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発表用資料

Large-Acceptance Multi-Particle Spectrometer

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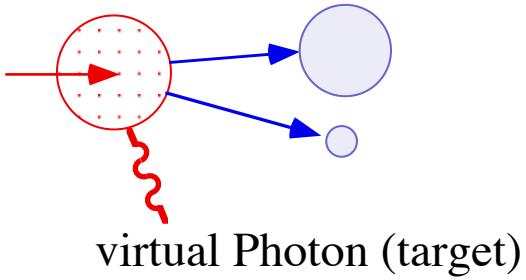
Contents

Samurai(7)

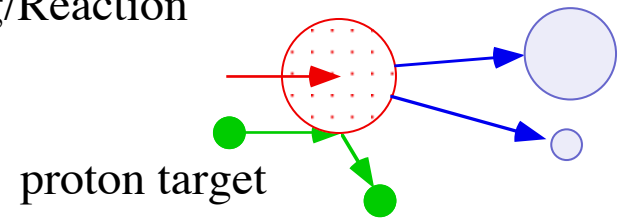
Superconducting Analyser for Multi particles
from RadioIsotope Beams
with 7Tm of bending power

Physics Subjects

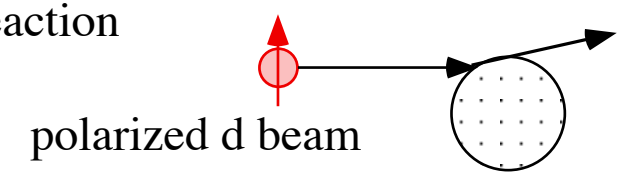
(1) Electromagnetic Dissociation (EMD)



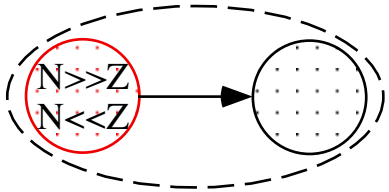
(2) Proton (p,d,He...) Scattering/Reaction



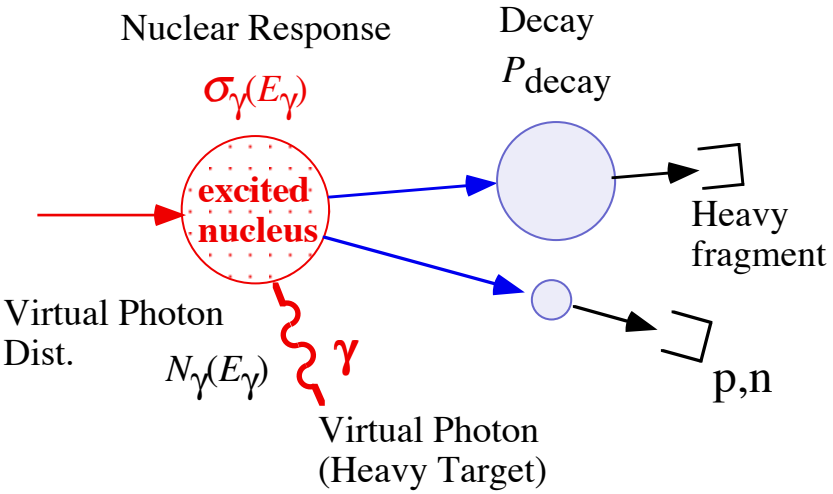
(3) Polarized deuteron-induced Reaction



(4) Multi Fragmentation

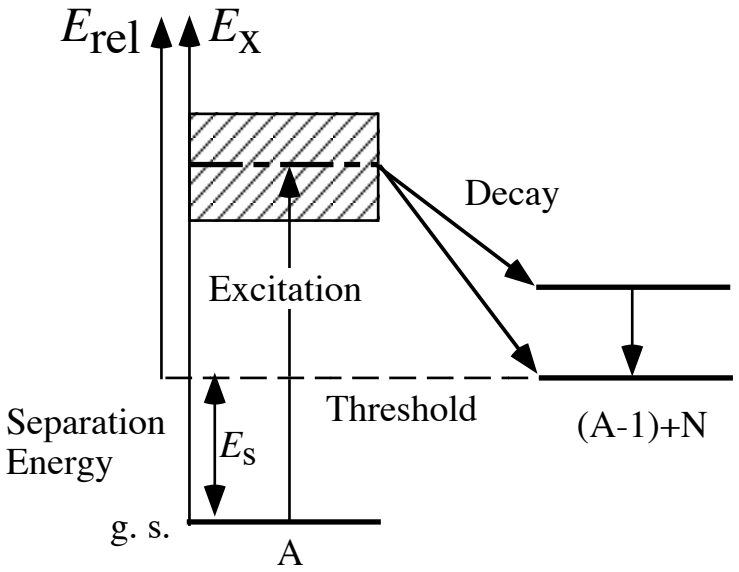


(1) Electromagnetic Dissociation



(γ,n) : softGDR, GDR: collective motion
non resonant excitation: single-particle orbit

(γ,p) : Nuclear Astrophysics
(p,γ)cross section via inverse reaction



Invariant-Mass method

$$E_X = \sqrt{\left(\sum E_i\right)^2 - \left(\sum P_i\right)^2} - \sum M_i + E_s$$

4-momenta of decay particles from excited nucleus

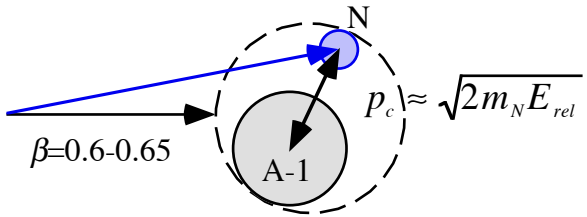
Projectile-rapidity heavy fragment
proton / neutron

(1) Electromagnetic Dissociation

Required Resolution

Excitation energy: $\sigma(E_{rel})=(0.1\text{-}0.2)\sqrt{E_{rel}}$ [MeV]

Required solid angle / momentum



E_{rel} = 3 (10) MeV, E_B = 250 MeV/A

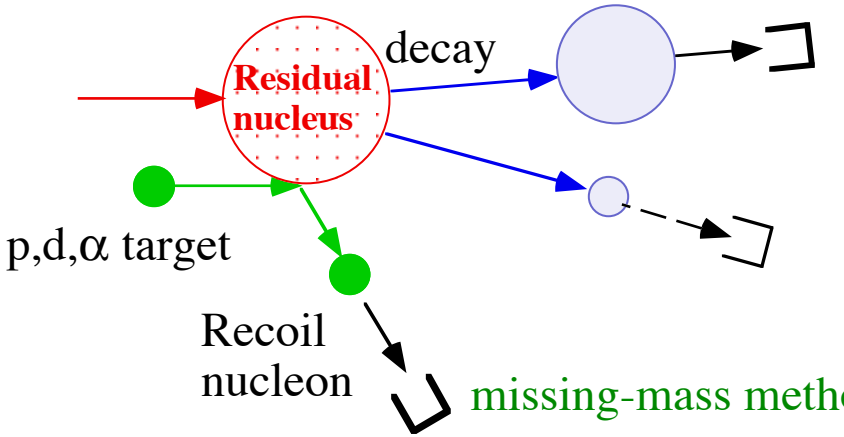
proton/neutron:

Angle: $\theta \leq \pm 6\ (11)°$

Momentum $\Delta p/p \leq \pm 13\ (24)\%$

← **need to detect p/n in wide angular & momentum range**

(2) Proton (p,d,He...) Scattering/Reaction



heavy fragment in the projectile rapidity

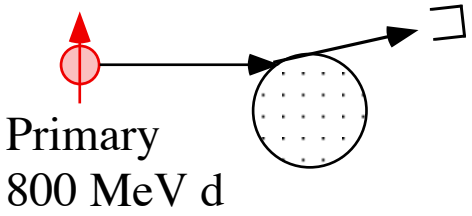
tagging decay mode of the residual nucleus with high (~100%) efficiency

missing-mass method by target detectors

(p,p), (p,p'), (p,n)
(p,d),
(p,pp), (p,pn),
(α,α), (α,α')

Nuclear structure of ground/excited states

(3) Polarized deuteron-induced Reaction



(d,d), (d,p)

Nucleon force:2-body/3-body force

Shore-range correlation

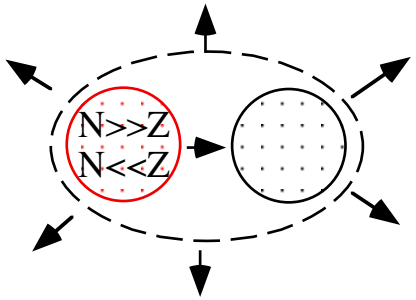
different experimental requirements

Solid angle: $\theta_{H,V} \leq \pm 50 mrad$

Momentum resolution: $\sigma_p / p \leq 1/1000$

Beam dump for primary beam

(4) Multi Fragmentation & Equation Of State



multiple particles

need 4π-type measurement

Particle Identification (PID)

PID: mass A, charge(atomic number) Z

charge:	Z	energy loss:	$dE/dx \propto (Z/\beta)^2$
momentum (Magnetic Rigidity):	$R=P/Z$ ⟵	magnetic analysis:	$P/Z \propto B\rho$
velocity:	β	Time of Flight:	$T \propto 1/\beta$

+additional limitation: $Q=Z$ + primary beam energy

⟶ RI beam energy: < 250 - 300 MeV/A
Mass number: < 100

Mass identification

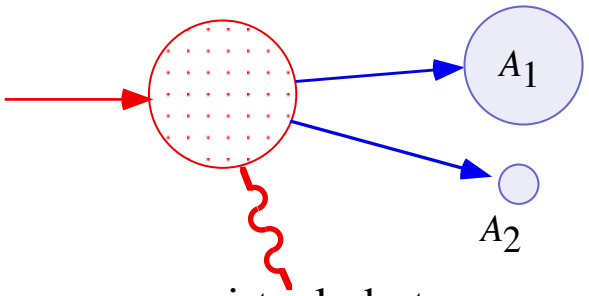
$$\frac{\sigma_A}{A} = \sqrt{\left(\frac{\sigma_R}{R}\right)^2 + \left(\gamma^2 \frac{\sigma_\beta}{\beta}\right)^2 + \left(\frac{\sigma_Z}{Z}\right)^2}$$

$\frac{\sigma_A}{A} = \frac{0.2}{100} \approx \frac{1}{500}$ ⟶ magnetic rigidity $\frac{\sigma_R}{R} \approx \frac{1}{700}$ @ $R = 2.2$ GeV/c ($A/Z = 3$, 250MeV/A)

velocity $\frac{\sigma_\beta}{\beta} \approx 9 \times 10^{-4}$ @ $\beta = 0.62$ ⟷ $\sigma_T \approx 50$ *psec* @ $L = 10$ *m*

charge $\sigma_Z \approx 0.2$

Invariant mass method required resolution



Relative-energy resolution

$$\sigma_{rel} \approx \sqrt{2\frac{E}{A}\frac{A_1 A_2}{A_1 + A_2}E_{rel}}\sqrt{\left(\frac{1}{\gamma_1^3}\frac{\sigma(p_1)}{p_1}\right)^2 + \left(\frac{\sigma(\beta_2)}{\gamma_2\beta_2}\right)^2 + \left(\sigma(\theta_{12})\right)^2}$$

Conditions

$E/A \approx 250\text{MeV/A}$

$p \approx 730\text{MeV/c/A}$

$\beta \approx 0.62$

$\gamma \approx 1.27$

Required Resolution

momentum (fragment): $\sigma_R / R \leq 1/700$

velocity (neutron): $\sigma_\beta / \beta \approx 6 \times 10^{-3}$ TOF : $L \approx 10\text{m}$, $\sigma_T \approx 0.3\text{nsec}$

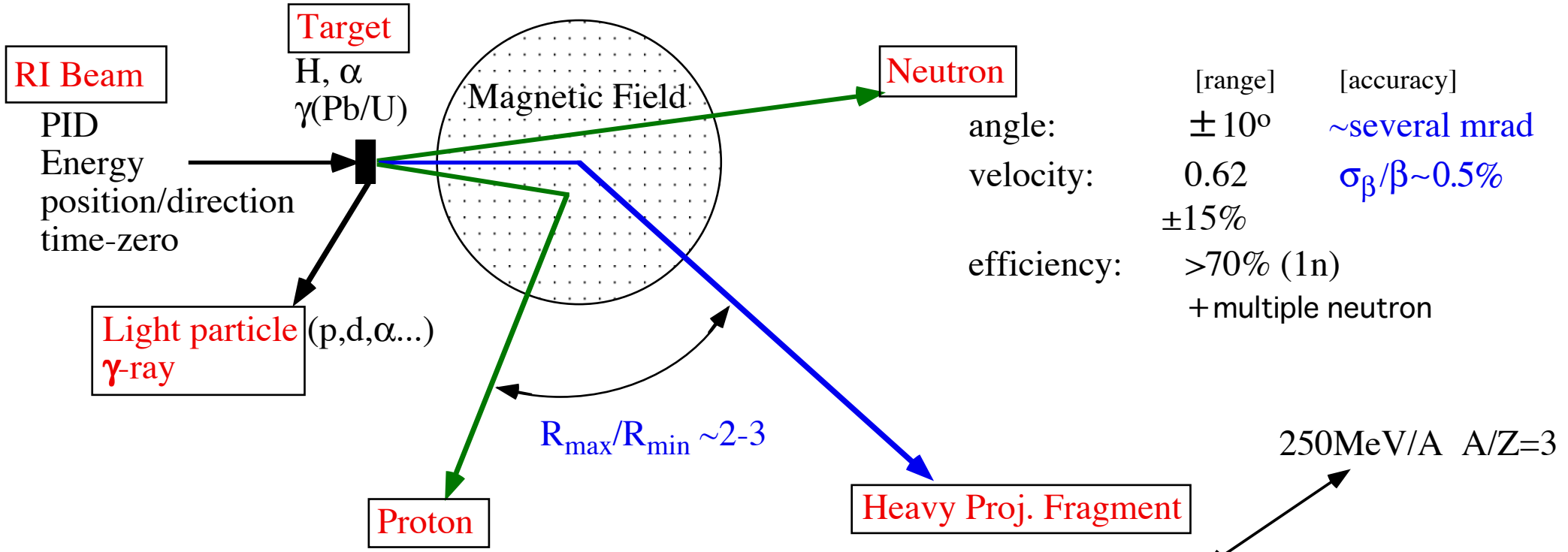
angle (neutron): $\sigma(\theta_{12}) \approx 5\text{mrad}$ $\sigma_x \approx 5\text{cm}$ @$L = 10\text{m}$

(cf) projectile fragmentation @250MeV/A A=50(80) ⟶ A-1=49(79)

momentum distribution of (A-1) system : $\frac{\sigma_p}{p} \approx \frac{1}{290(460)}$

Required Measurements

groups, range, accuracy



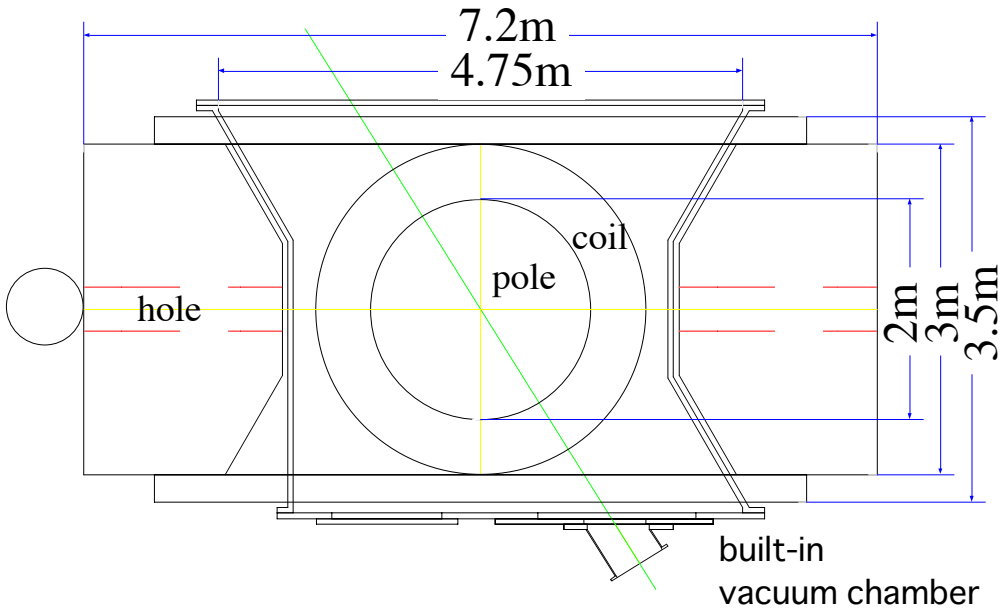
	[range]	[accuracy]
angle:	±10°	~several mrad
velocity:	0.62 ±15%	σ_β/β~0.5%
efficiency:	>70% (1n) +multiple neutron	

momentum:	0.7GeV/c ±15%	$\sigma_p/p < 1/100$
angle:	±5°	~few mrad
	[range]	[accuracy]

momentum:	R<2.2 GeV/c ±few%	$\sigma_R/R < 1/700$ $\sigma_p/p <$ 1/1000 (d)
angle:	< few°	<few mrad
charge:	< 50	σ_Z ~ 0.2
velocity:	0.62	$\sigma_\beta/\beta \sim 10^{-3}$
	[range]	[accuracy]

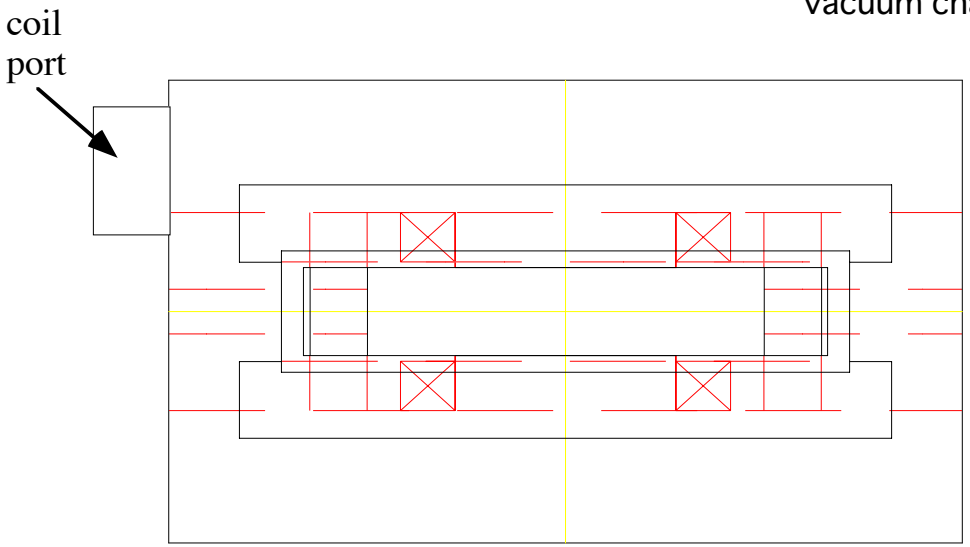
Spectrometer Magnet：

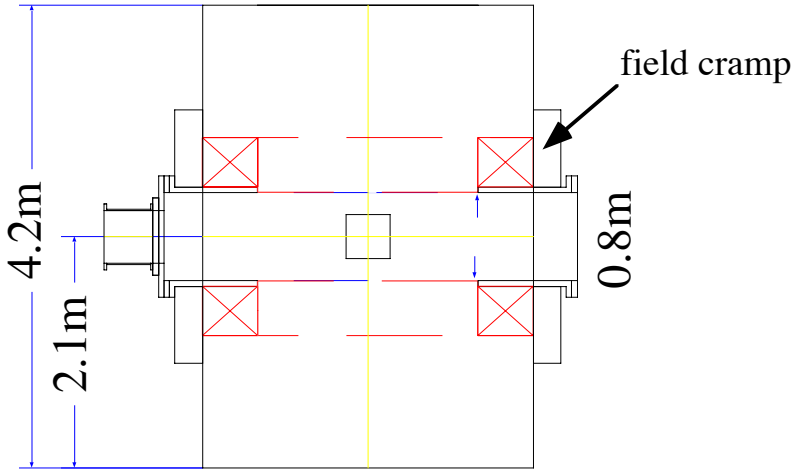
Superconducting magnet with round pole



parameters

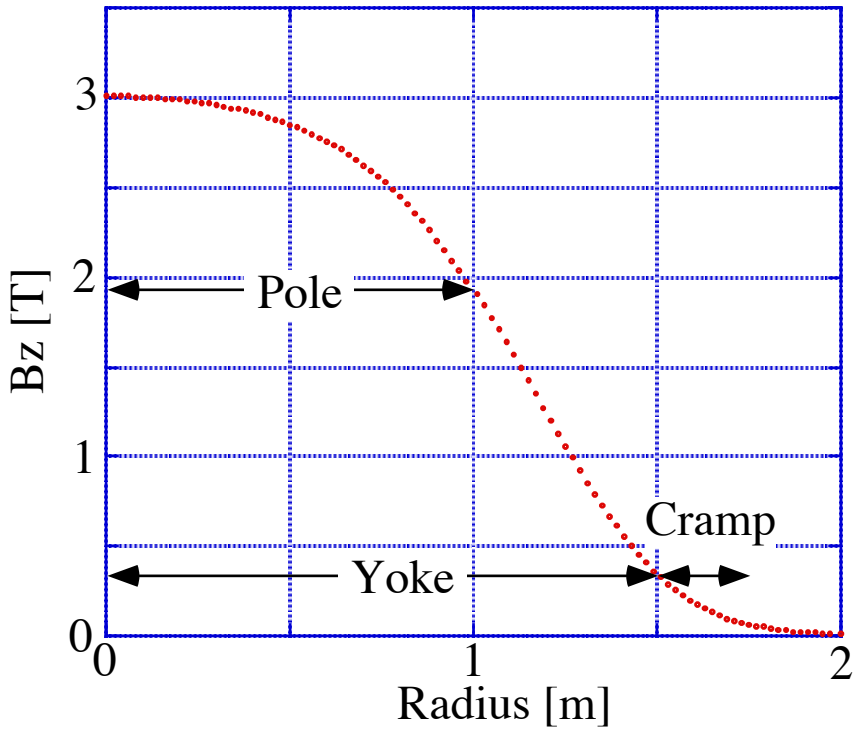
Pole:	2m diam., 0.8m gap
Field:	3 T @3.6 MAT
Turns/current:	800 turn / 4600 A
Field integral BL:	7 Tm
Stored energy:	28 MJ
Vertical force:	500 t
Weight:	650 t





Spectrometer Magnet: Magnetic Field

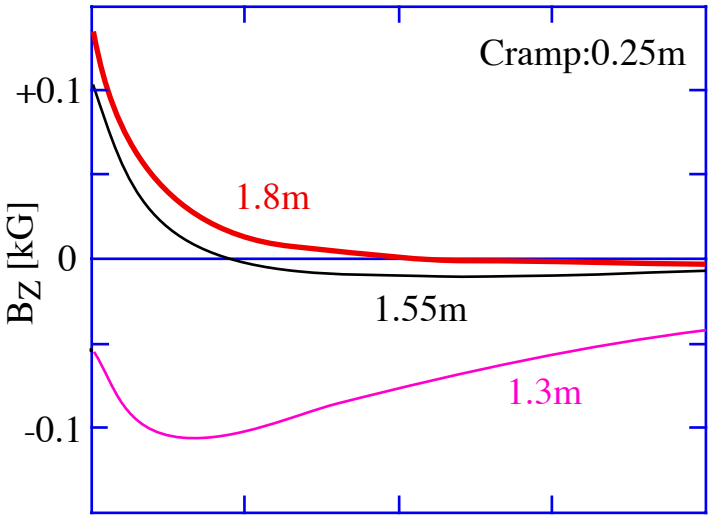
Field Distribution



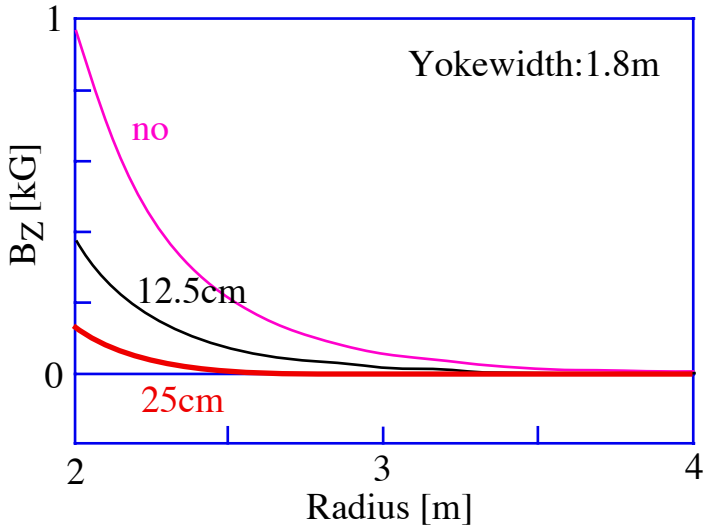
BL= 7 Tm: ~50º bend for 2.2GeV/c

+Reduction of fringing field
for target detectors
position detectors for momentum analysis

(1) sufficient Return yoke width

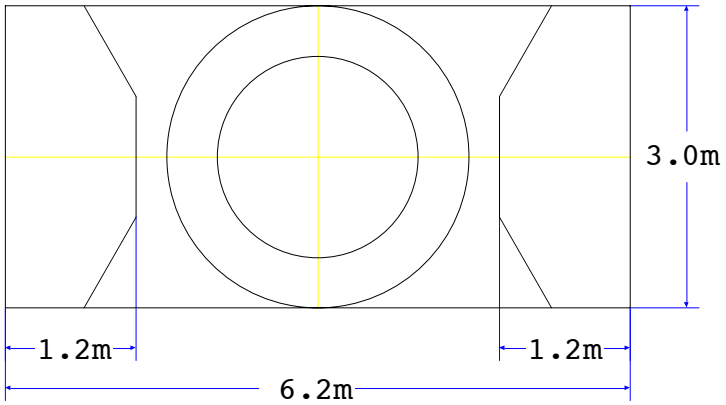


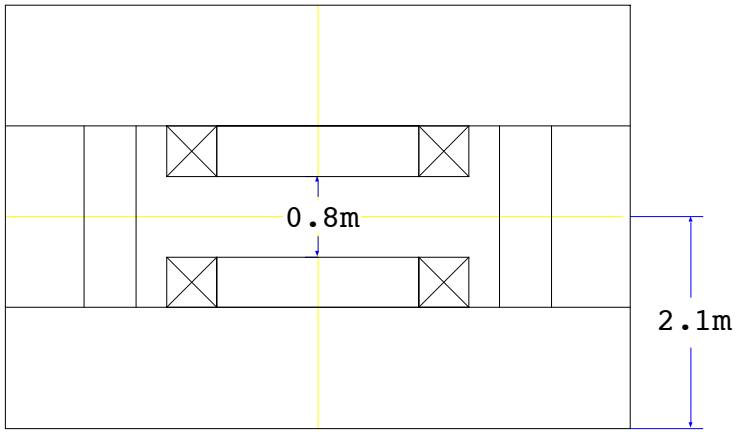
(2) add Field cramp

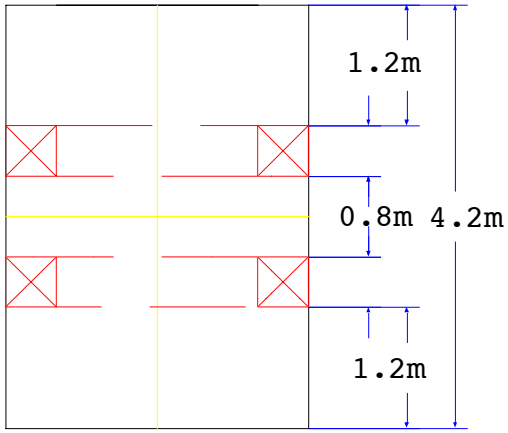


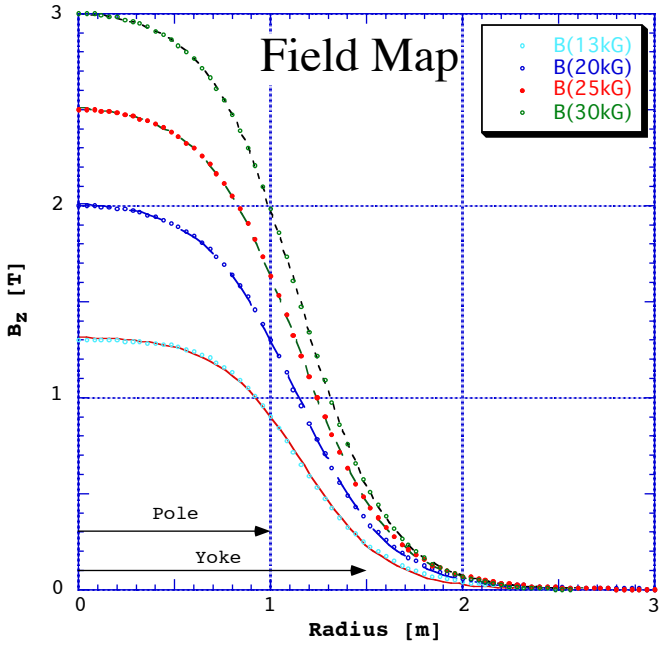
H-type round pole magnet w/o field cramp

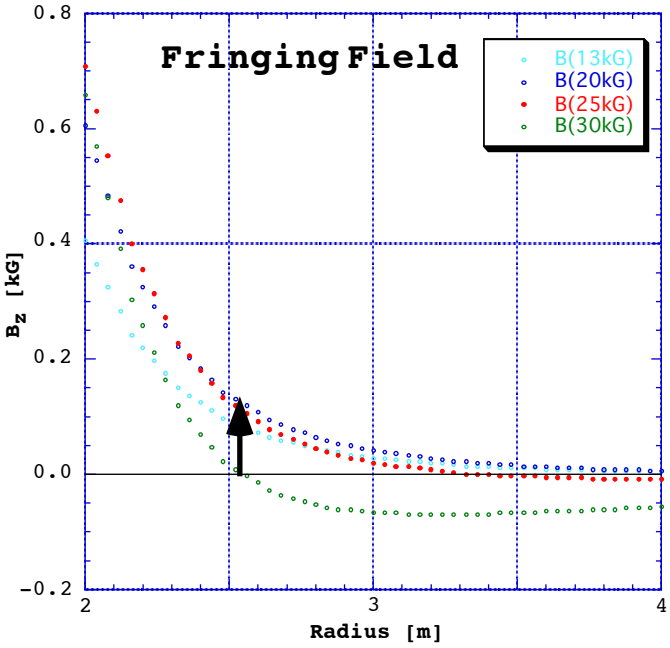
Pole:	Diam 2 m, Gap 0.8 m
Field:	3 T @3.6 MAT
Stored E:	28 MJ
BL:	7 Tm
vertical F.:	650 t(w/o coil link)





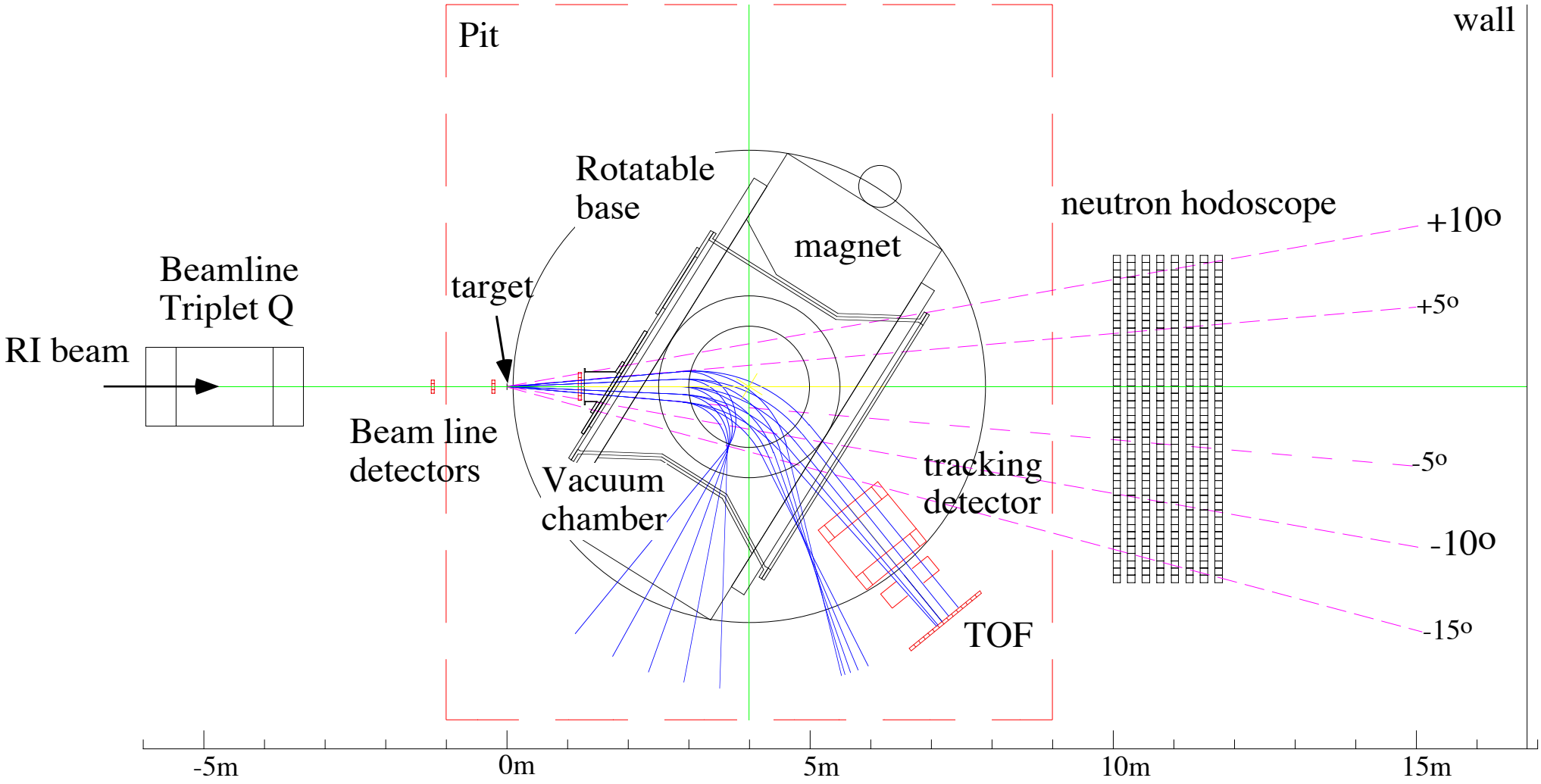






Setup for (γ,n) reaction

plan view Z_T=-4m

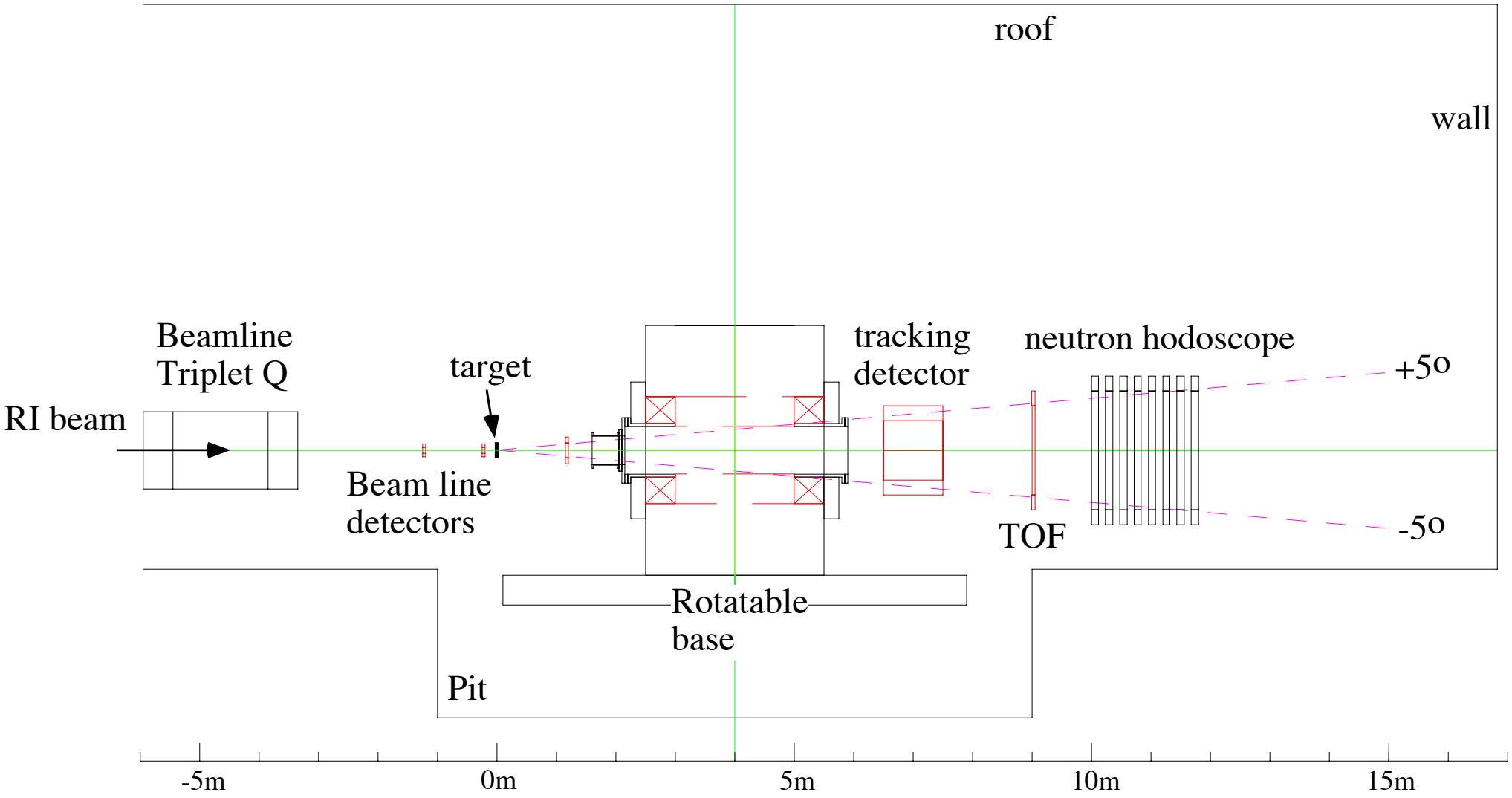


charged particles
250MeV/A
0o, ±2.5o, ±5o

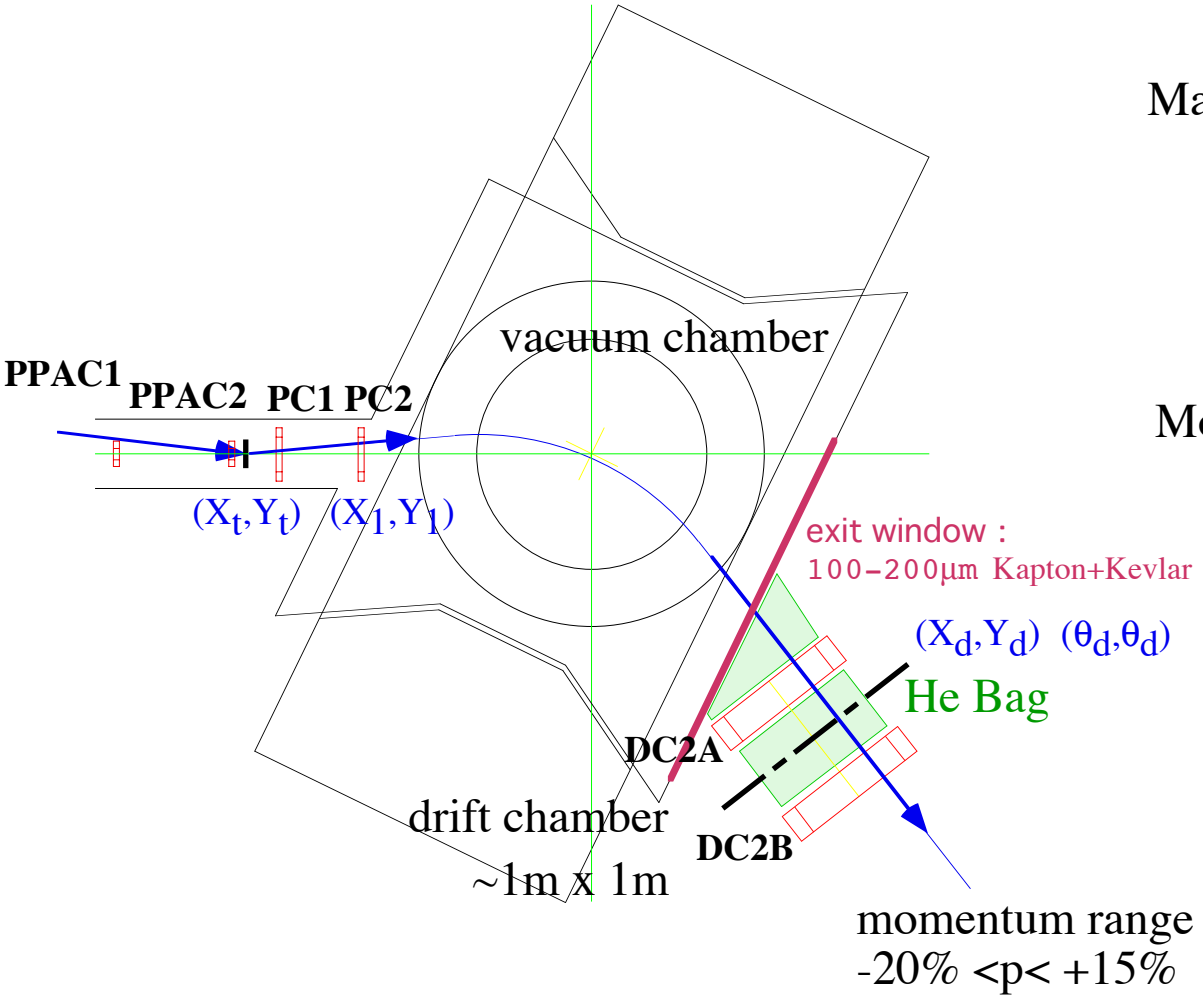
A/Z=1	A/Z=2	A/Z=3
0.73GeV/c	1.45GeV/c	2.2GeV/c

Setup for (γ,n) reaction

side view Z_T=-4m



Momentum analysis



Matrix: A/Z=3, 250 MeV/A

$$D = 2.4cm/\%,\ D' = 8mrad/\%$$
$$(x|x) = 0,\ (x|\theta) = 0.3cm/mrad,$$
$$(\theta|\theta) = 0.01,\ (\theta|x) = 3.3mrad/cm$$
$$D_{eff} = (\theta|\theta)D - (x|\theta)D' \approx -240cm$$

Momentum Resolution:

$$\left(\frac{\sigma_p}{p}\right)^2 = \left(\frac{(\theta|\theta)}{D_{eff}}\sigma(x_D)\right)^2 + \left(\frac{(x|\theta)}{D_{eff}}\sigma(x'_D)\right)^2 + \left(\frac{\sigma(x_T)}{D_{eff}}\right)^2$$

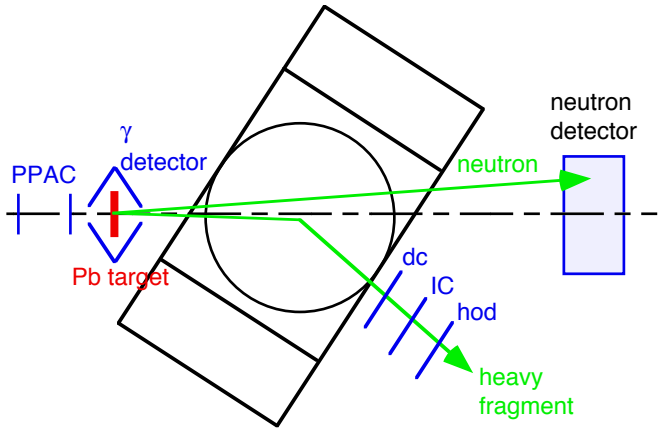
$$\sigma(x_D) \approx 0.3mm,$$
$$\sigma(x'_D) \approx 1mrad,$$
$$\sigma(x_T) \approx 0.5mm$$

$$\frac{\sigma_p}{p} \approx \frac{1}{770}$$

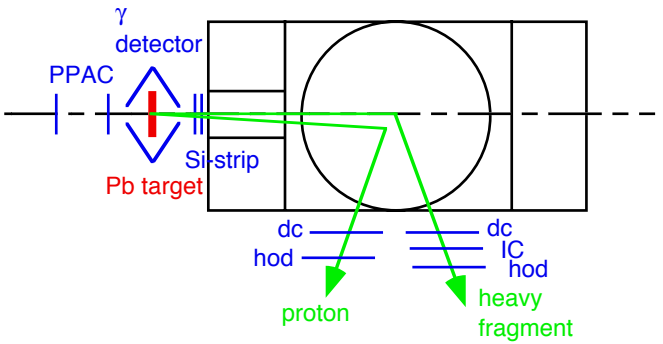
Low-mass chamber
$L/Lr < 10^{-3}$

Experimental Setup : various Configurations

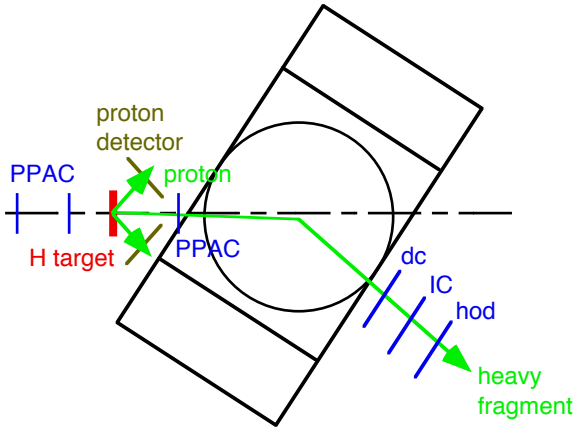
(γ,n) reaction: neutron-rich side



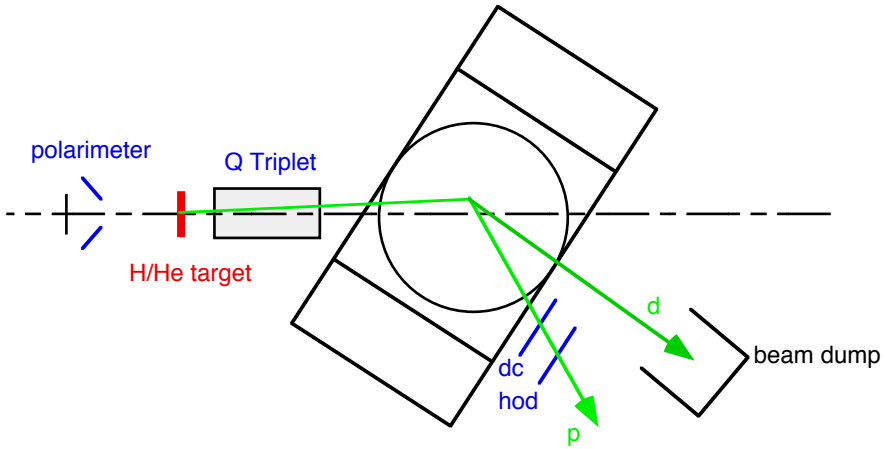
(γ,p) reaction: proton-rich side



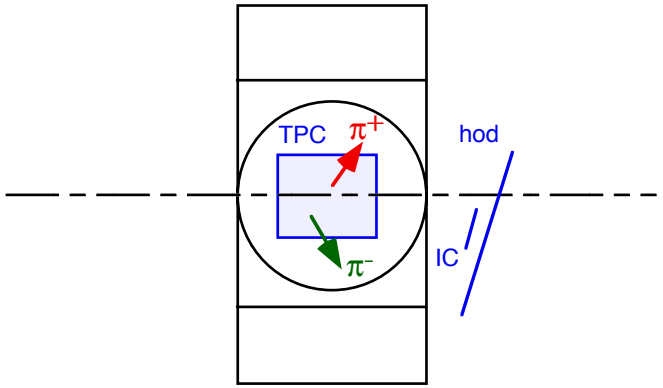
(p,p'), (p,2p) etc.



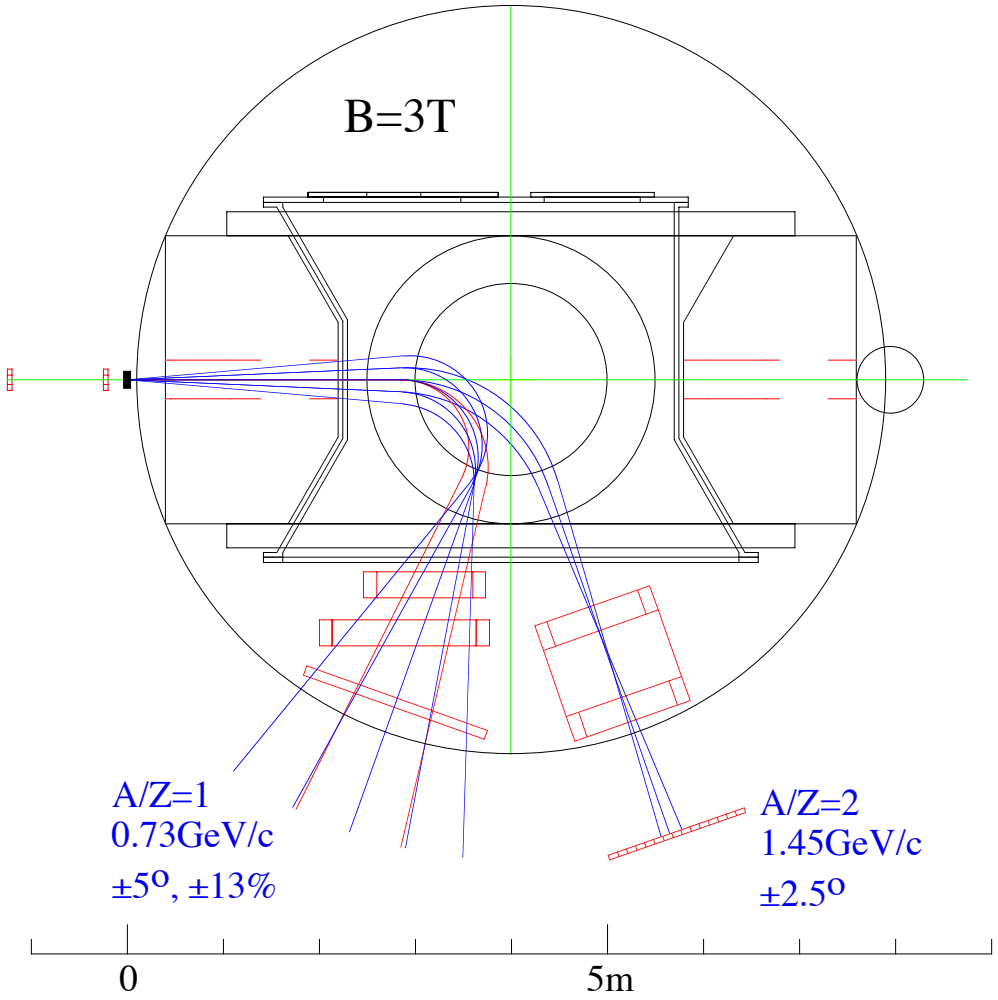
Pol. d-induced reaction

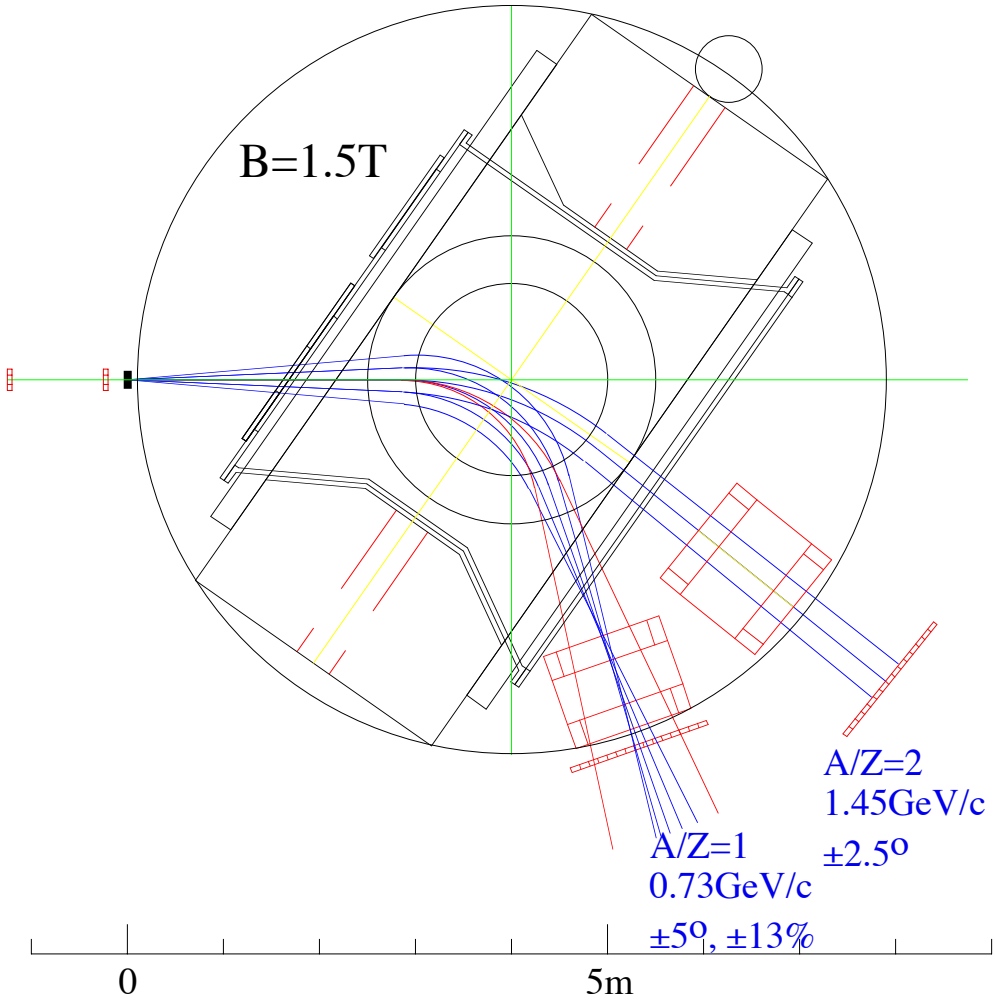


EOS measurement



Setup for (γ,p) reaction



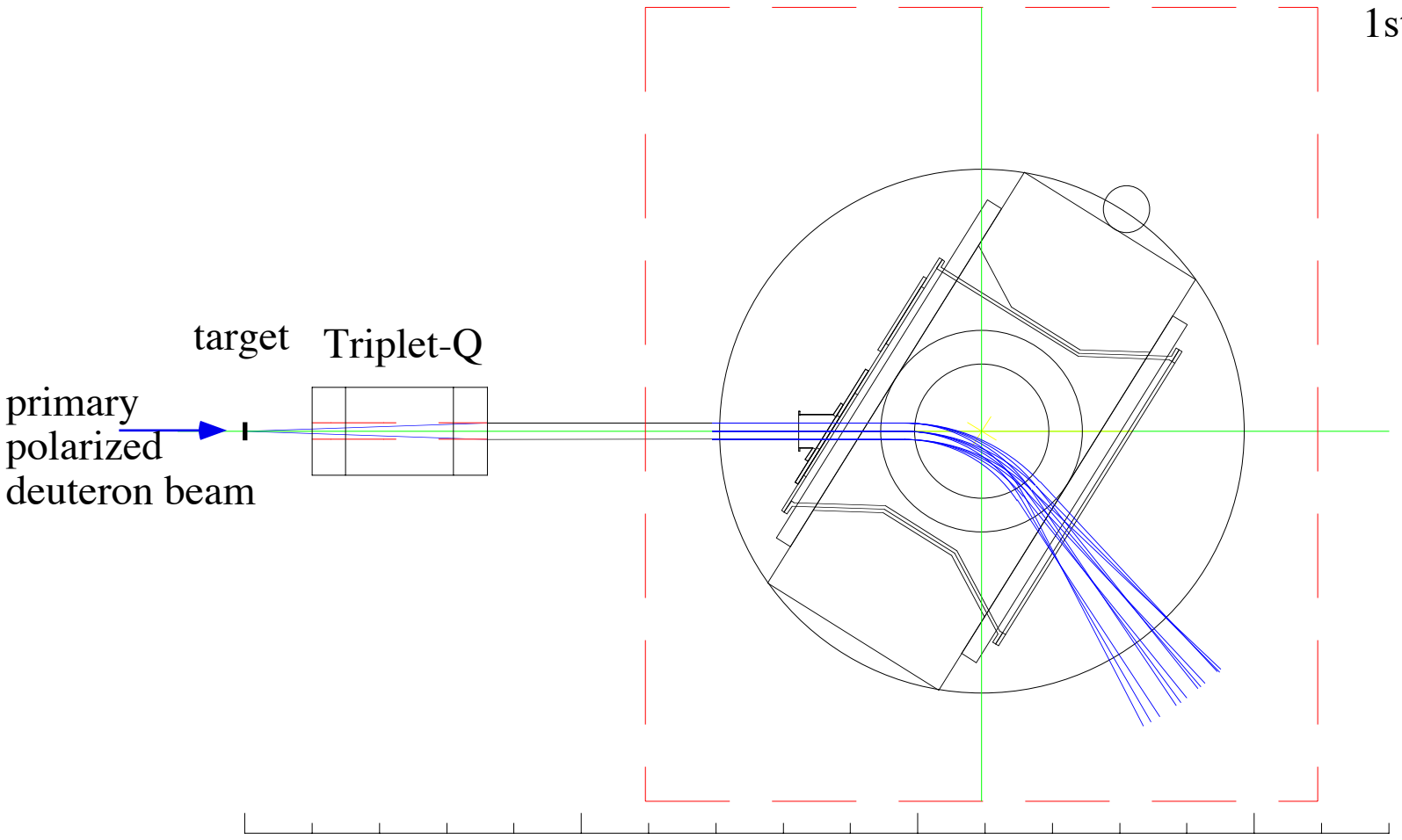


with maximum field for good PID

hole in the return yoke

Setup for primary deuteron beam

High resolution mode : Q3D = Beam-line triplet-Q + Dipole



1st order matrix elements

$\langle x'|x\rangle = -0.709$

$\langle x'|a\rangle = -0.0$

$\langle x'|\delta\rangle = 2.214$

Resolving Power: 3.122

Acceptance:

$\Delta\theta_x = \pm 30$ mr

$\Delta\theta_y = \pm 60$ mr

$\Delta\Omega = 9$ msr

Summary

(1) Detection of <u>multiple (few) particles</u> in the projectile rapidity

heavy fragment
proton / neutron(s) in coincidence ⟶ EMD studies via Invariant-Mass measurement

with large angular acceptance ~50msr
momentum acceptance ~300%
moderate momentum resolution ~1/600 (Q3D option for high resolution measurement)
particle identification A < 100

(a) Large field integral : BL= 7 Tm

PID ($\sigma_A \fallingdotseq 0.2$) + momentum resolution ($\sigma_R/R \fallingdotseq 1/600$ @2.2GeV/c)

(b) Magnet Gap : 0.8m

vertical acceptance for neutron: $\theta_V < \pm 5^o$, $\theta_H > \pm 10^o$

(c) Field Cramp

small fringing field : for detectors in the target region & tracking detectors

(d) Rotatable base + built-in vacuum chamber

for various experimental configuration

(e) Hole in the return yoke

heavy fragment & protons in coincidence : $R_{max}/R_{min} \fallingdotseq 2\text{-}3$

Summary 2

(2) Tagging decay particles from various direct reactions: (p,p'), (p,pN), etc

decay mode of the residual excited nucleus

providing enough space for detectors in the target region

(3) Large gap

4π measurement for EOS

Remaining problems / items

[1] Magnet

(1-1) Cost

still high ~1,000MY (10M$)

(1-2) Large-area exit (vacuum) window

100-200μm Kapton/Aramid + Kevlar

(1-3) Solid angle <---> Es coverage <---> Beam energy

50 msr (±10°x±5°) <10MeV < 350 MeV/A primary

not really "large solid-angle"

(1-4) Field map measurement

nightmare

Remaining problems / items

[2] Detectors

(2-1) Velocity measurement for PID

required : $\sigma_\beta/\beta=10^{-3}$ @β=0.6

TOF (50ps @L=10m) marginal

TIR (total internal reflection) Cherenkov?

(2-2) Neutron detector

(a) 12x12x170 cm^3 x 30 elements/layer x 8 layers, cost ~ 200 MY (2M$)

(b) Detection efficiency

$\varepsilon\sim$ 70% (1n)

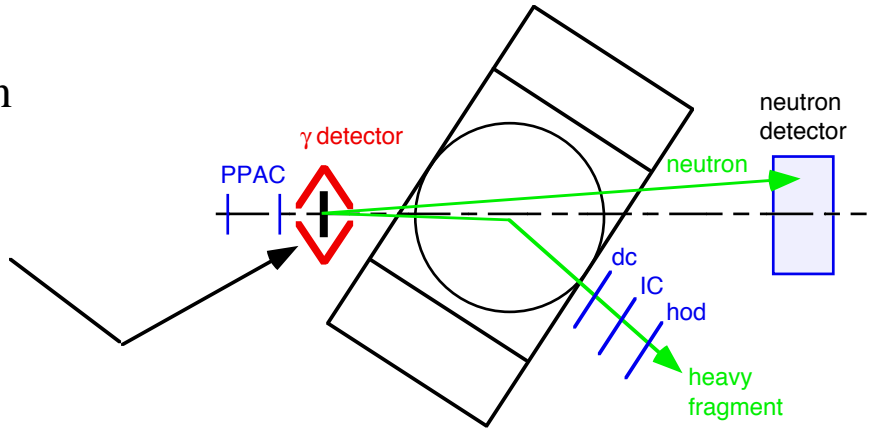
$\varepsilon\sim$ 30% (2n), but need cross-talk rejection

(c) γ-decay after neutron decay

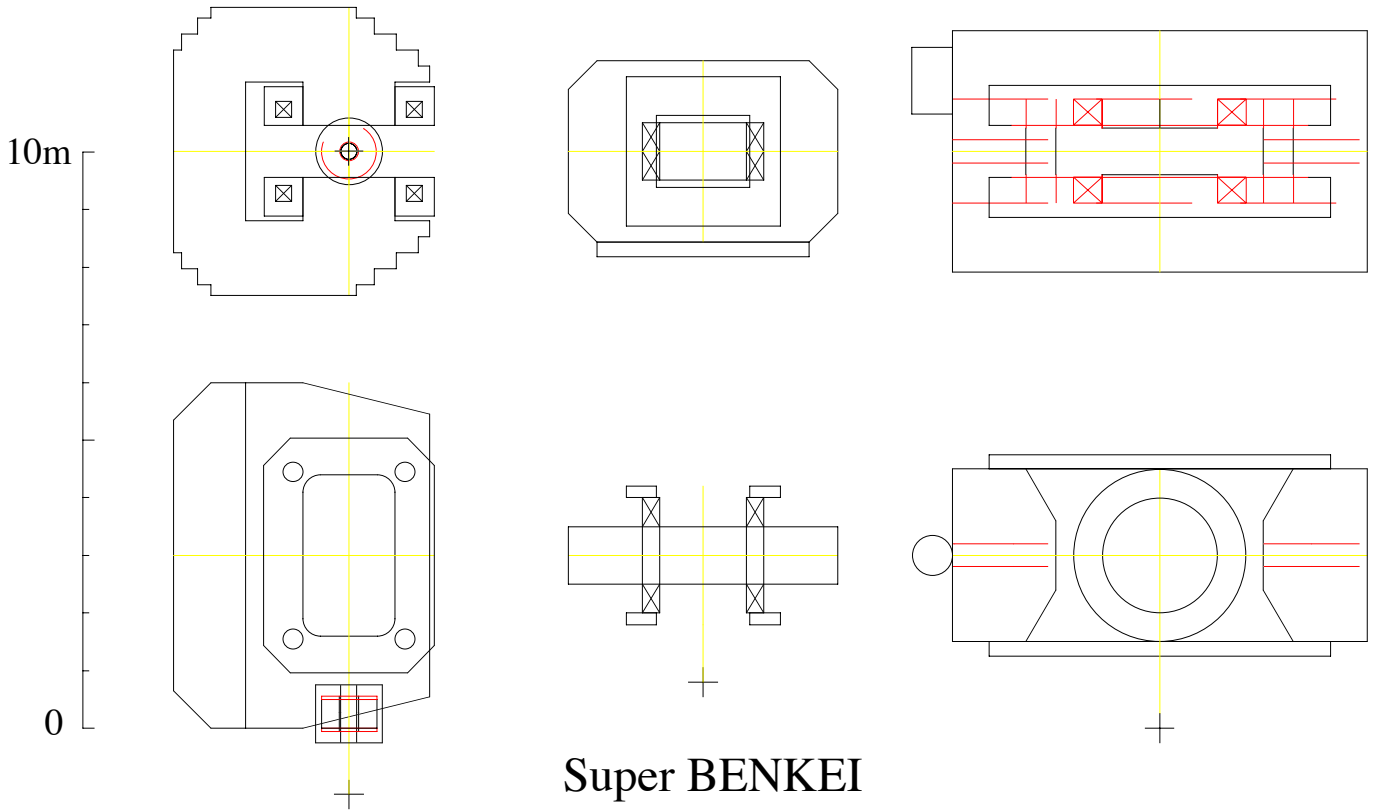
need high-efficiency segmented γ detector

(2-3) Charge measurement by Ion Chamber

small dead region



Magnetic Spectrometers so far considered



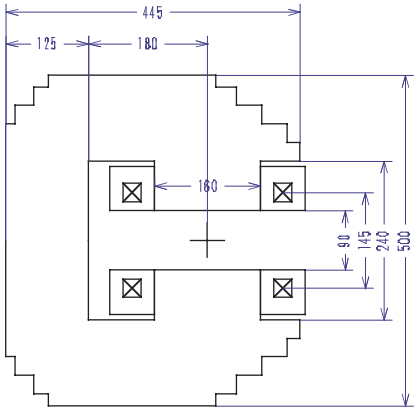
Super BENKEI

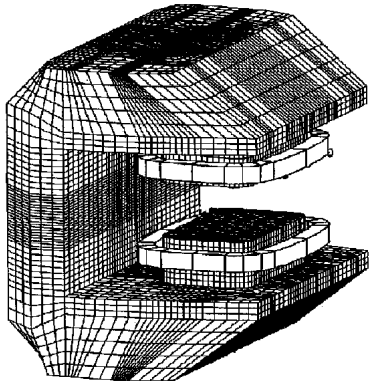
Type	Q + C-magnet	H-type window frame	H-type round pole
B_{max}[T], BL[Tm]	3 T, 7 Tm	1.5 T, 2.3 Tm	3 T, 7 Tm
pole&gap[m], weight[t]	1.6x2.8x1.0 m, 620 t	1.5x1.0x1.0 m, 140 t	2.0m diam.x0.8 m, 650 t
AT & Stored Energy	4.4 MAT, 36 MJ	1.4 MAT, 36 MJ	3.6 MAT, 28 MJ
cost	1500 MY	100 MY(transfer+mod.)	<1000 MY
angle for 2.2GeV/c	55°	18°	53°
angular focussing	yes	no	no
drawbacks	force, cost, fringing field	low field	no angular focus, focal plane

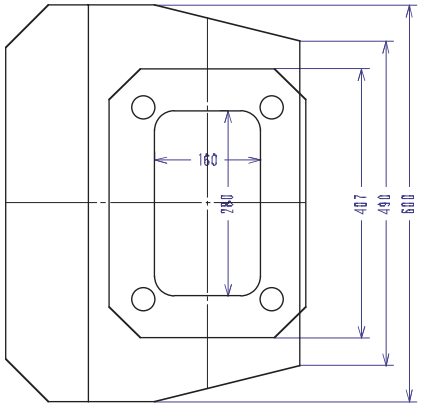
QD mode : C-magnet + Q

pole: 1.6(W)x 2.8 (D)x1.0m(G)
field: 3.0 T @4.4MAT
weight: 620 t (585 t + 35t)
stored energy: 36 MJ
max field on coil: 4.0 T

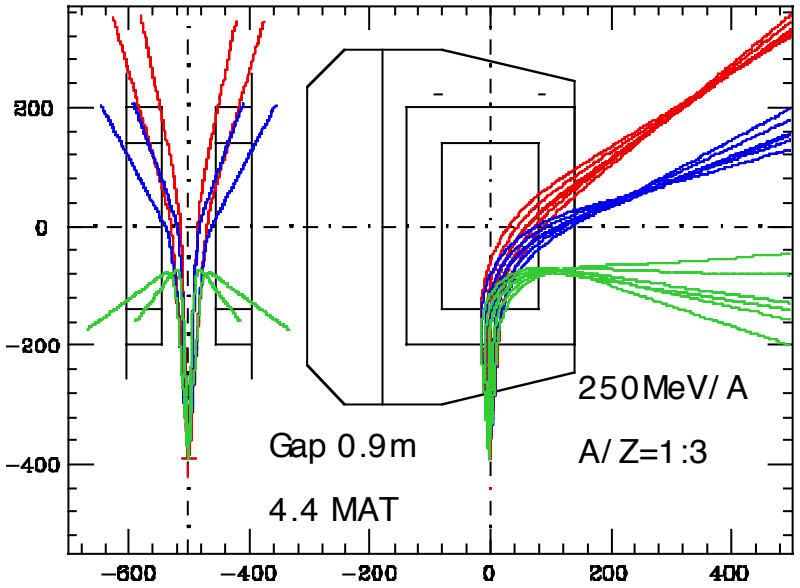
0.3m with Q



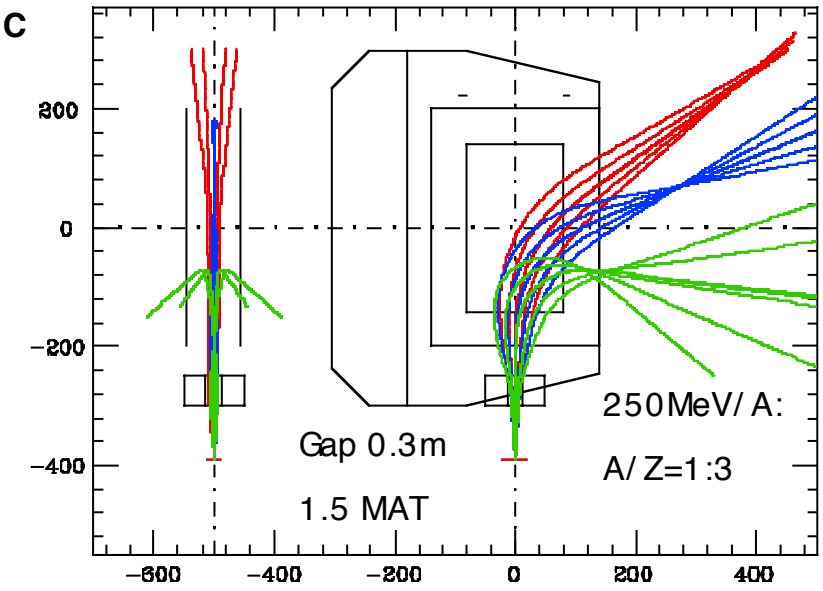


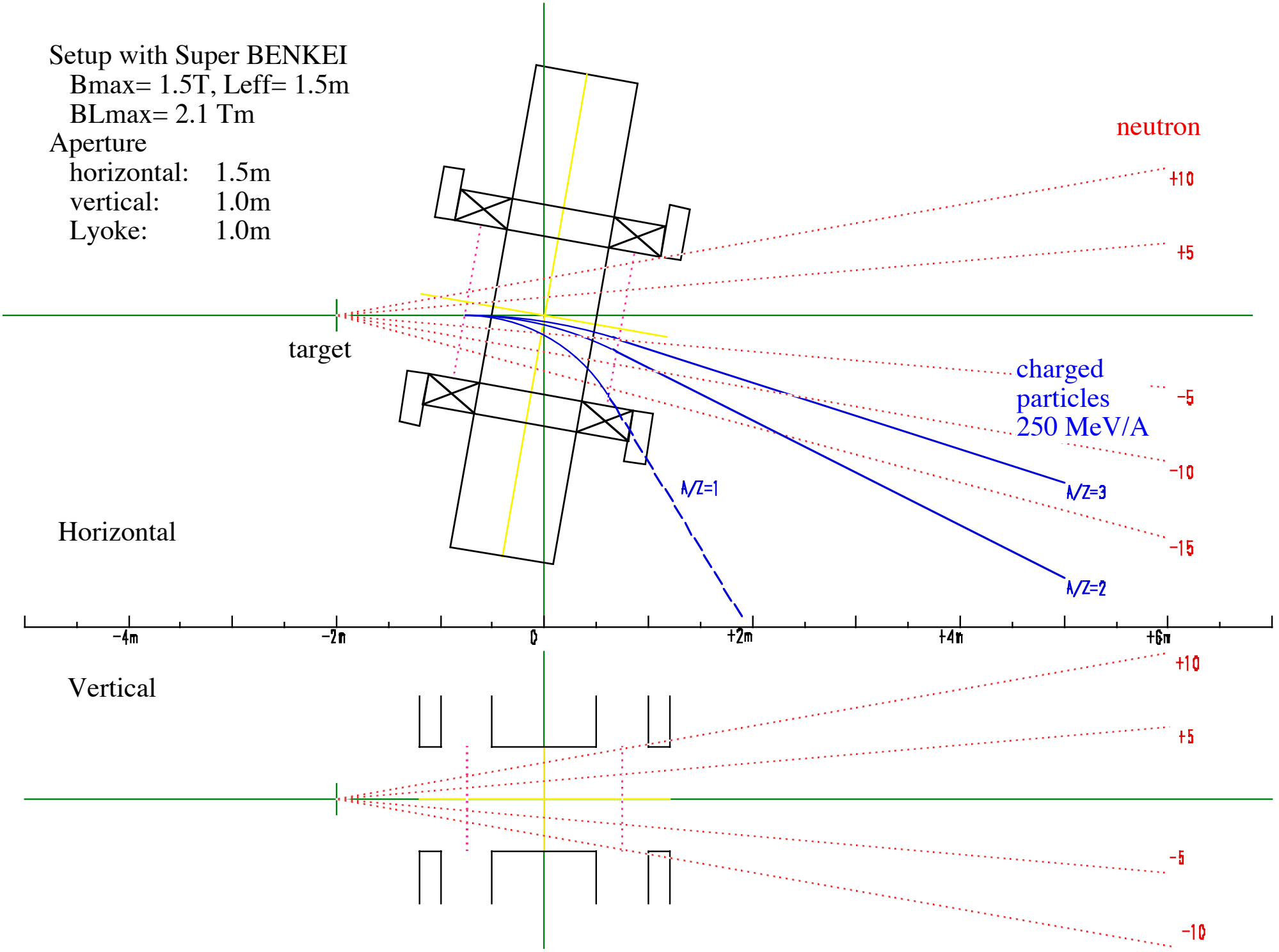


(1) C



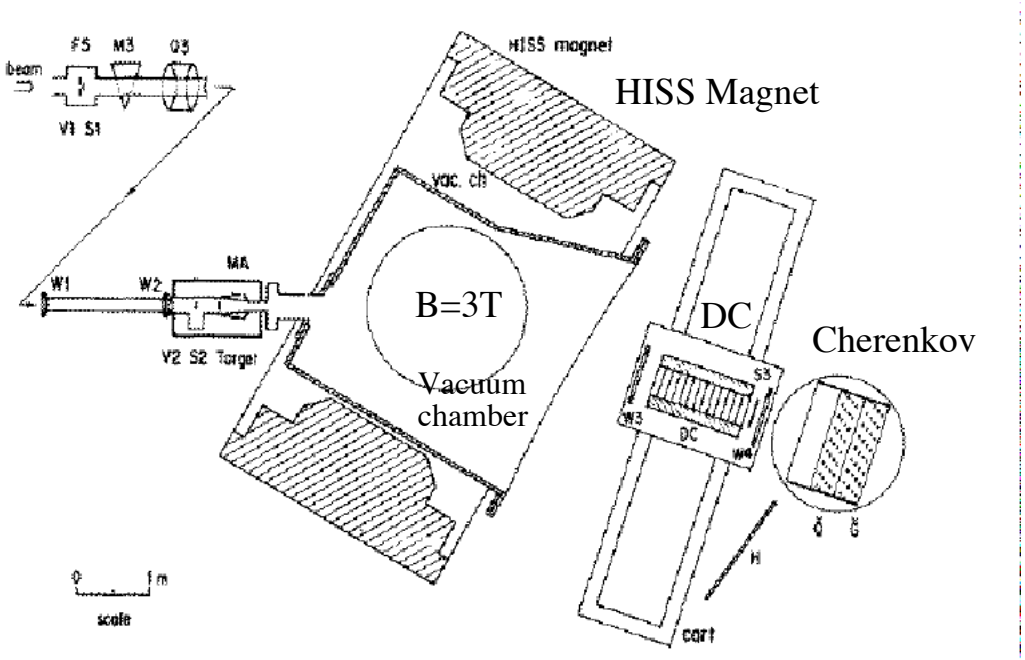
(2) Q+C



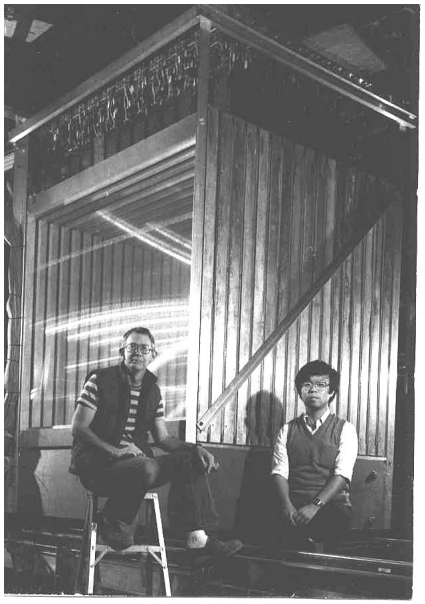

Setup with Super BENKEI
Bmax= 1.5T, Leff= 1.5m
BLmax= 2.1 Tm
Aperture
horizontal: 1.5m
vertical: 1.0m
Lyoke: 1.0m
neutron
+10
+5
target
charged
particles
250 MeV/A
-5
-10
-15
A/Z=1
A/Z=3
A/Z=2
Horizontal
-4m
-2m
0
+2m
+4m
+6m
Vertical
+10
+5
-5
-10

	SKS	BENKEI	HISS	DAIMAJIN
Bmax [T]	3	1.5	3	3
Stored Energy [MJ]	10	3.2	55	28
Pole [m]	sector	1.5x1	2.1	2
Gap [m]	0.5	1	1	0.8
AT [MAT]	2.2	1.4	5.1	3.6
Current [A]	500	610	2200	4600
Weight [t]	250	140	570	650

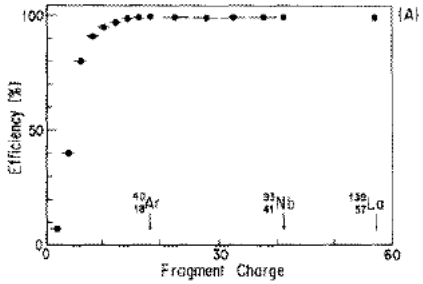
(very) similar system HISS@LBL



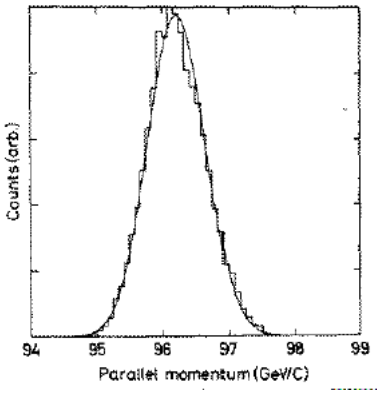
Large-area drift chamber



Drift chamber efficiency & resolution



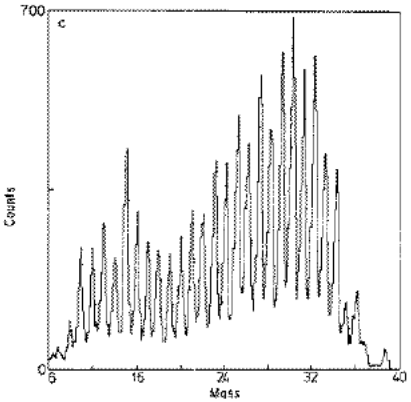
Momentum resolution



^{40}Ar,1.65GeV/A(R=5.4GeV/c)

$$\frac{\sigma_R}{R} = \frac{1}{200}$$

Mass resolution

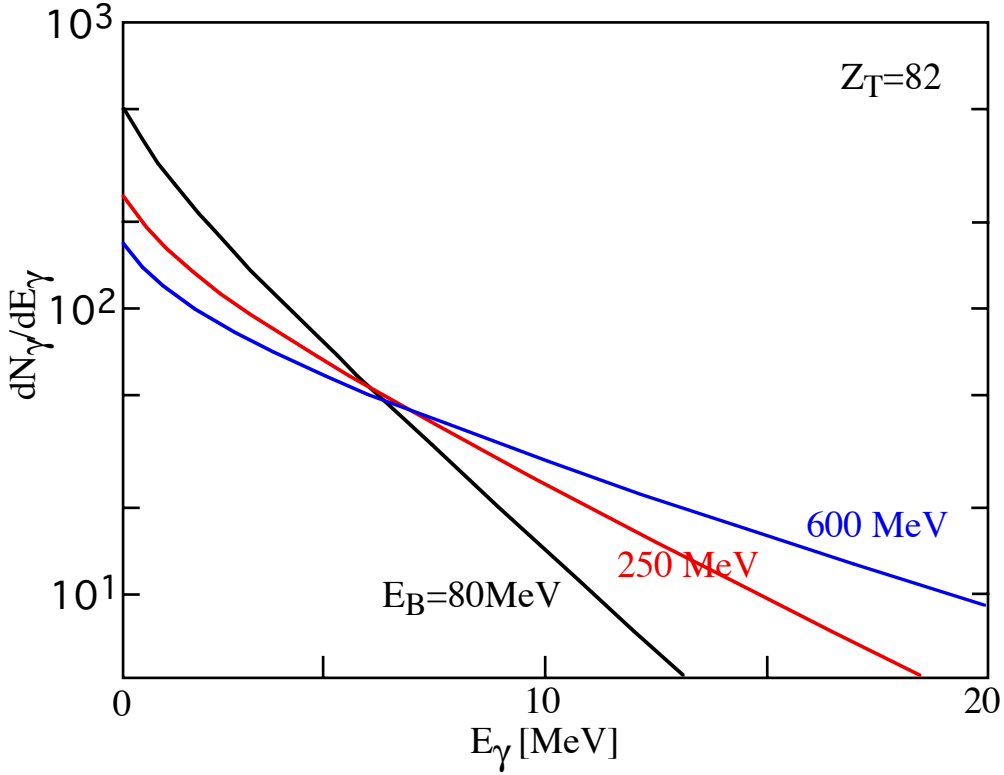


$$\sigma_A = 0.21$$

$$\frac{\sigma_\beta}{\beta} = 0.4 \times 10^{-3} \quad @\beta = 0.93$$

Virtual Photon & Acceptance

Virtual photon distribution



Neutron acceptance

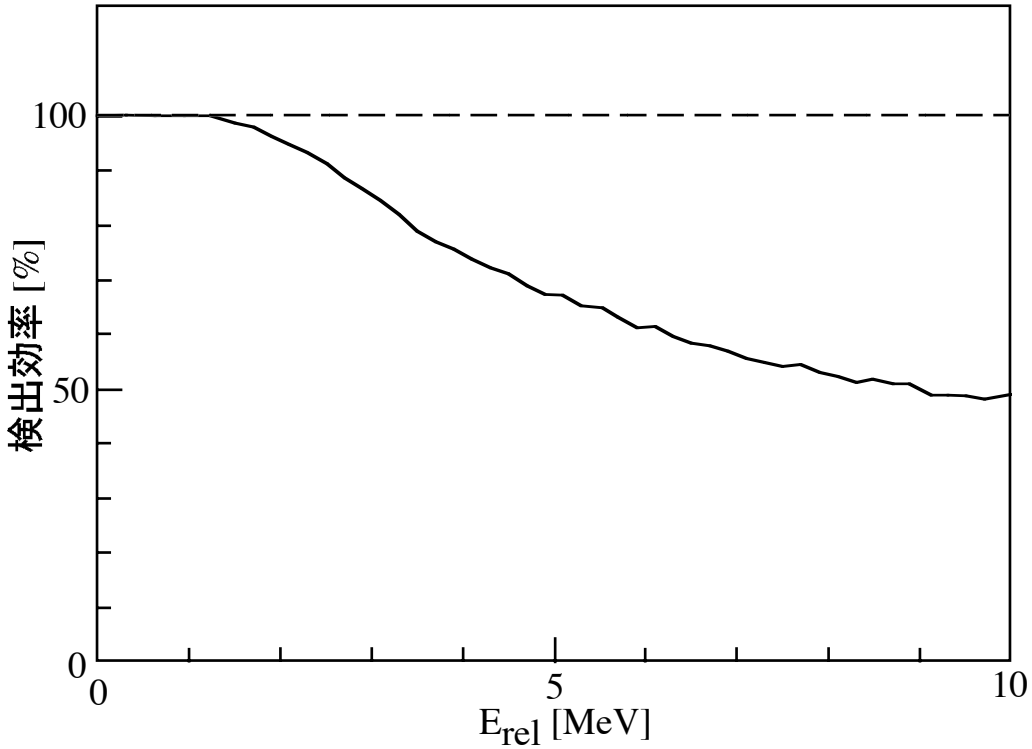


Figure of merit = virtual photon intensity
x beam intensity
x target thickness

Cost Estimate

[1] Magnetic Spectrometer

(1-1) Superconducting magnet: ~1,000 MY
+rotatable base,
build-in vacuum chamber,
cooling system

(1-2) Beam detectors, upstream detectors 5 MY
PPAC x(3-4)

(1-3) Downstream drift chambers 100 MY
+ electronics, stand
2 sets for heavy fragment, 2 sets for protons

(1-4) Plastic Scintillator hodoscope 30 MY
2 sets

(1-5) Ion Chamber (?) 5 MY

(1-6) Velocity detector (?) ?

(1-7) Beam dump for primary deuteron 50 MY

sub total 1.200 MY

[2] Additional detectors

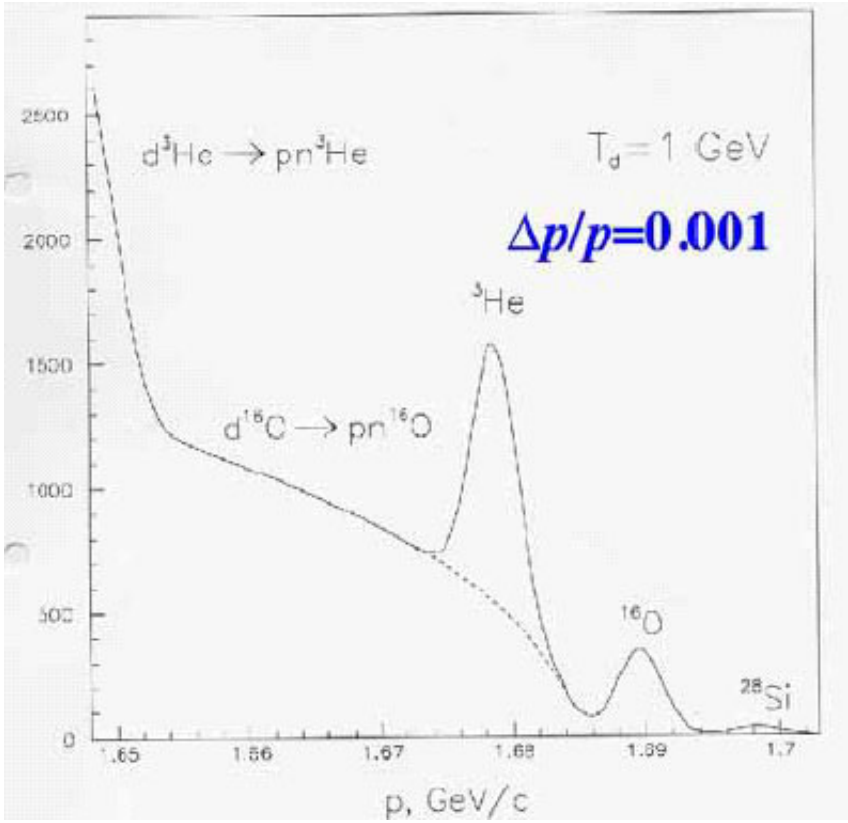
(2-1) Neutron Hodoscope 200 MY
30 x 8 elements, with electronics

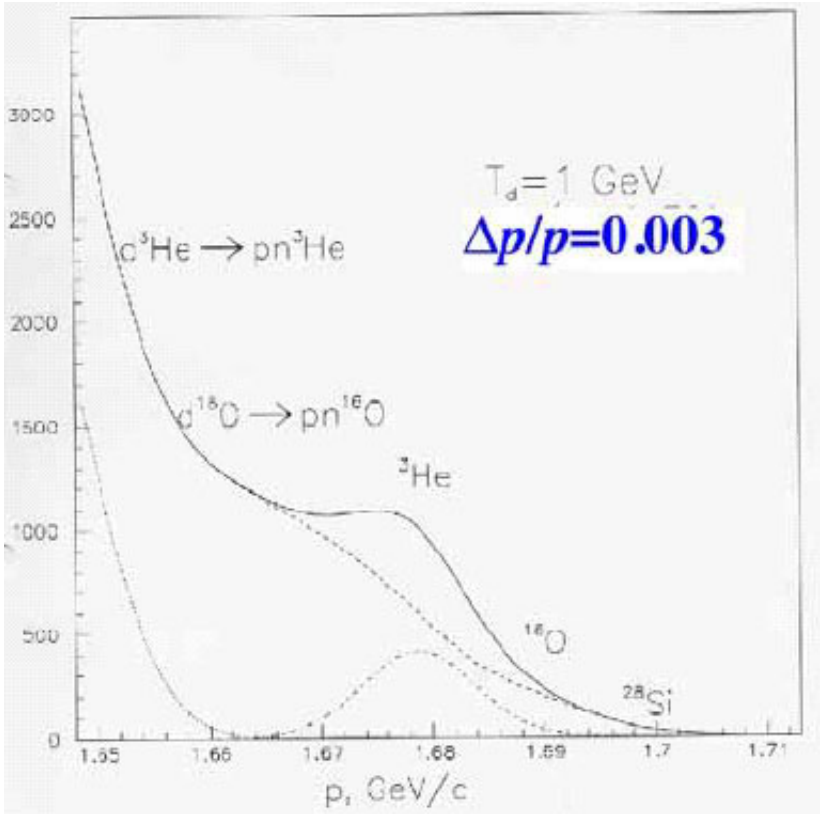
(2-2) Si-strip for upstream tracking 13 MY
for (γ,p)

(2-3) TPC 350 MY

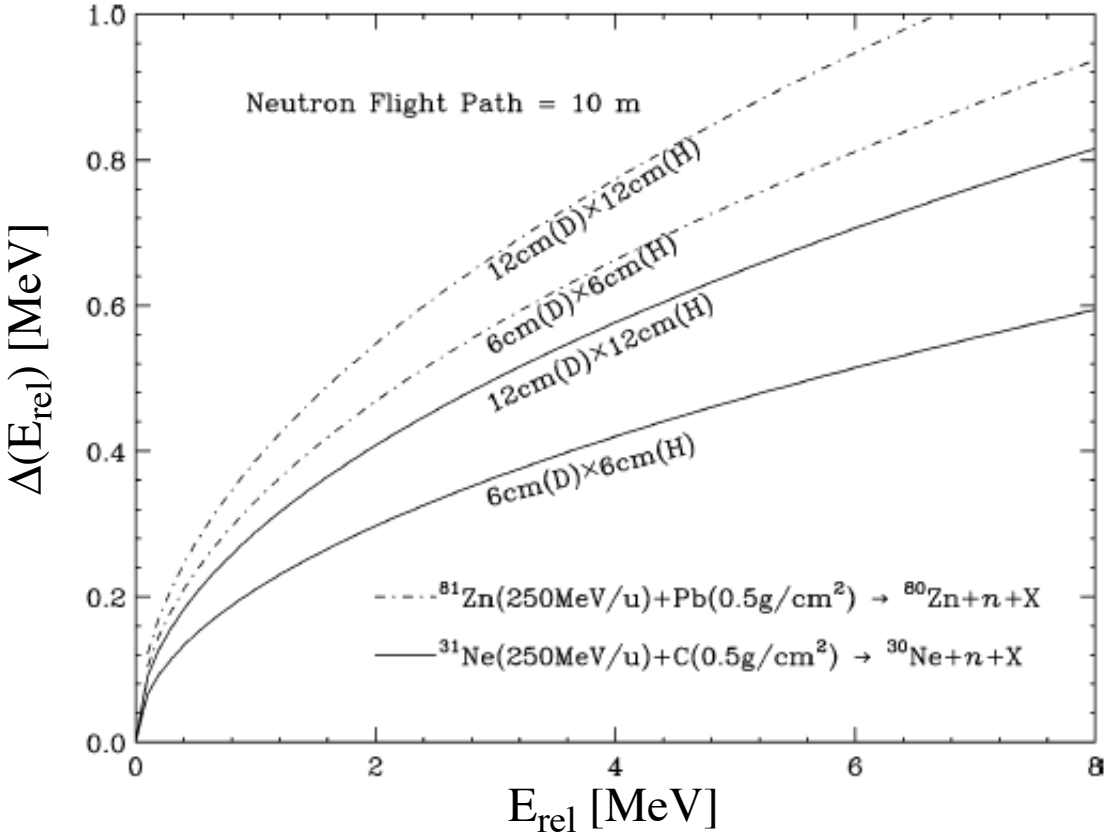
sub total 570 MY

backgrounds from gas-cell materials (^{16}O, ^{28}Si)

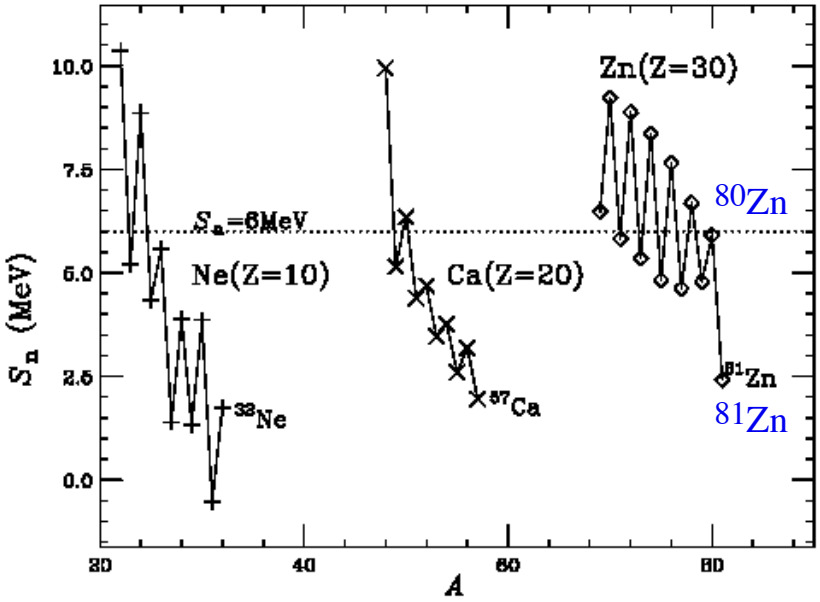




E_{rel} resolution



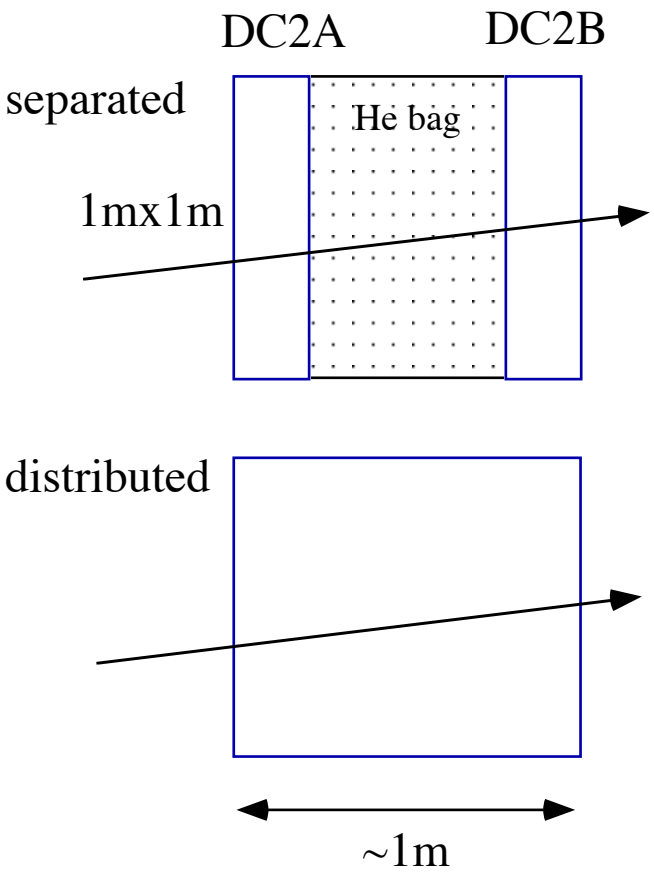
EMD: pilot experiment around N=50



	^{80}Zn	^{81}Zn
Z=28	^{78}Ni	

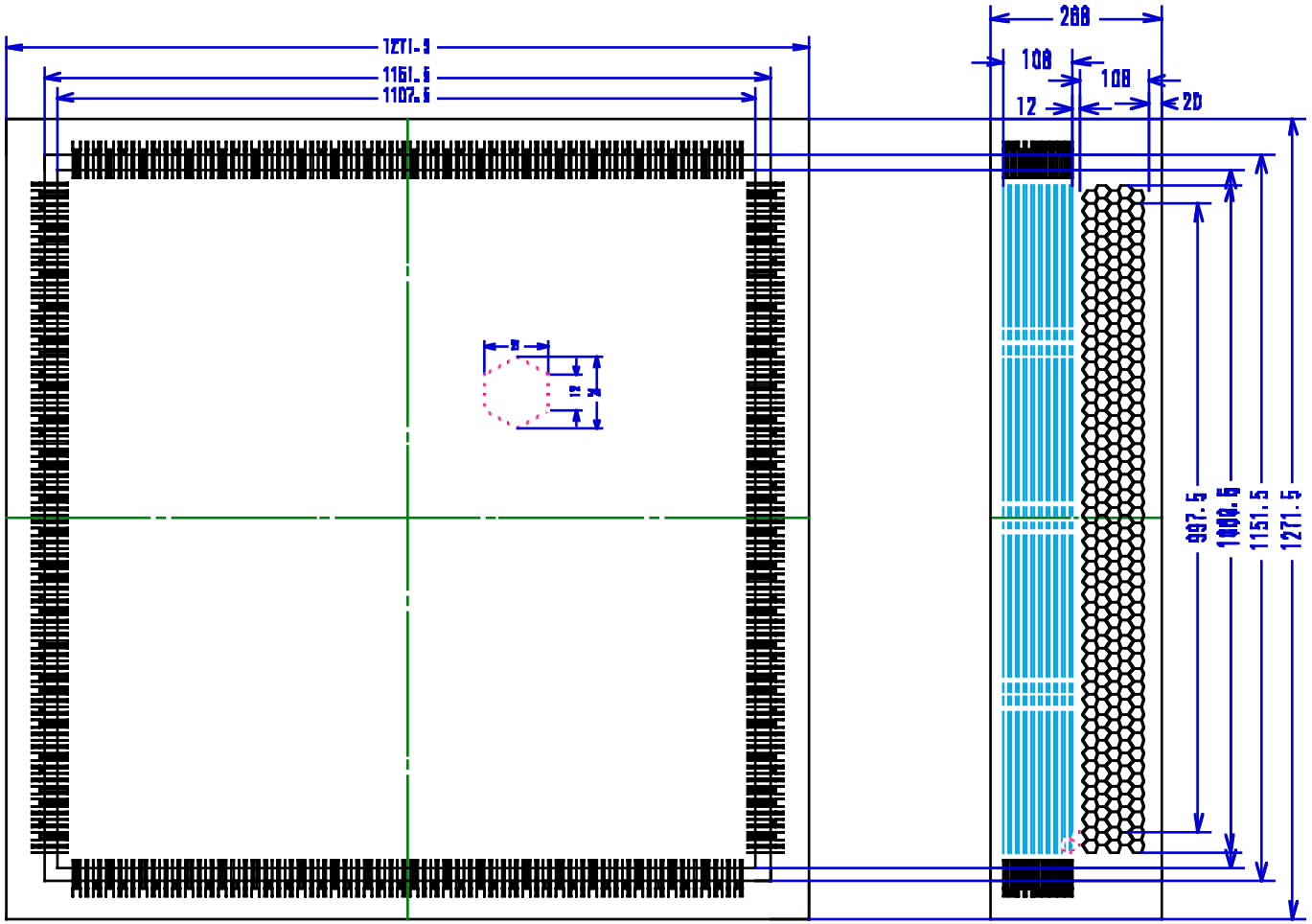
N=50

Downstream drift chamber

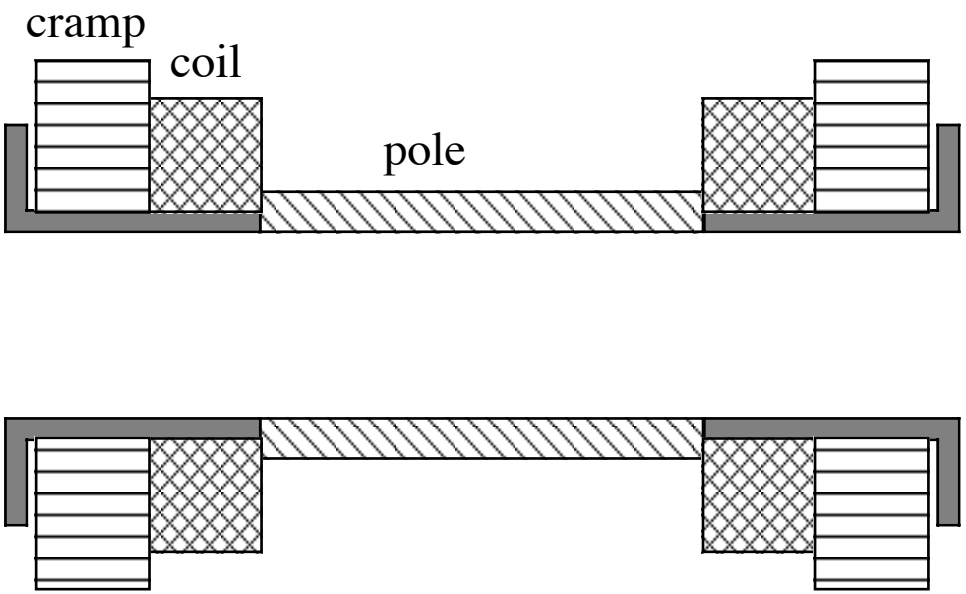


Example

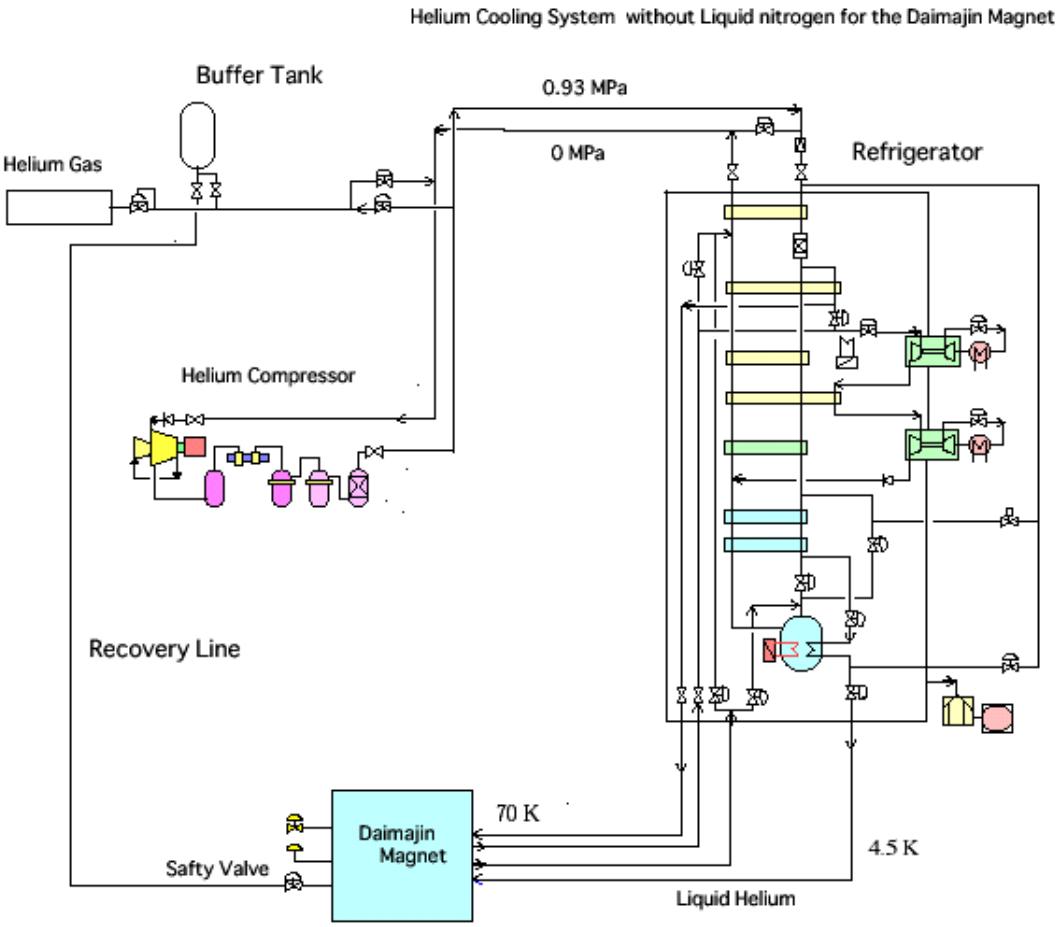
effective area :	1m x 1m x 30cm^t
cell:	hexagonal, L=10.5mm
readout:	48 anodes/plane, 480 anodes/chamber
configuration:	xx'xx'x, yy'yy'y
thickness:	L/Lr ~ 0.8 x 10^{-3}

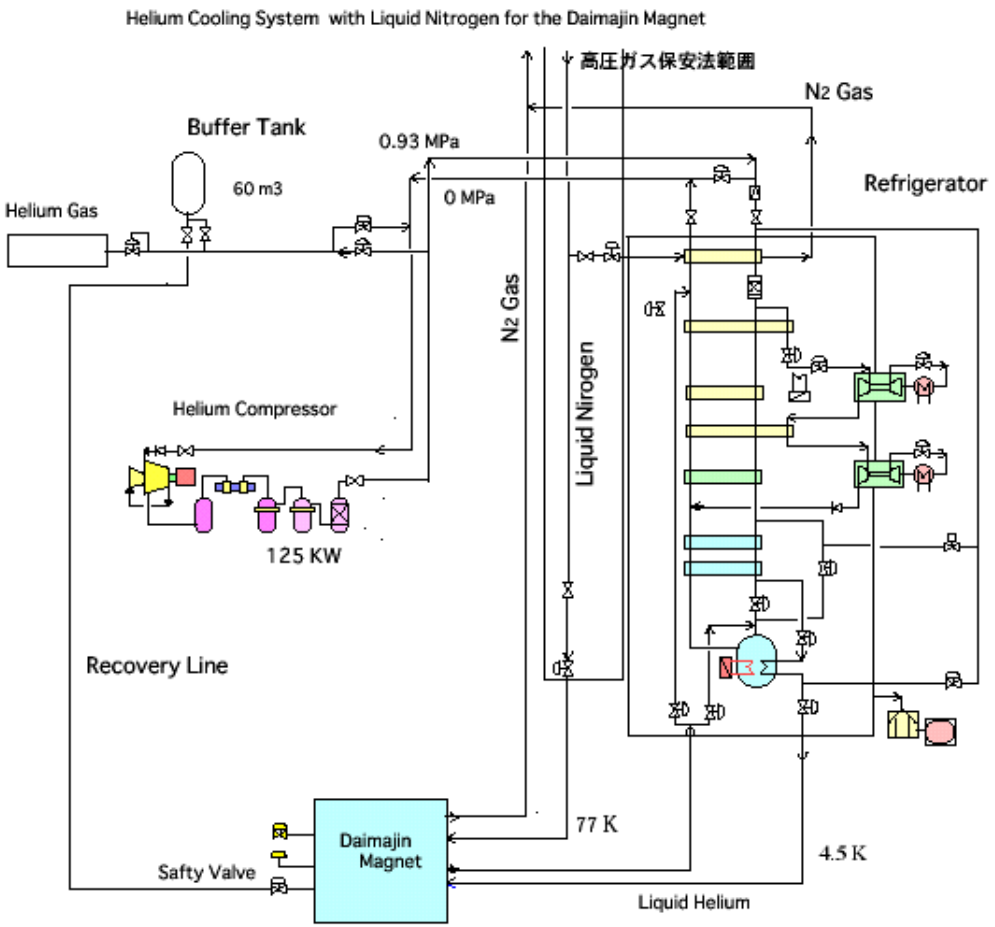


Built-in vacuum chamber



Cooling system for DAIMAJIN





	ZDS	SHARAQ	
Rmax [GeV/c]	2.2 - 2.7	2.04	
Angle [mrad] H x V	±45 x ±30	±30 x ±100 (12msr)	
Mom. Acceptance [%]	±3	±3	
Δp/p	1/1240 - 1/4130	1/15000	
Mom. dispersion [cm/%]	2.24 - 4.13	10.2	
Total length [m]	36	19	
Weight [t]		>400	

$$L \Big/ L_R \approx 10^{-3},\ 250\text{MeV/A} \rightarrow \sigma_{mcs} \approx 0.7 \frac{Z}{A}[\text{mrad}]$$