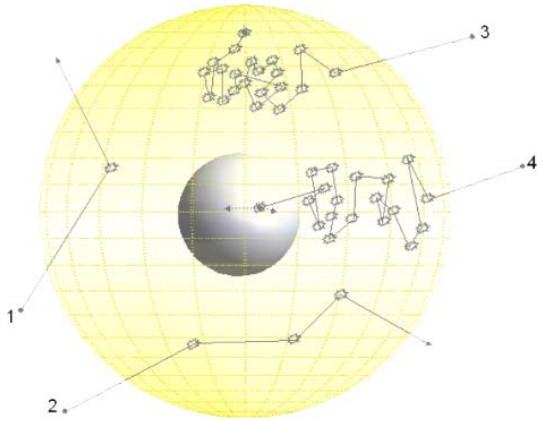
EURADOS comparison exercise on neutron spectra unfolding in Bonner spheres spectrometry (BSS)

Overview of the EURADOS exercise

The Bonner spheres spectrometer (BSS). Unfolding

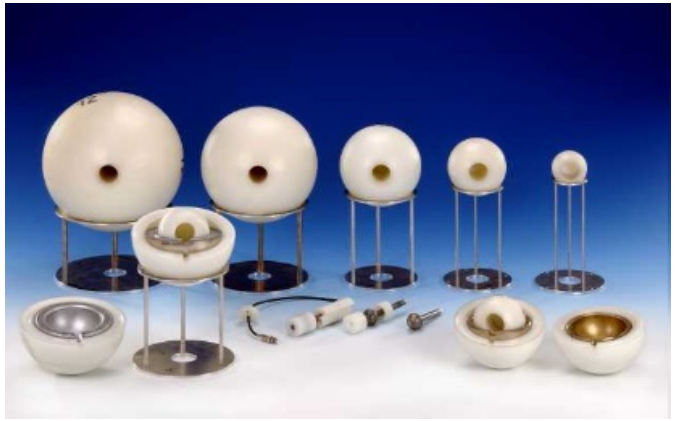


Set of moderating spheres with different radius.
A thermal neutron detector is located in the centre.

For every sphere (i), the fluence response, $R_i(E)$, to monoenergetic neutrons of energy E is:

$$R_i(E) = \frac{M_i}{\Phi_E}$$

M_i : instrument reading
Φ : neutron fluence



For a neutron spectrum with energy distribution of fluence Φ_E:

$$M_i = \int R_i(E)\Phi_E dE$$

For a neutron spectrum with N energy groups, ϕ_j:

$$M_i = \sum_{j=1}^{N} R_{ij}\phi_j$$

unfolding

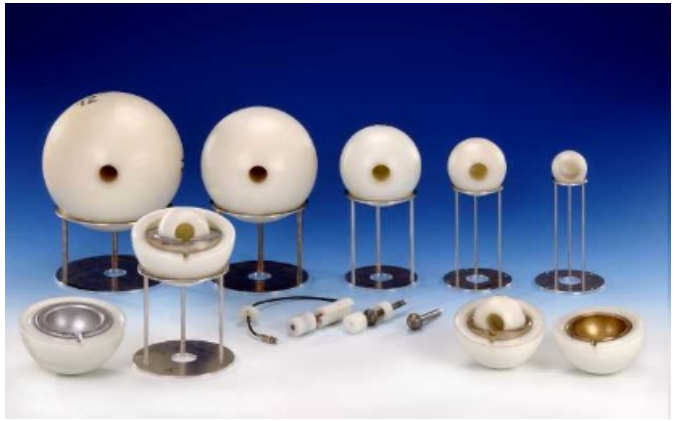
$$M_i \xrightarrow{R_{ij}} \Phi_E$$

- **D.J. Thomas, A.V. Alevra. *Bonner sphere spectrometers: a critical review*. Nucl. Instrum. Meth. A. 476 (2002) 12–20**
- **M. Matzke. *Neutron spectrometry in mixed fields: unfolding procedures*. Radiat. Prot. Dosim. 107 (2003) 37-72**
- **D.J. Thomas. Neutron spectrometry. Radiation Measurements 45 (2010) 1178-1185**

The Bonner spheres spectrometer (BSS). Unfolding

$$M_i = \sum_{j=1}^{N} R_{ij}\phi_j$$

number of spheres (number of equations) < number of energy groups (number of variables)



underdetermined problem
(infinite mathematically possible solutions)

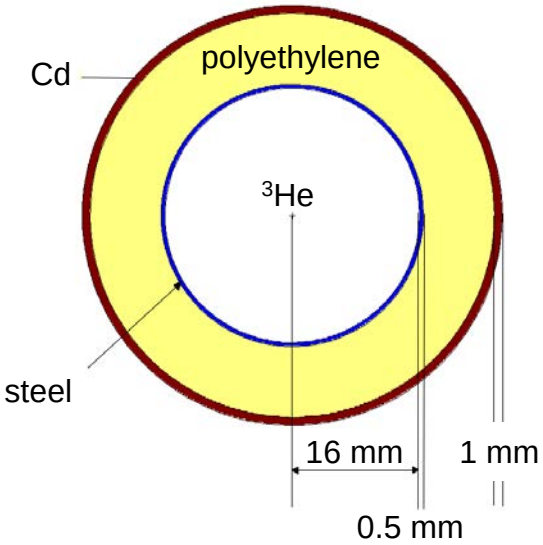
Spectrum is modelled as a function of (physically meaningful) parameters → initial guess values needed

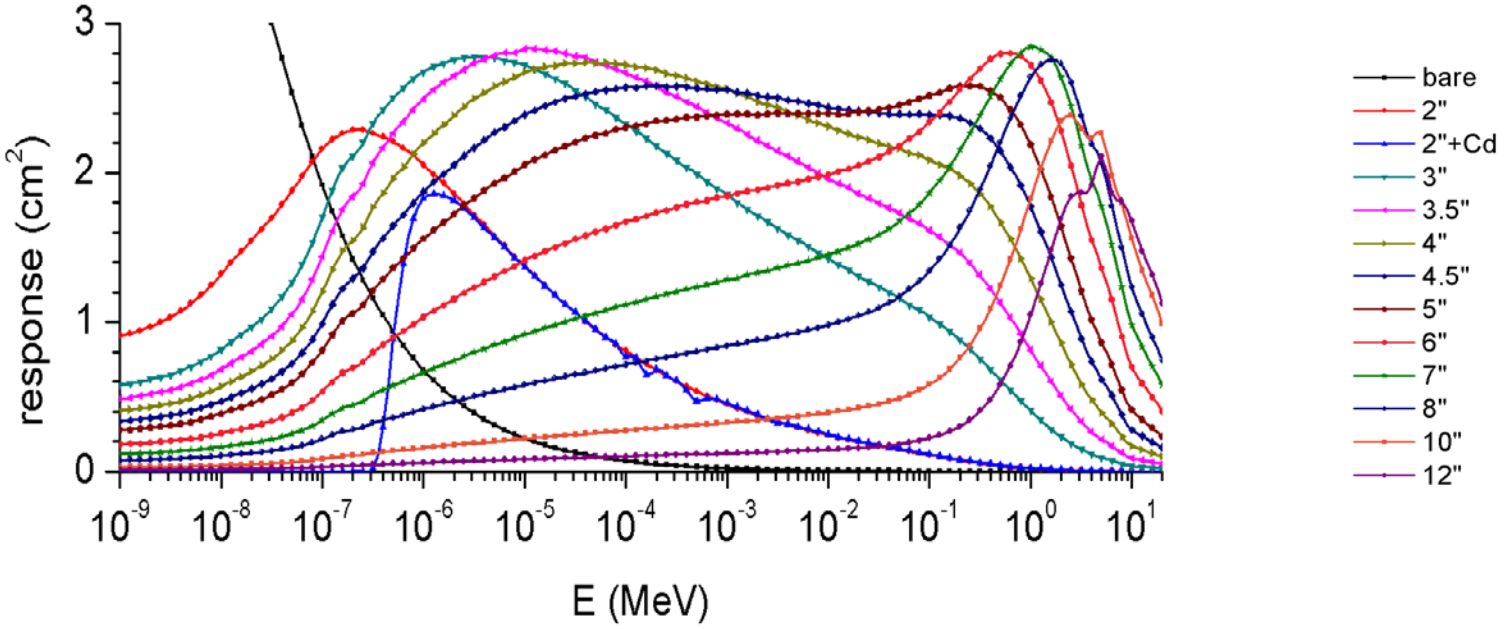
Spectrum is modelled as N_G energy groups ($N_G > N$) → guess spectrum needed

- **D.J. Thomas, A.V. Alevra. *Bonner sphere spectrometers: a critical review*. Nucl. Instrum. Meth. A. 476 (2002) 12–20**
- **M. Matzke. *Neutron spectrometry in mixed fields: unfolding procedures*. Radiat. Prot. Dosim. 107 (2003) 37-72**
- **D.J. Thomas. Neutron spectrometry. Radiation Measurements 45 (2010) 1178-1185**

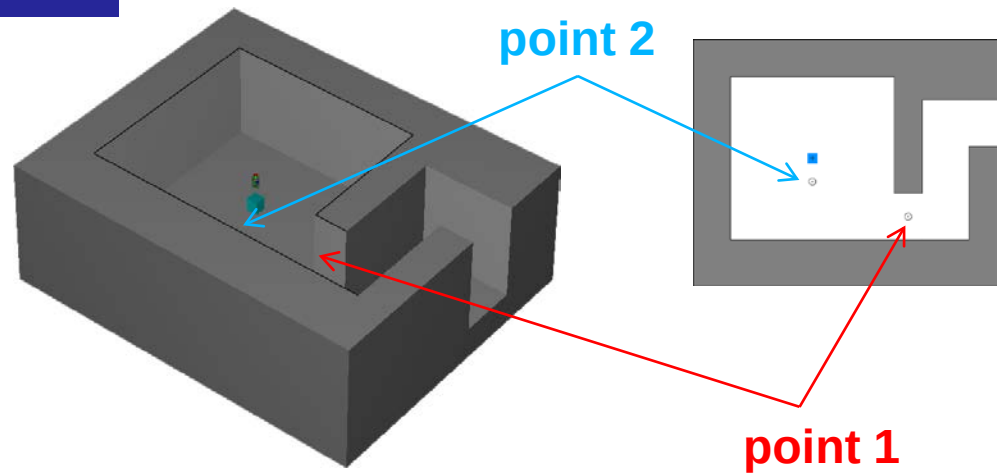
Proposed problem: BSS Response matrix

- **Detector**: Ø32 mm ^{3}He sphere + 0.5 mm steel case
- **Spheres set:** bare, 2”, 2”+1 mm Cd, 3”, 3.5”, 4”, 4.5”, 5”, 6”, 7”, 8”, 10”, 12”
- **Response:** number of ^{3}He(n,p)^{3}H





LINAC

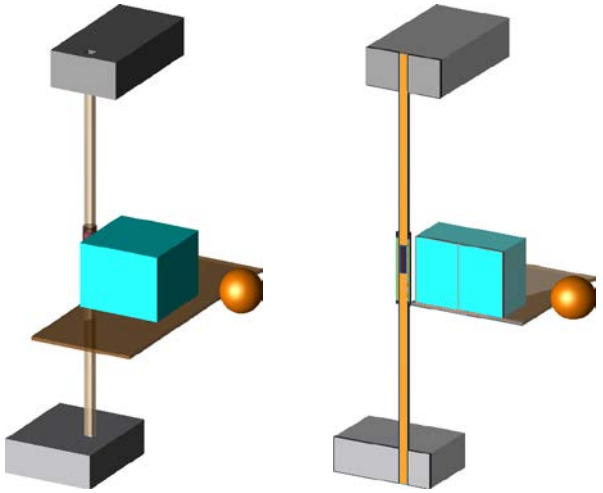


GE Saturne 43, 25 MV

Workplace field

Am-Be source suspended in a stainless steel tube

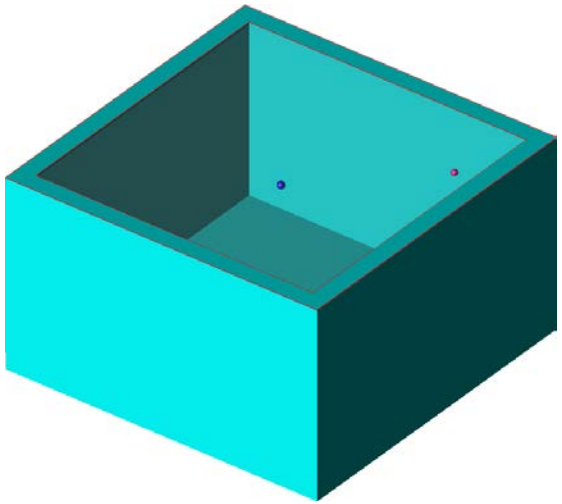
Measurement point: behind a water filled container



Irradiation room

Am-Be source in the centre of an iron sphere

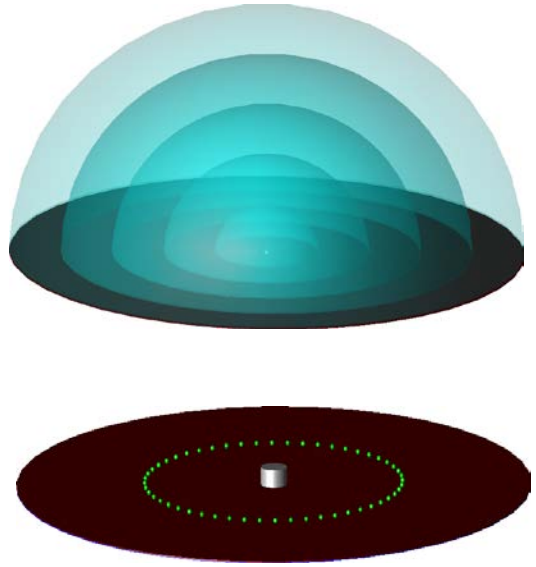
Measurement point: 4 m distance along one diagonal



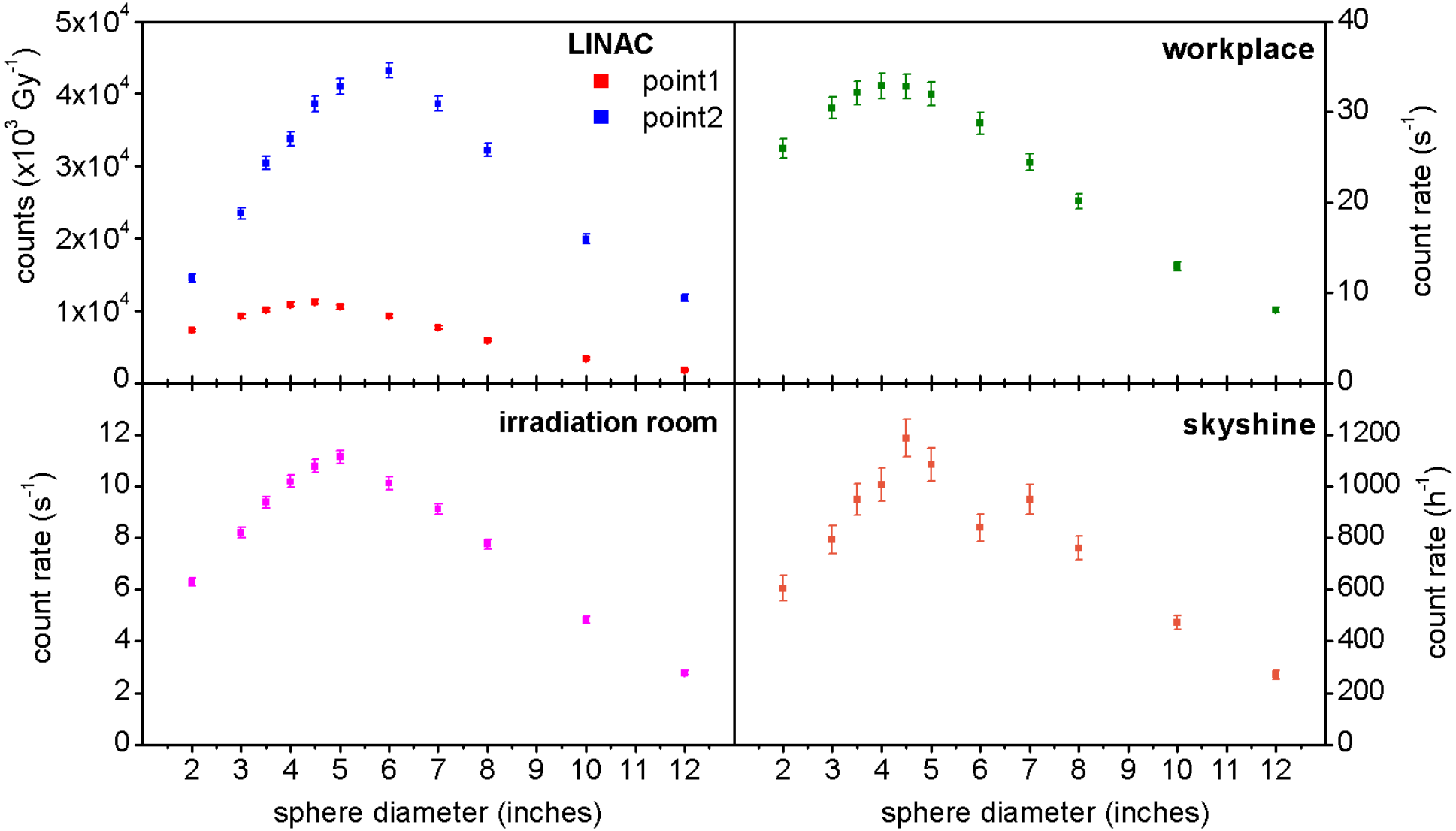
Skyskhine

(α, n) neutrons in the middle of a cylindrical room, H=10 m, R=10 m

Measurement point: 100 m distance, 1.5 m above the ground



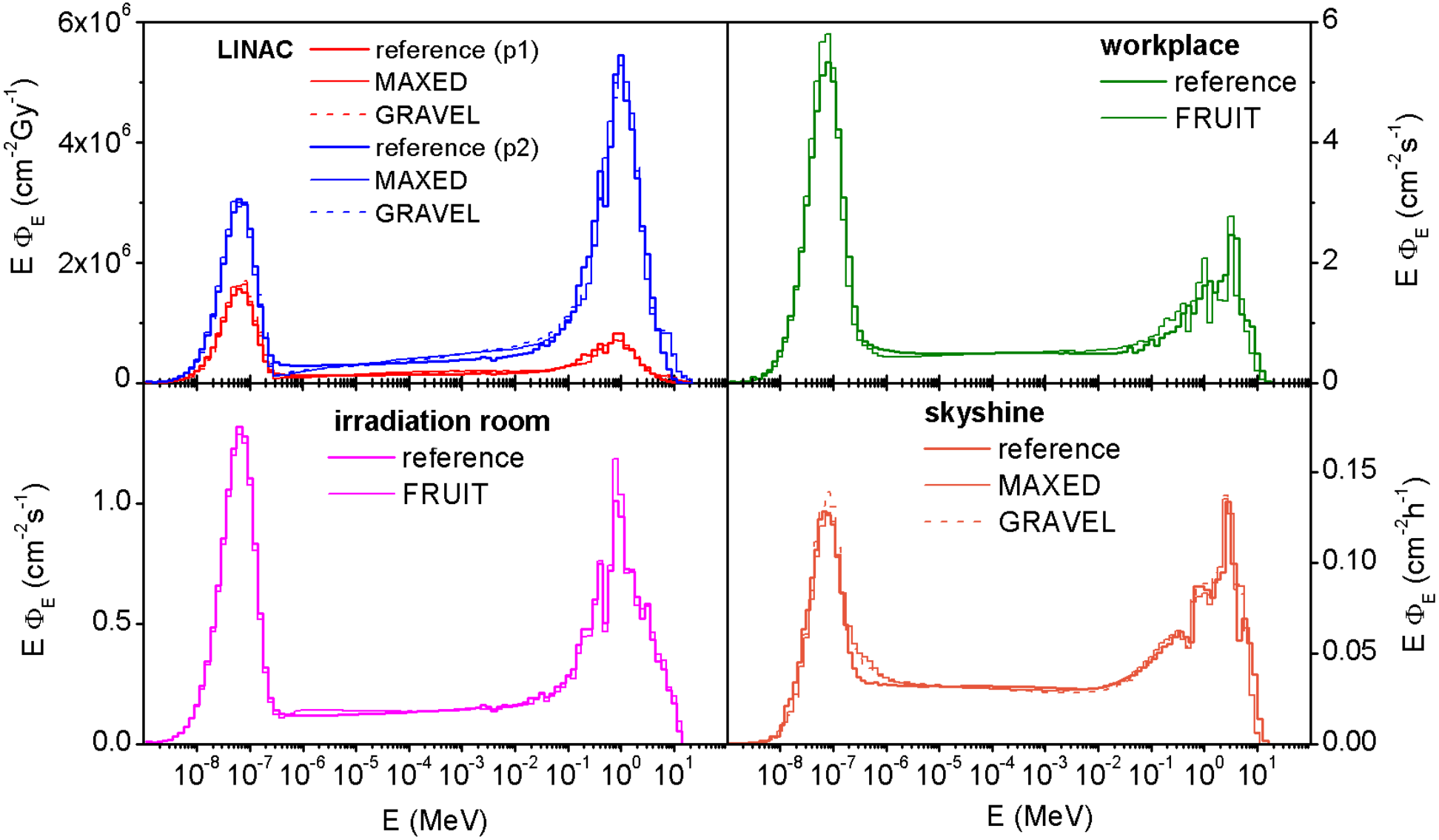
Proposed problem: BSS counts



Directly calculated [number of ^{3}He(n,p)^{3}H];

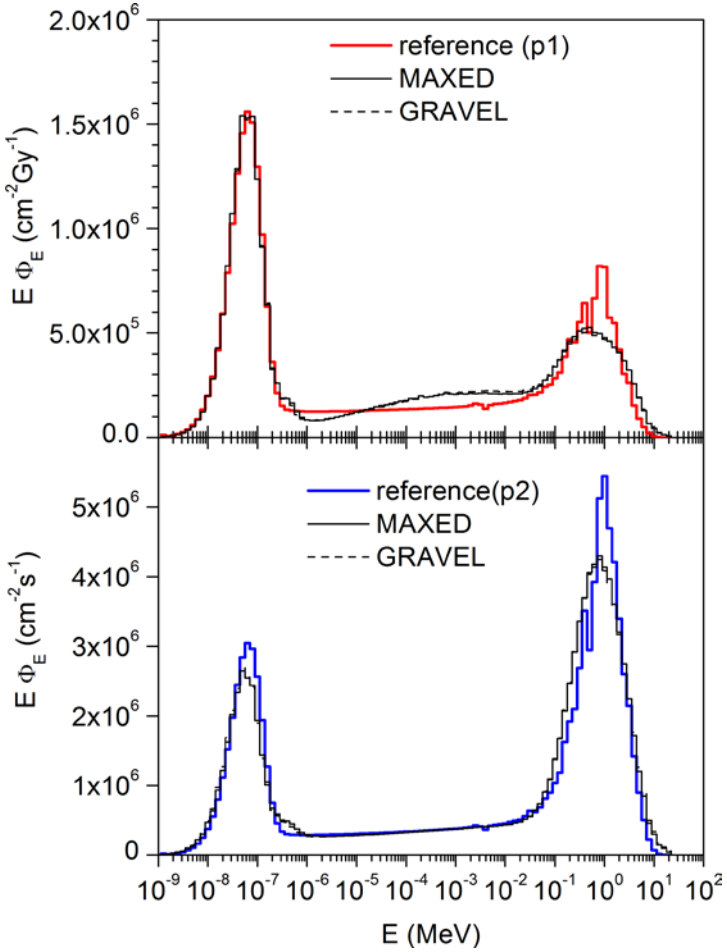
NOT by folding the reference spectra with the response matrix

Reference solution: unfolded spectra

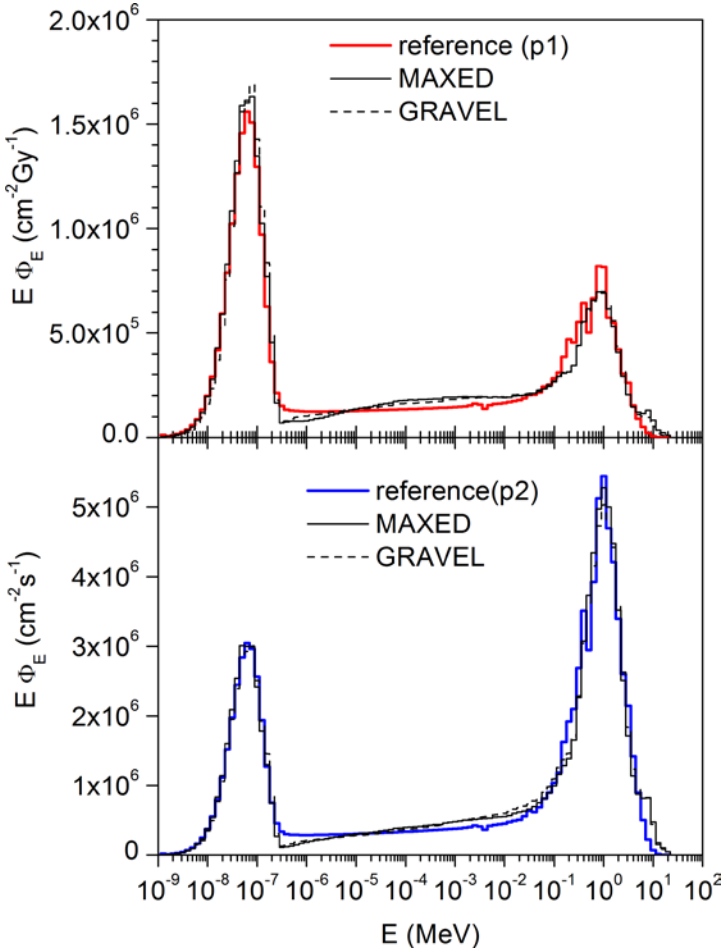


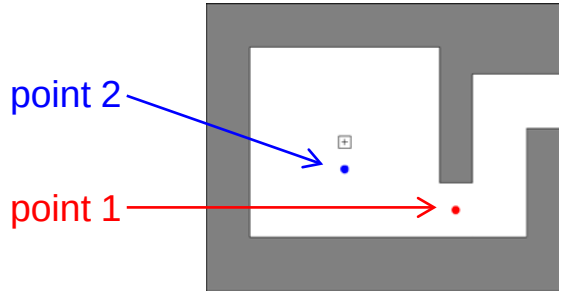
Reference solutions: unfolded spectra (LINAC)

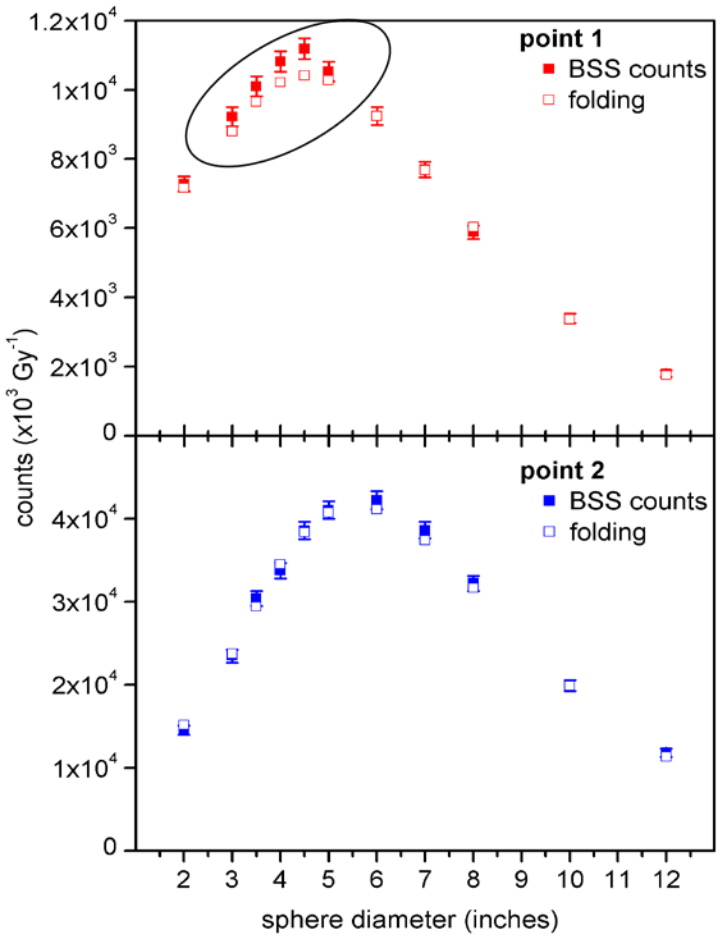
Guess: fitted high energy Gaussian peak with 1/E section + thermal Gaussian peak



Guess: 25MV LINAC spectrum from IAEA Tech. Rept. No. 318 + thermal Gaussian peak

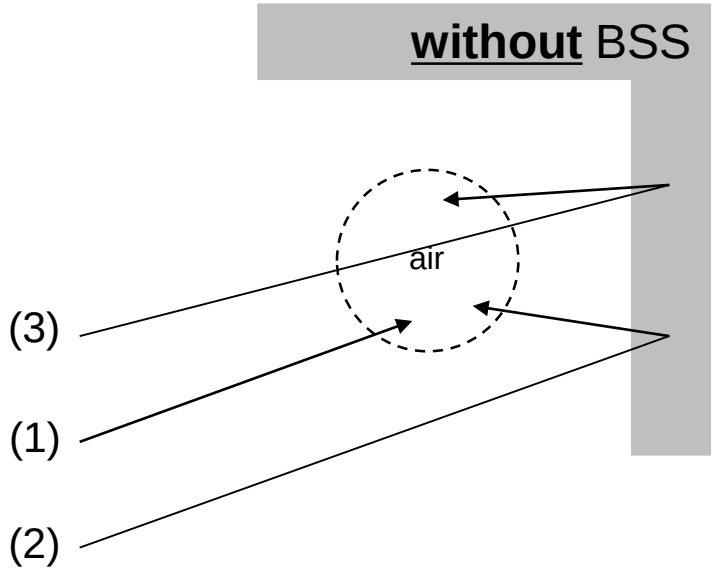


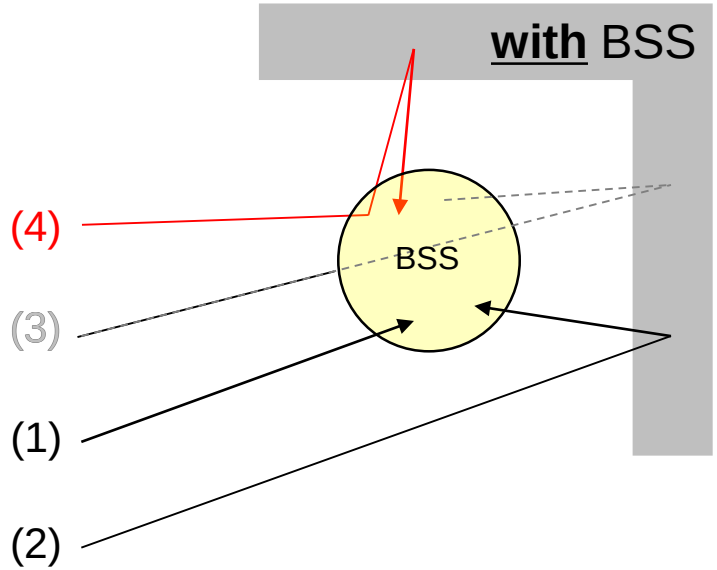




Perturbation of the neutron field

- Response matrix: **without** BSS perturbation
- Counts: **with** BSS perturbation





Contributions to neutron spectrum

(1) Direct neutrons

(2) Scattered neutrons

(3) Scattered neutrons (crossing target air volume)

Contributions to BS response

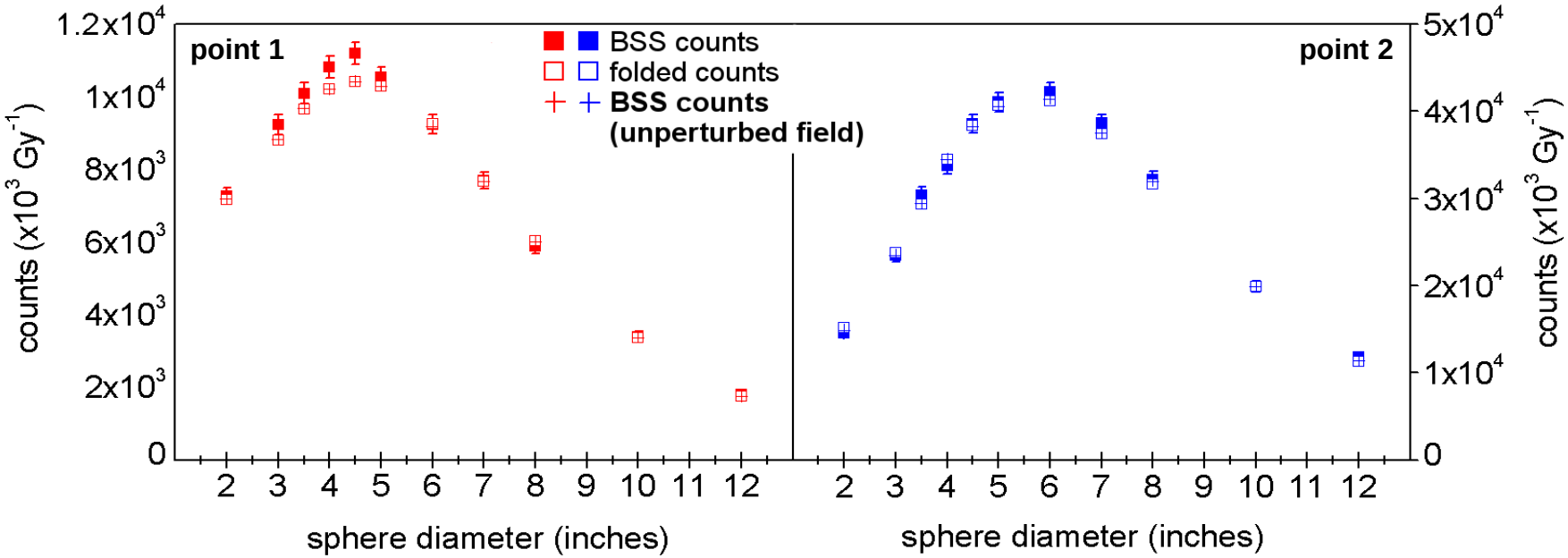
(1) Direct neutrons

(2) Scattered neutrons

(3) ~~Scattered neutrons (crossing target air volume)~~

(4) Backscattered neutrons (scattered by the Bonner sphere)

Effect of the perturbation (LINAC)

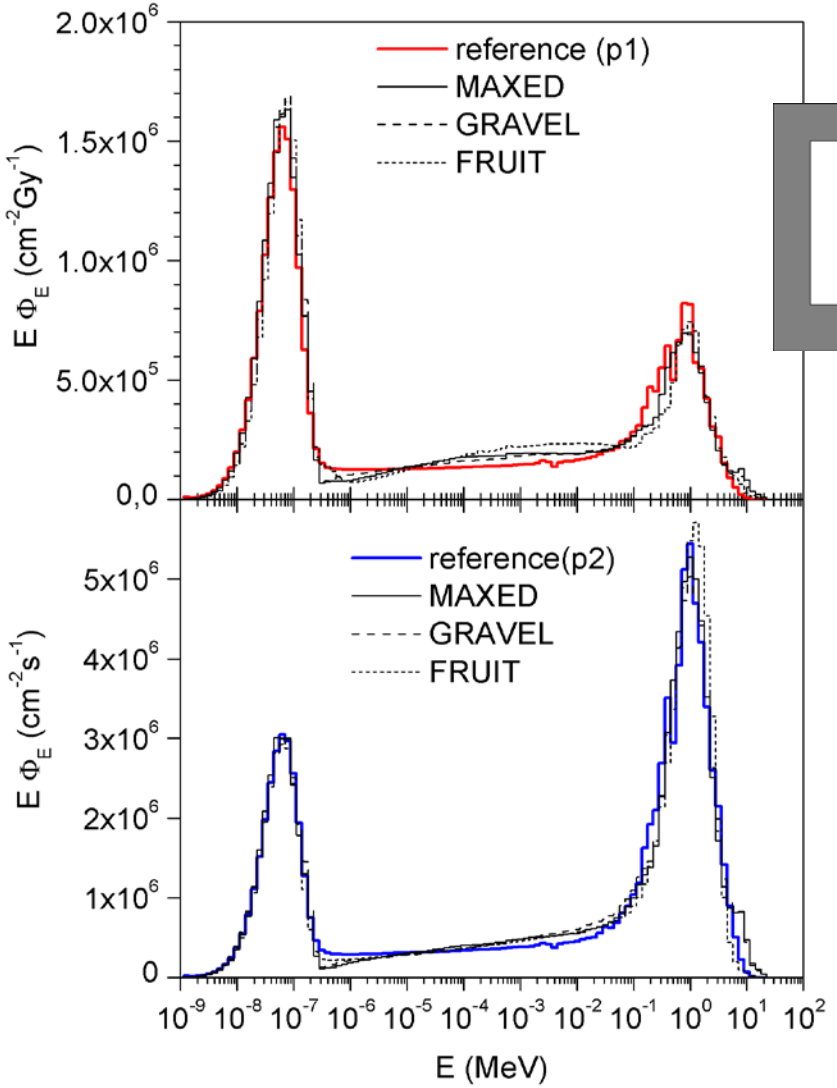


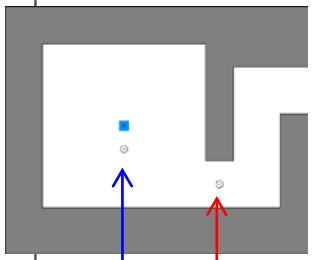
sphere	BSS	foldindg	unperturbed	(BSS-unp./BSS)
bare	8734	8716	8741	< 1%
2"	7280	7159	7193	1%
3"	9224	8796	8823	**4%**
3.5"	10099	9645	9682	**4%**
4"	10822	10206	10203	**6%**
4.5"	11186	10409	10426	**7%**
5"	10533	10272	10296	2%
6"	9240	9237	9189	< 1%
7"	7702	7670	7673	< 1%
8"	5888	6027	6021	-2%
10"	3397	3362	3369	< 1%
12"	1795	1745	1737	3%

sphere	BSS	foldindg	unperturbed	(BSS-unp./BSS)
bare	16716	17104	17150	-2%
2"	14534	15139	14892	-2%
3"	23471	23734	23465	< 1%
3.5"	30408	29388	29456	3%
4"	33755	34482	34509	-2%
4.5"	39586	38358	38292	3%
5"	41044	40708	40527	1%
6"	43241	41143	41435	4%
7"	38637	37411	37513	3%
8"	32222	31662	31983	< 1%
10"	19908	19870	19903	< 1%
12"	11822	11315	11372	4%

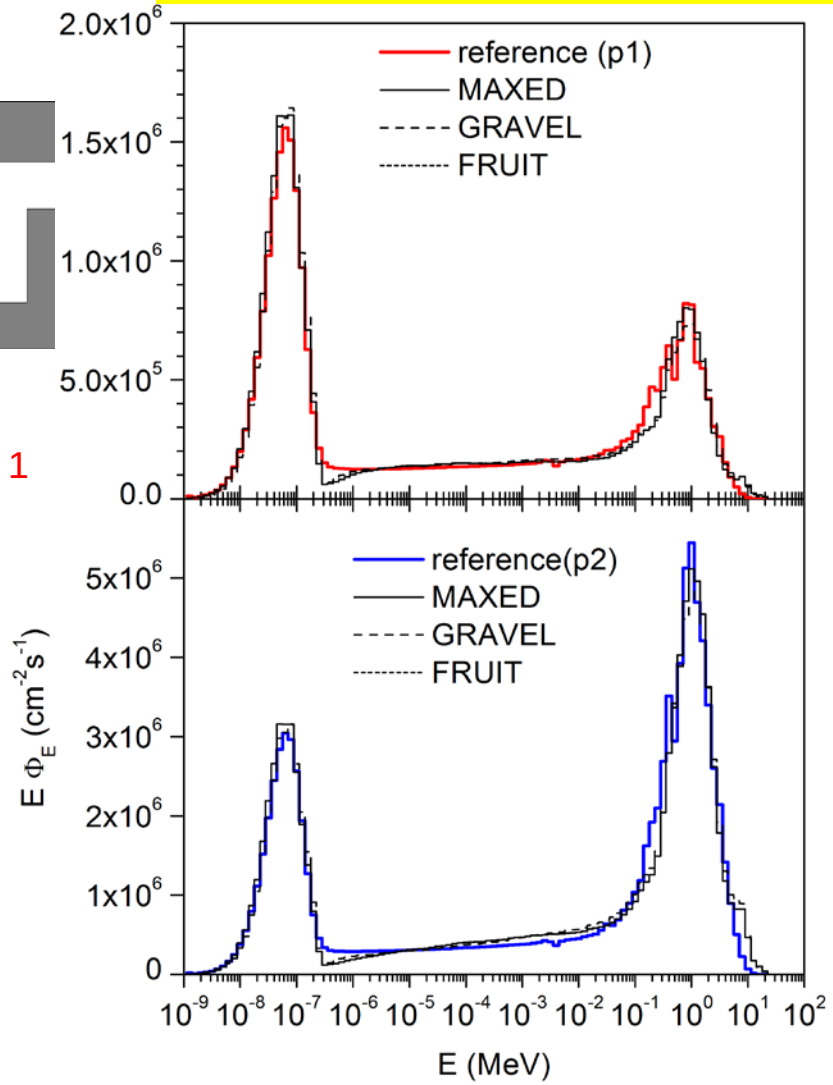
Effect of the perturbation (LINAC)

Unfolding BSS counts





Unfolding BSS counts (unperturbed field)



Summary

- ✓ BSS unfolding is un underdetermined problem. Additional information is required to get a physically meaningful solution: initial guess values or guess spectrum.

- ✓ A first check of the obtained unfolded spectrum can be made by folding it with the response matrix to compare the result with the BSS counts.

- ✓ Additional checks (e.g. comparison of the unfolded spectrum with previous result or published reference spectra) is highly advisable.

Amazing results use to be incorrect / inaccurate results 

- ✓ Additional details can be found at:

Radiat. Prot. Dosim. 180, 70-74 (2018), https://doi.org/10.1093/rpd/ncy002

Radiat. Meas. 153, 106755 (2022), https://doi.org/10.1016/j.radmeas.2022.106755