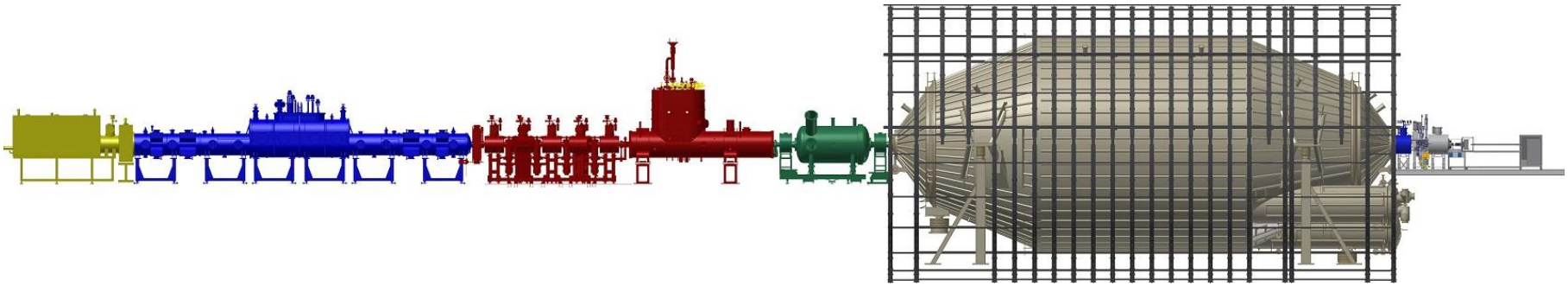
Karlsruhe Institute of Technology

Preliminary Krypton analysis from KNM1

Moritz Machatschek, KIT-ETP

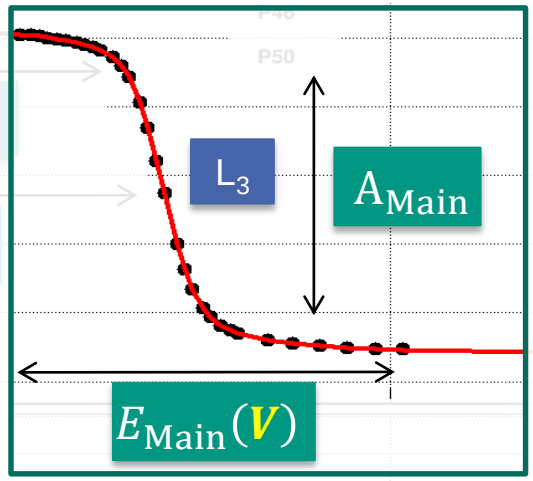


THE MEASURED SPECTRUM

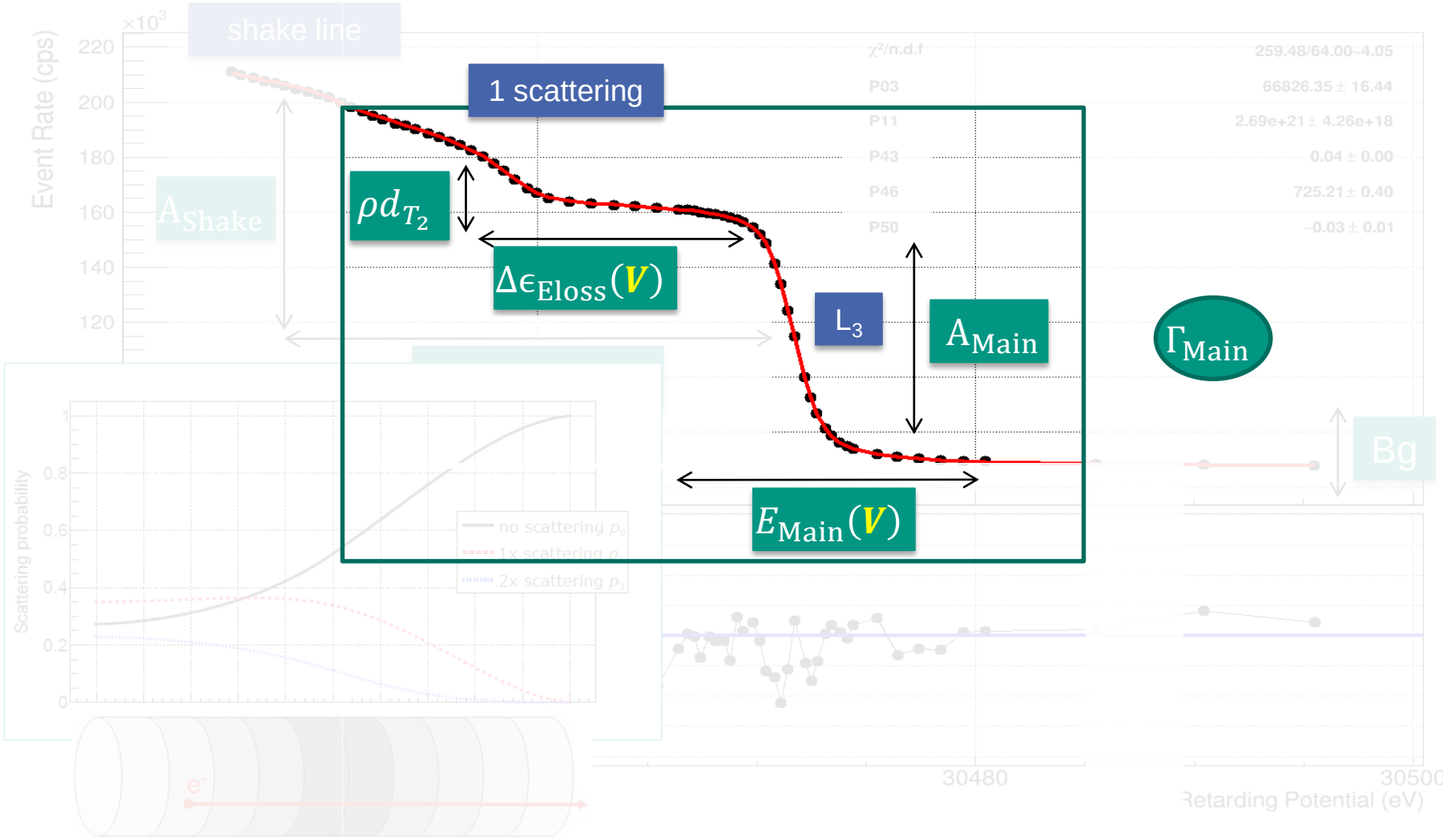
Requisite to understand the measurement principle and difficulties in the analysis.

Fitting of L_3-32 line

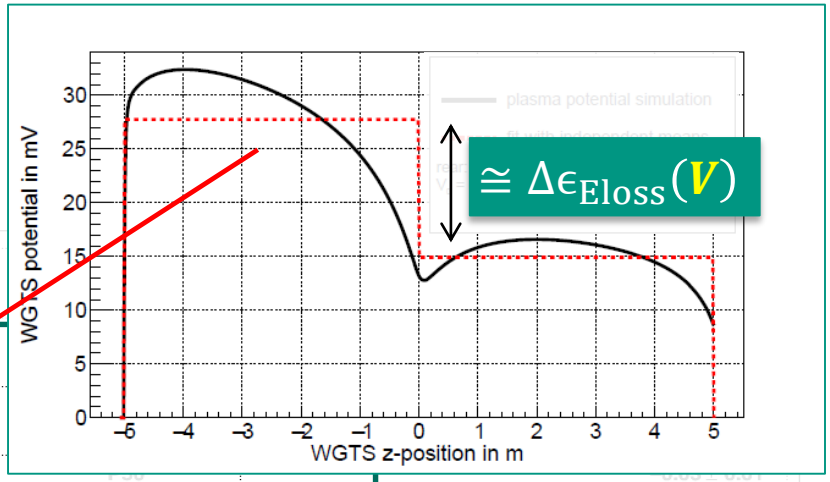
unknown plasma potential



Scattered electrons



z-sensitivity by scattering



shake line

A_{Shake}

1 scattering

ρd_{T_2}

$\Delta\epsilon_{\mathrm{Eloss}}(V)$

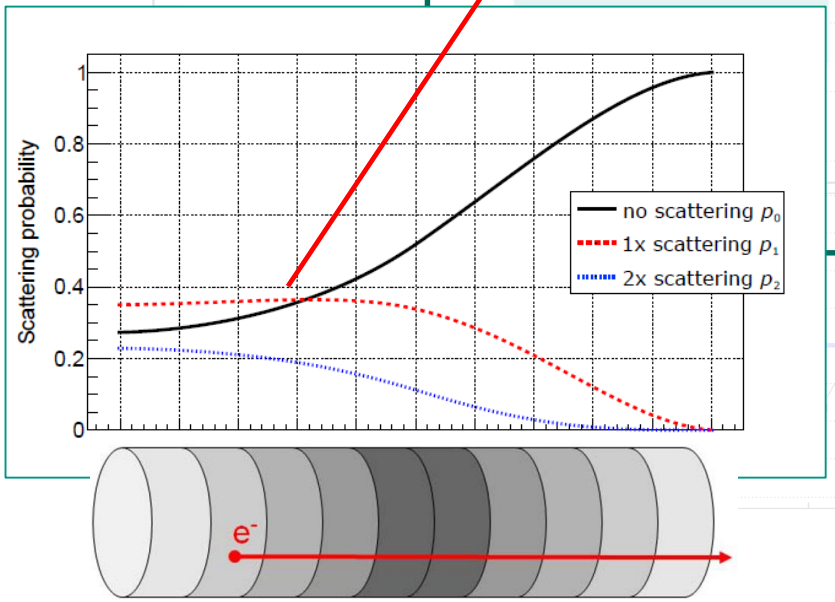
L_3

A_{Main}

Γ_{Main}

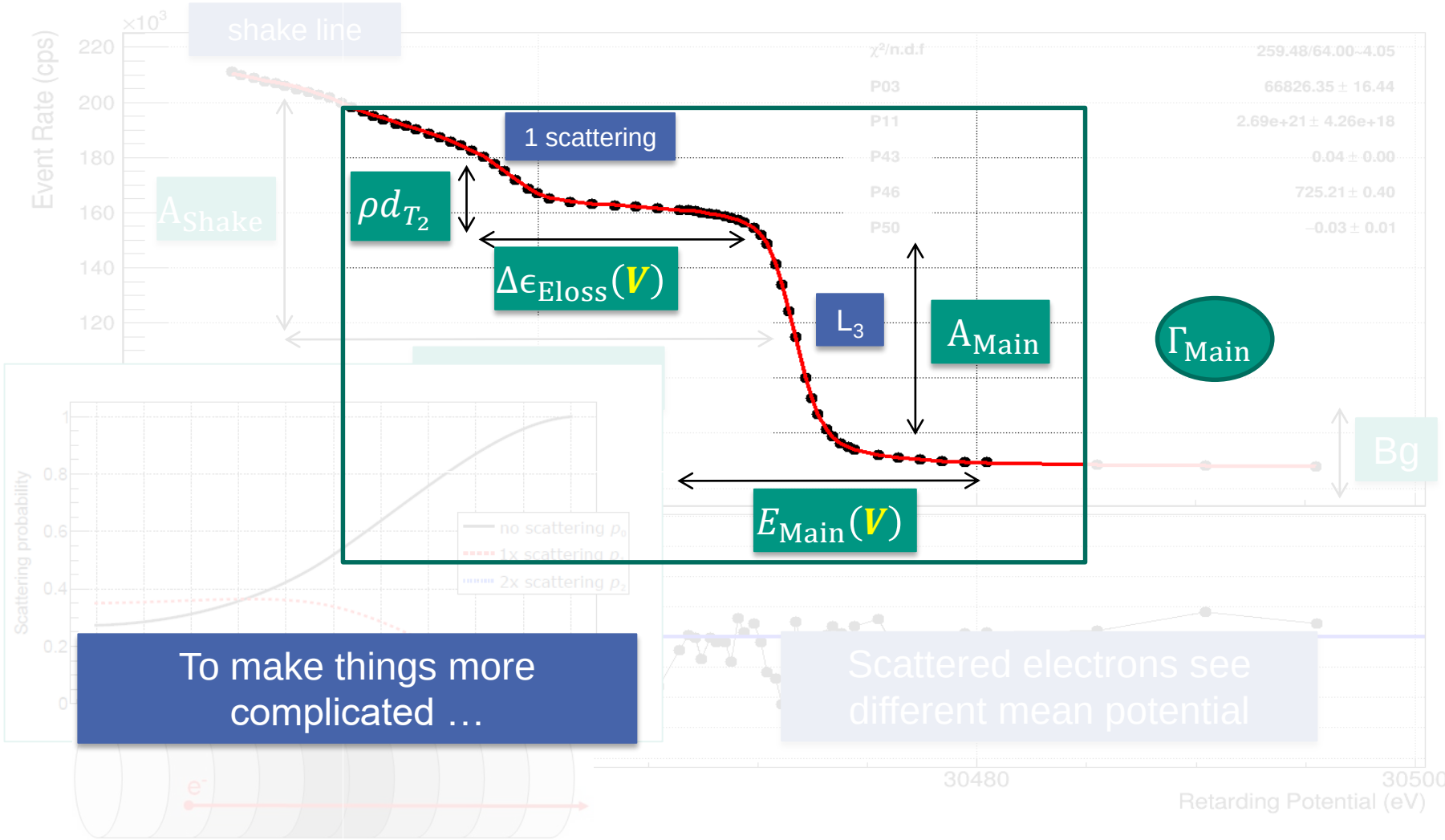
Bg

$E_{\mathrm{Main}}(V)$

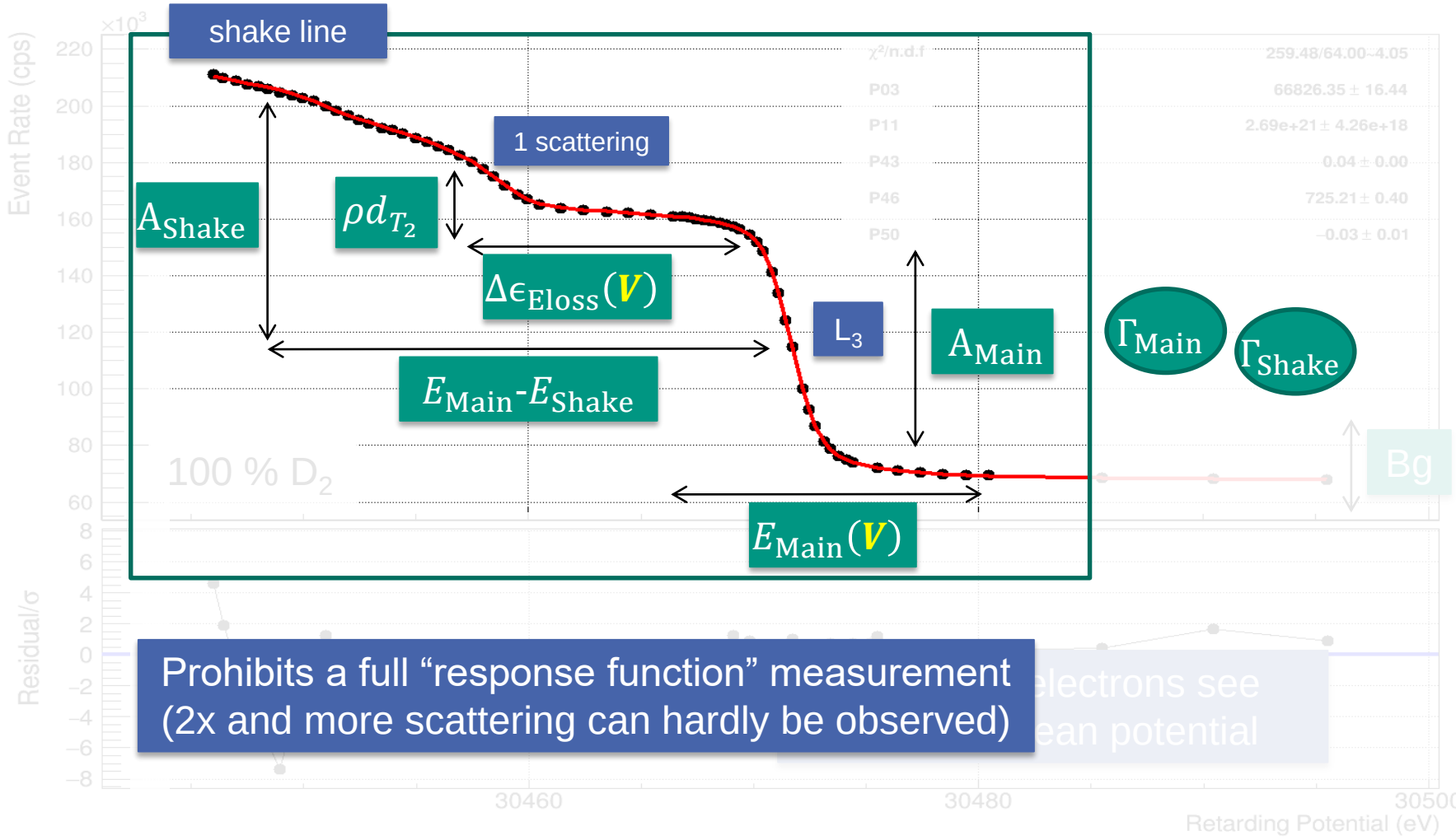


Scattered electrons see different mean potential

z-sensitivity by scattering

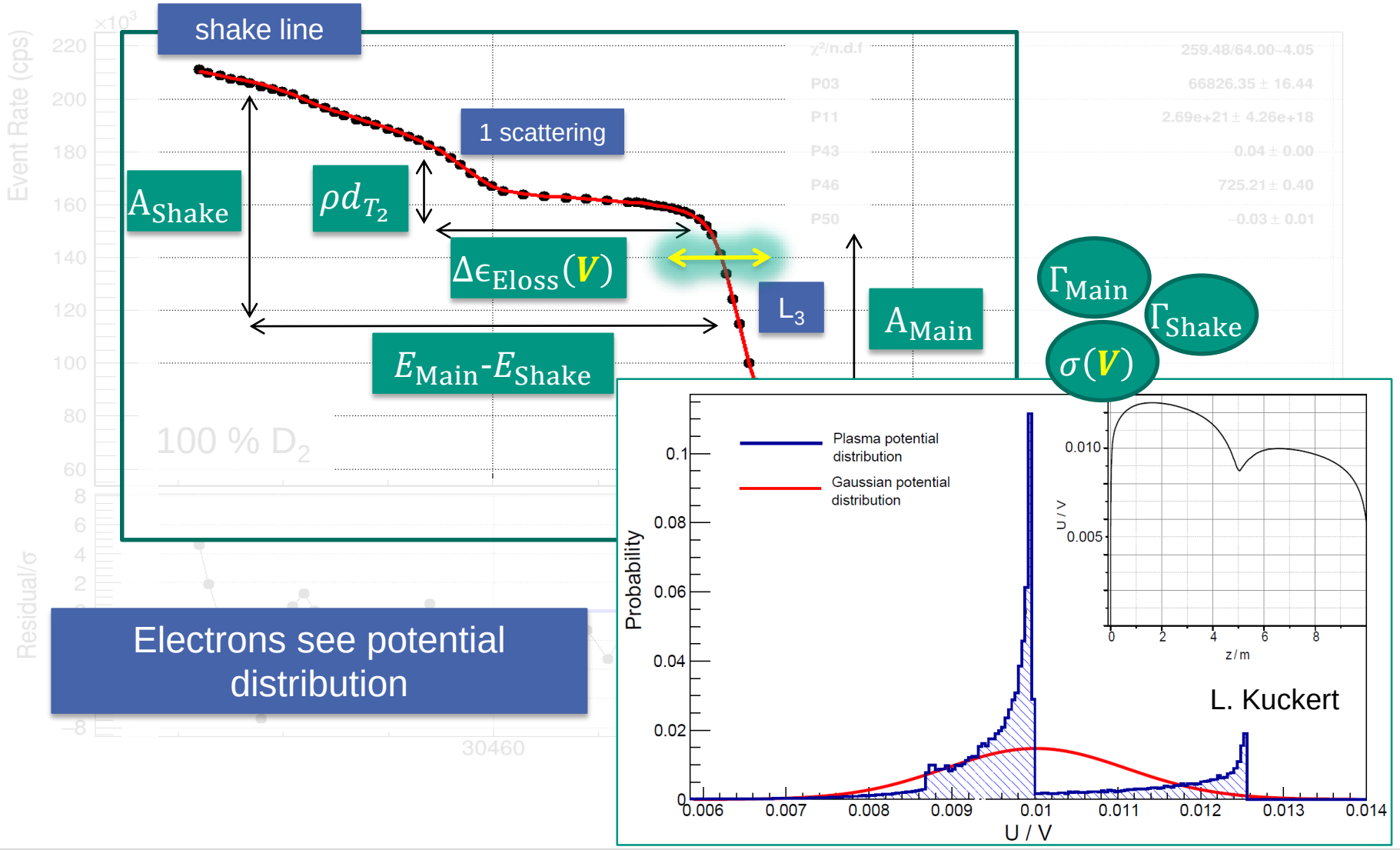


Interfering shake line



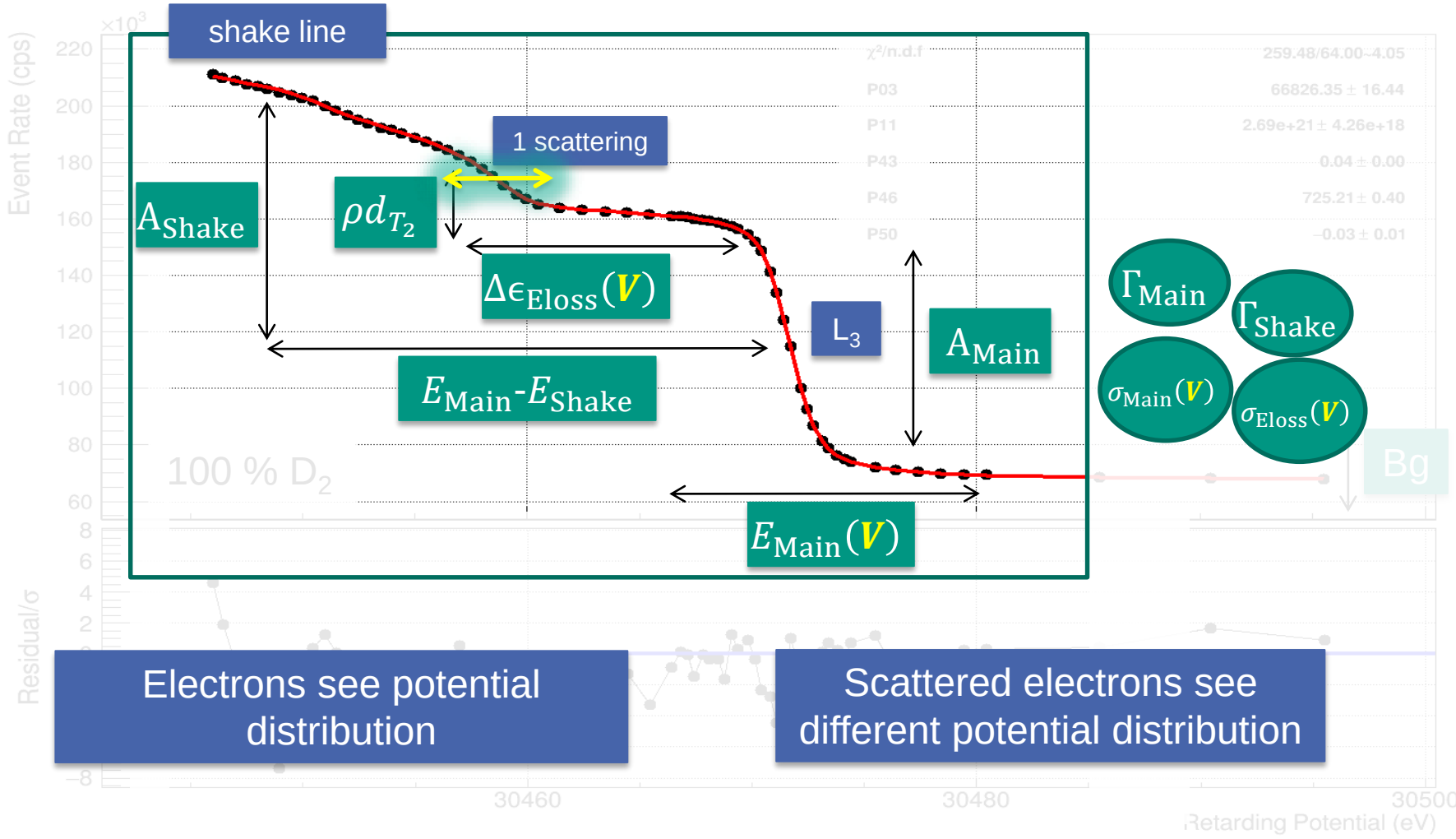
Prohibits a full “response function” measurement
(2x and more scattering can hardly be observed)

Gaussian Broadening due to plasma



Electrons see potential distribution

2x Gaussian Broadening due to plasma



Electrons see potential distribution

Scattered electrons see different potential distribution

Krypton L_3-32 Spectrum

Fixed to literature values:

E_{Main}-E_{Shake}

A_{Shake} / A_{Main}

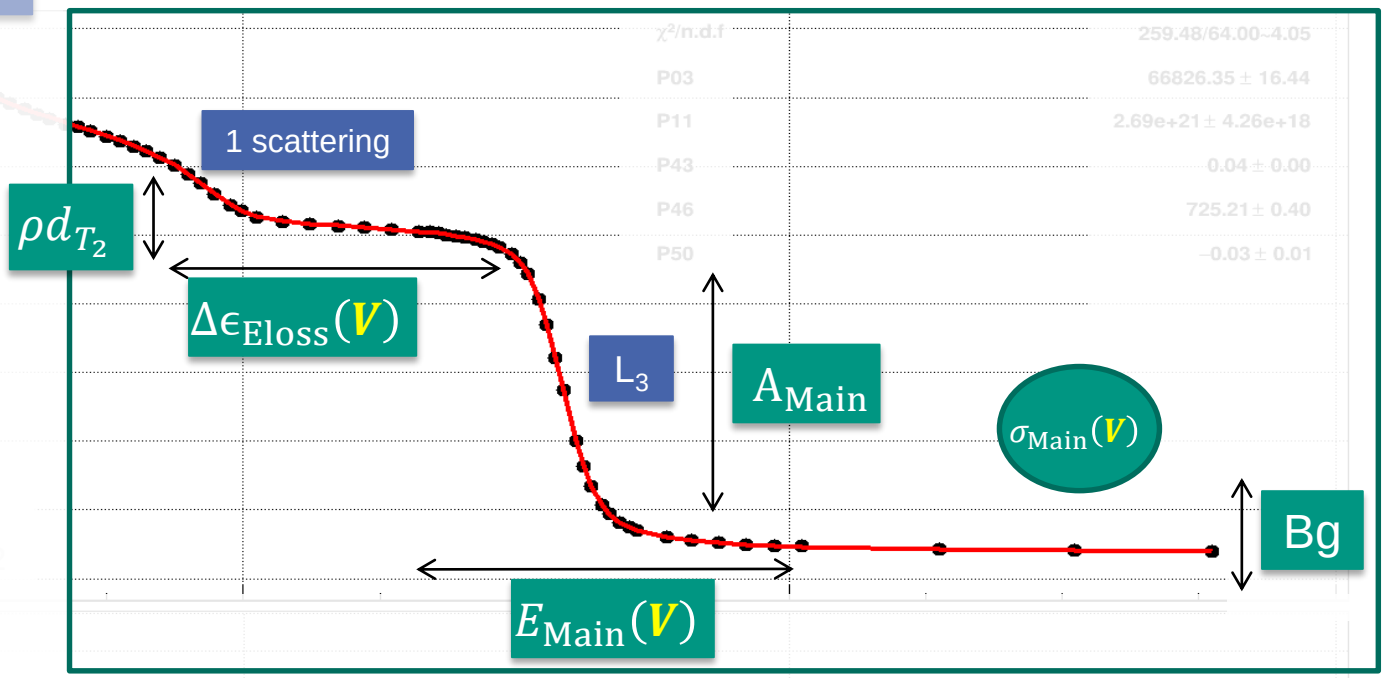
$\Gamma_{\mathrm{Shake}}(\sigma_{\mathrm{Main}} \equiv 0)$

Discarded:

$\sigma_{\mathrm{Eloss}}(V)$

Measured without T_2:

$\Gamma_{\mathrm{Main,Ref}}$



3 parameters which carry information on ***V***

6 parameter fit

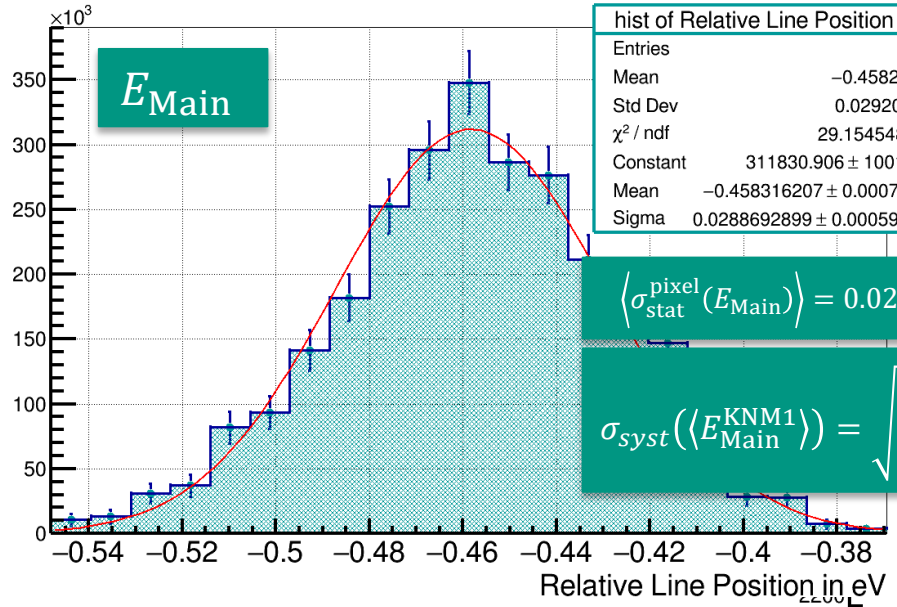
pixelwise

Minimizing 148 times $\mathcal{L}(\rho d_{T_2}, \mathrm{Bg}, E_{\mathrm{Main}}, \sigma^2_{\mathrm{Main}}, A_{\mathrm{Main}}, \Delta\epsilon_{\mathrm{Eloss}})$ is much easier than minimizing 1 time $\sum_{\mathrm{pixel}\ i} \mathcal{L}(\rho d_{T_2}, \mathrm{Bg}^i, {E_{\mathrm{Main}}}^i, {\sigma^2_{\mathrm{Main}}}^i, {A_{\mathrm{Main}}}^i, {\Delta\epsilon_{\mathrm{Eloss}}}^i)$

REFERENCE MEASUREMENT WITHOUT TRITIUM

Necessary to infer any (plasma related) line broadenings from the krypton measurements.

KNM1 L_3 Reference Measurement without T_2



E_{Main}

hist of Relative Line Position in eV	
Entries	1638
Mean	−0.458295313
Std Dev	0.0292084381
χ^2 / ndf	29.1545486 / 18
Constant	311830.906 ± 10011.543
Mean	−0.458316207 ± 0.000770190
Sigma	0.0288692899 ± 0.0005965176

$$\left\langle \sigma_{\mathrm{stat}}^{\mathrm{pixel}}(E_{\mathrm{Main}}) \right\rangle = 0.025 \text{ eV}$$

$$\sigma_{syst}\left(\left\langle E_{\mathrm{Main}}^{\mathrm{KNM1}} \right\rangle\right) = \sqrt{{\sigma_{hist}}^2 - \left\langle \sigma_{stat}^{pixel} \right\rangle^2} = 0.015 \text{ eV}$$

Reference value:
Kr-July17 measurement
$E_{\mathrm{Main}}^{\mathrm{July17}} = 30472.642(5)$ eV

-458 mV shift compared to Kr-July17

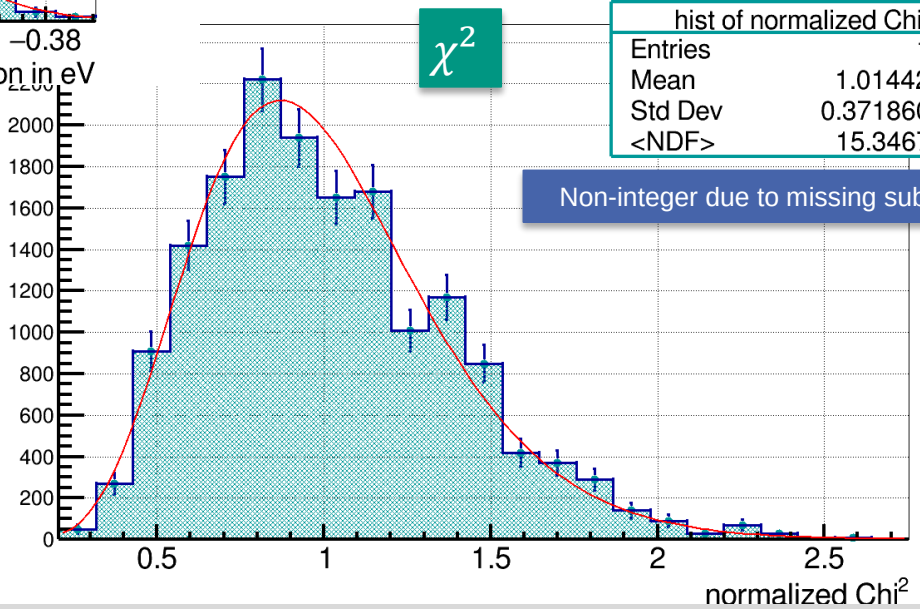
Small difference, errors preliminary

⟨ ⟩ indicates total (weighted) average of data set (i.e. over radial and temporal effects)

$$\left\langle E_{\mathrm{Main}}^{\mathrm{KNM1}} \right\rangle = \mathbf{30472.183(15)\ eV}$$

Larger error, most likely due to pixel wise analysis
(error conservative; i.e. covers systematics from alignment issues, neglected in uniform analysis from Kr-July17)

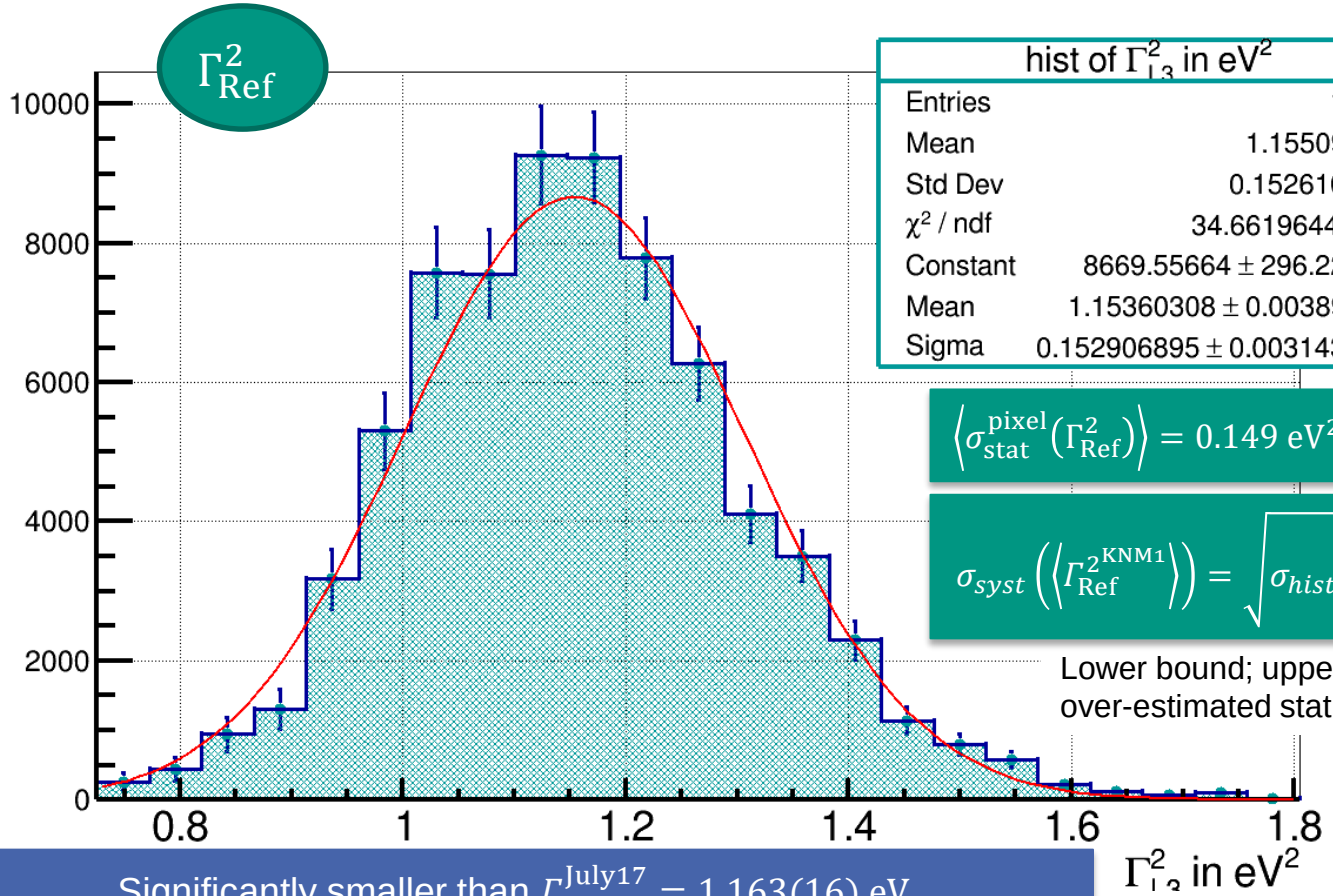
χ^2



hist of normalized Chi²	
Entries	1638
Mean	1.01442584
Std Dev	0.371860663
<NDF>	15.3467646

Non-integer due to missing subruns

KNM1 L_3 Reference Measurement without T_2



hist of $\Gamma^2_{L_3}$ in eV^2	
Entries	1638
Mean	1.15509659
Std Dev	0.152610572
χ^2 / ndf	34.6619644 / 20
Constant	8669.55664 ± 296.22498
Mean	1.15360308 ± 0.00389390
Sigma	0.152906895 ± 0.003143602

$$\left\langle \sigma_{\mathrm{stat}}^{\mathrm{pixel}}\left(\Gamma^2_{\mathrm{Ref}}\right)\right\rangle = 0.149\ \mathrm{eV}^2$$

Small difference, errors preliminary

$$\sigma_{syst}\left(\left\langle \Gamma^{2\,\mathrm{KNM1}}_{\mathrm{Ref}}\right\rangle\right) = \sqrt{{\sigma_{hist}}^2 - \left\langle \sigma_{stat}^{pixel}\right\rangle^2} = 0.06\ \mathrm{eV}^2$$

Lower bound; upper bound shows over-estimated stat. uncertainty

Significantly smaller than $\Gamma^{\mathrm{July17}}_{\mathrm{Ref}} = 1.163(16)$ eV.
Also error larger, due to included alignment systematics

Beam tube work function more homogeneous in KNM1?

Gaussian error propagation

$$\sqrt{\left\langle \Gamma^{2\,\mathrm{KNM1}}_{\mathrm{Ref}}\right\rangle} = 1.075(28)\ \mathrm{eV}$$

REAR WALL VOLTAGE DEPENDENCIES

Do we have a qualitative understanding of the WGTS plasma?

This is necessary to translate findings from Krypton to Tritium mode and to improve future measurements.

Rear Wall Voltage Dependencies

Varying rear wall potential

Best coupling of plasma to rear wall when U_{RW} matches work function difference of tube wall and rear wall

In this regime
- ***linear*** energy scaling with U_{RW}
- ***minimum*** longitudinal inhomogeneity

$E_{\mathrm{Main}}(\boldsymbol{V})$

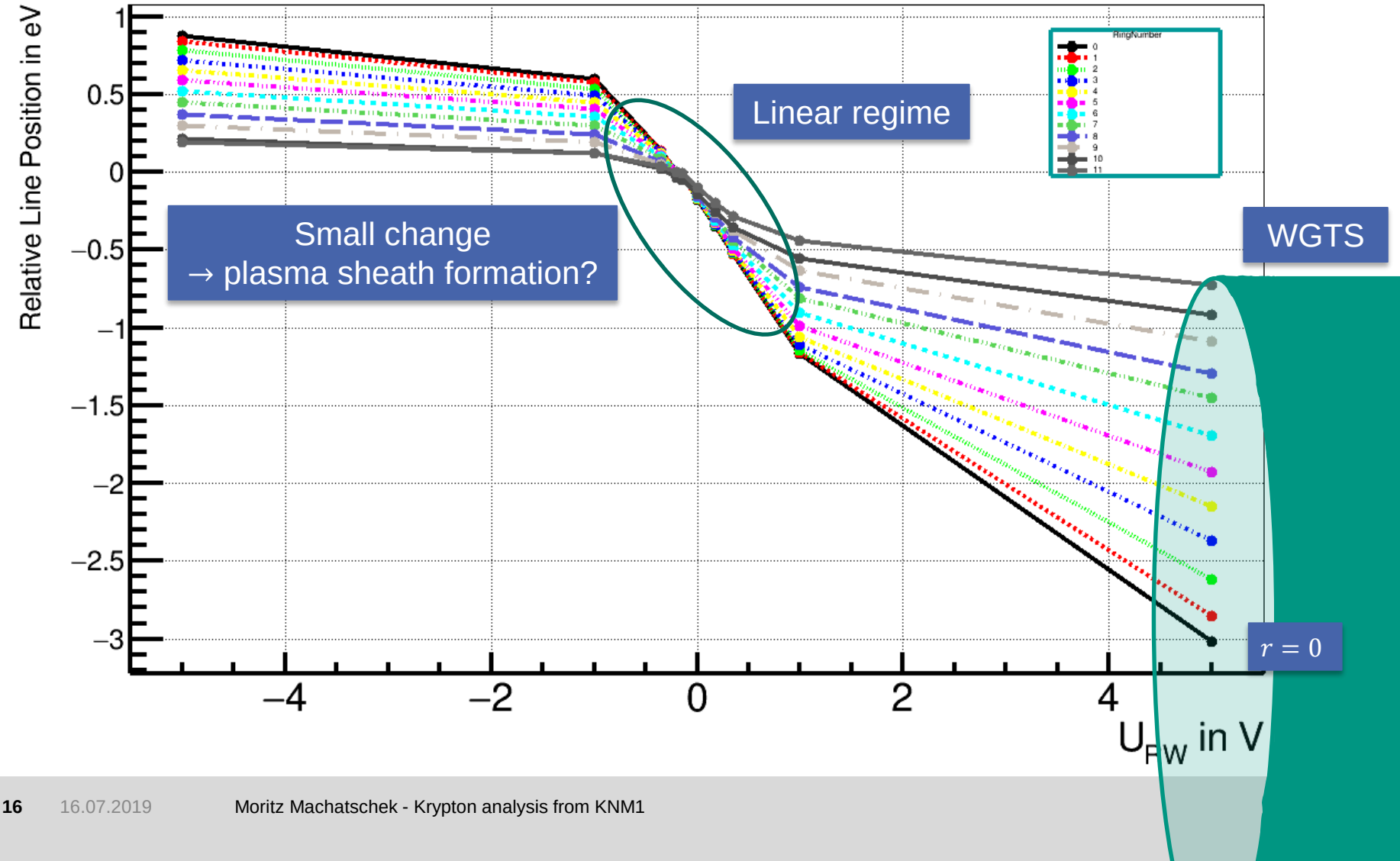
$\Delta\epsilon_{\mathrm{Eloss}}(\boldsymbol{V})$

$\sigma^2_{\mathrm{Main}}(\boldsymbol{V})$

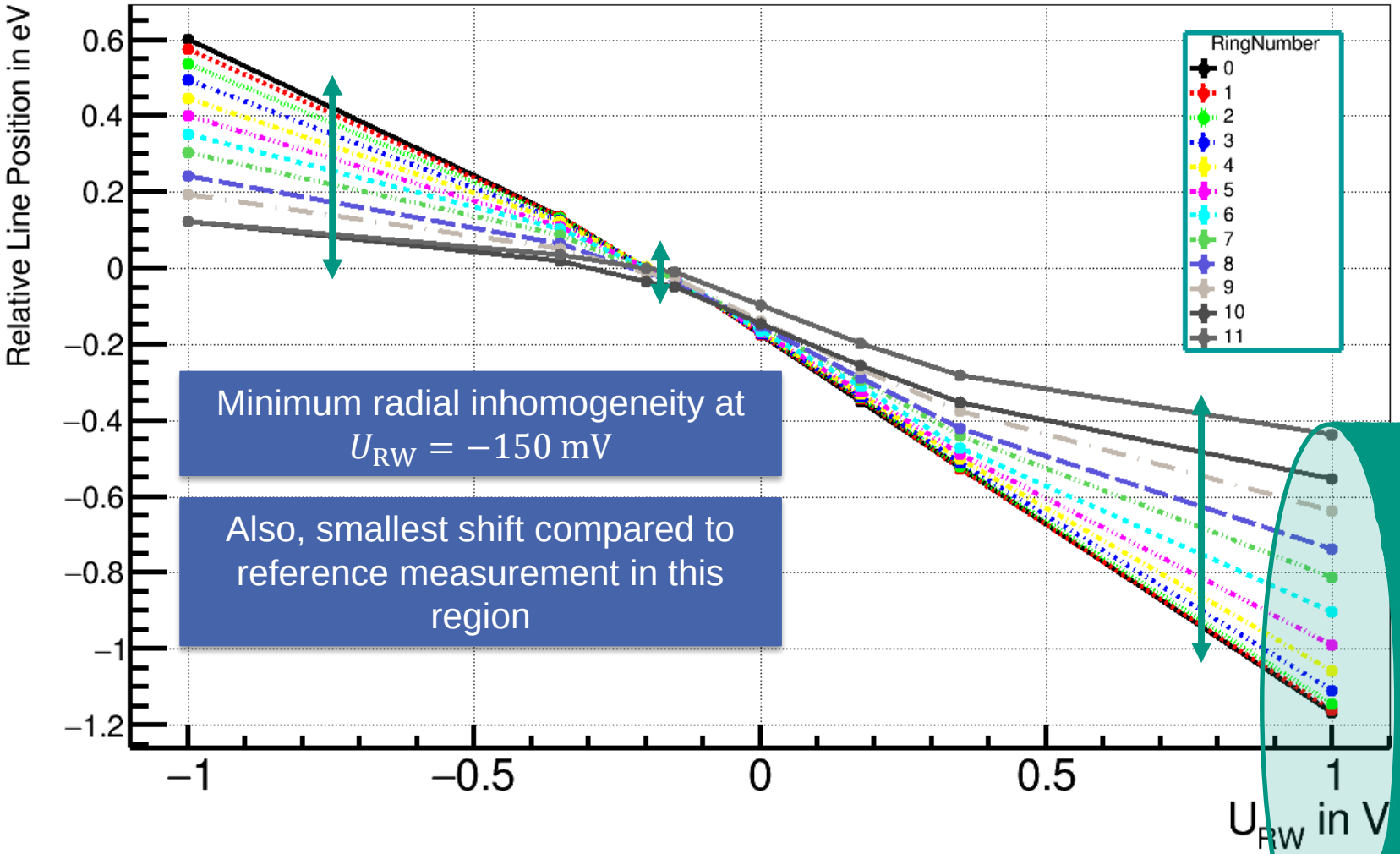
Rear wall coupling ***depends on radius*** (best for $r = 0$), full matching can not be expected

However, we also expect ***minimum longitudinal*** inhomogeneity with ***minimum radial*** inhomogeneity

Line Position $E_{\mathrm{Main}}(V)$

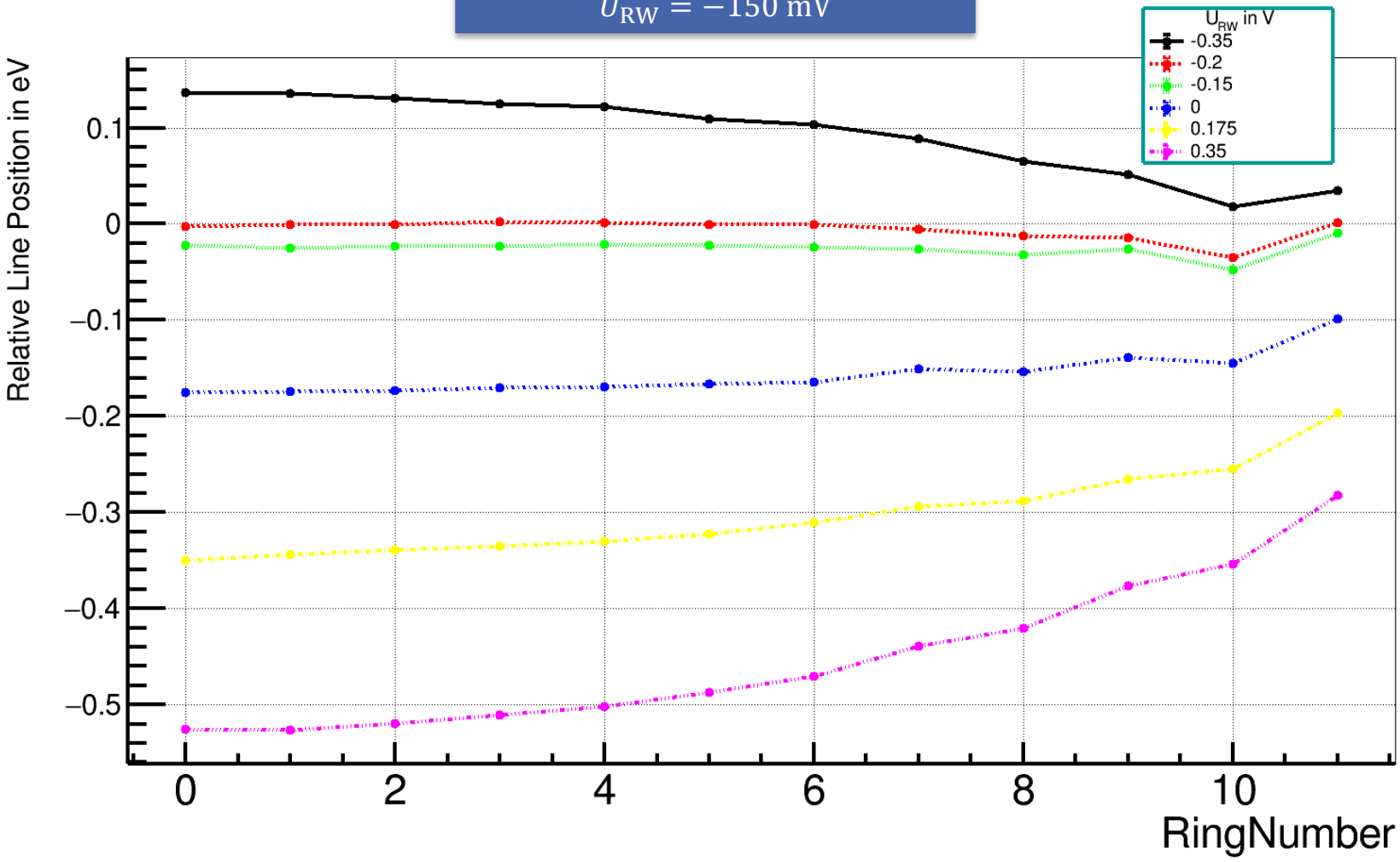


Line Position $E_{\mathrm{Main}}(V)$ radial

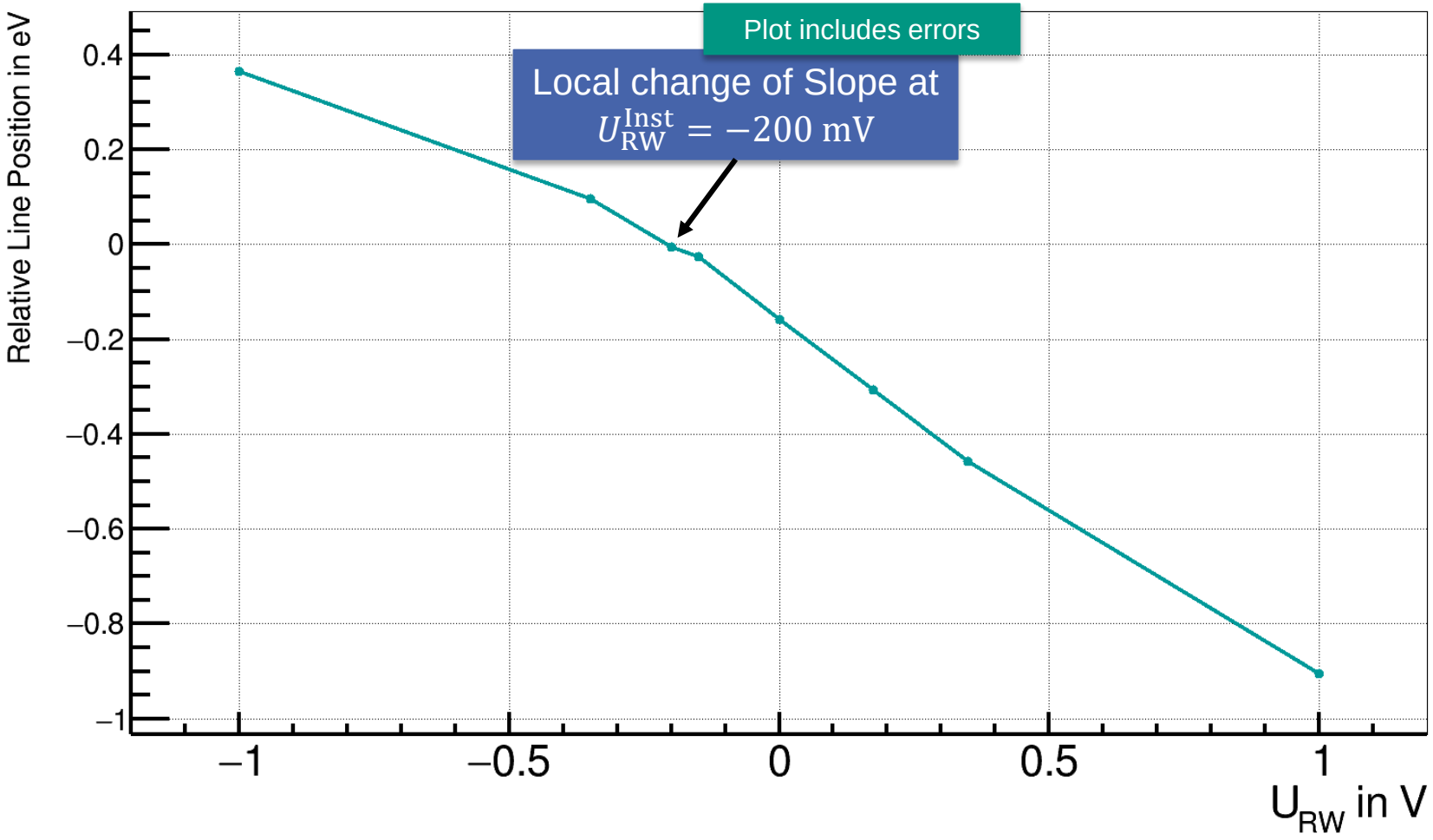


Line Position $E_{\mathrm{Main}}(V)$ radial

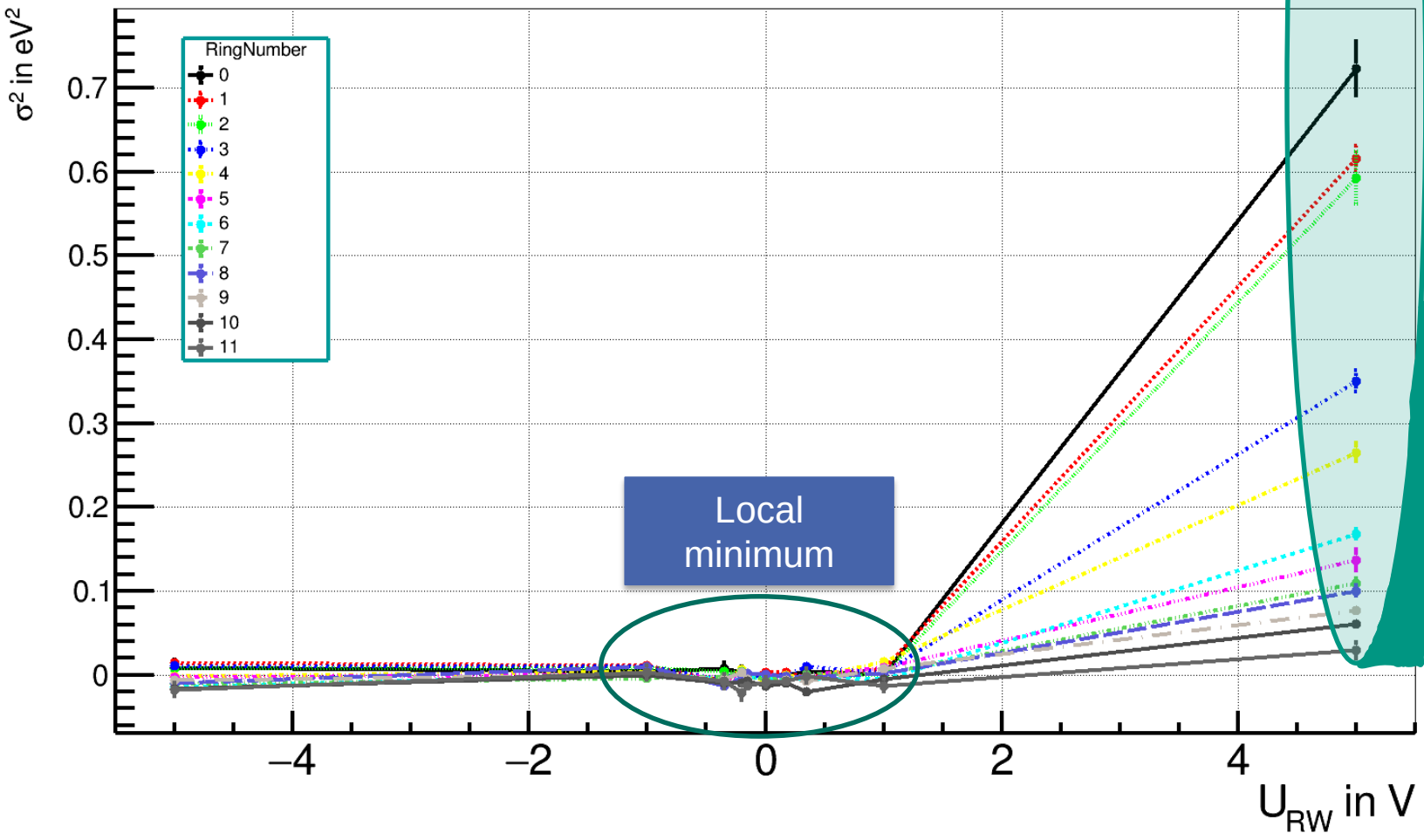
Minimum radial inhomogeneity at $U_{\mathrm{RW}} = -150\ \mathrm{mV}$



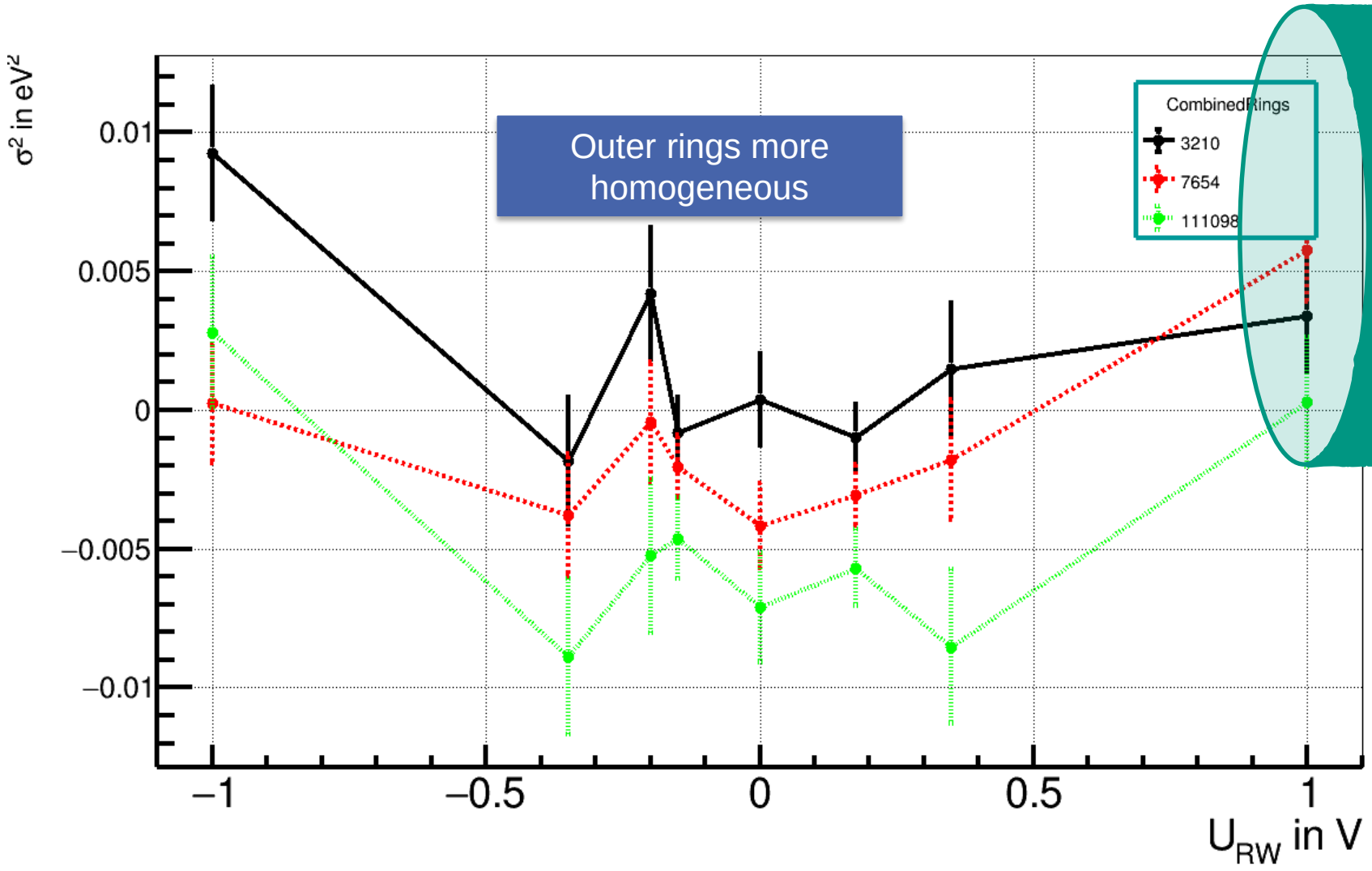
Line Position $E_{\mathrm{Main}}(V)$ uniform



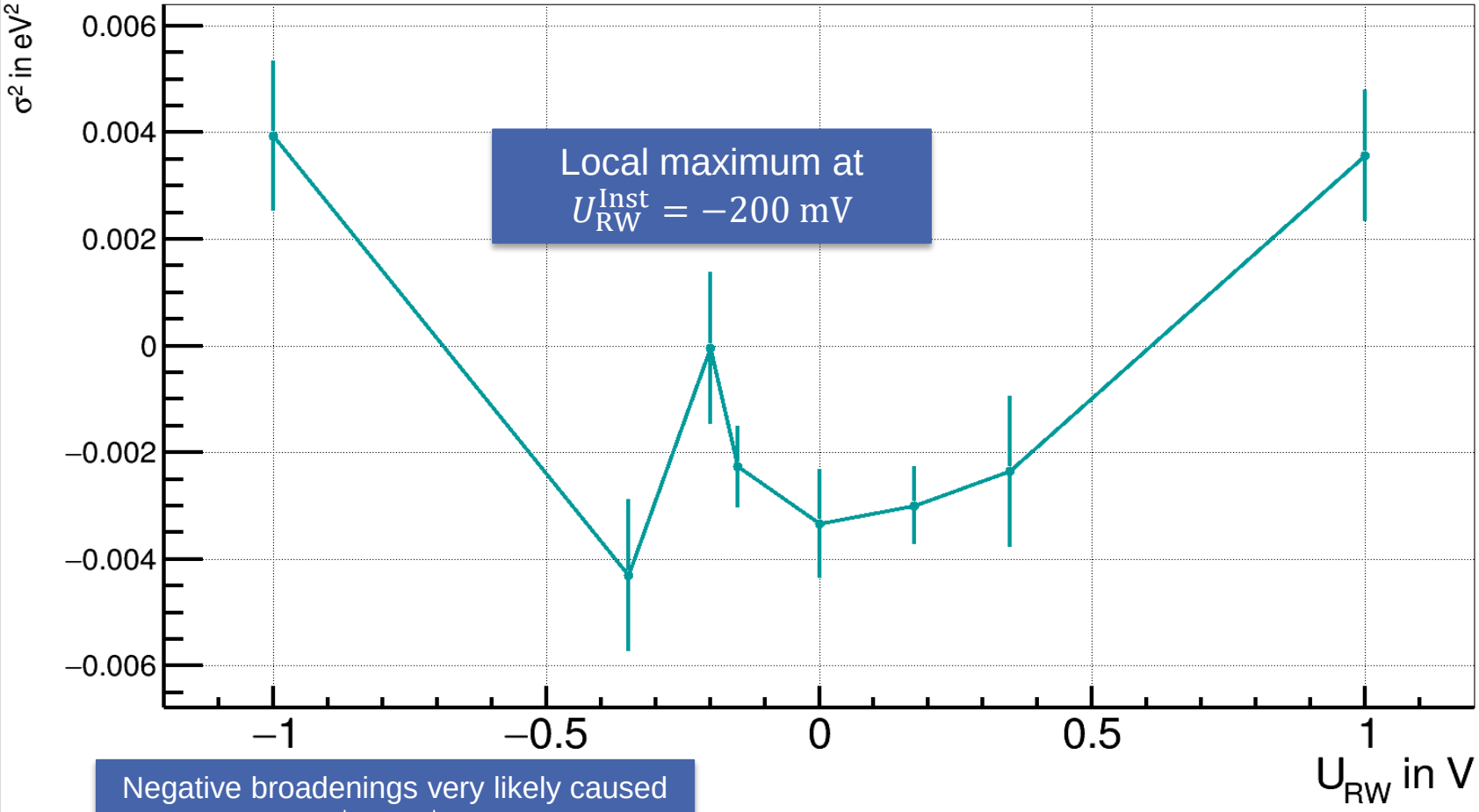
Line Broadening $\sigma^2_{\mathrm{Main}}(V)$



Line Broadening $\sigma^2_{\mathrm{Main}}(V)$ radial



Line Broadening $\sigma^2_{\mathrm{Main}}(V)$ uniform

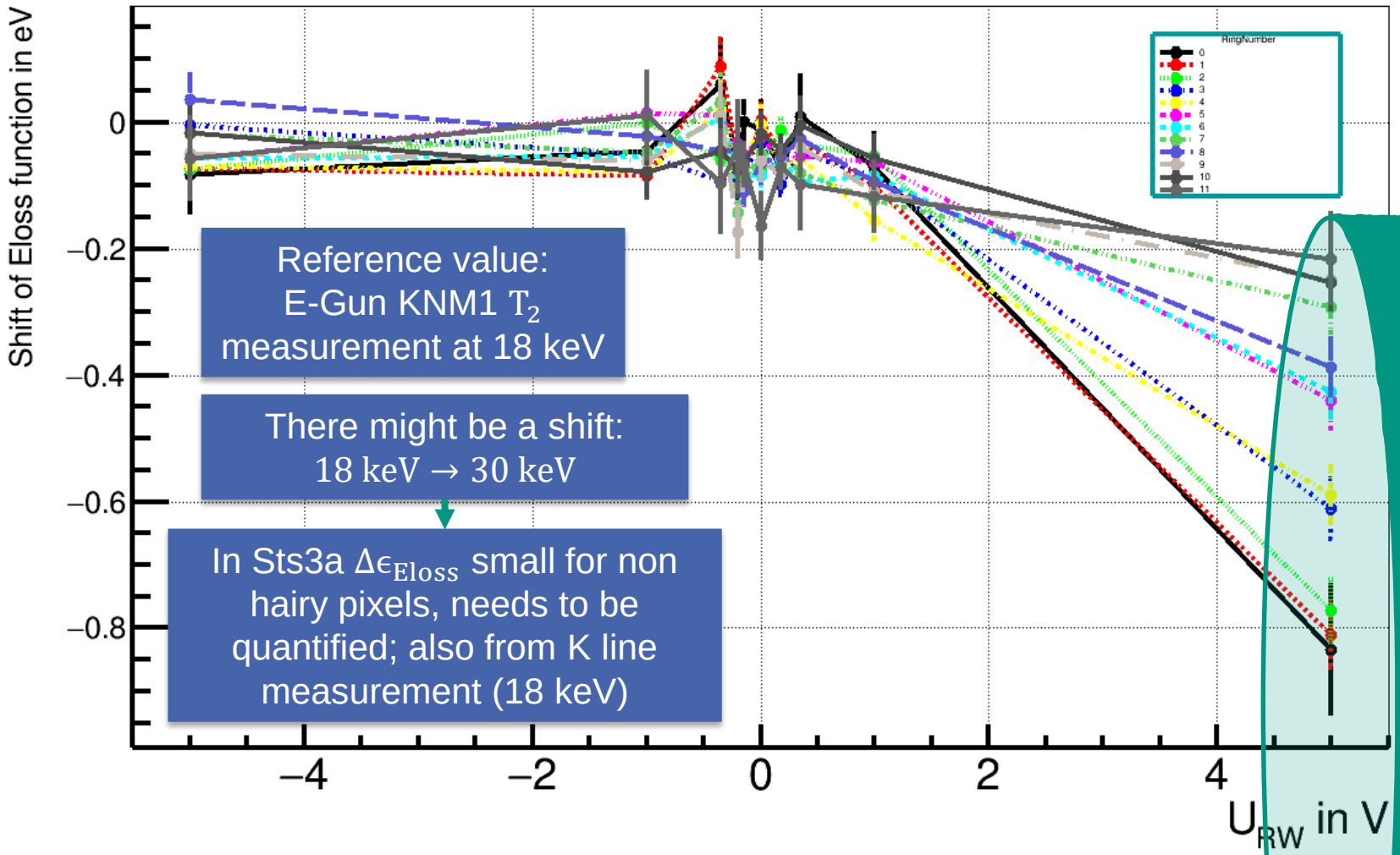


Negative broadenings very likely caused by too large $\left\langle \Gamma_{\mathrm{Ref}}^{2\,\mathrm{KNM1}} \right\rangle$ (within error)

$$0.004\ \mathrm{eV}^2 = 0.16 \cdot \sigma_{\mathrm{tot}}\left(\left\langle \Gamma_{\mathrm{Ref}}^{2\,\mathrm{KNM1}} \right\rangle\right)$$

Structure is independent of line profile (fit with total Lorentzian Γ^2_{Main} instead of $\Gamma_{\mathrm{Ref}}^{\mathrm{KNM1}}$ and σ^2_{Main})

Eloss Shift $\Delta\epsilon_{\mathrm{Eloss}}(V)$

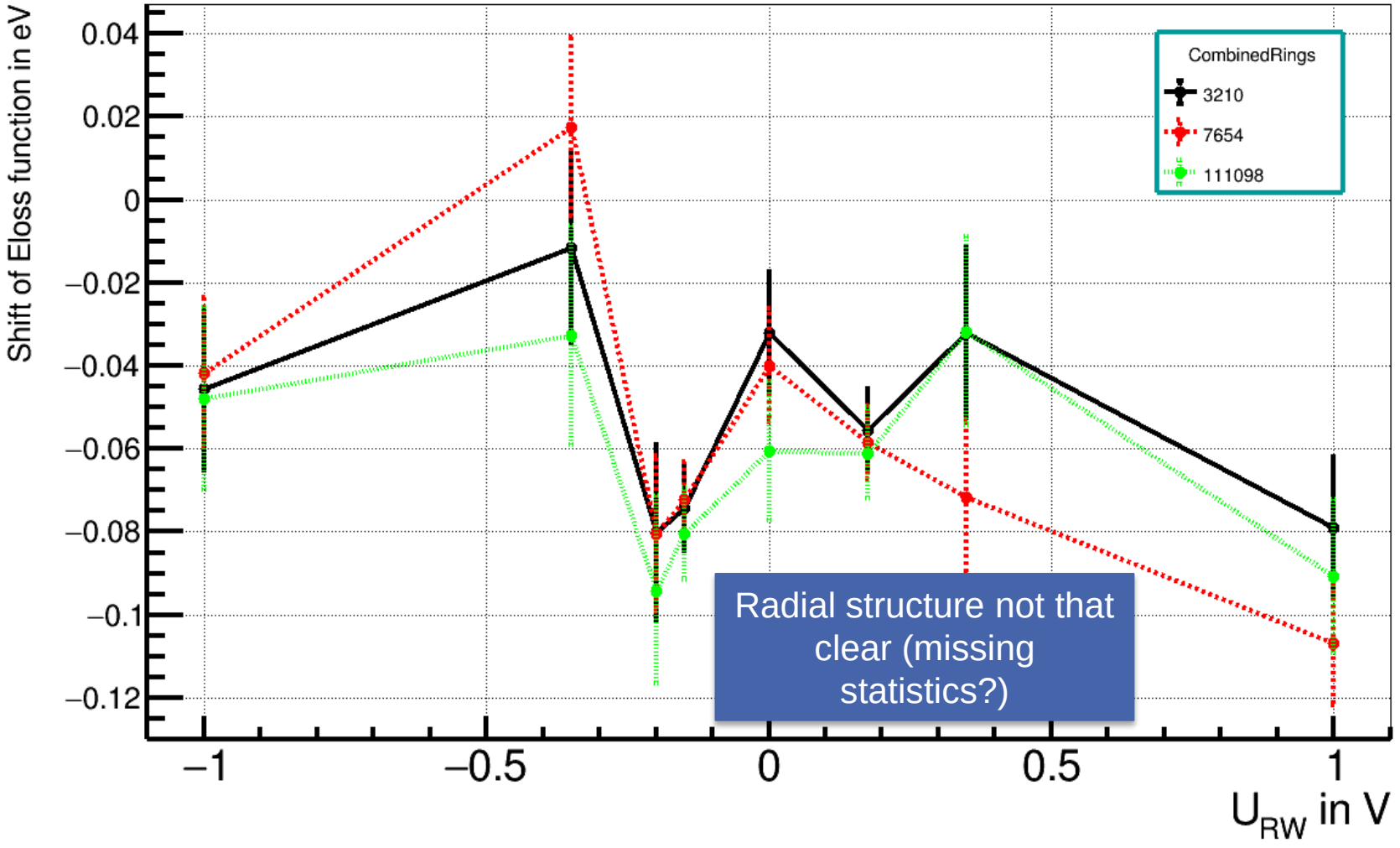


Reference value:
E-Gun KNM1 T_2 measurement at 18 keV

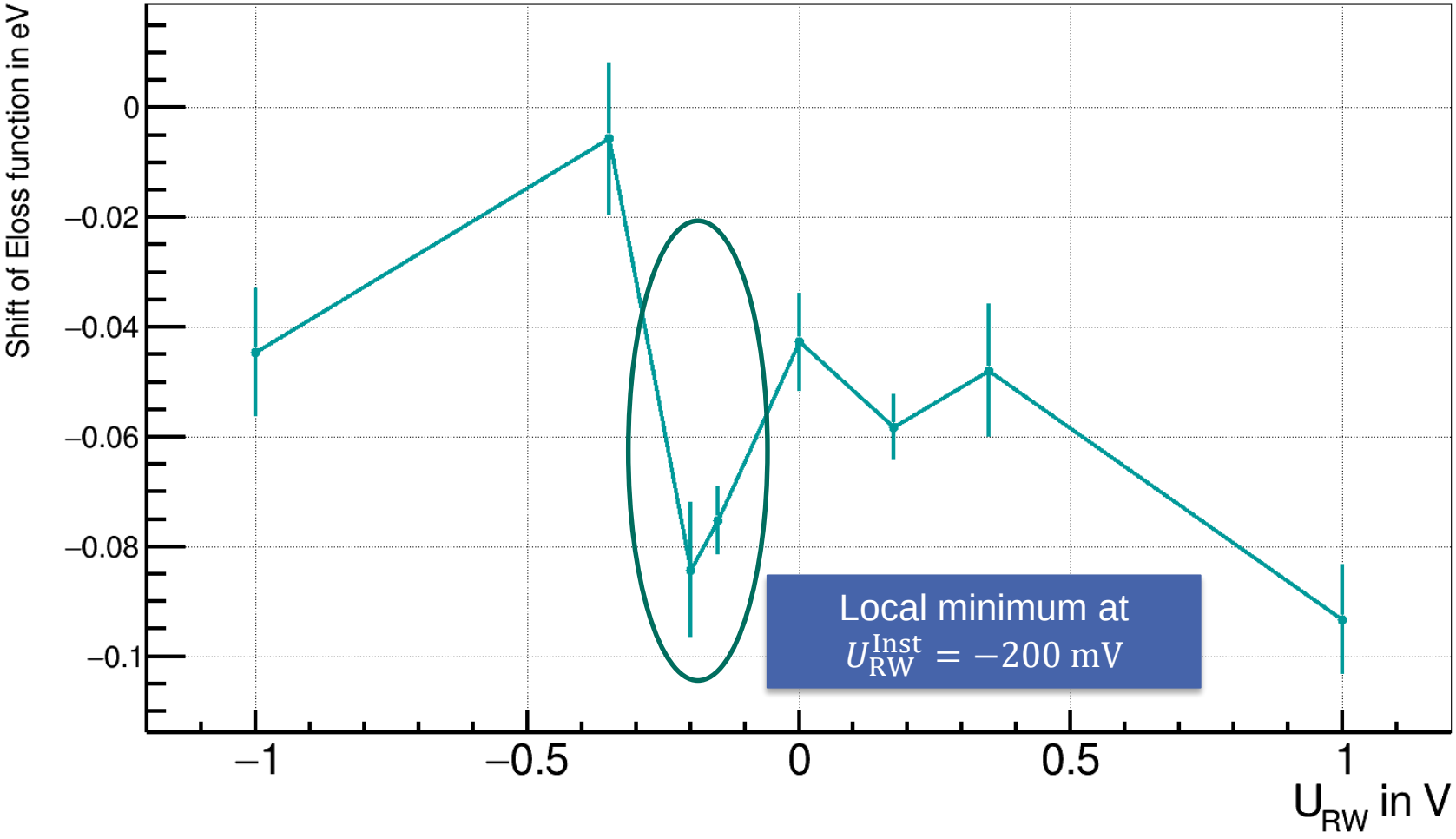
There might be a shift:
$18\ \mathrm{keV} \rightarrow 30\ \mathrm{keV}$

In Sts3a $\Delta\epsilon_{\mathrm{Eloss}}$ small for non hairy pixels, needs to be quantified; also from K line measurement (18 keV)

Eloss Shift $\Delta\epsilon_{\mathrm{Eloss}}(V)$ radial



Eloss Shift $\Delta\epsilon_{\mathrm{Eloss}}(V)$ uniform



Conclusions

Varying rear wall potential

Best coupling of plasma to rear wall when U_{RW} matches work function difference of tube wall and rear wall

In this regime
- ***linear*** energy scaling with U_{RW}
- ***minimum*** longitudinal inhomogeneity

$E_{\mathrm{Main}}(\boldsymbol{V})$ $\Delta\epsilon_{\mathrm{Eloss}}(\boldsymbol{V})$ $\Gamma_{\mathrm{Main}}(\boldsymbol{V})$

Rear wall coupling ***depends on radius*** (best for $r = 0$), full matching can not be expected

However, we also expect ***minimum longitudinal*** inhomogeneity with ***minimum radial*** inhomogeneity

---

In principle correct, however additional instability at $U_{\mathrm{RW}}^{\mathrm{Inst}} = -200\ \mathrm{mV}$ (visible in all estimators and further measurements) leads to locally different effects

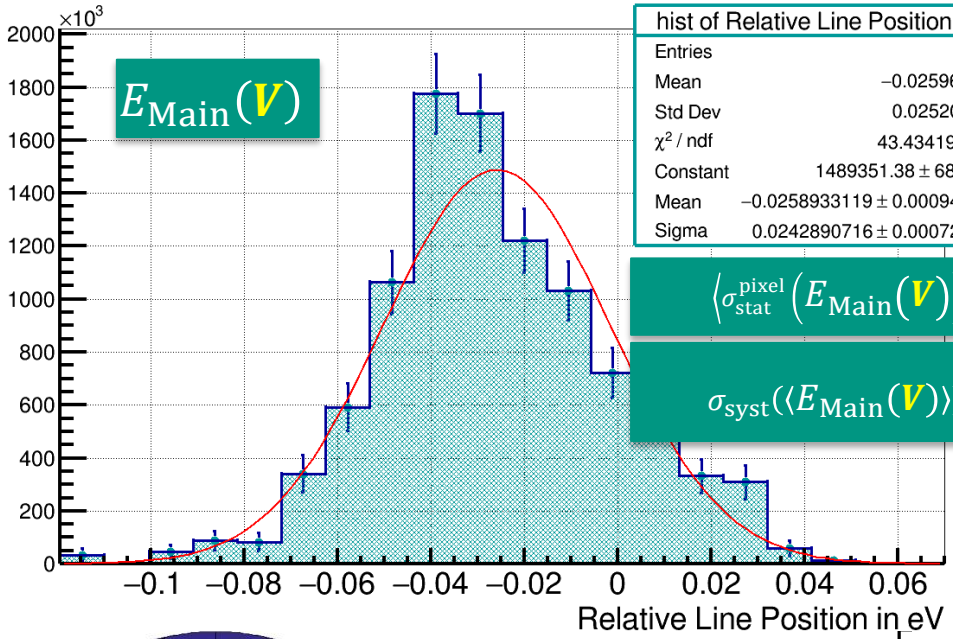
$\mathrm{U_{RW}} = -350\ \mathrm{mV}$ consistently shows the best longitudinal homogeneity

ANALYSIS OF REAR WALL VOLTAGES USED IN KNM1

Quantitative analysis of inferred systematics and neutrino mass shifts

KNM1 $L_3, U_{RW} = -150$ mV

All values for krypton mode plasma, tritium mode plasma effects should be smaller

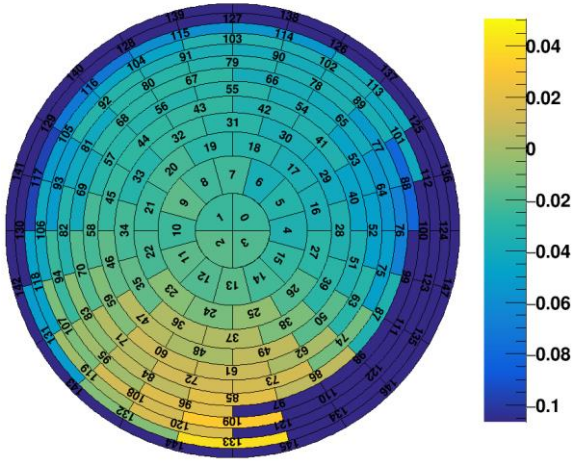


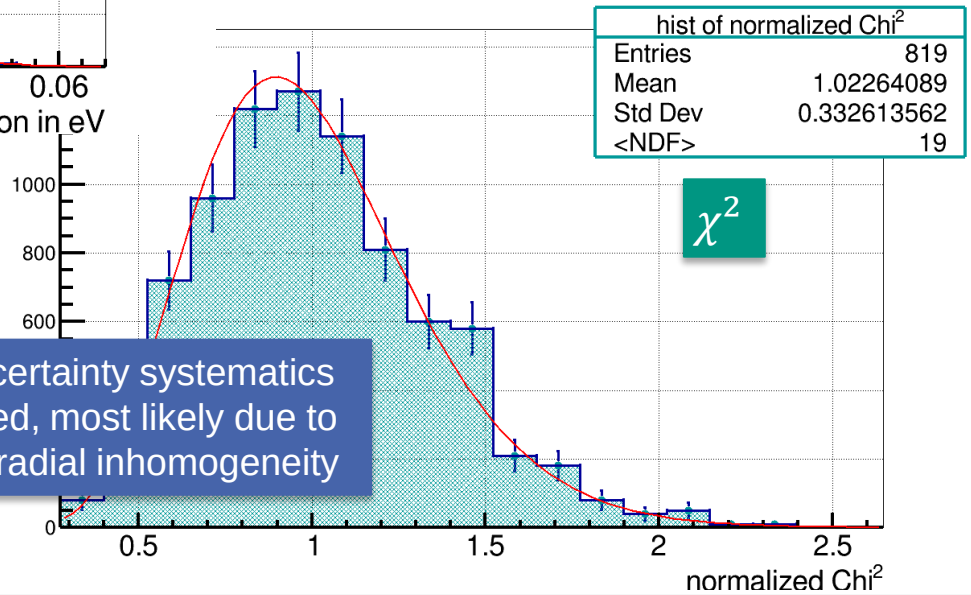
Plasma related shift:
$\langle E_{\mathrm{Main}}(V) \rangle = -26 \pm 23$ mV

$\left\langle \sigma_{\mathrm{stat}}^{\mathrm{pixel}} \left(E_{\mathrm{Main}}(V) \right) \right\rangle = 0.009$ eV

Systematics dominated

$\sigma_{\mathrm{syst}}(\langle E_{\mathrm{Main}}(V) \rangle) = \sqrt{{\sigma_{\mathrm{hist}}}^2 - \left\langle \sigma_{\mathrm{stat}}^{\mathrm{pixel}} \right\rangle^2} = 0.023$ eV



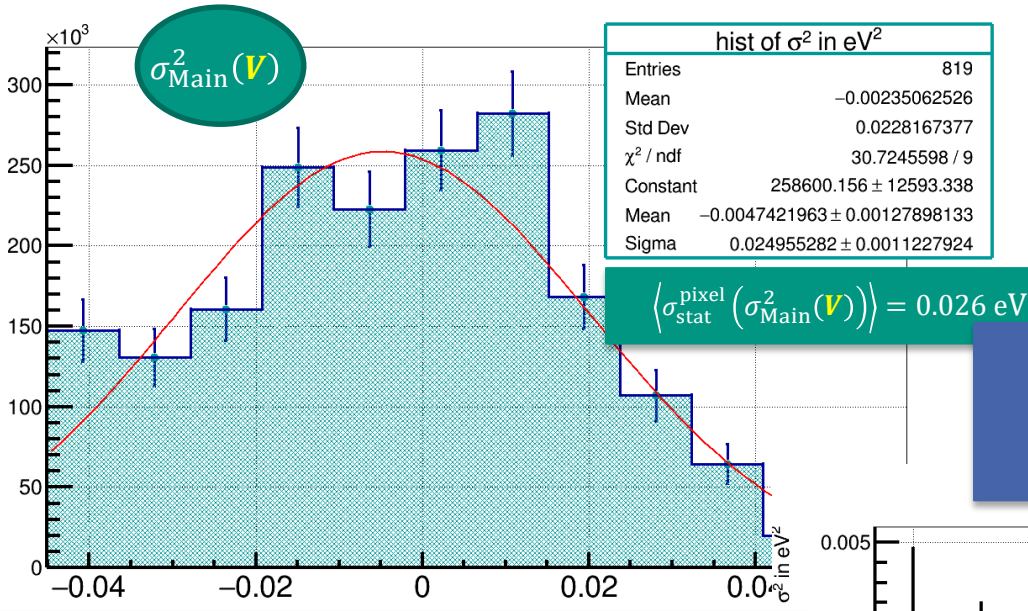


χ^2

Total uncertainty systematics dominated, most likely due to residual radial inhomogeneity

KNM1 $L_3, U_{RW} = -150$ mV

Problems with error estimation, values might change on the $10^{-2}\mathrm{eV}^2$ scale



$$\left\langle \sigma^2_{\mathrm{Main}}(V) \right\rangle = -0.005 \pm 0.025\ \mathrm{eV}^2$$

$$\Delta m_\nu^2 = -2\sigma^2_{\mathrm{Main}}(V)$$

$$\left\langle \sigma^{\mathrm{pixel}}_{\mathrm{stat}}\left(\sigma^2_{\mathrm{Main}}(V)\right)\right\rangle = 0.026\ \mathrm{eV}^2$$

Conservative approach:

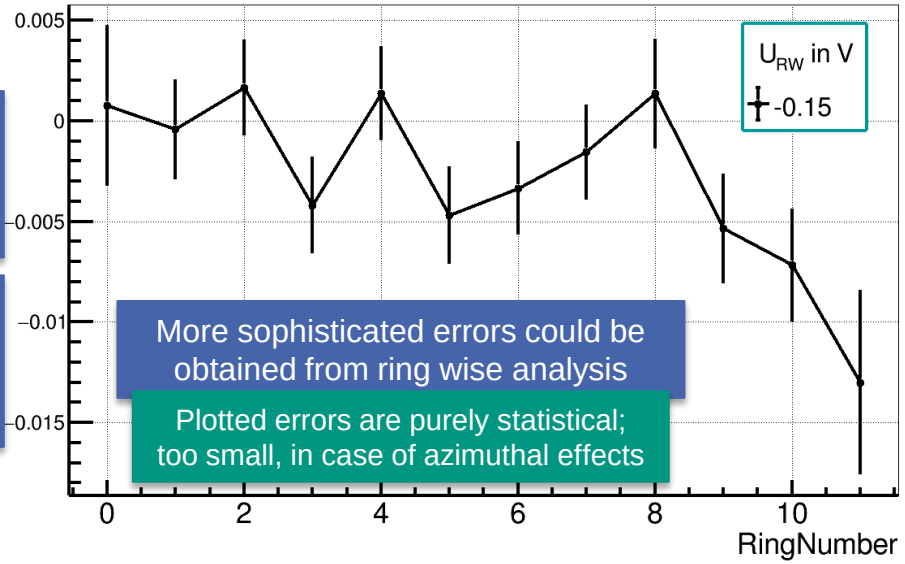
$$\left|\Delta m_\nu^2\left(\sigma^2_{\mathrm{Main}}(V)\right)\right| \leqslant \left|\Delta m_\nu^2(0.025\ \mathrm{eV}^2)\right| = 5 \cdot 10^{-2}\mathrm{eV}^2$$

If σ_{hist} was purely statistical, we would take the mean

$$\Delta m_\nu^2\left(\sigma^2_{\mathrm{Main}}(V)\right) = \Delta m_\nu^2(-0.005\ \mathrm{eV}^2) = \mathbf{1 \cdot 10^{-2}eV^2}$$

$\left\langle \sigma^{\mathrm{pixel}}_{\mathrm{stat}} \right\rangle < \sigma_{\mathrm{hist}}$:
too conservative error estimation, but certainly no large visible systematics

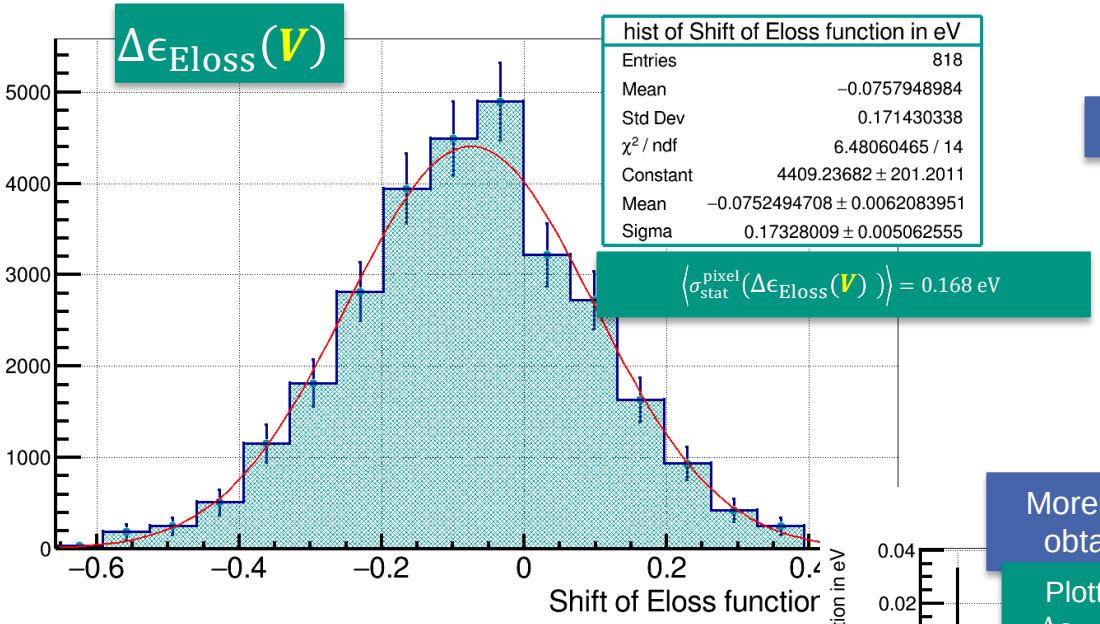
All values for krypton mode plasma, tritium mode plasma effects should be smaller



More sophisticated errors could be obtained from ring wise analysis

Plotted errors are purely statistical; too small, in case of azimuthal effects

KNM1 $L_3, U_{RW} = -150$ mV



$\left\langle \sigma_{\mathrm{stat}}^{\mathrm{pixel}}(\Delta\epsilon_{\mathrm{Eloss}}(V)) \right\rangle = 0.168$ eV

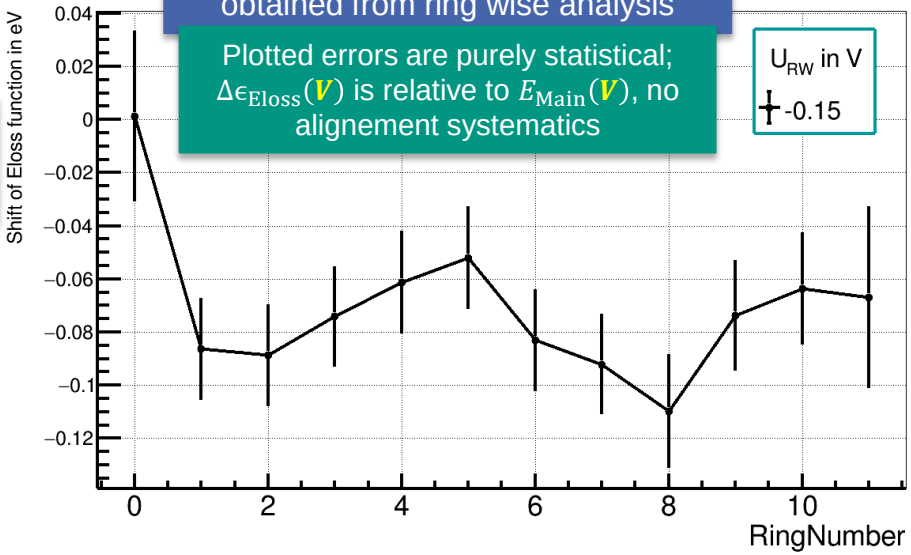
$\langle \Delta\epsilon_{\mathrm{Eloss}}(V) \rangle = -0.075 \pm 0.006$ eV

(purely statistical)

$\left\langle \sigma_{\mathrm{stat}}^{\mathrm{pixel}} \right\rangle \approx \sigma_{\mathrm{hist}}$:
Statistics dominated, no large visible systematics

More sophisticated errors could be obtained from ring wise analysis

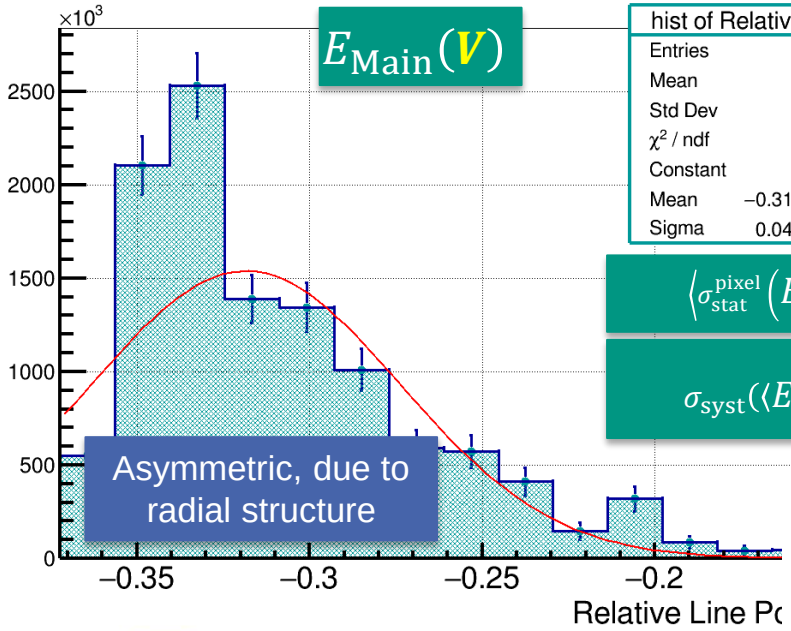
Plotted errors are purely statistical; $\Delta\epsilon_{\mathrm{Eloss}}(V)$ is relative to $E_{\mathrm{Main}}(V)$, no alignement systematics



All values for krypton mode plasma, tritium mode plasma effects should be smaller

KNM1 $L_3, U_{RW} = 175$ mV

All values for krypton mode plasma, tritium mode plasma effects should be smaller



$E_{\mathrm{Main}}(V)$

hist of Relative Line Position in eV	
Entries	936
Mean	−0.306704869
Std Dev	0.0451821107
χ^2 / ndf	134.580719 / 13
Constant	1538490 ± 86676.10
Mean	−0.318518728 ± 0.002003696
Sigma	0.04467576 ± 0.0028628029

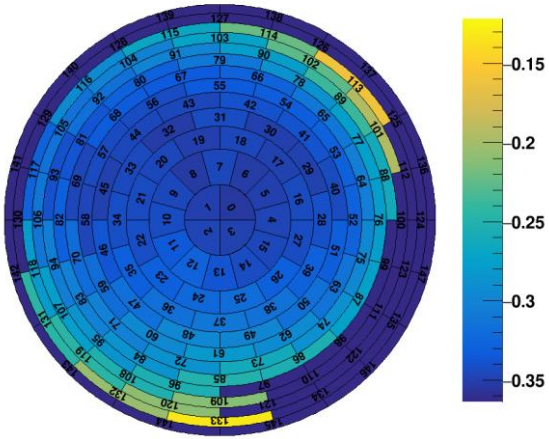
Asymmetric, due to radial structure

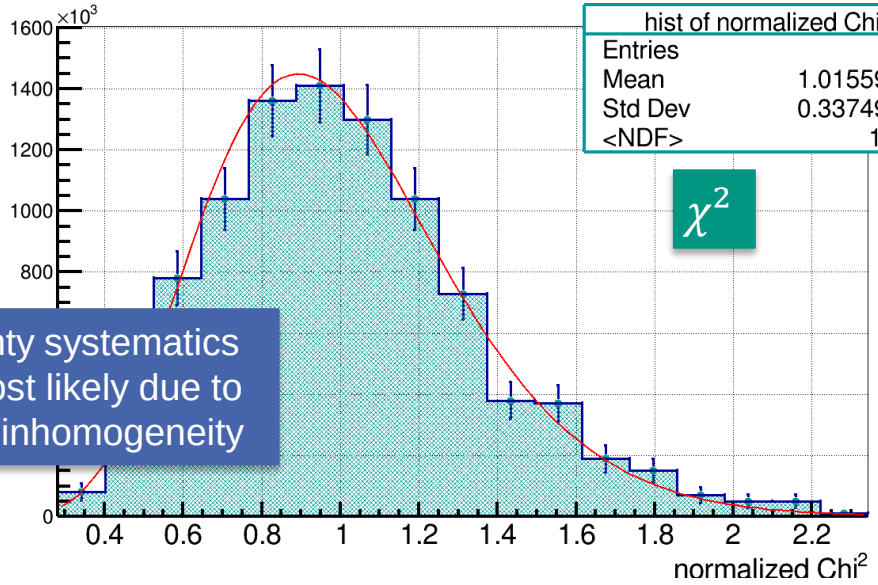
Plasma related shift:
$\langle E_{\mathrm{Main}}(V) \rangle = -319 \pm 43$ mV

$\left\langle \sigma_{\mathrm{stat}}^{\mathrm{pixel}} \left(E_{\mathrm{Main}}(V) \right) \right\rangle = 0.009$ eV

Systematics dominated

$\sigma_{\mathrm{syst}}(\langle E_{\mathrm{Main}}(V) \rangle) = \sqrt{\sigma_{\mathrm{hist}}{}^2 - \left\langle \sigma_{\mathrm{stat}}^{\mathrm{pixel}} \right\rangle^2} = 0.043$ eV



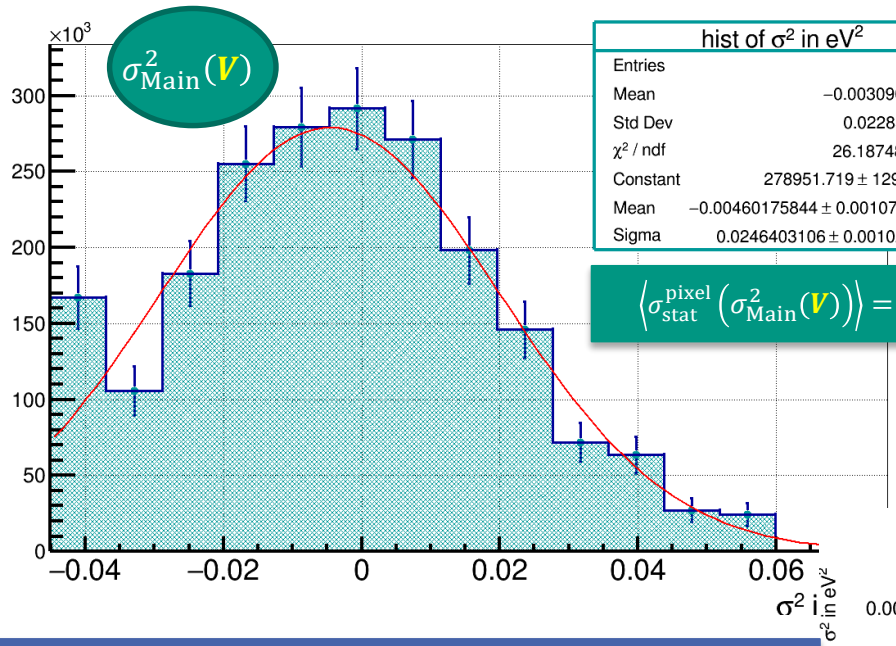


hist of normalized Chi²	
Entries	936
Mean	1.01559747
Std Dev	0.33749774
<NDF>	18.75

χ^2

Total uncertainty systematics dominated, most likely due to residual radial inhomogeneity

KNM1 $L_3, U_{RW} = 175$ mV



$\left\langle \sigma^{pixel}_{stat}\left(\sigma^2_{Main}(V)\right)\right\rangle = 0.026\ \mathrm{eV}^2$

Problems with error estimation, values might change on the $10^{-2}\mathrm{eV}^2$ scale

$\left\langle \sigma^2_{Main}(V)\right\rangle = -0.005 \pm 0.025\ \mathrm{eV}^2$

$\Delta m^2_\nu = -2\sigma^2_{Main}(V)$

Conservative approach:

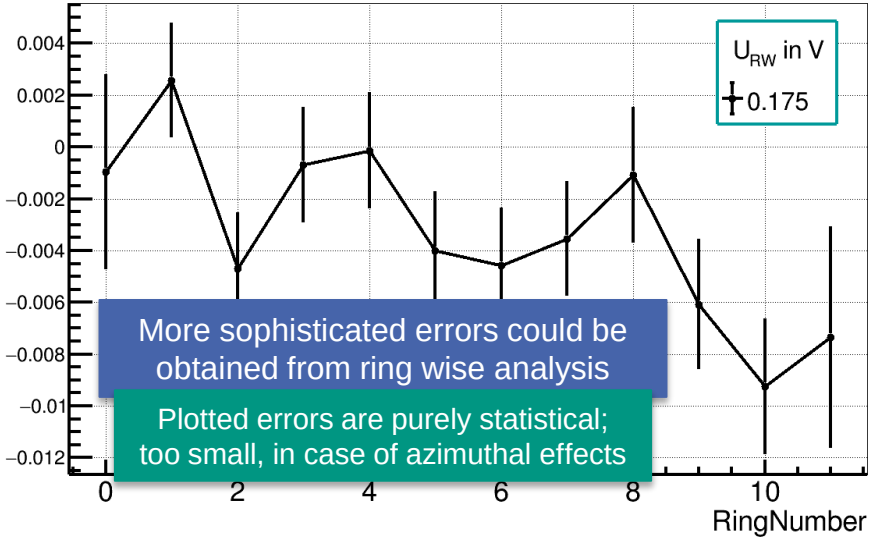
$\left|\Delta m^2_\nu\left(\sigma^2_{Main}(V)\right)\right| \leqslant |\Delta m^2_\nu(0.025\ \mathrm{eV}^2)| = 5 \cdot 10^{-2}\mathrm{eV}^2$

If σ_{hist} was purely statistical, we would take the mean

$\boldsymbol{\Delta m^2_\nu\left(\sigma^2_{Main}(V)\right) = \Delta m^2_\nu(-0.005\ \mathrm{eV}^2) = 1 \cdot 10^{-2}\mathrm{eV}^2}$

$\left\langle \sigma^{pixel}_{stat}\right\rangle < \sigma_{hist}$:
too conservative error estimation, but certainly no large visible systematics

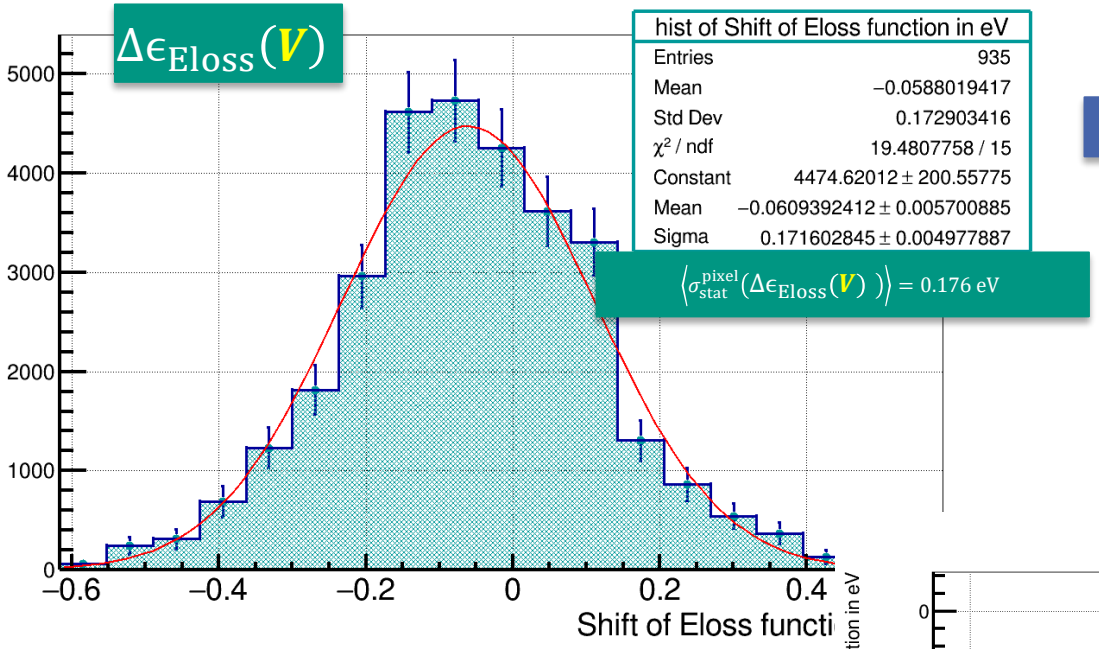
All values for krypton mode plasma, tritium mode plasma effects should be smaller



More sophisticated errors could be obtained from ring wise analysis

Plotted errors are purely statistical; too small, in case of azimuthal effects

KNM1 $L_3, U_{RW} = 175$ mV



$\langle \Delta\epsilon_{Eloss}(V) \rangle = -0.061 \pm 0.006\ \mathrm{eV}^2$

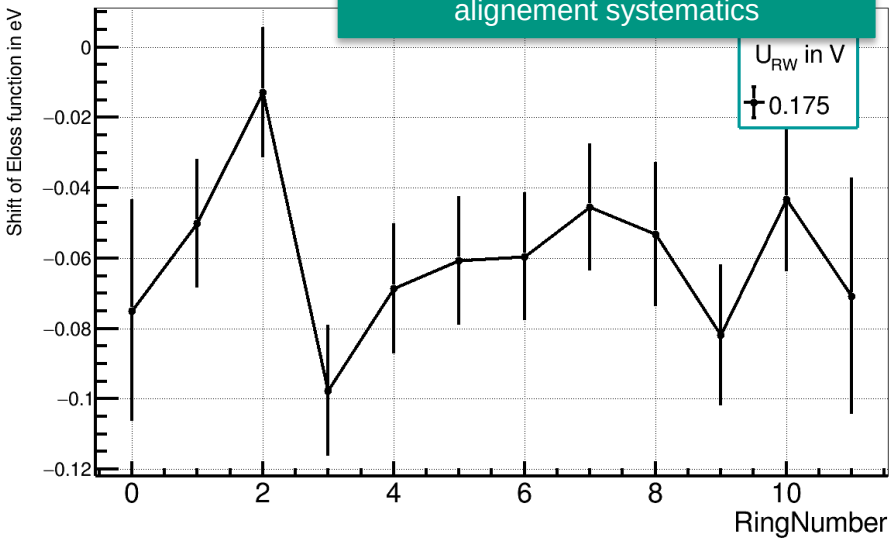
(purely statistical)

$\left\langle \sigma_{stat}^{pixel}(\Delta\epsilon_{Eloss}(V)) \right\rangle = 0.176$ eV

More sophisticated errors could be obtained from ring wise analysis

Plotted errors are purely statistical; $\Delta\epsilon_{Eloss}(V)$ is relative to $E_{Main}(V)$, no alignement systematics

$\left\langle \sigma_{stat}^{pixel} \right\rangle \approx \sigma_{hist}$:
Statistics dominated, no large visible systematics

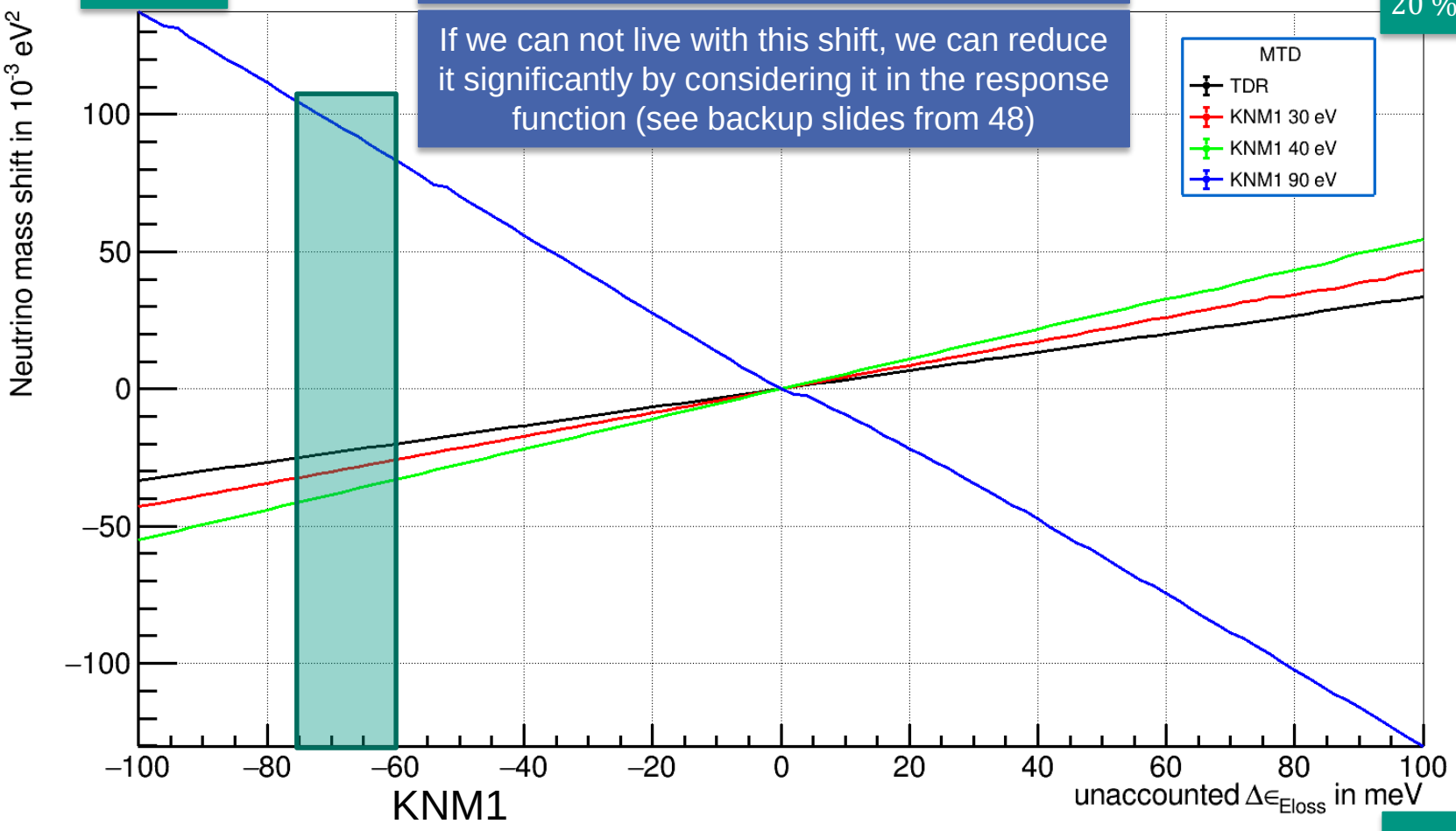


All values for krypton mode plasma, tritium mode plasma effects should be smaller

Systematic Δm_ν^2 due to Eloss Shift $\Delta\epsilon_{\mathrm{Eloss}}(V)$

Large shift; sign change with increasing MTD range often observed in scattering systematics

If we can not live with this shift, we can reduce it significantly by considering it in the response function (see backup slides from 48)



Summary

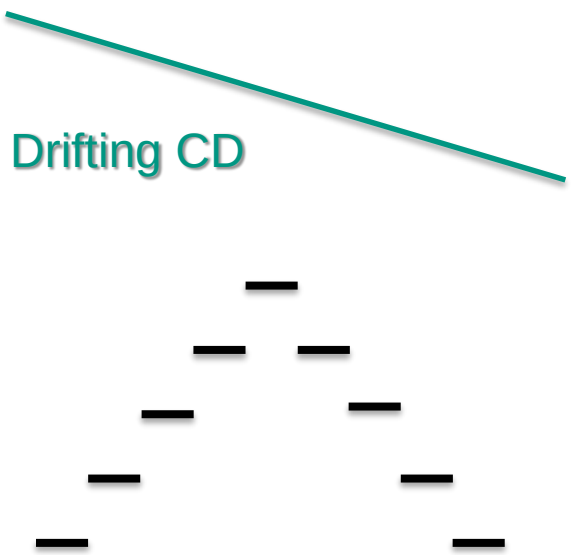
- Limits given for plasma related KNM1 neutrino mass systematics
- Longitudinal homogeneity indeed is connected to radial homogeneity
- Instability locally increases longitudinal inhomogeneity at expected minimum
- Consistent picture with other (PRO-KATRIN, $I(U_{\mathrm{RW}})$) measurements (not shown)
- Reference values of line width not fully understood

Outlook

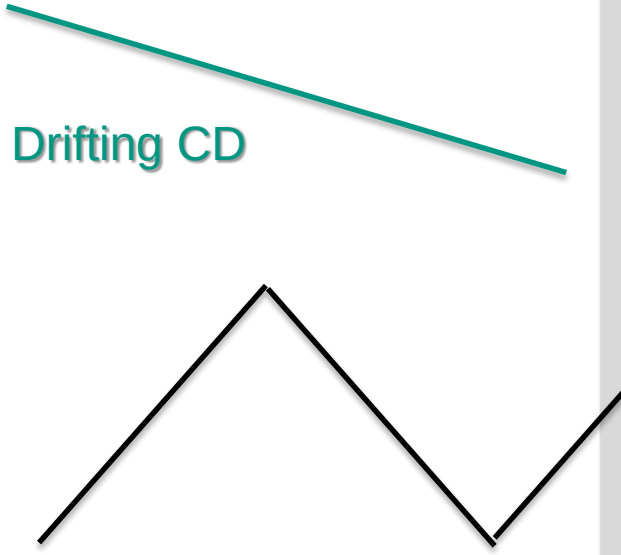
- Understand systematics and reference values
  - Further investigations on errors from radial analysis and drifts
  - Alignment
  - Incorporate time dependencies of column density and rate (reference measurement)
- Understand comparison to STS3a (no pixel dependent structure in KNM1, although equivalent analysis and experimental setup ($D_2 \rightarrow T_2$))
  - Plasma related, tritium related, tube wall, alignment changes?
- Increase statistics by using more of the data (do not wait for qU precision)
- Improve in future measurements…

Increasing statistics and reducing systematics in N²xT (or future campaigns)

- Current results on plasma effects limited by quality of data







Plan:
Up/down scan scheme should compensate drift in 1. order

Reality:
Deadtime reduces lifetime and leads to non-linear delay → No appropriate compensation!
Uncorrectable systematics

Suggestion:
Continuous U-ramp as in eloss measurements
→ Full drift compensation (reduction of systematics)
→ 33% more statistics

Better scanning scheme and more measurement time (e.g. for reference 120 h instead of 12 h!) → higher quality data

Back-up slides

Thanks to the plasma team: Manuel Klein, Alexander Fulst, Rudolf Sack, Fabian Friedel, Klaus Schlösser, Ferenc Glück, Magnus Schlösser, Guido Drexlin, …

Thanks to the krypton source: Drahos Venos, …

Thanks to the loops team: Alexander Marsteller, Michael Sturm, Florian Priester, …

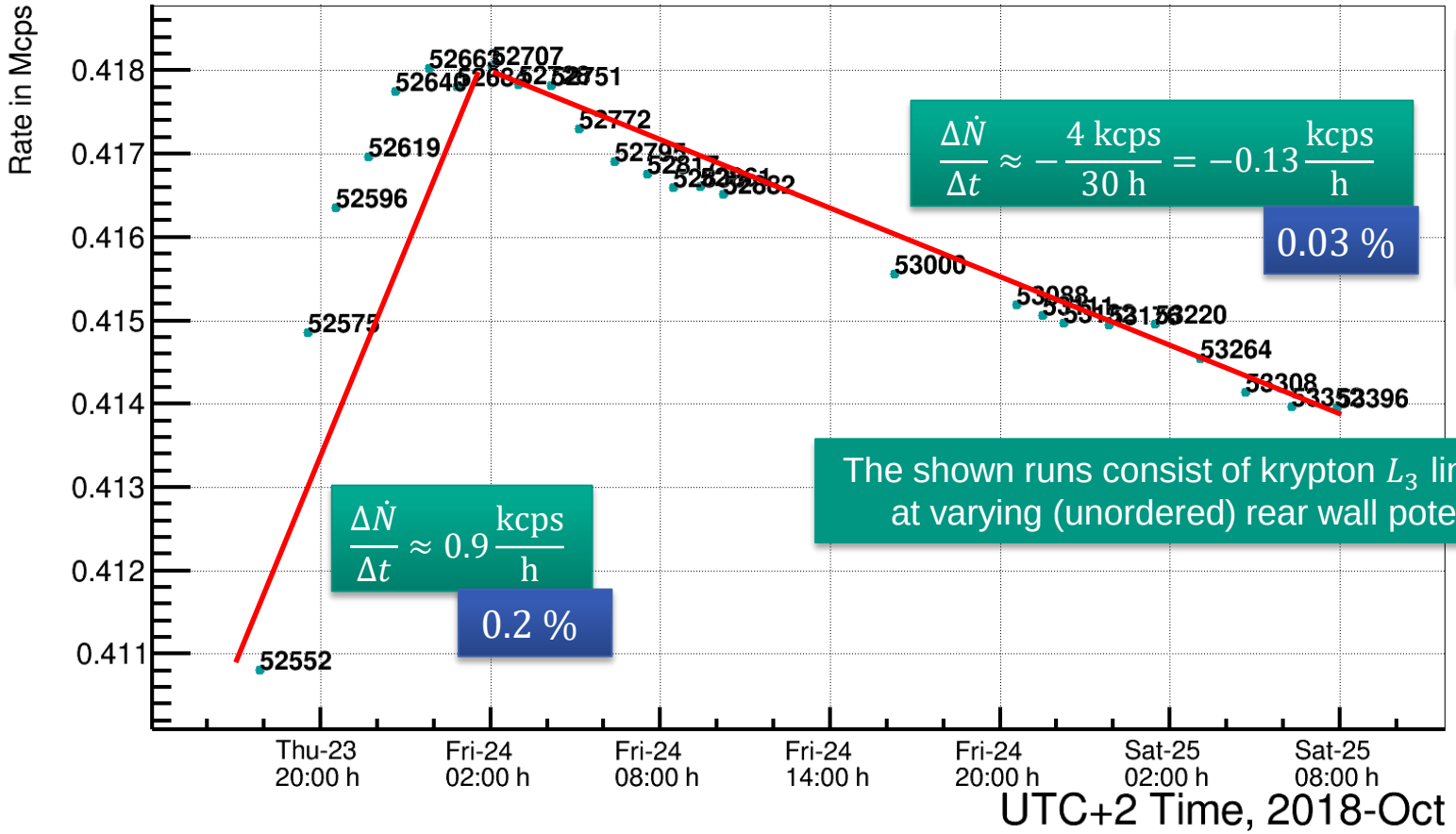
Thanks to the innominate operators!

STABILITY AND COLUMN DENSITY

Rate & rate stability: Plasma Measurements

Always measured at 30 keV for one minute

Rate variations are caused by drifting ρd_{T_2}



In **STS3a**: $\frac{\Delta\dot{N}}{\Delta t} \approx -0.25 \frac{\text{kcps}}{\text{h}}$, more linear and equal for all the runs

0.05 %

The shown runs consist of krypton L_3 line scans at varying (unordered) rear wall potentials

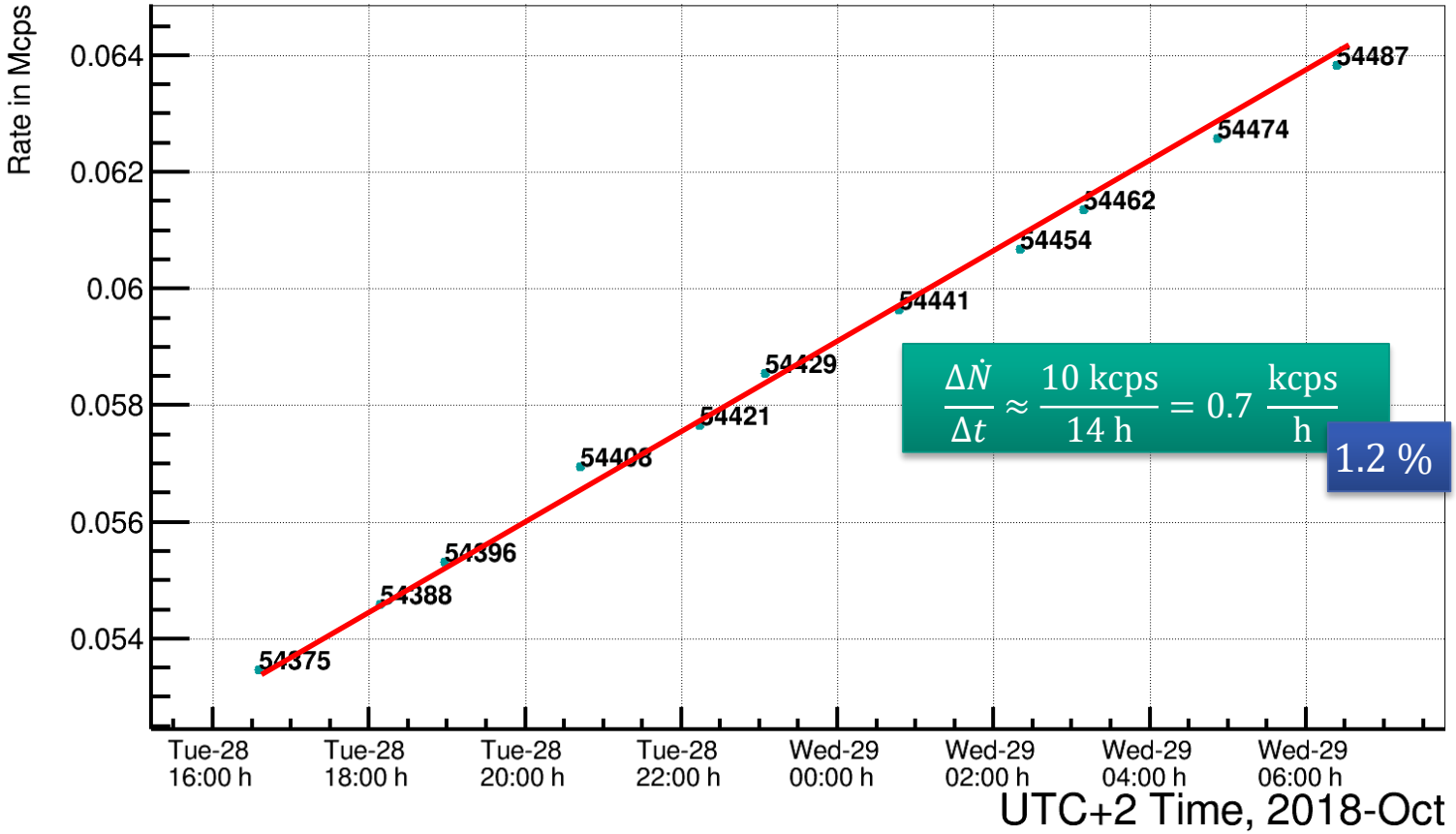
Typical run length ~ 1h

Total rate is quite optimal (Statistics vs. FPD-load)
Rate (ρd_{T_2}) stability in krypton mode is a problem which needs to be addressed in future measurements.
Measurements were (in most cases) performed up/down to eliminate linear drifts.

Rate & rate stability: Reference Measurements

Always measured at 30 keV for one minute

Rate variations are caused by filling of ρd_{Kr}



$$\frac{\Delta \dot{N}}{\Delta t} \approx \frac{10\ \mathrm{kcps}}{14\ \mathrm{h}} = 0.7\ \frac{\mathrm{kcps}}{\mathrm{h}}$$

1.2 %

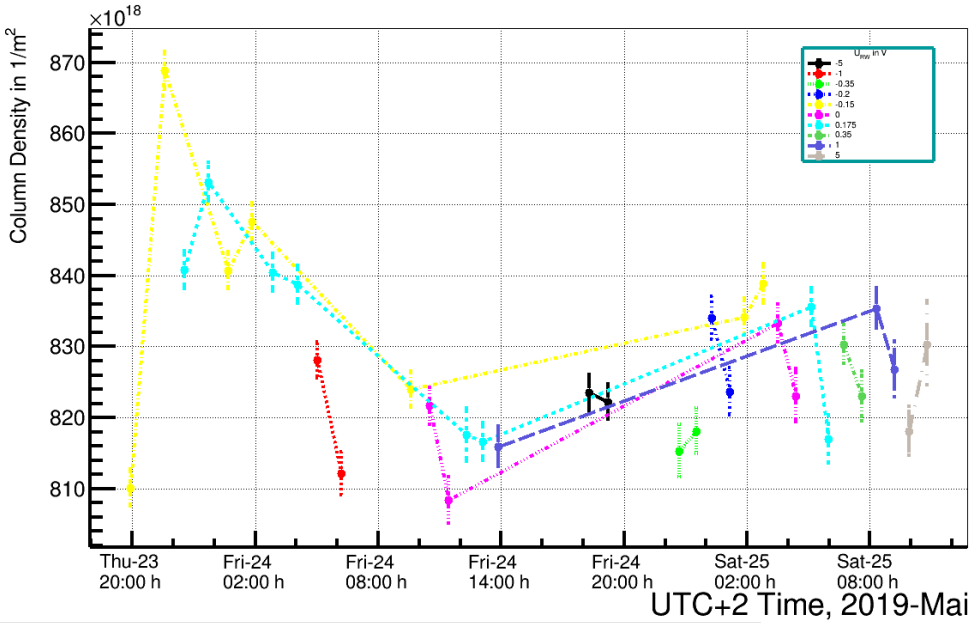
In **STS3a**: $\frac{\Delta \dot{N}}{\Delta t} \approx 1.8 \frac{\mathrm{kcps}}{\mathrm{h}}$, difficult to use at all.

5 %

(total rate slightly lower in STS3a)

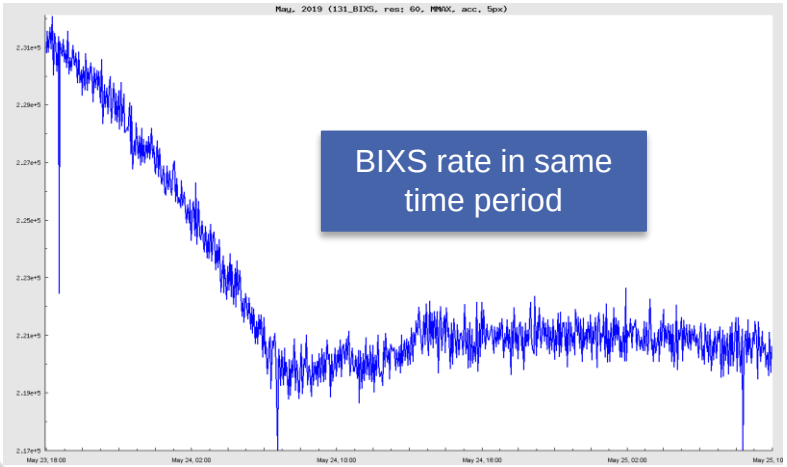
Total rate is factor 10 lower.
Rate (ρd_{Kr}) stability in krypton reference measurements is a severe problem, which can only be addressed by waiting even longer (> 2 d), after injection. However, we only need one really good measurement.

Column density ρd_{T_2}

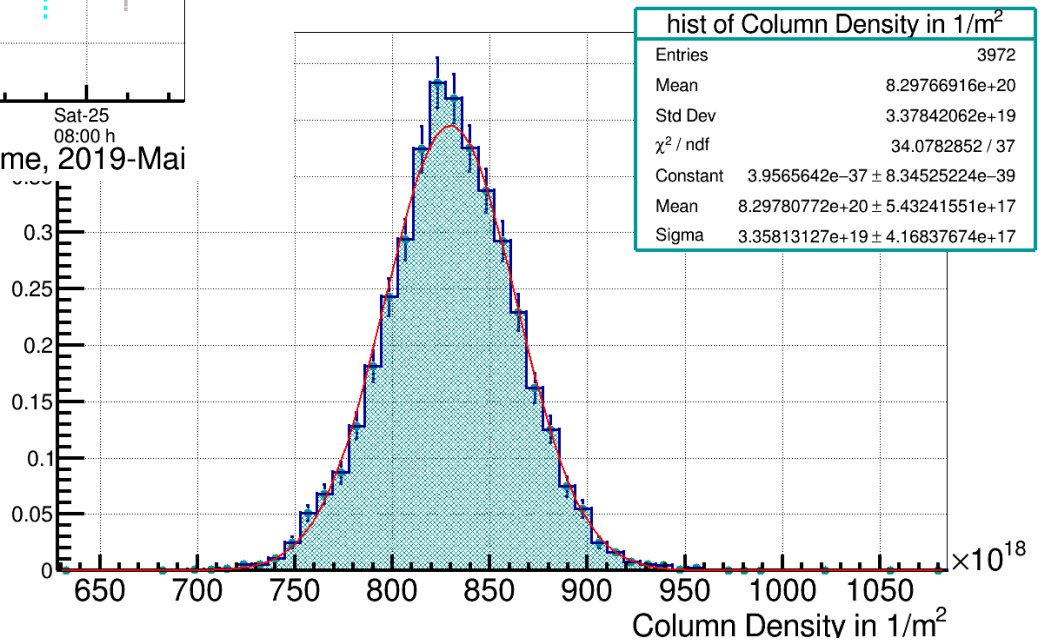


After first night: rather stable column density of 17 % nominal

(Fit from SSC Eloss and Gas model, Using the new $\sigma_{\mathrm{inel}}(30\ \mathrm{keV}) = 2.435 \cdot 10^{-22} \frac{1}{m^2}$)



BIXS rate in same time period



What do the errors mean?

Systematics dominated uniform average $E_{\mathrm{Main}}(V)$

Width of the histogram covers the whole uncertainty
(however: unknown, constant offsets like absolute work function)

We are sensitive to radial or pixel wise effects

Statistics dominated uniform average

Width of the histogram my largely overestimate the uncertainty, if there are no real radial or temporal dependencies

We are not sensitive to pixel wise effects and have to rely on expectations for radial analysis:

$\sigma^2_{\mathrm{Main}}(V)$ — Azimuthal dependency given by misalignment; ring wise averages have additional error

$\Delta\epsilon_{\mathrm{Eloss}}(V)$ — Measured relative to $E_{\mathrm{Main}}(V)$: no additional error in ring wise averages

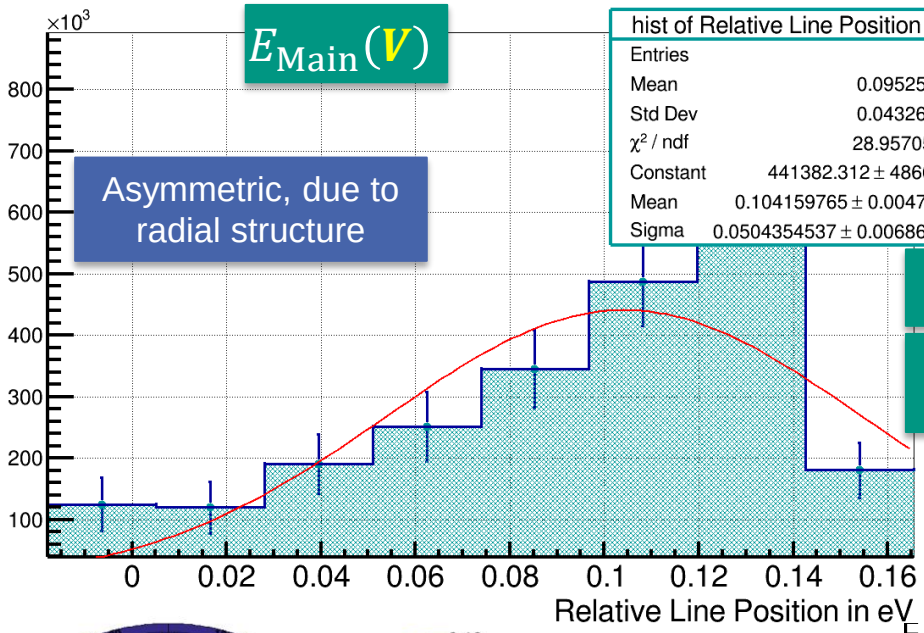
In both cases real physical radial dependencies due to plasma potential

REAR WALL VOLTAGE AT -0.350 V

Seems to show the best longitudinal homogeneity in the KNM1 measurement

KNM1 $L_3, U_{RW} = -350$ mV

All values for krypton mode plasma, tritium mode plasma effects should be smaller



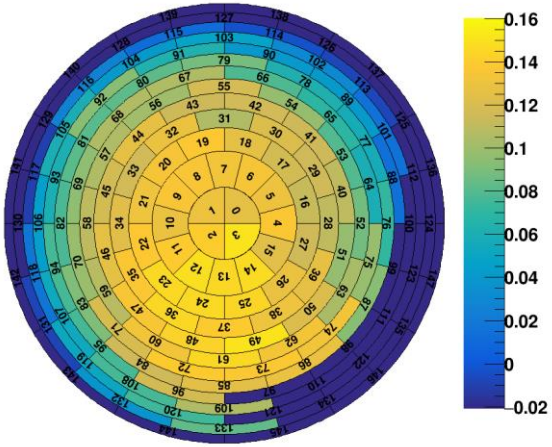
Asymmetric, due to radial structure

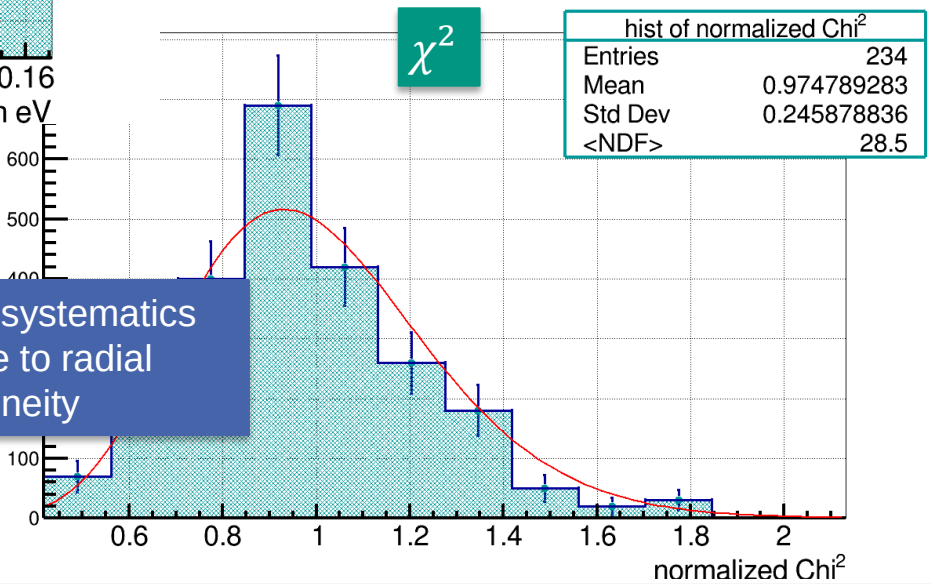
Plasma related shift: $\langle E_{Main}(V) \rangle = -104 \pm 40$ mV

$\left\langle \sigma_{stat}^{pixel} \left(E_{Main}(V) \right) \right\rangle = 0.01$ eV

Systematics dominated

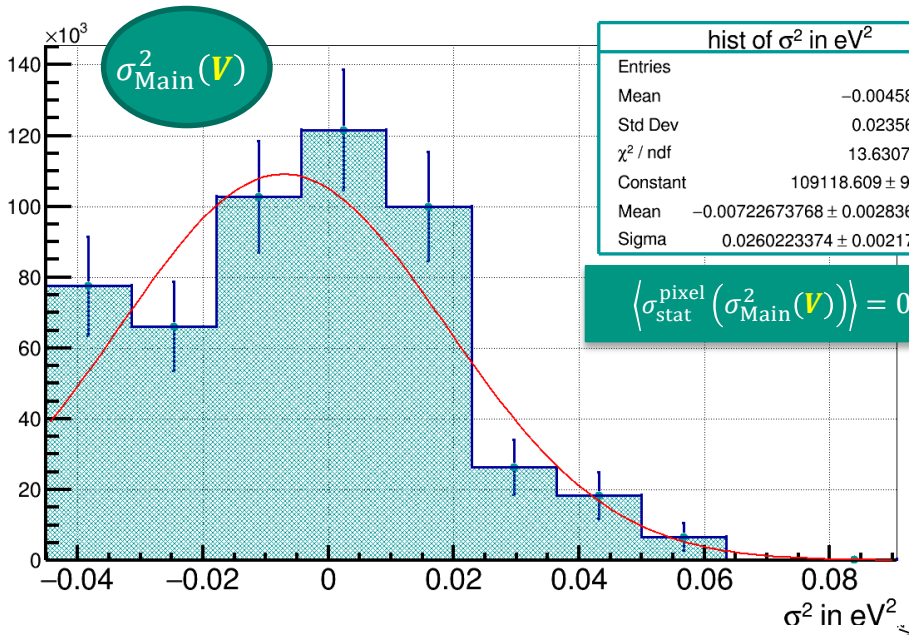
$\sigma_{syst}(\langle E_{Main}(V) \rangle) = \sqrt{\sigma_{hist}{}^2 - \left\langle \sigma_{stat}^{pixel} \right\rangle^2} = 0.040$ eV





Total uncertainty systematics dominated due to radial inhomogeneity

KNM1 $L_3, U_{RW} = -350$ mV



$\left\langle \sigma^{pixel}_{stat}\left(\sigma^2_{Main}(V)\right)\right\rangle = 0.024\ \mathrm{eV}^2$

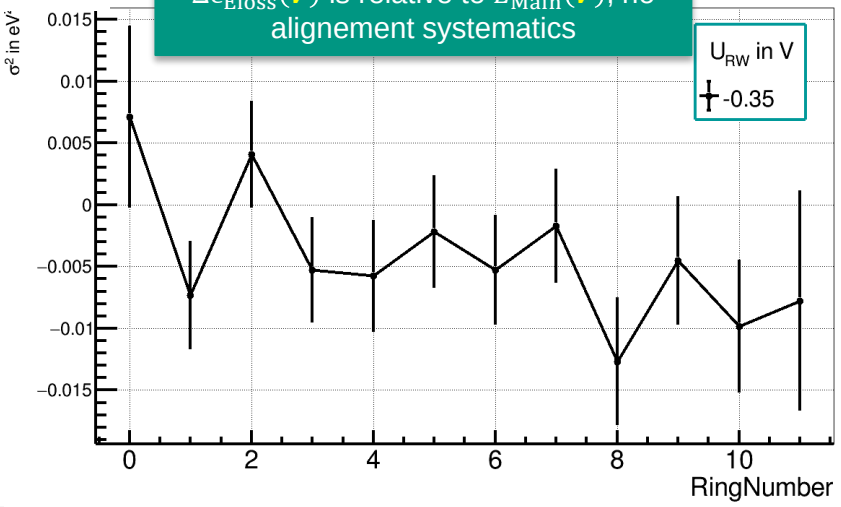
Problems with error estimation, values might change on the $10^{-2}\mathrm{eV}^2$ scale

$\left\langle \sigma^2_{Main}(V)\right\rangle = -0.007 \pm 0.026\ \mathrm{eV}^2$

(conservative)

More sophisticated errors could be obtained from ring wise analysis

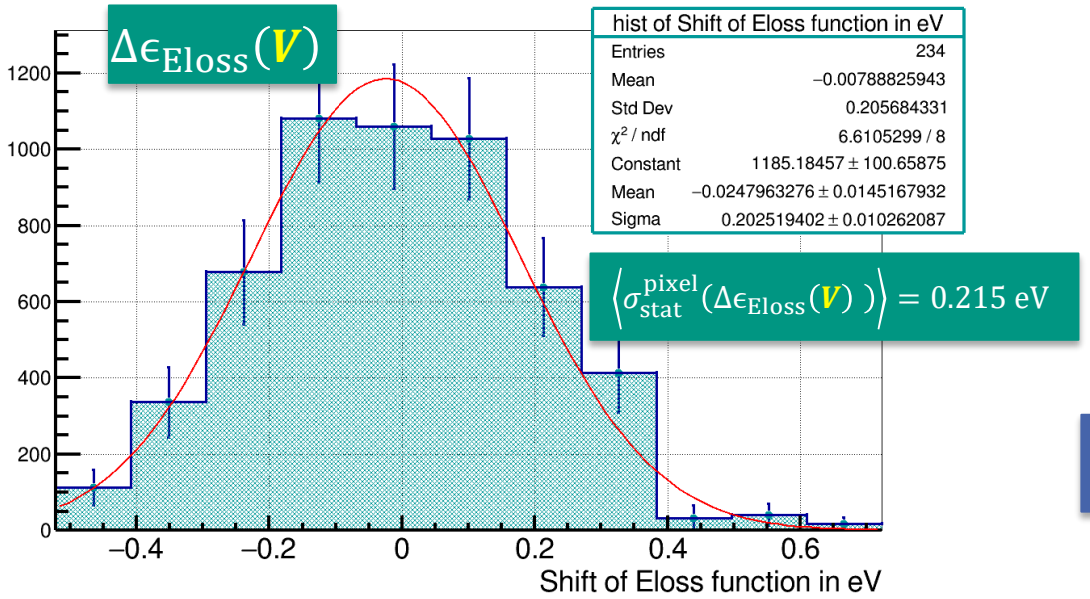
Plotted errors are purely statistical; $\Delta\epsilon_{Eloss}(V)$ is relative to $E_{Main}(V)$, no alignement systematics



$\left\langle \sigma^{pixel}_{stat}\right\rangle < \sigma_{hist}$:
too conservative error estimation, but certainly no large visible systematics

All values for krypton mode plasma, tritium mode plasma effects should be smaller

KNM1 $L_3, U_{RW} = -350$ mV



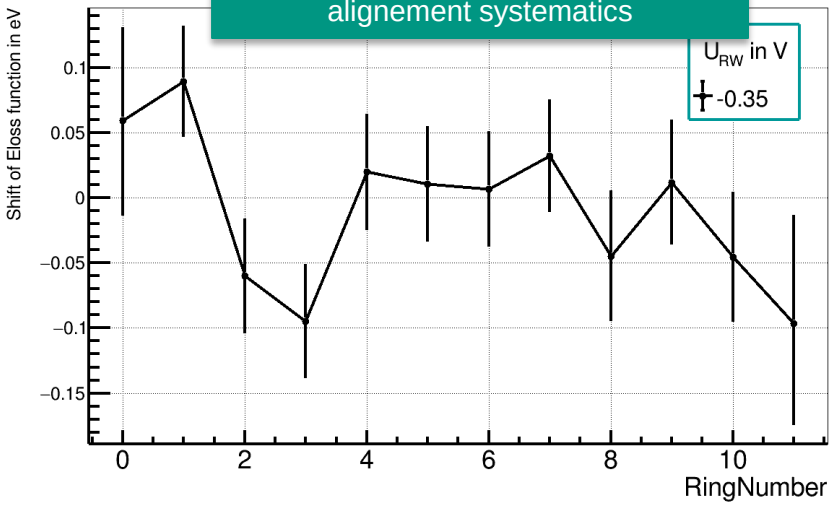
$\left\langle \sigma_{stat}^{pixel}(\Delta\epsilon_{Eloss}(V)) \right\rangle = 0.215$ eV

$\langle \Delta\epsilon_{Eloss}(V) \rangle = -0.025 \pm 0.015$ eV^2

(purely statistical)

More sophisticated errors could be obtained from ring wise analysis

Plotted errors are purely statistical; $\Delta\epsilon_{Eloss}(V)$ is relative to $E_{Main}(V)$, no alignement systematics



$\left\langle \sigma_{stat}^{pixel} \right\rangle \approx \sigma_{hist}$:
Statistics dominated, no large visible systematics

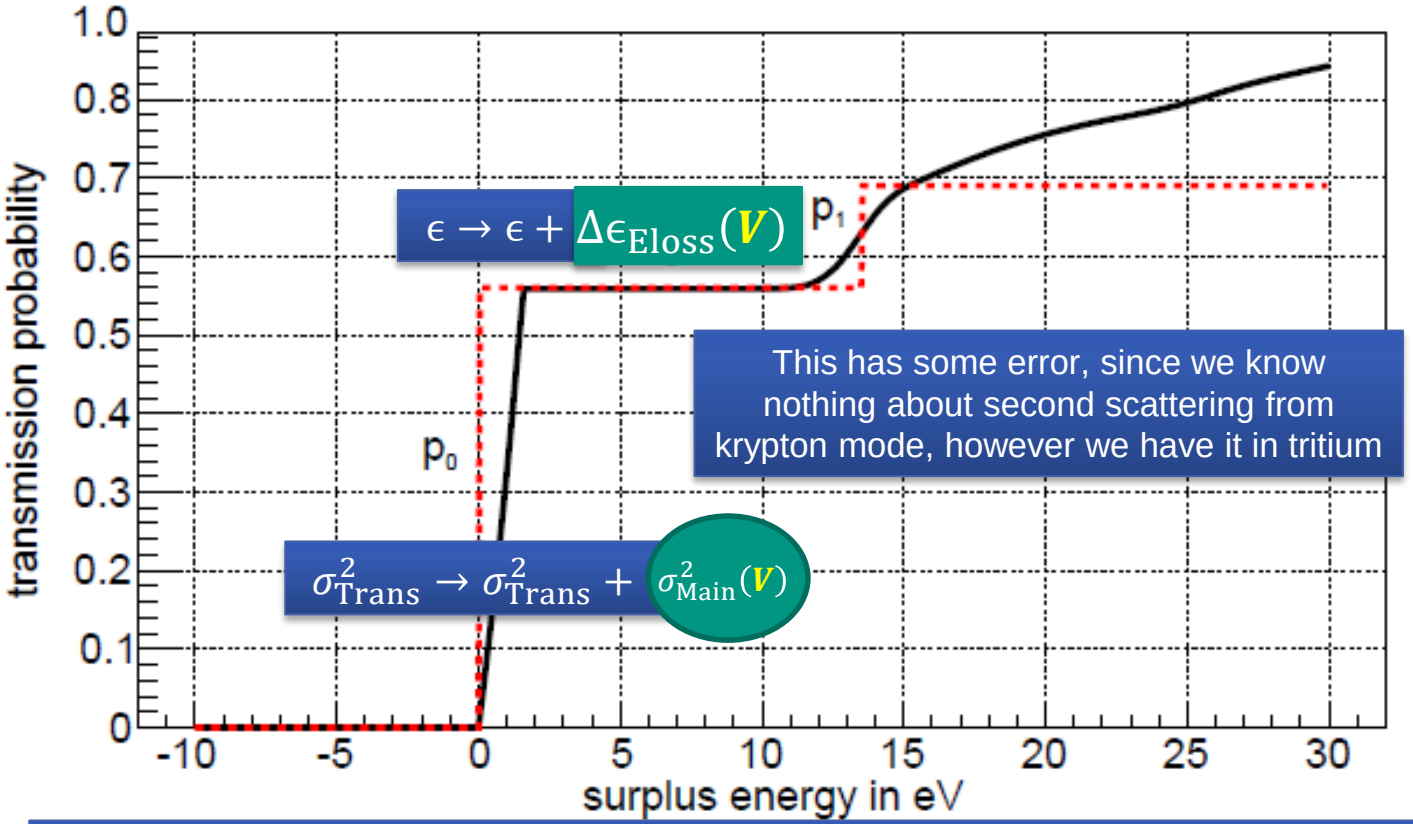
All values for krypton mode plasma, tritium mode plasma effects should be smaller

CORRECTING PLASMA INDUCED SYSTEMATICS

Quantitative analysis of the reduction of the neutrino mass shift by using a modified response function, which considers $\Delta\epsilon_{\mathrm{Eloss}}(\boldsymbol{V})$.

Correcting plasma induced systematics

Plasma induced systematics can be compensated by modifying the response function



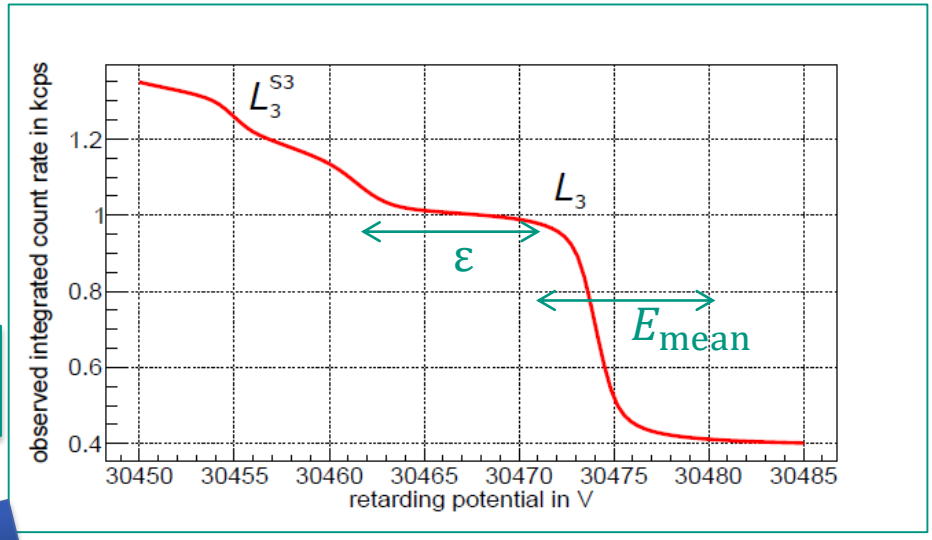
This has some error, since we know nothing about second scattering from krypton mode, however we have it in tritium

For KNM1 the errors on $\sigma^2_{\mathrm{Main}}(V)$ and $\Delta\epsilon_{\mathrm{Eloss}}(V)$ are large, such that including will not help and only conservative neutrino mass shift estimation is possible.
For full KATRIN, however, including is the only option.

Correction of plasma inhomogeneity systematic

1. Fit origin $\Delta\varepsilon$ of Eloss: $\varepsilon = 12\ \mathrm{eV} + \Delta\varepsilon(V)$
   Line position: $\Delta E_{\mathrm{mean}}(V_{\mathrm{K}})$

Krypton



2. Translate $\Delta\varepsilon(V_{\mathrm{K}})$ (krypton) to $\Delta\varepsilon'(V_{\mathrm{Model}})$ (tritium)
   $E_{\mathrm{mean}}(V_{\mathrm{K}})$ $\Delta E'_0(V_{\mathrm{Model}})$

- Exact way?
- Simplifications: $\Delta\varepsilon(V_{\mathrm{K}}) > \Delta\varepsilon'(V_{\mathrm{T2}})$?

Fancy theory

$a^2 + b^2 = c^2$

$e^{i\pi} = -1$

$1 + \frac{1}{4} + \frac{1}{8} + \frac{1}{16} + \cdots = \frac{\pi^2}{6}$

3. Fit with correctected Eloss $\Delta\varepsilon'(V_{\mathrm{Model}})$ and endpoint $\Delta E'_0(V_{\mathrm{Model}})$
   to obtain $\Delta m^2(V_{\mathrm{T2}}) = 0$ and $\Delta E_0(V_{\mathrm{T2}}) = 0$!!!

Tritium

- Or rather $\Delta m^2(V_{\mathrm{T2}}) \sim 10^{-5}$ and $\Delta E_0(V_{\mathrm{T2}}) \sim 10^{-4}$,
  but only if part 2. was done very well

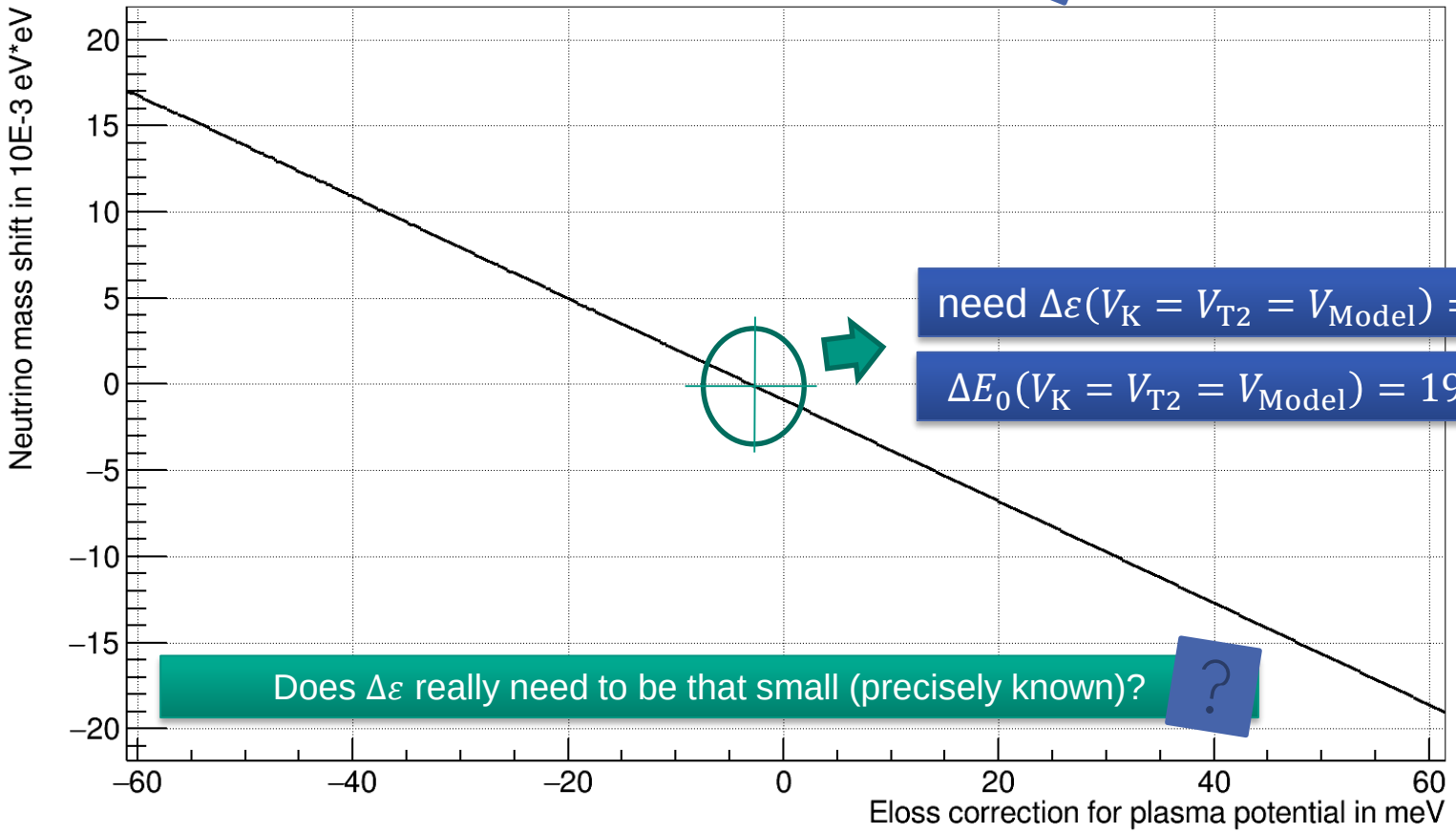
Since we do not know 2., start from the back…

… and also just use the same potential for everything

Tritium

3. Which $\Delta\varepsilon'$ do we need to get $\Delta m^2 = 0$, when we include a plasma potential, and what is $\Delta E'_0$ for this $\Delta\varepsilon'$ value

?



need $\Delta\varepsilon(V_K = V_{T2} = V_{Model}) = -3$ mV

$\Delta E_0(V_K = V_{T2} = V_{Model}) = 19.0$ mV

(not shown)

Does $\Delta\varepsilon$ really need to be that small (precisely known)?

?

Ask Stefan Groh

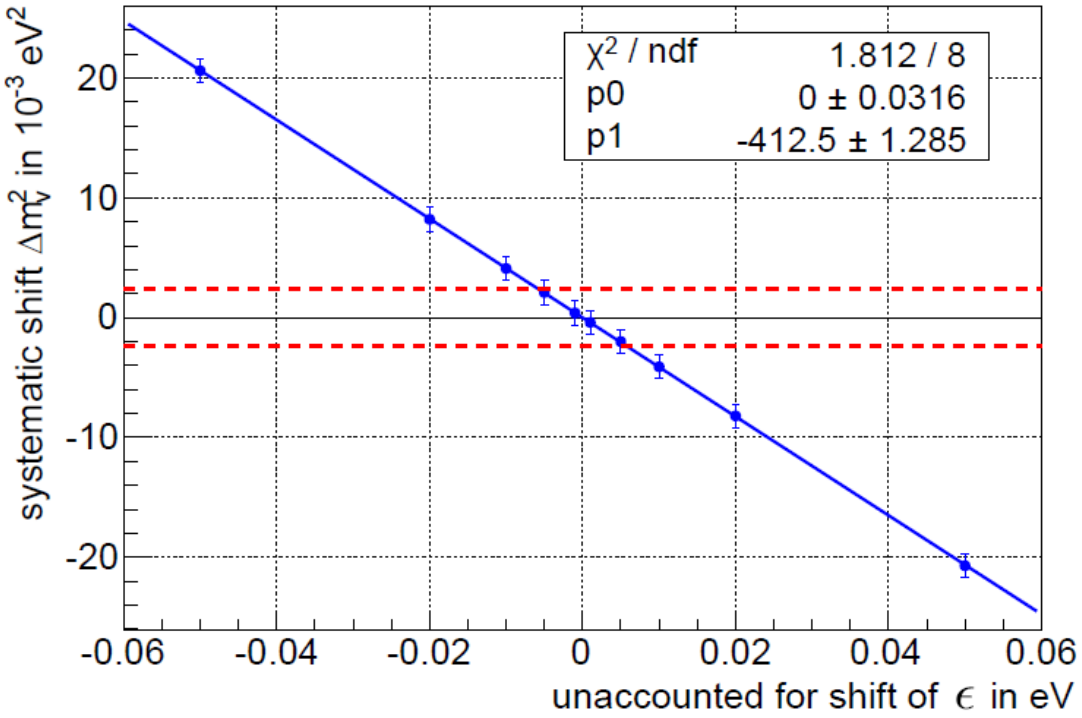


Figure 6.33: Systematic shifts on the neutrino mass due to an unaccounted for inelastic energy loss shift. The dashed red lines show the maximal allowed shift of $|\Delta m_\nu^2| = 2.4 \cdot 10^{-3}\,\mathrm{eV}^2$. The fitted linear function reveals the allowed deviation range of $[-5.8\,\mathrm{meV}, 5.8\,\mathrm{meV}]$. The shown error bars are increased by a factor of 10 for better visibility.

Already S. Groh stated, that 5.8 meV precision is necessary.

If we interpret the effect of plasma potential inhomogeneities as shift of the eloss function, we understand, why the systematic is that large.

So can we get this precise measurements for $\Delta\varepsilon$ from krypton?

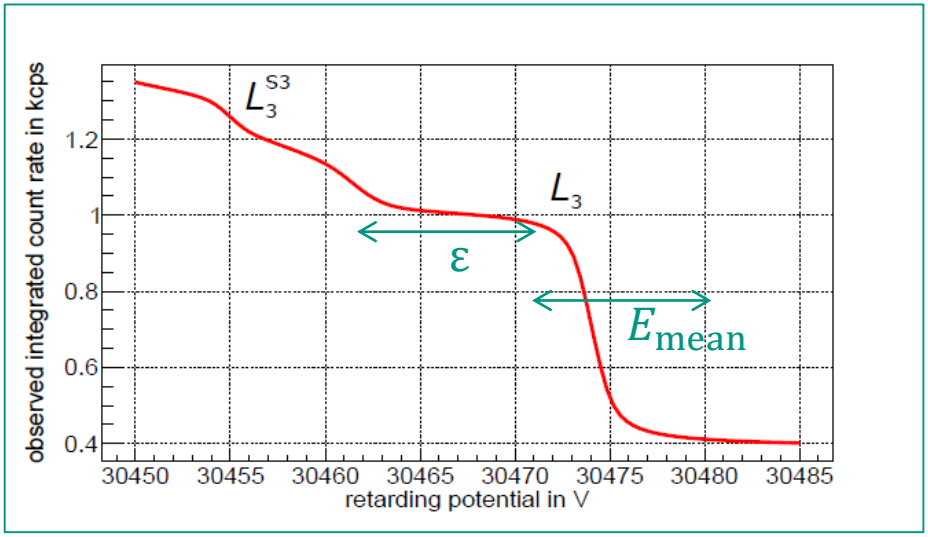
Krypton toy data fit

1. Fit origin $\Delta\varepsilon$ of Eloss: $\varepsilon = 12\ \mathrm{eV} + \Delta\varepsilon(V)$
   Line position: $\Delta E_{\mathrm{mean}}(V_{\mathrm{K}})$

Krypton

$$\Delta\varepsilon(V_{\mathrm{K}} = V_{\mathrm{T2}} = V_{\mathrm{Model}}) = 3.9\ \mathrm{mV}$$

$$\Delta E_{\mathrm{Mean}}(V_{\mathrm{K}} = V_{\mathrm{T2}} = V_{\mathrm{Model}}) = 18.9\ \mathrm{mV}$$



1 mV difference remains, which is due to different averaging of the krypton and tritium spectrum

It can be expected, that the change of the potential due to temperature change is much larger

Conclusion:

Endpoint correction seems to **work** to mV level

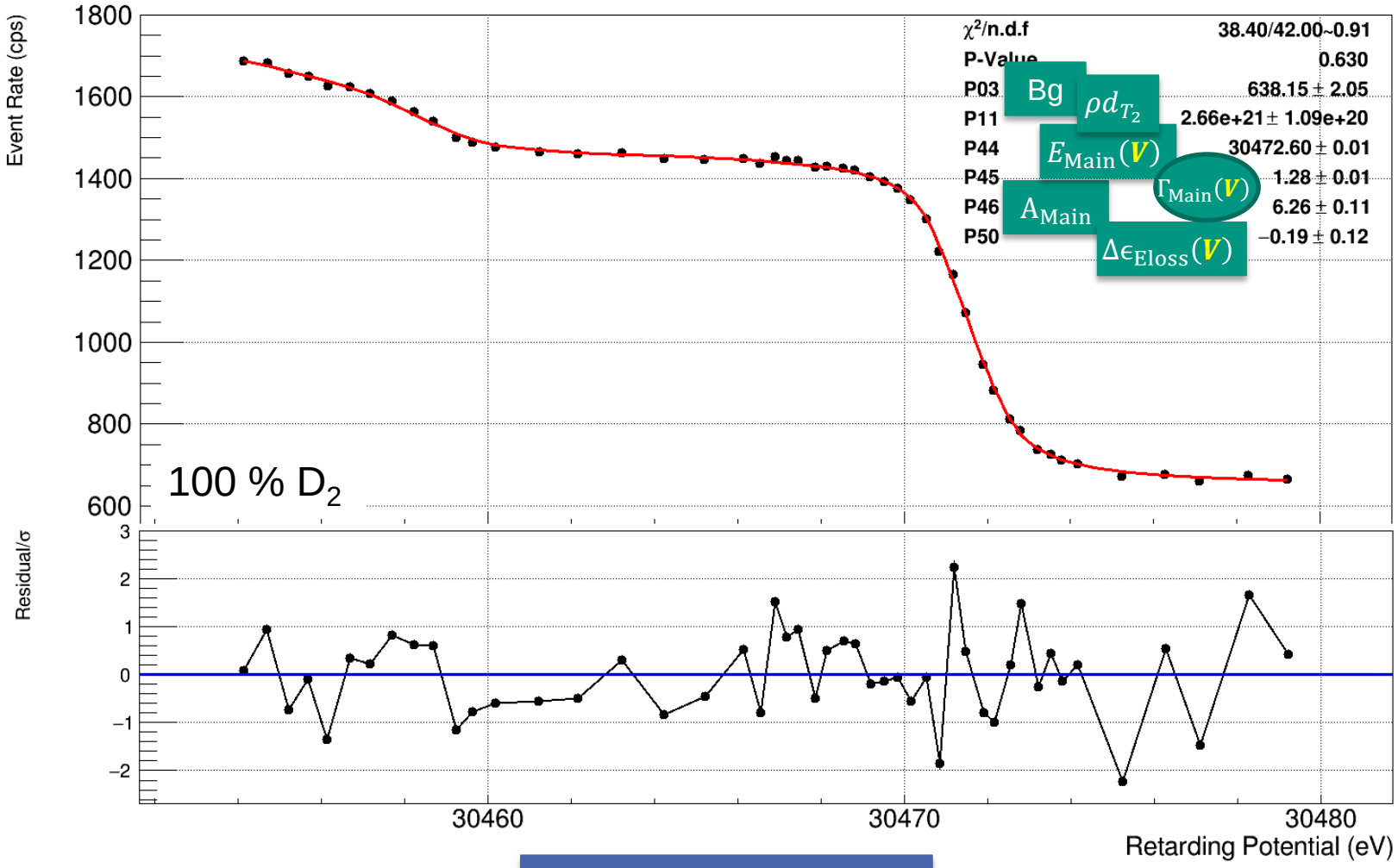
Eloss correction seems to **work** (although, it depends on the MTD)

Need investigations of step 2.!!!

RANDOM SPECTRUM

Just to show a fit

Pixelwise with reduced parameter set



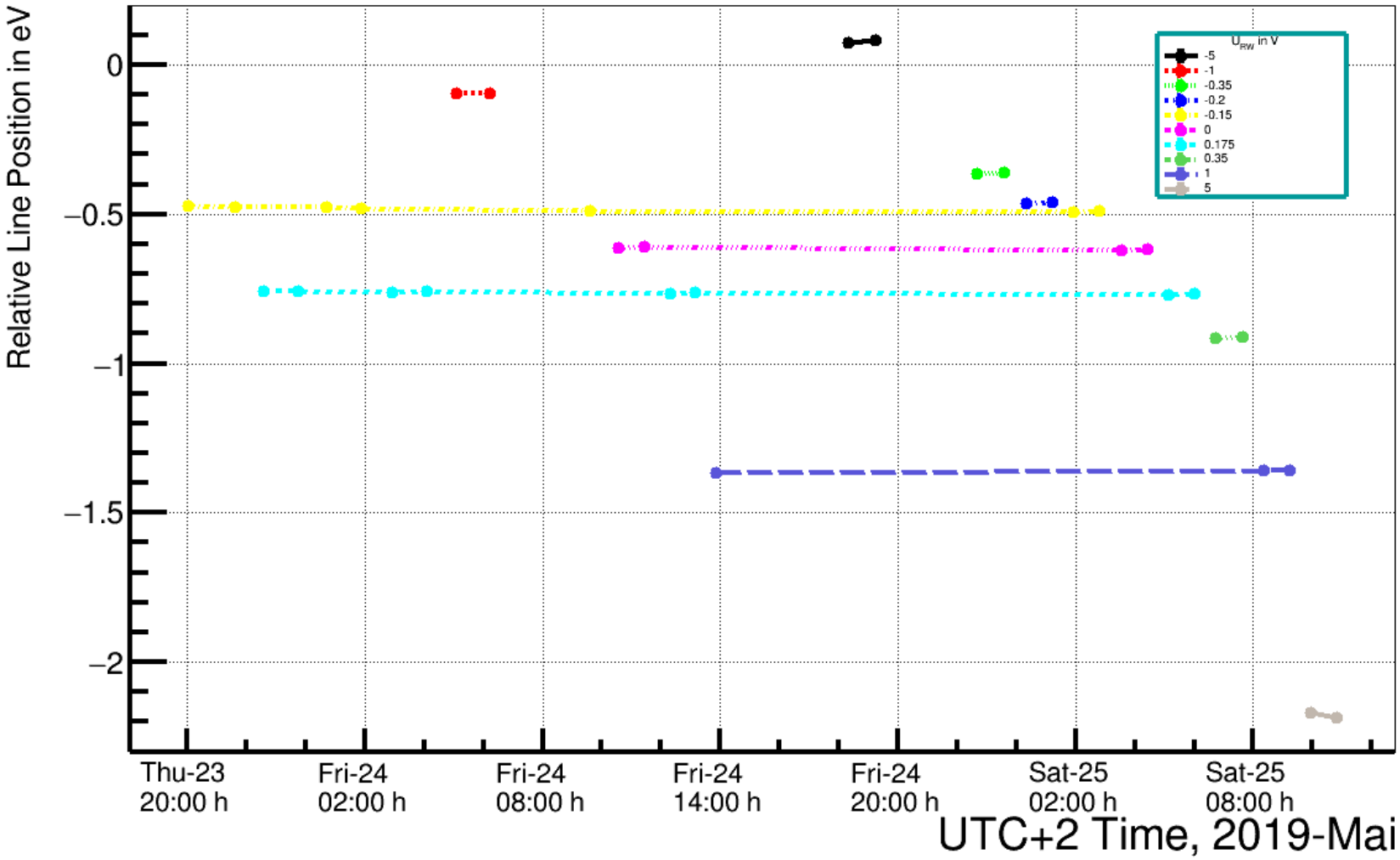
Fits work nicely

TIME DEPENDENCIES

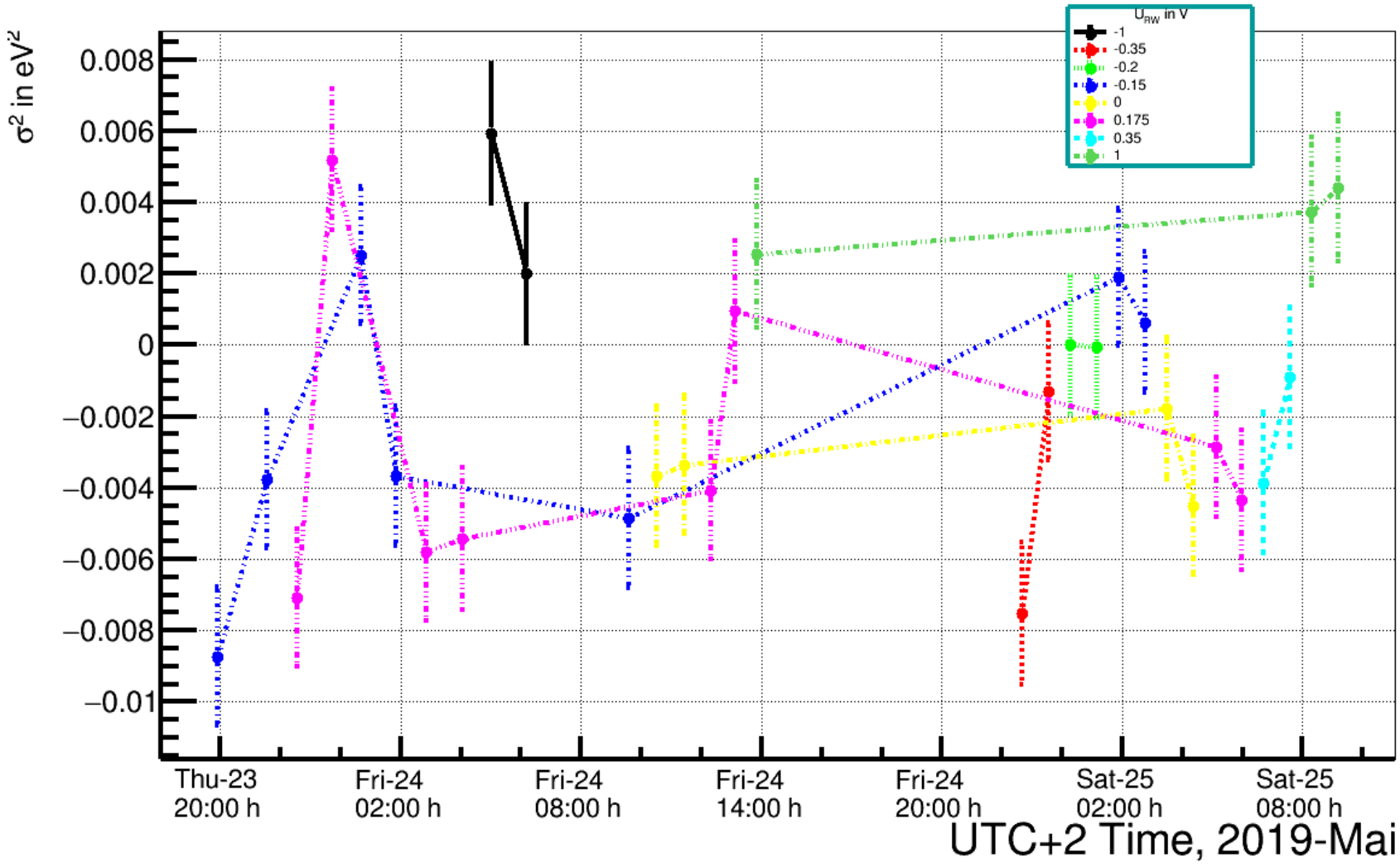
Important to look at for proper errors and also physical drifts

Line Position $E_{\mathrm{Main}}(V)$ vs. Time

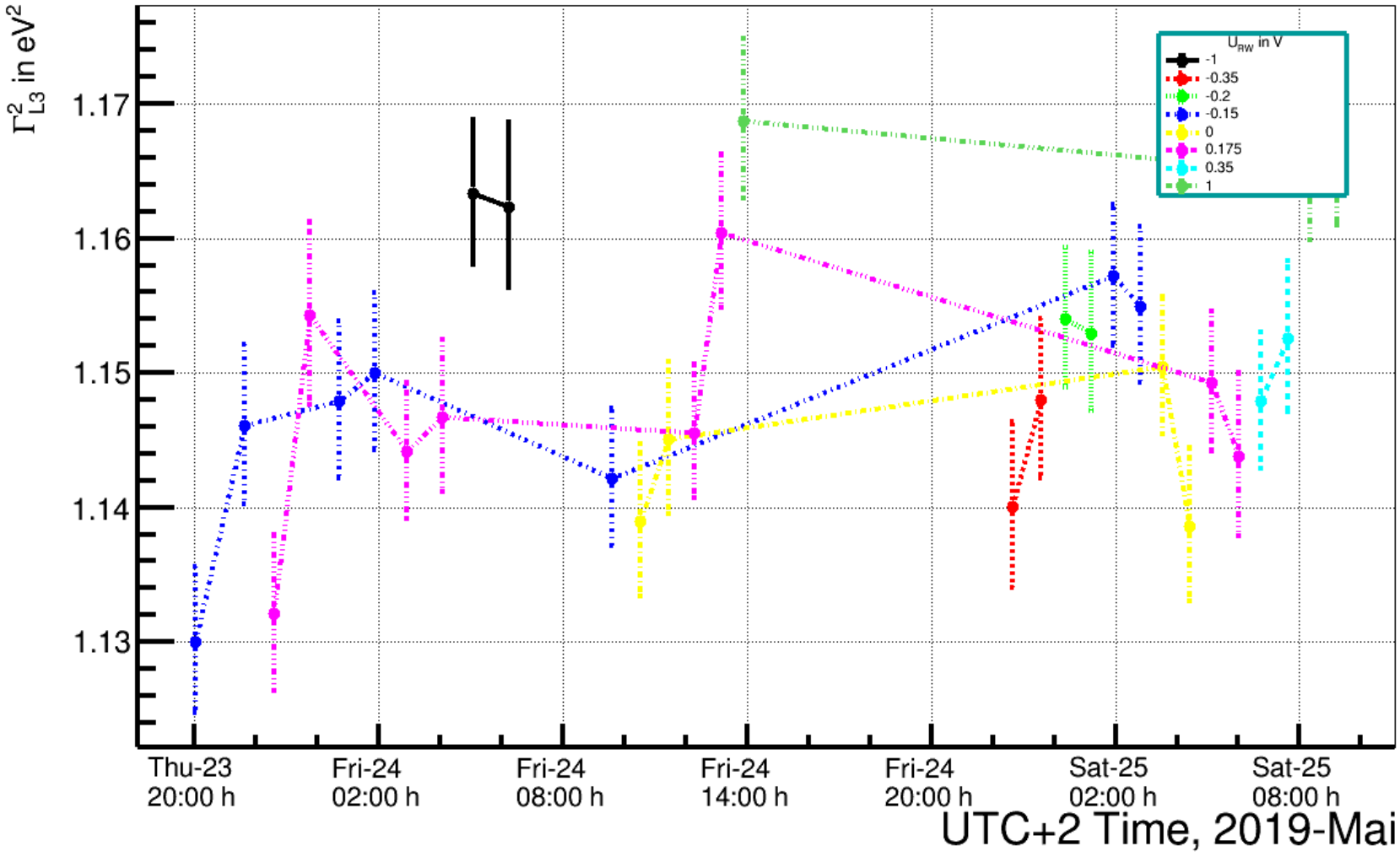
Old reference value



Line Broadening $\sigma^2_{\mathrm{Main}}(V)$ vs. Time

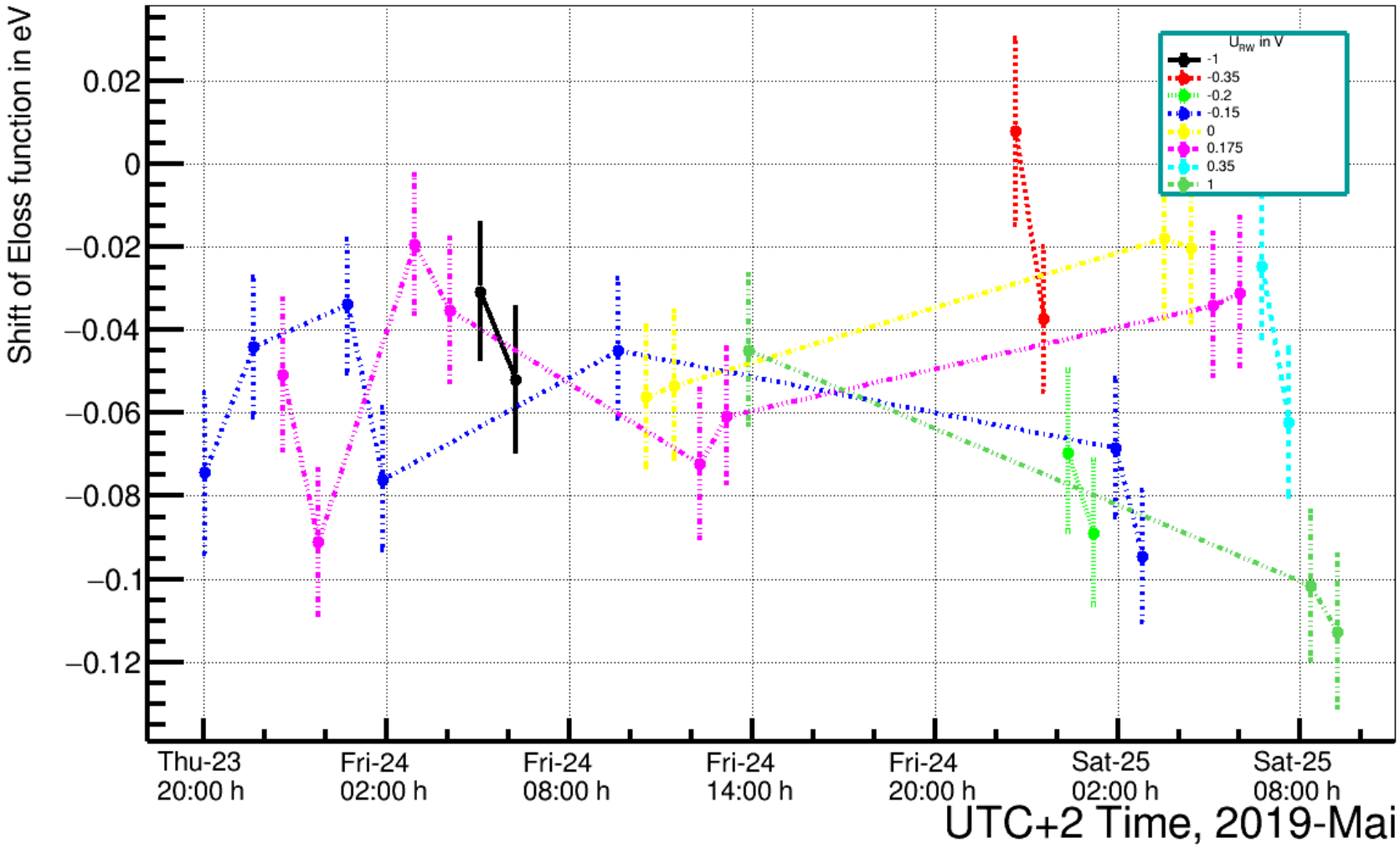


LineWidth $\Gamma_{\mathrm{Main}}(V)$ vs. Time



Eloss Shift $E_{\mathrm{Main}}(V)$ vs. Time

D2 eloss function



Systematic Δm_ν^2 due to broadening

$\Delta m_\nu^2 = -2\sigma^2$

Analysis/Ring	Broadening $\sigma_{\mathrm{Main}}(V)$ in mV	Systematic shift Δm_ν^2 in $10^{-3}\mathrm{eV}^2$
uniform		
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		

Systematic Δm_ν^2 due to Eloss shift

Analysis/Ring	Eloss shift $\Delta\epsilon_{\mathrm{Eloss}}(V)$ in mV	Systematic shift Δm_ν^2 in $10^{-3}\mathrm{eV}^2$
uniform		
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		