NuFact 11 August 1-6, 2011 Geneva, Switzerland

NuFact'11

Summary WG3

Elena Wildner, Alex Bogacz and Makoto Yoshida

NuFact'10 ⇨ NuFact'11

1) Is Project X a suitable proton driver for the Neutrino Factory?
Yes it is; A complete scheme emerged including stripping injection

2) What is the path for solving the problem of operating high gradient RF is strong magnetic field?
Ongoing, vigorous experimental program under way at MuCool and MTA at Fermi at LBNL (first experimental tests coming out)

3) Does energy deposition pose SC solenoid shielding problem for presently proposed proton drivers?
Challenging problem, robust engineering solution being worked out.

4) Do we have a working Injection/Extraction scheme for NS-FFAG Rings?
Working concept under study, specific components being modeled and optimized.

5) Is chromaticity correction sufficient to reduce the TOF problem for NS-FFAG?
EMMA demonstrated device feasibility. Conceptual solution is being studied

NuFact'10 ⇨ NuFact'11

6) Can Scaling FFAG be used in other-then-ring configurations?
Complete prototype lattices designed for new applications e.g. prototype decay ring for VLENF

7) Is there a synergetic path from the Neutrino Factory to MC?
A clear path emerged and being developed within MAP. Usage of components and techniques developed for NF-IDS.

8) Target handling for Multi MW targets ?
1 MW target handeling needs to be addressed

9) Proposed target systems are many, convergence?
Multiple designs required; different requirements for various applications

10) Material property evolution with time (from radiation, strain & stress and temperature)?
Appropriate material studies under way.

NuFact'10 ⇨ NuFact'11

11) Will the Beta Beam be possible in the CERN Complex?
Yes, the baseline beta beam is possible to implement

12) Verification of the 18Ne production for beta beams?
Tested experimentally.

13) Modeling of pion production complete?
Agreement between two models/codes (MARS and FLUKA) consistent within 10-20% with the HARP data

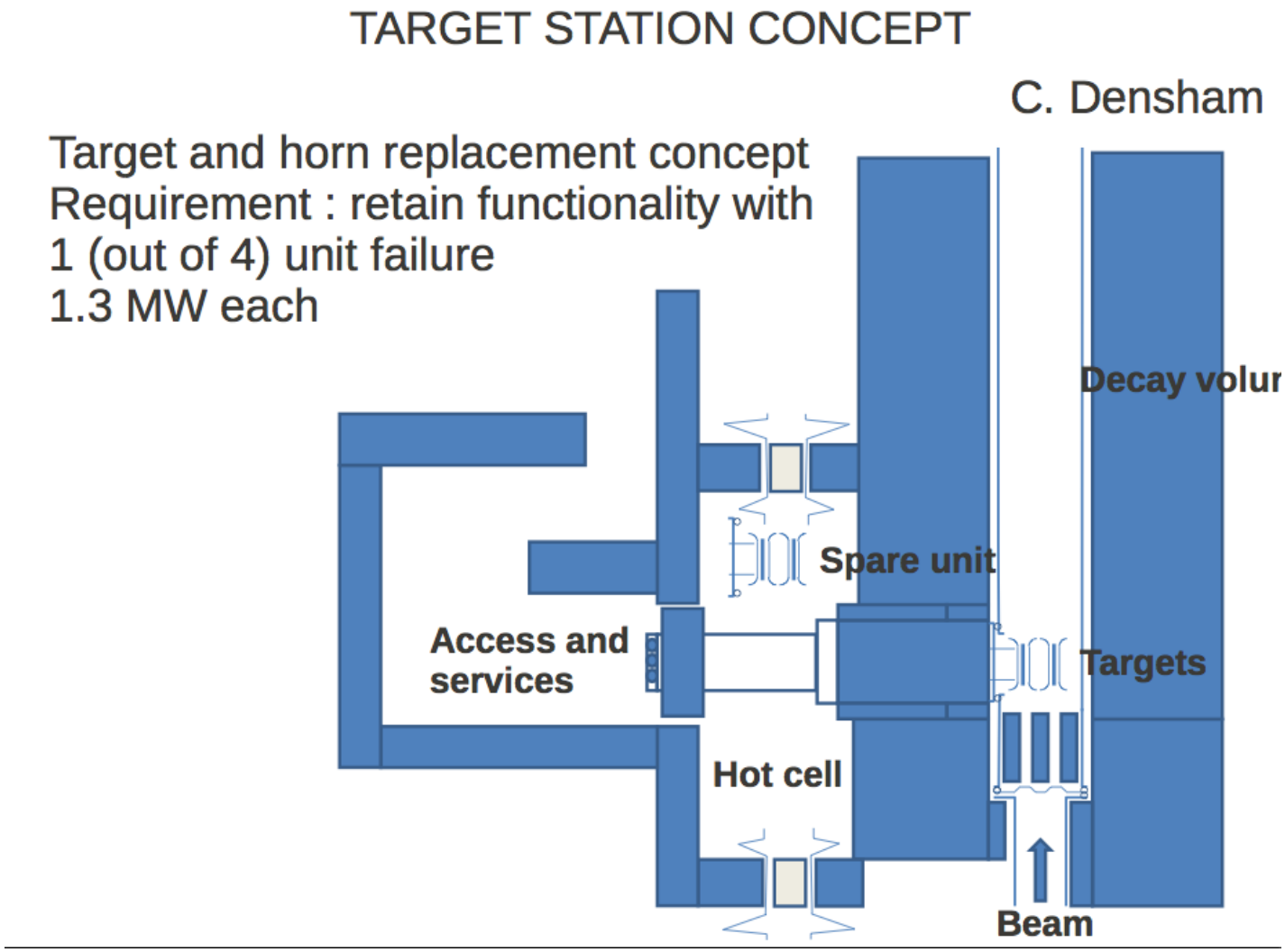
14) How serious is power deposition in the structures after/around the target (horn, solenoids…)?
Quite significant. They are modelled accurately; adequate shielding provided

15) Feasibility of mini-neutrino factory (low energy/intensity storage ring for short baseline measurement of cross-sections)
VLENF conceptual design with large acceptance decay ring, Scaling FFAG option

8) Target handling for Multi MW targets ?

Multi MW targets feasible; two robust designs exist (NF, LBNE)

Example for Frejus Superbeam:



8) Target handling for Multi MW targets ?

Multi MW targets feasible; two robust designs exist (NF, LBNE)

A few comments on future programme

- Target technology
  - main focus of NF/MC target station work since Study II (ie last 10 years)
  - at least 1 'champion' of each of 3/4 target technologies
  - Good to have alternatives (provided does not distract from other work that needs to be done – see below)
- Solenoid System
  - Most critical technological issue for NF/MC Target Station?
  - Current baseline appears far from feasible
  - NB 'Brute force' solution with extra shielding:
    - Stored energy α r^2
    - Only very recently receiving any attention
- Activation/handling/safety/environmental issues
  - The other most serious feasibility issue?

C. Densham

Question will remain till Nufact 12

9) Proposed target systems are many, convergence?

Yes, but multiple designs required; different requirements for various applications

Target options for NF:

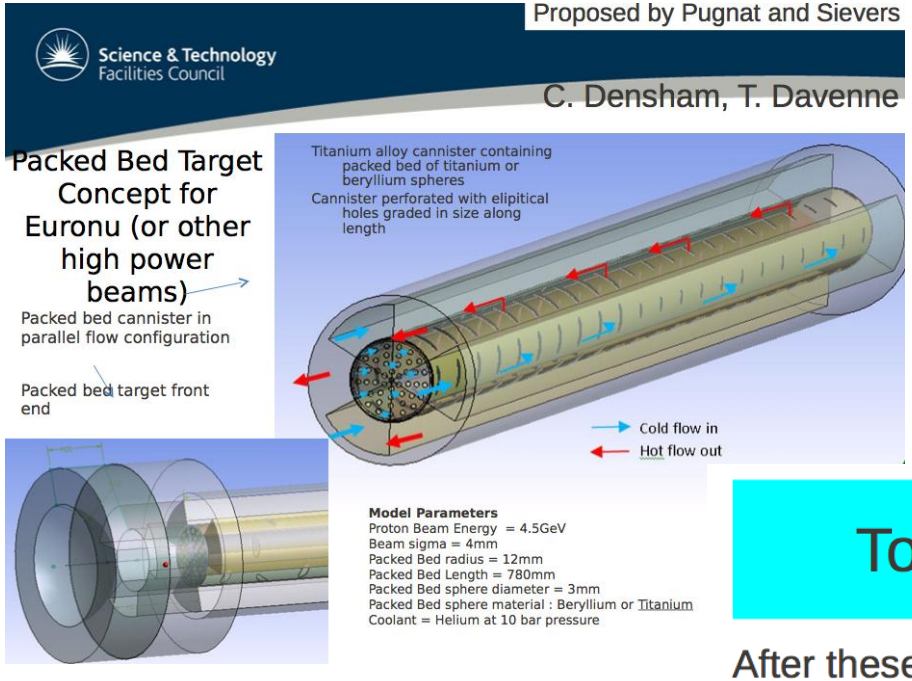
Hg -jet target is the baseline but energy deposition in the magnet is too-high, magnet shielding need to be improved (under re-design).

Metal-powder target and solid W bars (that can be exchanged between beam pulses) are studied as mitigation options in case the Hg-jet option energy deposition issue turn to be to difficult to solve.

Aim of the feasibility study is to push the Hg-jet option to a realistic design and define if the options under study are a realistic replacement option of the Hg-jet.

9) Proposed target systems are many, convergence?

Multiple designs required; different requirements for various applications



Superbeam to Frejus

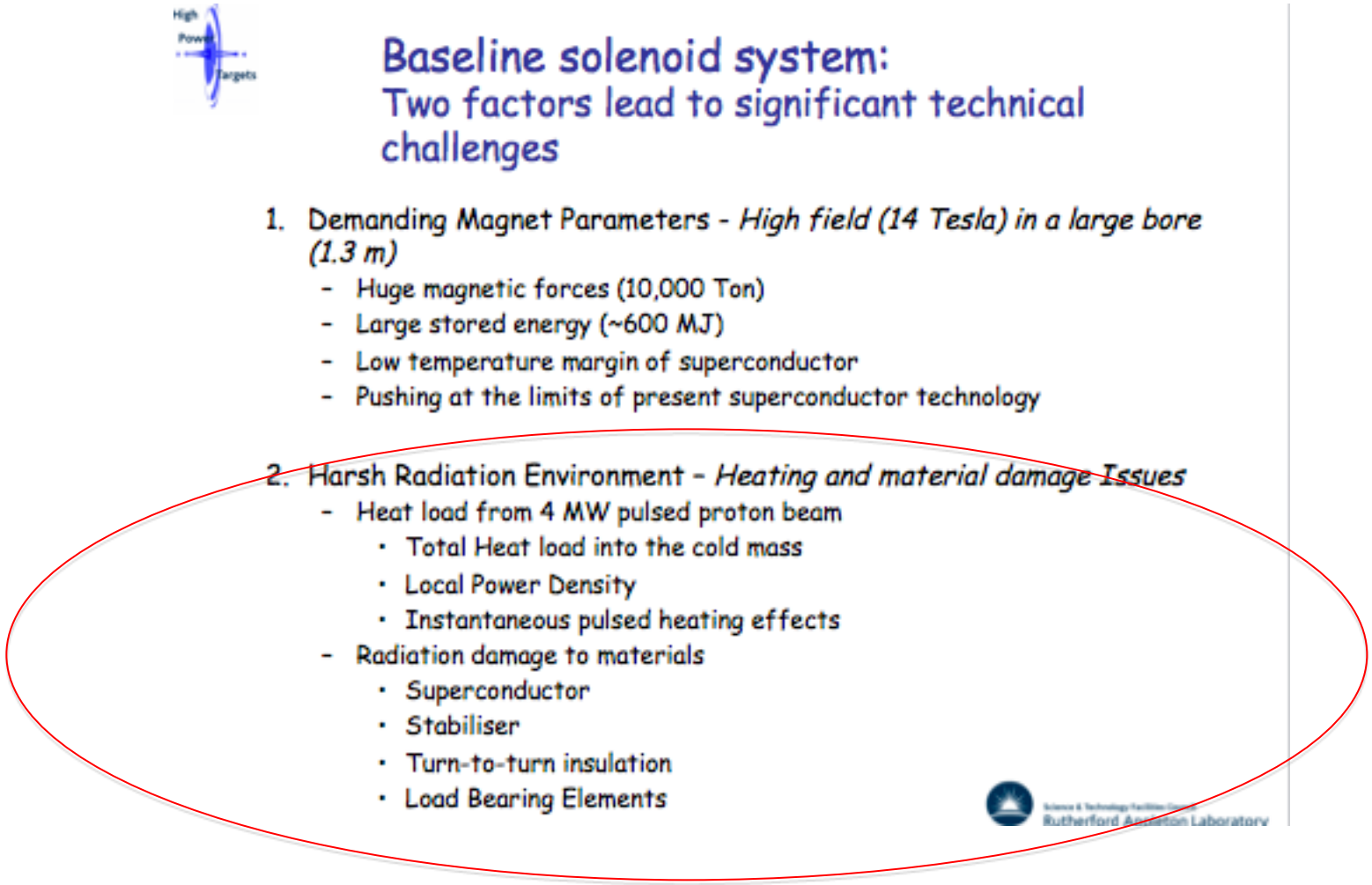
Towards the target baseline

After these studies we have concluded that

- The Titanium pebble bed target appears to be the best candidate (capable of multi-MW) → baseline choice
- The solid static target is feasible, pencil shape solution
- The embedded target is disfavored

10) Material property evolution with time (from radiation, strain & stress and temperature)?

Appropriate material studies under way.



Baseline solenoid system:
Two factors lead to significant technical challenges

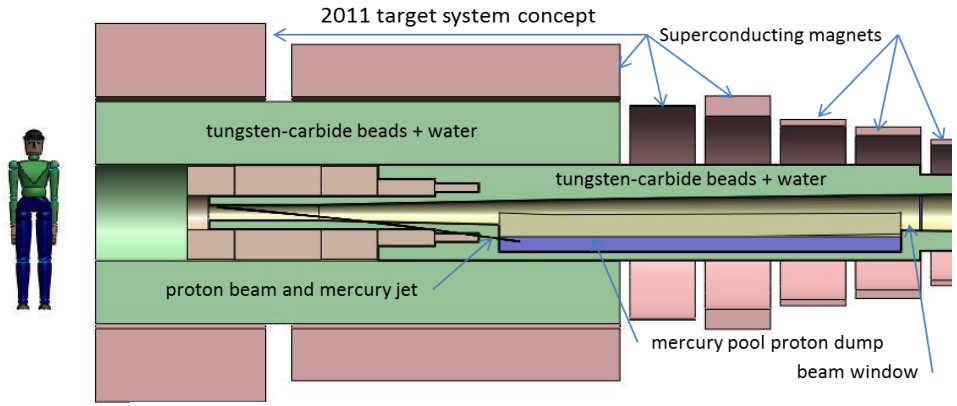
1. Demanding Magnet Parameters - *High field (14 Tesla) in a large bore (1.3 m)*
   - Huge magnetic forces (10,000 Ton)
   - Large stored energy (~600 MJ)
   - Low temperature margin of superconductor
   - Pushing at the limits of present superconductor technology

2. Harsh Radiation Environment – *Heating and material damage Issues*
   - Heat load from 4 MW pulsed proton beam
     - Total Heat load into the cold mass
     - Local Power Density
     - Instantaneous pulsed heating effects
   - Radiation damage to materials
     - Superconductor
     - Stabiliser
     - Turn-to-turn insulation
     - Load Bearing Elements

C. Densham

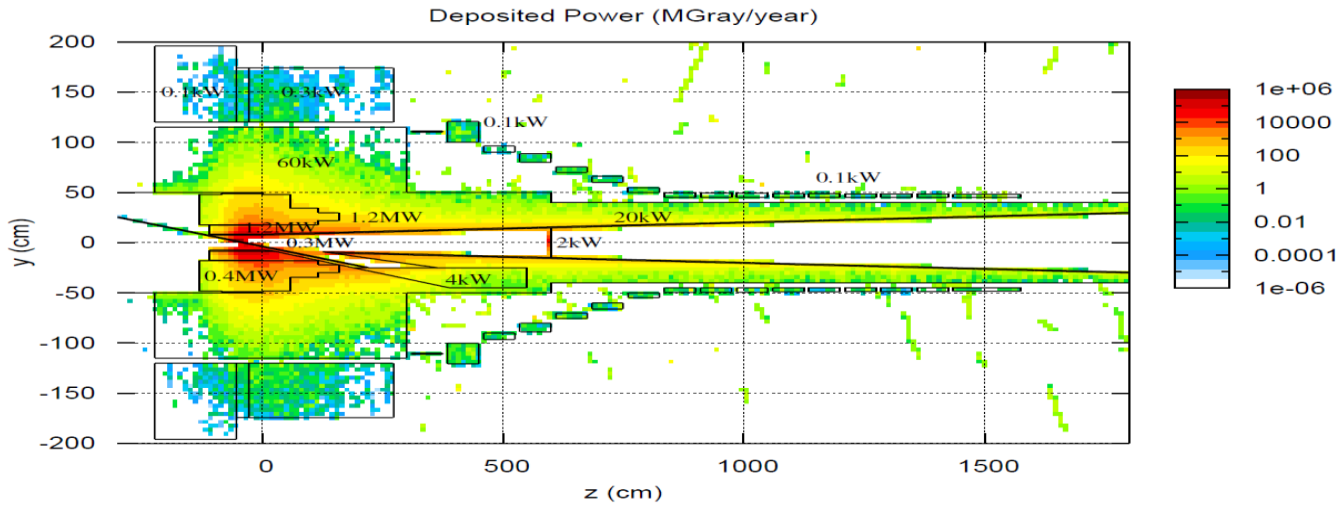
3) Does energy deposition pose SC solenoid shielding problem for presently proposed proton drivers?

Challenging problem, robust engineering solution being worked out.



Degradation of superconductor, insulator, thermal conductor, structure etc by irradiation
← some hints from COMET, ITER

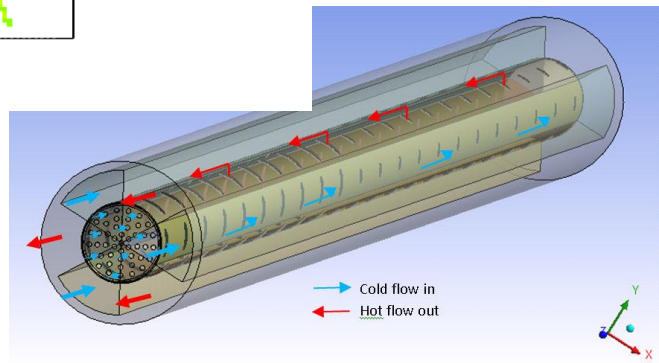
Increase inner shielding → 3GJ stored energy
Feasibility ?



C, Densham

Alternate target option with Low-Z?

Low-Z → less neutrons



13) Modeling of pion production complete?

Agreement between two models/codes (MARS and FLUKA) consistent within 10-20% with the HARP data

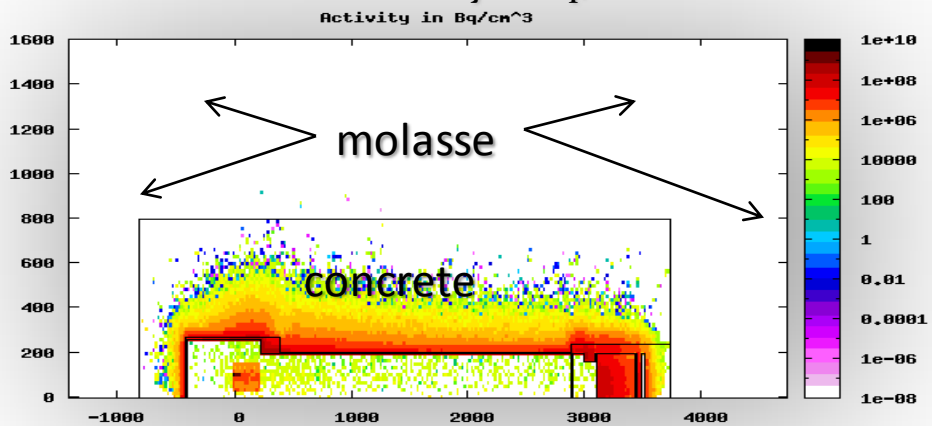
Recent updates from NA61 (talks in WG2).

14) How serious is power deposition in the structures after/around the target (horn, solenoids…)?

Quite significant. They are modelled accurately; adequate shielding provided

4MW Superbeam Horns

ACTIVITY density in Bq/cm³

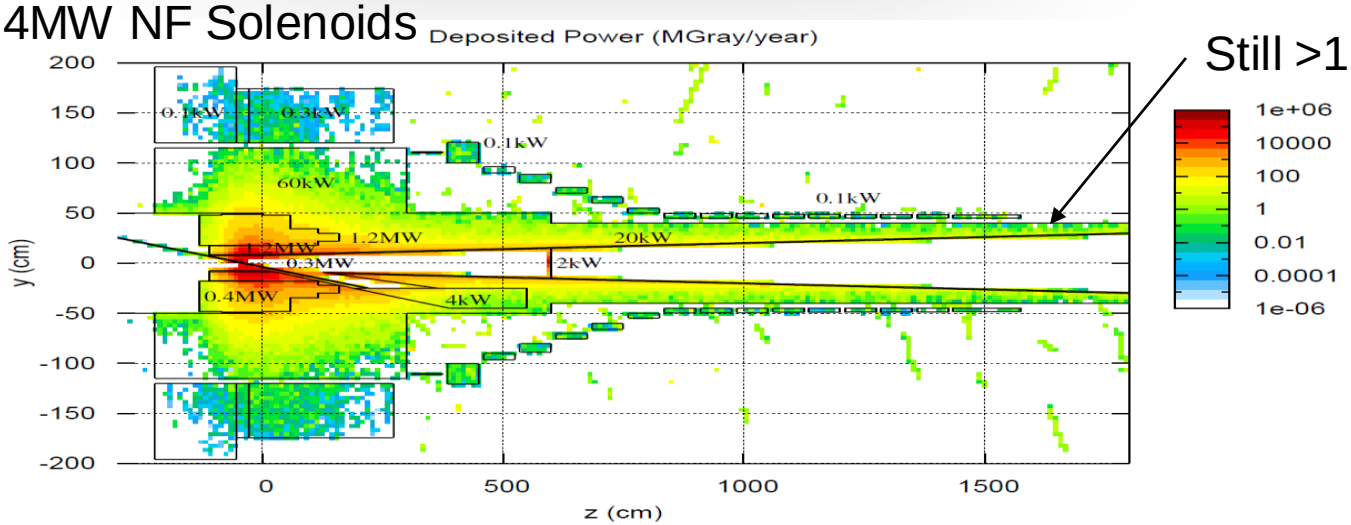


- ✓ packed Ti target, 65%d_{Ti}
- ✓ 4MW beam, 4horns, 200days of irradiation

CERN annual activity constraints in molasse (for achieving 0.3mSv for the public through water)		SuperBeam, (preliminary)
^{22}Na	4.2 x 10^{11} Bq	- (to be investigated)
tritium	3.1 x 10^{15} Bq	6x10^{8} Bq

N. Vassilopoulos

4MW NF Solenoids



Still >1MGy/year at downstream

need investigation on downstream materials

K. McDonald

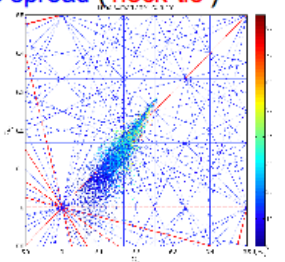
11) Will the Beta Beam be possible in the CERN Complex?

Yes, the baseline beta beam is possible to implement

Existing machines: PS

Space Charge

- Space-charge induces tune spread ('neck-tie')
- Particles can cross betatron resonance lines and
  - either lost
  - either emittance blow-up
- For BBeams max. (safe!) ΔQ=-0.22 @ 3.5GeV but e.g. Tof in PS has |ΔQ|~0.30

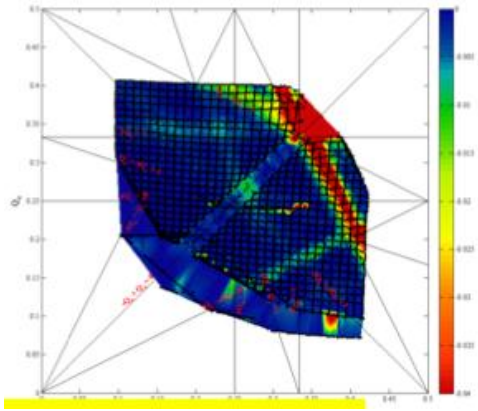


Courtesy S.Aumon

→ Identify SC limit (max tolerable ΔQ)

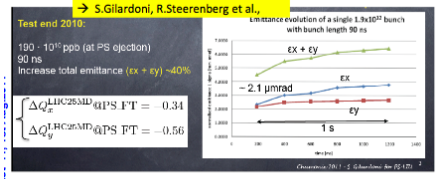
→ Determine the optimum working point

Tune scan @ 2GeV



E. Benedetto

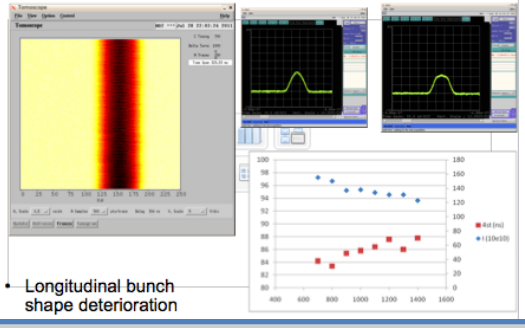
SC & Emittance growth



- See also *R.Cappi et al., PAC'93*
- Repeating them @ 2 GeV

→ Identify max allowed SC blow-up

SC & Losses (Preliminary!!!)



- Longitudinal bunch shape deterioration

High intensity studies: Started

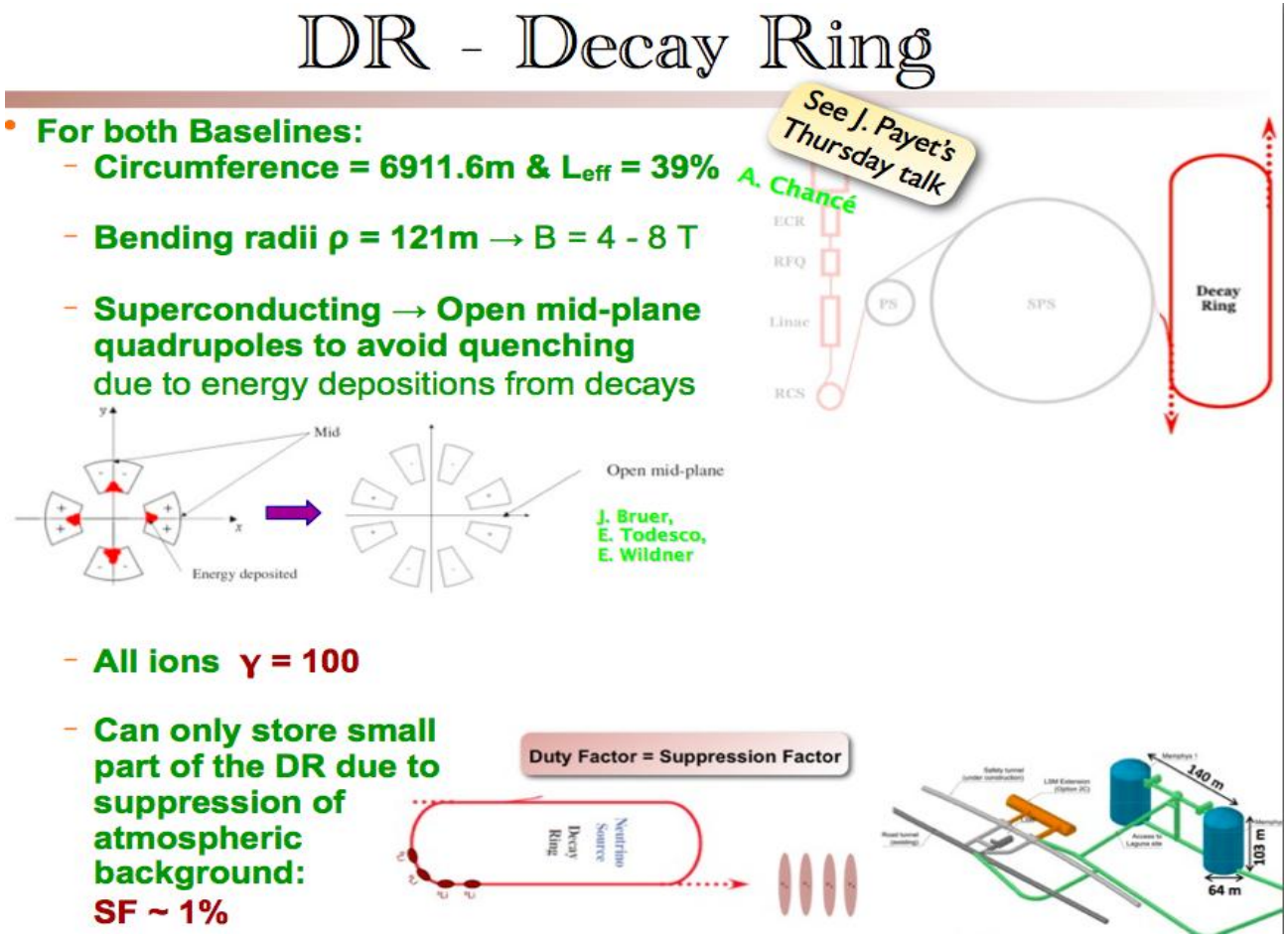
- Considered 2 different type of beams:
  - Small emittance, "LHC-type" beam
    - Expected (depending on the WP choice)
      - Beam emittance blow-up (integer crossing)
      - or Losses with bunch shape deformation
  - High intensity, large emittance, "Tof-like" (more similar to BetaBeams)
    - Beam blow-up will translate into losses
    - Aim is to identify different mechanisms…and find a cure!

Existing machines: SPS

still needs studies, Less constrained SF helps

11) Will the Beta Beam be possible in the CERN Complex?

Yes, the baseline beta beam is possible to implement



Decay Ring optimization good with higher SF, solutions exist for small theta13

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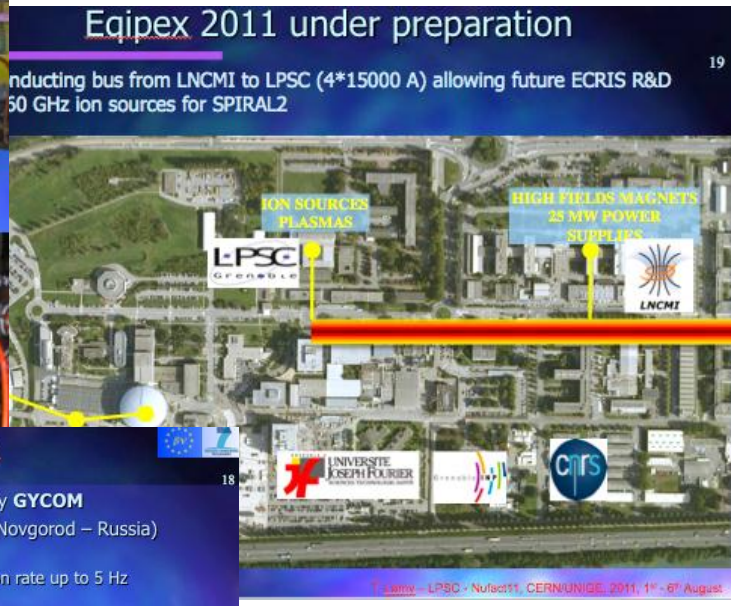
Yes, the baseline beta beam is possible to implement

ECR Source



T. Lamy

Efficiencies and beam parameters on the way

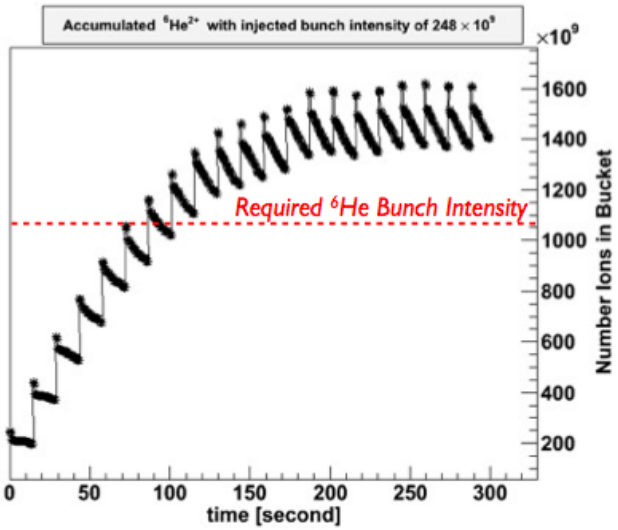
11) Will the Beta Beam be possible in the CERN Complex?

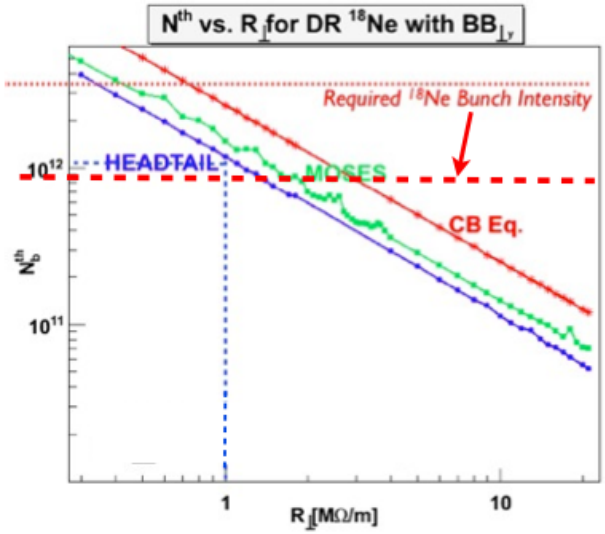
Yes, the baseline beta beam is possible to implement

Solved DR Limitations

LARGE θ_{13}

- **2.48e11 ^{6}He/bunch** enters DR in 80 bunches!
- 4 times less bunch intensity required
  - ➡ Enough intensity can be merged
  - ➡ Collective effect no longer problem (if $R_\perp^{DR}$ = 1 M/Ωm)
    - ✦ Resistive Wall and Longitudinal to be studied





Solutions for theta 13 smaller exsist

11) Will the Beta Beam be possible in the CERN Complex?

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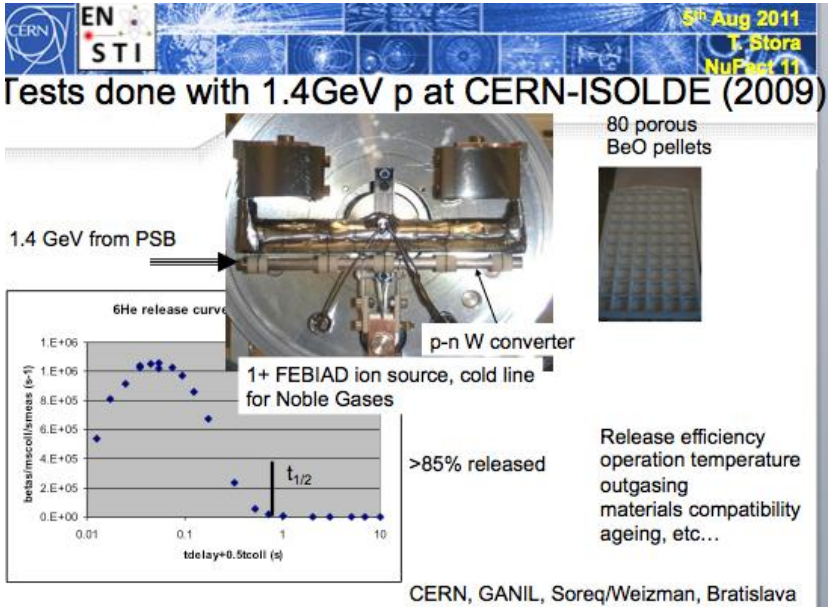
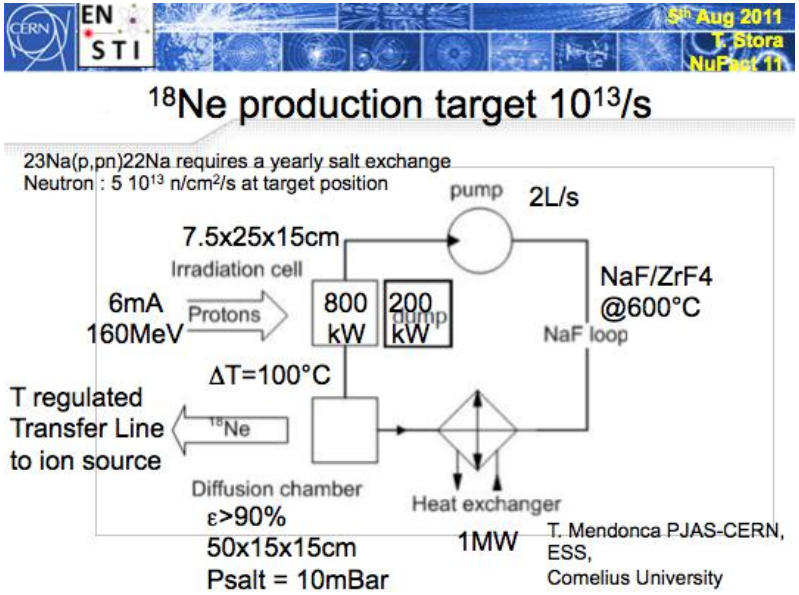
Ion Production

T. Stora

6He ok, operation feasable



18 Ne under test



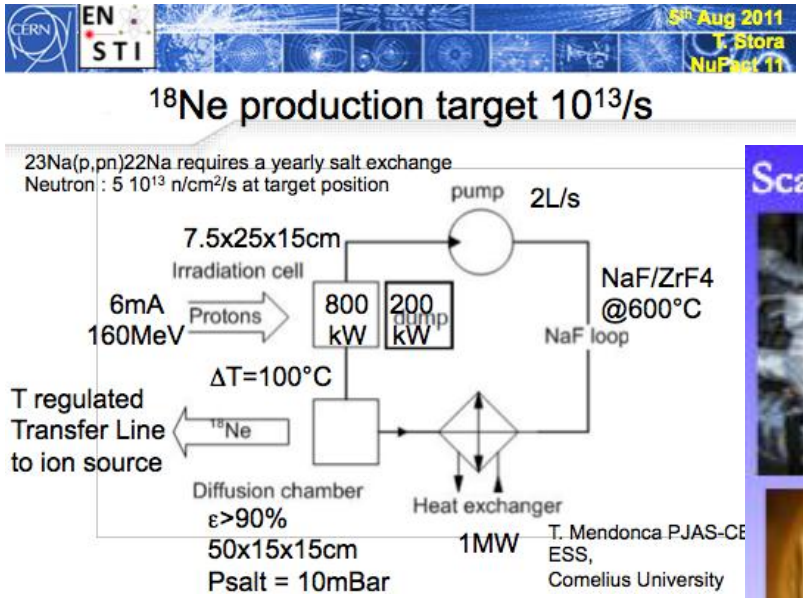
12) Verification of the 18Ne production for beta beams?

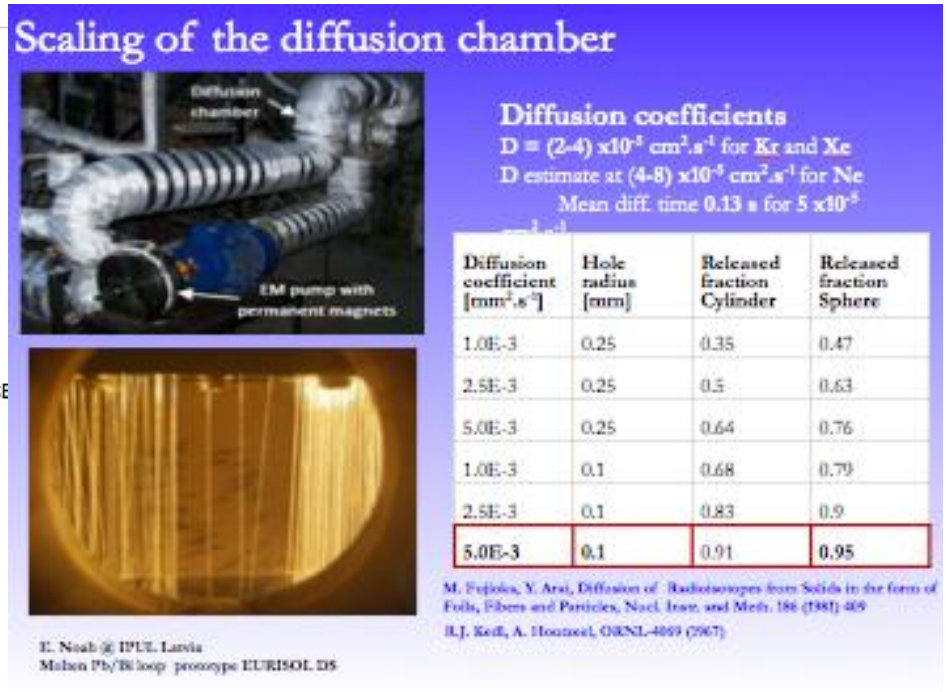
Tested experimentally

18Ne Production was a serious show stopper

18 Ne under test

Tânia Melo Mendonça
IFIMUP, Porto University and CERN





Diffusion coefficient [mm².s⁻¹]	Hole radius [mm]	Released fraction Cylinder	Released fraction Sphere
1.0E-3	0.25	0.35	0.47
2.5E-3	0.25	0.5	0.63
5.0E-3	0.25	0.64	0.76
1.0E-3	0.1	0.68	0.79
2.5E-3	0.1	0.83	0.9
5.0E-3	0.1	0.91	0.95

1) Is Project X a suitable proton driver for the Neutrino Factory?

Yes it is; A complete scheme emerged including stripping injection

Project X : Mission Goals

- A neutrino beam for long baseline neutrino oscillation experiments
  - 2 MW proton source at 60-120 GeV
- High intensity, low energy protons for kaon and muon based precision experiments
  - Operations simultaneous with the neutrino program
- A path toward a muon source for possible future Neutrino Factory and/or a Muon Collider
  - Requires ~4 MW at ~5-15 GeV .
- Possible missions beyond HEP
  - Standard Model Tests with nuclei and energy applications

R. Garoby

1) Is Project X a suitable proton driver for the Neutrino Factory?

Yes it is; A complete scheme emerged including stripping injection

Project X : Reference Design Capabilities

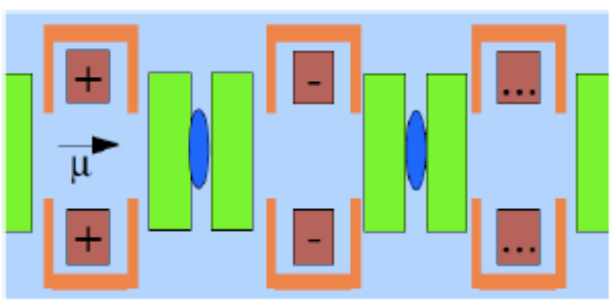
- 3 GeV CW superconducting H- linac with 1 mA average beam current.
  - Flexible provision for variable beam structures to multiple users
    - CW at time scales >1 μsec, 15% DF at <1 μsec
  - Supports rare processes programs at 3 GeV
  - Provision for 1 GeV extraction for nuclear energy program
- 3-8 GeV pulsed linac capable of delivering 300 kW at 8 GeV
  - Supports the neutrino program
  - Establishes a path toward a muon based facility
- Upgrades to the Recycler and Main Injector to provide ≥ 2 MW to the neutrino production target at 60-120 GeV.
- Day one experiment to be incorporated utilizing the CW linac

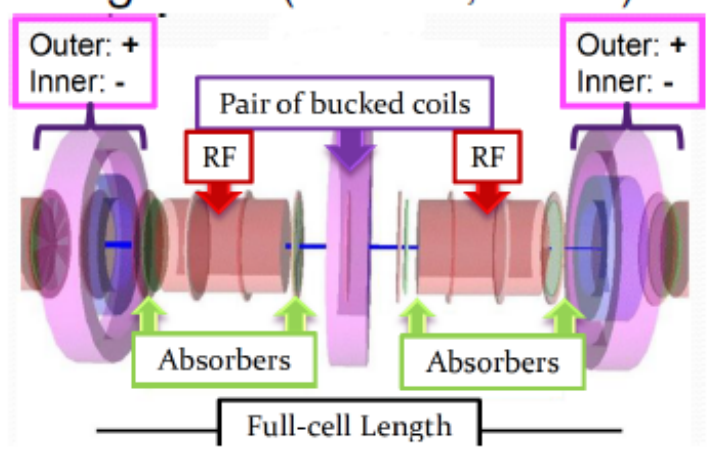
⇒ Utilization of a CW linac creates a facility that is unique in the world, with performance that cannot be matched in a synchrotron-based facility.

2) What is the path for solving the problem of operating high gradient RF is strong magnetic field?

Ongoing, vigorous experimental program under way at MuCool and MTA at Fermi (first experimental tests coming out)

1. Better materials: more robust against breakdown (melting point, energy loss, skin depth, thermal diffusion length, etc.)
2. Surface processing: suppress field emission (superconducting RF techniques, coatings, atomic layer deposition)
3. Shielding: iron (Rogers), bucking coils (Alekou, WG3)

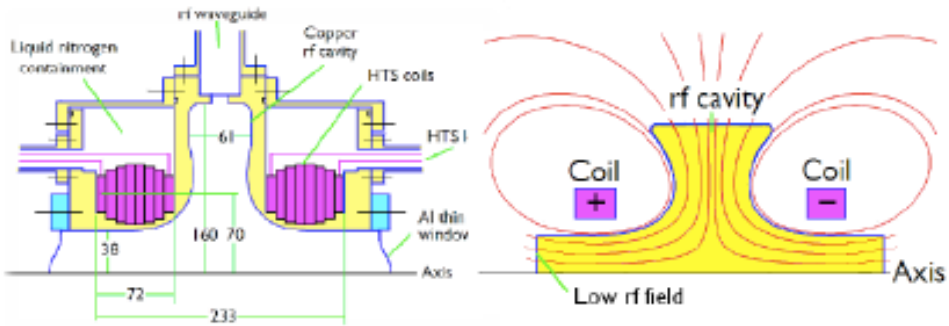




MuCool Yağmur Torun

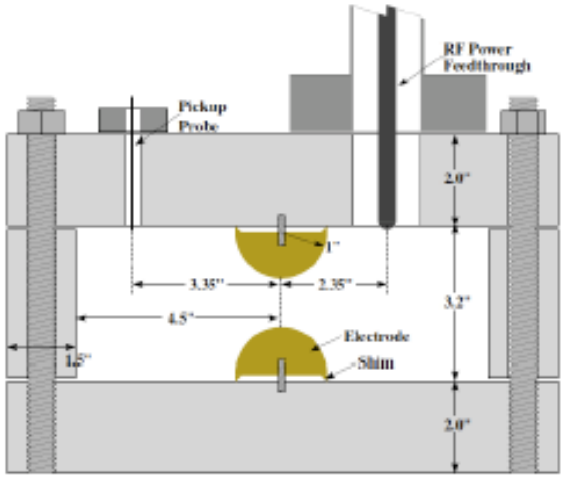
R&D program at Fermilab to develop ionization cooling components

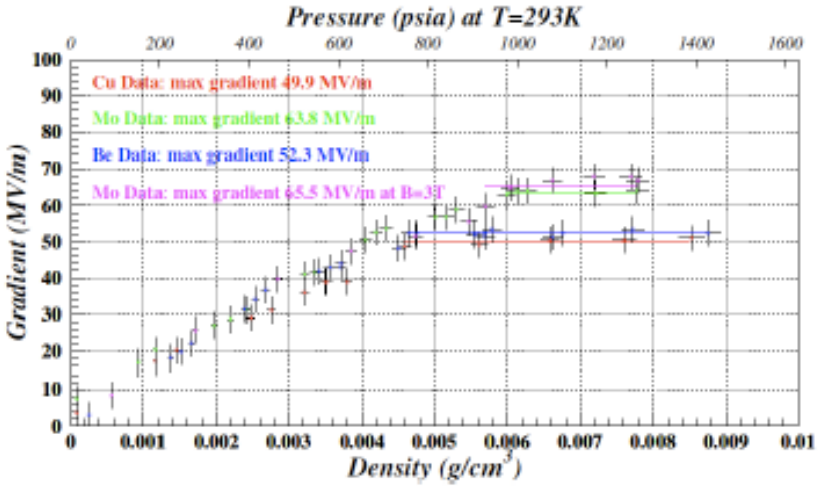
4. Magnetic insulation: modified cavity/coil designs to keep B⊥E on cavity surfaces (Palmer)



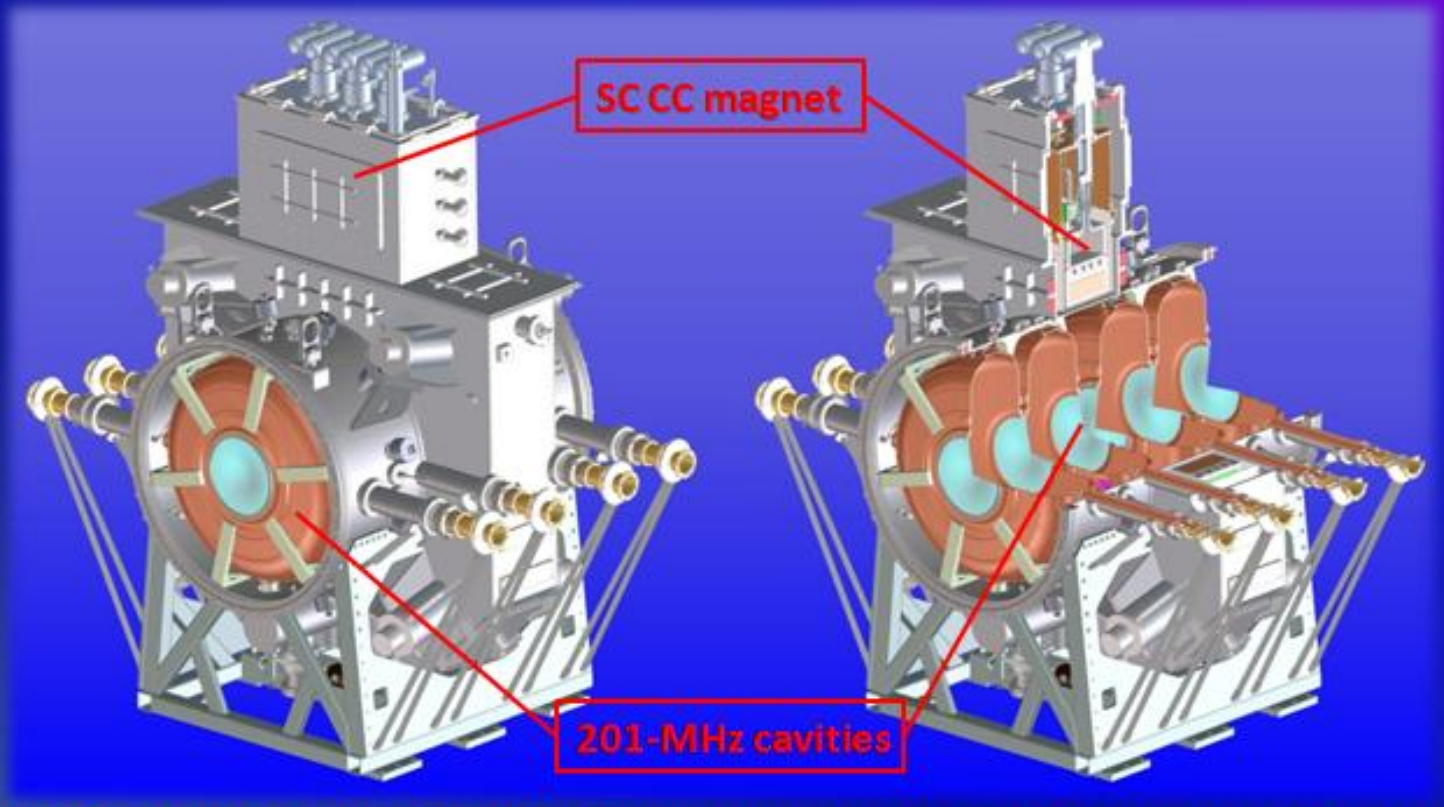
Loss of x 2 gradient advantage in pillbox geometry

5. High-pressure gas: suppress breakdown by moderating electrons (Muons Inc.) – beam test in progress (Yonehara)





MICE RFCC Module



Each RFCC module has four 201-MHz NC RF cavities and one SC coupling coil (solenoid) magnet; each RF cavity has a pair of curved Be windows and coaxial loop couplers

RF cavity operation in a few Tesla magnetic field at 8 MV/m

RF Cavity Processing and Testing Plan, M. Zisman, LBNL, NuFact-2011 4

High Power RF Testing

High power RF measurements with all needed diagnostics and controls

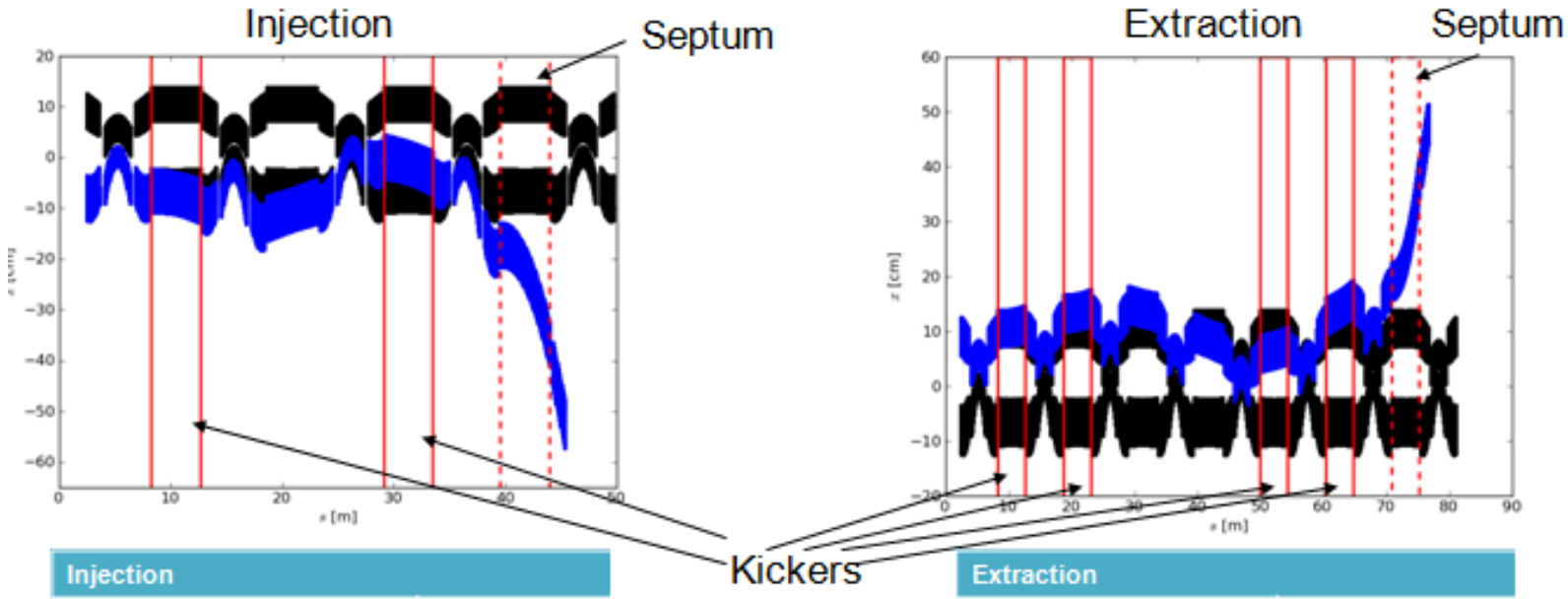
- Cavity conditioning/commissioning
- Frequency variation due to RF heating on beryllium windows and cavity body (may be done initially using the MTA prototype cavity)
- Measurement of cavity frequency shift as a function of average RF power and time
- Repeat above measurement with active tuners on the cavity and measure tuning range and sensitivity

- All above measurements will be conducted using the single cavity vessel
- Repeat the measurements with magnetic fields?
  - Where (MTA or RAL)?

4) Do we have a working Injection/Extraction scheme for NS-FFAG Rings?

Working concept under study, specific component being modeled and optimized.

FFAG Injection/Extraction geometries



Injection	
Plane	Horizontal
No. Kickers	2
Kicker field (T)	0.089
Kicker Polarity	+0+
Septum field (T)	0.92

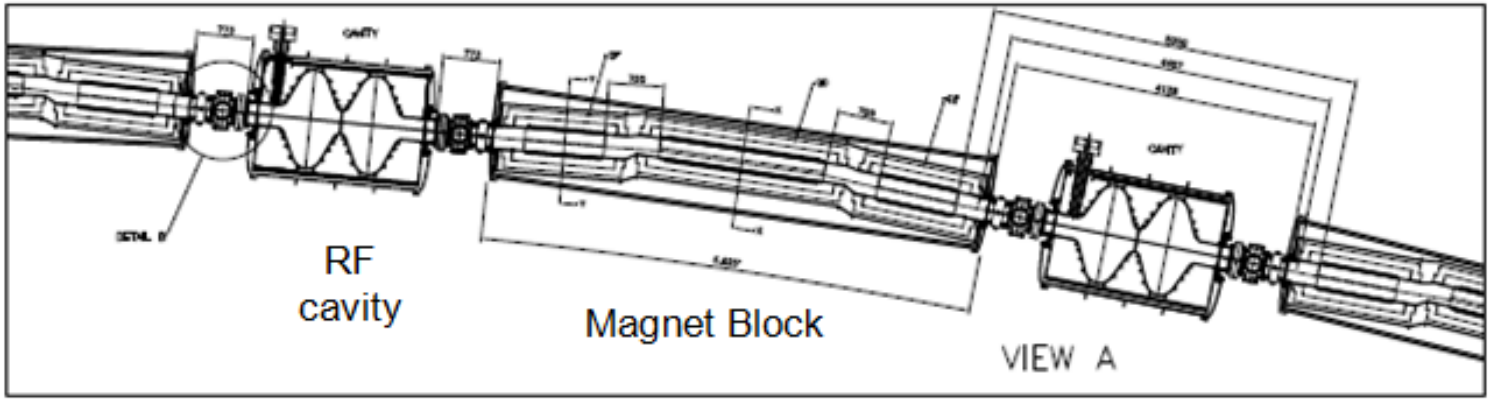
Extraction	
Plane	Horizontal
No. Kickers	4
Kicker field (T)	0.067
Polarity	++00++
Septum field (T)	1.76

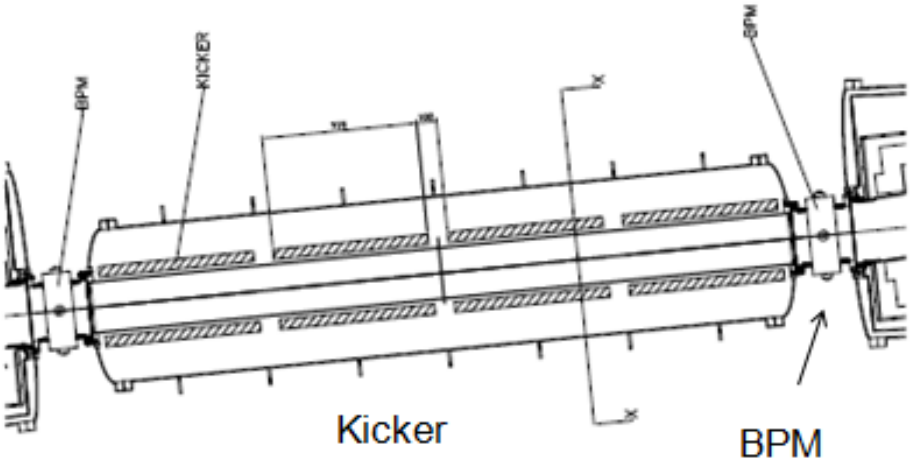
- Septum field was limited to 2 T by the stray fields studies (see next slides).
- Both injection and extraction are in the horizontal plane (minimal additional magnet aperture needed and no generation of the vertical dispersion).
- Larger apertures in the special magnets witch are needed have been calculated.

4) Do we have a working Injection/Extraction scheme for NS-FFAG Rings?

Working concept under study, specific component being modeled and optimized.

Start of engineering design for muon NS-FFAG





- Start of the engineering effort
- Effective drift length reduced to 4m (due to space for the cryostat and flanges).
- Kicker field increased 0.106 T
- Extraction septum field to 1.94 T
- Injection/extraction still feasible!

5) Is chromaticity correction sufficient to reduce the TOF problem for NS-FFAG?

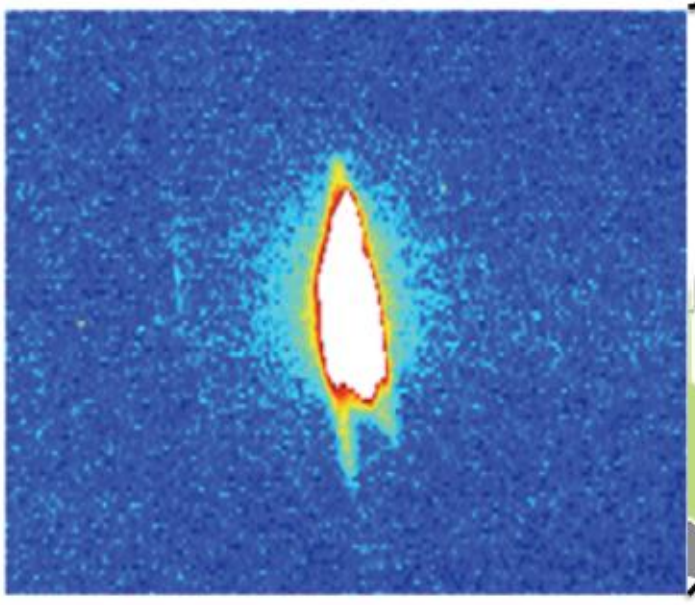
EMMA demonstrated device feasibility. Conceptual solution is being studied

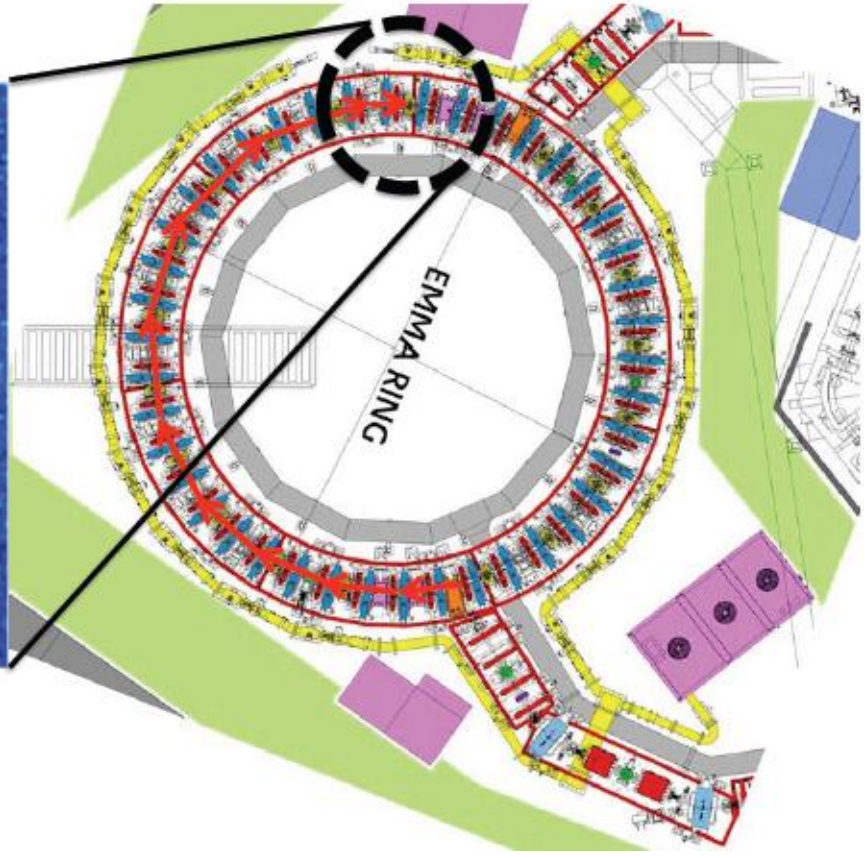
Science & Technology Facilities Council

Four sector commissioning

- Beam image on screen at the end of 4 sectors.

22:37 on 22 June 2010

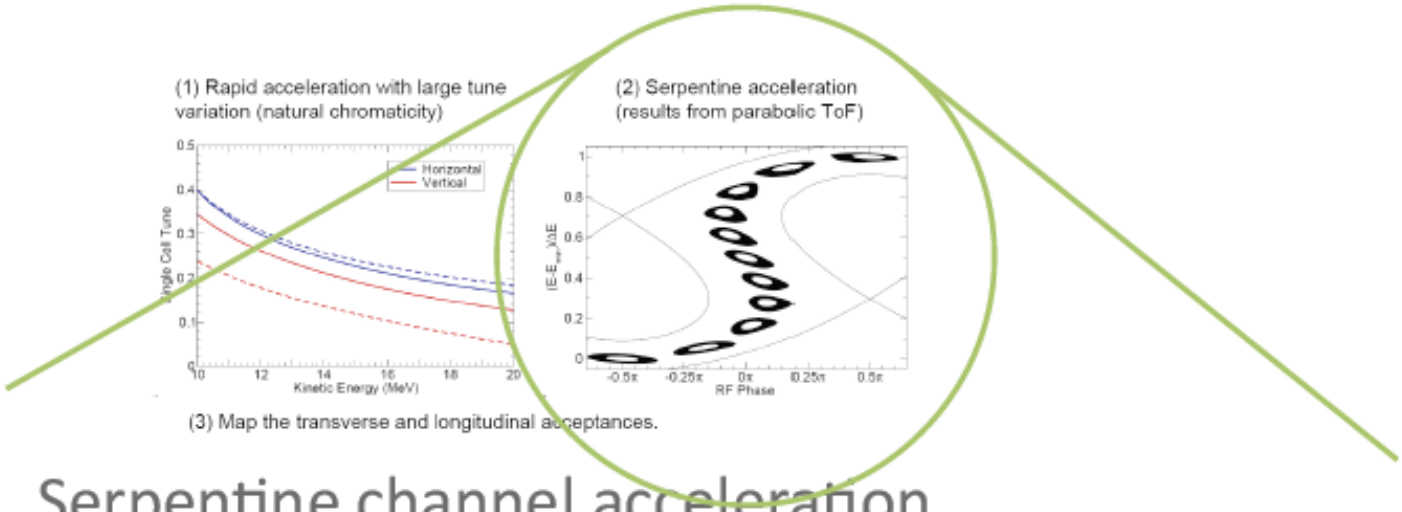




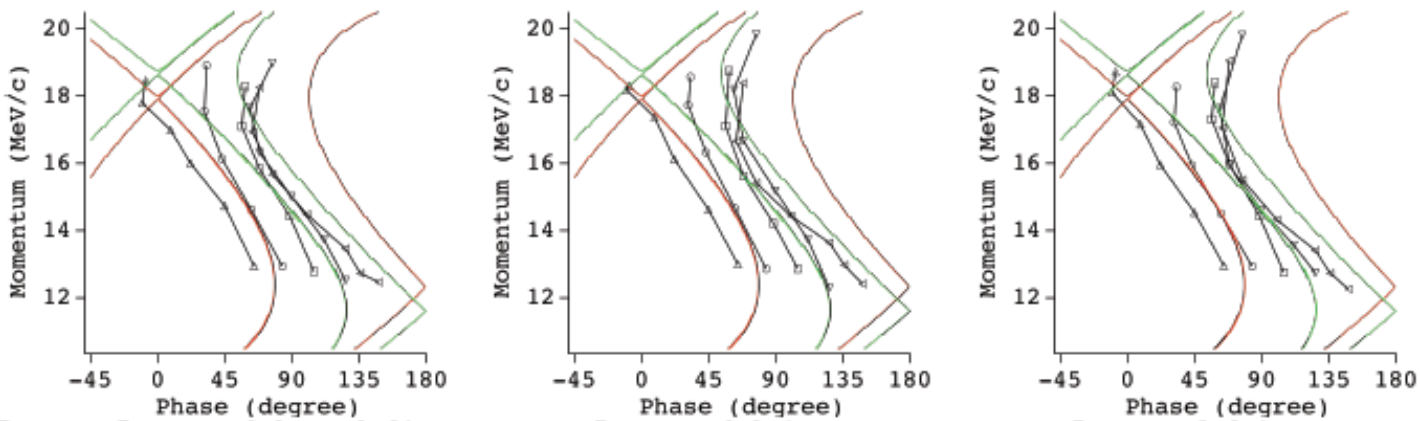
Shinji Machida

Shinji Machida

with 1.9 MV rf



- Serpentine channel acceleration

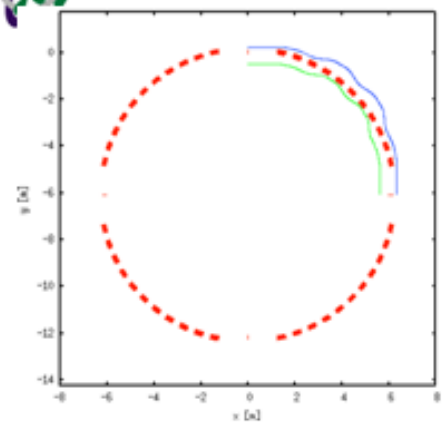


P from H orbit from H tune from V tune

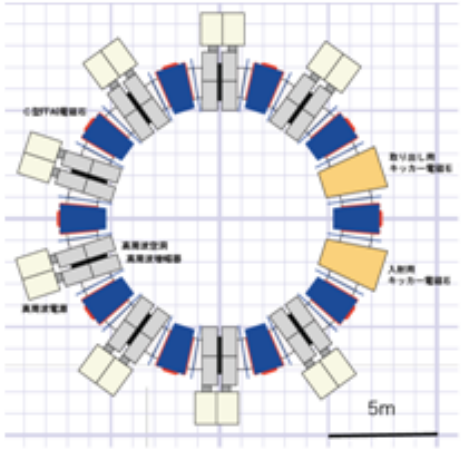
5) Is chromaticity correction sufficient to reduce the TOF problem for NS-FFAG?

EMMA demonstrated device feasibility. Conceptual solution is being studied

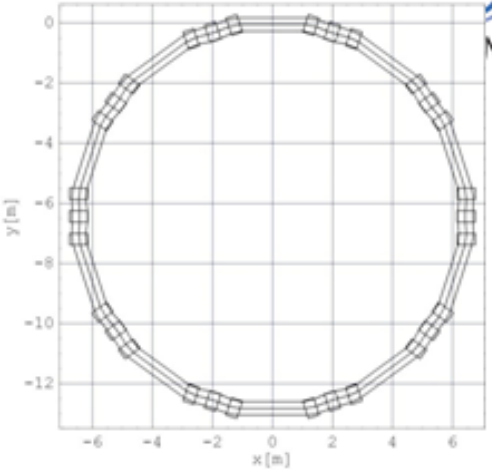
Alternative FFAG Ring Designs for PRISM



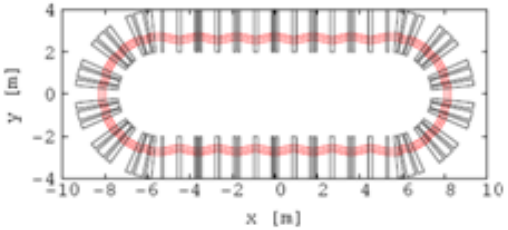
Scaling Superperiodic



Reference design

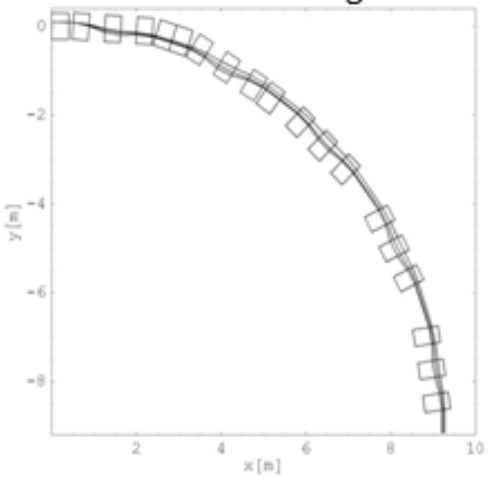


Non-Scaling



Advanced scaling FFAG

- We need to decide about the possible baseline update very soon.
- The choice is dictated by the performance.



Advanced NS-FFAG

Under study within the PRISM Task Force.

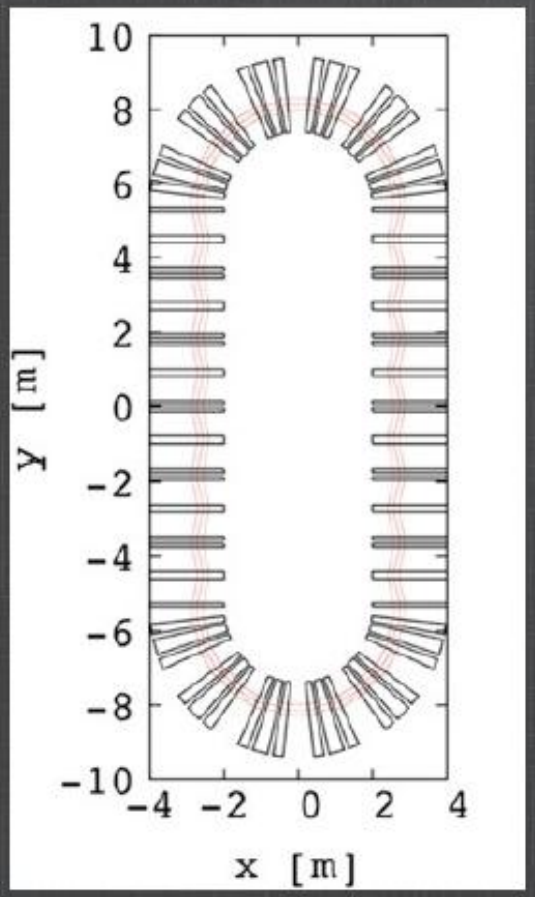
04.08.2011, Geneva, nufact'11

J. Pasternak

6) Can Scaling FFAG be used in other-then-ring configurations?

Complete prototype lattices designed for new applications e.g. prototype decay ring for VLENF

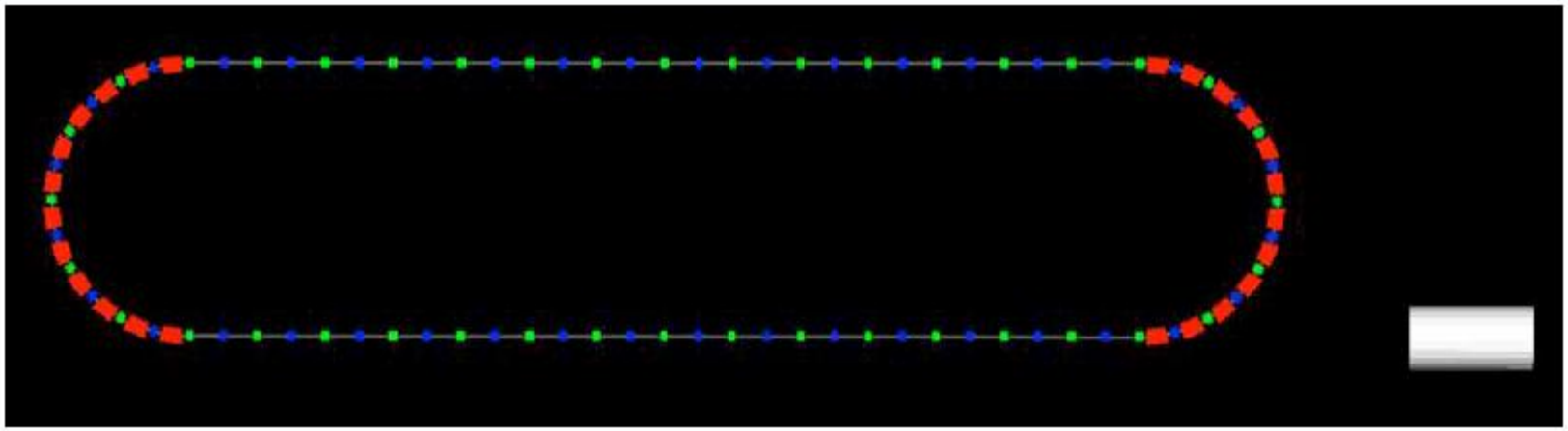
Race-track scaling FFAG PRISM



Bending cell FDF triplet	
k-value	2.55
Average radius	2.7 m
Phase advances:	
Horizontal μ_x	60 deg.
Vertical μ_z	90 deg.
Dispersion	0.8 m
Straight cell	
m-value	1.3 m^{-1}
Length	1.8 m
Phase advances:	
Horizontal μ_x	27 deg.
Vertical μ_z	94 deg.
Dispersion	0.8 m

15) Feasibility of mini-neutrino factory (low energy/intensity storage ring for short baseline measurement of cross-sections)

VLENF conceptual design with large acceptance decay ring, Scaling FFAG option

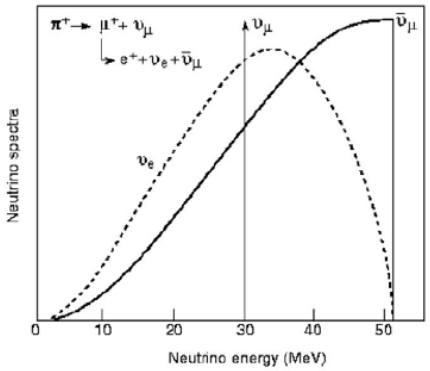


- 8 GeV protons on 2 λ_I Be target
- 3 GeV Racetrack ring (M. Popovic)
  - For now, injection is perfect
    - Not defined
- Tuned for μ^- with KE = 3.000 GeV
  - 3 GeV chosen primarily for x-section meas.
  - $\delta p/p \approx 2\%$
- Detectors (scintillator)
  - Near: 200T @ 20 m
  - Far: 800T @ 600 m

- Running with μ^-

$$\mu^- \rightarrow e^- + \nu_\mu + \bar{\nu}_e$$

- Well defined flavor composition & energy



15) Feasibility of mini-neutrino factory (low energy/intensity storage ring for short baseline measurement of cross-sections)

VLENF conceptual design with large acceptance decay ring, Scaling FFAG option

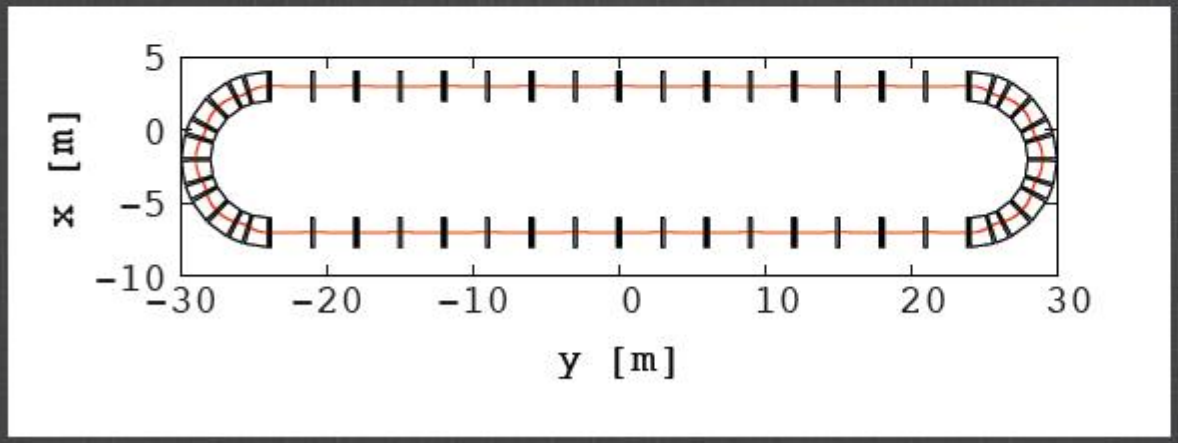
VLENF: storage ring proposal (Preliminary)

Beam momentum : 1 GeV/c (3 GeV/c)

Momentum acceptance ~± 50%

Transverse acceptance $\varepsilon_N > 30\,000\ \pi$ mm.mrad

Scallop in the straight part < 5 mrad



Bmax ~ 1.5 T

m ~ 8 m^{-1}

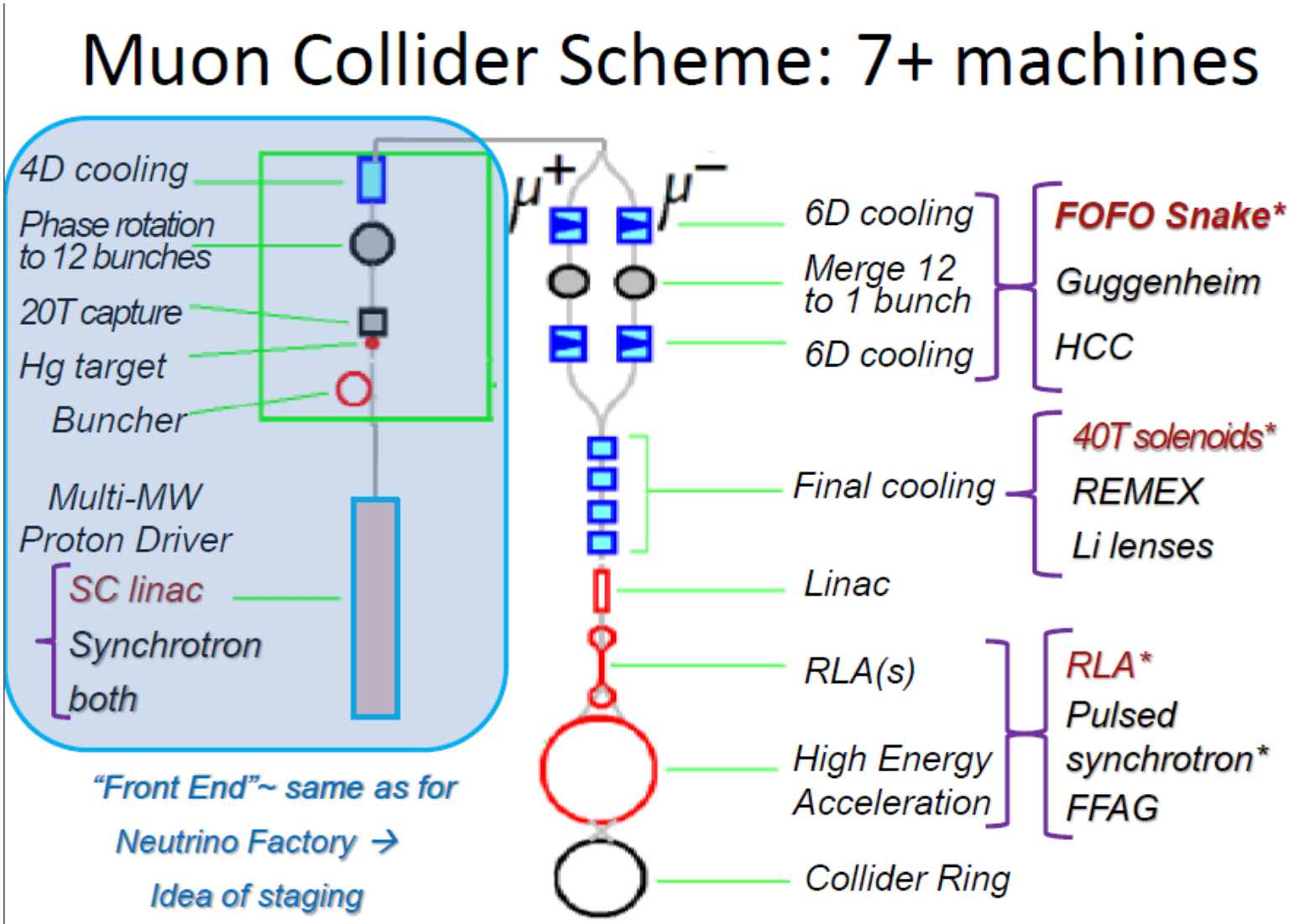
k ~ 2.5

r ~ 5 m

cf. T. Roberts, VLNEF July 2011: 6D acceptance > 100 times bigger

7) Is there a synergetic path from the Neutrino Factory to MC?

A clear path emerged and being developed within MAP. Usage of components and techniques developed for NF-IDS.



NufacF'11 ⇨ NuFact'12 (new)

1) What combination of proton beam energy and bunch length is the best compromise for integrated muon beam intensity?

2) Important to update the acceleration system of the beta beams from the source to the decay Ring

3) The PS (space charge, instabilities)

4) The SPS (instabilities and RF)

5) Impact of possible high θ_{13} on the neutrino facilities, design parameters

6) Operating high gradient normal conducting RF rf cavities in strong magnetic field; gradient degradation, effects of intense ionizing radiation traversing gas?
Ongoing, vigorous experimental program under way at LBNL and MTA at Fermi (first experimental tests coming out)

NuFact'11 ⇨ NuFact'12

7) Does energy deposition pose SC solenoid shielding problem for presently proposed proton drivers?
Challenging problem, robust engineering solution being worked out.

8) Do we have a working Injection/Extraction scheme for NS-FFAG Rings?
Working concept under study, specific component being modeled and optimized.

9) Is chromaticity correction sufficient to reduce the TOF problem for NS-FFAG?
EMMA demonstrated device feasibility. Conceptual solution is being studied

10) Target handling for Multi MW targets ?
1 MW target handeling needs to be addressed

11) Material property evolution with time (from radiation, strain & stress and temperature)?
Appropriate material studies under way.

NuFact'11 ⇨ NuFact'12

12) Modeling of pion production complete?
Agreement between two models/codes (MARS and FLUKA) consistent within 10-20% with the HARP data

13) How serious is power deposition in the structures after/around the target (horn, solenoids…)?
Quite significant. They are modelled accurately; adequate shielding provided

14) Feasibility of mini-neutrino factory (low energy/intensity storage ring for short baseline measurement of cross-sections)
VLENF conceptual design with large acceptance decay ring, Scaling FFAG option