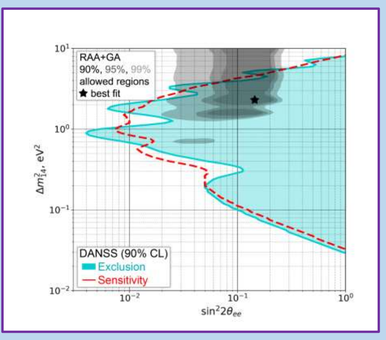
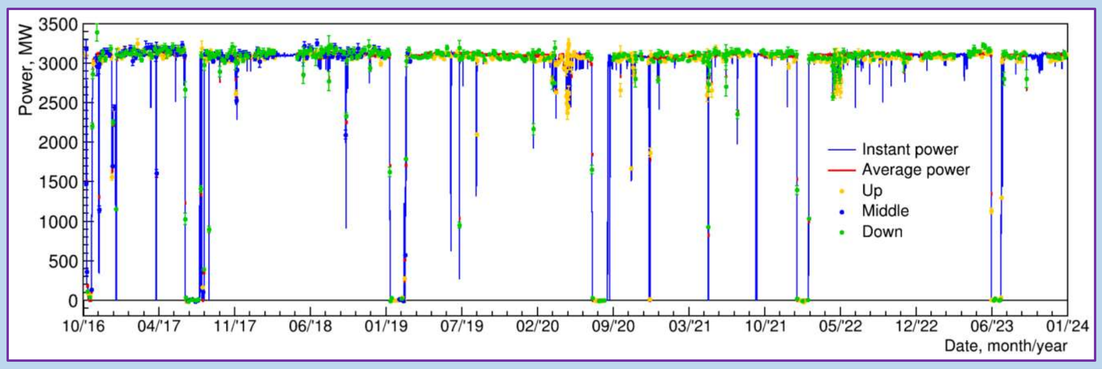
Calibration of the DANSS detector with stopped atmospheric muons and their decays

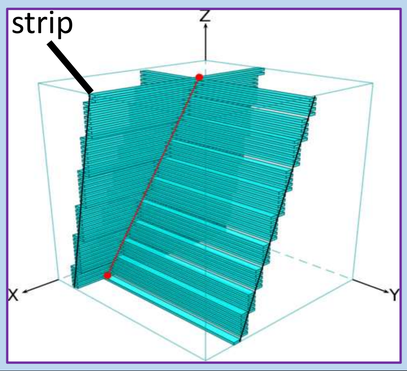
- **Detector AntiNeutrino based on Solid Scintillator**

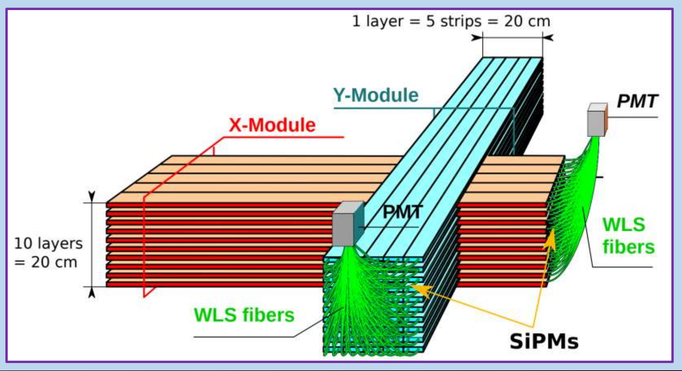
- Experiment is Placed under Kalinin Nuclear Power Plant (KNPP) reactor
- $> 8 \times 10^6$ Inverse Beta Decay (IBD) events were accumulated
- Reactor power is measured by the DANSS with neutrino flux with 1.3% accuracy in 3 days during more than 7 years
- The world's best model independent limits for sterile neutrino search in the Δm^2_{14} range $\sim 1\ eV^2$, $\sin^2 2\theta_{ee}$
- ..search for sterile neutrino → requirement of precise energy calibration

see talk by M.Shirchenko







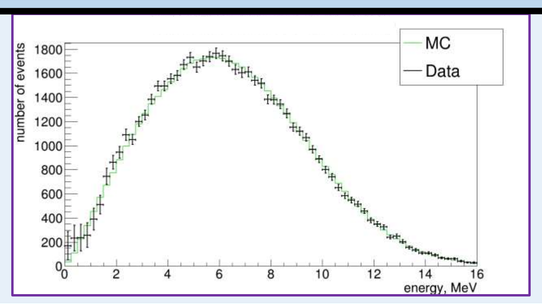


- **DANSS energy scale**

- Beta decay ^{12}B produced by muons

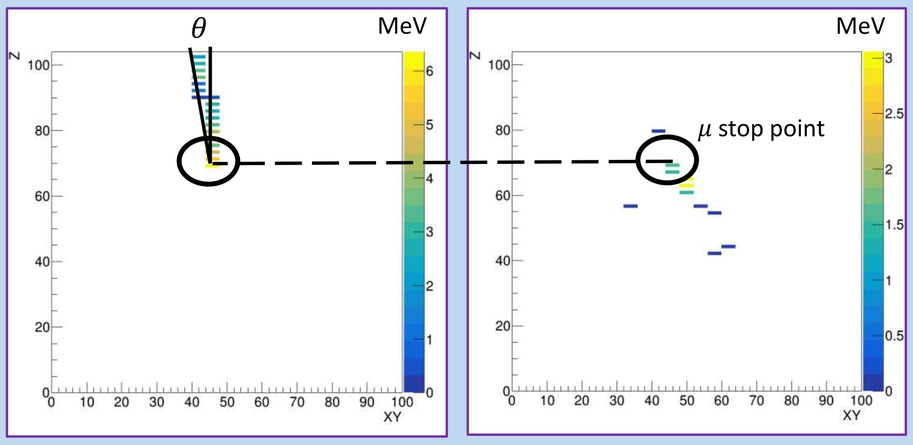
$$\mu^- + {}^{12}C \rightarrow {}^{12}B + \nu_\mu$$

- We show energy scale coefficient relatively to one from ^{12}B



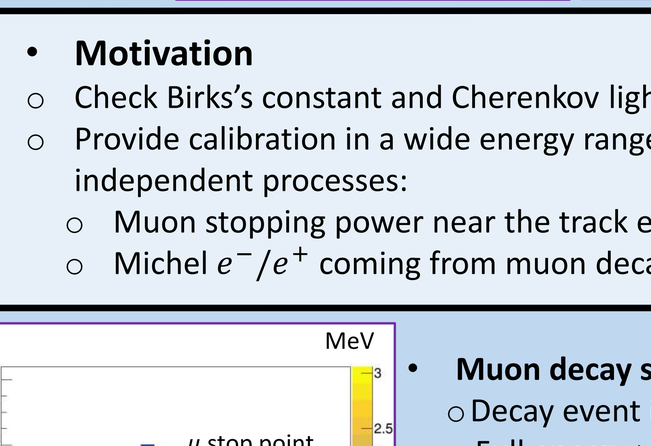
- **Motivation**
  - Check Birks's constant and Cherenkov light intensity
  - Provide calibration in a wide energy range (~2-12 MeV per strip) using two independent processes:
    - Muon stopping power near the track endpoint
    - Michel e^-/e^+ coming from muon decays

- **Stopped muon selection**
  - Signal in upper layer and no signal in 3 bottom layers and side strips
  - Muon is almost vertical ($\theta < 10^o$)
  - > 6 strips in both XZ and YZ planes
  - Dead channels are taken into account in both Data and MC
  - Decay in $1 - 7\ \mu s$ window



- **Muon decay selection**
  - Decay event in $1 - 7\ \mu s$ window after muon
  - Full energy > 5 MeV
  - ≥ 2 hits in strips neighbour to the strip of the muon stop
  - Muon stop point is in the inner cube with side 0.5 of the detector size

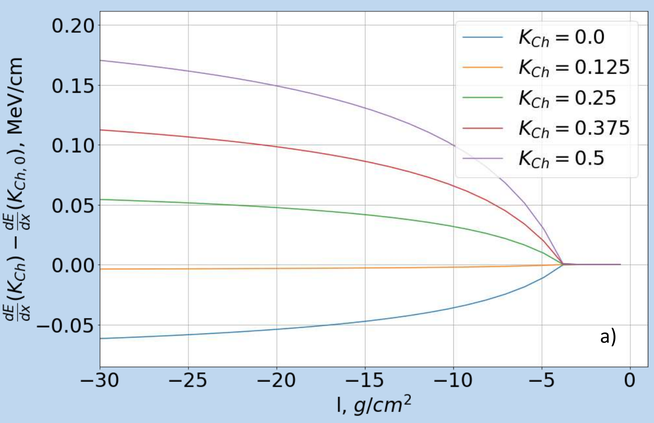
- **Bragg's curves**
  - Record signals from every strip as a pair $(-l, \frac{dE}{dx})$, where l – dist. to stop measured in g/cm^2. Fill 2D-histogram with these values
  - Split the histogram into slices along l-axis
  - Find median losses $\frac{dE}{dx_{med}}$ in slices over l
  - Bragg's curve – array of points $(-l, \frac{dE}{dx_{med}})$
  - Compare Bragg's curves obtained from MC and Data

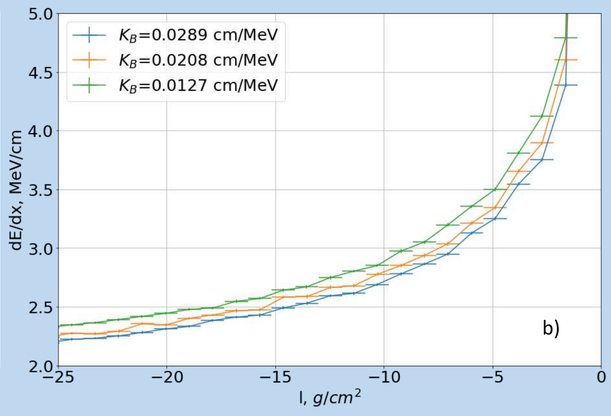


- **Calibration parameters**
  - K_B - Birks' constant for muon produced scintillation $[cm/MeV]$
  - K_{Ch} - intensity of Cherenkov light in $[MeV/cm]$
  - K_D - full effective strip thickness in $[g/cm^2]$
  - K_E - energy scale coefficient (proportionality between Data and MC)
  - K_S – MC spectrum smearing coefficient ($\sigma(E) = K_S \cdot E$)

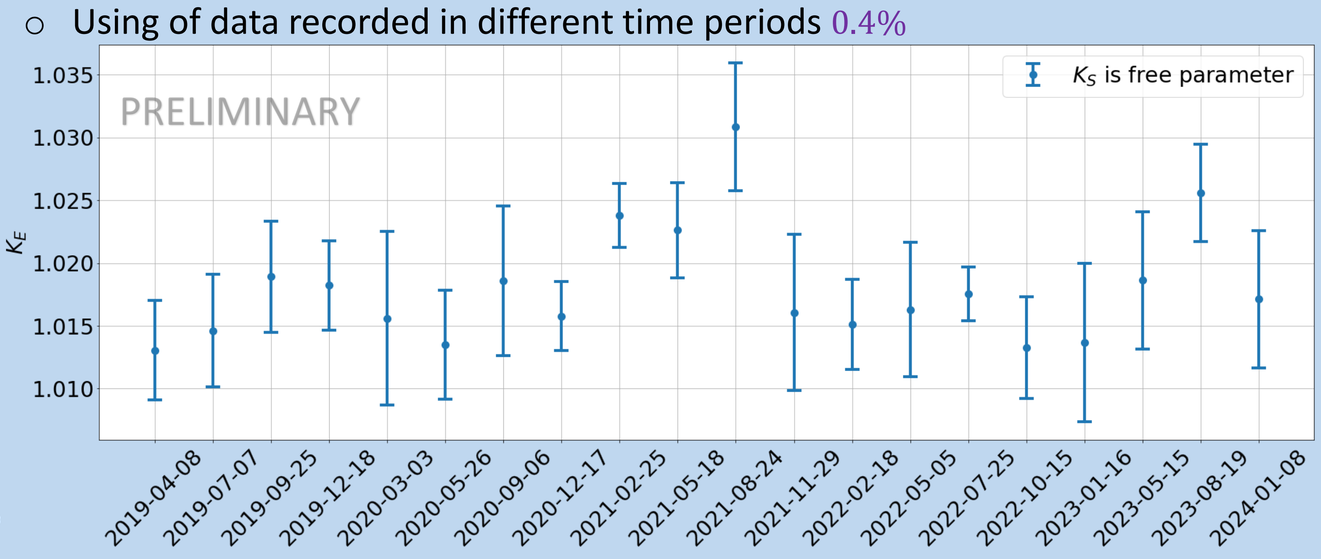
Bragg's curves

Muons decays





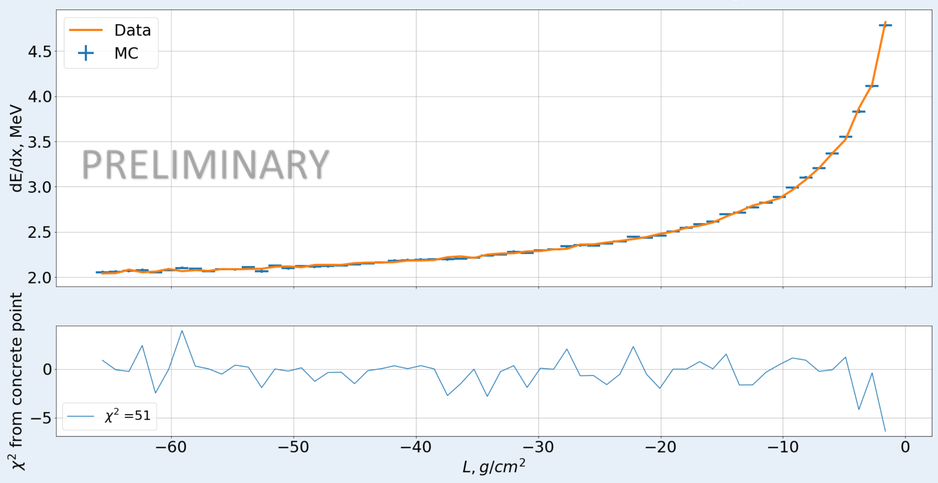
- **Systematic uncertainty studies (for K_E)**
  - Comparing decay spectra with and without rad. corrections 0.5%
  - Dividing dataset according to muon stop point 0.6%
  - Using of data recorded in different time periods 0.4%



Impact of K_{Ch} (a) and K_B (b) on Bragg's curves

K_E obtained with decays of stopped muons from July of 2019 to January of 2024

- **Results of SiPM calibration (Bragg's curves)**
  - K_E agrees with ^{12}B and Michele electrons
  - K_B & K_{Ch} were changed in the Model according to the results of this calibration
  - K_D agrees with value obtained from strip geometry 1.0744 g/cm^2



$K_B = 0.0208\ cm/MeV$

$K_{Ch} = 0.142 \pm 0.016_{stat} \pm 0.020_{syst}\ MeV/cm$

$K_D = 1.066 \pm 0.004_{stat} \pm 0.006_{syst}\ g/cm^2$

$\chi^2/NDF = 51/57$

$K_E = 1.016 \pm 0.004_{stat} \pm 0.007_{syst}$

- **Results of SiPM calibration (Michel e^-/e^+)**
  - K_E agrees with stopped muons and passing muons
  - Result is decent even without smearing

$\chi^2/NDF = 80/98$

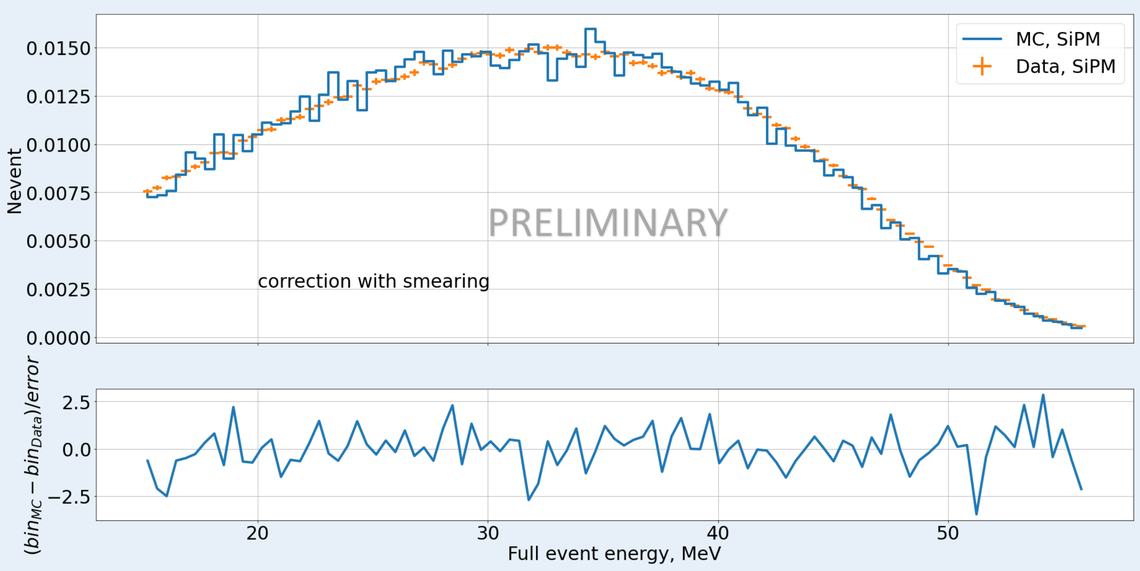
$K_E = 1.018 \pm 0.003_{stat} \pm 0.009_{syst}$

$K_S = 0.032 \pm 0.007_{stat} \pm 0.011_{syst}$

$\chi^2/NDF = 156/99$

$K_E = 1.014 \pm 0.002_{stat} \pm 0.009_{syst}$

$K_S = 0$



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