Low Emittance Muon Collider Workshop

Fermi National Accelerator Laboratory
February 6 - 10, 2006
Sponsored by Fermilab and Muons, Inc.

HIGHLIGHTS

K. Paul
Muons, Inc.

(http://www.muonsinc.com/mcwfeb06)

PURPOSE OF THE WORKSHOP

"The workshop will focus on the development of high-luminosity muon colliders using extreme muon beam cooling, where many constraints on muon collider designs are alleviated with beams of smaller emittance and lower intensity."

The workshop was intended to cover topics related to:

- ***proton drivers,***
- targetry,
- muon capture,
- bunching,
- ***cooling and cooling demonstration experiments,***
- ***bunch recombination,***
- ***muon acceleration,***
- ***collider lattices and interaction-point design,***
- ***site boundary radiation,***
- ***detector concepts***

BENEFITS OF LOW EMITTANCE...

"Lower emittance allows for a reduction in the required muon current for a given luminosity."

$$L = f \frac{N_\mu^2}{4\pi \, \sigma_x \, \sigma_y}$$

Reduced muon current diminishes:

- radiation levels due to the high energy neutrinos from muon beams circulating and decaying in the collider that interact in the earth near the site boundary;
- electrons from the same decays that cause background in the experimental detectors;
- difficulty in creating a high-power proton driver that can produce enough protons to create the muons;

...MORE BENEFITS

Reduced muon current also diminishes:

- proton target heat deposition and radiation levels;
- heating of the ionization cooling energy absorber;
- beam loading and wake field effects in the accelerating RF cavities.

Smaller emittance also:

- allows for smaller, higher-frequency RF cavities with higher gradient for acceleration;
- makes beam transport easier;
- allows for stronger focusing at the interaction point since (limited by the beam extension in the quadrupole magnets of the low beta insertion)

PARTICIPANTS: 65

NFMCC Members:	**34**
Fermilab	8
Thomas Jefferson Lab	1
Brookhaven National Lab	2
Argonne National Lab	1
Lawrence Berkeley National Lab	1
Illinois Institute of Technology	2
Michigan State University	5
University of California at Los Angeles	2
University of California at Riverside	2
University of Mississippi	2
KEK	1
Muons, Inc.	8
Non-NFMCC Members:	**31**
Fermilab	18
Thomas Jefferson Lab	2
Illinois Institute of Technology	2
University of Michigan	1
University of Tsukuba / Waseda University	1
Osaka University	2
KEK	1
Hbar Technologies, LLC	1
Muons, Inc.	2

WORKING GROUPS

We divided the workshop topics and staff into 6 working groups:

- **Users:**
  Theory, detector concepts, IP design, detector backgrounds, site boundary radiation,...
- **Production:**
  Muon production, proton driver, neutrino factory, targetry, capture, bunching, polarization,...
- **Cooling:**
  Precooling, postcooling, 6D cooling, demonstration experiments,...
- **Technology:**
  Magnets, SRF, conductors, materials, absorbers,...
- **Lattices:**
  Acceleration, rings, coalescing, recirculation, layout,...
- **Choreography:**
  Synthesis, group coordination, parameter consistency, alternatives,...

WORKSHOP AGENDA

Monday:
- **9:00AM – 12:30PM:** **Check-in & WG Organization**
- **1:30PM – 6:00PM:** **Plenary Session**

Tuesday:
- **9:00AM – 12:30PM:** ***Simulation Micro-School***
- **1:30PM – 4:00PM:** **Parallel Sessions**
- **4:00PM – 5:00PM:** ***Accelerator Physics & Technology Seminar***

Wednesday:
- **9:30AM – 12:30PM:** **Open Work Session**
- **1:30PM – 5:30PM:** **Parallel Sessions**

Thursday:
- **9:30AM – 12:30PM:** **Open Work Session**
- **1:30PM – 4:00PM:** **Parallel Sessions**
- **4:00PM – 5:00PM:** ***Accelerator Physics & Technology Seminar***
- **7:00PM – 5:00PM:** ***Workshop Dinner*** **(Chez Leon)**

Friday:
- **9:30AM – 12:30PM:** **Open Work Session**
- **1:30PM – 5:30PM:** **Plenary Summaries**

A WORD FROM THE THEORISTS

Bogdan Dobrescu (Fermilab Theory Group):

- "High center-of-mass energy is essential"
  - Most new physics expected to be **≥1.5 TeV**
  - For example: γ**'**, Z**'**
- "$\mu^+\mu^-$ collisions are special"
  - Higgs in the s-channel (*resonance*)
  - Probing second-generation physics
- "If you know how to build a muon collider, then go for it: the physics case is a slam dunk!"

...MORE FROM THE THEORISTS

Peter Skands (Fermilab Theory Group):

- High-Precision Machines:
  - Allows extrapolation to higher scales
  - Motivation for ILC, but works for MC, too!
  - "SUSY Higgs Factory" (D. Cline)
- High-Energy Machines:
  - Absolutely needed to explore new physics
  - There is a case for lower luminosity machines! ("Just give us a few collisions at high energy…")
- ILC could motivate a Muon Collider!

STRAWMAN PARAMETERS

R. Palmer
March 14

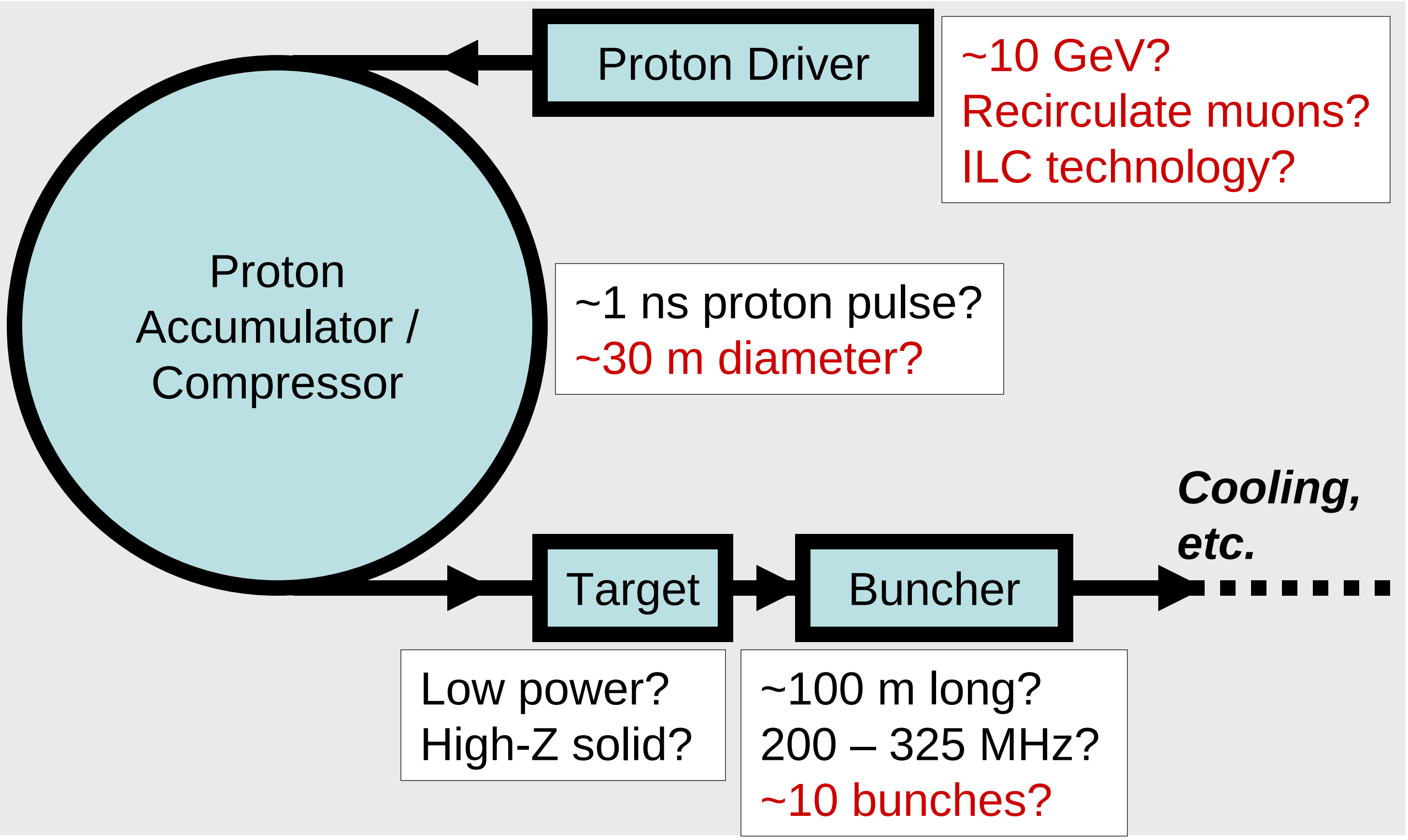
Energy:	**5 TeV**	(2 × 2.5 TeV)
Luminosity:	**10^{35} cm^{-2} s^{-1}**	
Normalized Emittance (ε_N):	**2 mm mrad**	
Interaction Focus (β*):	**5 mm**	
Proton Pulse Energy:	**~10 GeV**	
Proton Pulse Rate:	**~10 Hz**	
Number of Muons:	**~10^{11} per bunch**	**(~10 bunches!)** *NEW*
Beam-Beam Tune Shift:	**~0.1**	
Assumed Target Yield:	**~0.1 μ / *POT***	
Required Proton Power:	**~200 kW**	(assuming 25% transmission) *NEW*

Neutrino radiation may be acceptably small!

- Parameters consistent with acceptable radiation from 100m straight

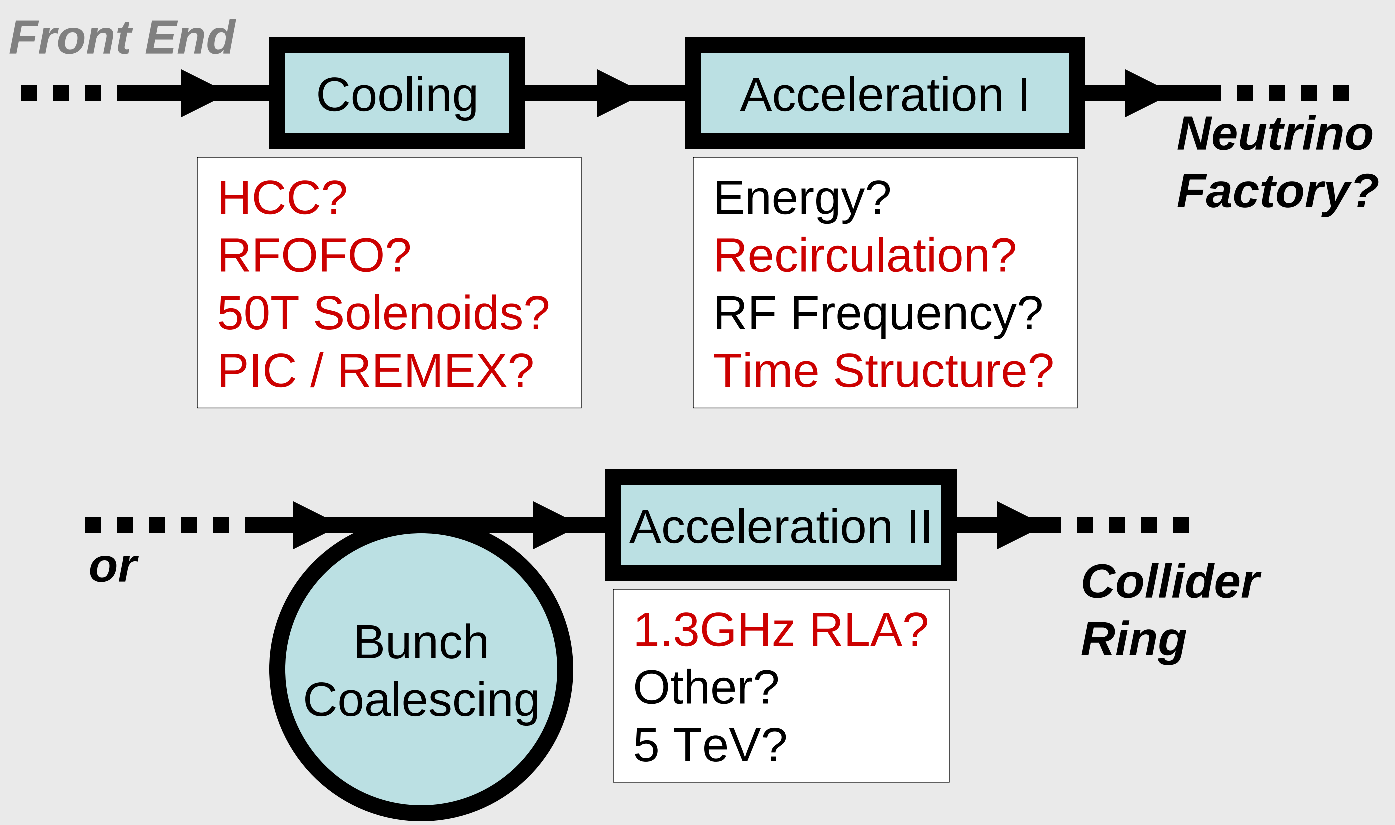
FRONTEND CONCEPT

R. Palmer
March 14



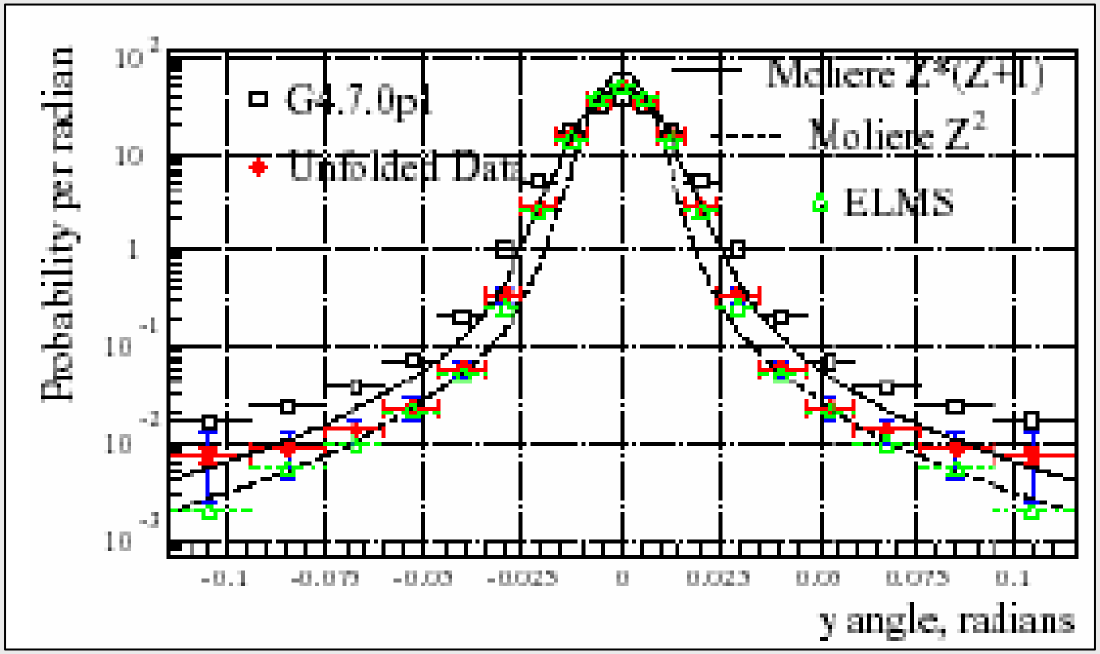
BEYOND THE FRONT END

R. Palmer
March 14



MUON SCATTERING

Scattering through 109mm of LH2 (~170 MeV/c)



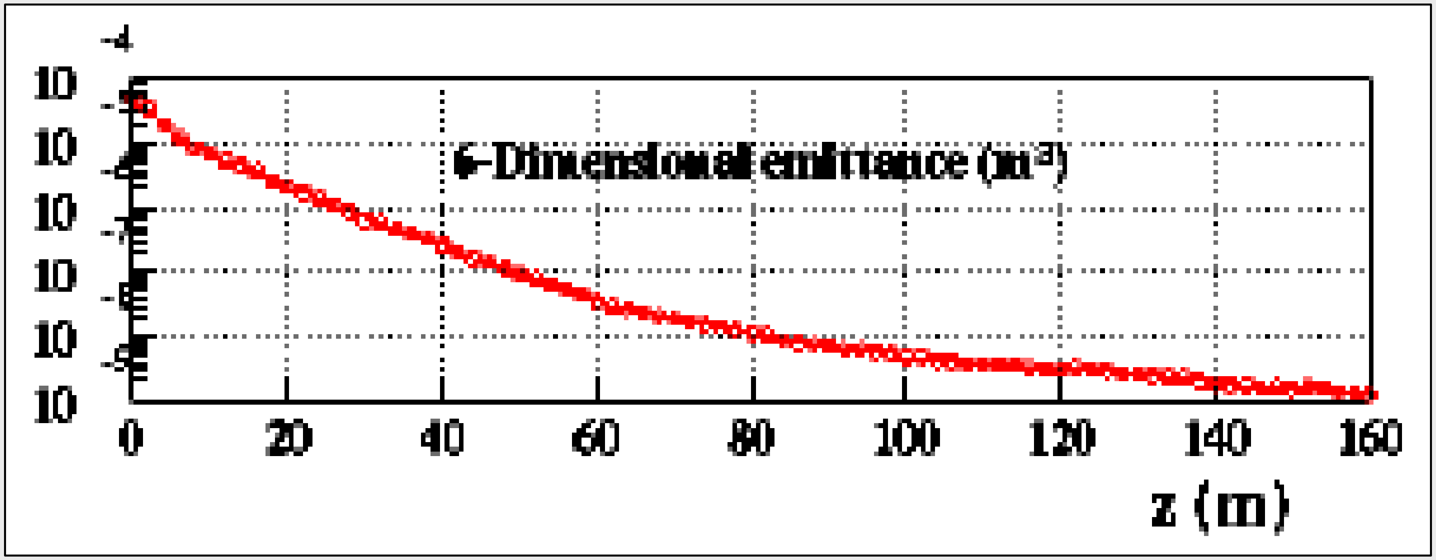
A. Tollestrup

For gosh sake, we should know this!

HELICAL COOLING CHANNEL

D. Newsham
March 14

4-Stage HCC: Factor of ~50,000 in 6D cooling over 160 m

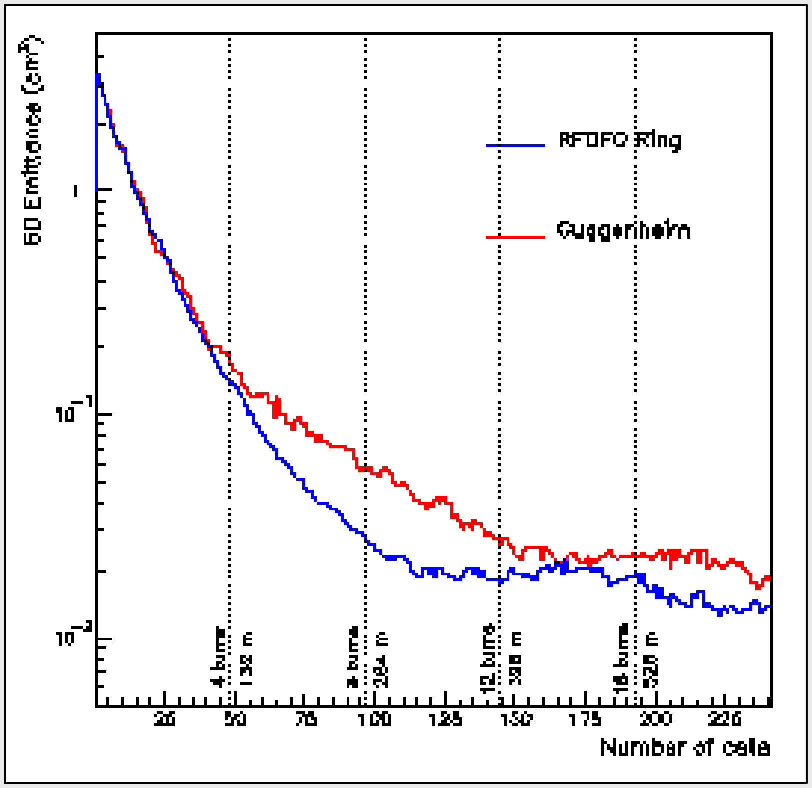


K. Yonehara

HP GH2 HCC / RF vs LH2 HCC / SC RF
Matching problems?
Realistic fields?

RFOFO GUGGENHEIM

A. Klier
March 13



A. Klier

20 Turn "Guggenheim":

Factor of ~250 in 6D cooling in 660 m

Is it too massive?
Shielding problems?
Realistic fields?

PIC

D. Newsham
March 14

Final Beam after HCC & 2-stage PIC / REMEX:

Energy	TeV	2.5
IP focal parameter, F	M	20
Beta-star/bunch length	mm	1/1
Energy spread	%	.1
Emittance ε_z, norm	cm	2. 5
Emittance $\varepsilon_\perp$, norm	μm	3

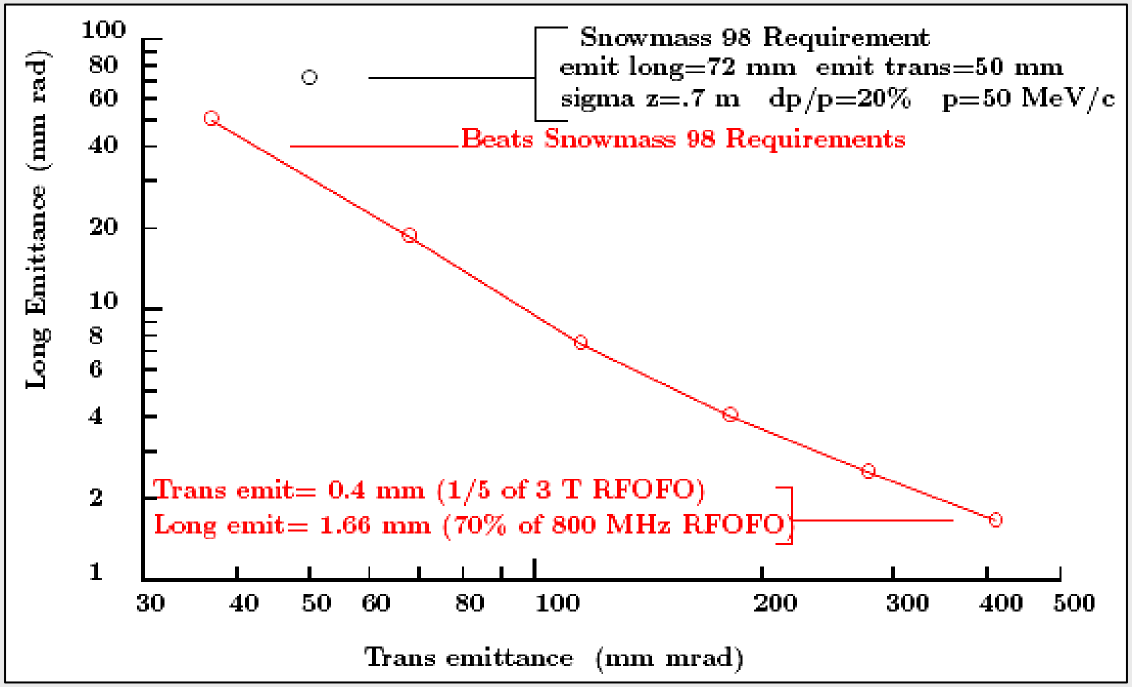
Y. Derbenev

Theory understood?
Combine with REMEX?
Does it work in realistic simulation?

HIGH-FIELD SOLENOIDS

S. Kahn
March 14

5 × HTS 60T Solenoids with Transverse Cooling:



S. Kahn

HTS?

Is ~50T possible?

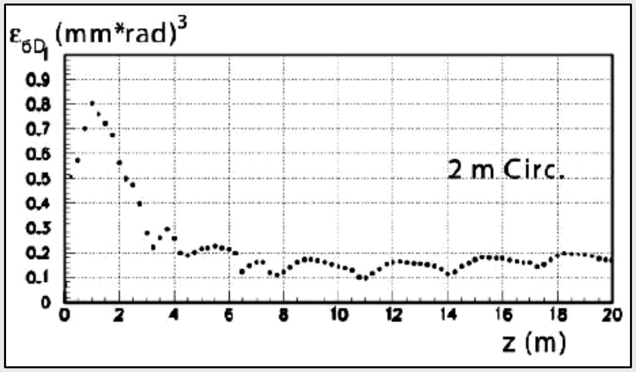
Matching problems?

Technically feasible?

Good "final stage"?

LITHIUM LENS OPTIONS

Curved lithium lenses for 6D cooling (Y. Fukui)



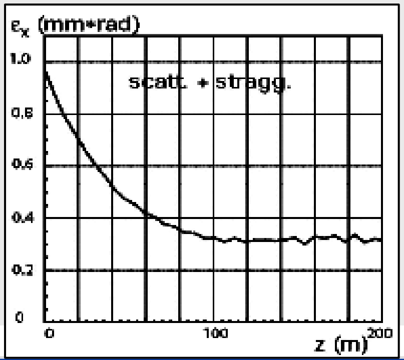
2m Circumference Li Ring

Very low equil emittance!

Exhibits REMEX

Requires more simulation

Straight lithium lenses in cooling rings (Y. Fukui)



Low transverse equilibrium emittance

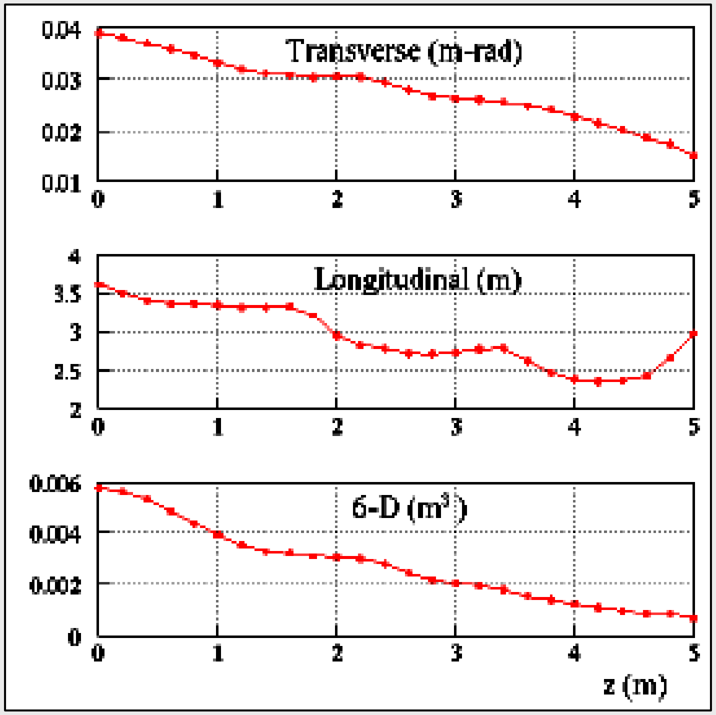
Exhibits REMEX

Requires more simulation

6D MANX

K. Yonehara
March 14

5m HCC Demonstration:



K. Yonehara

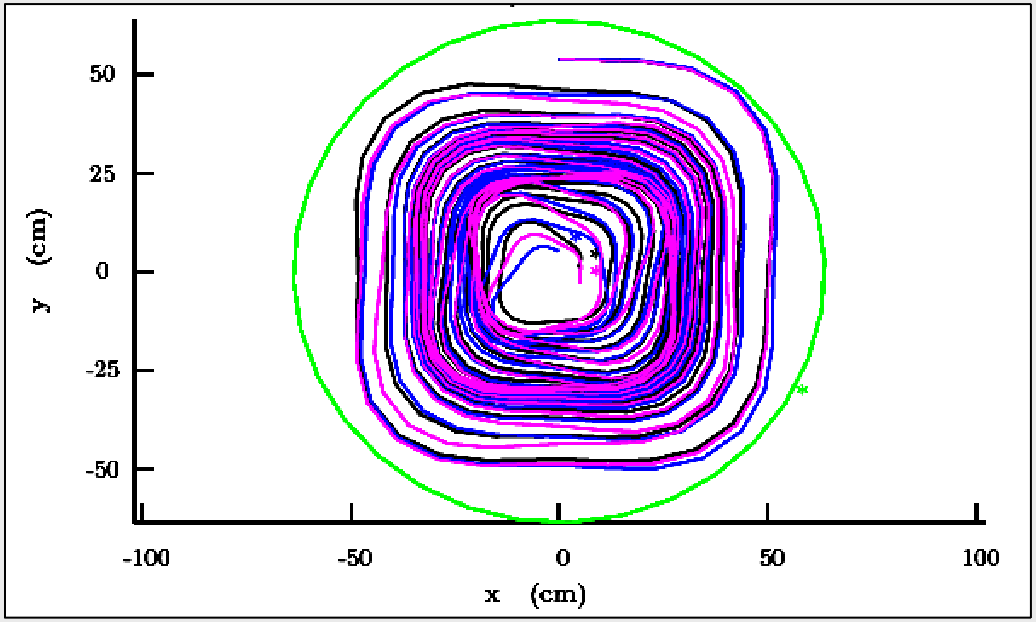
Cooling at 4m:

Trans cooling factor:	1.7
Long cooling factor:	1.4
6D cooling factor:	**4.5**

Field strength < 6T at conductors!

INVERSE CYCLOTRON

D. Summers?
March 14



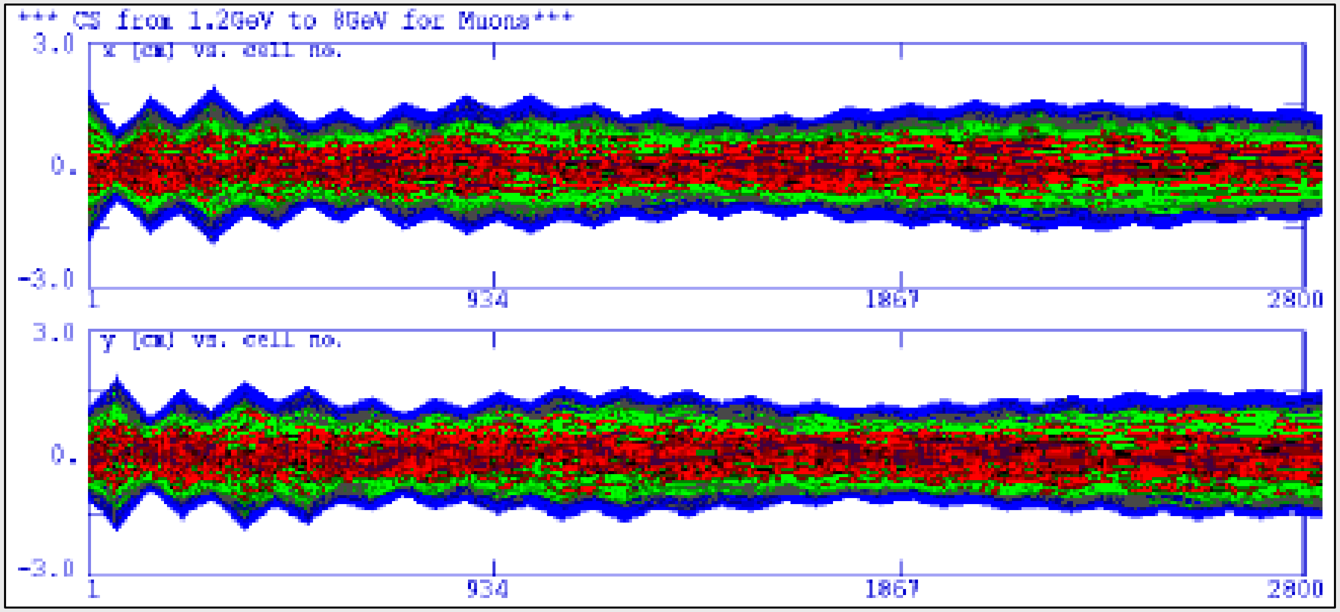
D. Summers

Possible extraction solution?
Potentially large cooling factors (10^6)!
Needs full simulation

1.3GHz RECIRC LINAC

M. Popovic
March 14

1.2GeV to 8GeV Acceleration of Muons in Proton Driver Linac



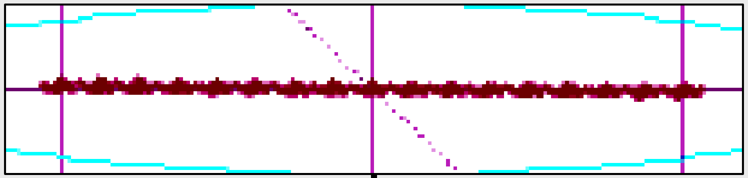
M. Popovic

Is heating from electrons an issue?
Matching muon beam after cooling?

BUNCH COELESCING

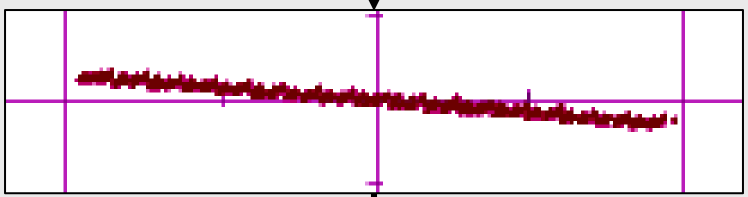
C. Ankenbrandt
March 14

Coelescing 17 1.3GHz/20GeV Bunches in 46μs (~45 Turns)



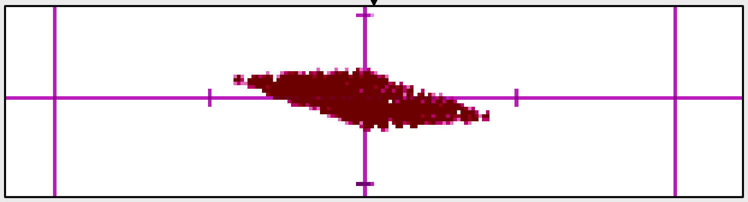
C. Bhat

13 ns long bunch train
20 MeV energy spread



C. Bhat

Prelinac phase rotation
(Frequency < 1.3 GHz)



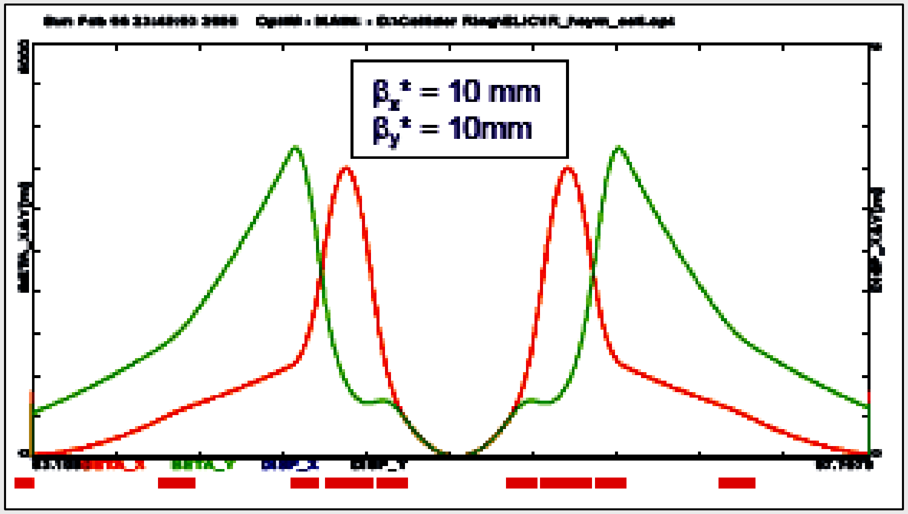
C. Bhat

4 ns long bunch
100 MeV energy spread

COLLIDER RINGS

S. Berg / C. Johnstone
March 14

A FODO-based 8.2 km Circumference / 2 TeV Collider Ring



A. Bogacz

- Energy = 2 TeV
- Circumference = 8208 m
- Phase adv/cell = 60 deg
- Number of cells = 12×36 = 432
- Bending field = 8.1 Tesla
- Number of IR = 2
- Betas at IR, $\beta^*_{x,y}$ = 10 mm
- Peak betas, $\beta^{max}_{x,y}$ = 4800 m

A. Bogacz

(work also contributed by C. Johnstone)

DETECTOR BACKGROUNDS

A good summary of previous work

- A carefully optimized design of the detector and the final focus system of the collider ring can significantly reduce the detector backgrounds.
  - The reduction of detector backgrounds will be an important consideration in the design of the collider ring.
- With the proper design the background levels are likely to be les than those expected at the LHC.

S. Kahn

Should be even better with lower number of muons!?

ACTION ITEMS

Critical path issues:

- **Cooling technology / demonstration / simulation**
- **Effects of heating in RF due to muon decays**

Other important action items:

- **Need a full simulation of the production and cooling**
- **Need a realistic simulation of bunch coelescing**
- **What is the final limit on number of muons per bunch? Space charge? Tune shift? Etc.**
- **What about neutrino radiation limits?**

"Missing Links" List on Workshop Agenda!

SPECIAL THANKS

The workshop was organized by *Muons, Inc.,* and sponsored by *Fermilab* and *Muons, Inc.*

- We at Muons, Inc., would like to thank Carol Kuc at *Complete Conference Coordinators, Inc.* for all her help with hotels.
- We would also like to thank Marilyn Smith in the *Fermilab Director's Office* for help with arranging rooms, special thanks to Victor Yarba at the *Fermilab Technical Division* for agreeing to sponsor the workshop at Fermilab, and Al Johnson in *Fermilab's Visual Media Services*.
- Thanks to Mike Perricone at the *Fermilab Office of Public Affairs* for allowing us to use the image of Wilson Hall in winter for our title image.