Engineering Department
STI - RBS

R&D for β-beams: tests with stable and radioactive ions

Eur. Phys. J. Special Topics 207, 1-117 (2012)
© EDP Sciences, Springer-Verlag 2012
DOI: 10.1140/epjst/e2012-01599-9

THE EUROPEAN PHYSICAL JOURNAL
SPECIAL TOPICS

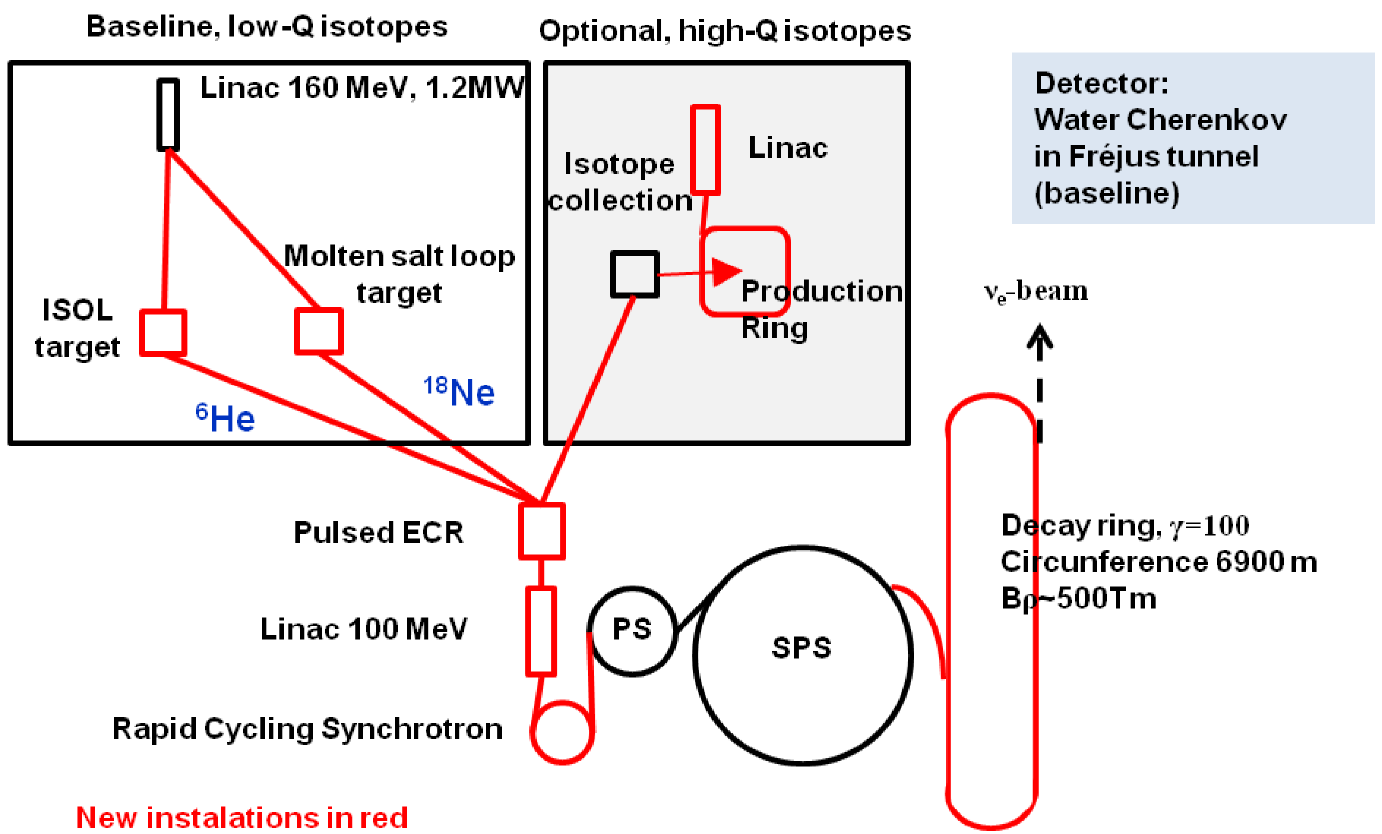
Review

Storage ring facility at HIE-ISOLDE

beams. The TSR might also be employed for removal of isobaric contaminants from stored ion beams and for systematic studies within the neutrino beam programme. In addition to experiments performed

With contributions from E. Wildner, C. Volpe, T. Mendonca, S. Mitrofanov, J. Nolen

The β-beams



As proposed at the end of FP7-EURONU, last summer

Engineering Department
STI - RBS

The β-beams

Intensities needed: Some scaling

- $L \sim \langle E_\nu \rangle / \Delta m^2 \sim \gamma Q$, $Flux \sim L^{-2}$ => $Flux \sim Q^{-2}$
- Cross section $\sim \langle E_\nu \rangle \sim \gamma Q$
- Merit factor for an experiment at the atmospheric oscillation maximum:

  $$M = \gamma / Q$$

- Decay ring length scales $\sim \gamma$ (ion lifetime)
- With FP7 ions we need ~ 5 times more ions (same γ & longer baseline)
- Other detector technology at higher energy requires another factor ~ 2 ?
- FP-7 proposal did not address these facts
- Assumed shortfall of 18Ne intended to be solved by producing Li/B ions
- The idea was to accelerate a similar number of ions for He/Ne and Li/B.
- Conclusion: Baseline beta beam scenario milestone B/Li will not be met

Assumed Parameters:

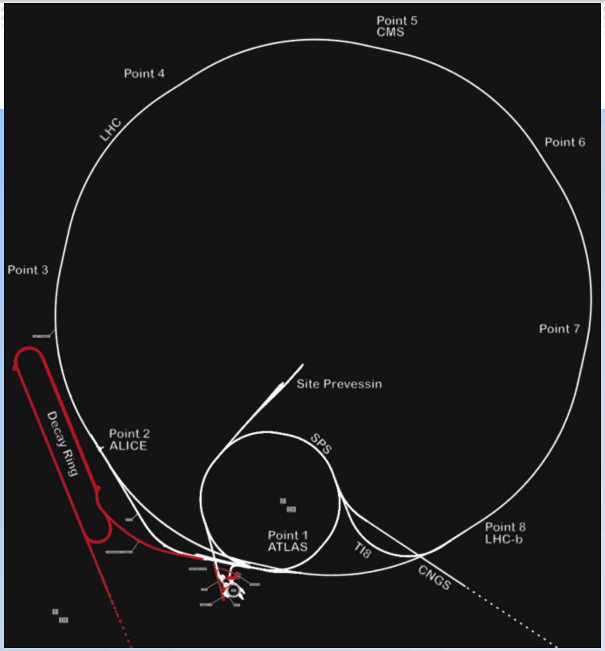
	18Ne Ions	6He Ions	8B Ions	8Li Ions
Source rate [ions/s]	2.01×10^{13}	4.98×10^{13}	$8.\times10^{11}$	$3.\times10^{13}$
ECR Ejection Energy [keV/Nucleon]	27.8	16.7	31.3	18.8
ECR Accumulation Time [ms]	97.5	97.5	97.5	97.5
ECR Dead Time [ms]	2.5	2.5	2.5	2.5
ECR Efficiency	0.21	0.31	0.11	0.13
RCS Accumulation Time [ms]	47.5	47.5	47.5	47.5
ECR Efficiency	0.5	0.5	0.5	0.5
PS Injection Energy [GeV/Nucleon]	1.65	0.787	1.93	0.942
PS Accumulation Time [s]	1.9	1.9	1.9	1.9
PS Acceleration Time [s]	0.8	0.8	0.8	0.8
SPS Injection Energy [GeV/Nucleon]	13.5	7.78	15.3	8.86
SPS Accumulation Time [s]	0.	0.	0.	0.
SPS Acceleration Time [s]	1.42	2.54	1.23	2.23
DR Mergings Ratio	14.	10.	10.	10.
Nominal Annual ν Rate	1.1×10^{18}	2.9×10^{18}	5.5×10^{18}	1.45×10^{19}

Gives the Following Intensities and Rates:

	# 18Ne Ions	# 6He Ions	# 8B Ions	# 8Li Ions
Source rate	2.01×10^{13}	4.98×10^{13}	$8.\times10^{11}$	$3.\times10^{13}$
ECR	4.03×10^{11}	1.44×10^{12}	8.21×10^{9}	3.65×10^{11}
RCS inj	2.01×10^{11}	7.19×10^{11}	4.09×10^{9}	1.82×10^{11}
RCS	1.99×10^{11}	6.99×10^{11}	$4.\times10^{9}$	1.77×10^{11}
PS inj	3.47×10^{12}	9.32×10^{12}	6.14×10^{10}	2.47×10^{12}
PS	3.31×10^{12}	8.03×10^{12}	5.62×10^{10}	2.17×10^{12}
SPS inj	3.31×10^{12}	8.03×10^{12}	5.62×10^{10}	2.17×10^{12}
SPS	3.27×10^{12}	7.59×10^{12}	5.49×10^{10}	2.07×10^{12}
Decay Ring	4.16×10^{13}	6.09×10^{13}	4.77×10^{11}	1.74×10^{13}
Annual ν Rate	6.69×10^{17}	1.98×10^{18}	1.65×10^{16}	5.51×10^{17}
ν-Rate Ratio	0.608	0.683	0.003	0.038

Engineering Department
STI - RBS

The β-beams



Several issues to solve at the same time.

Need to achieve high fluxes.

- Stress on production, ion source
- Machine stability, space charge issues at injection
- Machine activation, protection, impedance
- Decay ring dimensioning: this is the cost driver
- And of course, if at CERN, compatible with other physics programs

Success : most of the identified show-stoppers could be addressed. Yet a >1 Bi$ (sorry £, €) machine, w/o detector

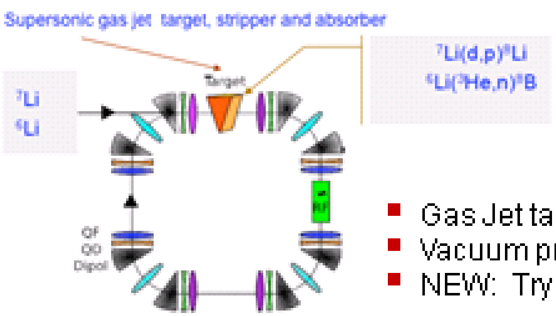
For what physics reach (CP violation, mass hierarchy, etc); competing with other projects in EU and elsewhere

Engineering Department
STI - RBS

How would the TSR be useful for this field

What is new:

The Production Ring (8B and 8Li)



Production of 8B and 8Li
C. Rubbia, EUROnu proposal

- Gas Jet target proposed in FP7: too high density
- Vacuum problems
- NEW: Try Direct Production (D. Neuffer)

- Basic lattice and 6D tracking ok, RF feasible (10 MHz, 300 kV)
- Charge exchange injection to be designed
- Direct kinematics could give good production efficiencies
- Simulations done so far can be scaled, tune for cooling
- Experiment/simulations at ERIT, (FFAG solution, larger aperture)
  - Seems today too expensive to adapt ERIT
- Experiment/simulations at TSR, ion storage ring, Heidelberg or CERN

Aachen Univ., GSI, CERN

Table II. Beta-Beam requirements for the Production Ring

Production Ring Parameters		
Particle		^{7}Li
Kinetic energy	E_{BB}	300 kEV
Relativistiv mass factor	γ_r	1.00383
Beam rigidity	$B\rho$	0.636 Tm
Circumference	C	12 m
Revolution frequency	f_{rev}	2.18 MHz
Transition γ	γ_t	3.58
Tune	$Q_{x,y}$	2.58, 1.63
Natural chromaticity	$Q'_{x,y}$	-3.67,-3.58
β @ target	$\beta^*_{x,y}$	2.62 m, 0.35 m
Dispersion @ target	$D^*_{x,y}$	0.523 m, 0 m
Target thickness	t_0	0.27 mg/cm^2
Target thickness	n_t	10^{19}atoms/cm^2
Energy loss @ target	E_c	25 MeV

We need to inject 160μA 7Li++,
Else we simply test with what
Is available, but HIE-EBIS highly
Desired.

Engineering Department
STI - RBS

The β-beams
Testing the 8B/Li collection device

S. Mitrofanov et al,
CRC, Louvain la Neuve

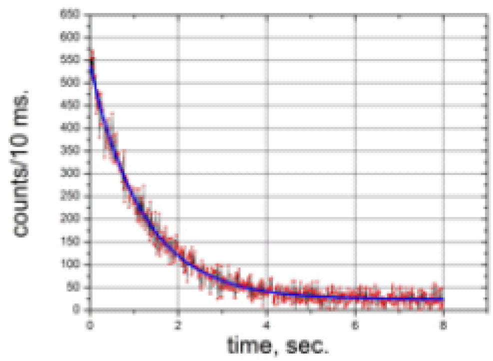
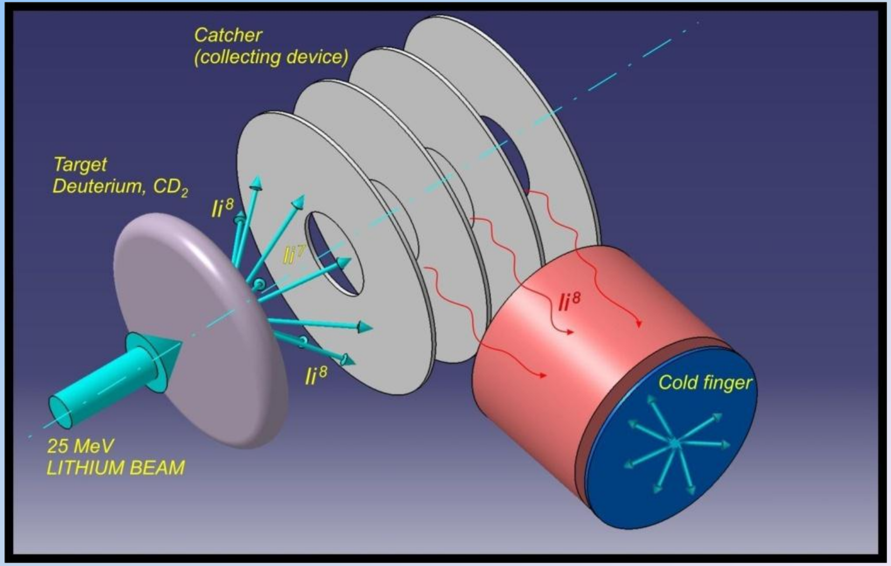


Figure 15. Decay of ^{8}Li (setup without the collection device). χ^2/n = $T_{1/2}$ = 826 ms in comparison with $T_{1/2}$ = 840 ms (from in literature adopted value).



The β-beams
Else tests in direct kinematics

Free flowing Li target (Soreq, ANL, IFMIF)

Table III. The rate (r) extracted from the source (using different production methods (^{6}He estimated from experiments, for ^{18}Ne from experiments and calculations and rates for ^{8}Li and ^{8}B are estimated from calculations).

Isotope	^{6}**He**	^{18}**Ne**	^{8}**Li**	^{8}**B**
Prod.	ISOL(n)	ISOL	P-Ring	P-Ring
Beam	SPL(p)	Linac4(p)	d	^{3}He
I [mA]	0.07	7	0.160	0.160
E [MeV]	2000	160	25	25
P [kW]	140	1120	4	4
Target	W/BeO	^{23}Na, ^{19}F	^{7}Li	^{6}Li
r [10^{13}/s]	5	1.0	0.1	0.08

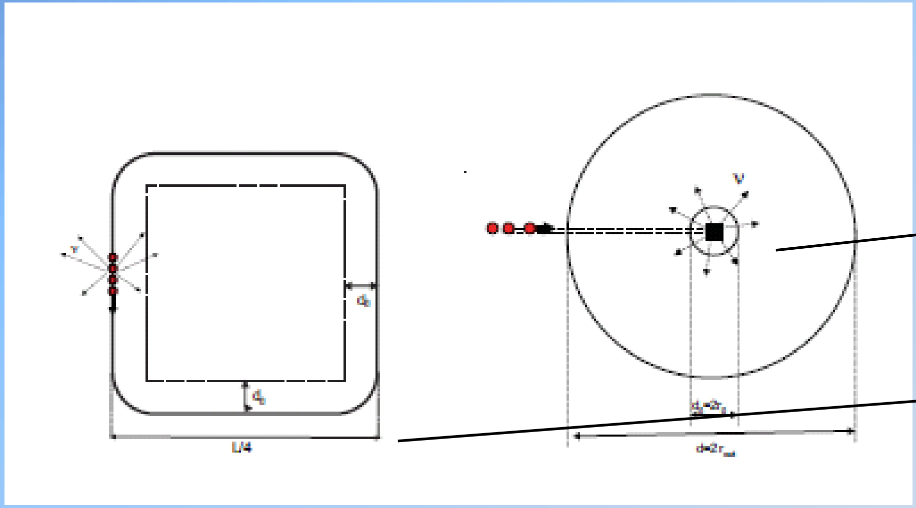
The β-beams

Exploiting intense sources of beta-decaying isotopes at γ=1 for neutrino physics

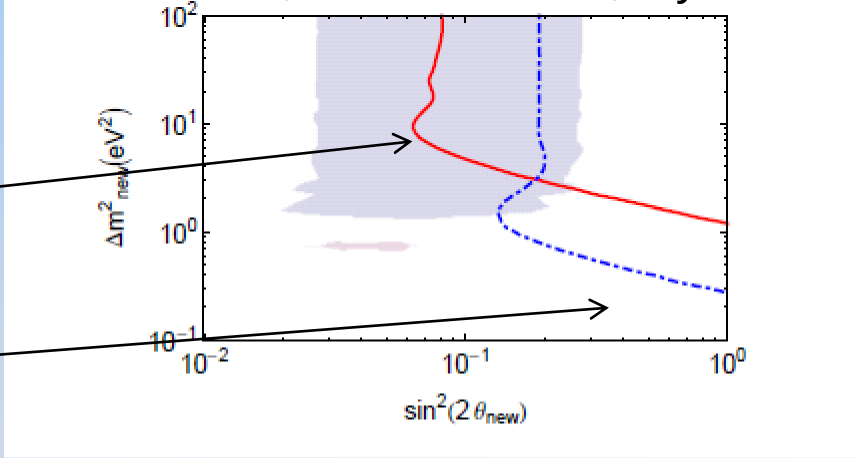
Espinoza, Lazauskas, Volpe arXiv:1203.0790v2 (sept 2012)

Other neutrino physics at TSR

While it is shown that almost no advantages are obtained for stored $\gamma=1$ vs point sources isotopes, for instance looking for sterile neutrinos …



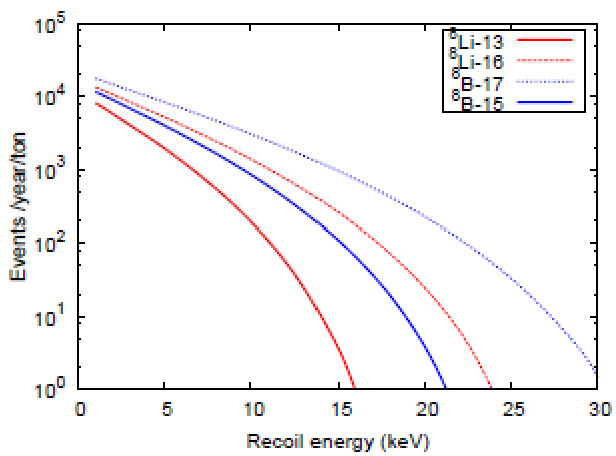
Exclusion plots for sterile neutrinos search
1e11-1e13 8Li/s, 1kton detector, 5 yrs



Other neutrino physics at TSR

If the method of isotope production is validated at the TSR, this could be used for ν-nucleus coherent scattering measurements

1e13 8Li or 8B/s, 1ton liquid Ne detector



Ion	Decay	Target	E_ν^{max}(MeV)	T_{min}(keV)	Events/ton/year
$^8_3$Li	β^-	Ne	13.103	10	192
$^8_3$Li	β^-	Ne	16.003	10	1373
$^8_5$B	β^+	Ne	15.079	10	846
$^8_5$B	β^+	Ne	17.979	10	3047

Conclusion

The TSR is an ideal test stand for the concepts yet to be validated for the production of the high Q ions for β-beams and other applications

It can be a precursor for a dedicated facility or for the decision to place a suitable detector at intense sources of radioisotopes.

Reserve

Other neutrino physics at TSR

And a last approach:

Measuring neutrino mass with radioactive ions in a storage ring

Lindroos et al., arXIv 0904.1089

To reach $\delta m\nu$ <0.2eV, one needs dp/p<1e-5, Q~10keV, and observe 1e18 decays.