Mo-99 2015 TOPICAL MEETING ON
MOLYBDENUM-99 TECHNOLOGICAL DEVELOPMENT
AUGUST 31-SEPTEMBER 3, 2015
HILTON BOSTON BACK BAY
BOSTON, MASSACHUSETTS

Feasibility of *transmutational* production and magnetic extraction of Moly-99 via 1-neutron knockout and exchange reactions in auto-colliding beam of natural Mo ions in strong-focusing Precetron ("EXYDER") and electric energy recuperation by ion decelerator*

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Early Version Presented at: Annual Meeting of the American Nuclear Society, June 7-11, 2015

*US Patent #4,788,024; also
Patent Pending #62/139,034

Making Mo-99 From Natural $^{92\text{-}100}Mo$

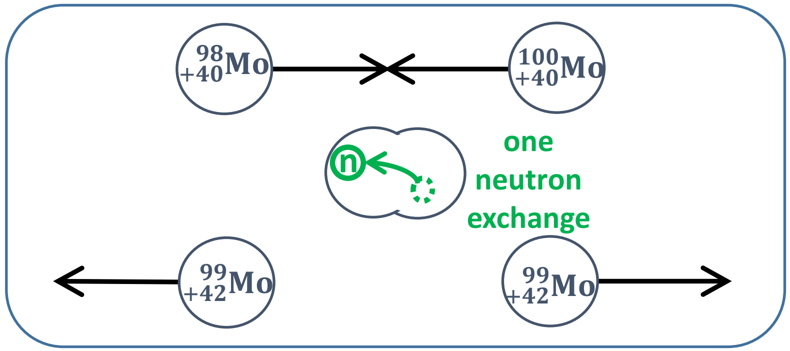
Colliding ^{98}U with ^{100}U

Knock out 1 n from 100, transition 98 → 99 + 99 **Resulting in TWO ^{99}Mo**

Stage 1

Stage 2

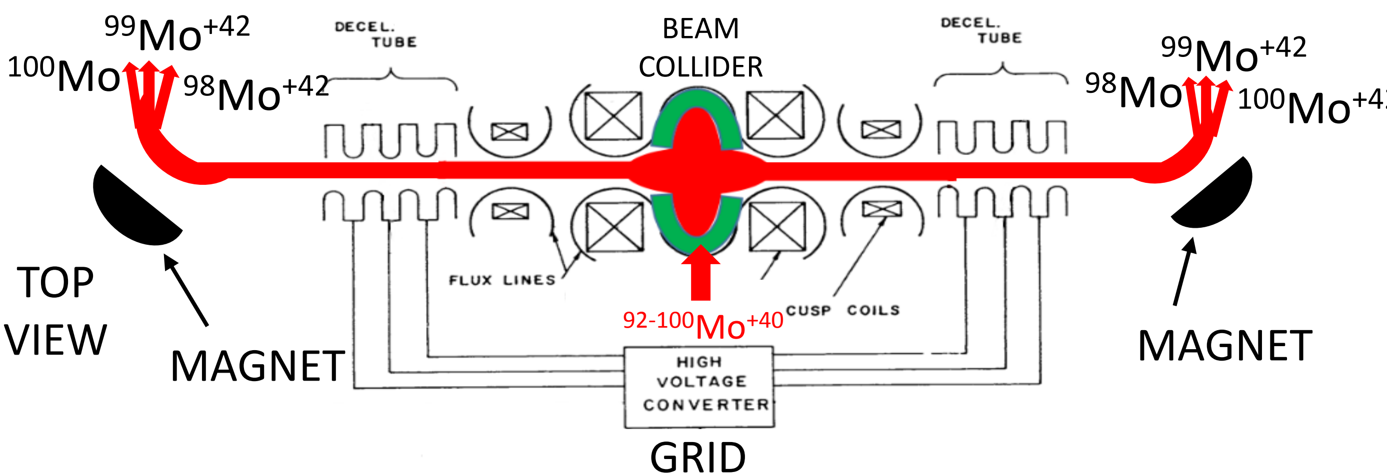
Stage 3



$$^{98}\text{Mo} + {}^{100}\text{Mo} \rightarrow {}^{99}\text{Mo} + {}^{99}\text{Mo} - 2.37\ \text{MeV}$$

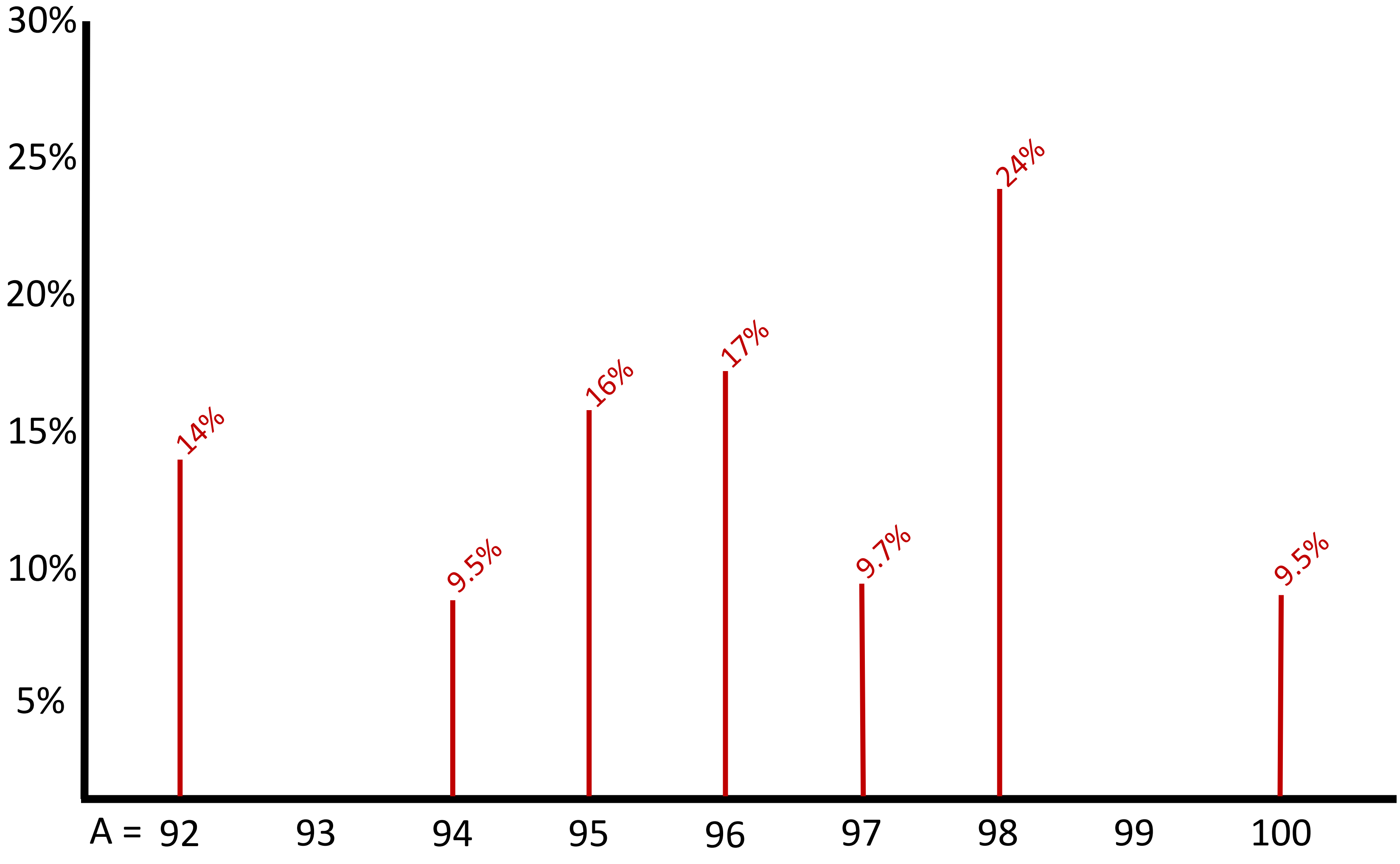
Stage 4

Stage 5

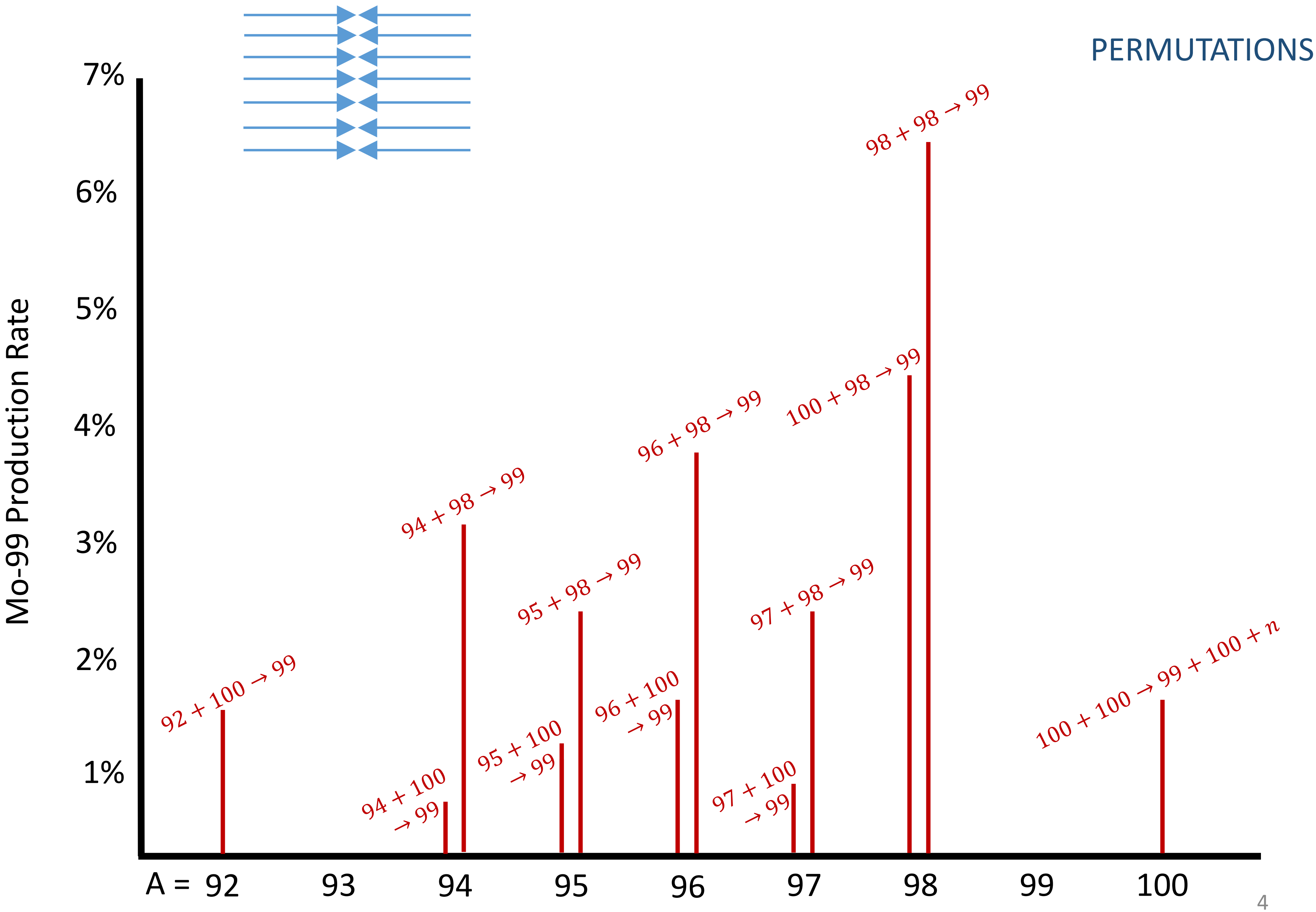


ALL WITHIN STATE OF THE OF ART PARTICLE BEAM PHYSICS & ACCEL. TECH.

7 Stable Mo Isotopes



7 Mo Isotopes ⟶ 12 1-n Exchange Reactions Producing 14 ^{99}Mo



ISR: Intersecting Storage Rings at CERN, 1971

For 100 years: beam-on-target:

Since 1971: beam-on-beam:

Opened

NEW ERA

In nuclear and particle physics

p (20 GeV) + p (20 GeV)

5 ADVANTAGES

<u>OF COLLIDING BEAMS</u>

1. Energy Confinement Time:

$$\boldsymbol{\tau = 5 \times 10^6\ \mathrm{sec}}$$
$$= \mathbf{2\ months}\ \text{(coasting)}$$

VACUUM $\sim 10^{-10}, 10^{-11}$ torr

KEY: PREVENT THERMALIZATION OPPOSITE TO MAXWELLIAN PLASMAS, IT IS AN <u>ORDERED PARTICLE MOTION SYSTEM CONTROLLED BY EXTERNAL STRONG FOCUSING FORCES AND EM FEED–BACK SIGNALS</u>

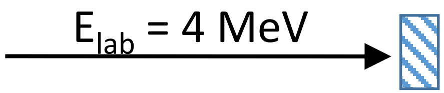
2012: Brookhaven Relativistic Heavy Ion Collider (RHIC) collided $^{238}U^{92+}$ (100 GeV) + $^{238}U^{92+}$ (100 GeV) observed σ_{total} = 487 barn = 13 X σ_{geo}

5 ADVANTAGES OF COLLIDING BEAMS

2. ENERGY FACTOR OF 8

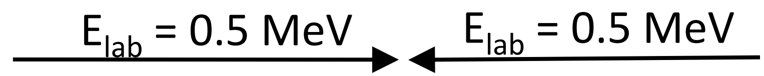
<u>Beam-on-target</u>

$$E_{COM} = \frac{1}{4} E_{Lab} = 1 \text{ MeV}$$



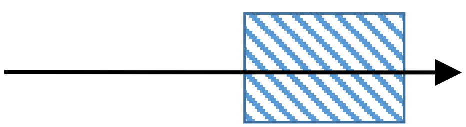
<u>Collider</u>

$$E_{COM} = E_{Lab} = 1 \text{ MeV}$$



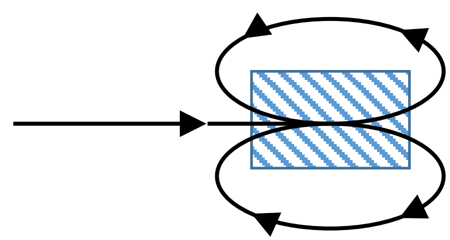
3. FACTOR OF 10^6 MULTIPLE TRAVERSAL

<u>Beam-on-target</u>



Single Traversal

<u>Collider</u>



Multiple Traversal
$\omega \sim 10^6 s^{-1}$

4. REACTION RATE

<u>Beam-on-target</u>

∝ ion current - LINEAR

$(\mathrm{R} \propto \mathrm{I})$

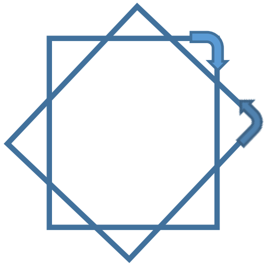
<u>Collider</u>

∝ (ion current) - QUADRATIC

$(\mathrm{R} \propto \mathrm{I}^2)$

5. BEAM BUNCHING FACTOR (From 4) LARGE INSTANTANEOUS POWER

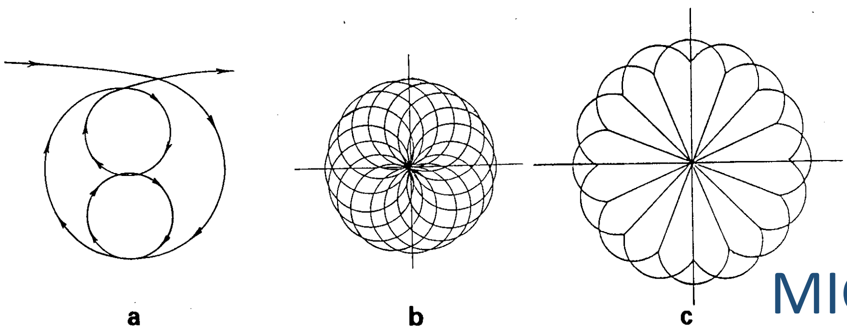
Time-of-Flight Selection



2 Intersecting Beams Counter Coasting

1975: INVENTION OF SELF-COLLIDING BEAM

One single beam collides head-on with itself via precession



KEY PHYSICS PRINCIPLE:

Canonical Angular Momentum = 0

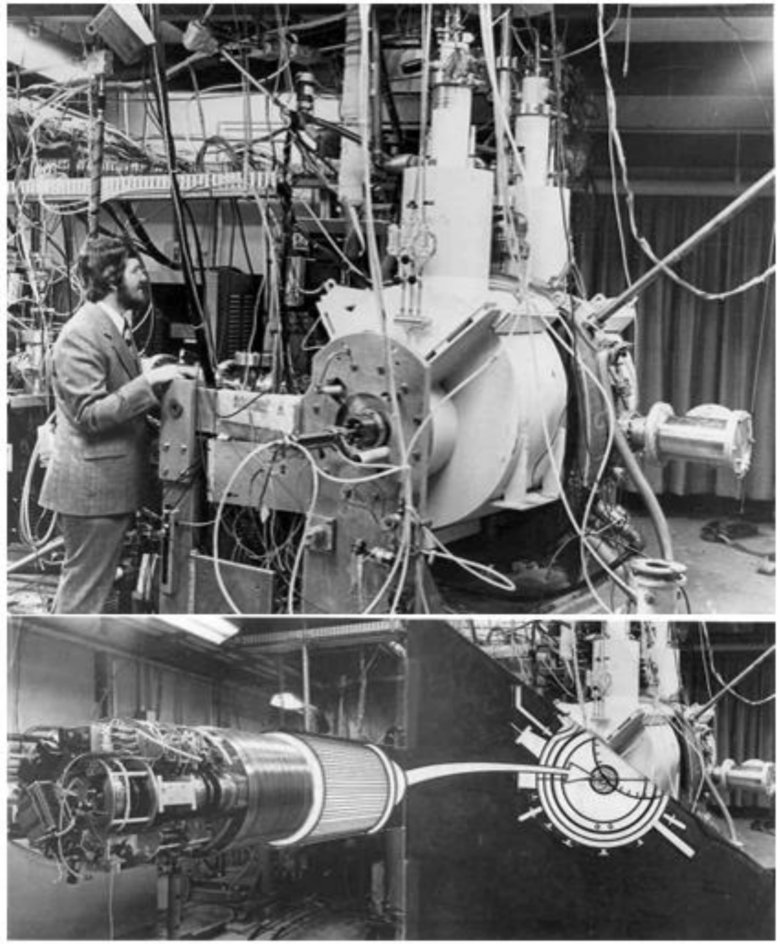
MIGMA = ORDERED MIXTURE OF ORBITS

"PRECETRON"

Princeton U. Physics Report PPAR – 14 1969

The principle of Self-Colliding Orbits Part. Accel. **1**, 121 (1970)

AUTO-COLLIDER MIGMA IV



ACCELERATOR INJECTION ENERGY:

D_2^+ ions of 1.45 MeV

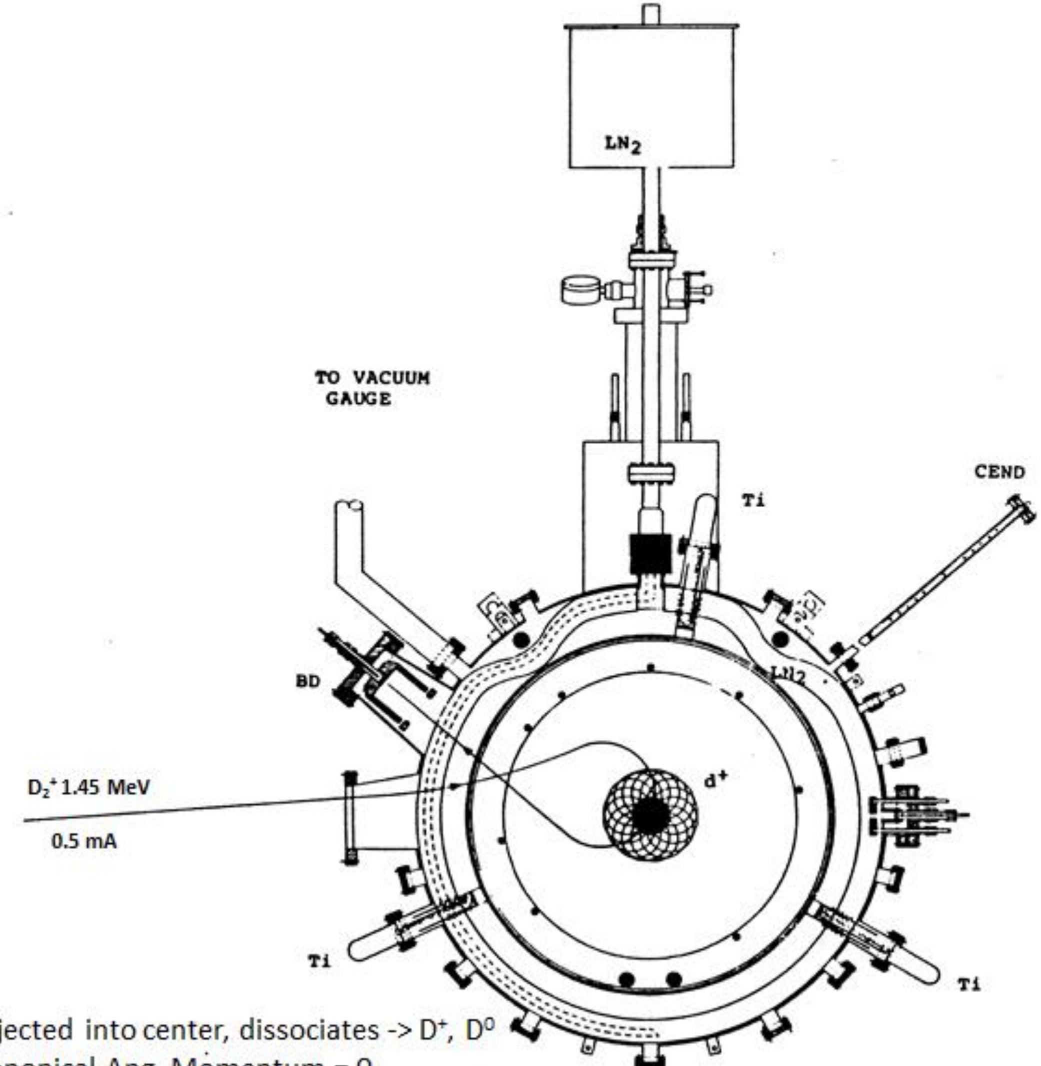
SUPERCONDUCTING NiTi MAGNET

6 Tesla on coil, **3.2 Tesla** midplane

VACUUM 10^{-11} Torr (static); 10^{-9} (beam in) **V = 5 liter**

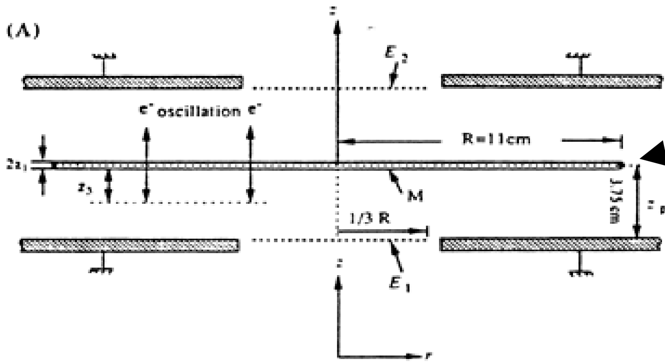
Baked 450°C 24 hours

Migma Institute of High Energy Fusion, Princeton 1986.



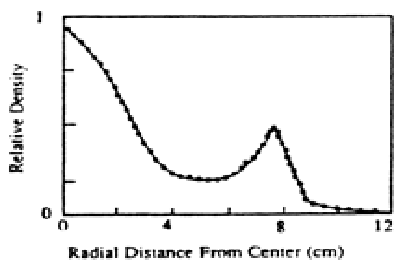
Injected into center, dissociates -> D^+, D^0
Canonical Ang. Momentum = 0.

Barkhausen Oscillator with virtual anode and cathode



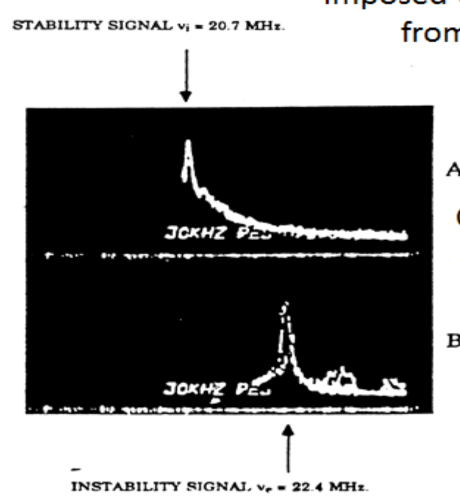
MIGMA

(B)



Nonliner Van der Pol equation:
$\ddot{x} + \eta\rho(x) + \nu_0 + \dot{x} + \nu_0^2 = 0$
η weak nonlinearity, ρ nonlinear *resistance*. Negative resistance, $\rho < 0$ instability; $\rho > 0$ stability.
Lashinsky and Dewan IEEE Trans. Autom. Contr. **12**, 244 (1967); **14** 212 (1969).

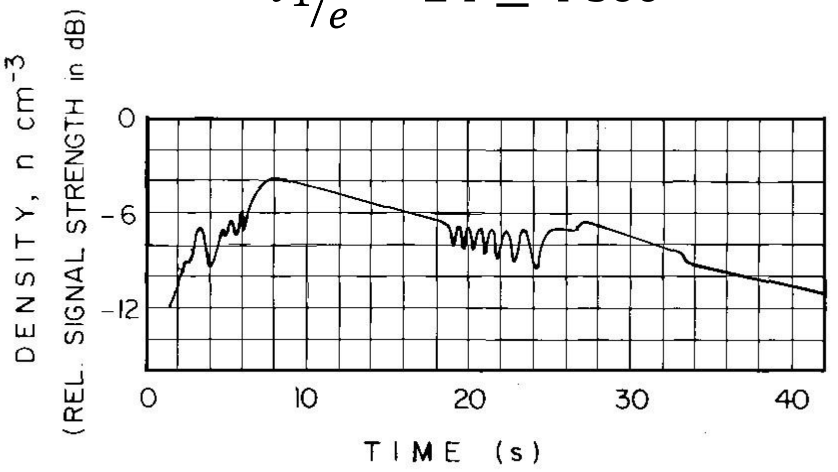
Imposed ν extracts energy from instability



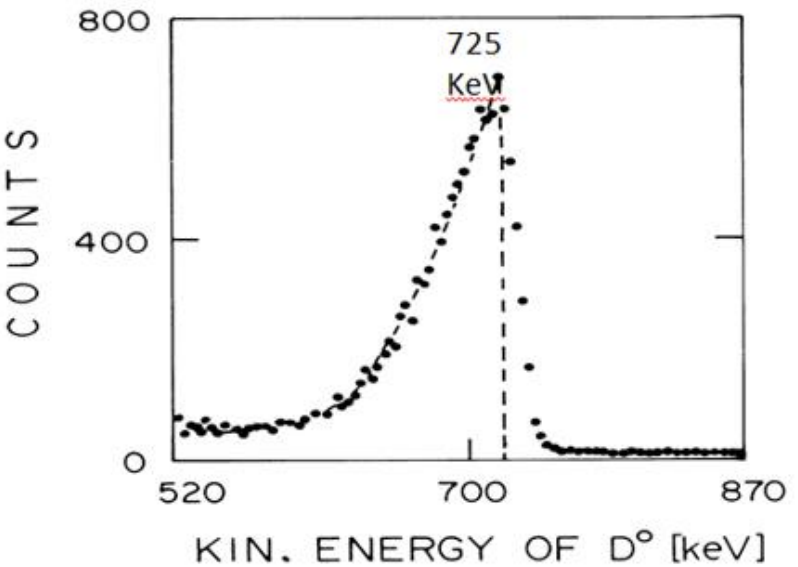
Radial frequency *vs.* (A) d^+ ion peak at 20.7 MHz when only d^+'s with a small impact parameter ≤ 0.1 cm are kept. Others removed by a mechanical scraper at $R > 11$ cm. (B) Instability peak at $\nu_{e,INS}$ at 22.4 MHz *axial* oscillations.

Longest Ion Energy Confinement Time in Fusion

$$\tau_{1/e} = 24 \pm 4 \text{ sec}$$



GOAL: Prevent Thermalization!



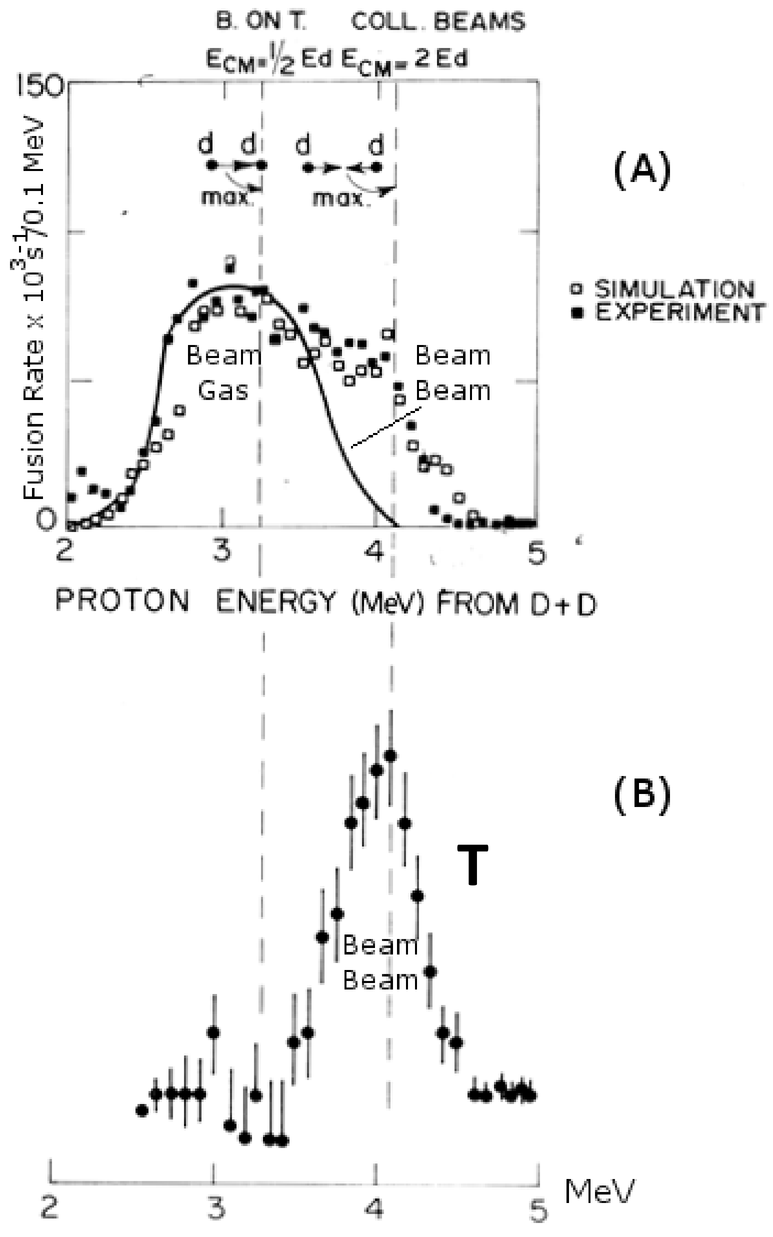
Energy spectrum of the neutrals from D^+ (fast) + D_2^0 (gas) →D^0 (fast) + D_2^+ observed in CEND.

Massive T and ^{3}He Production

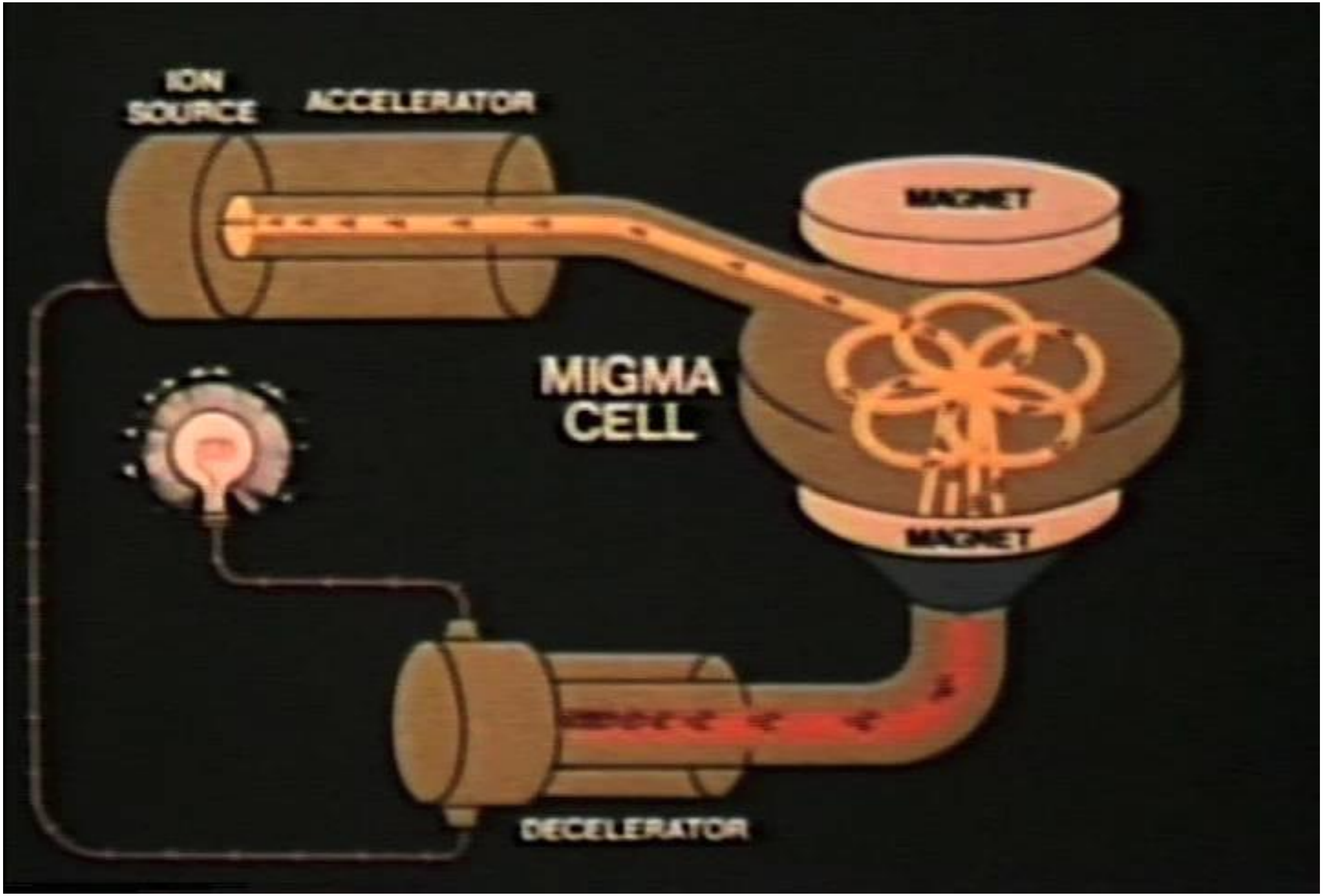
Luminosity

$$L = 3 \times 10^{43} V[m^3] I^2 \text{amp}$$

PROOF OF
BEAM→←BEAM
FUSION T AND ^{3}He
PRODUCTION



Molytron


ION SOURCE
ACCELERATOR
MAGNET
MIGMA CELL
MAGNET
DECELERATOR

With 3 MV Accelerator, $Z = 40 = 120$ MeV Beam!

WEP261 Proceedings of 2011 Particle Accelerator Conference, New York, NY, USA

PERFORMANCE OF THE NEW EBIS PREINJECTOR*

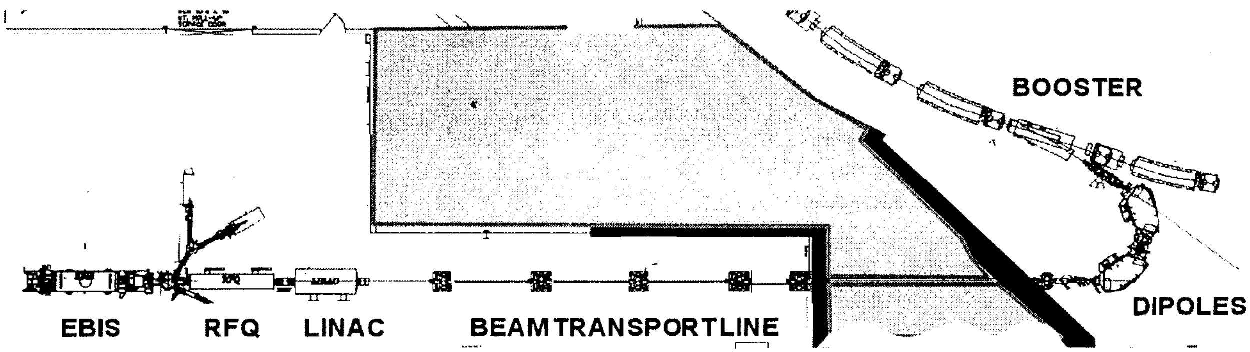


Figure 1: Schematic of the EBIS-based heavy ion preinjector

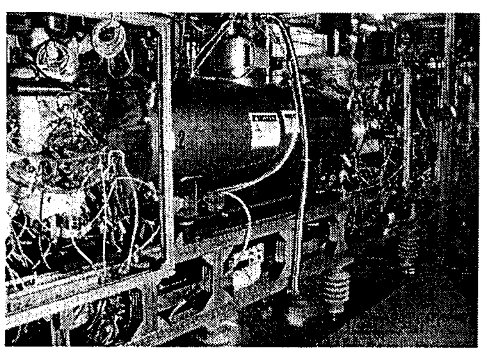


Figure 2: The EBIS source, with the 2m long superconducting solenoid producing a 1.5 m trap region.

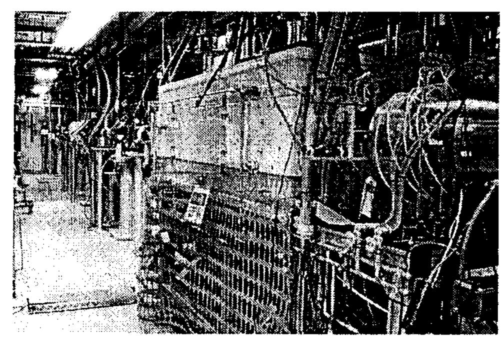


Figure 3: High energy end of the RFQ is seen on the right, linac (yellow) in the center, and the high energy transport on the left.

Auto-Collider MIGMA IV

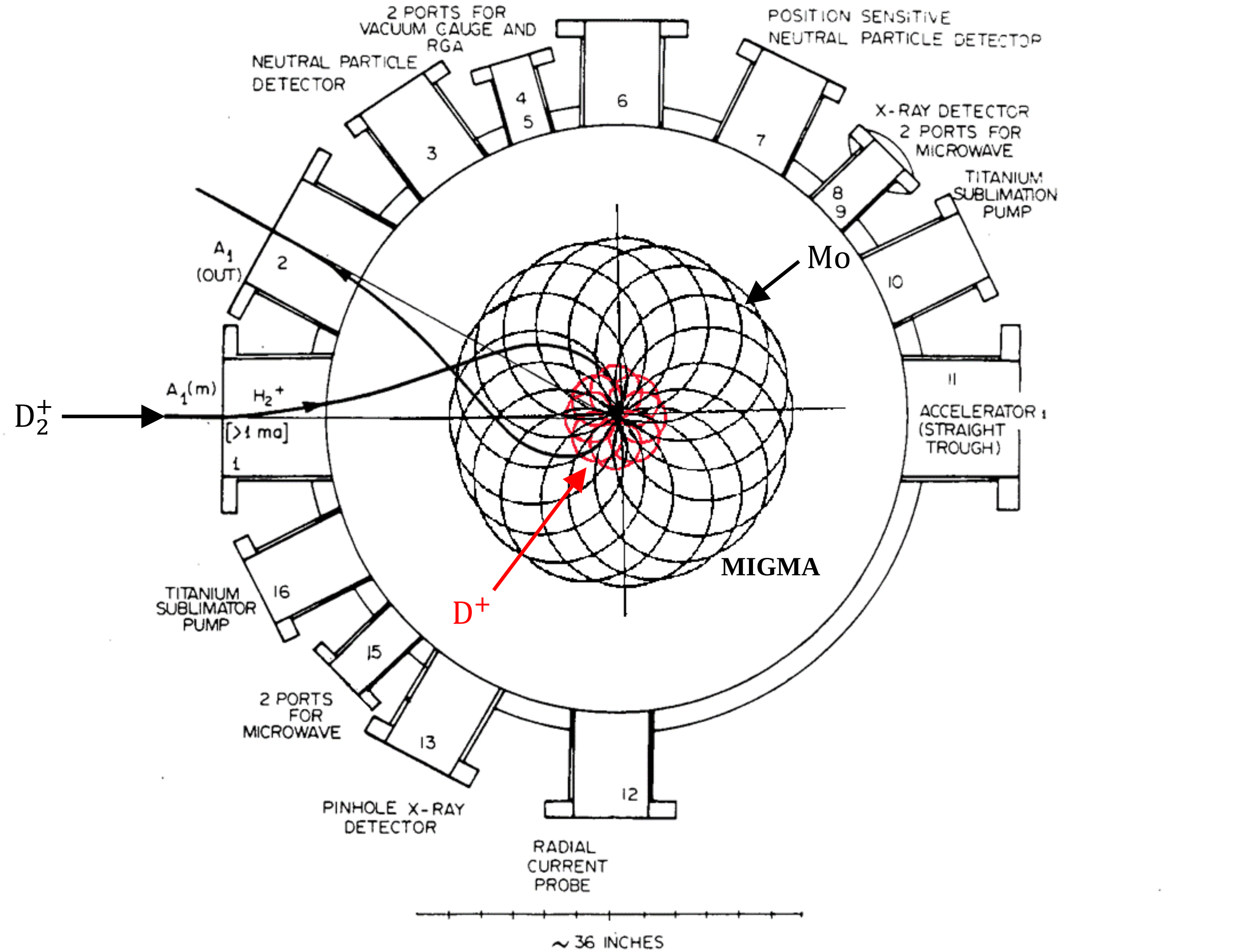
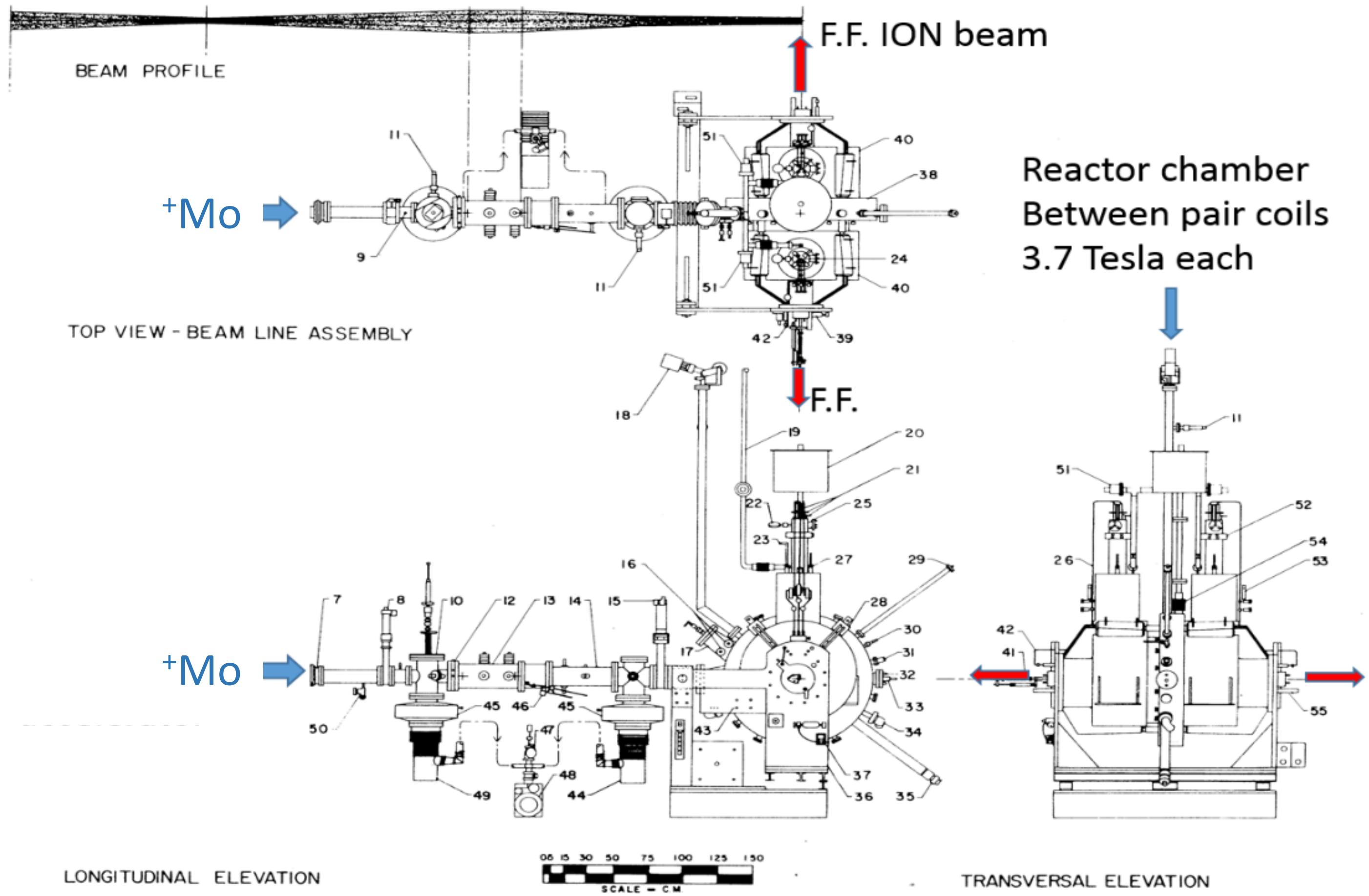
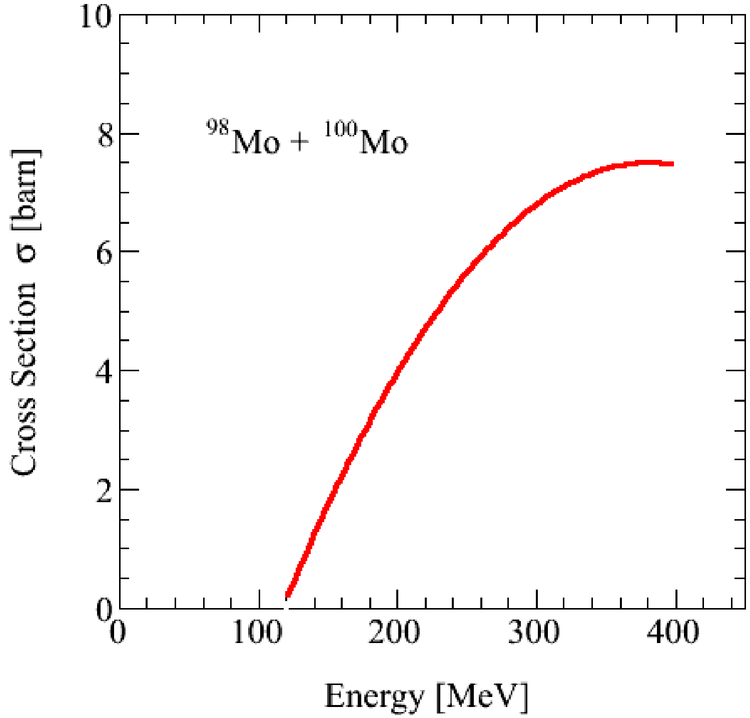


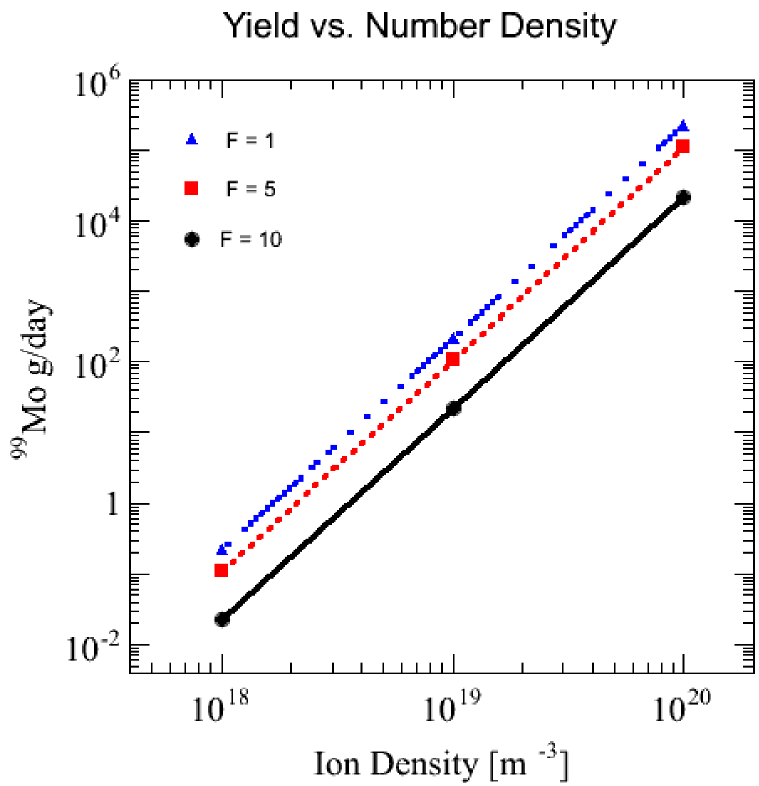
Fig. 5. Top view of the conceptual design of the migma chamber for the IVb experiment. The 1.4 MeV H_2^+ beam enters the chamber from the left through port #1; the undissociated beam goes to the beam dump through port #2.

PRECETRON MIGMA IV

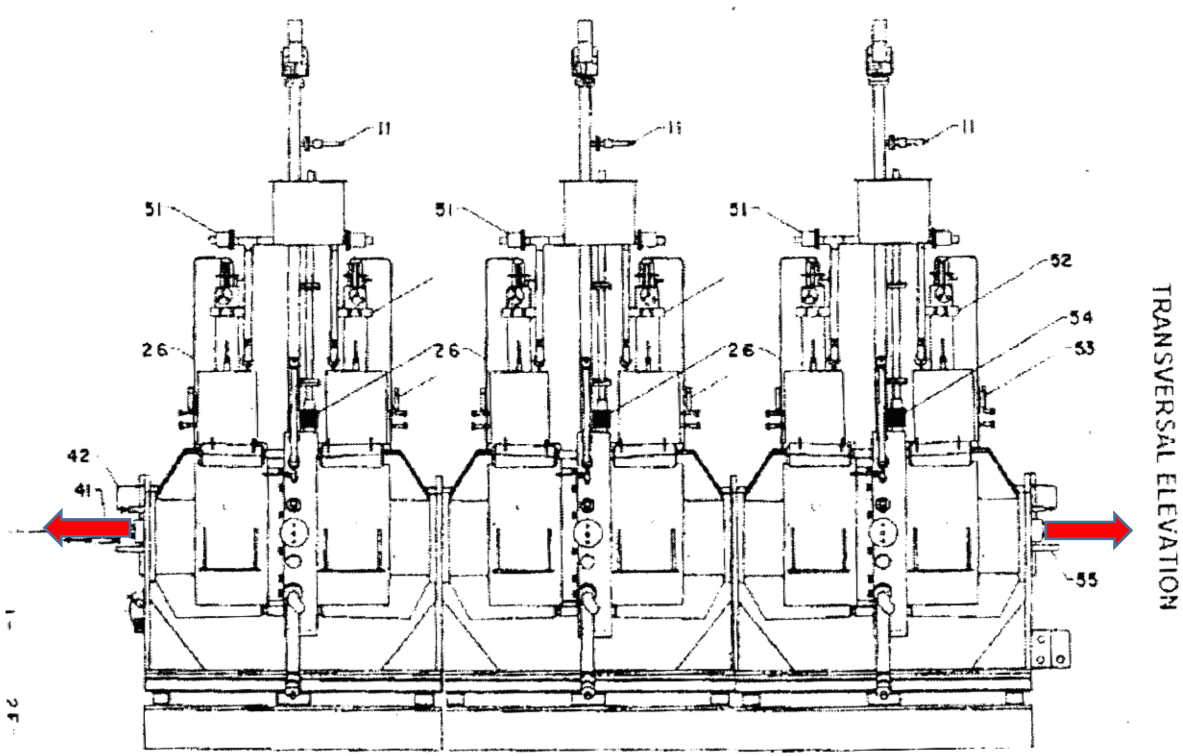


Layout of the beam transport system, chamber, and super conduction magnet


Cross Section σ [barn]
Energy [MeV]
^{98}Mo + ^{100}Mo
10
8
6
4
2
0
0
100
200
300
400


Yield vs. Number Density
^{99}Mo g/day
Ion Density [m $^{-3}$]
F = 1
F = 5
F = 10
10^6
10^4
10^2
1
10^{-2}
10^{18}
10^{19}
10^{20}

Economy of Mass Production



Stacking of MIGMA Cells