

# Postępy w projektowaniu Fabryki Neutrin w ramach Międzynarodowego Studium Projektowego – International Design Study (IDS-NF)

J. Pasternak, Imperial College, London / RAL STFC

# Plan:

- Wprowadzenie
- Międzynarodowe Studium Projektowe
- Wysoko- i Niskoenergetyczna Fabryka Neutrin
- Postępy w projekcie akceleratora
- Perspektywy na przyszłość
- Podsumowanie

# Standardowy Model Neutrin

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{-i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Dane eksperymentalne:

$$\theta_{12} \subset \{32.3^\circ \rightarrow 37.8^\circ\}$$

$$\theta_{31} \subset \{36.9^\circ \rightarrow 51.3^\circ\}$$

$$\theta_{13} < 10.3^\circ$$

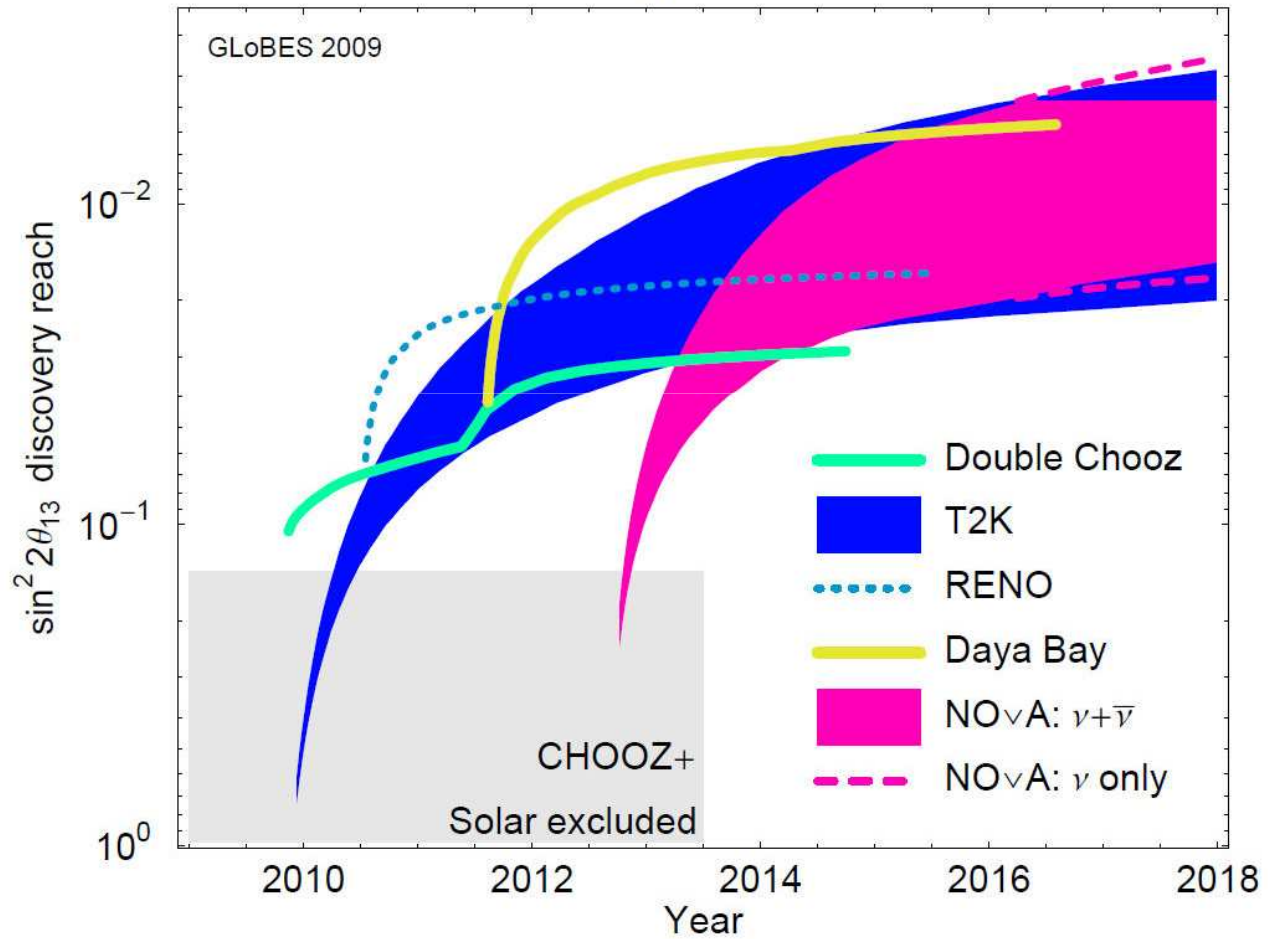
$$\Delta m_{21}^2 = (7.66 \pm 0.35) \times 10^{-5} \text{ eV}^2$$

$$|\Delta m_{31}^2| = (2.38 \pm 0.27) \times 10^{-3} \text{ eV}^2$$

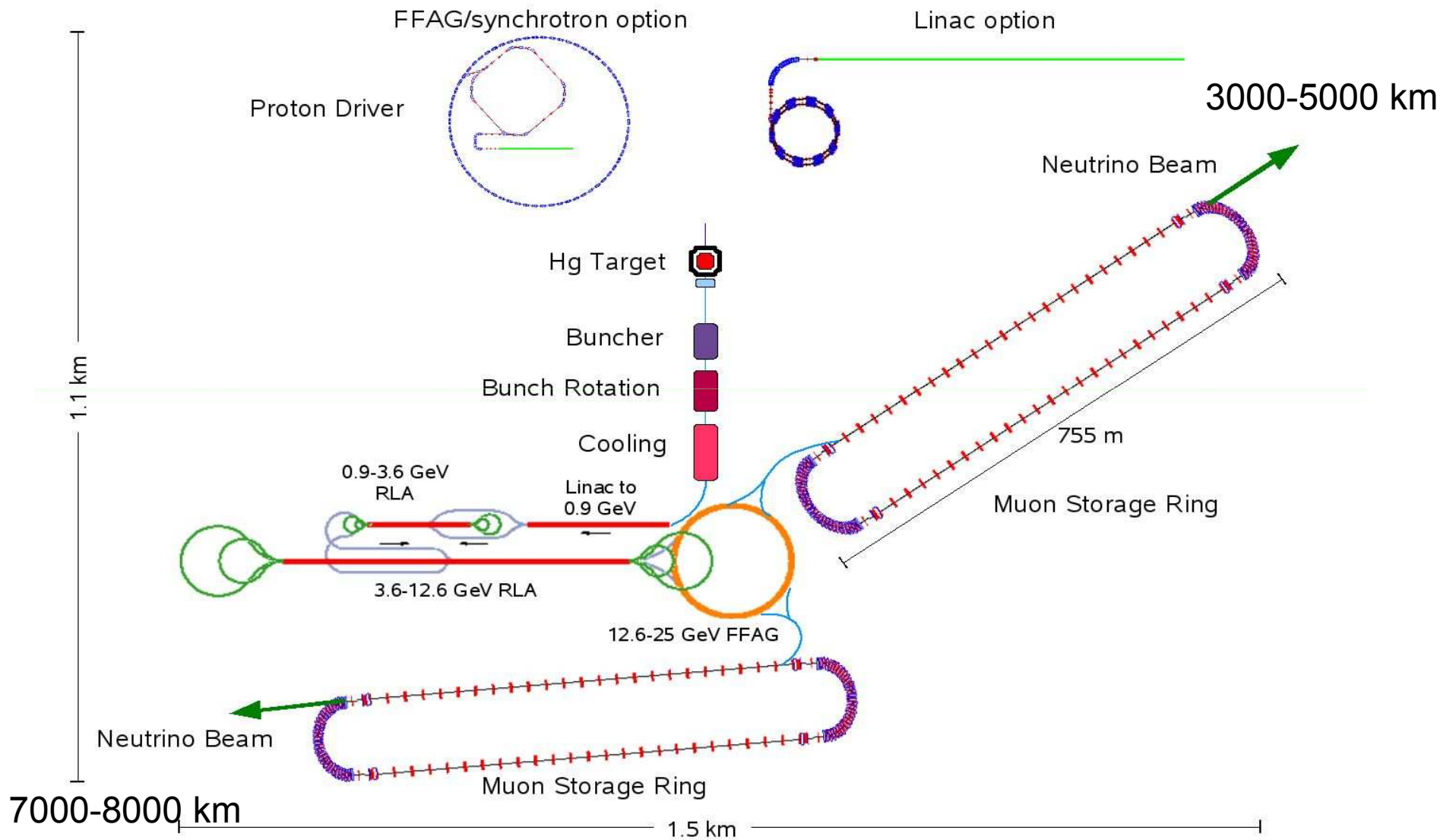
Nic nie wiadomo o fazie łamania symetrii CP!

# Perspektywy poszukiwania $\theta_{13}$

$\sin^2 2\theta_{13}$  discovery potential (NH, 90% CL)



# Projekt Fabryka Neutrin



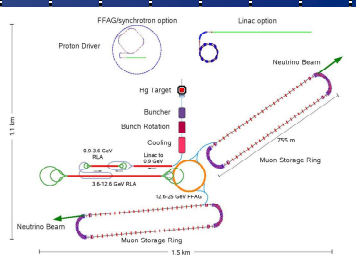
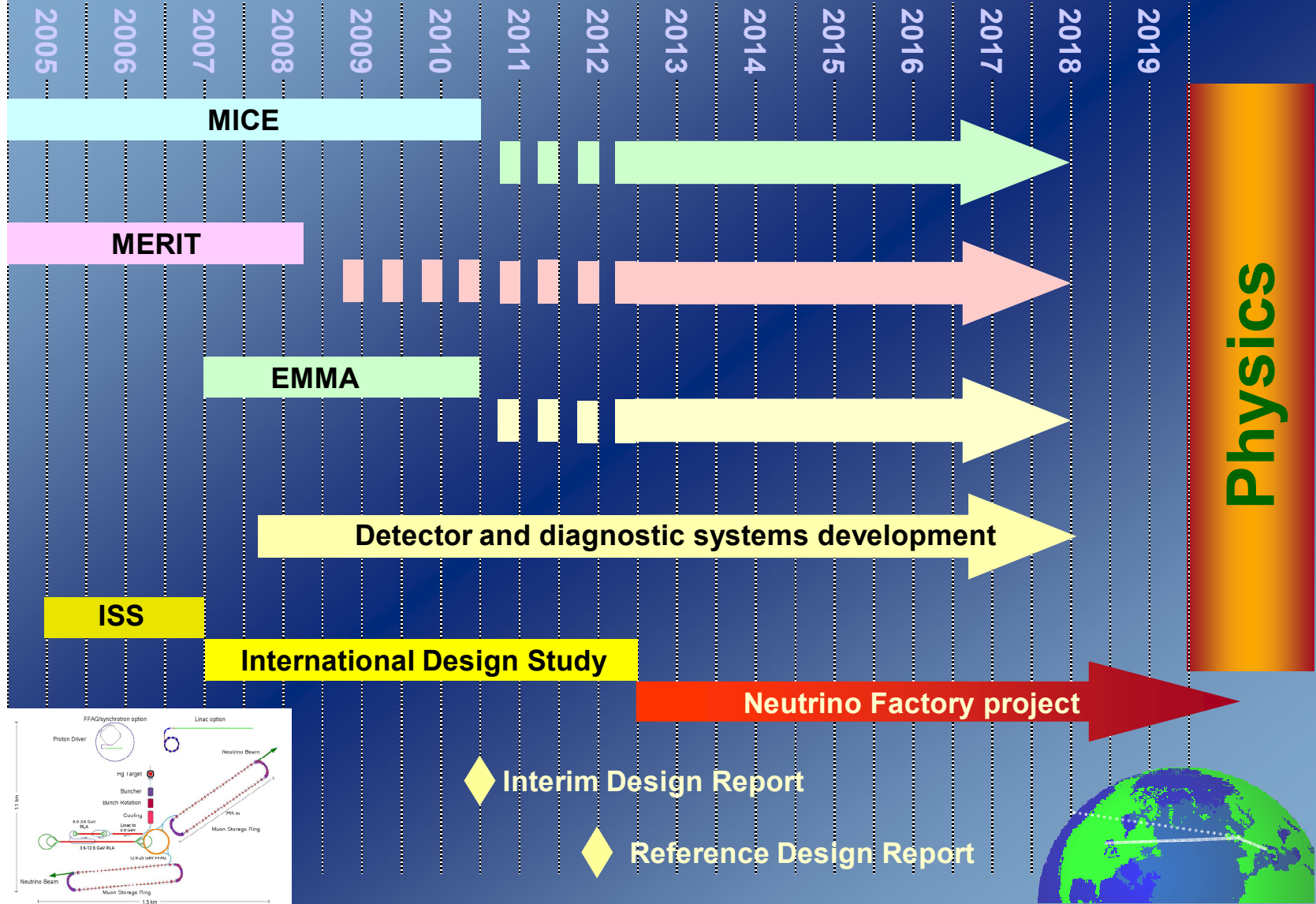
# Międzynarodowe Studium Projektowe Fabryki Neutrin – International Design Study (IDS-NF)

<b>IDS-NF Steering Group</b>	
<b>Committee</b>	
A Blondel	Geneva
M Zisman	LBLN
Y Kuno	Osaka
K Long	Imperial (Chair)
<b>Accelerator Conveners</b>	
S Berg	BNL
Y. Mori	Kyoto
C. Prior	STFC
J. Pozimski	Imperial
<b>Detector Conveners</b>	
A Bross	FNAL
P Soler	Glasgow
N. Mondal	Mumbai
A. Cervera	Valencia
<b>Physics and Performance Evaluation Group Conveners</b>	
A Donini	Madrid
P. Huber	CERN
S. Pascoli	Durham University
W. Winter	Universität Würzburg
O. Yasuda	Tokyo Metropolitan University

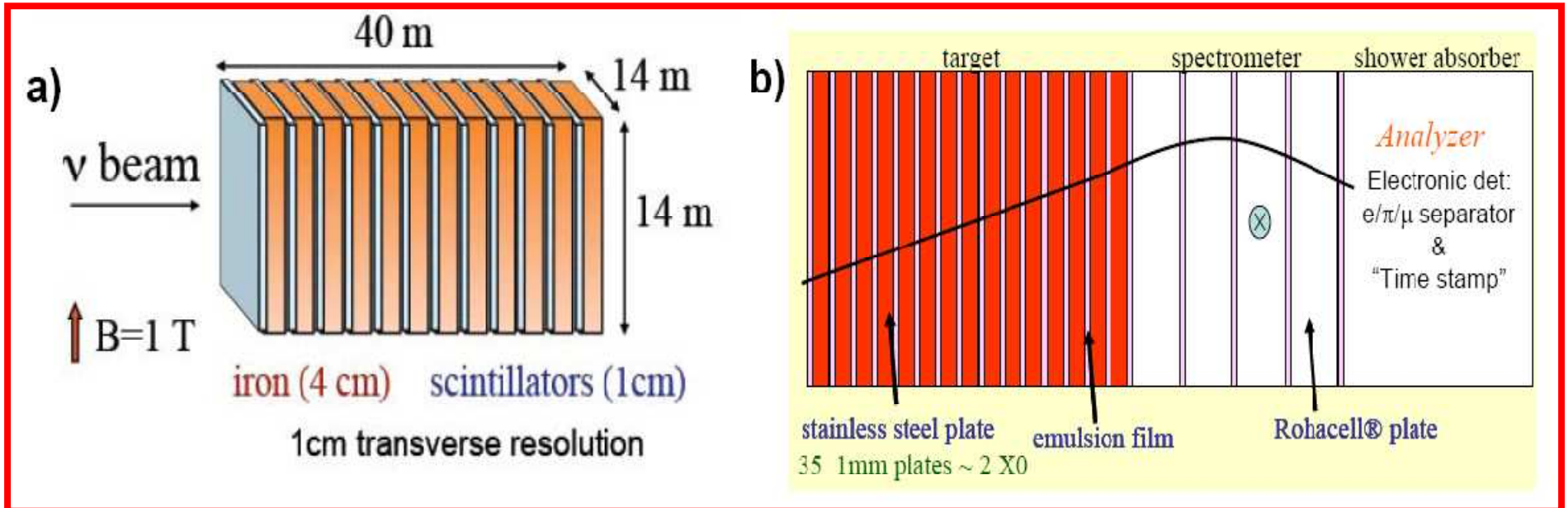
[www.ids-nf.org/](http://www.ids-nf.org/)



# Neutrino Factory roadmap



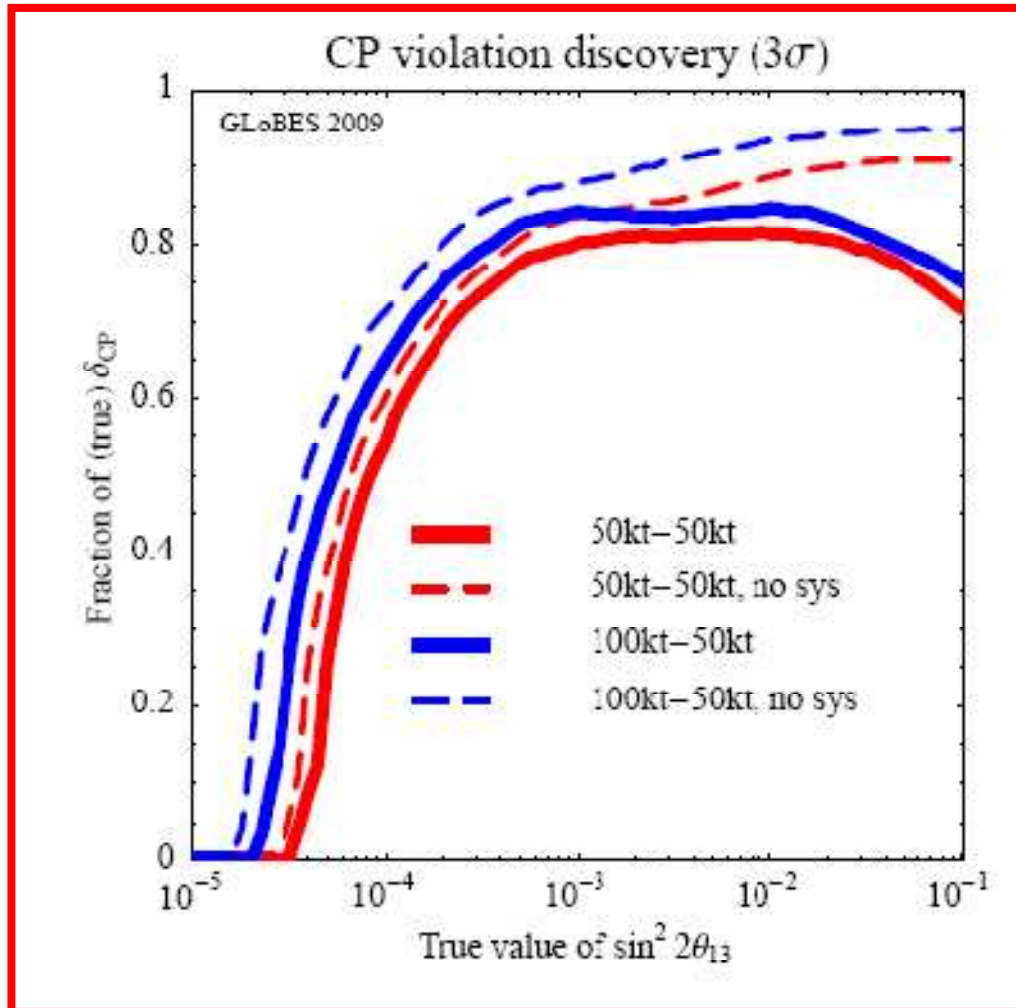
# Detektory dla Fabryki Neutrin



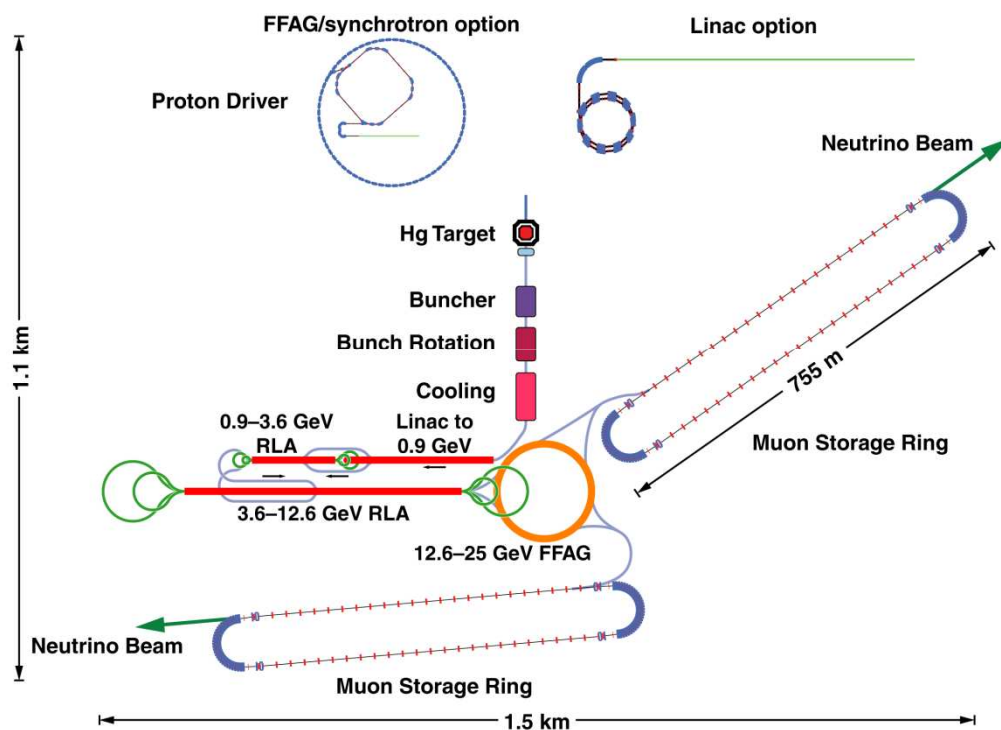
- MIND – Magnetised Iron Neutrino Detector dla obydwu wiązek wysyłanych na 3000-5000 i 7000-8000 km.
- Magnetyczny detektor emulsyjny do wykrywania taonów dla krótszej bazy



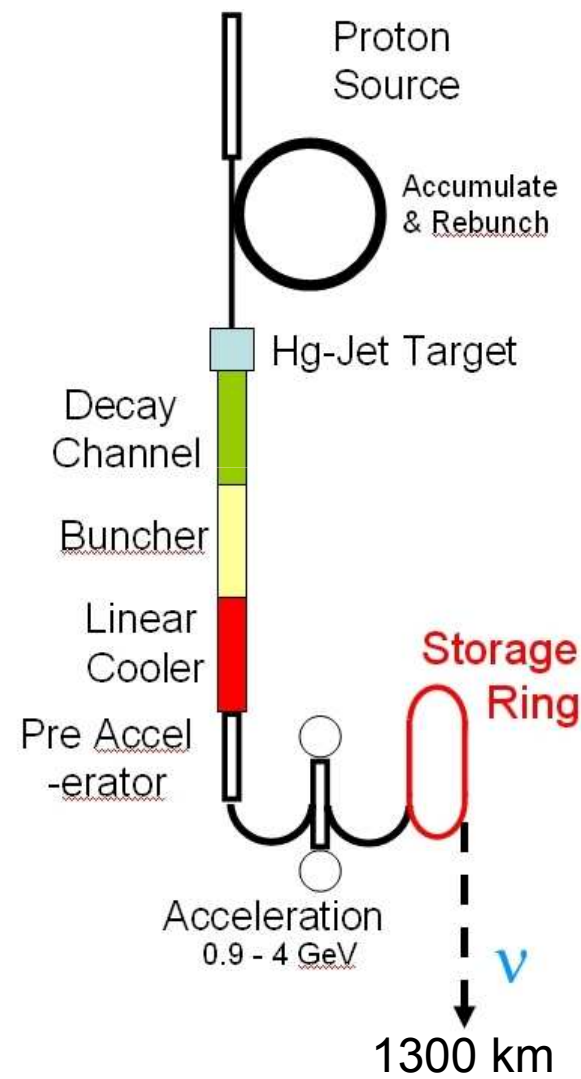
# Perspektywy poszukiwania łamania symetrii CP w Fabryce Neutrin



# Niskoenergetyczna Fabryka Neutrin

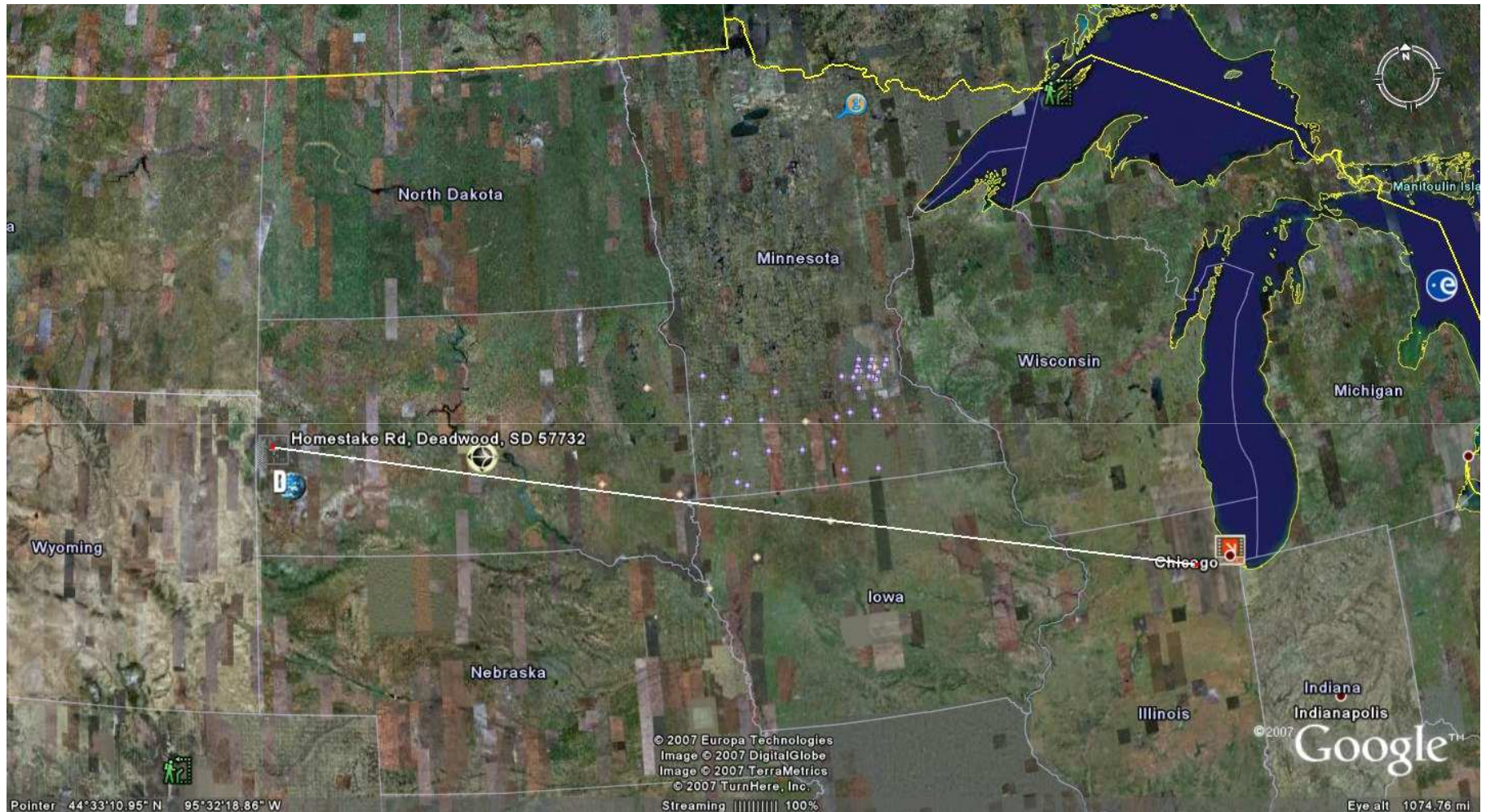


A. Bross, Fermilab



J. Pasternak

# Możliwa lokalizacja w USA

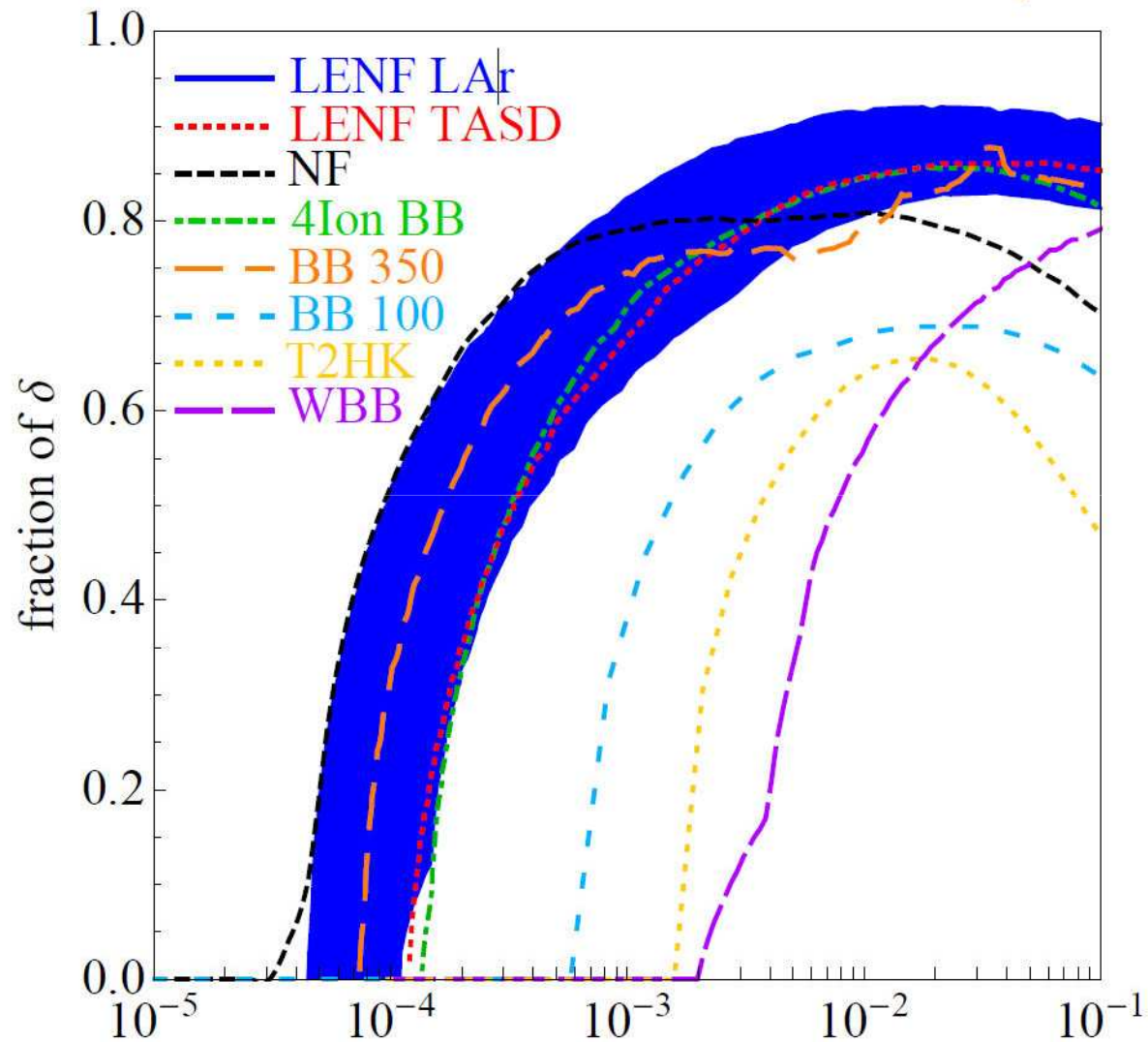


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Seminarium Neutrinowe

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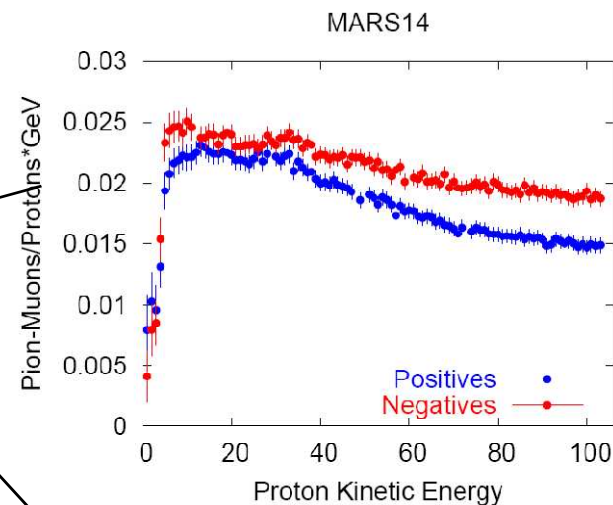
# Potencjał Niskoenergetycznej Fabryki Neutrin



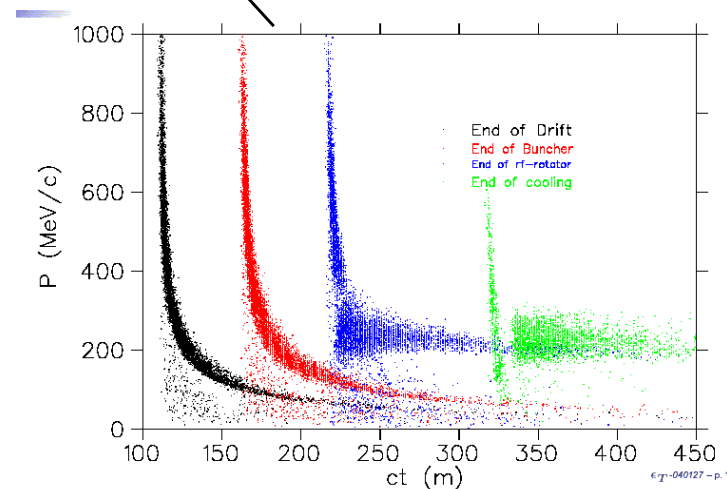
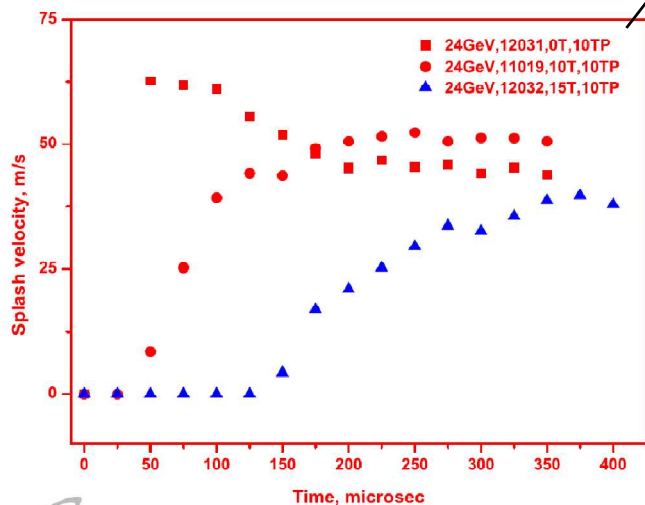
# Akcelerator protonowy

Parameter	Value
Average beam power (MW)	1
Pulse repetition frequency (Hz)	50
Proton energy (GeV)	$10 \pm 5$
Proton rms bunch length (ns)	$2 \pm 1$
No. of proton bunches	3 or 5
Sequential extraction delay ( $\mu$ s)	$\geq 17$
Pulse duration, liquid-Hg target ( $\mu$ s)	$\leq 40$
Pulse duration, solid target (ms)	$\geq 20$

?



Mesons/Proton normalized to beam power

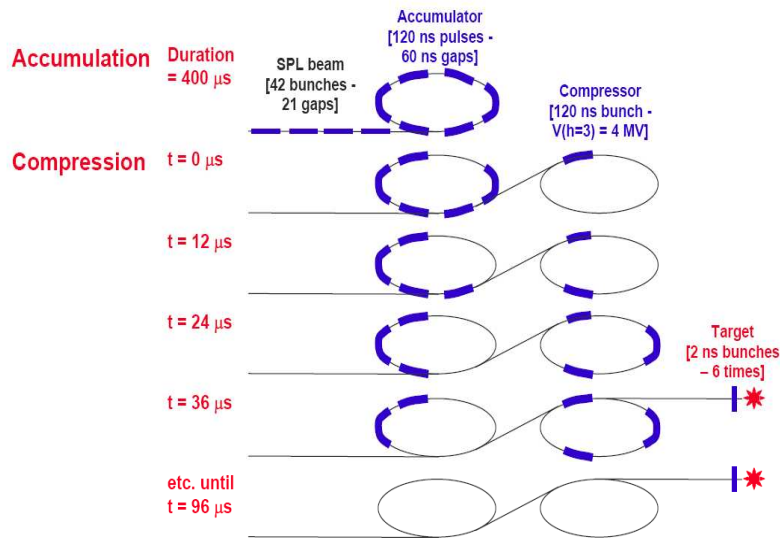


# Przykład, akcelerator protonowy dla CERN-u (M. Aiba)



Scenario for accumulation and compression (2/13)

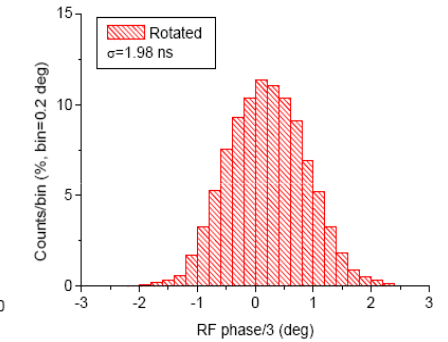
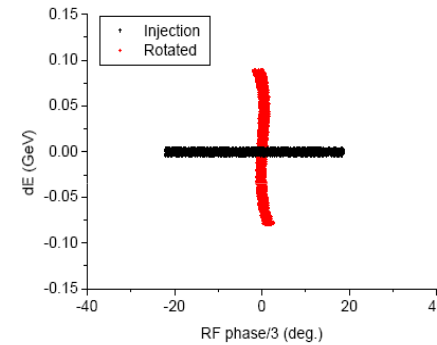
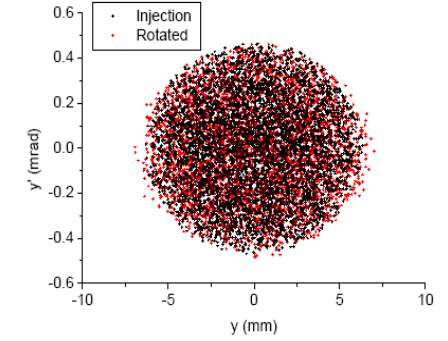
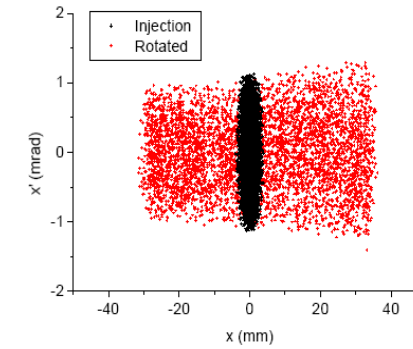
NuFact 06  
August 24-30, 2006



R.G.

9

27/08/2006



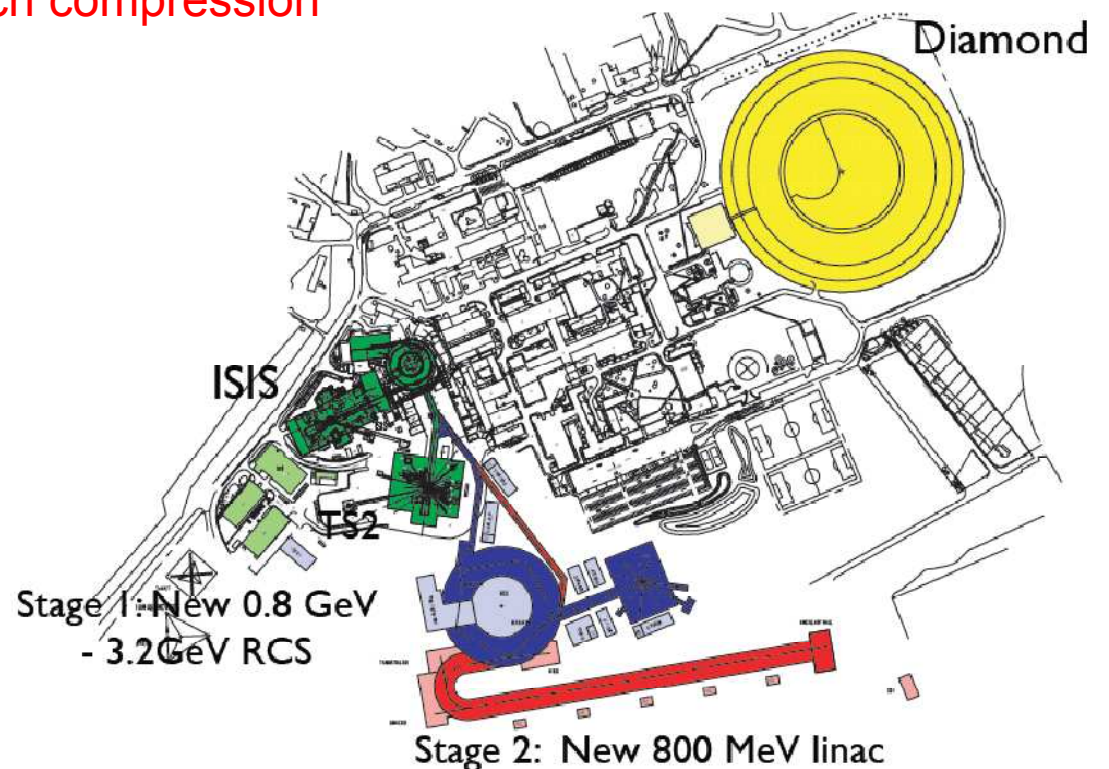
- Liniowy akcelerator jonów H<sup>-</sup>.
- Pierścień akumulacji protonów.
- Pierścień kompresji paczek.

# NF proton driver in synergy with ISIS Upgrade

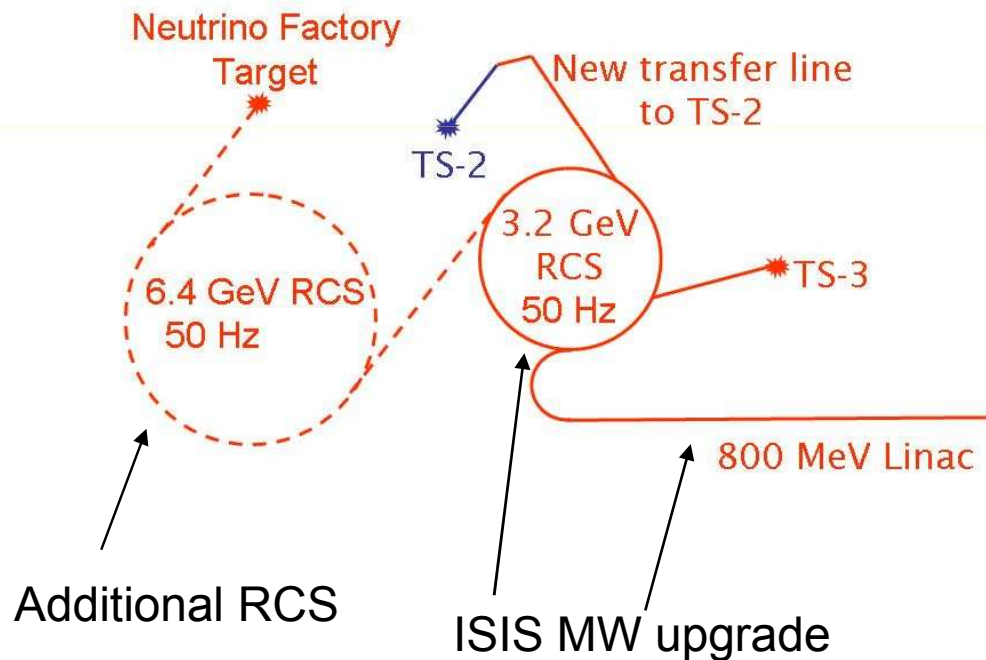
- The basic idea is to try to have a solution, which can deliver enough intensity for both NF and for the neutron spallation source.
- We could take 1-3 bunches at 3.2 GeV (1-2 MW) and accelerate it to achieve 4 MW again in another RCS
- Fundamental question – is **bunch compression** possible?

## ISIS Upgrade work plan

- collimation
- activation
- beam dump
- stripping
- space charge simulations



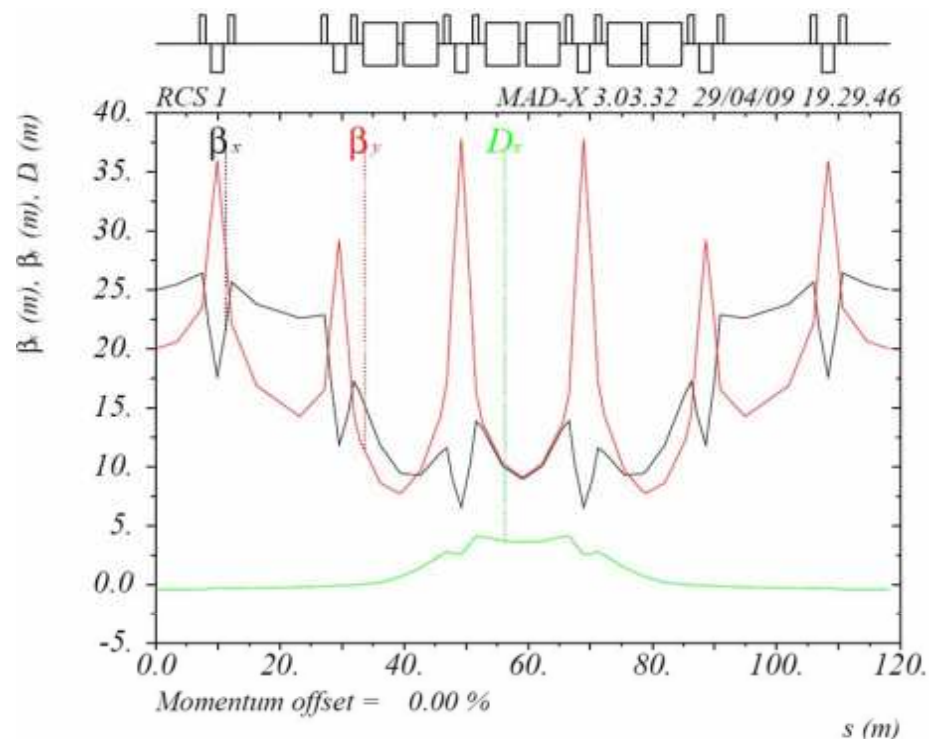
# Common Proton Driver for the Neutron Source and the Neutrino Factory



- Based on MW ISIS upgrade with 0.8 GeV linac and 3.2 GeV RCS.
- Assumes a sharing of the beam power at 3.2 GeV between the two facilities
- Requires additional RCS machine in order to meet the power and energy needs of the Neutrino Factory
- **Both facilities can have the same ion source, RFQ, chopper, linac, H<sup>-</sup> injection, accumulation and acceleration to 3.2 GeV**



# Preliminary design of the RCS for bunch compression



- Lattice may allow for flexibility in gamma transition choice (even with beam).
- Bunch compression scenario:
  1. bunch stretching (adiabatic ?).
  2. fast RF rotation
  3. stabilization if more than one bunch present (higher harmonic RF ?).
  4. Sequential extraction (do we need a flat-top?)

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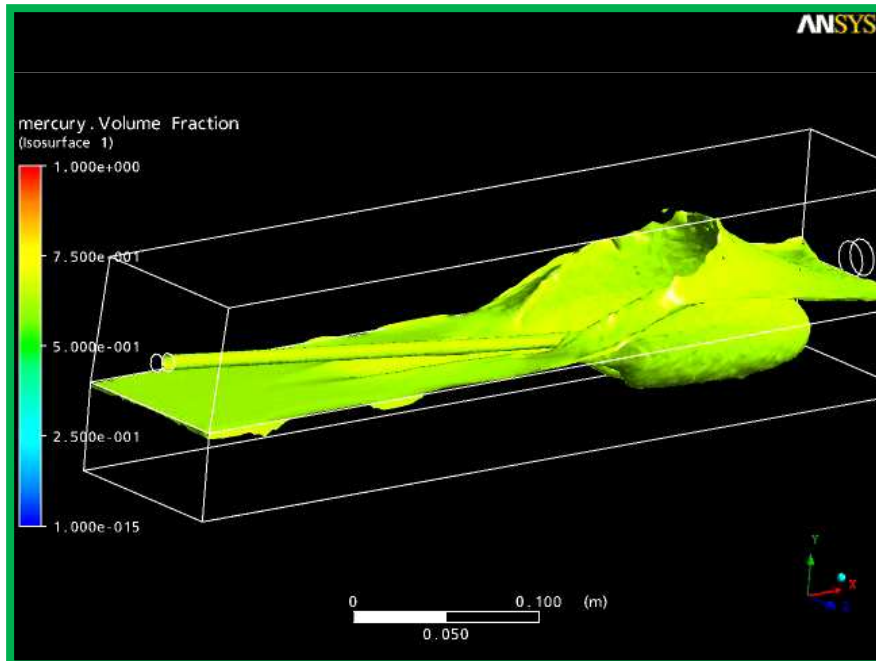
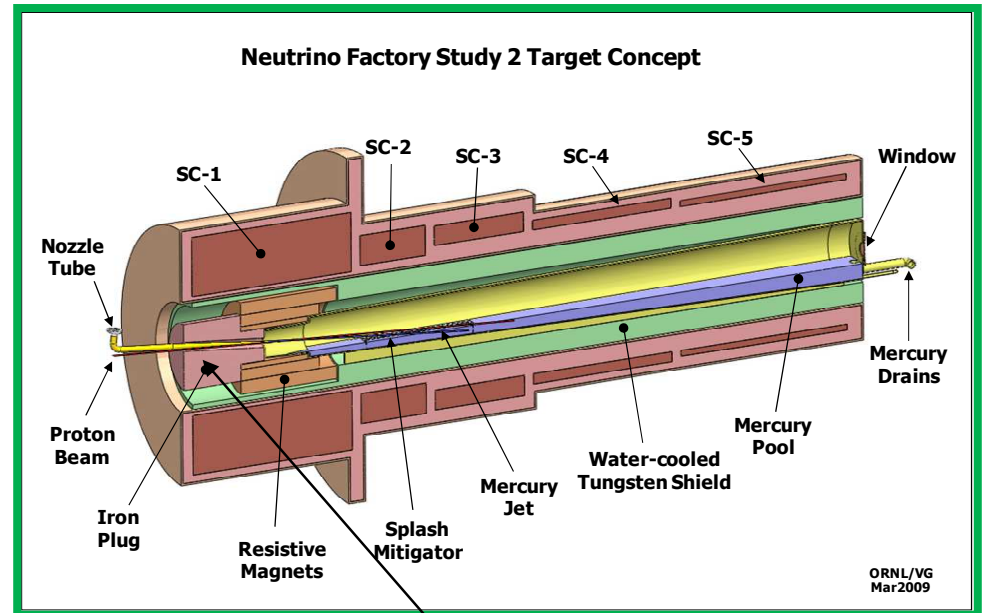
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Number of superperiods	6
Circumference	708.788 m
Harmonic number	6
RF frequency	2.4717-2.5289 MHz
Betatron tunes ( $Q_H, Q_V$ )	(7.81, 7.78)
Gamma transition	7.9056
Beam power at 6.4 GeV	<b>4 MW for 2 bunches</b>
Bunch area	1.8 eVs
$\Delta p/p$ at 3.2 GeV	$5.3 \cdot 10^{-3}$
Injection / extraction energy	3.2 / 6.4 [10.3] GeV
Repetition rate	50 Hz
Max B field in dipoles	1.2 T ( at 10.3 GeV)
Length of long drift	12 m

Parameters of 6.4 (10.3) GeV RCS

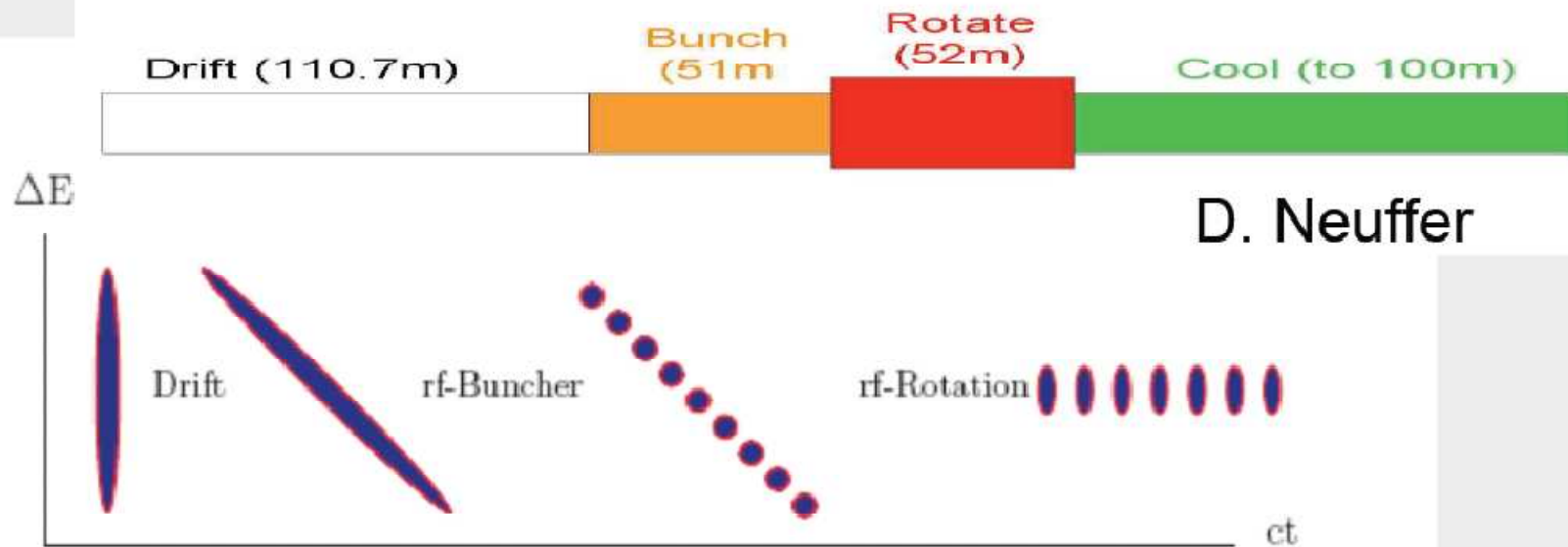
Work in progress!

# Tarcza Rtęciowa



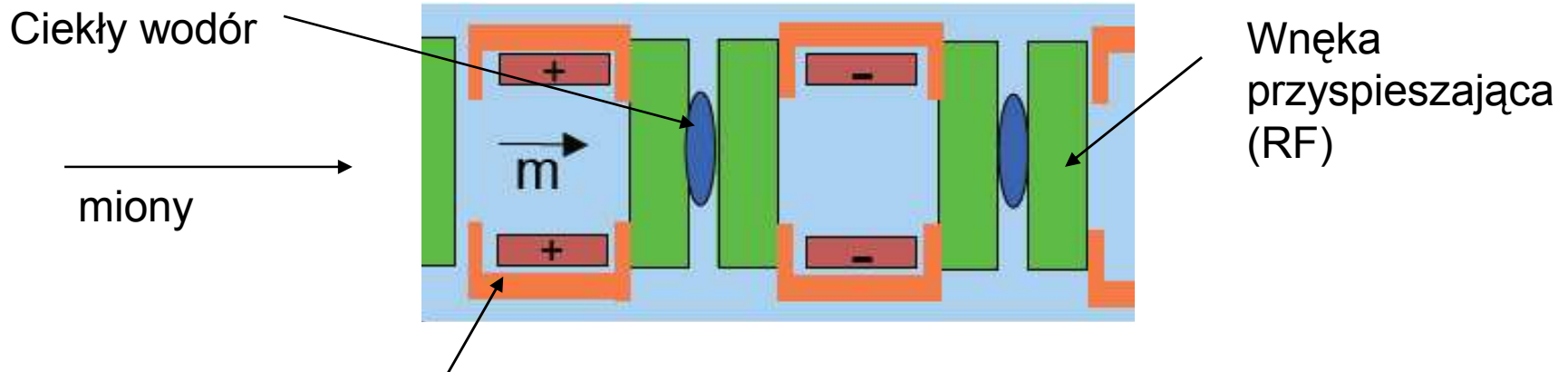
- Tarcza w postaci strumienia rtęci ze względu na olbrzymią moc wiązki (4 MW),
- Wysokie pole magnetyczne dla optymalizacji przechwytywania pionów,
- Basen rtęciowy jako hamulec wiązki i strumienia rtęci.

# Front-End Mionowy

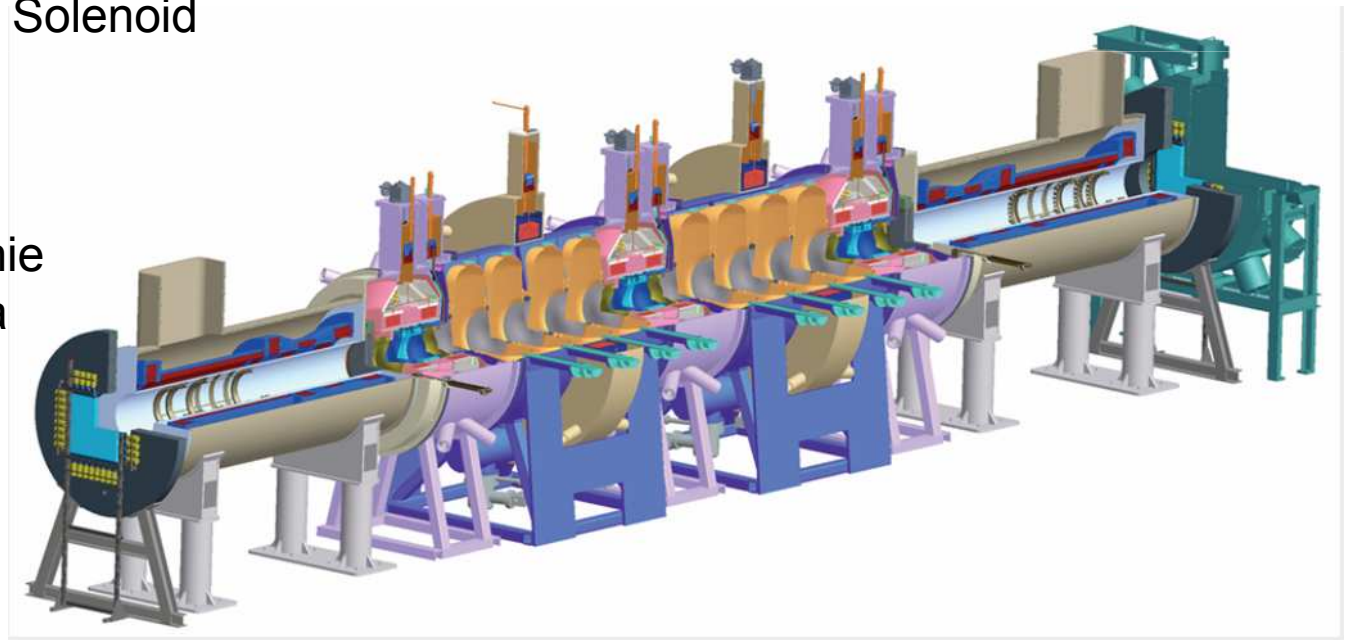


- Front end służy przygotowaniu wiązki do przyspieszania.
- Wiązka mionów jest podzielona na mniejsze paczki.
- Jej rozmycie energetyczne ulega zmniejszeniu.
- Emitancja wiązki (objętość w przestrzeni fazowej) ulega zmniejszeniu w chłodzeniu jonizacyjnym.

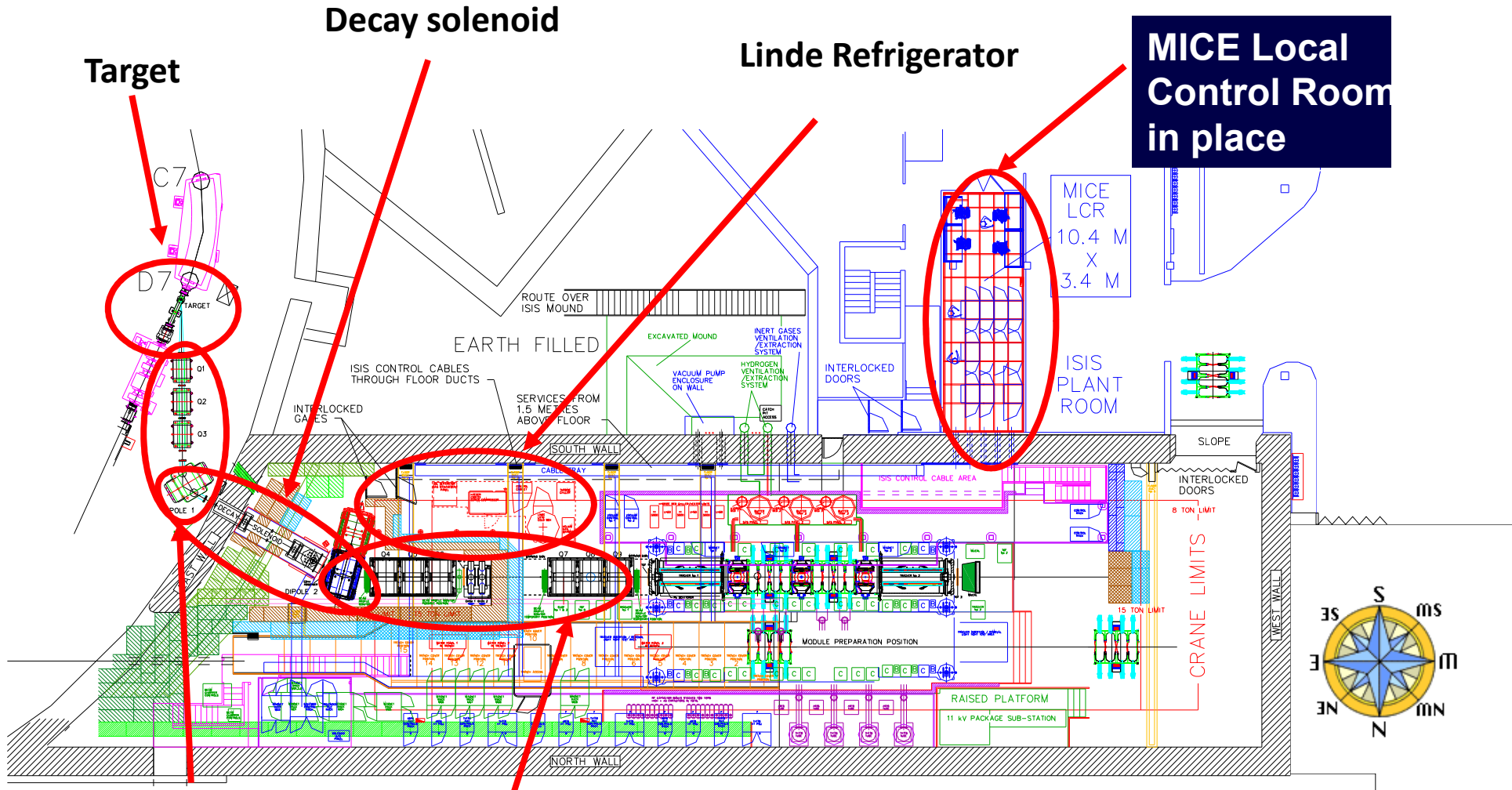
# Chłodzenia jonizacyjne mionów



Eksperyment MICE ma na celu przetestowanie jonizacyjnego chłodzenia mionów, RAL.



# Status of MICE, K. Long



**Upstream beam line**

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**Downstream beam line**

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**Instrumentation in place:**

- Beam profile monitors
- Trigger/rate scintillators
- CKovA&B, TOF0,1&2, KL

# MICE – hala eksperymentalna

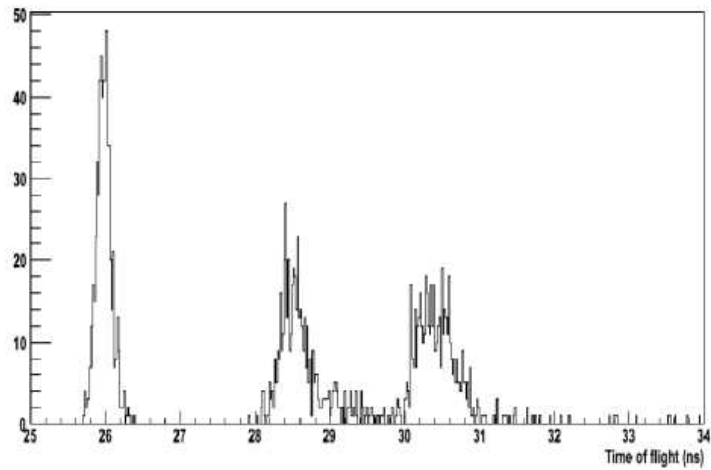
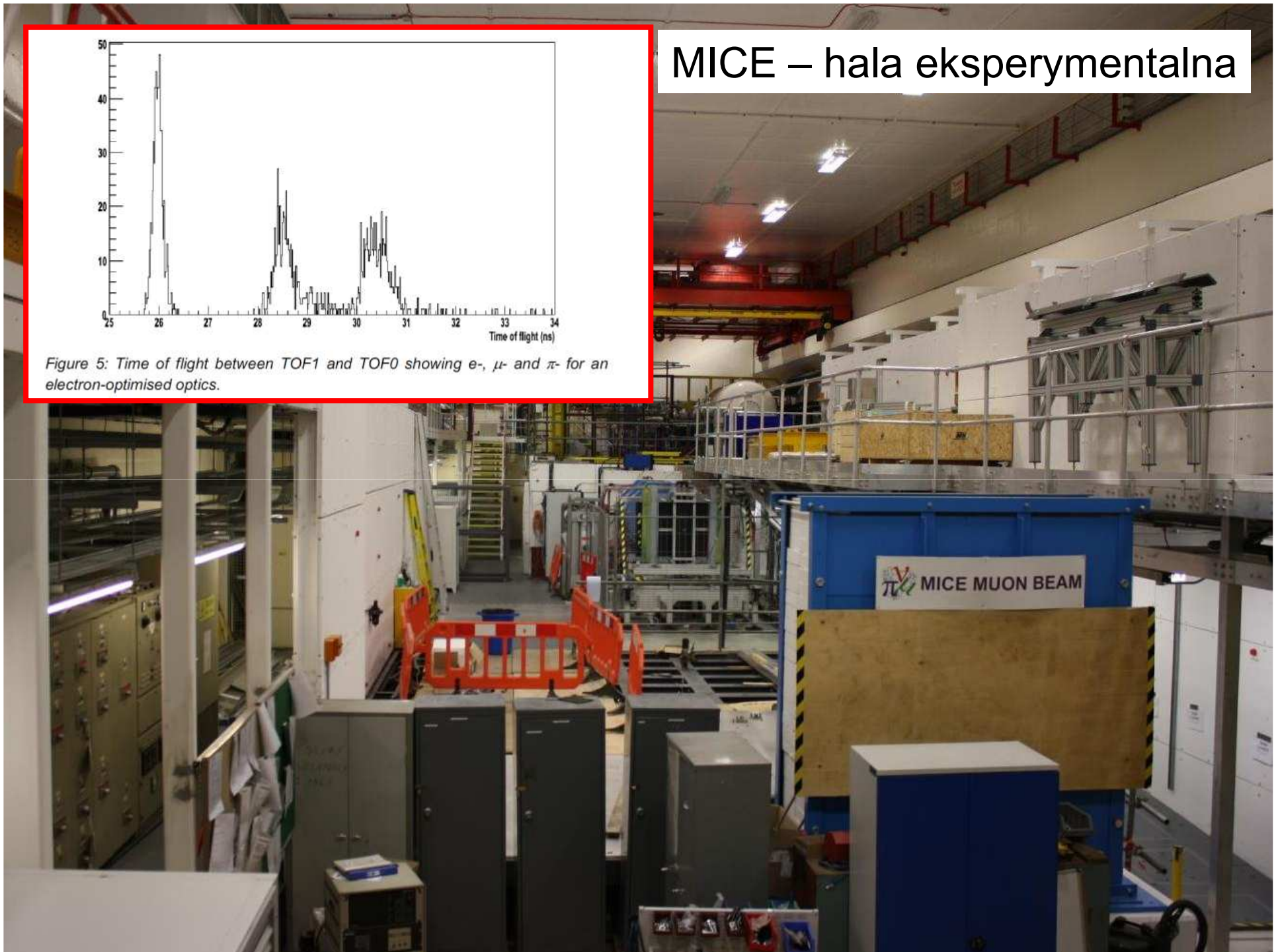
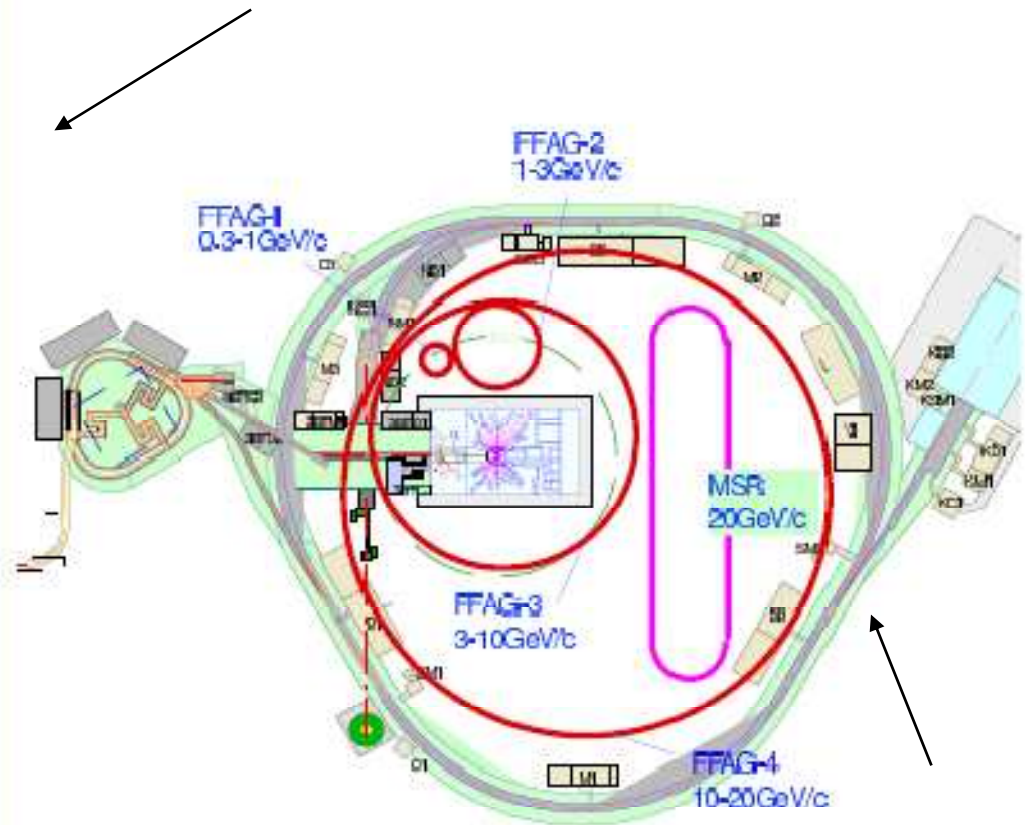
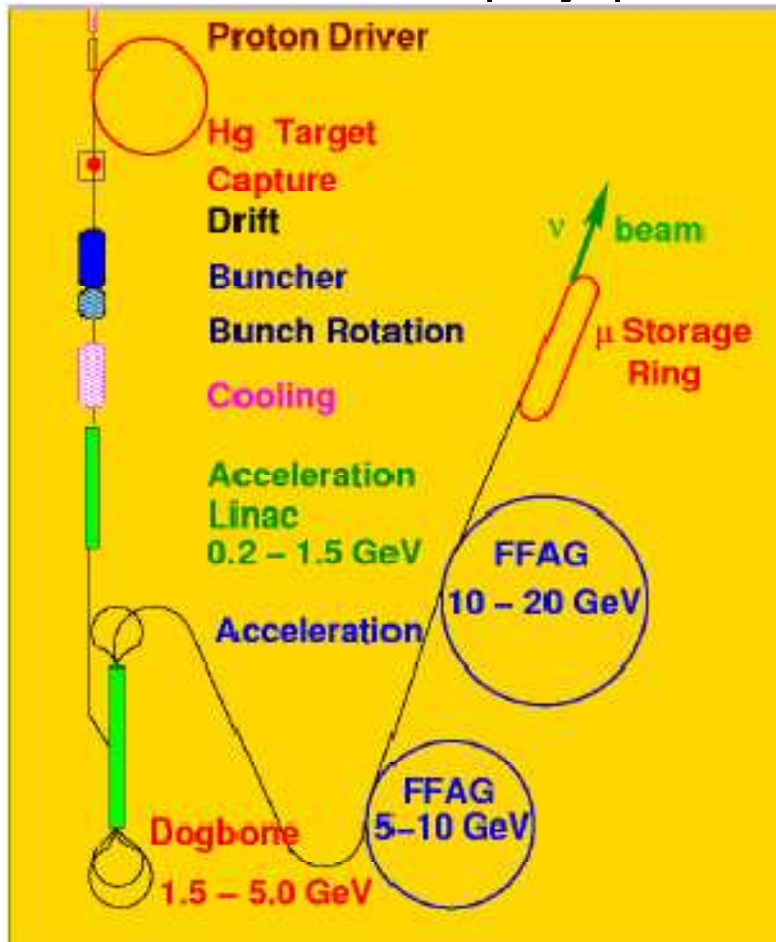


Figure 5: Time of flight between TOF1 and TOF0 showing  $e^-$ ,  $\mu^-$  and  $\pi^-$  for an electron-optimised optics.



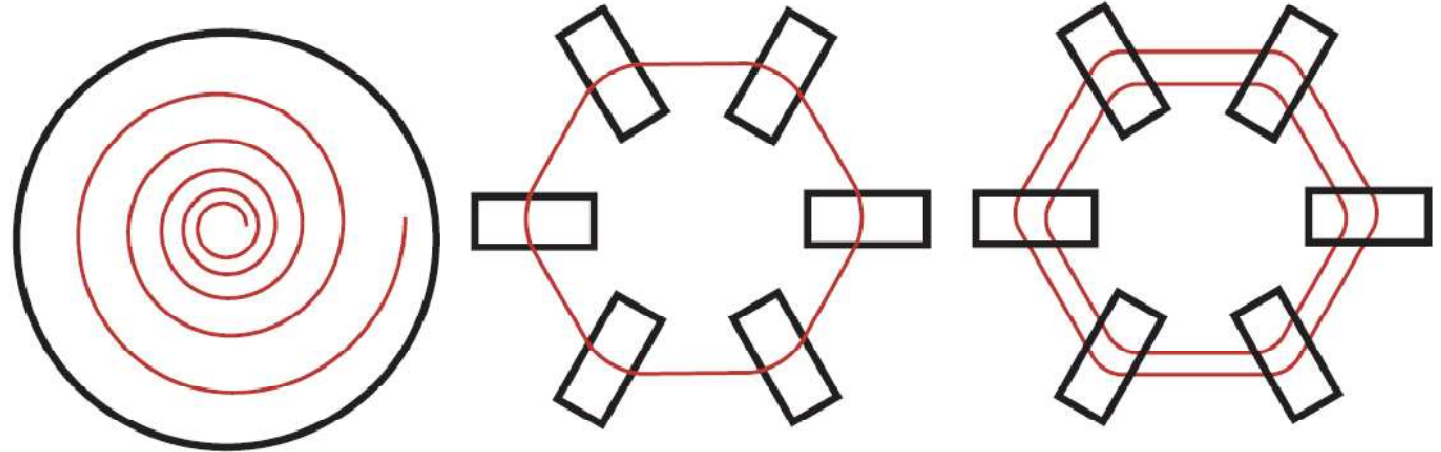
Akceleratory typu FFAG zaproponowano do przyspieszania mionów w Fabryce Neutrin  
Amerykański projekt FN



Japoński projekt FN

Przyspieszanie mionów dla Fabryki Neutrin (FN) w obecnych projektach zawiera akceleratory typu FFAG pracujące przy stałej częstotliwości RF.

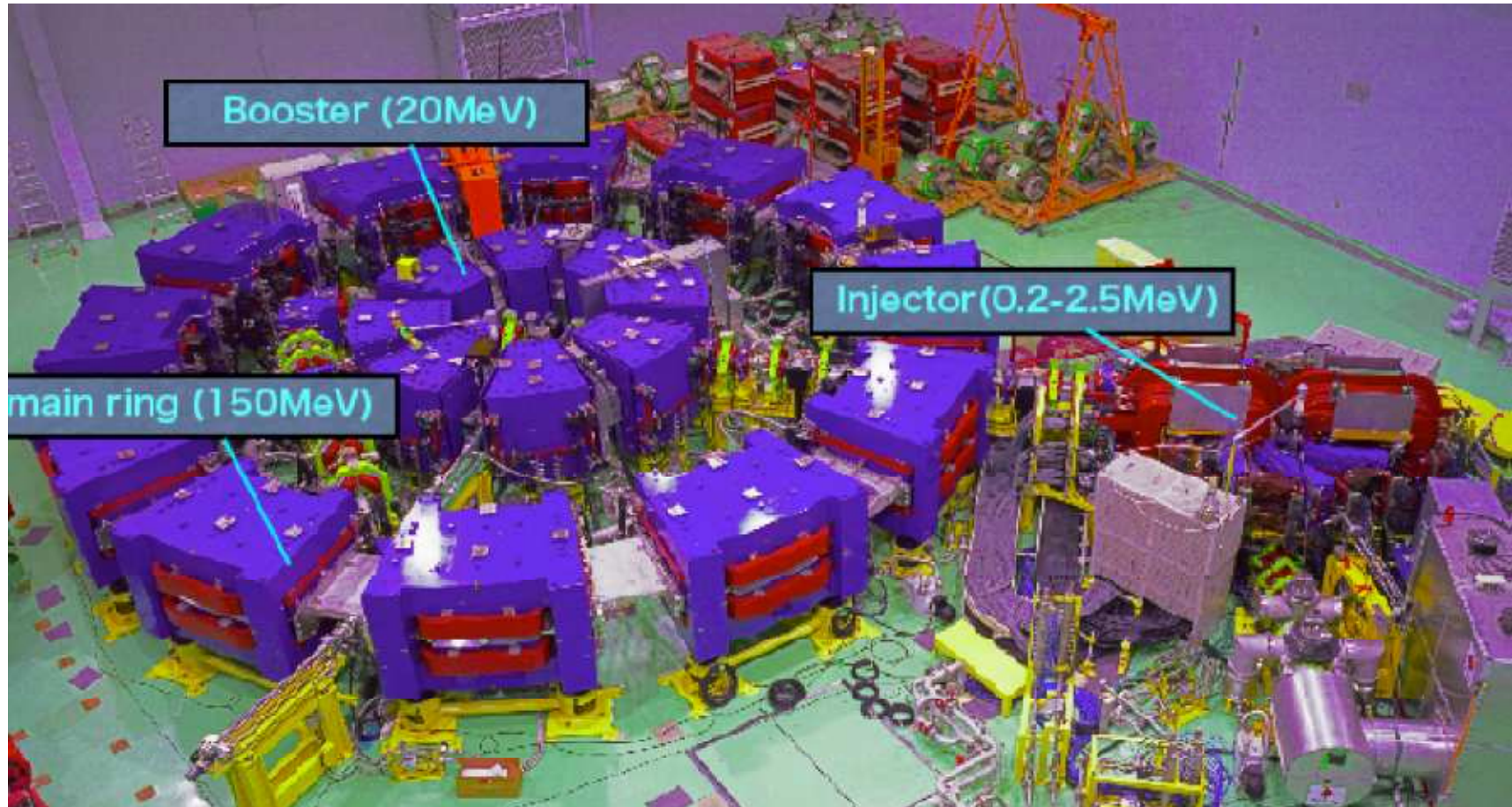
# Definicja akceleratora typu FFAG – Fixed Field Alternating Gradient



Typ Akcelerator	Cyclotron	Synchrotron	FFAG
Pole magnetyczne	stałe	zmienne	stałe
Częstotliwość RF-u	stała	zmienna	zmienna (nie zawsze)
Orbita	zmienna	stała	zmienna

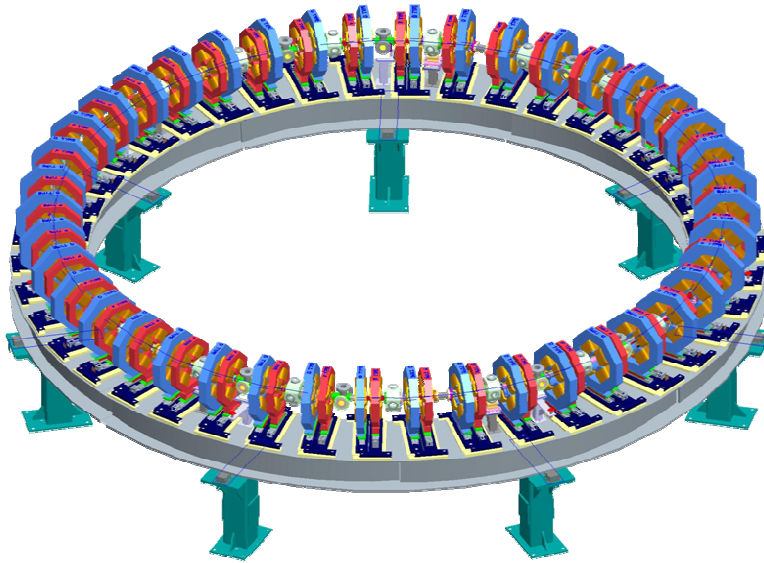


## Przykład akceleratorów FFAG, pierścienie w KURRI, Japonia



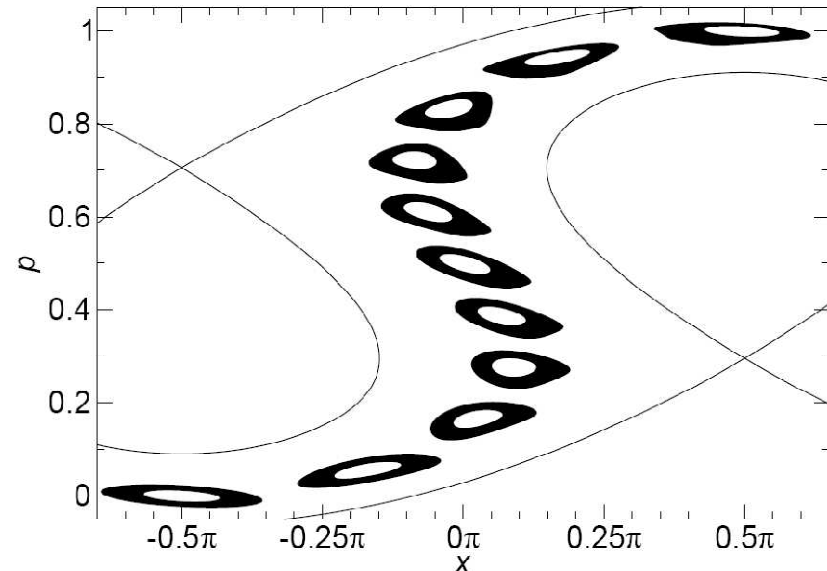
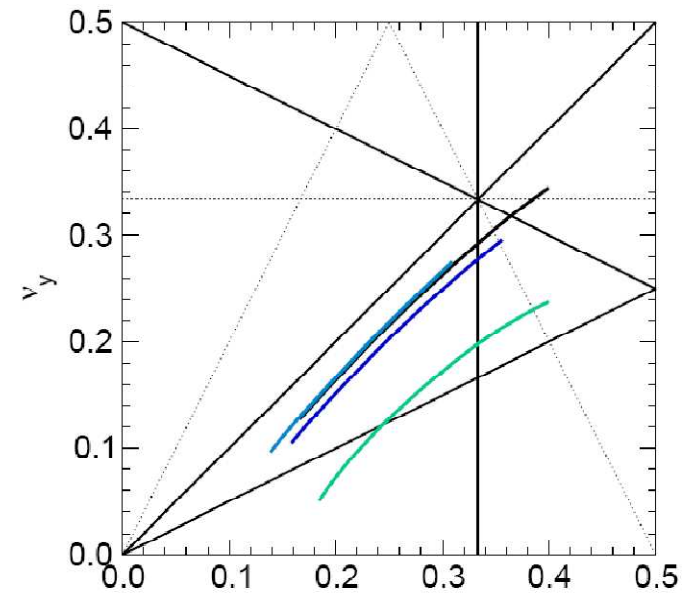
System 3 skalujących pierścieni FFAG zbudowanych w KURRI  
w celu badań nad systemami ADS  
Obecnie w trakcie testów z wiązką.

## EMMA (Electron Model for Many Applications)



EMMA – pierwszy pierścień nieskalujący:

- Model akceleratora mionów dla Fabryki Neutrin.
- Doświadczalna demonstracja nowego rodzaju przyspieszania (10 –20 MeV).
- Doświadczenia nad szybkim przekraczaniem rezonansów.
- Realizowany w Daresbury przy ALICE.



# Motivation for Nonscaling FFAG as the muon accelerator

## Advantages:

- quasi-isochronous –enables high frequency RF
- linear fields – gives huge DA and allows for simple magnets
- small orbit excursion – cost effective

## Main problems:

- TOF with amplitude
- beam loading (effect of beam on RF)
- **injection/extraction**

## Lattice choice **FODO**:

- cost-effective,
- allows for symmetric injection/extraction,
- but **short drift**
- good performance

## Triplet:

- more difficult,
- allows for symmetric injection/extraction,
- but **longer drift!**



## Parameters

	FCDC	FDCC	PDFCC	FDC	FDCC
Cells	62	62	55	77	70
D radius (cm)	9.5	10.2	12.5	7.7	9.2
D field (T)	7.6	8.3	7.3	8.1	7.7
F radius (cm)	20.7	20.3	16.7	14.0	12.2
F field (T)	3.4	3.1	3.9	4.0	4.2
Circ. (m)	462	467	445	426	422
RF Volt. (MV)	1526	1424	1246	903	814
Decay (%)	3.5	3.8	4.1	5.4	5.9

Old lattice parameters used in injection/extraction studies

Recent update of NS-FFAG parameters, J. Scott Berg



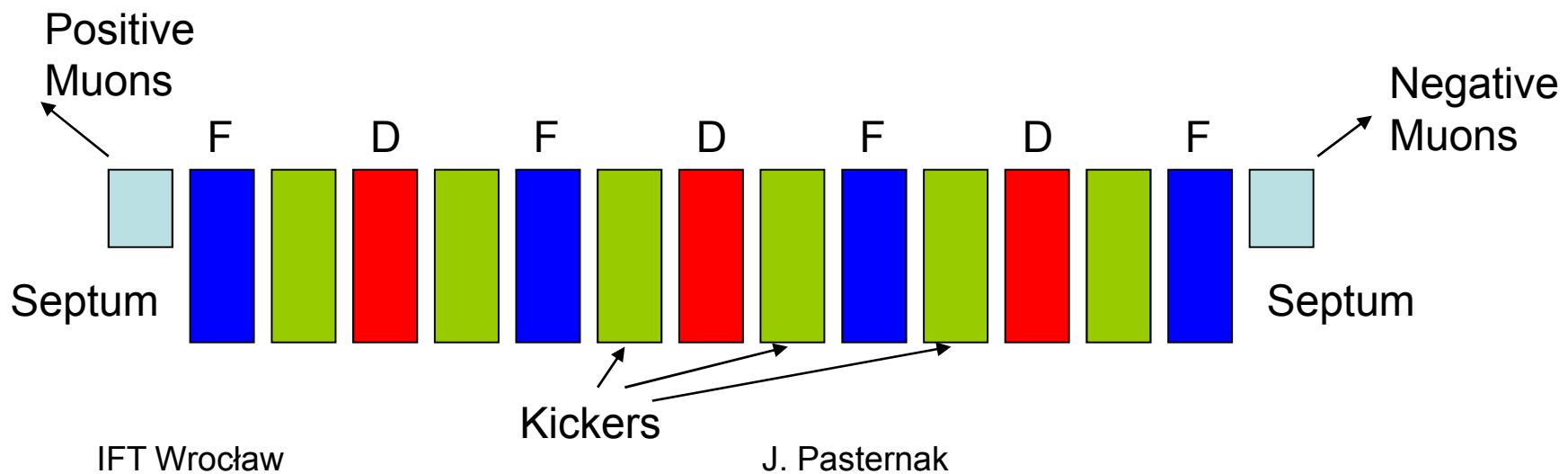
## IDS-NF FFAG Parameters

	FCDC	FDFCC	FDFC
Cells	68	60	80
D radius (mm)	94	102	87
D field (T)	6.4	7.9	7.0
F radius (mm)	200	144	115
F field (T)	3.1	4.0	4.0
Average Gradient (MV/m)	2.8	2.6	1.6
turns	9.0	13.0	17.3
Length (m)	521	393	479
Cost (A.U.)	170	155	142

# Introduction to injection/extraction

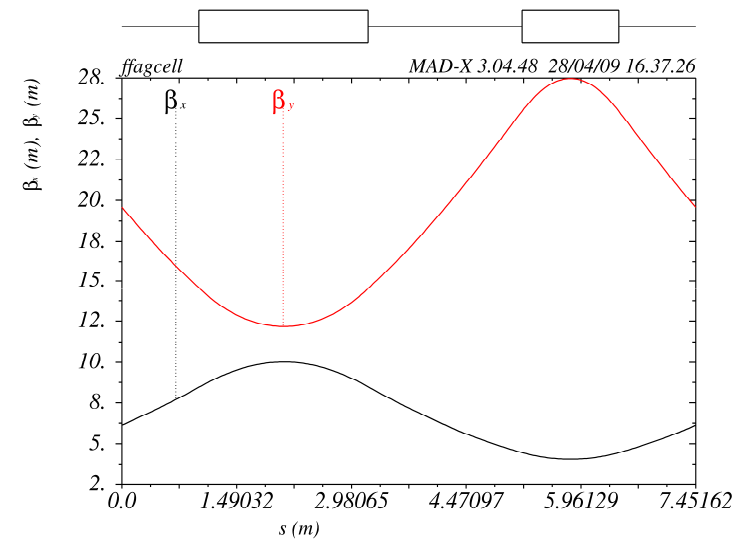
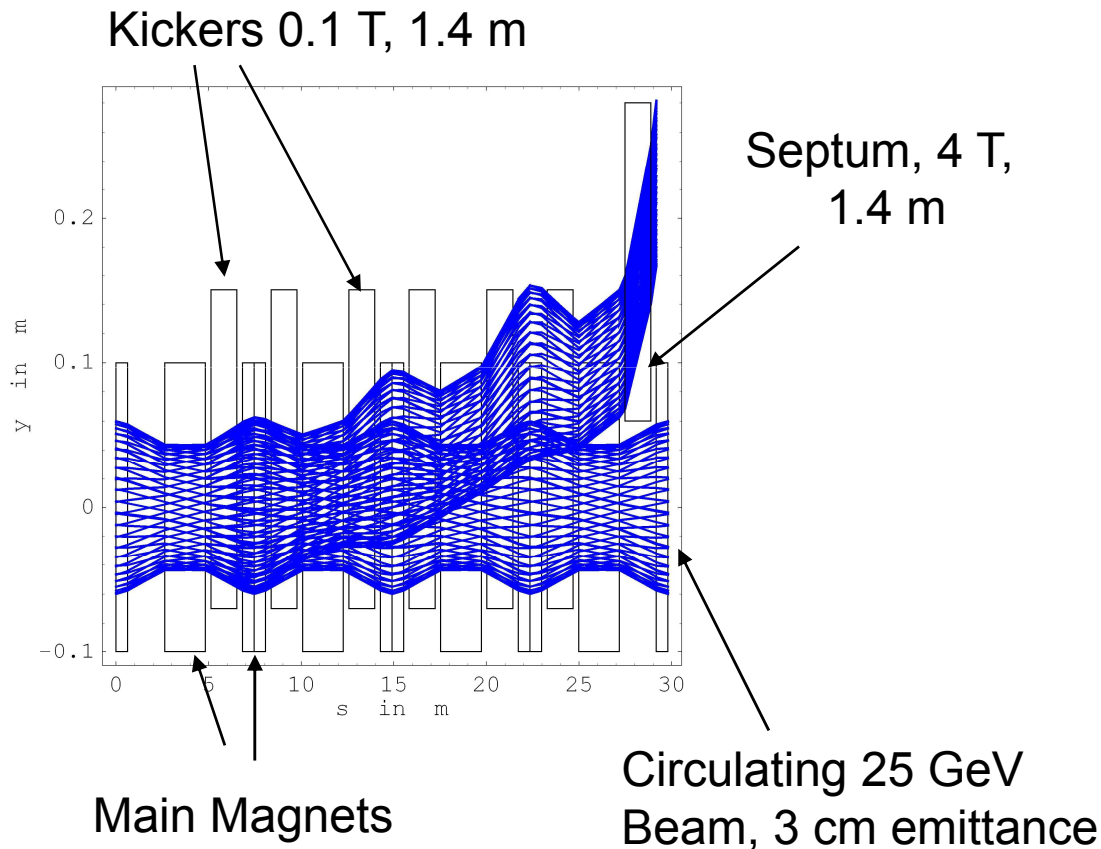
Working assumptions:

- Try to distribute kickers to reduce their strengths.
- Apply mirror symmetric solution to reuse kickers for both signs of muons.



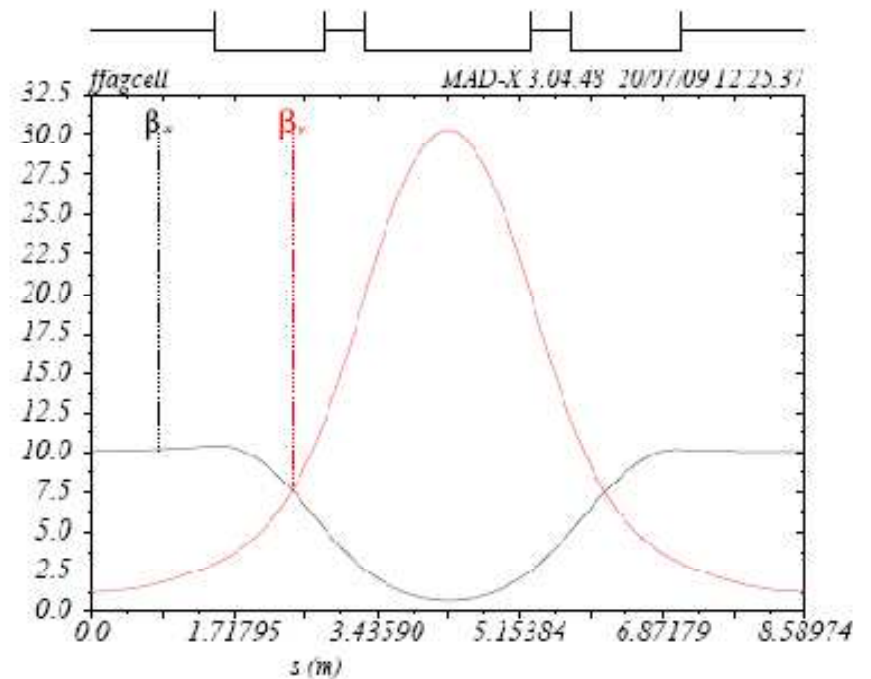
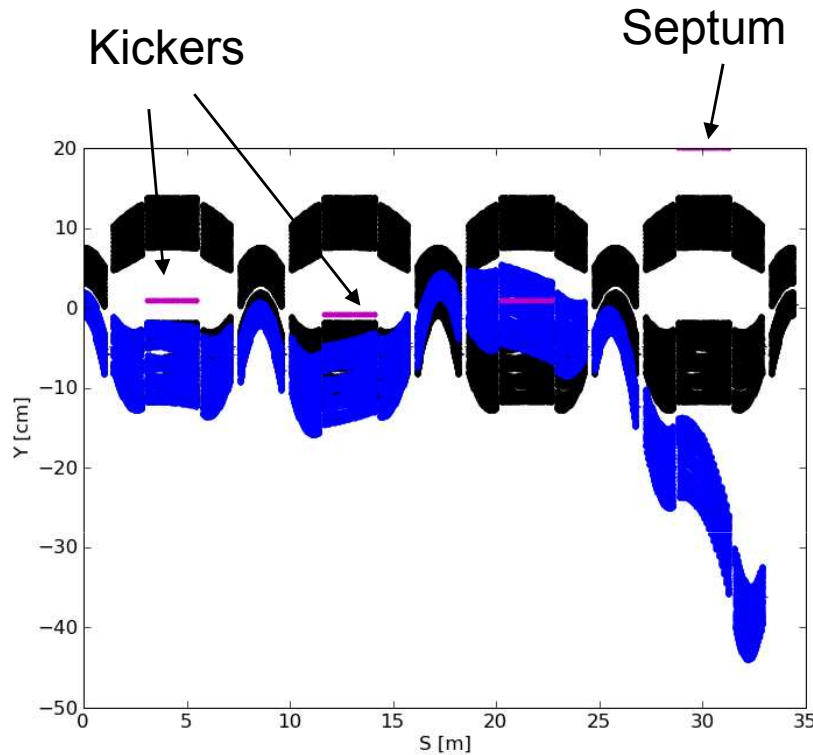
# Extraction from FODO ring

- No satisfactory solution was found in horizontal plane
- The scheme using vertical plane requires special magnets
- Symmetric for both signs.



Twiss functions in FODO at extraction

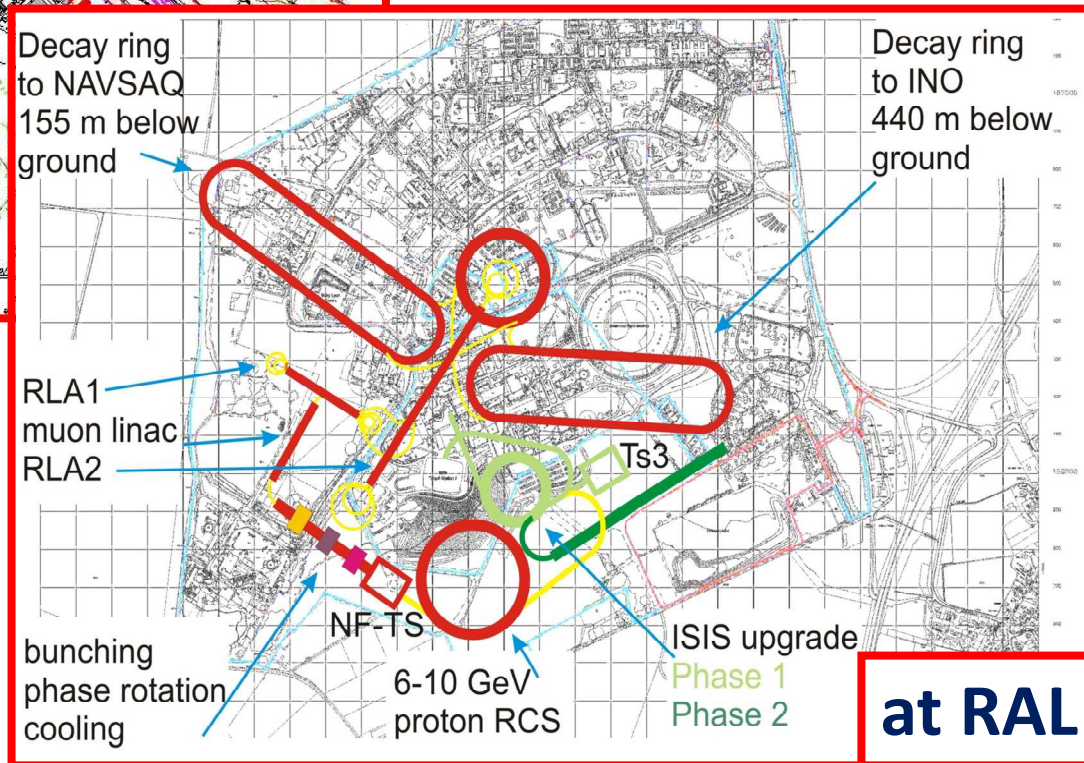
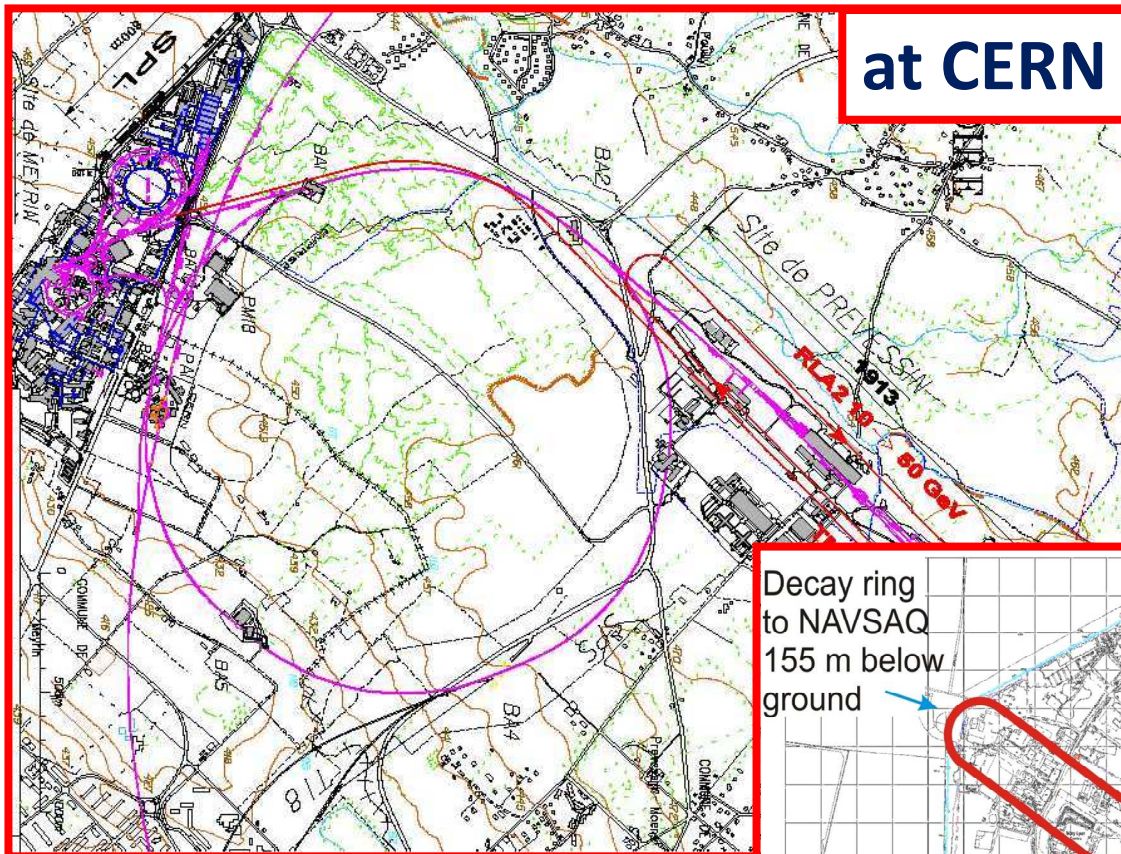
# Injection - Triplet



- Horizontal scheme is feasible in triplet.
- Scheme is less demanding with respect to special magnet needs.
- It uses 3 2.4 m long kickers at 0.0855 T and the 2.4 m long septum at 2 T.

In collaboration with D. Kelliher

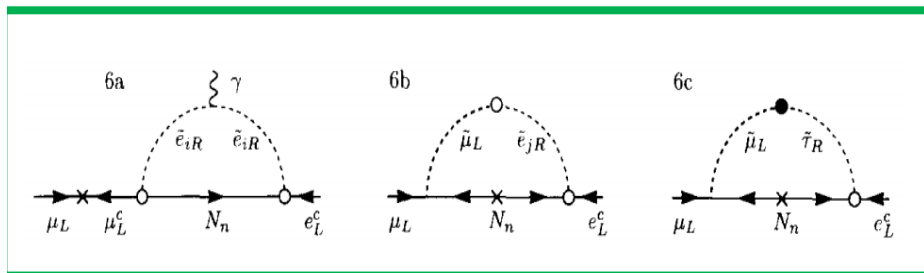
# Perspektywy na przyszłość



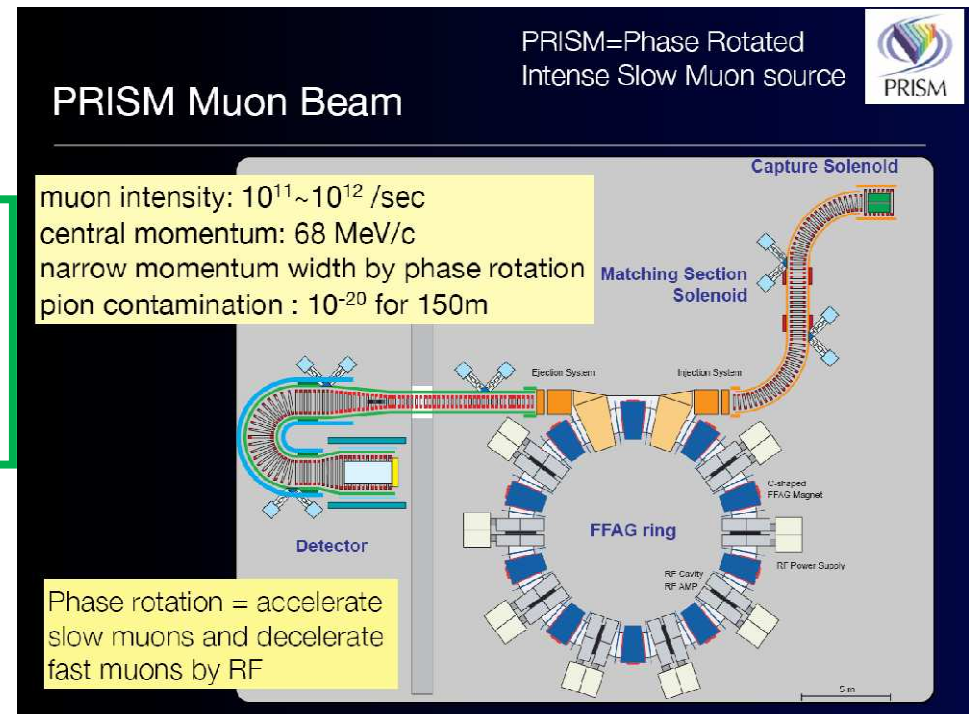


## Another Muon Beam Application: Search for cLFV:

- As charge lepton flavor violation (cLFV) is strongly suppressed in the Standard Model, its detection would be a clear signal for new physics!
- Search for cLFV is **complementary** to LHC.
- The  $\mu^- + N(A,Z) \rightarrow e^- + N(A,Z)$  seems to be the best laboratory for cLFV.
- The background is dominated by beam, which can be improved.
- The **COMET** and **Mu2e** were proposed.
- The **PRISM-FFAG** ring was proposed for a next generation experiment in order to:
  - reduce the muon beam energy spread by phase rotation,
  - purify the muon beam in the storage ring.



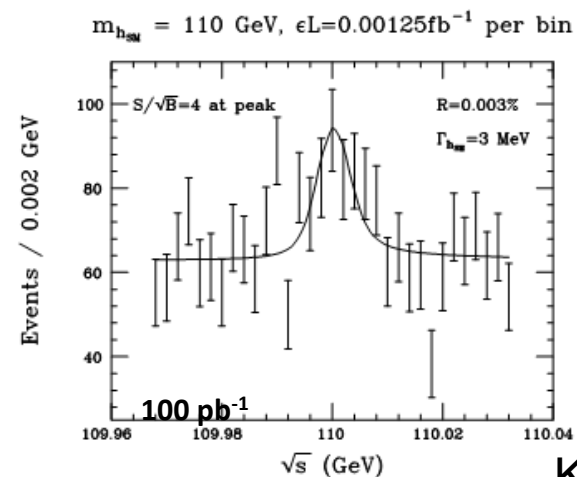
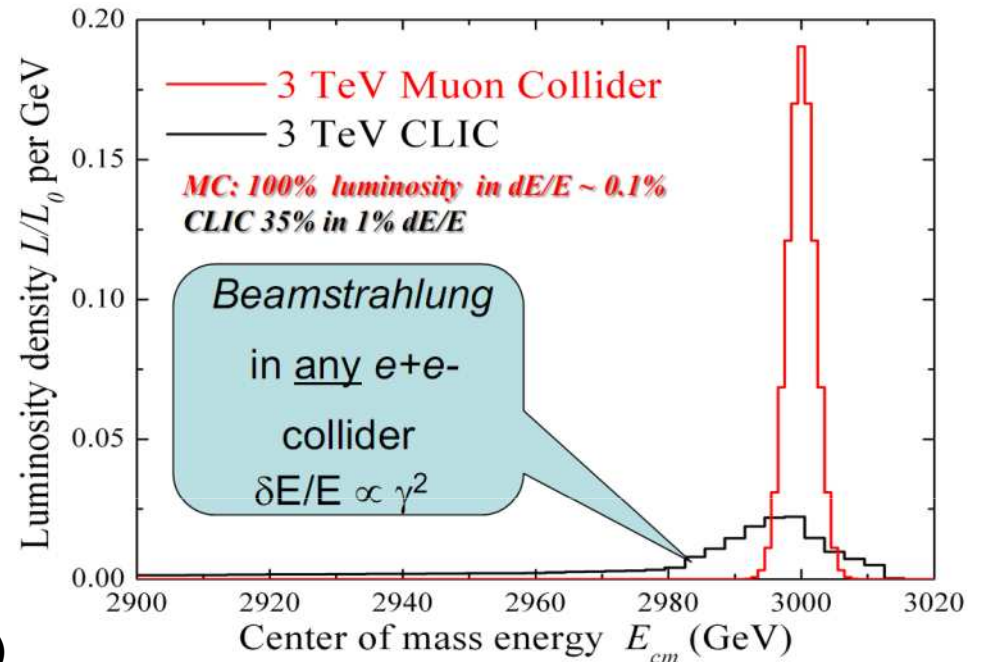
Important for supersymmetry search!



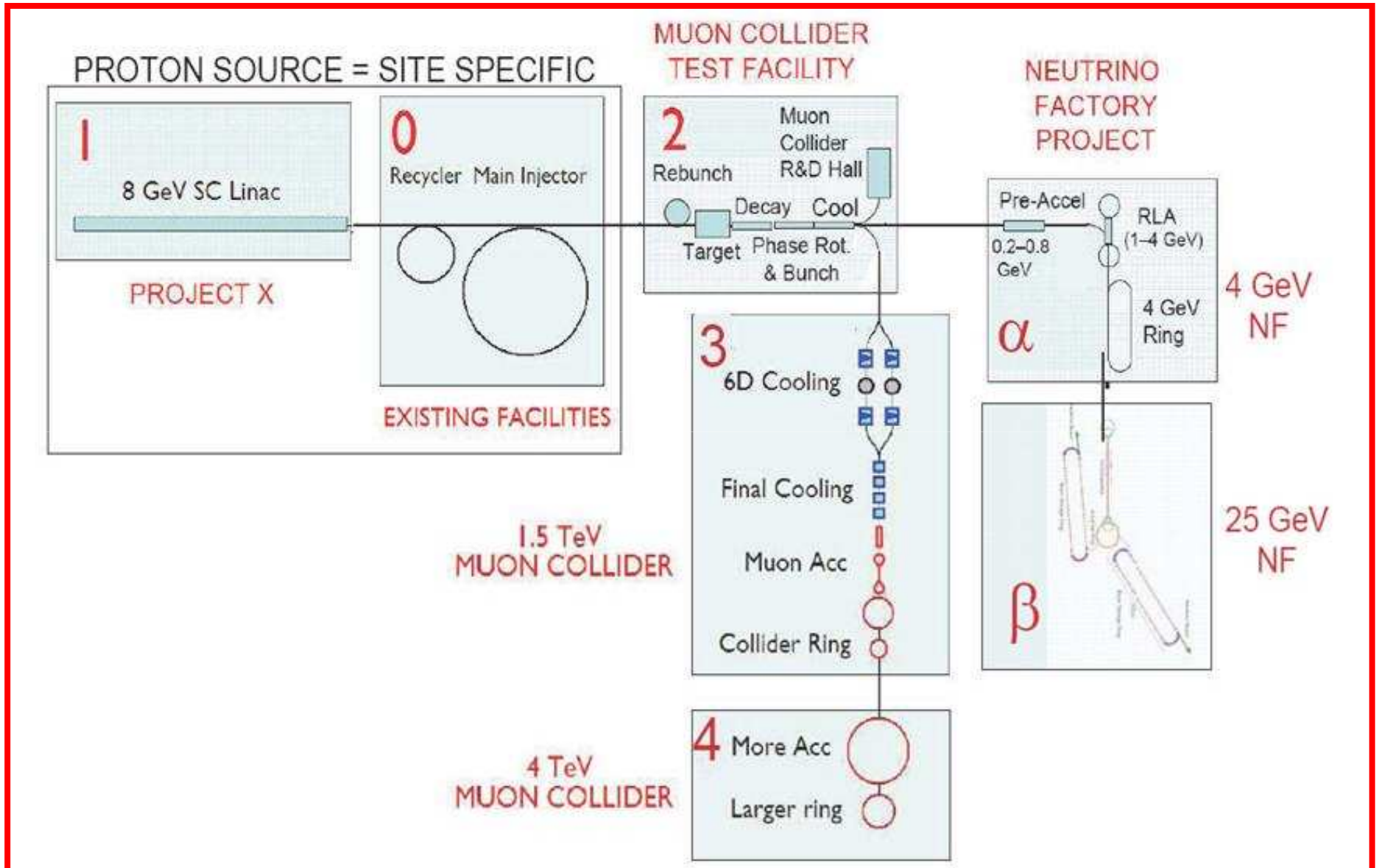
# Next step - Muon Collider: Why?

- Muon mass:  $106 \text{ MeV}/c^2$
- Consequences:
  - Negligible synchrotron radiation at Muon Collider:
    - Rate  $\propto m^4$ :  
 $\Rightarrow$  Muon Collider reduction factor:  $5 \times 10^{-10}$
    - Compact, *circular*, accelerator
    - Small energy spread
    - Possible to preserve polarisation at  $\sim 30\%$  level
      - Yields possibility to determine beam energy precisely (0.003%) using  $(g-2)$  precession
  - Strong coupling to Higgs:
    - Production rate  $\propto m^2$ :  
 $\Rightarrow$  Muon Collider enhancement factor:  $5 \times 10^4$
    - Large data set allows branching ratios to be measured

Electron mass:  $0.511 \text{ MeV}/c^2$



# Scenariusze rozwoju akceleratorów mionowych w Fermilab-ie:



# Podsumowanie

- Prace nad Fabryką Neutrin trwają.
- Niskoenergetyczna FN to interesująca alternatywa.
- Czekamy na wyniki obecnych eksperymentów!
- Konceptyjny projekt FN będzie gotowy w 2012.
- Przyszłość akceleratorów mionowych zapowiada się interesująco!