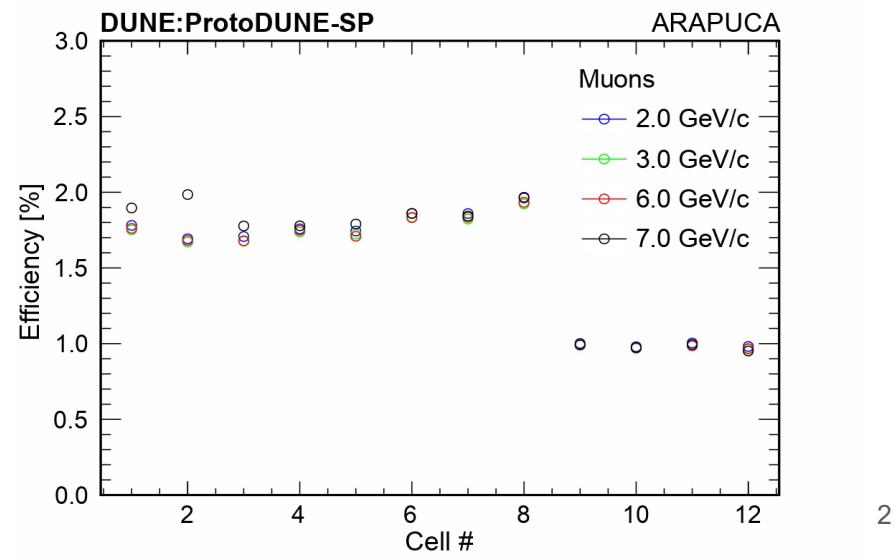
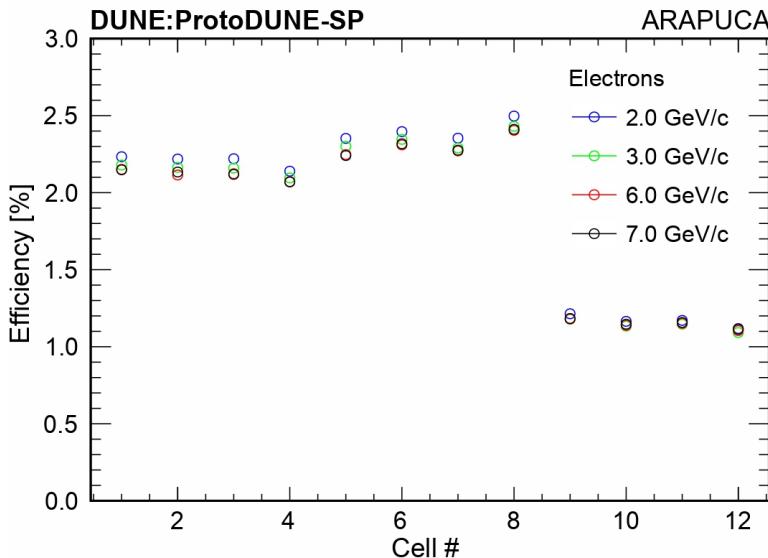


LArQL, a model for ionization charge and scintillation light in LAr

F. Cavana, F. Marinho, L. Paulucci, D. Totani

Motivation

- Lack of well defined mechanism for Scintillation Light emission in LAr inside LArG4/LArSoft
 - ◆ ProtoDUNE PDS data analysis results sensitive to some non yet adequately simulated effects of light from recombination



Goals and Limits

- 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:
 $2 \text{ MeV/cm} < dE/dx < 40 \text{ MeV/cm}$, $0.25 \text{ kV/cm} < \xi < 0.5 \text{ kV/cm}$
- Charge-light master equation

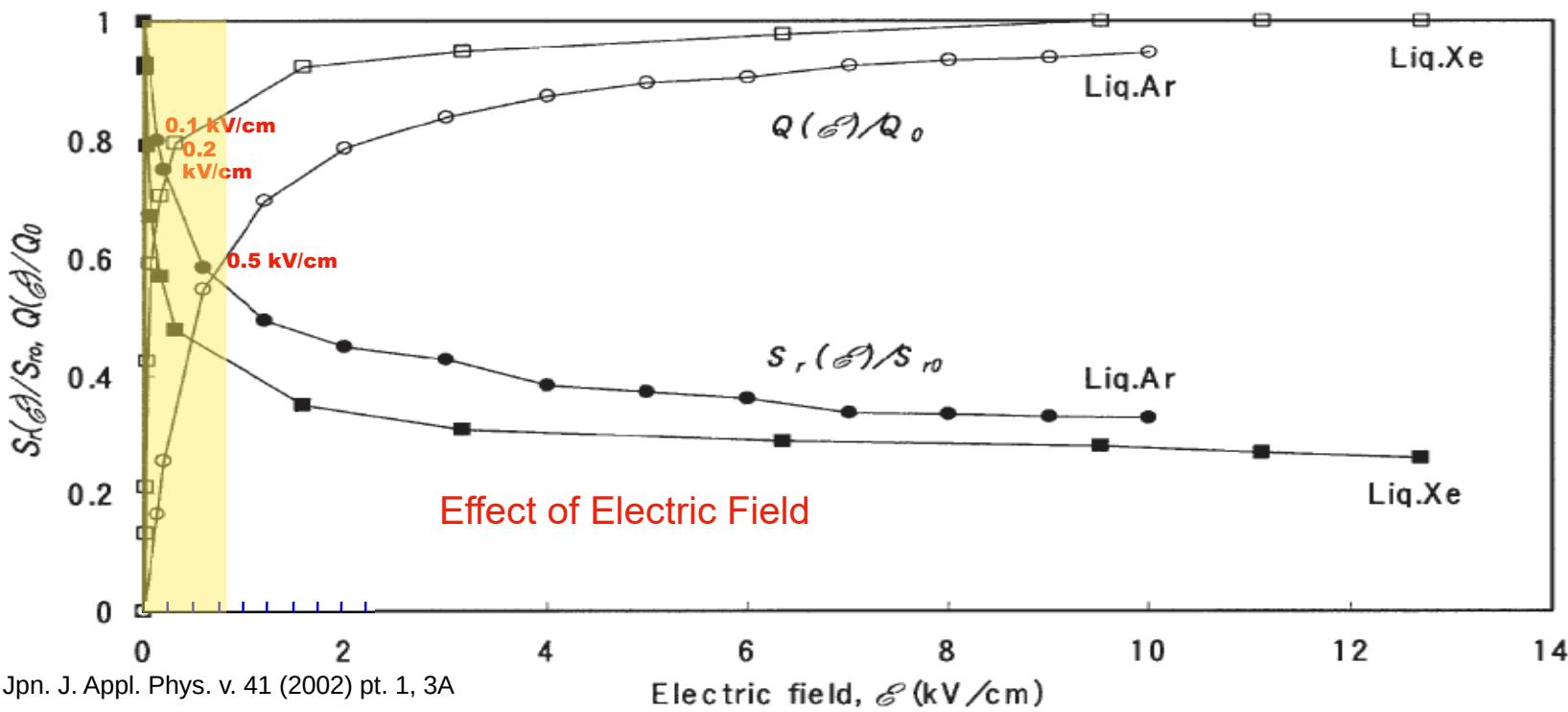
$$QY(dE/dx, \xi) + LY(dE/dx, \xi) = N_i + N_{ex}$$

Free Charge Yield: [e/MeV]

Light Yield: [ph/MeV]

Theoretical/Phenomenological Foundations

Free Ionization Charge and Scintillation Light AntiCorrelated-Complementary at a given $(dE/dx, \xi)$ pair



Theoretical/Phenomenological Foundations

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

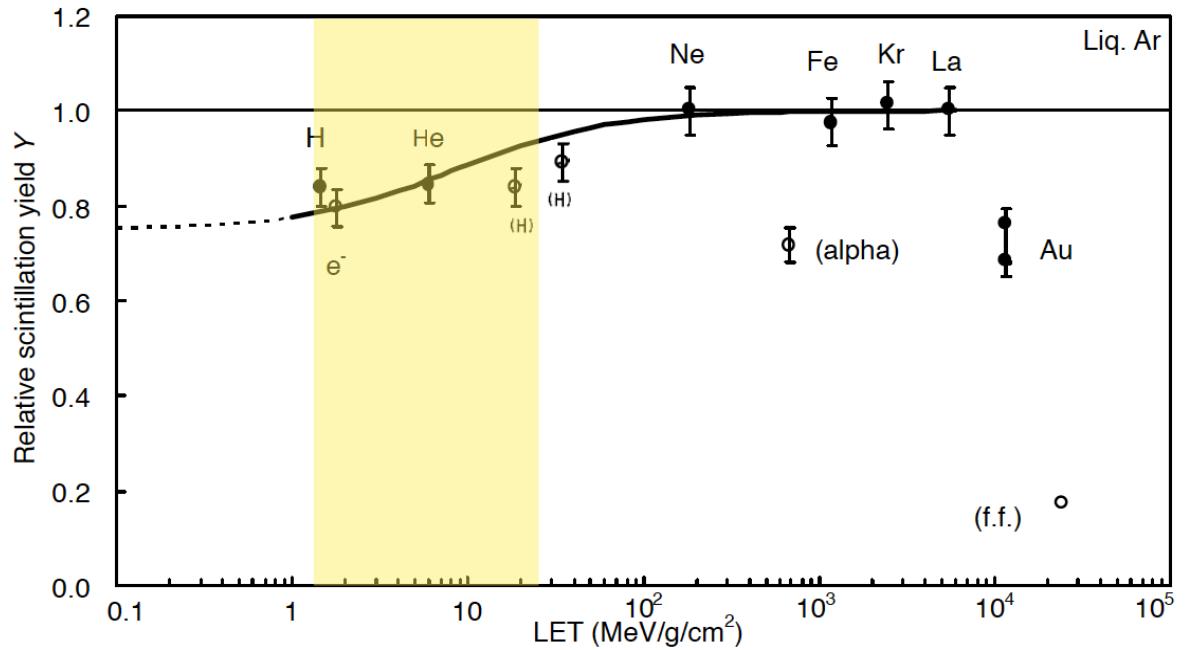
N_0 : # of escaping electrons per energy unit

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

Fractions of interest:

$1 - \eta_0$: missing photons

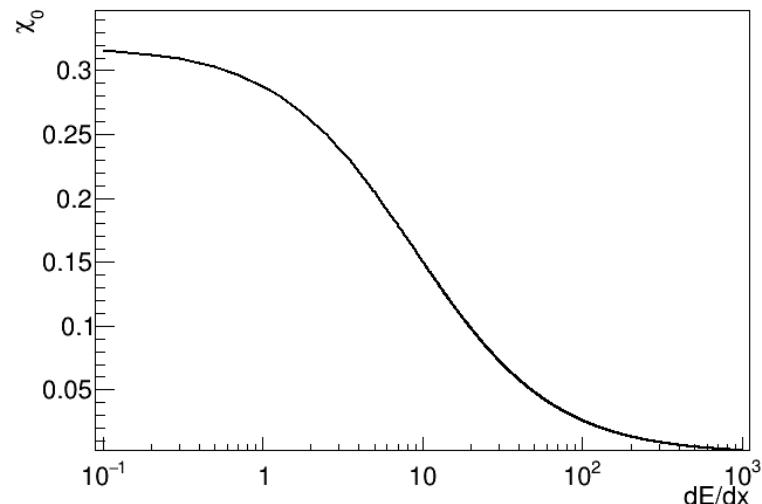
$\chi_0 = \frac{N_0}{N_i}$: escaping electrons



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

3 experimental parameters

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



Light yield obtained from free charge yield

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

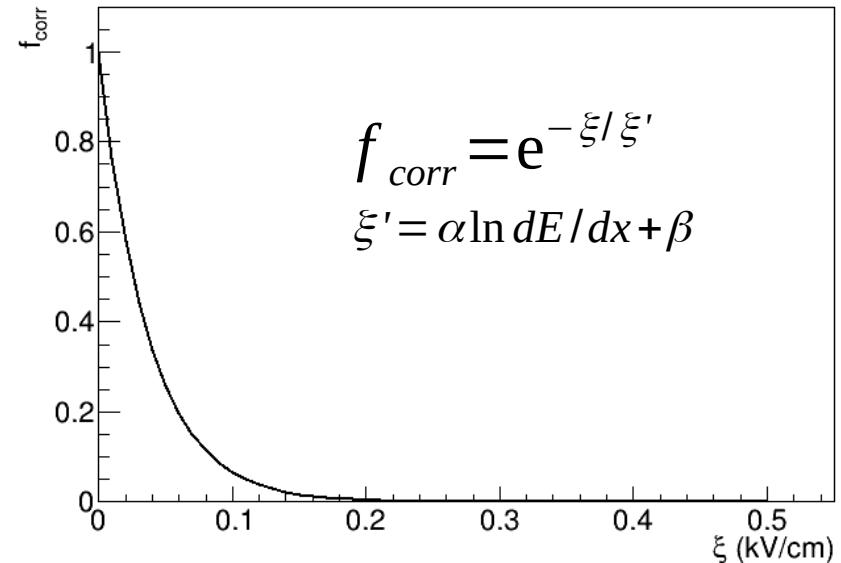
LArQL

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

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

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



LArQL

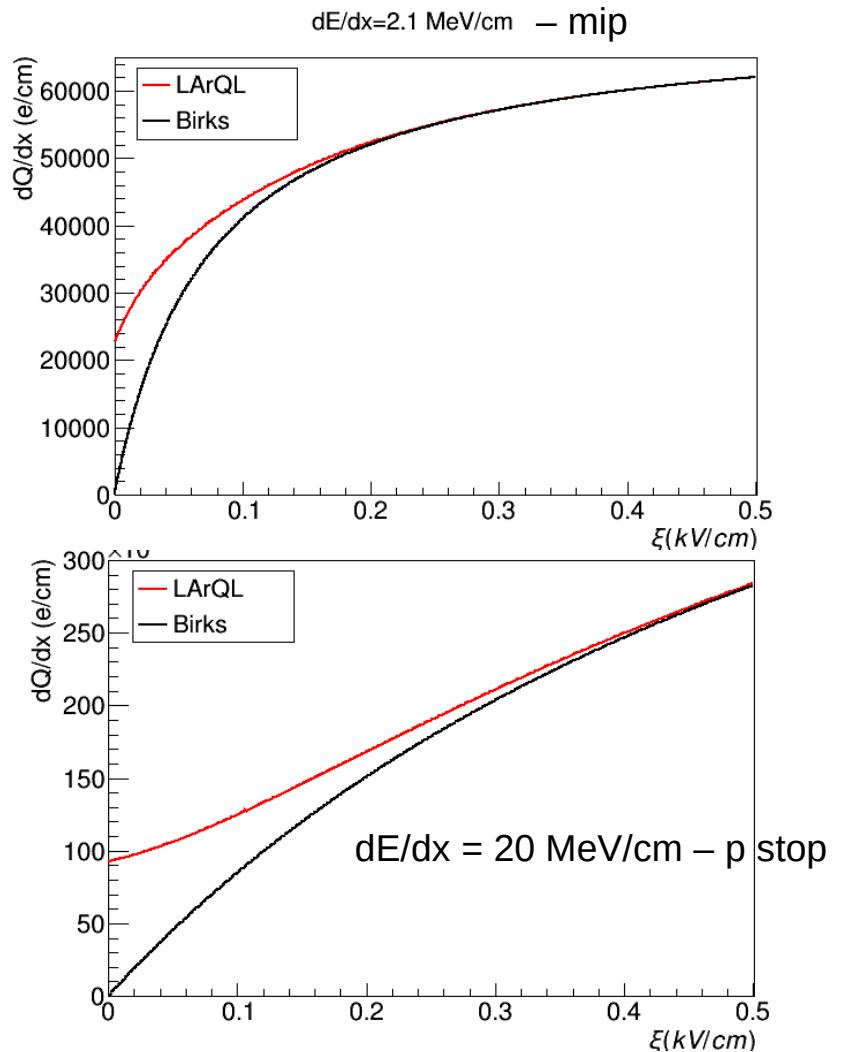
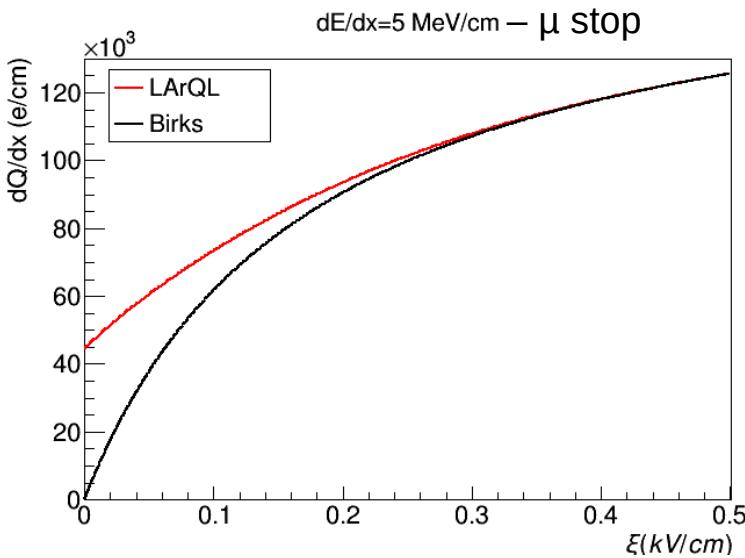
Modifies Birks charge model correcting for escaping and additional electrons at lower ξ range

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

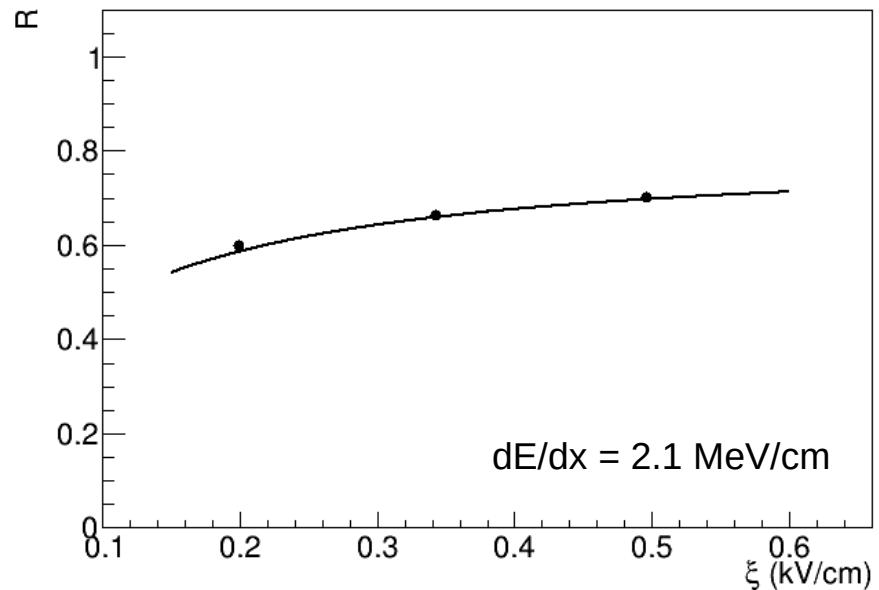
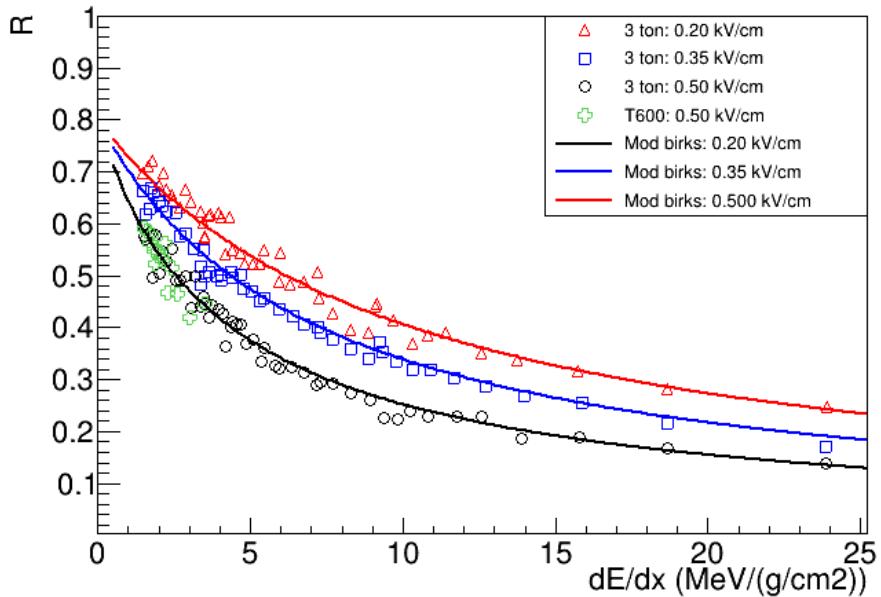
$$dQ/dE_{birks} \rightarrow dQ/dE_{birks} + \chi$$

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

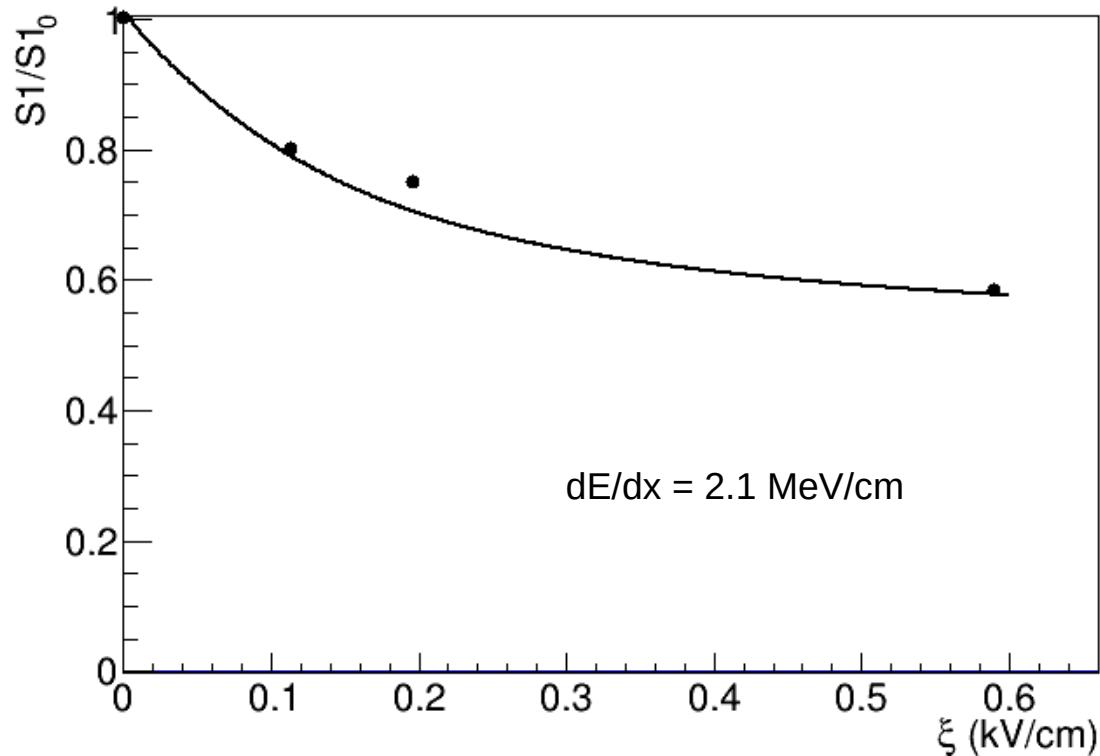
Predictions on charge sector
differ from Birks only for
heavily ionizing particles at
lower ξ



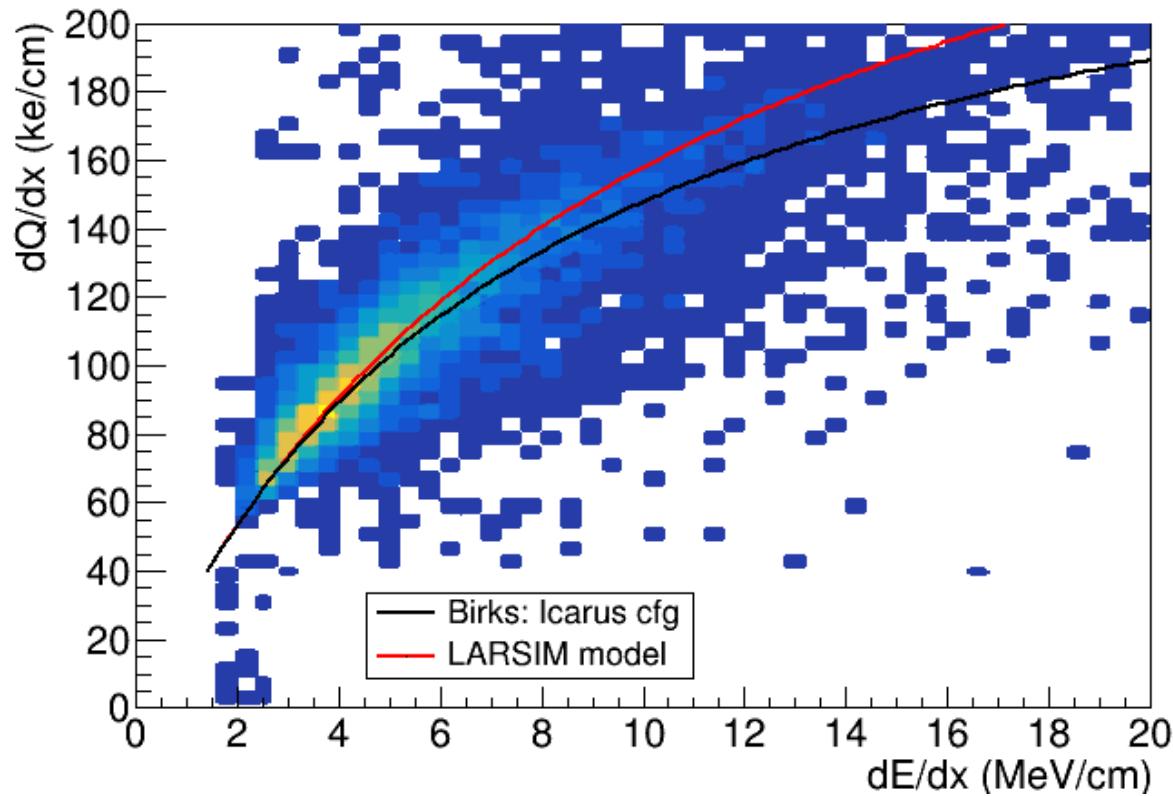
Charge data



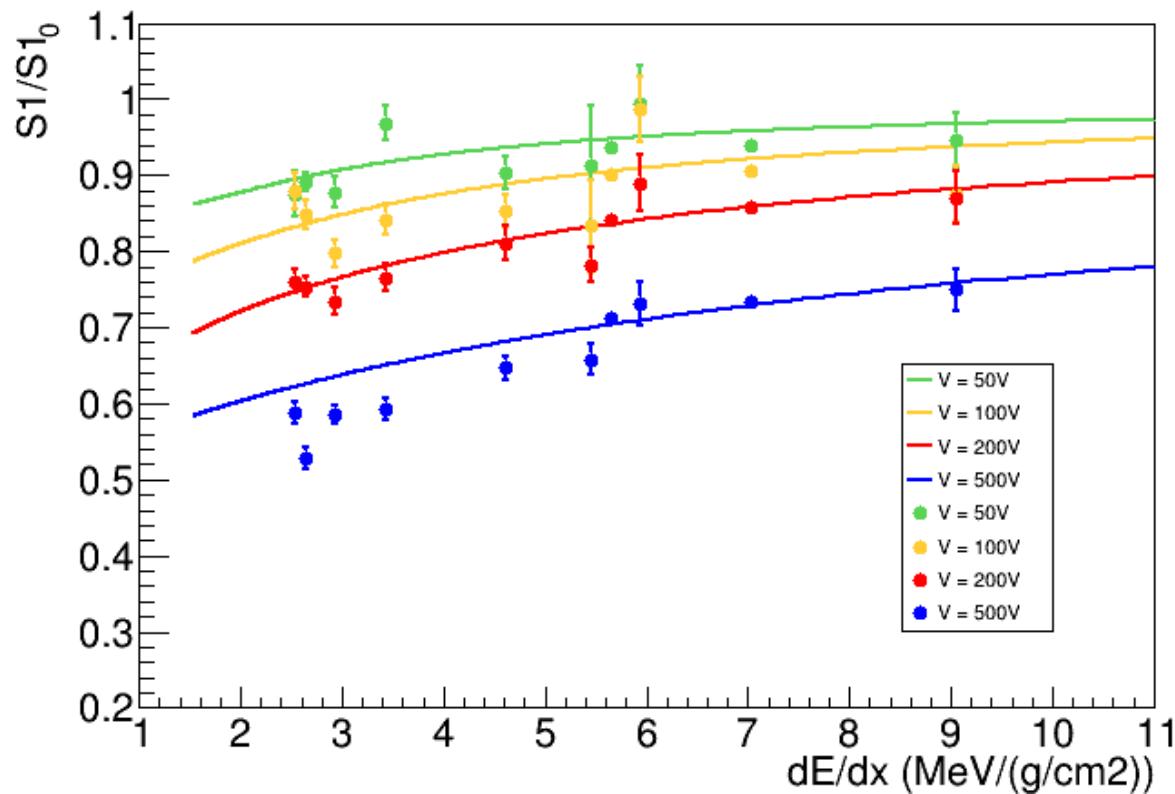
Scintillation data



LArQL: Microboone data @ 270 V/cm



LArQL: ARIS data

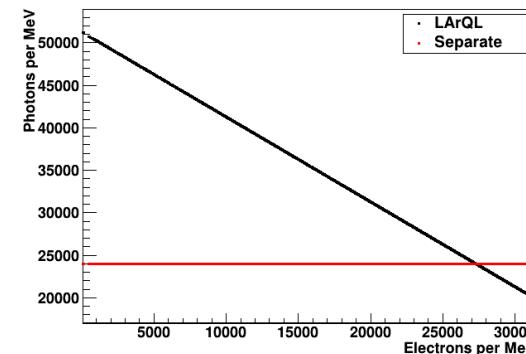


LArSoft implementation

- sim::SimEnergyDeposit: dE and dx
- detinfo::DetectorPropertiesData and spacecharge::SpaceCharge: ξ

- $dE/dx \rightarrow dQ/dE_{\text{birks}} + \chi$

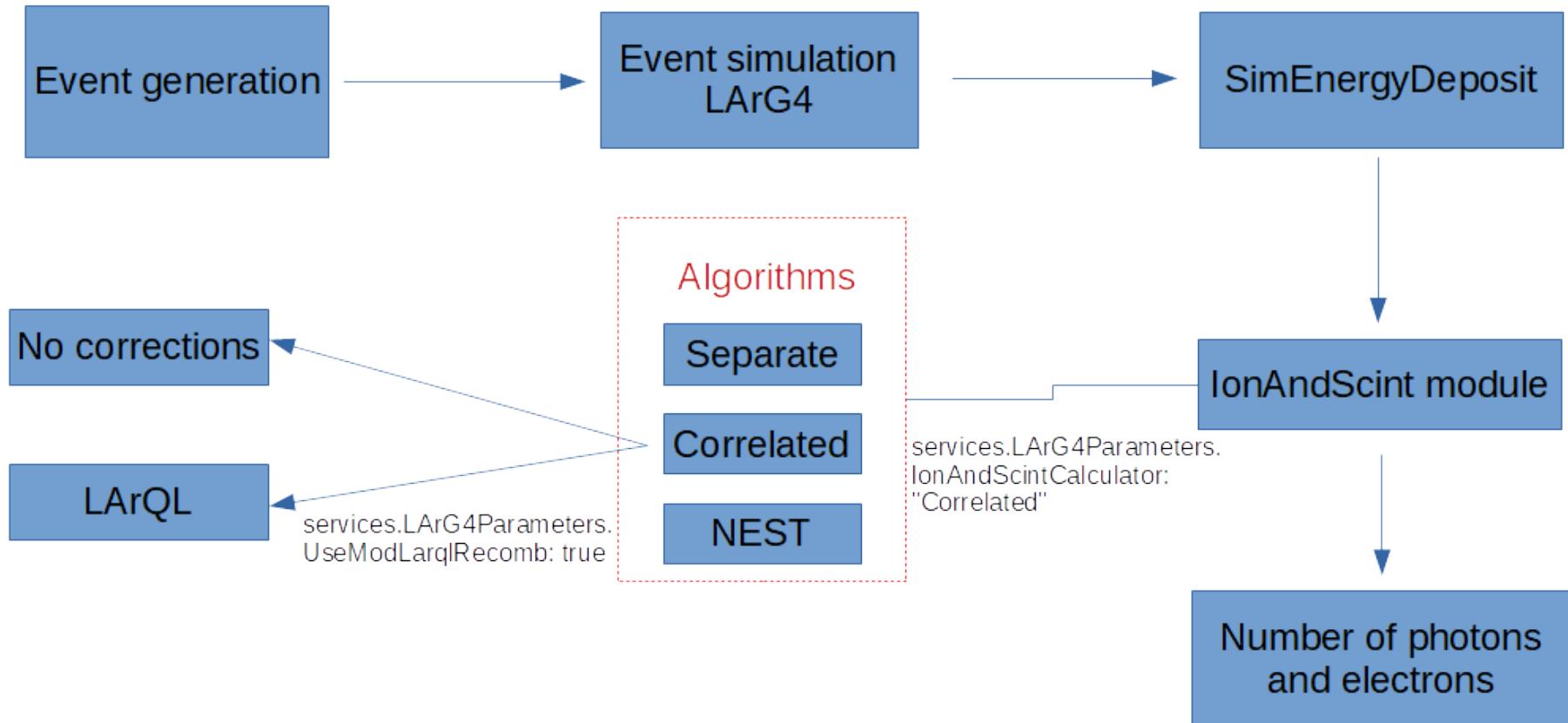
- $LY = N_i + N_{ex} - (dQ/dE_{\text{birks}} + \chi)$



- Modification of the **Correlated method** adjustable via **fcl** parameter

```
else
{
    recomb = fRecombA / (1. + dEdx * fRecombk / EFieldStep);
    if( fUseModLarqlRecomb ) //Use corrections from LARSIM model
        recomb += ch10(dEdx)*fcorr(EFieldStep, dEdx); //Correction for low EF
}
```

LArSoft implementation



Conclusions

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