

Temperature requirements for charge attenuation correction

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Introduction

- Jose's slide at CALCI scope review
- The idea is to derive the requirements on temperature measurements to achieve ~1% error on the transport calibration
- For the moment we focus on charge attenuation only

Energy calibration requirements

$$dE_{hit}(x, y, z)[MeV] = C_{recombination}(x, y, z)[MeV/e] \times C_{transport}(x, y, z) \times C_{collection}(wire) \times C_{electronics}(channel)[e/ADC] \times dQ(channel)[ADC]$$

- The goal of calibration is to determine these correction factors/ functions/maps
- The product of recombination, transport, collection and electronics corrections $C_r \times C_t \times C_c \times C_e$ must be known to **2% or better**
- Aim for 0.5% - 1% for each correction factor

Charge attenuation correction

- The charge Q arriving to the anode for a given drift time t and initial deposited charge Q_0 :

$$Q(t) = Q_0 \cdot e^{-t/\tau}$$

- where τ is the electron lifetime
- The charge attenuation correction is therefore, assuming τ does not change along the drift path,

$$C = e^{t/\tau}$$

- In practice, τ change along the drift path and therefore one needs to integrate

Electron lifetime prediction

- The electron lifetime is inversely proportional to the impurity concentration
- The electron lifetime at a given position \mathbf{r} can be computed using the reference lifetime (τ_0) and the normalized impurities at position \mathbf{r} given by CFD simulations, $I(\mathbf{r})$

$$\tau(\vec{r}) = \frac{\tau_0}{I(\vec{r})}$$

- The reference lifetime (τ_0) is the one measured using cosmics, purity monitors (PrM) and maybe laser tracks.

Error on charge att. correction

- The error on charge attenuation correction has several components:
 - Reference electron lifetime error (σ_{τ_0})
 - Error on Normalised impurity prediction from CFD (σ_I)

$$C = e^{t/\tau}$$
$$\tau(\vec{r}) = \frac{\tau_0}{I(\vec{r})}$$
$$\left(\frac{\sigma_C}{C}\right)^2 = \left(\frac{\sigma_{\tau_0}}{\tau_0}\right)^2 + \left(\frac{t}{\tau} \frac{\sigma_I}{I}\right)^2$$

- The higher the e- lifetime the lower the effect of the CFD extrapolation

Reference electron lifetime

$$\left(\frac{\sigma_C}{C}\right)^2 = \left(\frac{\sigma_{\tau_0}}{\tau_0}\right)^2 + \left(\frac{t}{\tau} \frac{\sigma_I}{I}\right)^2$$

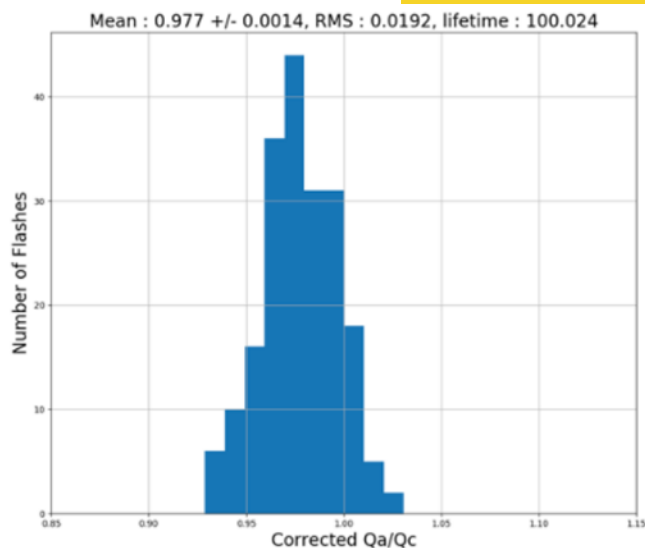
PrM lifetime error

from CALCI review answers

- Very small statistical uncertainty due to strong signal strength, low noise and large number of flashes in PrM measurement

$$\text{RMS}=2.0\% \quad \Delta_{\text{stat}}(\text{Qa/Qc})=2\%/\sqrt{N_{\text{flash}}}=0.14\%.$$

J.Bian



Long purity monitor can control uncertainty in PrM Qa/Qc within 2%

- Uncertainties in TPC Qa/Qc calibrated with PrMs depend on LAr purity and precision of PrM-to-TPC extrapolation
- Under high LAr purity or with good extrapolation technique, uncertainty in TPC Qa/Qc is same as PrM Qa/Qc

Table I: Summary of statistical and systematic uncertainties

		16 cm drift length (current) (column 1)	47cm drift length (2.9xcurrent) (column 2)	64cm drift length (4xcurrent) (column 3)
1	Statistical uncertainties in PrM Qa/Qc	0.14%	0.14%	0.14%
2	Run to run fluctuations PrM Qa/Qc	0.7%	0.7%	0.7%
3	Systematic uncertainties in PrM Qa/Qc	5.8%	2.1%	1.4%
4	Overall uncertainties in PrM Qa/Qc (drift time 2.3ms)	5.8%	2.2%	1.5%
5	Precision on TPC Qa/Qc at 3ms, 10ms, 100ms lifetimes (0% non-uniformity of impurity concentration)	5.8%	2.2%	1.5%
6	Precision on TPC Qa/Qc at 3ms lifetime (5% non-uniformity of impurity)	6.9%	4.3%	4.0%
7	Precision on TPC charge at 10ms lifetime (5% non-uniformity of impurity)	5.9%	2.5%	1.9%
8	Precision on TPC charge at 100ms lifetime (5% non-uniformity of impurity)	5.8%	2.2%	1.5%

Reference lifetime

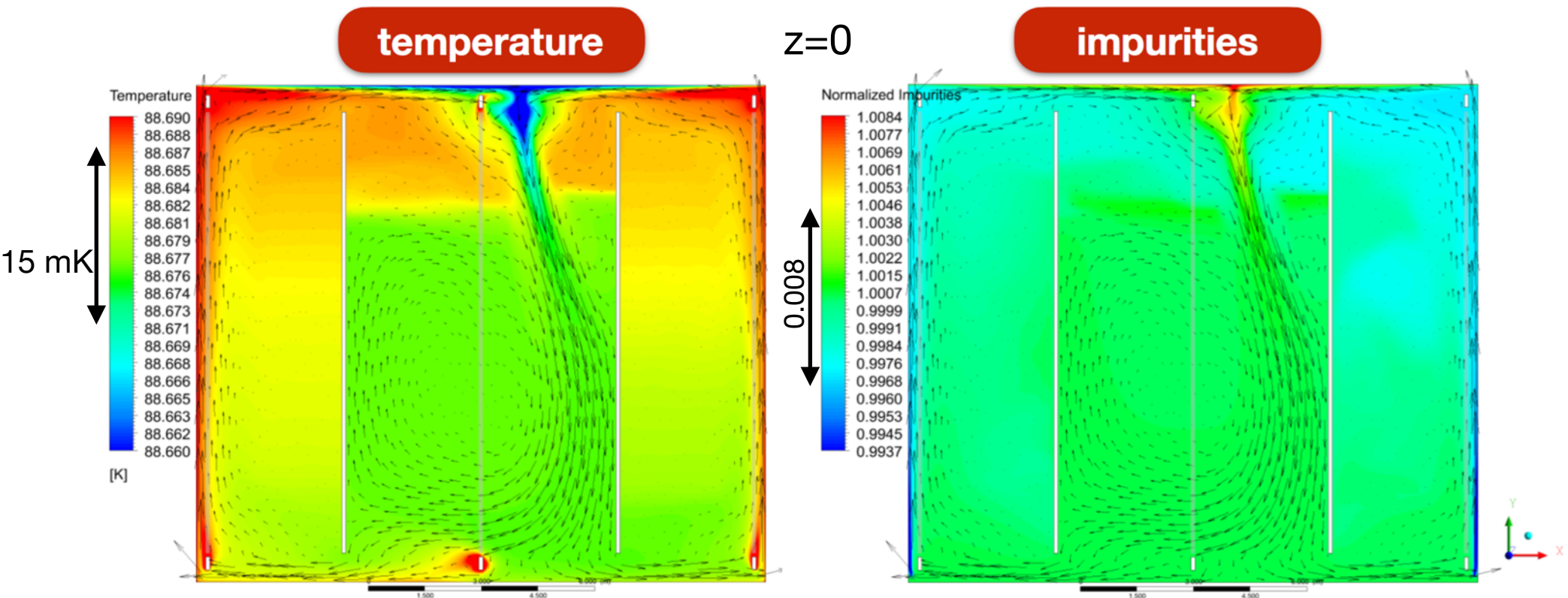
- It seems the PrM absolute lifetime measurement error cannot be smaller than 1.5% so we need other ways of estimating the reference lifetime, as cosmics (and probably laser)
- The PrM measurement will be used to study time variations of the reference lifetime
- Obviously PrM will be also used for an absolute lifetime measurement when the purity is low or when there are not sufficient cosmics
- To achieve an energy scale error better than 2% we need $\sim 1\%$ error on charge attenuation correction, what implies $< 1\%$ error on the reference lifetime measurement
 - Let's consider 1% error on the reference lifetime ($\sigma_{\tau_0}/\tau_0 = 0.01$)
 - And let's aim for a negligible CFD extrapolation error compared to that 1% such that the total error is $\sim 1\%$

Extrapolation using CFD

$$\left(\frac{\sigma_C}{C}\right)^2 = \left(\frac{\sigma_{\tau_0}}{\tau_0}\right)^2 + \left(\frac{t}{\tau} \frac{\sigma_I}{I}\right)^2$$

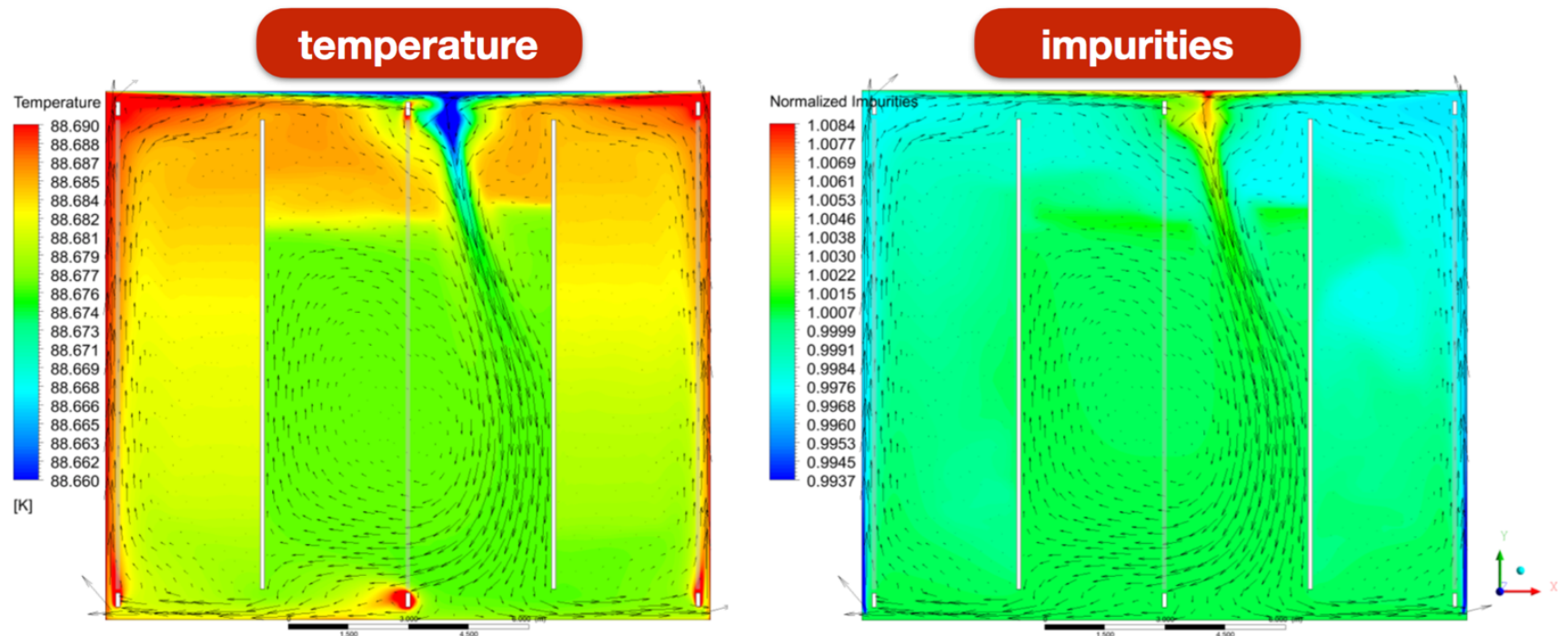
Impurities vs temperature

- Using Erik Voirin's CFD simulations (DUNE-doc-1046-v2) an inverse relation between impurities and temperature is observed
 - About 1% variation in normalized impurities for 15 mk variation in temperature
 - Not obvious what the assumptions are. To be investigated



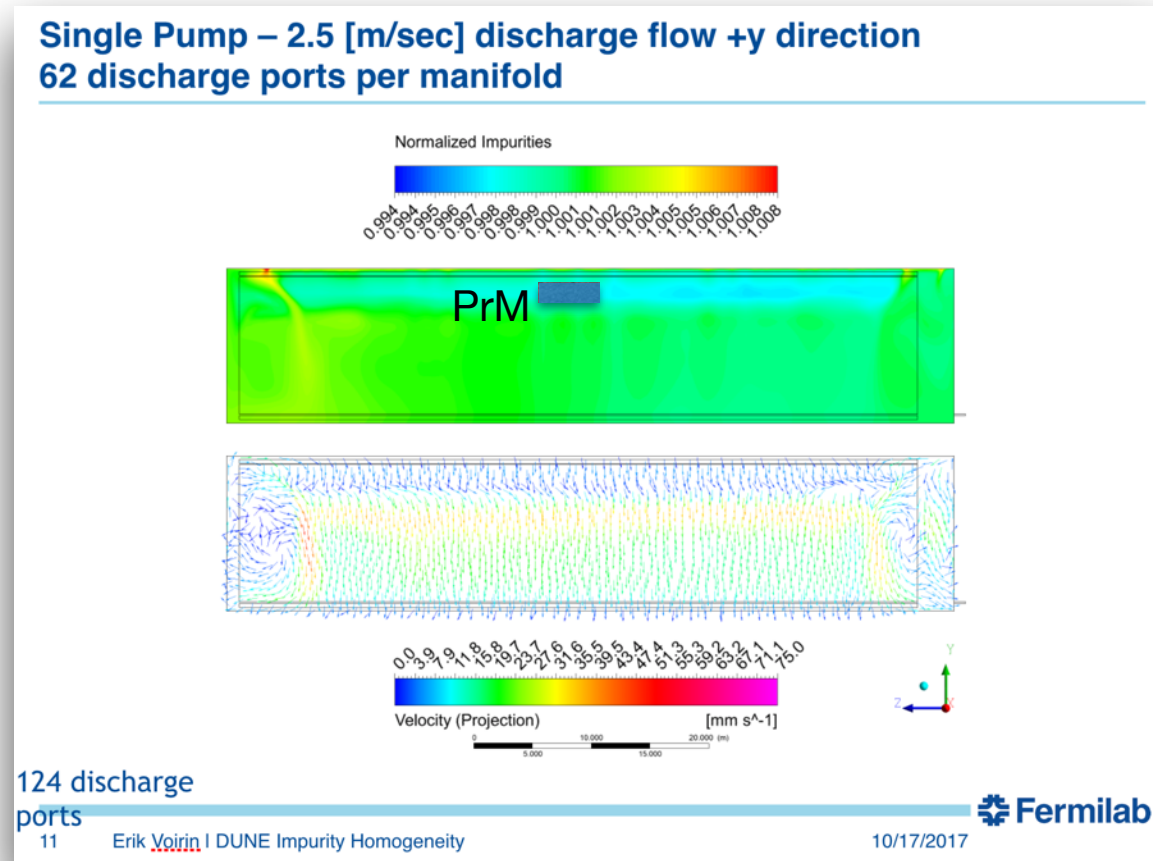
Why the inverse relation ?

- This is probably related to the LAr flow lines. The closer to the inlets (bottom edges) the less impure is the argon because it just came from the purification system. It is also there where it is warmer, as expected, because it is injected warmer in the cryostat
- On the contrary, the longest path is for LAr between the two cathodes, where the impurity is larger. The liquid is cooled down progressively when it enters in contact with the colder LAr in the cryostat, therefore is colder between the two cathodes.



Impurity range

- Those are simulations, but is there a way of measuring the impurity range ?
- It seems the Purity is larger near the LAr surface, maybe a PrM close to the surface (but not in the corners) could help is measuring the impurity range



CFD simulations

- The function $I(r)$ will be given by CFD simulations verified/tuned mainly with temperature data
- We don't have yet a clear way of estimating the error on the prediction of normalized impurities but it will depend:
 - On the agreement between measured and predicted temperature maps
 - On the temperature measurement error

Normalised impurities vs T

- We can parametrise it as follows (just a possible parameterization giving an inverse relation):

$$\frac{I - I_0}{I} = \beta \cdot (T - T_0) \longrightarrow I(T) = \frac{I_0}{1 - \beta \cdot (T - T_0)}$$

- Let's assume a worst scenario of 5% decrease in normalised impurities for 15 mk increase in temperature

$$\beta = \frac{(\Delta I / I)}{\Delta T} = \frac{-0.05}{15} = -0.0033 \text{ mK}^{-1}$$

- This means that the normalized impurities vary ~0.3% for each mK difference

Error on normalized impurities

- The relative error on the normalized impurities

$$\frac{\sigma_I}{I} = \frac{\beta}{1 - \beta \cdot (T - T_0)} \sigma_T$$

- And remember the total error on the charge attenuation correction

$$\left(\frac{\sigma_C}{C}\right)^2 = \left(\frac{\sigma_{\tau_0}}{\tau_0}\right)^2 + \left(\frac{t}{\tau} \frac{\sigma_I}{I}\right)^2$$

- In DUNE $t=2.3$ ms for the full drift

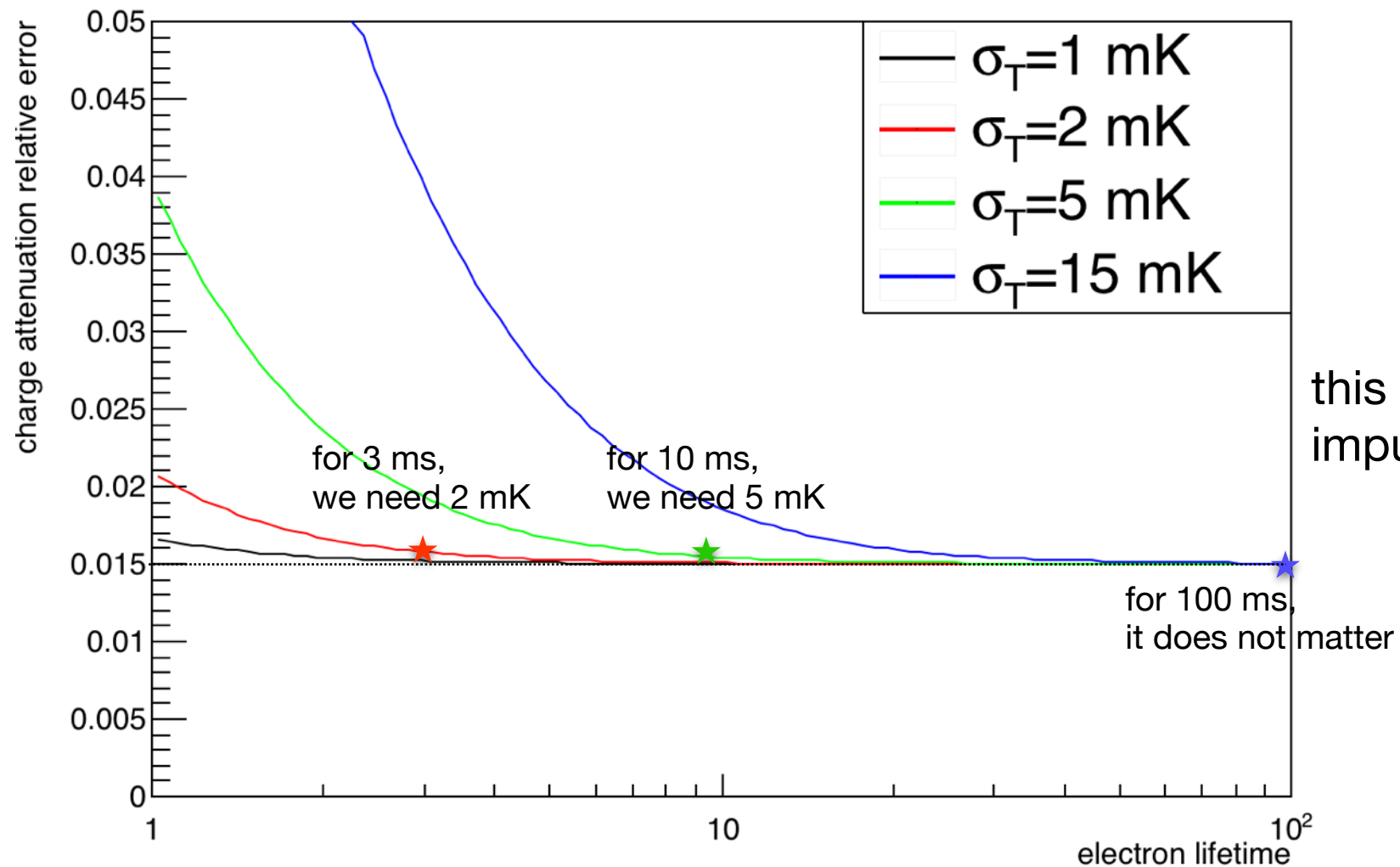
Results

$$\left(\frac{\sigma_C}{C}\right)^2 = \left(\frac{\sigma_{\tau_0}}{\tau_0}\right)^2 + \left(\frac{t}{\tau} \frac{\sigma_I}{I}\right)^2$$

1.5% reference lifetime error

- Aim is to have a small extrapolation error compared to σ_{τ_0}

$$\left(\frac{\sigma_C}{C}\right)^2 = \left(\frac{\sigma_{\tau_0}}{\tau_0}\right)^2 + \left(\frac{t}{\tau} \frac{\sigma_I}{I}\right)^2$$

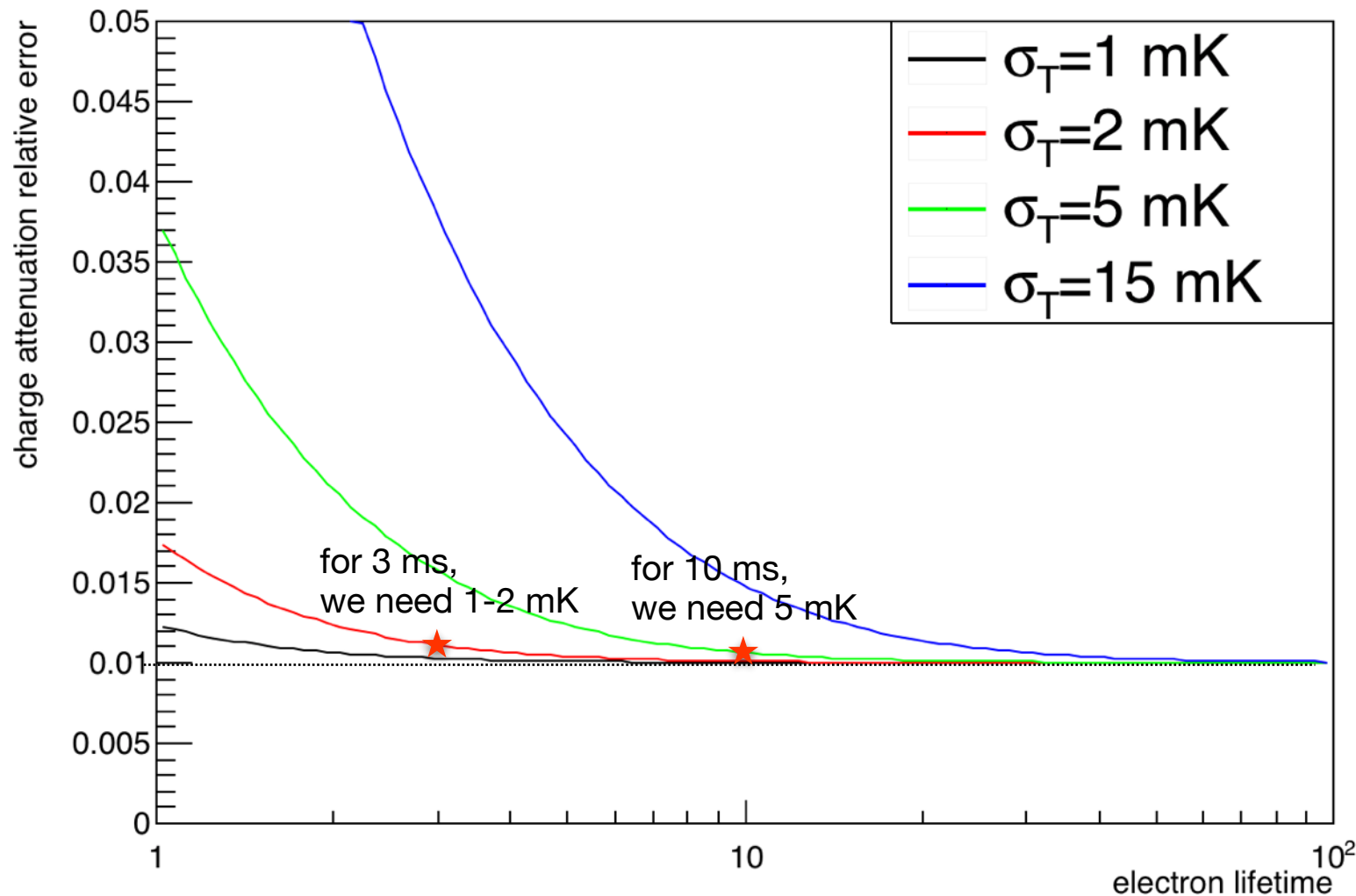


this is for 5% impurity range

1% reference lifetime error

- As mentioned above we need 1% in charge attenuation correction, so let's consider 1% in reference lifetime error

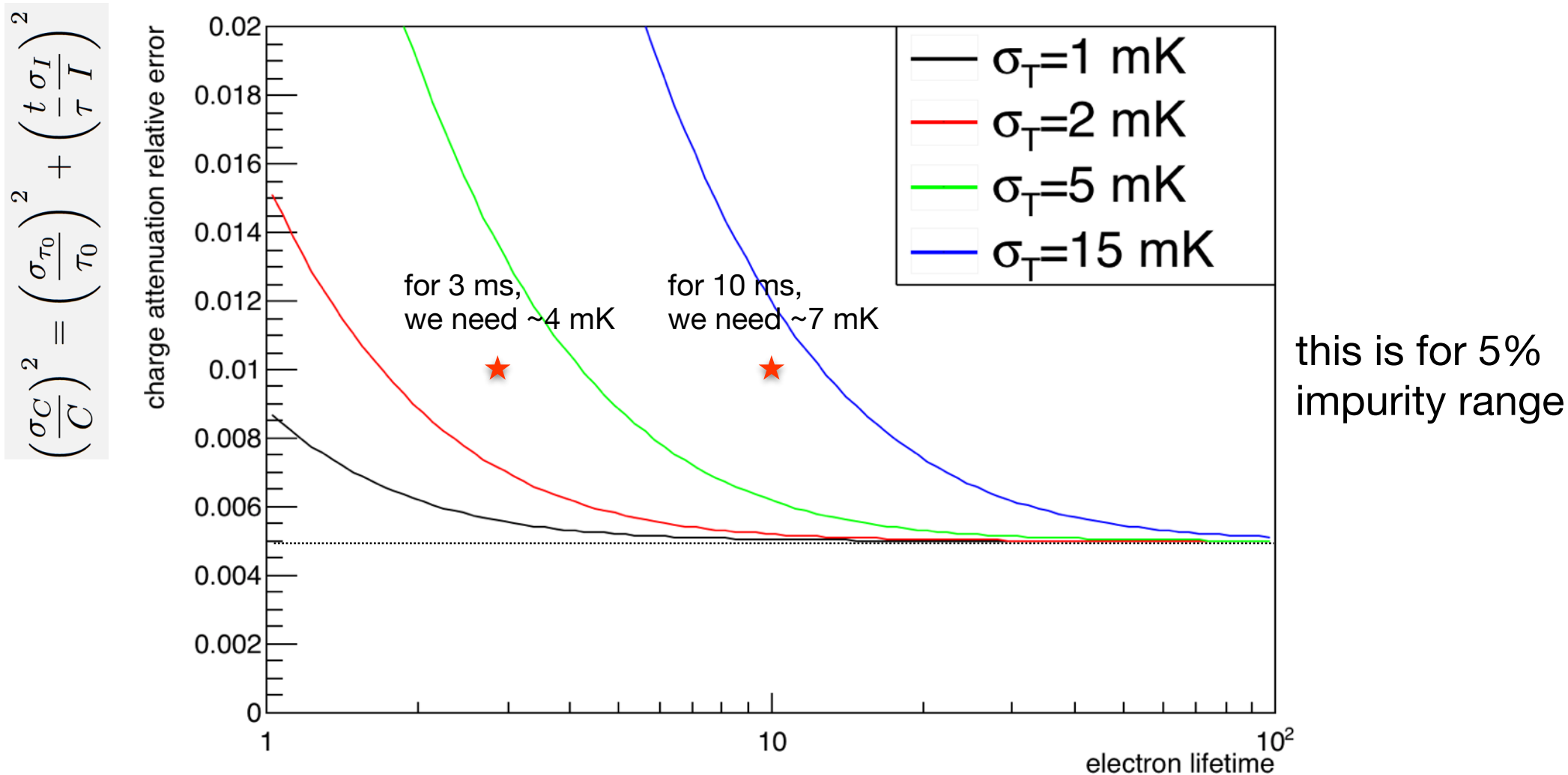
$$\left(\frac{\sigma_C}{C}\right)^2 = \left(\frac{\sigma_{\tau_0}}{\tau_0}\right)^2 + \left(\frac{t \sigma_I}{\tau I}\right)^2$$



this is for 5% impurity range

0.5% reference lifetime error

- In the case of a better lifetime error, requirements on temperature can be relaxed if we still aim for 1% error on charge attenuation correction



Summary

- Requirements for temperature map precision for different values of lifetime and reference lifetime error assuming **5% impurity range**

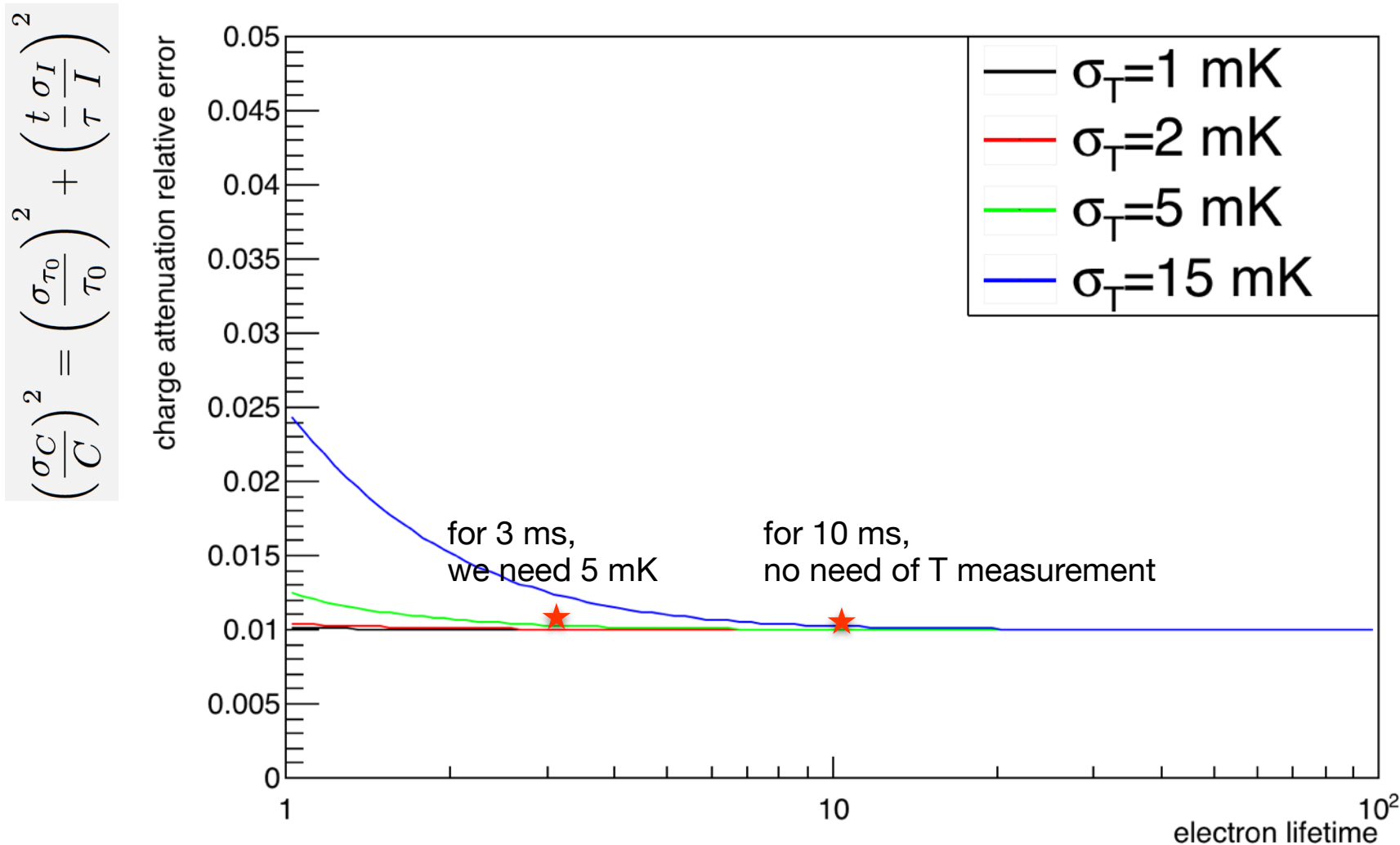
$$\left(\frac{\sigma_{\tau_0}}{\tau_0}\right)^2 + \left(\frac{t}{\tau} \frac{\sigma_I}{I}\right)^2 = \left(\frac{\sigma_C}{C}\right)^2$$

τ	$(\sigma_C/C)_{\tau_0}$	$(\sigma_C/C)_I$	σ_C/C	required σ_T (mK)
3	0,015	0,0048	0,0158	2,0
10	0,015	0,0051	0,0158	7,0
100	0,015	0,0011	0,0150	15,0
3	0,010	0,0036	0,0106	1,5
10	0,010	0,0036	0,0106	5,0
100	0,010	0,0011	0,0101	15,0
3	0,005	0,0096	0,0109	4,0
10	0,005	0,0087	0,0100	12,0
100	0,005	0,0011	0,0051	15,0

Results for 1% impurity range

1% reference lifetime error

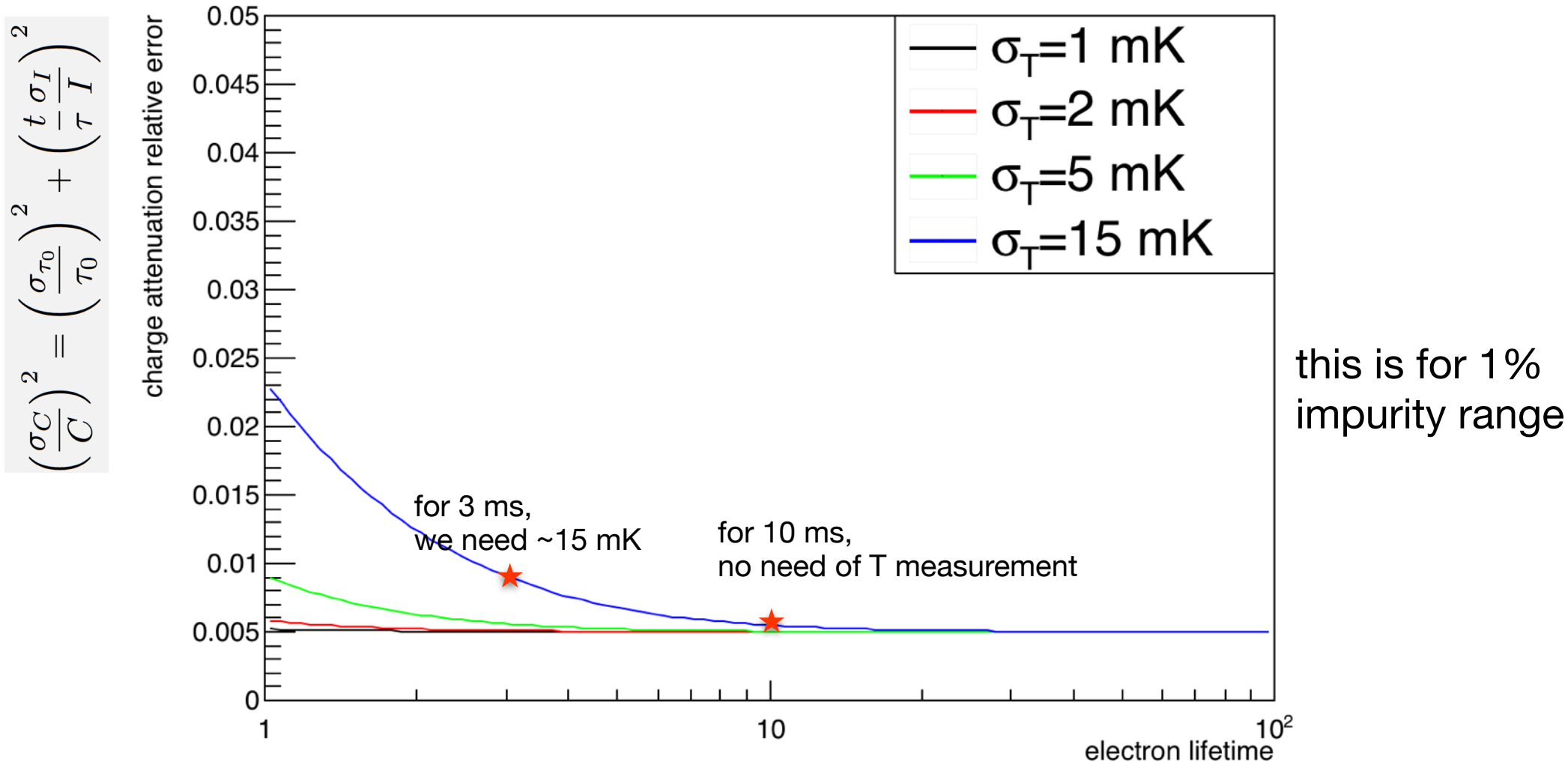
- As mentioned above we need 1% in charge attenuation correction, so let's consider 1% in reference lifetime error



this is for 1% impurity range

0.5% reference lifetime error

- In the case of a better lifetime error, requirements on temperature can be relaxed if we still aim for 1% error on charge attenuation correction



Summary II

- Requirements for temperature map precision for different values of lifetime and reference lifetime error assuming **1% impurity range**

$$\left(\frac{\sigma_{\tau_0}}{\tau_0}\right)^2 + \left(\frac{t}{\tau} \frac{\sigma_I}{I}\right)^2 = \left(\frac{\sigma_C}{C}\right)^2$$

τ	$(\sigma_C/C)_{\tau_0}$	$(\sigma_C/C)_I$	σ_C/C	required σ_T (mK)
3	0,015	0,0025	0,0152	5,0
10	0,015	0,0023	0,0152	15,0
100	0,015	0,0002	0,0150	15,0
3	0,010	0,0025	0,0103	5,0
10	0,010	0,0023	0,0103	15,0
100	0,010	0,0002	0,0100	15,0
3	0,005	0,0075	0,0090	15,0
10	0,005	0,0023	0,0055	15,0
100	0,005	0,0002	0,0050	15,0

Conclusions

- Required precision on temperature depends on electron lifetime, reference lifetime measurement error and impurity range
- To achieve an energy scale error better than 2% it is assumed we need ~1% error on charge attenuation correction, what implies ~1% error on the reference lifetime measurement (from cosmics, PrM and maybe laser)
- For 5% impurity range:
 - For 1% error on the reference lifetime measurement a local error on the temperature map of **5 mK is sufficient for a lifetime of 10 ms or higher**
 - For the worst scenario of 3 ms lifetime one would need to reduce the error on the temperature map to 1.5 mK
 - The quoted precision is for the temperature map, not for a local temperature measurement (a single sensor)
 - 1.5 mK is perfectly achievable having sufficient number of sensors and a good calibration (3-5 mK), already achieved in PD
- For 1% impurity range, **5 mK** is sufficient in all cases

Conclusions

- But how can we **measure** the impurity range (ΔI_{\max}) ? We would need local e-lifetime measurements to cover regions with large expected variations in impurities
 - We could use cosmics but would need long time
 - Can laser do that ?
 - Maybe a PrM in the middle of the cryostat close to the LAr surface, where we ave the maximum variation predicted by CFD (see slide)

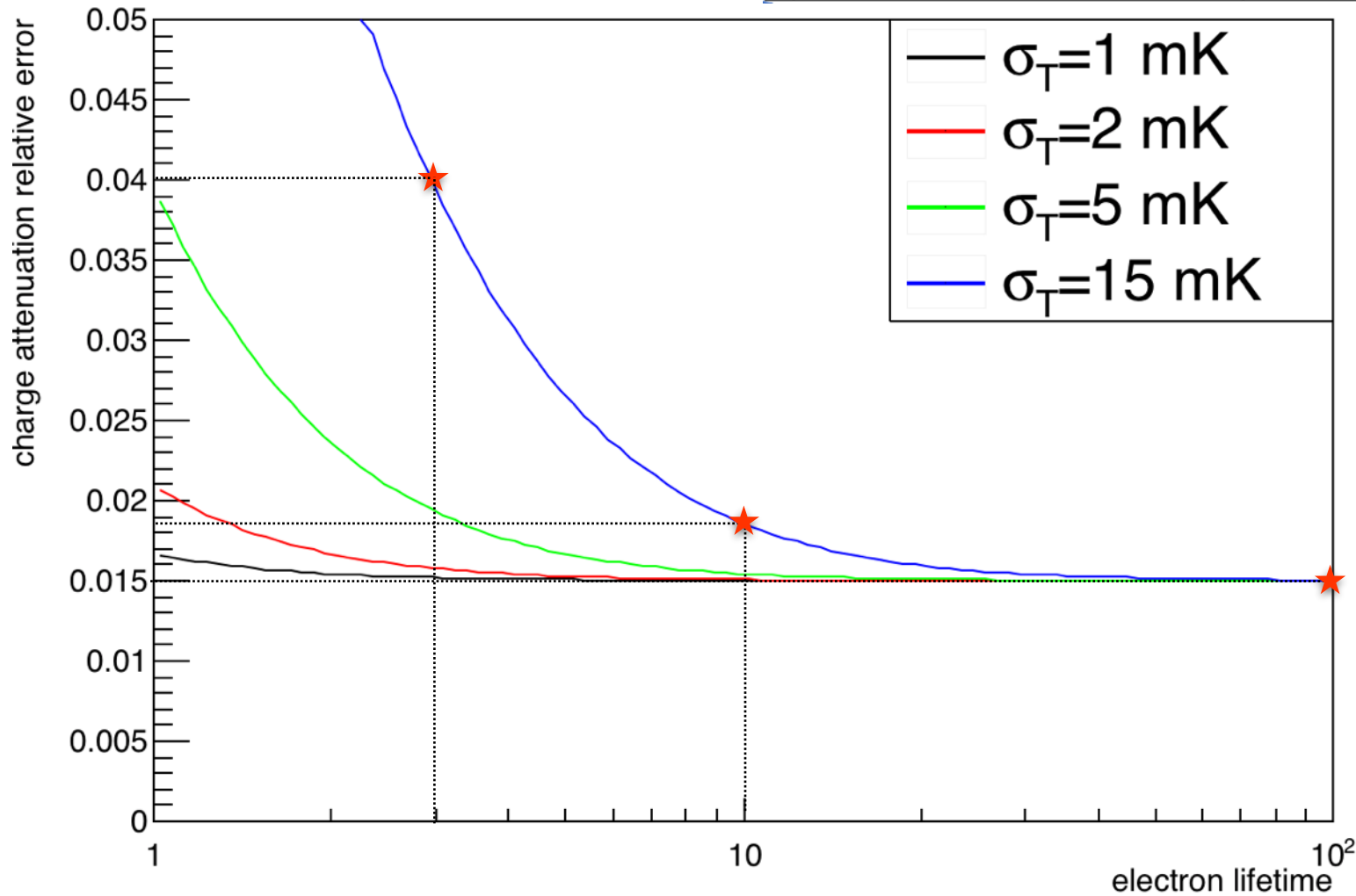
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Crosscheck

- For 1.5 % error on lifetime measurement we get agreement with Jianming's numbers

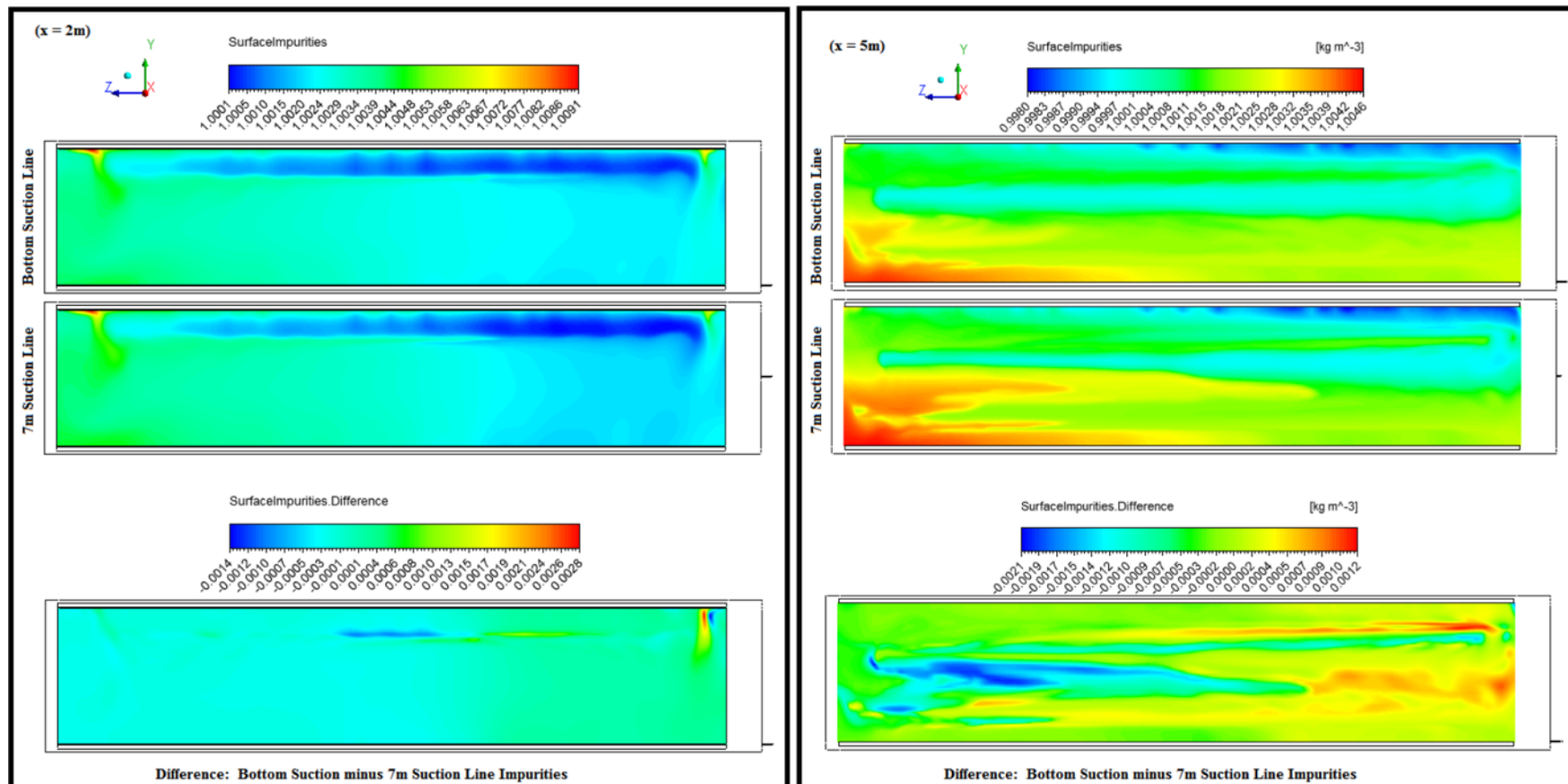
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$$\left(\frac{\sigma_C}{C}\right)^2 = \left(\frac{\sigma_{\tau_0}}{\tau_0}\right)^2 + \left(\frac{t \sigma_I}{\tau I}\right)^2$$

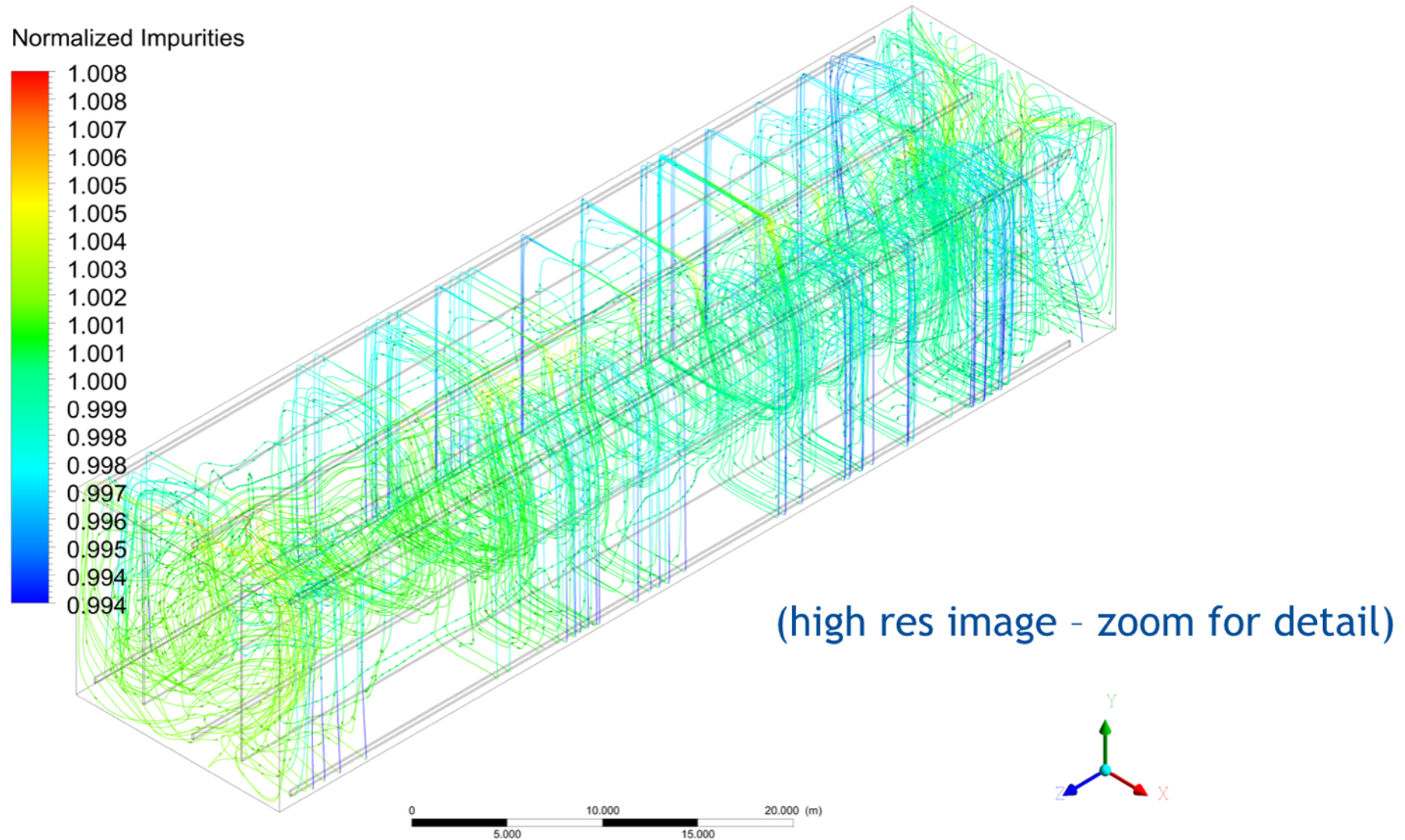


$\sigma_T = 15$ mK is equivalent to no temperature measurement and thus to a 5% error on impurity concentration. So we use that curve to compare with Jianming's numbers

Case Comparison of Impurities inside Field Cage Volume at several YZ planes: (negligible difference)



Normalized Impurity Streamlines



124 discharge
ports