

# **K**orea **U**niversity **N**uclear **P**hysics **L**aboratory

**Nuclear Physics School 2013**  
**Korea University**  
**Songkyo Lee**

- ① **INTRODUCTION**
  - : KUNPL People
  - : Research Overview
  
- ① **LAMPS**
  - : Time Projection Chamber
  - : Si-CsI Detector
  - : Neutron Detector Array
  - : Dipole Spectrometer
- ① **CMS**
- ① **PHENIX**
- ① **SAMURAI-TPC/BigRIPS**
  
- ① **SUMMARY**

- Ⓜ **Professor** : Byungsik Hong
- Ⓜ **Research Professor** : Kyong Sei Lee
- Ⓜ **Postdoctoral researcher**: Yongsun Kim
- Ⓜ **Ph.D. Students** : Hyunha Shim, Hyunchul Kim, Chong Kim, Mihee Jo, Eunah Joo, Genie Jhang, Kisoo Lee, Songkyo Lee, Yeonju Go, JungWoo Lee, Bumgon Kim
- Ⓜ **Master Students** : Benard Mulilo, JaeHee Yoo
- Ⓜ **Internship** : Shinhyung Kim, Jaeduck Lee



## CMS

### Heavy ion Physics

- Dilepton group
- $J/\psi$ ,  $\Upsilon$ ,  $Z$ , and  $B$  production



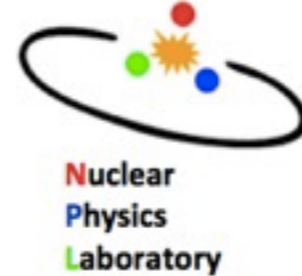
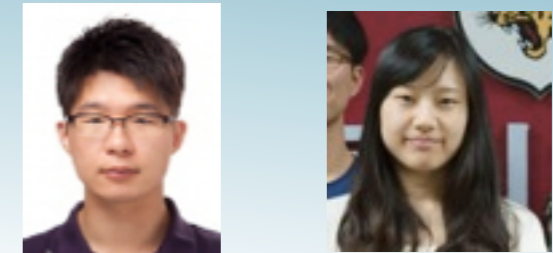
## PHENIX

### Heavy ion Physics

- Quarkonium production
- Drell–Yan Study

### Spin Physics

- $W$  single spin asymmetry



## SAMURAI-TPC /BigRIPS

### RI Physics

- Symmetry Energy



## LAMPS

### Design and R&D for

- TPC
- Dipole spectrometer
- Neutron Array
- Si–CsI detector



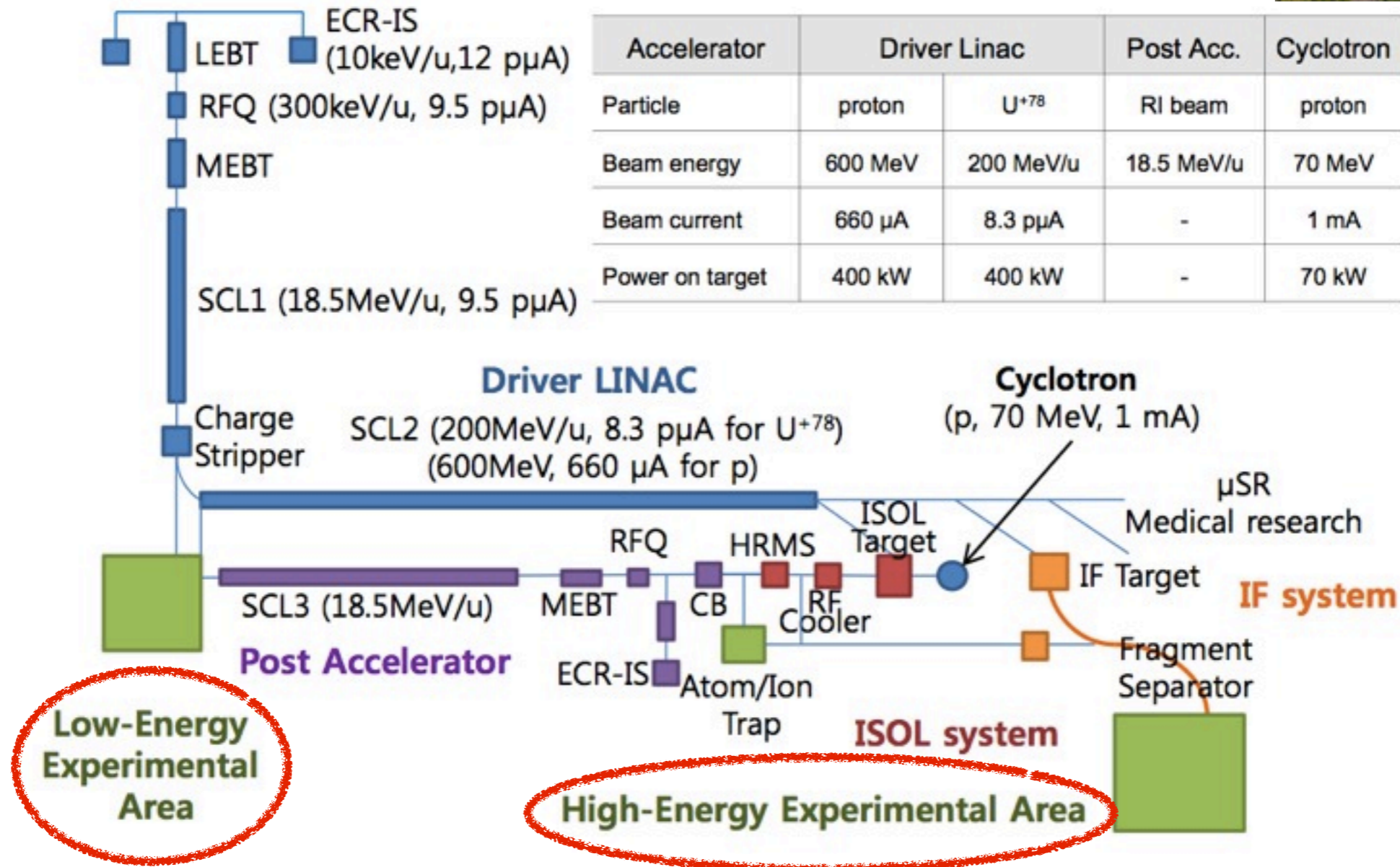
## Detector Development

- RPC
- GEM
- Scintillation Detector



## Ⓜ RAON (RI beam accelerator)

- Ⓜ Meaning 'delightful', 'joyful', 'happy'
- Ⓜ Multi-purpose for the basic and applied science

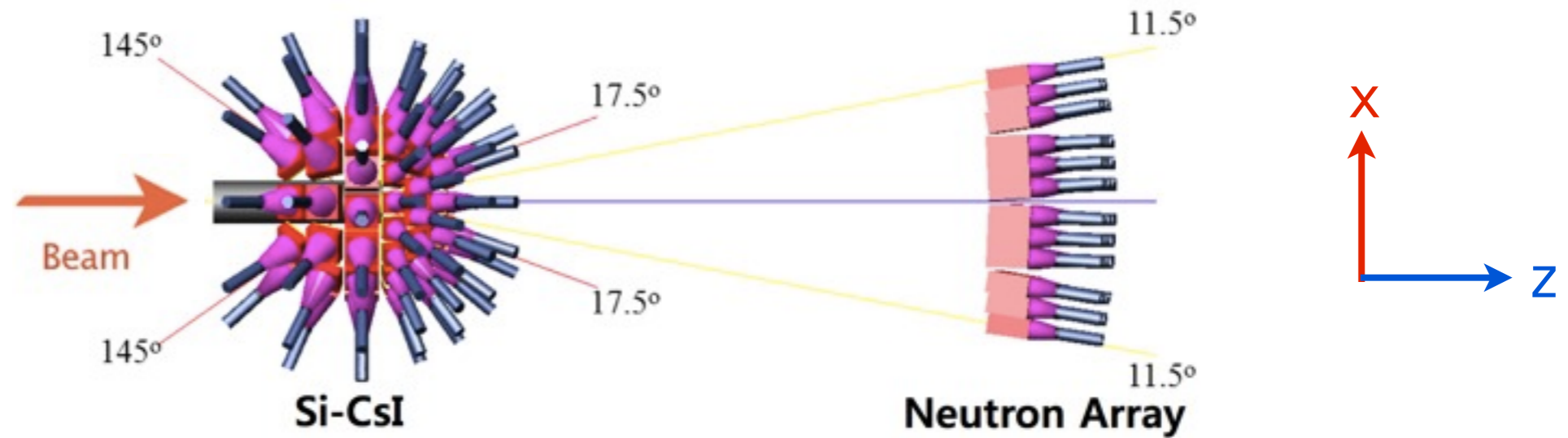


: Large Acceptance Multi-Purpose Spectrometer

## ⊕ LAMPS<sub>L</sub> :

( $E_{\text{beam}} < 18.5 \text{ MeV/u}$ )

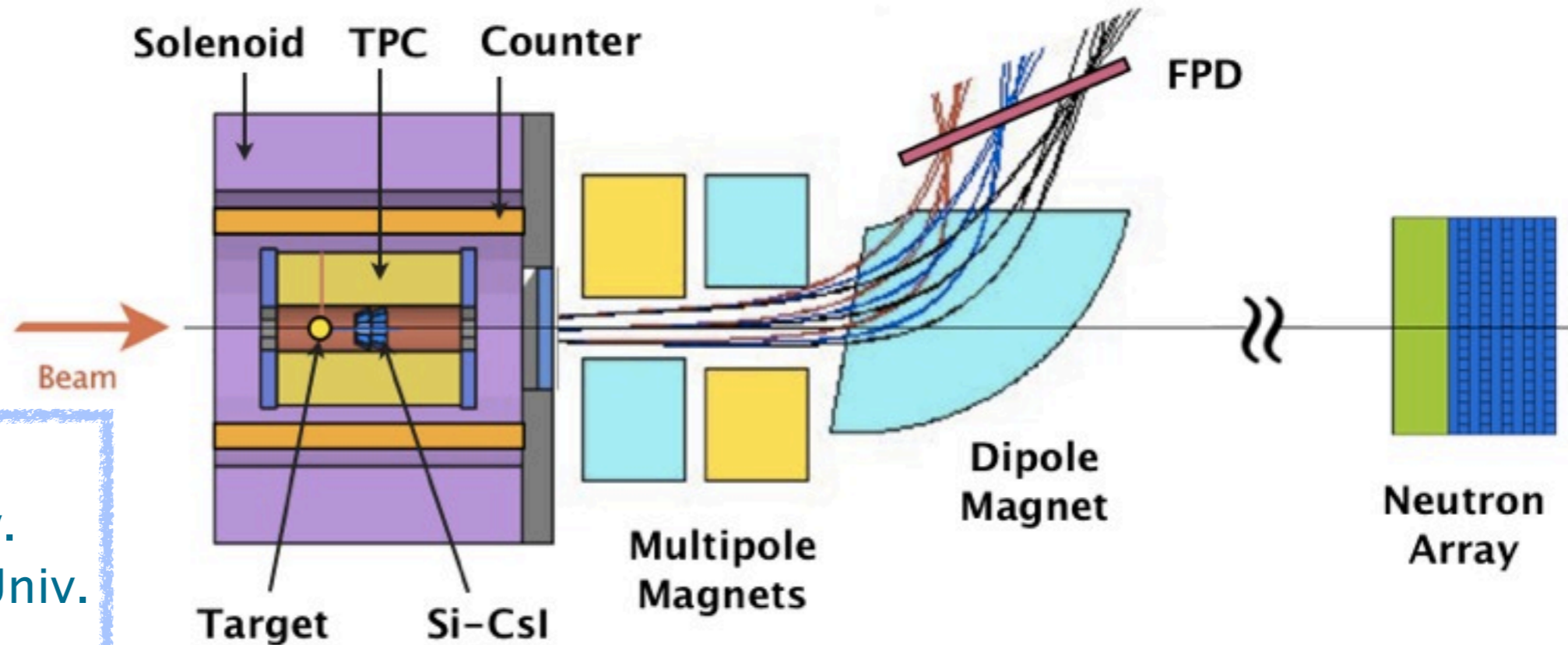
Nuclear Structure  
Nuclear Astrophysics  
Material Science  
 $\beta$ -NMR



## ⊕ LAMPS<sub>H</sub> :

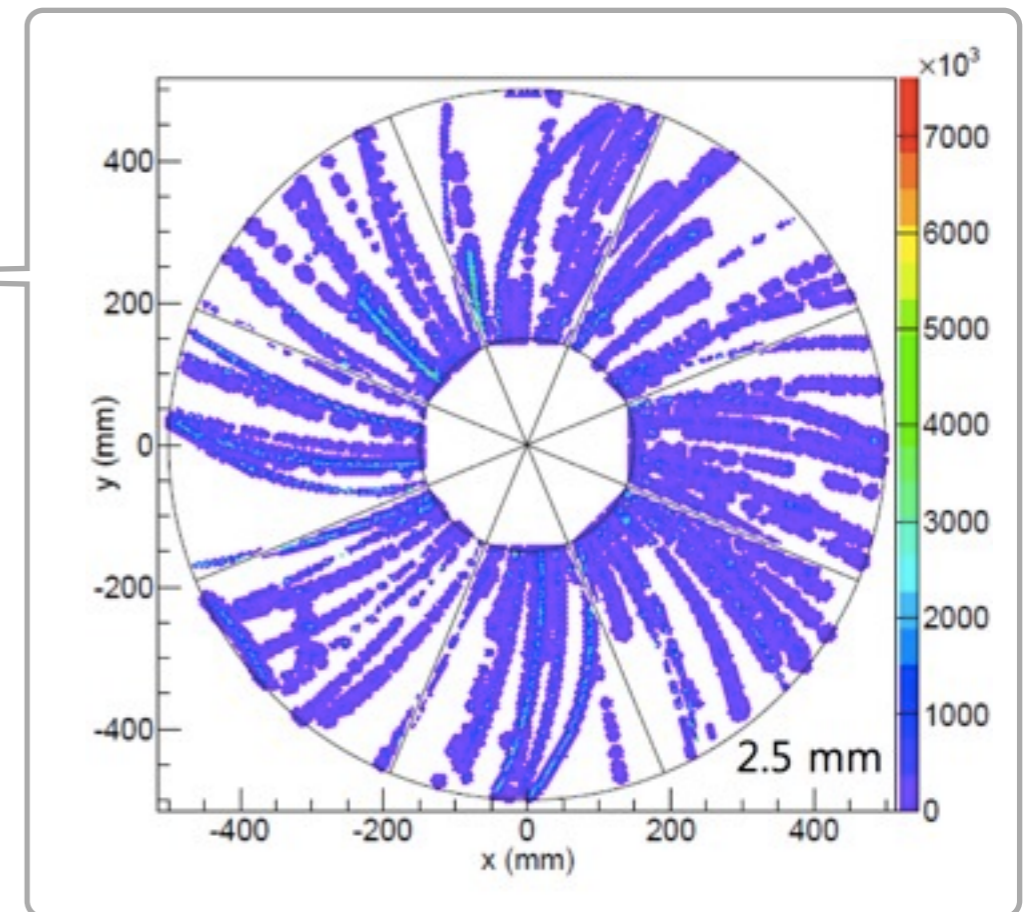
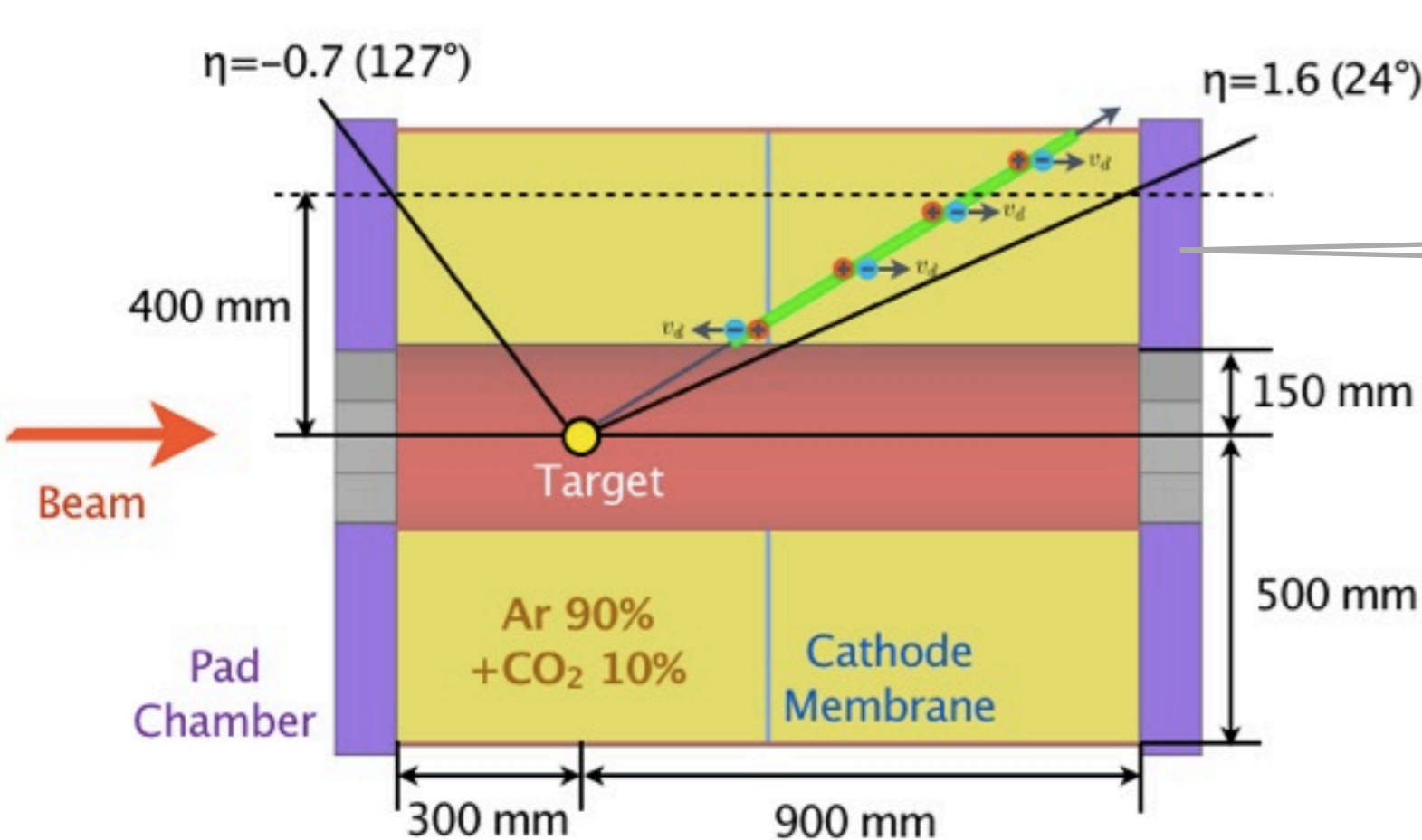
( $E_{\text{beam}} > 18.5 \text{ MeV/u}$ )

Nuclear Structure  
Symmetry Energy



## Collaboration

- Pusan National Univ.
- Chonbuk National Univ.
- RISP

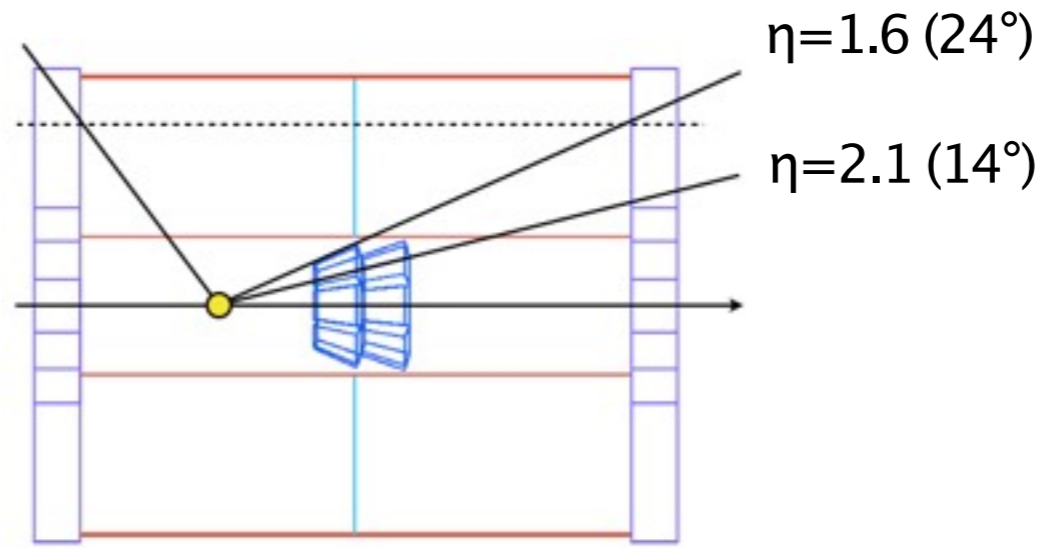
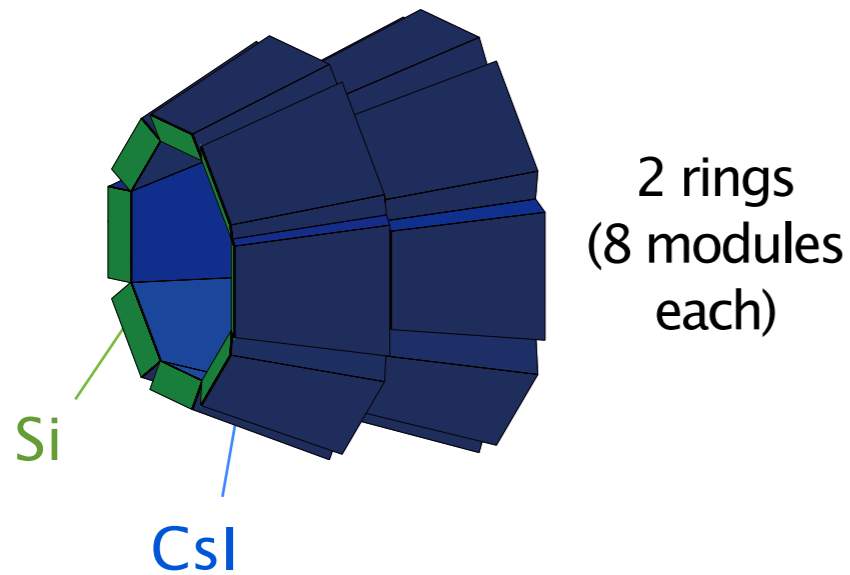


- ⊕ GEANT4 : Central Au+Au Collision at 250 AMeV (IQMD)
- ⊕ Garfield++ : simulation for triple GEM readout

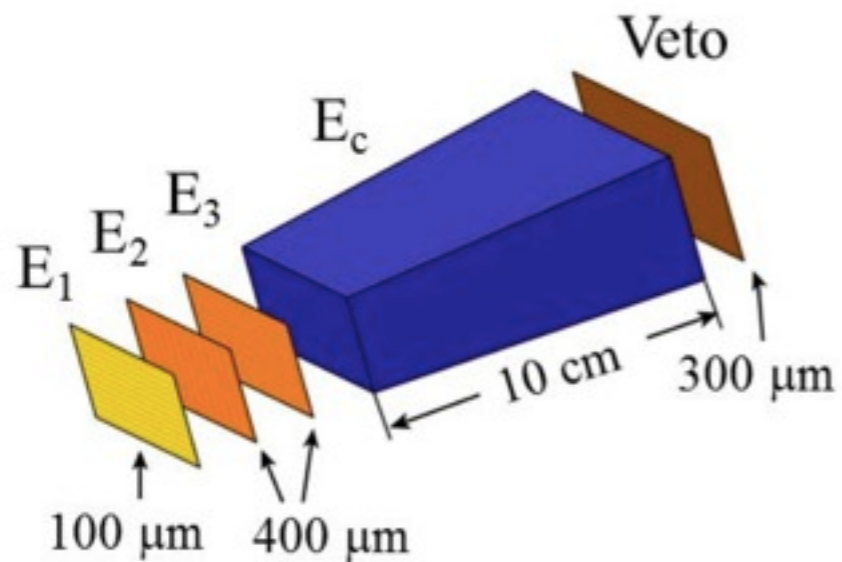
# Si-CsI Detector

- ① Cover the forward region

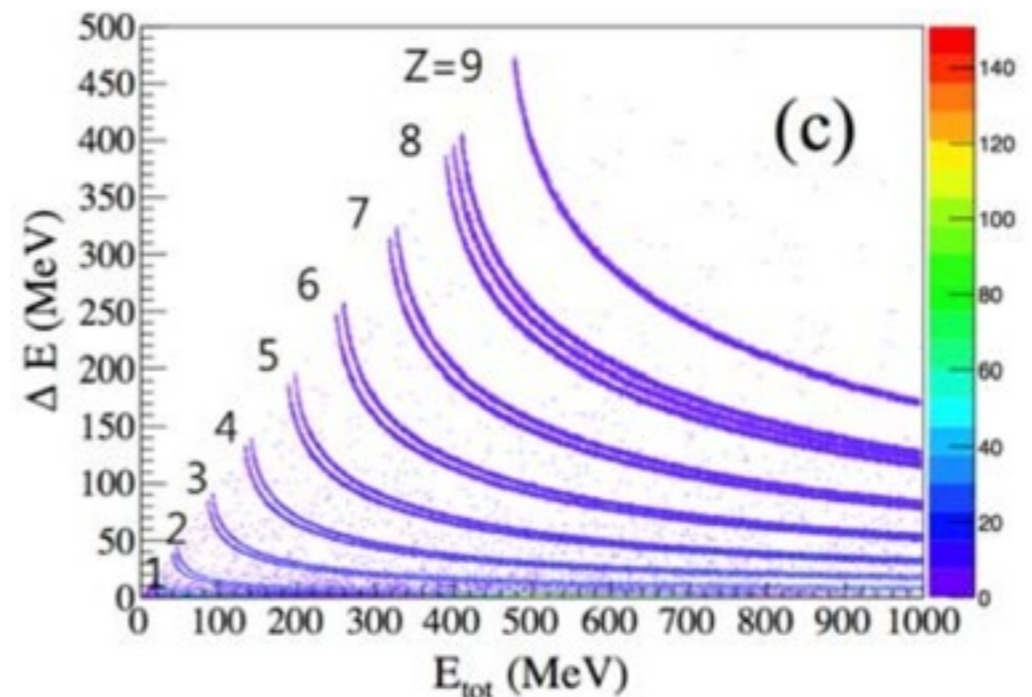
Songkyo Lee  
(Suhyun Lee)



- ① Particle ID (by  $\Delta E$  vs  $E_{\text{tot}}$  methods)



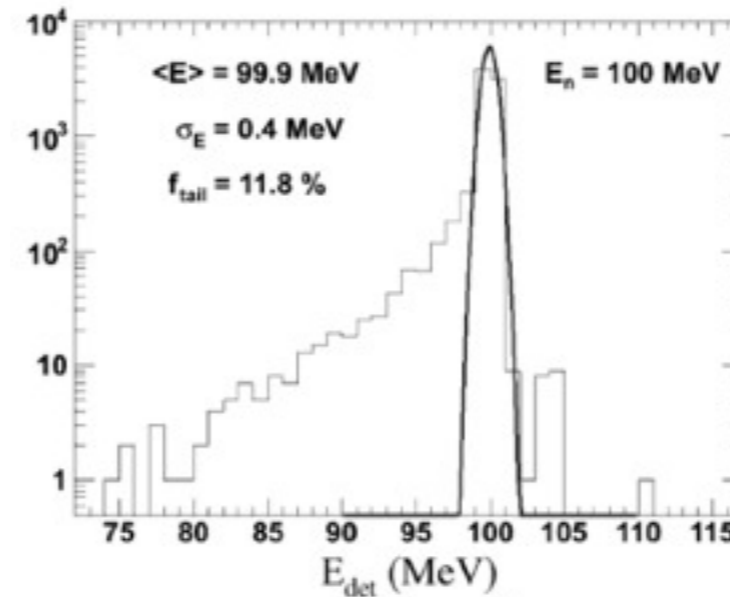
$$\Delta E = E_1 + E_2 + E_3$$



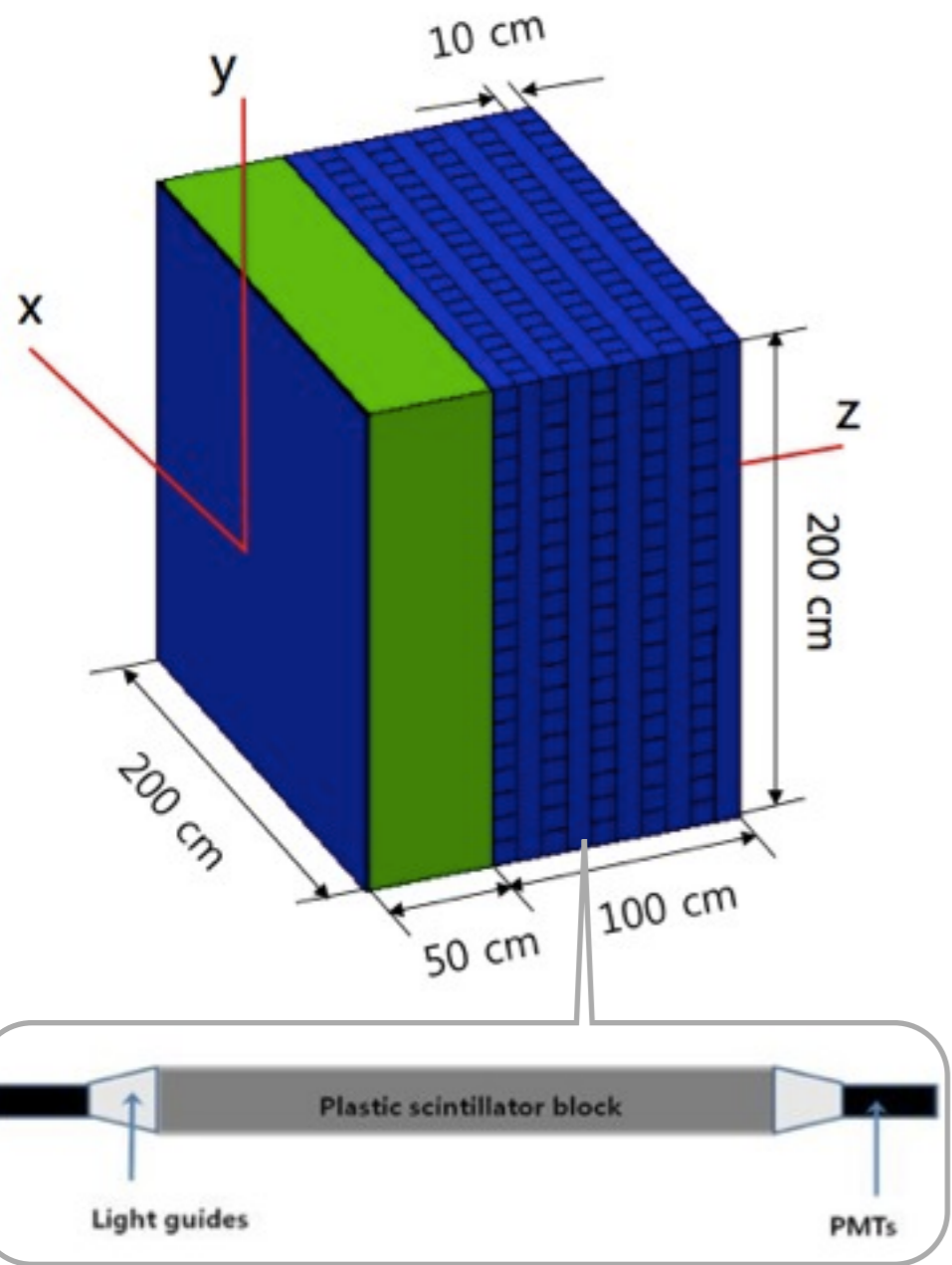
$$E_{\text{tot}} = E_1 + E_2 + E_3 + E_c$$



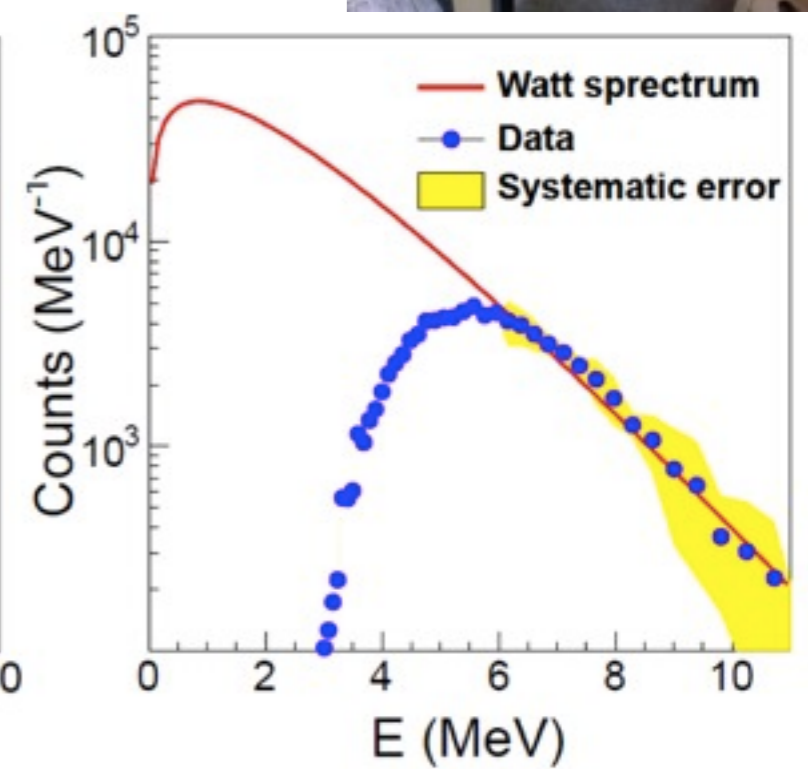
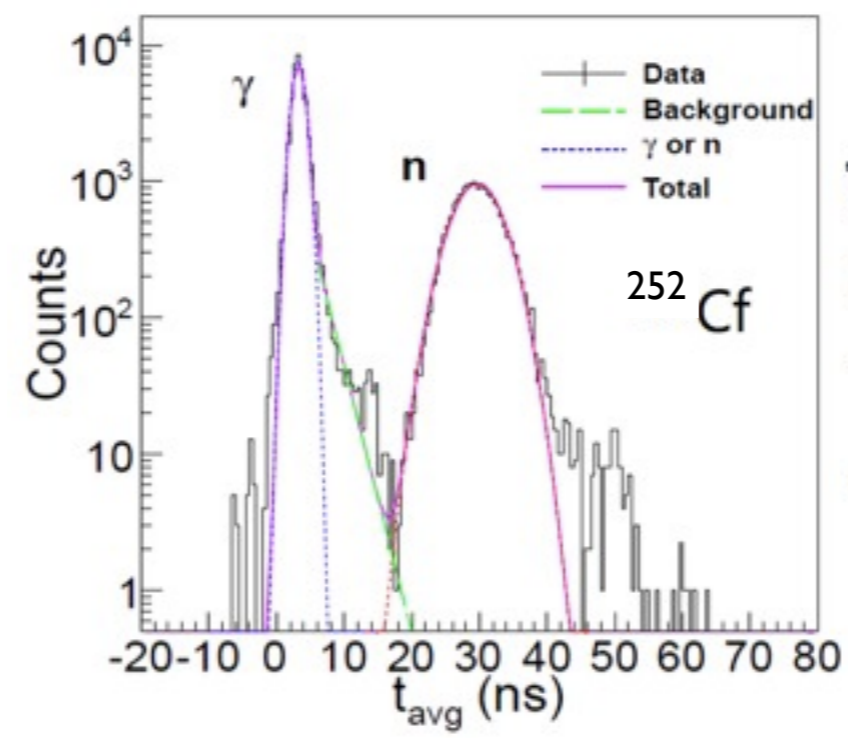
## GEANT4 Simulation



Kisoo Lee  
Benard Mulilo  
Eunah Joo  
Hyunha Shim



## The prototype detector test

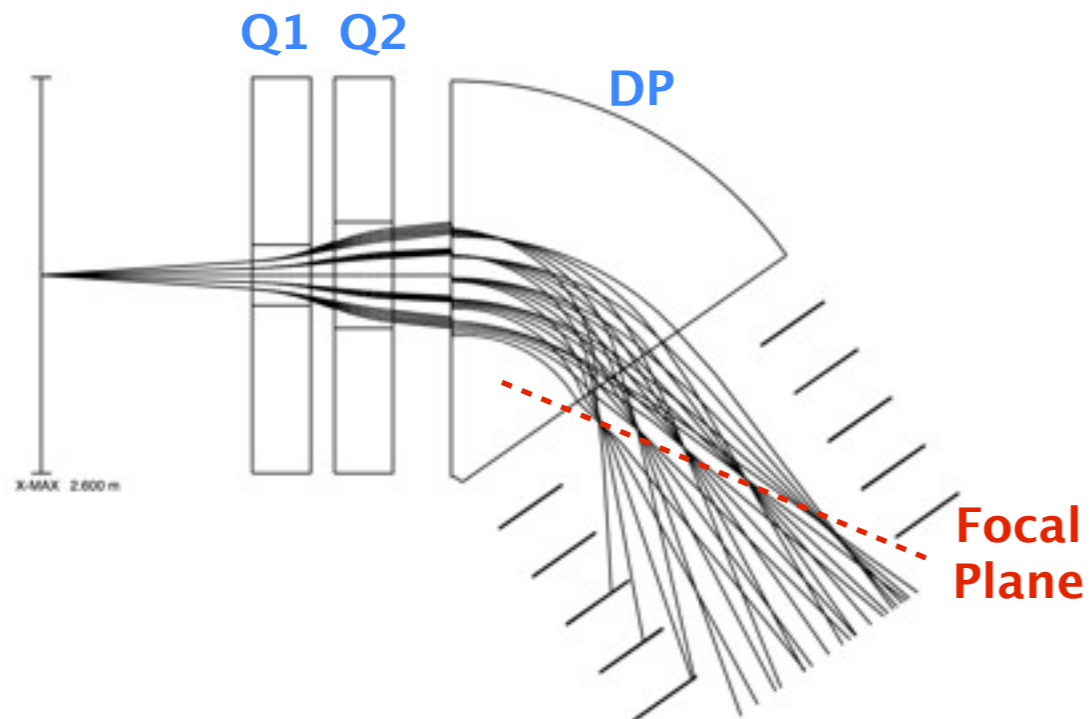


# Dipole Spectrometer

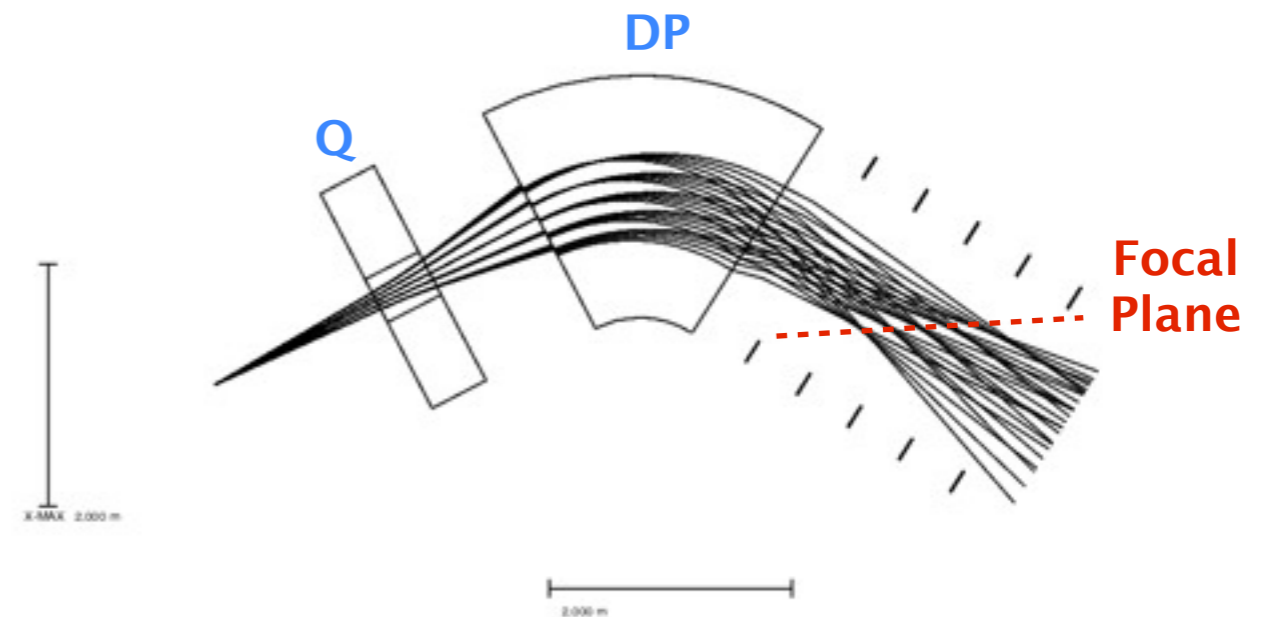
- ⊙ Various configurations are ongoing to optimize focal points
- ⊙ TRANSPORT, GICOGY, and GEANT4 simulation

Songkyo Lee

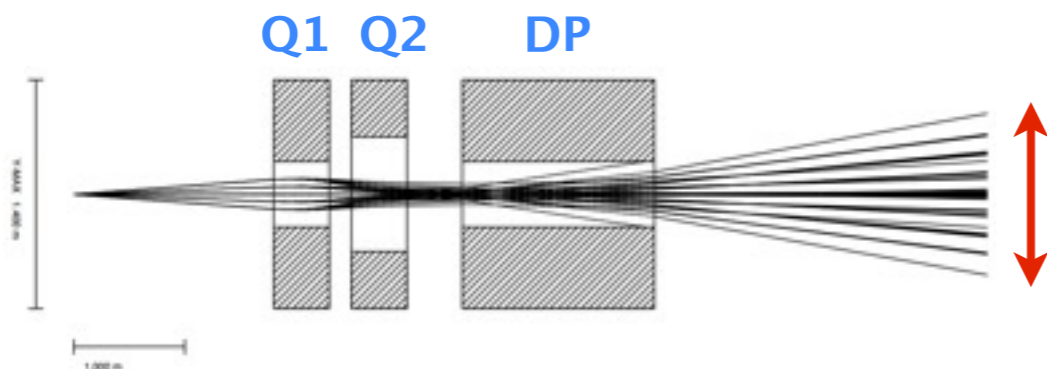
[ Top View ]



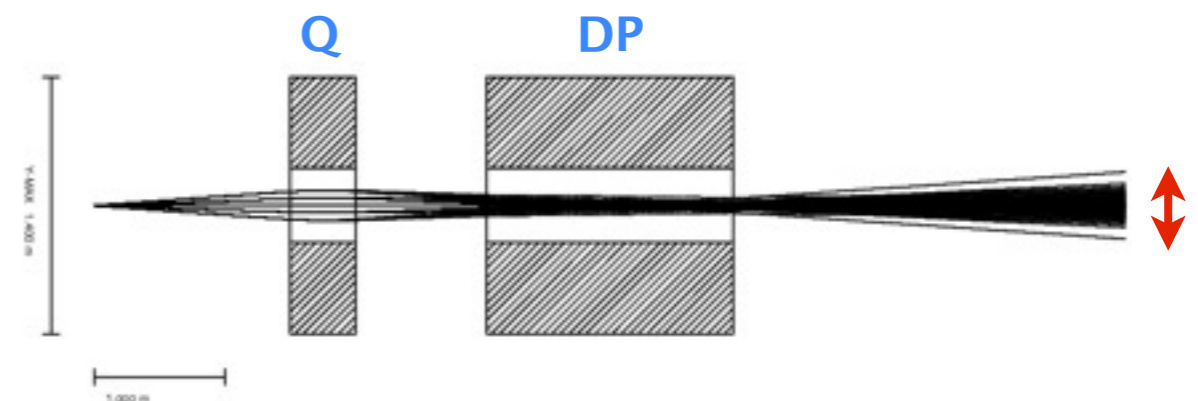
[ Top View ]



[ Side View ]



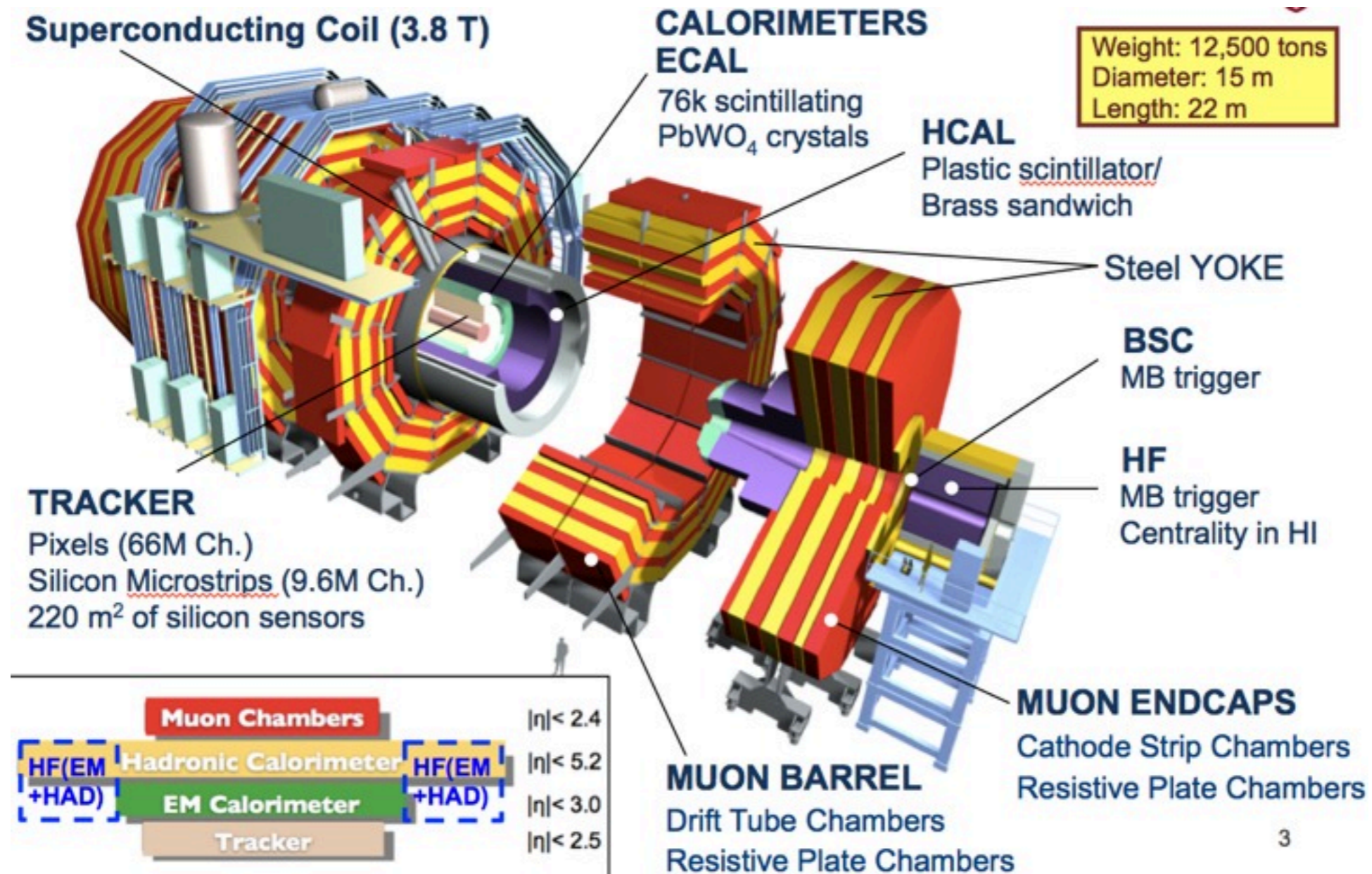
[ Side View ]



## : Compact Muon Solenoid

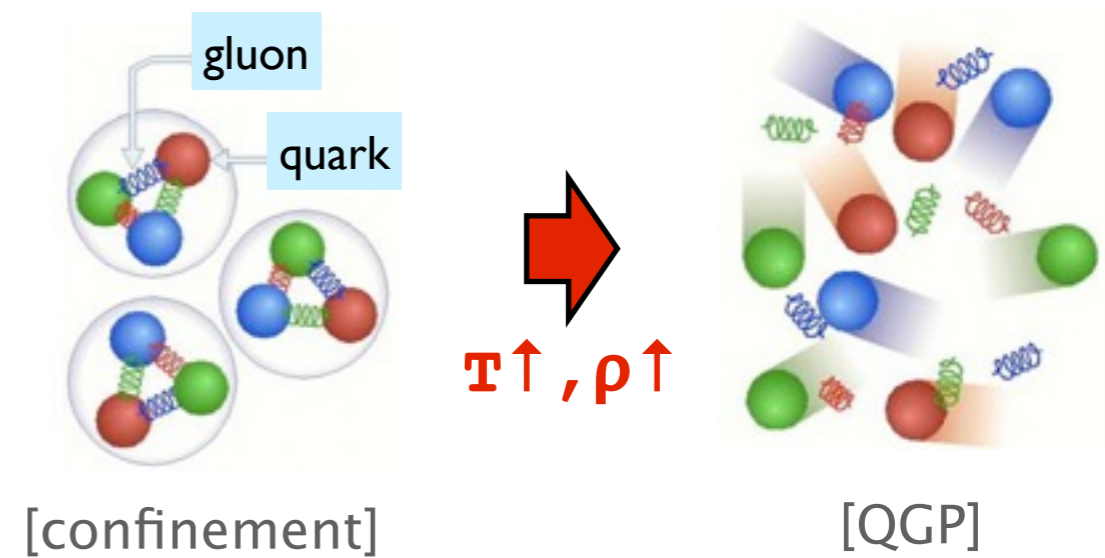
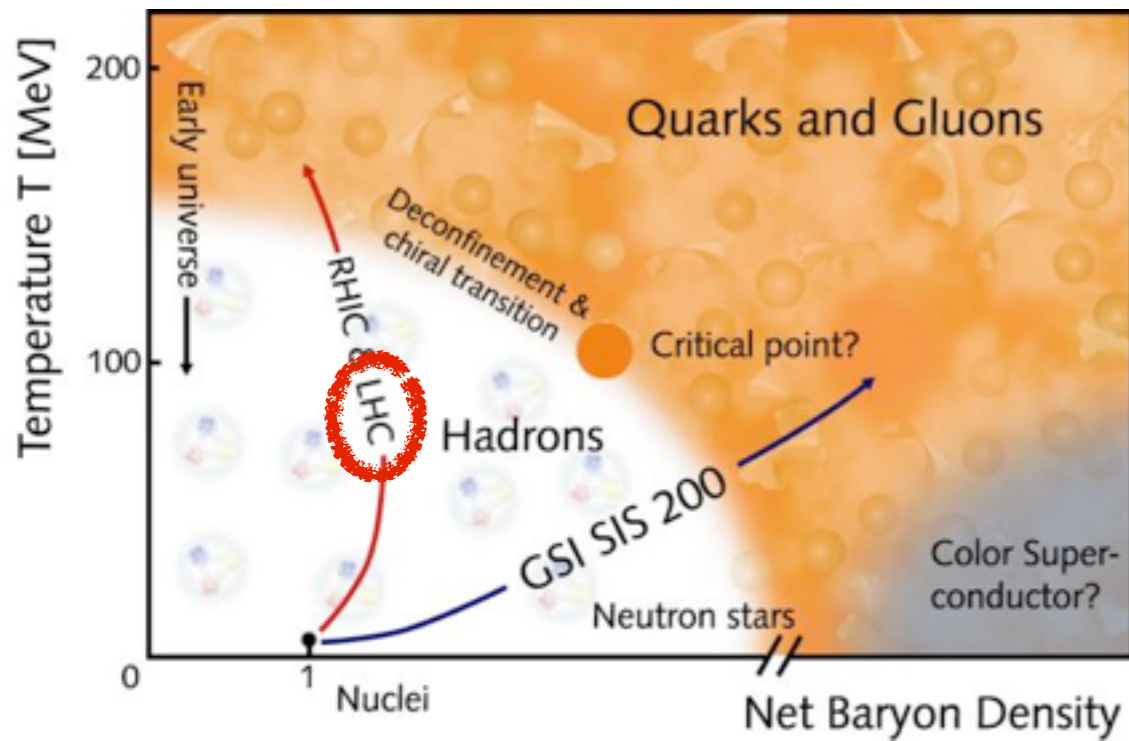
Yongsun Kim   Hyunchul Kim   Mihee Jo  
Kisoo Lee   Songkyo Lee

Collaboration :  
LLR, UC Davis, BARC, Chonnam National Univ.

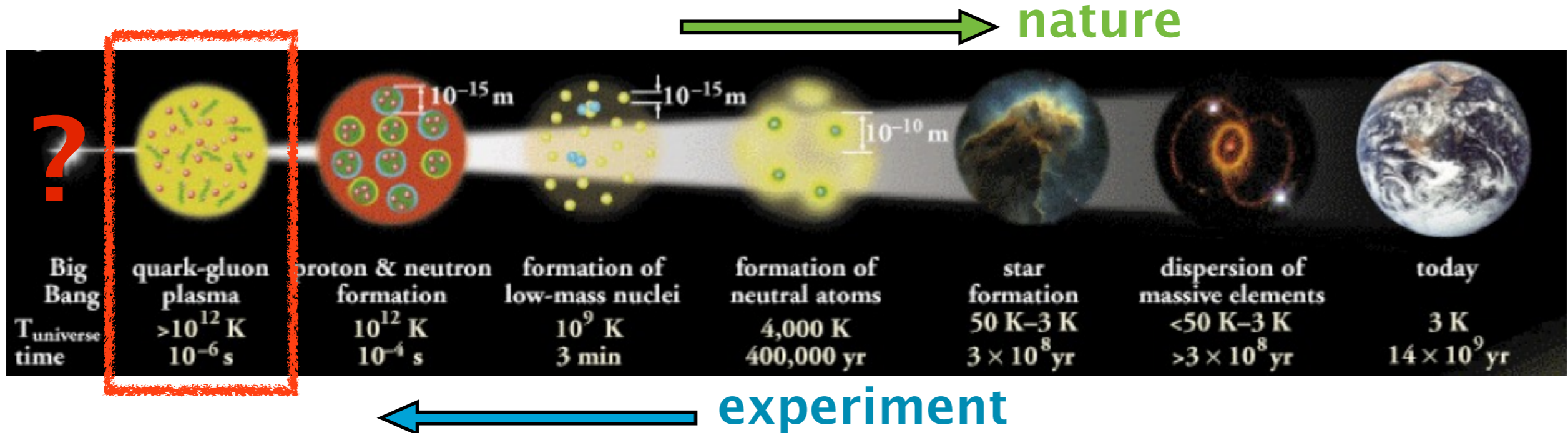


# Quark Gluon Plasma

## Phase Diagram of nuclear matter

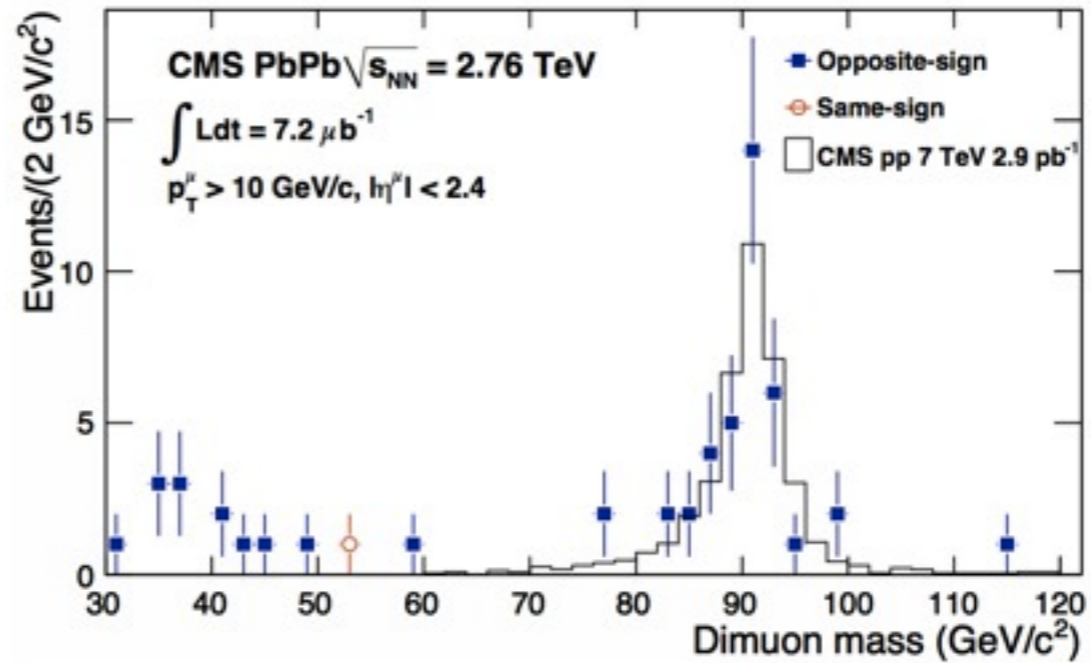
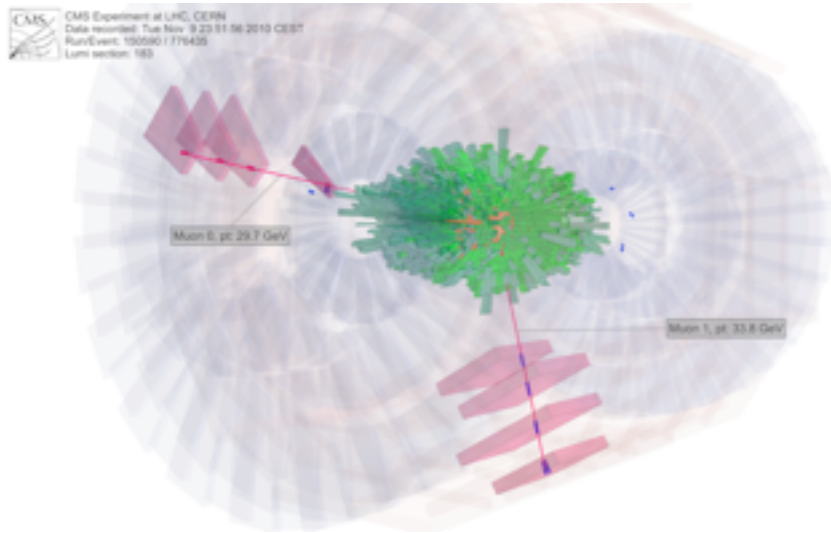


## Evolution of the Universe



# Dimuon Analysis

## ⊕ Z measurement



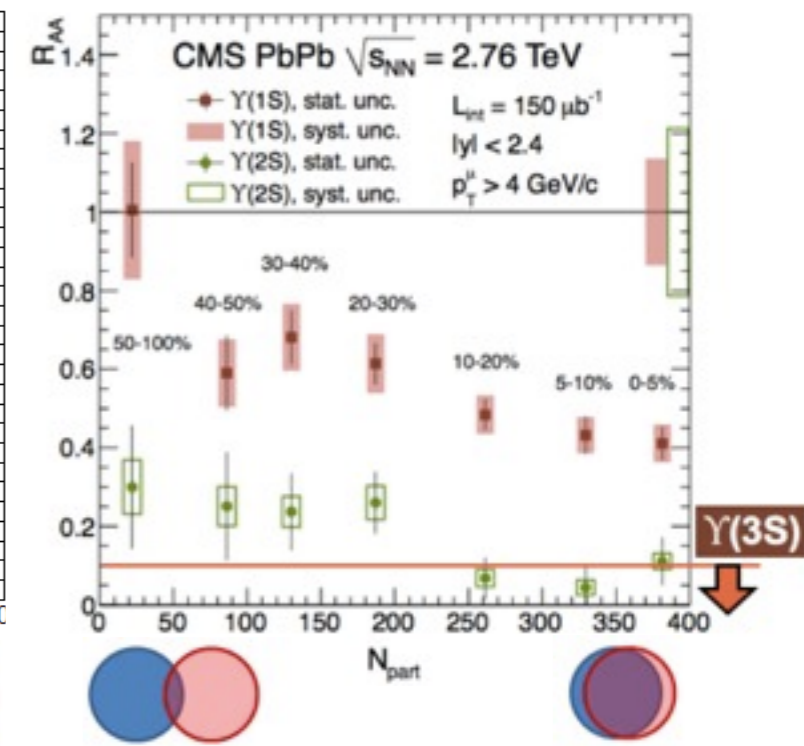
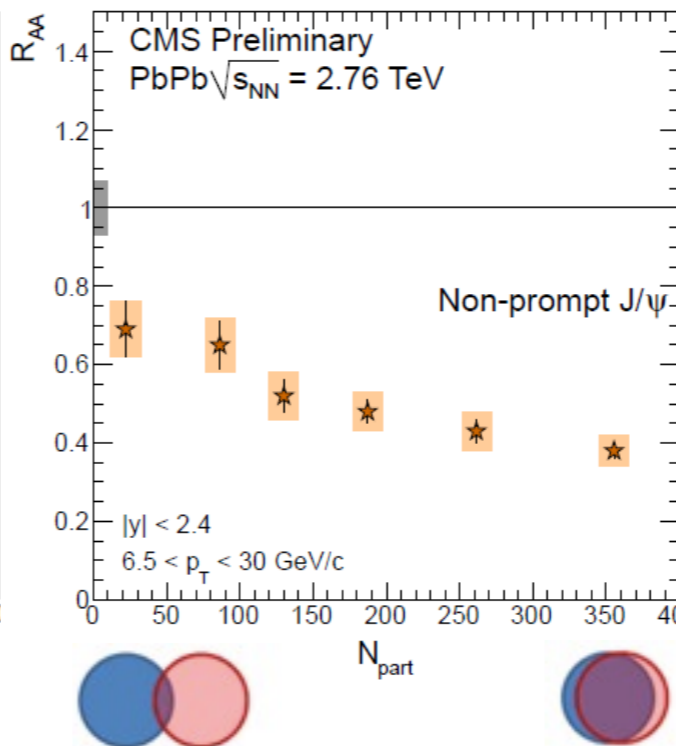
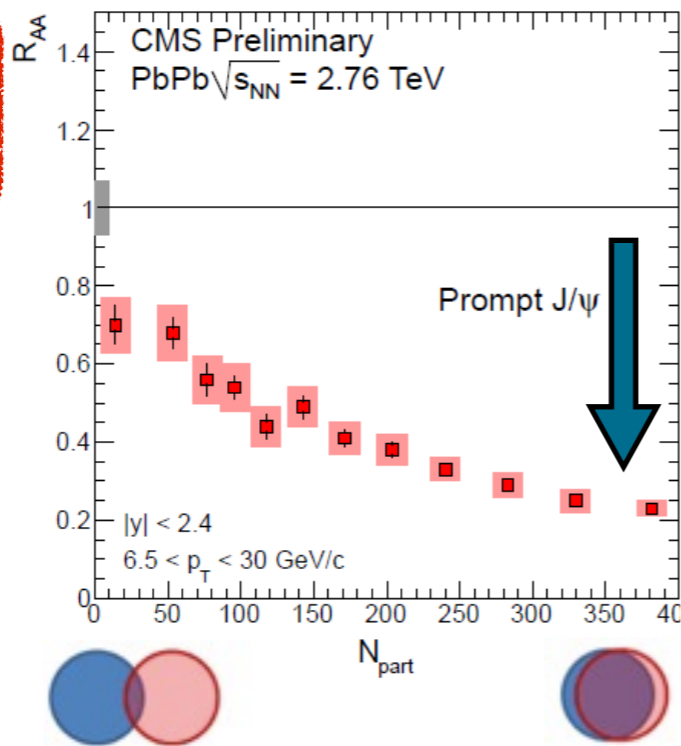
PRL 106 (2011) 212301

## ⊕ Suppression of Quarkonium

PRL 109 (2012) 222301

$$R_{AA} = \frac{1}{N_{coll}} \frac{N_{PbPb}}{N_{pp}}$$

$R_{AA} = 1$   
when AA is simple  
superposition of pp



## Ⓜ Papers

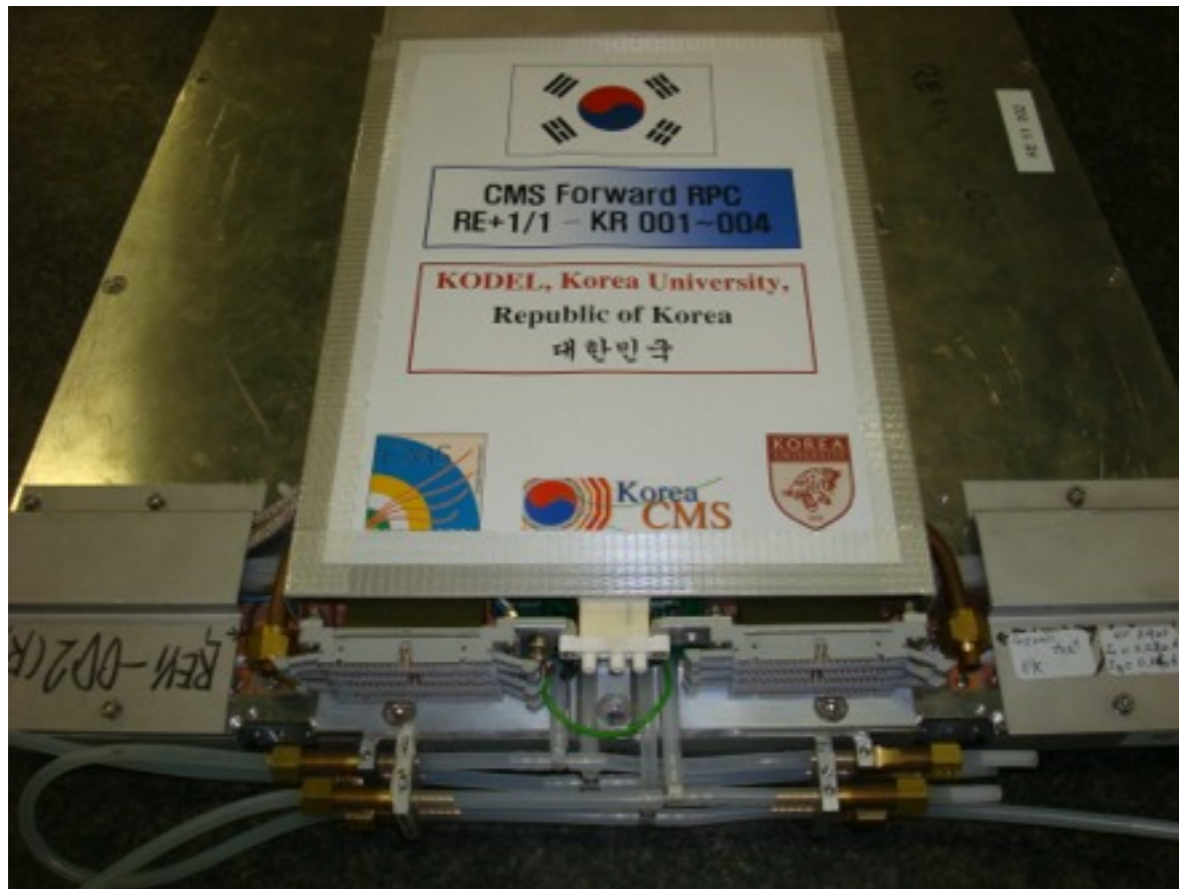
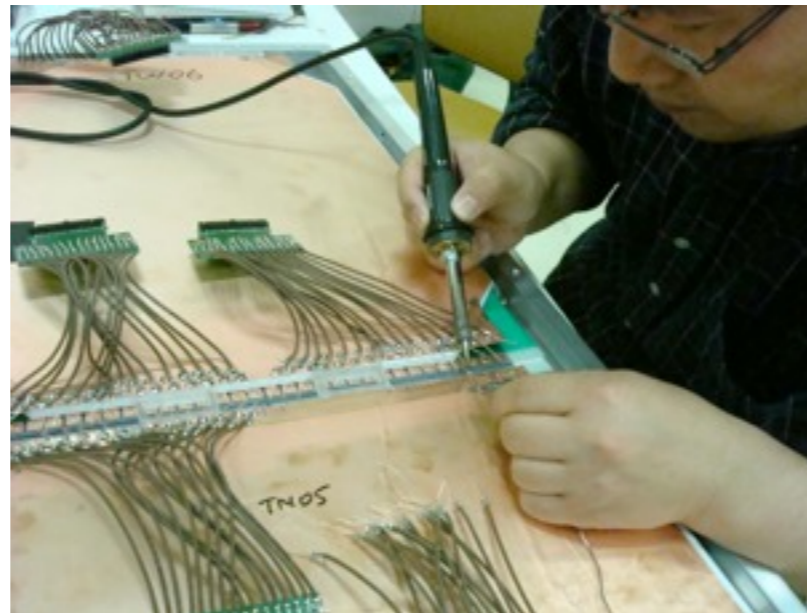
- Indications of suppression of excited  $\Upsilon$  states in PbPb collisions at  $\sqrt{s_{NN}}=2.76$  TeV,  
[PRL 107 \(2011\) 052302 \[ 93cites \]](#)
- Suppression of non-prompt  $J/\psi$ , prompt  $J/\psi$ , and  $\Upsilon(1S)$  in PbPb collisions at  $\sqrt{s_{NN}}=2.76$  TeV,  
[JHEP 1205 \(2012\) 063 \[ 91cites \]](#)
- Study of Z boson production in PbPb collisions at  $\sqrt{s_{NN}}=2.76$  TeV,  
[PRL 106 \(2011\) 212301 \[ 43cites \]](#)
- Observation of sequential Upsilon suppression in PbPb collisions,  
[PRL 109 \(2012\) 222301 \[ 31cites \]](#)

## Ⓜ Conferences

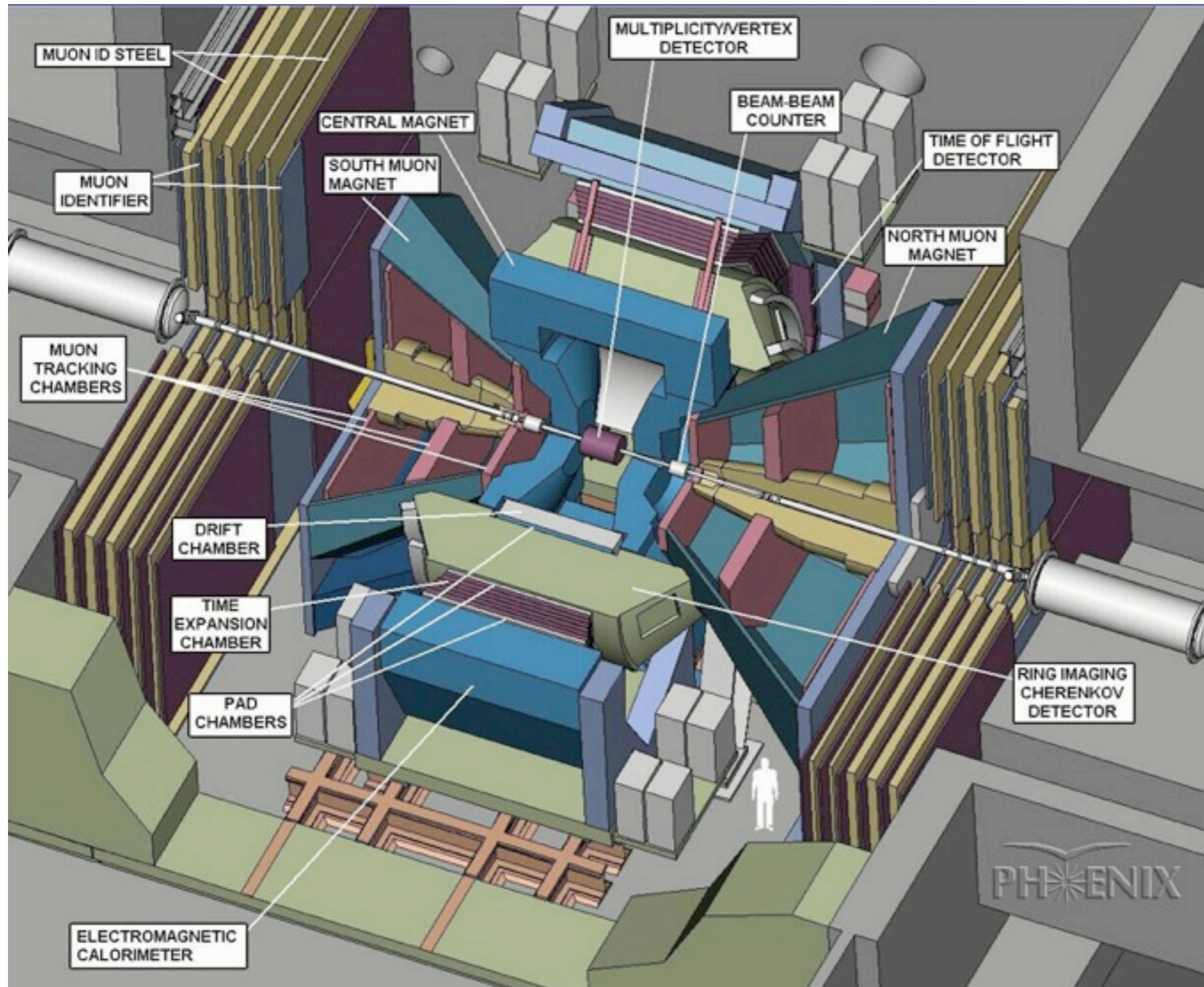
22-Jul-13	<a href="#">Open and closed heavy-flavour suppres..</a>	SQM2013	Mihee Jo
3-Jun-13	<a href="#">Quarkonia studies in heavy-ion collision..</a>	HIF-Q	Mihee Jo
24-Apr-13	<a href="#">First pPb Run at LHC and Data Taking b..</a>	KPS 2013 ..	Kisoo Lee
22-Apr-13	<a href="#">Charmonium suppression in Pb-Pb collisi..</a>	Quarkoniu..	Hyunchul Kim
22-Apr-13	<a href="#">Y(nS) sequential melting in Pb-Pb collisi..</a>	Quarkoniu..	Byungsik Hong
15-Nov-12	<a href="#">Recent Quarkonia results from CMS</a>	ATHIC2012	Hyunchul Kim
14-Nov-12	<a href="#">Overview of Heavy-Ion Results from CM..</a>	ATHIC2012	Byungsik Hong
13-Aug-12	<a href="#">Suppression of open bottom at high pT ..</a>	QM2012	Mihee Jo
13-Aug-12	<a href="#">Detailed measurements of charmonium ..</a>	QM2012	Dong Ho Moon
15-Jul-12	<a href="#">Heavy flavor and Quarkonia in heavy-io..</a>	HI-LHC12	Hyunchul Kim
27-May-12	<a href="#">Measurement of charmonium productio..</a>	HardProbes..	Dong Ho Moon
14-May-12	<a href="#">LHC results on charmonium in heavy ions</a>	Charm 2012	Byungsik Hong
26-Apr-12	<a href="#">Overview of Heavy-Ion Results from CM..</a>	KPS 2012 ..	Byungsik Hong
26-Apr-12	<a href="#">Summary of CMS Heavy-Ion Run in 2011</a>	KPS 2012 ..	Hyunchul Kim
26-Mar-12	<a href="#">Measurement of quarkonium production ..</a>	7HighpT	Mihee Jo
21-Mar-12	<a href="#">Measurement of prompt and non-prom..</a>	2012 Stude..	Mihee Jo
26-Sep-11	<a href="#">Dihadron correlations in pp and PbPb col..</a>	ISMD2011	Ji Hyun Kim
18-Sep-11	<a href="#">Heavy-flavor production in CMS</a>	SQM	Byungsik Hong
18-Jul-11	<a href="#">Quarkonium results from CMS</a>	Jet physics ..	Hyunchul Kim
6-Jul-11	<a href="#">Dimuon results in PbPb and pp collisions ..</a>	EPIC@LHC	Mihee Jo
30-May-11	<a href="#">Quarkonia and Vector Boson production ..</a>	HPHD	Mihee Jo
23-May-11	<a href="#">B-&gt;J/psi measurement in PbPb collision..</a>	QM2011	Mihee Jo
23-May-11	<a href="#">Effect of the polarization on the accepta..</a>	QM2011	Hyunchul Kim
23-May-11	<a href="#">Data-driven efficiencies for di-muon me..</a>	QM2011	Dong Ho Moon
4-Apr-11	<a href="#">Dimuon results in pp and PbPb collisions ..</a>	Utrecht2011	Dong Ho Moon
23-Mar-11	<a href="#">Study of Z boson production in PbPb coll..</a>	LHC studen..	Dong Ho Moon
20-Oct-10	<a href="#">Preparation of the first heavy-ion run di..</a>	KPS	Mihee Jo
18-Oct-10	<a href="#">CMS Heavy-Ion Program with Emphasis ..</a>	ATHIC	Ji Hyun Kim
21-Apr-10	<a href="#">Status of the LHC and the First Results f..</a>	KPS Meeting	Kwang-Souk Sim
18-Aug-09	<a href="#">Heavy-ion physics for high-density QCD ..</a>	NN2009	Byungsik Hong
29-Mar-09	<a href="#">Performance of CMS heavy-ion dimuon t..</a>	QM2009	Ji Hyun Kim
29-Mar-09	<a href="#">Study of the CMS dimuon trigger algorit..</a>	QM2009	Dong Ho Moon
6-Oct-08	<a href="#">Exploring High-Density QCD Matter with ..</a>	SQM2008	Byungsik Hong



## ① Production, Quality assurance, and Installation



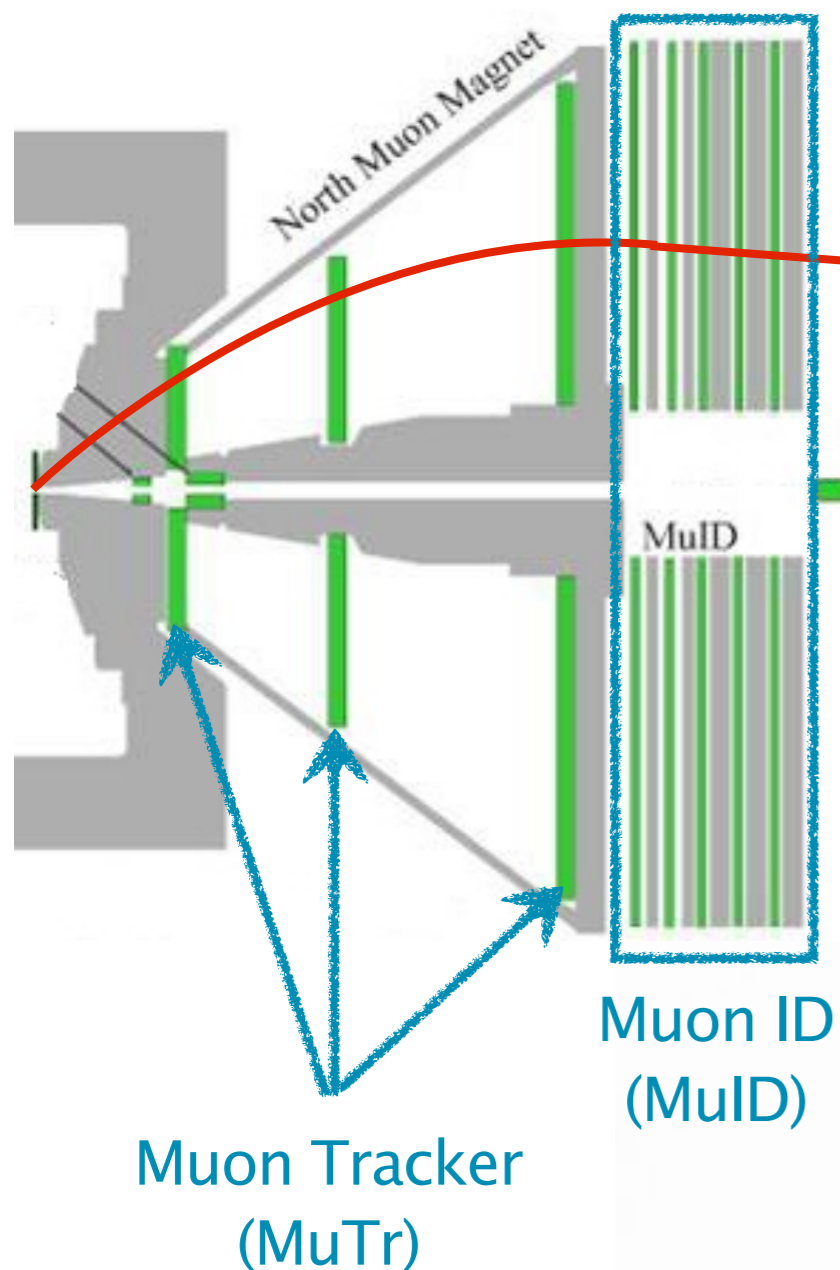
## : Pioneering High-Energy Nuclear Interaction eXperiment



Chong Kim  
Eunah Joo

Collaboration :  
RIKEN-PHENIX group



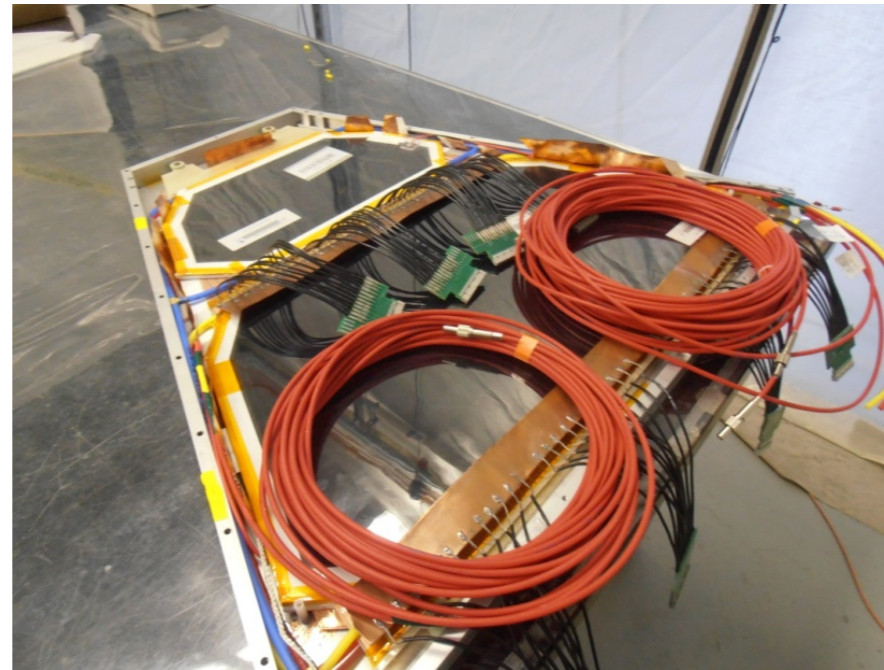
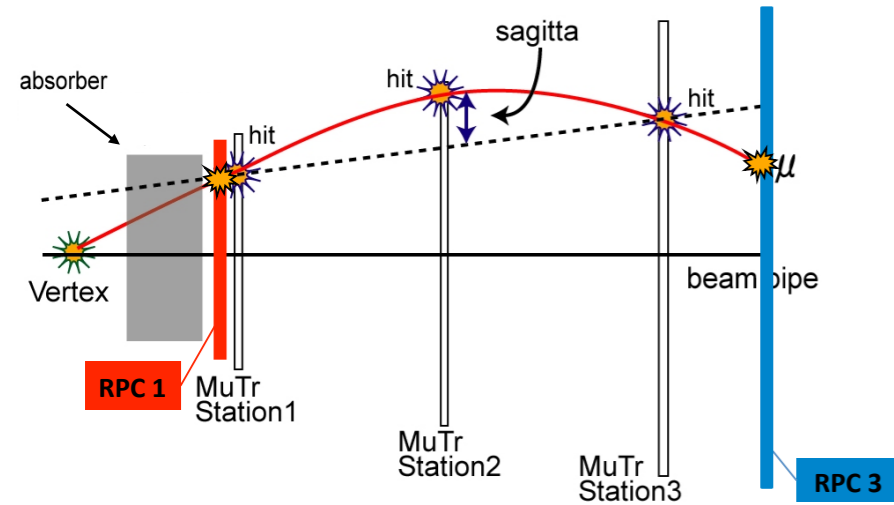


- ⊕ Contribution to CSC production
- ⊕ Quarkonium Production Analysis

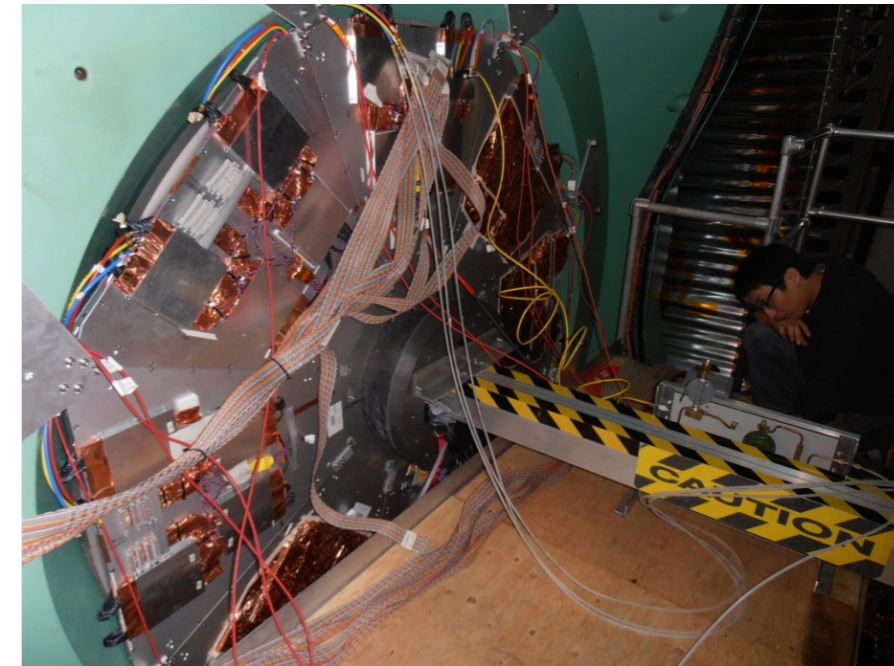


- ⊕ J/ψ Production at Forward Rapidity in  $\sqrt{s_{NN}}=200$  GeV Au+Au Collisions, [Min Jung Kweon](#)
- ⊕ Nuclear Modification Factor of Light Hadrons at Forward Rapidities in Au+Au Collisions at  $\sqrt{s_{NN}}=200$  GeV, [WooJin Park](#)
- ⊕ J/ψ Suppression with respect to the reaction plane in Au+Au collisions at  $\sqrt{s_{NN}}=200$  GeV by the PHENIX detector, [Byung Il Kim](#)
- ⊕ Production of  $\Upsilon$  and  $X_c$  in d + Au and p+p collisions at  $\sqrt{s_{NN}}=200$  GeV, [Kwang-Bok Lee](#)

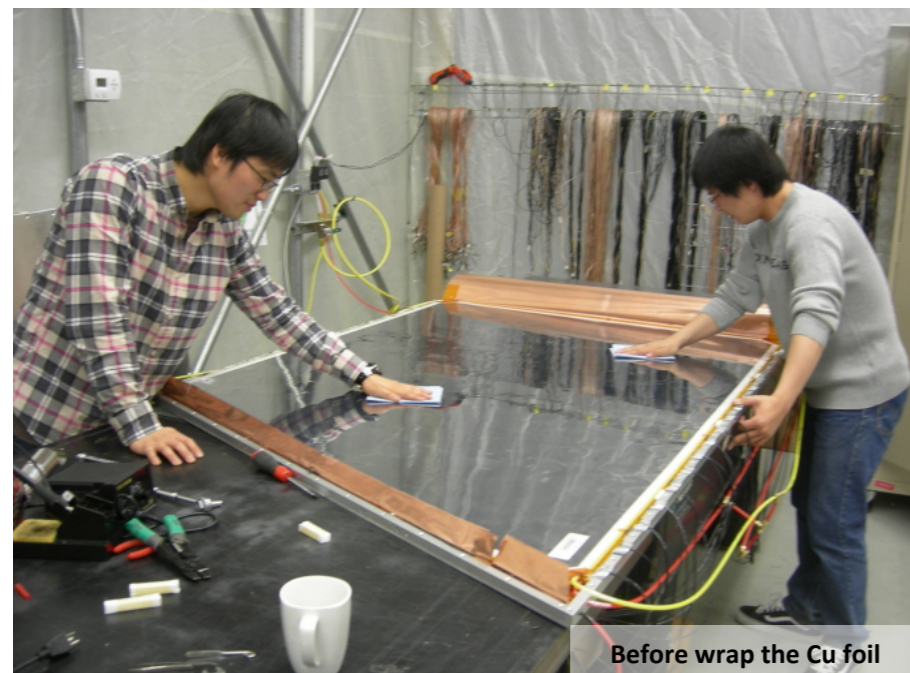
## Production, Quality assurance, and Installation



RPC1N - installation (Sep. 22<sup>nd</sup>, 2011)



RPC3S - installation (Sep. 22<sup>nd</sup>, 2010)

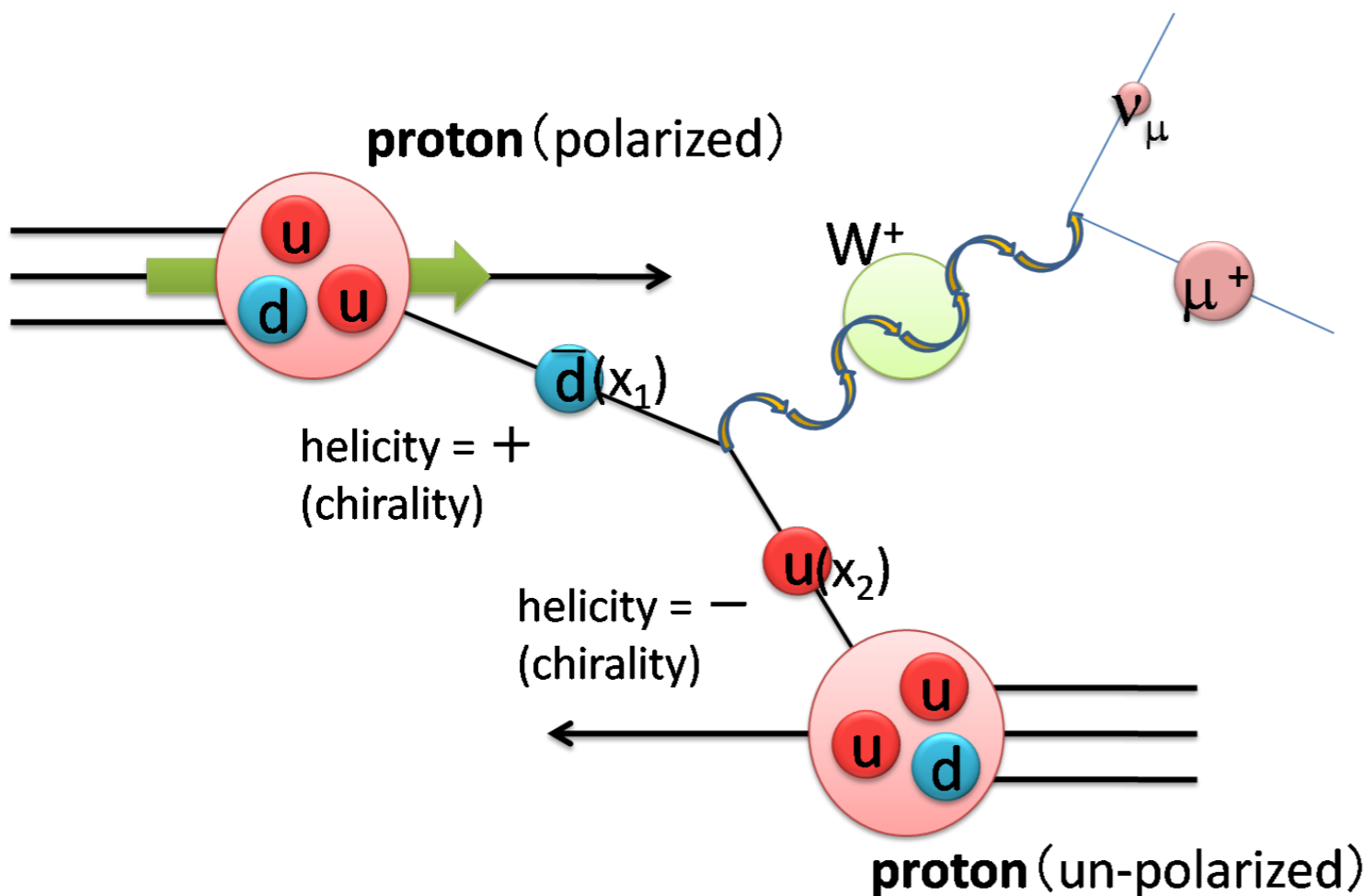


## Spin Crisis

- Proton spin is NOT a simple sum of its constituent quarks

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_z$$

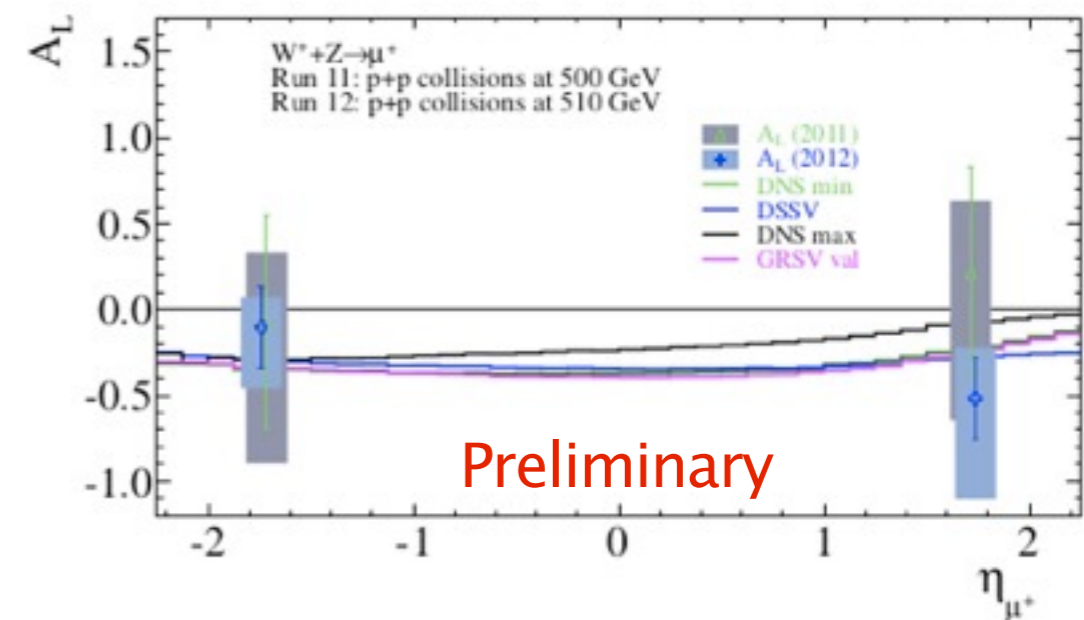
## W measurement in PHENIX



$$A_L^W = \frac{1}{p} \times \frac{N^L(W) - N^R(W)}{N^L(W) + N^R(W)}$$

$$A_L^{W^+} = \frac{\Delta u(x_1)\bar{d}(x_2) - \Delta\bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)} \quad \frac{\Delta u(x_1)}{u(x_1)} \text{ or } -\frac{\Delta\bar{d}(x_1)}{\bar{d}(x_1)}$$

( $x_1 \gg x_2$ )      ( $x_2 \gg x_1$ )



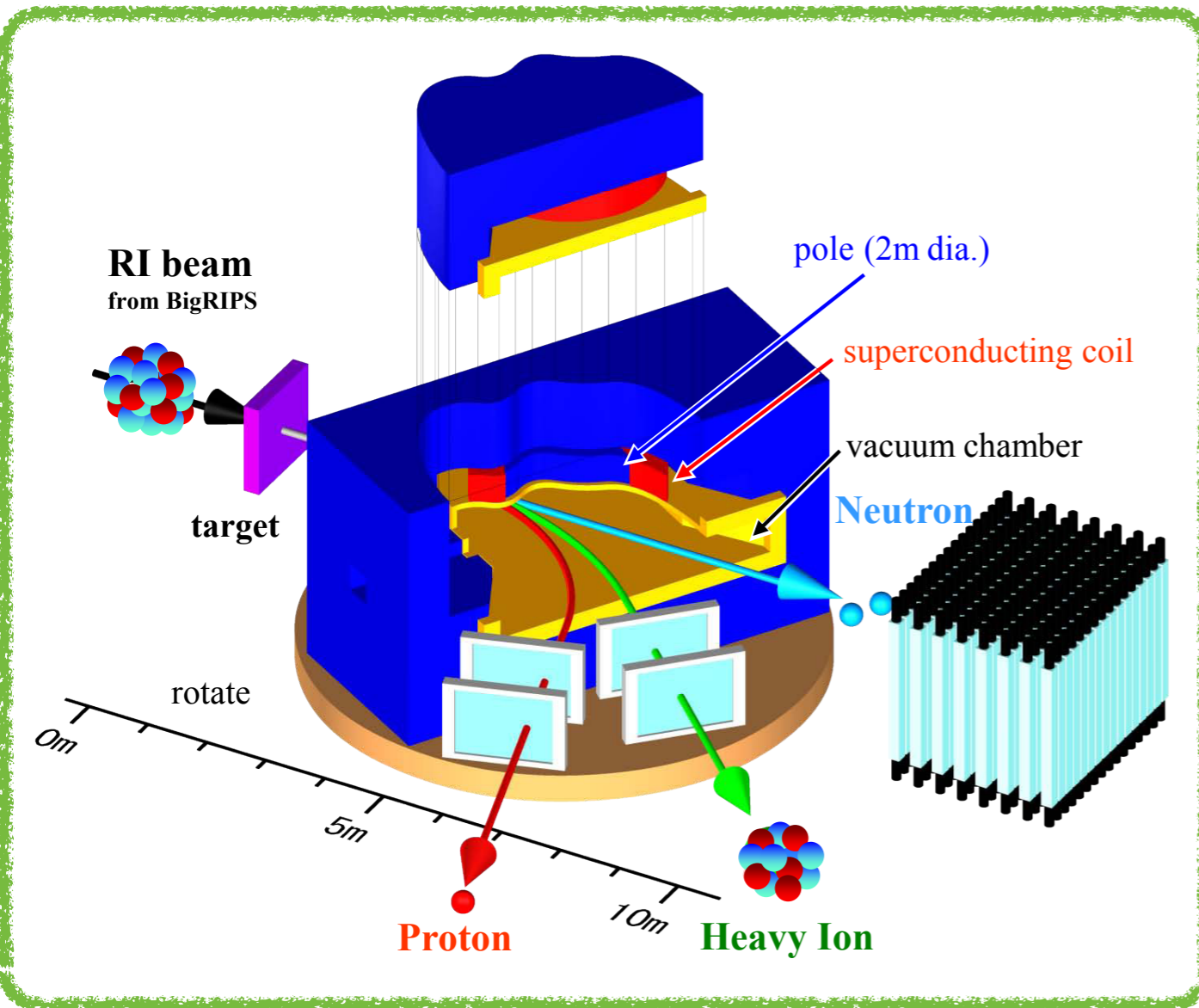
# SAMURAI-TPC/BigRIPS

: Superconducting Analyzer for MULTI-particle  
from Radioactive Isotope beam

Genie Jhang

## Collaboration

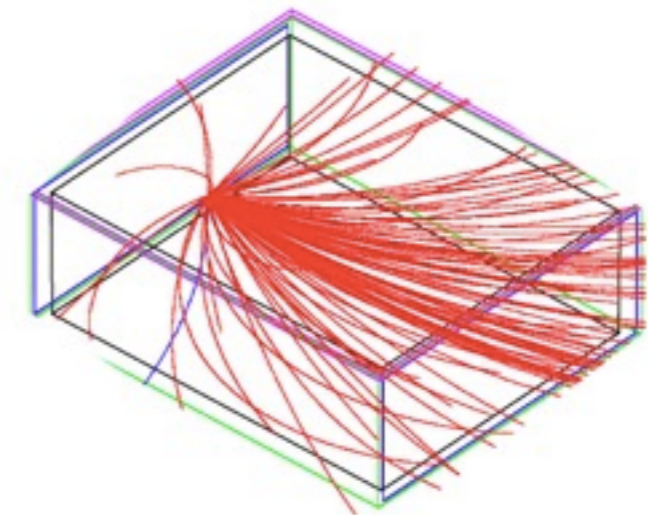
- RIKEN
- MSU
- Kyoto Univ.
- TEXAS A&M



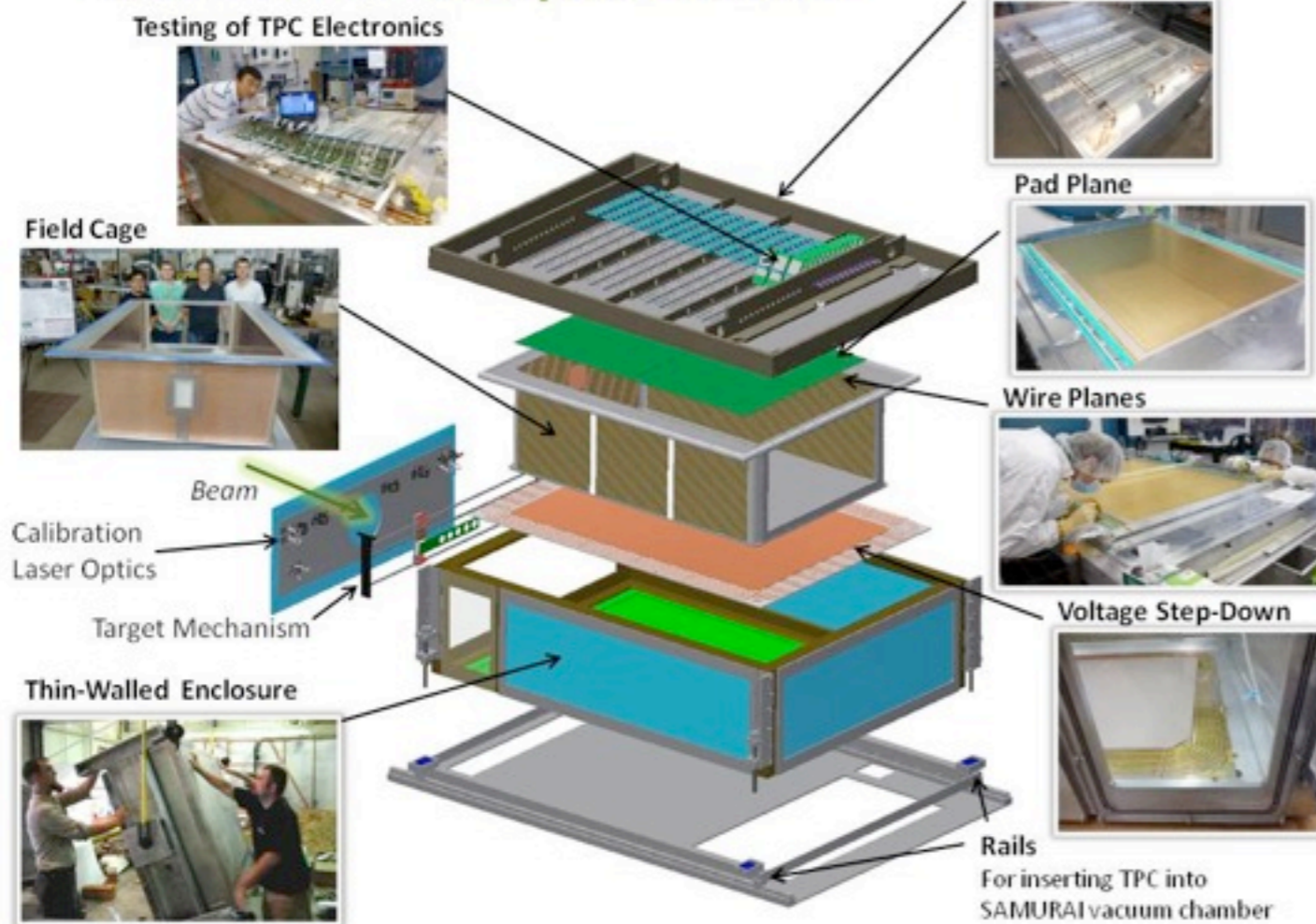
- ⊕ Probe the nuclear symmetry energy at  $\rho > \rho_0$   
:  $\pi^-/\pi^+$ ,  $\tau/{}^3\text{He}$  ratios and flows

GEANT simulation

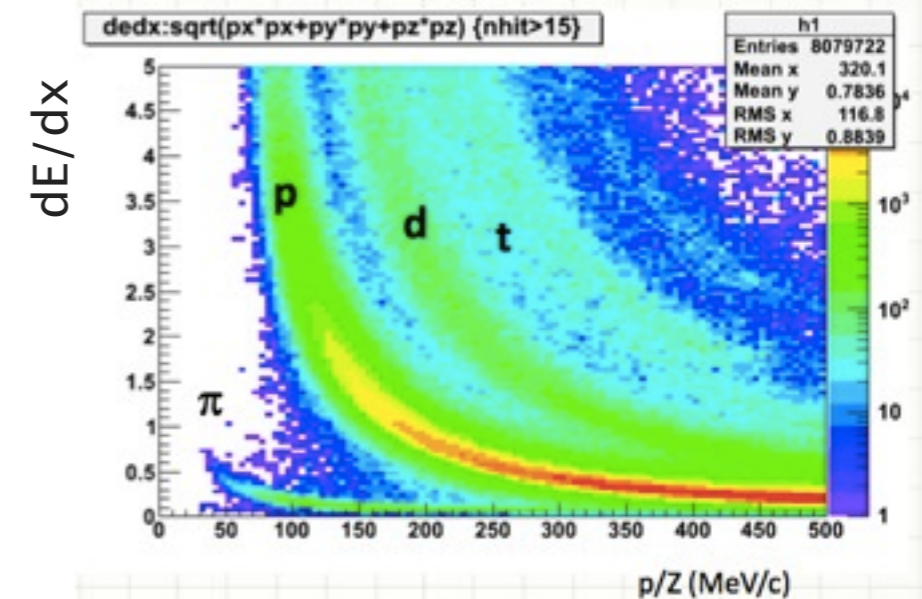
${}^{132}\text{Sn}+{}^{124}\text{Sn}$  collisions at  $E/A=300$  MeV



## SAMURAI TPC: Exploded View



## ${}^{124}\text{Sn}+{}^{124}\text{Sn}$ min. bias



We are actively involved in various research!

- ④ **LAMPS** : Design and R&D for various detectors by simulation tools and the prototype tests.
- ④ **CMS** :  $J/\psi$ ,  $\Upsilon$ , and  $Z$  production (probe for QGP)
- ④ **PHENIX** : Quarkonium production & Spin physics
- ④ RPC production & Installation for CMS & PHENIX
- ④ **SAMURAI-TPC/BigRIPS** : Symmetry energy study



# BACK-UP

# Equation of State (EoS) and Symmetry Energy

## ⊕ Energy of nuclear matter

$$E(\rho, \delta) / A = E(\rho, \delta = 0) + E_{sym}(\rho) \delta^2 + \mathcal{O}(\delta^4) + \dots$$

where  $\rho = \rho_n + \rho_p$  and  $\delta = \frac{\rho_n - \rho_p}{\rho_n + \rho_p}$

## ⊕ $E_{sym}$ = symmetry energy

$$E_{sym} \approx E(\rho, 1) - E(\rho, 0)$$

↑  
pure neutron  
matter

↑  
symmetric  
nuclear matter

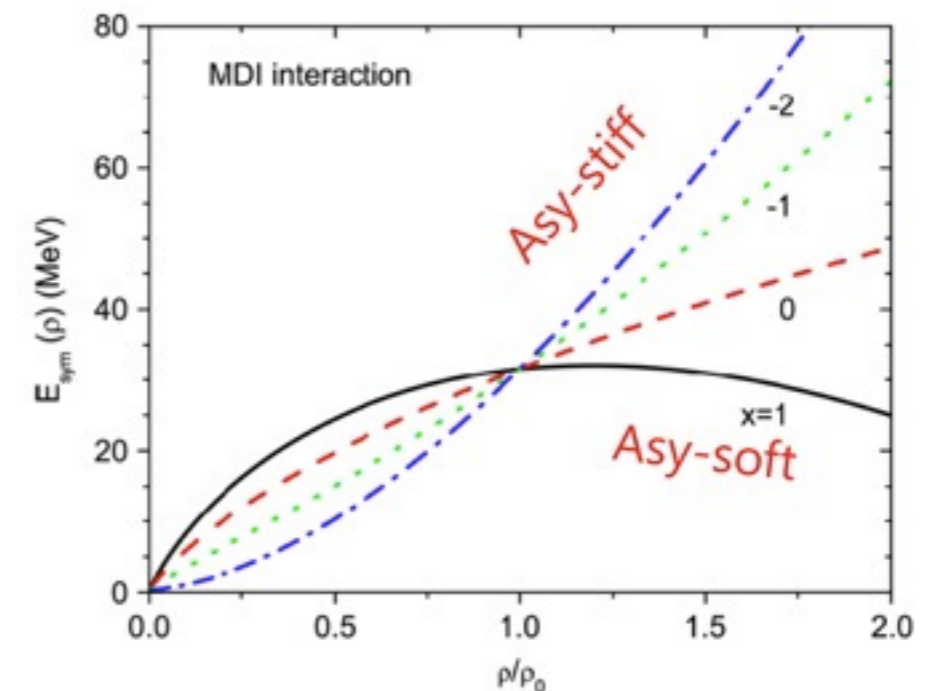
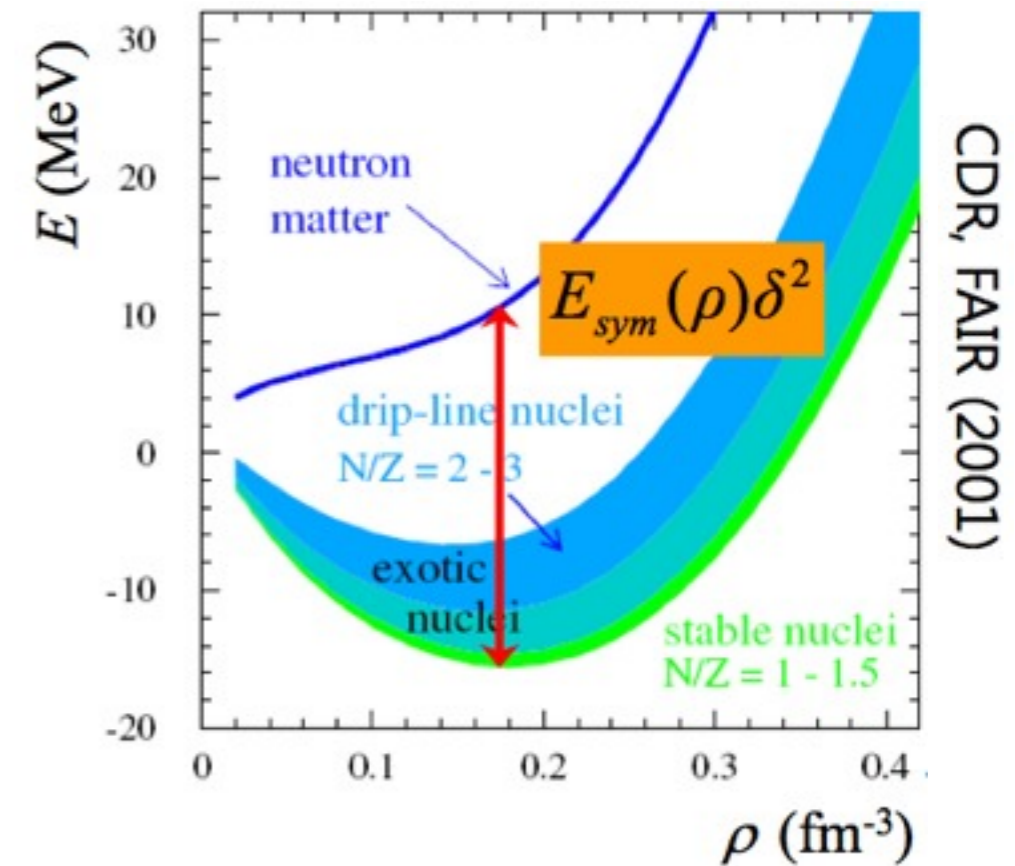
## ⊕ Expansion of $E_{sym}(\rho)$ around $\rho_0$

$$E_{sym}(\rho) = J + \frac{L}{3} \left( \frac{\rho - \rho_0}{\rho_0} \right) + \frac{K_{sym}}{18} \left( \frac{\rho - \rho_0}{\rho_0} \right)^2$$

where

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

$$K_{sym} = 9\rho_0^2 \left. \frac{\partial^2 E_{sym}(\rho)}{\partial \rho^2} \right|_{\rho=\rho_0}$$





## ⊕ **Korea Rare Isotope Accelerator**

: plan to deliver more exotic high-current RI beams by combining ISOL and IFF technologies

## ⊕ **LAMPS**

: full setup for high energy experiments (combination of solenoidal spectrometer, dipole spectrometer and neutron detector array)

## ⊕ **Symmetry energy in EoS**

: crucial to understand the neutron rich matter & several astrophysical objects

: long-standing unsolved problem in nuclear physics

**LAMPS would like to contribute to this effort**

## 1. Particle ratios

:  $n/p$ ,  ${}^3\text{H}/{}^3\text{He}$ ,  ${}^7\text{Li}/{}^7\text{Be}$ ,  $\pi^-/\pi^+$ , etc.

## 2. Collective flow

:  $v_1$  &  $v_2$  of  $n$ ,  $p$ , and heavier clusters

: Azimuthal angle dependence of  $n/p$  ratio with respect to the reaction plane

## 3. Pygmy dipole resonance

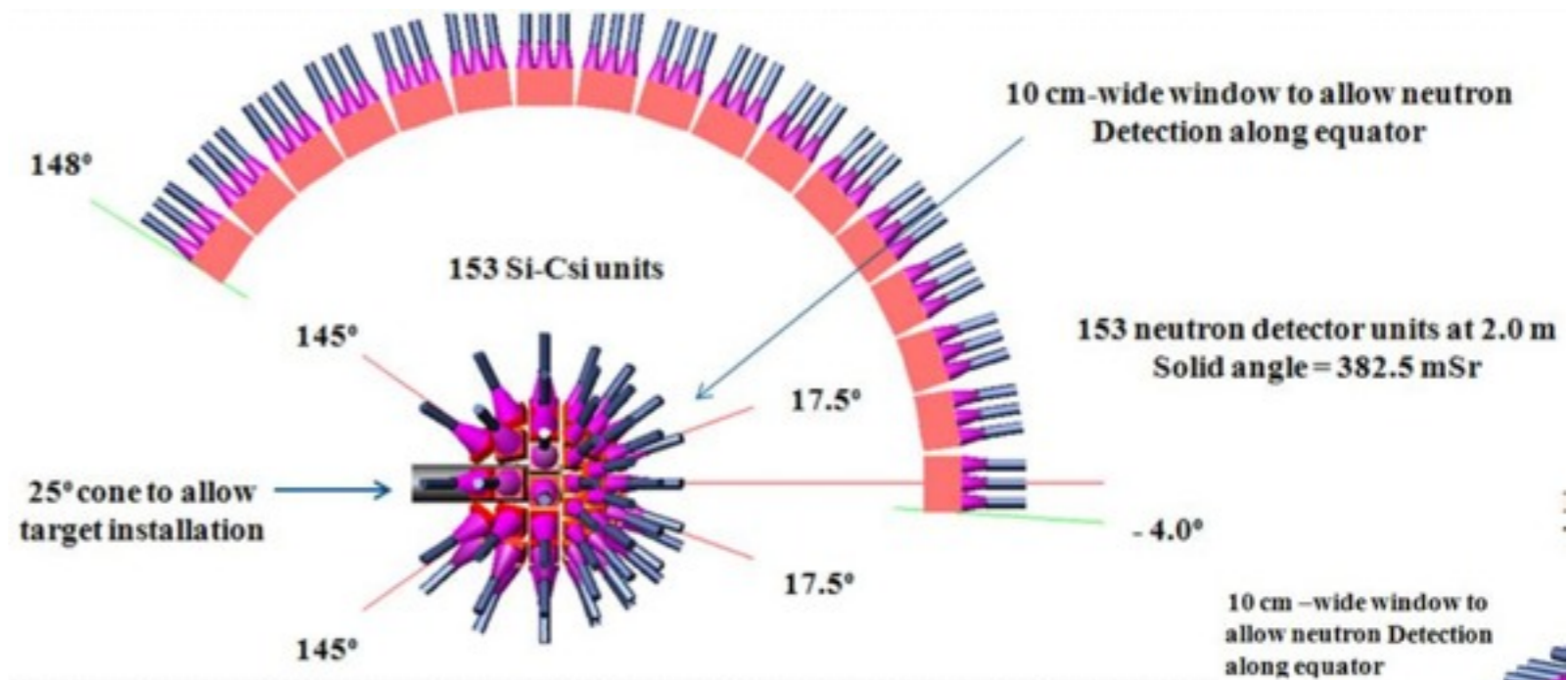
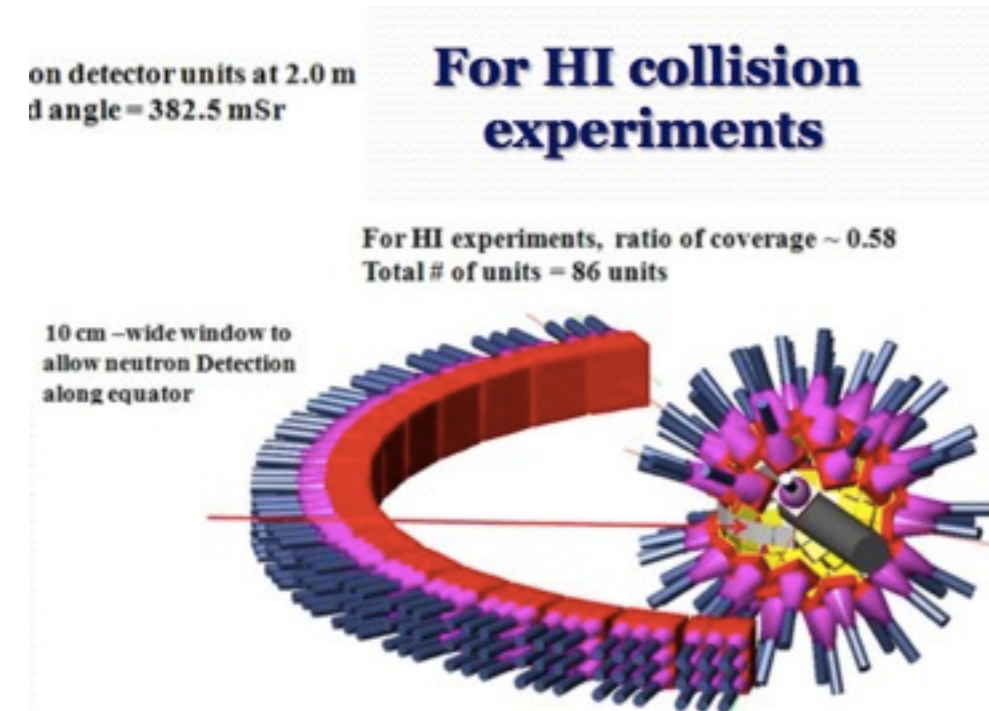
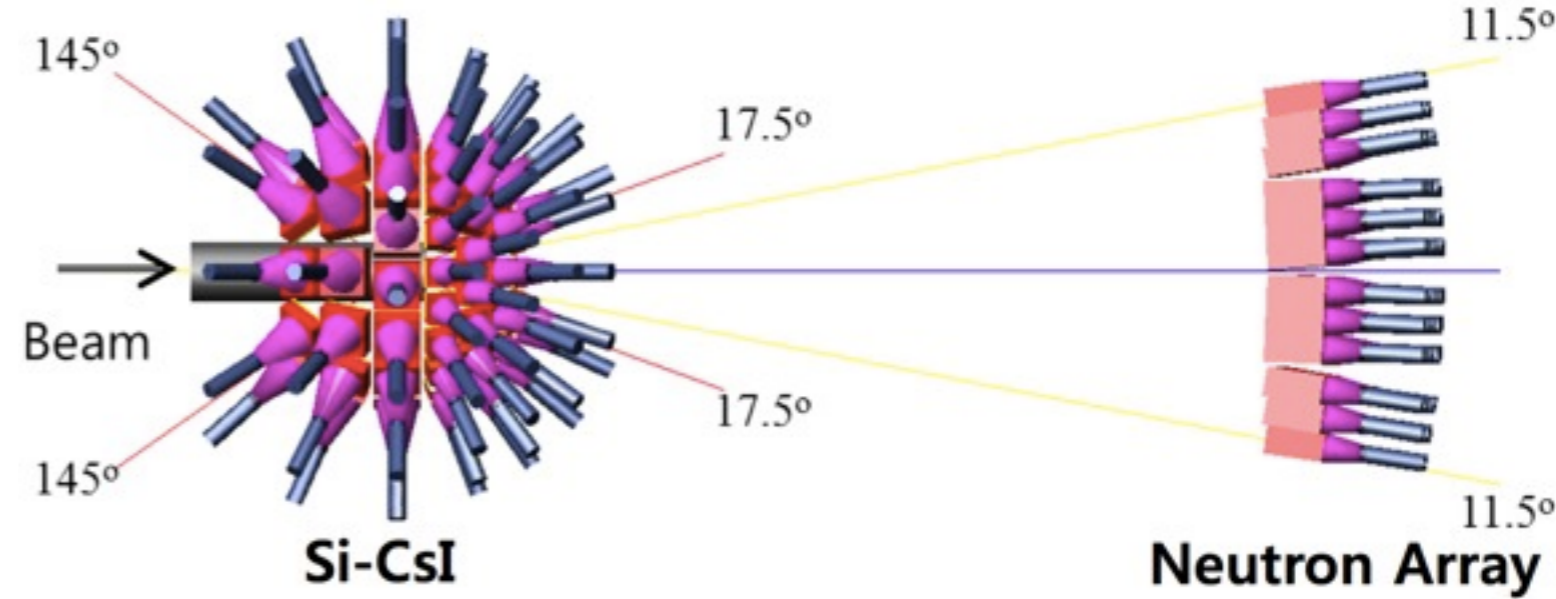
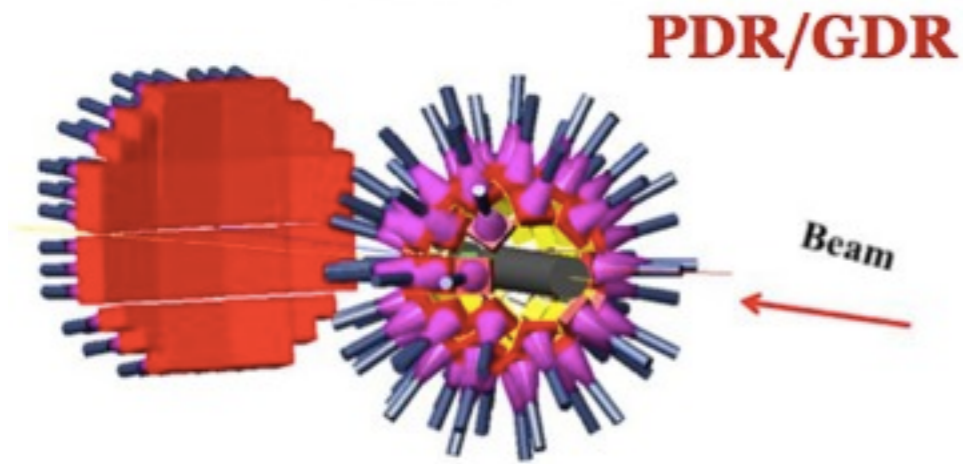
: Energy spectra of gammas

: Related to the radius of  $n$ -skin for unstable nuclei

## 4. Various isospin-dependent phenomena

: Isospin isoscaling in nuclear multifragmentation

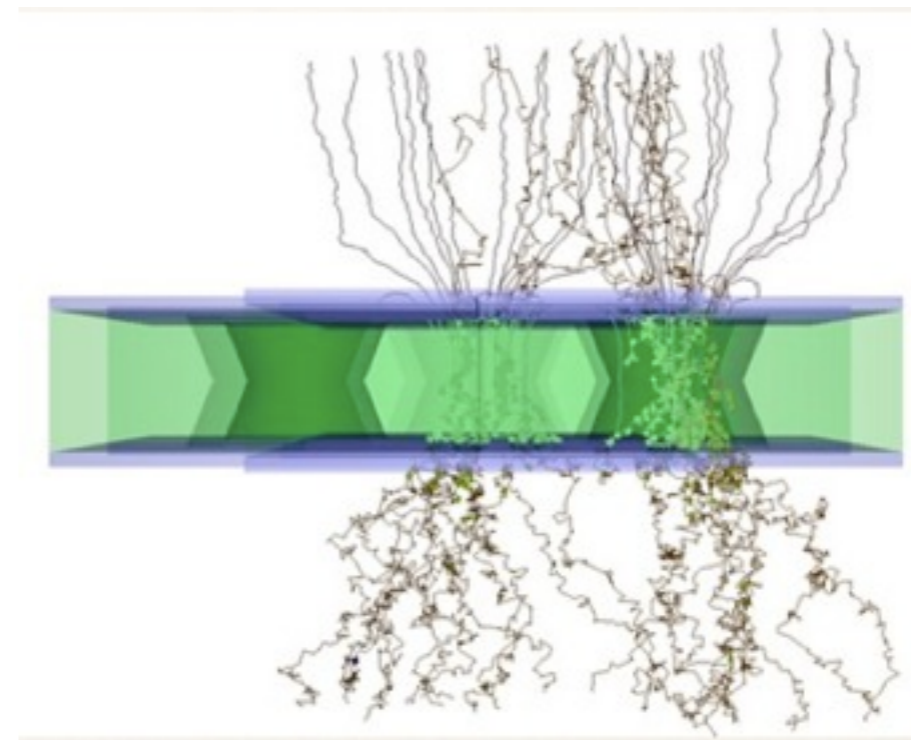
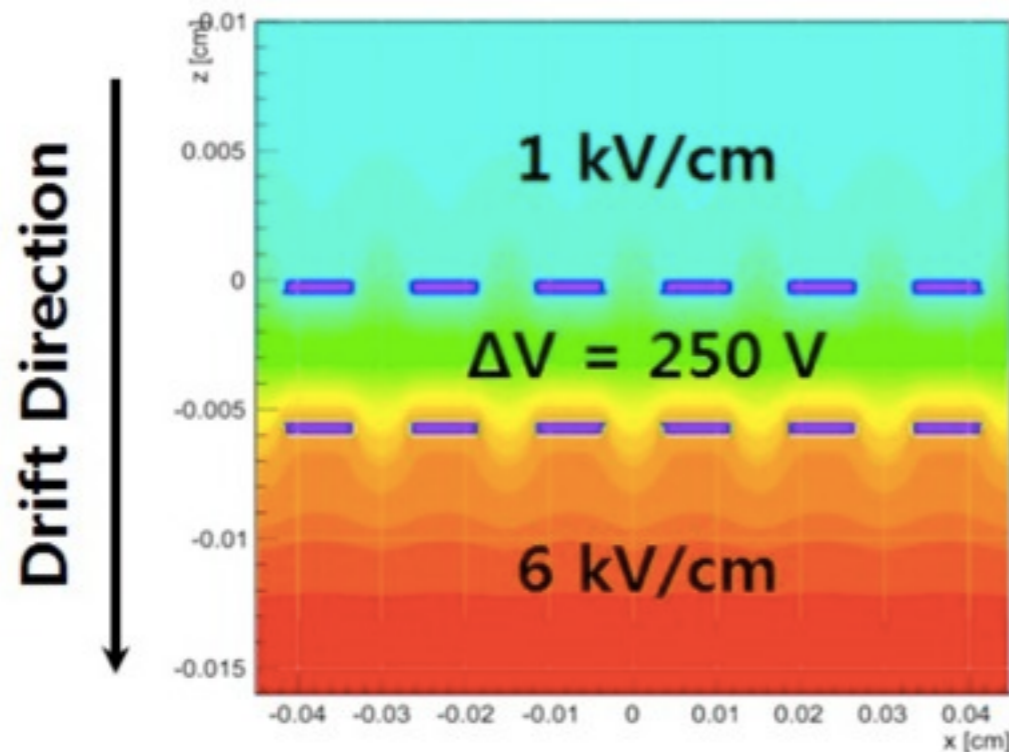
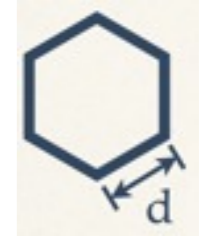
: Isospin diffusion (transport)



# GEM for TPC readout

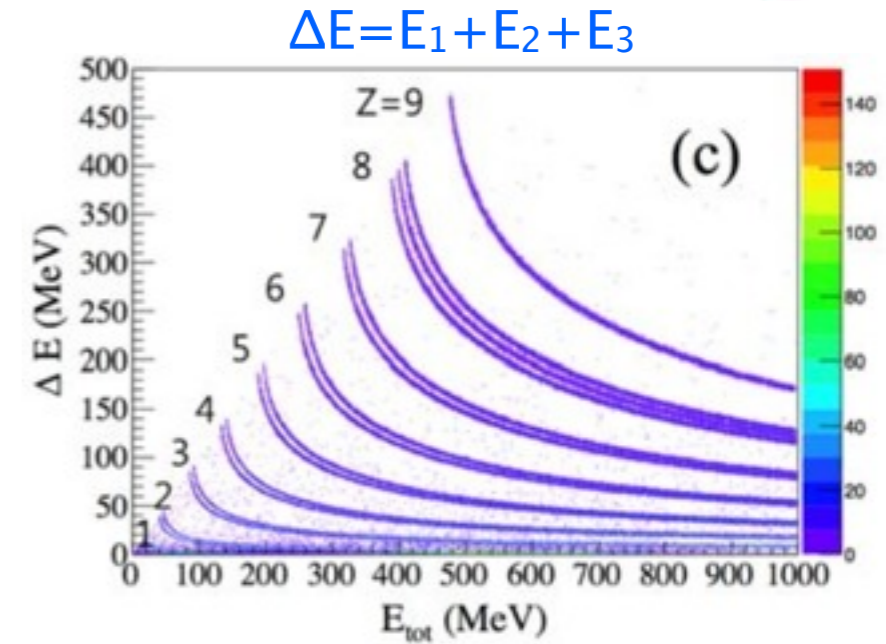
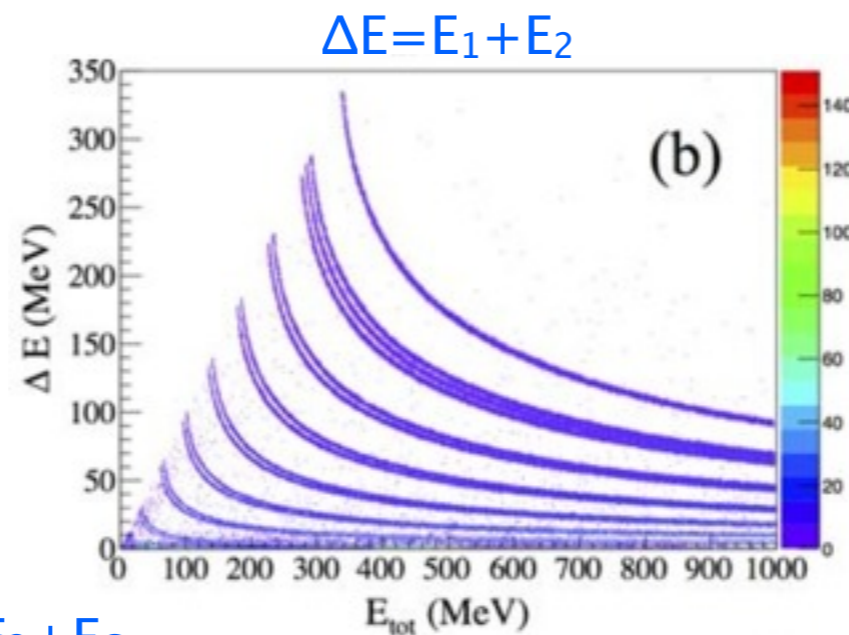
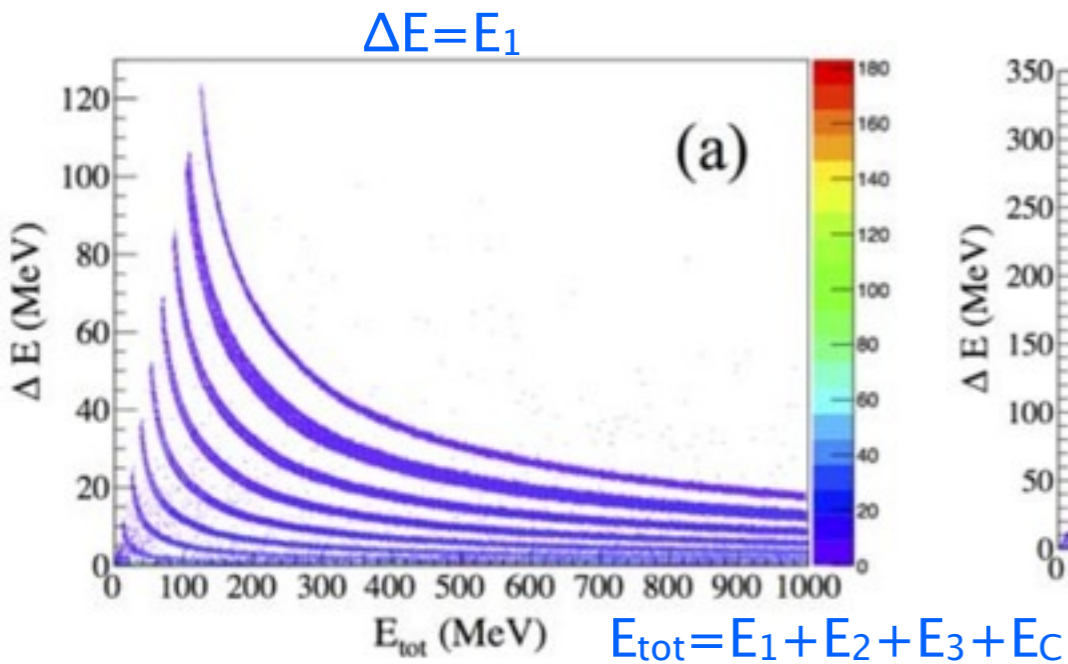
- ⊗ Gas Mixture : Ar 90% + CO<sub>2</sub> 10%
- ⊗ Voltage for each foil : 450 V

- ⊗ PAD
  - : hexagonal shaped
  - : Total number
    - 90,000 for d=2.5mm
    - 20,000 for d=5mm



- ⊗  $\langle \text{Gain} \rangle \sim 1.4 \times 10^6$
- ⊗  $\langle \text{drift velocity} \rangle \sim 50 \mu\text{m}/\text{sec}$ ,
- ⊗  $\langle \text{dispersion} \rangle$  after 60 cm < 3 mm

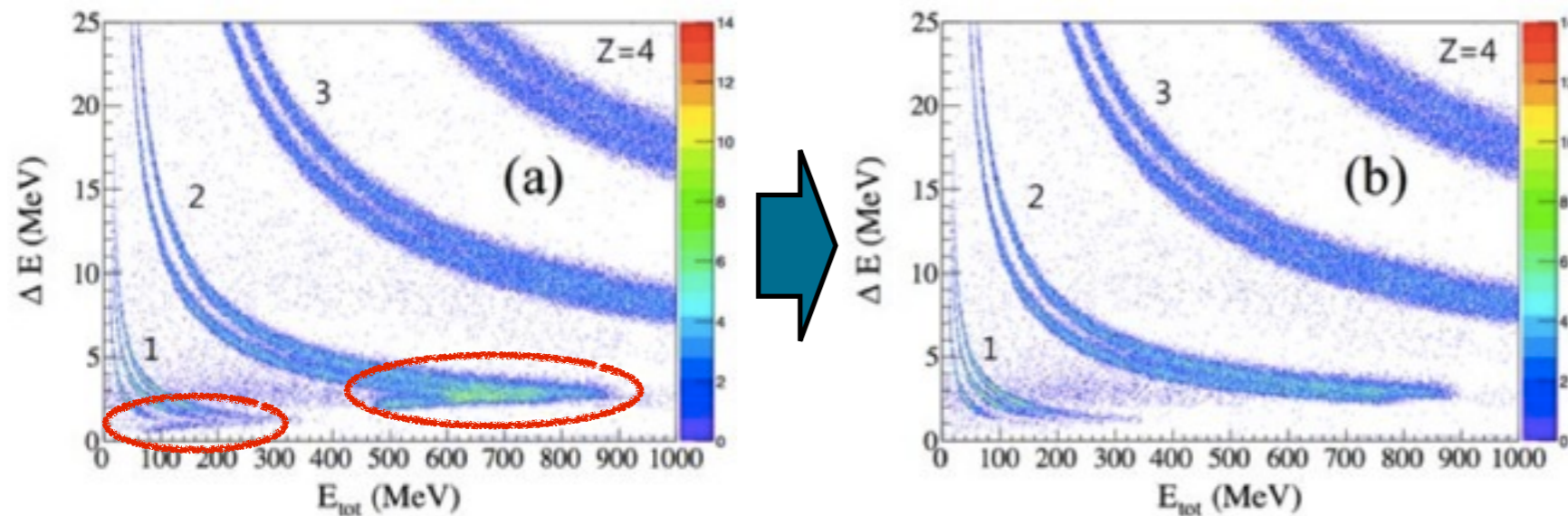
Reference: <http://garfieldpp.web.cern.ch/garfieldpp/>



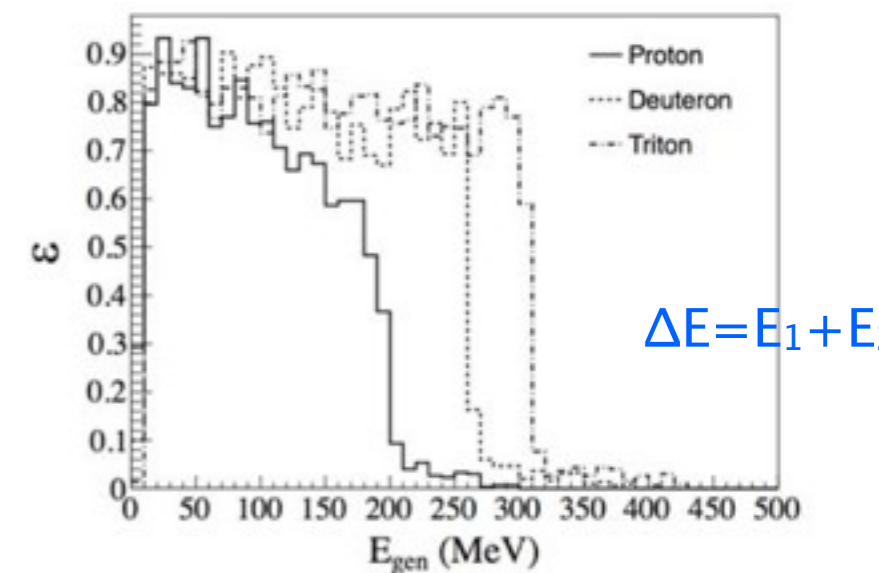
- ⊙  $\Delta E = E_1 + E_2 + E_3$  is preferred at high energy
- ⊙  $\Delta E = E_1$  is preferred at low energy

Suhyun Lee  
Songkyo Lee

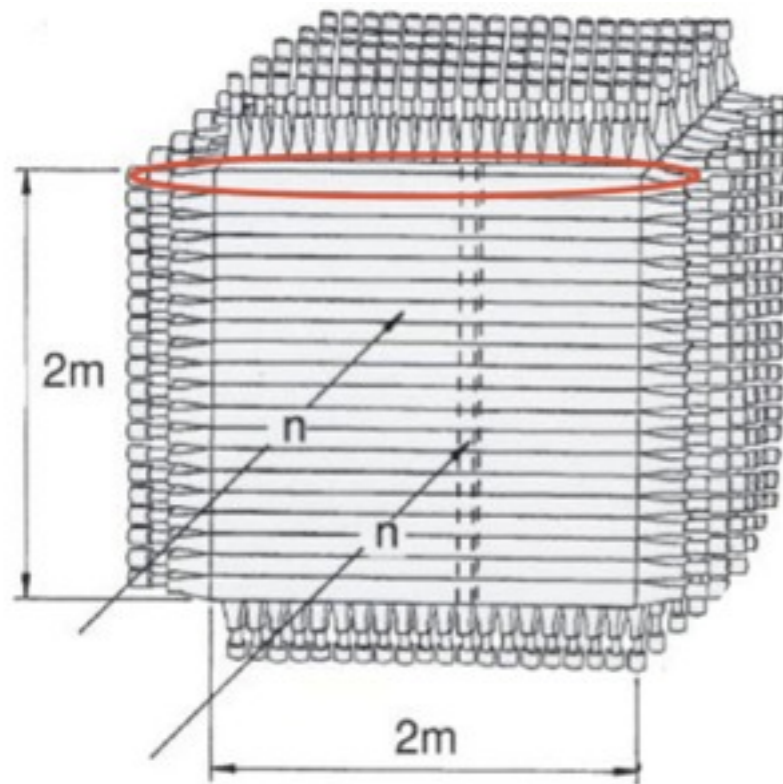
## ⊙ Veto counter



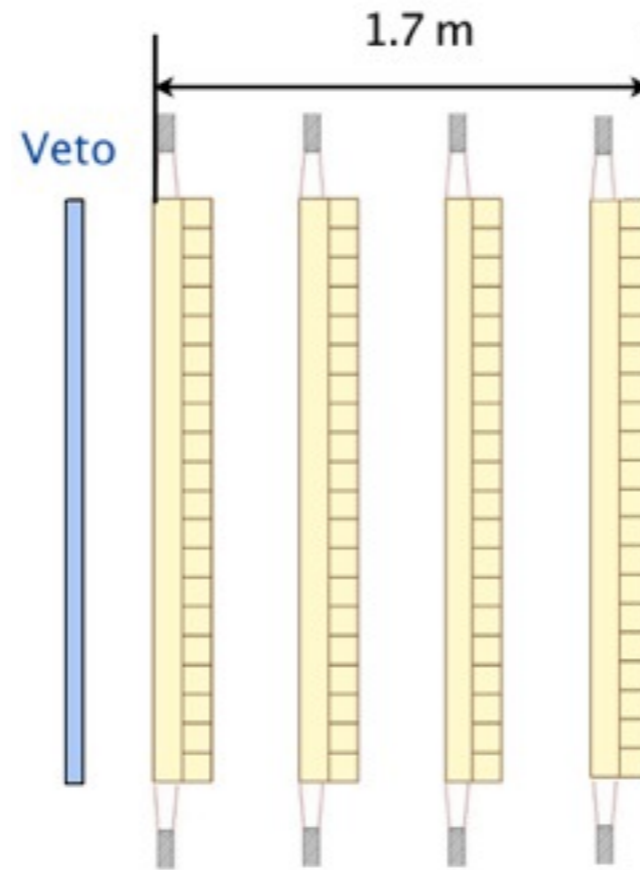
## ⊙ Identification efficiency



[Front View]

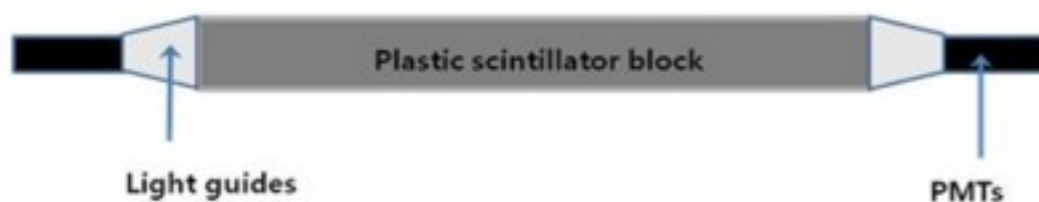


[Side View]



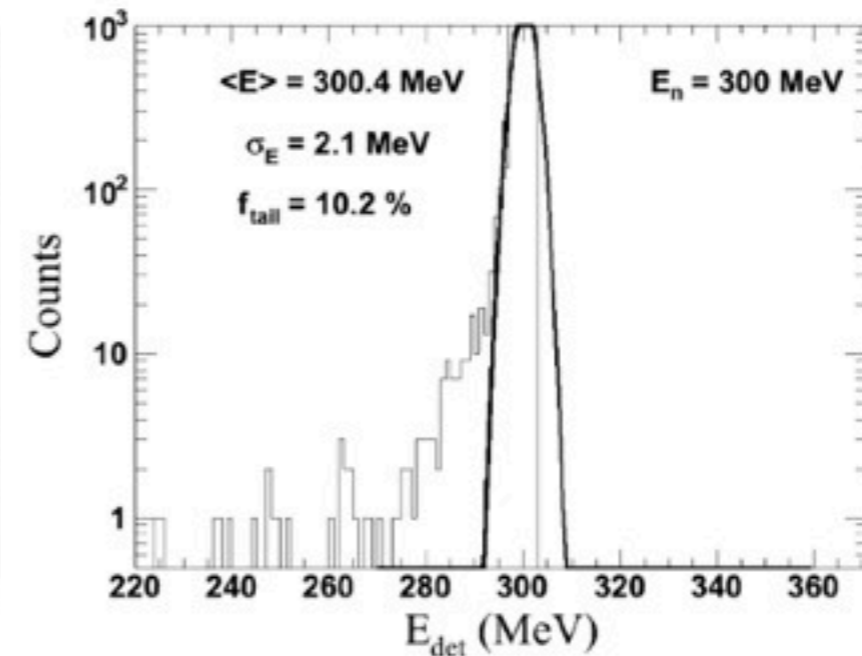
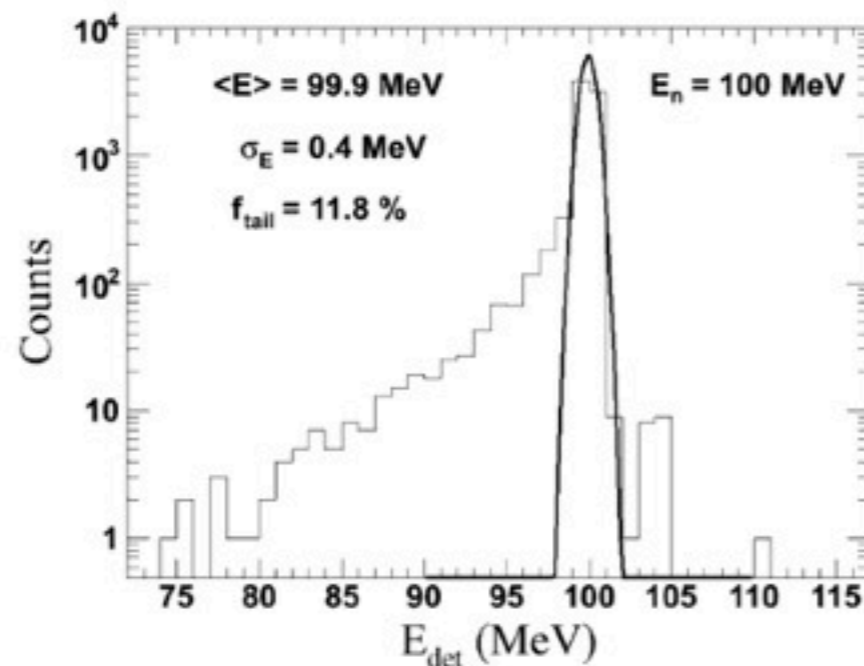
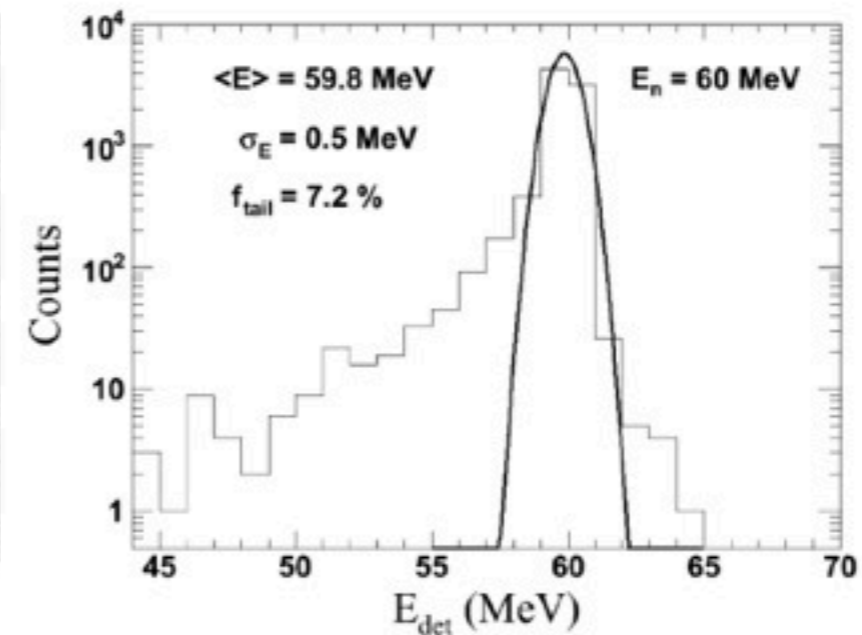
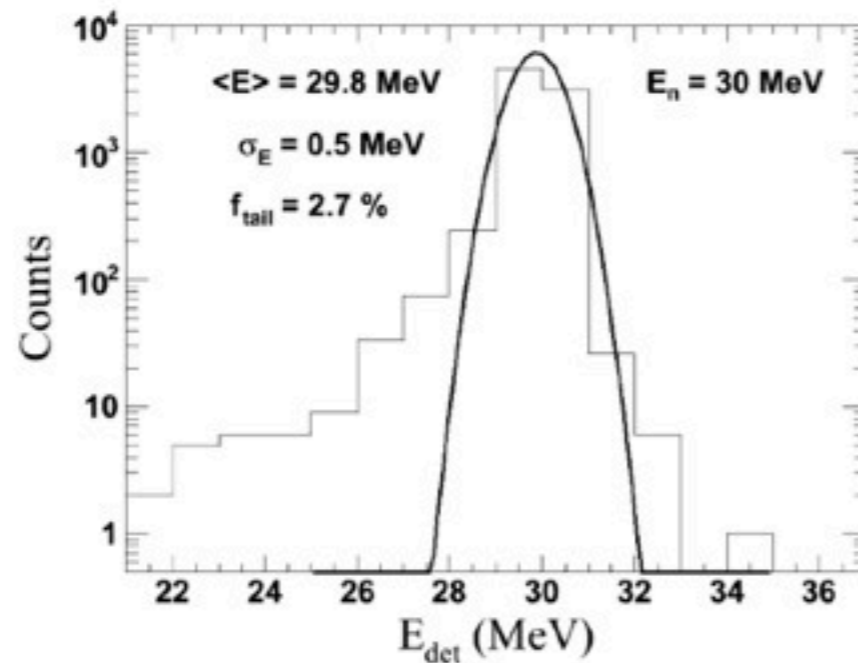
- ⊗ **One layer** :  $(2 \times 2 \times 0.2 \text{ m}^3)$   
horizontal 20 modules  
& vertical 20 modules
- ⊗ **Veto** charged particle

## ⊗ The prototype detector is tested

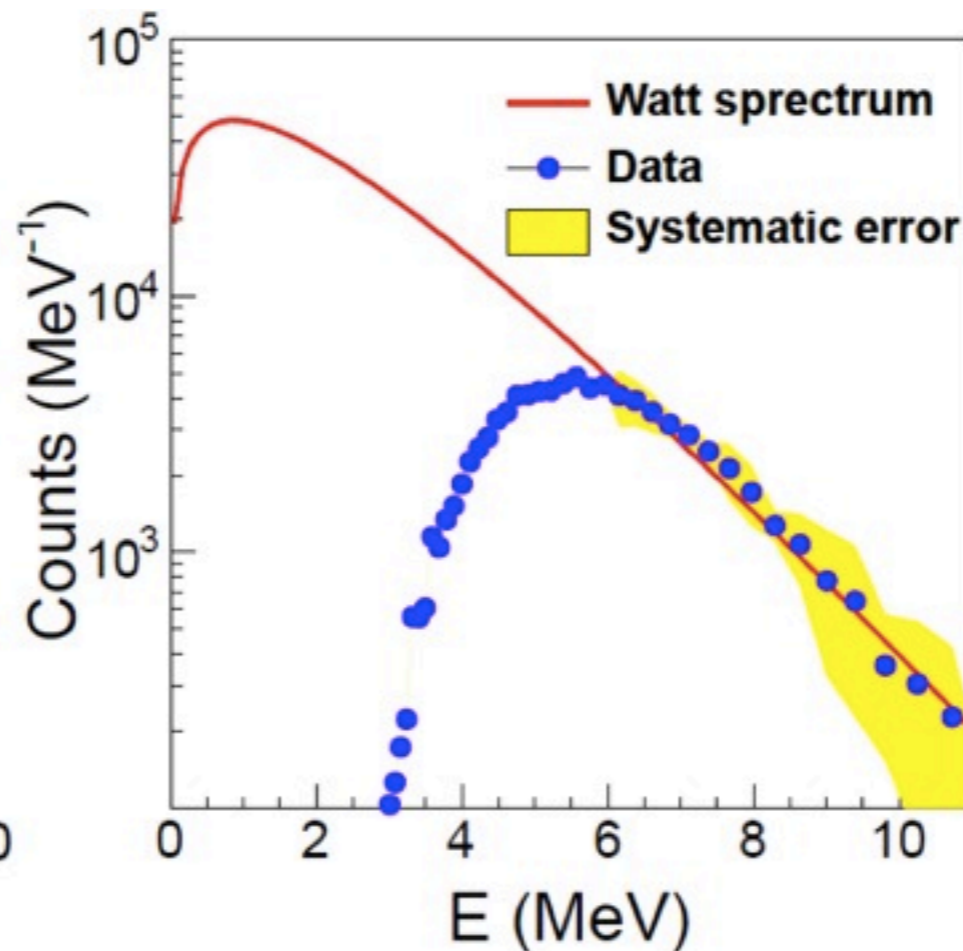
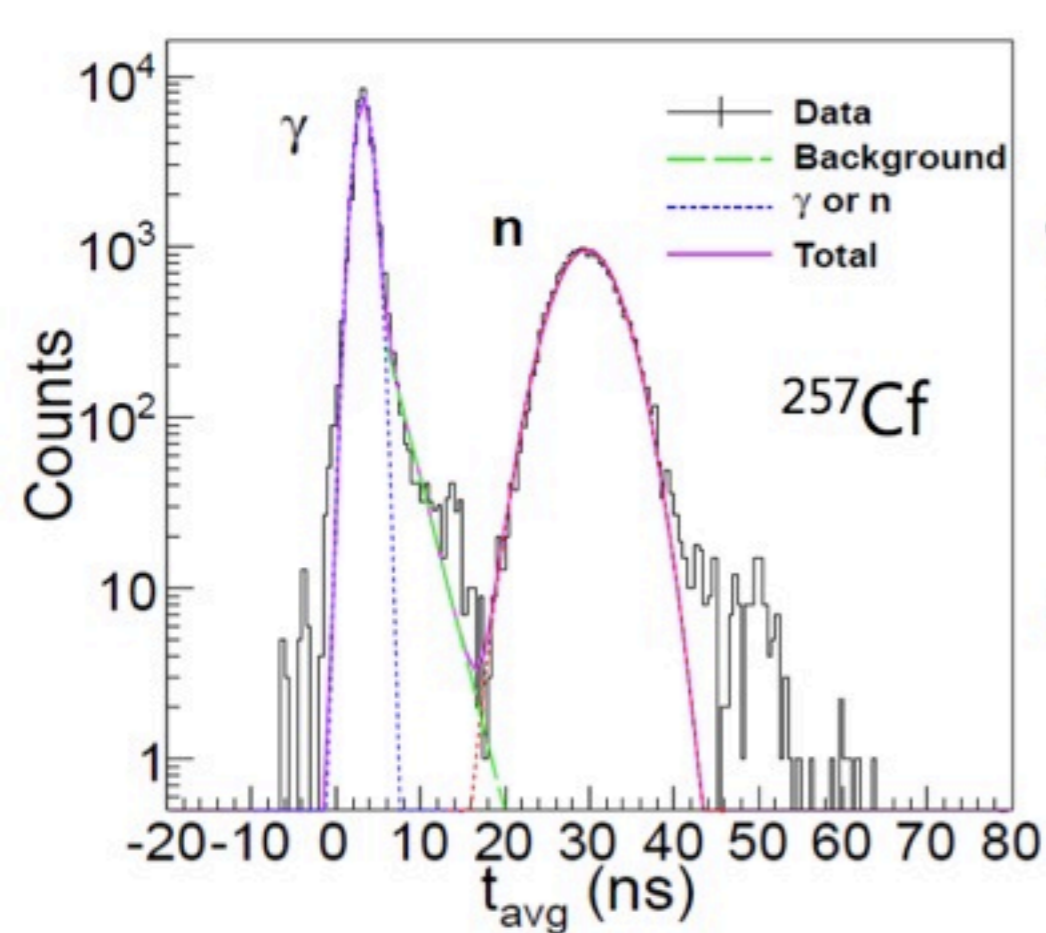


- ⊗ Dimension :  $0.1 \times 0.1 \times 1.0 \text{ m}^3$
- ⊗ Radiation Source :  $^{60}\text{Co}$  and  $^{252}\text{Cf}$
- ⊗ Time Resolution : 488 ps
- ⊗ Position Resolution  $\sim 8 \text{ cm}$  for CFD

- TOF measurement  $\Rightarrow$  Determination of energy



# Neutron Detector Array



$$\frac{dN}{dE} \propto e^{-aE} \sinh[\sqrt{bE}]$$

(  $a=0.88 \text{ MeV}^{-1}$   
 $b=2.0 \text{ MeV}^{-1}$  )

- ④ gammas and neutrons are distinguishable in TOF distribution (traveling length  $\sim 1$  m)
- ④ Measurement of the neutron energy is reliable above 6 MeV.
- ④ Block-shaped neutron detector is also on GEANT4 simulation and prototype test.

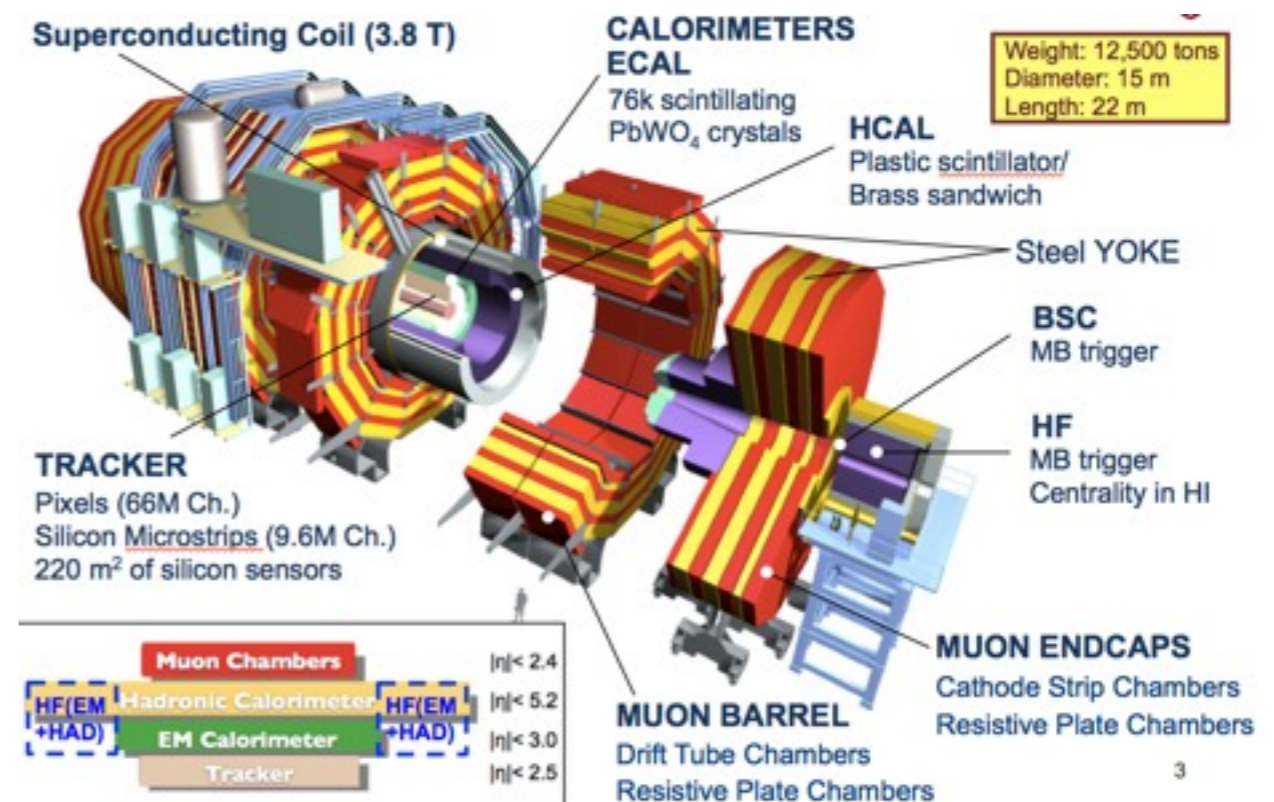


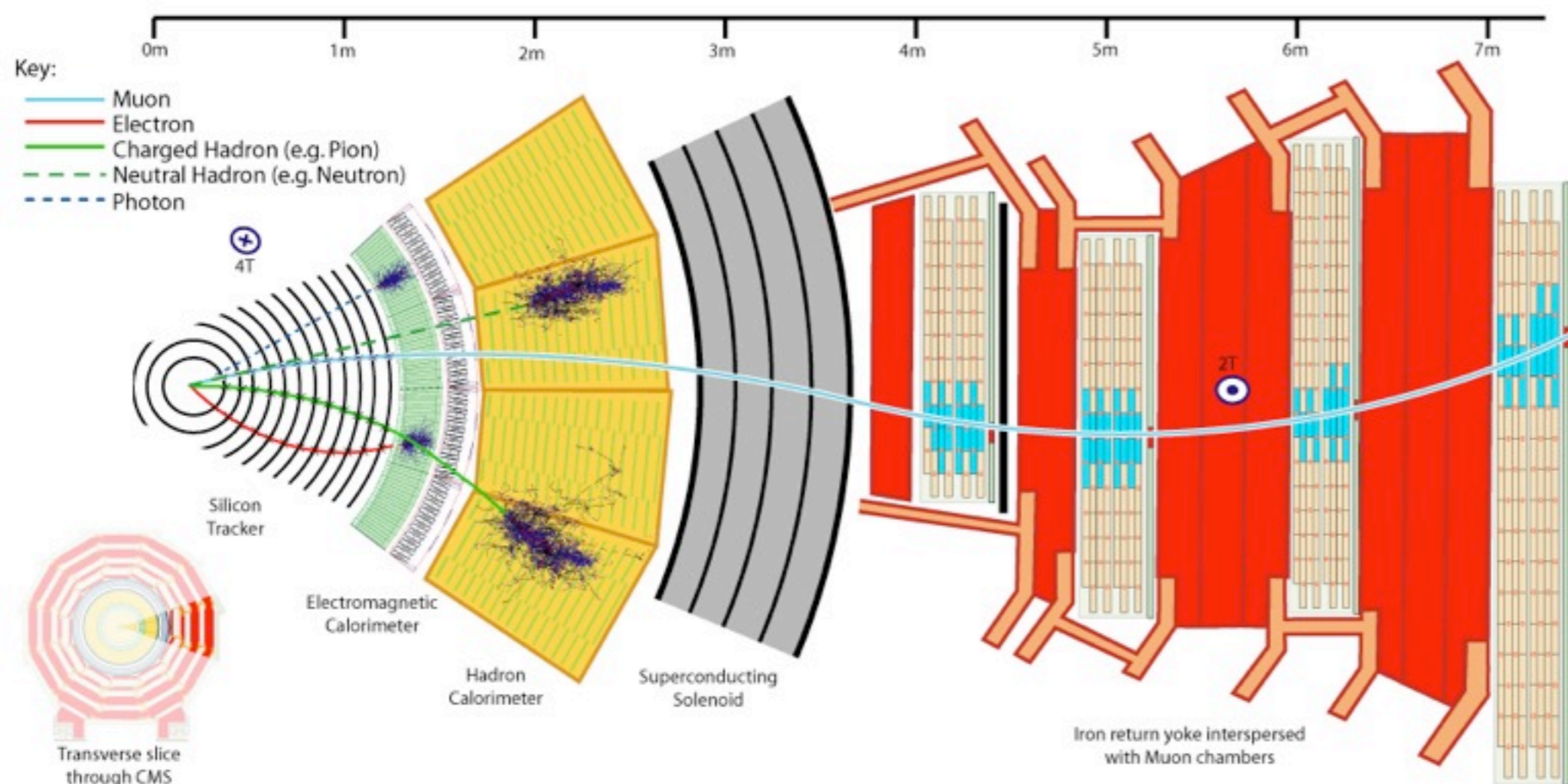
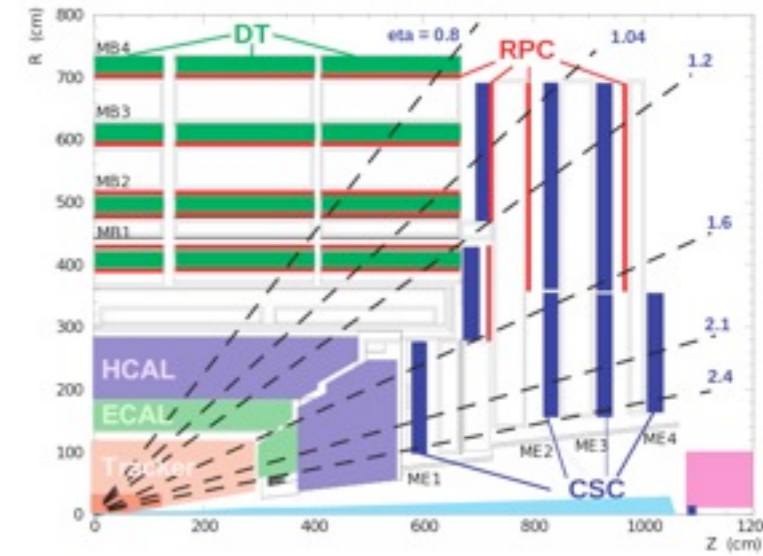
## ⊕ LHC (Larger Hadron Collider)

- ⊕ Max  $\sqrt{S_{NN}}$ (GeV) : 8 TeV (pp), 2.75 TeV (AA)
- ⊕ The world's largest and highest-energy particle accelerator

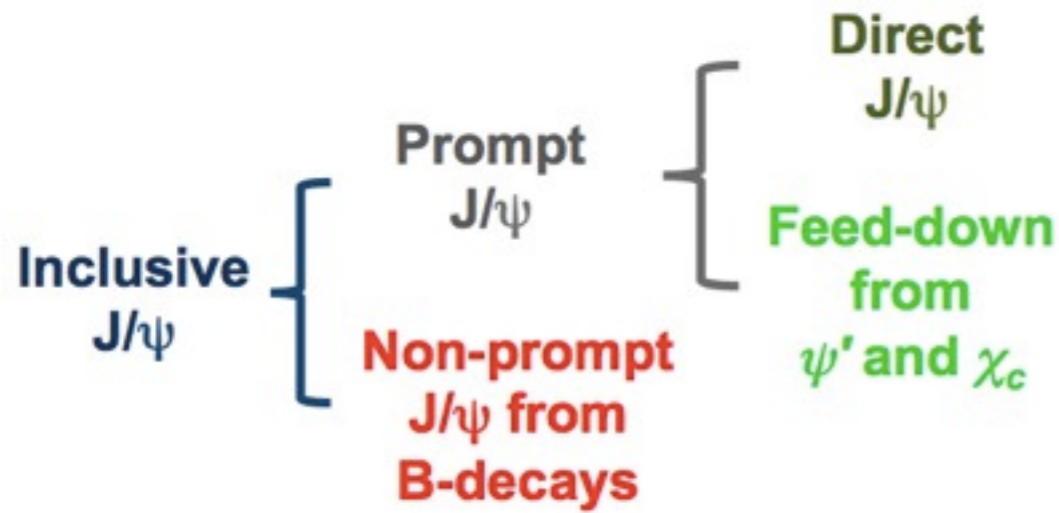
## ⊕ CMS (Compact Muon Solenoid)

- ⊕ general purpose detector  
( TeV-scale physics, Higgs boson, supersymmetry, heavy-ion collisions ..)



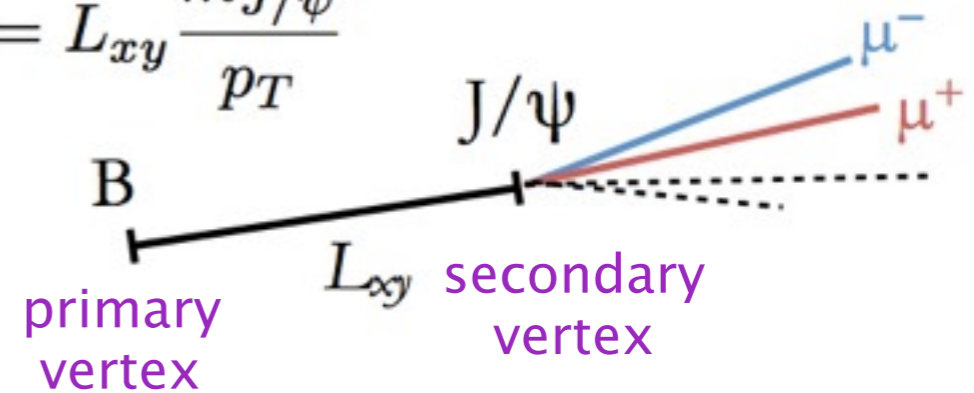


# J/ψ Signal Extraction



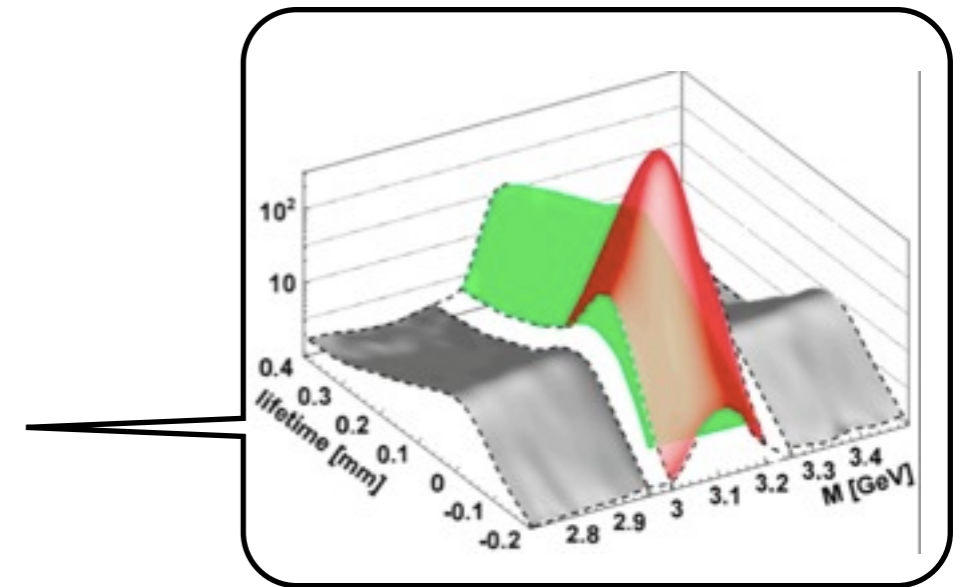
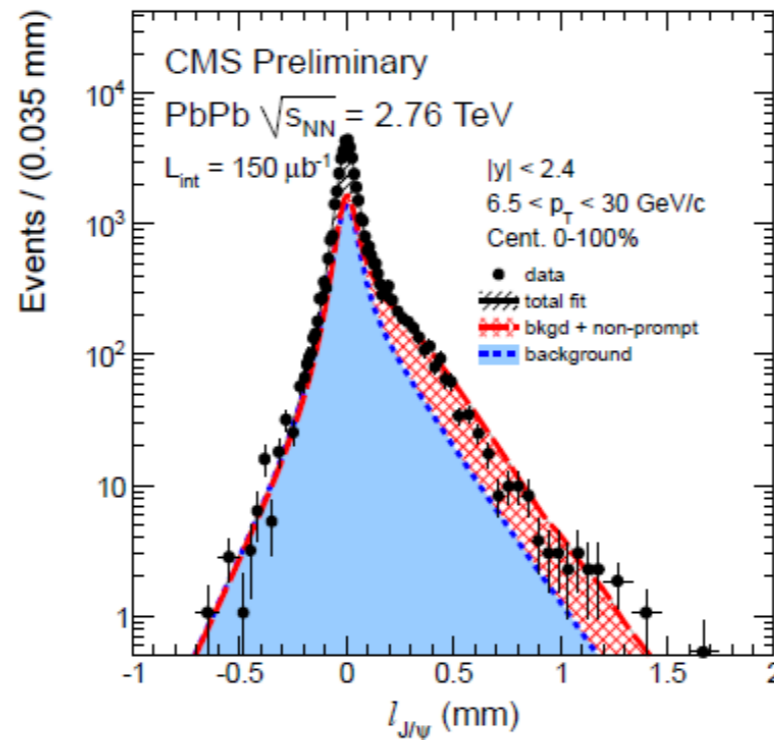
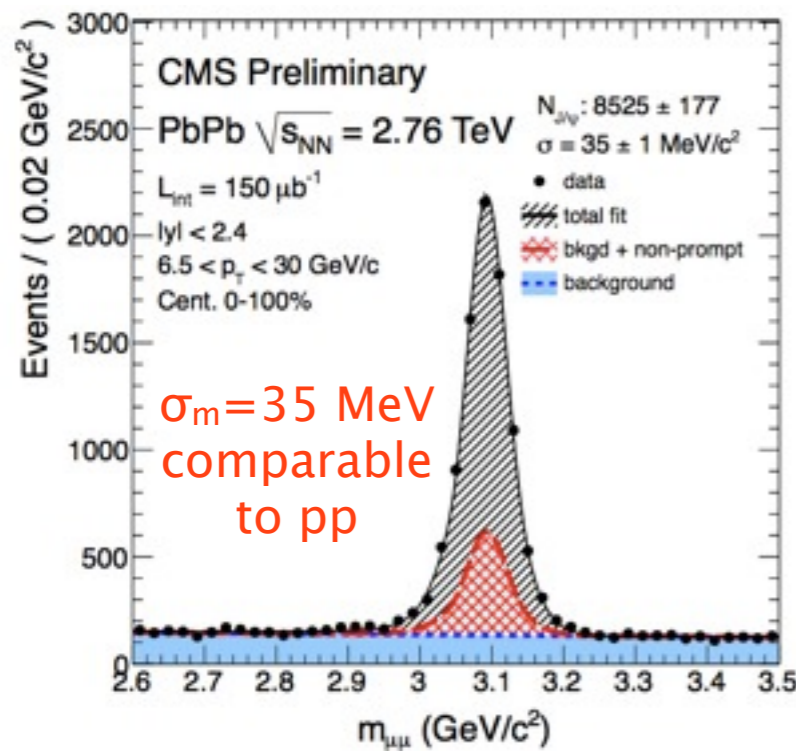
⊙ pseudo-proper decay length

$$\ell_{J/\psi} = L_{xy} \frac{m_{J/\psi}}{p_T}$$



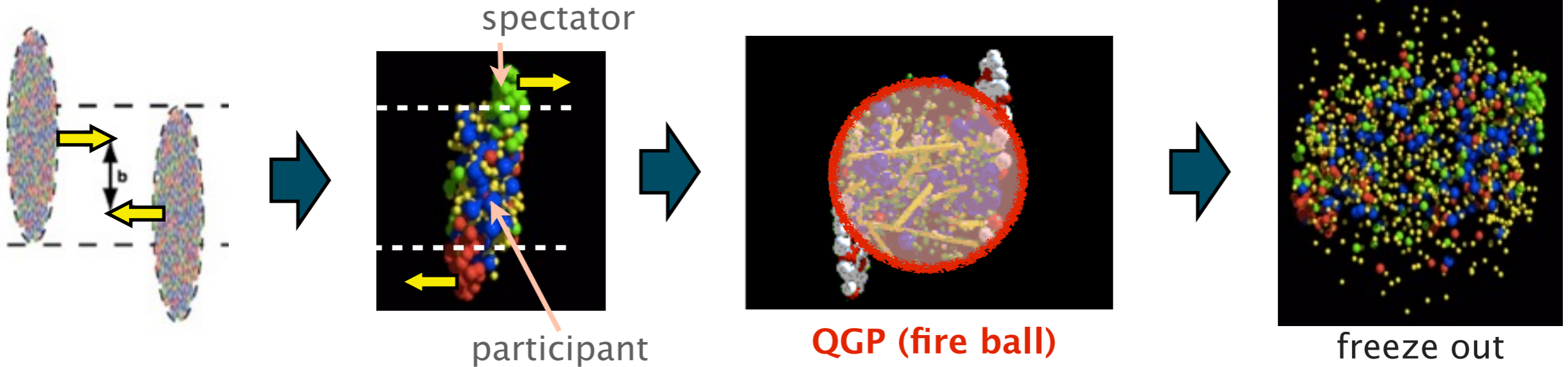
⊙ Reconstruct  $\mu^+\mu^-$  vertex

⊙ Separation of prompt and non-prompt J/ψ  $\Rightarrow$  2D simultaneous fit for  $m_{\mu\mu}$  &  $\ell_{J/\psi}$

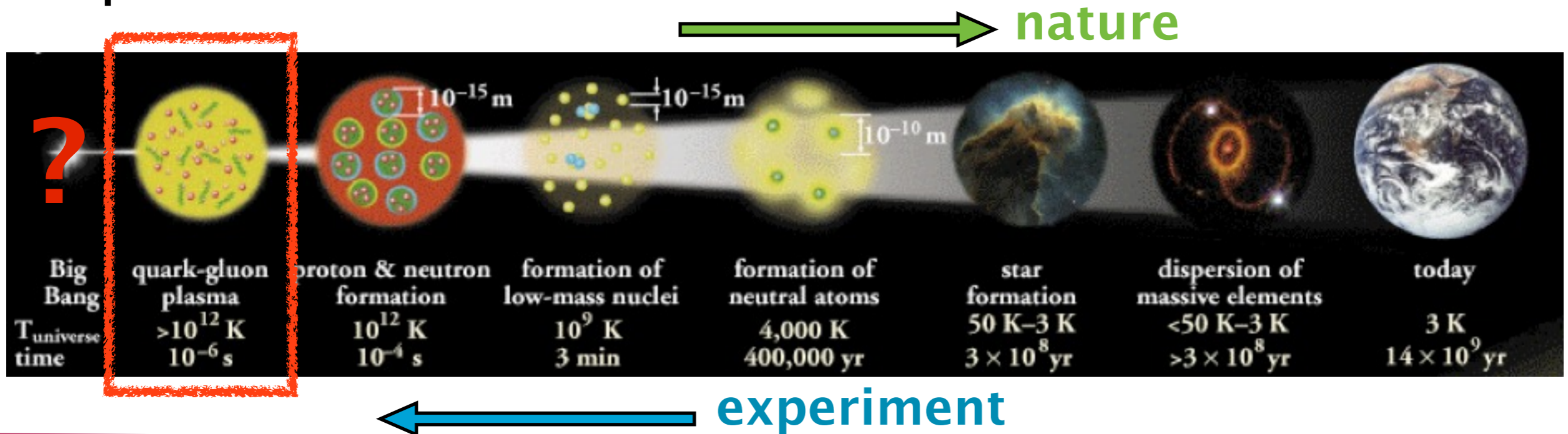


# Quark Gluon Plasma

- Ⓜ **relativistic Heavy Ion Collision**  
: Heavy Ions( $\rho$ ) with large colliding energy( $T$ )



- Ⓜ **Expansion of the Universe**

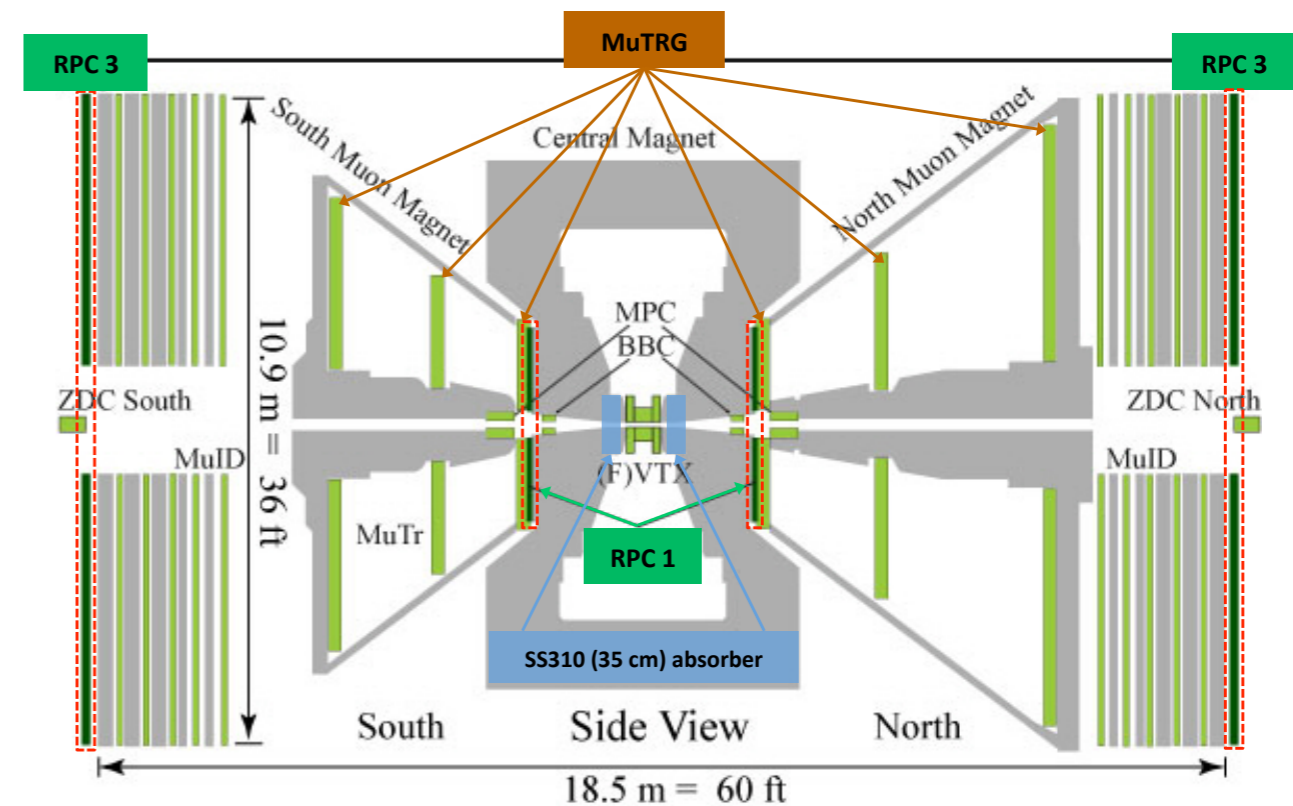
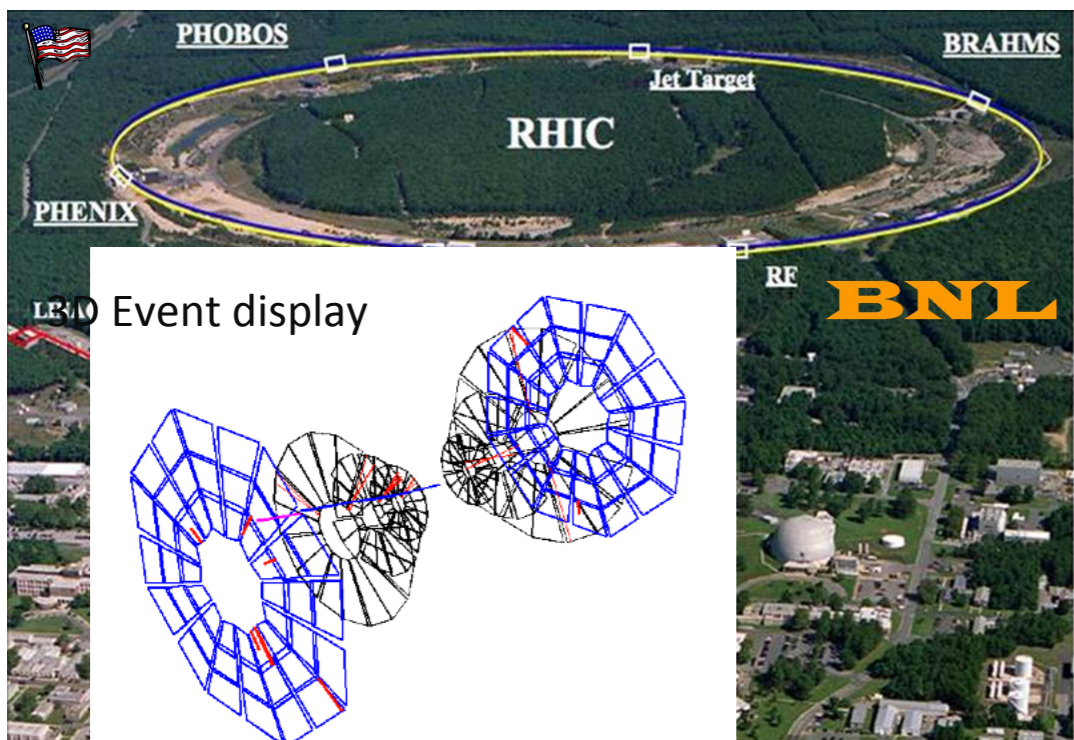


## ⊕ RHIC (Relativistic Heavy-Ion Collider)

- ⊕ Max  $\sqrt{S_{NN}}$ (GeV) : 510 GeV (pp), 200 GeV (AA)
- ⊕ The only machine capable of colliding high-energy polarized photon beams

## ⊕ PHENIX (Pioneering High-Energy Nuclear Interaction eXperiment)

- ⊕ One of the two ongoing physics experiments at RHIC
- ⊕ Goal : characterizing QGP & investigating the origin of proton spin



## Spin Crisis

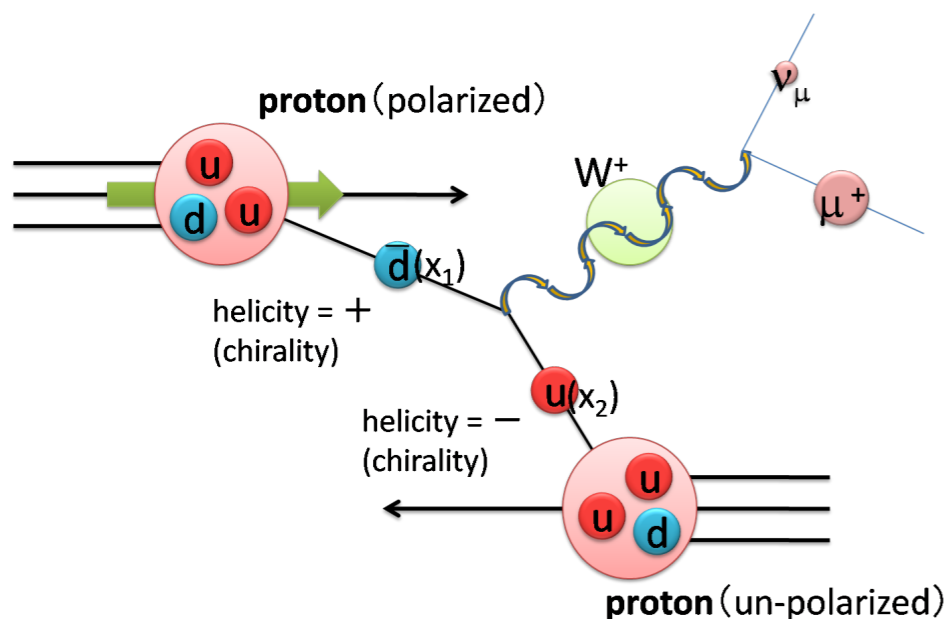
- Deep Inelastic Scattering (DIS) result at 1980s  
: proton spin is NOT a simple sum of its constituent quarks
- Component-by-component approach  
: quarks/antiquarks, gluons, and their angular momenta

$$\frac{1}{2} = \frac{1}{2} \Delta \Sigma + \Delta G + L_z \quad \leftarrow \quad \Delta \Sigma = \sim 0.37 \text{ for } Q^2 [\text{GeV}^2] = 10 \text{ and } 0.001 \leq x \leq 1$$

D. de Florian et al, PRD 80. 034030 (2009)

## W measurement in PHENIX

- Full flavor separation of quarks/antiquarks
- Measure the polarization of the quark by leptons decayed from W boson



$$A_L^W = \frac{1}{p} \times \frac{N^L(W) - N^R(W)}{N^L(W) + N^R(W)}$$

$A_L^W$ : single spin asymmetry

$p$ : beam polarization (Avg. 55 % for 510 GeV pp (Run 12))

$N^{L(R)}(W)$ : # of events contains the muons from W with corresponding helicity (L or R)

$$A_L^{W^+} = \frac{\Delta u(x_1) \bar{d}(x_2) - \Delta \bar{d}(x_1) u(x_2)}{u(x_1) \bar{d}(x_2) + \bar{d}(x_1) u(x_2)} \quad \frac{\Delta u(x_1)}{u(x_1)} \text{ or } - \frac{\Delta \bar{d}(x_1)}{\bar{d}(x_1)}$$

$(x_1 \gg x_2) \quad (x_2 \gg x_1)$