Current research activities on heavy-ion physics in Korea: hot and rare

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Introduction to Korean HI Community

Subject	Accelerator	Experiment	Participating institutes (# of faculties)
Hot QGP	LHC	ALICE	Inha (2), Pusan (1), Sejong (2), Yonsei (2)
		CMS	Chonnam (1), Korea (1)
	RHIC	PHENIX	Chonbuk (1), Ewha (1), Hanyang (1), Korea (1), Myongji (1), Seoul (1), Yonsei (2)
		STAR	Pusan (1)
Dense Matter	FAIR	CBM	Pusan (1)
RIB (EoS, E_{sym})	RIBF	SAMURAI TPC	IBS (1), Korea (1)
	RAON	LAMPS	Chonbuk (1), Chonnam (1), IBS (1), Inha (1), Korea (2)

- Small community: ≲16 experimental faculties
- Similar number of theoretical faculties

Major Experimental Contributions*

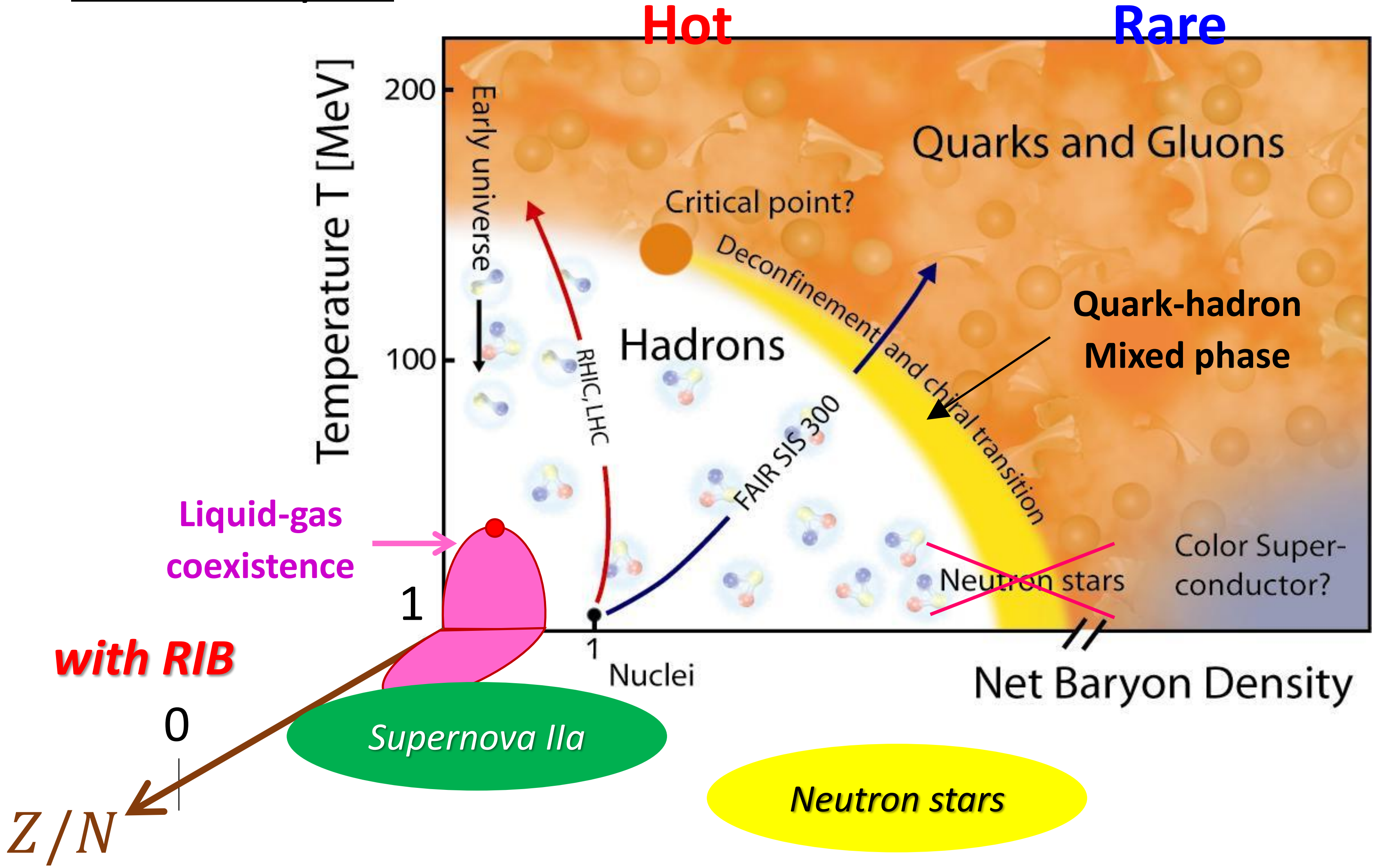
Experiment	Contributions	Leading institutes
ALICE	• ITS upgrade • Heavy-flavor production	Inha, Pusan, Yonsei Inha
CMS	• Forward RPC production • Quarkonium & HF productions in pA & AA	Korea Korea
PHENIX	• Forward RPC production • MPC-Ex Si sensor production • Quarkonium production in pp, pA & AA • Single muon production in pp, pA & AA • Spin structure of protons	Korea Yonsei Korea Yonsei Seoul, Korea
SAMURAI TPC	• Tracking software development	Korea
LAMPS	• TPC development • Neutron wall development	IBS, Korea Korea

- Hardware: Si sensors, Gas detectors (RPC & TPC), Neutron detectors
- Analysis: Muons, Quarkonia, Heavy flavors

* *Disclaimer: The list is not complete and may be a biased view.*

Nuclear Phase Diagram

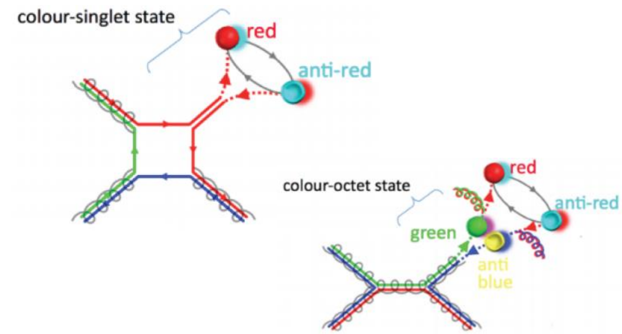
Two examples: **Quarkonium @ CMS** and **LAMPS @ RAON**



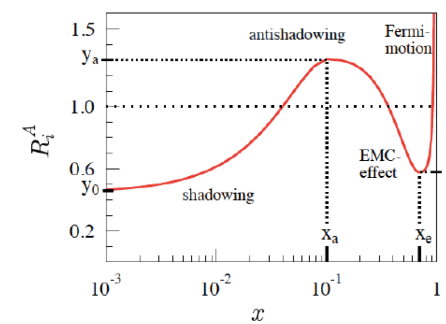
I. Quarkonium Analysis in CMS

Quarkonium Production

1. pp
   - Reference to understand pA and AA data
   - Production mechanism not well understood
     - Color Octet vs. Color Singlet
   - Polarization for interaction of quarkonia with surroundings, not affected by initial-state effect

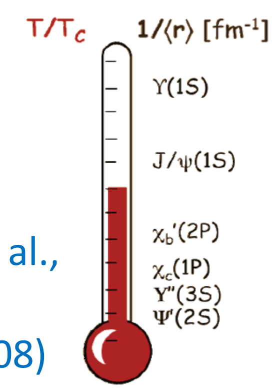


2. pA
   - Nuclear modification of gluon PDF (nPDF): shadowing, saturation, CGC, etc.
   - Medium-induced coherent gluon radiation
   - Co-mover absorption



3. AA
   - Color-charge screening effect: λ_D vs. r
     - Sequential suppression: Different states dissociate at different temperatures
   - Regeneration of q and $\bar{q}$
     - Expected to be larger for J/ψ than for Υ

A. Mocsy et al., PRD 77, 014501 (2008)



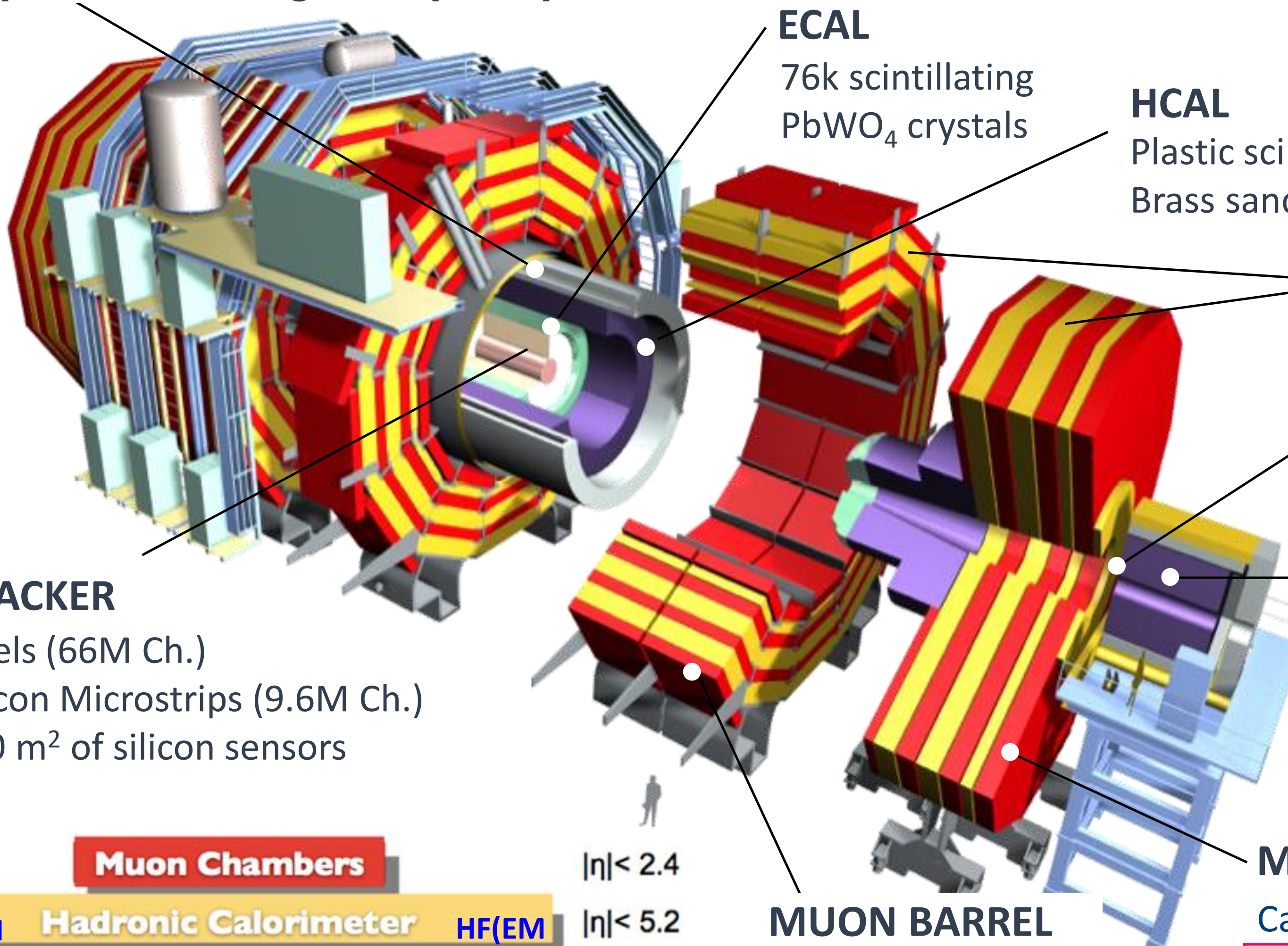
CMS Detector

Superconducting Coil (3.8 T)

CALORIMETERS
ECAL
76k scintillating
$PbWO_4$ crystals

HCAL
Plastic scintillator/
Brass sandwich

Weight: 12,500 tons
Diameter: 15 m
Length: 22 m

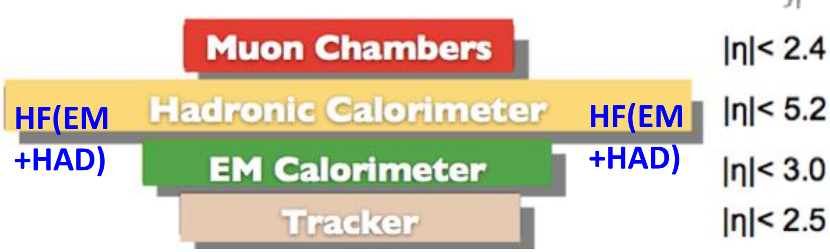


Steel YOKE

BSC
MB trigger

HF
MB trigger
Centrality in HI

TRACKER
Pixels (66M Ch.)
Silicon Microstrips (9.6M Ch.)
220 m^2 of silicon sensors

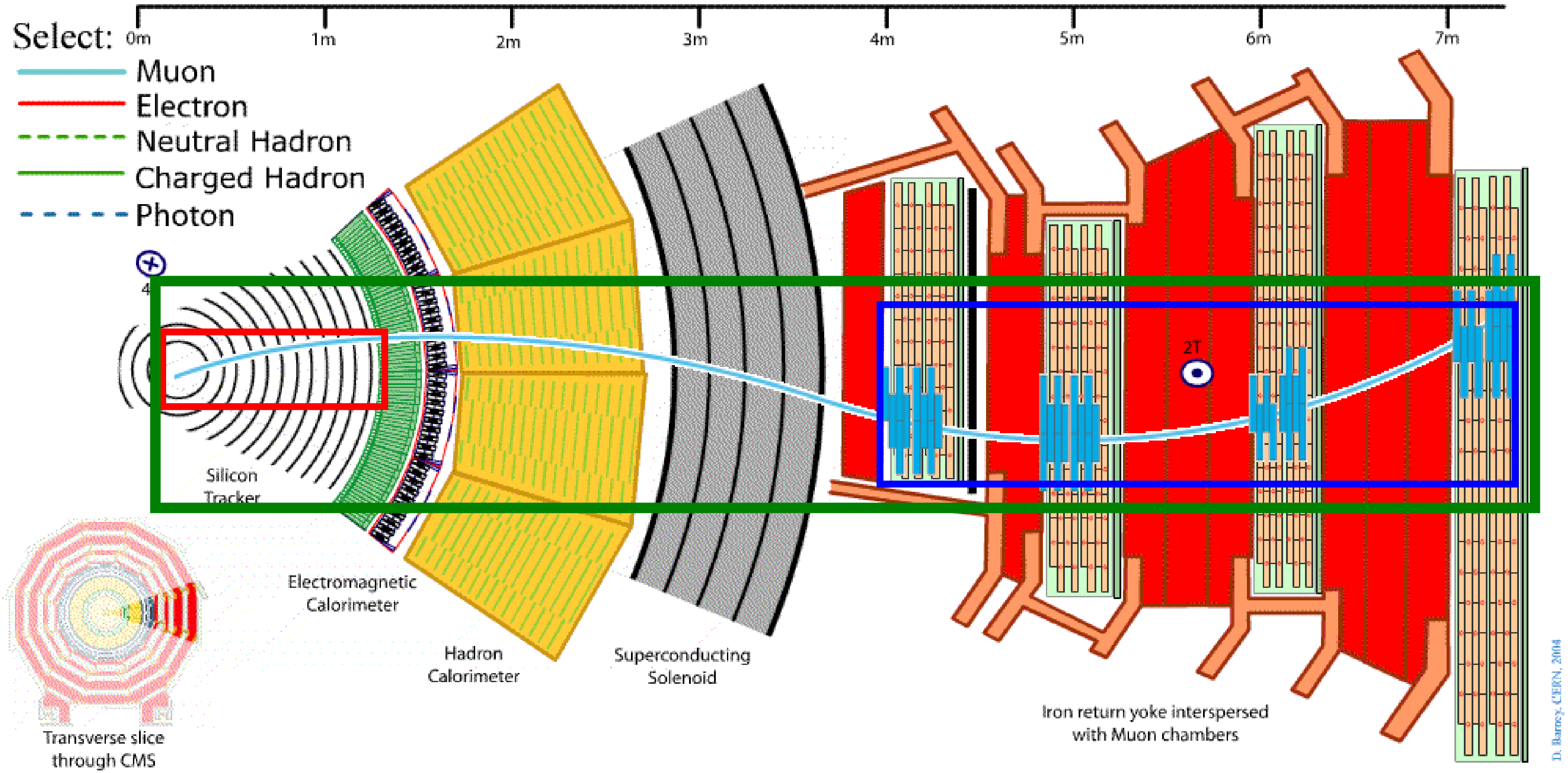


MUON BARREL
Drift Tube Chambers
Resistive Plate Chambers

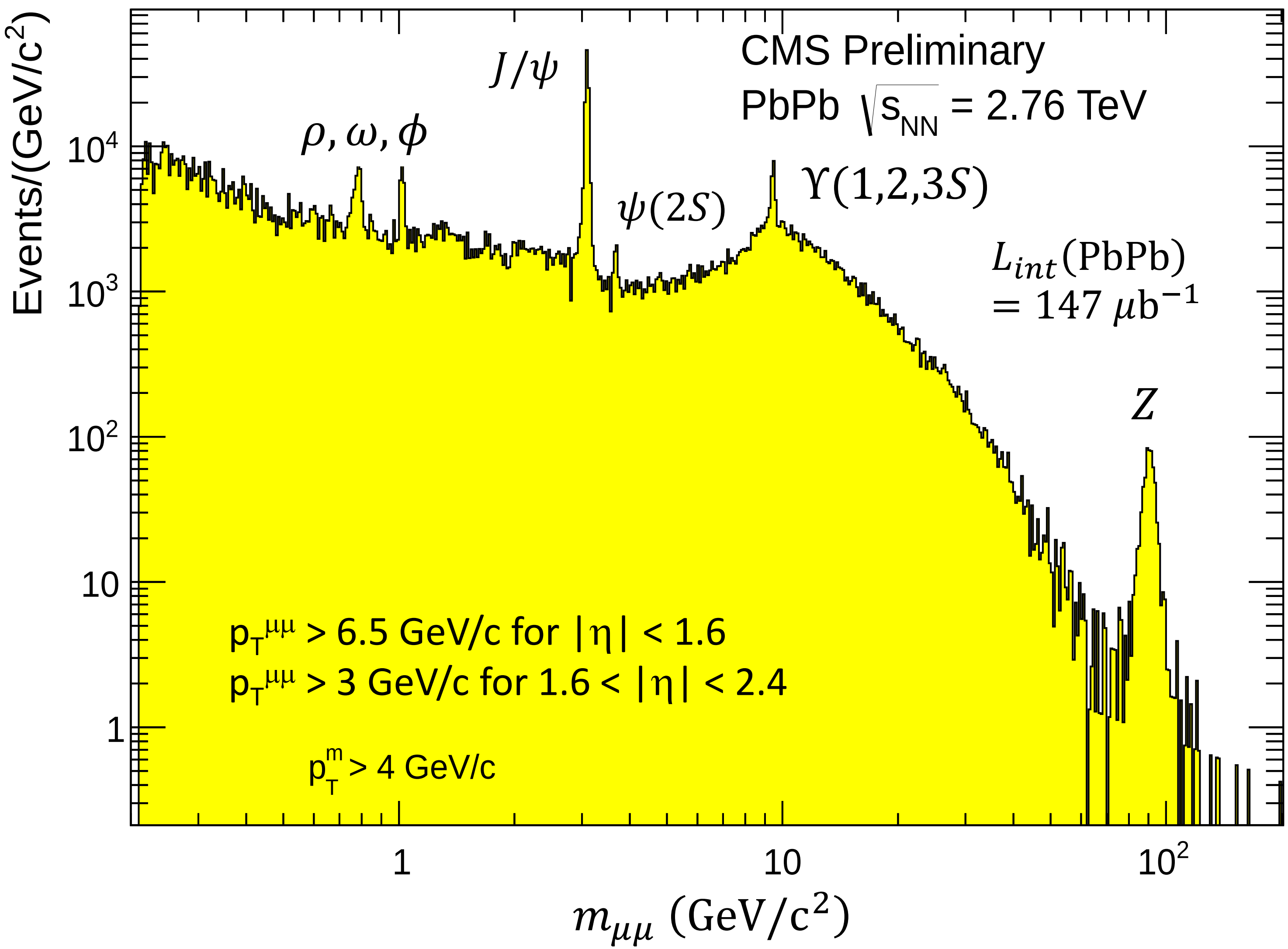
MUON ENDCAPS
Cathode Strip Chambers
Resistive Plate Chambers

Muons in CMS

- Excellent ID and triggering capabilities in the muon system
- Excellent momentum resolution in tracker (overall ~1-2%)
- Global muons = Standalone muons x Tracker information



$\mu^-\mu^+$ Invariant Mass in 2011

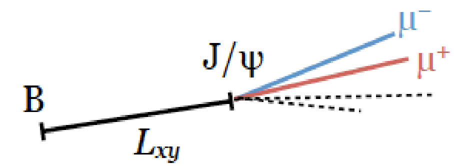


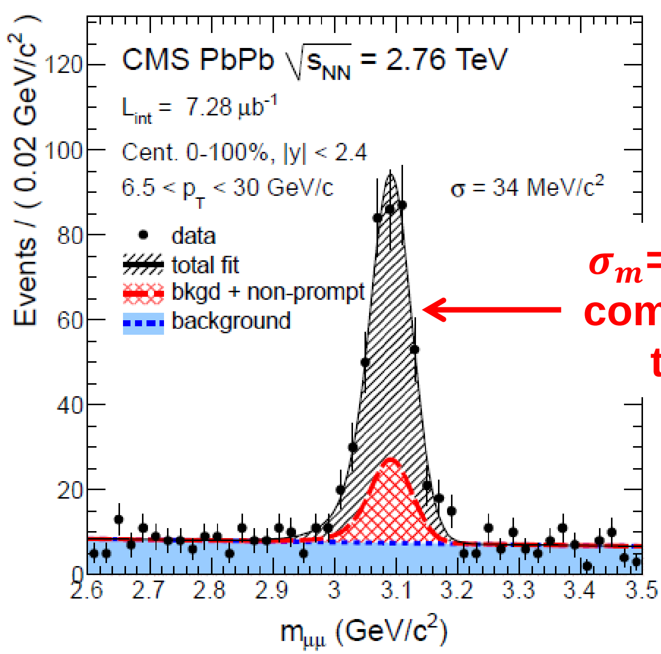
J/ψ Analysis Method

Inclusive J/ψ
- Prompt J/ψ
  - Direct J/ψ
  - Feed-down from ψ' and χ_c
- Non-prompt J/ψ from B decays

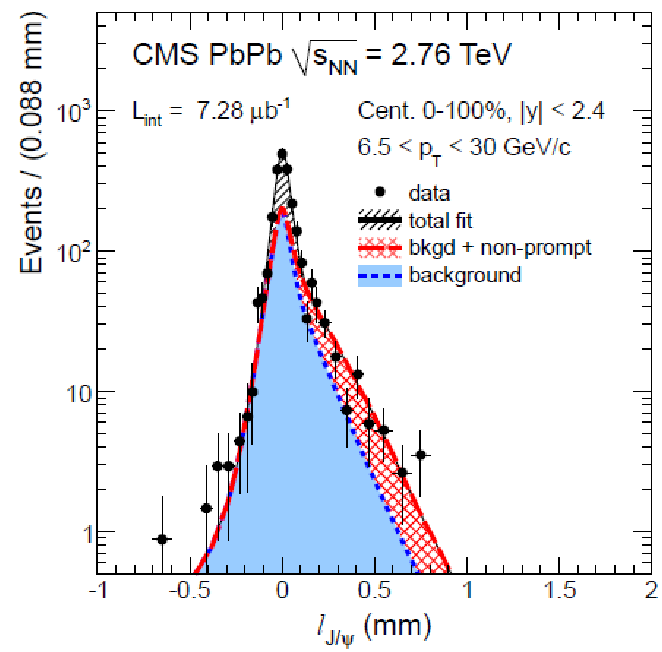
- Simultaneous fit
  - $\mu^-\mu^+$ invariant mass
  - Pseudo-proper decay length

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





σ_m= 34 MeV comparable to pp

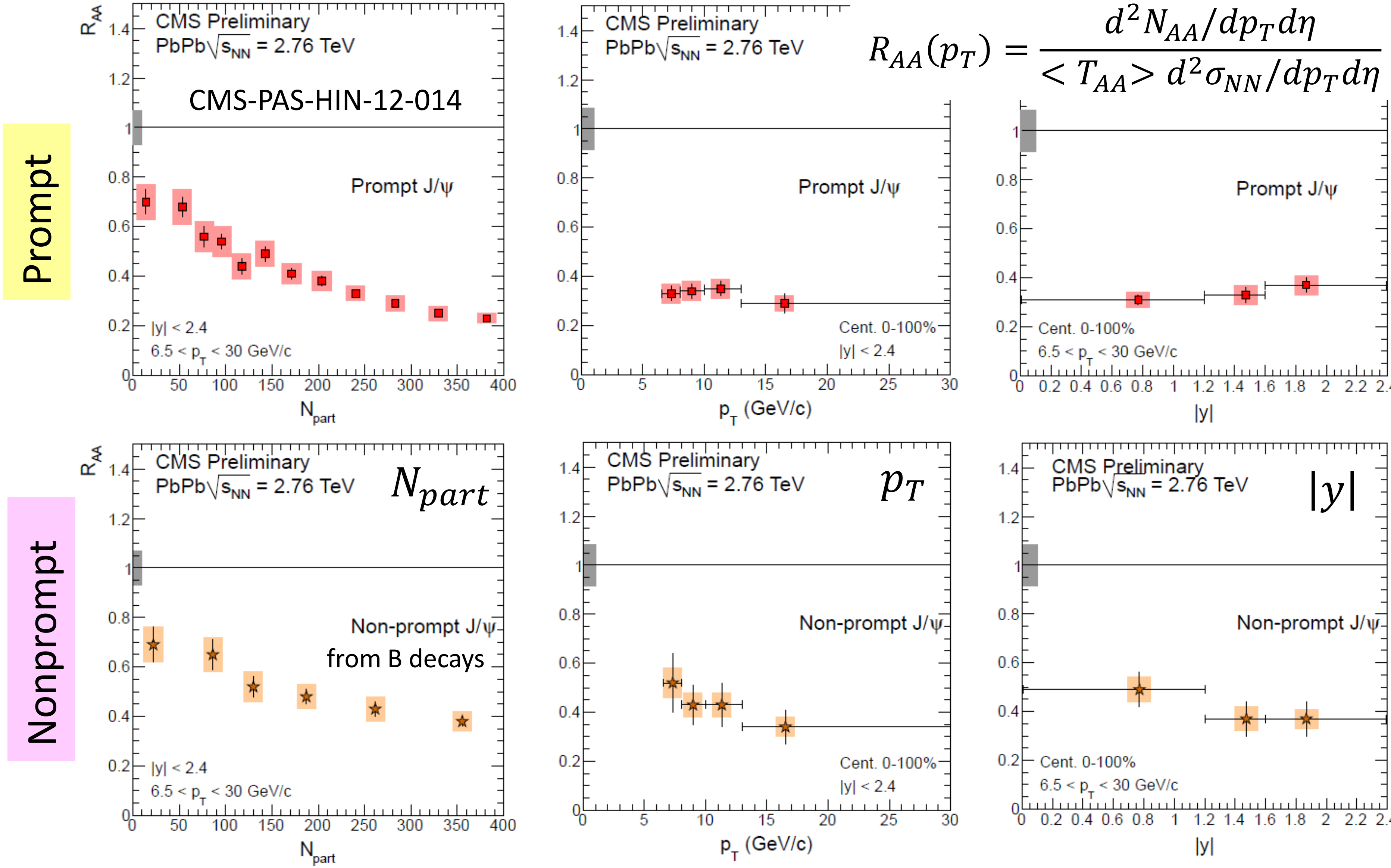


JHEP 05, 063 (2012)

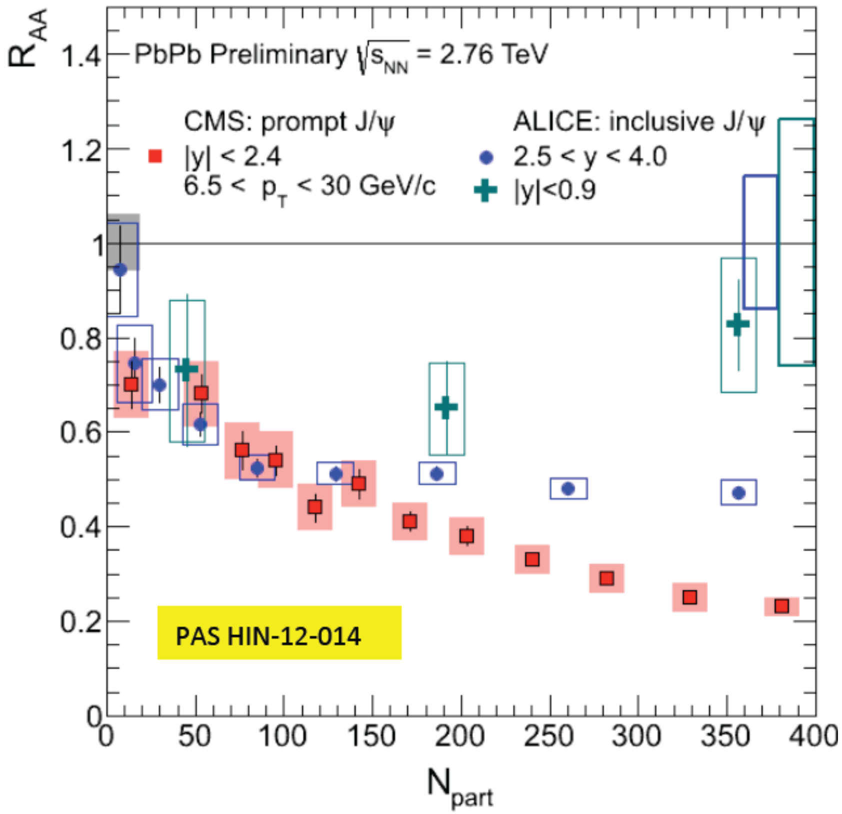
J/ψ in PbPb

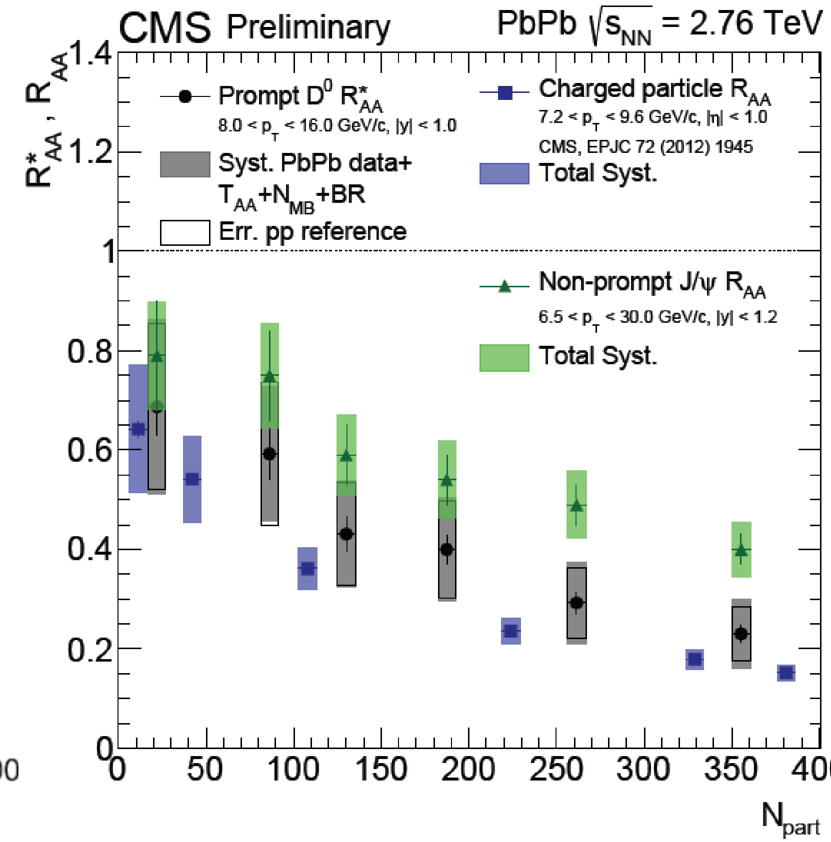
$$R_{AA}(p_T) = \frac{d^2N_{AA}/dp_T d\eta}{< T_{AA}> d^2\sigma_{NN}/dp_T d\eta}$$

CMS-PAS-HIN-12-014



J/ψ in PbPb





$B \rightarrow J/\psi$

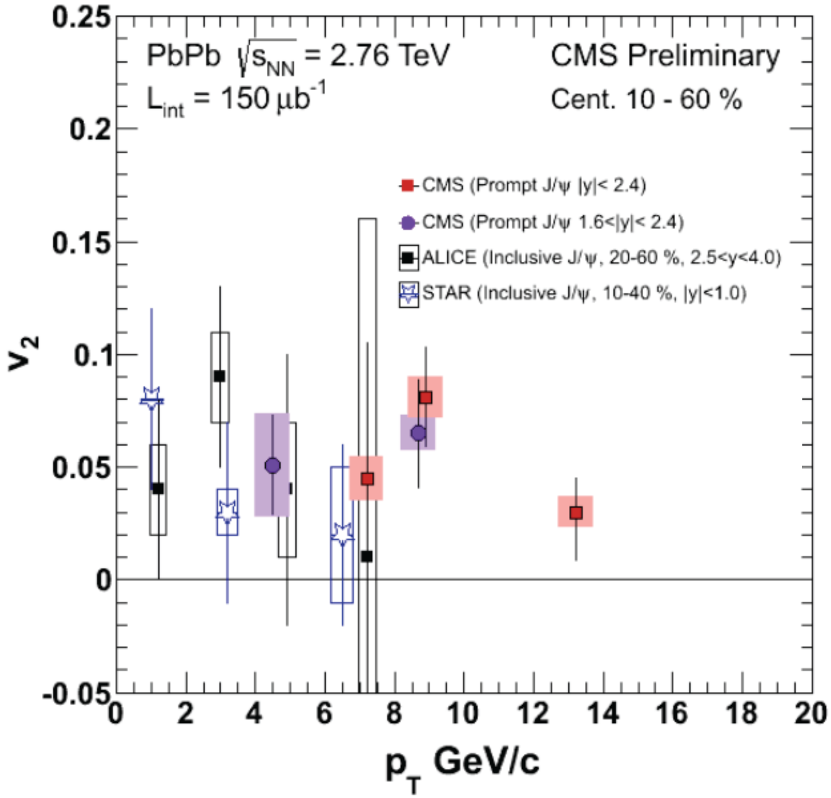
D^0

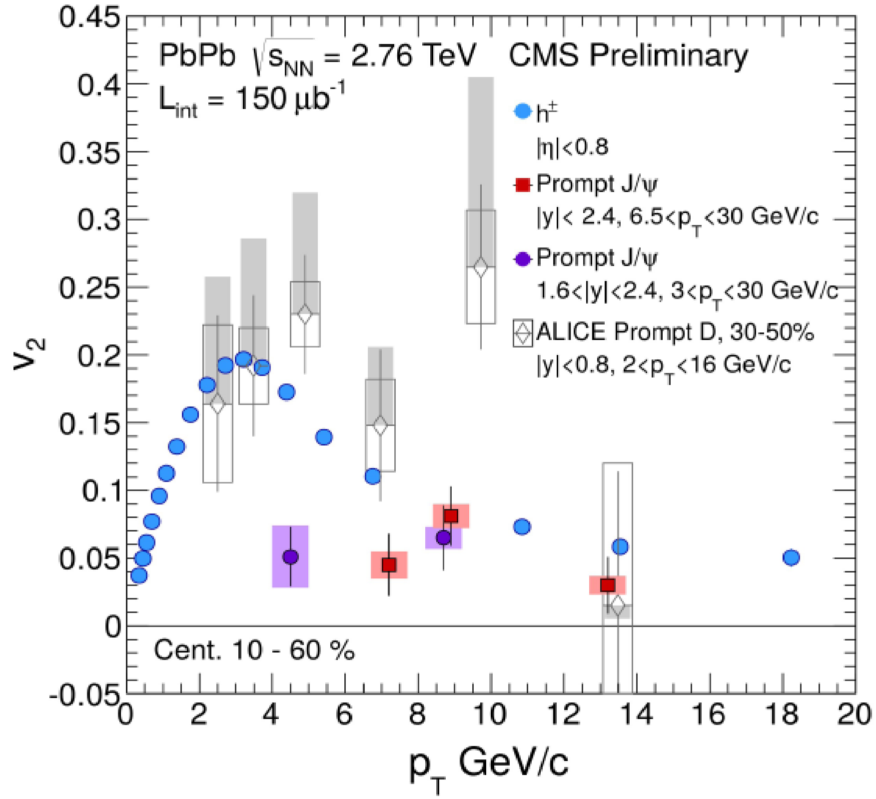
Charged hadrons

- Yield is larger at lower p_T and midrapidity in central PbPb
- Consistent with regeneration scenario
- Compare to ALICE D mesons
  $R_{AA}(B) > R_{AA}(D) > R_{AA}(h^{\pm})$
- Consistent with mass ordering
  - Dead cone effect?

v_2 of Prompt J/ψ in PbPb

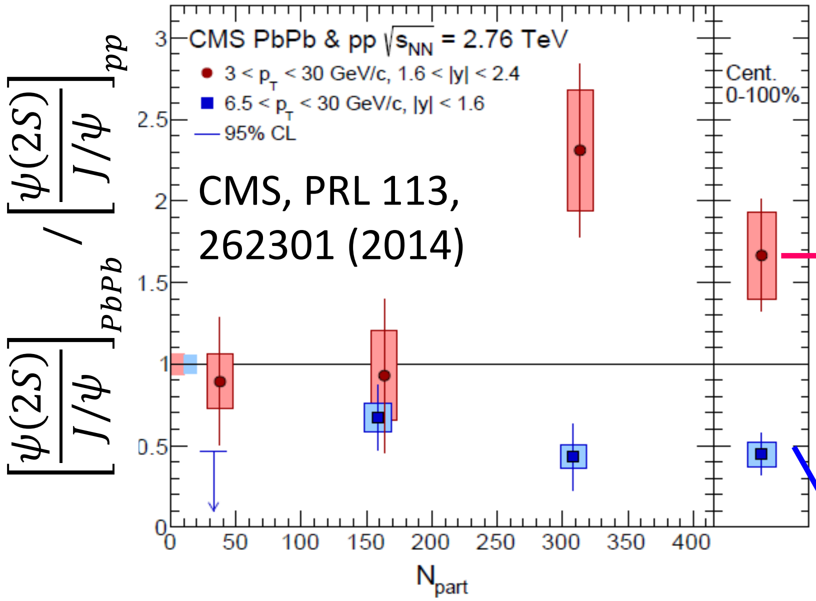
CMS-PAS-HIN-12-001

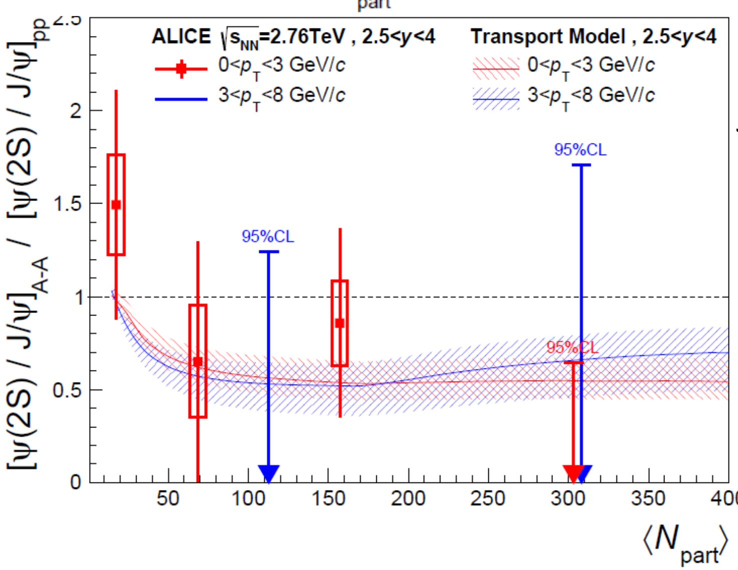




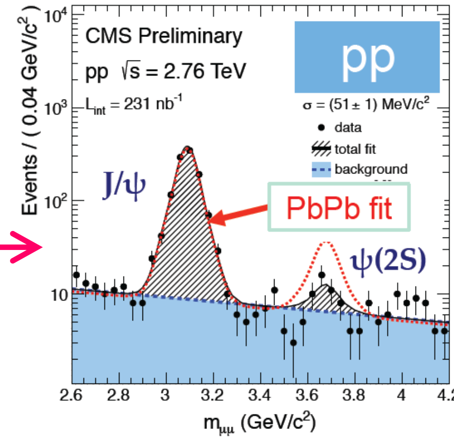
- Finite v_2 for prompt J/ψ in the measured p_T range
- Low p_T (< 8 GeV/c): v_2 for prompt J/ψ < v_2 for $h^{\pm}$ or prompt D
- High p_T (> 8 GeV/c): v_2 for prompt $J/\psi \approx v_2$ for $h^{\pm}$

$\psi(2S)$ in PbPb

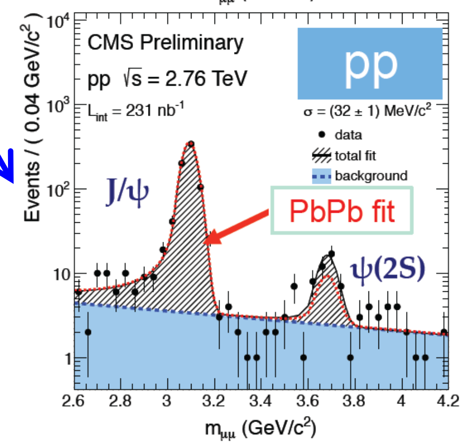




ALICE, arXiv:1506.08804



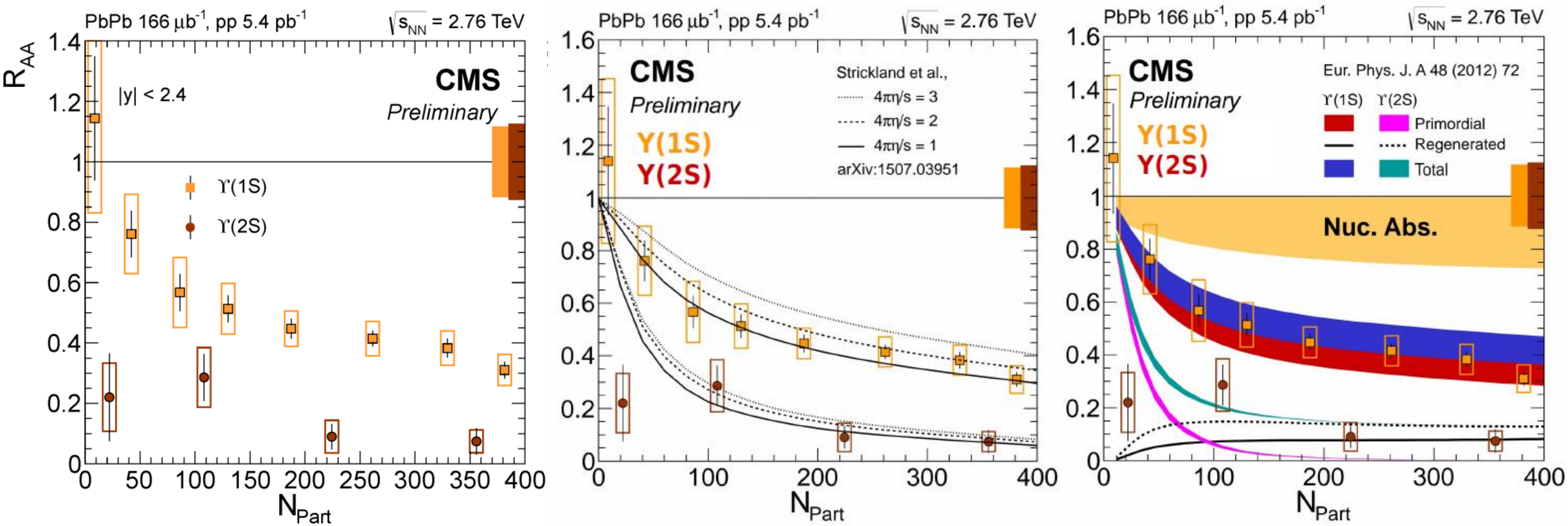
For $3 < p_T < 30$ GeV/c in $1.6 < |y| < 2.4$
$R_{\psi(2S)}$ in central (20%) PbPb is ~ 5 times larger than that in pp with larger systematic error.



For $6.5 < p_T < 30$ GeV/c in $|y| < 1.6$
$R_{\psi(2S)}$ in central (20%) PbPb is ~2 times smaller than that in pp.

- Indication of $\psi(2S)$ being less suppressed than J/ψ (<2σ effect) at low p_T in the most central events: Need more J/ψ statistics from Run II.

$\Upsilon(nS)$ in PbPb



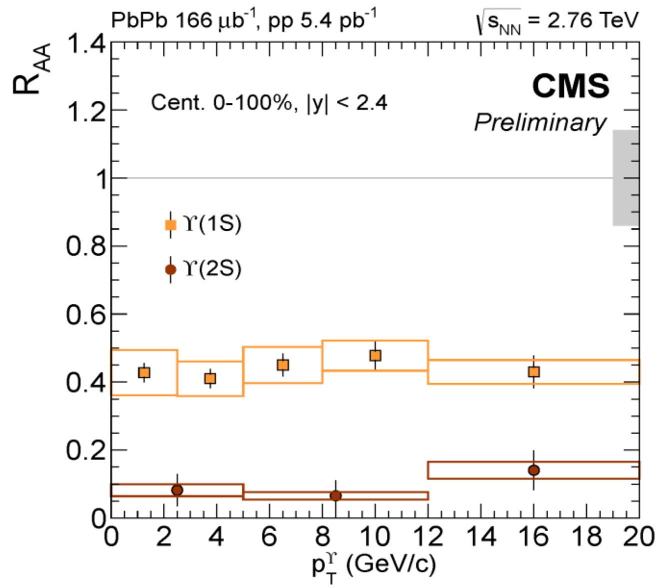
- Centrality integrated (0-100%) results: Υ states suppressed sequentially

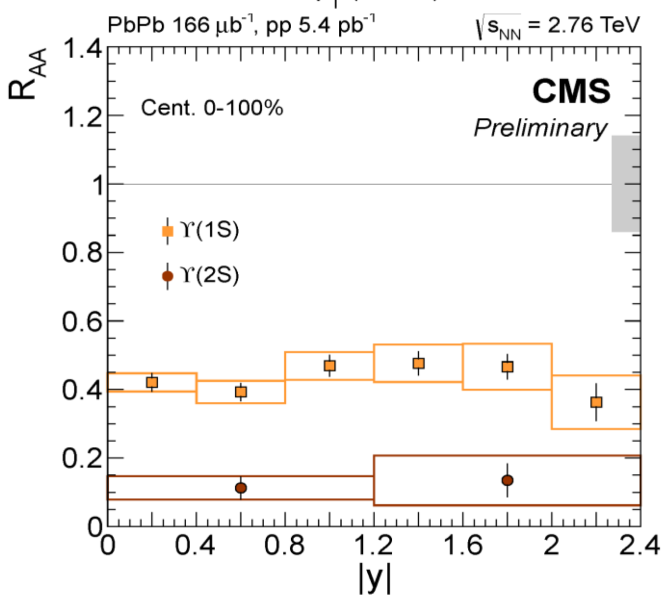
$$R_{AA}[\Upsilon(1S)] = 0.425 \pm 0.029 \pm 0.070$$
$$R_{AA}[\Upsilon(2S)] = 0.116 \pm 0.028 \pm 0.022$$
$$R_{AA}[\Upsilon(3S)] < 0.14 \text{ at } 95\% \text{ CL}$$

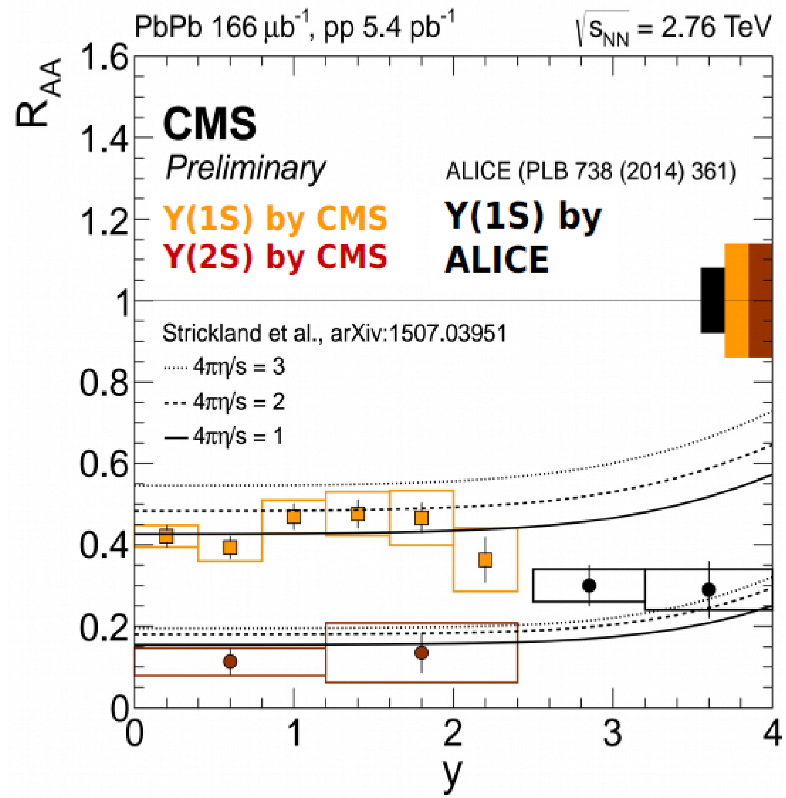
CMS-PAS-HIN-15-001

- Anisotropic hydrodynamic model for thermal suppression of bottomonia
  - 2 temperatures along y, 3 shear viscosities, no CNM, no regeneration, …
- Transport model taking into account CNM and regeneration

$\Upsilon(nS)$ in PbPb







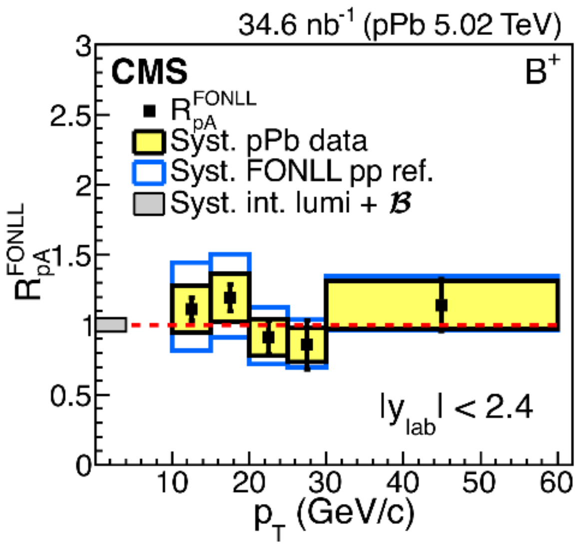
CMS-PAS-HIN-15-001

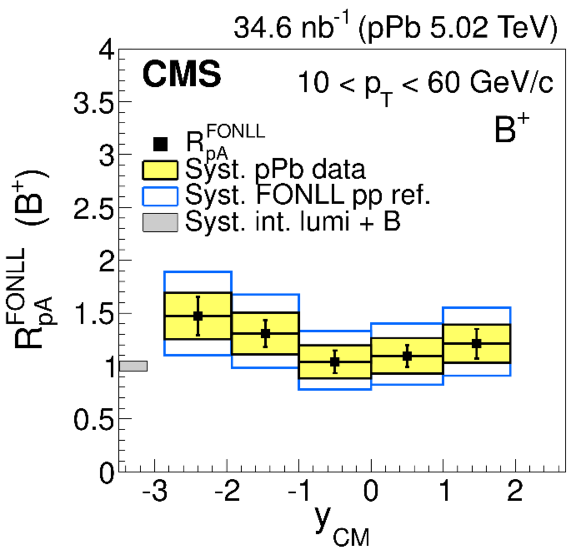
← Υ suppression does not strongly depend on kinematics.

↑ Anisotropic hydro model cannot reproduce the forward data: CNM may help?

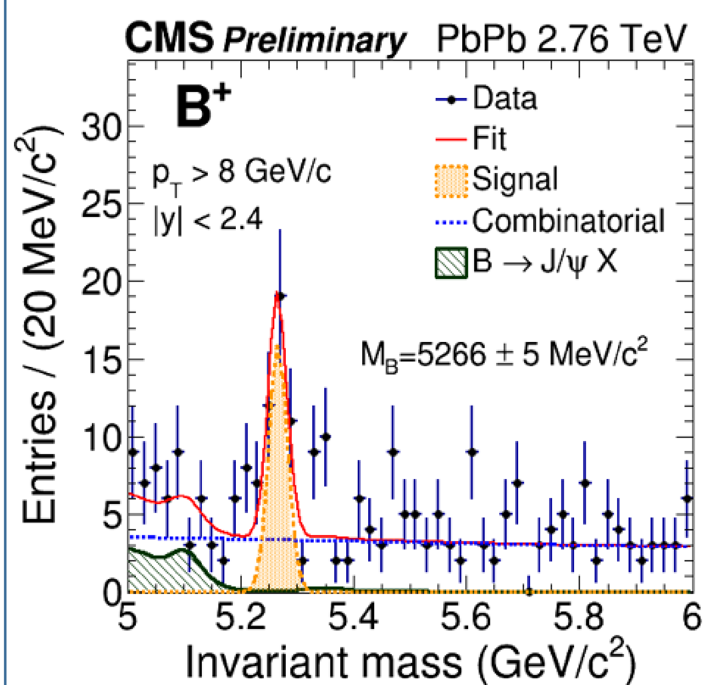
B production in pPb

CMS-PAS-HIN-14-004, arXiv:1508.06678, Submitted to PRL





CMS detector performance plot (2011 PbPb data at 2.76 TeV)

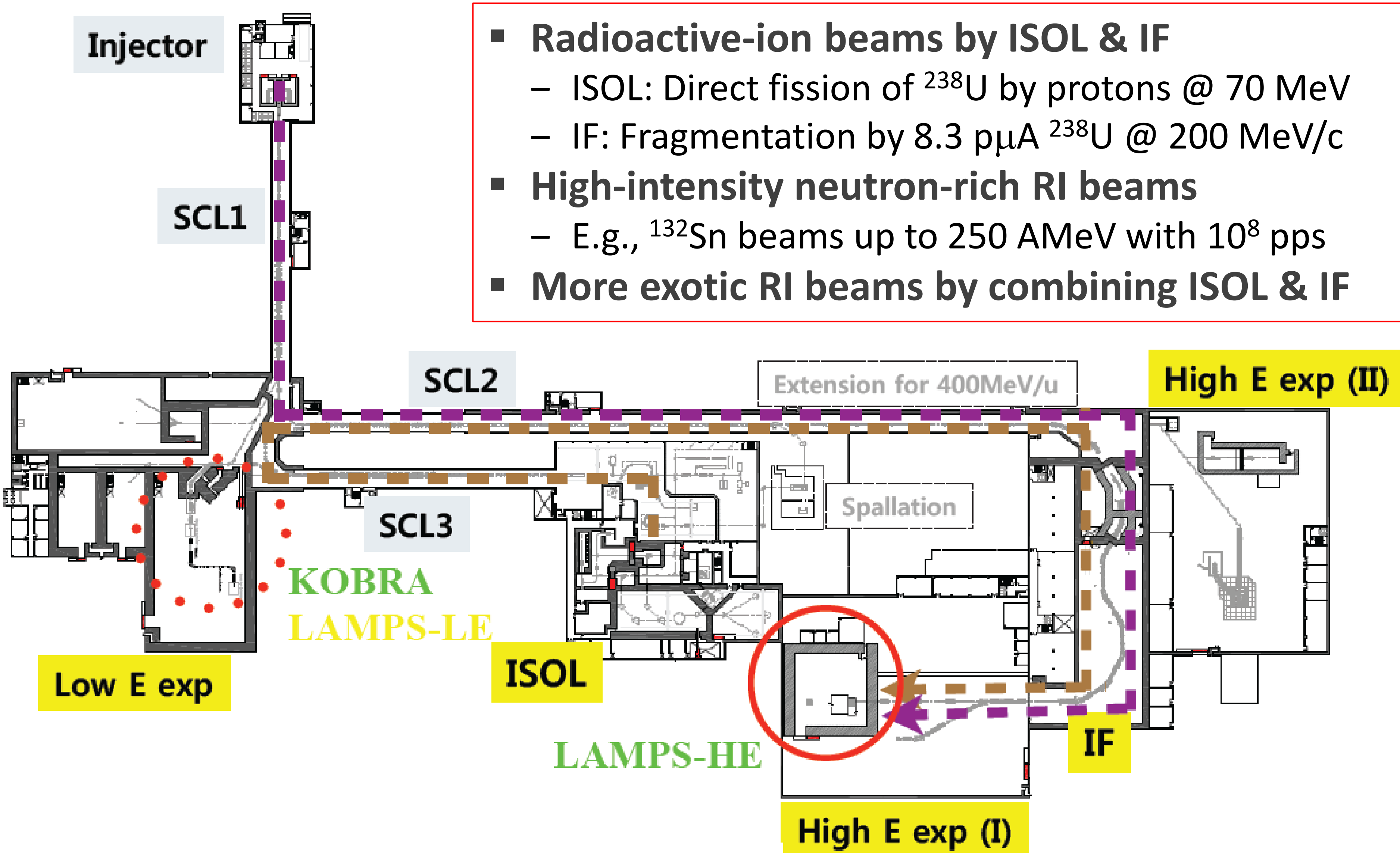


- B analysis in pPb
  - No modification for $B^{\pm}$, B^0, B_S^0 within uncertainties
  - Baseline for PbPb
- CMS capability to reconstruct B in PbPb
  - First fully reconstructed B in PbPb environment
  - Expect interesting physics results from RUN II PbPb with higher statistics

III. Detector Development for LAMPS @ RAON

RAON: New RIB Accelerator in Korea

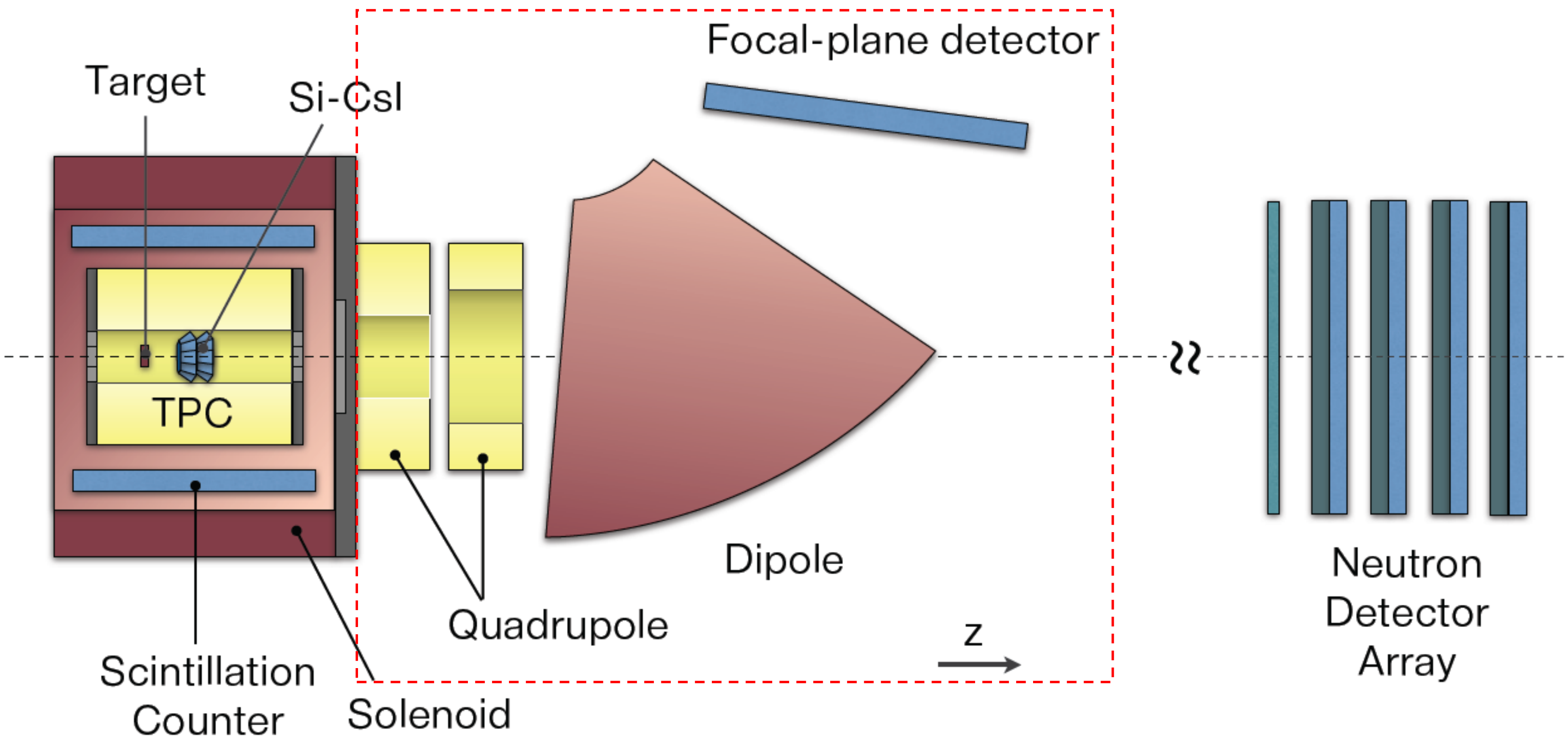
- **Radioactive-ion beams by ISOL & IF**
  - ISOL: Direct fission of ^{238}U by protons @ 70 MeV
  - IF: Fragmentation by 8.3 pμA ^{238}U @ 200 MeV/c
- **High-intensity neutron-rich RI beams**
  - E.g., ^{132}Sn beams up to 250 AMeV with 10^8 pps
- **More exotic RI beams by combining ISOL & IF**



LAMPS

Large-**A**cceptance **M**ulti-**P**urpose **S**pectrometer =

Solenoid Spectrometer ⊕ Dipole Spectrometer ⊕ Neutron Array



EoS and Symmetry Energy

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

with $\rho = \rho_n + \rho_p$ and $\delta = (\rho_n - \rho_p)/(\rho_n + \rho_p)$

- Useful expansion of $E_{sym}(\rho)$ around ρ_0

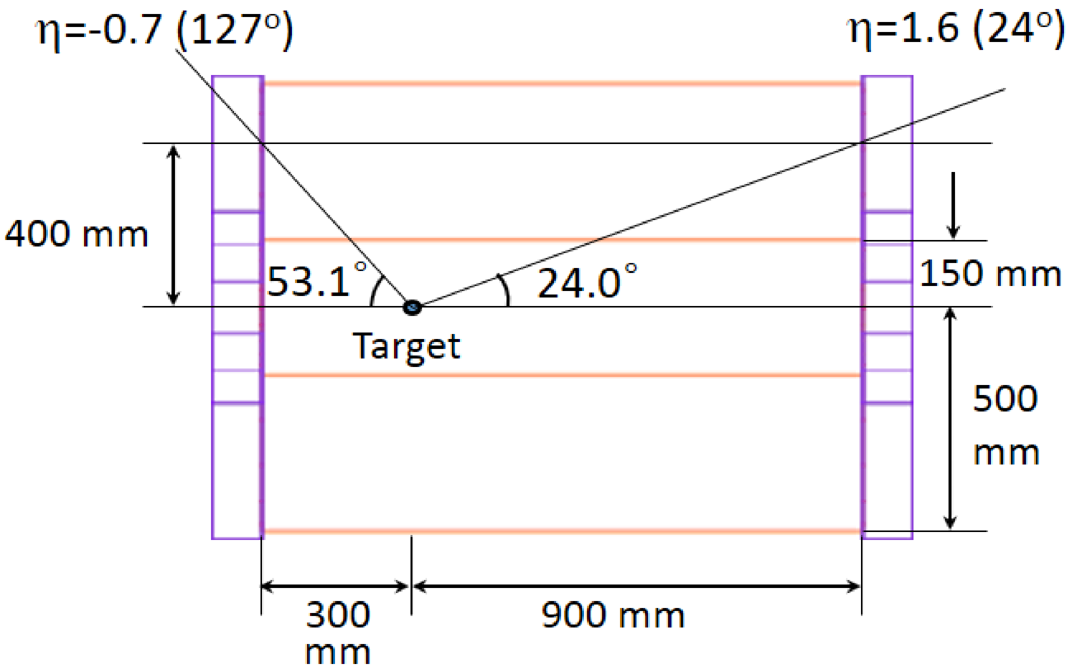
$$E_{sym}(\rho) = J + \frac{L}{3}\left(\frac{\rho-\rho_0}{\rho_0}\right) + \frac{K_{sym}}{18}\left(\frac{\rho-\rho_0}{\rho_0}\right)^2$$

$$L = \frac{3}{\rho_0}P_{sym} = 3\rho_0 \frac{\partial E_{sym}(\rho)}{\partial \rho}\bigg|_{\rho=\rho_0} \qquad \text{(slope)}$$

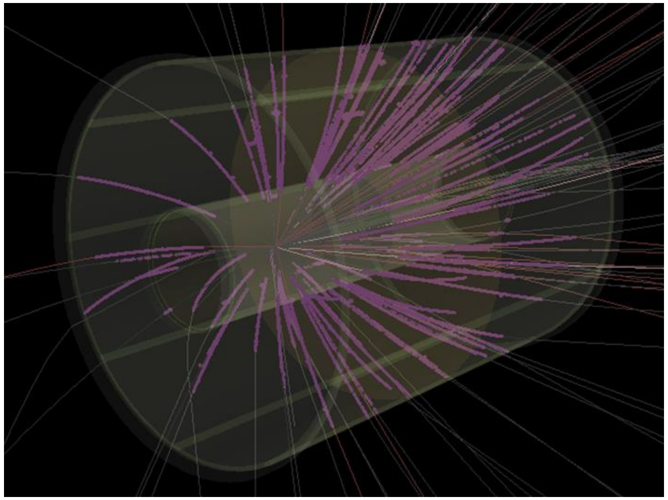
$$K_{sym} = 9{\rho_0}^2 \frac{\partial^2 E_{sym}(\rho)}{\partial \rho^2}\bigg|_{\rho=\rho_0} \qquad \text{(curvature)}$$

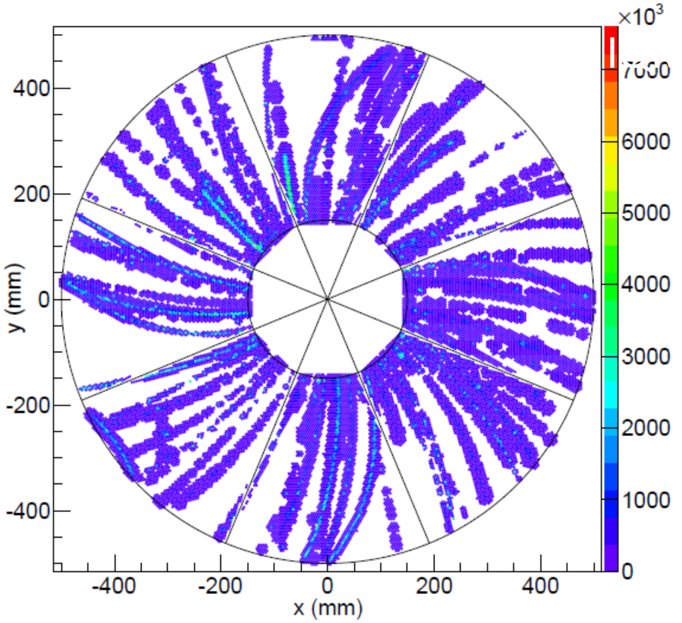
- Primary physics goal of LAMPS is
  - To explore the nuclear symmetry energy (J, L, K_{sym}) from sub-saturation to supra-saturation densities.

Time Projection Chamber



Central Au+Au at 250 AMeV

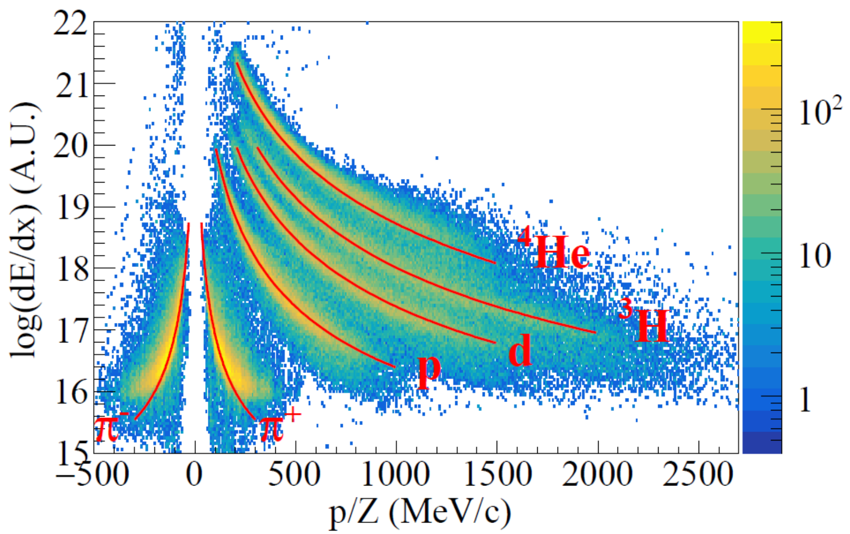




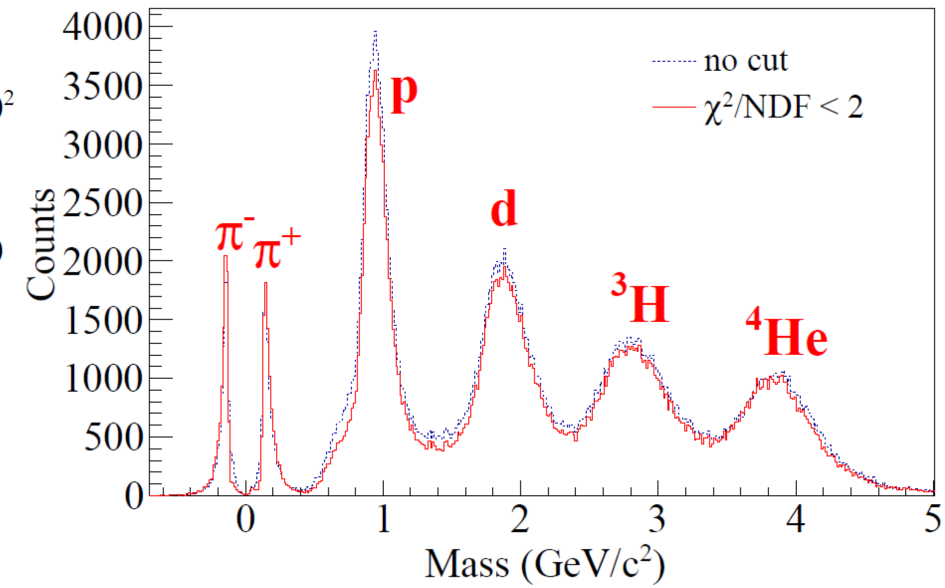
- Simulation of triple GEM by GARFIELD++
  - Gas mixture: Ar 90% + CH_4 10%
  - Voltage for each foil ~400 V
  - <Gain> ~ 1.4×10^6
  - <Drift velocity> ~ 50 mm/μs
  - <Dispersion> ≲ 3 mm

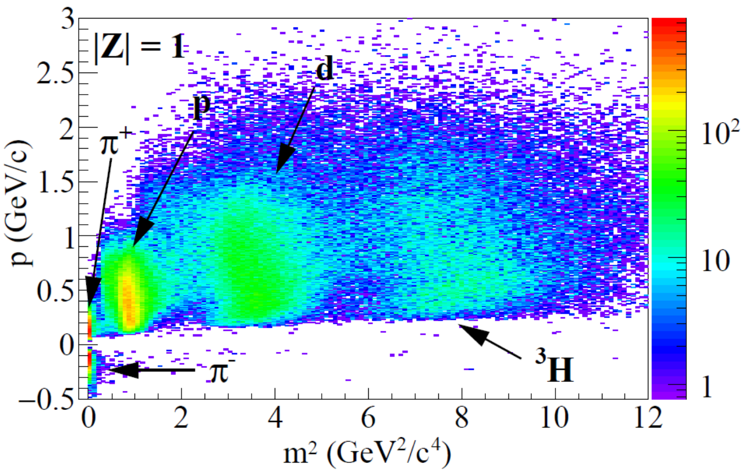
TPC Simulation

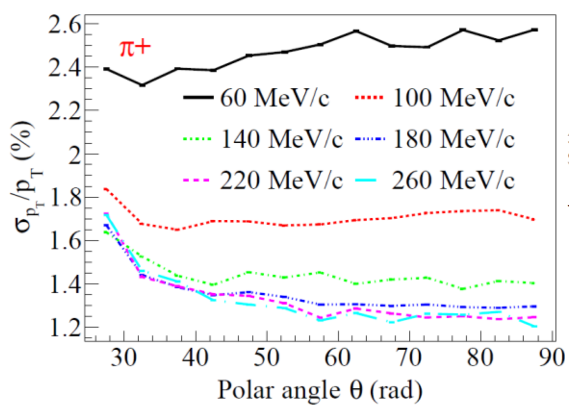
Central Au+Au at 250 AMeV

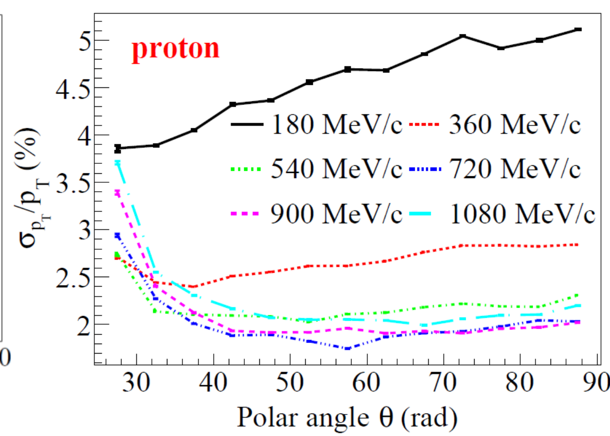


Track Recon=Riemann Tracking+GENFIT

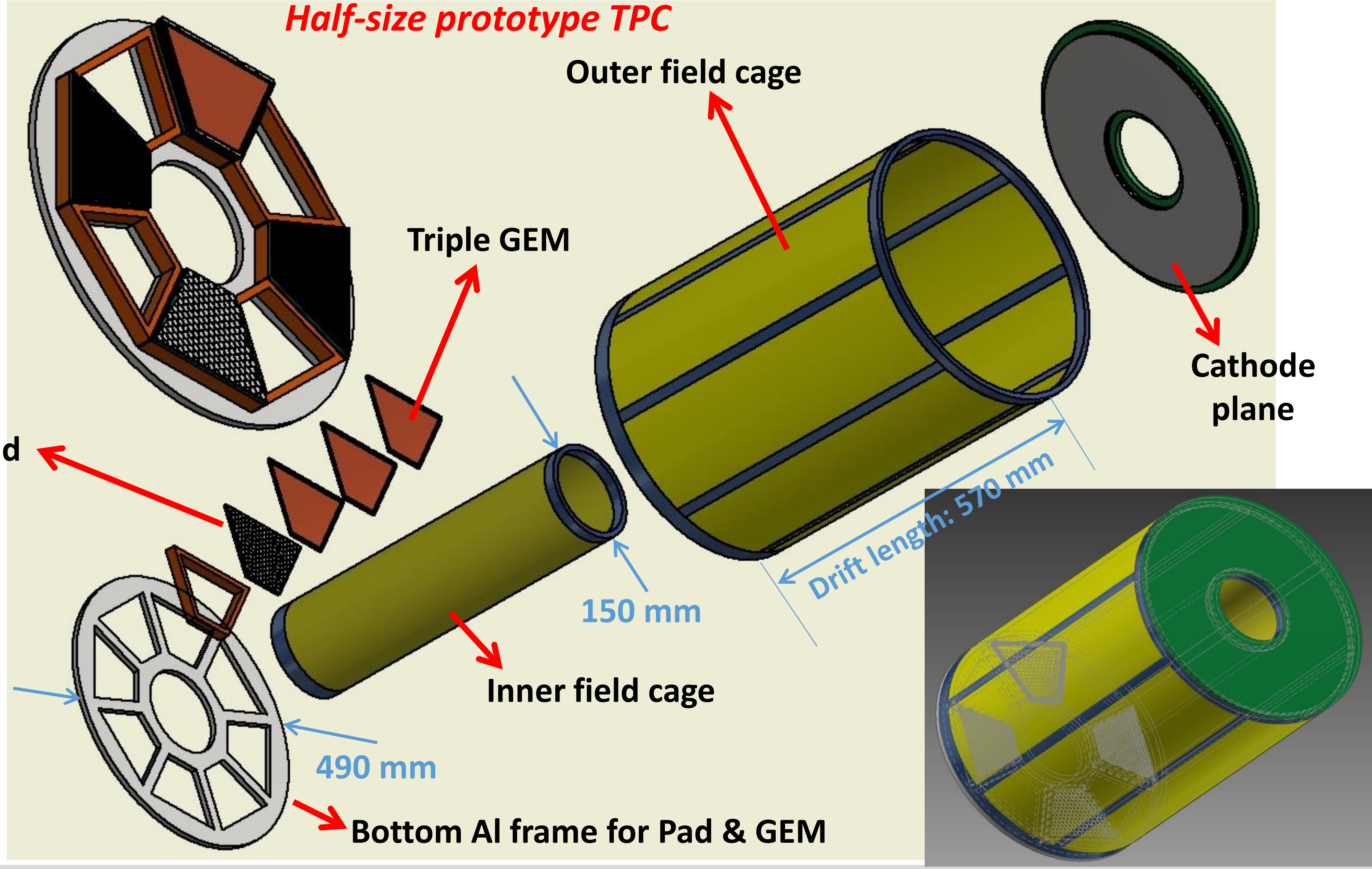






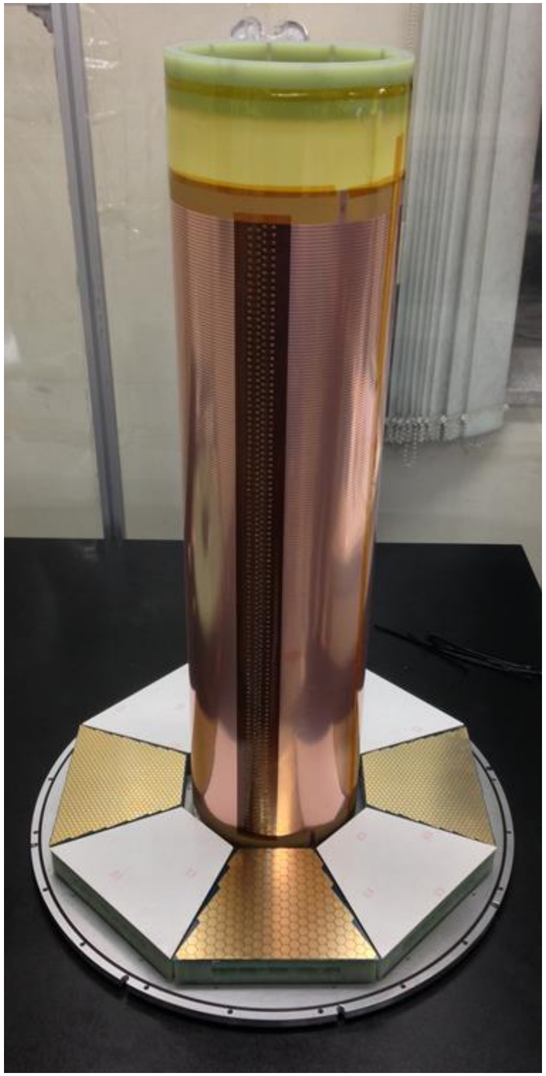


Design of Prototype TPC

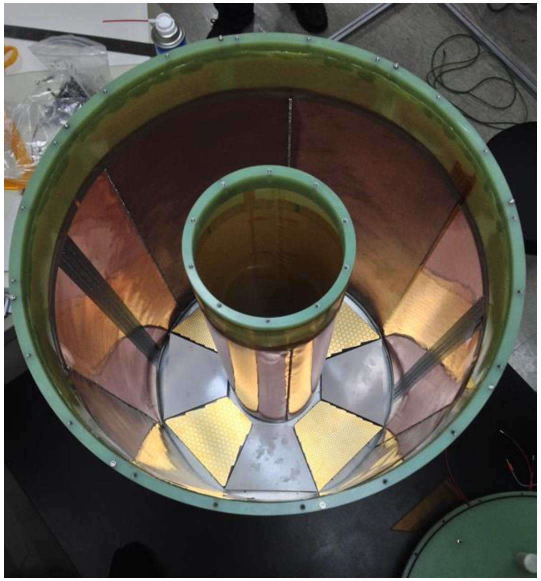


Assembly of Prototype TPC

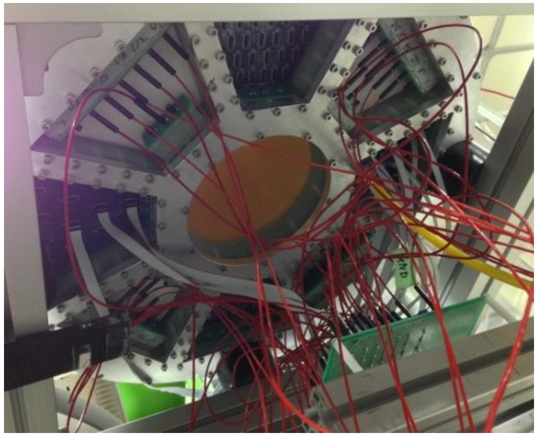
Inner Field Cage installed



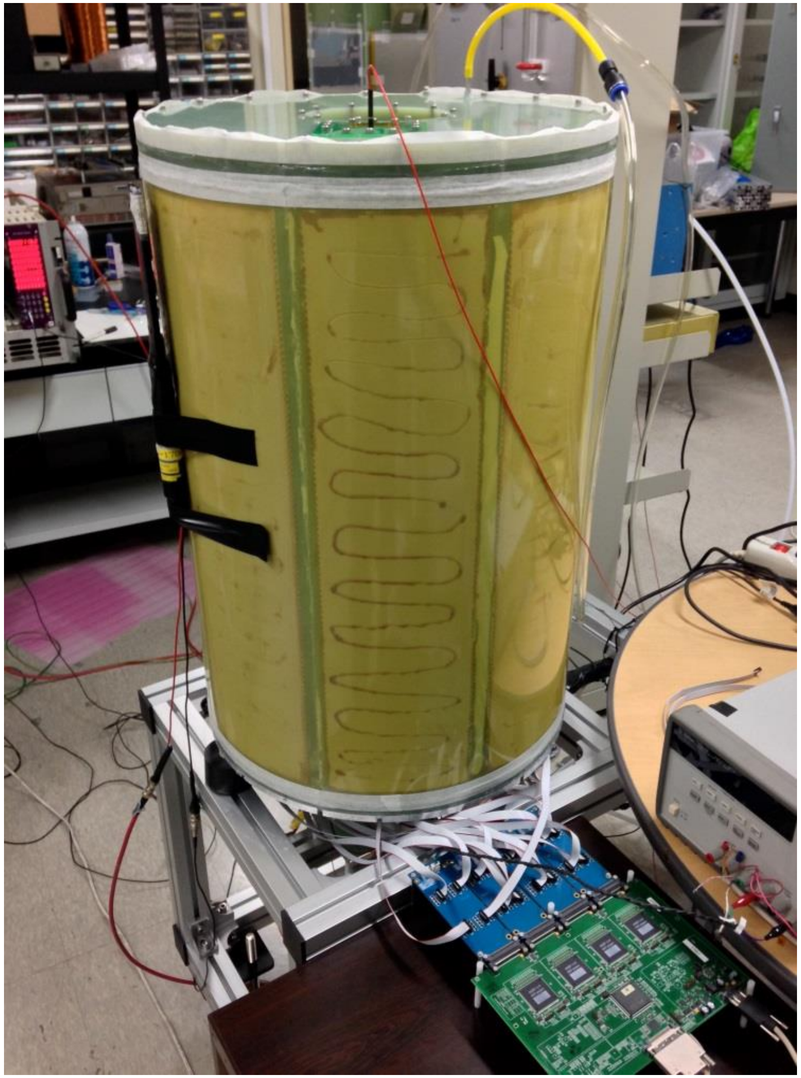
Outer Field Cage installed



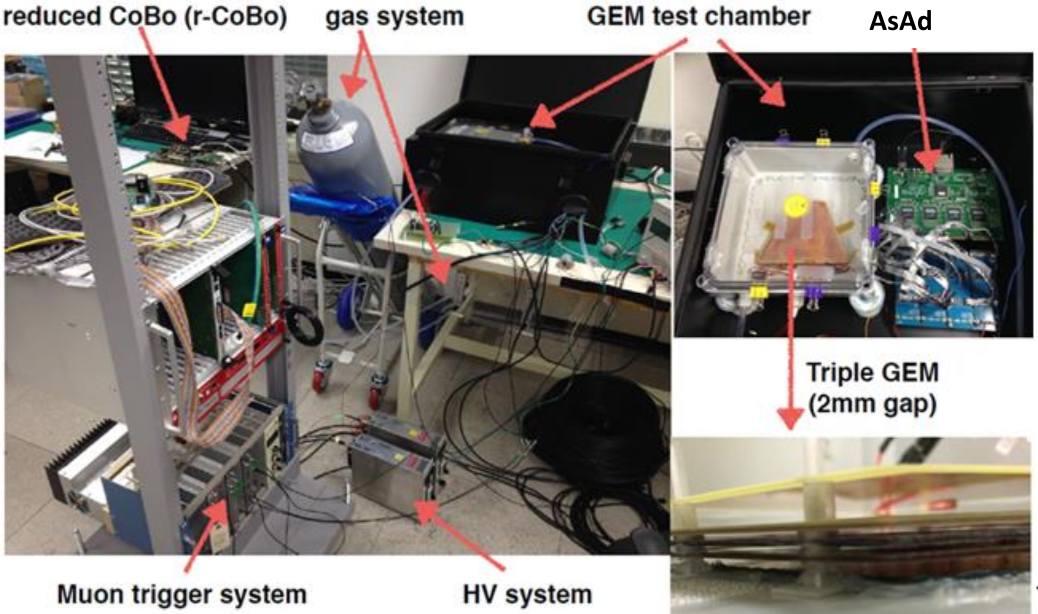
Prototype TPC: back

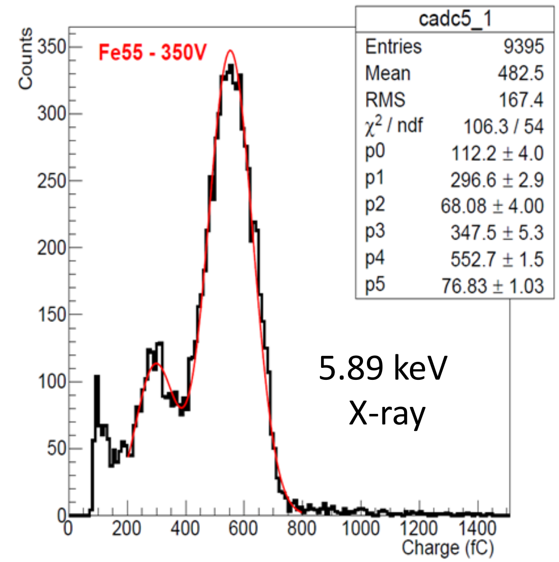


Prototype TPC assembled

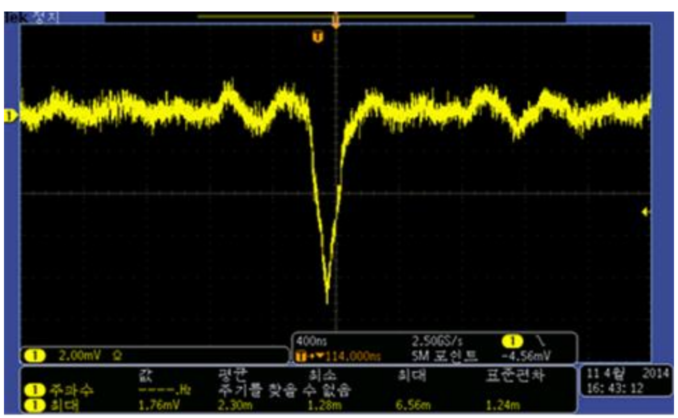


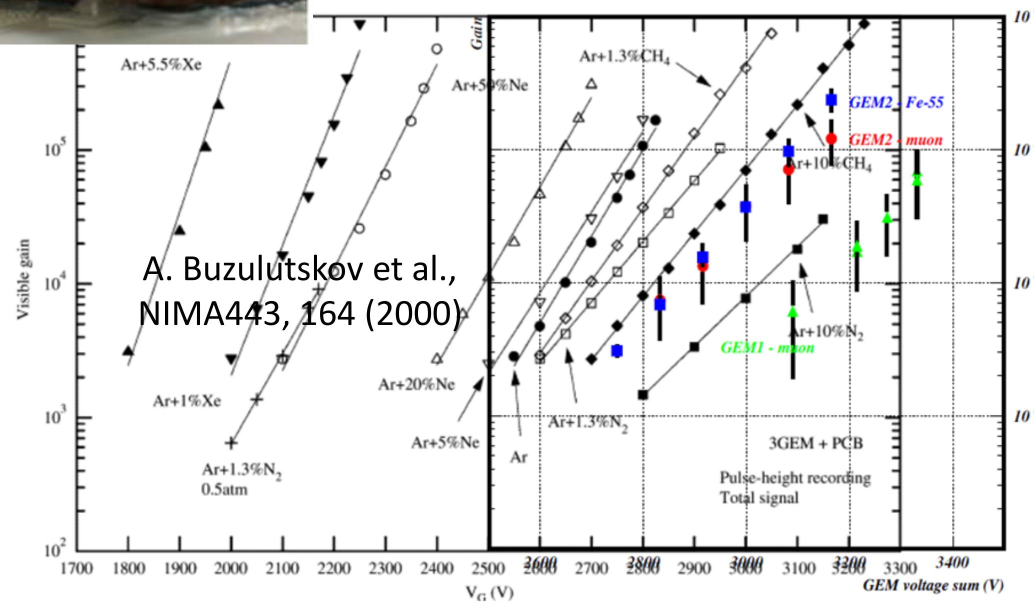
Test of Triple GEM Readout



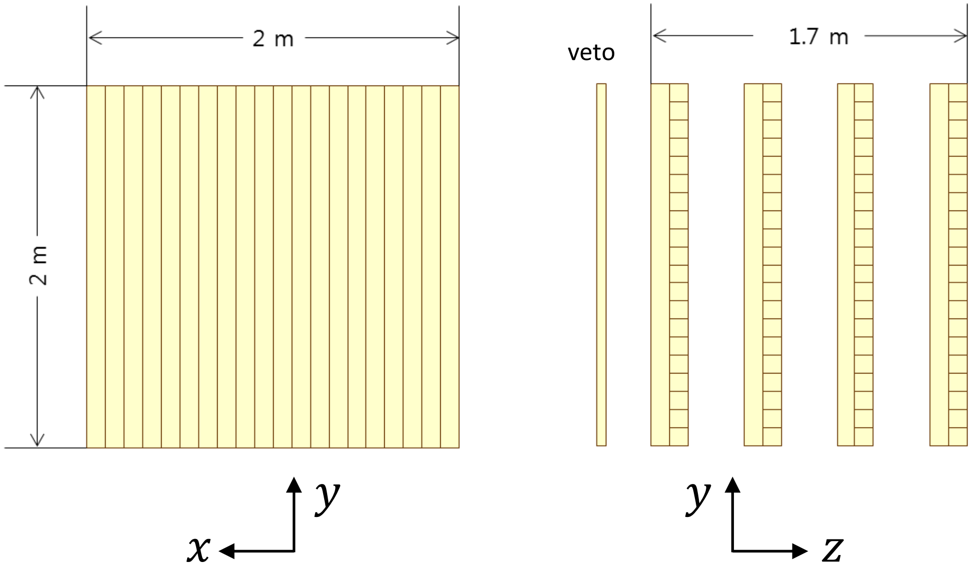


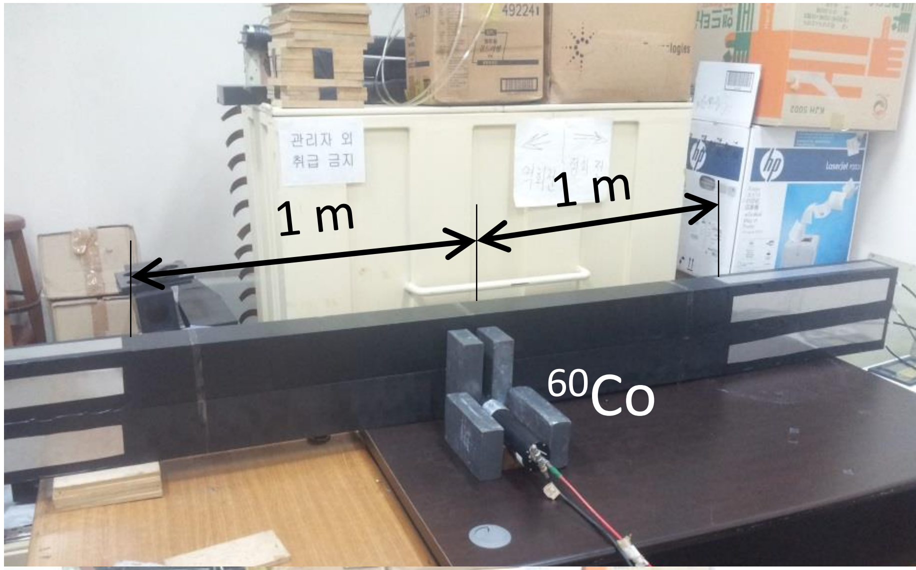
Signal from Fe-55 source

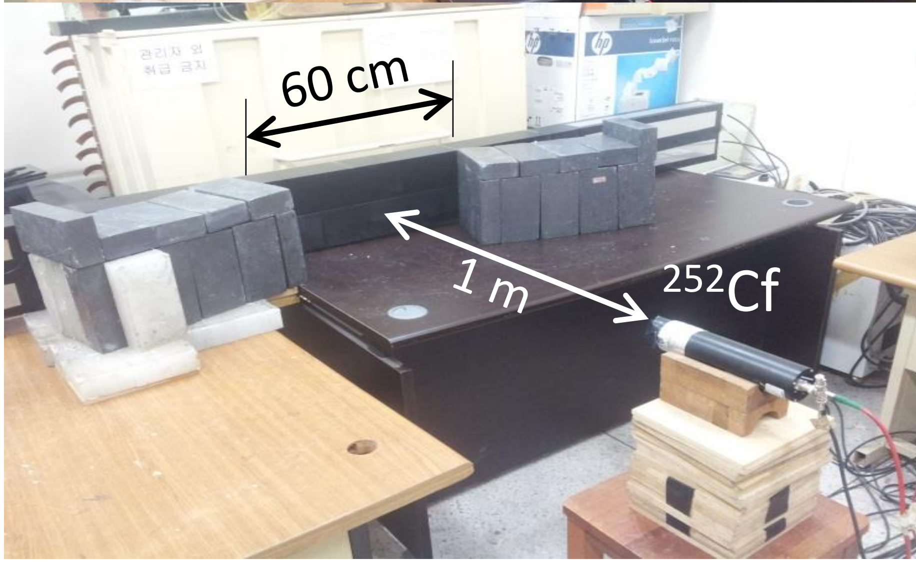




Neutron Detector Array



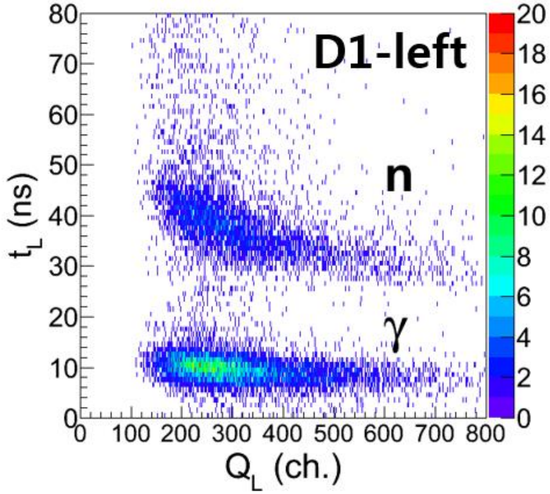


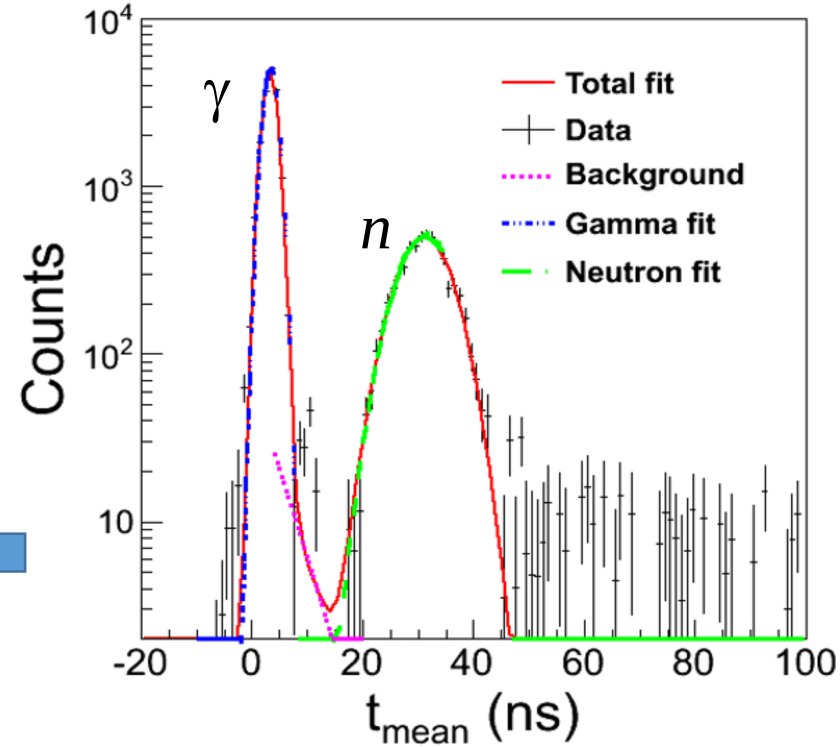


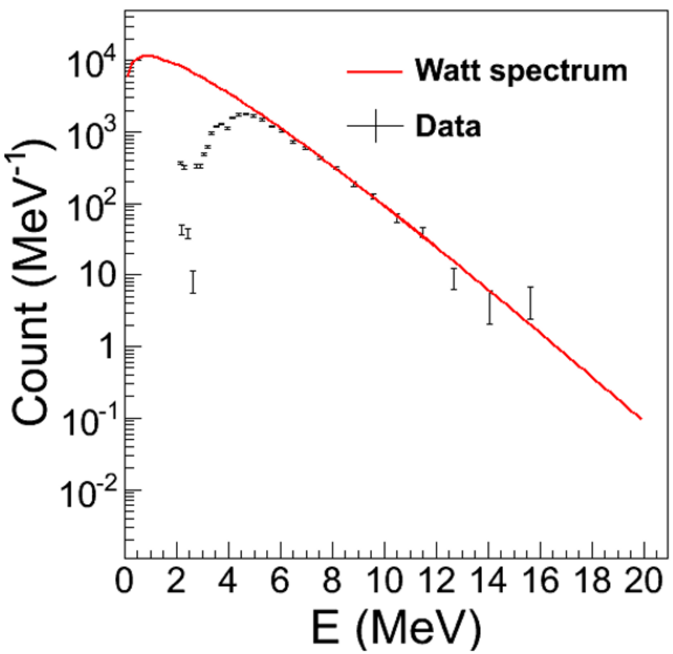
- Construction of real-size prototype detectors (0.1X0.1X2.0 m^3)
- Performance was tested using ^{60}Co and ^{252}Cf sources
- Plan to have a beam test this year

LAMPS Neutron Array

^{252}Cf







- Watt spectrum: ${}^{dN}/_{dE} \propto e^{-aE} \sinh \sqrt{bE}$
  - a=0.88 MeV^{-1} and b=2.0 MeV^{-1}
  - B. Watt, Physical Review 87, 1037 (1952)

Summary

1. Korean nuclear physics community is
   - Small, but active.
   - Participating in various experiments at LHC, RHIC, FAIR, RIBF, and RAON.
2. Examples
   - Heavy-ion physics at CMS
     - Major responsibility to the construction of forward RPC system
     - Quarkonium production in pA and AA collisions
   - RIB physics at LAMPS/RAON
     - Development of TPC: simulations, tracking software, construction and test of prototype
     - Development of neutron array: simulation, analysis software, construction and test of prototype
3. Final message
   - The Korean HI community is still in the developing stage. We expect a lot more to come.