Neutrino 2010, Athens

Beta-Beams

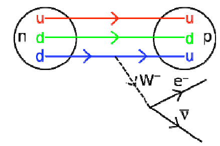
Status and Challenges

Elena Wildner, CERN

Outline

- Beta Beam Concepts
- A Beta Beam Scenario
- The challenges
- Other studies
- Conclusion

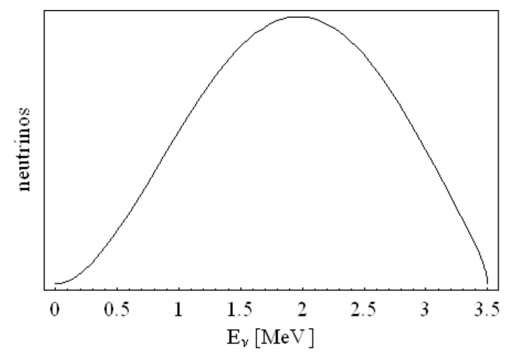
Beta-beams, recall 1



Aim:

Production of (anti-)neutrino beams from the beta decay of radio-active ions circulating in a storage ring with long straight sections.

- Similar the neutrino factory concept, but the parent particle is a beta-active isotope instead of a muon.



Beta-decay at rest

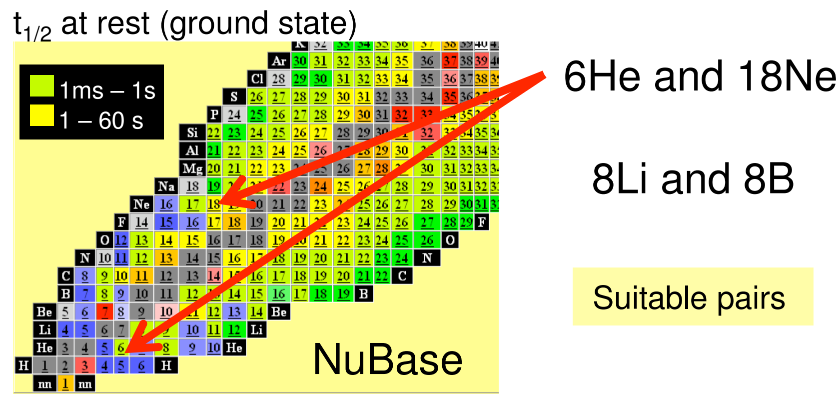
- ν–spectrum well known from the electron spectrum
- Reaction energy Q typically of a few MeV

Beta-beams, recall 2

- Accelerate parent ion to relativistic γ_{max}
  - Boosted neutrino energy spectrum: $E_\nu \leq 2\gamma Q$
  - Forward focusing of neutrinos: $\theta \leq 1/\gamma$
- Pure electron (anti-)neutrino beam!
  - Depending on β^+- or β^- - decay we get a neutrino or anti-neutrino
  - Two different parent ions for neutrino and anti-neutrino beams
- Physics applications of a beta-beam
  - Primarily neutrino oscillation physics and CP-violation (high energy)
  - Cross-sections of neutrino-nucleus interaction (low energy)

Choice of radioactive ion species

- Beta-active isotopes
  - Production rates
  - Life time
  - Dangerous rest products
  - Reactivity (Noble gases are good)



- Reasonable lifetime at rest
  - If too short: decay during acceleration
  - If too long: low neutrino production
  - Optimum life time given by acceleration scenario
  - In the order of a second

- Low Z preferred
  - Minimize ratio of accelerated mass/charges per neutrino produced
  - One ion produces one neutrino.
  - Reduce space charge problems

Neutrino energy: Q and γ

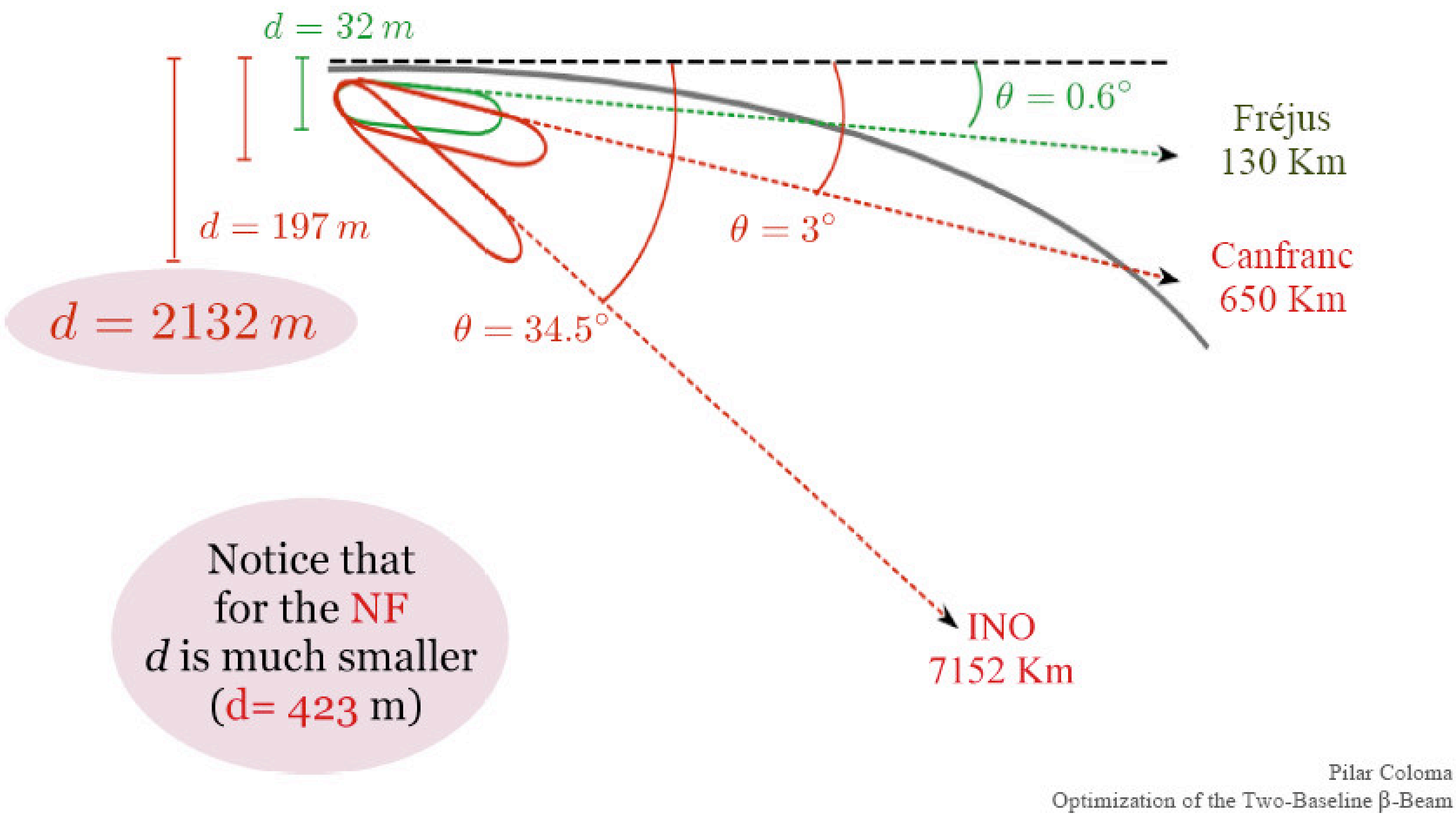
- Accelerators can accelerate ions up to Z/A × *the proton energy.*

Parent ion acceleration

Depends on the accelerated isotope

- $L \sim \langle E_\nu \rangle / \Delta m^2 \sim \gamma Q$, $Flux \sim L^{-2} \Rightarrow Flux \sim Q^{-2}$
- Cross section $\sim \langle E_\nu \rangle \sim \gamma Q$
- Merit factor (Flux * Cross-section) for an experiment at the atmospheric oscillation maximum: $M = \gamma / Q$
- Remember: ion lifetime $\sim \gamma$, therefore we need longer straight sections in the decay ring to give the same flux for the same number of stored ions in the accelerator.
- Accelerator challenges: high γ and high intensities

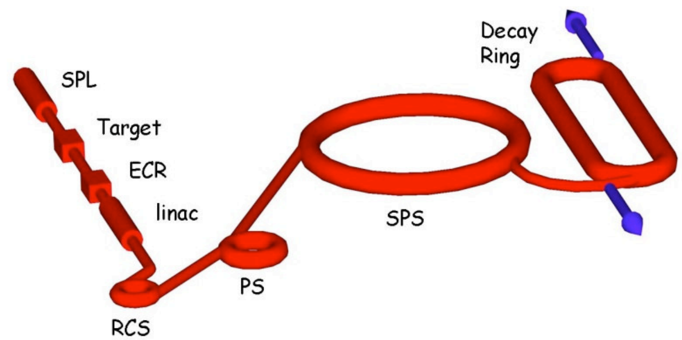
Beta beam to different baselines



The EUROSOL scenario(*) boundaries

- Based on CERN boundaries
- Ion choice: ^6He and ^{18}Ne
- Based on existing technology and machines
  - Ion production through ISOL technique
  - Bunching and first acceleration: ECR, linac
  - Rapid cycling synchrotron
  - Use of existing machines: PS and SPS
- Relativistic gamma=100 for both ions
  - SPS allows maximum of 150 (^6He) or 250 (^{18}Ne)
  - Gamma choice optimized for physics reach
- Opportunity to share a Mton Water Cherenkov detector with a CERN super-beam, proton decay studies and a neutrino observatory

EURISOL scenario



- Achieve an annual neutrino rate of
  - 2.9×10^{18} anti-neutrinos from ^6He
  - $1.1 \; 10^{18}$ neutrinos from ^{18}Ne

top-down approach

- The EURISOL scenario will serve as reference for further studies and developments: Within Euroν we will study ^8Li and ^8B

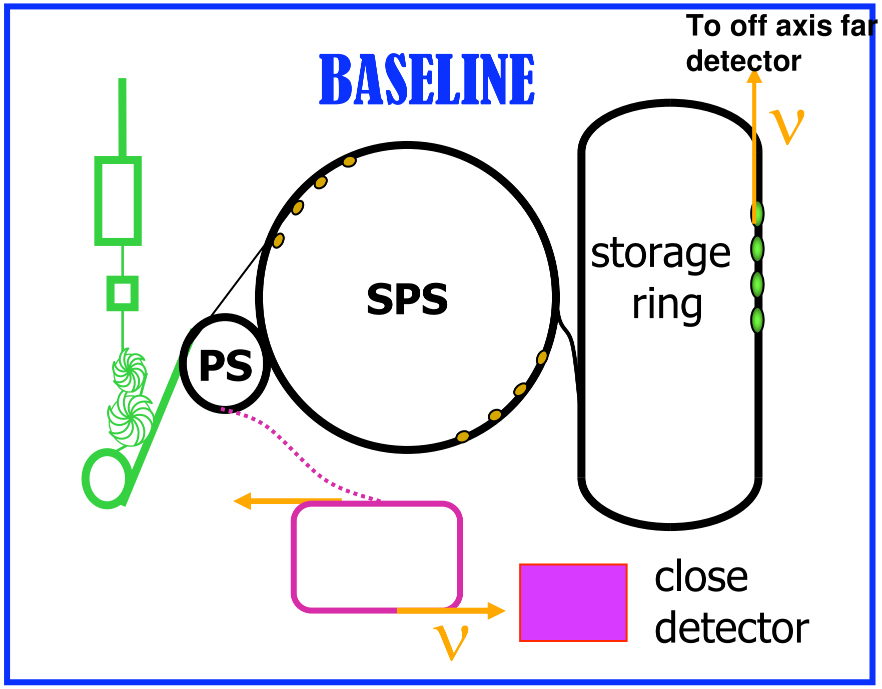
(*) FP6 "Research Infrastructure Action - Structuring the European Research Area" EURISOL DS Project Contract no. 515768 RIDS

Low energy Beta Beams

Christina Volpe:

A proposal to establish a facility for the production of intense and pure low energy neutrino beams.

J Phys G 30 (2004) L1.

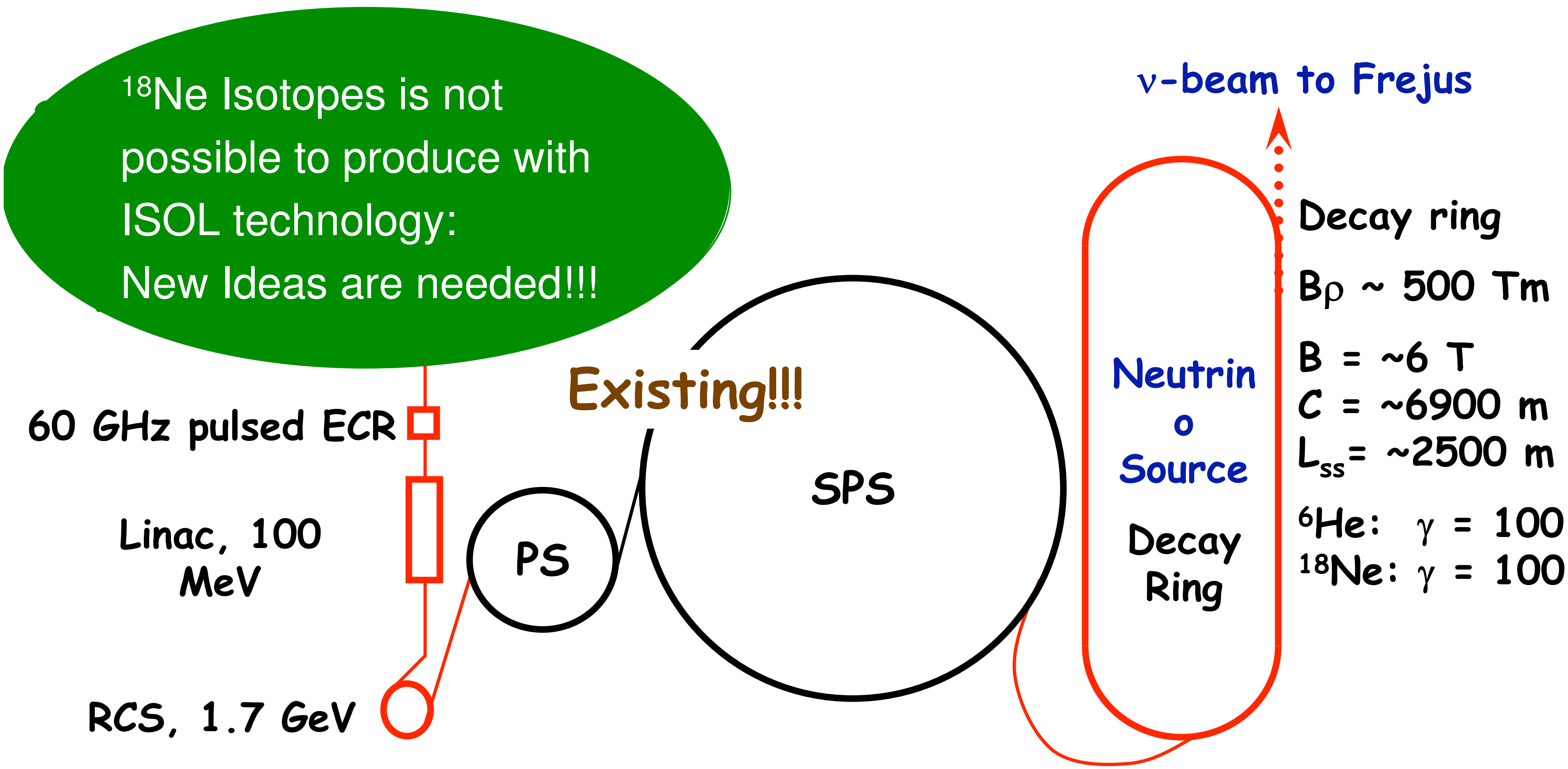


PHYSICS POTENTIAL

- n-nucleus cross sections (detector's response, r-process, 2β-decay)
- fundamental interactions studies (Weinberg angle, CVC test, μ_ν)
- astrophysical applications

PHYSICS STUDIED WITHIN THE EURISOL D 009)

Beta Beam scenario 6He/18Ne



New approaches for ion production

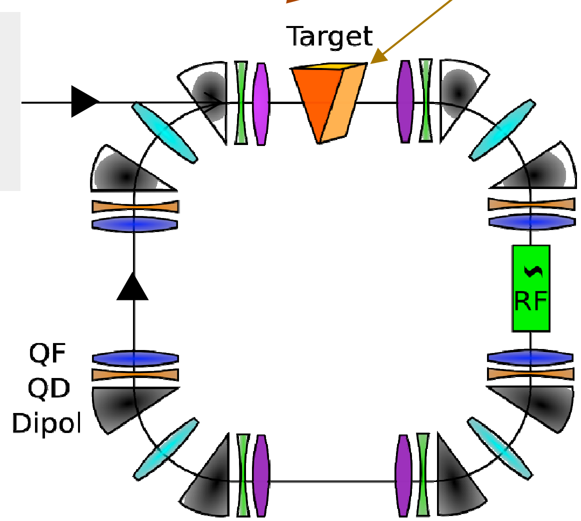
“Beam cooling with ionisation losses” – C. Rubbia, A Ferrari, Y. Kadi and V. Vlachoudis in NIM A 568 (2006) 475–487

“Development of FFAG accelerators and their applications for intense secondary particle production”, Y. Mori, NIM A562(2006)591

Supersonic gas jet target, stripper and absorber

Production of ions using inverse kinematics

^{7}Li
^{6}Li

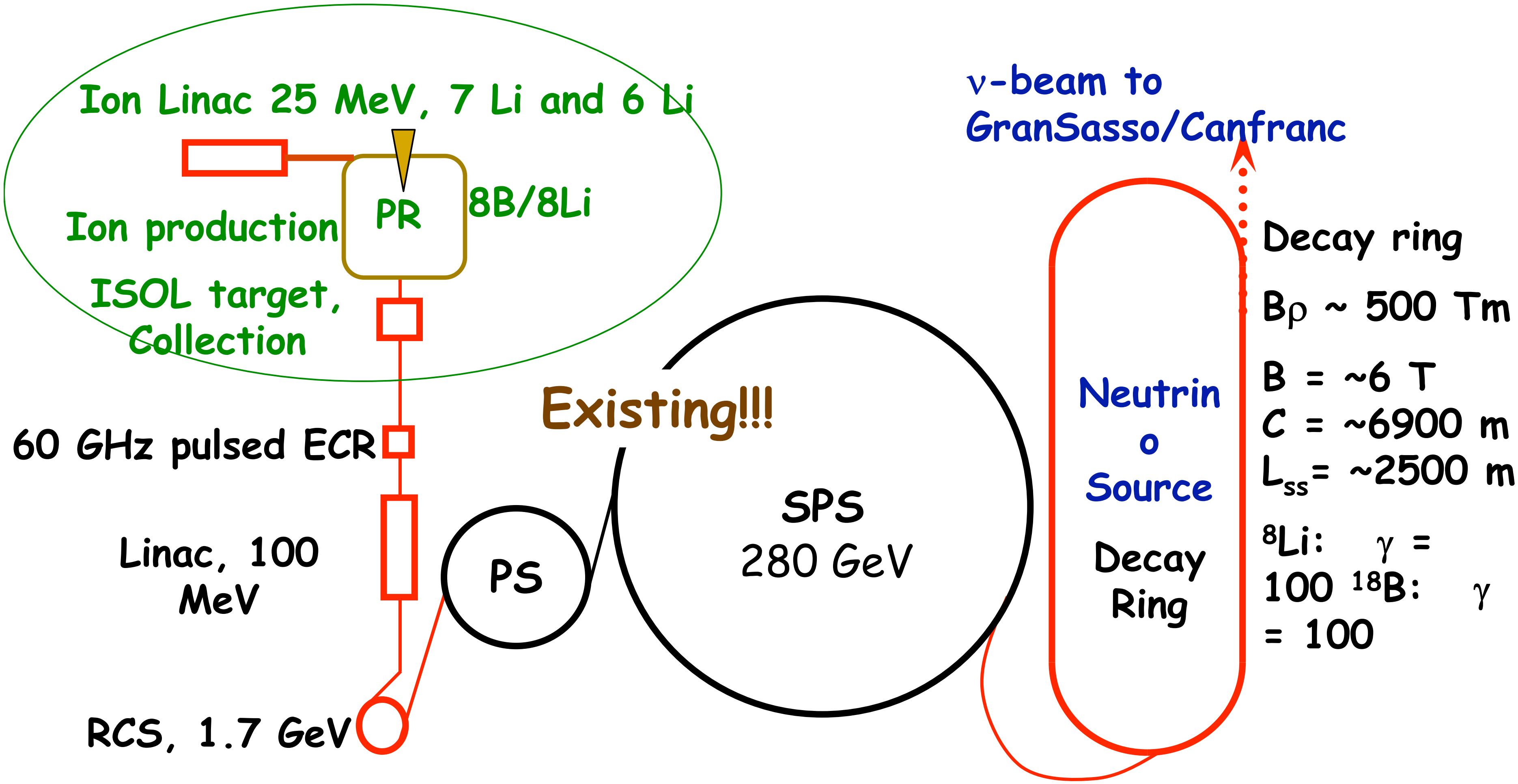


$^{7}Li(d,p)^{8}Li$
$^{6}Li(^{3}He,n)^{8}B$

Studied within Euroν FP7 (*)

(*) FP7 “Design Studies” (Research Infrastructures) EUROnu
(Grant agreement no.: 212372)

Beta Beam scenario $^{8}Li/^{8}B$



Gas Jet Targets and Cooling (GSI)

Cluster Beam Densities (Status)

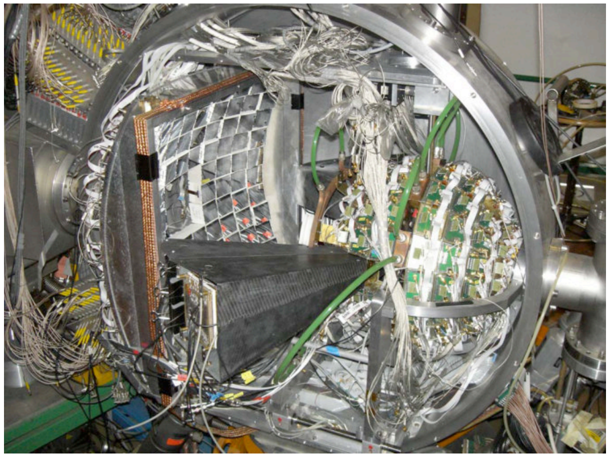
	CELSIUS	E835 FERMILAB	Genova/GSI	ANKE and COSY-11	Münster
nozzle diameter	100 µm	37 µm	26 µm	11-16 µm	11-28 µm
gas temperature	20-35 K	20-32 K	28-35 K	22-35 K	20-35 K
gas pressure	1,4 bar	[illegible]	[illegible]	[illegible]	>18 bar
distance from nozzle	0,32 m	[illegible]	[illegible]	[illegible]	2,1 m = PANDA geometry!
target density	$1{,}3\times10^{14}$ cm^{-2}	[illegible]	[illegible]	[illegible]	8×10^{14} cm^{-2}

We need 10^{19} cm^{-2} in our production ring
Vacuum in beam pipe a problem (pumping)

even higher densities expected for the PANDA Cluster-Source Prototype

Alfons Khoukaz

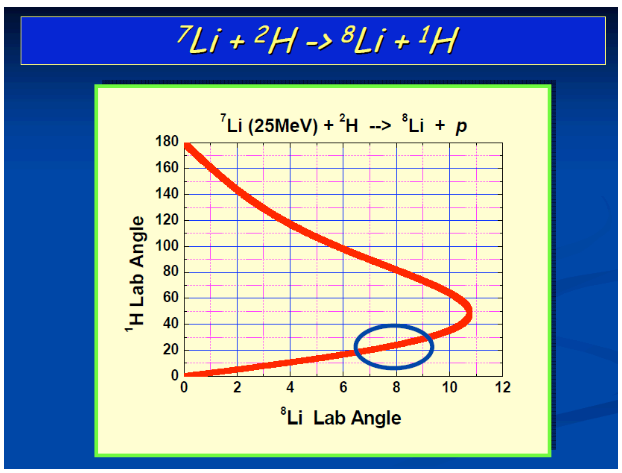
X-sections & angles, ^{8}Li and ^{8}B



Inverse kinematic reaction:

^{7}Li + CD_2 target   E=25 MeV

Status: Measurements performed for the production of ^{8}Li

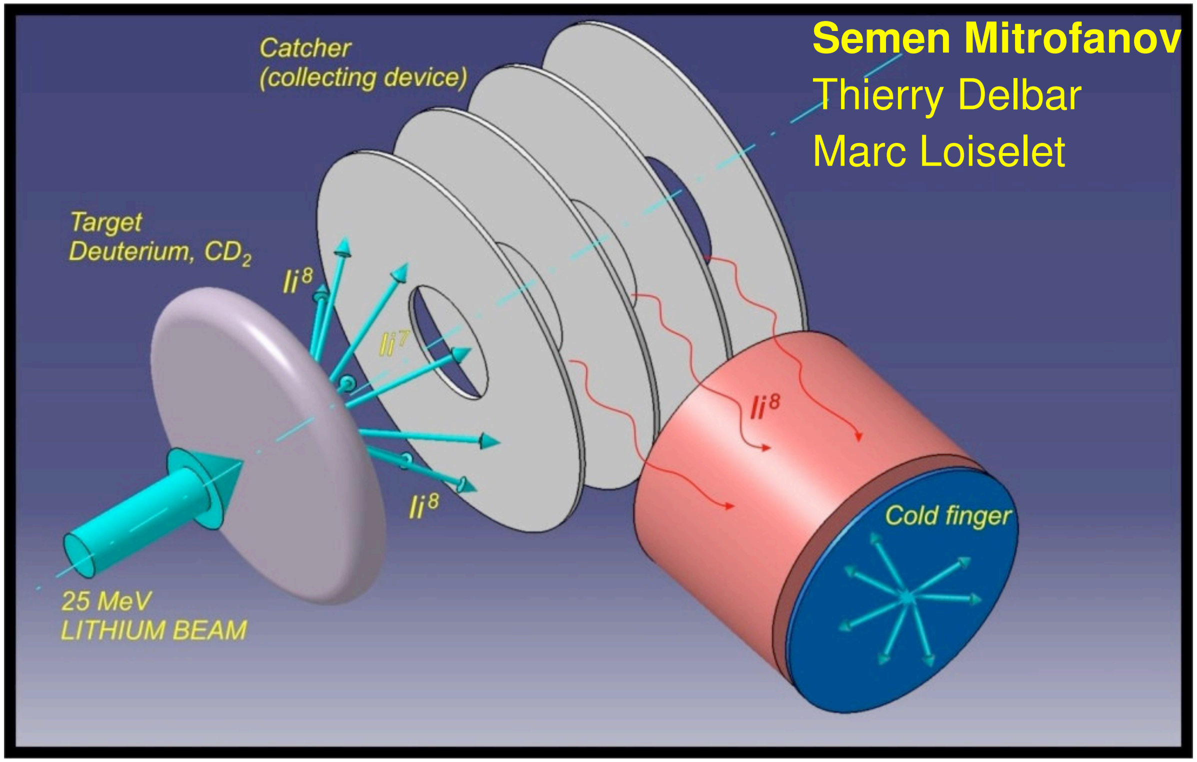


^{8}B production experiments are being planned at INFN, Legnaro

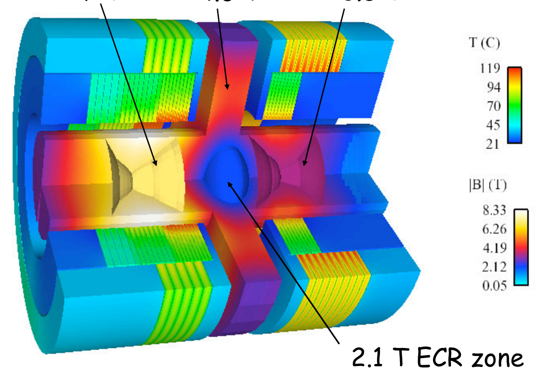
We may need to investigate normal kinematics (liquid curtain targets)

Challenge: collection device

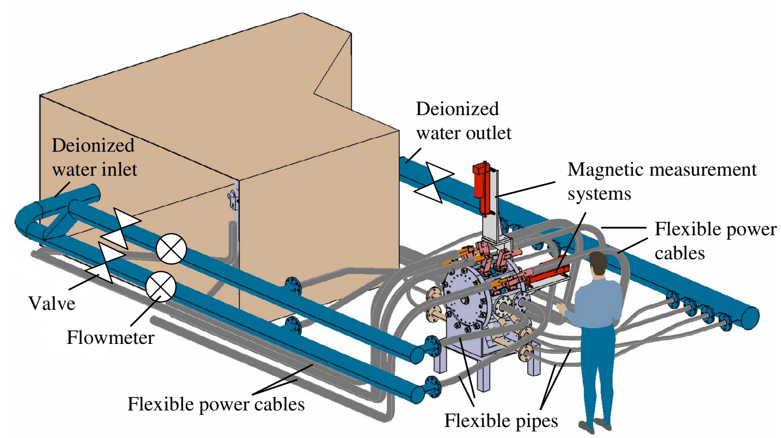
Status: The collection device is under test, results expected end summer 2010 for 8Li. Tests for 8B will follow.



ECR Source 60 GHz



Challenges:
Produce stripped ions (more difficult for high A ions)
Adapted pulse length and beam emittance
Optimize with further acceleration: Linac
The source is developed for He, Ne, B and Li



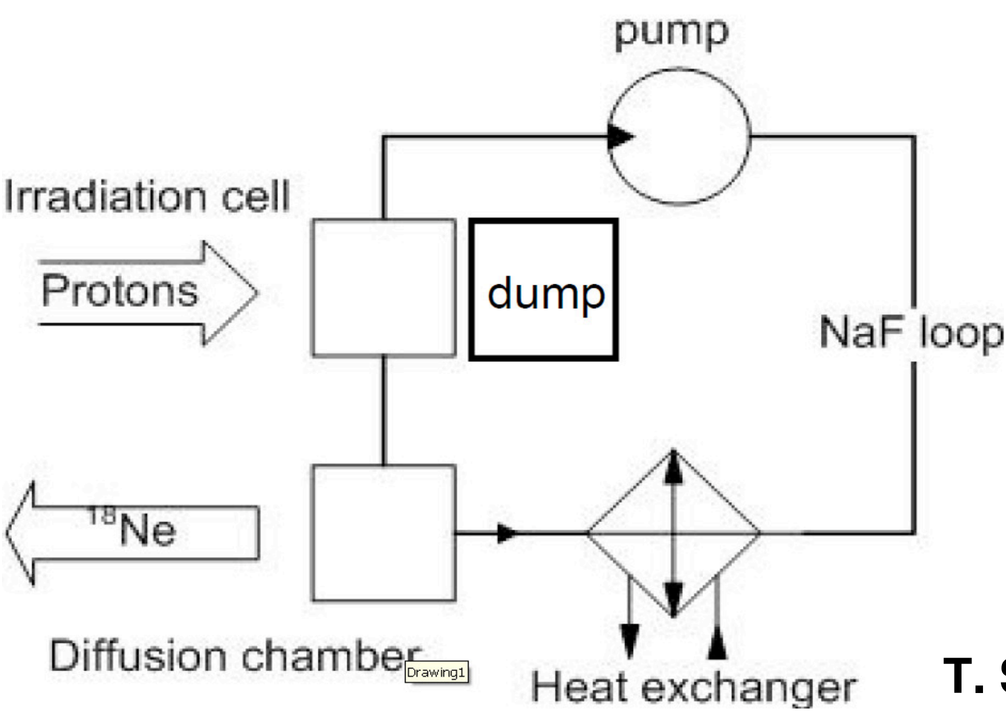
Status:
Magnetic tests scheduled for mid 2010
60 GHz gyrotron for mid 2011

The SEISM Collaboration:

New ideas: $^{19}F(p, 2n)\ ^{18}Ne$

The ν_e beam needs production of $2.0\ 10^{13}\ \ ^{18}Ne/s$

Theoretically possible with 10 mA 70 MeV protons on NaF ($^{19}F(p, 2n)^{18}Ne$)



Status:
Experimental verification is planned at CERN (ISOLDE), Timescale unknown

T. Stora, P. Valko

Summary of options for production

Courtesy T. Stora, P Valko

Type	Accelerator	Beam	I_{beam} mA	E_{beam} MeV	P_{beam} kW	Target	Isotope	Flux s^{-1}	Ok?
ISOL & n-converter	SPL	p	0.1	$2\ 10^3$	200	W/BeO	6He	$5\ 10^{13}$	
ISOL & n-converter	Saraf/GANIL	d	15	40	600	C/BeO	6He	$5\ 10^{13}$	
ISOL	Linac 4	p	6	160	700	19F Molten NaF loop	18Ne	$1\ 10^{13}$	
ISOL	Cyclo/Linac	p	10	70	700	19F Molten NaF loop	18Ne	$2\ 10^{13}$	
ISOL	LinacX1	3He	> 170	21	3600	MgO 80 cm disk	18Ne	$2\ 10^{13}$	
P-Ring	LinacX2	7Li	0.160	25	4	d	8Li	$?1\ 10^{14}$	
P-Ring	LinacX2	6Li	0.160	25	4	3He	8B	$?1\ 10^{14}$	

Possible

Challenging

Needs some optimization

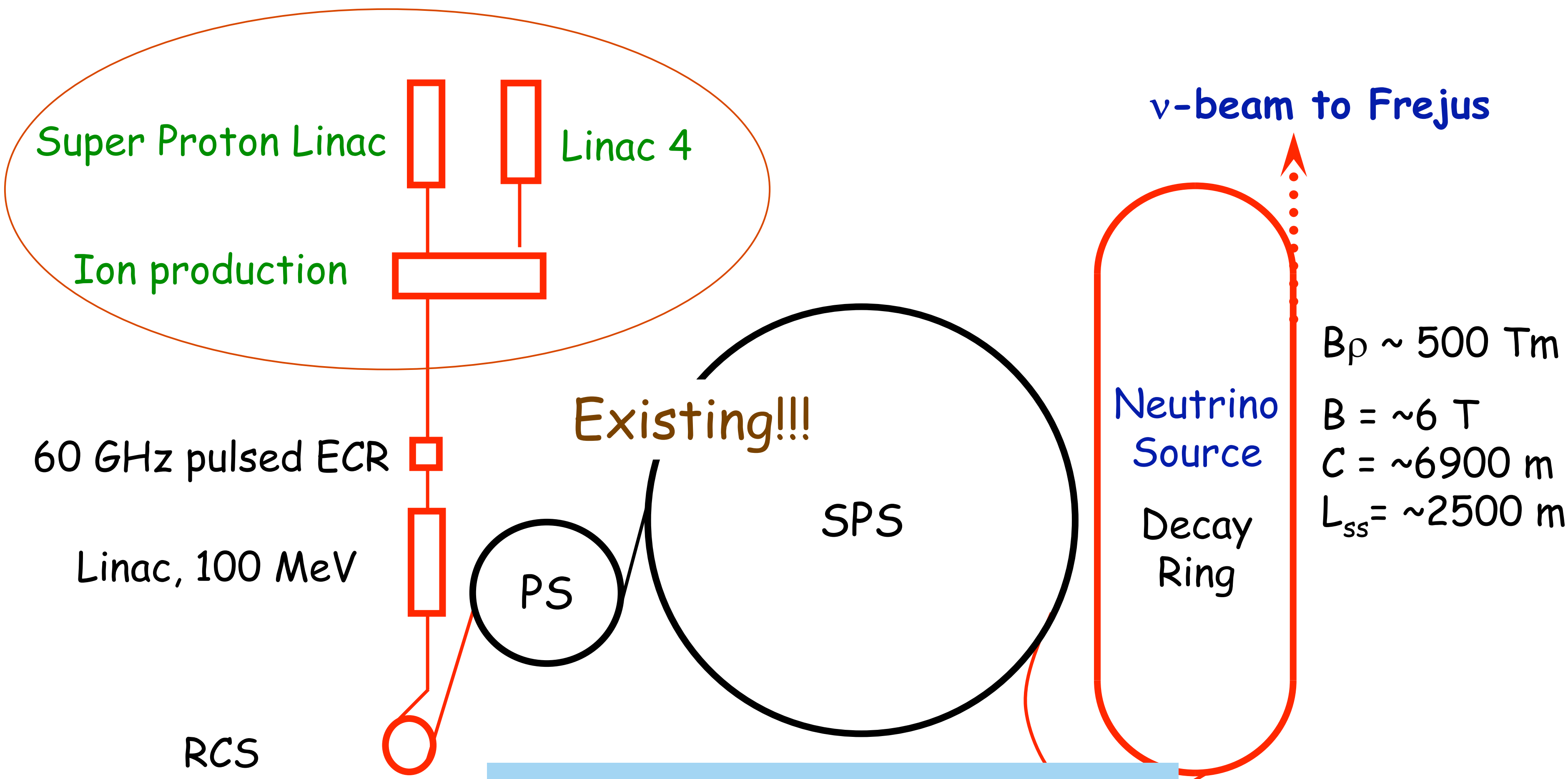
R & D !!!

Experimentally OK

On paper, may be OK

Not OK yet

$^{6}He/^{18}Ne$ beta beam



Gamma = 100 if we use present SPS
Q-values ~ 3.5

Radioprotection

Residual Ambient Dose Equivalent Rate at 1 m distance from the beam line (mSv h^{-1})				
	RCS (quad - ^{18}Ne)	PS (dip - ^{6}He)	SPS	DR (arc - ^{18}Ne)
1 hour	[illegible]	[illegible]	-	[illegible]
1 day	[illegible]	[illegible]	[illegible]	[illegible]
1 week	2	2	-	1.4

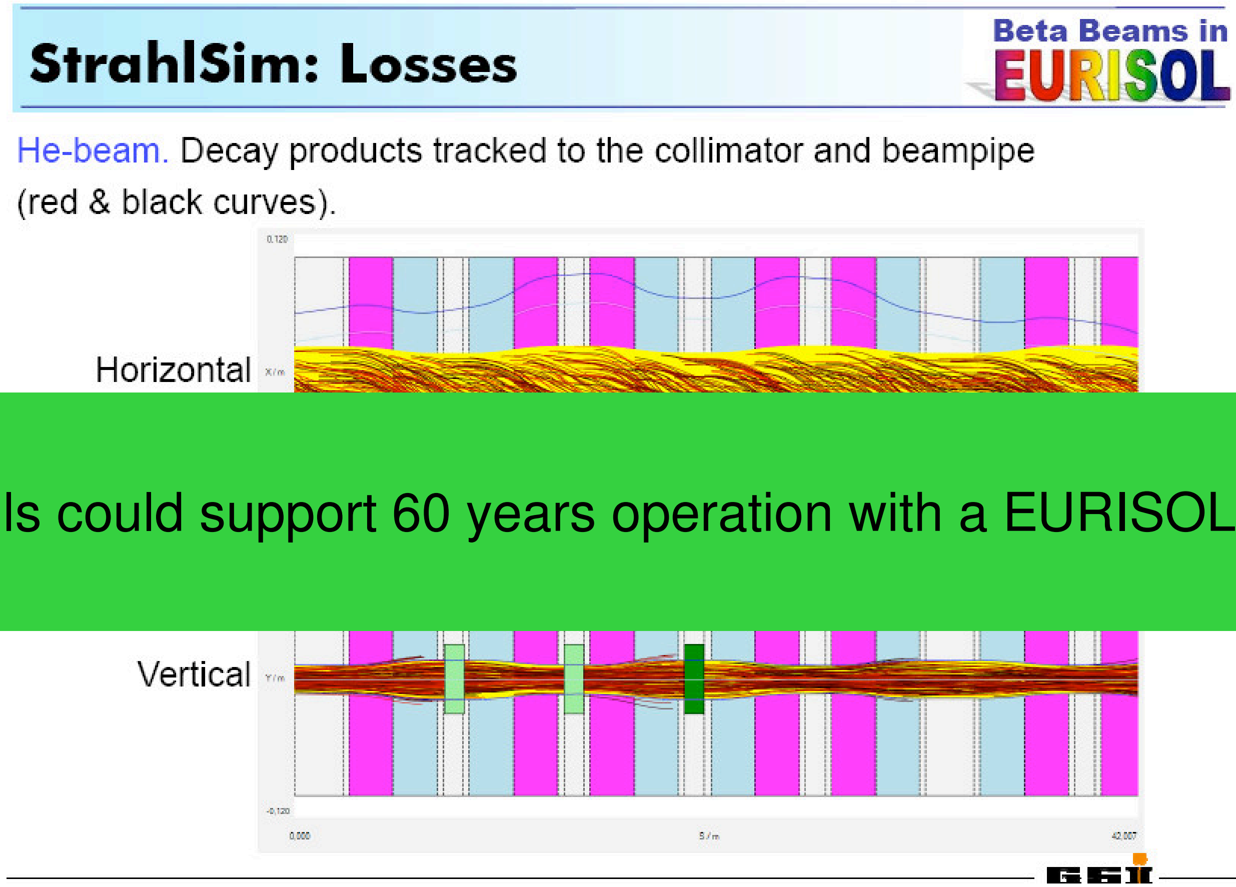
Not a show stopper

Annual Effective Dose to the Reference Population (µSv)			
RCS	PS	SPS	DR
0.67	0.64	-	5.6 (only decay losses)

Stefania Trovati, Matteo Magistris, CERN

Yacin Kadi et al. , CERN

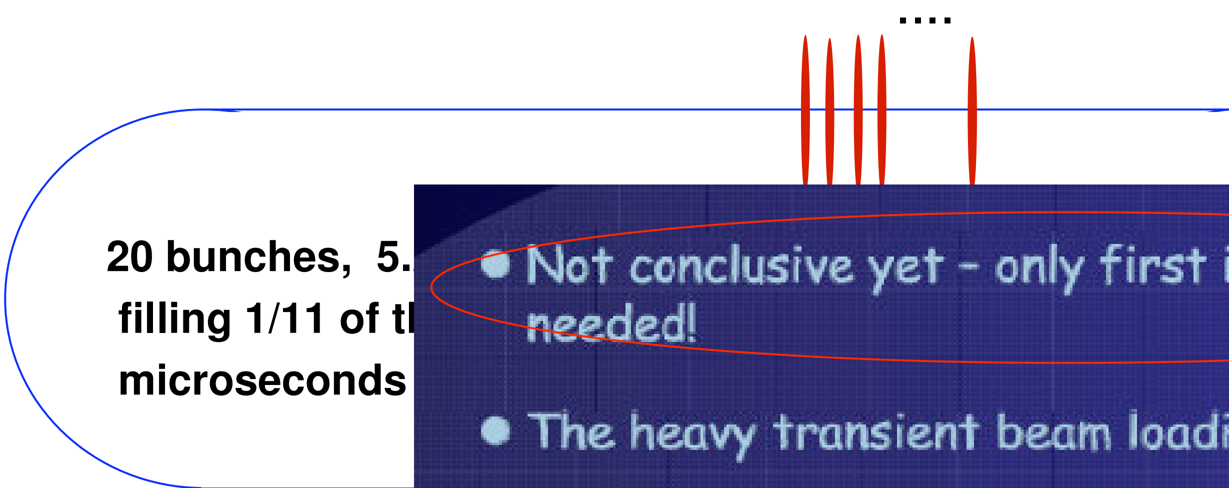
Activation and coil damage in the PS



The coils could support 60 years operation with a EURISOL type beta-beam

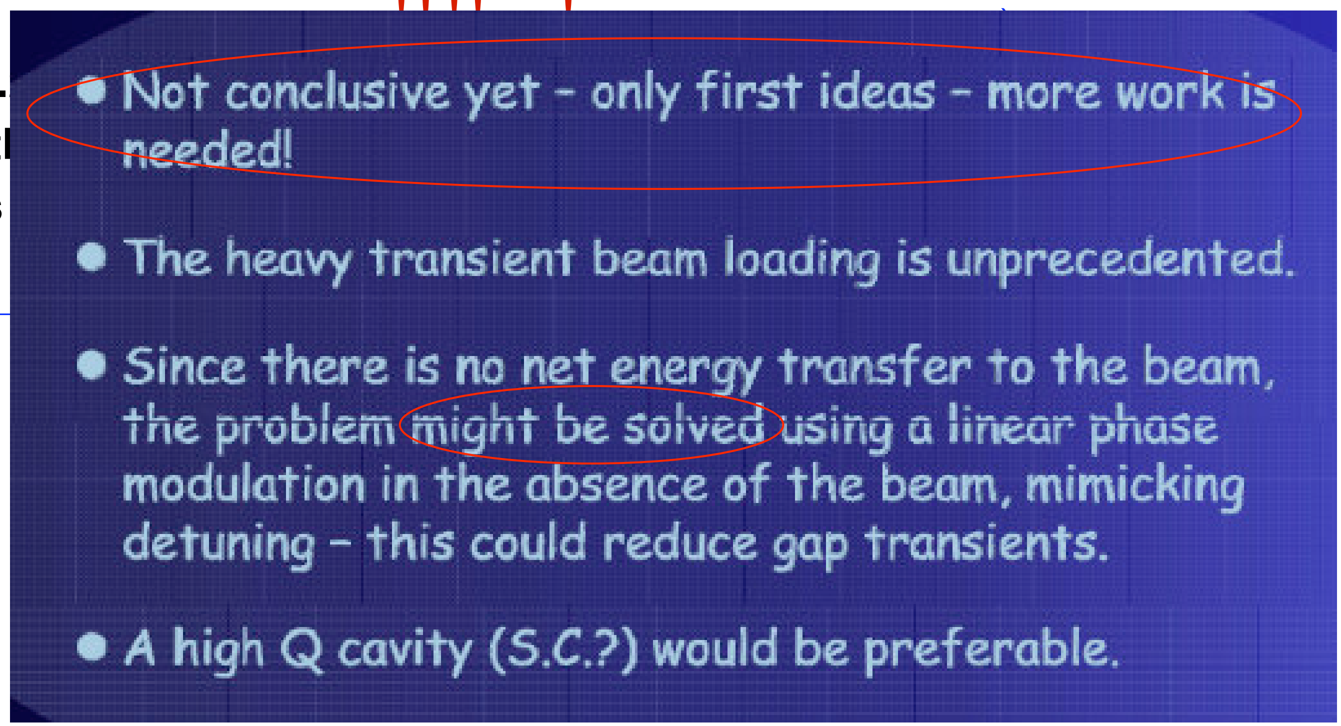
Duty factor and RF Cavities

10^{14} ions, 0.5% duty (supression) factor for background suppression for He/Ne Q - values and gamma = 100.



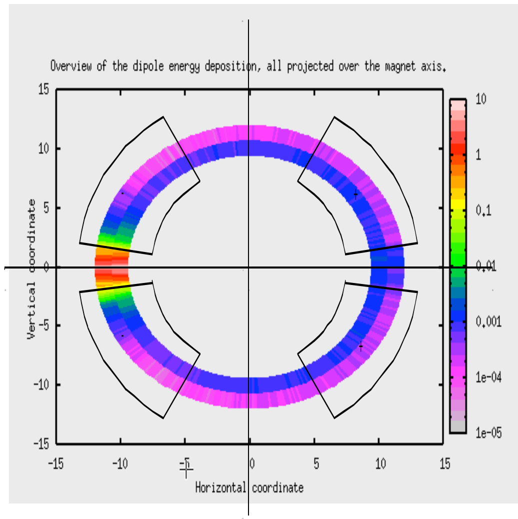
Erk Jensen, CERN

20 bunches, 5.
filling 1/11 of t
microseconds

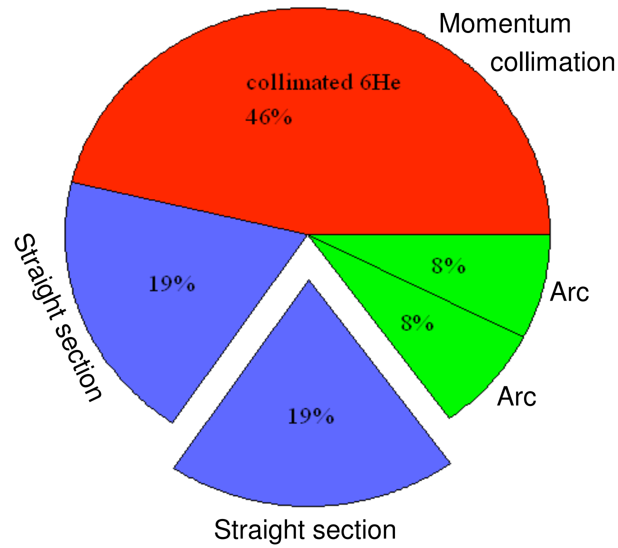


Particle deposition in Decay Ring

Cosθ design open midplane magnet



J. Bruer, E. Todesco, E. Wildner, CERN



Superconducting Magnet:
Manageable (7 T operational)
with Nb -Ti at 1.9 K

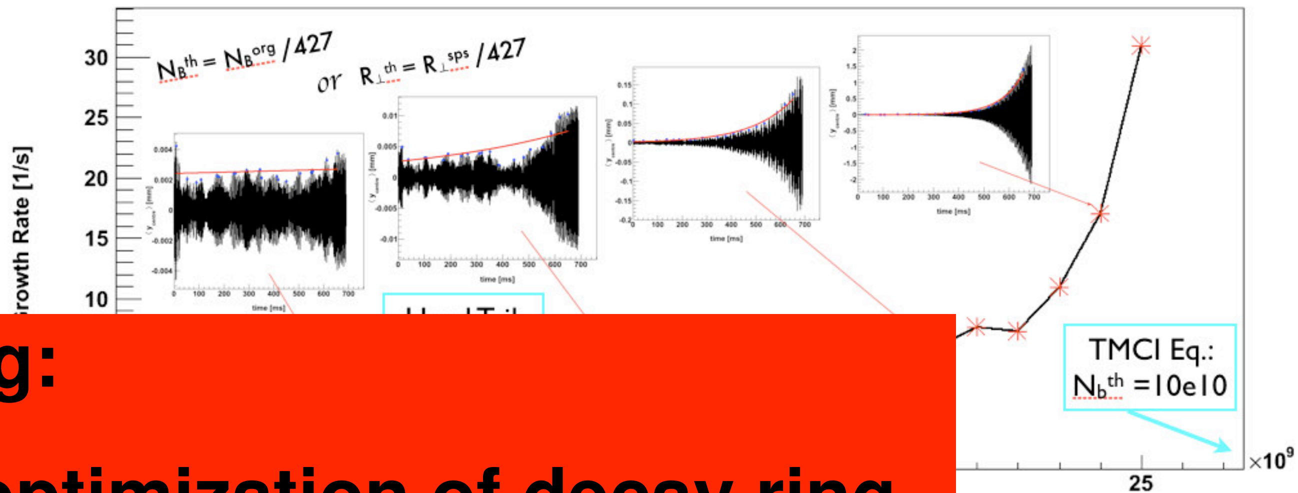
Momentum collimation (study ongoing):
Very high challenge!

Beam Stability (collective effects)

Instability dependencies of bunch intensities are being investigated for all machines

(ongoing for DR and SPS)

Transversal broad band impedance for ^{6}He in DR istab.



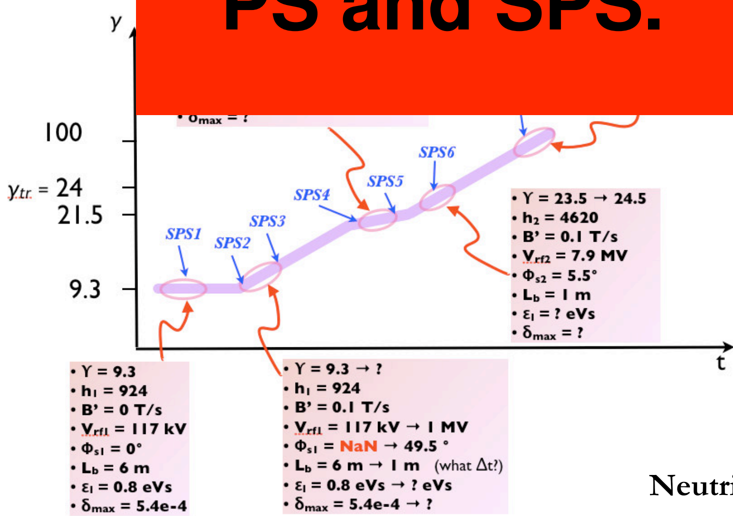
C. H

Challenging:

may need optimization of decay ring, PS and SPS.

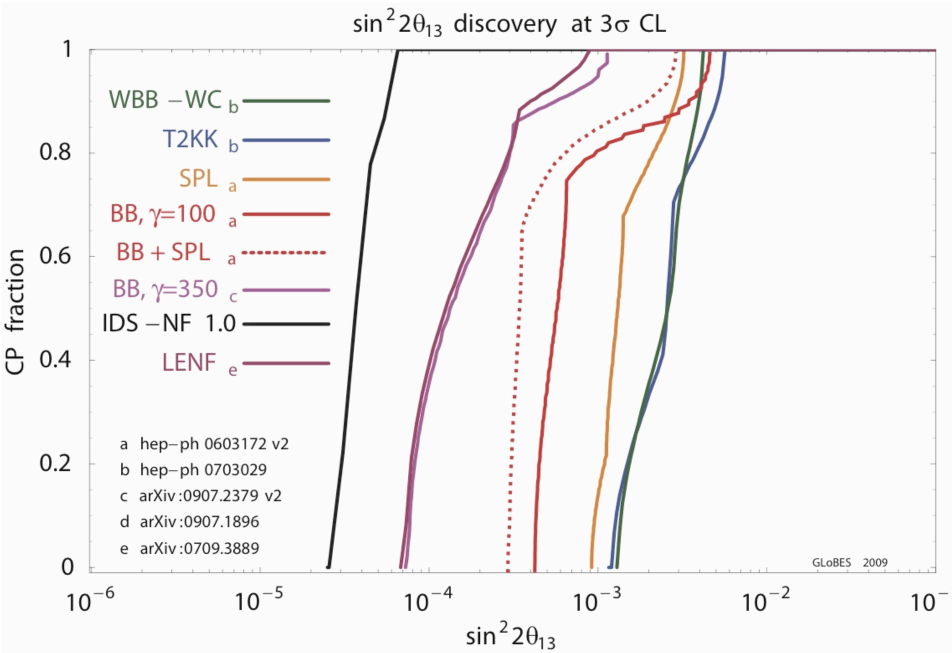
ible with DR

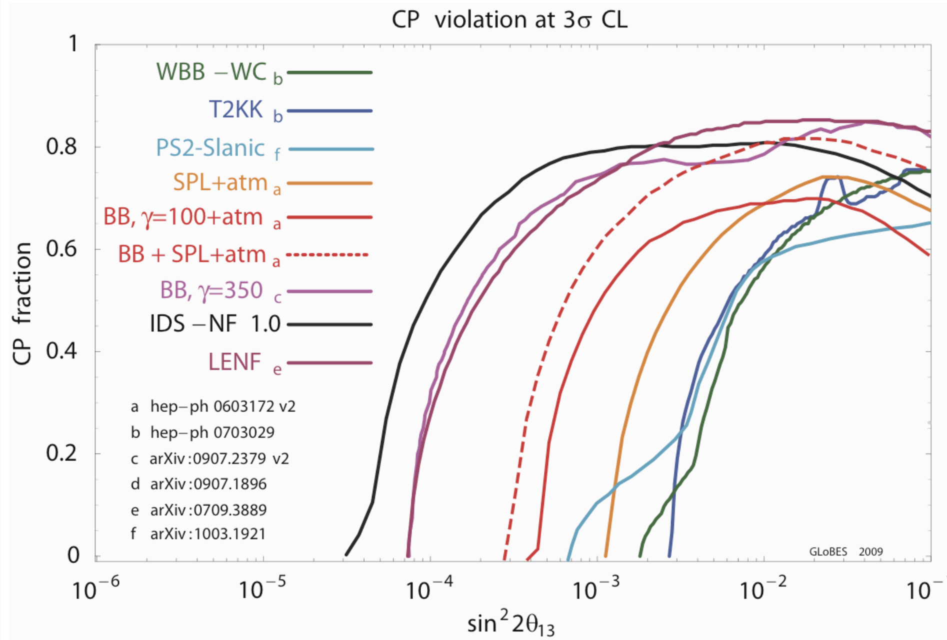
nches ???



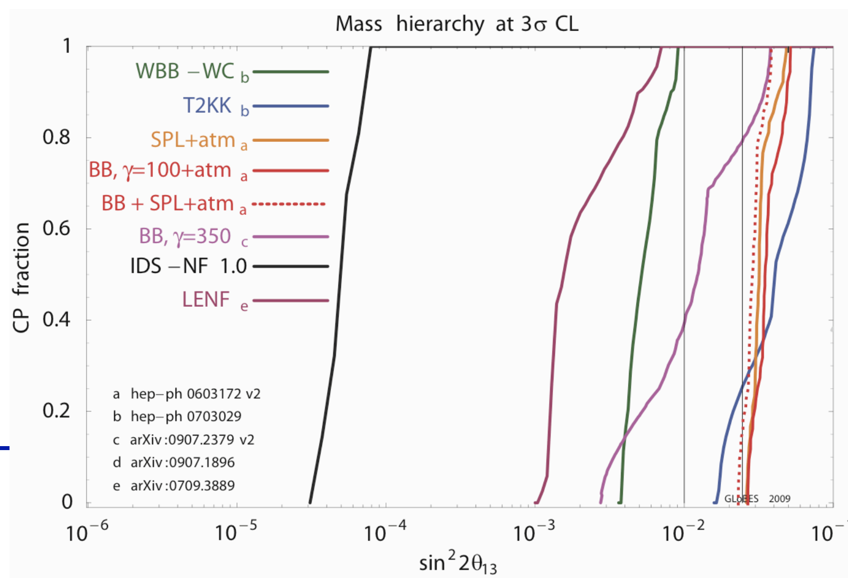
The SPS RF programs are currently being developed in detail (A. Chancé, CEA) for the Instability Studies

Physics reach





Plots provided by M. Mezetto



Beta Beams in the world

- Work on a beta beam facility (CERN infastructre) and physics reach is going on within EUROnu

- Other laboratories (physics reach and facilities)
  - INO, India
  - Fermilab, USA
  - IPN, France
  - University of Valencia, Spain
  - …

Summary, Beta-Beam status

- Production of isotopes
  - Production issues for ^{8}Li and ^{8}B studied in EUROnu
  - Sufficient yields of ^{6}He obtained from experiments
  - Yields for ^{18}Ne production: we wait for experimental verification
- CERN Complex beta beam baseline
  - Gamma = 100, ^{6}He and ^{18}Ne
  - Accelerator: RF and Collective Effects being studied
  - Costing
  - Advantage: existing infrastructure and technologies can be used
  - Comparison of performance with other neutrino facilities
- Synergy for physics reach: Beta Beams/Superbeams
- Higher gamma beta beams need CERN upgrades or other accelerators.

Acknowledgements

FP6 “Research Infrastructure Action - Structuring the European Research Area” EURISOL DS Project Contract no. 515768 RIDS) and

FP7 “Design Studies” (Research Infrastructures) EUROnu (Grant agreement no.: 212372)

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M. Benedikt, (EURISOL study)

M. Lindroos

T. Stora

M. Mezetto

and all contributing institutes and collaborators