Study of Data/MC Discrepancies in Isotope Analysis

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Background and Motivation

Choose a set of tuning parameters to describe Data/MC discrepancy.
Perform mass fits and find the minimum χ^2 value in this parameter space.

- Use β shift and smear directly as tuning parameter.
- Rigidity discrepancy between Data/MC.
- Different χ^2 -minimization methods.

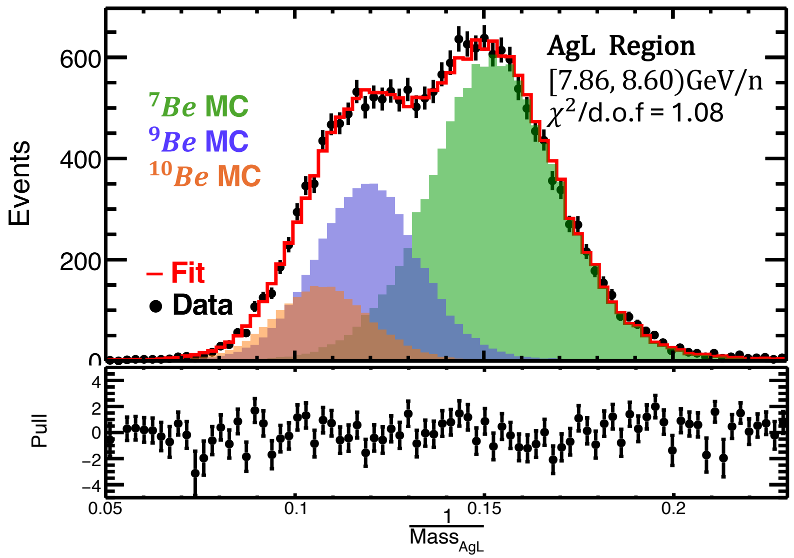
1 Isotopes Fraction Determination Mass Fit Method (Call back)

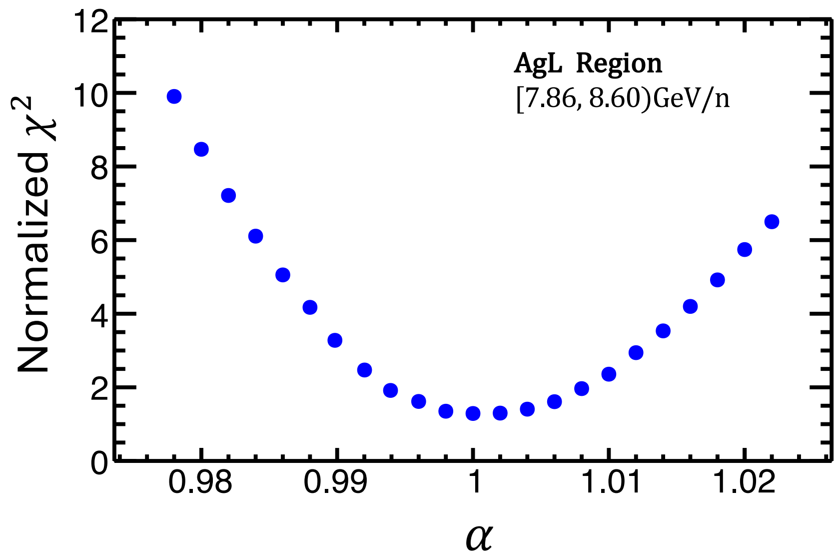
Tune β_{NaF} and β_{AgL} :

- Uniformity corrections (index, reflection rate, run), on Data and MC.
- Calibration of expension length, on Data
- Smearing of $1/\beta$, on MC

Tune β_{TOF} based on β_{NaF} , for MC:

- Match the core σ of $\frac{1}{\beta_{TOF}} - \frac{1}{\beta_{NaF}}$ between data/MC
- β_{TOF} tuning BetaHR::DoMCtuneNew()





$$\left(\frac{1}{M}\right)' = \alpha \cdot \left(\frac{1}{M}\right), \quad \beta' = \frac{\alpha\beta}{\sqrt{1-\beta^2+\alpha^2\beta^2}}$$

2 Add R smearing

The resolution of mass can presented as:

$$\frac{\boldsymbol{\sigma_{1/m}}}{\boldsymbol{1/m}} = \sqrt{(\frac{\boldsymbol{\sigma_R}}{\boldsymbol{R}})^2 + \boldsymbol{\gamma}^4(\frac{\boldsymbol{\sigma_{1/\beta}}}{\boldsymbol{1/\beta}})^2}$$

The discrepancy between data and MC is likely due to multiple scattering effects :

$$\frac{\sigma_R^{MS}}{R} \sim \frac{\theta_{MS}^{plane}}{\theta_B} = \frac{0.0136}{0.3\boldsymbol{\beta}\cdot B[\mathrm{T}]L[\mathrm{m}]} \cdot \sqrt{\frac{x}{X_0}} \cdot [1 + 0.038\ln(\frac{x}{X_0})]$$

If Data/MC discrepancy comes from multiple scattering, rigidity smearing value should be:

$$\frac{\delta\sigma_R}{R} \sim f\left(\frac{1}{\beta}\right) \sim p_0/\beta$$

Thus, choose $\frac{\delta\sigma_R}{R}$ as the 3rd parameter to do 3D parameter scan

2 Studying MC–Data Discrepancies via Mass Template Fit χ^2

Basic Steps:

Add the smearing of $\frac{\delta\sigma_R}{R}$ as 3rd parameter.

1. Setting two parameters to tune MC, shift μ and smearing σ :
   - $1/\beta' = \frac{1}{\beta} + \delta, \quad \delta \sim \mathcal{N}(\delta\mu, \delta{\sigma_\beta}^2)$, β' is the tuned velocity, and β is raw velocity
   - $R' = R + \delta_R, \quad \delta_R \sim \mathcal{N}(0, \delta{\sigma_R}^2)$
2. Scan the χ^2 of parameters, the scan range:
   - $\delta\,\mu \in \left[\frac{1}{\beta}(\alpha_0 - 0.02), \frac{1}{\beta}(\alpha_0 + 0.02)\right]$, ν is the shift value of $1/\beta$ corresponding to the minimum−χ^2 from α *method*.
   - $\delta\sigma_\beta \in [0,\ 10.0 \cdot \Sigma_{1/\beta}]$, $\Sigma_{TOF} = 10 * \Sigma_{NaF}$, smearing value of $\frac{1}{\beta_{NaF}}$ from high energy (rigidity>100GV).
   - $\frac{1}{R}\delta\sigma_R \in [0,\ 10.0 \cdot \boldsymbol{\beta\gamma^2}\Sigma_{1/\beta}]$, the factor $\beta\gamma^2$ ensures that the scanning range contributes similarly to 1/m.

$\Sigma_{1/\beta}$	TOF	NaF	AgL
Li	~8.1×10^{-3}	0.81×10^{-3}	0.24×10^{-3}
Be	~6.2×10^{-3}	0.62×10^{-3}	0.20×10^{-3}
B	~5.2×10^{-3}	0.52×10^{-3}	0.18×10^{-3}
O	~4.8×10^{-3}	0.48×10^{-3}	0.15×10^{-3}

From Twiki

2 Method of Searching Minimum χ^2

Tune MC:

Apply the corrections (shift & smear) event by event, fill kinetic bins, accordingly, perform template fit and χ^2-scanning in each bin.

Use ROOT::Math::Minimizer to do the 3D minimum

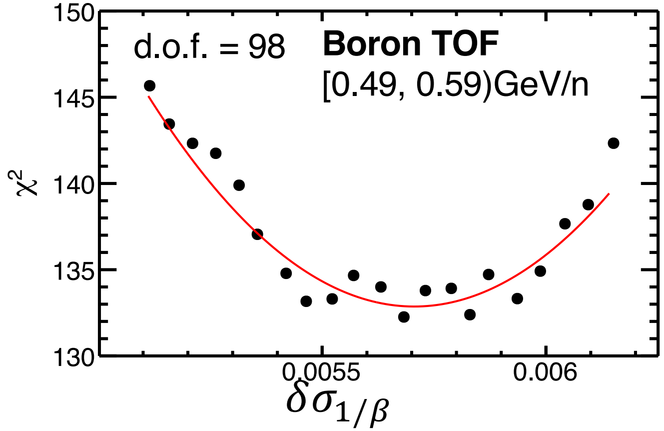
1. **Normalization:** parameters to range [0, 1].
2. **Simulated Annealing :** Explore the parameter space and identify the global minimum region
3. **Migrad + Hesse :** estimate parameter errors using Hessian matrix.

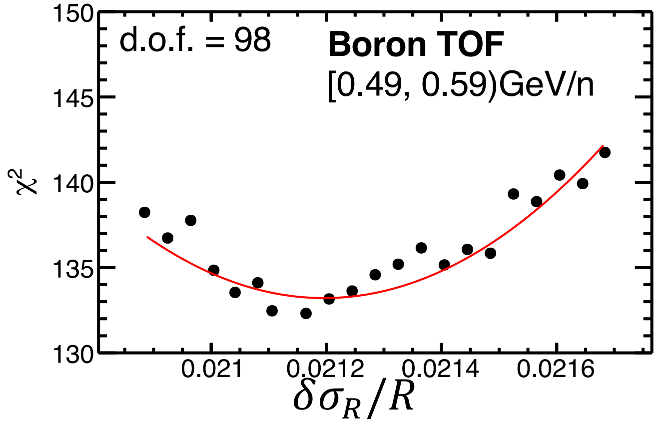
Perform minizations:

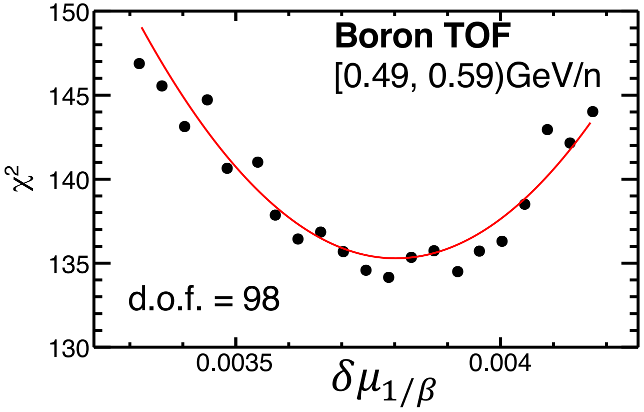
- **2D** $\delta\mu_{1/\beta}+\delta\sigma_{1/\beta}$
- **2D** $\delta\mu_{1/\beta}+\delta\sigma_R/R$ **with fixed** $\delta\sigma_{1/\beta}$(twiki smearing)
- **3D** $\delta\mu_{1/\beta}+\delta\sigma_{1/\beta}+\delta\sigma_R/R$

2 Validation of Minimizer Performance

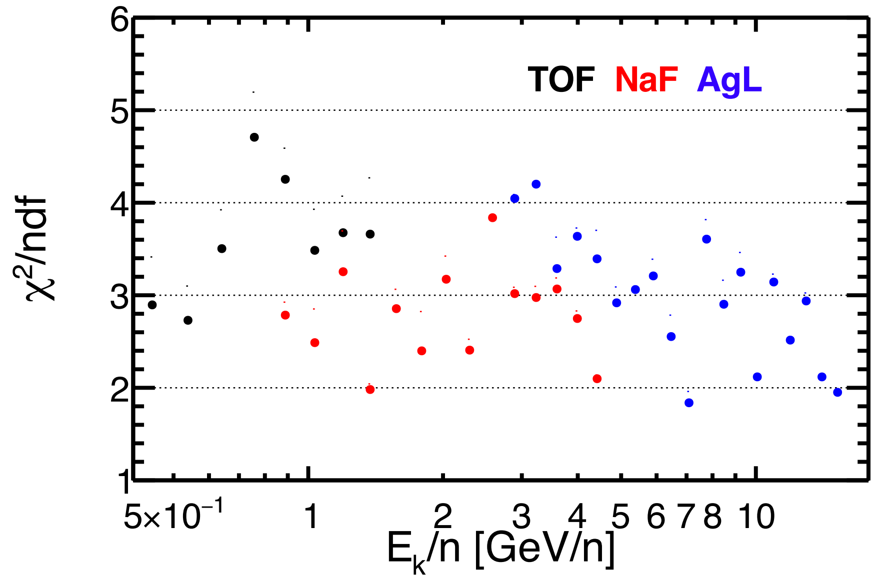
χ^2 Projection on 3 parameters:



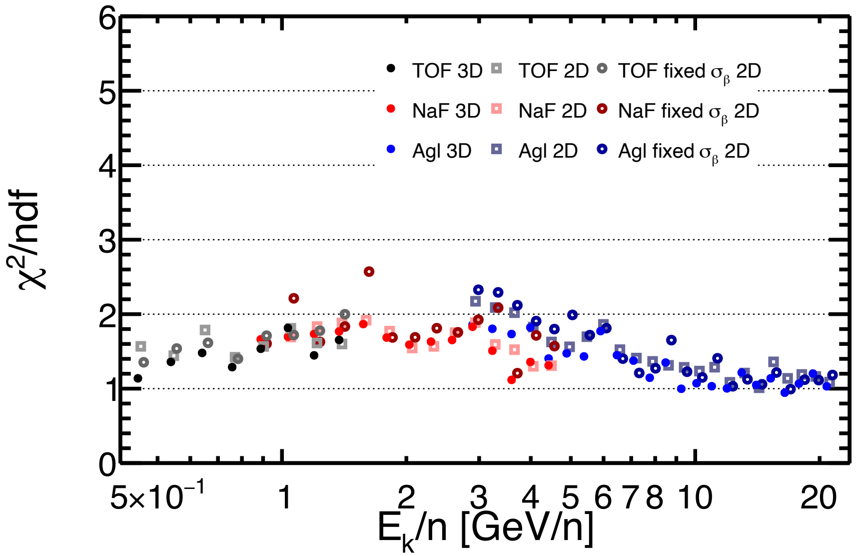




Boron massfit χ^2 (no tune)

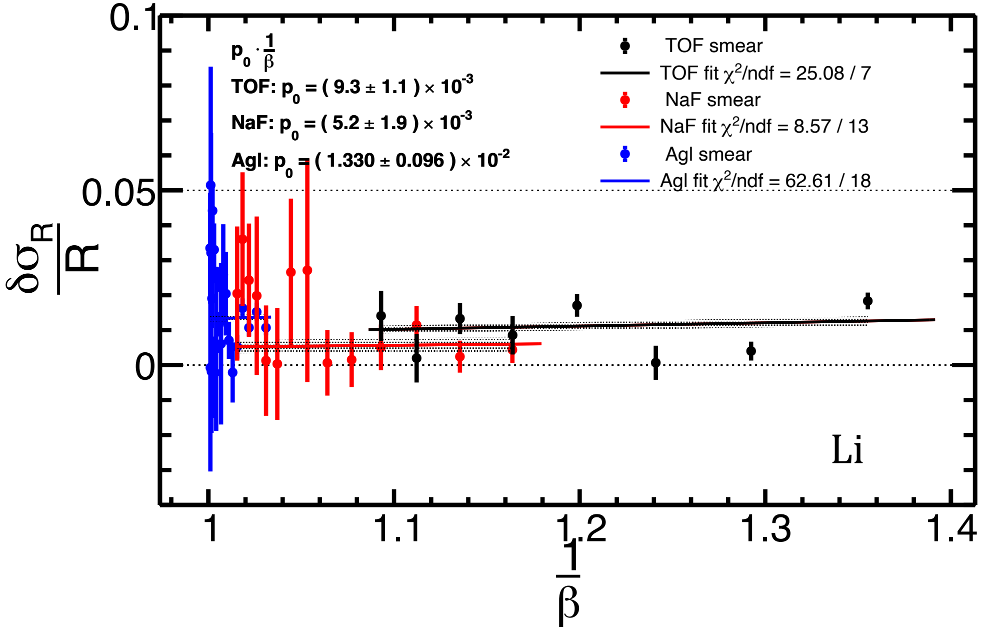


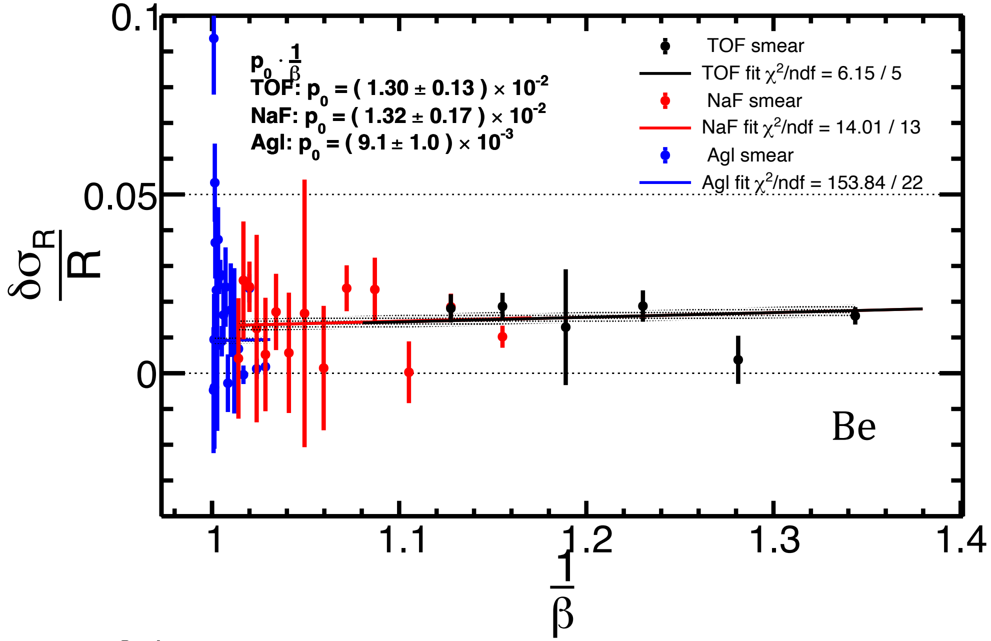
Boron massfit χ^2

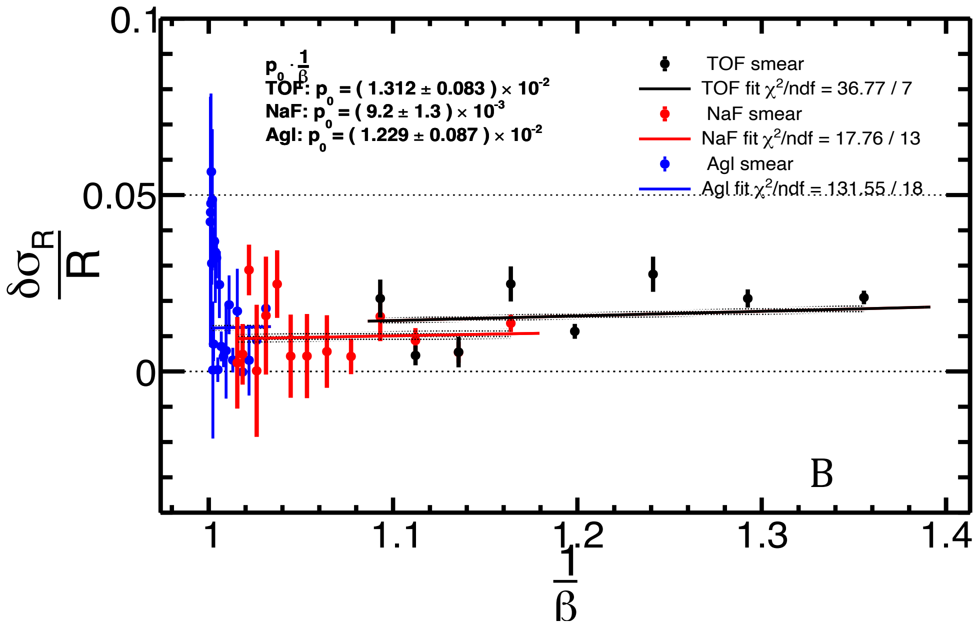


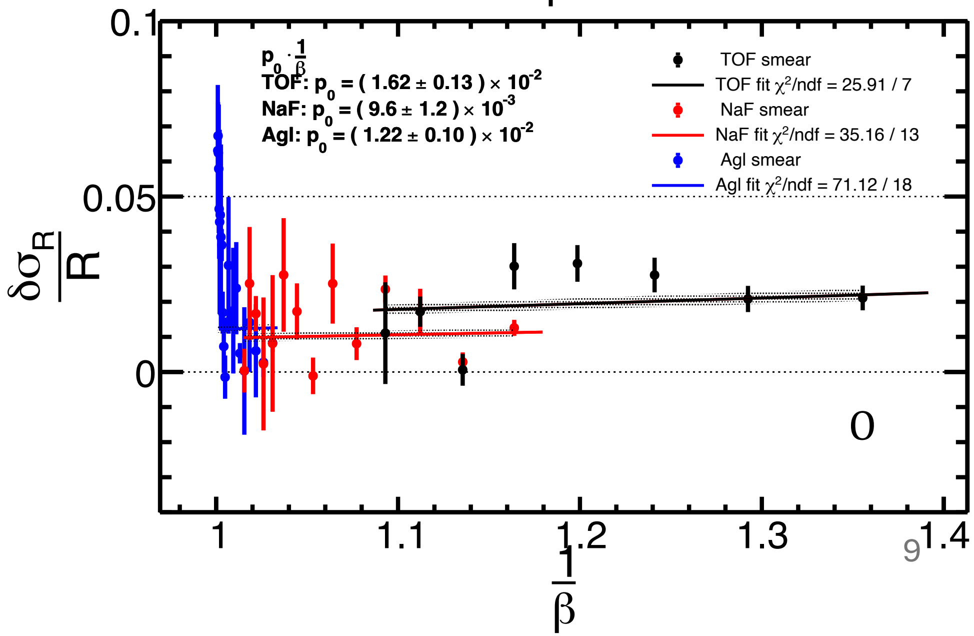
1/m Fitting range [0.05, 0.16]

2 Smearing Value of 1/ R_{inner} for Li, Be, B and O



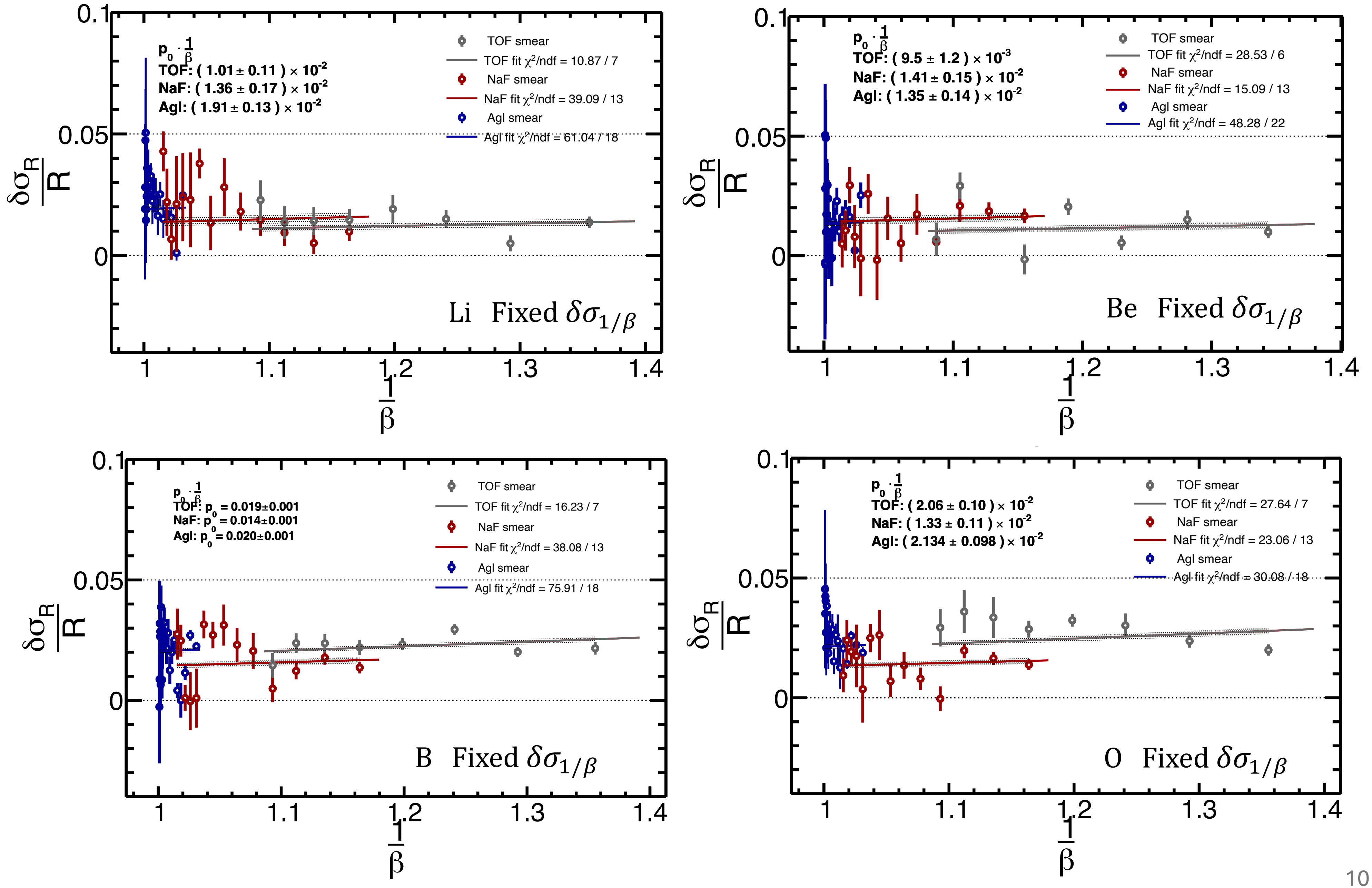






2 Smearing Value of 1/ R_{inner} for Li, Be, B and O

Fit with p_0/β



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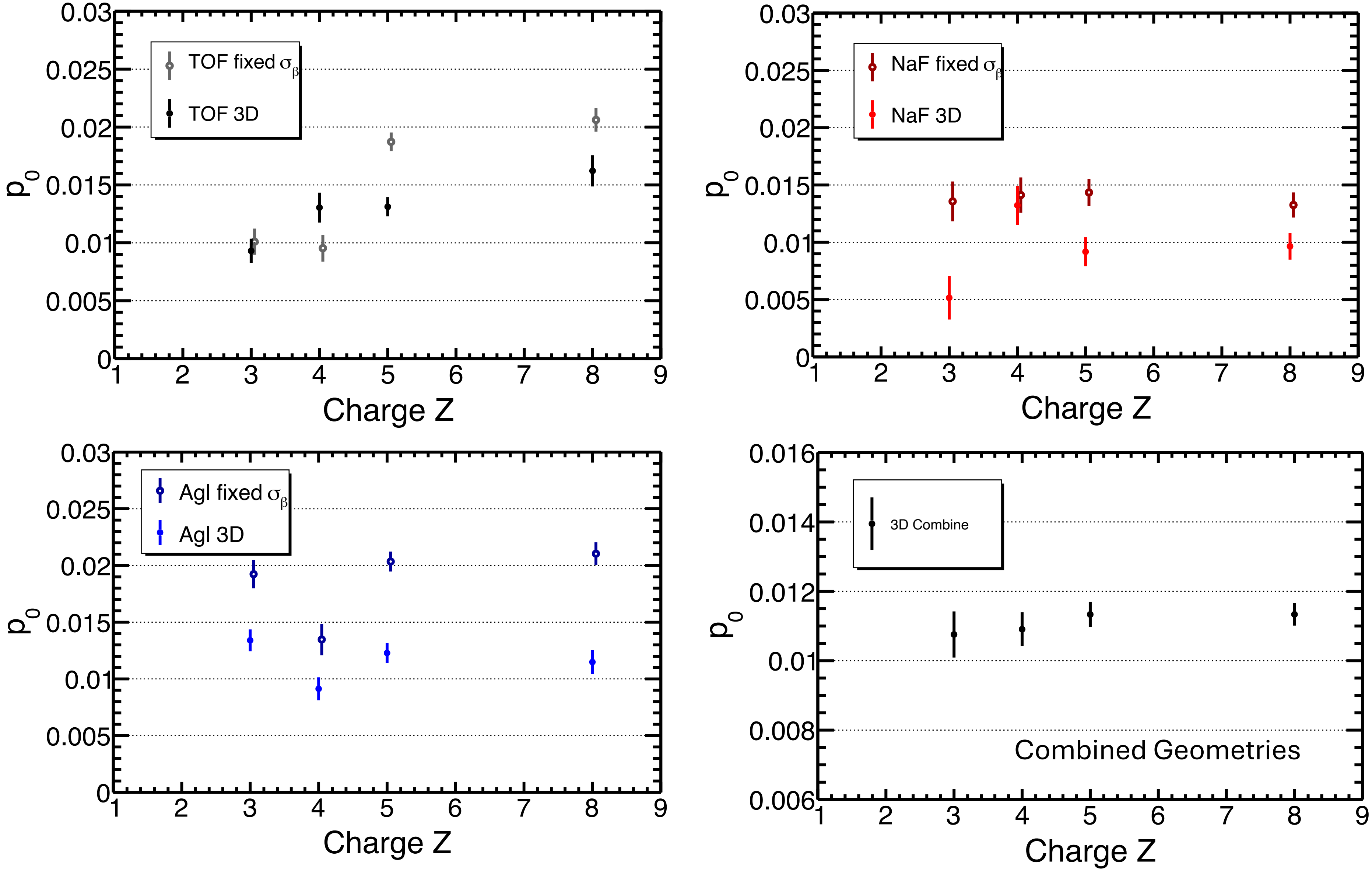
Smearing Value of 1/ R_{inner} for Li, Be, B and O

Fit with p_0/β



3 Verification of R smearing
Spatial Residual of L2

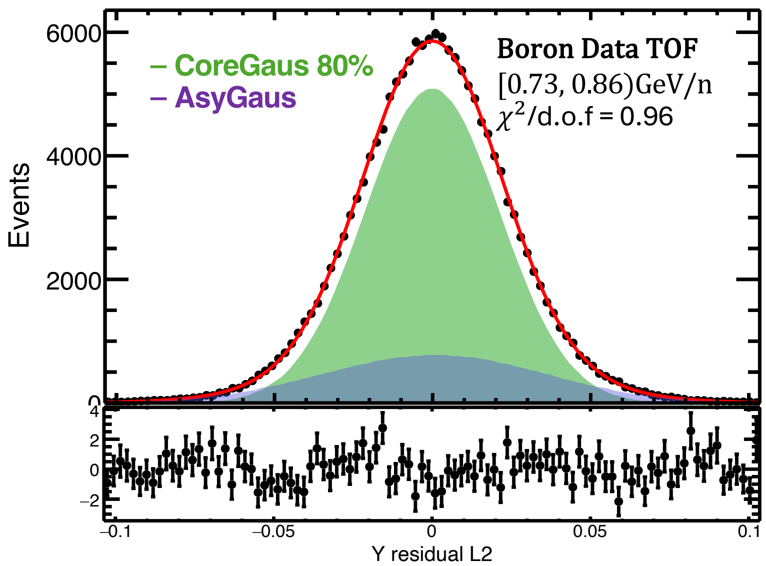
The L2 spatial residual can serve as a proxy for R_{inner} resolution

Use the exclude residual on y-direction:

$$residual = y_{hit}^{l2} - y_{track}^{l2}$$

- TrTrackR::GetResidualJ()
  - Track Geometry : inner L2&&(L3||L4)&&(L5||L6)&&(L7||L8), $N_{hits}^{inner} \geq 5$
  - Fit Geometry : inner exclude L2
  - Algorithm : V. Choutko
  - Alignment: V6
- Isotopes selections

Sigma of Core Gaussin



3 Cross Check of R smearing Spatial Residual of L2

$$\sigma_{residual} = \sqrt{\sigma_{IN}^2 + \boldsymbol{\sigma_{MS}^2}}$$

At low energies, the residual caused by multiple scattering:

$$\boldsymbol{\sigma_{MS}} \approx L \cdot \theta_{MS}^{plane} \sim L \cdot \frac{0.0136 \cdot Z}{0.3\beta \cdot p} \cdot \sqrt{\frac{x}{X_0}} \cdot \left[1 + 0.038 \ln\left(\frac{x}{X_0}\right)\right] \propto \frac{1}{\beta R}$$

$$\frac{\sigma_R^{MS}}{R} \approx \frac{\mathbf{0.0136}}{0.3\boldsymbol{\beta} \cdot B[\mathrm{T}]L[\mathrm{m}]} \cdot \sqrt{\frac{\boldsymbol{x}}{\boldsymbol{X_0}}} \cdot [\mathbf{1} + \mathbf{0.038}\mathbf{ln}(\frac{\boldsymbol{x}}{\boldsymbol{X_0}})]$$

$$R \cdot \boldsymbol{\sigma_{MS}} \approx \mathrm{B[T]L^2}[m] \cdot \frac{\boldsymbol{\sigma_R}}{\boldsymbol{R}}, \quad B \sim 0.14T$$

Factor σ_{IN} is estimated by events $R_{inner} > 300GV$

$$R \cdot \boldsymbol{\sigma_{MS}} \approx R \cdot \sqrt{\sigma_{residual}^2 - \sigma_{IN}^2} \propto \frac{1}{\beta}$$

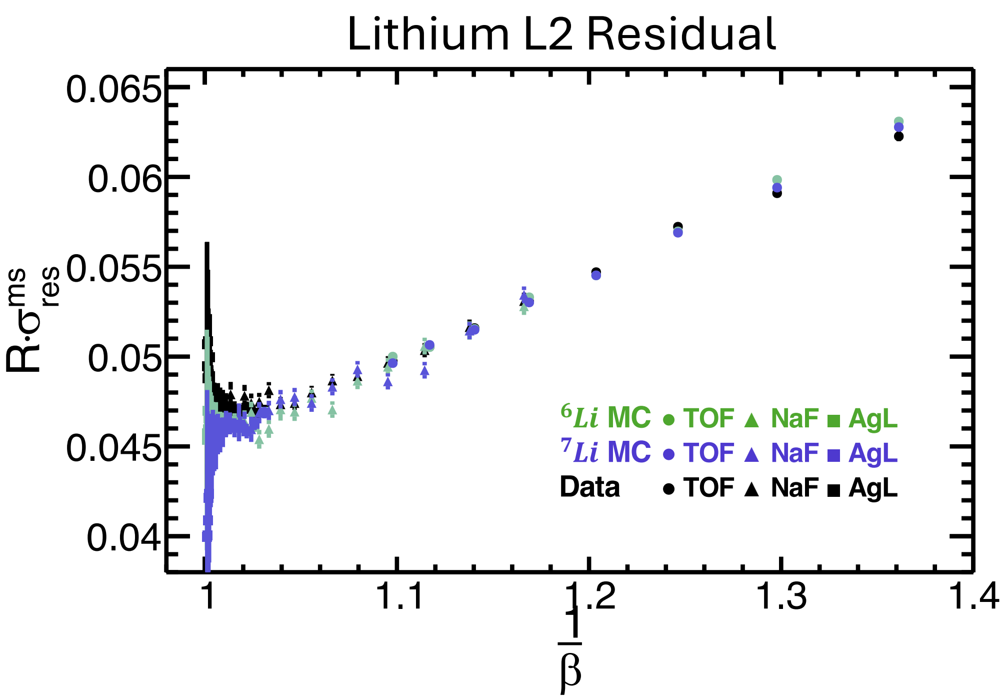
3

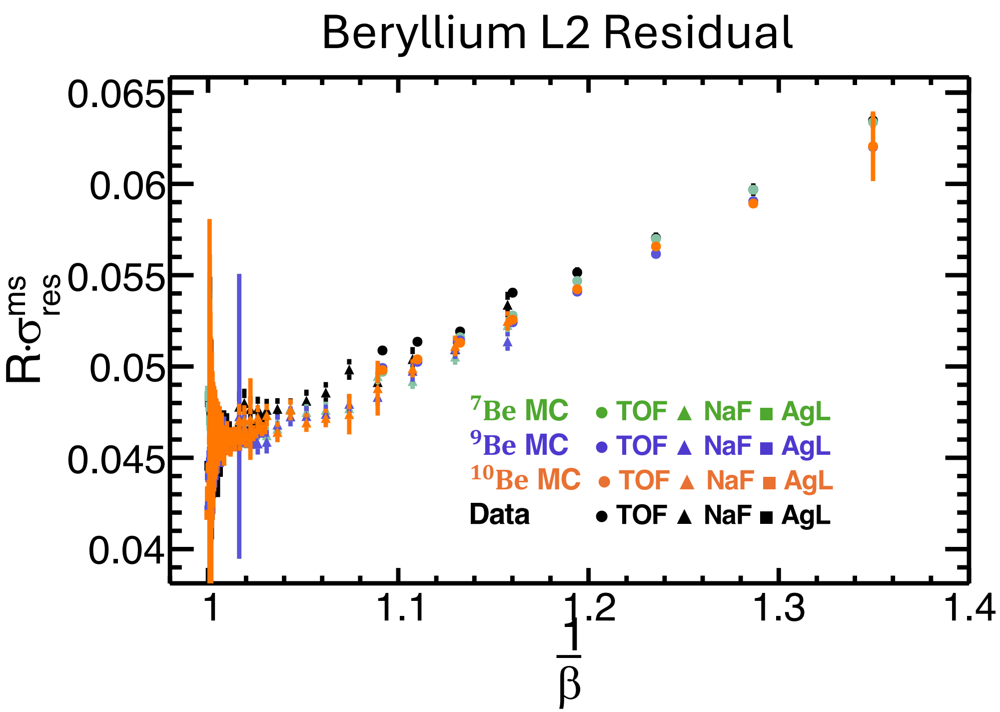
Cross Check of R smearing Spatial Residual of L2 (Li, Be)

As expected, $R \cdot \boldsymbol{\sigma_{MS}}$ is proportional to $1/\beta$

$$R \cdot \boldsymbol{\sigma_{MS}} \approx R \cdot \sqrt{\sigma_{residual}^2 - \sigma_{IN}^2} \propto \frac{1}{\beta}$$

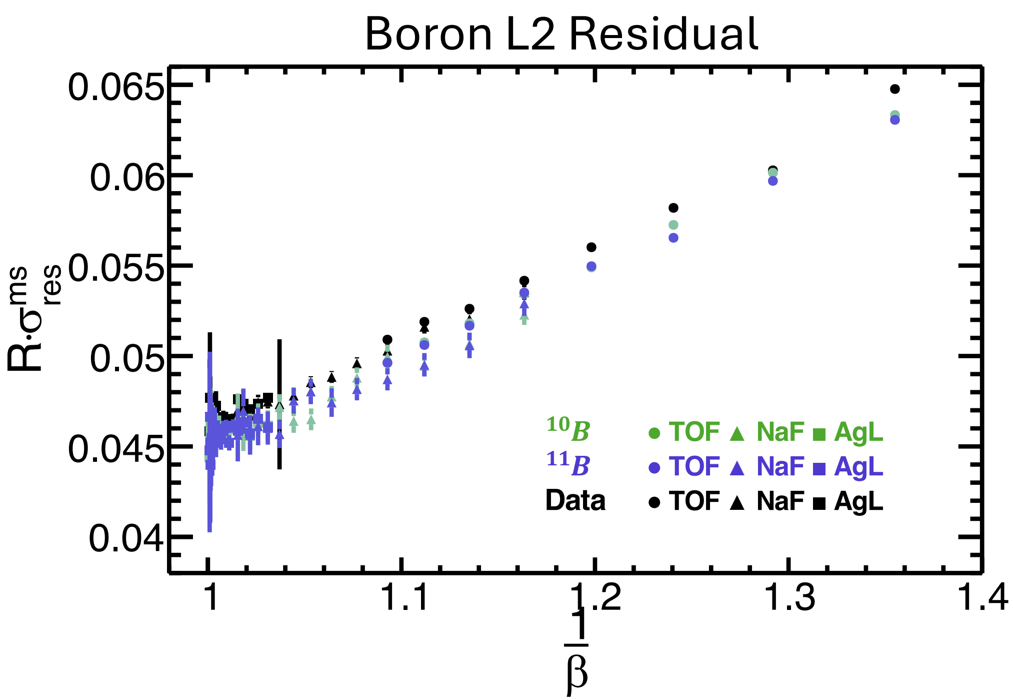
For Lithium and Beryllium, L2 residuals show agreements between MC and Data.

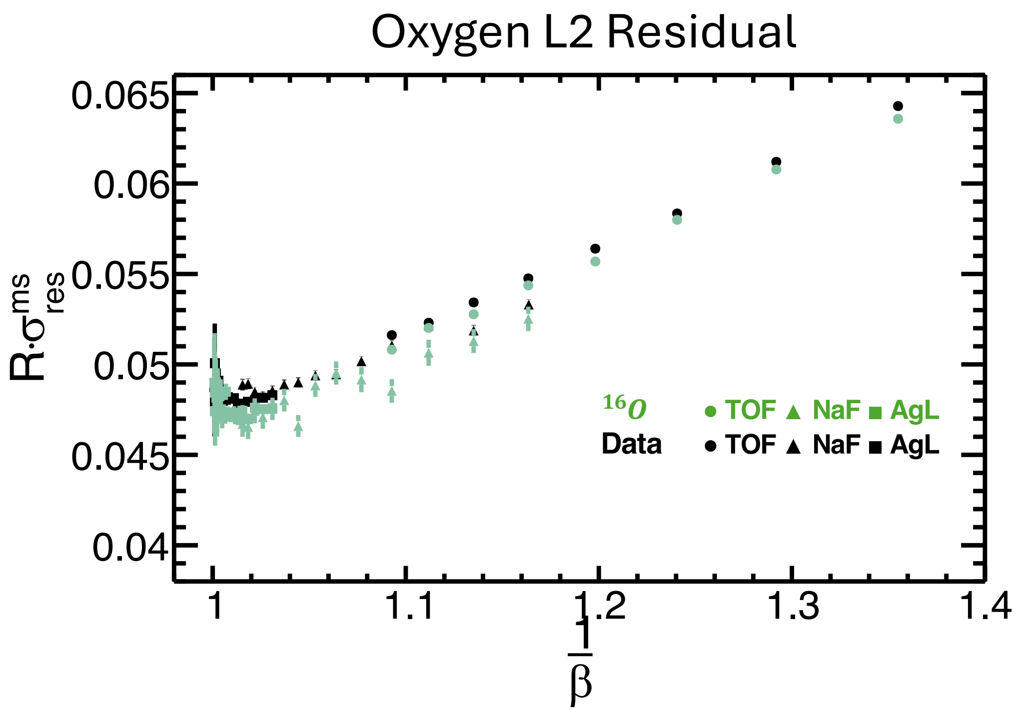




Cross Check of R smearing
Spatial Residual of L2 (B ,O)

For Boron and oxygen, the MC/Data discrepancies are more significiant .

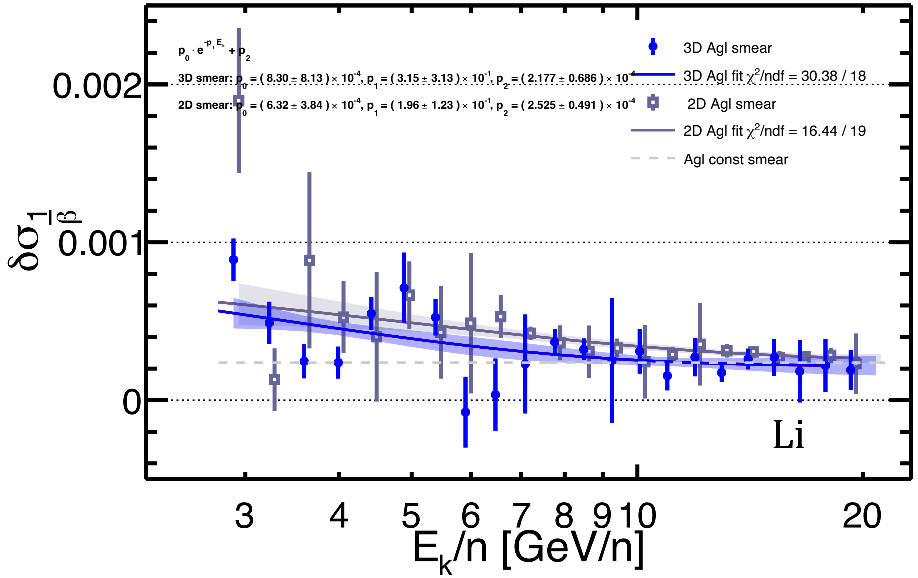


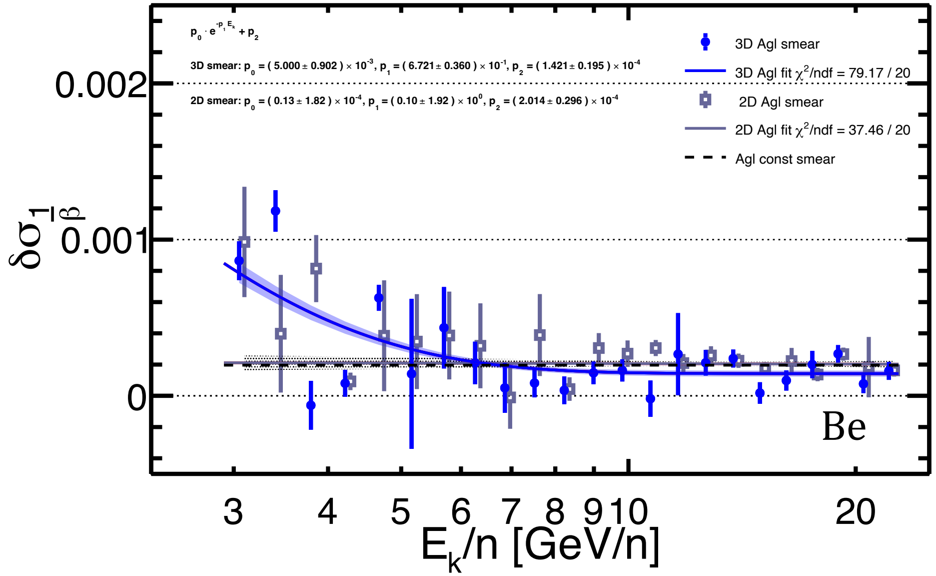


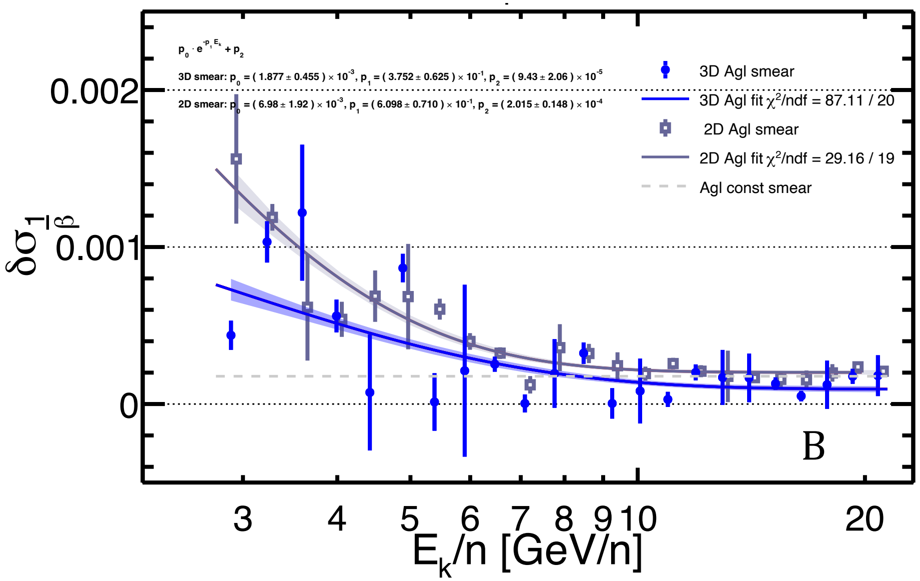
2 $1/\beta_{AgL}$ Smear for Li, Be, B and O

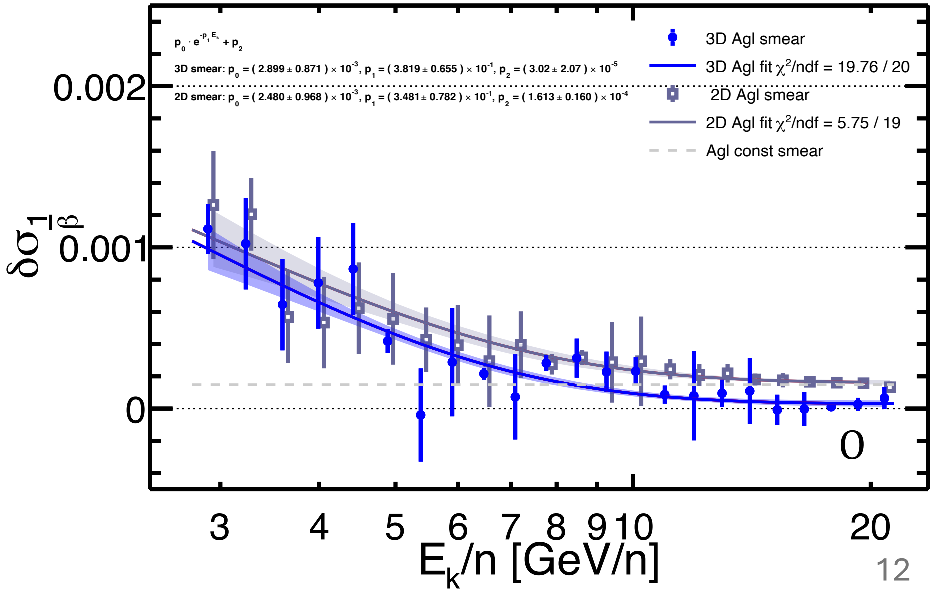
$1/\beta_{AgL}$ smears obtained by TMinimizer have difference from the α method at low energies

Fit with $p_0 \cdot e^{-p_1 E_k} + p_2$

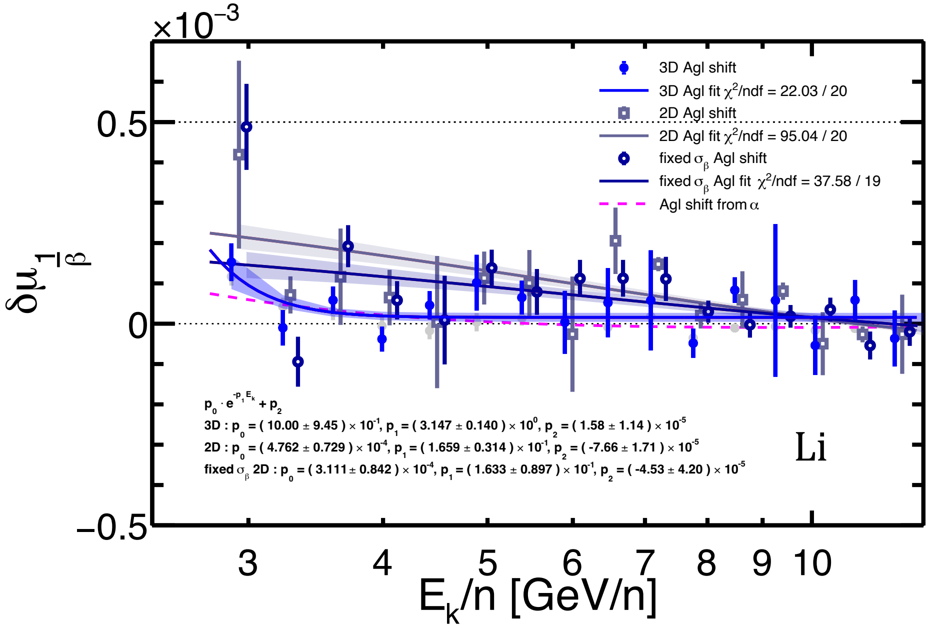


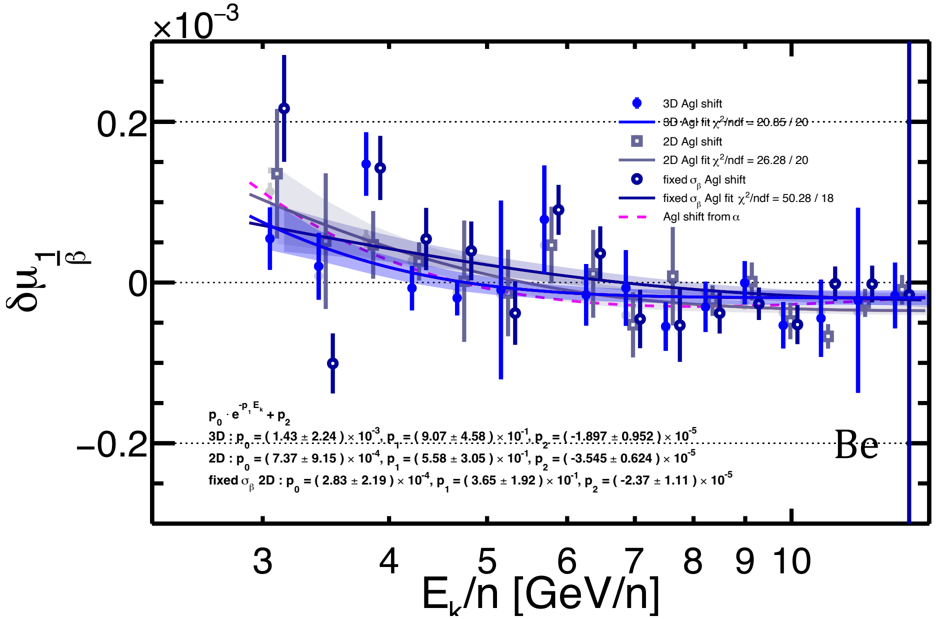


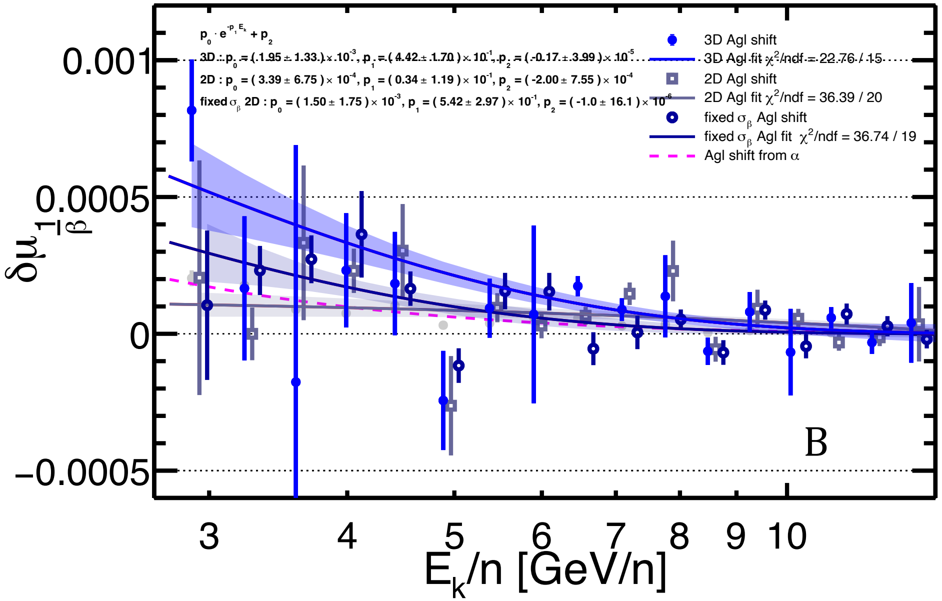


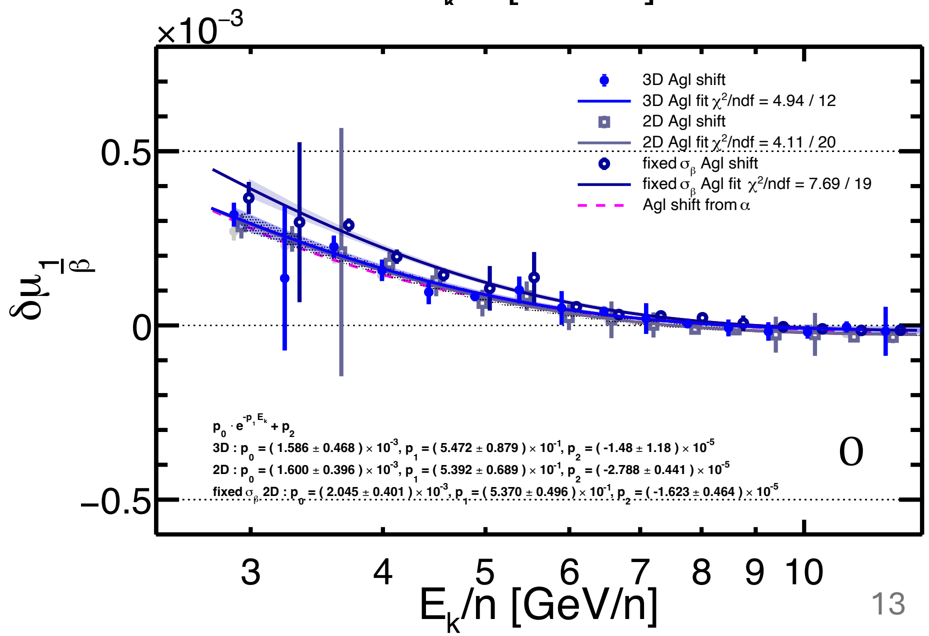


2 $1/\beta_{AgL}$ Shift for Li, Be, B and O





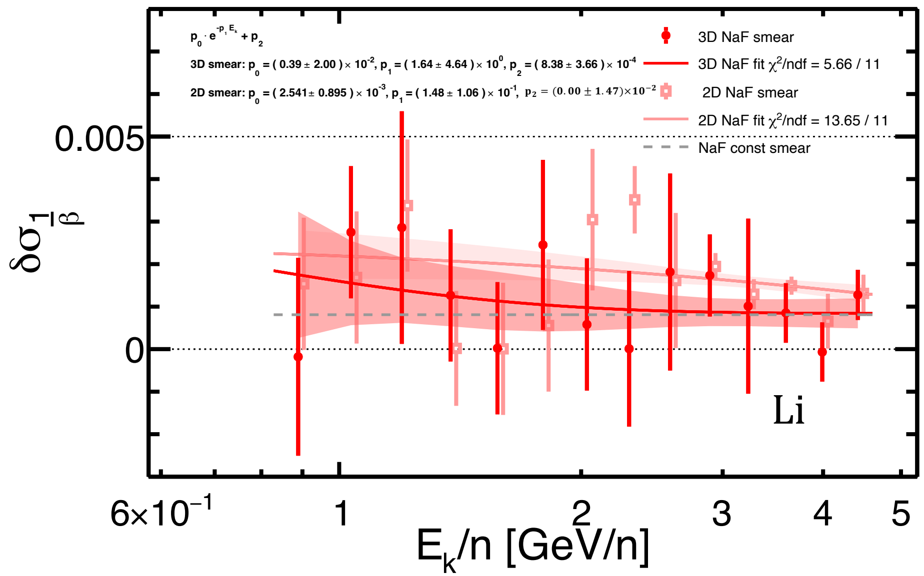


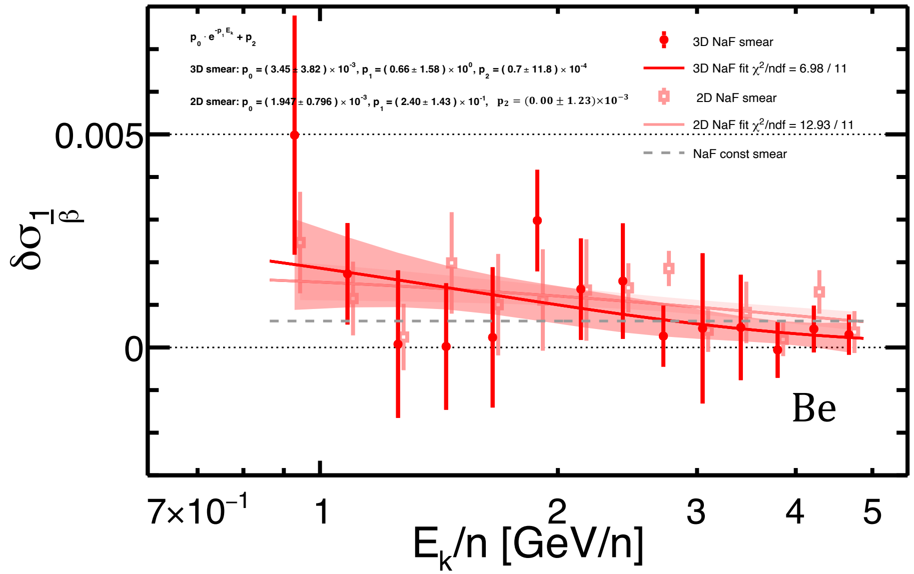


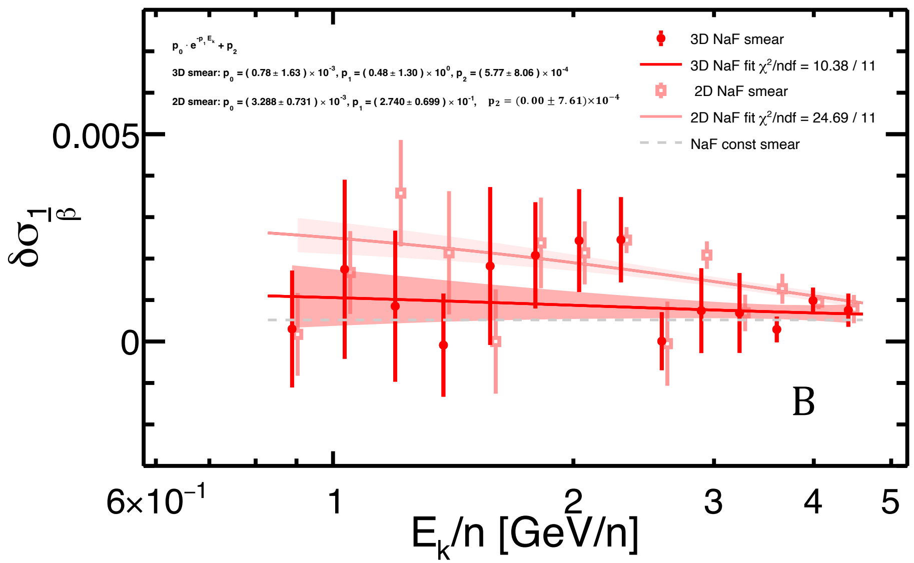
2 $1/\beta_{NaF}$ smear for Li, Be, B and O

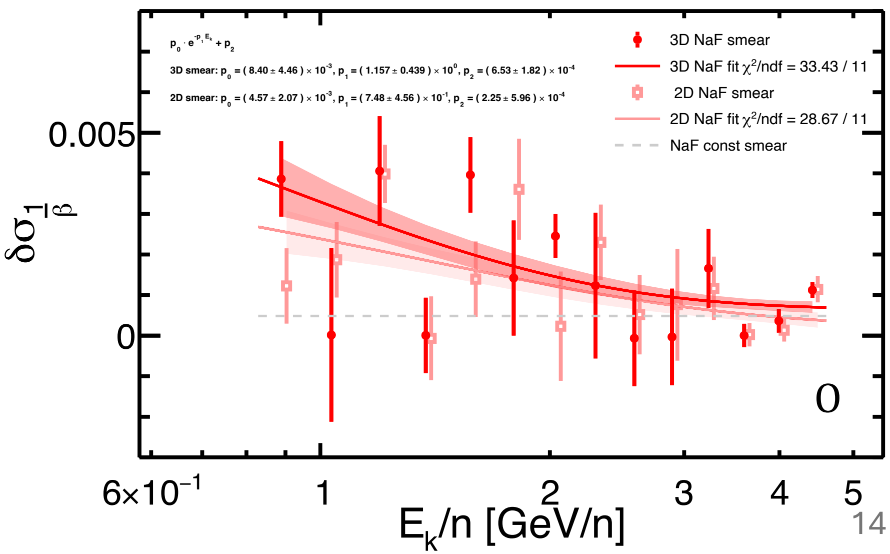
$1/\beta_{NaF}$ smears obtained by TMinimizer have difference from the α method at lower energies

Fit with $p_0 \cdot e^{-p_1 E_k} + p_2$









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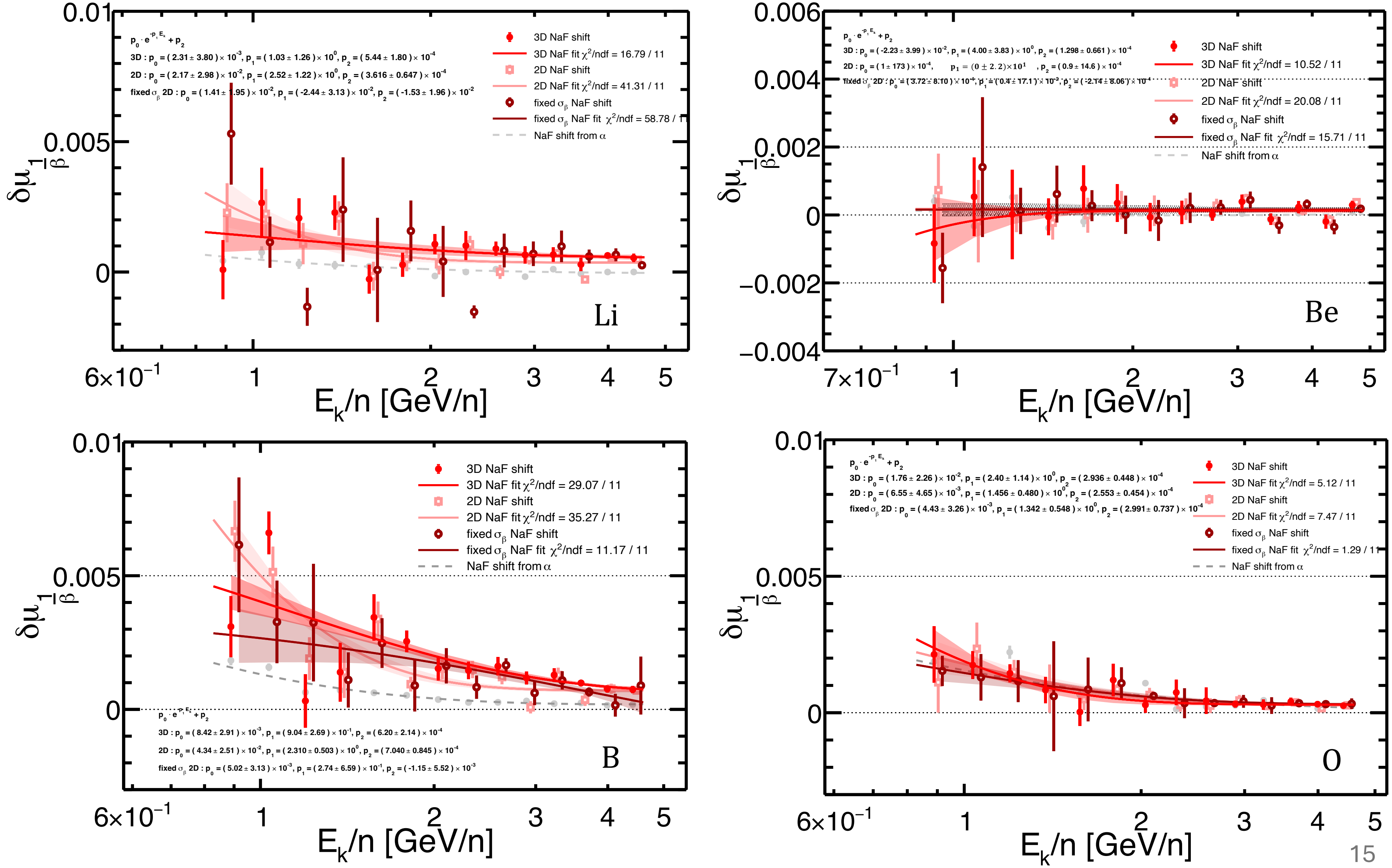
$1/\beta_{NaF}$ Shift for Li, Be, B and O

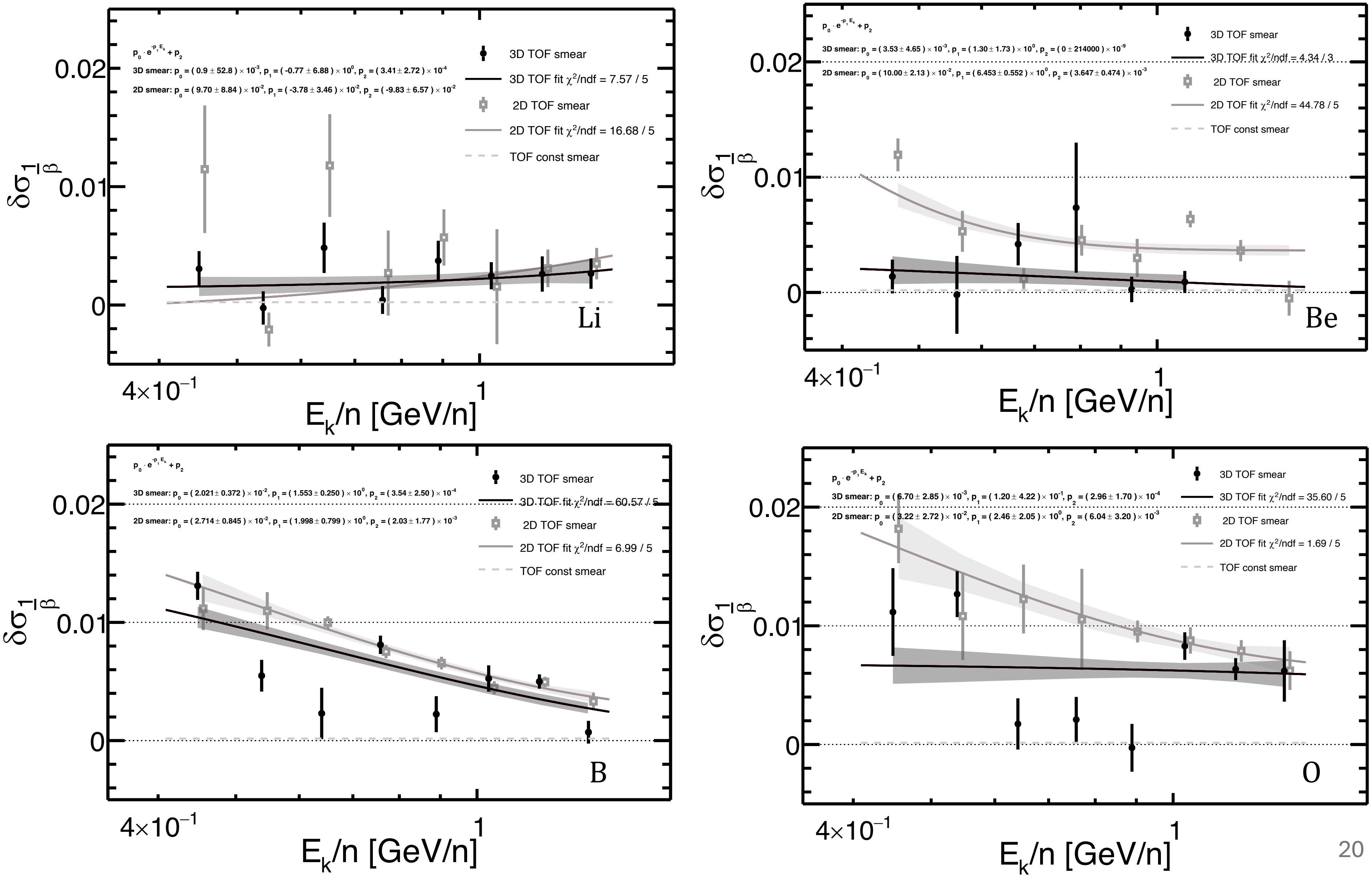
$1/\beta_{NaF}$ shifts results are still beyond understanding...

Fit with $p_0 \cdot e^{-p_1 E_k} + p_2$



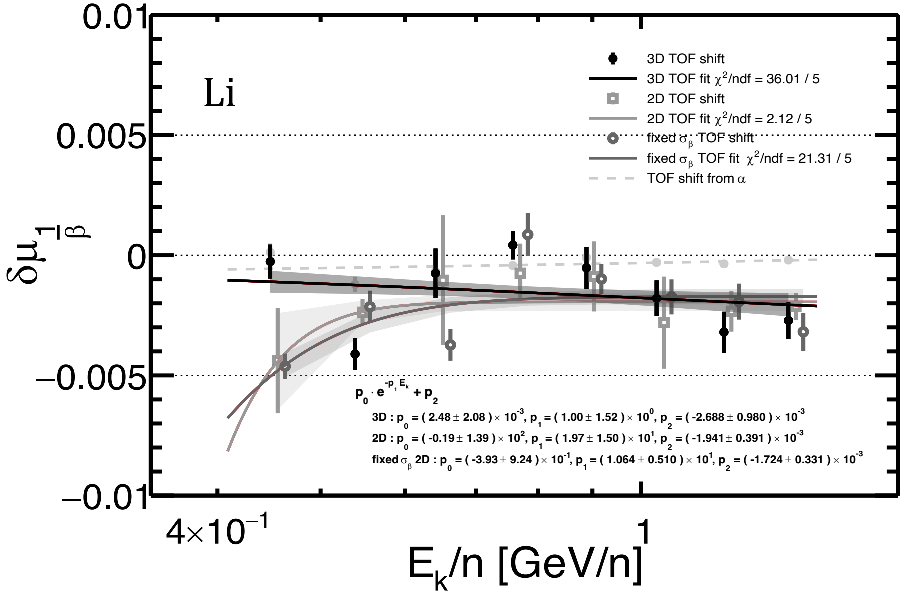
3 1/ β_{ToF} Smear for Li, Be, B and O

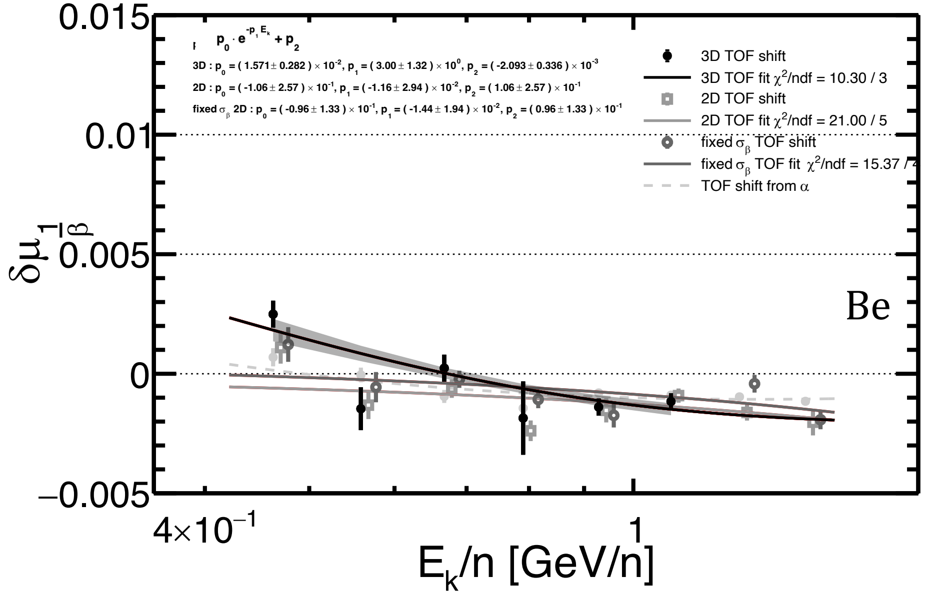
Fit with $p_0 \cdot e^{-p_1 E_k} + p_2$

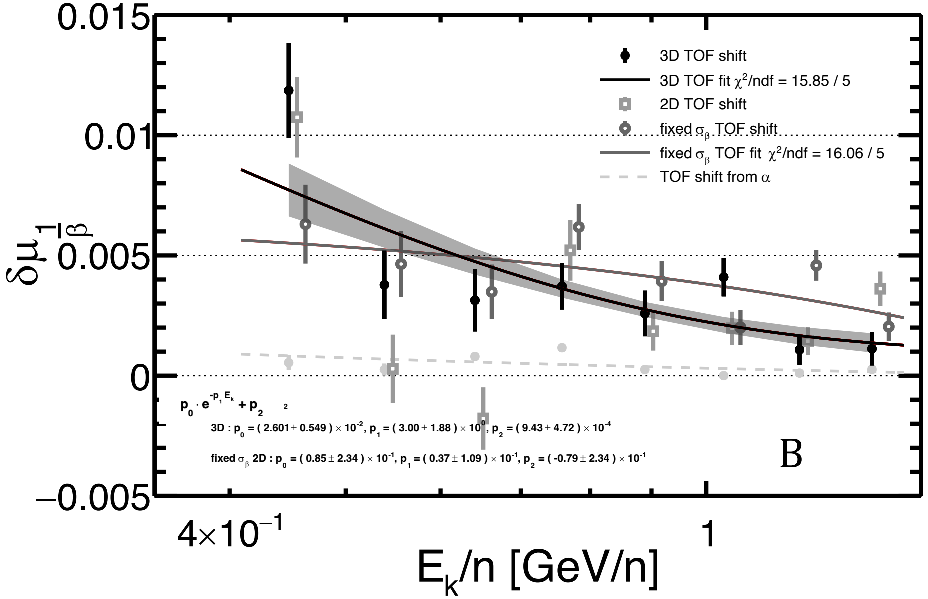


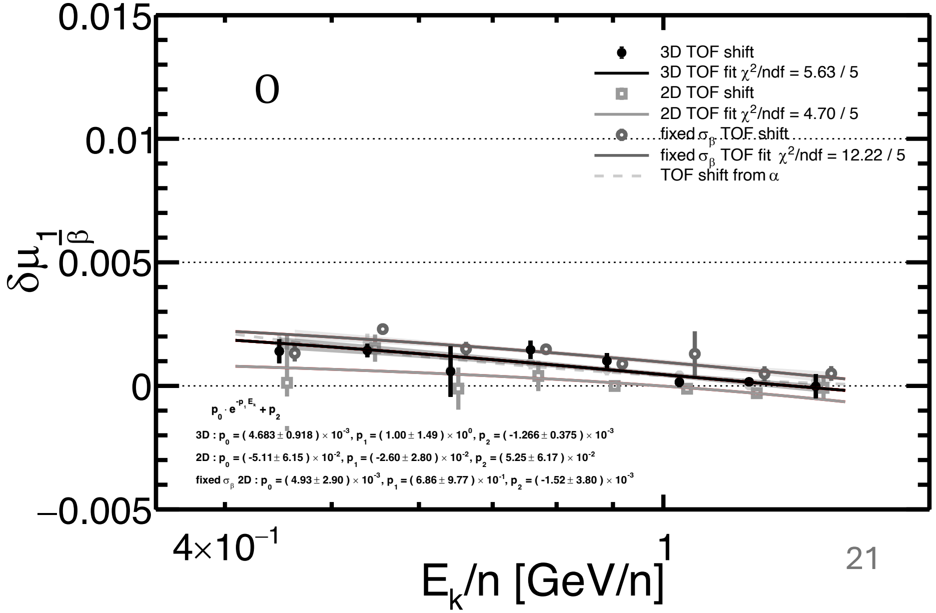
3 $1/\beta_{ToF}$ Smear for Li, Be, B and O

Fit with $p_0 \cdot e^{-p_1 E_k} + p_2$





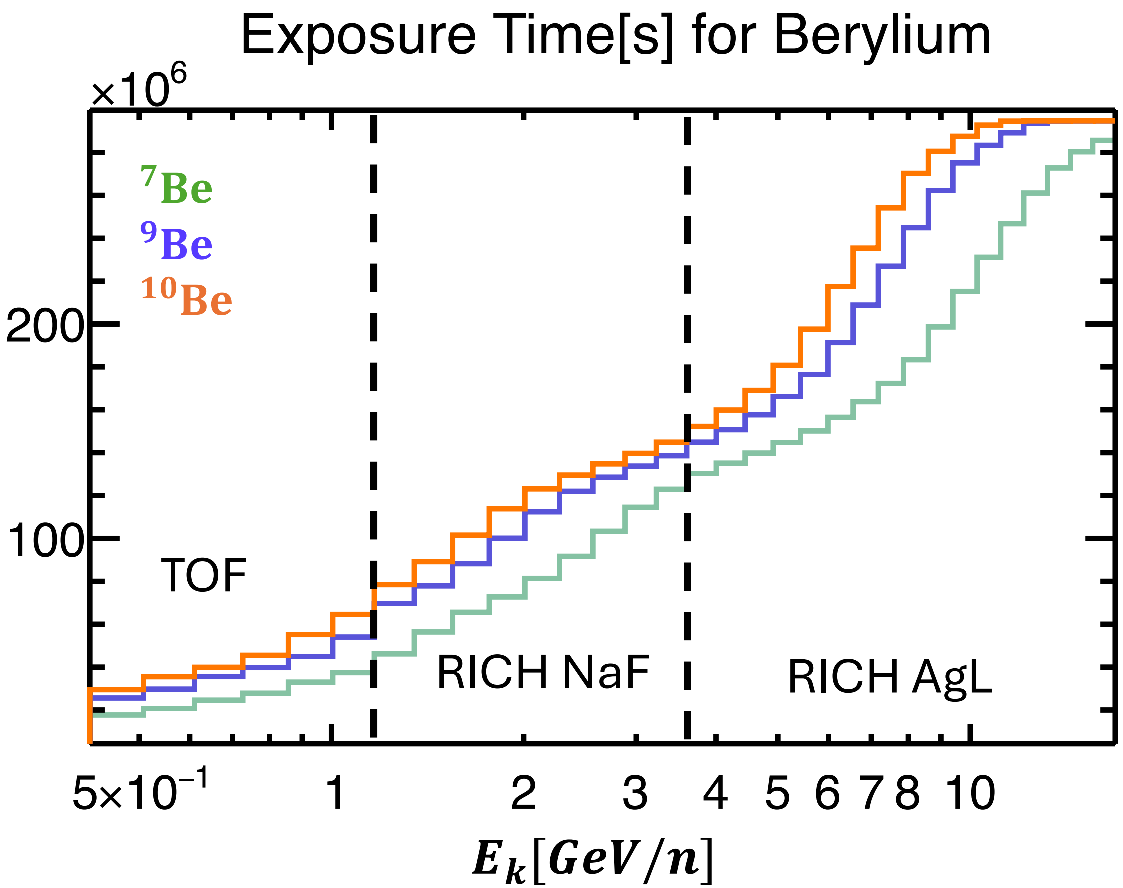


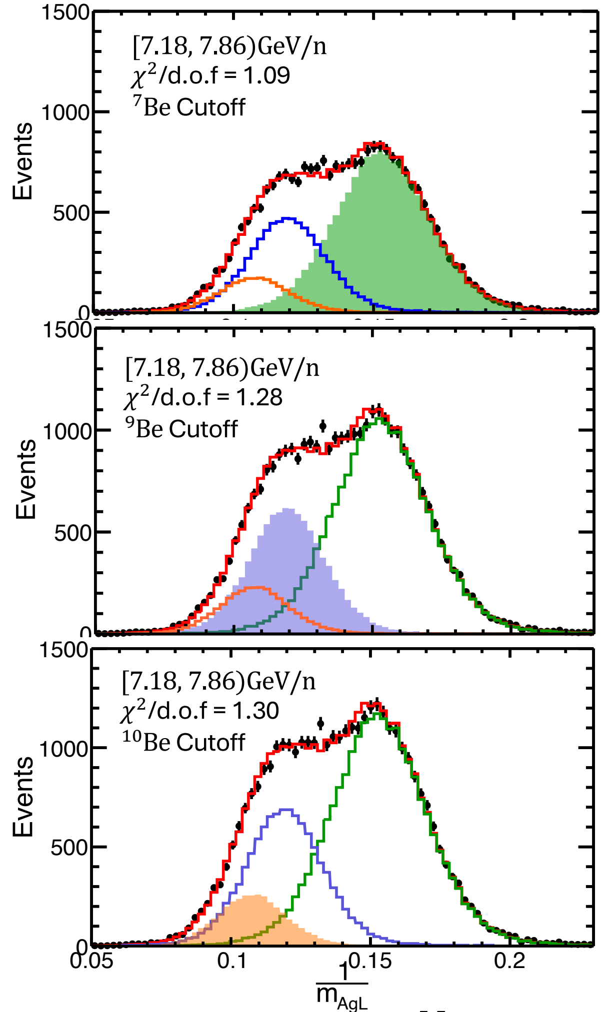


3 Enhance Statistical Precision in Isotopic Fraction Measurements

The fraction of $^{10}\mathrm{Be}$ has significant statistical erros. We can make use of different isotopic cutsoff to increase the statistics.

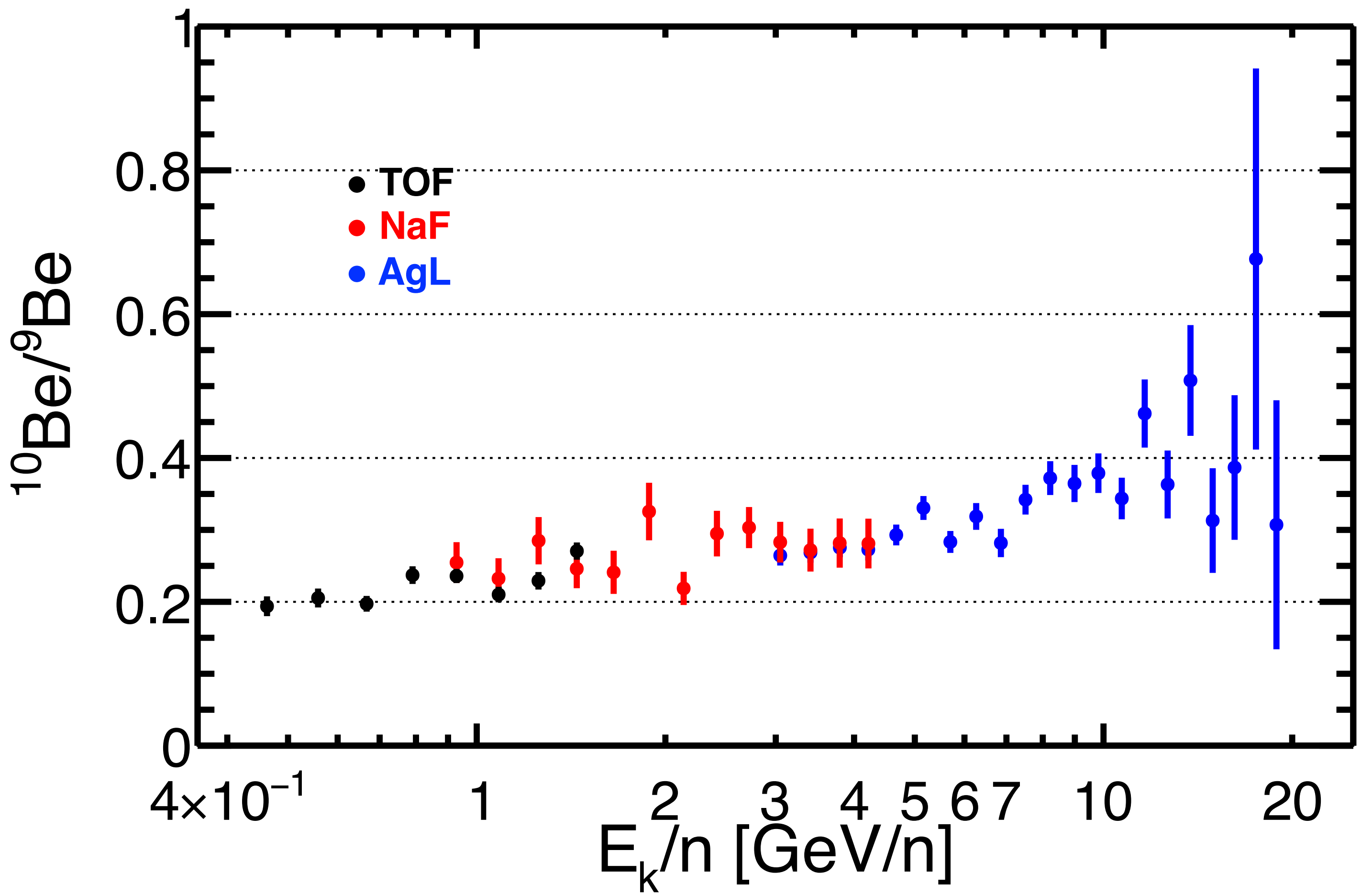
$$\beta_{co}(m_i) = \frac{f \cdot R_{co} \cdot Z}{\sqrt{R_{co}^2 \cdot Z^2 + m_i^2}}$$





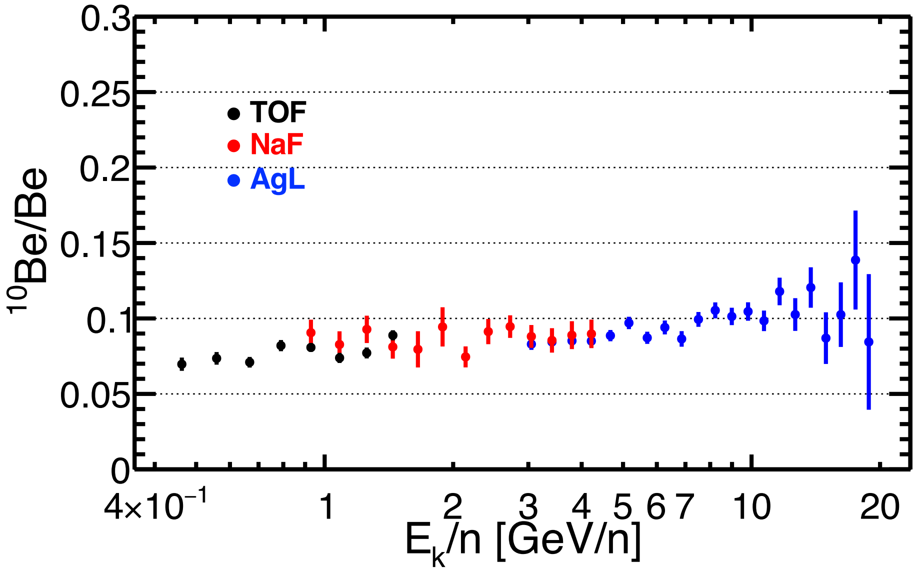
$$N_i = \frac{t_0}{t_i} \cdot n_i, \qquad f_i = \frac{N_i}{\sum N_j}$$

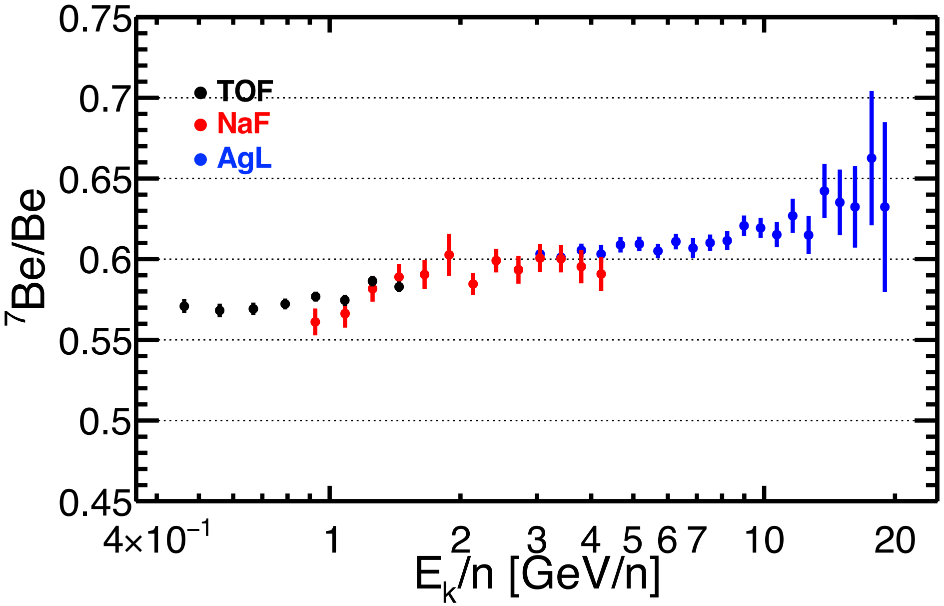
3 Enhance Statistical Precision in Isotopic Fraction Measurements Be

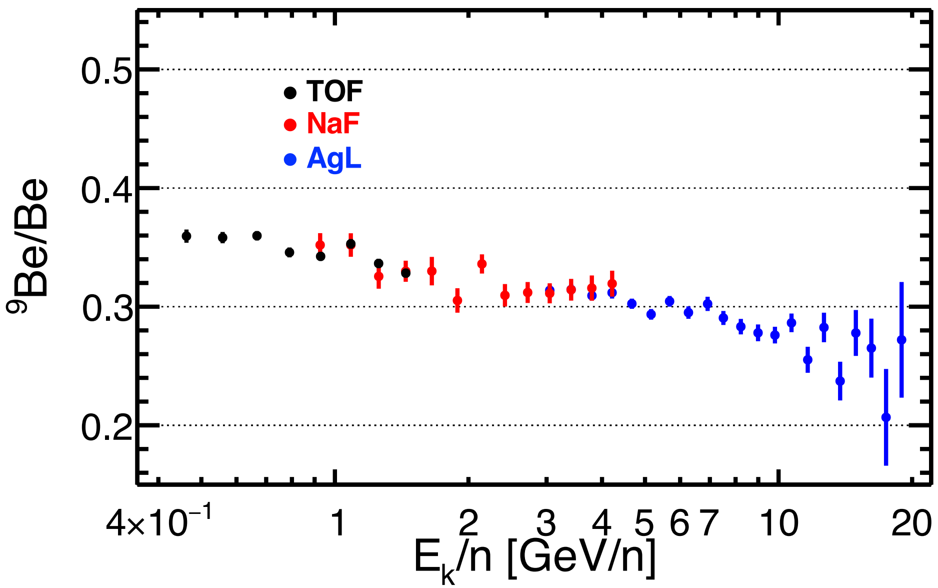


3 Enhance Statistical Precision in Isotopic Fraction Measurements Be

^{10}Be by 3D minimizer Tuning







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Summary and Plans

1. Use minimum χ^2 to study the discrepancies from Data/MC, for $1/\beta$:
    - Smear at lower energies is larger than the value from high energies.
    - Shifts value are still beyond understanding, especially for 2-isotope fitting.
2. A potential rigidity discrepancy $\delta\sigma_R/R\sim 10^{-2}$. the results still need valid verification.

The results still need valid verification from detectors.

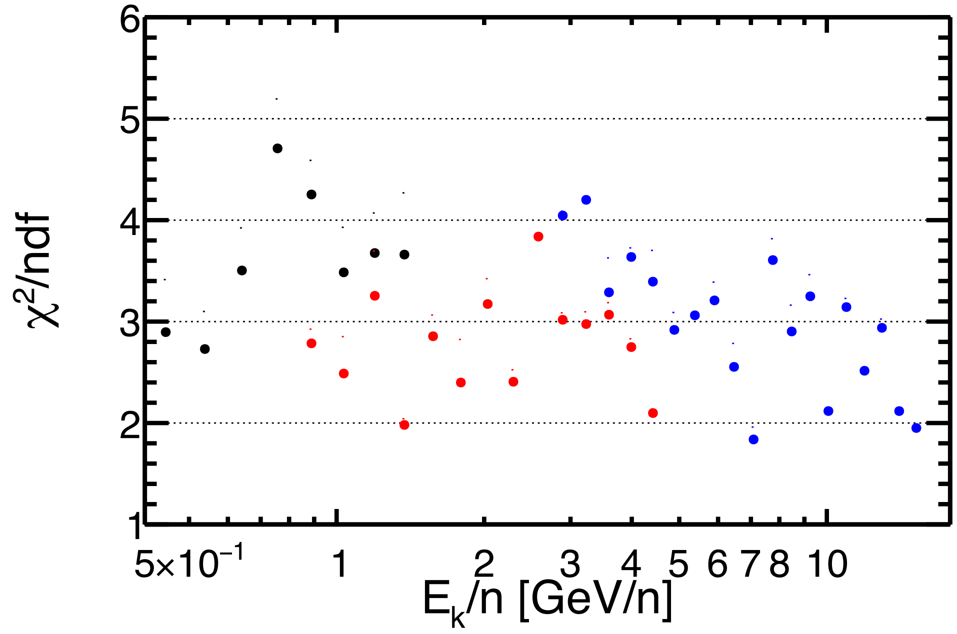
Backup

3 Use the Scan Method with Boron and Oxygen

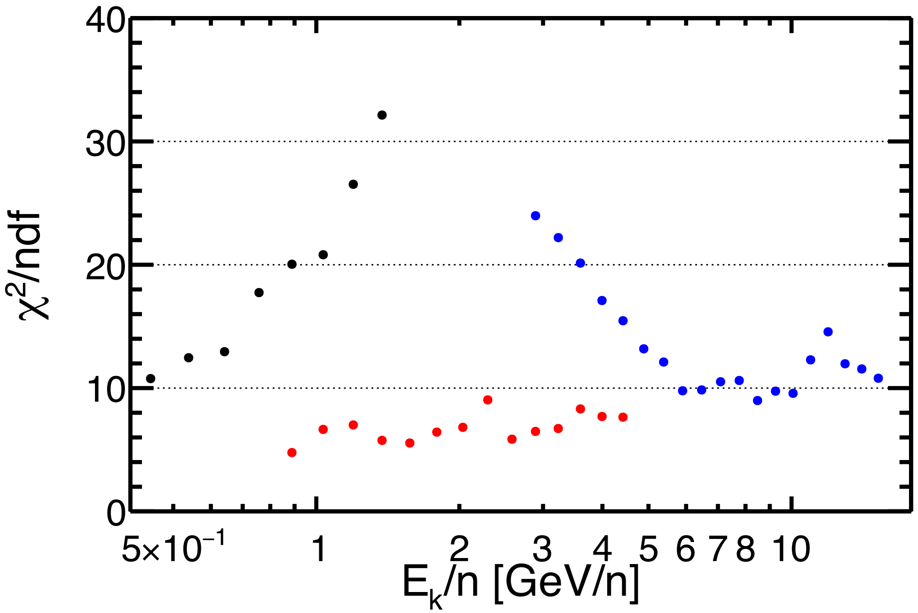
For Boron and Oxygen, the 2D quadratic function fitting is not satisfactory:

- The χ^2 /ndf value aren't close to 1. B~3, O~10 (only ^{16}O template)
- Difficult to do 2D-fitting across the wider scanning range.
- There is a potential contribution from rigidity.

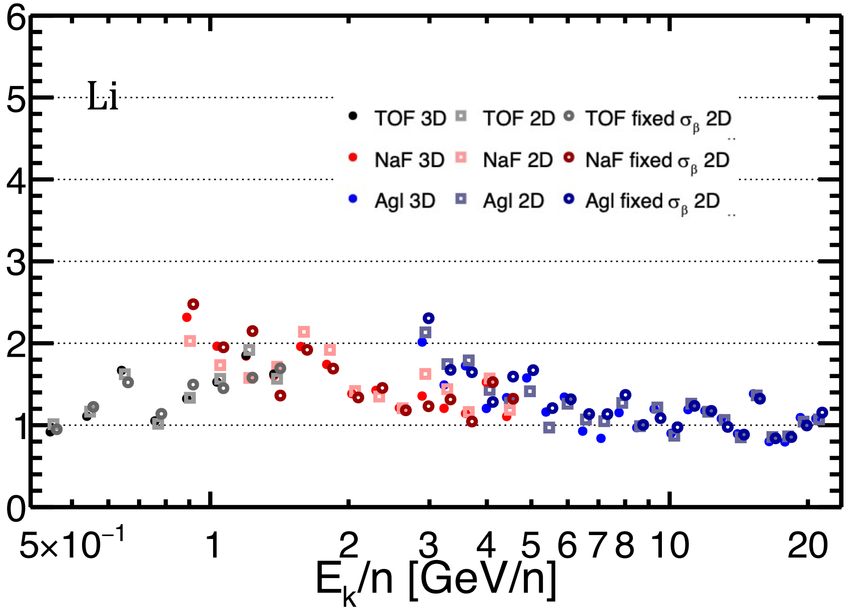
Boron massfit χ^2 (no tune)

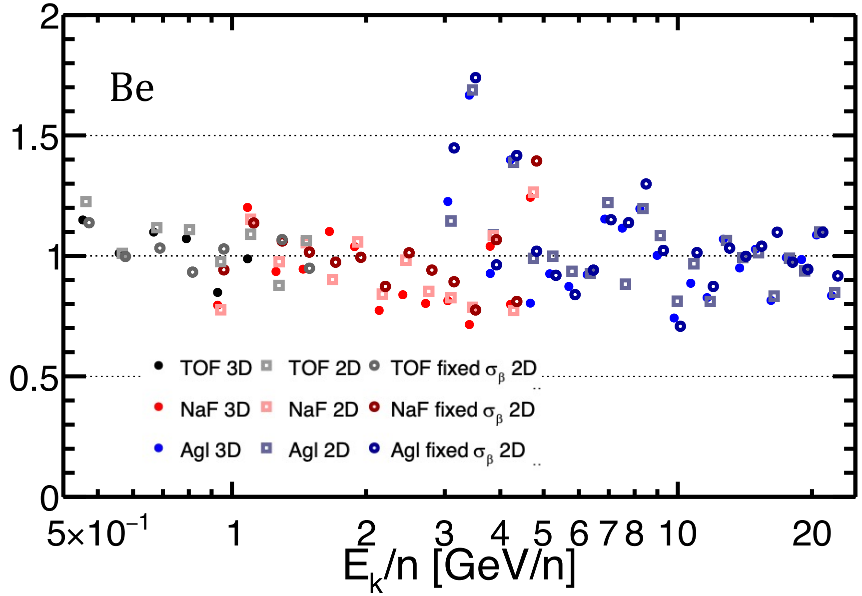


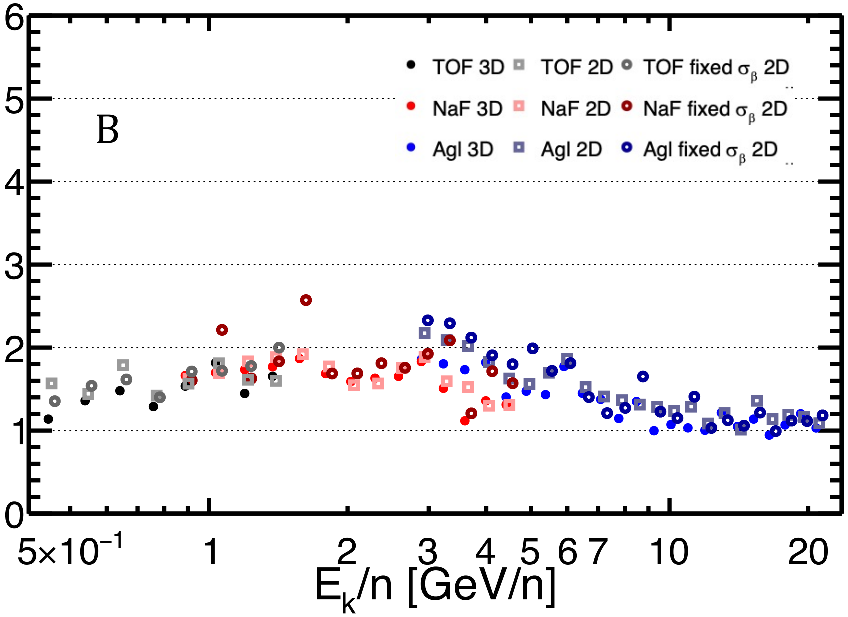
Oxygen massfit χ^2 (no tune)

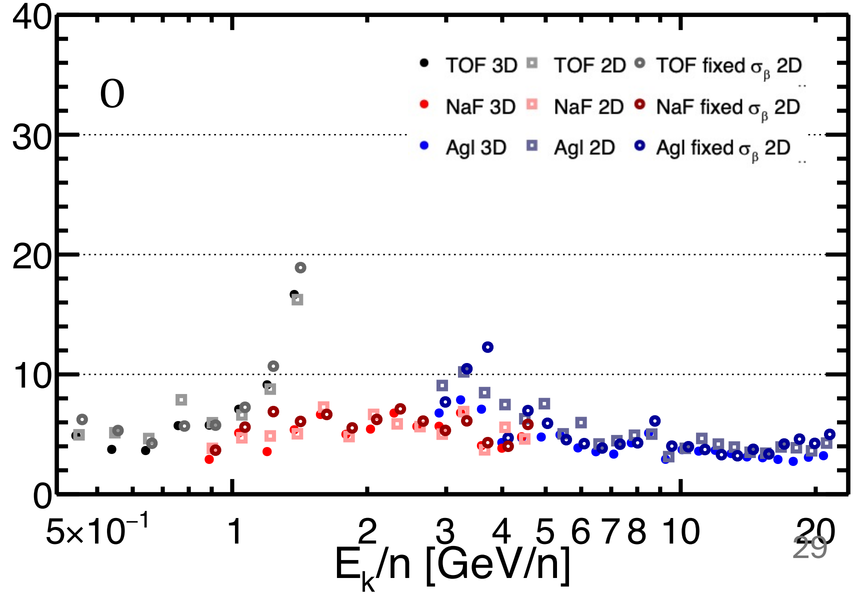


3 Minimum χ^2 of for Li, Be, B and O



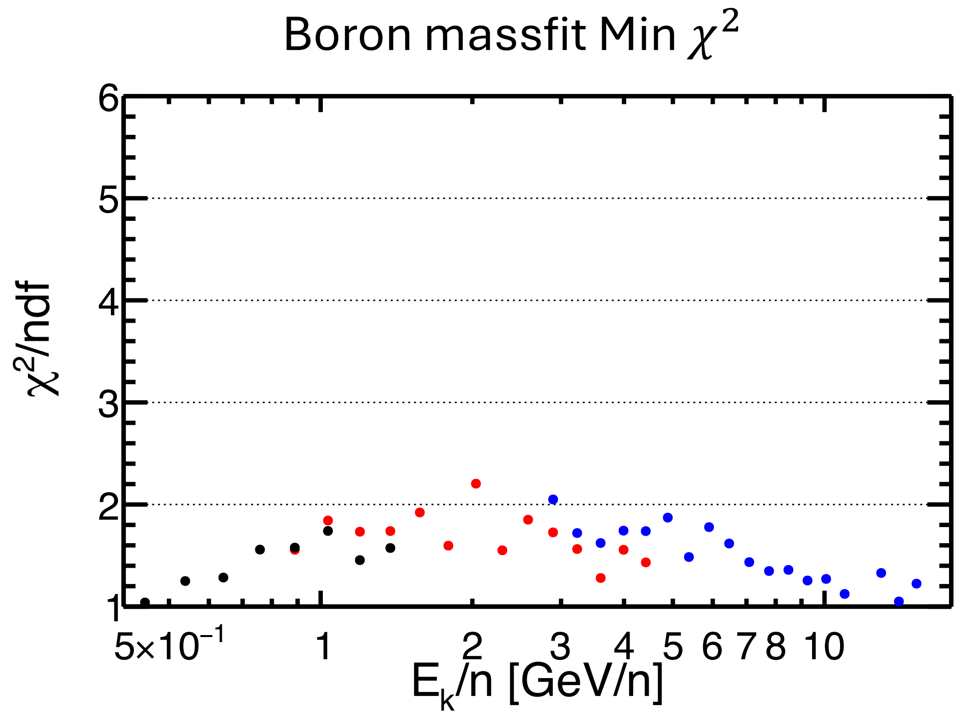


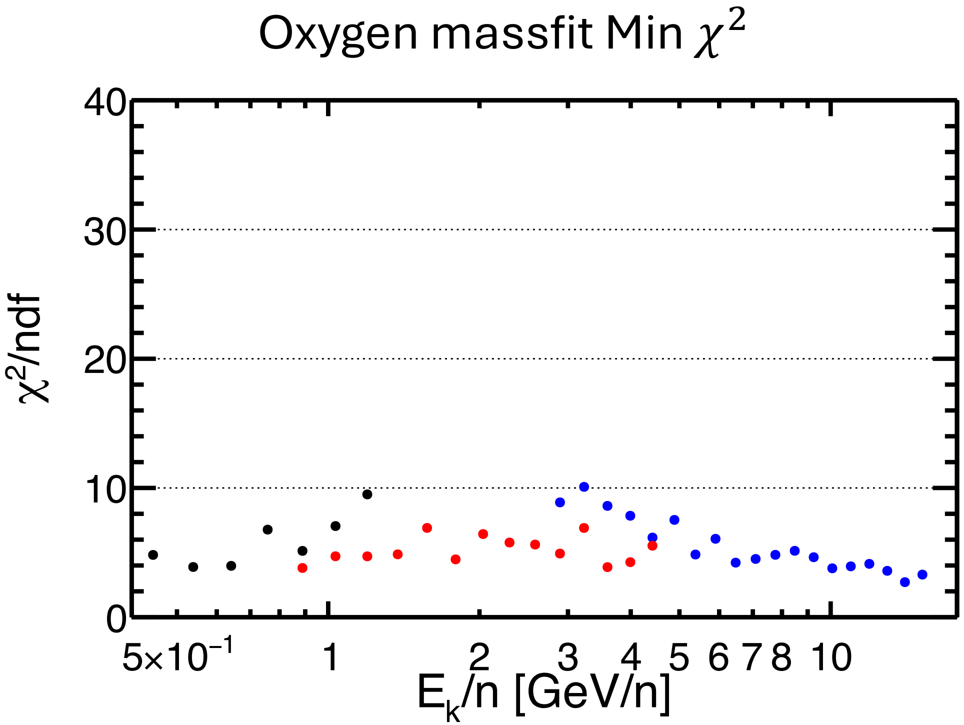




3 Reference: Minimum χ^2

The minimum found in the parameter space by TMinimizer is significantly smaller than the original value.





2

Method Correction

For the traditional beta shift method:

$$\left(\frac{1}{M}\right)' = \alpha \cdot \left(\frac{1}{M}\right), \beta' = \frac{\alpha\beta}{\sqrt{1-\beta^2+\alpha^2\beta^2}}$$

If the shift is applied solely to β, it will also alter the rigidity distribution within each bin, consequently changing the mass template.

Apply shift and smear to the events, fill the bins accordingly, and perform a template fit in each bin.

3 Towards understanding of R smearing

The resolution of rigidity can presented by:

$$\sigma_{1/R} = \sqrt{\sigma_{IN}^2 + \sigma_{MS}^2}$$

At high energies, the resolution is dominated by the intrinsic spatial resolution, where data and MC are in good agreement.
At low energies, the discrepancy between data and MC is likely due to multiple scattering effects:

$$\frac{\sigma_R^{MS}}{R} = \frac{\theta_{MS}^{plane}}{\theta_B} \sim \frac{0.0136}{0.3\beta \cdot B[\mathrm{T}]L[\mathrm{m}]} \cdot \sqrt{\frac{x}{X_0}} \cdot [1 + 0.038\ln(\frac{x}{X_0})]$$

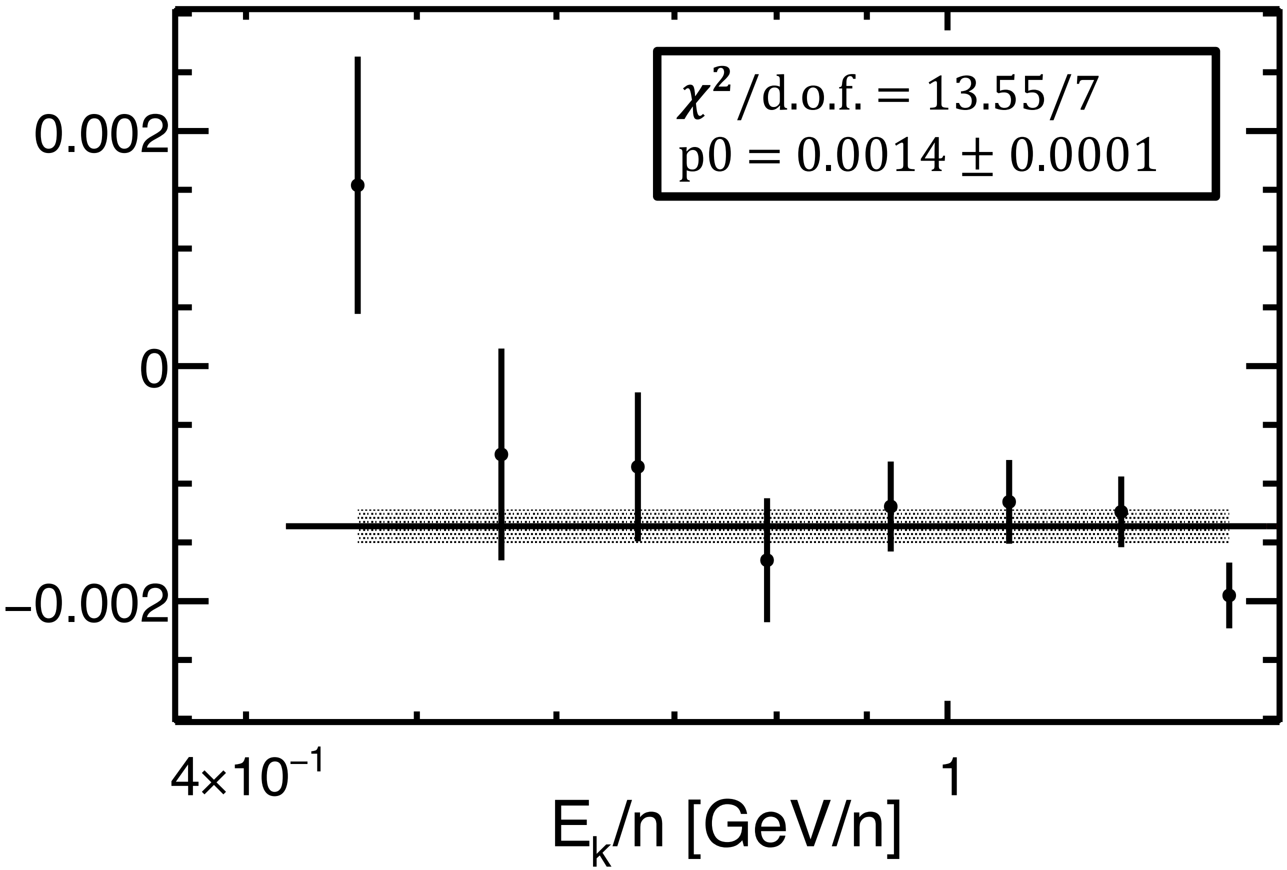
If Data/MC discrepancy comes from multiple scattering, the smearing value should be:

$$\frac{\sigma_R^{Data/MC}}{R} \sim f(\frac{1}{\beta})$$

1 Check of Position of TOF Layers

If the ISS/MC discripency is from discripency in layers z-position. The shift value can use to estimate the z-coordinate discripency.
Inspired by Y.Chen's pre, this method offers a potential cross-check at low energies.

Relative Shift $r = \mu_{\frac{1}{\beta'} - \frac{1}{\beta}} / \frac{1}{\beta}$



$$\Delta d = \frac{1}{\frac{1}{r} + 1} \times 127.30\ cm$$

r is the fit from this plots. 127.30 cm.is the z-distance from Low-TOF to Up-TOF.

$$\boldsymbol{\Delta d = (-0.18 \pm 0.02) cm}$$

1 Data Base & Events Counts

ISS B1236 pass8(12.5 years) MC B1308 pass8

Track Cuts

Standard cuts

- good RTI & good run & Physical trigger
- Above geometry IGRF cutoff

Tracker

- Within L1Inner Fiducial volume
- L1XY & N_InnerHitsY>=5&L2&(L3IL4)&(L5IL6)&(L7IL8)& InnerNormChisY<10
- charge:
  q_inner ∈ [3.55, 4.45]
  qL1(unbias) ∈ [3.38, 4.65]
  good qL1 status

BG reduction

- 1 track II no good 2nd track II rigidity2nd<0.5GV

TOF

- beta > 0.4
- charge: q_uptof ∈ [3.4, 5.5]

Beta Reconstruction Cuts

TOF

- tof_beta > 0.4 & betah BuildType < 10
- coo_chis < 5 & time_chis < 10
- Not passing TOF edges
- q_lowtof ∈ [3.4, 5.5]

RICH general (pos correction accoding z)

- good status & clean
- Kolmogorov test probability > 0.01
- N_pmt > 2
- charge: q_rich ∈ [3, 6]

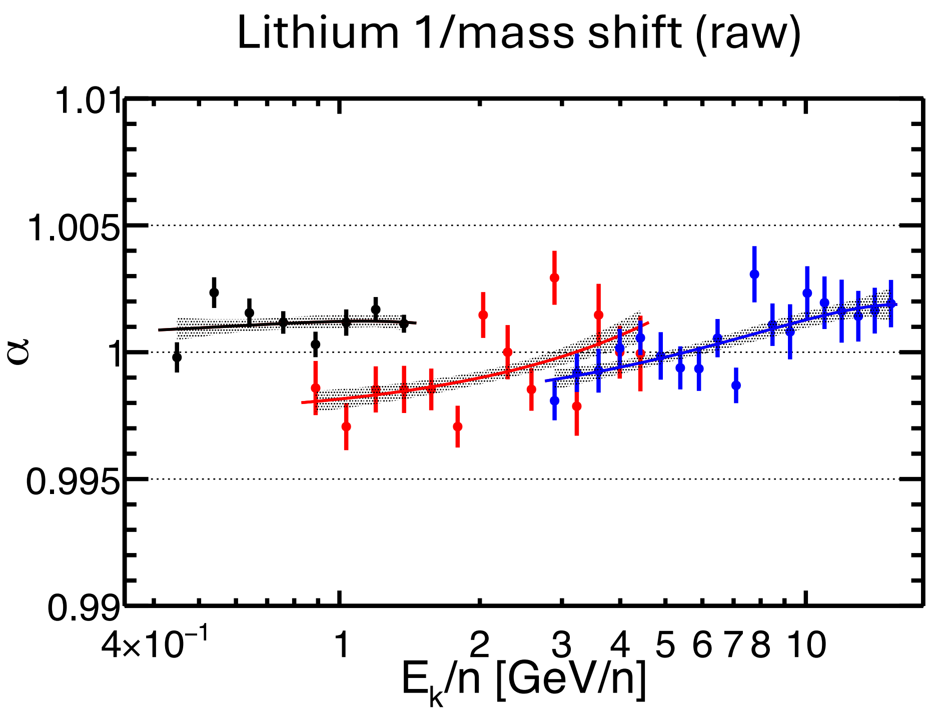
NaF

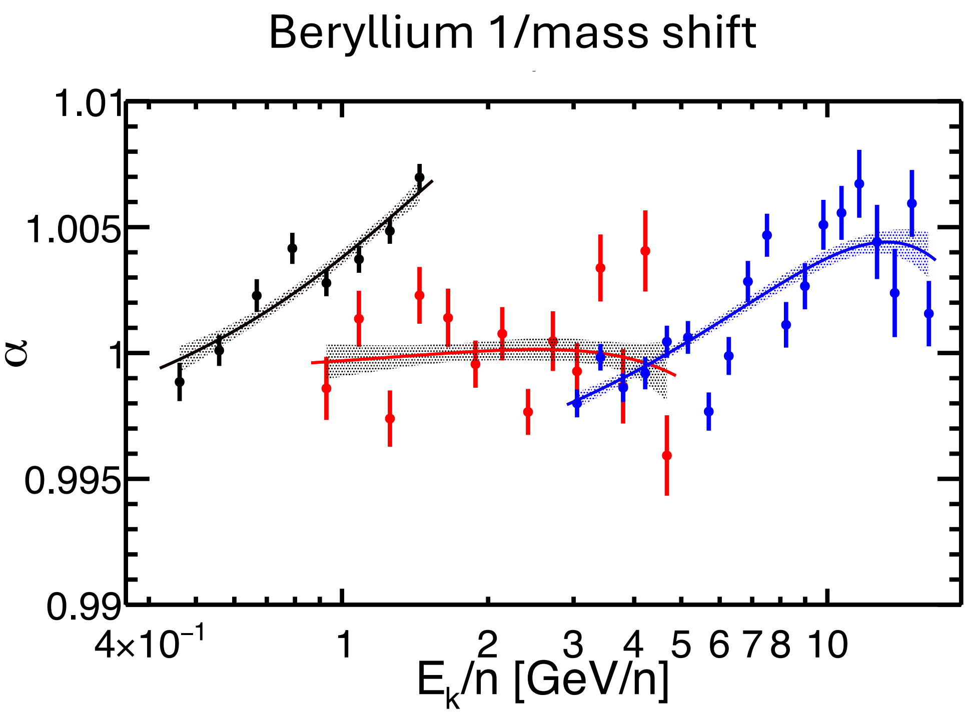
- Good NaF status Region
- N_pe(ring)/N_pe(total)>0.45

AgL

- Good Agl status Region & remove bad tiles&remove border
- N_pe(ring)/N_pe(total)>0.4

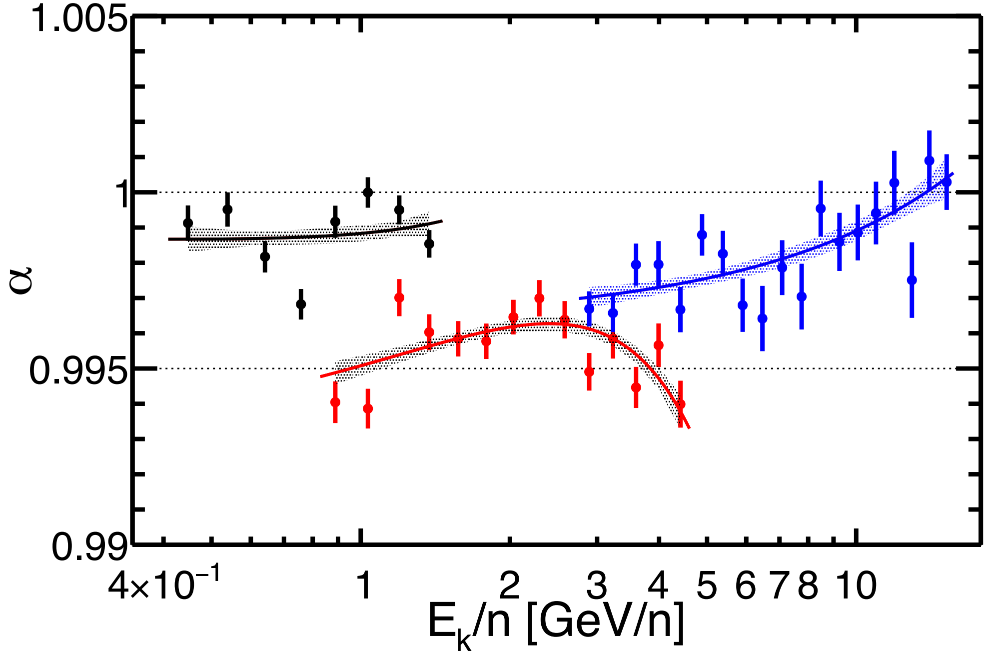
2 Lithium and Boron





2 Move to Boron and Oxygen

Boron 1/mass shift (raw)



Oxygen 1/mass shift (raw)