Production and bunching of RIBs for beta-beams

Pierre Delahaye, ISOLDE

For beta-beams

The beta-beam concept

P. Zucchelli, PLB 2002

- A pure beam of ν_e to study the $\nu_e \rightarrow \nu_\mu$ oscillation
  - A beam of ν_e, $\bar{\nu}_e$ from β-decaying nuclides
- A Lorentz boost for a collimated beam (high γ)
  - From Wikipedia:

For a boost in an arbitrary direction with velocity $\vec{v}$, it is convenient to decompose the spatial vector $\vec{r}$ into components perpendicular and parallel to the velocity $\vec{v}$: $\vec{r} = \vec{r}_\perp + \vec{r}_\parallel$. Then only the component $\vec{r}_\parallel$ in the direction of $\vec{v}$ is 'warped' by the gamma factor:

$$\begin{cases} t' = \gamma \left(t - \dfrac{\vec{r} \cdot \vec{v}}{c^2} \right) \\ \vec{r'} = \vec{r}_\perp + \gamma (\vec{r}_\parallel - \vec{v} t) \end{cases}$$

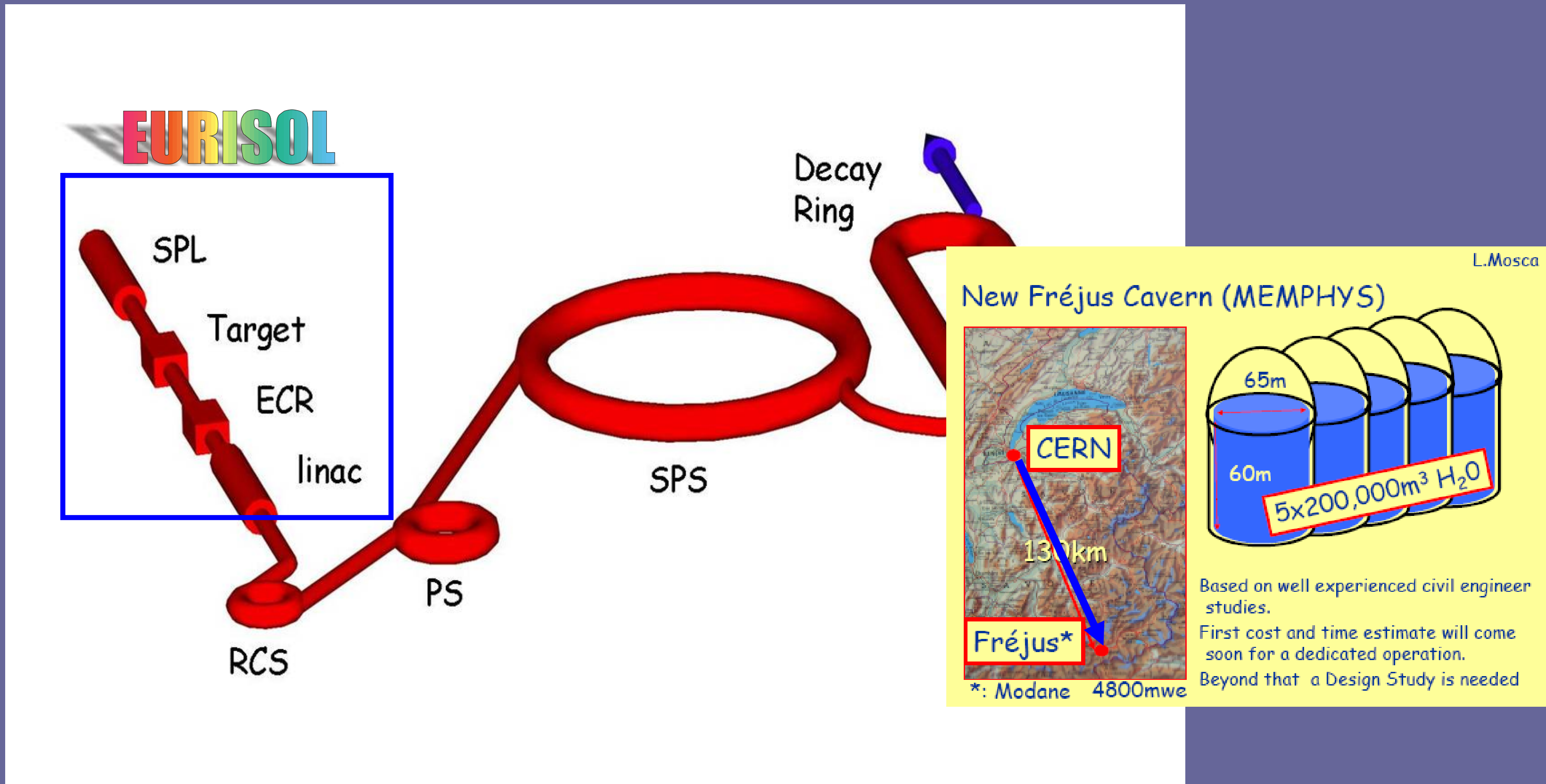
where now $\gamma \equiv \dfrac{1}{\sqrt{1 - \vec{v} \cdot \vec{v} / c^2}}$

$\theta \rightarrow 1/\gamma$

EURISOL Design Study

Beta-beams and EURISOL

- CERN baseline scenario



EURISOL Design Study

Production of the beta-beams

- **Different candidates, ^{6}He and ^{18}Ne as preferred ones**
- **Factors influencing ion choice**
  - Need to produce reasonable amounts of ions
  - Noble gases preferred - simple diffusion out of target, gaseous at room temperature.
  - Not too short half-life to get reasonable intensities.
  - Not too long half-life as otherwise no decay at high energy.
  - Avoid potentially dangerous and long-lived decay products.
- **Best compromise**
  - Helium-6 to produce antineutrinos:

$$^{6}_{2}He \rightarrow ^{6}_{3}Li\ e^{-}\ \overline{\nu}$$
$$\text{Average } E_{cms} = 1.937 \text{ MeV}$$

  - Neon-18 to produce neutrinos:

$$^{18}_{10}Ne \rightarrow ^{18}_{9}F\ e^{+}\ \nu$$
$$\text{Average } E_{cms} = 1.86 \text{ MeV}$$

- **New ideas**
  - **^{8}Li, ^{8}B Rubbia et al**
  - **EC decays for monochromatic beams J. Bernabeu et al**

The requirements

- The first beta-beams study was aiming for:
  - A beta-beam facility that will run for a “normalized” year of 10^7 seconds
  - An annual rate of 2.9 10^{18} anti-neutrinos (^{6}He) and 1.1 10^{18} neutrinos (^{18}Ne) at γ=100

with an Ion production in the target to the ECR source:

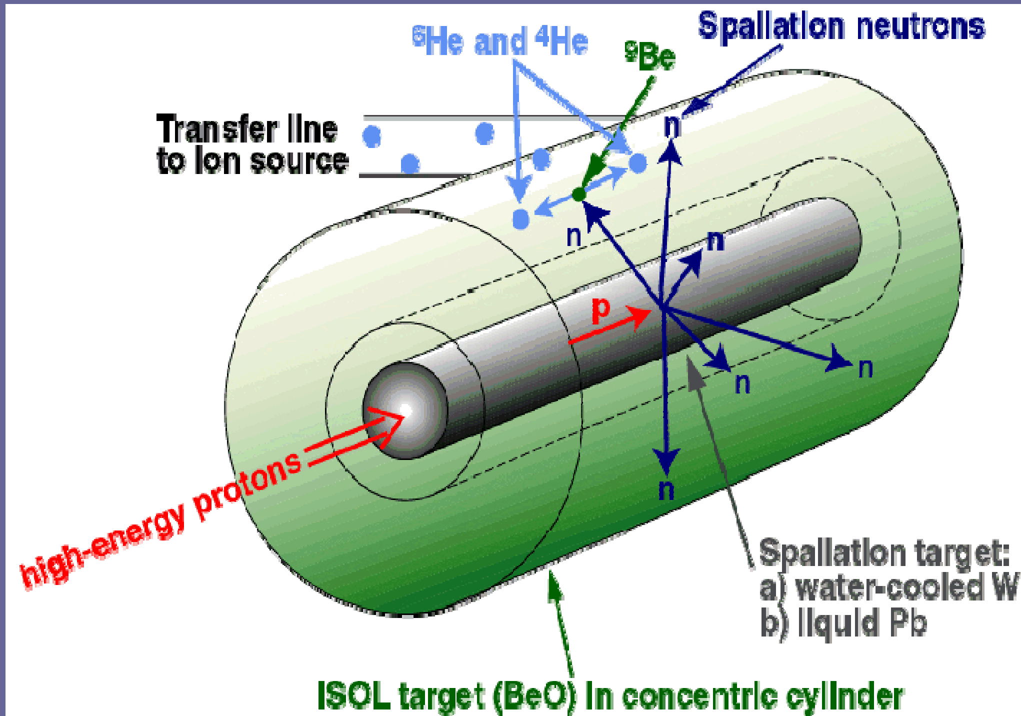
- **^{6}He= 3.3 10^{13} atoms per second**
- **^{18}Ne= 2.1 10^{13} atoms per second**

- The often quoted beta-beam facility flux for ten years running is:
  - Anti-neutrinos: 29 10^{18} decays along one straight section
  - Neutrinos: 11 10^{18} decays along one straight section

^{6}He production from ^{9}Be(n,α)

- Using the converter technology

Converter technology:
(*J. Nolen, NPA 701 (2002) 312c*)

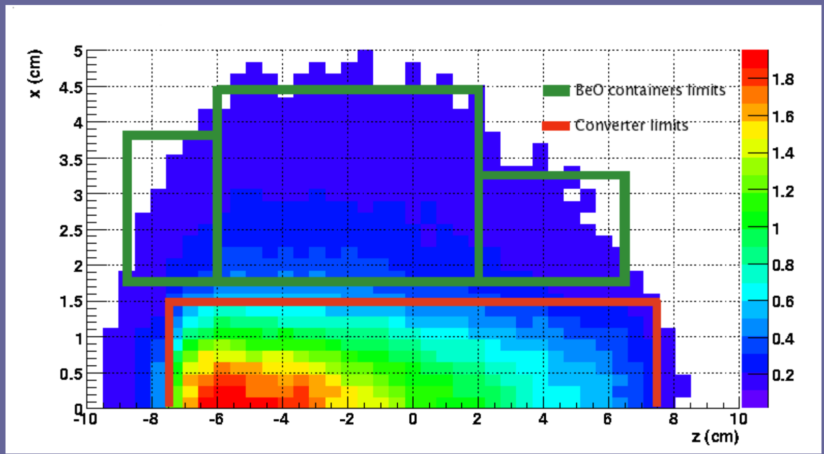


- **Preferred to direct irradiation (heat transfer and efficient cooling allows higher power compared to insulating BeO).**
- **^{6}He production rate is ~2x10^{13} ions/s (dc) for ~200 kW on target**
- **Use of a 4MW target is a priori possible**

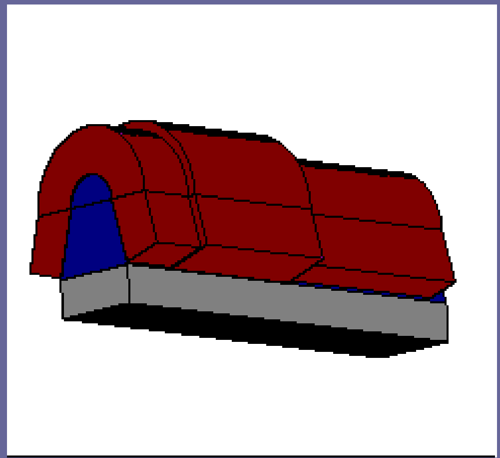
Optimized geometry

- **Original geometry: T. Stora, E. Bouquerelle, J. Lettry, task 3 internal note**
- **Optimized geometry: N. Thiollière, J.C. David, V. Blideanu, D. Doré, B. Rapp, D. Ridikas**

Soon available as a preprint DAPNIA, CEA Saclay (November 2006) at http://www-dapnia.cea.fr/Documentation/Publications/index.php



Neutron flux selection versus x and z-dimension superposed with converter and BeO containers limits.



The optimized (in terms of in target yields) target geometry to produce ^{6}He beams.

Using MCNPX

2 GeV 200 kW → 10^{14} in target production
~ fulfills the requirements

^{18}Ne from a MgO or Al_2O_3 target

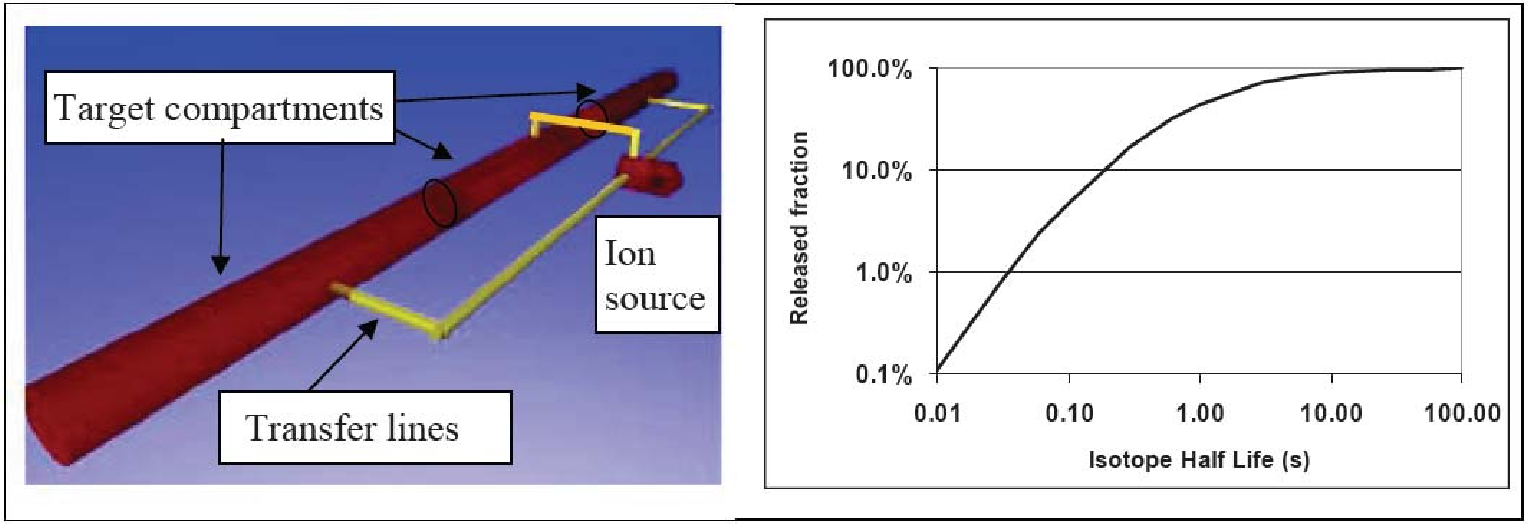


Figure 4: Ne released fraction computed with RIBO for 1 m long Al_2O_3 target with two separation walls and three transfer lines geometry [**28**].

Task 3 internal note from T. Stora et al, feasibility study of the 100kW targets

About 8 10^{11}/s instead of 2.1 10^{13}/s out of the target

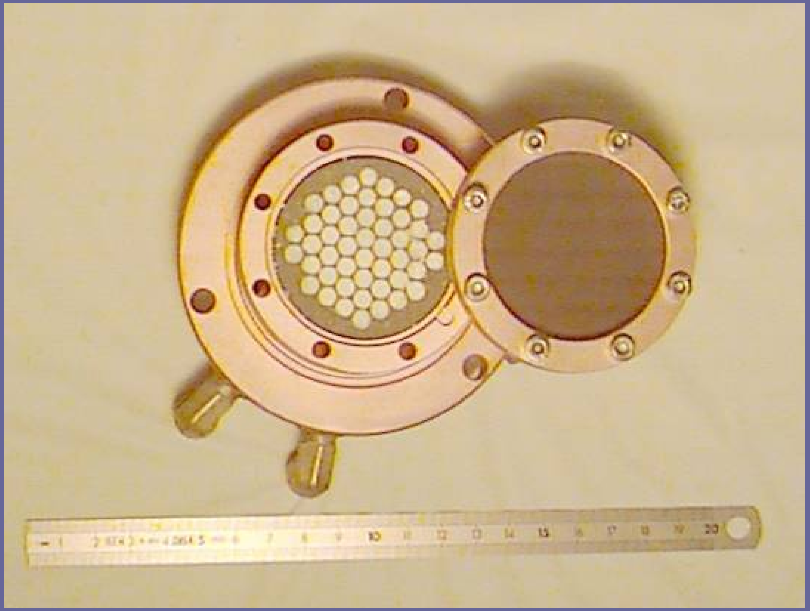
A factor of ~24 missing

EURISOL Design Study

Dedicated experiments for alternative production methods

- ^{7}**Li** (p,2p)^{6}**He**
- ^{19}**F** (p,n)^{19}**Ne**
- ^{19}**F** (p,2n)^{18}**Ne**
- ^{16}**O** (^{3}He,n) ^{18}**Ne**

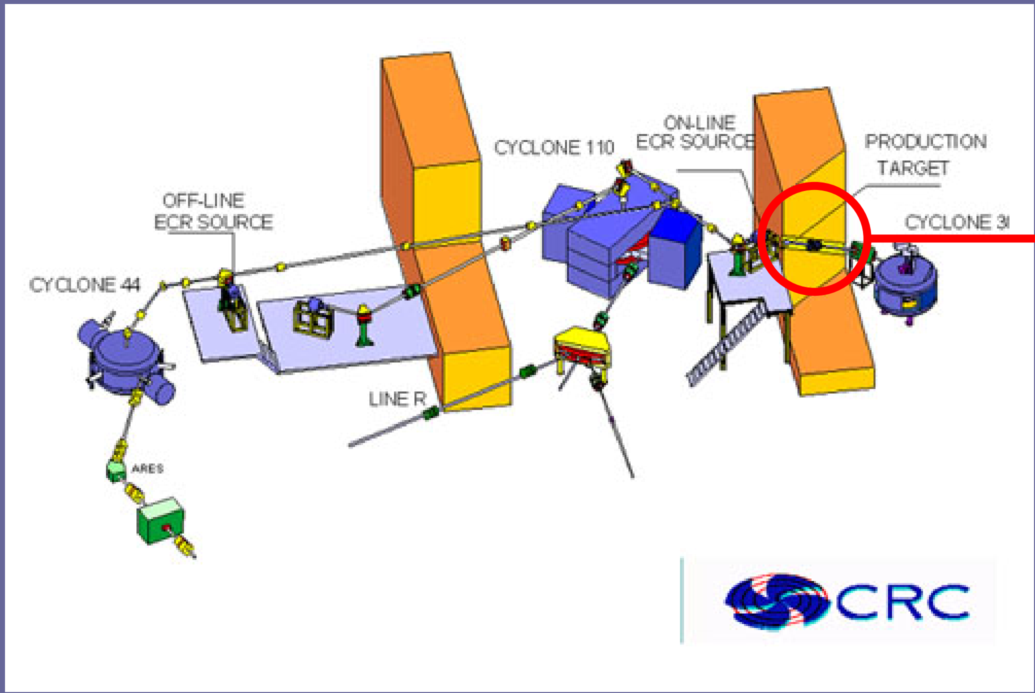
> 300 μA, 30 MeV protons

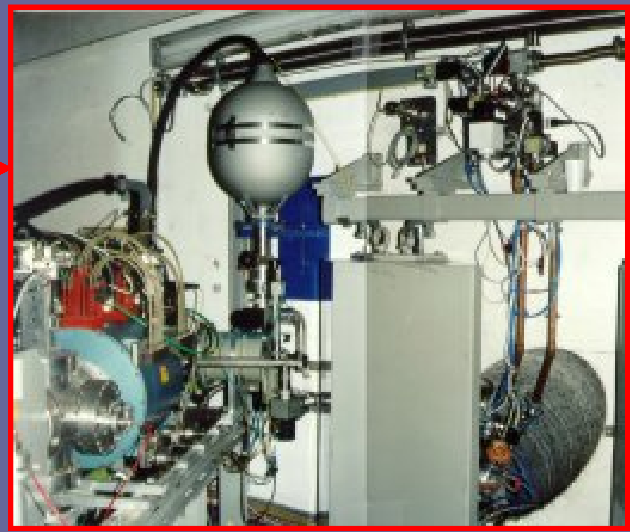


LLN: Marc Loiselet, Semen Mitrofanov

Light particles at low energy, “cleaner” production

Tests at Louvain-La-Neuve





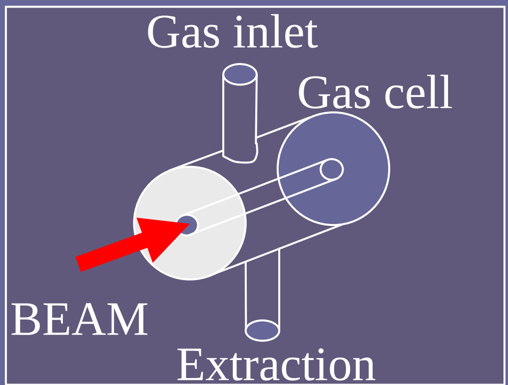
Routinely 200µA, 30MeV protons

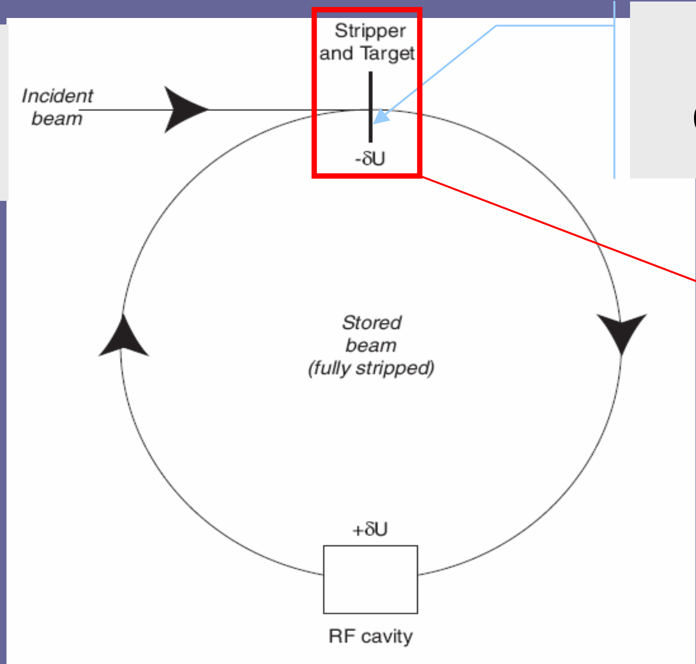
A new approach

Beam cooling with ionisation losses – C. Rubbia, A Ferrari, Y. Kadi and V. Vlachoudis in NIM A, In press

"Many other applications in a number of different fields may also take profit of **intense beams of radioactive ions**."

^{7}Li
^{6}Li





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

ISOL or IGISOL extraction
M. Lindroos et al, NIC-IX proceedings

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

Other reactions of interest

- **$^{20}Ne(p,T)^{18}Ne$**
  – H.Backhausen et al, RCA,29(1981)1

- **$^{16}O(^{3}He,n)^{18}Ne$**
  – V.Tatischeff et al, PRC,68(2003)025804

- **$^{12}C(CO_2,^{6}He)^{18}Ne$?**
  – K.I.Hahn et al, PRC,54(1996)199

- **$^{7}Li(T,A)^{6}He$**

Multi-ionization and bunching

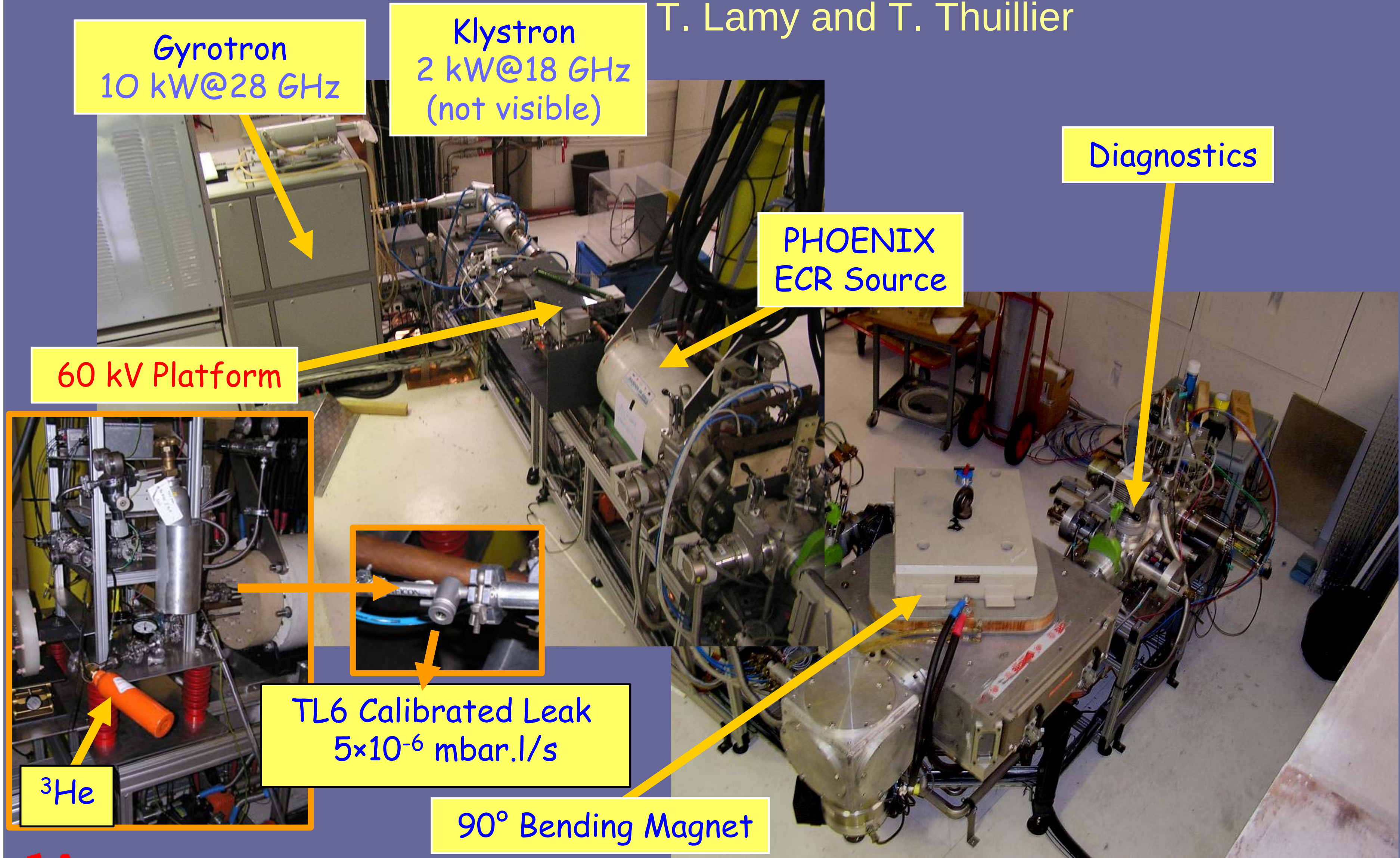
- **Even if the charge breeding is not mandatory, the bunching of a high intensity beam is mandatory**
  - 50µs pulses, 10-20Hz repetition

- A high frequency ECR source may do the job

- Preliminary preglow and afterglow studies at 18 and 28GHz at LPSC Grenoble

Experiments at LPSC Grenoble

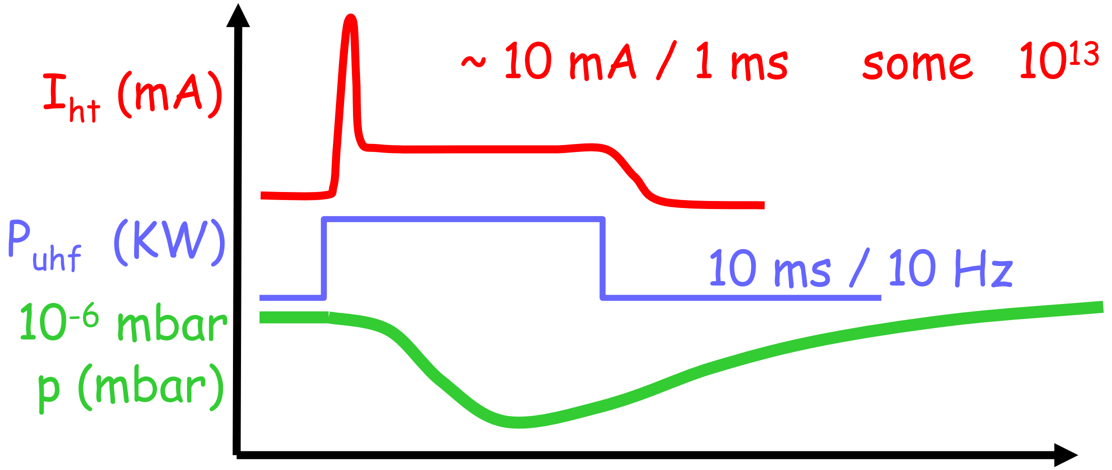
T. Lamy and T. Thuillier



ECRIS capabilities

- Pulsed modes of the ECRIS: afterglow and preglow
  - Afterglow: well-known from 10 to 18 GHz (Pb^{27+} LHC beam)
  - Preglow: experimental evidence at LPSC, predicted by a simple model, data analysis under progress.

Pumping effect during the preglow - of high interest!

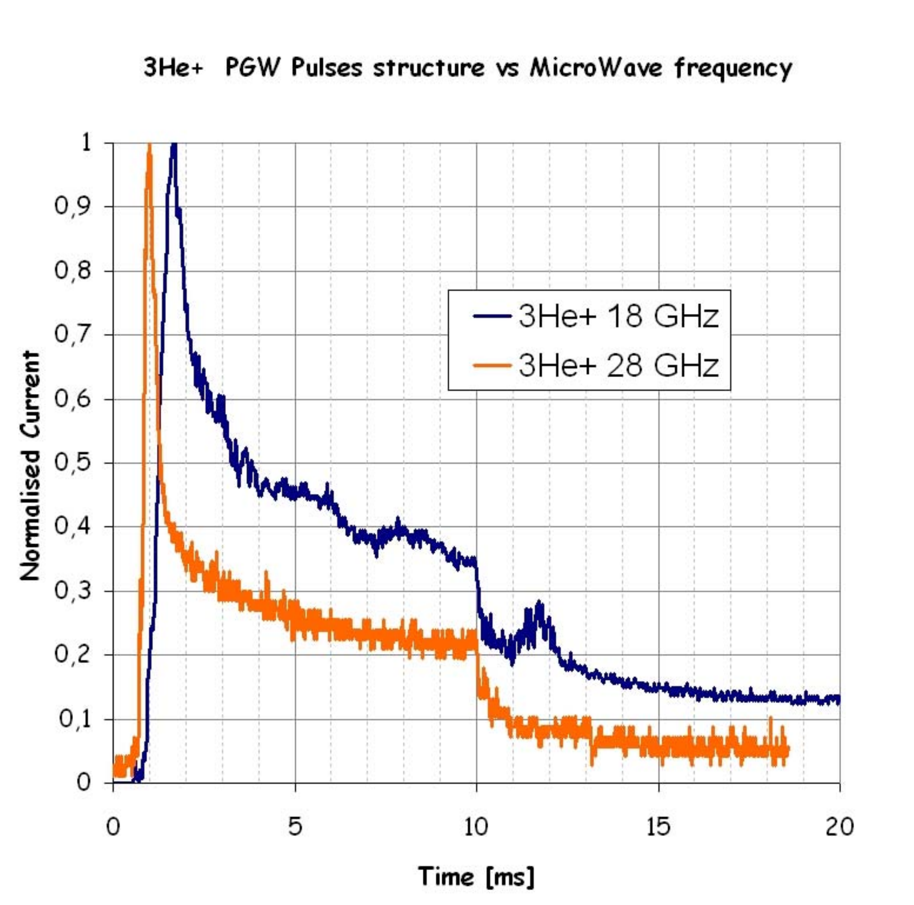


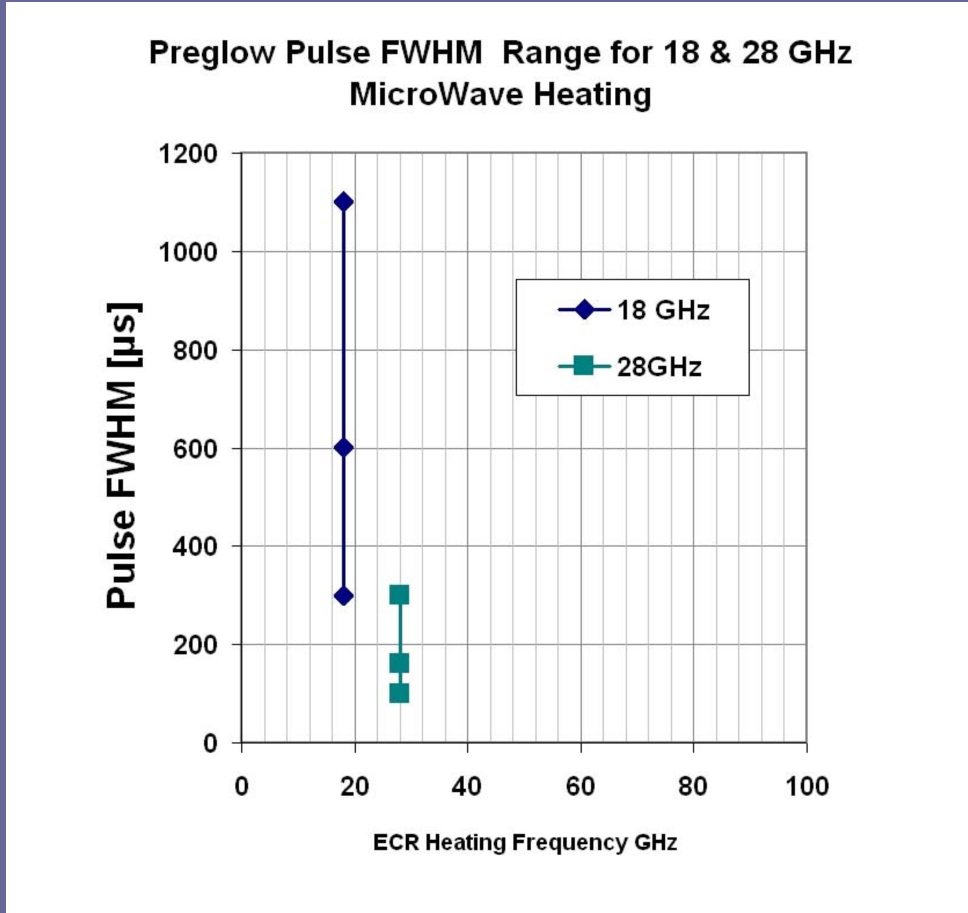
Some 10^{-6} mbar / 2 liters plasma chamber / some 10^{13} atoms

Present status

- Preglow experiments at 18 and 28GHz for ^{3}He and ^{22}Ne gases have been achieved, still under analysis (background suppression ^{12}C, ^{14}N, ^{16}O)
- Collaboration with the Grenoble HMFL for the 60GHz magnetic structure
- 60GHz ion source + Gyrotron funding: ANR refused - **CPER accepted, under final negociation** ~1M€
- Collaboration with the IAP of **Nizhniy Novgorod** (2006-2008) 37.5 GHz and 75 GHz plasma studies

Preglow pulse time structure with PHOENIX V2 ECR Ion Source

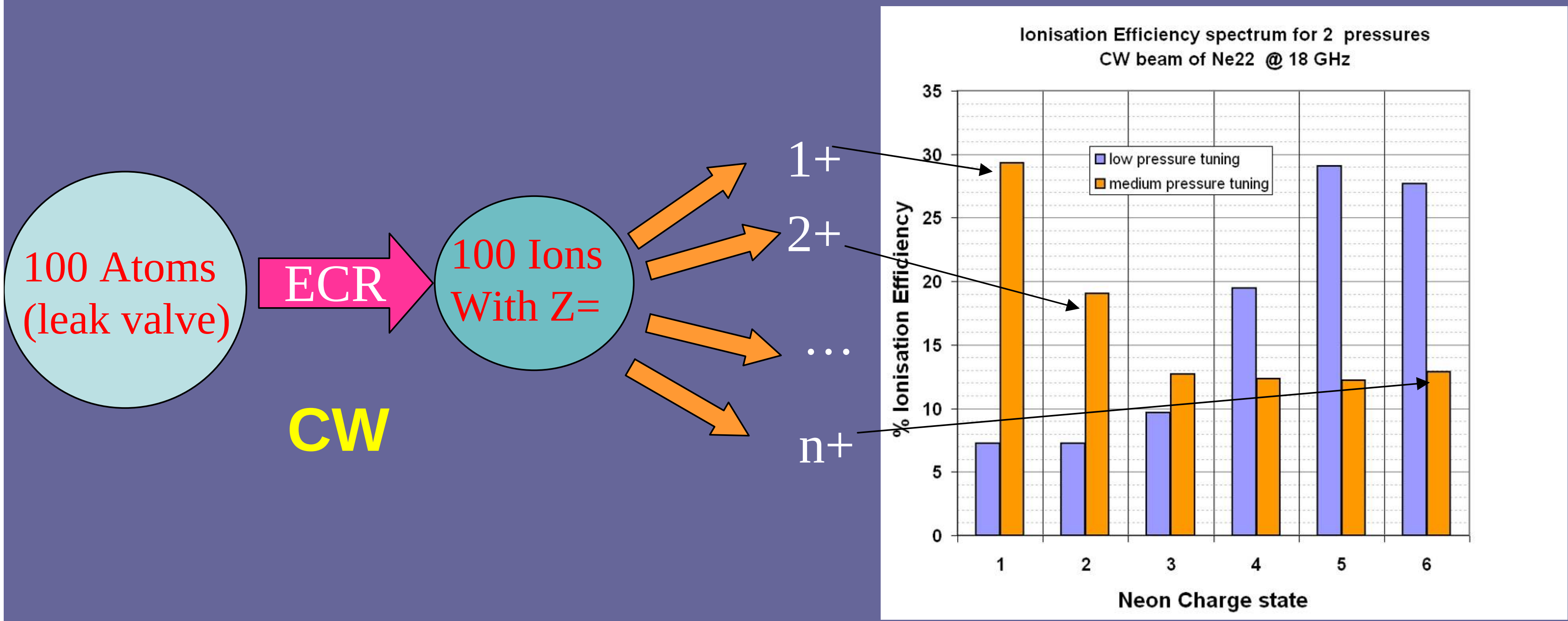




18 GHz : high Magnetic confinement => “large” FWHM (300<T<1100 µs)
28 GHz : low magnetic confinement => “short” FWHM (150<T<300 µs)
60 GHz T< 50 µs ?

Neon Ionization Efficiency Study with PHOENIX V2 ECR Ion Source

- calibrated leak TL6 = $5*10^{-6}$ mbar.l.s-1
- CW operation @ 18 GHz
- 0_2 buffer Gas

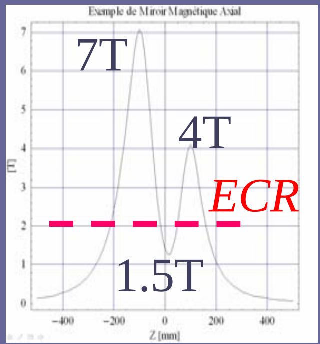


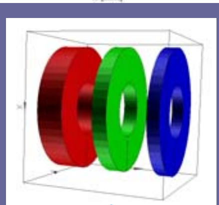
⇒Global Ionization Efficiency of Neon is ~100%

⇒Max CW efficiency on one charge state is ~25%

60 GHz ECR Ion Source Prototype (Preliminary Design)

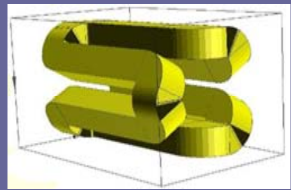
High Axial magnetic confinement



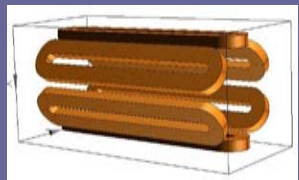


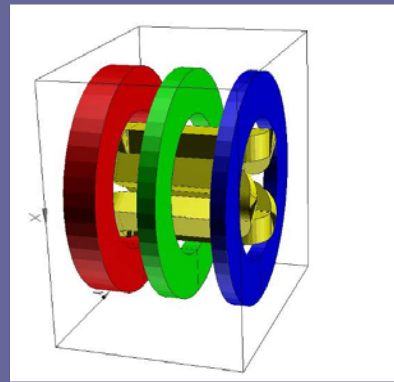
+

4 T radial magnetic confinement



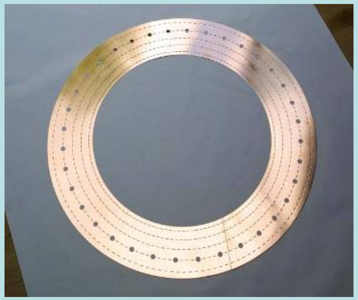
or

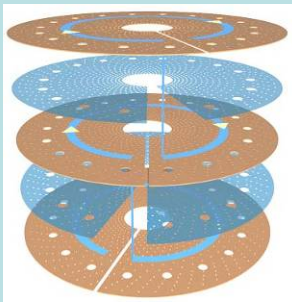




High Magnetic Confinement for optimal 60 GHz Microwave injection

GHMFL





Using Bitter Coil (or PolyHelix) Technology

Will enable pulse study in :

- Afterglow mode
- 1+ n+ ECRIT mode
- Preglow mode

International Scientific Collaboration Program

PICS CNRS - LPSC Grenoble / RAS - IAP Nizhny Novgorod Russia (2006-2008)

- Experimental and theoretical collaboration on pulsed Gyrotron generated ECR plasmas
- Gas dynamic regime with cusp or simple mirror magnetic structures at IAP (37.5, 75 GHz)
- Classic ECR magnetic bottles (i.e. radial field) at LPSC (18, 28, future 60 GHz)
- He and Ne Efficiency measurements and time structures with different configurations and parameters

LPSC outlook

Objectives: Bunching capabilities for CW gas injection

- Afterglow time structure: 60GHz <50µs ?
- Preglow time structure: 60GHz <50µs ?
- Efficiencies He, Ne?

- Performed: Phoenix (1.6T axial, 1.3 T radial)
  - 18 GHz (good confinement) preglow and afterglow regimes
  - 28 GHz (low magnetic confinement vs RF) preglow only
- Summer 2007: A-Phoenix (3T axial, 2T radial) built
  - 18 GHz: B influence on preglow and afterglow regimes
  - 28 GHz: (good confinement) preglow and afterglow regimes
  - 28+18 GHz higher charge states
- Winter 2007: 60 GHz Bitter coils based prototype (7T axial)
  - Magnetic field influence
- 2008: 60 GHz magnetic bottle
  - Afterglow, preglow regimes in tunable magnetic field confinement
  - End of 2008: 60 GHz injection

Conclusions (1)

- The production of the antineutrinos from the decay of ^{6}He seems feasible ~2 10^{13}/s
- The production of the neutrinos from the decay of ^{18}Ne seems difficult
  - In target production too low with the standard techniques (factor 24 missing)

Alternative production techniques

- tests at LLN - Marc Loiselet
- magnetic ring with target/stripper - C. Rubbia et al

Alternative candidates

Conclusion (2)

- High intensity beam bunching
  - The length of the afterglow and preglow pulses from an ECR source is decreasing rapidly with the frequency (18GHz / 28GHz tests). Is it still true from 28 to 60GHz?
  - In CW mode, gas injection, the efficiencies are compatible with those accounted for. He:100% Ne: ~30% in one charge state. Is it possible to reach the same efficiencies with any of the two bunching modes?

The 60 GHz prototype is on the way to be funded
- it should answer to these questions!

Thanks a lot for your attention!

Special thanks to

- Marc Loiselet, Louvain-La-Neuve
- Thierry Lamy, Thomas Thuillier, LPSC Grenoble
- Thierry Stora, Mats Lindroos, CERN-ISOLDE
- Danas Ridikas, Nicolas Thiollière, Jean-Christophe David, CEA Saclay
- The beta-beams collaboration

Open possibilities for the beam bunching

Afterglow:
18GHz 1ms
28GHz 150µs
60GHz – ?<50µs?

1+ $\rightarrow$ n+
10 - 14 GHz
a few % for Kr, Rb, Xe

Gas injection
Under investigation

Preglow:
18GHz 1ms
28GHz 150µs
60GHz – ?<50µs?

1+ $\rightarrow$ n+
??

Gas injection
Under investigation

Continuous

1+ $\rightarrow$ n+
14GHz
a few % per charge state

Gas injection
18GHz
~ 100% He
~ 30% Ne on 1 charge state

Rappeler les efficacités demandées