Garfield++
Primary Ionization Calculations

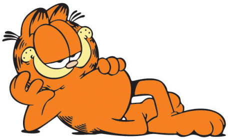
H. Schindler

6th RD51 Collaboration Meeting

October 9, 2010

Part I

Garfield++



Garfield++

Concept

- object-oriented toolkit for detailed simulation of gaseous and semiconductor detectors
- library of C++ classes
- translation and extension of Fortran Garfield routines
- visualization, statistics → ROOT

Team

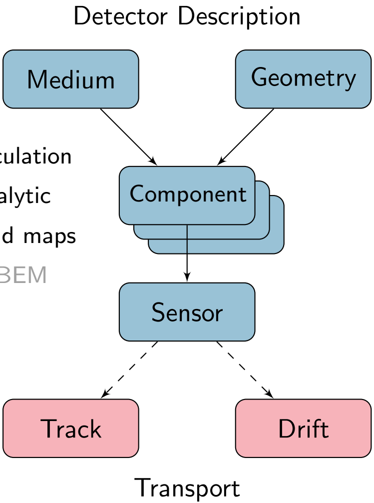
R. Veenhof, A. Bellerive, N. Shiell, HS

Further contributors are most welcome...

Garfield++

material properties

- gas → Magboltz
- silicon



field calculation

- analytic
- field maps
- neBEM

primary ionization

- Heed
- ...

charge transport

- microscopic
- MC
- RKF

Garfield++

Recent Activities

In the last few months (since the Freiburg meeting) we have worked mainly on

- analytic two-dimensional fields (wrapper and rewrite)
- interface to Heed++
- creation and interpolation of gas tables

How to get the code

- `http://svnweb.cern.ch/trac/garfield`
- `http://svnweb.cern.ch/world/wsvn/garfield`

First release within the next weeks or so.
Any feedback is highly appreciated...

Part II

Primary Ionization

Tools

Heed

- author: I. Smirnov
- based on PAI model, extended by shell separation and atomic relaxation
- phenomenological model for δ electron transport
- interface to C++ version (2005) is now available

Magboltz/MIP

- author: S. Biagi
- electron cross-sections extended to mip energy
- new program "MIP"
  - cluster size distribution
  - δ electron range
  - W, F
- δ electrons (up to $\approx$ 10 keV) can also be simulated on event-by-event basis (microscopic tracking)

PAI Model

Differential Cross-Section

$$
\begin{aligned}
N\frac{\mathrm{d}\sigma}{\mathrm{d}E} = & \frac{z^2\alpha}{\beta^2\pi\hbar c}\mathrm{Im}\left(\frac{-1}{\varepsilon(E)}\right)\ln\frac{2m\beta^2c^2}{E} + \\
+ & \frac{z^2\alpha}{\beta^2\pi\hbar c}\mathrm{Im}\left(\frac{-1}{\varepsilon(E)}\right)\ln\frac{1}{|1-\beta^2\varepsilon(E)|} + \\
+ & \frac{z^2\alpha}{\beta^2\pi\hbar c}\left(\beta^2 - \frac{\varepsilon'(E)}{|\varepsilon(E)|^2}\right)\left(\frac{\pi}{2} - \arctan\frac{1-\beta^2\varepsilon'(E)}{\beta^2\varepsilon''(E)}\right) + \\
+ & \frac{z^2\alpha}{\beta^2\pi\hbar c}\frac{1}{E^2}\int_0^E E'\mathrm{Im}\left(\frac{-1}{\varepsilon(E')}\right)\mathrm{d}E'
\end{aligned}
$$

Heed:

$$
\varepsilon''(E) \rightarrow \frac{N\hbar c}{E}\sigma_\gamma(E)
$$

Magboltz/MIP

- total cross-section

  Bethe-Born cross-section (for $\varepsilon > 10$ keV):

$$\sigma_{\text{ion}}(\varepsilon) = 4\pi \left(\frac{\hbar}{mc}\right)^2 \frac{1}{\beta^2} \left[M^2 \left(\ln\left(\beta^2\gamma^2\right) - \beta^2\right) + C \right]$$

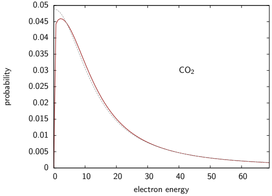
tuned to exp. data

- energy distribution of δ electrons

  parameterization by Opal, Beaty and Peterson

$$\frac{d\sigma}{dE} \propto \frac{1}{1 + \left(\frac{E}{E_{\text{OBP}}}\right)^2},$$

slightly modified



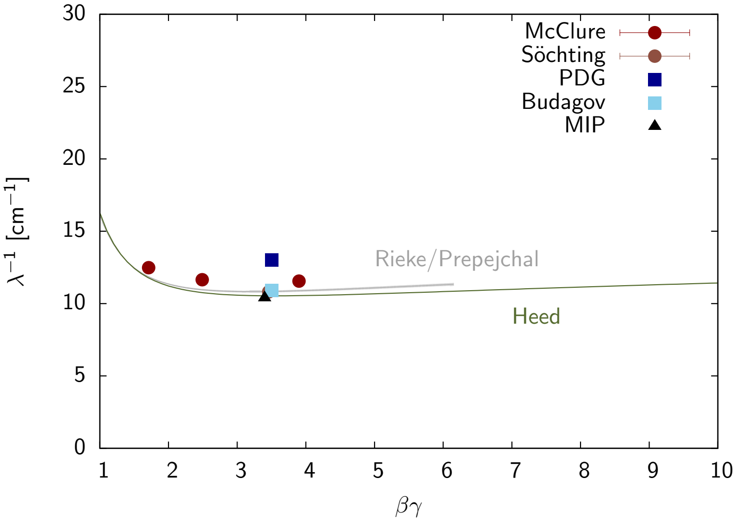
Cluster Density

Comparison is made at $T = 20^\circ$ C, $p = 760$ Torr.

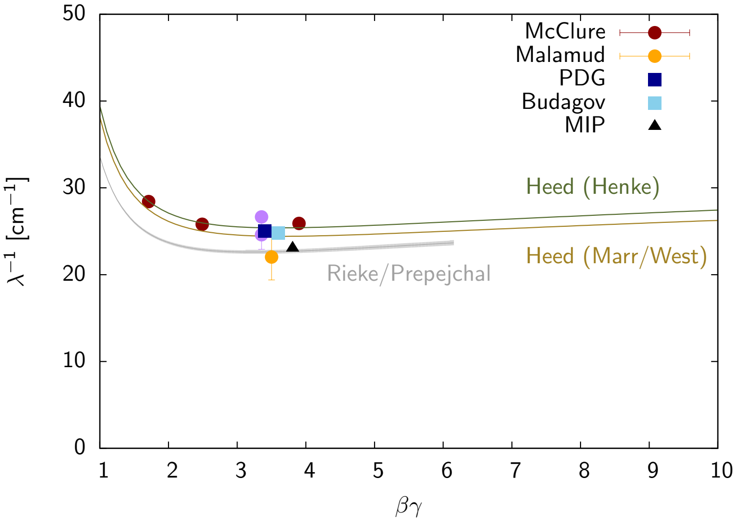
Experimental Data (σ_{ion})

- G. W. McClure, Phys. Rev. **90** (1953), 796-803
- F. Rieke, W. Prepejchal, Phys. Rev. A **6** (1972), 1507-1519
- G. Malamud et al., J. Appl. Phys. **74** (1993), 3645-3651
- other compilations
    - Particle Physics Booklet
    - Sitar et al., *Ionization Measurements in High Energy Physics*
    - Blum, Riegler, Rolandi, *Particle Detection with Drift Chambers*

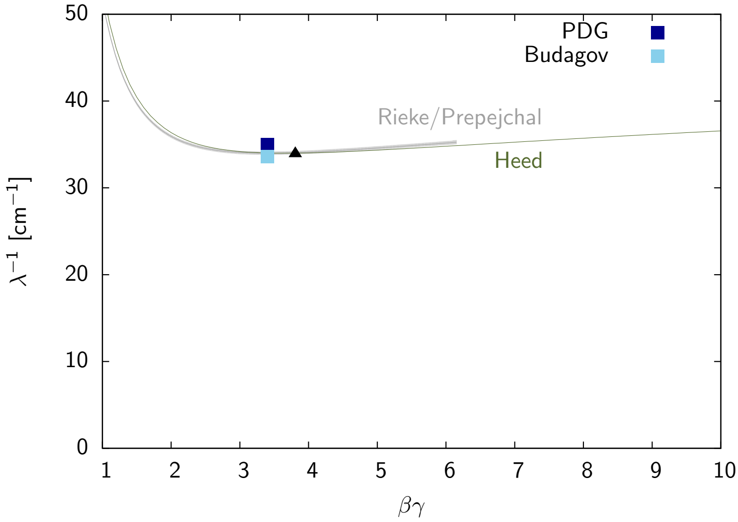
Cluster Density - Neon



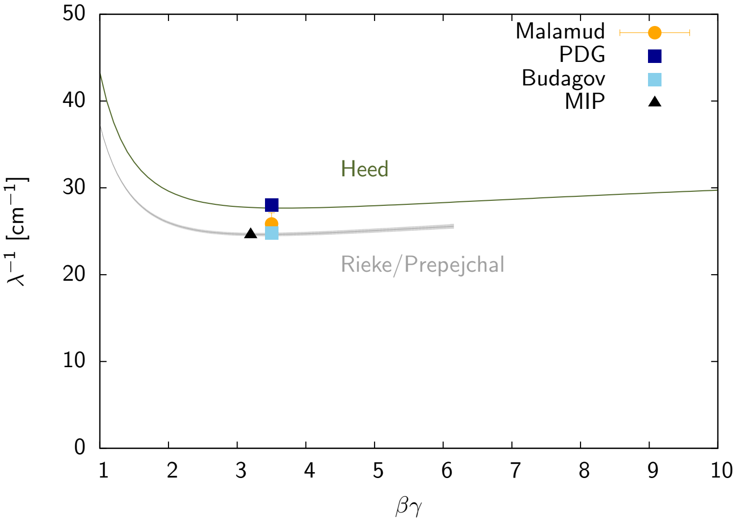
Cluster Density - Argon



Cluster Density - CO_2



Cluster Density - CH_4



Delta Electron Transport

Energy distribution of δ electrons would logically be the next point of comparison, but is skipped here (some questions to be clarified).

Transformation of δ electrons to low energy electrons

Heed
- phenomenological algorithm for creation of conduction electrons along the track
- generic, requires only asymptotic W value and Fano factor F (default 0.19)

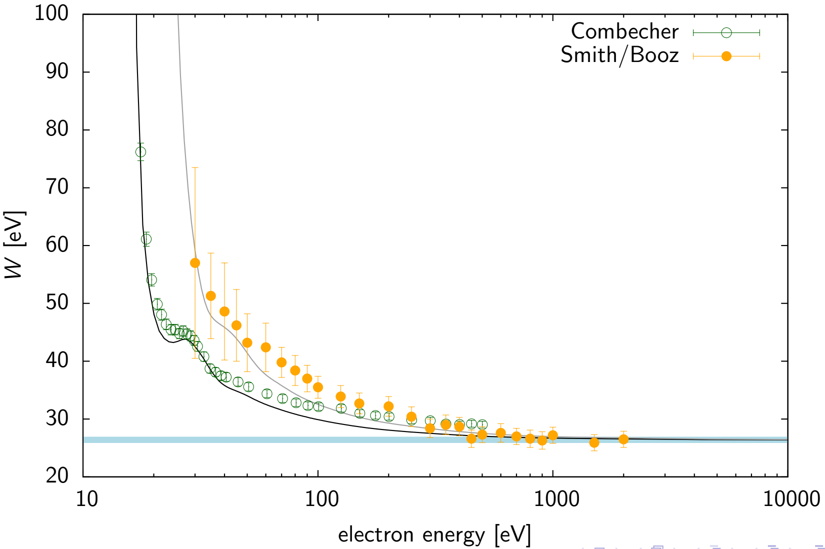
Magboltz/Mip
- follow individual collisions with gas molecules
- allows simulation of Penning transfers

Delta Electron Transport

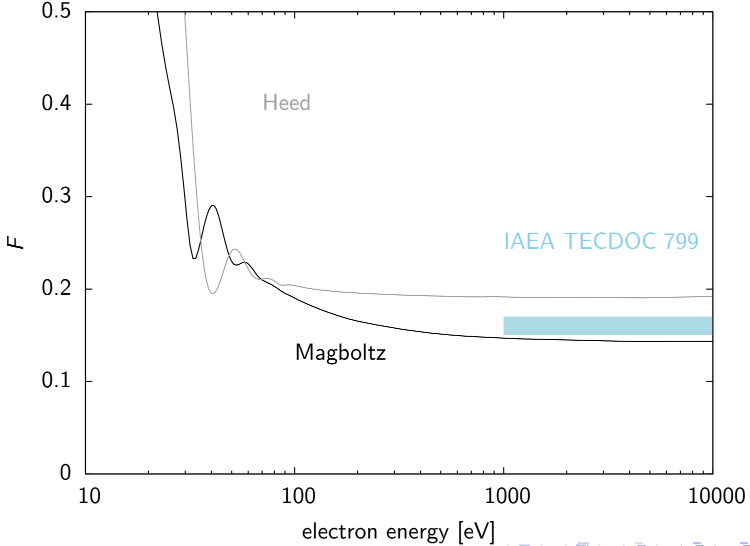
Experimental Data (W)

- ICRU Report 31 → asymptotic value
- D. Combecher, Rad. Res. **84** (1980), 189-218
- E. Waibel and B. Grosswendt
  - Nucl. Instr. Meth. **211** (1983), 487-498
  - Proc. 8^{th} Symp. Microdosimetry, Luxembourg (1983), 301-310
  - Nucl. Instr. Meth. B **53** (1991), 239-250
- B. G. R. Smith and J. Booz, Proc. 6^{th} Symp. Microdosimetry, Brussels (1977), 759-775
- I. Krajcar-Bronič et al., Rad. Res. **115** (1988), 213-222

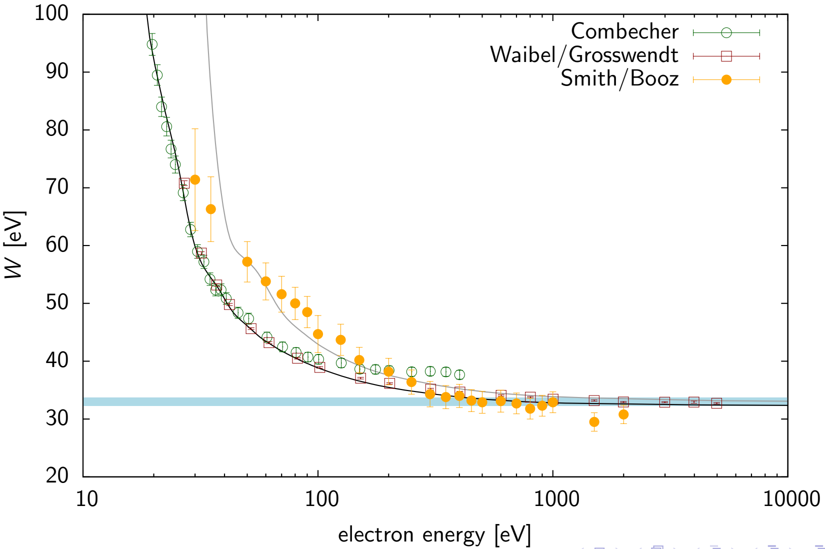
Delta Electron Transport - Argon



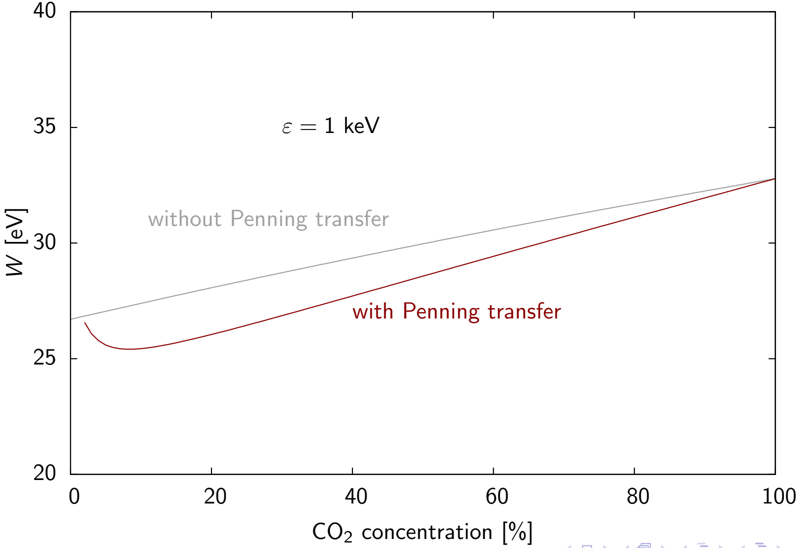
Delta Electron Transport - Argon



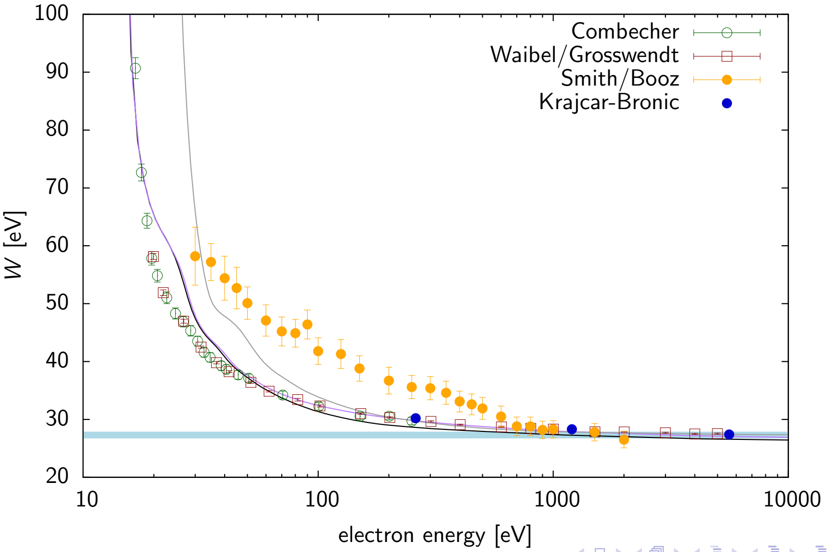
Delta Electron Transport - CO_2



Delta Electron Transport - Ar/CO_2



Delta Electron Transport - CH_4



Cluster Size Distribution

Experimental Data

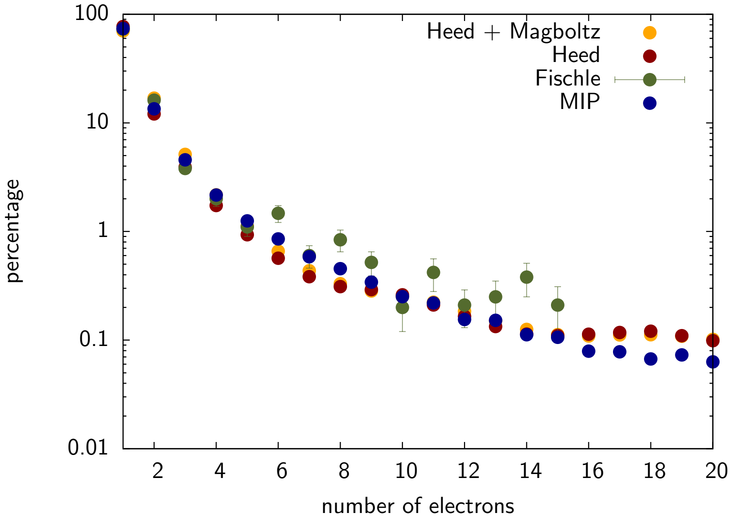
H. Fischle et al., Nucl. Instr. Meth. A **301** (1991), 202-214

Example: CO_2

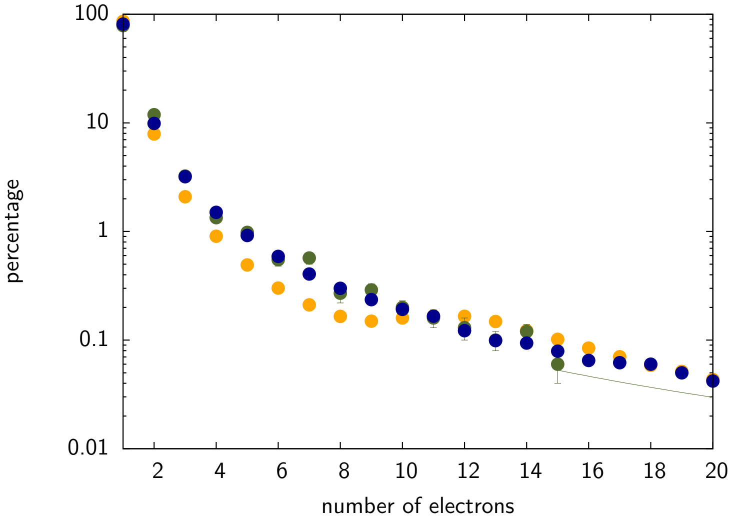
n	Fischle	MIP	Heed	Heed + Magboltz
1	73.0 ± 2.8	73.9	77.1	70.2
2	16.2 ± 1.2	13.5	12.1	16.9
3	3.8 ± 0.4	4.6	3.9	5.1
4	2.0 ± 0.3	2.2	1.7	2.2
5	1.1 ± 0.2	1.2	0.9	1.1

in general: Heed gives higher probability for single-electron clusters

Cluster Size Distribution - CO_2



Cluster Size Distribution - CH_4



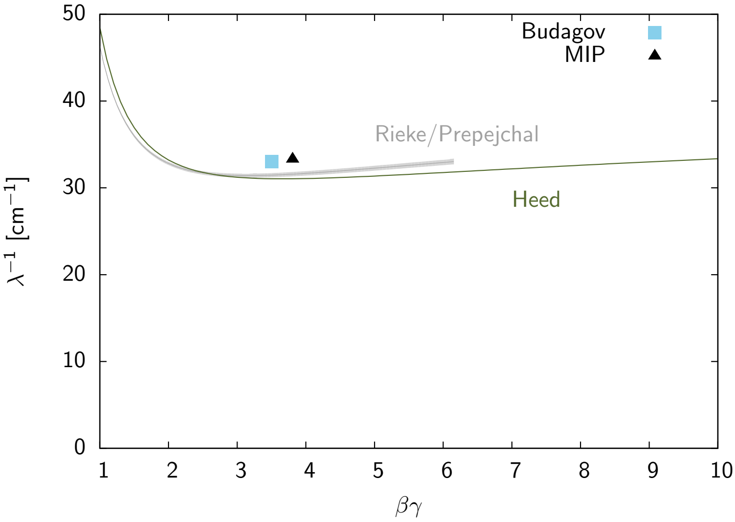
Summary and Outlook

- For the calculation of primary ionization in gases, two complementary tools (Heed, Mip) are available.
- Systematic uncertainties need to be understood and quantified:

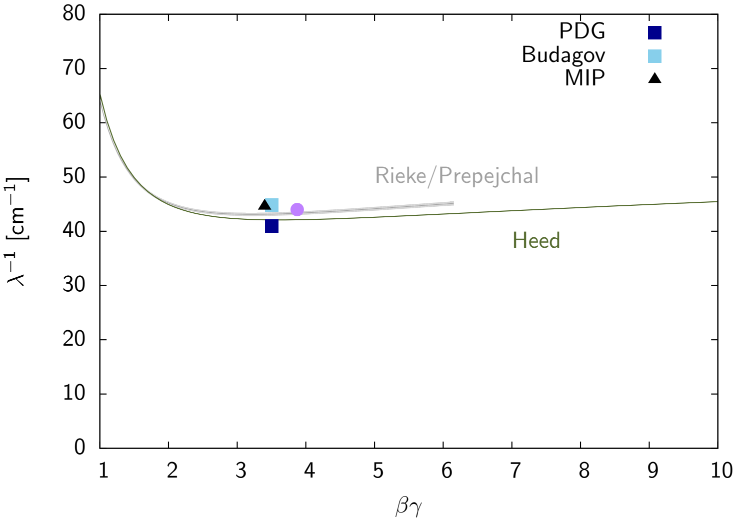
  Magboltz/Mip: uncertainties in excitation cross-sections (e. g. CH_4)

  Heed:
  - shell separation and δ production $\rightarrow$ cluster size distribution
  - photoabsorption cross-section $\rightarrow$ cluster density

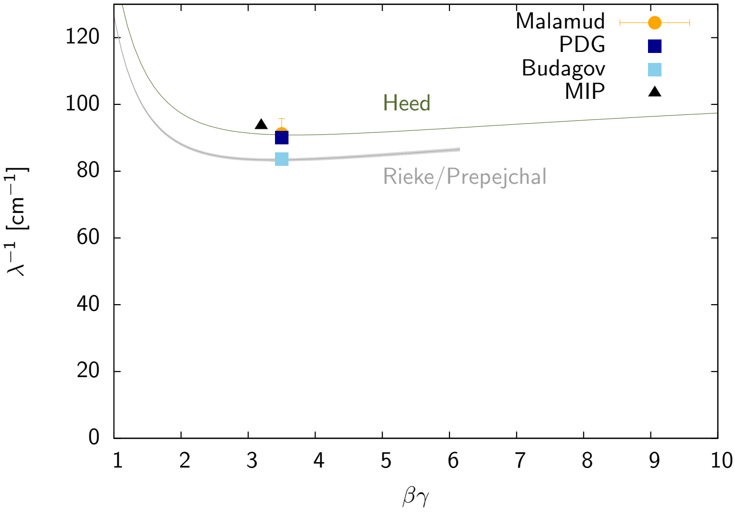
Cluster Density - Krypton



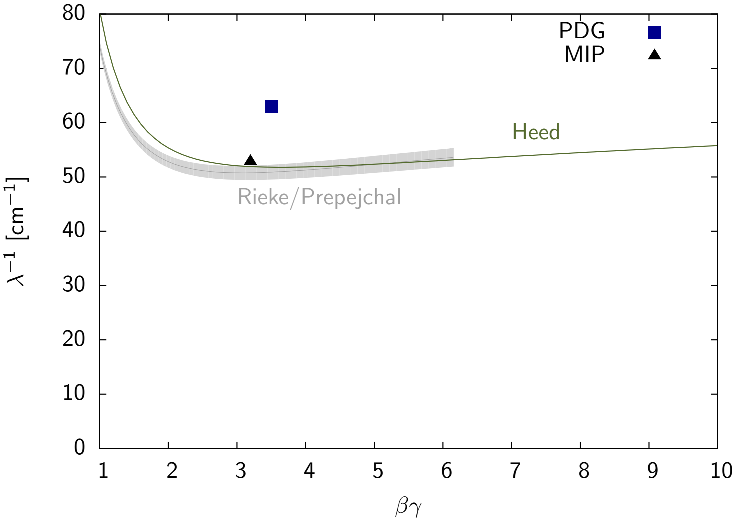
Cluster Density - Xenon



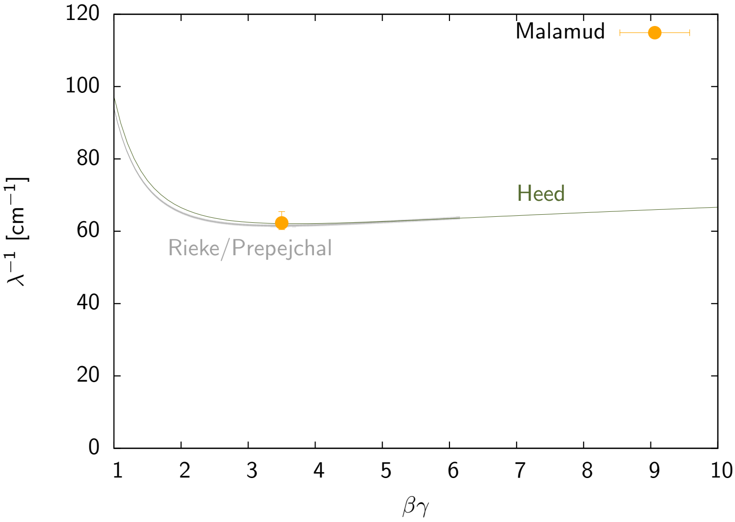
Cluster Density - iC_4H_{10}



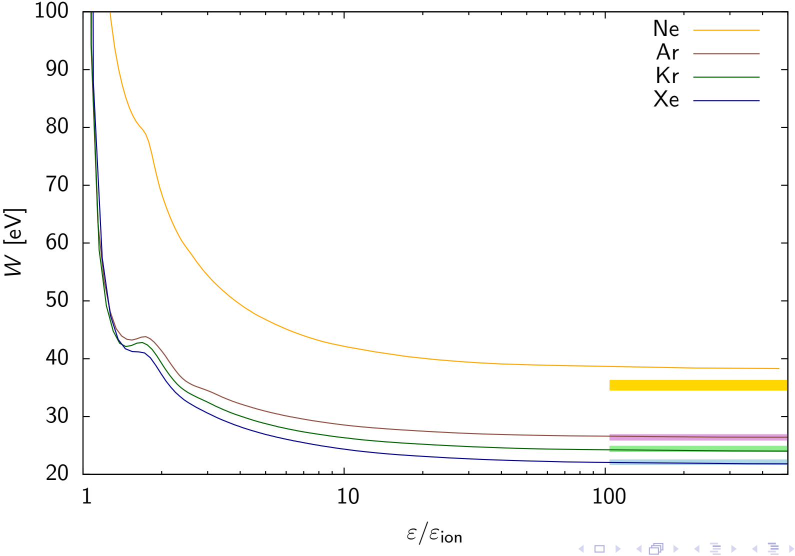
Cluster Density - CF_4



Cluster Density - DME



Delta Electron Transport - Noble Gases



Delta Electron Transport - N_2