Group Lattice, Injection, Extraction + Ion Fragmentation/Collection

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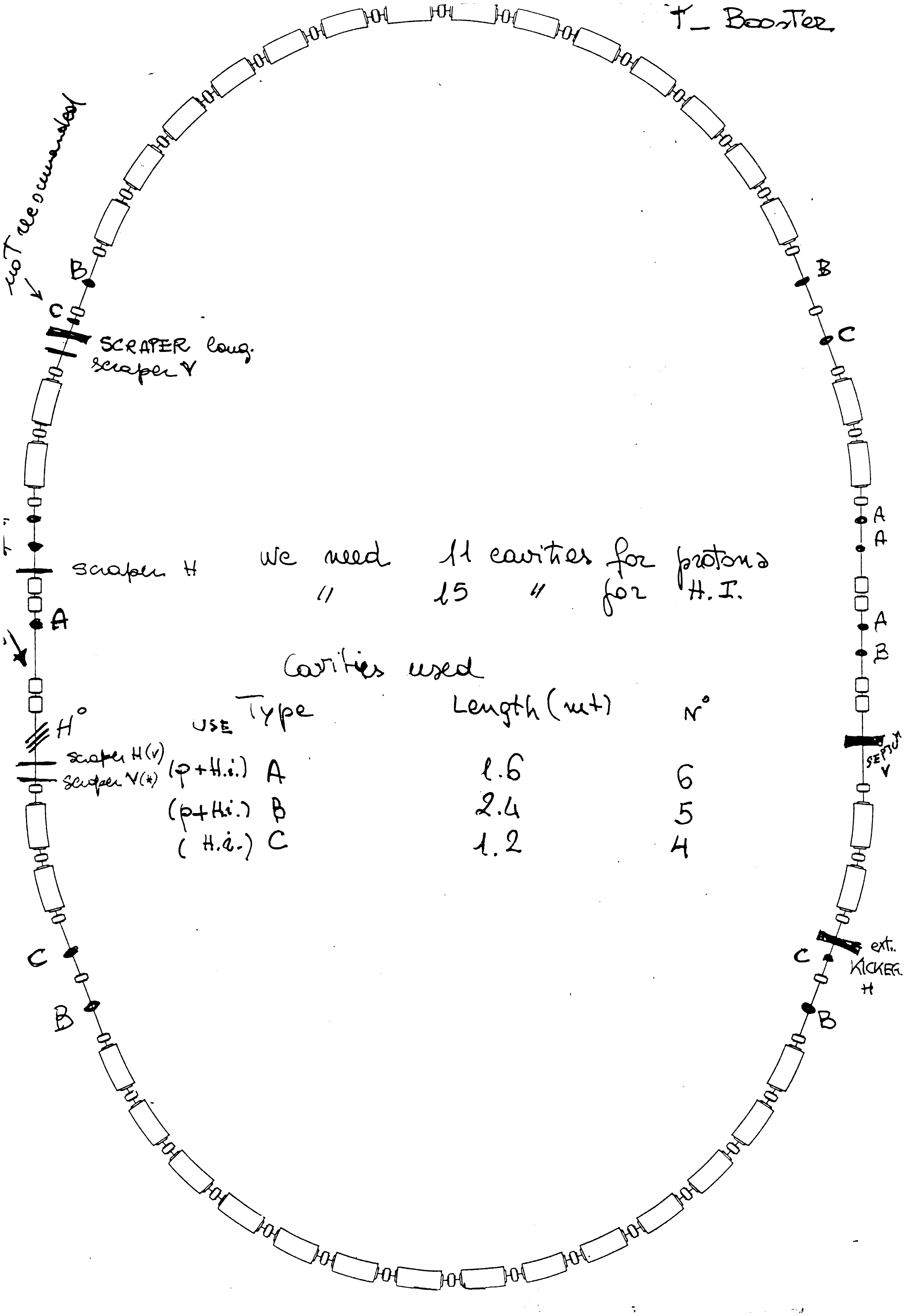
T_ Booster



we need 11 cavities for protons
" 15 " for H.I.

Cavities used

USE	Type	Length (mt)	N°
(p+H.i.)	A	1.6	6
(p+H.i.)	B	2.4	5
(H.i.)	C	1.2	4

New suggested
RF cavities distribution
(starting point)

- requirements for location:
  - $Q_s = .43$ (high value) $\Rightarrow$ locate cavities simmetrically
  - (A) cavities require dispersion free region
  - it's better to avoid the regions where is the longitudinal scraper and to leave one free for H^0 evacuation

$\Downarrow$

we need more space

Starting from our new suggested pre-booster lattice we find the final distribution:
shortening the arcs from 7 cells $\rightarrow$ 6
(one cell is moved in long straight section)
we can gain ~ 4 mt on each side

Injection

- Combined H^- and Heavy Ion Injection
  - Requires ~ 10 m Straight Section
  - $\beta_H > \beta_V$ with Double Waist
  - Has Adequate H^- and H^0 Dumps (in next straight section)
  - Septum for Heavy Ions (inserted Mechanically
- WARNING MESSAGE:
  - Great Difficulty to Achieve Σ_{turns} Efficiency (turn) > 10
  - Heavy Ion Intensity may be overstated × 10
- If 2-D Multi-Turn Injection Attempted
  - requires "L" shaped septum
  - no experience at other machines

Simulation Required

H^- Injection, horizontal plane:

EX.: PRE-HOLDING RING LATTICE

$\beta_{H,Foil} = 14.8\,m$

$\varepsilon_H(100\%) = 44\pi \quad (1.25 \times \varepsilon(2\sigma))$

$\hat{x} = 25.5\,mm$

$\frac{\beta_f}{\beta_L} = \left(\frac{\varepsilon_f}{\varepsilon_L}\right)^{\frac{1}{3}} = 2$

$\beta_{H,L} = 7.4\,m$

$\Delta x_L = 6.4\,mm$

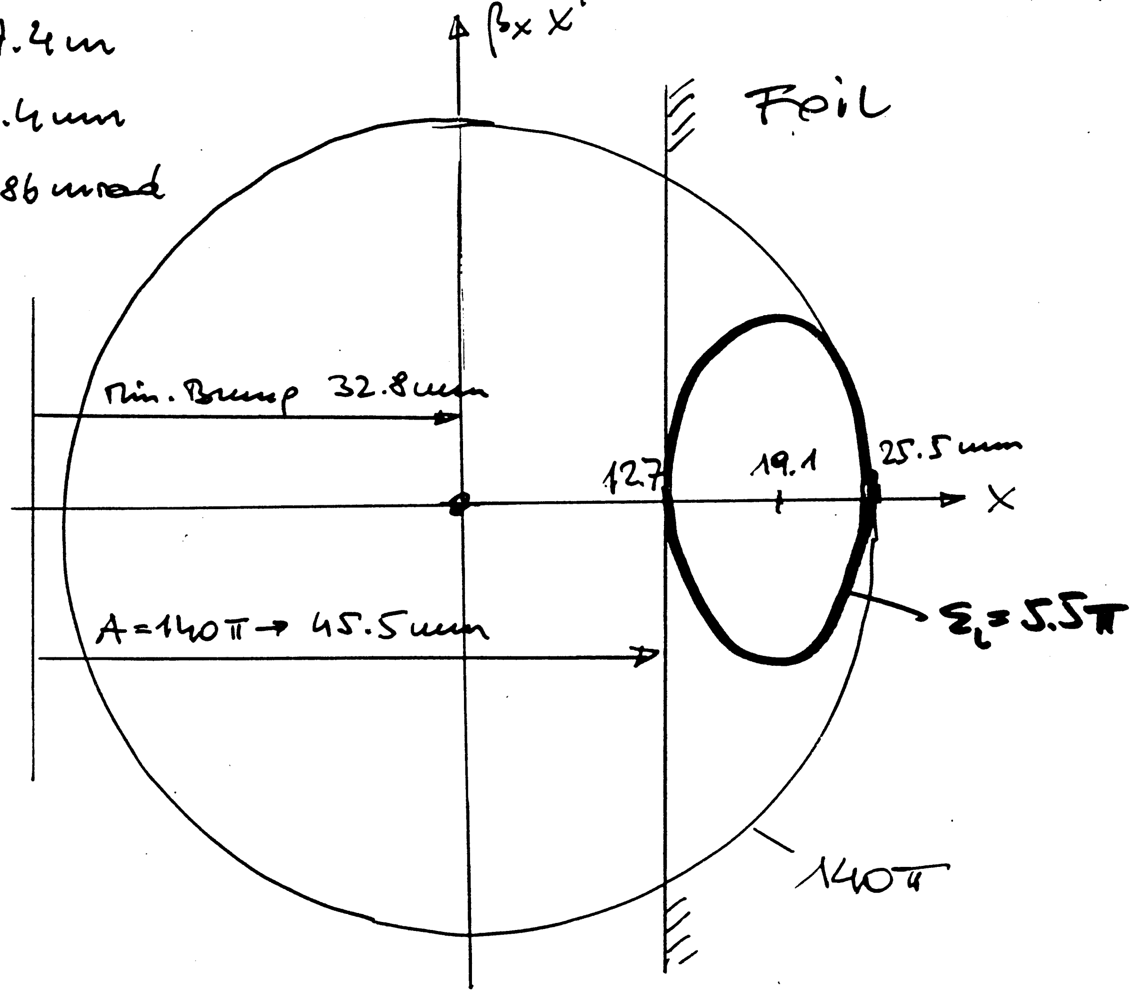
$\Delta x'_L = 0.86\,mrad$

Linac:

$\varepsilon_L^*(\sigma) = 0.65\pi$

$\varepsilon_L(\sigma) = 0.92\pi$

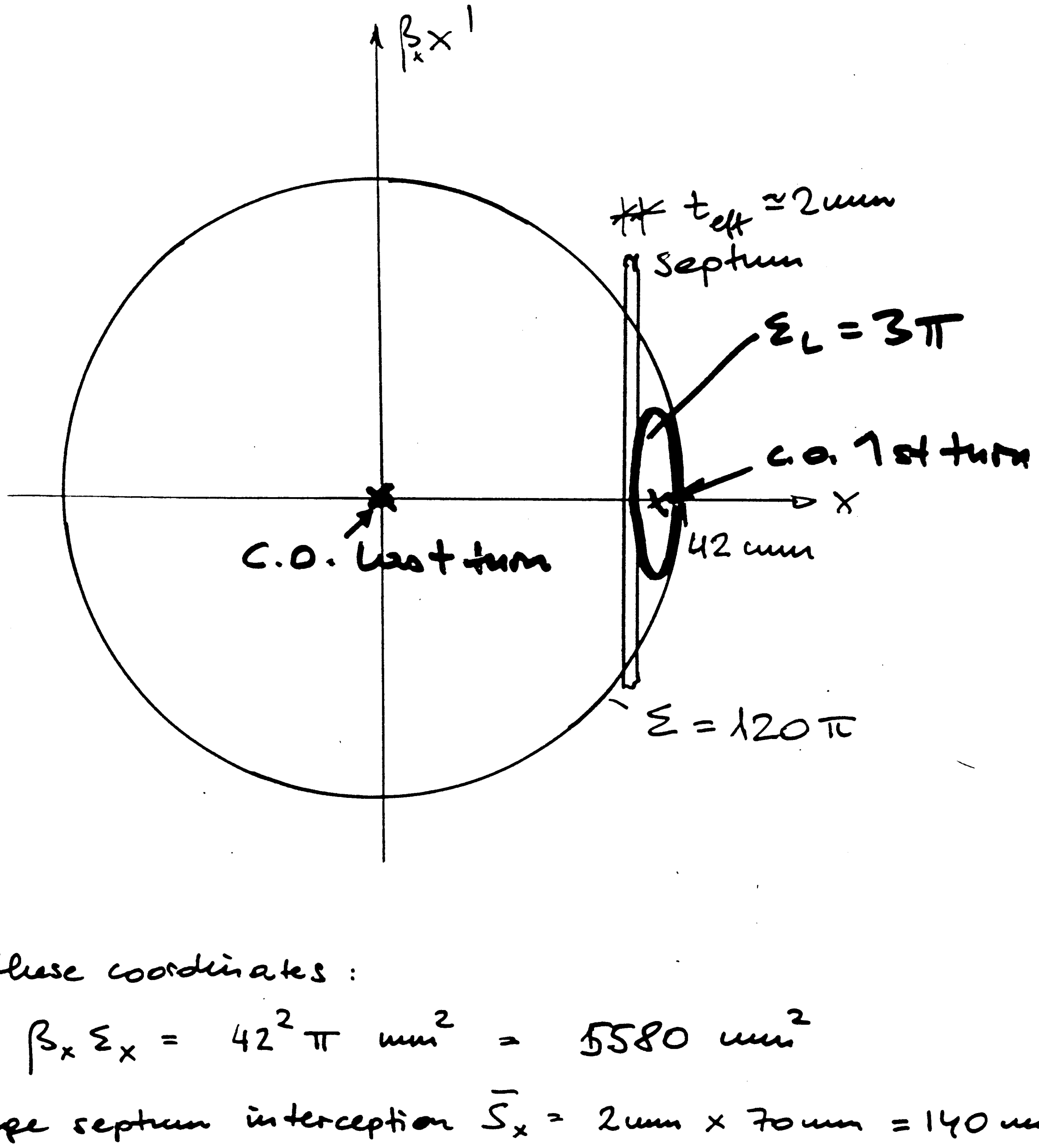
$\varepsilon_L(6\sigma) = 5.5\pi$



Heavy Ion Multiturn Injection

140π Acceptance
120π .. Emittance
3π .. Linac emittance (3σ)

$\beta_x = 14.8$ m



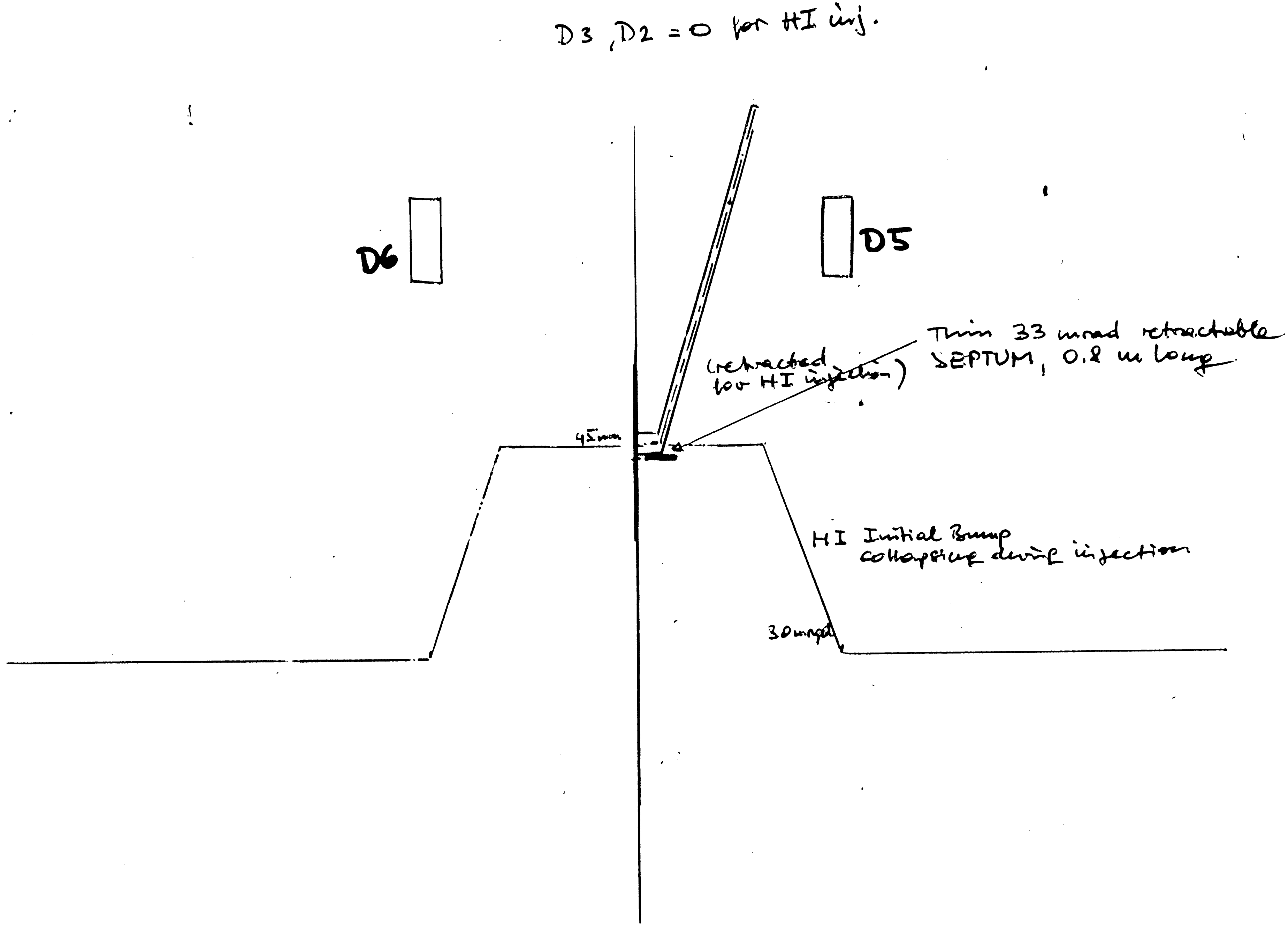
In these coordinates:

$$E_x = \beta_x \varepsilon_x = 42^2 \pi \text{ mm}^2 = 5580 \text{ mm}^2$$

Average septum interception $\bar{S}_x = 2 \text{ mm} \times 70 \text{ mm} = 140$ mm

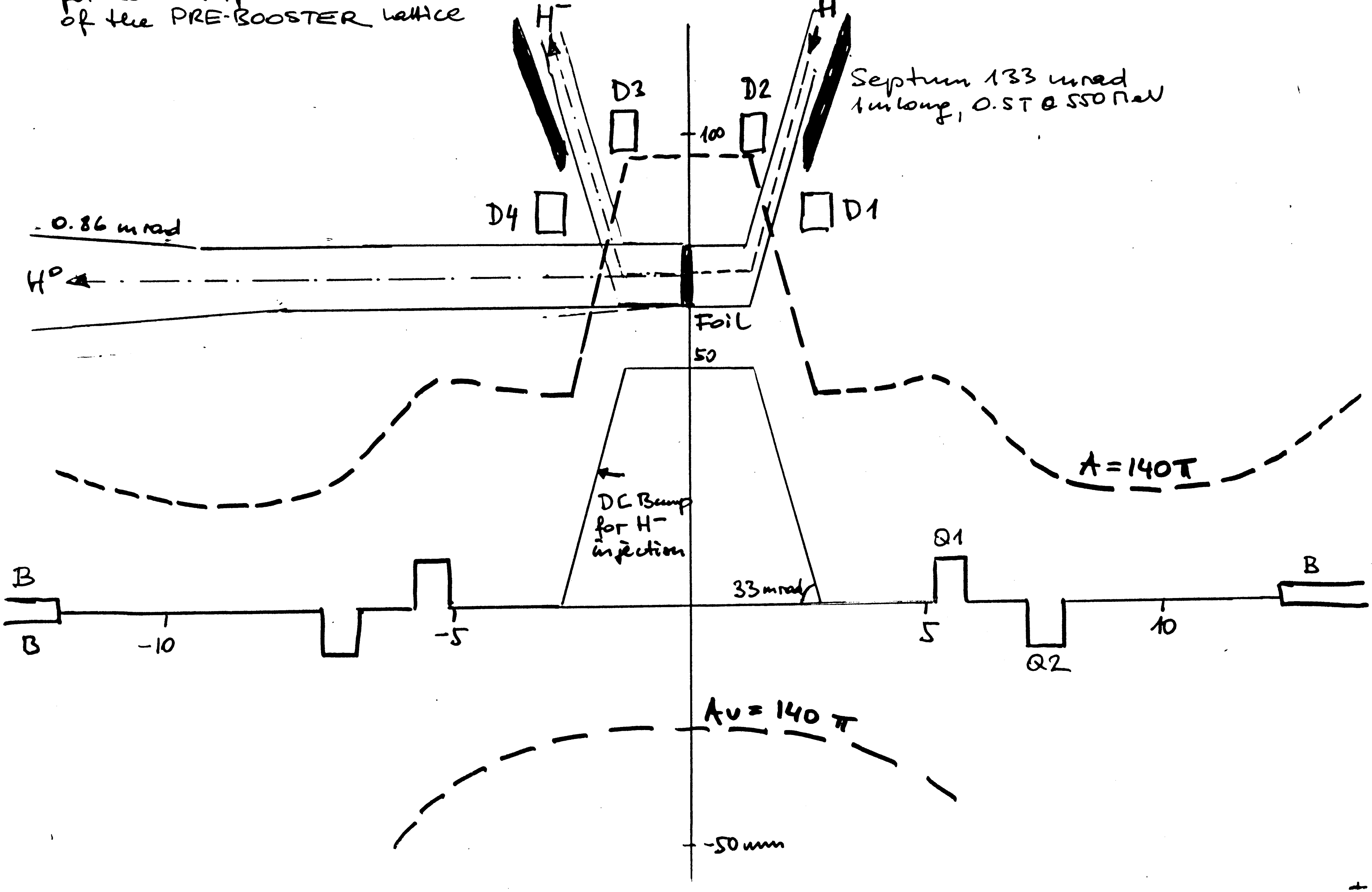
'Total coverage' $= \frac{E_x}{S_x} \doteq 40$

40 turns injection not very meaningful ...
max. ~ 20 turns


D3, D2 = 0 for HI inj.
D6
D5
Thin 33 mrad retractable SEPTUM, 0.8 m long
(retracted for HI injection)
45 mm
HI Initial Bump collapsing during injection
30 mrad

PREHOLDING RING
LATTICE as an example
for a modified insertion
of the PRE-BOOSTER lattice

H⁻ Injection



Fast Extraction

- Recommend Kicker ~ 98 from Septum
  - original layout required a kicker which cannot be built
  - revised layout consistent with CERN SPS
- Kicker Design Requires Bumper
  - to move beam to edge of aperture
  - just before extraction
- Warning Message:
  - must provide space for bump
- Cost of Kicker System

  ~ 800K SF

KICKER OPTIONS

1. TRAVELLING WAVE, TERMINATED

2. TRAVELLING WAVE, SHORT-CIRCUITED

3 LUMPED INDUCTANCE, TERMINATED BUT WITH MISMATCH

4 LUMPED INDUCTANCE, SHORT-CIRCUITED

5 LUMPED INDUCTANCE, TERMINATED AND FULLY MATCHED

Options 1-4 have been examined and provide reasonable solutions

Option 5 is inefficient and has been discarded.

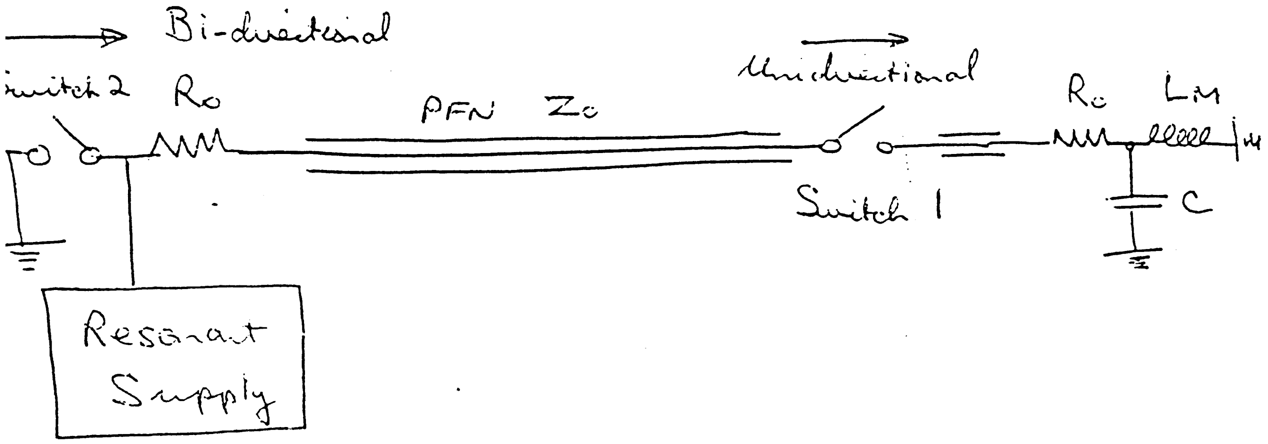
KICKER SPECIFICATION

KICK STRENGTH	360 gauss-meters (protons) 572 " " (heavy-ions
RISE (FALL) TIME 1-99%	150 ns
FLAT - TOP ($\int Bdl$)	860 ns
REPETITION RATE	50 Hz (protons) 10 Hz (heavy-ions)
KICK DIRECTION	Horizontal
APERTURE	136 mm horiz. 49 mm vertical
LOCATION	Inside machine vacuum.

CHARACTERISTICS \ TYPE OF KICKER	TRAVELLING WAVE, TERMINATED	TRAVELLING WAVE, SHORT-CIRCUITED	LUMPED INDUCTANCE, TERMINATED	LUMPED INDUCTANCE, SHORT-CIRCUITED
Kick Strength (gm) P	360	360	360	360
HI	572	572	572	572
No. of Magnets	2	2	3	3
Overall straight section (m)	1,4	1,2	2,3	1,2
No. of Thyratrons	2	4	6	6
PFN Z_0 (Ω)	15	25	25	25
PFN Voltage (kV) P	36,3	37,7	36,3	39,5
HI	57,8	59,9	57,7	62,9
Switched Current (kA) P	1,21	0,75	0,73	0,79
HI	1,93	1,20	1,15	1,26
* System Cost (MFS)	0,69	0,78	0,99	0,99
Remarks	Only one pulser, minimum switchgear. Expensive large magnets, special cable, high switched current. Follows CERN PS experience	Smaller magnets but more switches. Voltage reversal in part of circuit. Lower stored energy. Coupling impedance?	More magnets and more switches. Some bi-directional. Simpler magnets and vacuum tank.	All switches uni-directional if RLC circuit used. Some voltage reversal. Simple magnets. Coupling impedance

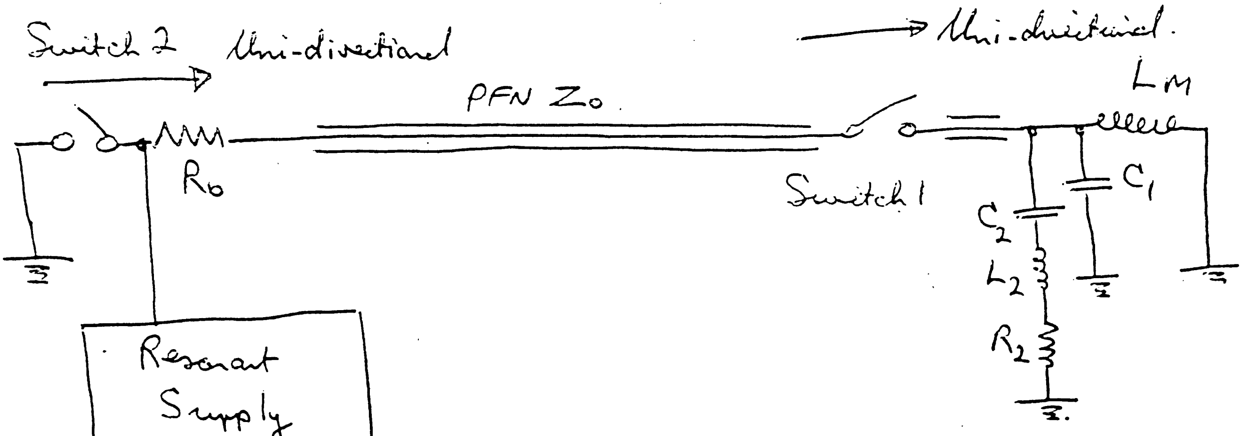
* "In-house" engineering, sub-contracting assemblies to industry, "in-house" assembly and test. In-house effort cost-free.

LUMPED INDUCTANCE, TERMINATED BUT WITH MISMATCH



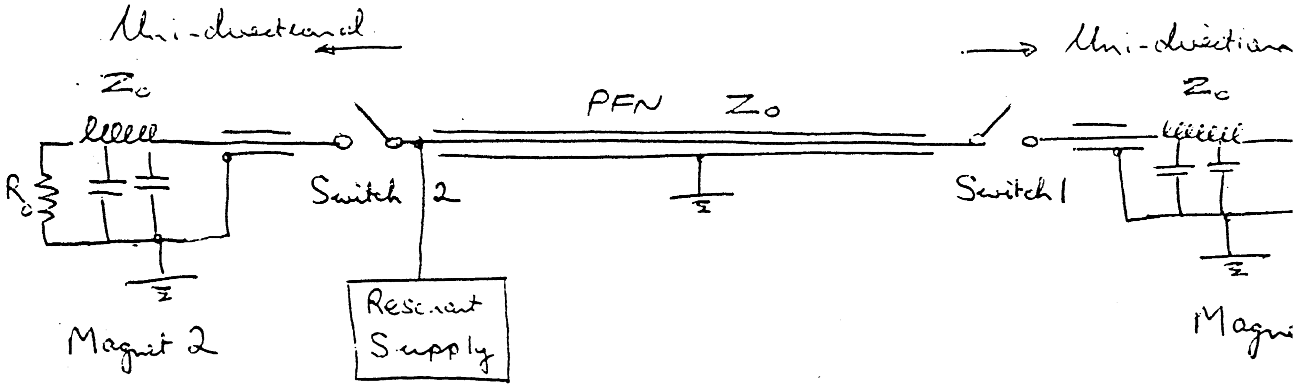
Only 1 Magnet can be supplied from 1 PFN / Power Supply

LUMPED INDUCTANCE, SHORT-CIRCUITED



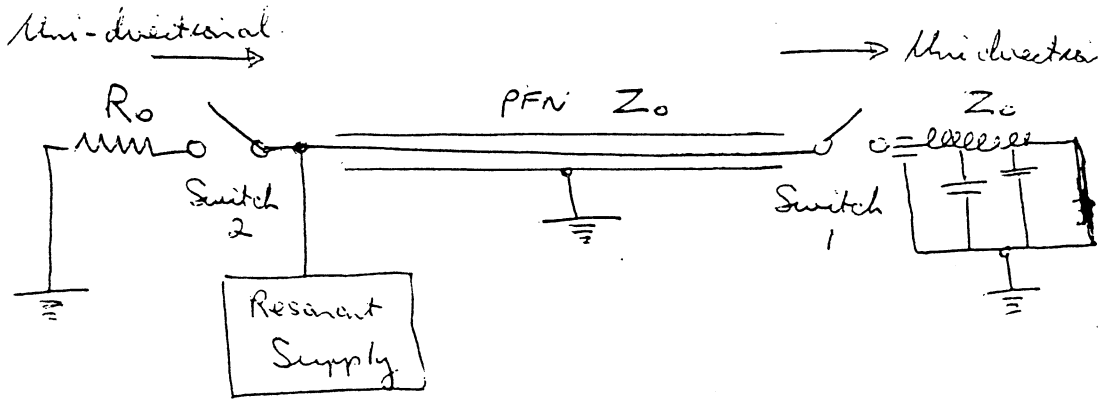
Only 1 Magnet can be supplied from 1 PFN / Power Supply

TRAVELLING WAVE (TERMINATED)



2 Magnets can be supplied from 1 PFN / Powe Sup

TRAVELLING WAVE (SHORT-CIRCUITED)



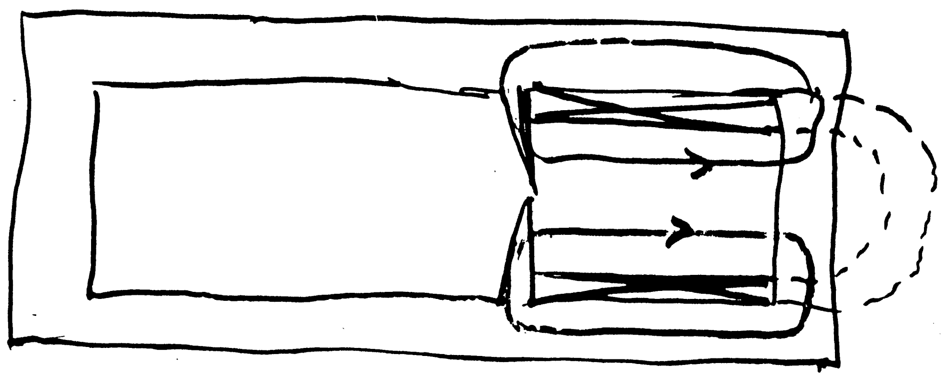
Only 1 Magnet can be supplied from 1 PFN / Pow Sup

Magnetic Septum

- Suggest "Lambertson" Septum
  - Vert. Ext. ⟷ Horiz Kick
  - Horiz. Ext. ⟷ Vertical Kick

- Reasons for Suggestion
  - Robust ⟷ no coil near beam
  - Small Leakage Flux
    - see F. Mills tak in '88 or '89 AHF Workshop
  - Requires Low Current Density
    - more robust cooling
  - Can Achieve 0.5-1 Tesla

Typical Lambertson Septum



Advantages:

1. Low leakage to beam
2. High field ~0.5T
3. Low Current Density
4. Robust

B=0 B=0.5T

Horizontal Kick → Vertical Extraction

or Vertical Kick → Horizontal Extraction

Collimators

Require $\Delta p/p$ Collimator (Highest Priority)

- Thick Collimator at η_{large} location
- Second Collimator for Junk collection
  - at end of same straight section
- If $\Delta p/p$ limit required at extraction
  - bump to collimator just before extraction
- Design for Remote or Rapid Handling

Require X collimator + Y collimator (lower Priority)

- Suggest Thin, High Z Scatterers
- Followed by Dumping Collectors
  - 90° Downstream
- To Avoid Extraction Losses
  - must bump against X+Y collimat just before extraction
- Design for Remote or Rapid Handli

Warning Message:

- Do Not omit Collimators
- Provide 90° for Dump Collectors
- Provide Bumpers

Halo Scraping

I) Longitudinal

- importance:
  very important, since buckets are completely filled

- equipment:
  primary collector on inside of ring to stop most of the halo;
  secondary collector on opposite side of the same straight section, to collect the few percent of scattered halo;
  not clear that a bumper system helps

- Location:
  dispersive straight section just upstream of injection straight section

II) transverse

- importance:
  not as important, but do the best you can with the given lattice

- equipment:
  (ideally), short scraper to scatter the halo and collectors immediately downstream and at ≈ 90° and at ≈ 180° to stop scattered halo;
  a bumper system is beneficial

- location:
  it is difficult, in the present lattice, to find suitable spaces, particularly with bumper system

caution: computer simulations are necessary to judge the performance of any scraper system, particularly in the presence of space charge

collector materials:
graphite is good, stainless steel is an alternative

Transfer PBR → PHR

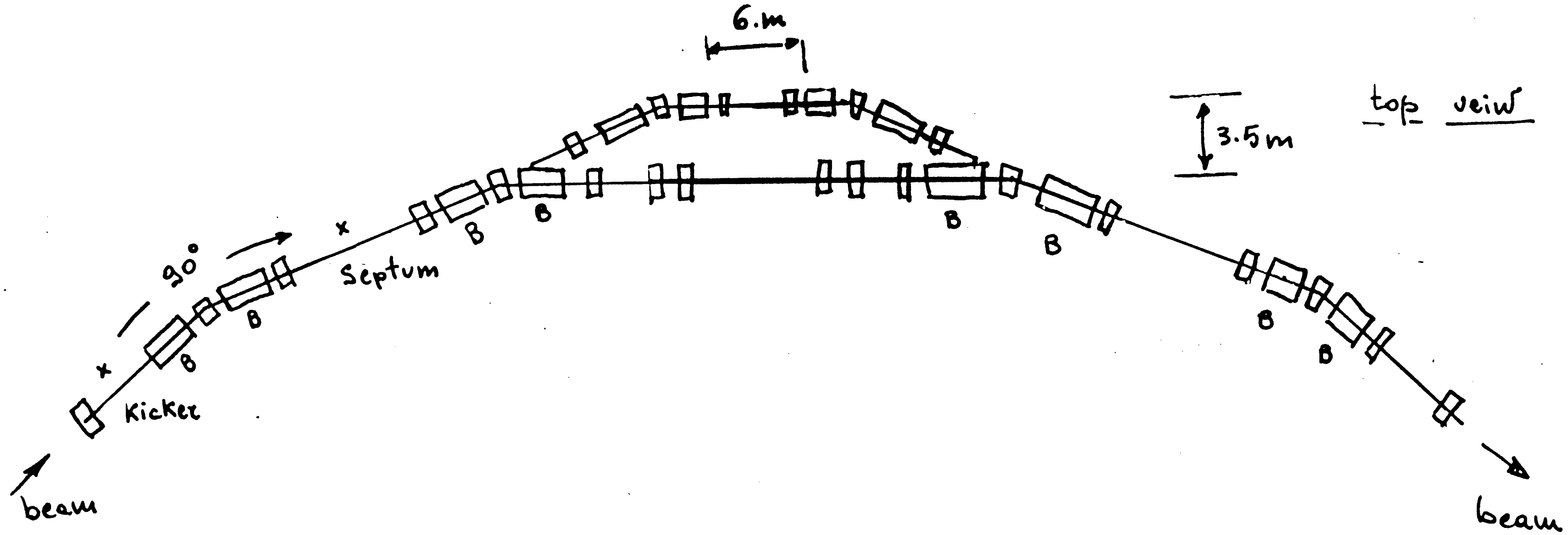
- Original Proposal
  - did not match in 6-D
    $\beta_x, \alpha_x, \beta_y, \alpha_y, \eta, \eta'$

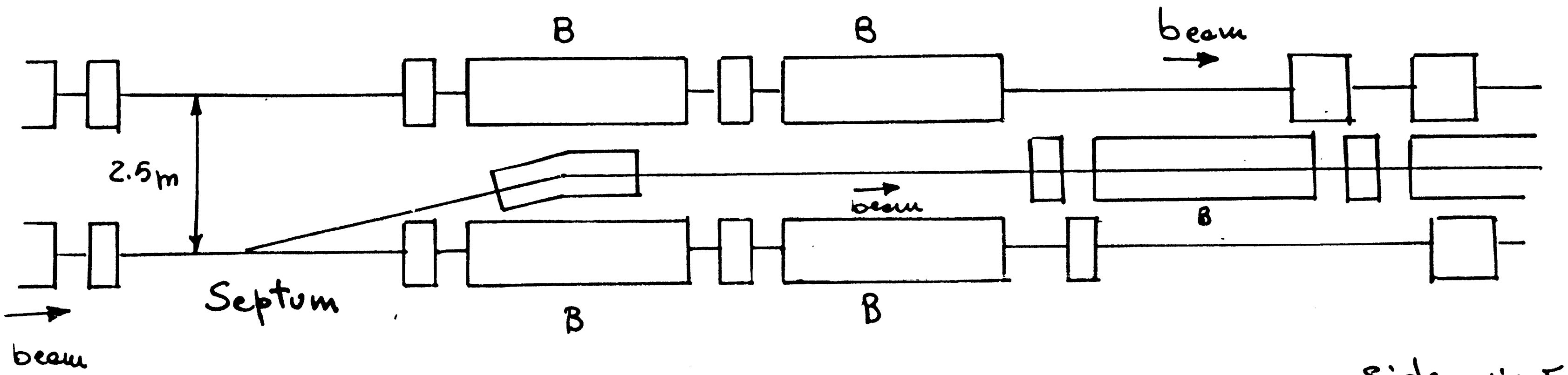
- Some suggestions to "Cure" Problem
  - two proposals
  - may require longer straight section

Warning Message:

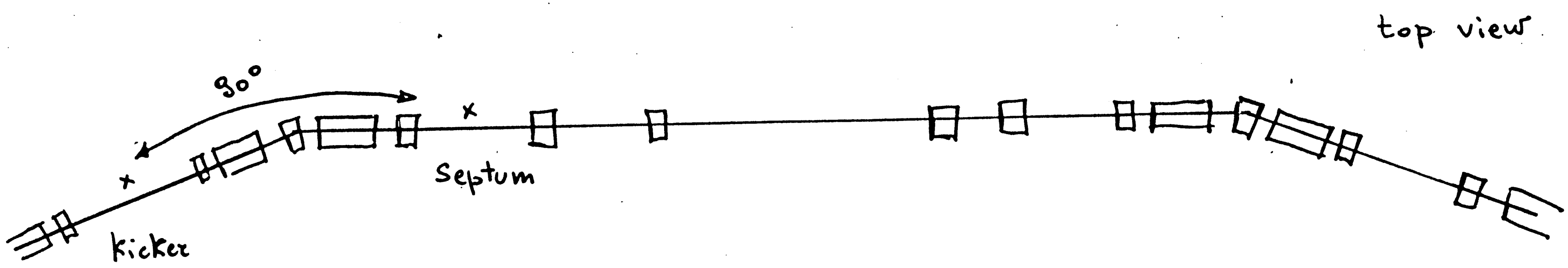
- It Is Possible To Design System which is <u>Impossible</u> to match
- Require study <u>Soon</u>!
- Do Not Accept New Lattice Before 6-D Match Achieved

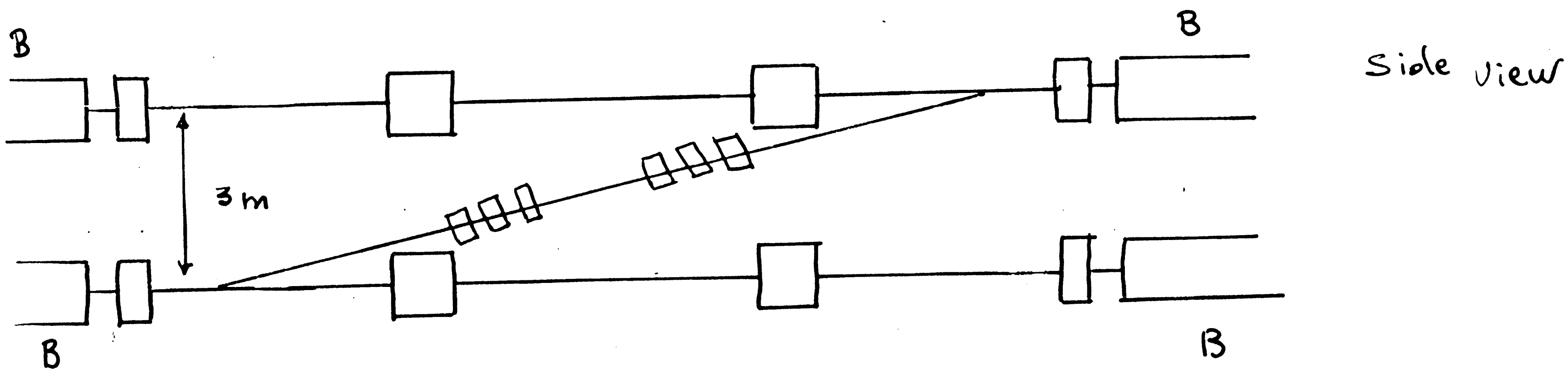
Scheme A (no drastic changes in the proposed lattice)





Scheme B (longer straight section ; different lattice)





Scheme "B"
Matching PBR → PHR

Thin Lens Model

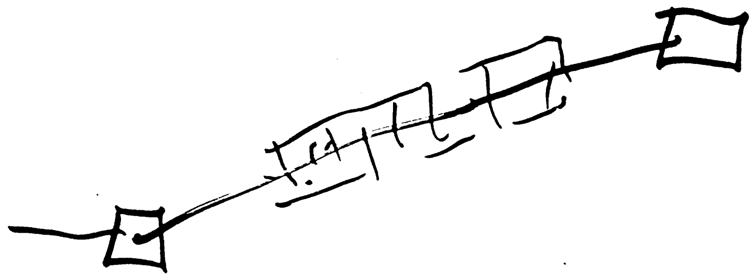
$$\text{septum} \approx \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & \theta \\ 0 & 0 & 1 \end{pmatrix}$$

Quad Matching System
Symmetric About Center

$$\begin{pmatrix} a & b & 0 \\ c & a & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

consider

septum quads septum



PBR → PHR

$$\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & -\theta \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} a & b & 0 \\ c & a & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & \theta \\ 0 & 0 & 1 \end{pmatrix}$$

after Matrix Multiplication

$$\begin{pmatrix} a & b & b\theta \\ c & a & a\theta - \theta \\ 0 & 0 & 1 \end{pmatrix}$$

But we require

$$b\theta = 0$$

$$a\theta - \theta = 0$$

$$\Rightarrow \quad a = +1$$

$$b = 0$$

$\therefore$ for quads

$$\begin{pmatrix} +1 & 0 & 0 \\ c & +1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

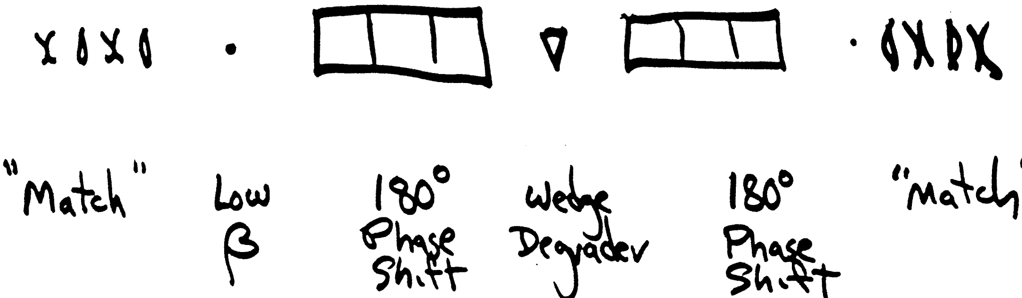
PBR ⟶ PHR

Adjusting c can accomplish required transformation

Suggest  match in both planes

Ion Fragment Production & Collection

- Made a Reference Design



$$\begin{pmatrix} -1 & 0 & 2\eta \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \quad \begin{pmatrix} -1 & 0 & 2\eta \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \rightarrow \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

- Looks Like Arc of PHR

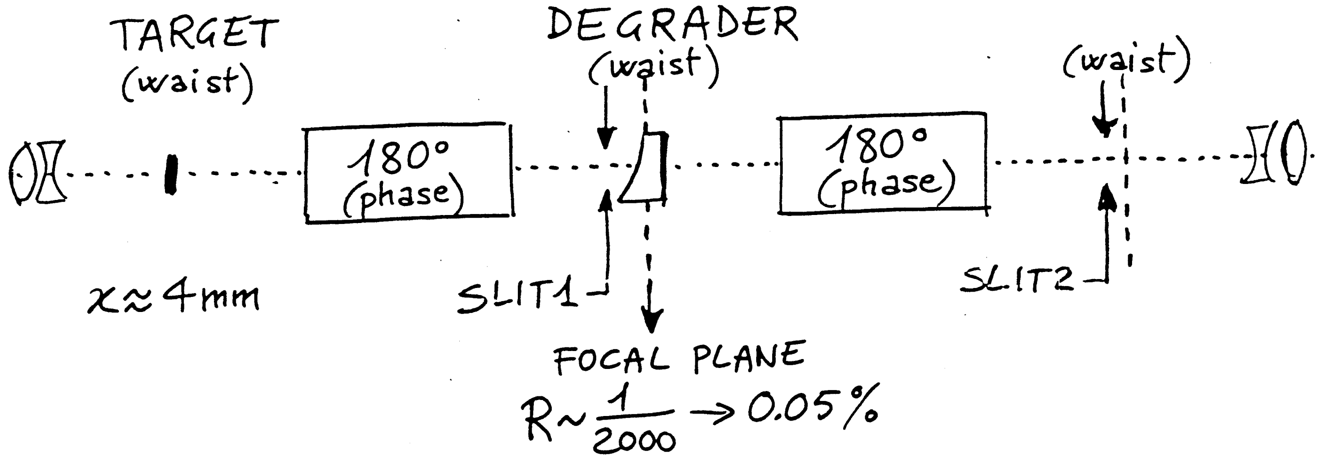
- Considered
  - use PBR arc (No Good)
  - use PHR arc (Might Work !)
  - sepaate arc (More Flexible)

- To Avoid 2nd Injection System
  - put protons thru system

- Warning Message:
  if dp/p reduced by factor f
  then X increased by factor f

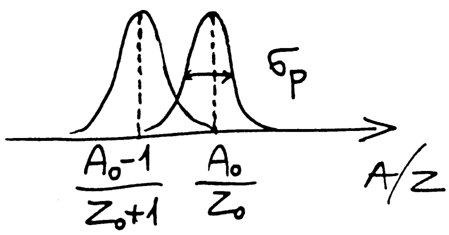
HEAVY ION FRAGMENTATION

1) Using ~ 1/2 of "existing" PHR



- σ_p (one fragment) = 0.5 to 3 % from reaction kinematics (straggling "negligible": ~0.1%)

$$\frac{\Delta(A/Z)}{A/Z} \gtrsim 0.4\ \%$$



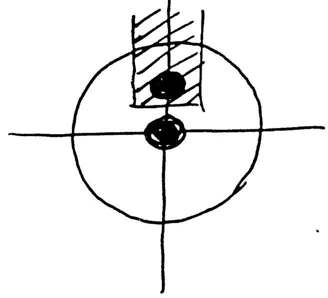
- R = 0.05% exceedingly good
  Disp. at degrader ≈ 8 m →
  → if σ_p = 0.5% → x = 40 mm at SLIT 2 → compensation needed

- DEGRADER: $\Delta p_z / p_z \sim 1\%$?

  ▱ profiled → achromaticity for the selected ${}^{Z}A$ only

PROBLEMS and POSSIBLE APPROACHES

→ TARGET and DEGRADER in the PHR



(kickers!)

→ $(P_z/Q)_{Fragm.}$ BEFORE and AFTER the degrader is ≠

? if $\frac{\Delta p_z}{p_z} \sim 1\%$ → two "beams" within acceptance

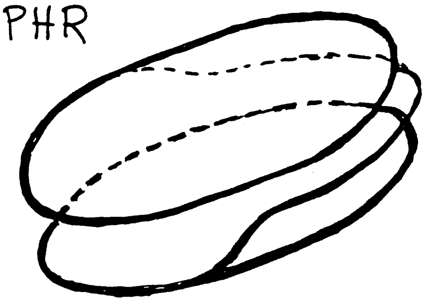
BUT

the off-axis beam needs CORRECTIONS

→ ACTIVATION

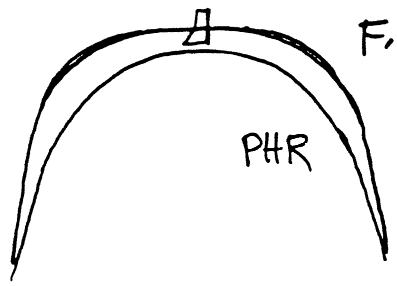
2) F.S. in <u>between</u> PBR and PHR

- Geometry can be OPTIMIZED
- COST is higher



3) F.S. <u>"around"</u> PHR

- (similar)



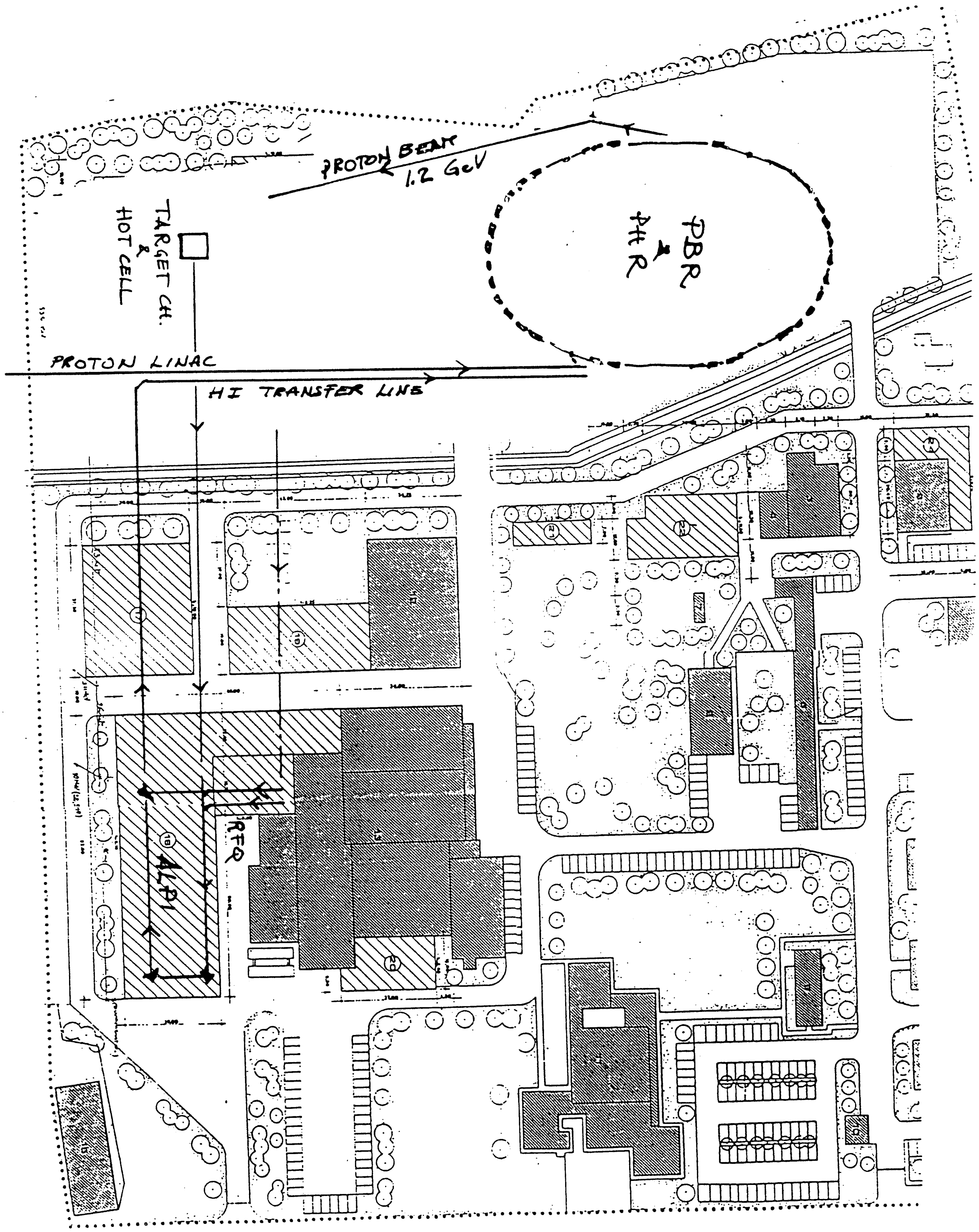
Suggest Spallation Ion Source

Use 1 GeV Protons

Ion Source Like Isolde

Inject Into ALPI

Requires Long Transport Line


PROTON BEAM
1.2 GeV
PBR
&
PHR
TARGET CH.
&
HOT CELL
PROTON LINAC
HI TRANSFER LINE
RFQ
ALPI

GOALS:

- RADIOACTIVE BEAM: with kinetic energy ≃ 6 MeV/amu for heavy nuclei (above Coulomb barrier)

- SUITABLE CURRENT (Avoid stripping process)
  high charge state directly from the source
  Current Ratio $\frac{I_{EX}}{I_{t}} \simeq$ 50 μA of p-beam →

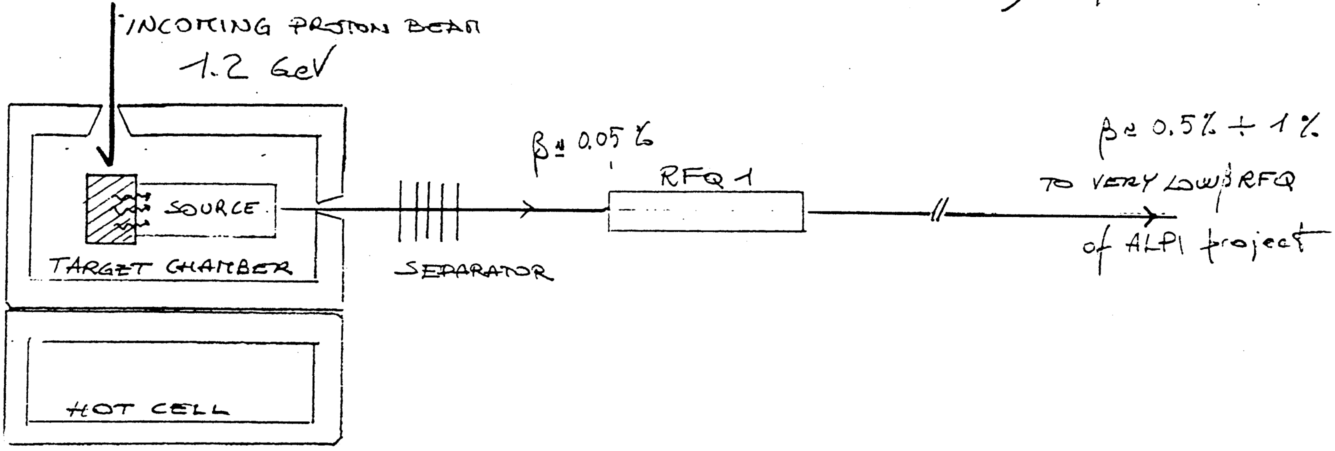
- PROBLEMS:

- SHIELDING (4 m of STEEL + 1 m of CONCRETE)
  + UNDERGROUND

- MATCH the frequency of the RFQ1 with the frequency of the very low-β RFQ of the ALPI project.

EXOTIC BEAMS from SPALLATION SOURCE

The 1.2 GeV intense proton beam makes possible to realize a SPALLATION SOURCE for the production of RADIOACTIVE EXOTIC BEA[MS] at very low velocity with the following scheme (ISOLDE-like SOURCE 3 μA proton beam)



because of the high temperature (2000 °C) of the target, the radioactive nuclei diffuse into the source chamber where the ionization process produces ions with a suitable charge state.

Crucial, in order to obtain a good current, is the choice of the ionization mechanism:

- ELECTRON CYCLOTRON RESONANCE — ECRIS
- ELECTRON BEAM — EBIS
- LASER EXCITATION — LEIS

- The CHEMISTRY of the TARGET is also very important

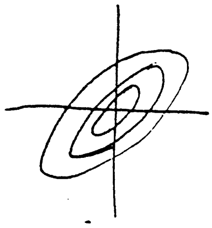
- the Voltage of the source can be of the order of 50 ÷ 60 kV

$\Rightarrow$ extraction energy $\simeq 50 \frac{Q}{A}$ keV/amu

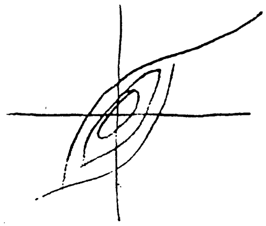
Slow Extraction

- A Tutorial Only!
- A Big Deal!
  - needs a "Slow Extraction Person"
- Warning Message:
  - if $\gtrsim$ 95% Efficiency Req'd
  - Must Have Dedicated Lattice Design

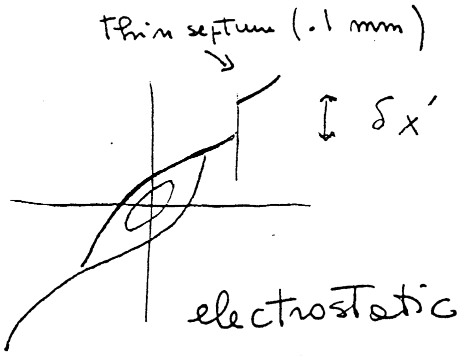
How SLOW RESONANT EXTRACTION Works. 8.



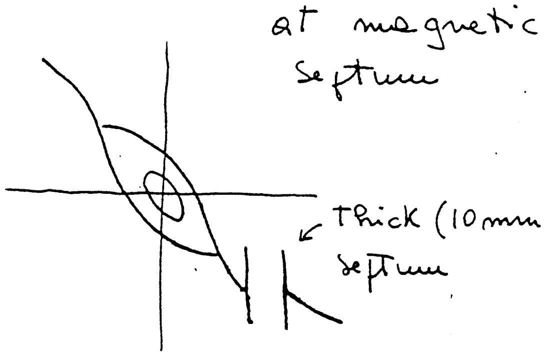
The stable beam is perturbed via a couple of quadrupoles + a couple of octupoles, so that the tune approaches the second order resonance and larger amplitude particles become unstable. *)



If somewhere, one inserts a very thin septum inside the beam, at the proper distance from the centre of the beam, one can give a small deflection only to the unstable particles and have them extracted downstream (~ 90°) by a magnetic septum.



electrostatic septum action



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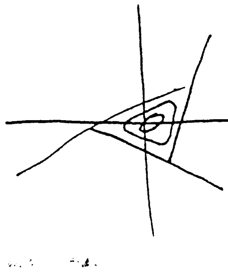
*) If two sextupoles are used, one can use the third order resonance, but efficiency is smaller!



HOW TO PROCEED

1) Change the horizontal tune towards the second order resonance (from 4.77 this means about + or - 90° to be distributed among the arc cells). Qy must be changed consequently.

2) Find locations for the septa around the ring. They must be 90° apart, and in places such that $(\beta_{ES} * \beta_{MS})$ is as large as possible.

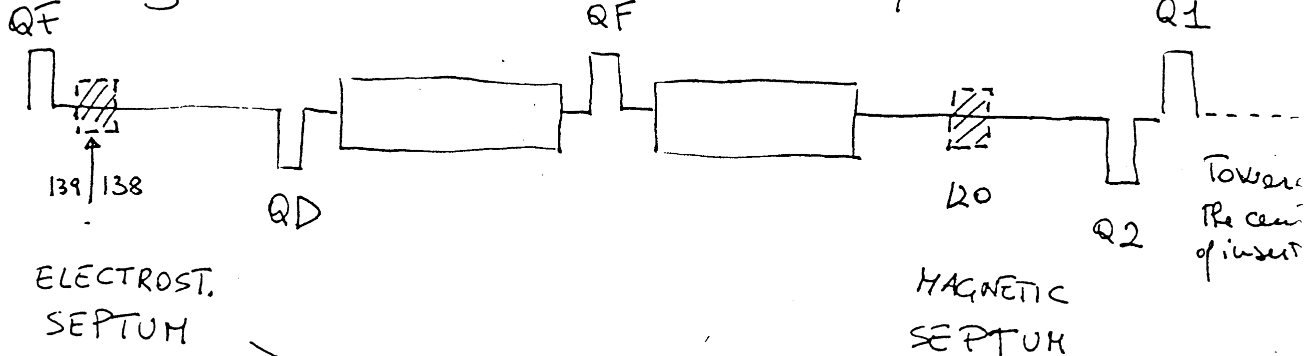
3) Find locations for extra quadrupoles and octupoles: they must be diametrically opposite in the ring at the proper distance in phase from the electrostatic septum.

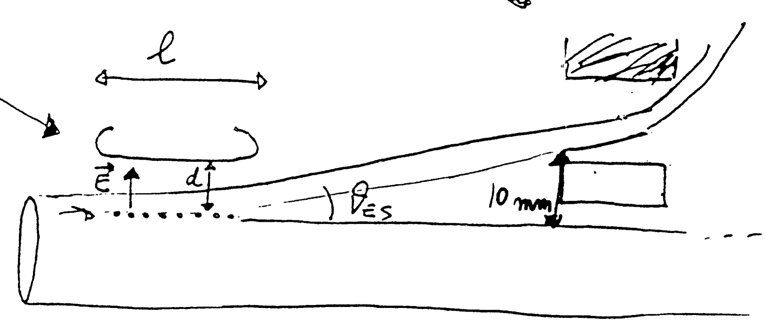
4) Find extra quadrupoles and octupoles strength.

5) Track. Find the optimum displacement from the centre of the beam for the electrostatic septum. Work out the efficiency.

- If efficiency is NOT "SATISFACTORY" start again from point 4), or even from point 3).

The SEPTA LOCATION is the only thing one can calculate easily (without computers)





$\beta_{ES} \cong 14$ m

$\beta_{MS} \cong 4.8$ m

$\Delta\phi = 90°$

$$\vartheta_{ES} = x'_{ES} = \frac{x_{MS}}{\sqrt{\beta_{ES}\beta_{MS}} \sin\Delta\phi}$$

required $x_{MS} = 10_{mm}$ minimum $\Rightarrow$ $\vartheta_{ES} = 1.22$ mrad

$$\vartheta_{ES} = \frac{E\,l}{p\,\beta} = \frac{V\,l}{d}\,\frac{1}{p\beta}$$

assuming $d = 2$ cm
$p = 1.7$ GeV per N
$\beta = .876$

$Vl = 36.34$ KV m

$\Rightarrow$ possible electrostatic septa are: $\rightarrow$ $l = .25$ m with $V \cong 150$ kV
or $l = .5$ m with $V \cong 75$ kV.

QUESTION N. 1

Which is the minimum "SATISFACTORY" efficiency of extraction with the heavy ions beams we are dealing with?

IN OTHER WORDS

What will be the maximum intensity of heavy ions that the septum wires (.1 mm) will stand?

WARNING!

A required efficiency larger than 97% (feeling number) might require big efforts and a dedicated lattice design.

QUESTION N.2

What will be the amount of activation all around the ring due to the residual interactions of the beam with the septum?

WARNING!

Proper shielding and collimators might be necessary right after the Lambertson.

If Lattice Requires More Space

Suggestion
- Arcs with 6 Cells + Dispersion Killer
  - add cell to straight section
- Higher Bending Field
- Make Both Rings like PHR
  - with 10 m straight section
- Higher Bend field
  - only for 10 Hz (Heavy Ions)

A. Dainelli Promises New Lattice
- with help of A. Ruggiero
- in 3-4 weeks
- A. Lombardi input on transfer line is required
- P. Spolaore input on heavy ion fragmentation + collection is required