Nuclear spallation Simulation in the PHENIX Muon Arms

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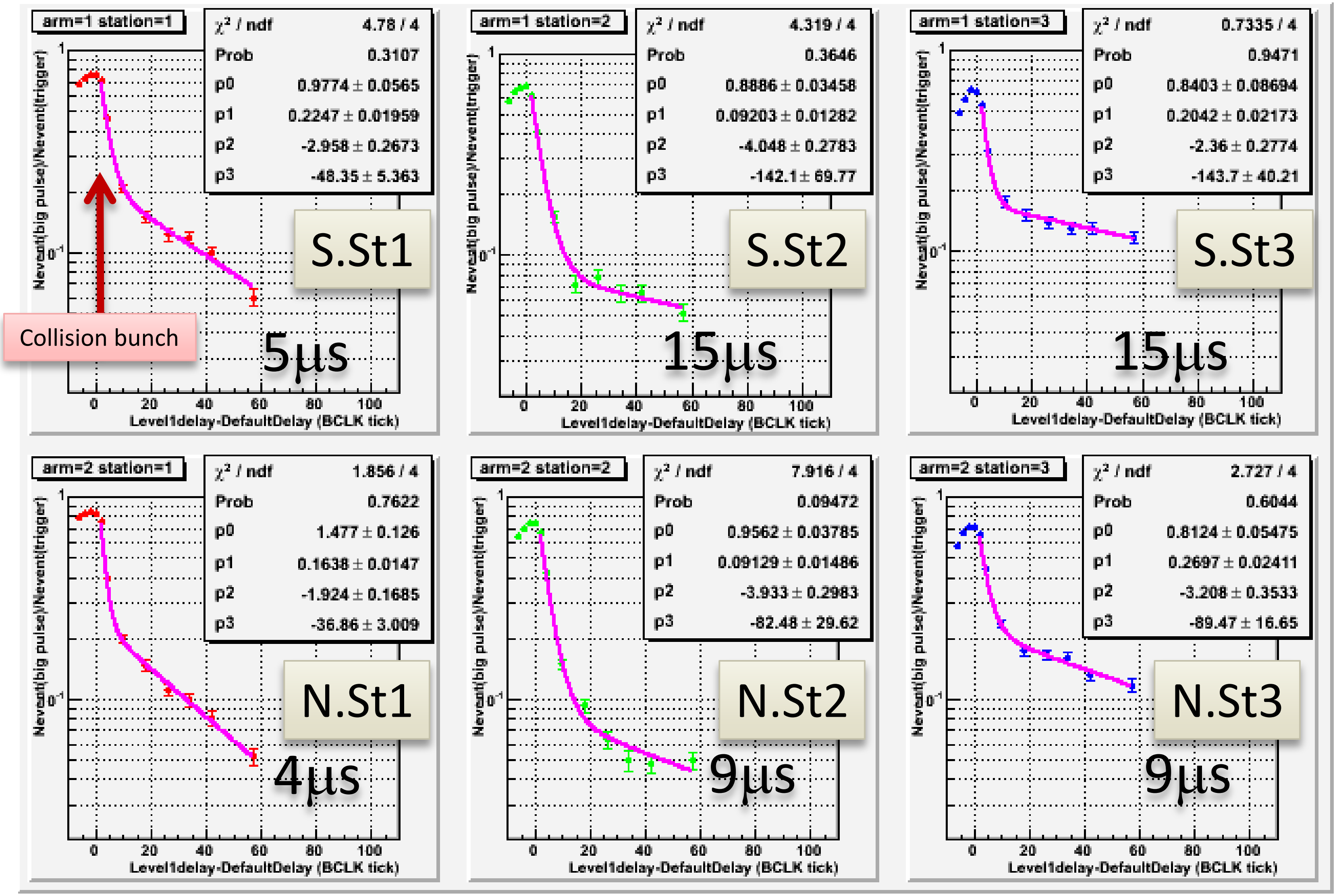
Single bunch analysis (run10)



Collision bunch

S.St1

5μs

S.St2

15μs

S.St3

15μs

N.St1

4μs

N.St2

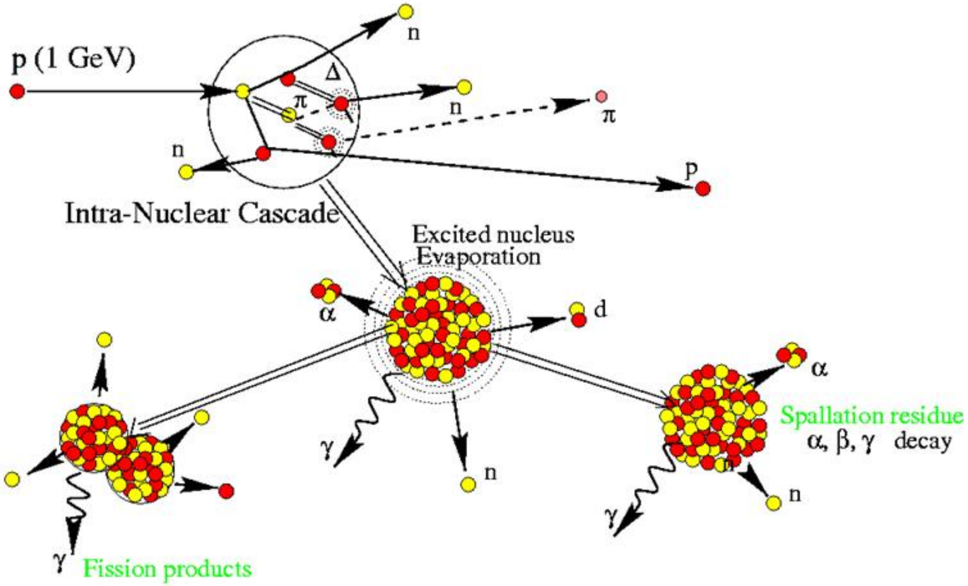
9μs

N.St3

9μs

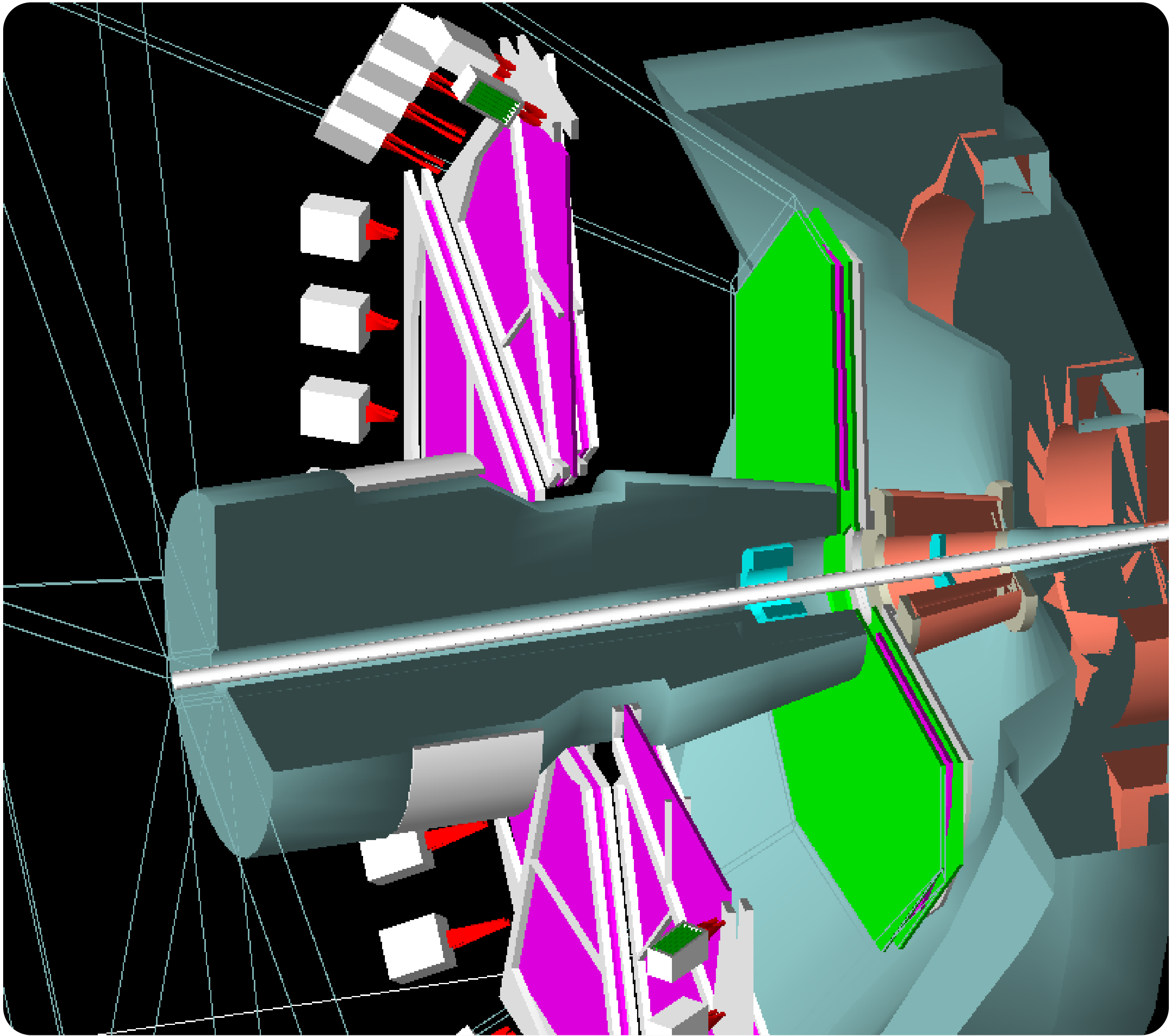
Spallation

Nuclear spallation

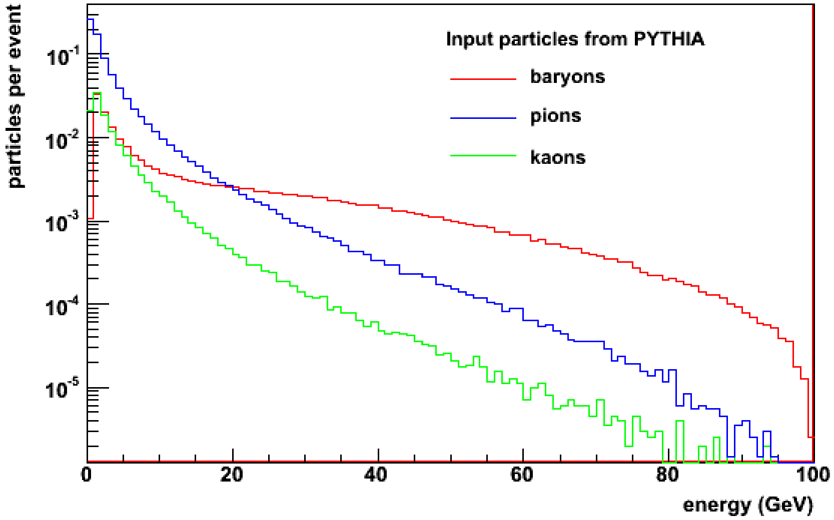


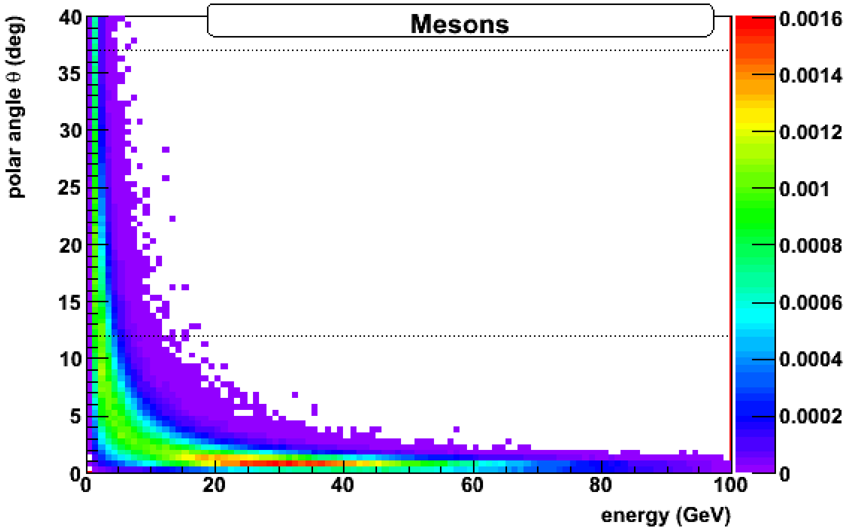
Setup in GEANT4

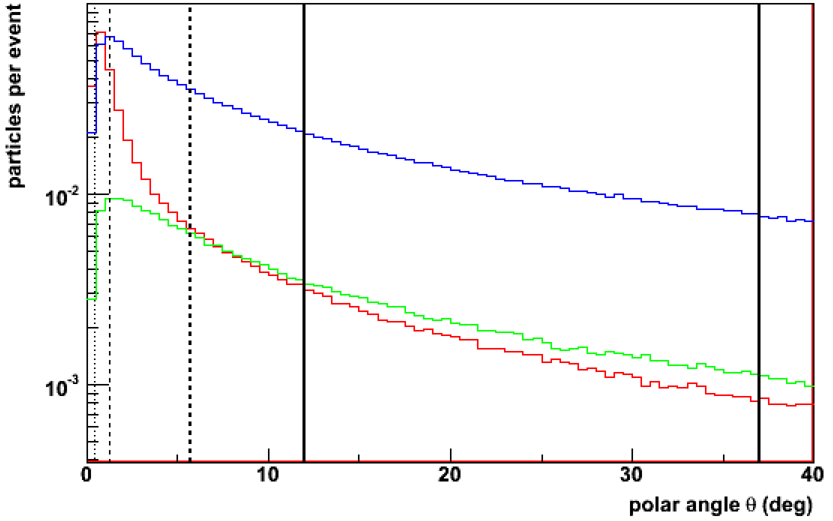
- Complete south muon arm with central magnet yoke
- Complete isotope mix for materials
- QGSP_BERT_HP
  - optimized neutron thermalization
  - Bertini cascade for spallation
- ABLA
  - detailed modeling of spallation process
  - mean free path of particle in medium
  - intranuclear cascade, pre-equilibrium, equilibrium

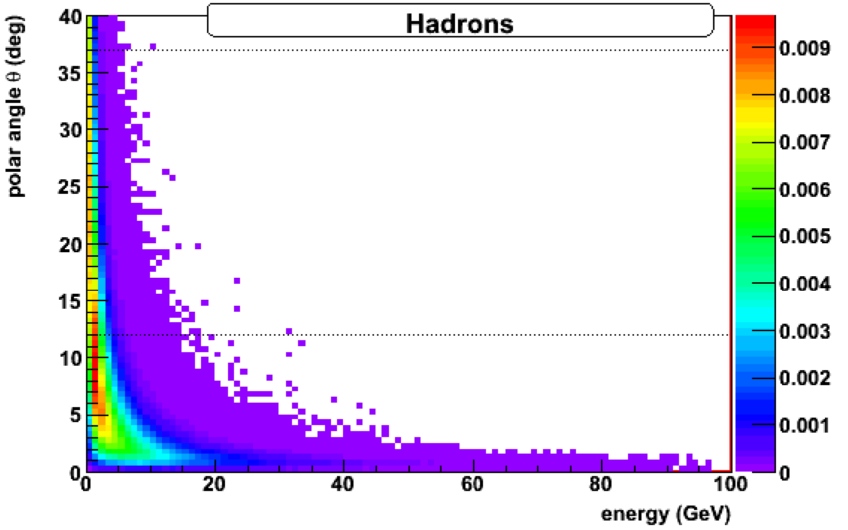


PYTHIA input

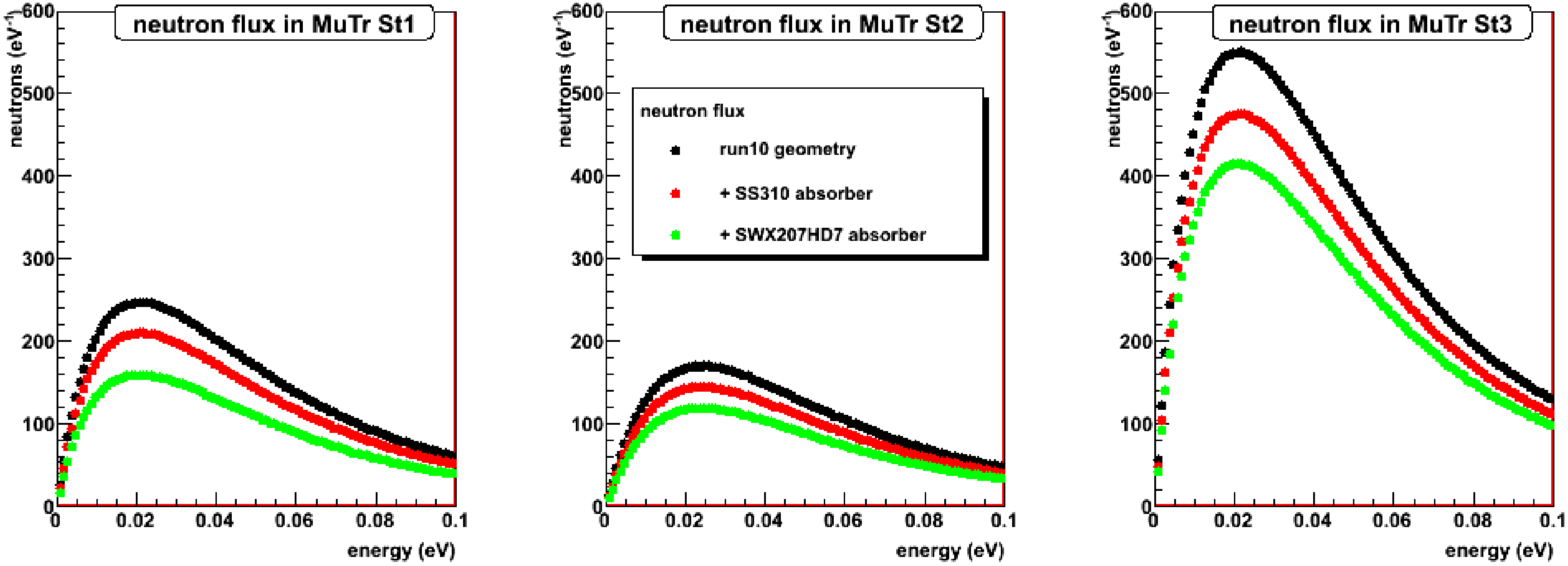




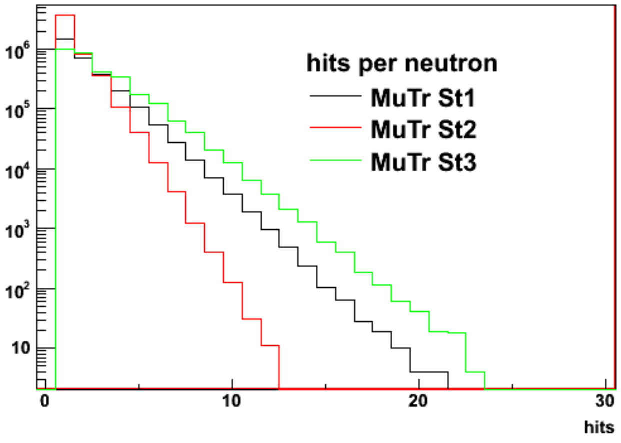




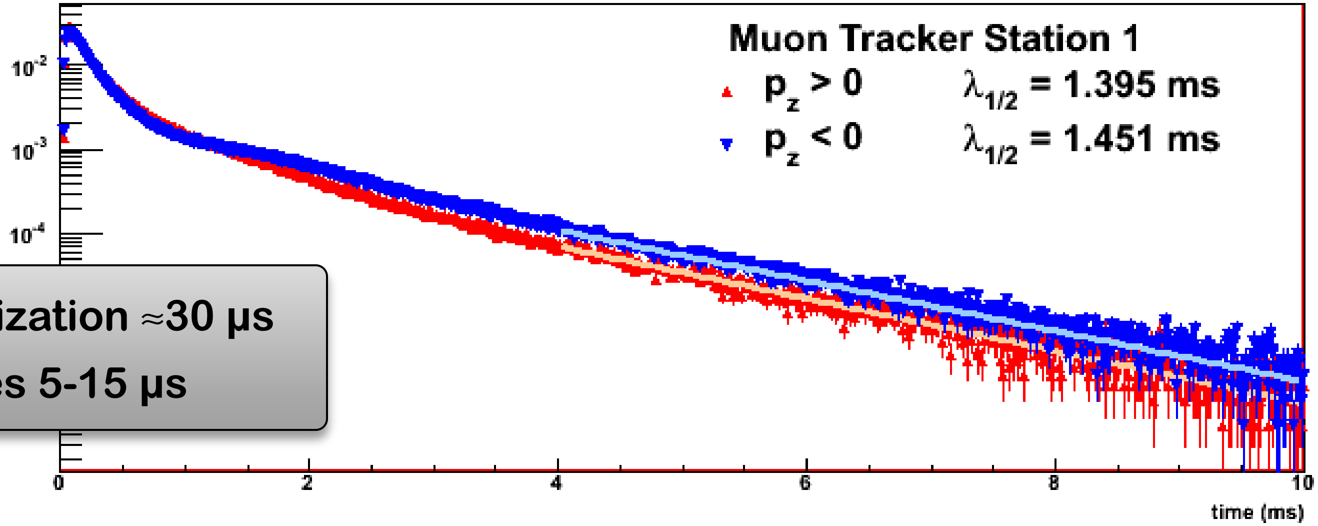
Neutron spectra



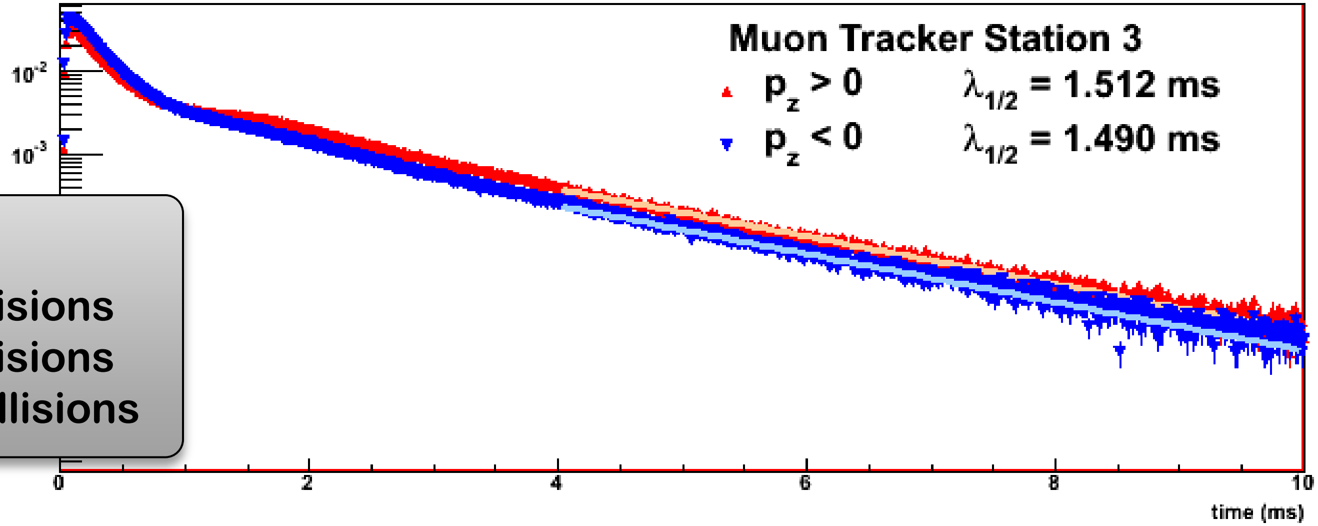
- SS310 does not increase the thermal neutron flux
- Thermal neutrons behave gas-like



Thermalization times



- ❖ **Effective thermalization ≈30 μs**
- ❖ **Compare life times 5-15 μs**

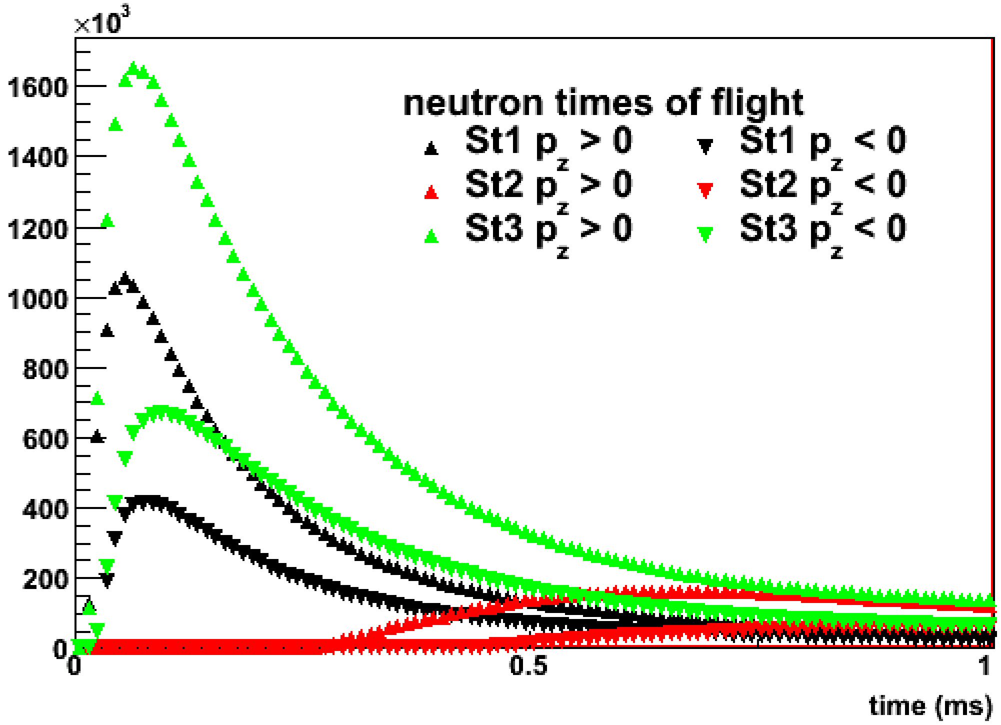


Thermalization

- Carbon: 110 collisions
- Iron: 500 collisions
- Lead: 1800 collisions

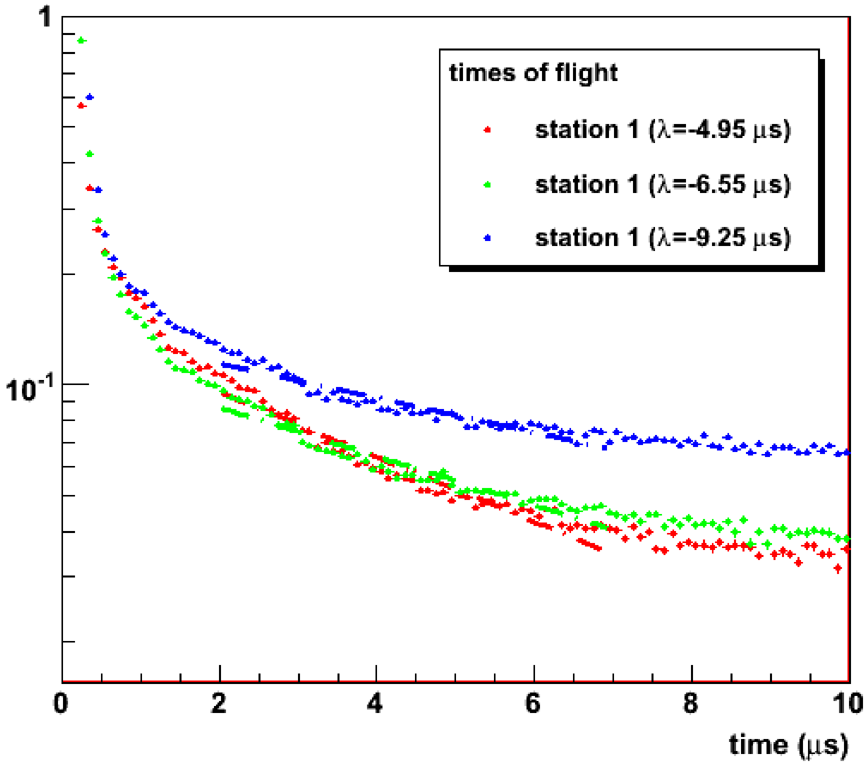
Times of Flight

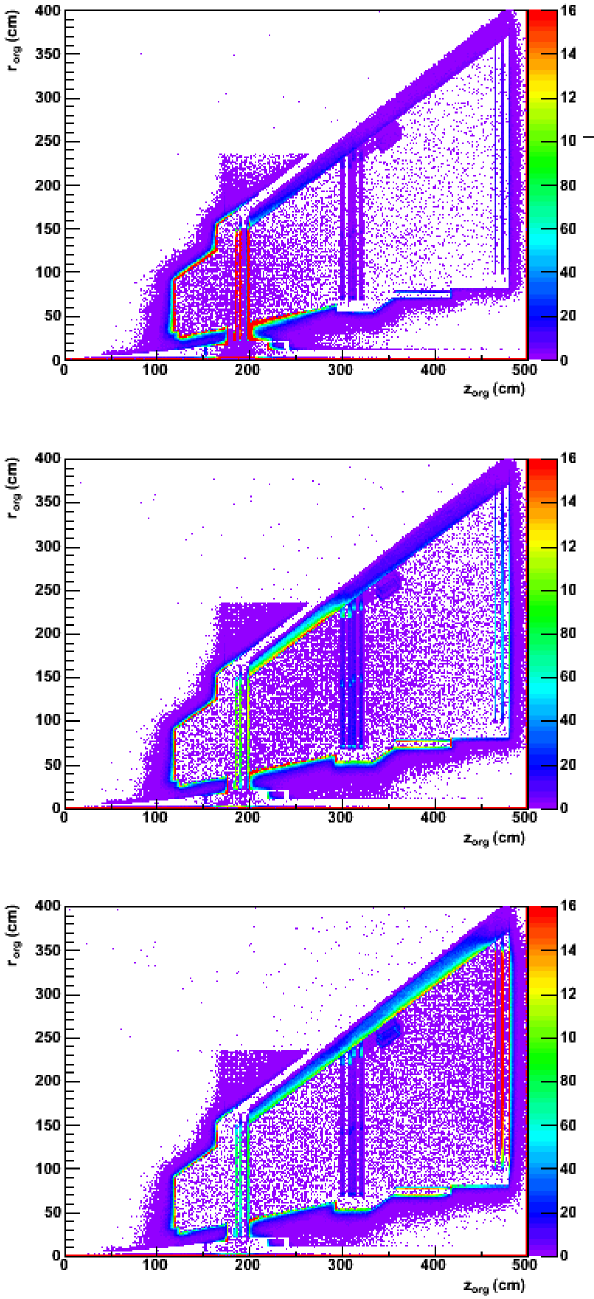
- ☐ Times in Station 2 looks different than in Stations 1 & 3 (no G10 plates)
- ☐ Neutron mean velocities:
  - ○ $v_{thermal} = 2.2\,\frac{km}{s}$
  - ○ $\Delta t(z_{St1}\,\_\,zS_{t2}) = 500\ \mu s$
  - ○ $v_{fast} = 14000\,\frac{km}{s}$
  - ○ $\Delta t(z_{St1}\,\_\,z_{St2}) = 72\ ns$
- ☐ $|z_{St1}\,\_\,z_{St2}| < |zSt_2\,\_\,z_{St3_|}$
- ☐ All thermal neutrons passing through St2 have thermalized far from the detector



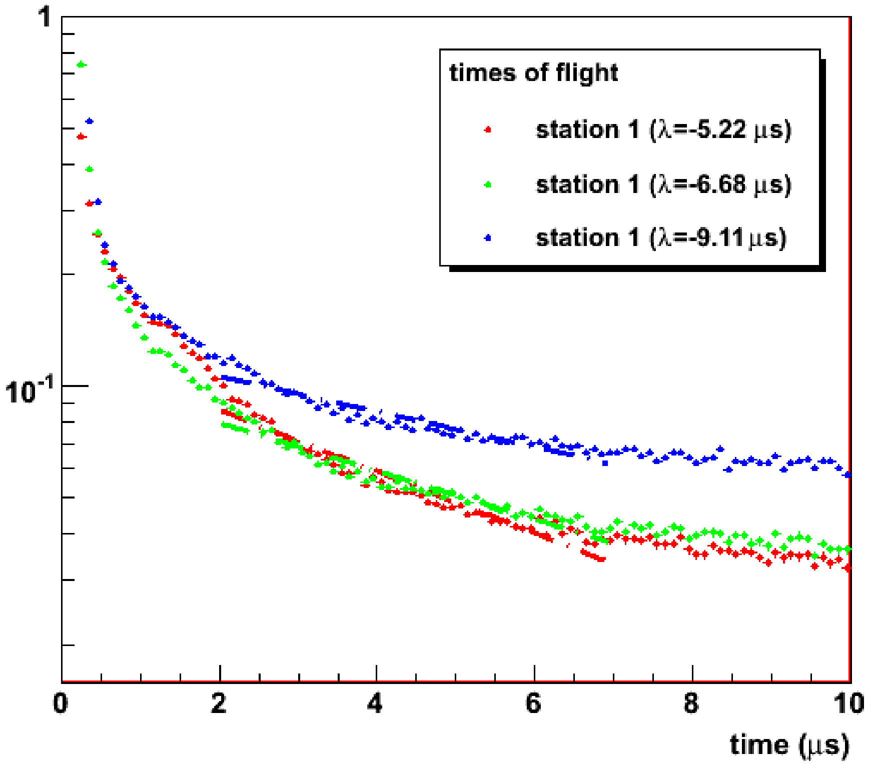
High energy photons

- Everything above a few eV
- Late / leaking showers in material
- De-excitation from spallation compound nuclei

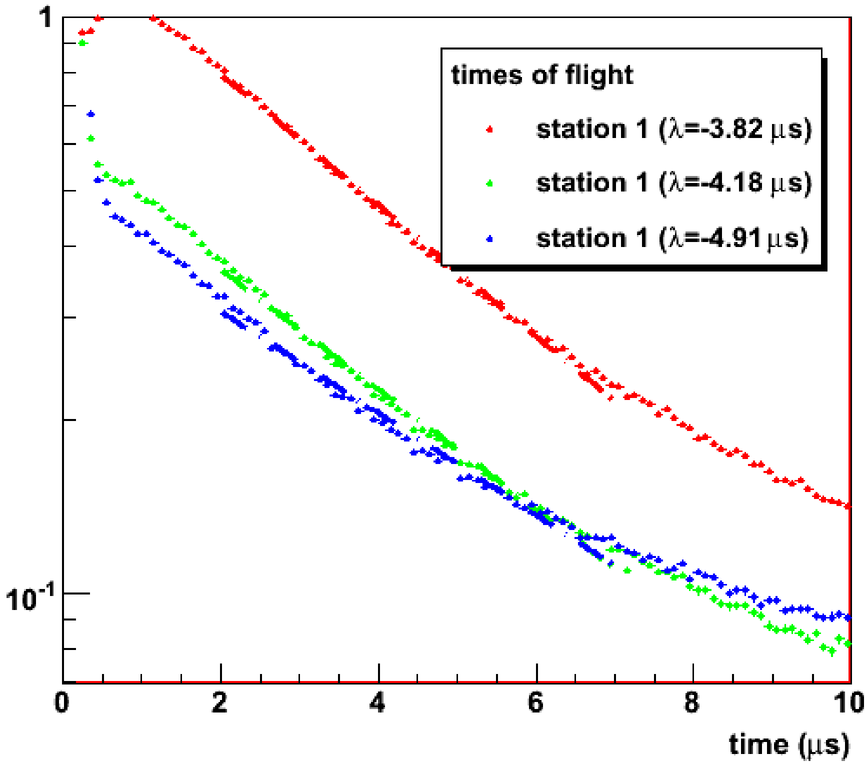




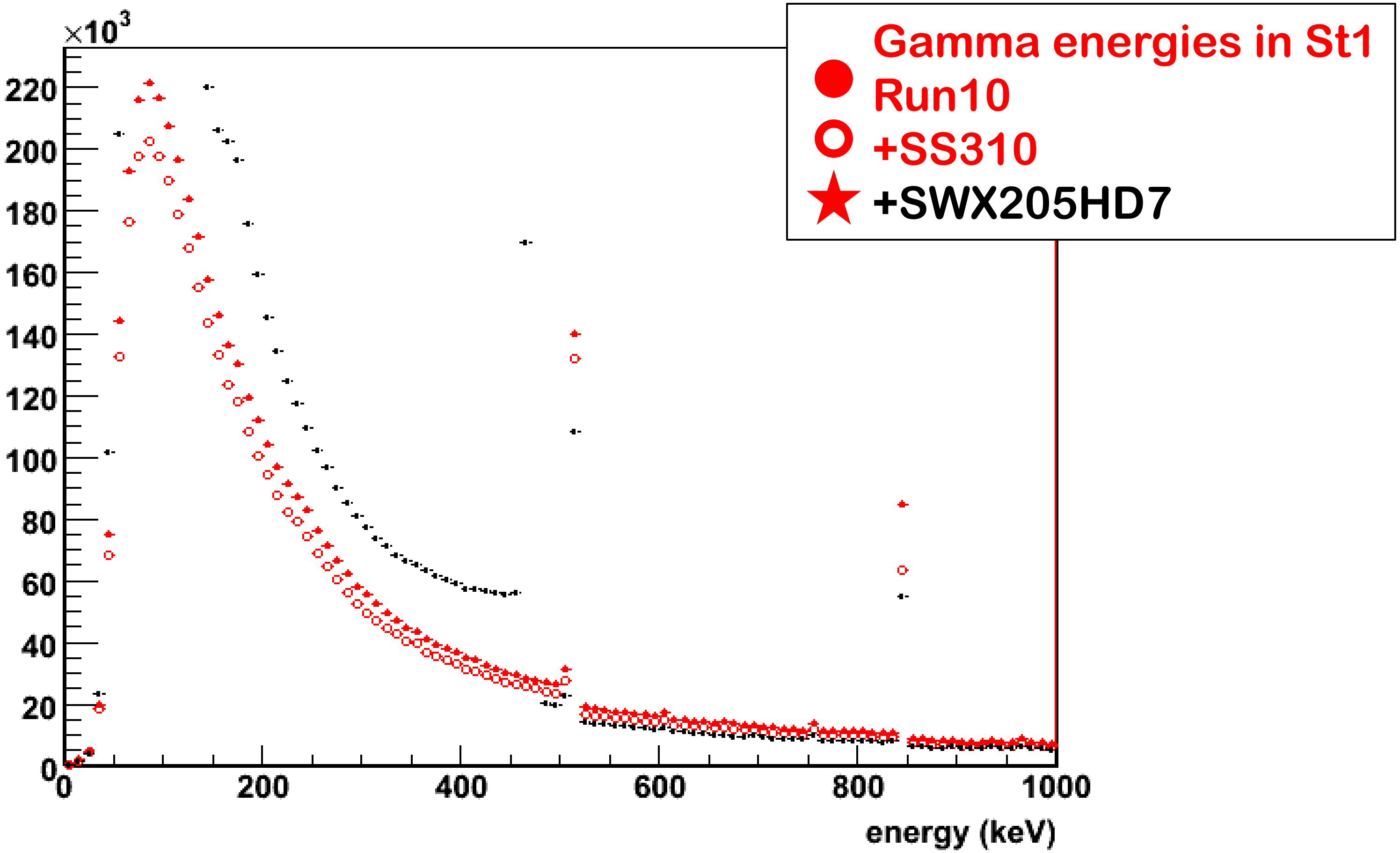
Additional SS310



Additional SWX205HD7



Photon energies



- The interaction package reproduces the gamma emission from neutron capture in ^{10}B
- prev. slide: thermalization is a lot faster than G10

Li_2CO_3 absorber

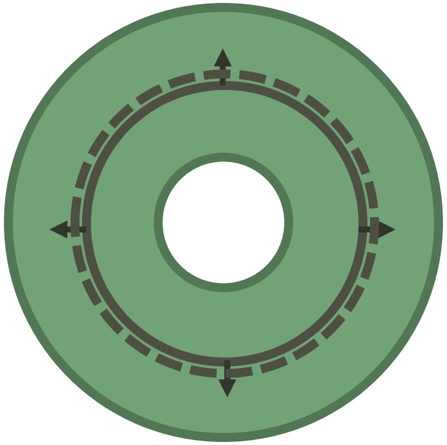
- Neutron capture in lithium
    - Li^6 σ=940 barn
    - Li^7 σ=0.045 barn
- Natural lithium σ=70.5 barn
- Enriched lithium σ=893 barn
- Absorption length
    - Enriched λ=0.33 mm
    - Natural λ=4.3 mm

Natural Li

d (mm)	N/N_0
10	11.4%
15	3.8%
17	2.5%

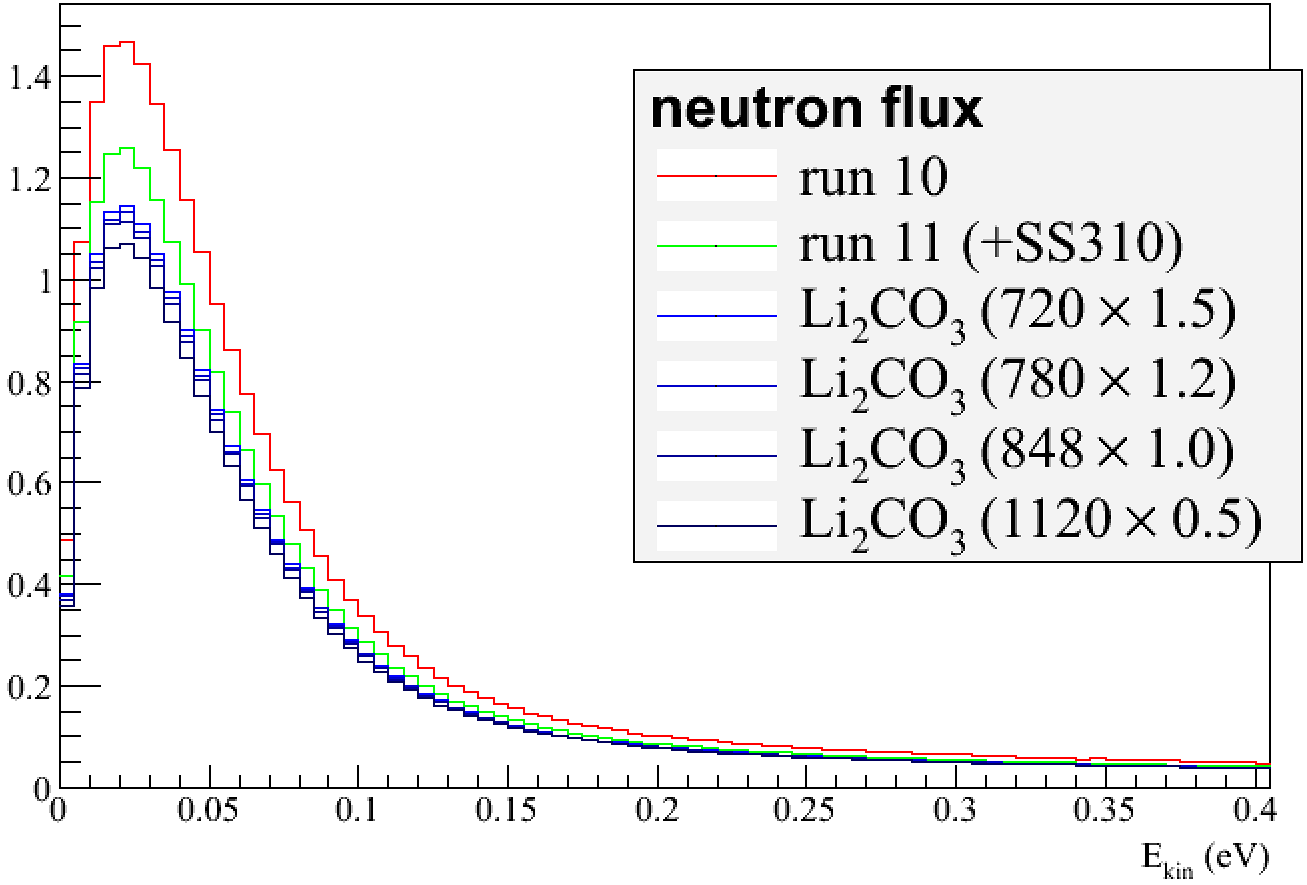
Enriched Li

d (mm)	r_{max} (cm)	N/N_0
1.5	72.0	1.0%
1.2	78.0	2.5%
1.0	84.8	4.6%
0.53	112.0	19.6%



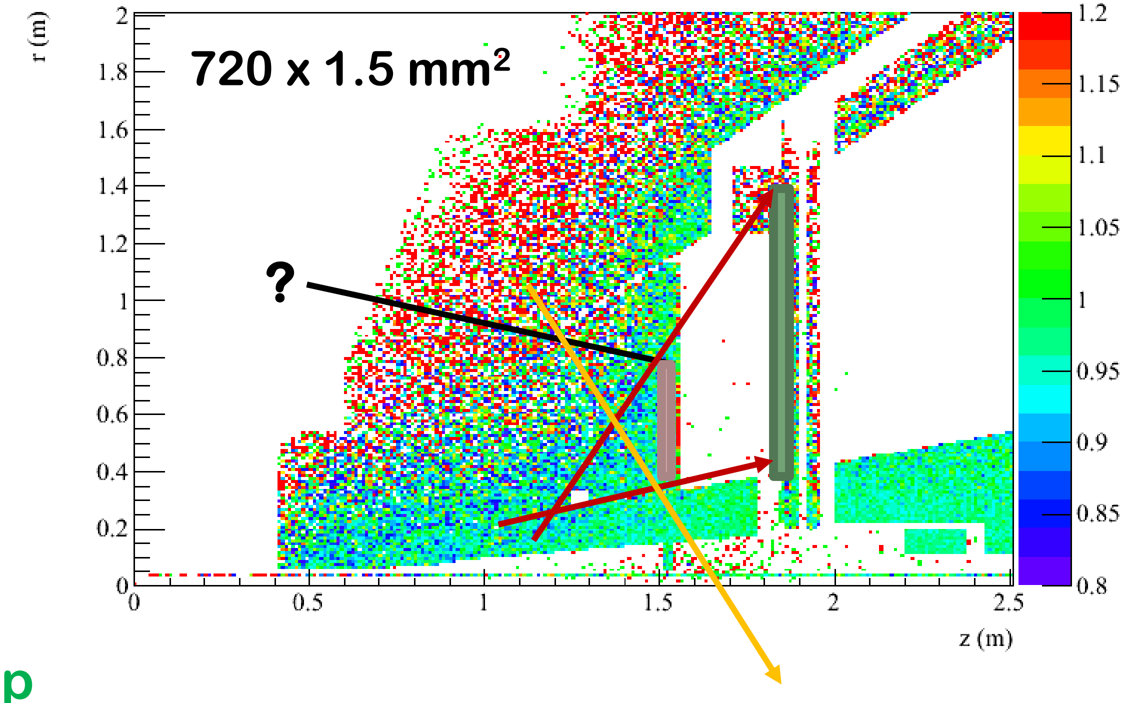
- 34 cm < r < 112 cm (last layer SS310)
- 8 kg enriched Li_2CO_3 for both arms @ UIUC
- ρ=2.1 g/cm³ → V=3800 cm³

Thermal neutron flux



- Area of absorber is more important than thickness

Thermal neutron origins

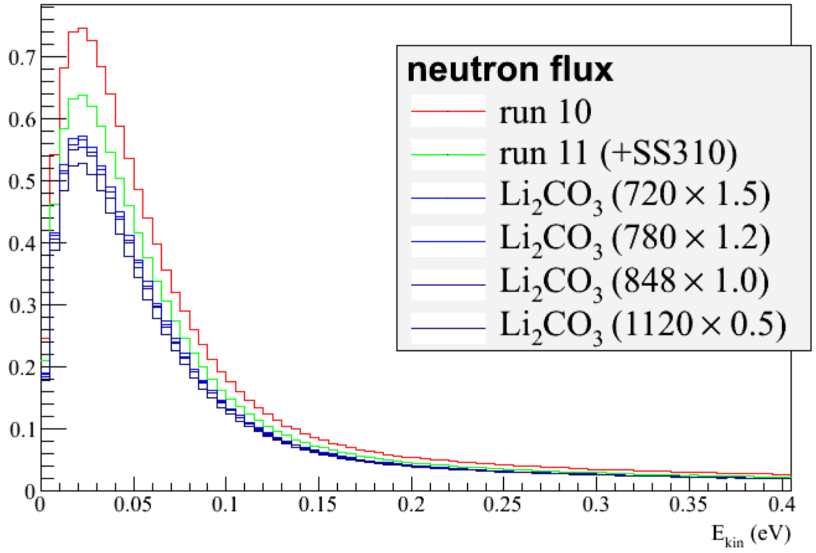


- Relative to run11 setup

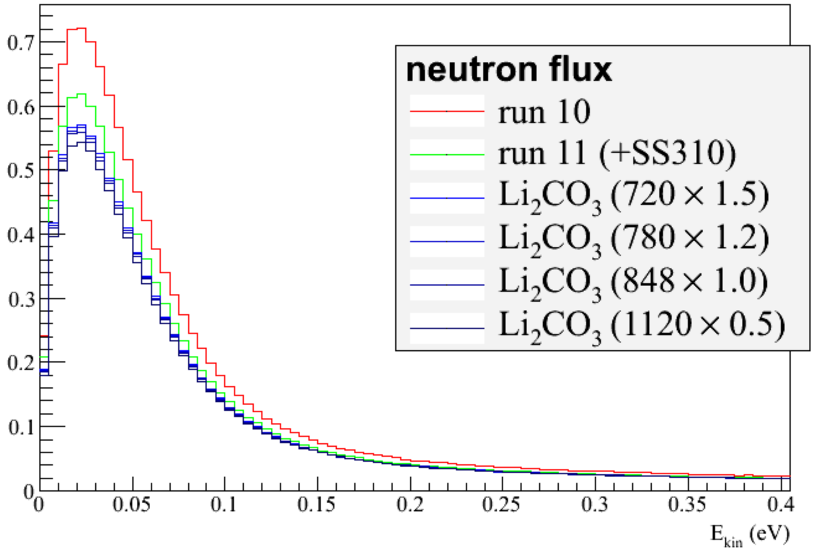
- No clear edge can be seen where the lithium absorber ends
- Total shadowing of the absorber is significantly smaller for reduced area of absorber (rotational symmetry of detector)
- Straight lines are not correct for thermal neutrons

Thermal neutron flux II

neutrons going downstream $p_z > 0$

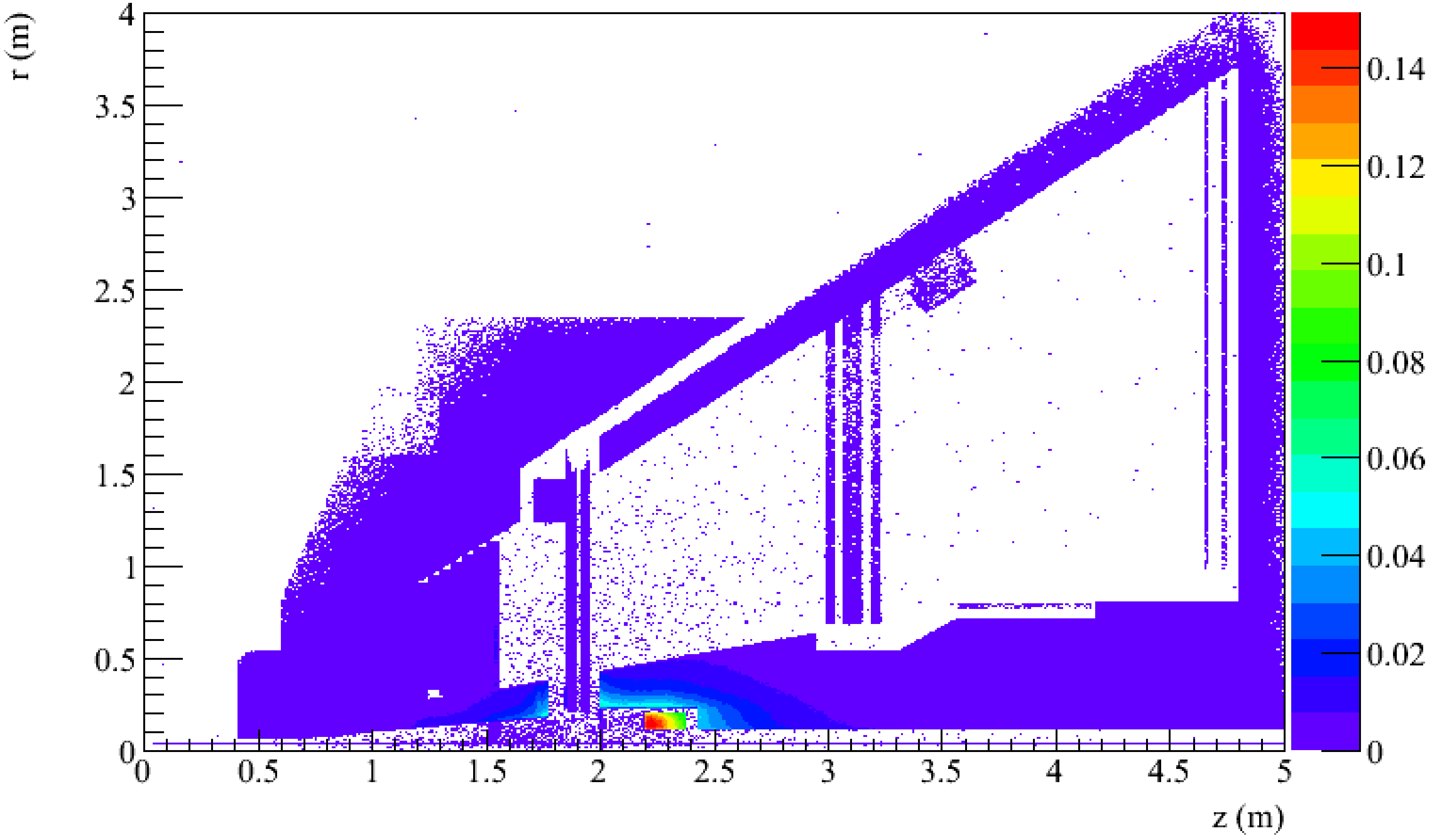


neutrons going upstream $p_z < 0$



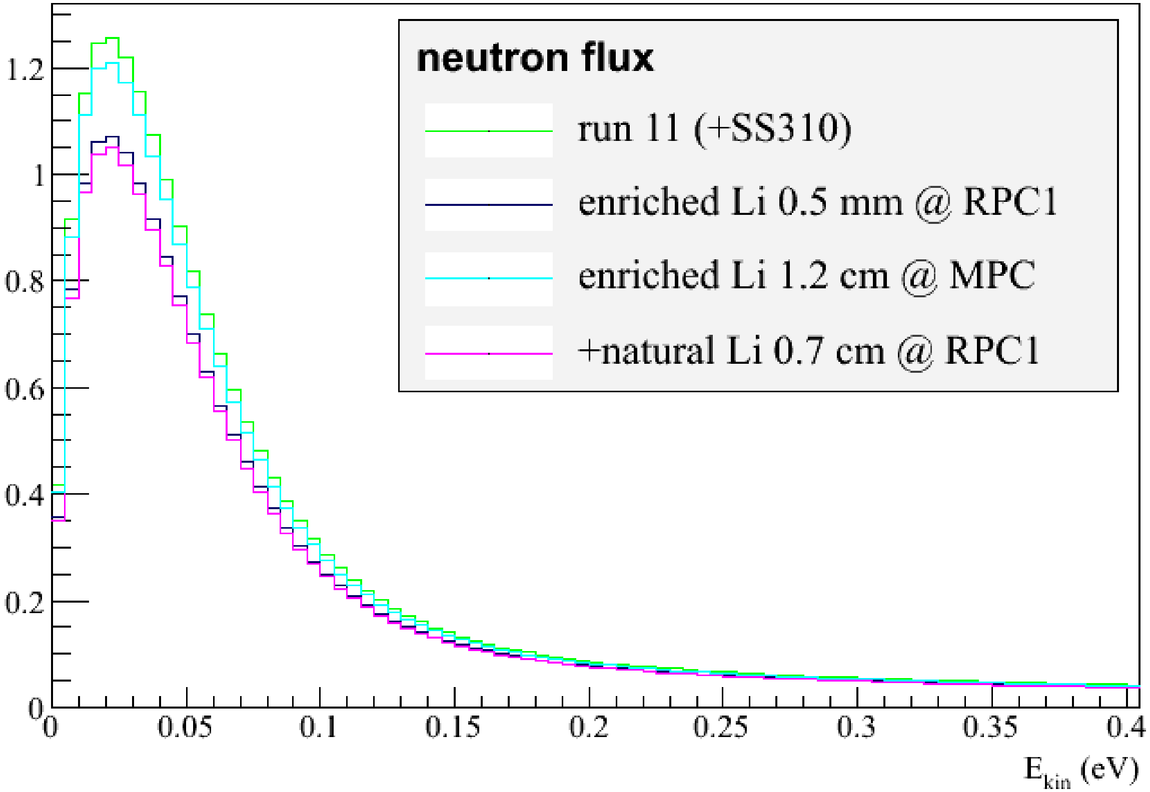
- The absorber has a slightly larger effect on downstream going neutrons.

More effective absobers?



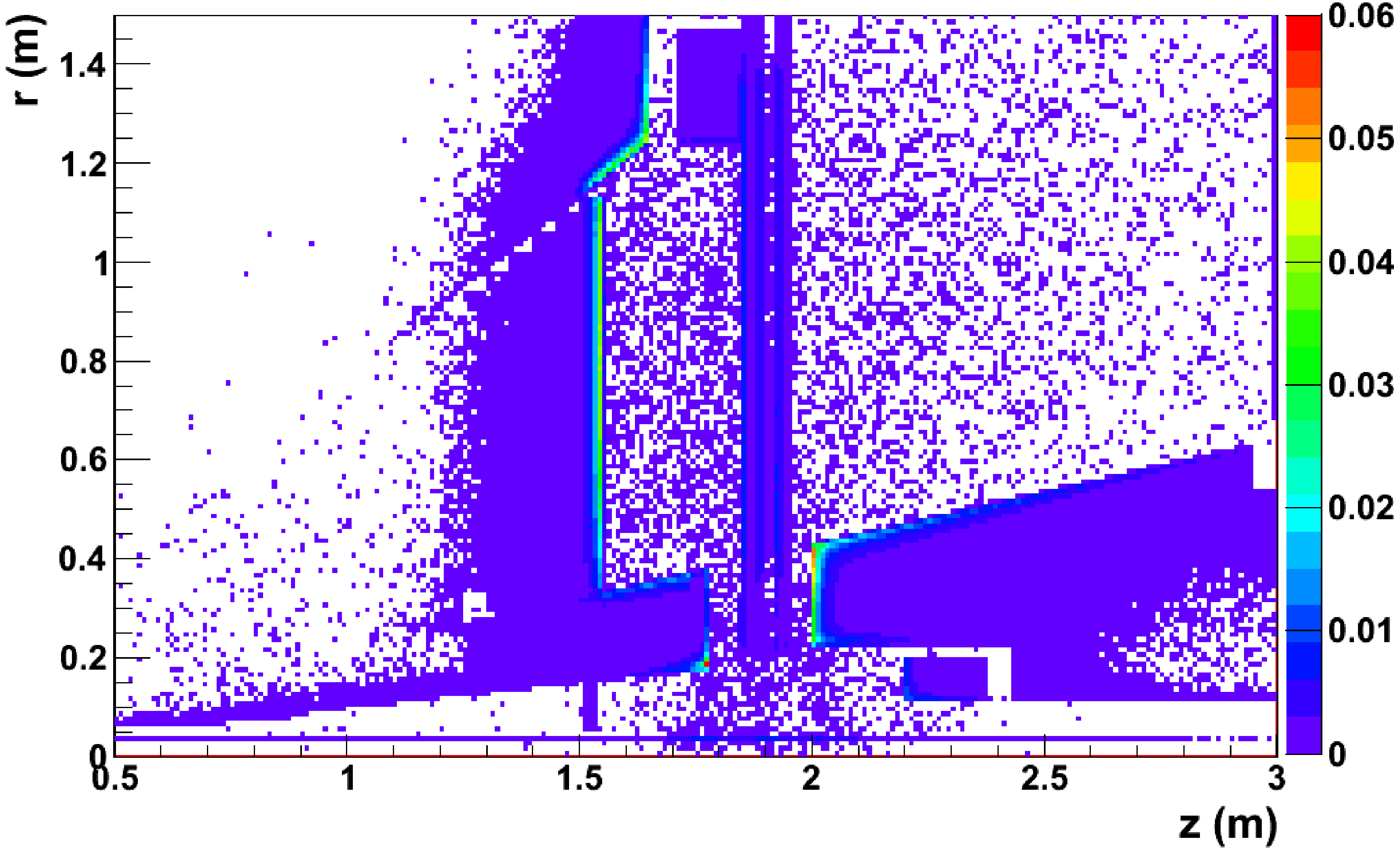
Absorber in the piston hole

- Li_2CO_3 absorber at the <u>opening</u> of the piston hole
- Using all UIUC Li_2CO_3
- 22.0 cm radius
- 1.2 cm thick



⇒ neutrons do not thermalize in the piston hole

Photons in MuTr St1



Summary

- New steel absorber is not increasing the thermal neutron flux anywhere in the muon arms
- Additional neutron absorber scenarios are less effective than expected
- Large area of lithium absorber seems to work best
- Neutrons do not thermalize close to their origin
- Additional photon absorber may be beneficial

- Finalize absorber studies/scenarios
- Finalize cross checks (ABLA model)
- Finish analysis note

⇒ CVS: offline/analysis/MuonArmNeutrons/