6D ionization cooling demonstration

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MAP Friday phone meeting

September 20, 2013

6D ICE goals

- Description: Development of experimental concepts and hardware specifications necessary to validate the feasibility of 6D ionization cooling.
- Bench test:
  - Cooling channel: will be based on the choices made as part of the Initial Baseline Selection process in D&S by FY15.
    - Key options are a Vacuum RF cooling channel and a HCC, latter stages with 650 MHz RF are preferred, but can be challenging given the distribution of muons we are likely to have (based on nuSTORM analysis).
  - Hardware: component development will take place through the TD effort. Targeting component availability by conclusion of Phase II (FY18).
  - Systems Demonstration:
    - Test of 6D cooling cell components.
    - Integration issues.
    - Developing detailed specifications for the tests.

6D ICE goals (contd.)

- Develop an instrumentation plan for characterizing the performance of a 6D cooling channel:
  - Instrumentation techniques.
  - Performance evaluation vs intensity (current efforts are based on the nuSTORM beam).
- Evaluate the necessity for a beam demonstration:
  - We cannot launch a demonstration unless we have a clear path to success.
  - Any demonstration is likely to be expensive, overall requires a very careful cost-benefit analysis.
  - Except for a few cases (nuSTORM), impacts on working facilities are likely.
- Is there a route that would provide hardware that could immediately address experimental needs?

6D ICE goals (contd.)

- Missing physics issues are of particular concern for the performance of a 6D cooling channel:
  - space charge screening in material,
  - ionization of material,
  - plasma effects from ionized electrons and ions.
- MICE, being a single particle experiment, will not address those effects.
- Explore options for confirming elements of the performance with high intensity beams:
  - At what intensities do we expect various processes to become apparent? (Coordinate with D&S to estimate the impact of specific physics processes.)

Deliverables

- Feasibility Phase I through FY15:
  - Development of a plan for a MAP 6D cooling bench test.
  - Close coordination with D&S and TD activities.
  - Development of a suite of experimental options.
  - Report during FY15.
- Feasibility Phase II through FY18:
  - Detailed evaluation of potential beam demonstrations.
  - Setup for the 6D bench test.
  - Possible proposal at the conclusion of the Feasibility Assessment.

Proton beam options

ERIT FFAG ring option

Proton beam options

- Last month Chris Rogers presented his idea that ERIT FFAG ring can be used for intense proton beam tests we are interested in.
- The next few slides are from his presentation at a recent 6D ICE phone meeting.

KURRI-FFAG Collaboration

- Collaboration with KURRI to study physics processes in an FFAG in a high intensity environment with a charge exchange foil
  - Understand effects of intensity dominated beams in non-scaling FFAG
  - Understand effects of hadronic processes, dE/dx and multiple scattering
  - Understand effects of hadronic processes, dE/dx and multiple scattering in intensity dominated regime
  - Put another data point on the “ionisation cooling (heating)” landscape
- Focus is in planning
  - Code development and simulation
  - Studies of both “main ring” and ERIT
  - Focus here is on ERIT
- Manpower limited effort

MICE missing processes

- Collective effects in vacuum
  - Space charge model in ionisation cooling ring
  - Quite a different lattice to e.g. guggenheim
  - Many more turns
  - Much less dominant absorber effects
  - Transverse emittance is dominant (few MHz RF frequency)

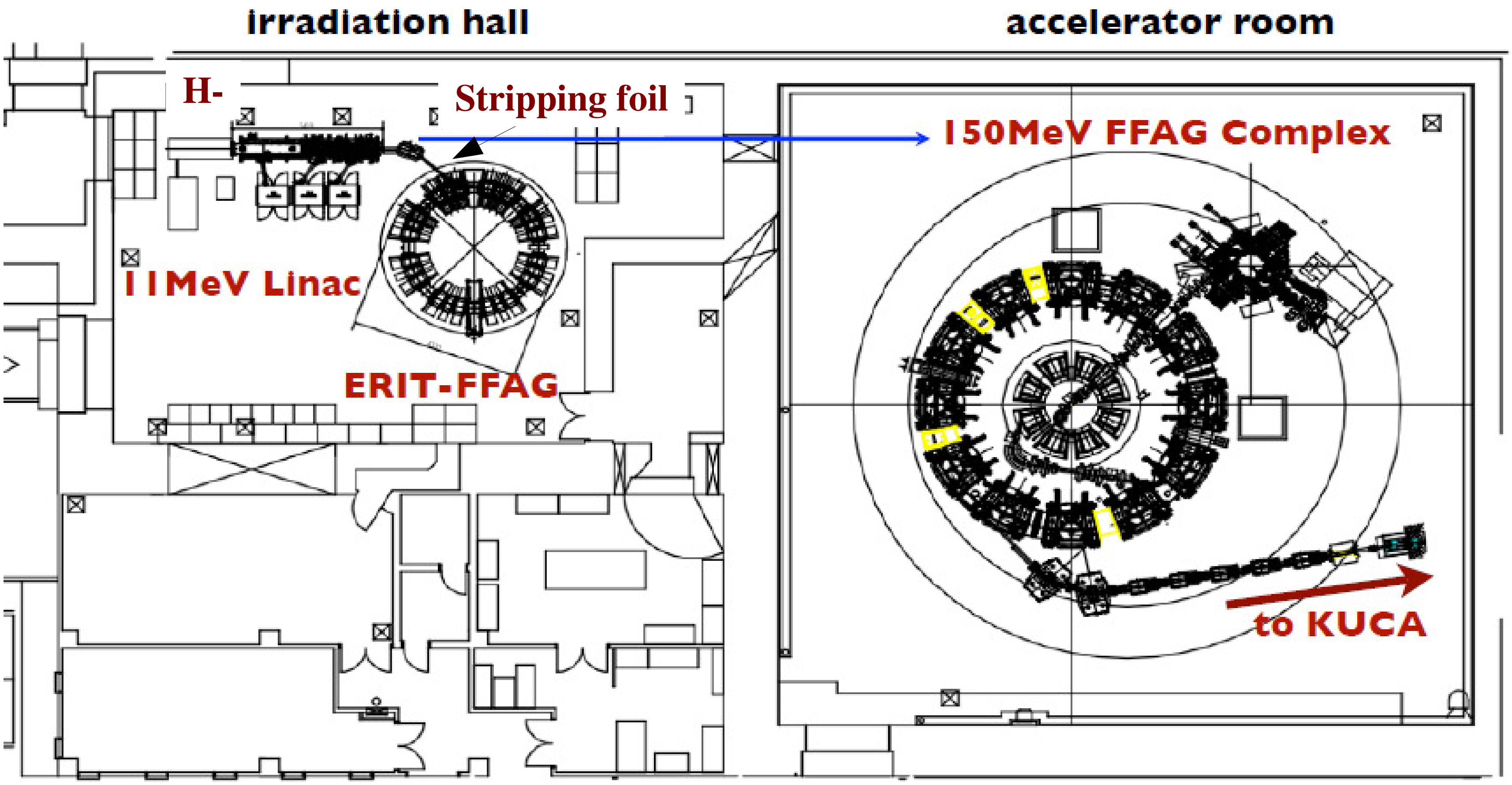
Collective Effects
Error in space charge models
Error in wake field effects
Unexpected beam-beam interactions
Electron cloud effects
Decay of macro-particles

MICE missing processes

- Collective effects in material
  - Many more passes through material
  - Number of ionisations is large relative to ionisation cooling channels

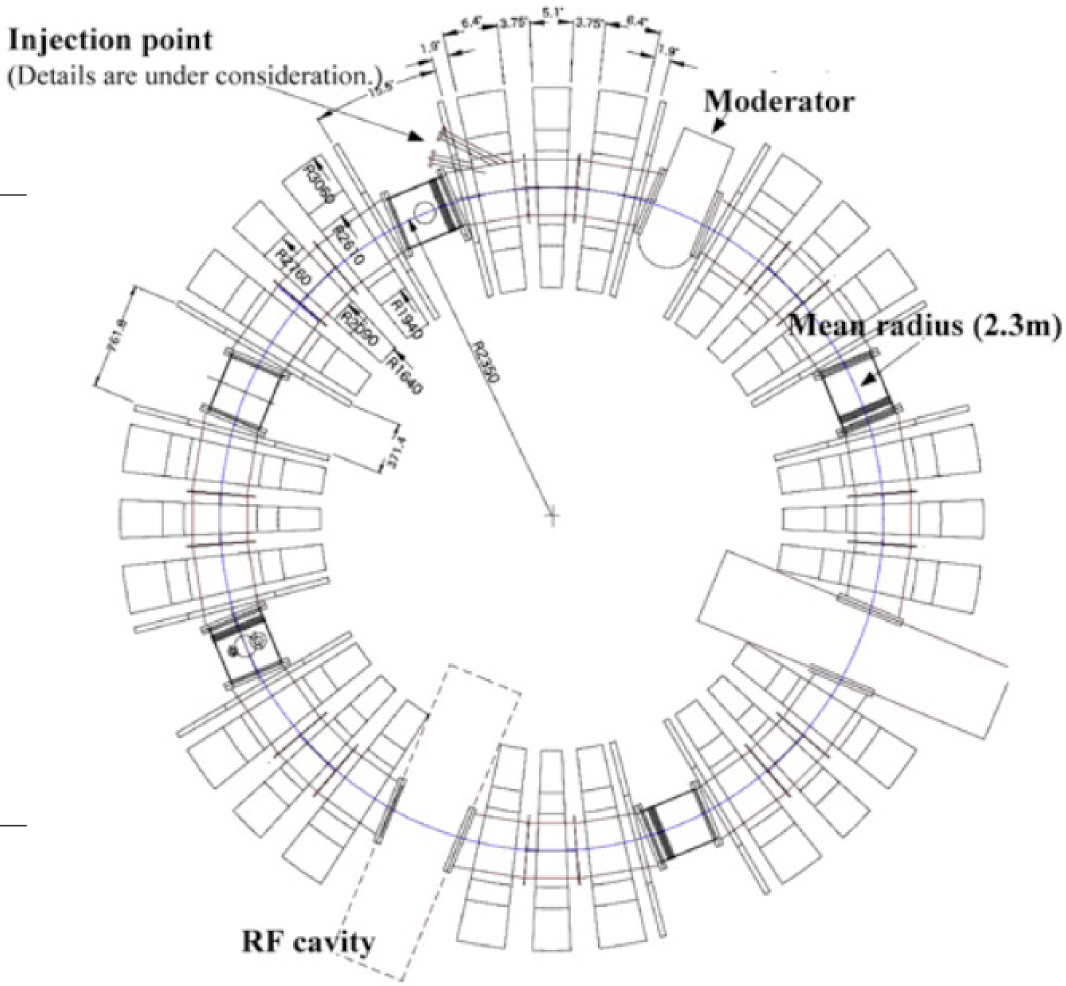
Collective Effects in Matter
Space charge screening by material
Bulk ionisation of material
Polarization of material
Plasma effects from ionized electrons and ions
LH2 bubble formation/thermal damage
Bulk DPA
Energy loss and multiple scattering from knock-on particles
Beam particles screening each other
Effect of plasma on atomic response
Effect of matter on wake fields and beam loading

KURRI accelerator chain



ERIT

Lattice	FDF radial
Mean radius (r_0)	2.35 [m]
Number of sectors	8
Field index k value	1.92
FD ratio	~ 3
Horizontal tune, Vertical tune	1.73, 2.22
Horizontal acceptance, Vertical acceptance	7000π [mm mrad] 3000π [mm mrad]
β_x, β_y @ target	1.36, 0.79 [m]
Revolution frequency	~ 3.02 [MHz]
rf frequency	18.1 [MHz] (h = 6)
rf gap voltage	225 [kV]



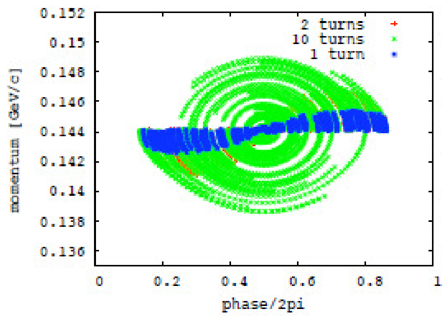
Top view of FFAG-ERIT ring

Diagnostics

- Current monitor
  - Measure emittance growth by scraping the beam
- Horizontal and vertical BPMs
  - closed orbit
  - Tunes
- Screen

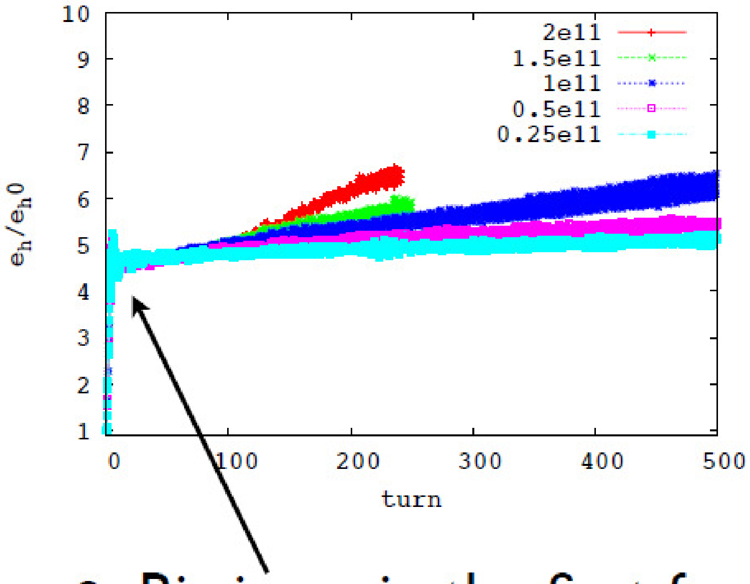
Space Charge MC (ERIT/S-Code)

S. Machida, RAL

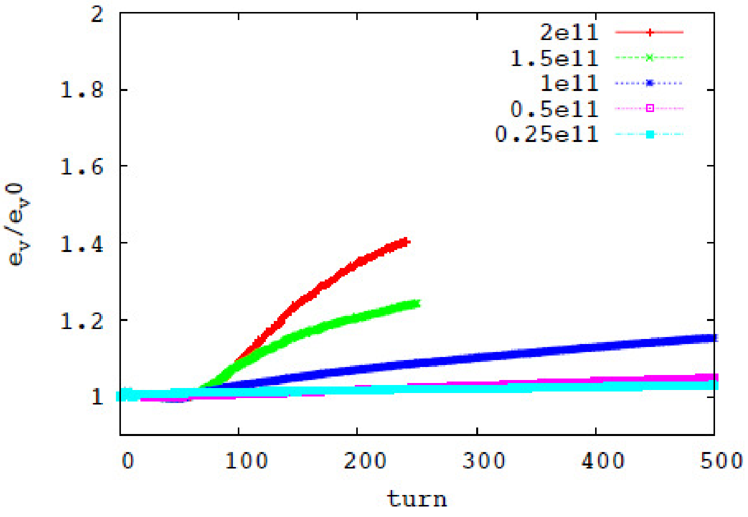


Intensity dependence

- horizontal



- vertical



- Big jump in the first few turns in H is due to the increase of momentum spread in a rf bucket.

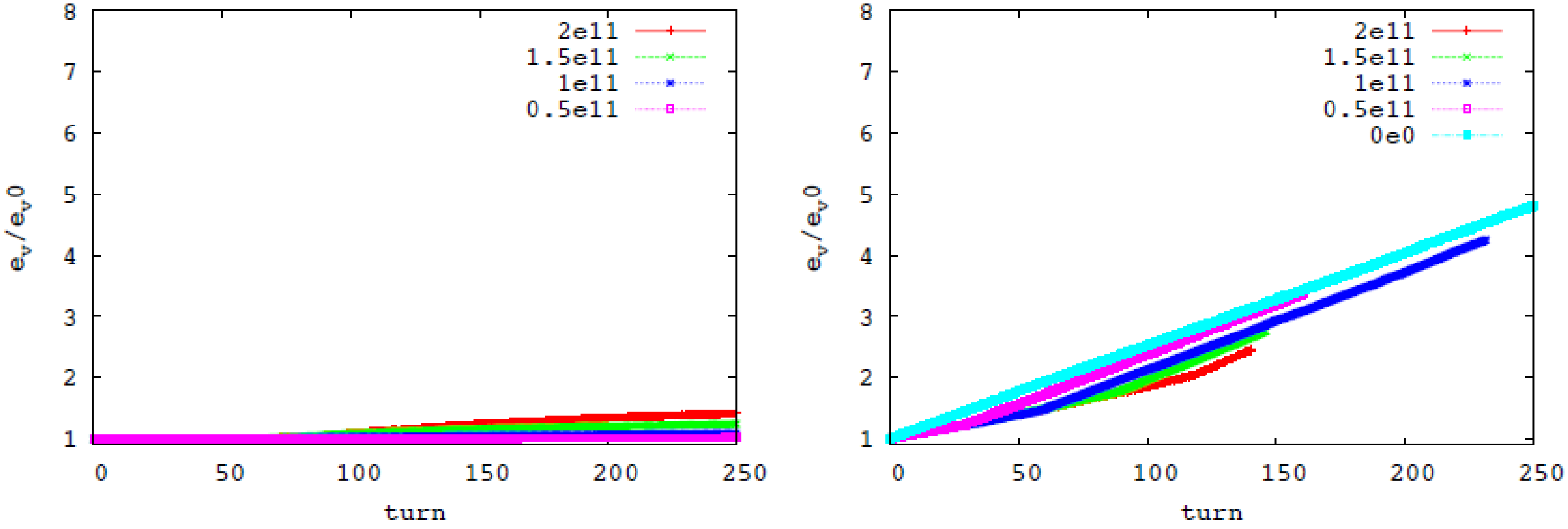
Space Charge + foil (ERIT/S-Code)

- Note that this is not consistent with Rogers result
  - Shinji's result is based on fit to ICOOL
  - Not clear which ICOOL model/etc

S. Machida, RAL

Intensity dependence without alignment error

- without foil scattering
- with foil scattering



Plan

- Clarify discrepancy in scattering models
- Can we inject enough particles to beat foil scattering?
    - 2e11 is not a physical limit on number of particles
- Beam time possibly winter 2013/14

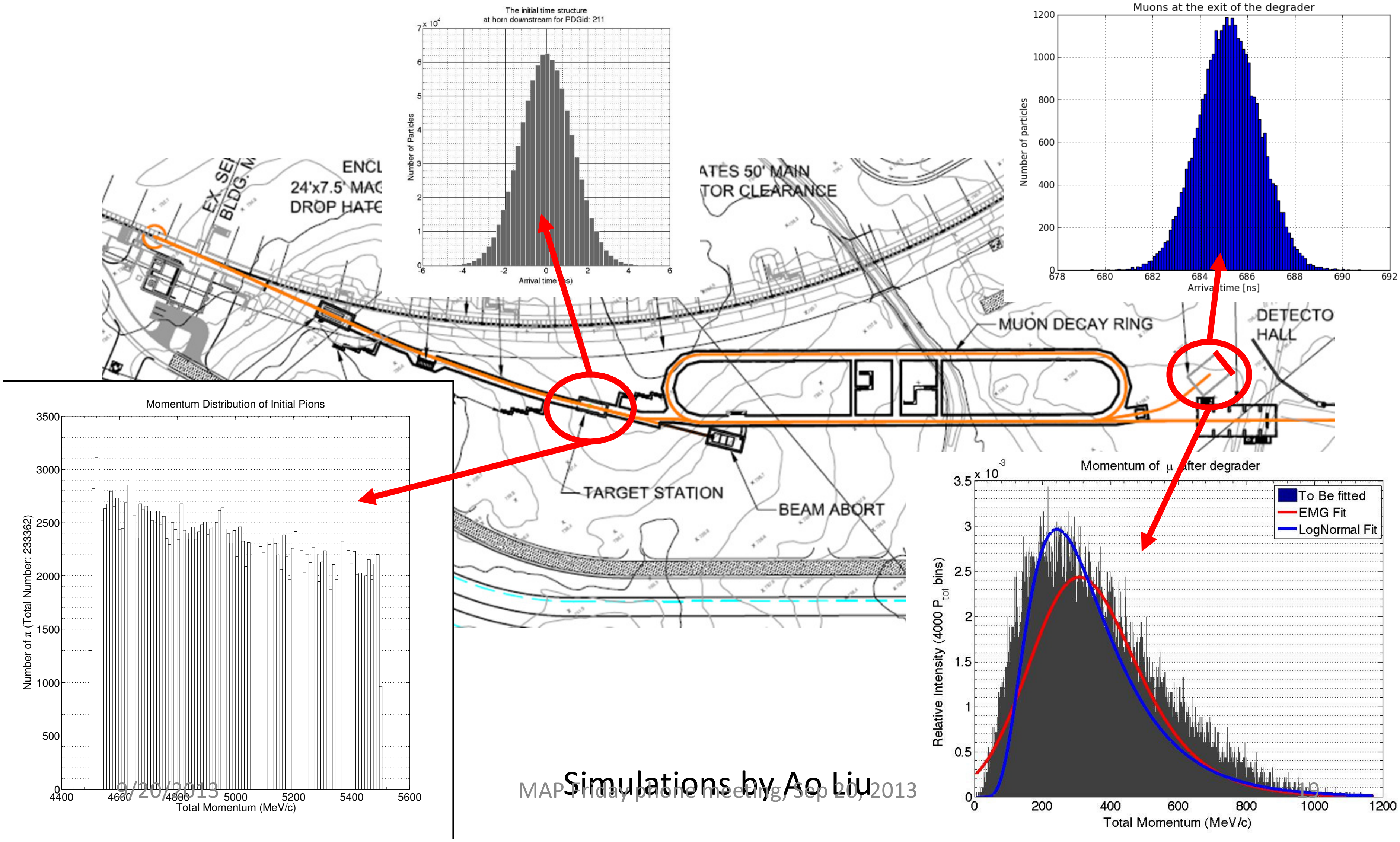
Muon beam options

nuSTORM beam option

Muon beam options

- "Beyond MICE" experiment utilizing the existing infrastructure:
  - the scene is set,
  - impact on ISIS,
  - low muon intensities.
- nuSTORM:
  - "spent" beam, little overhead,
  - little/no disruption to the running neutrino program,
  - relatively high muon beam intensity.

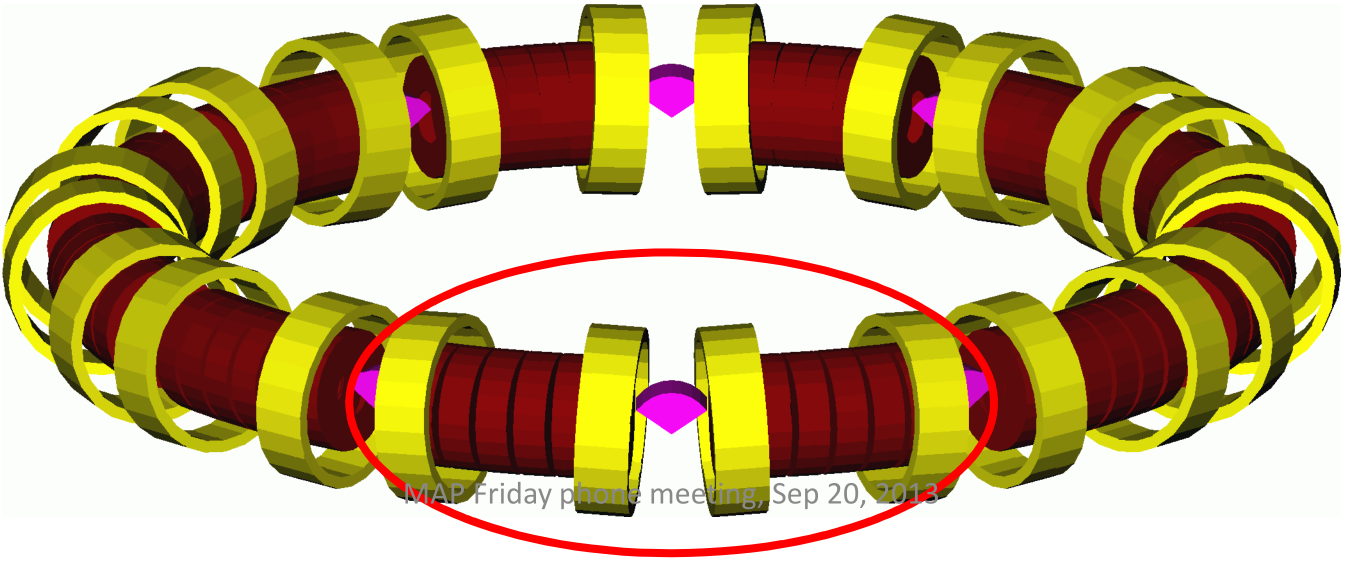
Muon beam @ nuSTORM



Simulations by Ao Liu

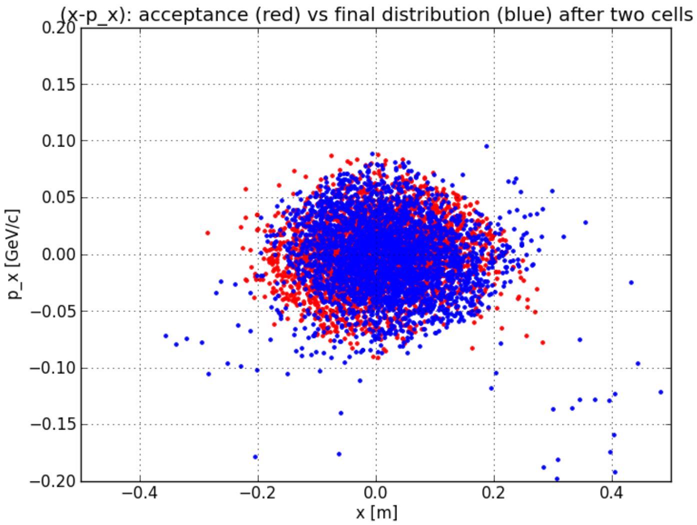
Cooling cells

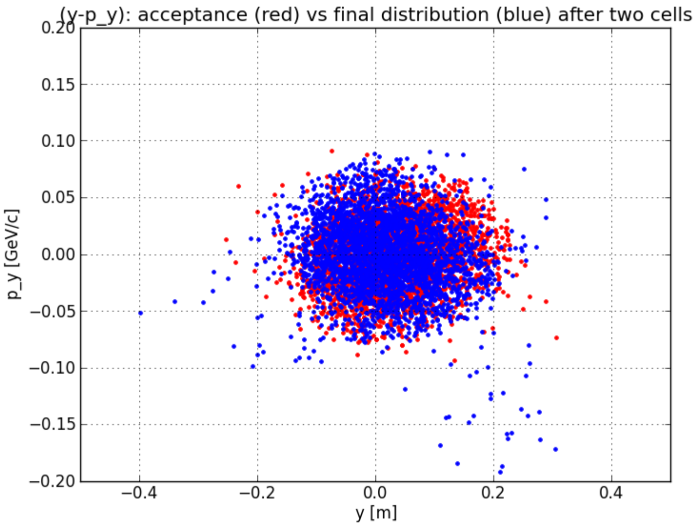
- Two cells of a basic 201.25 MHz RFOFO cooling channel.
- No matching section.
- Aperture is limited to 25 cm (for beam size calculation).
- 9.4% transmission within aperture cuts.



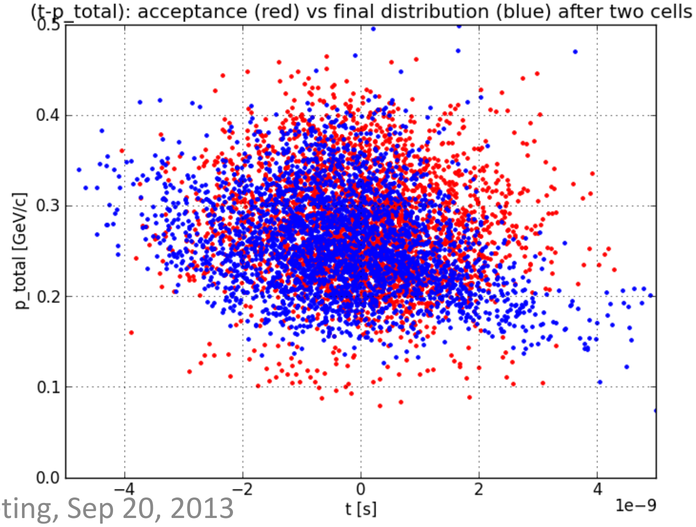
Distribution before and after

(x-p_x)





(y-p_y)



(Δt-P_{total})

Acceptance (red) and distribution after two cooling cells (blue)

Beam sizes before and after

	Before cooling	After cooling
σ_x [m]	0.085	0.081
σ_y [m]	0.078	0.076
σ_t [ns]	1.19	1.23
σ_{px} [m]	0.031	0.032
σ_{py} [m]	0.030	0.032
σ_p [m]	0.083	0.079

- No observable cooling in transverse or longitudinal direction, but no heating either.
- Matching section is required.
- The result will be worse with a 325 MHz cell.

nuSTORM beam structure

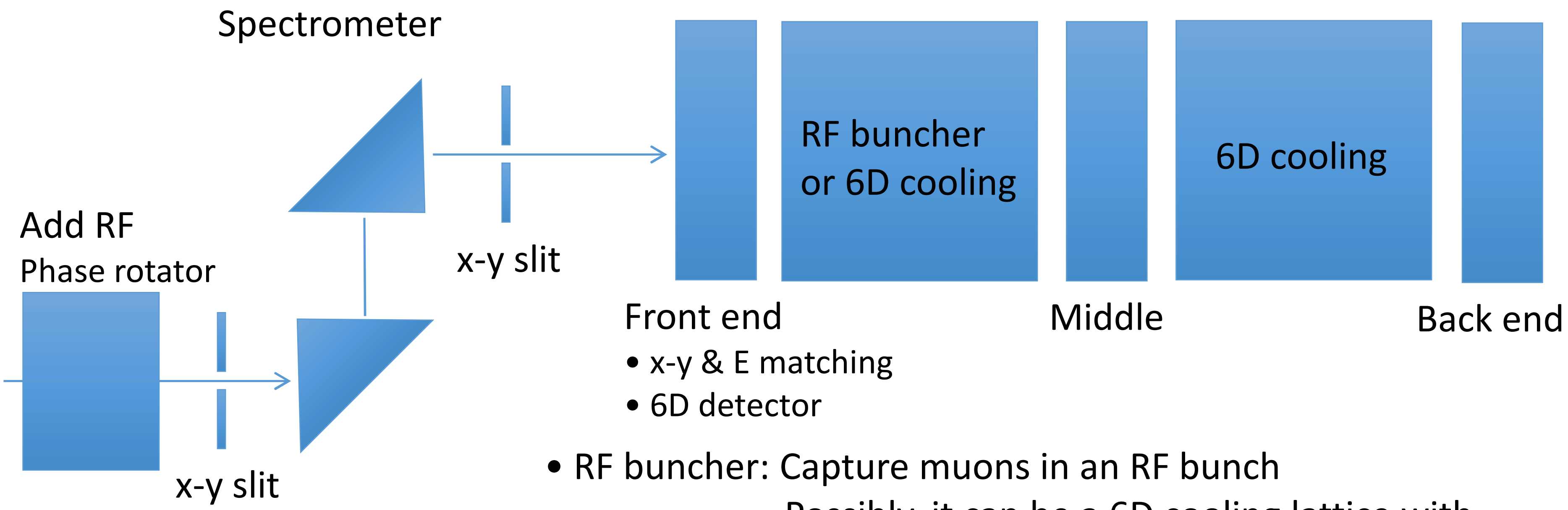
- 80-85 bunches @ 53 MHz (18.8 ns)
- About 1.33 sec apart
- 10^{10} muons per pulse in the range (0,300) MeV/c
- How to match to the experiment?
  - 53x6 = 318 MHz, 53x12 = 636 MHz, 53x15 = 795 MHz
- More cooling cells vs more precise diagnostics?
- Longitudinal diagnostics: single-particle vs multi-particle?
- Background is not an issue (simulated by Ao Liu)

6D ICE detectors/design

Following the idea by Katsuya Yonehara

(Slide by Katsuya Yonehara)

General 6D ICE layout



Spectrometer

Add RF
Phase rotator

x-y slit

x-y slit

RF buncher
or 6D cooling

6D cooling

Front end

- x-y & E matching
- 6D detector

Middle

Back end

- RF buncher: Capture muons in an RF bunch
  Possibly, it can be a 6D cooling lattice with
  zero-crossing RF system w/o cooling material
- Add RF phase rotator in front of a spectrometer
  Increase number of useful muons in a 6D cooling

- How to measure the time distribution and its evolution to demonstrate longitudinal cooling?
  - Strongly depends on the number of useful muons

Summary

- Another proton beam option: ERIT FFAG ring
- nuSTORM muon beam:
  - no cooling with two cooling cells @ 201 MHz and no matching section, but no heating either,
  - background is not an issue,
  - matching section + 325 MHz cooling cells will be studied.
- 6D ICE detectors/design:
  - first look at conceptual level,
  - should be relatively independent of the cooling channel choice (to what extent?)
  - a lot of extra beam gymnastics to maximize cooling efficiency.