

Cosmic Backgrounds in Surface Measurements

Applied Antineutrino Physics — December 7, 2015

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on behalf of the PROSPECT Collaboration



scope of relevance

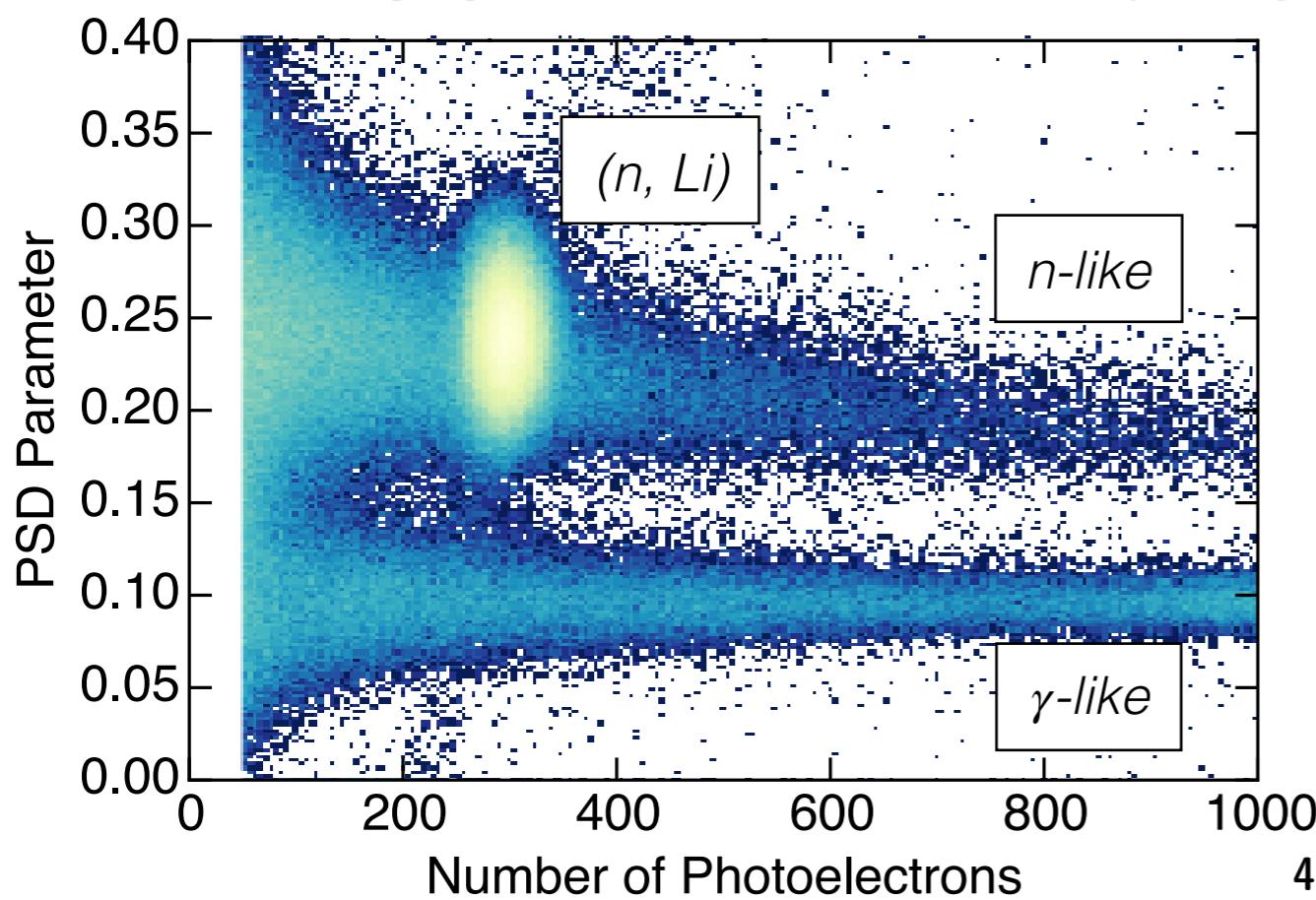
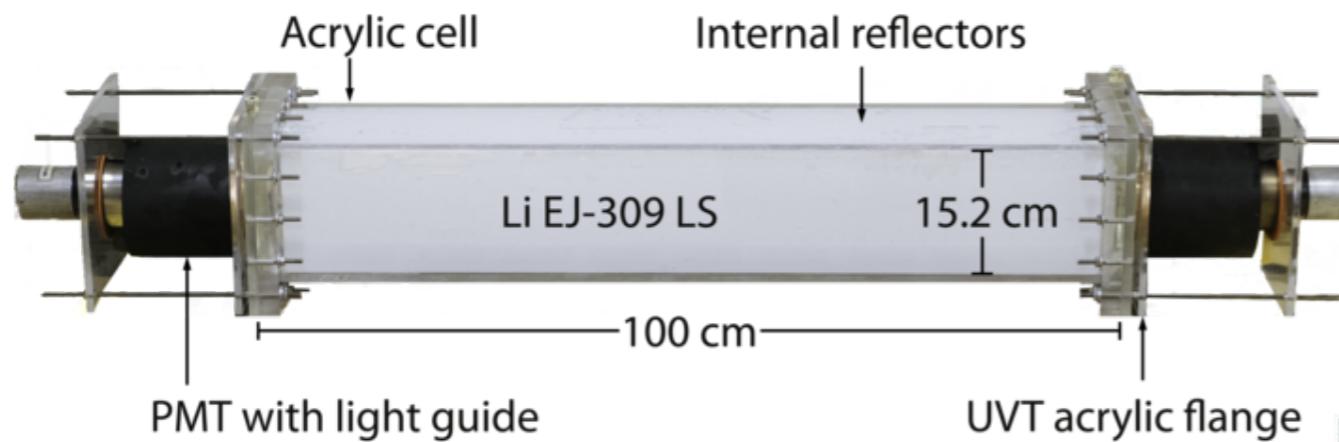
- detector is ~~PROSPECT~~
- detector operates in near-surface environment
- signal of interest is neutron-capture correlated (IBD, fast neutrons, induced fission) and low-rate
- applications: antineutrinos, fast neutron spectroscopy, SNM detection, active/passive interrogation

detection characteristics

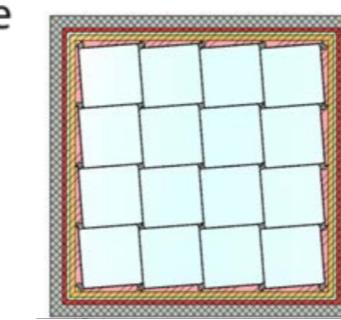
- neutron capture coincidence is a distinctive signal: $O(10\text{-}100\mu\text{s})$ timescale for capture is long compared to ns-scale electron/gamma physics, but short compared to accidental coincidence rates
- backgrounds of concern require the presence of actual neutron(s)

PROSPECT detectors

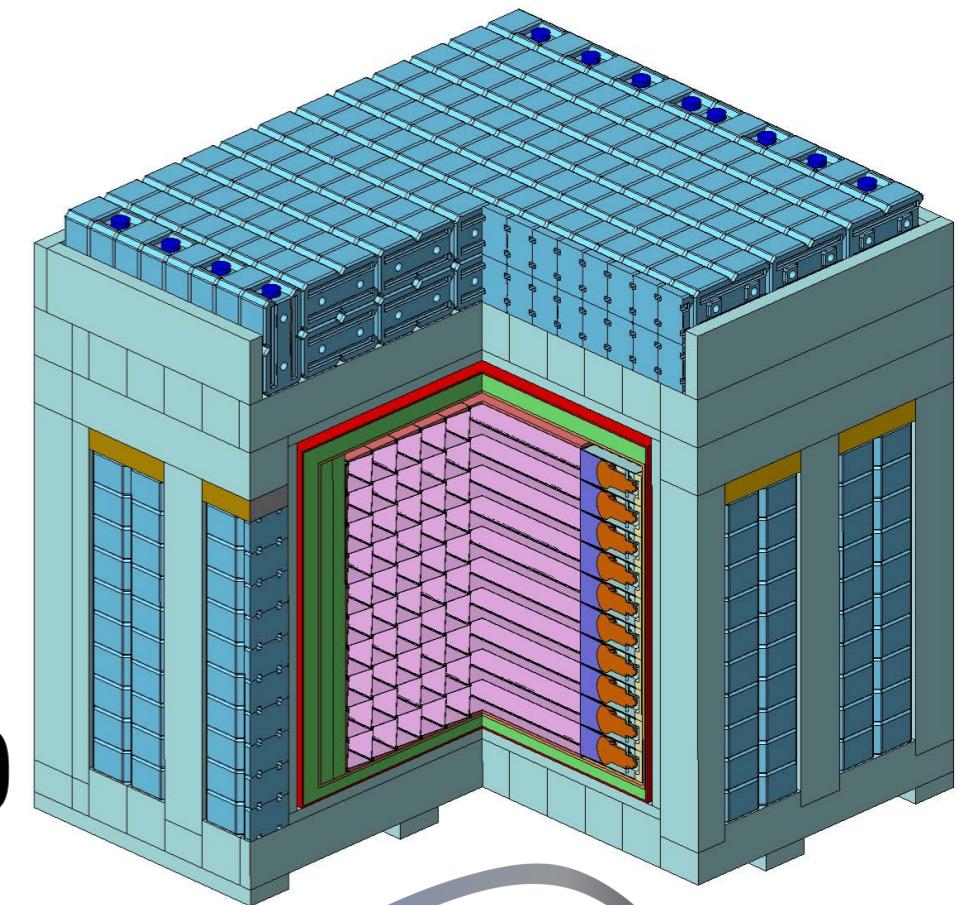
P20 prototype cell
20-liter 0.1% ${}^6\text{Li}$ -loaded EJ-309



“Phase I” design
120x P20 cells



“P400”
16x P20



PROSPECT

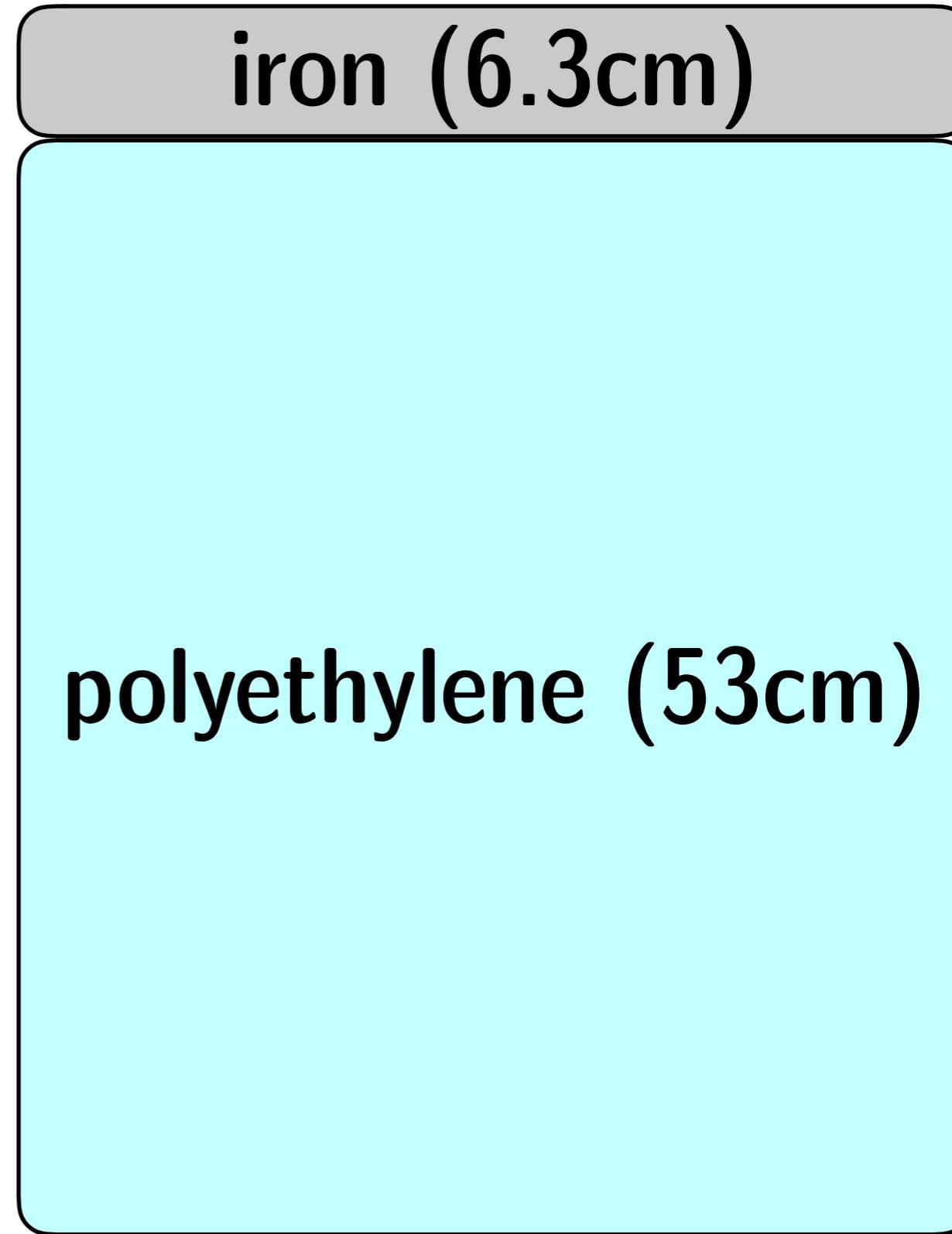
where do neutron backgrounds
come from?

large overburden

- km-scale overburden: long-lived radioisotopes in surrounding rock (n,α decays); contamination brought from surface (including cosmic-ray-activated isotopes)
- 10m-scale overburden: cosmic-ray-induced neutron spallation showers

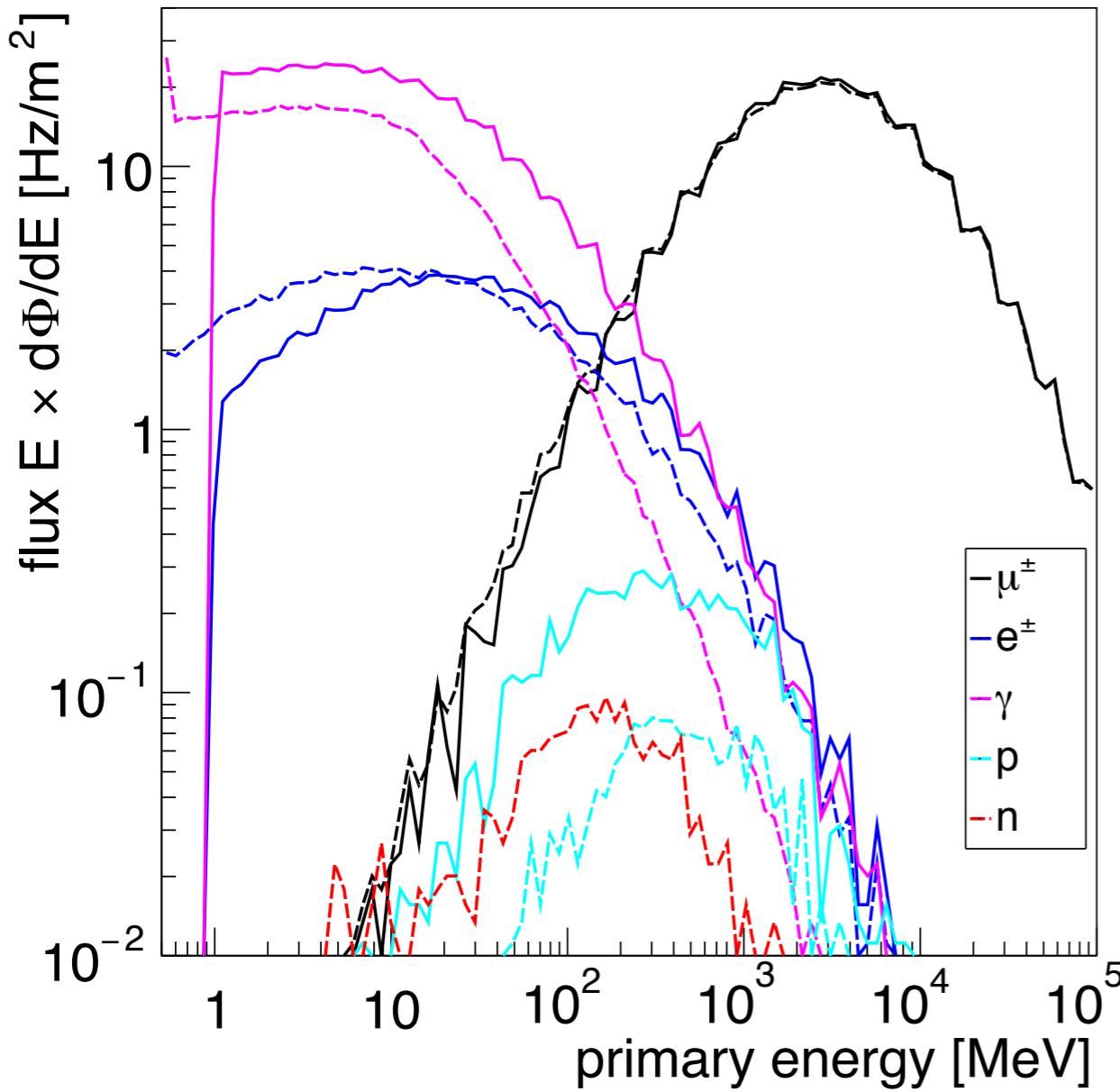
meter-scale overburden

toy model:
1 MWE shield;
equal-mass layers
iron and
polyethylene
+ surface cosmic
backgrounds



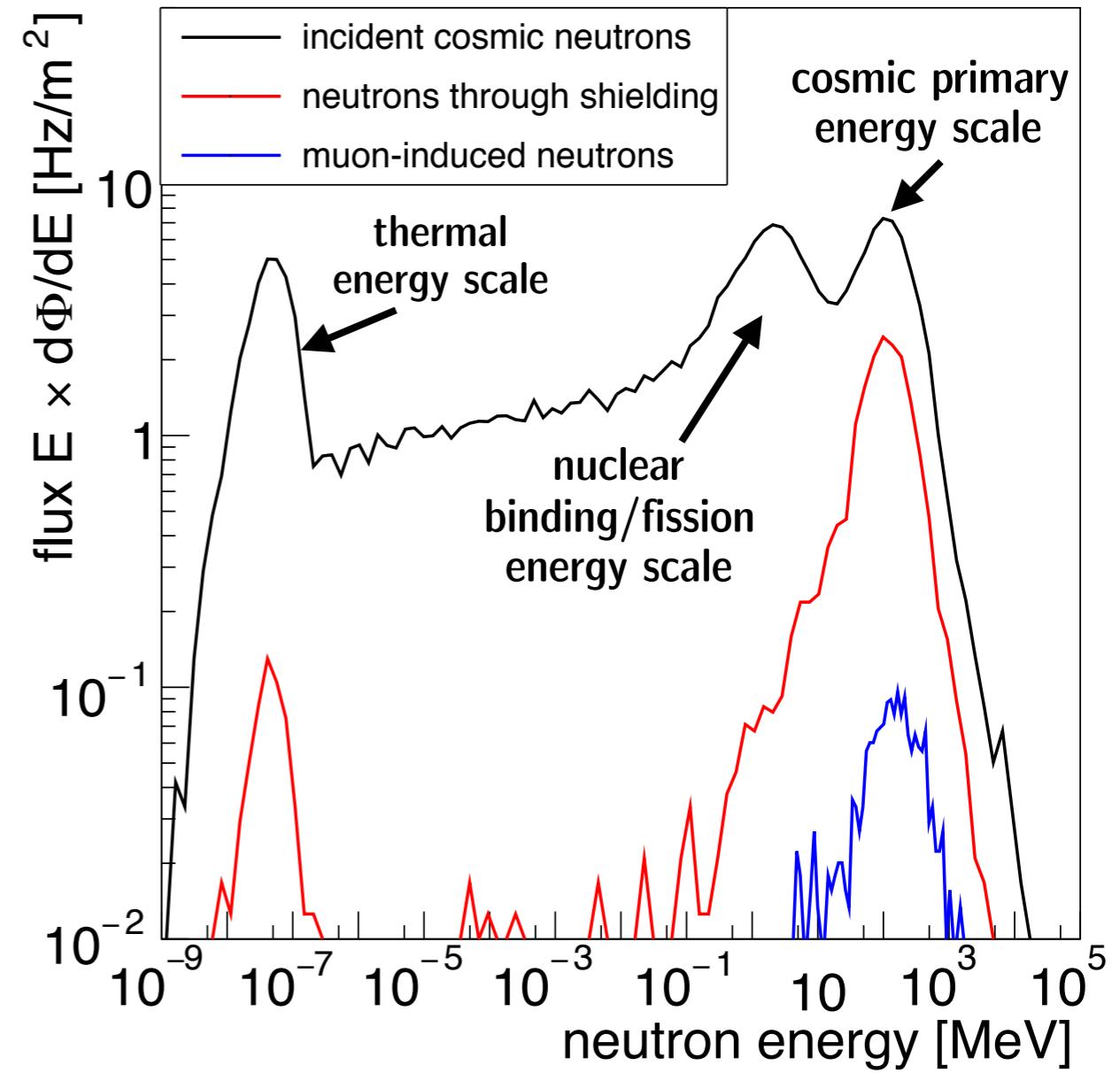
meter-scale overburden

non-neutron cosmics

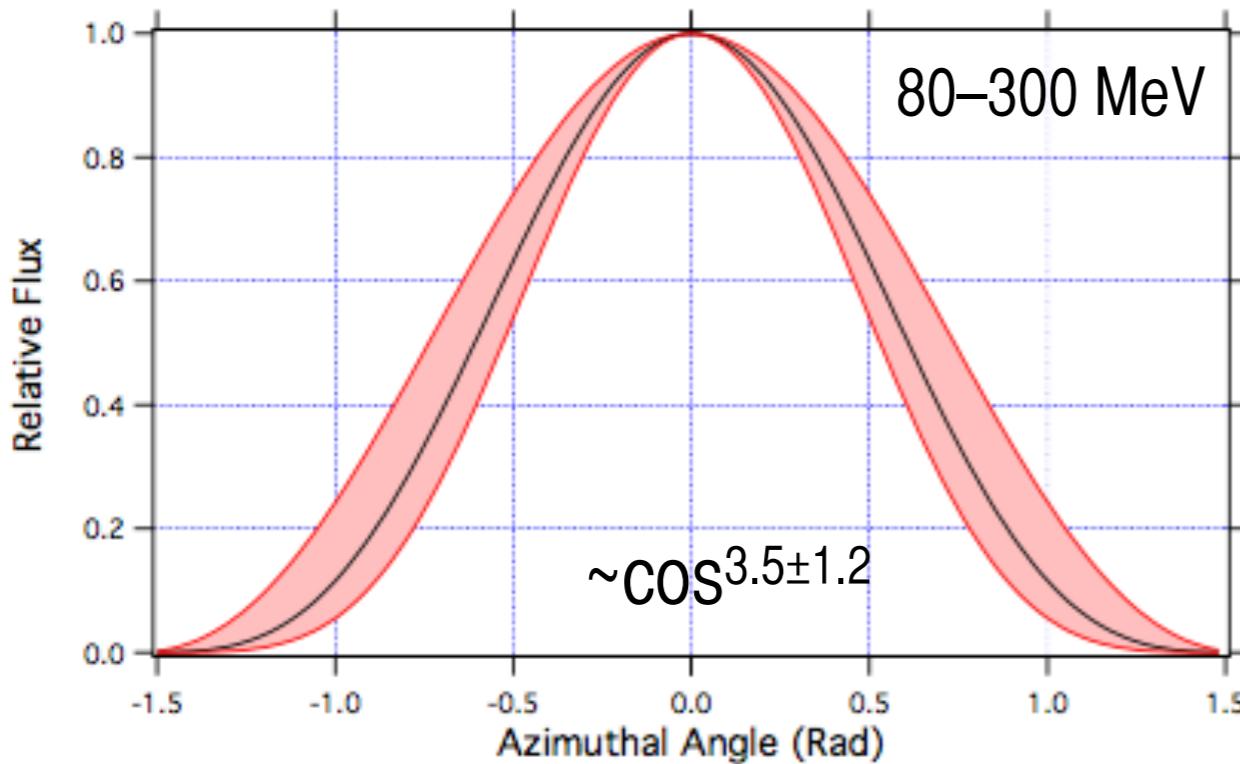


(CRYv1.7 primaries)

cosmic neutrons

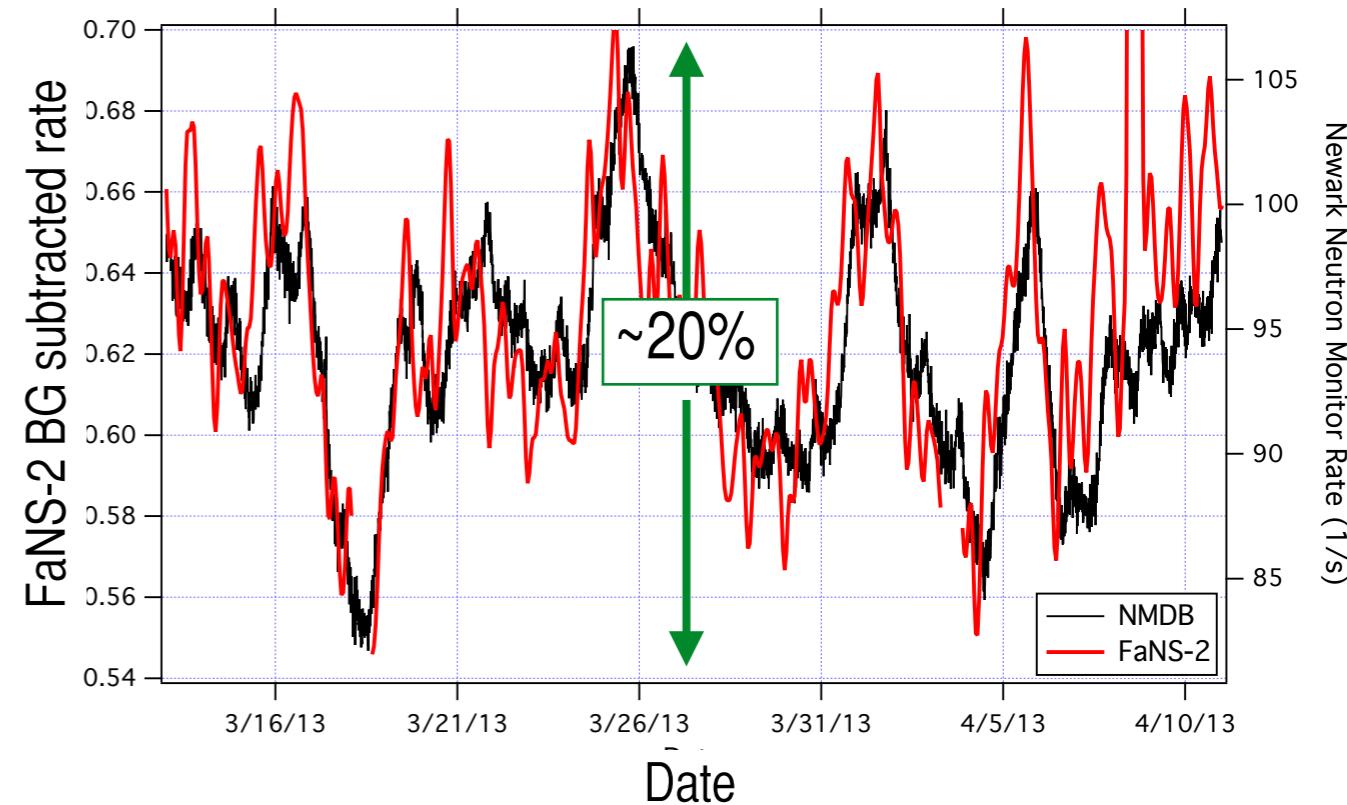


fast neutron component



E. Heidbreder, K. Pinkau, C. Reppin, and V. Schonfelder,
Journal of Geo- physical Research 76, 2905 (1971).

highest-energy component
largely downward-directed
(lower energy components
isotropized by shielding)

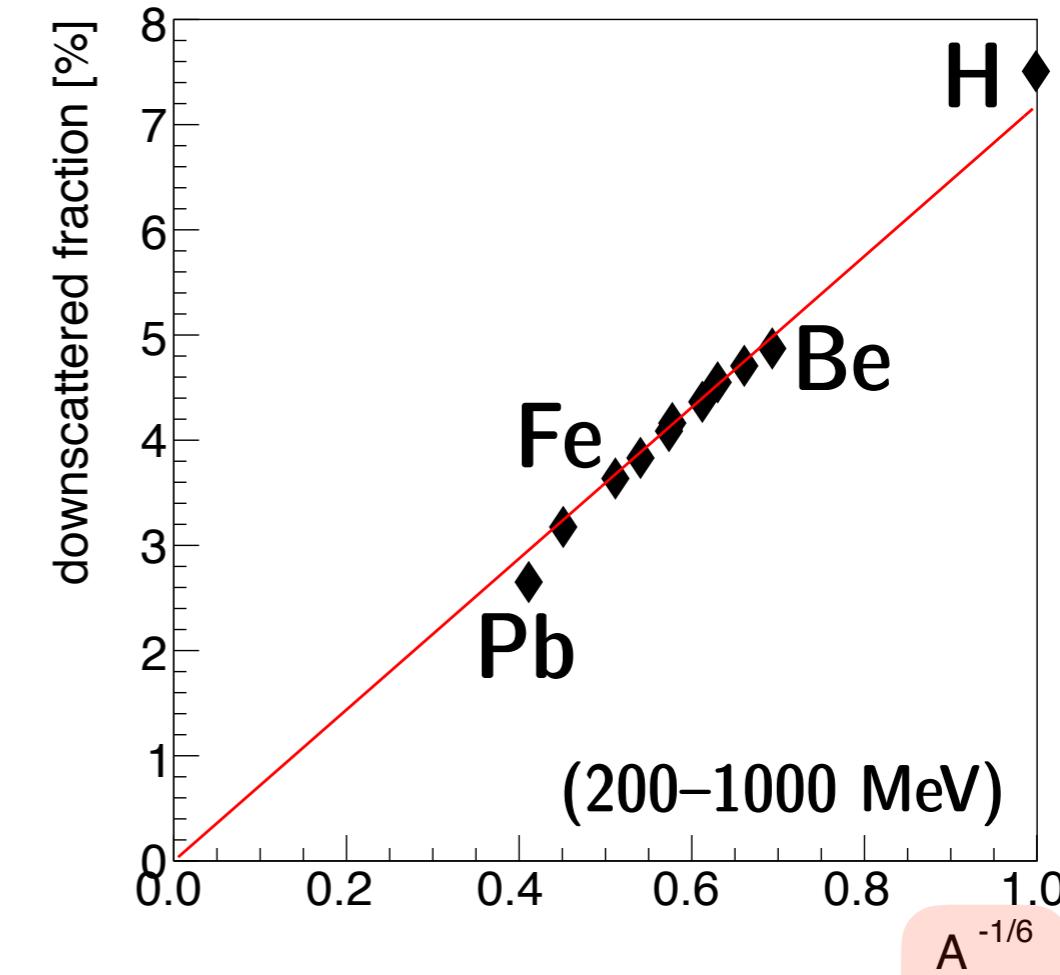
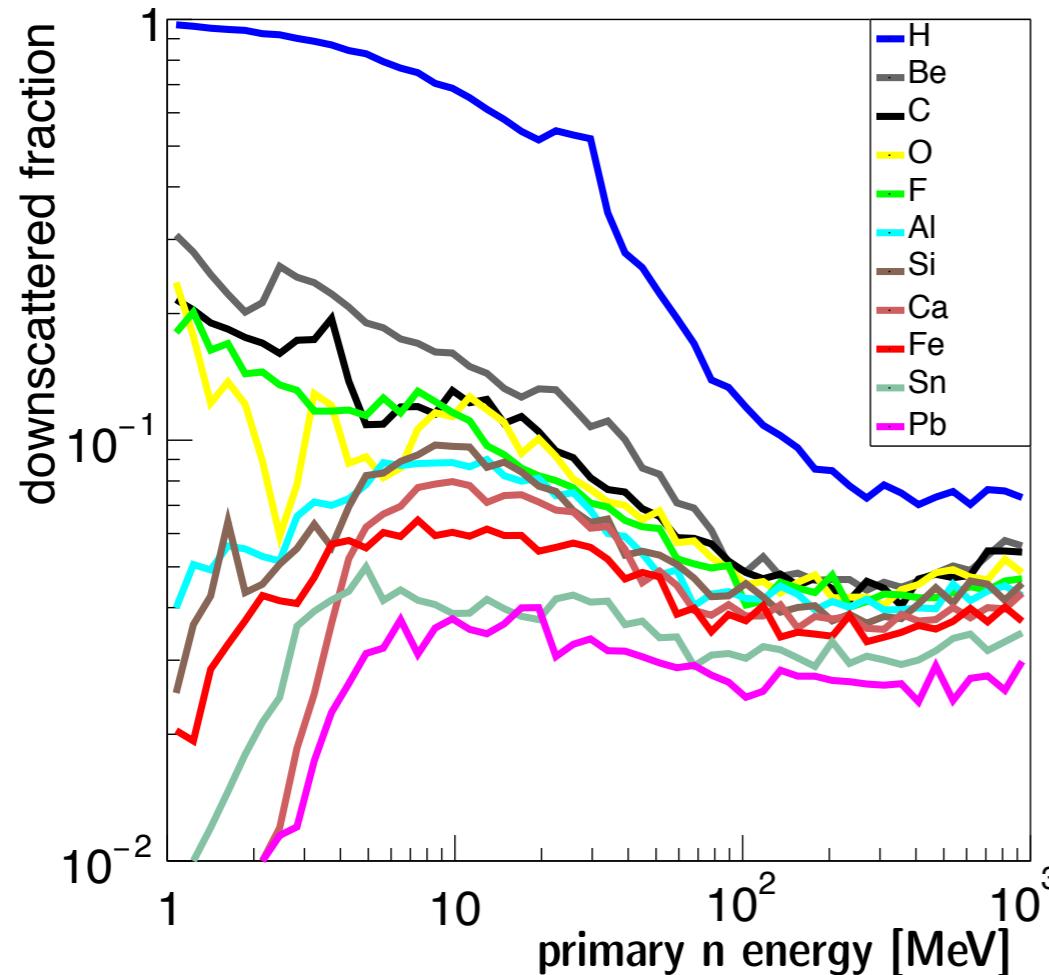
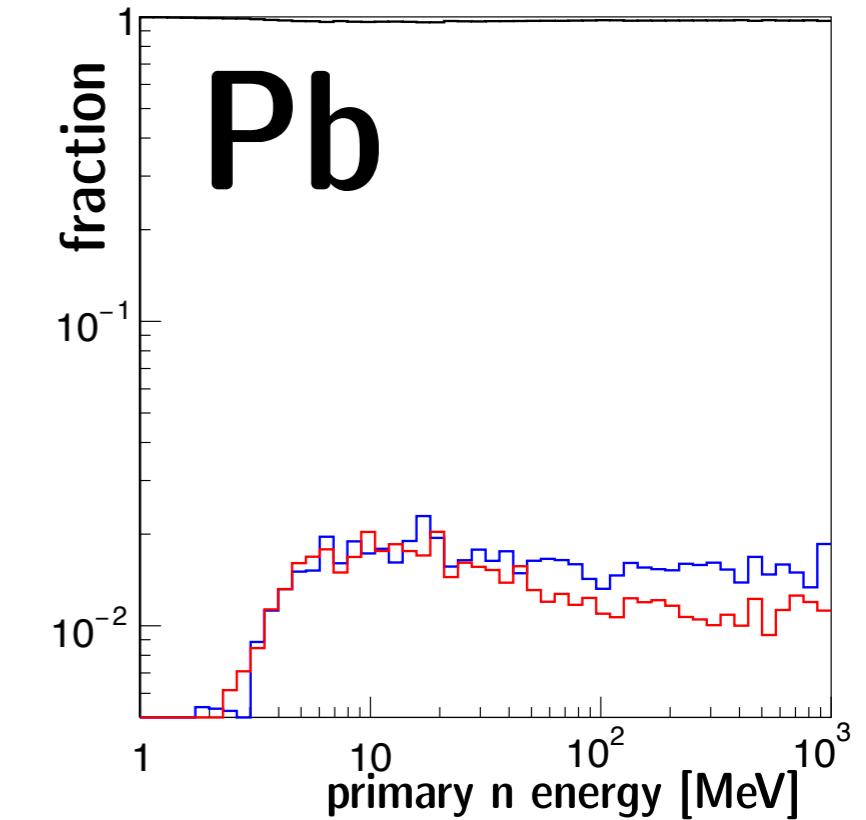
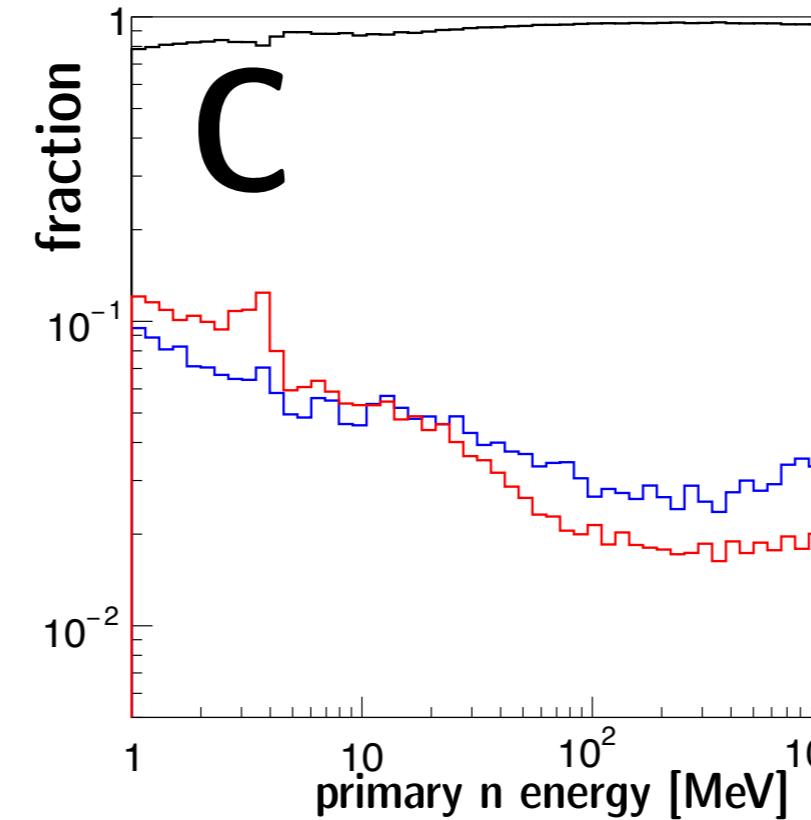
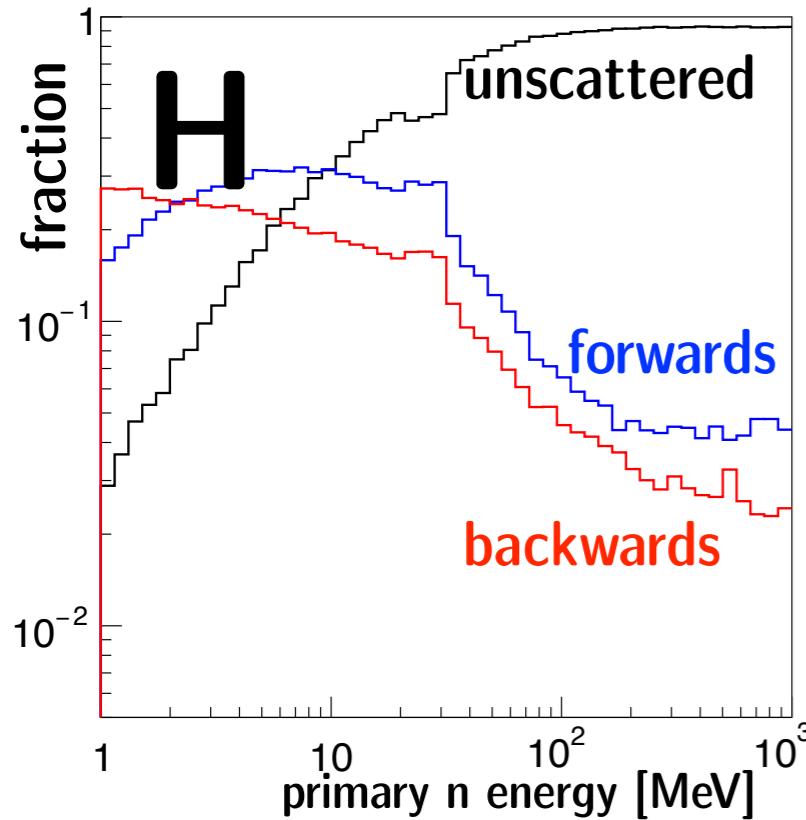


time-varying from (well
measured) solar weather,
atmospheric pressure,
local weather

fast neutron interactions: survey of elements

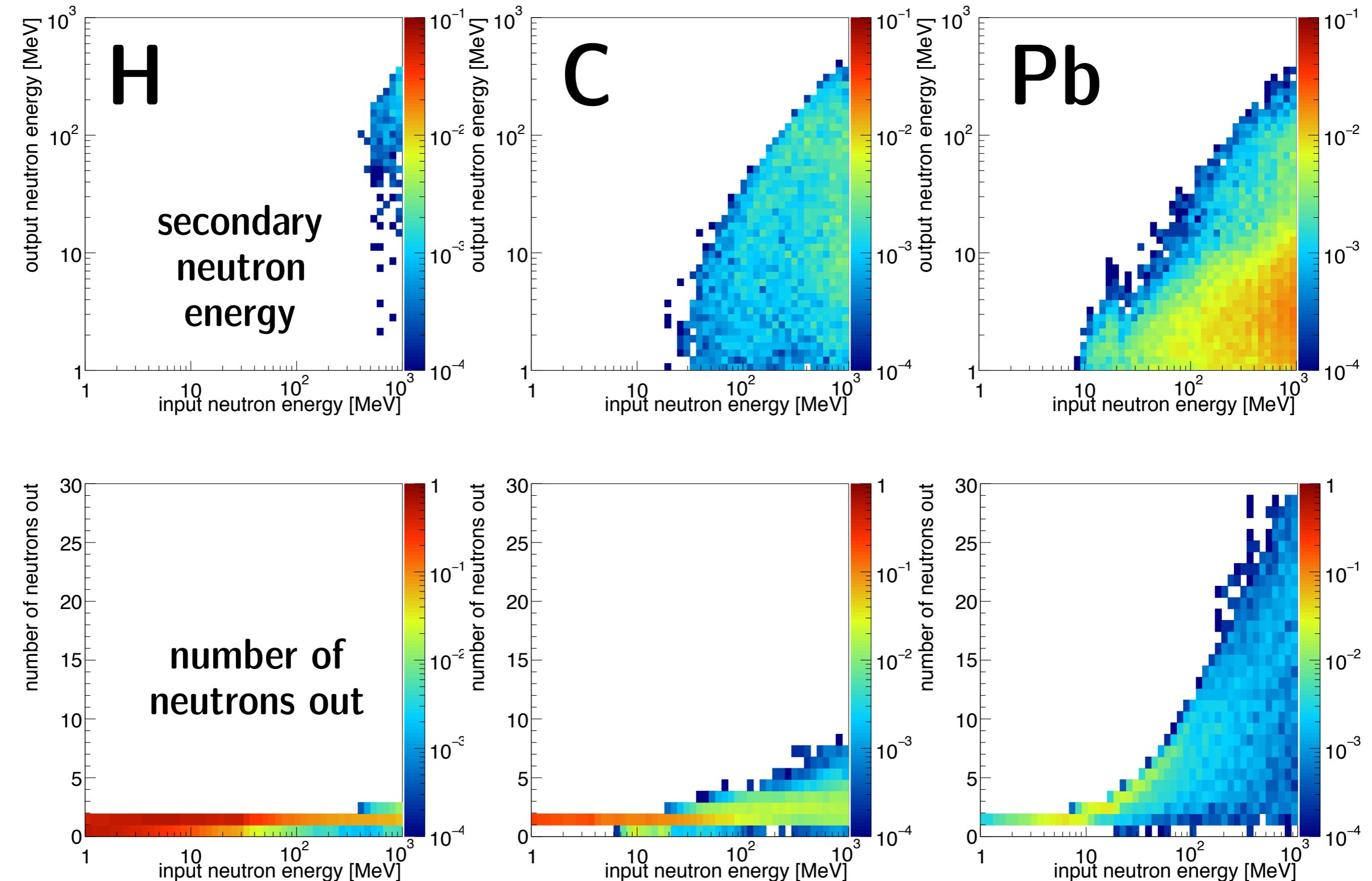
- bulk materials in detector, shielding
- normalized to constant mass, $1\text{g}/\text{cm}^2$ layer
- Geant4 (4.10.01) cross-sections, natural isotopic ratios

primary neutron downscattering

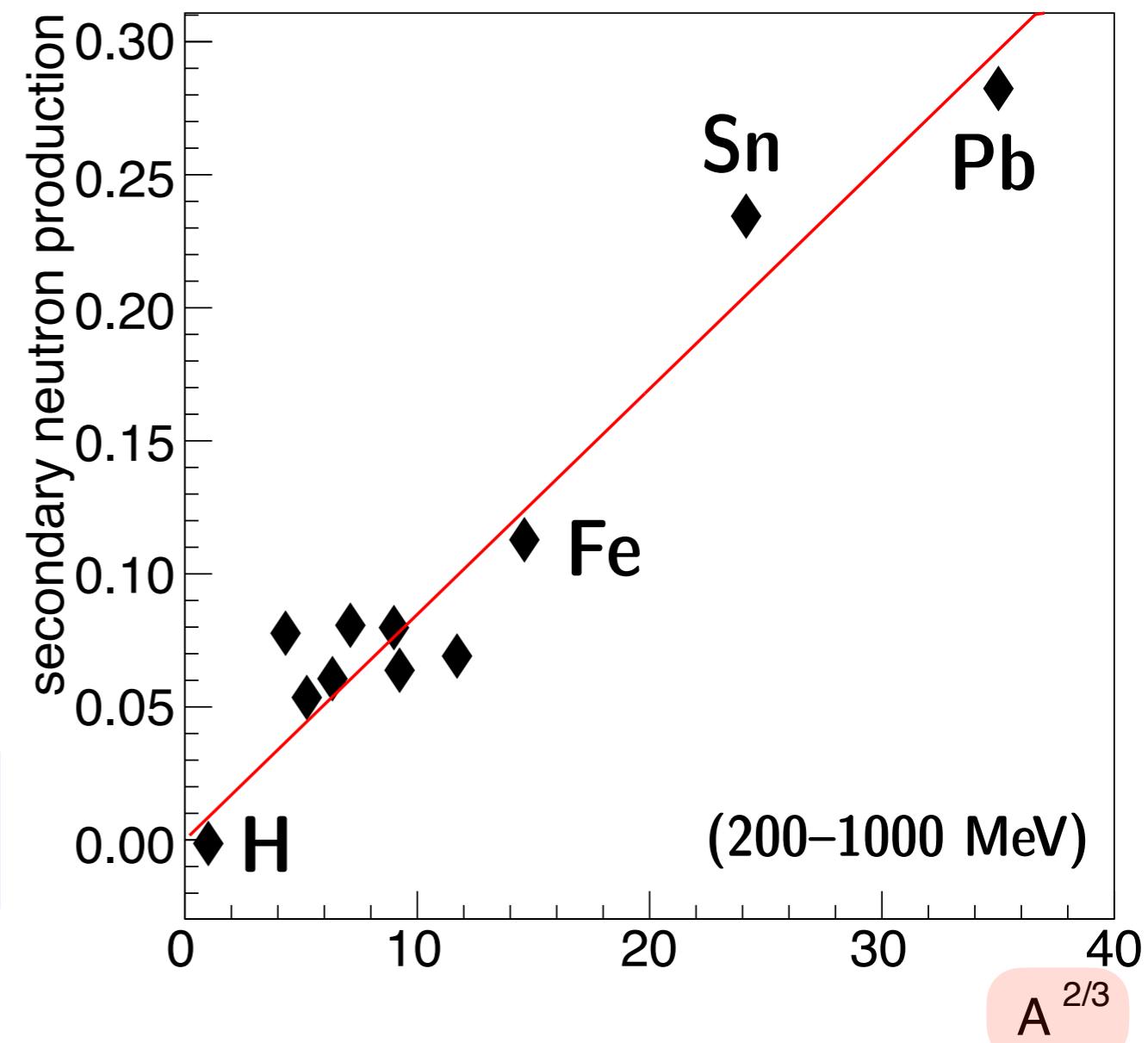
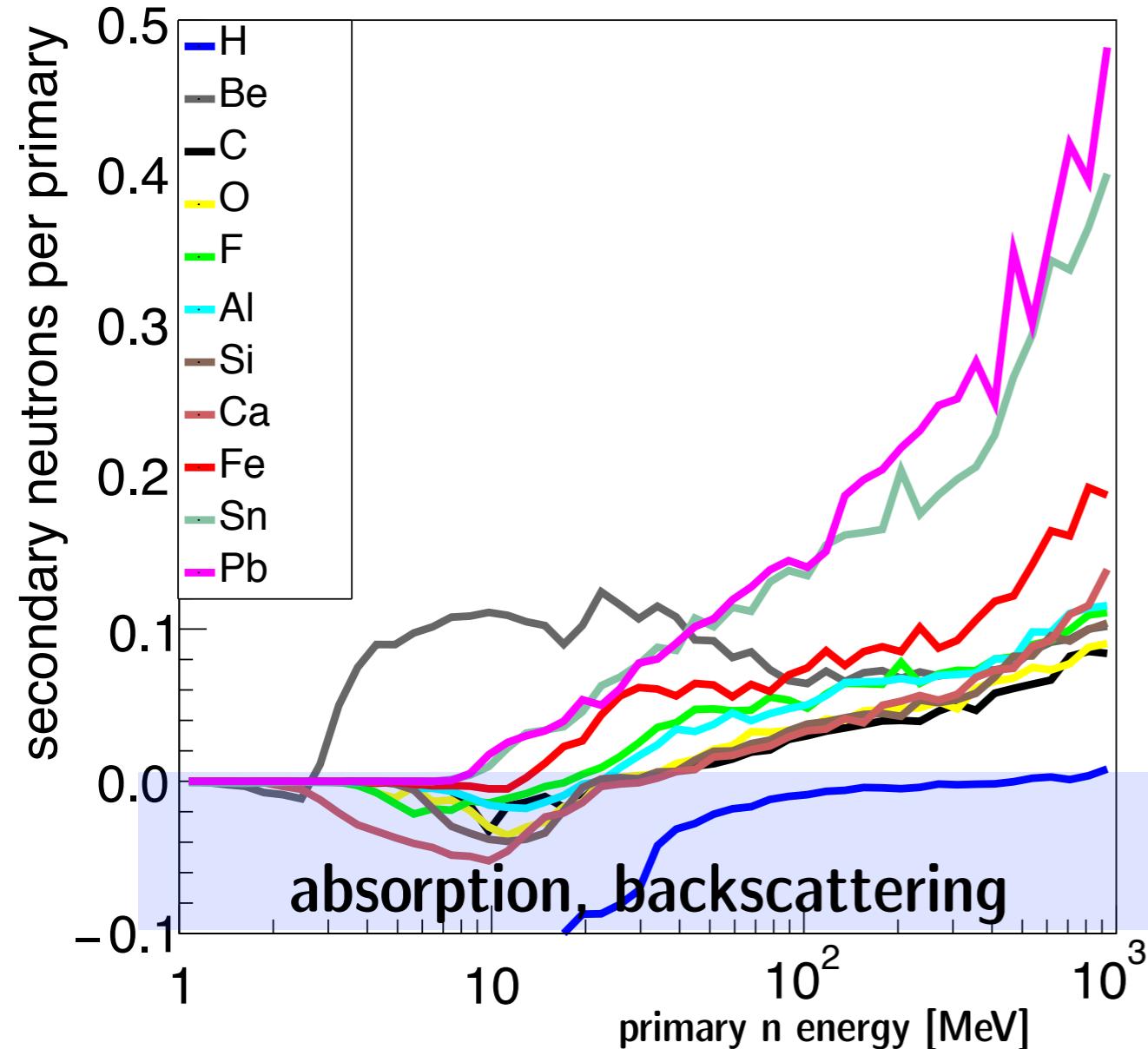


$A^{-1/6}$

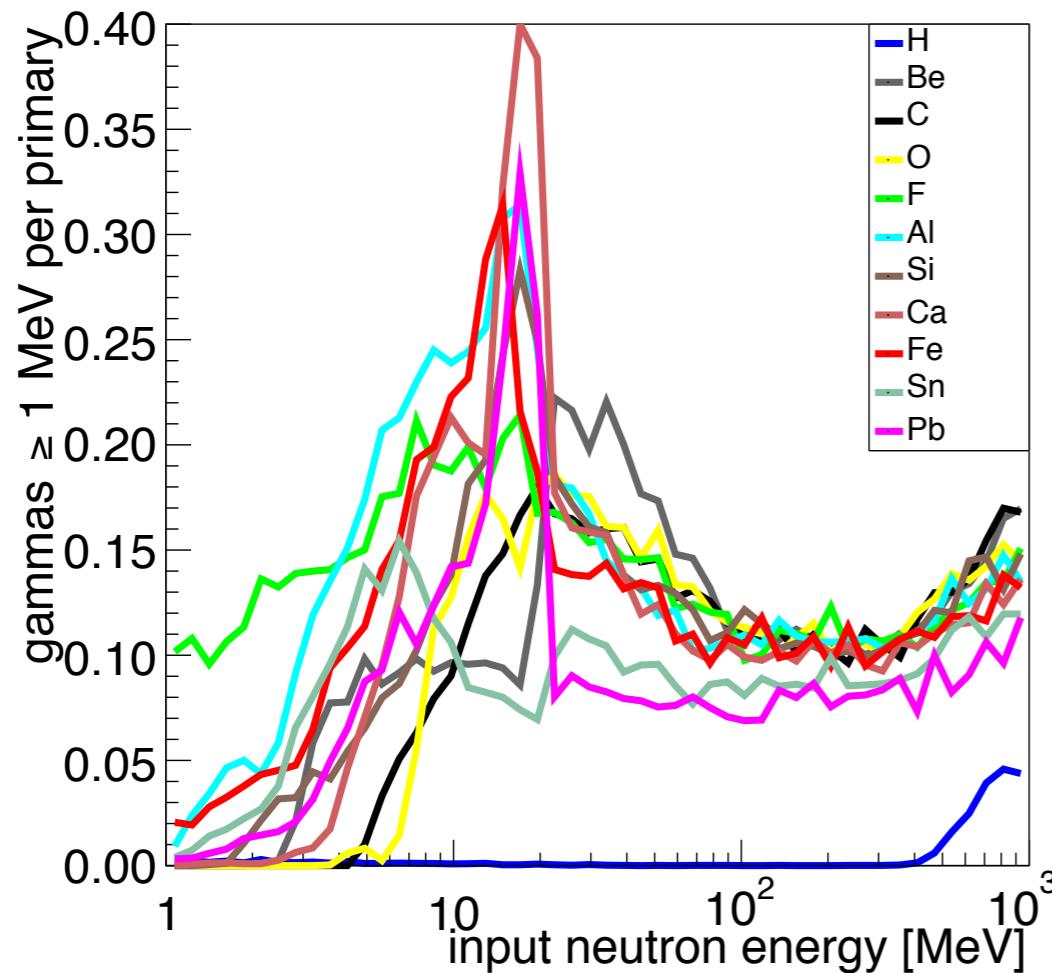
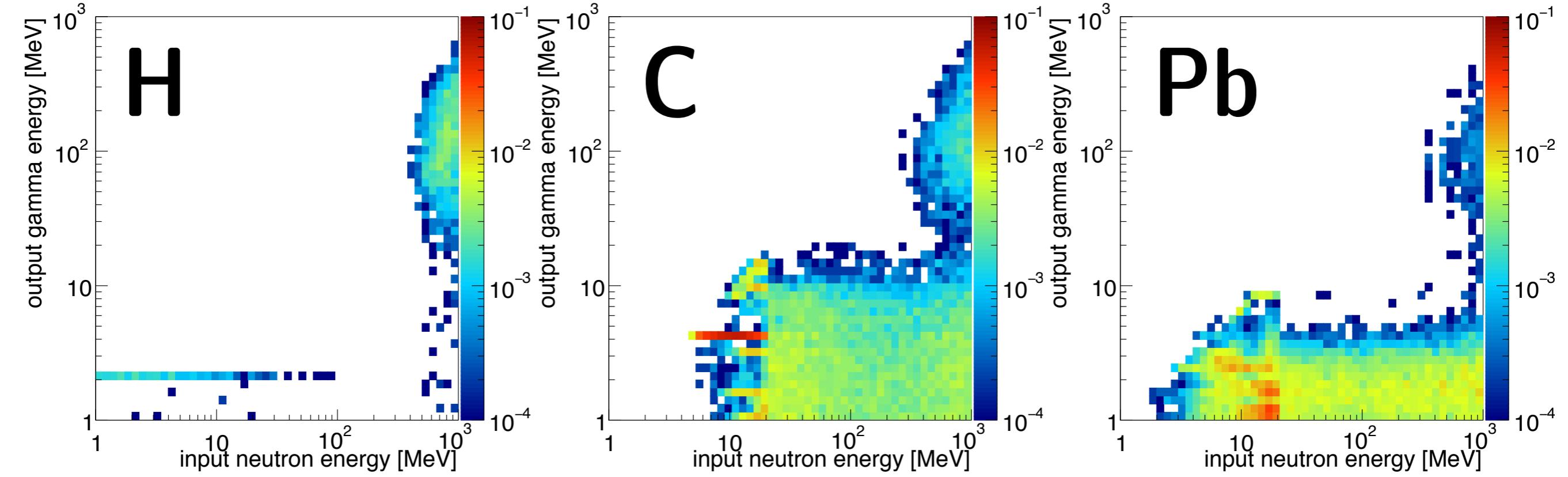
Secondary neutron production



Secondary neutron production



Gamma production



isotope-dependent,
similar scale

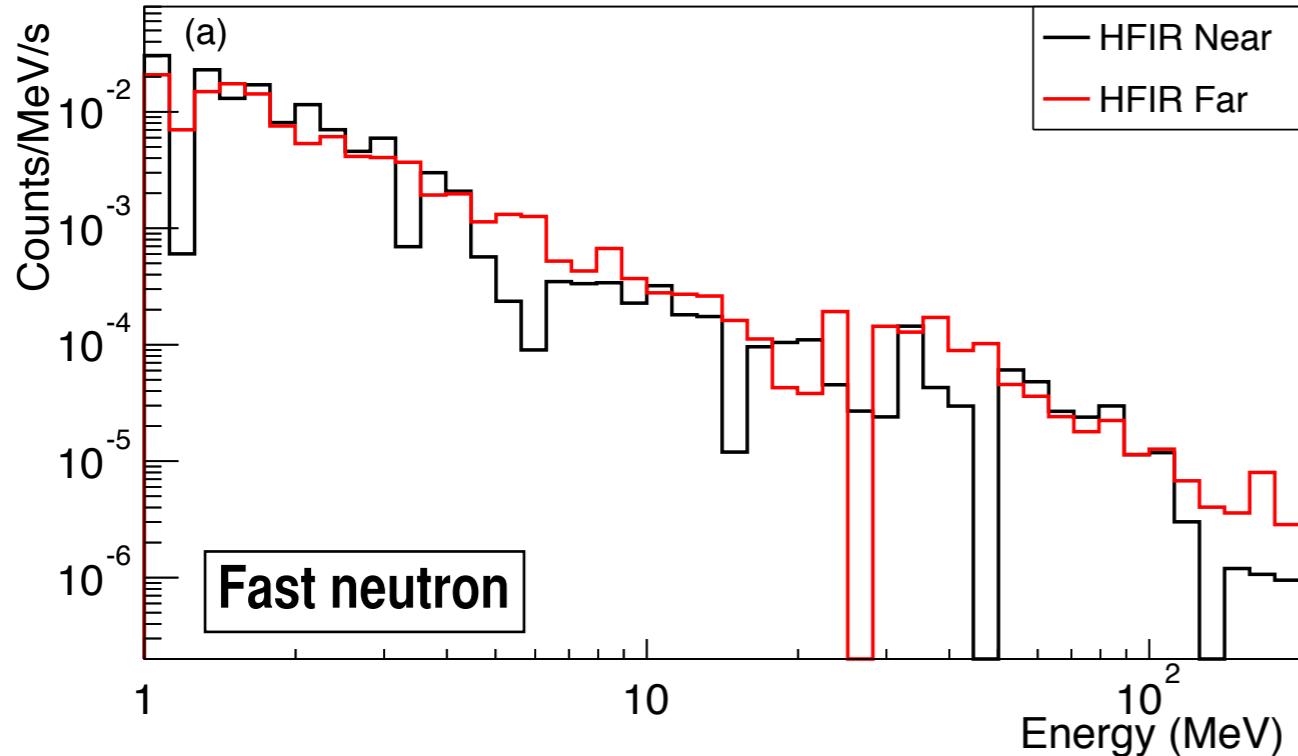
sanity check:

MC benchmarking

are MC predictions of cosmic neutron backgrounds, shielding/detector interactions usefully accurate?

compare against PROSPECT-20 prototype cell data.

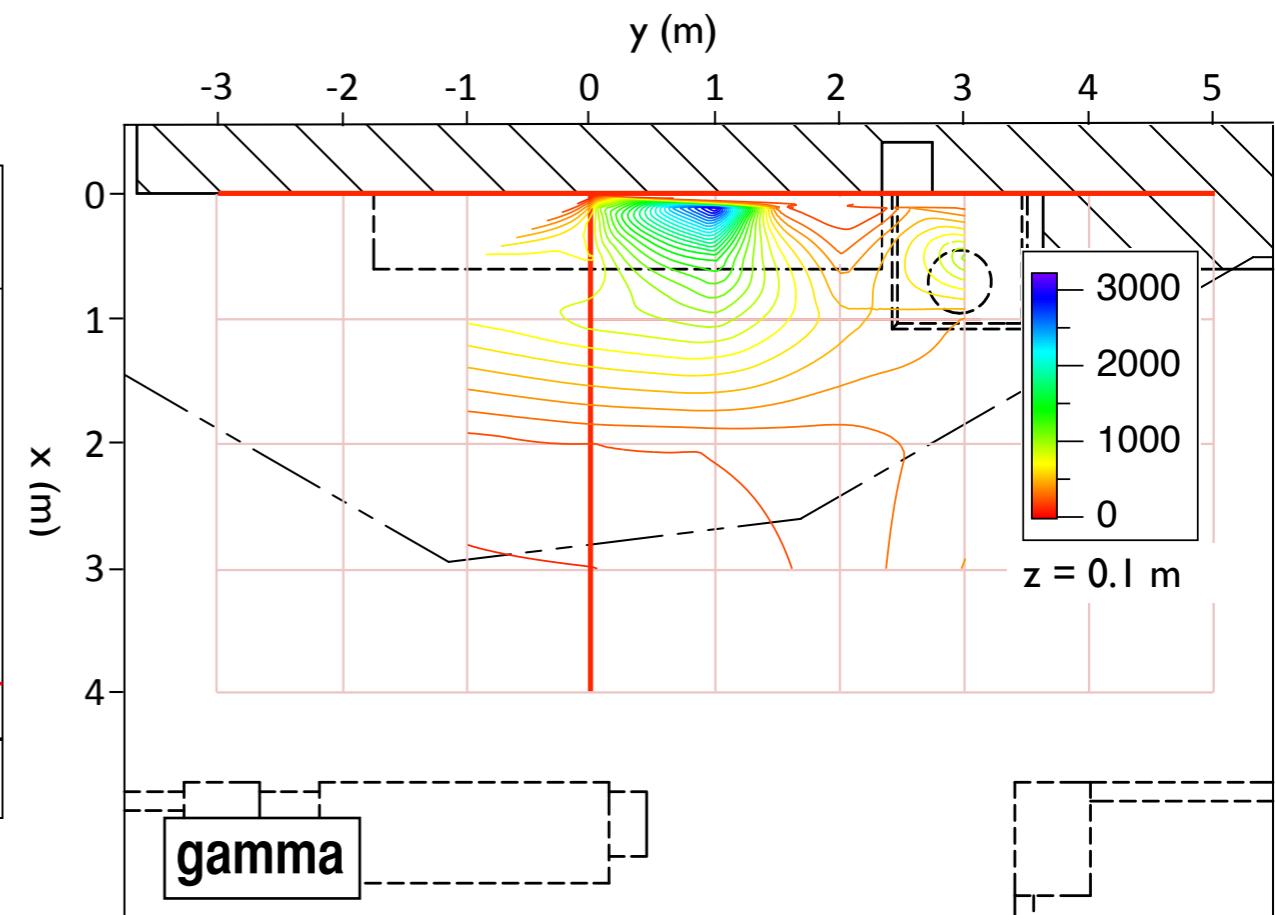
characterization of HFIR environment



Fast neutron spectra verify expectations with overburden and altitude

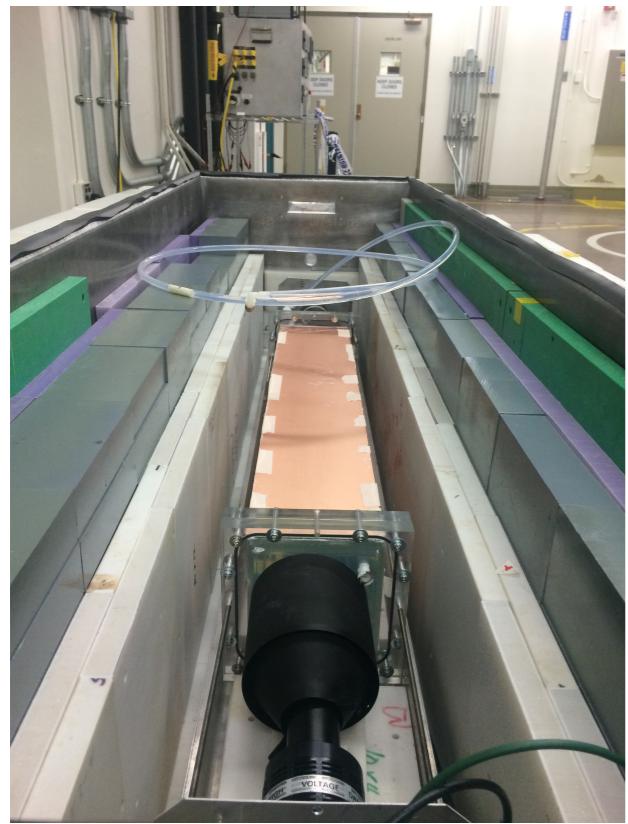
Extensive background surveys

- thermal and fast neutron, muons, gamma
- reactor on-off
- motivate targeted localized shielding

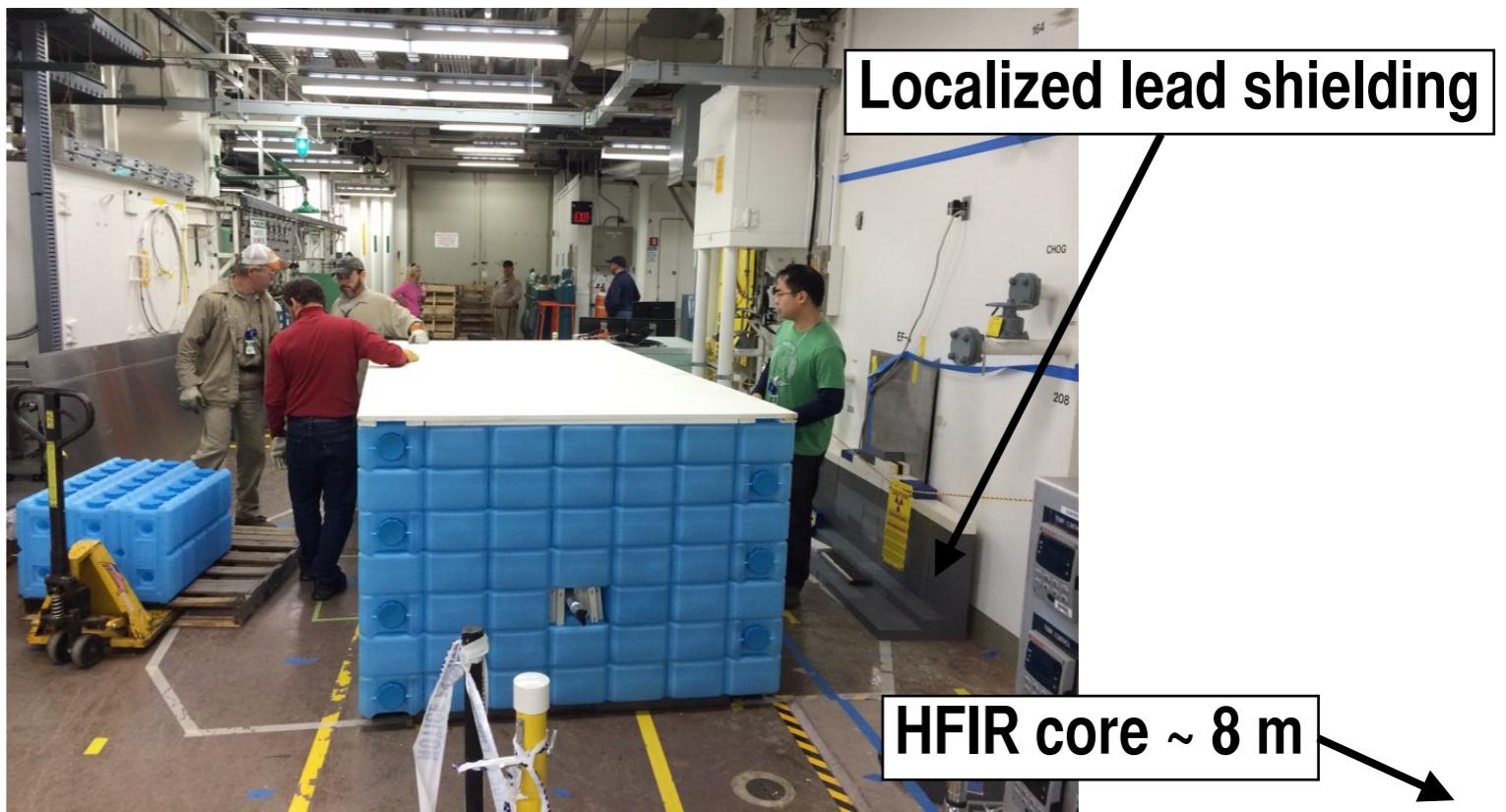


Significant reactor-related spatially varying gamma and thermal neutron fields

P20 cell

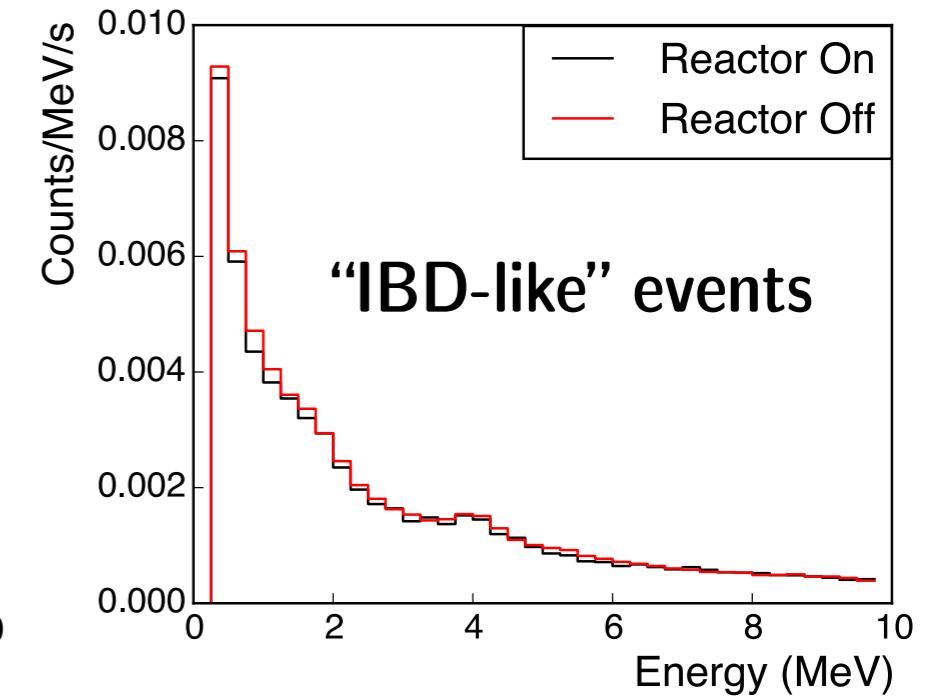
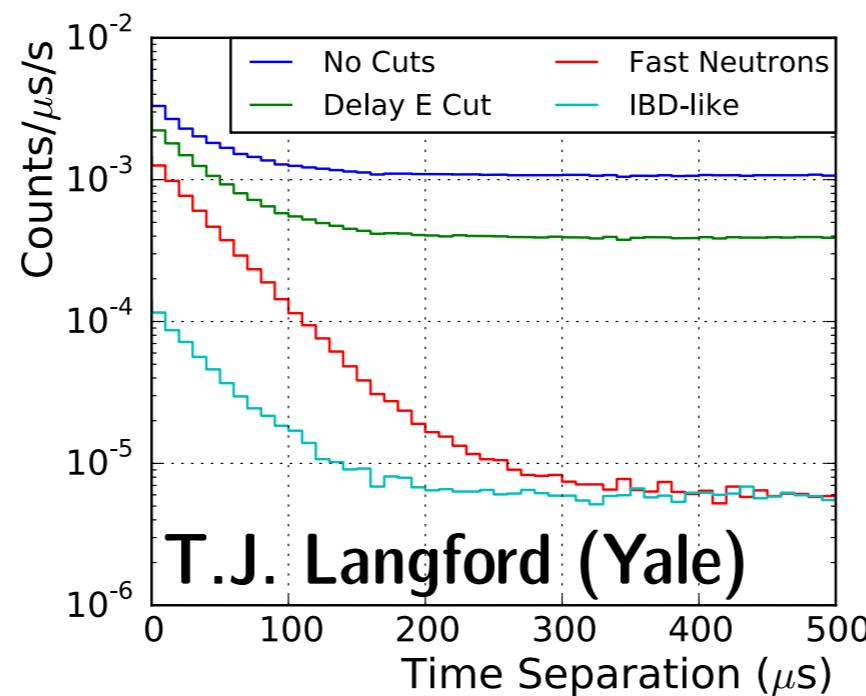


in shielding at HFIR



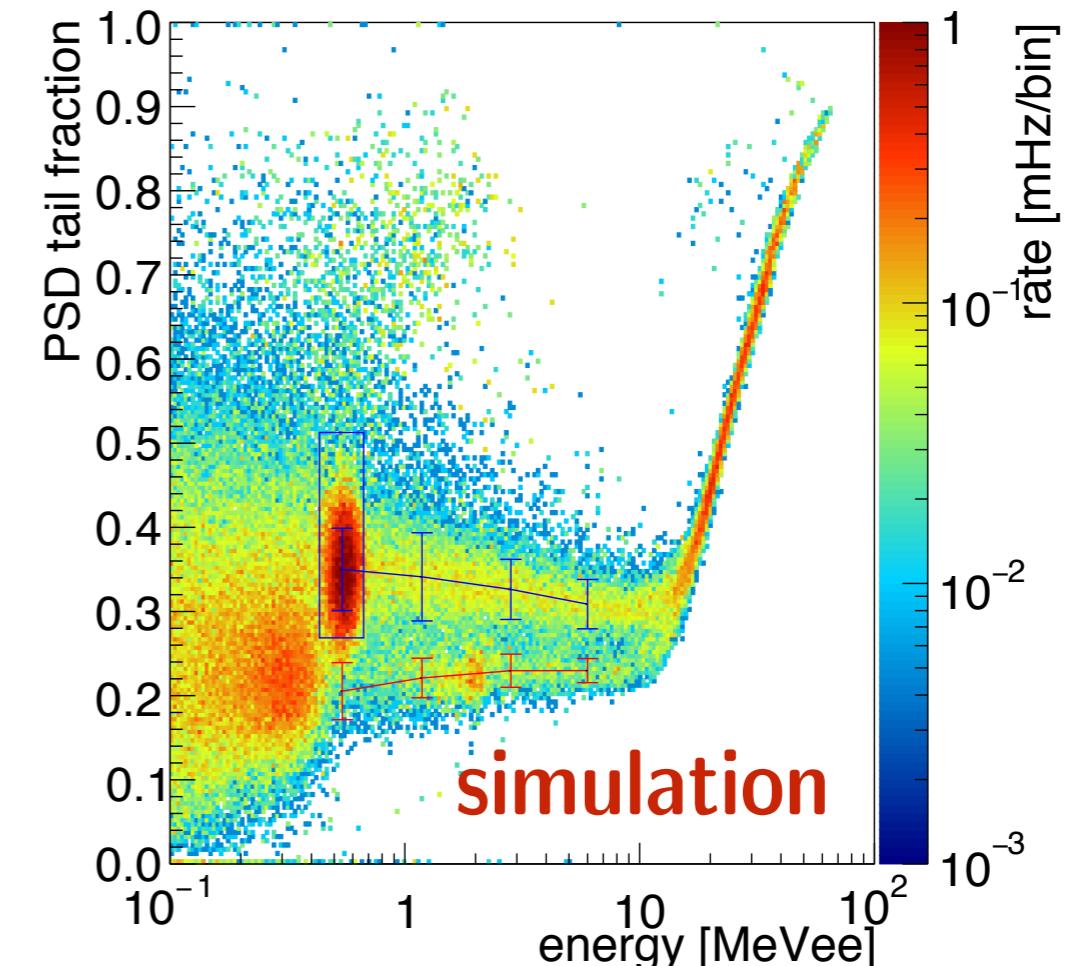
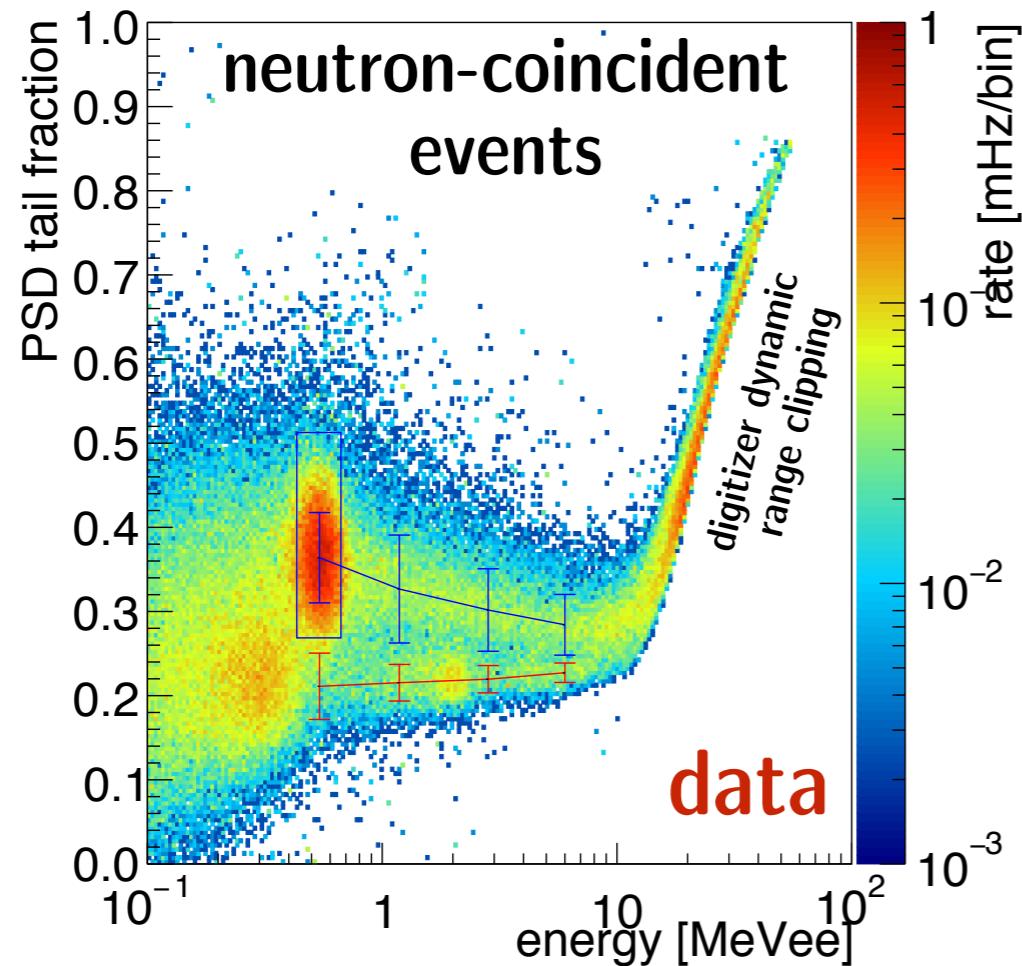
P20 shielding (outside – in):

- Water filled bricks: 9"
- HDPE slabs: 8"
- 30% borated HDPE: 4"
- lead bricks: 2" or 4"
- 5% borated HDPE: 4"



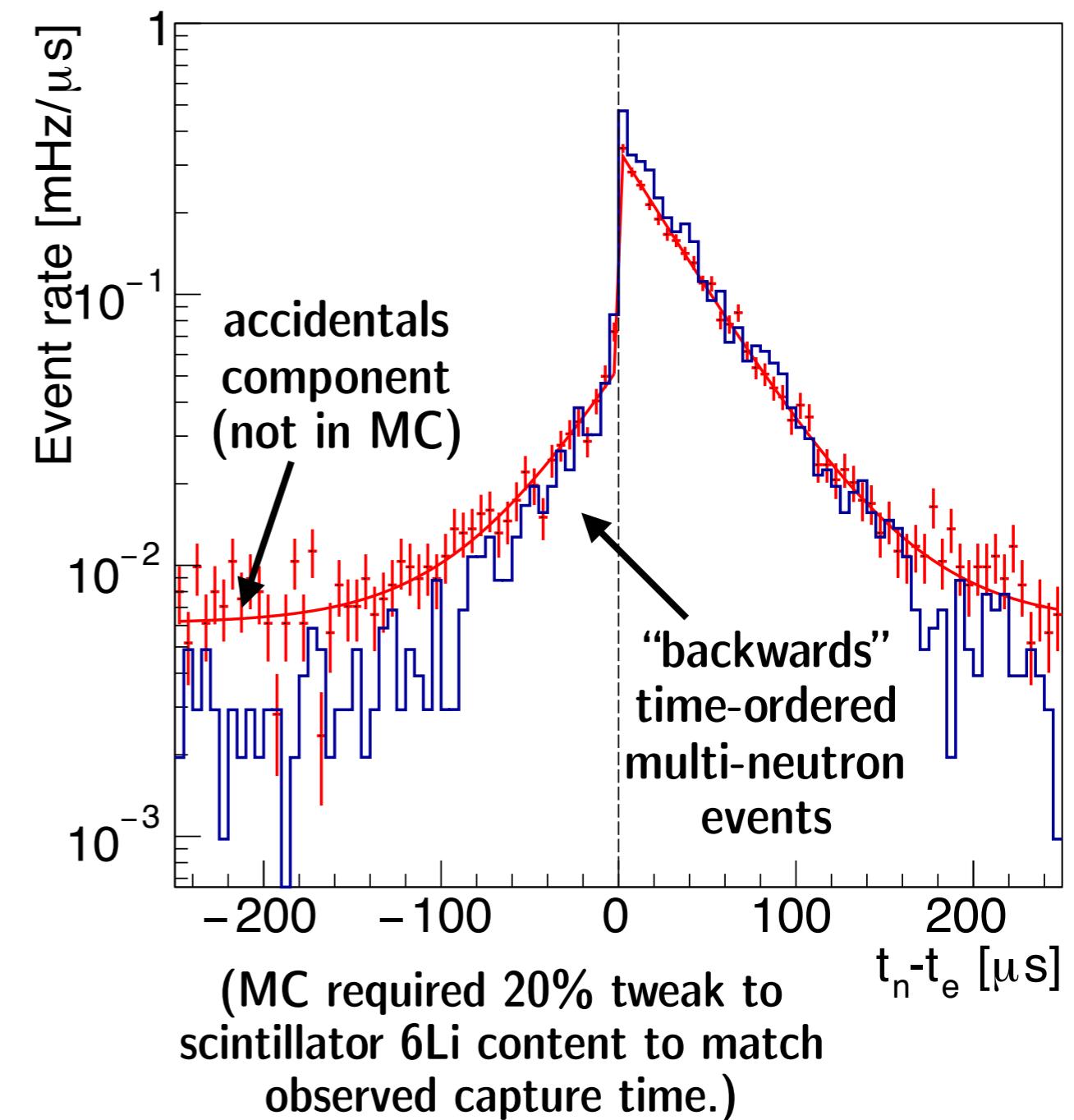
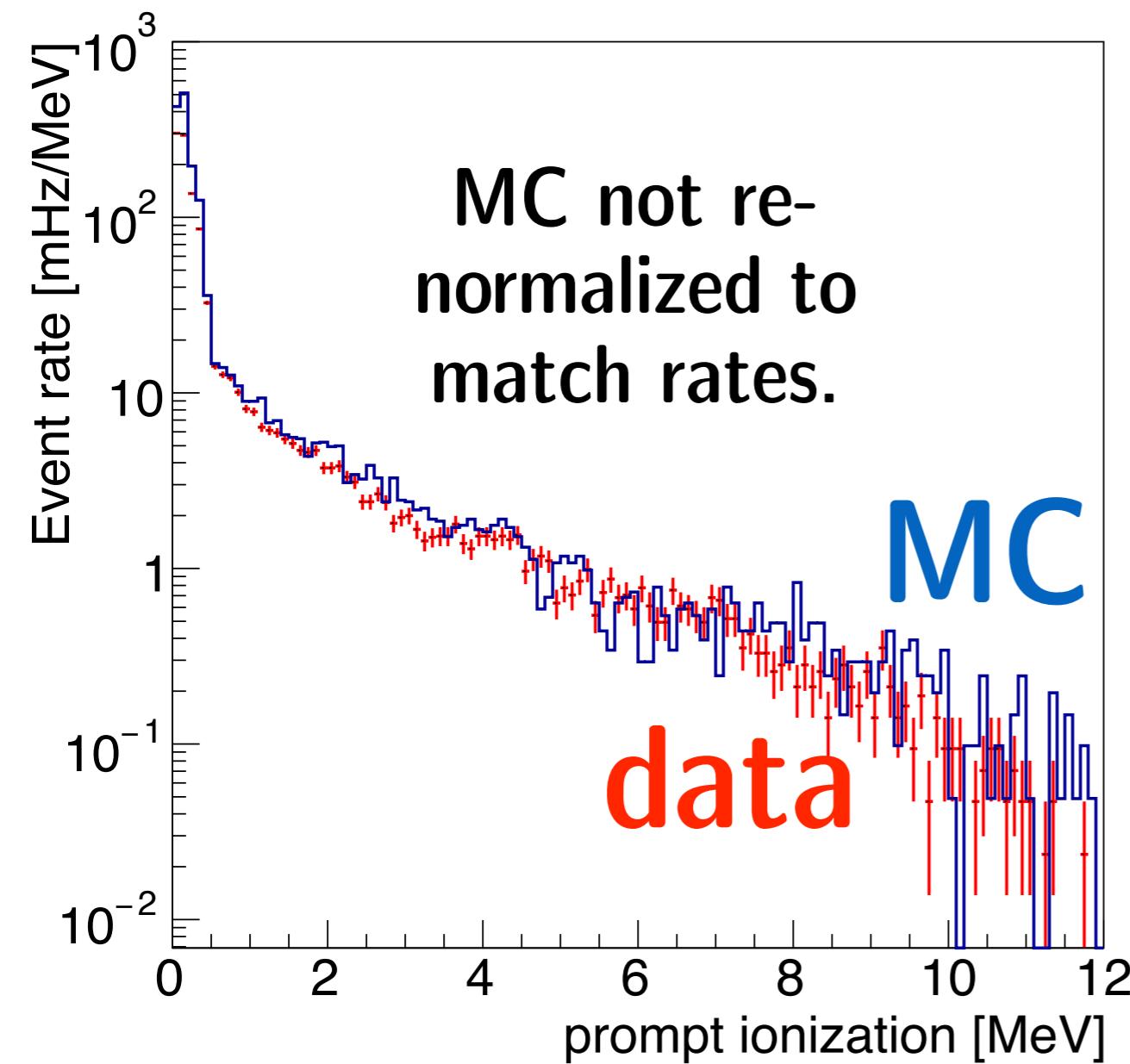
with shielding, reactor backgrounds
have minimal impact on “IBD-like” rate

cosmic BG P20 simulations



“realistic” detector response
quenching, PSD (sum pulse shapes), energy resolution

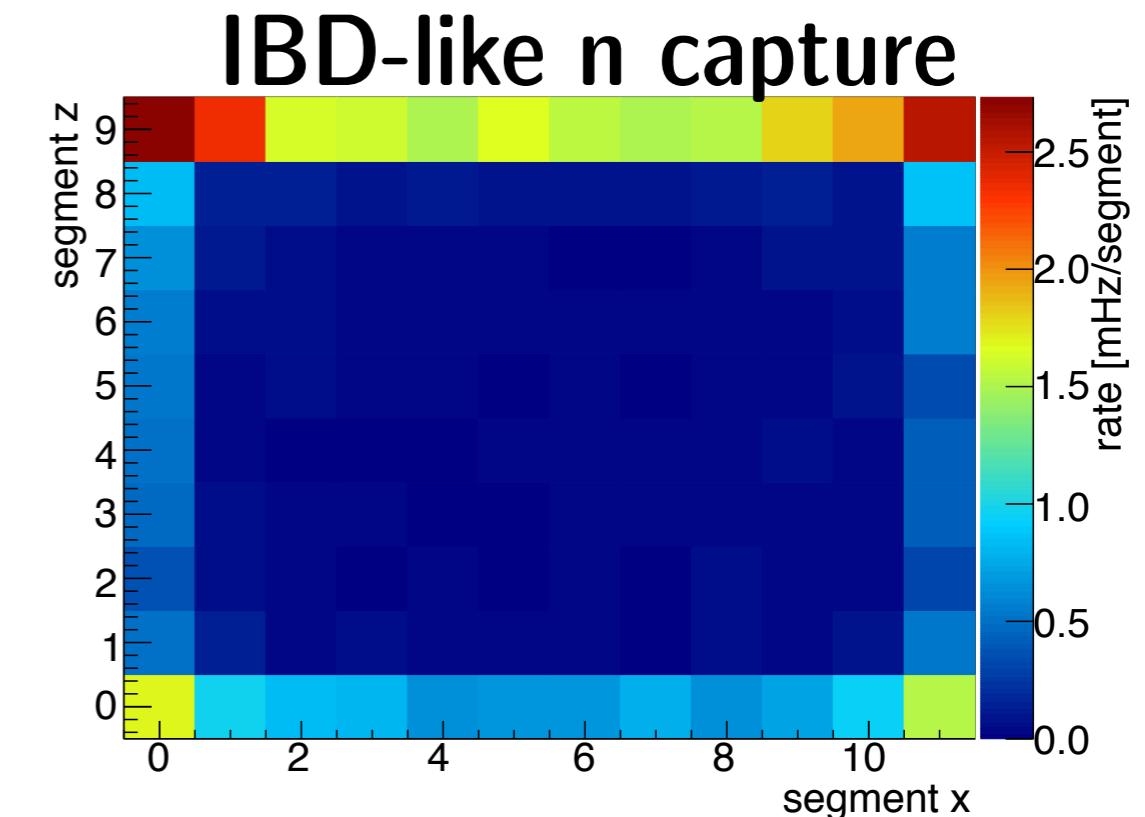
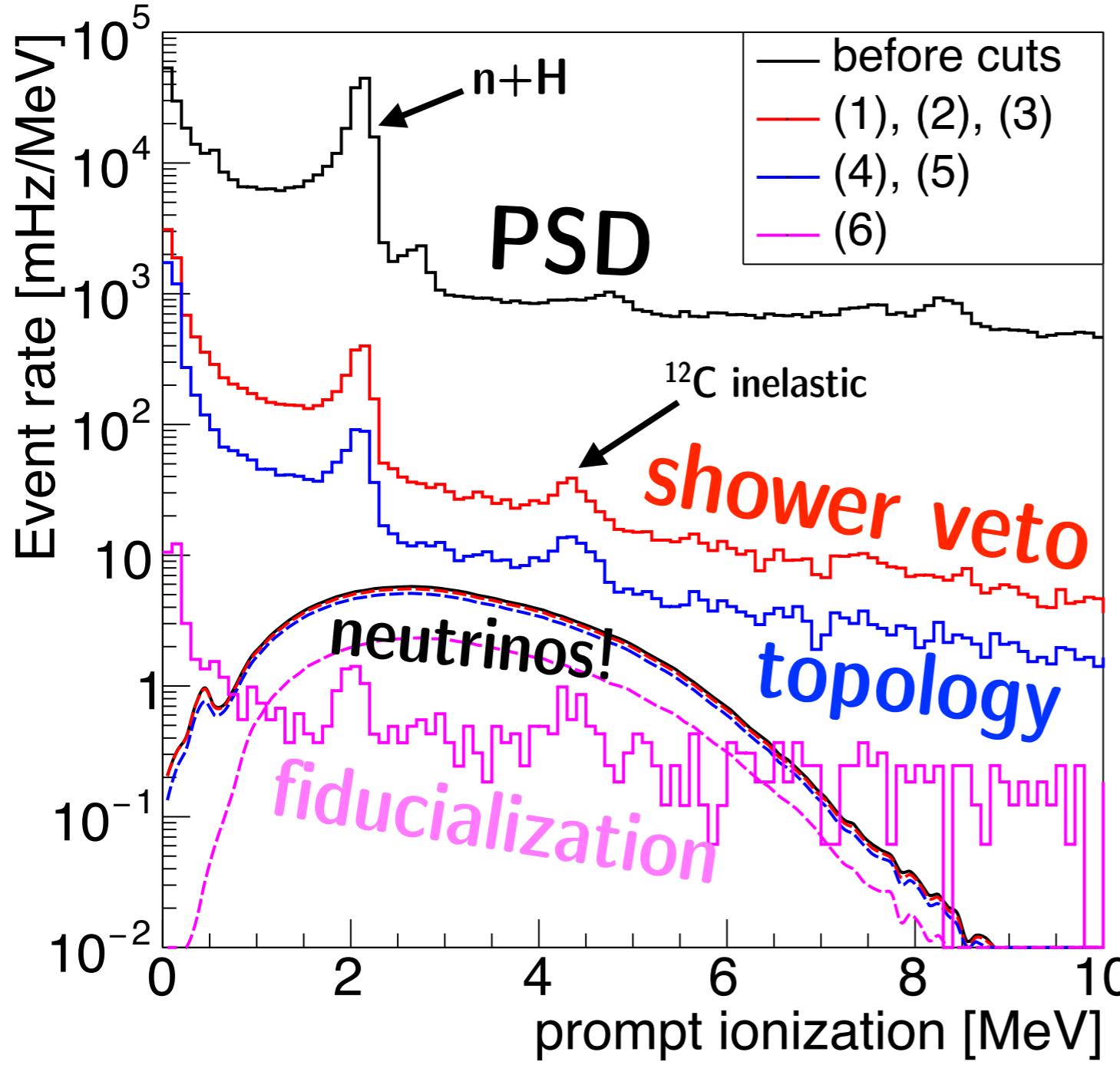
P20 “IBD-like” neutron-coincident events vs. MC cosmic background



looks like MC works pretty well for this.

simulation extrapolation to Phase I

neutron-coincident events

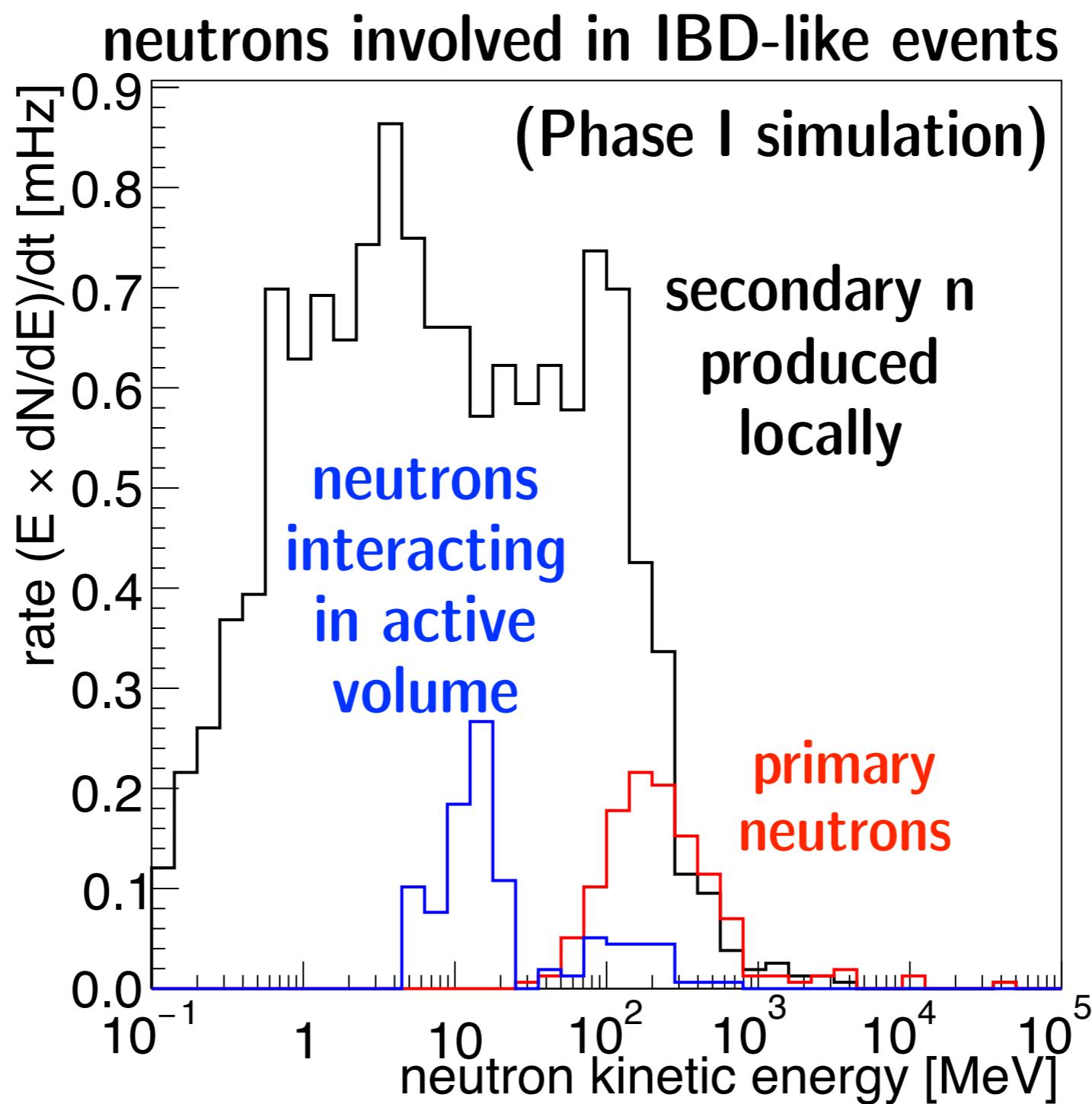


active veto requirements:

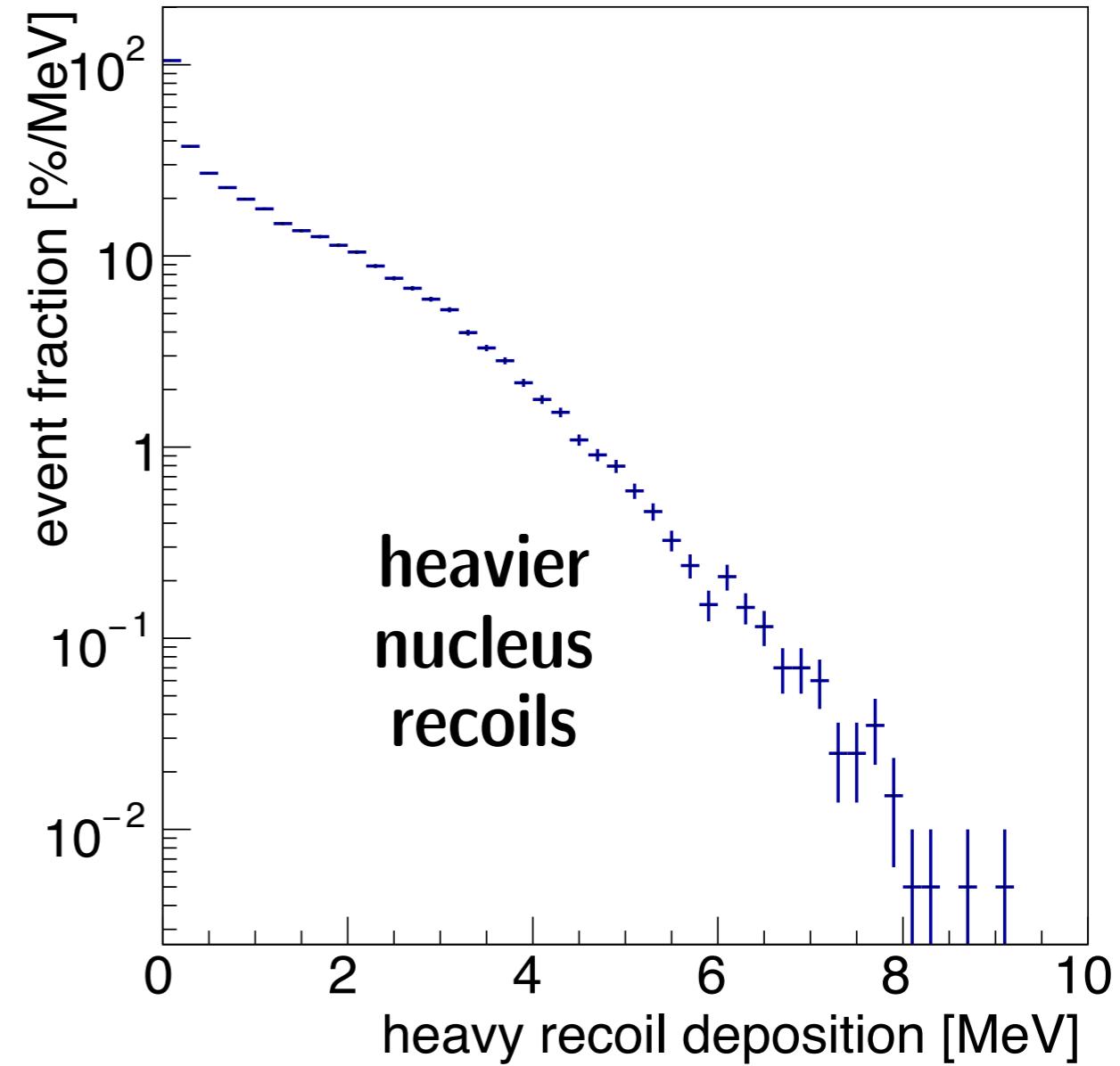
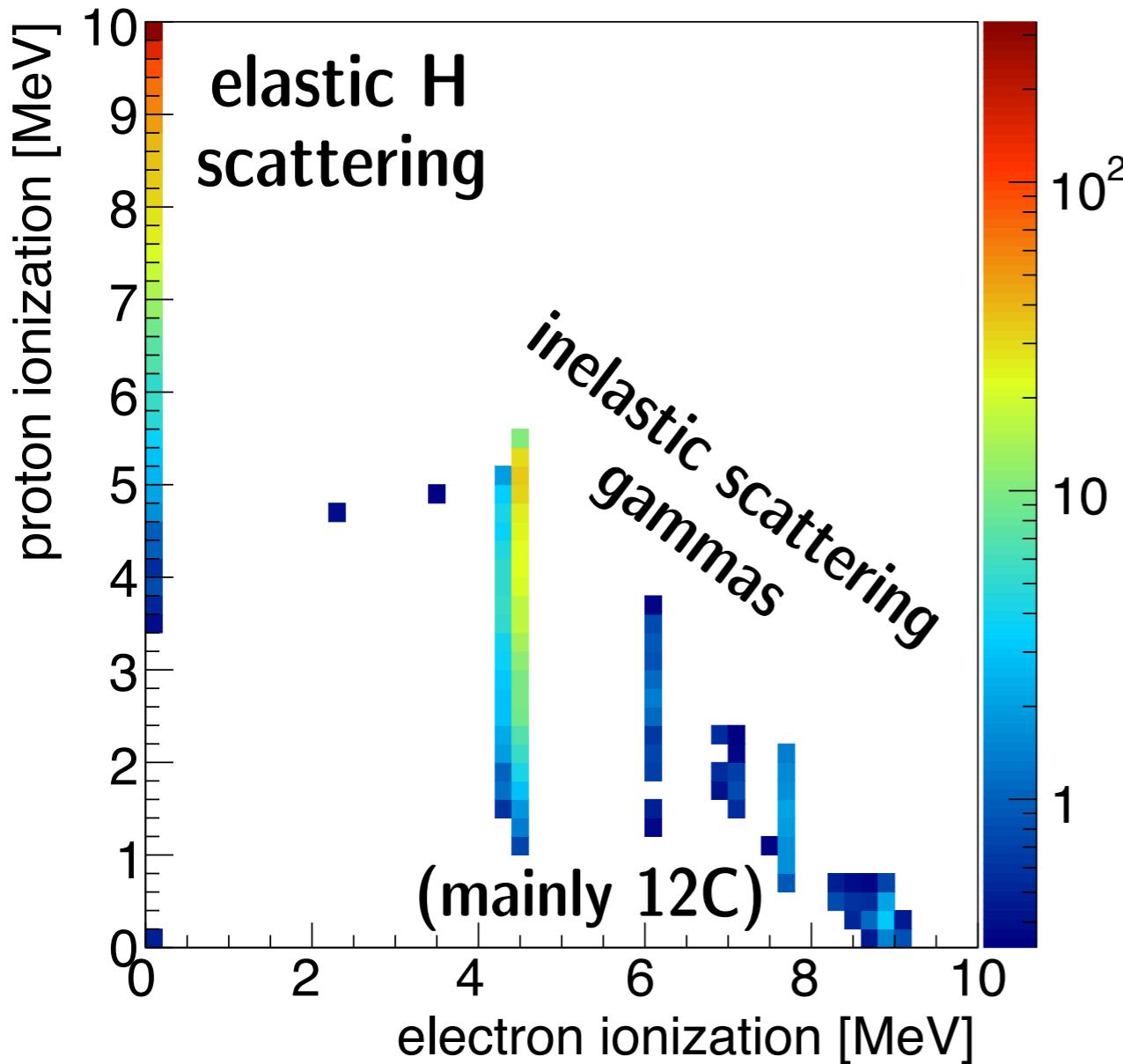
- neutron capture
- recoil PSD
- E,time,position tracking

= same properties as
detector bulk; use same
technology and fiducialize.

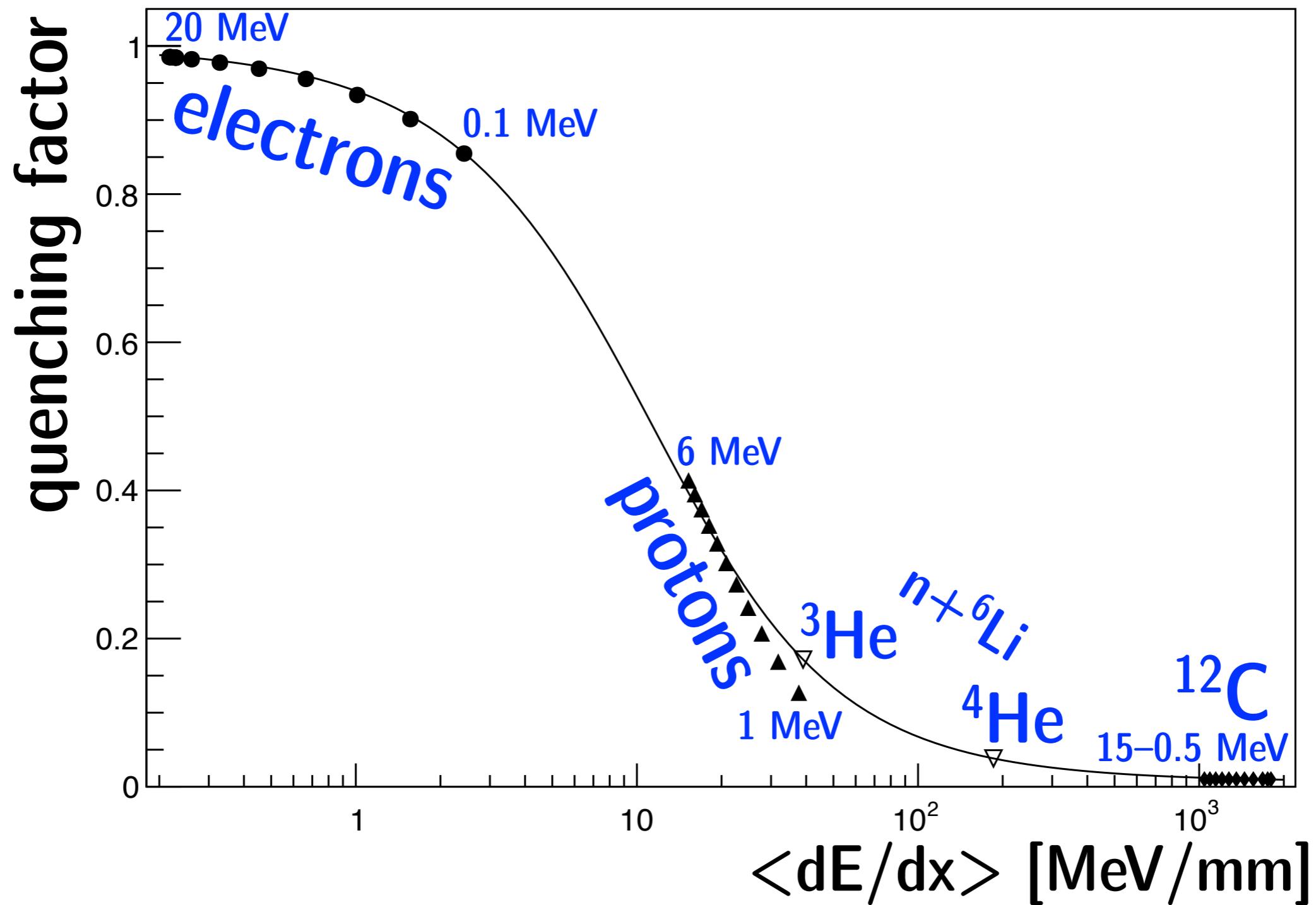
what causes remaining IBD-like coincidences?



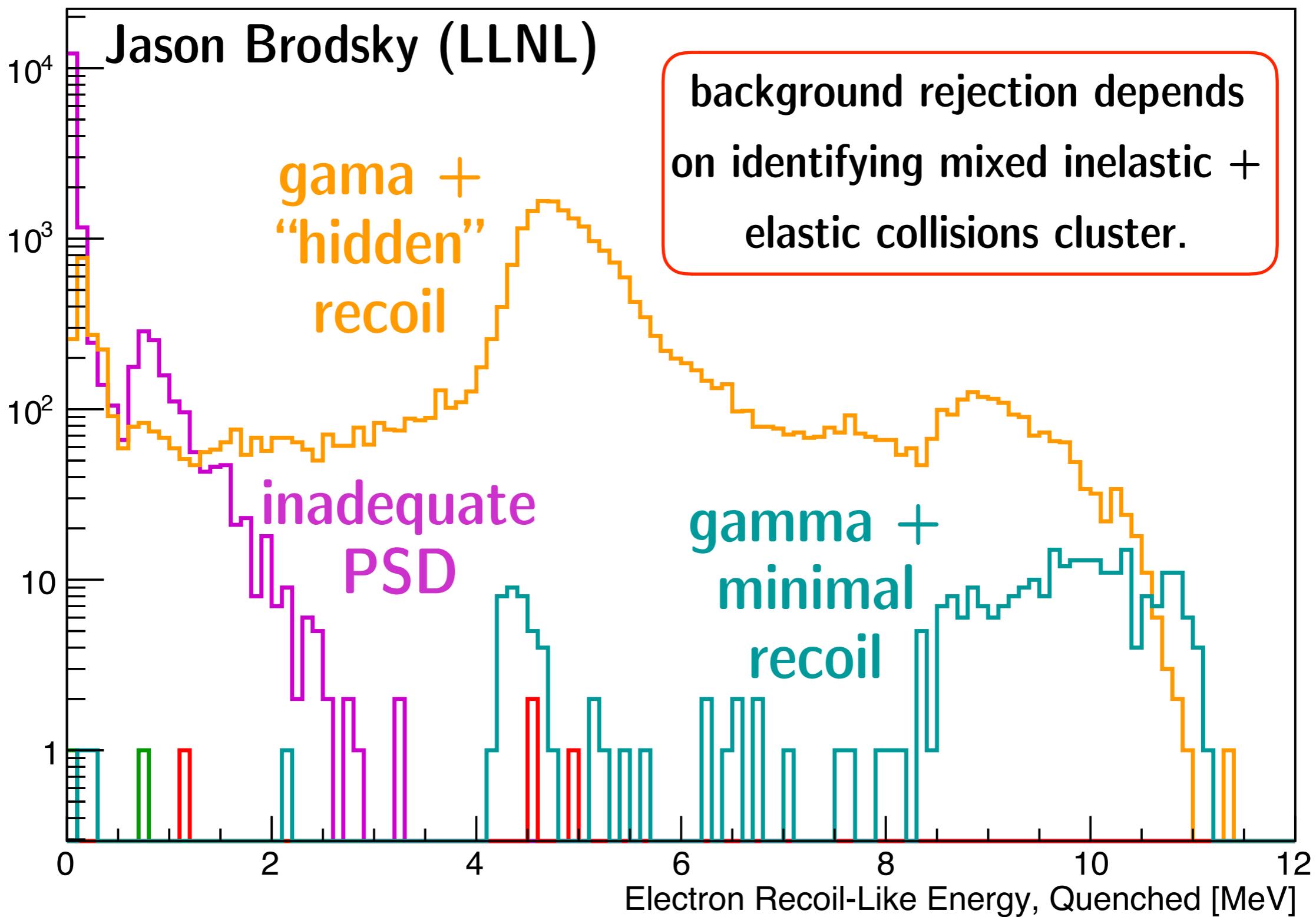
10 MeV neutron in scintillator: energy deposition



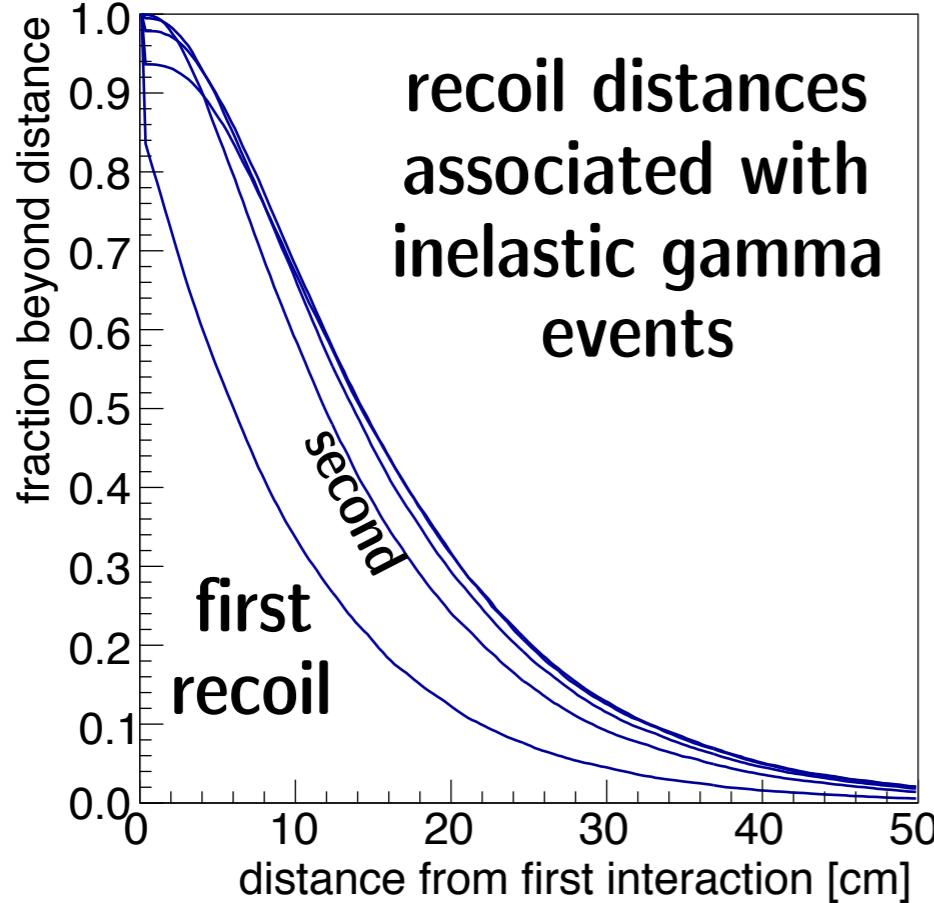
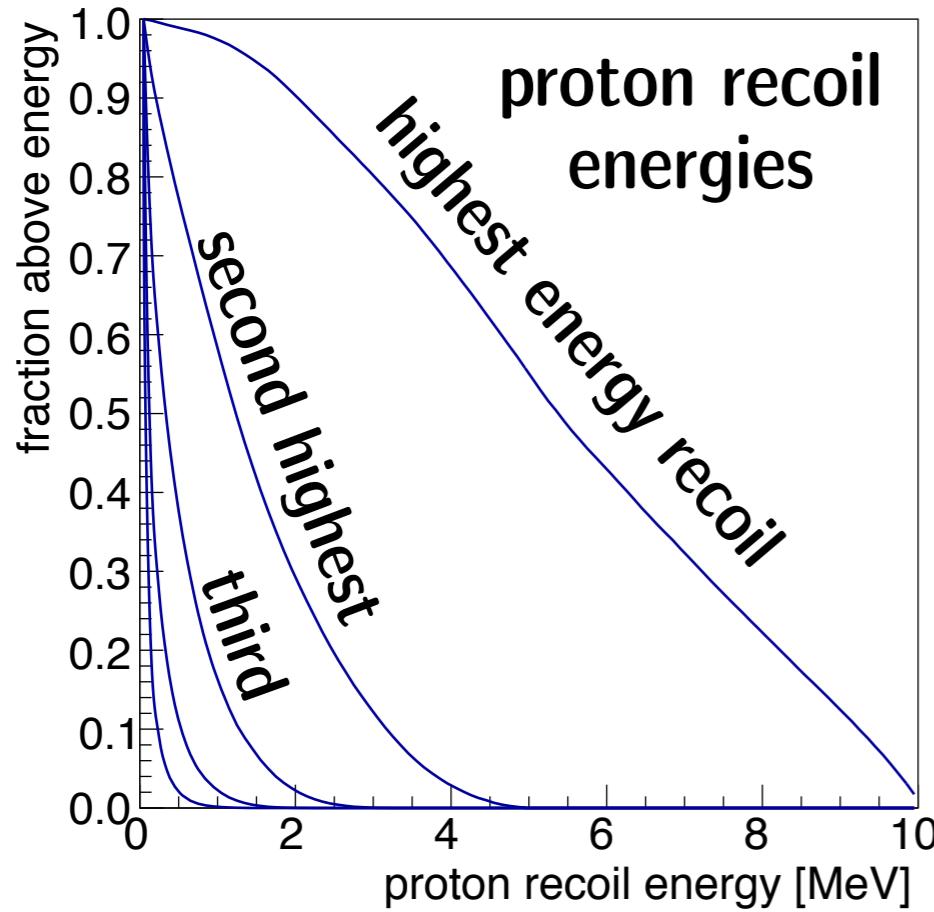
approximate scintillator quenching curve



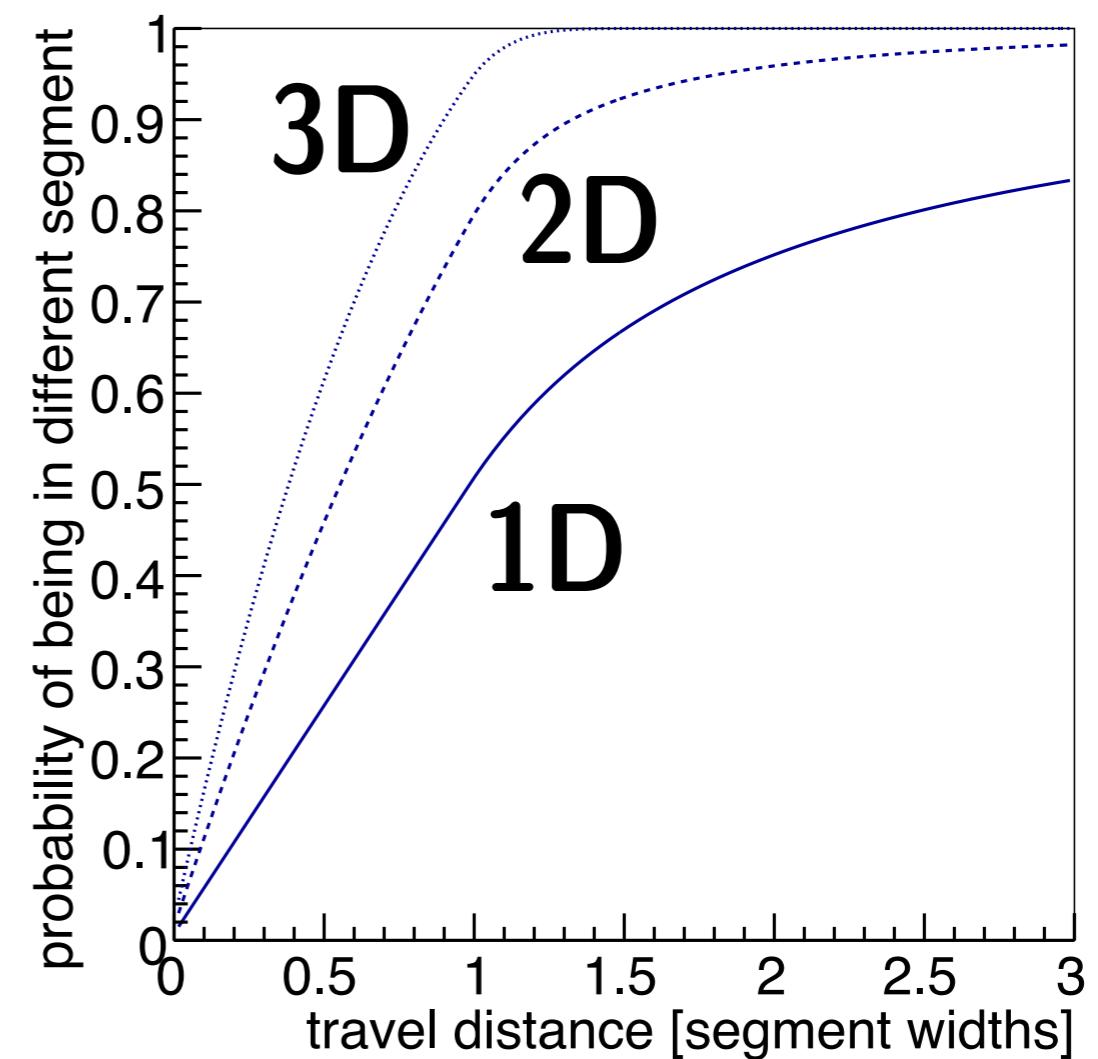
toy model: “IBD-like” coincidences from 4–12MeV neutrons



10 MeV n primary

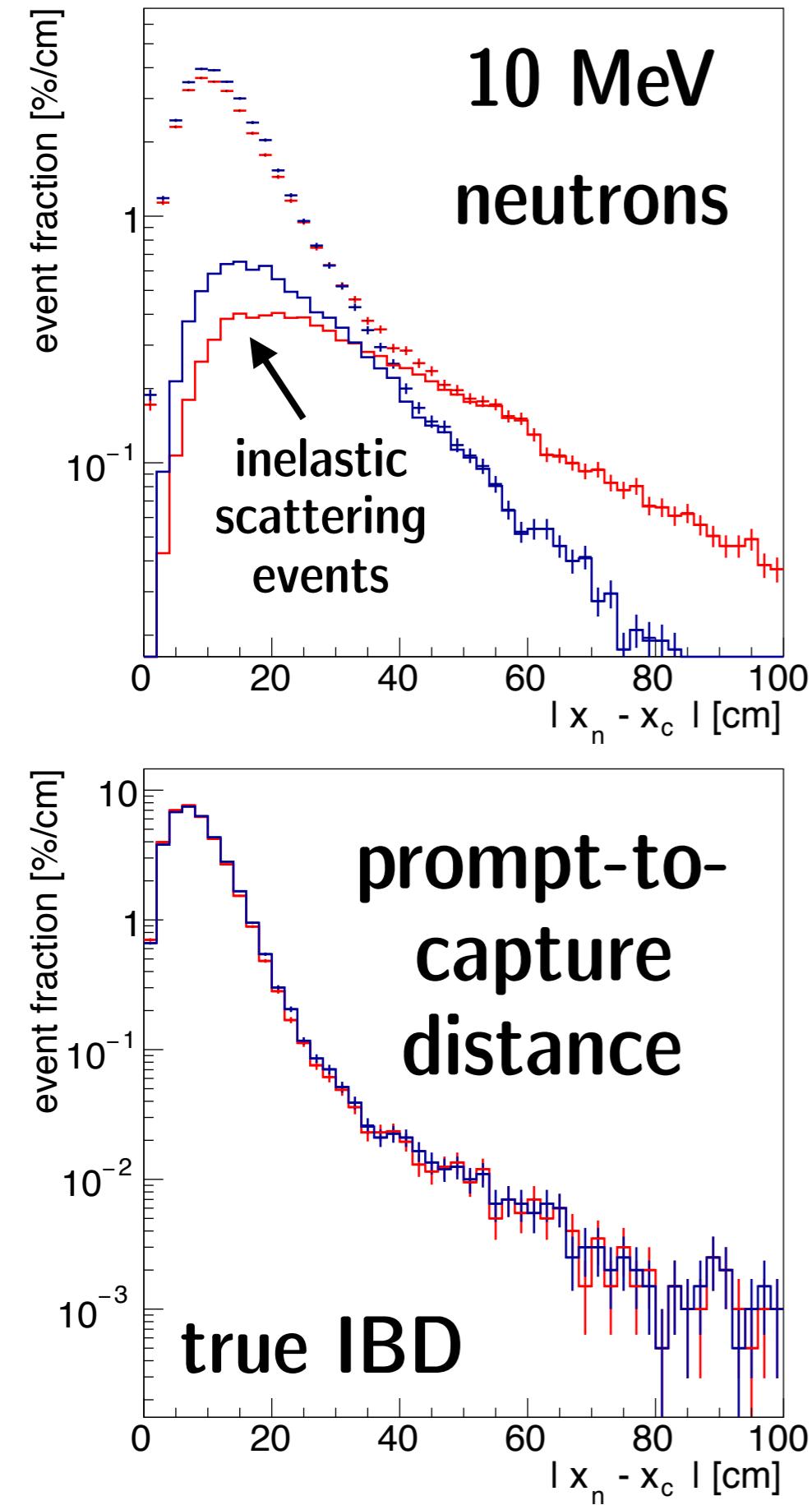


resolve mixed events by
spacial segmentation

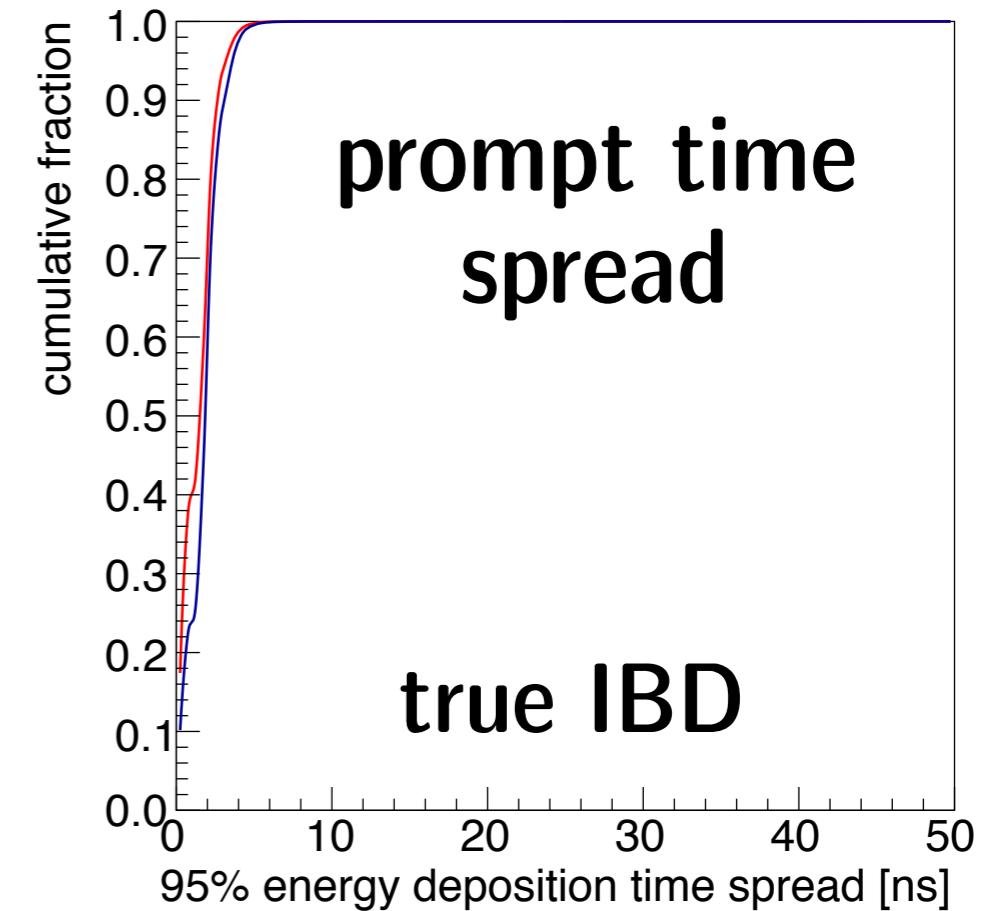
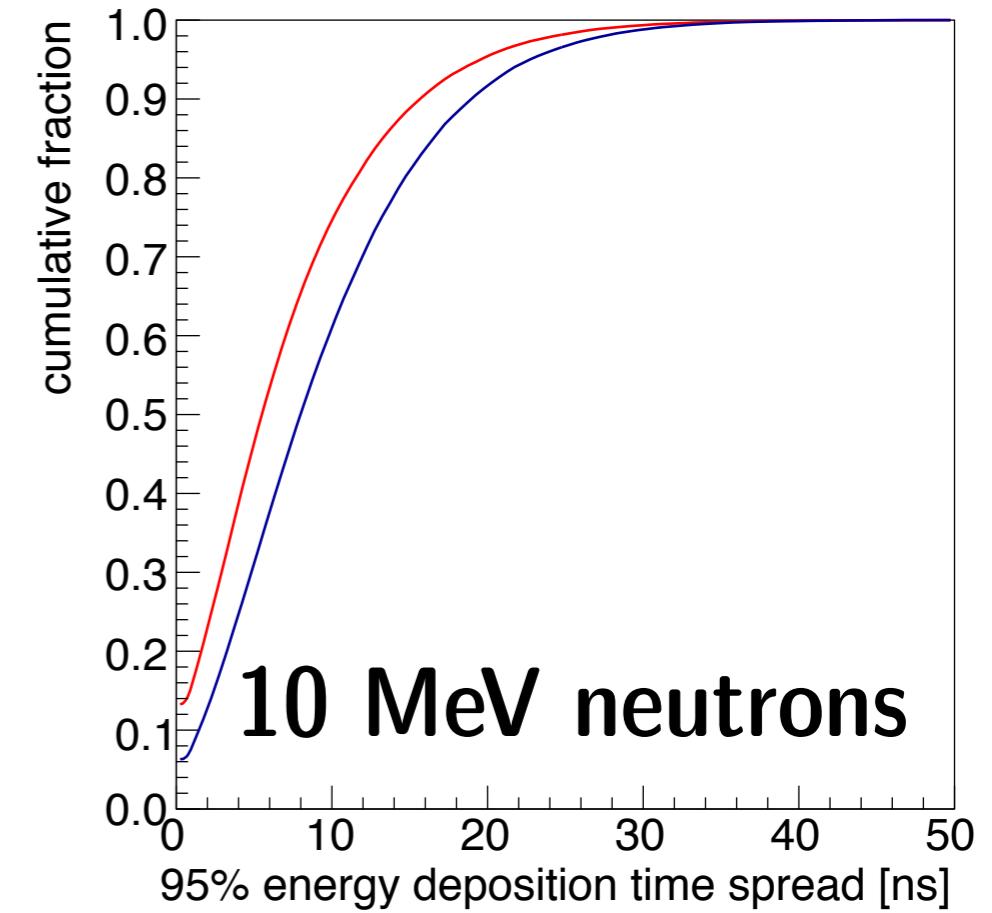


isolate recoils by
segmentation

non-PSD event identification parameters



spacial extent
time extent

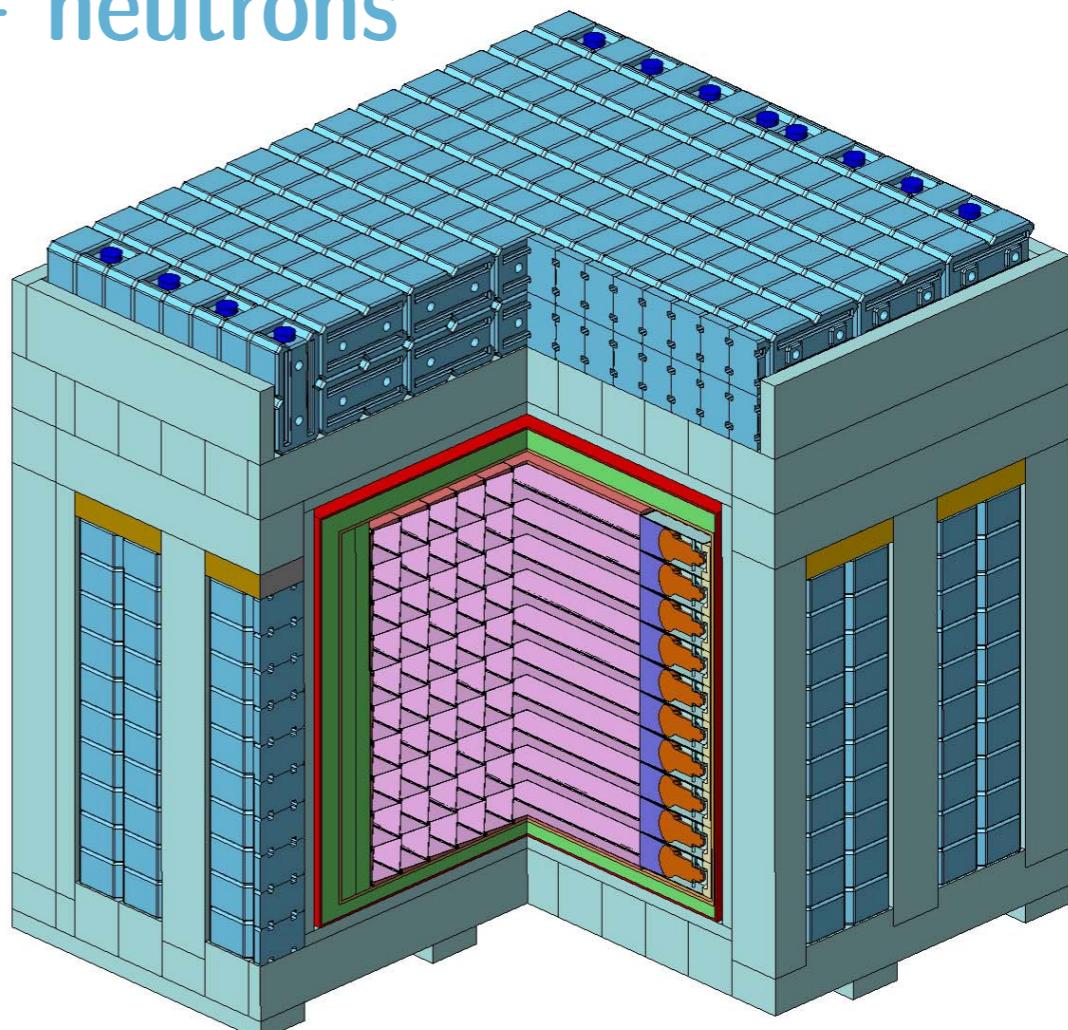


example: application to Phase I detector design

shielding: water, polyethylene; “top-heavy”; focus on 100MeV+ neutrons

small lead layer;
poly inside to block
spallation

segmented detector
(120 14x14x119cm³ cells)
with PSD scintillator



questions/comments?