PHYS 3446 – Lecture #14

Wednesday, Oct. 19, 2016

Dr. Jae Yu

- Energy Deposition in Media
  - Neutron Interactions
  - Hadron Interactions
- Particle Detection
  - Ionization Detectors
  - MWPC
  - Scintillation Counters
  - Time of Flight

Physics Department
The University of Texas at Arlington
COLLOQUIUM

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The Pursuit of Data Reduction in Medical Imaging

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Wednesday October 19, 2016
4:00 Room 100 Science Hall

Since Wilhelm Roentgen discovered X-ray in 1985, medical imaging has become an essential component of medical care. Different medical imaging modalities use various physical methods to reveal the clinically relevant information inside the human body, which is a spatial (and temporal) distribution of certain physical properties. In the last decade, along side with significant improvement of image quality achieved by advanced methods using sophisticated imaging models, a huge effort has been devoted to reduce the data collected in a single medical imaging session, which can lead to lower radiation dose and/or shorter imaging time. In this talk, advanced imaging techniques and reconstruction methods will be presented for X-ray computed tomography (CT), cone-beam CT (CBCT), and single photon emission computed tomography (SPECT). In these cases, the results show that medical images reconstructed by using 50% to 80% less data can convey as accurate information as that of conventional methods, if not better. Other ongoing projects and future work on several imaging and modeling topics will be introduced at the end.

Refreshments will be served at 3:30 p.m. in the Physics Library

Reminder for Homework #6

- Perform the detailed calculations in examples 1 – 7 in CH6
- Due for these homework problems is Monday, Oct. 24.

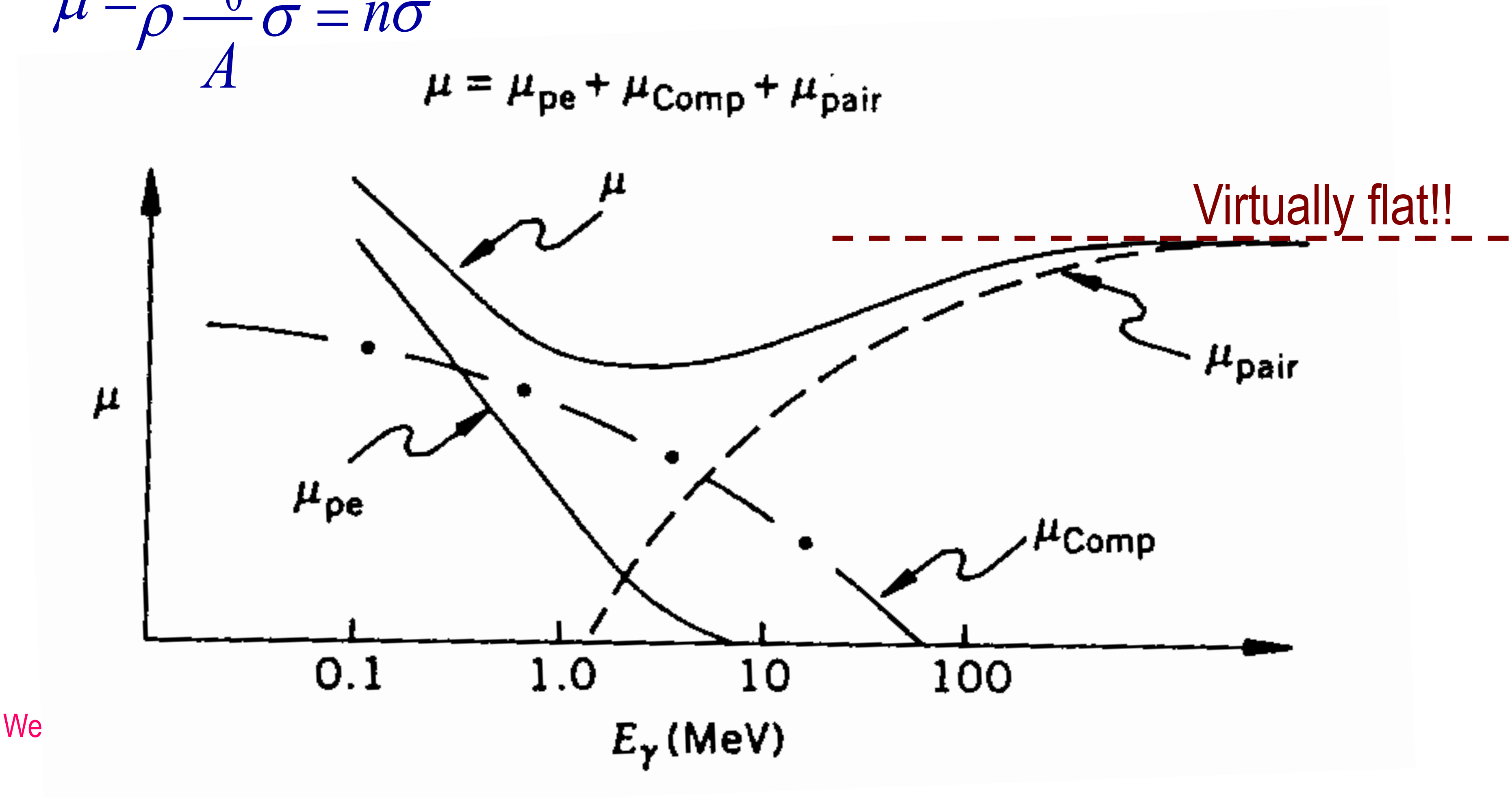
Photon Energy Loss Processes

- Total absorption coefficient of photons in a medium can be written as

$$\mu = \mu_{pe} + \mu_{Comp} + \mu_{pair}$$

- The absorption coefficient can be related to the cross section as

$$\mu = \rho \frac{A_0}{A} \sigma = n\sigma$$



We

Example 6.5

- The total absorption coefficient for 5MeV photons in lead is about $0.04cm^2/g$. (a) If the density of lead is $11.3g/cm^3$, what is the half thickness of lead for these photons? (b) What thickness of lead would be required to reduce the intensity of such photons to 6% of the initial value?
- (a) First convert the absorption coefficient to cm^{-1}.

$$\mu = 0.04\,cm^2/g \cdot 11.3\,g/cm^3 \;= 0.45\,cm^{-1}$$

$$\Rightarrow x_{1/2} = 0.693/\mu \quad = 0.693/0.45 = 1.53cm$$

- (b) Using the intensity formula:

$$\frac{I}{I_0} = e^{-\mu x} \quad \Rightarrow 0.06 = e^{-\mu x}$$

- Solving for x, we obtain

$$x = -\ln(0.06)/\mu \quad = -\ln(0.06)/0.45 = 6.2(cm)$$

- Typical thickness of lead in an apron is 0.25mm to 0.5mm
  - What percentage of gamma ray radiations can these thicknesses stop?

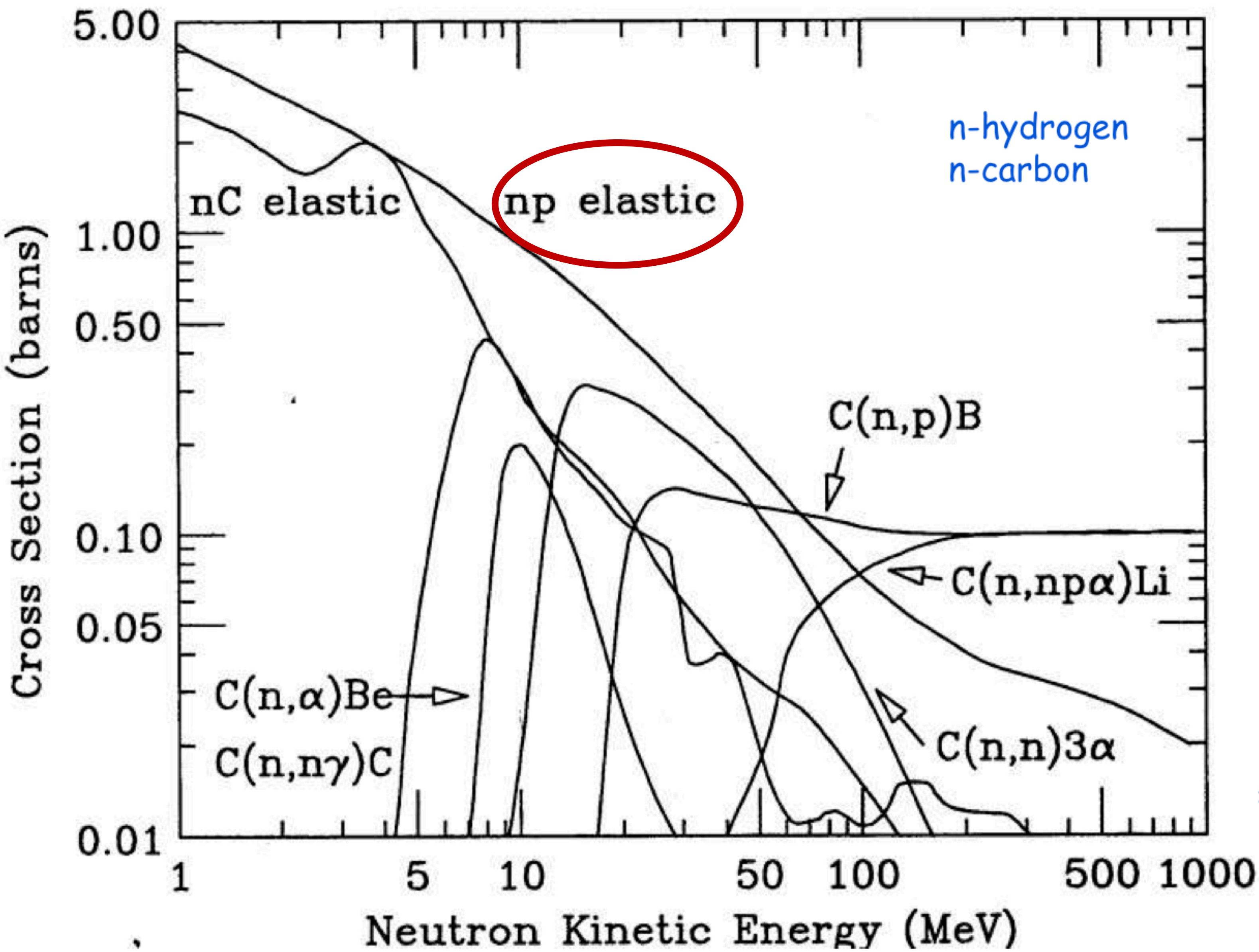
Interaction of Neutrons

- What are the characteristics of neutrons?
  – A constituent of nuclei
  – Have the same nucleon number as protons
  – Have the same spin as protons
  – Electrically neutral ➔ Do not interact through Coulomb force
  – Interacts through strong nuclear force
- When low energy neutrons interact inelastically
  – Nucleus get excited and decay to ground levels through emission of photons or other particles
  – Such photons or other particles can be detected through other processes

Interaction of Neutrons

- In an elastic scattering of neutrons, it loses smaller amount of energy if the media's nucleus is heavy
  - Hydrogen rich paraffin is used to slow down neutrons
- When neutrons are produced in experiments, they can penetrate deep
  - Since normally there are no hydrogen nuclei available for kinetic energy absorption
  - The neutron that shines or "albedoes" at accelerators and reactors is often a major source of background
    - Can only be reduced with the use of appropriate moderators

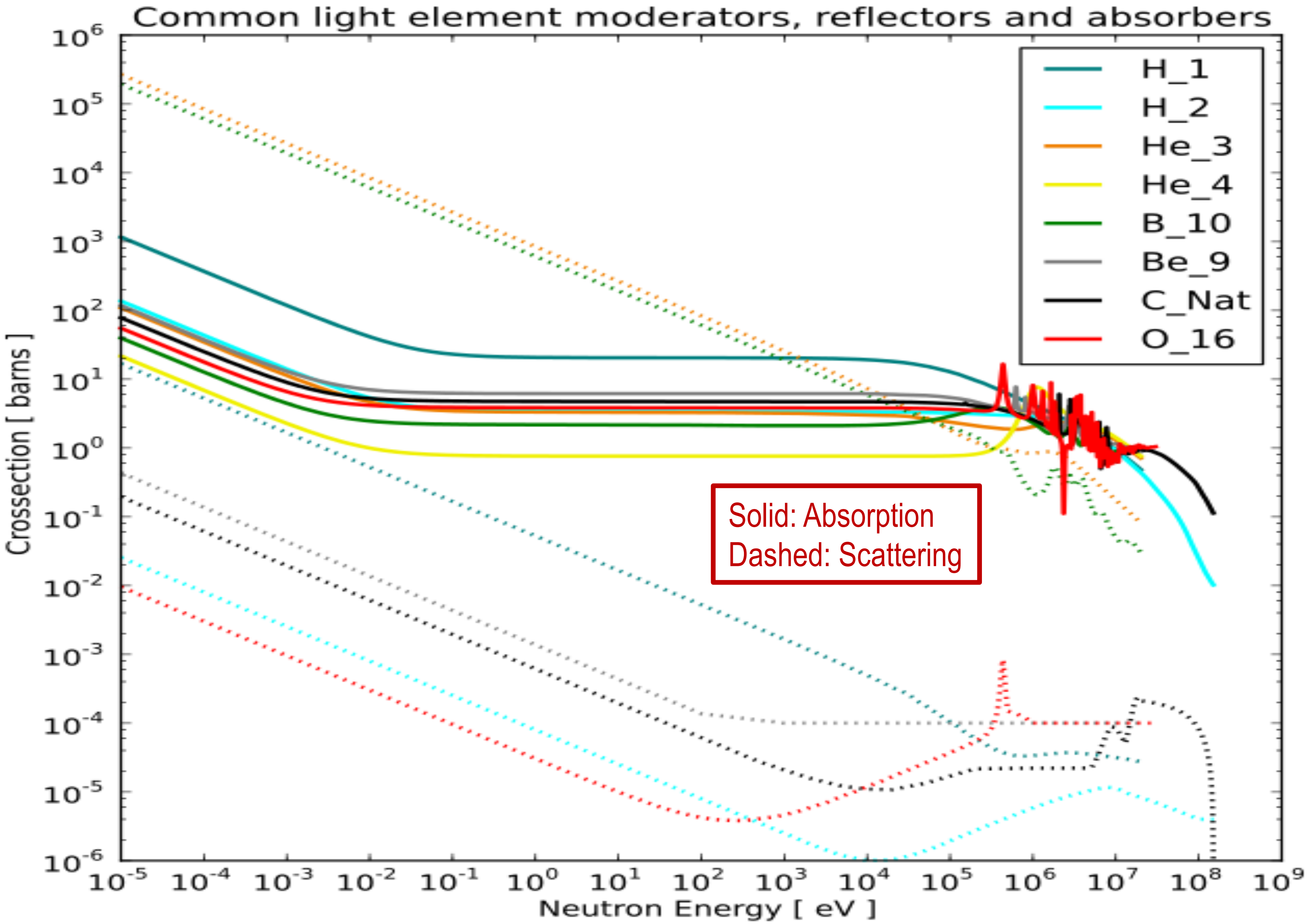
Neutron X-sec w/ H and C



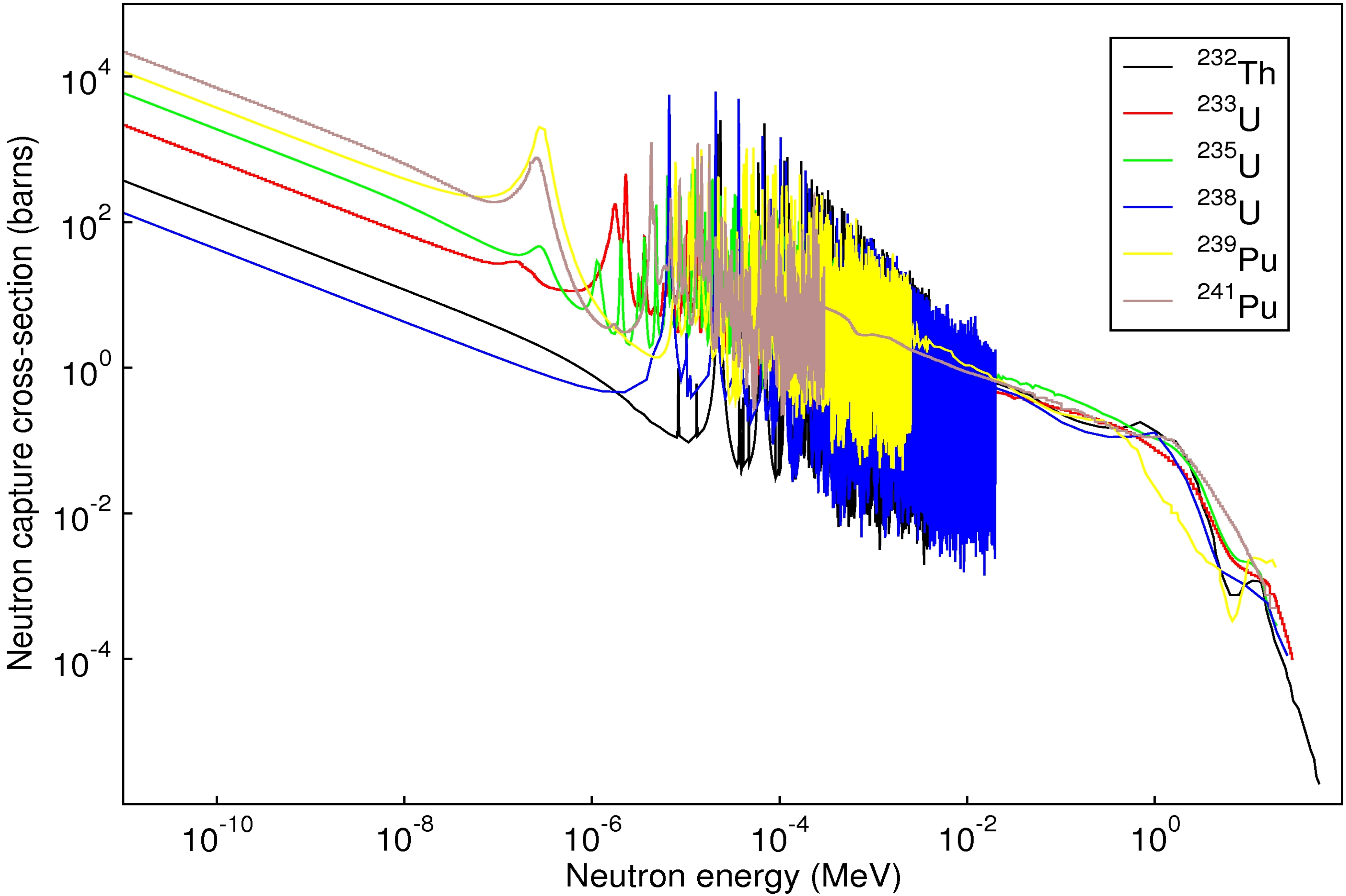
n-hydrogen
n-carbon

1b= 10^{-24}cm^2 =100fm^2

Neutron X-sec w/ Moderators



Neutron Capture X-sec



Interaction of Hadrons at High Energies

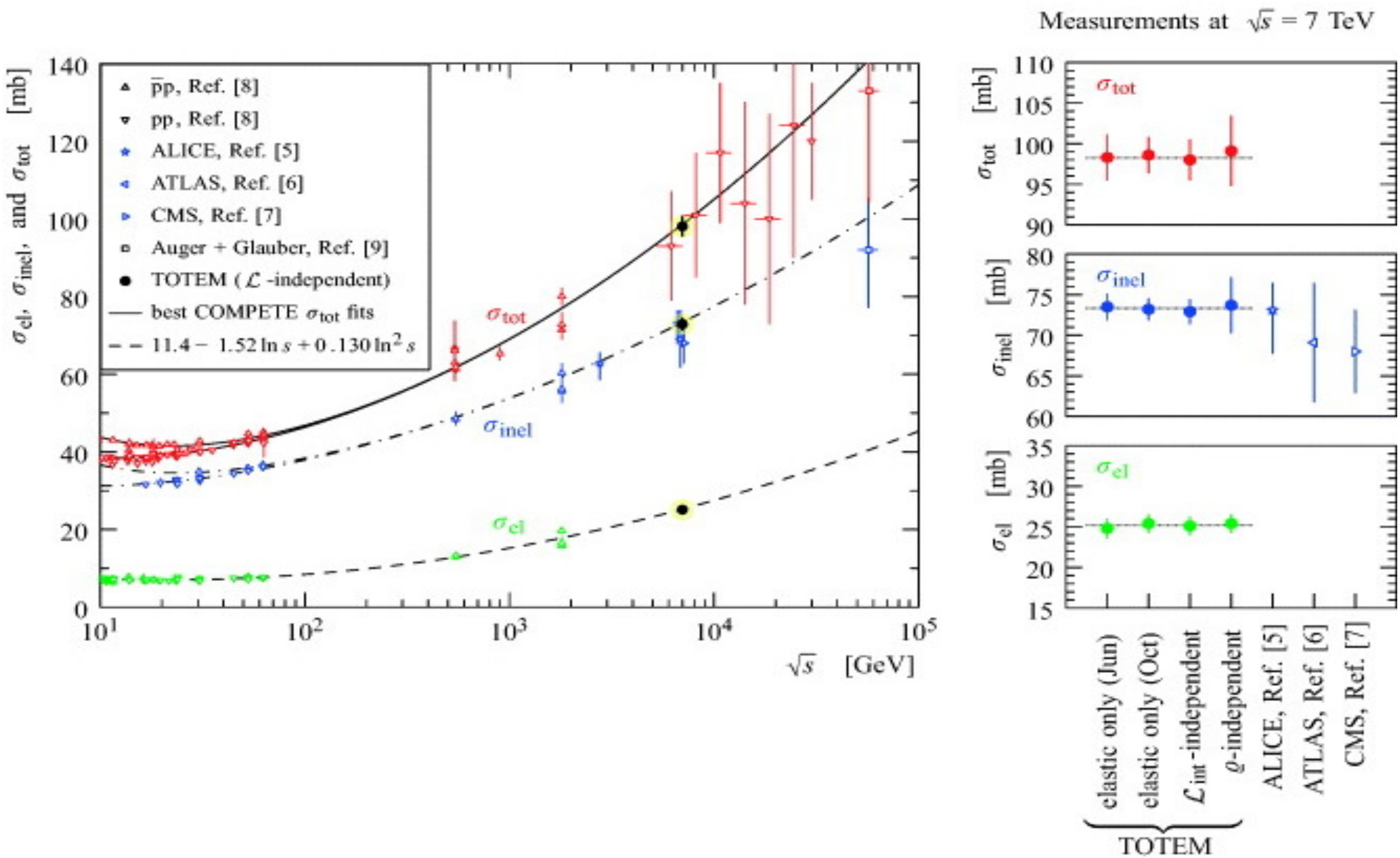
- What are hadrons?
  - All particles made of quarks & interact through the strong nuclear force
  - Examples?
    - Neutrons, protons, pions, kaons, etc
  - Protons are easy to obtain and interact with other particles to produce mesons
- At low (<2GeV) energies, the cross sections between different particles differ dramatically
  - The collision cross sections of any two hadrons vary rapidly with energy
  - Nuclear effect is significant
- Above 5GeV, the total cross section of hadron-hadron interaction changes slightly as a function of energy
  - Typical size of the cross section is 20 – 40 mb at 70 – 100 GeV
  - And increases logarithmically as a function of energy

Interaction of Hadrons at High Energies

- Hadronic collisions involve very small momentum transfers, small production angles and interaction distance of order 1fm
- Typical momentum transfer in hadronic collisions are of the order $q^2 \sim 0.1\ (\mathrm{GeV}/c)^2$
- Mean number of particles produced in hadronic collisions grows logarithmically as a function of incident energy
  - ~3 at 5GeV
  - ~12 at 500GeV
- When high energy hadrons interact with matter, they break apart nuclei, produce mesons and other hadrons
  - These secondary particle then interact through strong forces subsequently in the matter and deposit energy

Proton Interaction X-sec

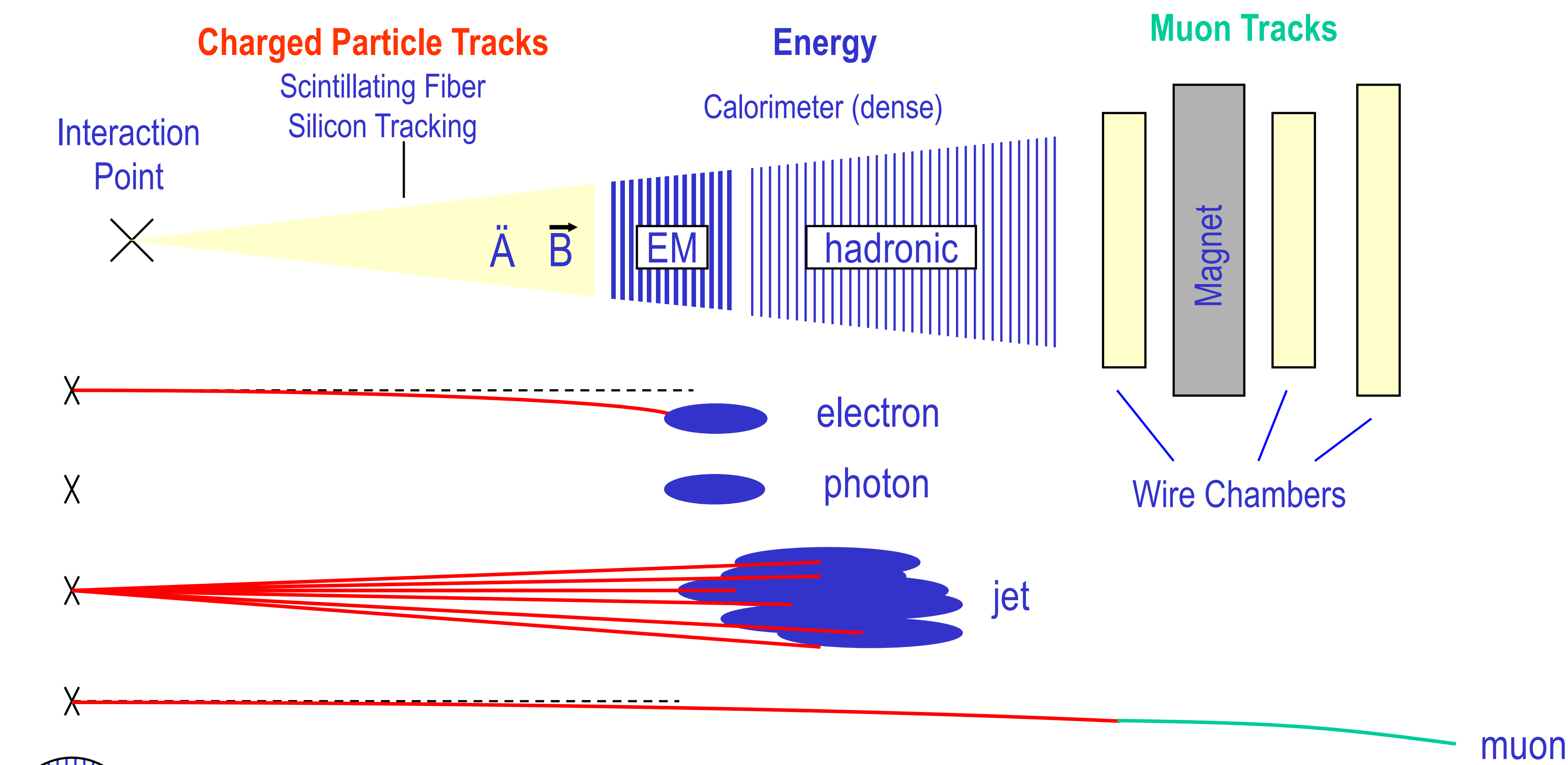
Fig. 1: from The TOTEM Collaboration et al 2013 EPL 101 21004

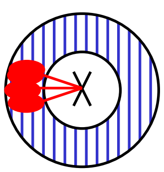


Particle Detectors

- Subatomic particles cannot be seen by naked eyes but can be detected through their interactions within matter
- What do you think we need to know first to construct a detector?
  - What kind of particles do we want to detect?
    - Charged particles and neutral particles
  - What do we want to measure?
    - Their momenta
    - Trajectories
    - Energies
    - Origin of the interaction (interaction vertex)
    - Etc
  - To what precision do we want to measure?
- Depending on the answers to the above questions we use different detection techniques

Particle Detection





neutrinos -- or any non-interacting particle
missing transverse momentum

We know x,y starting momenta is zero, but along the z axis it is not, so many of our measurements are in the xy plane, or transverse