

Problem P1: Recoil-Proton Telescope Detector

Stefano Agosteo and Andrea Pola

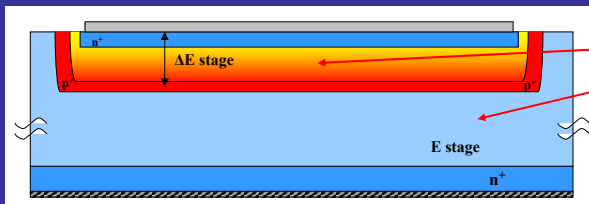
Dipartimento di Ingegneria Nucleare, Politecnico di Milano, via Ponzio 34/3,
20133 Milano, Italy

and

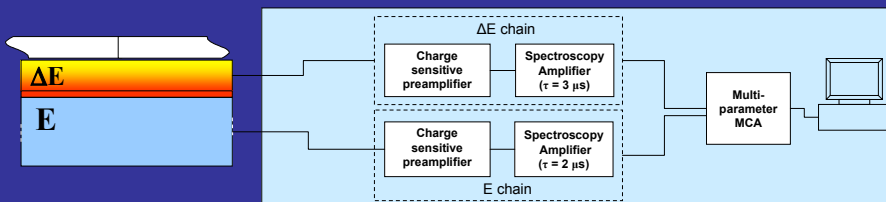
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Monolithic Silicon Telescope ΔE -E

Sensitive area: 1 mm²



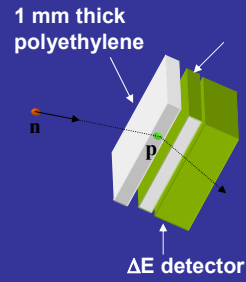
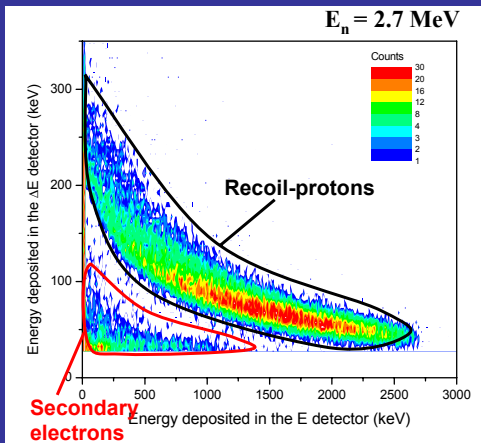
ΔE thickness: $\sim 2 \mu\text{m}$
E thickness: $\sim 500 \mu\text{m}$



[1] Tudisco, S., et al. A new large area monolithic silicon telescope. Nucl. Instrum. Meth. A 428, 436-445 (1999).

ΔE -E Scatter Plot

Secondary electrons above coincidence threshold are removed off-line



Distributions well-discriminated

Recoil-protons only

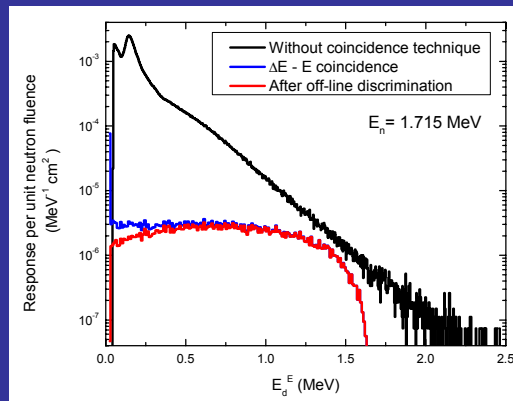


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ΔE -E Coincidence Technique and Particle Discrimination

E stage response function to 1.715 MeV neutrons

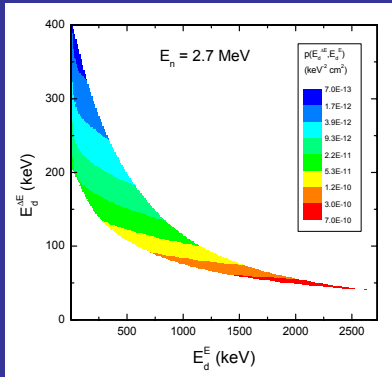


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Analytical model of response functions

$$p(E_d^{AE}, E_d^E) = \frac{2 \cdot h^3}{R^{\text{poly}}(E_n)} \cdot \frac{1}{(R^{\text{Si}}(E_d^{AE} + E_d^E) - R^{\text{Si}}(E_n^E))^4} \cdot \frac{S^{\text{Si}}\left(E^{\text{Si}}\left(R^{\text{Si}}(E_n^E) + \frac{a+h}{h} \cdot (R^{\text{Si}}(E_d^{AE} + E_d^E) - R^{\text{Si}}(E_n^E))\right)\right)}{S^{\text{poly}}\left(E^{\text{Si}}\left(R^{\text{Si}}(E_n^E) + \frac{a+h}{h} \cdot (R^{\text{Si}}(E_d^{AE} + E_d^E) - R^{\text{Si}}(E_n^E))\right)\right)} \cdot \frac{S^{\text{Si}}(E_d^{AE} + E_d^E)}{S^{\text{Si}}(E_n^E)}$$



Bivariate distribution normalized to the unit neutron fluence

The model does not take into account statistical uncertainties (straggling, electronic noise)

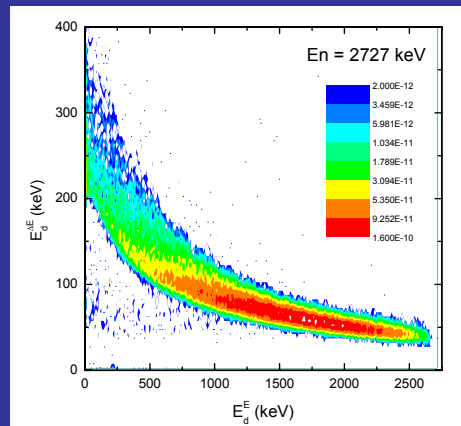


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FLUKA simulation



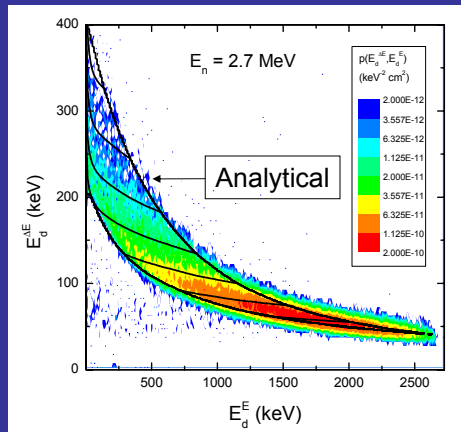
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FLUKA simulation and analytical model

Comparison between analytical model and simulation



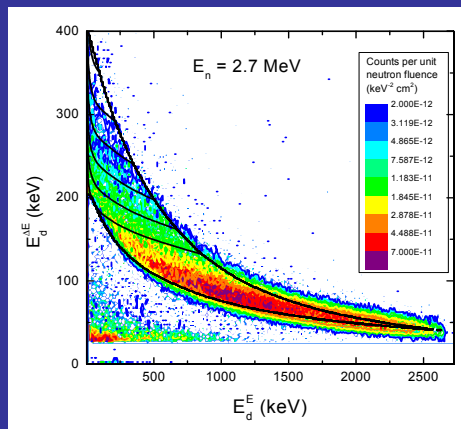
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FLUKA simulation, analytical model and experiment

Comparison among analytical model, simulation and experiment

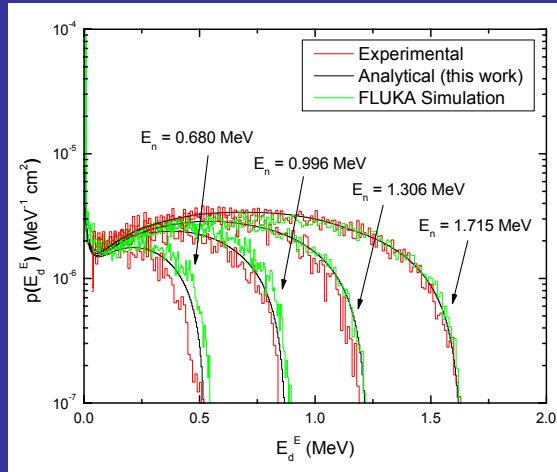


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Irradiations with quasi-monoenergetic neutrons (at INFN-LNL)

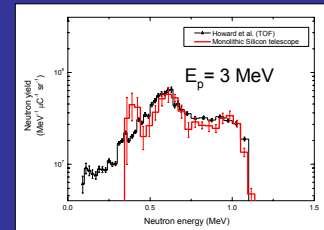
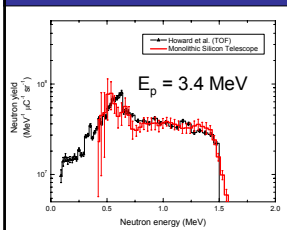
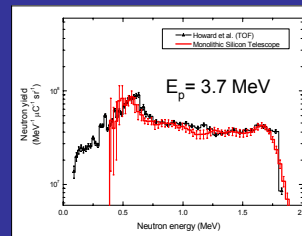
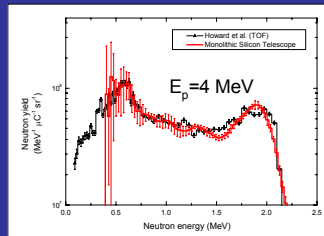
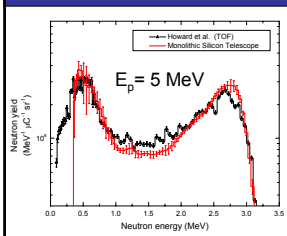


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Measurements: neutrons generated at 0° by protons of several energies on a thick Be target



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Total neutron yield

Proton bombarding energy (MeV)	Angle	Neutron yield above 0.4 MeV ($\mu\text{C}^{-1} \text{sr}^{-1}$)	
		This work	Howard et al.
3	0°	$(2.24 \pm 0.46) \times 10^7$	$(2.53 \pm 0.17) \times 10^7$
3.4	0°	$(4.41 \pm 0.83) \times 10^7$	$(4.42 \pm 0.23) \times 10^7$
3.7	0°	$(6.31 \pm 1.17) \times 10^7$	$(6.61 \pm 0.30) \times 10^7$
4	0°	$(1.02 \pm 0.15) \times 10^8$	$(1.02 \pm 0.04) \times 10^8$
5.0	0°	$(3.98 \pm 0.39) \times 10^8$	$(3.88 \pm 0.11) \times 10^8$

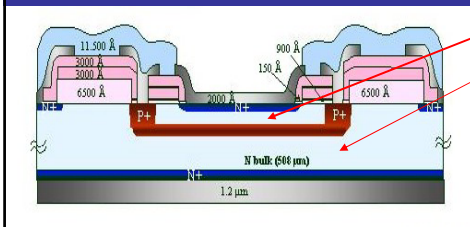


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Monolithic silicon telescope



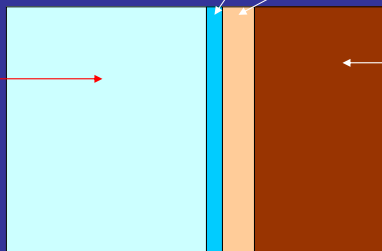
ΔE thickness: $\sim 1.9 \mu\text{m}$
E thickness: $\sim 500 \mu\text{m}$

Dead layer (Ti) $0.24 \mu\text{m}$

ΔE detector
($1.9 \mu\text{m}$)

Simulation geometry:

Polyethylene
converter
(1 mm)



E detector
($500 \mu\text{m}$)

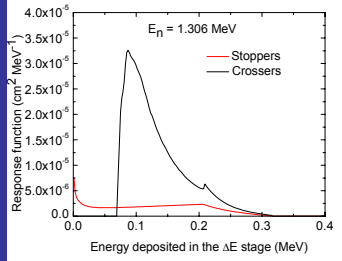
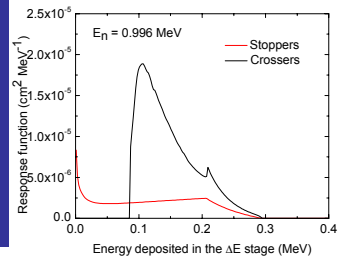
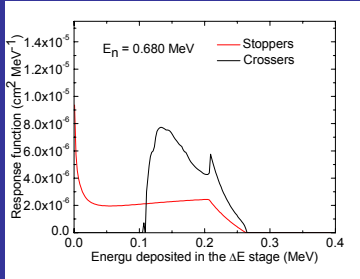


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ΔE stage: stoppers and crossers

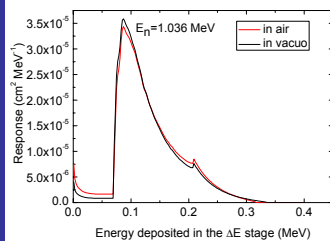
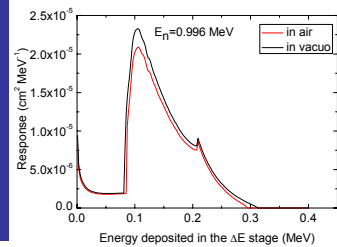
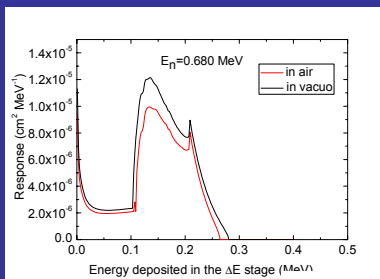


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ΔE stage: in air vs. in vacuo

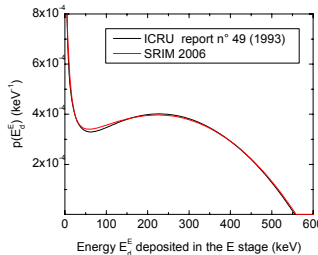
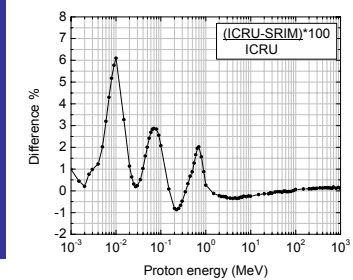
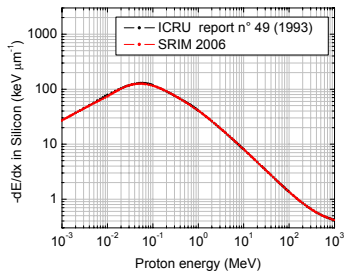


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The effect of $-dE/dx$ data on the response function

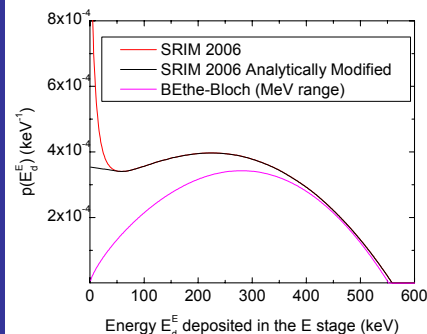
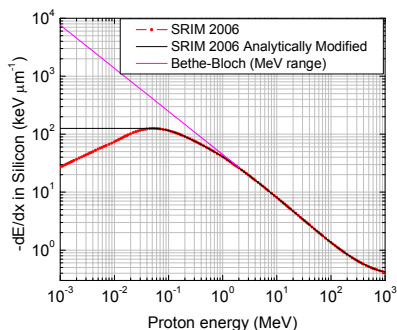


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The effect of $-dE/dx$ data on the response function



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Neutrons: author's simulation

- FLUKA 2006.3 and 2006.3b;
- Secondary proton cut-off energy: 1 keV;
- Secondary electrons transported – cut-off 10 keV;
- Straggling accounted for;
- Step for electron multiple scattering (Molière): 1%;
- Step for proton multiple scattering (Molière): 1%;
- 5×10^8 histories.



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Codes

- MCNPX vers. 2.4.0, 2.5.0, 2.6.a, 2.6.b;
- AMOS-NCP.



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P1-A neutrons

- Bin with for energy deposition: 10 keV;
- No additional assumptions for the simulation geometry.



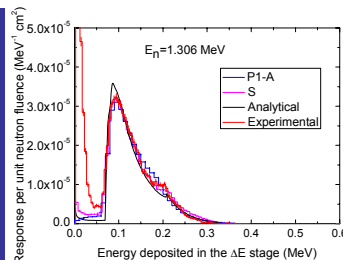
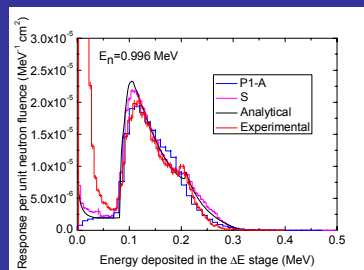
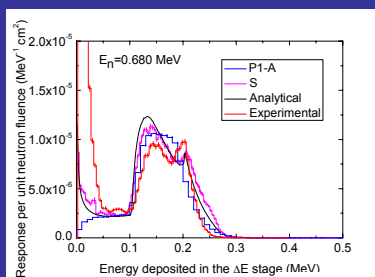
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P1-A neutrons - ΔE stage



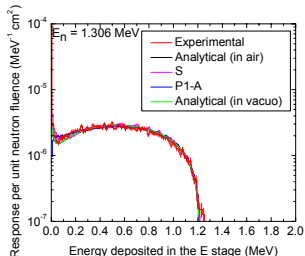
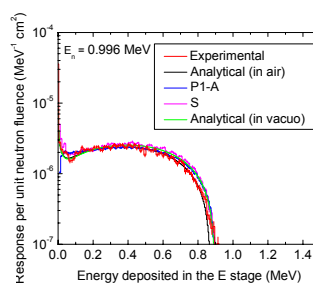
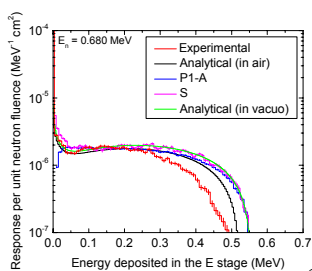
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P1-A neutrons - E stage



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P1-B neutrons

- Bin width for energy deposition: 50 keV;
- Proton energy cut-off: 1.0494 keV;
- Secondary electrons not transported;
- No variance reduction techniques.

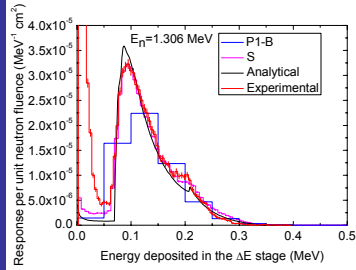
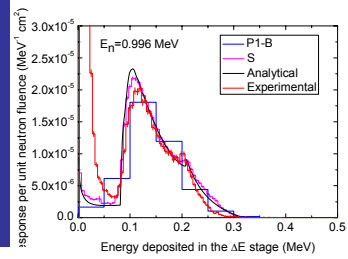
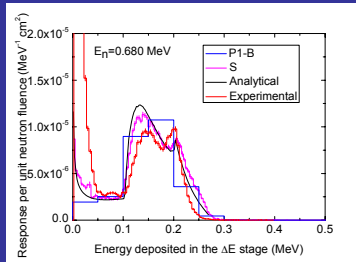


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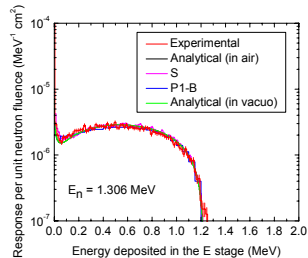
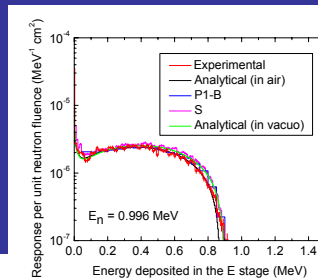
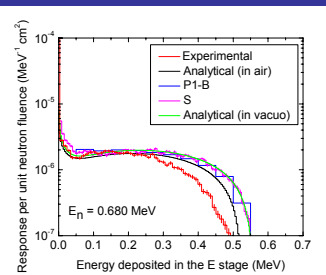
P1-B neutrons - ΔE stage



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P1-B neutrons – E stage



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P1-C neutrons

- Bin with for energy deposition: 10 keV;



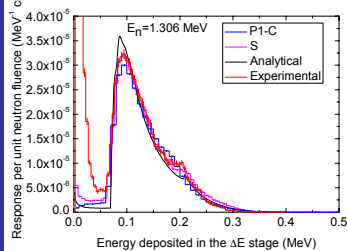
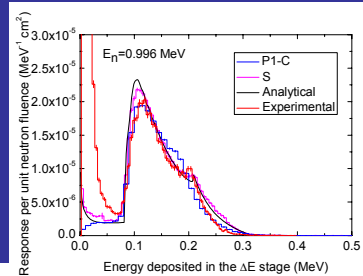
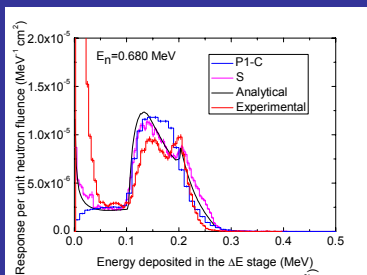
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P1-C neutrons - ΔE stage



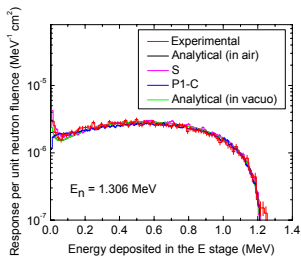
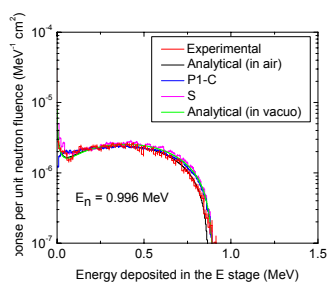
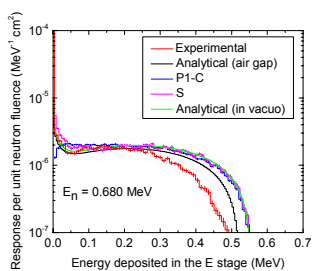
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P1-C neutrons - E stage



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P1-D neutrons

- Bin width for energy deposition: 10 keV;
- Proton energy cut-off: 1 keV;
- 5×10^8 histories.

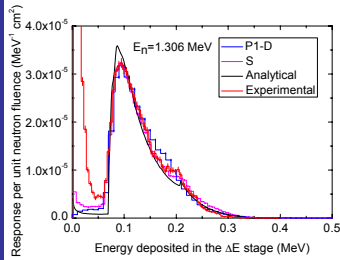
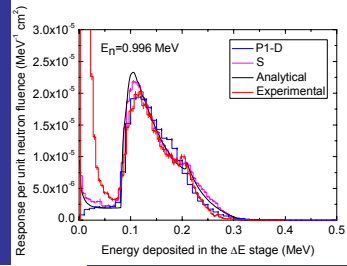
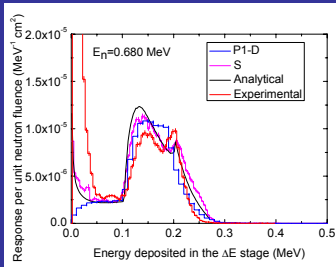


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P1-D neutrons - ΔE stage

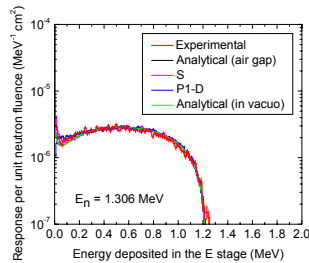
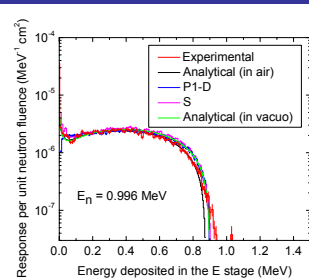
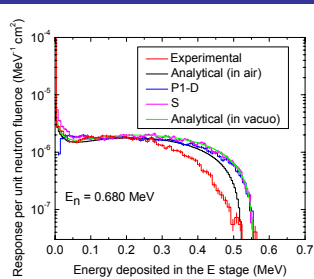


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P1-D neutrons - E stage



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P1-E neutrons

- Bin width for energy deposition: 0.1 keV;
- 10^8 histories;
- Thickness of the converter optimized against the proton range in PE. This allows to decrease the computing time;

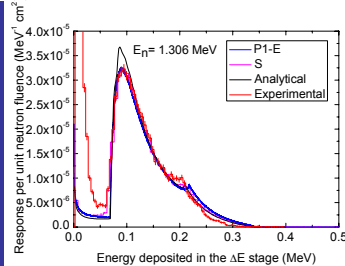
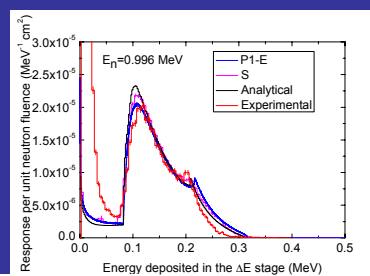
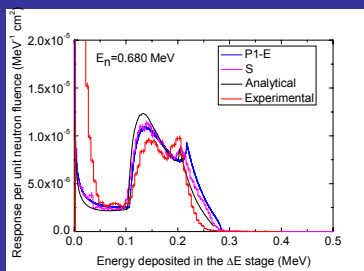


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P1-E neutrons - ΔE stage

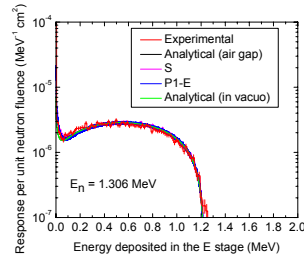
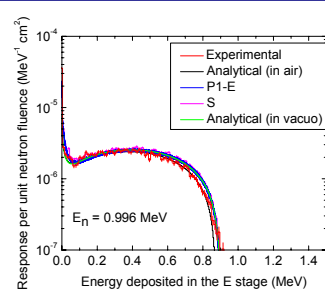
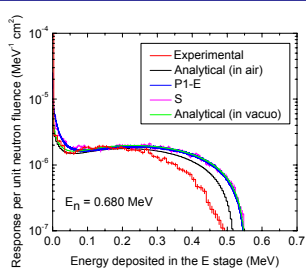


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P1-E neutrons - E stage



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P1-F neutrons

- Bin width for energy deposition: 10 keV;
- Proton energy cut-off: 1 keV;
- $S(\alpha, \beta)$ for hydrogen bound in PE.

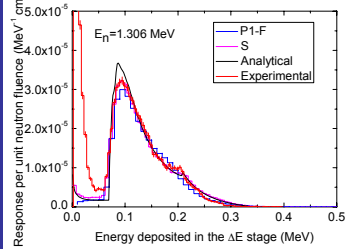
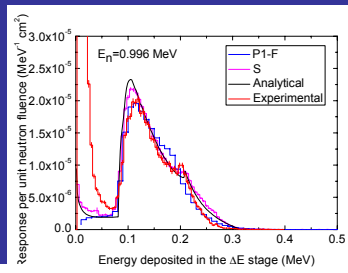
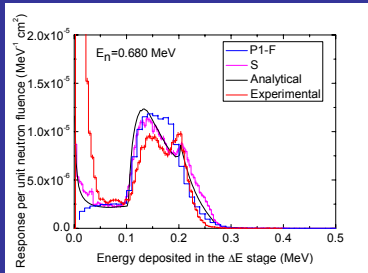


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P1-F neutrons - ΔE stage

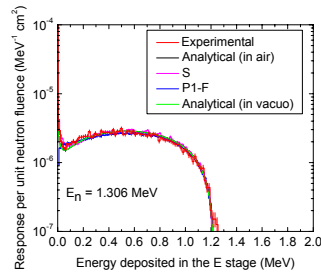
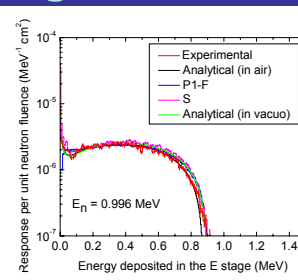
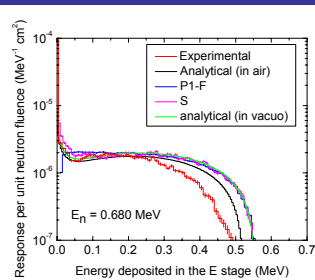


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P1-F neutrons - E stage

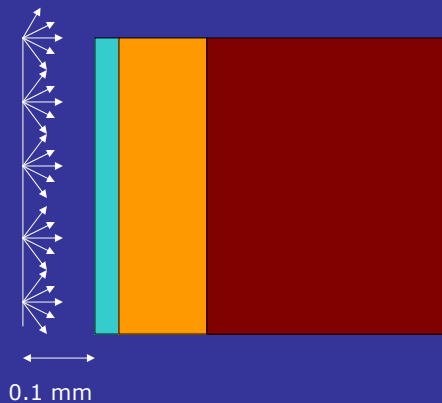


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Electrons



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Problem P1: Recoil-Proton Telescope Detector



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Electrons: author's simulation

- FLUKA code;
- Electron cut-off 1 keV;
- Straggling accounted for;
- Step for electron multiple scattering (Molière): 1%;
- 5×10^6 histories.



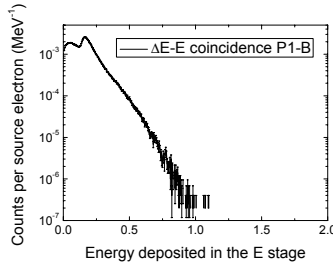
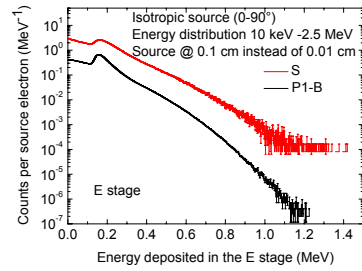
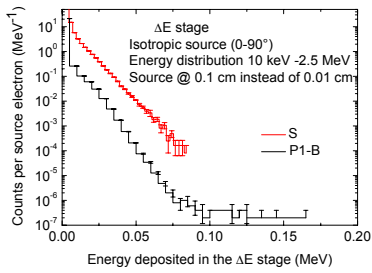
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P1-B electrons

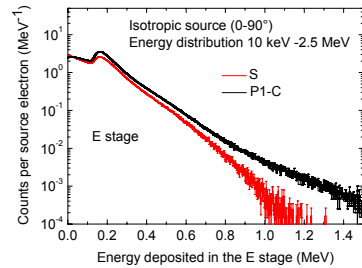
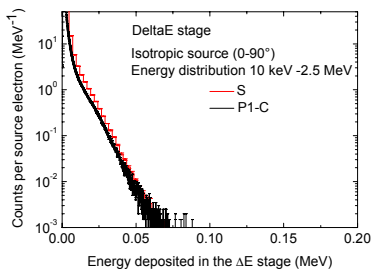


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P1-C Electrons

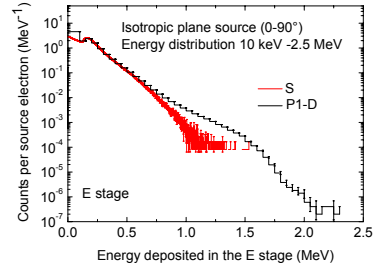
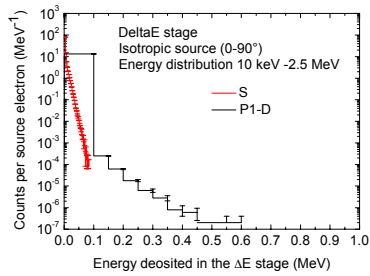


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P1-D Electrons

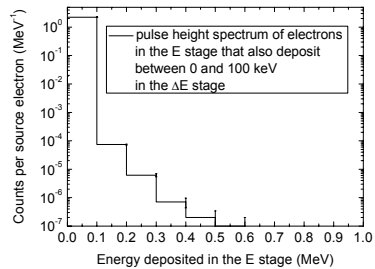
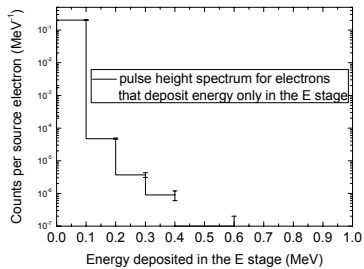


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P1-D Electrons: coincidence

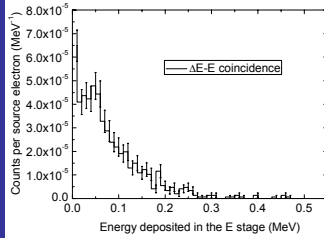
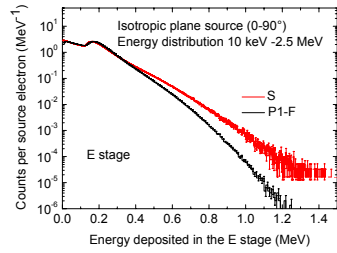
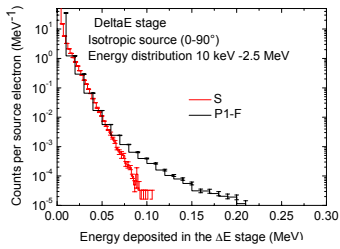


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P1-F Electrons

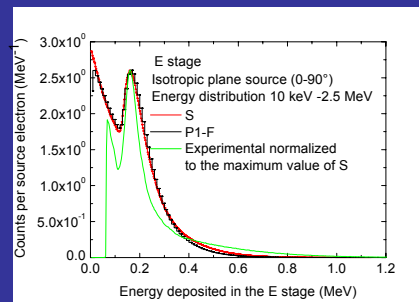
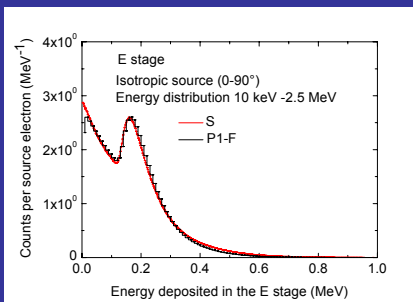


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P1-F Electrons

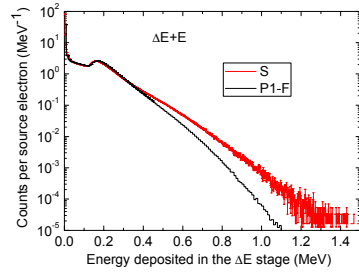
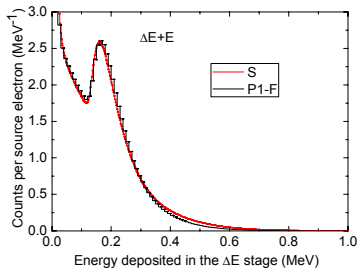


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P1-F $\Delta E+E$

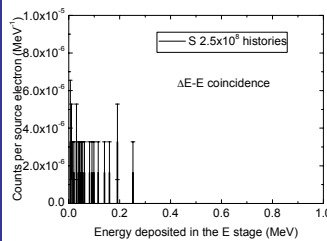
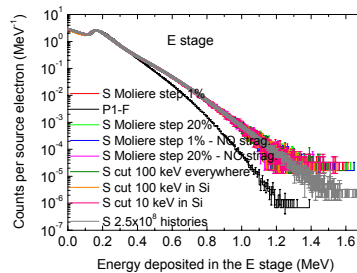
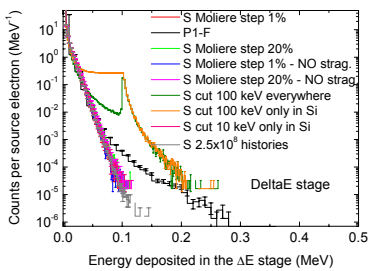


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Some trials



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Conclusions

- Response to neutrons (recoil-protons): satisfactory agreement (apart at low energies for some cases);
- Response to electrons: discrepancies (due to electron transport in very thin layers?).



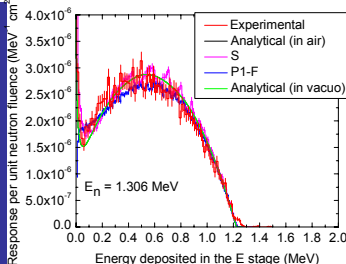
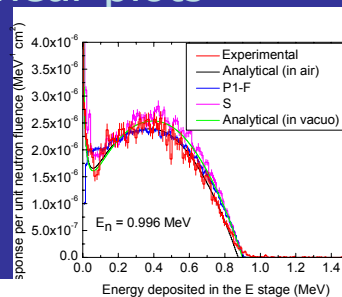
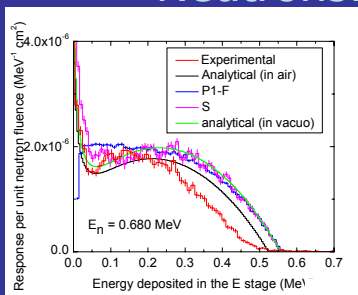
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Neutrons: E stage linear plots



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