
# WG3-Accelerator Group Summary

Conveners:

A. Bogacz, JLab

J. Pasternak (presenter) Imperial College London/STFC-RAL

M. Yoshida, KEK

# Nufact11 ⇨ Nufact12

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 in strong magnetic field?
Ongoing, vigorous experimental program under way at LBNL and MTA at Fermi (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 component 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

# Nufact11 ⇨ Nufact12

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

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.

# Nufact11 ⇨ Nufact12

11) Will the Beta Beam be possible in the CERN Complex?
Yes, Conceptual designs of more than one scheme exist

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

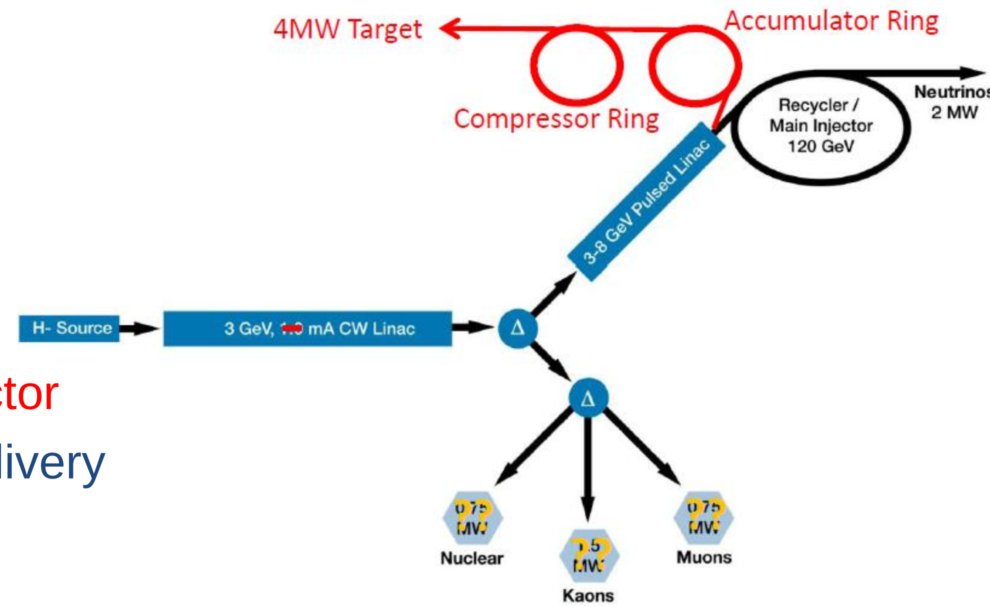
# Nufact11 ⇨ Nufact12 (new)

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

17) Operating high gradient normal conducting RF rf cavities in strong magnetic field; gradient degradation, effects of intense ionizing radiation traversing gas ?
Further experimental program needed (LBNL and MTA at Fermilab)

18) Given the complications of producing and capturing $^{8}Li$ and $^{8}B$, and the need for 5x higher intensity, is the cost-benefit ratio for this option really favorable?
Needs looking into…

1) Is Project X a suitable proton driver for the Neutrino Factory?
Answered-YES. Proposed to be eliminated from the list.
Yes it is; A complete scheme emerged including stripping injection.
Designs for the accumulator and compressor rings have been created.




- Upgrade Project X
  - 4 MW at 8 GeV
    - Increase particles per linac bunch
    - Increase pulsed linac duty factor
- Repackage linac beam for ~50 Hz delivery
  - Accumulator Ring
    - Collect linac beam into bunches
  - Compressor Ring
    - Narrow bunches to <= 3 ns
  - Single Bunch Transfer/Extraction

- Project X will be staged, with cost of 1st 3 stages < $1B:
  - Stage 1: 1 mA @ 1 GeV from a CW linac
  - Stage 2: 1 mA @ 1 GeV + 1 mA @ 3 GeV from a CW linac +potentials for the development of an interesting program at 3 GeV (C. Ankenbrandt)
  - Stage 3: adds a pulsed linac to 8 GeV
  - Stage 4: upgrades to a proton driver for MC and/or NF

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

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

Unclear experimental situation!

We have seen:

1

Pillbox with flat windows: extensive breakdown damage.

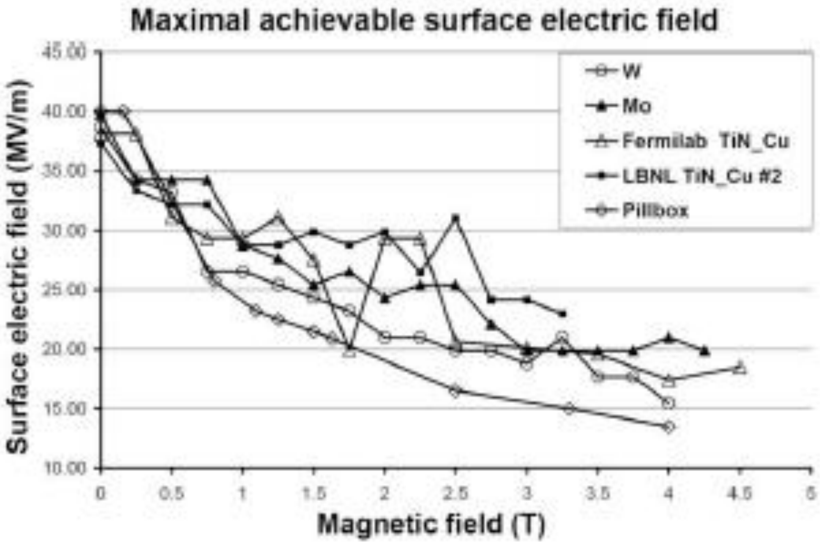
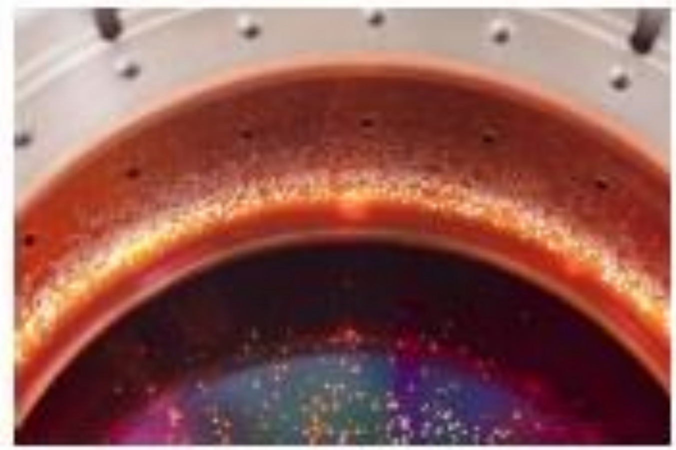
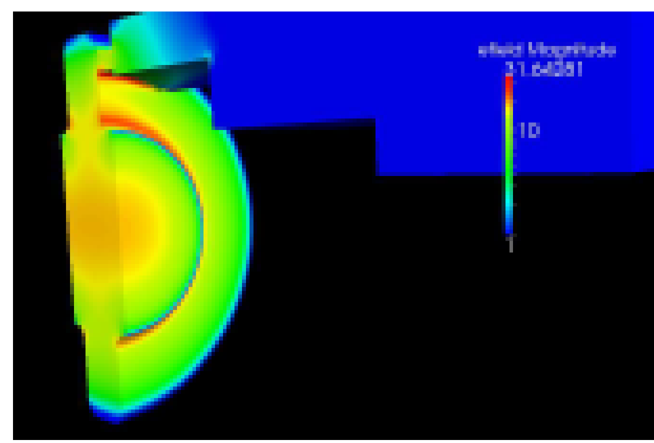



Figure: D. Huang *et al.*, *RF studies at Fermilab MuCool Test Area*, PAC09, Vancouver, May 2009, TU5PFP032, p. 888 (2009). http://www.JACoW.org.





From D. Bowring's talk

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

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

**2**

**BUT…**

## Summary of tested Cu cavities

From A. Morretti's talk

| Cavity type | Magnetic Field T | Gradient Surface MV/m, 1/100,000 sparking rate | Cavity length cm |
|---|---|---|---|
| Pillbox Flat | 3 | 16 & 10* | 8.1 |
| Pillbox 1 But | 3 | 23 | 8.52 |
| Pillbox 2 But | 3 | 28 | 5.56 |
| Orthogonal | 0 | 50 | 12.38 |
| All-Seasons** | 3 & 0 | 25 | 15.0 |
| 6 Cell Open | 3 & 0 | 53 | 16.2 |

*** 2 versions: original (16 MV/m) and refurbished (10 MV/m)**

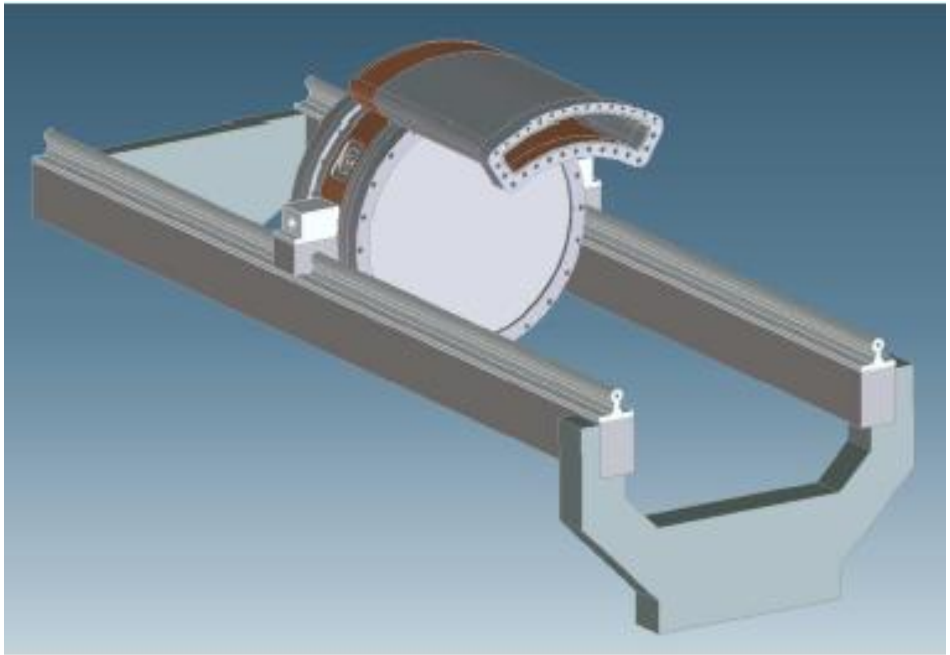
**** The All-Seasons cavity was not instrumented with a cavity Voltage pickup during this test and it was difficult to determine the source of the sparking limit and even if it was sparking. The next test will be done with a Voltage pickup and if possible sparking light pickup.**

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

**3**

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

**Recommendations: repeat measurements with a new cavity under construction with fully instrumented setup and extended experimental program.**



- One button mounted opposite a detector: directly measure breakdown current.
- Button vs. anti-button: Separate roles of electric field, cyclic fatigue during breakdown.
- **Vary gap length**, evaluate role of stored energy, transit time during breakdown. Modular design makes this easy. Muons, Inc. cavity may also be helpful here.
- Build, test walls from harder, stronger materials (W, Mo, CuZr, CuAg, Glidcop) to evaluate role of pulsed heating, cyclic fatigue.

From D. Bowring's talk

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

Proposed redefinition

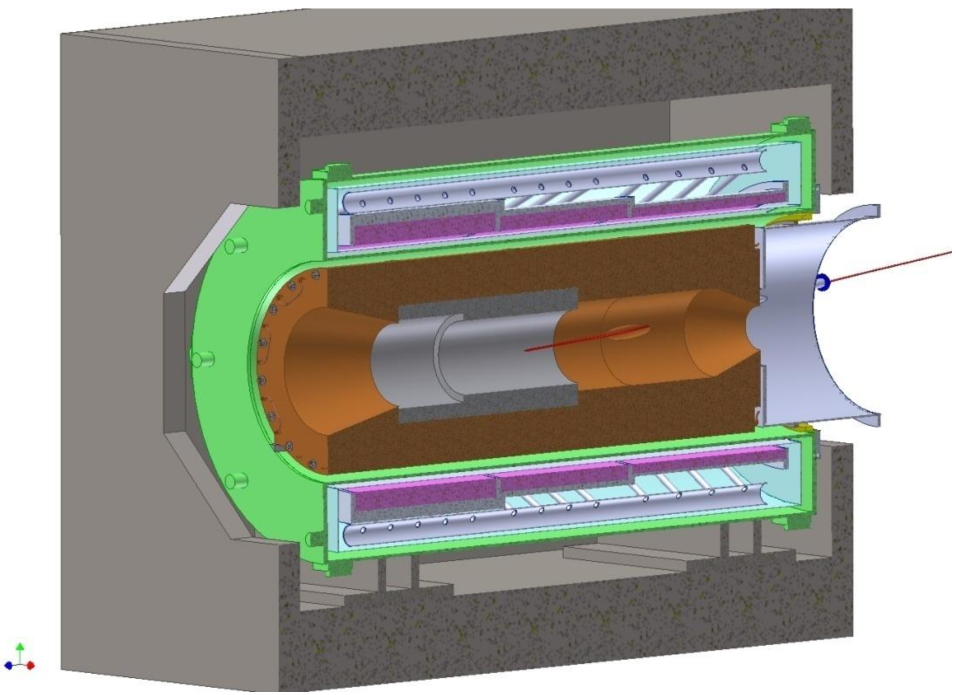
3) Does energy deposition pose SC solenoid shielding problem for presently proposed target/capture systems?

1

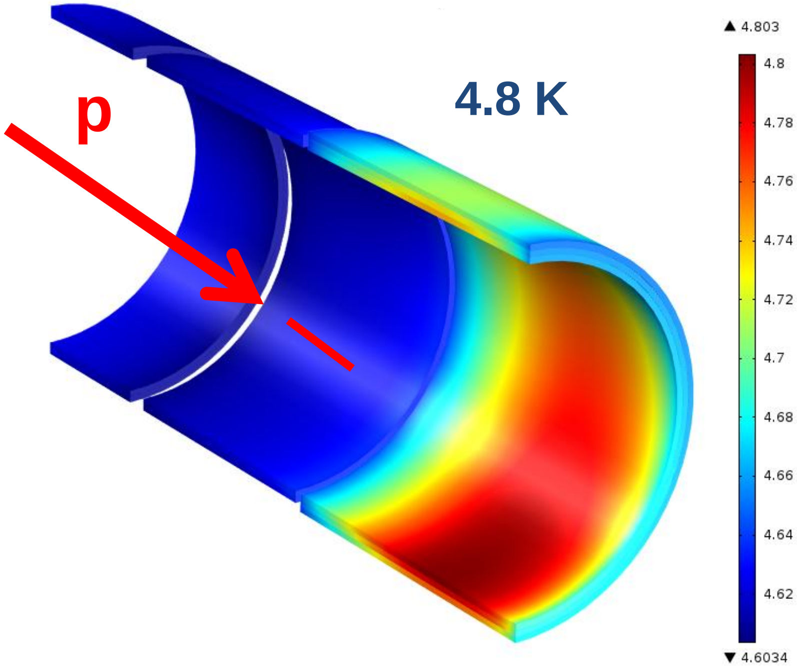
Challenging problem, robust engineering solution being worked out.

Difficult ,but a substantial progress achieved! More studies are needed.

Mu2e target solenoid



Volume temperature, K




T plot for $T_0$ =4.6K (liquid He temp)
$T_c$ = 6.5K; (supercond+field)
$T_{peak}$ = $T_c$-1.5K = 5.0K.
Peak coil temperature starts to violate allowable value based on 1.5 K thermal margin and 5 T field after 30 μW/g

From V. Pronskikh's talk

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

Proposed redefinition

2

3) Does energy deposition pose SC solenoid shielding problem for presently proposed target/capture systems?

Challenging problem, robust engineering solution being worked out.

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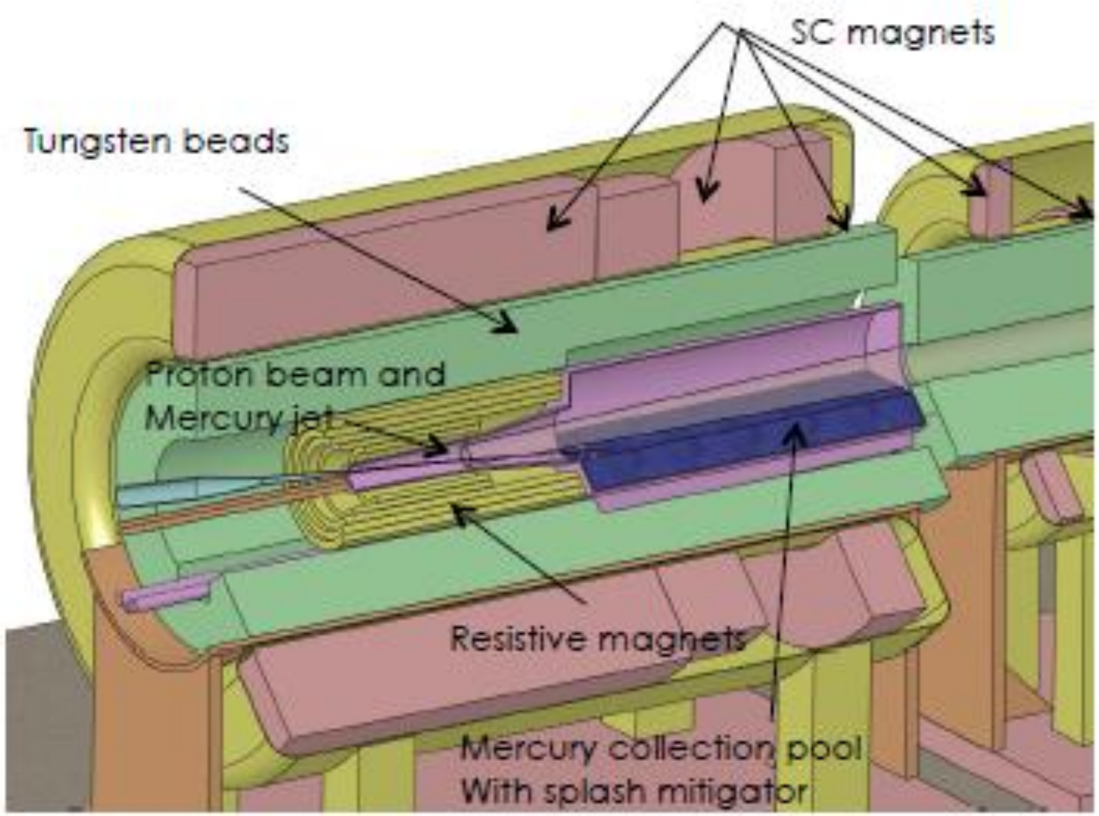


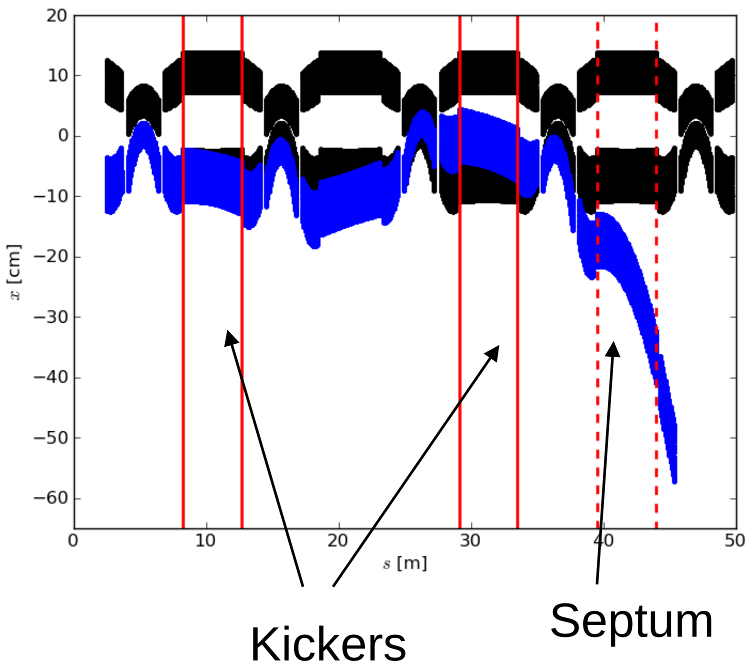

Hisham Kamal Sayed & Harold Kirk

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

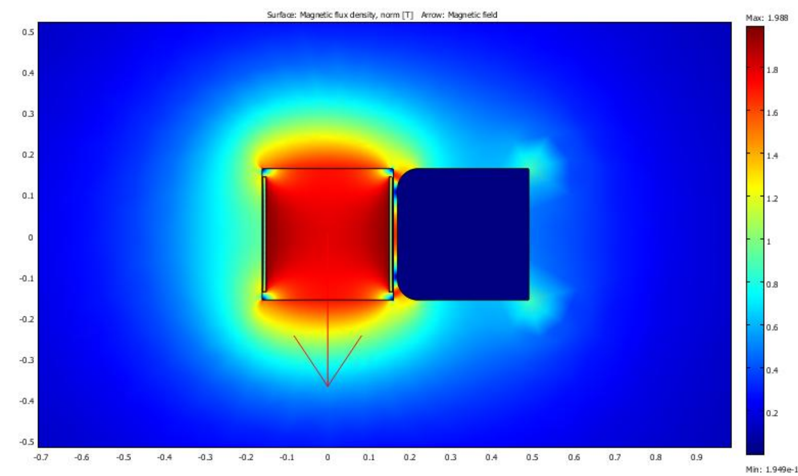
Working concept under study, specific component being modeled and optimized.

Injection/extraction still feasible after taking into account the space limitations imposed by the cryogenics. More definitions needed in the hardware design, especially for the superconducting septum.

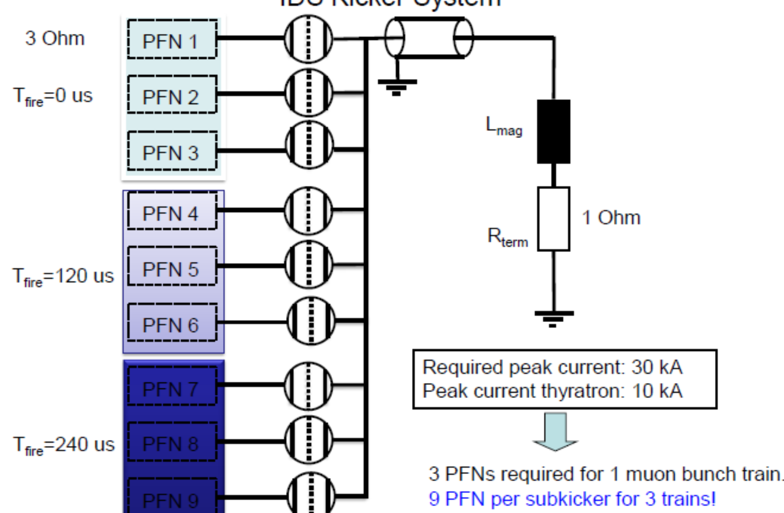
Injection geometry




Septum simulations



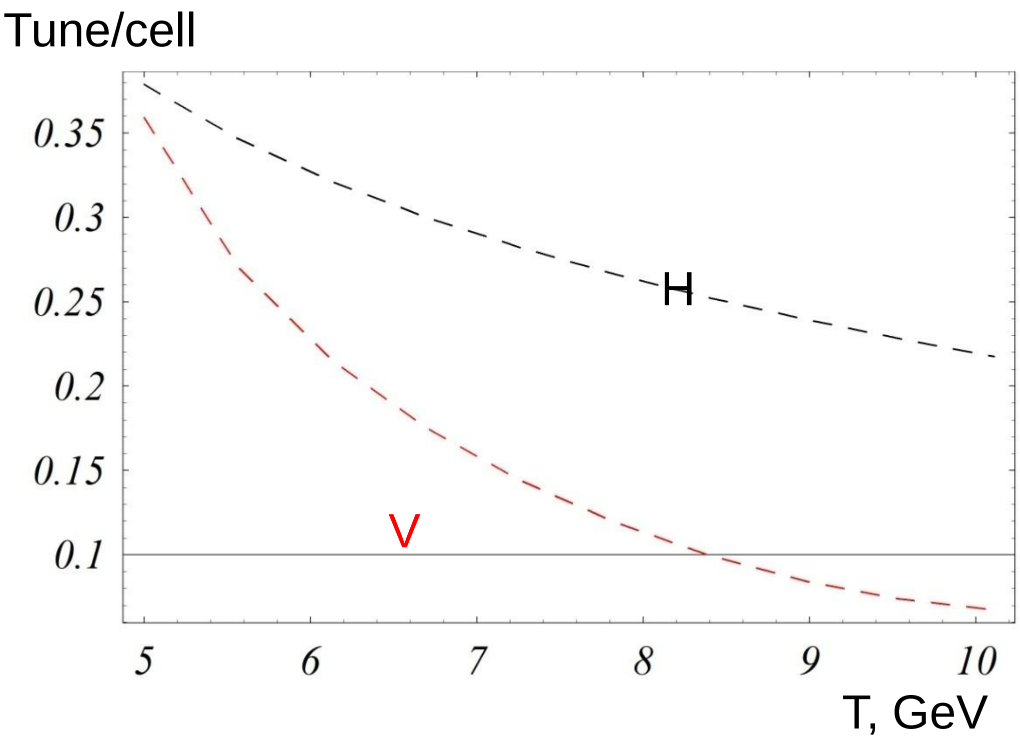
IDS Kicker System




From J. Pasternak's talk

5) Is chromaticity correction sufficient to reduce the TOF problem for NS-FFAG?
EMMA demonstrated device feasibility. Conceptual solution is being studied.
EMMA cannot currently study the chromaticity correction.
The use of sextupole correction is being studied to improve machine properties (including ToF). Preliminary results with 10-15% correction are promising.
More studies are needed.

NS-FFAG design for muon acceleration 5-10 GeV (preliminary)




- FDF triplet
- Drift length 3.5 m
- Assumed single 201 MHz cavity in a drift.
- B max 6.3 T
- N cells 49
- Small level of chromaticity correction assumed (to improve the off-momentum stability and partially improve the ToF problem).
- Machine seems to have a sufficient DA.

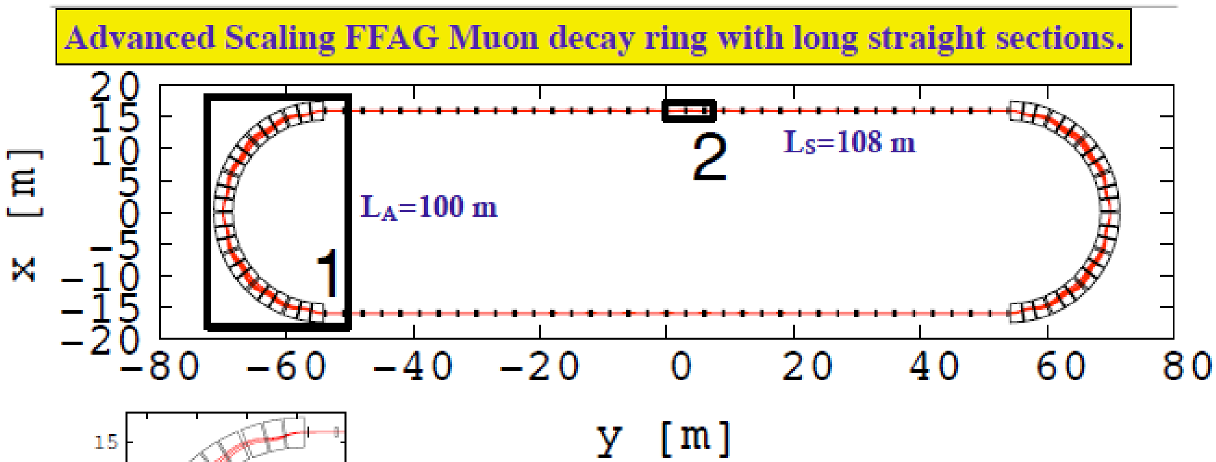
From J. Pasternak's talk

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

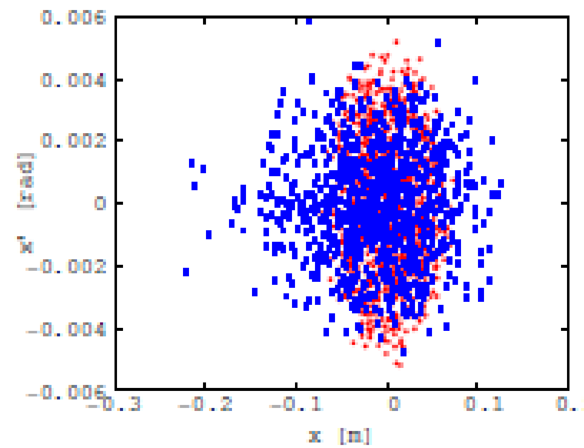
Complete prototype lattices designed for new applications e.g. prototype decay ring f for VLENF.

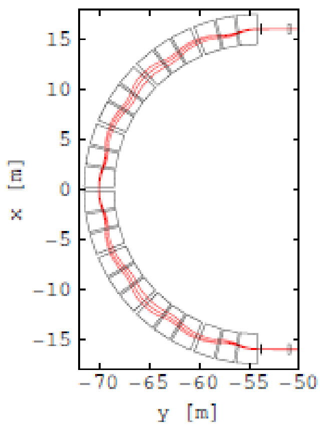
Answered-YES. Proposed to be eliminated from the list.

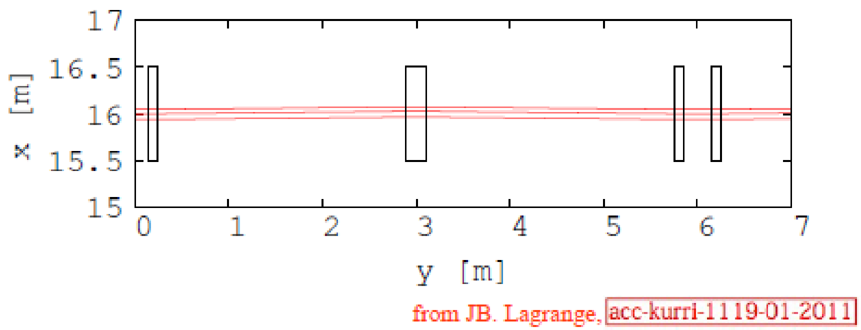
JB's Lattice for $E_\mu$=2GeV, $\Delta p/p_0$=±16%

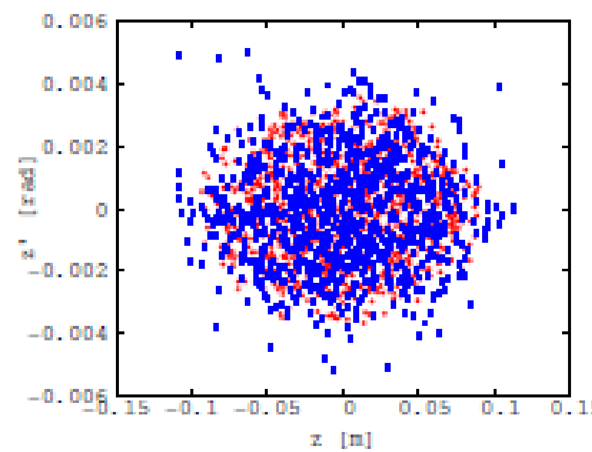



After 100 turns: Blue




From A. Sato's talk

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

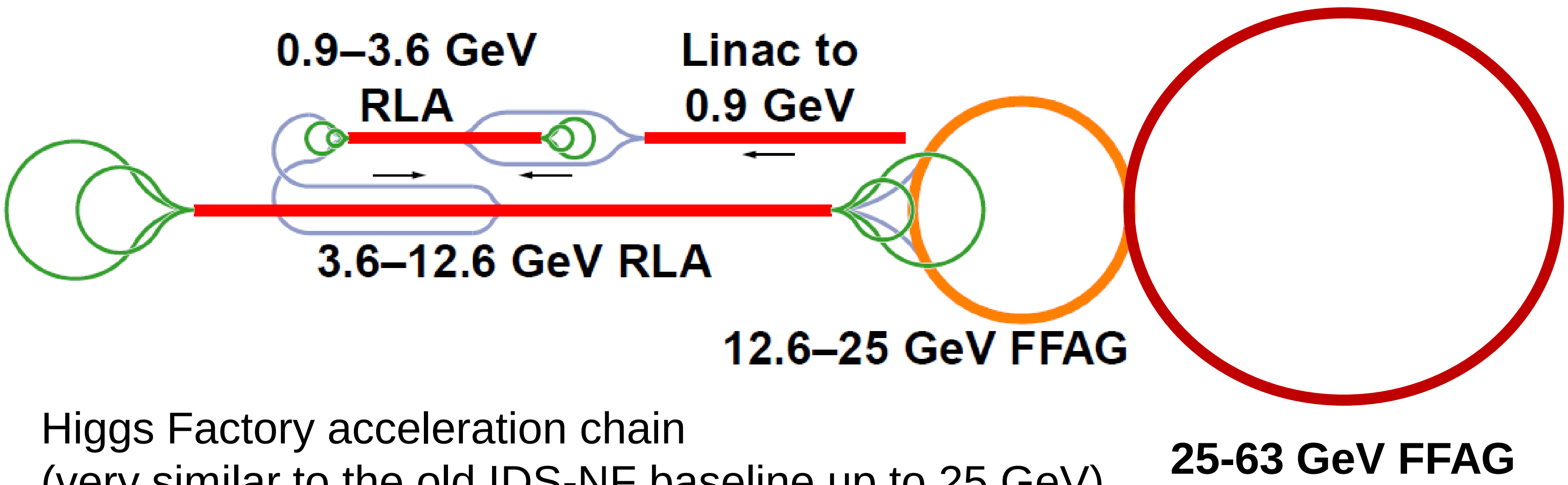
Proposed redefinition

7) Is there a synergetic path from the Neutrino Factory to low energy MC (Higgs Factory) and the energy frontier MC?

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

There is a path! Worth further studies!

From D. Neuffer's talk




Higgs Factory acceleration chain
(very similar to the old IDS-NF baseline up to 25 GeV).

8) Target handling for Multi MW targets ?

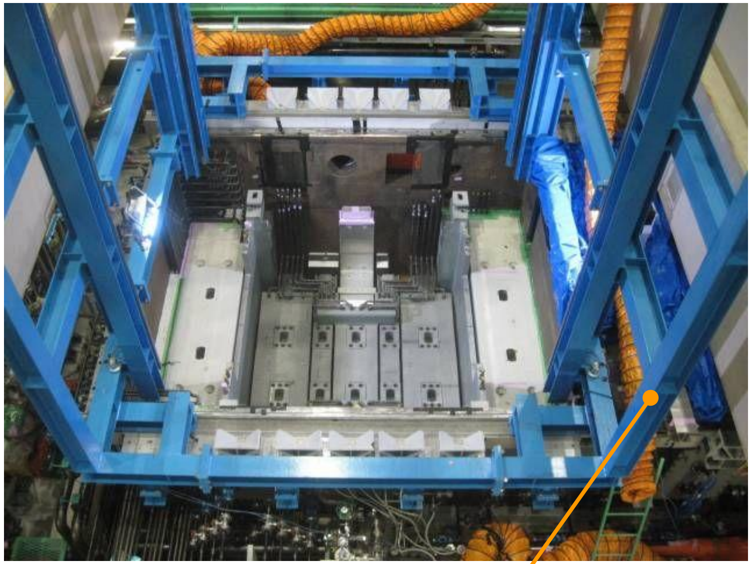
1 MW targets feasible; two robust designs exist (NF, LBNE)

Solutions exist for current target stations and are being developed for future systems. Needs further studies.



Crane with coordinate control

Handling machine for shields



Guide cell for Horn handling

Handling of horn at J-Parc, From T.Ishida's talk

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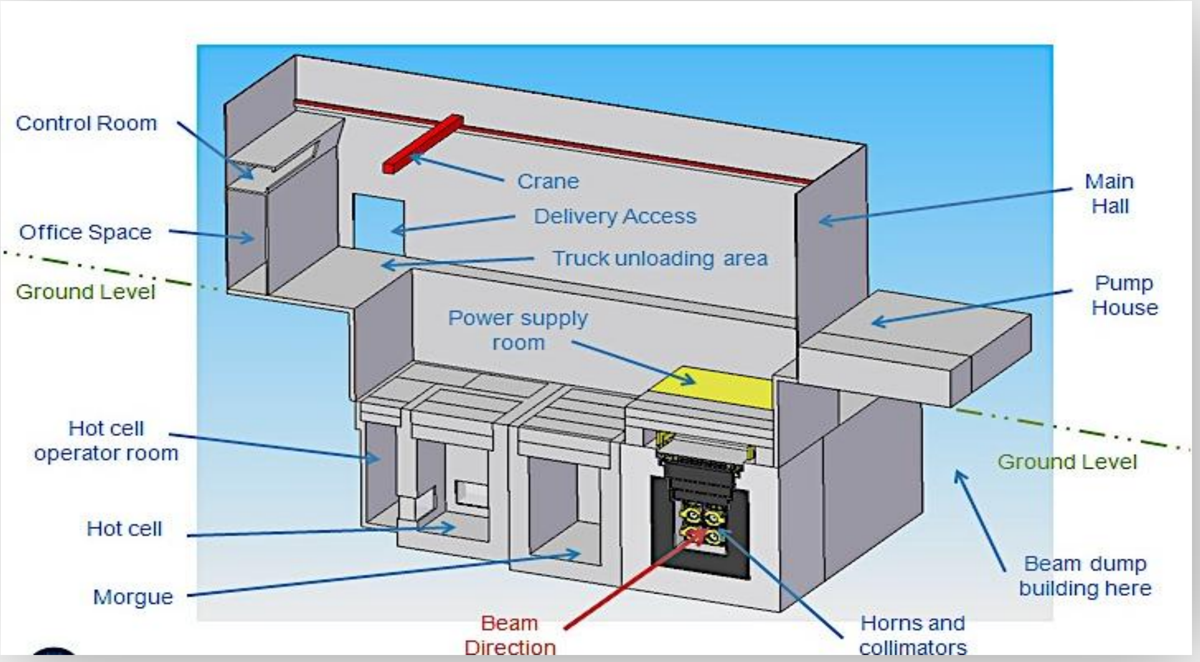
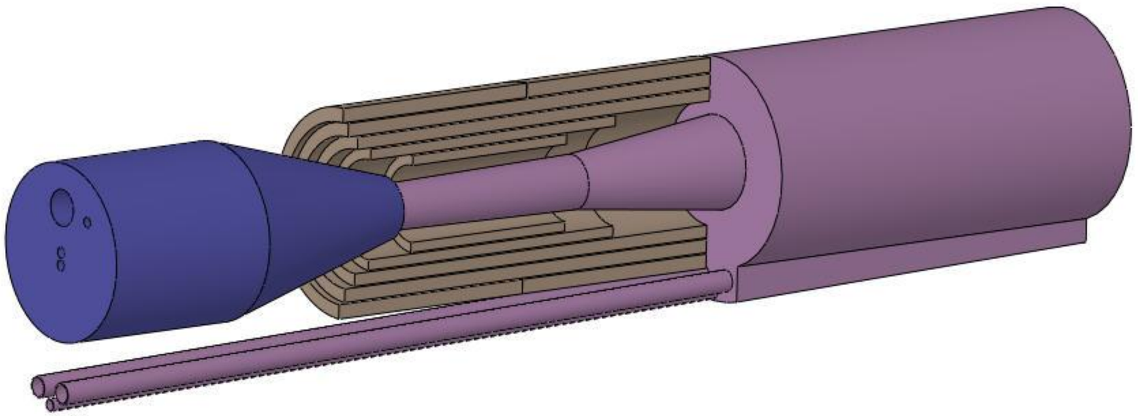



Target station concept for the SPL Super Beam, N. Vassilopoulos.

Modular design for the NF target, from H. Kirk's talk at IDS meeting (VT).



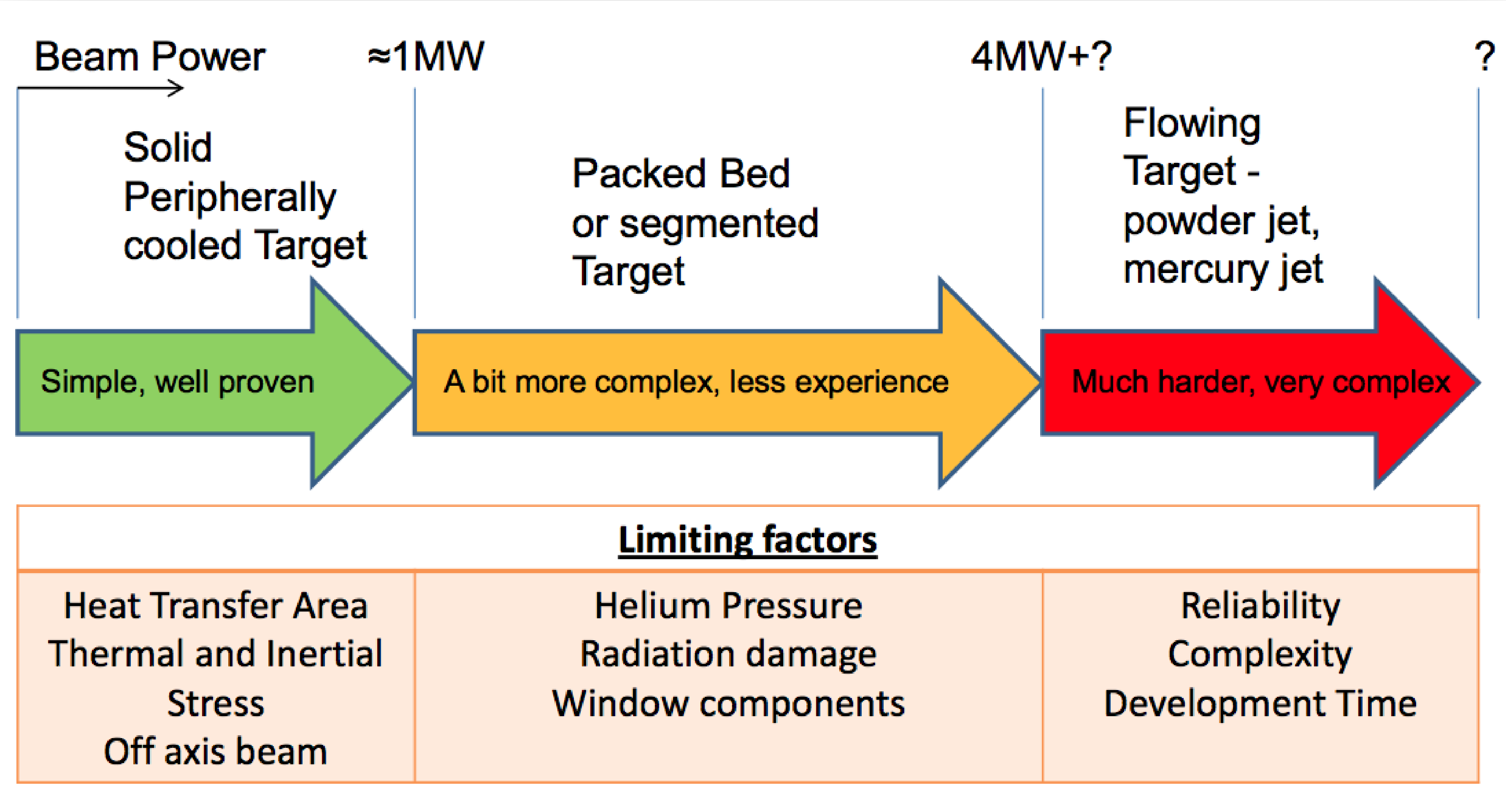
9) Proposed target systems are many, convergence?

Multiple designs required; different requirements for various applications.

Needs further study, no real convergence on the horizon.

1

N. Vassilopoulos.



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Multiple designs required; different requirements for various applications.

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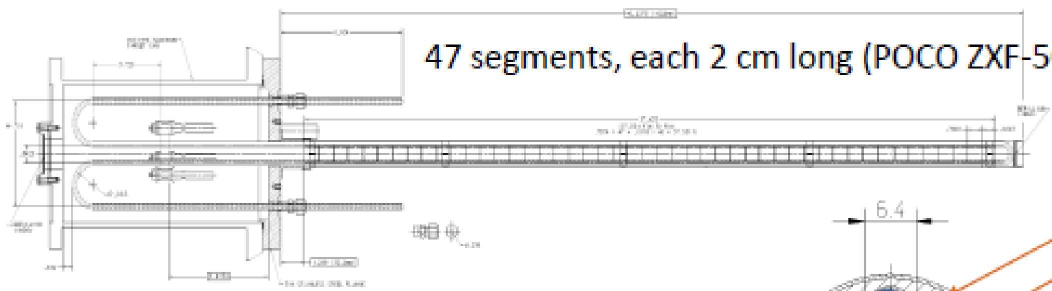
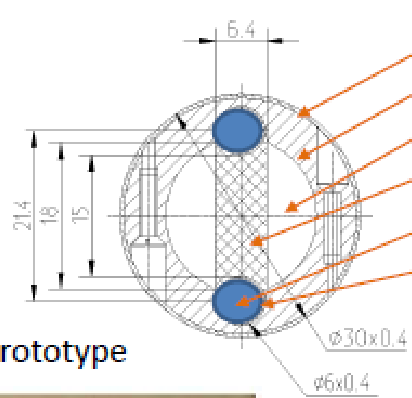
**2**

## Conceptual design of a NuMI-LE like target for LBNE for 700 kW operation

V. Papadimitriou's talk

47 segments, each 2 cm long (POCO ZXF-5Q)






The first Titanium-tube water cooling line prototype

Taking advantage of work done for the:

- 700 kW ANU-NOvA medium energy target
- R&D towards making the NuMI-MINOS low energy target more robust

July 24, 2012 NuFACT 2012 - Vaia Papadimitriou

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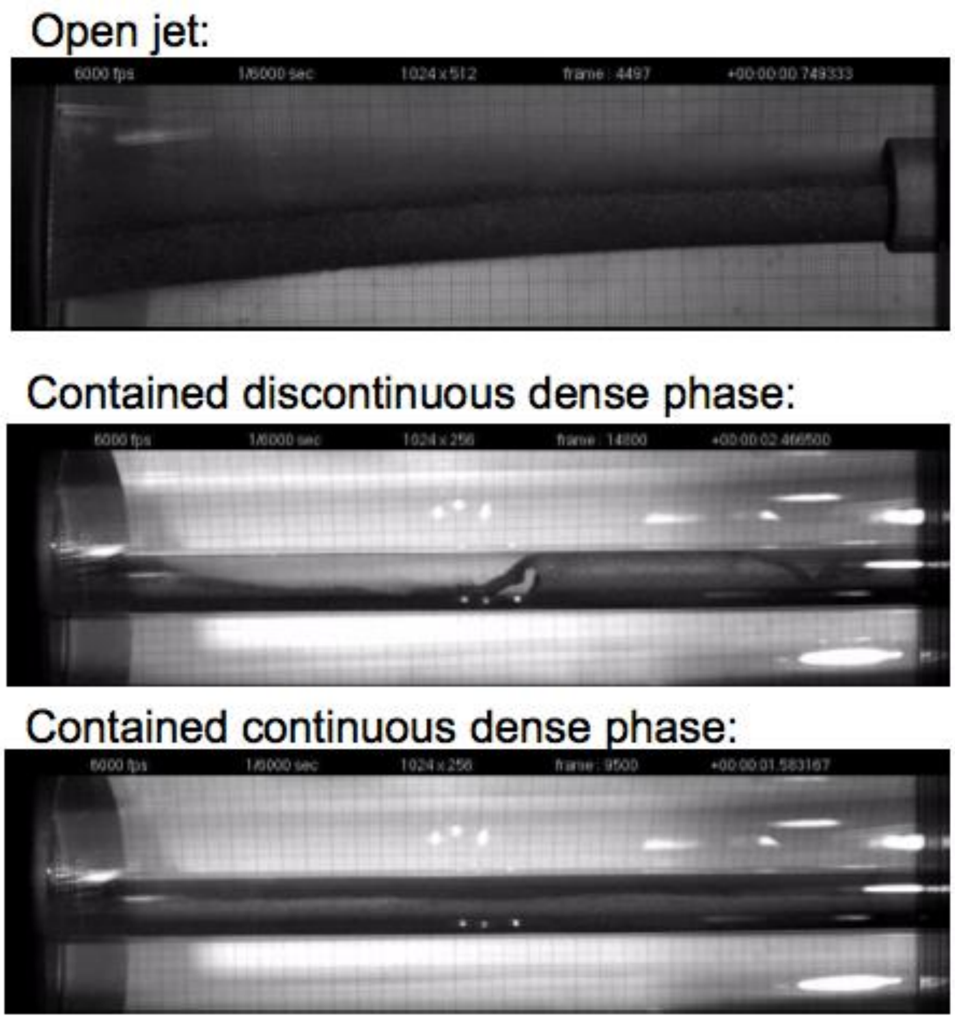
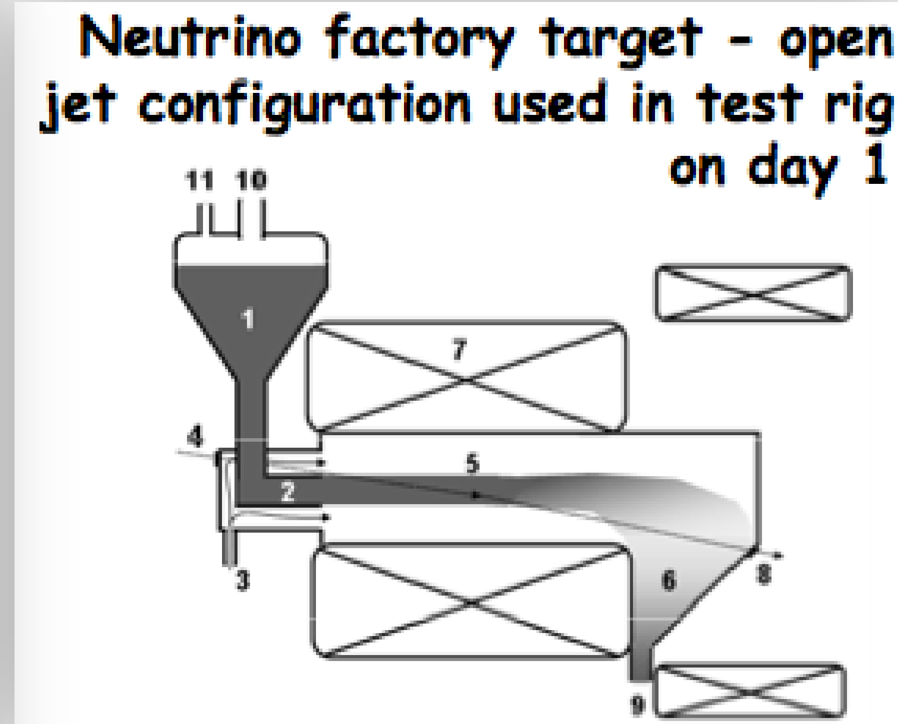
N. Vassilopoulos. **3**




Results of powder jet experiment at CERN




Powder jet schematic

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

Appropriate material studies under way.

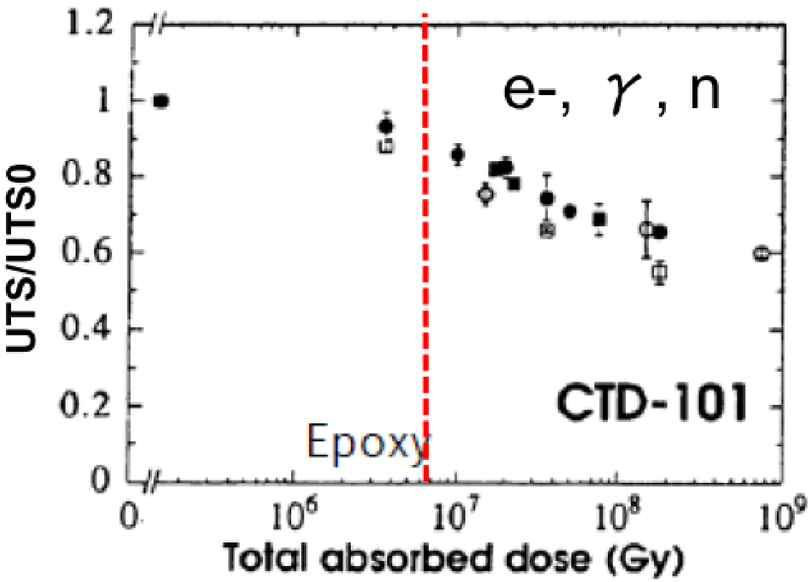
Important progress in experimental studies and simulations.

Very important, needs more study!

**1**

# Requirements. Absorbed dose to organic materials

Ultimate tensile strength degradation




7 MGy before 10% degradation of ultimate tensile strength (shear modulus).

also Radiation Hard Coils, A. Zeller et al, 2003, http://supercon.lbl.gov/WAAM

Mu2e apparatus lifetime is 5 years

Current LHC limit 25-50 MGy over the lifetime

From M.Eisterer, RESMM12 Workshop, February 2012, Fermilab

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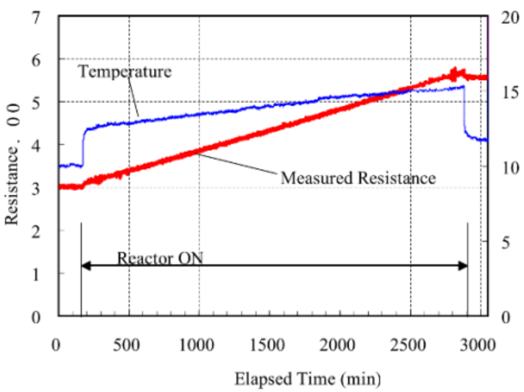
**2**

## RRR degradation per DPA

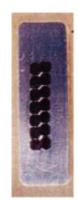



- Kyoto University Reactor
- 5MW max. thermal power
- Cryostat close to reactor core
- Sample cool down to 10K - 20K
- CERNOX sensors
- Fast neutron flux $1.4\times10^{15}$ $n/m^2/s$ (>0.1MeV) @1MW
- 45 hours

M.Yoshida

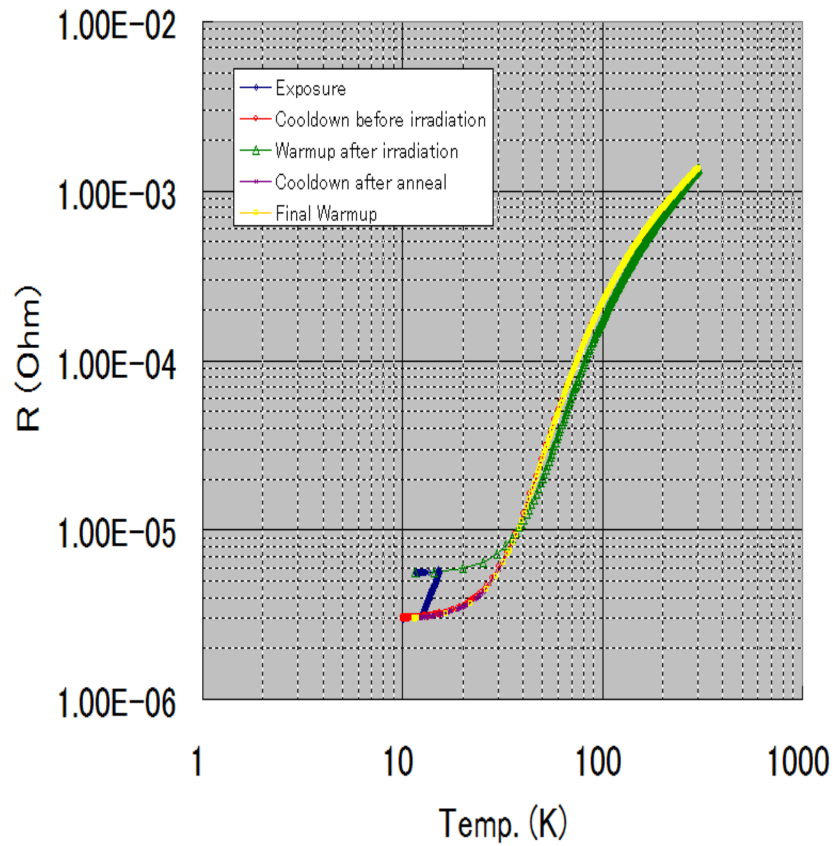
$3.1\mu\Omega \rightarrow 5.7\mu\Omega$
induced $\rho_i = 0.056$ nΩ.m
for $2.3\times10^{20}$ $n/m^2$
(>0.1MeV)
Mu2e Expected fluence
(>0.1 MeV) ~ $2.5\times10^{21}$ $n/m^2$

- Aluminum stabilizer sample
- 1mmx1mmx70mm



11

V. Pronskikh, Radiation damage, NuFact'12, July 23-28, Williamsburg




From V. Pronskikh's talk

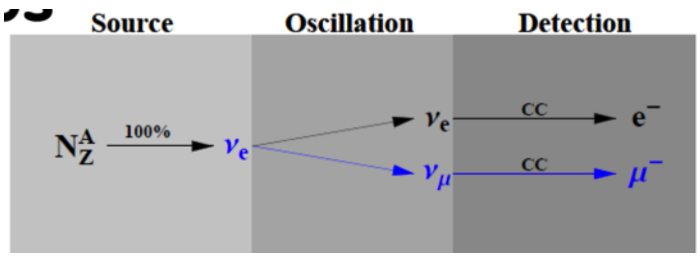
Fully recovered with room temp. anneal, from M. Lamm's talk

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

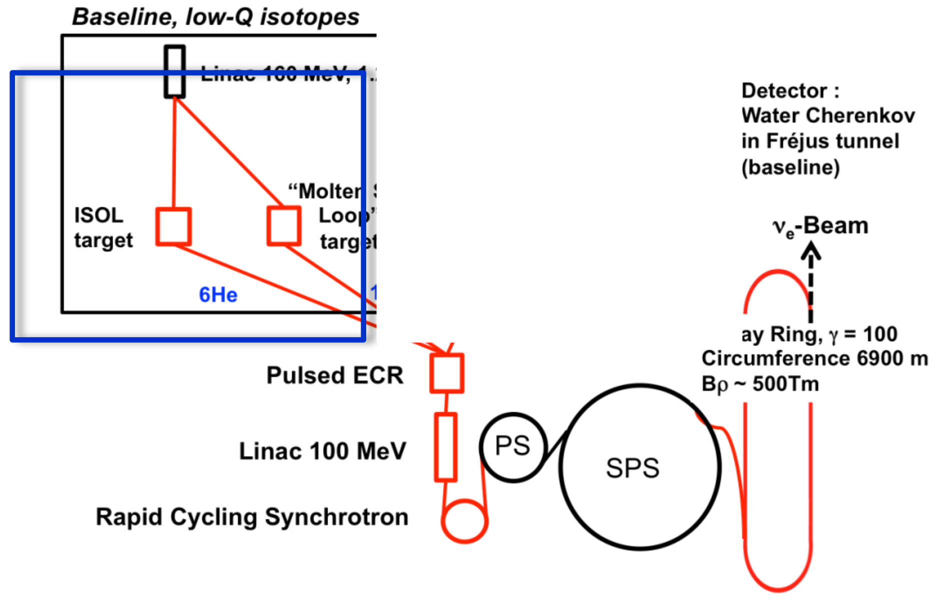
Yes, Conceptual designs of more than one scheme exist

Answer is YES, but the implementation of BB is seriously limited by the LHC operation and there is no clear cost advantage comparing to NF (EUROnu conclusion). Proposed to be eliminated from the list.

- The Low-Q option $^{6}He/^{18}Ne$ (CERN-Fréjus) is the baseline








| Isotope | $^{6}$He | $^{18}$Ne |
|---|---|---|
| Prod. | ISOL(n) | ISOL |
| Beam | SPL(p) | Linac4(p) |
| I [mA] | 0.07 | 6 |
| E [MeV] | 2000 | 160 |
| P [kW] | 140 | 960 |
| Target | W/BeO | $^{23}$Na, $^{19}$F |
| r [$10^{13}$/s] | 5 | 0.9 |

**CERN Specific, Beta Beam favored by $\theta_{13}$ results**

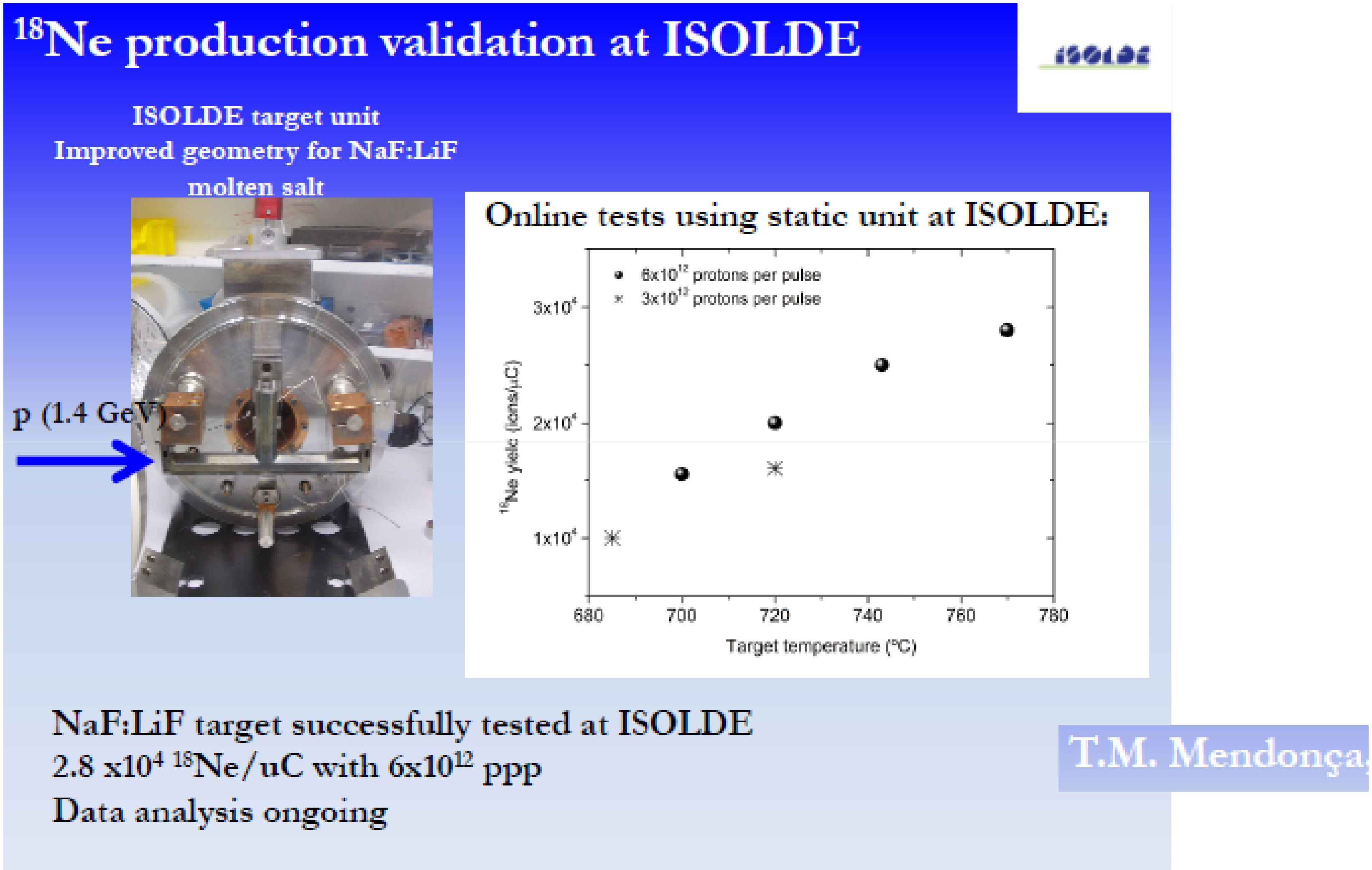
D.Duchesneau

Decay Ring: $B\rho$ ~ 500 Tm, B = ~7 T, C = ~6900 m, $L_{ss}$ = ~2500 m, $\gamma$ = 100, all ions

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

Tested experimentally.

Huge experimental progress, answer seems to be around the corner.

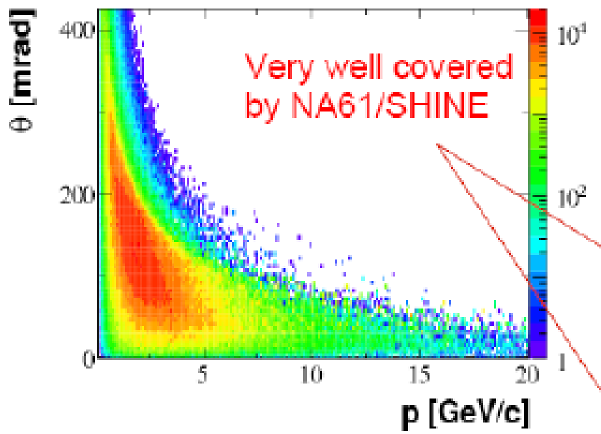


13) Modeling of pion production complete?

Agreement between two models/codes (MARS and FLUKA) consistent within 10-20% with the HARP data. **1**

Uncertainties at 20% level seem to persist, may be awaiting the implementation into the MC generators?. Needs to be looked at.

# NA61 p + C -> $\pi^+$ + X @ 30 GeV

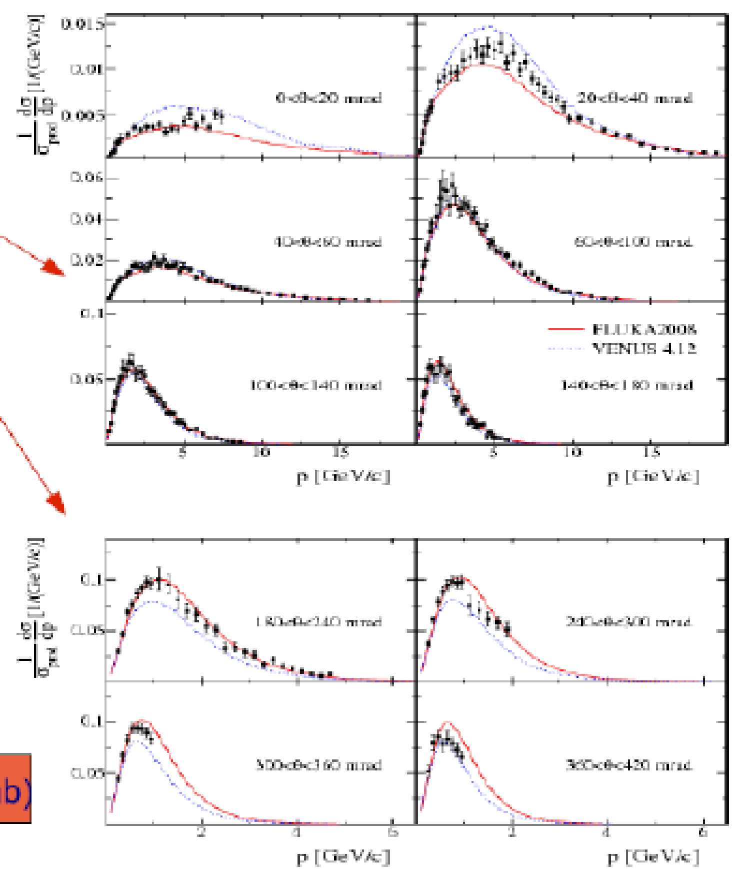



T2K beam simulation: the {p,θ} distribution for $\pi^+$ weighted by the probability that their decay produces a $\nu_\mu$ passing through SK

NA61/SHINE measurements

$\sigma_{prod}$ (pC@31GeV/c)= 229.3 ± 1.9 ± 9.0 (mb)

*Published in PRC 84 (2011) 034604*




From A. Bravar's talk

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



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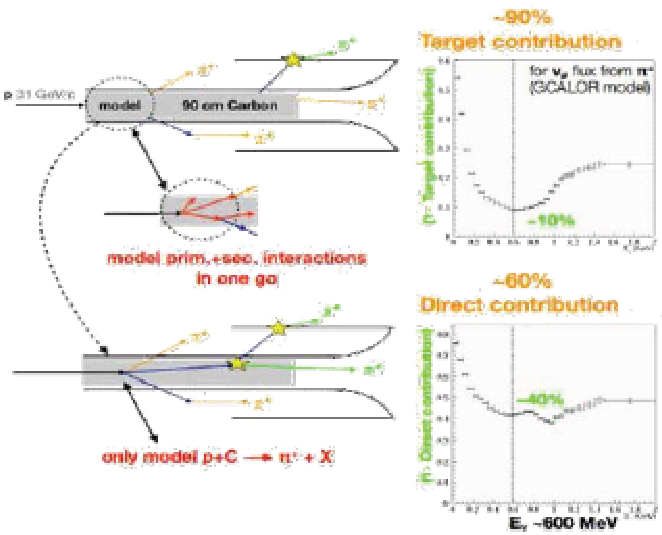
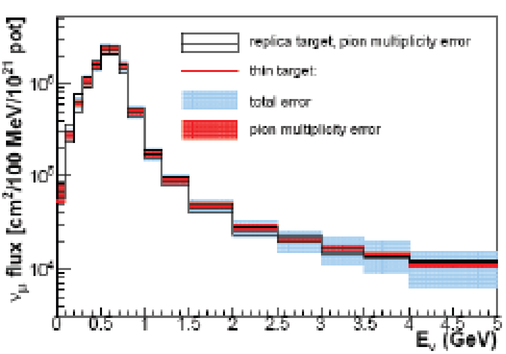
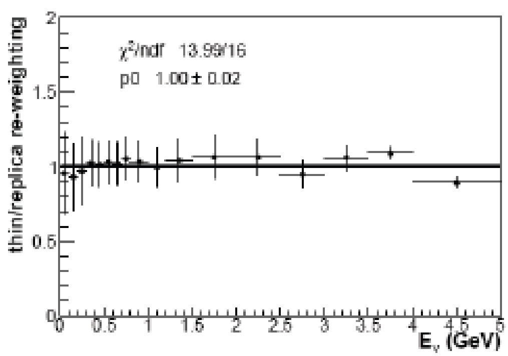
# ν Flux Prediction with T2K Replica Target




- Hadron multiplicities are parametrized at the target surface (no vertex reconstruction)
- Analysis in bins of ($p$, $\theta$, $z$)
- Re-weighting multiplicities of hadrons exiting the target in the T2K beam simulation
- Model dependence is reduced down to 10% as compared to 40% in the standard approach

From A. Bravar's talk




comparison ν flux predictions
thin target
replica target

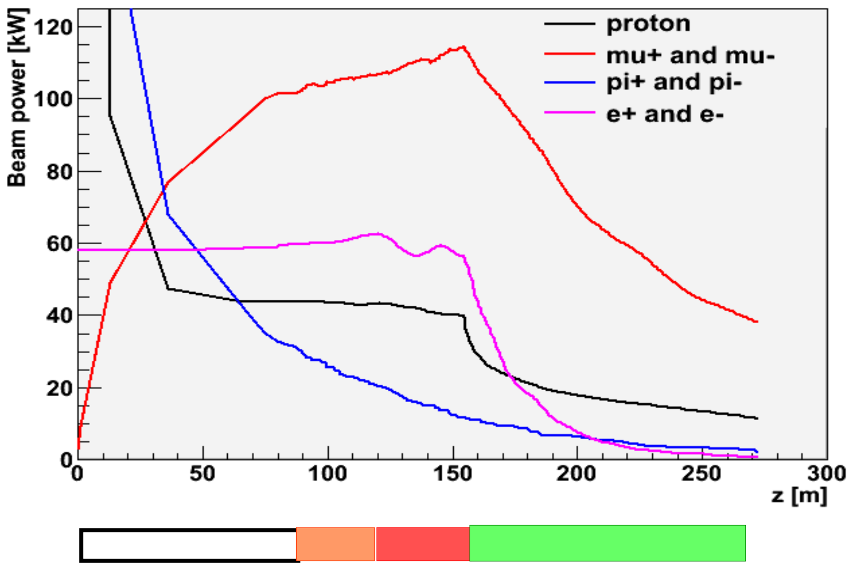
in very good agreement
just an accident or real ?

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

Quite significant. They are modelled accurately; adequate shielding provided.

SIGNIFICANT! Progress in many systems, but mitigating scenarios need to be improved.

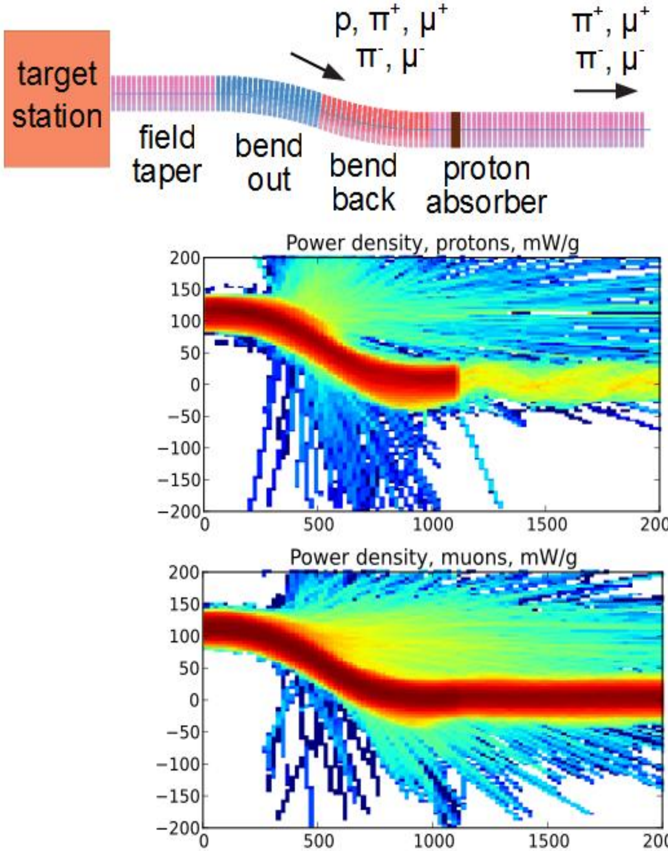
Beam losses along Front End of NF




Want “Hands-on” maintenance

hadronic losses < 1W/m

Booster, PSR criteria




Power density, protons, mW/g

Power density, muons, mW/g

Power density in the NF front end chicane

From D. Neuffer’s talk

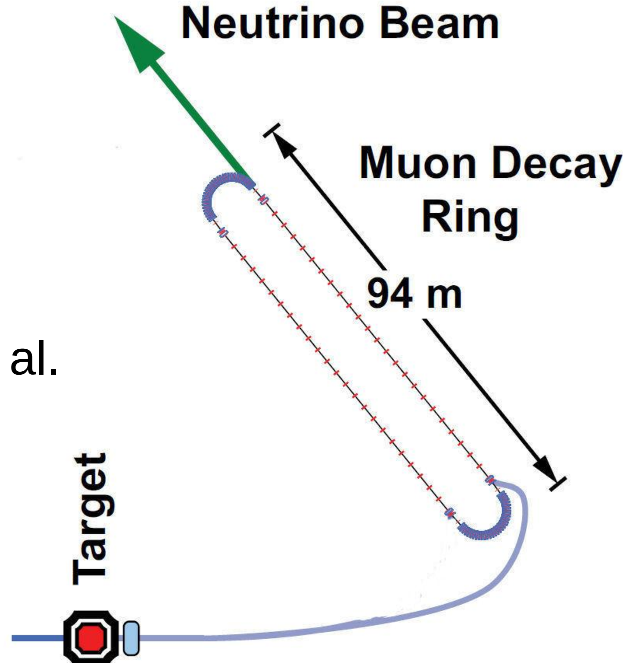
15) Feasibility of mini-neutrino factory (low energy/intensity storage ring for short baseline measurement of cross-sections)

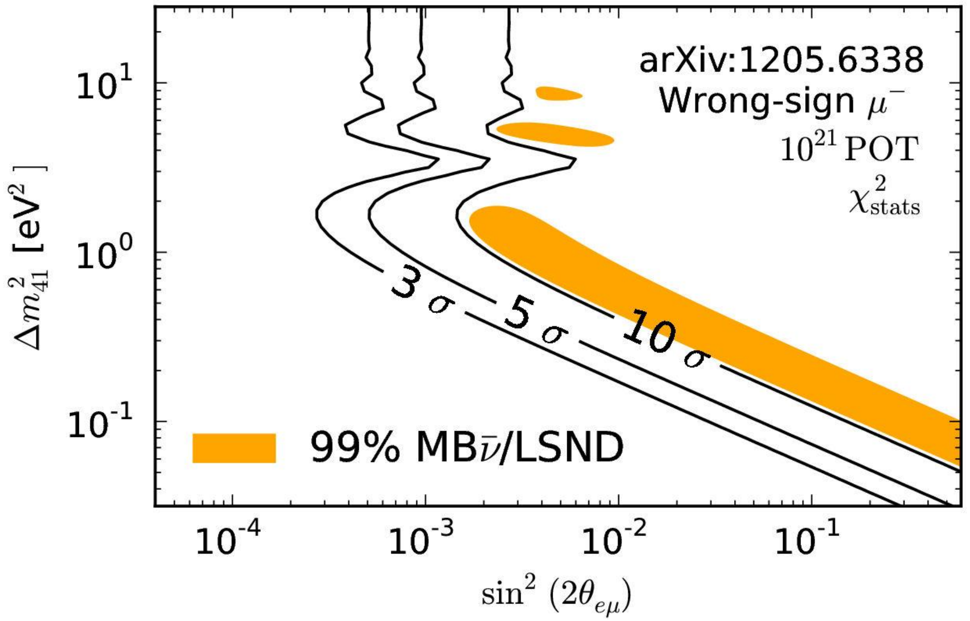
VLENF conceptual design with large acceptance decay ring, Scaling FFAG option

GREAT PROGRESS! Further substantial progress expected soon.

nuSTORM Concepts

A. Bross et al.




Sensitivity to test the MiniBoone/LSND anomaly

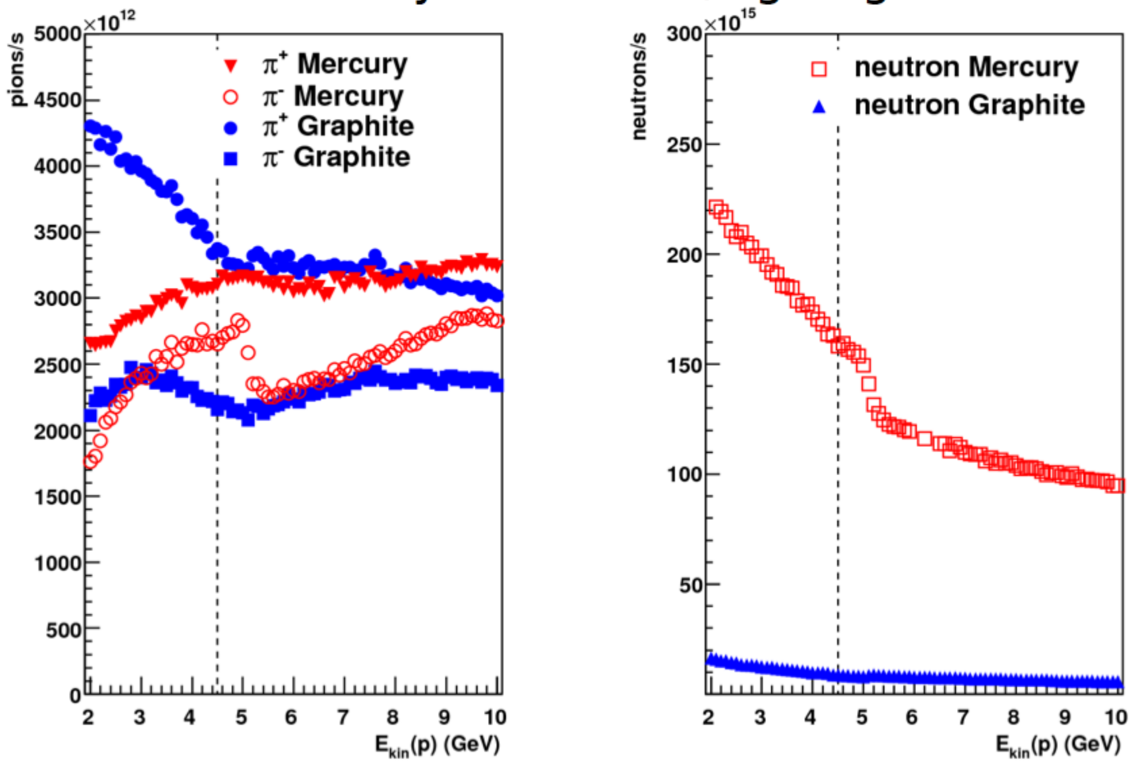
Also Mu-storage ring presents only way to measure $\nu_\mu$ & $\nu_e$ & anti- ($\nu_\mu$ & $\nu_e$) x-sections in the same experiment.

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

Needs exploring.

Needs exploring.

## Particle yields with C/Hg targets




Up to 15 times more neutrons per proton in Hg than Gr

Less radiation with Gr

Comparable particle yields

A. Longhin

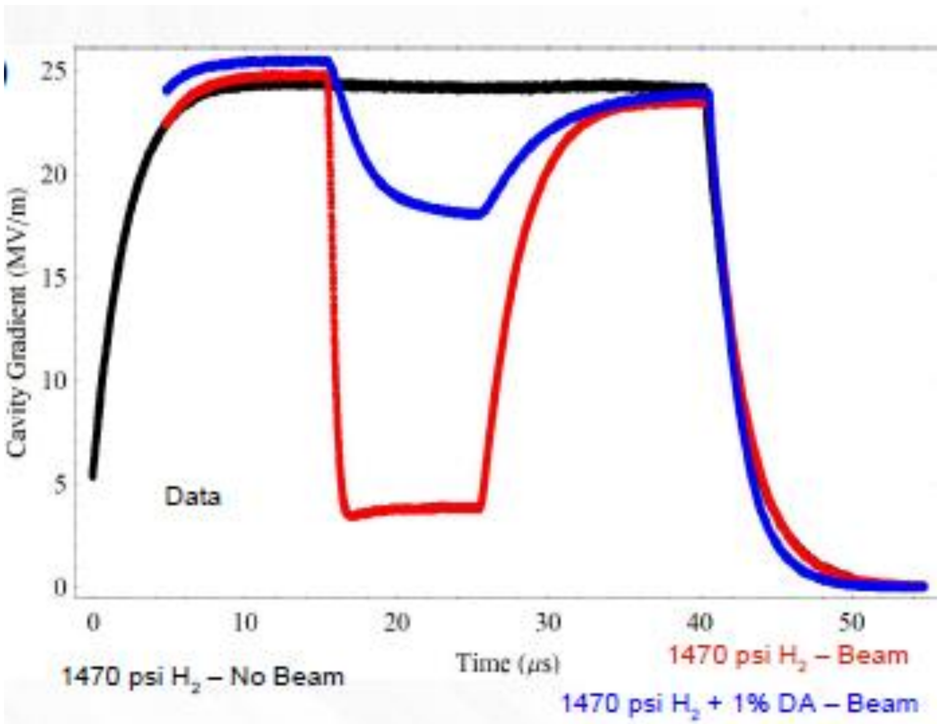
17) Operating high gradient normal conducting RF rf cavities in strong magnetic field; gradient degradation, effects of intense ionizing radiation traversing gas?

Proposed redefinition

17) Does the operation of RF cavities with high pressure gas solve the problem of RF breakdown in the magnetic field?

Further experimental program needed (LBNL and MTA at Fermilab).

Substantial progress has been achieved. More experimental studies needed, in particular addressing feasibility (engineering, safety, etc..)




- Energy loss in pure and doped Hydrogen is well understood
- HPRF cavity should operate in a Neutrino Factory
- HPRF cavity will probably work for a Muon Collider
- Further R&D is required to confirm feasibility

From Ben Freemire's talk

18) Given the complications of producing and capturing $^{8}Li$ and $^{8}B$, and the need for 5x higher intensity, is the cost-benefit ratio for this option really favorable?

Needs looking into…

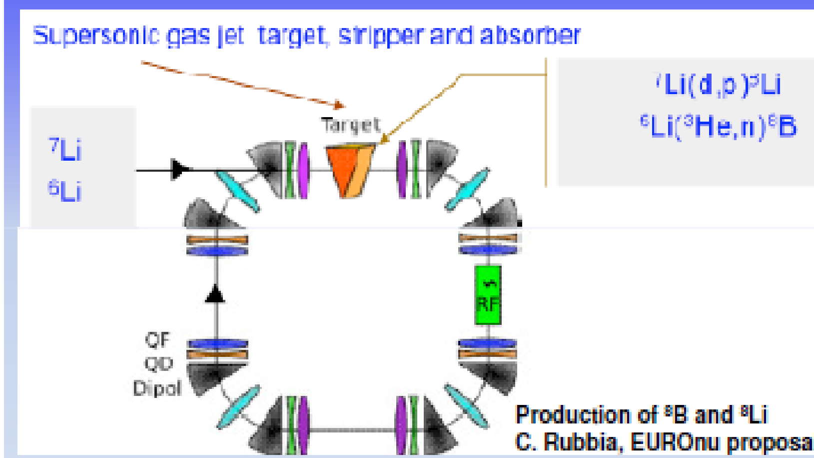
Progress, but more studies are required.

## High-Q isotopes: $^{8}B/^{8}Li$

Production of $^{8}B/^{8}Li$ using a compact ring

25 MeV Li beam interacts with gas-jet target (D or $^{3}He$) – inverse kinematics

Collection device to stop and transport ions to ECR ion source




Production of $^{8}B$ and $^{8}Li$
C. Rubbia, EUROnu proposal

Gas jet target:

- too high density would be needed ($10^{19}$ atoms/$cm^2$)
- vacuum problems

Alternative – use of solid or liquid target in direct kinematics feasibility under study

T.M. Mendonça

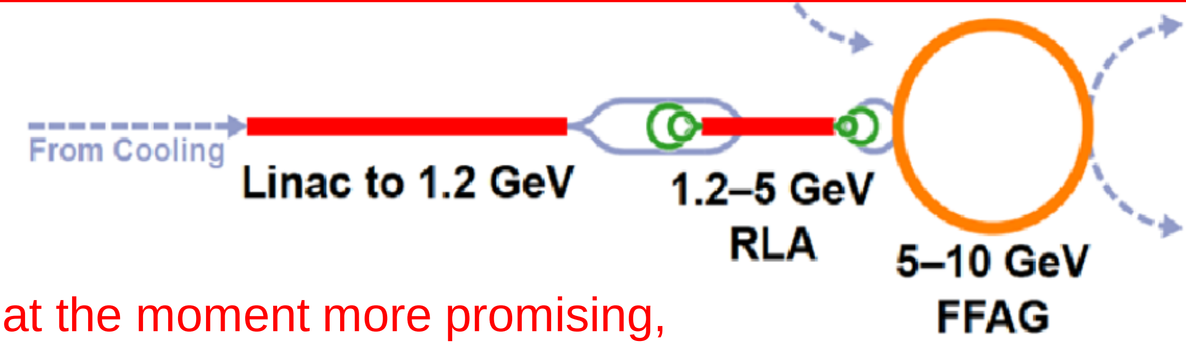
# Nufact12 ⇨ Nufact13 (new)

1. What is the most cost effective way to accelerate muons for the Neutrino Factory?

   Comment: the final decision may be influenced by the physics case.

## Option I


## Option II

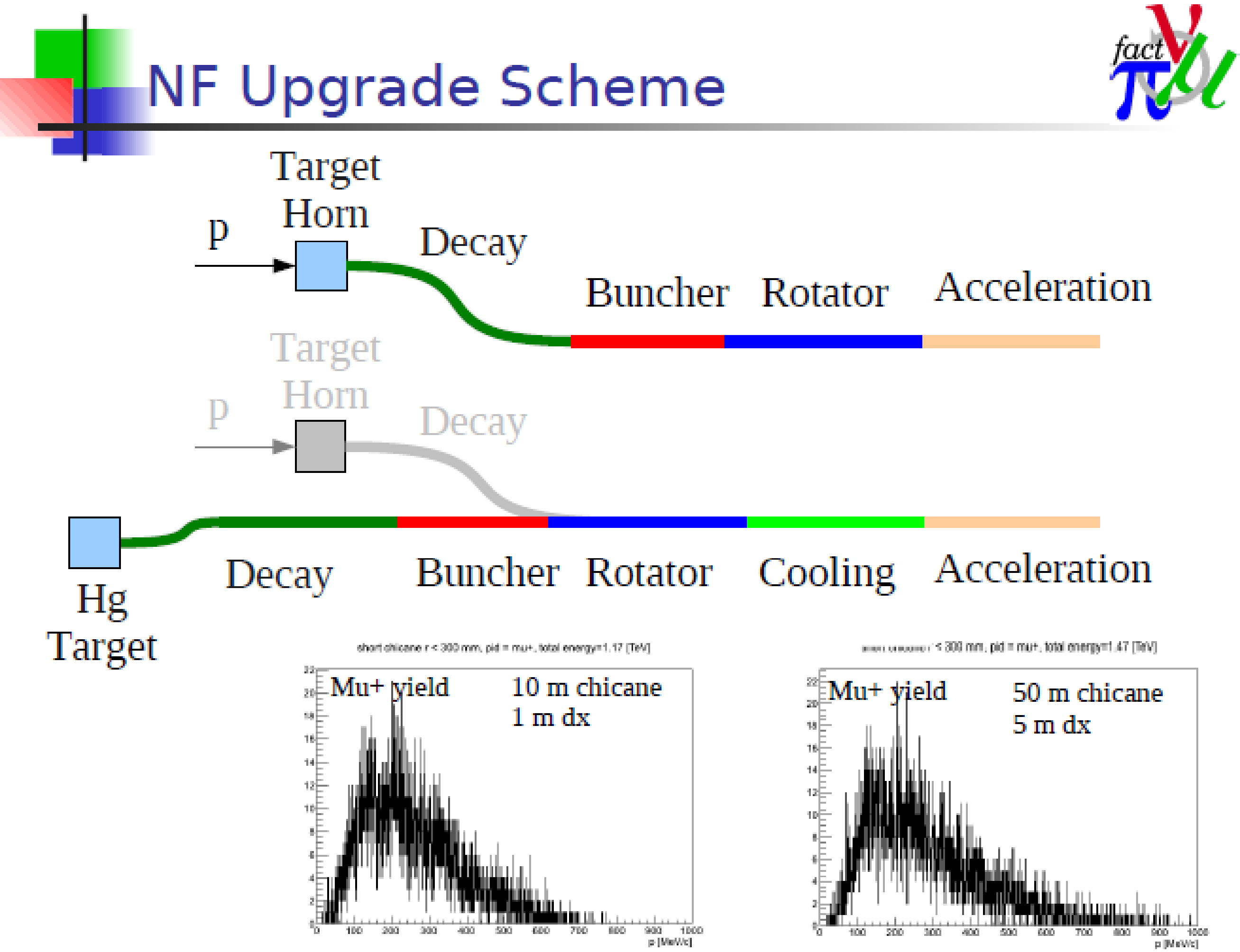



This option looks at the moment more promising, mostly due to the stronger physics case in the possible staging at the breaking point 4-5 GeV!

NuFact'12, A. Bogacz, M. Yoshida and J. Pasternak

# Nufact12 ⇨ Nufact13 (new)

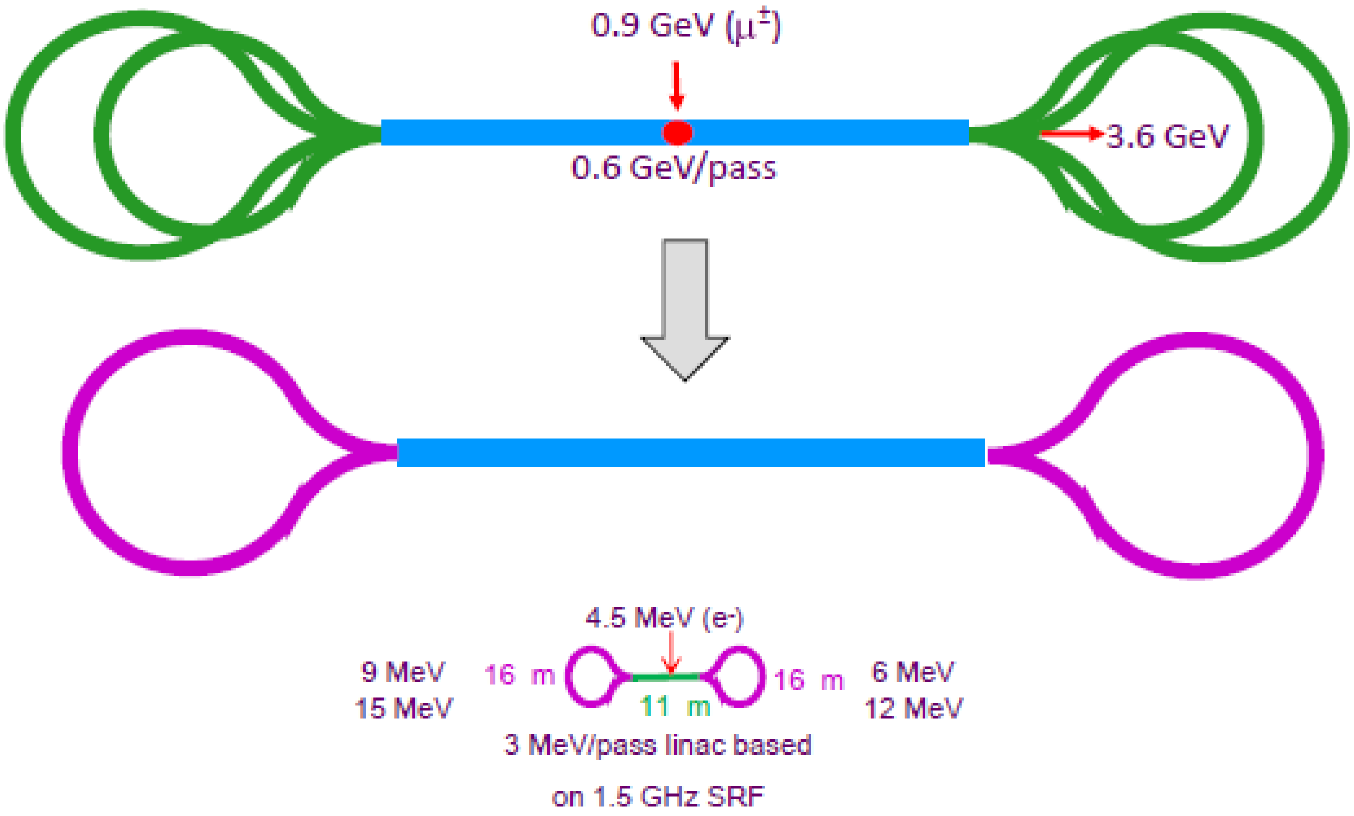
2. How the incremental scenario (staging) for the NF could be implemented?




Proposed by C. Rogers at PASI meeting 07.2012

# Nufact12 ⇨ Nufact13 (new)

3. Is the multi-pass arc RLA feasible (proposed electron model JEMMRLA)?

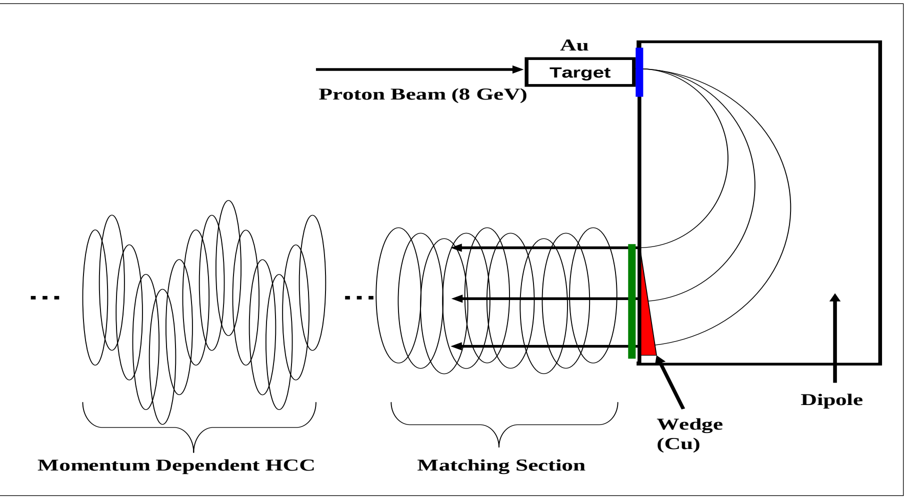



JEMMRLA,
Yves Roblin, Kevin Beard,
Alex Bogacz, Vasiliy Morozov

# Nufact12 ⇨ Nufact13 (new)

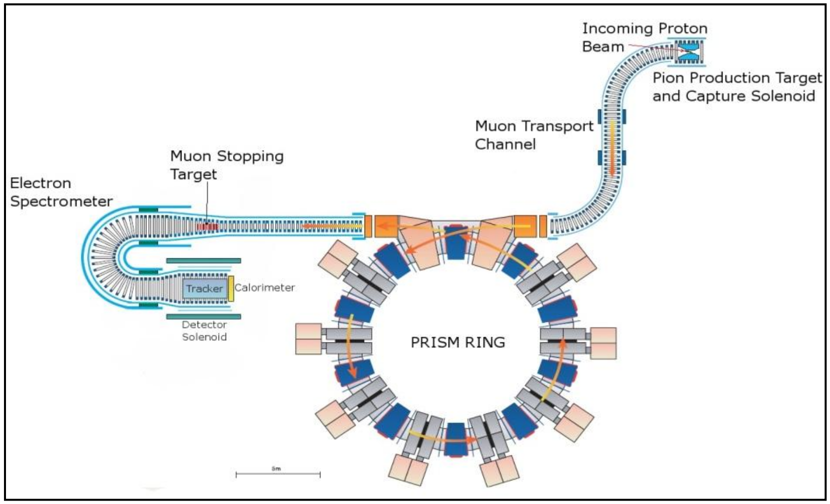
4. How to design next generation muon experiments based on future proton beams( like the ones expected at the Project-X)?

C. Ankenbrandt's et al. system




OR

PRISM - Phase Rotated Intense Slow Muon beam




OR COMBINATION OF BOTH?