6D ICE: status and plans

P. Snopok, IIT/Fermilab

MAP Friday phone meeting

January 31, 2014

6D ICE goals

- Description: Development of experimental concepts and hardware specifications necessary to validate the feasibility of 6D ionization cooling. Relevant activities:
  - development of a plan for a MAP 6D cooling bench test in close coordination with Design and Simulation and Technology Development group activities;
  - development of a suite of experimental options;
  - detailed evaluation of potential beam demonstrations;
  - setup for the 6D bench test;
  - possible proposal at the conclusion of the Feasibility Assessment.

Summary of FY13 activities

Proton beam options

Proton source at ASTA and FFAG rings at KURRI

Proton beam options: ASTA

- Proton source at ASTA: 2.5 MeV protons, $>10^{15}$ protons/s, 1 ms pulses, 5 Hz bunches, planned operation 2017.
- Very low energy, requires a very thin solid or gaseous/liquid absorber.
- Structure and beam parameters are far from the typical muon beam regime of interest.

Proton beam: rings at KURRI

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

From the presentation by Chris Rogers at one of the 6D ICE meetings

Effects that can be addressed at KURRI

- Errors in space charge models (in vacuum)
- Space charge screening by material
- Bulk ionization of material
- Polarization of material

- ERIT ring: 11 MeV protons, up to $2*10^{11}$ protons per bunch
- ADS ring: 150 MeV protons, 10^{10} protons per bunch

KURRI accelerator chain

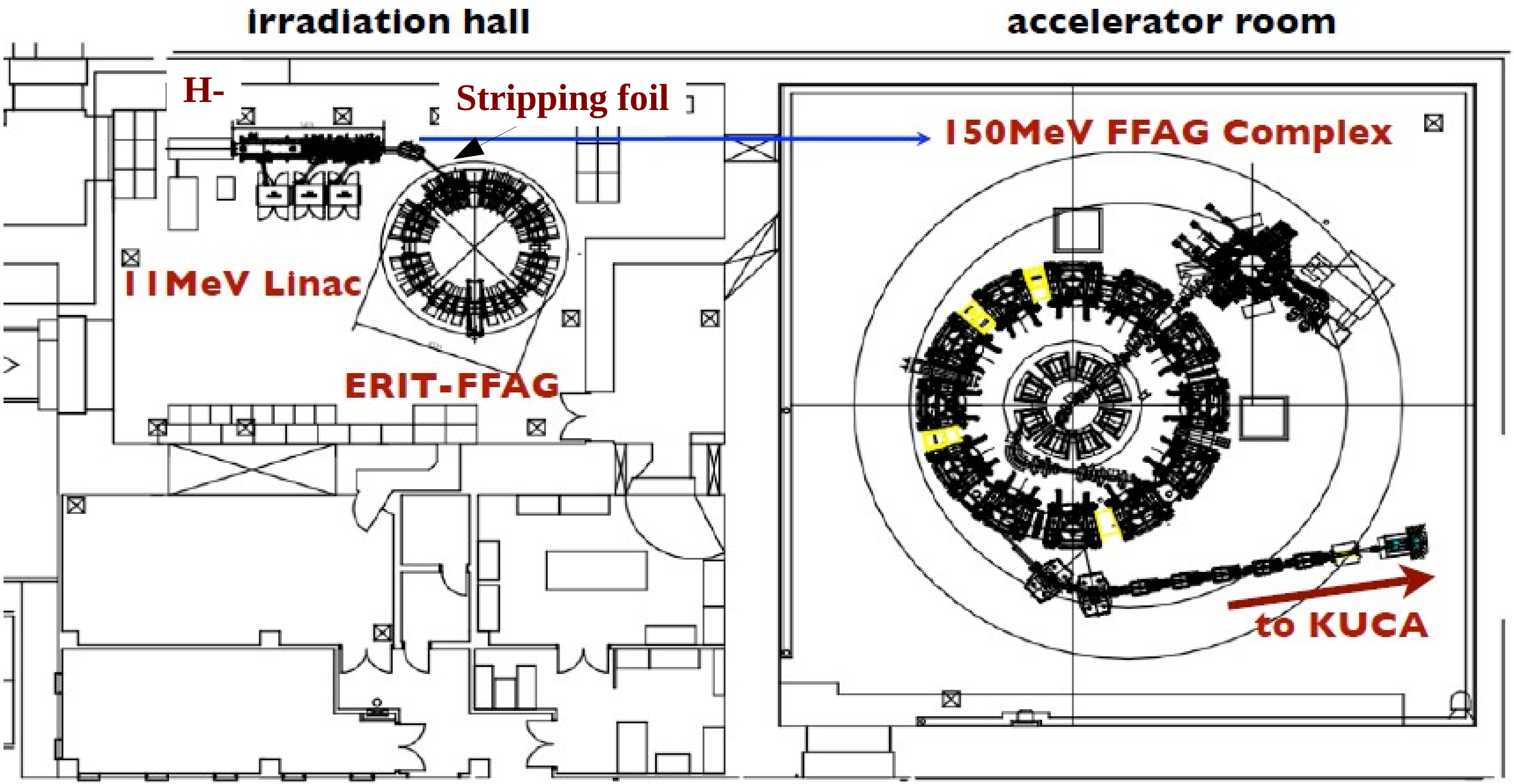
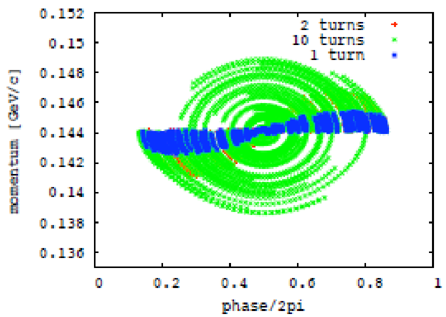


Diagram of the KURRI accelerator chain
From the presentation by Chris Rogers at one of the 6D ICE meetings

Space charge effect simulation in the ERIT (smaller) ring by S. Machida
From the presentation by Chris Rogers at one of the 6D ICE meetings

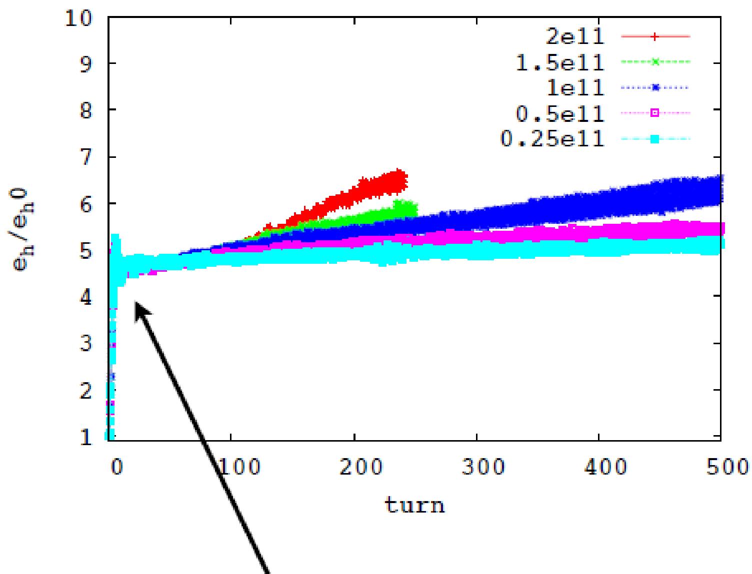
Space Charge MC (ERIT/S-Code)

S. Machida, RAL

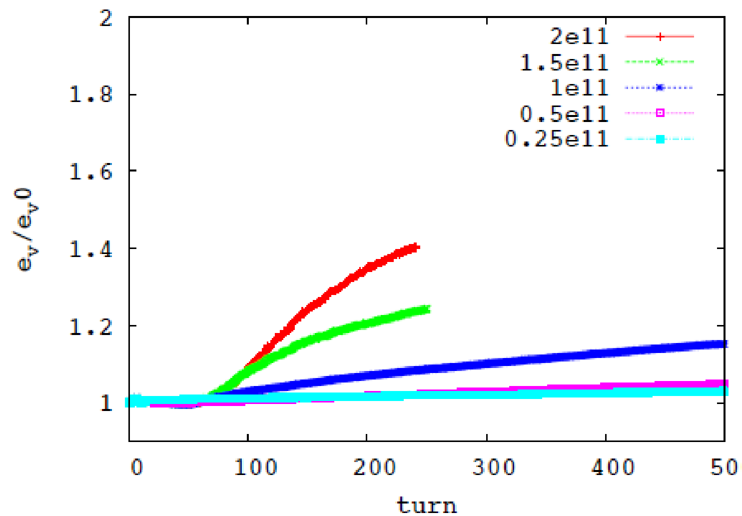


Intensity dependence

- horizontal



- vertical



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

Proton beam options (contd.)

- Latest update from Chris Rogers: attention focusing on the KURRI ADS ring rather than ERIT ring, 150 MeV protons;
- both transverse and longitudinal emittances nominally small, experimentally much larger due to mismatch;
- the foil is Carbon, 20 μg/cm^2;
- Intensity is 10^{10} protons/bunch;
- RAL people go to Kyoto with some regularity to sort out issues.

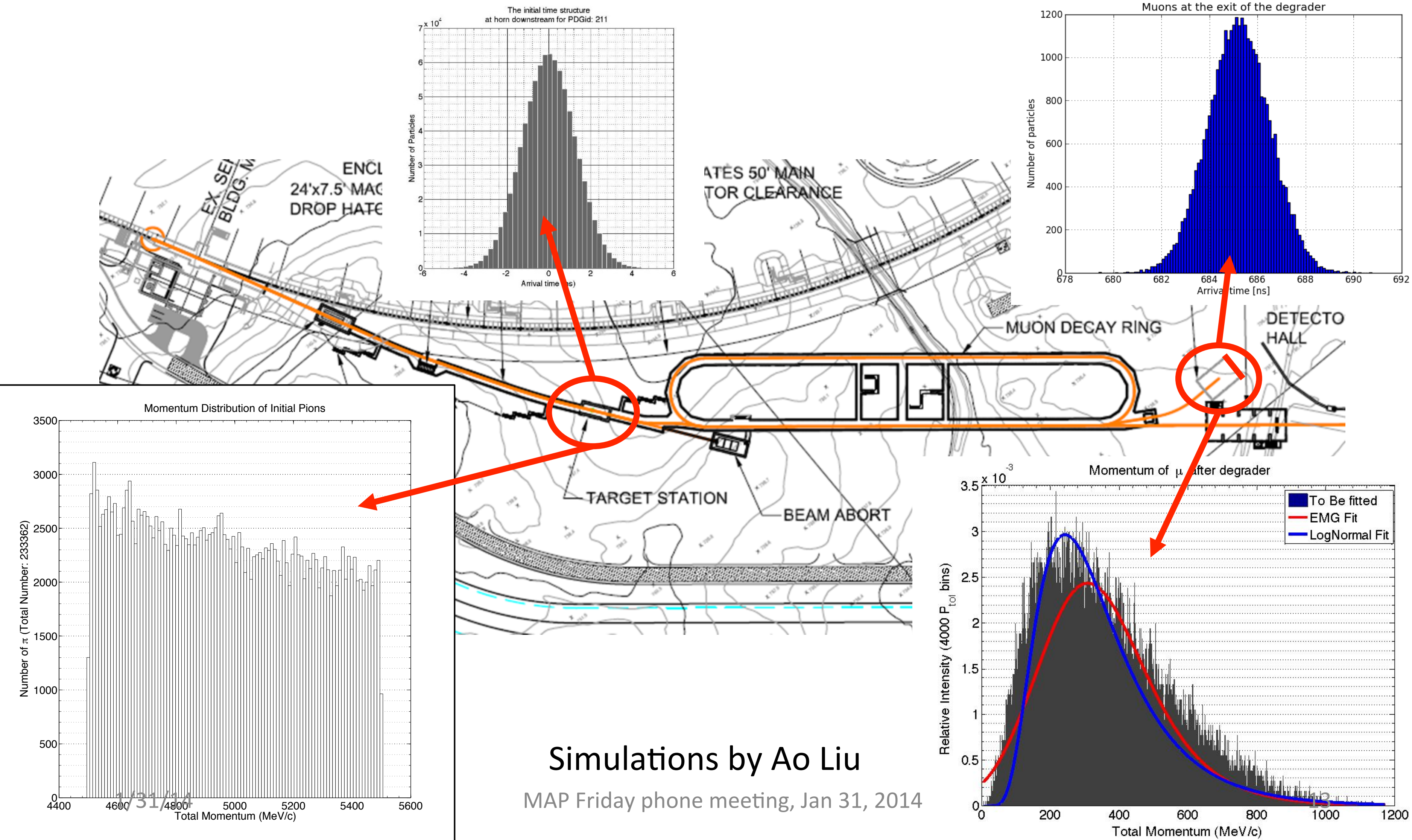
Muon beam options

nuSTORM and AP0 beam lines

Muon beam options

- nuSTORM:
  - “spent” beam, little overhead,
  - little/no disruption to the running neutrino program,
  - relatively high muon beam intensity.
- AP0 g-2 beam line:
  - runs (semi-)parasitically off the g-2 beam,
  - little disruption to the running experimental program,
  - some hardware to get the pion beam out to AP0,
  - some infrastructure is in place.
- Details in the next slides.

Muon beam @ nuSTORM



Simulations by Ao Liu

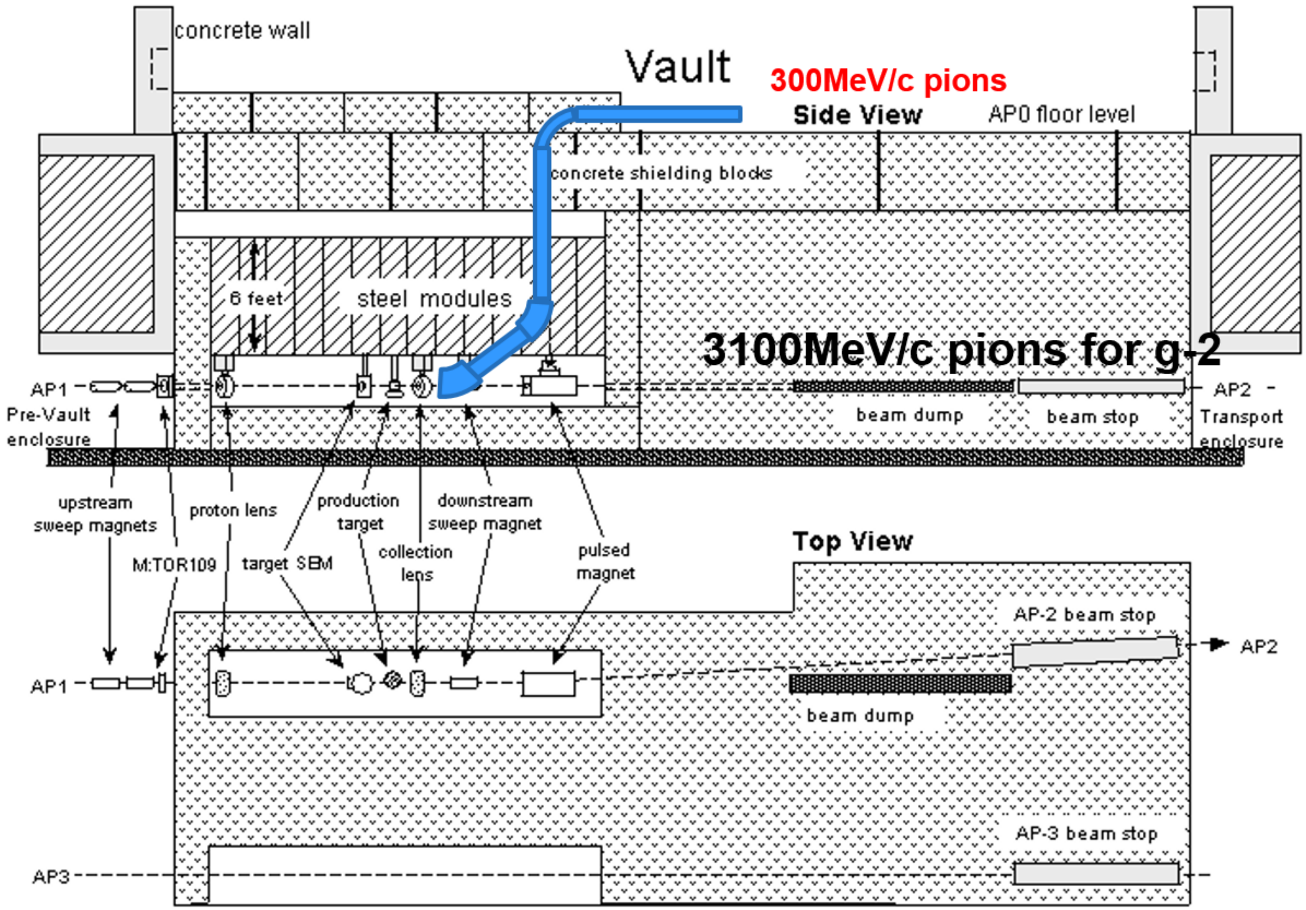
nuSTORM beam structure

- 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.
- Frequency mismatch between the muon beam and the cooling cell does not lead to particle loss or emittance blowup (1D simulation, 3D underway).
- Matching section is needed to increase transmission and emittance reduction.
- Background is not an issue (simulated by Ao Liu).

Muon beam at AP0

- Proposal by M. Popovic
- Momenta in the (0,300) MeV/c range,
- 10^8 muons/s,
- frequency could be changed as needed provided there are RF cavities to put in the Recycler,
- muon beam emittance will depend on the parameters of the pion transfer line, somewhat tunable.

AP0 transfer line



Comparison of muon sources

	PSI[1] (μE4)	MuSIC	COMET[2]	NuFACT[3]	AP0 with g-2
Muon intensity (/sec)	3.5×10^{8}	$10^{8\text{-}9}$	10^{11}	$10^{12\text{-}13}$	$\sim 10^{8}$
Proton beam energy (GeV)	0.590	0.4	8	8	8
Proton beam power (W)	1.2M	400	56k	4M	~40kW
Production efficiency (muon/W)	292	$2.5 \times 10^{5\text{-}6}$	1.7×10^{6}	$2.5 \times 10^{5\text{-}6}$	
Time structure	Continuous	Continuous	Pulsed	Pulsed	Pulsed
Muon momentum (MeV/c)	85-125[4]	20-70	20-70	170-500	~20-300
Beam current (μA)	1.8	1	7	Not given	
Production target	Graphite	Graphite	Tungsten	Mercury jet	Inconel
Max Solenoid Field Strength (T)	5.0	3.5	5.0	20	Li Lens

(1) Based on: "A New High-intensity, Low-momentum Muon Beam for theGeneration of Low-energy Muons at PSI", Prokscha, T.; Morenzoni, E.et al. (Hyperfine Interactions, Vol.159, Issue 1-4, pp. 385-388)
(2) COMET CDR
(3) Based on The Muon Collider/Neutrino Factory Target System, H.Kirk and K.McDonald (Aug.14,2010) and Study-II report
(4) Range over all beamlines

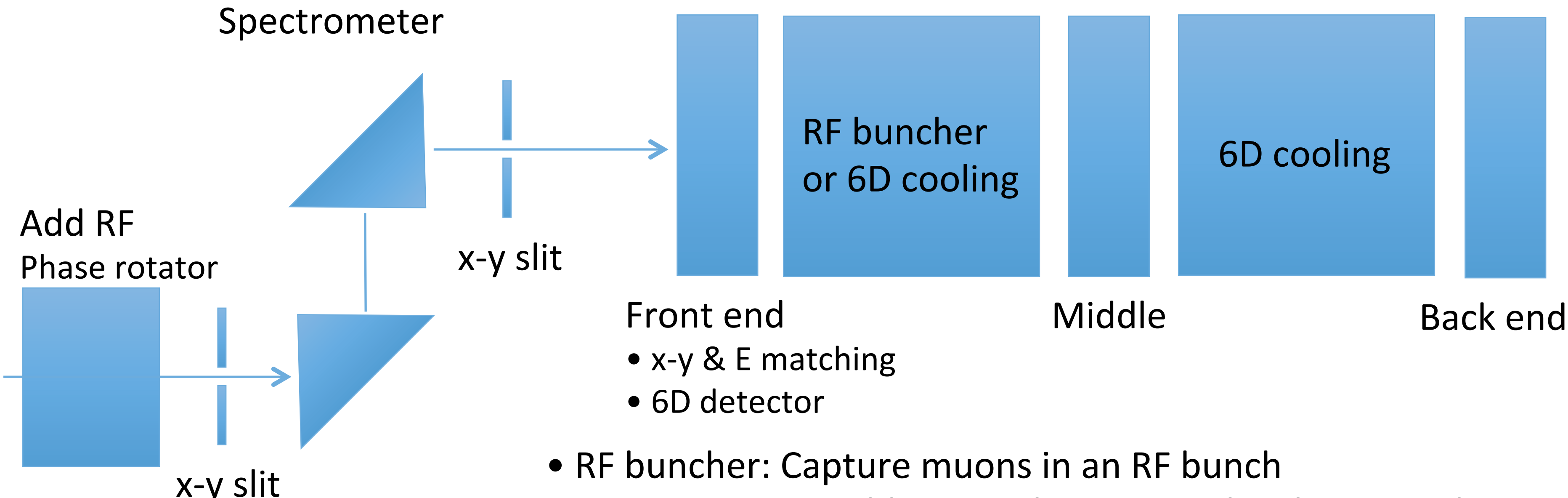
3rd April 2012 Sam Cook 7

6D ICE detectors/design

Following the idea by Katsuya Yonehara

(Slide by Katsuya Yonehara)

General 6D ICE layout



- 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

Other relevant activities

- Contributed to the Muon Accelerator Staging Study and the corresponding White Paper for the Community Summer Study 2013.
- Contributed to the NuStorm Proposal, section on using NuStorm as a testbed for the 6D muon cooling demonstration.

Plans moving forward

Plans moving forward

- Throughout the rest of Feasibility Phase I 6D cooling demonstration activities will be carried out as part of Muon Accelerator Staging Study due to synergies.
- These would include continued studies of the NuStorm-based 6D cooling demonstration and expanding the pool of proton and muon beam options for the experimental program.
- In Feasibility Phase II the focus will return to the Systems Demonstrations area after certain key decision are made, notably the Initial Baseline Selection, and Bench Test preparation could commence.