BESIII探测器及其升级

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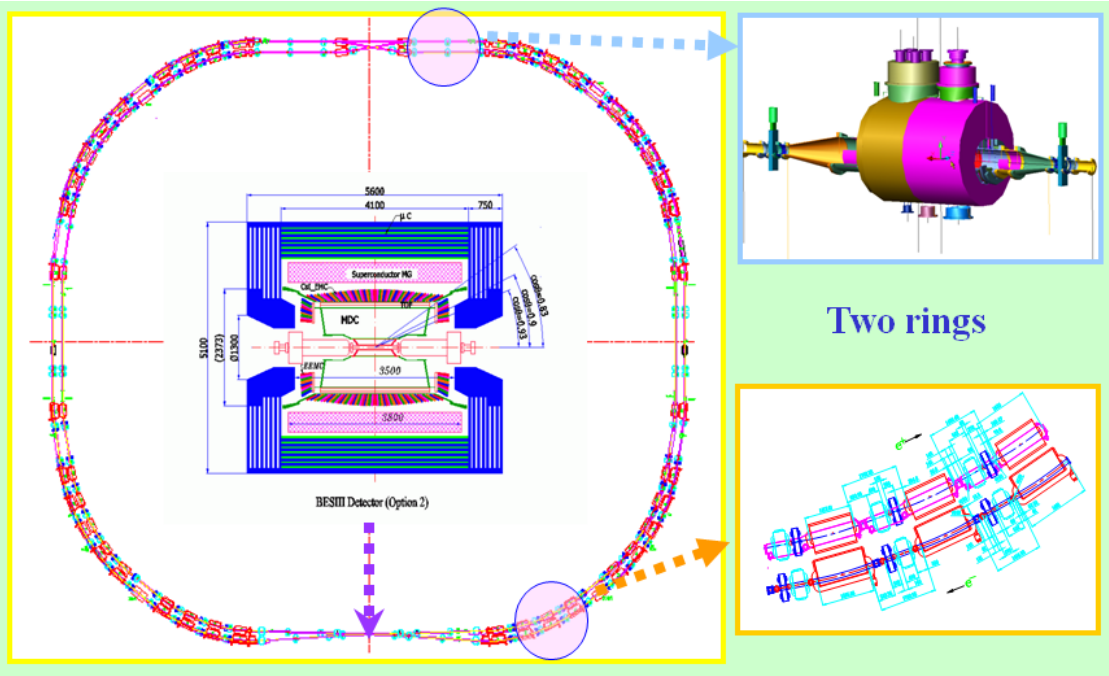
Outline

- Introduction of BEPCII and BESIII
- Sub detectors of BESIII
- Upgrade of EFOF and inner drift chamber

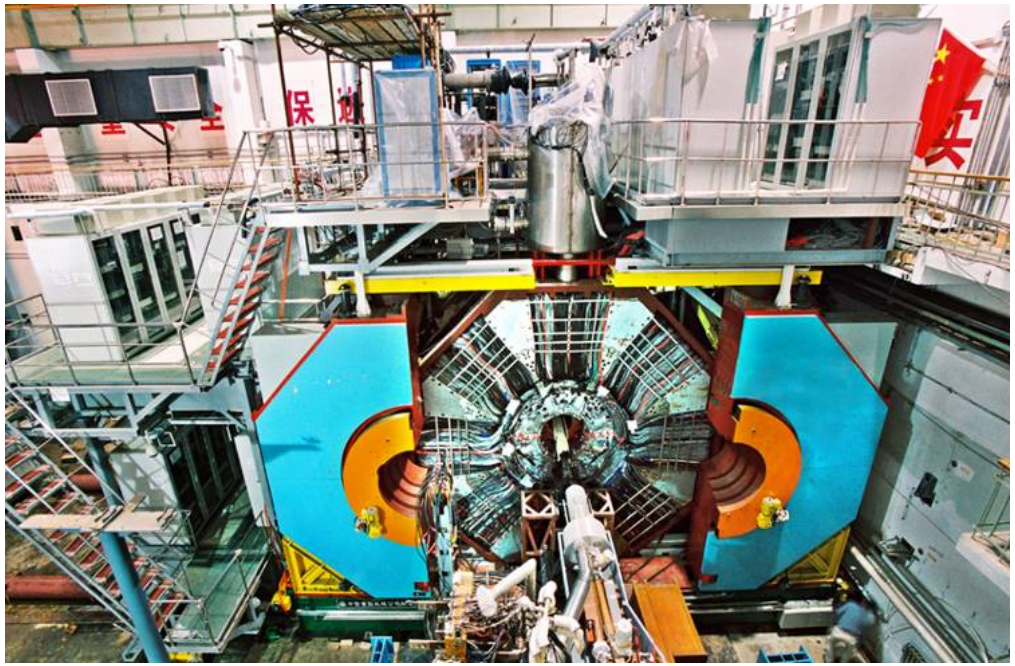
北京正负电子对撞机（BEPCII）

- BEPCII是一个高亮度、多束团的双环对撞机，2~5GeV, τ-粲物理研究

  由BEPC升级而来，在原有隧道内新建一个储存环，采用多束团、大交叉角对撞方式，亮度提高2个数量级，达到$1\times10^{33}\ cm^{-2}s^{-1}@E_{cm}=3.78GeV$。
- BEPCII 包括直线部分和储存环部分。LINAC(200米)，用于产生高能正负电子， 储存环(周长为240.4米)，用于高能正负电子存储、对撞等

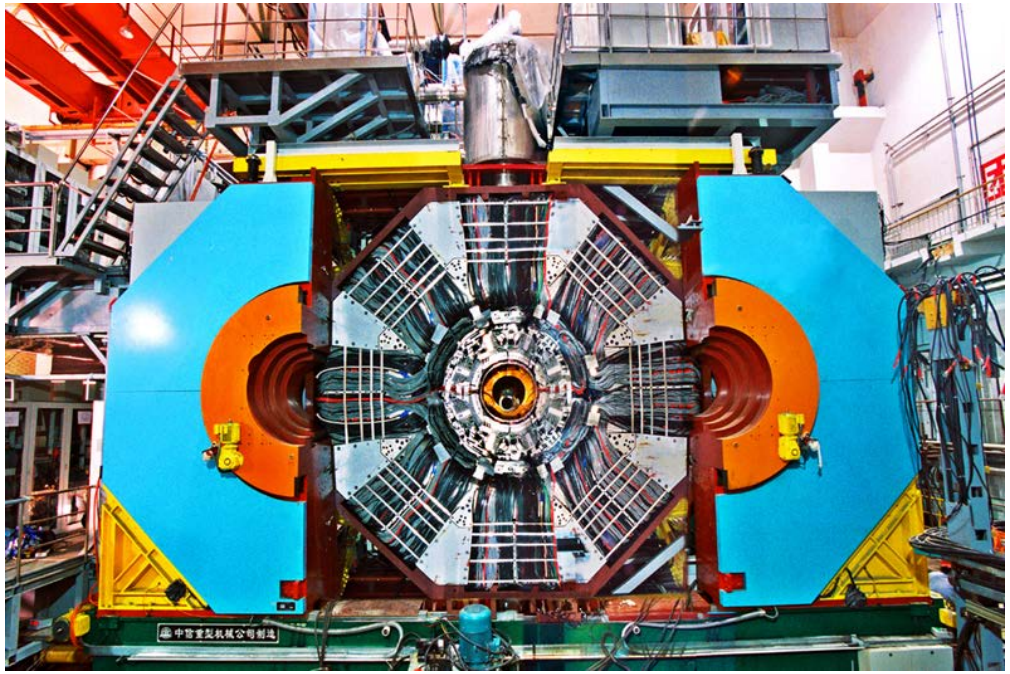


北京谱仪 (BESIII)



- Beijing Spectrometer(BESIII) is a general purpose detector at Beijing Electron-positron Collider (BEPCII)
- Versatile researches in τ-charm physics

- 四个子探测器： MDC，TOF , EMC, MUC
- SSM: Solenoid Superconducting Magnet
- Trigger system
- DAQ system
- Slow control system
- ……



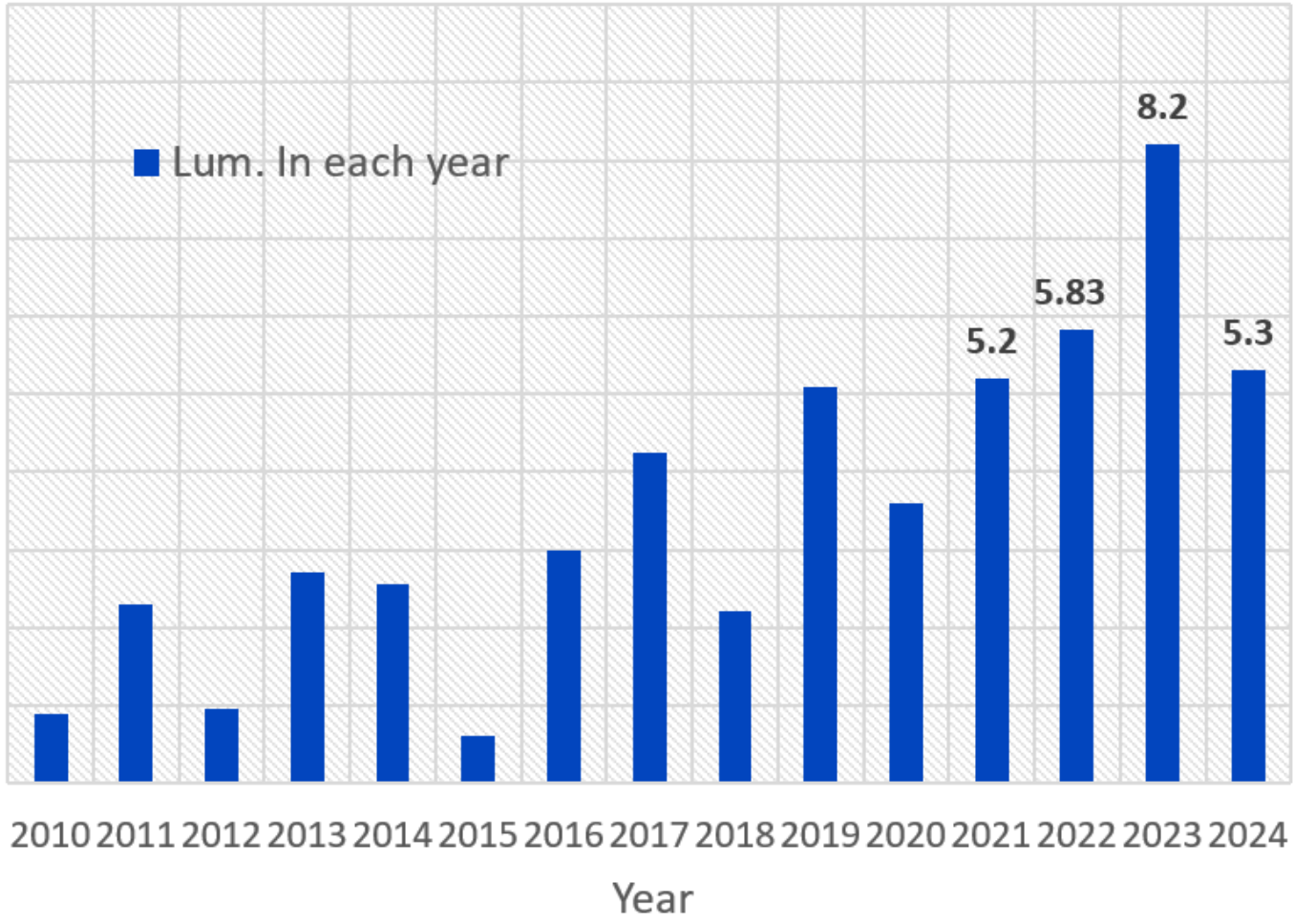
BESIII collaboration

- 成立于2006.10
- 目前：
  - >600 members
  - 85 institutes
  - 16 countries and regions

积分亮度

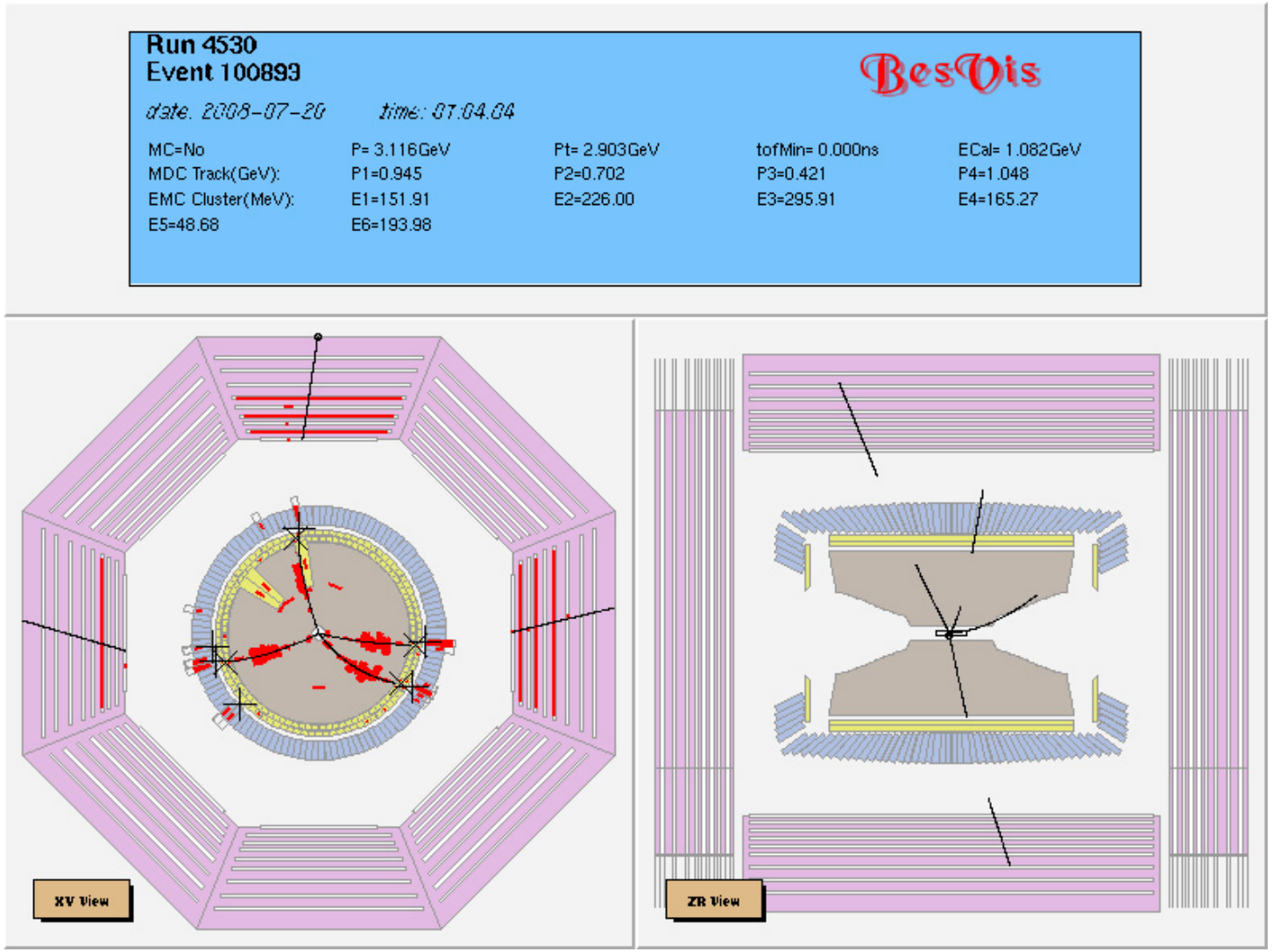
- 总积分亮度: 52.6 fb^{-1}
  - 10B J/ψ events
  - 2.7B ψ(2S)events
  - 20 fb^{-1} ψ(3770)
  - 3.2 fb^{-1} Ds
  - 21.9 fb^{-1} E_{cm} >4GeV data

- Most of them are the largest events in the world



The BESIII experiment

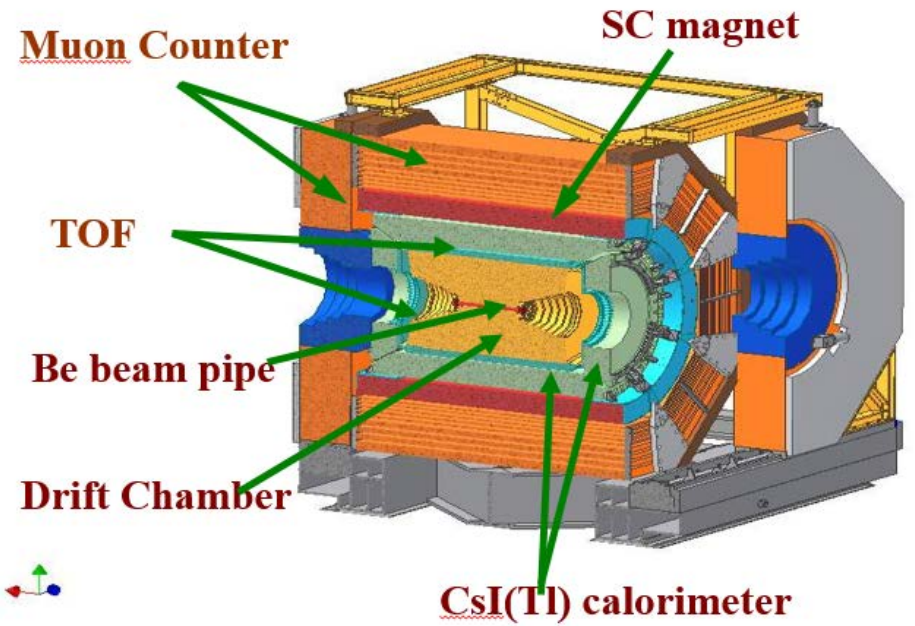
- Started commissioning run in July, 2008
- Started data collection in 2009
- More than 15 years operation
- BEPC and inner tracker of BESIII were upgraded this year
- BESIII will continue to operate until 2030

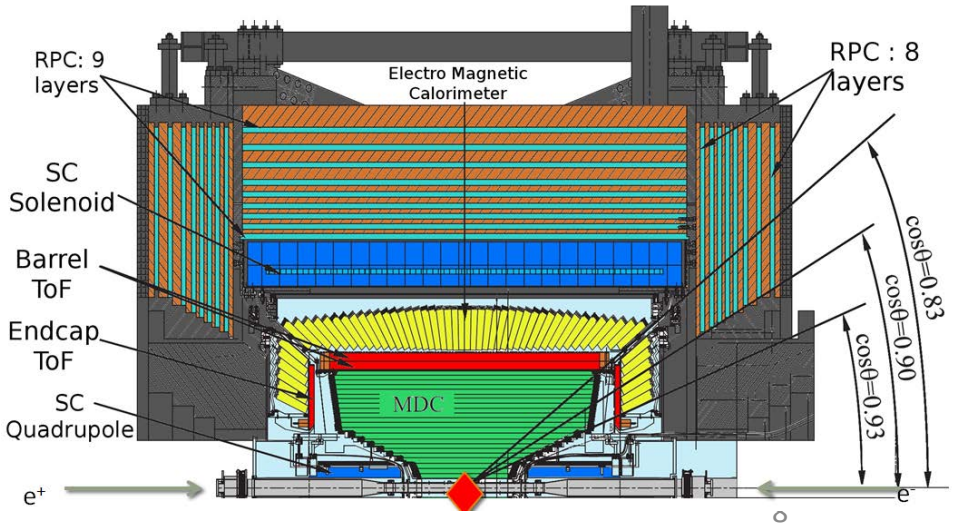


Design and construction of BESIII

与BEPCII的高事例率相匹配，满足精确测量的要求，BESIII必须是高精度的探测器

a) 单丝分辨率好于130μm的He基气体漂移室
b) 能量分辨率好于2.5%@1GeV的CsI晶体电磁量能器
c) 时间分辨好于100ps的TOF
d) 磁场强度为1Tesla的超导螺旋管磁铁
e) 基于RPC的μ子探测器





Drifter chamber (MDC)

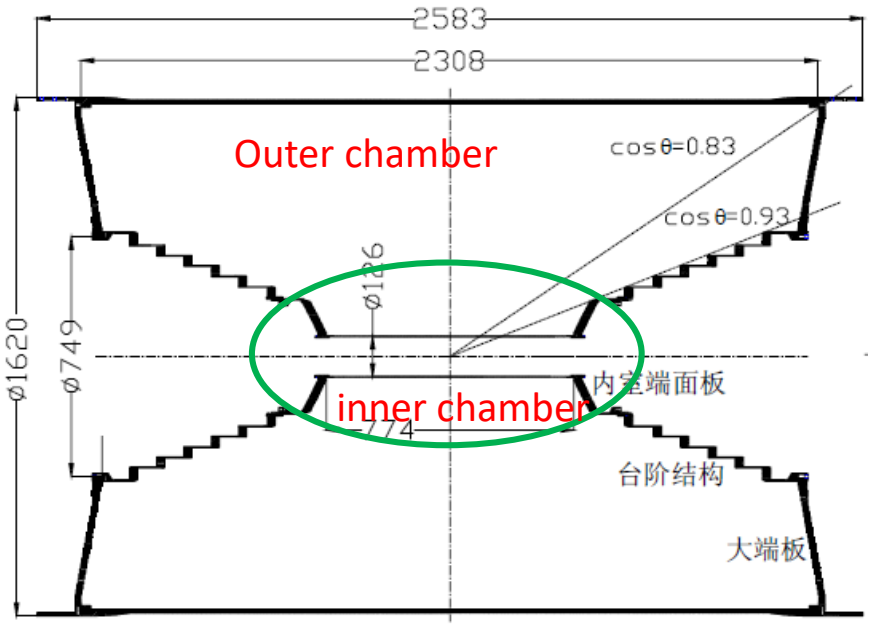
- Main tracking detector for the charged particles

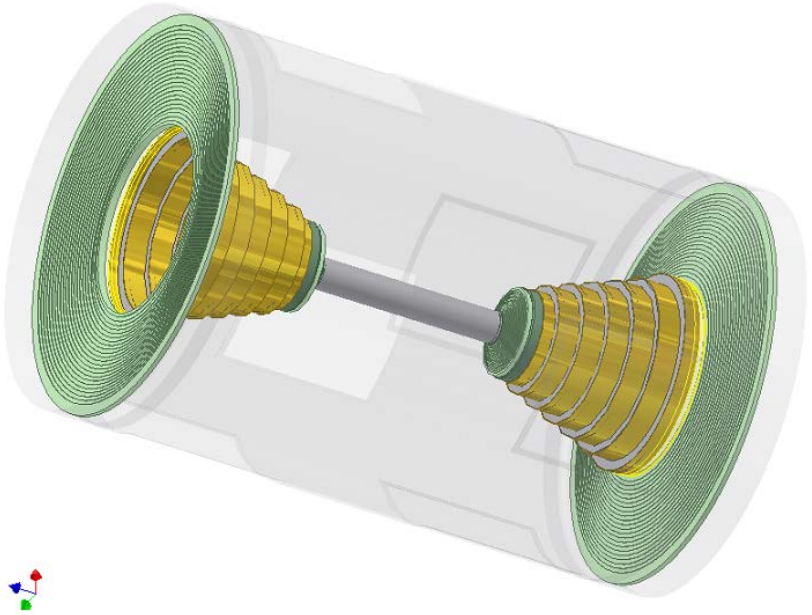
  Position, momentum and dE/dx measurements

- Consists of inner chamber and outer chamber
- 43 layers in total

  8 layers (Inner chamber)+35 layers(Outer chamber)

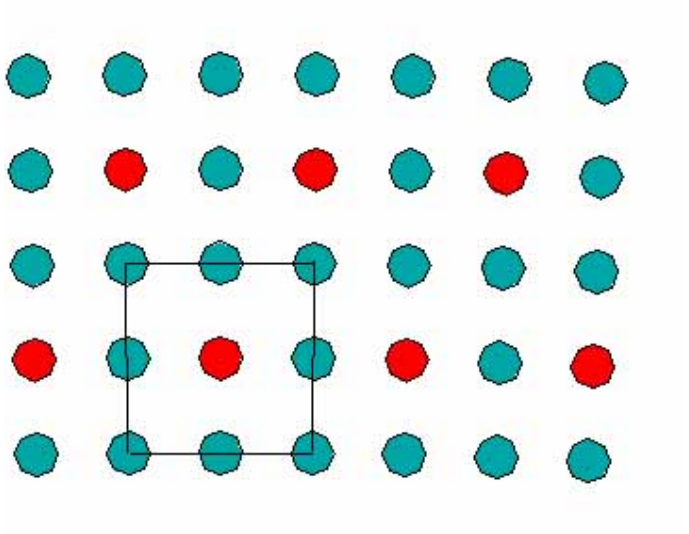
  19 axial layers, 24 stereo layers, 6796 cells in total





- Radius extension : 63 mm → 810 mm
- Length: 2308 mm
- Inner cylinder: 1.2mm carbon fiber
- Outer cylinder: 11.5 mm CF with 8 windows
- End plates: 18 mm Al (6 stepped and inner end plates : 25 mm Al)

小单元设计和氦基工作气体



- cell size：
  inner chamber: 12mm×12mm
  outer chamber: 16.2mm×16.2mm

- Sense wires: ϕ25μm W (Au)
- field wires: ϕ110μm Al (Au)
- 28680 wires in total

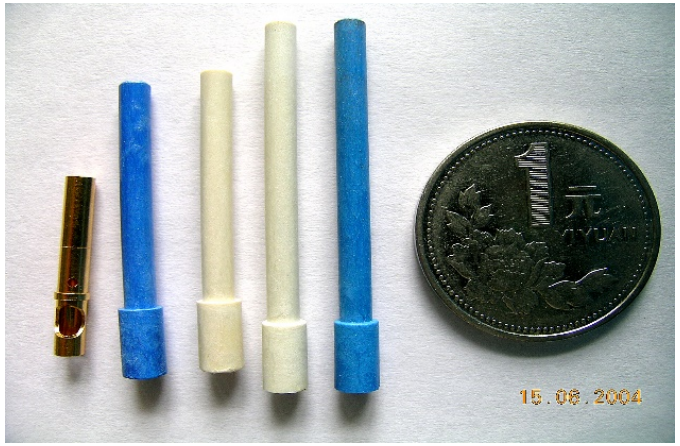
Attractive features of small cells

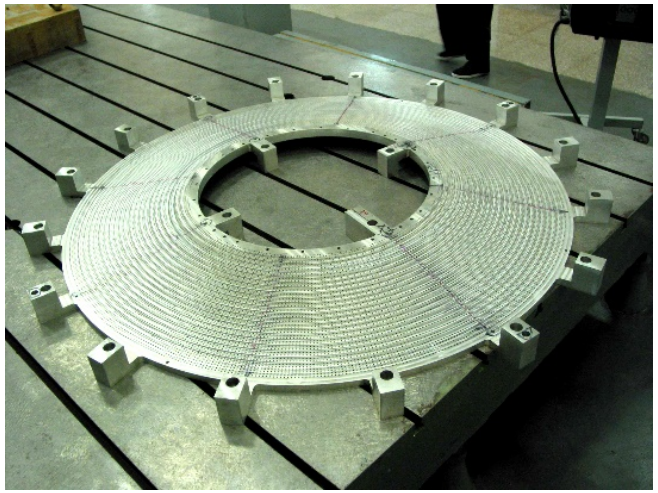
- Small drift distance → fast trigger
- Can reduce electron diffusion → improve spatial resolution
- Can put more layers in limited space → improve $\sigma_{dE/dx}$
- Reduce accumulated charge of the cells → slow down aging

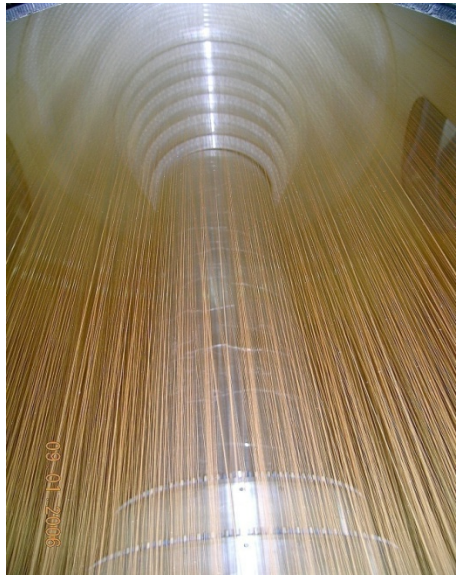
- He based gas mixture
- He : C_3H_8 = 60% : 40%
- low material budget to reduce multiple scattering， X_0: 500 m, v_e=3.8 cm/μs

Construction of MDC

- Main R&D:
  - Materials: wire(tension, creeping, …), glue(aging, radiation hardness), feedthrough(precision, HV resistance), …
  - Prototyping & test beam
- Manufacturing and assembly:
  - Precision of end-plates: very difficult，failed twice
  - Feedthrough: precision, …
  - Wiring, carbon fiber cylinders，precision of assembly, gas tightness, …

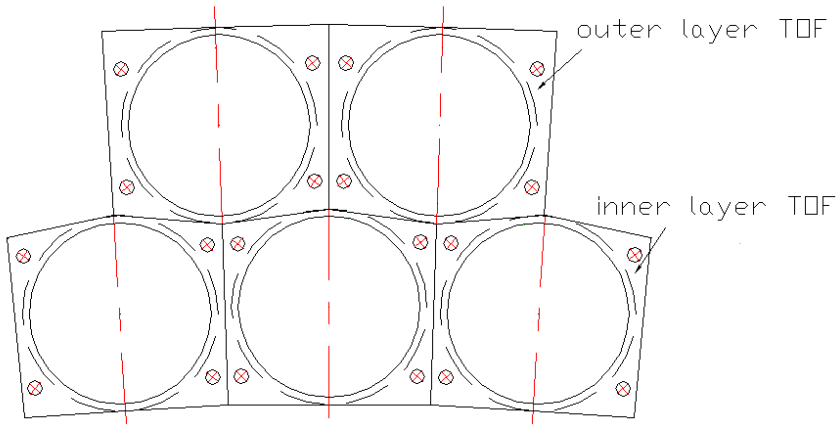


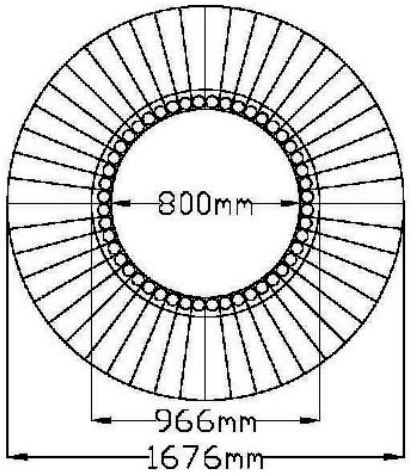


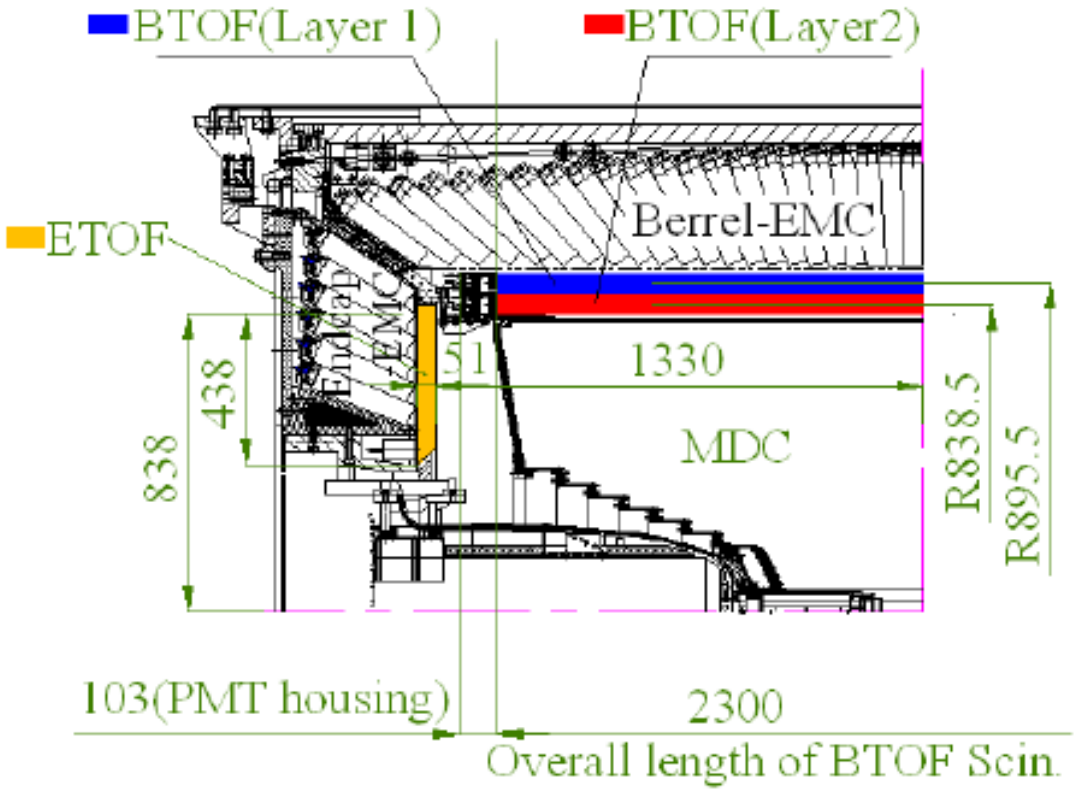


飞行时间探测器 (TOF)

- 测量粒子飞行时间，用于粒子鉴别
- 包括桶部和两个端盖探测器
- 桶部
  - 双层设计，2 层 88×2 个 BC408 闪烁体
  - 尺寸：50mm × 60mm × 2320 mm (inner layer)
- 端盖
  - 每个端该48个扇形BC404闪烁体
- PMT: Hamamatsu R5942

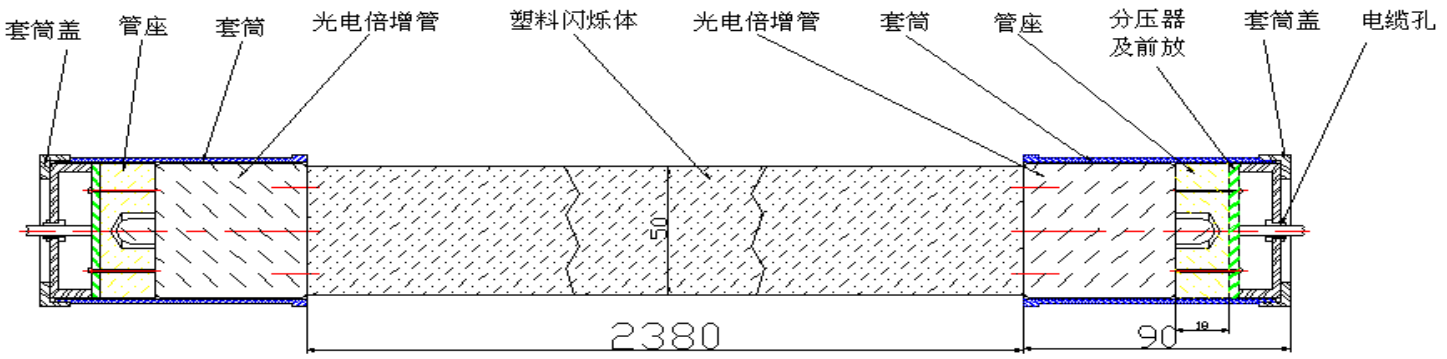




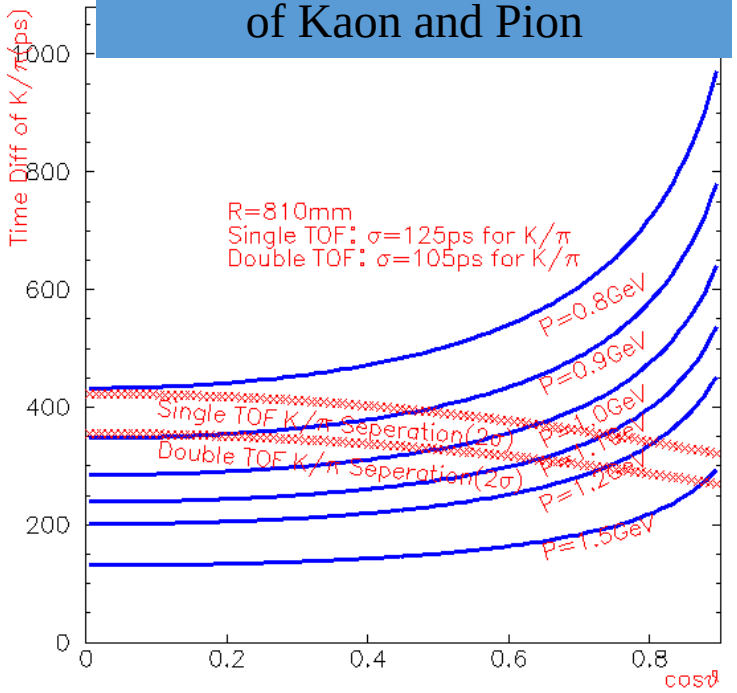


Construction of TOF

- Module study and production : radiation hardness, wrapping, optical coupling, effects of magnetic field, test beam, …

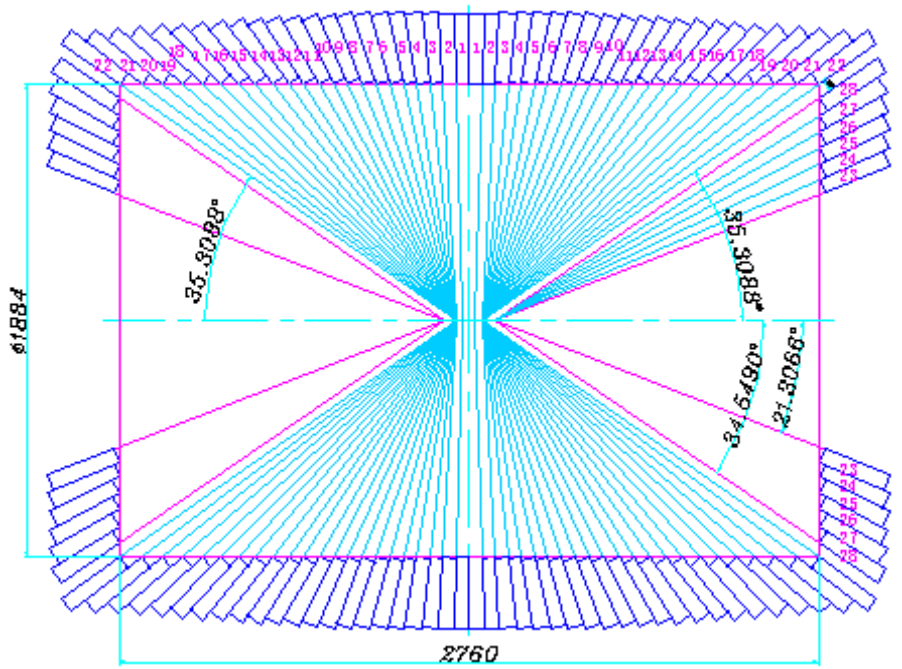


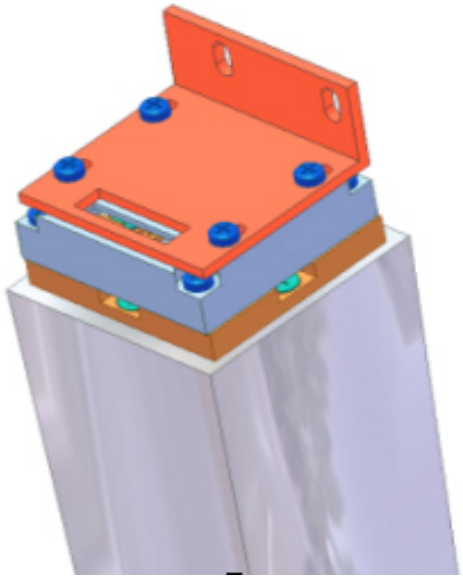
Capability of separation of Kaon and Pion



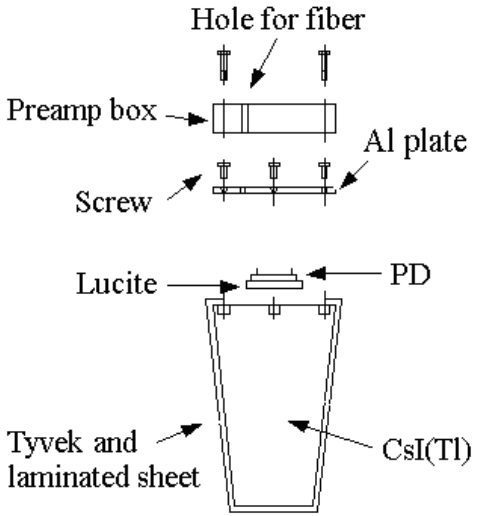
电磁量能器 (EMC)

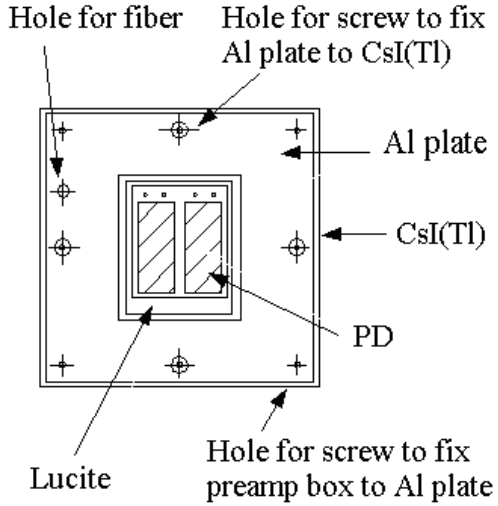
- 精确测量 γ 和电子的能量和位置
- 全吸收型电磁量能器：包括桶部和两个端盖
- CsI(Tl) crystal， 耦合PD(Hamamatsu S2744-08)读出
- 晶体单元：5280 (桶部)+ 960 （端盖），共6240 晶体单元





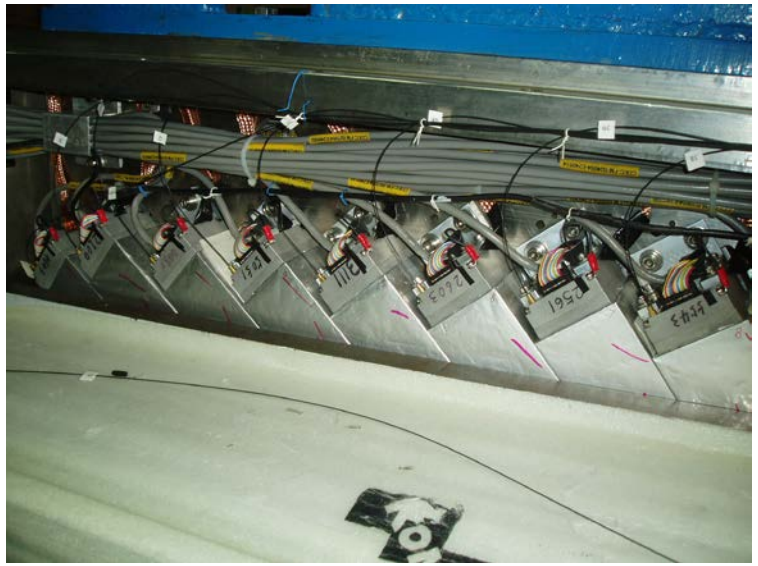
CsI(Tl)晶体探测单元





Construction of EMC

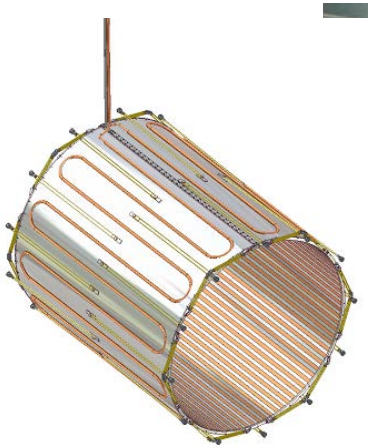
- Crystal module study and production: light yield, uniformity, wrapping, PD, test beam,…
- CsI(Tl) crystals produced from SIC, Hamamatsu and Saint-Gobain in order to control the risk, cost and quality
- Low noise electronics: 1000 e equivalent ~ 220 keV
- Using screws instead of honeycomb structure to hold crystals

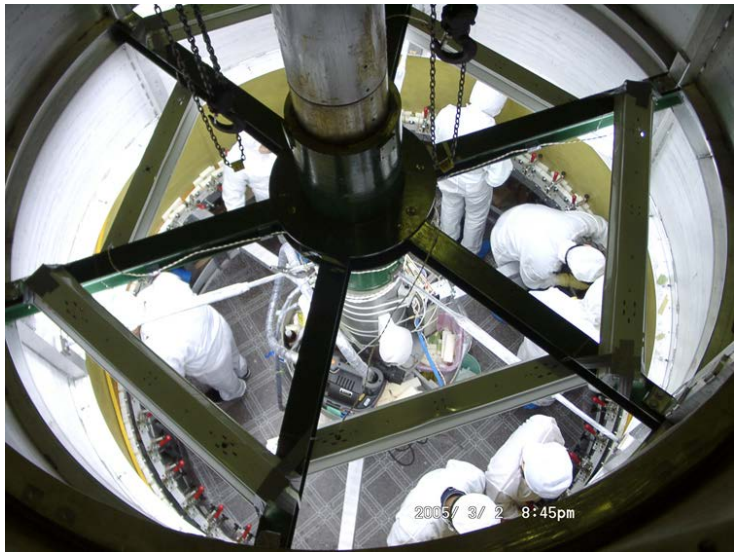


Superconducting Magnet

- 提供1T轴向磁场
- Key Issues: structure, cable winding, assembly, valve box…
- Huge risk: not possible to test before the final curing
  - too late if we know it is not good
- After 3 times of quenching, the magnet reached 1T
- **Field mapping: $\Delta r < 0.5$ mm, $\Delta B < 0.1\%$**

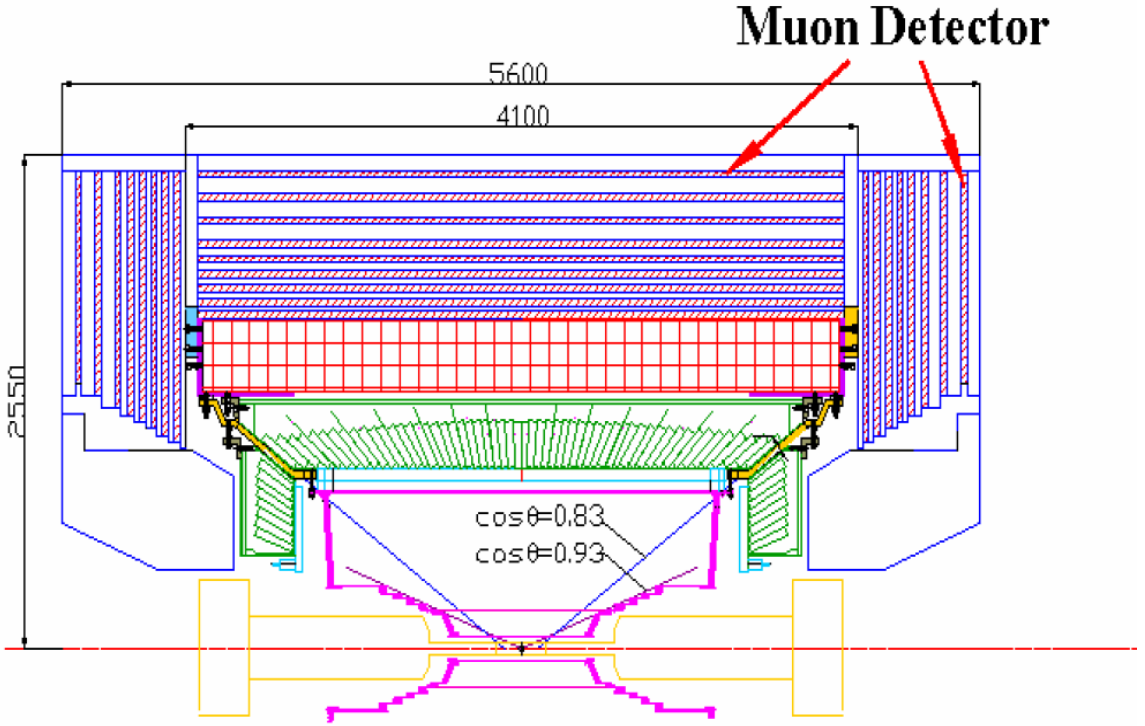
- 迄今为止，国内最大的单磁体超导磁铁

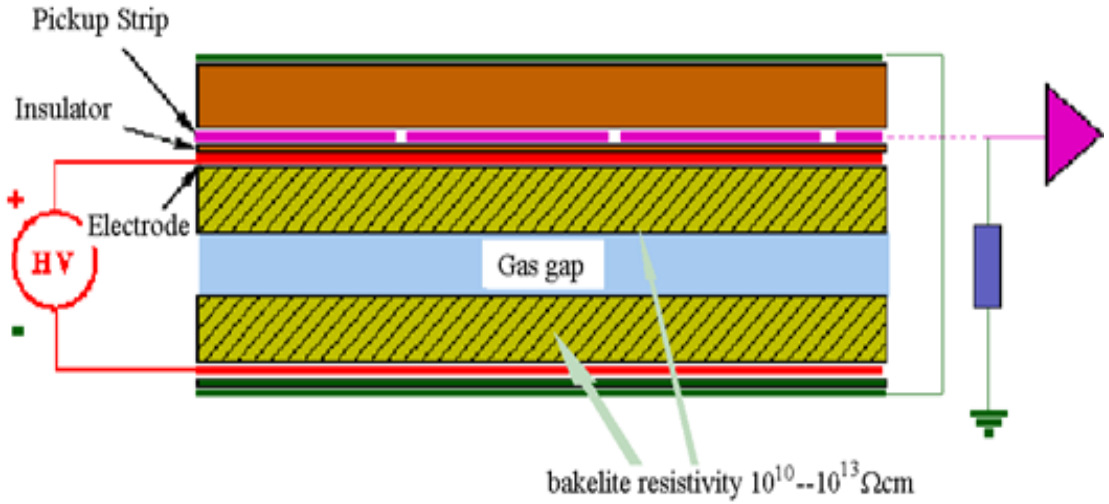


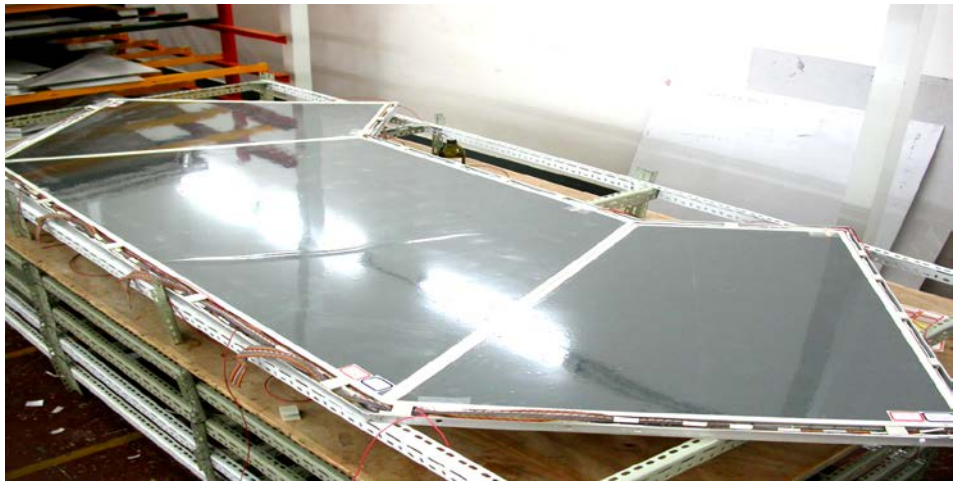


Muon detector (MUC)

- μ探测器位于BESIII探测器的最外层，测量反应末态中的μ子的位置和大致飞行轨迹
- 包括桶部 (9 layers)和 2 个端盖 (8 layers)，由μ探测器和强子吸收体组成
- 基于阻性板（RPC）探测器， 约2000 m^2 RPC
- 4cm 宽读出条，约9000 channels

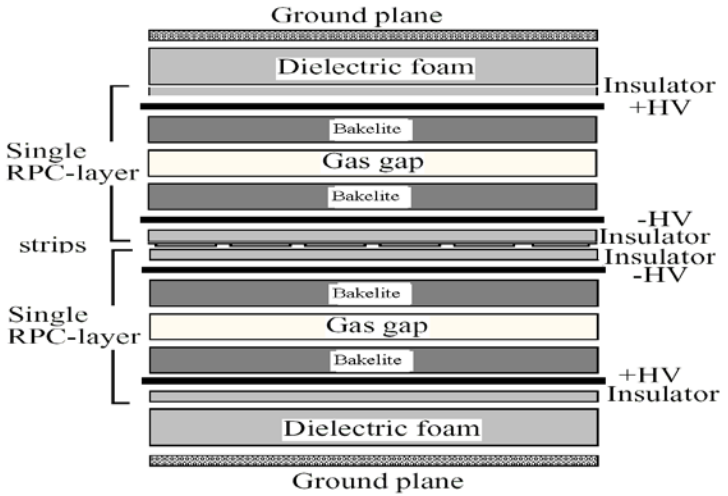




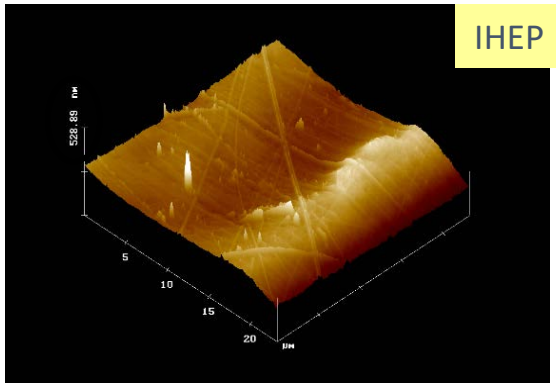


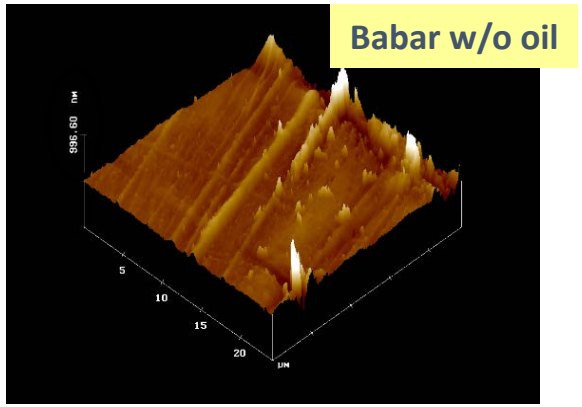
Construction of RPC muon chamber

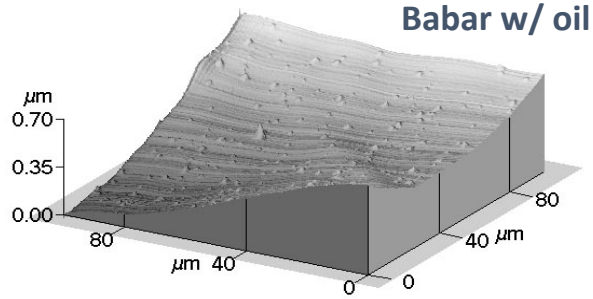
- 电极用特殊的石碳酸纸贴在酚醛塑料板上做成，用50μm的膜代替亚麻油
- 国际首创的无油阻性板RPC技术，解决了寿命问题
- 噪声小于 0.05 Hz/cm2
- RPC探测效率高，噪声计数率和暗电流低，长时间工作稳定性好

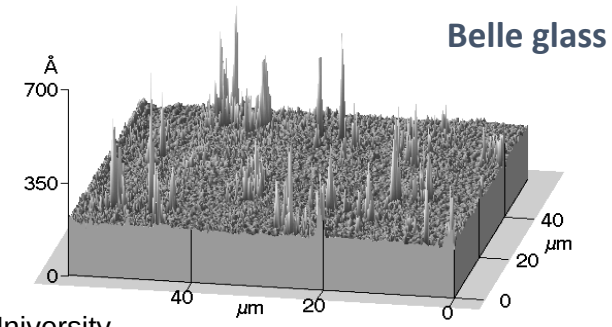


RPC surface seen by **the atomic force microscope**









C. Lu, Princeton University

Other systems

- Beam pipe
- Electronics, Slow Control and Grounding
- Trigger system
- DAQ system
- Software and data flow
- ……

BESIII performance

Sub detector		Design Performance	Achieved Performance
MDC		$\sigma_{r\phi} = 130\mu m$ $\Delta p/p = 0.5\%@1GeV$ (B=1T) $\sigma_{dE/dx} = 6\%$	$\sigma_{r\phi} = 115\mu m$ $\Delta p/p = 0.5\%@1GeV$ (B=1T) $\sigma_{dE/dx} = 6\%$
TOF	Barrel	$\sigma_T = 80\sim90\ ps$	$\sigma_T = 68ps$
	Endcap	$\sigma_T = 110\sim120ps$ (before upgrade) $80ps\sim100ps$ (after upgrade)	$\sigma_T = 110ps$ (before upgrade) $60ps$ (after upgrade)
EMC		$\Delta E/E = 2.5\%\ @1GeV$ $\sigma = 6\ mm/\sqrt{E}$	$\Delta E/E = 2.5\%\ @1GeV$ $\sigma = 6\ mm/\sqrt{E}$
MUC		$\sigma_{r\phi} = 14mm\sim17mm$ $\sigma_z\sim17mm$	$\sigma_{r\phi} = 14mm\sim15mm$ $\sigma_z\sim17mm$

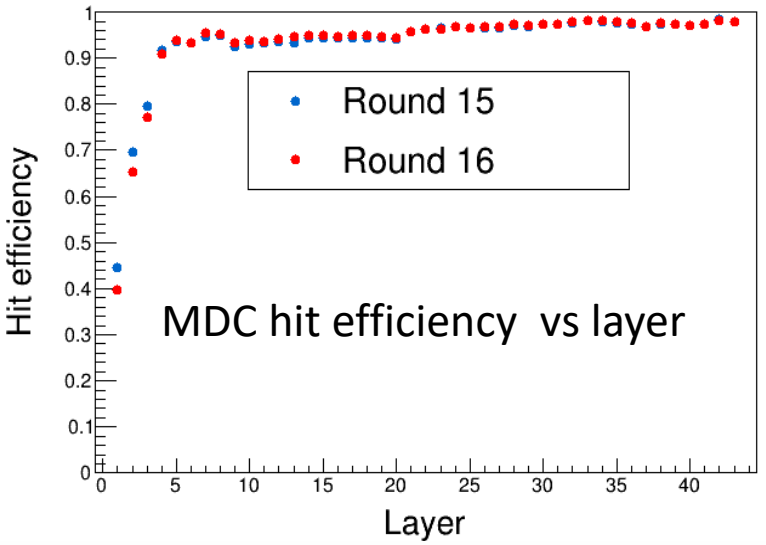
BESIII 各子探测器性能均达到或超过设计指标，通过国家验收

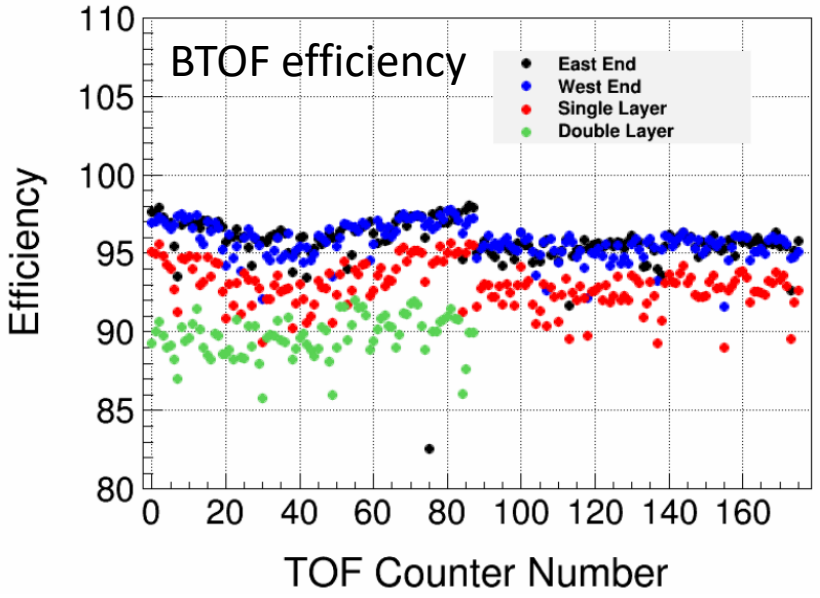
Comparison between BESIII, BESII,CLEOc and Belle

system	BES III	BES II	CLEOc	Belle
MDC	σ_{XY} = 115μm	250μm	130μm	130μm
	△P/P (%) = 0.5 %(1 GeV)	2.4 %(1 GeV)	0.5 %(1 GeV)	0.5 %(1 GeV)
	$\sigma_{dE/dx}$ (%) = 6%	9%	6%	7%
EMC	△E/√E(%) = 2.5 %(1 GeV) $\Delta\theta$=5 mrad(1 GeV)	20 %(1 GeV) $\Delta\theta$=25 mrad(1 GeV)	2.3 %(1 GeV) $\Delta\theta$=5 mrad(1 GeV)	2.2%(1 GeV) $\Delta\theta$=5 mrad(1 GeV)
TOF	σ_T (ps) = 68 ps Barrel 110 ps endcap 60 ps new MRPC endcap(2015)	180 ps Barrel 350 ps endcap	139 ps	90-100ps
μ counter	9 / 8 layers	3 layers	3 layers	14 layers
Magnet	1.0 tesla	0.4 tesla	1.0 tesla	1.5 tesla

Stable operation for 16 years

- MDC :
  - No broken wire. 43 dead channels in total, 40 channels can be repaired due to preamp issues
  - Hit efficiency: 90%~97%, except for the first 3 layers
- EMC:
  - No dead crystal module. 27 unglued modules，light yield of 5 modules dropped to about 60-70%
  - Efficiency : Almost 100%, except for the 5 unglued modules
- BTOF:
  - No dead channel
  - Efficiency : 95%~97% for single end
- ETOF:
  - 6 dead channels can be repaired due to preamp issues
  - Efficiency : 98.5%, except for the dead channels
- MUC:
  - 1 module dead (east endcap layer0)
  - Efficiency : >90%





BESIII探测器的升级

- 端盖TOF升级
- 漂移室内室升级

端盖TOF升级

相比于桶部TOF，端盖TOF时间分辨较大(110ps)

1．物质层散射－－＞端盖径迹长度不确定性增加；

2．ＭＤＣ较少丝层可用于小角度的径迹重建－－＞Ｚ向击中位置不确定性，~90ps/cm

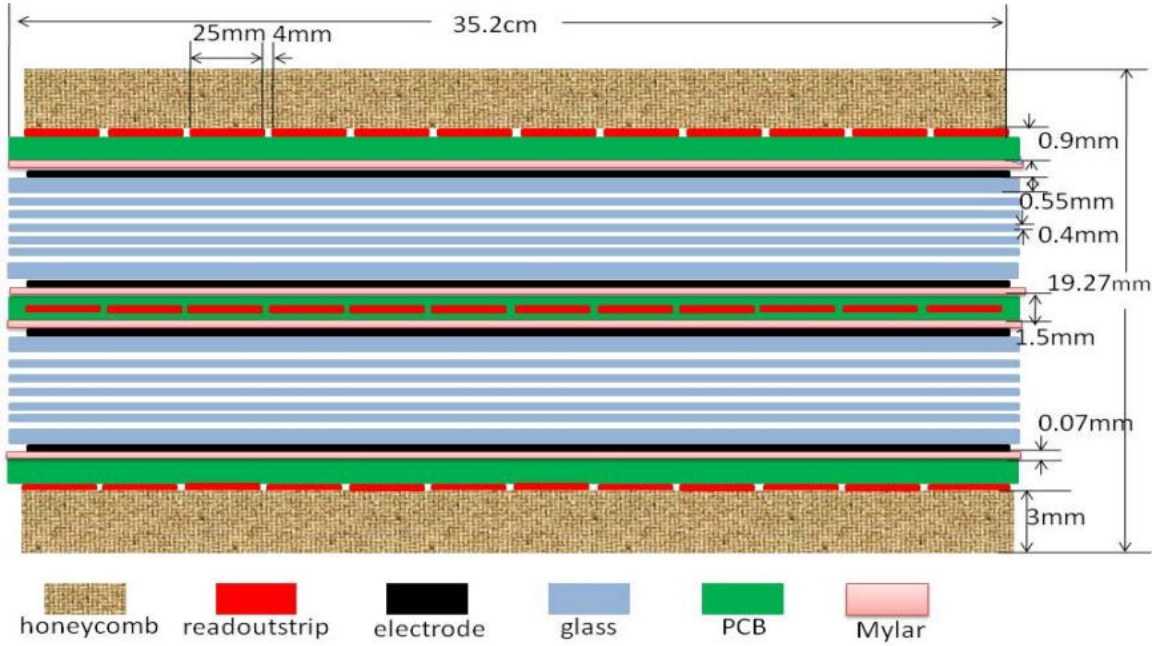
3. Multi-hit: 75%

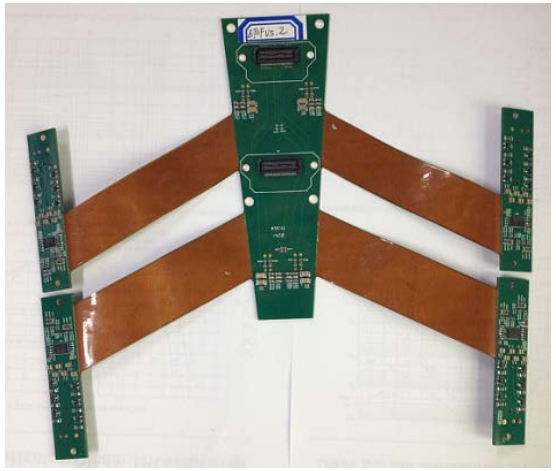
4.端盖TOF受到噪声问题的困扰；

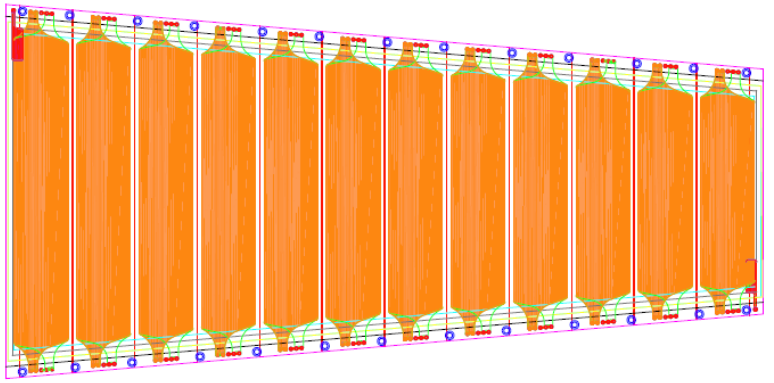
经过预研，采用MRPC探测器进行端盖TOF的升级

主要方案

- 探测器： MRPC
- 探测器读出：
  - Small Pad 且双端读出： 去除位置不确定的影响
- 前端电子学： Nino chips
  - 包含数字化
  - 幅度测量使用TOT
  - 14ps
- 后端电子学： HPTDC
  - 10~20ps

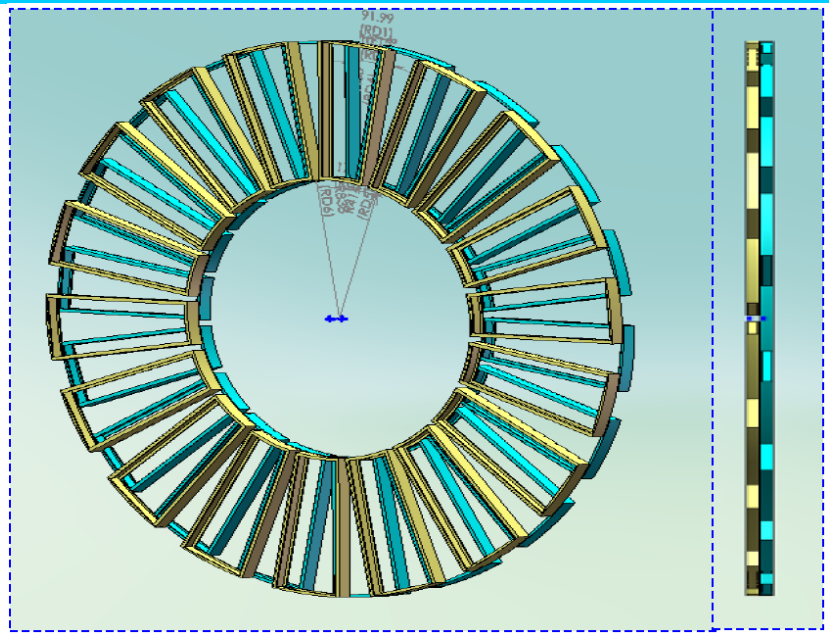


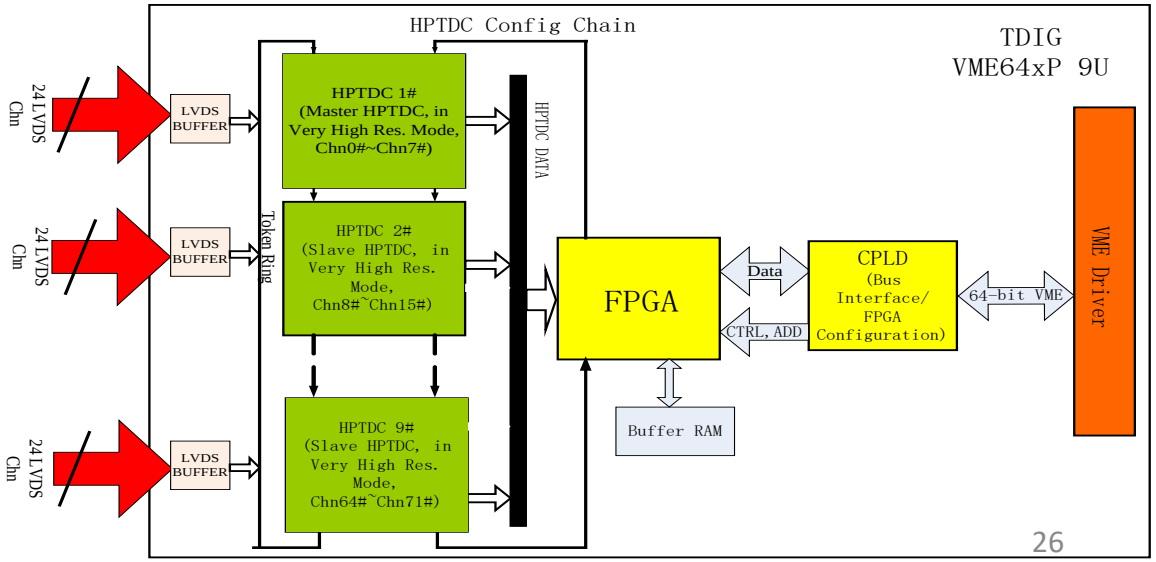




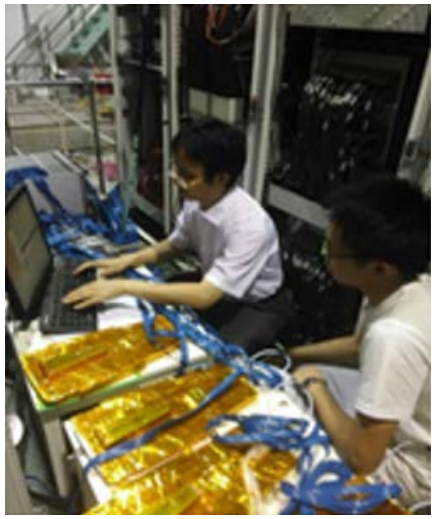
探测器设计

- 探测器：
  - 每个端盖两层，每层厚度小于25m
  - 每端36个模块,谱仪东西端部共72个模块
  - 每个模块12 strips，双端读出
- 电子学
  - 1728路
  - 前端电子学：72 块
  - 后端电子学：24 TDIG插件
  - 另有CTTP和快控制插件提供触发和控制



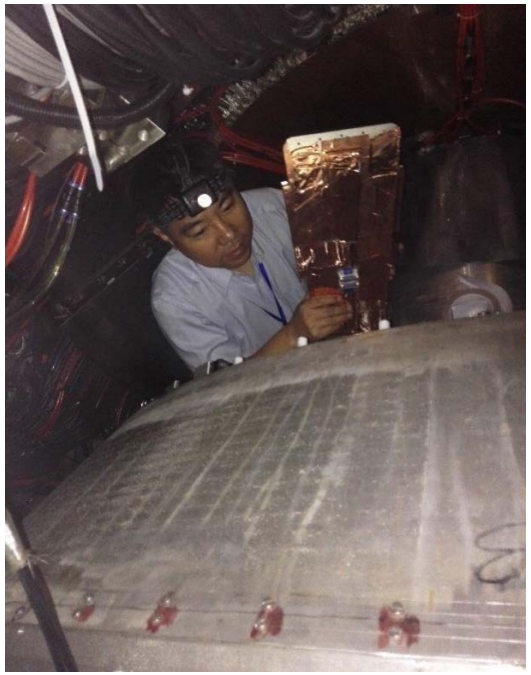


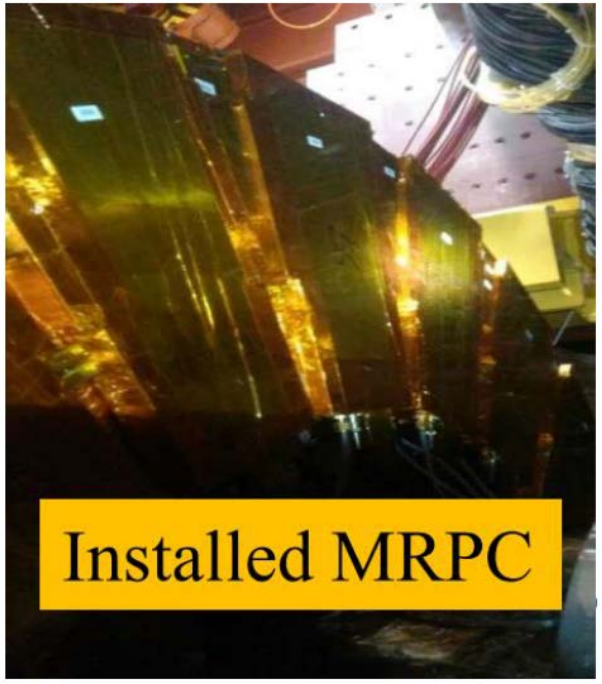
探测器建造和安装



- 2015年夏季完成安装，性能稳定

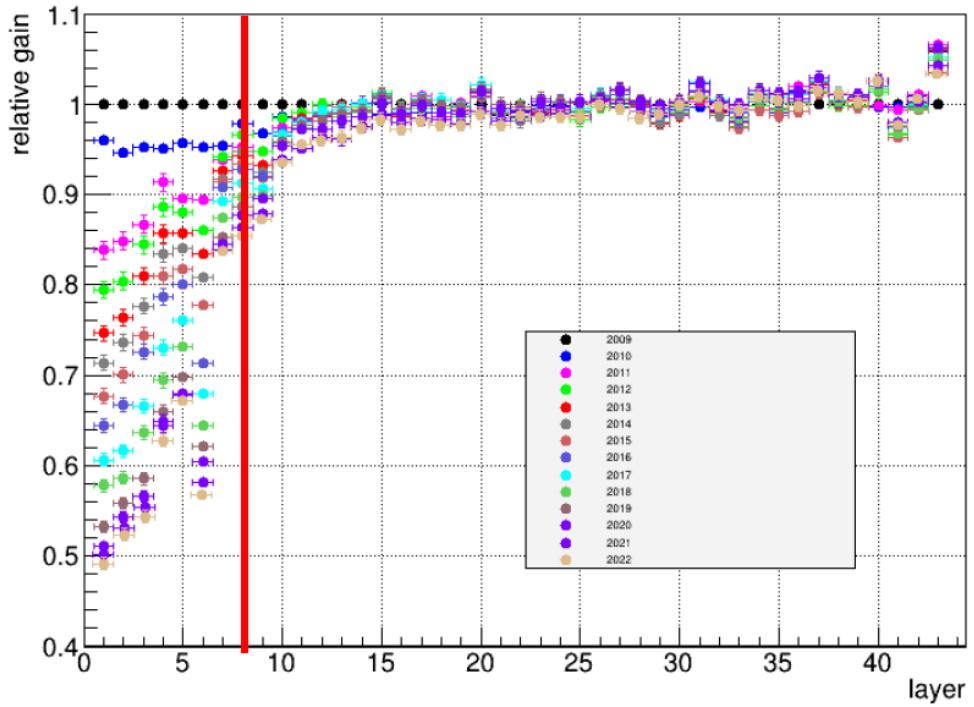
- 时间分辨率大幅提高：
  110ps → ~ 60ps

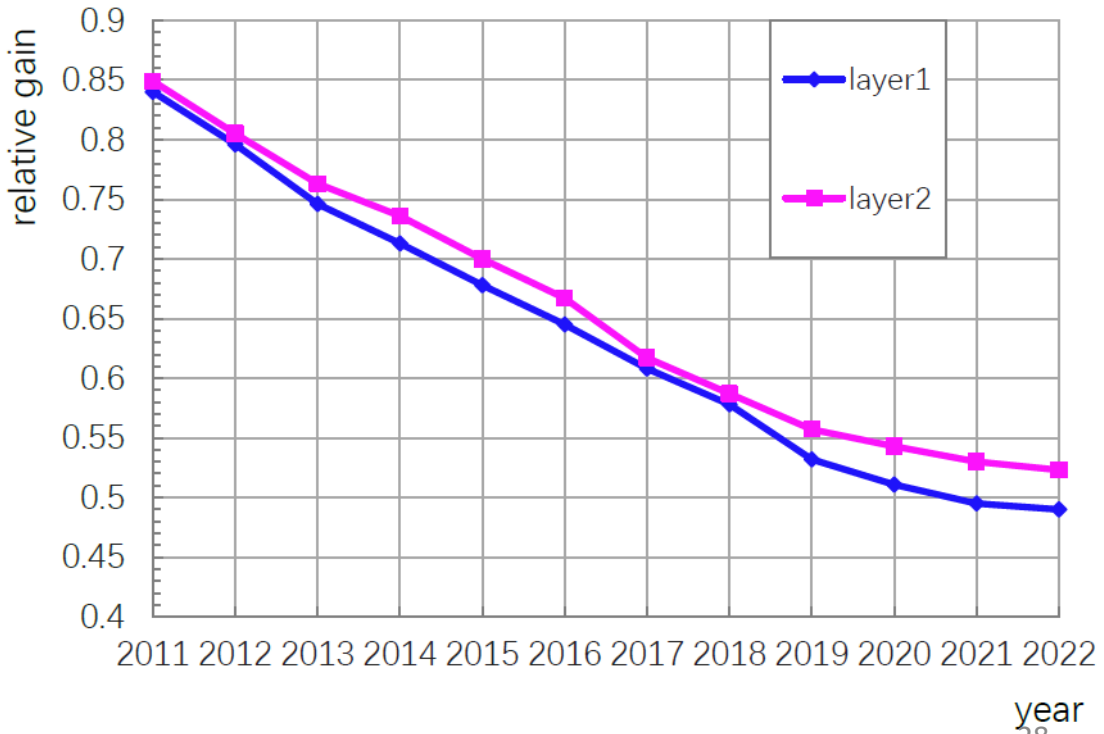




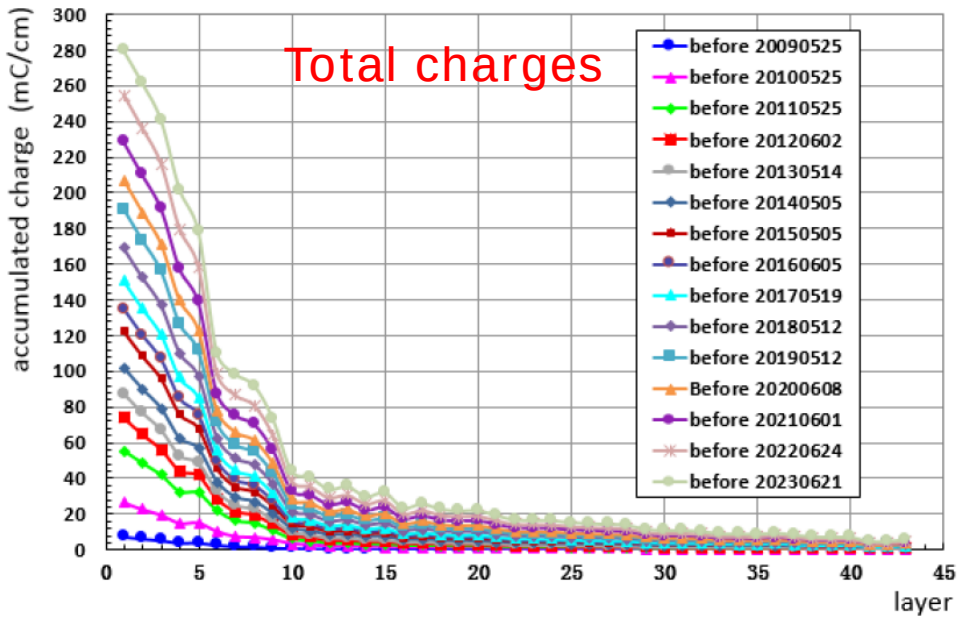
MDC aging issue

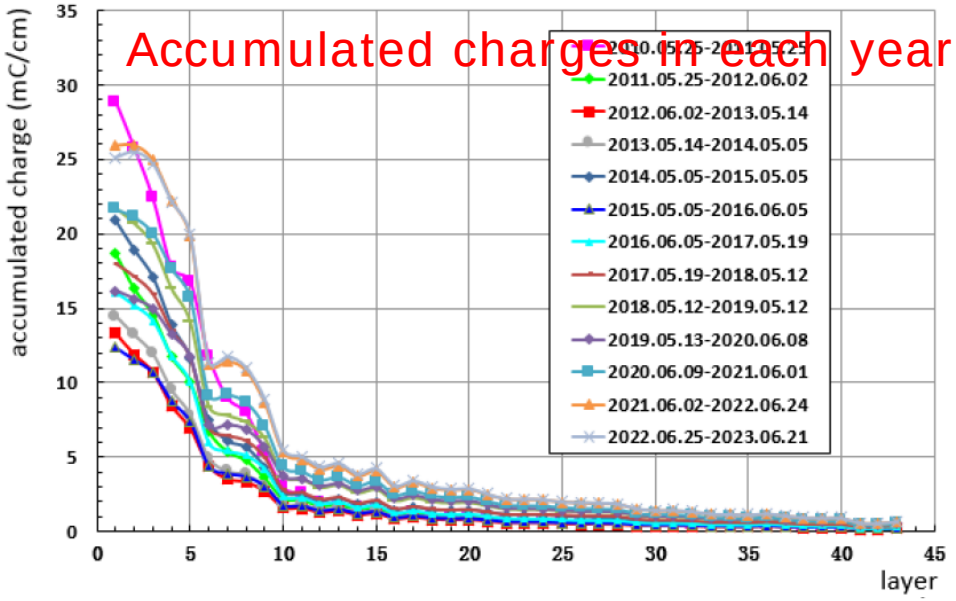
- Gains of inner chamber dropped, about 50% for the first layer cells
- No significant change in gain for outer layers
- Gain decreased by about 3% /year for layer1 and layer2, but slowed down in last three years

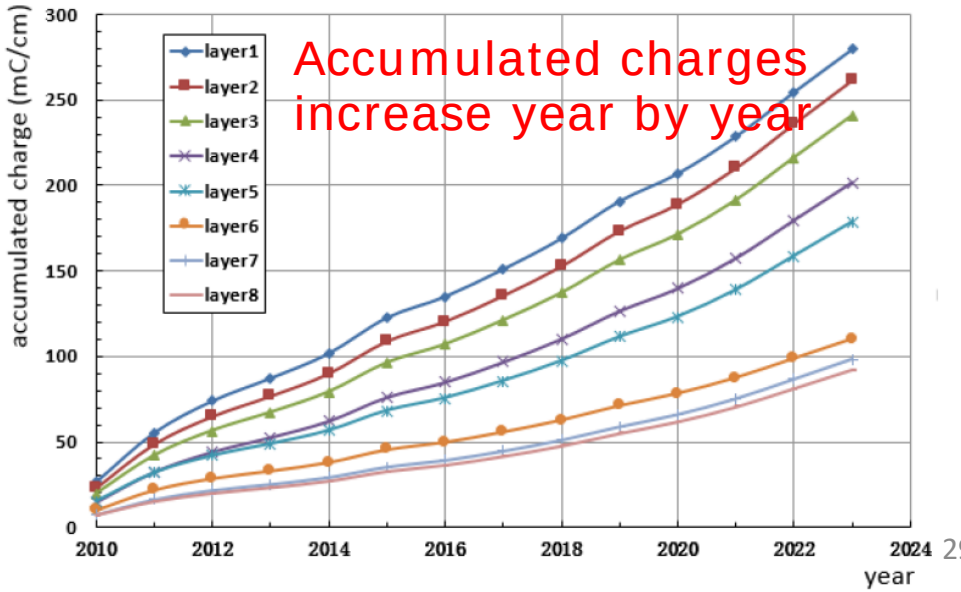




Accumulated charges

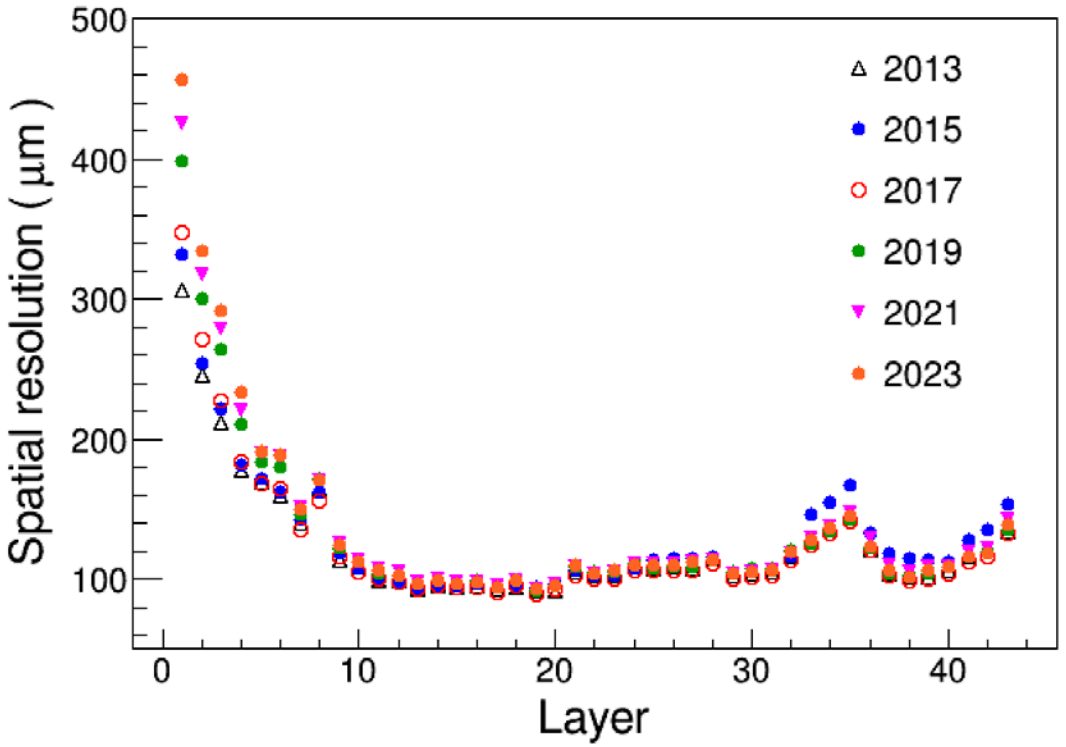


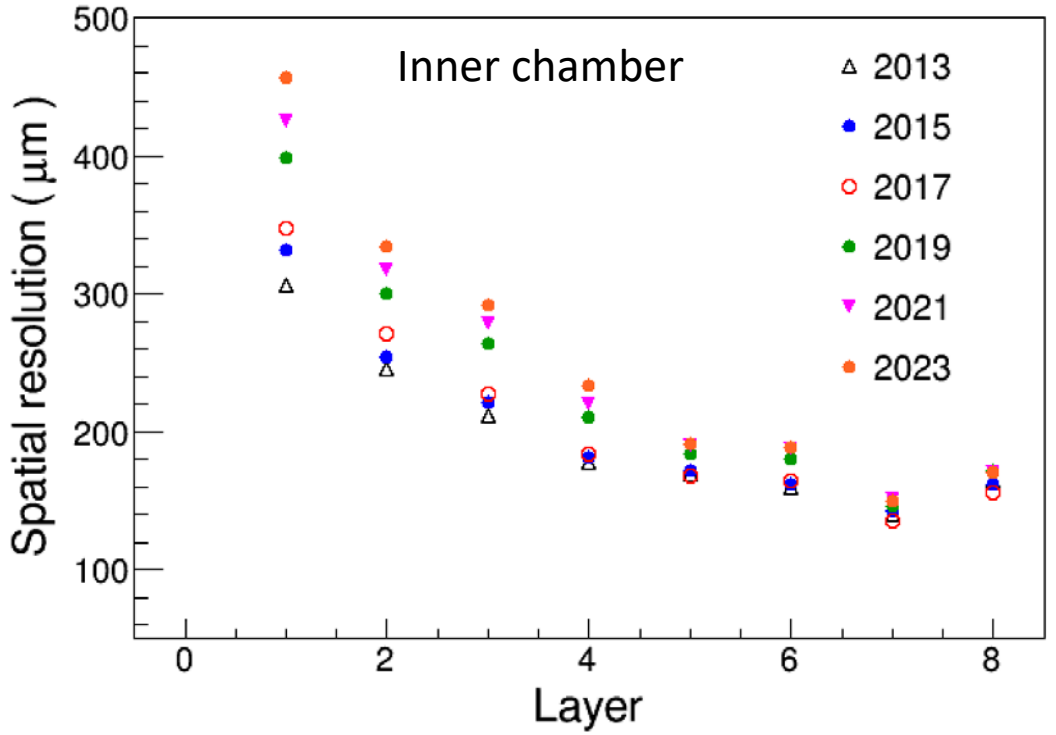




- Integrate currents of each cell to get accumulated charges
- Total charges are about 280mC/cm for the first layer
- Total charges decrease rapidly for the cells far away from the IP

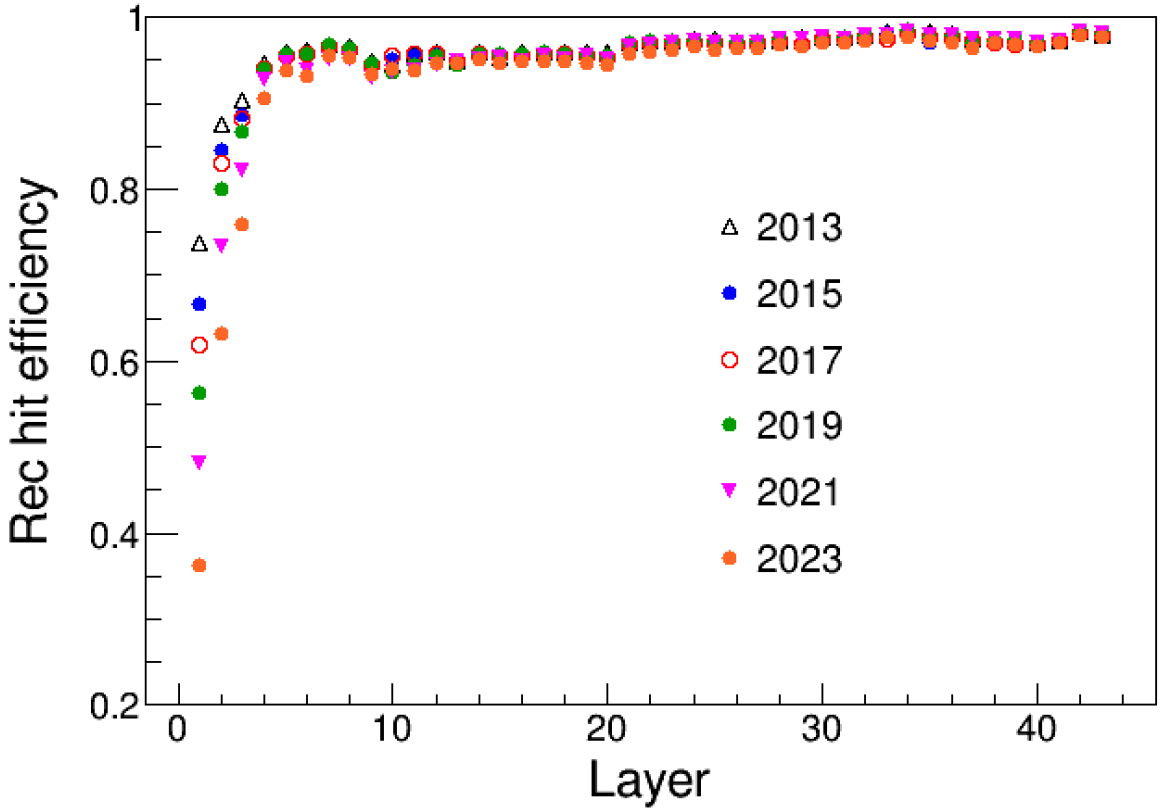
MDC spatial resolution

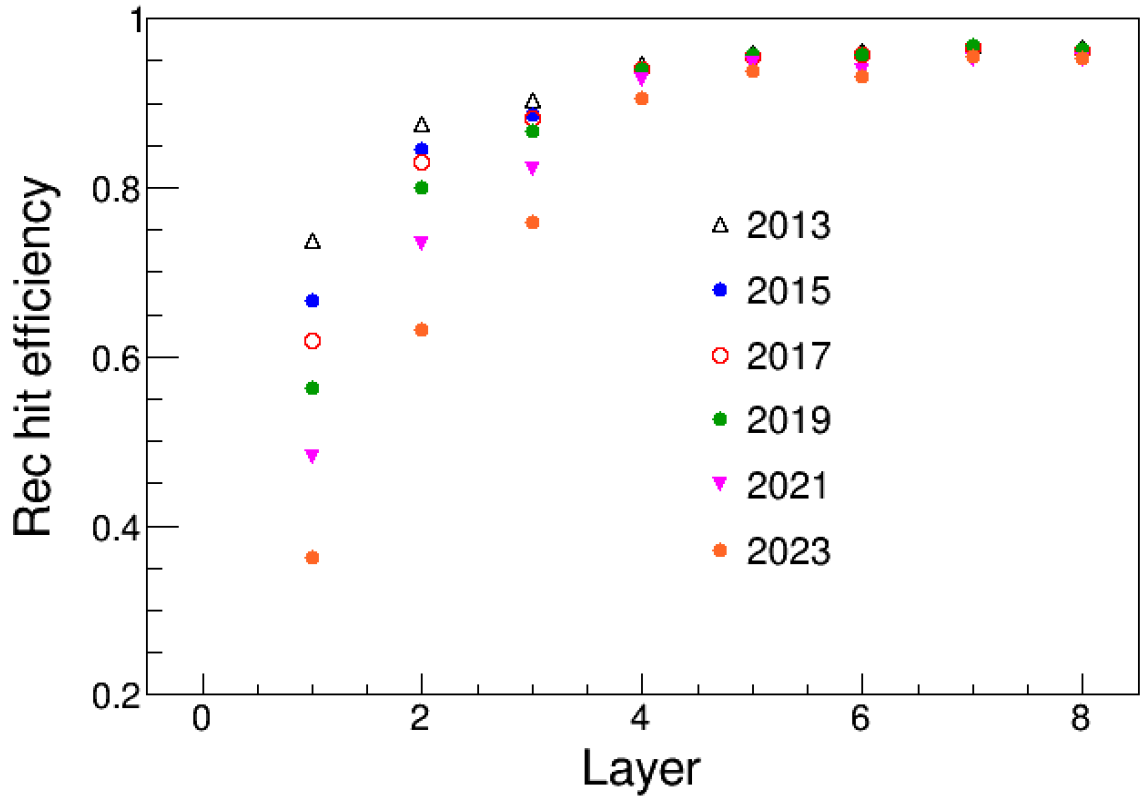




- The resolution of the inner chamber has significantly decreased
  - Decrease in gain caused by aging
  - Low voltage setting leads to low gain for the first four layers
- Almost no changes for the outer chamber

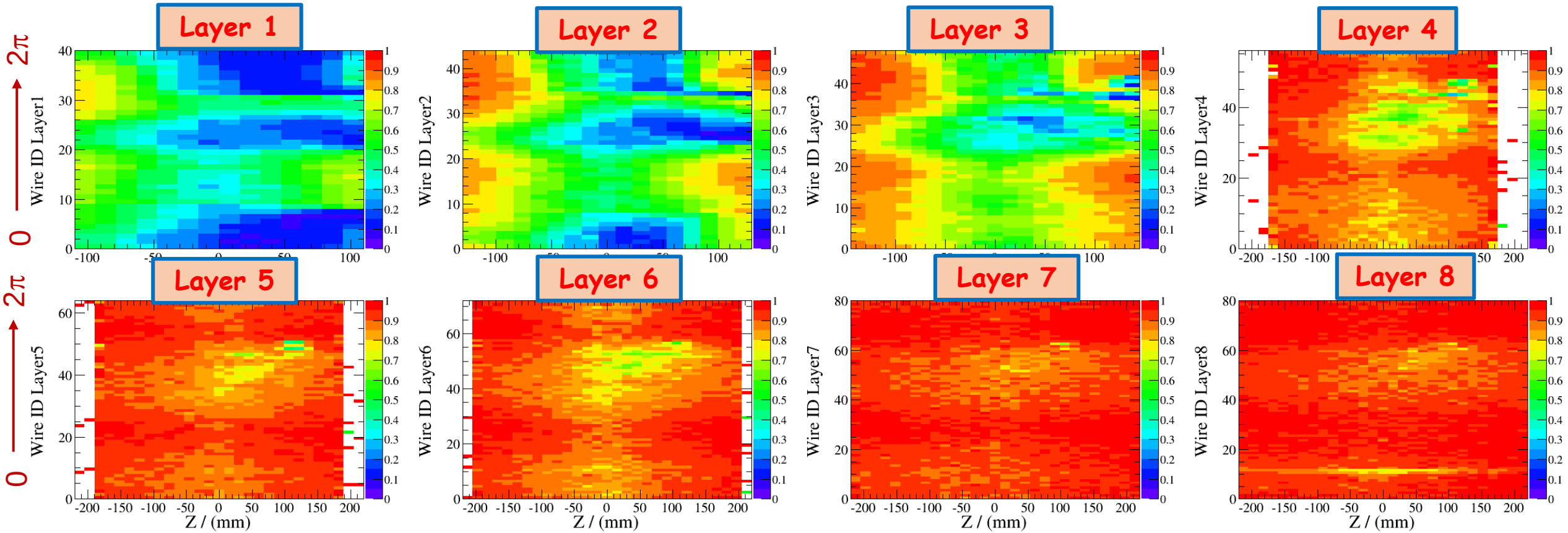
Reconstruction hit efficiency





- No significant decrease for most layers
- Hit efficiency of the first three layers decreased year by year

Rec hit efficiency

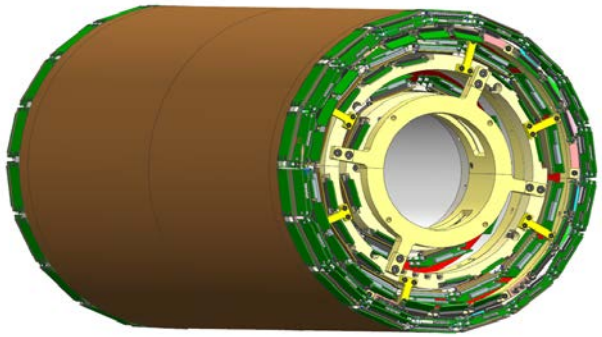


- The efficiency of the first three layers are nonuniform
- Some region is quite low (~*20%*) , Signals are lower than threshold

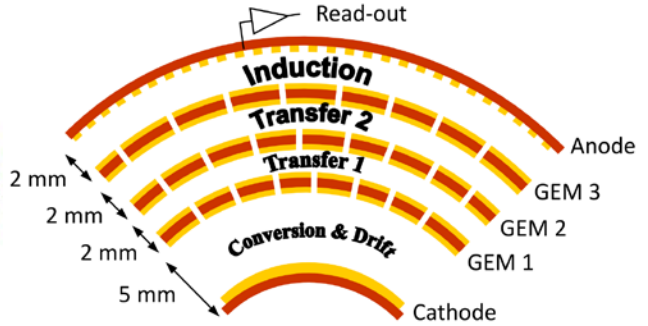
Cylindrical GEM inner tracker (CGEM)

- Built a 3-layer cylindrical GEM inner tracker for inner drift chamber upgrade (INFN and IHEP)
  - High counting rate (>10^4 Hz/cm^2)
  - Strong anti-aging ability
  - Significantly improve z-direction resolution (~1.5 mm →~0.5 mm)

现金微结构气体探测器在**BESIII**上的首次使用

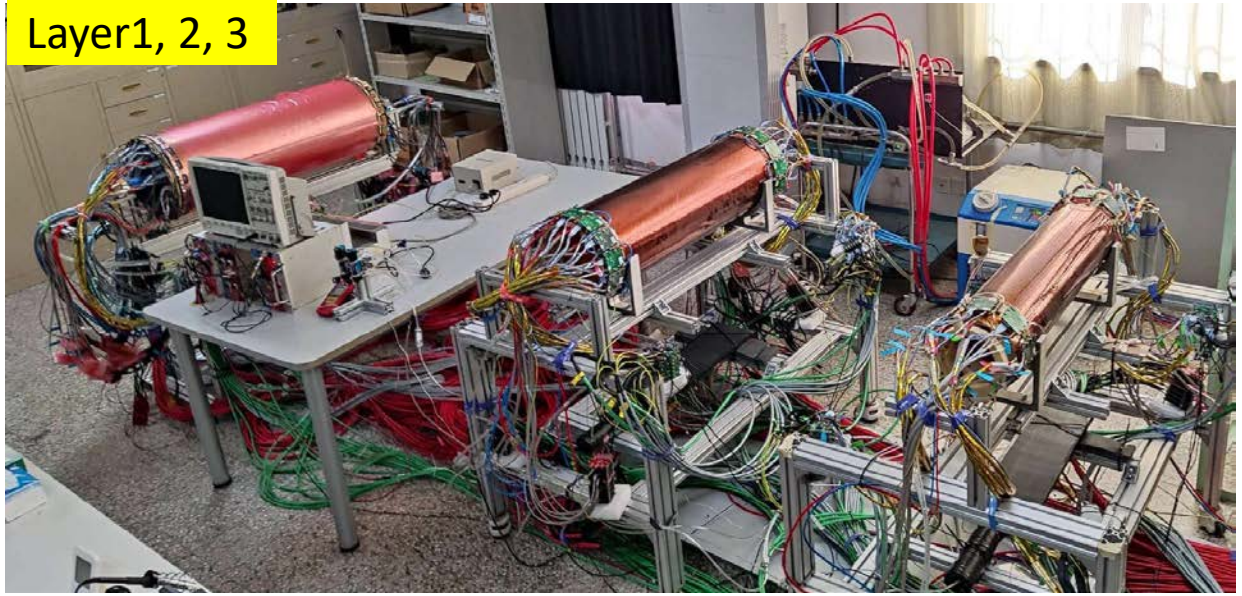


CGEM-IT

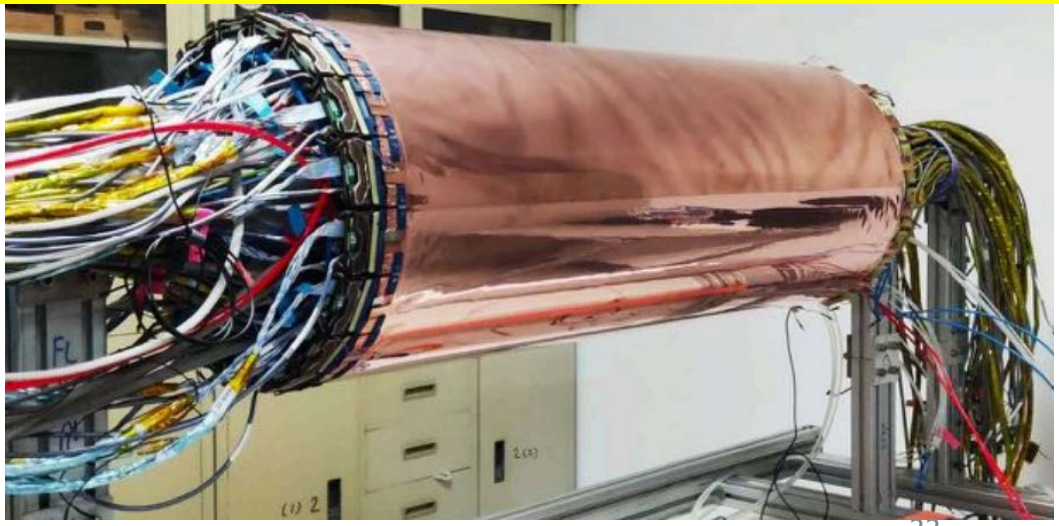


NIMA 824, (2016)515-517

Layer1, 2, 3



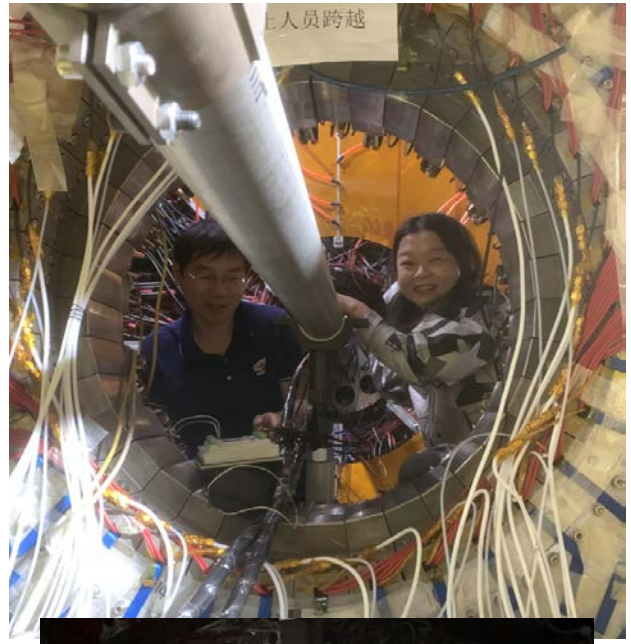
Assembled three layers together for cosmic-ray tests

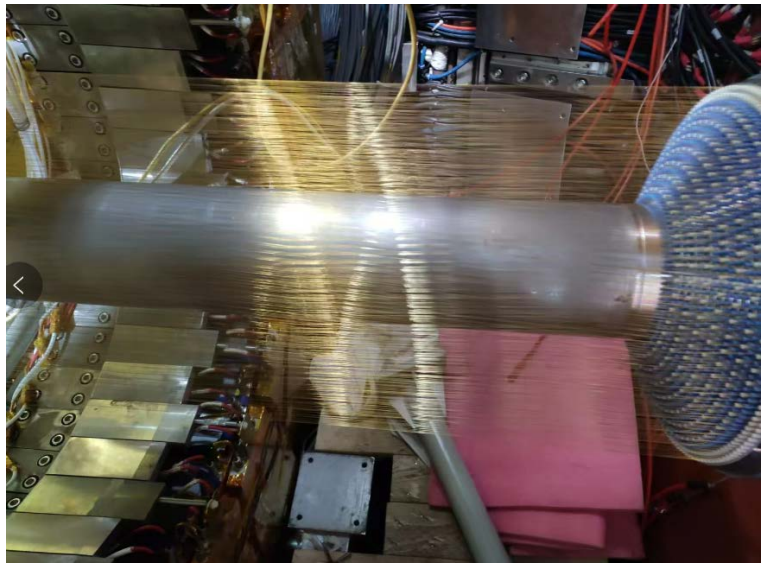


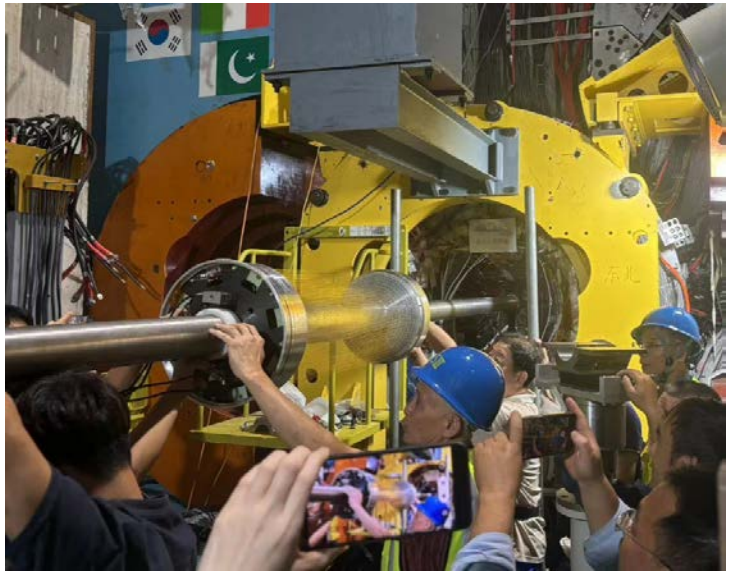
BESIII漂移室内室升级

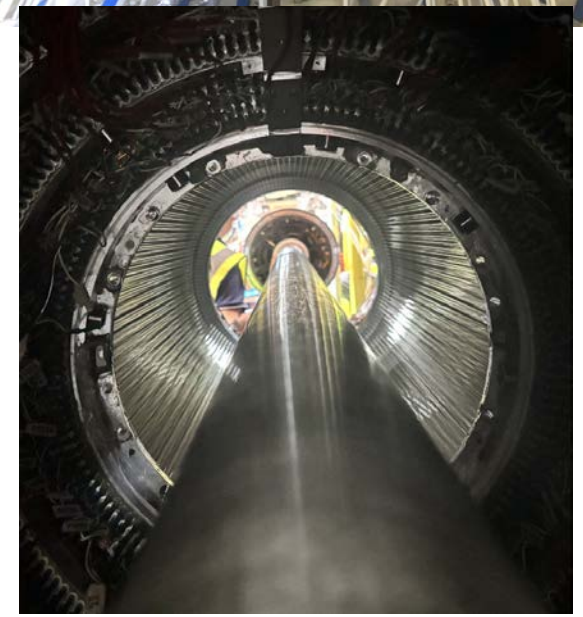
内室拆卸

- MDC内外室公用同一个腔室，在端板处紧密配合以及加胶密封，内室拆卸风险极大
- 多种拆卸方案，充分的实验，确定了最可靠的方案以及可能出现问题的预案
- 拆卸过程中，位移监测、丝张力检测，温度监测等

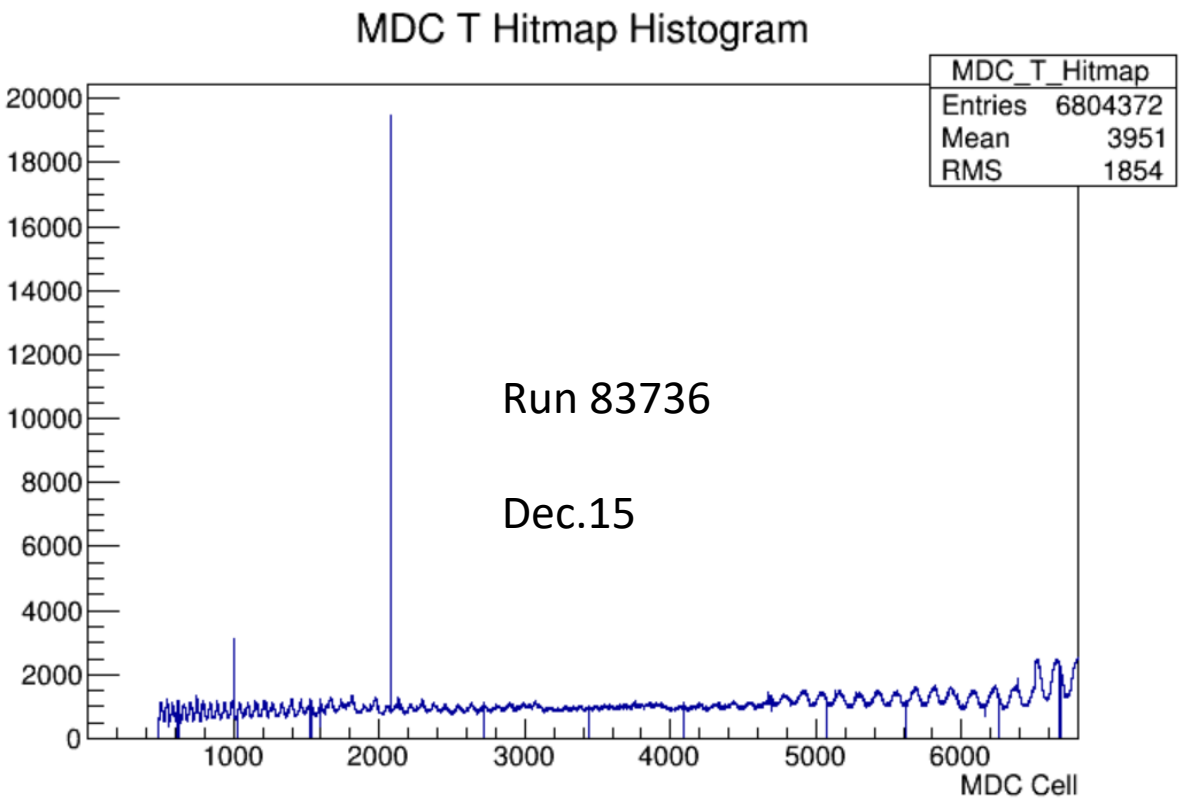


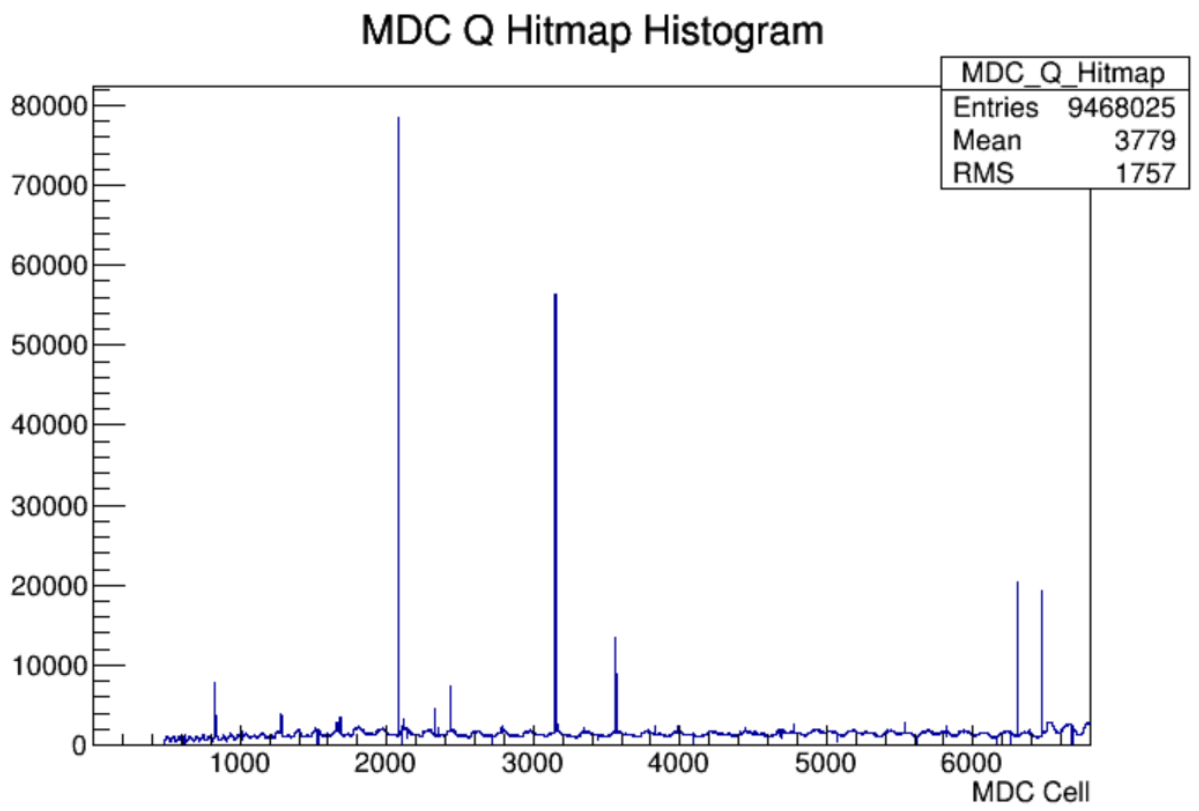






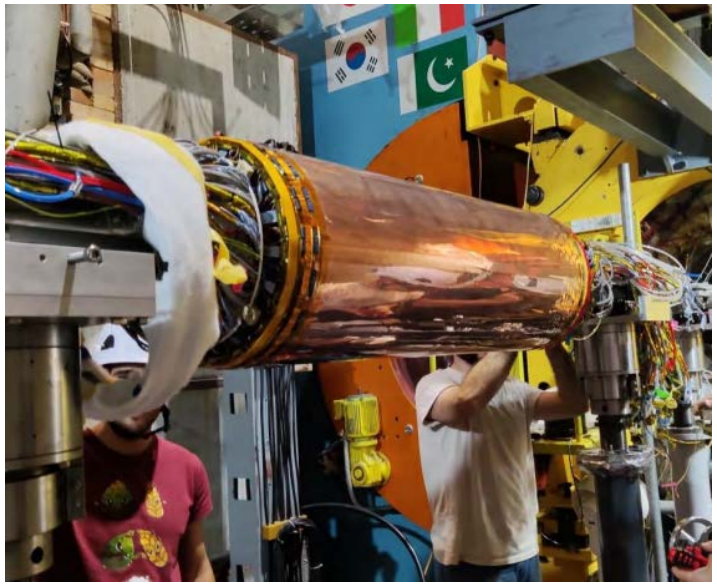
Cosmic-ray test

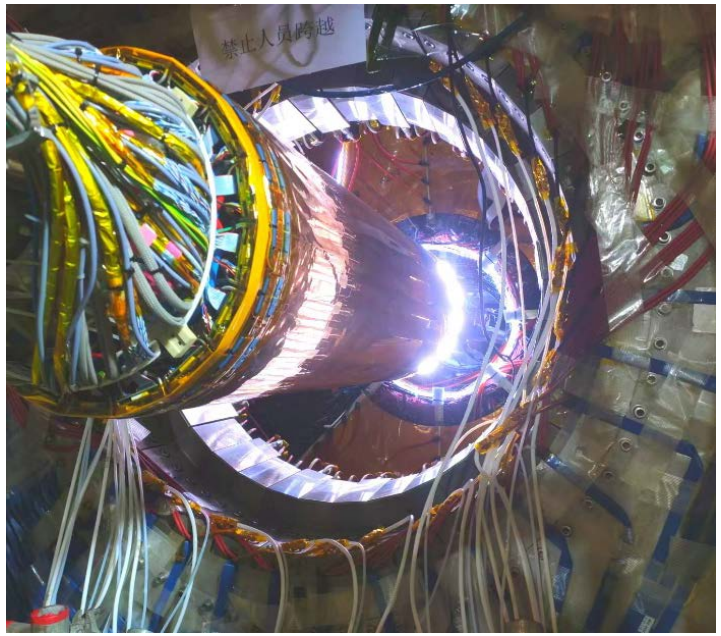


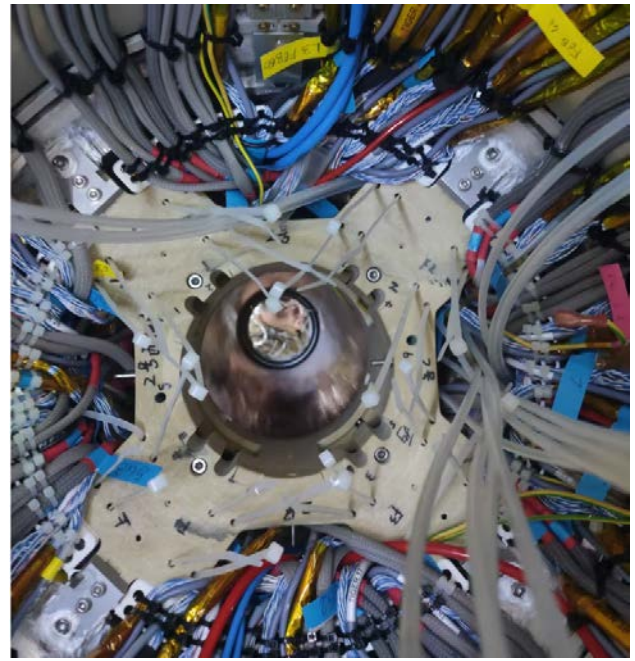


BESIII漂移室内室升级

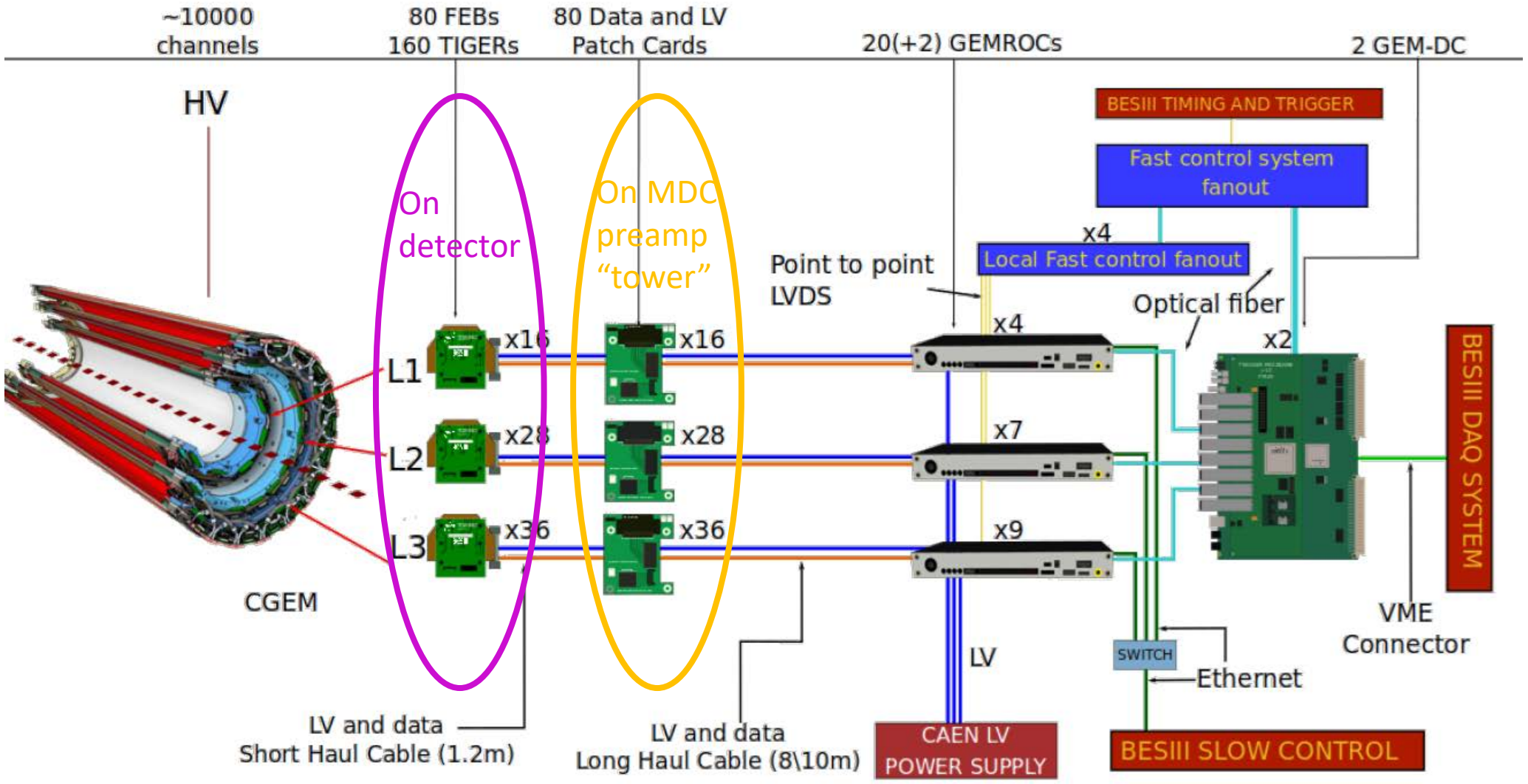
- CGEM的安装
  - 通道数：484—>约10000
  - 电缆数：增加3倍，且电缆直径大
  - 安装空间紧张
  - 顺利对接及联合测试
  - 经过测试，CGEM可以在正常高压下工作。标志着BESIII内径迹室升级的成功







CGEM readout



Summary

- BESIII 各子探测器性能均达到或超过设计指标。
- 已经连续运行16年，其稳定的运行状态及高精度的性能为τ-粲物理多个前沿课题获取了大批高质量的数据，大部分是目前世界上最大的数据样本。
- 北京谱仪III运行以来，已陆续发表了近600篇重要的物理成果，如$Z_c(3900)$，X(2370)等，为我国在高能物理研究领域达到世界先进水平做出重要贡献。
- 端盖TOF和MDC内室升级已经完成。
- BEPCII/BESIII 未来将取得更多重要物理成果，继续保持陶粲能区的物理研究处于国际领先地位。

Thanks for your attention