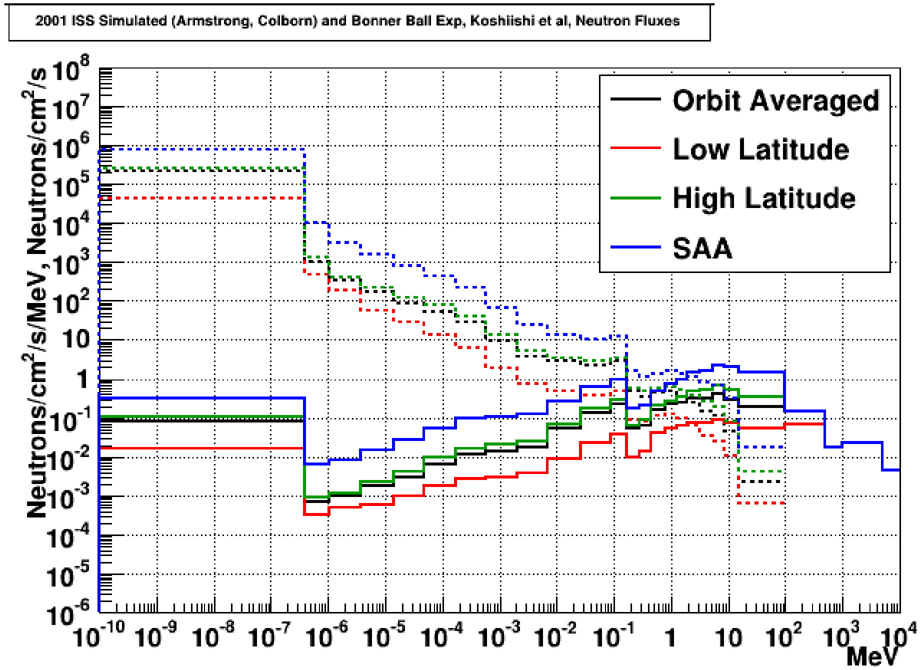




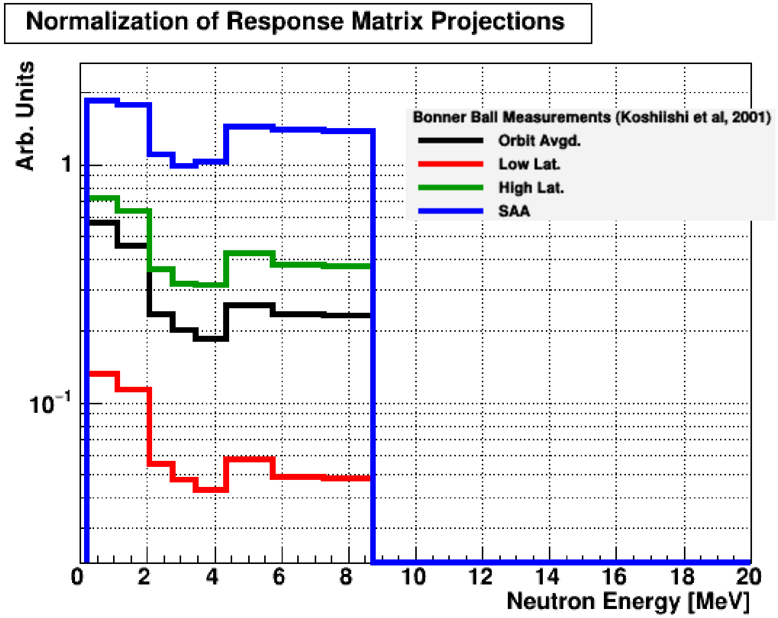
2. Response Matrix Assembly

- Can choose ‘input spectrum’ freely: weighting of columns of response matrix relative to each other
- Choose ‘input spectrum’ close to expected truth:
  - * Koshiishi et al, published 2007 (data from 2001);
  - * three data points filled for energies [100 MeV; 10 GeV) from simulation
- Integral orbit averaged flux (black line):
  - * thermal to 200 keV: ~0.6 n/cm^2/s, > 8.5 MeV: 0.6 n/cm^2/s
  - * total ~3.0 n/cm^2/s

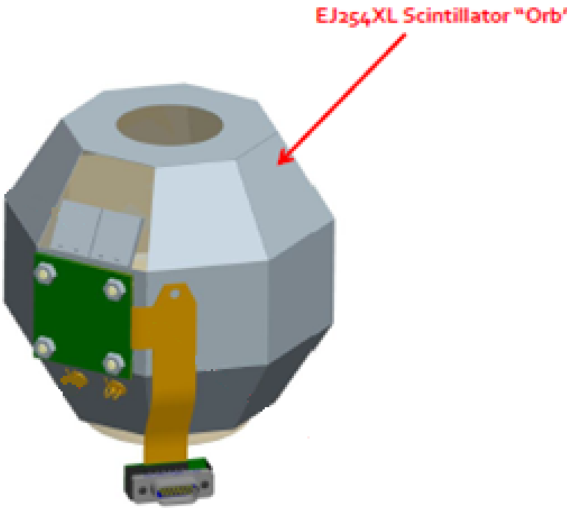
H. Koshiishi et al,
Rad. Meas. 42 (2007), 1510ff



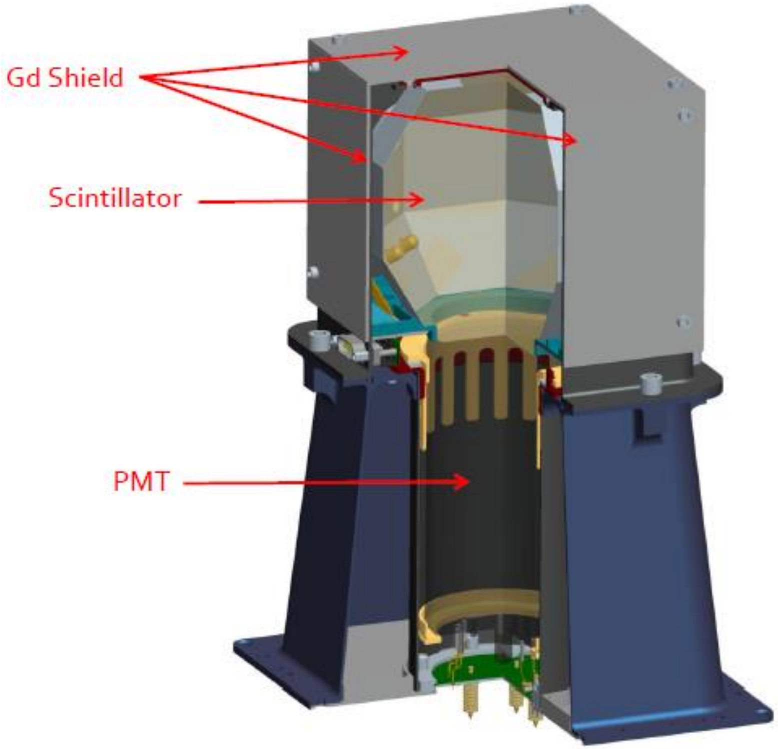
Rebin



3. Ground Verification of Analysis Methods

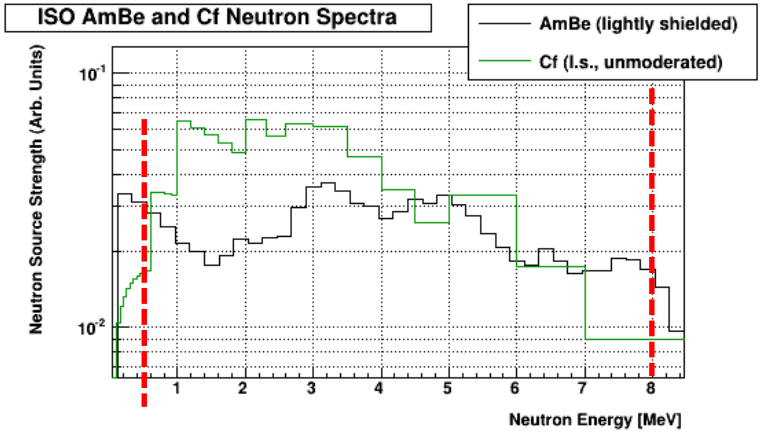


graphics modified from SwRI



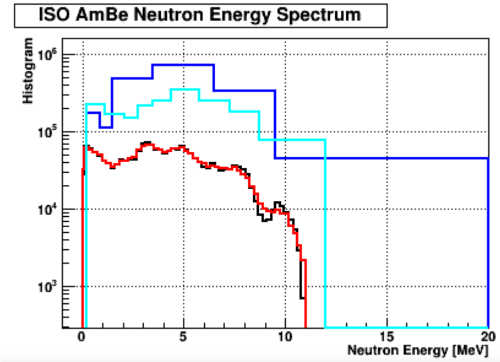
3. Ground Verification- PTB Source Runs

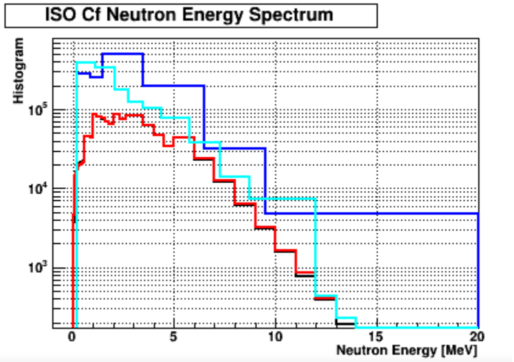
- AmBe and Cf-254 source runs in PTB precision source bunker; corrections for effective depth and FND energy acceptance
- Extract reference dose and spectra from ISO distributions for 0.5 to 8 MeV energy range
- True rate: 0.708 muSv/min AmBe, 0.495 muSv/min Cf
- Online: 0.673 muSv/min AmBe, 1.091 muSv/min Cf
- Offline light: 0.696 muSv/min Ambe, 0.537 muSv/min Cf
- Already see online algorithm sensitivity to chance coincidence pulses due to impossibility to perform background subtraction

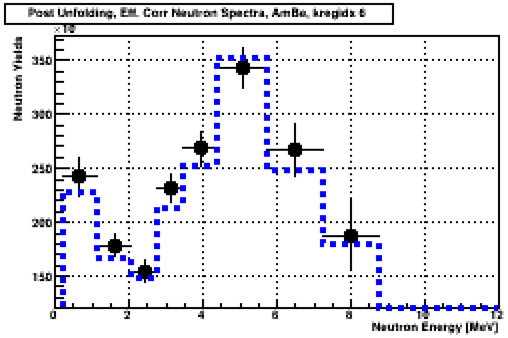


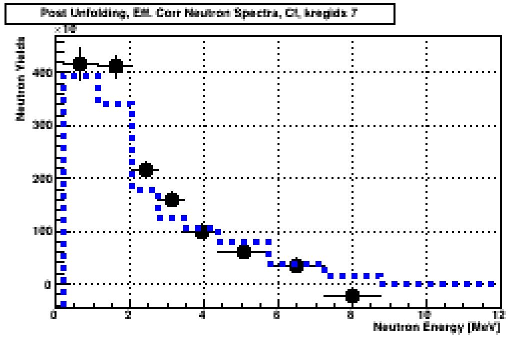
3. Ground Verification- PTB Source Runns

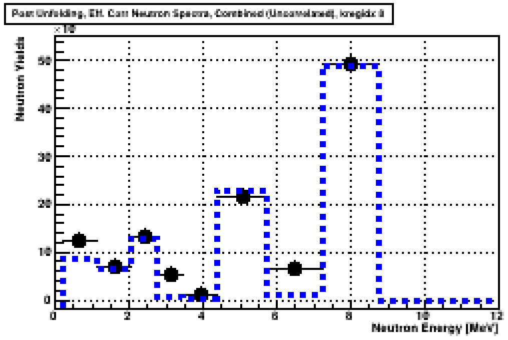
- AmBe and Cf-254 source runs in PTB precision source bunker; corrections for effective depth and FND energy acceptance
- Offline heavy:
  * Subtraction of room return to compare to ISO spectra
  * AmBe: unfolding results within 10% of AmBe in all bins
  * Cf: within 26%: possible reason for larger deviation is rapid decay of Cf spectrum in energy range (factor 30), vs AmBe and Orbital < 3
- Test unfold of artificial combination sample of monoenergetic sources within 30% on non-empty bins


ISO AmBe Neutron Energy Spectrum

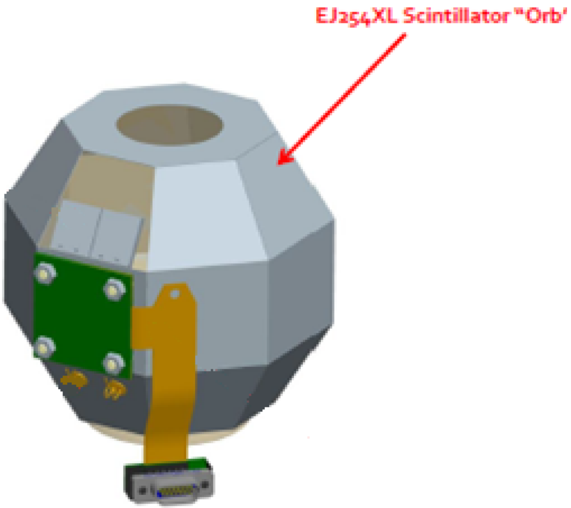

ISO Cf Neutron Energy Spectrum


Post Unfolding, Eff. Corr Neutron Spectra, AmBe, kregids 6

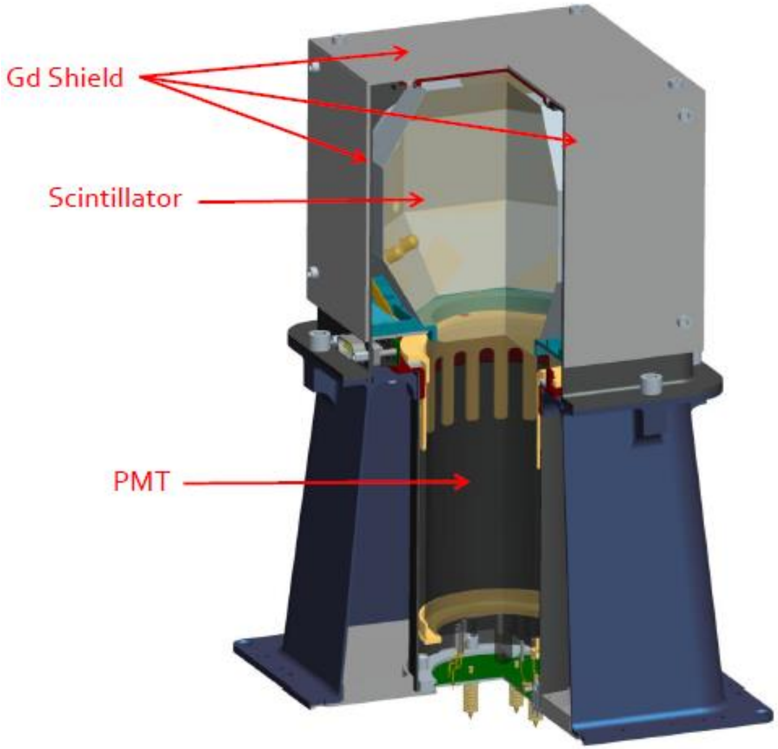

Post Unfolding, Eff. Corr Neutron Spectra, Cf, kregids 7


Post Unfolding, Eff. Corr Neutron Spectra, Combined (Uncorrelated), kregids 8

4. Orbital Raw Data

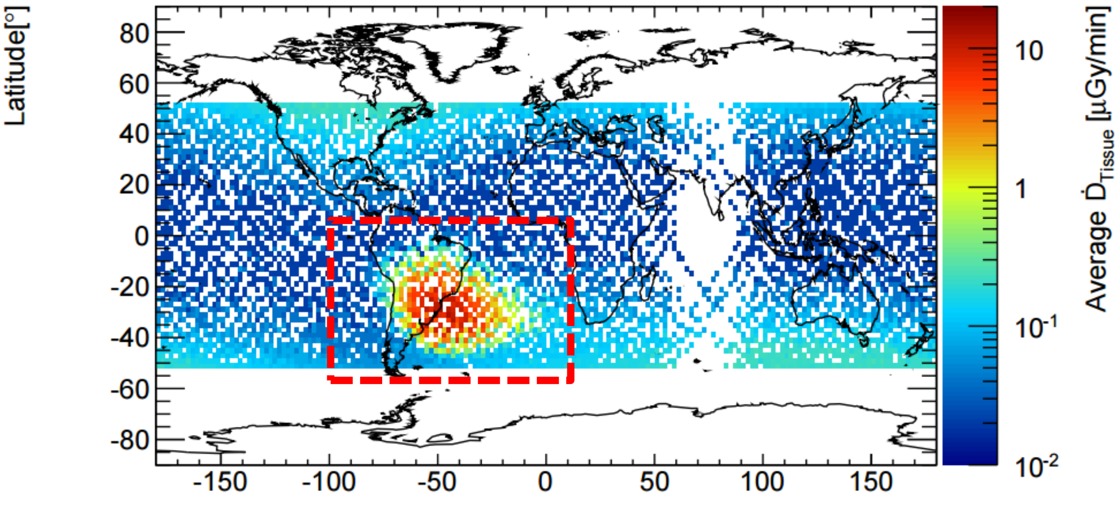


graphics modified from SwRI

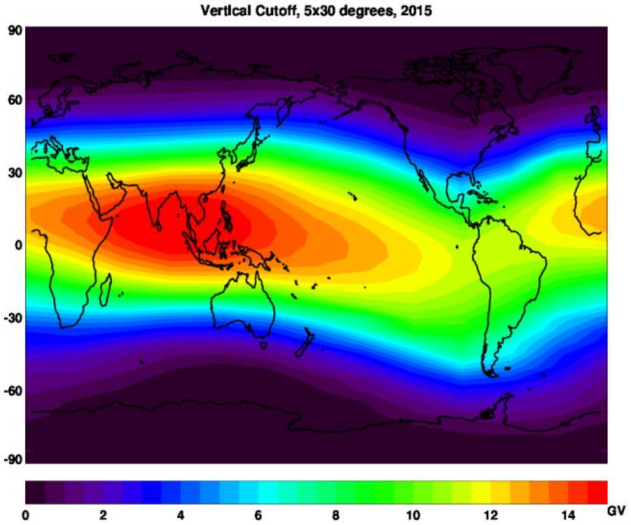


4. Longitutde/Latitude Binning

- SAA selection: use cuts: lon in [-90;10); lat < 10 && FND singles rate derivative cut
- Koshiishi et al selections: ‘high latitude’ < 1 GV geomagnetic rigidity cutoff, >13 GV for ‘low latitude’ (from CREME 86)
- To determine rigidity per data point, use 2015 lookup table from LaRC with looser cuts for better statistics: high lat <3 GV, low lat >=11 GV
- Comparisons for FND vs Koshiishi et al low and high lat will be apples to oranges as magnetic environment changed in last 20-30 years

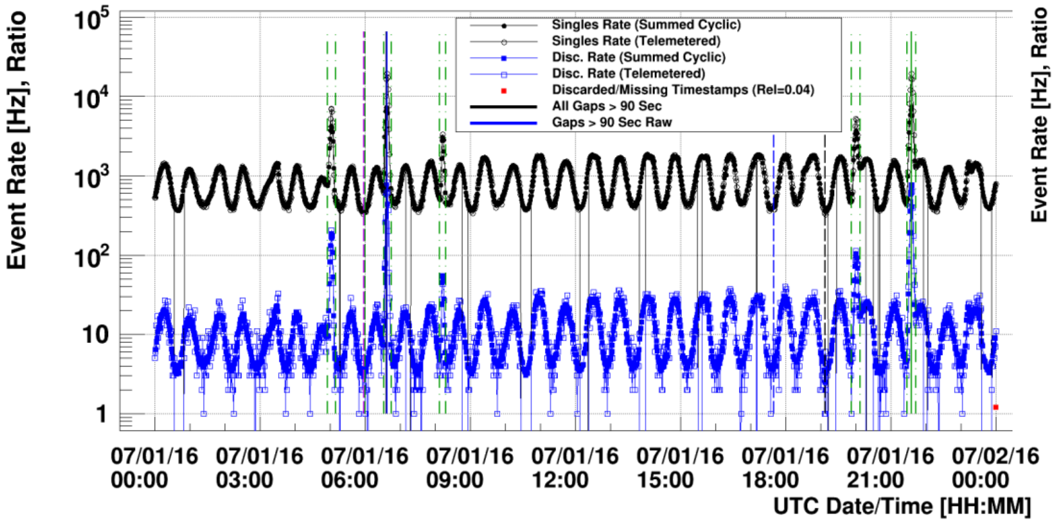


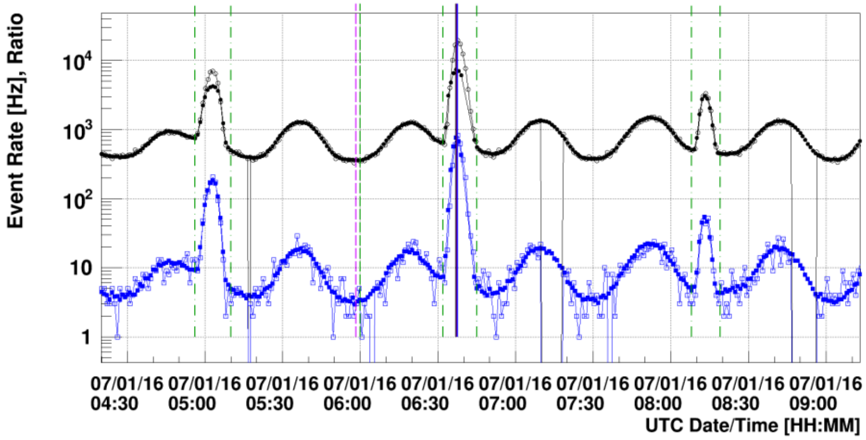
TEPC: 2016-05-18 00:00:13 → 2016-05-24 18:58:02

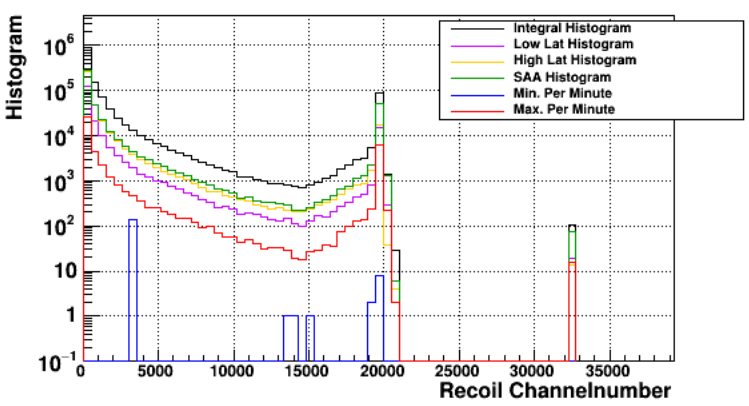

Vertical Cutoff, 5x30 degrees, 2015

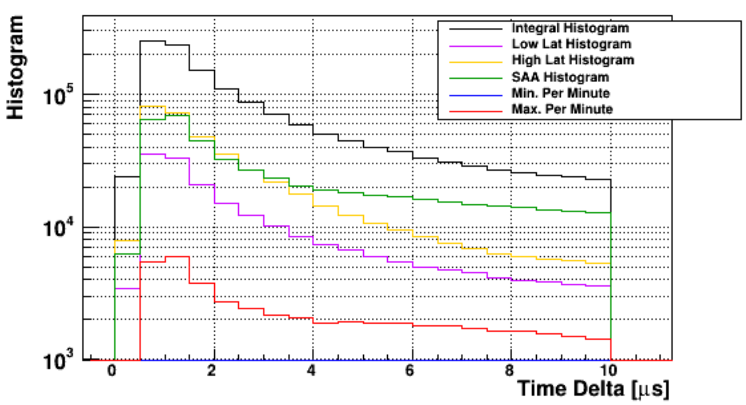
4. Exemplary Raw Orbit Data

- 24 hr slice from 7/1/16 with largest SAA pass to date
- Shown are singles and discriminated rates
- Discriminated rate increases by factor 30-40 inside SAA compare to magnetically unshielded areas outside of SAA


Singles and Disc Rates, 2016-07-01 00:00:00 to 2016-07-02 00:00:00, Cutlevel 1

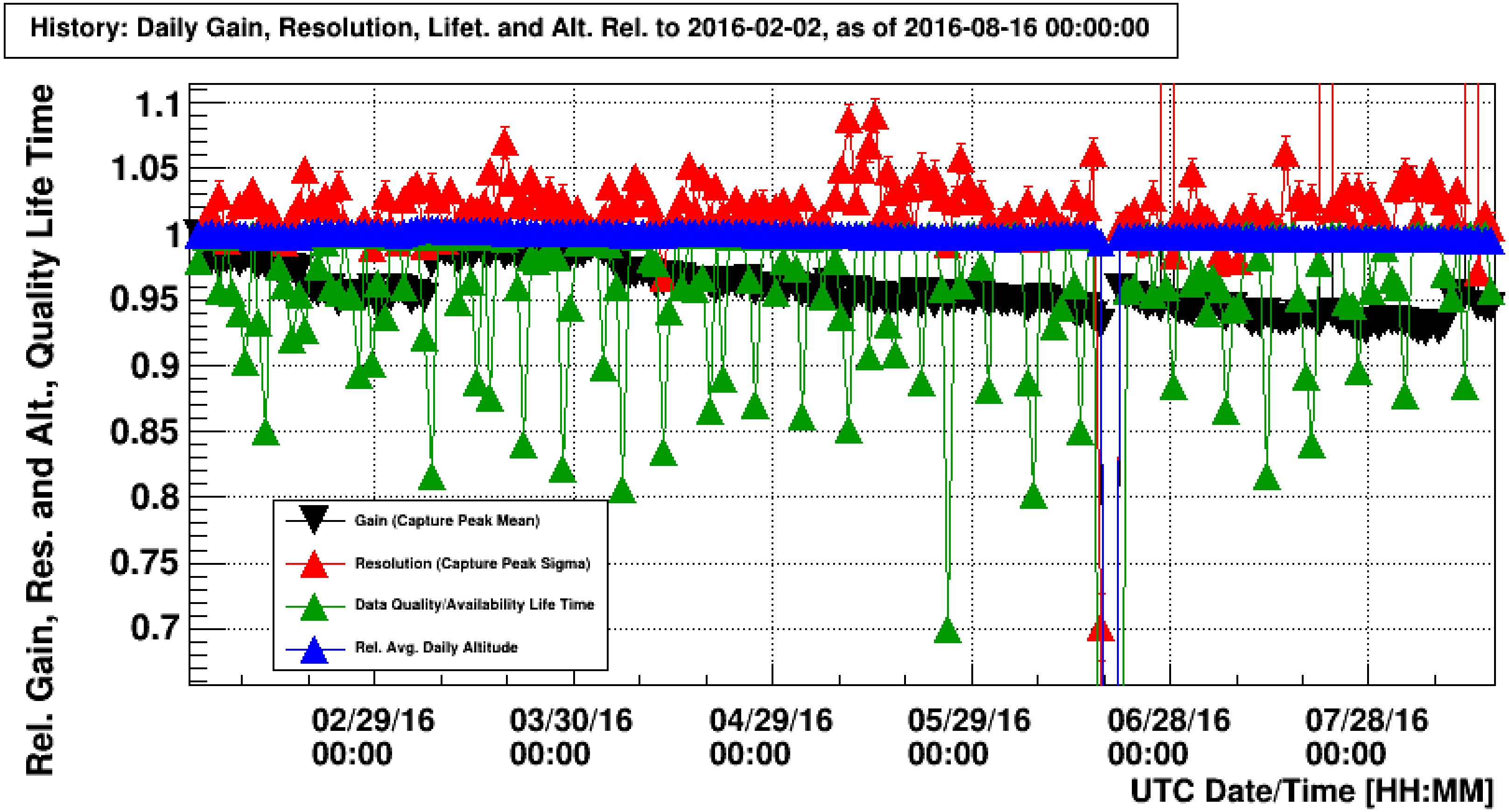

Singles and Disc Rates, 2016-07-01 00:00:00 to 2016-07-02 00:00:00, Cutlevel 1


Recoil, 2016-07-01 00:00:00 to 2016-07-02 00:00:00, Cutlevel 1

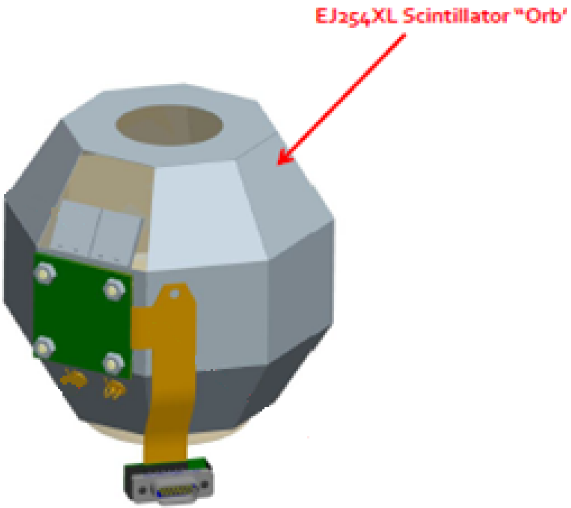

Time Delta, 2016-07-01 00:00:00 to 2016-07-02 00:00:00, Cutlevel 1

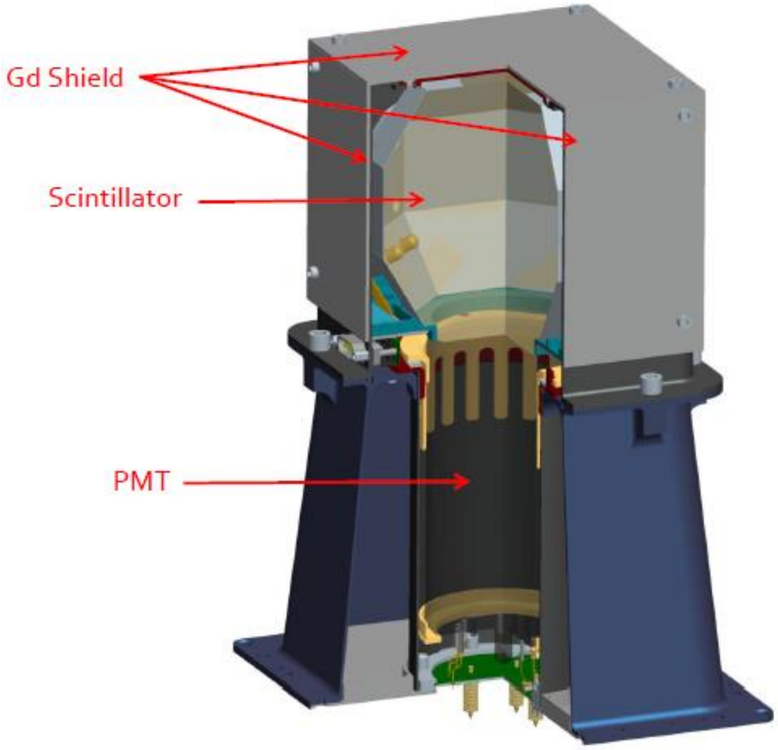
4. Exemplary Raw Orbit Data

- ISS altitude mostly constant/ within 1% since ACO start
- Fraction of available data >5% in about 1/3 of ACO period- correction investigations to be performed
- Rework of ground analysis software in ROOT (R. Rios) largely improved data quality and handling



5. ACO Results, Status

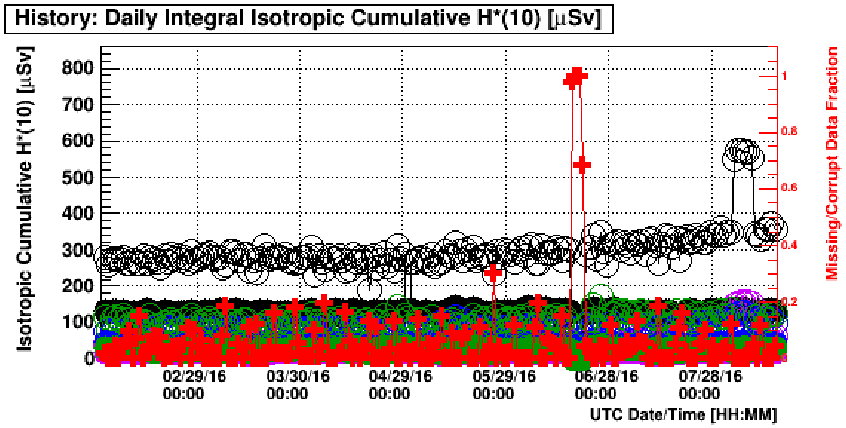


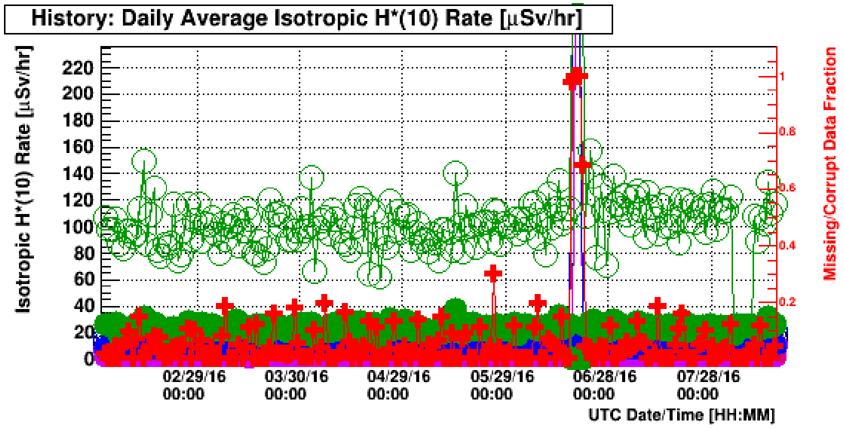


graphics modified from SwRI

5. Dose Equivalent Results ACO Period, Daily Values

- Online, offline light and offline heavy: Dose equivalent results vs time, daily values


History: Daily Integral Isotropic Cumulative H*(10) [μSv]


History: Daily Average Isotropic H*(10) Rate [μSv/hr]

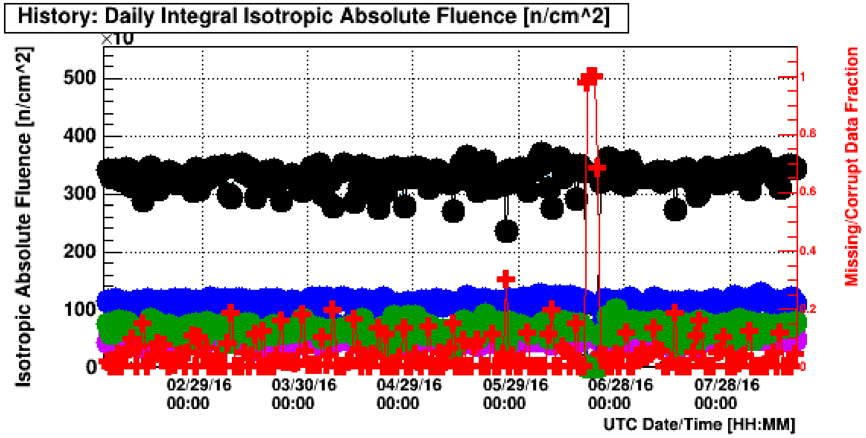
Analysis Type:

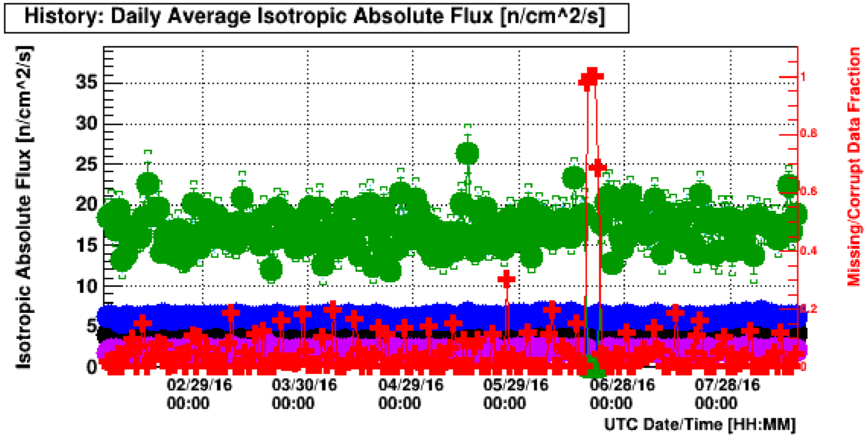
● Ground Regularized Unfolding

○ On-board Cyclic Telemetered Dose Eq

— Ground Conversion

- Offline heavy: Neutron flux daily values


History: Daily Integral Isotropic Absolute Fluence [n/cm^2]


History: Daily Average Isotropic Absolute Flux [n/cm^2/s]

5. Dose Equivalent Results ACO Period Totals/Averages

- Online, offline light and offline heavy: Dose equivalent results vs time, totals and averages (overall %missing data/rejected 24 hr slices)

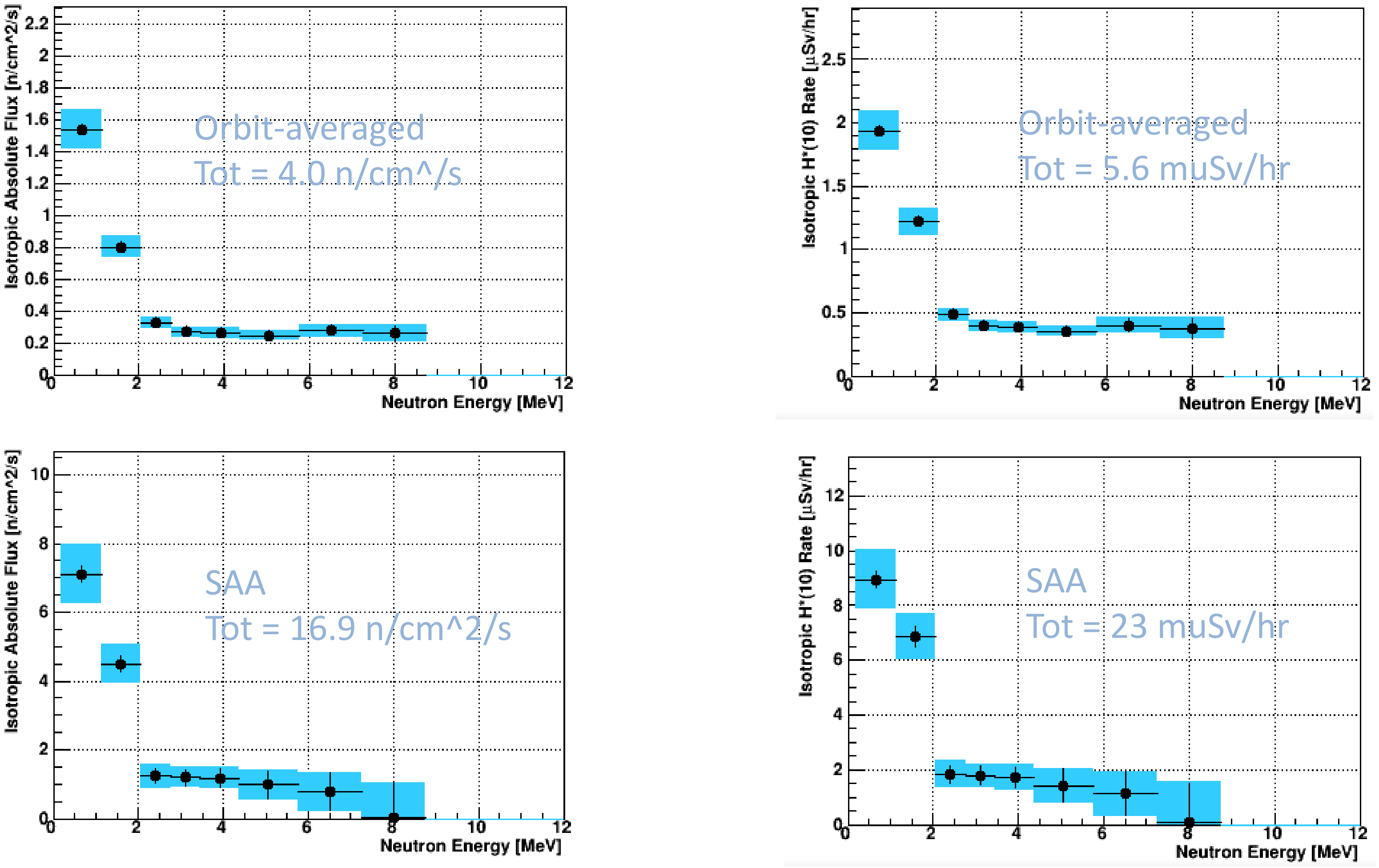
Analysis Method	Integral (orbit averaged)	Low Lat	High Lat	SAA
Online	40 mGy	11 mGy	55 mGy	67 mGy
Offline light	30 mGy	7 mGy	35 mGy	45 mGy
Offline heavy	27 mGy	6 mGy	33 mGy	41 mGy

- Offline heavy: Neutron fluence totals/averages

Integral (orbit averaged)	Low Lat	High Lat	SAA
3.45e+05 n/cm^2	2.07e+05 n/cm^2	5.78e+05 n/cm^2	9.43e+05 n/cm^2

5. Dose Equivalent Results ACO Period Totals/Averages

- Offline heavy: Neutron flux energy distributions



Isotropic Neutron Flux [n/cm^2/s]

H*(10) Dose Eq Rate [muSv/hr]

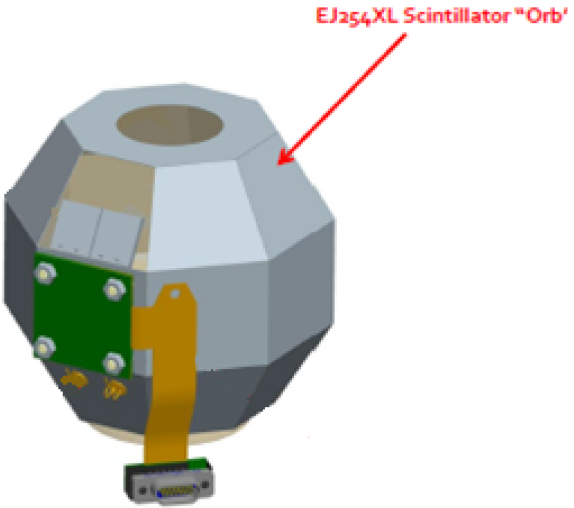
Orbit-averaged
Tot = 4.0 n/cm^/s

Orbit-averaged
Tot = 5.6 muSv/hr

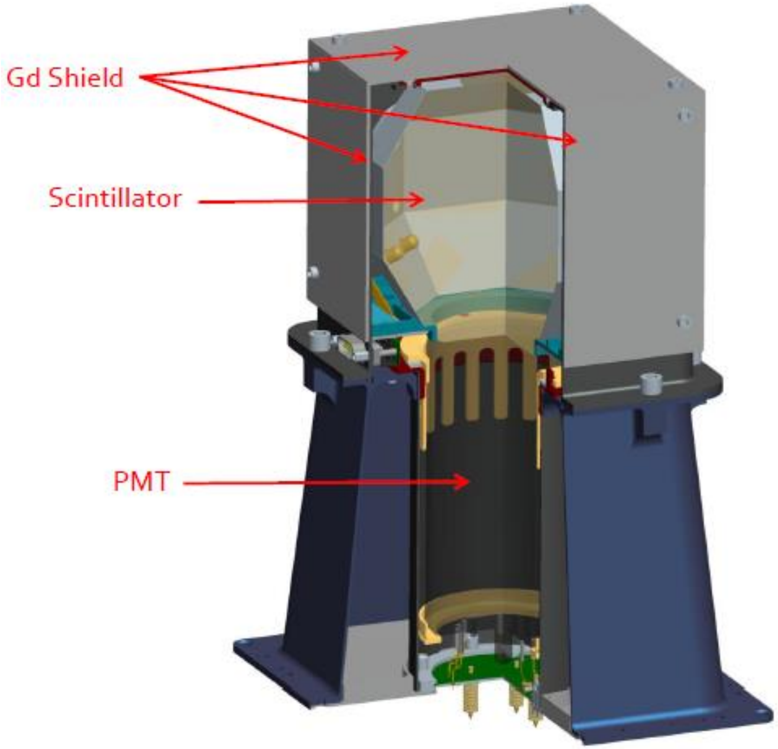
SAA
Tot = 16.9 n/cm^2/s

SAA
Tot = 23 muSv/hr

5.2 Comparing ACO to Simulated Data, Status

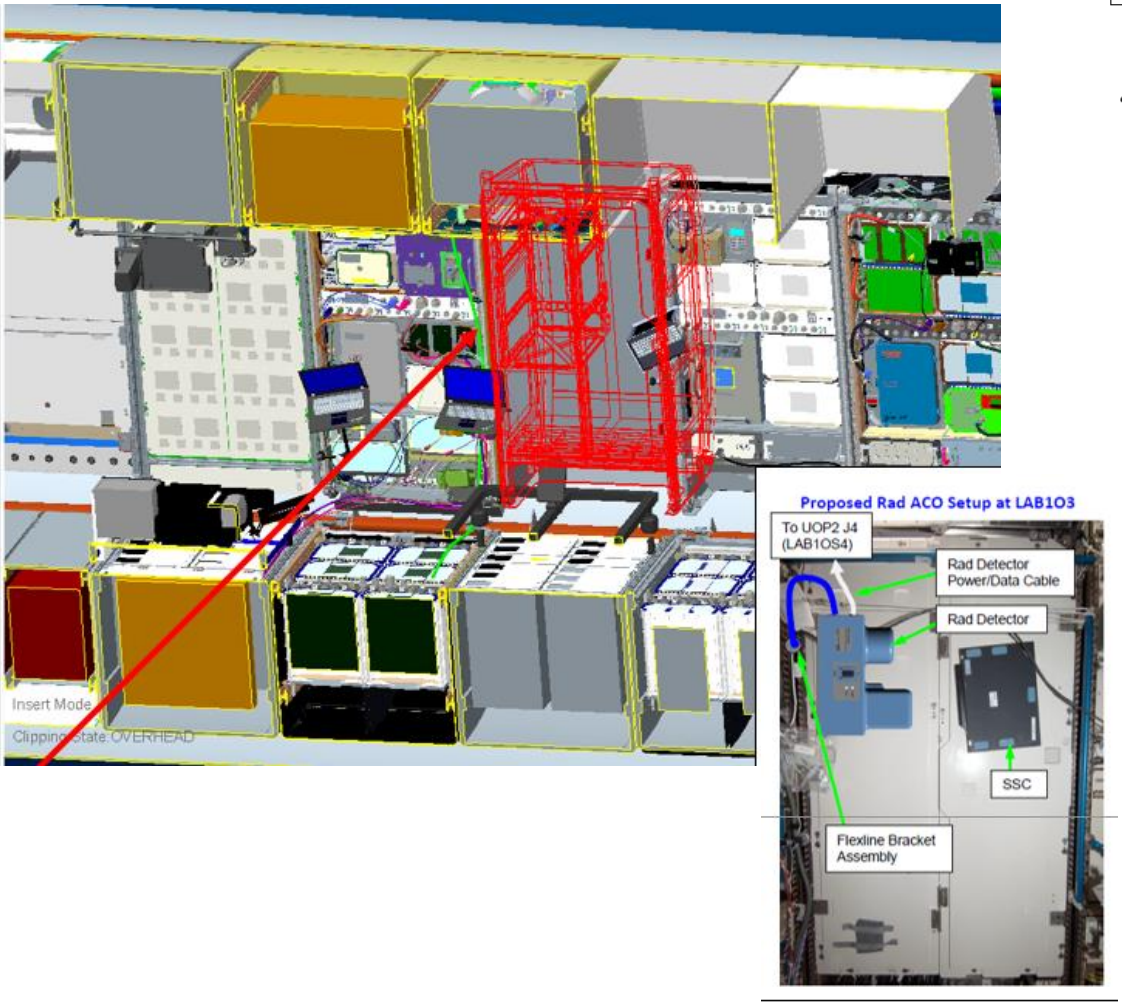


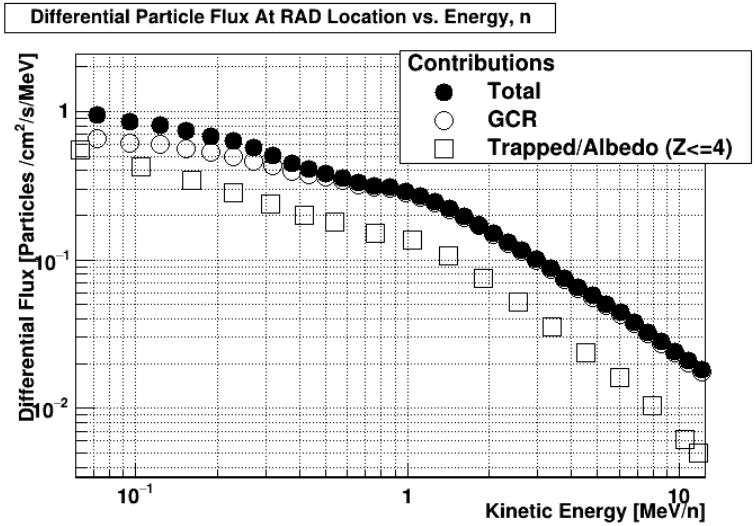
graphics modified from SwRI

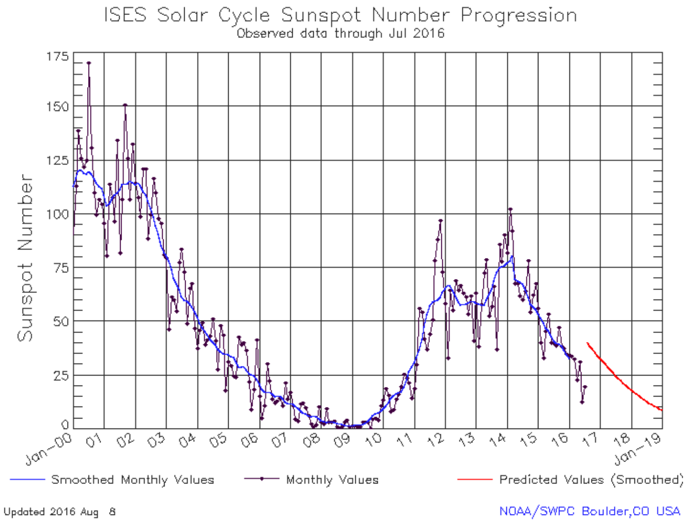


5.2 Dose Equivalent Results ACO Period Totals/Averages

- Comparison to Oltaris (HZETRN-based) simulated data
- Ray-trace of material in US lab with latest US lab shield configuration file
- Attempt to match solar conditions: same sunspot number period matched







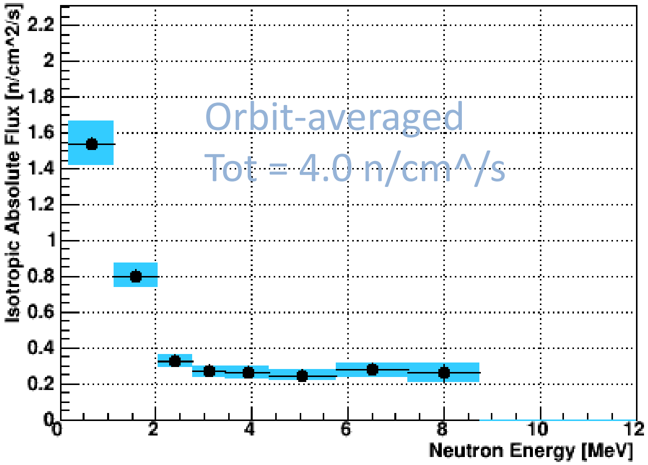
5.2 Dose Equivalent Results ACO Period Totals/Averages

- Comparison to Oltaris

Data Source	Integral (orbit averaged)
Online	40 mGy
Offline light	30 mGy
Offline heavy	27 mGy
Oltaris simulated	15 mGy

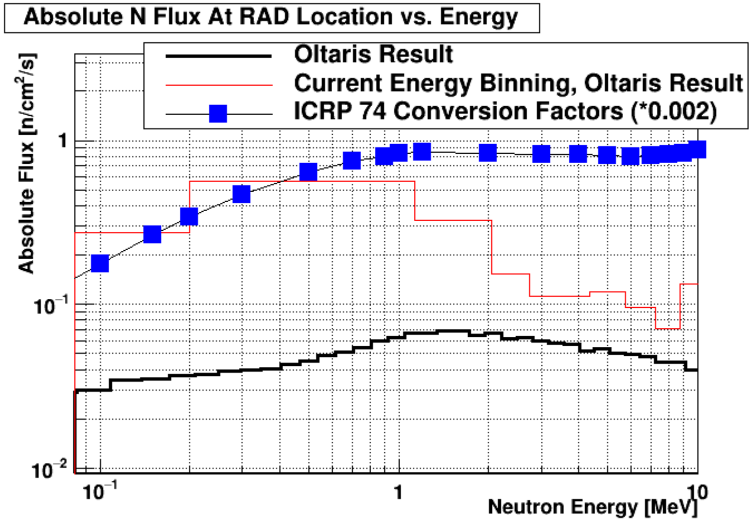
- Spectral comparison to offline heavy: Neutron fluence totals/averages

Isotropic Neutron Flux [n/cm^2/s]

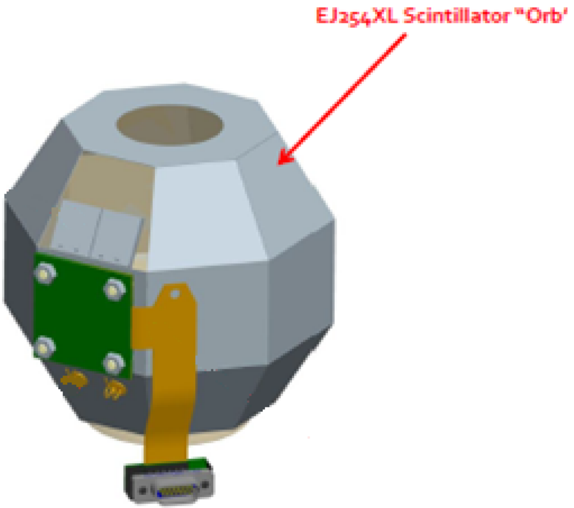


Orbit-averaged

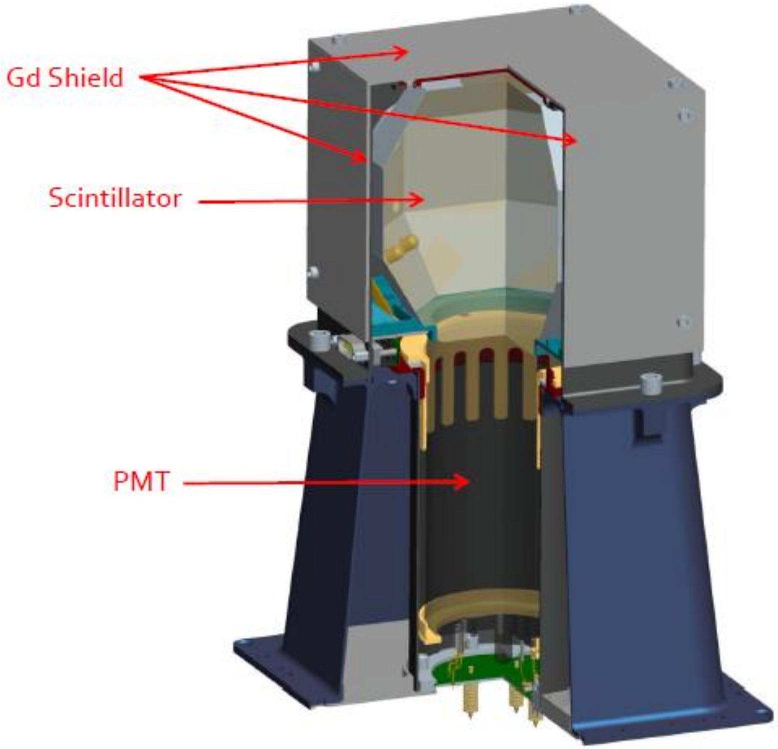
Tot = 4.0 n/cm^/s



5.3 Comparing ACO to Other Experimental Measurements, Status

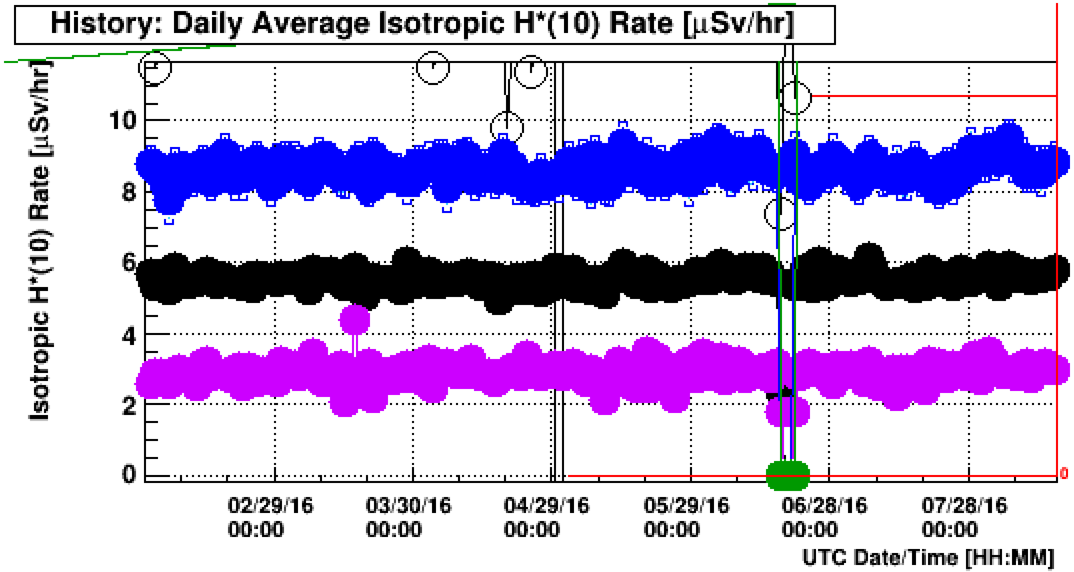


graphics modified from SwRI

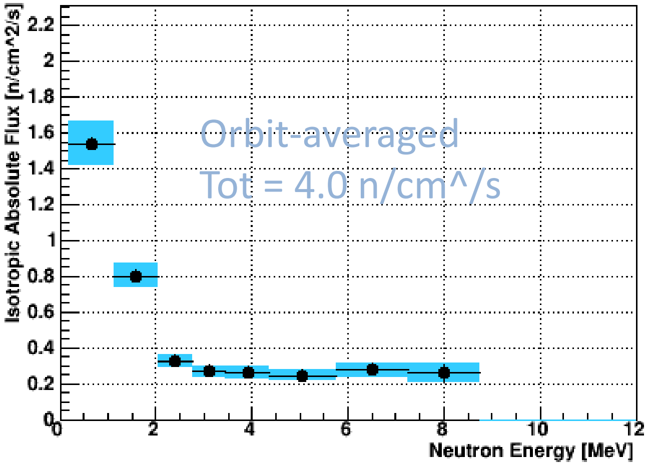


5.3 Dose Equivalent Results ACO Period Totals/Averages

- Previous neutron measurements: Koshiishi et al 2007 (Bonner Ball Experiments 2001)
- Bubble detectors, M. Smith et al (US lab data)
- IV-TEPC, data with LET > 15 keV/mum (neutrons + heavy ions, US Lab data)



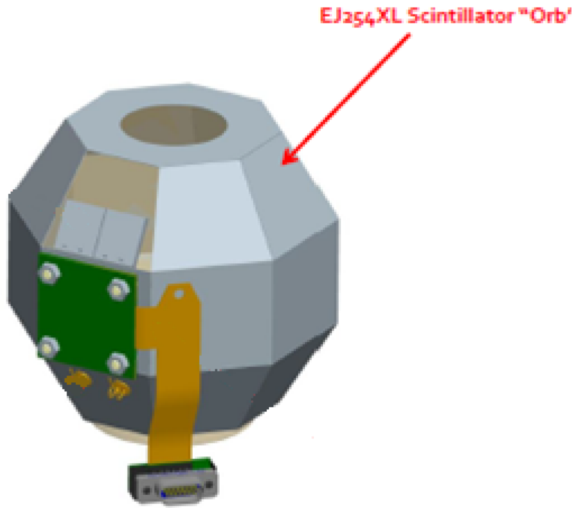
Orbit averaged



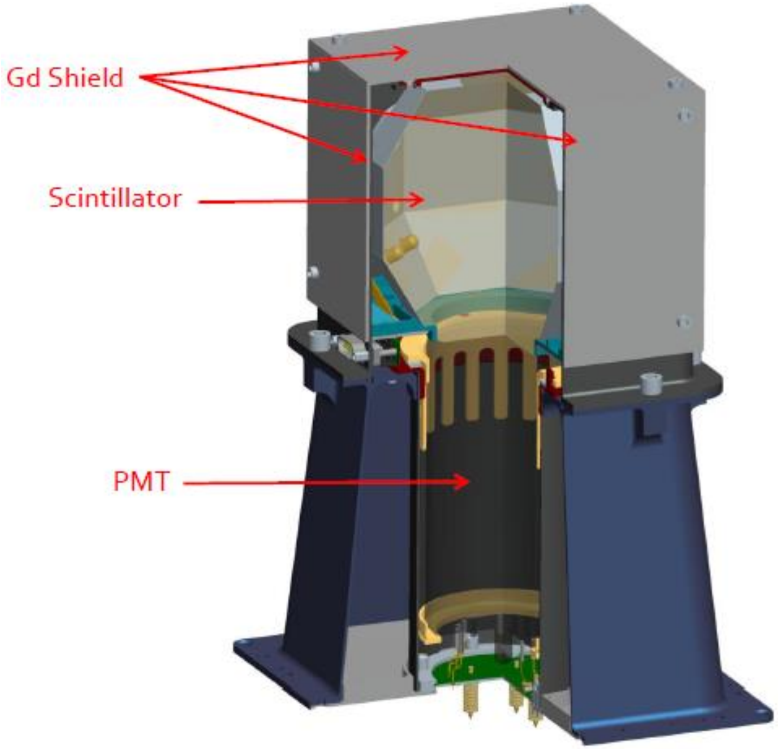
Orbit-averaged
Tot = 4.0 n/cm^/s

Data Source	Integral (orbit averaged)
Online	40 mGy
Offline light	30 mGy
Offline heavy	27 mGy
Oltaris simulated	15 mGy
Koshiishi et al	26 mGy
Bubble detectors	25 mGy
IV-TEPC (>15 keV/mum)	35 mGy

6. Forward Work



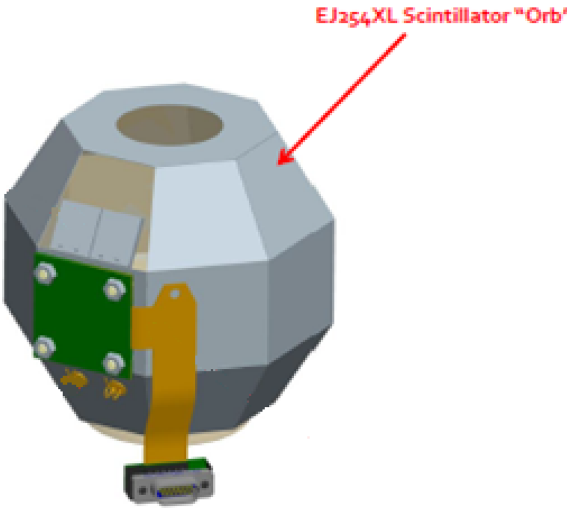
graphics modified from SwRI



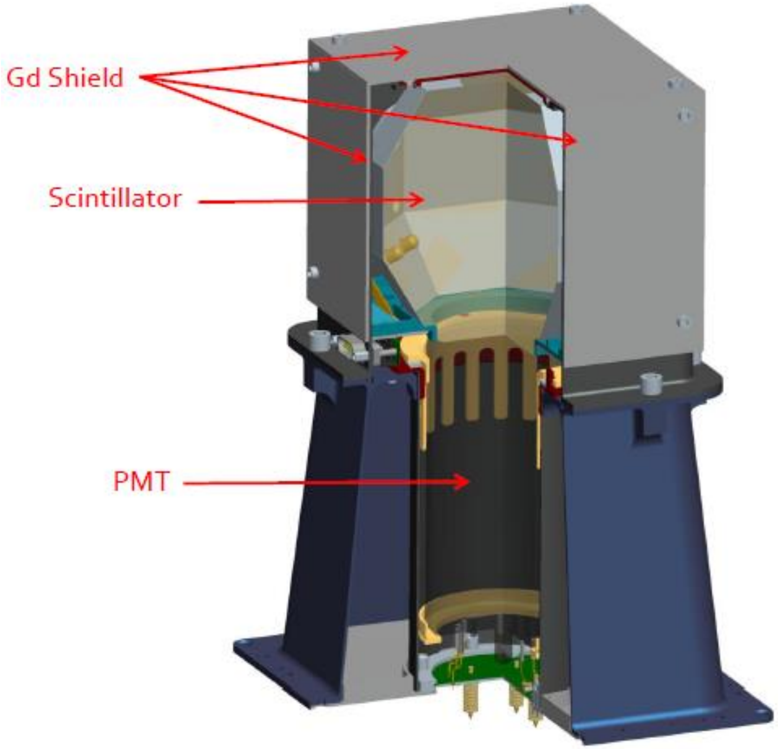
6. Plan Ahead/Systematic Studies

- Correction for missing/corrupted data [scaling, 2D-interpolation, uncertainty (SAA)]
- Estimate sample impurities from exp data (TRIUMF) and simulation (GEANT)
- Calculate 3D efficiency from EM experimental data (PTB 2015)
- Calculate full systematic uncertainties from unfolding (boundary effects, etc.)
- Potential improvement on low energy resolution through software update (pending)

-> Publish!



graphics modified from SwRI



Backup

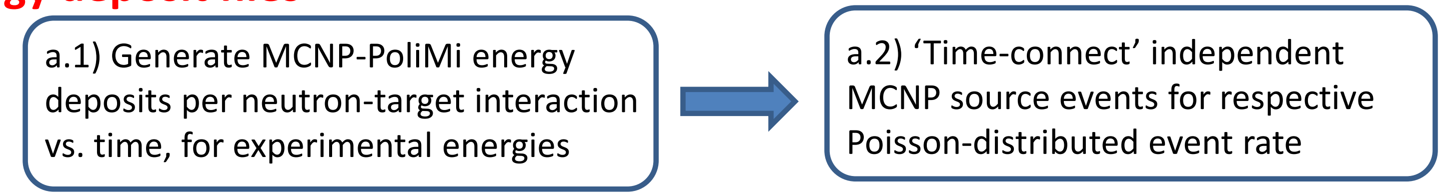
B: Orbital Peculiarities

B: Light Calibration

2. Light Function Calibration- Flowchart

- Goal: Extract continuous light function describing scintillator behavior to freely choose energy binning
- For each experimental monoenergetic data sample, start from first principles:

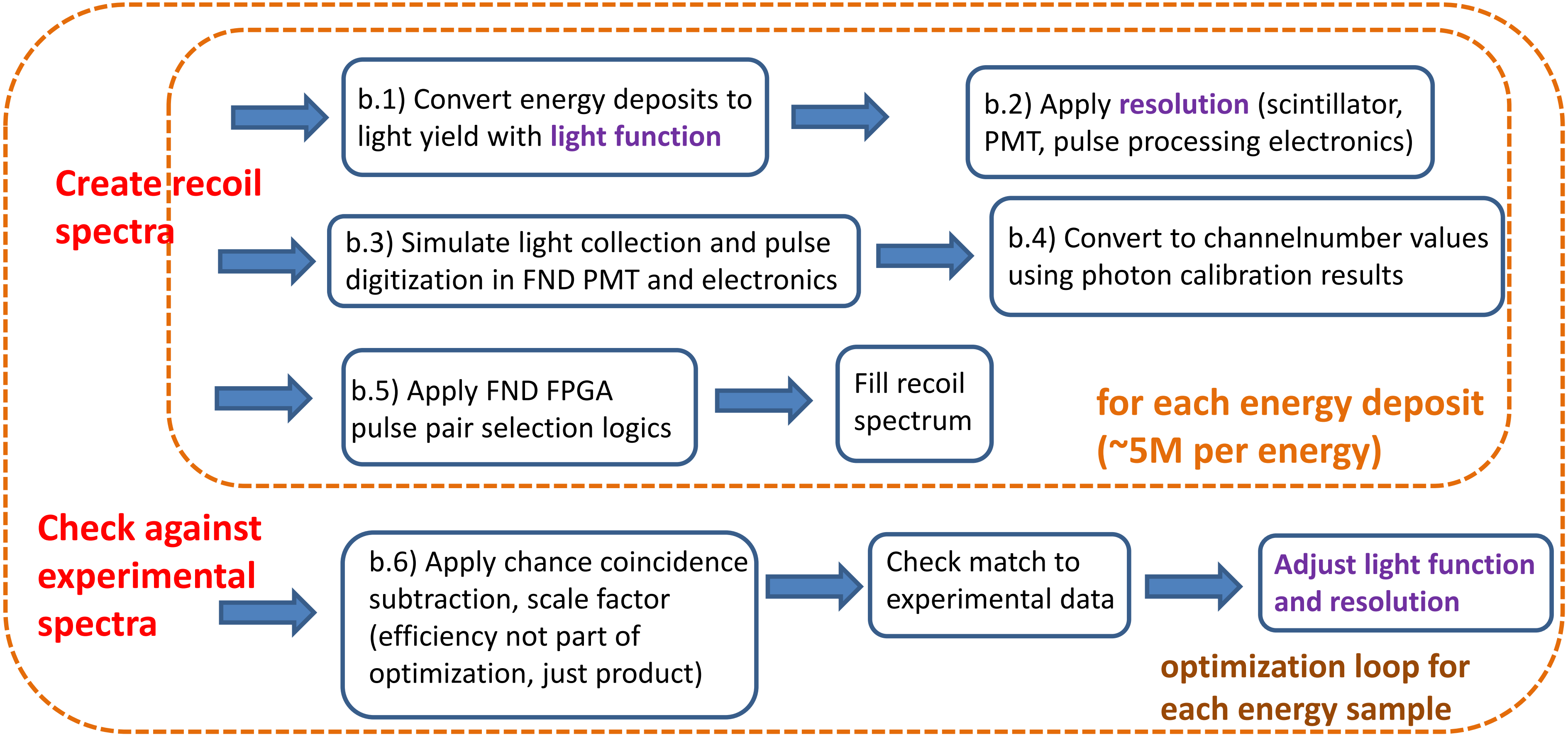
a) Create energy deposit files



a.1) Generate MCNP-PoliMi energy deposits per neutron-target interaction vs. time, for experimental energies

a.2) 'Time-connect' independent MCNP source events for respective Poisson-distributed event rate

b) Light function calibration



Create recoil spectra

b.1) Convert energy deposits to light yield with **light function**

b.2) Apply **resolution** (scintillator, PMT, pulse processing electronics)

b.3) Simulate light collection and pulse digitization in FND PMT and electronics

b.4) Convert to channelnumber values using photon calibration results

b.5) Apply FND FPGA pulse pair selection logics

Fill recoil spectrum

for each energy deposit (~5M per energy)

Check against experimental spectra

b.6) Apply chance coincidence subtraction, scale factor (efficiency not part of optimization, just product)

Check match to experimental data

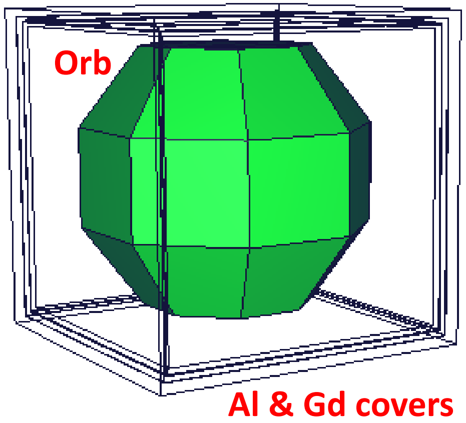
Adjust light function and resolution

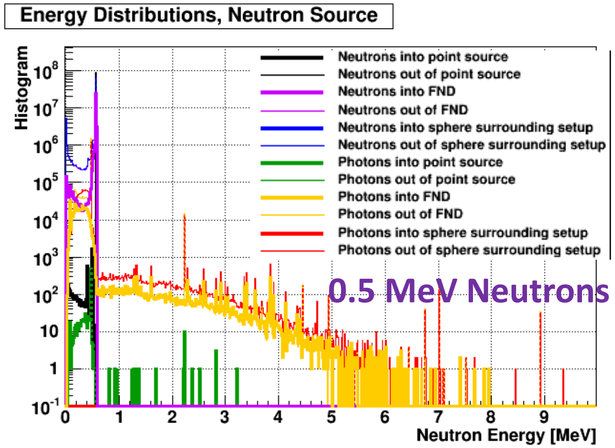
optimization loop for each energy sample

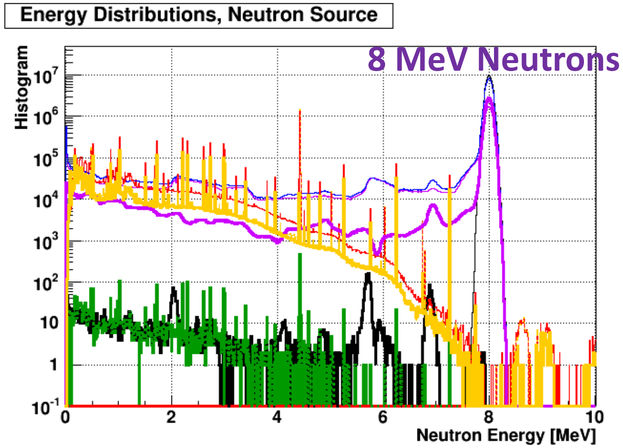
2.a.1 Generation of Neutron Energy Deposits: MCNP-PoliMi

- Use MCNP-**PoliMi** package:
  - * MCNP limitations for neutron propagation and fission/inelastic scattering simulation:
    - @ only returns total energy deposition of each neutron in target volume for conversion to light
    - @ photon and neutron productions in fission/inelastic collision events not correlated in time/energy/multiplicity
  - * PoliMi package writes out each interaction of single neutrons and photons
    - @ time correlation within each single history, resolution in 100 ps
      - **=> energy-to-light conversion possible on per-interaction-basis**
    - @ elastic, (n,gamma) and (n,n') interactions accurately modeled/propagated
  - * Generations of 1e+08 n per experimental energy in bias cone around FND

Model started by A. Bahadori (SRAG)







2.a.2 ‘Time-connect’ Neutron Energy Deposits from MCNP-PoliMi

- Output of PoliMi: ASCII file containing interactions of neutrons and photons with target material:

```
                            Interaction
                    Particle Number                                                                          Code
                                                 Energy Deposited [MeV]               Z-Coord.
         History   Particle Type   ZAID    Cell                          X-Coord.                  Generation Nr  Energy Prior to Collision [MeV]
                                                           Time [Shakes]        Y-Coord.       Weight      Number of Scatters
H-scatter 2805   1  1  -99  1001    10  3.589902      8.08   2.05  -1.30  -3.78  1.000E+00  0   0   0   4.958E+00
          2805   1  1  -99  1001    10  1.112997      8.28   0.39   0.26  -1.68  1.000E+00  0   1   0   1.368E+00
          2805   1  1  -99  1001    10  0.003554      8.79   2.27   2.43   0.51  1.000E+00  0   2   0   2.549E-01
          2805   1  1  -99  1001    10  0.181367      8.82   2.39   2.53   0.64  1.000E+00  0   3   0   2.514E-01
          2805   1  1  -99  6000    10  0.004136      8.82   2.39   2.53   0.65  1.000E+00  0   4   0   7.007E-02
B10       2805   1  1  -99  1001    10  0.043889      9.05   2.41   1.76   0.89  1.000E+00  0   5   0   6.590E-02
Capture!  2805   1  1    0  5010    10  2.789669     24.20  -0.40   2.31   2.63  1.000E+00  0  14   0   1.375E-04
Capture   2805   2  2    1     6    10  0.099156     24.22  -1.92   0.93  -2.22  1.000E+00  0   0 801   4.776E-01
photon
```

- Limitation in PoliMi: no transport of non-neutron/photon decay products of capture/fission reactions -> manually distribute recoil energy among decay products & convert to light

- To create realistic succession of neutron events in scintillator: ‘time-connect’ PoliMi events to experimental flux (30-310 /s/cm^2):

```
          Particle Type
History          Interaction  ZAID   Energy Deposited [MeV]   Absolute Time [μs]
 15        1     -99     6000     0.3258       200.9430278347747105272
 15        1     -1      6000     1.223006     200.9446278347747067983
 15        1     -99     1001     1.19312      200.9471278347747045245
 20        1     -1      6000     1.153536     249.6897651601931613641
 21        1     -99     6000     2.070328     258.0006369570315882811
 35        1     -99     6000     0.027568     372.9355042009522662738
 ...
 99999932     1     -99     6000     0.009083     943205800.4175952672958
 99999958     1     -99     1001     1.209701     943206036.2944241762161
 99999988     1     -1      6000     0.332827     943206258.0235788822174
 99999988     1     -99     1001     0.772745     943206258.0235788822174
 99999997     1     -99     1001     1.429591     943206423.4481251239777   → ~15 min
```

2.b.1 Convert Energy Deposit to Light- Function Parameterization

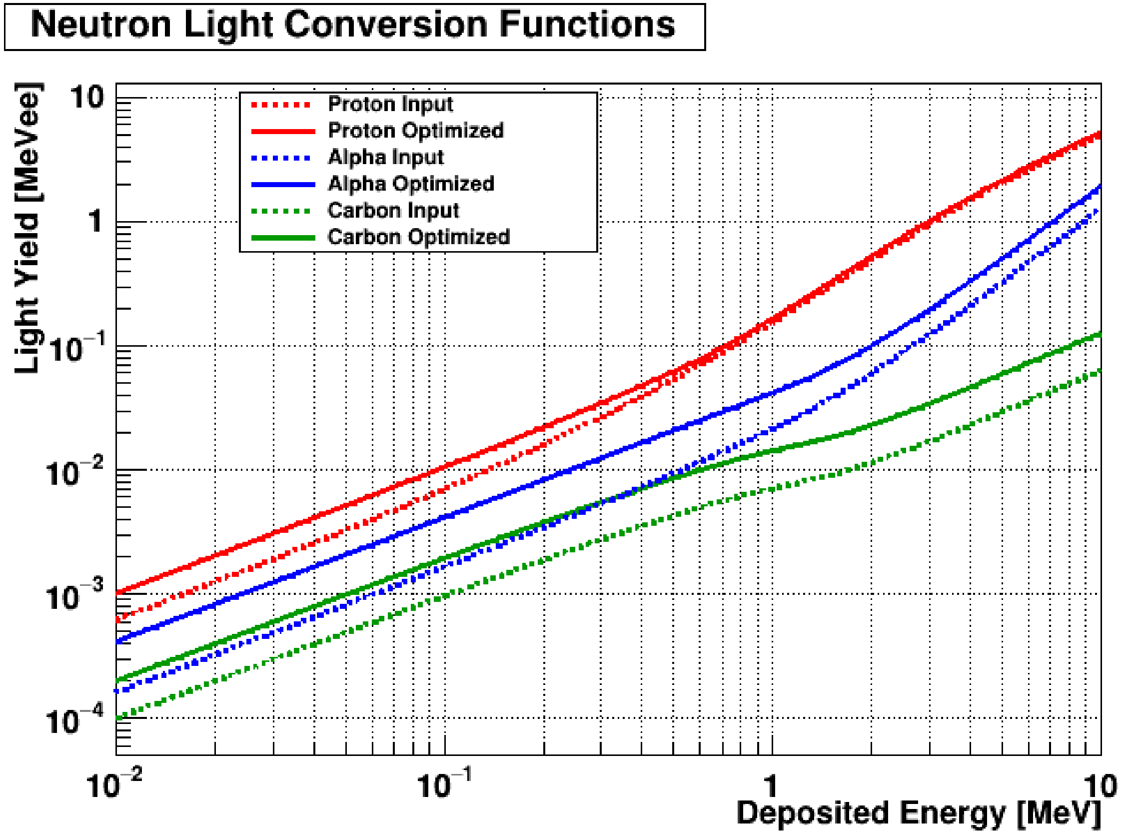
- Fit to Verbinski data parameterized as: 2nd order polynomial at low deposited energy;
  sqrt(const+E^2) at high energy
- Change 5 parameters to optimize match with experimental data

$$L(x_{ED}) = \begin{cases} a x_{ED} + b x_{ED}^2 & \text{for x < g} \\ c + d\sqrt{e^2 + f^2 x_{ED}^2} & \text{for x >= g, where} \end{cases}$$

$$a = \frac{df^2 g}{\sqrt{e^2 + f^2 g^2}} - 2bg$$

$$c = ag + bg^2 - d\sqrt{e^2 + f^2 g^2}$$

Continuity requirements for 1st and 2nd derivative

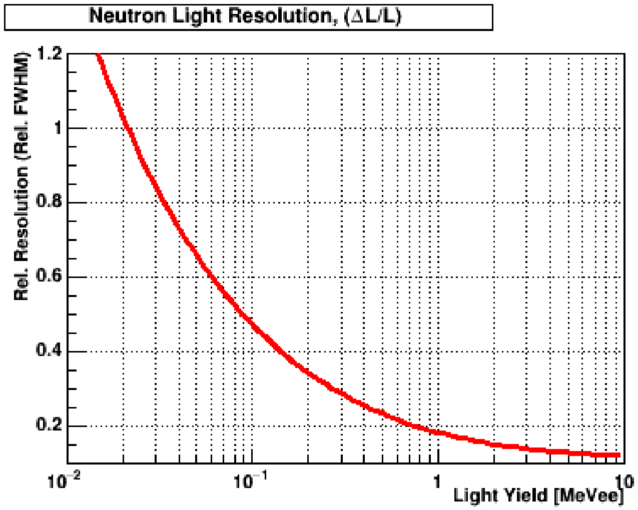


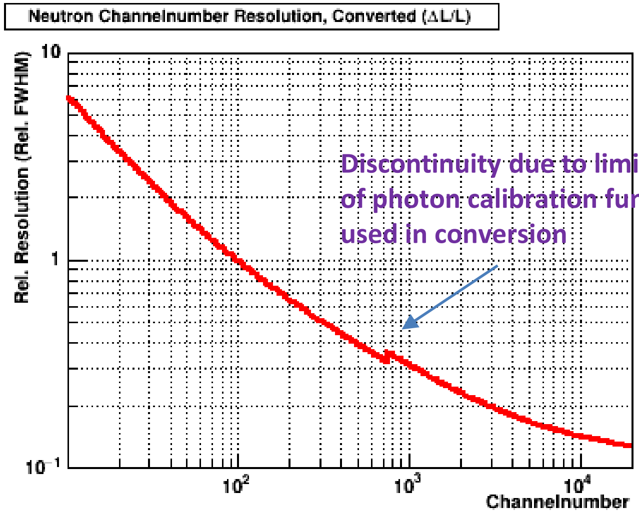
2.b.2 Apply Resolution- Implementation

- Single-point implementation of all experimental resolution contributions:
    - * light production/quenching/reflections in plastic,
    - * light coupling scintillator to PMT
    - * PMT photon detection
    - * electronic noise (PMT/amplifier) etc
- Optimize 3 parameters to match experimental data

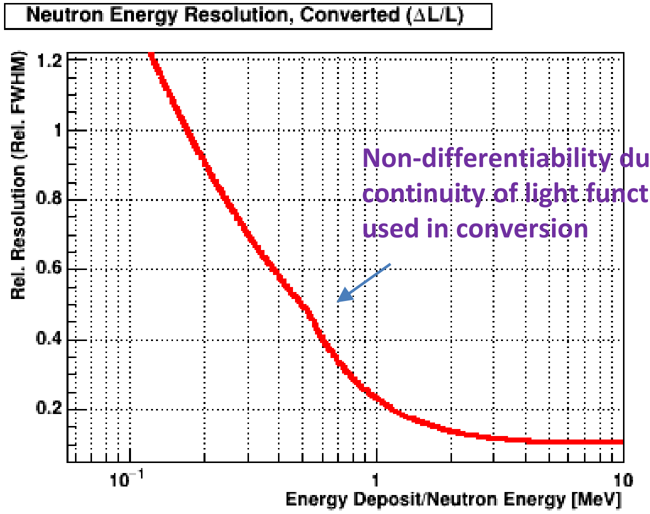
ΔL / L (rel. FWHM):

$$\frac{\Delta L}{L} = \left(\alpha^2 + \frac{\beta^2}{L} + \frac{\gamma^2}{L^2}\right)^{1/2}.$$


Neutron Light Resolution, (ΔL/L)


Neutron Channelnumber Resolution, Converted (ΔL/L)

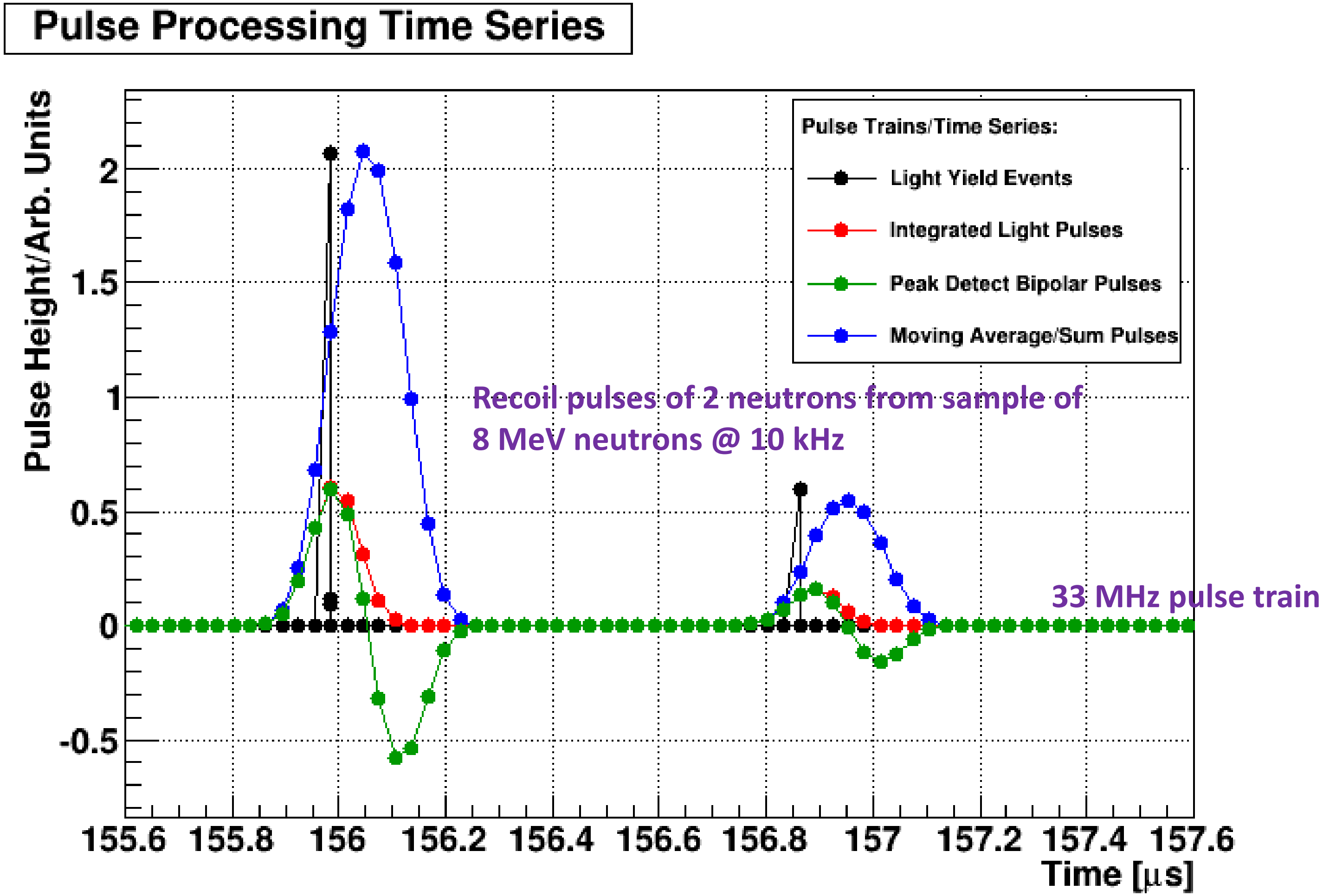
Discontinuity due to limited continuity of of photon calibration function (1st order) used in conversion


Neutron Energy Resolution, Converted (ΔL/L)

Non-differentiability due to limited continuity of light function (2nd order) used in conversion

2.b.3 Light Collection/Pulse Digitization (see Michael V.'s talk)

- Convert light yields to corresponding **electronics signal pulses** via Gaussian function sampled by 33 MHz clock; area normalized to light yield
- Two filters create **bipolar signals** for peak detection and '**moving average (sum)**' for signal height
- Time width of Gaussian chosen to match experimental signal processing pulse width (full width ~390 ns)

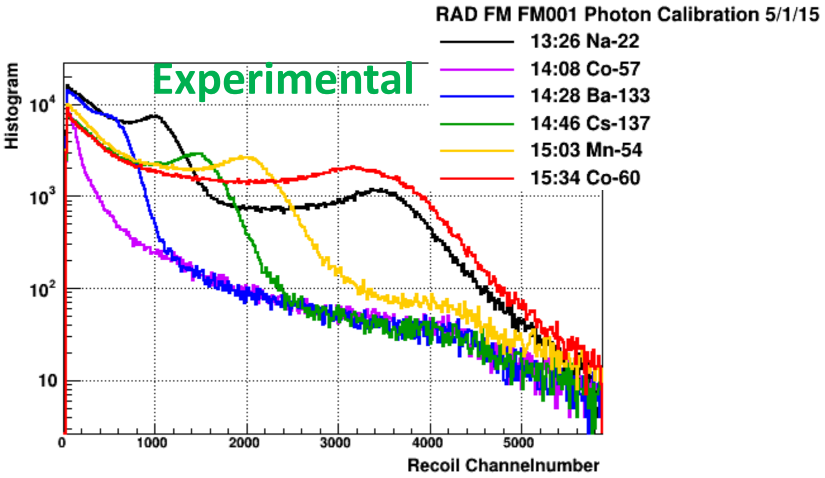


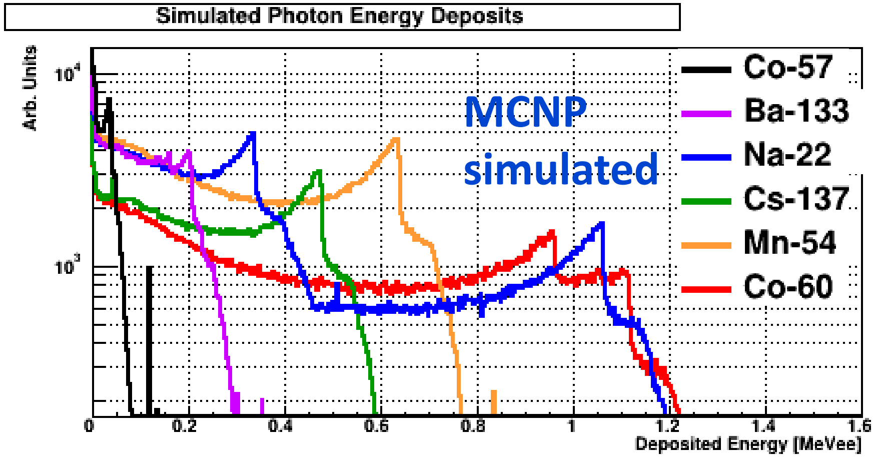
Recoil pulses of 2 neutrons from sample of 8 MeV neutrons @ 10 kHz

33 MHz pulse train

2.b.4 Light to Channelnumber Conversion: Photon Calibration

- Inputs: experimental photon source and MCNP-simulated energy deposit spectra
- Perform global fit of conversion function parameters: create channelnumber spectra from generated deposited energy spectra





experimental

$$N_{\text{Exp. Gamma}}(x_{CHN}) = N_{\text{Exp. Bg}}(x_{CHN}) + \int R(x_{CHN}, x_{ED})\, N_{\text{Sim. MC}}(x_{ED})\, dx_{ED}$$

$$R(x_{CHN}, x_{ED}) = e^{-\frac{(ED(x_{CHN}) - x_{ED})^2}{2\sigma^2}}$$

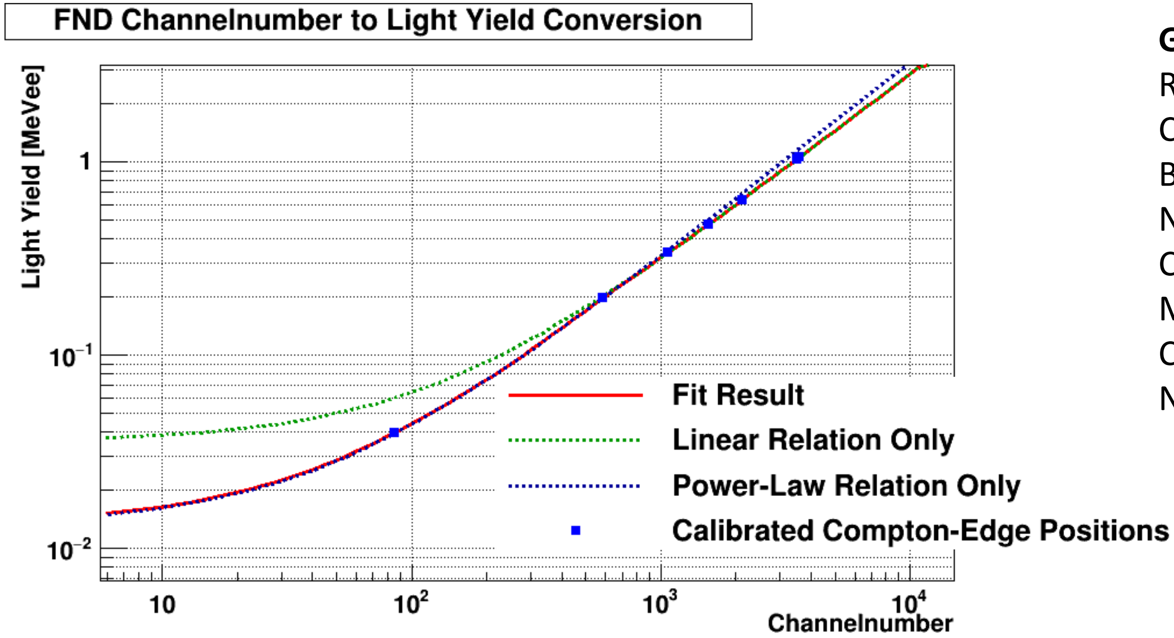
Channelnumber-to-light yield conversion:

$$ED(x_{CHN}) = \begin{cases} a + b x_{CHN}^{c} & \text{for x < e} \\ d + b x_{CHN} & \text{for x >= e, where } d = a + be^{c} - be \end{cases}$$

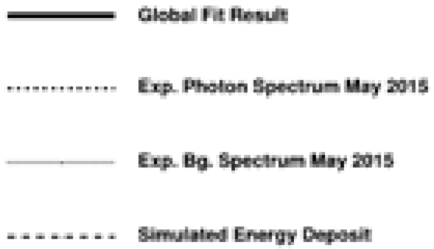
Continuity requirement

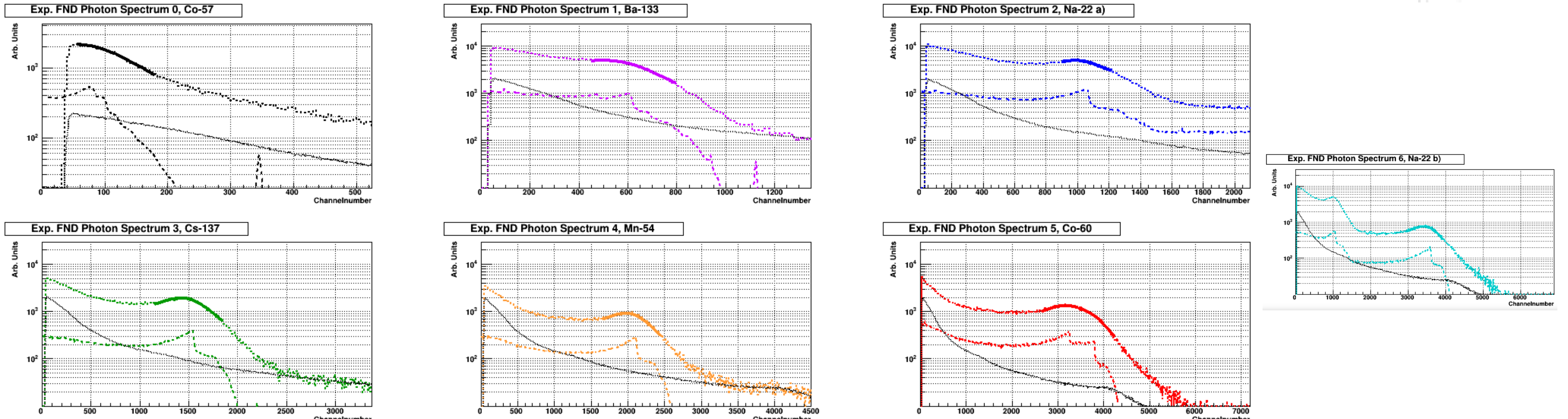
2.b.4 Light to Channelnumber Conversion: Photon Calibration

- Result: Low light yield region prefers nonlinear (power law) shape (also seen in other literature):



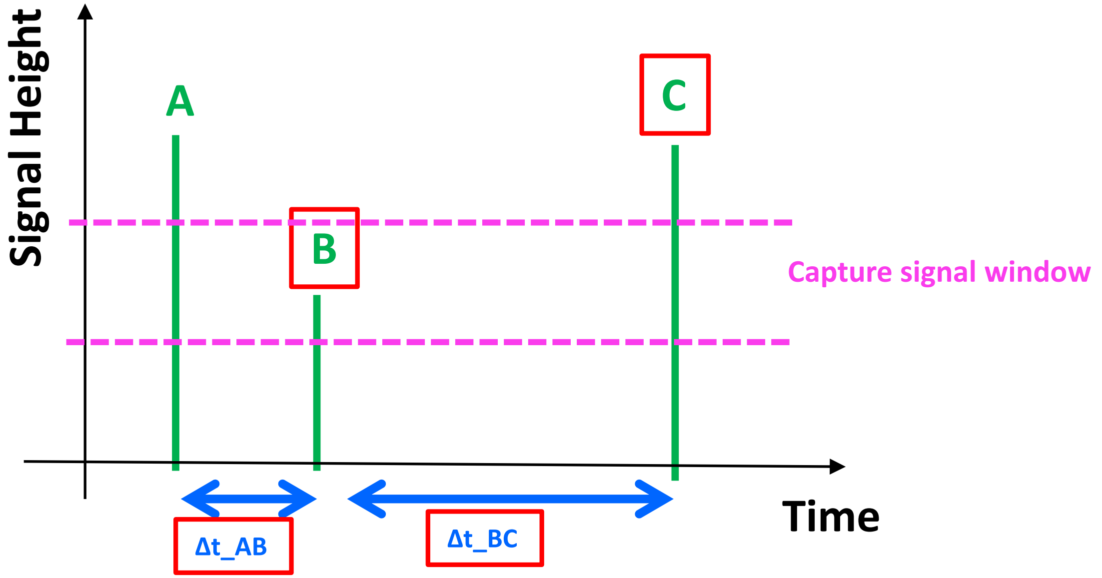
Global red. chisq. = 695 / 490 = 1.42
Red. chisq. for single plots:
Co-57: 27/31 = 0.86
Ba-133: 63 / 35 = 1.80
Na-22 a): 53 / 32 = 1.67
Cs-137: 108 / 70 = 1.54
Mn-54: 69 / 80 = 0.86
Co-60: 211 / 160 = 1.32
Na-22 b): 164 / 100 = 1.64





2.b.5 FND Pulse Pair Selection (see Michael V.'s talk)

- Apply same selection as FND FPGA
- Algorithm considers three latest detected pulse amplitudes (moving averages) and time intervals between them (zero crossing of bipolar signal)



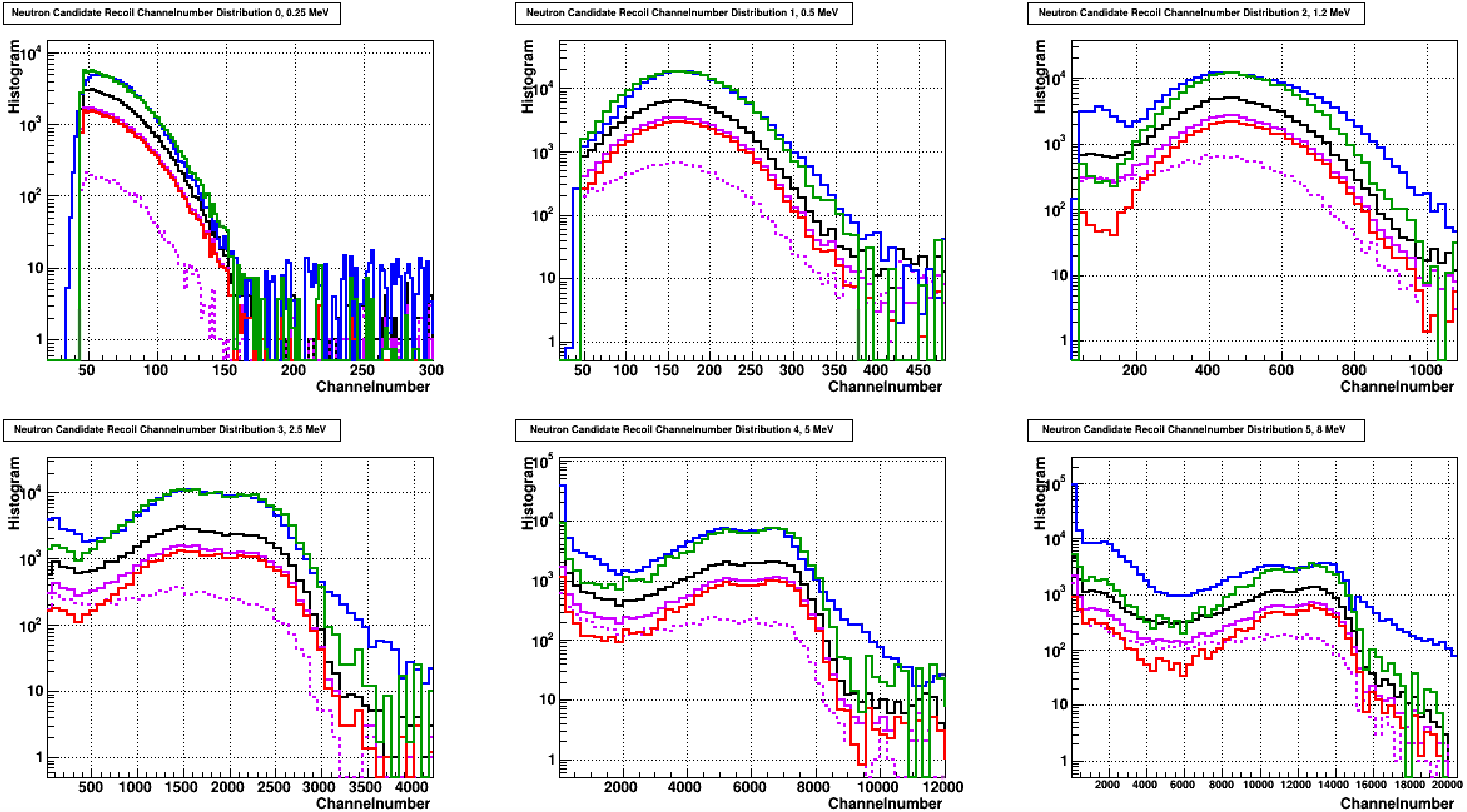
- **Pulse selection logics**: accept A, B as pulse pair:

I) SH_B in capture signal window &&
II) Δt_AB in capture time window &&
III) Δ t_AB < Δ t_BC ||
(SH_C outside of capture signal window || Δ t_BC outside of capture time window)

2. Preliminary Calibration Results- Recoil Spectra Match

- Deviations for low channelnumbers at mid to high energies: further analysis to be done to identify missing process/incorrect treatment of neutron interactions; resolution to be adjusted as well

— **Simulated Selected Recoil Pulses**
— **Sim. Sel. Recoil Pulses, $\Delta t_{Capt.}$ in [1;5) μs**
┄ **Sim. Sel. Recoil Pulses, $\Delta t_{Capt.}$ in [5;10) μs**
— **Sim. Final Background-Subtracted**
━ **Sim. Fit Result to Exp.**
— **Exp. PTB 15, Bg.-Sub.**

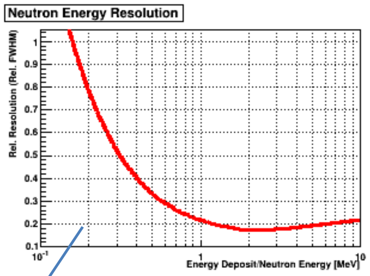


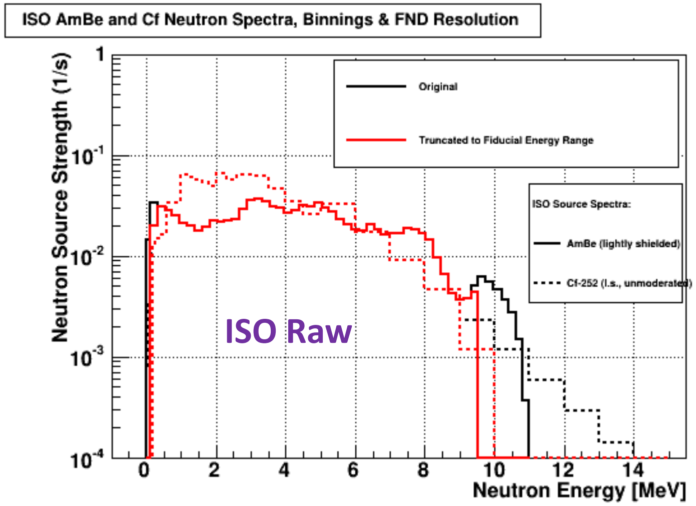
B: Isotropic Source Term Correction

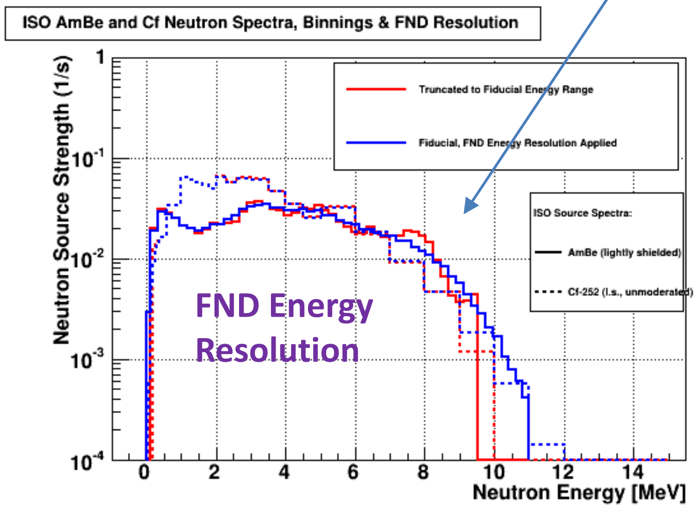
B: Offline Light Spectrum Extraction Study

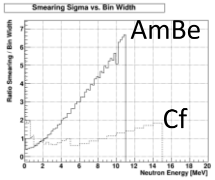
2c) Direct Mapping/Conversion Spectral Match Test

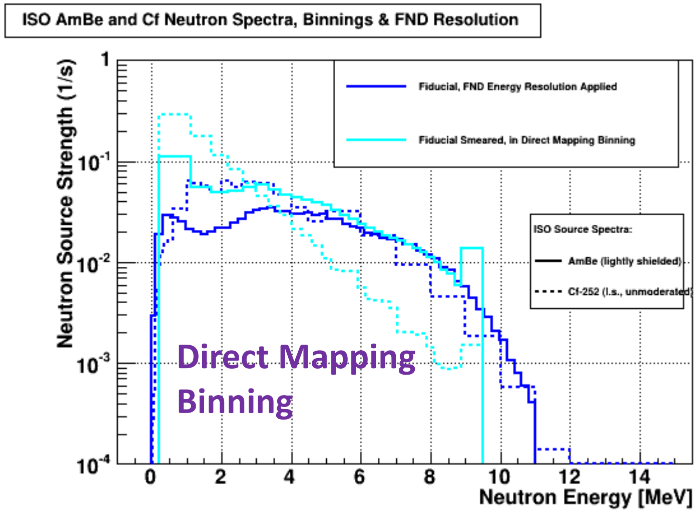
- Created ‘truth’ distributions from ISO for AmBe and Cf sources:
  apply detector resolution, direct mapping binning and energy range selection (0.5-8 MeV)
  * Cf ISO binning mostly too wide for smearing to have effect;

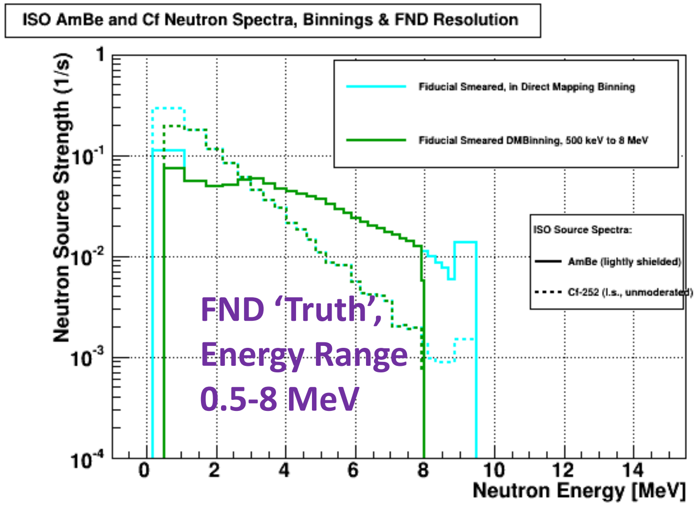










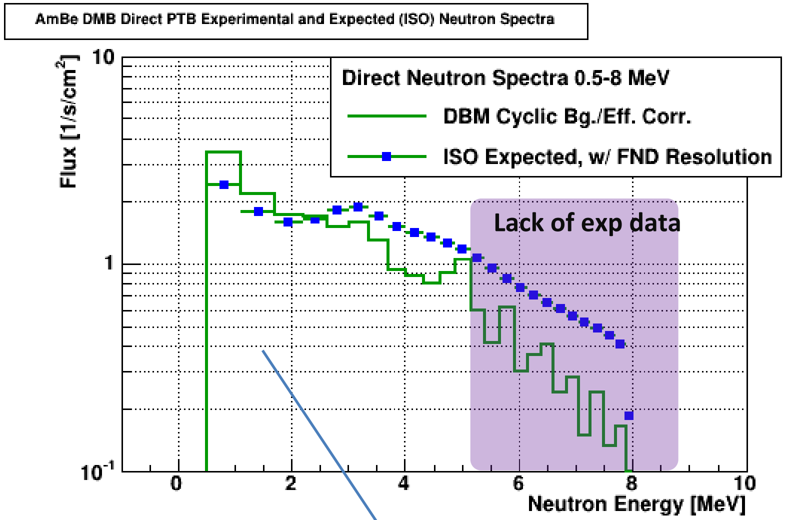


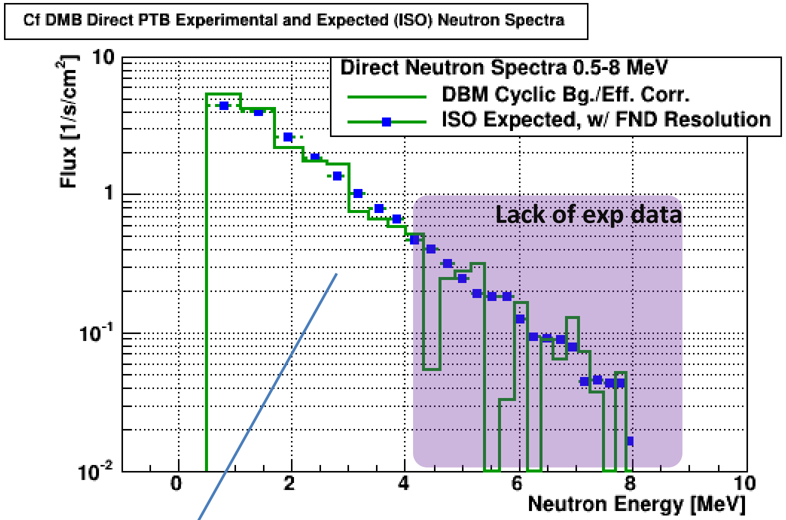
2c) Direct Mapping/Conversion Spectral Match Test

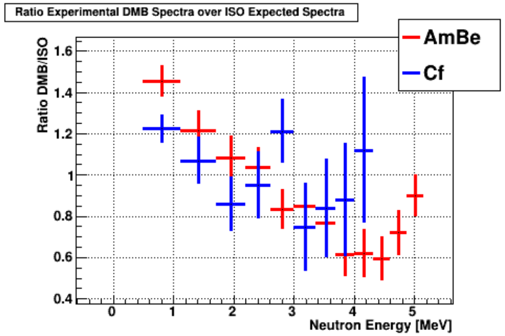
- Scale ‘truth’ histograms with PTB reported (adjusted) neutron flux
- Comparison with GAS analysis results statistics-limited to <~ 5 MeV (only spotty shadow cone and background subtraction data at higher chn bins):

@ Expected: Low energy spectrum overestimated, medium/high energy spectrum underestimated
@ AmBe spectrum shows structure in ISO-truth, not reflected in DBM spectrum: deviations +45% to -41%;
@ Cf spectrum closer (statistics limited): overestimate at low bins ~22%, medium energy bins large uncertainties, in part consistent;

- Conclusion: Direct Mapping/Conversion analysis method by design shows limitations in reproducing neutron energy spectra.


AmBe DMB Direct PTB Experimental and Expected (ISO) Neutron Spectra

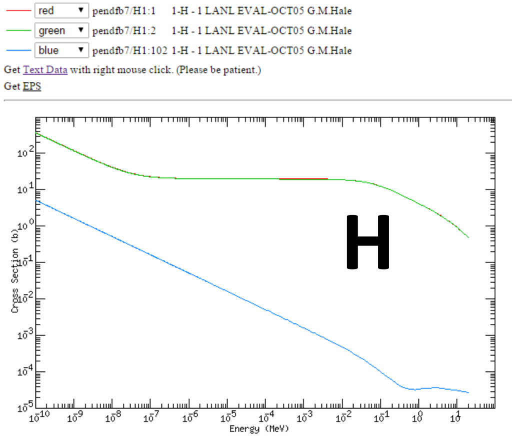

Cf DMB Direct PTB Experimental and Expected (ISO) Neutron Spectra


Ratio Experimental DMB Spectra over ISO Expected Spectra

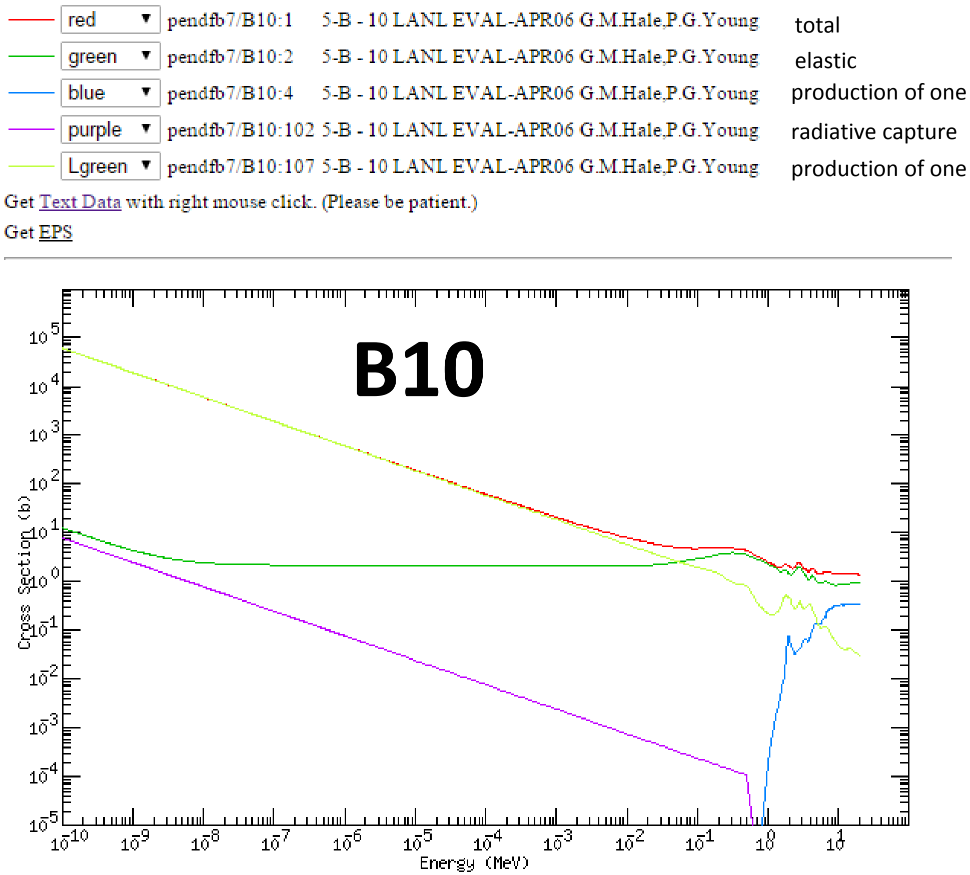
B: MCNP Neutron Cross Sections

4.1a Simulation of Neutron Energy Deposits: MCNP-PoliMi

- for all materials use ENDF-VII library at 300 K, assembled in 2005; max energy 20 MeV, 500-3500 energies depending on material



red ▼ pendfb7/H1:1 1-H - 1 LANL EVAL-OCT05 G.M.Hale
green ▼ pendfb7/H1:2 1-H - 1 LANL EVAL-OCT05 G.M.Hale
blue ▼ pendfb7/H1:102 1-H - 1 LANL EVAL-OCT05 G.M.Hale
Get Text Data with right mouse click. (Please be patient.)
Get EPS

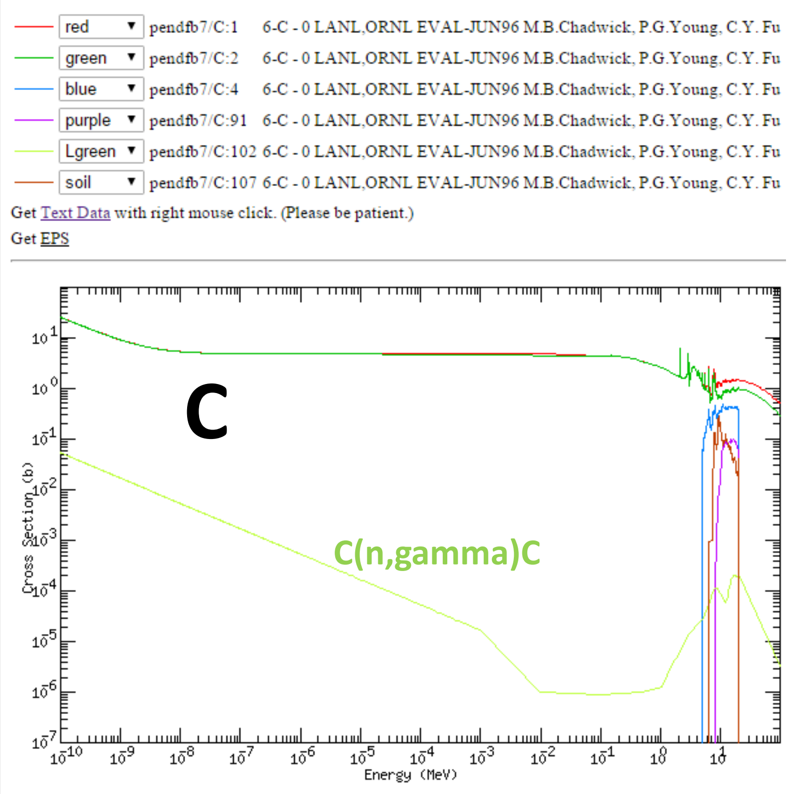


red ▼	pendfb7/B10:1	5-B - 10 LANL EVAL-APR06 G.M.Hale,P.G.Young	total
green ▼	pendfb7/B10:2	5-B - 10 LANL EVAL-APR06 G.M.Hale,P.G.Young	elastic
blue ▼	pendfb7/B10:4	5-B - 10 LANL EVAL-APR06 G.M.Hale,P.G.Young	production of one n in exit channel
purple ▼	pendfb7/B10:102	5-B - 10 LANL EVAL-APR06 G.M.Hale,P.G.Young	radiative capture
Lgreen ▼	pendfb7/B10:107	5-B - 10 LANL EVAL-APR06 G.M.Hale,P.G.Young	production of one alpha particle + residual

Get Text Data with right mouse click. (Please be patient.)
Get EPS

4.1a Simulation of Neutron Energy Deposits: MCNP-PoliMi

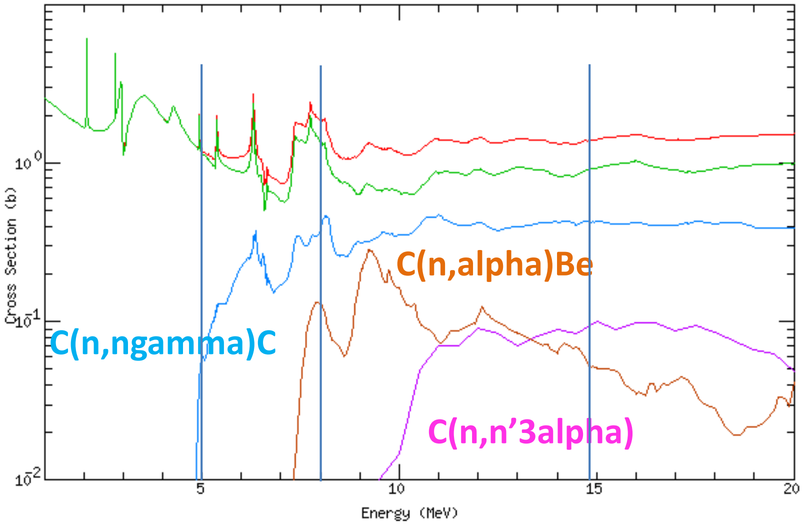
- for all materials use ENDF-VII library at 300 K, assembled in 2005; max energy 20 MeV, 500-3500 energies depending on material



red ▼	pendfb7/C:1	6-C - 0 LANL,ORNL EVAL-JUN96 M.B.Chadwick, P.G.Young, C.Y. Fu	total
green ▼	pendfb7/C:2	6-C - 0 LANL,ORNL EVAL-JUN96 M.B.Chadwick, P.G.Young, C.Y. Fu	elastic
blue ▼	pendfb7/C:4	6-C - 0 LANL,ORNL EVAL-JUN96 M.B.Chadwick, P.G.Young, C.Y. Fu	production of one n in exit channel
purple ▼	pendfb7/C:91	6-C - 0 LANL,ORNL EVAL-JUN96 M.B.Chadwick, P.G.Young, C.Y. Fu	production of one n in continuum not included in separate listings
Lgreen ▼	pendfb7/C:102	6-C - 0 LANL,ORNL EVAL-JUN96 M.B.Chadwick, P.G.Young, C.Y. Fu	radiative capture
soil ▼	pendfb7/C:107	6-C - 0 LANL,ORNL EVAL-JUN96 M.B.Chadwick, P.G.Young, C.Y. Fu	production of one alpha particle + residual

Get Text Data with right mouse click. (Please be patient.)

Get EPS



B: Photon Calibration Nonlinearities

6) Low Energy Nonlinear Light Output in Literature

Literature c)

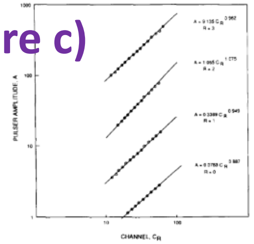
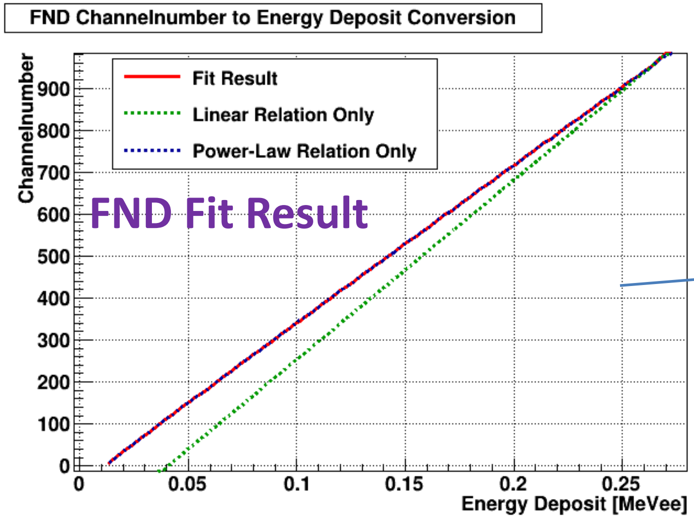


Fig. 4. Pulser calibration data for the rod-1 ADC and the associated gated-integrator assembly of the ABE detector. *R* denotes the range of amplification fed to the 6-bit ADC.

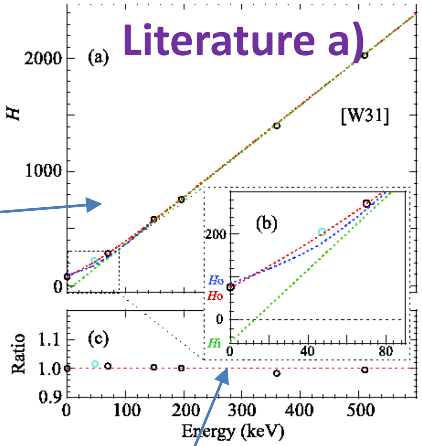
Feldman et al, NIM A 306 (1991) 350 ff

FND Fit Result:
A ~ C^(1.02)

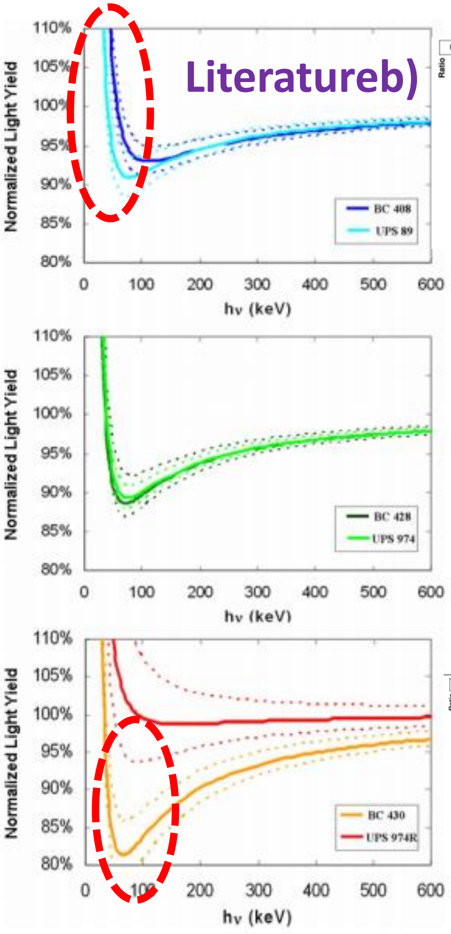
Energy deposit -> Light Yield -> Channelnumber



FND Fit Result

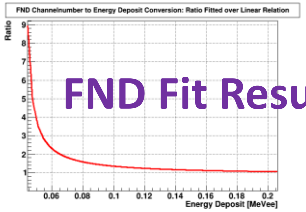


Literature a)



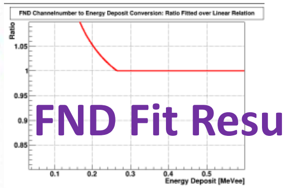
Literatureb)

Fig. 11. Mean light amount for photons for the blue, green, and red scintillators (from top to bottom). The dotted lines represent the experimental uncertainties.



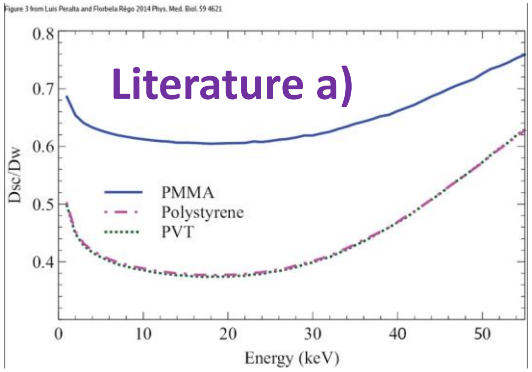
FND Fit Resu

Assumed linear

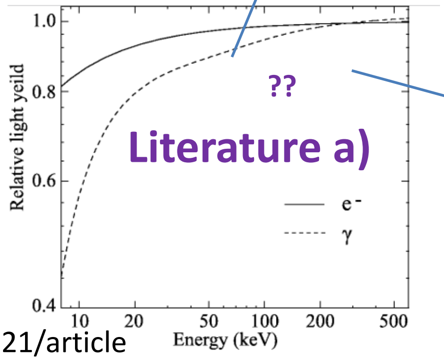


FND Fit Resul

Figure 3 from Luis Peralta and Florbela Rêgo 2014 Phys. Med. Biol. 59 4621



Literature a)



??

Literature a)

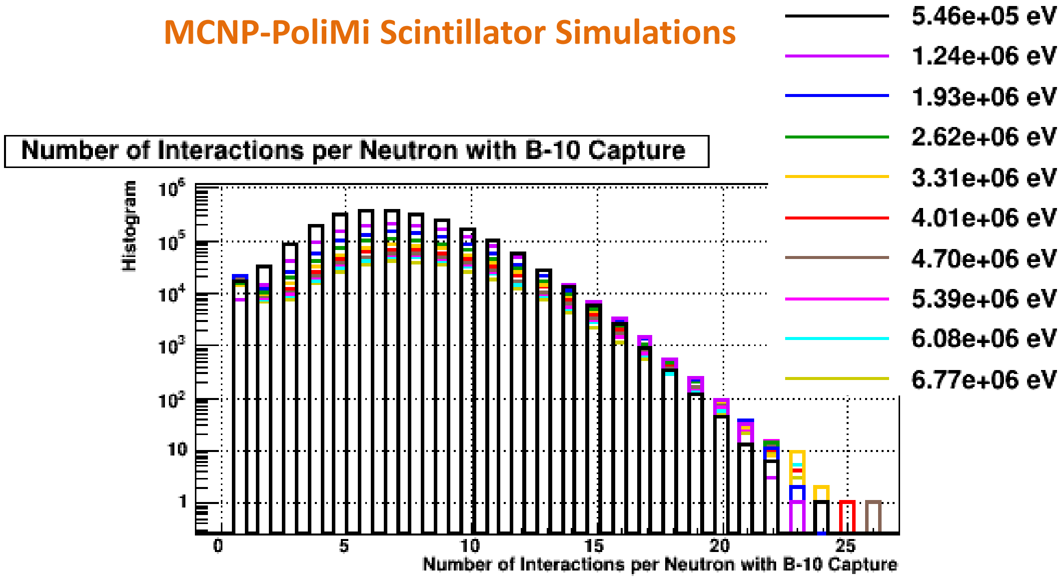
http://iopscience.iop.org/0031-9155/59/16/4621/article

http://pasj.asj.or.jp/v63/sp3/63s303/63s303-frame.html

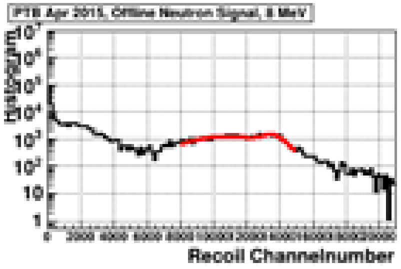
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4696573

4. Scintillation Light Creation/Propagation: Light Function Formalism

MCNP-PoliMi Scintillator Simulations



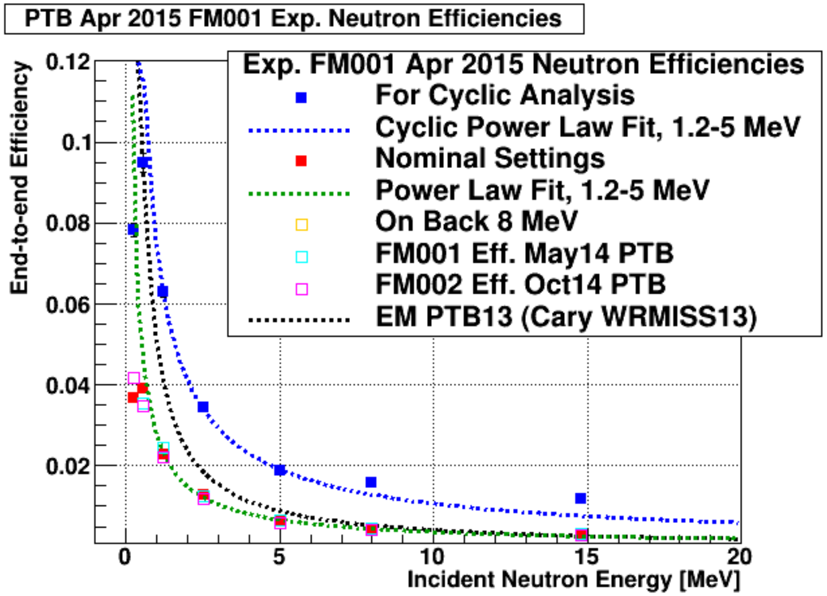
Exp. Recoil of 8 MeV Monoenergetic



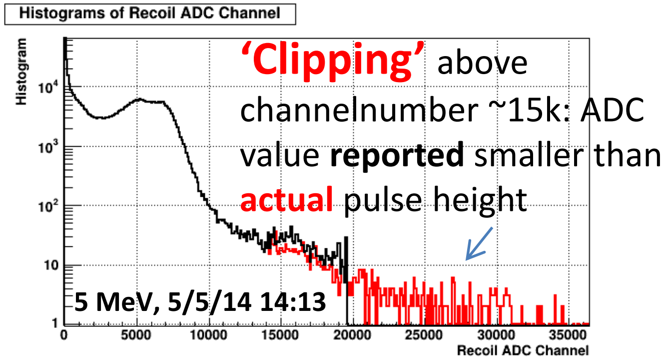
B: Misc Auxiliary Analysis Items

2) Neutron Efficiency Results, ADC Saturation

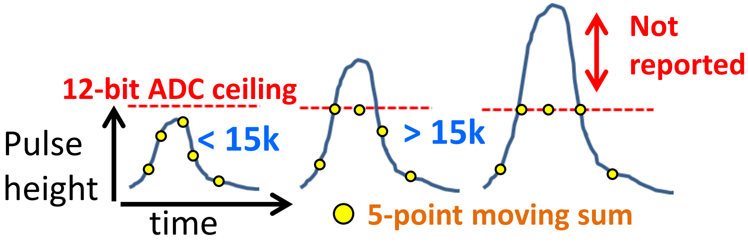
- Efficiencies from PTB datasets: Rel. uncertainties 2-3%;



- ADC saturation for high pulse heights

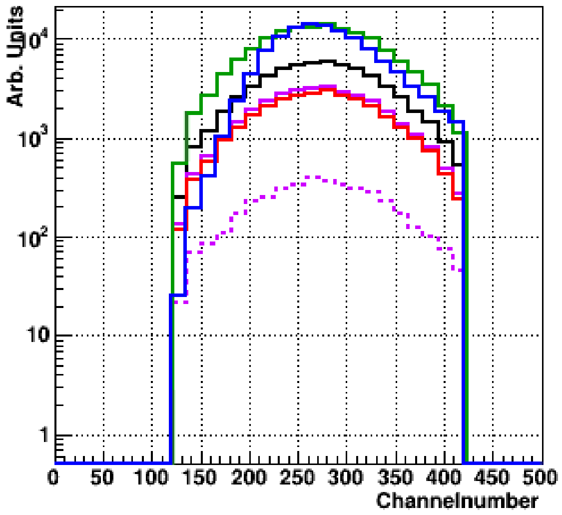


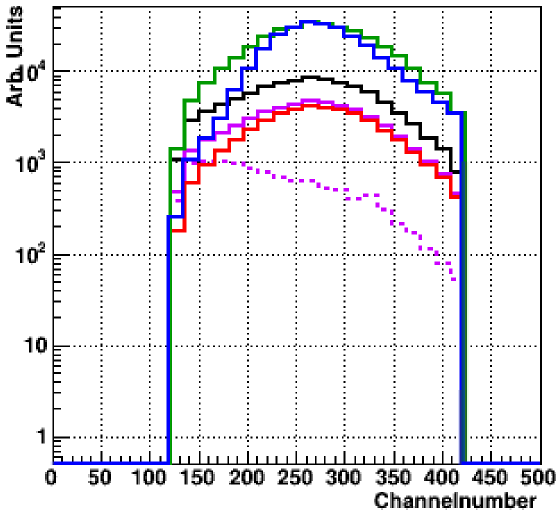
'Clipping' above channelnumber ~15k: ADC value **reported** smaller than **actual** pulse height

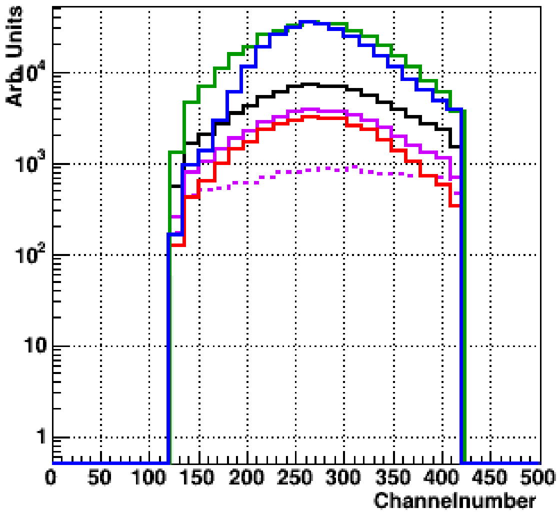


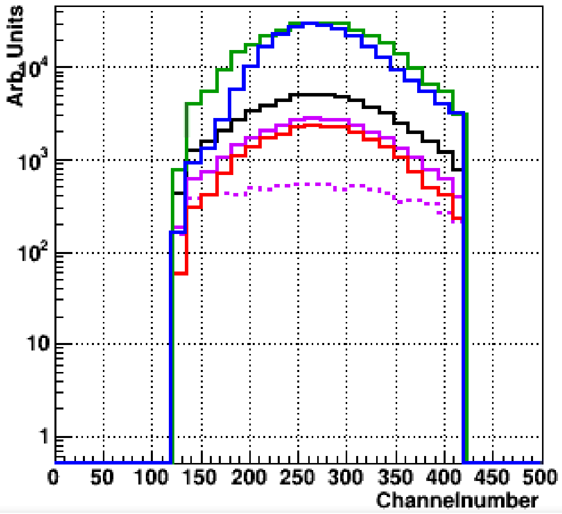
2) Preliminary Fit Result to Capture Pulse Distributions

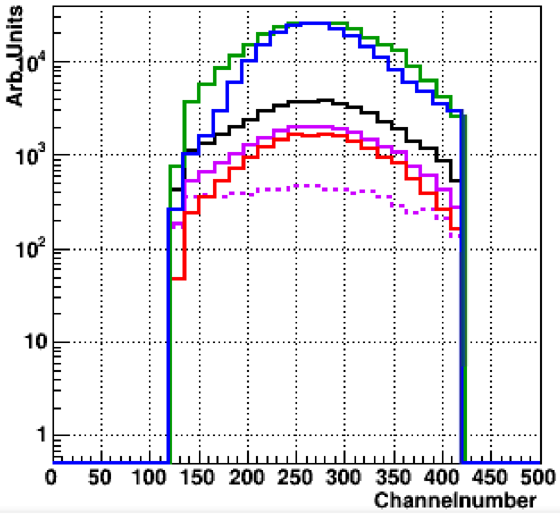
- Experimental data not corrected for beam background/room return

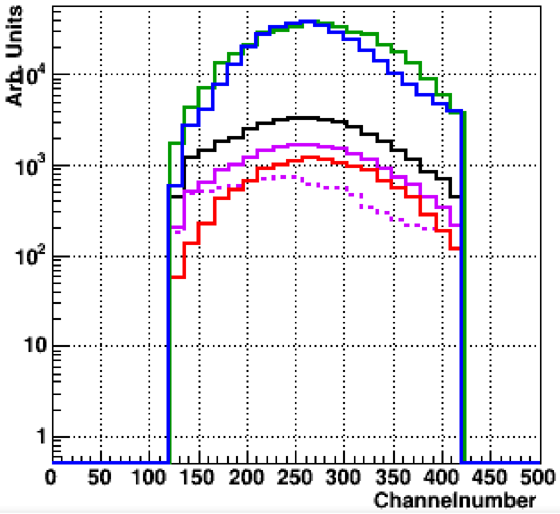

Neutron Candidate Capture Channelnumber Distribution, 0.25 MeV


Neutron Candidate Capture Channelnumber Distribution, 0.5 MeV


Neutron Candidate Capture Channelnumber Distribution, 1.2 MeV

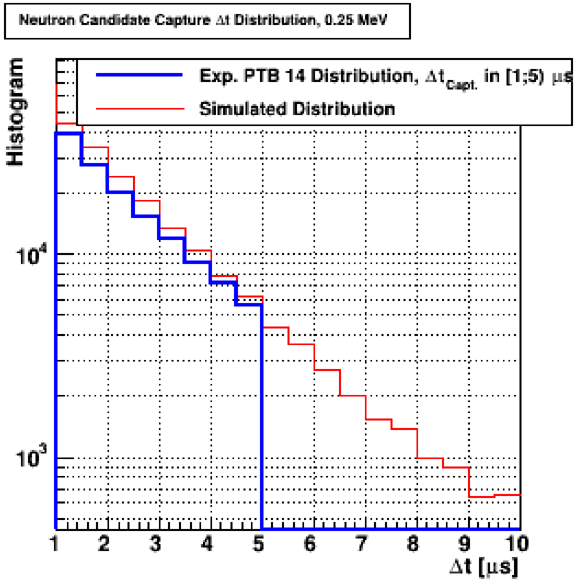

Neutron Candidate Capture Channelnumber Distribution, 2.5 MeV

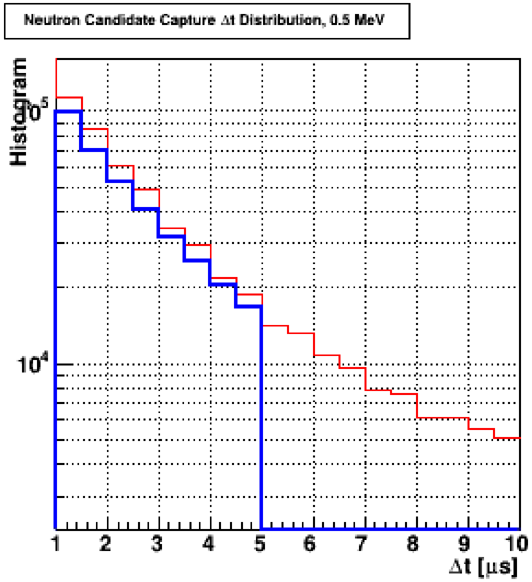

Neutron Candidate Capture Channelnumber Distribution, 5 MeV

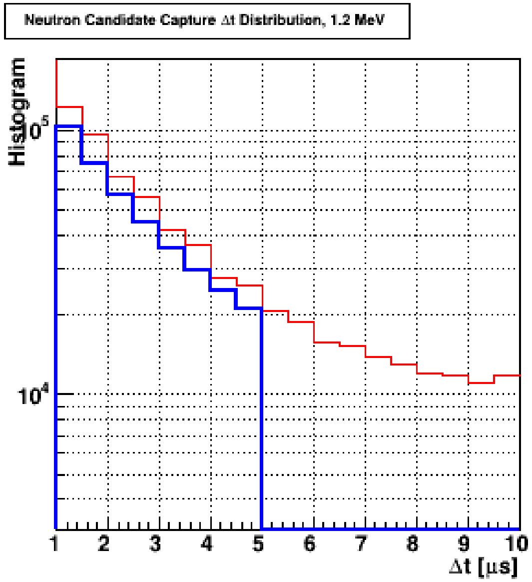

Neutron Candidate Capture Channelnumber Distribution, 8 MeV

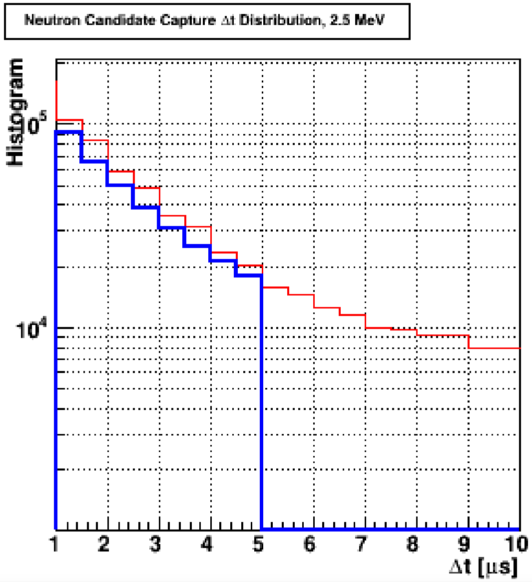
2) Preliminary Simulation Result for Delta t Capture Distribition

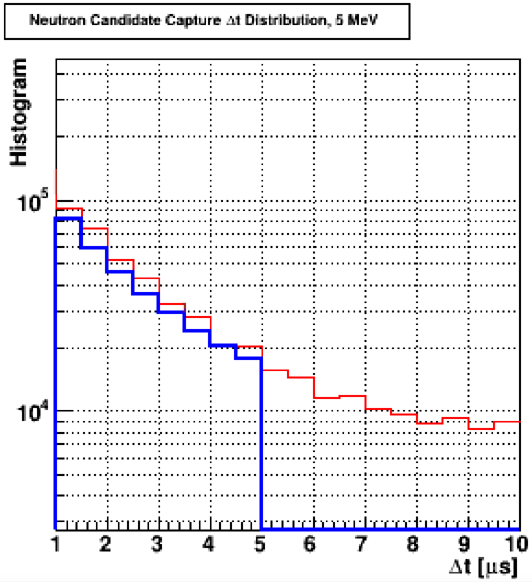
- Experimental data not corrected for beam background/room return

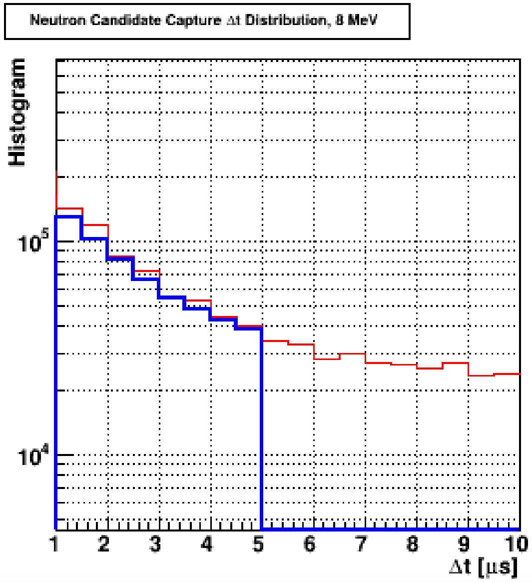












B2) Test: AmBe vs. Distance, Extraction of Absorption Depth

- To be able to approximate FND as point detector

- fit doubles rates with shifted inverse squares:

$$f(d) = [0] + [1] * \frac{1}{(d + [2])}$$

* only fit >=20cm data to avoid geometry issues (point source approximation);

* fit results:

@ [0]: background rate 0.5 +- 0.07 Hz;

@ [2]: **effective absorption depth** of RAD = **7.2 +- 0.5 cm**

* deduce distance from JSC source to expose FND to roughly 50 muSv/hr for reference (neglecting room scattering, probably ~20%):

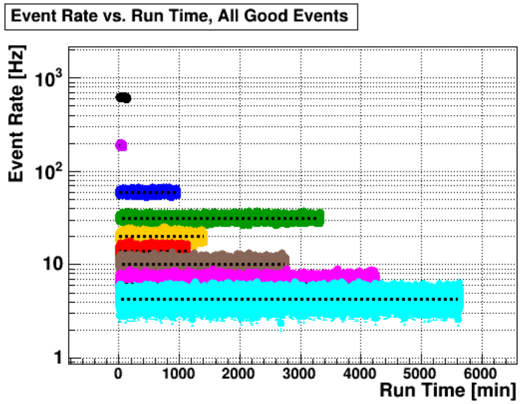
@ JSC calibration 5/21/14: source strength 2.380e+05 Hz;

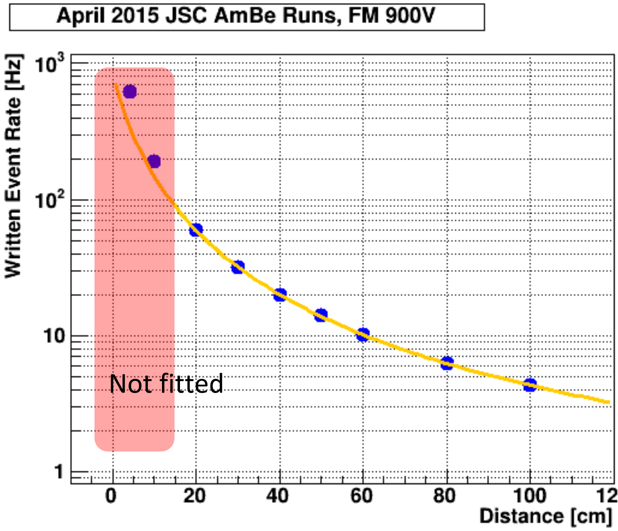
@ with ICRP74 AmBe conversion factor 391 pSv*cm^2 per n:

-> distance from absorption center to source = 23.1 cm;

-> distance from side of FND stack to source = **15.9 cm.**

RAD FM, JSC AmBe vs. Distance
● 4 cm 3/18 14:15 UTC
● 10 cm 4/2 14:45 UTC
● 20 cm 4/1 22:42 UTC
● 30 cm 3/30 14:45 UTC
● 40 cm 3/19 14:29 UTC
● 50 cm 3/18 19:28 UTC
● 60 cm 3/23 14:42 UTC
● 80 cm 3/20 15:18 UTC
● 100 cm 3/26 16:21 UTC





red chisq. of fit = 5.52/4 = 1.38