Large-Acceptance Multi-Particle Spectrometer

Samurai(7)

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

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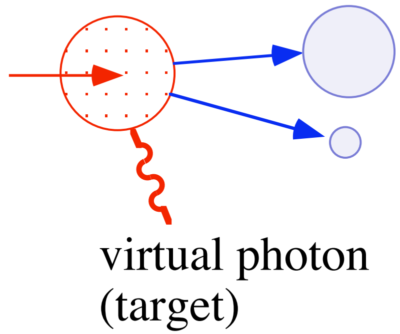
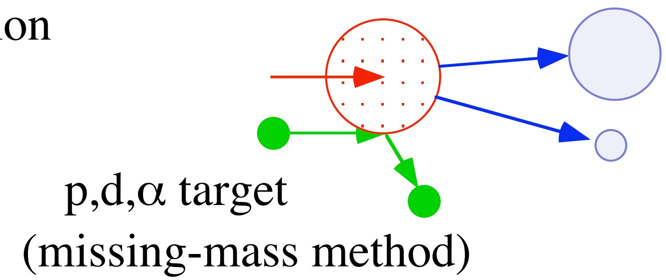
[1] Physics Subjects

(1) Electromagnetic Dissociation (EMD)



with Invariant-mass method

(2) p,d,α-induced Scattering/Reaction



tagging

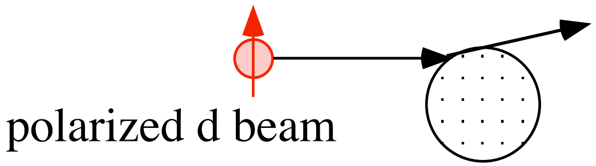
the decay of residual nucleus

(with Invariant-mass method)

(3) Polarized deuteron-induced Reaction

few-nucleon systems

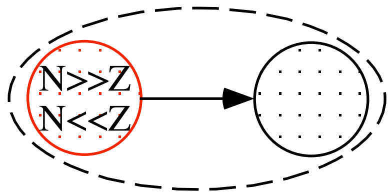
large momentum acceptance



(4) Multi Fragmentation

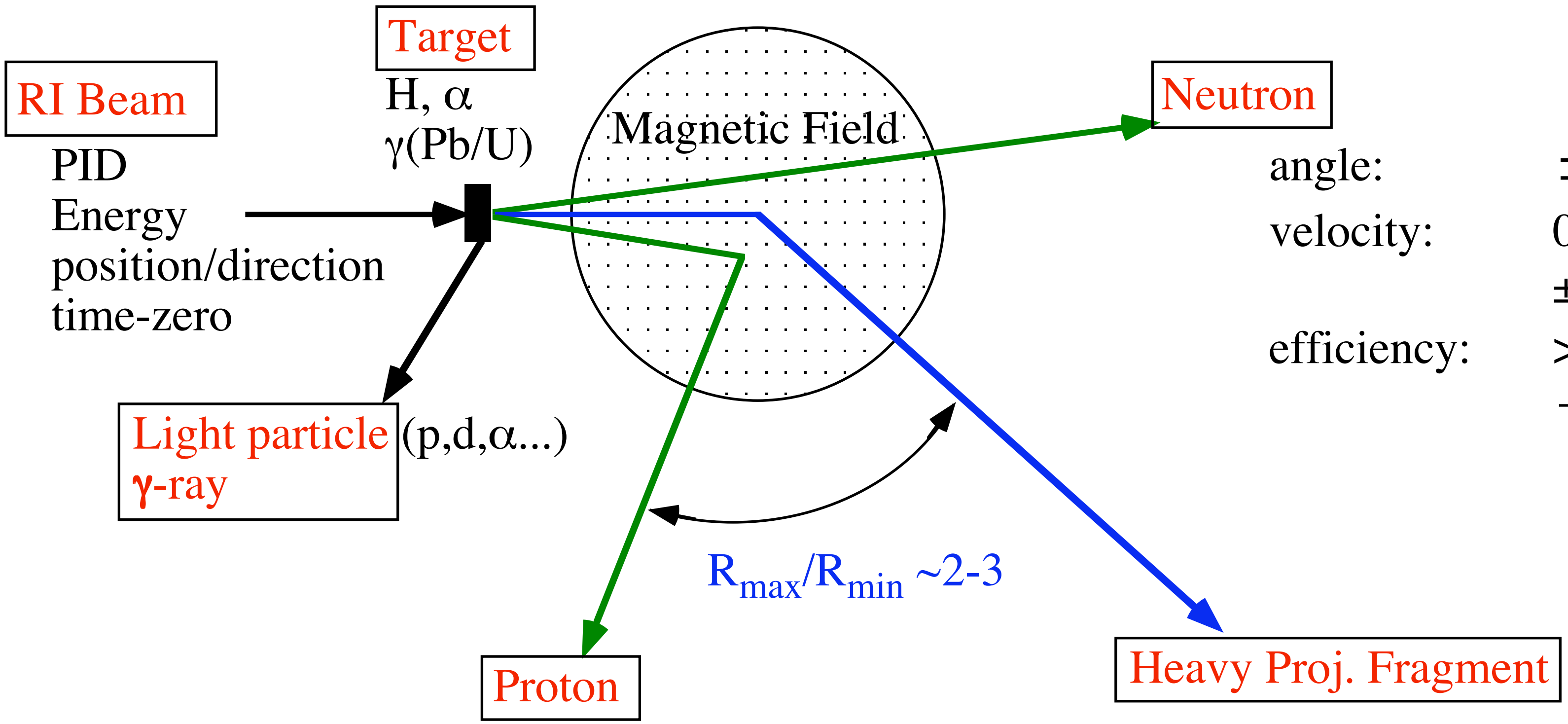
EOS studies

large magnetic volume



[2] Required Measurements

groups, range, accuracy



Neutron

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

Proton

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

Heavy Proj. Fragment (250MeV/A A/Z=3)

	[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	$\sigma_Z \sim 0.2$
velocity:	0.62	$\sigma_\beta/\beta \sim 10^{-3}$

[2-1] 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: $Q=Z$ (fully stripped) + primary beam energy

→ RI beam energy: < 250 - 350 MeV/A
Mass number: < 100

Mass identification

$$\frac{\sigma_A}{A} = \sqrt{\left(\frac{\sigma_R}{R}\right)^2 + \left(\gamma^2 \frac{\sigma_\beta}{\beta}\right)^2 + \left(\frac{\sigma_Z}{Z}\right)^2} \qquad \frac{\sigma_A}{A} = \sqrt{\left(\frac{\sigma_R}{R}\right)^2 + \left(\frac{\sigma_Z}{Z}\right)^2 + \left(\frac{\gamma}{\gamma+1}\frac{\sigma_E}{E}\right)^2}$$

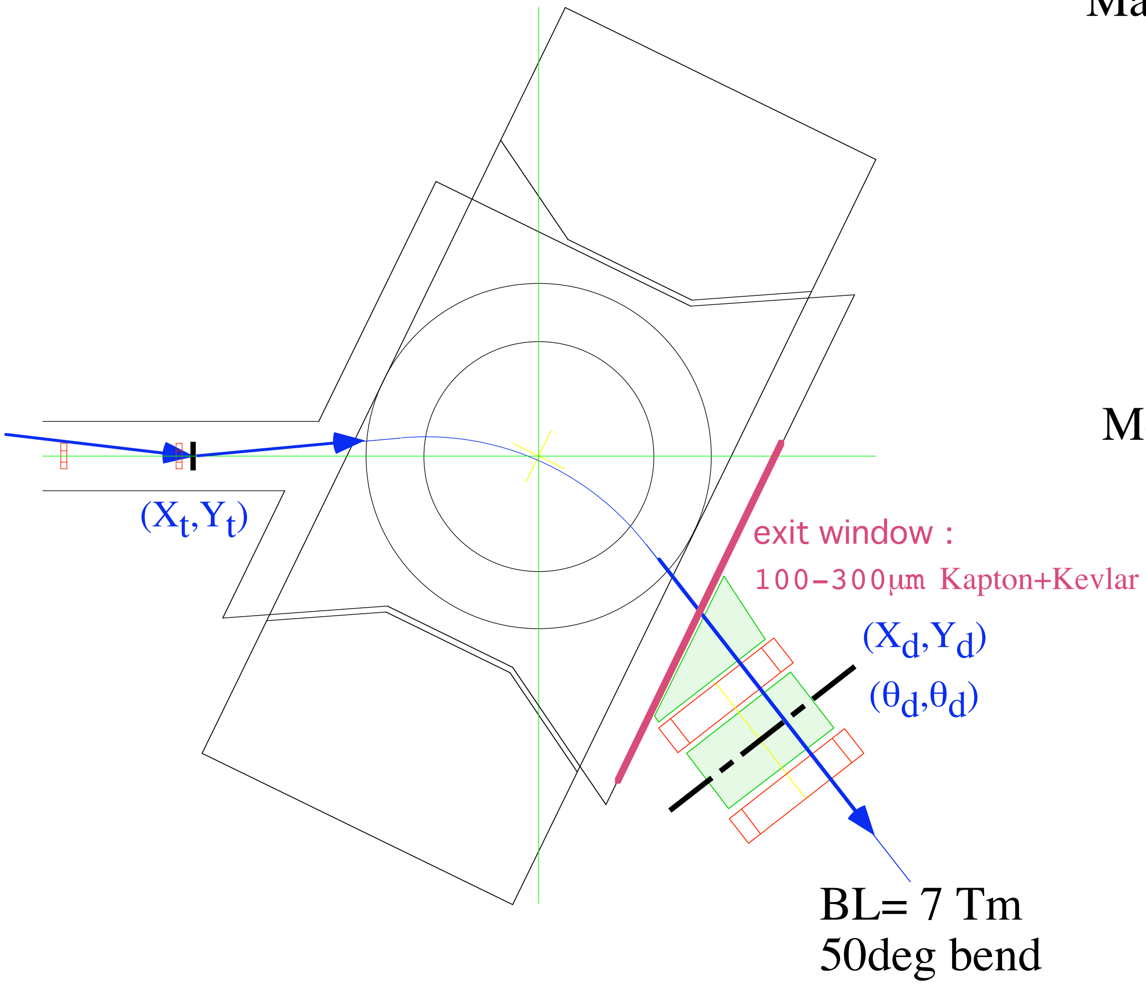
$\frac{\sigma_A}{A} = \frac{0.2}{100} \approx \frac{1}{500}$ → magnetic rigidity $\frac{\sigma_R}{R} \leq \frac{1}{700}$ $@R = 2.2$ GeV/c ($A/Z = 3$, 250MeV/A)

velocity $\frac{\sigma_\beta}{\beta} \leq \frac{1}{1100}$ ↔ $\sigma_T \approx 50\ psec \quad @\ L = 10\ m \quad \beta \approx 0.6$

or

energy $\frac{\sigma_E}{E} \leq \frac{1}{400}$ for E_{tot}=30GeV (0.3GeV/A x 100)

charge $\sigma_Z \approx 0.2$



Matrix: A/Z=3, 250 MeV/A (2.2GeV/c)

$D \approx 2.0 cm/\%$ $\quad D' \approx 7.9 mrad/\%$

$(x|\theta) \approx 0.32 cm/\%$ $\quad (\theta|\theta) \approx 0.12$

$D_{eff} = (\theta|\theta) D - (x|\theta) D' \approx -2.3 cm/\%$

Momentum Resolution:

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

$\sigma(x_D) \approx 0.3 mm,$

$\sigma(x'_D) \approx 1 mrad,$

$\sigma(x_T) \approx 0.5 mm$

⟷ $\dfrac{\sigma_p}{p} \approx \dfrac{1}{770}$

minimum requirements

[3] Magnet Design

Requirements | method

Experimental side

(1) Large field integral :	high precision momentum analysis	
(2) Large magnet gap :	large vertical acceptance for neutrons	Built in vacuum chamber
(3) No coil link :	large acceptance (space) in the horizontal direction	
(4) Small fringing field :	detectors in the target region & tracking detectors	Field cramp
(5) Flexibility :	various experimental configuration	Rotatable base
(6) Large momentum acceptance :	heavy fragment & protons in coincidence	(Hole in return yoke)
(7) High Momentum resolution :	<1/700 with broad-range spectrometer	
	<1/3000 for d-induced reactions	Q3D option

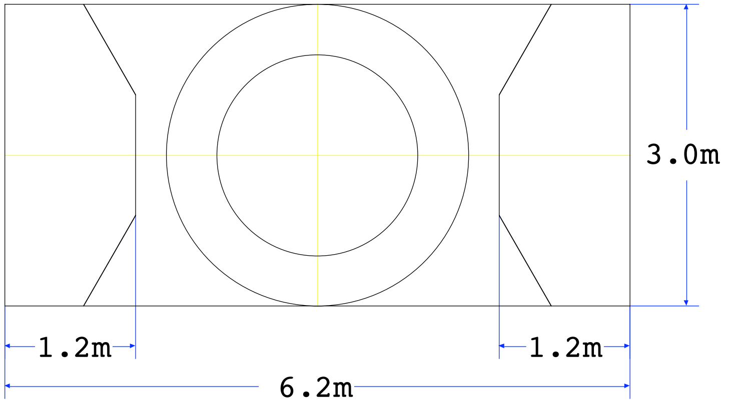
Magnet construction

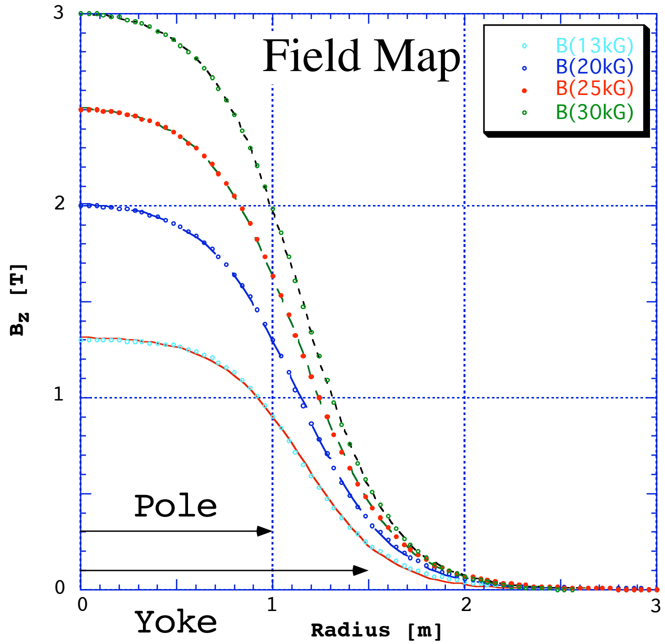
(1) Simple structure :	
(2) Cryostat similar to SRC :	proved/existing technology
(3) Utilize available superconductor :	reduce cost
(4) Utilize avalilable system :	TCF30 cryogenics

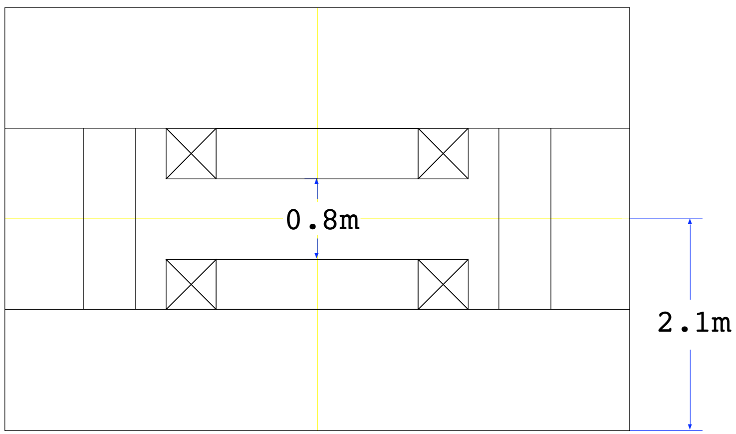
H-type superconducting magnet with round pole/coil (similar to HISS)

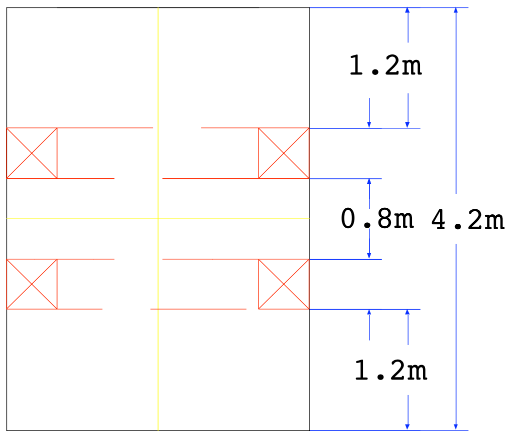
starting point : H-type round pole magnet w/o field cramp ~HISS (gap=1m)

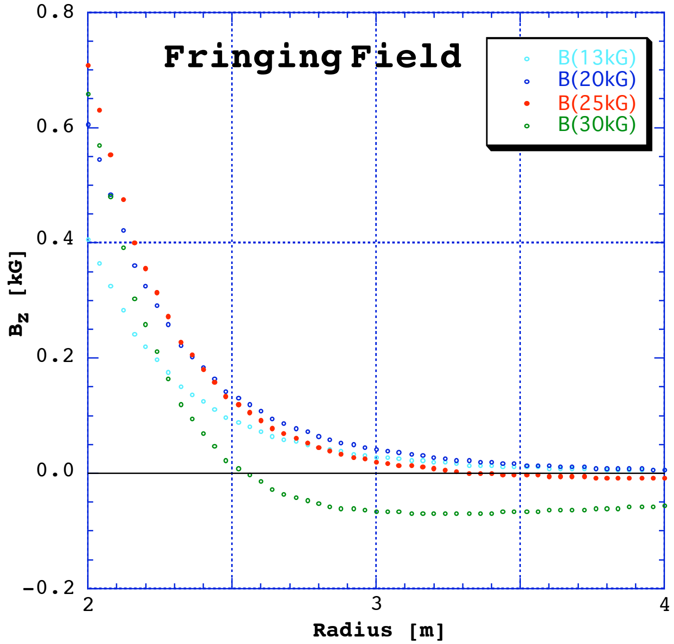
Pole:	Diam 2 m, Gap 0.8 m
Field:	3 T @3.6 MAT
Stored E:	28 MJ
BL:	7 Tm
Weight:	~500 ton
Vertical F.:	~650 t(w/o coil link)





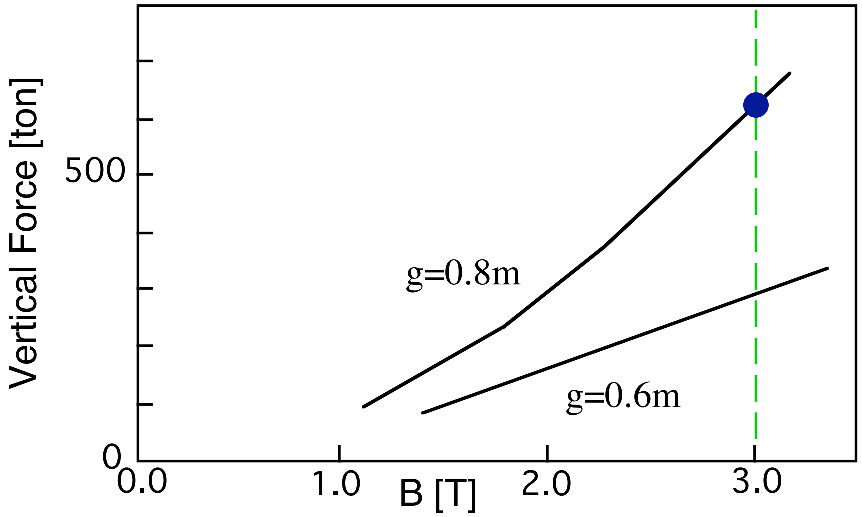






Magnet Gap

(1) Vertical force



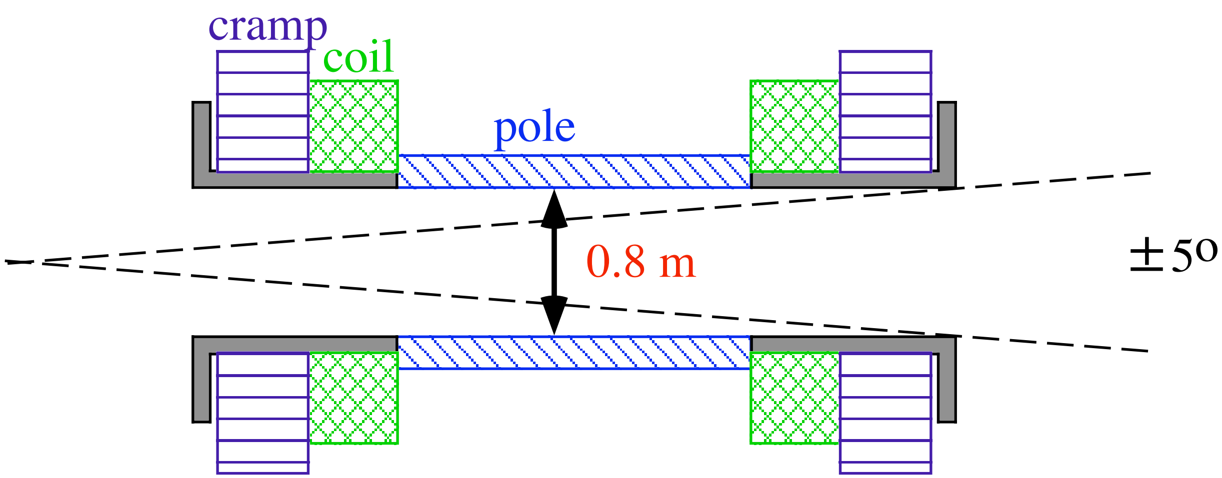
(2) Expansion force

200 ton/m
self support possible

no coil link
for large horizontal acceptance

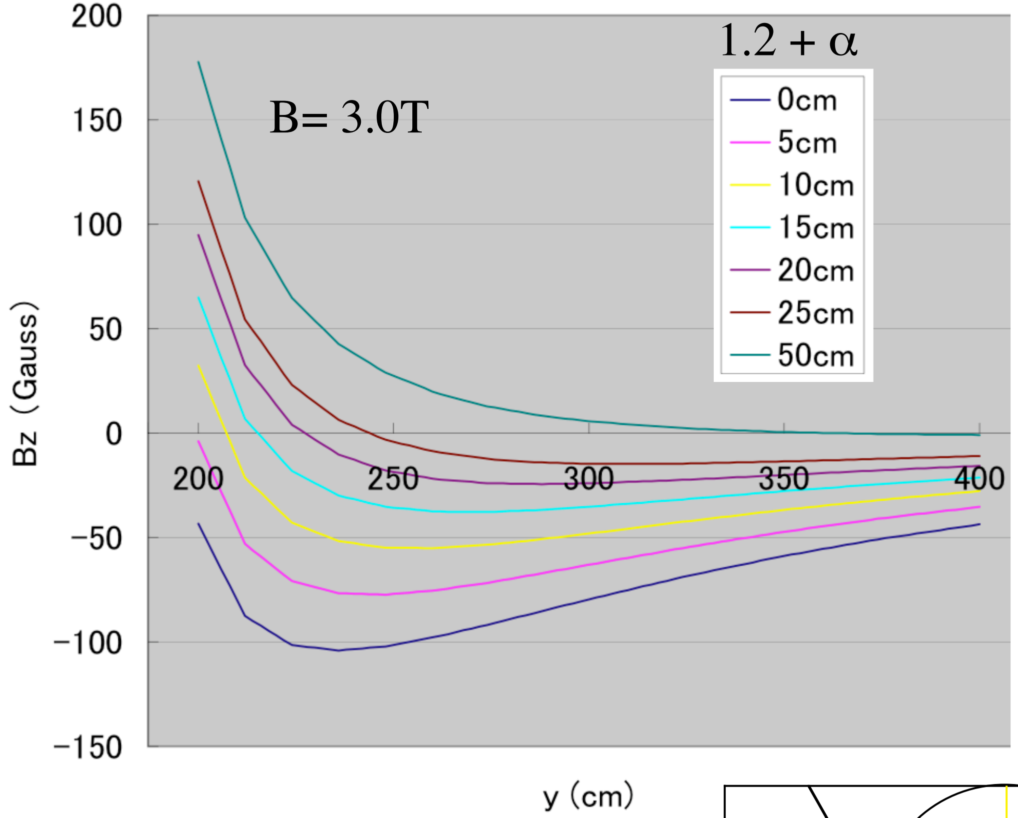
(3) Utilize gap

built-in vac. chamber, by welding

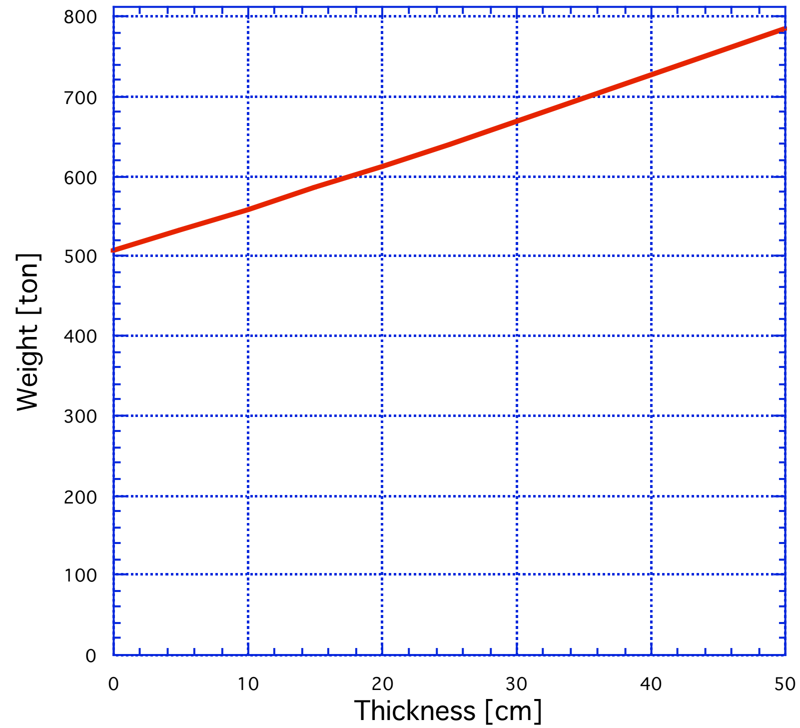


Return Yoke Thickness

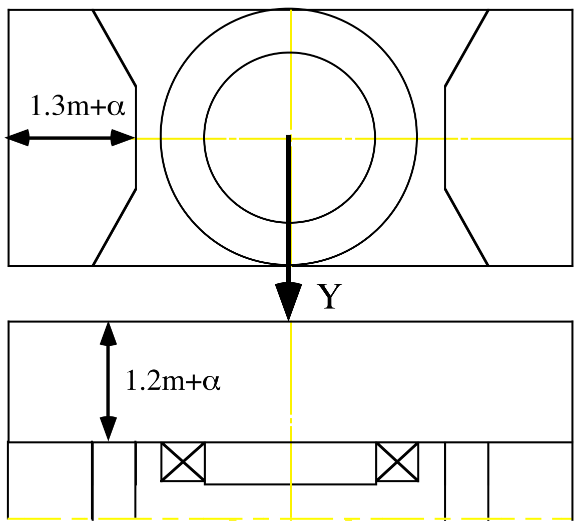
Fringing Field : Yoke thickness dep.



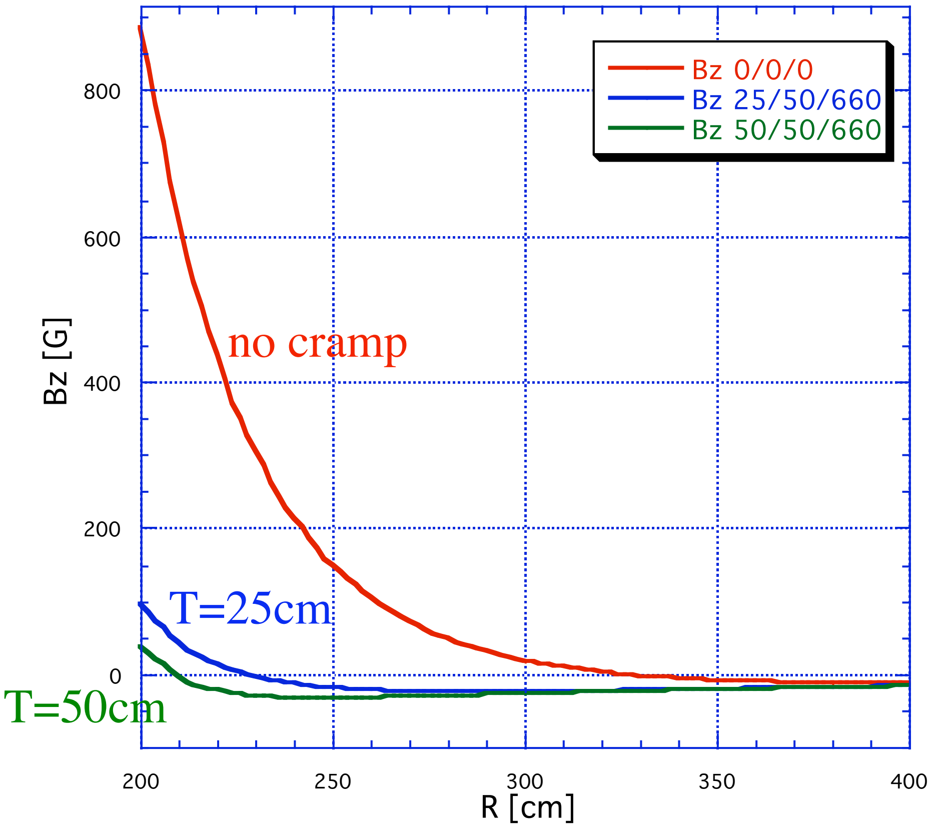
Weight

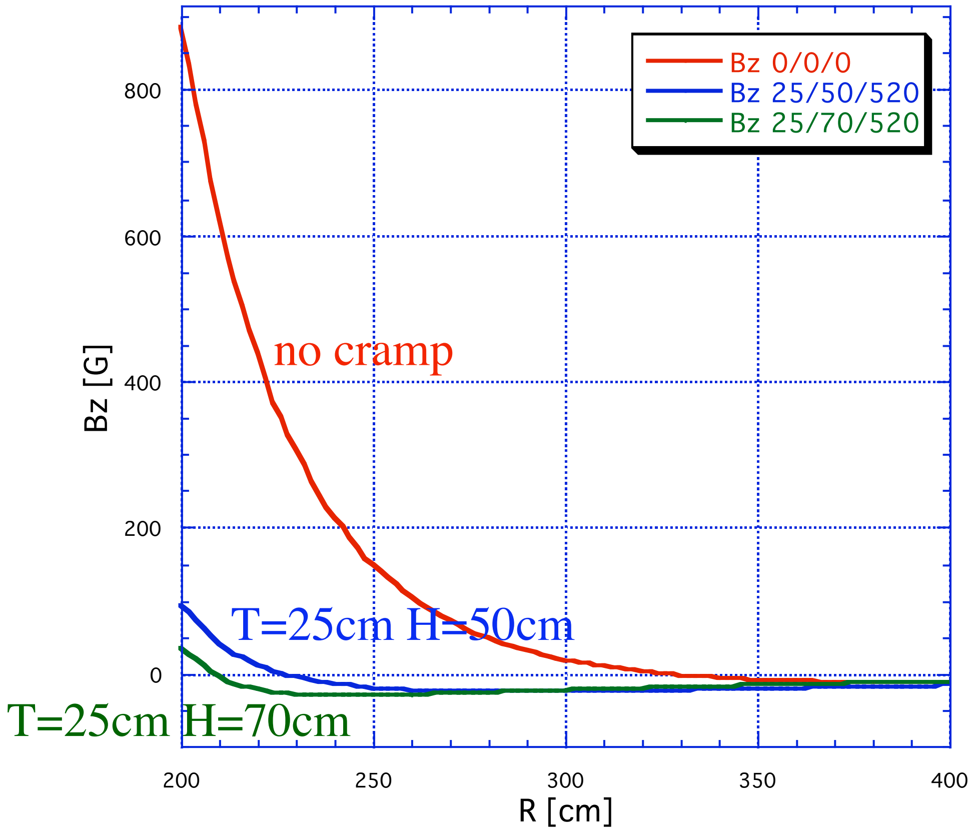


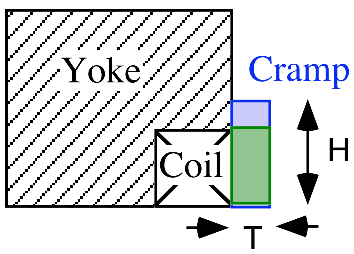
→ + 20cm



Fringing Field : Field cramp thickness/height dep. @B= 3.0T





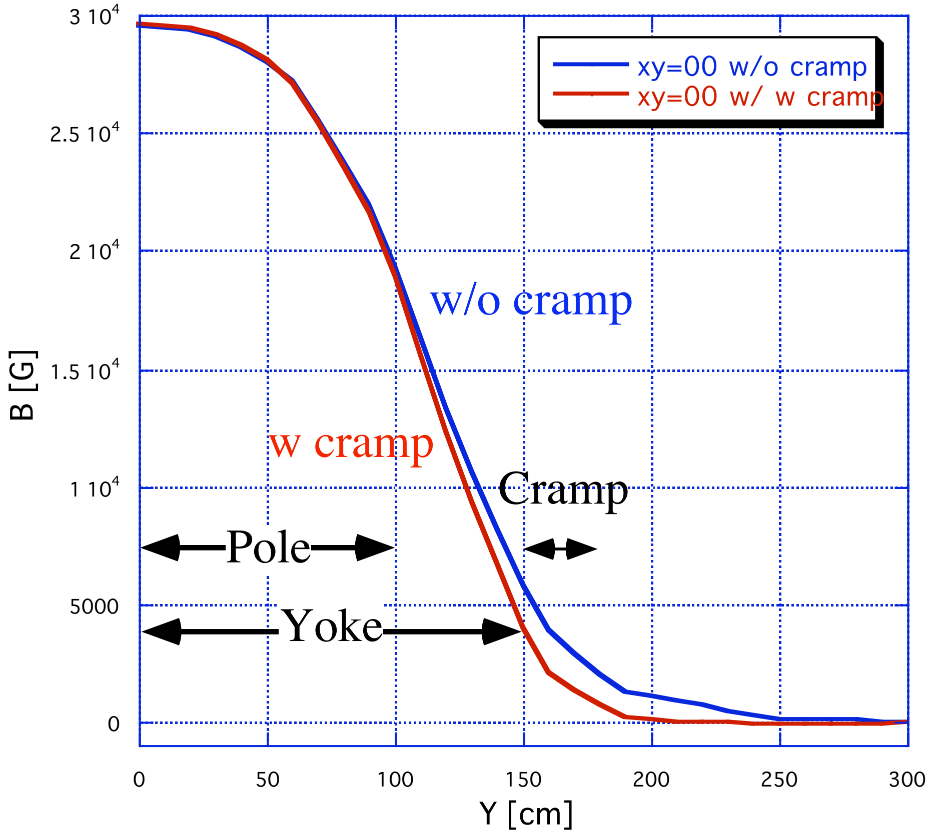


→ T=25cm H=70cm

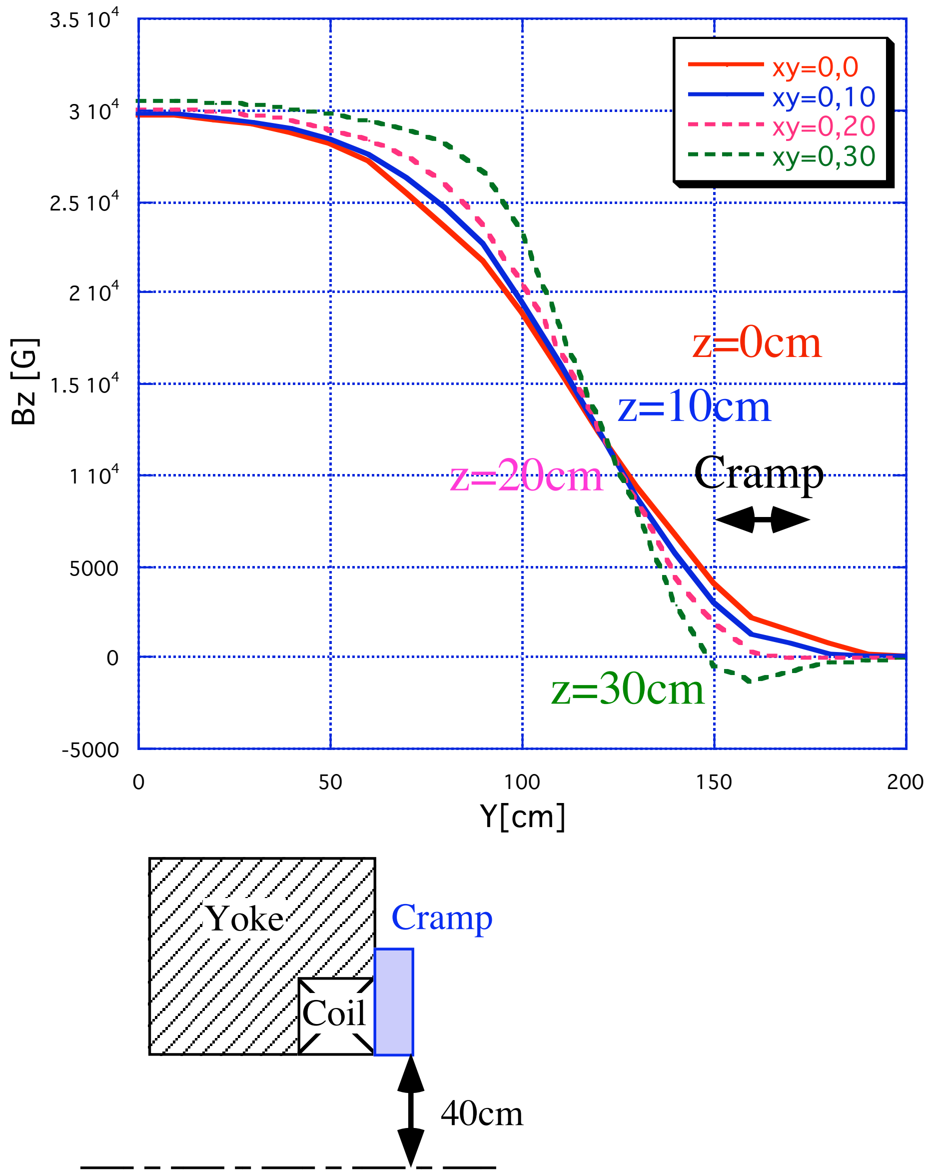
Bz < 30 G

Magnetic Field @B= 3.0T

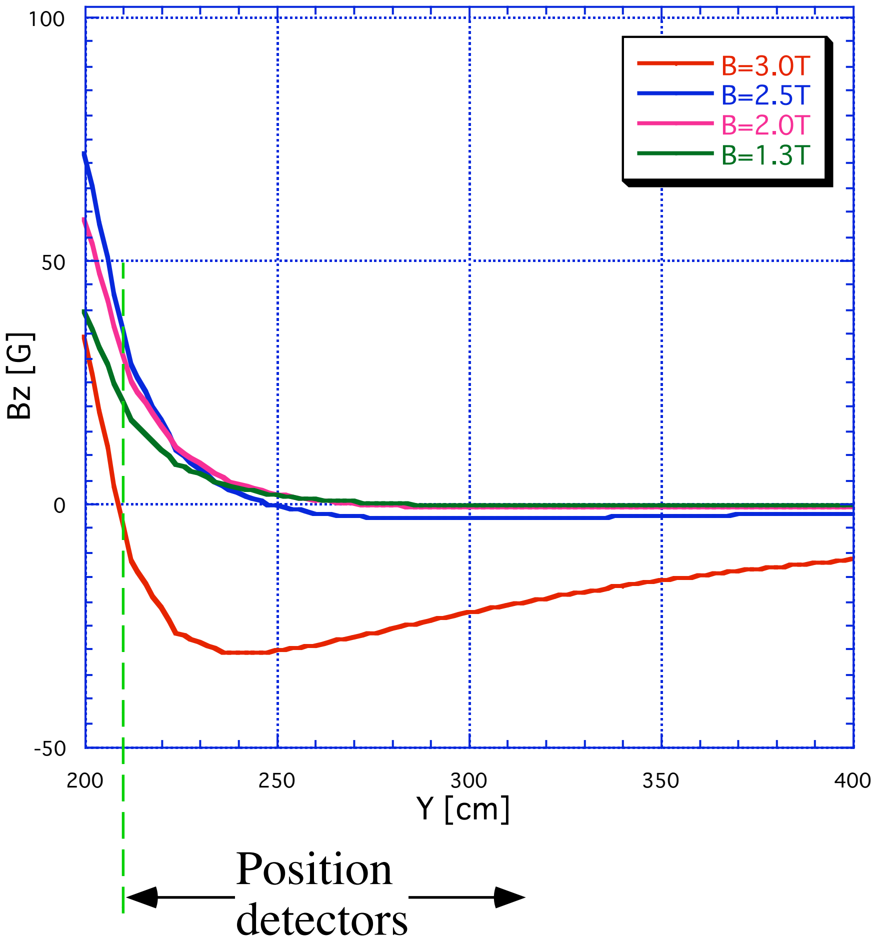
Mid plane (z=0)



Vertical pos.(z) dep.



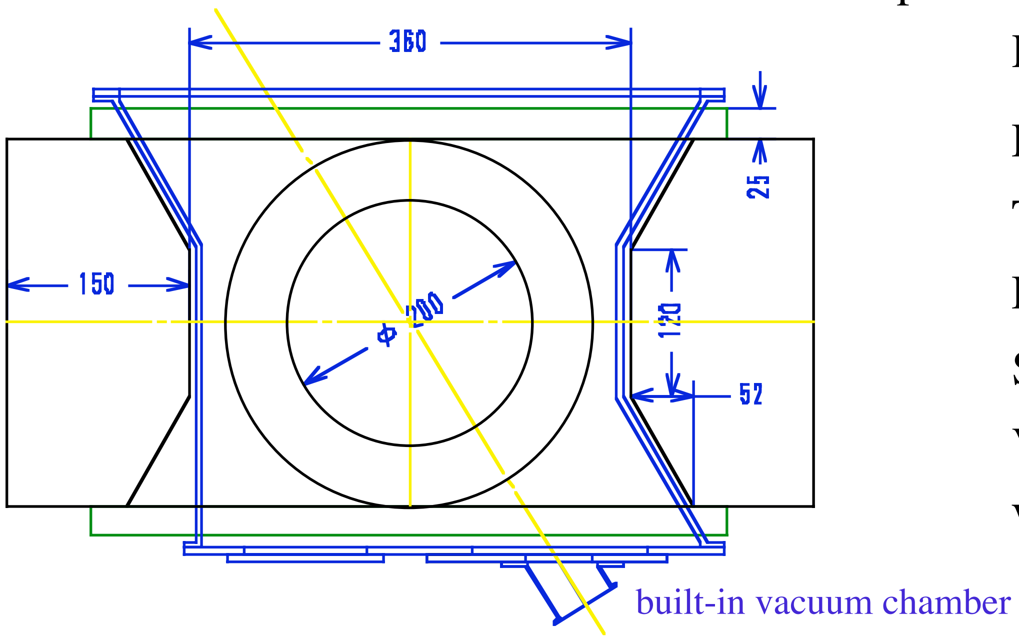
Fringing Field : B_{max} dep.



BL (2.0<Y<3.0)= 0.002 Tm @B=3.0T

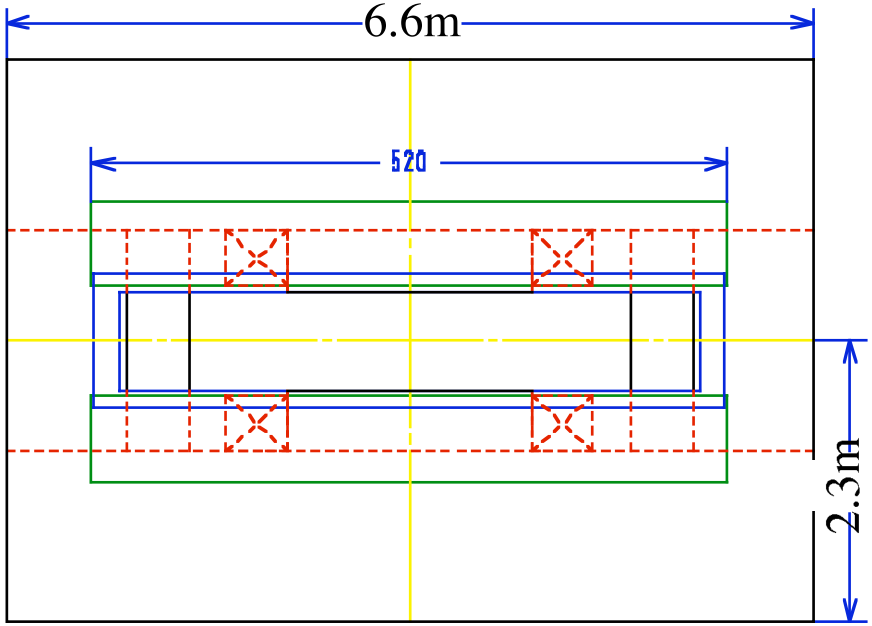
↔ $\theta_{bend} < 0.3$ mrad

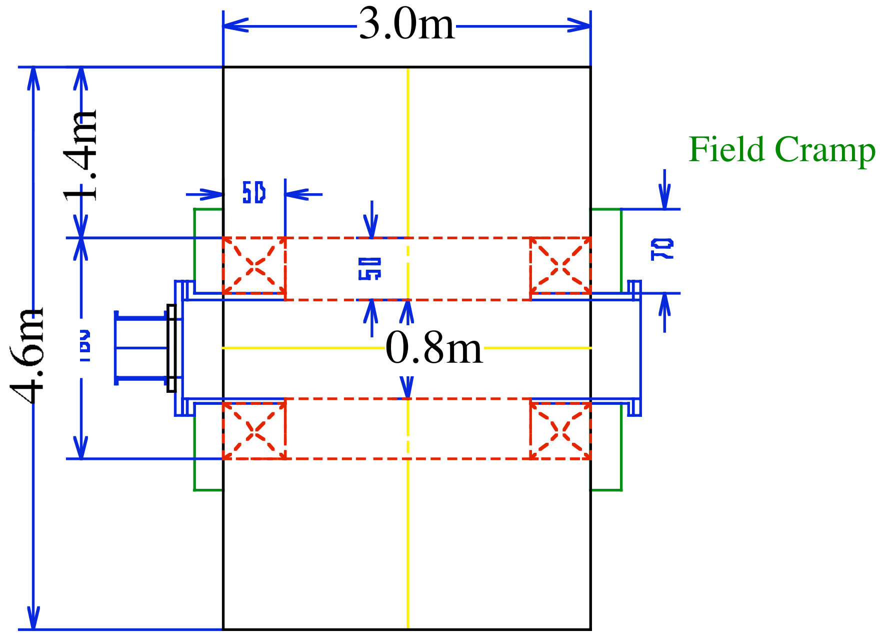
Spectrometer Magnet：



parameters

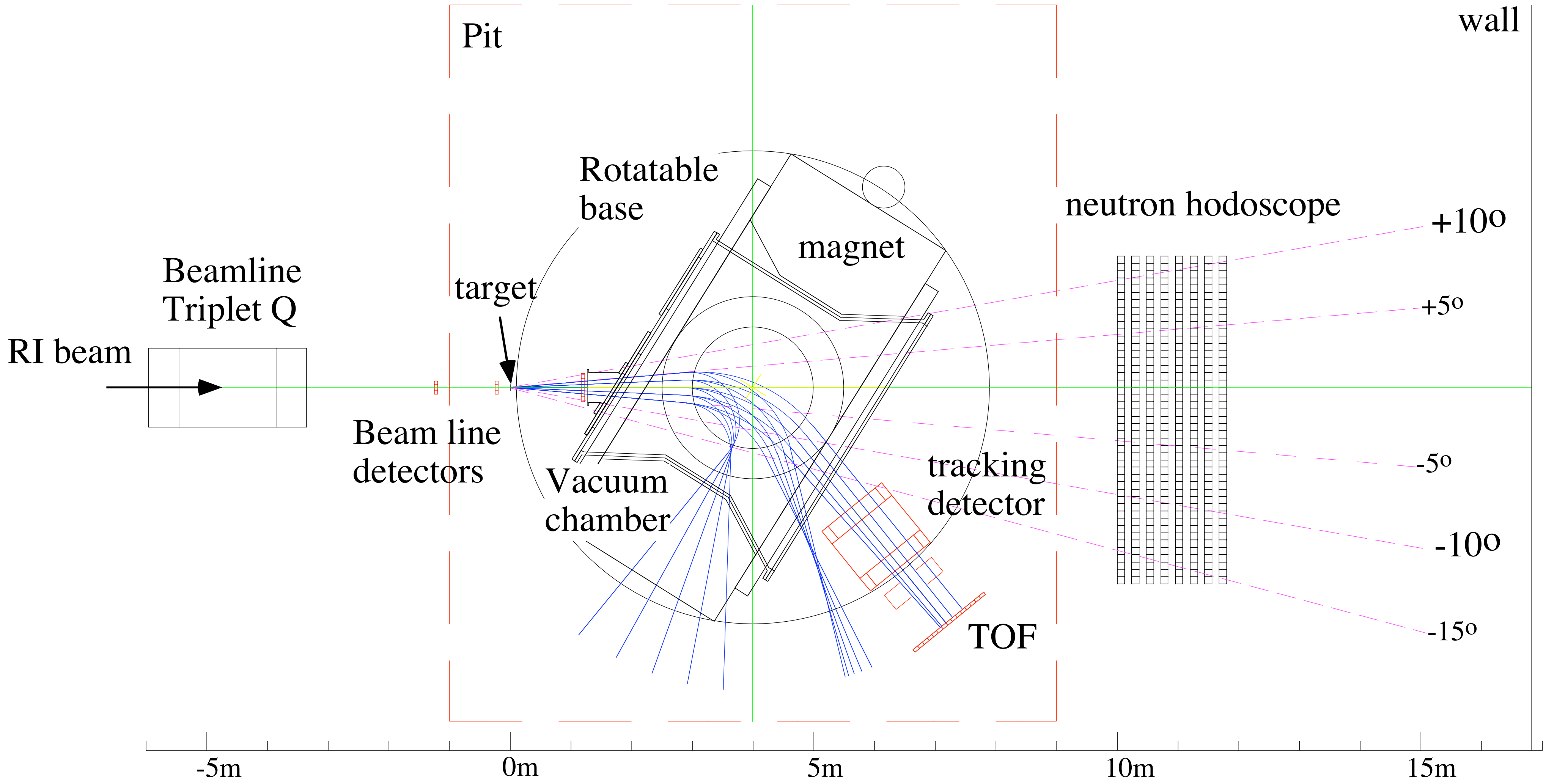
Pole:	2m diam., 0.8m gap
Field:	3 T @3.6 MAT
Turns/current:	396x2 turns / 4600 A
Field integral BL:	7 Tm
Stored energy:	28 MJ
Vertical force:	650ton
Weight:	611 ton +coil/cryostat





Setup for (γ,n) reaction

plan view Z_T=-4m



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

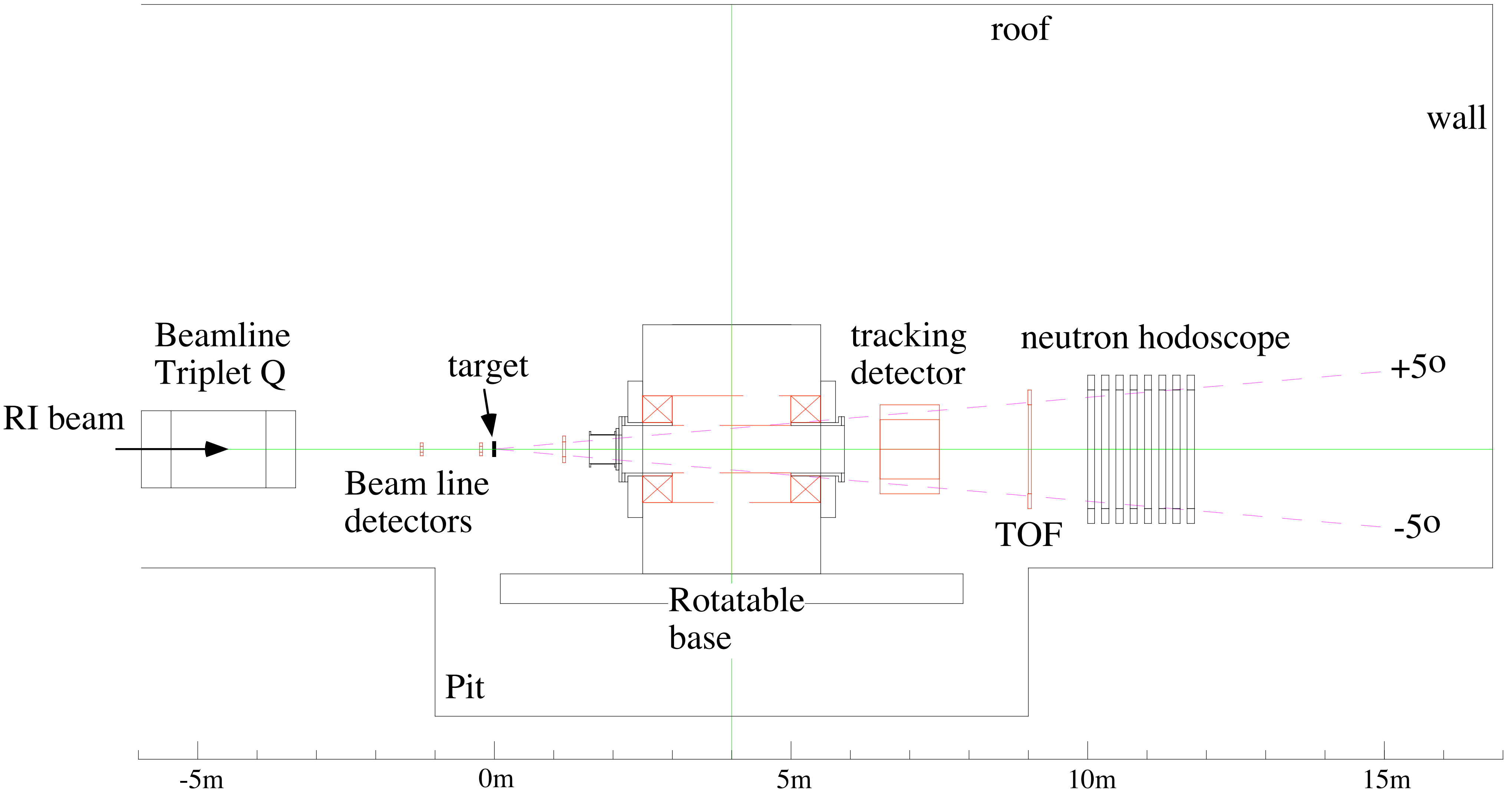
A/Z=1
0.73GeV/c

A/Z=2
1.45GeV/c

A/Z=3
2.2GeV/c

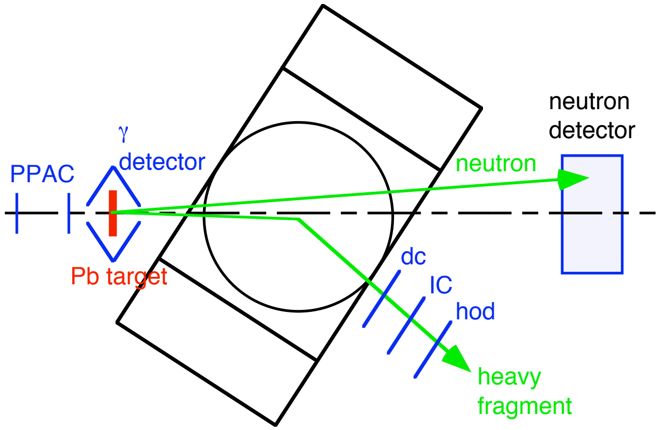
Setup for (γ,n) reaction

side view Z_T=-4m

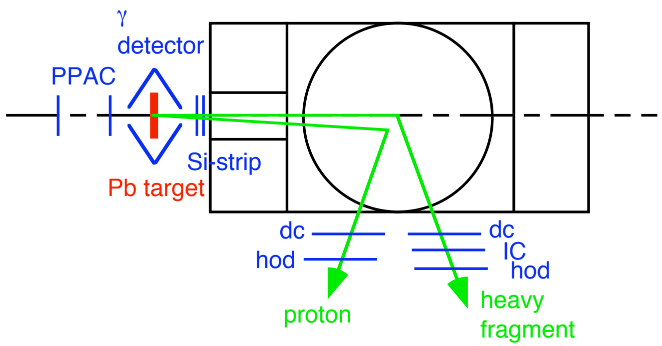


Experimental Setup : various Configurations

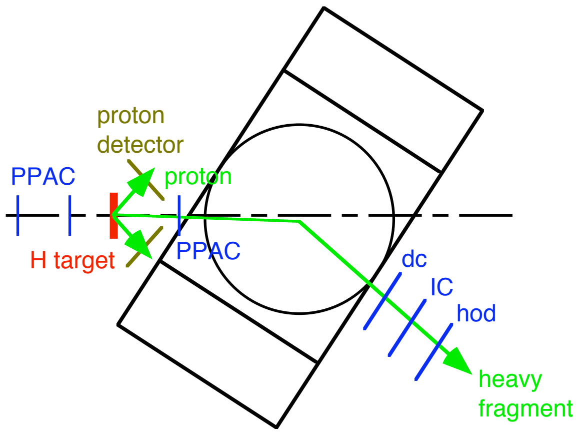
(γ,n) reaction: neutron-rich side



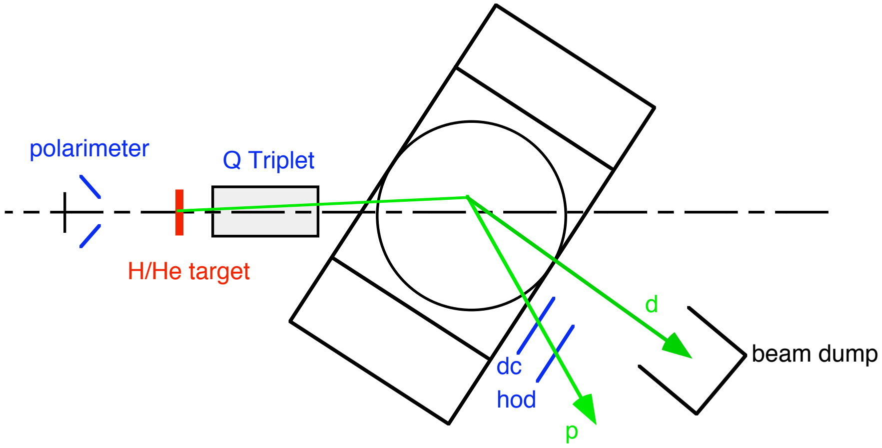
(γ,p) reaction: proton-rich side



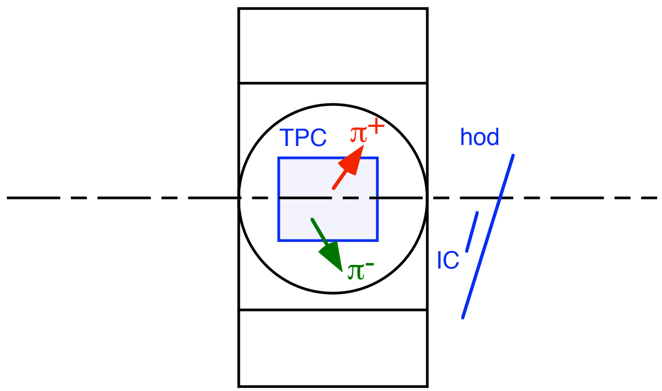
(p,p'), (p,2p) etc.



Pol. d-induced reaction

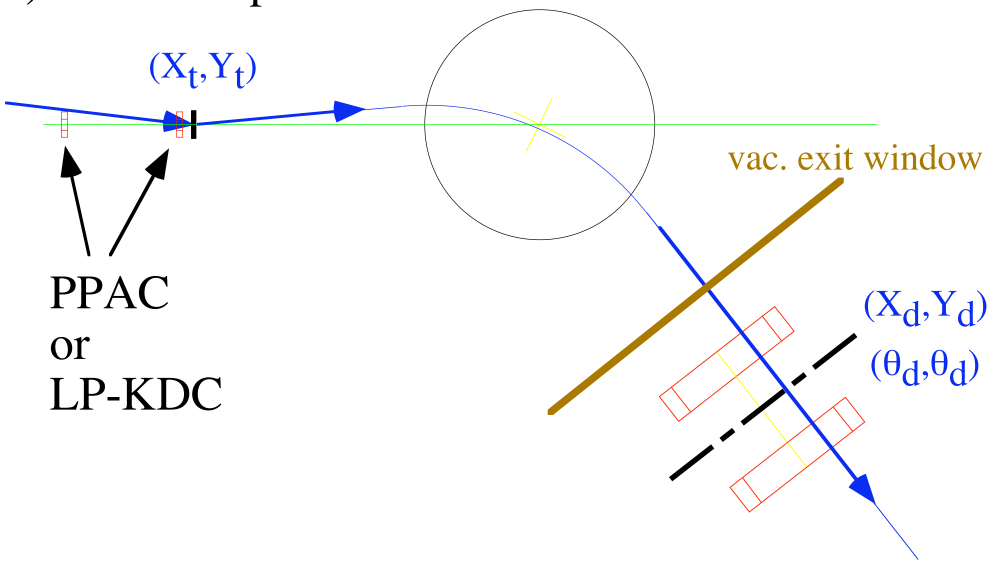


EOS measurement



[4-1] Rigidity Analysis

(1) Basic setup



1 mrad (rms) angular resolution

↓

Downstream tracking detectors

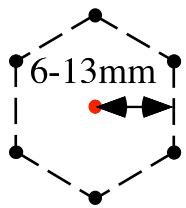
- good position resolution $\sigma \leq 200 \mu m$
- thin $\frac{L}{L_R} \leq 10^{-3}$
- large incident-angle variation

cell with rotational sym.

Drift chamber with hexagonal (square) cell

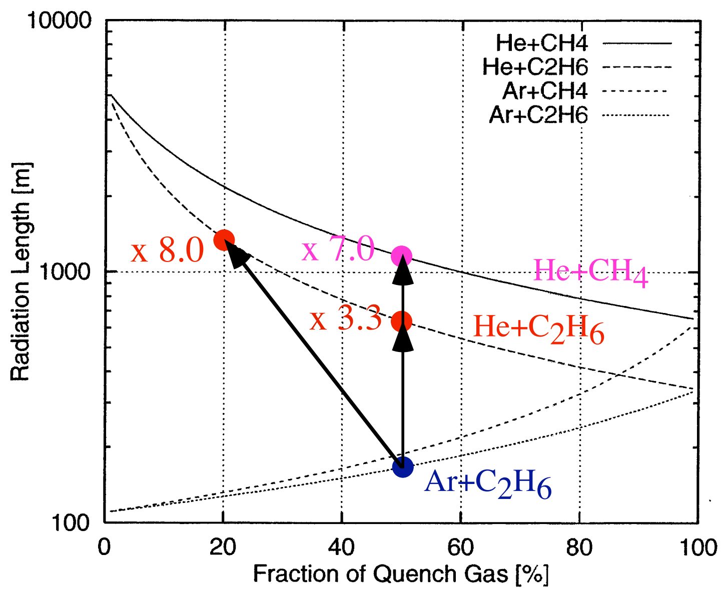
number of wires : minimum

field : rotational symmetry



He-based gas mixture

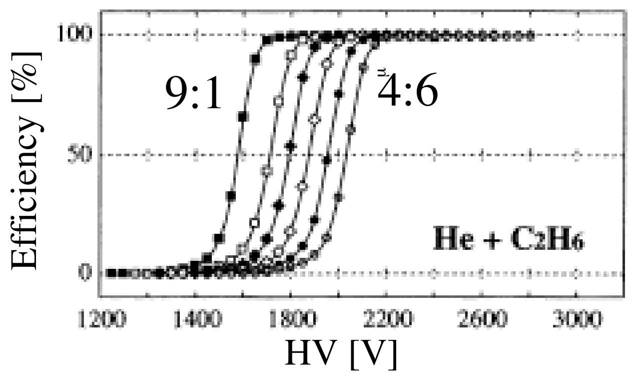
low-mass / Z : reduce multiple Coulomb scattering



Hexagonal D.C. (He+50%C_2H_6 @1atm)

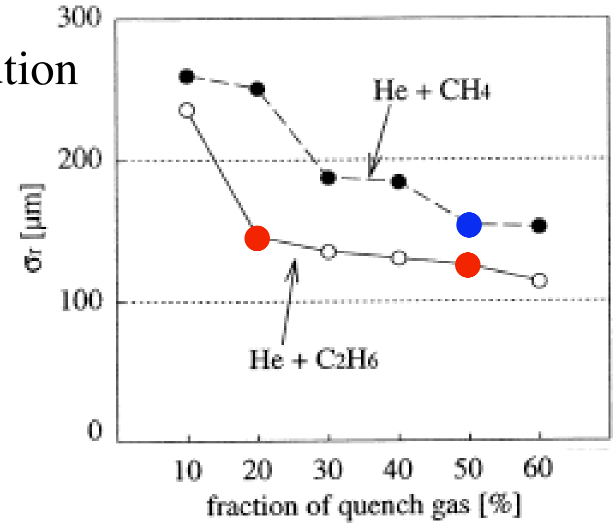
(1) Minimum Ionizing particles (μ)

Efficiency

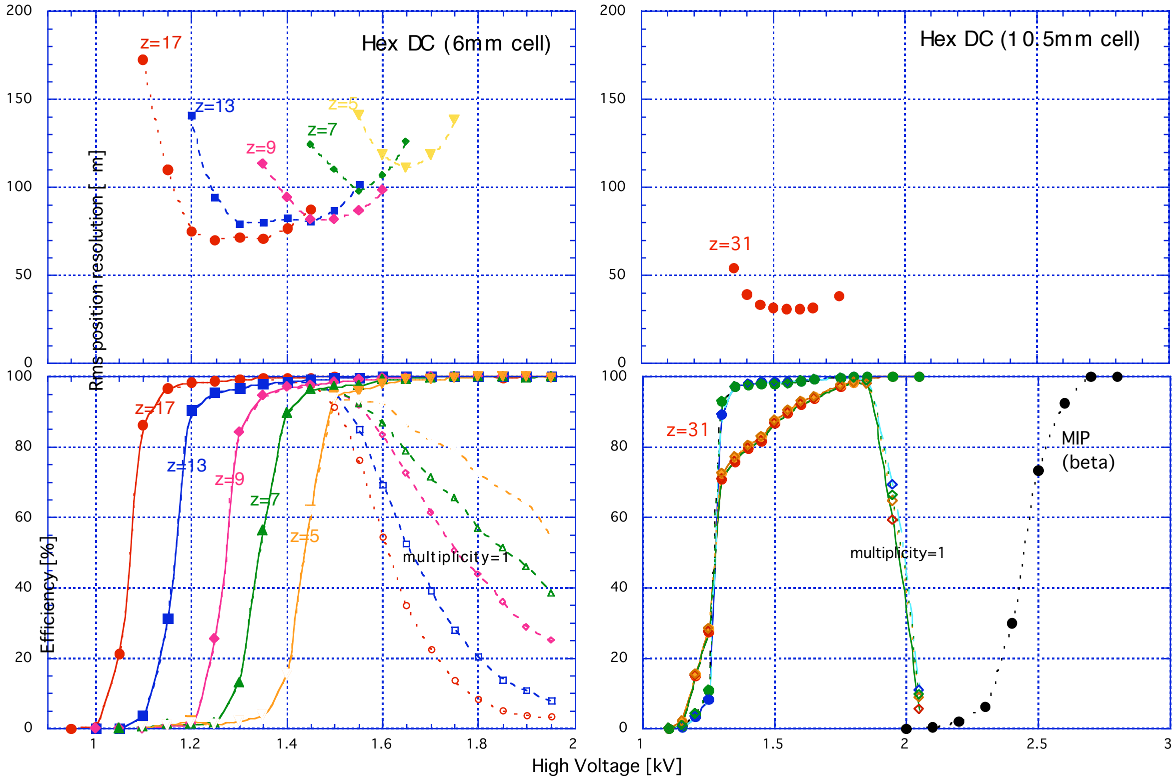


6mm cell

Position Resolution



(2) Heavy Ions @250-300MeV/A : 2MIPxZ^2



→ Downstream D.C.

Hex structure

xx'xx'xx'yy'yy'yy'

with shield planes

$$\frac{L}{L_R}(\mathrm{wire+window}) \approx 1.7\times10^{-4}$$

$$\frac{L}{L_R}(\mathrm{gas25cm}) \approx 4\times10^{-4}$$

Possible improvements : Hexagonal D.C. at low pressure

(1) avoid thick exit window :

Kapton/Kevlar 200-300μm^t (L/Lr~10^{-3})

operation in vacuum chamber

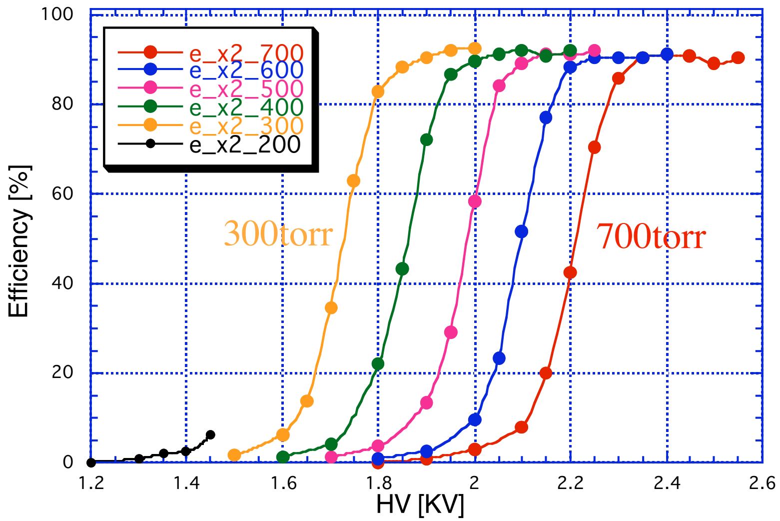
(2) reduce mass

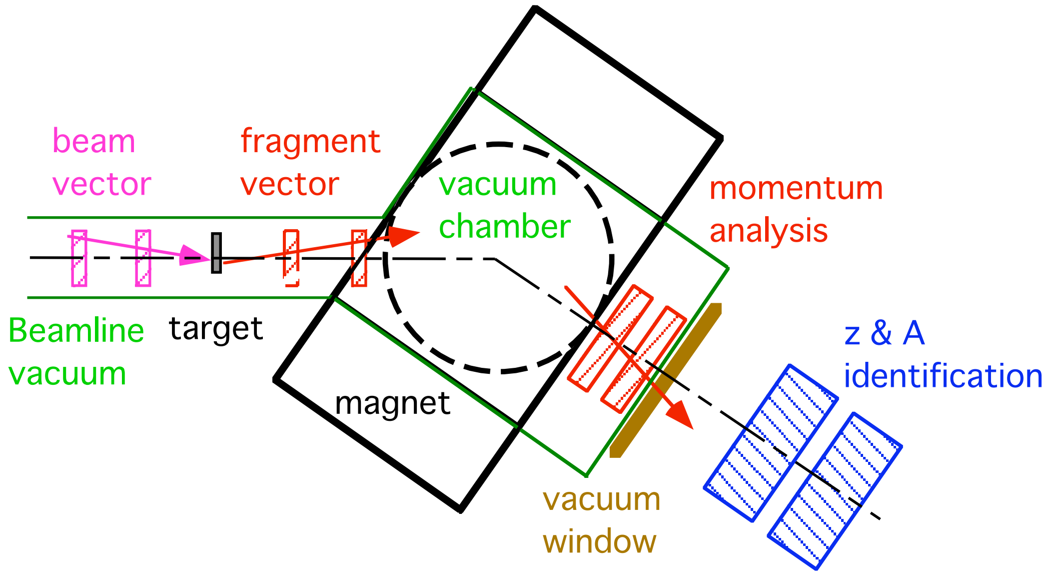
gas(He+C_2H_6) > wire (average thickness) @1atm

(3) increase number of control parameters :

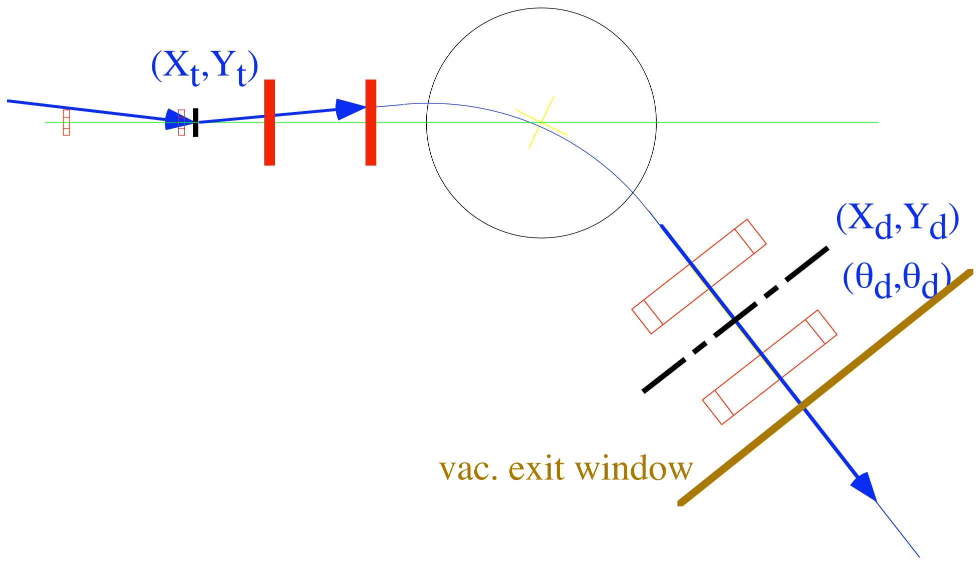
HV --> HV & pressure (gas gain & drift field)

Preliminary test for MIP with pure C_2H_6



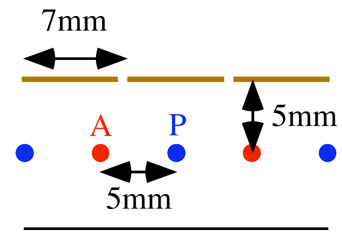


(2) Optional upstream detectors to improve momentum resolution

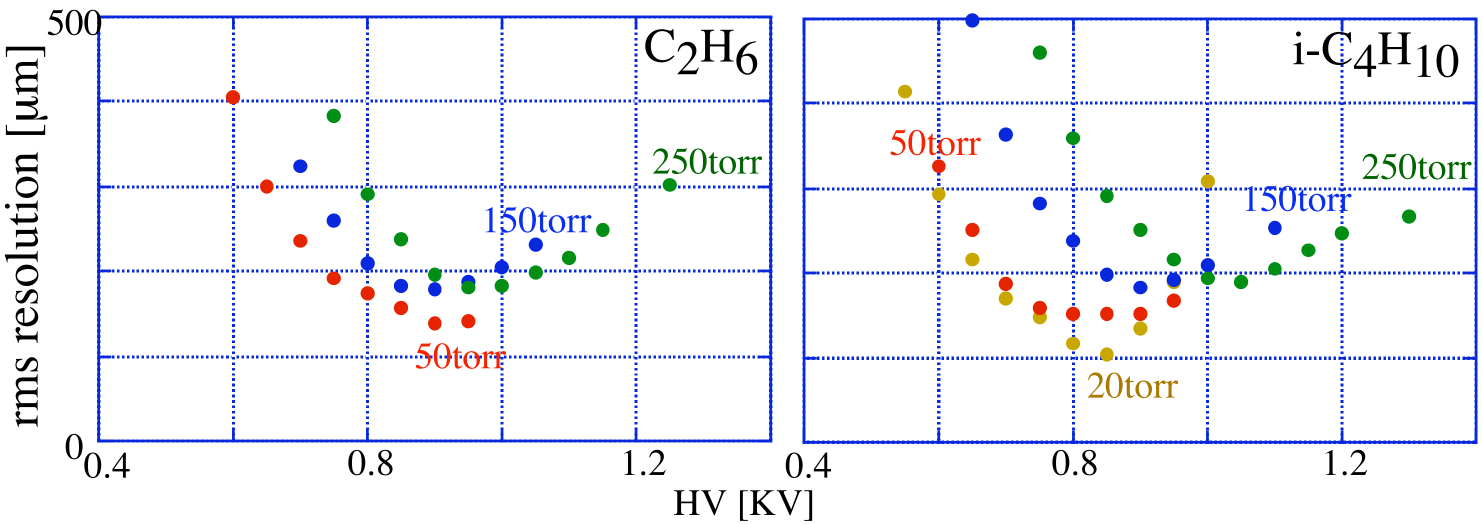


Ultra-thin detectors in vacuum (MIP-sensitive)

Low-Pressure Cathode-Readout DC



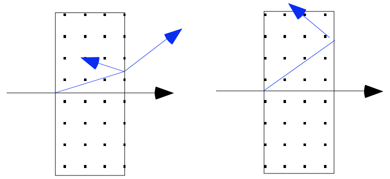
w - Kx - Ay - K - Ax - Ky -w $L/L_r=0.08\times10^{-3}$

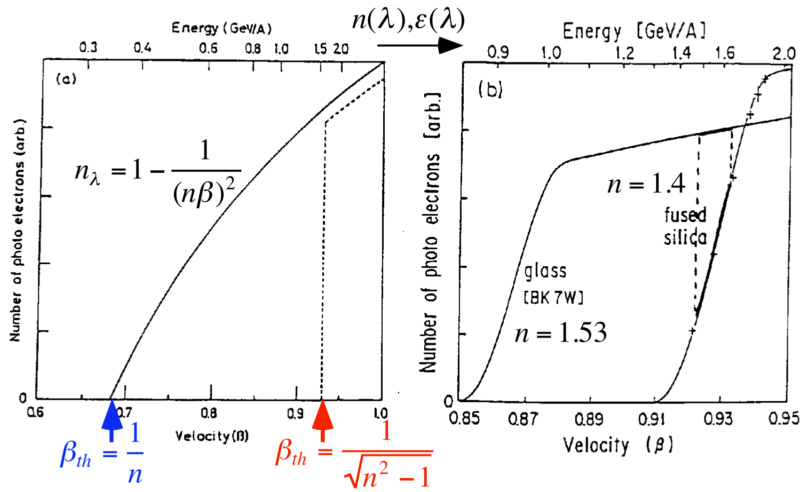


300MeV/A Kr

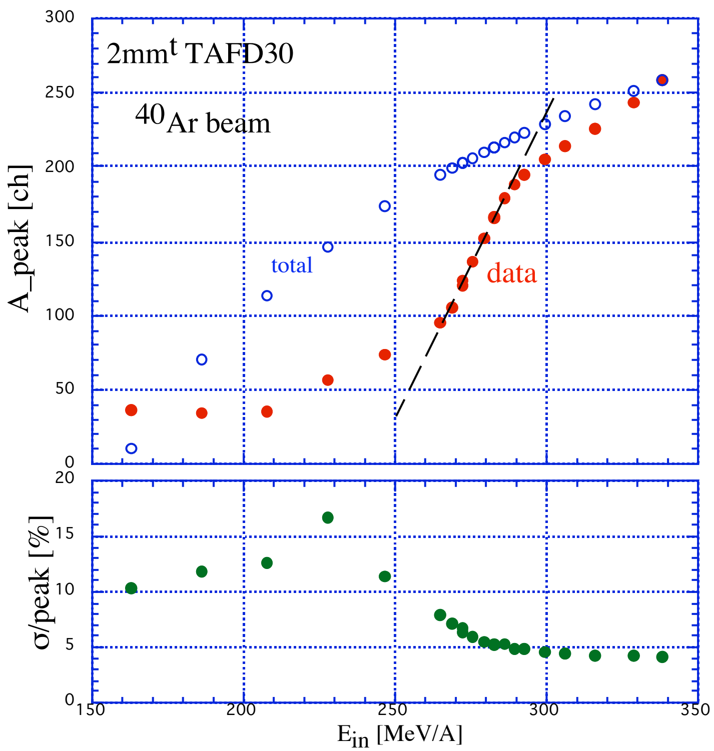
[4-2] Particle Identification : velocity measurement

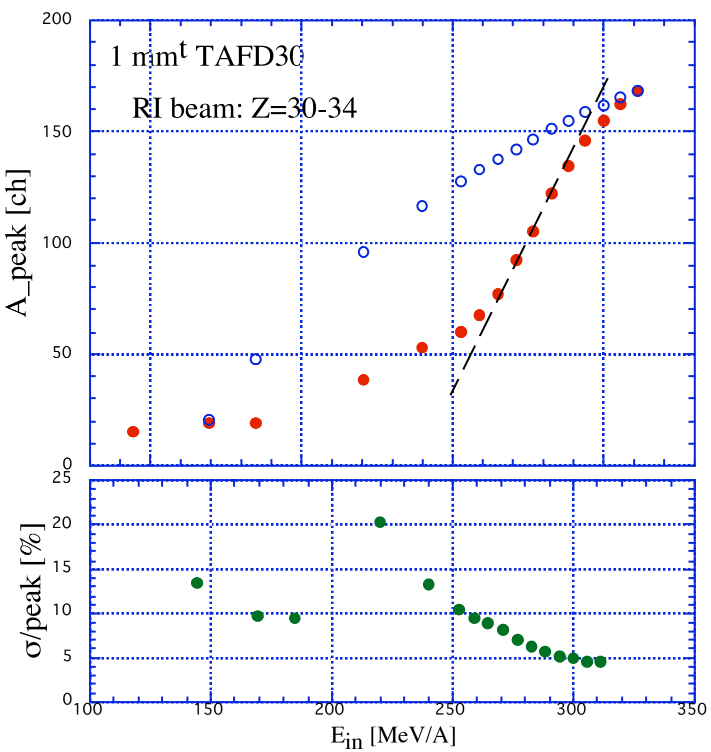
Total internal reflection Cherenkov

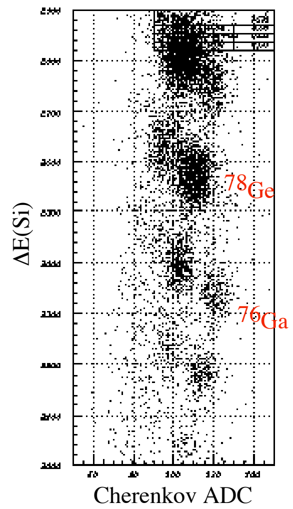




TAFD30(n=1.92) @250MeV/A

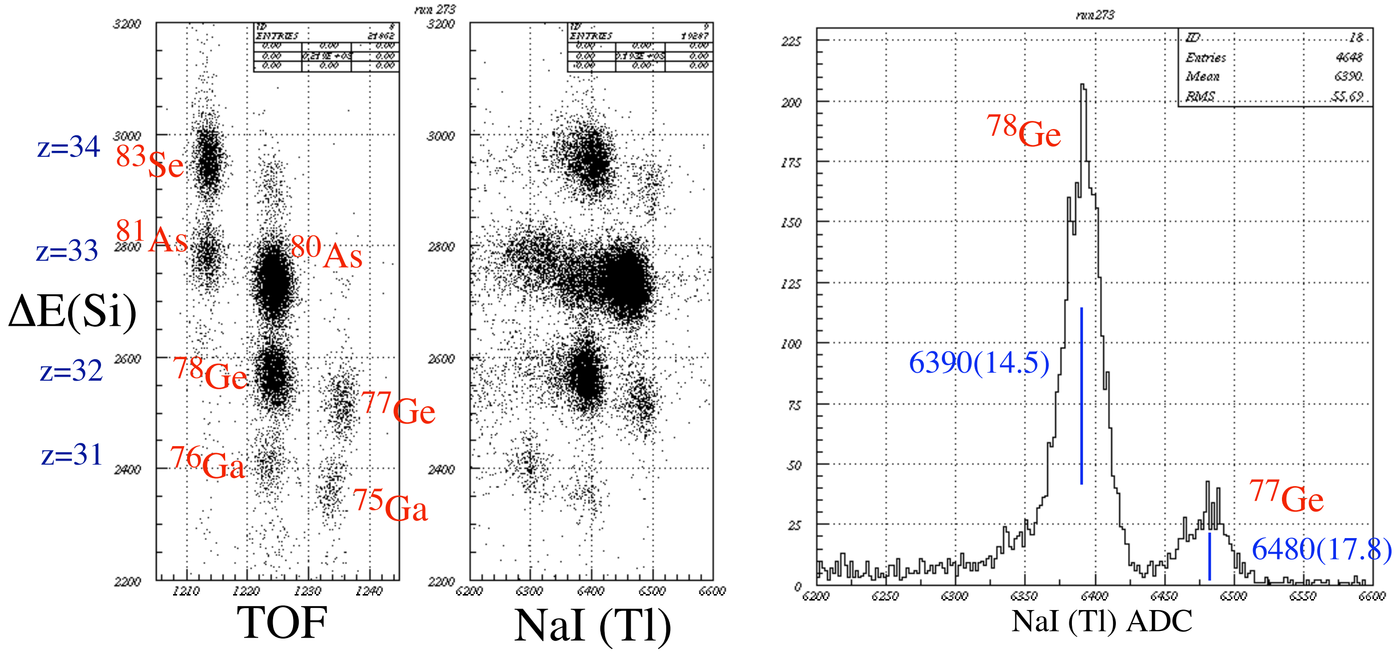






promising as non-stopping detector

ΔE [Si / Ion Chamber] + E [NaI(Tl)] with momentum tagging(~0.1%)



$\frac{\sigma_E}{E} \approx 0.15\%$ for ^{78}Ge @290MeV/A

Problems :

non-uniformity / position dependence

PMT operated at very low HV ⟶ CsI(Tl)+PD

Covering large area :

NaI(Tl) : 37cm x 37cm x 5cm

viewed by 16 x 3"square PMT

[4-4] Budget for tracking/PID detectors

(1) Beam tracking detectors :	7,080K JPY
2 x Cathode-readout DC (128mm x 128mm)	
(2) Optional upstream tracking detectors :	9,620K JPY
2 x Cathode-readout DC (256mm x 256mm)	
(3) Downstream chamber for heavy fragments :	58,800K JPY
2 x Hexagonal-cell DC (100cm x 60cm)	
(4) Total-energy detectors :	7,000K JPY
NaI(Tl) (37cm x 37cm x 5cm) + 16PMT's	
(5) Ion chamber	4,360K JPY
Segmented ion chamber (37cm x 37cm x 6 readout)	
	~87M JPY

Man power

Kobayashi T, ChigaN

2-3 graduate stufents (Tohoku Univ.)

Still need several detector R&D : scheduled in Dec. 2005 @HIMAC

Low-Pressure Hexagonal D.C.
NaI(Tl), CsI(Tl) for total-E measurement

[5] Neutron Detector NEBULA for (γ,n)-type measurements

NEutron-detection system for **B**reakup of **U**nstable Nuclei with **L**arge **A**cceptance

Invariant mass spectroscopy

by measuring core fragment + neutrons in coincidence

Giant Resonance (Soft Resonance, Pigmy resonance)

Low-lying discrete states at drip lines (1st 2^+ state etc.)

Unbound ground states ($^{25\text{-}28}O$, '4n' etc.)

Features

Large acceptance (require a large gap of SAMURAI)

Good energy resolution

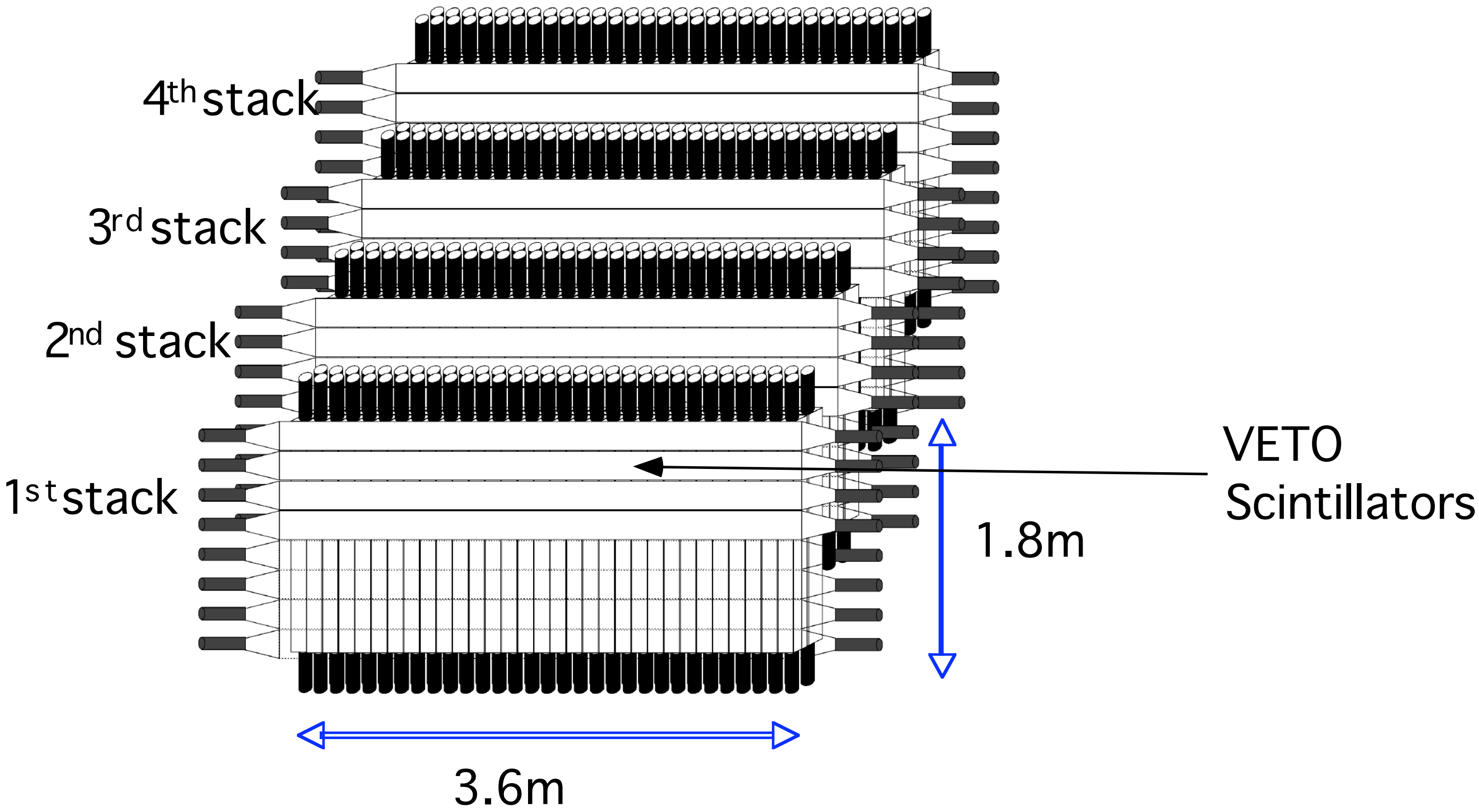
Multi-neutron detection

Flexibility of setup configuration

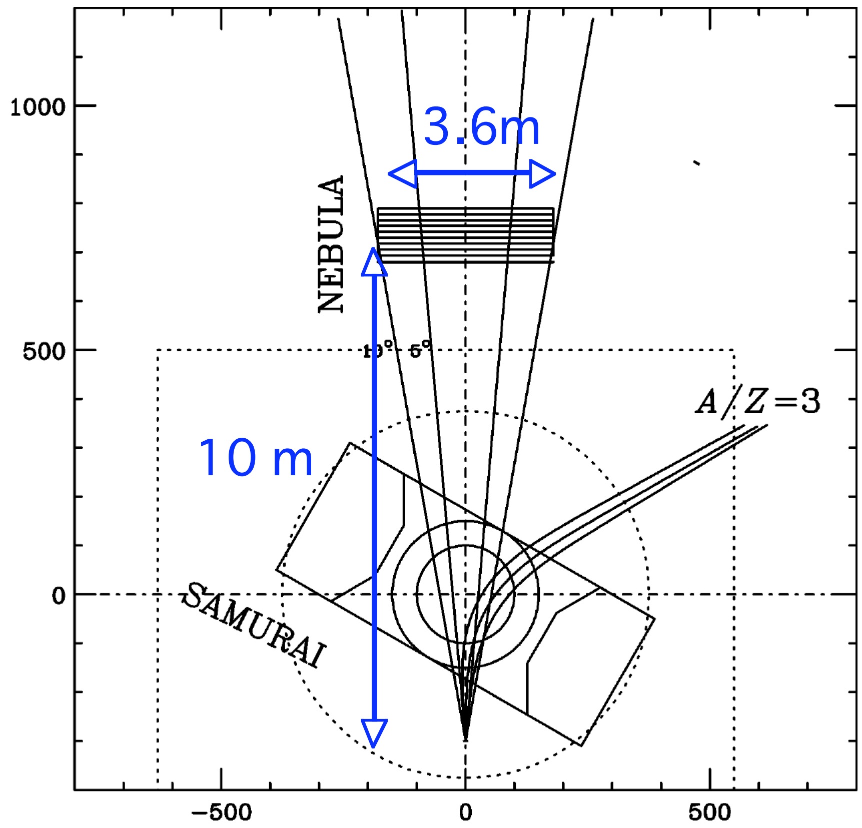
1 module : 12cm(H) x 12cm(D) x 180cm(H) plastic scintillator coupled to 2 PMT s

1 stack : veto scintillators + 60 (30 x 2) modules

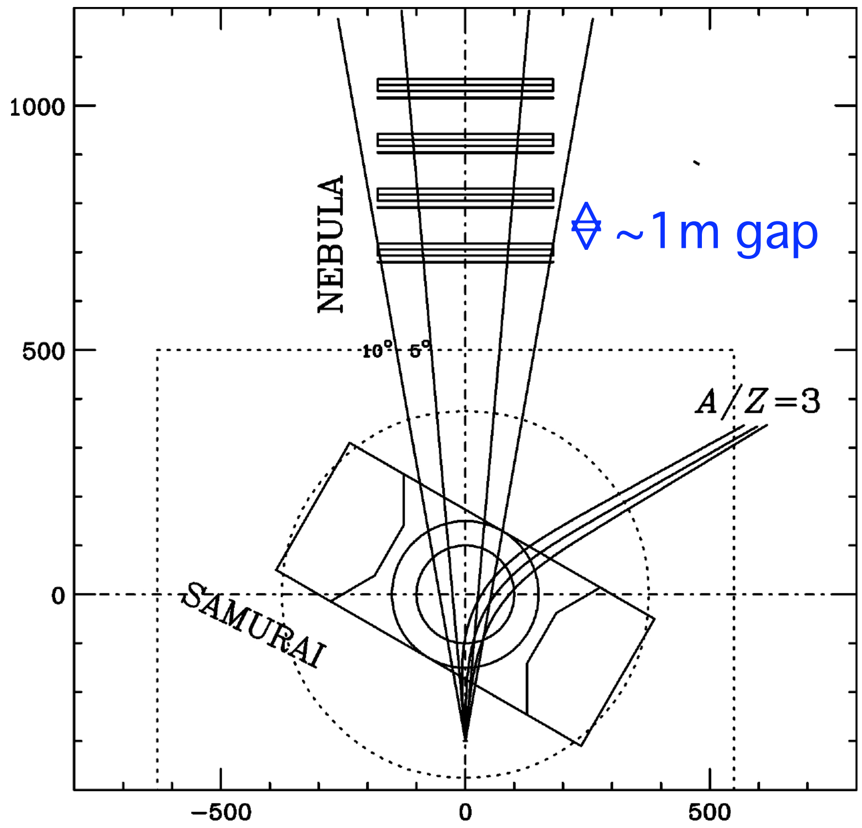
4 stacks : ~1m thick



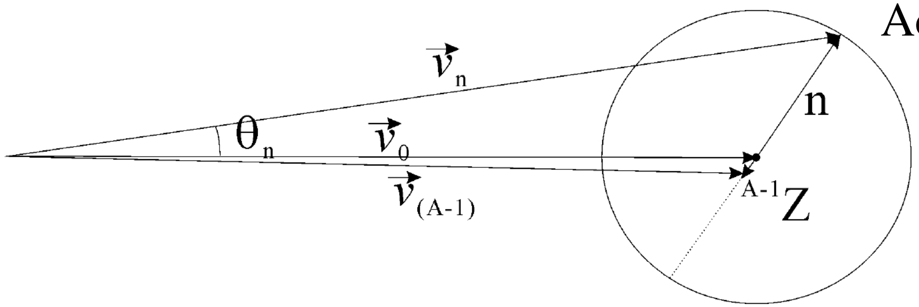
1n + core fragment
1-stack configuration



4n + core fragment
4-stack configuration

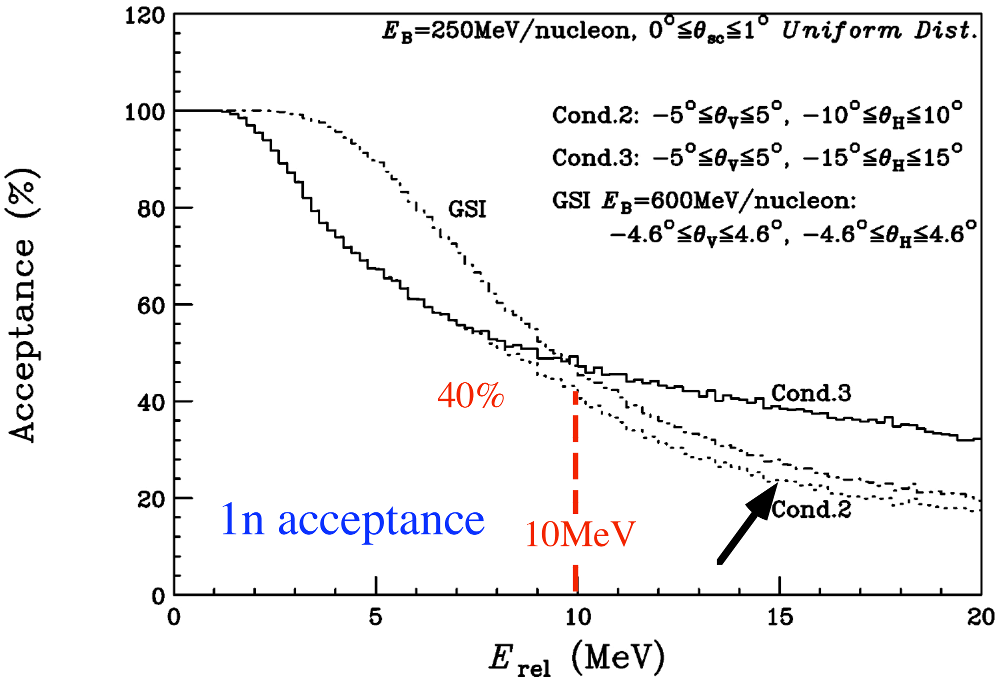


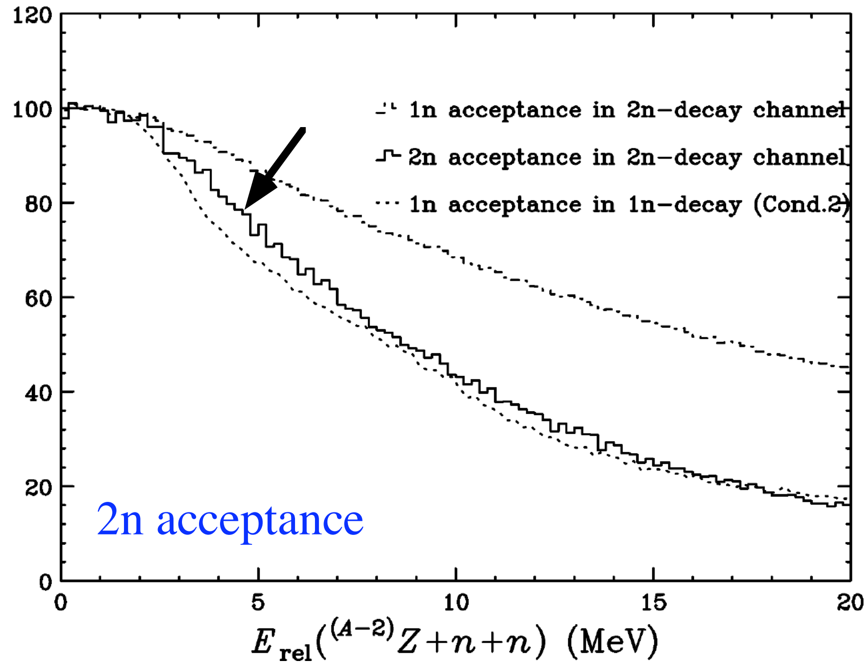
[5-3] Acceptance



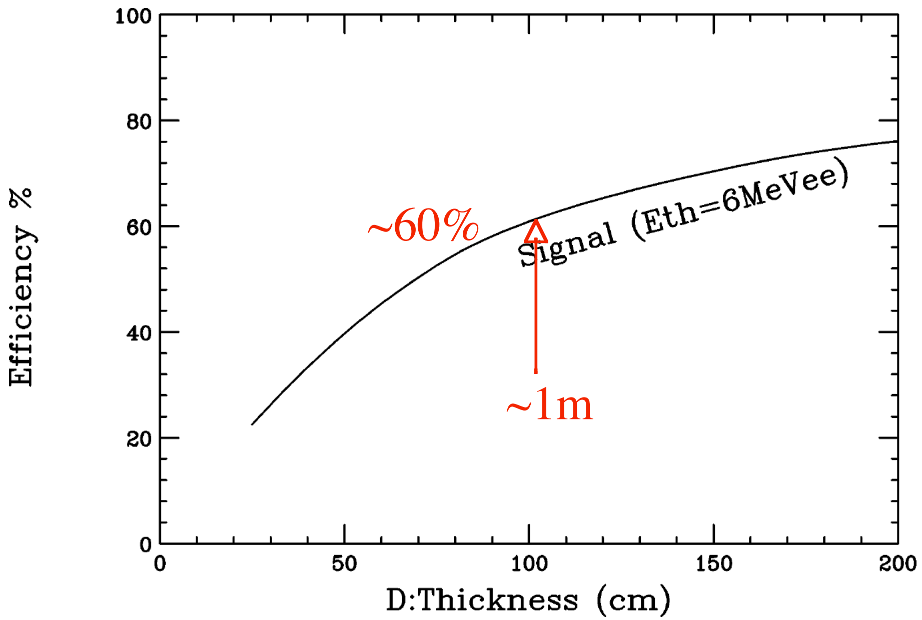
Acceptance is dictated by neutron

Basic setup : Horizontal ±10°, Vertical ±5°

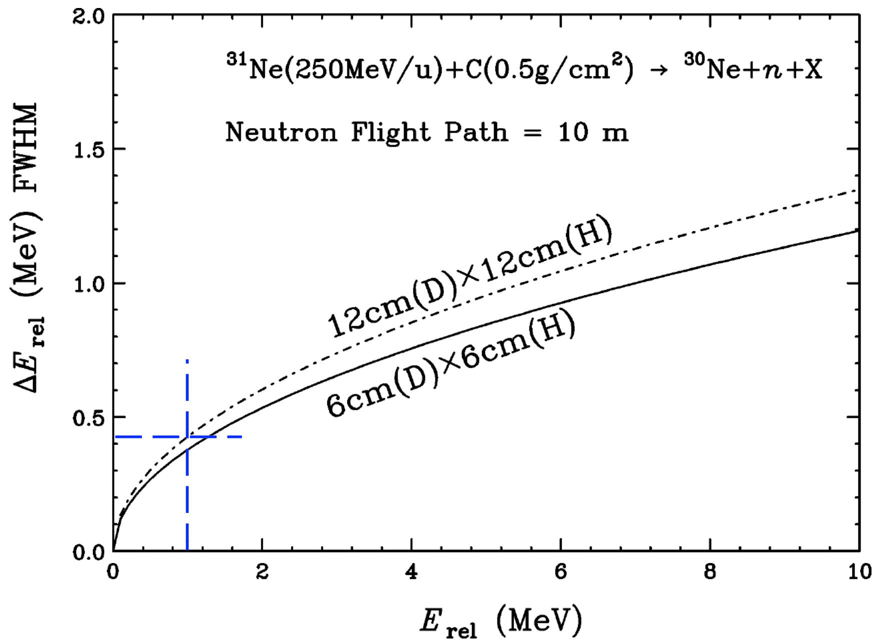




efficiency



resolution



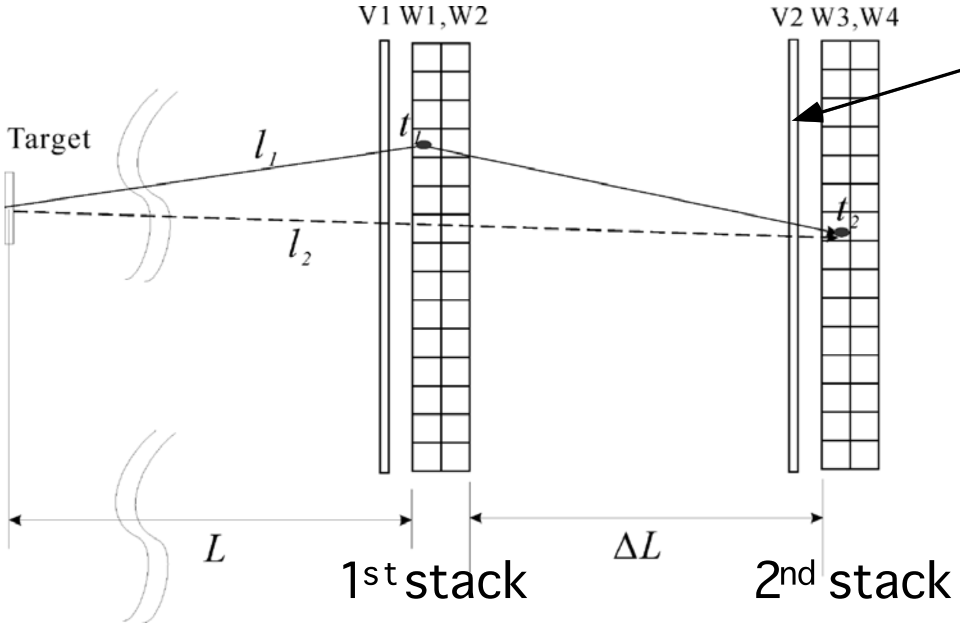
12cmx12cm dimension is o.k.
In terms of the timing resolution

(for 2n separation, 6cmx6cm dimension
is significantly better than 12cmx12cm)

[5-5] Multi-neutron detection

Kinematical condition with the setup composed of spatially-separated stacks

➡ Nearly perfect rejection of crosstalk events



Need of veto for each stack:
for high energy neutrons > 200MeV,
to remove cross-talks from recoil protons

$$\beta_1 \leq \beta_2$$

Finite timing resolution ➡ ΔL should be about 1m for 12cmx12cm

(Non-distinguishable events ~ 2%)

(For 6cm x 6cm dimension ΔL could be about 0.7m)

[5-6] NEBULA

Budget

Plastic scintillators	~100M JPY
Photomultiplier Tubes	~ 60M JPY
Electronics	~ 50M JPY
	~210M JPY

Man Power

T.Nakamura, Y.Satou (Tokyo Inst. of Tech.)

K.Yoneda, T.Motobayashi (RIKEN)

Postdoc (1)

Ph.D Students (2)

[6] (γ,p)-type measurement in the proton-rich side

Physics :

nuclear structure of proton unbound states in the proton-rich region

(γ,p) radiative capture reactions for astrophysics

Method : Invariant mass method

via Coulomb dissociation,

proton-breakup reactions by p/d/α targets,

knockout reactions

Requirements :

Angular acceptance : $< \pm 60$ mrad @E_{rel}=1MeV

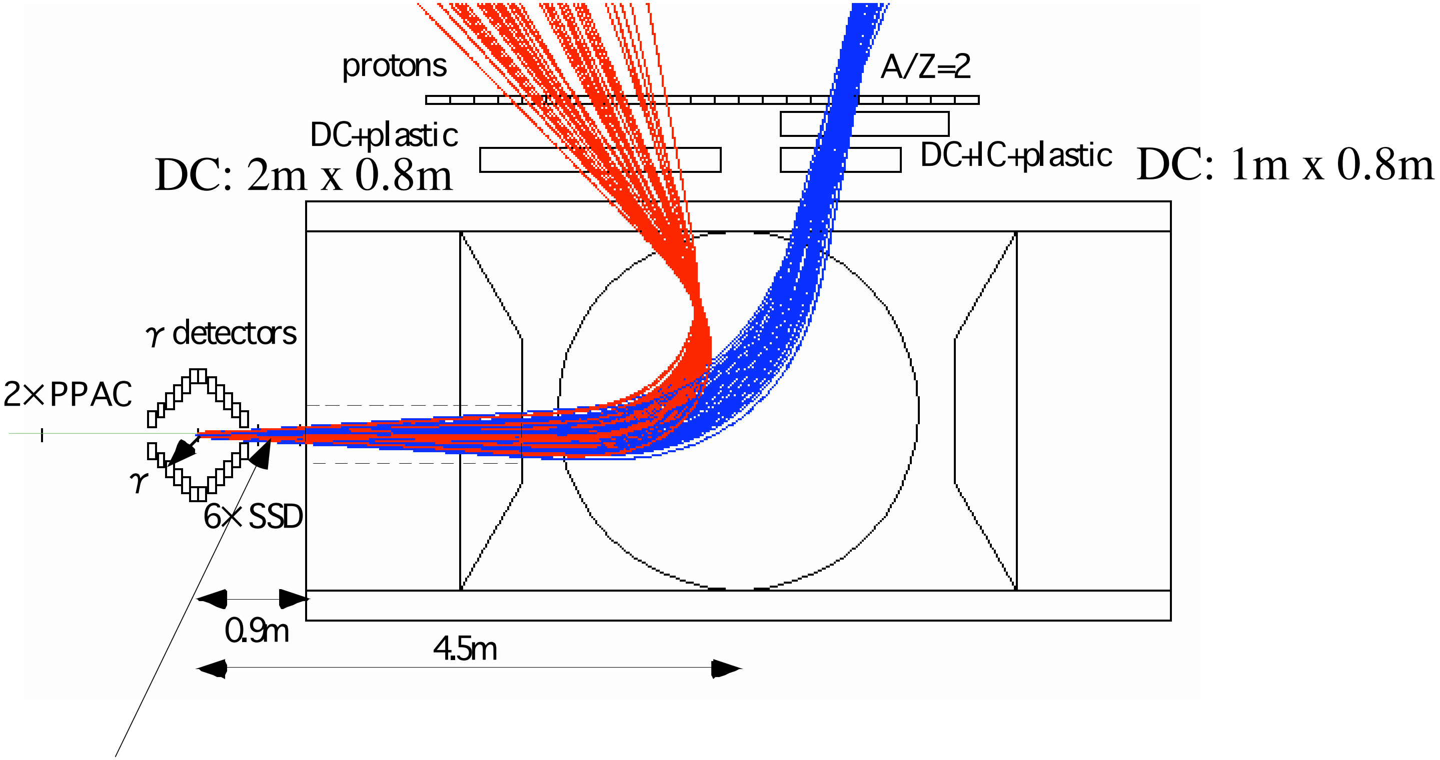
Momentum acceptance : $P_{max}/P_{min} \sim$ 2-3

E_{rel} resolution : 0.1 MeV (rms) @1MeV ⇔

Angular resolution : 2 mrad

Momentum resolution : 0.5% > 0.2% for mass identification

[6-1] High resolution mode



Si-Strip : XYU + XYU   for protons & heavy ions

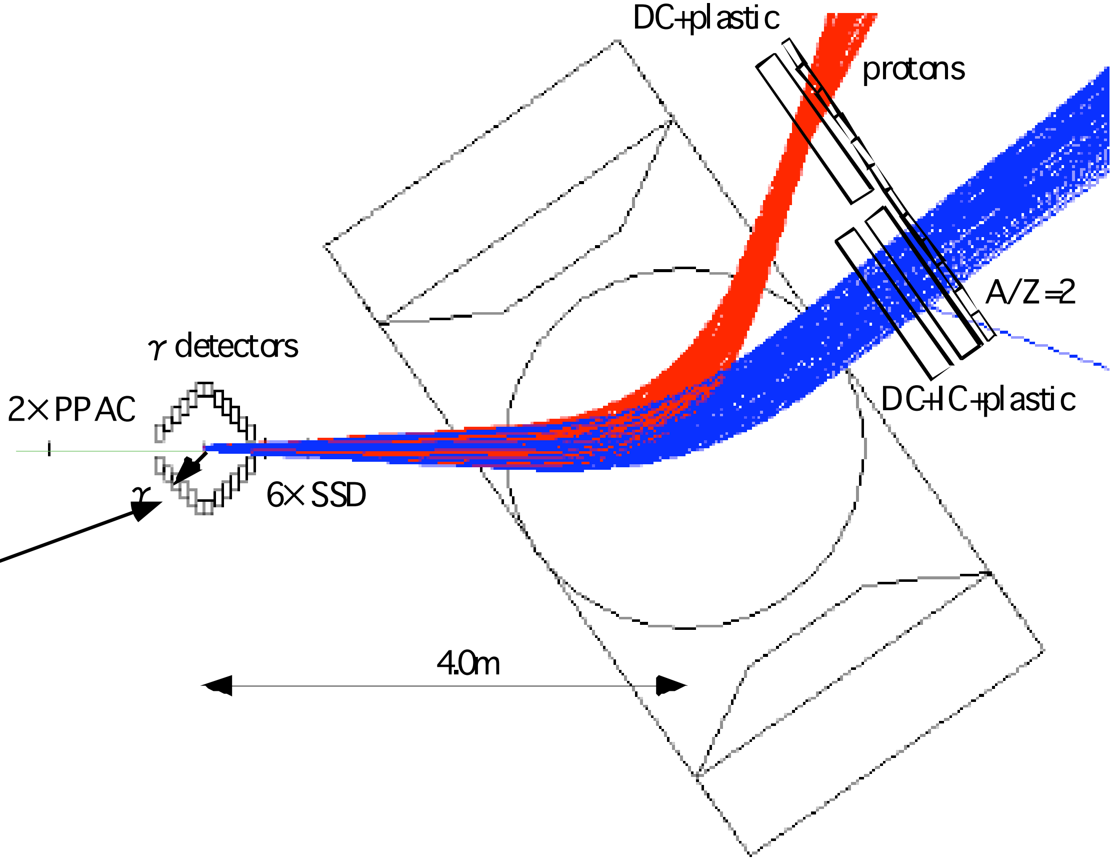
thickness :	100μm
pitch:	0.2mm
distance:	150mm
MCS:	1.7mrad(p), 1.0mrad(HI)

[6-2] exclusive measurement mode

(γ,p)

+ useful for (p,2pn)-type

- no mass separation for A>30



Decay γ tagging
DALI-II or GRAPE

Additionall device necessary for proton-rich side

RF deflector

[6-3] Cost Estimate & Man power

Cost Estimate

(1) (RF deflector):	(100M JPY)
(2) Si-strip detector :	15.8M JPY
(3) Drift Chamber for protons :	35M JPY
	50.8M JPY

Man Power

Iwasa (Tohoku)

Suemmerer (GSI)

Bishop, Gomi, Motobayashi, Takeuchi, Yamada, Yoneda (RIKEN)

2-3 graduate students (Tohoku, Rikkyo)

[7] Pol. d Experiment

- pol. d beam : E_d = 500-880MeV (p_d = 1.4 GeV/c – 2.0 GeV/c)

- Physics Subjects :

  Study of Three Nucleon Forces via Few Nucleon System

  ***dp* elastic/breakup reactions**

  ***dp* $\rightarrow$ ^{3}He + γ radiative capture**

  Short-Range Part of the NN Tensor Interactions

  ^{3}He(*d*,*p*)^{4}He

- Observables :

  Analyzing powers

  Polarization transfer coefficients (double scattering measurement)

  Spin correlation coefficients

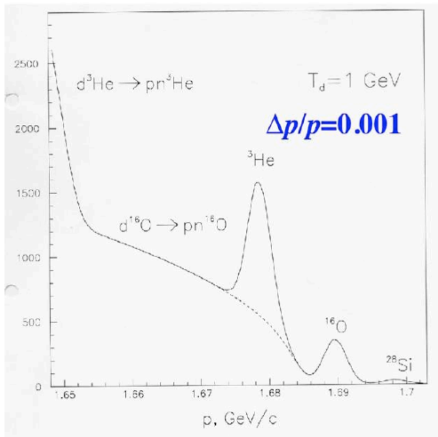
[7-1] Experimental Conditions

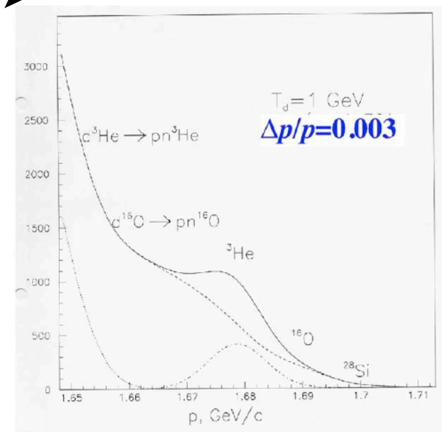
Reaction	dp elastic scattering	dp → ^{3}He + γ	^{3}He(d,p)^{4}He
Measured Observables	dσ/dΩ, Analyzing powers	dσ/dΩ, Analyzing Powers	Spin correlations coefficients
dσ/dΩ (cm.)	~50mb/sr	~10nb/sr	~5mb/sr
Angular Range (θ_{cm}.)	160° – 180°	130° – 180°	0° – 1.6°
Angular Range (θ_{lab}.)	0° – 5°	0° – 7°	0° – 1°
Beam	880MeV (2.0GeV/c) Polarized Deuterons		
Target	CH_2 (3mm^t)	Liq. Hydrogen (5mm^t)	Polarized ^{3}He gas target
Detected Particles (DP)	proton	^{3}He	proton
Kinetic Energy of DP	800MeV	380MeV ~440MeV	870MeV
Momentum of DP	~1.5GeV/c	1.5GeV/c ~1.6GeV/c	~1.6GeV/c
Momentum Ratio : P_{beam} /[P(DP)/Q]	~1.4	2.4 ~2.7	~1.3
Momentum Resolution p/δp	1600	600	1000
Angular Resolution (dθ_{lab}.)	0.5°	0.5°	0.5°

ΔE~1 MeV
to keep
reasonable S/N ratio

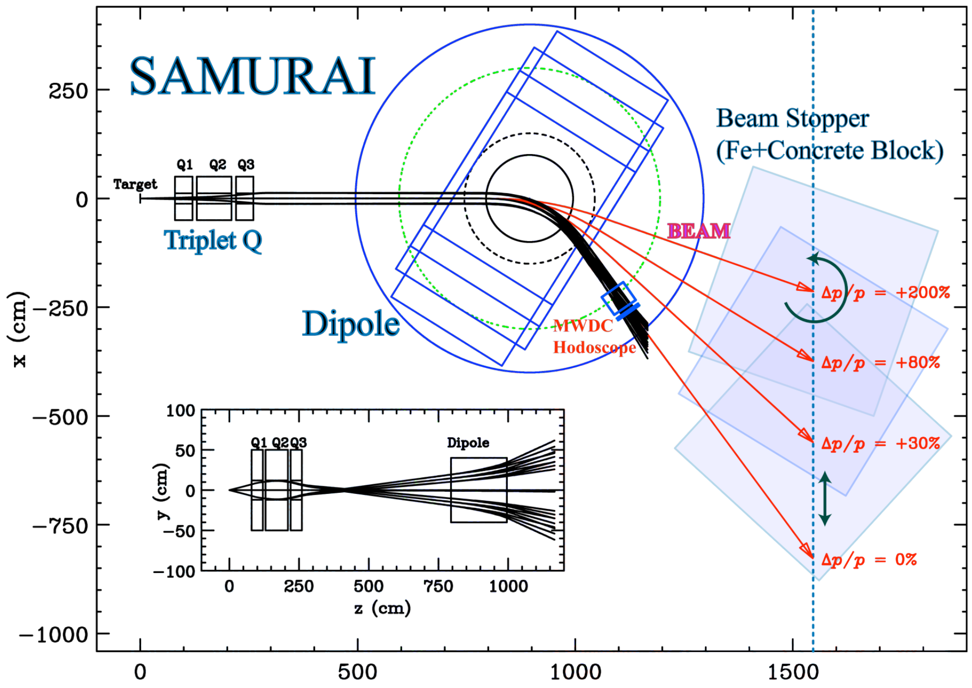
large solid angle
necessary

background rejection





[7-2] High resolution option (Q3D mode)



Q1 : - 1.0 T
Q2 : - 1.1 T
Q3 : 1.3 T
SAMURAI : 3 T

- **Dispersion** 2.25 m
- **Bending Angle** 53.6°
- **Magnification**
  (x|x) = −0.48, (y|y) = 15.7
- **Angular acceptance**
  (h,v) = (±20 mrad, ±90 mrad)

- **Momentum Resolution** $p/dp \sim 3000$
- **Angular resolution** $d\theta = 0.5°$

[including detector resolutions]

Detectors

MWDC

- Volume : $70\text{cm}^W \times 120\text{cm}^H \times 50\text{cm}^D$
  (to cover Δp/p ±4%)

Plastic scintillator hodoscope

- Size : $70\text{cm}^W \times 120\text{cm}^H \times 1\text{cm}^T$, 2 layers

Beam Dump

Fe (40cm^T) + Concrete Blocks

- Volume : $72\ \text{m}^3$ ($4\text{m}^D \times 4.5\text{m}^W \times 4\text{m}^H$)
- Movable & Rotary

Magnetic field is changed and a beam dump is moved correspondingly to maintain the good resolution at the focal plane.

[7-3] Other requirements

- **beam line** which connect between the RRC and SRC but skips the IRC
- **beam monitoring devices** for light ions (Z=1) at Big RIPS
- **beam line polarimeter** installed downstream of the SRC
- **beam line polarimeter** installed on the beam line which directly connect the RRC and the SRC

Schedule

FY2006
detector studies and R&Ds
FY2007
Construction ofbeam tuning devices
beam line polarimeter : detector & target system
and installation of beam dump at SAMUDAI
scattering chamber & target system for SAMURAI Q3D-mode
Polarized deuteron beam acceleration at RIBF
Calibration of deuteron beam-line polarimeter
dp elastic measurements with beam line polarimeter system
FY2008
dp breakup measurements with beam line polarimeter
Constuction of detector systems at SAMURAI
FY2009
Experiments at SAMURAI with polarized deuteron beams
Construction of focal plane polarimeter system at SAMURAI (upgrade)

[7-4] Budget

(1) Detectors @SAMURAI	
1. MWDC :	10M JPY
2. Hodoscope :	4.8M JPY
3. Holder :	5M JPY
4. Electronics :	3.5M JPY
(2) Beam minitor	7.0M JPY
(3) Beam Dump	25M JPY
(4) chamber/target for Q3D	3M JPY
(5) Beam line polarimeter	5M JPY
	64M JPY

[8] Time Projection Chamber (TPC) for EOS studies

Requirements for magnet

- large magnetic volume : TPC with 1.5m x 1.0m x 0.6m (similar to EOS TPC)
- precise field map at B=1.5T

Requirements for TPC

- Detection of p, π^+, π^- in the presence of projectile fragments & intermediate-mass fragments (IMF)
- two-track separation of 3.6cm for M=80

  (12mm x 8mm) x 15360 pads : EOS TPC
- π^+, π^- yield with 1% accuracy

  p, π^+ separation important

Required R&D

- mechanics of TPC vessel
- pad layout

⟷ detector performance

[9] Summary

Schedule	FY2006 – FY2010
SAMURAI Magnet [2-1]	Design → Construction Test → Operation
Drift Chambers [2-2-1]	R&D Design → Construction Test → Operation
PID Detectors [2-2-2]	R&D Design → Construction Test → Operation
Neutron Detectors [2-3]	R&D Design → Construction Test → Operation
(g,p) Exp. [2-4]	R&D Design → Construction Test → Operation
Pol. Deuteron Exp. [2-5]	R&D Design → Construction Test → Operation
SAMURAI TPC [2-6]	R&D Design → TPC Construction → Electronics → Operation

Manpower Cost [MYen]	FY2006	FY2007	FY2008	FY2009	FY2010	Total
SAMURAI Magnet [2-1]		RIKEN Accelerator Group 500.	500.			1,000.
Drift Chambers [2-2-1]	2 persons + 1 prof. staff	2 persons + 1 prof. staff 29.4	2 persons + 1 prof. staff 46.1	2 persons + 1 prof. staff	2 persons + 1 prof. staff	75.5
PID Detectors [2-2-2]	2 persons + 1 prof. staff	2 persons + 1 prof. staff 2.4	2 persons + 1 prof. staff 9.0	2 persons + 1 prof. staff	2 persons + 1 prof. staff	11.4
Neutron Detectors [2-3]	2 persons	2 persons + 1 prof. staff 20.	2 persons + 1 prof. staff 190.	2 persons + 1 prof. staff	2 persons + 1 prof. staff	210.
(g,p) Exp. [2-4]	2 persons	2 persons	2 persons + 1 prof. staff 20.8	2 persons + 1 prof. staff 30.	2 persons + 1 prof. staff	50.8
Pol. Deuteron Exp. [2-5]	2 persons	2 persons 40.	3 persons 23.3	3 persons	3 persons	63.3
SAMURAI TPC [2-6]		2 persons 10.	2 persons 20.	2 persons + 1 prof. staff 15.	2 persons + 1 prof. staff 25.	70.
Total Cost		601.8	809.2	45.	25.	1,481.

(TPC costs are assuming collaboration with a forein institute)

1,000MY
75.5MY
11.4MY
210.MY
50.8MY
63.3MY
70.MY

1481MY

[10] remaining ...

(1) Magnet

still expensive

large ambiguity on cost estimate

large exit window + safety

field map measurement (?) ⇔ momentum resolution

new design ?

(2) Tracking & PID detectors

much progress last year : OK for small prototypes

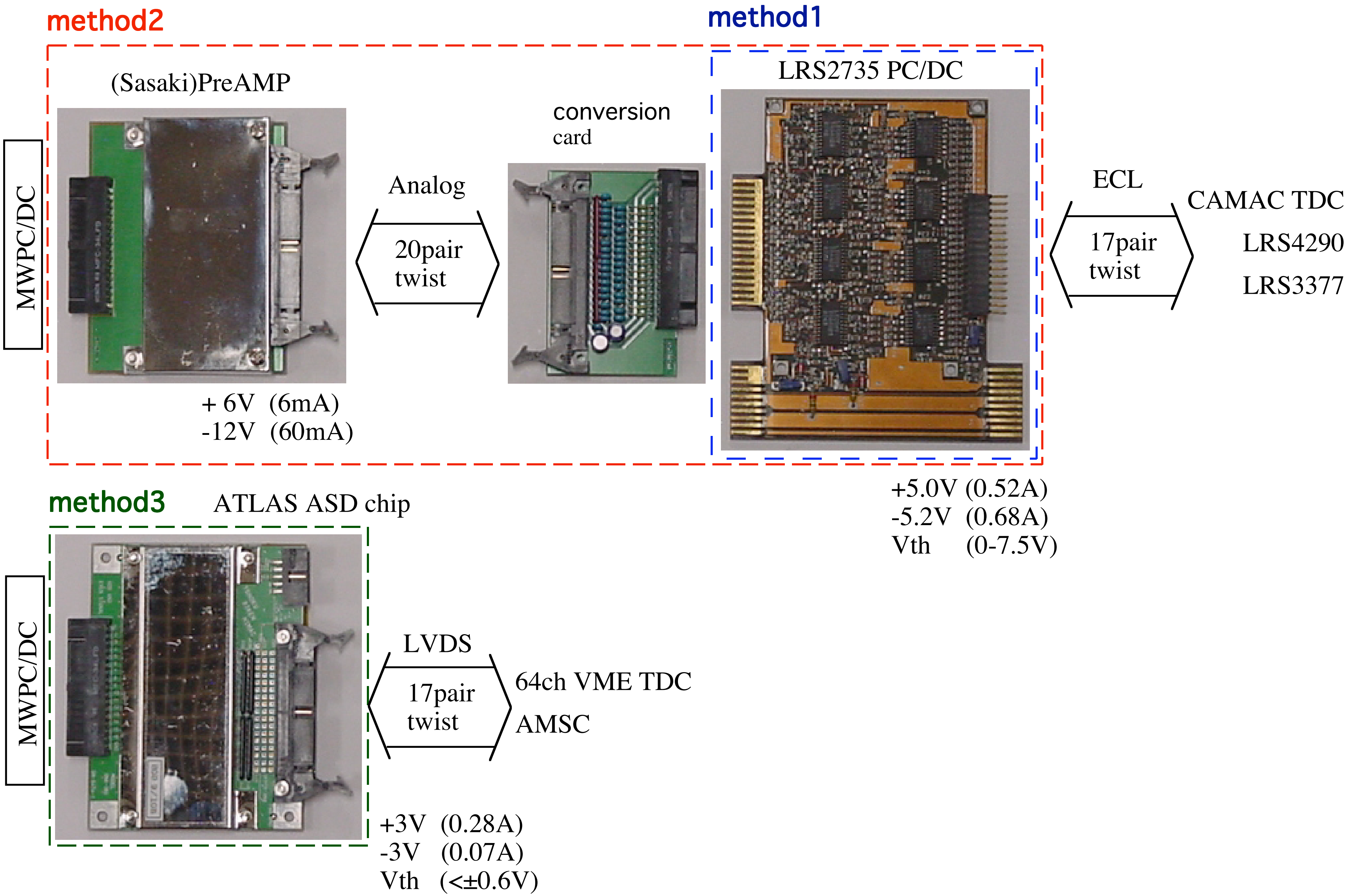
high-rate capability ? total E detector

(3) Decay γ-ray tagging for invariant mass spectroscopy

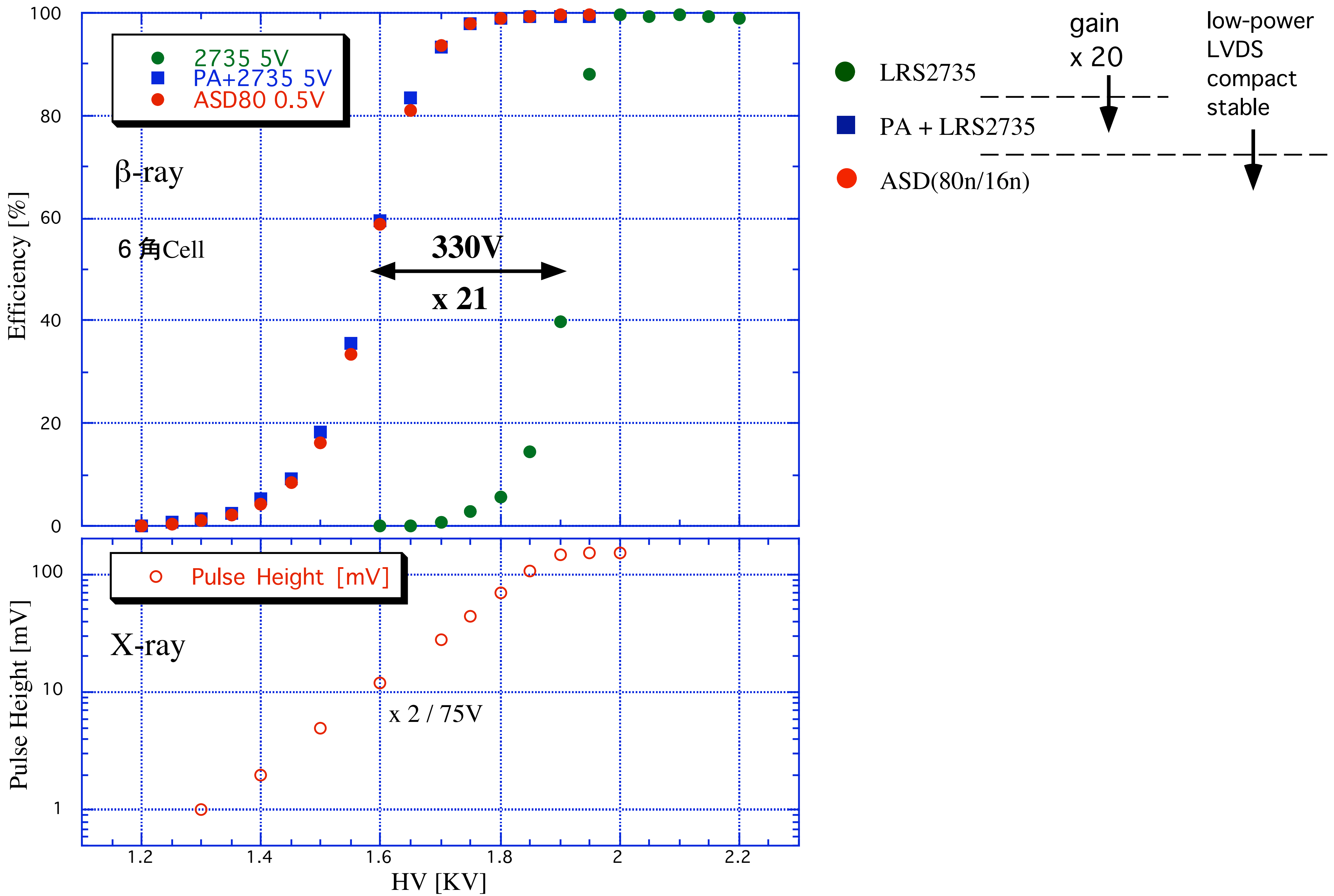
high-efficiency segmented detector

Readout electronics for MWPC/DC

high rate : ~ electronics with high gain



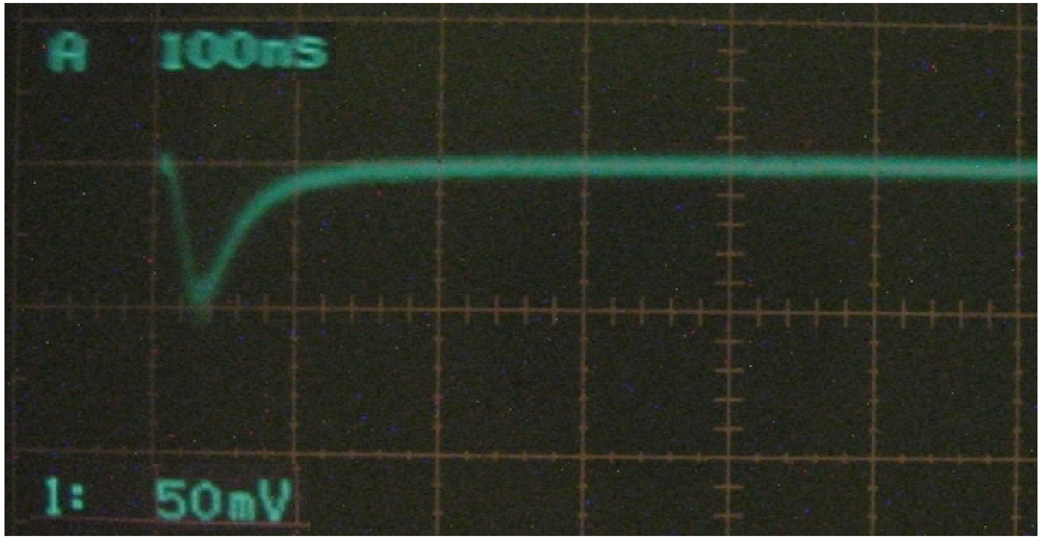
Readout electronics



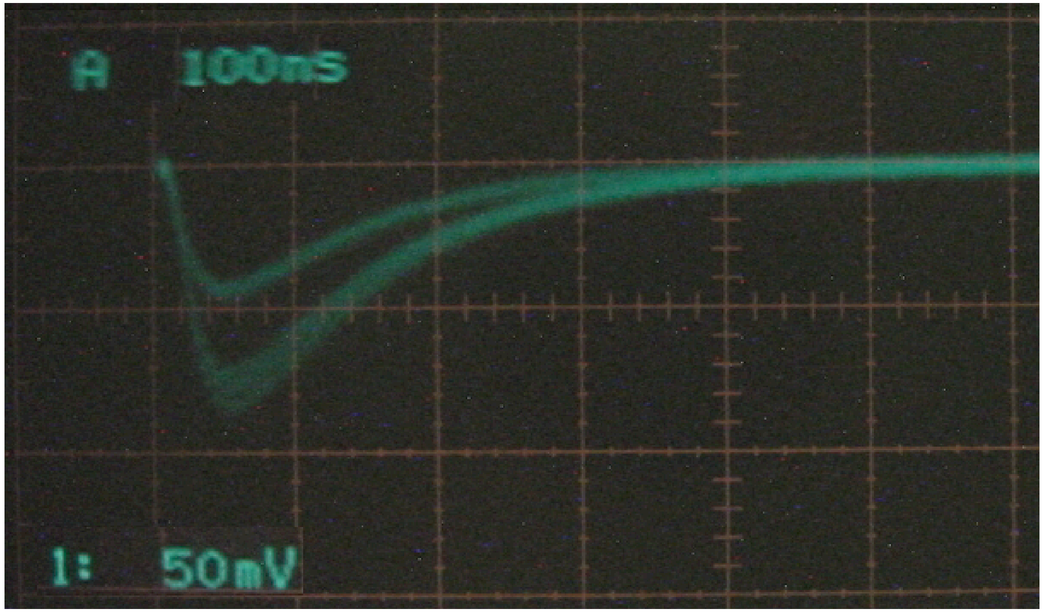
ASD : 2 types

X-ray signal

C_F= 1pF



Sasaki(ATLAS) τ= 16 nsec



Tanimori τ= 80 nsec