Introduction to the Nuclear Physics Group of Korea University & Korean Contribution to the CMS Heavy-Ion Program

Byungsik Hong

Korea University

Summary of Present Activities

- Heavy-ion collision experiments from intermediate to ultra-relativistic beam energies
  - $\sqrt{s_{NN}}$ = 5.5 TeV : CMS at LHC/CERN
  - $\sqrt{s_{NN}}$ = 200 GeV : PHENIX at RHIC/BNL
  - $E_{beam} \leq$ 2A GeV : FOPI at SIS18/GSI
  - $E_{beam} \leq$ 30A GeV : CBM at SIS300/GSI (future)
- Detector R&D and Applications
  - Muon Trigger RPCs for CMS and PHENIX
  - ToF RPCs for FOPI and CBM
  - Thermal Neutron Detectors
  - Animal PET Development

CMS at LHC/CERN

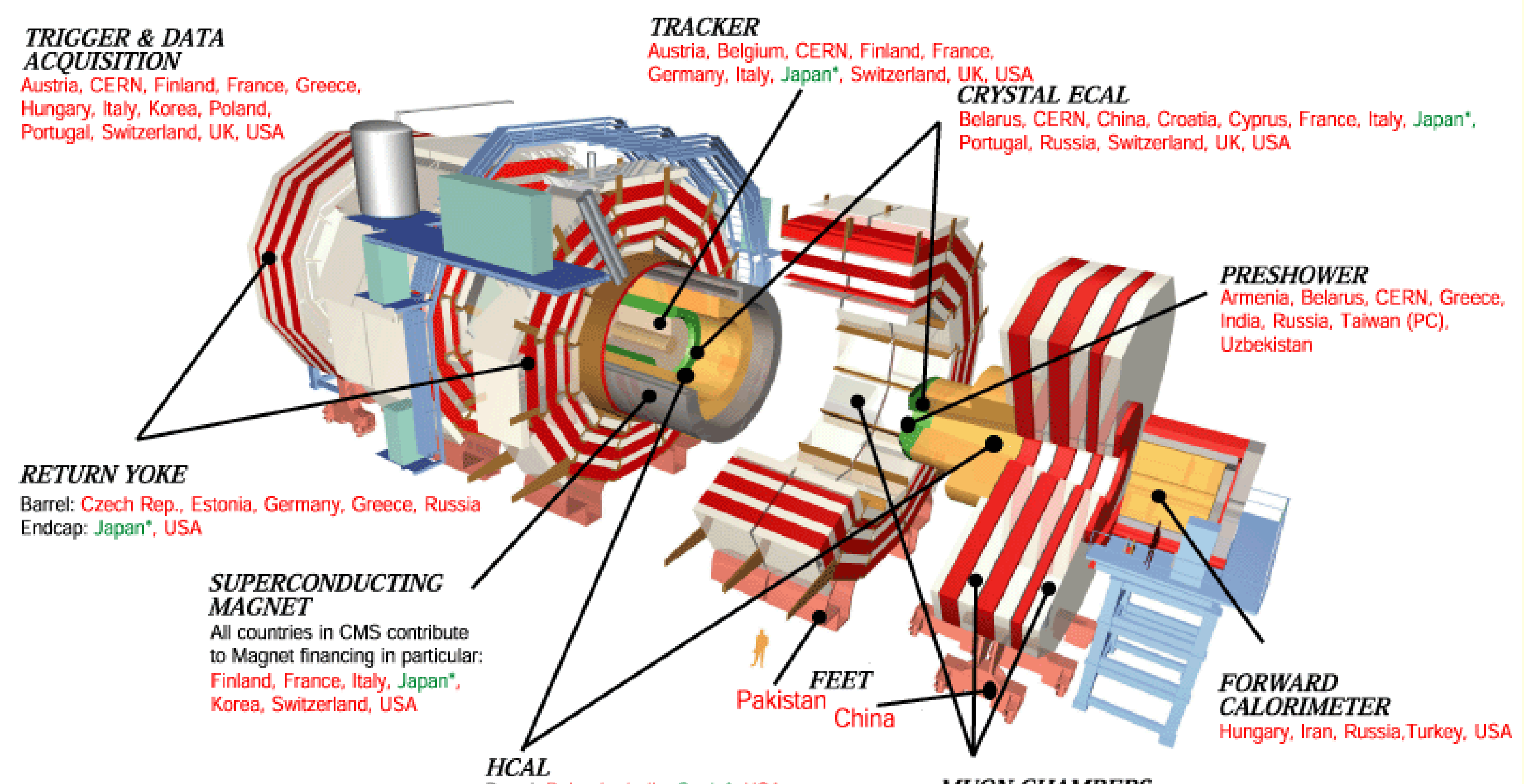
- **Detectors**
  - **Construction of endcap RPCs**

    (More details in the next few pages)
- **Physics**
  - J/ψ **and** γ **productions via dimuons**
  - **B-meson production via the decayed** J/ψ**'s into dileptons**
  - **b-tagging jet production**

    (To be presented later in this talk)

CMS Endcap RPCs

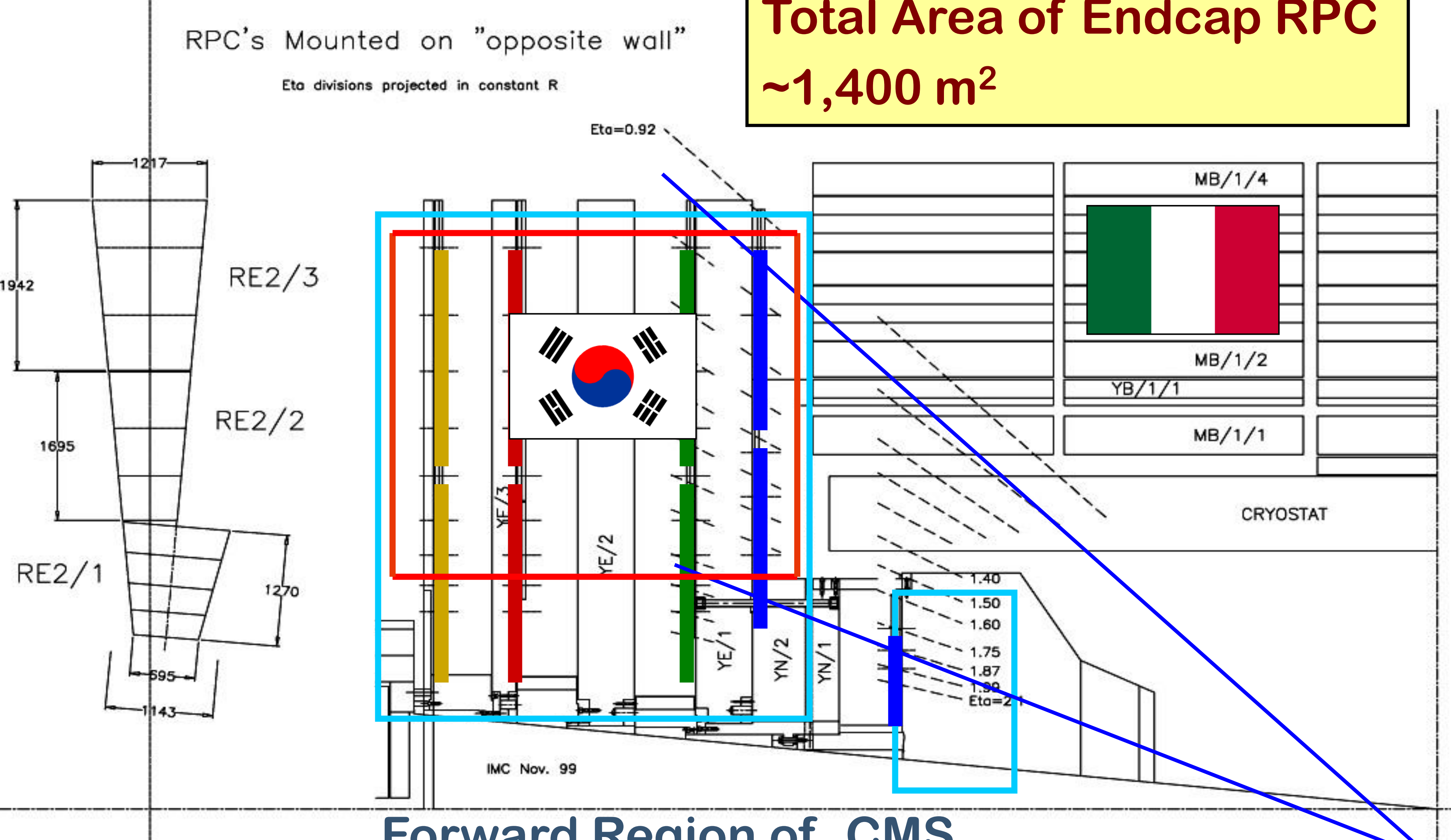
The nuclear & high-energy physics groups of Korea University have been active for the CMS(Compact Muon Solenoid) Collaboration of LHC at CERN since 1997.



Total weight	:	**12500 T**
Overall diameter	:	**15.0 m**
Overall length	:	**21.5 m**
Magnetic field	:	**4 Tesla**

CMS Endcap RPCs

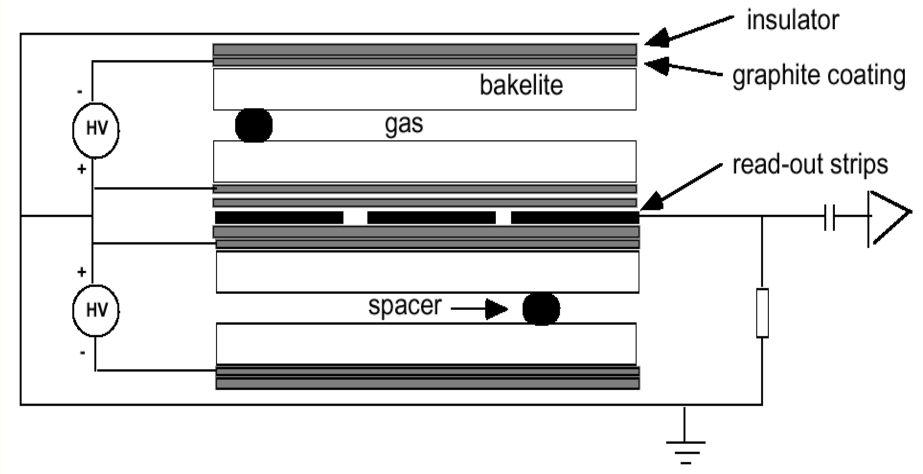
Total Area of Endcap RPC ~1,400 m²

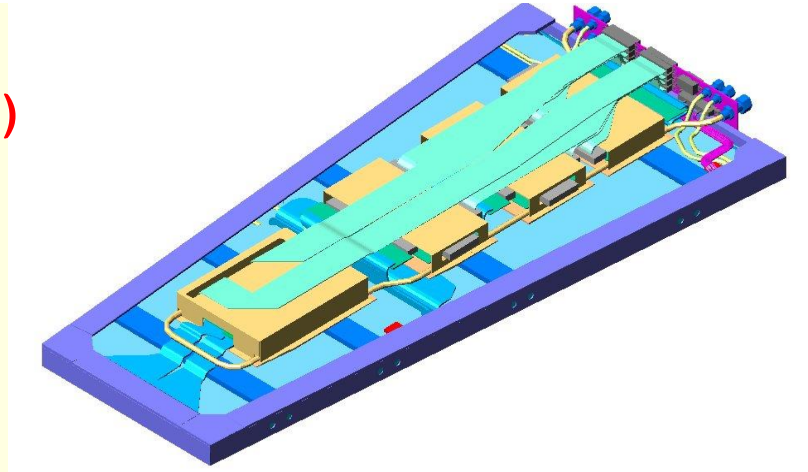


Forward Region of CMS

CMS Endcap RPCs

1. **Function : L1 muon triggers**
   - 2 wings (RE+, RE-)
   - 4 stations (RE1, RE2, RE3, RE4)
   - Pseudo rapidity coverage :
     - $0.9 < \eta < 2.1$ (1.6)
   - η segmentations : 10 (6)
2. **Total # of RPCs : 756 (432)**
   - Total # of FEBs : 2,268 (1,296)
   - Total # of channels : 85,248 (41,472)
3. **By March 2007,**
   the gap production for phase I ($0.9 < \eta < 1.6$) was completed for the first operation of CMS in 2008.

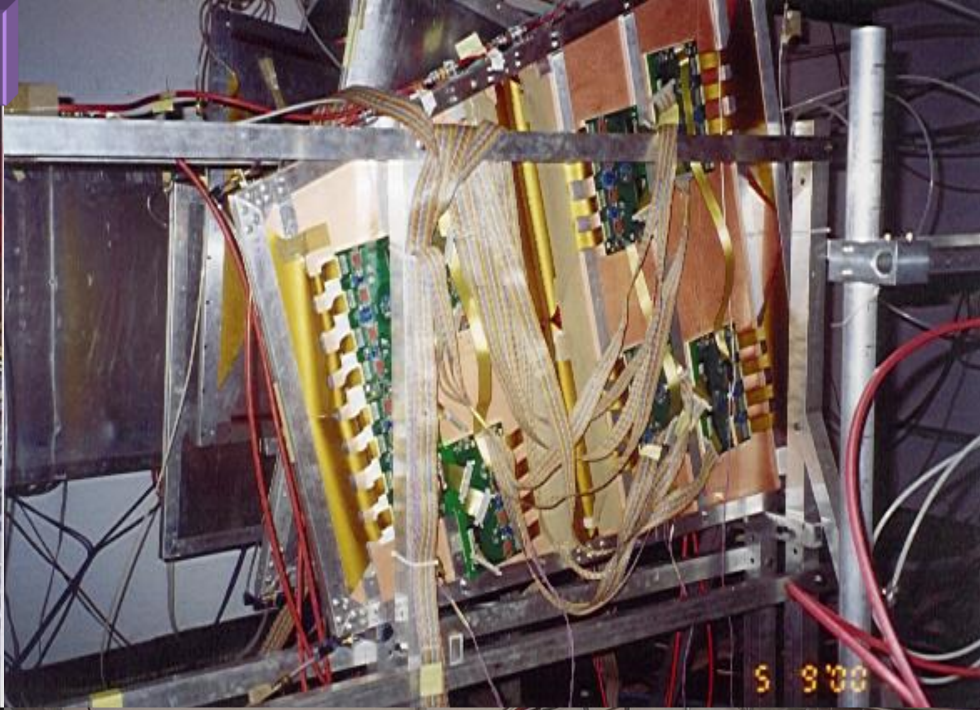


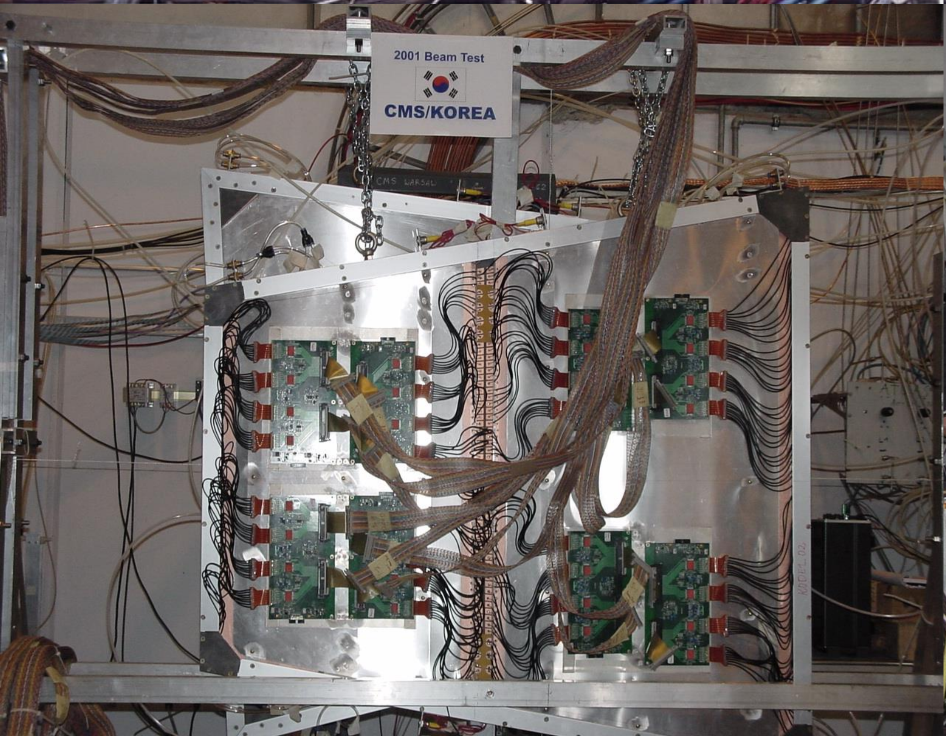


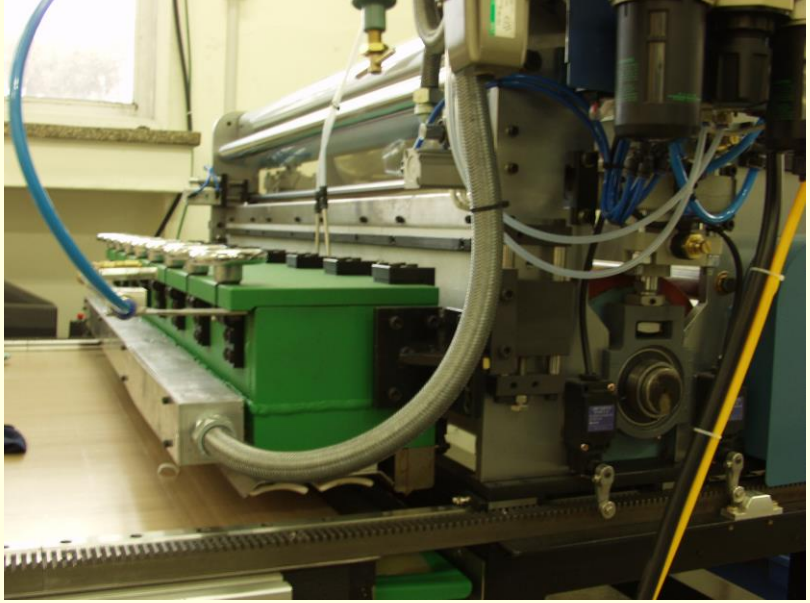
A Brief Research History

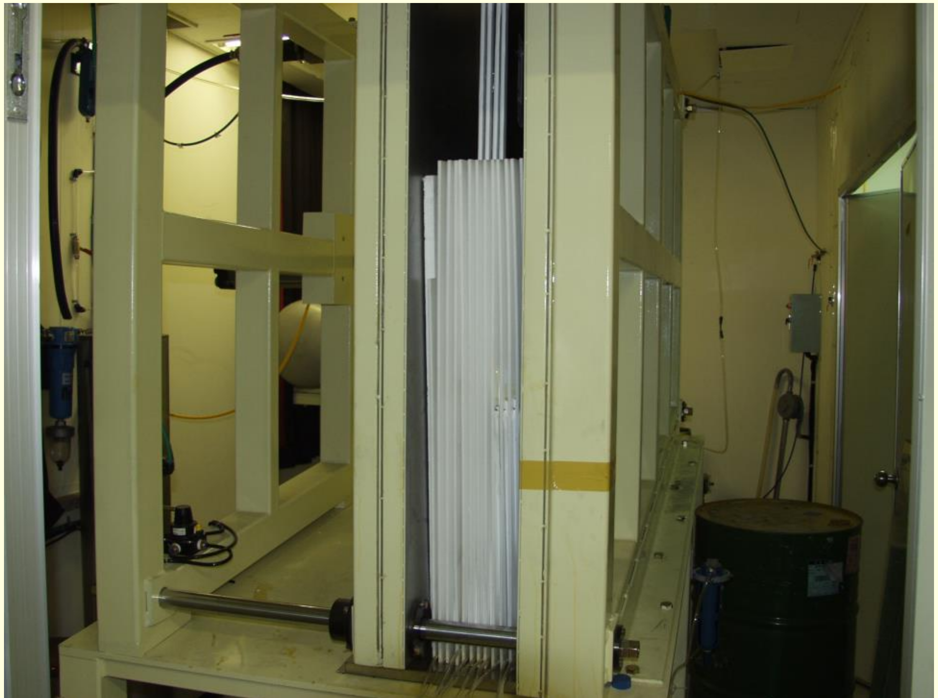
1. Fundamental studies to develop the endcap RPCs (1997~)
   1) Beam tests by using high intensity muon beams at CERN
   2) Cosmic ray muon tests in Korea
   3) Long term aging studies by γ's and neutron beams in Korea
2. Design of double gap RPCs for the endcap region (2000~2003)
   1) Gas gap design
   2) Services for HV, LV, gas, electronics on the chamber level
3. Manufacturing the production facilities at Korea Univ. (2000~2003)
   1) Gap and chamber production facilities
   2) Testing facilities for the quality assurance control
4. Mass production of the endcap RPCs (2004~)
   1) Phase I production ($0.9 < \eta < 1.6$, total 432 gaps) was completed.
   2) Phase II production ($1.6 < \eta < 2.1$) is expected to start next year.

Beam Tests at CERN (1998 ~ 2003)







Performance of Korean RPCs

Characteristics	CMS Requirements	Test Results the world best quality
Time Resolution	< 3 ns	< 1.5 ns
Efficiency	> 95 %	> 95 %
Rate Capability	> 1 kHz/cm^2	> 1 kHz/cm^2
Noise Rate	< 15 Hz/cm^2	< 10 Hz/cm^2
Plateau Region	> 300 V	> 400 V

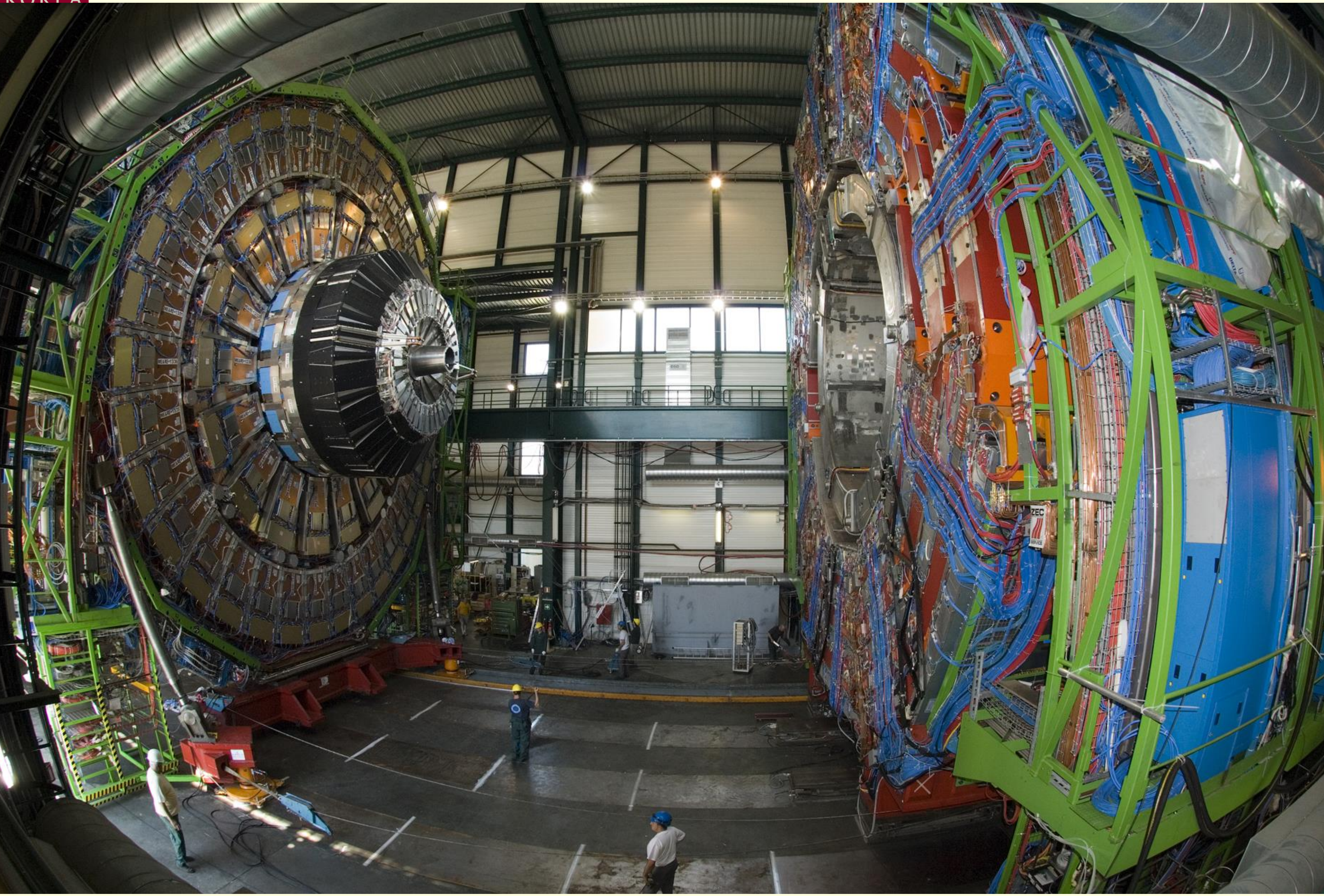
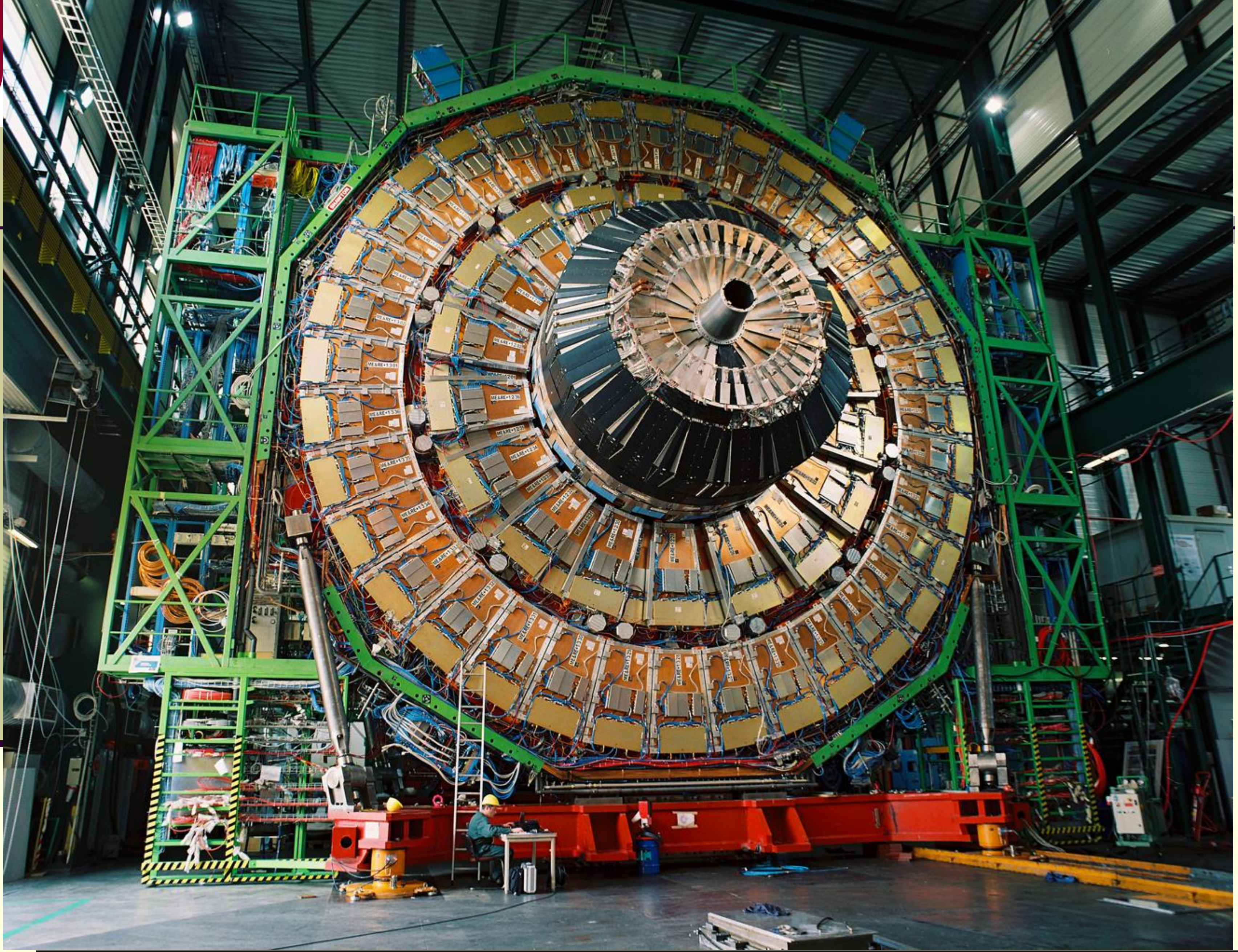


Photo taken in Nov. 2006

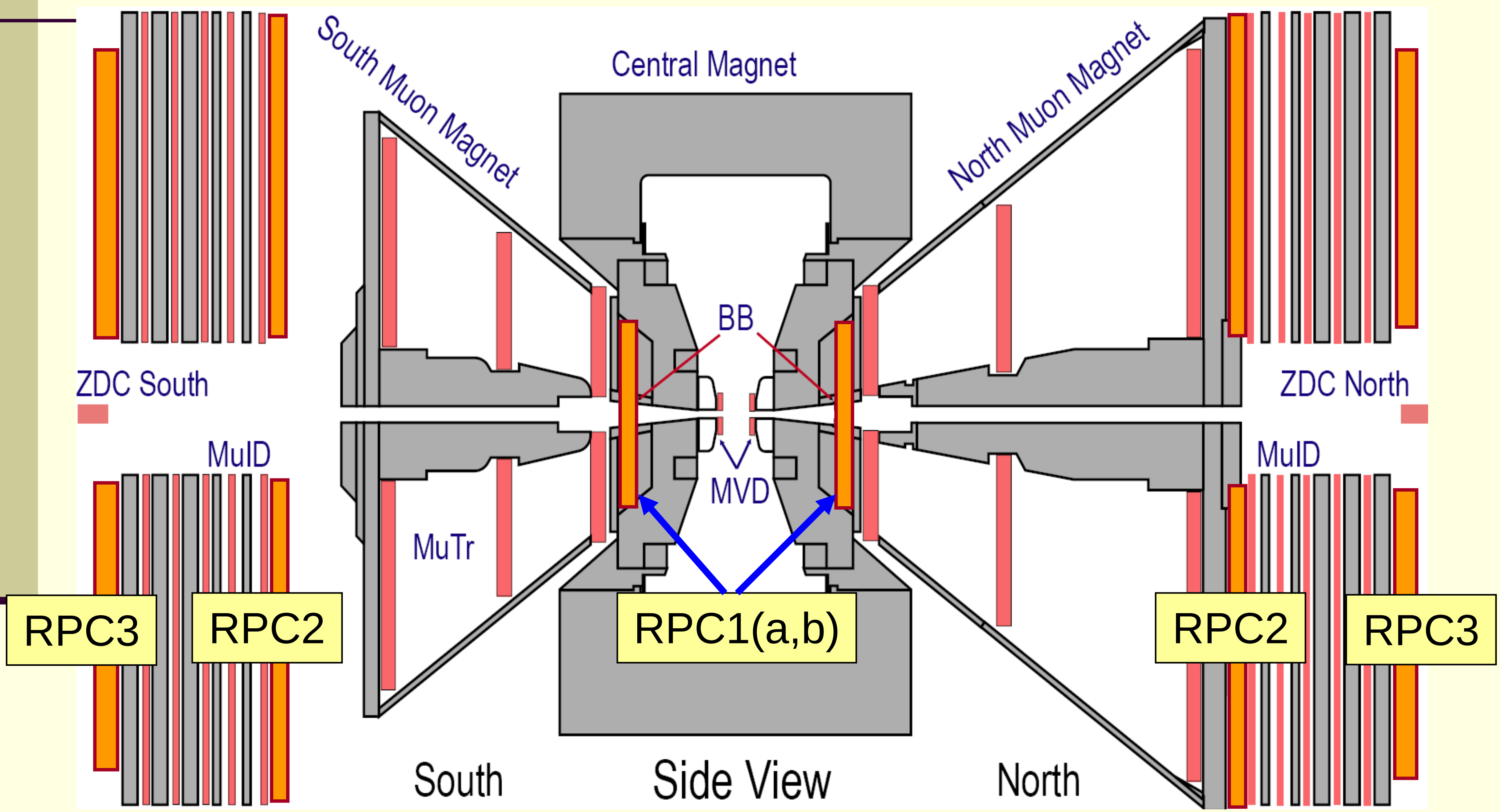


RPC1+CSC1 installed successfully

PHENIX at RHIC/BNL

- **Physics**
  - **Quarkonium production via dimuon channels**
  - **Flow of heavy vector mesons**
  - **Feasibility study of measuring chi_c**
- **Detectors**
  - **Construction of the muon trackers (CSC)**
  - **In collaboration with the high-energy physics group of Korea University, we will produce all RPC gas gaps for the muon trigger upgrade. (More details in next pages)**
  - **In collaboration with Yonsei, Ewha, and Myungji Universities, we participate in the NCC upgrade R&D.**

PHENIX RPC Locations



lengths in mm
theta in deg.

	theta (deg)	RPC1a Radius	RPC1a width	RPC1b radius	RPC1b width	RPC2 radius	RPC2 width	RPC3 [illegible]	RPC3 width
possible						5280.2			
	34.36	933.2	773.1	1016.8	842.3	4675.4	[illegible]	[illegible]	[illegible]
ring 8		*strips: 181.4 x 12.1 (64)*		*strips: 197.7 x 13.2 (64)*		*strips: [illegible]*		[illegible]	
	31.60					[illegible]			
ring 7						[illegible]			
	28.84	751.8	622.8	819.1	[illegible]	[illegible]	[illegible]20.3	4991.4	4135.0
ring 6		*strips: 164.3 x 9.7 (64)*		*strips: 17[illegible]*		*[illegible].8 (64)*		*strips: 554.2 x 64.6 (64)*	
	26.09					[illegible]	2773.9	4437.2	3675.9
ring 5						*[illegible]ps: 298.9 x 48.8 (57)*		*strips: 528.6 x 64.6 (57)*	
	23.33	588.7	487.7	[illegible]	[illegible]	2949.4	2443.4	3908.6	3238.0
ring 4		*strips: 151.1 x 1[illegible]*		*[illegible].6 (32)*		*strips: 382.7 x 38.2 (64)*		*strips: 507.1 x 50.6 (64)*	
	20.57					22566.8	2126.4	3401.5	2817.9
ring 3						*strips: 369.1 x 38.2 (56)*		*strips: 493.3 x 50.6 (56)*	
	17.81	[illegible]	[illegible]	[illegible]77.9	395.9	2197.7	1820.6	2912.3	2412.7
ring2		[illegible]		*strips: 153.6 x 12.4 (32)*		*strips: 357.8 x 28.4 (64)*		*strips: 474.2 x 37.7 (64)*	
	15.0[illegible]					1839.8	1524.2	2438.1	2019.8
ring1						*strips: 3548.7 x 28.4 (54)*		*strips: 462.1 x 37.7 (54)*	
	[illegible]	[illegible]	246.6	324.3	268.6	1491.1	1235.3	1976.1	1637.0
possi[illegible]						1468.4		1926.4	
		split gap: ring 4 and 5		split gaps: ring 2 and 3 + ring 6.and 7		no split gaps		no split gaps	

The Korea University will produce total 256 RPC gas gaps and 48 spares.

* strip leng[illegible] and width consider full acceptance in theta and phi in the octants (i.e. no loss due to readout and boxes)
* strip widths are determined at the outer radius of two paired rings

PHENIX Schedule

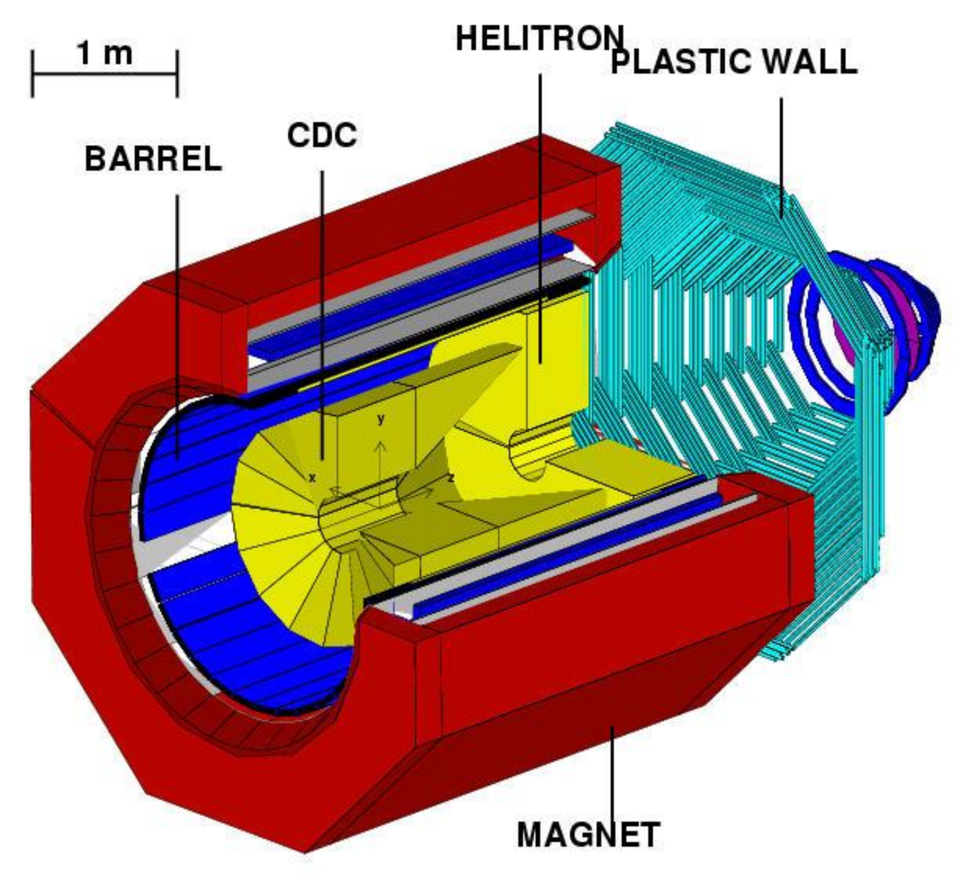
- ~Feb. 2008
  - Production of complete half octant (prototype D)
- ~July 2008
  - Complete assembly and testing RPC3
- 2009
  - Complete the installation of all RPCs
- 2009-2012
  - Running at $\sqrt{s}$ = 500 GeV
  - Projected yield of $\int L dt \sim 950\ pb^{-1}$

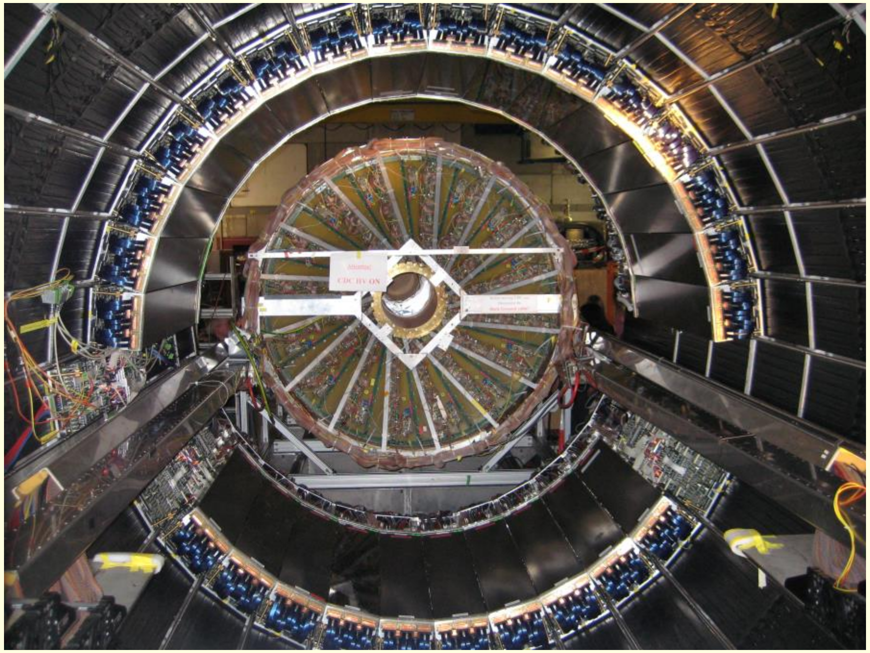
FOPI at SIS18

- Physics
  - Nuclear stopping power and radial flow
    - Phys. Rev. C 66, 034901 (2002); Phys. Rev. Lett. 84, 1120 (2000), Phys. Rev. C 57, 244 (1998); Nucl. Phys. A 721, 317 (2003)
    - Beam energy dependence in preparation
  - Pion production and resonance analysis
    - Phys. Rev. C 71, 034902 (2005); Phys. Lett. B 407, 115 (1997)
  - Strangeness production and in-medium effects
    - Nucl. Phys. A 625, 307 (1997)
    - Charged kaon flow in preparation
- Detectors
  - Multigap Resistive Plate Chambers for the Time-of-Flight Detectors

    (This is also a part of the CBM ToF detector R&D.)
  - Upgrade and maintenance of the Central Drift Chamber

FOPI Detector



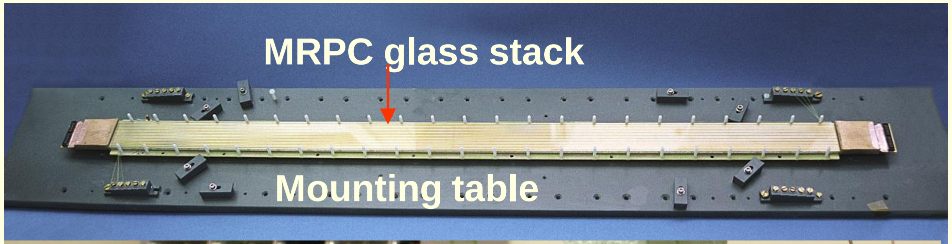


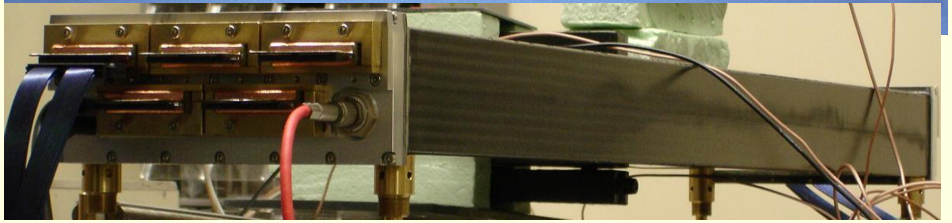
New 26 RPC super modules were installed in August 2007, and are being operated.

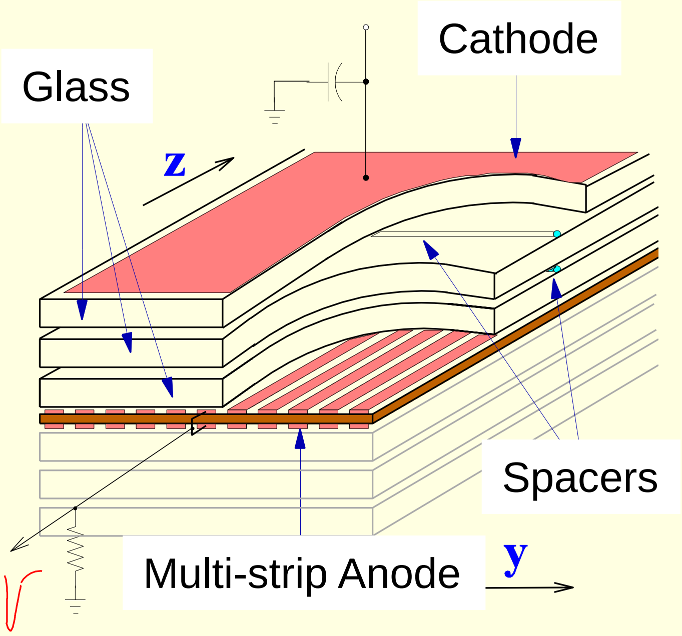
Multi-strip Multi-gap RPC

New MM RPC Time-of-Flight system

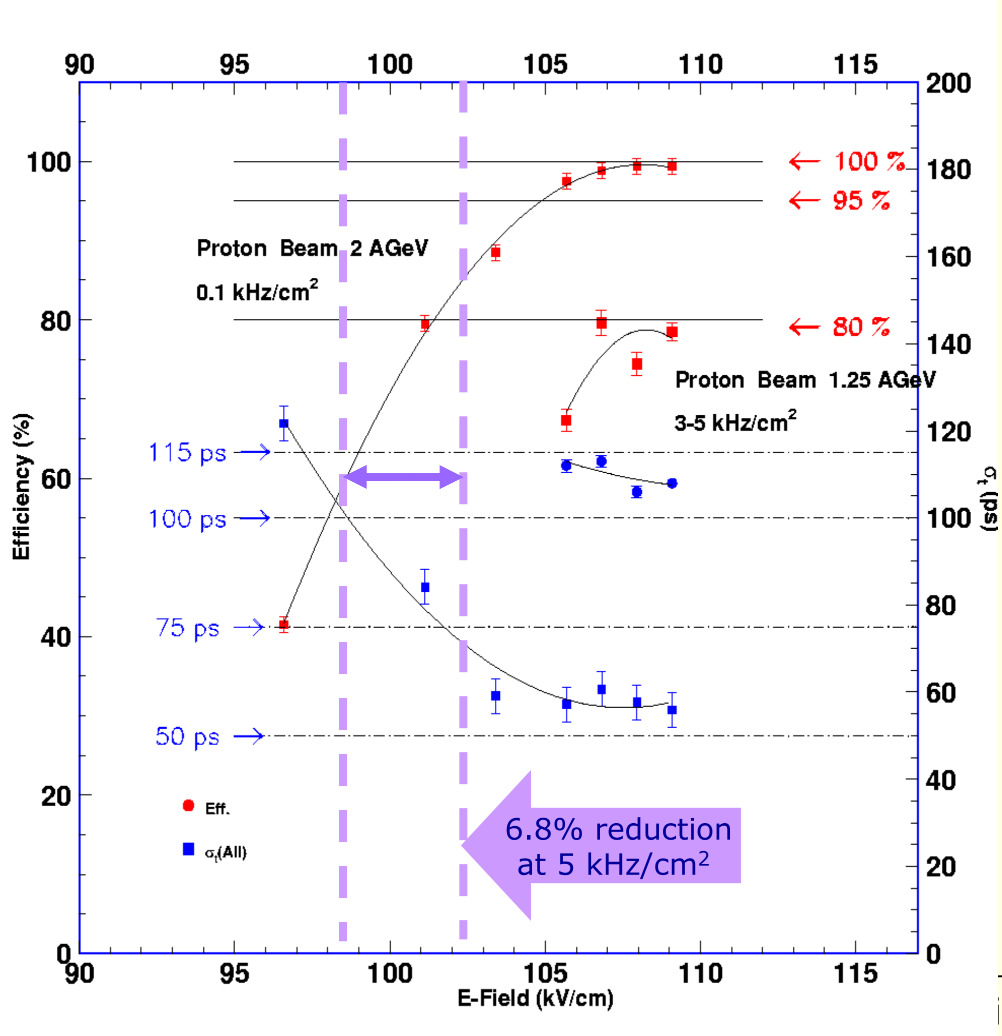
- **Completed R & D (2000-2005)**
- **6 m^2 active area and 4800 electronic channels**
- **Gas: $C_2F_4H_2$/isobutane/SF_6 = 85/5/10**
- **Time resolution (σ_t) < 75 ps**
- **Efficiency (ε) > 95 %**







Multi-strip Multi-gap RPC



High rate R&D for the CBM collaboration at FAIR

Neutron Sensitive RPCs

Detector	Structure (electrodes)	Read Out	Operating Mode
Gd-RPC/ Plain-RPC	Single Gap (bakelite)	2D-Strips	Streamer
Gd-RPC/ Plain-RPC	Double Gap (bakelite)	Pad	Streamer
LiF-RPC	Double Gap (glass)	Pad	Low Gain Avalanche

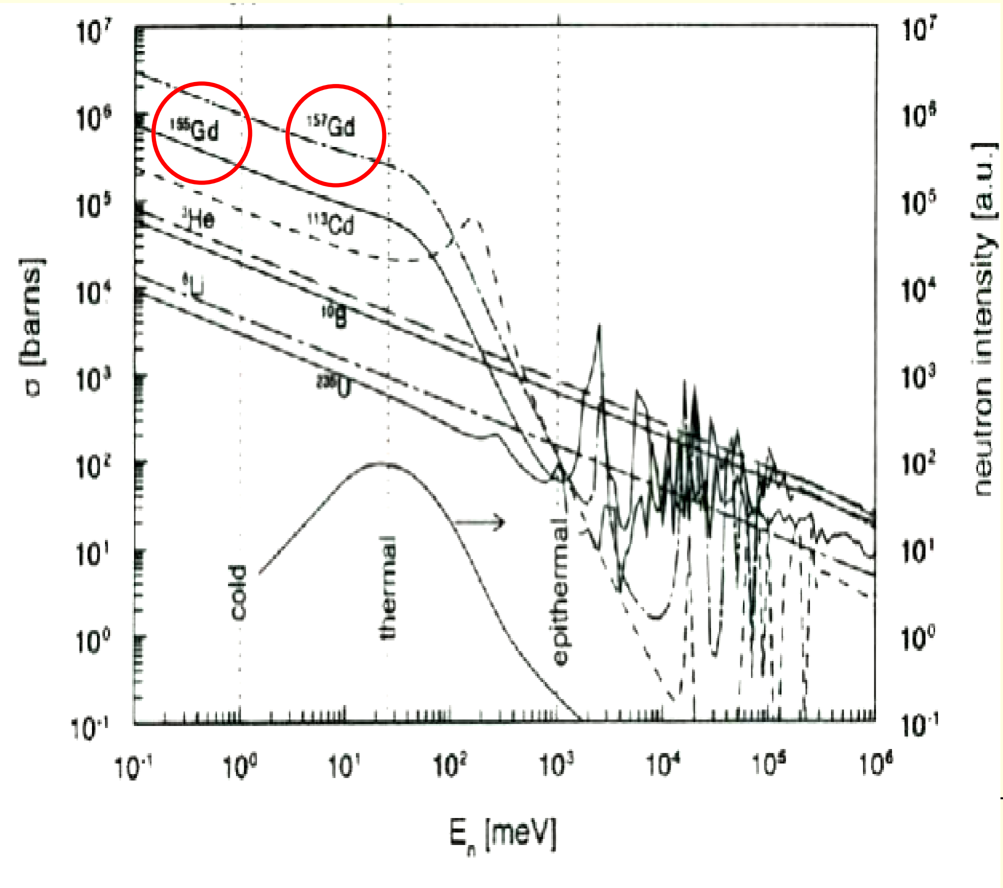
Tested with the moderated neutrons emitted by the ^{252}Cf source at KAERI

Neutron Sensitive Material

Interesting isotopes are about 30% in natural Gd_2O_3.

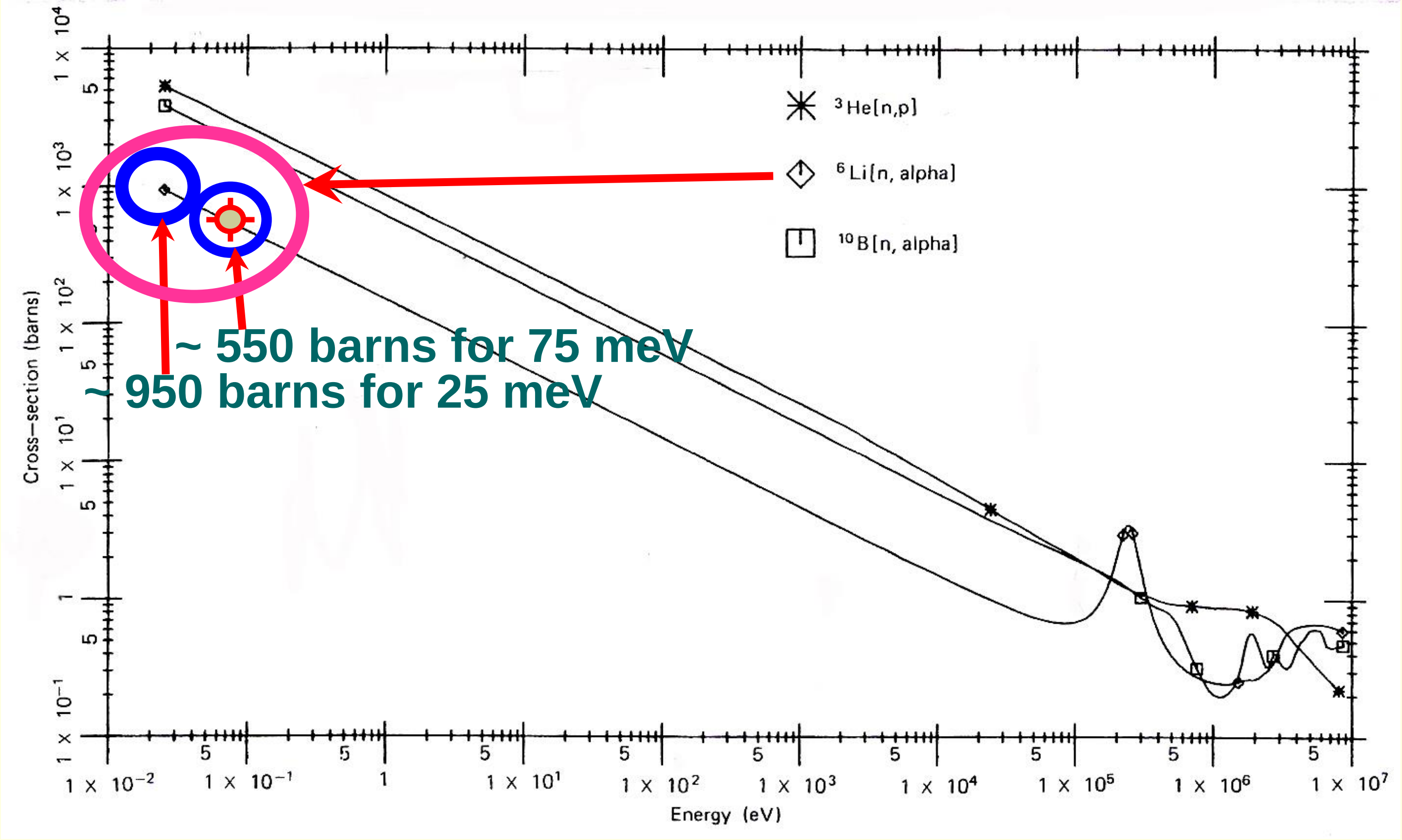
Ref.) M. Abbrescia et al., NIMA 533 (2004) 149.

Mass No.	%
152	0.2
154	2.2
155	14.8
156	20.5
157	15.7
158	24.8
160	21.8

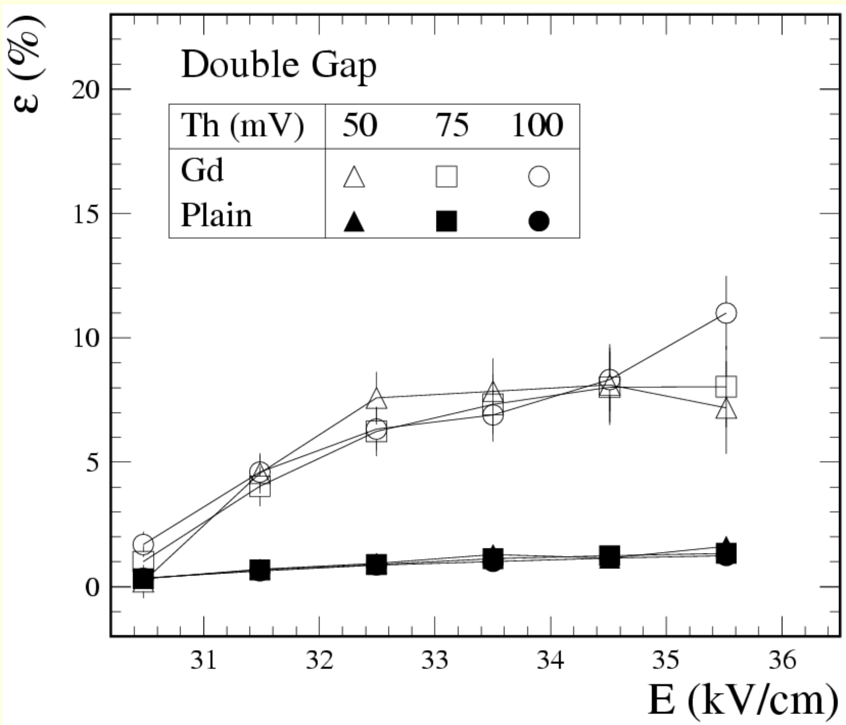


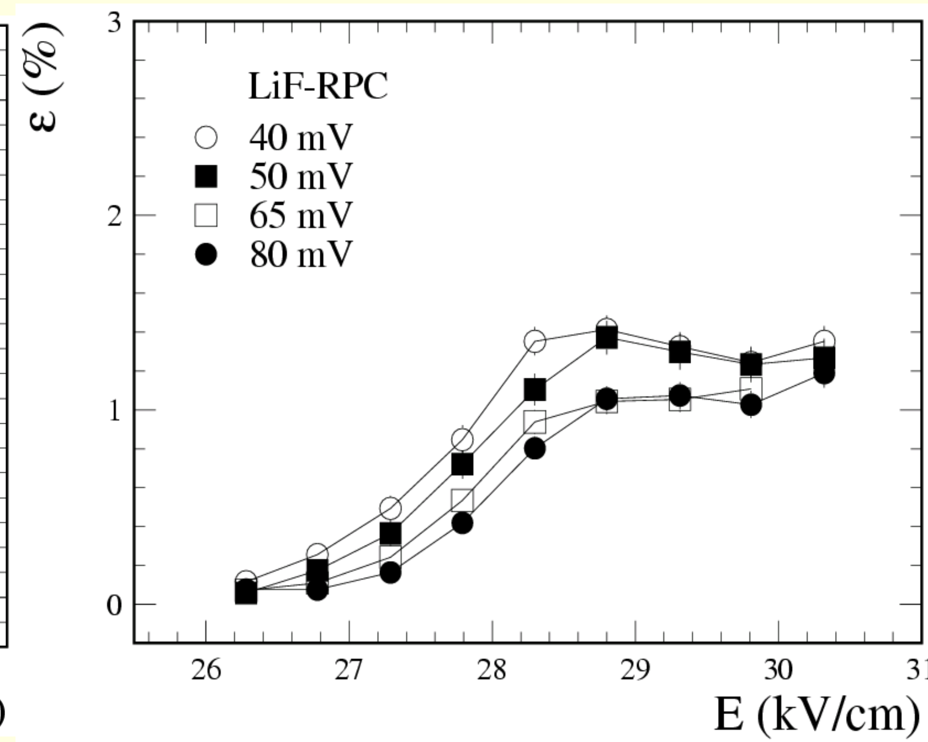
Neutron Sensitive Material

$n + {}^{6}Li \rightarrow \alpha + {}^{3}H$ (Q = 4.78 MeV, E_{α} = 2.05 MeV, E_{H} = 2.73 MeV)



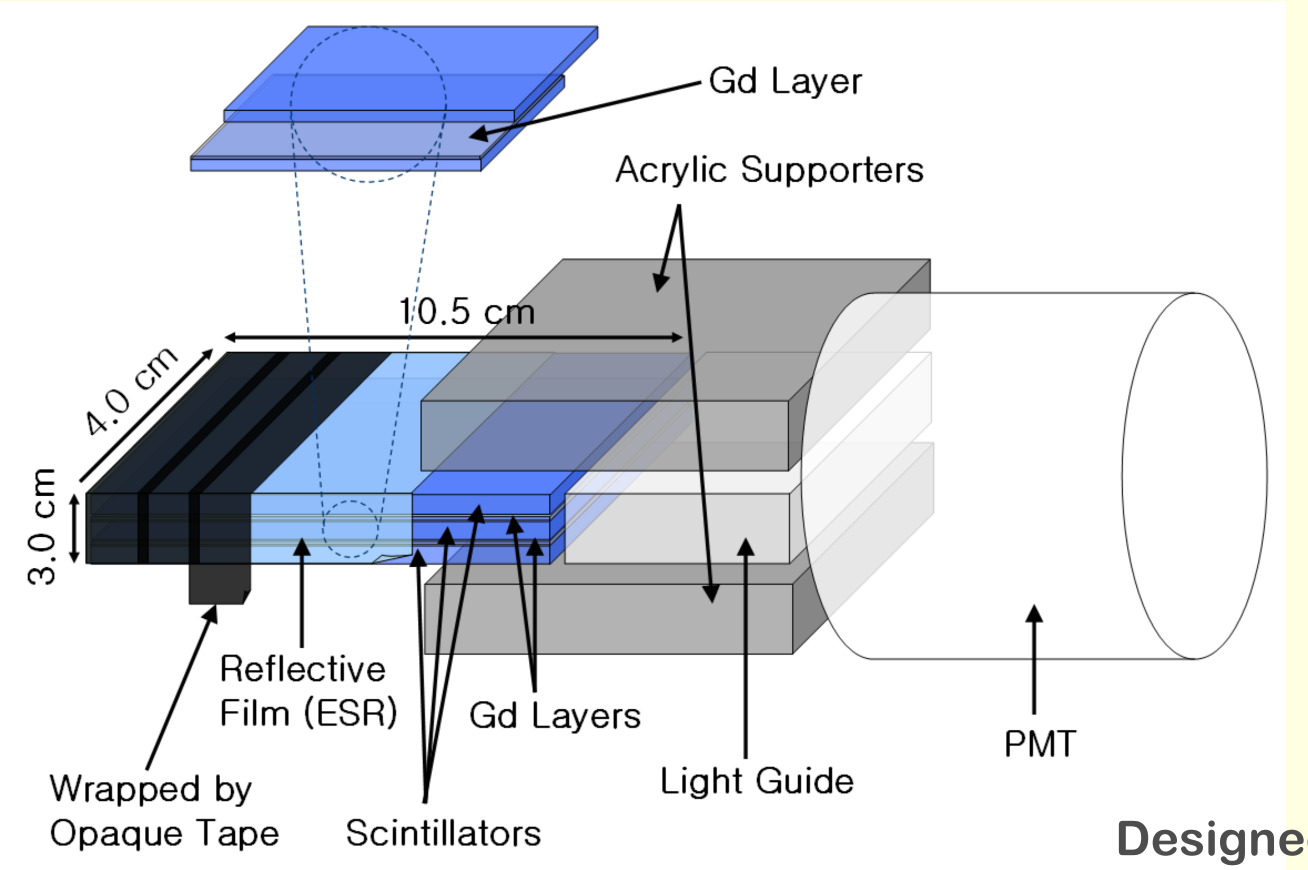
Neutron Sensitive RPCs





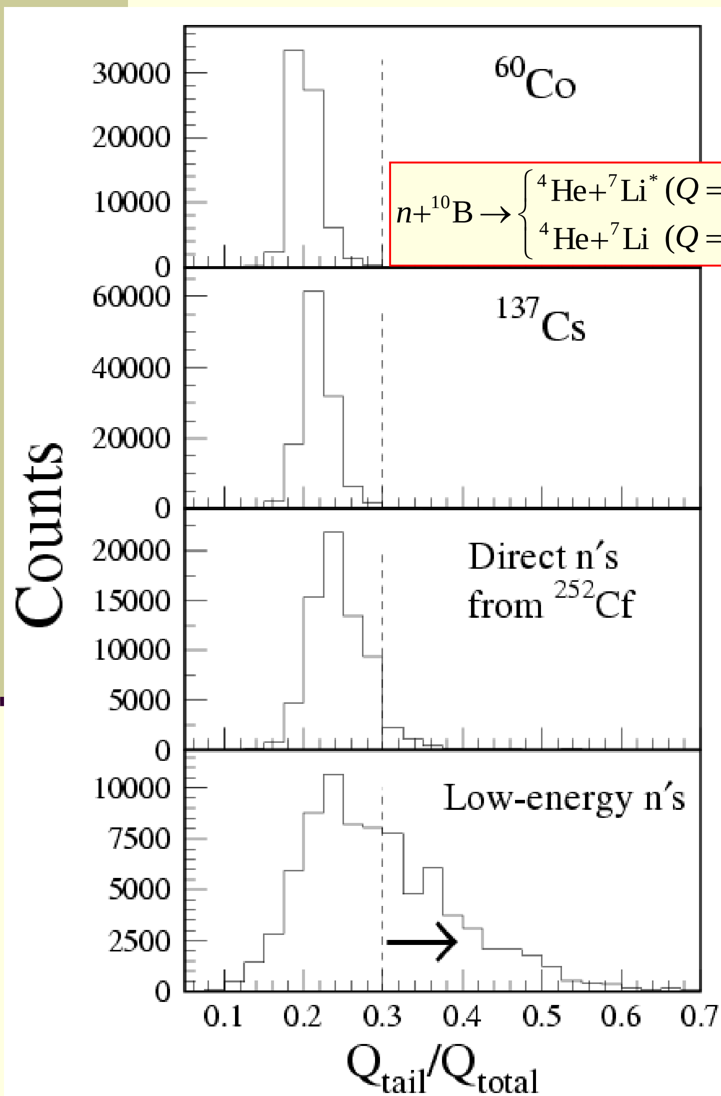
Analyzed by Hyun Chul Kim, Ji Hyun Kim, and Rongjiang Hu

Neutron Sensitive Hybrid Plastic Scintillator Detectors



Designed and made by Chong Kim

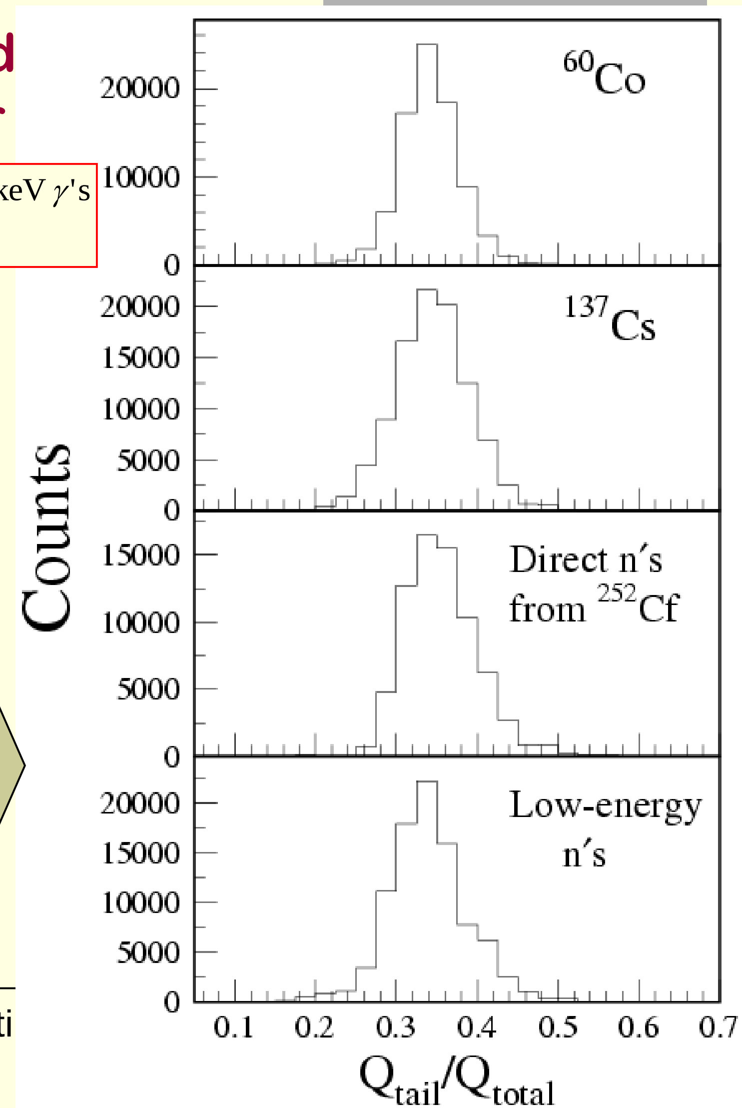
Neutron Sensitive Hybrid Plastic Scintillator Detectors



B-loaded detector

$$n + {}^{10}\mathrm{B} \rightarrow \begin{cases} {}^{4}\mathrm{He} + {}^{7}\mathrm{Li}^{*}\ (Q = 2.310\ \mathrm{MeV},\ 94\%) : \text{emits}\ \ 478\ \mathrm{keV}\ \gamma\text{'s} \\ {}^{4}\mathrm{He} + {}^{7}\mathrm{Li}\ \ (Q = 2.792\ \mathrm{MeV},\ \ 6\%) \end{cases}$$

Gd-layer implanted detector



Korean Contribution to the CMS Heavy-Ion Program

Korean CMS Heavy Ioner's

Physics Team

<u>Korea Univ.</u>
<u>(quarkonium and jet)</u>

Prof. Kwang Souk Sim
Prof. Byungsik Hong
Dr. Gopika Sood
Dongho Moon
Jihyun Kim
Hyunchul Kim

<u>Univ. of Seoul</u>
<u>(jet Reco. and γ-jet)</u>

Prof. Inkyu Park
Dr. Geunbum Kim
Garam Hahn

<u>Chonbuk Nat'l Univ.</u>
<u>(?)</u>

Prof. Eunjoo Kim

Computing Team

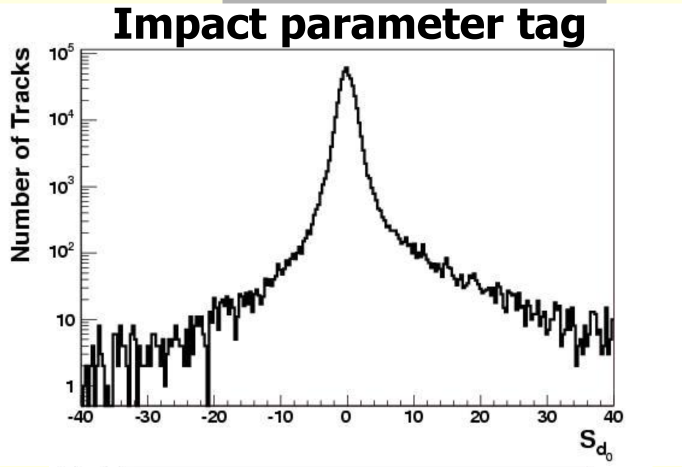
<u>Tier2 @ SSCC</u>
Prof. Inkyu Park (Director)
Dr. Jongkwan Woo (Coordinator)
Jinwoo Park (HW), Garam Hahn (SW)
Yusang Kim (Support), Minkyu Choi (Web, Twiki)

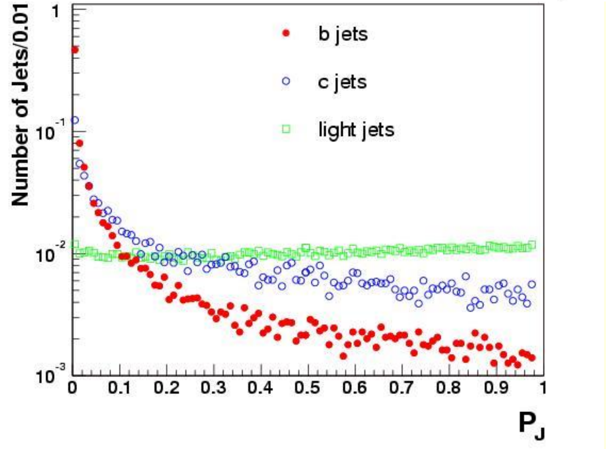
Summary of Analysis Topics

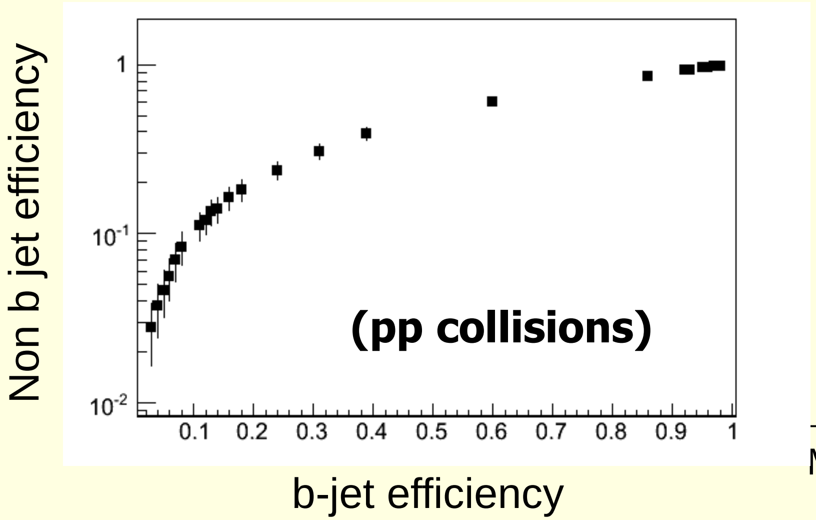
- b-tagging jet analysis (Dr. Gopika Sood)
- B-meson production via secondary J/ψ's (J.H. Kim)
- Quarkonium production and muon reconstruction (D.H. Moon)
- Gamma-Jet study (G.R. Hahn)
- Jet reconstruction in Heavy Ion data (Prof. I.C. Park)

b-tagging Jet in Heavy Ion

- Motivation
  - b-tagging jet: CP violation, Higgs search
  - Important for the heavy quark production and quenching in heavy-ion collisions
- Method
  - Large impact parameter due to wider jet shape
  - Probability lifetime tagging method, etc.
- Results
- Dr. G. Sood (Korea Univ.)



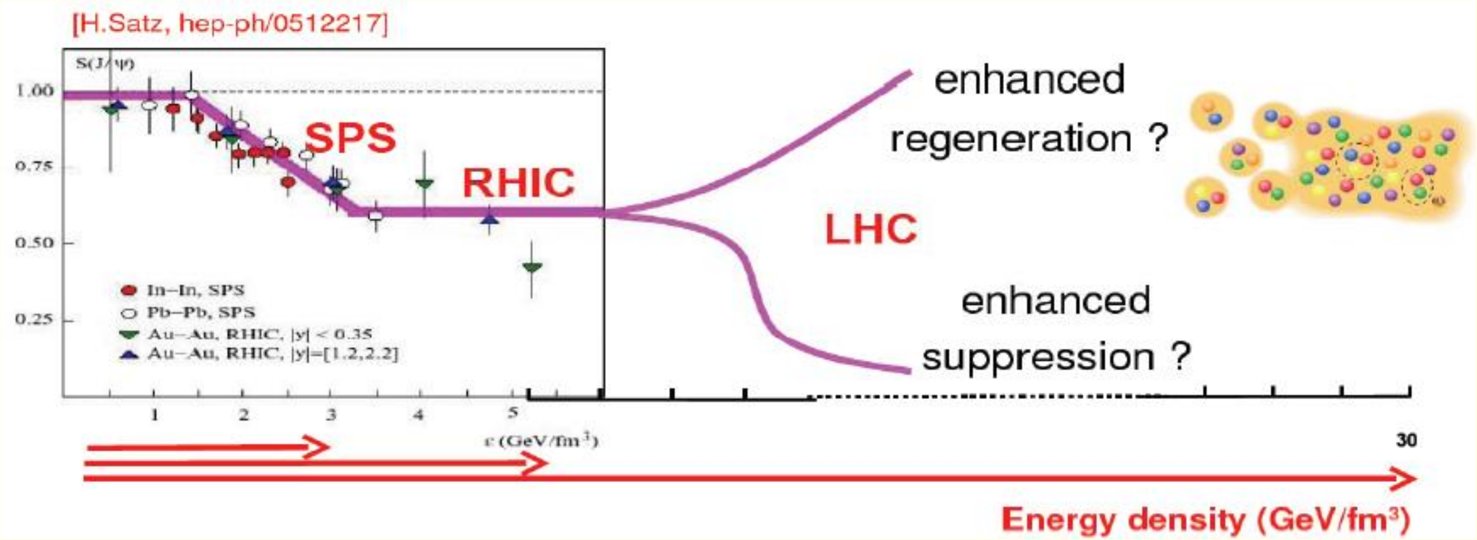




$$P_{jet} = \Pi \cdot \sum_{j=0}^{N_{tr-1}} \frac{(-\ln \Pi)^j}{j!}, \quad \Pi = \prod_{i=1}^{N_{tr}} P_{tr\,i}$$

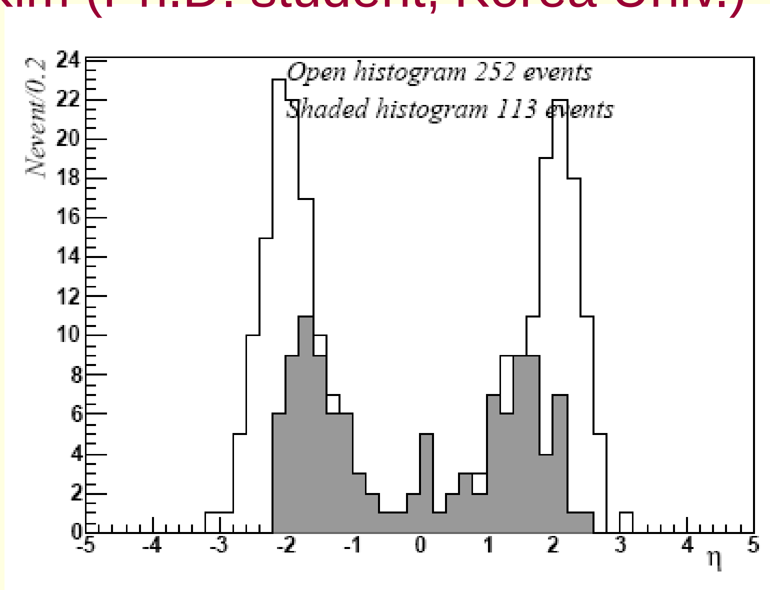
Quarkonium Production

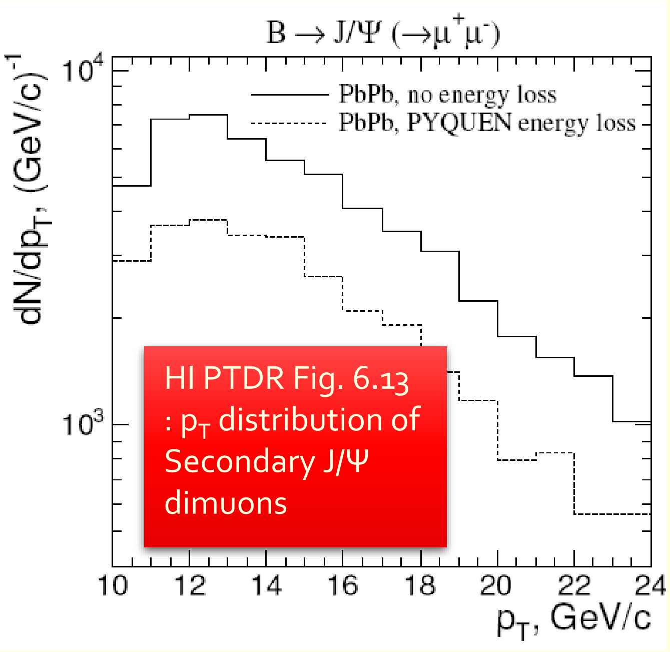
- Motivation
  - Quarkonium production (Υ and *J/ψ* families)
    - Stepwise suppression in QGP?
- Methods
  - Effect of the L1/L2/L3 dimuon trigger
- D.H. Moon (Ph.D. student, Korea Univ.)



B-meson Production

- Motivation
  - Heavy flavor production and radiative quark energy loss in medium
- Goal
  - B meson reconstruction via secondary J/ψ's
  - Measure the yields and E/pT spectra
- J.H. Kim (Ph.D. student, Korea Univ.)

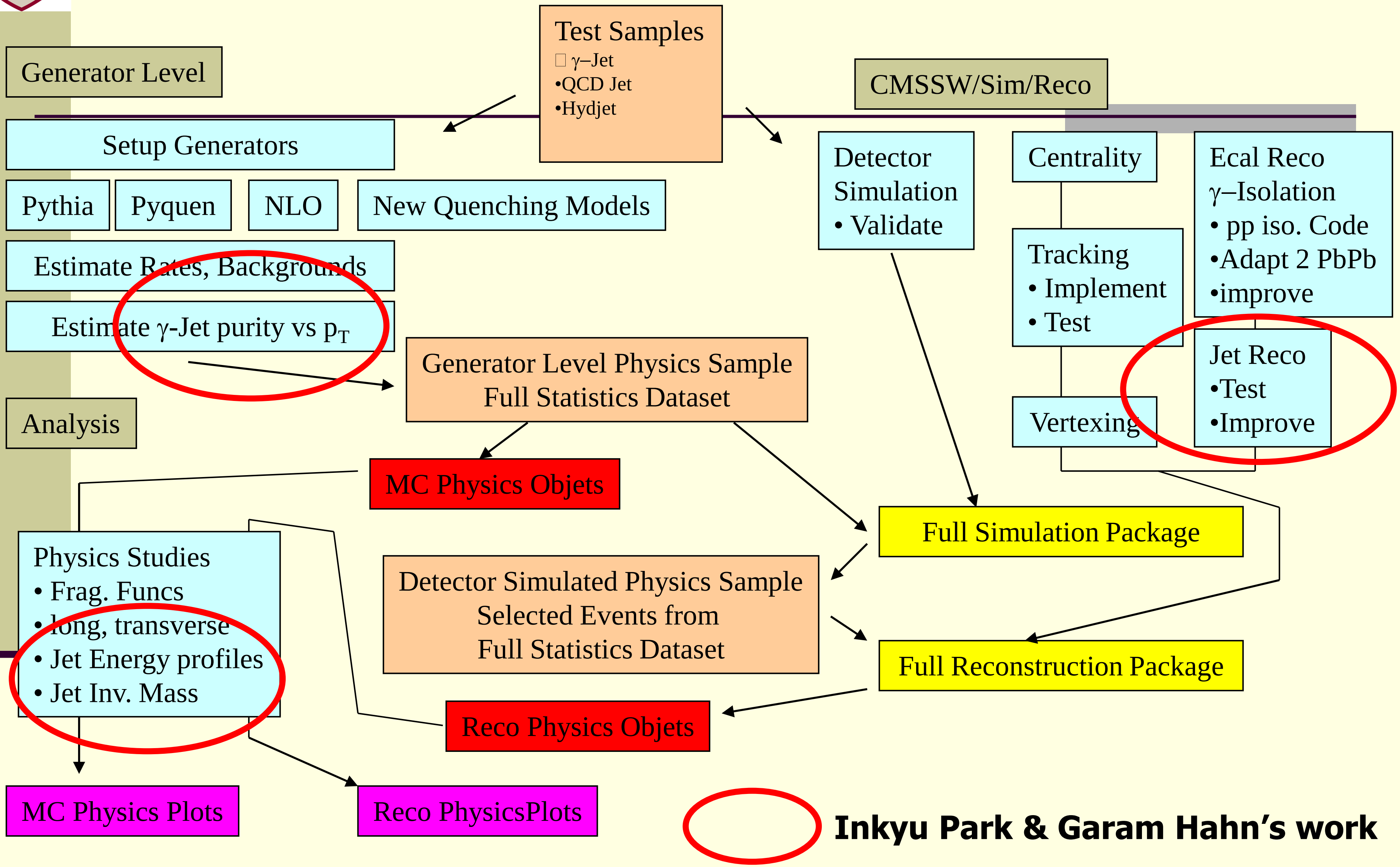




Gamma-jet Analysis

- Motivation
  - jet quenching found at RHIC
    - Mono jet at LHC?
  - photons will not be influenced by partonic matter
    - Provides the reference of the jet quenching systematics
- Service works
  - Jet algorithm implementation
  - Jet performance benchmark
  - Jet Pt distribution, multiplicity
- Goal
  - Definition of direct photons
  - Reconstruction of jet and gamma-jet events
  - G.R. Hahn and Inkyu Park (Univ. of Seoul)

Gamma-jet Analysis Flow Chart



Results so far

Directory: /pnfs/cmsaf…/../gammajets/
Files: pythia, pythia_mixed, pyquen, pyquen mixed

"Particles"

CMSSW processed

CreateCaloComp

$\Delta\eta$=0.087 $\Delta\phi$ = 0.044

"CaloJets"

R=0.5, Seed=2, Th=10

IterativeCone

R=0.5, Seed=2,5,10
Th=30

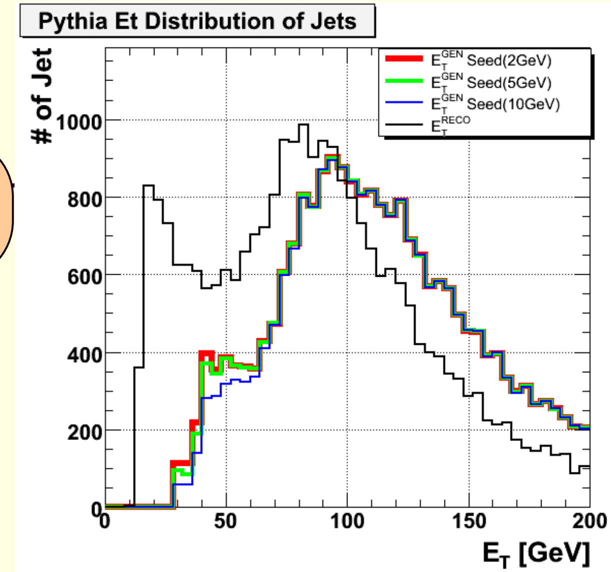
Cut (Th=30)

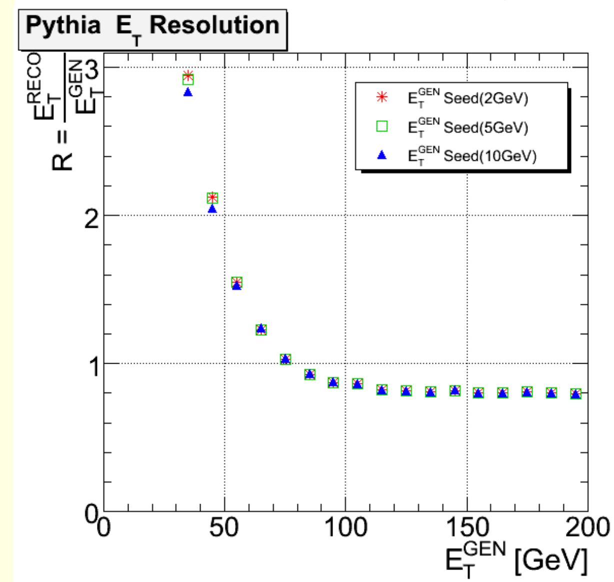
Matching < 0.2

GenCaloJets

RecCaloJets

Compare





Summary

(Part I)

Presently, very active research programs are progressing both in relativistic heavy-ion collisions and the detector developments in the nuclear physics group of Korea University.

(Part II)

Presently, very active analysis programs for heavy-ion collisions and the RPC construction project by Koreans are progressing in CMS.