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# Beam and Ring Measurements

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Fermilab

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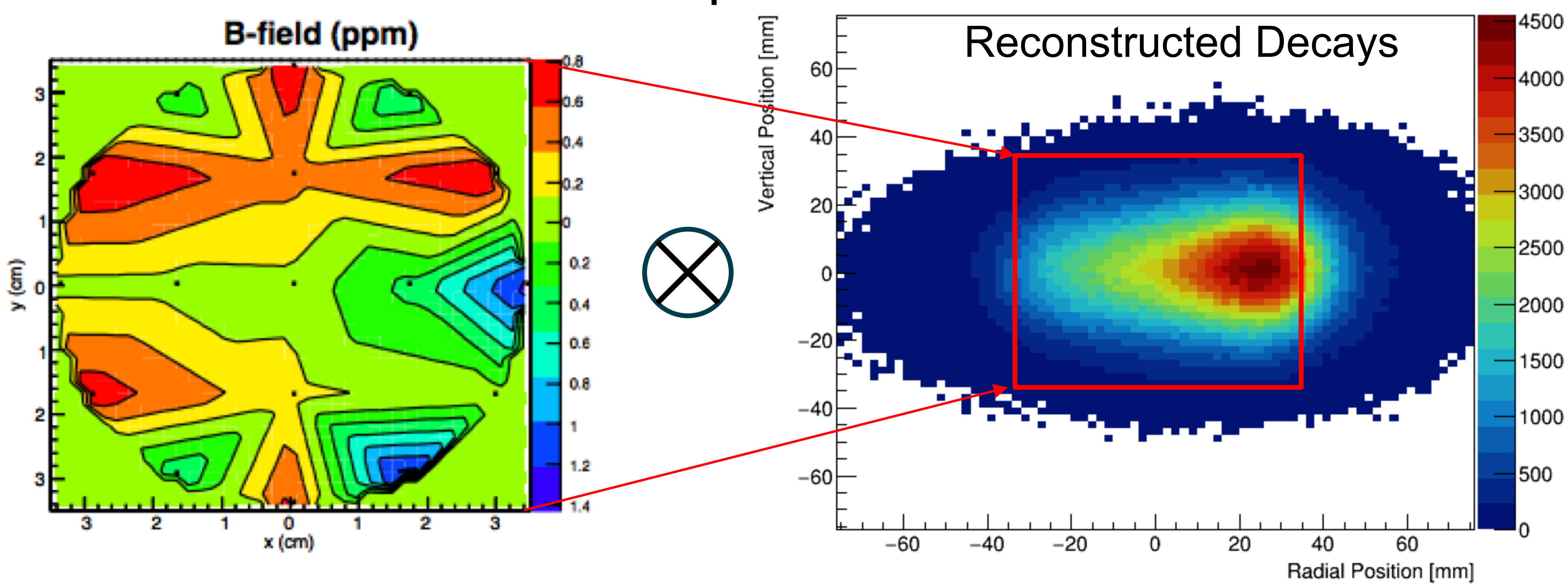
# Field Quality

***Next few slides and information are from James Mott, Joe Price & Tracker Team g-2 Field Meeting – 03/08/18***

we actually want to know the average field for a wiggle-plot muon.

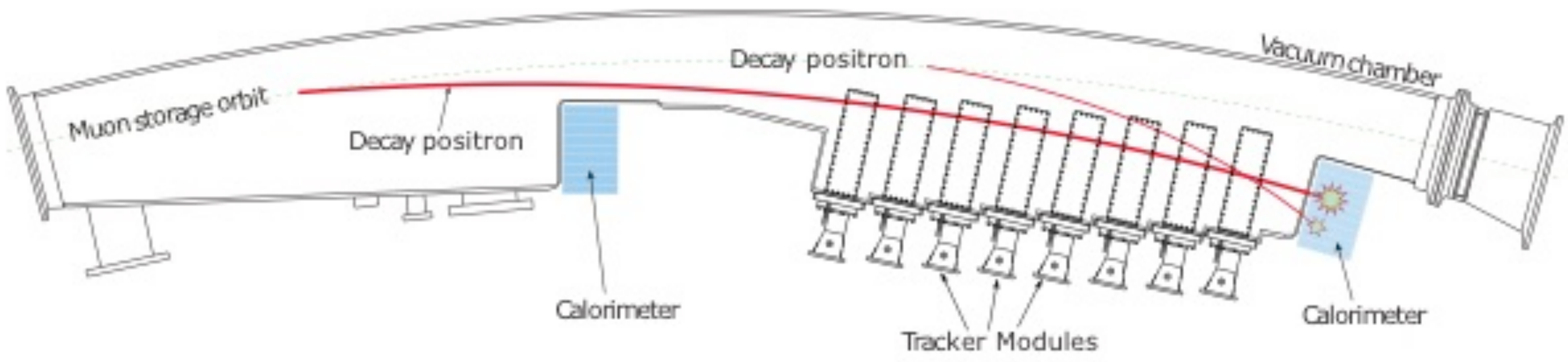
- So we need to convolute map with muon distribution.

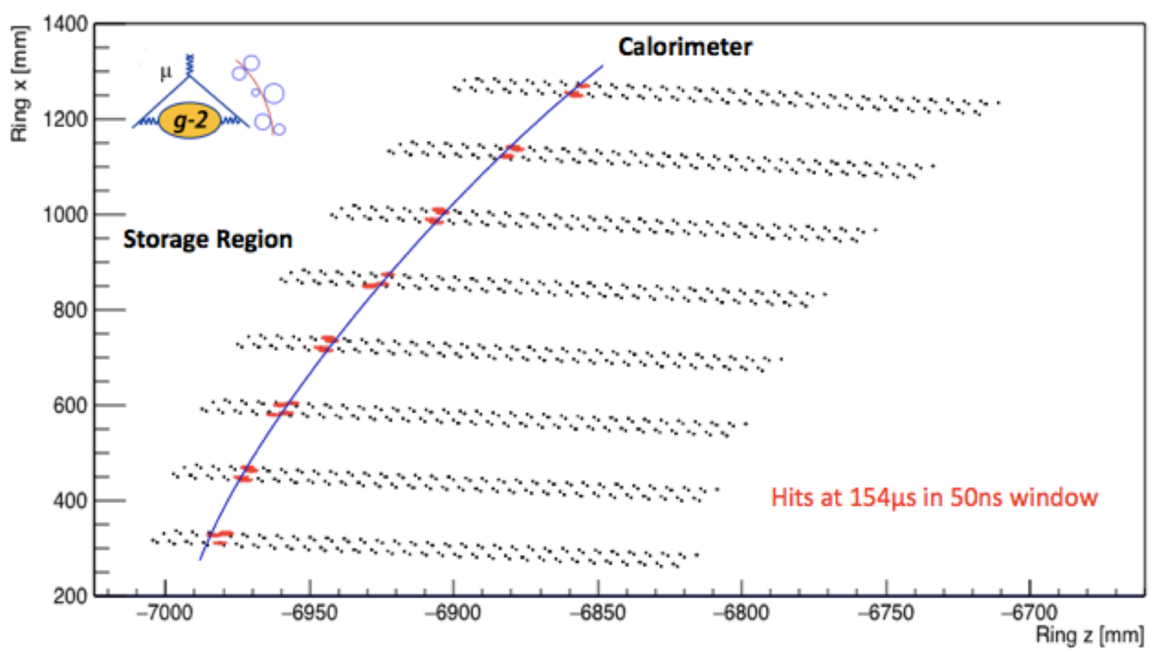



- Beam location affects the choices of which multipoles to focus on squashing

# Typical Beam Signals

## What does the tracker measure?




- We take e⁺ hits from tracker and reconstruct track parameters at entry point:

$$P_{tot}, P_x, P_y, x, y, t$$

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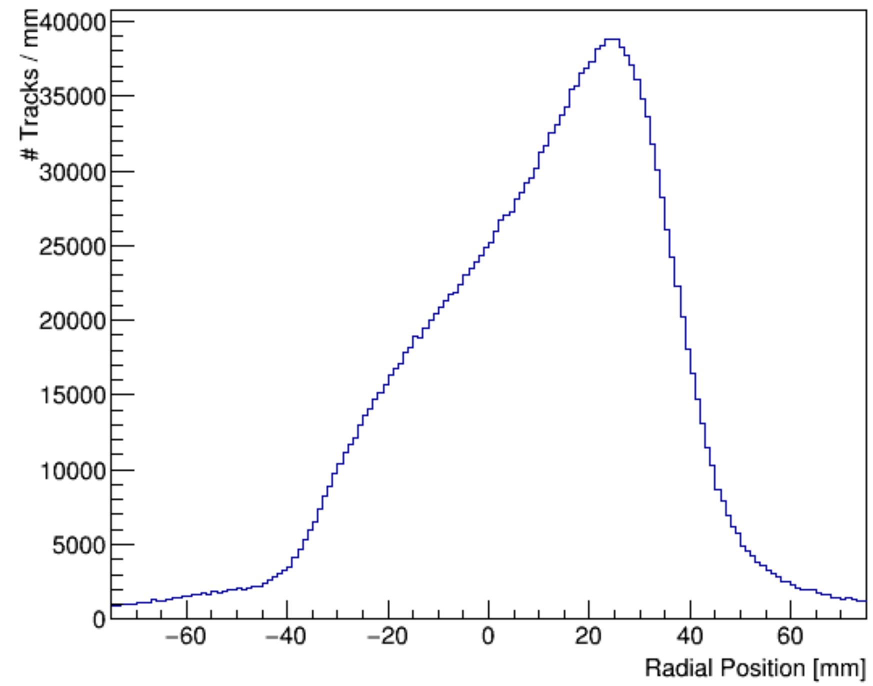
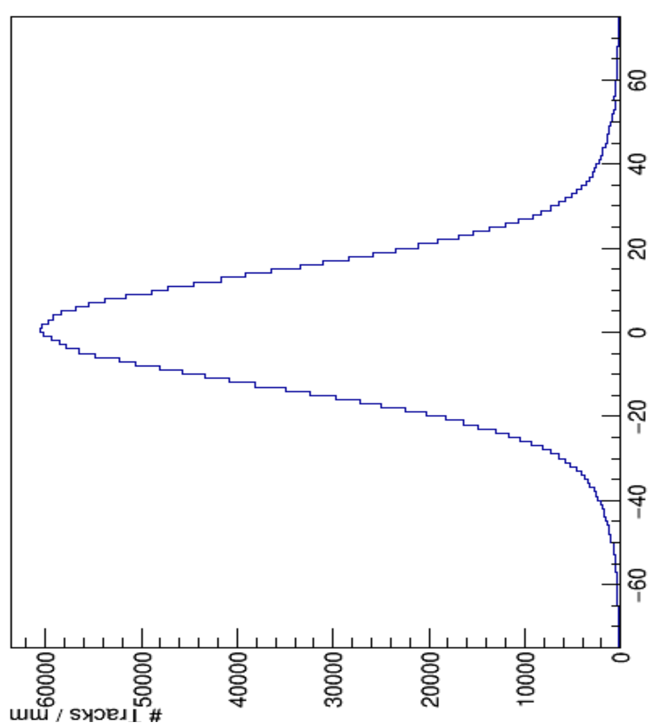
# Beam Distribution:

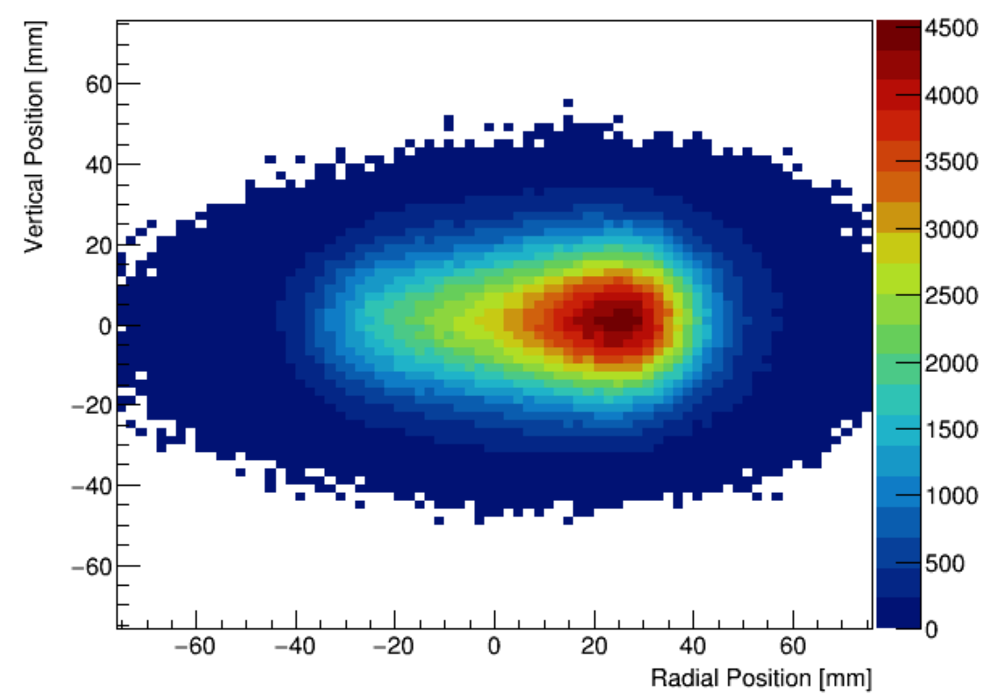
Flattening down reconstructed position to radial and vertical

All times in these plots

Radial position is clearly much higher than we want – we don't store lower momentum muons

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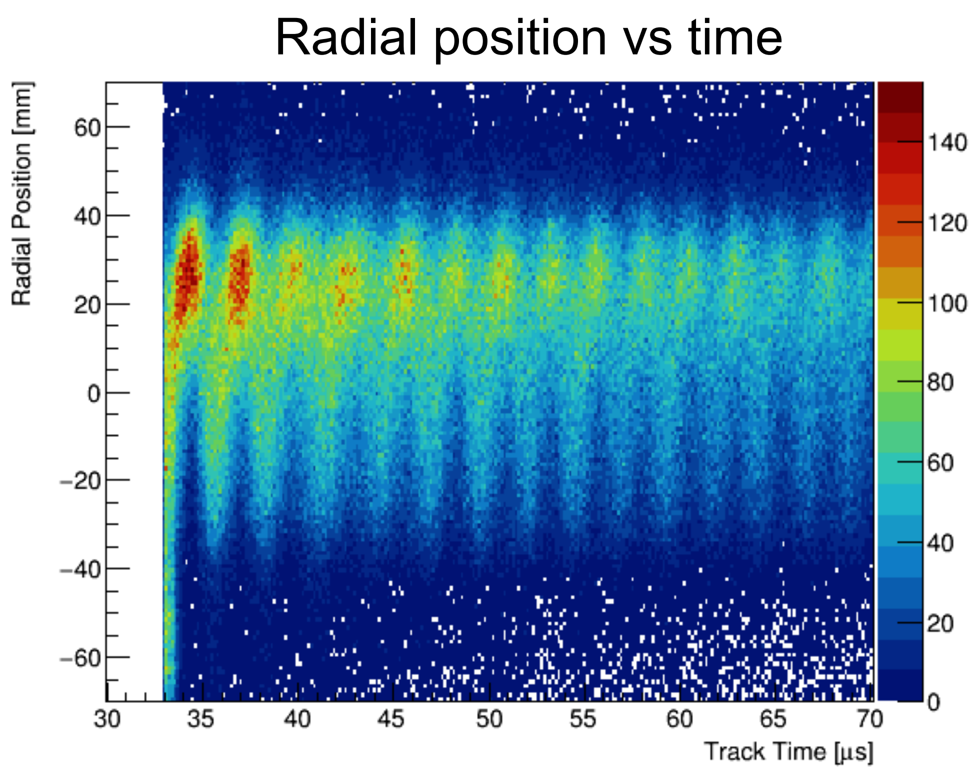
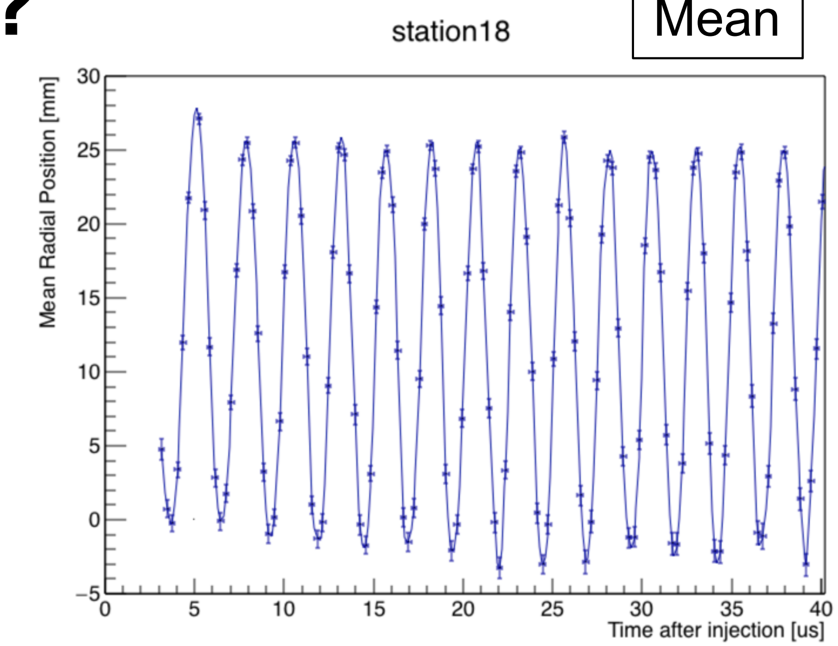
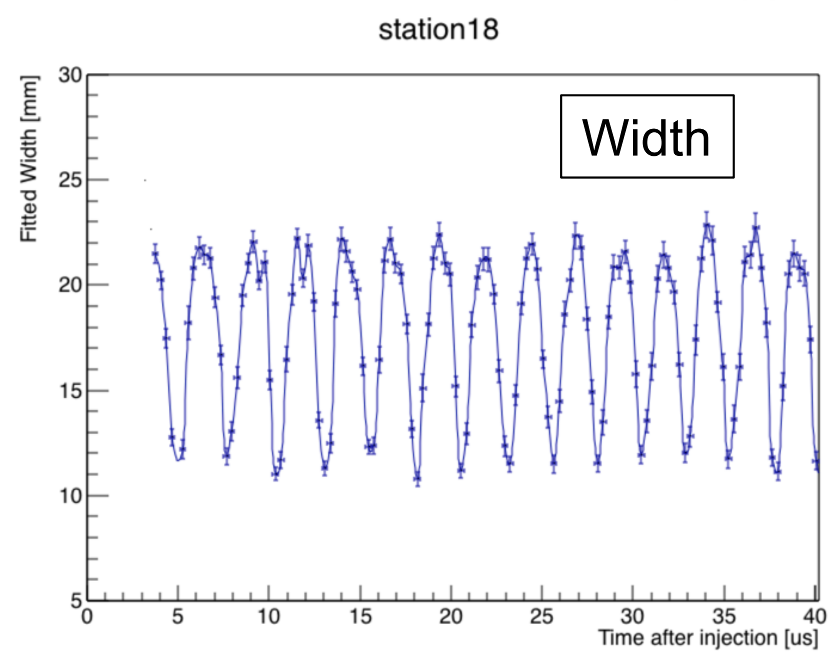
# What do we see radially?



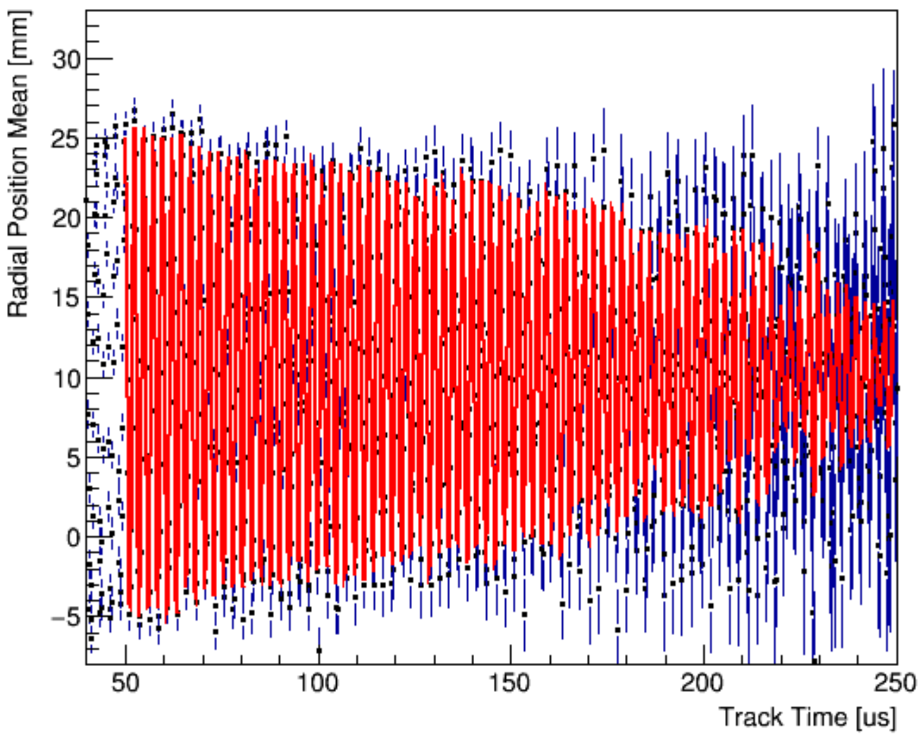



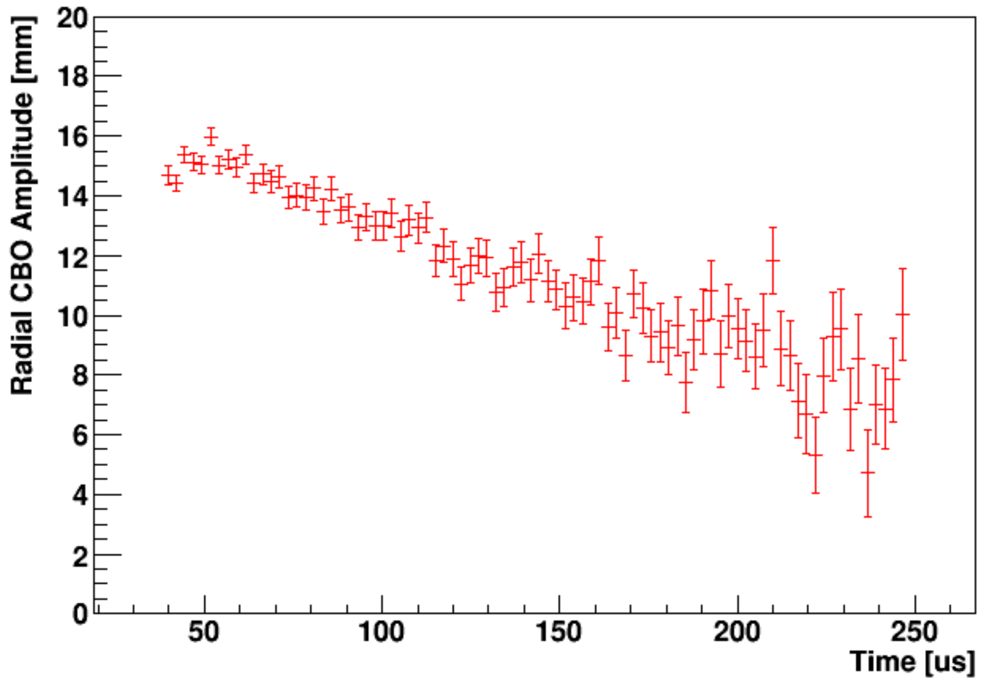

Leading contribution to width of radial distribution is CBO

Many different momenta (average radii) with different amplitudes for each

# Hitting a moving target: CBO Amplitude

CBO amplitude also decreases over time:

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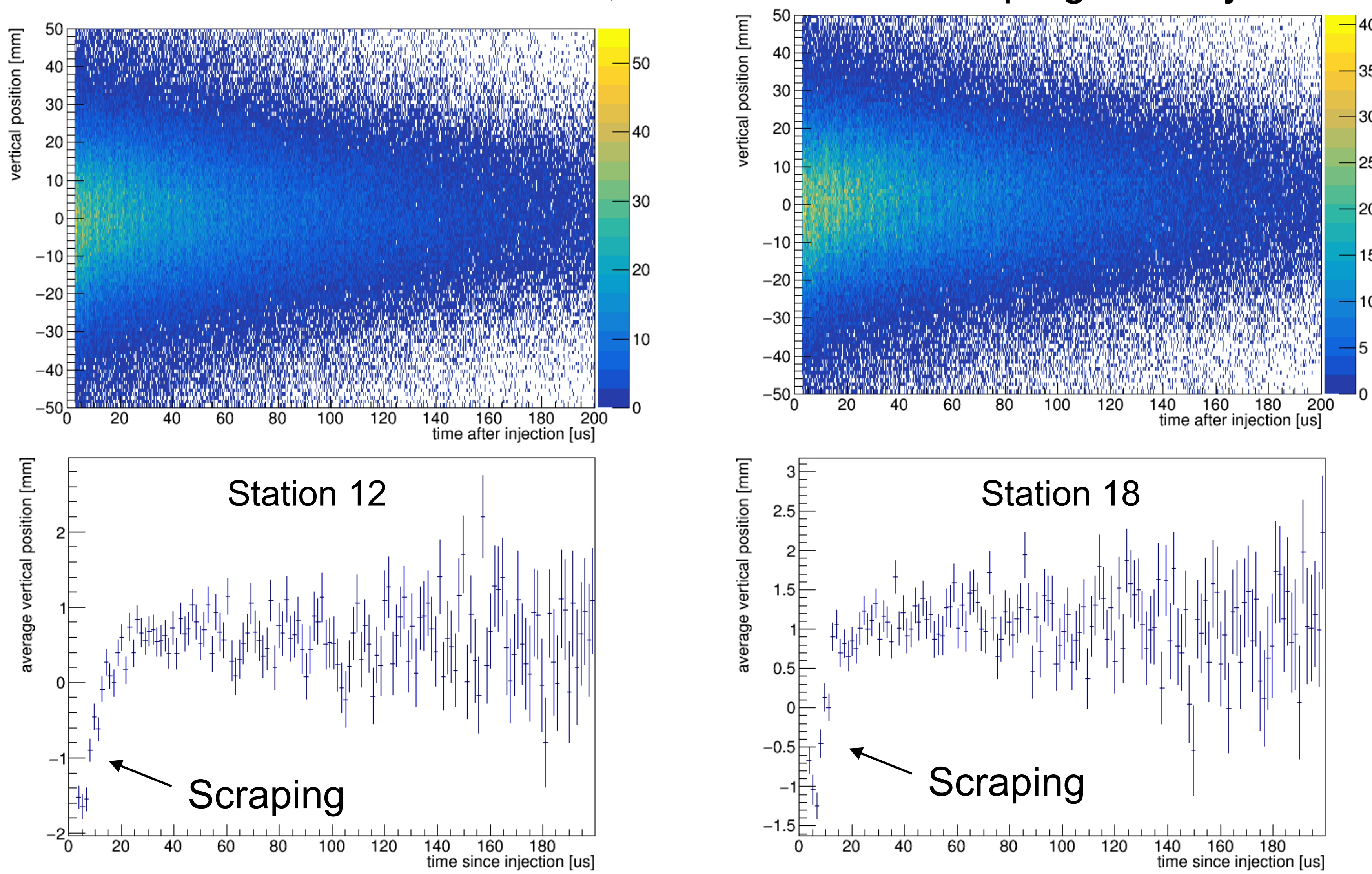
# What do we see vertically?

- Haven’t seen the vertical CBO, but we do see scraping at early times




Two vertical means don’t line up – is this misalignment, radial field, something else? 8

# Tune Measurements

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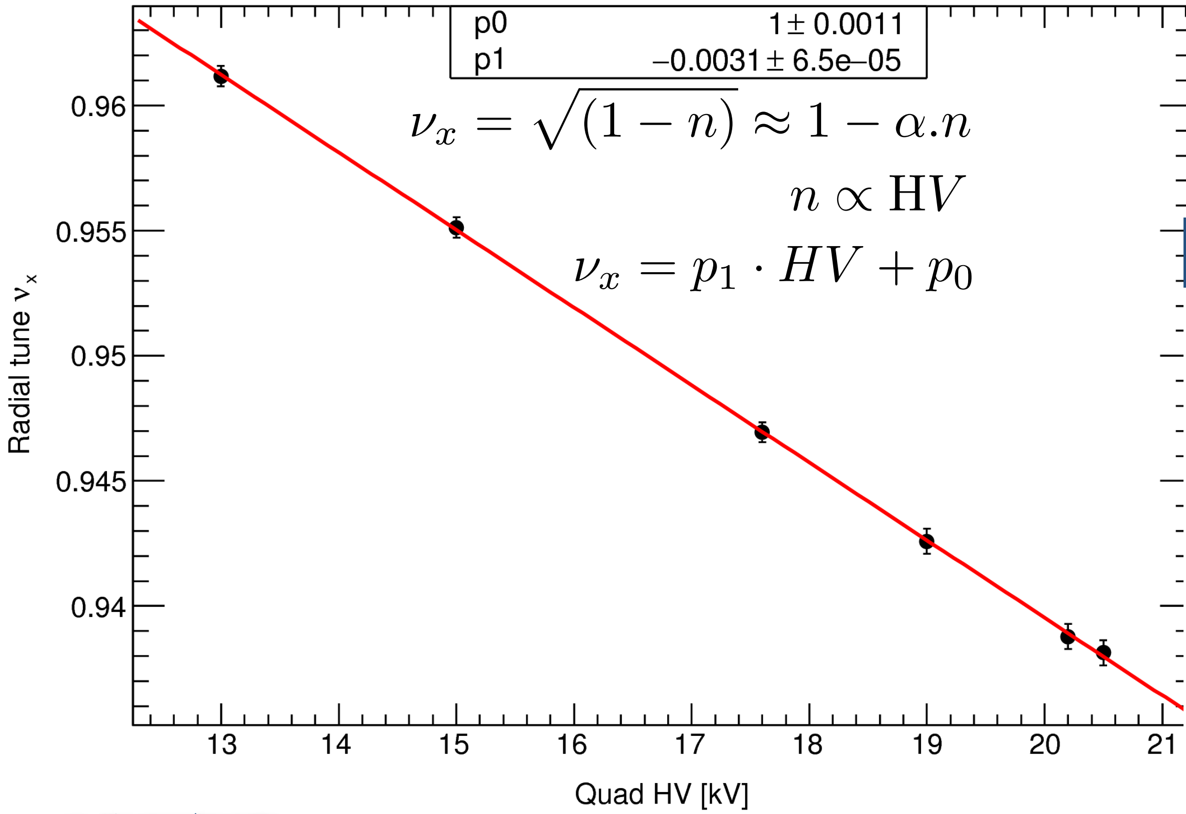
## Radial tune

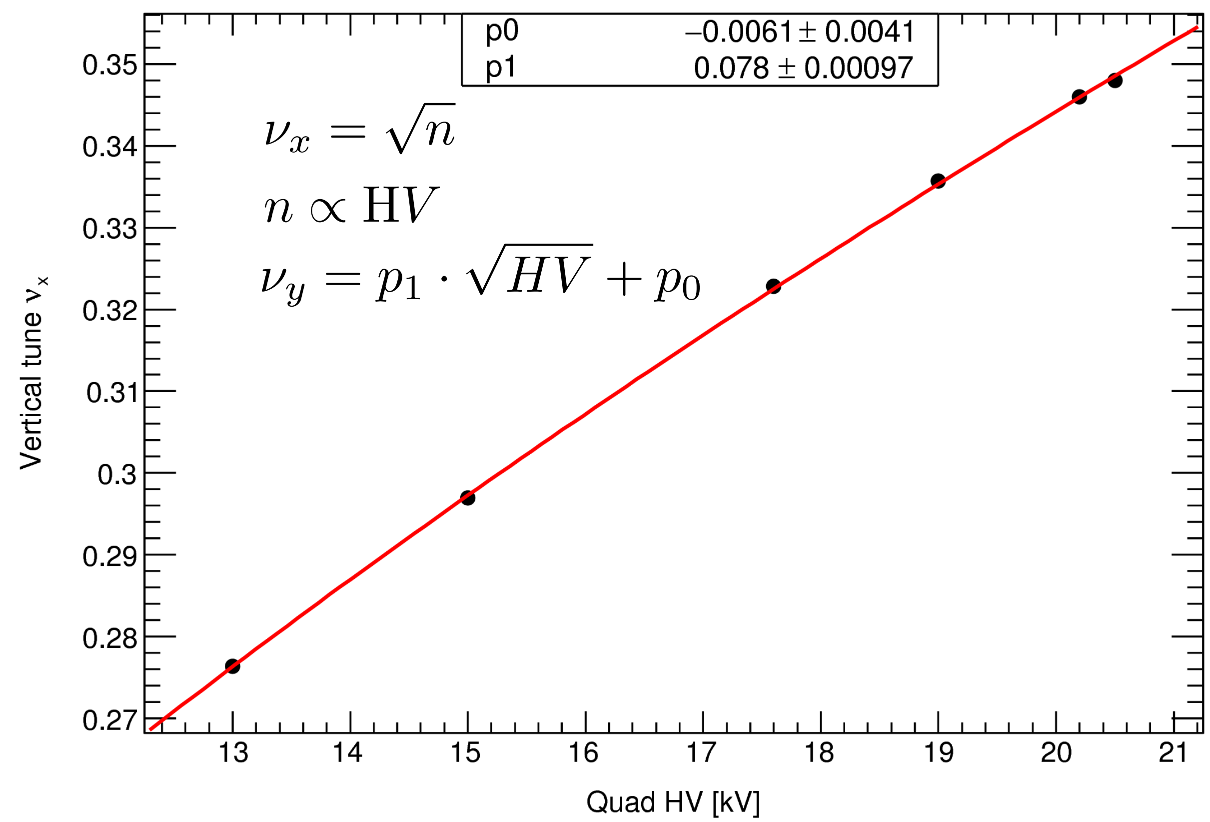
first order polynomial fit






## Vertical tune

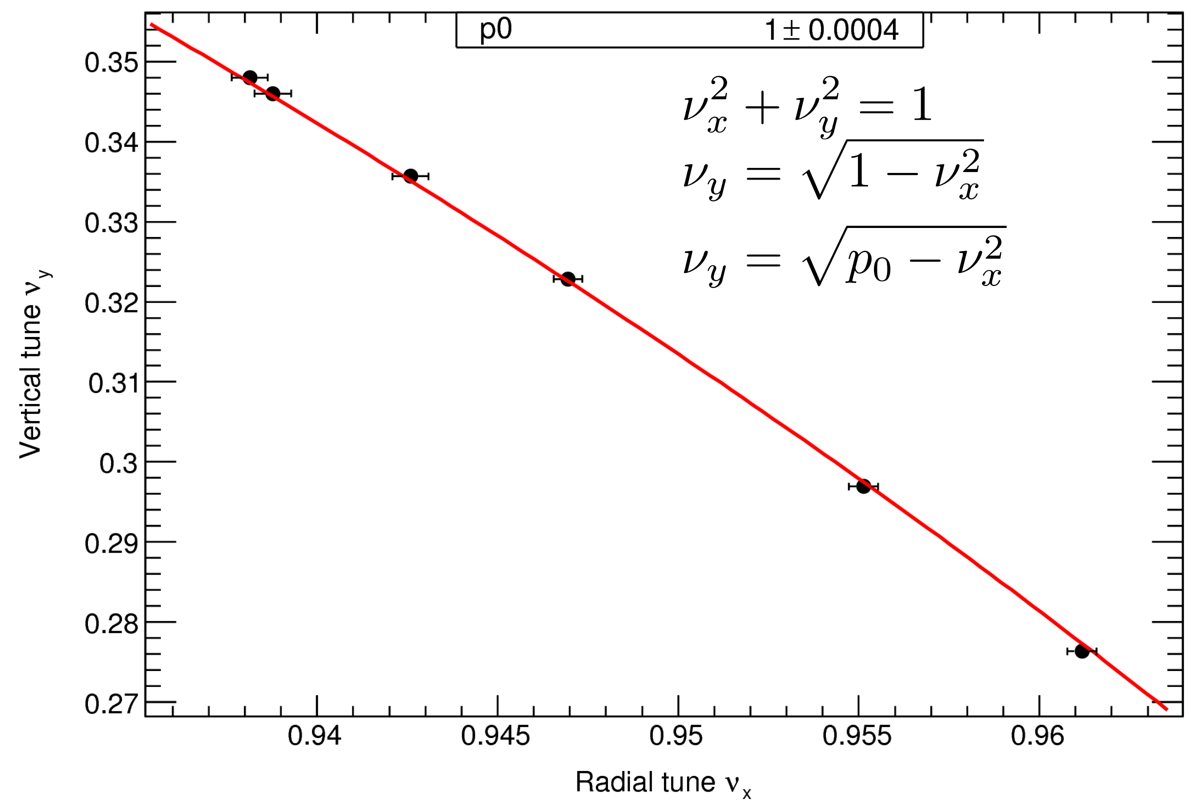
square root fit




*uncertainties smaller than the points*

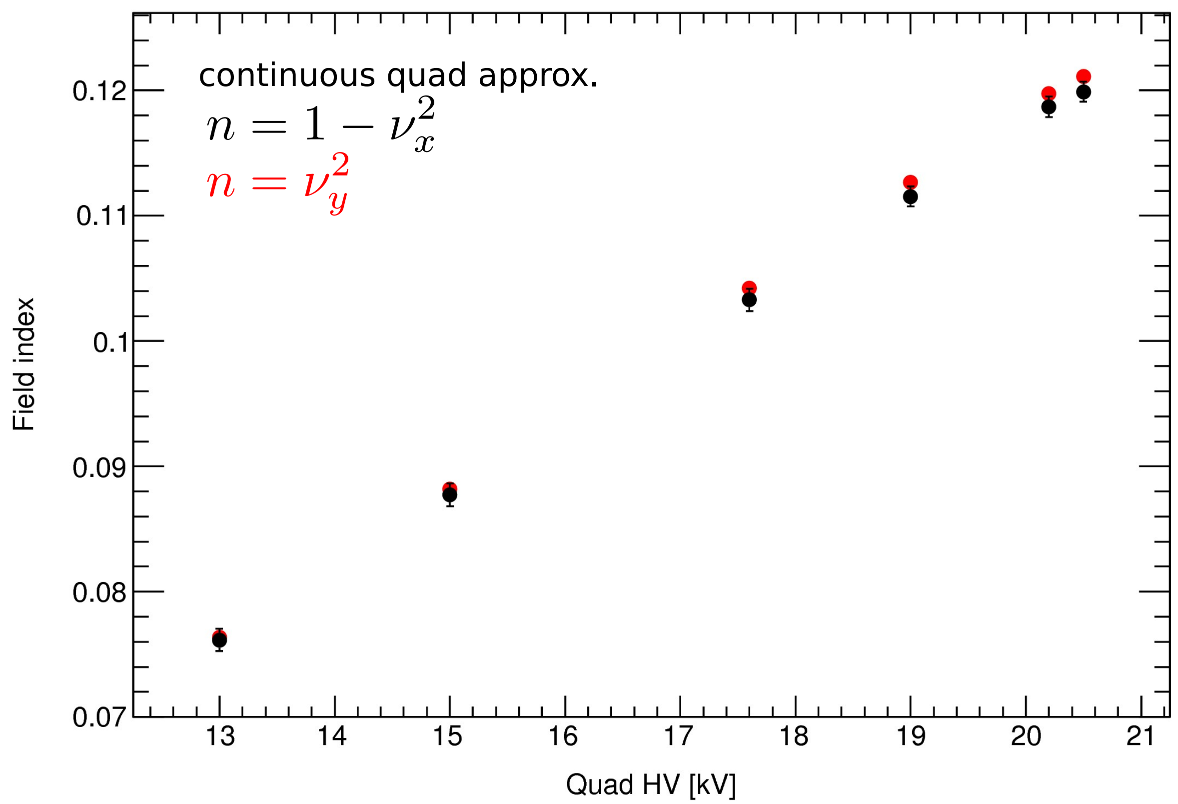
## 2D tune plane

square root fit




Antoine Chapelain | Tunes measurement w/ Fiber Harps | April 2

## Field index




Antoine Chapelain | Tunes measurement w/ Fiber Harps | April 26, 2018 | 10

# Measured Momentum Distributions

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## The Fourier transform (FT) approach

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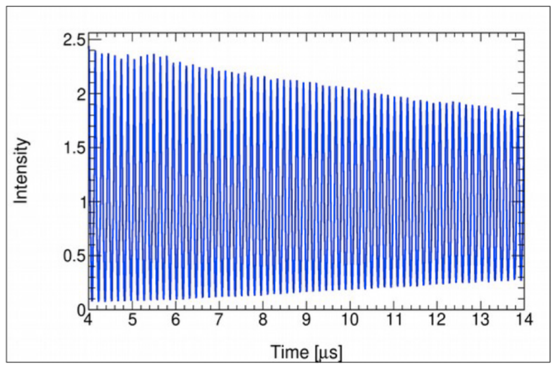
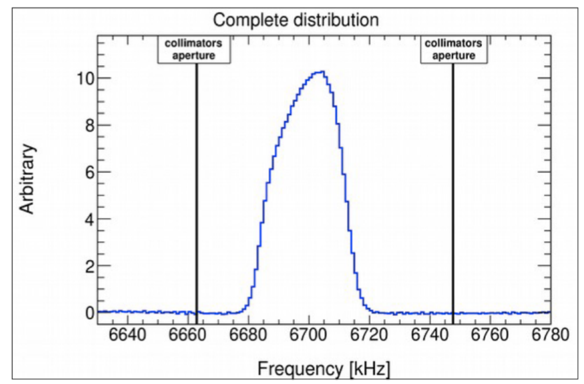
From Antoine:

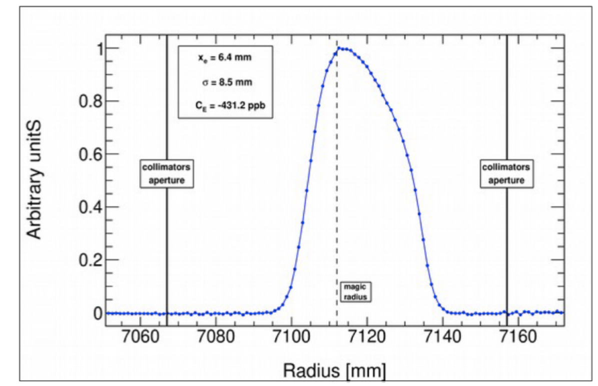
Produce FR spectrum




Produce frequency distribution w/ $t_0$ optimization




Produce radial distribution and estimate $C_E$




Partial-time Fourier analysis approach possible because in a weak focusing ring:
Frequency ↔ Radius

*end time of available signal*

*start time of available signal*

*fast rotation signal*

Parabola correction term to account for missing time between $t_0 \rightarrow t_s$

$$\Phi(\omega) = S(\omega, t_s = t_0, t_m) = \int_{t_0}^{t_m} S(t) cos\omega(t - t_0) dt + A \cdot \int_{\omega^-}^{\omega^+} S_{app}(\omega') \frac{\sin(\omega-\omega')(t_s - t_0)}{\omega - \omega'} d\omega' + B$$

*frequency distribution*

*center of mass of the beam passing the detector the first time*

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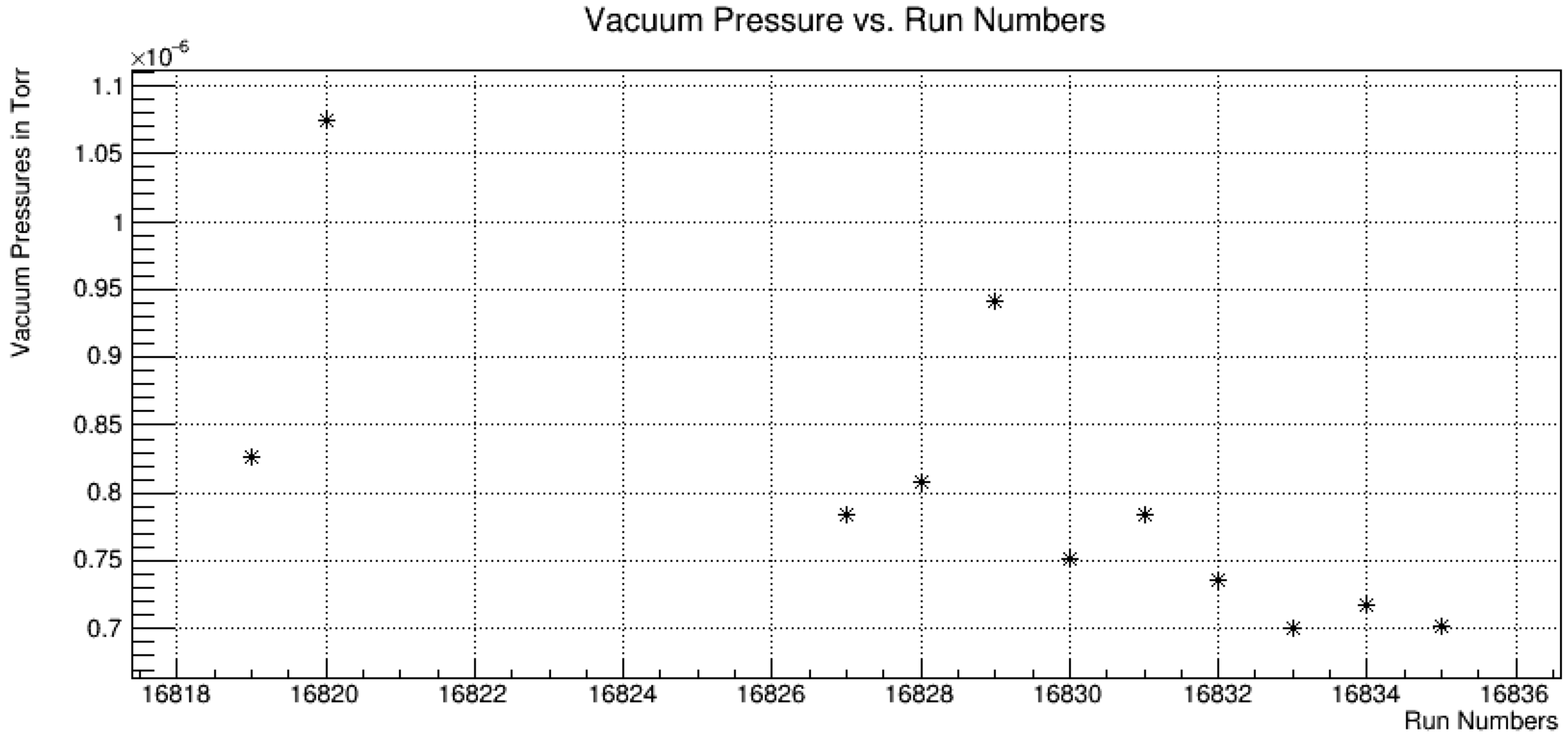
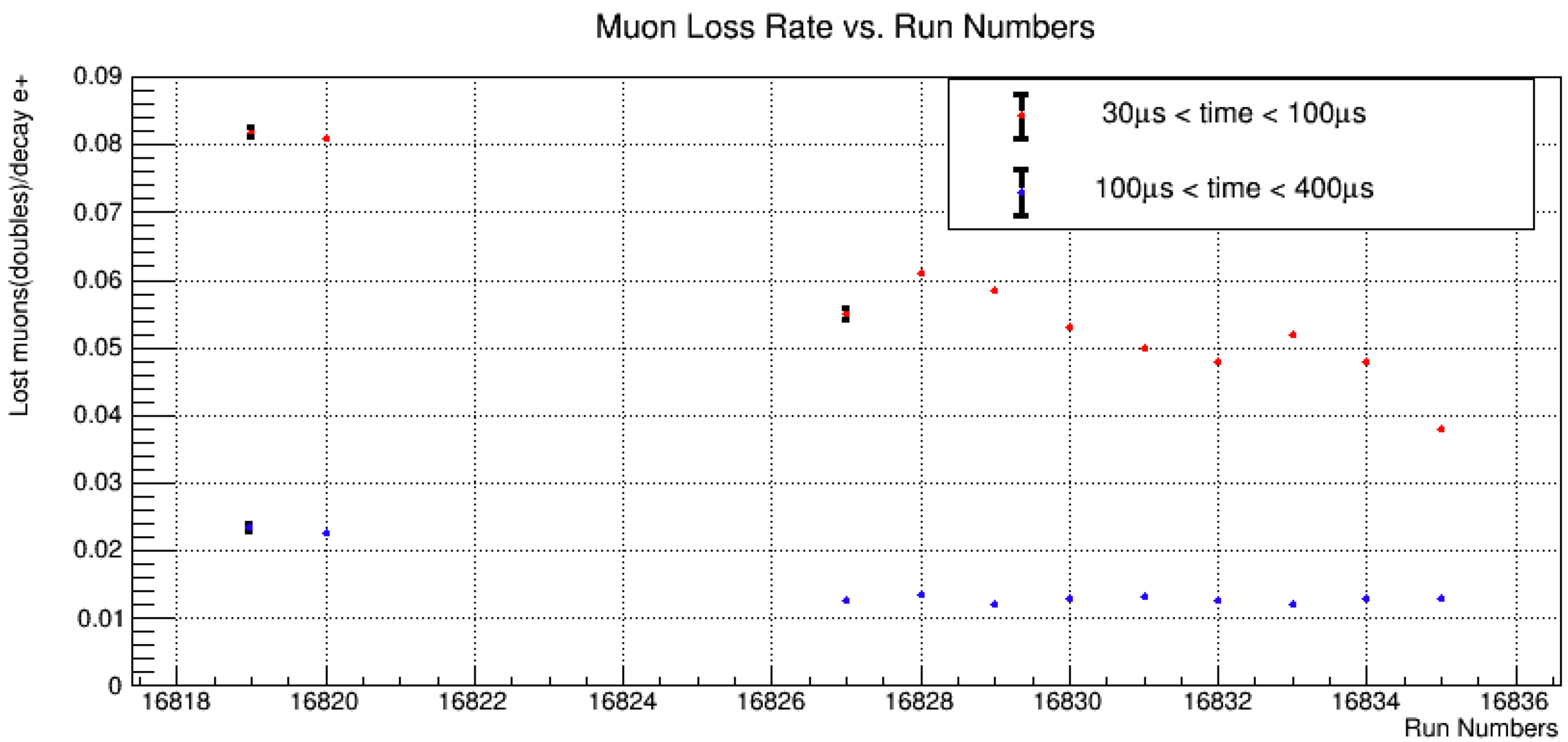
# Gas Scattering Verification



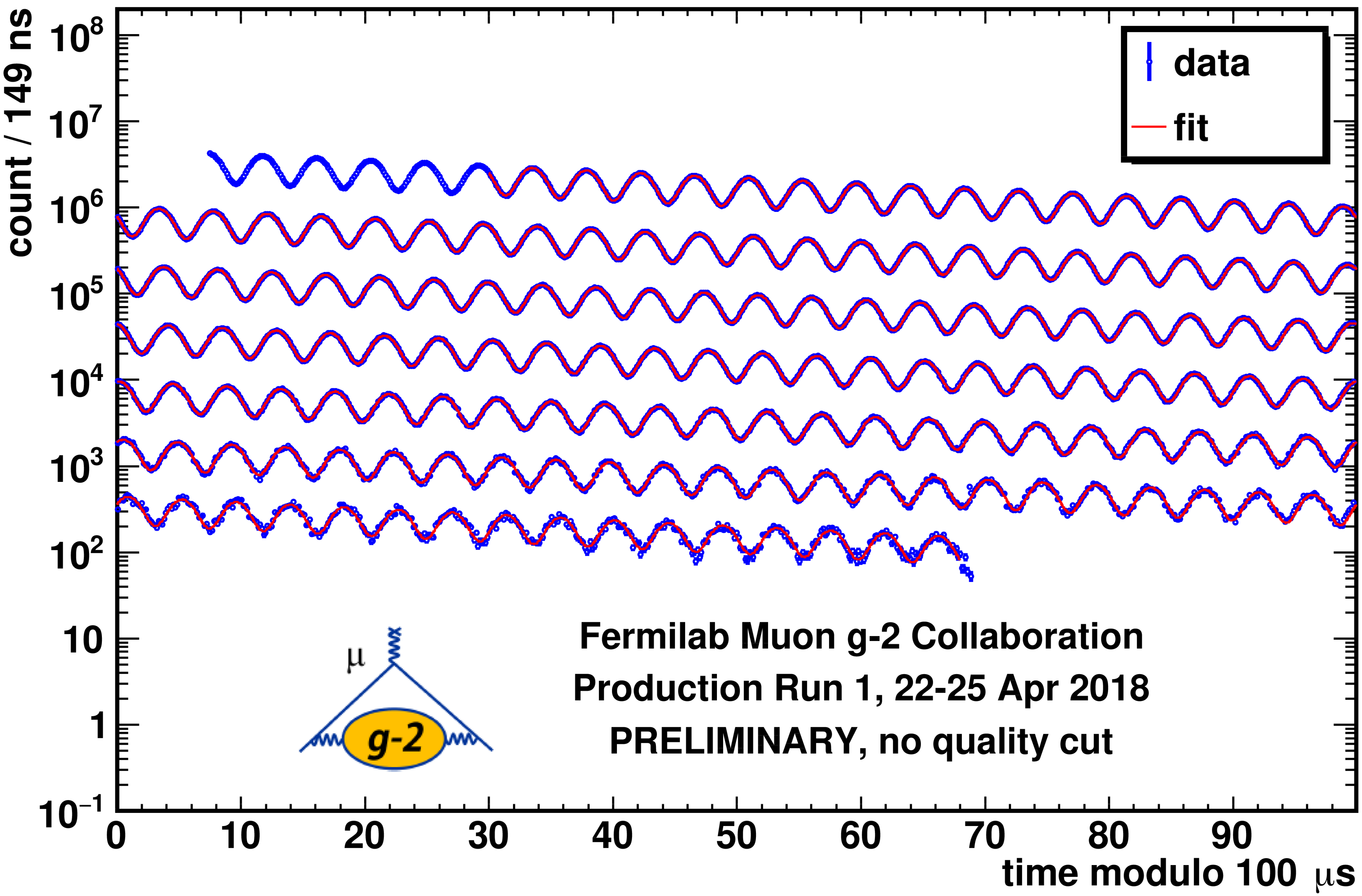




from Sudeshna, *et al.*

# A Wiggle Plot

$$N(t) = \left(\frac{N_0}{\tau}\right) e^{-t/\tau} \left[1 - A\cos(\omega_a t + \phi\right]$$

(*5-parameter fit*)



# Systematic: E-Field Contribution

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- Important to tabulate and tackle the various **systematic errors** present in the data analysis in the determination of *a*
- Example: Not all (any?) muons are at the *magic momentum*, so a momentum offset or an asymmetry in the momentum distribution can generate a systematic error:

*how well is this cancelled?*

$$\vec{\omega_a} = -\frac{e}{m}\left[a\vec{B}_0 + \left(a - \frac{1}{\gamma^2 - 1}\right)\frac{\vec{E}\times\vec{\beta}}{c}\right]$$

$$x_e = D \cdot \frac{\Delta p}{p}$$

$$\frac{\Delta\omega}{\omega} = -2n(1-n)\beta^2\frac{\langle x_e^2\rangle}{R_0^2} \equiv C_E$$

*here, n = "field index" of the weak-focusing system*

- Hence, precise determination of the momentum distribution for each store is important

# Systematic: Pitch Correction

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- Betatron oscillations lead to terms in the spin precession in which

$$\frac{d\vec{S}}{dt} = \vec{\omega}_s \times \vec{S} = -\frac{e}{\gamma m}\left[(1+a\gamma)\vec{B}_\perp + (1+a)\vec{B}_{||} + \left(a\gamma + \frac{\gamma}{\gamma+1}\right)\frac{\vec{E}\times\vec{\beta}}{c}\right]\times\vec{S}$$

$$\vec{B}\cdot\vec{\beta} \neq 0 \qquad (B_{||} \text{ terms})$$

- in particular, the vertical oscillations can contribute to the spin precession in the horizontal plane

$$\vec{\omega_a} \approx -\frac{q}{m}\left[a\vec{B} - a\left(\frac{\gamma}{\gamma+1}\right)(\vec{\beta}\cdot\vec{B})\vec{\beta}\right]$$

- Due to vertical betatron oscillations we would have

$$\vec{\omega'_a} \approx -\frac{q}{m}\left[a\hat{y}B_y - a\left(\frac{\gamma}{\gamma+1}\right)\beta_y B_y(\hat{s}\beta_s + \hat{y}\beta_y)\right]$$

$$\approx -\frac{q}{m}aB_y(1 - \frac{1}{2}\hat{y'}^2\cos^2\omega_y t)$$

or, $$\vec{\omega'_a} \approx -\frac{q}{m}\left[a\hat{y}B_y - a\left(\frac{\gamma}{\gamma+1}\right)\beta_y B_y(\hat{s}\beta_s + \hat{y}\beta_y)\right]$$

$$\frac{\Delta\omega}{\omega} = -\frac{\langle y'^2\rangle}{2} = -\frac{\langle \hat{y'}^2\rangle}{4} = -\frac{n}{4}\frac{\langle y_0^2\rangle}{R_0^2} \equiv C_P$$

*precise particle tracking required*

# Resonances and Losses

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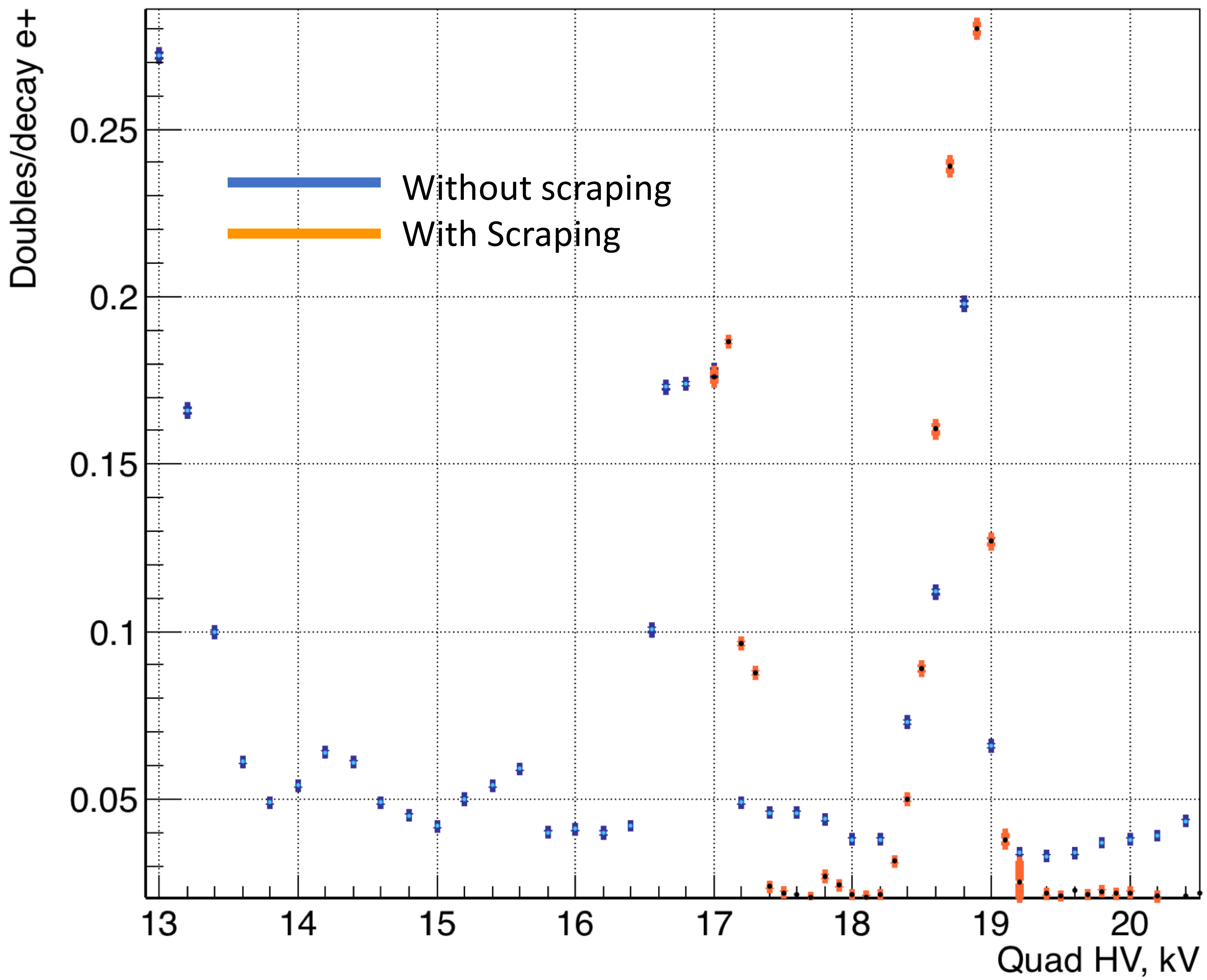
$$N(t) = \left(\frac{N_0}{\tau}\right) e^{-t/\tau}\left[1 - A\cos(\omega_a t + \phi)\right]$$

must modify, since rate at which particles are *lost* is governed by other than *decay*




from Sudeshna, *et al.*

Lost muon doubles vs. quad HVPS set-points for t > 30μs after injection, with scraping and without scraping.

# Loss Simulations

*D. Tarazona, MSU*

lost muons (sim) vs. HV[kV] (t=121-186μs)