



LArQL: A phenomenological model for treating light and charge production in liquid argon

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Overview

- Theoretical background and motivation
- Preliminary evaluation and potentialities
- Conclusions/perspectives

LArQL

Motivations, Goals and Limits

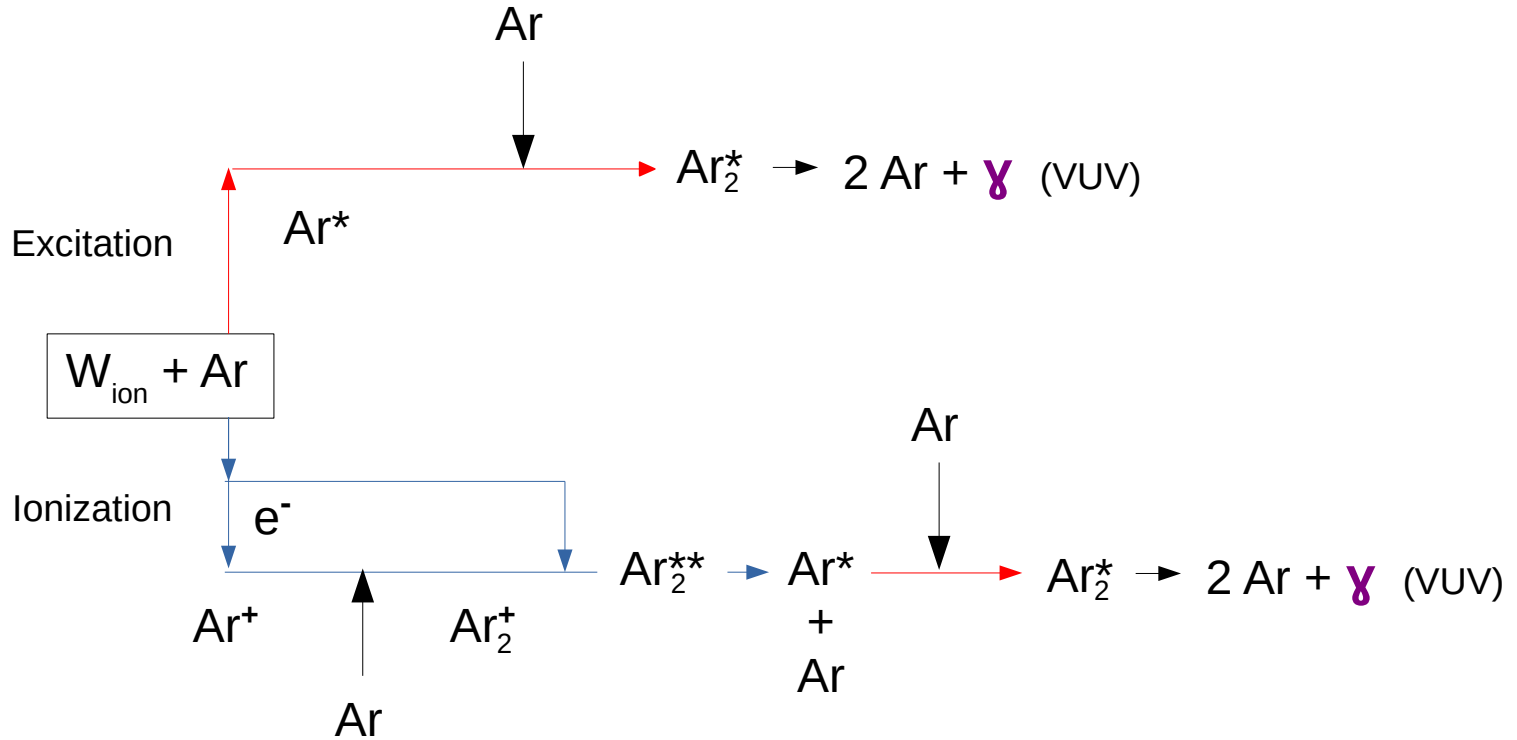
- Lack of well defined mechanism for Scintillation Light emission in LAr inside LArG4/LArSoft
 - ✦ Data analysis results sensitive to some non yet adequately simulated effects of light from recombination
- Unitary model for Ionization Charge AND Scintillation Light in LAr as function of deposited energy density (dE/dx) and electric field (ξ)
 - ✦ Cover the range of interest for LArTPC for Neutrino Experiments:

$$2 \text{ MeV/cm} < dE/dx < 40 \text{ MeV/cm}, \quad 0 \leftarrow 0.25 \text{ kV/cm} < \xi < 0.5 \text{ kV/cm} \rightarrow 0.75$$

Theoretical/Phenomenological foundations:

- Free ionization charge and scintillation light anticorrelated/complementary at a given $(dE/dx, \xi)$ pair: **Charge - Light Master Equation**
 - Observed reduction of scintillation light in the low dE/dx region at $\xi = 0$ attributed to “escaping electrons”.
- T. Doke, Fundamental properties of liquid Argon, Krypton and Xenon as Radiation detector media, Portugal Phys. 12 (1981), 9.
 - S. Kubota, A. Nakamoto, T. Takahashi, T. Hamada, E. Shibamura, M. Miyajima, K. Masuda and T. Doke, “ Phys. Rev. B 17 (1978) 2762.
 - T. Doke, H. J. Crawford, A. Hitachi, J. Kikuchi, P. J. Lindstrom, K. Masuda, E. Shibamura and T. Takahashi: Nucl. Instrum. & Methods A 269 (1988) 291
 - T. Doke, A. Hitachi, J. Kikuchi, K. Masuda, H. Okada and E. Shibamura, Absolute Scintillation Yields in Liquid Argon and Xenon for Various Particles, Jpn. J. Appl. Phys. 41 (2002) 1538

Scintillation light production

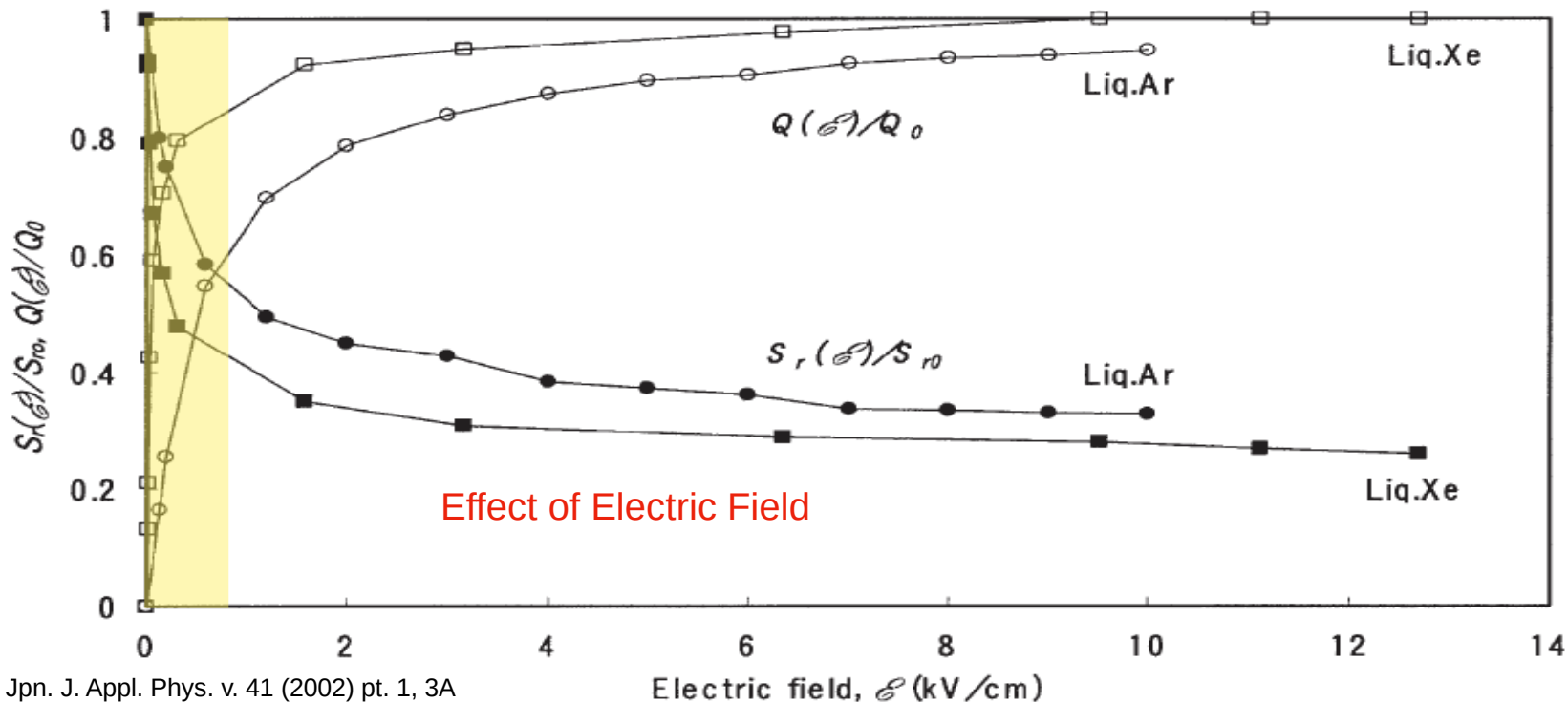


Charge – light master equation

$$QY(dE/dx, \xi) + LY(dE/dx, \xi) = N_i + N_{ex}$$

Free Charge Yield: [e/MeV]

Light Yield: [ph/MeV]



Effect of deposited energy density

Light reduction at $\xi=0$ and low dE/dx due to electrons escaping recombination

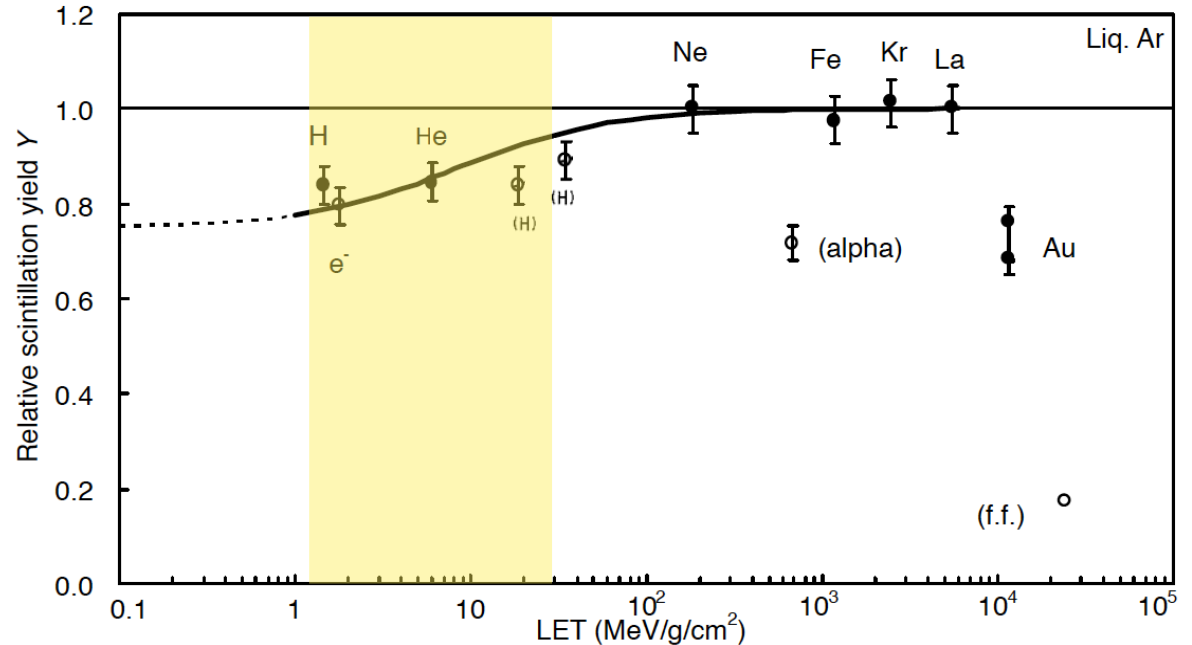
N_0 : # of escaping electrons per energy unit

$$\eta_0 = \frac{N_i - N_0 + N_{ex}}{N_i + N_{ex}}$$

Fractions of interest:

$1 - \eta_0$: missing photons

$\chi_0 = \frac{N_0}{N_i}$: escaping electrons



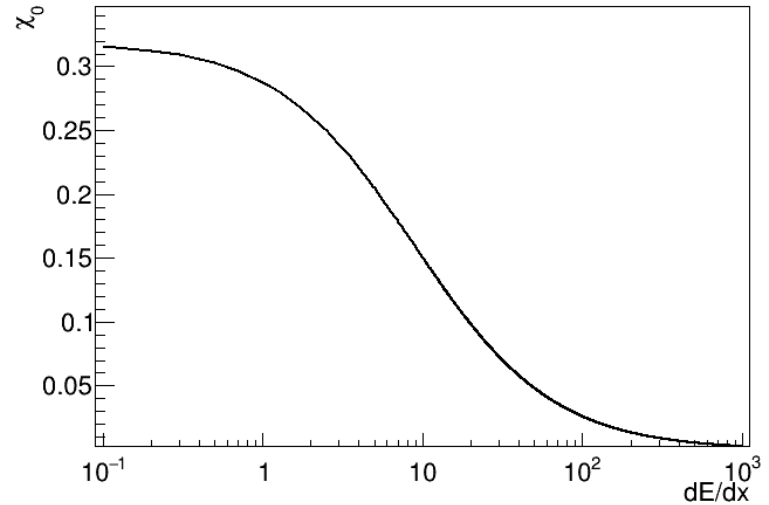
LArQL: QY vs LY relationship at $\xi = 0$ kV/cm

3 experimental parameters

- $N_i = 1/W_{\text{ion}}$: ionizations per energy unit
- N_{ex}/N_i : excitations/ionizations
- $\chi_0(dE/dx)$

Light yield obtained from free charge yield

$$LY = N_i - QY + N_{\text{ex}} = LY_{\text{rec}} + LY_{\text{ex}}, \text{ as } e_{\text{rec}}^- = \text{ph}_{\text{from rec}}$$



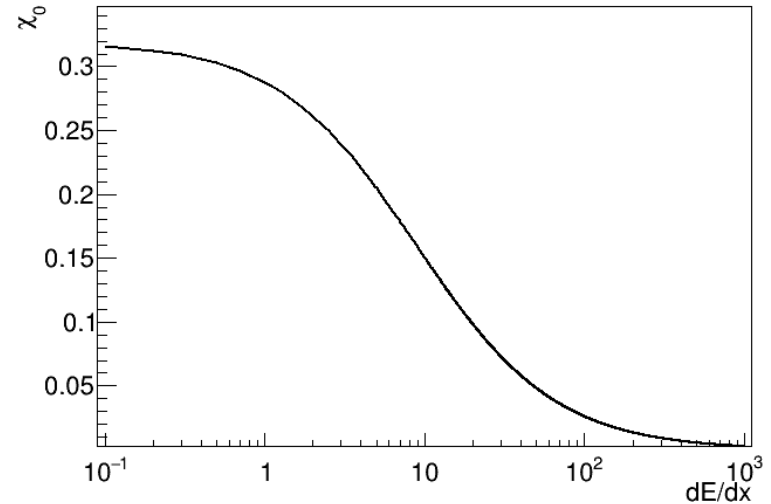
LArQL: QY vs LY relationship at $\xi = 0$ kV/cm

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$$\chi_0(dE/dx) \neq dQ/dE_{\text{birks/box}} = 0$$

In friction with charge models



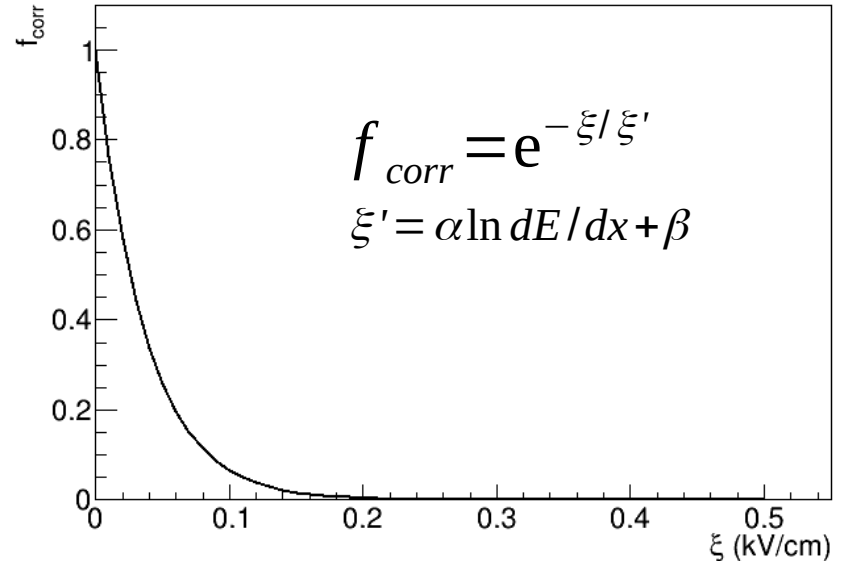
LArQL

Modifies Birks charge model correcting for escaping and additional electrons at lower ξ range

- 1- At $\xi = 0$, escaping electrons taken into account
- 2- Just above $\xi = 0$ adds field extracted electrons
- 3- At higher, escaping $e^- \rightarrow 0$ and Birks recovered

$$\chi_0 \rightarrow \chi = \chi_0 (dE/dx) f_{corr}(\xi, dE/dx)$$

$$dQ/dE_{birks} \rightarrow dQ/dE_{birks} + \chi$$



LArQL

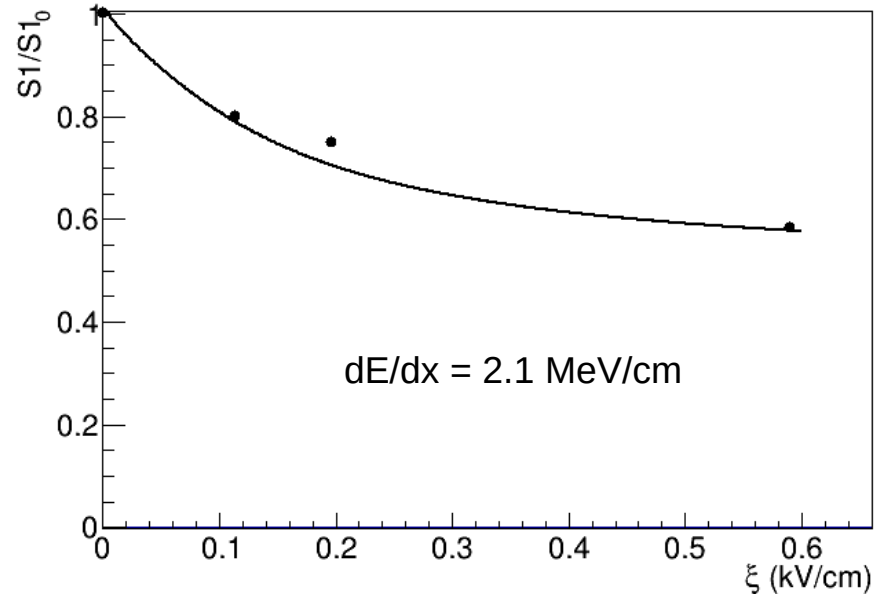
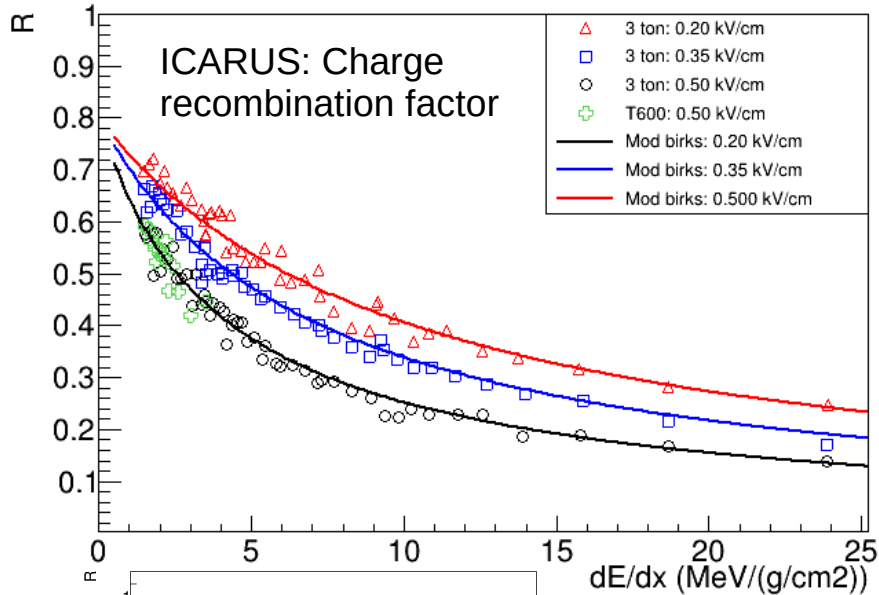
Modifies Birks charge model correcting for escaping and additional electrons at lower ξ range

$$\chi_0 \rightarrow \chi = \chi_0 (dE/dx) f_{corr}(\xi, dE/dx)$$

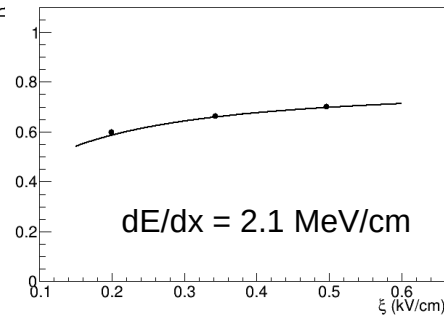
$$dQ/dE_{birks} \rightarrow dQ/dE_{birks} + \chi$$

$$dQ/dx = \left(\frac{A_B}{1 + \frac{k_B}{\xi \rho_{LAr}} \frac{dE}{dx}} + \chi_0 (dE/dx) f_{corr}(\xi, dE/dx) \right) \frac{1}{W_{ion}} \frac{dE}{dx}$$

Charge and light data

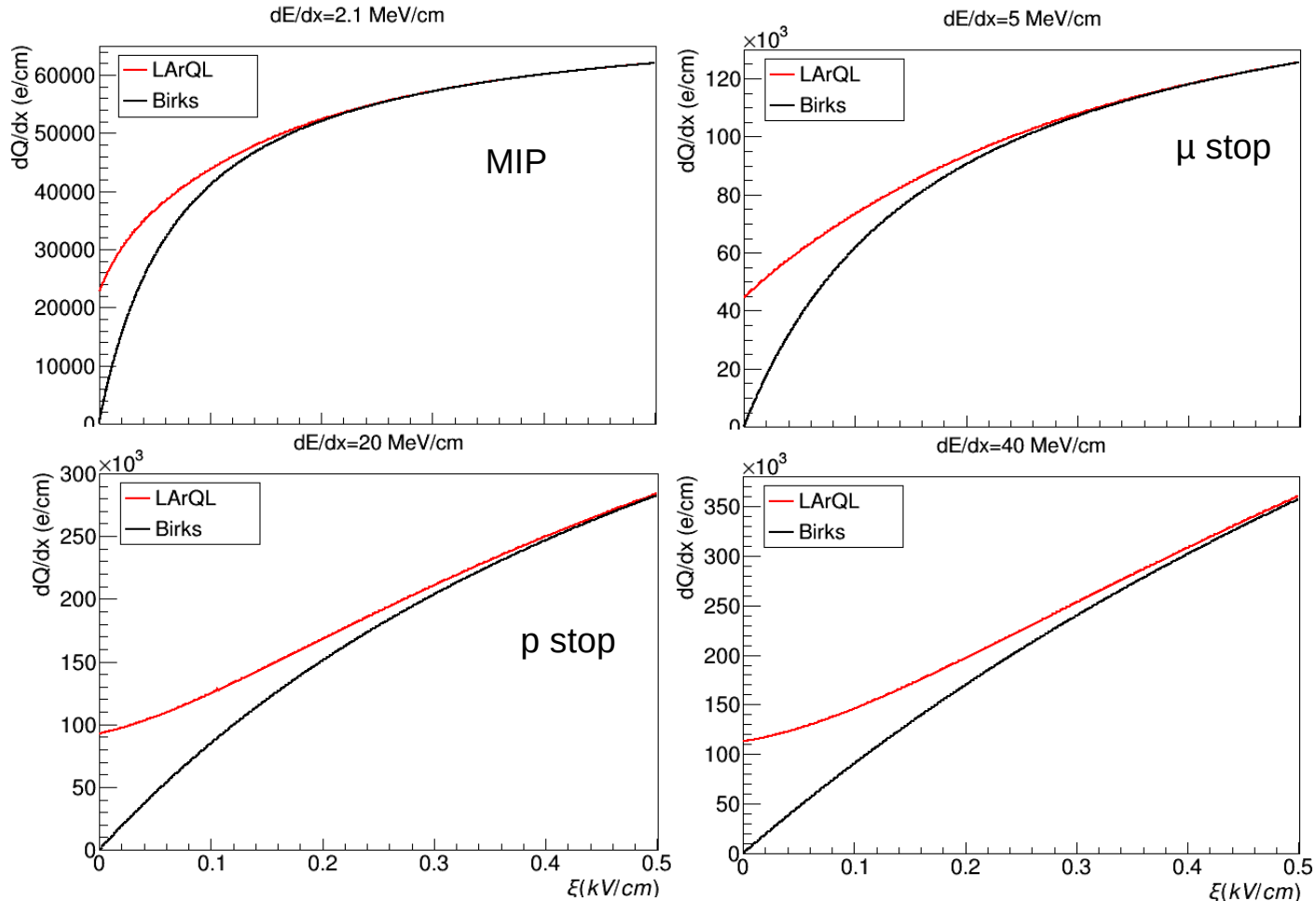


Jpn. J. Appl. Phys. v. 41 (2002) pt. 1, 3A



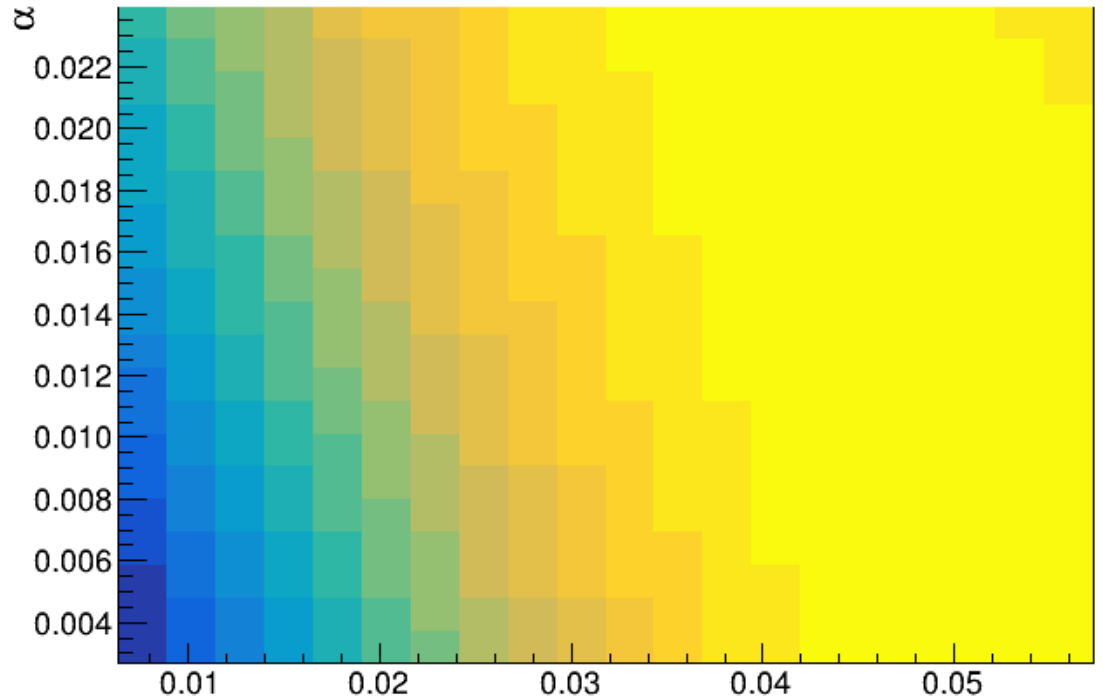
NIMA 523 (2004) 275–286

Predictions on charge sector differ from Birks only for heavily ionizing particles at lower ξ

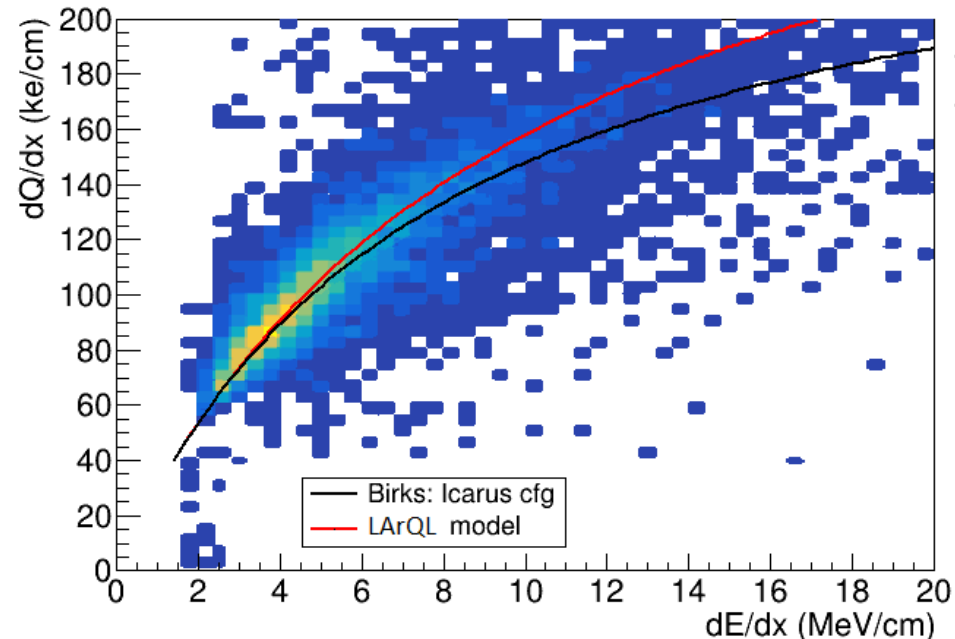


Combined fit procedure: early exercise

- Previous data + ARIS ($S1/S1_0$)
- Minimize model-data point residuals
- Only f_{corr} parameters varied
- Birks and χ_0 parameters fixed

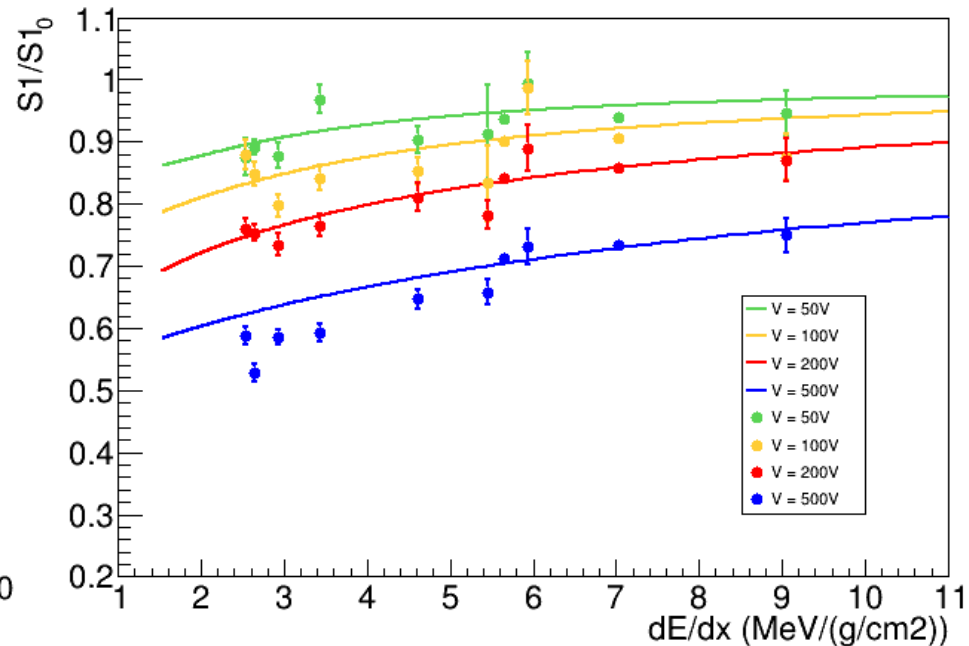


LArQL model vs data comparison



Microboone charge data @ 270 V/cm

C. Adams et al., JINST 15 (2020) P03022



ARIS experiment data

P. Agnes et al., Phys. Rev. D97 (2018) 112005

Conclusions

- A novel model for constrained free charge and scintillation light in LAr
- Satisfactory description at dE/dx and field ranges
- Improvements via data sets compilation and “global” fit
 - model perfecting possible if needed
- LArSoft implementation already available