NaI(Tl) and CsI(Tl) for heavy ion

RIBF Detector WS, 2008/03/17-18,
Hideaki Otsu(RIKEN Nishina Center)

- Requirement for Total Energy counter in RIBF
- Experiments in HIMAC facility
- NaI(Tl) response for HI
- CsI(Tl) response for HI

  ※ N. Endo, part of master thesis in Tohoku U.
- Consideration
- Summary

Motivation

- Particle Identification for Reaction Residue
  - c.f. 2nd beam from ($B\varrho$, $\varDelta E$, L/t)

- Candidates:
  - (1) ($B\varrho$, $\varDelta E$, L/t)
  - (2) ($B\varrho$, $\varDelta E$, E)
  - (3) (L/t, $\varDelta E$, E)

- c.f.

  Magnetic Rigidity : $Ap_1/Z=cB\varrho\equiv R$

  Energy Deposite : $z^2/\beta^2 \equiv D=\varDelta E$

  TOF : $L/\beta \quad \equiv t$

  Total E : $AT_1 \quad \equiv E$

- Assume that $Z=Q$ for Z≃40 or less at T_1≃250 MeV

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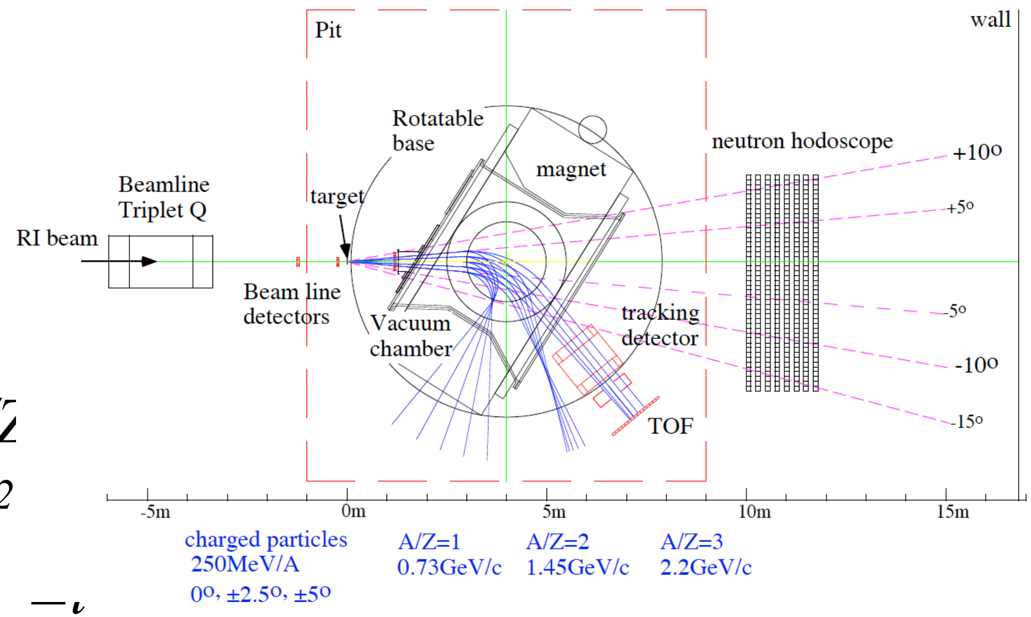

- c.f.
  Magnetic Rigidity : Ap_1/Z
  Energy Deposite : z^2/β^2
  TOF : L/β —
  Total E : $AT_1 \equiv E$

- Assume that $Z=Q$ for Z≃40 or less at T_1≃250 MeV

PID (*R*,*D*,*t*) / (*R*,*D*,*E*)

- (*R*,*D*,*t*):

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

- (*R*,*D*,*E*):

$$\frac{\sigma_A}{A} = \sqrt{\left((\gamma+1)\frac{\sigma_R}{R}\right)^2 + \left((\gamma+1)\frac{\sigma_z}{z}\right)^2 + \left(\gamma\frac{\sigma_E}{E}\right)^2}$$

- c.f. (*D*,*E*,*t*)

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

PID (*R*,*D*,*t*) / (*R*,*D*,*E*)

- (*R*,*D*,*t*):

z Quantized

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

same amount

- $\sigma_A/A=0.2/100=1/500$
  - $\sigma_R/R=1/700$
  - $\sigma_\beta/\beta=1/700/\gamma^2\sim 1/1100$ $@\beta=0.62$
    - Even if $\sigma_t=50ps$ is obtained, $L=10m$ is required.
    - If $\sigma_t=100ps$, $L=20m$ is needed.
    - $\sigma_L/L \ll \sigma_\beta/\beta$ is also required.
    - Alternative method?

PID (R,D,t) / (R,D,E)

- (R,D,E):

$$\frac{\sigma_A}{A} = \sqrt{\left((\gamma+1)\frac{\sigma_R}{R}\right)^2 + \left((\gamma+1)\frac{\sigma_z}{z}\right)^2 + \left(\gamma\frac{\sigma_E}{E}\right)^2}$$

same amount

Quantized

- $\sigma_A/A=0.2/100=1/500$
  - $\sigma_R/R=1/700/(\gamma+1) \sim 1/1600$
  - $\sigma_E/E=1/700/\gamma \sim 1/900$
- Goal(Expected) : $\sigma_E/E=1/1000$

Motivation

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- Candidates:
  - (1) ($B\varrho$, ΔE, L/t)
  - (2) ($B\varrho$, ΔE, E) *)
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- c.f.

  Magnetic Rigidity : $Ap_1/Z = cB\varrho \equiv R$

  Energy Deposite : $z^2/\beta^2 \equiv D = \Delta E$

  TOF : $L/\beta \equiv t$

  Total E : $AT_1 \equiv E$

- Assume that $Z=Q$ for Z≃40 or less at $T_1 \simeq 250$ MeV

NaI(Tl) motivation

- response to γ : well known
- response to p : relatively well known

- Scaling : 662 keV γ : $\Delta E/E$ = 8 %(FWHM)
  - 250AMeV
  - A=40 : E=10GeV ⇒ $\Delta E/E$ = 0.065 %(FWHM)
  - A=132 : E=33GeV ⇒ $\Delta E/E$ = 0.035 %(FWHM)

NaI(Tl) motivation

- response to γ : well known
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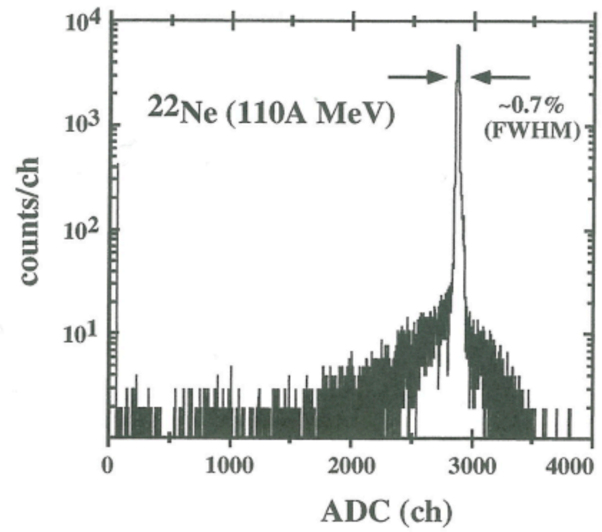


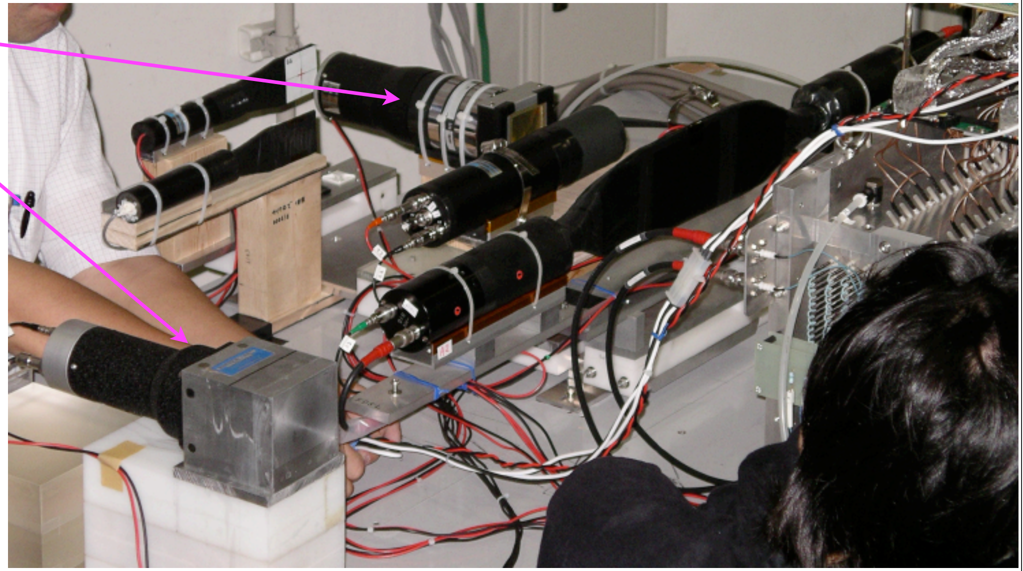
Fig. 1. Pulse height spectrum of the NaI(Tl) detector for ^{22}Ne beam of 110A MeV.

- ^{22}Ne primary 110 AMeV (T. Suda, Progress Rep. 2002, p.171)
  - Results 0.7%(FWHM) ⇄ Scaling 0.13%(FWHM) ???
- Re-scaling with ^{22}Ne results
  - A=40 : E=10GeV ⇒ $\Delta E/E$ = 0.34 %; σ_E/E=0.14 %
  - A=132 : E=33GeV ⇒ $\Delta E/E$ = 0.18 %; σ_E/E=0.08 %

Experiment

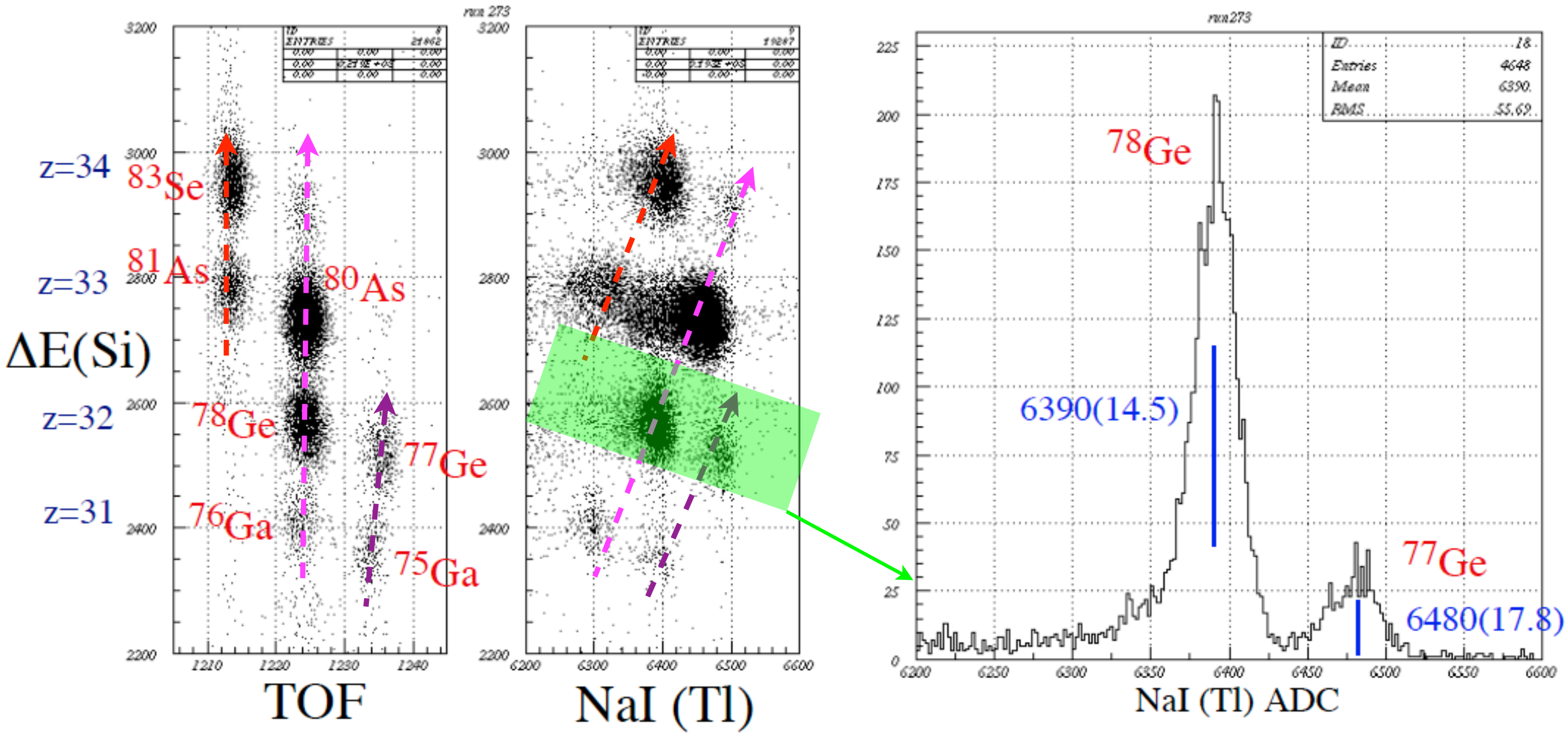
- HIMAC SB2 Beam line
- ^{40}Ar(Z=18), ^{84}Kr(Z=36) @ 400 AMeV
- 2nd Beam Z<34 @ 250-300 AMeV
  - $\Delta p/p$=0.1% @ F1 by Slit

- For (*R*,*D*,*E*) study
  - Si+NaI(Tl)
    - 3"ϕ×3"t
    - 3" cubic (Harshow)
  - Si+CsI(Tl)
  - (Si+HPGe)



NaI(Tl) results

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

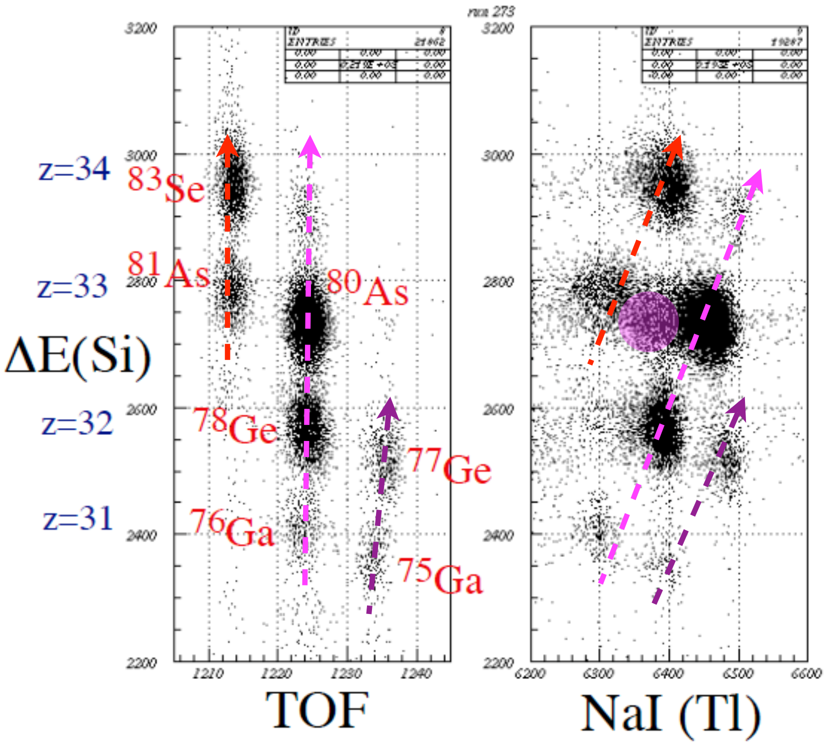


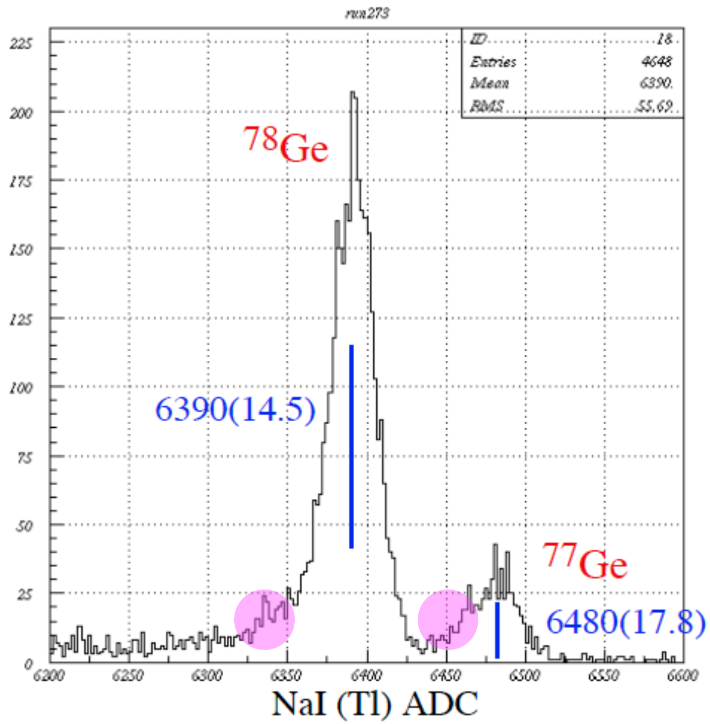
$$\frac{\sigma_E}{E} \approx 0.15\% \text{ for } {}^{78}\text{Ge} \text{ @290MeV/A}$$

HIMAC p181 exp.

NaI(Tl) results

ΔE [Si / Ion Chamber] + E [NaI(Tl)] with momentum tagging(~0.1%) at F1





× reaction tail

× rate limit (< 0.5~1 kHz)

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

HIMAC p181 exp.

Summary of NaI(Tl)

- σ_E/E=0.15% for ^{78}Ge 290 AMeV
  Scaling from Suda's results σ_E/E=0.10%

- Quenching effect ? (not confirmed yet)
- reaction tail ⇒ worse S/N

- rate < 0.5~1.0 kHz
- etc.
  - How to use PMT properly ? -500 V or less for H1191
  - NaI : easily cracked

CsI(Tl) motivation

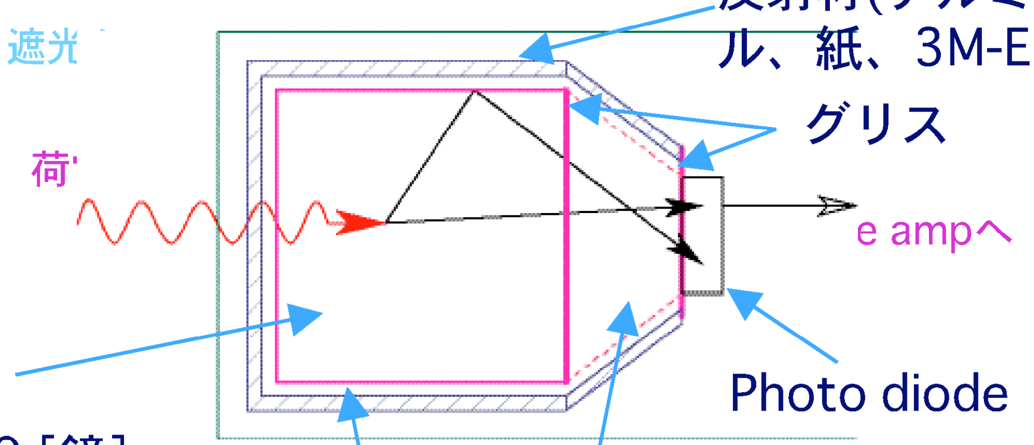
- Comparison with NaI(Tl) properties

	CsI(Tl)		NaI(Tl)
water absorption	small	>	yes
τ	$1\mu s$	<	$0.2\mu s$
density	4.51 g/cm^3	>	3.67 g/cm^3
λ_{MAX}	540 nm		415 nm
I_e	56 eV	<	25 eV
Readout ε	~100%?(PD)	>	20% (PMT)
# of seed ratio	100/56	x2 > ?	20/25

- relatively easy to handle
- Large area coverage with small dead region

CsI(Tl) preparation

CsI(Tl)検出器の測定原理



$10^2 \times 50$ [鏡]

$30^2 \times 40$ [鏡/スリ]

40^3 [鏡/スリ]
(40cube)

50^3 [鏡]
(50cube)

10^2(200、300μm^t)
:50V

18^2 (300μm^t):100V

28^2 (300μm^t):100V

CsI(Tl) preparation

$10^2 \times 50$小型結晶のテスト

(Photo diode 10^2
pre amp 142A C_f1pF)

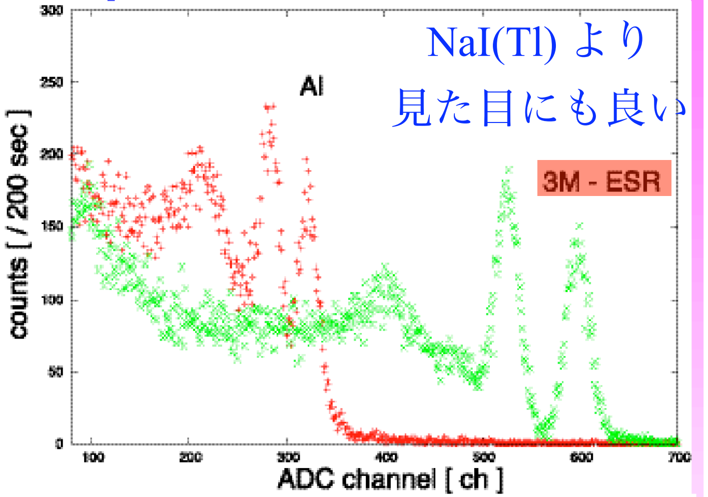
- 反射材に3M-ESR
→アルミホイルの2倍の分解能
- 表面状態はスリガラスより鏡面

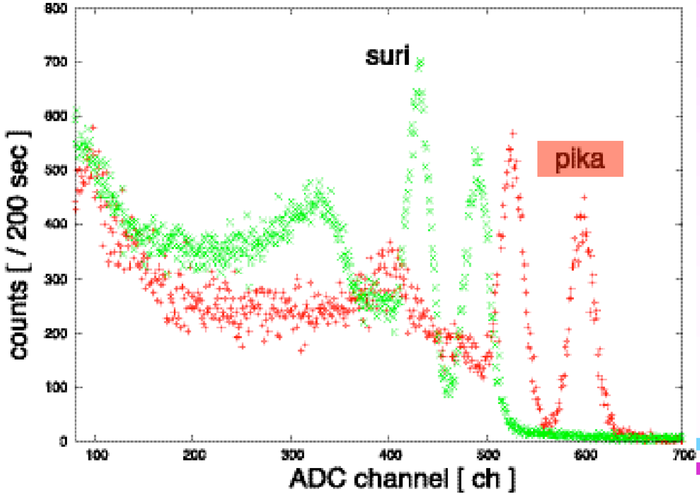
⇩

◆結晶、Photo diodeの大型化(集光、容量)

◆Pre ampのC_f大

NaI(Tl) より
見た目にも良い





CsI(Tl) preparation

Pre amp

✧ ハイブリッド

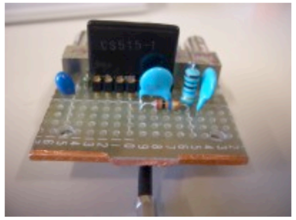
1. Clear Pulse CS515-1
2. SOSHIN CS AMP-3
3. HOHSHIN N012-1

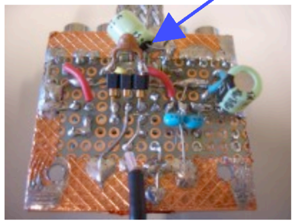
組み込む基板作成

- γ線源(^{60}Co)でテスト
  →分解能
- C_f'大きくし、動作確認

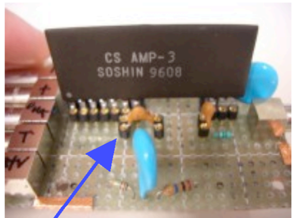
  →ビーム試験で使用する
  pre amp決定

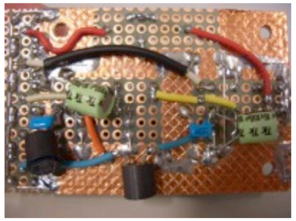
C_f'、R_f'



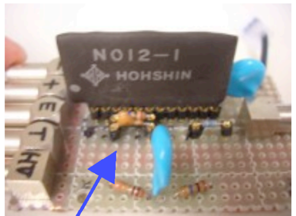


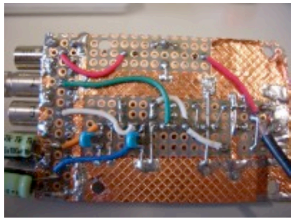
CS515-1





C_f'、R_f'　CS AMP-3

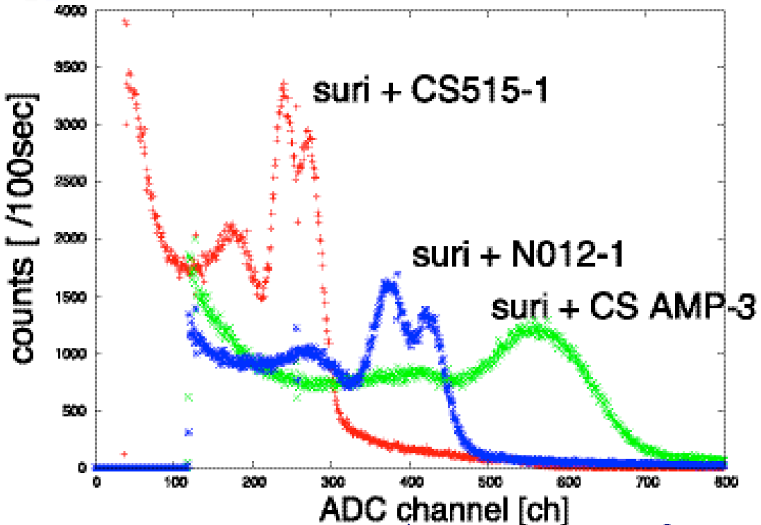




C_f'、R_f'　N012-1

CsI(Tl) preparation

Pre ampの決定



40cube スリガラス+PD 28^2
Pre amp C_f'=1pF

C_f'	CS 515-1	CS AMP-3	N012-1
1pF	○	○	○
10pF	○	○	○
100pF	○	○	×

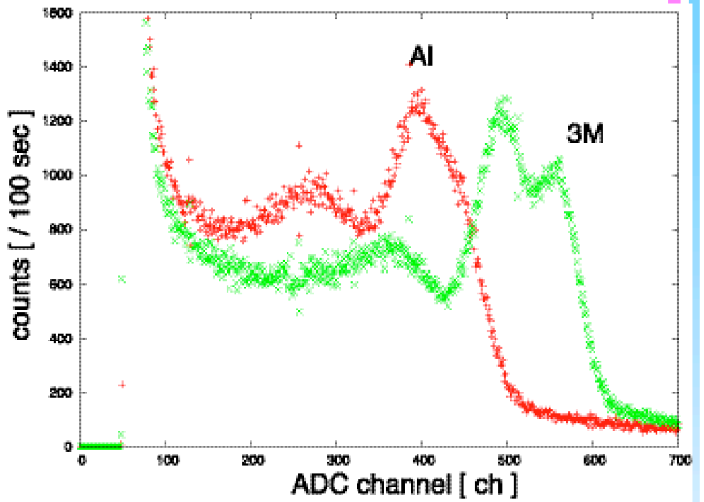
→ CsI : CS515-1にC_f'=100pF、R_f'=1MΩ

Si : N012-1にC_f'=10pF、R_f'=10MΩ

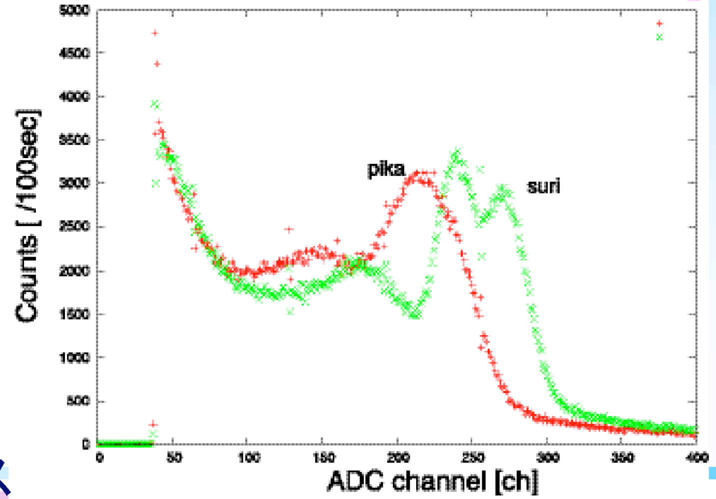
CsI(Tl) preparation

大型結晶のテスト

- 反射材
  3M-ESR→アルミホイルではわかれなかった^{60}Coの二つのピークが見える
  (40Cubeスリガラス+PD 28^2、ORTEC142A C_f=1pF)



- 表面状態
  鏡面よりスリガラス
  大型結晶で^{60}Coの2つのピークがわかれる
  (40cube+PD28^2　3M-ESR、CS515-1 C_f=1pF)



小型：鏡面　大型：スリガラス

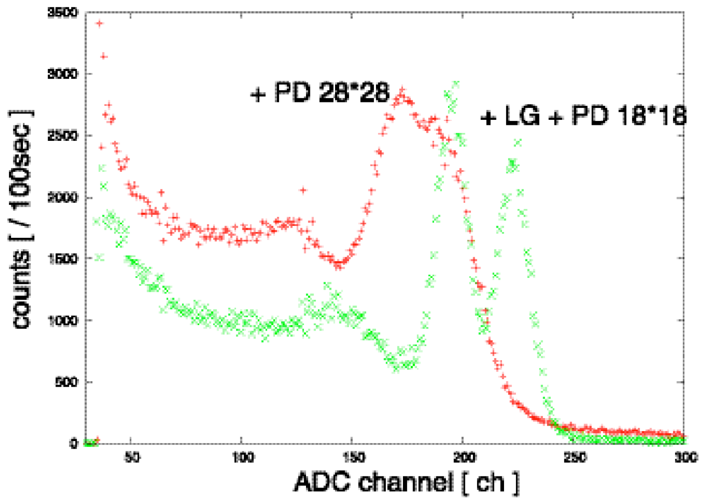
CsI(Tl) preparation

●ライトガイド

ライトガイドをつけることにより、分解能良くなる

(50cube鏡面 3M-ESR、

N012-1 C_f=1pF)



大型結晶でも

反射材：3M-ESRフィルム

ライトガイドつける

⇩

^{60}Coのふたつのピークがわかれるようになる

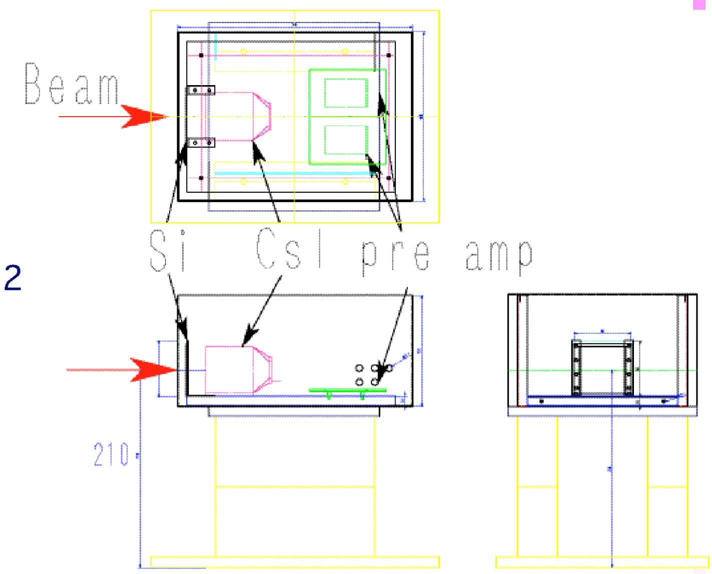
CsI(Tl) experiment

ビーム試験

結晶とPhoto diodeの組み合わせ

- CsI 50cube(鏡面) + LG + PD 18^2
- CsI 50cube(鏡面) + LG + PD 28^2
- CsI 40cube(鏡面) + PD 28^2
- CsI 40cube(スリガラス) + PD 28^2
- CsI 40cube(スリガラス) + LG + PD 18^2
- CsI 18^2×40(スリガラス) + PD 18^2
- CsI 18^2×40(スリガラス) + PD 28^2

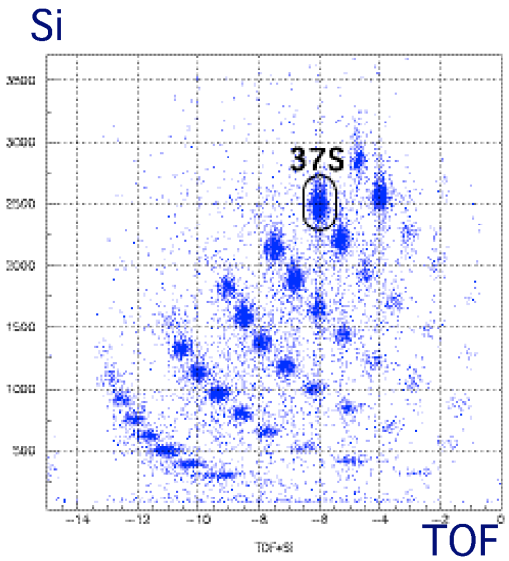
セットアップ

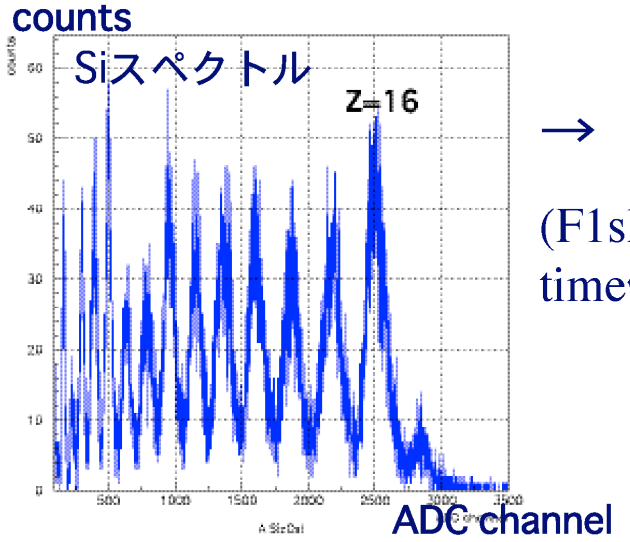


アルミ箱

CsI(Tl) experiment

^{40}Ar 二次ビーム 解析　粒子の選択　^{37}S(Z=16)





→　分解能

(F1slit幅、shaping time依存性)

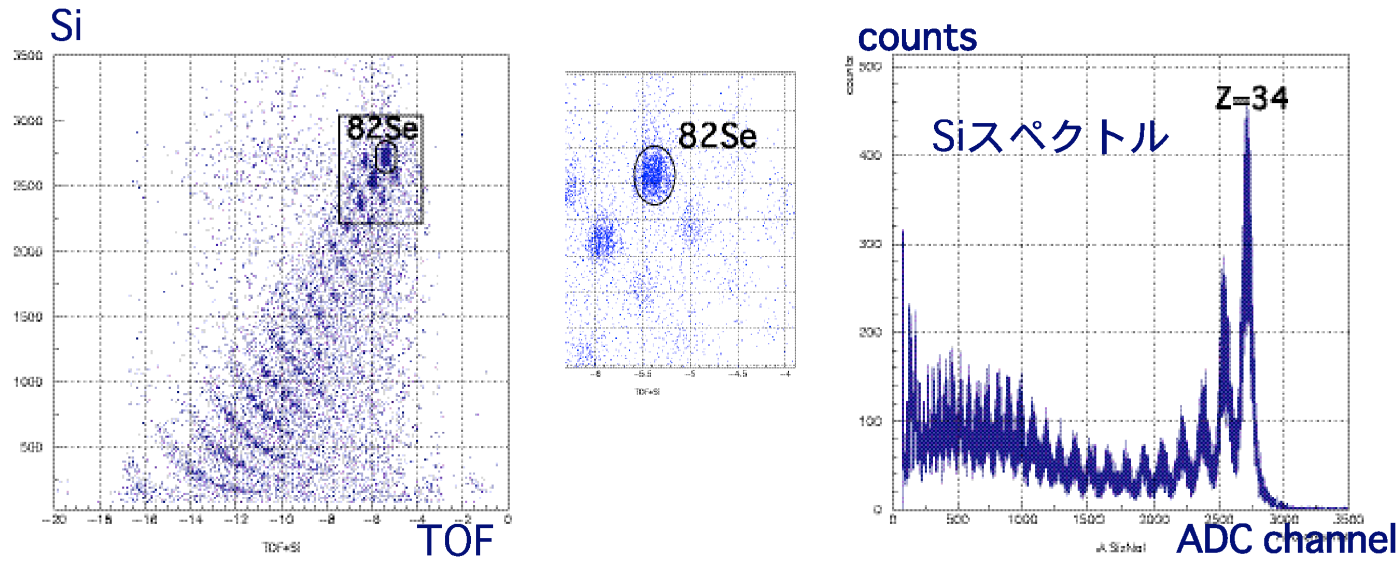
$B_2\rho_2$＝5.78Tmより F2でのエネルギー 264MeV/A

↓　エネルギー損失(Al真空隔壁、F3プラシンチ、BDC、入射窓アルミホイル、Si)

CsIの入射エネルギー <u>254MeV/A</u> (R=2.1cm)

CsI(Tl) experiment

^{84}Kr 二次ビーム 解析　粒子



$B_2\rho_2$＝6.11Tmより F2でのエネルギー 270MeV/A

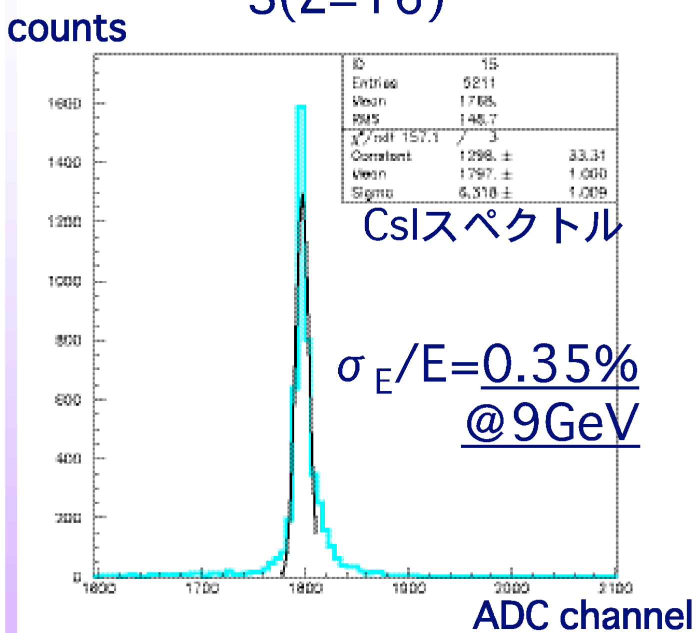
↓ エネルギー損失(Al真空隔壁、F3プラシンチ、BDC、入射窓アルミホイル、Si)

CsIの入射エネルギー <u>243MeV/A</u> (R=1.0cm)

CsI(Tl) results

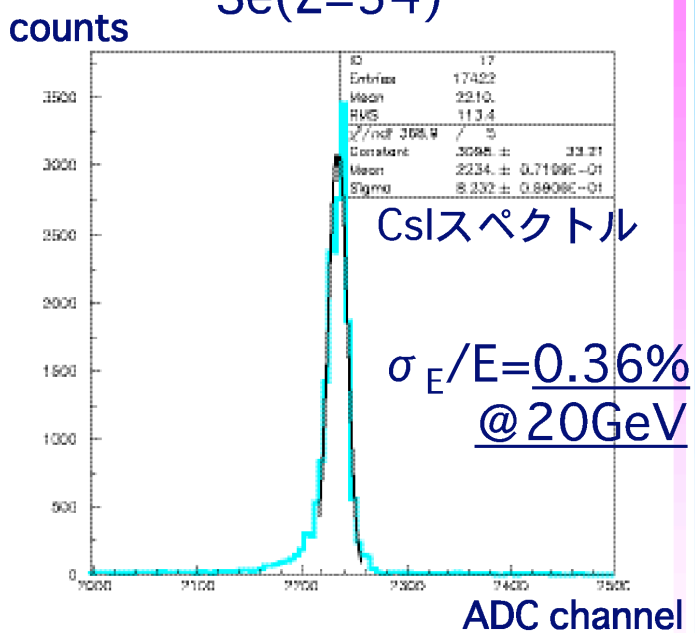
ビーム試験　結果

$^{37}S(Z=16)$



CsI 50cube(鏡面)
+ LG + PD 28^2

$^{82}Se(Z=34)$



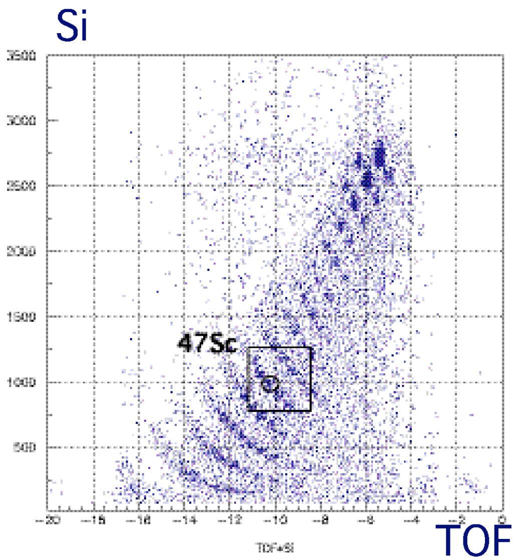
CsI 40cube(スリガラス)
+ LG + PD 18^2

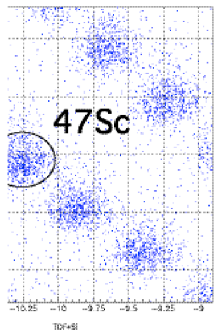
CsI(Tl) experiment

分解能：　全エネルギー依存性

^{84}Kr 二次ビーム

粒子の選択
^{47}Sc(Z=21)



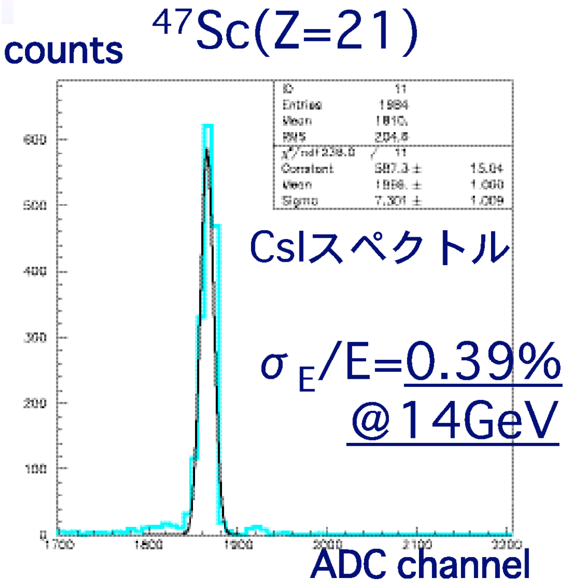


$B_2 \rho_2$＝6.11Tmより F2でのエネルギー 308MeV/A

↓ エネルギー損失(Al真空隔壁、F3プラシンチ、BDC、入射窓アルミホイル、Si)

CsIの入射エネルギー <u>295MeV/A</u> (R=2.0cm)

CsI(Tl) results



CsI 40cube(スリガラス)
+ LG + PD 18^2

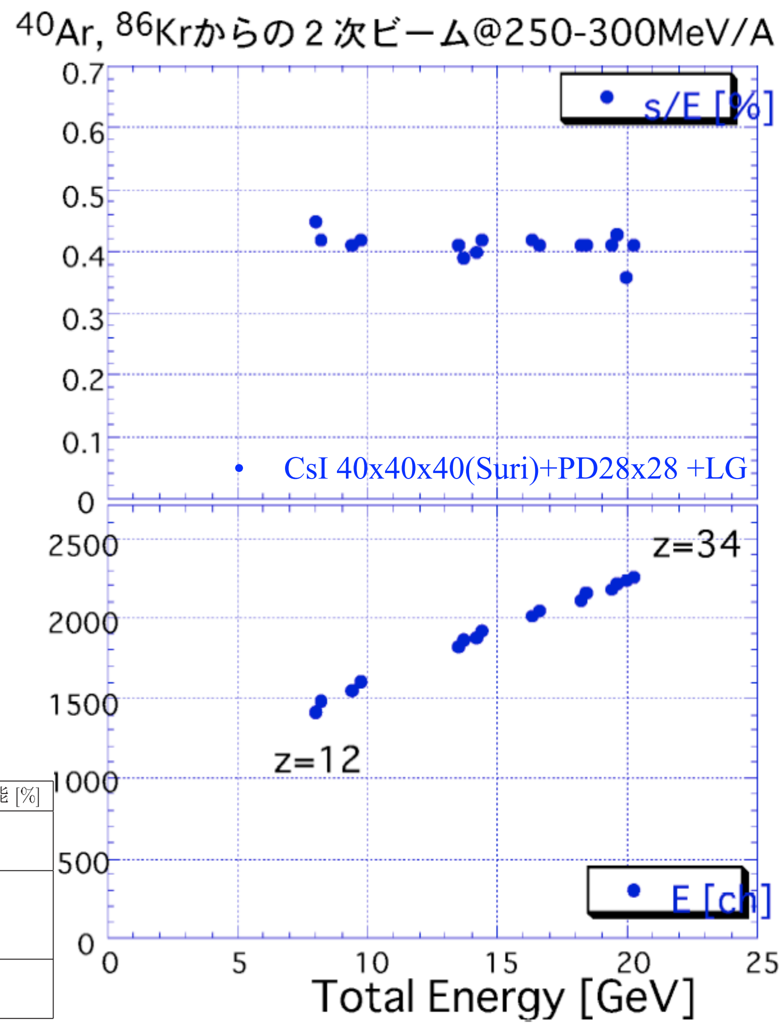
	^{84}Se	^{47}Sc
σ_E/E	0.36%	0.39%
E	20GeV	14GeV

分解能　：　全エネルギーに
　　　　　　あまり依存しない

スケール：　飽和

CsI(Tl) results

- σ_E/E=0.4 %
- Independent of Total Energy
- Pulse height : Satulation
- Best performance
  CsI 18x18x40(Suri)+PD18x18
  σ_E/E=0.34 - 0.37 %
- Better performance
  CsI 40x40x40(Suri)+PD28x28
  +LG
  σ_E/E=0.36 - 0.40 %



^{82}Se のエネルギー分解能と比較したものを表 44 に示す。

CsI と Photo diode の組合せ	^{82}Se のエネルギー分解能 [%]	^{47}Sc のエネルギー分解能 [%]
CsI50×50×50(鏡面)+LG+PD18×18	0.57	0.67
CsI50×50×50(鏡面)+LG+PD28×28	0.41	0.45
CsI40×40×40(鏡面)+PD28×28	0.40	0.57
CsI40×40×40(スリガラス)+PD28×28	0.38	0.40
CsI40×40×40(スリガラス)+LG+PD28×28	0.36	0.39
CsI18×18×40(スリガラス)+PD18×18	0.34	0.37
CsI18×18×40(スリガラス)+PD28×28	0.48	0.45

表 44: エネルギー分解能の比較

CsI(Tl) summary

- σ_E/E=0.4 %
  Independent of Total Energy
- Pulse height : Satulation
  Where?
- For large area coverage :
  Better performance by
  CsI 40x40x40(Suri)+PD28x28+LG : σ_E/E=0.36 - 0.40 %

- $\times 4$ of expectation value of σ_E/E=0.1 %

- To be studied :
  - Saturation (of photon?) in CsI(Tl)? : Tl control?
  - PD optimization
  - preAMP : C_f 1pF⇒100pF + other treatment?

Considerations

- σ_E/E=0.15 % @3" NaI(Tl)+PMT
- σ_E/E=0.4 % @40^3 CsI(Tl)+LG+$PD28^2$
- ×5~15 of scaling from 662keV γ
  ⇒ saturation somewhere

- Tolerance : < 0.5-1.0 kHz

- Material Uniformity upstream of *E* detector
  c.f. 23 μm Al foil(6.2mg/cm^2) :
  250 A MeV Z=32 : 0.25A MeV loss, $\Delta E/E$=0.1%

- Next step ?

Summary

- σ_E/E=0.15 % @3" NaI(Tl)+PMT
- σ_E/E=0.4 %   @40^3 CsI(Tl)+LG+$PD28^2$

- ×1.4~4 worse than requirement : σ_E/E=0.1 % (5σ sep.@A=100)

- NaI(Tl) : 4σ separation @ A<80
- CsI(Tl) : 4σ separation @ A<30

- Tolerance : < 0.5-1.0 kHz

- Saturation

- CsI(pure)+PMT ? (Terashima-san's talk)

p181 experiment collaborators

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Thank you for your attention

HIMAC SB2

HIMAC 2次ビームライン　　P_{max}= 2.4 GeV/c