The National Superconducting Cyclotron Laboratory

Michigan State University

U.S. flagship user facility for rare isotope research and education in nuclear science, astro-nuclear physics, accelerator physics, and societal applications

Betty Tsang for the SπRIT Collaboration

JCNP2015, Osaka,

November 8, 2015

Nuclear Symmetry Energy: From Nucleus to Neutron Stars

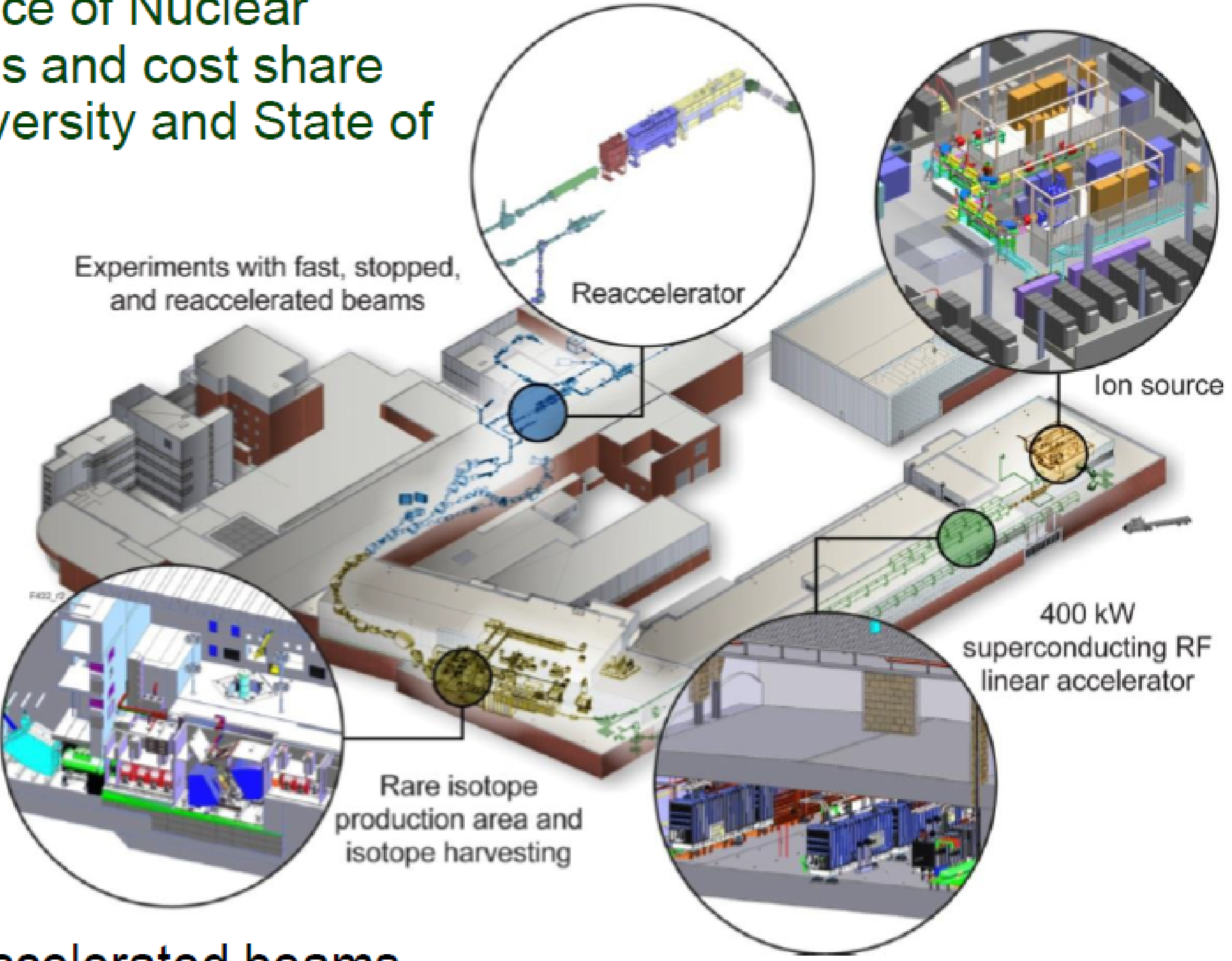

USA
State and Capital
N
C A N A D A
New York City
Chicago
San Francisco
Los Angeles
PACIFIC
OCEAN
MEXICO
CANADA
Pacific
Ocean
Pacific
Ocean

NSCL

Michigan State University

From NSCL to Facility for Rare Isotope Beams (FRIB)

- Funded by DOE–SC Office of Nuclear Physics with contributions and cost share from Michigan State University and State of Michigan
- Managing to early completion in Dec 2020
- Key feature is 400 kW beam power for all ions (5×10^{13} $^{238}U/s$)
- Separation of isotopes in-flight
  - Fast development time for any isotope
  - Suited for all elements and short half-lives
  - Fast, stopped, and reaccelerated beams



FRIB

FIRB Construction Progress

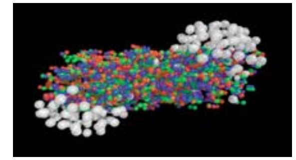
March 17, 2014

above ground! April 1, 2015

$730 M project: 2009 – 2020 (early completion)

November 4, 2015

Symmetry Energy Project



LAMPS

FRIB

NSCL

GSI

RAON

GANIL

IMP

TAMU

Catania

RIBF

Yennello
Natowitz

HiRA Indra RB3, Hades ASY-EOS CEE SπRIT

International Collaboration is the key

JUSTIPEN provide funds for US scientists to travel to RIBF… to collaborate with Japanese scientists

JUSTIPEN
Japan-U.S. Theory Institute for Physics with Exotic Nuclei

- JUSTIPEN Home
- JUSTIPEN Visit Application Form
- Conferences, Schools, and Seminars
- Visitors
- Visitor Information
- Publications
- Collaborations
- Job Postings
- JUSTIPEN Policies
- Governing Board
- RNB Resources
- Photo Gallery
- Links
- News

JUSTIPEN
ジャスティペン
Office of Science
U.S. Department of Energy

About JUSTIPEN

Purpose:
Deliver an international venue for research on the physics of nuclei during an era of experimental investigations on rare isotopes.

Location:
RIKEN, at the new RIB Factory

US Participation:
Provide travel and local support for U.S. visits to JUSTIPEN

Synopsis:
The Japan-U.S. Theory Institute for Physics with Exotic Nuc (JUSTIPEN) has been established in order to facilitate colla between U.S. and Japanese scientists whose main research in the area of the physics of nuclei. JUSTIPEN is located at RIKEN RIB Experimental Facility in Wako, near Tokyo, Japa participation in JUSTIPEN is in the form of travel grants and subsistence grants to those individuals who are interested i collaborating with Japanese scientists. JUSTIPEN's purview area of physics of or with exotic nuclei, including nuclear str and reaction theory, nuclear astrophysics, and tests of the s model using exotic nuclei. While JUSTIPEN primarily focuse


2011-FUSTIPEN


2006-2014

Time to change "Theory" to "Experiment)" (2009)

JUSTIPEN

Japan-U.S. Theory Institute for Physics with Exotic Nuclei

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JUSTIPEN provide funds for US scientists to travel to RIBF… to collaborate with Japanese scientists

JUSEIPEN Japan-U.S. Experimental Institute for Physics with Exotic Beams

- Home
- JUSEIPEN Organization
- JUSEIPEN Policies
- Grant Application Form
- Meetings
- JUSEIPEN related links

About JUSEIPEN

The Japan-US Experimental Institute for Physics with Exotic Nuclei (JUSEIPEN) has been established to help promote and develop strong US-Japan experimental collaborations using rare isotope beams.

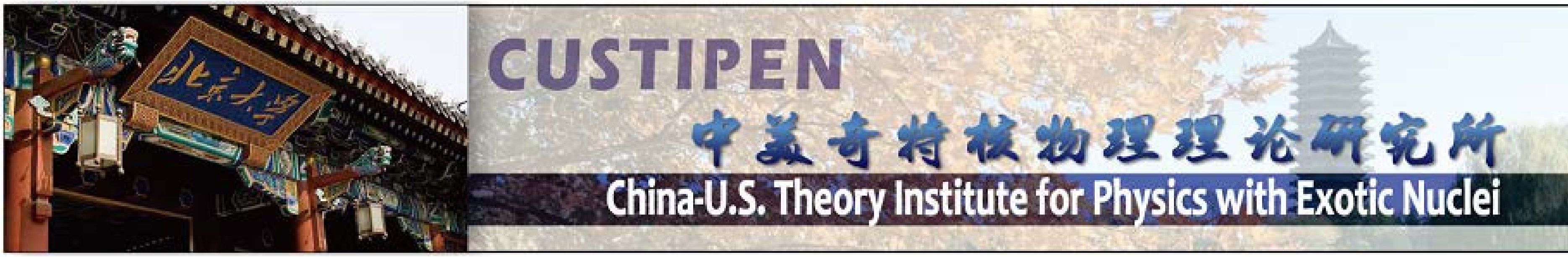
JUSEIPEN can provide funds for U.S. scientist to travel to the RI Beam factory (RIBF) at the RIKEN Nishina Center in Wako near Tokyo, and to other institutes in support of JUSEIPEN's goals. JUSEIPEN can also provide a framework to organize and support workshops and meetings to help coordinate effort on the science goals and logistics for U.S. involvement in RIBF.

If you are a scientist working at a US institution interested in developing or joining a collaboration with Japanese colleagues to carry out experiments at the RI Beam factory, RIKEN, and you think JUSEIPEN can help, then please feel free contact the steering committee (via pfallon@lbl.gov). Information on applyng for a travel funds is given under JUSEIPEN Policies

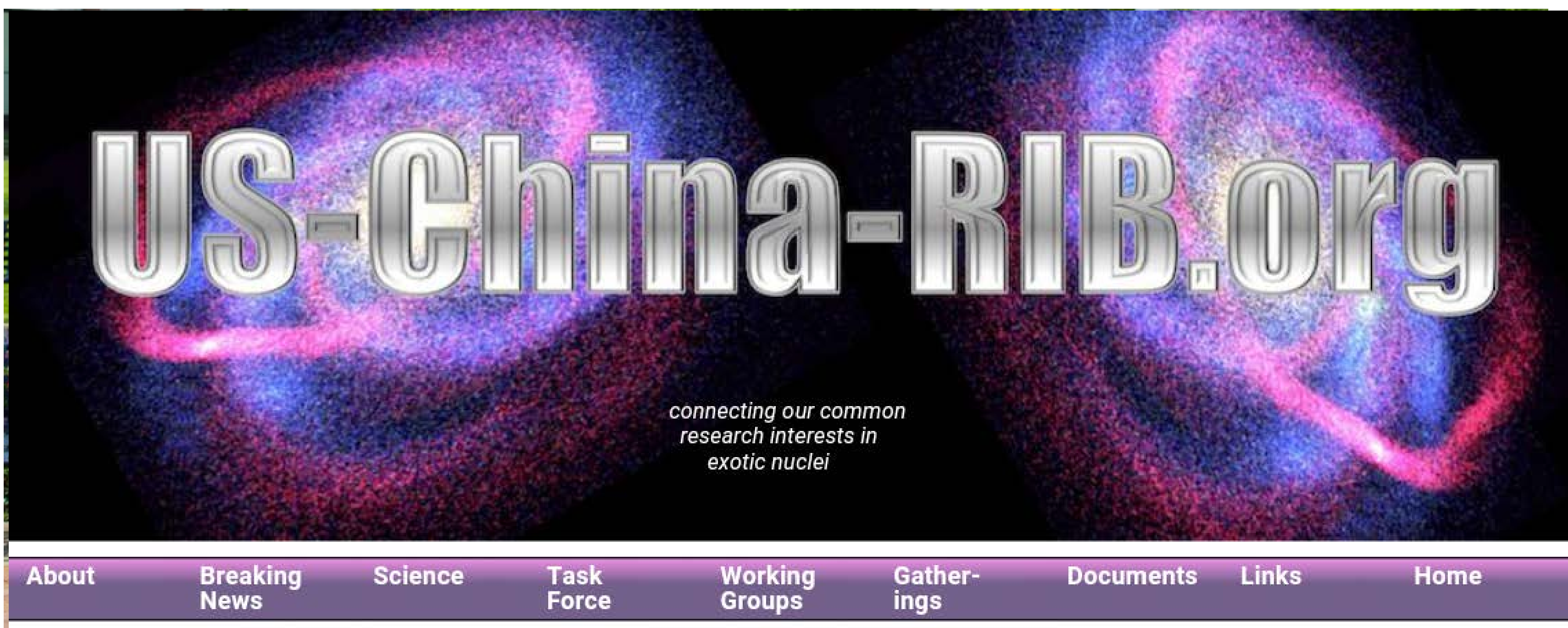
JUSEIPEN provide funds for US scientists to travel to RIBF…

EN's activities is carried
tives from the U.S. and
the Office of Nuclear
The present cycle of
ugh FY2013.

For more information on JUSEIPEN please contact pfallon@lbl.gov


CUSTIPEN
中美奇特核物理理论研究所
China-U.S. Theory Institute for Physics with Exotic Nuclei


The First FRIB-China Workshop on Physics of Nuclei and Hadrons
May 28-30, NSCL, Michigan State University


US-China-RIB.org
connecting our common
research interests in
exotic nuclei
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Nuclear Symmetry Energy:
From Nucleus to Neutron Stars

曾敏兒 -- Betty Tsang

Outline

1. Introduction : Different forms of EoS
2. How did we get here? Current constraints on density dependence of symmetry energy.
3. Where are we going? Future challenges and opportunities.
4. Research funded by DOE, NEXT and JUSEIPEN.
5. Summary

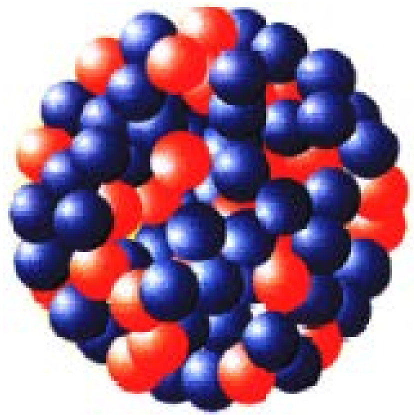
Nuclear Symmetry Energy: From Nucleus to Neutron Stars

Equation of State of nuclear matter

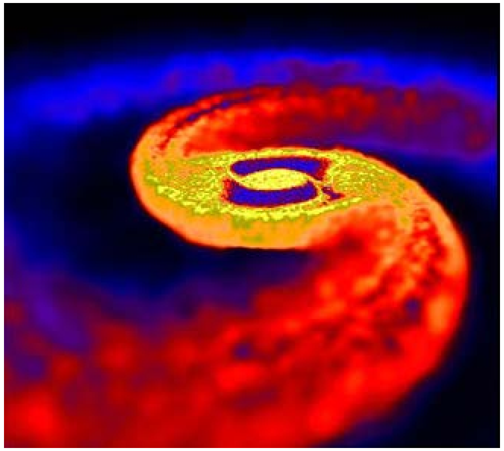
$$E/A(\rho,\delta) = E/A(\rho,0) + \delta^2 \cdot S(\rho)$$

$$\delta = (\rho_n - \rho_p)/(\rho_n + \rho_p) = (N-Z)/A$$

Symmetry Energy of asymmetric matter

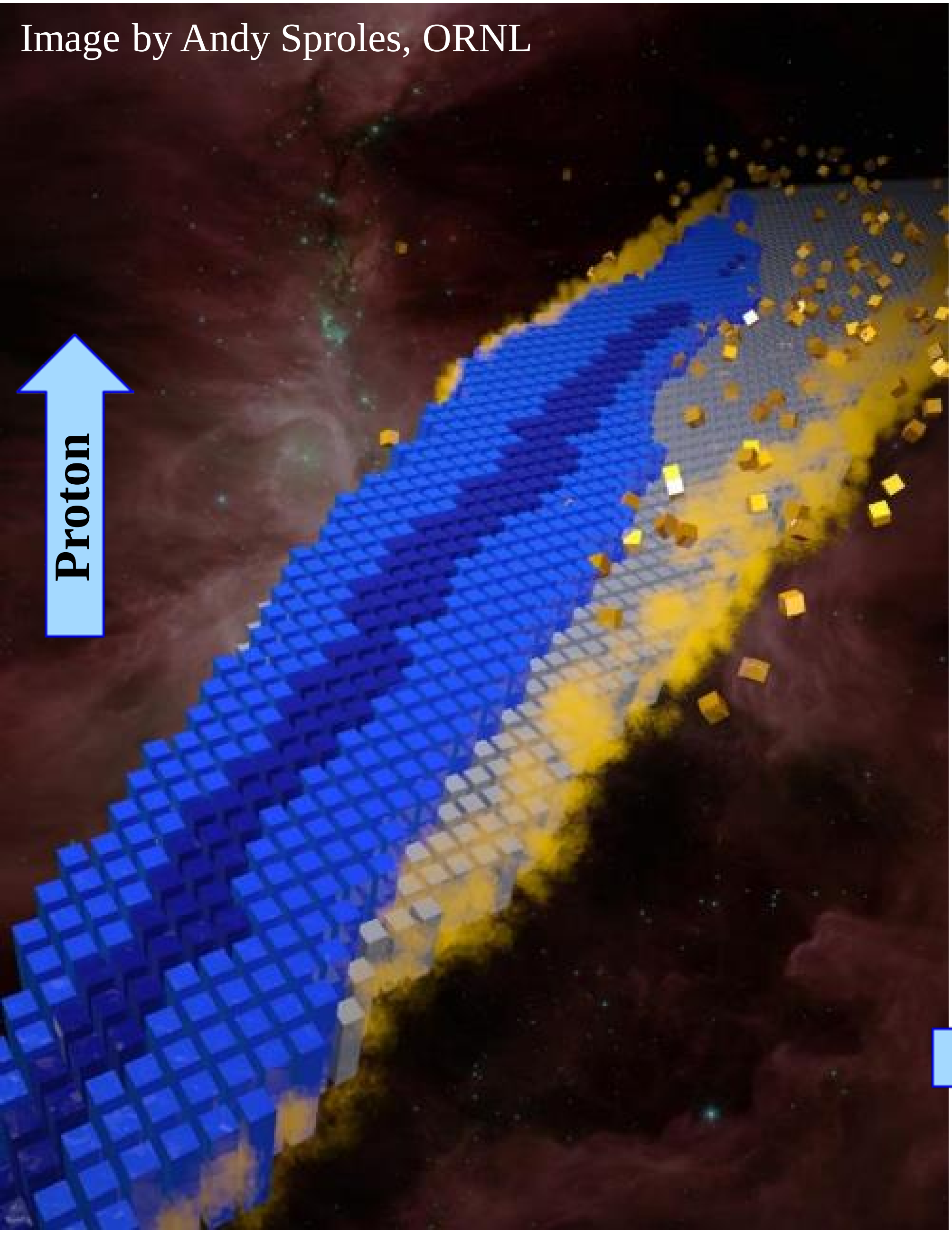


^{208}Pb



- To probe fundamental questions on the nature of nuclear matter especially the isospin asymmetric matter.
- To recreate and study astrophysical environments

Symmetry Energy



$$B = a_V A - a_S A^{2/3} - a_C \frac{Z(Z-1)}{A^{1/3}}$$

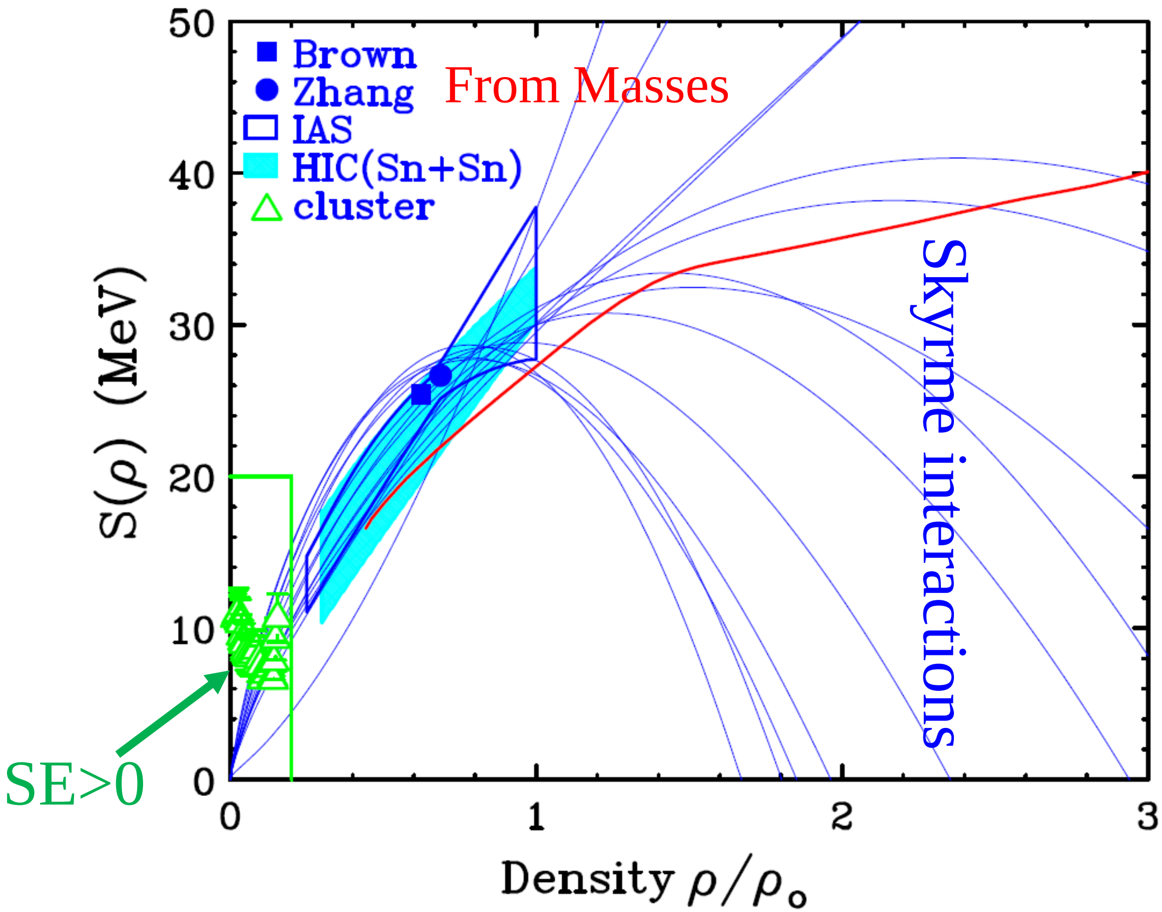
$$- a_{sym} \frac{(A-2Z)^2}{A}$$

$$(a^V_{sym} A - a^S_{sym} A^{2/3}) \frac{(A-2Z)^2}{A^2}$$

Inclusion of surface terms in symmetry

Neutron

Hubble ST



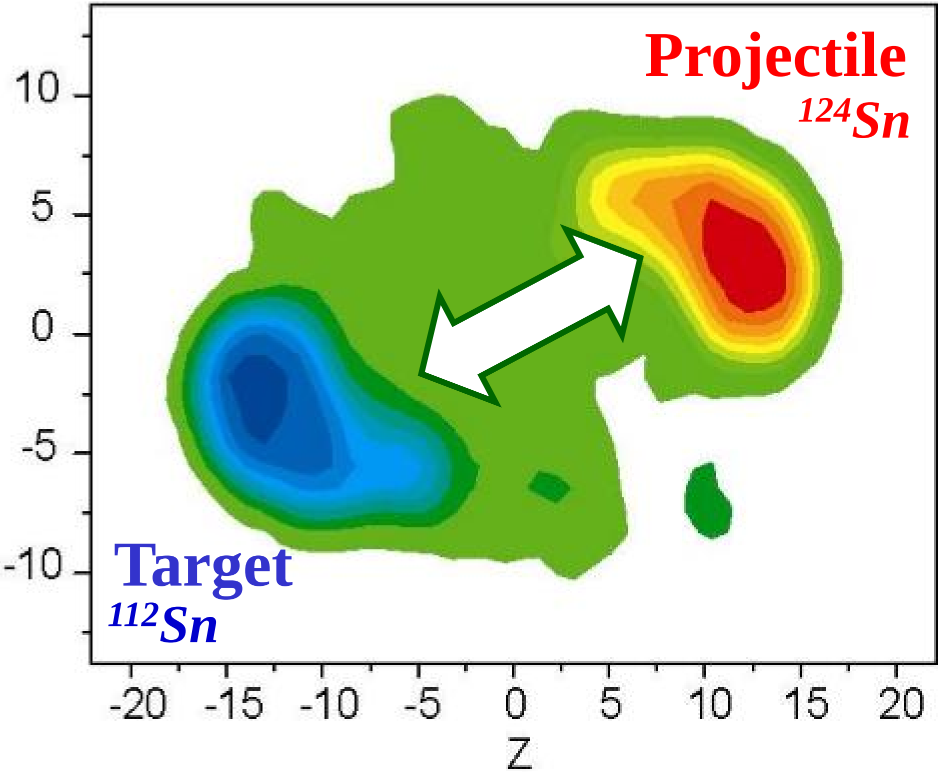
Recommendation to US Long Range Plan from EOS working group

- At $\rho \ll \rho_0$: Establish observables to study cluster effect and link to neutrinosphere physics.
- At $\rho \leq \rho_0$: Improve constraints from both structure and reaction experiments:
- At $\rho \approx 1.5 - 2\rho_0$: Determine symmetry energy and the momentum dependence of the isovector potential.

Isospin Diffusion observable to study E_{sym} with Heavy Ion Collisions

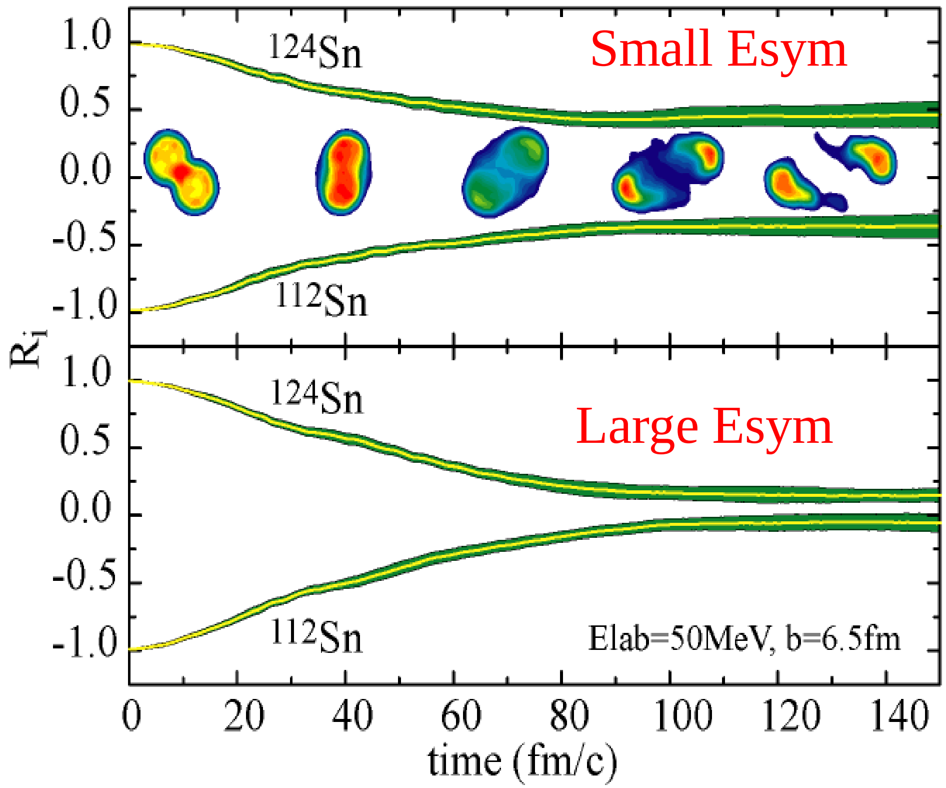
$\delta=(N-Z)/A$

Tsang et al., PRL 92 (2004) 062701



$S(\rho)=12.5(\rho/\rho_o)^{2/3}+C(\rho/\rho_o)^{\gamma_i}$

Tsang, Shi et al., PRL92, 062701(2004)



Isospin Diffusion; low ρ, E_{beam}

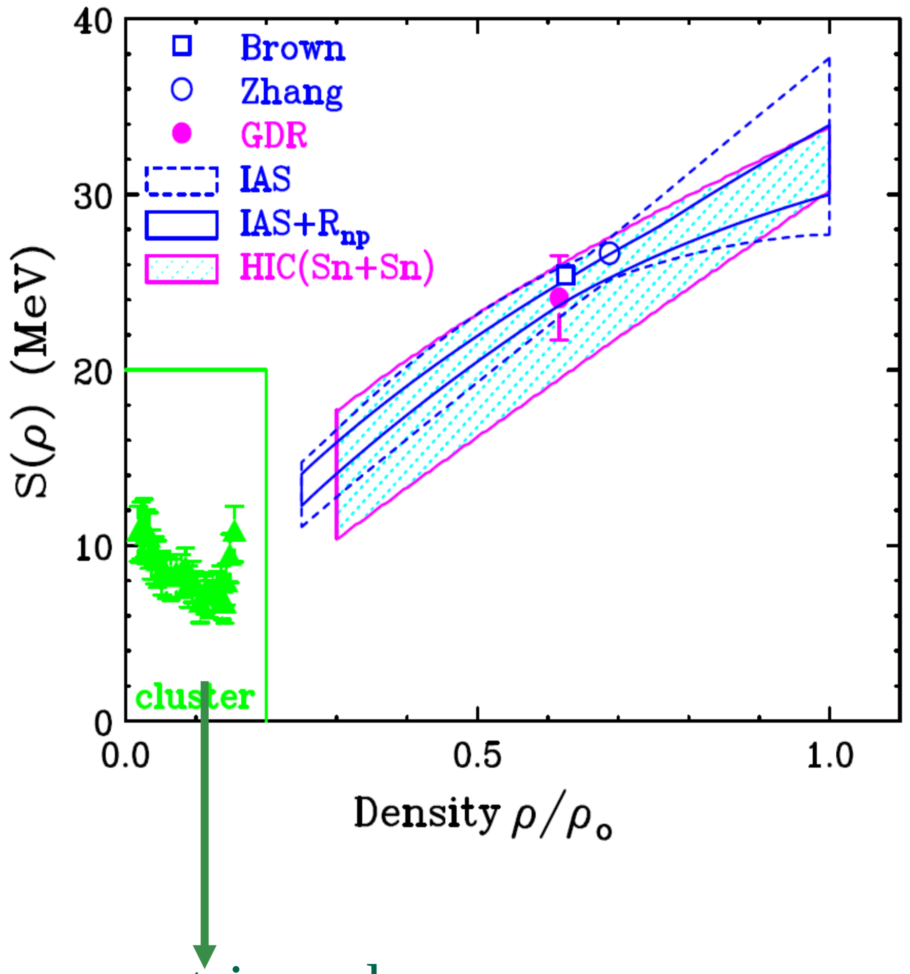
$$R_i = 2\frac{\delta_{AB}-(\delta_{AA}+\delta_{BB})/2}{\delta_{AA}-\delta_{BB}}$$

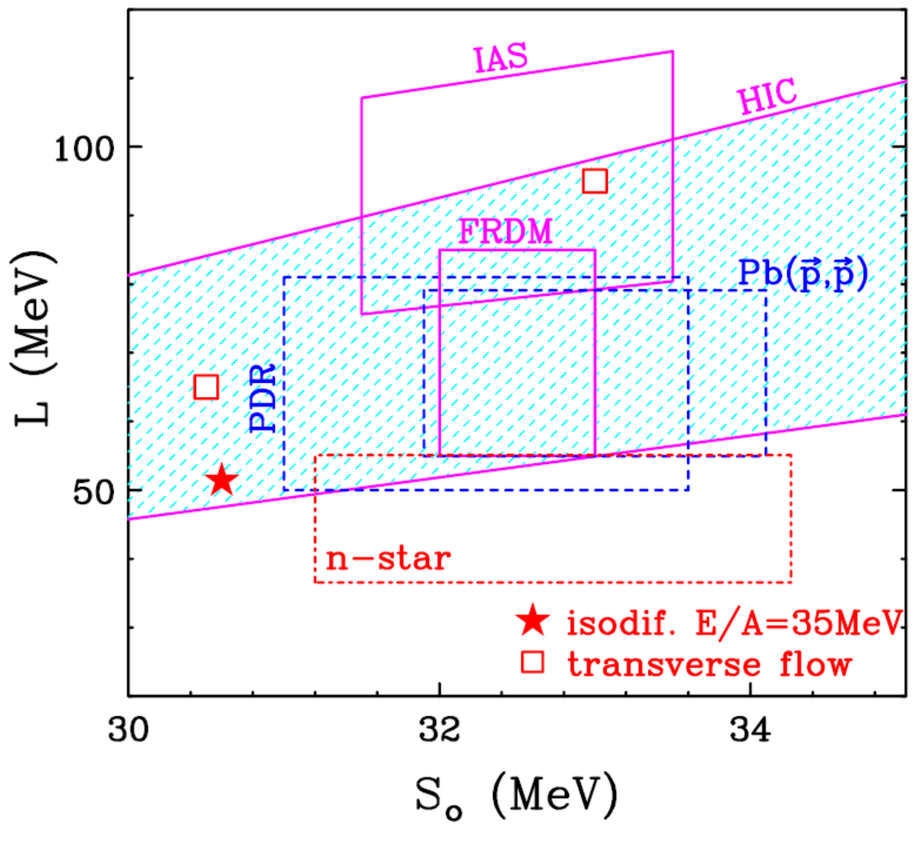
Bao-An Li et al., Phys. Rep. 464, 113 (2008)
Tsang, Zhang et al., PRL122, 122701(2009)

Status of Constraints from nuclear structure and reactions

$S(\rho) = 12.5(\rho/\rho_o)^{2/3} + C\,(\rho/\rho_o)$

$$S(\rho) = S_o + \frac{L}{3}\left(\frac{\rho_B - \rho_0}{\rho_0}\right) + \ldots$$





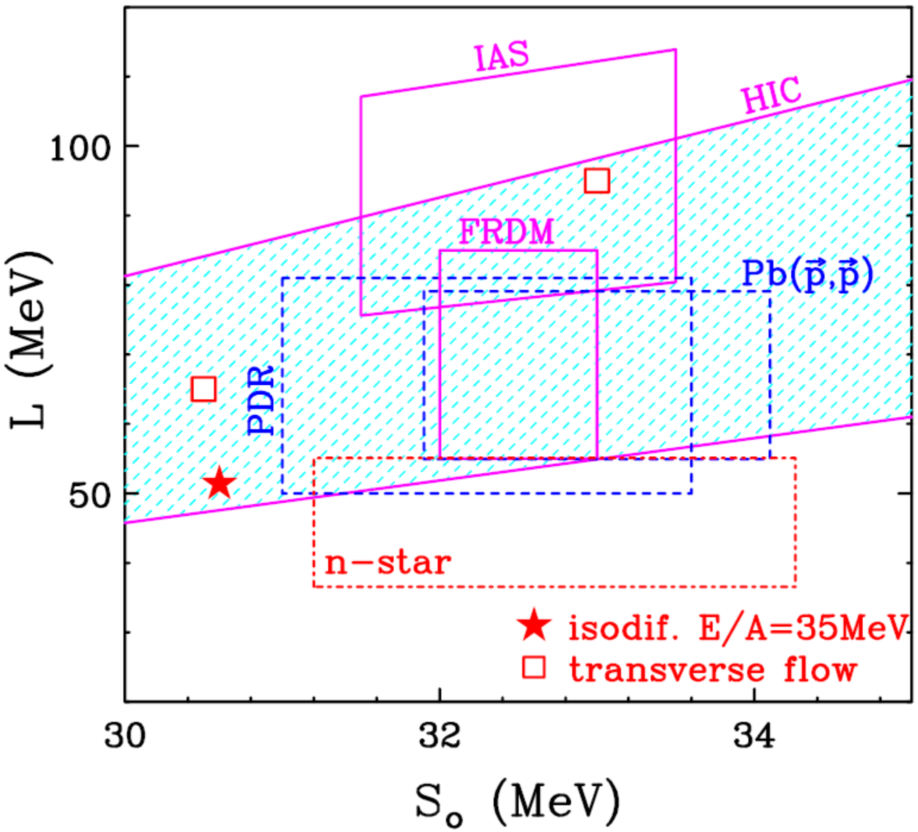
neutrinosphere

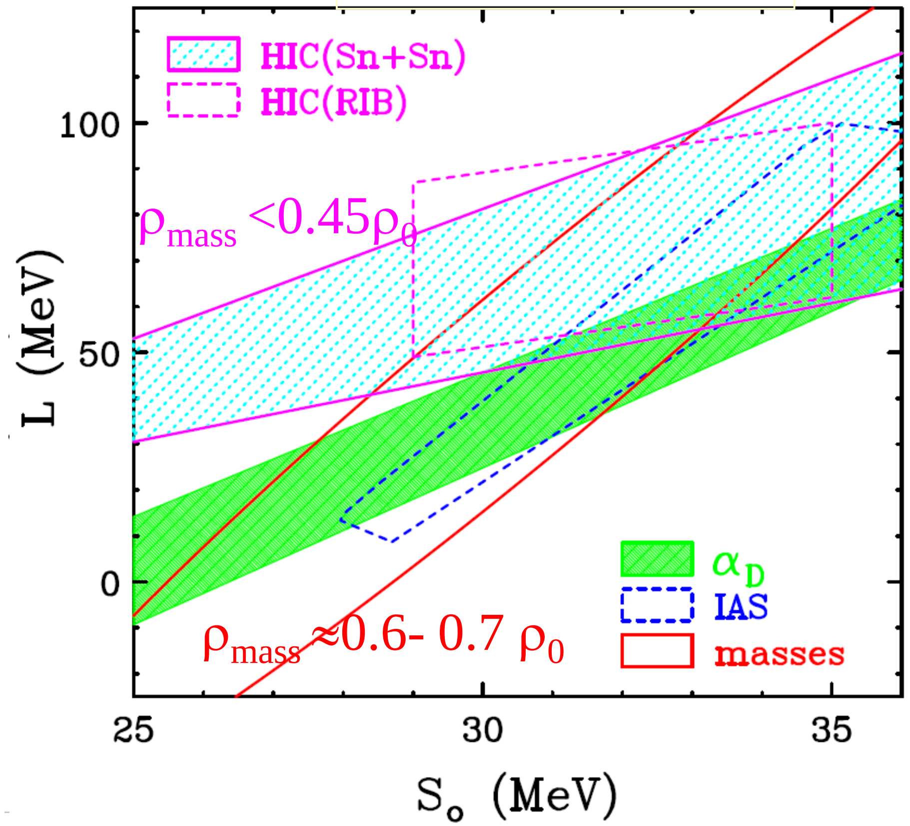
Tsang et al, 86, 015803 (2012)

Consistent Constraints from nuclear structure and reactions with credible uncertainties NuSYM13 & ICNT2013

$$S(\rho) = S_o + \frac{L}{3}\left(\frac{\rho_B - \rho_0}{\rho_0}\right) + \ldots$$

Tsang et al, 86, 015803 (2012)





$S(\rho)=12.5(\rho/\rho_o)^{2/3} + C\,(\rho/\rho_o)$

$\rho_{sens.} = \rho_0\left(1-3/M\right)$; M is slope

Equation of State of Neutron Matter

Hubble ST

Neutron Star: balance of Gravity (pulls in) and Symmetry energy pressure (pushes out): Masses vs. Radii

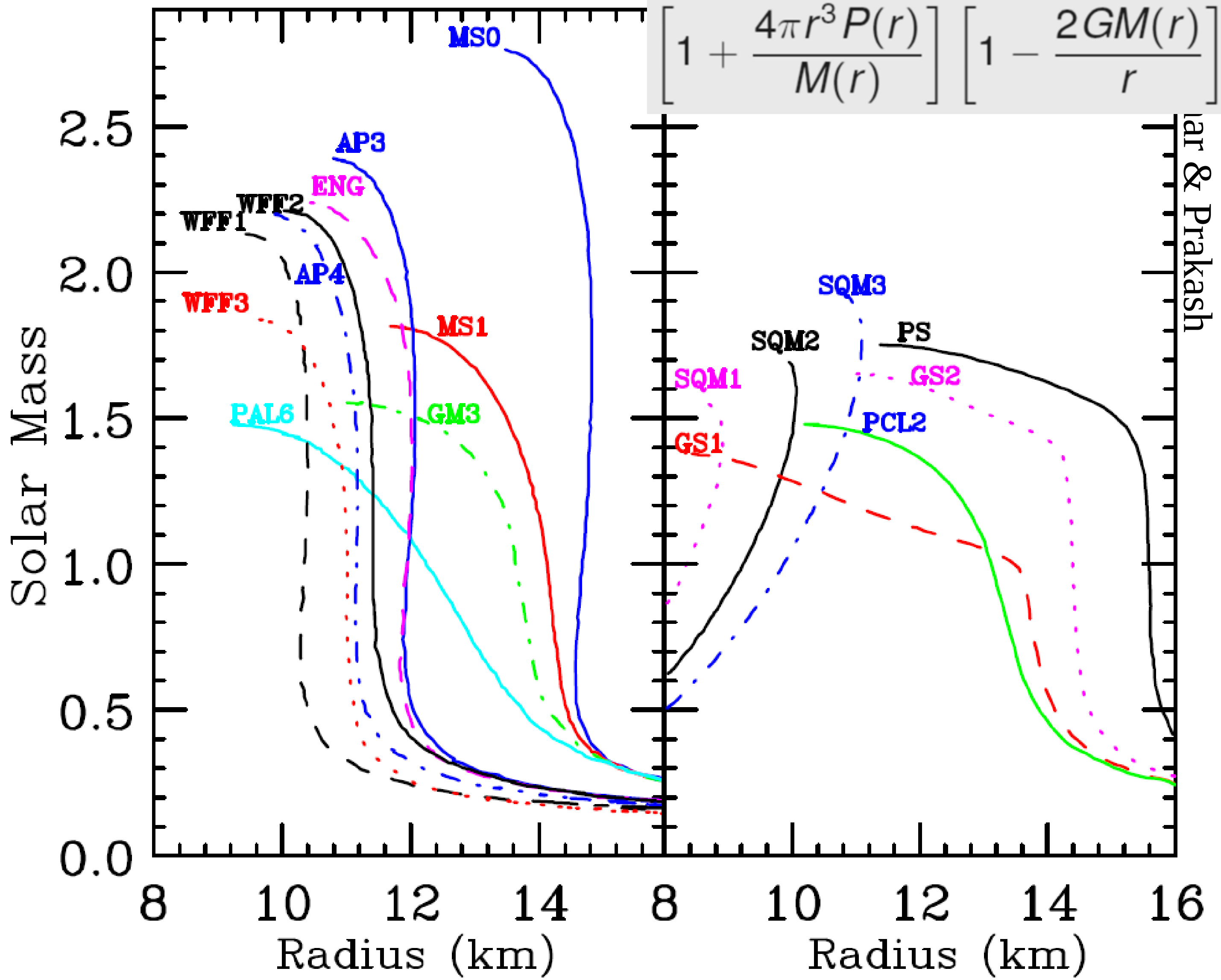
$$\frac{dM}{dr} = 4\pi r^2 \mathcal{E}(r)$$

$$\frac{dP}{dr} = -G\frac{\mathcal{E}(r)M(r)}{r^2}\left[1 + \frac{P(r)}{\mathcal{E}(r)}\right] \left[1 + \frac{4\pi r^3 P(r)}{M(r)}\right] \left[1 - \frac{2GM(r)}{r}\right]^{-1}$$

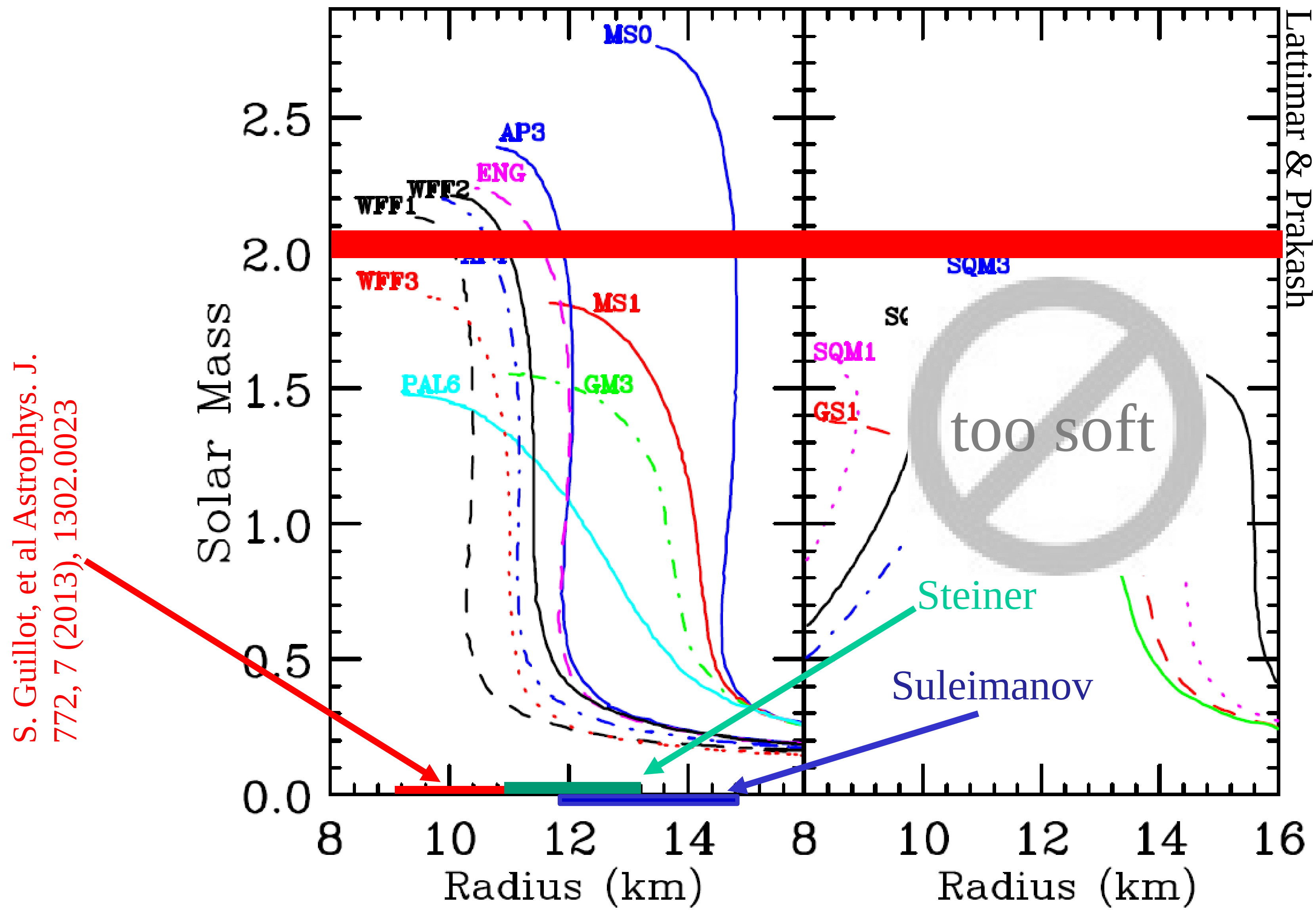
EoS of pure neutron matter: Symmetry Energy as function of pressure (density)

$$\frac{dM}{dr} = 4\pi r^2 \mathcal{E}(r)$$

$$\frac{dP}{dr} = -G\frac{\mathcal{E}(r)M(r)}{r^2}\left[1+\frac{P(r)}{\mathcal{E}(r)}\right]\left[1+\frac{4\pi r^3 P(r)}{M(r)}\right]\left[1-\frac{2GM(r)}{r}\right]^{-1}$$



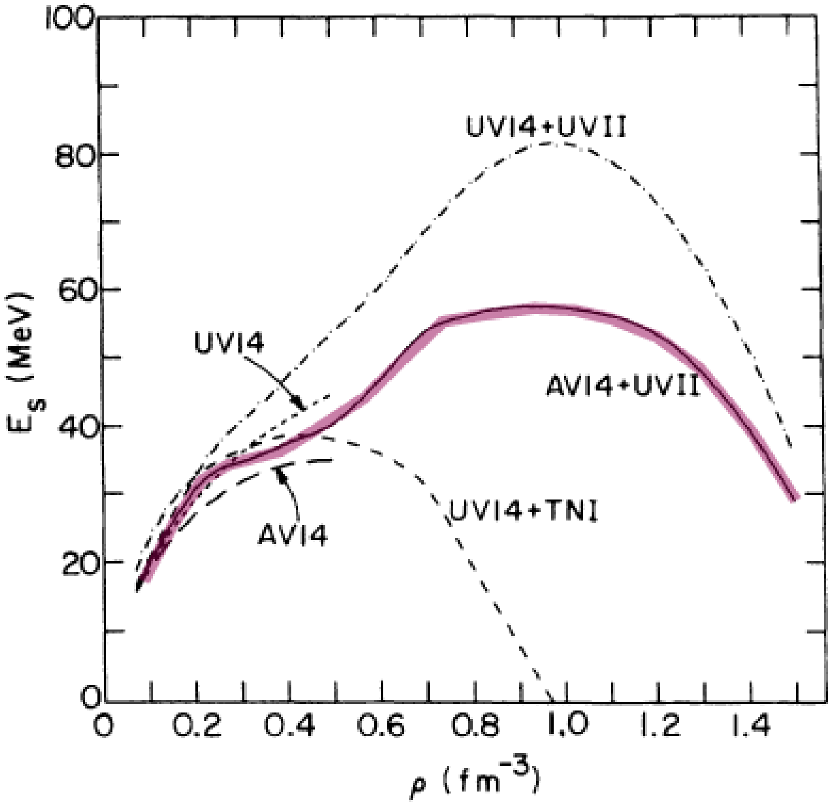
Recent observations of Neutron Stars (radius/Radii)



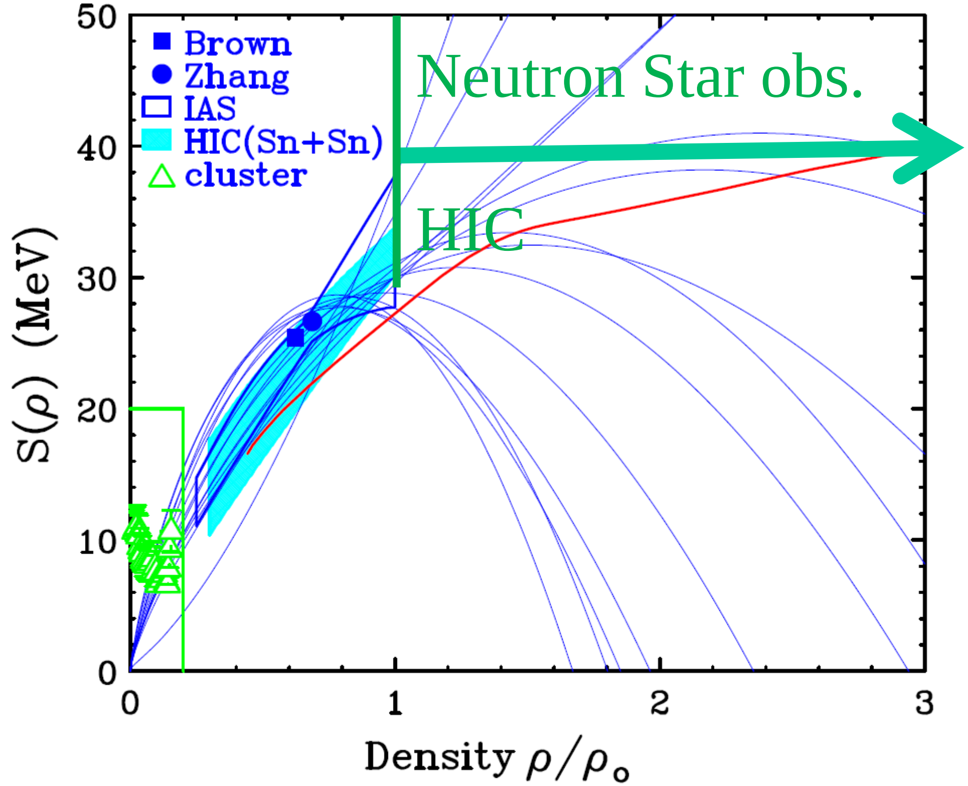
Very small Neutron Star radius rules out nearly all EOS

Density dependence of symmetry energy at supra-saturation density

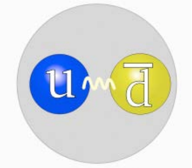
Wiringa, Fiks, & Fabrocini 1988



Skyrme interactions



Above saturation density, the symmetry energy density dependence may have a different energy dependence than Skyrme interactions.



Pion Observable

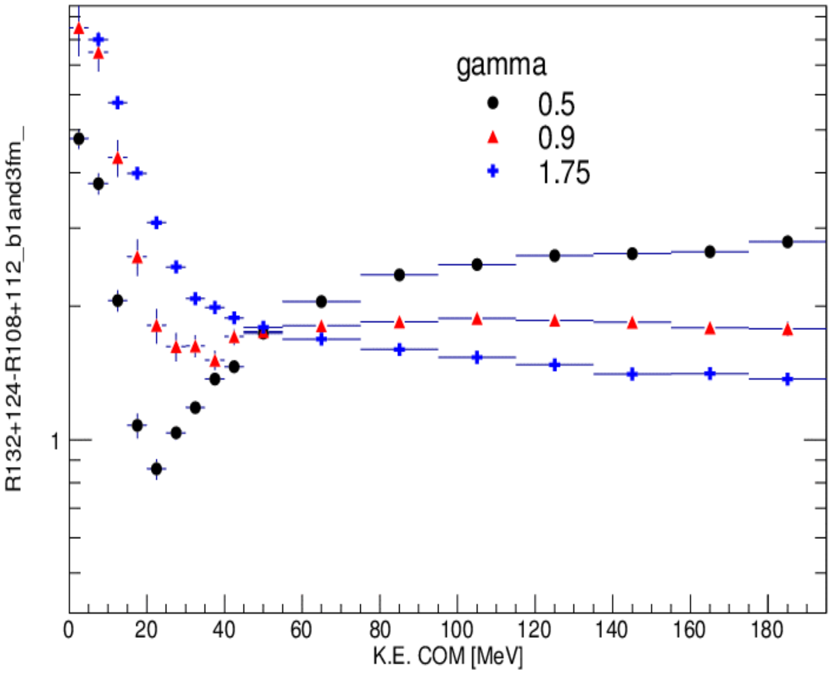
Resonance	Quarks	Δ Formation	Δ Decay
Δ^{++}	uuu	$p + p \rightarrow n + \Delta^{++}$	$\Delta^{++} \rightarrow \pi^{+} + p$
Δ^{+}	uud	$p + p \rightarrow p + \Delta^{+}$	$\Delta^{+} \rightarrow \pi^{+} + n$
Δ^{o}	udd	$n + n \rightarrow n + \Delta^{o}$	$\Delta^{o} \rightarrow \pi^{-} + p$
Δ^{-}	ddd	$n + n \rightarrow p + \Delta^{-}$	$\Delta^{-} \rightarrow \pi^{-} + n$

Pros:

- Produced in direct n p collisions – sensitive to symmetry energy
- exit in early time

Cons:

- Cross-section is low and
- Easily reabsorbed in collision medium



- Pion ratios are most sensitive compared to n/p or t/3He rtaios
- Differences of pion spectra are more sensitive than ratios of integrated yields.
- A new detector is needed to probe these observables

New Detector

Radioactive Beam:

- low luminosity ➔ large coverage

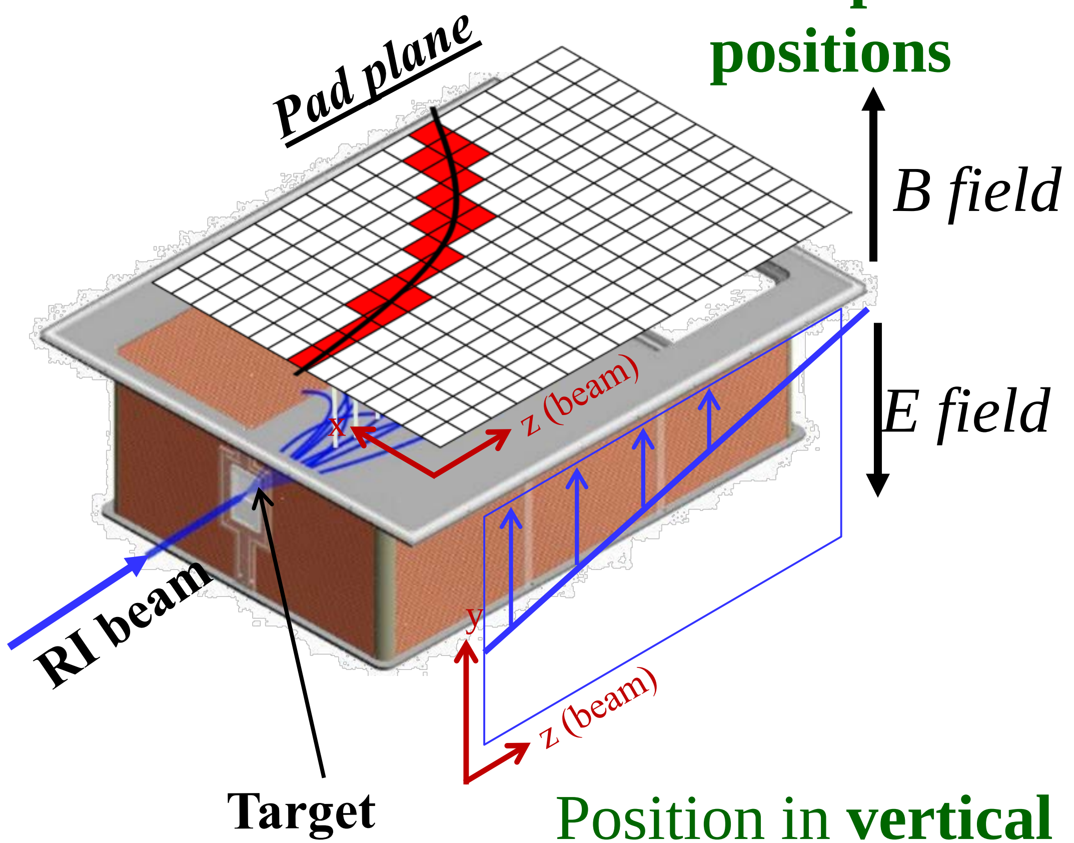
High Resolution:

- resolve many different species of produced particles
- distinguish particles by mass and charge (π^+, π^-)
- track particles in an applied magnetic field

Versatile for a wide range of experimental programs

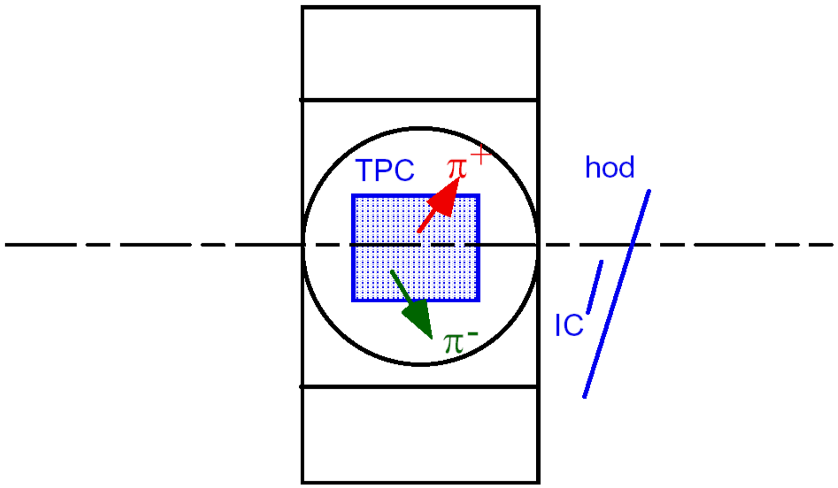
Time-Projection Chamber

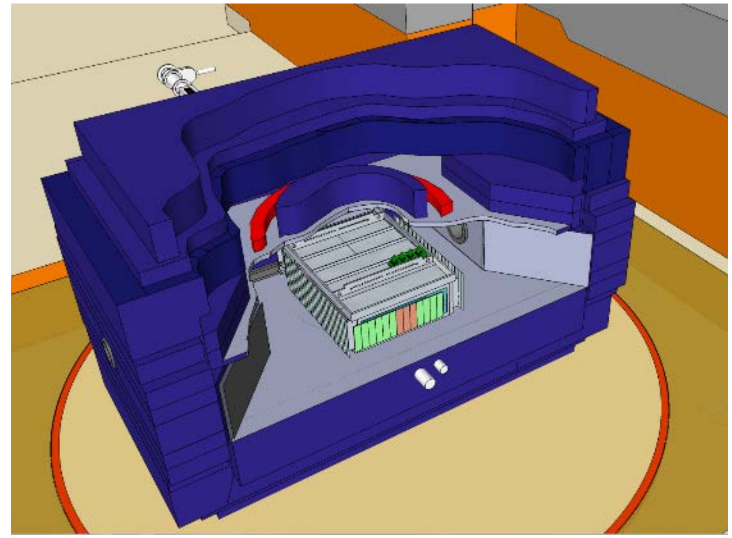
- Products from reaction ionize detector gas inside a field cage
- Electron signal is amplified by a wire plane
- The time at which the electrons hit the pads provides the third dimension



2006 March RIKEN workshop, by Bill Lynch

Possible RIKEN (EOS) program





July 23, 2014

SπRIT
collaboration

Joint US-Japan project

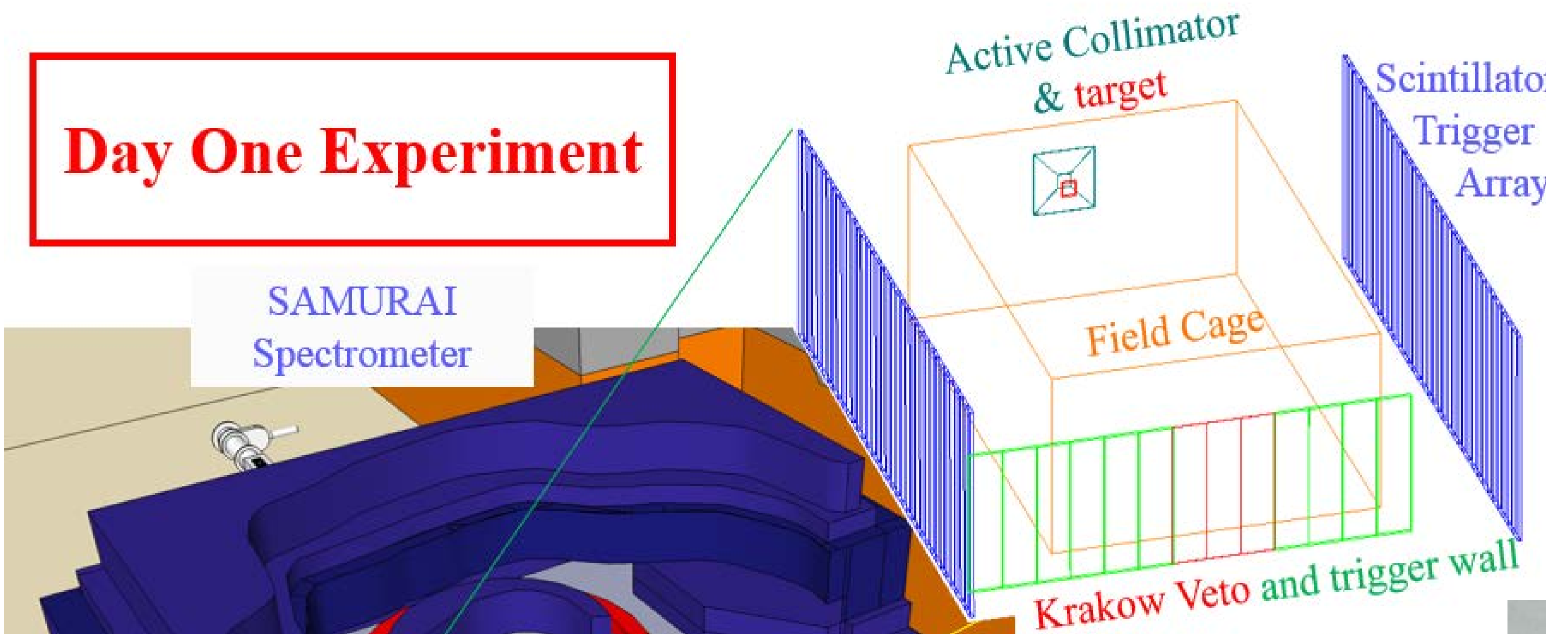
US Collaboration:
December/2008: submit DOE FOA proposal for $1.2 M
November/2009: Proposal approved (CAGRA, SAMURAI-Si, JUSEIPEN)
October/2010: Project start date; Construction & Shipment of TPC, and travel (help from JUSEIPEN)

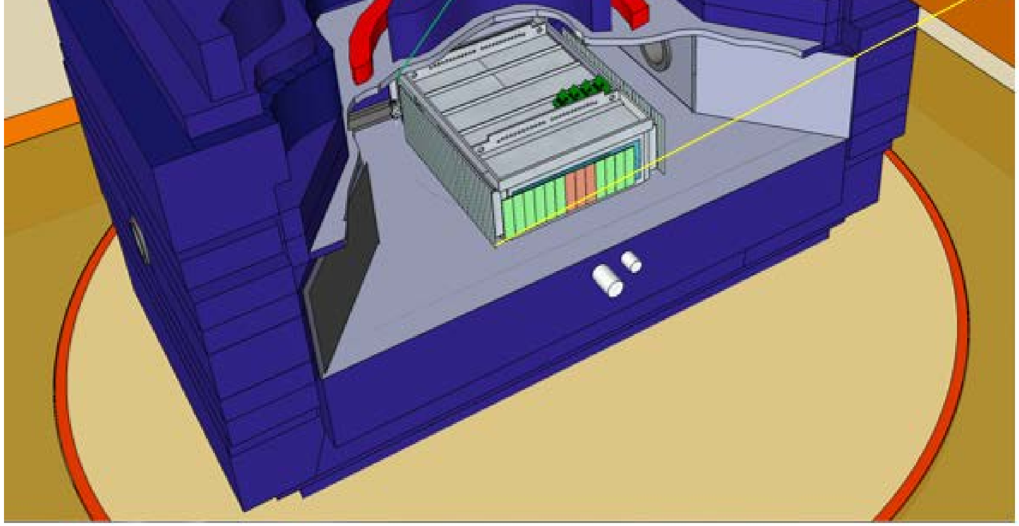
Japanese collaboration: NEXT
Part of "Material Science of Quarks"
~100 M yen for TPC electronics, Ancillary trigger scintillation array, Targets, TPC gas handling system ,TPC laser calibration system, Data acquisition

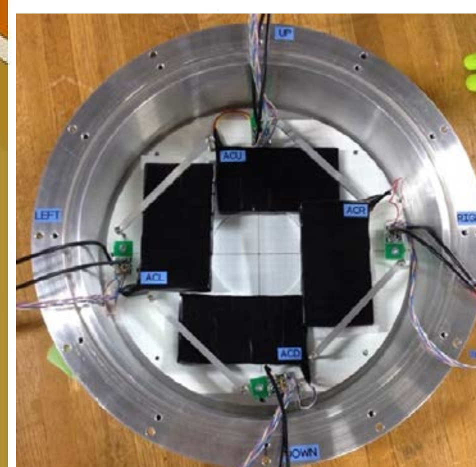
Approved experiments at RIKEN

Primary	Secondary	Target	δ_{CN}
^{238}U	^{132}Sn	^{124}Sn	**0.22**
	^{124}Sn	^{112}Sn	**0.15**
^{124}Xe	^{108}Sn	^{112}Sn	**0.09**
	^{112}Sn	^{124}Sn	**0.15**

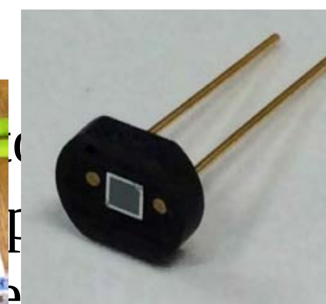
Day 1 experiment: Triggered by multiplicity and beam veto







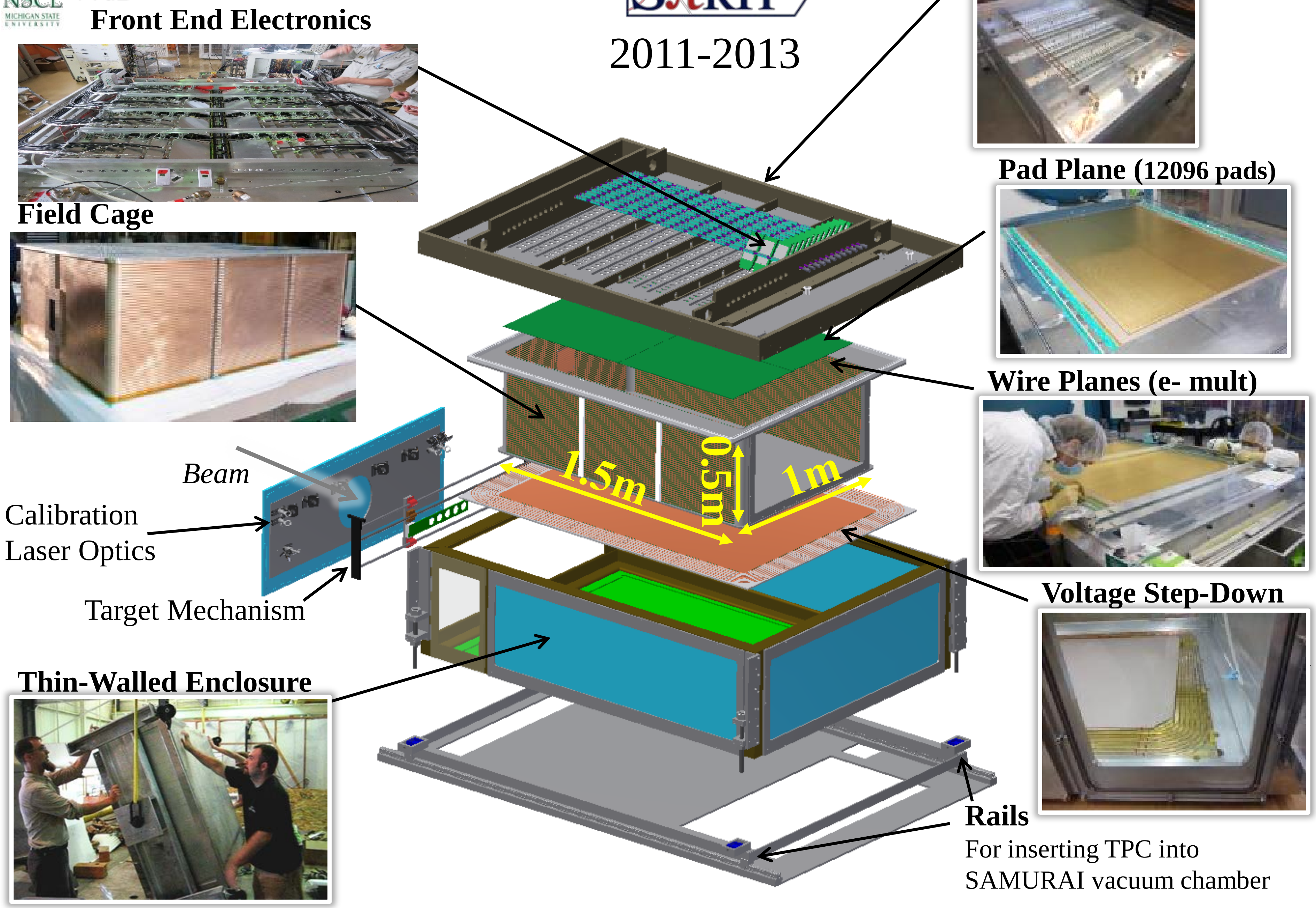
Yan Zhang, THU



MPPC ranges from 1x1 to 3x3 mm^2

Anatomy of SπRIT

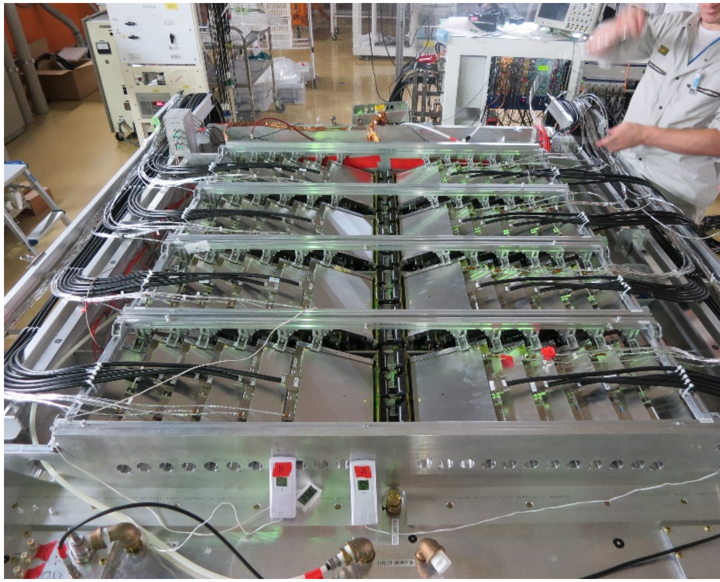
2011-2013



May, 2013

Feb, 2014

July, 2014



August, 2015

Commissioning of SπRIT outside SAMURAI

U.S. DEPARTMENT OF ENERGY
Office of Science

SπRIT

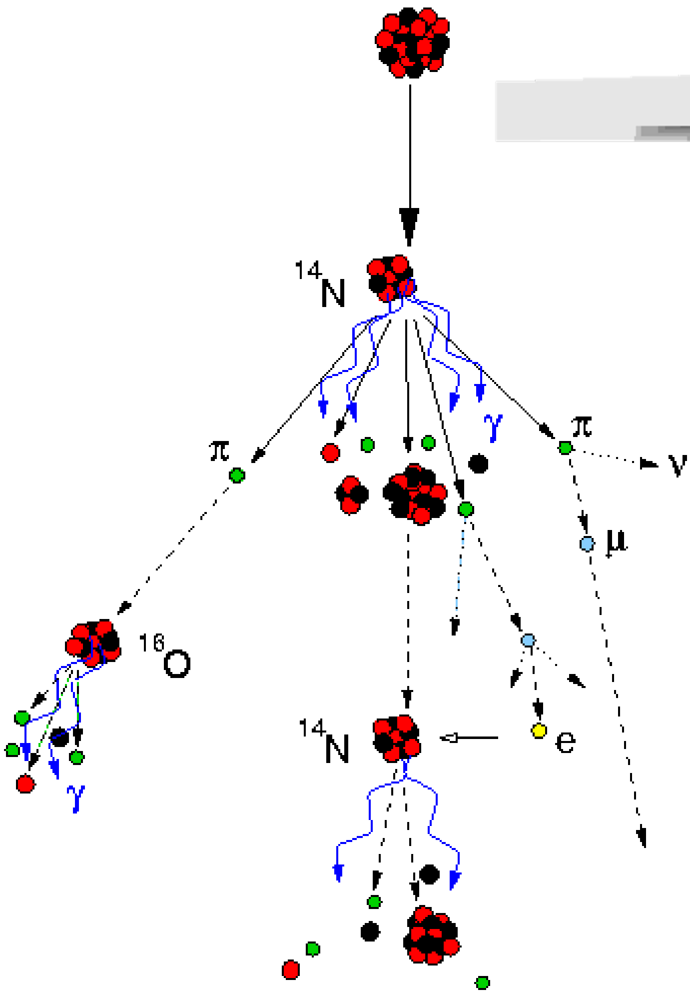
文部科学省
MEXT

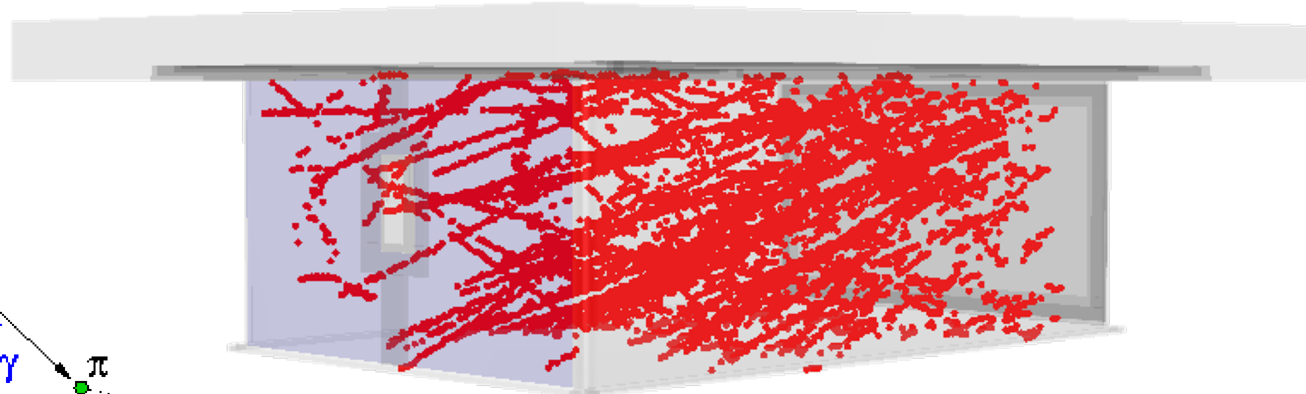
On Site Experimenters (10/23 & 29)

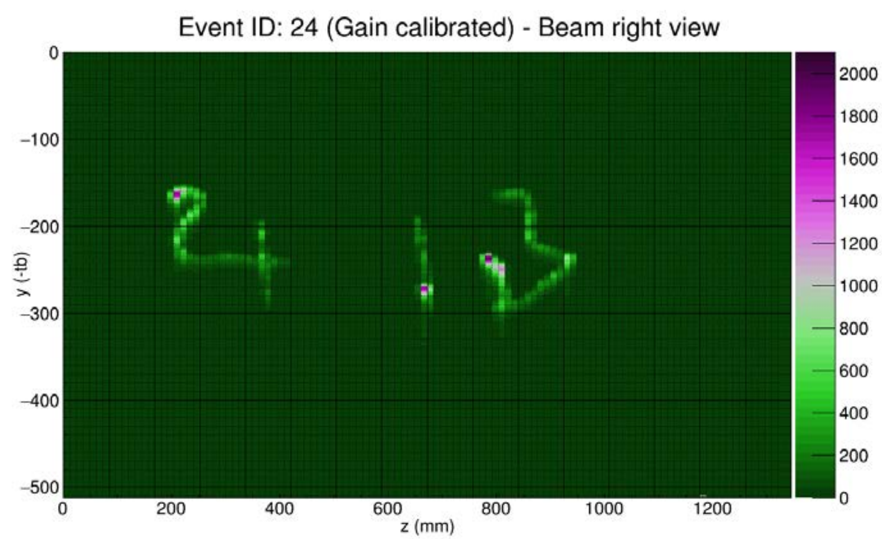
J. Barney (MSU)
G. Cerizza (MSU)
J. Estee (MSU)
*T. Isobe (RIKEN)**
G. Jhang (Korea U)
M. Kaneko (Kyoto U)
Y. Kim (RISP)
M. Kurata-Nishimura (RIKEN)
P. Lasko (IFN, Krakow)
H. Lee (RISP)
J. Lee (Korea U)
J. Lukasik (IFN, Krakow)
*W. Lynch (MSU)**
*T. Murakami (Kyoto U)**
P. Pawlowski (IFN, Krakow)
K. Pelczar (IFN, Krakow)
C. Santamaria (MSU)
D. Suzuki (RIKEN)
*B. Tsang (MSU)**
Y. Zhang (Tsinghua U)

*spokesperson

Commissioning of SπRIT Cosmic Events October, 2015







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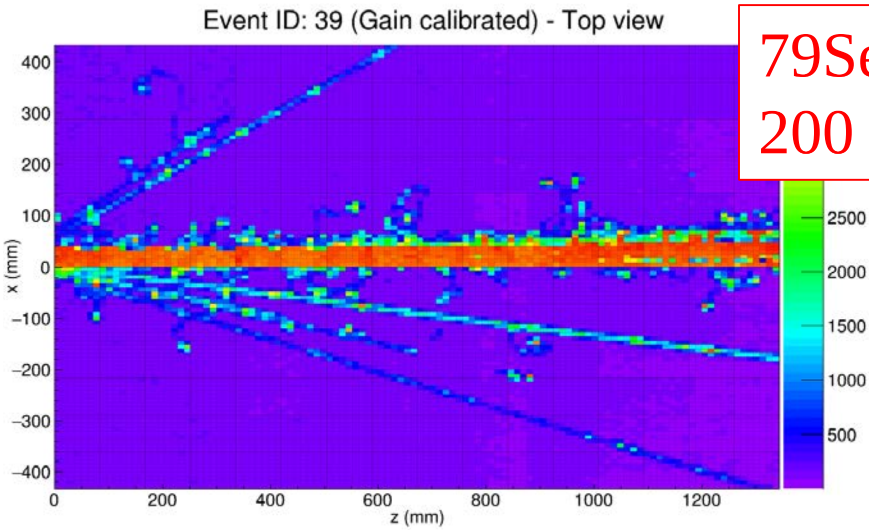
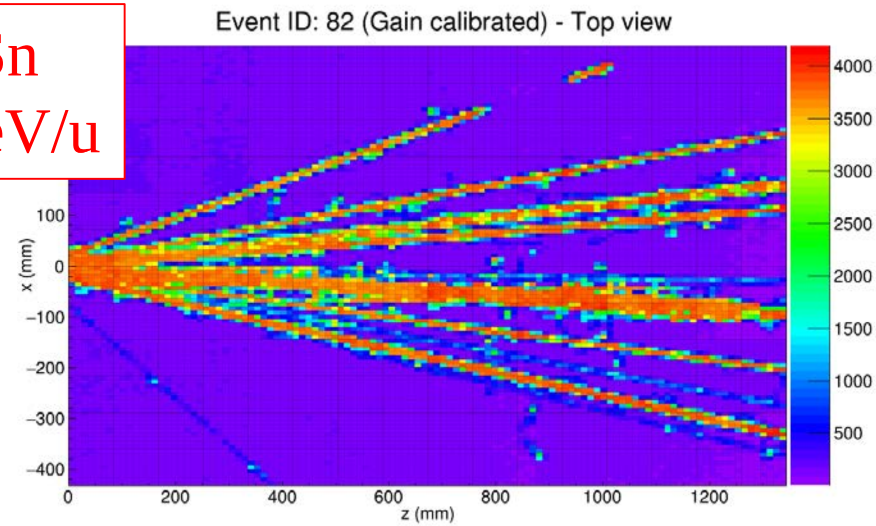
MINISTRY OF EDUCATION, CULTURE, SPORTS, SCIENCE AND TECHNOLOGY-JAPAN

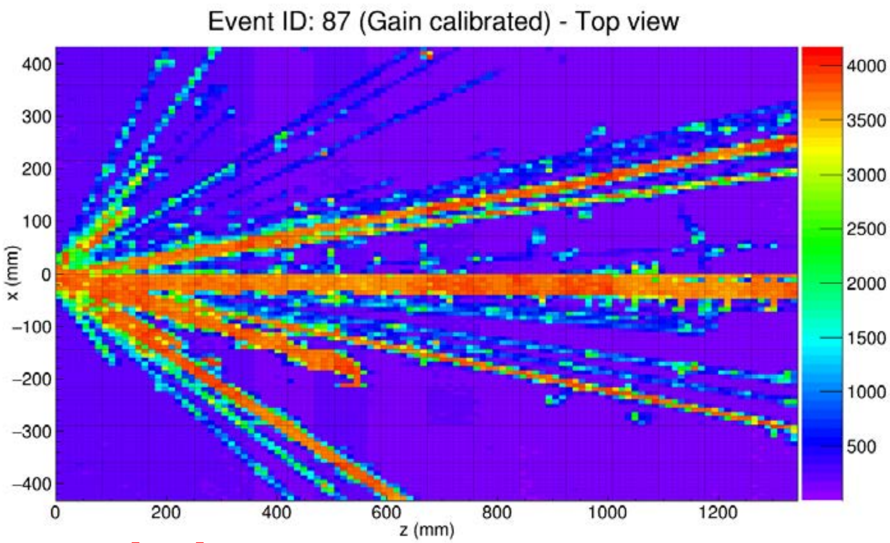
79Se+Sn
200 MeV/u

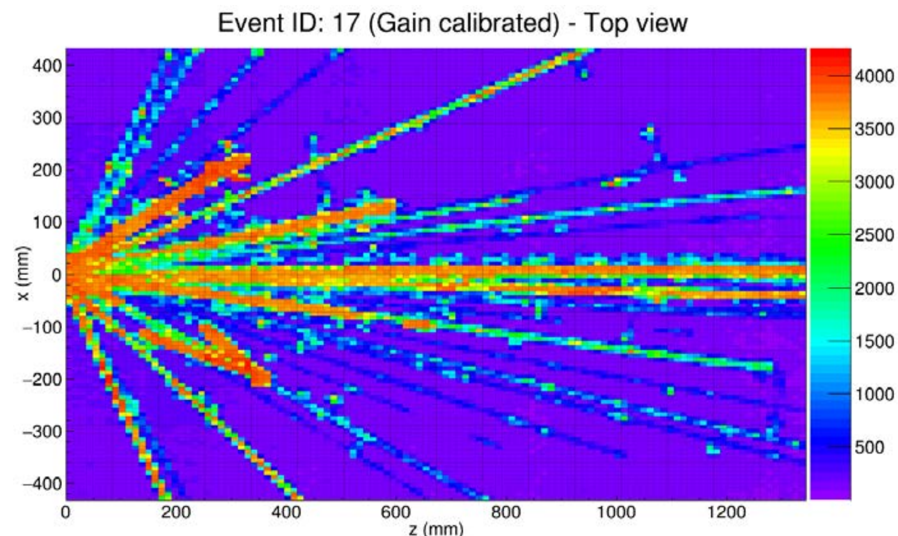




Event from Kyoto multiplicity>0 trigger + beam veto

multiplicity>1





multiplicity>2

Event from Katana central trigger + beam veto

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文部科学省
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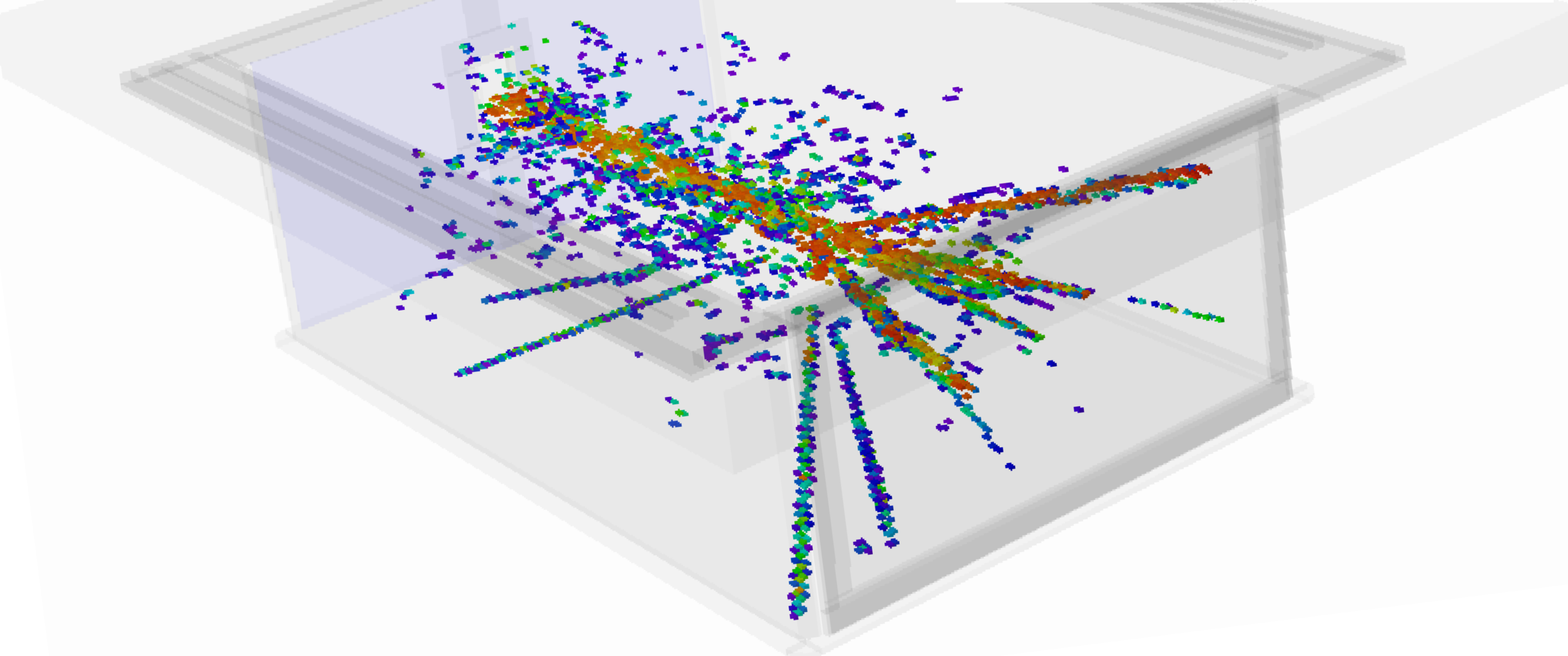
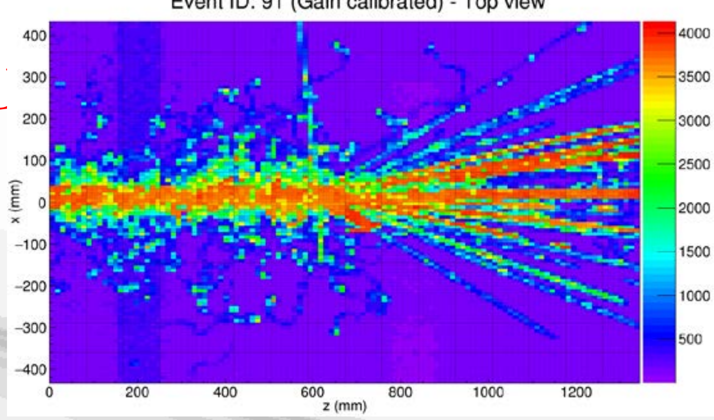
October 29, 2015

Commissioning of SπRIT outside SAMU





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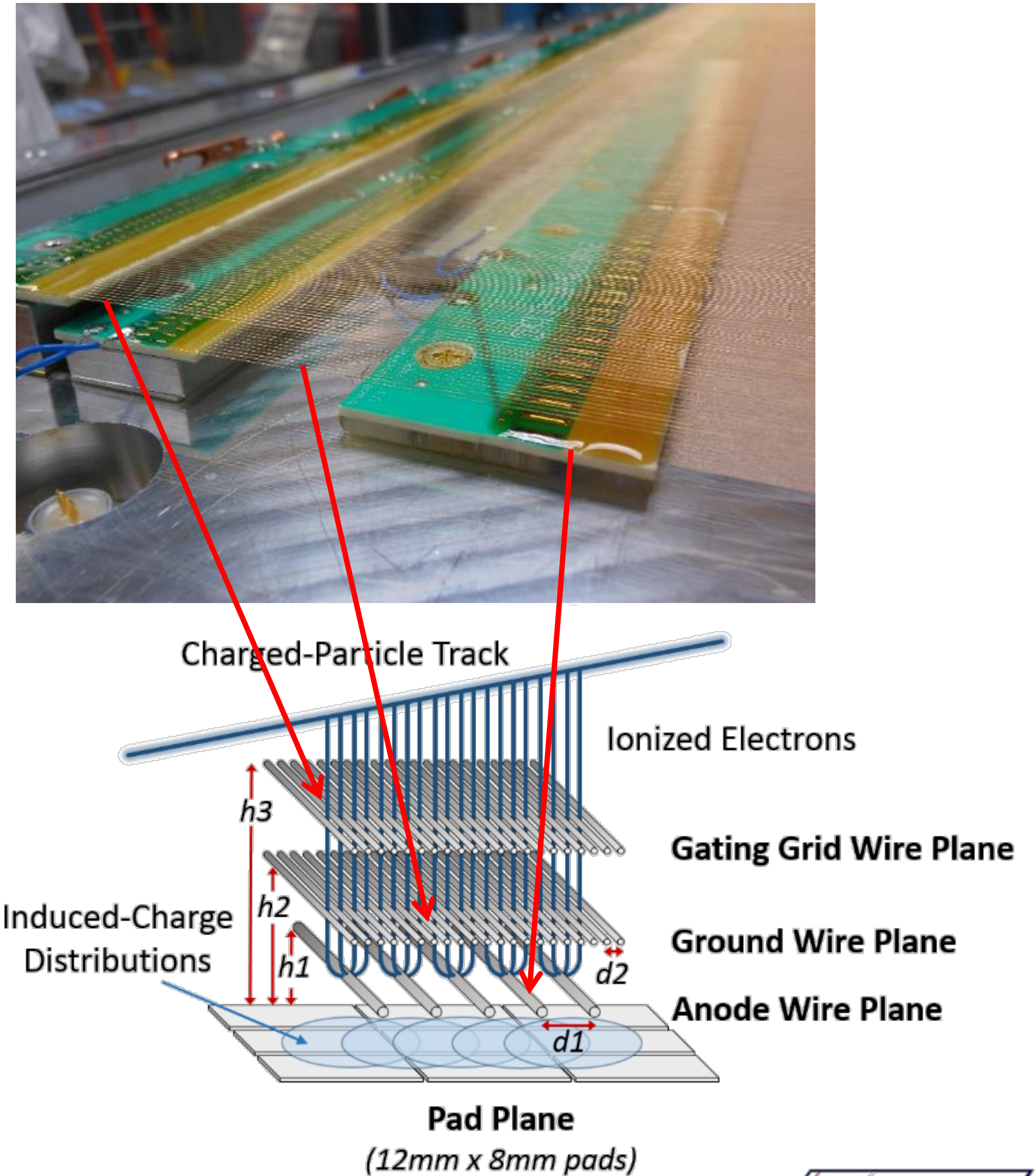
October 29, 2015

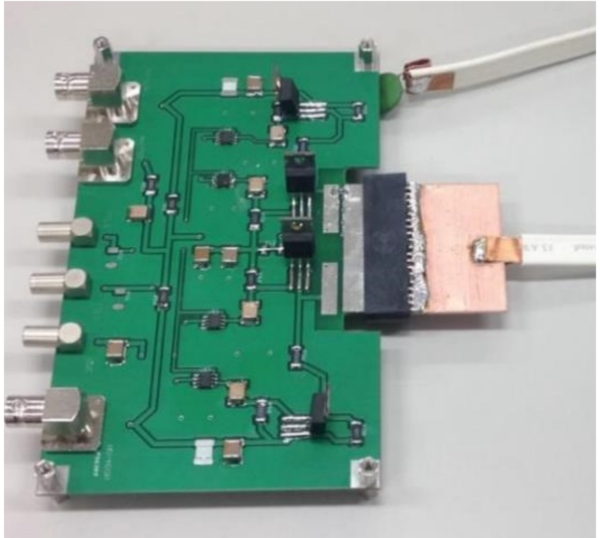
Wire planes

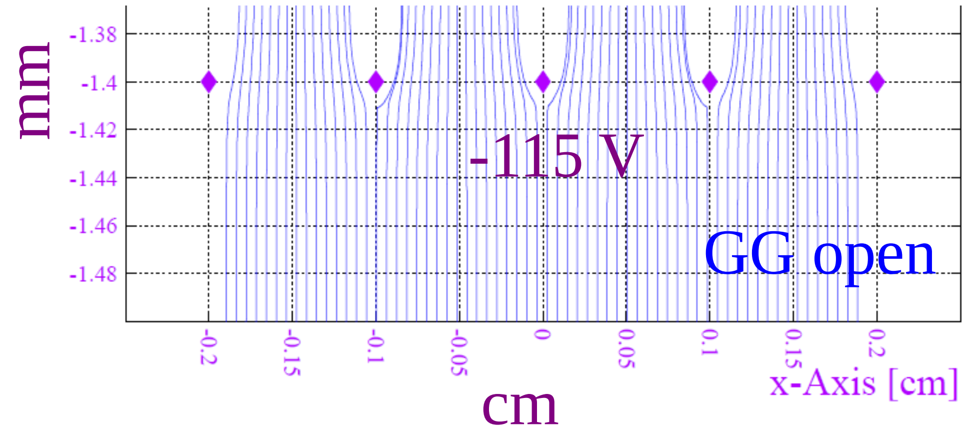
- Anode and ground plane creates avalanche region for electrons
- Anode plane induces image charge on the pad plane
- Gating grid closes off amplification region when not triggered

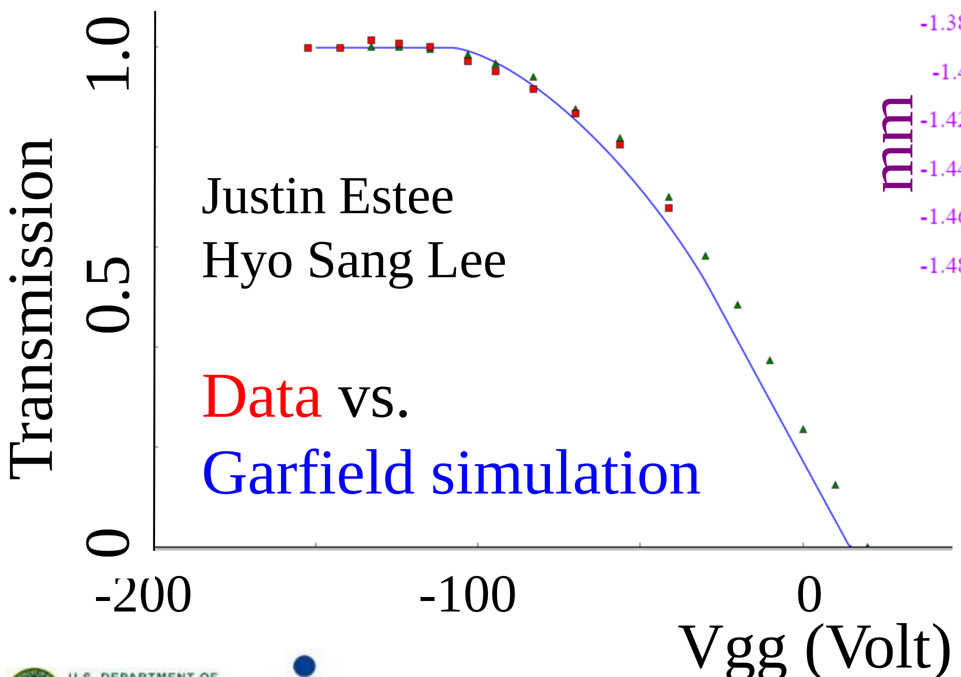
Plane	height (mm)	pitch (mm)	diameter(μm)
Anode	4.05	4	20
Ground	8.1	1	75
Gating grid	14	1	75

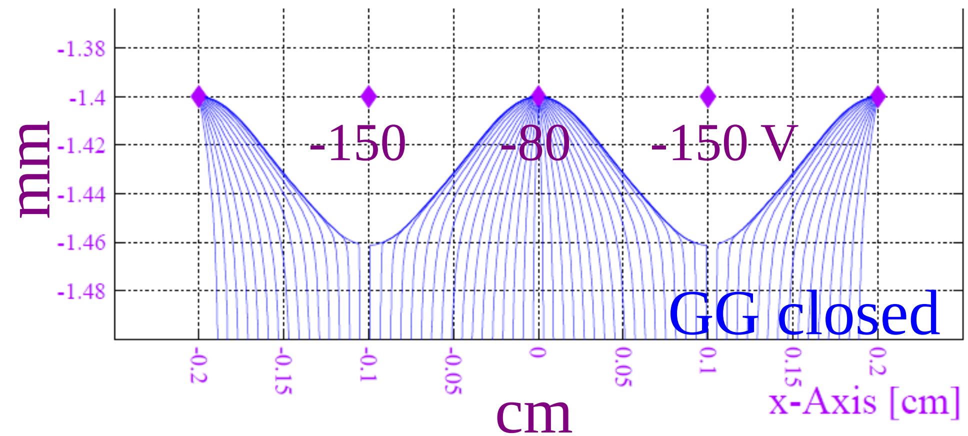


Gating grid (Suwat Tangwancharoen)



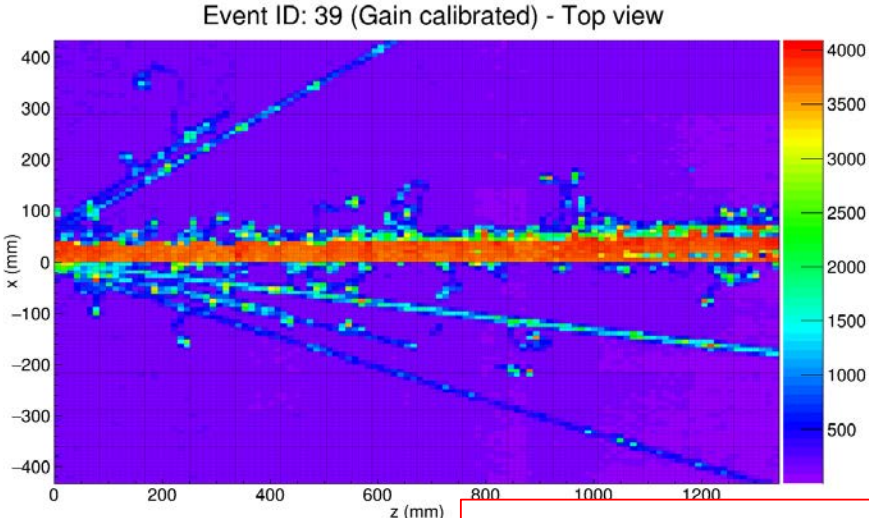


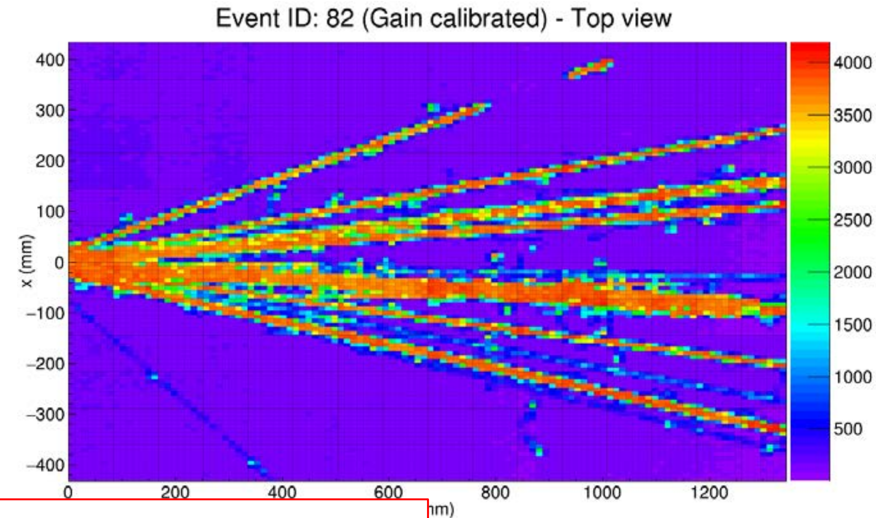




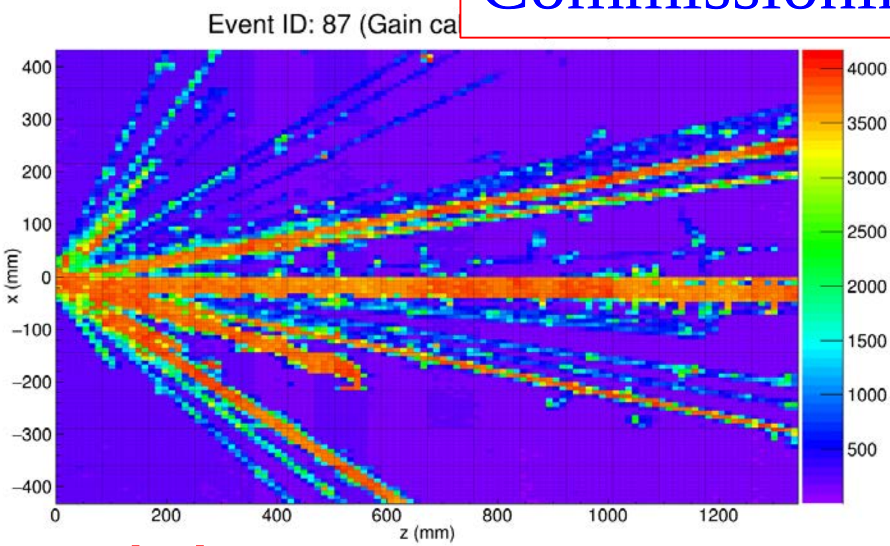
Yao-Feng Zhang, BNU
S. Tangwanchoren
J. Justin

Challenge I: Analysis of Commissioning Data (4 TB)

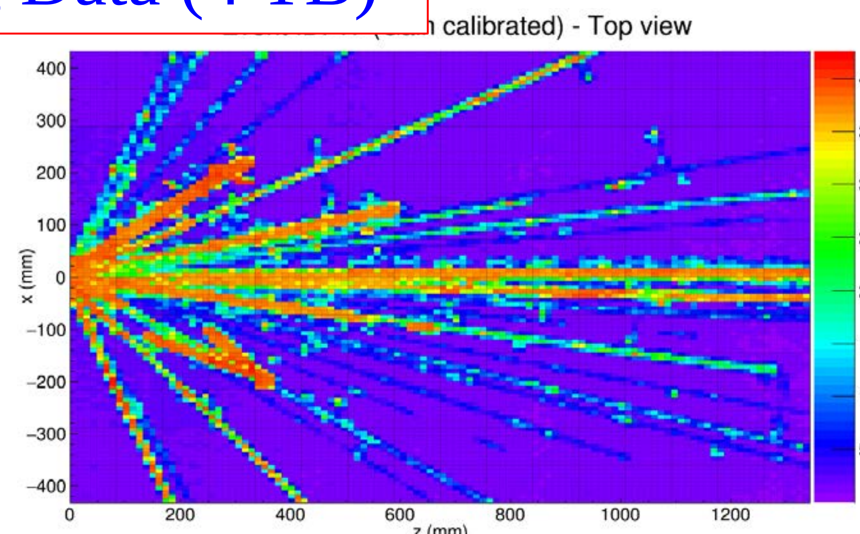




Event from Kyoto trigger + beam vet



multiplicity>2



Event from Katana central trigger + beam veto

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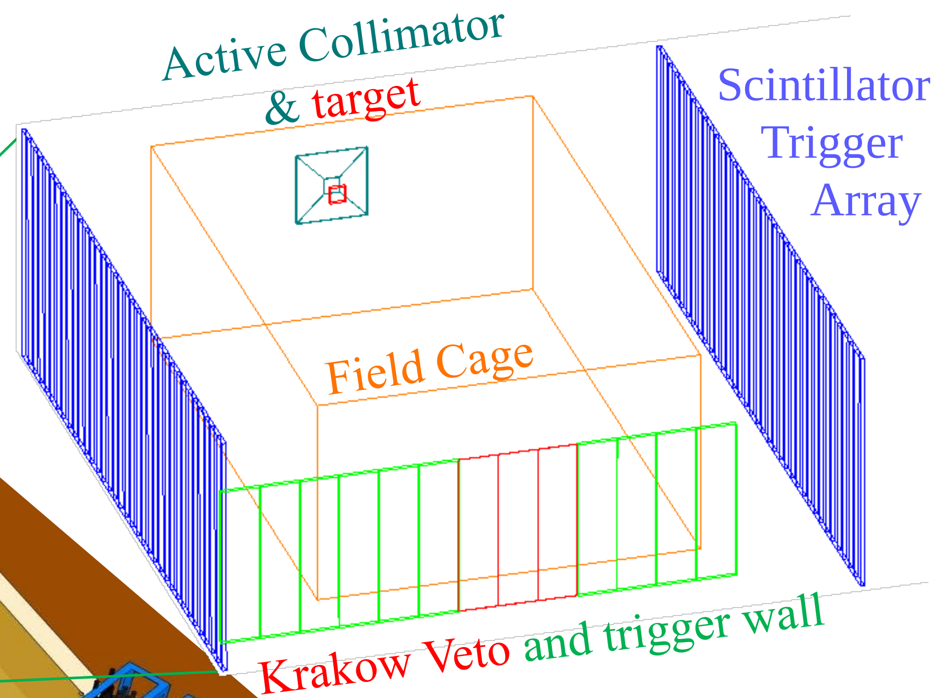
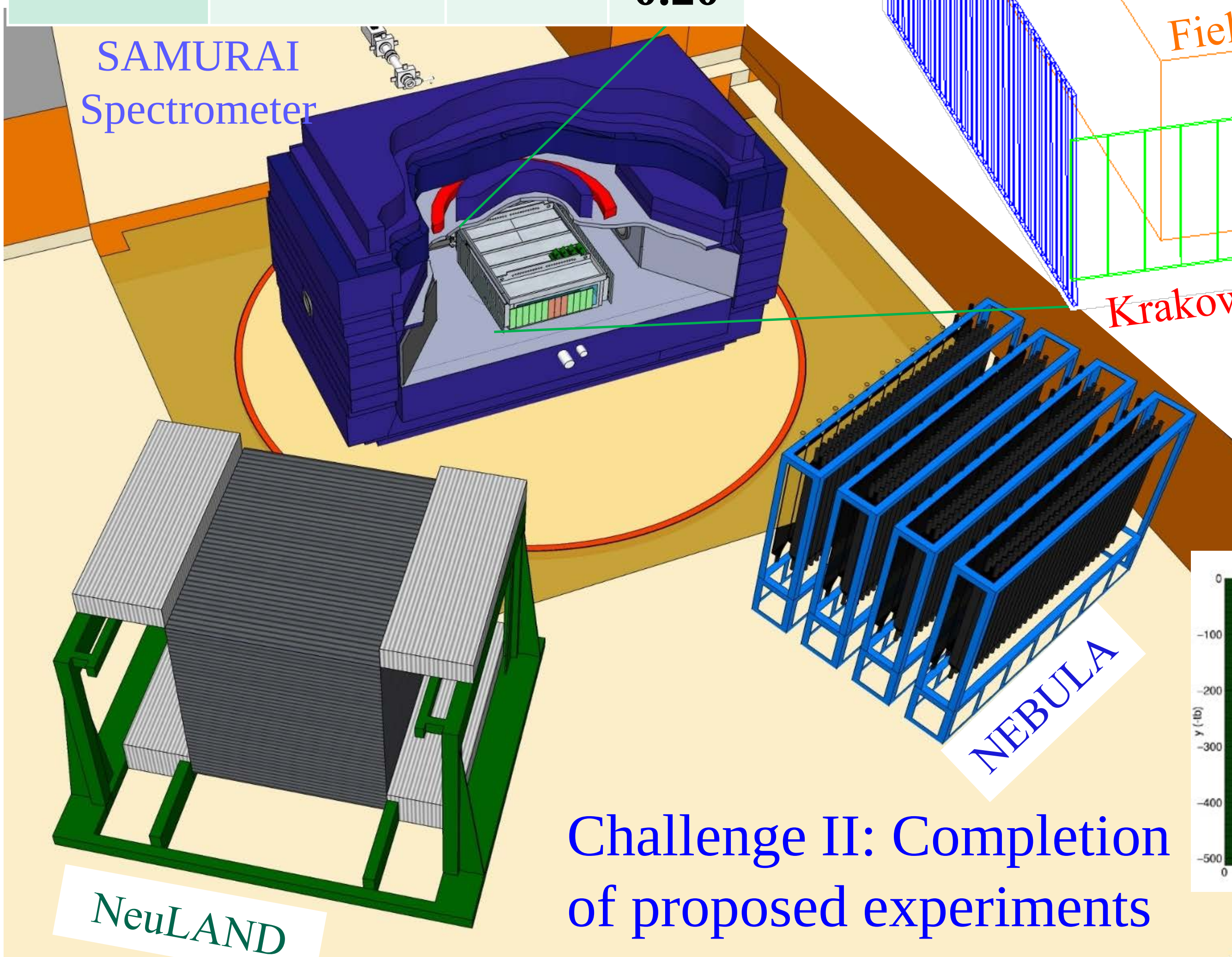
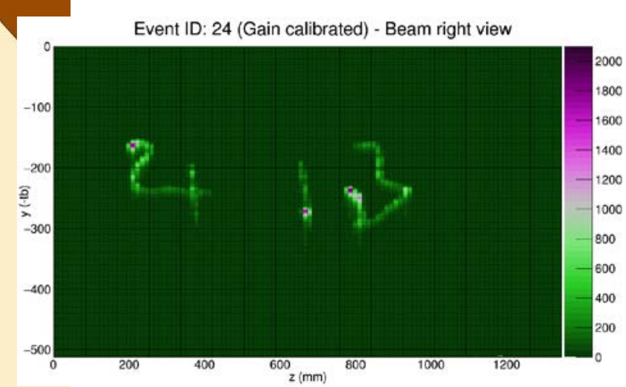
Primary	Secondary	Target	δ
^{238}U	^{132}Sn	^{124}Sn	**0.22**
	^{124}Sn	^{112}Sn	**0.15**
^{124}Xe	^{108}Sn	^{112}Sn	**0.09**
	^{112}Sn	^{124}Sn	**0.20**





Challenge II: Completion of proposed experiments



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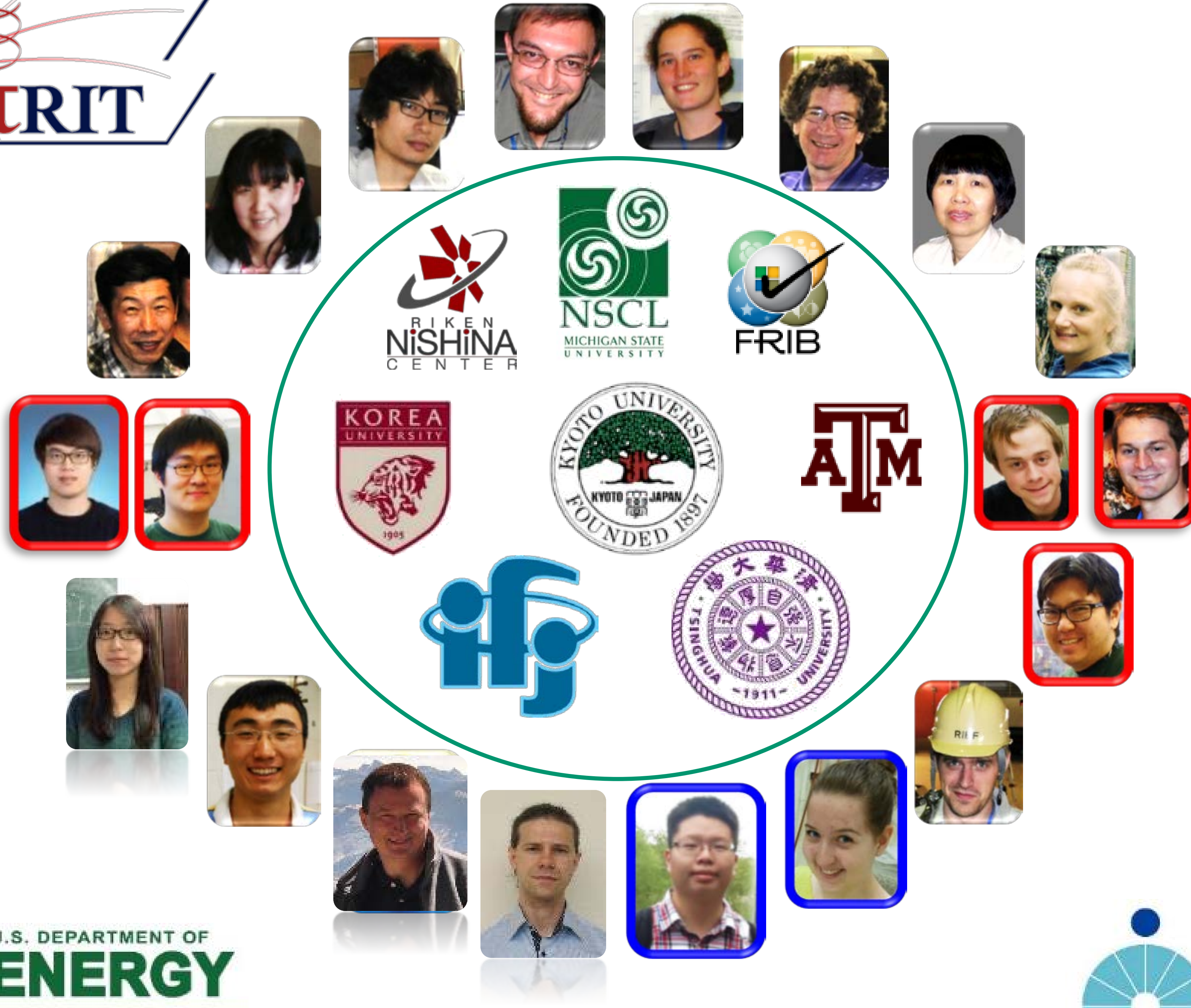

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Commissioning of SπRIT outside SAMURAI

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On Site Experimenters (10/23 & 29)

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G. Cerizza (MSU)
J. Estee (MSU)
*T. Isobe (RIKEN)**
G. Jhang (Korea U)
M. Kaneko (Kyoto U)
Y. Kim (RISP)
M. Kurata-Nishimura (RIKEN)
P. Lasko (IFN, Krakow)
H. Lee (RISP)
J. Lee (Korea U)
J. Lukasik (IFN, Krakow)
*W. Lynch (MSU)**
*T. Murakami (Kyoto U)**
P. Pawlowski (IFN, Krakow)
K. Pelczar (IFN, Krakow)
C. Santamaria (MSU)
D. Suzuki (RIKEN)
*B. Tsang (MSU)**
Y. Zhang (Tsinghua U)

**spokesperson*

Welcome to

6th international symposium on nuclear symmetry energy

(NuSym2016)

Tsinghua University, Beijing, Jun. 13-17, 2016