MICE Step IV Physics 'Deliverables'

AKA "What will we learn from Step IV?"

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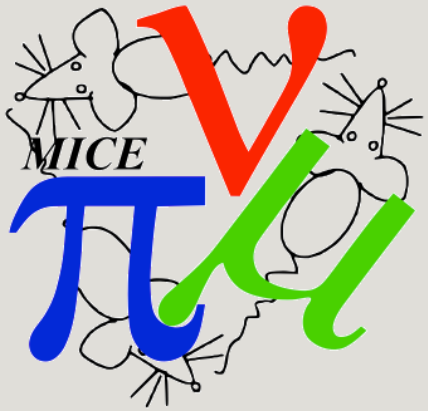
MAP 2014 Spring Meeting

30th May, 2014



UNIVERSITY OF OXFORD

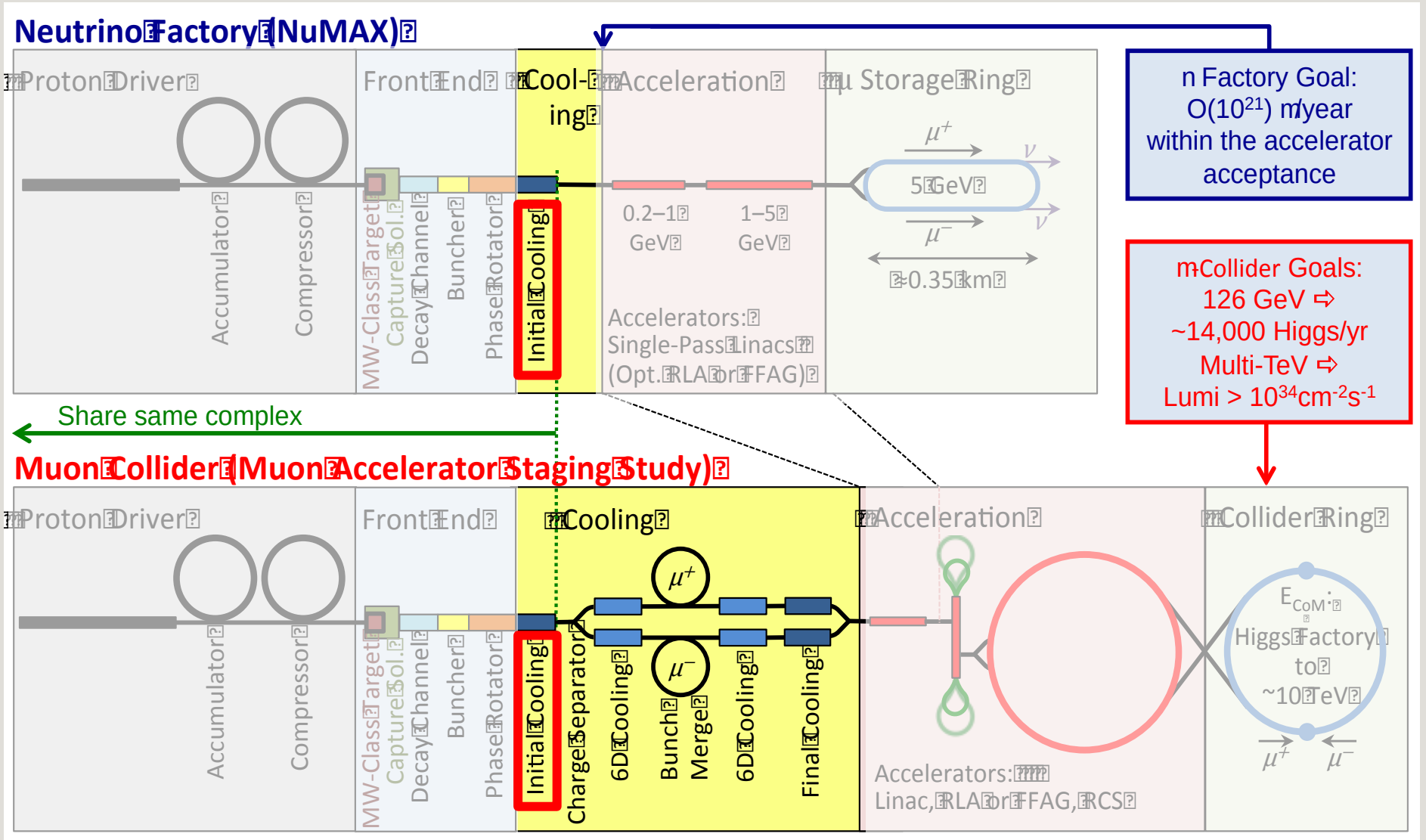
John Adams Institute for Accelerator Science

MICE Step IV Physics 'Deliverables'

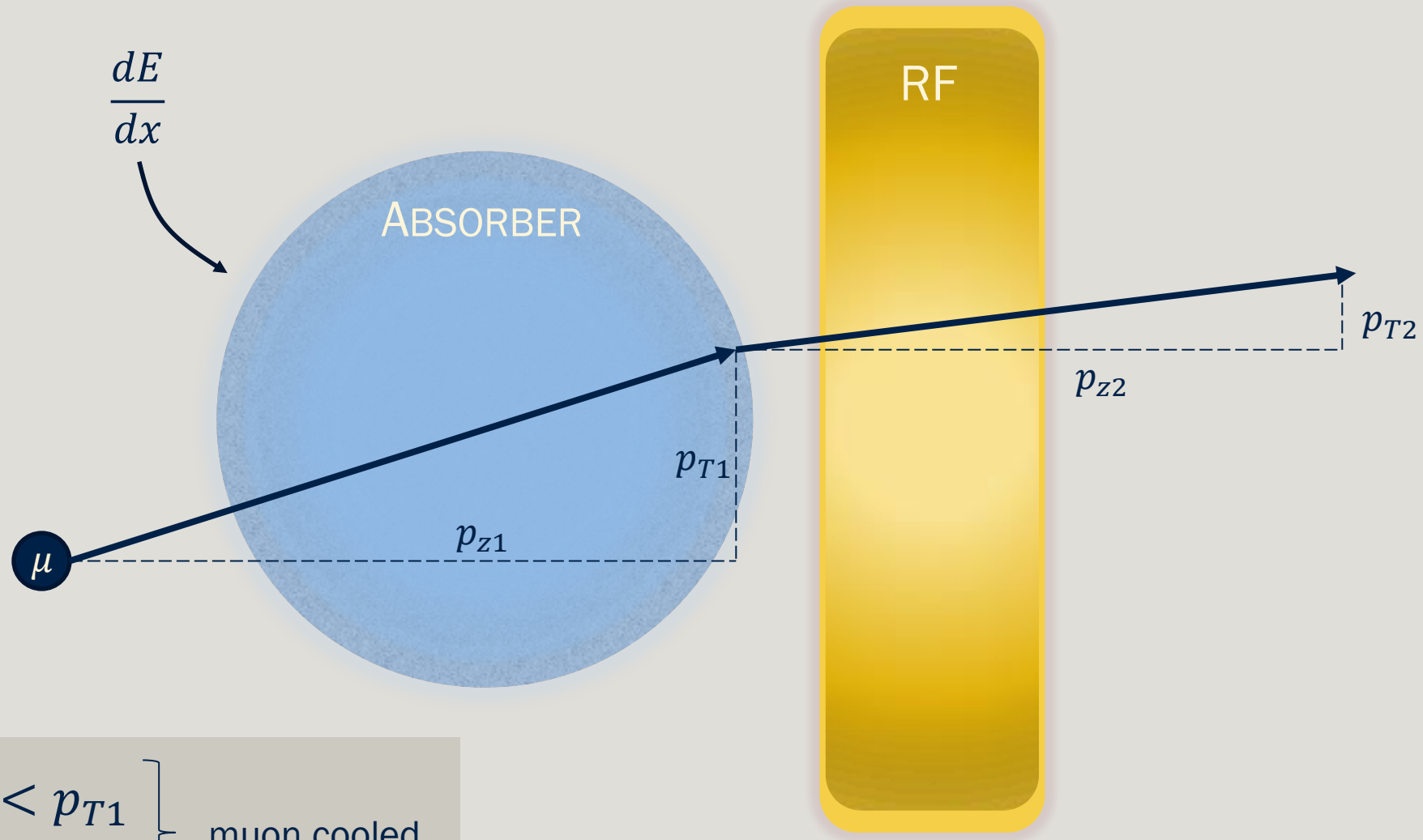
- Why MICE?
- What is Step IV?
- What will Step IV tell us?
- Summary

Why MICE?

More? See talks by D. Kaplan & A. Bross



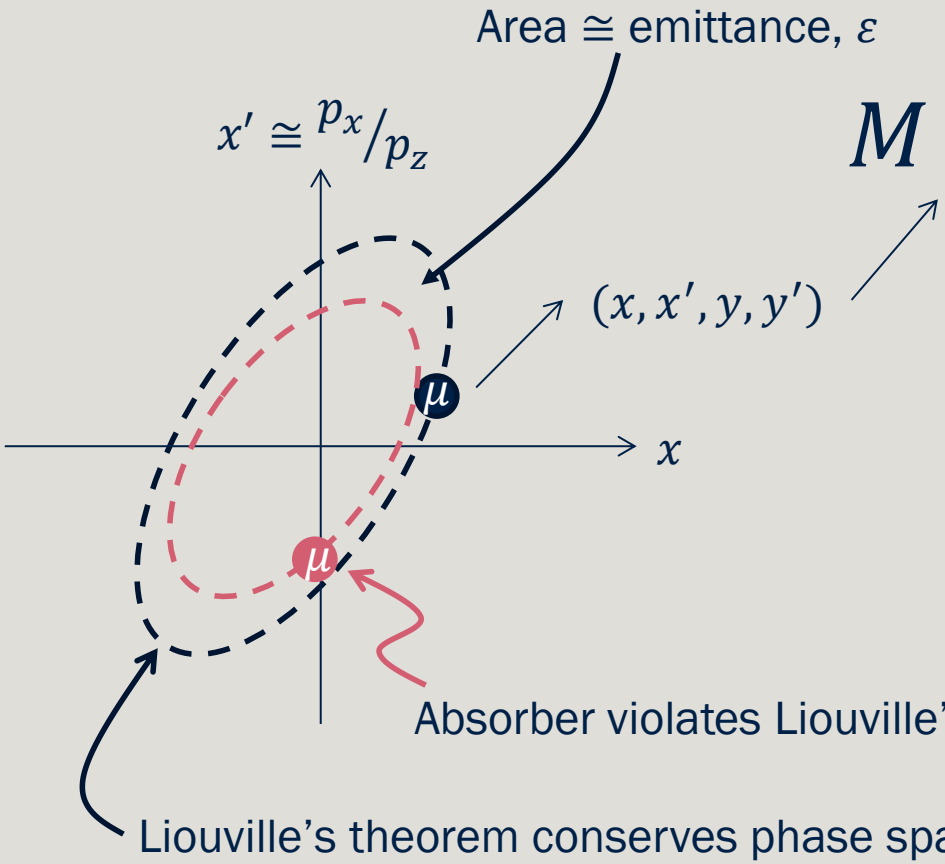
Ionisation Cooling



$p_{T2} < p_{T1}$
$p_{z2} = p_{z1}$
} muon cooled

Measuring "Cooling"

"Cooling" = reduction in phase space
MICE will measure a ~10% reduction in emittance to 1% relative precision

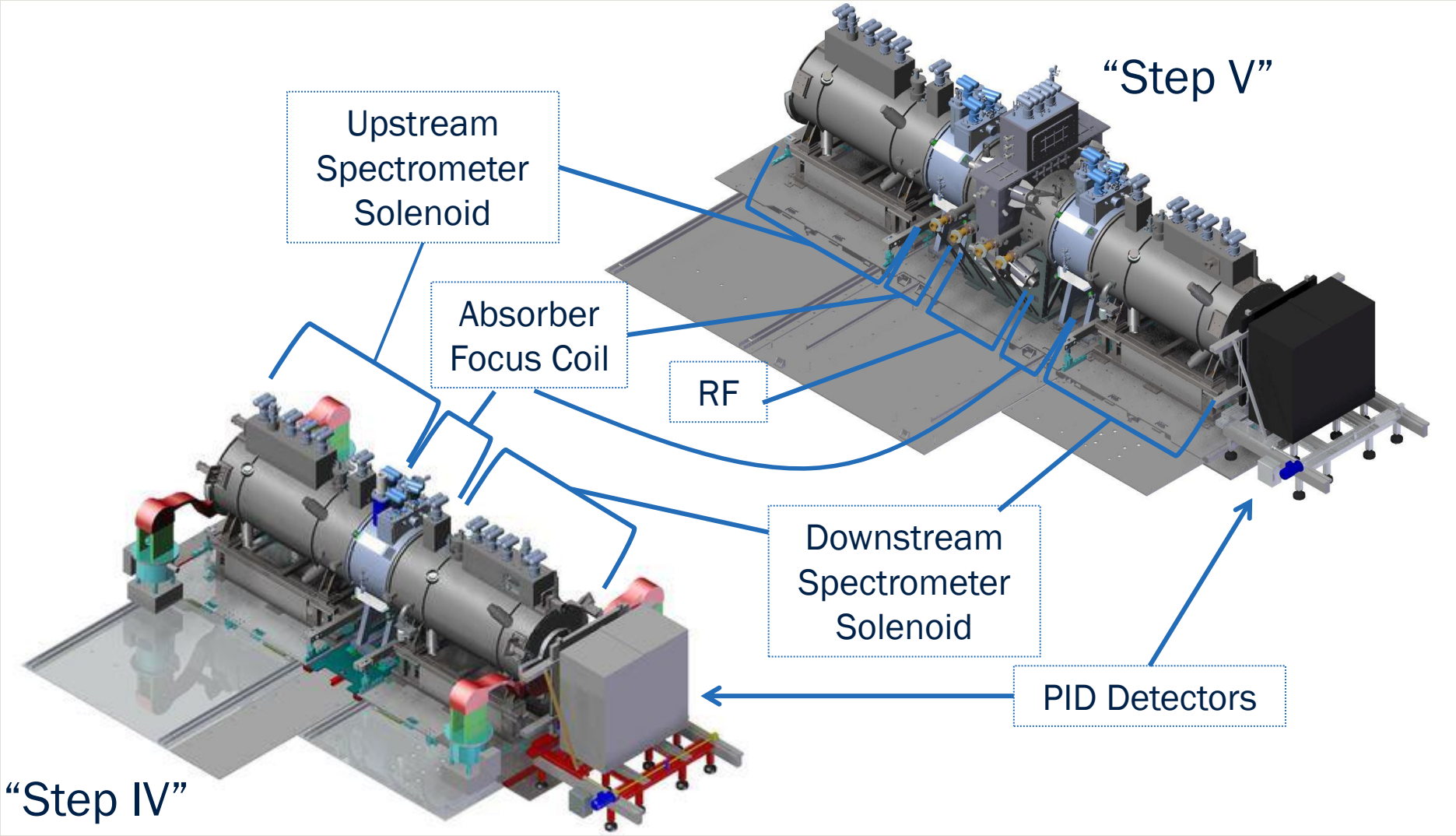


$$M = \begin{pmatrix} \langle xx \rangle & \langle xx' \rangle & \langle xy \rangle & \langle xy' \rangle \\ \langle xx' \rangle & \langle x'x' \rangle & \langle x'y \rangle & \langle x'y' \rangle \\ \langle xy \rangle & \langle x'y \rangle & \langle yy \rangle & \langle yy' \rangle \\ \langle xy' \rangle & \langle x'y' \rangle & \langle yy' \rangle & \langle y'y' \rangle \end{pmatrix}$$

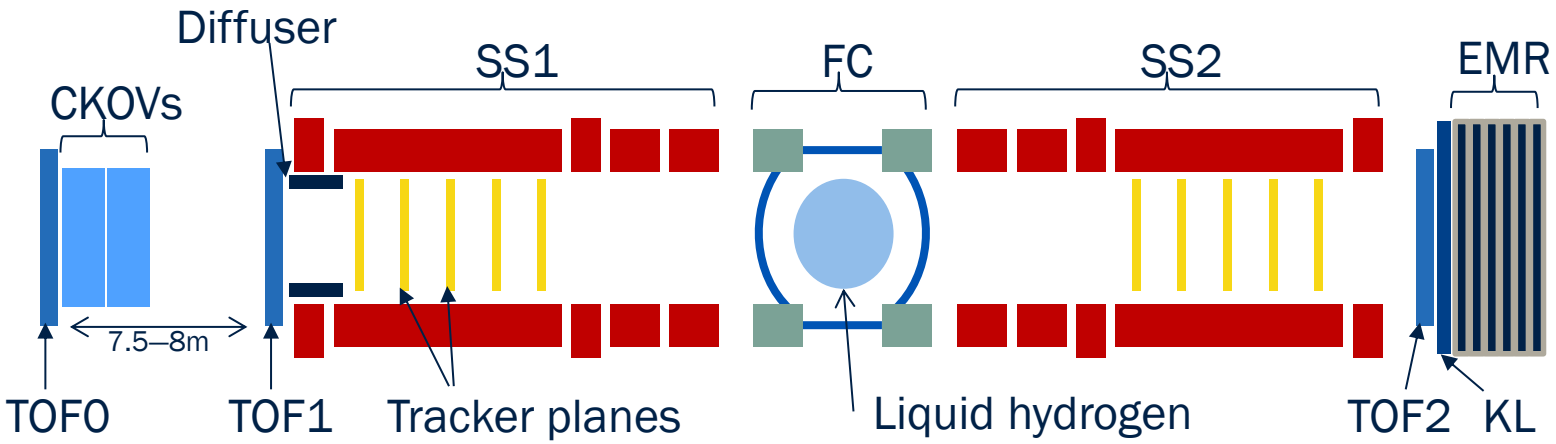
where $\langle xy \rangle = \overline{xy} - \bar{x}\bar{y}$

Build a **particle-by-particle** covariance matrix (M) and calculate $\varepsilon_N = \sqrt[4]{\det M}$
→ if $\varepsilon_{\text{out}} < \varepsilon_{\text{in}}$, **measured cooling**

Muon Ionisation Cooling Experiment



MICE Step IV



- One absorber
- No RF, no restoration of longitudinal momentum
- Aim: Demonstrate ionisation cooling without re-acceleration

- Detectors:
  - Time of flight (TOF0/1/2) counters measure (t, x, y, p_z) of individual muons
  - Tracker planes measure (x, y, p_x, p_y) of individual muons
  - KL and EMR for PID

Ionisation Cooling Approximation

- What do we expect to happen?
  - Step IV ~ 5% reduction in emittance
  - *More in Step V*

Ionisation Cooling

Multiple scattering

$$\frac{d\varepsilon}{ds} = \frac{-\varepsilon_n}{\beta^2 E}\left\langle\frac{dE}{dX}\right\rangle + \frac{\beta_t (13.6\ \mathrm{MeV})^2}{2\beta^3 E m_\mu X_0}$$

Measure a change in emittance

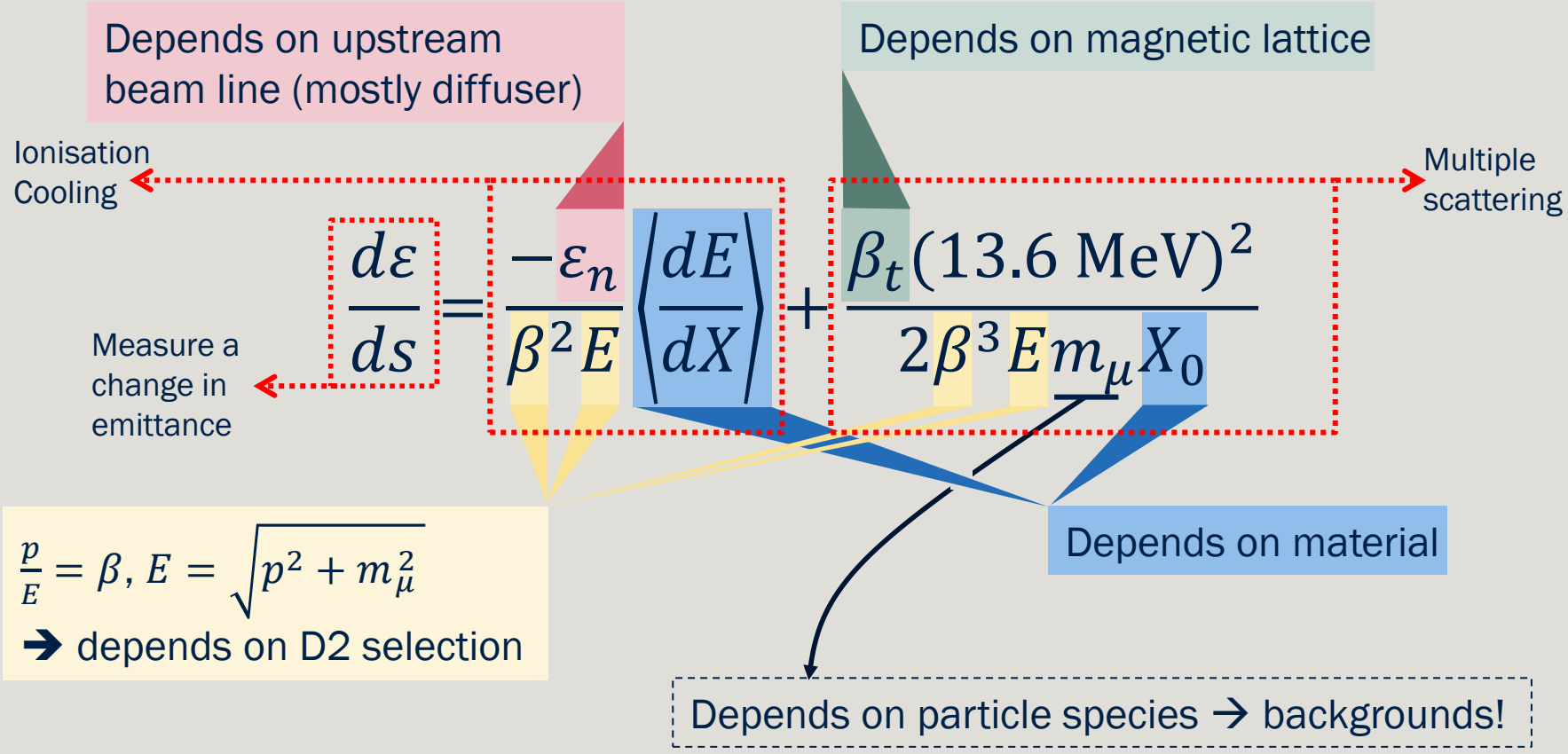
For maximum cooling:

- Large $\varepsilon_{\mathrm{in}}$
- Large $^{dE}/_{dX}$
- Depends on absorber, initial emittance and momentum

For maximum cooling:

- Small β_t
- Large X_0 (implies low-Z)
- Depends on absorber, momentum and optics

Ionisation Cooling Approximation



Many parameters that we can **tune** and/or **measure**

The MICE Physics Program (TBD*)

Definition of terms:

Essential: This result must be measured for MICE to achieve its goals. It cannot be delayed until a later Step.

Core: A critical result that could be delayed until a later Step given careful planning.

Optimal: An important result that could be better explored in a later Step.

Step	Result	Priority	Dependencies
IV	1. First demonstration of ionisation cooling	Essential	--
	2. Measurement of ionisation cooling with LH2 and LiH absorbers	Core	1.
	3. Initial study of factors affecting performance of ionisation cooling lattices	Optimal	1, 2
	4. Initial study of emittance exchange in an ionisation cooling lattice	Optimal	1, 2
V	5. First demonstration of ionisation cooling with re-acceleration	Essential	1
	6. Measurement of transverse emittance reduction and longitudinal emittance preservation in an ionisation cooling lattice	Essential	1, 2
	7. Study of factors affecting the performance of ionisation cooling lattices	Essential	1, 2, (3)
	8. Management of canonical angular momentum in an ionisation cooling lattice	Essential	1, (3), 5, (6, 7)

Physics deliverables depend on number of run cycles…
…Run cycles depend on installation of Step V

* Will be discussed at next CM

With ∞ time…

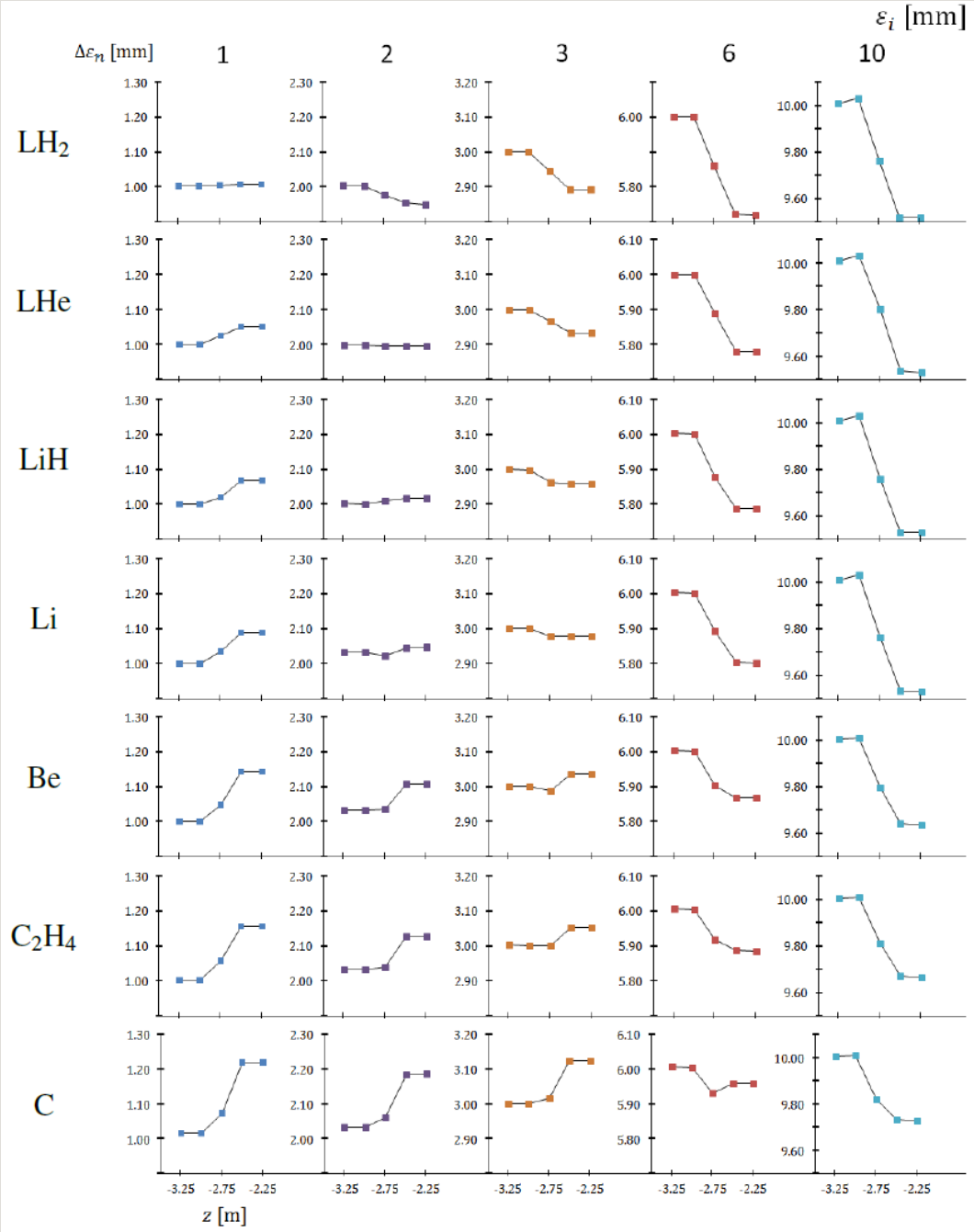
Change in emittance depends on:

- **Absorber material**
- **Initial emittance**
- β at absorber
- Momentum

Can study cooling vs. heating as a function of absorber material and initial emittance.

If initial emittance < equilibrium emittance → heat.

If initial emittance > equilibrium emittance → cool.



With ℜ[time]…

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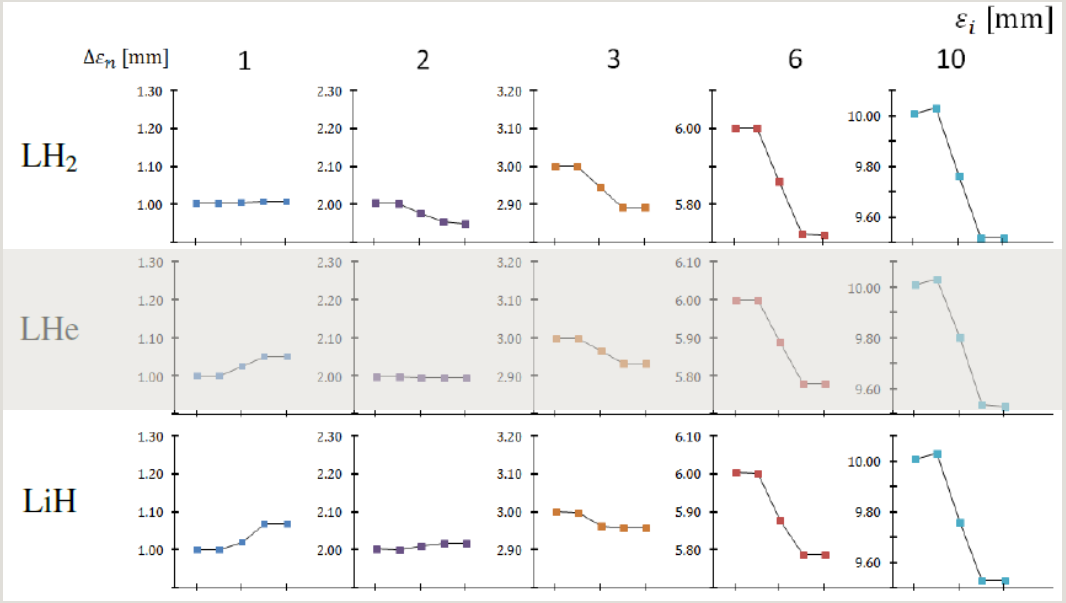
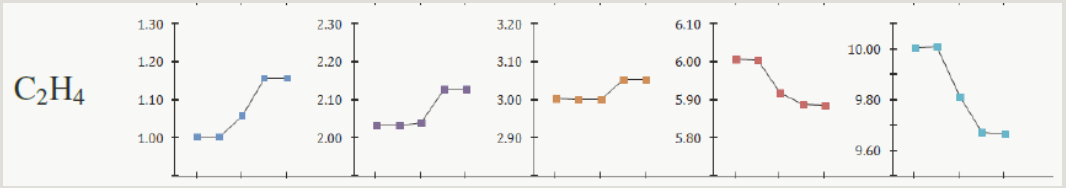


Time (and cryostat) permitting
+ LiH wedge absorber studies



Beyond Emittance

- Can do more than 'just' measure emittance and benchmark simulations.

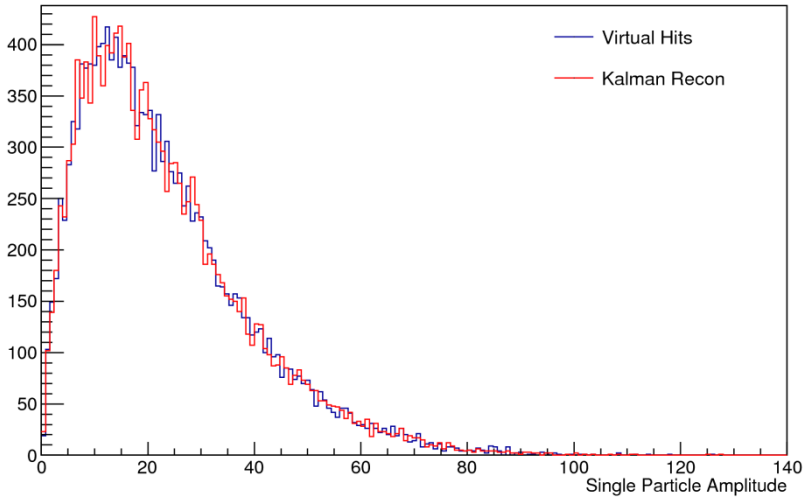
- MICE measures (x, y, p_x, p_y, p_z, t) for individual particles
  - Measured as a function of **magnetic optics** and **absorber material**
  - Majority of "other physics" is free and complementary to emittance measurement

- Amplitude distributions
- Optics studies ('easy') → test momentum acceptance, beam matching
- Transmission studies (easy)
- Particle tracking (easy)
- Muon polarisation (hard)
- Multiple Coulomb Scattering (hard) → complement MuScat
- Energy straggling (difficult) → compare to theory

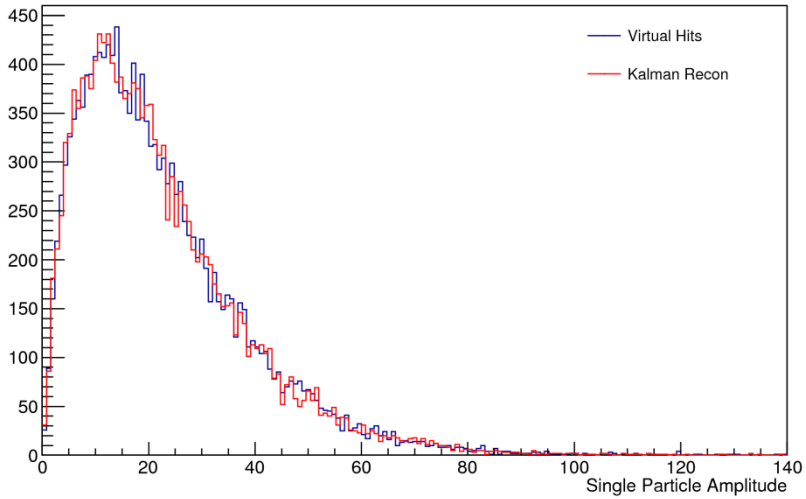
- **Preparation for Step V physics**

Single Particle Amplitude's

Upstream

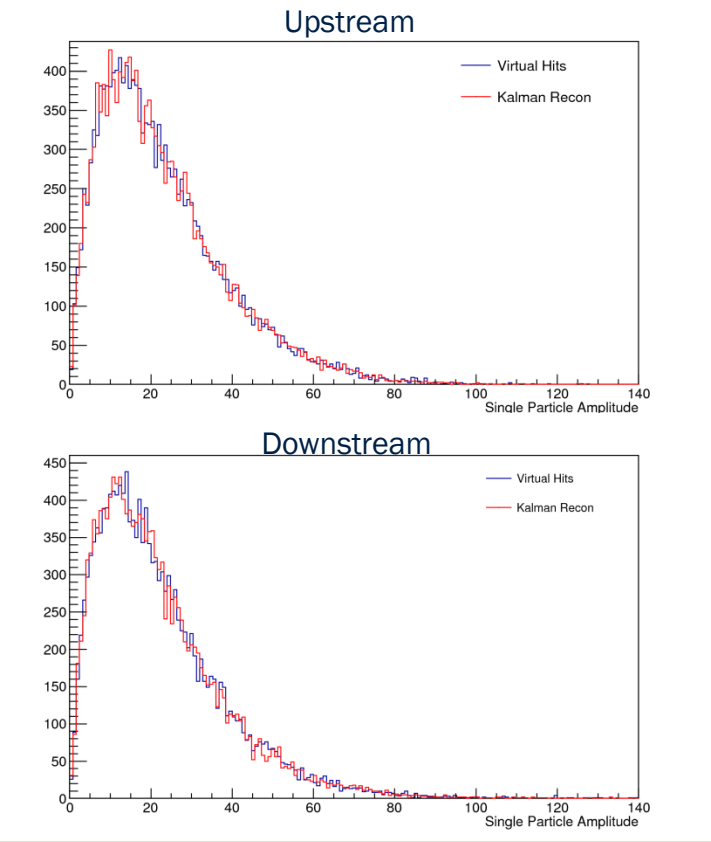


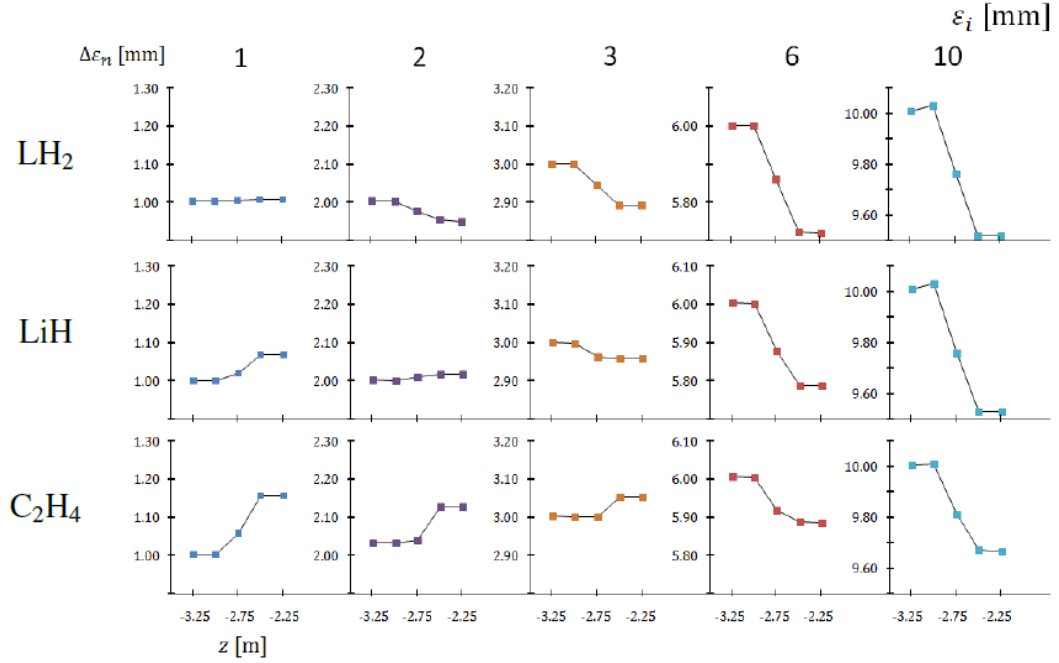
Downstream



- Emittance is a single number that describes the 'average' beam.
- We also measure the amplitude of individual muons
- Mean of the amplitude distribution = 4ε
- More particles at lower amplitude downstream (in Step IV)

Summary





- A lot can be learned from Step IV
- Exactly <u>how much</u> depends on installation of Step V → <u>reacceleration</u> is the ultimate demonstration of ionisation cooling!