RPC Upgrade for PHENIX

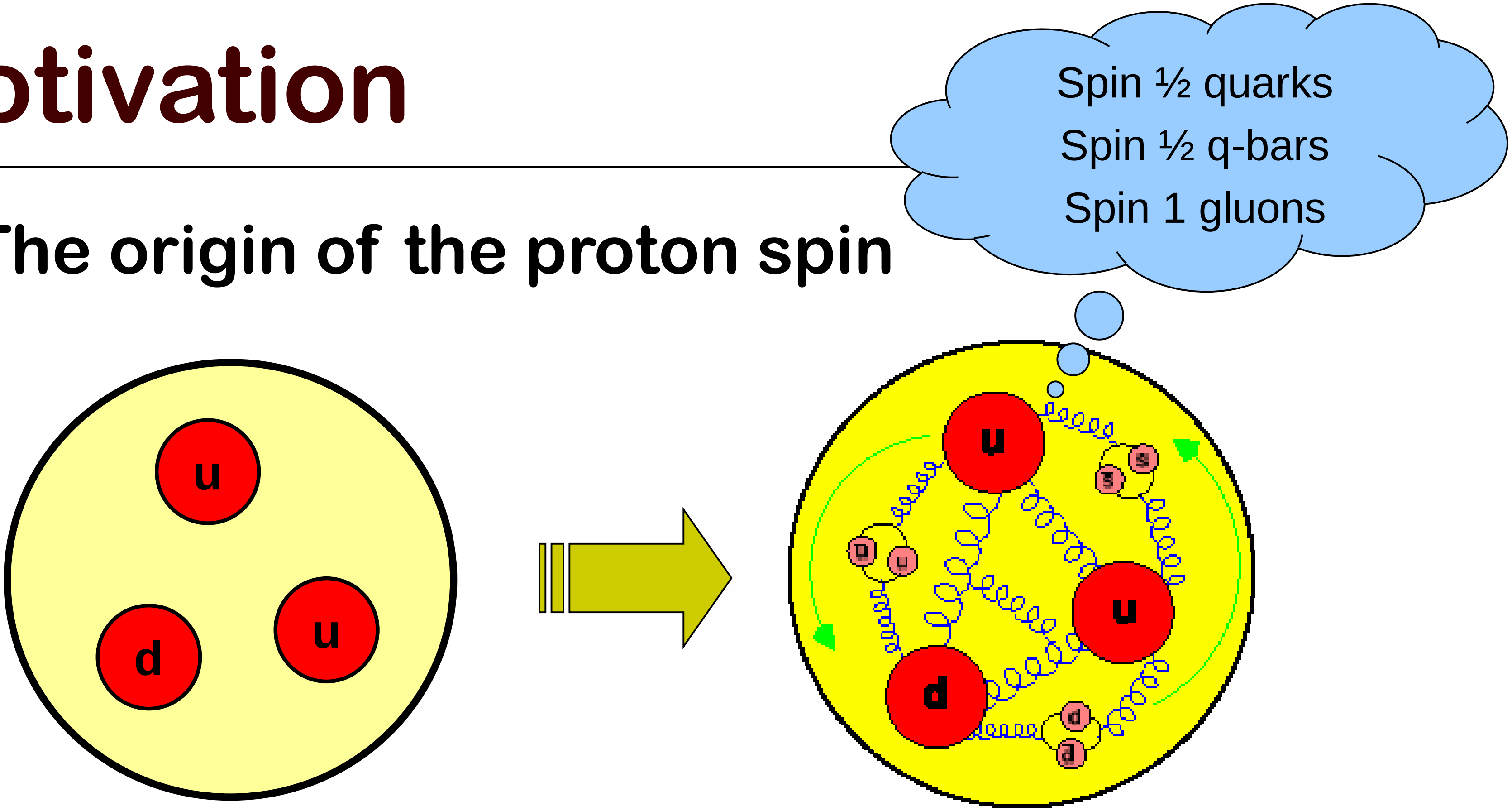
Byungsik Hong
Korea University

Contents

- Motivations
- PHENIX RPC system
- RPC production facilities at Korea University
- PHENIX schedule
- Summary

Motivation

- The origin of the proton spin



Quark Spin $\Delta\Sigma = 0.25 \mp 0.10$

→ known as Spin Crisis

Ref.) EMC, Phys.Lett.B206, 364 (1988); Nucl.Phys.B328, 1 (1989)

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma_{valence+sea} + \Delta G + L_z$$

Parton Distribution Functions

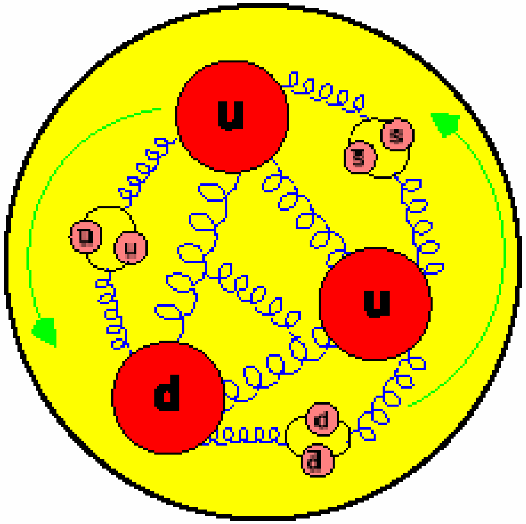
- Spin independent quark momentum distribution $q(x)$
- Spin independent gluon momentum distribution $G(x)$

- Spin dependent quark distribution

$$\Delta q(x) = q^{\uparrow\uparrow}(x) - q^{\uparrow\downarrow}(x)$$

- Spin dependent gluon distribution

$$\Delta G(x) = G^{\uparrow\uparrow}(x) - G^{\uparrow\downarrow}(x)$$



Bjorken $x = p_{parton} / p_{proton}$

(Momentum fraction of the parton in the proton)

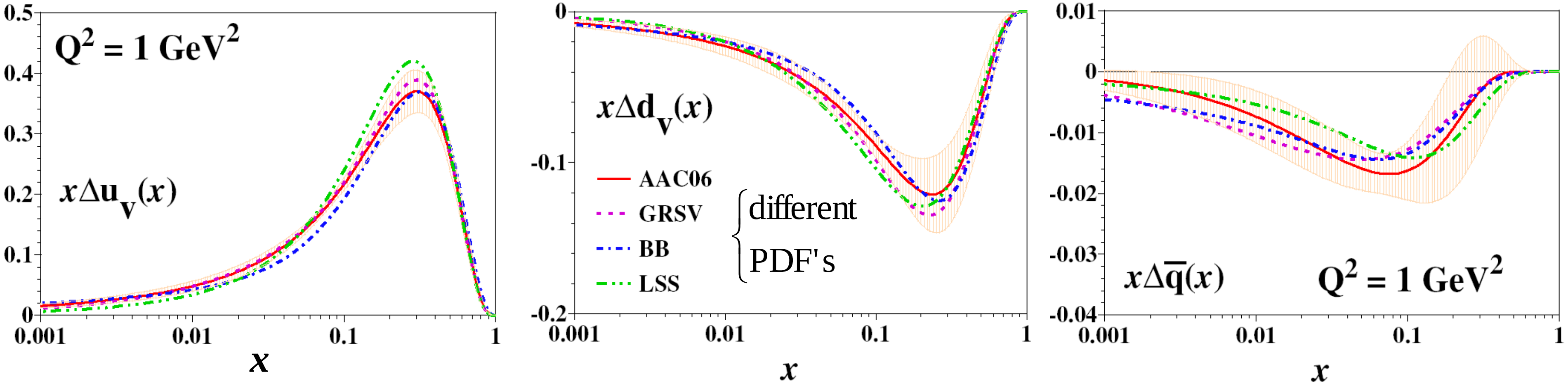
Present Understanding

- Spin dependent quark distribution functions by the QCD analysis of DIS data

  - M. Hirai, S. Kumano, N. Saito, Phys. Rev. D 74, 014015 (2006)

  - $\Delta q(x)$: well known
  - $\Delta \bar{q}(x)$: not well known

$$\Delta \bar{q}(x) \approx \Delta \bar{u}(x) \approx \Delta \bar{d}(x) \approx \Delta \bar{s}(x) \approx \Delta s(x)$$

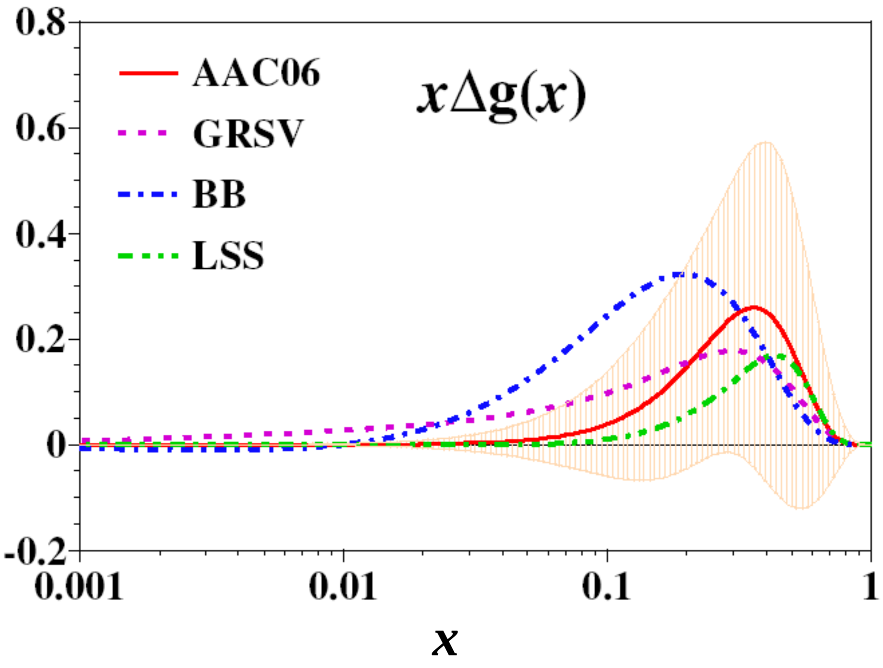


Present Understanding

- **Spin dependent gluon distribution functions by the QCD analysis of DIS data**

  - M. Hirai, S. Kumano, N. Saito, Phys. Rev. D 74, 014015 (2006)

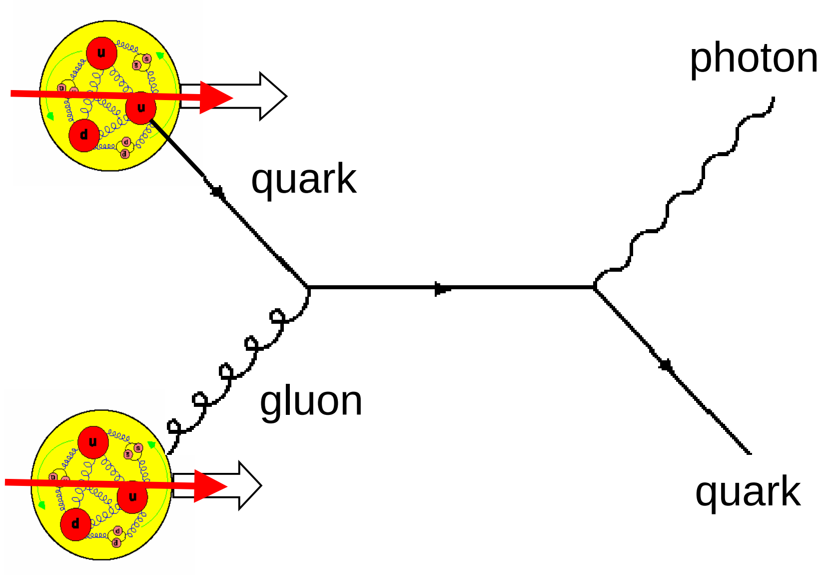
  - $\Delta G(x)$: largely unknown
  - ΔG = 0.47 ∓ 1.08



Testing Gluon Spin

- Direct photon (+single jet) production
  - Double spin asymmetry
  - PHENIX NCC can be used

    (See the talk by Prof. Youngil Kwon tomorrow)



$$A_{LL} = \frac{N_{\gamma}^{\uparrow\downarrow} - N_{\gamma}^{\uparrow\uparrow}}{N_{\gamma}^{\uparrow\downarrow} + N_{\gamma}^{\uparrow\uparrow}}$$

experimental double spin asymmetry

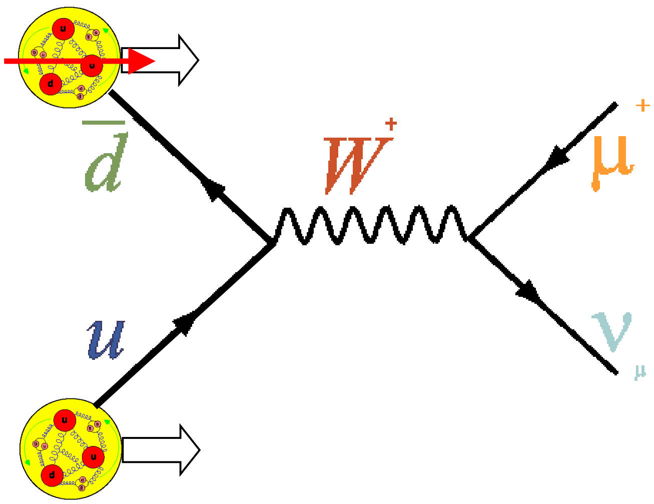
$$= \underbrace{a_{LL}(qg \rightarrow q\gamma)}_{\text{pQCD}} \cdot \underbrace{\frac{\Delta G(x_1)}{G(x_1)}}_{?} \cdot \underbrace{A_1(x_2)}_{\text{DIS}}$$

Testing Quark and Antiquark Spins

- Main motivation for RPC upgrade
- W-boson production
  - The sea quark polarizations of the proton can be probed by
  - The single spin asymmetry, A_L, of W^+ and W^-.

$$A_L^{W^+} = \frac{1}{P} \times \frac{N^{\uparrow}(W^+ \to \mu^+) - N^{\downarrow}(W^+ \to \mu^+)}{N^{\uparrow}(W^+ \to \mu^+) + N^{\downarrow}(W^+ \to \mu^+)}$$

$$A_L^{W^-} = \frac{1}{P} \times \frac{N^{\uparrow}(W^- \to \mu^-) - N^{\downarrow}(W^- \to \mu^-)}{N^{\uparrow}(W^- \to \mu^-) + N^{\downarrow}(W^- \to \mu^-)}$$



Analysis Method

- The quark and antiquark polarizations of the proton can be estimated through A_L, at $Q^2 = M_W^2$,

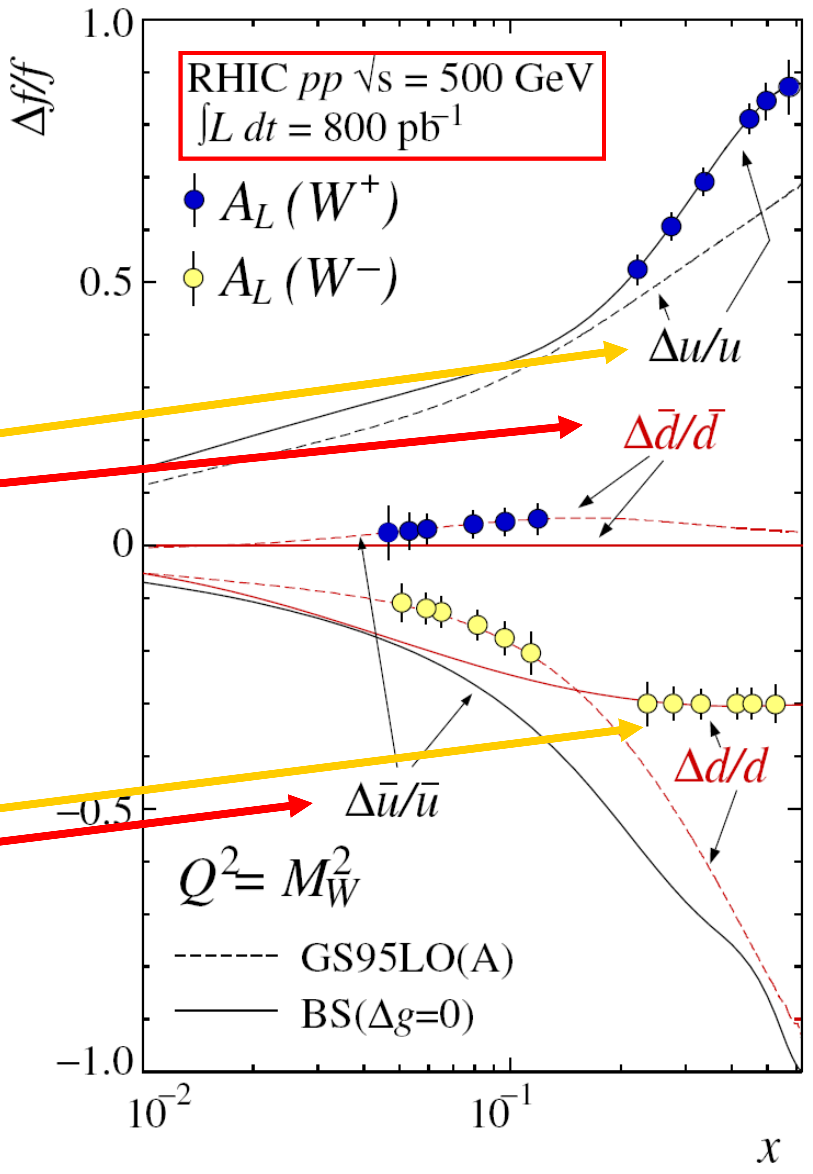
$$A_L^{W^+} = \frac{\Delta u(x_1)\bar{d}(x_2) - \Delta\bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)}$$

Large x_1 Large x_2

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

Large x_1 Large x_2

$$x_1 = \left(Q/\sqrt{s}\right)^{+y_W},\ x_2 = \left(Q/\sqrt{s}\right)^{-y_W}$$



Testing Flavor Asymmetry

$$R(x_F) \equiv \frac{d\sigma(pp \to W^+ + X \to \mu^+ + X)/dx_F}{d\sigma(pp \to W^- + X \to \mu^- + X)/dx_F} \approx \frac{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)}{\bar{u}(x_1)d(x_2) + d(x_1)\bar{u}(x_2)}$$

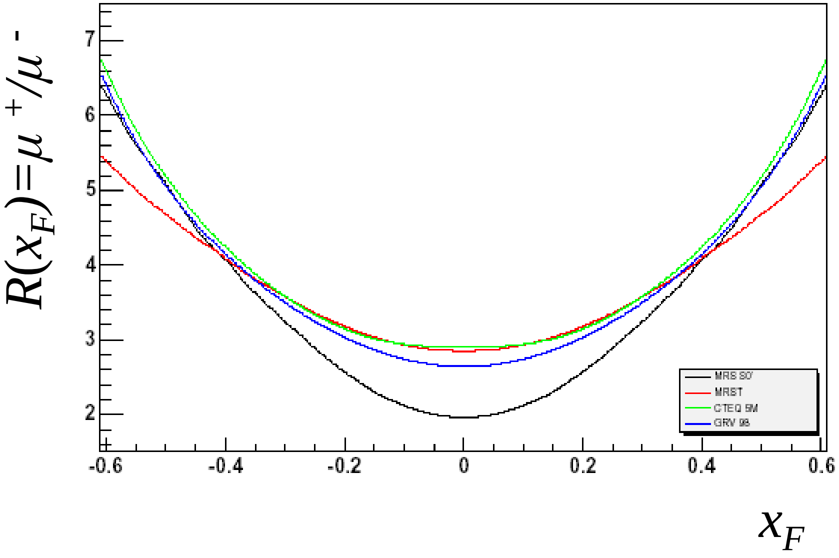
where $x_F = x_1 - x_2$.

(Case I) For $x_F = 0, x = x_1 = x_2$

$(x = 0.16$ at $\sqrt{s} = 500\,\text{GeV}),$

$$R(x_F = 0) \approx \frac{u(x)}{d(x)}\,\frac{\bar{d}(x)}{\bar{u}(x)}$$

$$\left[\frac{u(x)}{d(x)} \approx 2.0\right] \Rightarrow \left[\frac{\bar{d}(x)}{\bar{u}(x)} \approx \frac{1}{2}R(0)\right]$$



Testing Flavor Asymmetry

(Case II) For large x_F (or $x_1 >> x_2$),

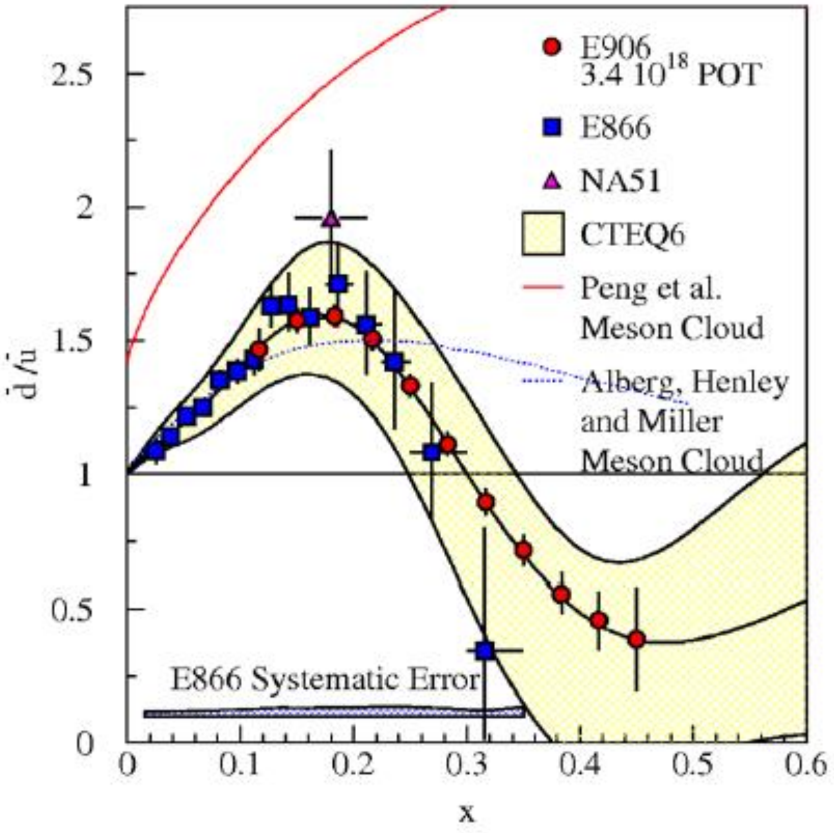
$$R(x_F) \approx \frac{u(x_1)}{d(x_1)}\frac{\bar{d}(x_2)}{\bar{u}(x_2)}$$

$$\boxed{\frac{\bar{d}(x_2)}{\bar{u}(x_2)} \to 1 \text{ by pQCD, as } x_2 \to 0}$$

$$\frac{u(x_1)}{d(x_1)} \approx R(x_F)\ \boxed{\text{at large } x_1}$$

For $\sqrt{s} = 500\,\text{GeV}$ at RHIC,

$$\begin{pmatrix} x_1 \text{ can be as large as } 0.83 \\ x_2 \text{ can be as small as } 0.03 \end{pmatrix}$$



The *u/d* ratio at large-*x* region is not well known, and the theoretical predictions are diverse, depending on how to treat nuclear effects.

Requirements

Design Luminosity

$\sqrt{s}$ = 500 GeV (σ_{tot} = 60 mb)

L = 2x10^{32}/cm^2/s

Raw rate in PHENIX = 12 MHz

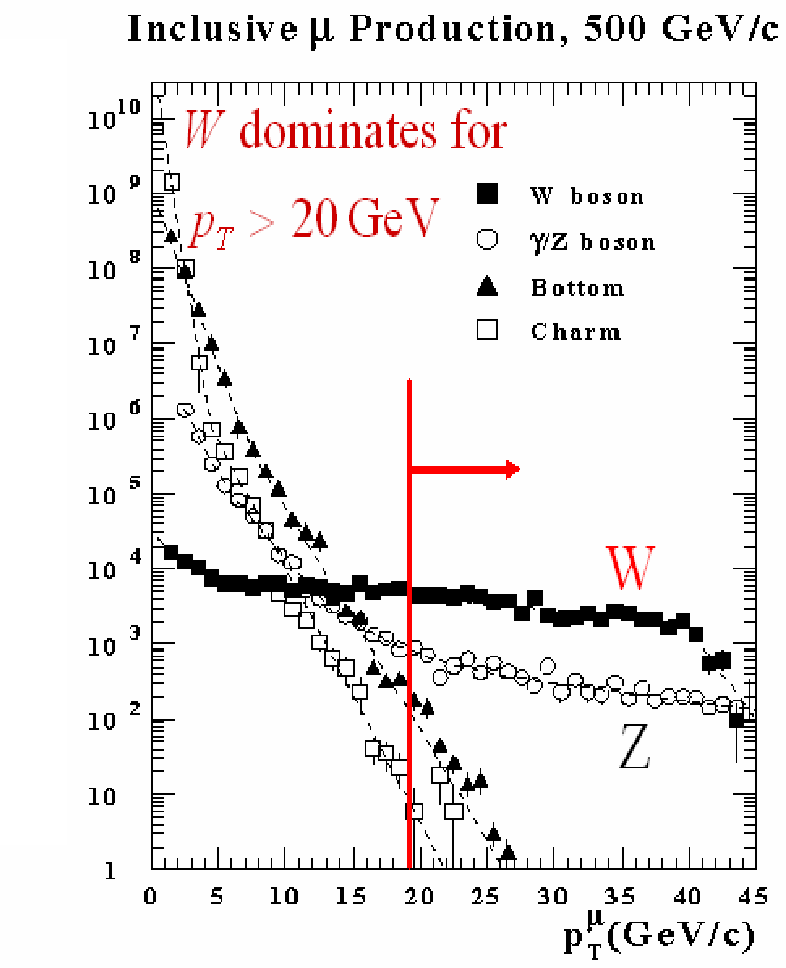
PHENIX DAQ limit ≈ 2 kHz for muon arms

Required RF ~ 6,000

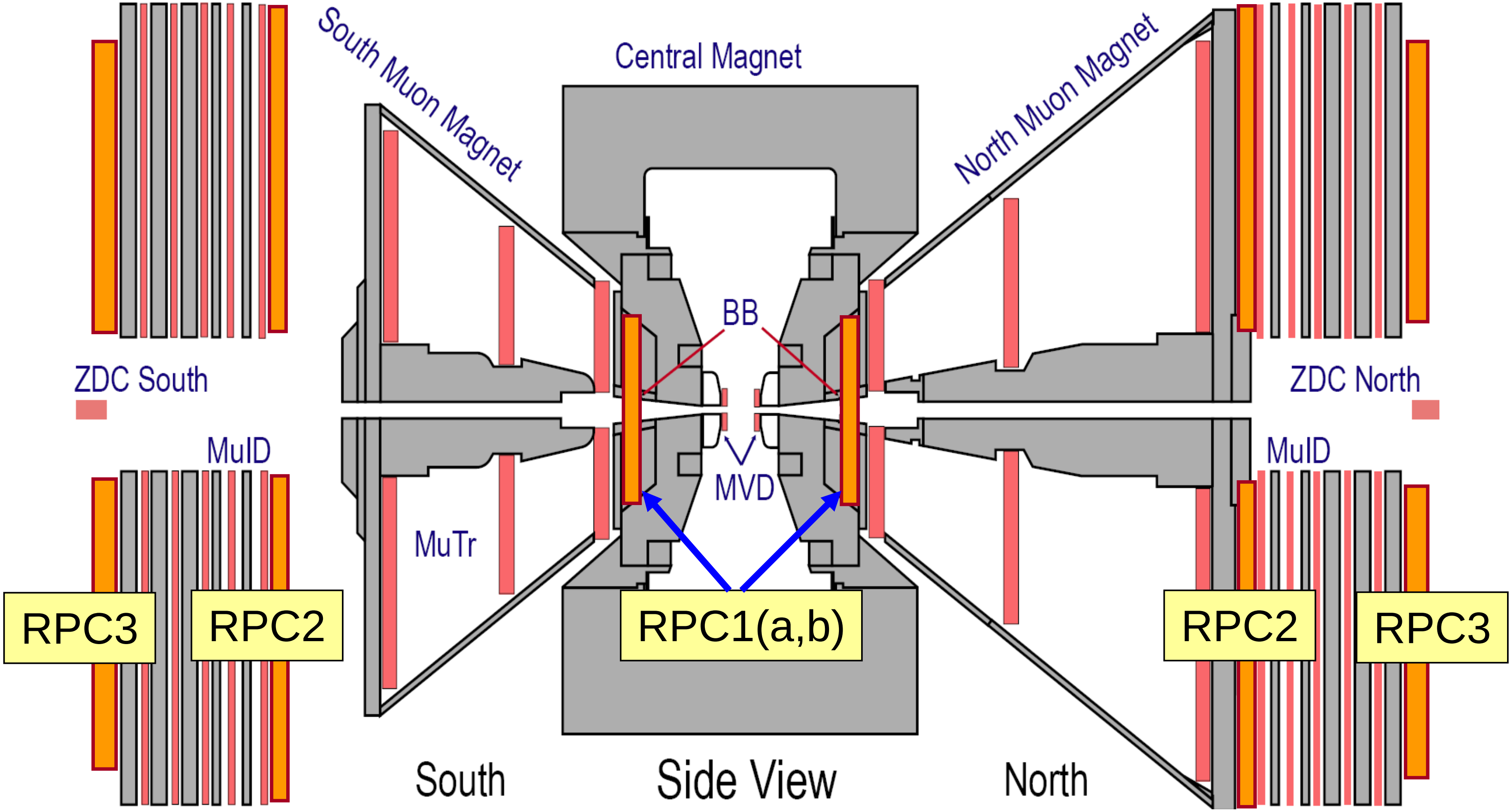
Cf.) Current RF by MuID trigger ~ 500

Need to introduce the momentum resolution in the muon trigger

→ **RPC based trigger upgrade**



PHENIX RPC Locations



lengths in mm
theta in deg.

		RPC1a		RPC1b		RPC2		RPC3	
	theta (deg)	Radius	width	radius	width	radius	width		width
possible						5280.2			
	34.36	933.2	773.1	1016.8	842.3	4675.4			
ring 8		*strips: 181.4 x 12.1 (64)*		*strips: 197.7 x 13.2 (64)*		*strips: 467.*			
	31.60					42			
ring 7									
	28.84	751.8	622.8	819.1	678.6			4991.4	4135.0
ring 6		*strips: 164.3 x 9.7 (64)*		*strips: 177.7*		*4)*		*strips: 554.2 x 64.6 (64)*	
	26.09						2773.9	4437.2	3675.9
ring 5						*8.9 x 48.8 (57)*		*strips: 528.6 x 64.6 (57)*	
	23.33	588.7	487.7			2949.4	2443.4	3908.6	3238.0
ring 4		*strips: 151.1 x 15.2 (3*		*)*		*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	438			395.9	2197.7	1820.6	2912.3	2412.7
ring2				*strips: 153.6 x 12.4 (32)*		*strips: 357.8 x 28.4 (64)*		*strips: 474.2 x 37.7 (64)*	
	15.06					1839.8	1524.2	2438.1	2019.8
ring1						*strips: 3548.7 x 28.4 (54)*		*strips: 462.1 x 37.7 (54)*	
			246.6	324.3	268.6	1491.1	1235.3	1976.1	1637.0
pos						1468.4		1926.4	
		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.

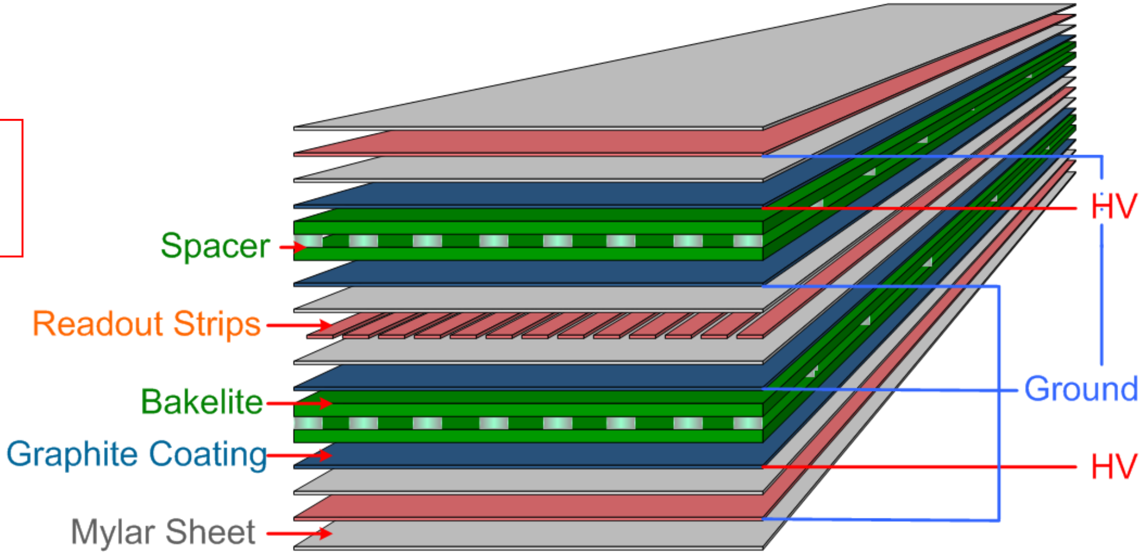
*** strip le dth consider full acceptance in theta and phi in the octants (i.e. no loss due to readout and boxes)**
*** strip wid e determined at the outer radius of two paired rings**

Why RPC?

- Characteristics of RPC
  - Fast Response
    - Suitable for the trigger device
  - Good timing resolution: 1~2 ns
  - Good spatial resolution: typically ~cm
    - determined by the strip width
  - Low cost

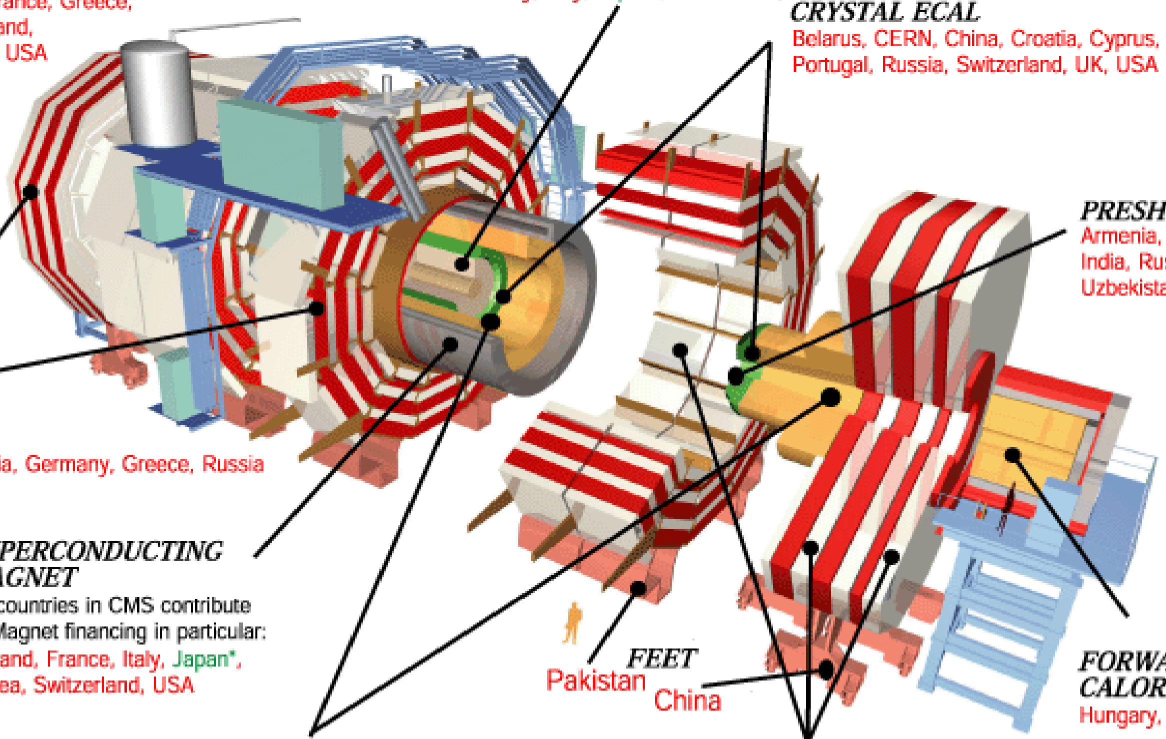
Typical gas mixture:

96% $C_2H_2F_4$+3.5% i-C_4H_{10}+0.5% SF_6



Why Korea University?

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



TRIGGER & DATA ACQUISITION
Austria, CERN, Finland, France, Greece, Hungary, Italy, Korea, Poland, Portugal, Switzerland, UK, USA

TRACKER
Austria, Belgium, CERN, Finland, France, Germany, Italy, Japan*, Switzerland, UK, USA

CRYSTAL ECAL
Belarus, CERN, China, Croatia, Cyprus, France, Italy, Japan*, Portugal, Russia, Switzerland, UK, USA

PRESHOWER
Armenia, Belarus, CERN, Greece, India, Russia, Taiwan (PC), Uzbekistan

RETURN YOKE
Barrel: Czech Rep., Estonia, Germany, Greece, Russia
Endcap: Japan*, USA

SUPERCONDUCTING MAGNET
All countries in CMS contribute to Magnet financing in particular:
Finland, France, Italy, Japan*, Korea, Switzerland, USA

FEET
Pakistan
China

FORWARD CALORIMETER
Hungary, Iran, Russia, Turkey, USA

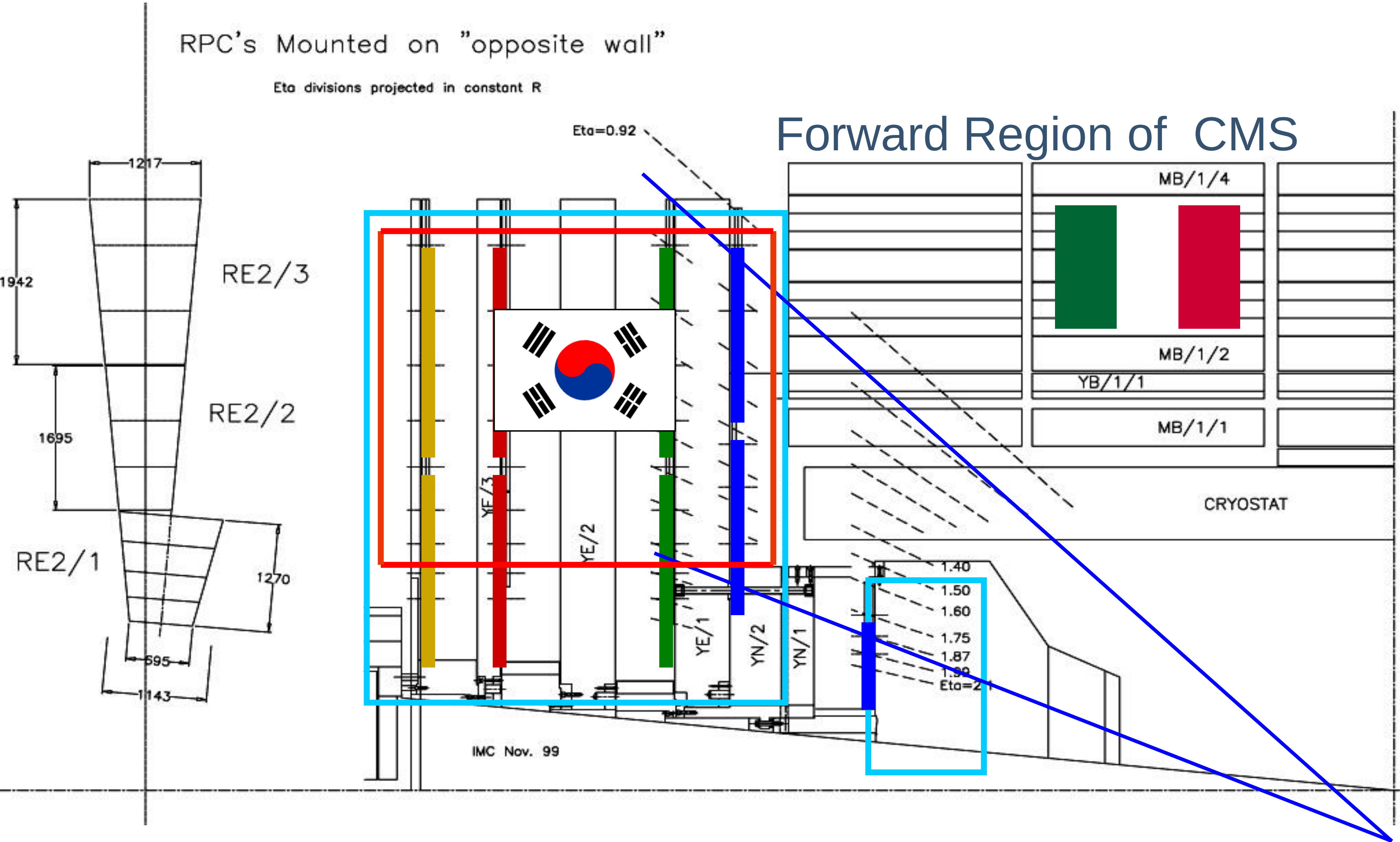
HCAL
Barrel: Bulgaria, India, Spain*, USA
Endcap: Belarus, Bulgaria, Russia, Ukraine
HO: India

MUON CHAMBERS
Barrel: Austria, Bulgaria, CERN, China, Germany, Hungary, Italy, Spain,
Endcap: Belarus, Bulgaria, China, Korea, akistan, Russia, USA

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

* Only through industrial contracts

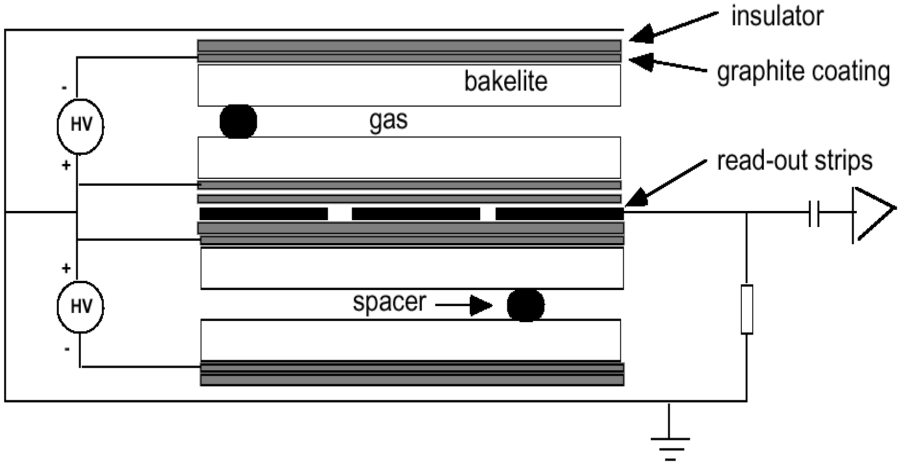
Korean RPCs in CMS

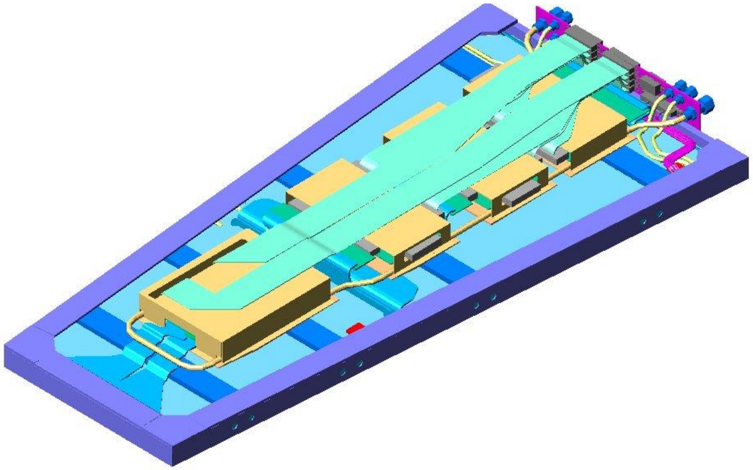


Forward Region of CMS

CMS Endcap RPCs

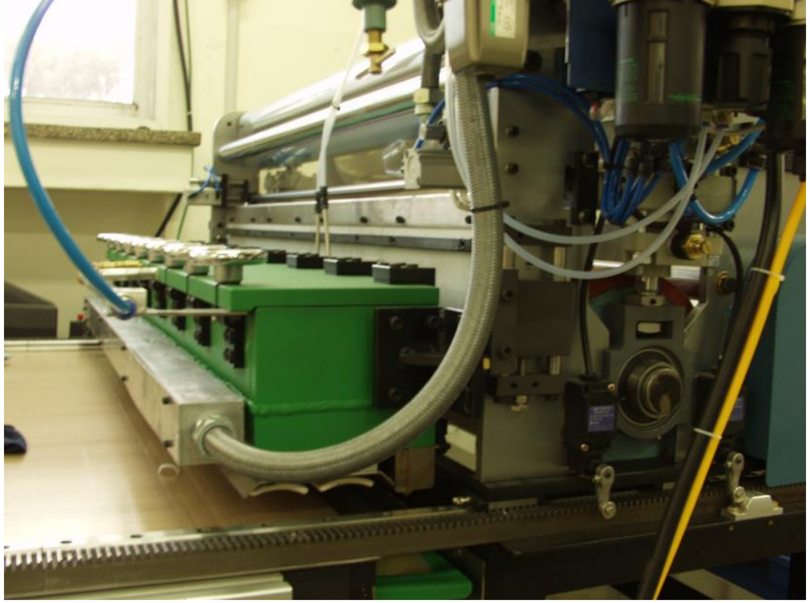
1. **Function : L1 muon triggers**
   - 2 wings (RE+, RE-)
   - 4 stations (RE1, RE2, RE3, RE4)
   - Pseudo rapidity coverage :
     $0.9 < \eta < 2.1$ (1.6)
   - η segmentations : 10 (6)
2. **Total # of RPCs : 756 (432)**
   - Total # of FEBs : 2,268 (1,296)
   - Total # of channels : 85,248 (41,472)
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.

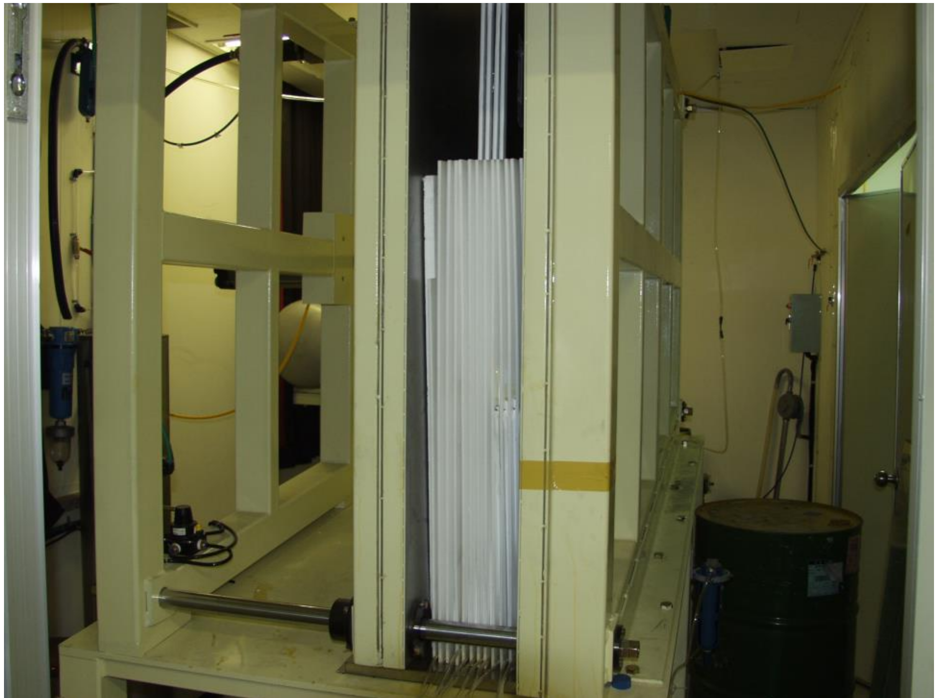




A Brief History

1. Fundamental studies to develop the endcap RPCs (1997~)
    1) Beam tests by using high intensity muon beams at CERN
    2) Cosmic muon tests at Korea Univ.
    3) Long term aging studies by γ's and neutrons at Korea Univ.
2. Design of double gap RPCs for the endcap region (2000~2003)
    1) Chamber designs
    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 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.





Performance of Korean RPCs

Characteristics	CMS Requirements	Test Results
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

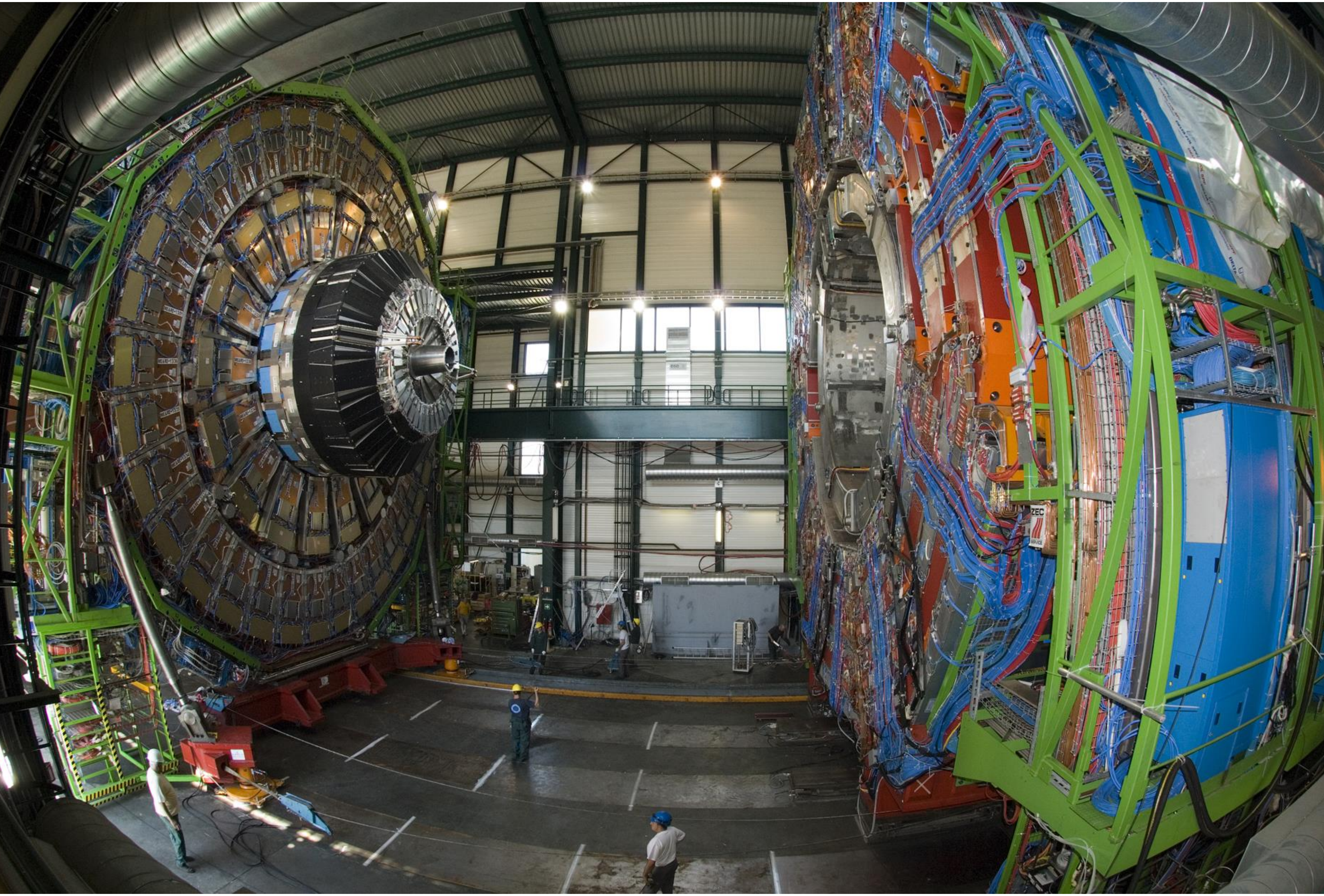
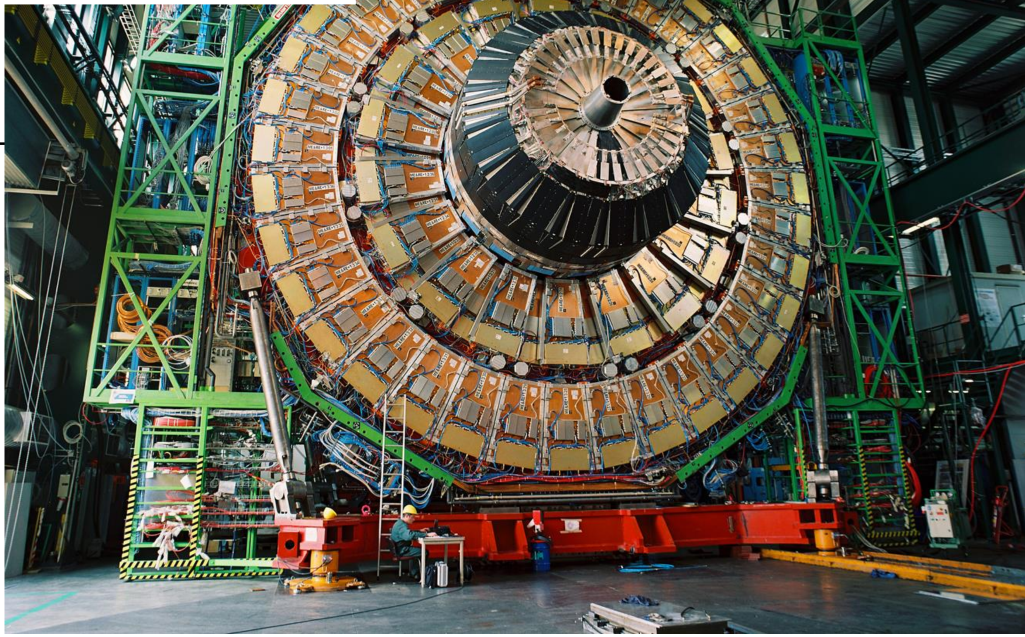
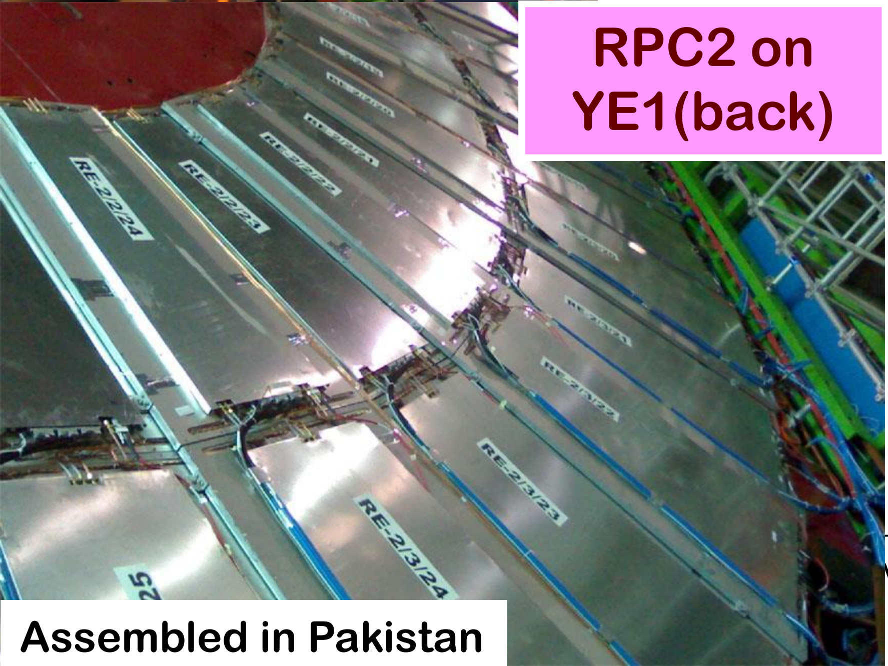


Photo taken in Nov. 2006

Assembled by Chinese at CERN

RPC1+CSC1 on YE1 (front)

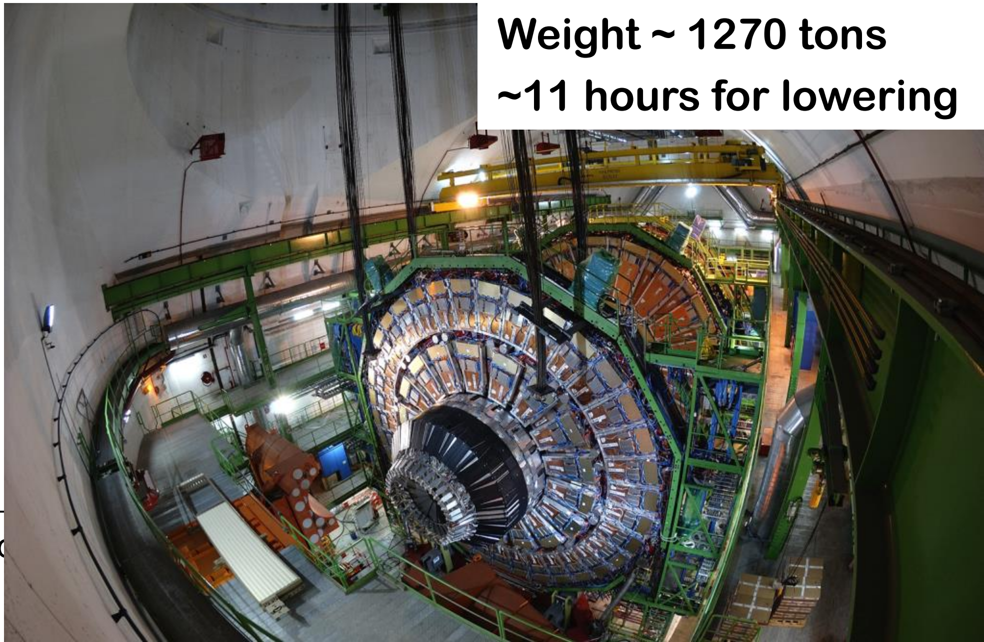




RPC2 on YE1(back)

Assembled in Pakistan

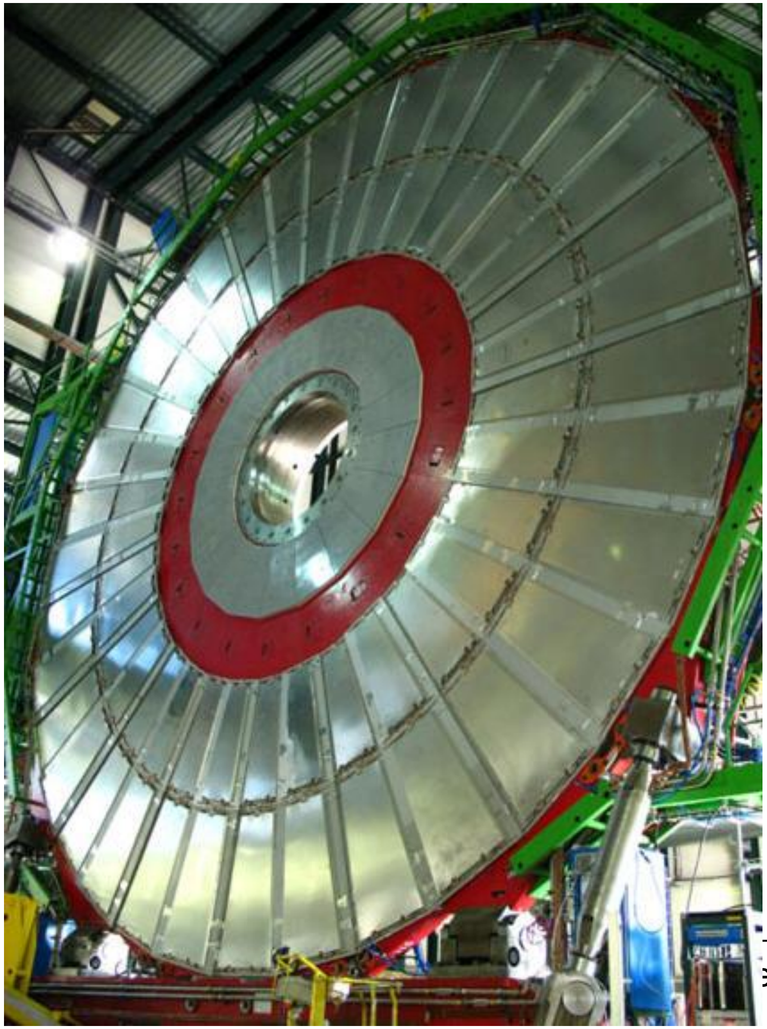
vy lo

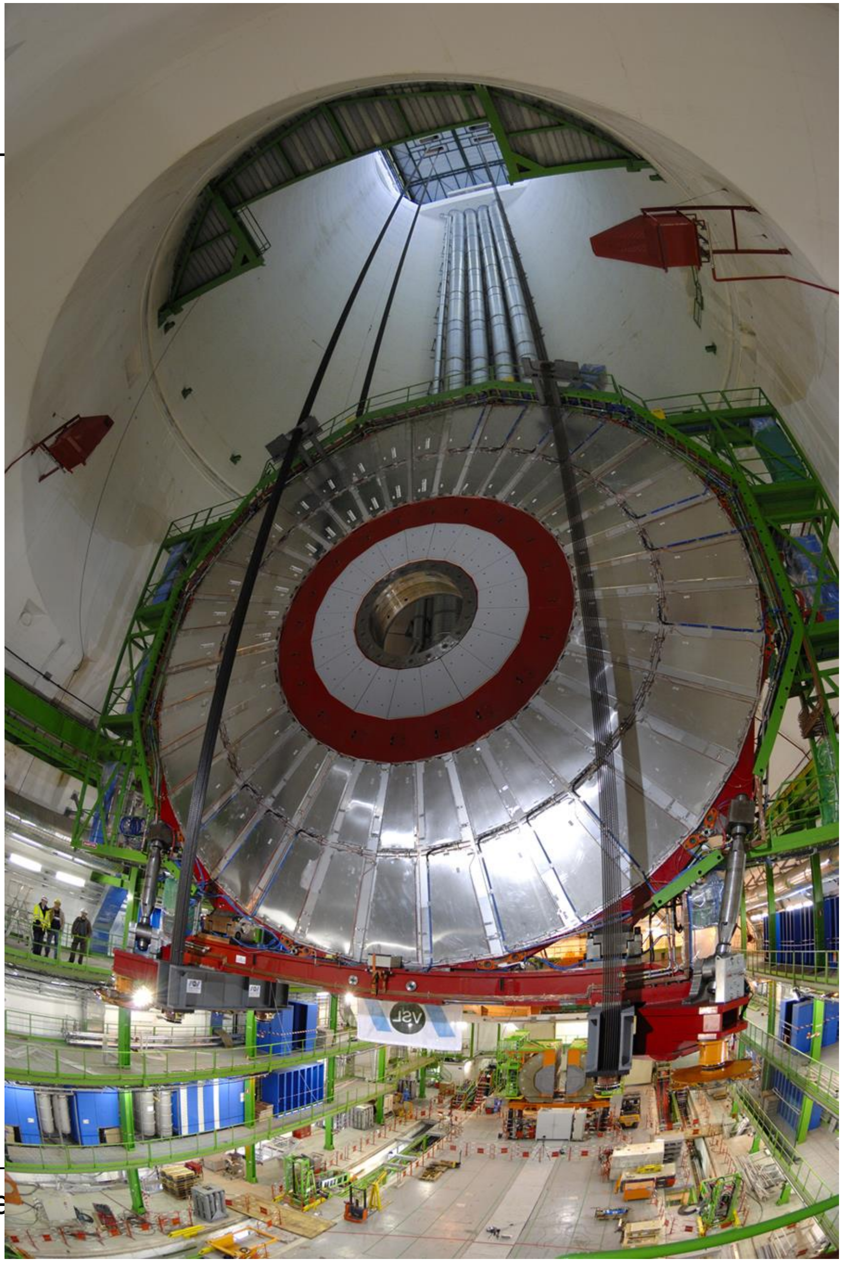


Weight ~ 1270 tons

~11 hours for lowering

RPC3 on YE3





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 $\int L dt$ ~ 950 pb^{-1}

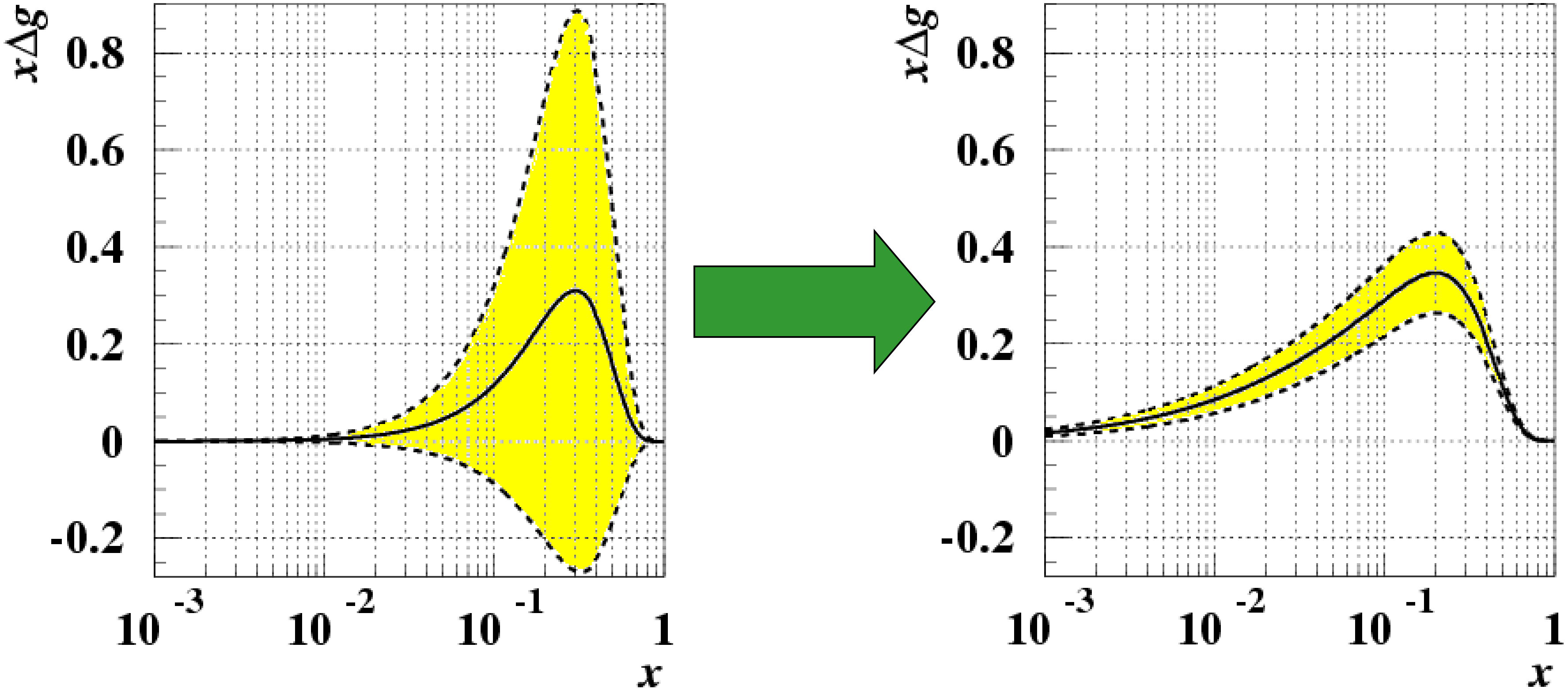
Summary

- The origin of the proton spin is the fundamental question of nuclear physics.
- The PHENIX is upgrading the muon trigger system by using the RPCs in order to filter out the small cross section W candidate events.
    - The flavor dependent quark and anti-quark spin distribution functions can be measured.
- The Korea University is responsible for the production of all RPC gas gaps.
- The mass production and installation will be completed by the end of 2009.
- Additional potential application of *the L1 muon trigger for heavy-ion collisions* still need to be explored, for example,
    - Heavy-flavor trigger in combination with the forward vertex upgrade
    - Dimuon trigger for the vector mesons for RHIC II

Extras

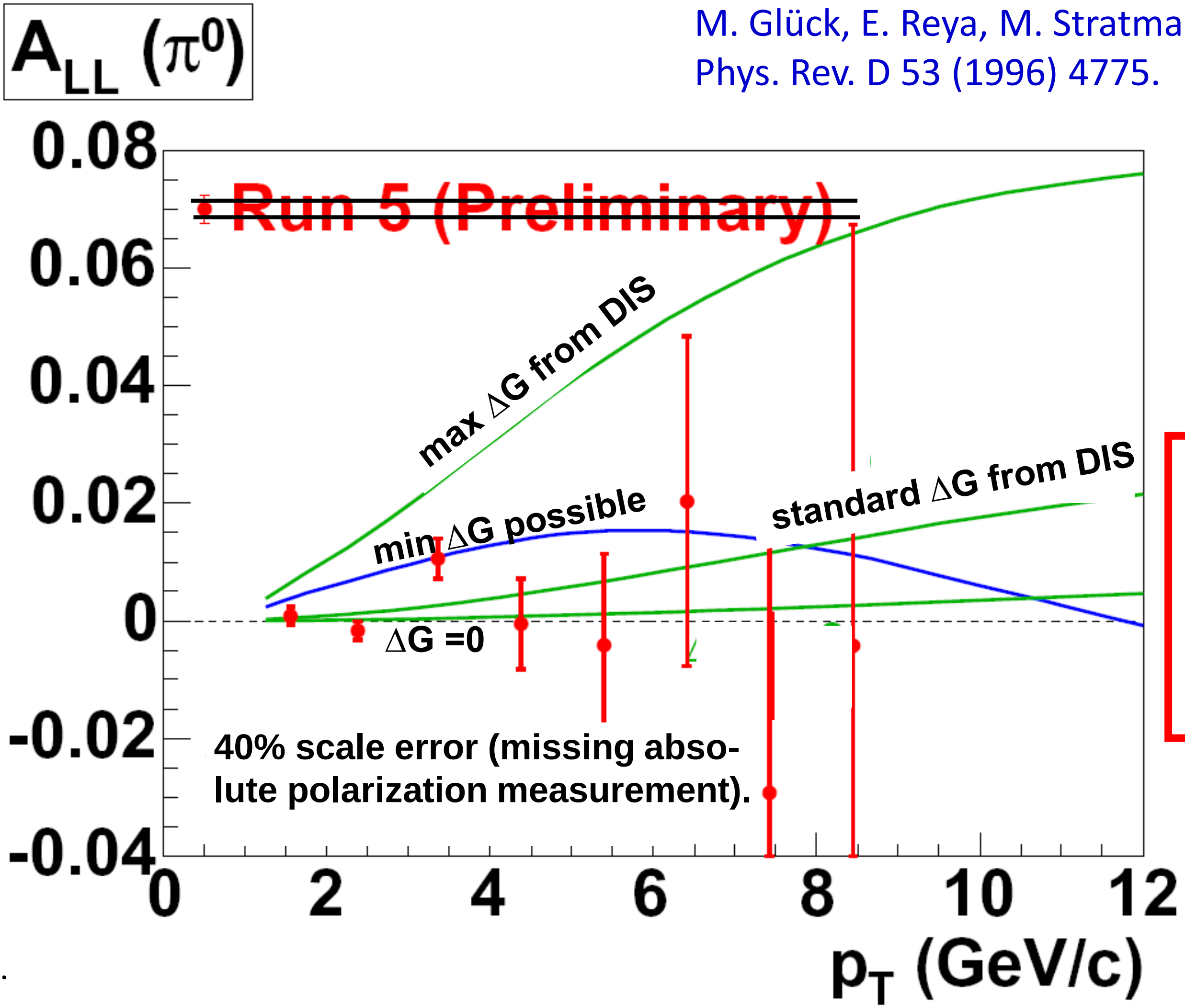
PHENIX Sensitivity for Gluion Spin

M. Hirai, H.Kobayashi, M. Miyama, *et al.*



First Constraint for ΔG by $A_{LL}(\pi^0)$

M. Glück, E. Reya, M. Stratmann, and W. Vogelsang,
Phys. Rev. D 53 (1996) 4775.



$$\int L dt = 2.7\ \mathrm{pb}^{-1}$$

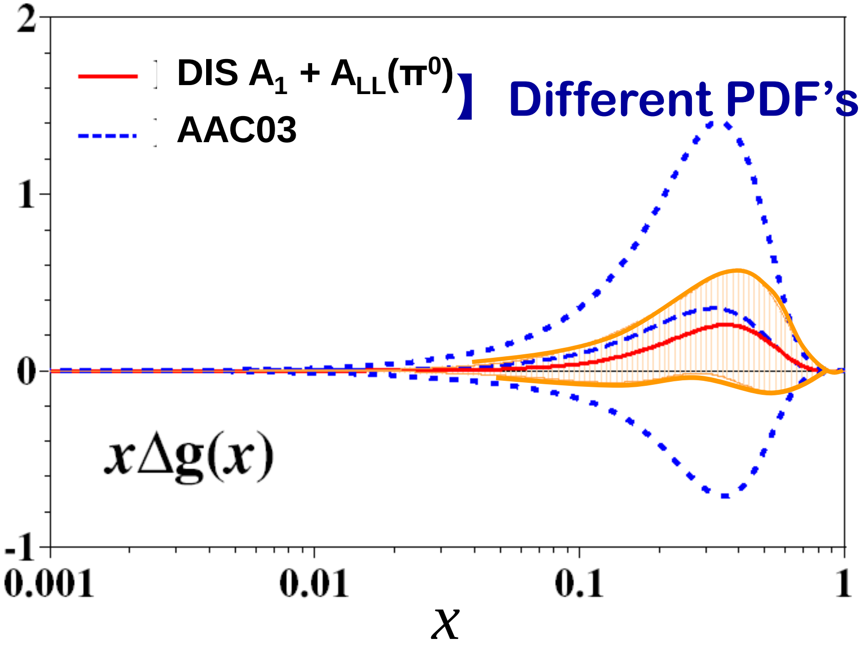
$$P \approx 0.45\ \ (\mathrm{RUN\ 2005})$$

Excludes large gluon spin contributions!

Needs to be quantified with NLO pQCD analysis!

NLO QCD Analysis of DIS A_1+$A_{LL}(\pi^0)$

M. Hirai, S. Kumano, N. Saito, hep-ph/0603212
(Asymmetry Analysis Collaboration)



	$\int \Delta G(x)dx$	$\Delta\Sigma$
DIS $A_1 + A_{LL}(\pi^0)$	0.31 ± 0.32	0.27 ± 0.07
DIS A_1	0.47 ± 1.08	0.25 ± 0.10
AAC03	0.5 ± 1.27	0.21 ± 0.14

PHENIX RUN 5 already reduces the ΔG uncertainties significantly.