Step IV Physics Paper Readiness

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Step IV Papers

- For quick release (these are papers):
  - **Description of MICE Step IV**
  - **First observation transverse emittance reduction**
- Slower boil, worthy of a publication, maybe not one per bullet
  - **Diagnostics**
    - Global track fitting
  - **Magnetics**
    - Measurement of optical emittance growth and non-linearities
    - Direct measurement of the transfer map including higher order terms
  - **Absorber**
    - Energy loss
    - Multiple scattering
    - Angular momentum
    - Beam (de)polarisation
    - Wedge
  - **"Cooling Channel"**
    - (Long, probably following end of Step IV with all results in) Observation of transverse emittance reduction
    - Emittance exchange with wedge

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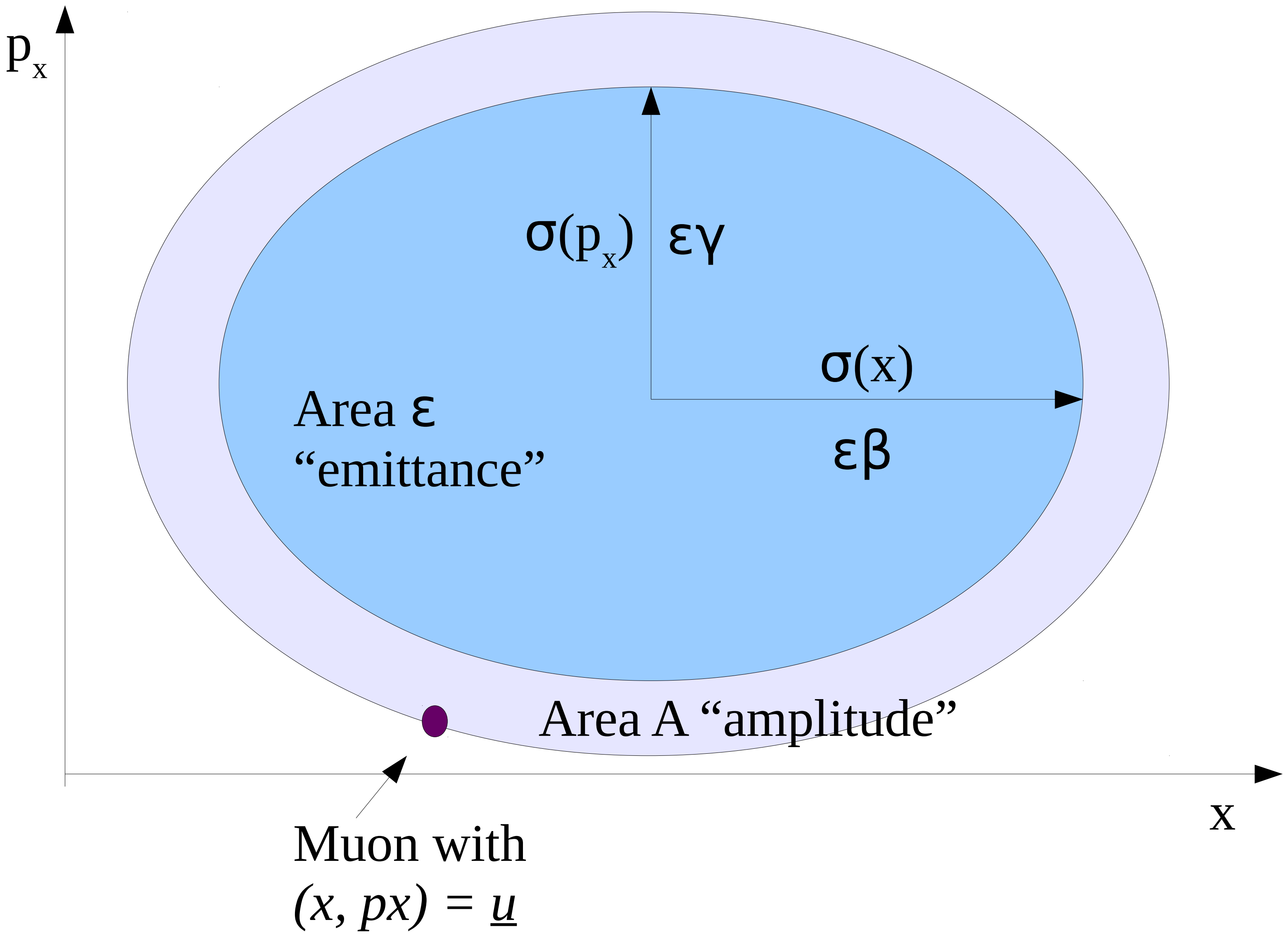
Description of MICE Step IV

- Detectors and Diagnostics
  - Reconstruction efficiencies
  - Reconstruction residuals – u/s versus d/s
  - Validation of Particle ID routines
- Description of incoming beam/beamline
  - Match through diffuser to tracker
  - Beam impurity
- Description of magnets
  - Magnet mapping
  - Beam-based alignment
- Cooling channel optics
  - Measurement of beam upstream and downstream

First Observation of Emittance Reduction

- Measurements all with LiH
  - Dependence on optical beta function
  - Dependence on momentum
  - Dependence on emittance
  - Change in particle amplitude
- Basic analysis
  - Beam selection
  - Errors – pid
  - Errors – phase space vector
- Data taking
  - Real run settings
  - Analysis tools
- To Do List

Reminder of Terms - 2D



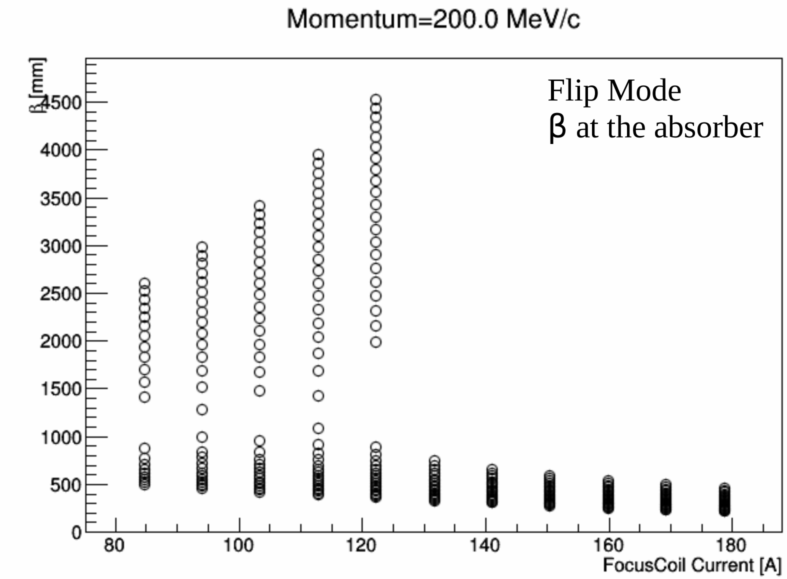
Basis for run settings

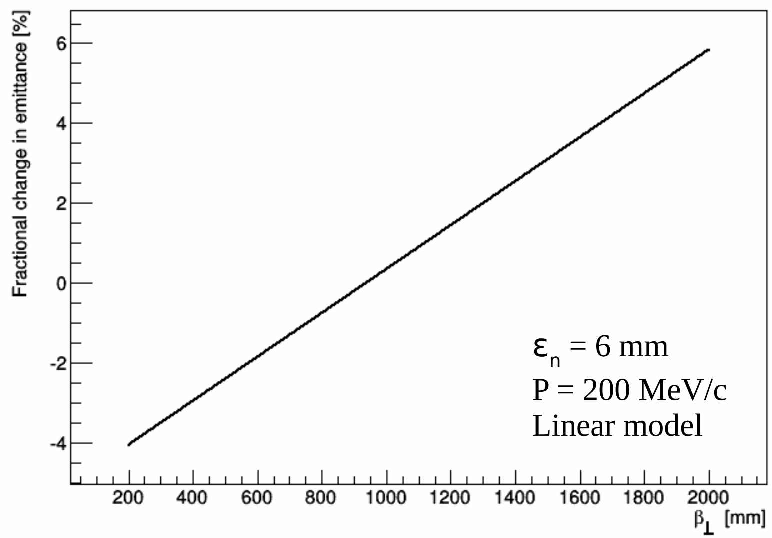
- Aim is to explore the "emittance reduction" formula

$$\frac{d\epsilon_N}{ds} = -\frac{1}{\beta^2}\frac{dE_\mu}{ds}\frac{\epsilon_N}{E_\mu} + \frac{\beta_\perp (0.014\mathrm{GeV})^2}{2\beta^3 E_\mu m_\mu L_R}$$

  - Dependence on optical beta $\beta_\perp$
  - Dependence on energy - E_μ and β
  - Dependence on input emittance ε_n
  - (Dependence on material - L_R and dE_μ/ds)
- Plan to:
  - Scan about the centre on each variable with ~ 10 points
  - Large statistics run at center of parameter space
  - Check corners of the parameter space
- Consider accessible phase space as:
  - 140 MeV/c < P < 240 MeV/c
  - ε < 10 mm; difficult to get below ~ 3-4 mm (but we should try)
  - B < 1000-2000 mm; difficult to get below ~ 200 mm

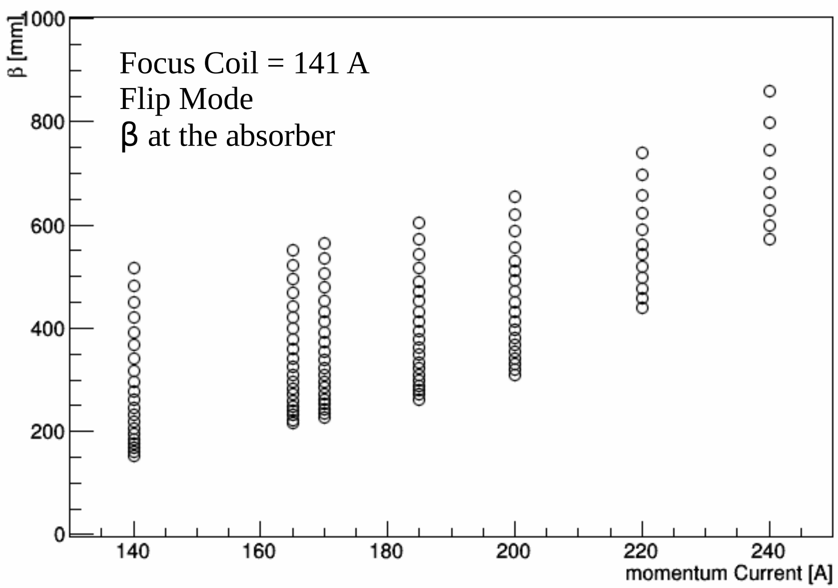
Measurements - Beta function scan

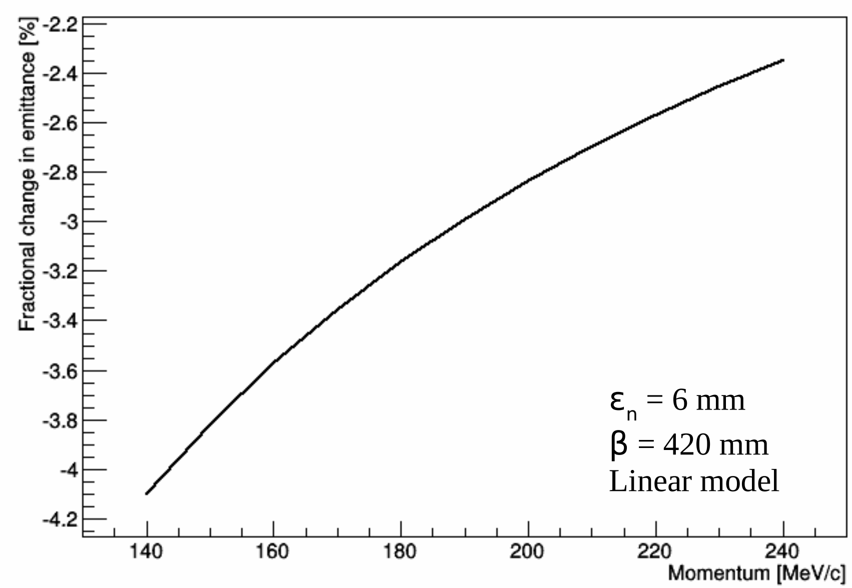




- At 200 MeV/c – wide range of available optics
  - Smallest $\beta_\perp$ 218 mm (flip mode)
  - Is it worth scanning with constant FC current?
- Tighter focussing is available at 140 MeV/c
  - dp/p is greater here
  - May find more cooling at 140 MeV/c

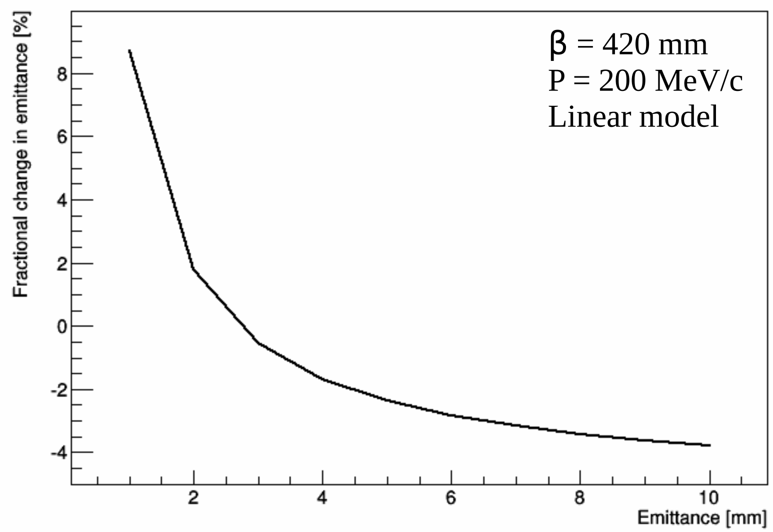
Measurements – Momentum scan





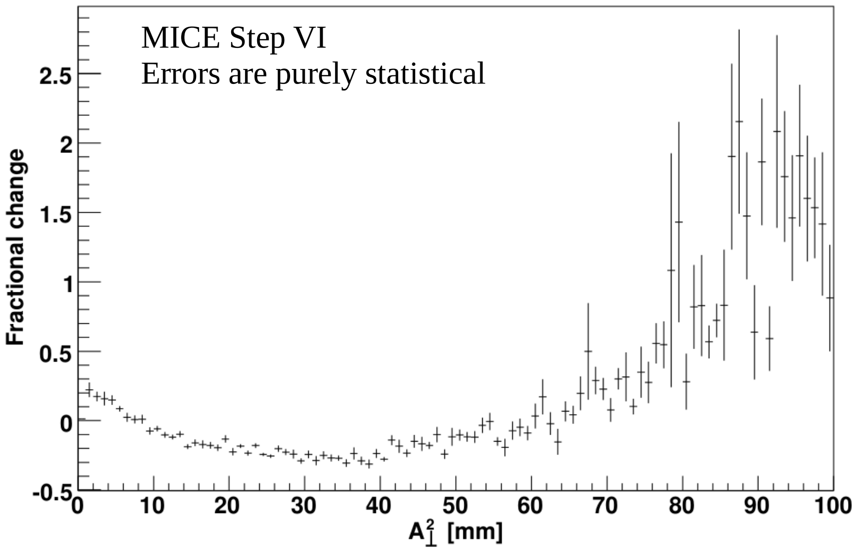
- At different momenta we get different cooling performance
  - Can we hold beta constant at different momenta?

Measurements – Dependence on Emittance



- Show dependence on emittance
- Find zero crossing “equilibrium emittance”
  - Tough for lower beta functions; the beamline cannot deliver

Measurements – Particle Amplitude

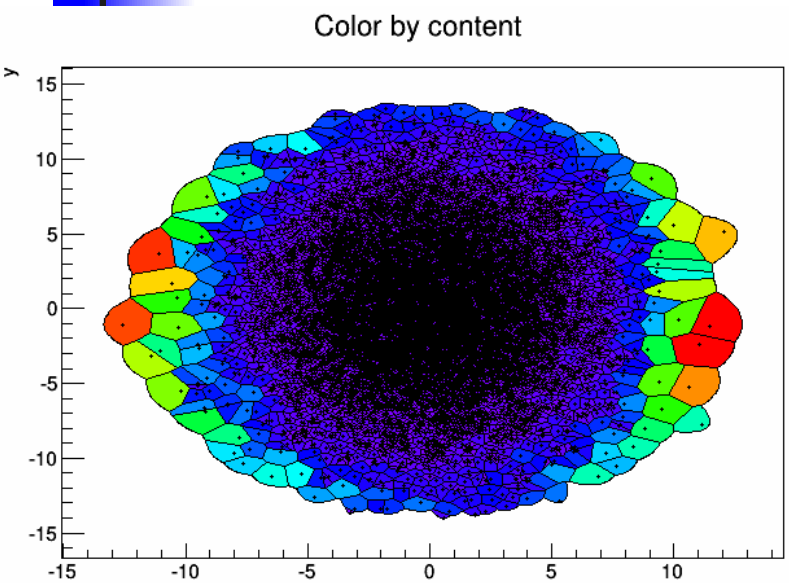


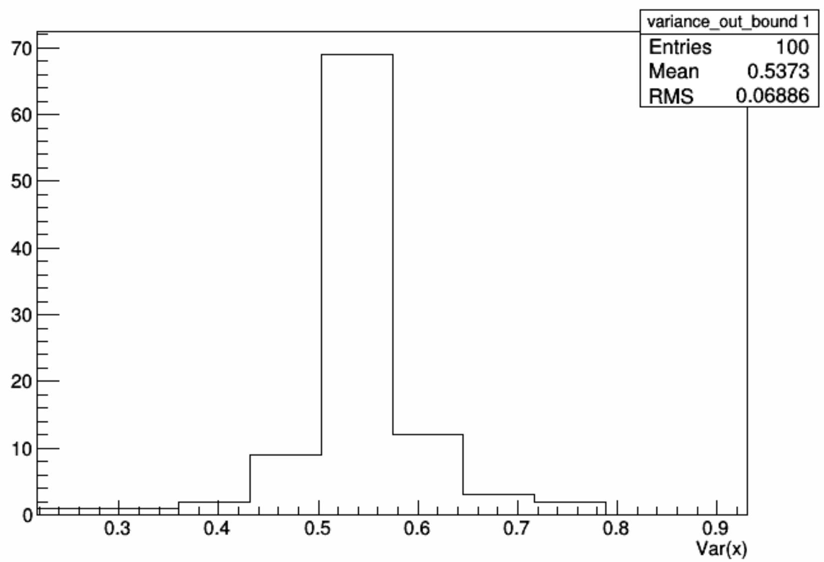
- Sit at a single optics and momentum
- Take data covering a large portion of phase space
- Calculate change in particle amplitudes over this phase space

Comment on “Corners”

- Seek to take good statistics in the “corners” of the parameter space
  - i.e. min/max emittance, momentum, beta
- This is useful for checking MC code
  - But I do not anticipate a massive MC exercise to be a part of this paper i.e. we report cooling performance with little comparison to MC
  - Comparison to MC comes later
- May be able to make some amplitude plots

Beam Weighting - Voronoi

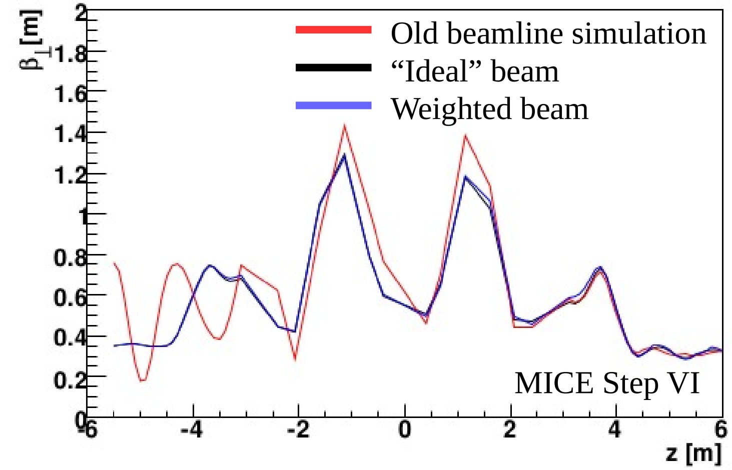


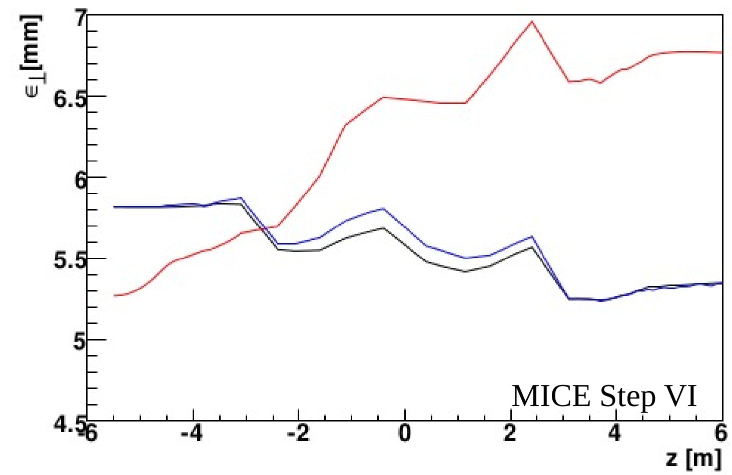


- For each particle, find the region nearest to that particle
  - Nearest neighbour algorithms are well-known
  - I choose Voronoi algorithm, which is fast enough and accurate
- Calculate the volume c_i of that region
  - Not quite straightforward in higher dimensions
- Calculate the desired pdf f_i at that point
- Assign a statistical weight given by
  - $w_i = c_i f_i$

Beam Weighting - Moments

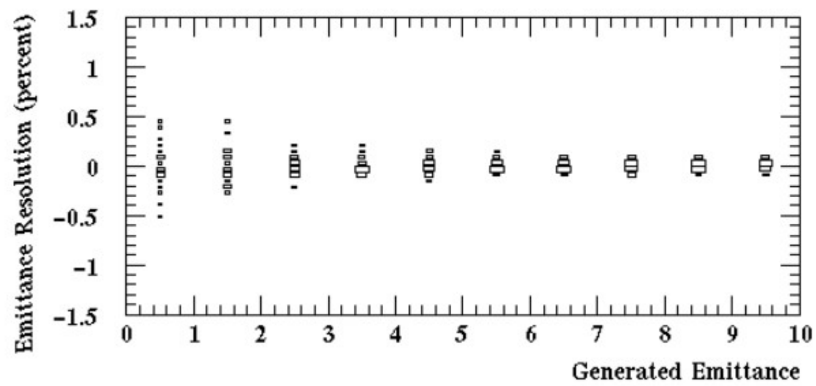
- Estimate the phase space density by calculating beam moments
- Weight using a polynomial *f(u)* in phase space vector coordinates *u*
  - $w_i = f(\underline{u}_i)$
  - Linear relationship exists between input moments, output moments and polynomial coefficients for the weighting
- Issue:
  - Weights can be positive and negative
- To do:
  - Find a set of basis functions that are always positive

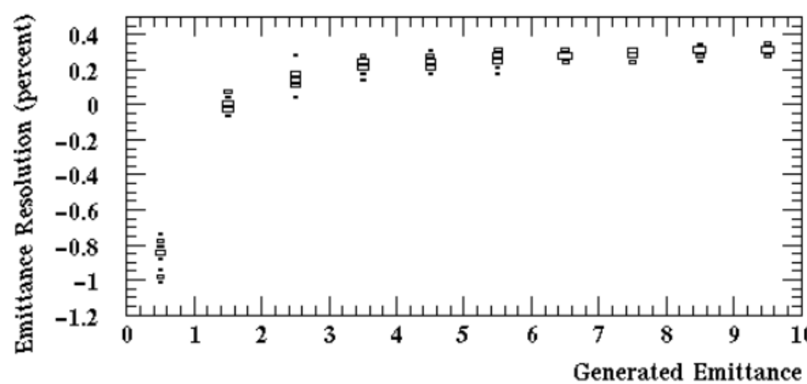




Error analysis – Phase Space

- Beam RMS ellipse can be deduced from
  - $\mathbf{V}_{\mathbf{measured}} = \mathbf{V}_{\mathbf{true}} + \mathbf{C} + \mathbf{R} + \mathbf{R}^{\mathbf{T}}$
  - **V** is the matrix that describes the beam ellipse
  - **C** is the matrix that describes the errors
  - **R** is the matrix that describes correlations between the true phase space vectors and the errors
  - We know **R** is significant e.g. we know p_z errors are large for small p_t
- Questions:
  - Can we deduce the error matrices from the measured Kalman fit errors?
  - What is the effect of known misalignment on track fit? Can recon cope?





Error analysis – PID Speculation

- 4D emittance is related to particle amplitude by
  - $\varepsilon = \langle A \rangle / 4$
- Effect of mis-PID depends where in phase space the mis-identified particles are
  - Probably PID is worst at high amplitude
- Upstream
  - μ identified as e/π only effects sampling efficiency
  - π identified as μ - guess – look like larger upstream emittance
    - They will probably decay to π by downstream detectors
  - e identified as μ – guess – look like too much scraping
    - They will probably be identified correctly downstream
- Downstream
  - μ identified as e will look like too much scraping
  - e identified as μ will look like not enough scraping, larger downstream emittance
- To do:
  - Make this quantitative, rather than speculative

Data taking - settings

- Beamline settings
  - We have reasonable set of beamlines (J. Pasternak)
  - Further optimisation is in progress
- Cooling channel optics
  - Ideal settings shown above
  - PRY → Holger is developing non-linear scaling from ideal currents to real currents
    - Preliminary analysis indicates scalings are <= 5 %
  - Near to Virostek plates, a field map may be needed
  - Misalignments will need to be understood; may feed into run settings

Data taking – analysis tools

- Physics shifter tool
  - Physics shifter tool is now automatically checking for new data sets and performing checks every hour
  - Would like to fold in “online reconstruction” plots but run against the offline reconstructed data set
- Online analysis tool
  - An event display has been foreseen for many years with beam envelopes etc superimposed
  - Some prototype code exists but is not ready for deployment to MLCR

To Do List

- Determine run settings
  - Optics studies for basic magnet settings
  - Tracking studies for momentum acceptance
  - Tracking studies for dynamic aperture checks
  - Tracking studies for cooling performance
  - Fold in “real world“ effects – windows, iron, misalignments ...
- Improve online/offline “data quality” tools
- Get a better grasp on errors


WINTER IS COMING
DATA
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