European Strategy for Neutrino Oscillation Physics – II

14-16 May 2012, CERN

Beta Beams

Elena Wildner, CERN

The Beta Beam studies

EURISOL Design Study *Design Study, 2004-2008*

EUROnu *Design Study, 2008-2012:*

Next generation neutrino oscillation facilities in Europe

- Beta Beam is one of 3 facilities in EUROnu
- CERN to Frejus/Canfranc/Gran Sasso
- Performance of baseline detector
- Physics reach

Feeding back to the design of the Beta Beam Facility

Participating Institutes, Beta Beams

- Full Partners
  - CEA, Saclay
  - CERN, Geneva
  - LPSC, Grenoble
  - LNMCI, Grenoble
  - UCL, Louvain la Neuve
  - INFN, Legnaro
- Associates
  - IAP, Novgorod
  - Technical University of Aachen, Aachen
  - Weizmann Institute of Science, Revohot
  - GSI, Darmstadt
  - Cockcroft Institute, Daresbury

Collaborators, Beta Beams

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et al.

The Beta Beam concept

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

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

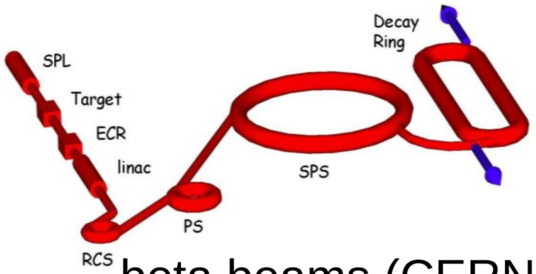
- Accelerate parent ion to relativistic γ_{max}
  - Boosted neutrino energy spectrum: $E_\nu \leq 2\gamma Q$
  - Forward focusing of neutrinos: $\theta \leq 1/\gamma$

- 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

- Possible physics applications of a beta-beam
  - Primarily neutrino oscillation physics and CP-violation (high energy)
  - Cross-sections of neutrino-nucleus interaction, sterile neutrinos (low energy)

Beta beams at CERN

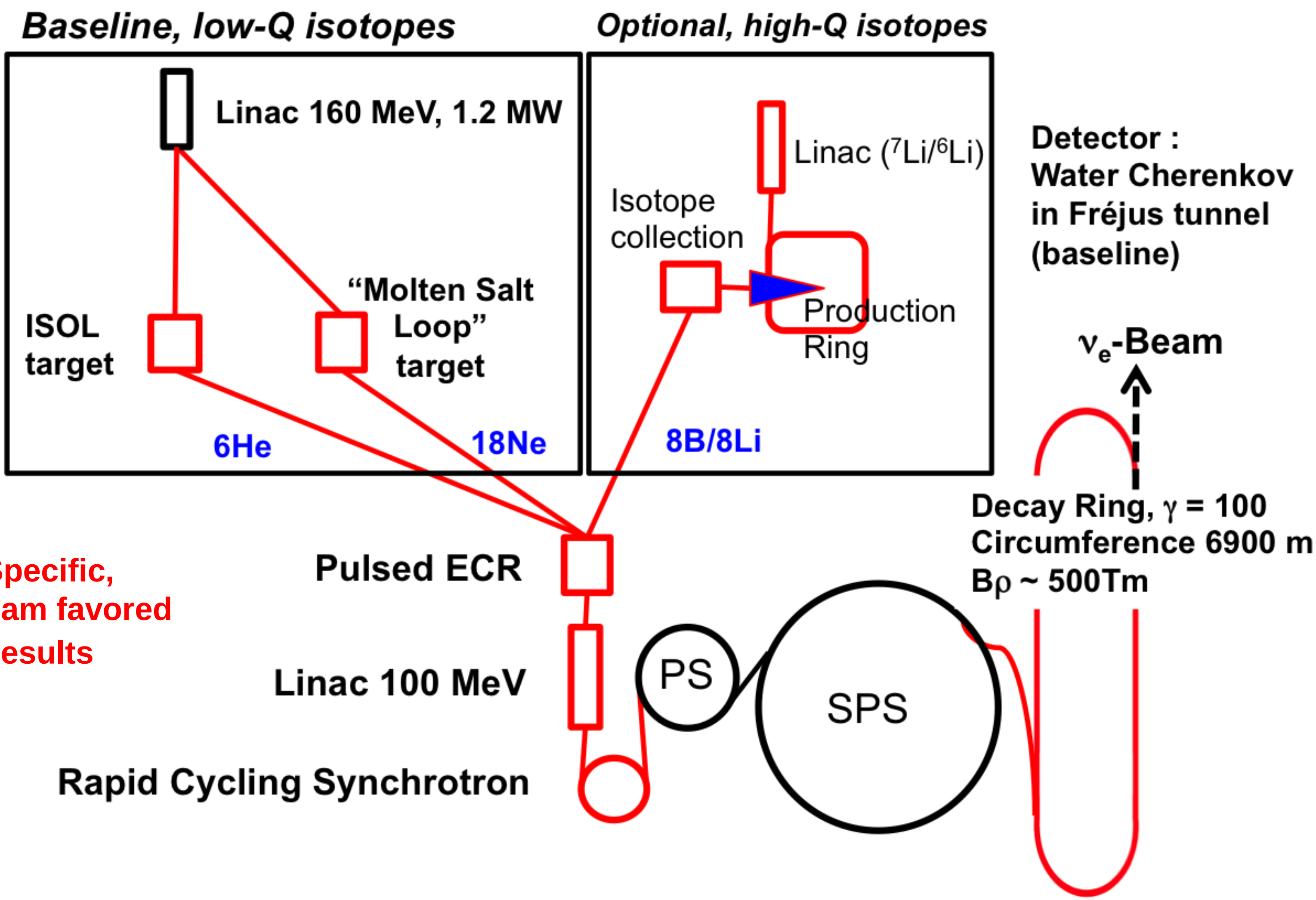
- Use of CERN machines and infrastructures, technology
  - Use of existing machines: PS and SPS
- Relativistic gamma=100 for both ions
  - SPS allows maximum of 150 (^{6}He) or 250 (^{18}Ne)
  - Gamma choice optimized for physics reach



beta beams (CERN)

- Opportunity to share detectors
  - Frejus (baseline option), Gran Sasso, Canfranc ???
- Assumed rates for estimations
  - $2.9*10^{18}$ anti-neutrinos from ^{6}He
  - $1.1\ 10^{18}$ neutrinos from ^{18}Ne

The CERN Beta Beam

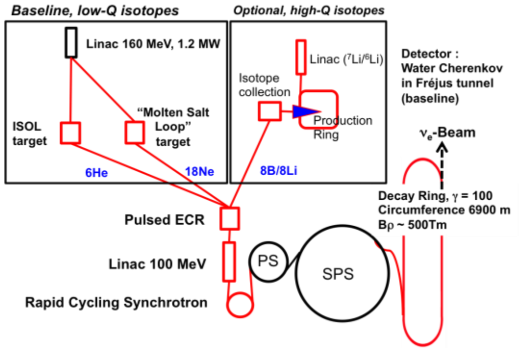


CERN Specific, Beta Beam favored by θ_{13} results

Decay Ring: Bρ ~ 500 Tm, B = ~7 T, C = ~6900 m, L_{ss}= ~2500 m, γ = 100, all ions

Research Beta Beams

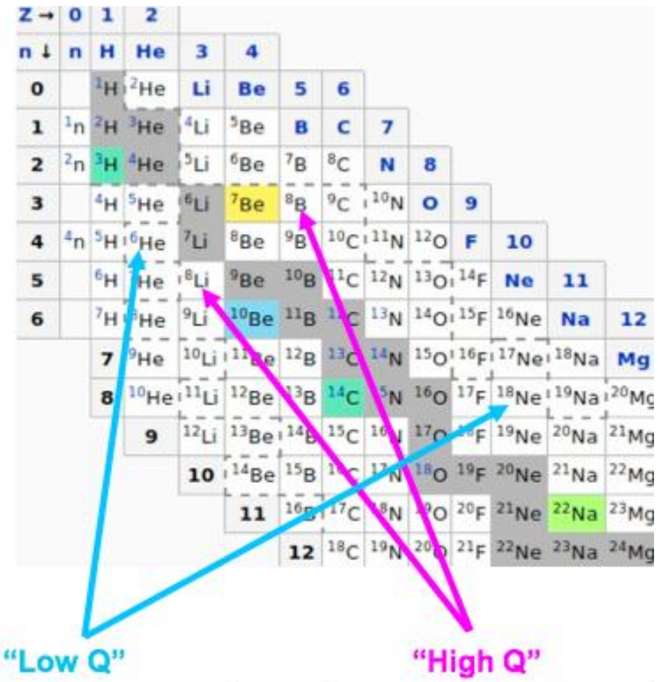
- Isotope Production (β^- and β^+)
- Cross section measurements
- Collection of isotopes
- Ionizing isotopes
- Accelerate optimally a stable ion beam
- Optimize the acceleration and cycling
- Radioprotection



Choice of isotopes

Considerations

- **Pair of β⁺ and β⁻ active ions**
  for ν and anti-ν …
- **Production rates**
  isol method or production ring
- **Life time**
  optimized for baseline ~1s
- **Reactivity**
  noble gases are good
- **Low Z preferred**
  minimize accelerated mass per charge
  reduce space charge problems
- **Q value**
  defines ν-energy & baseline



Isotope	^{18}Ne	^{6}He		^{8}B	^{8}Li
A/Z	1.8	3		1.6	2.7
Emitter	β⁺ (ν)	β⁻ (anti-ν)		β⁺ (ν)	β⁻ (anti-ν)
$\tau_{1/2}$ [s]	1.67	0.81		0.77	0.83
Q [MeV]	3.3	3.5		13.9	13.0

"Q value" is the kinetic energy release of a particle at rest"

E.g. for the neutron decay

$$Q = m_n - m_p - m_{\bar{\nu}} - m_e$$

Production of β-active isotopes

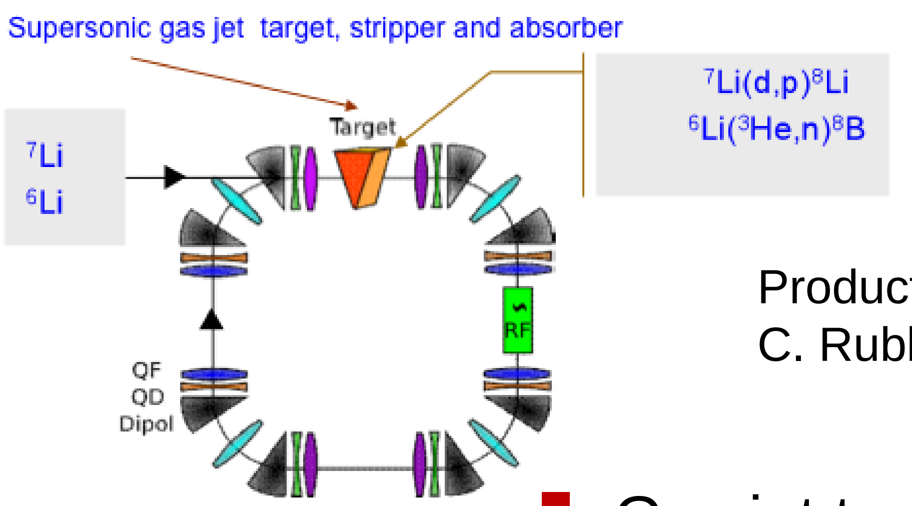
Aim ^{6}He and ^{18}Ne: 2 10^{13}/s **Targets below MWatt is a considerable advantage!**

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	6	0.160	0.160
E [MeV]	2000	160	25	25
P [kW]	140	960	4	4
Target	W/BeO	^{23}Na, ^{19}F	^{7}Li	^{6}Li
r [10^{13}/s]	5	0.9	0.1	0.08

^{6}He production exp. T. Stora, CERN-2010-003, pp. 110-117

The Production Ring (^{8}B and ^{8}Li)

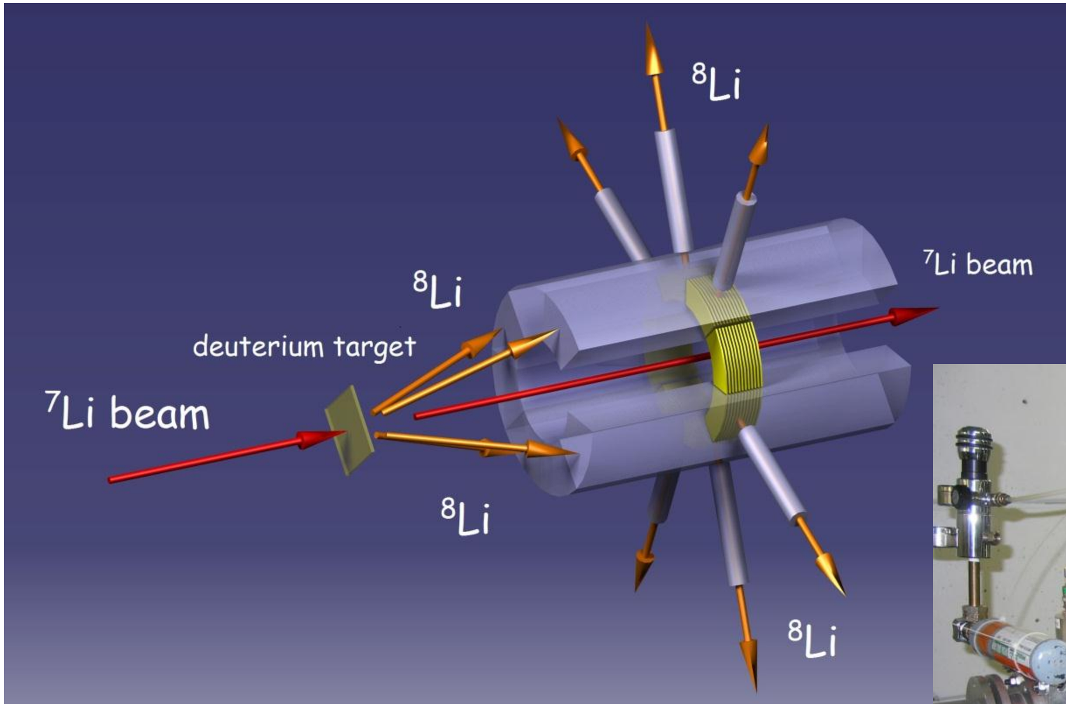
Aachen Univ., GSI, CERN, ANL

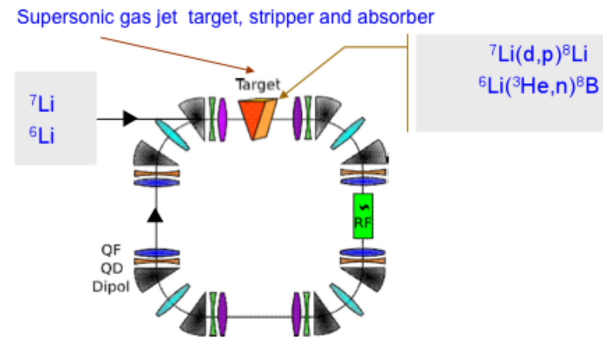


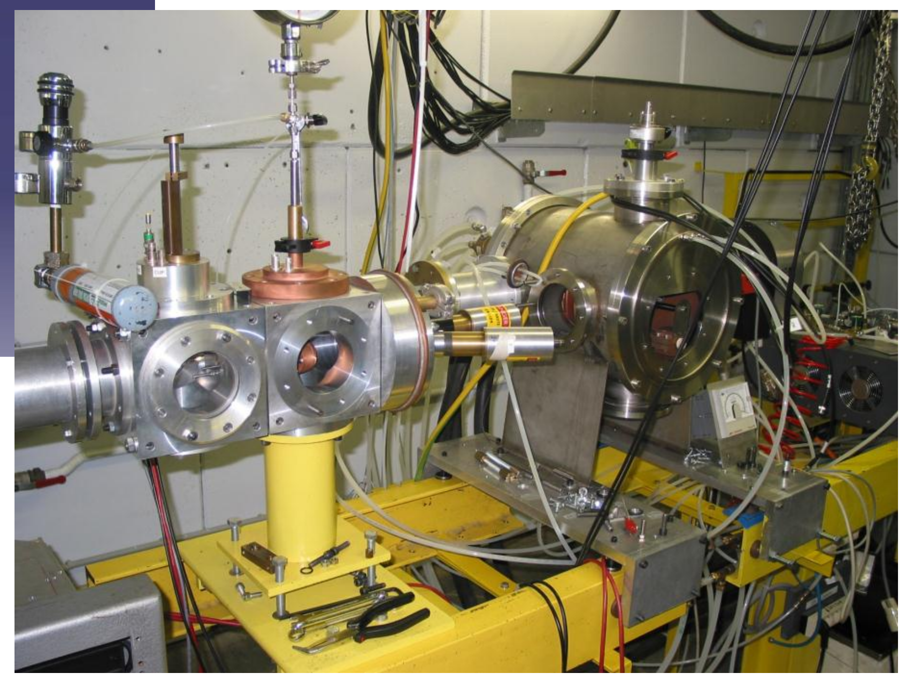
Production of 8B and 8Li
C. Rubbia, EUROnu proposal

- Gas jet target:
  - too high density would be needed
  - vacuum problems
- Direct production with liquid Li film targets

The collection device



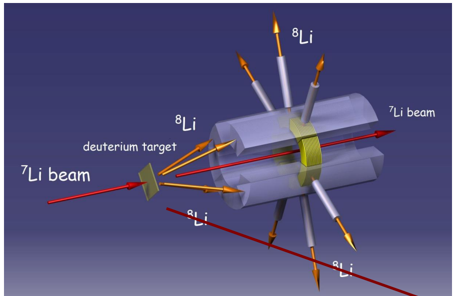




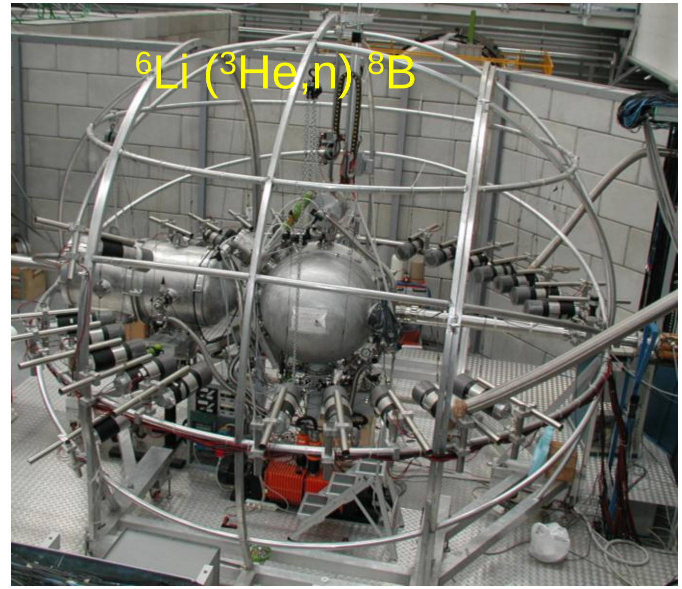
UCL, Louvain la Neuve

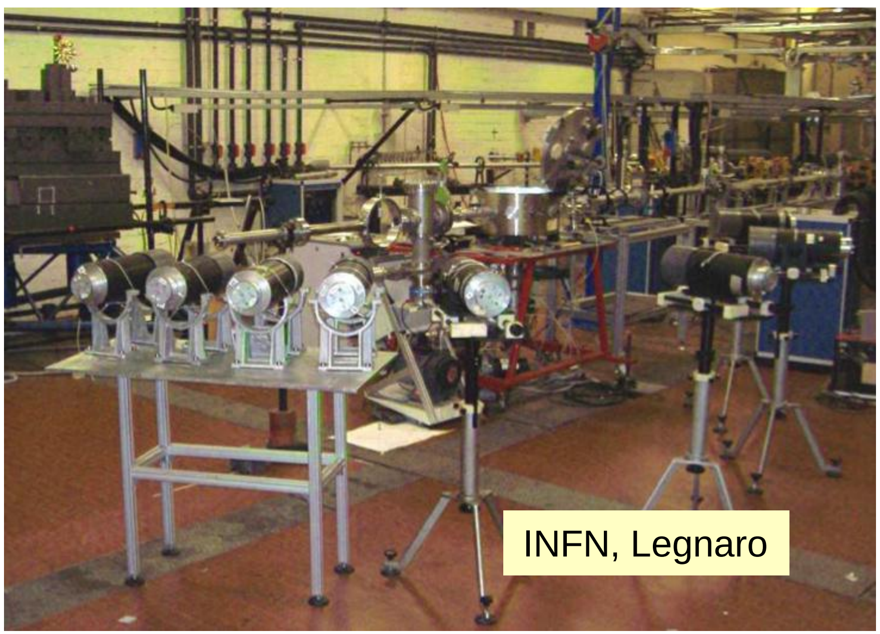
Production and collection finished
Efficiencies will be reported July 2012

^{8}B & ^{8}Li production: X-sections



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





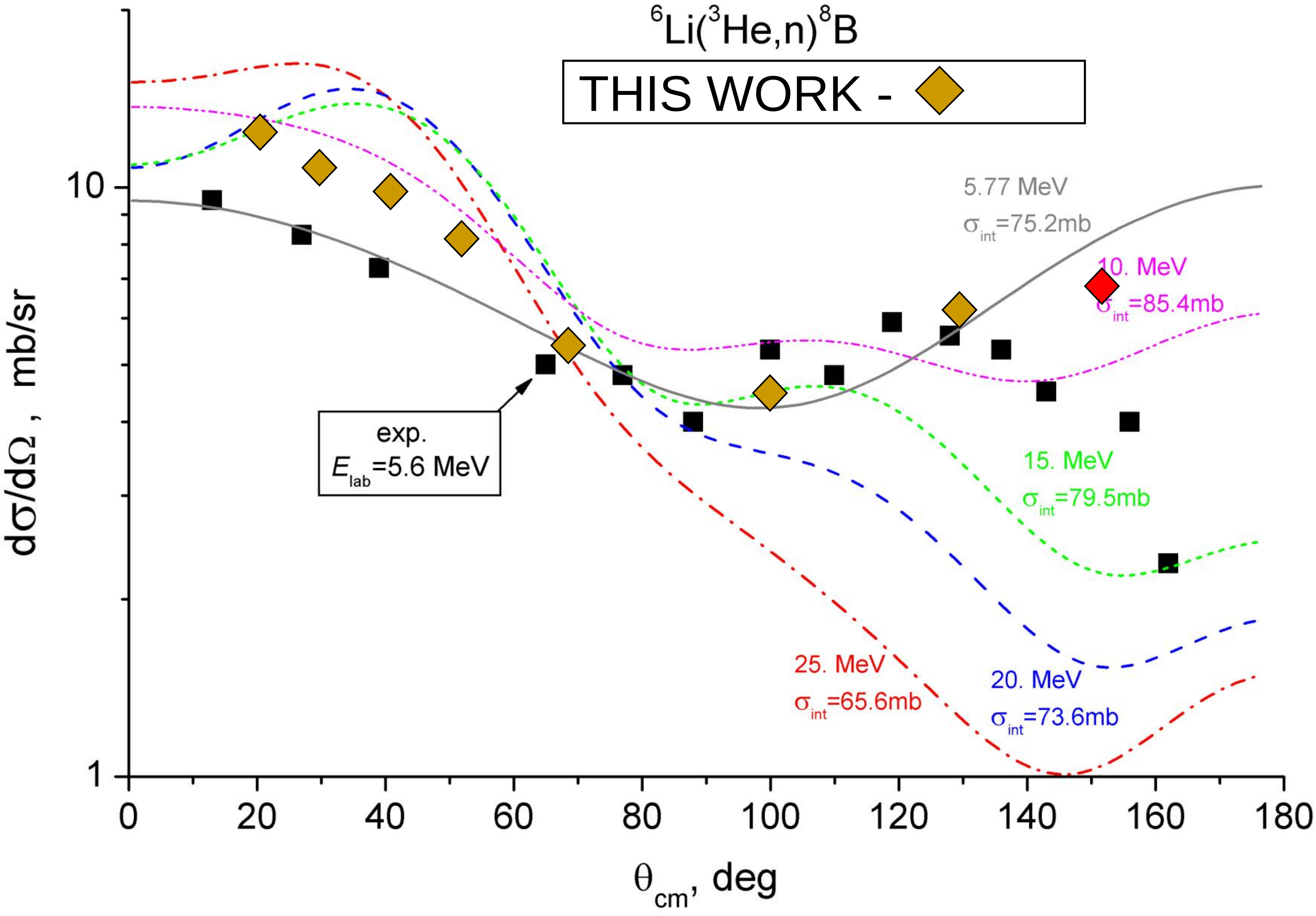
^{8}Li

90±18 mb at E_{lab}(7Li) = 25 MeV, between 6 and 10 degrees.

^{8}B

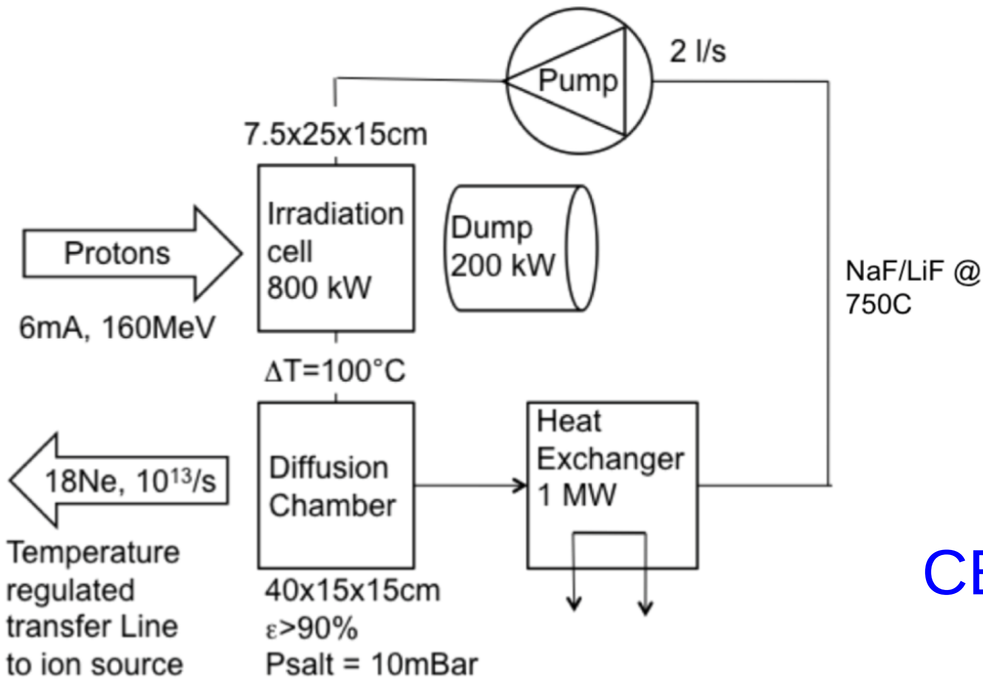
Very good agreement with theory, for beam energies available for the test (need experiments at 20MeV to 25 MeV)

^8B production (Preliminary)



^{18}Ne Experiments for Beta Beams 1

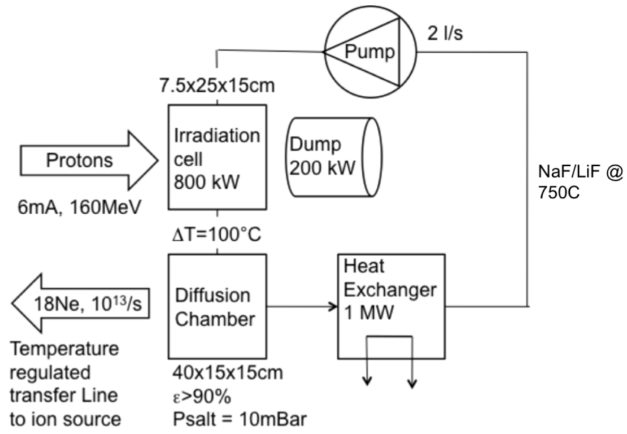
- Molten salt loop experiment to produce 18Ne
- Tests with beam at CERN & LPSC (Grenoble) in June 2012



CERN ISOLDE

^{18}Ne production rate estimated to 0.9 x10^{13} ions/s (dc) for 960 kW on target.

^{18}Ne Experiments for Beta Beams 2

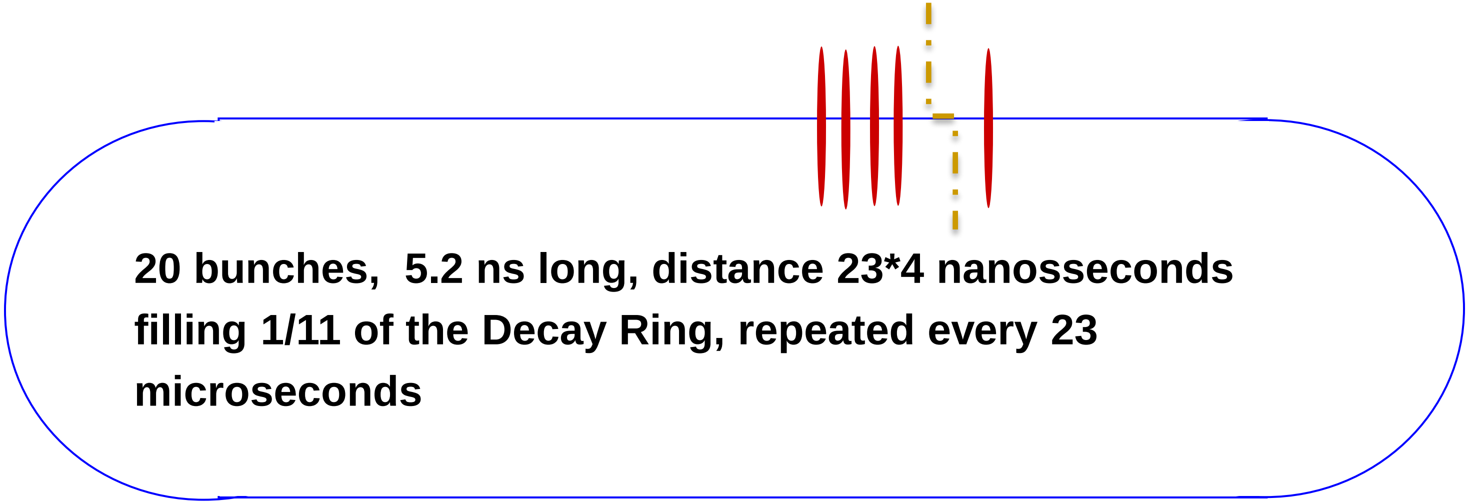


- NaF:ZrF4 sublimation of ZrF4 limits its use in a molten salt loop.
- Eutectic binary NaF:LiF system: ongoing experiments
- The effects of temperature and proton beam impact, which strongly affects the release efficiency in molten targets, are measured.
- Results expected July

Duty factor in DR small θ_{13}

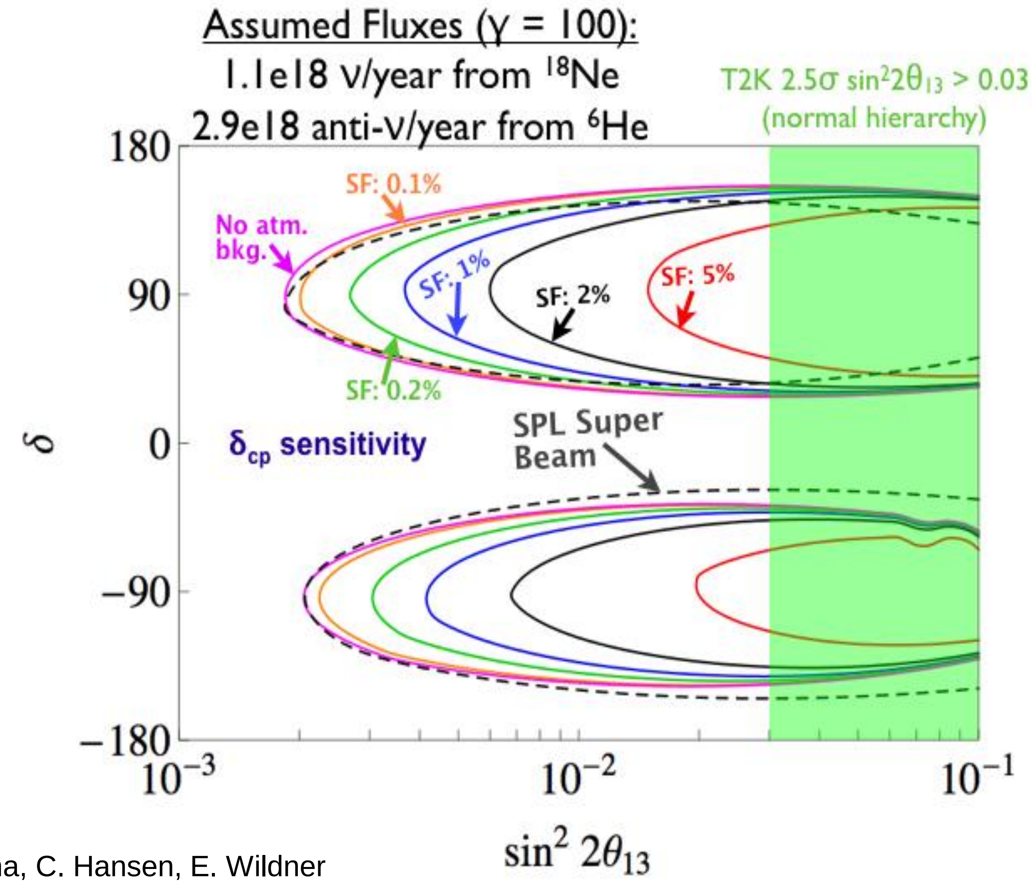
- 10^{14} ions and ~0.5% duty factor (atmospheric background suppression in the detector)

- RF system fulfilling requirements has recently been designed and costed



CPV dependence on SF (Fréjus option)

SF 2% seems sufficient for larger $\sin^2 2\theta_{13}$ (0.6% used up till now)
Permits higher fluxes and reach will increase (needs optimization)

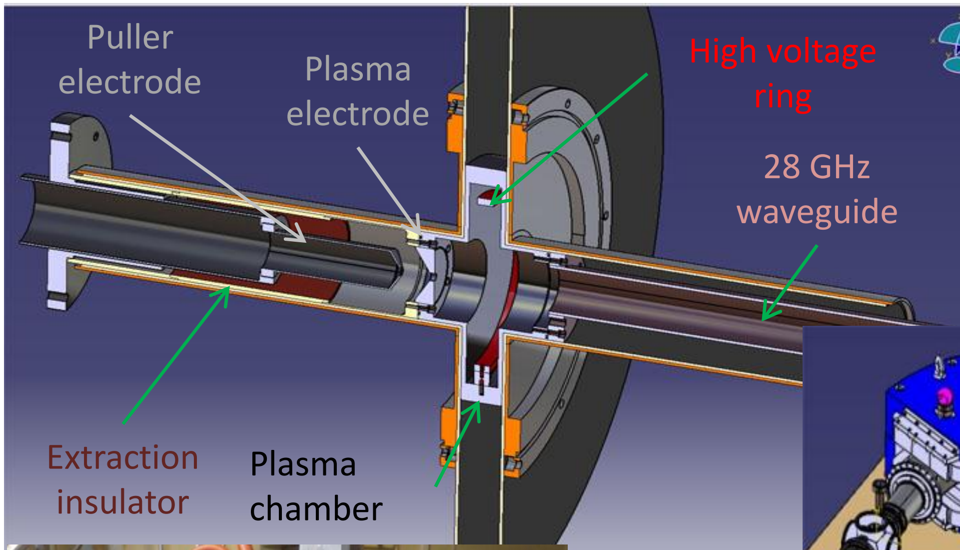


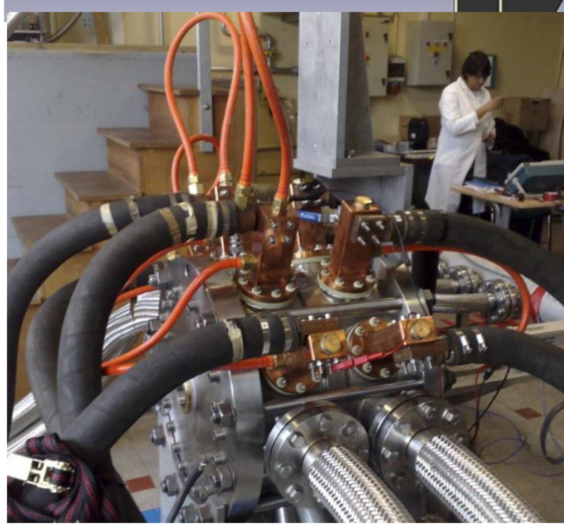
E. Fernandez, P. Coloma, C. Hansen, E. Wildner

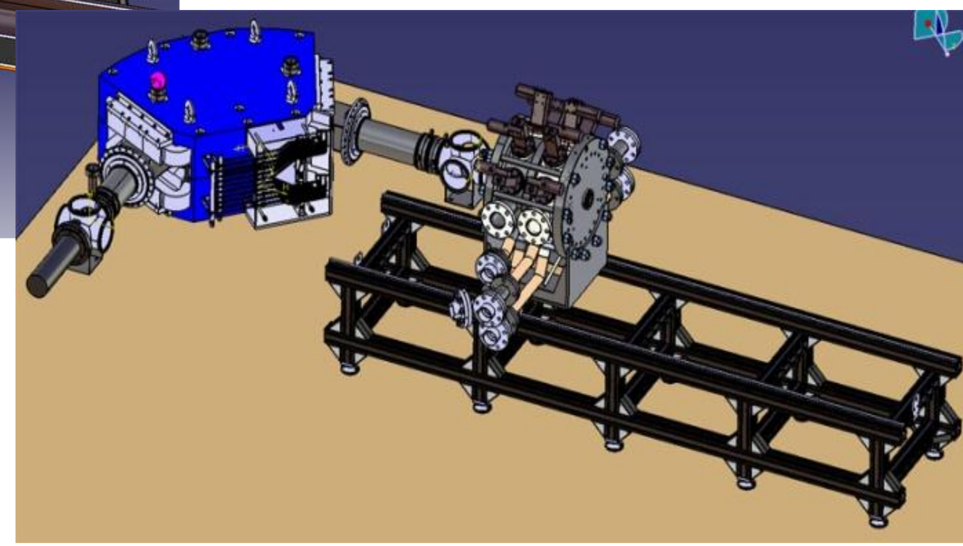
Duty factor in DR large θ_{13}

- 10^{14} ions and ~2% duty factor by having more bunches(atmospheric background suppression in the detector)
- RF system can be relaxed
- Optimize intensity distribution
- Beam stability is better
- Higher neutrino flux ?

60 GHz ECR Source







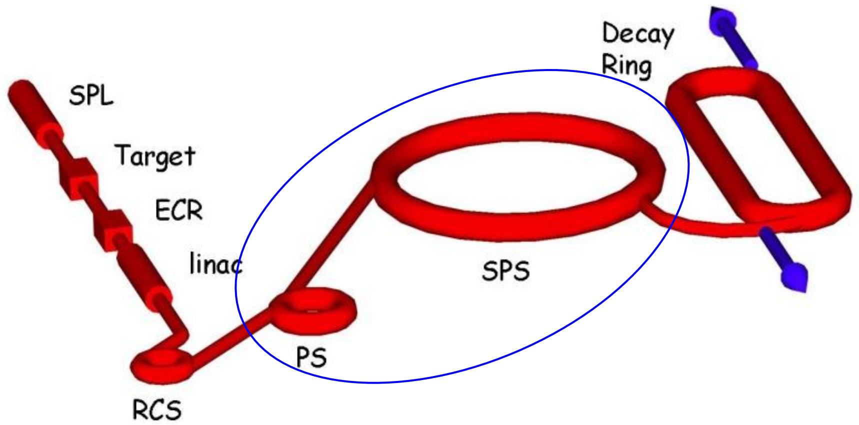
The SEISM Collaboration

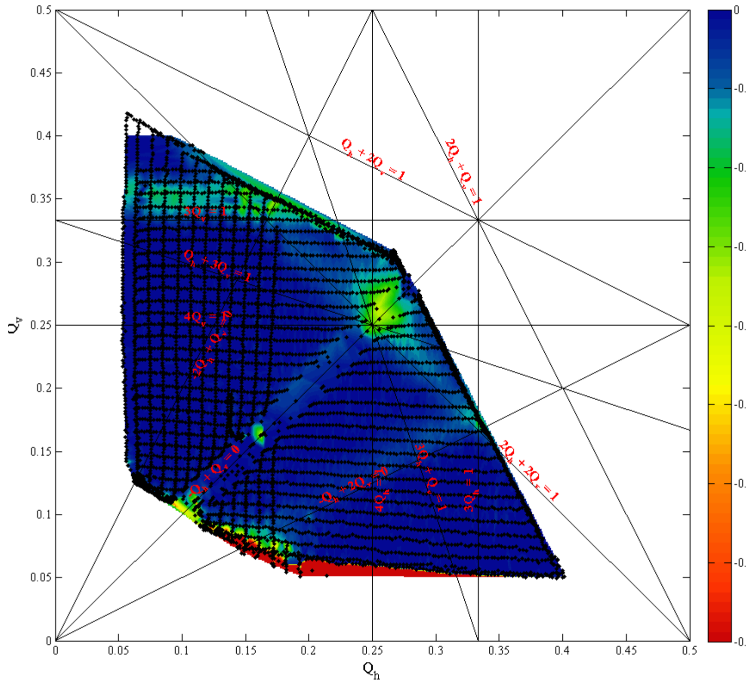
T. Lamy

60 GHz ECR Source tests

- The 60 GHz ECR source prototype assembled
- The magnetic field has been measured at half intensity
- Experimental data, 28 GHz operation, show good agreement with simulations.
- The 60 GHz gyrotron (Russia) will be tested in June 2012.
- The first beam experiments at 28 GHz in July 2012 followed by 60 GHz operation

Integration: PS & SPS

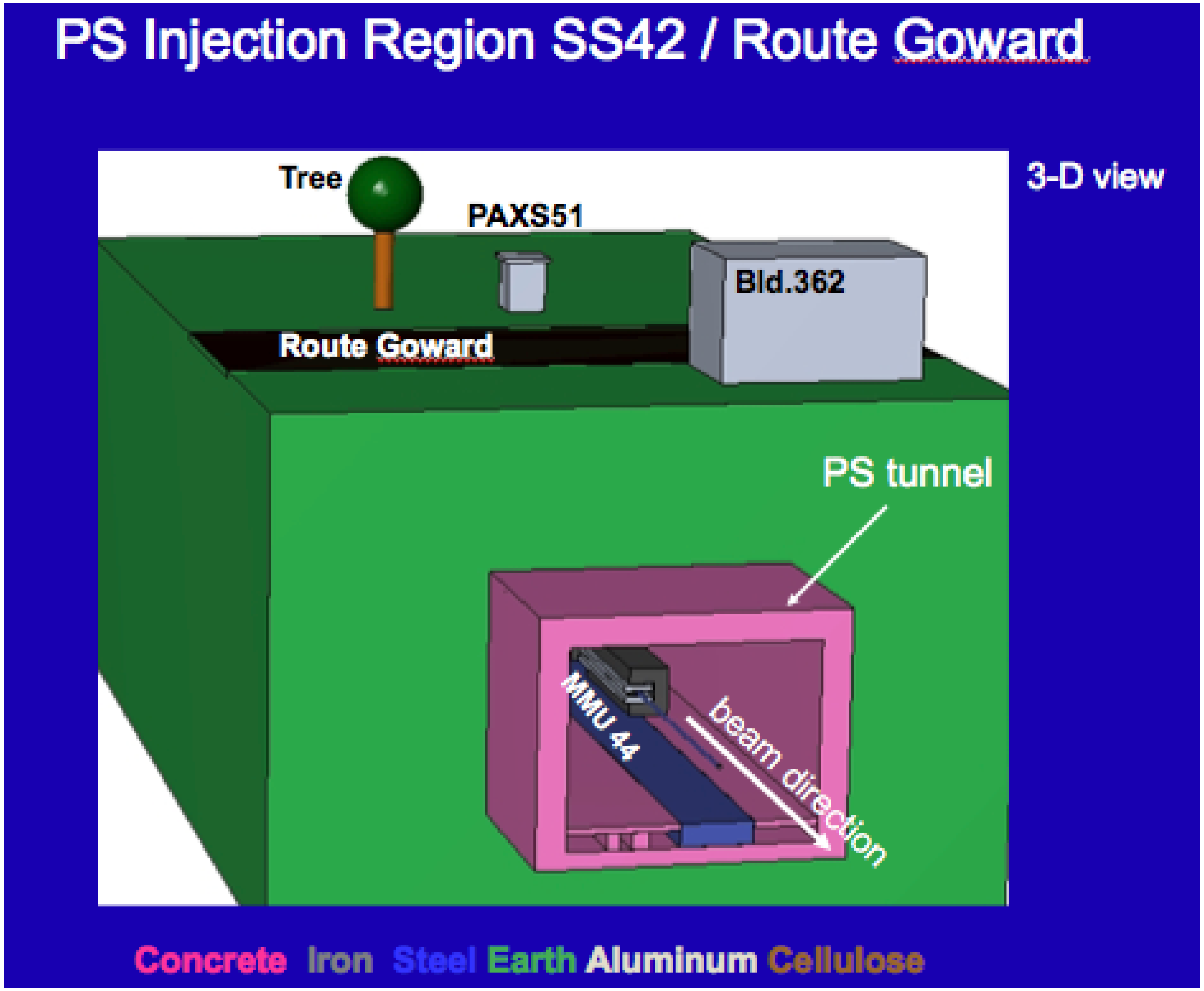




- Tune scans in PS
- 6He will survive, 18Ne needs resonance compensation (PS)
- Beam stability in the PS and the SPS still needs studies

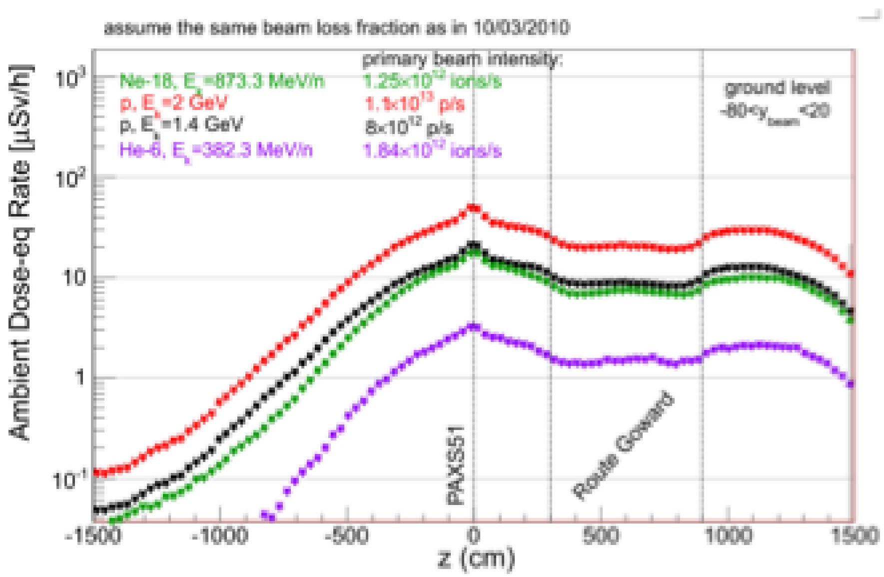
Integration: PS, radiation studies (1)

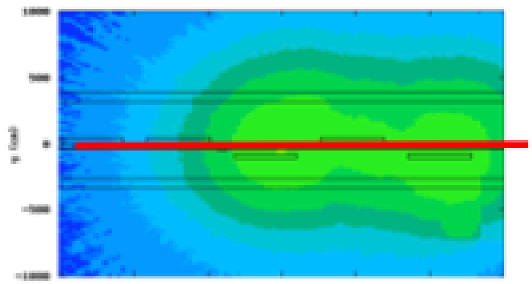
S. Damjanovic
DGS-RP, CERN



Integration: PS, radiation studies (2)

Ambient Dose-Eq Rate [μSv/h] above the Ground Level





Dose Rates extracted assuming the same relative beam loss as of 10/03/2010 when 6μSv/h was measured by PAXS51

values at PAXS51:

Ne-18, Ek=873.3 MeV/n:	17 μSv/h
He-6, Ek=382.3 MeV/n :	3 μSv/h
p, E_k=2 GeV:	49 μSv/h
p, E_k=1.4 GeV:	21 μSv/h

for the full proton beam intensities of 8×10^{12}p/s (E_k=1.4 GeV) and 1.1×10^{13}p/s (E_k=2 GeV) Dose Rates highest for the proton beams than for the beta beams.

Dose Rates higher by factors of 2.3, 3, 16 for p E_k=2 GeV beam losses compared to H-proton E_k=1.4 GeV, Ne-18 and He-6, resp.

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Costing and Safety Beta Beams

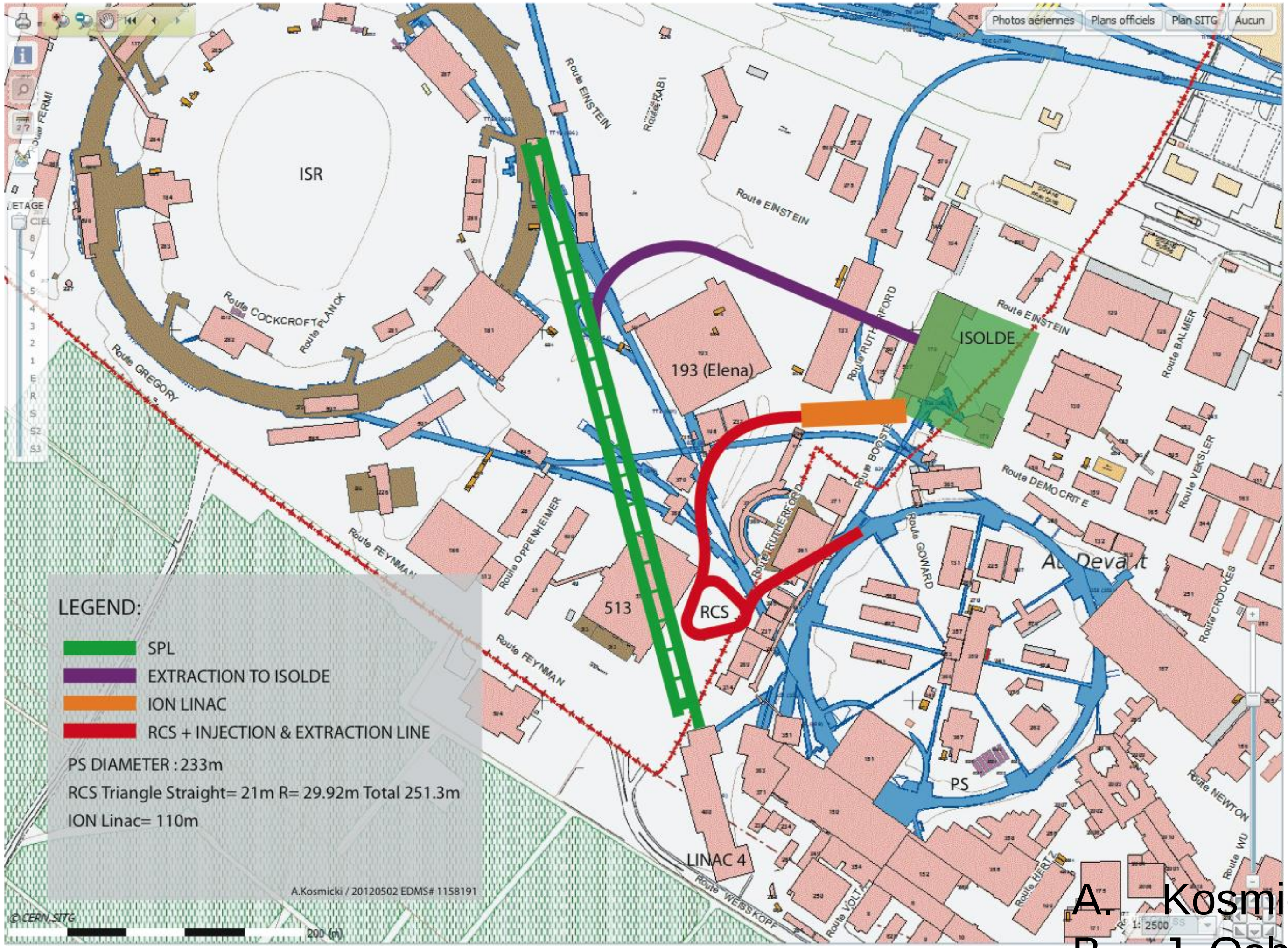
- Work Breakdown Structure (WBS) set up
  - Costing tool (CERN) is used

- Cost of equipment will be estimated as well as possible
  - Some equipment need resources for design

- Layout & civil engineering cost driving
  - Simple layout will be costed, infrastructure scaled

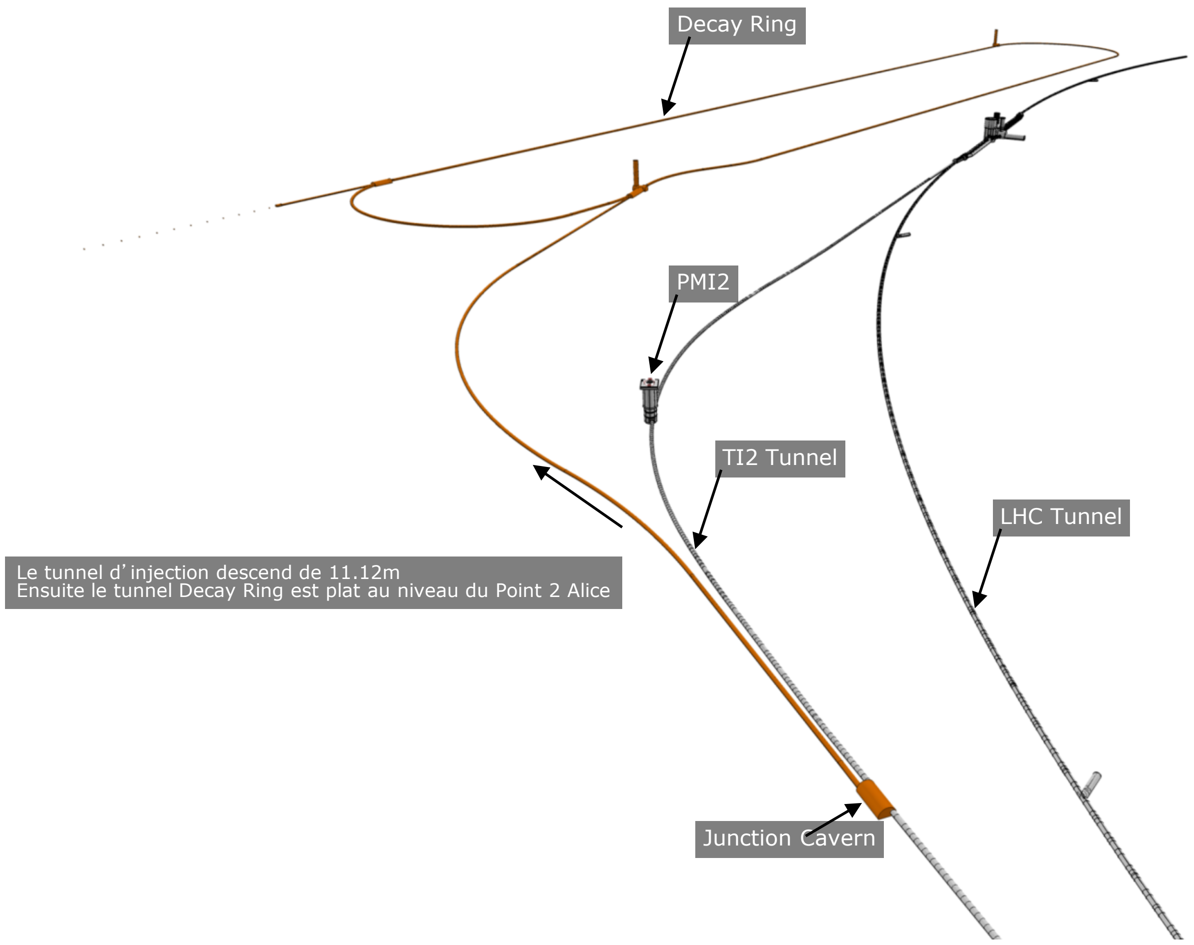
- Extensive list of safety items for beta beams is set up
  - Standard CERN
  - Specific for Acceleration of Radiocative Ions

Layout BB: Low Energy part



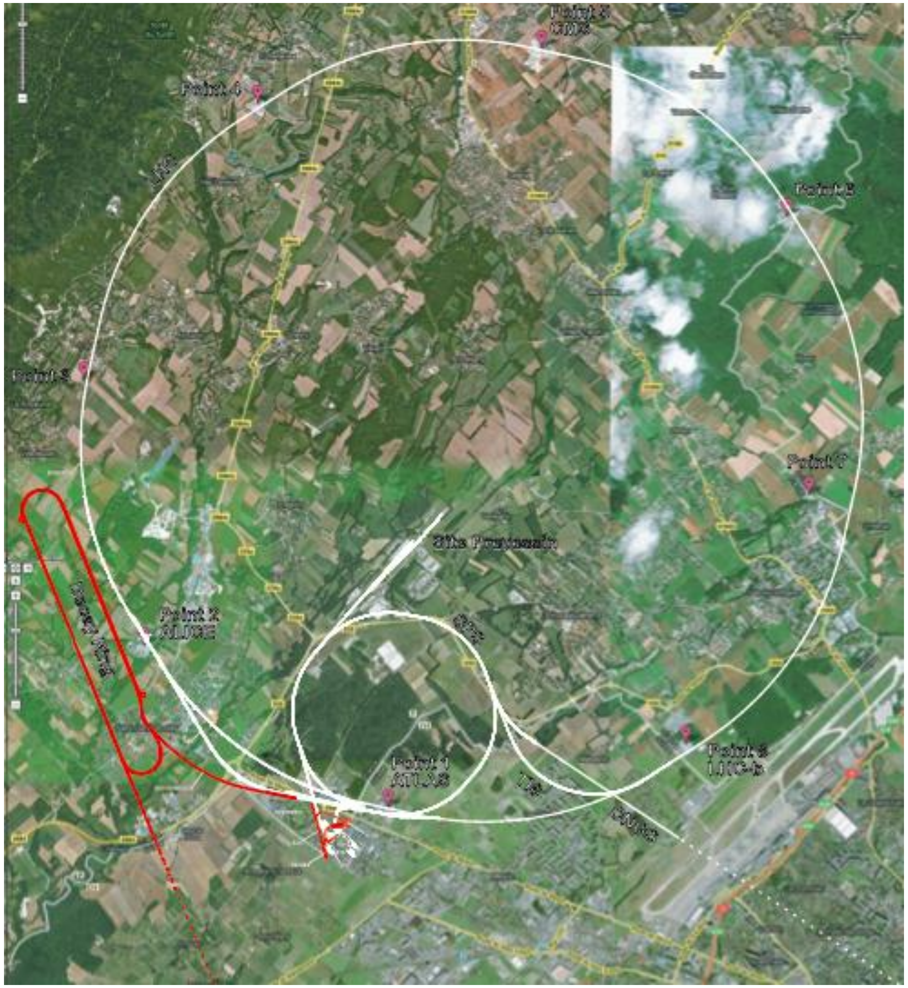
A. Kosmicki
B. J. Osborne

Layout BB: Decay Ring Injection



A. Kosmicki
B. J. Osborne

Footprint Beta Beam



A. Kosmicki
B. J. Osborne

Conclusion

- The EUROnu Beta Beam work ending August 2012
- The Low-Q option $^{6}He/^{18}Ne$ (CERN-Fréjus) is our baseline
    - Used for cost/performance evaluations
- Preliminary RP studies : no show stopper
- Studies remaining
    - Optimizations of bunching in the acceleration chain
    - Consolidate Beam stability (PS, SPS, DR)
    - Magnet protection DR
    - Radioprotection