Report on the Analysis Group & Plans

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MICE VC 163

Thursday, 12th December 2013

The Final Paper:

A full and definitive exploration of the ionisation cooling equation
+ Proof that we can *predict* it
+ Proof that we can *measure* it

Depends on upstream beam line (mostly diffuser)

Depends on magnetic lattice

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

$\frac{p}{E} = \beta$, $E = \sqrt{p^2 + m_\mu^2}$
➔ depends on D2 selection

Depends on material

Depends on particle species → backgrounds!

+ RF, an additional requirement for other facilities, + canonical angular momentum, +...

The Final Paper:

- Actually, Step IV will have addressed the cooling formula (albeit with less cooling) before the final paper
- Step V/VI will address cooling with reacceleration and the lattice efficiency:
  - Operation of RF cavities in a magnetic field
  - Timing of RF phase to muon spill
  - Efficiency of longitudinal momentum restoration
  - Cooling channel transmission efficiency
  - Studies on the build-up/cancellation of canonical angular momentum (i.e. flip vs. solenoid mode)
  - PID/background studies
  - Then: Transverse cooling with reacceleration

The Cooling Paper:

- The cooling formula can be fully explored by Step IV ("first demonstration")
- Requires us to demonstrate our understanding off all its points:
  - Momentum selection/creation/transport of particles
    - Alignment of beam line
  - Detection of particles
    - Alignment and calibration
  - Background rates
  - Beam matching and emittance generation through the diffuser
    - Don't forget matching at end of lattice
  - Transmission efficiency through the lattice (at different $\varepsilon_n, \beta_t, p$)
  - Canonical angular momentum study
  - Multiple scattering and its influence on measurements
  - Energy losses in material
  - Timing/spill structure study (for future RF work)
  - Then explore cooling for each material; fill in the $(\varepsilon_n, \beta_t, p)$ measurement matrix.
    - Find the equilibrium emittance

Analysis Overview:

Key:
- Completed (paper published)
- Near completion (paper being drafted)
- In progress (paper being thought of)
- At risk (not currently being looked at)

Our "job": Get the publications!

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1. Momentum selection/creation/transport of particles, alignment of the beam line
   a) Beam line documentation – Step I "beam line paper"
   b) Characterisation of the upstream beam line – Step I "emittance paper"
   c) Understanding the momentum and spatial distributions
      - Step I "emittance paper" looked at expected vs. measured momenta and spatial distributions
      - Mismatch observed between simulated and measured dispersion in the beam (i.e. incorrect beam line assumptions in simulation)
      - New G4BL simulations of upstream beam line are in much better agreement (Nugent, Soler, Blackmore)
   d) Transport of particles – Step I "emittance paper" demonstrates we can do this
   e) Alignment of Q789 using Step I data
      - Upstream beam line (possibly) not perfectly aligned. Measured beam is smaller than expected. Scan Q789 quadrupoles and look at beam position at TOF1 to judge alignment. (Overton)

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2. Detection of particles
   a) CKOV, TOFs, KL instrumentation documented in beam line paper
   b) EMR and tracker(?) instrumentation documented
   c) Particle ID with EMR
   d) Particle ID using TOFs/KL/Ckovs (?) – Pion contamination paper
   e) Global PID (requires part 3 to be completed)
3. Alignment and calibration
   a) Calibration of TOFs is documented (bar "rate effect"!)
   b) Calibration of EMR
   c) Alignment and calibration of trackers
   d) Alignment of Step IV PID detectors (*i.e.* straight track check, all detectors)

   NB: A lot of "alignment" is just a survey of the main body of the detector
4. Background rates
   a) Demonstrate understanding of our pion and muon production – pion contamination paper
   b) EMR analysis, further information on pion and muon production. Standalone or could feed into pion contamination paper depending on analysis requirements.

Uchida, Dobbs if ?=no

Blondel, Asfandiyarov, Drielsma

Orestano

Taylor, Pidcott

Rajaram, Bonesini

Blondel, Asfandiyarov, Drielsma

Uchida

Needs Step IV

Needs a champion: Taylor, Pidcott?

Orestano

Blondel, Asfandiyarov, Drielsma

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5. Beam matching and emittance generation
   a) Required for maximising beam without field and matching through new diffuser with/without field. Depends on 1c, 6a (with field). ← Leonova, Nugent
   b) Measure multiple scattering through diffuser in Step IV (no field) ← Blackmore
      i. Confirms beam behaves as expected through distributed diffuser, gives confidence in matching abilities
   c) Measure beam matching (with field) in Step IV upstream and downstream of cooling channel (depends on 5d, 6a) ← Probably Blackmore, Rogers
   d) *Lattice re-match with reduced FC currents* ← Rogers began study: Santos, Rogers, Blackmore to complete?

6. Transmission efficiency through lattice
   a) Understand solenoid field ← Blackmore
   b) Study of transmitted number of muons through Step IV with/without field ← Santos
   c) Expected efficiency of cooling in Step IV (with/without reduced FC currents) ← Santos

7. Canonical angular momenta
   a) Understand what happens to canonical angular momentum in flip and solenoid mode ← Probably Rogers

Needs Step IV → 5b, 5c, 5d, 6b, 6c, 7a

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8. Multiple Scattering
   a) Multiple scattering in channel is a background we must understand
   b) Multiple scattering in an absorber is part of the cooling formula
      a) Same input beam, same absorber, different β_t at absorber
      b) Same input beam, same absorber, different p at absorber
      c) Repeat for different absorbers
      d) No absorber, detector limitations (background)
   c) Multiple scattering is best measured without field

Thesis completed

Cobb, Carlisle

Santos

Needs Step IV

9. Energy Losses
   a) Similar to multiple scattering, but comparison momentum loss instead of scattered angles (also useful for RF in Step V/VI)

Needs champion: Probably Rogers, Cobb, Blackmore (Spiers?)

10. Timing/spill structure
    a) Depends on understanding 9.
    b) Timing of muons passing through Step IV upstream/downstream as expected
    c) Required confirmation for Step V/VI with RF
    d) Using Step IV beams as input, propagate through RF simulation

Needs champion: Probably Karadzhov, Rogers, Spiers

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11. First Demonstration of Ionisation Cooling
    a) Depends on understanding 1—10.
    b) Can now explore full parameter space: $\varepsilon_n, p, \beta_t, X_0, \langle {}^{dE}/_{dX} \rangle$
    c) Find equilibrium emittance for each absorber material and each lattice (i.e. β_t at FC)

By this point we should:

i. Understand our measurement techniques, detectors, and errors on those measurements
ii. Understand our backgrounds
iii. Understand our PID and track reconstruction
iv. Understand the lattice behaviour
v. Understand all of the "inputs" into the cooling formula and be able to estimate the amount of cooling we expect to see in Step IV
vi. Exploit the measurements to improve our understanding of Step V/VI

Step IV complete (<u>**and an awful lot learned**</u>)!

The Final Paper: (Déjà vu)

- Now that we've explored the cooling formula...
  - Revisit any part of Step IV with improved precision (e.g. more absorbers → more noticeable cooling effect)
- Step V/VI will address cooling with reacceleration and the lattice efficiency:
  - Operation of RF cavities in a magnetic field
  - Timing of RF phase to muon spill (did our expectations work?)
  - Efficiency of longitudinal momentum restoration
  - Cooling channel transmission efficiency (longer/full lattice)
  - Studies on the build-up/cancellation of canonical angular momentum (i.e. flip vs. solenoid mode) in a longer lattice
  - PID/background studies (now with RF!)
  - Then: Transverse cooling with reacceleration

All of this incredibly interesting and fun stuff needs championing!

Summary

- Everyone should want to be part of the analysis!
  - The analysis-regulars need assistance if all is to be completed on time.
  - The collaboration consists of more than just **Asfandiyarov, Blackmore, Blondel, Carlisle, Cobb, Dobbs, Drielsma, Leonova, Nugent, Overton, Pidcott, Rajaram, Rogers, Santos, Soler, Taylor, Uchida**.
- If you have an idea: Let us know!
  - Don't do analysis in the dark
  - Do this instead!