EOS needs - Summary first

1. Active Target Time Projection Chamber (AT-TPC) **The Primary tool !**

The Science

1. GMR ➔ Nuclear incompressibility K_asy for small density osc.

   ➔with the AT-TPC

2. The symmetry energy project, large density differences form sat

   ➔ AT-TPC ++

3. Fission measurements [B_F (asymmetry)] ➔ AT-TPC

Associated equipment

1. Neutron walls, (are new arrays needed? Discrete N-detector arrays?
2. Si arrays (NTD development needed)
3. Floor needs (S2 +AT-TPC)
4. AT-TPC crane movability between low- and high-energy (S2) areas

Start with Sci. review then double back to TPC and finally to additional equipment.

1. GMR ➔ nuclear incompressibility

$$K_A = K_{nm} + K_{surf} A^{-1/3} + K_{asym} \left(\frac{N-Z}{A}\right)^2 + K_{coul} \frac{Z^2}{A^{4/3}}.$$

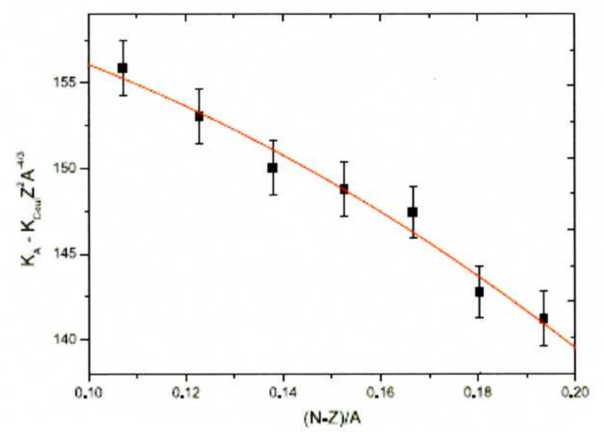
$$K_A - K_{Coul} Z^2 A^{-4/3} = K_{asym}\, x^2 + b$$

From GMR data on ^{208}Pb and ^{90}Zr,

$$E_{GMR} = \hbar \sqrt{\frac{K_A}{m \langle r^2 \rangle}}.$$

$K_\infty = 240 \pm 10$ MeV

[see, *e.g.*, G. Colo *et al.*, Phys. Rev. C **70**, 024307 (2004)]



Need to measure asymmetry dependence more accurately

A direct measurement of the asymmetry contribution to the incompressibility was recently provided by measurements of GMR in stable Sn isotopes: **$K_\tau \cong -550 \pm 100$ MeV**

To obtain a more precise measurement of K_τ, data from on nuclei farther from stability are needed.

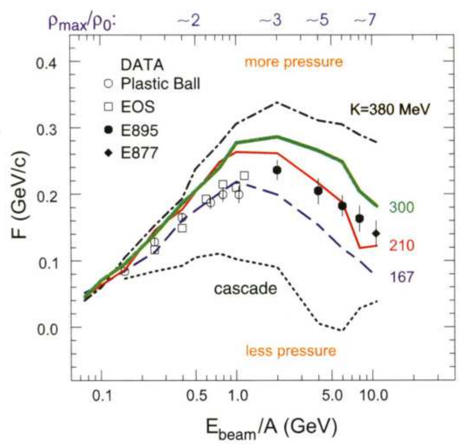
GMR measurements must be performed using radioactive beams on light targets (d or ^{4}He). The AT-TPC provides the most promising environment because the counter gas is both target and detection medium. Low energy recoils can be measured with reduced chamber pressures and the large geometrical acceptance of the detector provides the necessary angular coverage. These features, the AT-TPC will allow GMR measurements of more exotic nuclei

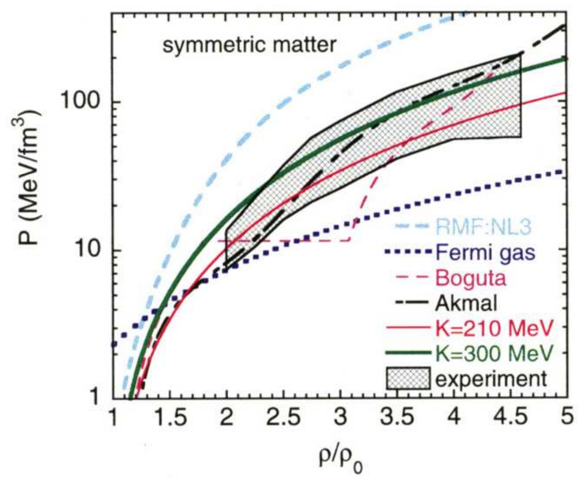
AT-TPC ➔ E_GMR on : ^{54}Ni-^{70}Ni and ^{106}Sn-^{127}Sn via inelastic scattering studies in inverse kinematics

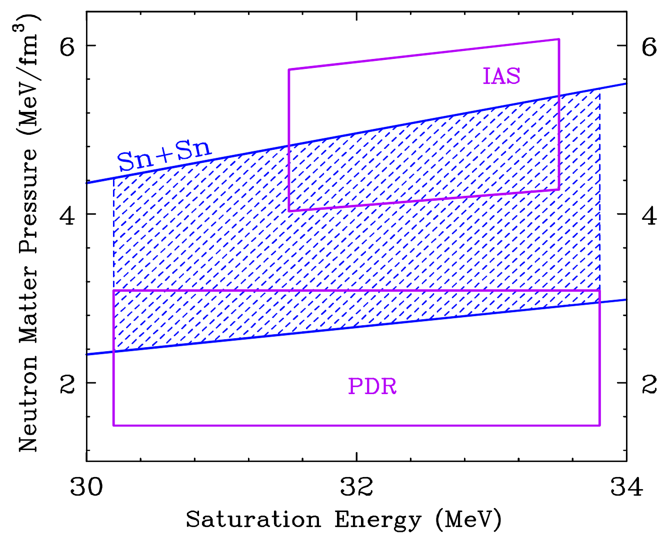
2. Symmetry Energy Project - Tsang

On to… Large density changes, esp. ρ >ρ_o.

$$P = -\left(\frac{\partial \varepsilon}{\partial v}\right)_s = \rho^2\left(\frac{\partial \varepsilon}{\partial \rho}\right)_s = \rho^2\left[\left(\frac{\partial \varepsilon_o}{\partial \rho}\right)_s\right] + \rho^2\left\{\left(\frac{\partial \varepsilon_{asym}}{\partial \rho}\right)_s\right\}. \qquad K_{nm}[MeV] \equiv 9\left(\frac{\partial P}{\partial \rho}\right)_s = 9\rho_{sat}{}^2\left(\frac{\partial^2 \varepsilon}{\partial^2 \rho}\right)_s\Big|_{\rho=\rho_{sat}} .$$







NSCL-FAIR-RIKEN-FRIB

Isospin transport

n/p ratios

Differential n/p flow

+- Pion production

Conservative Conclusions:

$32(\rho/\rho_0)^{0.7} \leq E_{sym}(\rho) \leq 32(\rho/\rho_0)^{1.1}$

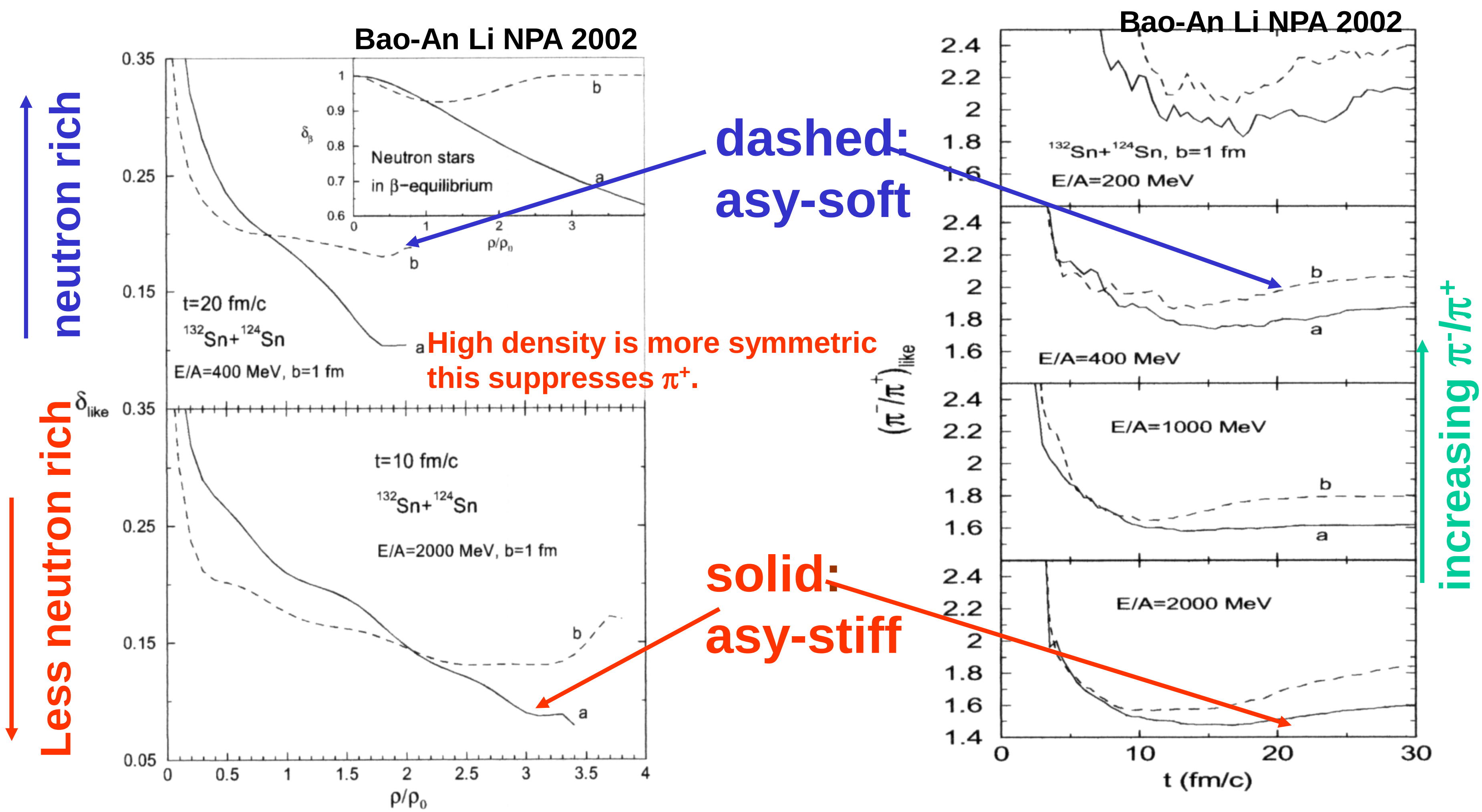
$K_{asy}(\rho_0) \approx -500 \pm 50$ MeV

for $\rho \leq 1.2\rho_0$

Most promising FRIB exp. on Pion yields

SOFTER asy: allows n-rich dense regions ➔ larger π^-/π^+

STIFFER asy: favors sym. dense regions (more +) ➔ smaller π^-/π^+



There are observables for both below and above the saturation density

	Density Regime $\rho<\rho_0$	Density Regime $\rho>\rho_0$	
✓	t/^{3}He production	π^-/π^+ production and flow	✓
✓	Pre-equilibrium nucleon ratio	K^+/K^0 production	X
✓	Isoscaling and Isospin fractionation	n- p and t-^{3}He transverse flow	✓
✓	Isospin diffusion	n- p and t-^{3}He elliptical flow at high p	✓
✓	Neutron-proton correlation functions	Nucleon differential flow	✓

These observables require more than TPC
Large Si arrays and large Arrays of N detectors.

3. Fission
Tracking Fissility with (N-Z)/A

Fission "recycling" (In N-stars)

When X>1

➔ a mononucleus becomes unstable wrt prolate deformations?

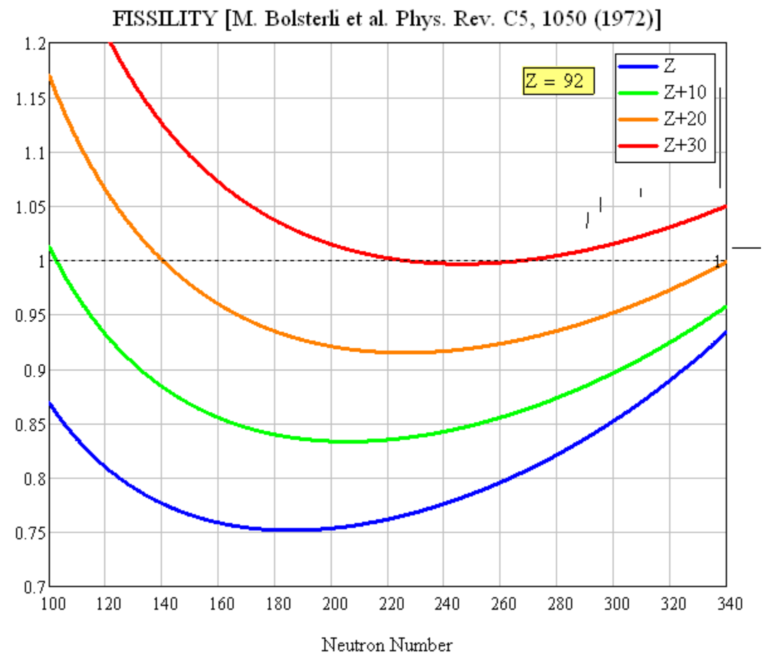
X = ("Coulomb energy")/2(surface energy")

Volume energy is conserved in fission

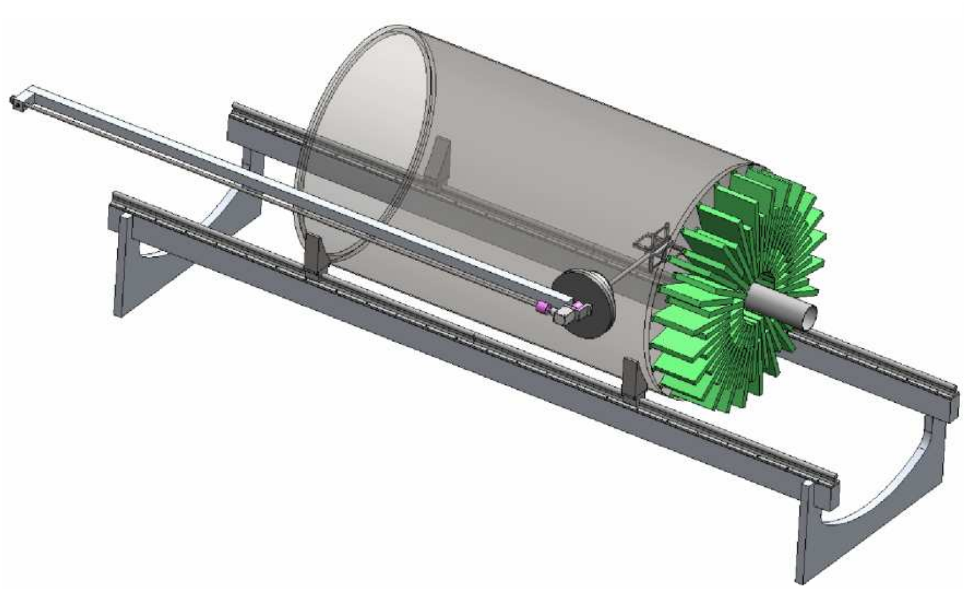
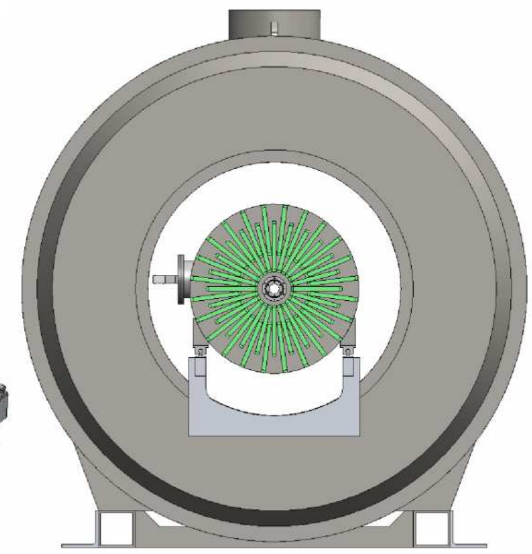
$$X(N,Z) := \frac{Z^2}{C1\cdot(N+Z)\cdot\left[1 - C2\left[\frac{(N-Z)}{(N+Z)}\right]^2\right]}$$

Can one see that this physics is ~ correct, i.e that the fissility Would go up IF the asymmetry got large enough?

Measure B_f over long Isotopic chains.

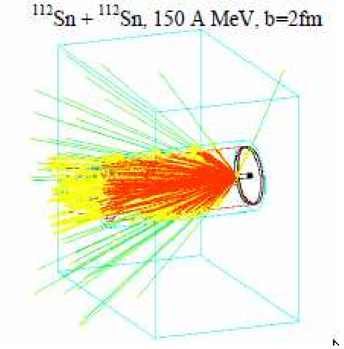


1. MSU TPC: Funded via MRI


8000 pads, 70 cm in dia, 120 cm long, 0.2 < P(atm) < 1

TWIST (2T) magnet



MicroMegas (MicroMEsh GAseous Structure)

Gas**E**lectron**M**ultiplcation

2. RIKEN TPC project: Also funded by DOE

Collaboration

LBL: I-Yang Lee, Larry Phair
LLNL: Mike Heffner
Notre Dame: Umesh Garg, Jim Kolata
NSCL MSU: Abigail Bickley*, Bill Lynch, Wolfgang Mittig, Fernando Montes, Gary Westfall
St. Mary's (Canada): Rituparna Kanungo
WMU: Michael Famiano

There is more to the AT-TPC (non EoS) Overview of AT-TPC projects

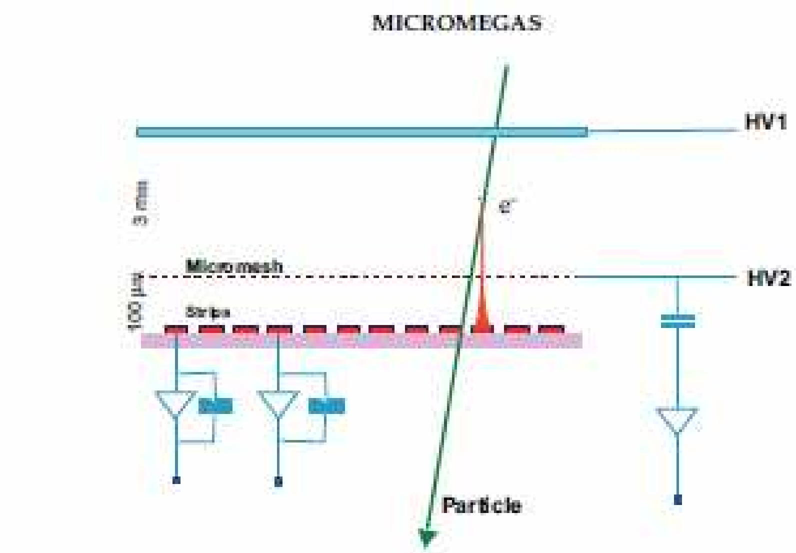
Table 1: Overview of the AT-TPC scientific program.

Measurement	Physics	Beam Examples	Beam Energy (A MeV)	Min Beam (pps)	Scientific Leader
Transfer & Resonant Reactions	Nuclear Structure	$^{32}Mg(d,p)^{33}Mg$ $^{26}Ne(p,p)^{26}Ne$	3	100	Kanungo
Astrophysical Reactions	Nucleosynthesis	$^{25}Al(^{3}He,d)^{26}Si$	3	100	Famiano
Fusion and Breakup	Nuclear Structure	$^{8}B+^{40}Ar$	3	1000	Kolata
Fission Barriers	Nuclear Structure	^{199}Tl, ^{192}Pt	20 - 60	10,000	Phair
Giant Resonances	Nuclear EOS, Nuclear Astro.	^{54}Ni-^{70}Ni, ^{106}Sn-^{127}Sn	50 - 200	50,000	Garg
Heavy Ion Reactions	Nuclear EOS	^{106}Sn - ^{126}Sn, ^{37}Ca - ^{49}Ca	50 - 200	50,000	Lynch

Require Fast beams

Some of these are for discussion elsewhere.

Interesting detector tech . Much work on both this and the electronics,



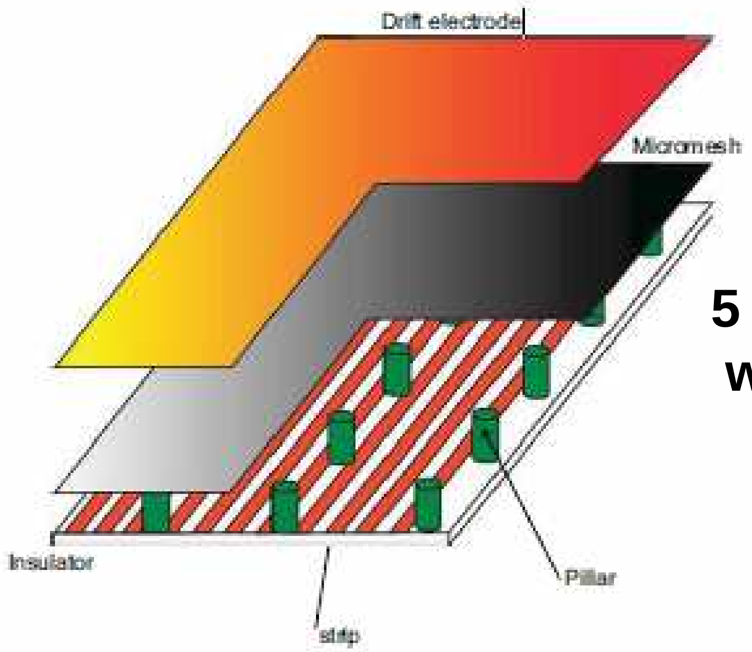


Fig. 1. Micromegas device.

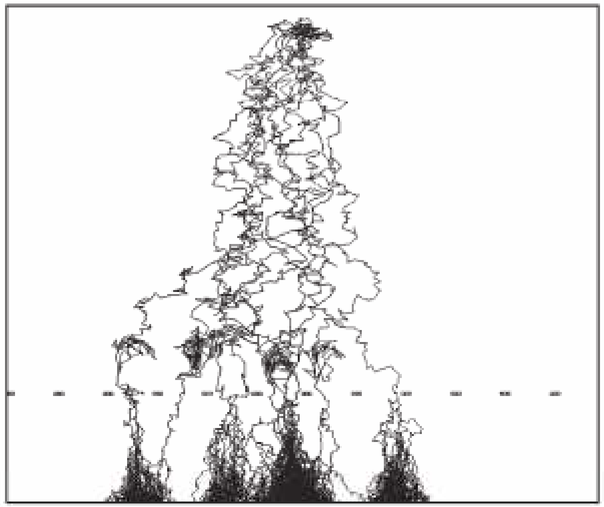
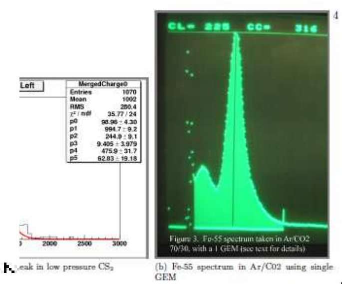


Fig. 2. GARFIELD simulation of electron drift and multiplication in Micromegas.

5 um metalic mesh with 25-50 um pitch

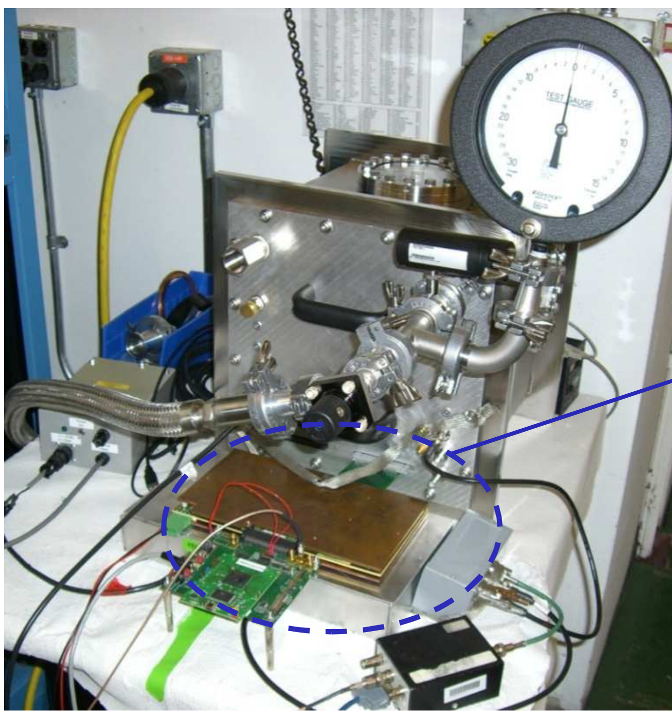


(b) Fe-55 spectrum in Ar/CO2 using single GEM

Figure 1: Micronic Mesh: 1 mil wires with 400 wires/inch

T2K electronics

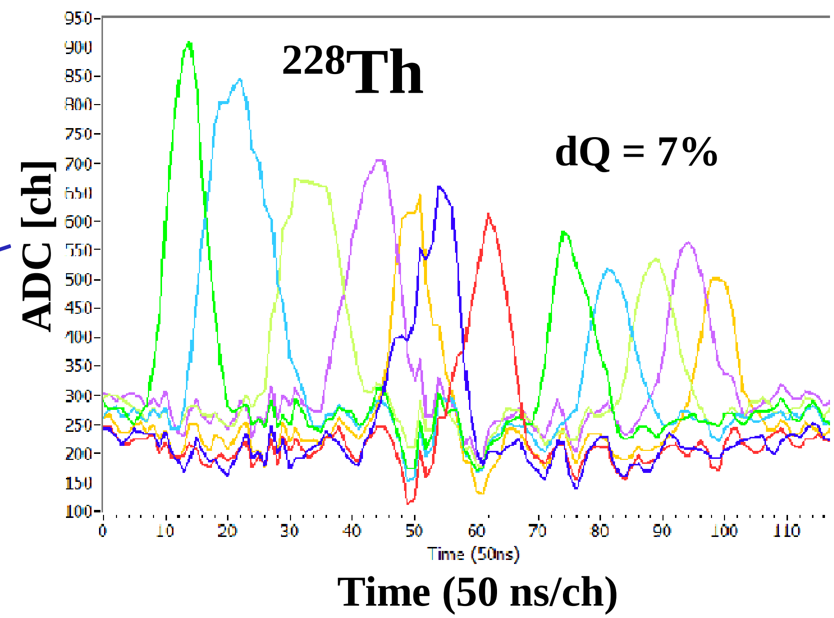
- **4 ASIC with 72 inputs**
- **511 switching capacitor array**
  Sampling freq. = 1~50 MHz
- **12-bit ADC**



Limitations

- **No internal trigger**
- **Trigger rate < 200 Hz**
  -Bottleneck; SCA readout 25 MHz
  -USB2.0 -> Gigabit link

Limitions addressed by GET electronics project U.S.-France-Japan



A SEP meeting just finished to discuss the “RIKEN” TPC

USA + Japan + China + Germany +UK + Brazil +France + Italy

Determination of the nuclear equation of state of asymmetric matter and understanding the nature of dense neutron-rich matter in neutron stars. This is one of the physics goals of FIB.

Preliminary constraints have been obtained recently at the sub-saturation density region.
The goal of “Symmetry Energy Project” is to determine the density dependence of the symmetry energy beyond the normal nuclear matter density and to improve the constraints obtained in the subnormal nuclear matter density regions.

8:30 AM	Tsang	Overview of the SAMURAI-TPC project
9:00 AM	Verde	Report from the European collaboration
9:15 AM	Suzuki	Dtatus of AT/TPC
9:40 AM	Murakami	Status of SAMURAI -TPC Japanese
10:05 AM	Isobe	Status of SAMURAI dipole
10:30 AM		Coffee Break
11:00 AM	Taketani	Status of the SAMURAI-TPC electronics
11:25 AM	Famiano	SAMURAI-TPC laser system
11:50 AM	Yennello	Construction of TPC chamber
	Lynch	What do we use for a test chamber
	Westfall	Status of acquisition of STAR electronics
12:30 PM	Lynch	Technical questions and schedule of SAMURI-TPC project
1:00 AM	End	Lunch

Name	Institution	Role	Expertise
Abigail Bickley	NSCL/MSU	Principal Investigator	Heavy Ion Reactions
Michael Famiano	W. Michigan	Scientific Coordinator	Astrophysical Reactions
Umesh Garg	Notre Dame	Scientific Coordinator	GMR Reactions
Michael Heffner	LLNL	Project Advisor	TPC Expert & Electronics Dev.
Rituparna Kanungo	St. Mary's	Scientific Coordinator	Transfer & Resonant Reactions
Jim Kolata	Notre Dame	Scientific Coordinator	Fusion & Breakup Reactions
I-Yang Lee	LBNL	Project Advisor	Electronics Development
William Lynch	NSCL/MSU	Project Advisor	Heavy Ion Reactions
Wolfgang Mittig	NSCL/MSU	Project Advisor	Electronics & Low Energy Reactions
Fernando Montes	NSCL/MSU	Project Advisor	Astrophysical Reactions
Larry Phair	LBNL	Scientific Coordinator	Fission Barriers
Gary Westfall	NSCL/MSU	Project Advisor	TPC Expert & EOS Heavy Ion Reactions

Principals

- **Collaborators and Co-editors**

ASINS, Poland	GSI, Germany	IMP, China	INP, France	NSCL MSU	RU, Japan	UT, Japan
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J.E. Ducret	C. Schwarz	G. Wang	MSIP, Poland	A. Vander Molen	U of Wisconsin	
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E. Le Gentil	H. Simon	N.R. Yoder	J. Brzychczyk	A. Wagner	W.A. Friedman	
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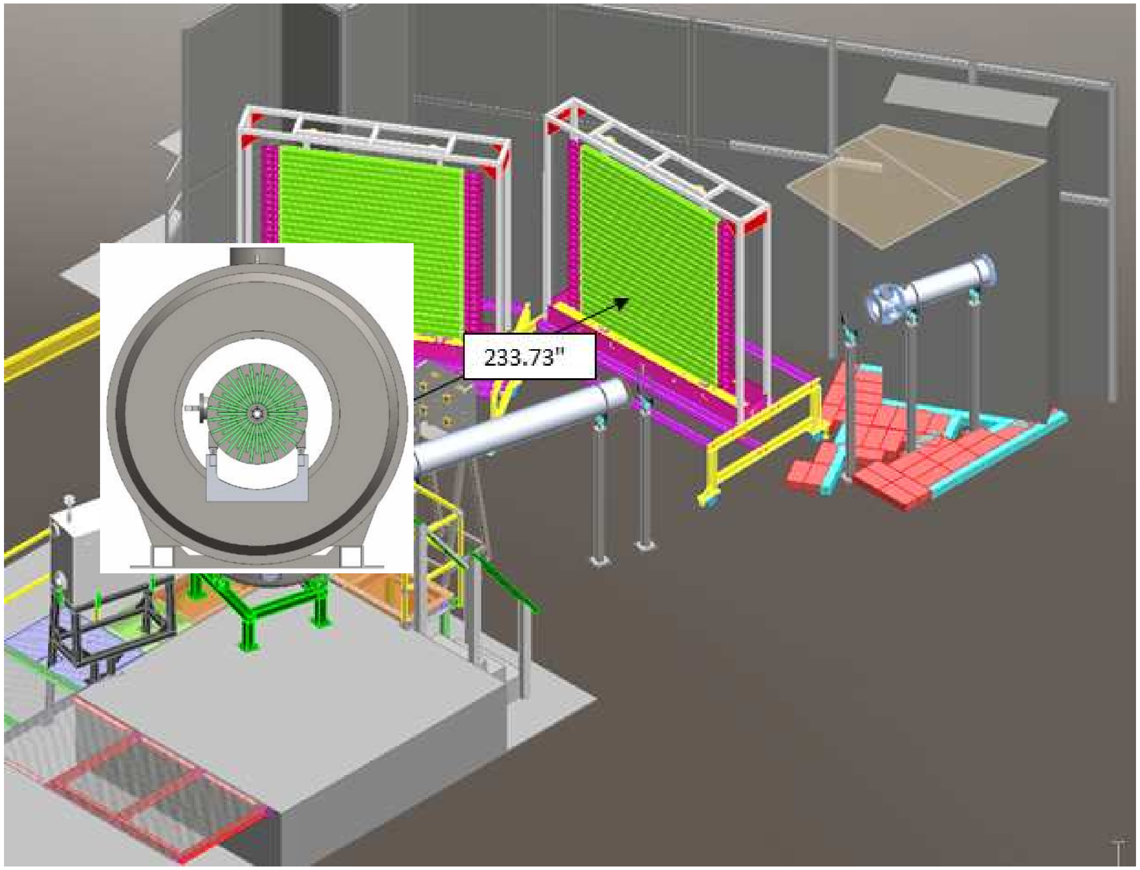
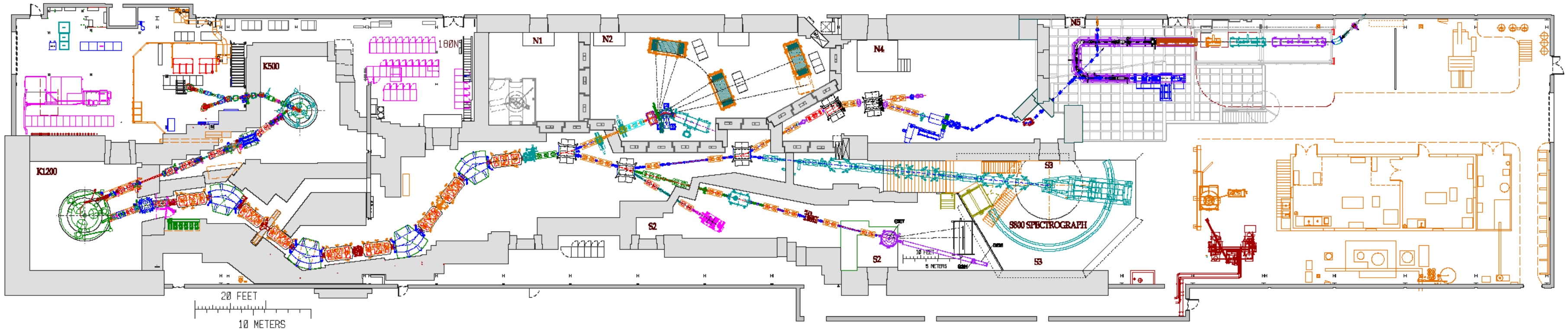
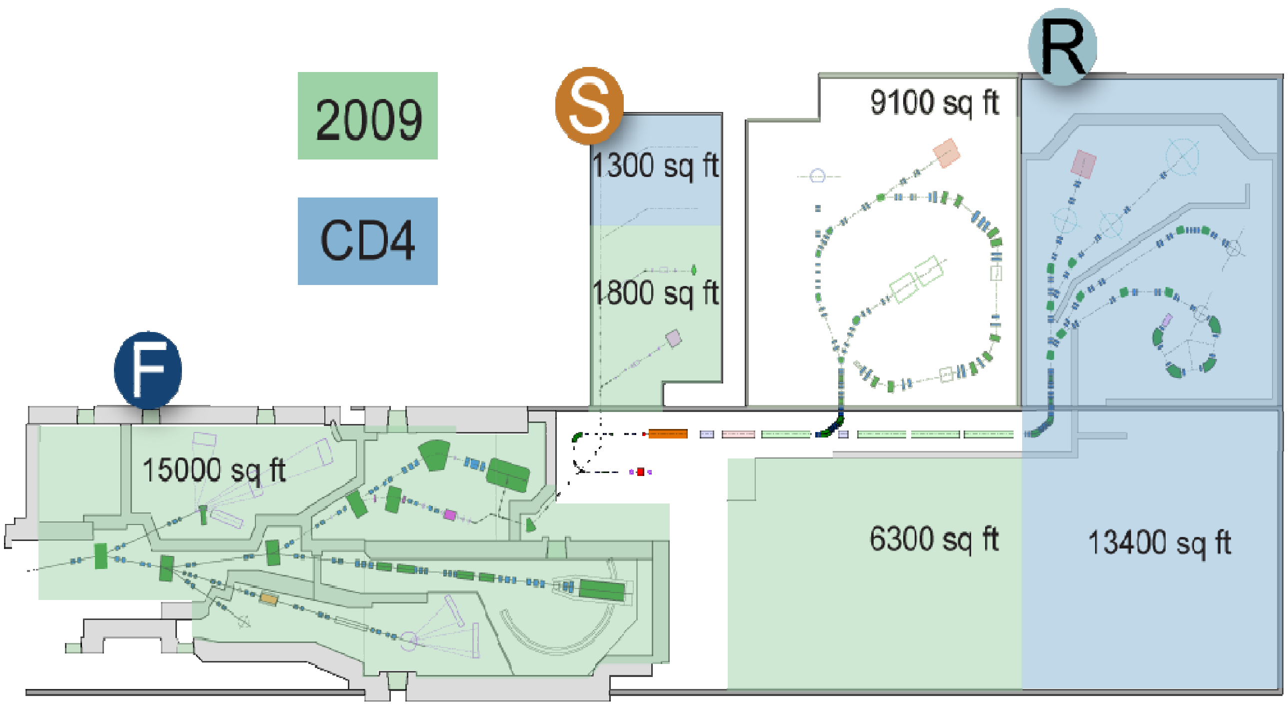
D. Lacroix	J. Cibor	G. Raciti	PU, China	S. Takeuchi		
C. Volant	B. Czech	E. Rapisarda	H. Hua			

Actors

Space – need it in both fast beams and RIA-3 and 12 areas AND crane to move from one area to another




K500
K1200
N1
N2
N4
S2
S3
S800 SPECTROGRAPH
20 FEET
10 METERS


2009
CD4
S
R
F
1300 sq ft
1800 sq ft
9100 sq ft
15000 sq ft
6300 sq ft
13400 sq ft

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