# Improved description of ion stopping power in *compounds* in MARS code

**Igor Rakhno**

***Fermilab, APC***

**February 14, 2012**

**RESMM'12**

# Outline

- Motivation
- Formalism
- Comparisons with measurements

# Motivation: Does it really matter? Does it matter for μ2e?

- Accelerator magnets usually contain insulation materials such as **G10, kapton, epoxy** (most radiation prone) → all are compounds.

- Stopping power dE/dx for compounds is usually described using **Bragg's rule**:

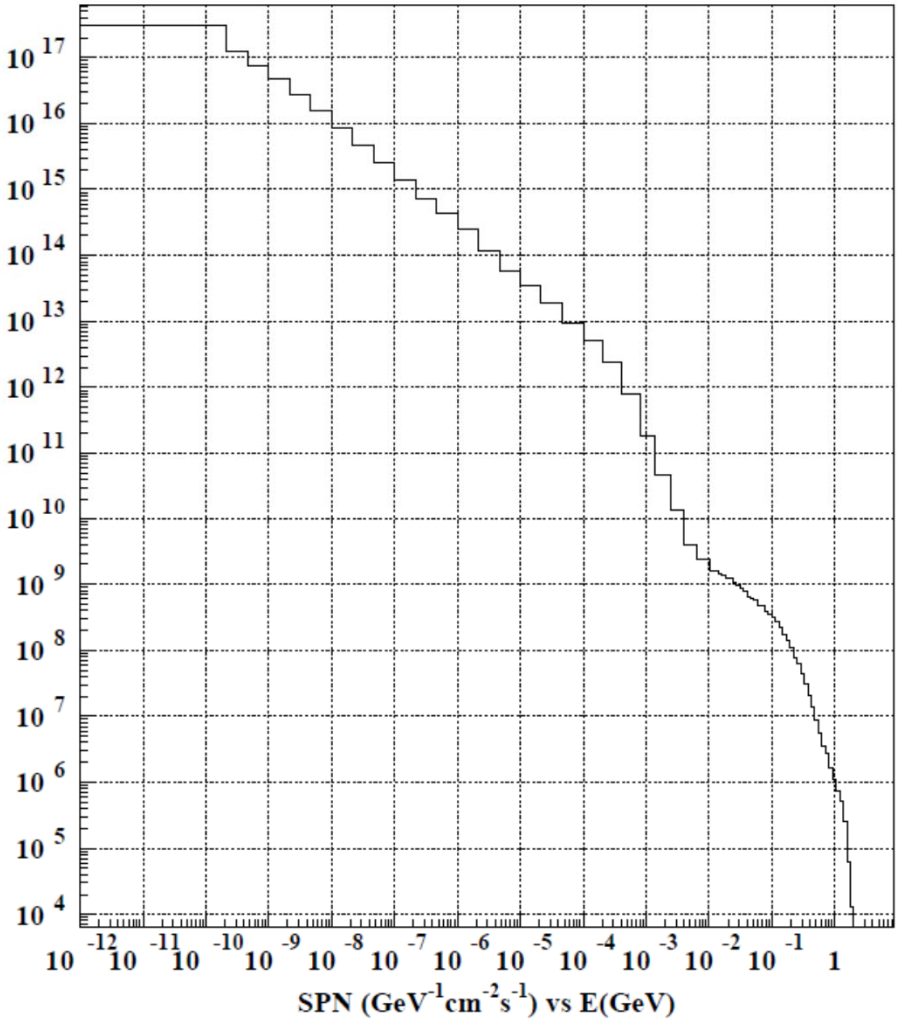
$$\frac{dE}{dx} = \sum_i \left( \frac{dE}{dx} \right)_i$$

- At low energies, ~100 keV/amu, for **low-Z materials** (Z<12, especially **hydrocarbons**) the recipe introduces errors, and the difference between theory and experiment can be as large as **20%**.

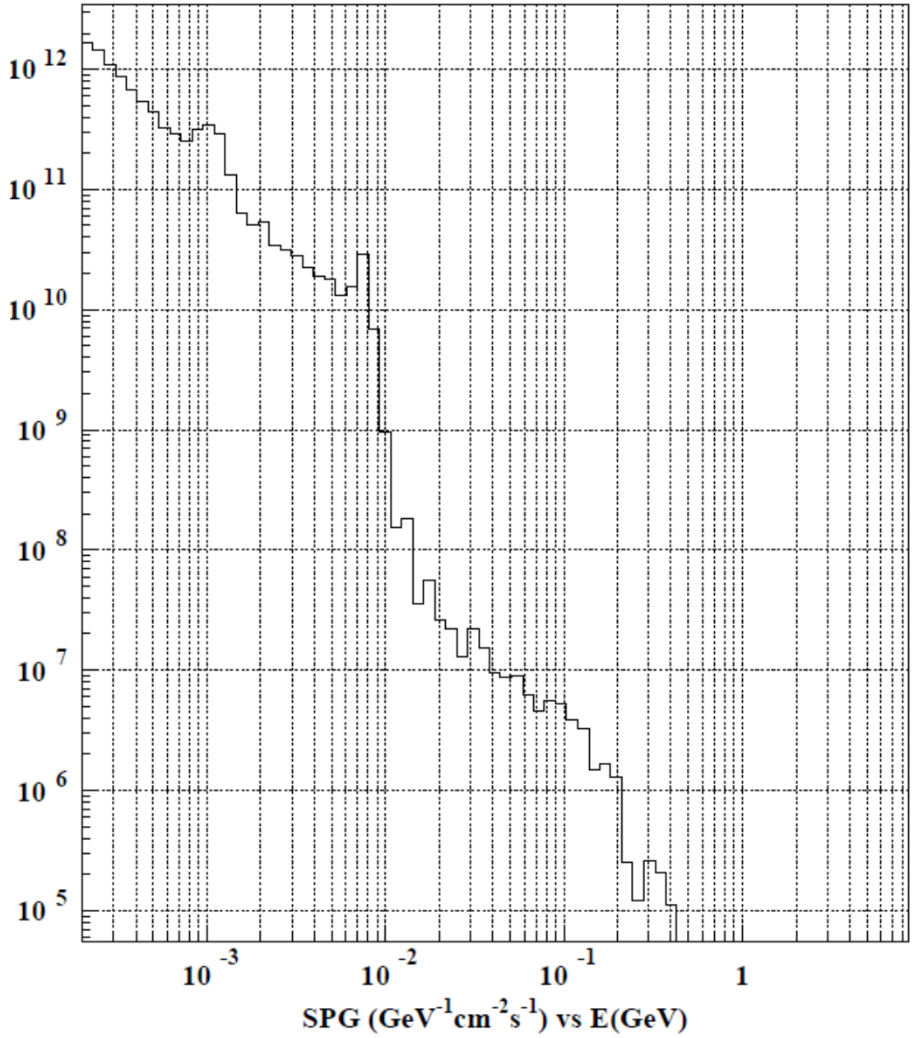
- Let us see what energy spectra we get in Production Solenoid coil.

Vitaly Pronskikh provided particle energy spectra in the **hottest spot** of the Production Solenoid coil calculated at ~1/3 nominal power ($6.7\times10^{12}$ p/s)

## *Neutrons*



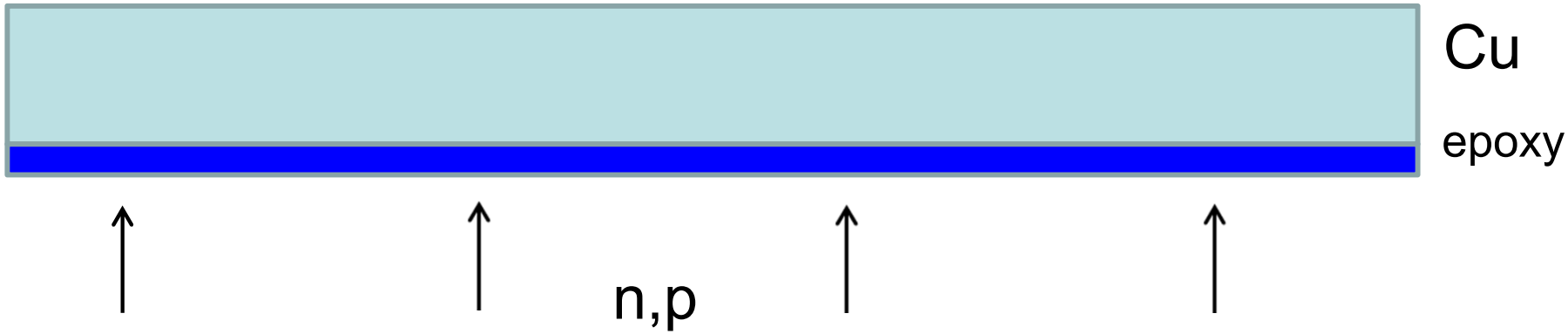

## *Gammas*



- Comparison between partial contributions to ***energy deposition*** (absorbed dose) in an epoxy layer (ethylene oxide $C_2H_4O$) 2.5 mm thick.

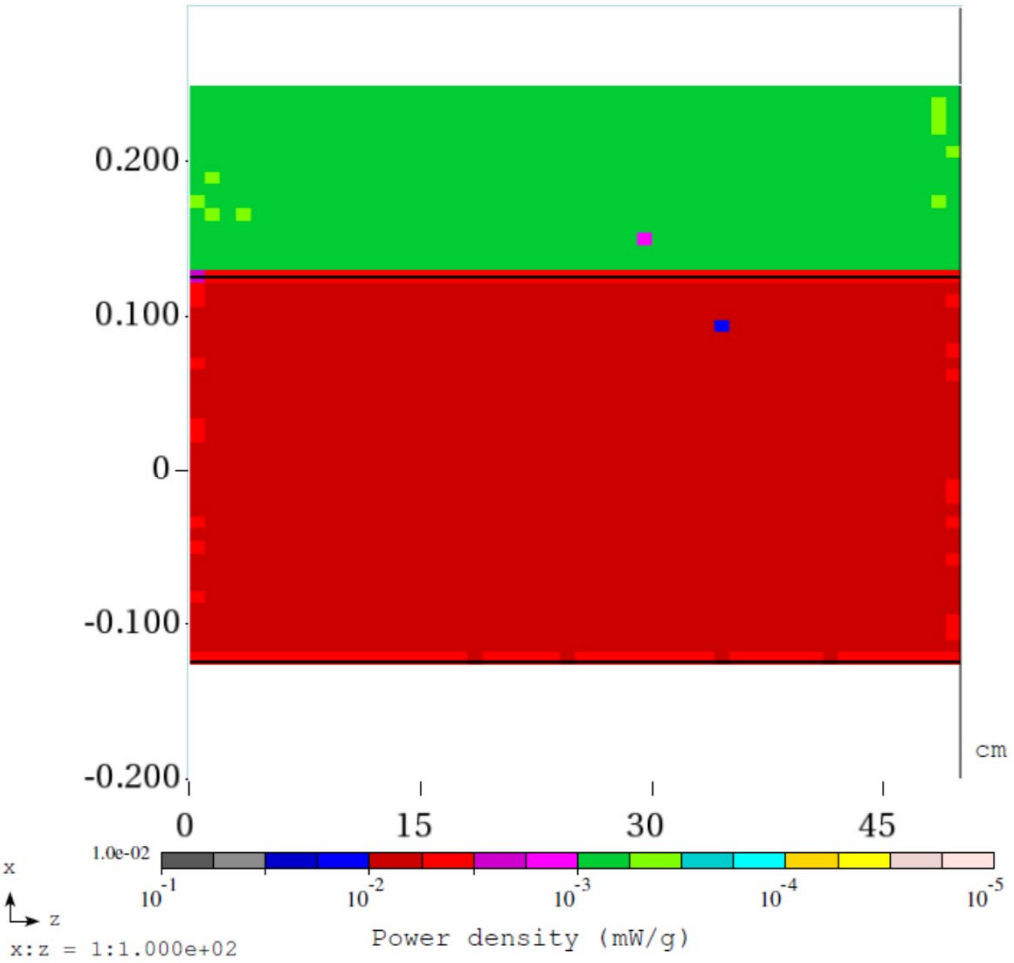
- $\boldsymbol{\phi_n = 5.5\times10^9\ cm^{-2}s^{-1}}$, $\boldsymbol{\phi_p = 4.7\times10^5\ cm^{-2}s^{-1}}$

- Separate calculation for a simple model in order to get a more reliable result in the thin epoxy layer.

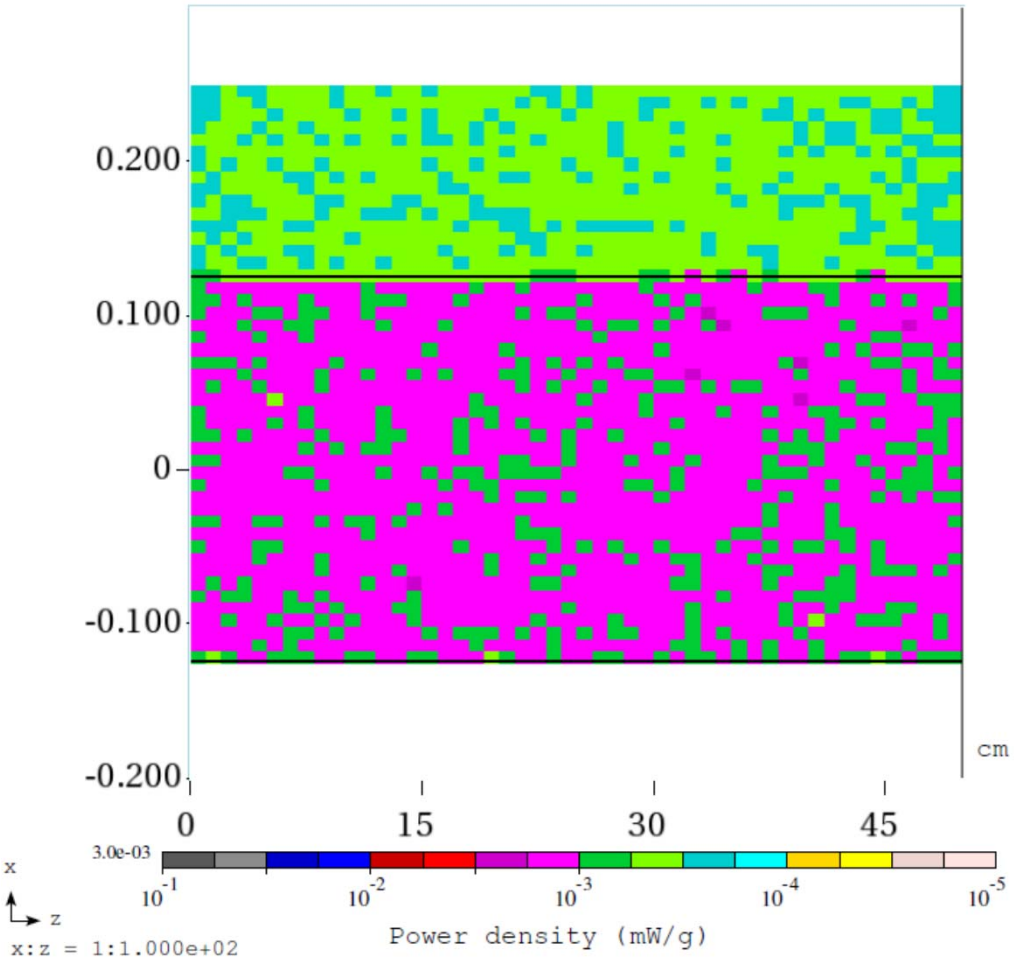


# Power density (arbitrary normalization)

## Total

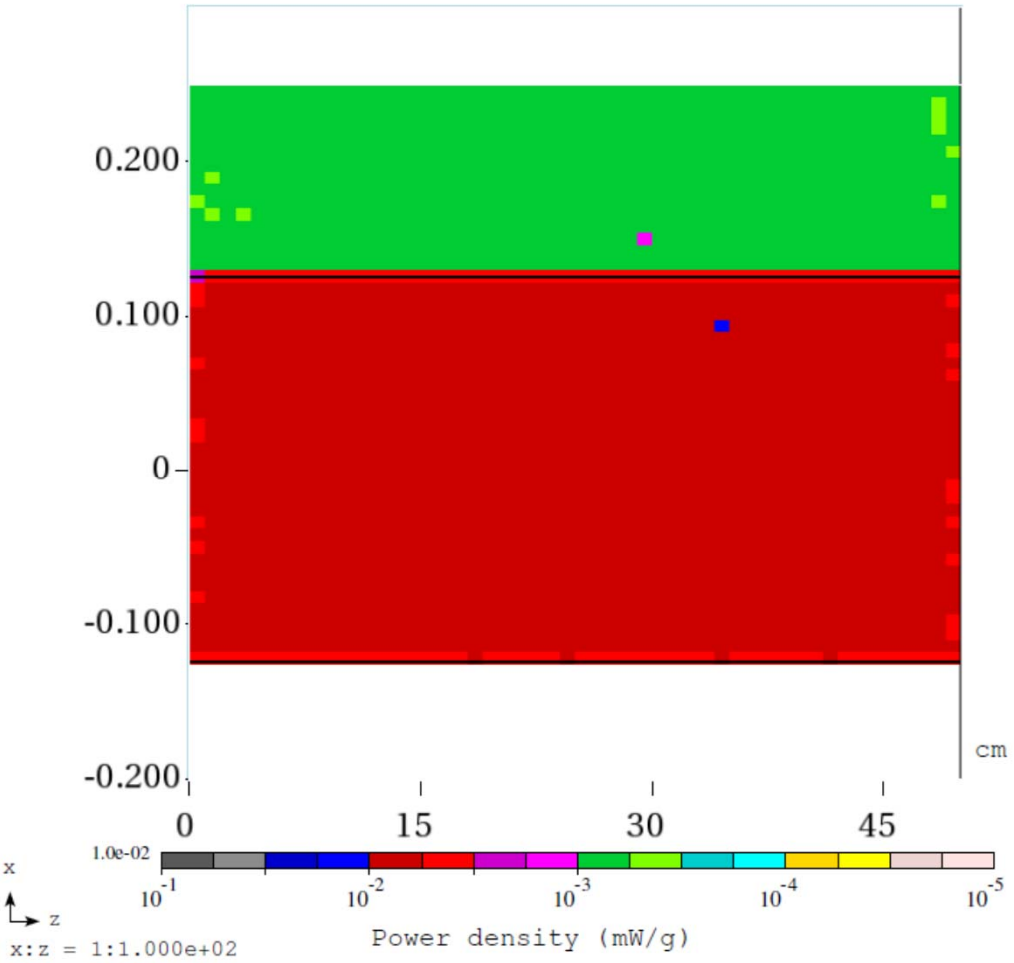



## Neutron contribution

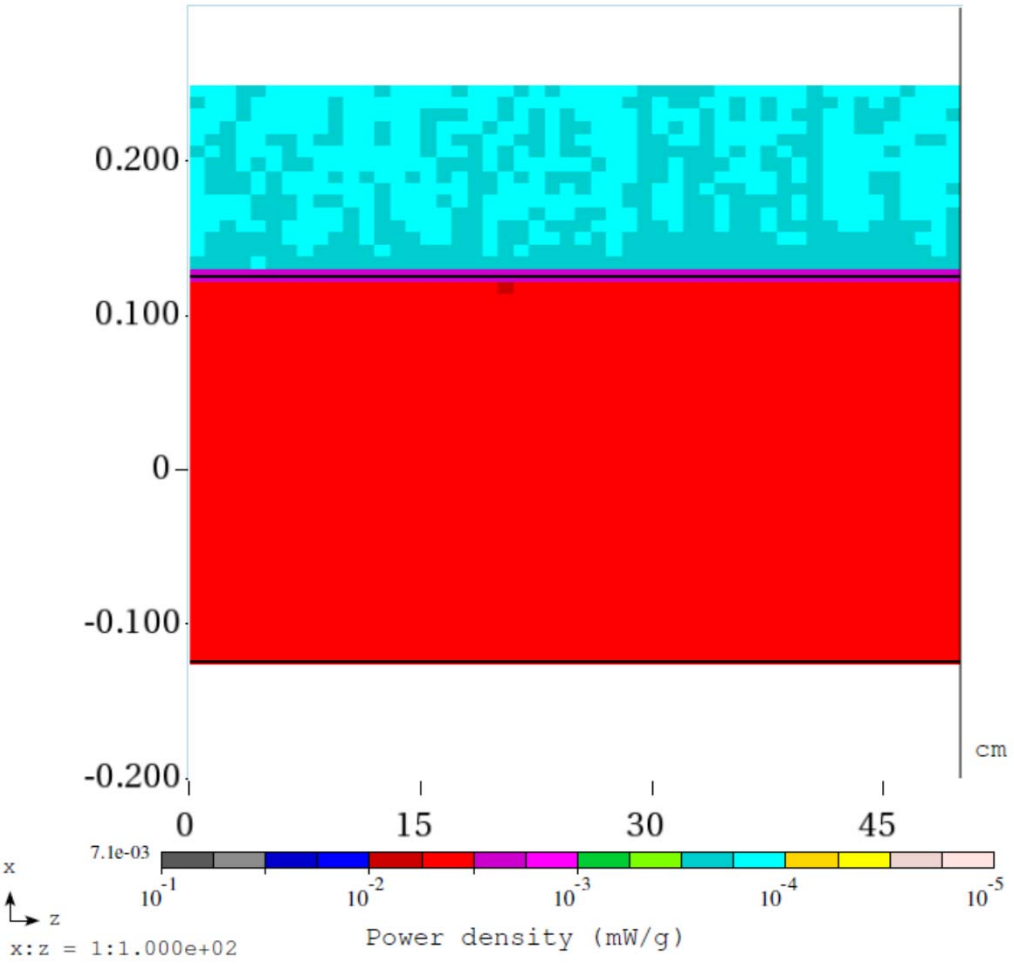


# Power density (arbitrary normalization)

Total




Proton contribution



# Numerical data on average power density

- Total ~ $8\times10^{-3}$ mW/g
- Neutron contribution ~ $1\times10^{-3}$ mW/g
- Proton contribution ~ $7\times10^{-3}$ mW/g

- Neutrons (~90% with energy lower than 0.5 MeV) transfer energy mostly in **elastic collisions** with target nuclei. ***Small fraction*** of neutron kinetic energy is transferred to nuclei like C, O.

# Stopping power in compounds (a little boring chemistry)

- There is no need to invent the wheel: the ***Cores-and-Bonds*** approach (CAB) was developed in 80s by G. Both *et al.*, Köln University.

- $S_{ion} \xrightarrow{Z_{eff}} S_p \rightarrow S_{p,Bragg}$, $S_{p,Bragg}$(125 keV) and $S_{p,CAB}$(125 keV)

- $S_{p,CAB}(125\ keV) = \sum Cores + \sum Bonds$

- Cores: **atoms** from H to Cl.
- Bonds: **single** like H-H, C-H *etc*, **double** like C=C, C=O *etc*, **triple** like C≡C, O≡O.

# Stopping power in compounds (a little boring chemistry)

- All chemical bonds in a compound (may be tricky for some compounds).

- CAB developers claim that such an approach provides accuracy of about 1% (difference between measurement and theory). More than 100 comparisons for a variety of compounds.

- More info at www.srim.org

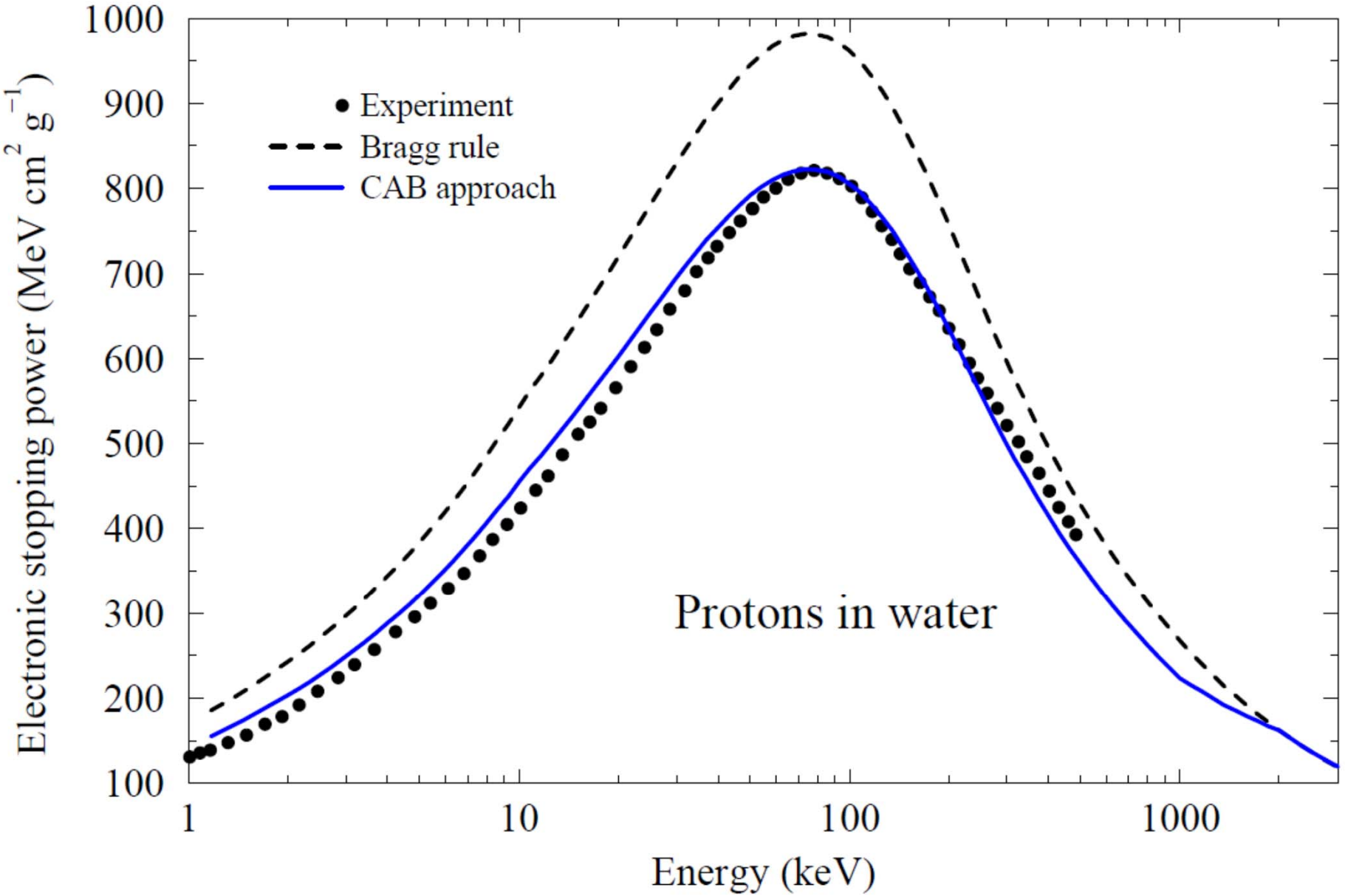
  Computer code by J. Ziegler et al.,

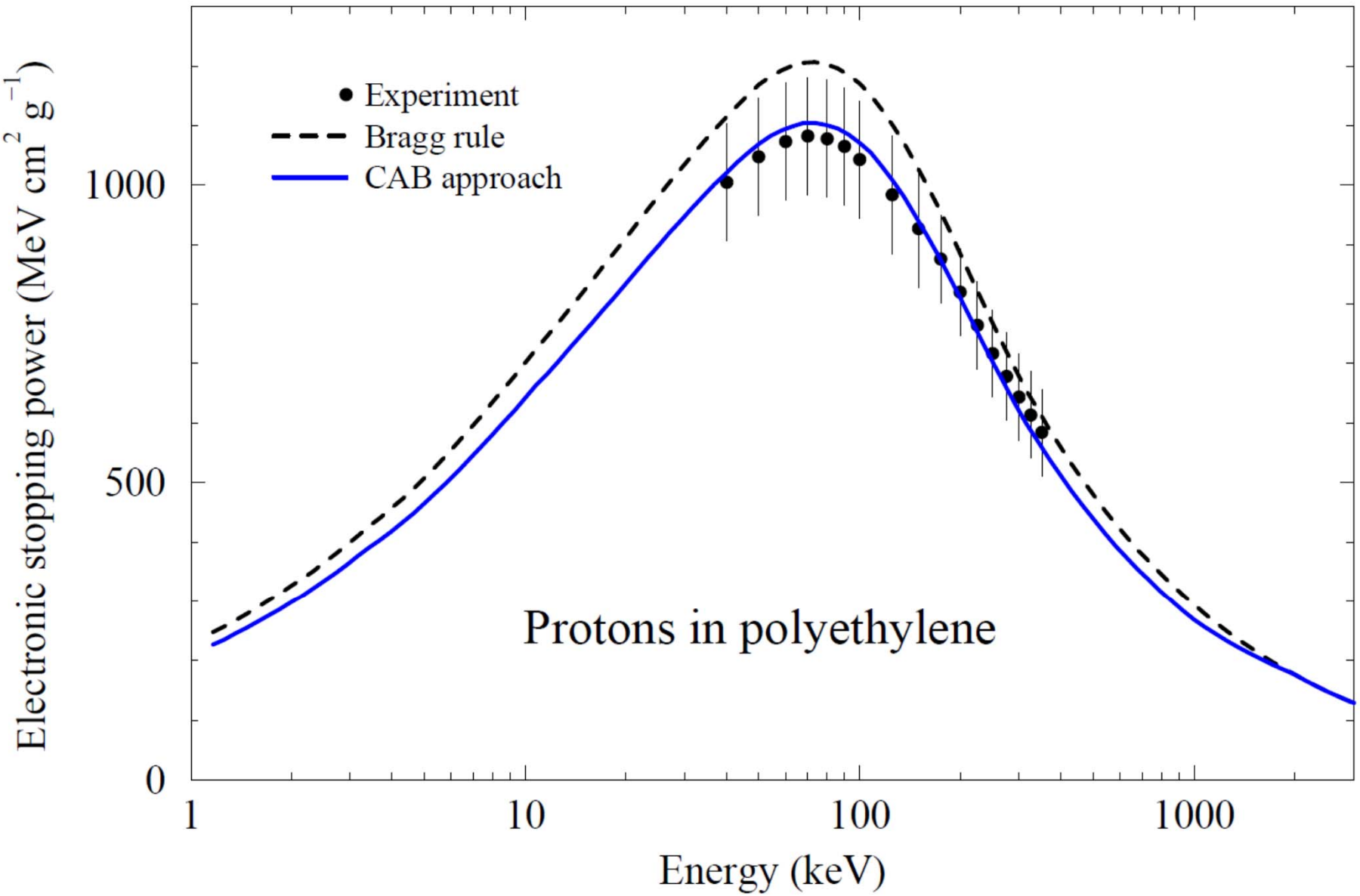
  **S**topping ang **R**ange of **I**ons in Matter

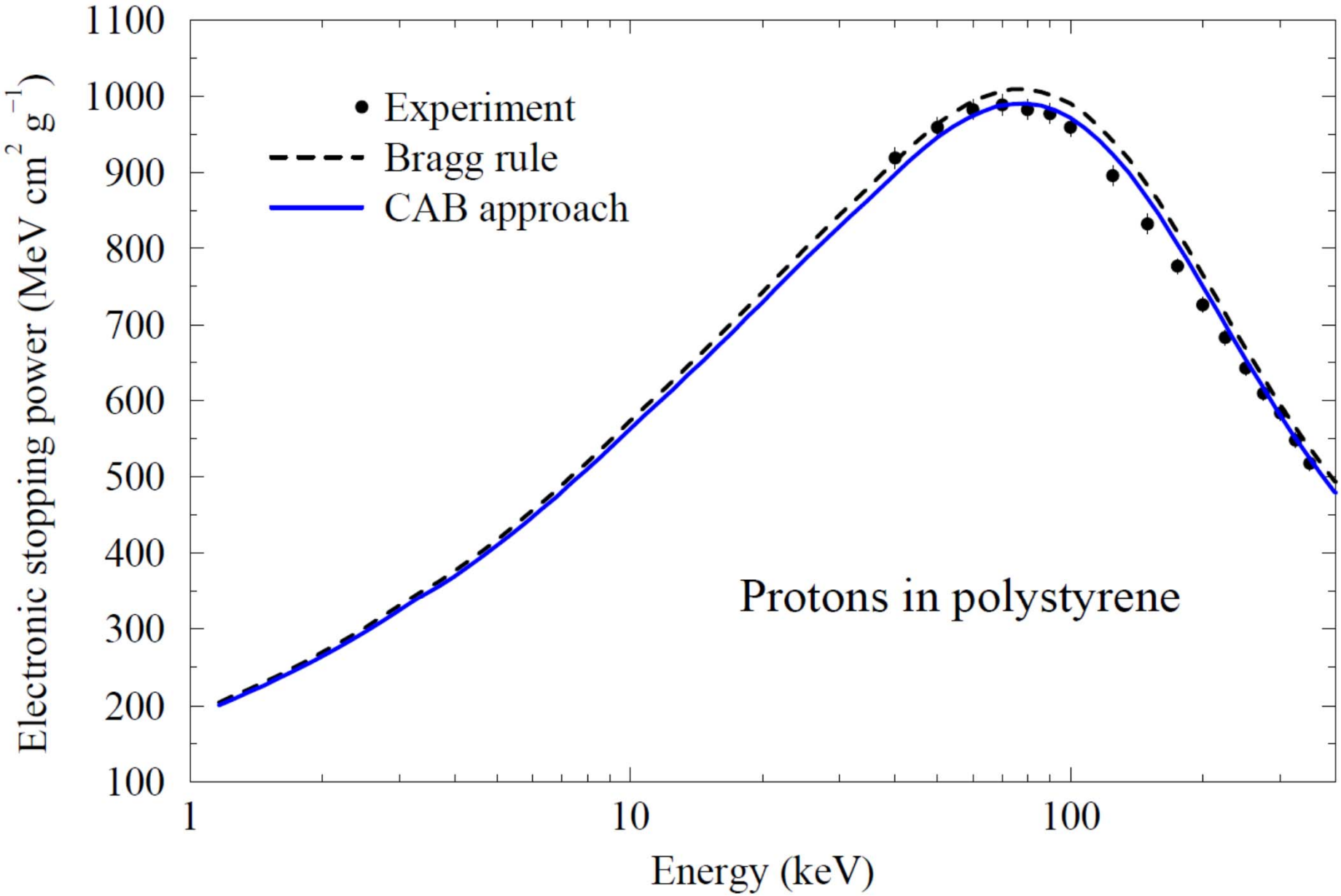
# Implementation & comparisons

- The CAB method was implemented in MARS code recently for **several** most important **compounds**: water, polyethylene, polystyrene, epoxy.

- Currently MARS users can define composition of compounds using input file. It might be makes sense to provide a possibility to enter the CAB data in the input file if a user wants to do so.


Experiment
Bragg rule
CAB approach
Protons in water
Electronic stopping power (MeV cm$^2$ g$^{-1}$)
Energy (keV)
1000
900
800
700
600
500
400
300
200
100
1
10
100
1000


Experiment
Bragg rule
CAB approach
Protons in polyethylene
Electronic stopping power (MeV cm$^2$ g$^{-1}$)
Energy (keV)
0
500
1000
1
10
100
1000


Experiment
Bragg rule
CAB approach
Protons in polystyrene
Electronic stopping power (MeV cm$^2$ g$^{-1}$)
Energy (keV)
1100
1000
900
800
700
600
500
400
300
200
100
1
10
100