The Beta-beam

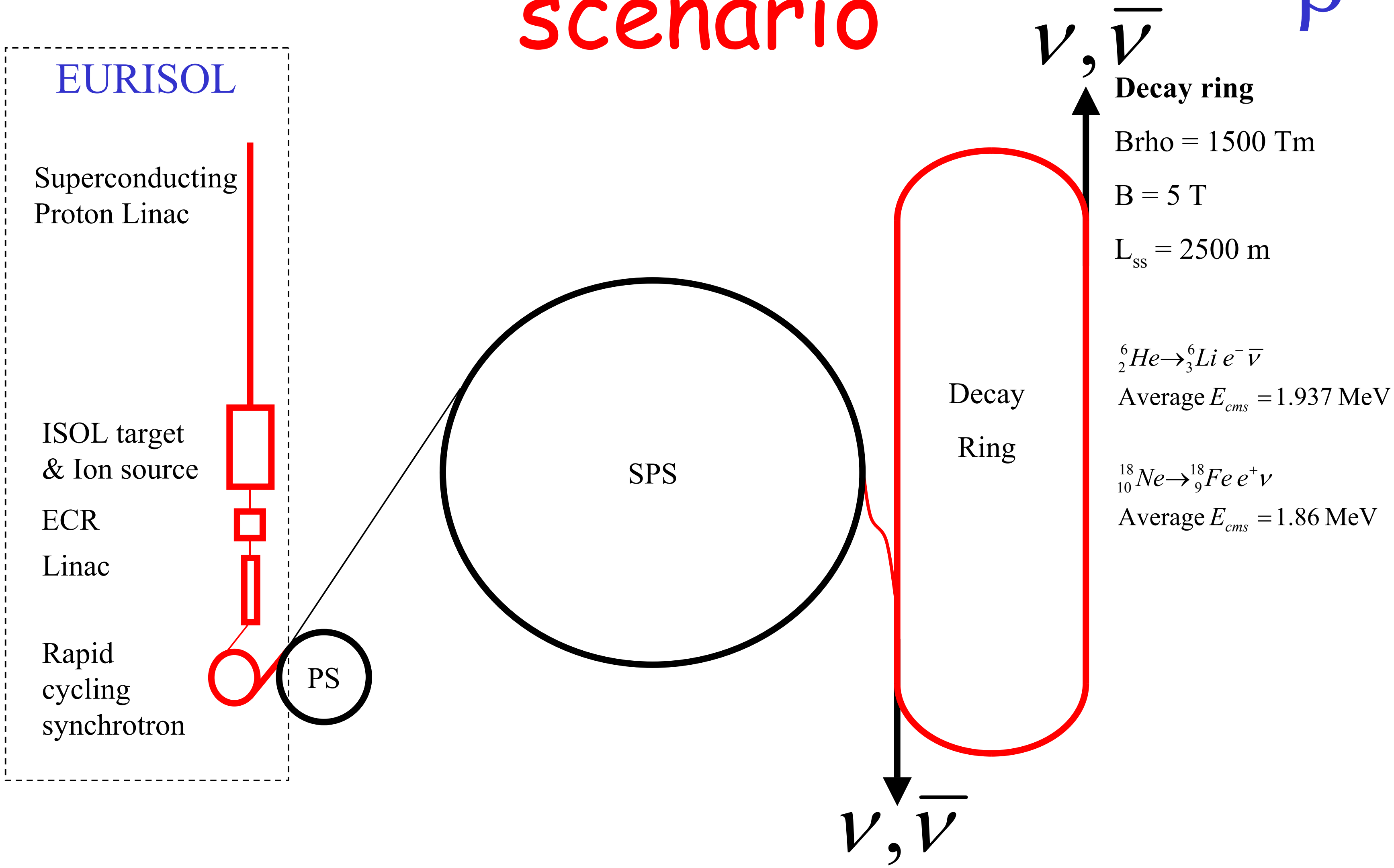
http://beta-beam.web.cern.ch/beta-beam/

The beta-beam study group

The beta-beam

- Idea by Piero Zuchelli, CERN
- The CERN base line scenario
  - Avoid anything that requires a "technology jump" which would cost time and money (and be risky)
  - Make use of a maximum of the existing infrastructure
  - If possible find an "existing" detector site

CERN: β-beam baseline scenario



Conceptual design: decay ring

^{6}Helium^{2+}

- Intensity: 1.0×10^{14} ions
- Energy: 139 GeV/u
- Rel. gamma: 150
- Rigidity: 1500 Tm

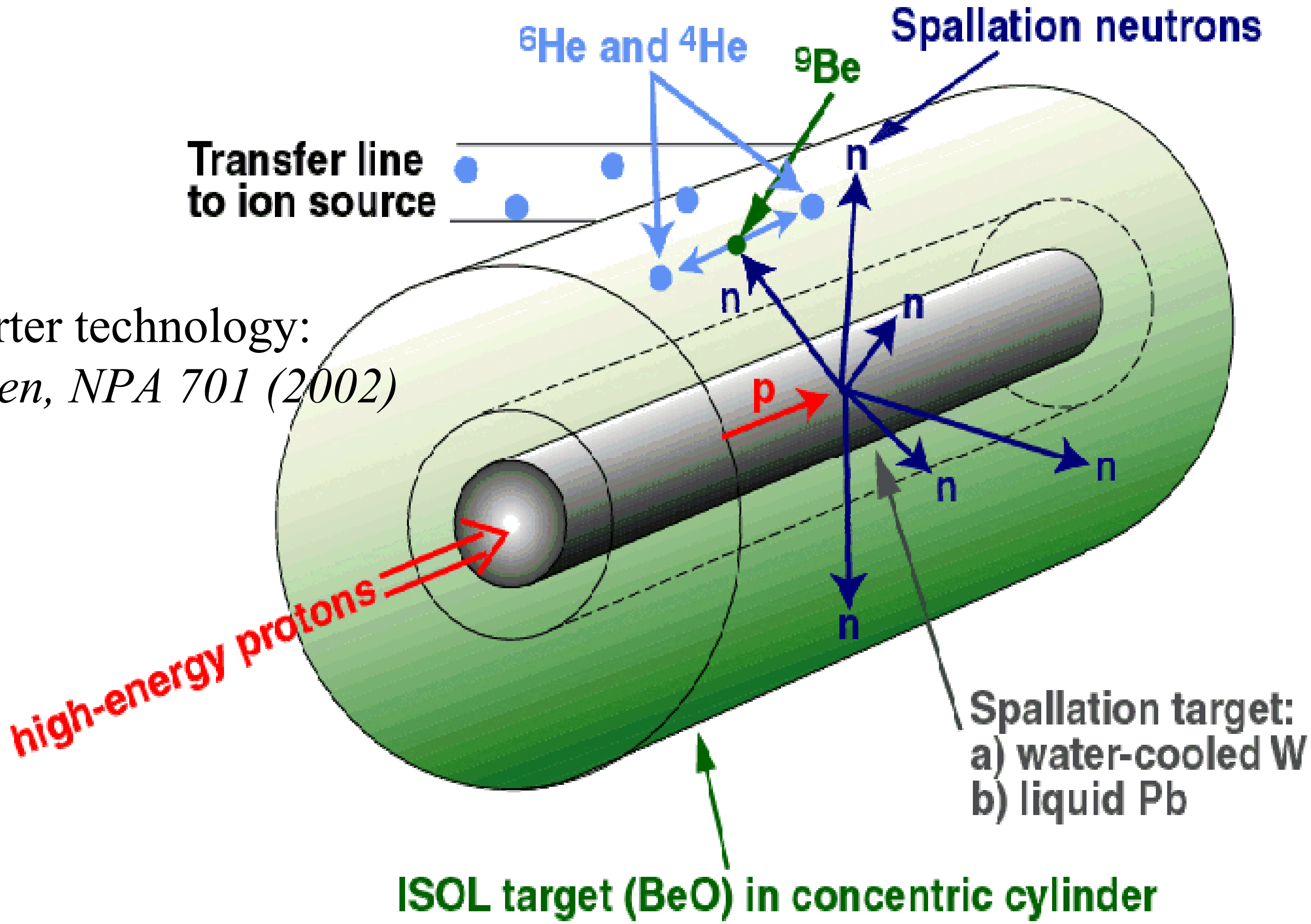
^{18}Neon^{10+} (single target)

- Intensity: 4.5×10^{12} ions
- Energy: 55 GeV/u
- Rel. gamma: 60
- Rigidity: 335 Tm

- The neutrino beam at the experiment should have the "time stamp" of the circulating beam in the decay ring.
- The beam has to be concentrated to as few and as short bunches as possible to maximize the number of ions/nanosecond. (background suppression), duty factor 10^{-4}

^{6}He production by ^{9}Be(n,a)

Converter technology:
(*J. Nolen, NPA 701 (2002) 312c)*



Layout very similar to planned EURISOL converter target aiming for 10^{15} fissions per s.

Production of β^+ emitters

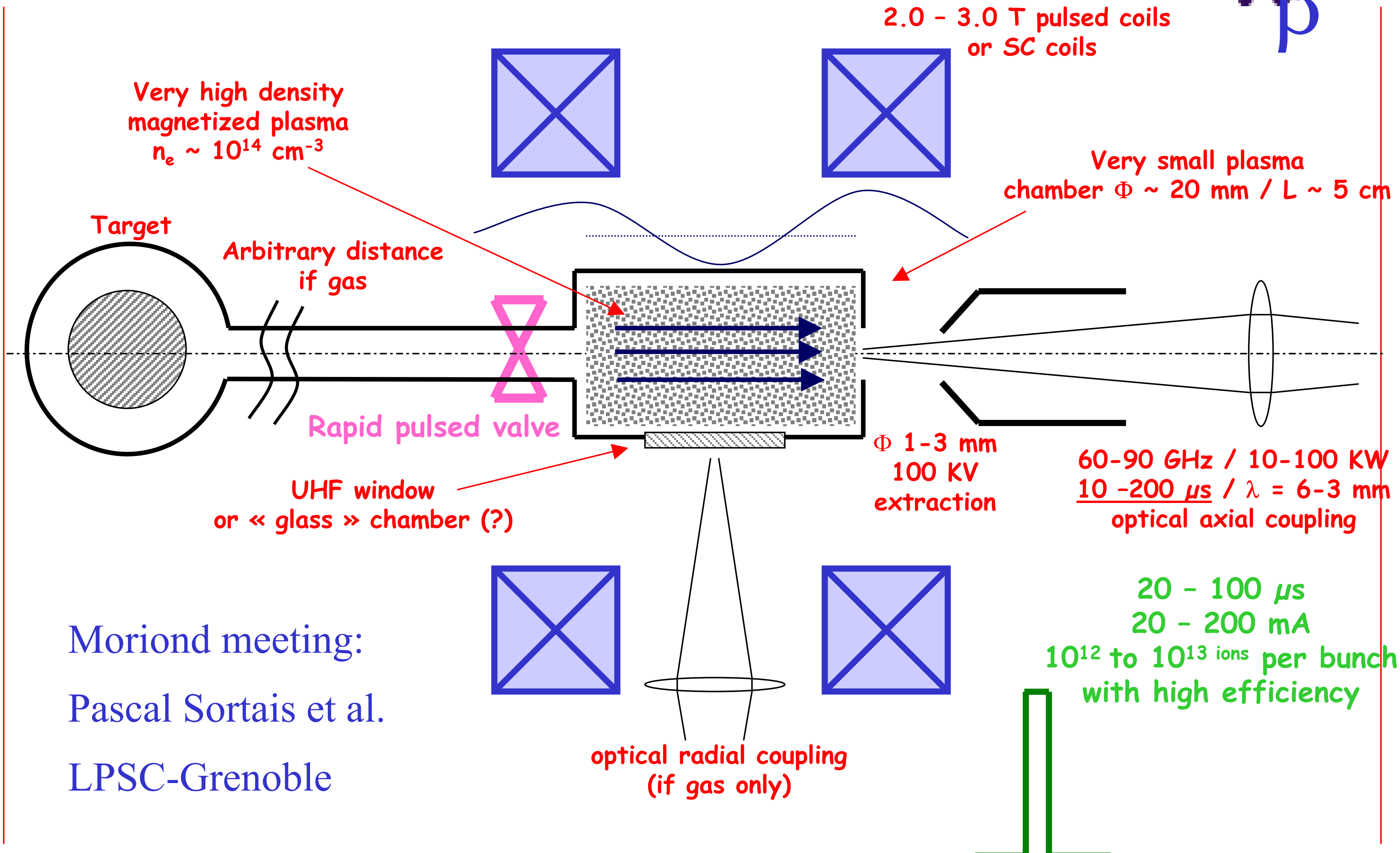
Scenario 1

- **Spallation of close-by target nuclides:**
  $^{18,19}Ne$ from MgO and $^{34,35}Ar$ in CaO
  – **Production rate for ^{18}Ne is $1 \times 10^{12}\ s^{-1}$ (with 2.2 GeV 100 μA proton beam, cross-sections of some mb and a 1 m long oxide target of 10% theoretical density)**
  – **^{19}Ne can be produced with one order of magnitude higher intensity but the half life is 17 seconds!**

Scenario 2

- **alternatively use (α,n) and (^3He,n) reactions:**
  $^{12}C(^{3,4}He,n)^{14,15}O$, $^{16}O(^{3,4}He,n)^{18,19}Ne$, $^{32}S(^{3,4}He,n)^{34,35}Ar$
  – **Intense $^{3,4}He$ beams of 10-100 mA 50 MeV are required**

60-90 GHz « ECR Duoplasmatron » for pre-bunching of gaseous RIB

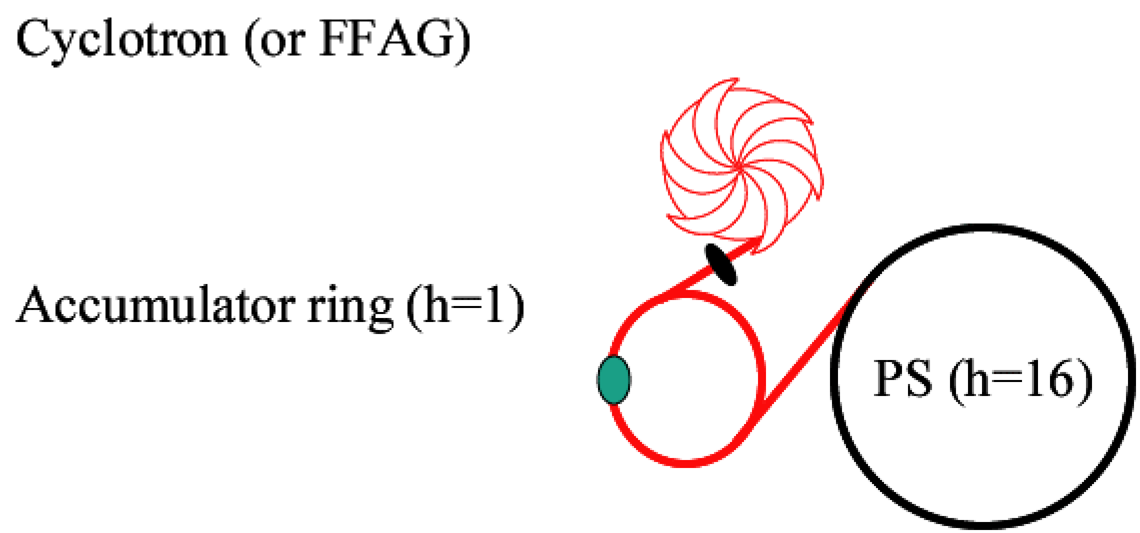


Moriond meeting:

Pascal Sortais et al.

LPSC-Grenoble

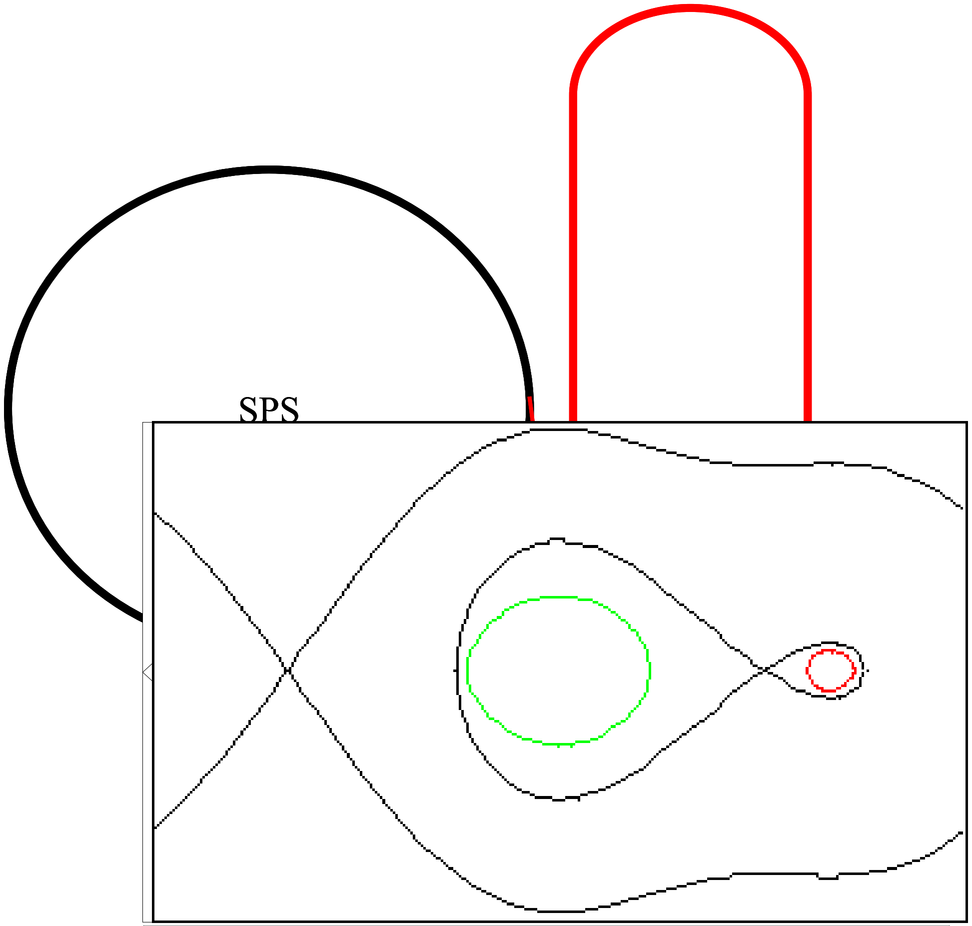
Overview: Accumulation



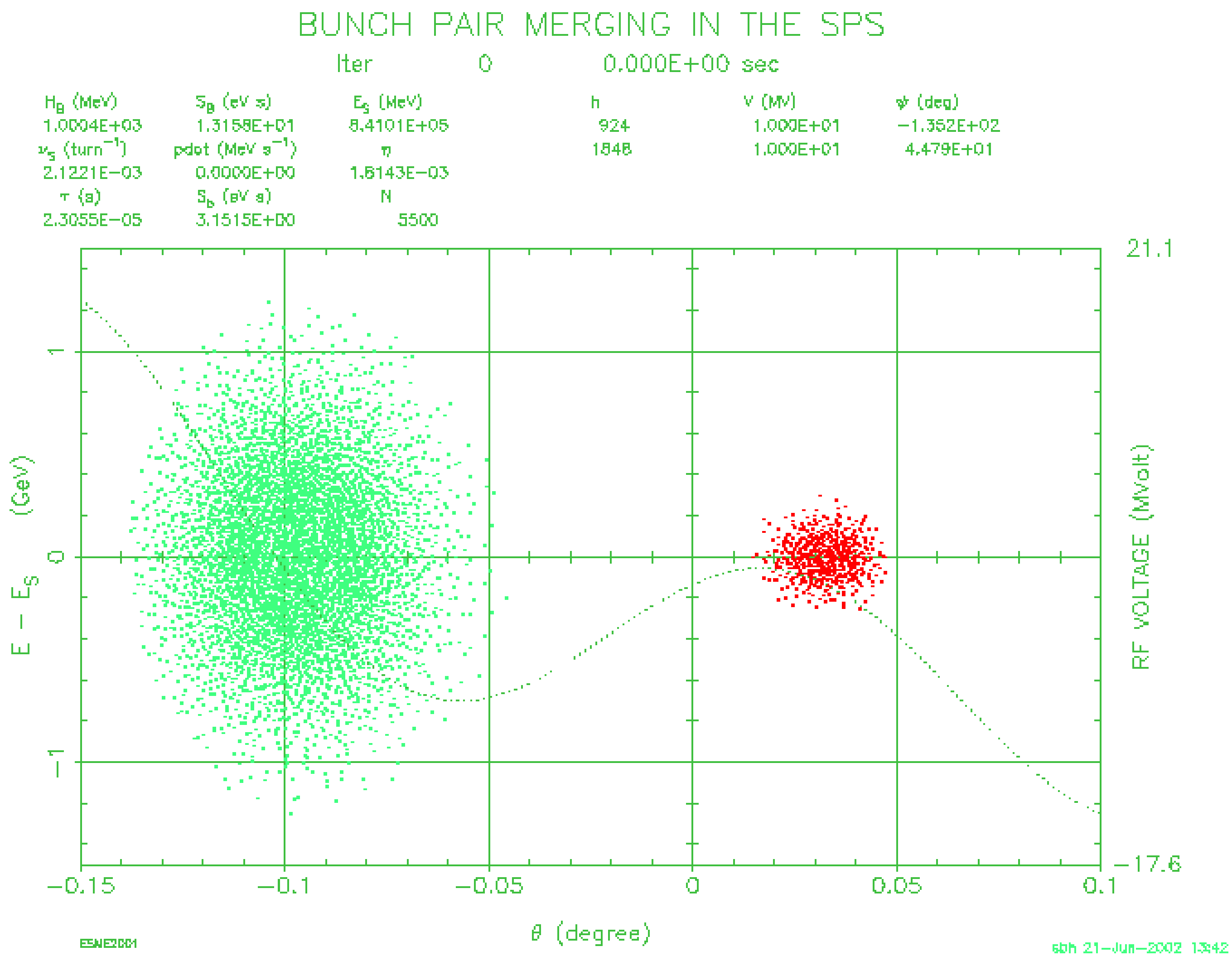
- Sequential filling of 16 buckets in the PS from the storage ring

Stacking in the Decay ring

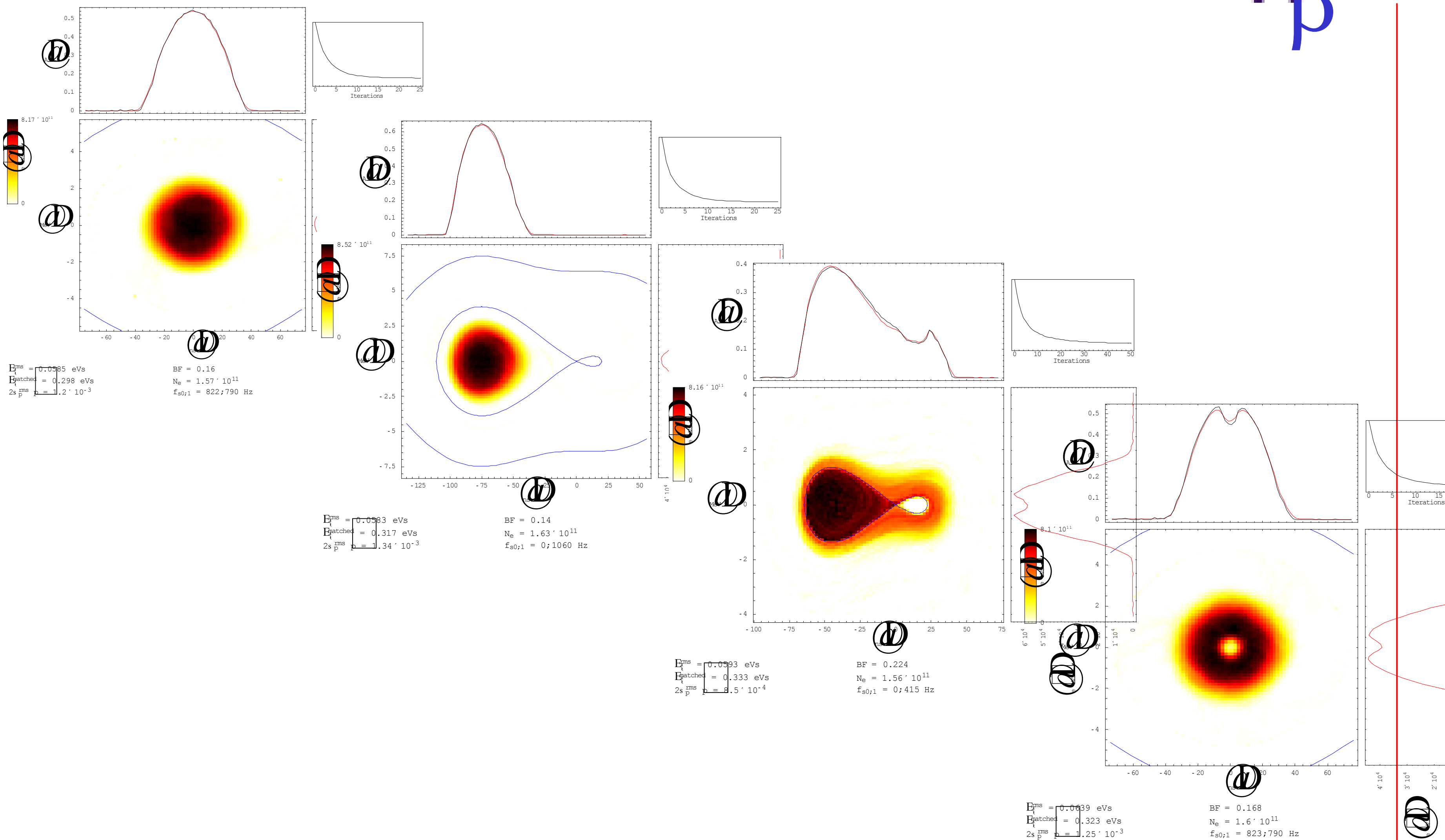
- Ejection to matched dispersion trajectory
- Asymmetric bunch merging



Asymmetric bunch merging



Asymmetric bunch merging



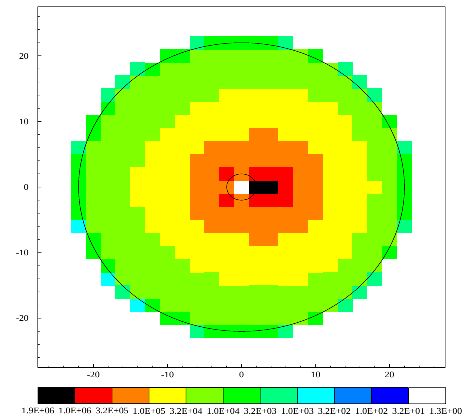
Decay losses

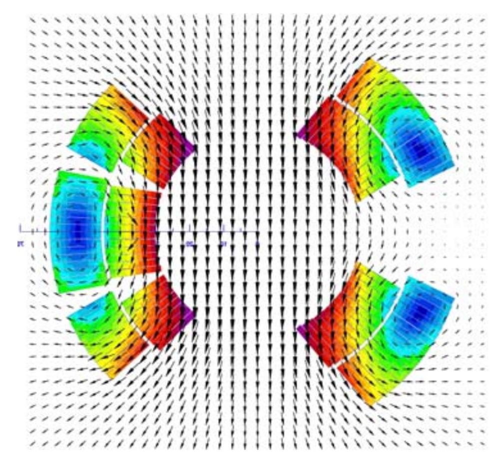
- Losses during acceleration are being studied:
  - Full FLUKA simulations in progress for all stages (M. Magistris, CERN-TIS)
  - Preliminary results:
    - Can be managed in low energy part
    - PS will be heavily activated
      - New fast cycling PS?
    - SPS OK!
    - Full FLUKA simulations of decay ring losses:
      - Tritium and Sodium production surrounding rock well below national limits
      - Reasonable requirements of concreting of tunnel walls to enable decommissioning of the tunnel and fixation of Tritium and Sodium

A. Jansson

SC magnets

- Dipoles can be built with no coils in the path of the decaying particles to minimize peak power density in superconductor
  - The losses have been simulated and a first dipole design has been proposed

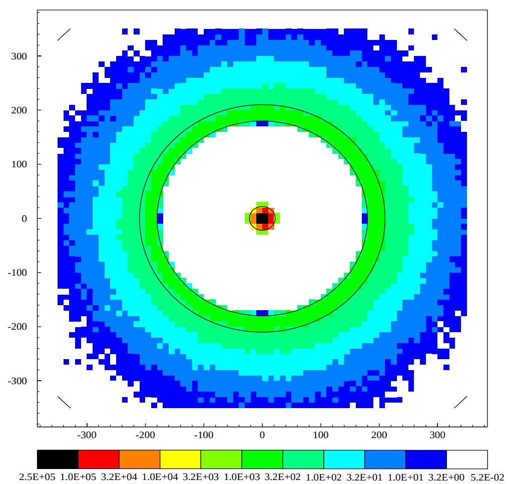




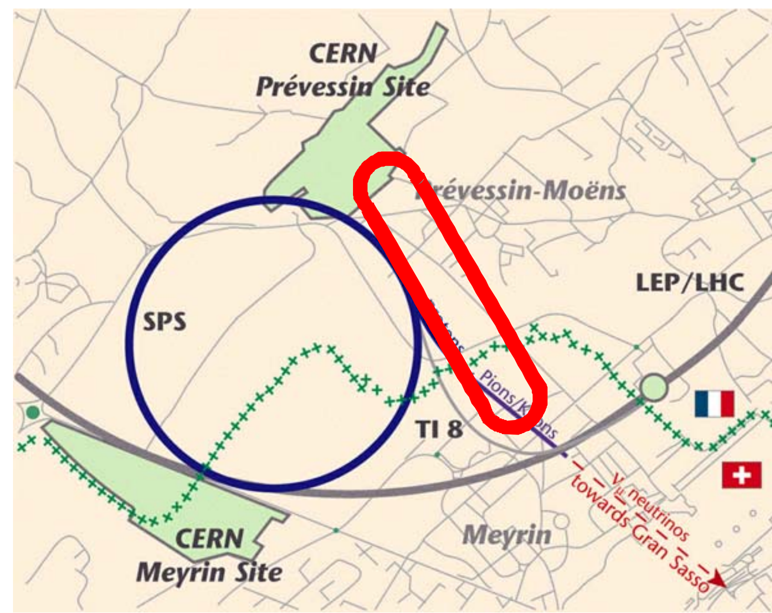
S. Russenschuck, CERN

Tunnels and Magnets

- Civil engineering costs: Estimate of 400 MCHF for 1.3% incline (13.9 mrad)
  - Ringlenth: 6850 m, Radius=300 m, Straight sections=2500 m
- Magnet cost: First estimate at 100 MCHF



FLUKA simulated losses in surrounding rock (no public health implications)



Intensities

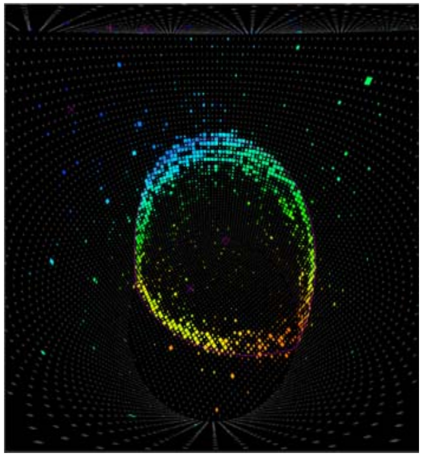
Stage	^{6}He	^{18}Ne (single target)
From ECR source:	2.0×10^{13} ions per second	0.8×10^{11} ions per second
Storage ring:	1.0×10^{12} ions per bunch	4.1×10^{10} ions per bunch
Fast cycling synch:	1.0×10^{12} ion per bunch	4.1×10^{10} ion per bunch
PS after acceleration:	1.0×10^{13} ions per batch	5.2×10^{11} ions per batch
SPS after acceleration:	0.9×10^{13} ions per batch	4.9×10^{11} ions per batch
Decay ring:	2.0×10^{14} ions in four 10 ns long bunch	9.1×10^{12} ions in four 10 ns long bunch

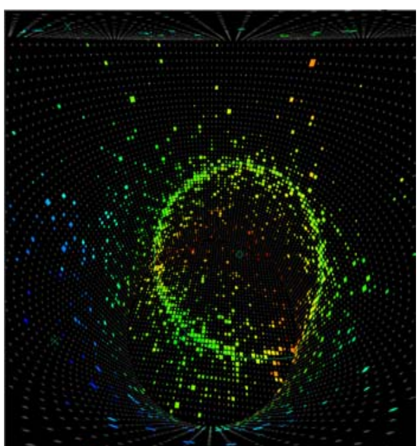
Only β-decay losses accounted for, add efficiency losses (50%)

Required R&D

- Production of RIB
  - Simulations (GEANT)
  - Target design, only 100 kW primary proton beam in present design
- Pre-bunching of high intensity ion beams
  - 60 GHz ECR source
- Superconducting dipoles
  - Pulsed for new PS/SPS (GSI study)
  - High field dipoles for decay ring to reduce arc length
  - Radiation hardness

Combination of beta beam with low energy super beam





Unique to CERN:

combines CP and T violation tests

$$\nu_e \rightarrow \nu_\mu \quad (\beta+) \quad \Leftrightarrow \boxed{T} \Leftrightarrow \quad \nu_\mu \rightarrow \nu_e \quad (\pi^+)$$

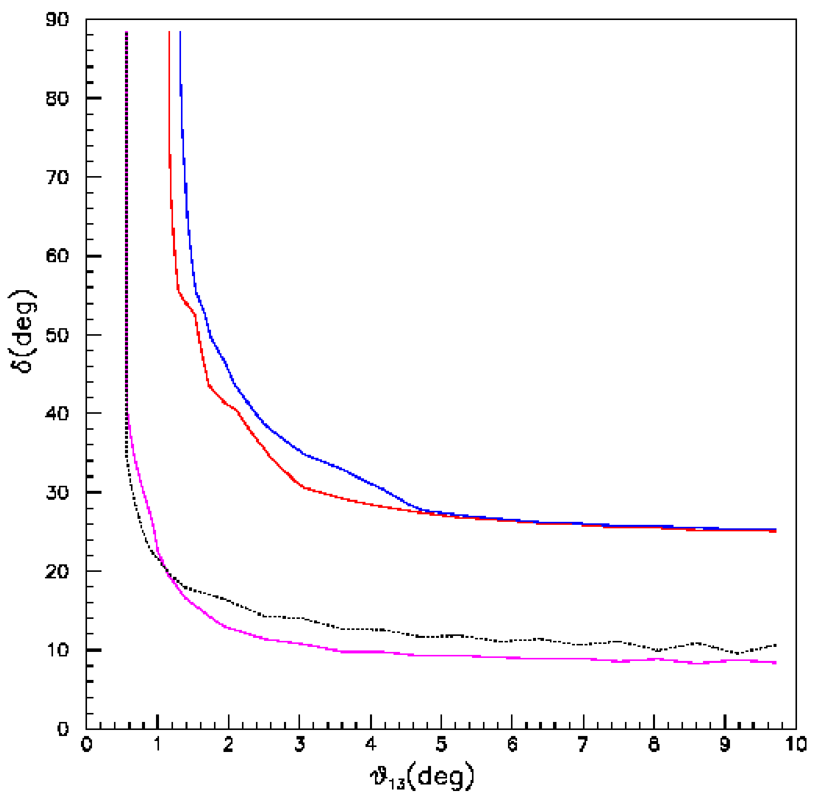
$$\Updownarrow \boxed{CP} \qquad\qquad\qquad\qquad \Updownarrow \boxed{CP}$$

$$\bar{\nu}_e \rightarrow \bar{\nu}_\mu \quad (\beta-) \quad \Leftrightarrow \boxed{T} \Leftrightarrow \quad \bar{\nu}_\mu \rightarrow \bar{\nu}_e \quad (\pi^-)$$

A. Blondel

Higher gamma?

- New detector site or new site for beta-beam facility
  - GSI-FREJUS, 600 km
  - RAL-FREJUS, 1000 km
- Increased physics reach
  - J. Burguet, D. Casper, F. García, P. Hernández, JJ. Gomez Cadenas
- Reduction of atmospheric background
  - Increase in duty factor, at least 10^{-2}
  - Detailed calculations for the required duty factor in progress



Design study

- EURISOL
  - European nuclear physics proposal for Isotope Separation On-Line facility with proton driver
    - Hot thick targets – RIB produced at rest
    - High intensities of RIB
  - Studied in EU 5^{th} framework program
  - Proposed as design study in EU 6^{th} Framework program
- Decision by NUPECC, ESGARD and EMCOG to merge the beta-beam design study and EURISOL

EURISOL DESIGN STUDY
"Three orders of magnitude better "

Production of an **Engineering Oriented Design** (**EOD**), of the facility, in particular in relation to its **most technologically advanced aspect**" (i.e. excluding the detailed design of standard elements of the infrastructure)

- TDR for ISOL and Nuclear Structure facility
- CDR for beta-beam

Carrying out the **Technical Preparatory Work** (**TPW**) related to components, subsystems, material or techniques (dedicated software is included) that are **critical** for the future development of the new facility

EURISOL tasks

TASKS	Leader	Topics	Contact Personn Management board
2) Liquid Metal Target/Ion Source 1^+	H. Ravn	TAR	P. Butler
3) Direct Target/Ion-Source 1^+	J. Lettry	TAR	P. Butler
4) Solid Converter Target/Ion-Source 1^+	L. Tecchio	TAR	P. Butler
5) Safety & Radioprotection	D. Ridikas	ISS	Y. Blumenfeld
6) Heavy-Ion Accelerator Design	M-H. Moscatello	ACC	G. Fortuna
7) Proton Accelerator Design	A. Facco	ACC	G. Fortuna
8) SC Cavity Development	S. Bousson	ACC	G. Fortuna
9) Beam Preparation	A. Jokinen	BBB	M. Lindroos
10) Physics and Instrumentation	R. Page	ISS	Y. Blumenfeld
11) Beam Intensity Calculations	K.H. Schmidt	ISS	Y. Blumenfeld
12) Beta Beams Aspects	M. Benedikt	BBB	M. Lindroos

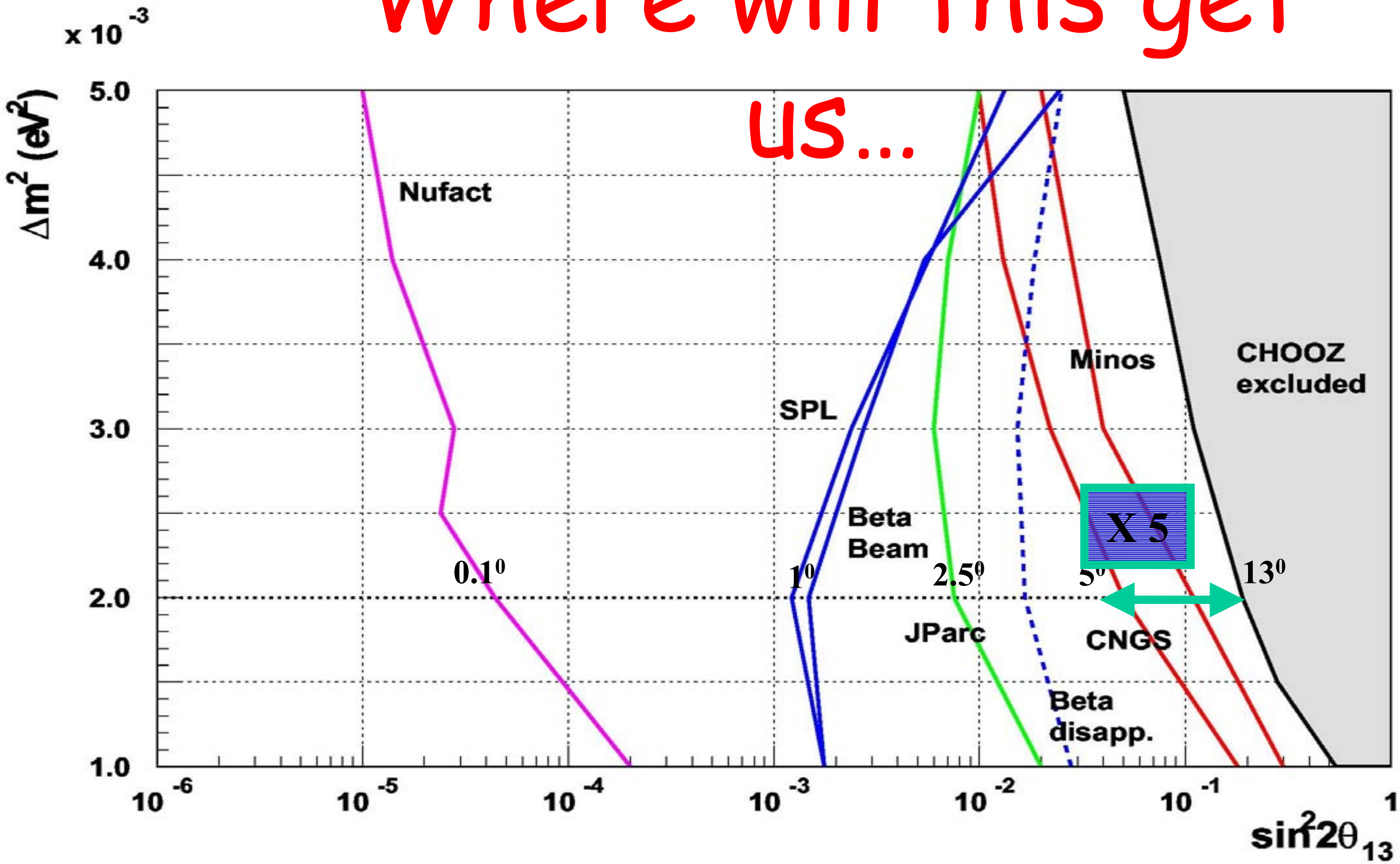
Conclusions

- Physics:
  - Super beam, beta-beam and FREJUS: *A possibility for neutrino physics!*
  - EURISOL/beta-beam design study proposal submitted
  - Low energy beta-beam: Nuclear Physics!
- Workshop on Exploring the Impact of New Neutrino Beams, ECT*, Trento, Italy, *18-22 October 2004*, (C. Volpe, J. Bouchez, M. Lindroos, M. Mezzetto, T. Nilsson)

Collaborators

- The beta-beam study group:
  - **CEA, France:** Jacques Bouchez, Saclay, Paris Olivier Napoly, Saclay, Paris Jacques Payet, Saclay, Paris
  - **CERN, Switzerland:** Michael Benedikt, AB Peter Butler, EP Roland Garoby, AB Steven Hancock, AB Ulli Koester, EP Mats Lindroos, AB Matteo Magistris, TIS Thomas Nilsson, EP Fredrik Wenander, AB
  - **Geneva University, Switzerland:** Alain Blondel Simone Gilardoni
  - **GSI, Germany:** Oliver Boine-Frankenheim B. Franzke R. Hollinger Markus Steck Peter Spiller Helmuth Weick
  - **IFIC, Valencia:** Jordi Burguet Juan-Jose Gomez-Cadenas Pilar Hernandez
  - **IN2P3, France:** Bernard Laune, Orsay, Paris Alex Mueller, Orsay, Paris Pascal Sortais, Grenoble Antonio Villari, GANIL, CAEN Cristina Volpe, Orsay, Paris
  - **INFN, Italy:** Alberto Facco, Legnaro Mauro Mezzetto, Padua Vittorio Palladino, Napoli Andrea Pisent, Legnaro Piero Zucchelli, Sezione di Ferrara
  - **Louvain-la-neuve, Belgium:** Thierry Delbar Guido Ryckewaert **UK:** Marielle Chartier, Liverpool university Chris Prior, RAL and Oxford university
  - **Uppsala university, The Svedberg laboratory, Sweden:** Dag Reistad
  - **Associate:** Rick Baartman, TRIUMF, Vancouver, Canada Andreas Jansson, Fermi lab, USA

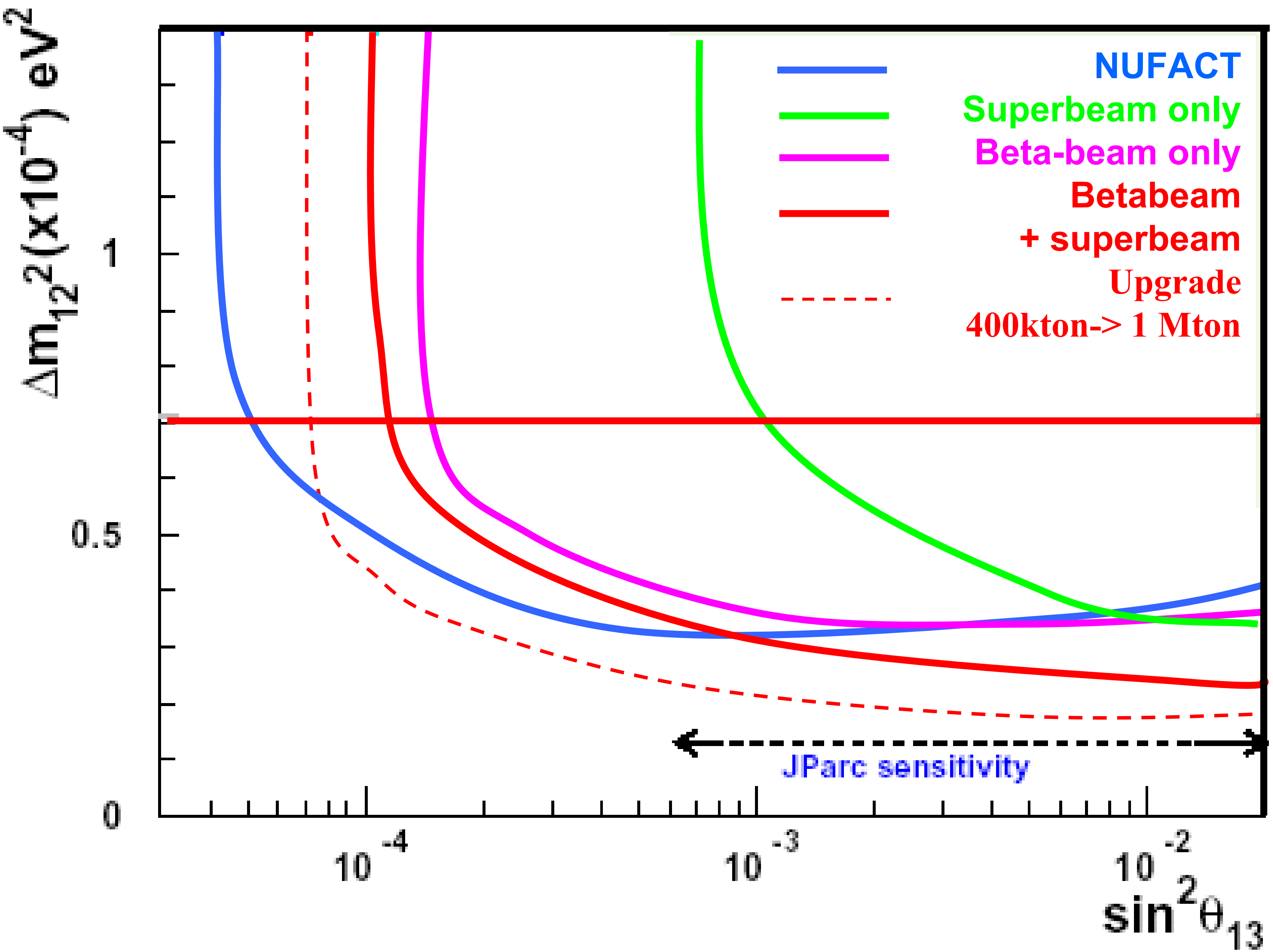
Where will this get us…

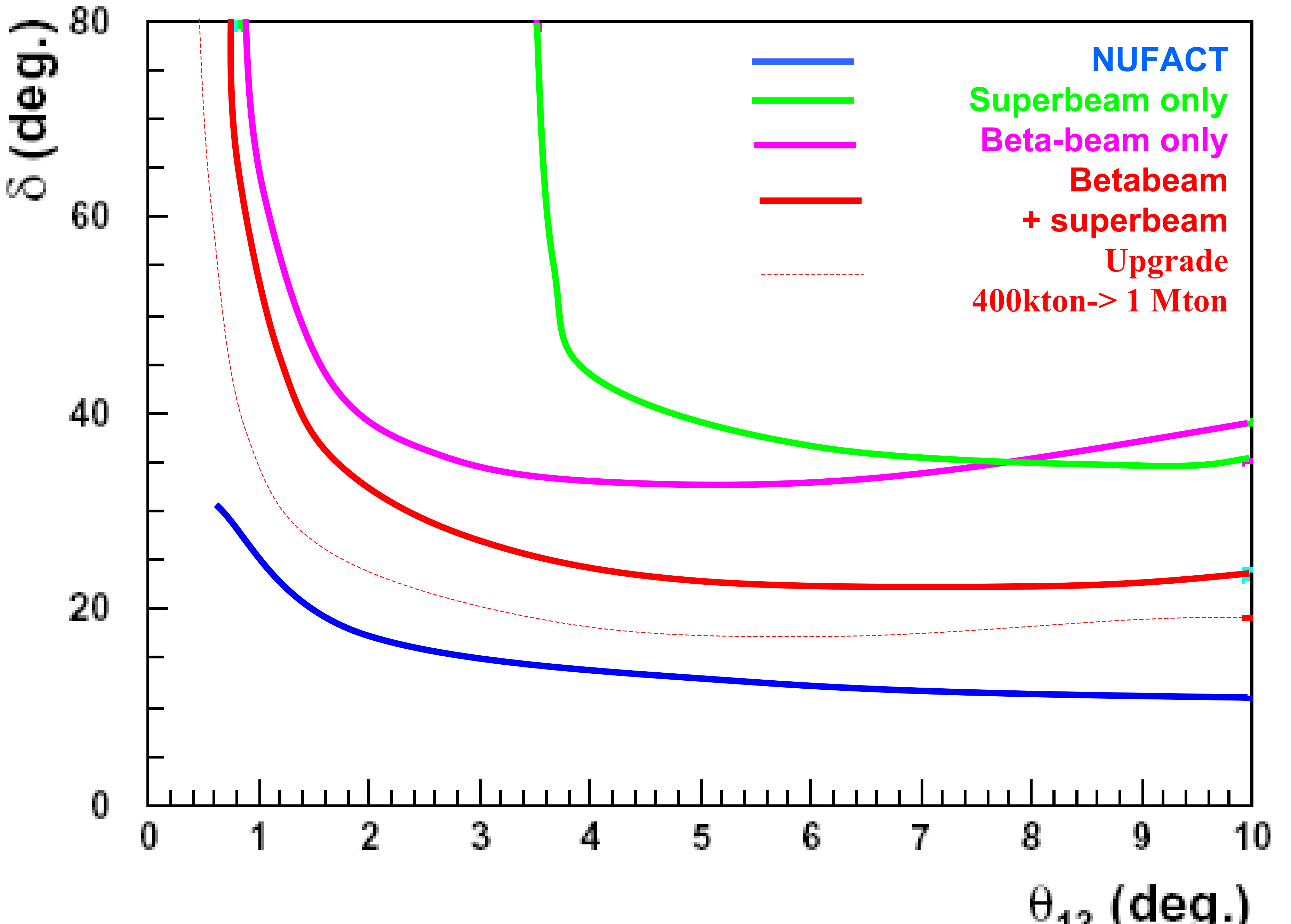


Mezzetto

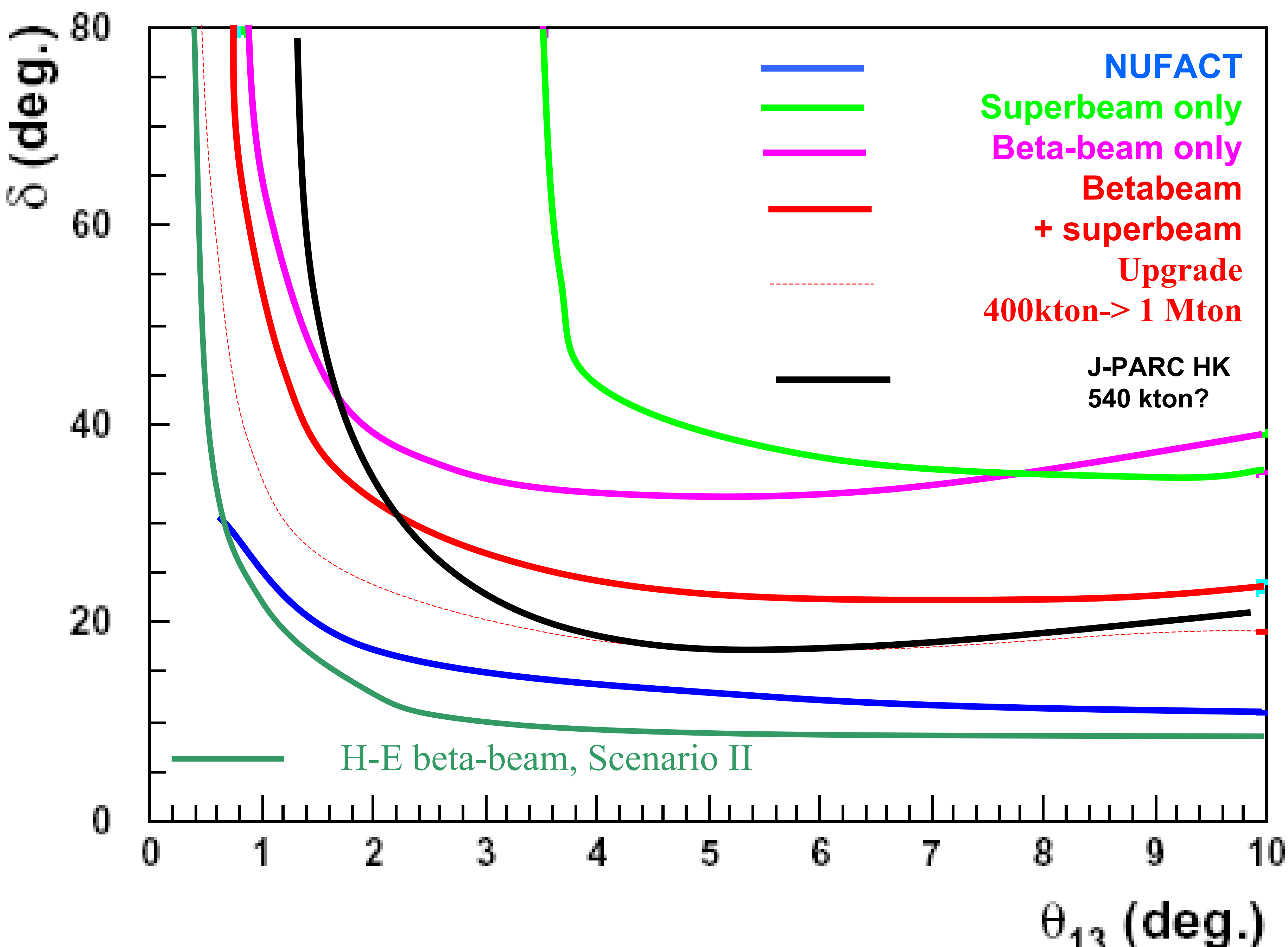
comparison of reach in the oscillations; right to left:
present limit from the CHOOZ experiment,
expected sensitivity from the MINOS experiment, CNGS (OPERA+ICARUS)
0.75 MW JHF to super Kamiokande with an off-axis narrow-band beam,
Superbeam: 4 MW CERN-SPL to a 400 kton water Cerenkov in Fréjus (J-PARC phase II similar)
from a Neutrino Factory with 40 kton large magnetic detector.

Area of phase space in which CP violation can be seen (Mezzetto)





NUFACT
Superbeam only
Beta-beam only
Betabeam
+ superbeam
Upgrade
400kton-> 1 Mton
δ (deg.)
θ13 (deg.)
0
20
40
60
80
0
1
2
3
4
5
6
7
8
9
10


δ (deg.)
80
60
40
20
0
0
1
2
3
4
5
6
7
8
9
10
θ13 (deg.)
NUFACT
Superbeam only
Beta-beam only
Betabeam
+ superbeam
Upgrade
400kton-> 1 Mton
J-PARC HK
540 kton?
H-E beta-beam, Scenario II

Superbeam & Beta Beam cost estimates(2002)

Educated guess on possible costs	USD/CHF	1.60
UNO	960	MCHF
SUPERBEAM LINE	100	MCHF
SPL	300	MCHF
PS UPGR.	100	MCHF
SOURCE (EURISOL), STORAGE RING	100	MCHF
SPS	5	MCHF
DECAY RING CIVIL ENG.	400	MCHF
DECAY RING OPTICS	100	MCHF
TOTAL (MCHF)	**2065**	MCHF
TOTAL (MUSD)	**1291**	MUSD
INCREMENTAL COST (MCHF)	705	MCHF
INCREMENTAL COST (MUSD)	441	MUSD

beta-beam energy spectrum

$E_\nu^* = 1.5\text{-}1.8$ MeV

in the forward direction:

end point $E_\nu = 2\ E_\nu^*\ \gamma_{parent}$

for CERN SPS $\gamma_{parent} = 150$ (at most) ($\sim E_{proton}/3$)

and $E_\nu = 450$ MeV

Fermilab

$\gamma = 600\ E_\nu = 2$ GeV

at LHC

$\gamma = 2300\ E_\nu = 6$ GeV this already has some tau cross-section