Ion Production Needs for Beta Beams

Elena Wildner, CERN

ISOLDE Workshop and Users meeting 2009

Acknowledgements

Work on beta beams:

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)

M. Benedikt, FP6 Leader

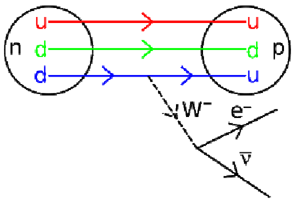
M. Lindroos

All contributing institutes and collaborators

Outline

- The Beta Beam Concept
- A Beta Beam Scenario
- Ion Production for neutrino beams
- Intensities
- Conclusion

Beta-beams, recall



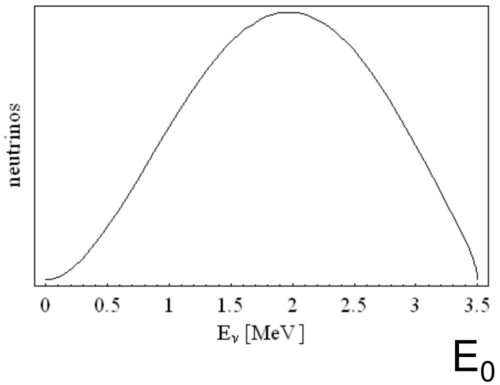
Aim: production of (anti-)neutrino beams from the beta decay of radio-active ions circulating in a storage ring

- Similar concept to the neutrino factory, but 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

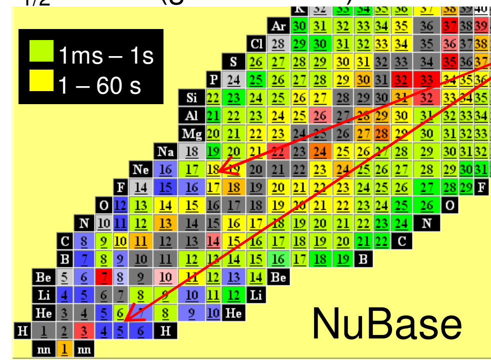
- Accelerate parent ion to relativistic γ_{max}
  - Boosted neutrino energy spectrum: $E_\nu \leq 2\gamma Q$
  - Forward focusing of neutrinos: $\theta \leq 1/\gamma$
- Pure electron (anti-)neutrino beam!
  - Depending on β^+- or β^-- decay we get a neutrino or anti-neutrino
  - Two different parent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



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

$t_{1/2}$ at rest (ground state)



6He and 18Ne

8Li and 8B

Isotope	A/Z	T ½ (s)	Q_β g.s to g.s (MeV)	Q_β eff (MeV)	E_β av (MeV)	E_ν av (MeV)	Ions/bunch	Decay rate (s^{-1})
^{6}He	3.0	0.80	3.5	3.5	1.57	1.94	$5\cdot10^{12}$	$4\cdot10^{10}$
^{8}He	4.0	0.11	10.7	9.1	4.35	4.80	$5\cdot10^{12}$	$3\cdot10^{11}$
^{8}Li	2.7	0.83	16.0	13.0	6.24	6.72	$3\cdot10^{12}$	$3\cdot10^{11}$
^{9}Li	3.0	0.17	13.6	11.9	5.73	6.20	$3\cdot10^{12}$	$1\cdot10^{11}$
^{11}Be	2.8	13.8	11.5	9.8	4.65	5.11	$3\cdot10^{12}$	$1\cdot10^{9}$
^{15}C	2.5	2.44	9.8	6.4	2.87	3.55	$2\cdot10^{12}$	$5\cdot10^{9}$
^{16}C	2.7	0.74	8.0	4.5	2.05	2.46	$2\cdot10^{12}$	$2\cdot10^{10}$
^{16}N	2.3	7.13	10.4	5.9	4.59	1.33	$1\cdot10^{12}$	$1\cdot10^{9}$
^{17}N	2.4	4.17	8.7	3.8	1.71	2.10	$1\cdot10^{12}$	$2\cdot10^{9}$
^{18}N	2.6	0.64	13.9	8.0	5.33	2.67	$1\cdot10^{12}$	$2\cdot10^{10}$

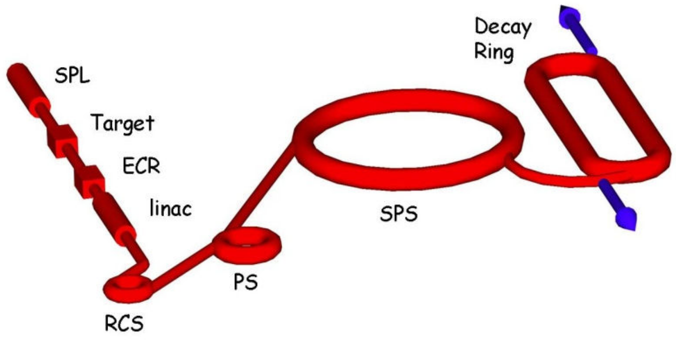
Isotope	A/Z	T ½ (s)	Q_β g.s. to g.s. (MeV)	Q_β eff (MeV)	E_β av (MeV)	E_ν av (MeV)	Ions/bunch	Decay rate (s^{-1})	rate / $E_{\nu\ av}$ (s^{-1})
^{8}B	1.6	0.77	17.0	13.9	6.55	7.37	$2\cdot10^{12}$	$2\cdot10^{10}$	$2\cdot10^{9}$
^{10}C	1.7	19.3	2.6	1.9	0.81	1.08	$2\cdot10^{12}$	$6\cdot10^{8}$	$6\cdot10^{8}$
^{14}O	1.8	70.6	4.1	1.8	0.78	1.05	$1\cdot10^{12}$	$1\cdot10^{8}$	$1\cdot10^{8}$
^{15}O	1.9	122.	1.7	1.7	0.74	1.00	$1\cdot10^{12}$	$7\cdot10^{7}$	$7\cdot10^{7}$
^{18}Ne	1.8	1.67	3.3	3.0	1.50	1.52	$1\cdot10^{12}$	$4\cdot10^{9}$	$3\cdot10^{9}$
^{19}Ne	1.9	17.3	2.2	2.2	0.96	1.25	$1\cdot10^{12}$	$4\cdot10^{8}$	$3\cdot10^{8}$
^{21}Na	1.9	22.4	2.5	2.5	1.10	1.41	$9\cdot10^{11}$	$3\cdot10^{8}$	$2\cdot10^{8}$

$1\cdot10^{9}$
$1\cdot10^{9}$
$6\cdot10^{9}$

The EURISOL scenario(*) boundaries

- Based on CERN boundaries
- Ion choice: ^{6}He 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 (^{6}He) 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 ^{6}He
  - $1.1\ 10^{18}$ neutrinos from ^{18}Ne

top-down approach

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

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

The EURISOL scenario
Design Study

Aimed:

He 2.9 10^{18} (2.0 10^{13}/s after target)

Ne 1.1 10^{18} (2.0 10^{13}/s after target)

Decay ring

$B\rho$ = 1500 Tm

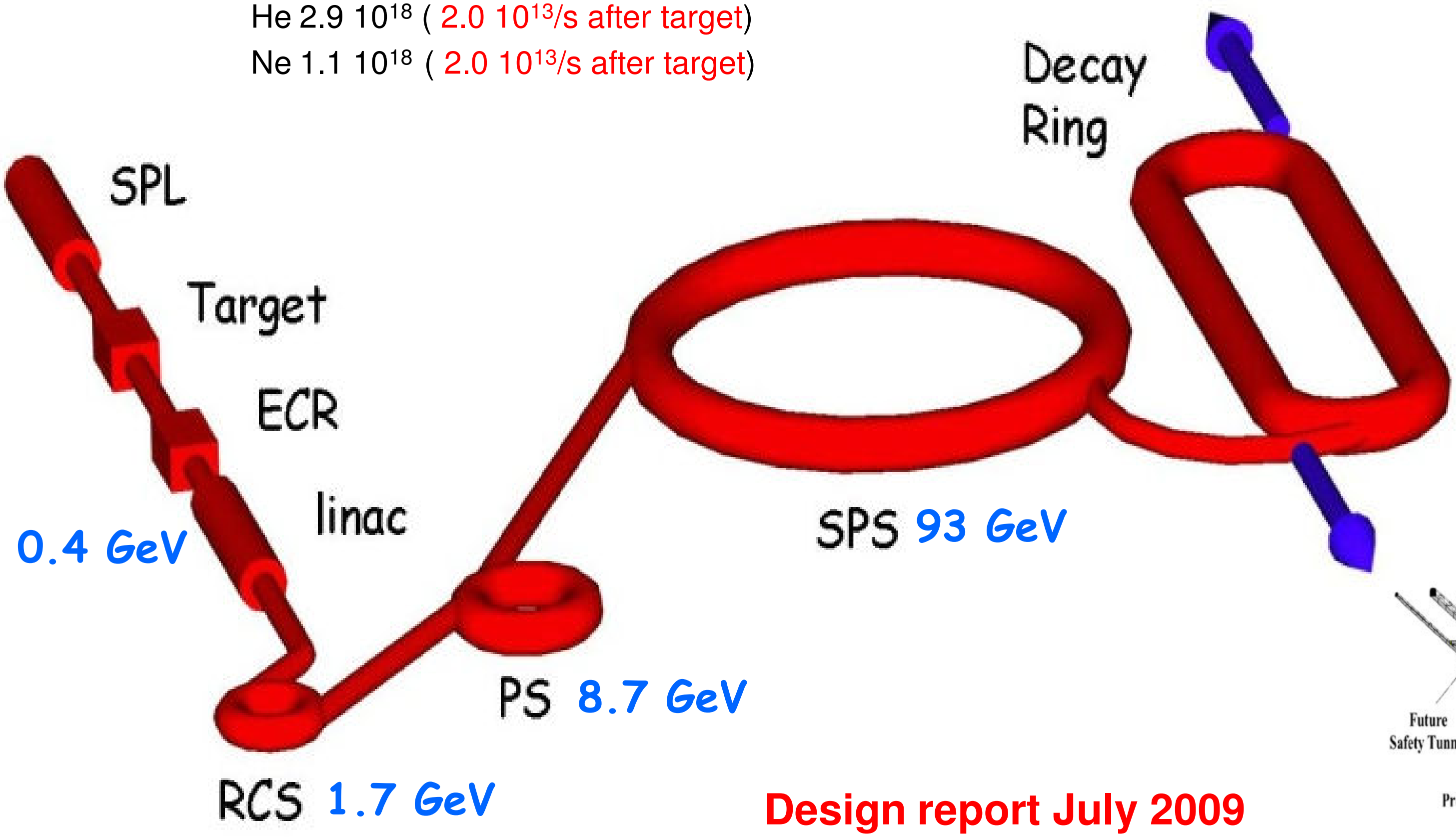
B = ~6 T

C = ~6900 m

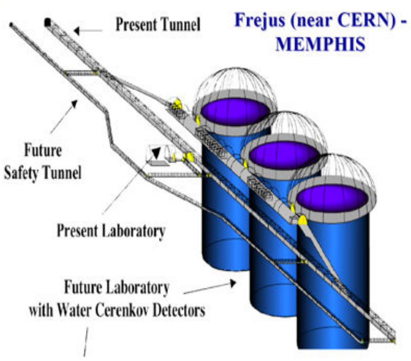
L_{ss} = ~2500 m

^{6}He: γ = 100

^{18}Ne: γ = 100



Design report July 2009



Options for production

- ISOL method at 1-2 GeV protons (200 kW)
  - ~3 10^{13} ^{6}He per second
  - <8 10^{11} ^{18}Ne per second
  - Studied within EURISOL
- Direct production
  - >1 10^{13} (?) ^{6}He per second
  - 2 10^{13} ^{18}Ne per second
  - Studied at LLN, Soreq, WI and GANIL
- Production ring
  - 10^{14} (?) ^{8}Li
  - >10^{13} (?) ^{8}B
  - Will be studied Within EUROν

Courtesy T Stora

Aimed:

He 2.9 10^{18} (2.0 10^{13}/s)

Ne 1.1 10^{18} (2.0 10^{13}/s)

Li 2.9 10^{18} (2.0*5 10^{13}/s)

B 1.1 10^{18} (2.0*5 10^{13}/s)

B/Li needs several factors more at the production stage due to longer baselines

N.B. Nuclear Physics has limited interest in those elements => Production rates not pushed!
Try to get ressources to persue ideas to produce Ne!

New approaches for ion production

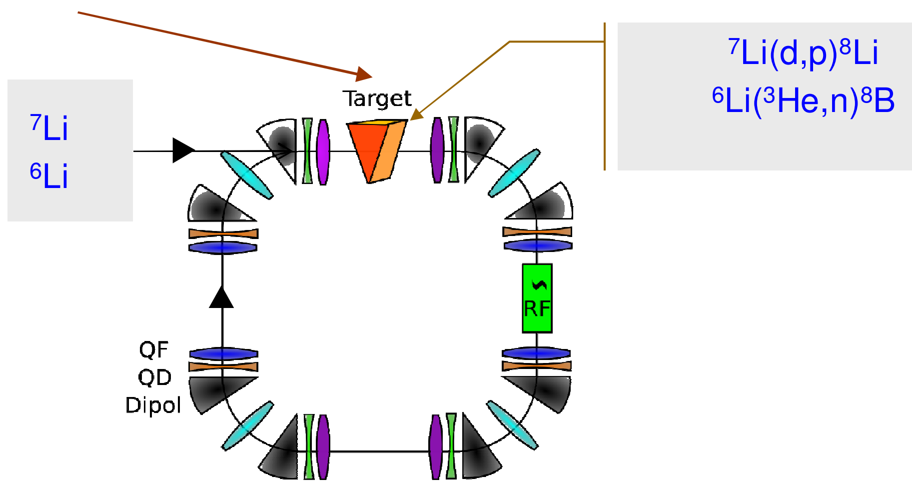
Shortfall of Ne & better physics reach led to new ideas:

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

Similar idea:

"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



Studied within Euroν FP7 (*)

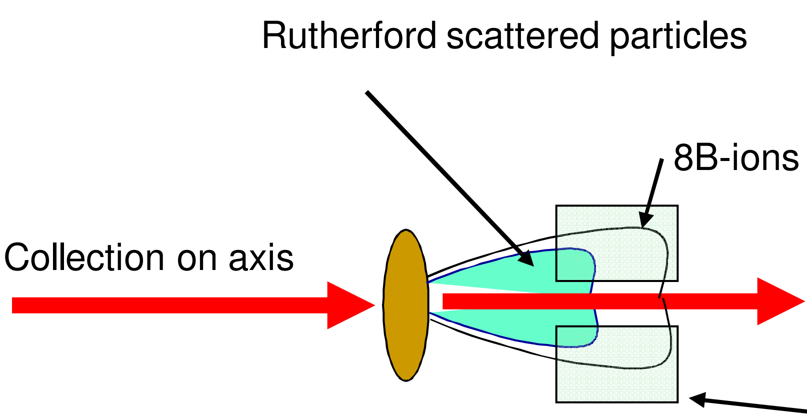
(*) FP7 "Design Studies" (Research Infrastructures) EUROnu (Grant agreement no.: 212372)

Challenge: collection device

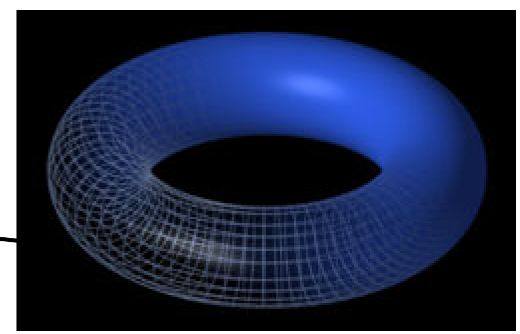
- A large proportion of beam particles (^{6}Li) will be scattered into the collection device.

CRC
Louvain-la-Neuve

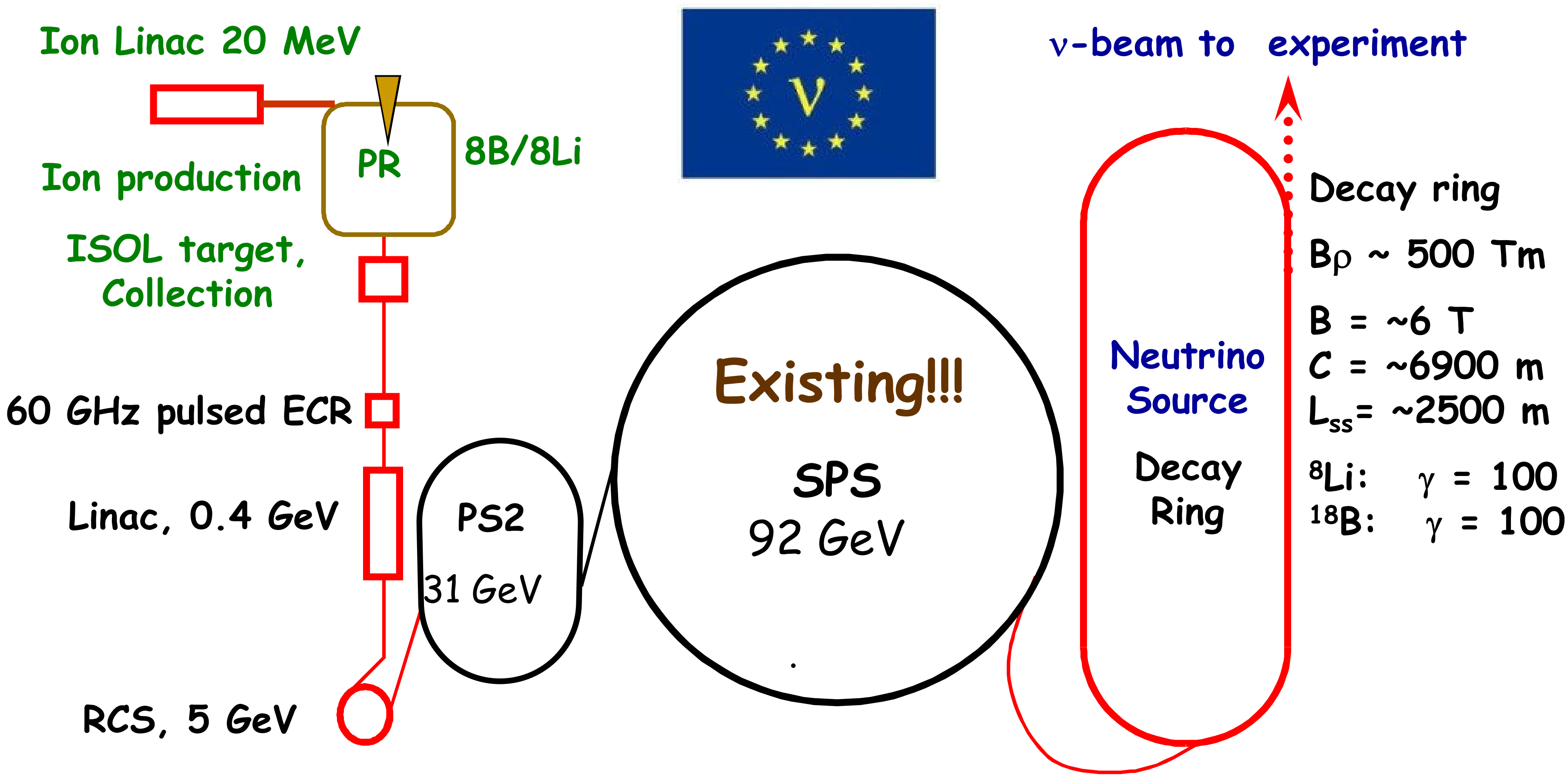
- Production of ^{8}Li and ^{8}B:
  $^{7}Li(d,p)\,^{8}Li$ and $^{6}Li(^{3}He,n)\,^{8}B$ reactions
  using low energy and low intensity ~ 1nA beams of ^{6}Li(4-15 MeV) and ^{7}Li(10-25 MeV) hitting the deuteron or ^{3}He target.



- **Semen Mitrofanov**
- Marc Loiselet
- Thierry Delbar



Beta Beam scenario EUROnu, FP7



Detector Gran Sasso (~ 5 times higher Q)

The beta-beam in EURONU DS (I)

- Focus on ion production issues
- ^{8}Li and ^{8}B
  - ^{8}B is highly reactive and has never been produced as an ISOL beam
  - ^{8}Li and ^{6}He from spallation neutron reactions
  - Production ring: enhanced direct production
- ^{18}Ne
  - We strongly encourage and work on ^{18}Ne production and acceleration (^{6}He seems good) to complete the study of the EURISOL beta beam scenario
- EC beams: Monochromatic
- EC & beta beams

Intensities

- High-Q (higher neutrino energy E at the same gamma boost)
  -> longer baselines (L) to get the same E/L

  Take into account cross sections for higher energies and smaller fluxes at longer baselines:

  Merit factor for an experiment at the atmospheric oscillation maximum: $M = \gamma / Q$

  - For higher Q values we need higher intensities for the same E/L: we cannot fully profit of higher production rates
  - The increased production needed for High-Q isotopes has to be accelerated throughout the accelerator chain and stored in the decay ring

Increased Physics reach, ^{156}Yb

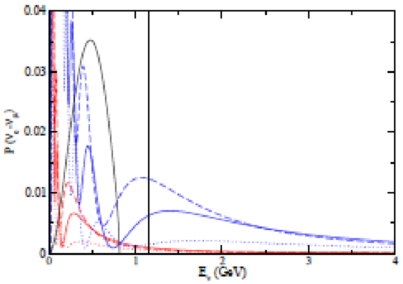
- Beta decay and EC with one ion

- Decay time 3.1 s at rest
  - at gamma 166 -> ~500 s
  - at gamma 369 -> ~1000 s
  - EURISOL beta beam gamma 100-> ~ 100 s

- Intensities will have to be ~3 times higher in our decay ring compared to EURISOL scenario (required intensities for B/Li case is 5 time EURISOL intensities)

- Space charge and loss of electrons to be investigated

- Interesting energy-dependence



Bernabeu et al. arXiv:0902.4903v1 [hep-ph] 27 Feb 2009

Conclusions

- The EURISOL beta-beam conceptual design report will be presented in second half of 2009
  - First coherent study of a beta-beam facility
  - Top down approach
  - 18Ne shortfall, getting solved?
- A beta-beam facility using ^{8}Li and ^{8}B (EUROnu)
  - Production of 8B & 8Li a challenge
  - Production of 8B & 8Li at ISOLDE? Other ways?
  - Results by 2012
- Other (complementary) isotopes?

Gamma and decay-ring size, ^{6}He

Gamma	Rigidity [Tm]	Ring length <u>T=5 T</u> <u>f=0.36</u>	Dipole Field <u>rho=300 m</u> <u>Length=6885m</u>
100	938	4916	3.1
150	1404	6421	4.7
200	1867	7917	6.2
350	3277	12474	10.9
500	4678	17000	15.6

Magnet R&D