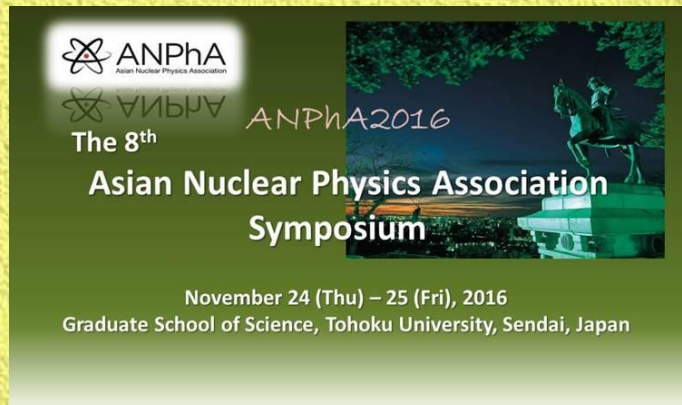
Nuclear Physics Related Research Activities in Taiwan

- **Overview & Highlights:**
  Who, What, Where, How

Henry T. Wong / 王子敬

2016/11

Academia Sinica / 中央研究院



"Nuclear Physics" Eco-system in Taiwan

- (Relatively) Small community
- ***NOT*** an exclusive community with exclusive (secured) budget
- Mix well (part of) with atomic / particle / astro physics , depending on subjects (both theory & experiments)
- Both domestic programs and participation in international projects, world-wide

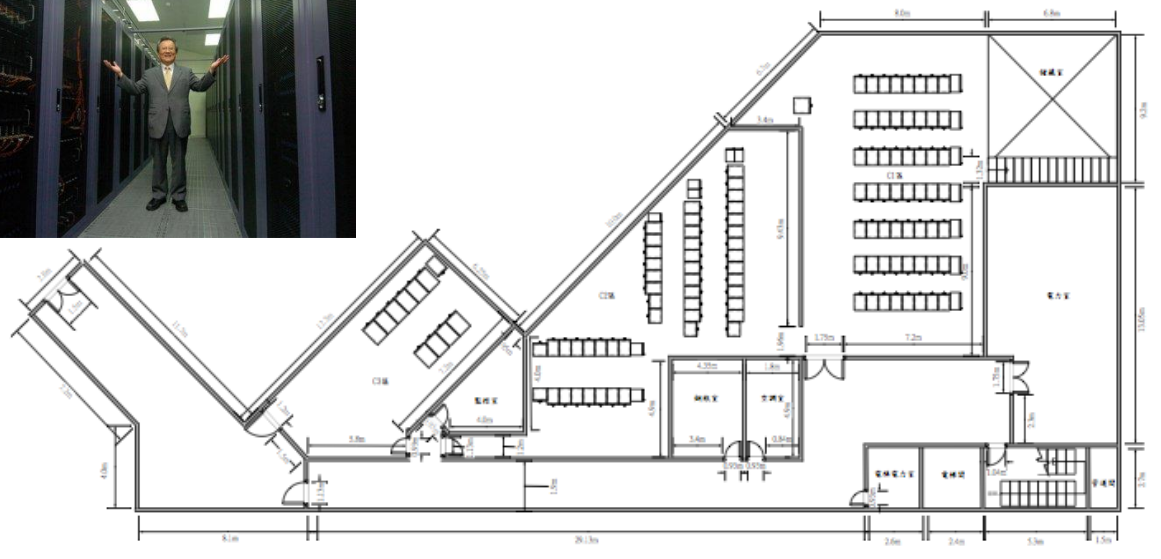
Related Particle/Astro Physics Program/Facilities

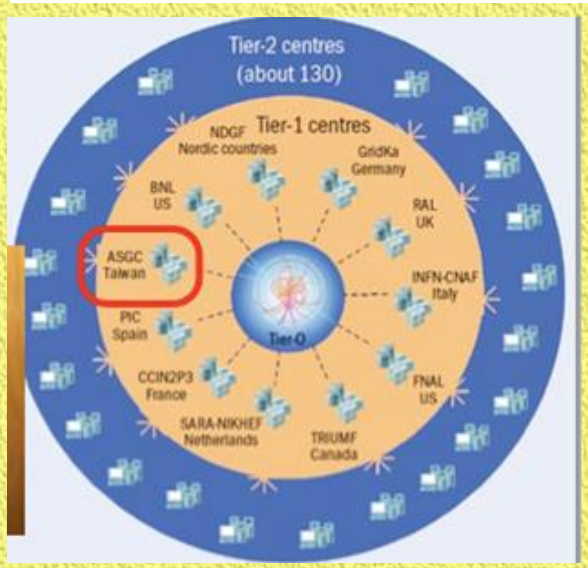
- Collider Experiments : ATLAS/CMS @ LHC @ CERN *(AS, NTU, NCU, NTHU …)*
  - Tier-1 GRID Computing
- B-Factory : Belle @ KEK (NTU)
- Rare K-Decays : KOTO @ J-PARC *(NTU)*
- Astroparticle Physics: AMS @ ISS *(AS, NCU, NCKU…)*
  - Asia Payload Center
- MeV Gamma-Ray Astronomy : NCT, COSI @ Balloon *(NTHU)*
- Neutrino Telescope : ANITA/ARA @ South Pole *(NTU)*
- Low Energy Nuclear Physics Accelerators : nuclear industry, material science, radiation damage etc… *(INER, NTHU)*

ASGC Computing Center

- **Total Capacity**
  - 2MW, 400 tons AHUs
  - 93 racks
  - ~ 800 m^2
- **Resources**
  - 20,000 CPU Cores
  - 12.5 PB Disk
- **Rack Space Usage (Racks)**
  - AS e-Science: 48.6 (52.3%)
  - RCEC: 11.1 (11.9%)
  - IPAS: 5.5 (5.8%)
  - ASCC: 3.3 (3.6%)
  - IES: 2.5 (2.6%)
  - Free: 22.2 (23.9%)

Cooling Power : CPU Power
1 : 2





- **LHC-Tier 1 Center**
- **Player in Development of e-Science @ national & international stages**

!!! July 4, 2012

- ROC President Ma, Defense Minister Kao, Academicians Ting, Y.T. Lee and S.C.Lee attending the ceremony of AMS operation center
- S. Haino reported on AMS

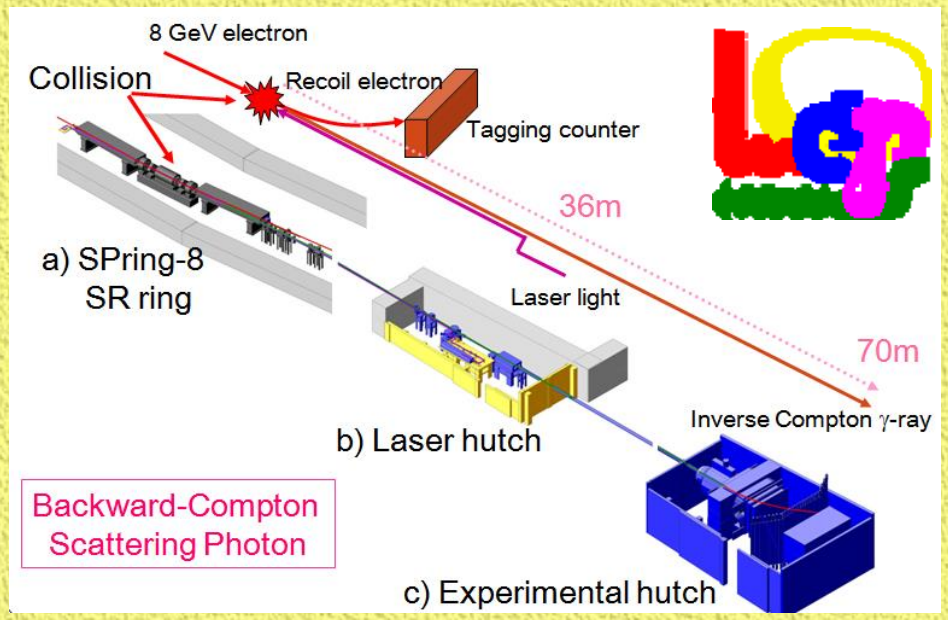
Hadron/Nucleon Physics

[W..C. Chen @ AS ; R.S. Guo @ NKNU]

(Nuclear Physics Background)

participation in international programs based at facilities world-wide

LEPS @ SPring-8, Japan (1999 ~)
Probing Nucleons by 2.5 GeV Polarized Photon

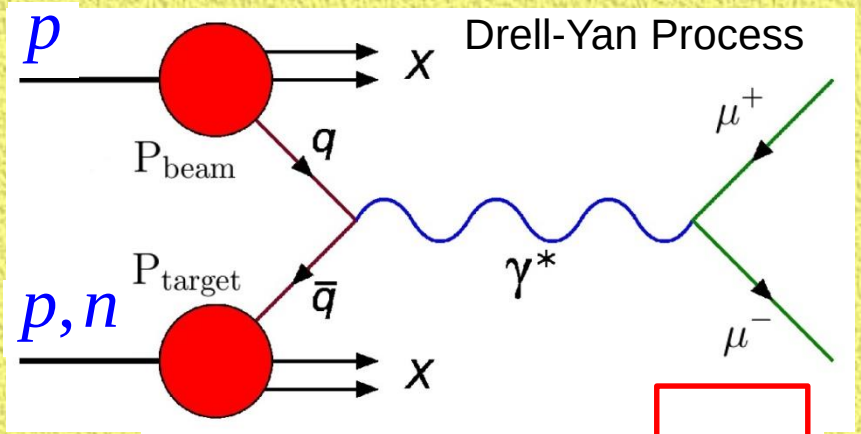


Characterize photo-production of strangeness from protons and deuterons near threshold at low energies:

- ☑ $\gamma N \rightarrow \phi N$
- ☑ $\gamma N \rightarrow \Lambda(1520)\, N$
- ☑ $\gamma N \rightarrow \Lambda(1405)\, N$

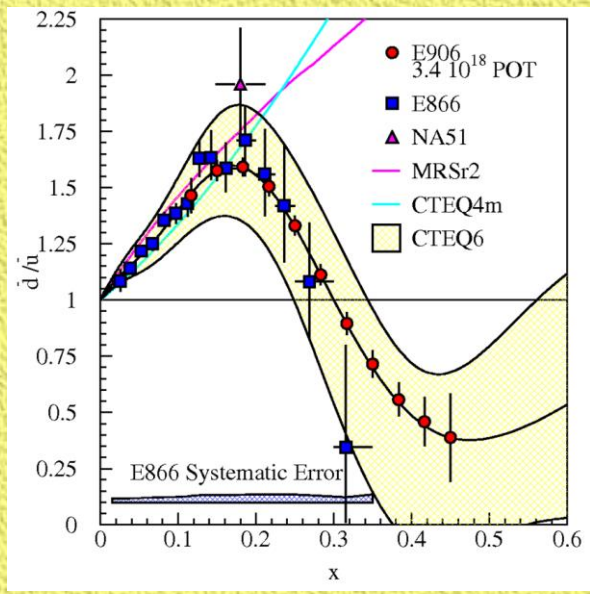
SeaQuest/E906 at FNAL (2009 ~) : Probing Nucleons by 120-GeV Protons

- ☑ **Primary physics goal:**
  Flavor-asymmetry in light sea-quark
  $\bar{d}/\bar{u}(x)$ of protons at x=0.15-0.45.
- ☑ **Contributions from Taiwan team:**
  - Readout electronics
  - FPGA dimuon trigger system
  - DAQ
  - Physics Analysis:
    - ☑ Suppression of J/psi production in nuclear medium.
    - ☑ Quark energy loss in moving through nuclear medium.
- ☑ **Status:** **Data Taking 2012-2017**

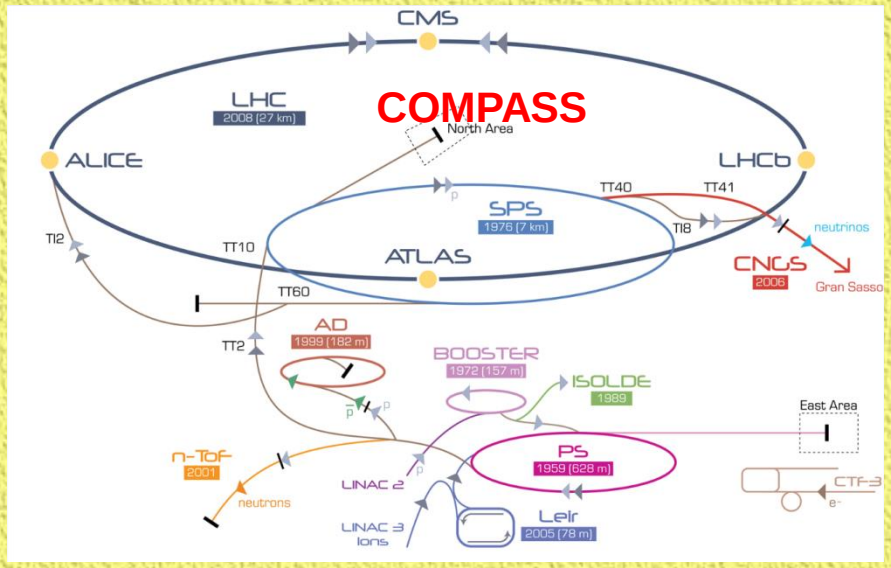


$$\left.\frac{\sigma^{pd}}{2\sigma^{pp}}\right|_{x_b \gg x_t} \approx \frac{1}{2}\left[1 + \frac{\bar{d}(x_t)}{\bar{u}(x_t)}\right]$$

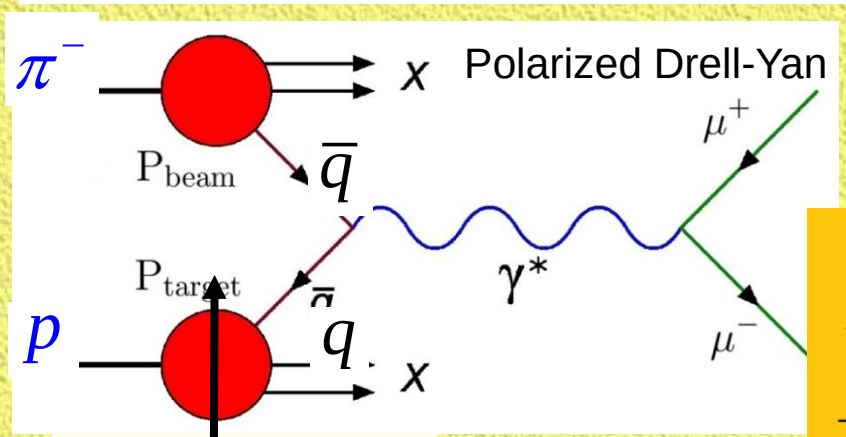
Expected sensitivity of total statistics

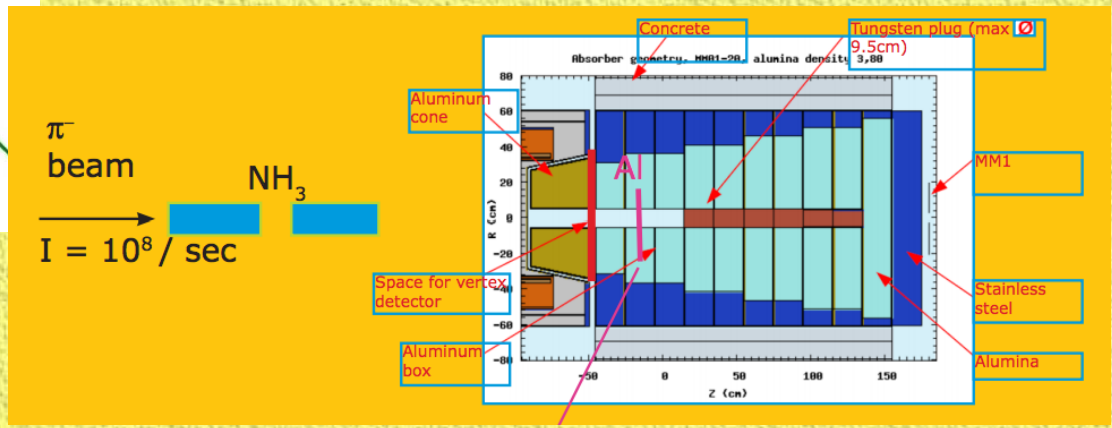


COMPASS @ CERN (2012 ~) : Probing Nucleon TMD by 190-GeV pions



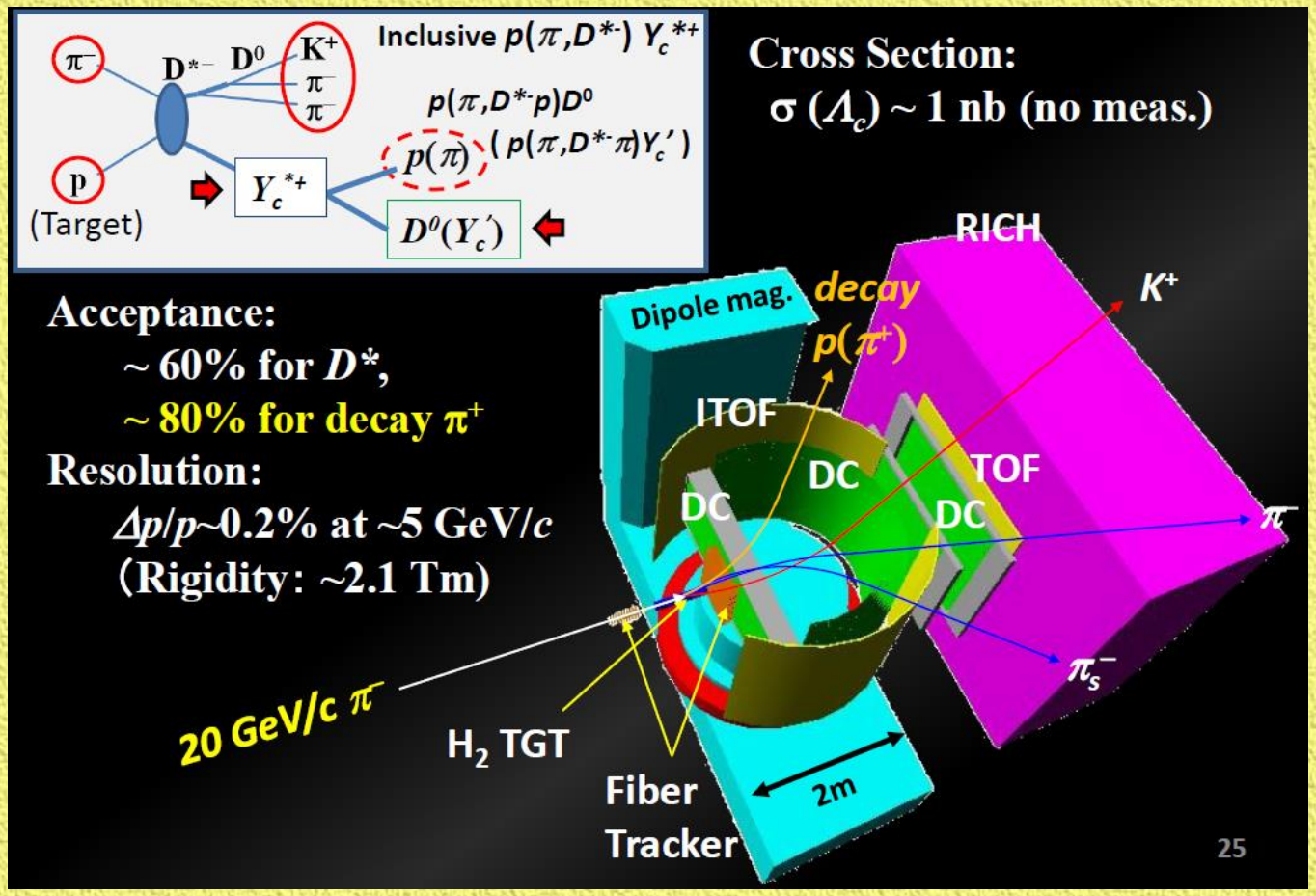
- **Primary physics goal**: Transverse-momentum-dependent (TMD) Sivers functions $f_{1T}^{\perp}(x, k_T)$ of valence quarks of protons ; Generalized Parton Distributions -- in polarized Drell-Yan Process
- **Contributions from Taiwan team**:
  - Readout electronics (FEM, DCM) of new drift chamber DC5
  - Monte-Carlo and feasibility study
  - **Physics Analysis:**
  - ☑ Sivers function of nucleon valence quarks from Drell-Yan process.
  - ☑ Drell-Yan process and J/psi production close to exclusive production limit.
- **Status : Data Taking (2015-2018)**





J-PARC E50 Experiment *[π @ HI-P BL]*
(Charmed Baryon Spectroscopy)

Stage-1 approved by J-PARC PAC-18, August 12, 2014.



Exclusive Drell-Yan measurement with 10-20 GeV π^- beam

Precision laser spectroscopy for Nuclear Size

(Y.W. Liu @ NTHU)

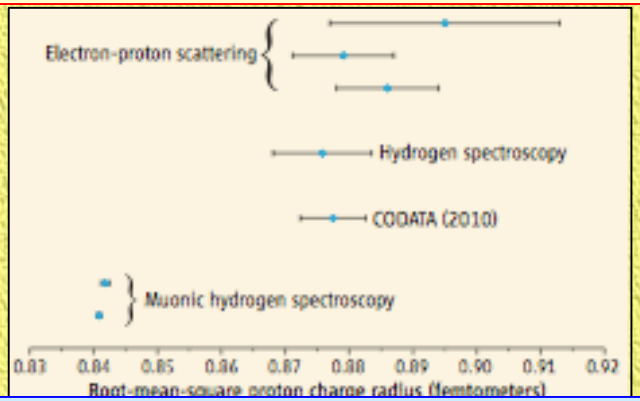
[Atomic Physics Traditions]

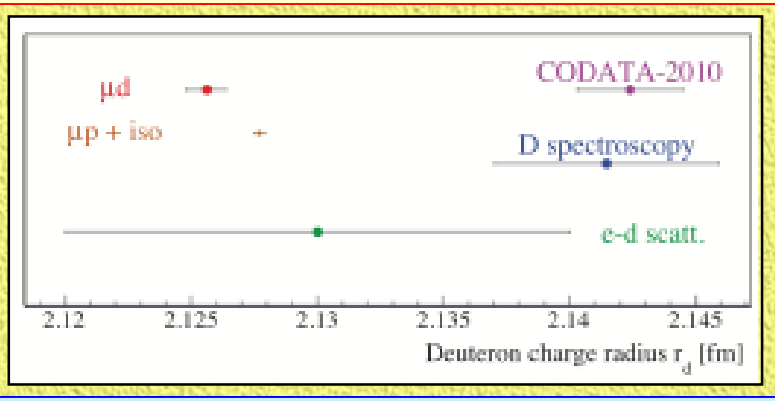
Charge Radius Experiment with Muonic Atoms —International CREMA collaboration

[12 institutes, 6 countries]

- ☑ **Muon facility at PSI, Switzerland**
- ☑ **Take advantage of the larger mass of muon, laser spectroscopy of muonic atoms is a powerful tool to understand various nuclei with much higher precision.**
- ☑ **Experiments on proton, deuteron, alpha particle and ^{3}He nucleus have been performed.**

- ☑ experimental results of proton charge radius, deduced from muonic hydrogen, are 7σ away from CODATA. This is called "Proton Size Puzzle" now.(Nature 2010, Science 2013)
- ☑ Muonic deuterium spectroscopy also showed a smaller deuteron size. The "Puzzle" was therefore amplified. The ratio of discrepancy μp/μd =1.3(2) is expected by some Beyond Standard Model theories.(Science 2016)
- ☑ Ongoing : muonic helium ; hyperfine splittings …..





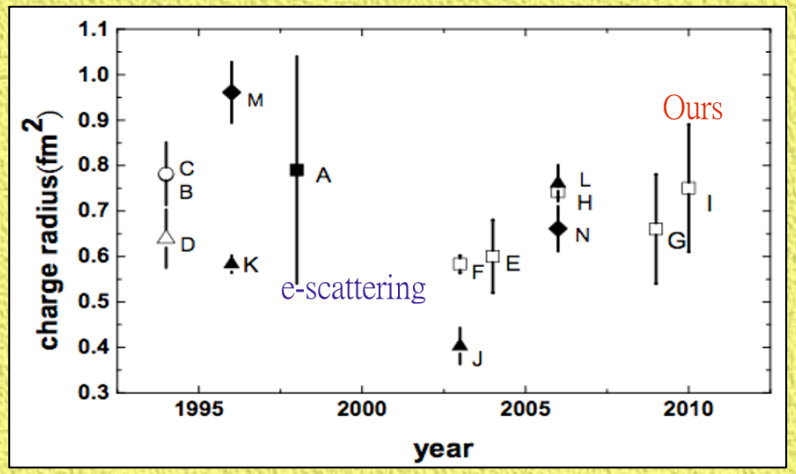
- These results jeopardize the current CODATA system, including Rydberg constant.
- There could be:
  - ✓ unknown experimental systematic effects on laser spectroscopy.
  - ✓ unexplored interaction between proton and muon (or electron). New physics?

Lithium

Domestic Program : Lithium 2s-3s precision spectroscopy

Transition energy = QED + Nuclear Structure

Charge radius difference (^{7}Li-^{6}Li) & comparison of the measurements with various transitions



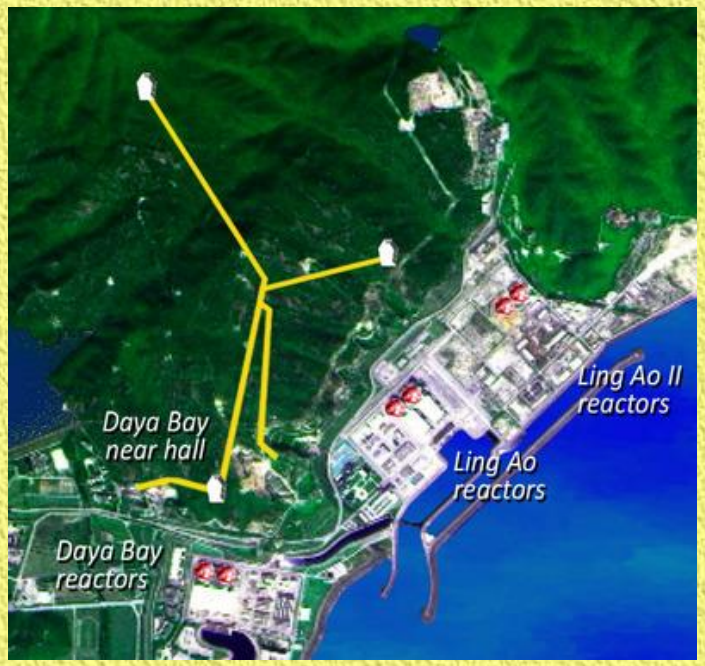
Method	$\Delta\gamma_c^2$(fm^2)	Reference
Electron scattering	-0.79(25)	[13]
$Li^+(2^3s_1 - 2^3p_0)$	-0.779(57)	[14]
$Li^+(2^3s_1 - 2^3p_1)$	-0.782(69)	[14]
$Li^+(2^3s_1 - 2^3p_2)$	-0.639(64)	[14]
$Li(2^2s_{1/2} - 3^2s_{1/2})$	-0.60(8)	[8]
	-0.583(19)	[3]
	-0.66(12)	[1]
	-0.742(12)	[12]
	-0.75(14)	This work
$Li(2^2s_{1/2} - 2^2p_{1/2})$	-0.403(40)	[3]
	-0.583(19)	[15]
	-0.761(40)	[16]
$Li(2^2s_{1/2} - 2^2p_{3/2})$	-0.961(67)	[15]
	-0.661(50)	[16]

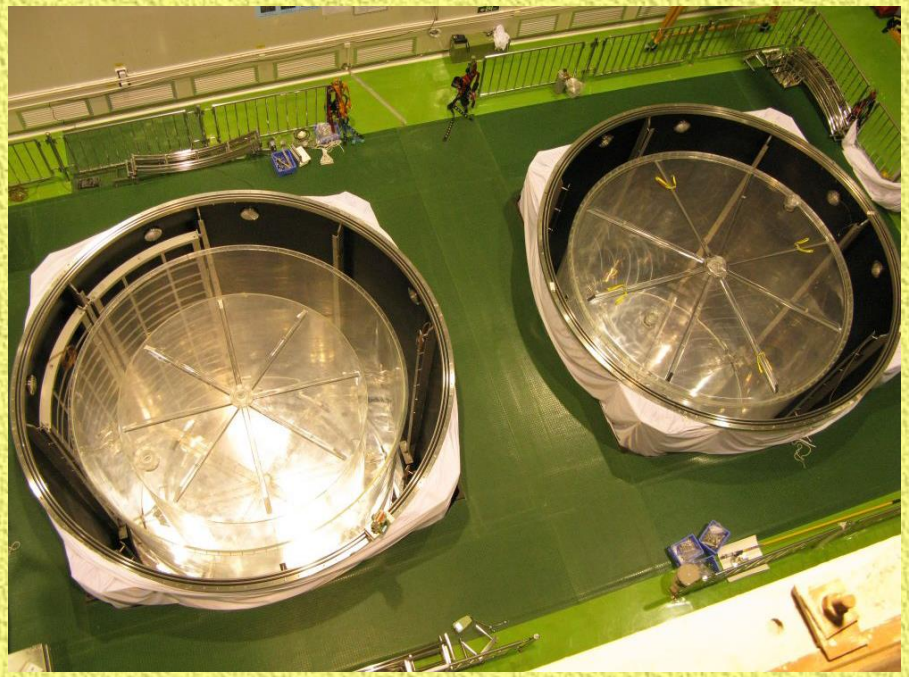
- **The resulted charge radius difference is consistent with most of previous measurements.**

Taiwan Groups @ Daya Bay, China

[B. Hsiung @ NTU, G.L. Lin @ NCTU, C.H Wang @ NUU]

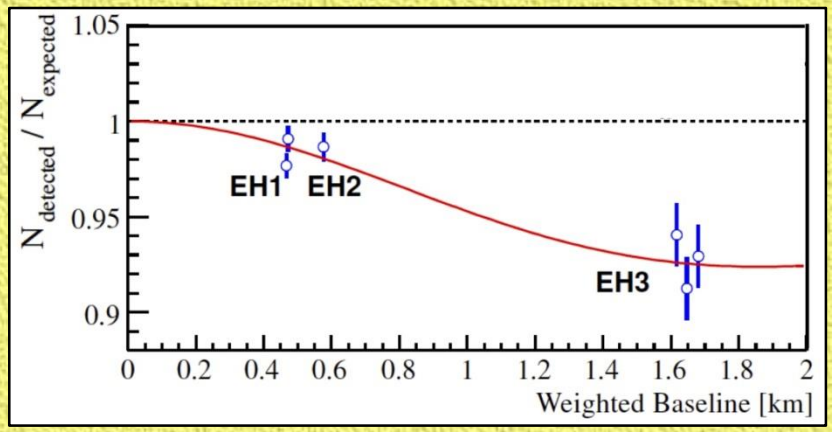
(Accelerator Particle Physics Background)





Contributions:

- All 8 inner (3m) acrylic vessels to contain the “target”, GdLS, are built in Taiwan.
- DAQ/Trigger and Control R&D
- PMT gain calibration and monitoring
- Calibration Database update and validation
- Data Quality Check

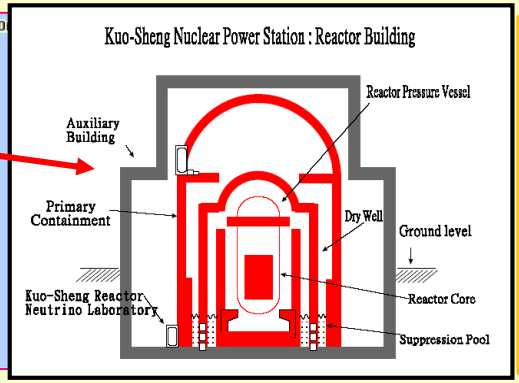


TEXONO Program

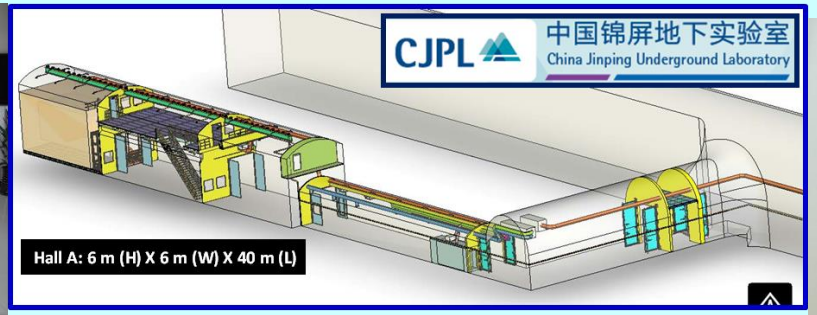
[Low Energy Neutrino and Dark Matter Physics]

H.T. Wong @ AS (Non-Accelerator Particle Physics Background)

Neutrino Physics at Kuo-Sheng Reactor Neutrino Laboratory (KSNL) in Taiwan *[Taiwan (AS …), India (BHU), Turkey (METU,DEU)]*

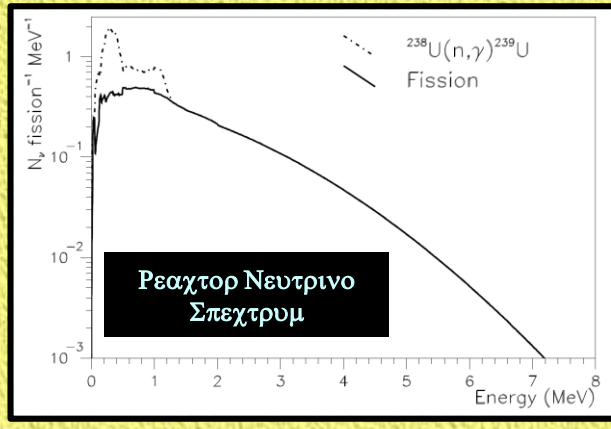


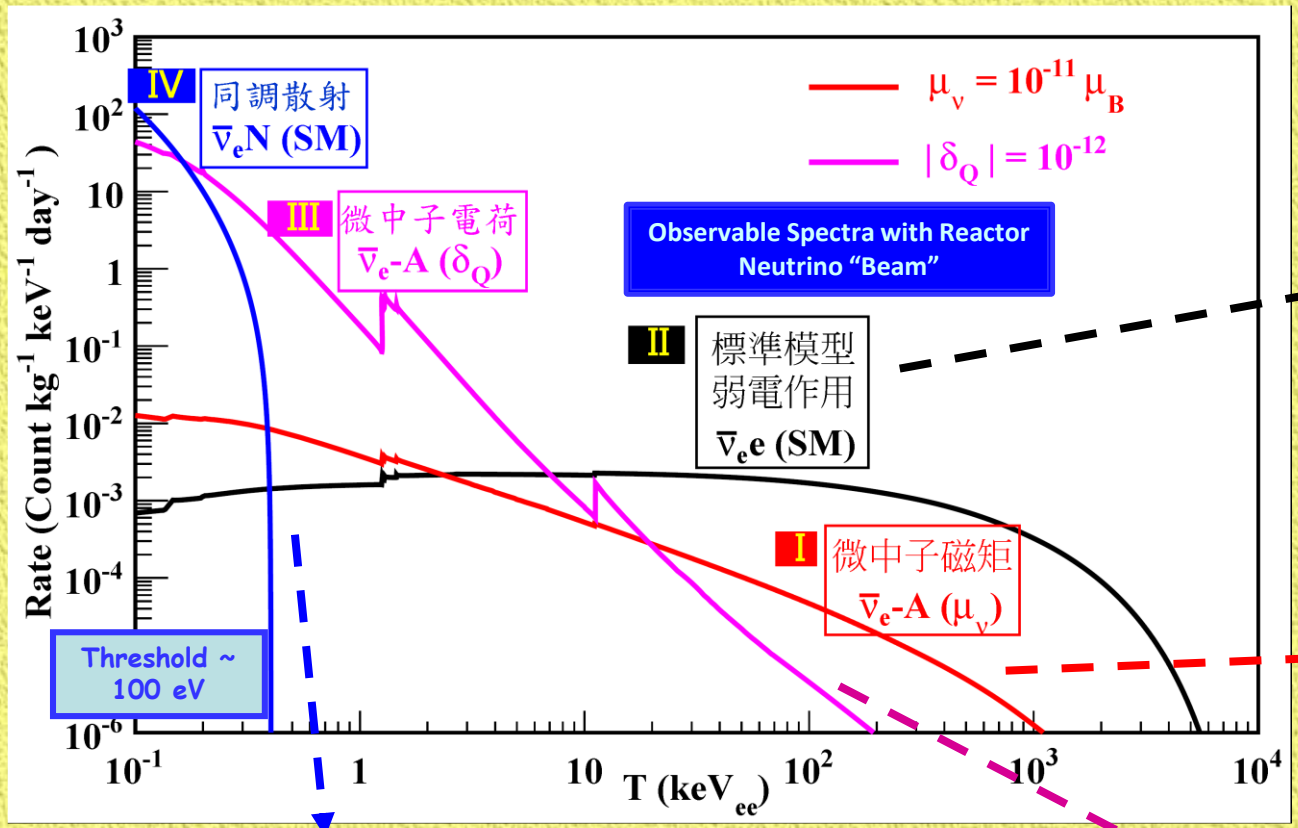
Dark Matter Searches in CDEX Program @ China Jin-Ping Underground Laboratory (CJPL) *[China (THU, SCU ….)*



Neutrino Properties & Interactions at Reactor

quality ← **Detector requirements** → **mass**



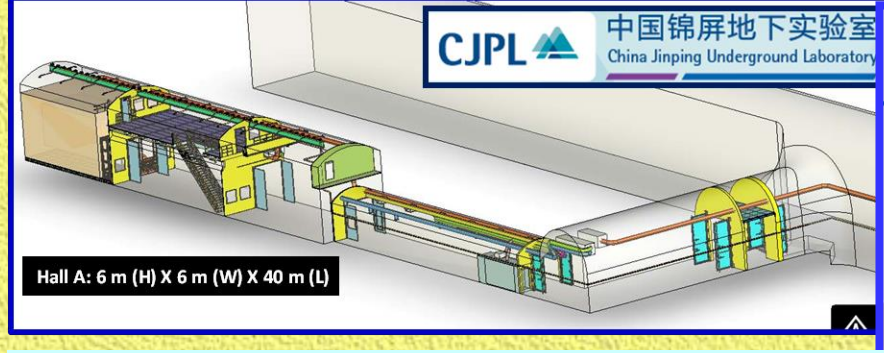


SM & NSI/BSM
ν-e Scattering
[PRD10,PRD10,PRD12,PRD15]
⇨ **200 kg CsI(Tl)**

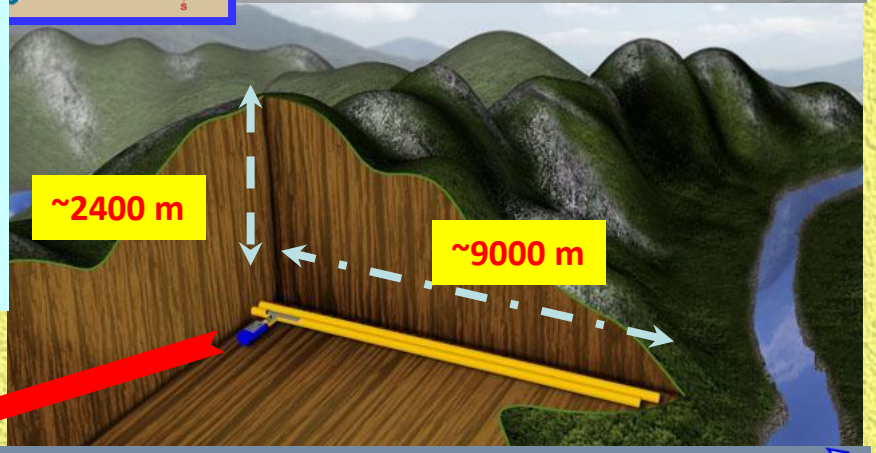
Magnetic Moments
[PRL03,PRD05,PRD07]
⇨ **1 kg HPGe**

νN Coherent Scattering *[Current Theme;PRD16]*
⇨ **sub-keV O(kg) ULEGe / PCGe**
- **Dark Matter Searches @ KSNL** *[PRD09,PRL13,AP14]*
- **CDEX Program@CJPL** *[PRD13,PRD14,PRD14;PRD16]*
- **Theory Program**

Neutrino Milli-charge *[PRD14]*
⇨ **sub-keV O(kg) ULEGe / PCGe**



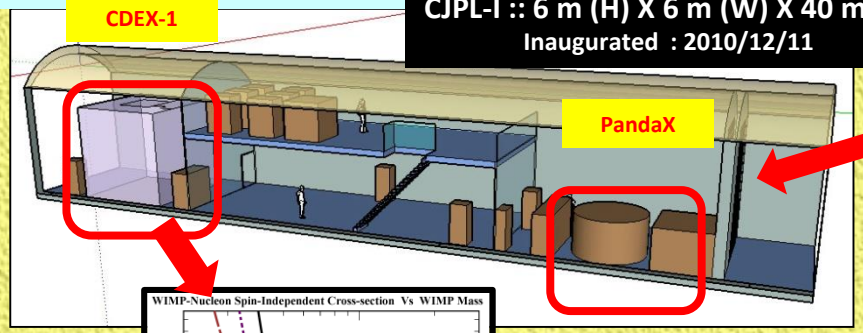
- 2400+ m rock overburden, drive-in road tunnel access
- ~6 muons/m^2-month *(cf sea-level 100 Hz/m^2)*
- *Deepest and Largest Underground Facility.*



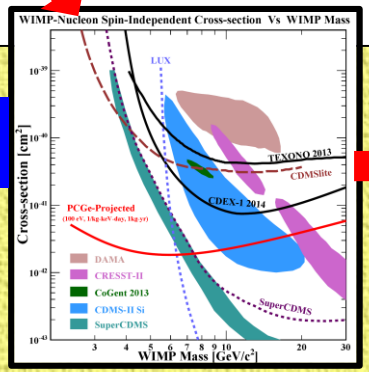
CDEX-1

CJPL-I :: 6 m (H) X 6 m (W) X 40 m (L)
Inaugurated : 2010/12/11

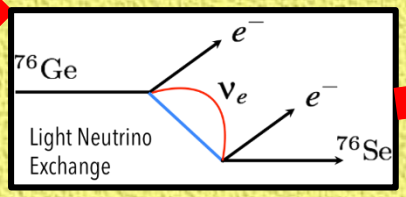
PandaX

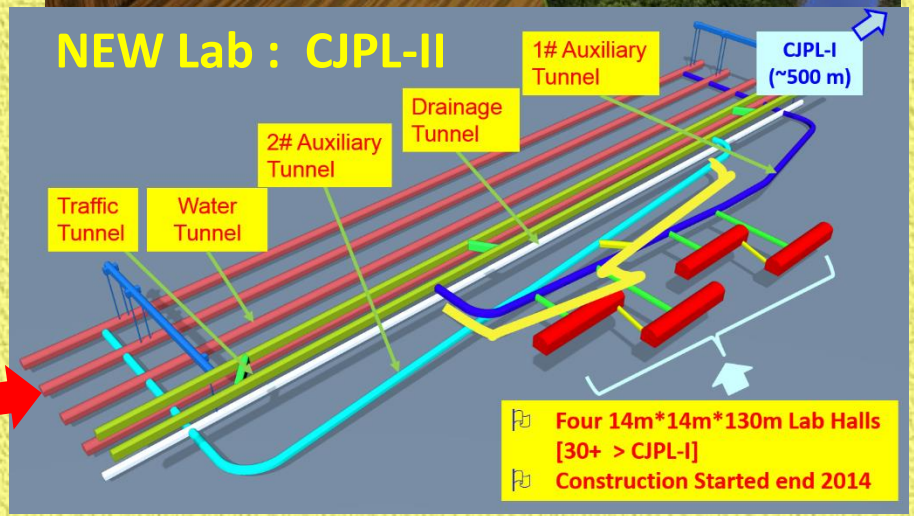


Dark Matter Searches



Double Beta Decay (Future)



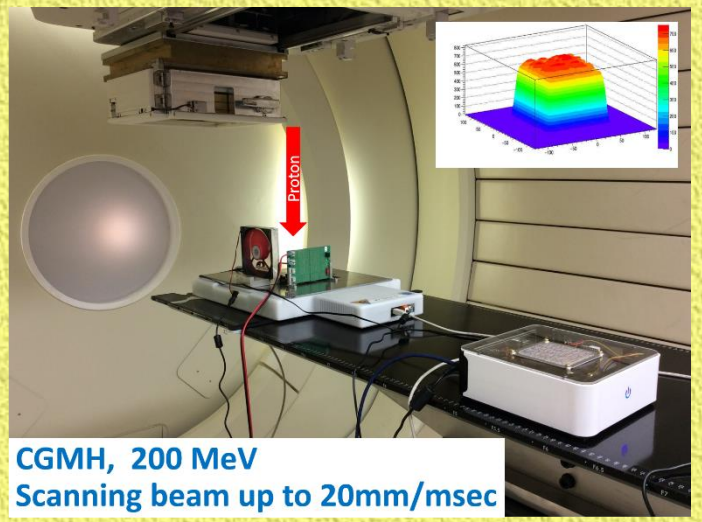


Instrumentation Projects

[M.L. Chu, C.H. Lin, P.K. Teng @ AS ; A. Chen @ NCU et al …]

(Accelerator Particle Physics Background)

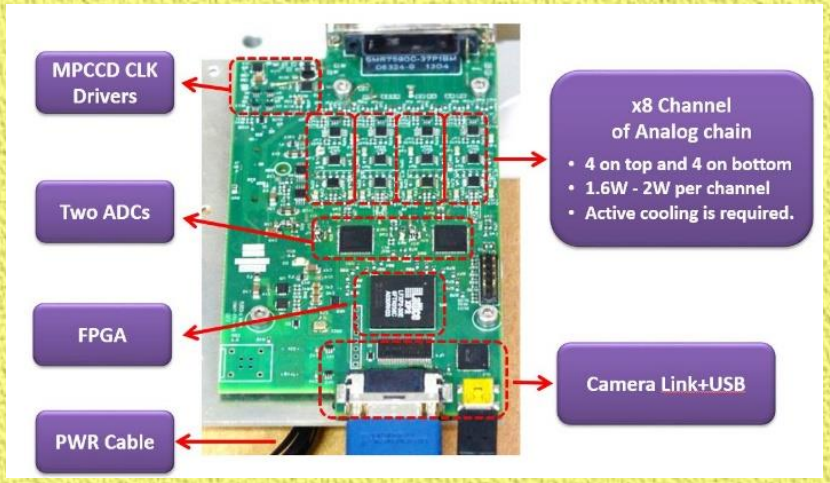


CGMH, 200 MeV
Scanning beam up to 20mm/msec

Projects with Nuclear Physics Flavor:

- ☑ Beam monitoring detectors for Proton Therepy (@ Cheng-Gang Memorial Hospital)
- ☑ MPCCD Readout Electronics for SACLE-XFEL , Japan.
- ☑ Radiation Damage Tests
- ☑ …….



Proton Beam Facility in Taiwan

- **Institute of Nuclear Energy Research (INER)**
  - **30 MeV**
  - **High current, > 0.5 nA**
  - **Proton TID test for analog parts, like OPA, MOSFET, Diode … etc**
- **Chang-Gung Memorial Hospital (CGMH)**
  - **90 – 230 MeV**
  - **Scanning beam to produce uniform dose distribution**
  - **Proton SEU test for IC and modules**
- **Accelerator Lab, National Tsing Hua University**
  - **0.3 – 5 MeV**
  - **Proton TID test for bare IC die and solar cells**

Theory Activities

- ☑ Integrated well with theory program on particle physics & cosmology
- ☑ esp. aspects of nucleon/hadron physics with QCD effective theories & Lattice QCD; aspects of atomic/nuclear physics in particle-matter interactions
- ☑ **Practitioners:** C.W. Chen, T.W. Chiu (NTU) ; D. Lin (NCTU) ; C.W. Kao (CYCU) ; C.P. Liu (NDHU) ;





Summary & Outlook

- ☑ Taiwan Nuclear Physics Research Activities : small but active community
- ☑ focused but diverse programs ; based on facilities world-wide ; Bottom-Up Evolution
- ☑ Both domestic and international programs ; strong experiment-theory connection
- ☑ Different background/disciplines & nuclear physics program mutually enhance and contribute to each other.