Birks' Coefficient for the AHCAL

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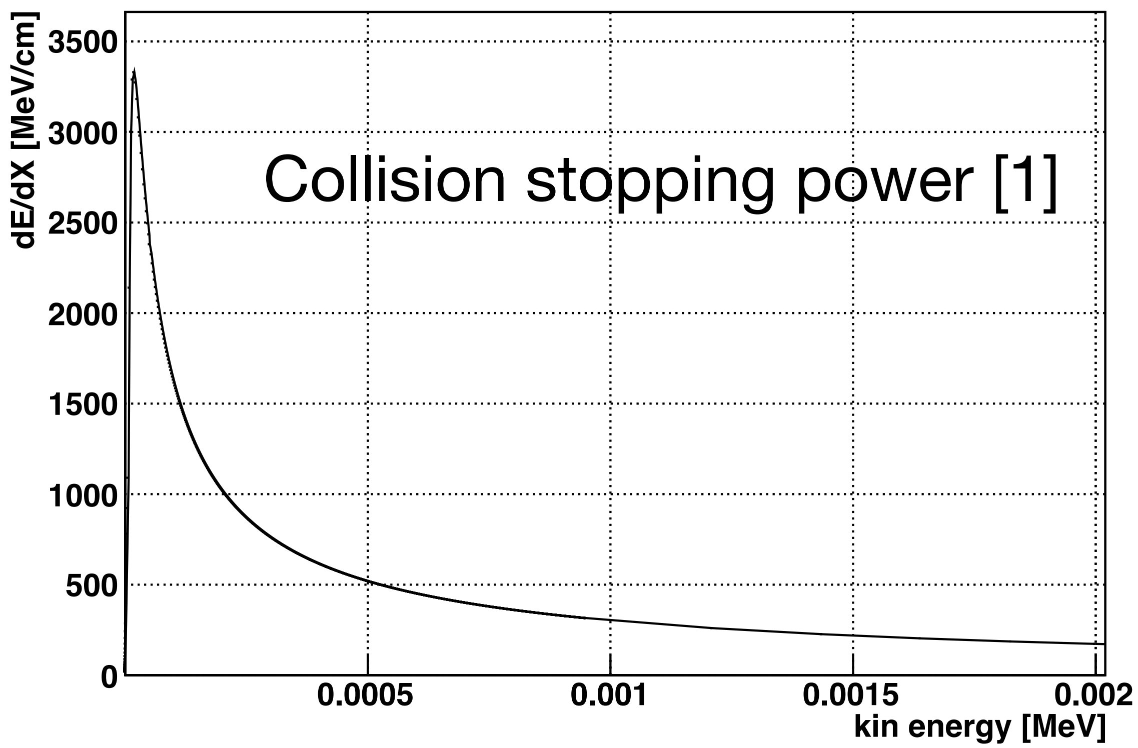
Outline

- Scintillator quenching
  - Birks' saturation formula
- Experimental setup
- Data analysis with two different methods
  - Numerical calculation (method1)
  - Geant4 simulation (method 2)
- Comparison of Results

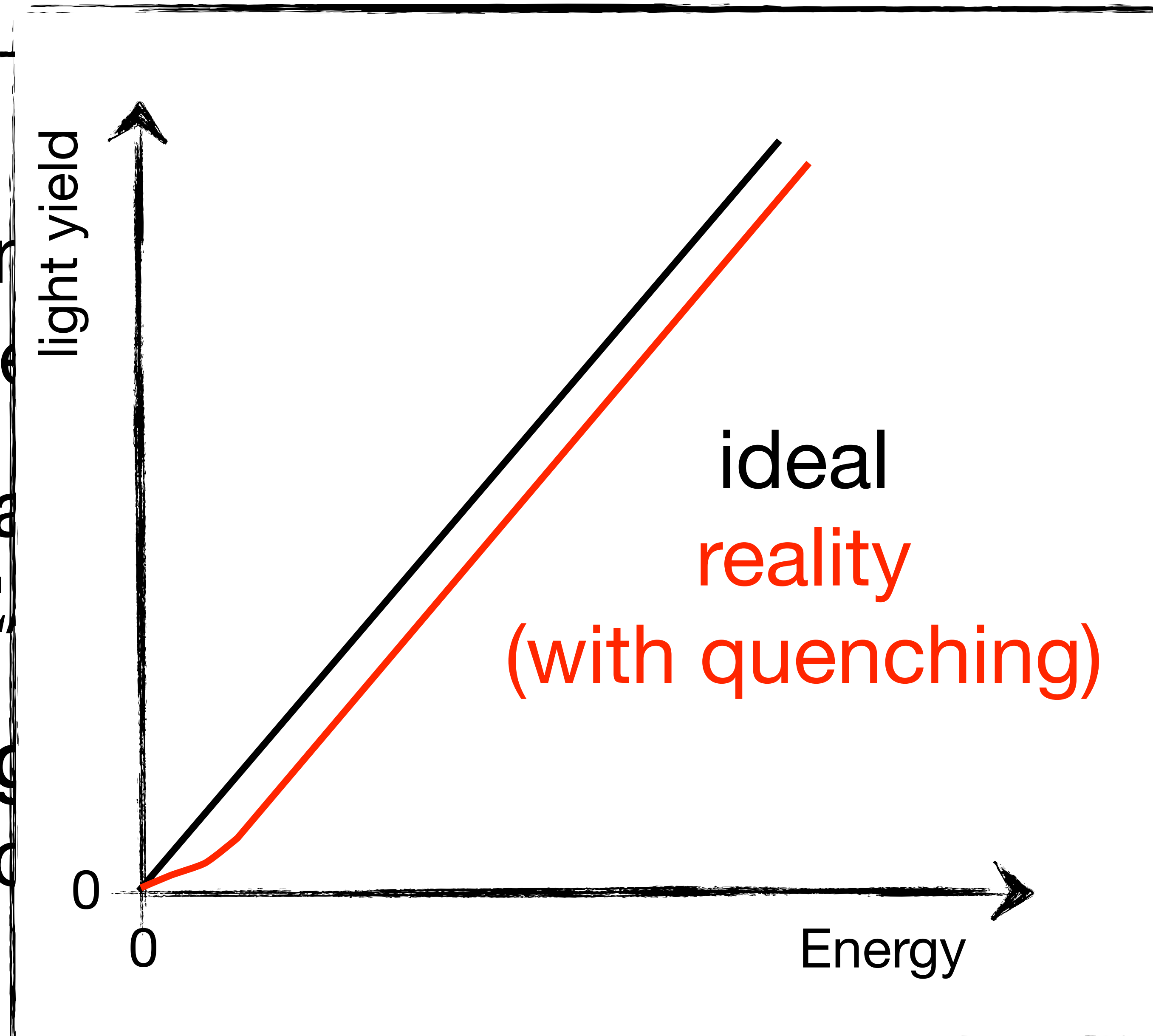
Scintillator Quenching

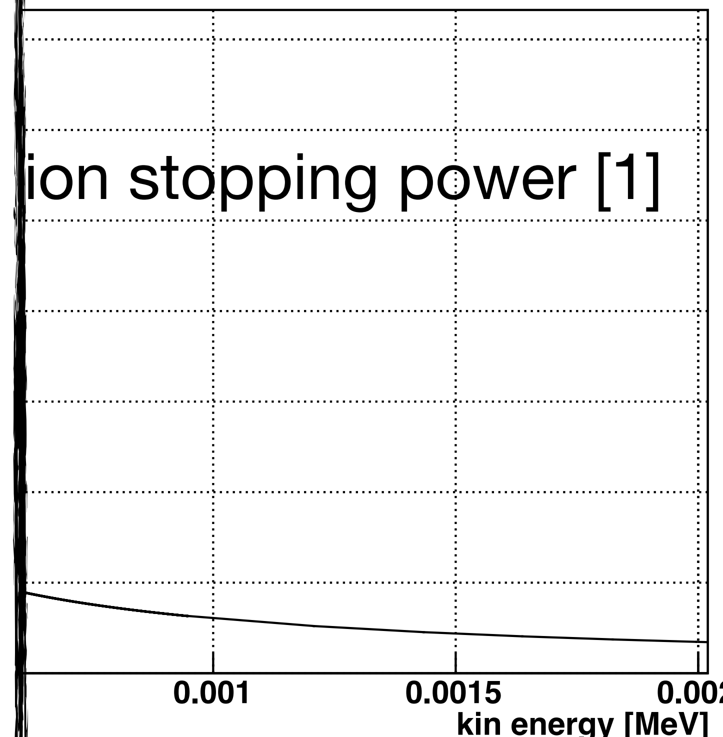


- Specific energy loss **dE/dx** is high before particle is stopped
- High ionization density **dI/dx α dE/dx**
- **Quenching:** Excited molecules can interact and may de-excite radiationless
- Light yield per unit length **dL/dx** is reduced for high **dE/dx**
- Non-linearity described by Birks' formula:

$$\frac{dL}{dx} = \frac{S\frac{dE}{dx}}{1 + kB\frac{dE}{dx}}$$

Scintillator Quenching





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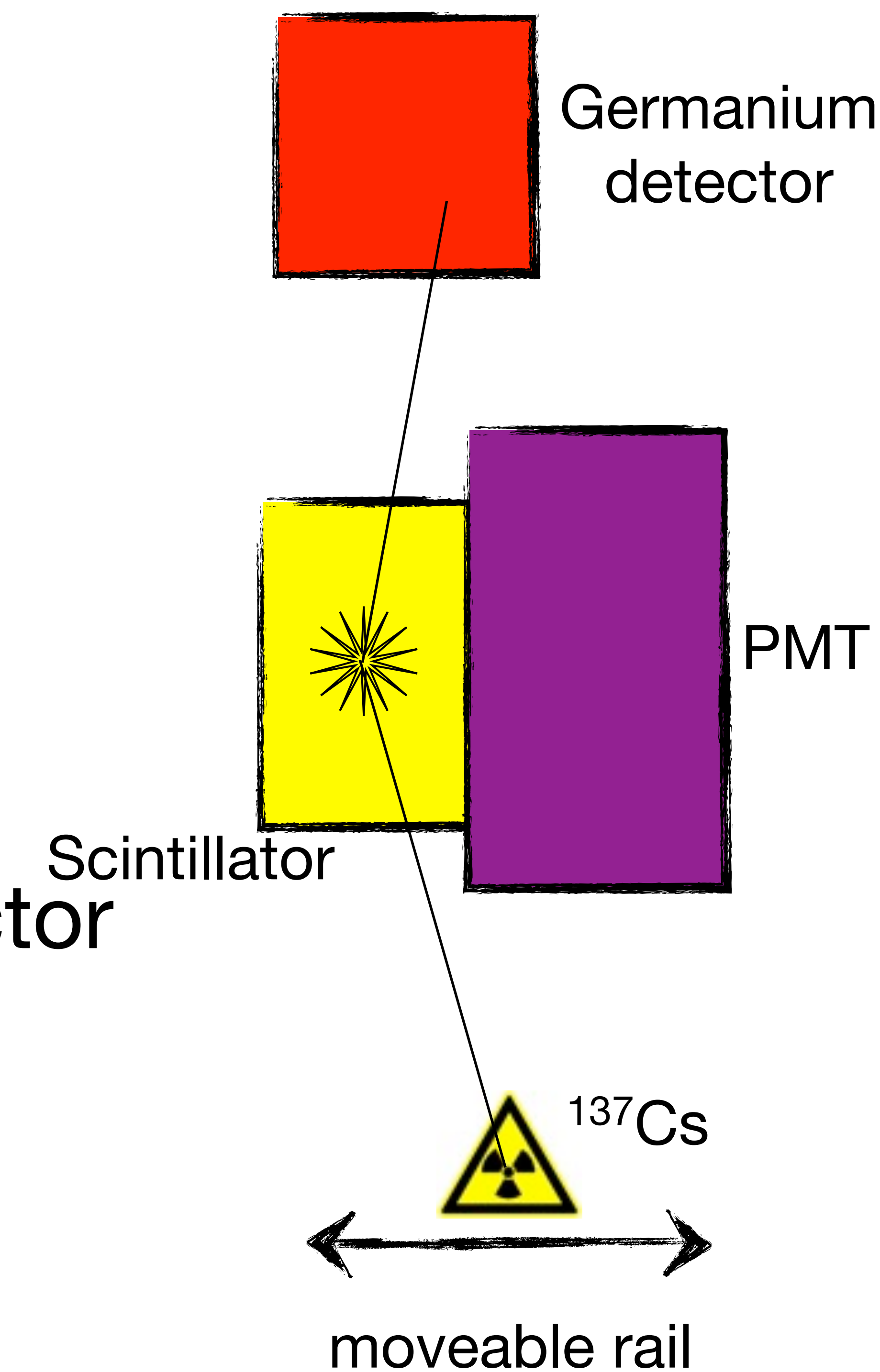
Experimental Setup (MPIK Heidelberg)

- Thanks to Christoph Aberle and Stefan Wagner for the ability to use the setup
- PMT measures light yield
- Germanium detector measures Energy of Compton scattered photon E_{Ge}

$$E_{e^-} = 662\,keV - E_{Ge}$$

- Coincidence trigger PMT and Ge-detector
- Measured energy range of electrons ~ 30 - 140 keV
- Detailed setup description in [4]



Experimental Setup (MPIK Heidelberg)

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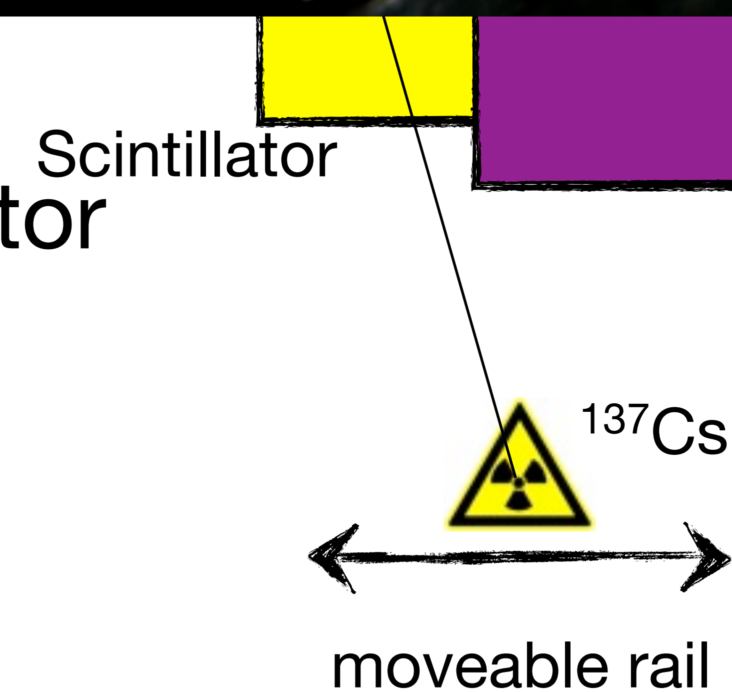
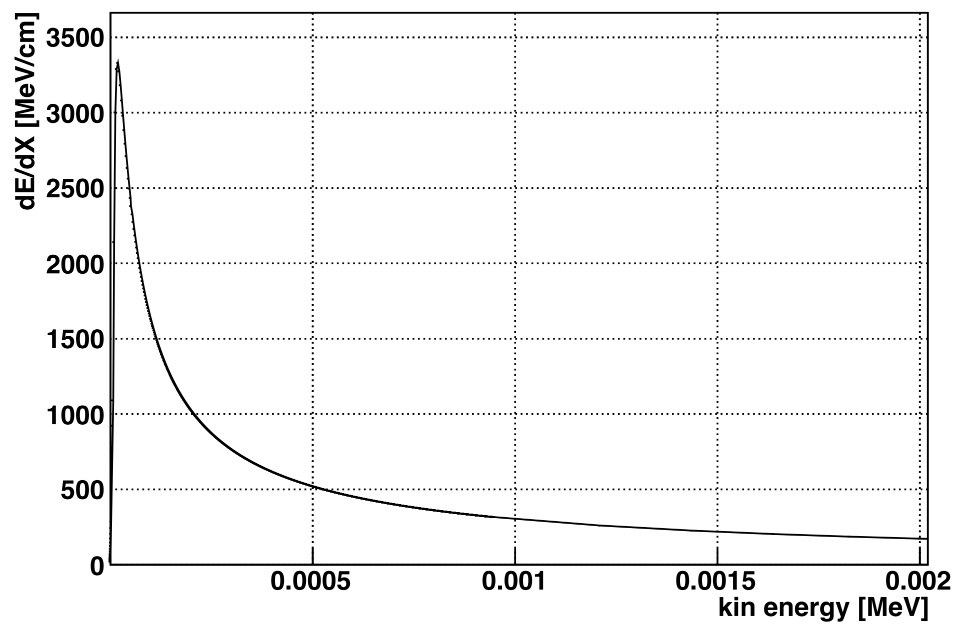
- P
- G ... s En ...
  o ... E_{Ge} ... T
- C ... Ge-detector
- M ... ctrons
  ~
- D ... 4]



Analysis Method 1

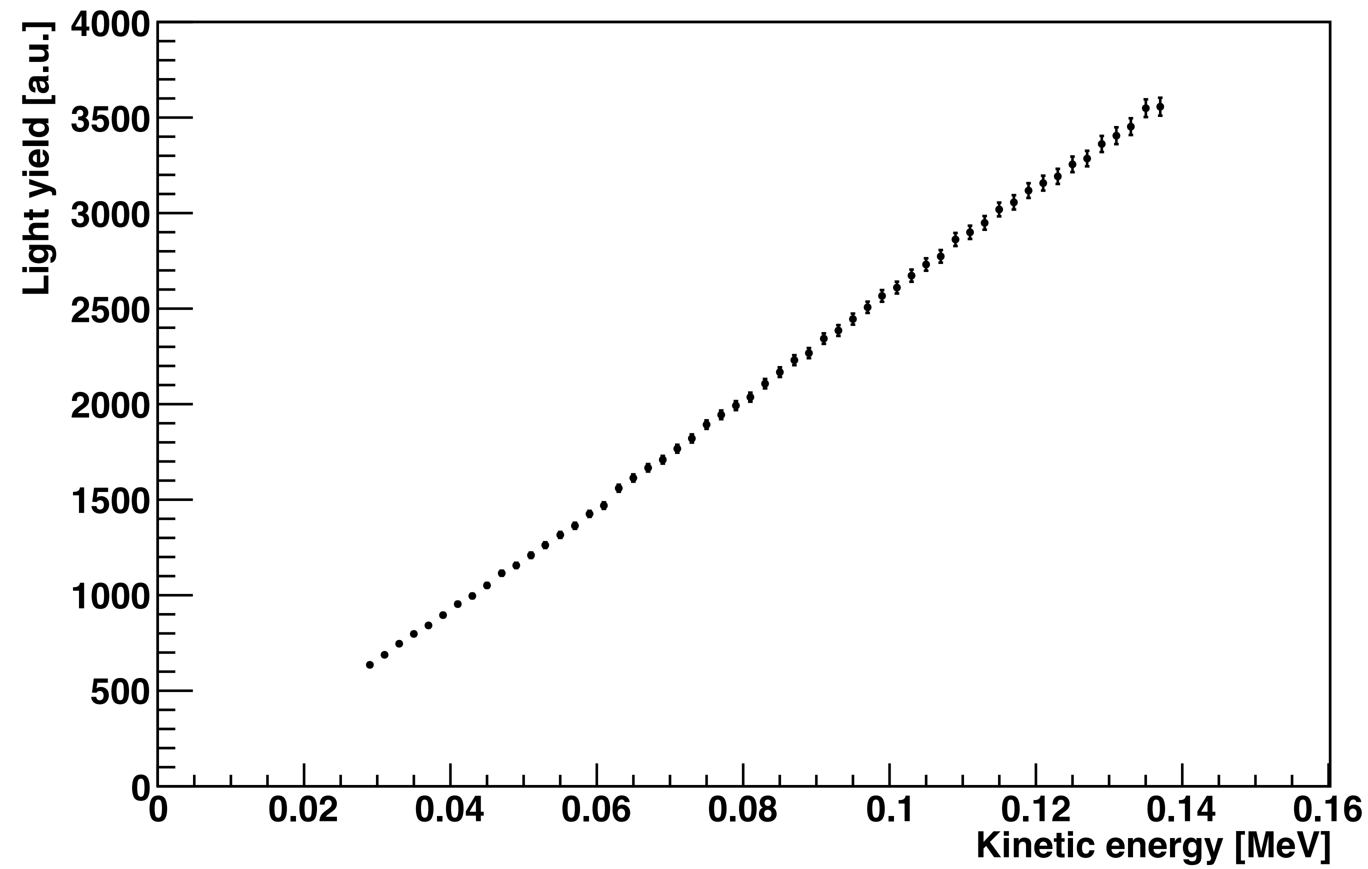
- Calculate dE/dx curve
- Light yield

$$LY = \sum_{steps} \frac{dL}{dx} dx = \sum_{steps} \frac{S \frac{dE}{dx}}{1 + kB \frac{dE}{dx}} dx$$



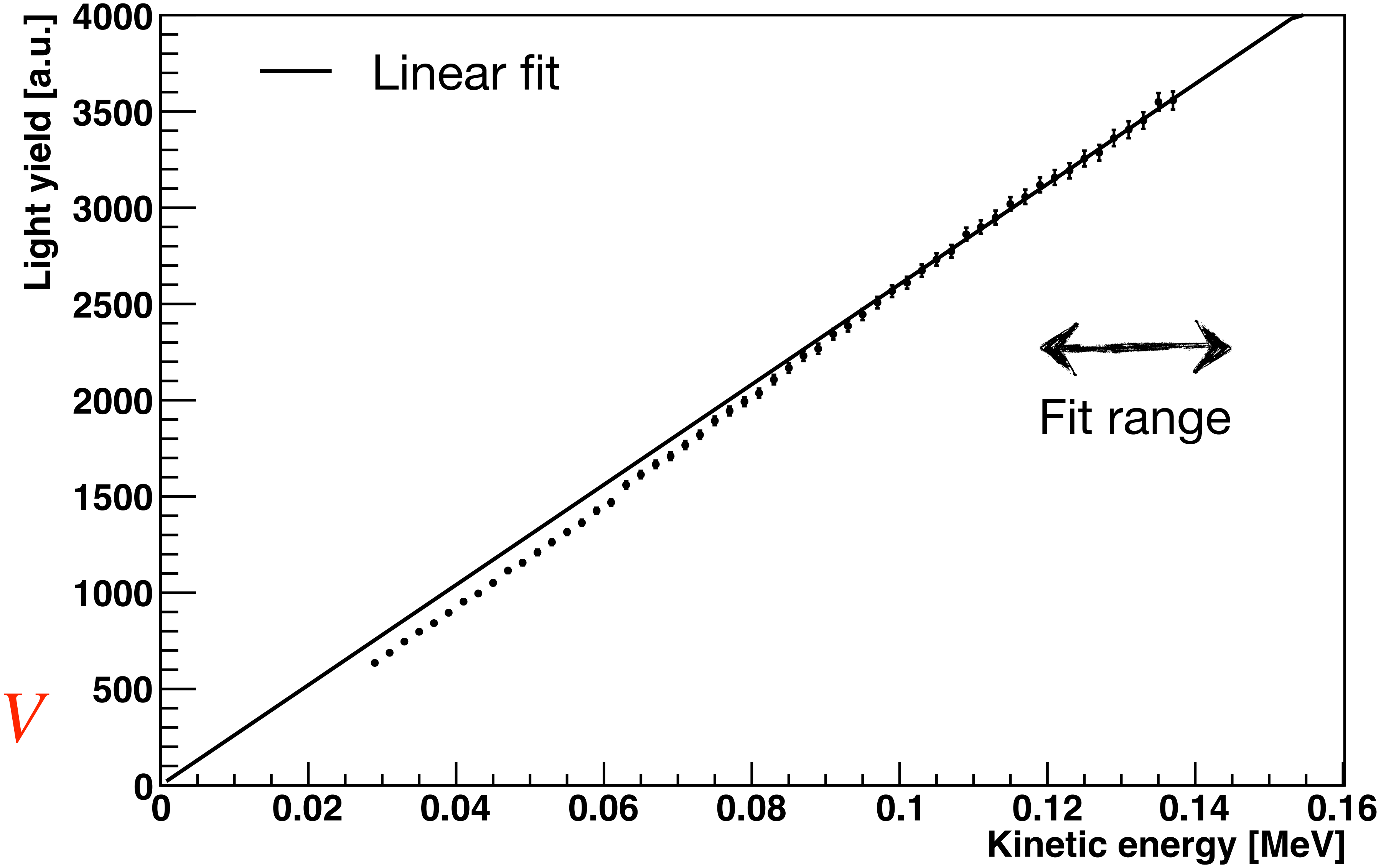
- dE/dx ~ constant during step
  - ➡ If energy > 1keV:
    step size dx = 10 nm
    else:
    step size dx = 0.01 nm

- Variation of S and kB
  Minimize Chi-square



Results Method 1

- Data not described by linear fit (kB=0)
- Well described by Birks' formula
- Best fit for $kB = 0.0151\ cm/MeV$



- Remember:
  Calculation done with small step size (0.01-$10\ nm$)!

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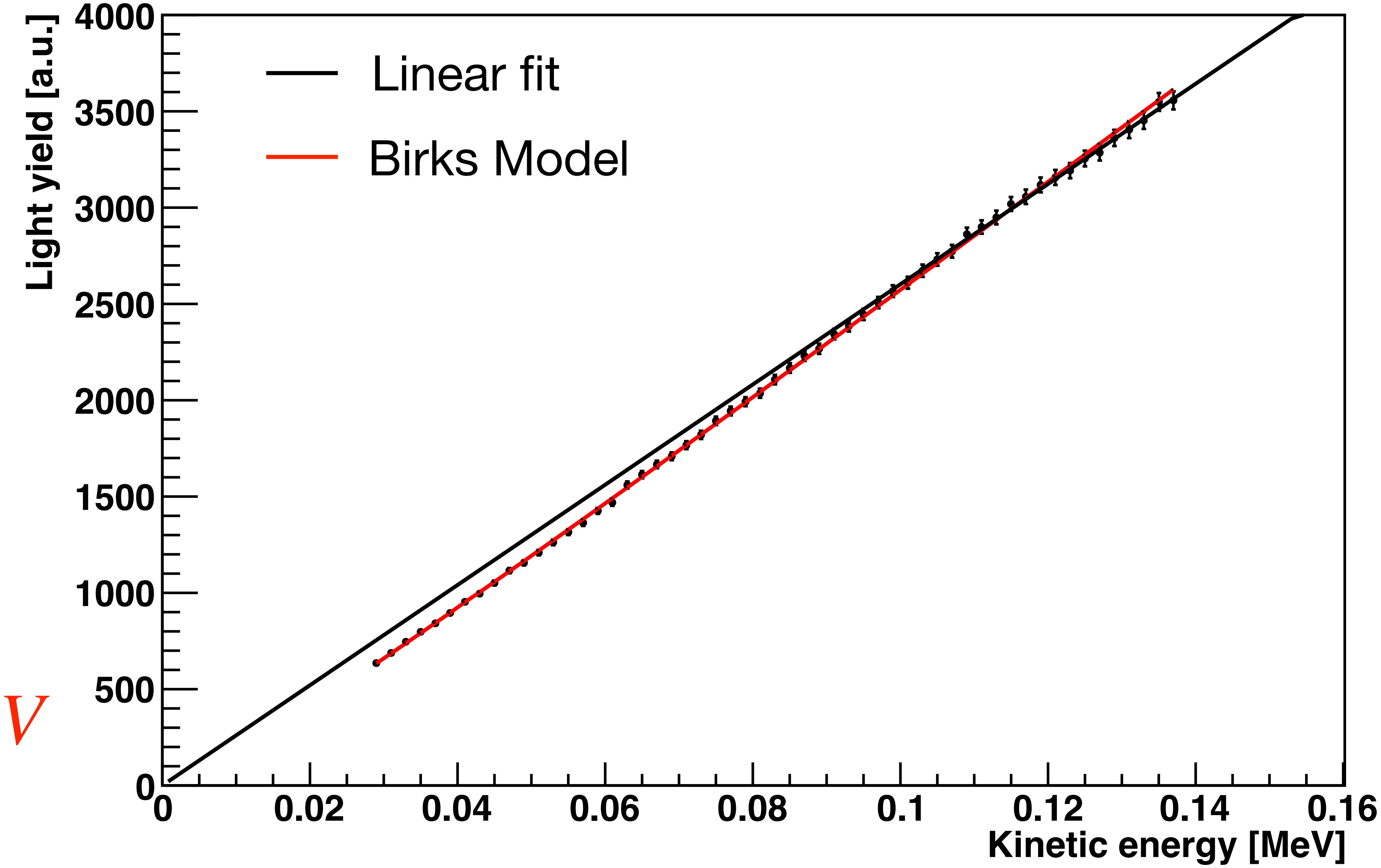

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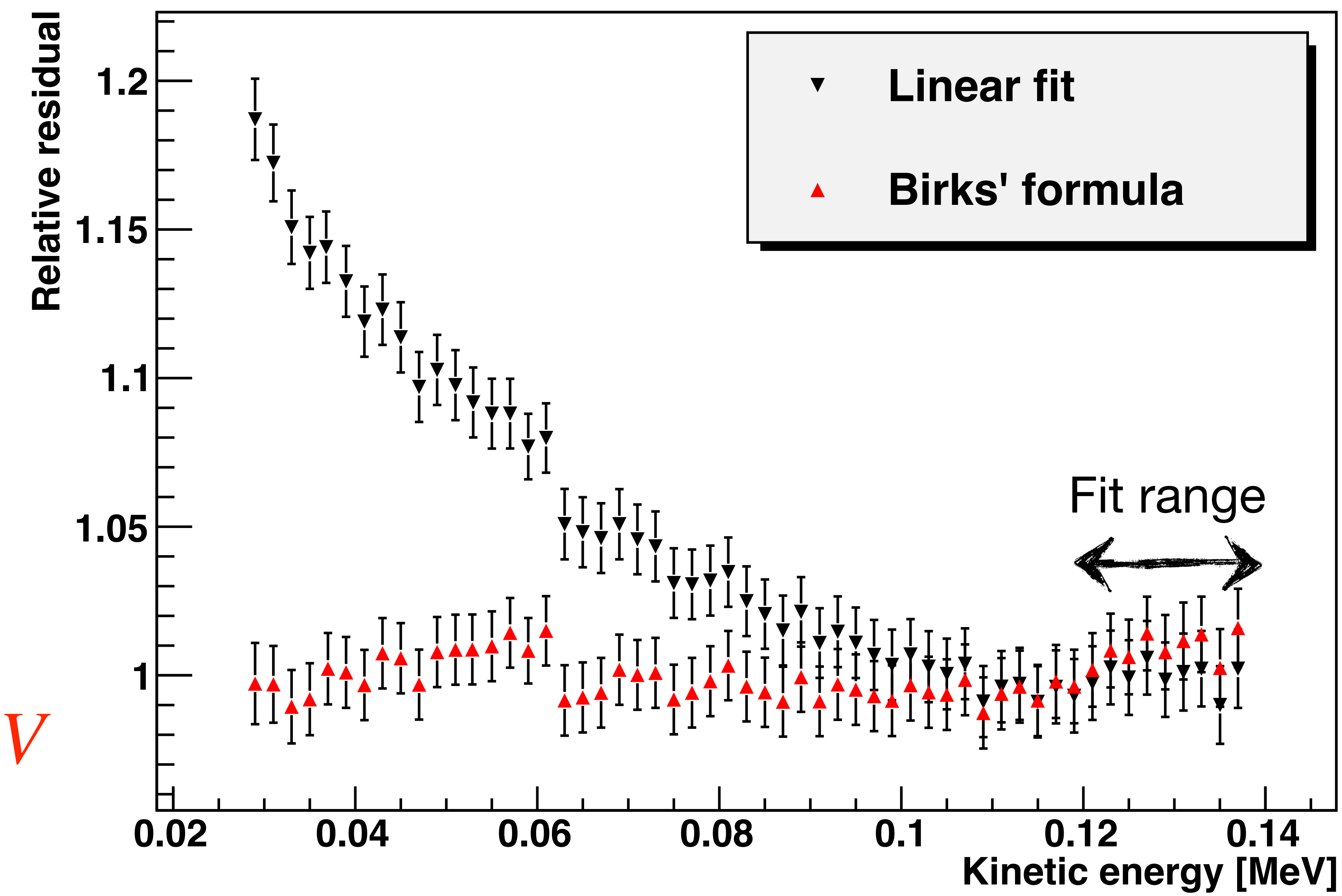


- Remember:
  Calculation done with small step size (0.01-10 nm)!

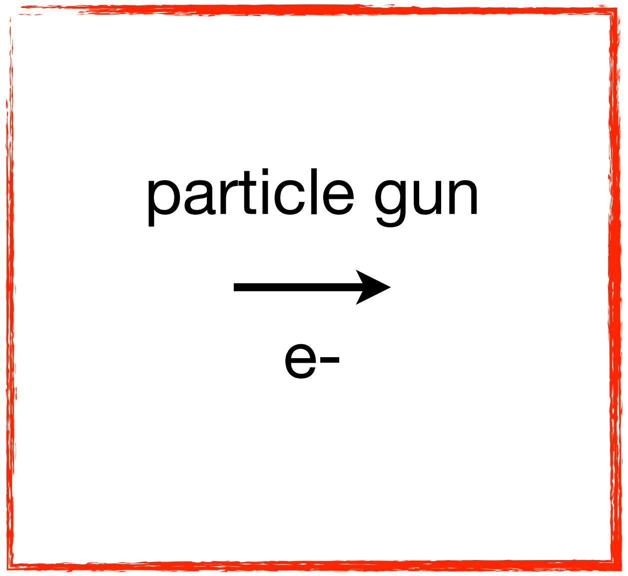
Method 2: Geant4 (Work in progress)

- Finally, Birks' Coefficient will be used in Mokka/Geant4
  Therefore it should be determined using Mokka/Geant4
- Reason: Differences to method 1 calculation
  - Computational effort limits number of steps
    i.e. if electron range is smaller than 1mm
    -> energy is lost in a few/single step ➜ dE/dx !!!
  - Explicit simulation of delta electrons (above range cut, default value in Mokka 0.005mm)

➡ These differences in the calculation yield to a different value of kB

Geant4 Setup

- Scintillator Block 10x10cm (G4_Polystyrene)
- Standard em-processes
  - Multiple scattering
  - Ionization
  - Bremsstrahlung
- Fit simulated data to measured data, variation of S and kB
- Study impact of step size and range-cut



Results Geant4

- If step-size is small (as in method 1):

  Energy loss per step < 0.01%
  Step size > 0.01nm
  Range cut: 1mm (no delta electrons)

UI Command:
/process/eLoss/StepFunction 0.0001 1e-11 m

➡ Same result as “method 1” calculation

$$kB = 0.0151\ cm/MeV$$

- However, the default configuration in Geant4/Mokka is:

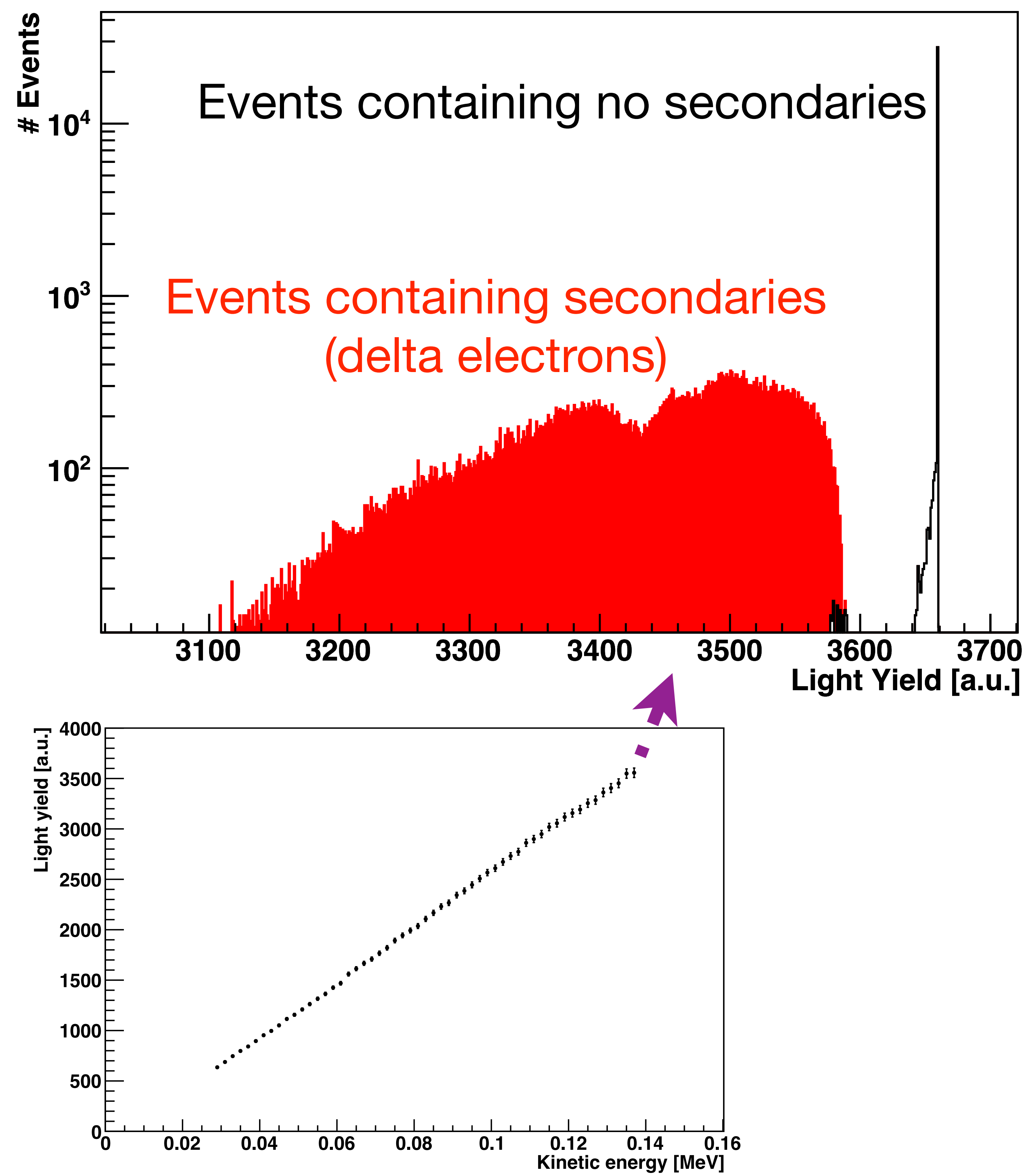
  Energy loss per step < 20%
  Step size > 1mm
  Range cut: 0.005mm

➡ Different kB value

Delta electrons

- Light yield smaller if delta-electrons are generated
- Mean shifted to smaller value
- Fewer delta-electrons generated for small energies (fixed range cut)
- Strong impact on kB value

<u>Light yield spectrum for 138keV electrons</u>



Summary of Results

Method	kB [cm/MeV]
Previous result *False assumption on average ionization potential (~ 8eV)*	0.007300
Method 1 (Numerical calculation)	0.0151
Method 2 (Geant4) *small step < 0.01%; > 0.01nm* *large range cut 1mm*	0.0151
Method 2 (Geant4) *standard step-size < 20%; > 1mm* *range cut 0.005mm (Mokka default)*	0.0184 - 0.0224 (work in progress)
Present value in Mokka/Geant4 [5] *SCSN-38 (ZEUS Calorimeter)*	0.007943

Conclusions

- Birks' coefficient is a model-dependent parameter!
- Both methods give same kB value if step-size small and range cut high
- Larger value of kB in case of Geant4 simulation for default step size and range cut
- Future: Determine impact of larger kB value on simulated pion showers (Thanks to Alex Kaplan and Angela)

Backup Slides

Birks' Formula

- In the absence of quenching, the light yield is prop. to energy loss $$\frac{dL}{dx} = S\frac{dE}{dx}$$
- Density of damages molecules described by $B'\frac{dE}{dx}$
- Fraction k will quench; density: $n_q = kB'\frac{dE}{dx}$
- Scintillating fraction $$\frac{n_S}{n_S + n_q} = \frac{1}{1 + kB\frac{dE}{dx}}$$
- Birks' formula [2] $$\frac{dL}{dx} = \frac{S\frac{dE}{dx}}{1 + kB\frac{dE}{dx}}$$

References

- [1] S. M. Seltzer and M. J. Berger, *“Improved Procedure for Calculating the Collision Stopping Power of Elements and Compounds for Electrons and Positrons”*, Int. J. Appl. Radiat. Isot. Vol. 35, No, 7, pp. 665-676. 1984
- [2] J. B. Birks, *“The Theory and Practice of Scintillation Counting”*, Pergamon Press, Oxford, 1964
- [3] C.N. Chou, Phys. Rev. 87 (1952) 904
- [4] Stefan Wagner, “*Ionization Quenching by Low Energy Electrons in the Double Chooz Scintillators”*, Diploma Thesis (2010)
- [5] M. Hirschberg et. al. *“Precise Measurement of Birks kB Parameter in Plastic Scintillators”, IEEE Trans. Nucl. Sc., Vol. 39, No. 4, 1992*

Energy Loss of Electrons

- Formula for collision stopping power used [1]

$$-\left(\frac{dE}{dx}\right)_{coll} = \rho\,\frac{0.153536}{\beta^2}\,\frac{Z}{A}B(T) \qquad \tau = T/mc^2$$

$$B(T) = B_0(T) - 2\,ln(I/mc^2) - \delta$$

$$B_0(T) = ln[\tau^2(\tau+2)/2] + [1 + \tau^2/8 - (2\tau+1)ln2]/(\tau+1)^2$$

- Radiation stopping power can be neglected at low energies

- Need: ionization potential I, density ρ, and Z/A