International Contributions to Neutrino Factory and Muon Collider Studies

R&D Experiments:
- MERIT@CERN   MICE@RAL   EMMA@Daresbury Lab
- proton accelerator R&D (CERN SPL; RAL Front End study)
- FFAG (Kyoto), MuSiC (Osaka)

Other prospects:
- RF in magnetic field
- Muon Cooling Test Facility @ RAL
- + other, speculative ideas

Design Study: IDS-NF -- European contributions
- Plans, recent successes, comment on sites

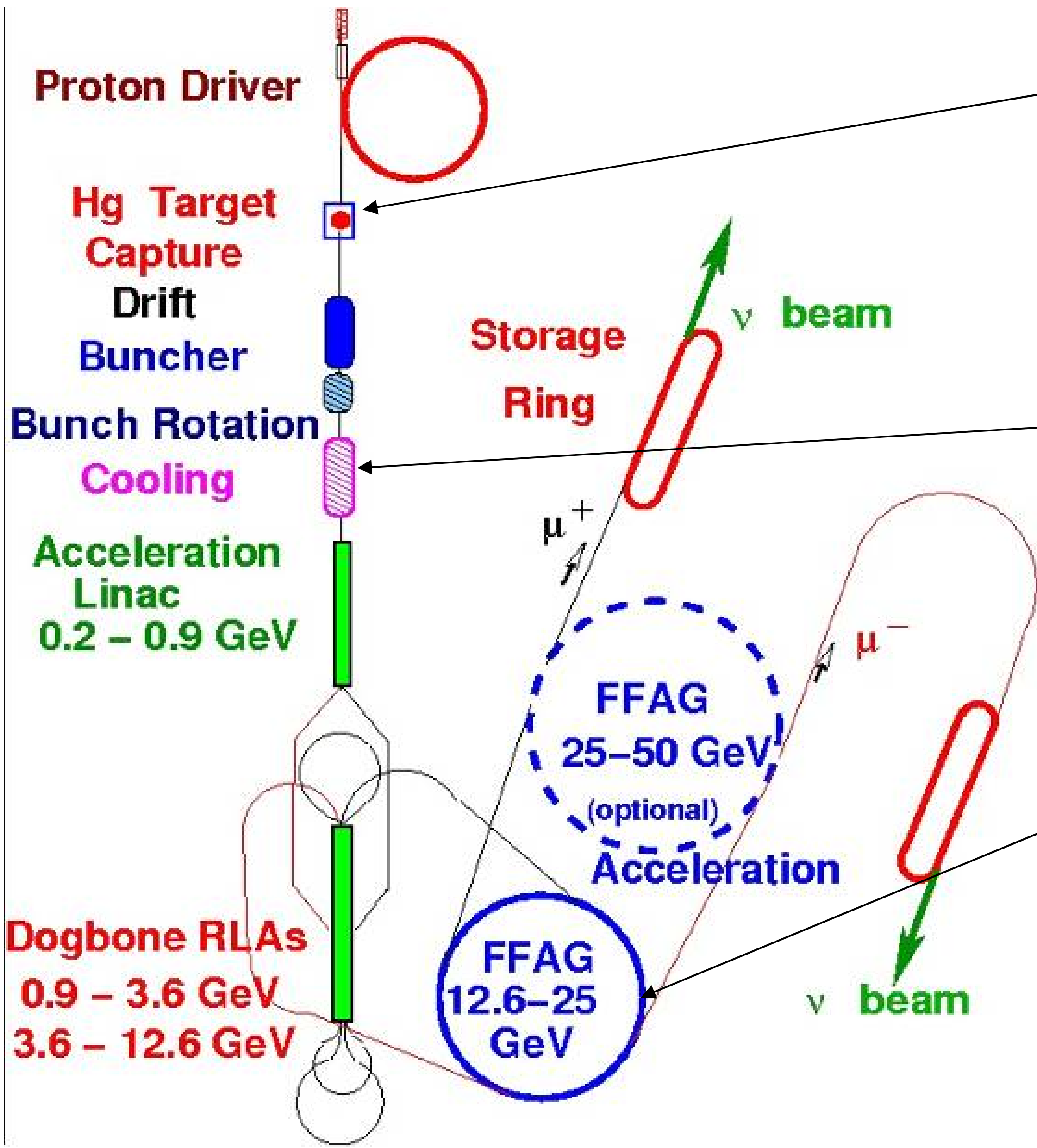
Detector R&D for neutrino factory

C.E.R.N. SPC report; what it said about neutrino factory

(Muon Collider?)

MERIT and MICE essential but have been discussed elsewhere – will mostly skip

Major challenges tackled by R&D expts

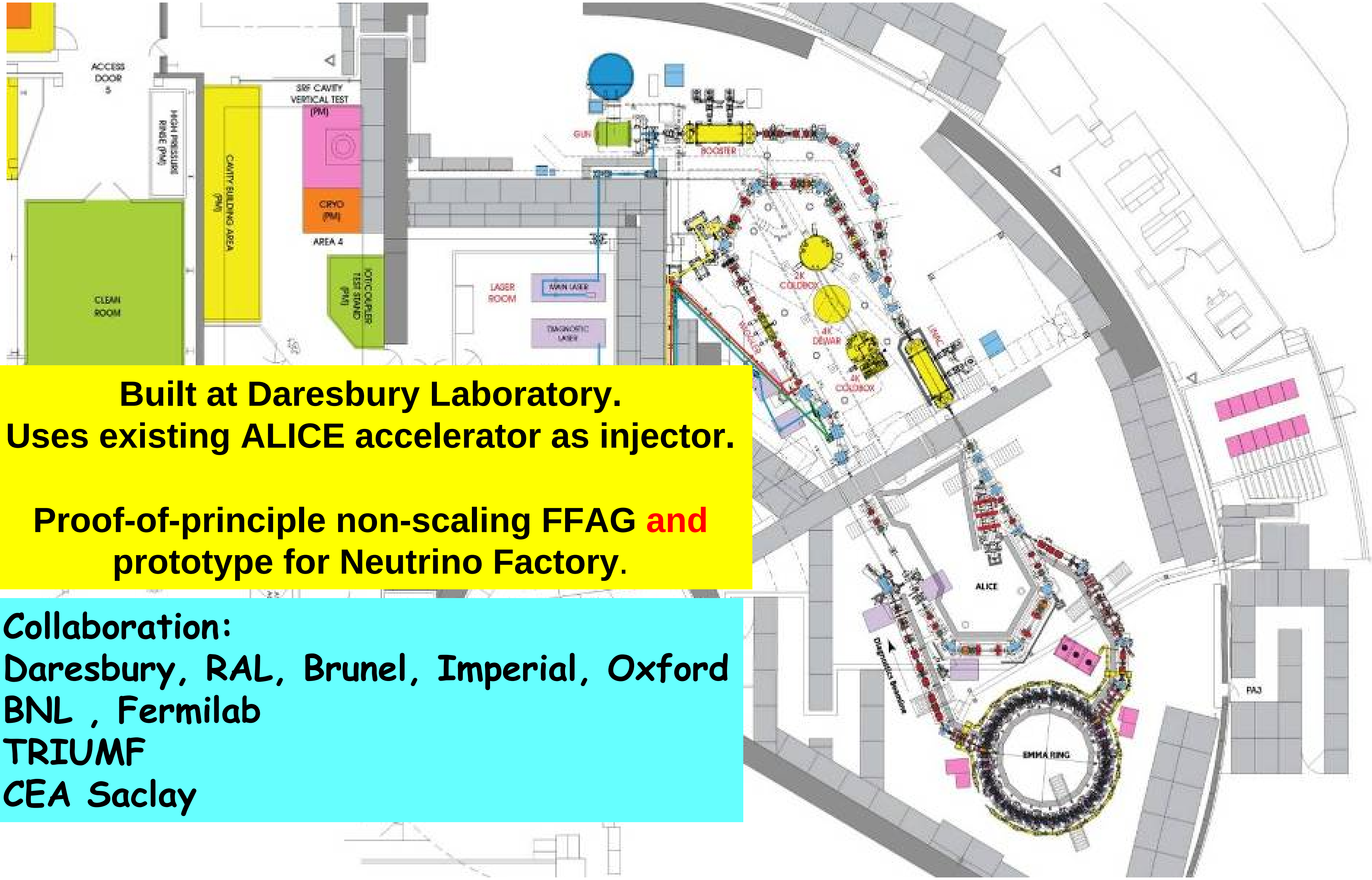


High-power target
. 4MW
. good transmission
MERIT experiment (CERN)

Fast muon cooling
MICE experiment (RAL)

Fast, large aperture accelerator (FFAG)
EMMA (Daresbury)

EMMA – Electron Model for Many Applications

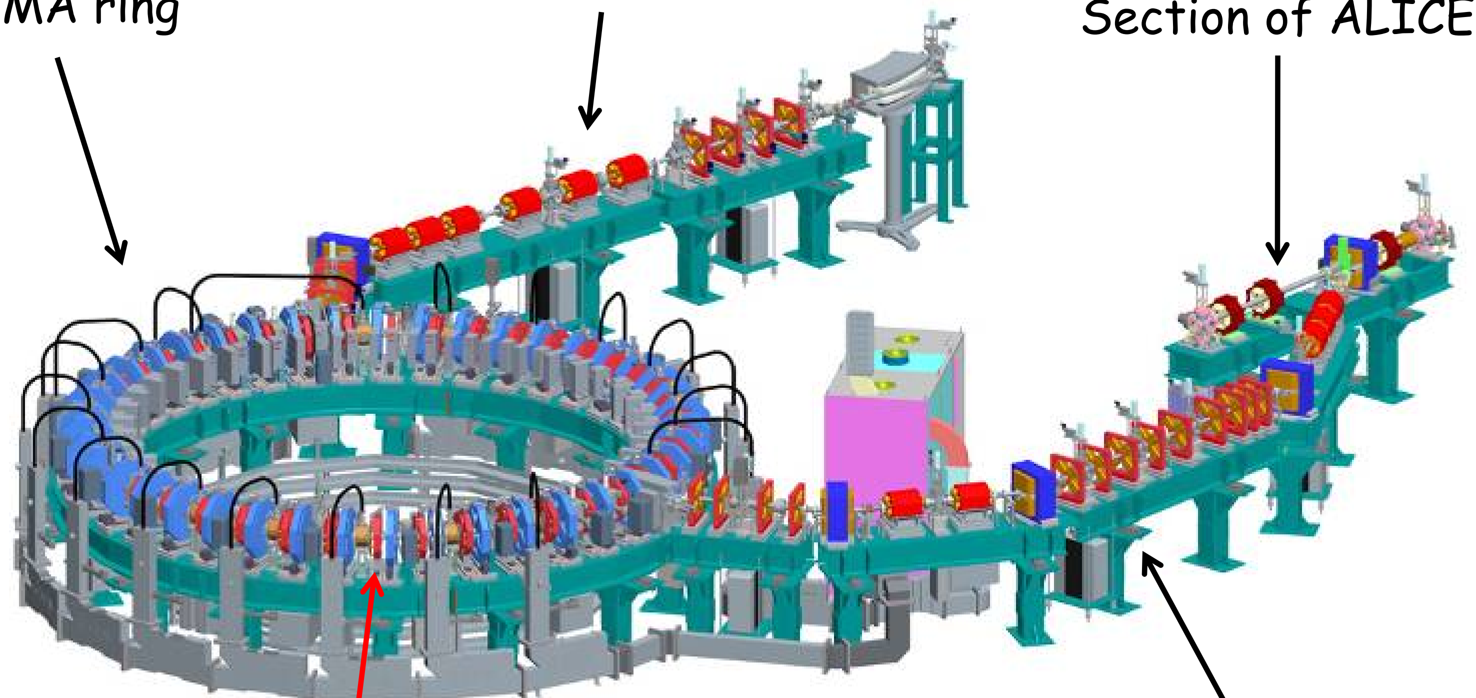


Built at Daresbury Laboratory.
Uses existing ALICE accelerator as injector.

Proof-of-principle non-scaling FFAG and prototype for Neutrino Factory.

Collaboration:
Daresbury, RAL, Brunel, Imperial, Oxford
BNL , Fermilab
TRIUMF
CEA Saclay

EMMA Layout



EMMA cell

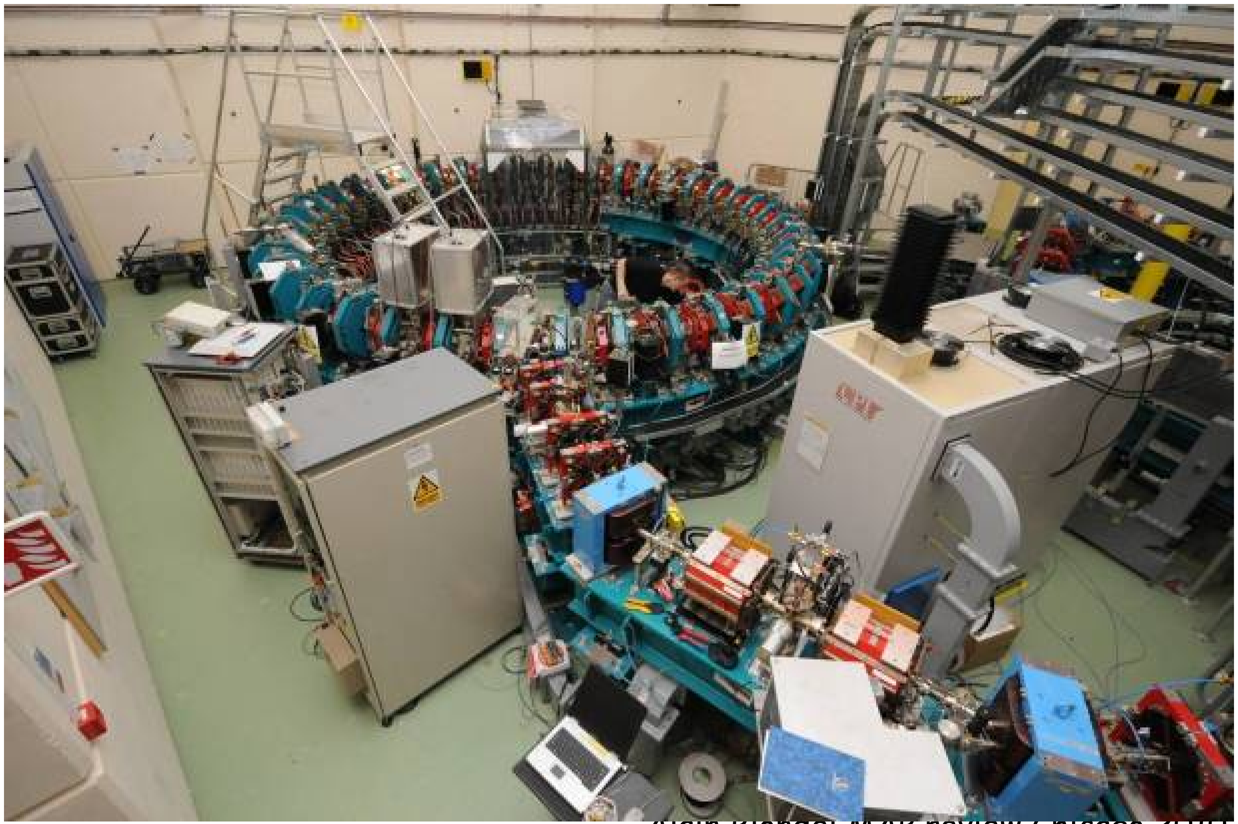
<u>EMMA ring:</u>

42 cells, each ~40cm long.
Mounted on 7 girders/sectors.
16.5m in circumference.

Status

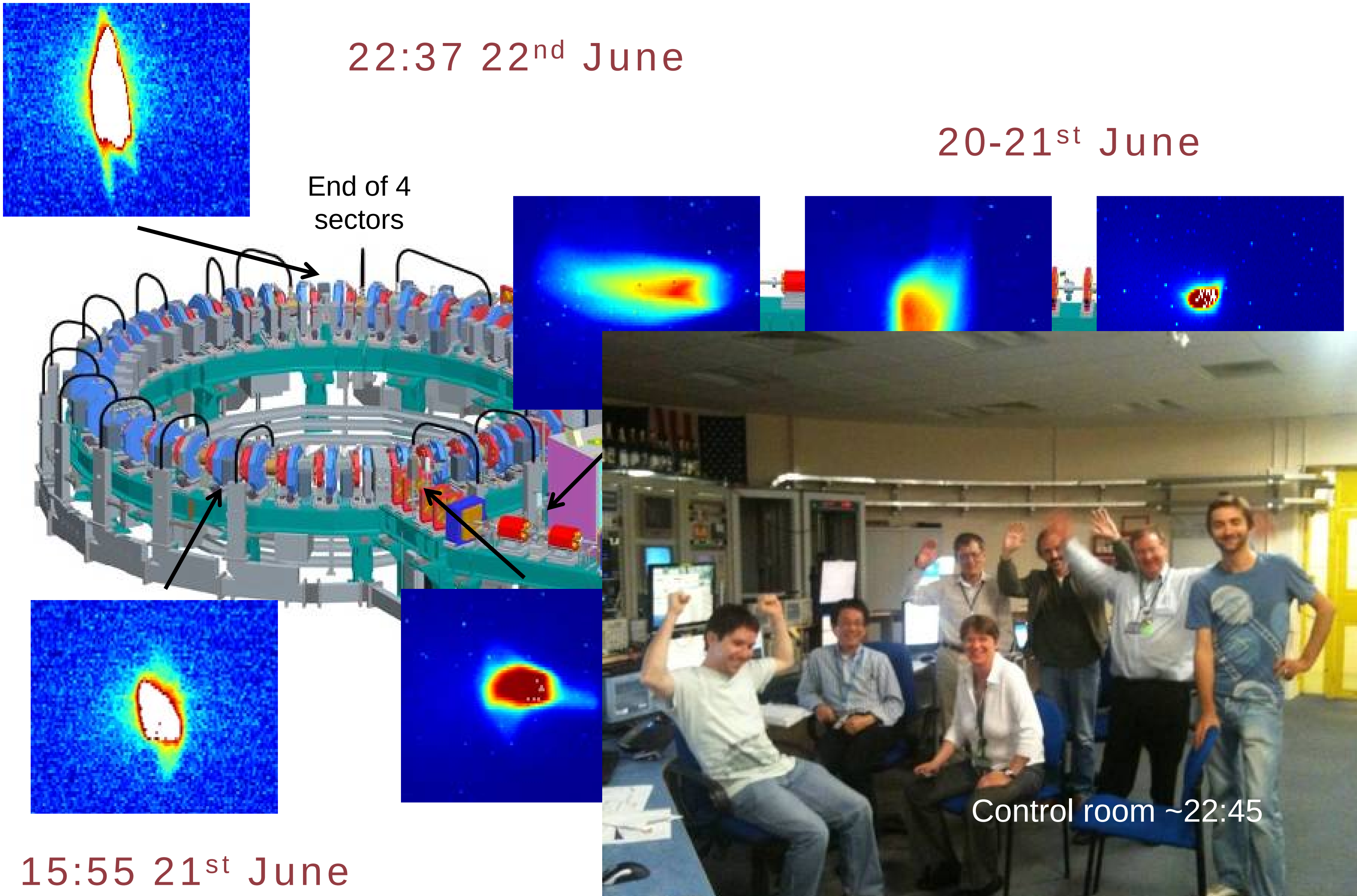
- Injection line: completed in March - 1st beam: 26th March
- Ring: "completed" 18th June - Start up: 20th June

All sectors in place, 1 not connected up.
Beam possible through 4: "4 sector commissioning"



EMMA on 18th June 2010

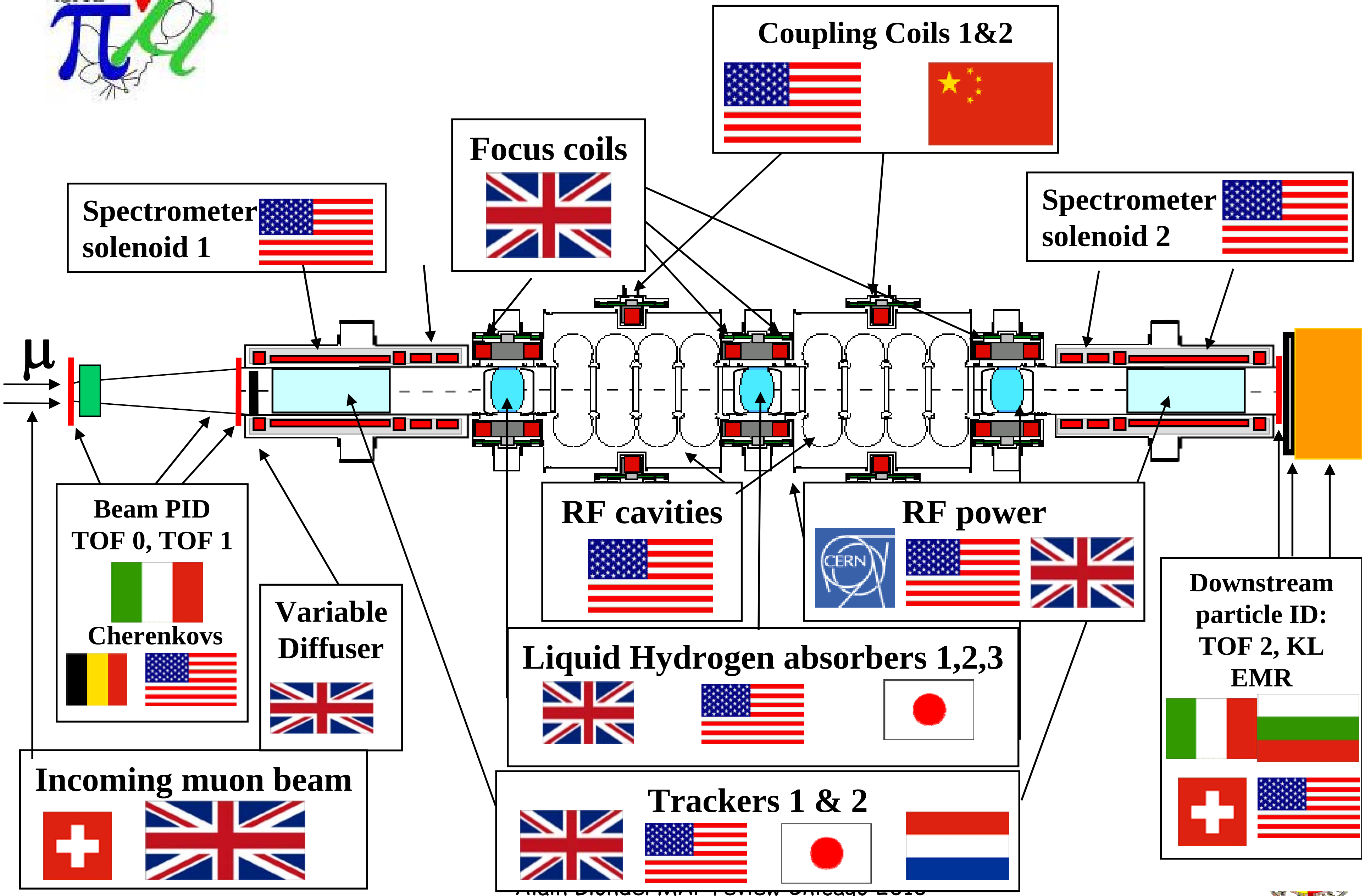
EMMA Start-up



EMMA Status

• 4 sector commissioning:	on-going
• Last sector cabling/connection to vacuum:	on-going
• Full ring commissioning:	on-going
• RF commissioning:	late August
• Acceleration:	~end August
• Diagnostics beam line part 1:	~Sep/Oct
• “ “ “ part 2:	~late 2010

MICE Collaboration across the planet



Beyond MICE -- Ideas for a « Muon Cooling Test Facility »

ONCE MICE will be completed, having equipped the MICE hall with
-- spectrometers, TOF and PID able to measure 6D emittance to 10^{-3}
-- 8 MW of 201MHz RF power
-- 23 MV of RF acceleration
-- Liquid Hydrogen infrastructure and safety

MICE can evolve into a Muon Cooling Test Facility
Some funding will be devoted to this within the FP7 program 'TIARA'

Such ideas were proposed:

A. with the existing MICE hardware test optics beyond Neutrino Factory study II:
non flip optics,
low-beta optics (down to 5 cm vs 42 cm nominal)
other absorber materials He, Li, LiH, etc.. and shapes (wedge, see P. Snopok)
LN2 cooled RF cavities

B. with additional hardware:
-- A. Skrinsky to test a lithium lens available at Novosibirsk
-- Muons Inc. proposed to test a helicoidal channel (MANX)
-- other cooling cells and possibly a more complete 6D Cooling Experiment

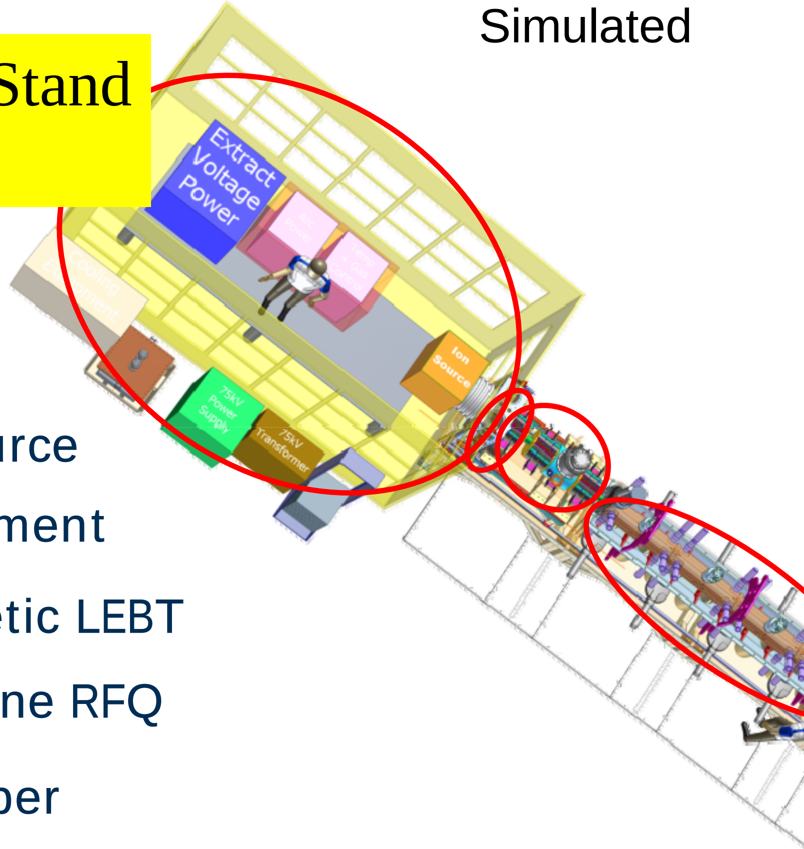
Proton driver R&D (RAL and CERN)

The Front End Test Stand (UK)

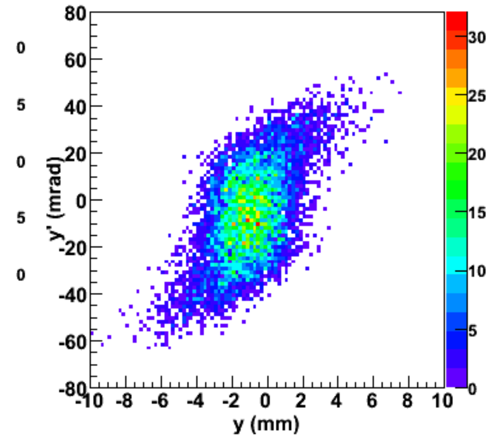
- A high power proton driver for the UKNF

1. High power H^- ion source
2. Laser profile measurement
3. Three solenoid magnetic LEBT
4. 324 MHz, 3 MeV, 4 vane RFQ
5. MEBT and beam chopper
6. Beam dump

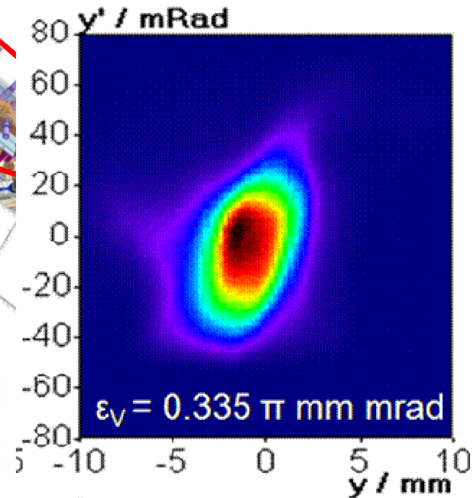
ISIS, Astec, ICL, Warwick, Royal Holloway, Pays Vasco Frackfurt TU

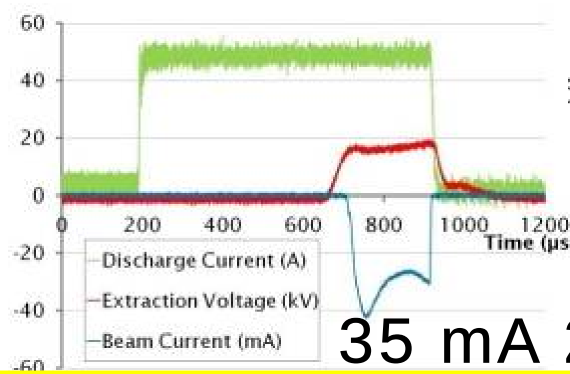


Simulated



Measured



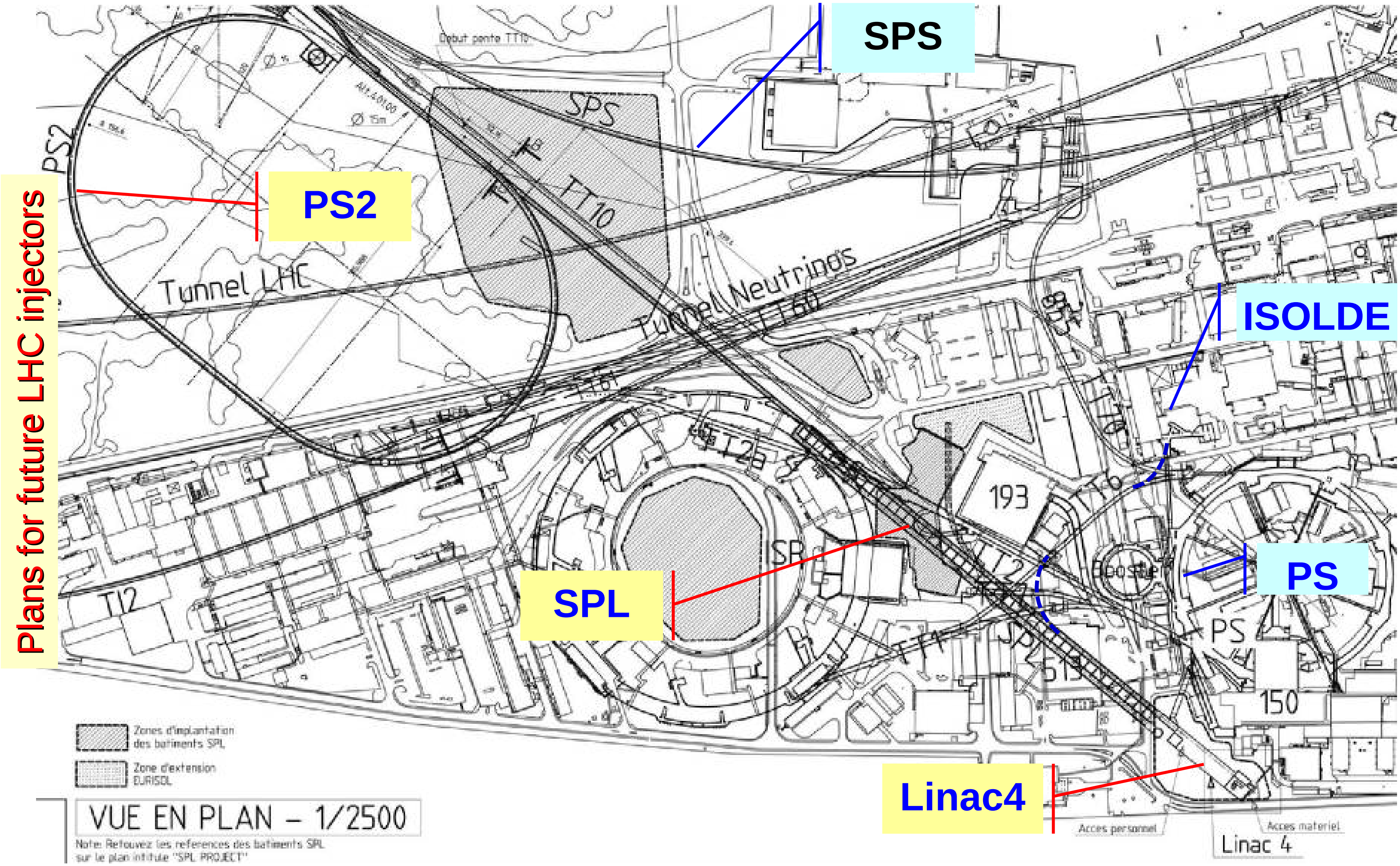


1st FETS Beam April 2009

35 mA 200 μs 50 Hz

Also: LINAC IV at CERN under construction as part of LHC!

CERN SPL and PS2 Site layout



High Power SPL (beyond LHC)

Beam characteristics of the main options

	Option 1	Option 2
Energy (GeV)	2.5 or 5	2.5 and 5
Beam power (MW)	2.25 MW (2.5 GeV) or 4.5 MW (5 GeV)	5 MW (2.5 GeV) and 4 MW (5 GeV)
Rep. frequency (Hz)	50	50
Protons/pulse (x 10^{14})	1.1	2 (2.5 GeV) + 1 (5 GeV)
Av. Pulse current (mA)	20	40
Pulse duration (ms)	0.9	1 (2.5 GeV) + 0.4 (5 GeV)

Plans for future LHC injectors

Faster rep. rate ⇒ new power supplies, more cooling etc.

2 x beam current → 2 x nb. of klystrons etc .

Until Jan 2010 a 4 GeV/ 200 kW SPL was baseline option for LHC injector upgrade. Emphasis now on understanding upgrades to SPS and booster. R&D on high power SPL will continue however.

Muon research in Japan

MUSIC at Osaka University (Kuno-san group)

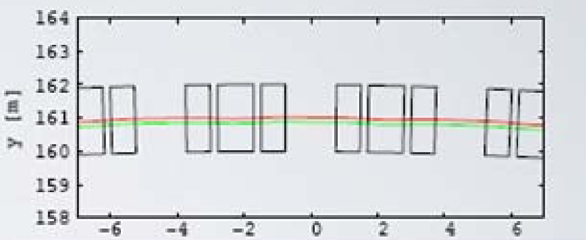
FFAG studies at Kyoto (Mori-san Group)

COMET experiment at JPARC (see back-up slides)

Lattice type	FDF triplet
Injection/extraction energy	3.6/12.6 GeV
RF frequency	200 MHz
Number of turns	6
RF peak voltage (per turn)	1.8 GV
Synchronous energy	8.04 GeV
Mean radius	~160.9 m
B_{max}(@ 12.6 GeV)	3.9 T
Field index k	1390
Total orbit excursion	14.3 cm
Harmonic number h	675
Number of cells	225
Long drift length	~1.5 m
Horiz. phase adv. per cell	85.86 deg.
Vert. phase adv. per cell	33.81 deg.

Table I - Example of 3.6 to 12.6 GeV muon scaling FFAG ring parameters.

6



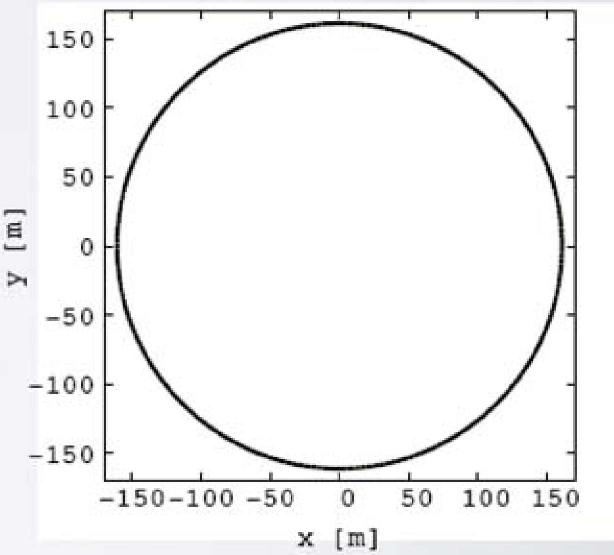
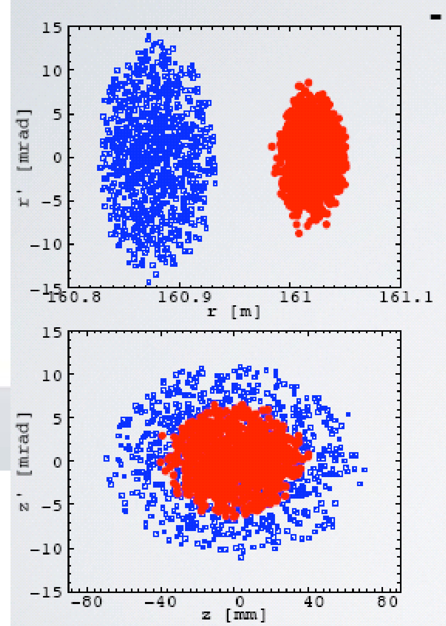
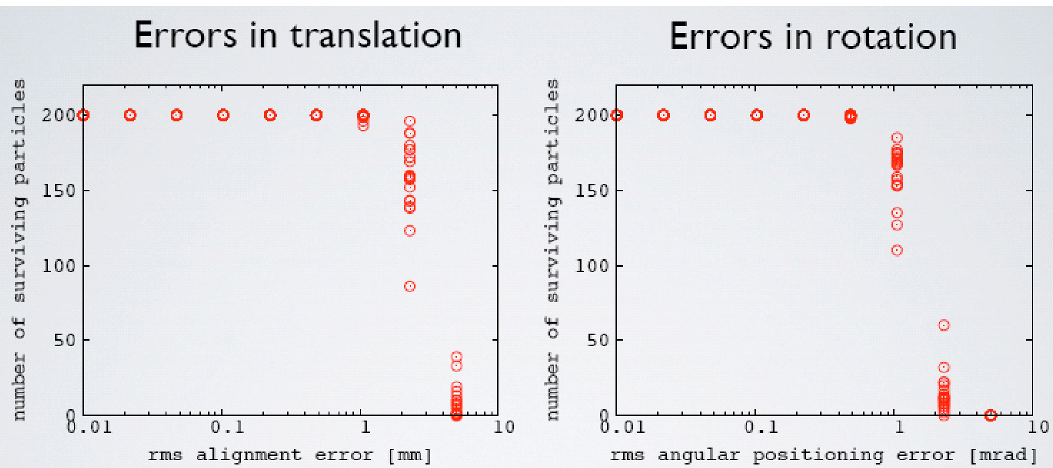


Figure 3 - Ring layout.

Studies of a 3.6 - 12.6 GeV Scaling FFAG -- Kyoto --



Figures 8 - Initial (blue) and final (red) particles distribution in the horizontal (top), and vertical (bottom) phase space.

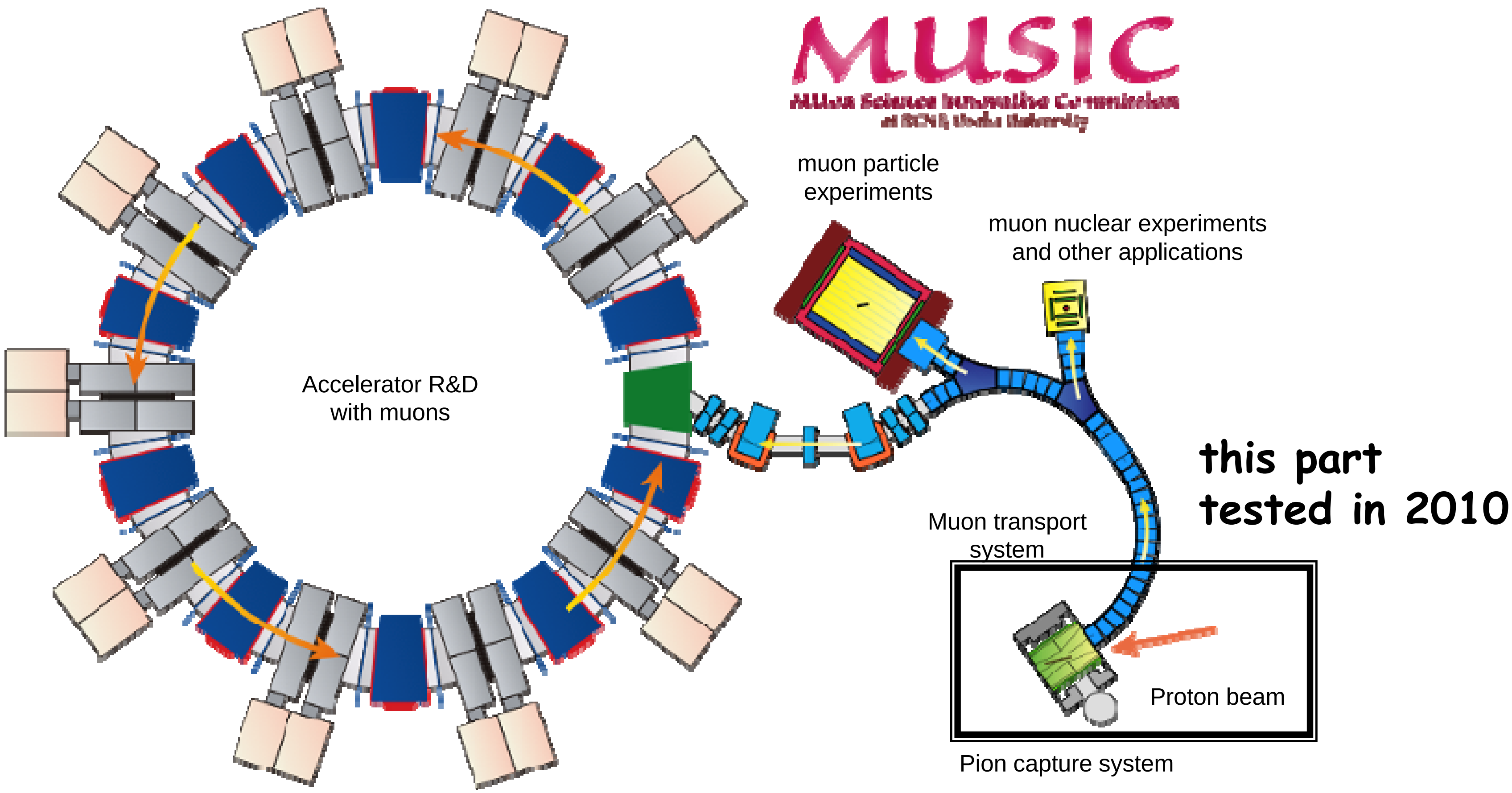


Figures 10 - Number of surviving particles depending on the rms error. 20 different lattices have been generated and tested for each value of rms error.

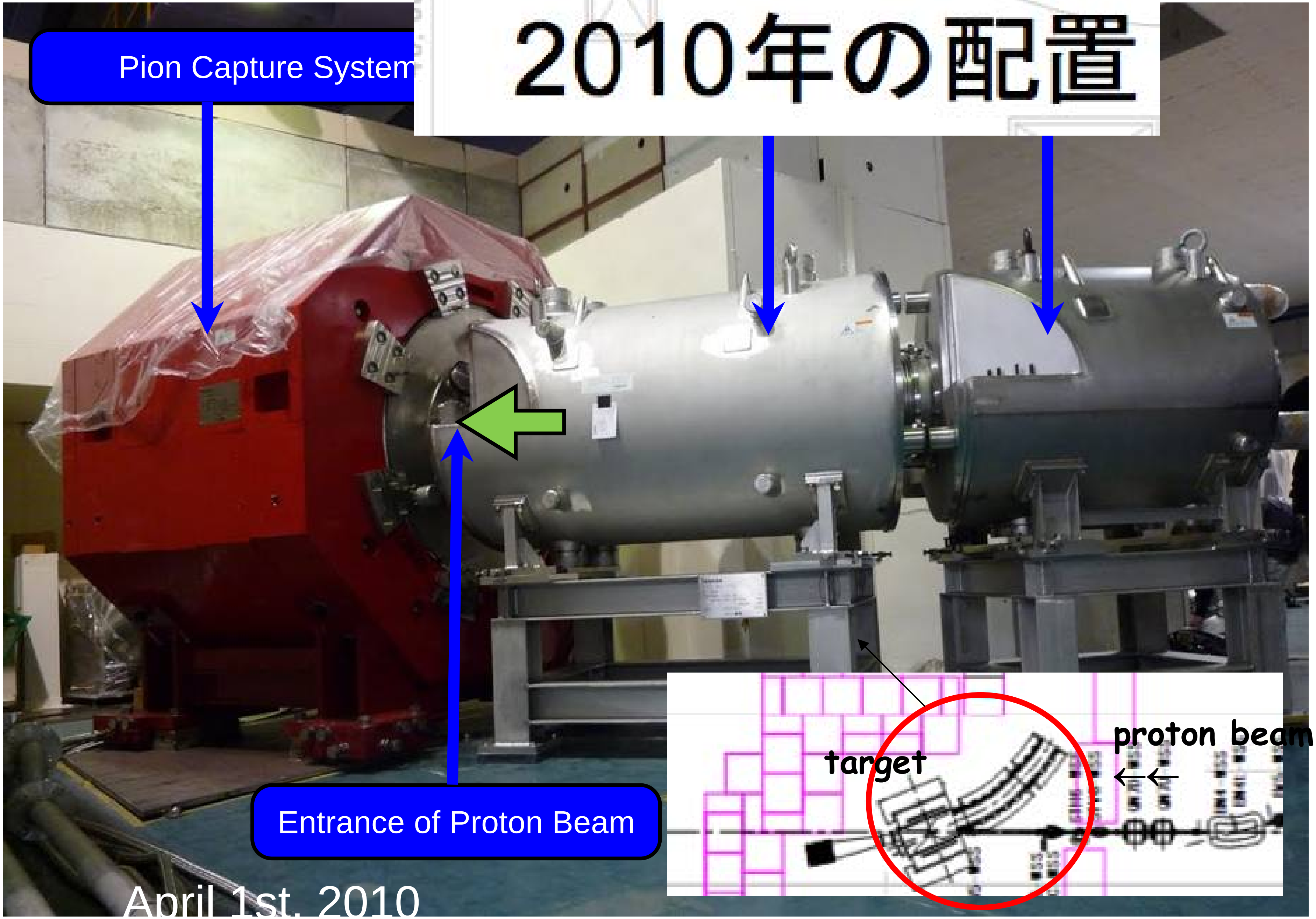
More tolerant to errors than non-scaling FFAG

What is the MUSIC@RCNP ?

- MUSIC (=**MU**on **S**cience oriented **I**ntense beam **C**hannel)



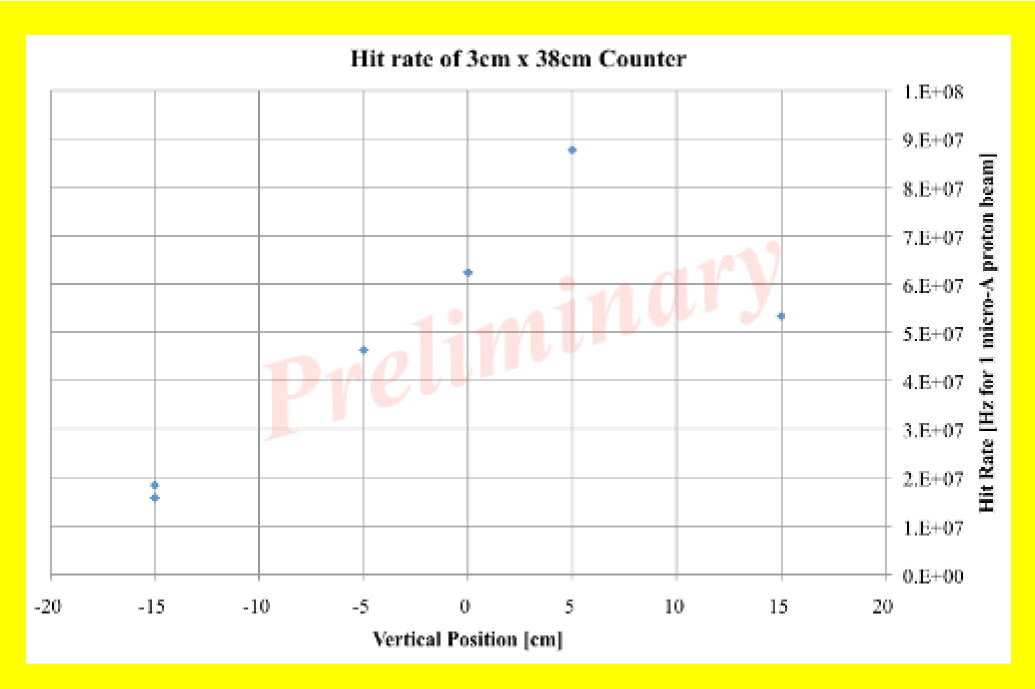
2010年の配置


Pion Capture System
Entrance of Proton Beam
target
proton beam
April 1st, 2010

MuSIC First Beam from 29th and 30th, July, 2010

- A 36 hour beam time with 1 nA
- Measurements on
  - beam intensity and
  - beam spatial distribution
- Analysis is still being made.
- Preliminary results (right)
  - vertical beam distribution
  - integrated rate: 6×10^{8} Hz/μA
  - some further corrections needed to get final numbers.
- Future works
  - particle ID
    - mixture of pions, muons and electrons
  - momentum distribution
  - dipole field correction

counting rates as a function of vertical position



MuSIC Summary

- **The first demonstration a the pion capture system by a solenoidal field has been made at the MuSIC facility at Osaka University.**
    - The RCNP cyclotron has a 400 MeV cyclotron with 1 micro A at maximum (only 400 Watts beam power)
- The superconducting magnets for pion capture and pion transport systems have been constructed by April 1st, 2010 and tested this spring.
- **In our first beam time of July 29th and 30th, about 10^6 particles were measured at the end of the beam channel for a 0.4 Watt proton beam**

- It is expected that for a full beam intensity of 400 Watt proton beam at RCNP, more than about 10^8 muons can be obtained, which is the same as the world highest.
    - **This demonstrates that pion capture efficiency has been improved by about a factor of 1000.**
- This would be the first demonstration of the front end of a muon collider and a neutrino factory.
- The funding for the muon transport system (180 degree bending part) is being requested to the funding agency (MEXT).

RF in magnetic field @ CERN

At CERN a large superconducting magnet M1 has been located

Could be used to test high gradient RF cavities
201 MHz first (MICE), and
88 MHz at a later stage

Under study (cost evaluation).
aim : to complement the MTA programme.

A mini-neutrino factory?

At T2K/Minerva/NOvA near detector one can measure muon-neutrino AND anti-neutrino cross-sections

what about electron-neutrinos?

crucial for CP/T asymmetry!

a mini beta beam? (but E=2Qγ so need SPS type rigidity….☹)

a muon storage ring (mini-neutrino-factory)?

A muon storage ring for 0.6-1.5 GeV muons gives same spectrum as γ=100 6He or 18Ne… or as the ν_e appearance signal in the next generation of neutrino experiments.

The International Design Study of the Neutrino Factory

NeutrinicaLtd,
Oulu, Finland

International Design Study IDS-NF

https://www.ids-nf.org

Aim: produce CDR for 2012/2013

'CDR' implies:

Physics performance of *costed* scenario
Conceived as input to cost/performance comparison (presumably) required at e.g. next C.E.R.N. Council's Strategy (CCS) Workshop/Process 2012/13

NB depending on schedule of CCS we may use the IDS Interim Design Report in preparation.

IDS-NF Steering Group

Committee:

A. Blondel	Geneva U.
M. Zisman	LBNL
Y. Kuno	Osaka U.
K. Long	Imperial Coll. (chair)

Detectors Conveners:

A. Bross	FNAL
P. Soler	Glasgow U.
N. Mondal	Mumbai U.
A. Cervera	Valencia U.

Physics & Performance Evaluation Conveners:

A. Donini	Madrid U.
P. Huber	Virginia Tech.
S. Pascoli	Durham U.
W. Winter	Universität Würzburg
O. Yasuda	Tokyo Metropolitan U.

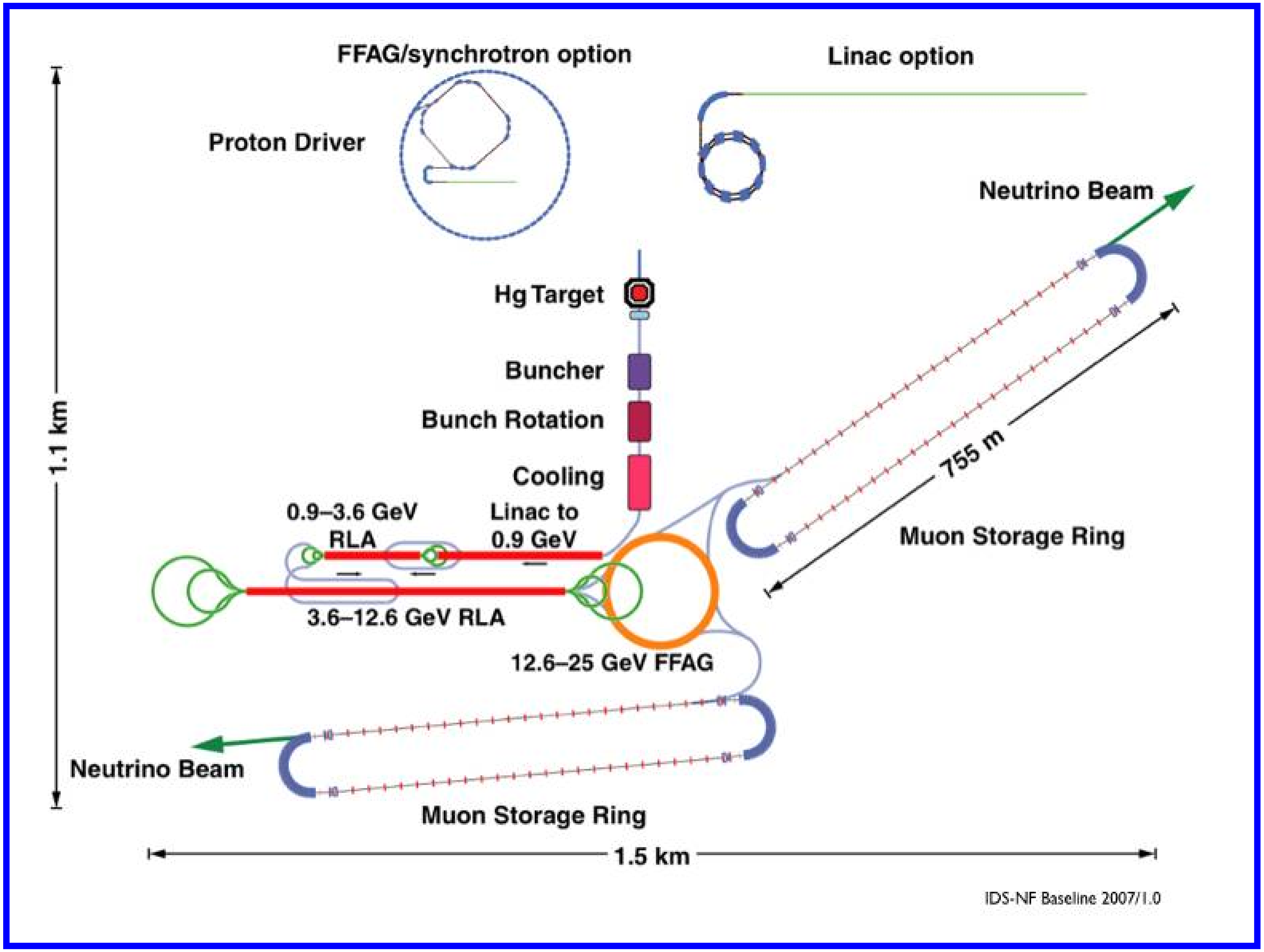
Accelerator Conveners:

S. Berg	BNL
Y. Mori	Kyoto U.
C. Prior	STFC
J. Pozimski	Imperial Coll.

EU component is partly funded by FP7 EUROnu

IDS-NF

good baselines: 2000-5000 km (e.g. FNAL– west coast or CERN-Finland)
+ magic baseline 7000-7500 (FNAL-GranSasso or CERN-India)



IDS-NF: A sample of contributions

-- powder target study (originally for T2K high power) (Densham)

-- shielded RF for phase rotation and cooling channel (Rogers)
(assurance against possible loss of gradient in magnetic field)

-- On detector side : extensive study of MIND (Laing et al)
(100 kton Magnetized Iron Neutrino Detector) (baseline)

-- magnetized TASD and Liquid Argon

-- on phenomenology side: observation of $\nu_e \rightarrow \nu_\tau$ oscillation through wrong sign muons from tau decay (Donini)

see backup slides

CERN and neutrino facilities

At the request of the UK delegation a panel of the CERN scientific policy committee (SPC) prepared a report – which was endorsed with minor modification by the full SPC.

CERN/SPC/940 CERN/2894
http://indico.cern.ch/conferenceDisplay.py?confId=86142 under Item 17 a

Question 1

- What is the view of the SPC on the importance of precise measurements of the neutrino oscillation parameters, in particular the CP violating phase and mass hierarchy?

Question 2

One of the most promising techniques for such measurements is the neutrino factory and there is currently an International Design Study (IDS) to produce a conceptual design report for a neutrino factory by 2012. This is not site specific. What is the view of the SPC on the overall value of the IDS for the future of the subject? Should CERN take a more active role in enabling the study to reach its goals, irrespective of where such a facility would be sited?

Question 3

What other high intensity neutrino facilities are technically possible and how would they address the measurements above? What should be the involvement of CERN in studies of these facilities, in particular with regard to the planned LHC upgrades?

Question 4

What is the view of the SPC on the merit of a European strategy in this phase of neutrino experimentation and whether it should have a place on the future CERN road map?

Alain Blonde

Recommendations for specific support from CERN to enable strategic decisions

• **Costing.** Support for providing comparable costing of the superbeam, beta beam and neutrino factory options is needed within the EUROnu/IDS-NF framework. In Europe the expertise required for such a comprehensive work is only available from CERN.

• **Radioprotection and general safety issues.** The development at CERN of a high power target facility, preferably with international collaboration from other laboratories would be a major asset, not only for the neutrino programme but also for the increasing number of areas where high power proton beams are needed.

• **Completing key R&D programmes:**
For the Beta Beam, it is vital to demonstrate the feasibility of producing sufficient ^{18}**Ne**.
For the **Neutrino Factory** continued contributions to the **MICE** experiment are important to demonstrate ionization cooling in a timely fashion for 2012/2013.

• R&D for future neutrino detectors. This has been taking place in Europe for some time and support from CERN, e.g. by supplying test beams, would be highly beneficial.

Long term strategy planning

- It is unrealistic to expect to have a high intensity neutrino source of any kind in Europe before early 2020's.

- By this time it is reasonable to expect that there will be many years of operating and upgrading Superbeams in Japan and in the USA. This should be closely followed.

- **Thus if Europe is to be competitive in the 2020's it should concentrate on the R&D for a new intense source, i.e. the Neutrino Factory or the Beta Beam. It would be advisable to systematically review the progress and prospects of this work.**

Conclusions

1. The key demonstration experiments for the neutrino factory and muon collider are run by largely international collaborations.

2. The level of community involvement is uneven, it varies from a few isolated institutes (in Bg, CH, F, IT, Sp, In etc..) to a large national effort effort (UKNF), Jp in between

3. at CERN some effort is made to keep contact –
but this is hard in the present time
focus has been defined by SPC report: costing, safety, MICE

4. The pioneering (intellectual, organizational and financial) input from the US groups is essential …. and recognized!

Back-up slides

Fluidised Powder Jet

- ~250μm tungsten powder driven by gas
- Number of potential advantages
  - can deliver material without splitting solenoid
  - carries heat away
  - but not a liquid
- Number of issues
  - never used as a target before
  - will need to be licensed
  - density, erosion, DC operation, etc
- Test rig built at RAL to test

Powder

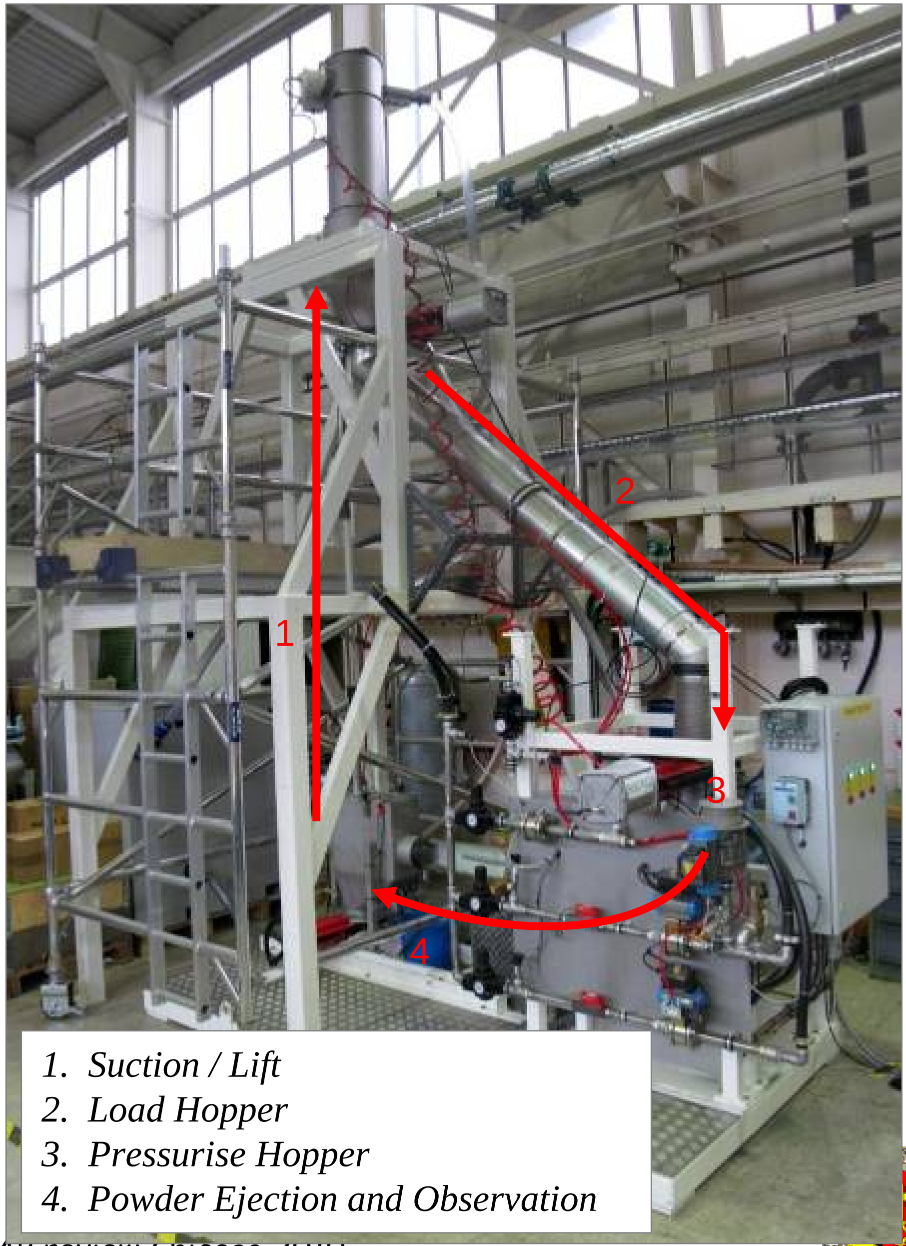
- Rig contains 150 kg Tungsten
- Particle size < 250 microns

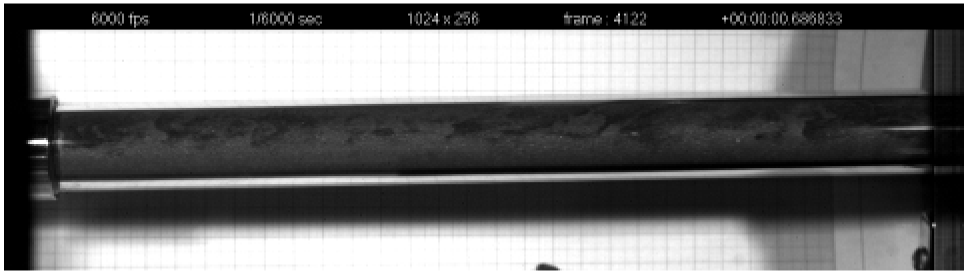
Total ~8,000 kg powder conveyed

- 90 ejection cycles
- Equivalent to 15 mins continuous operation

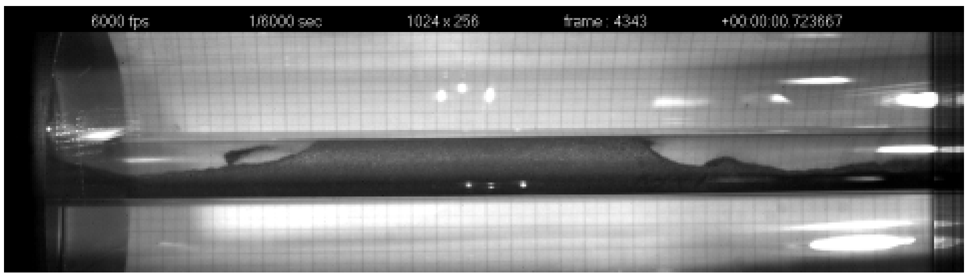
Batch mode

- Test out individual handling processes before moving to a continuous flow loop





Turbulent flow ~3bar



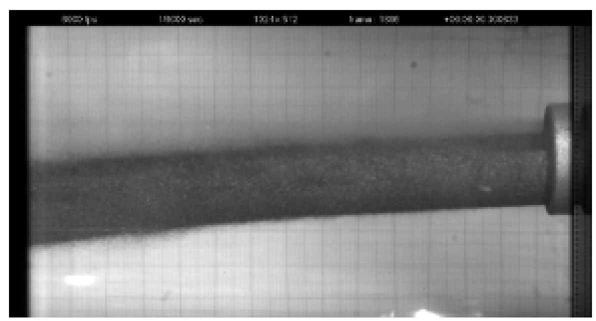
Dune flow ~1.5bar

It works!

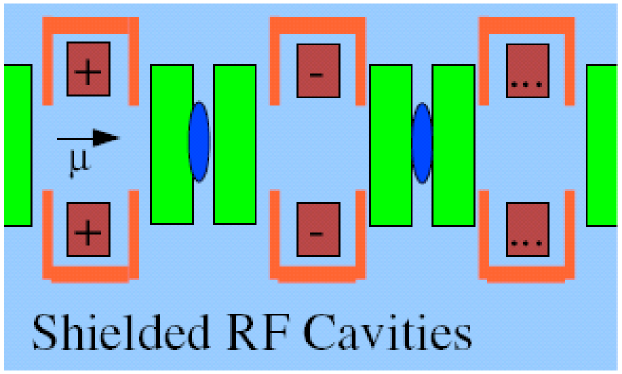
Initial density measurement: 42 ± 5%

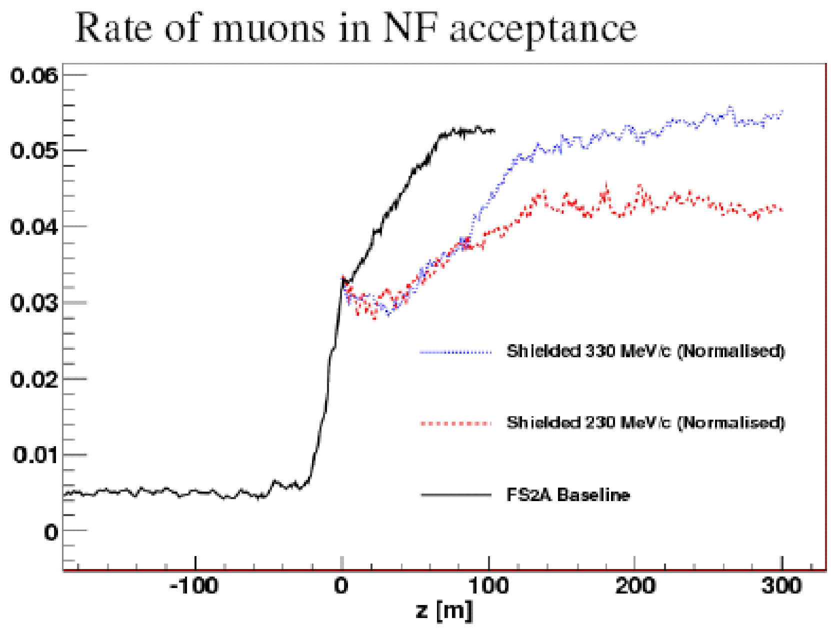
Various improvements planned:
- prevent phase separation
- DC operation
- minimise erosion
- etc

Pulsing flow ~1.5bar



Coherent jet ~2bar





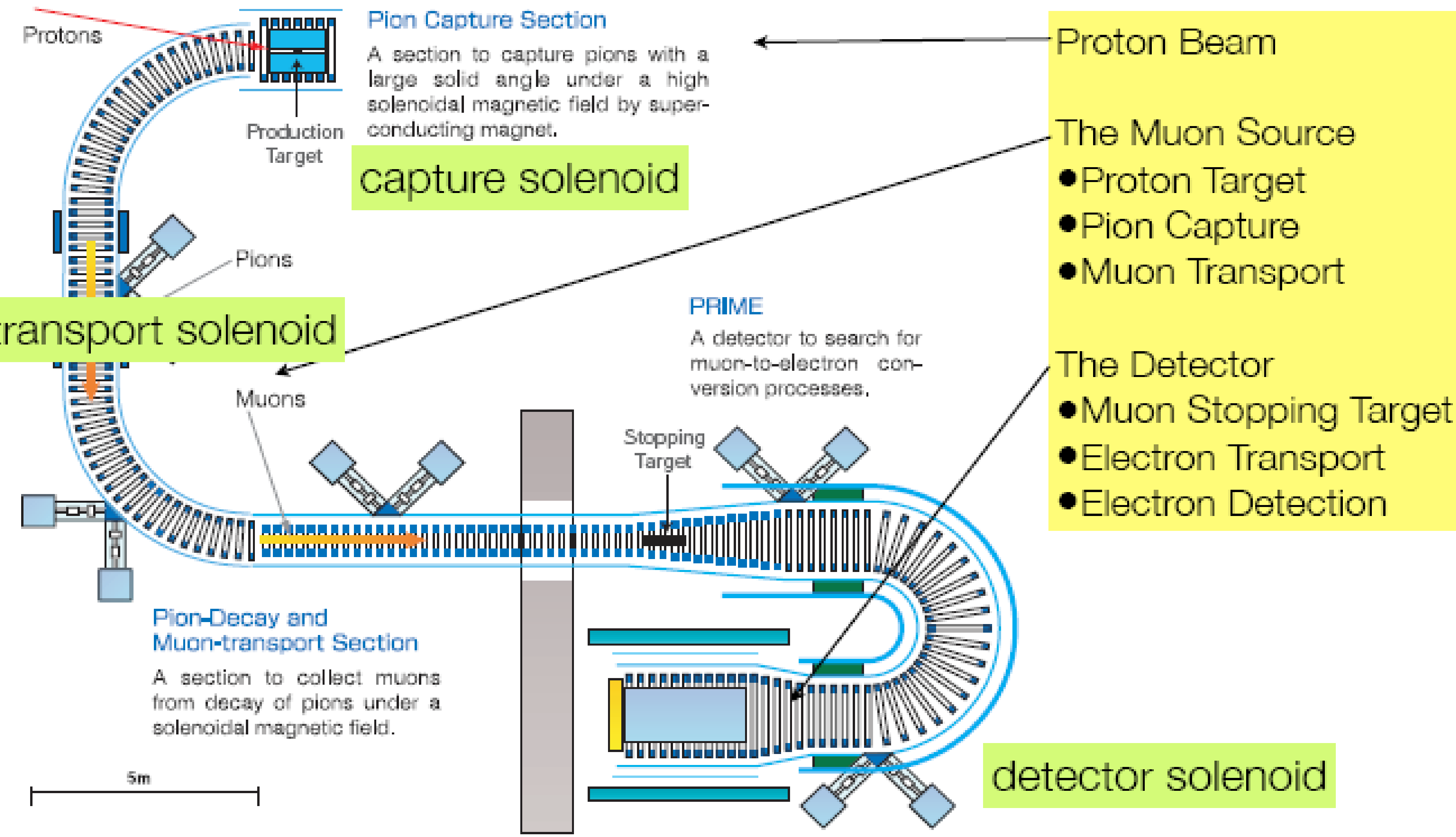
make channel longer to allow for shielding of RF against guiding field (and make higher RF gradient)

recover most of performance
Extra cost because of length and higher power needed higher acceleration

Japanese R&D

- COMET R&D
  - Design of superconducting solenoid magnets is underway.
    - pion capture system , muon transport system, detector system
  - Prototyping of solenoid coils for the muon transport section has been made by March, 2009.
- PRISM FFAG R&D
  - Muon storage ring R&D based on FFAG (PRISM-FFAG)
  - The 6-cell FFAG ring has been tested by using alpha-particles from a radioactive source.
- MUSIC R&D
  - The MUSIC project is a project to construct a high-intensity muon source at Research Center of Nuclear Physics, Osaka University.
  - The pion capture solenoid system has been funded. The construction will be completed by March, 2010.
  - The first beam is expected at April, 2010.

Layout of the COMET Experiment (COherent Muon to Electron Transition)



R&D on the PRISM Muon Storage (FFAG) Ring at Osaka University