CAT(S)

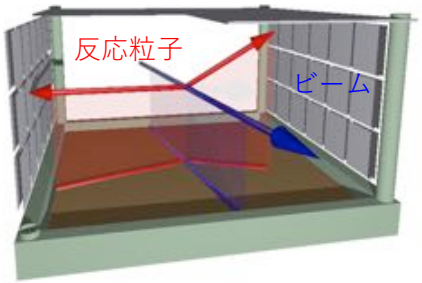
CNS Active Target

大田　晋輔

（東大CNS）

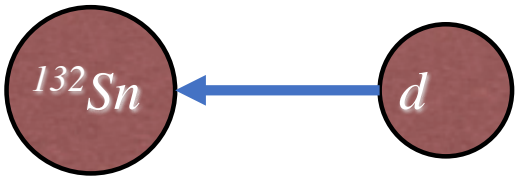
B01班公募研究 2015年度ー2016年度

CAT(M)



背景

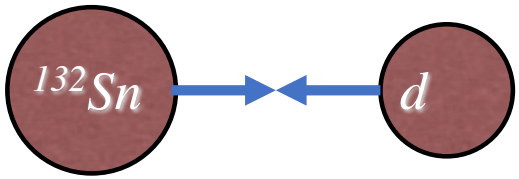
順運動学



寿命40秒

インプラント標的?

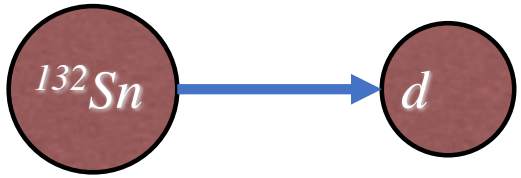
コライダー



寿命40秒

ストレージリング？
e散乱は SCRIT

逆運動学



寿命40秒

我々の手法

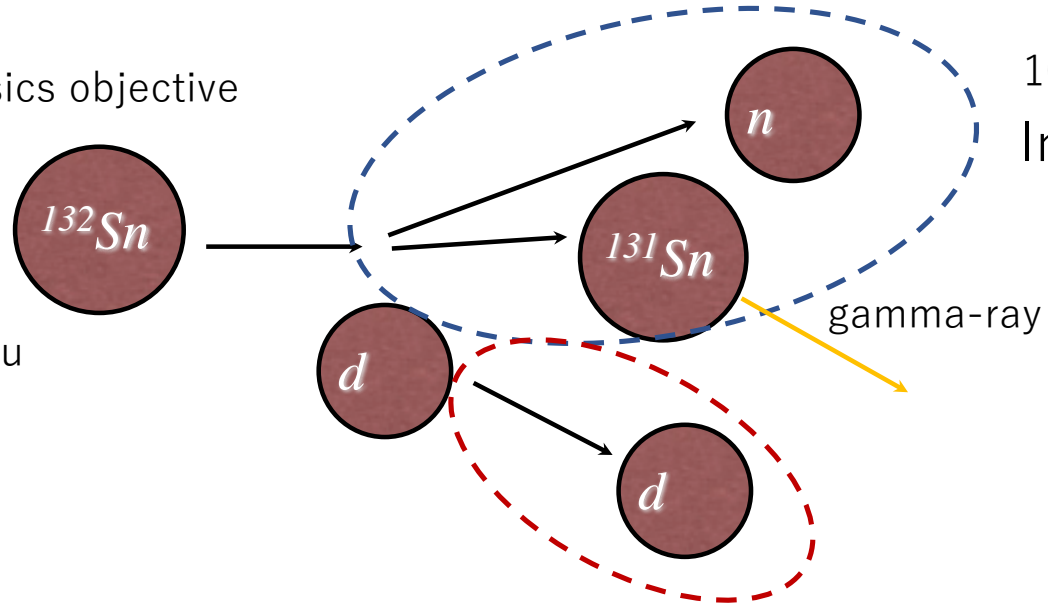
問題

不安定原子核の**高励起状態**への**重心系２度程度を含む**角度・エネルギー二重微分断面積を測りなさい。ただし測る粒子はビームを除いて**荷電粒子一個**とする。

ルミノシティ　0.01mb^{-1} で１０日間
ビーム 10^6 個/秒
標的　10^{19} 個/秒

質量欠損分光in inverse kinematics =反跳粒子測定

Beam = Physics objective



100-300MeV/u

100-300MeV/u

Invariant mass

gamma-ray

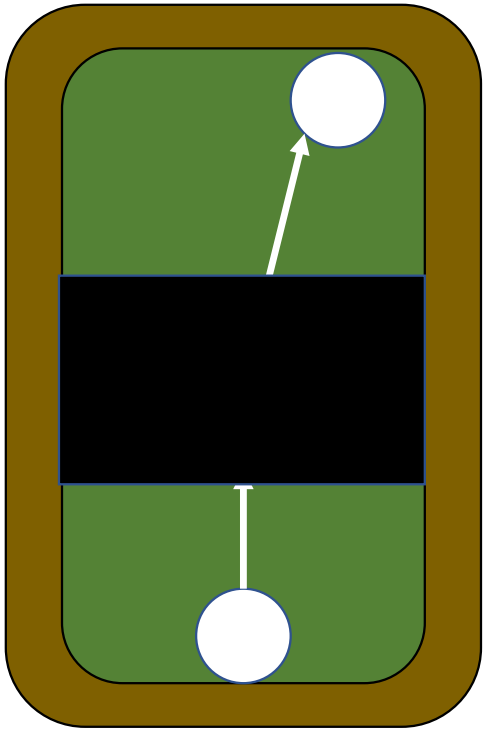
(TKE) 0.2MeV – 20MeV

Missing mass

(a,a'), (d,d') : ISGR
(p,p') : M1, Dipolarizability
(p,p) : proton-neutron distribution
(p,2p), (p,pn), (p,pa) : single particle / nucleon corr.
(p,n), (d,2p) : GT, SDR …
Coulex: IVGR

ざっくり各10日 @100kcps
全部やると50日以上

原子核散乱（ビリヤード）の反応点近傍まで見たい！！



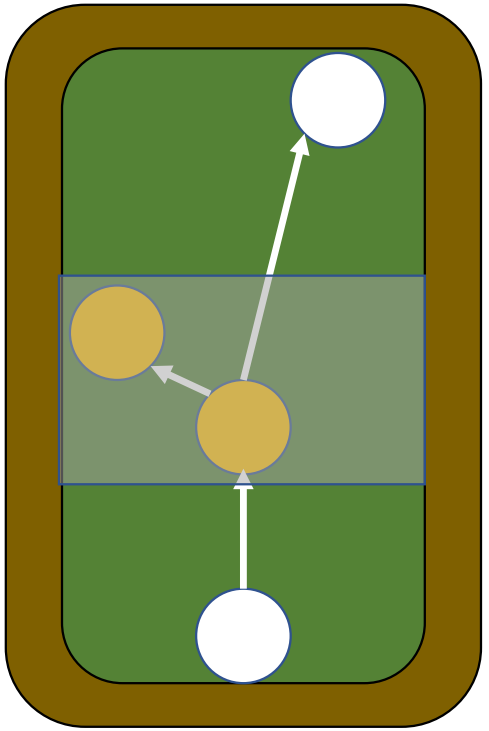
どんな反応も見逃さない原子核反応３Ｄカメラ

というのが目標ですが、実際には限界というものが必ずありますがそれは後ほど。

３Ｄ撮影技術
＝TPC
＝ガス検出器

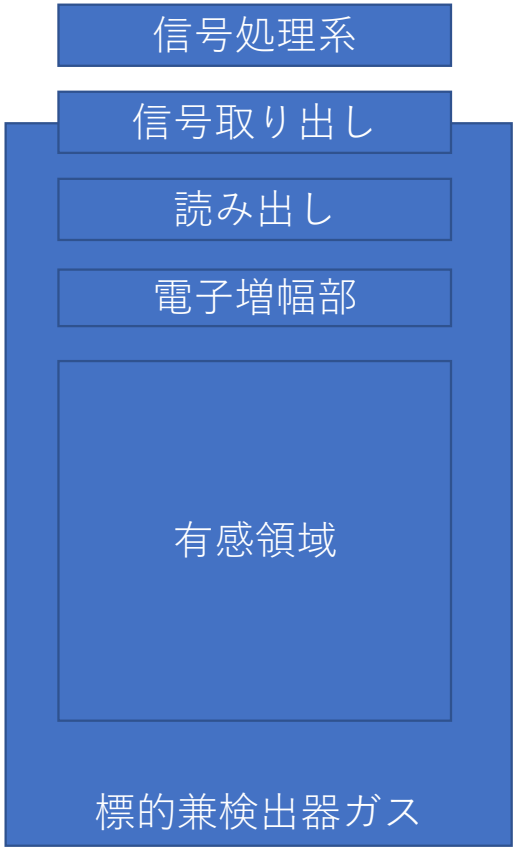
検出器ガスを標的にすれば反応点まで測定できる！！

逆に言うと標的ガスを使ってTPCを実現するということです



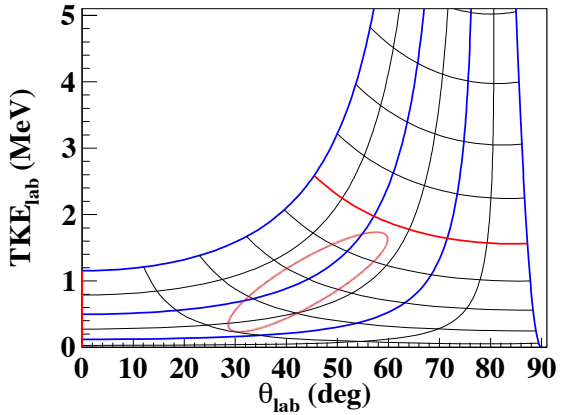
アクティブターゲット＝標的+検出器(TPC)

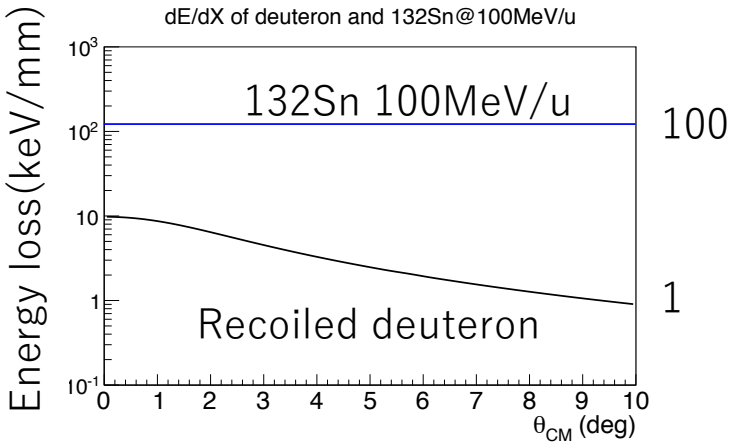
アクティブターゲットとしては他にもある
Siドリフト検出器
ファイバーシンチレータアレイ



Experimental condition

- Consider 132Sn (d,d')
  - Incident energy of 100 MeV/u
  - cross section ~ 0.1 mb within the acceptance of CAT
- Luminosity : 0.01 mb^{-1}
  - target thickness: 0.3 mg/cm2 (D_2, ~5cm, 0.4 atm)
  - Very high intensity: maximum 1Mcps (purity ~ 10%)
    - **Typical injection rate 300kcps**
- Heavy ions: Z~50, A~130
  - Large energy deposition
  - **Huge number of secondary electrons (delta rays)**



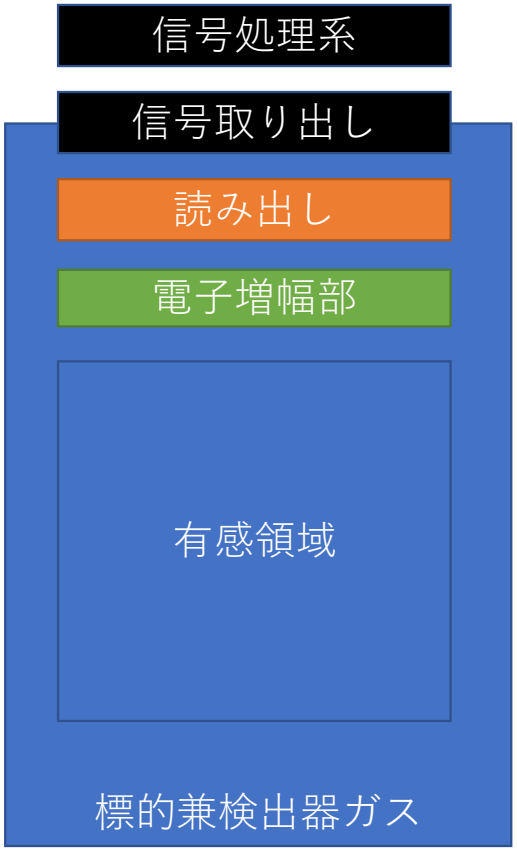


アクティブターゲットのポイント

ゲーティングリッドなし
磁場なし

アクティブ標的

- 水素、重水素、ヘリウムでTPC
- ビームと反跳粒子を同時測定
  - 単位時間あたりに生成される電子・イオン対は１０万倍以上の差
  - デルタ線がわんさかでる
- 読み出し数 VS 分解能
- 高い運動量の反跳粒子検出器として Silicon を使う
- 標的数とアクセプタンス

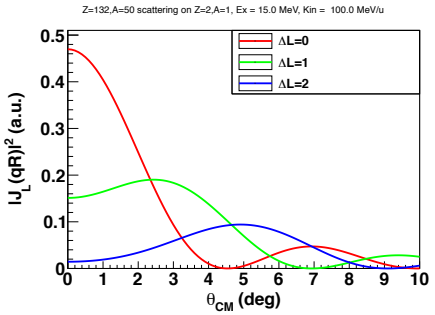


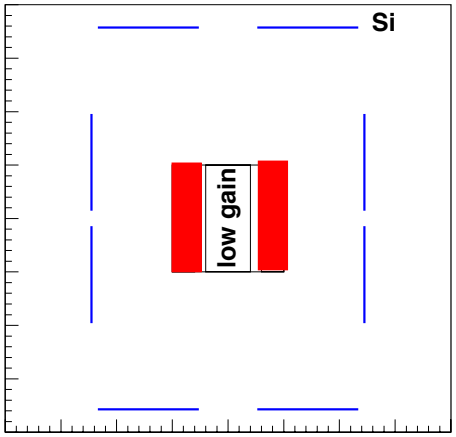
Contents

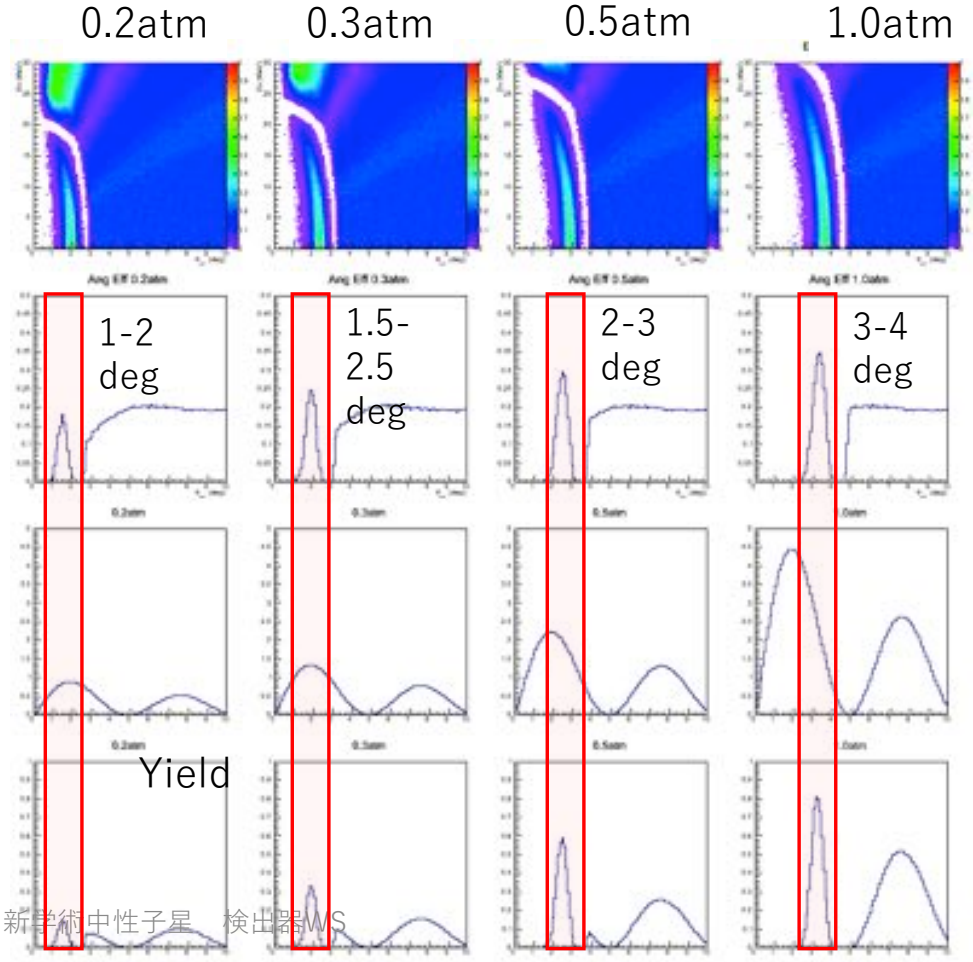
- Active Target TPC
  - Gas pressure optimization
  - Multiplication : THGEM / M-THGEM
  - Readout pad and tracking method
- Activities
  - Roadmap
  - EOS and First RI beam experiment
  - Next step
  - Other Physics case

Consideration of operation pressure

Monte Carlo simulation
Not taking into account
the tracking efficiency





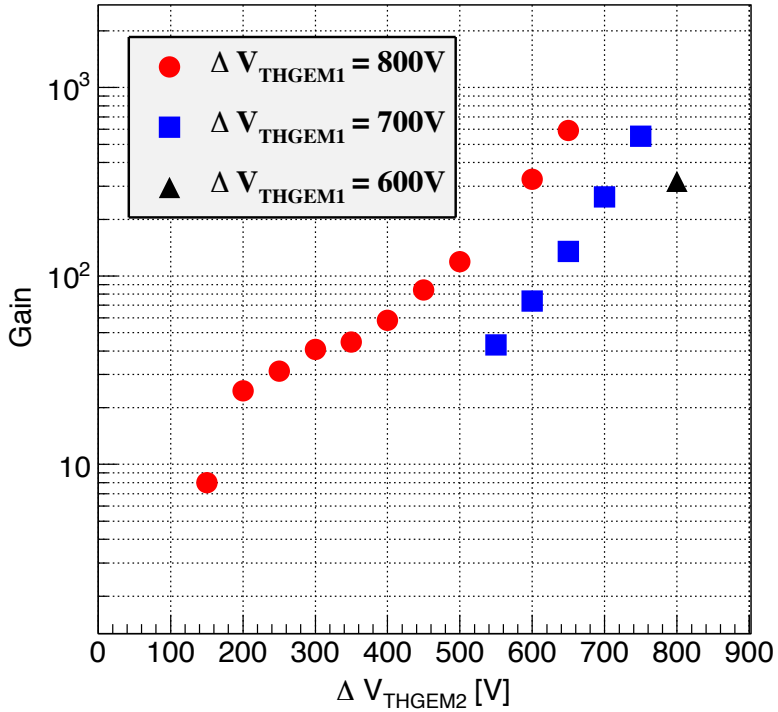


Multiplication &
Dual gain operation

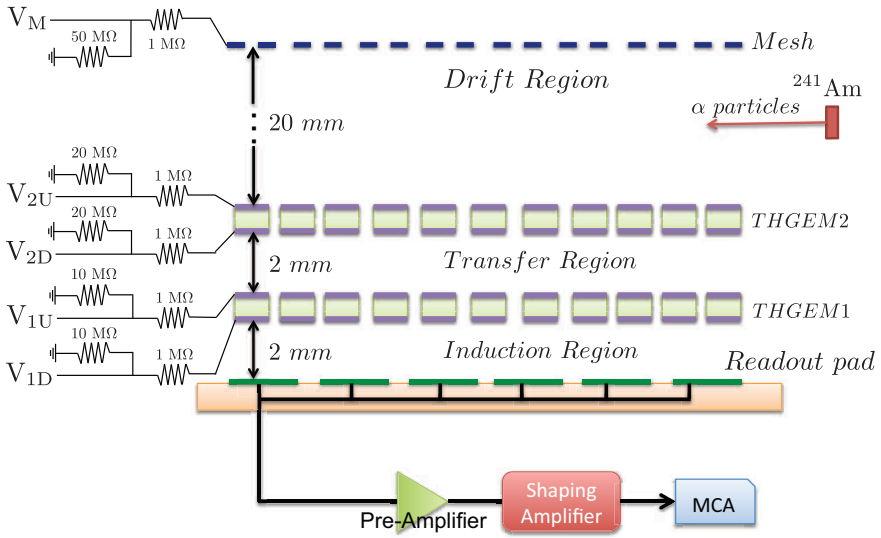
Multiplication

- ガスは水素、重水素、ヘリウム
- ガス圧は 0.4 atm 以下
- ビームと反跳粒子でゲインを大きく変えたい

0.4-atm 重水素 two THGEMs



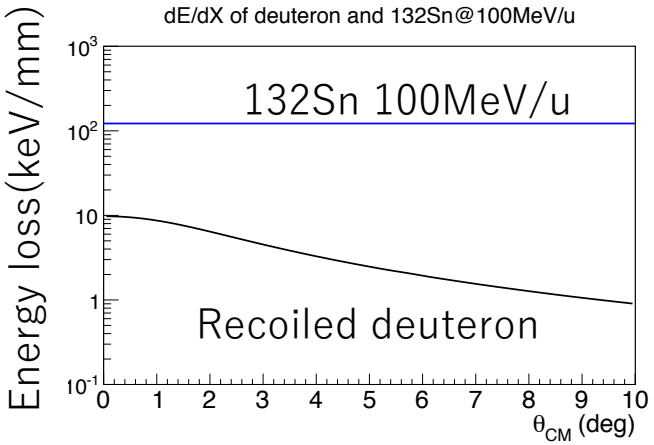
400 um thick, 300 um diameter, 700 um pitch

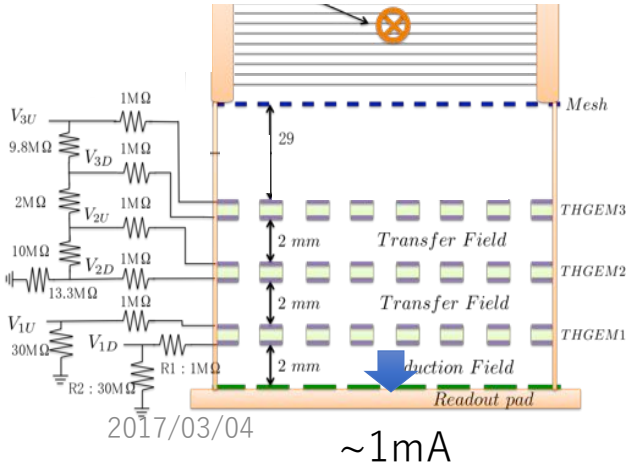


実際には３層にしてゲイン３０００程度で使用している

Operation with high-intensity beams

w/ beam intensity of 10^6 cps
=> O(1) mA at last THGEM.

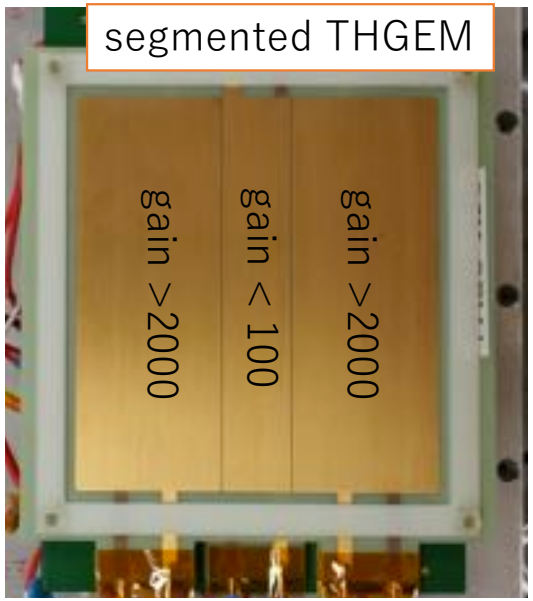


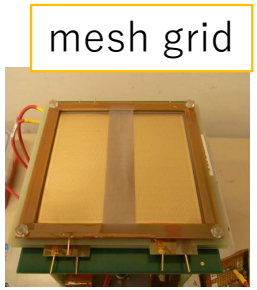


~1mA

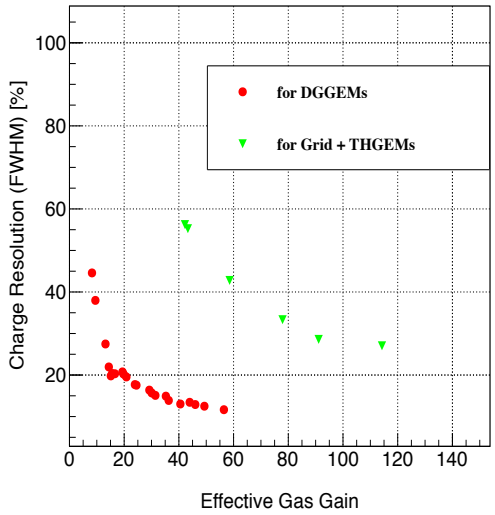
100

1





Segmented THGEM provides better energy resolution than mesh grid along the beam path.
=> stable with up to the 500-kcps 100-MeV/u 132Xe beam

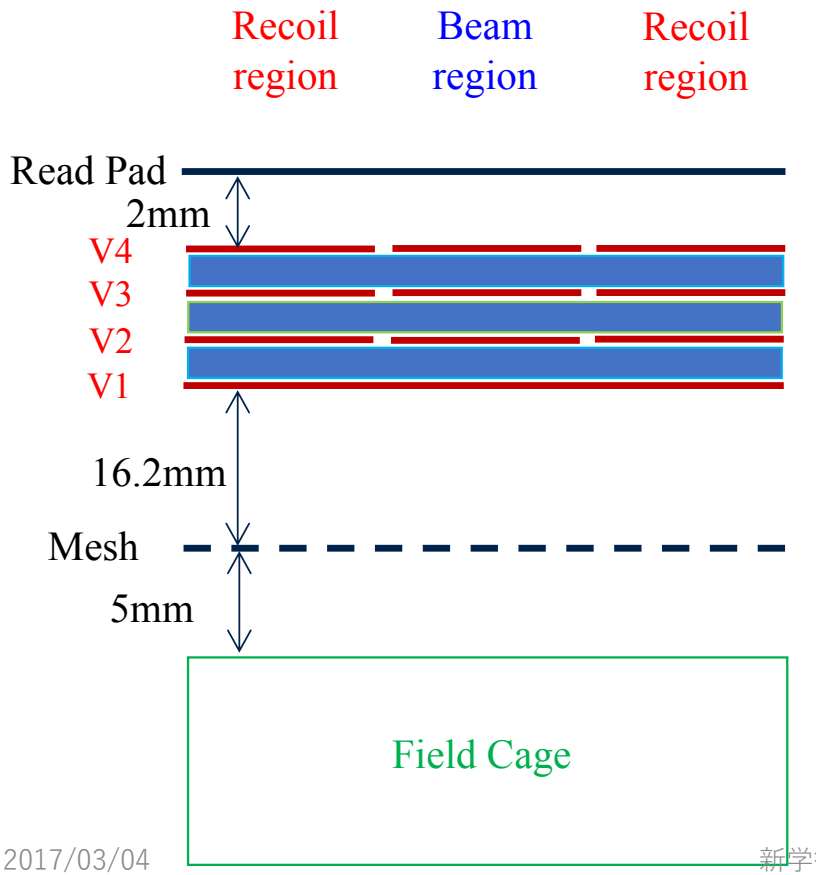


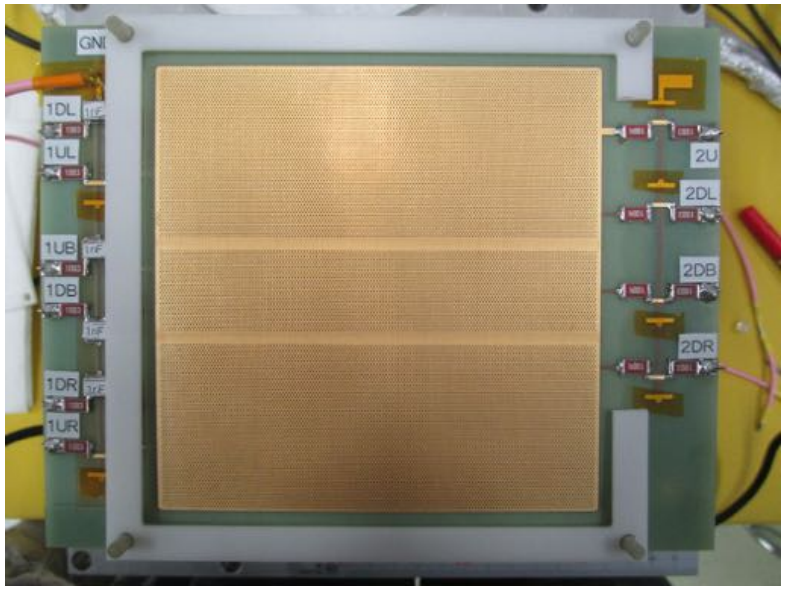
for gain>2000
at recoil region

S. Ota et al, J. Radioanal. Nucl. Chem. 305 (2005)

0.4-atm 水素 Dual gain Multilayered THGEM

M-THGEM: Inspired by development at MSU (2016)

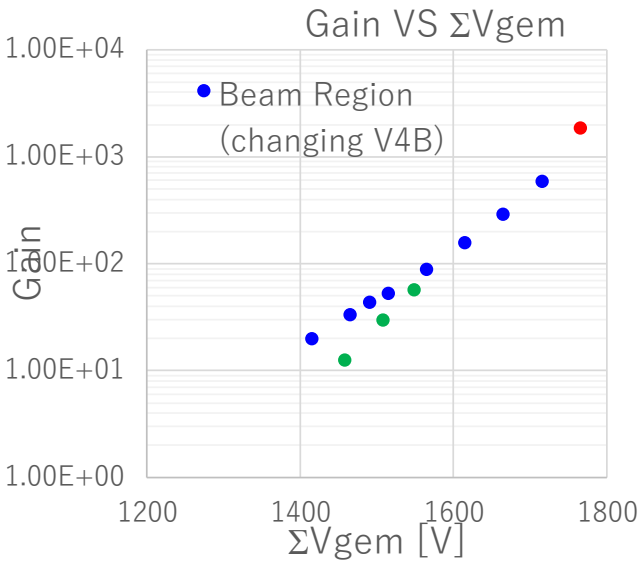


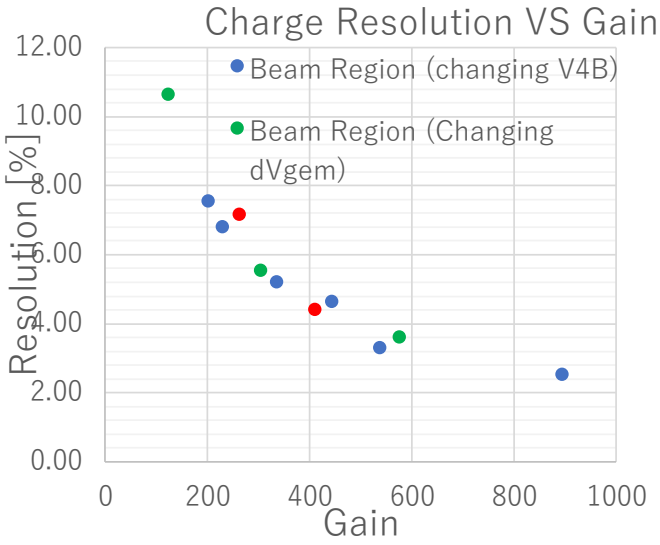


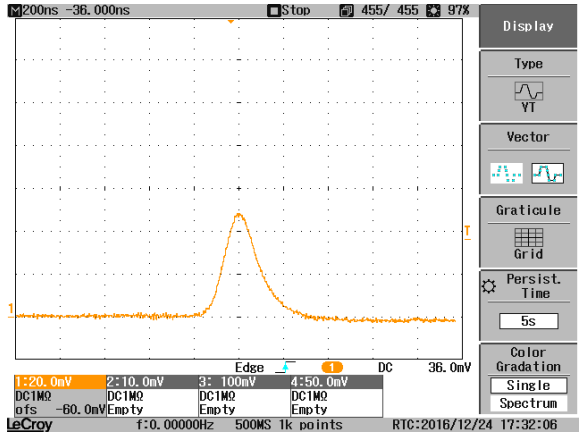
	Energy	dE/100mm [MeV/100mm]	dE/dx [MeV/mm]
132Xe	184.4 MeV/u	9.54	0.0954
Alpha	3.64 MeV	1.10	0.00976

ゲインと分解能　(M-THGEM)

Dec2016, 15H307 @ HIMAC







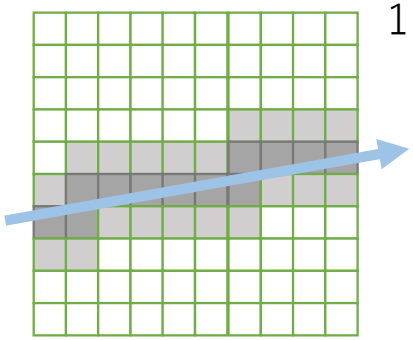
10cm分の積分値で評価
（50keV程度になると15%くらいになる）

	Energy	dE/100mm [MeV/100mm]	dE/dx [MeV/mm]
132Xe	184.4 MeV/u	9.54	0.0954
Alpha	3.64 MeV	1.10	0.00976

Readout & Tracking

Readout pad

- Concept: small number of readout channel (relatively low definition)
  - Challenge to improve the resolution of track with low-definition pad array.
    - Using charge information to deduce the position
  - (Unexpectedly) Important for the delta-ray discrimination for the trigger



1 * 100 = 100

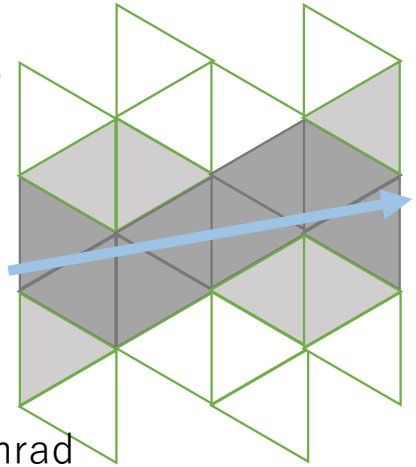
4K

32 hits

3.9 * 24 = 93.5

HD

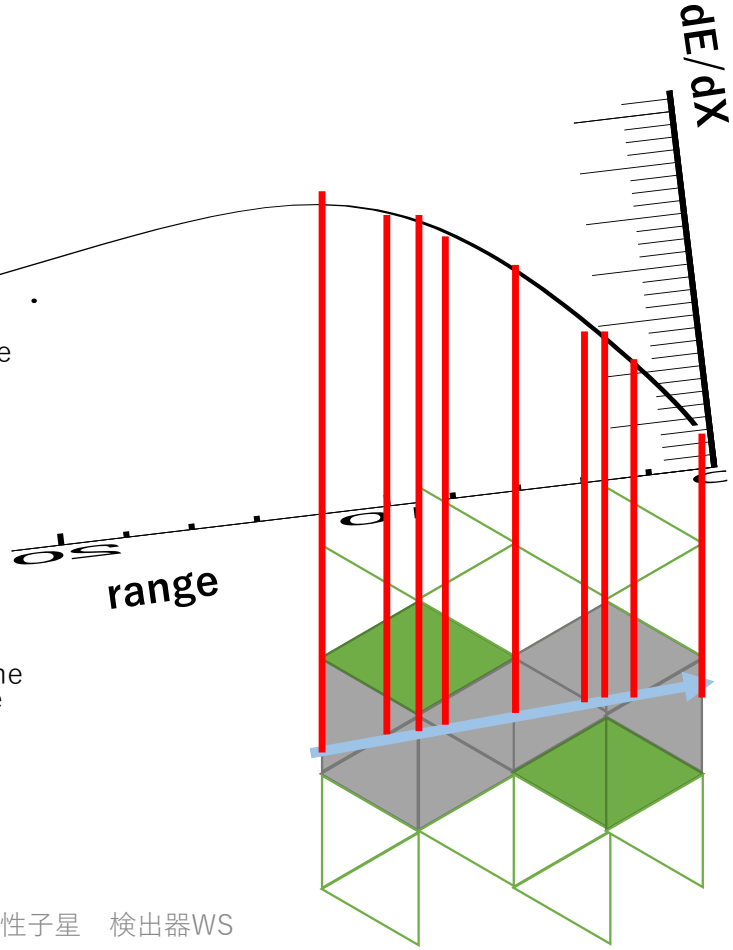
14 hits



3*10%/sqrt(4)
= 0.1 mm?
or 0.3/10 = 30mrad
for de/e = 10%

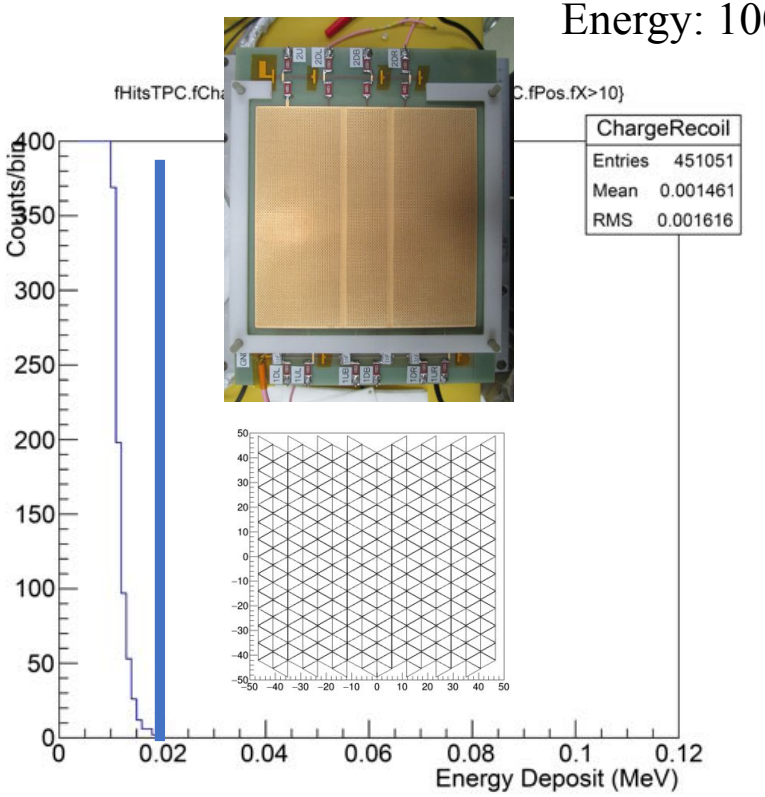
Bragg curve fitting

- fitting the calculated charge to the measured charge
- How to calculate the charge
  - Needs brag curve
  - If there is no diffusion
    - Assume a line segment = track of particle
    - Calculate intersection of the line segment and a readout pad
    - Calculate the total kinetic energy at each intersection and deduce the energy deposit
  - There is diffusion
    - Response function for an energy deposit at a certain point
    - Integrate the response to the energy deposition along the trajectory

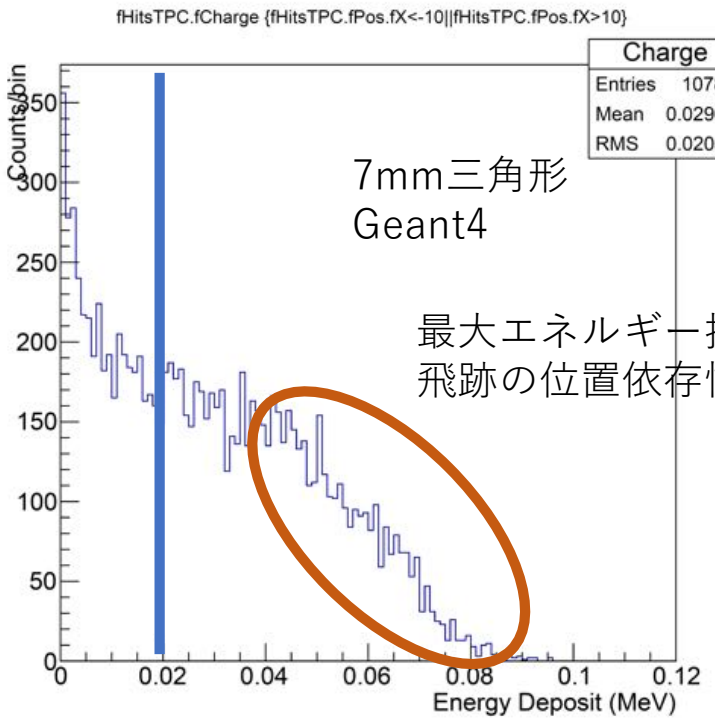


Estimation of delta-ray by irradiating high intensity beam

Projectile 132Sn 2000 particle
Energy: 100MeV/u

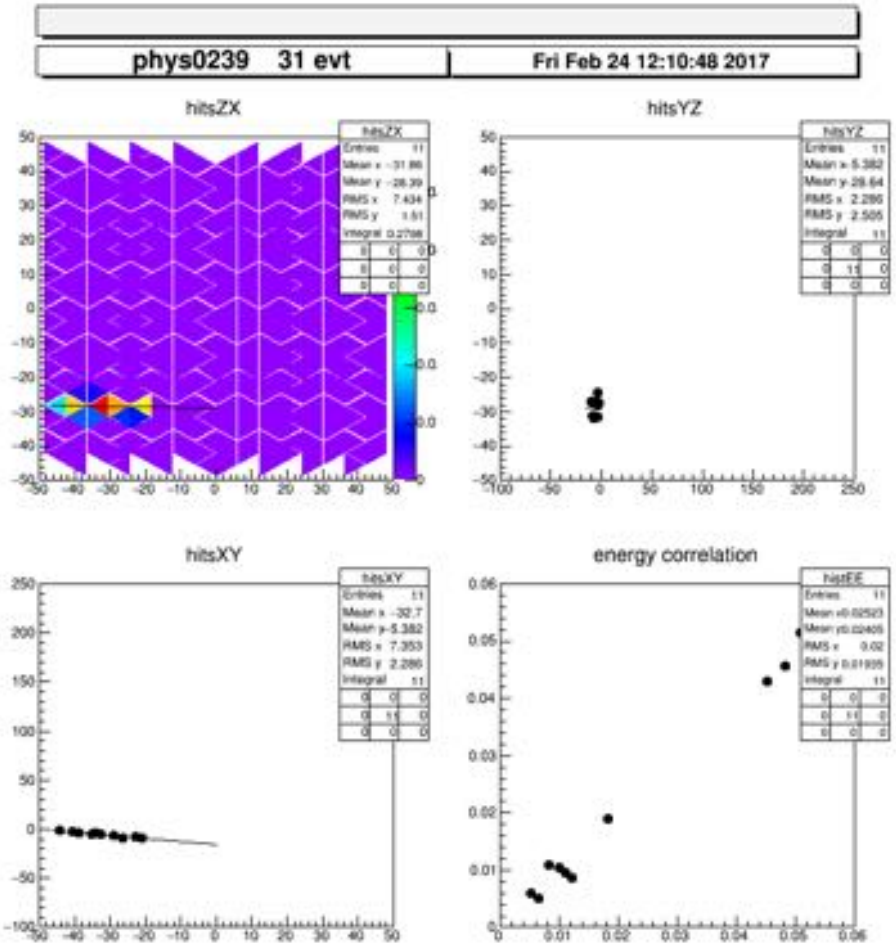


Projectile 132Sn 2000 particle
Energy: 100MeV/u



Recoil deuteron 2000 particle
Ex: 14MeV – 15MeV
θcm: 1.5deg – 2.5 deg

Example


phys0239 31 evt
Fri Feb 24 12:10:48 2017
hitsZX
hitsYZ
hitsXY
energy correlation

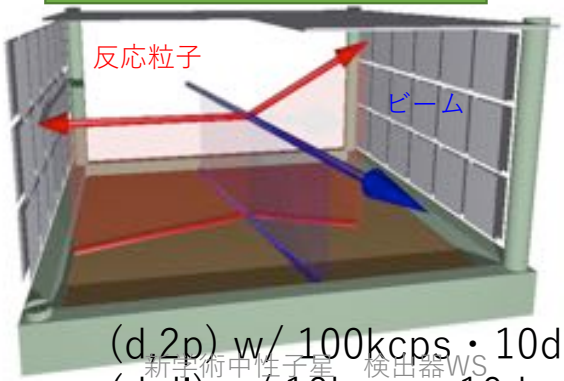
Roadmap for Development

平成	21	22	23	24	25	26	27	28	29	30	31	32	33
年度	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
S	研究・開発												
M								開発			共同研究		
L										設計・資金			

CAT1
(**S**ilvestris)
10cm x 10cm x 25cm

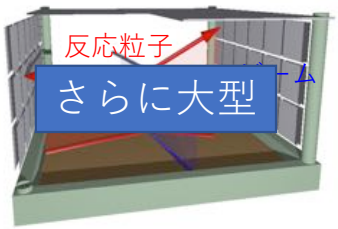
(d,d') w/ 100kcps・10day

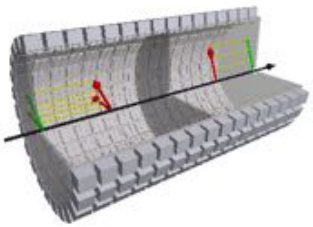
CAT2
(**M**anul)
30cm x 30cm x 20 cm



(d,2p) w/ 100kcps・10day
(d,d') w/ 10kcps・10day

CAT3
(**L**ynx)
Large Volume + Gamma



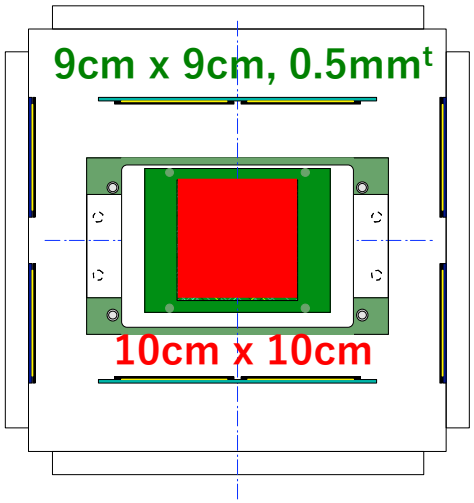


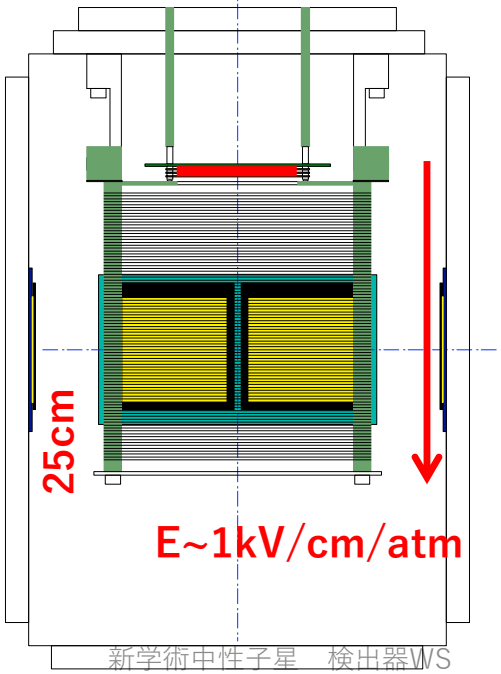
ϕ 50cm x 2m
or 50cm x 50cm x 2m

First RI beam experiment

CNS Active Target (S)

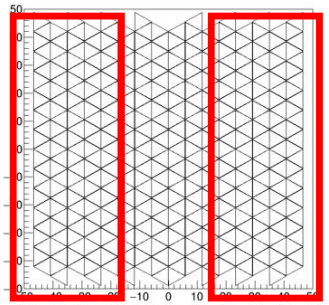
TPC + Silicon
pure Deuterium or Hydrogen, or He + CO2
No magnetic field
Charge measurement is essential

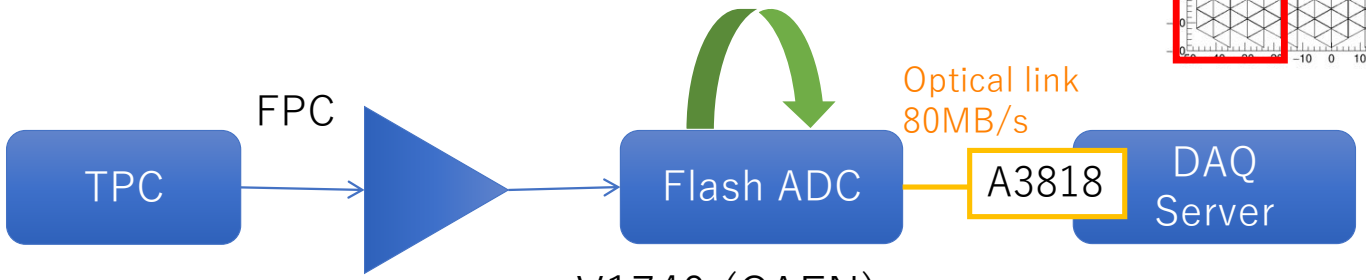




現在のReadout system

Self triggering using side pad
+ ext. trigger by SSD
300 Hz accept, so far / 12bit 1500sample

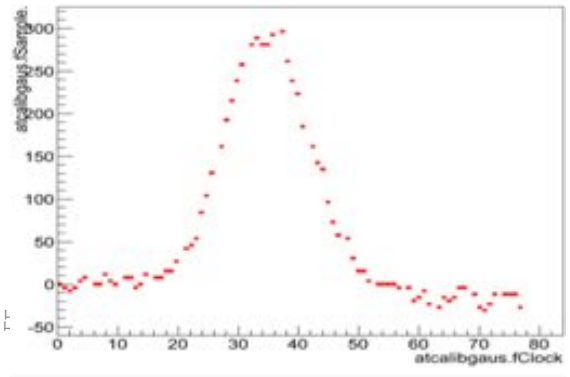




preamp (REPIC)
τ ~ 80 ns
0.3V/pC

V1740 (CAEN)
12bit 2Vpp 50MS

pulse shape



Commercial base and low cost (easy to get in 2009)
=> V1740 CAEN

Ktau and ISGMR in A=132 nuclei

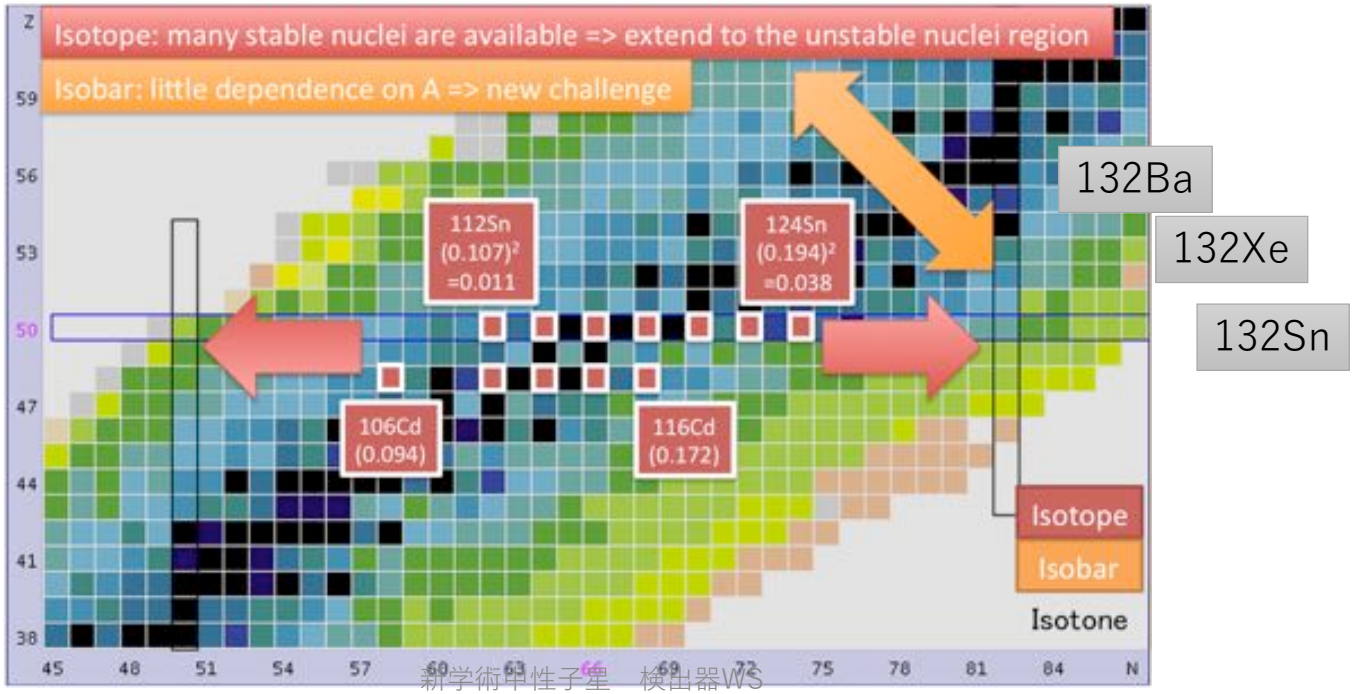
@RIBF

Incompressibility

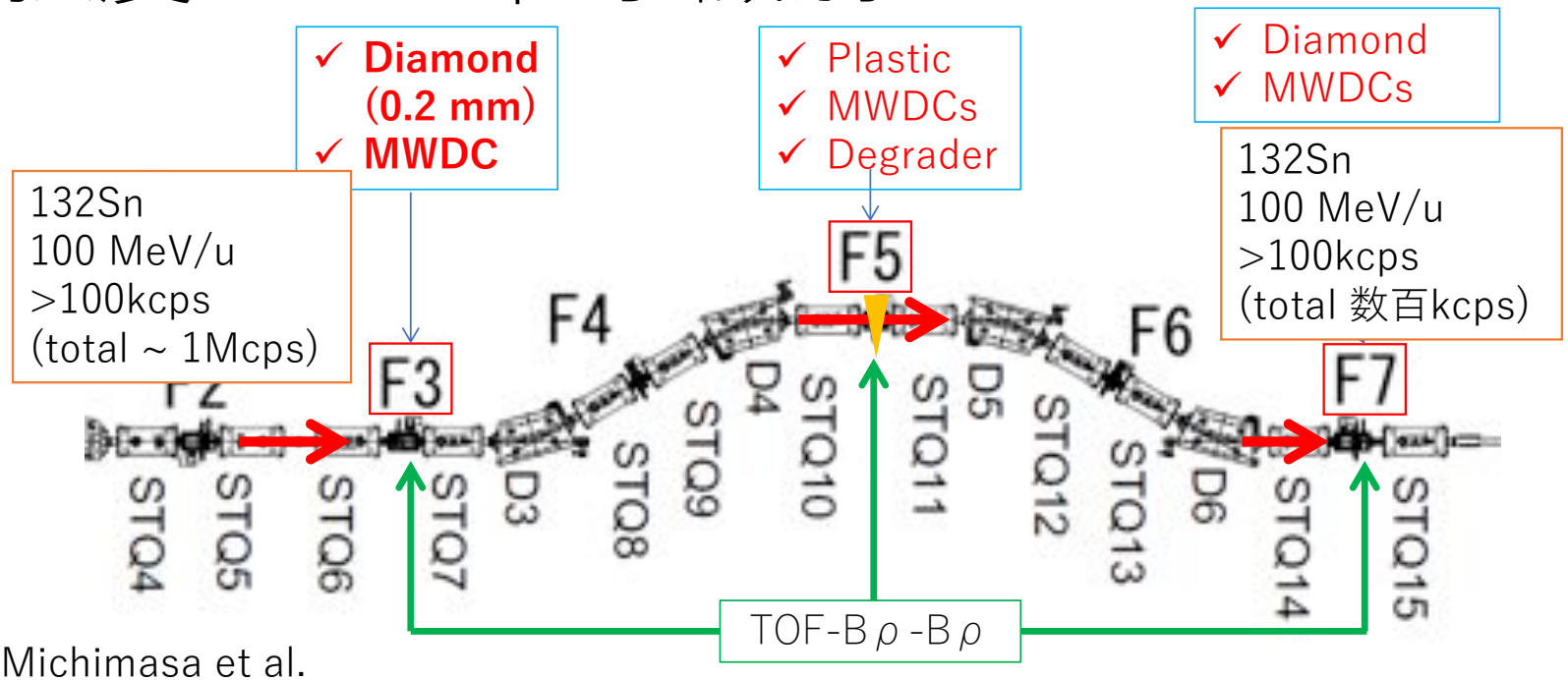
$$E_{\mathrm{GMR}} = \hbar\sqrt{\frac{K_A}{m < r^2 >}},$$

$$K_A \sim K_{\mathrm{vol}}(1 + cA^{-1/3}) + K_\tau[(N - Z)/A]^2 + K_{\mathrm{Coul}}Z^2A^{-4/3},$$

asymmetric term of incompressibility



大強度ビーム粒子識別



Diamond: S. Michimasa et al. (2013)
LP-MWDC: H. Miya et al., (2013)

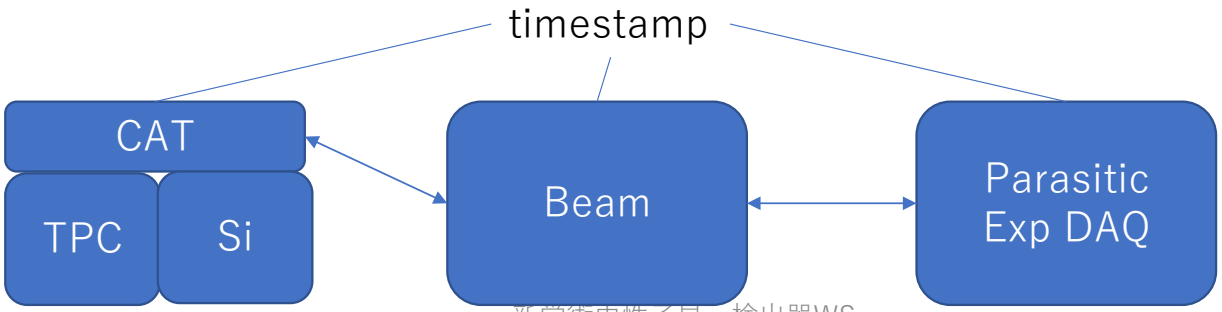
時間測定のみ

10^6cps を越える大強度ビームを分離、識別し使用可能にする
二次ビーム粒子識別: 応答の早い検出器システムを用いる

ルミノシティ 10^5 cps x 10^{20}cm^{-2} ~ 0.01 mb^{-1}s^{-1}

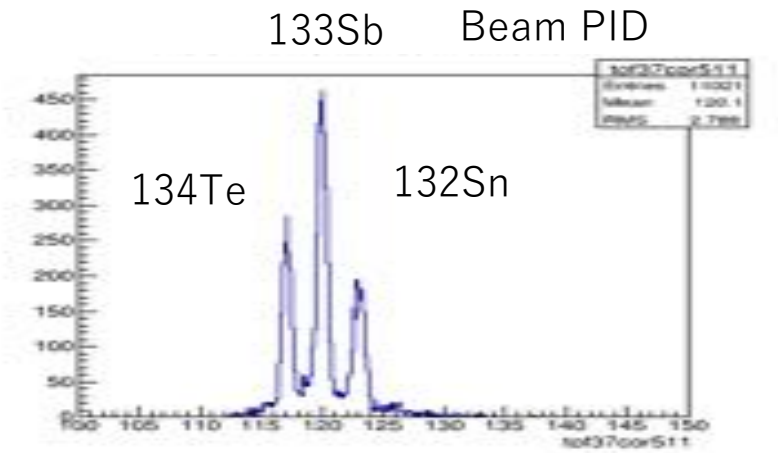
Data acquisition system

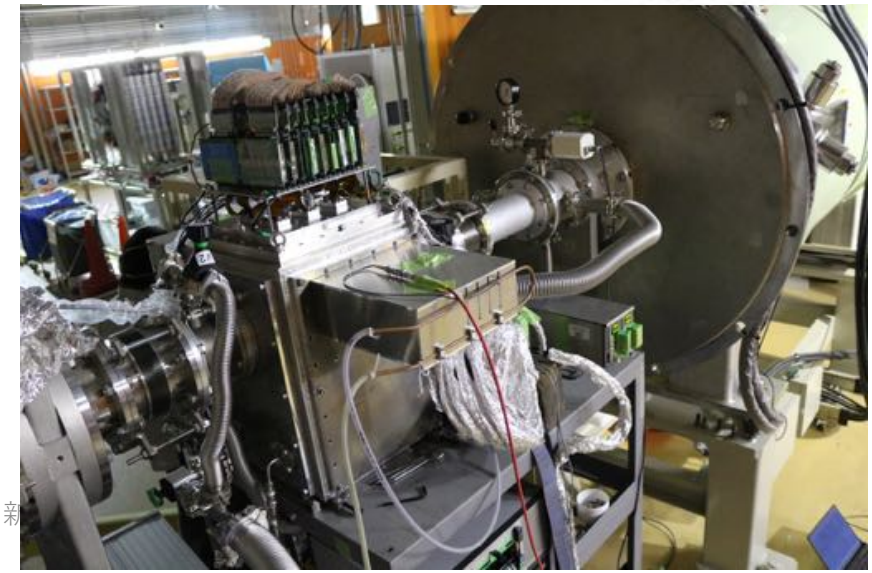
- TPC part
  - High density FADC from CAEN
  - High speed optical link readout (~60 MB/sec)
  - Software zero suppression
- Silicon part
  - HIMP system (for SAMURAI Silicon at RIKEN)
- Beam part
  - Single VME board readout (MOCO)
  - Data rate and live time
- Parasitic



The first experiment at RIBF

- 132Sn 100 MeV
  - Intensity : 350kcps
  - Purity: 25-30%
- Beam PID is done w/o dE information
- 25TB data in total

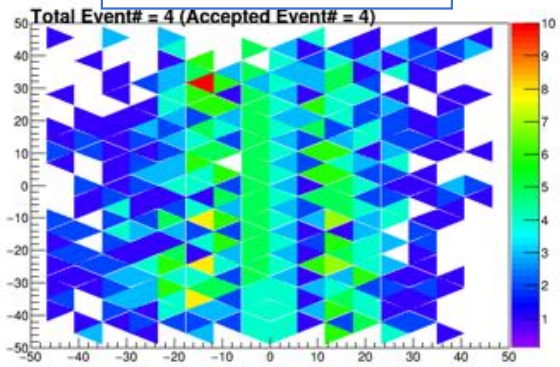




Preliminary result w/o beam information

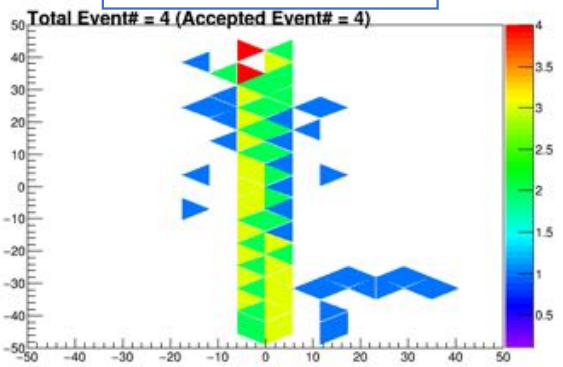
- Rejection of delta rays
  - Pulse height cut
  - Clustering
- Rejection of beam-like particles
  - Event selection by pre-tracking w/ centroid tracking

Recorded pulses



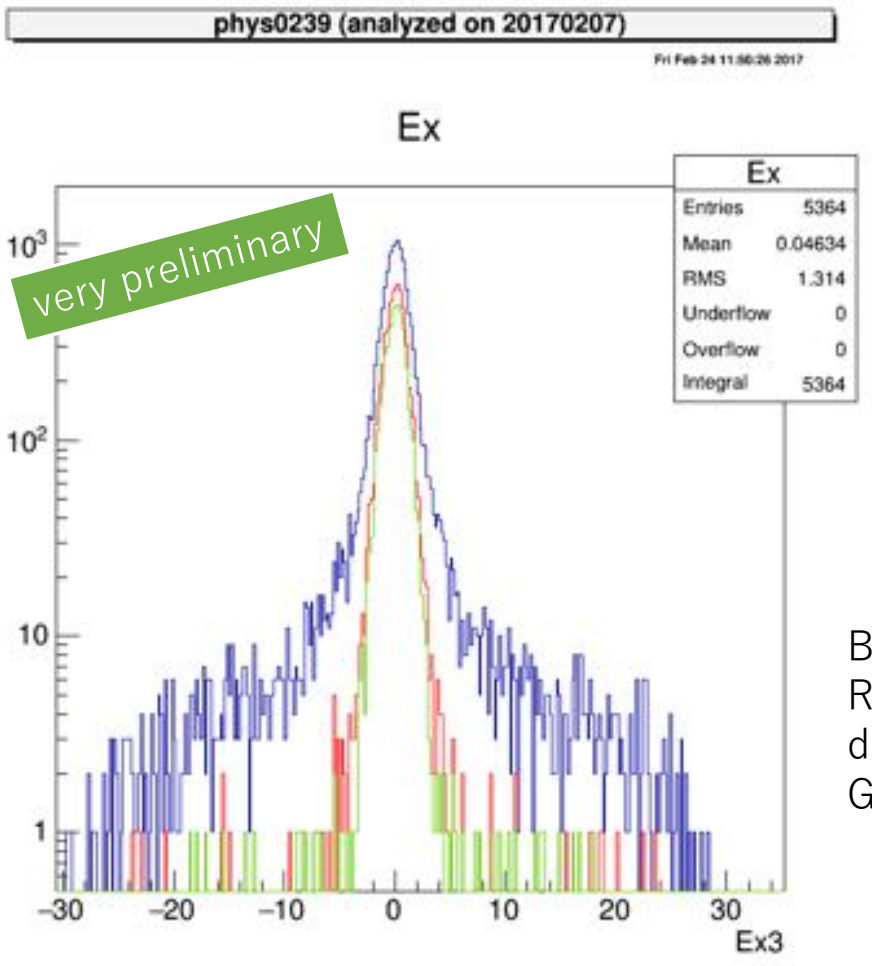
roi

Selected pulses



Tokieda's talk

data acquired for 1500 sec



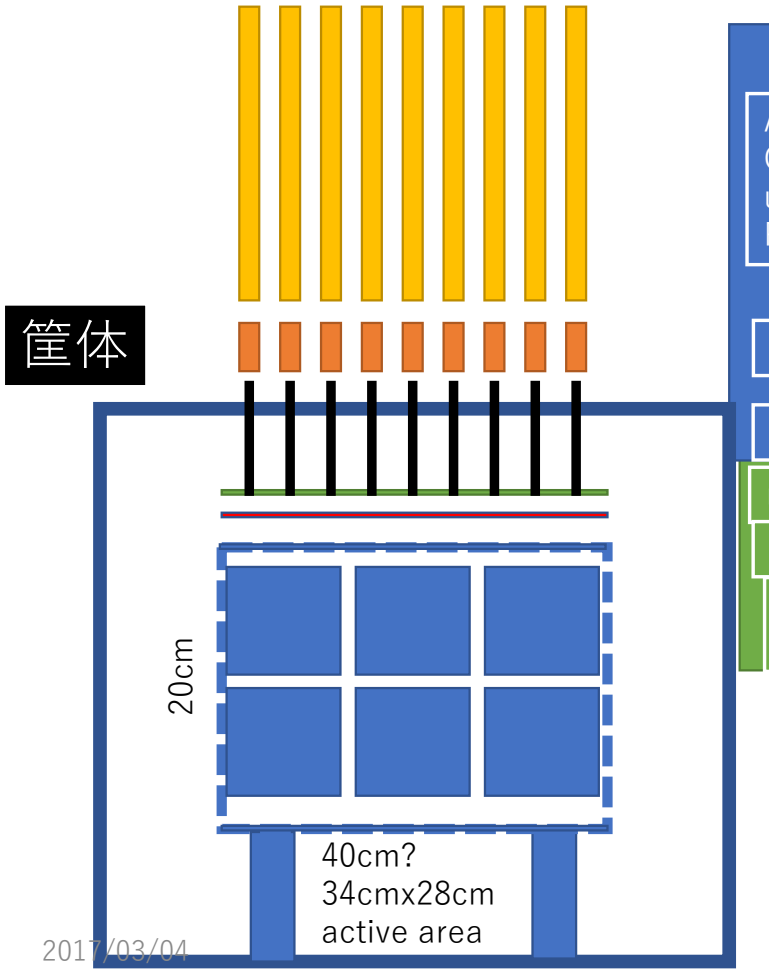
Only one true event for GMR is expected in this spectrum

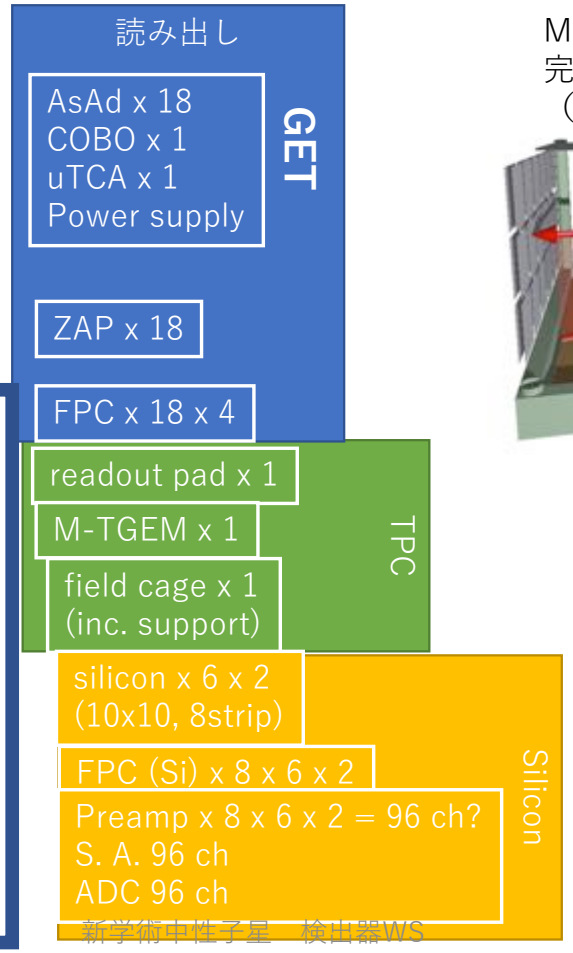
Blue: stop in TPC
Red: 1.5 (Chi2 ratio of deuteron and proton)
Green: 2.0

実機製作：若手(B)＋CNS
実験遂行：新領域

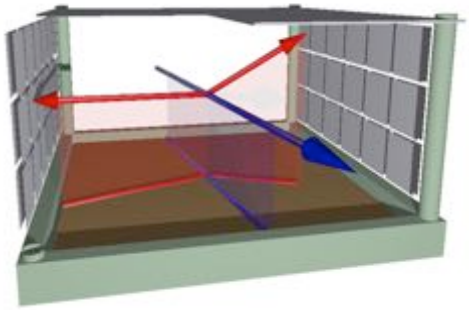
Next step

CAT (M) 製作中（設計中）２０１８年度完成予定





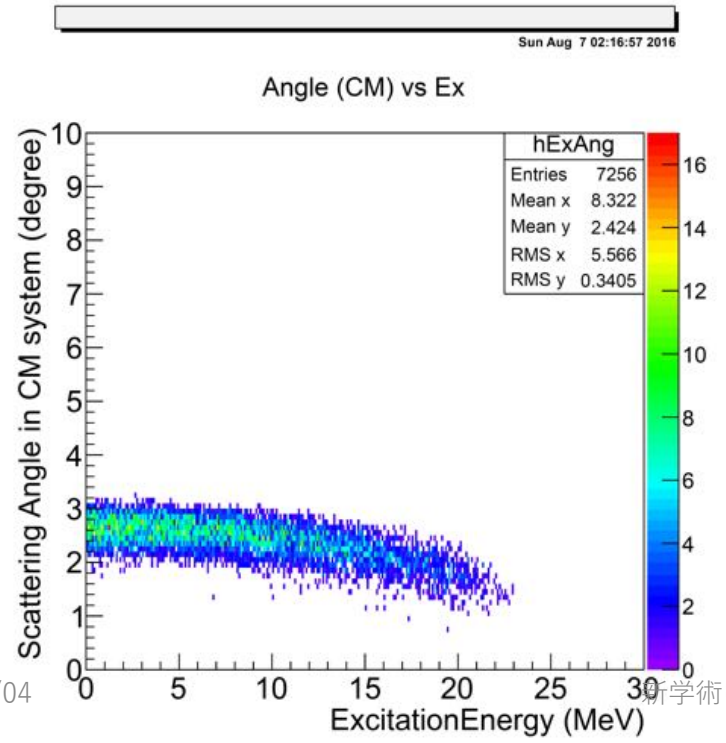
Manul
完成予想図
（Siの枚数は異なる）



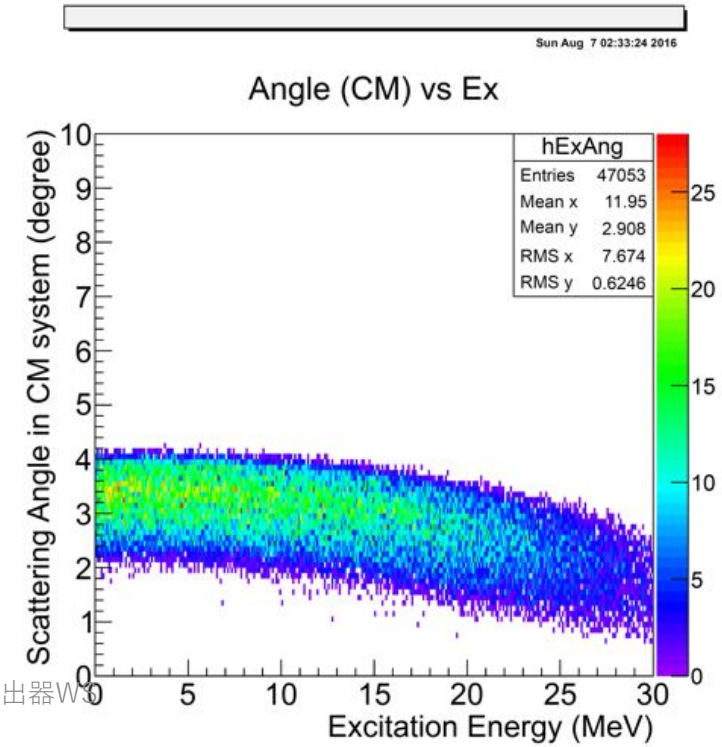
もしデルタ線が多くないならば、1.2cmのストリップでもよい？

収量１０倍：有効標的厚５倍、アクセプタンス２倍

Active region: (x,y,z) = (100,100,100)
Reaction points of Z: +/- 100mm
Sigma of beam: 5mm



Active region: (x,y,z) = (300,200,300)
Reaction points of Z: +/- 300mm
Sigma of beam: 5mm



探しています

- 高速・大容量読み出し回路 (GET 回路 or other)
- シリコン検出器（ストリップ幅検討中）＋回路
- マンパワー

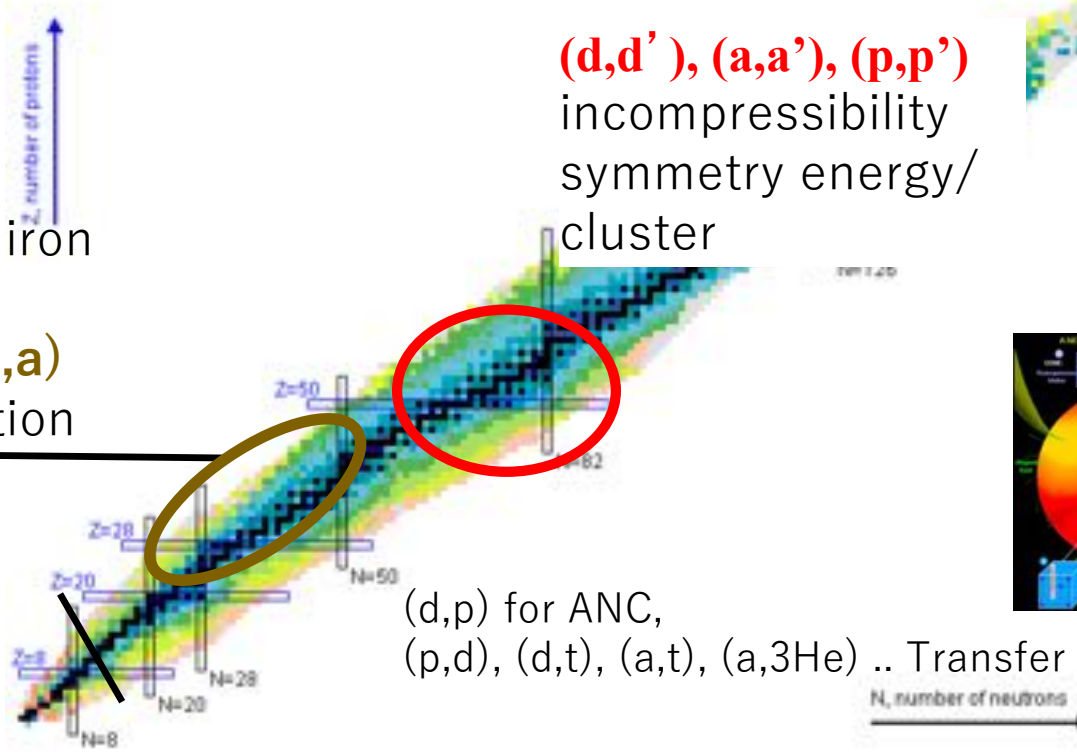
Physics case

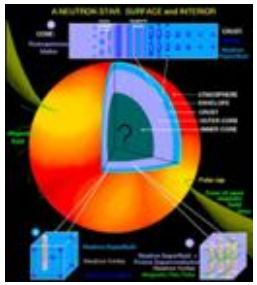
- Equation of state through proton-neutron finite system
  - relation between colored and colorless matter
  - relation between finite and infinite system
- Degrees of freedom of nucleon
  - Effect of pair interaction, many body force
  - Forming cluster
    - nucleon-nucleon pair (T=0 / T=1)
    - alpha particle
    - others?
- Astrophysics
  - Nucleosynthesis

Field of study

(d,2p)
GT+ strength in iron group
(a,d), (a,6Li), (a,a)
Nucleon correlation

(d,d’), (a,a’), (p,p’)
incompressibility
symmetry energy/
cluster





(d,p) for ANC,
(p,d), (d,t), (a,t), (a,3He) .. Transfer reactions

Tools for physics

- Missing mass spectroscopy of unstable nuclei
  - inverse kinematics
    - elastic / inelastic scattering
    - transfer / pickup reaction
  - normal kinematics => SHARAQ/**OEDO**
    - exothermic reaction (positive Q value)

Active Target + BigRIPS / OEDO

- Key of experiment
  - high luminosity
    - high intensity beam
    - thick target
  - event-by-event particle identification of high intensity beam (1us)
  - detectors for probe
  - high-rate large scale data acquisition

Machine Learning

1usで粒子識別完了させたい

まとめ

- CAT-S が完成した
  - 数100kcpsを超えるビームで動作可能なアクティブターゲットができた
- RIBFでの実験を遂行することができた
  - 新学術公募研究により実験遂行費用が確保できました
- 現在大型化を進めている＝＞CAT-M
  - 検出器・回路・解析手法（人工知能など）など