SAMURAIとTPC
現状と将来

京都大学大学院理学研究科
村上哲也

～80の日本の核物理の状況

ほんとに原子核を理解したのか？

NUCLEARPHYSICS　核構造　低エネルギー核現象

UNCLEARPHYSICS　核物質　核　力　高エネルギー重イオン反応

新しい窓を開いて地平を拓く

UNCLEARPHYSICSへの挑戦

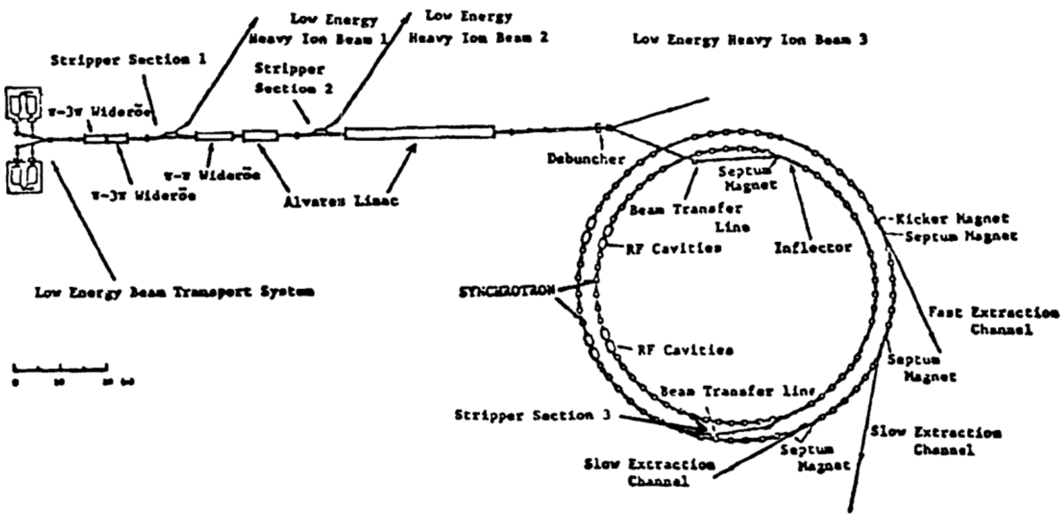
1975 NUMATRON計画

高エネルギー重イオン物理　坂井、杉本、山口、山崎

高エネルギー重イオン加速　平尾

中井浩二氏の 幻の「NUMATRON」が拓いた原子核研究の地平 より

Bevalac /Berkeley



Layout of NUMATRON

Numatron Parameters

A. Particle, Energy and Intensity

Particle	Max. Energy (GeV/u)	Intensity (pps)
U^{92+}	1.27	$\sim 10^{9}$
Kr^{36+}	1.47	$\sim 10^{11}$*
Ne^{10+}	1.81	$\sim 10^{11}$*

*Space Charge Limit

B. Injector

	T/A(MeV)	Freq. (MHz)	β(v/c)	ε(q/A)
Cockcroft-Walton (500 KV)	0.0147	—	0.006	0.029(U^{7+})
Wideröe (π-3π)	0.146	25	0.018	—
Wideröe (π-3π)	0.305	25	0.026	—
Stripping	—	—	—	0.067(U^{16+})
Wideröe (π)	1.10	25	0.048	—
Alvarez	1.60	100	0.059	—
Stripping	—	—	—	0.193(U^{46+})
Alvarez	10.0	100	0.146	—

C. 1st Synchrotron

Injection Energy		10 MeV/u
Maximum Energy		250 MeV/u
Repetition Rate of RF Stacking		100
Momentum Spread of Stacked Beam		± 0.7 %
Useful Aperture	radial	18 cm
	vertical	5 cm
Vacuum		2×10^{-11} torr
Space Charge Limit		
Number of Particles/sec		

D. 2nd Synchrotron

Guide Field (B_{max})		18.0 kG
Quadrupole Field $(dB/dr)_{max}$		1.38 kG/cm
Repetition Rate		1 Hz
Magnetic Radius		9.55 m
Average Radius		33.6 m
Circumference		211.2 m
Number of Normal Periods		24
Number of Long Straight Sections		8
Focusing Structure		FODO
Useful Aperture	radial	9 cm
	vertical	3.5 cm
Number of Betatron Oscillations		6.25
Phase Advance per Normal Period		70°
Vacuum		1×10^{-9} torr

1981 TRISTAN建設開始 → 原子核研究計画見直し

NUMATRON計画

高エネルギー
重イオン物理

BEVALAC AGS RHIC LHC

KEK-PS J-PARC

RIKEN RIBF

核物質の物性（QGP）

中高エネルギー核物理

ＲＩビーム物理

高エネルギー
重イオン加速器

HIMAC

重粒子線医療

中井浩二氏の 幻の「NUMATRON」が拓いた原子核研究の地平 より

90年代初め

日本で高温高密原子核?!

@RARF?　〉〉〉　人も物（検出器）もない

理研リングサイクロトロン建設計画

一期工事（1980－1986）　　ファーストビーム（1986）
二期工事（1987－1988）　　ビーム利用の開始　（1989）
　代表者、上坪宏道、
　加速器グループ：矢野安重、後藤彰、加瀬昌之、藤沢高志、元永昭七など
　施設インフラ・ビームライン：稲村卓、畑中吉治、市原卓など

主要実験計画の設定（1984）：編成責任者（石原放射線研主任研究員）

vs.　世界の動向：高温高密度原子核に集中！⇒「異分野を狙え！」
　八木浩介核物理委員長⇒宮島龍興理事長；「外部研究者にも開放して！」

GARIS-IGISOL ：代表者、野村　享（核研）；超重元素探査
　成功：森田浩介ほか、超重元素113の発見（200x）、

全国区

SMART　　；代表者、大沼　甫(東工大)；高分解能荷電粒子分光
　成功：酒井英行ほか、偏極重水素ビーム→ 3体力の研究

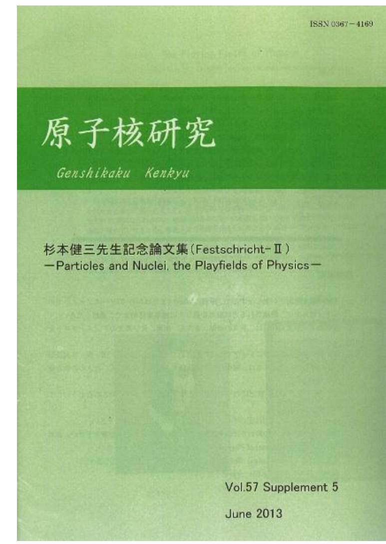
全国区

ASHURA　　；代表者、李　相茂（筑波大）；高温高圧原子核
　失敗：　後発性→競争力不足→中絶

RIB（→RIPS）　；代表者、石原正泰(理研)；RIビーム物理

理研：久保、旭、石原

　触発：Bevalac 実験（谷畑、杉本他）　　－RIビーム物理揺籃期
　成功：RIビーム物理分野の形成@RIPS　－ RIビーム物理第2世代
　　　RIビーム物理分野の拡張@RIBF　－ RIビーム物理第3世代



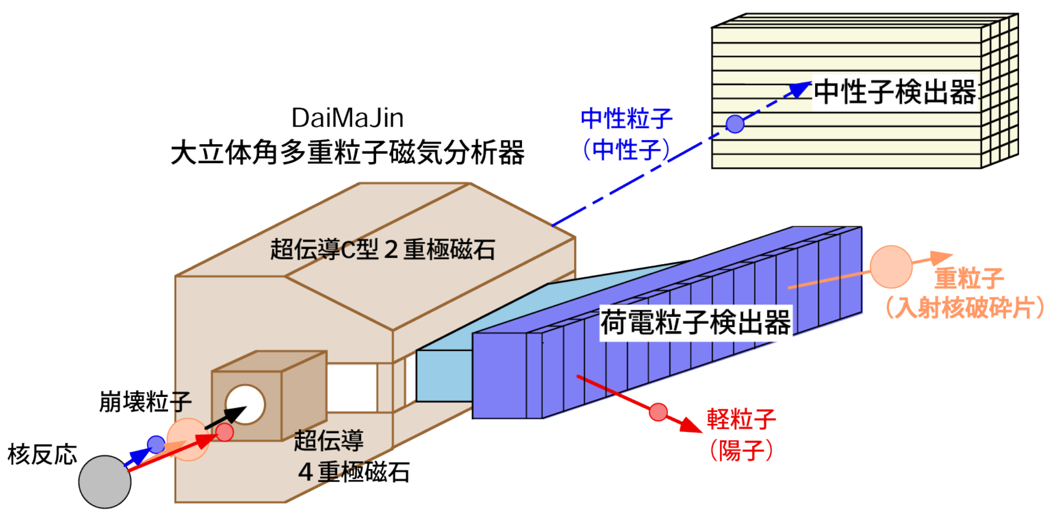
石原正泰氏

杉本先生と理研の原子核研究

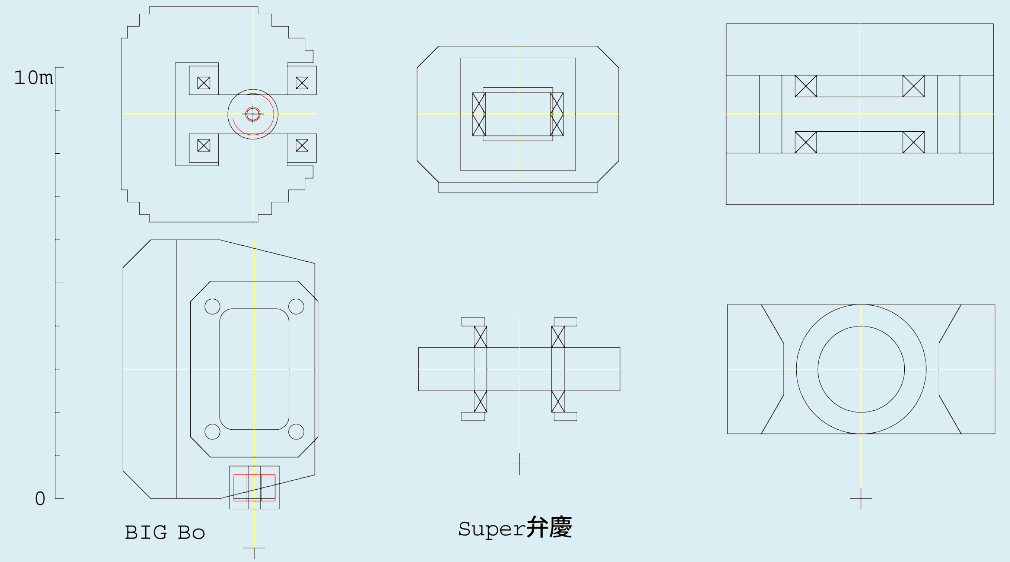
RIBF用　新実験装置 2000～

大立体角多重粒子磁気分析器：　DaiMaJin
Dai-Rittaikaku Multi-Particle Jiki-Bunnsekiki

小林：　磁気分析器
中村：　中性子検出
上坂：　偏極重陽子

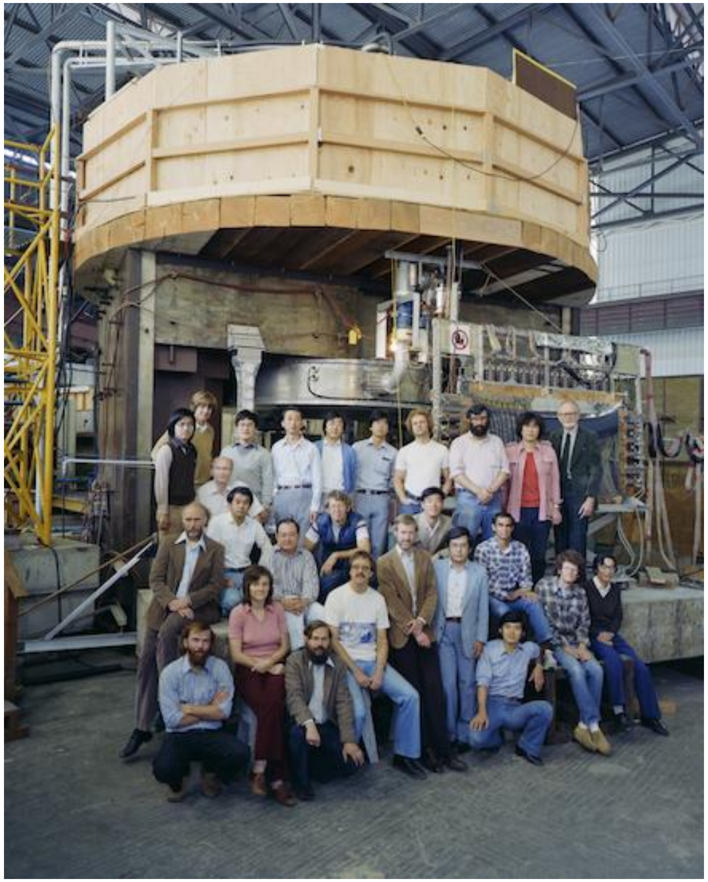


予算面で振り回される



形式	C型磁石+Q	H型Window Frame	H型円形ポール
Bmax [T] , BL [Tm]	3 T, 7 Tm	1.5 T, 2.3 Tm	3 T, 7 Tm
Pole&Gap [m] , 重量 [t]	1.6x2.8x1.0 m, 620 t	1.5x1.0x1.0 m, 140 t	直径2.0mx0.8 m, 480 t
AT & Stored Energy	4.4 MAT, 36 MJ	1.4 MAT, 36 MJ	3.6 MAT, 28 MJ
費用概算	1200 MY	100 MY(移設+改造)	few x 100 MY(?)
2.2GeV/c粒子偏向角	55°	18°	53°
角度収束	有	無	無
欠点	力、費用、漏磁場	低磁場	

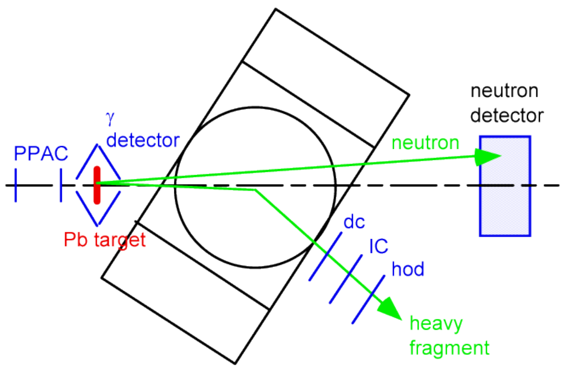
HISS @ LBL/Bevalac



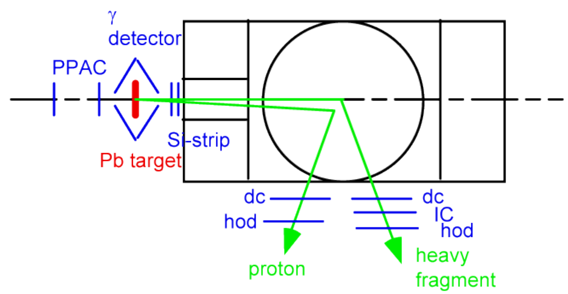
そっくりさんは作りたくない by 小林

結局　Request of Badget

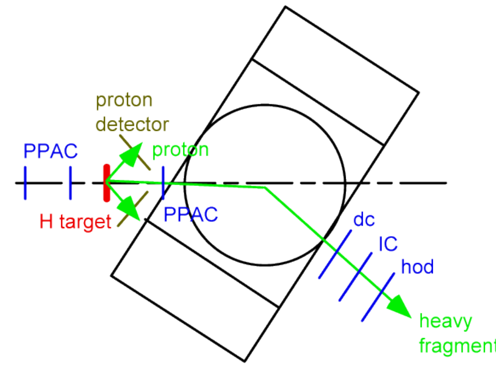
(γ,n) reaction: neutron-rich side



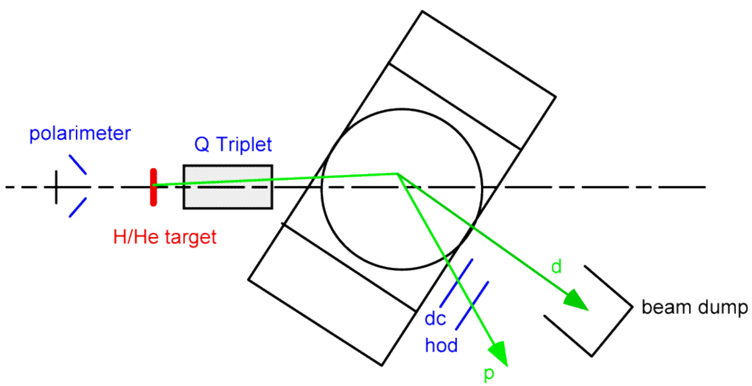
(γ,p) reaction: proton-rich side



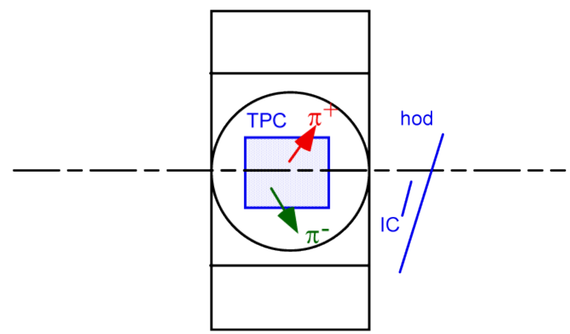
(p,p'), (p,2p) etc.



Pol. d-induced reaction

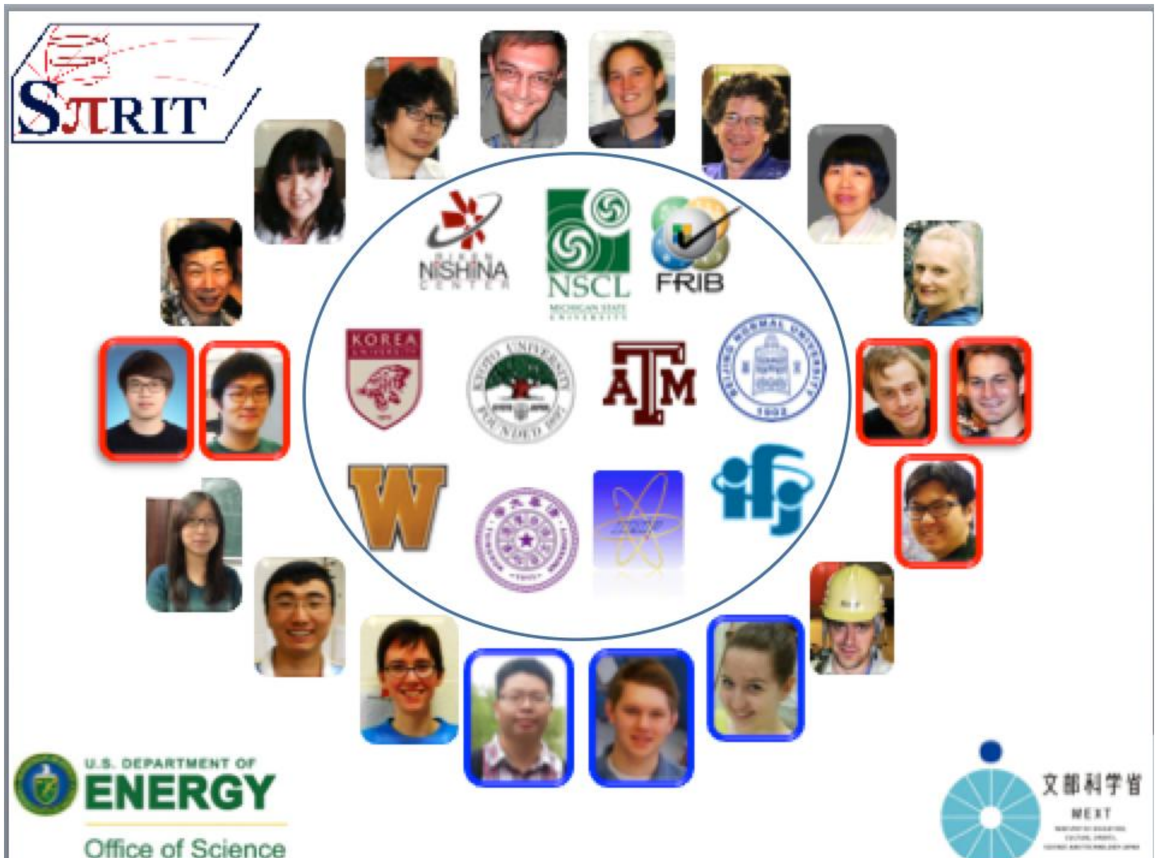


EOS measurement



High density matter in neutron stars investigated through nucleus-nucleus collision

SAMURAI Pion Reconstruction and Ion-Tracker



Nuclear Equation of State

$$E(\rho,\delta)=E(\rho,0)+E_{sym}(\rho)\delta^2+o(\delta^4)$$

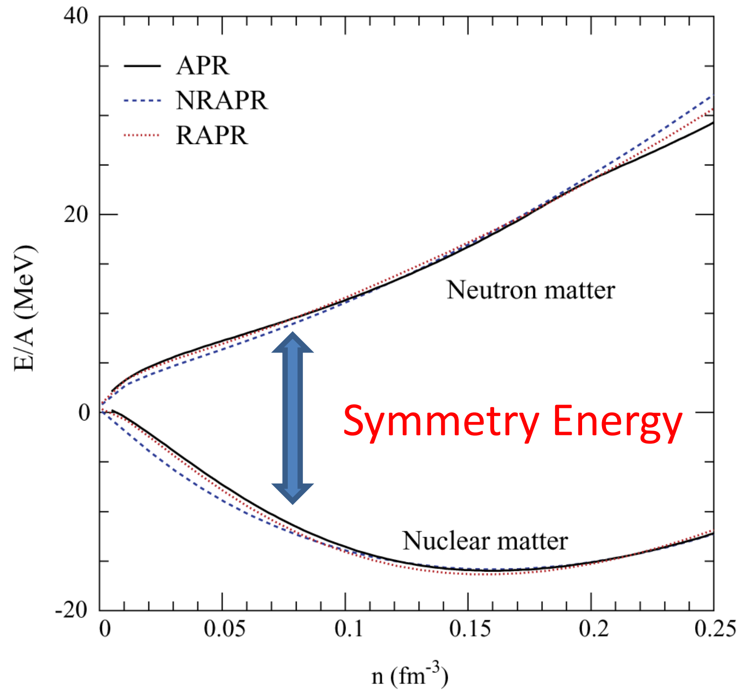
$$\delta=(\rho_n-\rho_p)/\rho$$

$$\boxed{E_{sym}(\rho)=E_{sym}(\rho_0)+L\varepsilon+\frac{K_{sym}}{2}\varepsilon^2+o(\varepsilon^3)}$$

$$\varepsilon=(\rho-\rho_0)/3\rho_0$$

$$S_0=E_{sym}(\rho_0)\Rightarrow J\,;sometimes$$

$$L=3\rho_0\left.\frac{\partial E_{sym}(\rho)}{\partial\rho}\right|_{\rho=\rho_0}=(3/\rho_0)P_0$$



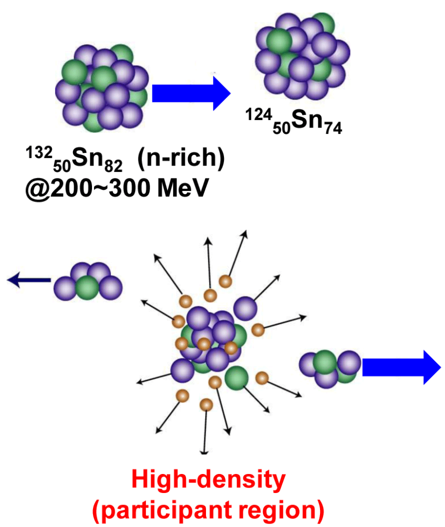
A.W. Steiner et al., Phys. Reports 411 (2005) 325

Almost all we want to measure

Primary	Beam	Target	E_{beam}/A	δ_{sys}	Goal	Days
^{238}U	^{132}Sn	^{124}Sn	300	0.22	Probe maximum δ	3
	^{124}Sn	^{112}Sn	300	0.15	Probe intermed. δ	3
^{124}Xe	^{108}Sn	^{112}Sn	300	0.09	Probe minimum δ	3
	^{112}Sn	^{124}Sn	300	0.15	Probe intermed. δ	3

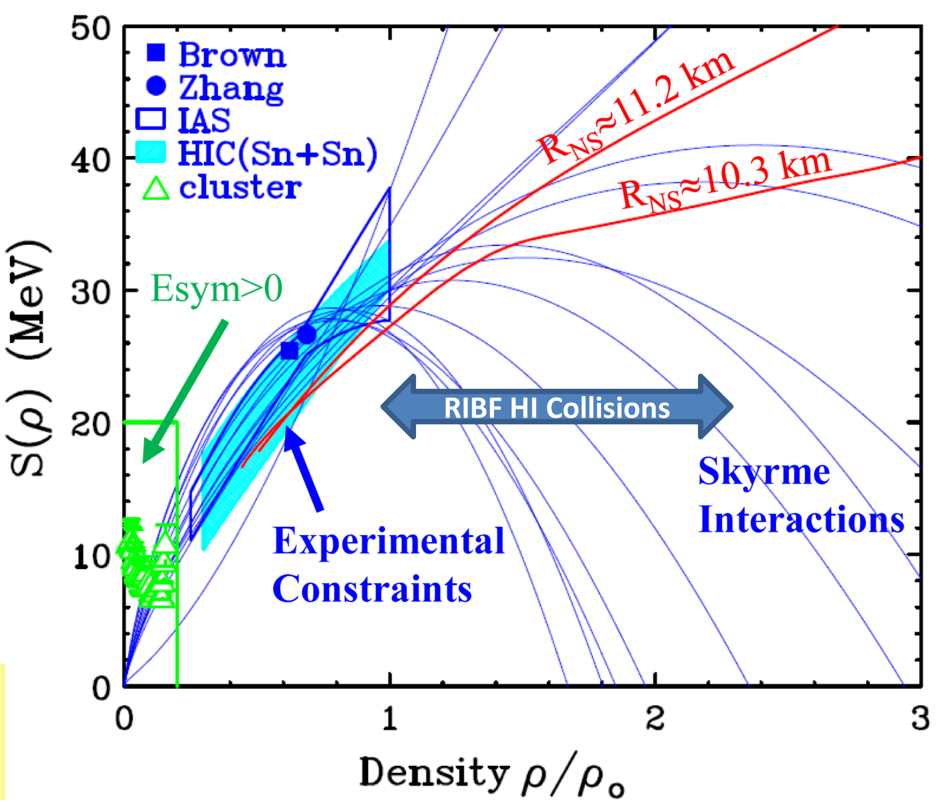
SAMURAI15

SAMURAI22



ρ/ρ_0~(γ+1) 2.3 @ 300 MeV/nucleon

Change initial (N/Z)p_{roj} (N/Z)$_{target}$ combination to see the change of participant.



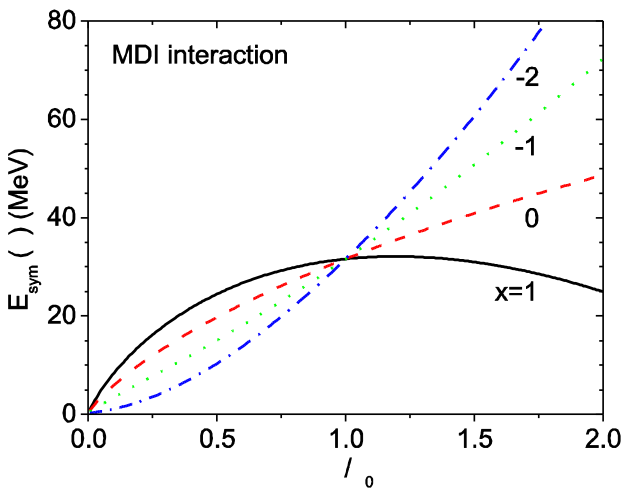
Tsang et al. Phys. Rev. C 86, 015803 (2012)

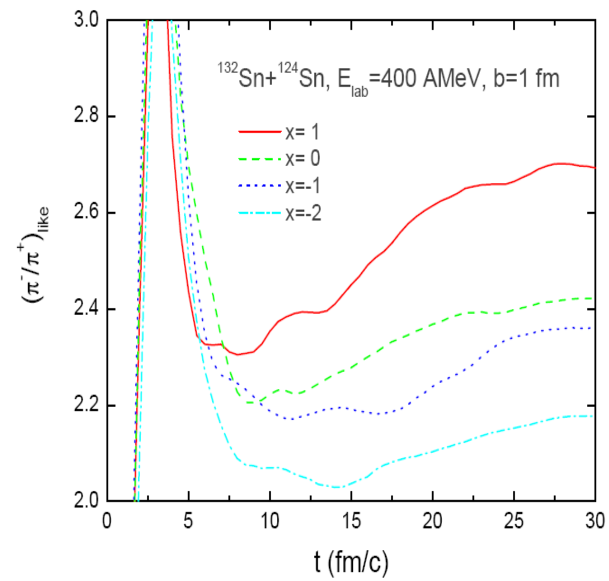
Influence of symmetry pressure: Possible Probe

The symmetry pressure expels neutrons from and attracts protons to high density region of neutron-rich system.

Prediction of transport theory

Suppress Y(n)/Y(p), $Y(\pi^-)/Y(\pi^+)$, etc.



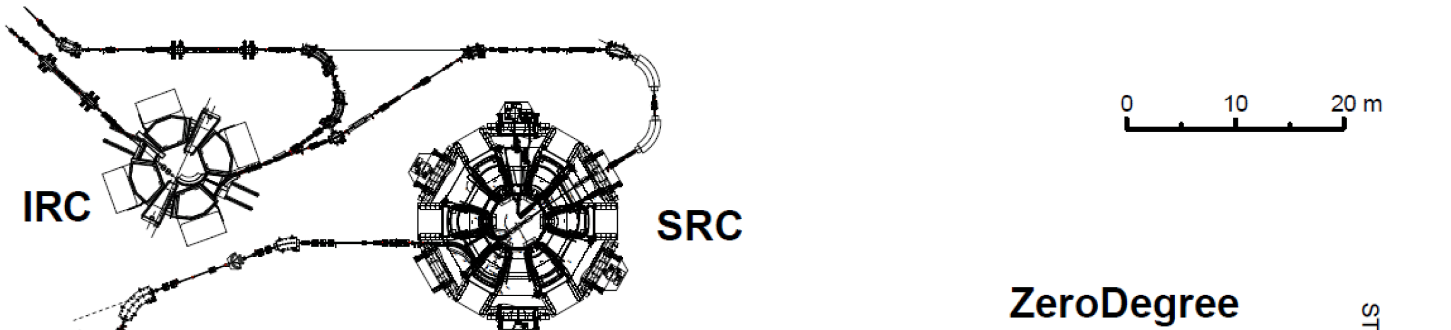


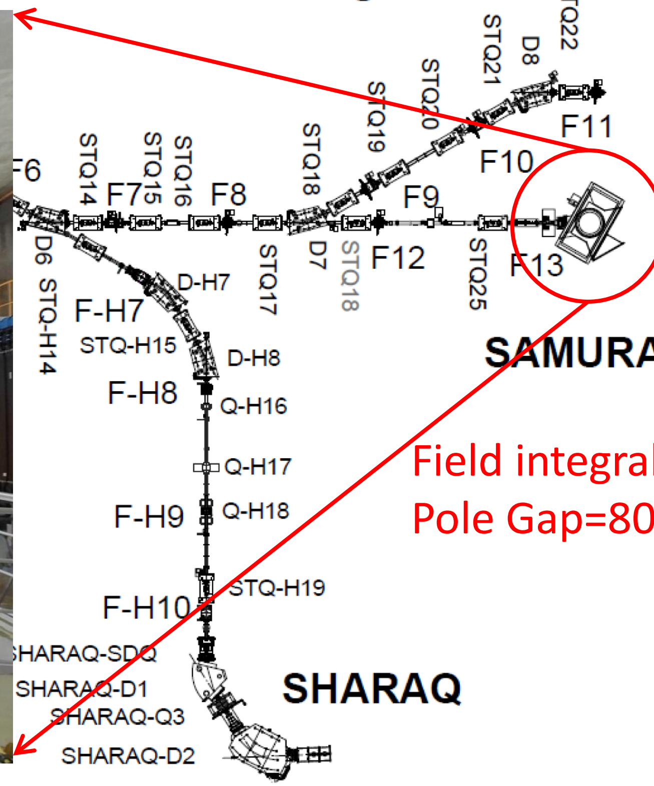
Bao-An Li et al., Phys. Rev. C 71, 014608 (2005)

One of good probes

π^-–π^+ production ratio from HI collisions in wide range of δ

SAMURAI
Superconducting Analyzer for Multi particles from Radio Isotope Beams

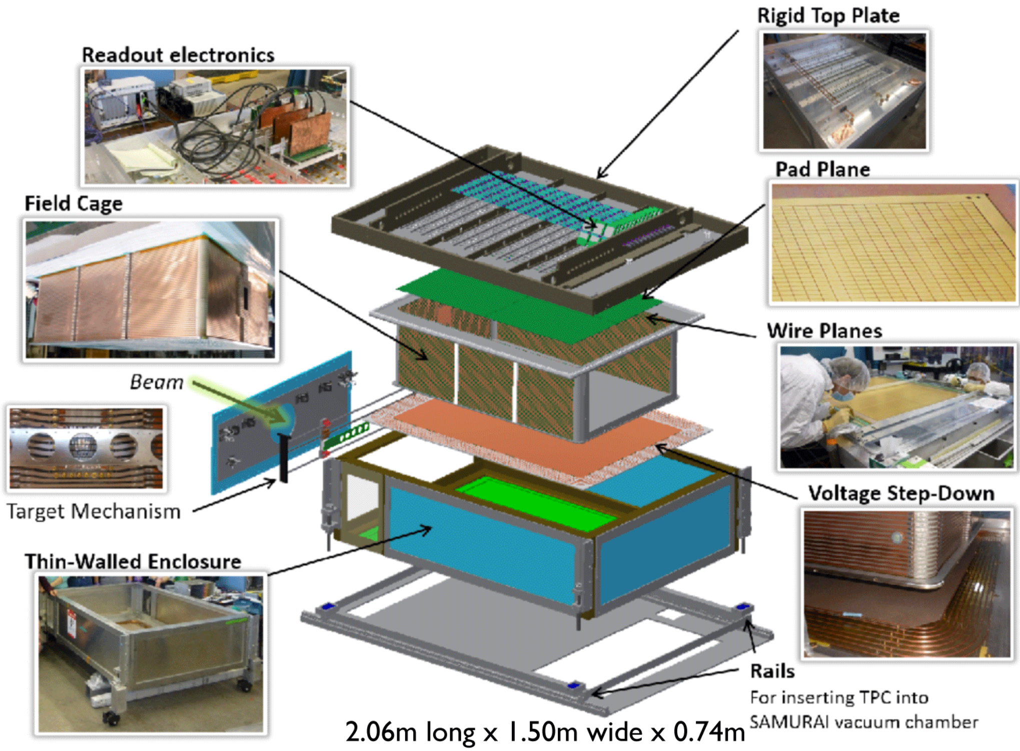




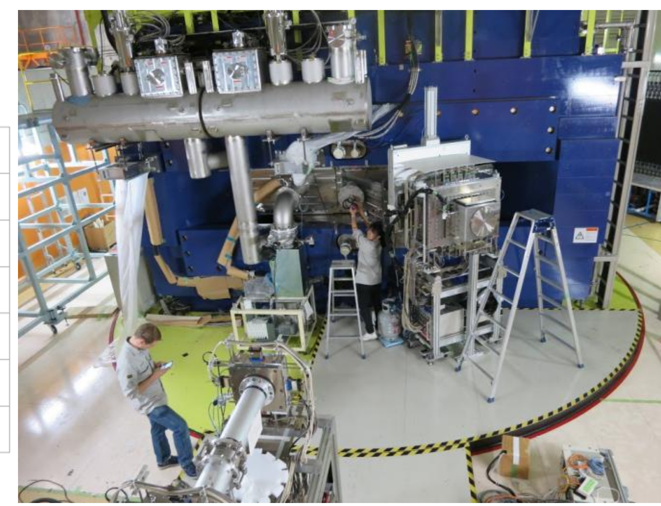
Field integral =7Tm
Pole Gap=80cm

SπRIT-TPC structure

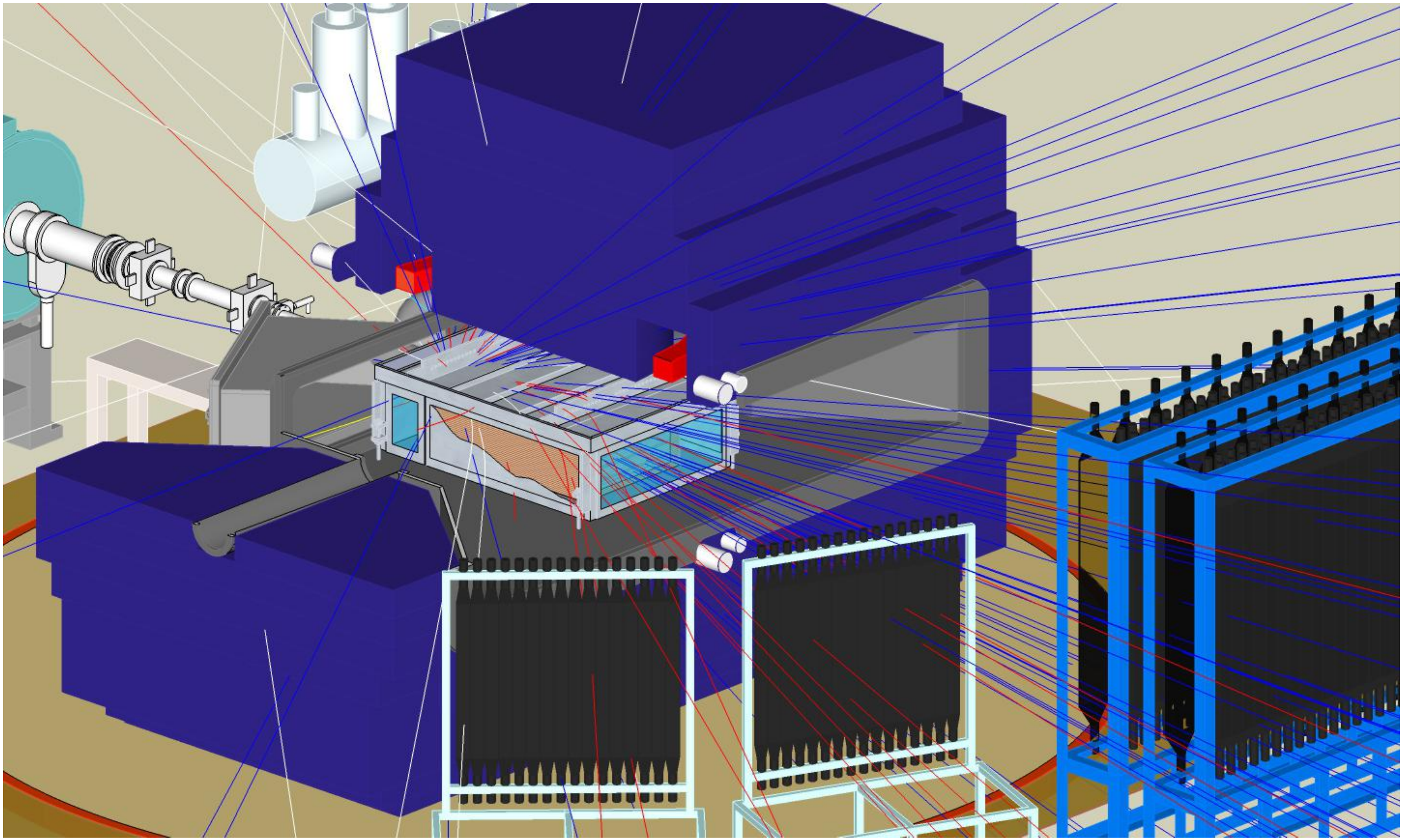
NIM A 784 (2015) 513–517.



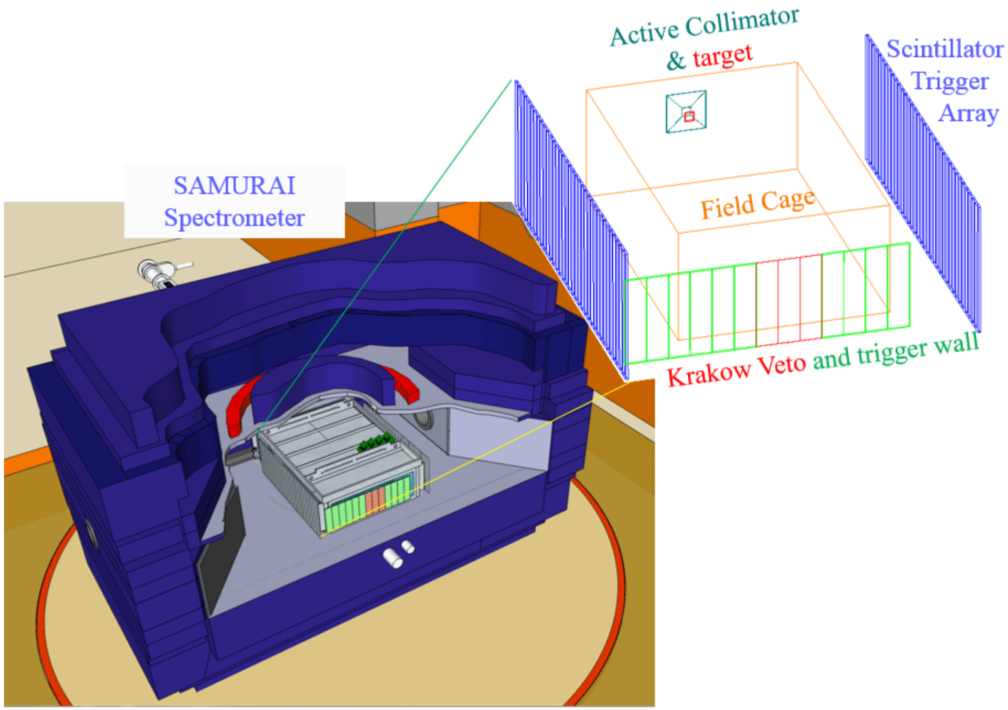
Pad Plane Area	1.3 m x 0.9 m	**Gas Gain**	2000
Number of Pads	12096 (112x108)	**E-field**	135 V/cm
Pad size	12 mm x 8 mm	**Drift velocity**	5.5 cm/μs
Drift Distance	50 cm	**dE/dx range**	Z=1-8, π, p, d, t, He, Li-O
Pressure	1 atmosphere	**Two-track res.**	2.5 cm
Gas composition	90% Ar + 10% CH_4	**Multiplicity limit**	200



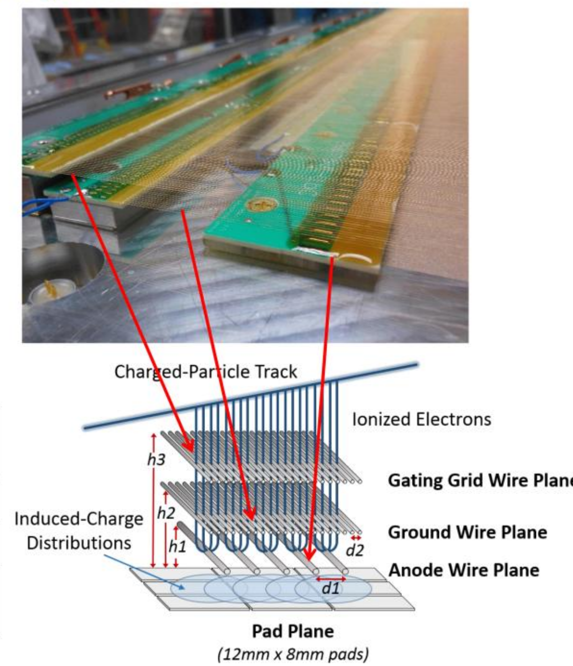
Simulated results for $^{132}Sn+^{124}Sn$ at 300A MeV



Trigger system

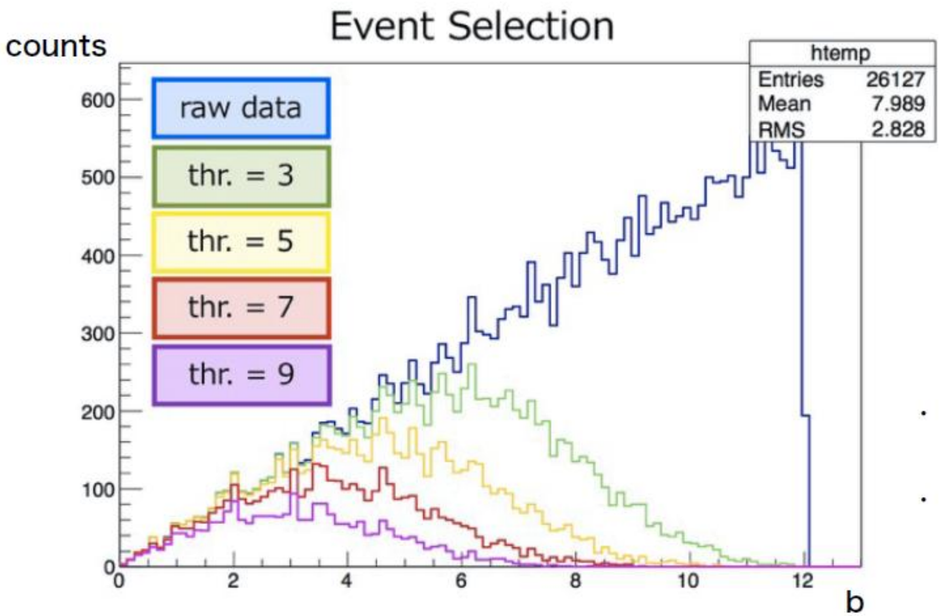


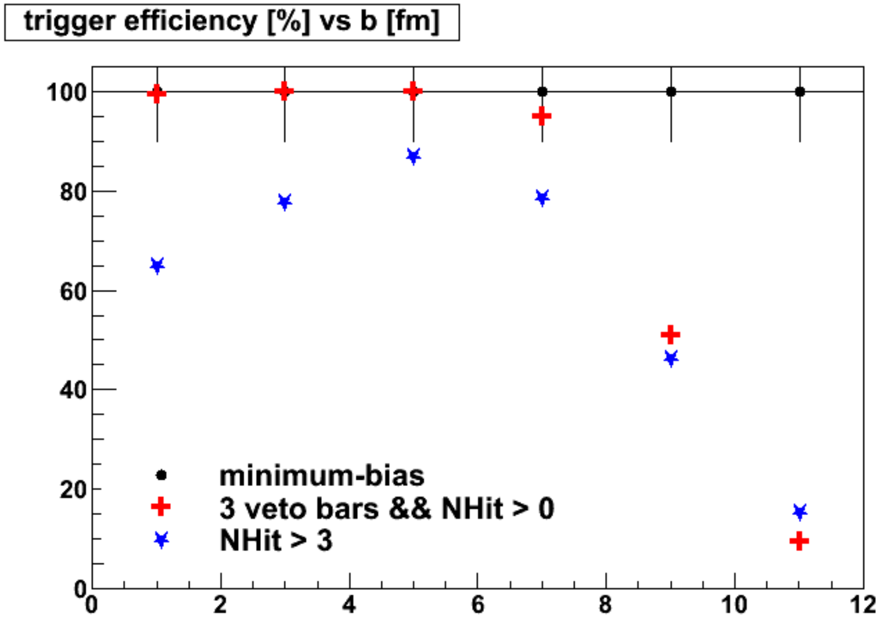
Wire planes



Plane	height (mm)	pitch (mm)	diameter(μm)
Anode	4.05	4	20
Ground	8.1	1	75
Gating grid	14	1	75

Side array & Front array

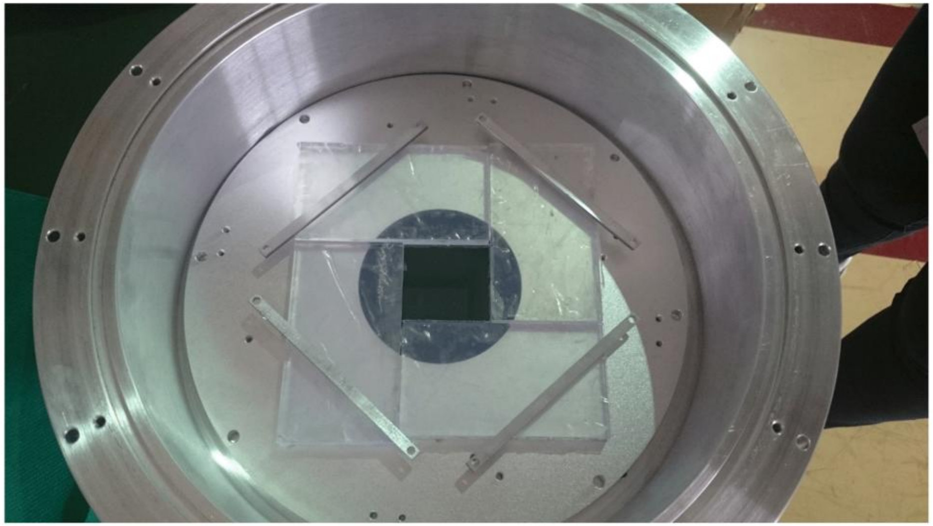


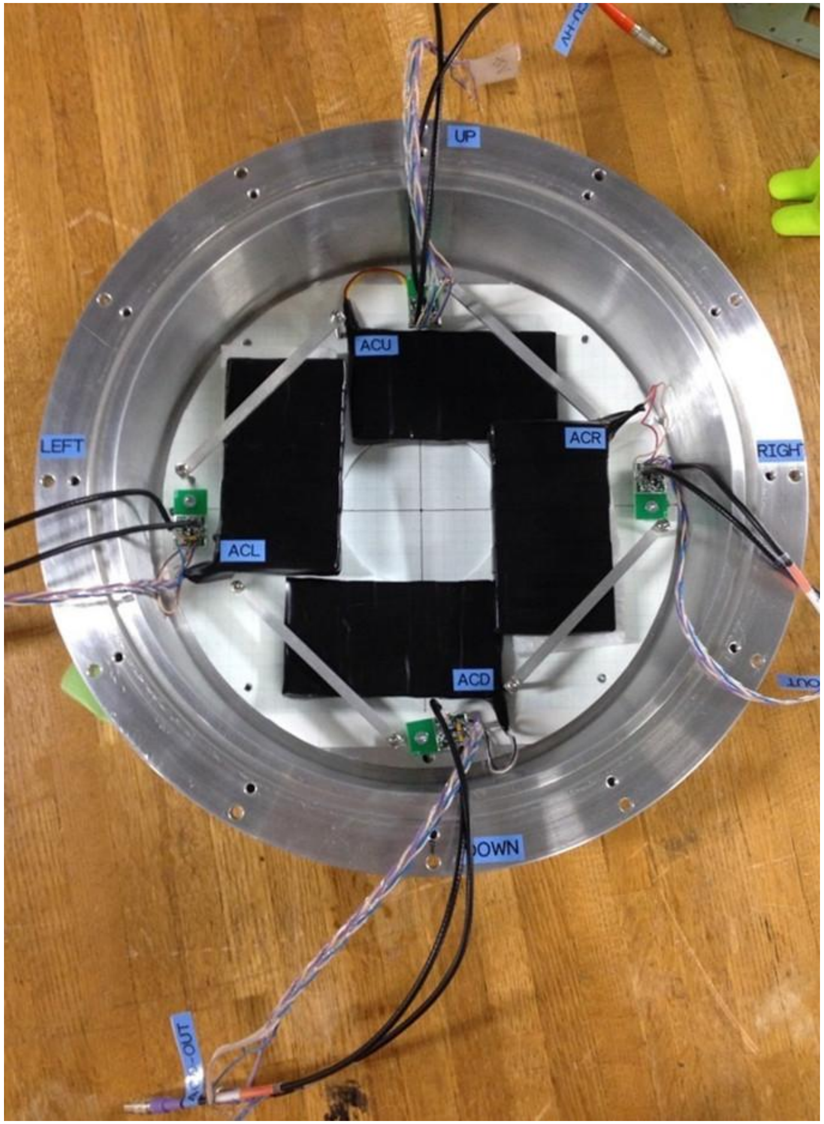


【 Input data of Simulation 】
UrQMD code is used for event generation
: 300 MeV/A, $^{132}Sn + ^{124}Sn$, b = 0-12 fm,
& SAMURAI magnet magnet field map (0.5 T)

Impact parameter

Active Collimator(Tsingha)

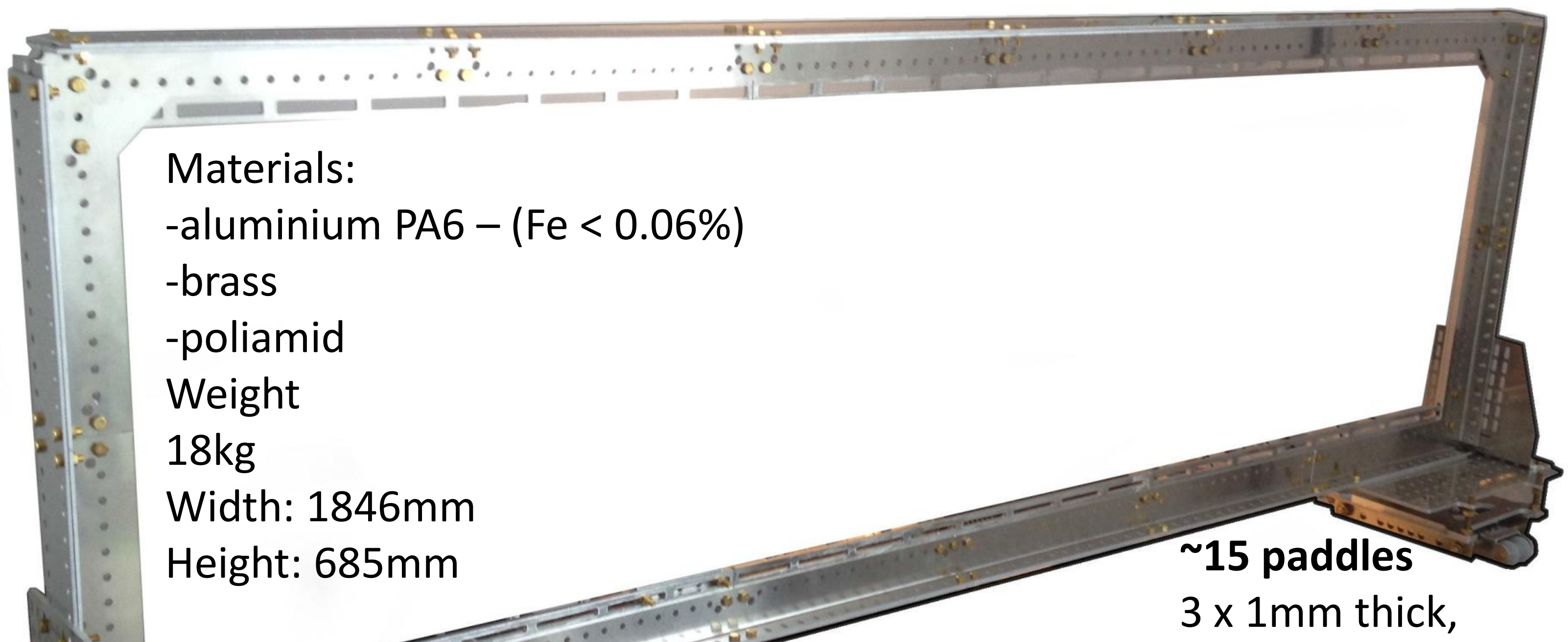




Plastic:BC-408	Size	Wavelength of Max. Emission
	90mm*50mm*6mm	425nm

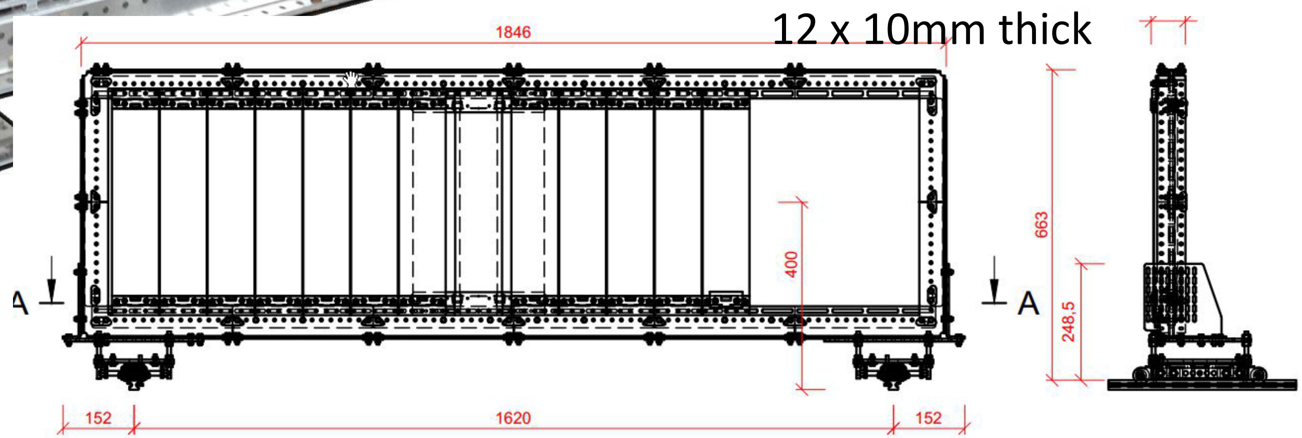
MPPC:S10931-100P	Size	Peak sensitive wavelength
	3mm*3mm	440nm

KATANA(Kracow)

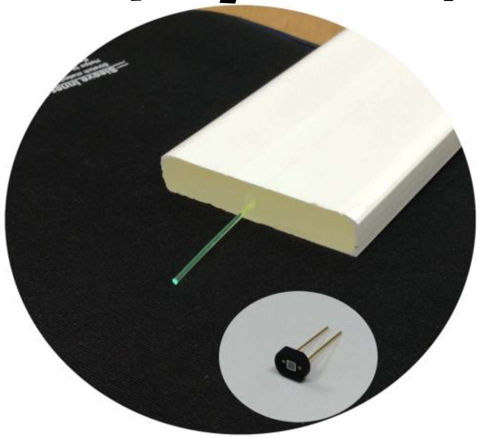


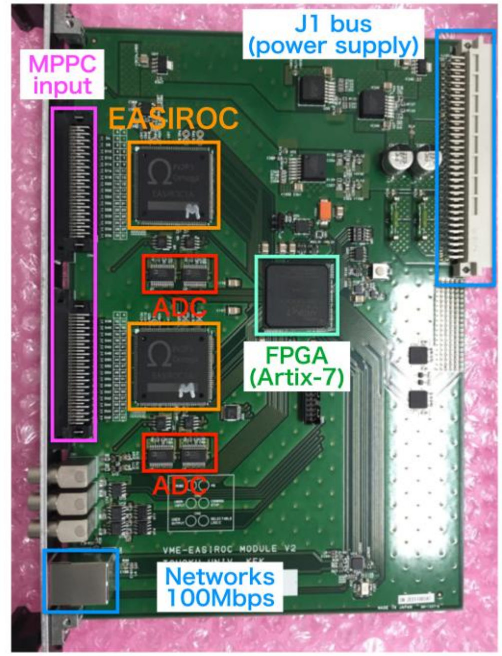
Materials:
-aluminium PA6 – (Fe < 0.06%)
-brass
-poliamid
Weight
18kg
Width: 1846mm
Height: 685mm

~15 paddles
3 x 1mm thick,
12 x 10mm thick



Multiplicity Array (Kyoto)



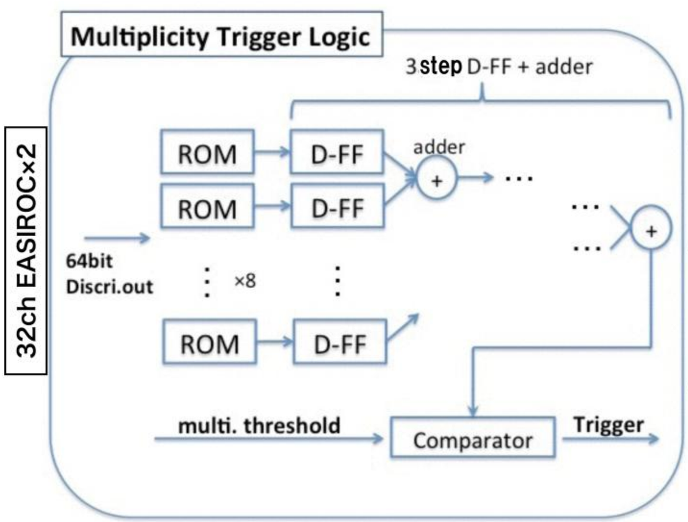


VME-EASIROC

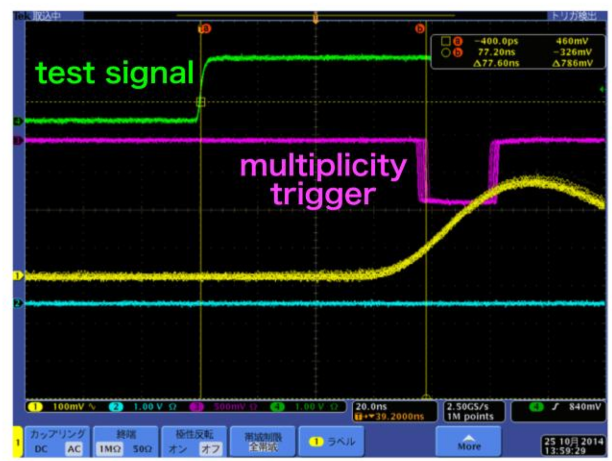
【Specification】

- I/O (current)
  64ch MPPC input,
  shaper, discriminator, trigger,
  probe (NIM)output
- ADC
  Pulse height hold type
- MHTDC in FPGA
  LSB = 1ns
  Leading/Trailing
  Time Window = 4μs
- Multiplicity Trigger logic in FPGA

Multiplicity Logic



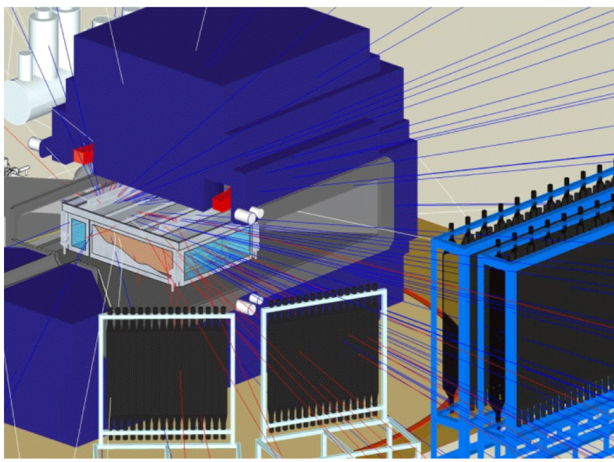
- ROM
  8bit calculation
- D_FripFrop
  for synchronization
  of signal
- adder circuit
  add two numbers

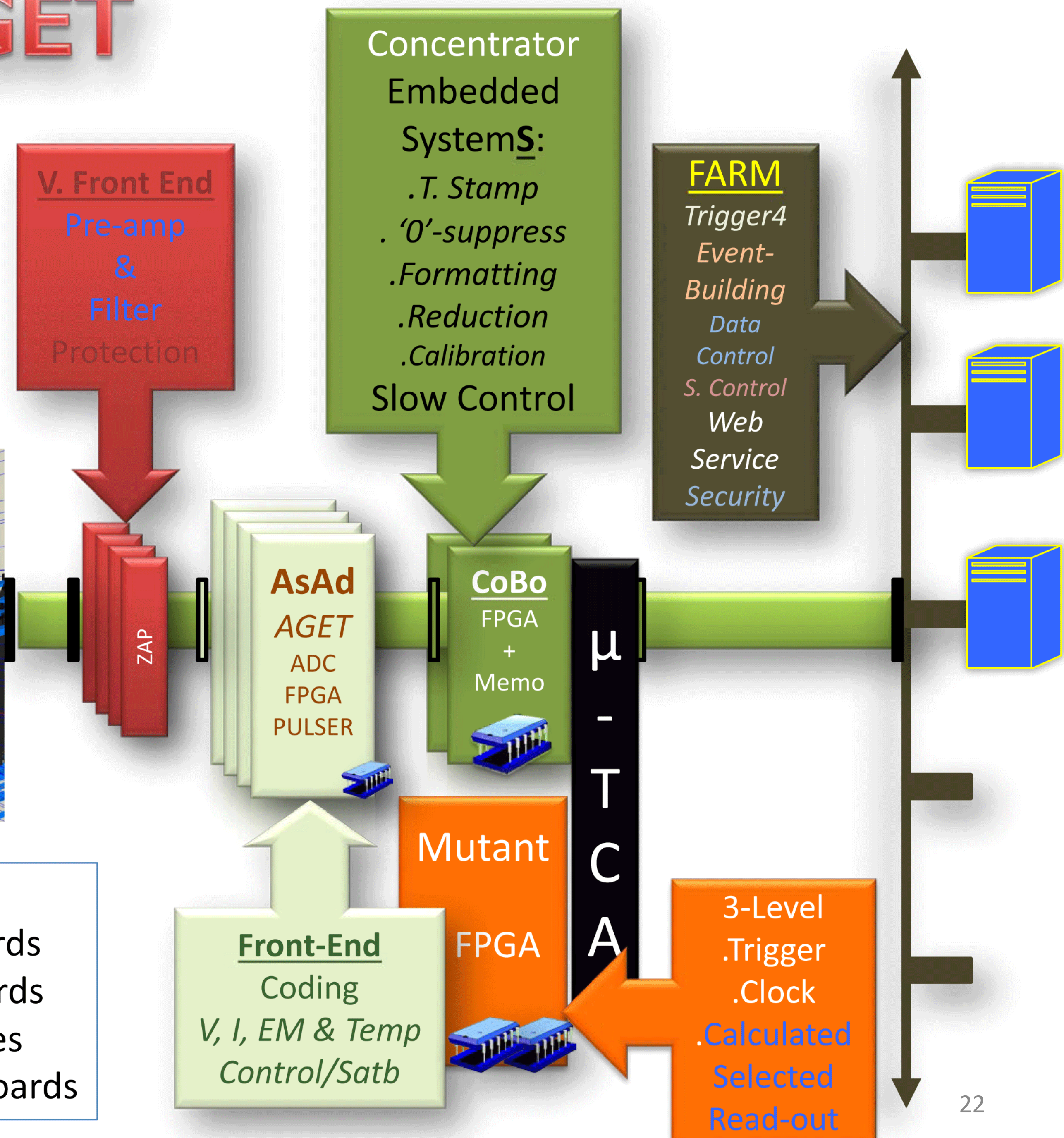


- test by function generator
  multiplicity = 4
- jitter comes from D_FF
  ~ 3nsec width
- rough estimation of timing delay
  ~ 52nsec
  by subtracting
  cable delay

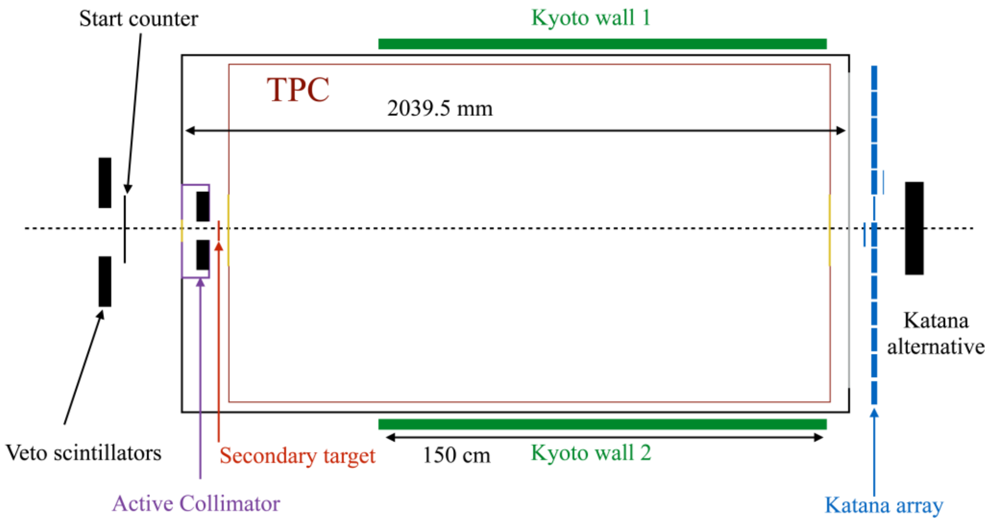
SYSTEM GET

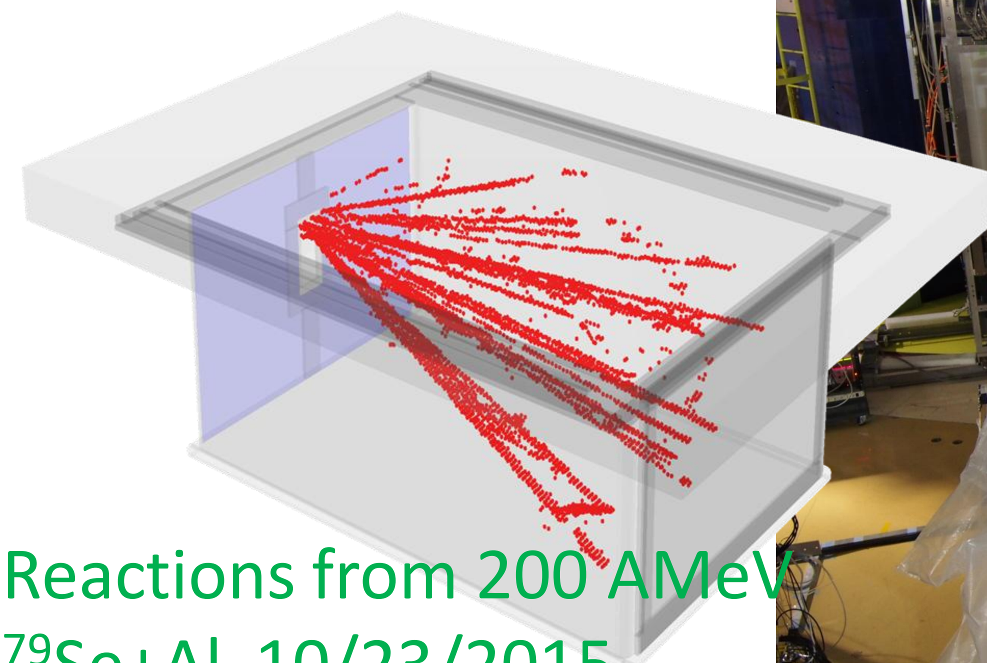
Generic Structure (H&S)
2^{12} Final Dyn Rnge
10Gbit B.width
4 Level Digital Trigger

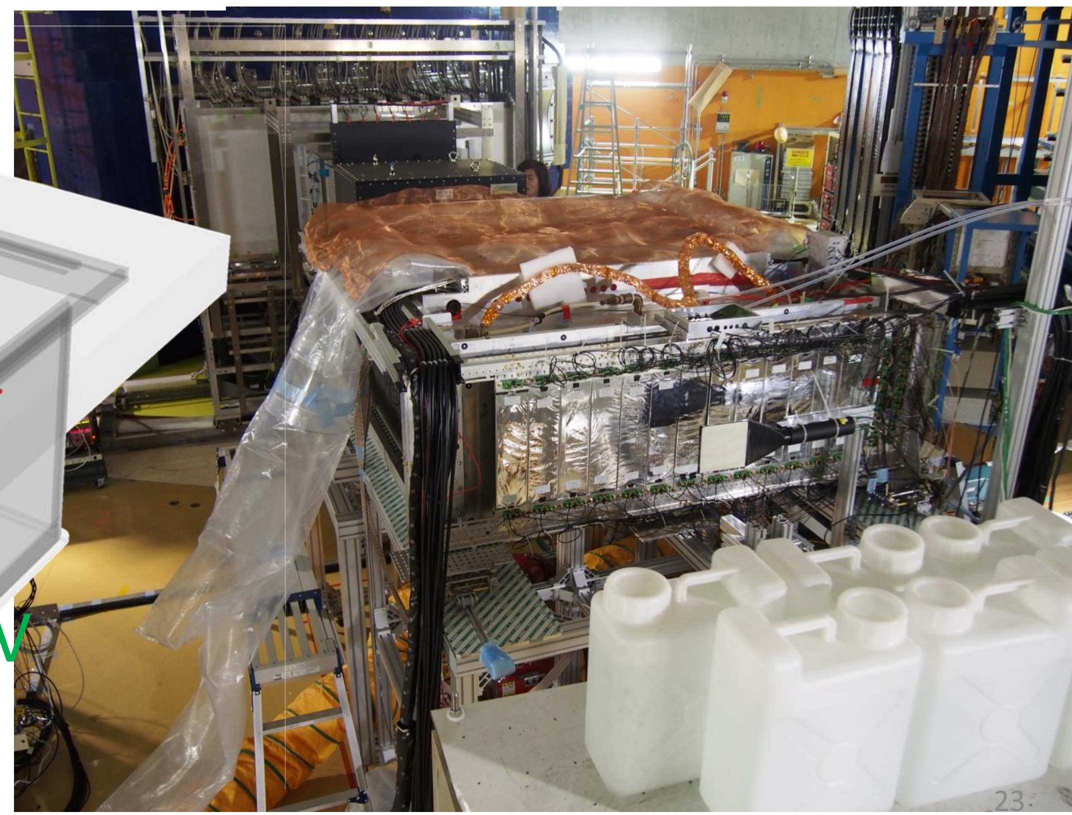




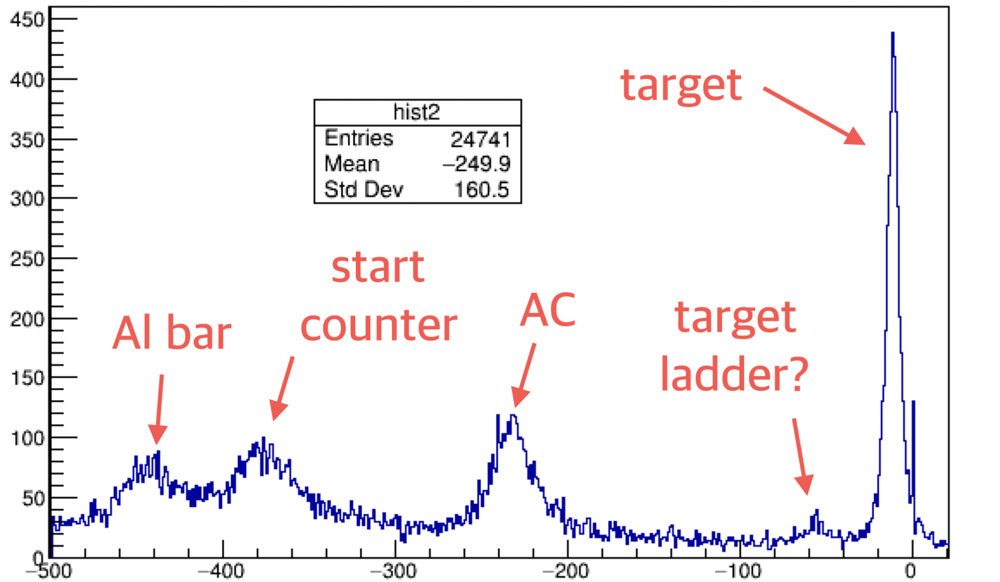
SPiRIT TPC:
48 AsAd boards
12 CoBo boards
2 μ-TCA crates
2 MuTANT boards



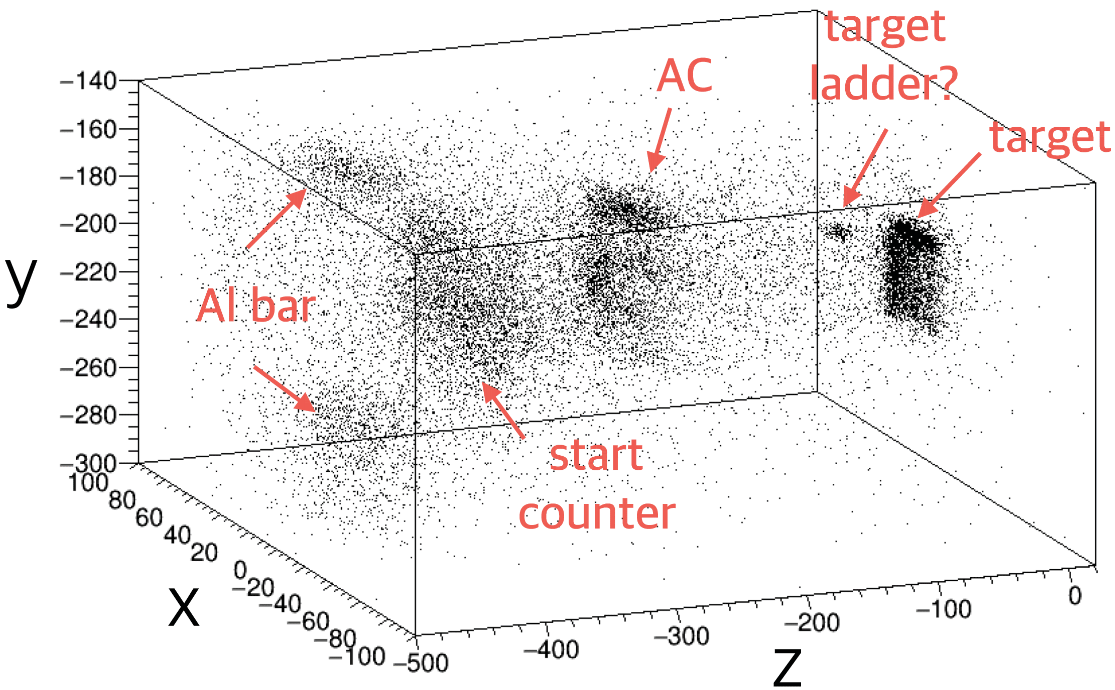




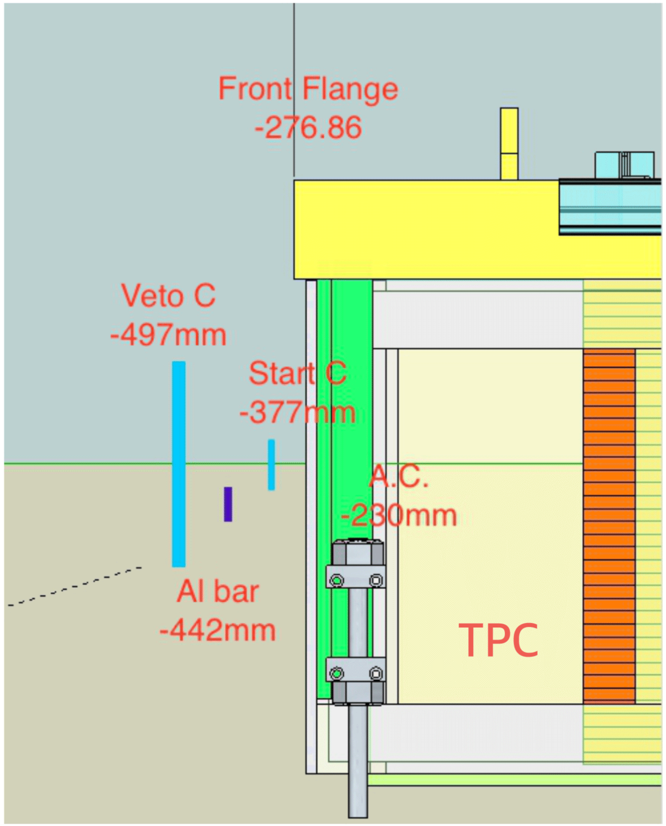
Reactions from 200 AMeV
^{79}Se+Al 10/23/2015
As Commission Run



hist2
Entries 24741
Mean −249.9
Std Dev 160.5
target
start counter
AC
target ladder?
Al bar
450
400
350
300
250
200
150
100
50
0
−500
−400
−300
−200
−100
0



target ladder?
AC
target
Al bar
start counter
y
x
z
−140
−160
−180
−200
−220
−240
−260
−280
−300
100 80 60 40 20 0 −20 −40 −60 −80 −100
−500 −400 −300 −200 −100 0

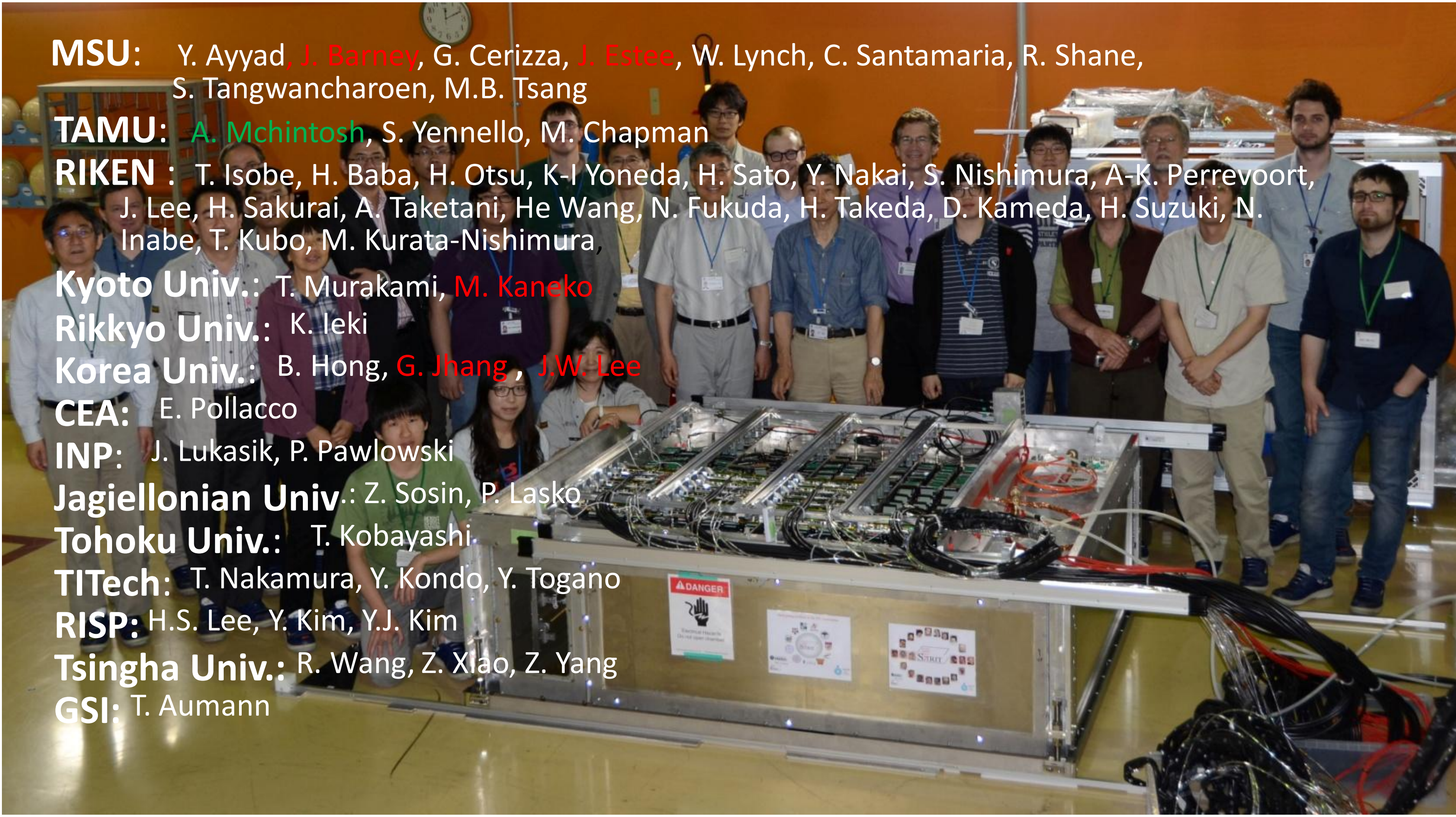


Front Flange
-276.86
Veto C
-497mm
Start C
-377mm
A.C.
-230mm
Al bar
-442mm
TPC

Summary Rough roadmap

- Oct. 2015: Commission of TPC outside SAMURAI magnet.
- Nov. 2015 – Mar, 2016: Data analysis, calibration and improvement and development of online/offline software.
- Jan – Mar, 2016: Remedy any issues arising from the commission run. Insert and test TPC as well as all auxiliary detectors inside SAMURAI magnet. Set up experiment SAMURAI15.
- Early April, 2016: Commission of TPC inside SAMURAI magnet
- Late April, 2016: Performance of SAMURAI15 experiment.
- (May, 2016: Performance of SAMURAI22 experiment.)
- May-October, 2016: Calibration of TPC and all the auxiliary detectors.
- December, 2016: Preliminary results from SAMURAI15 and proposal of new TPC experiments

SπRIT collaboration+



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将来

- 1.2万チャンネル超の読み出し回路一式

  ～総額7000万円 （遺産）
- 個人的な見解:

一連の当初想定していた実験が終了した段階で回路類を継承するプロジェクトの公募をするのが良い（多分）