Role of event reconstruction algorithm and new radiation sources

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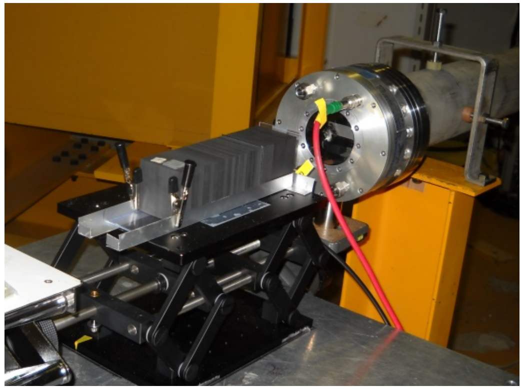
Special thanks to Y.Iwamoto, S.Abe, (JAEA) and K.Niita (RIST)

Structure

- Who am I ?
  - Experiment: GeV neutron shielding, Fragment yield
  - Calculation: FLUKA & MCNP5 user, PHITS development

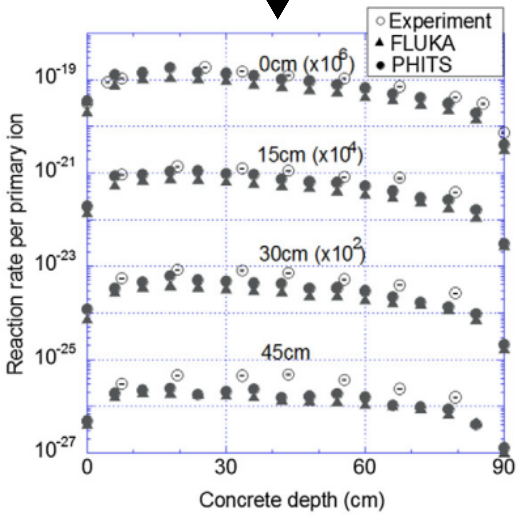
- Proposals on radiation characterization
  - Comparison of event reconstruction algorithm
  - Source-term evaluation of new-type sources
    - Secondary radiation of polarized photon sources
    - (p,n) reactions for neutron sources

My background (experiment)

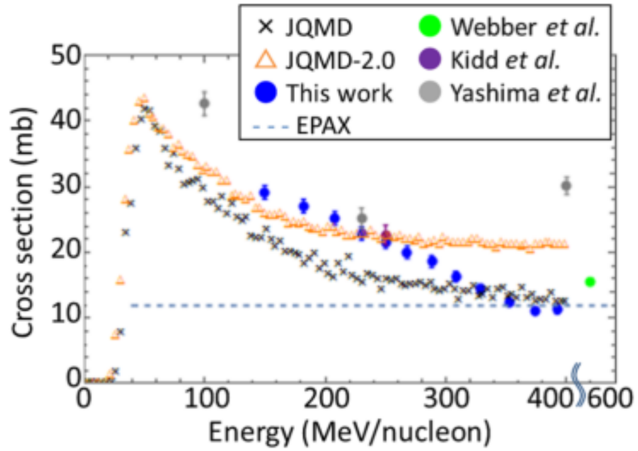


Concrete shielding experiment at heavy ion accelerator (HIMAC)

Heavy ion fragmentation cross section measurement at heavy ion accelerator (HIMAC)



Activity depth profile (exp, FLUKA, PHITS)

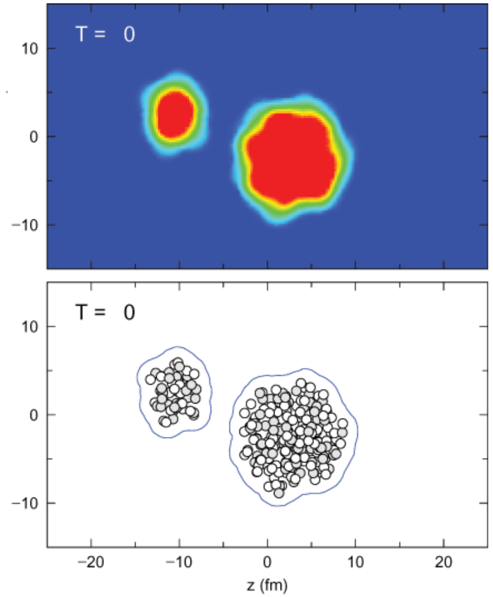


Cross section (exp, PHITS)

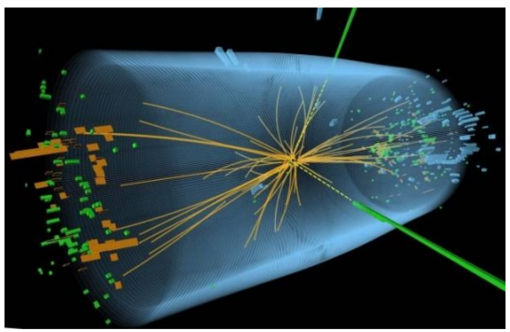
* T.Ogawa, *et al.*, *PHYSICAL REVIEW C*, **92**, 024614 (2015), ** T.Ogawa *et al.*, *NIM B*, **269,** 1929–1939 (2011)

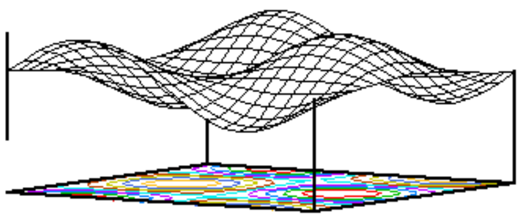
My background (simulation)

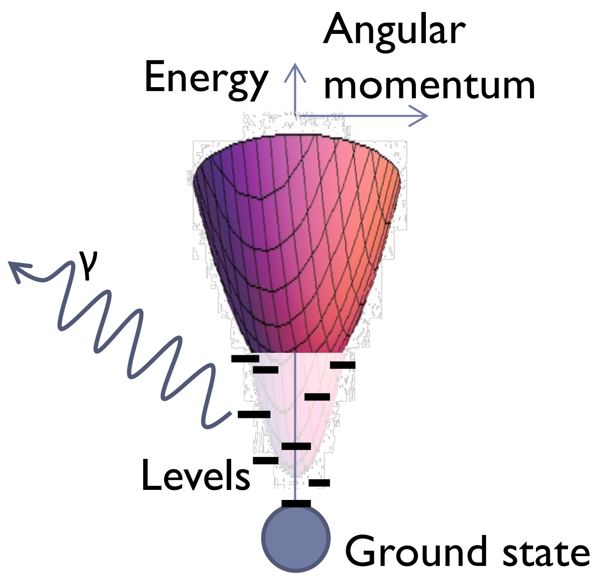
- Heavy ion reaction model (JQMD)
- Statistical γ-decay, multi-fragmentation
- Event reconstruction from inclusive data



Nuclear Physics 90% + Mathematics 10%
→ New reaction models







* Jiji.com, https://www.jiji.com/jc/d4?p=hig705&d=d4_acs * PHITS official lecture note

* T.Ogawa, *et al.*, *PHYSICAL REVIEW C*, **92**, 024614 (2015),

My proposals on radiation characterization

- Comparison of event reconstruction algorithm
  - Reconstruction from inclusive data to event-by-event data
  - Damage (displacement per atom) evaluation
  - Semiconductor soft error
  - Heat of thin materials

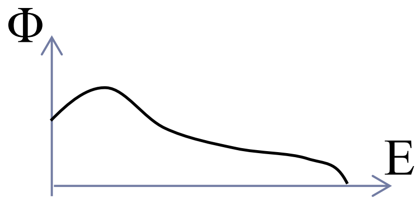
- Source-term evaluation of new-type sources
  - Polarized photon source
  - (p,n) reactions for neutron source

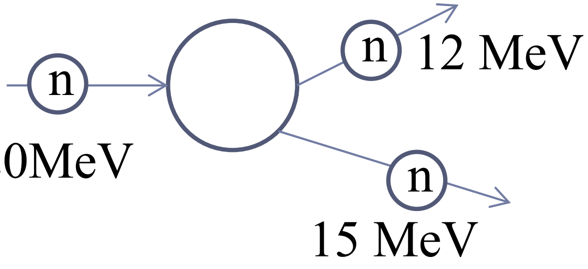
Event reconstruction, why?

Let's think about (n,2n) reaction + detector simulation

○Sampling scheme

Neutron energies are sampled independently



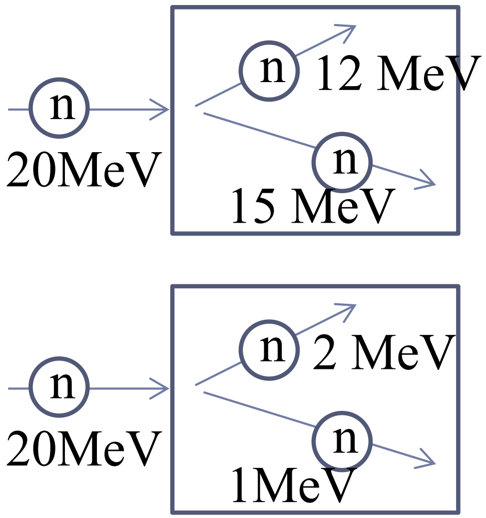


20 ≠ 12+15 → Energy is **not conserved**

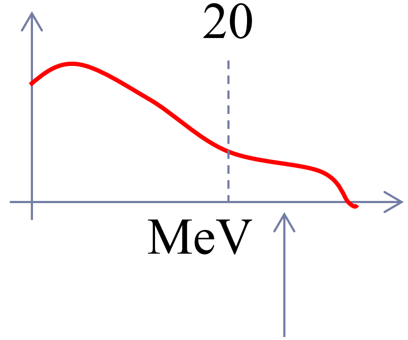
Recoil/Excitation is not considered

But average over lots of events is O.K.

○Application



If (Q value)=0



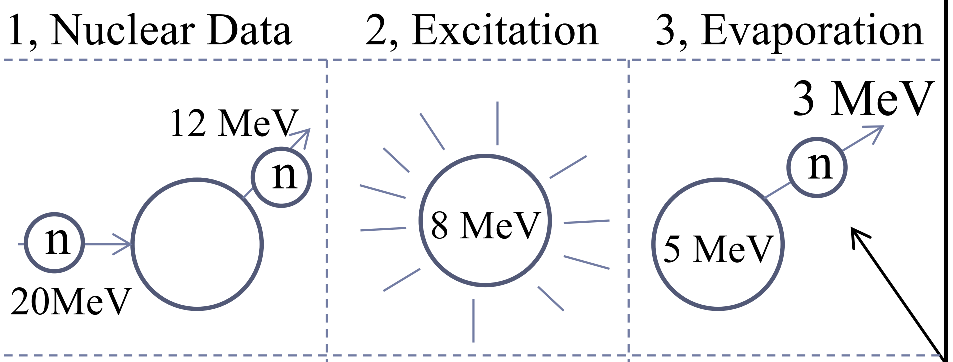
Unrealistic!!

Good in **average** / Wrong in event-by-event

Event reconstruction, why?

○Sampling scheme

Simulate as sequence of two-body reactions

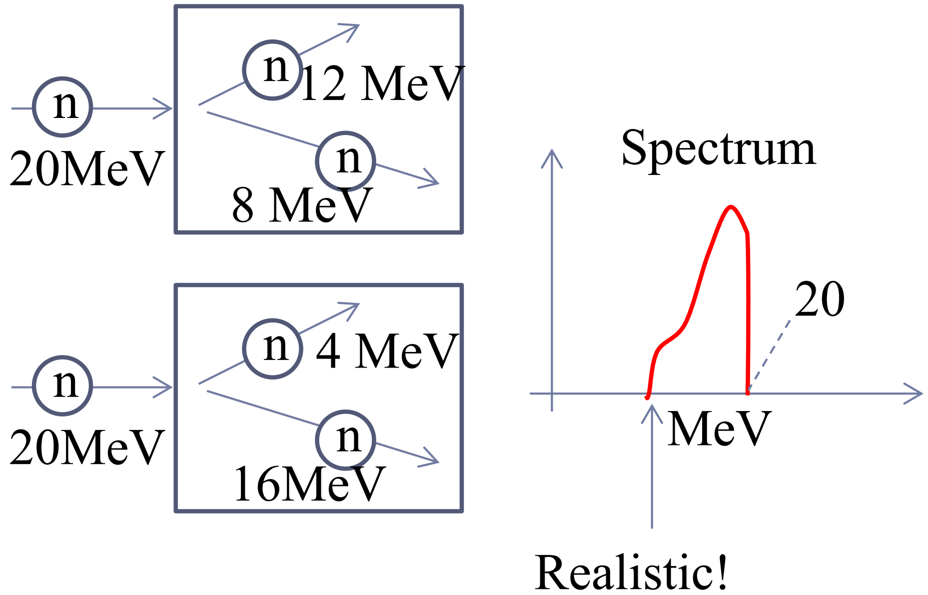


Two-body kinematics

→ Energy/Momentum are conserved !

○ Energy deposition (e.g. Detector response)

○Application

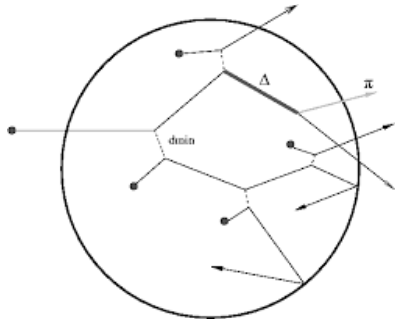


Necessary for detector response

Average slightly disagrees with nuclear data

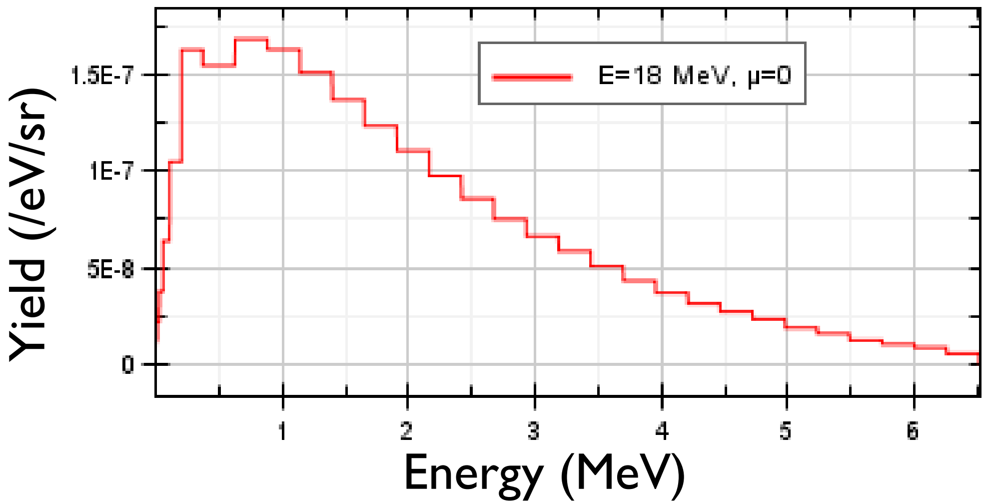
Event reconstruction, how?

- High energy reaction models (Bertini, INCL, CEM, etc.)
  - = Event generators
  - No need to think of reconstruction



- Nuclear data (Inclusive data)

^{56}Fe(n,2n)

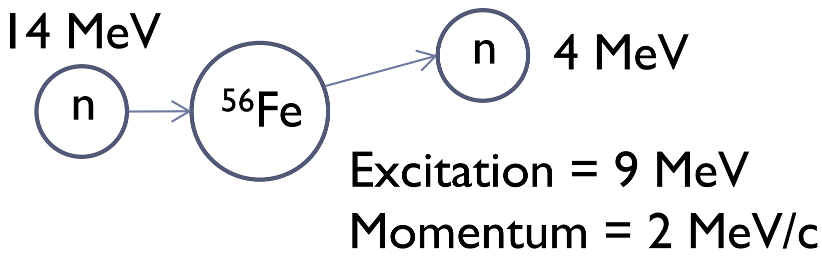


Correlations between outgoing 2 neutrons are lost

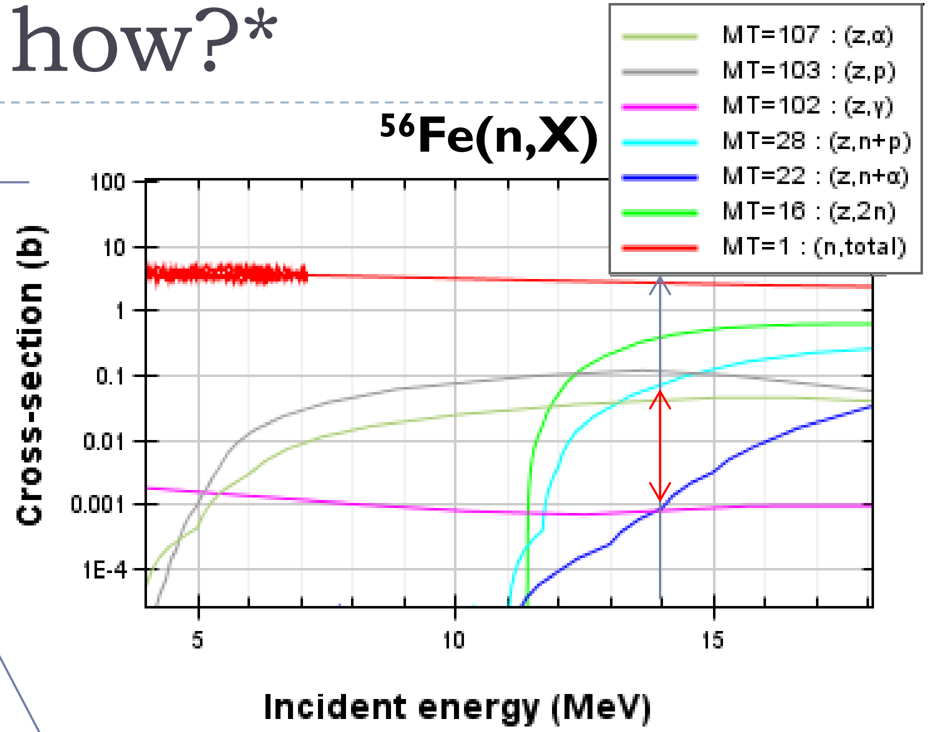
* K.Niita *et al.*, *proceedings of ND2007*, 307, (2008), T.Ogawa, *et al.*, *NIMA*, 763, 575-590 (2014)

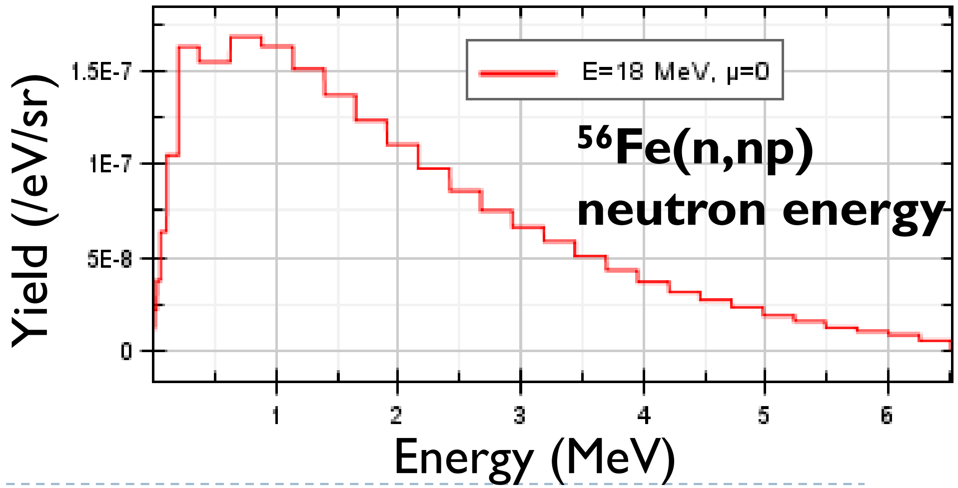
Event reconstruction, how?*

1. Choose a reaction channel
   1. e.g. (n,np) reaction
2. Sample neutron energy/angle from distribution
3. Determine mid-way state based on energy/momentum conservation



4. Proton and gamma emission by evaporation model





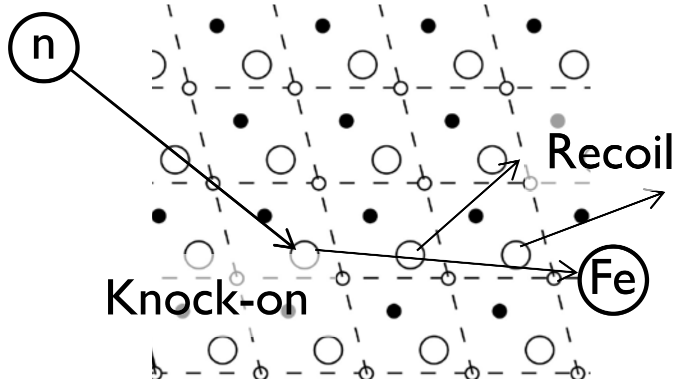
Final state (n, p, ^{55}Mn are left)

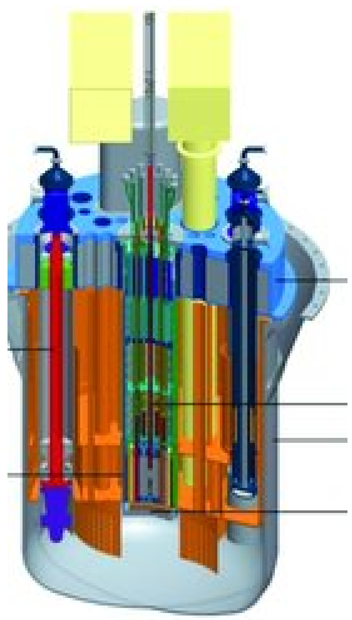
Who needs event reconstruction?

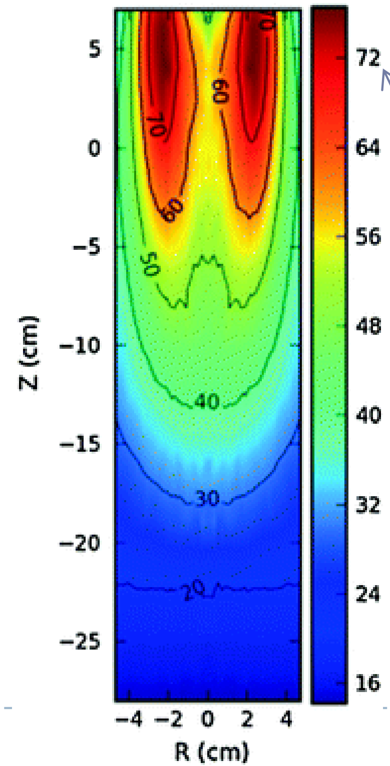
- Neutron-induced radiation damage
- Semiconductor error
- Heat

Neutron-induced damage

- Neutrons induce damages in metals, ceramics, etc.
- Problem in heavy-irradiation facilities
  - e.g. MYRRHA





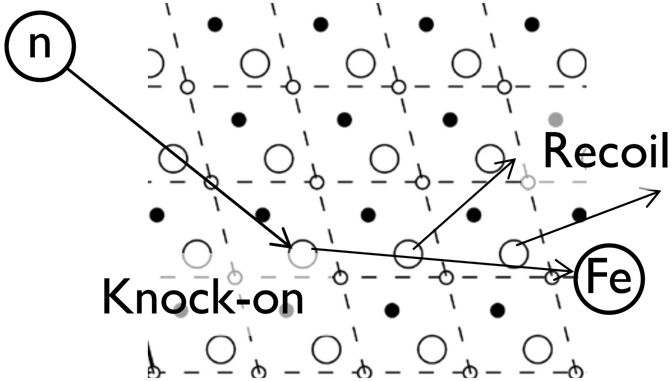


Displacement per atom distribution
72 times displaced

* Aït Abderrahim H. (2016) MYRRHA: A Flexible and Fast-Spectrum Irradiation Facility. In: Revol JP., et al., Thorium Energy for the World. Springer, Cham

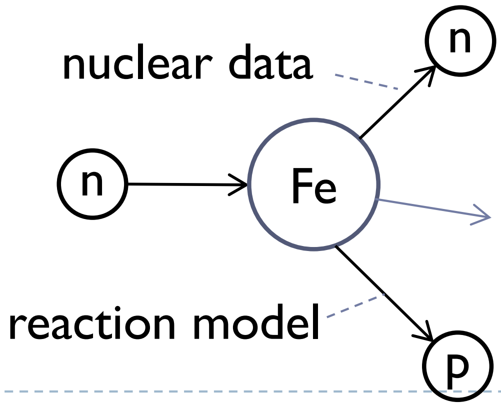
Neutron induced damage

- Recoil of target



Target nucleus recoil (heaviest → recoil nuclei)

Kinematics (energy, species) of reaction products are important



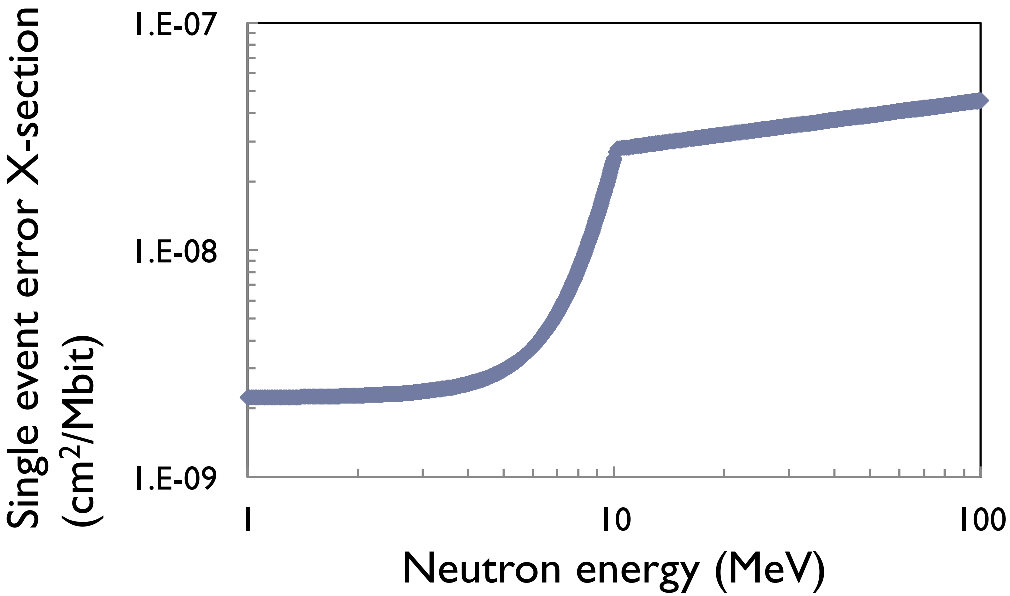
Target recoil is determined by energy/momentum conservation
→ Least accurate.
→ Accurate event reconstruction and benchmark are necessary

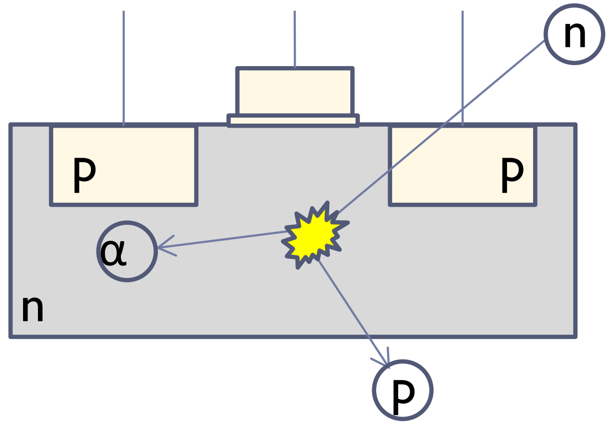
Semiconductor error

- Your laptop, iphone, and TV are facing soft errors.
  - Total dose error (those induced by coincident multiple quants) is unlikely (except inside nuclear reactors)
  - Single event error (those induced by single quant) is know to induce soft errors
  - Cosmic ray neutrons are the most responsible for soft errors
    - Neutrons → **(n,p), (n,α) reactions** → Energy deposition → Error !

Single event error

- Neutrons above 10 MeV are said to be the most important





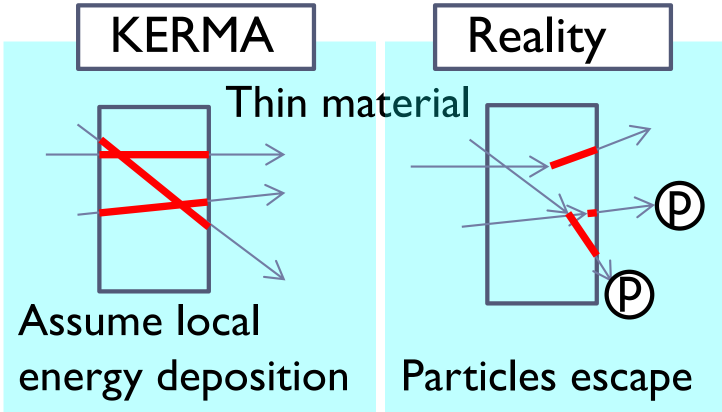
Energy, angle, species are important (reconstructed by models)

- Verification of event reconstruction algorithm and soft error benchmark are ongoing

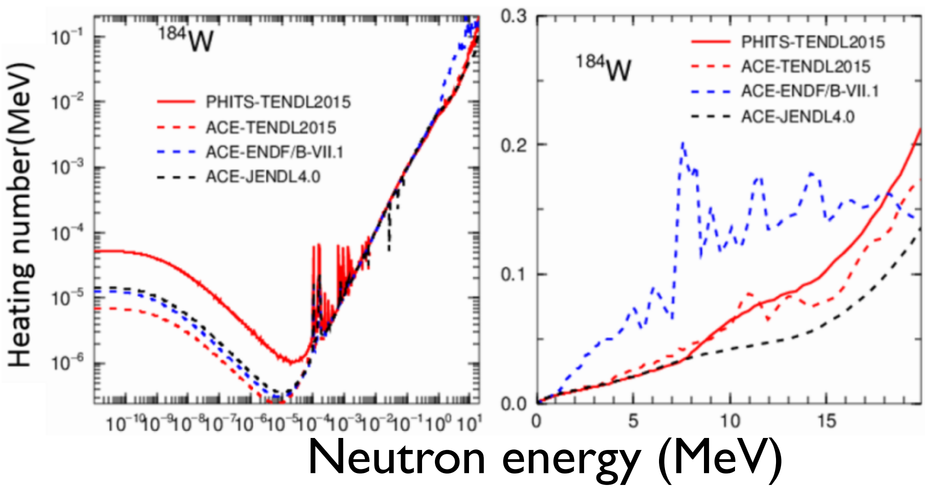
*S.Abe, *et al.*, *IEEE TRANSACTIONS ON NUCLEAR SCIENCE*, **61**, (2014) 3519

Heat

- Heating is normally calculated by KERMA but …
  - Overestimates heat in thin materials
    - KERMA is approximation for thick targets
    - Problem for neutron-induced heat



  - KERMA is nuclear-data dependent
    - KERMA factor is based on energy-balance in some nuclear data
      - Kinematics method is better
    - KERMA depends on considered reaction channels



* International Nuclear Data Committee INDC(NDS)-0719, pp43-51 (2016)

Proposal on event reconstruction

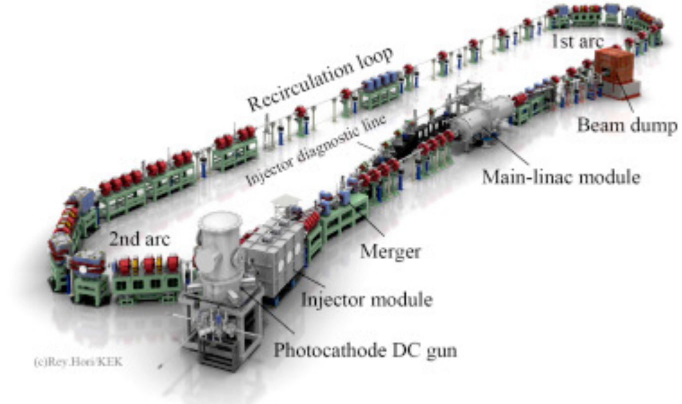
- Compare and evaluate event reconstruction algorithms
  - PHITS event generator mode *"Rakic"*
  - Geant4 event reconstruction
  - MCNP6 event reconstruction
  - Something else? (HEATR of NJOY, FRENDY)

- Clarify which algorithm is the best for
  - Neutron-induced radiation damage
  - Semiconductor single event errors
  - Heat

Who can do better ?

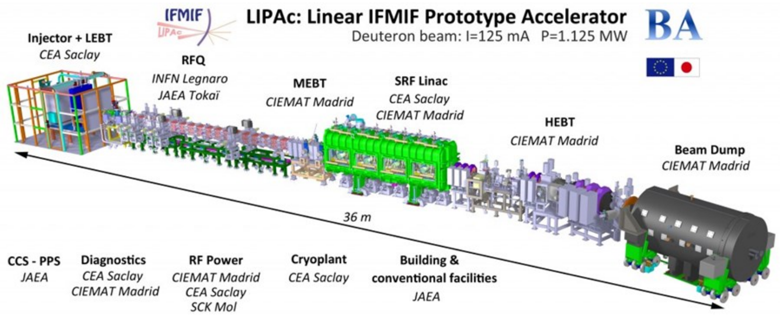
Source-term evaluation of new-type sources

- Emerging new-type sources
  - Laser Compton scattering (LCS) photons
    - Energy selectivity
    - Polarization



Laser Compton scattering γ-ray source

  - Accelerator-based neutron sources
    - Compact (not reactor-based)
    - Light target (Li, Be)

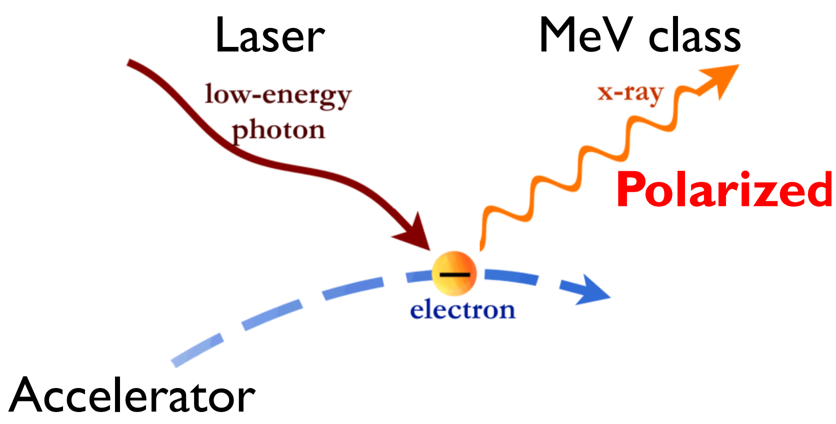


Accelerator-based neutron source

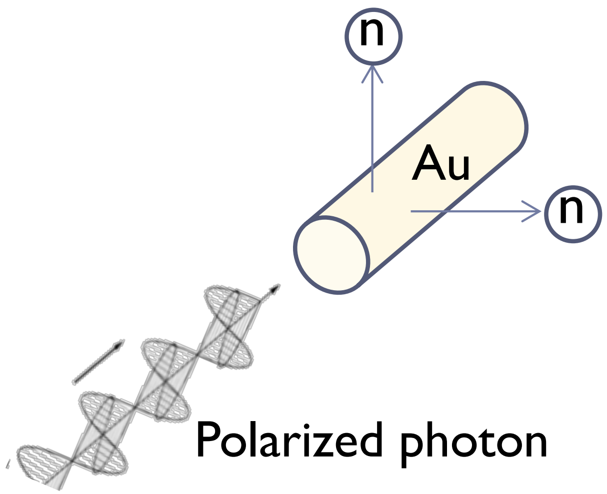
* Akemoto *et al.*, *NIMA*, **877**, 197-219 (2018), ** J.Knaster, ITER newsline

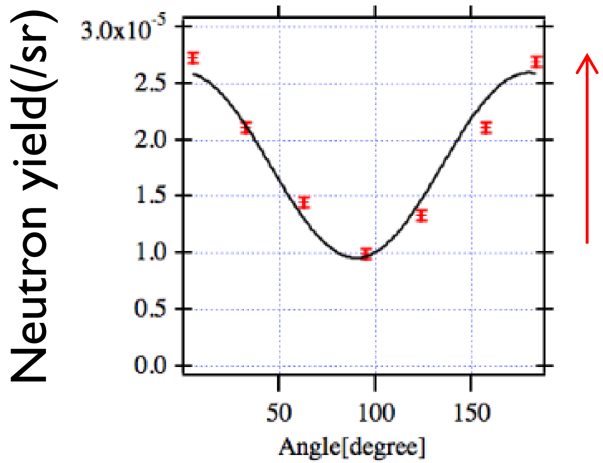
Laser Compton scattering photons

- Inverse of Compton scattering
  - Compton : Photon kicks electron
  - Inverse : Electron kicks photon

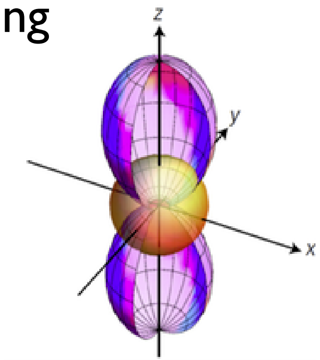


- Polarized photon → Anisotropic secondary radiation





Factor of more than 2.
Big effect on shielding



* A.Takemoto et al., Proceedings of the 12th Annual Meeting of Particle Accelerator Society of Japan, 2015, Chiba, Japan

Secondary particles of LCS photons

- Secondary neutron distribution is anisotropic
  - Some experimental data exists
    - H, He, C, V, Mn, Fe, Co, Ni, Kr, Sr, Ba, Th, U, Pu (acc. to Exfor)
  - Distribution is $I = a + b\ cos(2\theta)$
  - where *a* and *b* are target dependent parameters
  - Neutron come out from giant-dipole resonance or Quasi-deuteron decay
  - No code (official release) can consider it ?

- My proposals
  - Evaluation of *a* and *b*
  - Model development
  - Benchmarking against experiment

Accelerator-based neutron sources

Terrorism

Inspection

Politics

Government

Accelerator

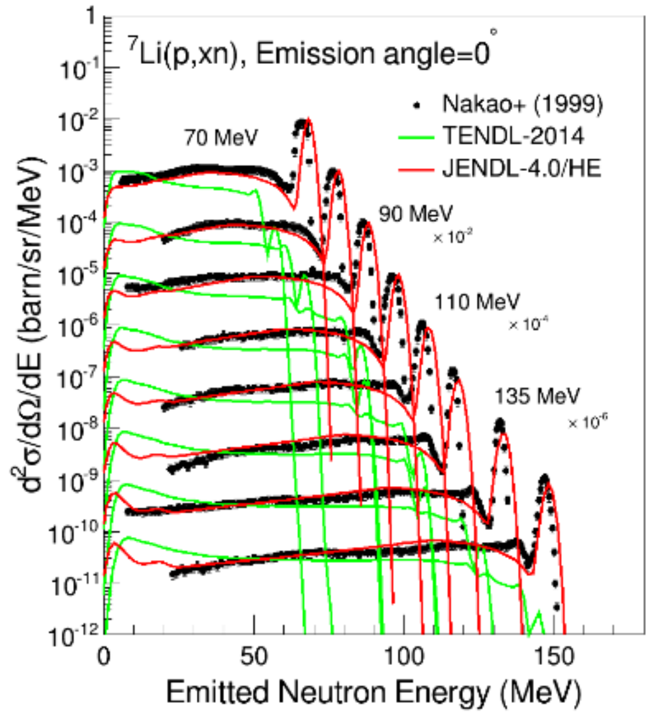
Its tough to run reactor-based neutron sources.

Easier to run accelerator-based ones.

* RANS project official website (http://rans.riken.jp/)

Accelerator-based neutron sources

- Li(p,n), Be(p,n) reactions are suitable for neutron sources
  - Low threshold (Li : 1.8 MeV, Be : 2.06 MeV)
  - High neutron yield



- Theories cannot predict them
  - INCL, Bertini, QMD...
  - Energy is too low (cascade picture does not apply)

- Evaluated nuclear data is the only way
  - JENDL, TENDL, what else?

* S. Kunieda *et al.*, "Overview of JENDL-4.0/HE and benchmark calculation" JAEA-Conf 2016-004, pp. 41-46 (2016).

Accelerator-based neutron sources

- Double-differential secondary neutron yield
  - Some experimental data exists (Li, Be)

- My proposals
  - Competition of evaluated data (JENDL, TENDL, something else?)
    - Some reaction models could also work well (DWBA, CDCC...)
  - Thick target integral benchmark
    - Neutron yield double-differential yield

Summary

- Proposals for radiation characterization benchmark
  - Event reconstruction algorithm
    - Important for radiation damage, soft error, heating
    - List up available algorithms → Compare which is better
  - Secondary radiation by polarized photon sources
    - Neutrons by laser-Compton scattering photons are anisotropic
    - Evaluate distribution parameters
  - (p,n) reactions for neutron sources
    - A few evaluated X-section data exist
    - Need for integral benchmark
      (e.g., thick target yield)

* http://tonton.hamazo.tv/e4594066.html