



Beta Beams,
EUROnu WP4



FFAG10, International Workshop
on FFAG Accelerators, 28-31 Oct
2010, KURRI, Osaka

Beta Beams and radioactive isotopes Production Ring



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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

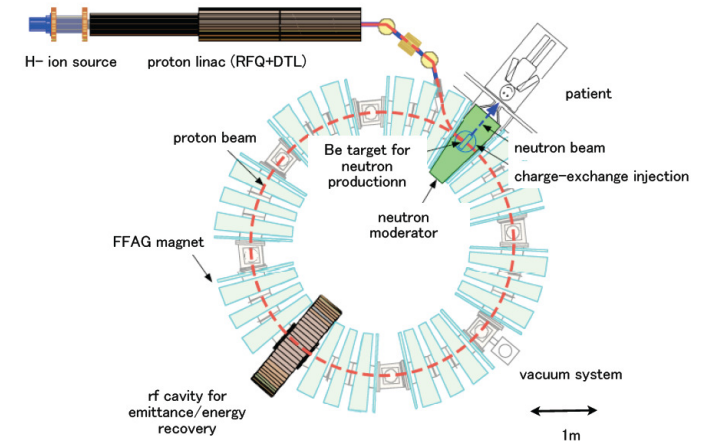
Development of FFAG accelerators and their applications for intense secondary particle production[☆]

Yoshiharu Mori^{*}

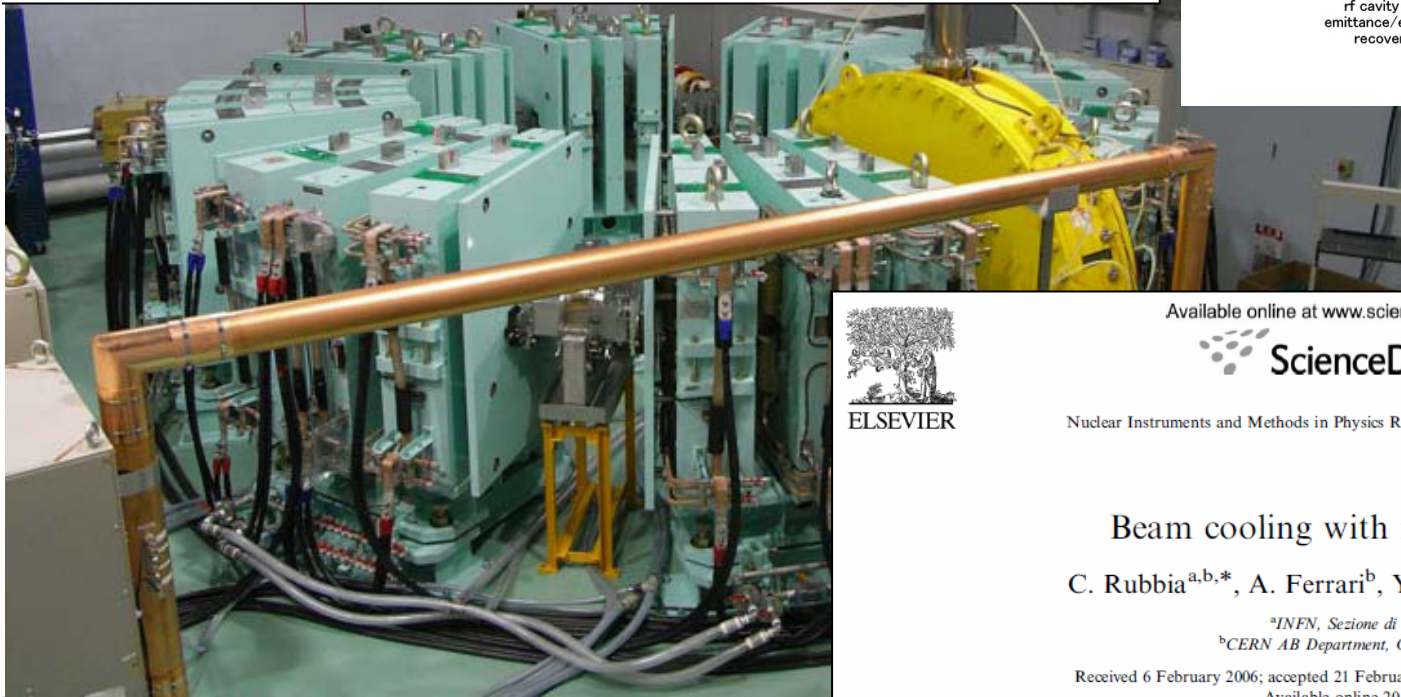
Kyoto University, Research Reactor Institute, Kumatori, Osaka 590-0494, Japan

Available online 3 March 2006

Schematic layout of FFAG-ERIT



K.Okabe et al, IPAC10, EPAC08,...



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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

Beam cooling with ionization losses

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E. Benedetto, FFAG'10, 30/10/10



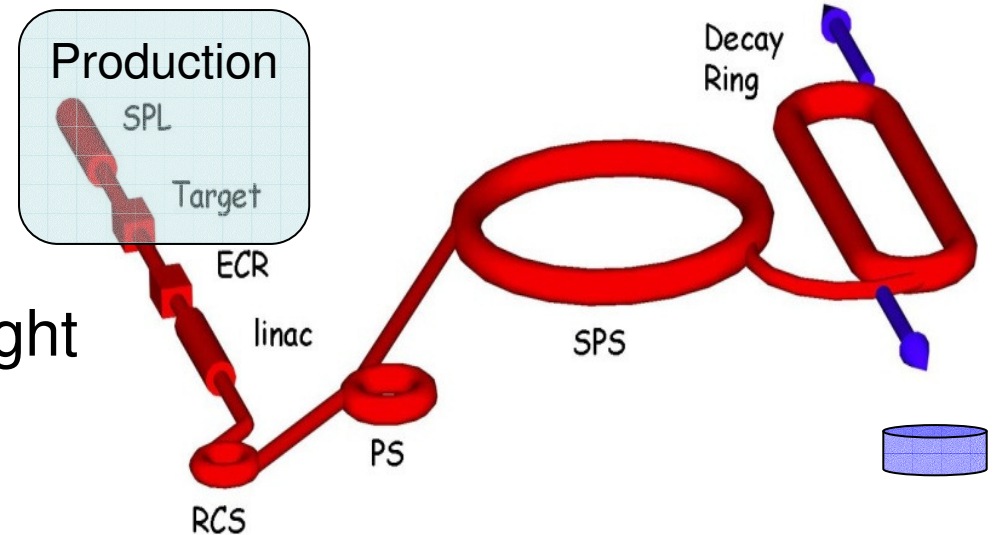
Outline

- BetaBeams to produce pure e-neutrino beams
 - The idea, the isotopes, challenges,...
- The Production Ring
 - Ionization cooling
 - Status of the studies
 - Challenges
 - What if I was using ERIT-FFAG?
- Summary

Beta-Beams: the idea

- Aim: production of **electron (anti-)neutrino** beams from **β -decay** of radioactive ions circulating in a **storage ring**
(P. Zucchelli, *Phys. Let. B*, 532 (2002)166-172)

- **Produce** radio-isotopes
- **Accelerate** them
- **Store** in Decay Ring (DR)
- **Let them β -decay** (a straight section points to detector)



- **Pure ν_e /anti- ν_e** are emitted (need a pair of β^+/β^- emitters)
 - with a known energy spectrum ($E_\nu \sim 2\gamma Q$)
 - in forward direction, (cone $\theta < 1/\gamma$)

$Q = \text{Reaction Energy} \sim \text{few MeV}$

Beta-Beams: the ions

- **Need a pair of neutrino and antineutrino emitters**
 - **Lifetime at rest:** $\tau_{1/2} \sim 1\text{s}$
 - **Low Z** (minimize accelerated mass/charge & reduce space-charge)
 - **Production rates**
- Stored in a race-track Decay Ring at $\gamma=100$
- Q = Reaction Energy

“Low-Q” isotopes

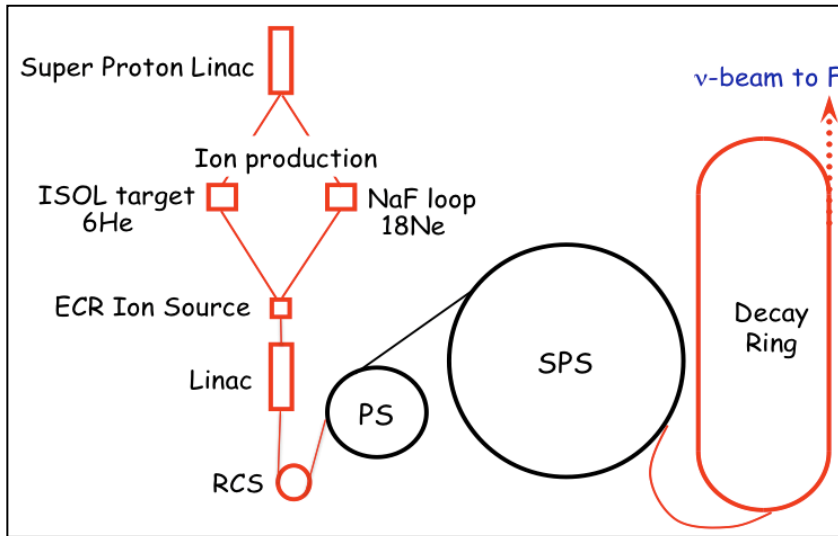
<i>Isotope</i>	<i>⁶He</i>	<i>¹⁸Ne</i>
<i>A/Z</i>	3	1.8
<i>emitter</i>	β^-	β^+
<i>$\tau_{1/2}$ (s)</i>	0.81	1.67
<i>Q (MeV)</i>	3.51	3.0

“High-Q” isotopes

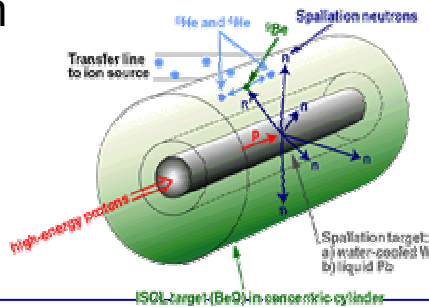
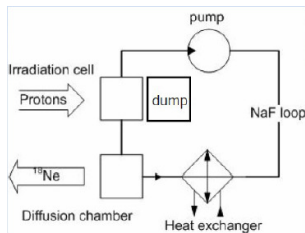
<i>Isotope</i>	<i>⁸Li</i>	<i>⁸B</i>
<i>A/Z</i>	2.7	1.6
<i>Emitter</i>	β^-	β^+
<i>$\tau_{1/2}$ (s)</i>	0.83	0.77
<i>Q (MeV)</i>	12.96	13.92

Beta-Beams: the 2 scenarios

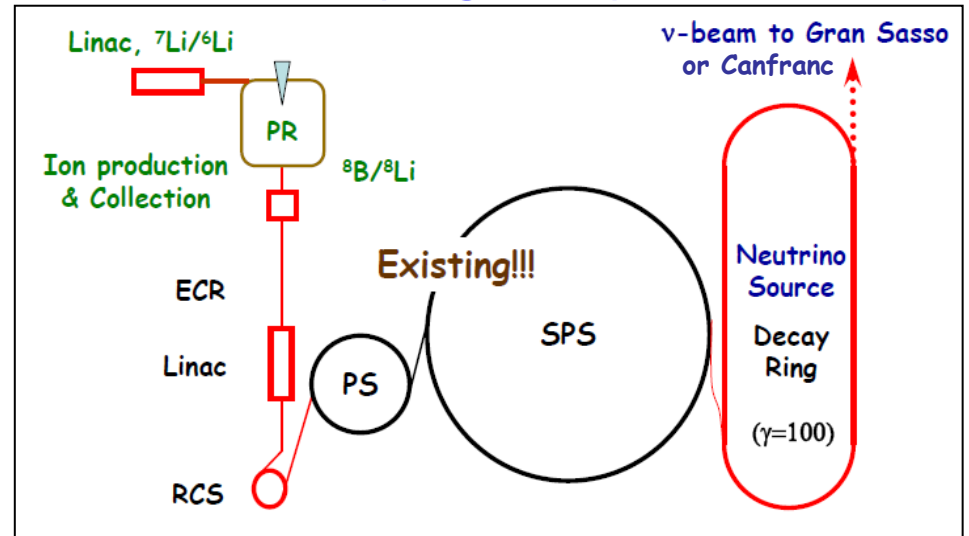
- ${}^6\text{He}, {}^{18}\text{Ne}$



- Detector @ Frejus (L=130 Km)
- ISOL production

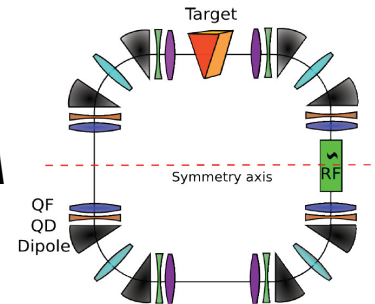


- ${}^8\text{Li}, {}^8\text{B}$ (high Q)



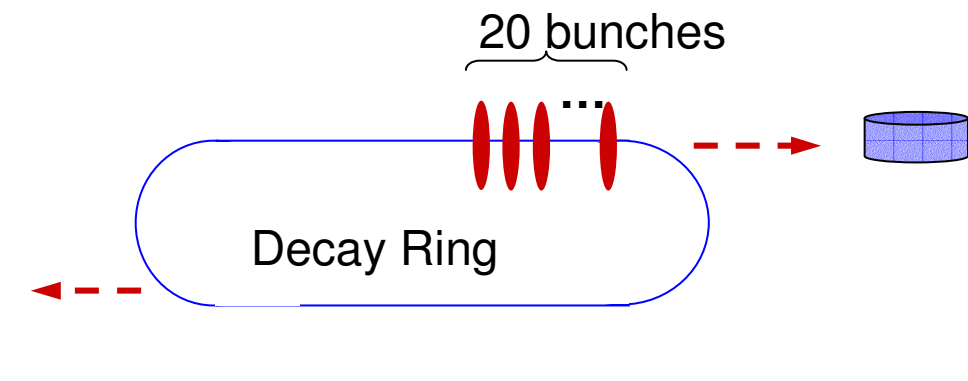
- Longer baseline (L=~700 Km)
- Production Ring

C. Rubbia et al, NIM A 568 (2006) 475–487



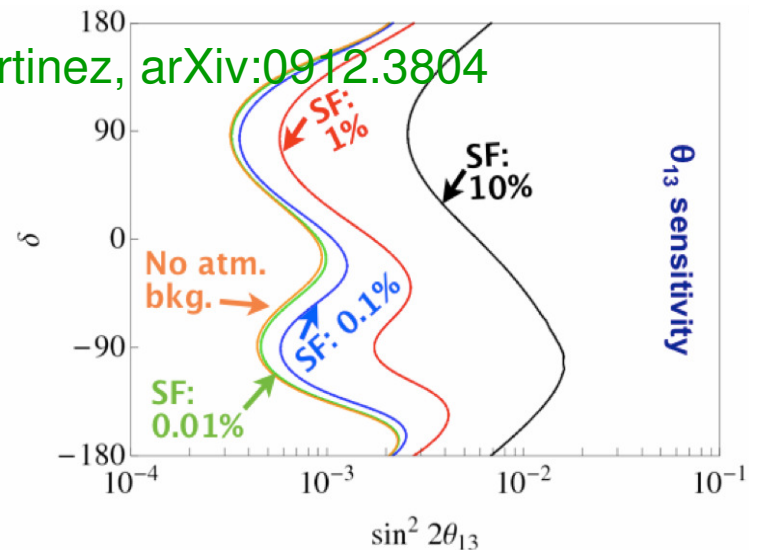
Beta-Beams: the required flux

- To get good sensitivity to θ_{13} and δ_{cp} needed:
 - **Very high intensities**
 - Annual (10^7 s) neutrino rate x 10 years run $\sim 10^{19}$ neutrino
 - Corresponding to production (@ source) of: $10^{14}/s$ ^8Li , ^8B
 - It is a factor 5 more than for ^6He , ^{18}Ne
 - **Small Duty Factor** (to suppress atmospheric bkg):
 - Beam in Decay Ring is bunched & occupies $<1\%$ circumference



E. Benedetto, FFAG'10, 30

E.Martinez, arXiv:0912.3804



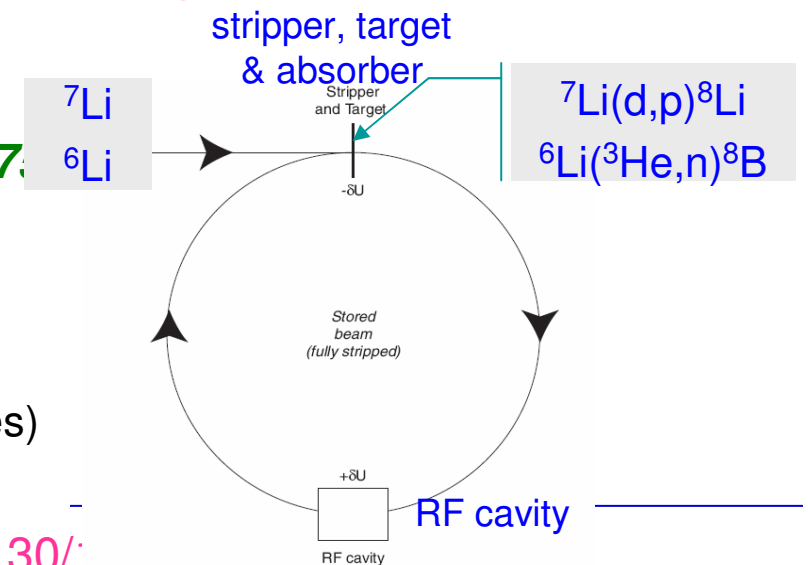
Beta-Beams: the challenges

- **Issues** mainly due to high intensity **identified** all along the chain
- **R&D** done and/or ongoing to find **mitigation or alternatives**
- Challenges include:
 - **Production rates** (discussed next)
 - Many losses/"wasted" ions (**<10% reach Decay Ring**)
 - (source efficiency, multiturn injection in RCS, β -decay, slow ramp rate...)
 - **Collective effects**
 - Collimation and **power deposition** in SC Decay Ring
 - **RF cavities beam loading** (small Duty Factor) in DR

Production Ring: the idea

- ^8Li , ^8B isotopes
 - Originally introduced to overcome lack of ^{18}Ne (maybe not the case any more)
 - Longer baseline for oscillation experiments
 - Studies started in 2009, within EUROnu(*)
- Production ring
 - Multi-passage through an **internal target**
 - Ionization cooling

- *C. Rubbia et al, NIM A 568 (2006) 47*
- *D. Neuffer, NIM A 585 (2008) 109*
- *Y. Mori, NIM A 562 (2006) 591*



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

Production Ring: ionization cooling

- Energy losses (dE/ds) in

$$-\frac{dE}{dx} = K z^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \right]$$

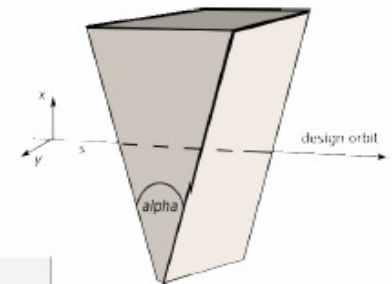
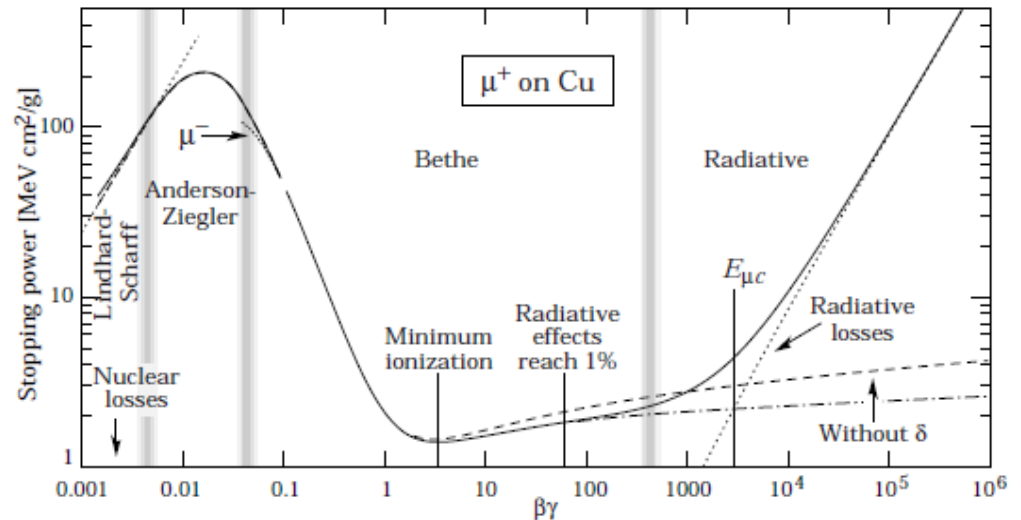
- Only longitudinal comp → Transverse emittance sl

- Cooling in 6D

- (dE/ds) ~ β⁻² smaller at higher energies → cooling not effective in longitudinal
- need coupling between transverse and longitudinal:

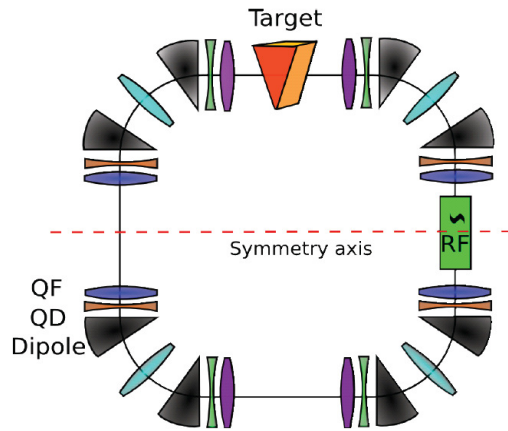
→ Dispersion & wedge-shaped target

Faster ions will travel on an outer orbit and see a larger target thickness → they will get more (dE/ds)

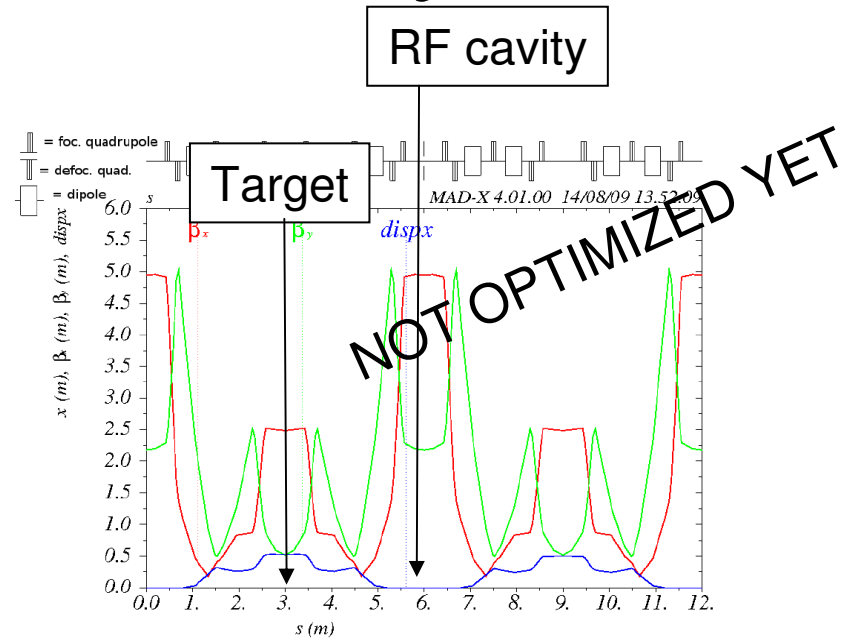


Target:
width @ closed orbit = 5 cm
t = 0.289 mg/cm²
If angle = 20° → D_x > 24 cm

Production Ring: preliminary lattice



M. Schaumann, CERN-THESIS-2009-128



Particle		${}^7\text{Li}$
Energy	E_c	25 MeV
Relativistic gamma	γ_r	1.00383
Beam rigidity	$B\rho$	0.636 T m
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
	n_t	10 ¹⁹ atoms/cm ²
Energy losses @ target	E_{BB}	~ 0.30 MeV

- C=12m
- normal-conducting magnets
- Capacitive loaded RF cavity
- Charge-exchange injection Li⁺¹

Production Ring: simulations

- Sixtrack

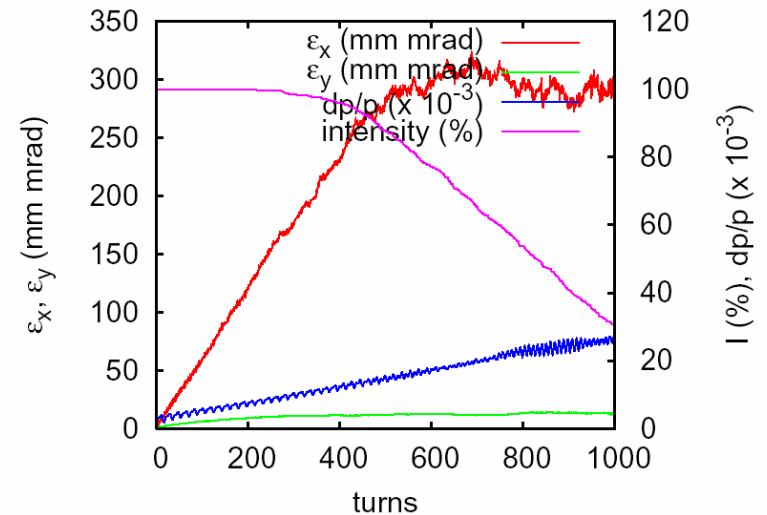
- Tracking code @ CERN
- Fully 6D, symplectic
- Reads MADX lattice

- Collimation version

- Tracking large # of particles,
- Interaction w. Collimators & special elements

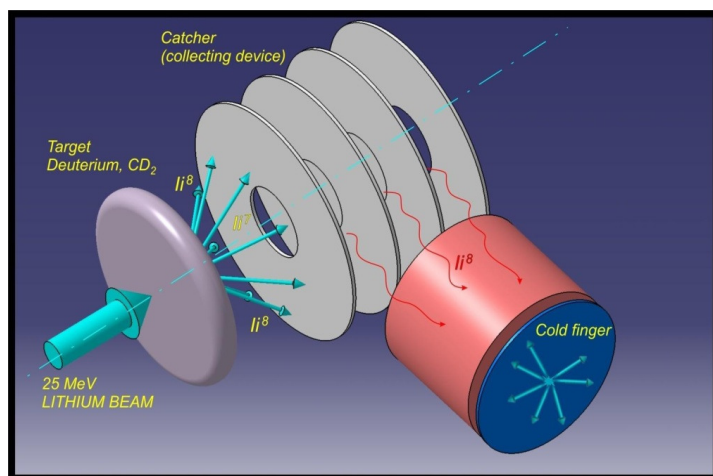
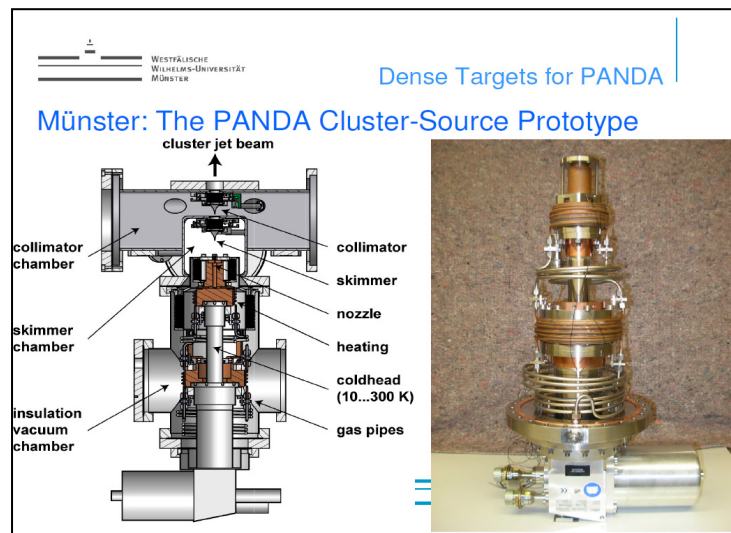
- Adapted to the Production Ring needs

- i.e. Target implemented
 - BetheBloch, Straggling, Multiple Coulomb Scattering (simple formula)
- Coupling w. MonteCarlo code FLUKA ongoing
 - *V.Vlauchoudis, D.Sinuela, E.B. (CERN)*



Production Ring: main challenges

- High density gas-jet target (10^{19} atoms/cm²) in vacuum environment
 - Factor 10^4 missing !!!
(from existing cluster-jet targets)
- Collection device investigation



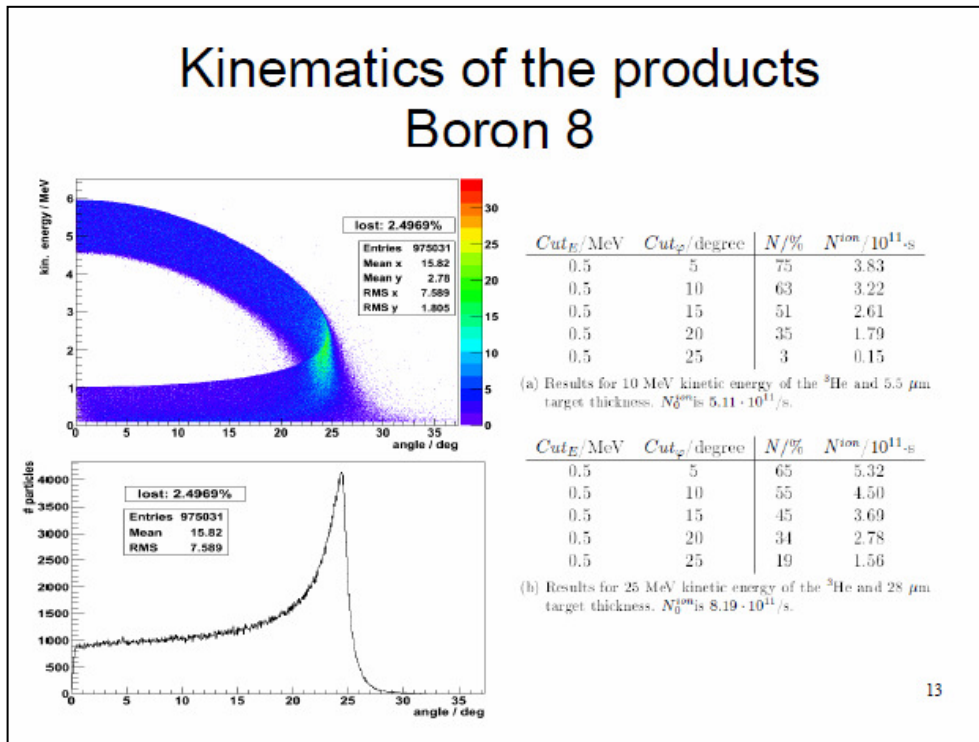
- Cross section & angular distribution measurements @ low energy
 - *V. Kravtchouk et al, INFN Legnaro*
- Collection device
 - experimental set-up ready for ⁸Li
 - ⁸B will follow...chemistry???
 - *S. Mitrofanov, T. Delbar, M. Loiselet, CRC, Louvain La Neuve*

Production Ring: alternative solution

- Direct kinematics + solid/liquid target
 - Solid (how to remove heat?) or liquid (instabilities of jet?)?
 - How to separate products ${}^8\text{Li}/{}^8\text{B}$ from circulating $\text{D}/{}^3\text{He}$?
 - angle & velocity of produced ions
 - do they still exit the target?
 - do we need to stop ions & diffusion/effusion mechanism, or... ?
 - Lithium liquid target technology
 - see e.g. **Y. Momozaki, J. Nolen, C. Reed, V. Novick, J. Specht.**
*Development of a liquid lithium thin film for use as a heavy ion beam stripper. **Journal of Instr.**, 4(04):P04005, 2009.*
 - Which energy?
 - target thickness + stopping power + production cross section...

Production Ring: alternative solutions

- Direct kinematics + solid/liquid target



→ T. Weber (RTWH Aachen)

- Factor 1000 gained
- Still factor 10-100 missing
- (assuming beam Nb=10¹²)
- Maybe higher energies:
 - from 10MeV to 24MeV
 - cross-section smaller
 - freq increases
 - but straggling increases

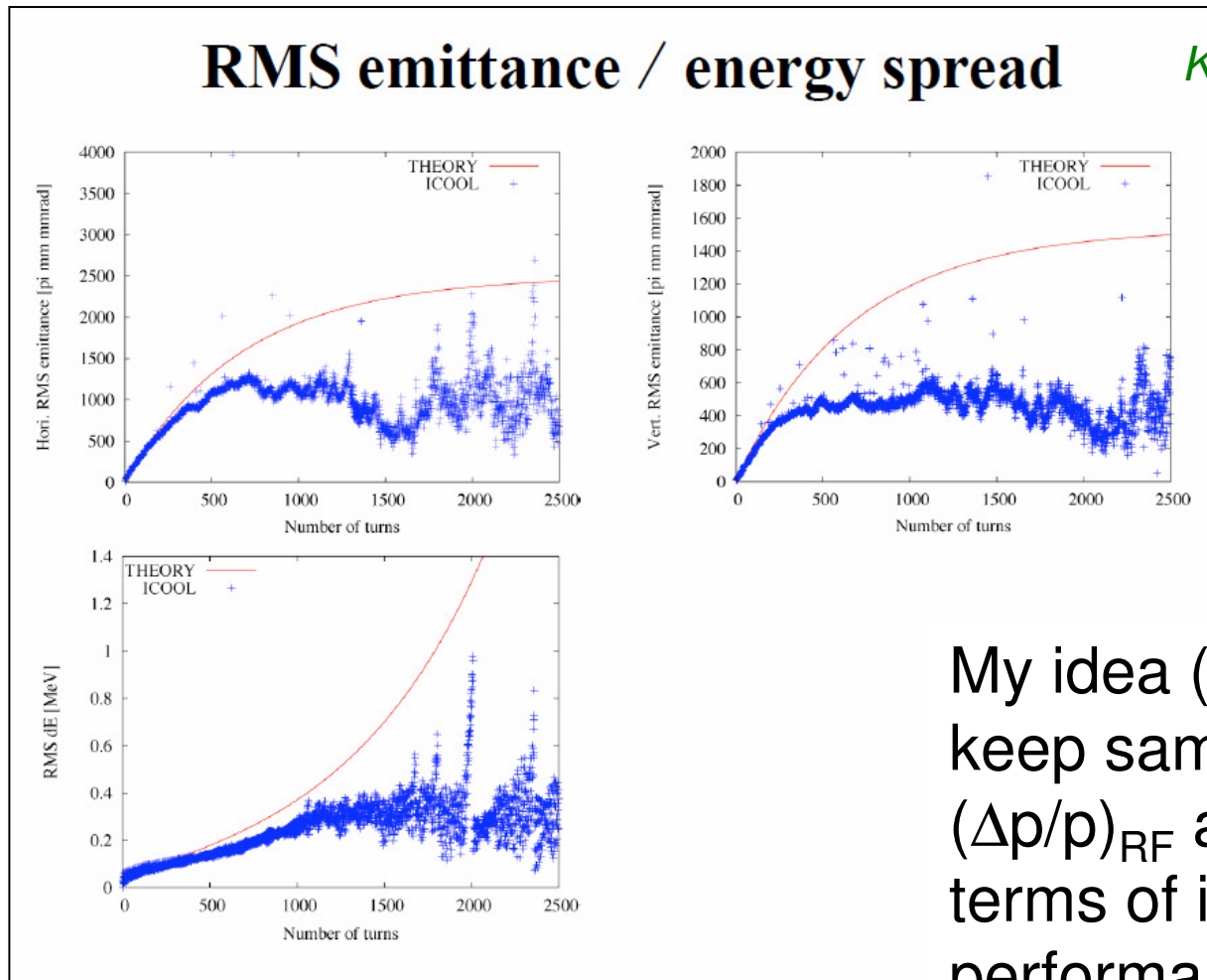
- IF production at target ok, maybe use existing CERN ring
 - Multibunches, electron-cooling,... (LEIR, AD,...)
- ...or an FFAG!!!

What if I could use ERIT-FFAG for my ions

Stolen from K.Okabe's presentation

- **FFAG-ERIT ring**
 - circ. beam current 70mA
 - beam life(# of turns) 1000turns
 - acceptance $\Delta v > 500 \text{mm.mrad(rms)}$, $\Delta p/p > \pm 5\%$ (full)
 - magnet large aperture, small fringing field
 ➔ gap height 15cm
 - rf cavity
 ➔ frequency $\sim 20 \text{MHz}$ (harmonic number :5)
 ➔ rf voltage $> 200 \text{kV}$ Injector
 - beam energy 11MeV
 - averaged beam current $70 \mu \text{A}$
- **Injector**
 - beam current $> 70 \mu \text{A}$ (20–200Hz, duty $\sim 2\%$)
- **Neutron production target**
 - Be, $10 \mu \text{m}$ heat load $< 6.6 \text{W/cm}^2$, Lifetime > 1 month
- **Moderator**
 - thermal+epithermal $> 10^9 \text{ n/cm}^2/\text{sec}$
 - gamma-ray+fast neutron Nuclear reactor level (IAEA)

What if I could use ERIT-FFAG for my ions



K. Okabe

My idea (the easiest) is to keep same $B\rho=0.48\text{Tm}$ and $(\Delta p/p)_{\text{RF}}$ and see what I get in terms of ionization cooling performance

Summary

- **BetaBeams:**
 - electron (anti-)neutrino beams from β -decay of radioactive ions, for oscillation experiments
 - Challenges due to high intensity beams
- **Production Ring for Li, B**
 - Uses internal target & ionization cooling
 - Preliminary design, tracking exist
 - Still a lot of R&D for a feasible solution (enough flux)
 - e.g. Existing gas-jet targets cannot reach the densities proposed in [C.Rubbia, *et. al*] in a vacuum environment
 - Liquid lithium target and D/³He beam may be the solution, studies started
 - Here to investigate use of ERIT-type FFAG to produce Li, B
 - **BUT: first priority find feasible solution for target!!!**