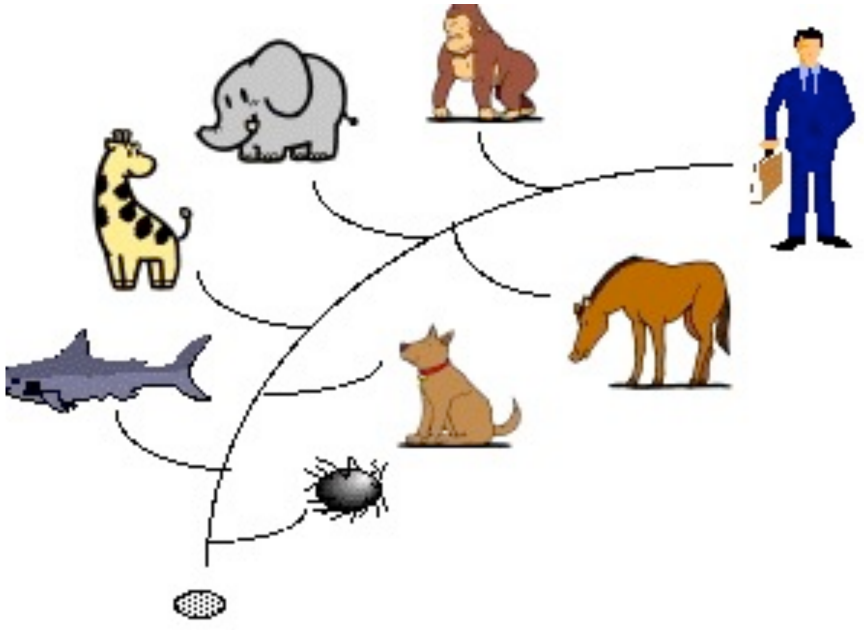
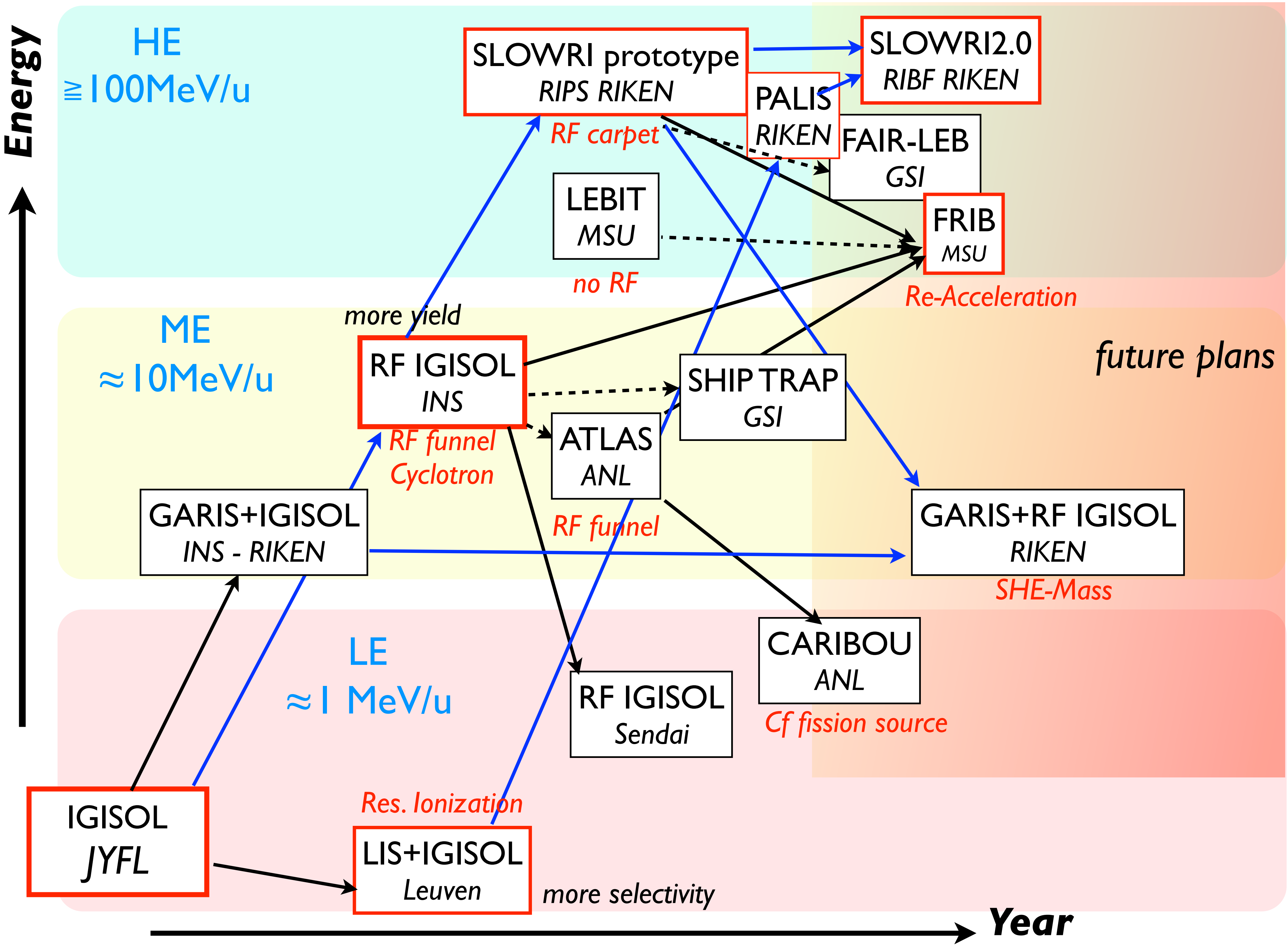
# Genealogy of Gas Cell for low-energy RI-beams

Michiharu Wada, RIKEN Nishina Center



- IGISOL as Roots
- DC and RF in Gas Cell
- Various Improvements

# Gas Cell Genealogy ~personal view~



# ISOL

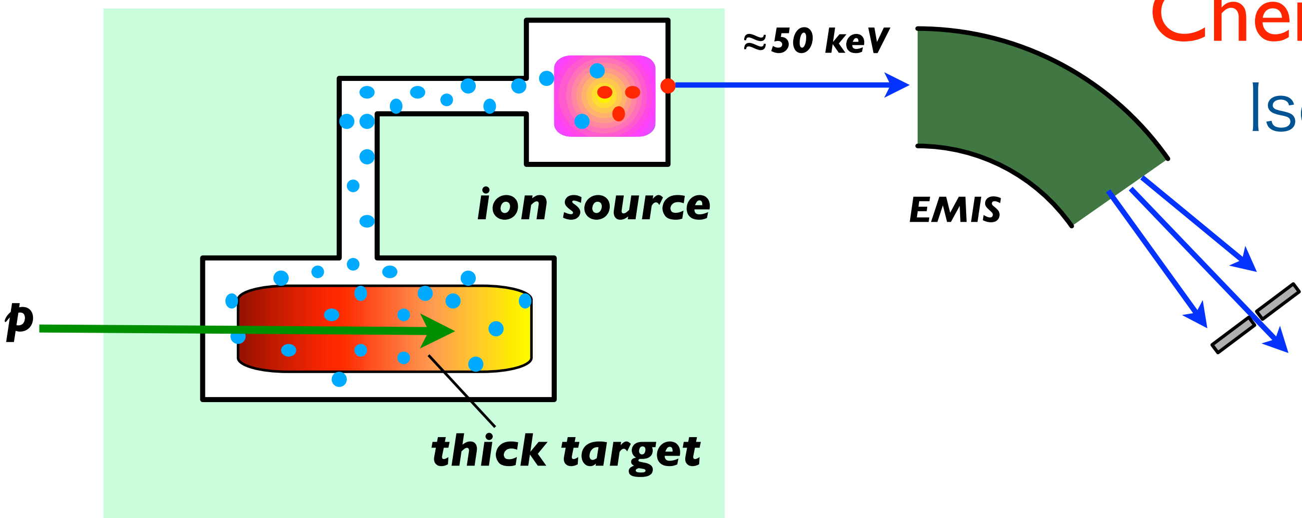
***comprehensive study of RI since '60s***

***ISOLDE, OSIRIS, TRISTAN, TISOL ....***

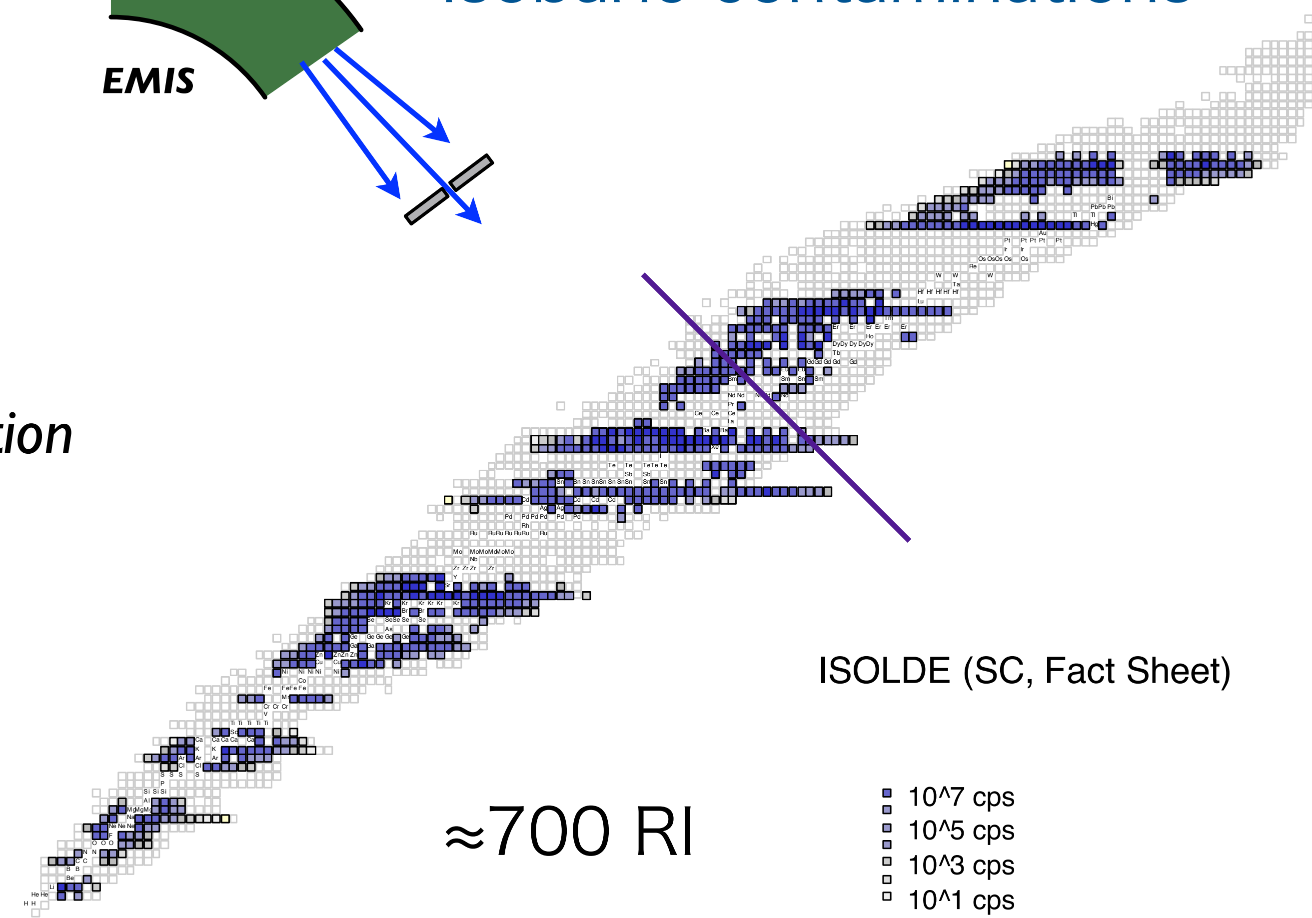
High Yield, but difficult for
Refractory elements,
Chemically active elements

Isobaric contaminations

*ionization in IS*




*stop in target, diffusion, evaporation*



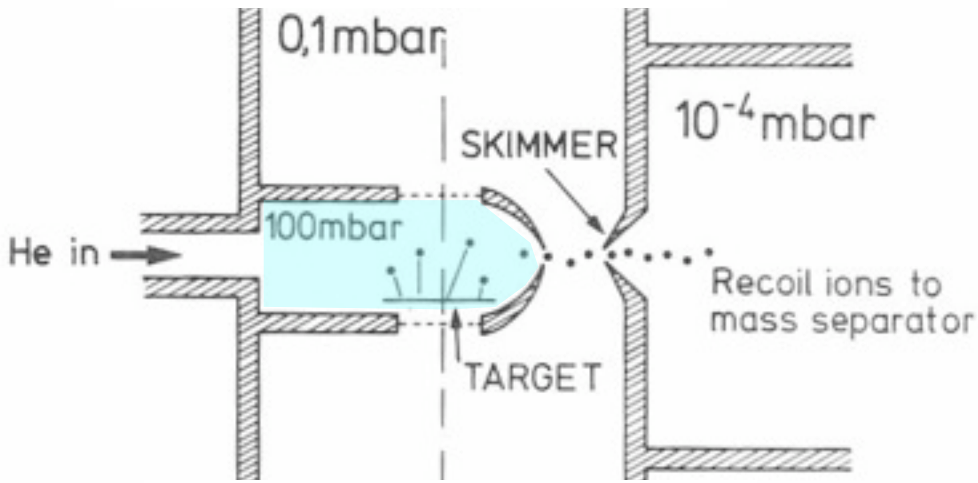

***note: laser ion source just supports ionization process, not in target***

# First Beak Through: IGISOL @JYFL

Ion Guide ISOL

J. Ärje, K. Valli: NIM 179(1981)533.

ISOL for All Elements, Fast Extraction




Problems:
1) Poor Emittance (Gas Collision)
2) Low Efficiency @HI (Plasma Effect)
3) Isobaric Contamination (Universal)
4) Low Yield (Thin Effective Target)
....

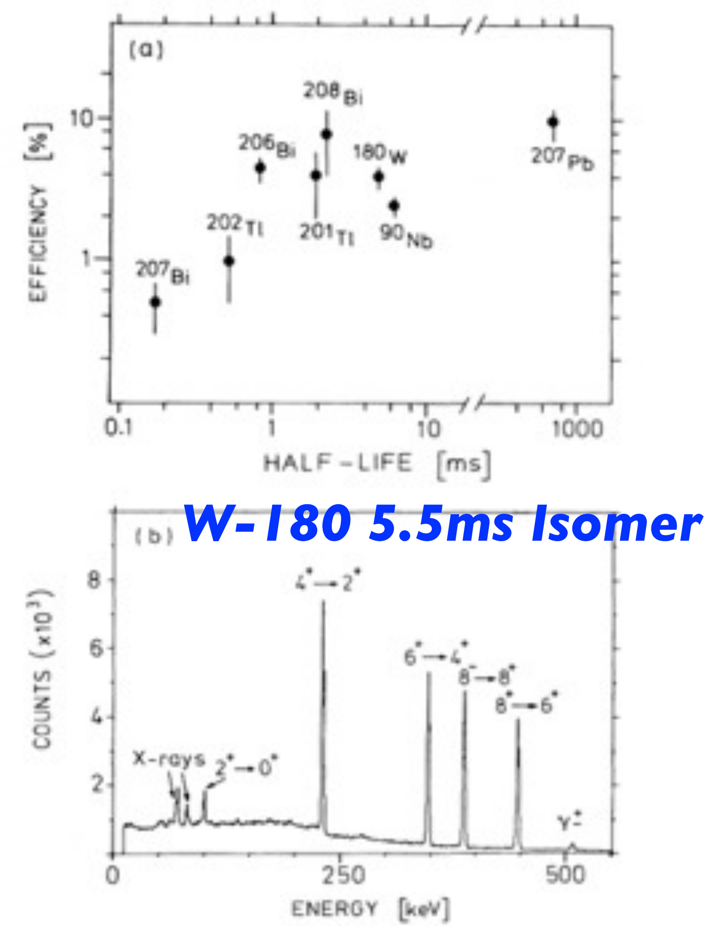
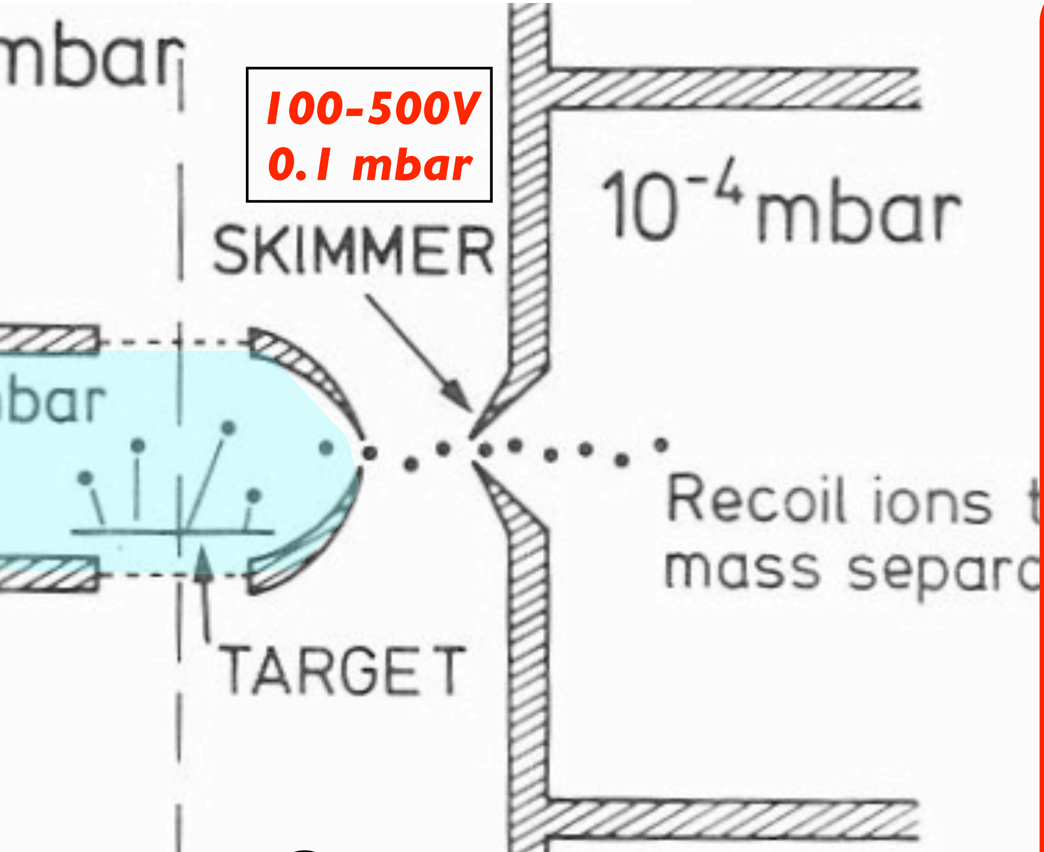



FIG. 1. (a) Overall transmission efficiency for some heavy nuclides in their isomeric states as a function of the half-life. The error bars are due to statistical uncertainties in the measurements. (b) A gamma spectrum from the decay of the mass separated 5.5-ms $8^-$ isomer of $^{180}$W produced via the 20-MeV $p+{}^{nat}$Ta reaction. The total running time was 30 min with the 0.7-$\mu$A beam intensity.

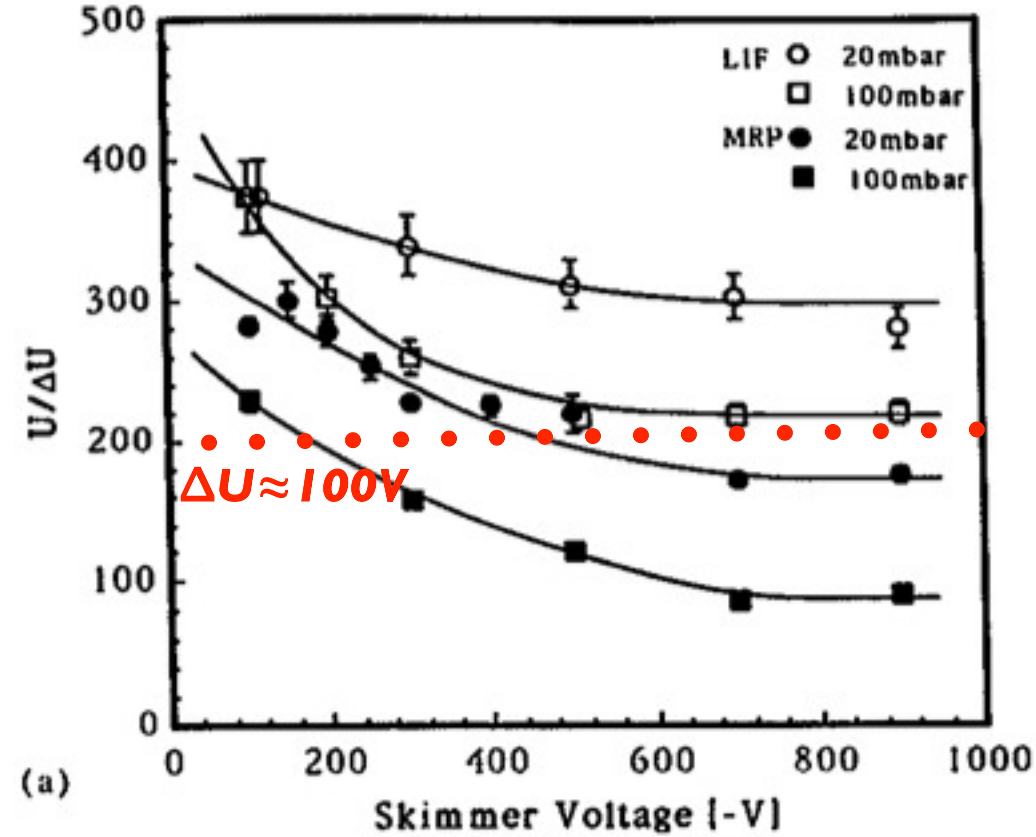
J. Ärje, J. Äystö et al: PRL 54(1985)99.

# 1) Poor Emittance (Gas Collision at Skimmer)




SPIG @INS

***Energy Spread vs Skimmer Voltage by Laser Spectroscopy***




***TT. Inamura, M. Koizumi et al, NIMB70(1992)226***

***We must transport through Skimmers without Acceleration***

# SPIG: rf 6-pole Ion beam Guide

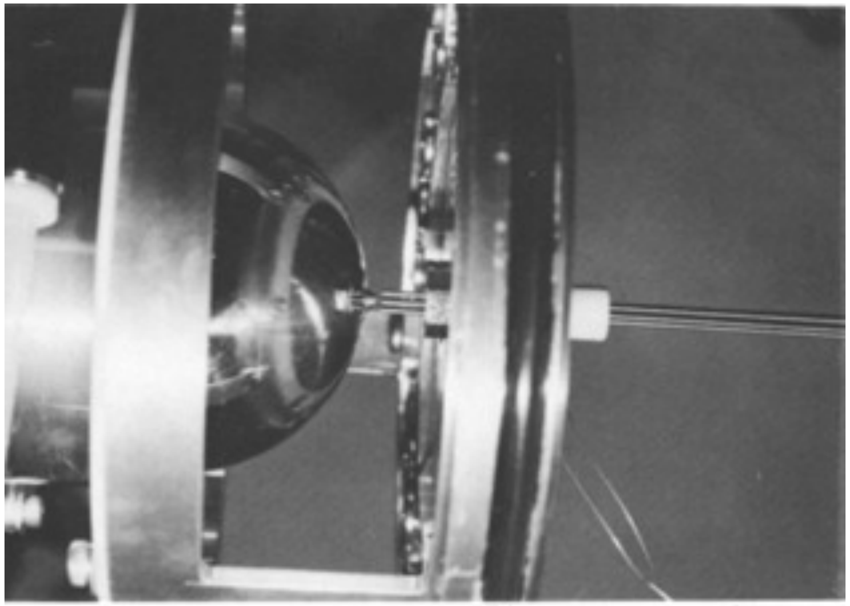


Fig. 2. Photograph of the gas chamber showing the nozzle and the SPIG.

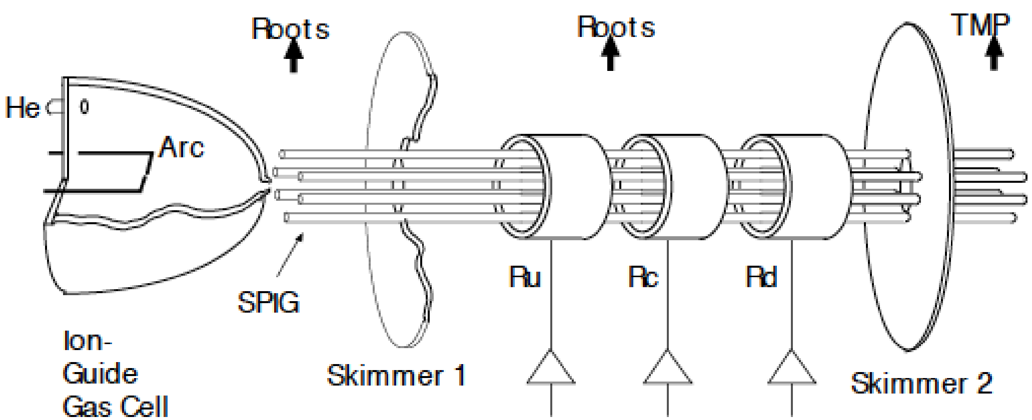
**Transport through Skimmers without Acceleration, Even Cooling Ions**

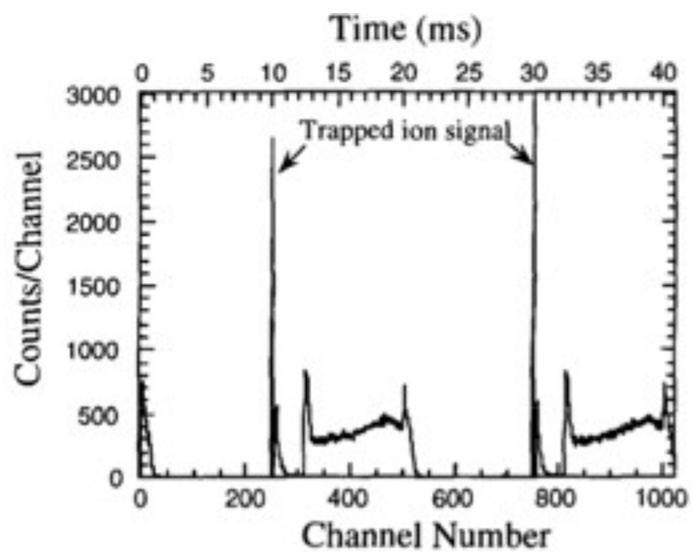
**ΔE≈0.8 eV**

H. Xu, M. Wada, I. Katayama et al: NIM A222(1993)274.

**Multiple Skimmers : Easy Pumping**

**Trapping in SPIG**

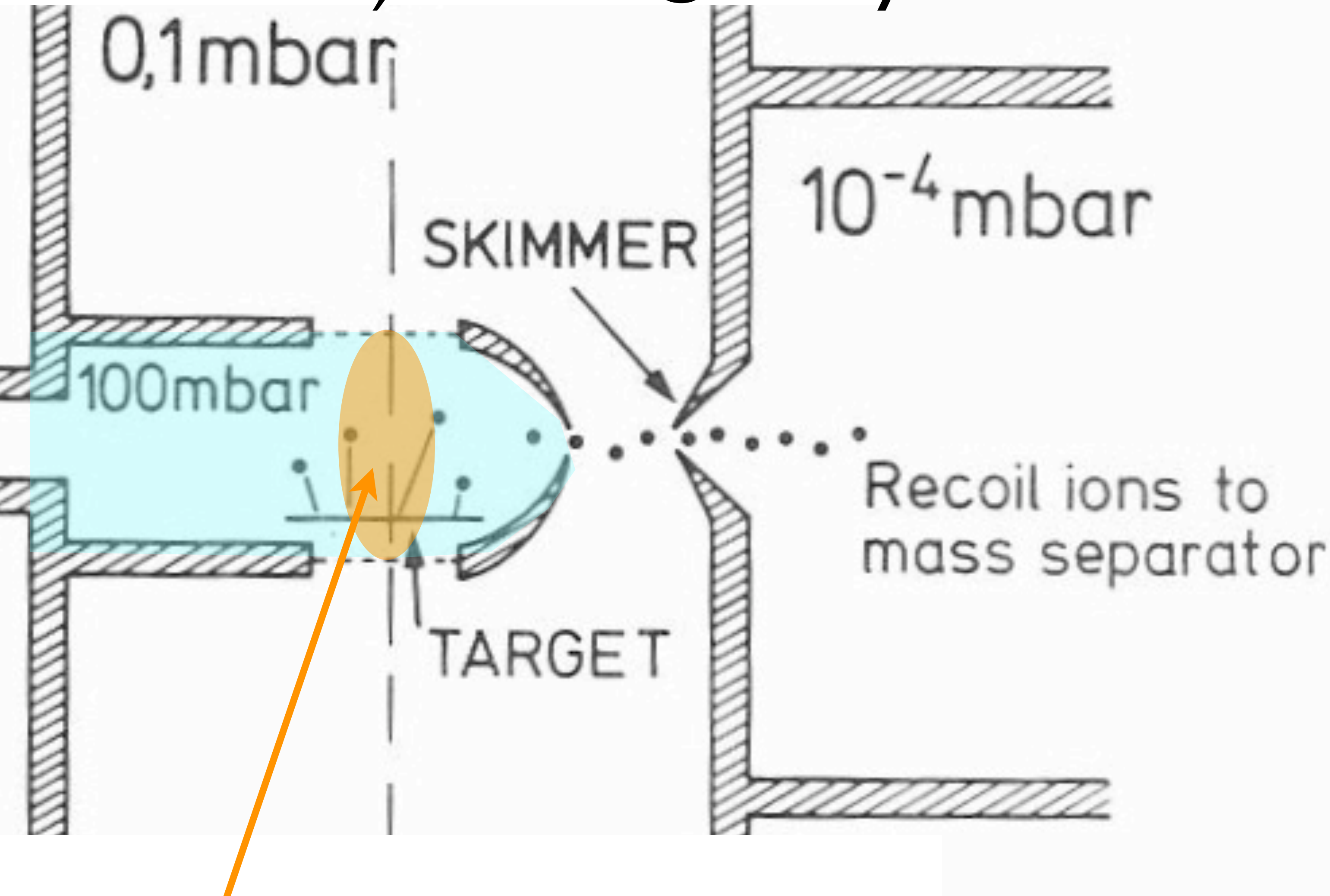



Trap Efficiency:
10% @10ms
>80% @ 0.3ms

S. Fujitaka, M. Wada, I.Katayama et al: NIMB126(1997)386.

# 2) Low ε @Heavy Ion: Plasma Effect



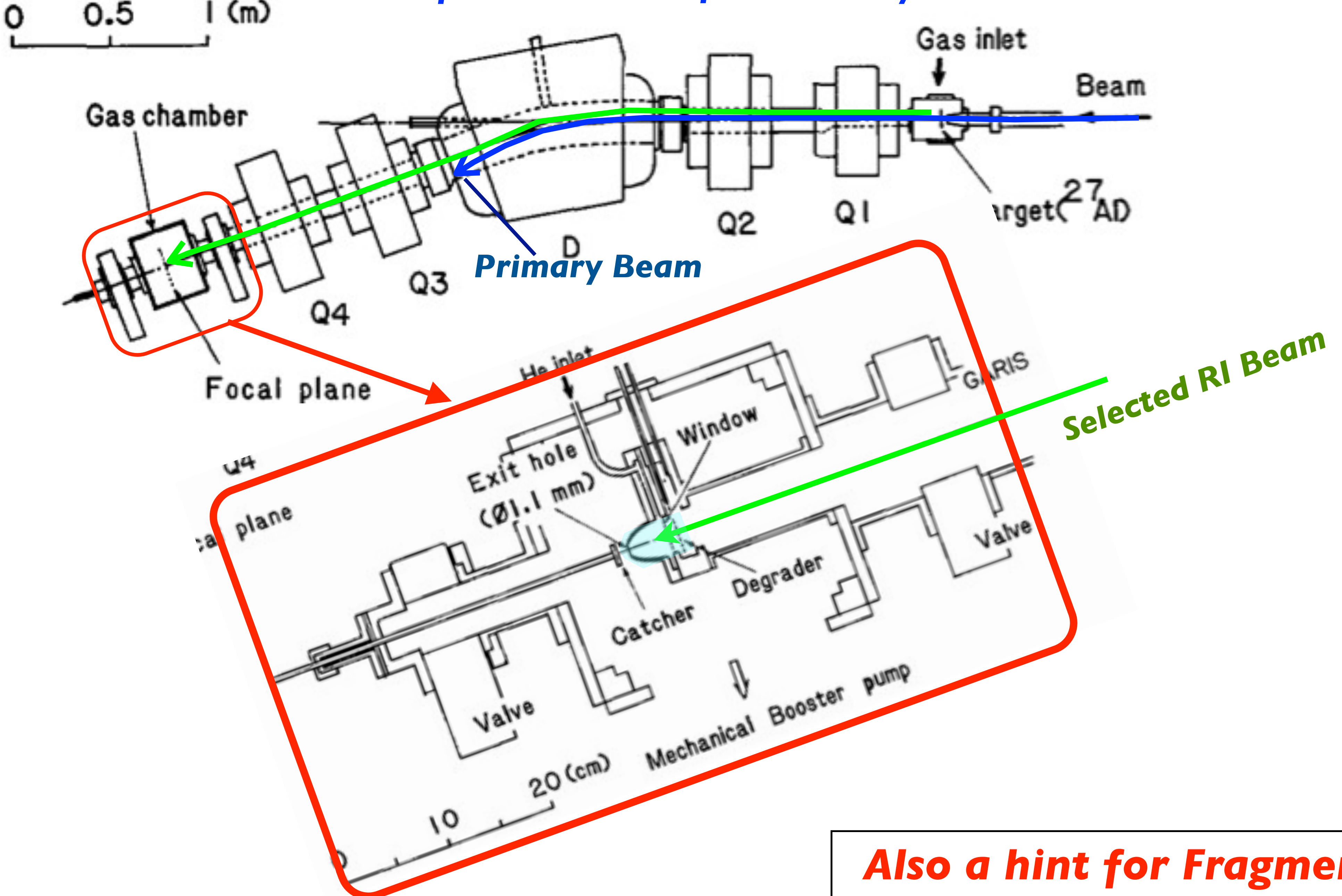

***Plasma by Primary Beam: Space-Charge effect***

***We must Isolate Primary Beam and RI Beam!***

# GARIS-IGISOL

*T. Nomura et al, NIMA269(1988)23*

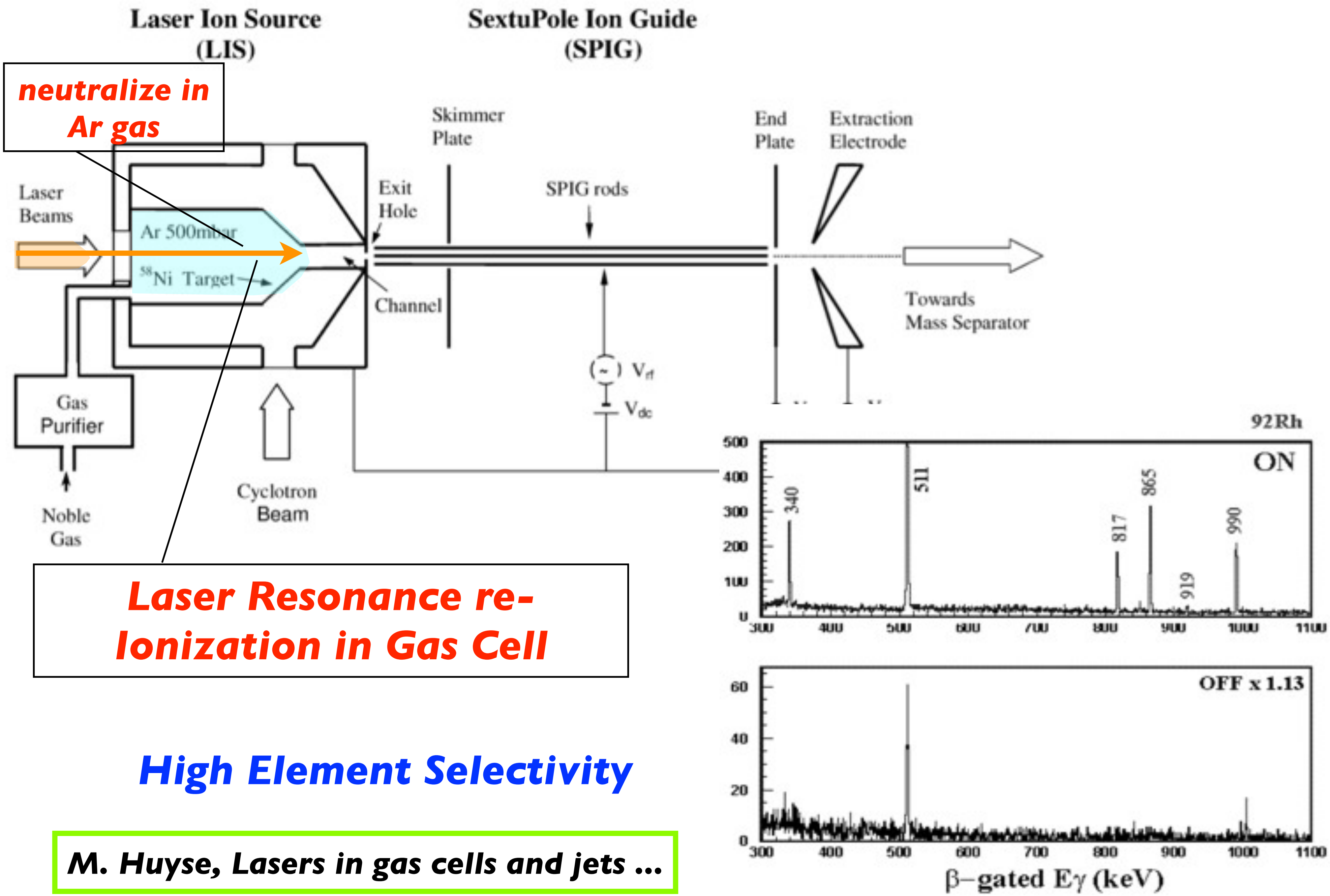
**Separate RI Beam from Primary Beam**




**Also a hint for Fragment Separator + Gas Cell**

# 3) Isobaric Contamination (Universality)

*Yu. Kudryavtsev et al, NP A701(2002)465c*

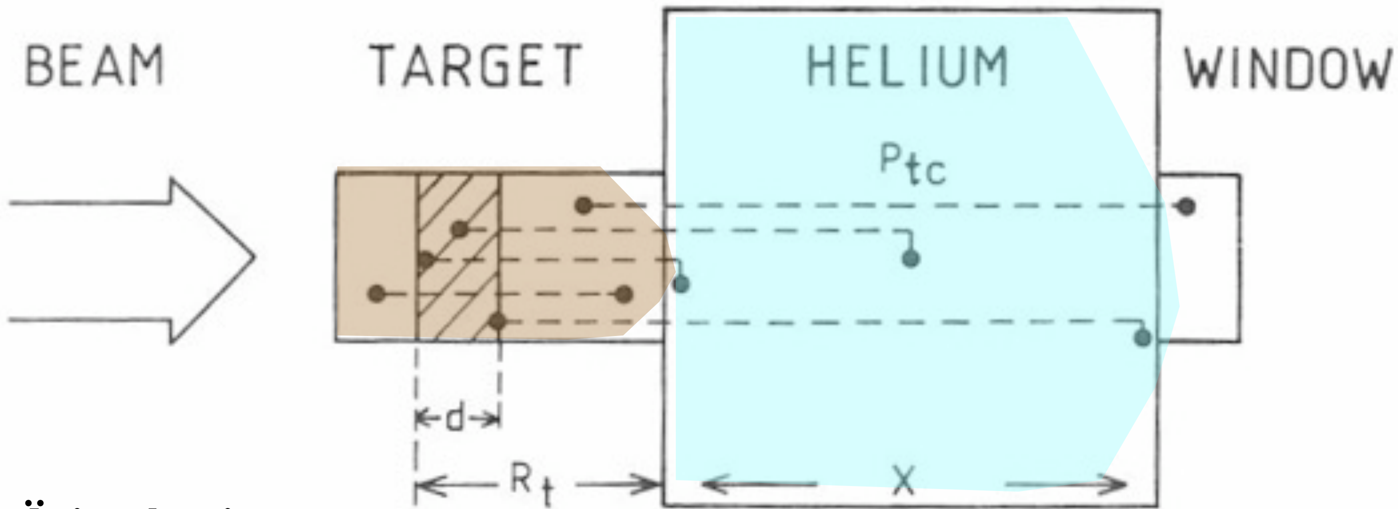



***High Element Selectivity***

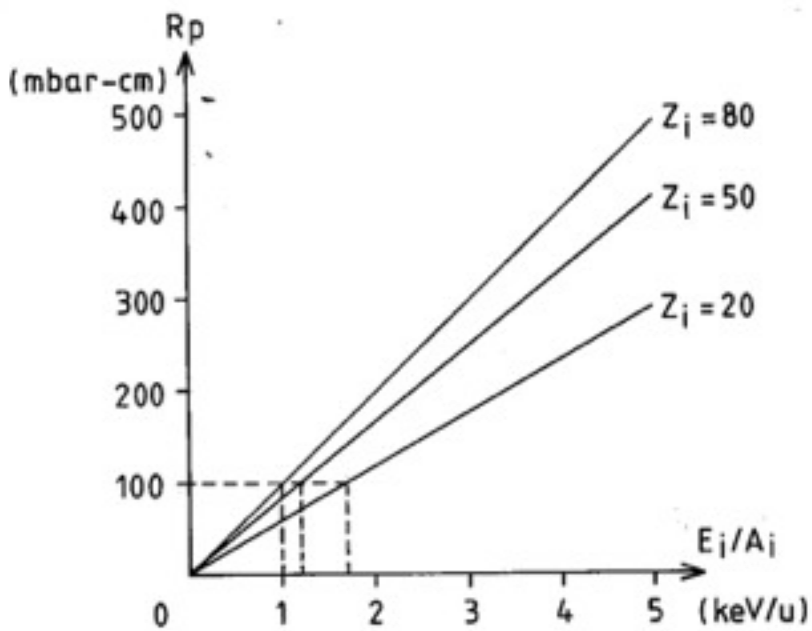
***M. Huyse, Lasers in gas cells and jets ...***

# 4) Low Yield (Effective Target Thickness)

***~ most serious problem ~***




***J.Ärje thesis***




***effective target thickness:***
***stopping capability of gas***

Large Cell? Slow Extraction!

Electric Field in Cell!

# Big Gas Cells

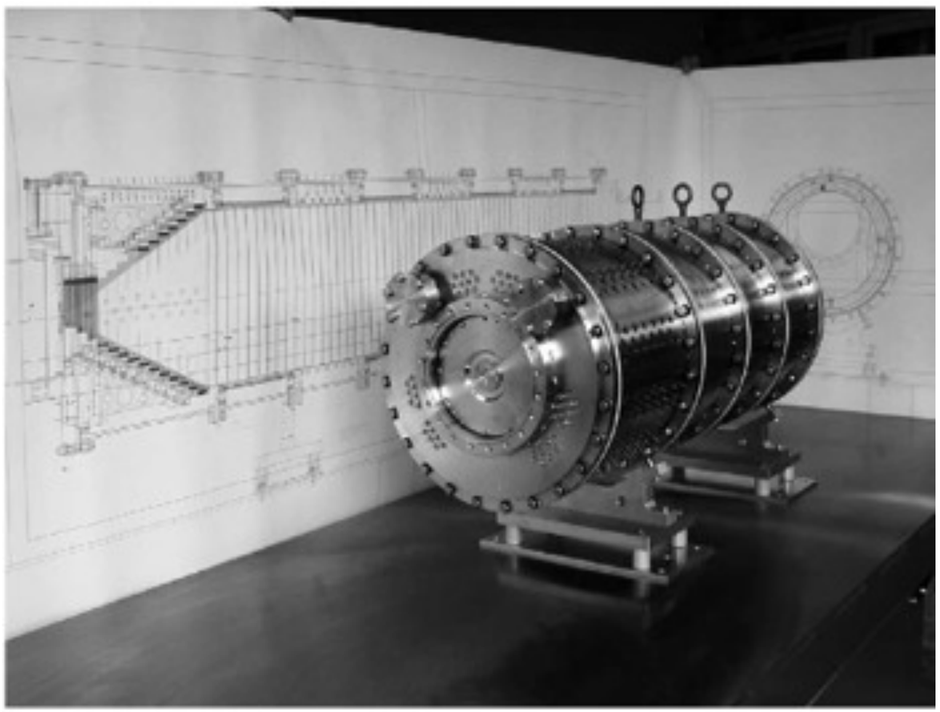
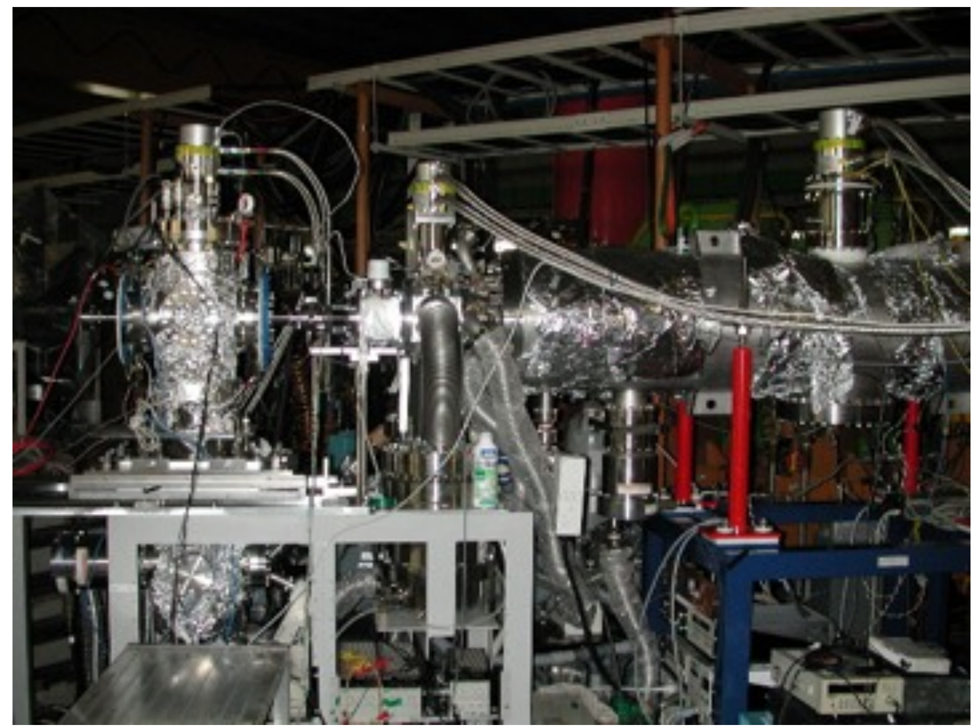


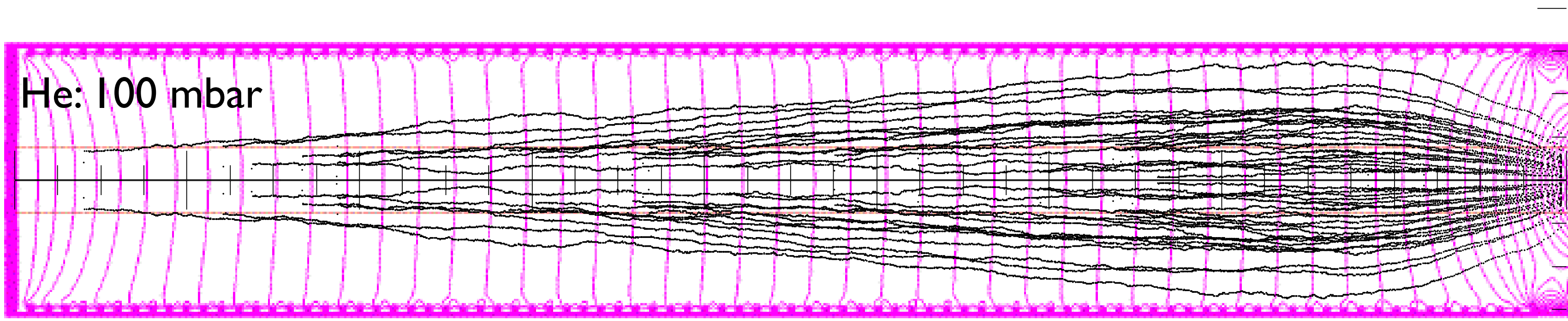
Fig. 3. View of the large gas catcher being developed for testing at the FRS.

FRS Gas Cell
(1st gen.)



Gas Cell at RIPS

# use a DC field in Gas Cell?



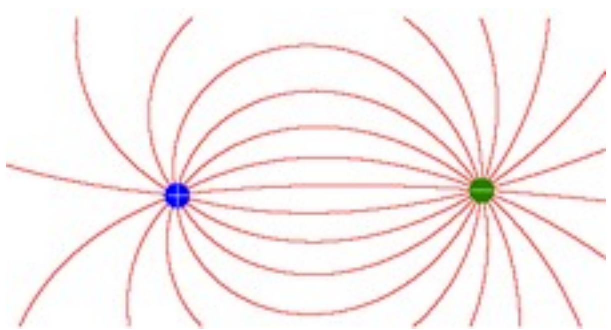

$E_{\mathrm{DC}} \approx 10\ \mathrm{V/cm} \quad \mu = 200\ \mathrm{cm^2/Vs}$

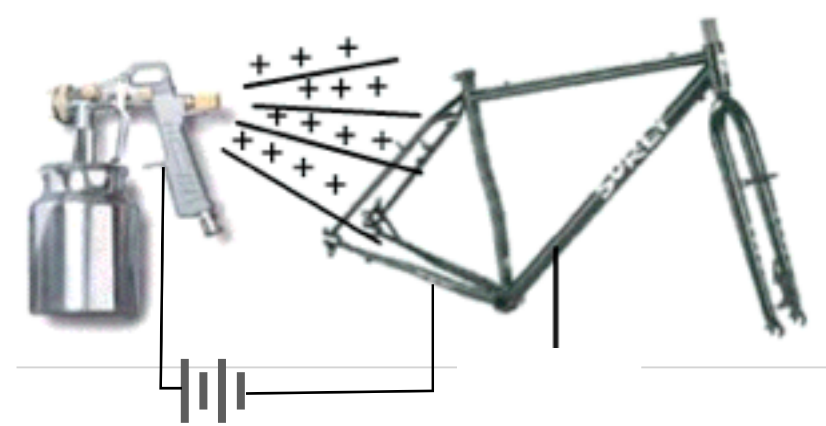
$v_{\mathrm{d}} = \mu E = 20\ \mathrm{m/s}$

***Cathode***

## Drift Motion: Follow Electric Field Line

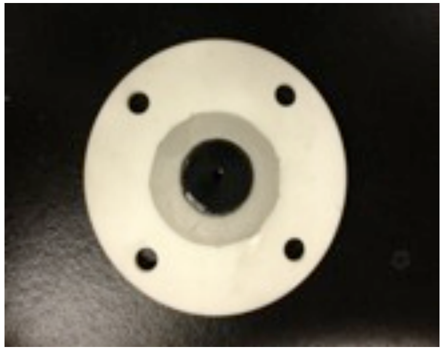
***Always terminated at Cathode Electrode***

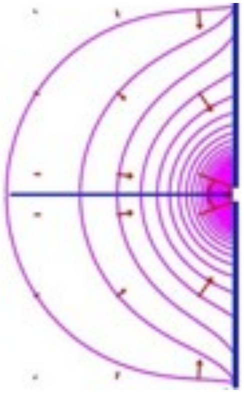




***Even if Cathode is a Mesh***

# if a point Cathode is virtually outside Cell





***Surface Current***

$$V \approx \frac{V_0}{r}$$

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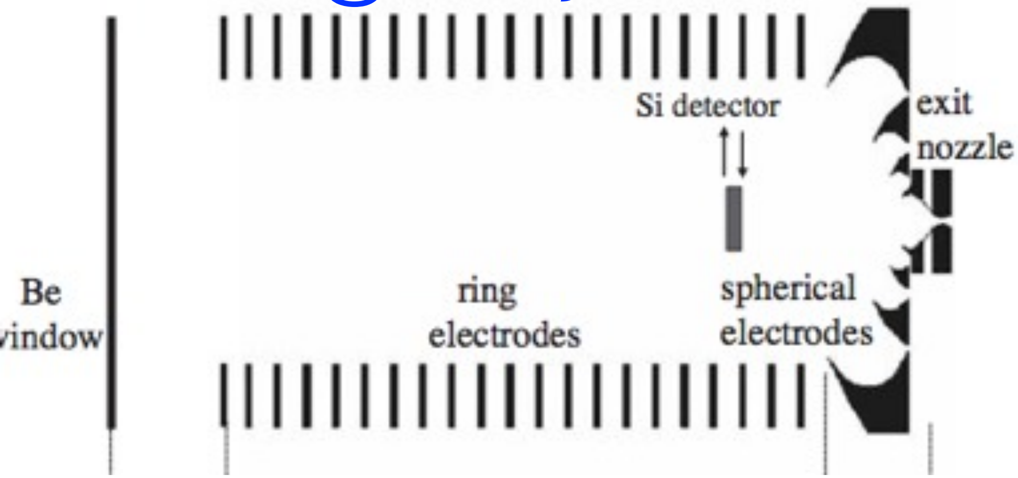
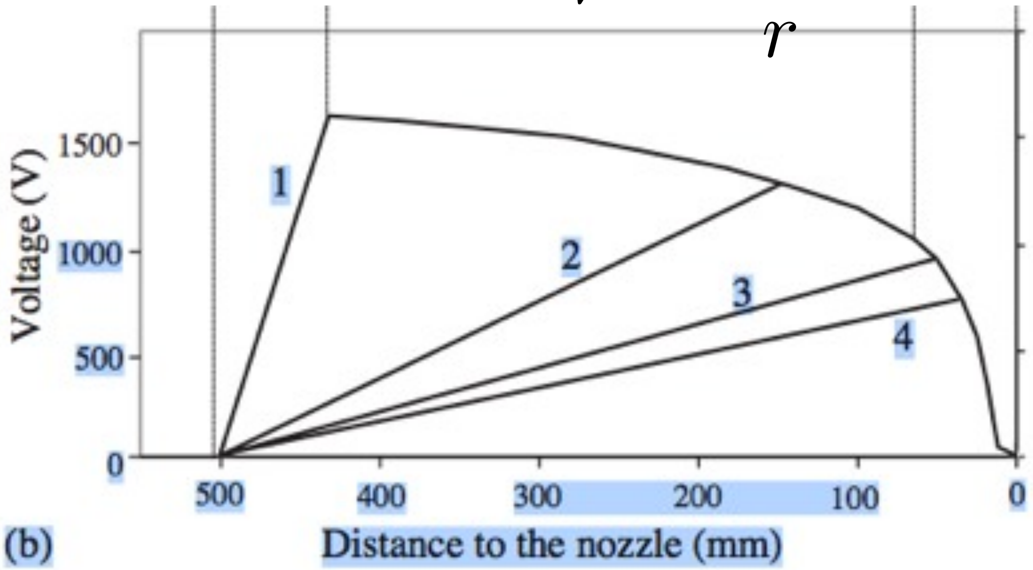
***Spherical Electrodes @LEBIT, MSU***




$$V \approx \frac{V_0}{r}$$

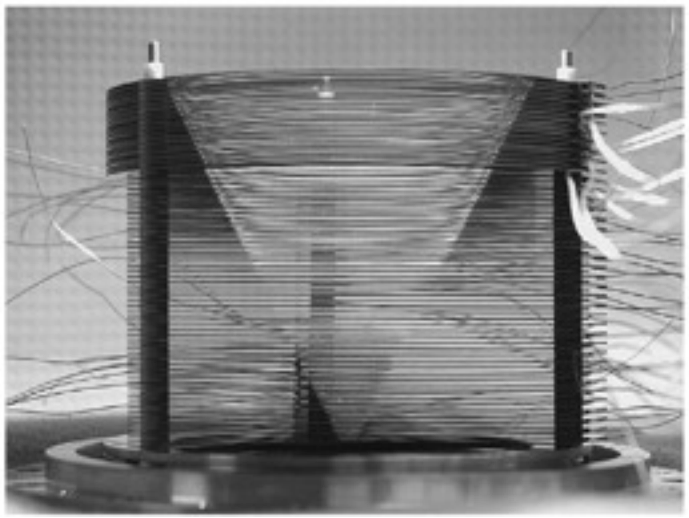



***L. Weissman et al, NIMA 540(2005)245***

***38Ca Mass Measurement @NSCL*** ***(G. Bollen et al, PRL 96(2006)152501)***

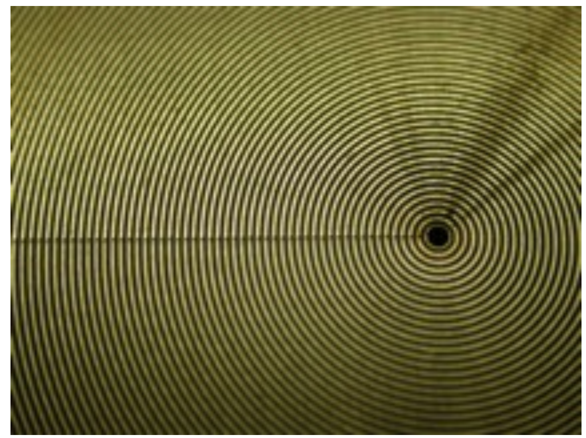
# RF Ion Barrier on Cathode

G. Savard et al. / Nucl. Instr. and Meth. in Phys. Res. B 204 (2003) 582–586



***ANL RF-Funnel***
***G. Savard et al***

→ **CARIBOU @ATLAS**
**one of ReA3 @NSCL**
**@TAM**



***INS-RIKEN***
***RF Carpet***
***M. Wada et al***

→ ***SLOWRI@RIBF***

***cyclotron RF@MSU***
***ion surfing RF@MSU***

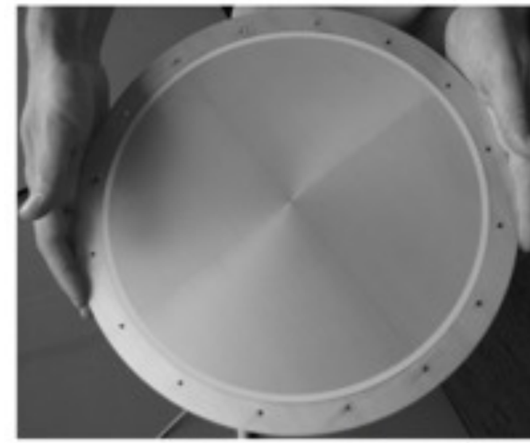
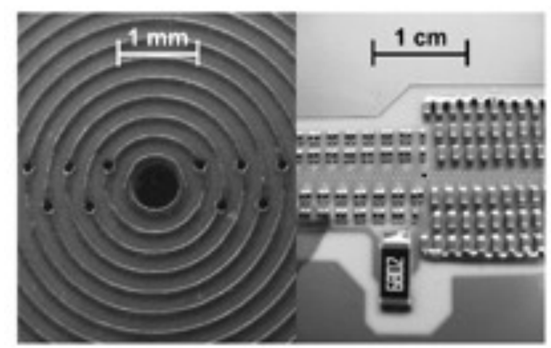


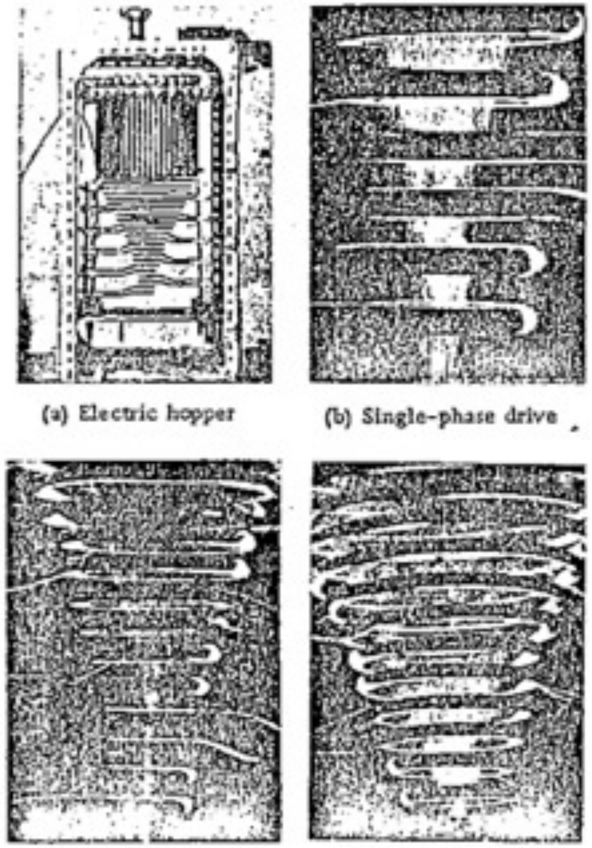
Figure 4.14: Front view of the RF carpet.




***KVI Cryo RF Carpet***
***P. Dendooven et al***

→ ***FRS@GSI***

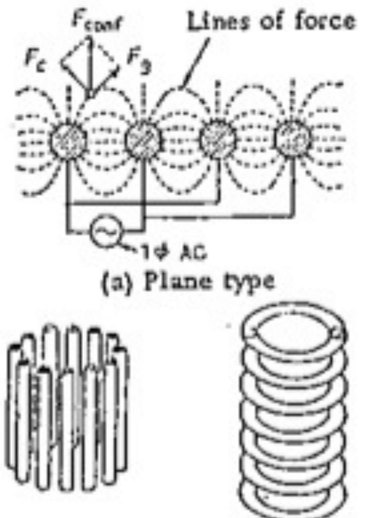
# Invention of electric curtain with standing & traveling wave, in 1972



(a) Electric hopper (b) Single-phase drive

(c) Three-phase drive (phase direc.: downwards) (d) Three-phase drive (phase direc. : upwards)

Fig. 7. Electric hopper and its modes of operation (polarity of particle charge: positive).




(a) Plane type

(b) Cage type (c) Ring type

Fig. 1. Principle and basic constructions tric curtain.

Senichi Masuda (
1926 in Imchon,
Department of Elec
sity of Tokyo in 19
He joined with C
Research Engineer
fessor at the Depar
University of Toky
1968. He retired f
1987 and is now
Technology. His re
of electrostatics and its applications, inclu
pulse energization, electrodynamics of char

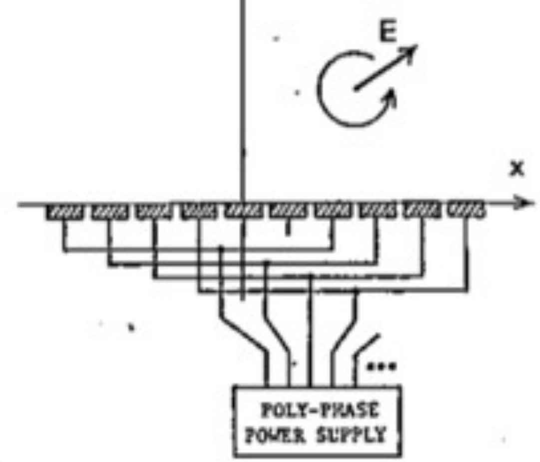
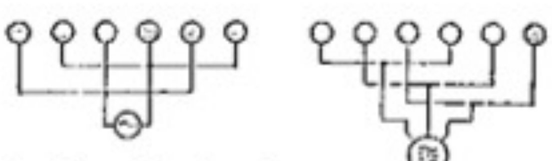



Fig. 1. Traveling-field-type electric curtain device.



(a) Single-phase drive (standing-wave type) (b) Polyphase drive (traveling-wave type)

Fig. 2. Electric energization.

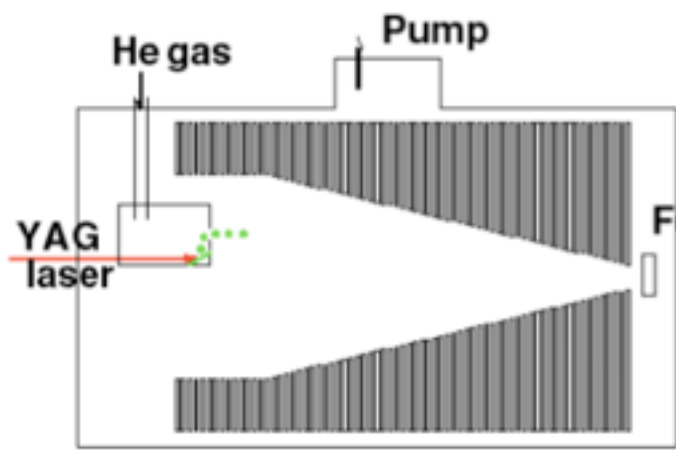
- Invention of rf hopper, curtain
- transport aerosol, organic cell ions in air

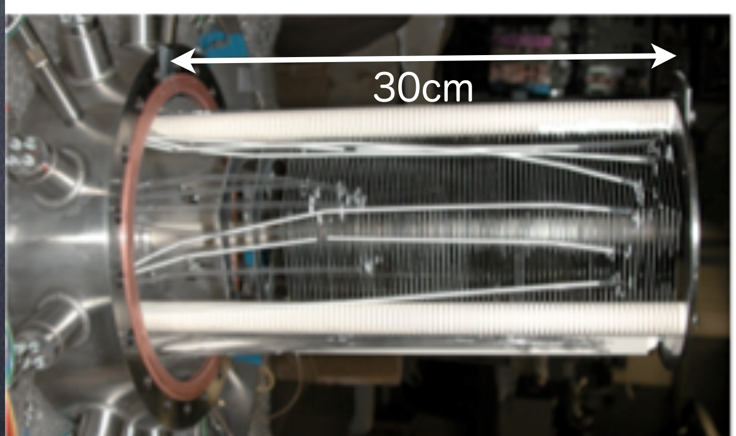
©1972 IEEE. Reprinted, with permission, from Electrical Engineering in Japan, Vol. 92, pp. 9-18,

IEEE, translation from Trans. IEE Japan, Vol. 92B, pp. 9-18 (1972).

# History of RF Ion Guide @INS-RIKEN

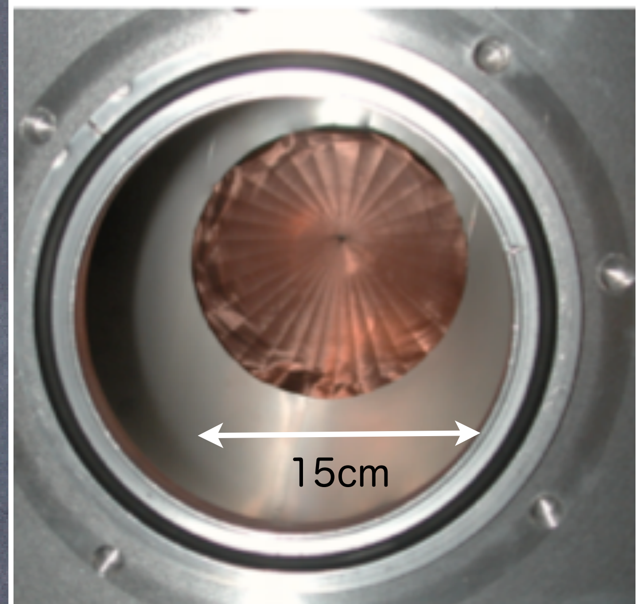
First Off-Line Test with Ta ion

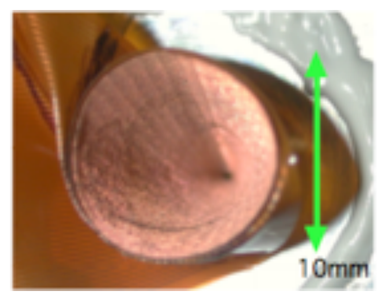



***first off-line test for Ta at INS 1997-1998***

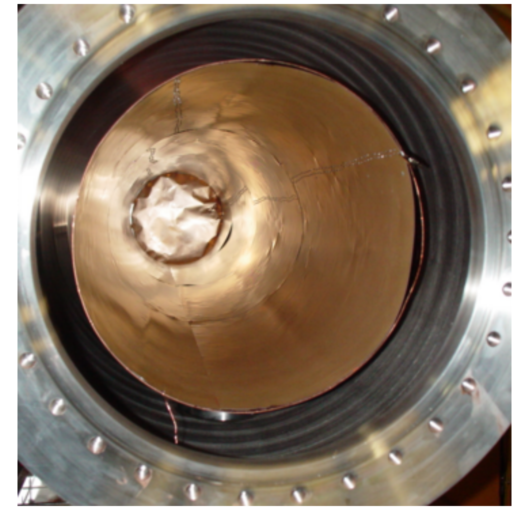
two stage rf
Funnel Structure

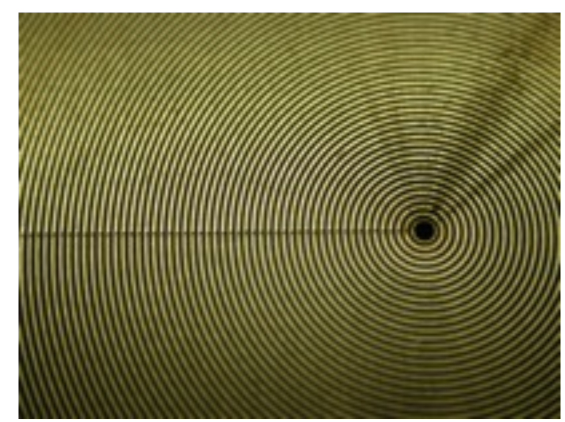



***first on-line test for Li-8 at RIKEN 2000***

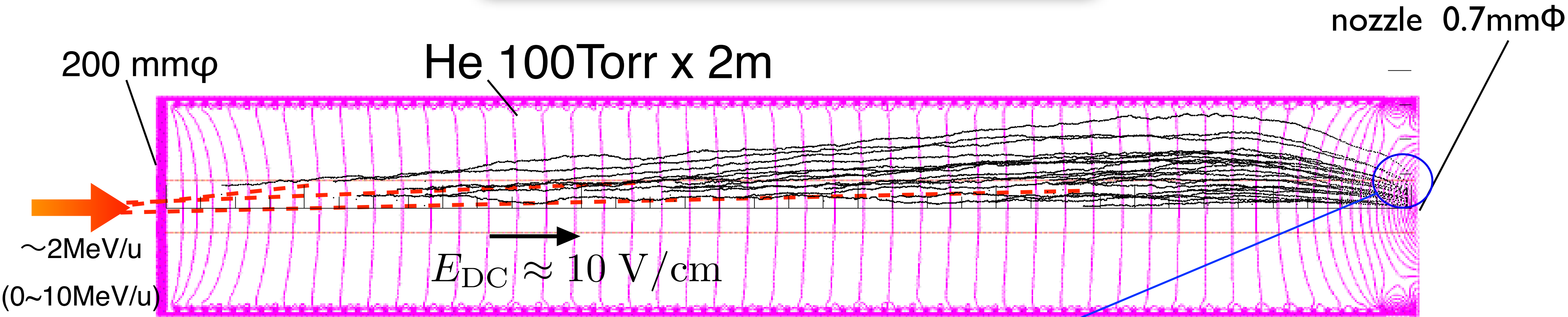
2m cylinder and RF carpet





***Laser Spectroscopy of Be 2005~ MRTOF 2011~***

# RF-Carpet Ion Guide™



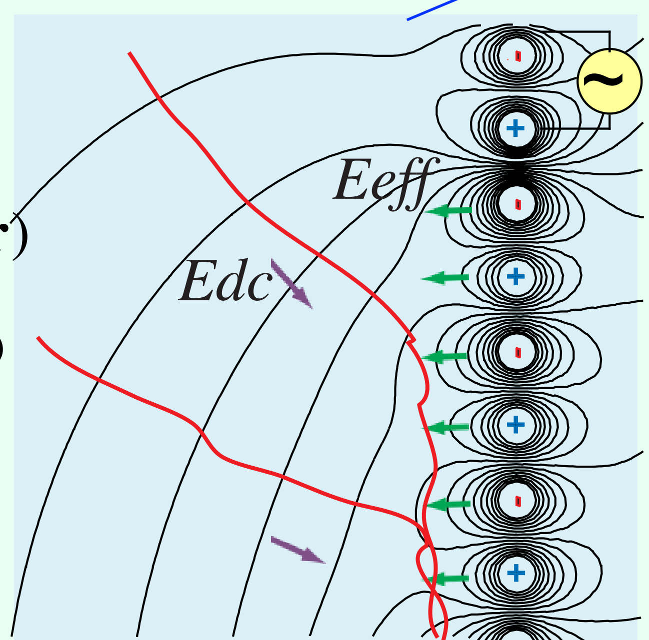

## RF gradient Field: Barrier

$$\bar{F} = -\frac{e^2}{4m}\frac{1}{(\Omega^2 + 1/\tau_v^2)}\nabla \mathbf{E}_{rf}^2(\mathbf{r})$$

$(\mathbf{E}(\mathbf{r},t) = \mathbf{E}_{rf}(\mathbf{r})\cos(\Omega t),\ \tau_v$: relax time)

$$E_{\text{eff in gas}}^{\max} = \frac{m\mu^2 V_{rf}^2}{e r_0^3}$$

$2r_0 \approx$ electrode distance





M.Wada et al, NIM B204 (2003) 570.

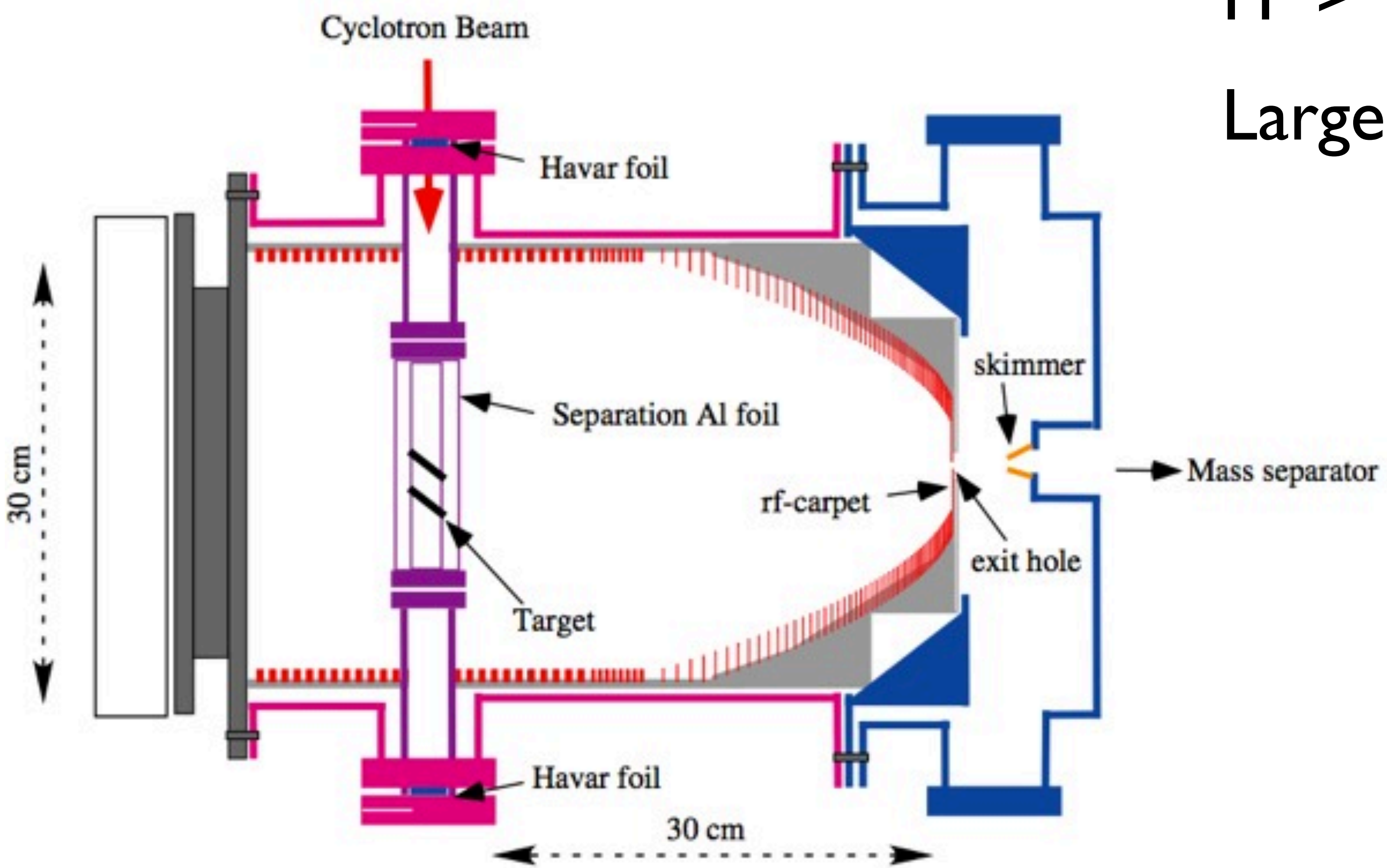
More Precise Analytical Formulation

S. Schwarz, IJMS 299(2011)71.

# feedback to IGISOL (Fission)

FP > 1 MeV/u

Larger Cell Gain




***RF-IGISOL @Sendai***
***T. Sonoda et al***

T. Sonoda et al, NIMB 254 (2007) 295-299

# Issues & Solutions

1. Space-charge effect due to ionized He

   Effective Volume Reduction

2. Contamination

   All UHV Materials: ANL

   Cryogenic Gas Cell: KVI-GSI

3. Longer Stopping Length

   Cyclotron Gas Cell

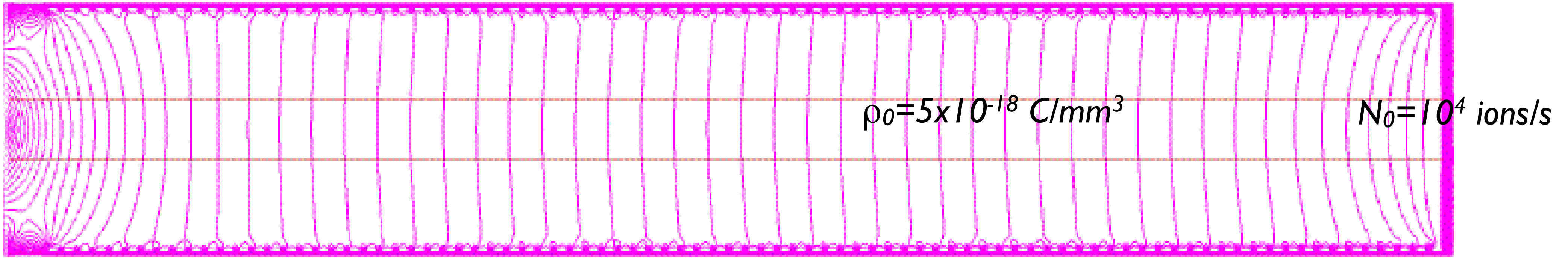
4. Faster Extraction

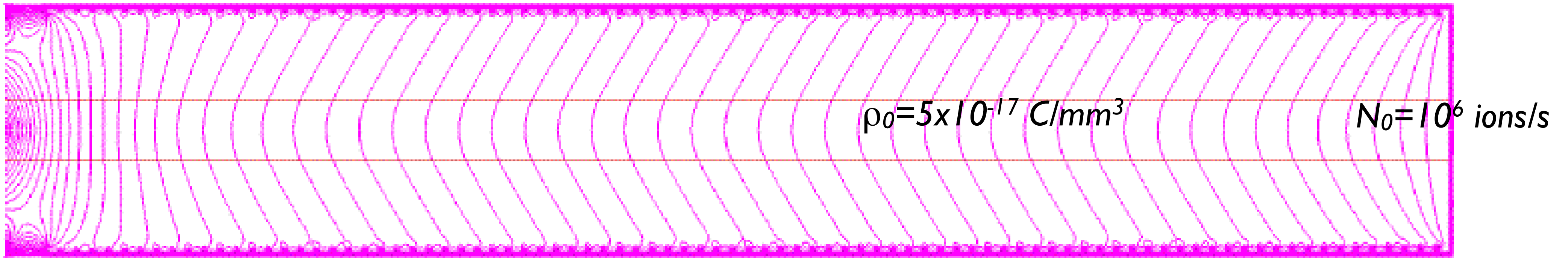
   Cyclotron Gas Cell

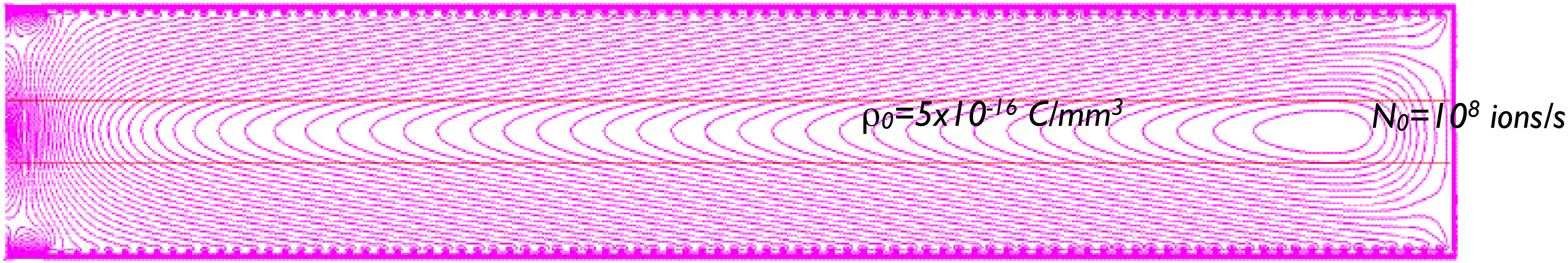
   Traveling Wave

5. ...

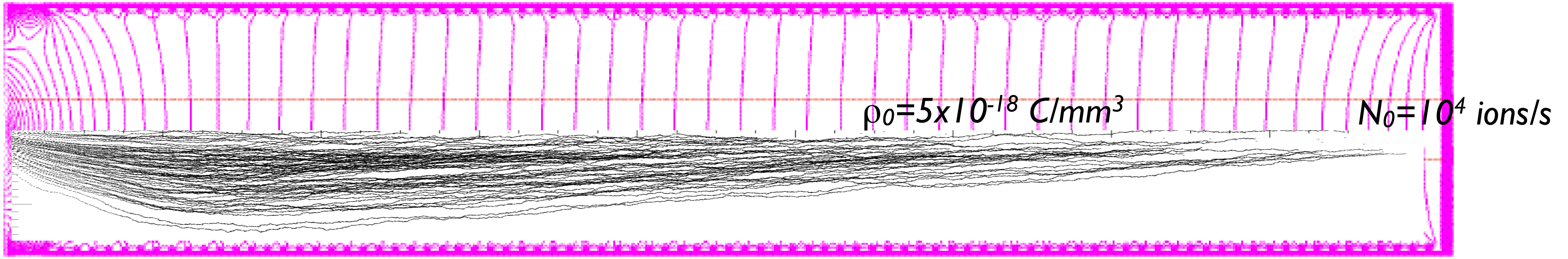
# Ion Trajectories under space-charge

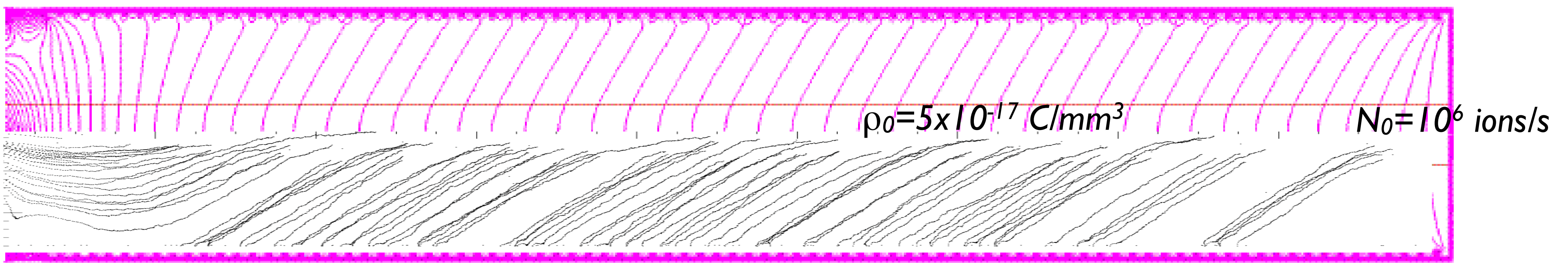


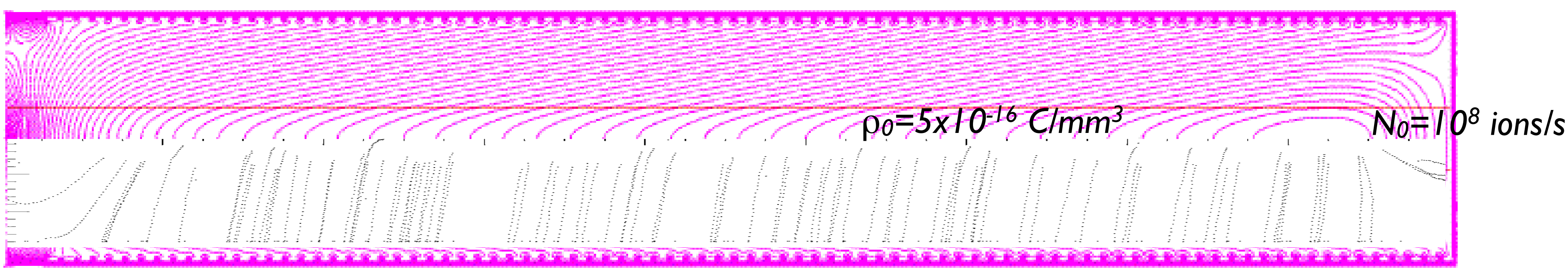



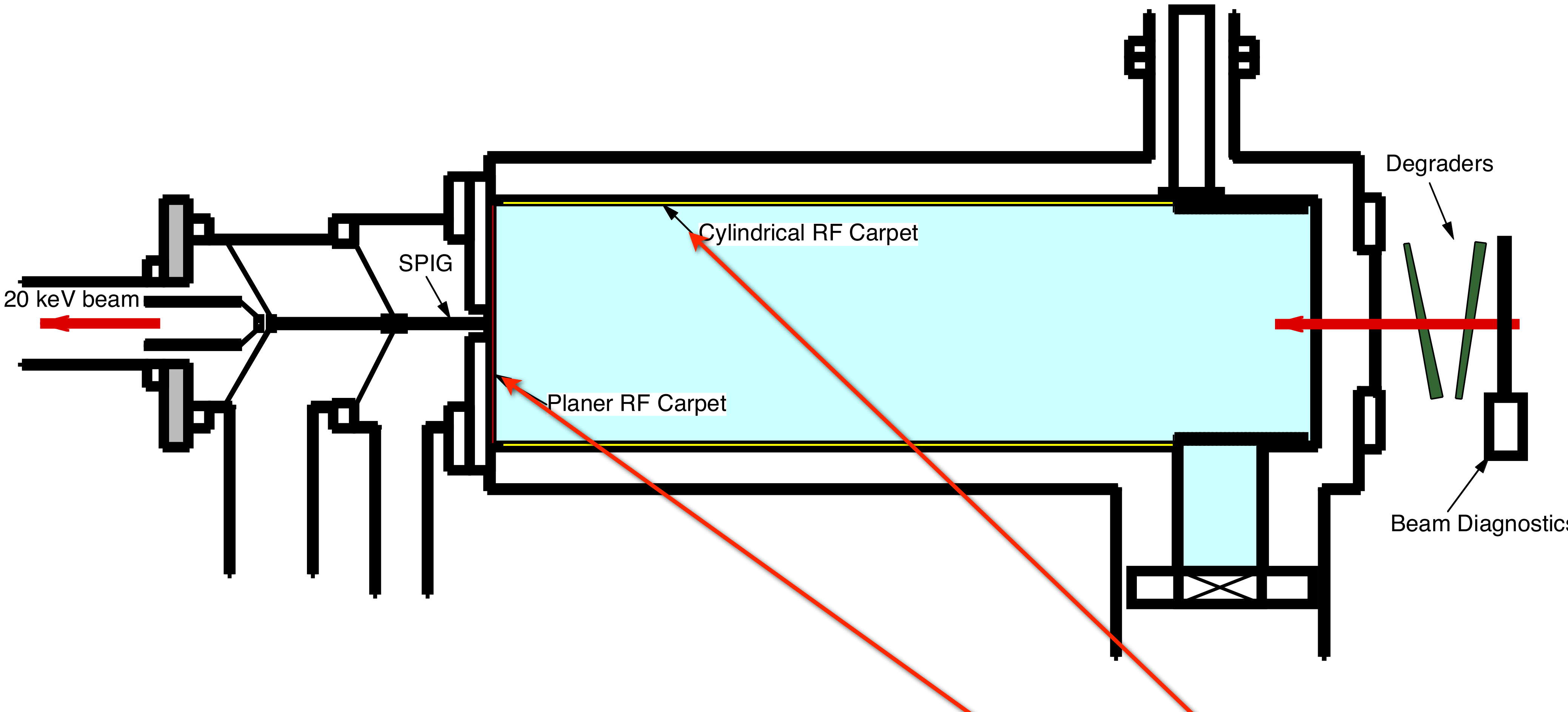
# Ion Trajectories under space-charge



# New Ion Guide Gas Cell




- Fully covered RF carpets (planer & cylindrical)
- Cryogenic cooling by thermal isolation

# Cryogenic Gas Cell
# @KVI →GSI

M.Ranjan, thesis

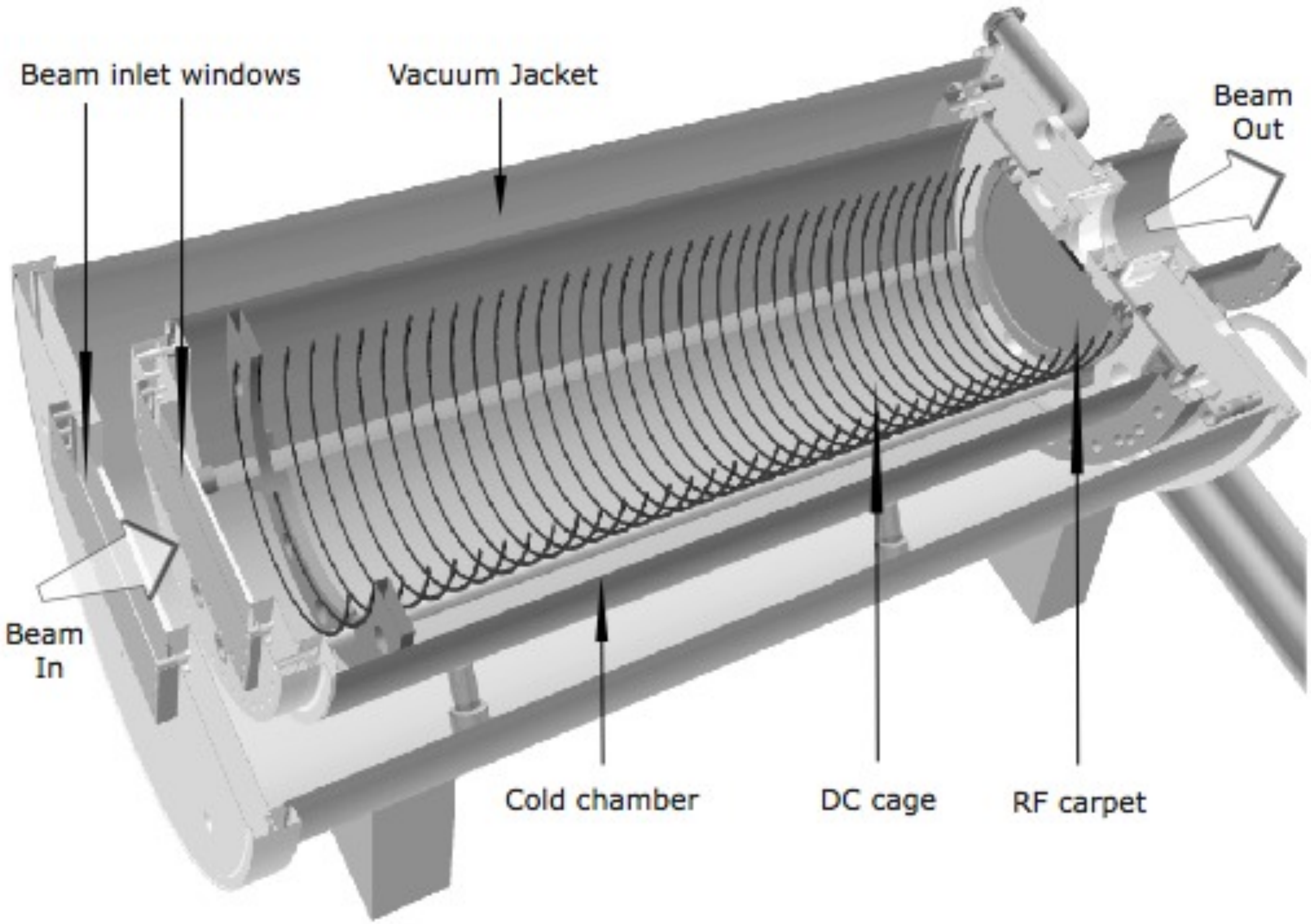



Figure 4.8: General construction of Cryogenic Stopping Cell.

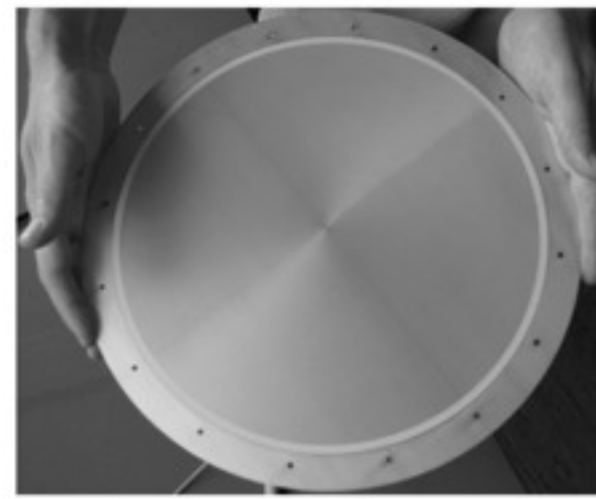
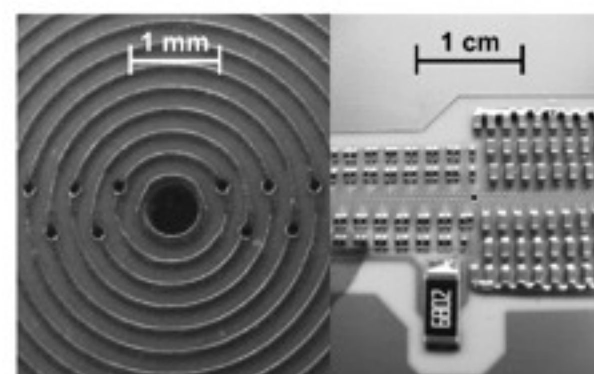


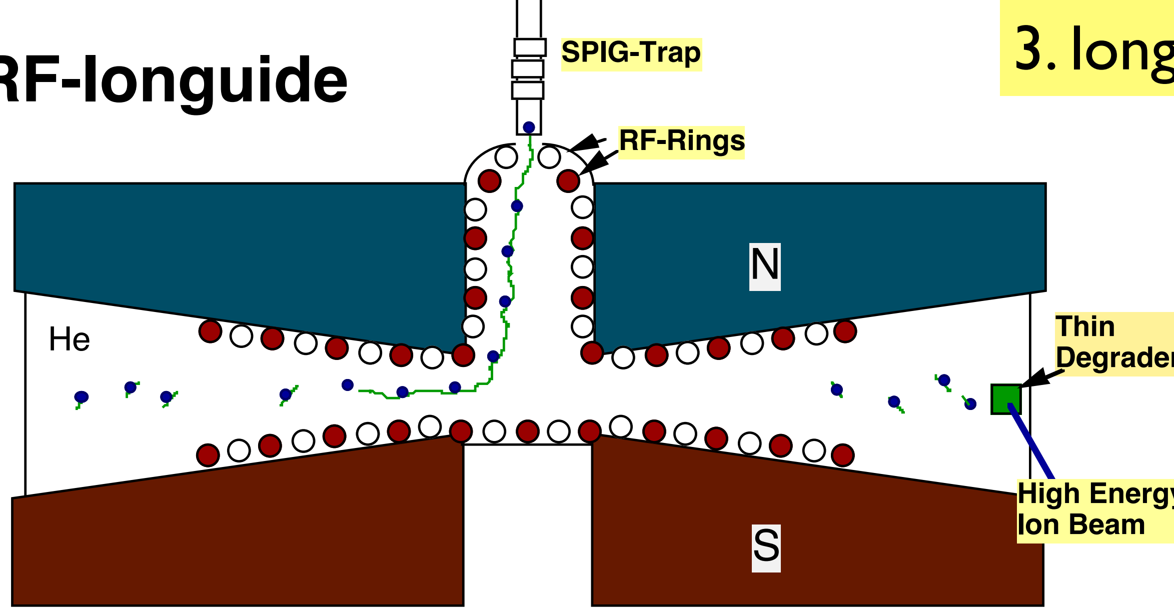
Figure 4.14: Front view of the RF carpet.




***W. Plaß, The FRS Ion Catcher***

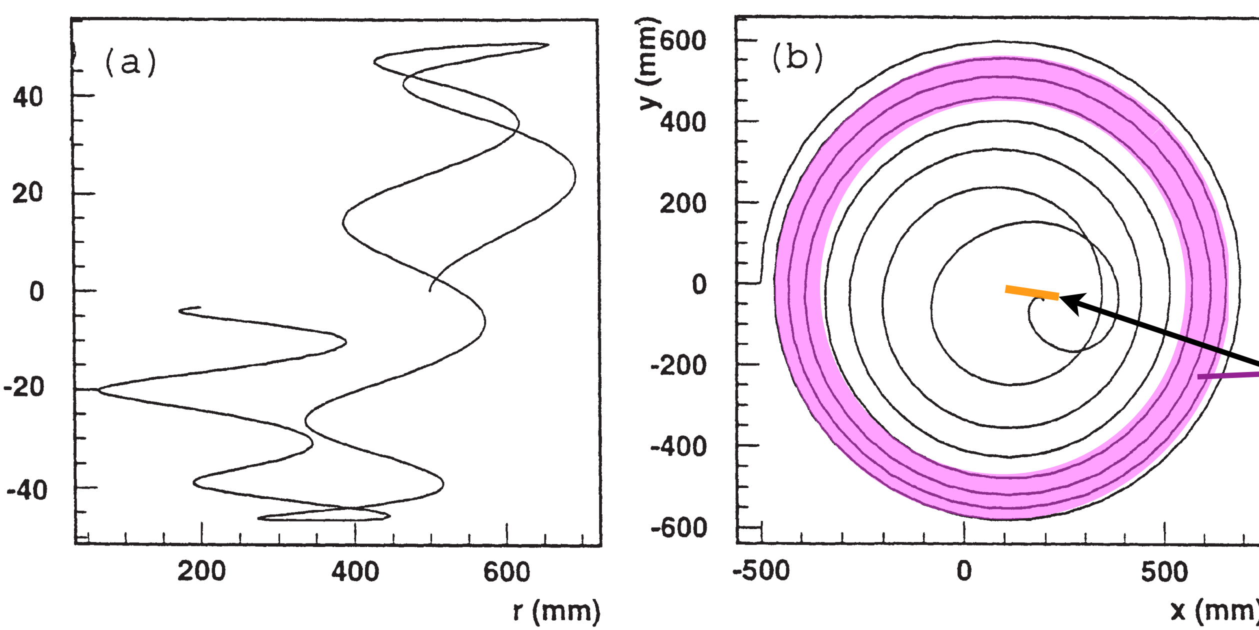
# Cyclotron-RF-Ionguide

## 3. longer stopping length




I. Katayama, M. Wada et al, Hyp. Int. 115 (1998) 165. (proc. Ferrara 1997)

*I. Katayama et al. / Cyclotron ion guide for energetic radioactive nuclear ions* 167




gure 2. A trajectory of a 5 MeV/u $^{11}Be^{4+}$ ion coming out of a proper Ta energy degrader at $R = 50$ cm d 5000 Pa He gas. The ion starts with an azimuthal velocity of $v_x = 3.1 \times 10^7$ m/s and $v_z =$ $2 \times 10^5$ m/s at $(x_0, y_0, z) = (-500, 0, -3)$ mm. The charge state of ion is assumed to follow a charge uilibrium given in [8]. Magnetic field is taken to be $B_z = B_0(1 - 0.25r/R)$ and $B_r = 0.25B_0 z/R$ th $B_0 = 17$ kG. The result shows (a) the ion orbit in $(z, r)$-plane, and (b) the ion orbit in $(x, y)$-plane.

- Long stopping length
  >10 m
- Short drift path < 30cm
- Isolated
  high space-charge &
  drift path

*Ideal condition for:*
*Fast extraction &*
*High Intensity*

# Cyclotron Gas Stopper @ MSU

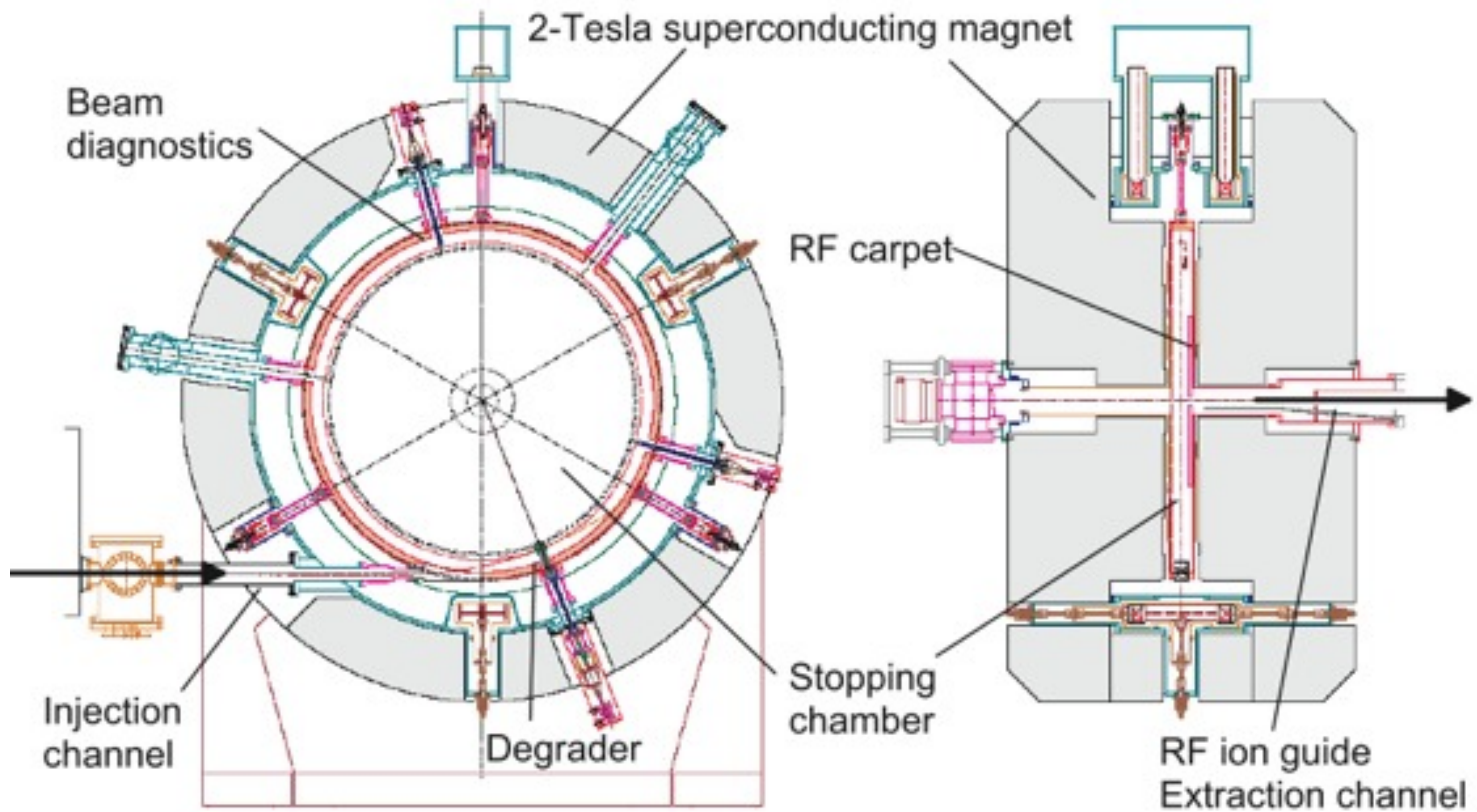


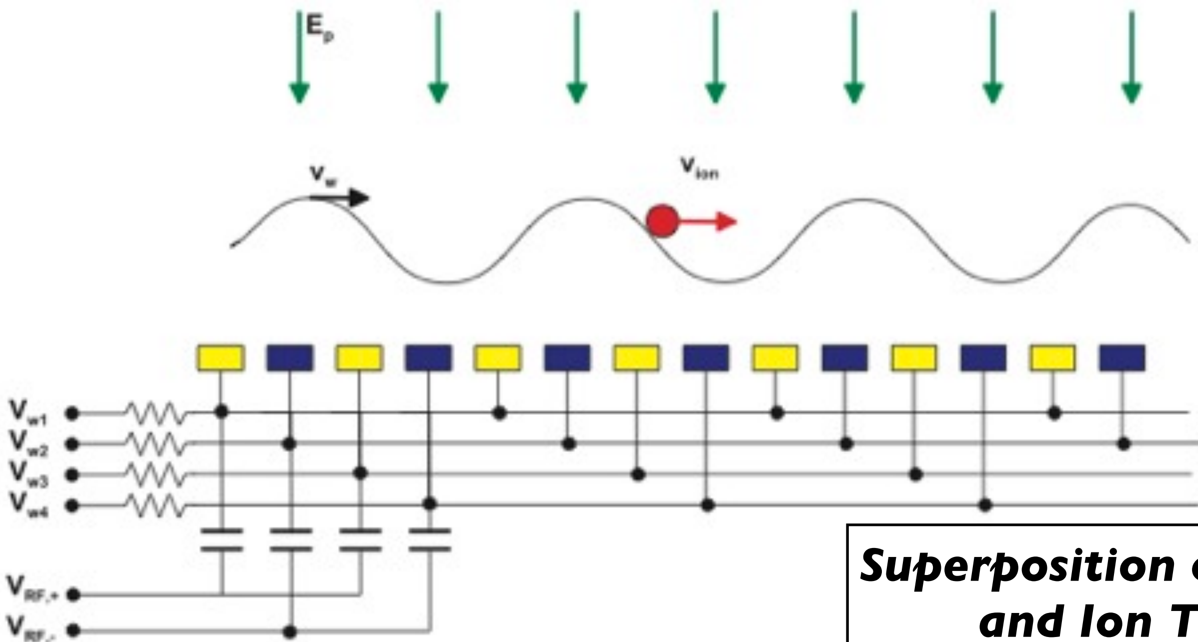

**Fig. 2.** Design concept of a vertical cyclotron stopper.

***G. Bollen et al, NIMA 550(2005)27,***
***Eur. Phys. J. ST 150(2007)265.*** → ***S. Schwarz, under construction***

***CF. M. Sternburg, G. Savard, NIMA 596(2008) 257.***

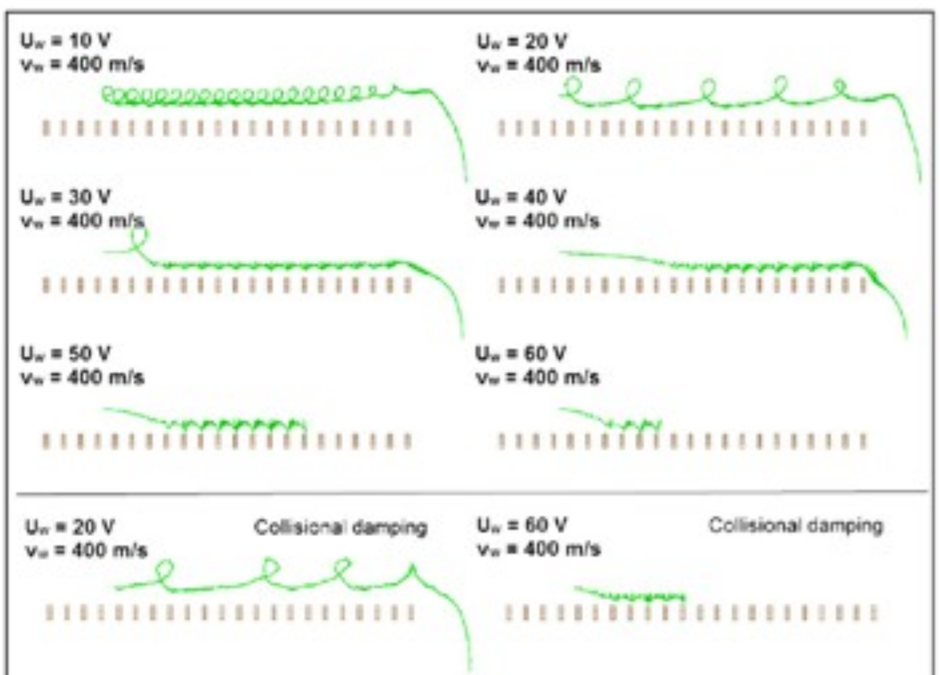
another evaluation for Cyclotron Gas Stopping Concept.

# Ion Surfing RF-Carpet using Traveling Wave




4. faster extraction

***Superposition of Ion Barrier RF (Radio Freq.) and Ion Transport RF (Audio Freq.)***

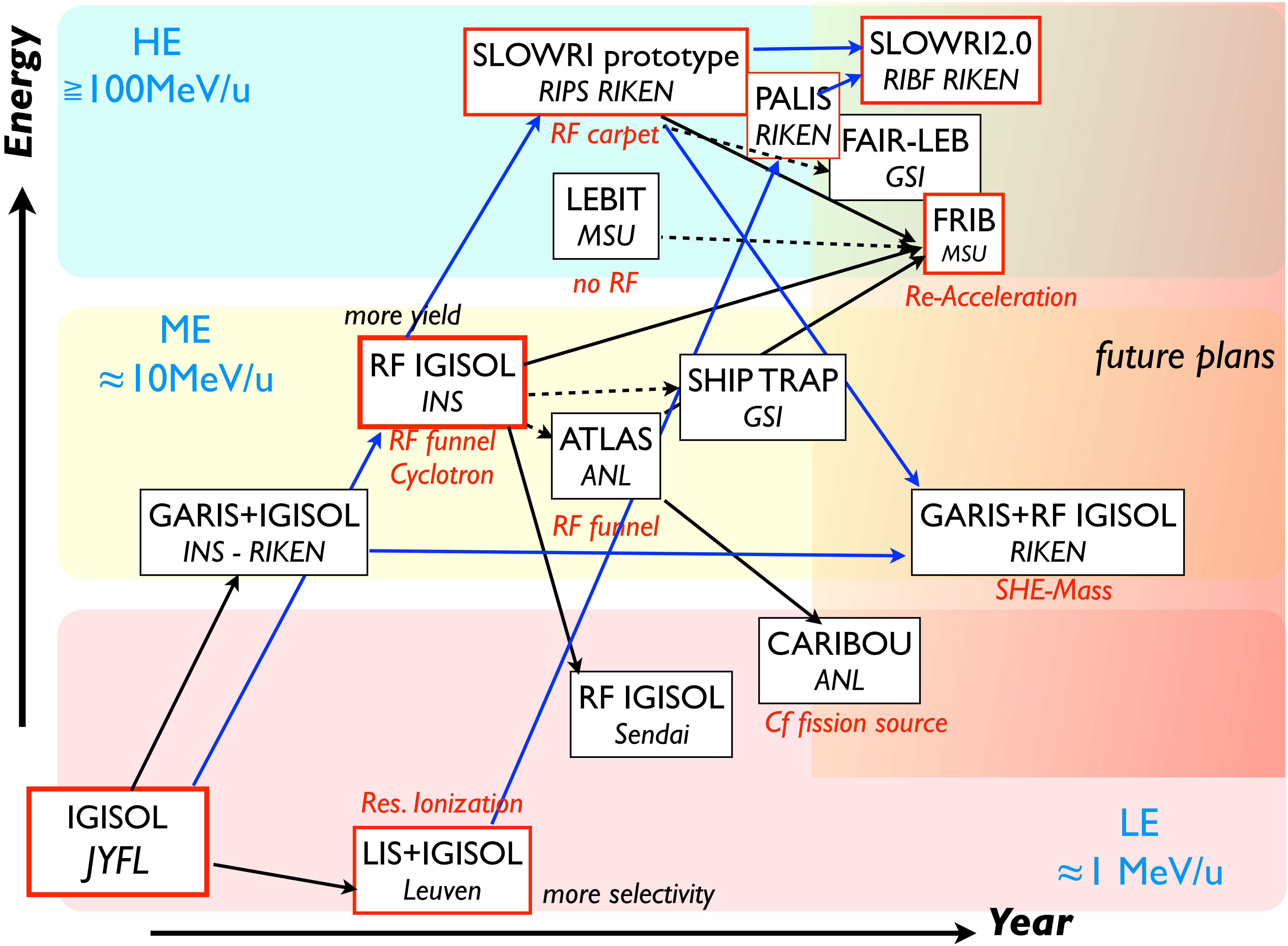



***G. Bollen, IJMS 299(2011)131-138***

- no DC High Vol in He
- Faster Extraction

***M. Brodeur, Traveling wave ...***

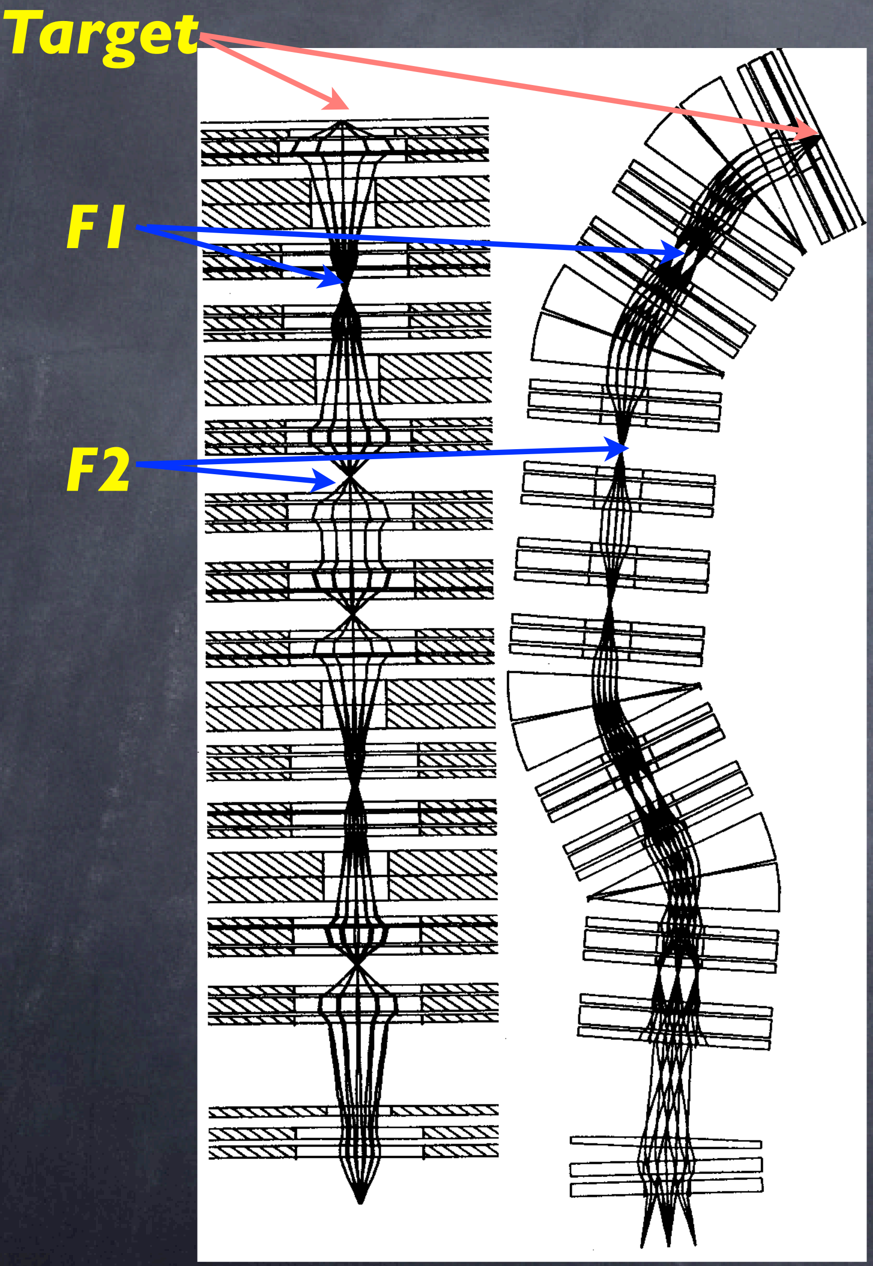
# Gas Cell Genealogy

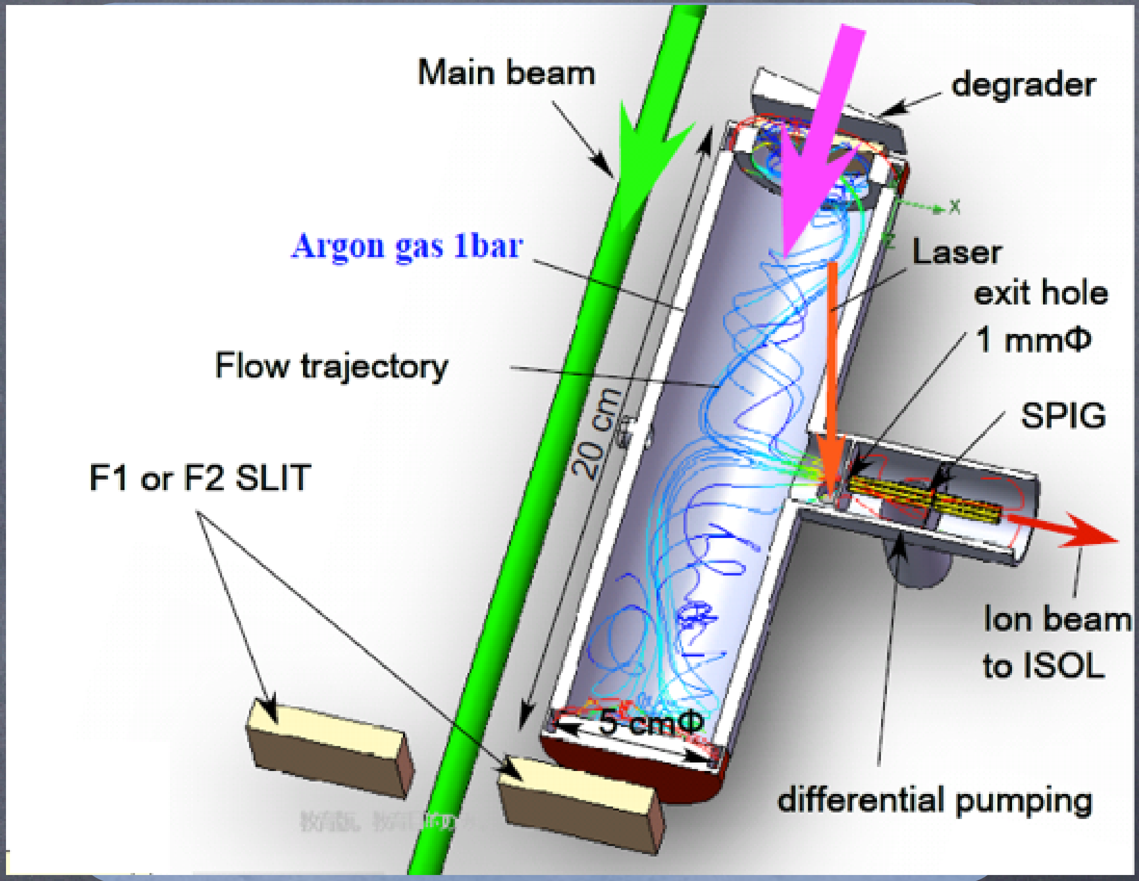


end

# PALIS

***PArasitic slow RI-beam with gas catcher Laser Ion Source***



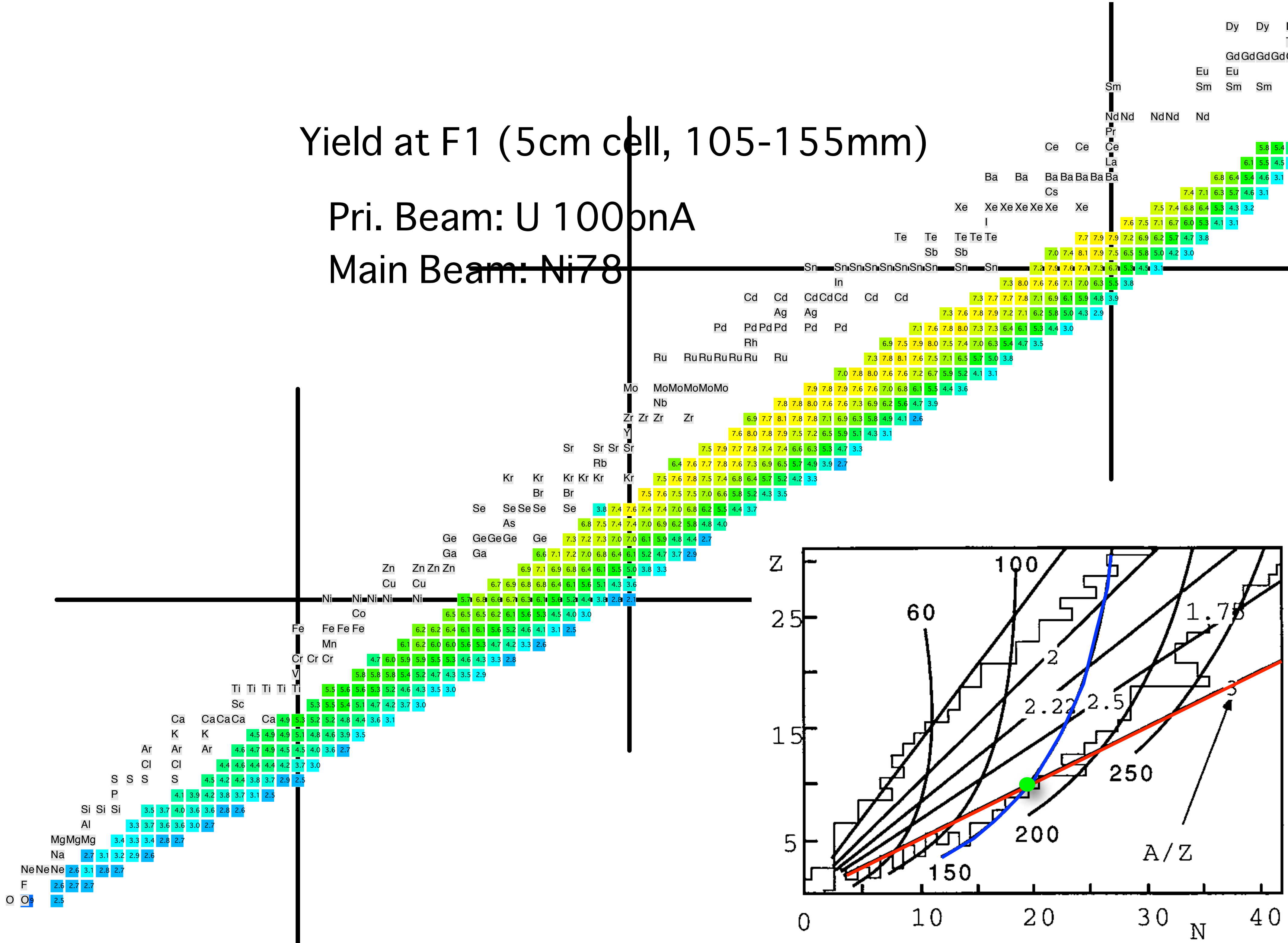

1) Stop & Neutralize in Ar (1 bar)
2) Extract by Gas Flow
3) Re-Ionize at Exit and SPIG

***not universal, not very fast but***
***A/Z, Z, A separation***

# Yield at F1 (5cm cell, 105-155mm)

Pri. Beam: U 100pnA

Main Beam: Ni78



# SLOWRI 2.0 floor plan

***To be constructed in FY2012 (approved)***