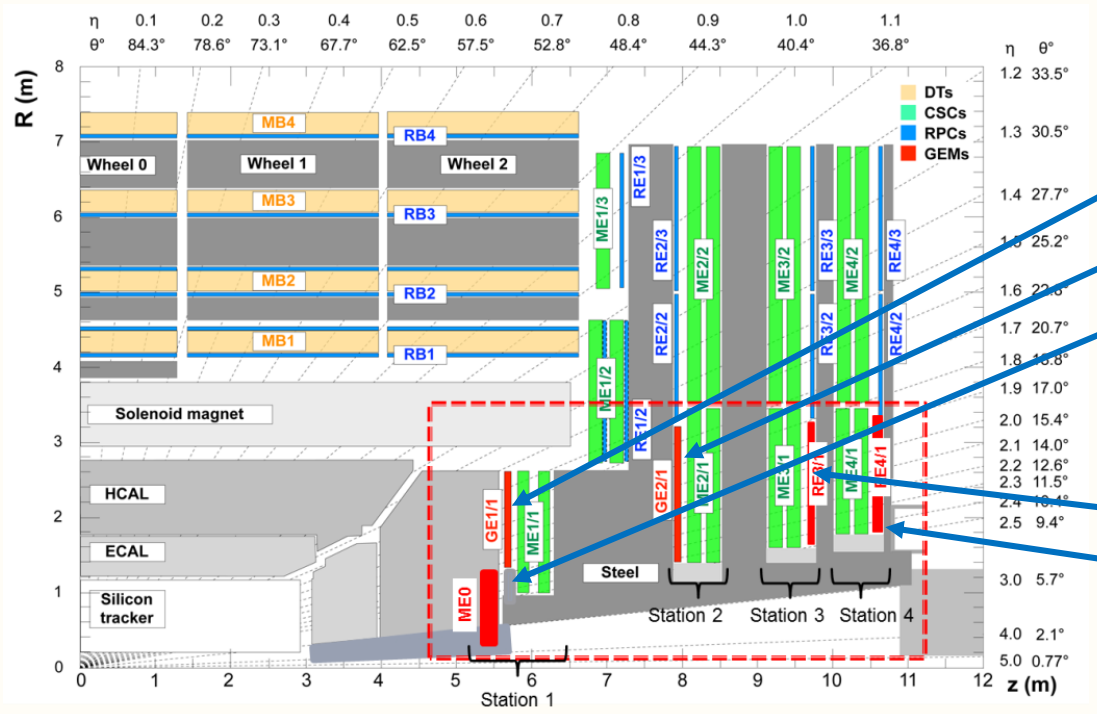
# 课题三：CMS 端盖谬子探测器升级项目进展

班勇，北京大学，2020/08/11

2020年LHC 探测器升级研讨会




端盖GEM μ探测器升级：

GE1/1

GE2/1

ME0

端盖iRPC μ探测器升级：

RE3/1

RE4/1

# 内容：

**CMS-GEM升级项目进展（北大）**

- GEM前端电子学板研制与生产
- 在CERN的GE1/1升级项目
- GEM组装测试基地建设

**CMS-MRPC研发进展（清华）**

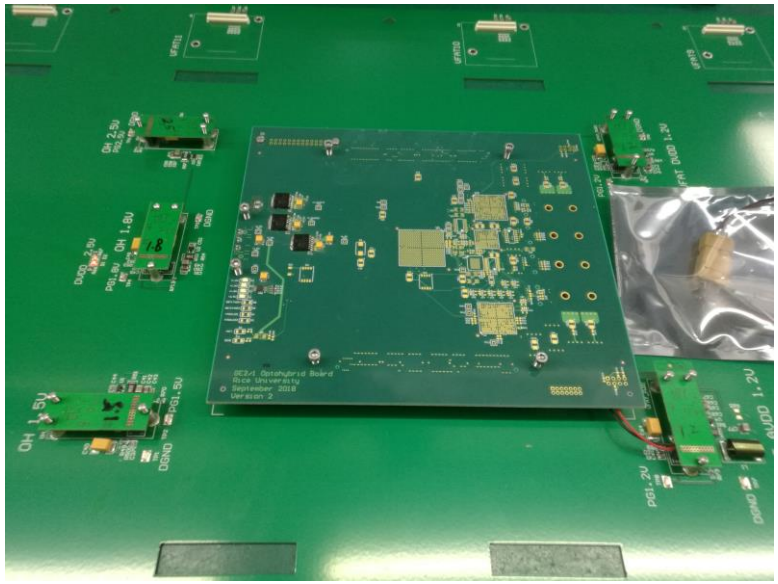
- 超高时间分辨MRPC的研发高和新型环保工作气体研究
- 密封型MRPC研制；

**LHCb-MRPC项目进展（清华）**

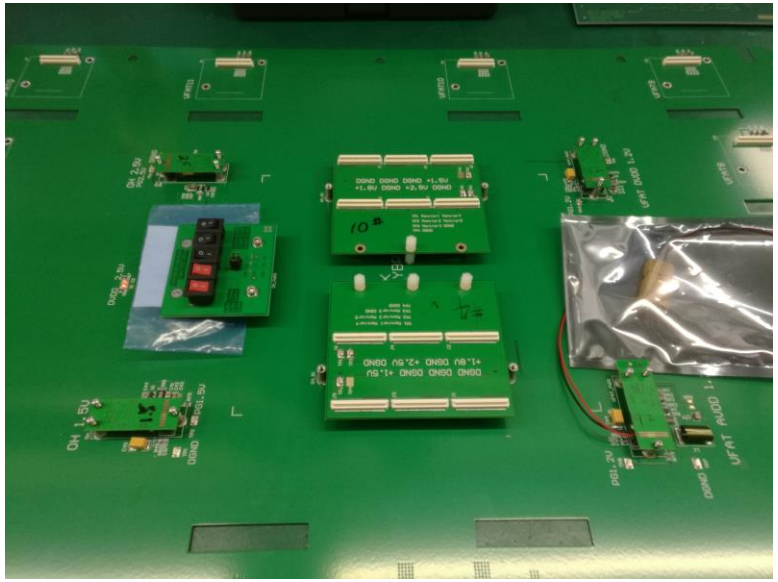
# CMS-GEM升级进展：GEB研发与批量生产

**GEM前端电子学板研制与生产（薛志华、王珂、梁子寒、李哲等）：**

- GE1/1 GEB 生产于2019年10月全部完成并运往CERN，组装到GEM探测器上；
- GE2/1 GEB 研制：2019年8月，第一版GE2/1 GEB M1-M4模块完成设计，在深圳鑫诺捷公司完成样机生产及测试，运至CERN、FIT和Rice大学组装测试成功。至2019年12月，第一版GE2/1 GEB M5-M8 模块完成设计和样机生产，顺利通过北大组的质量检测控制，分别运输至CERN和莱斯大学进行了成功的测试。



GE2/1 GEB M5在进行机械兼容性测试

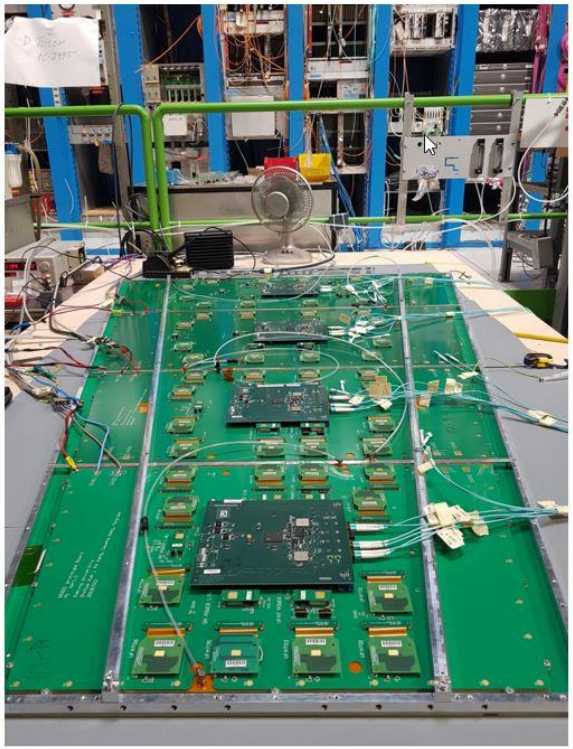


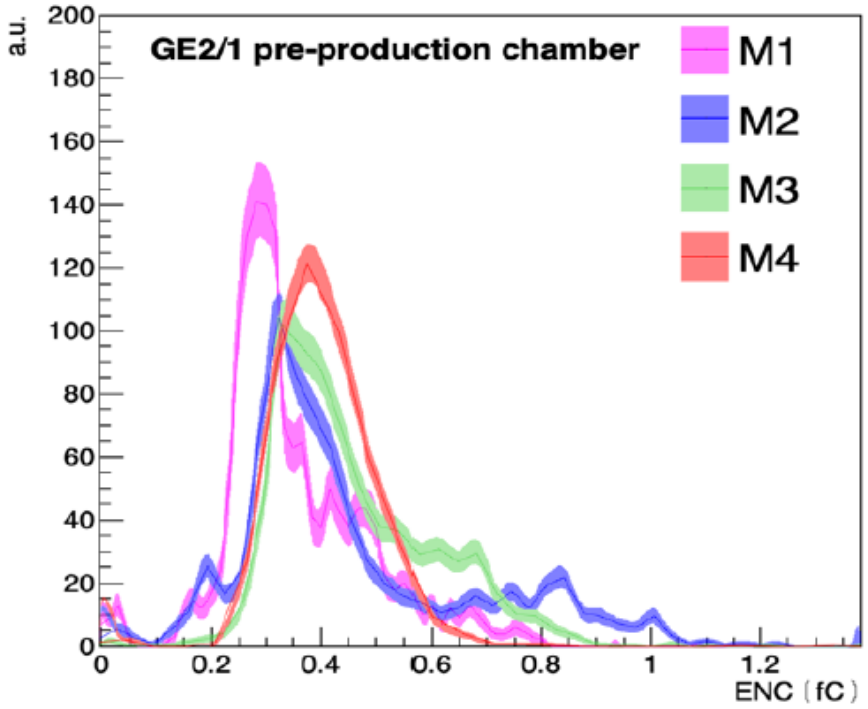
GE2/1 GEB M6在进行电气性测试

# CMS-GEM升级进展：GE2/1 GEB性能测试

- **M1-M4 GEM探测器前端电子学板Z在Rice大学的测试：**

测试平台如图。测试结果表明，我们的设计满足了CMS-GEM探测器信号传输的的要求。对信号噪声的测试结果也显示在右图6中，可以看到，GEB原型M1-M4的噪声测试范围在0.3fC至0.7fC之间，噪声水平很低。

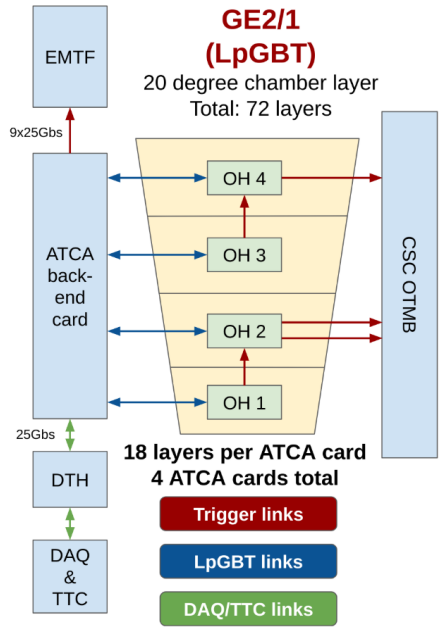




# CMS-GEM升级进展：第二版GE2/1 GEB研发

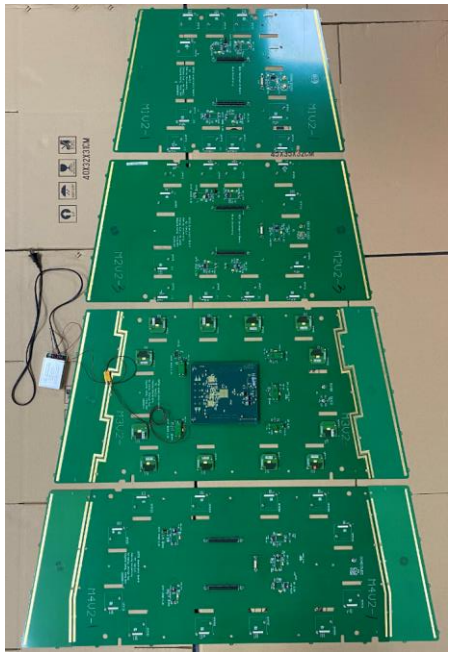
- 2019年12月开始第二版GE2/1 GEB M1-M4（批量生产版本）模块设计：增加了二进制电阻定位功能，并采用数字电源和模拟电源独立设计向12个VFAT3提供电源，进一步地完善设计目标。

- 至2020年6月，完成了第二版GE2/1 GEB M1、M2、M3、M4设计，通过了最后Review，并在深圳鑫诺捷公司进行样机生产。7月底生产完成并通过测试，本周将发往美国及CERN进行性能测试。测试完成后GE2/1 GEB全部模块的研制阶段将结束，批量生产可以开始。



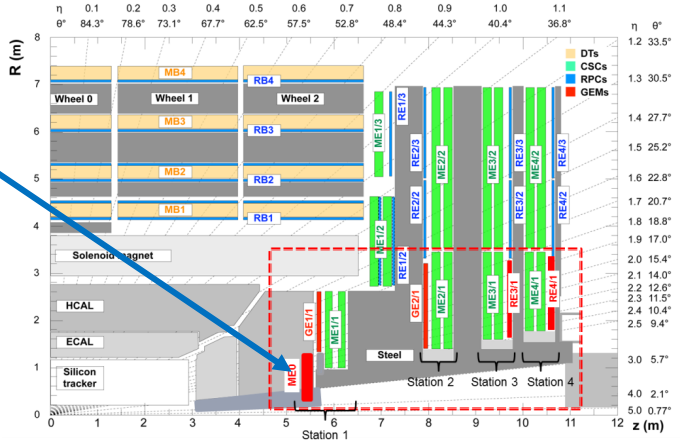

M1-M4 GEB Prototypes

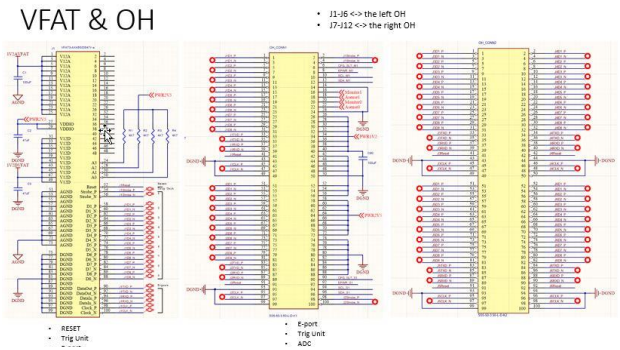
M1-M4 GEB (V2) Prototypes

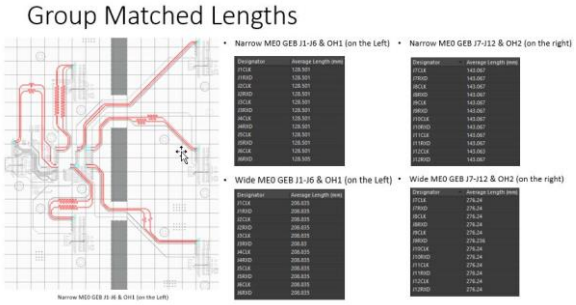


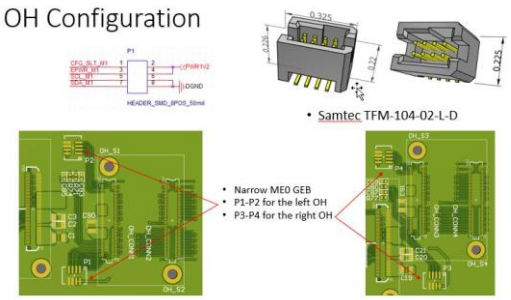
# CMS-GEM升级：ME0探测器GEB设计进展

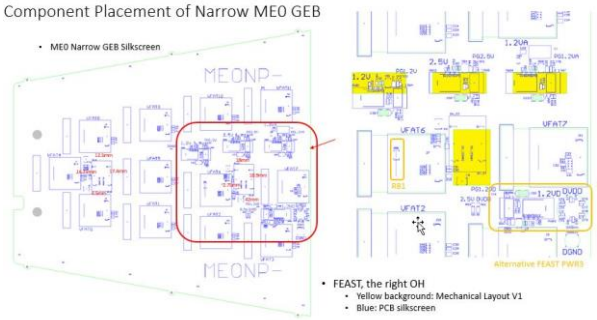
- ME0安装计划较晚（与HGCAL同时），前端电子学板GEB于2019年10月开始由北大组独立负责开始设计；
- 经过多轮讨论，第一版设计已经完成并通过了最后Review；
- 与CMS-GEM组各项检查完成后将开始生产**第一版样机。**

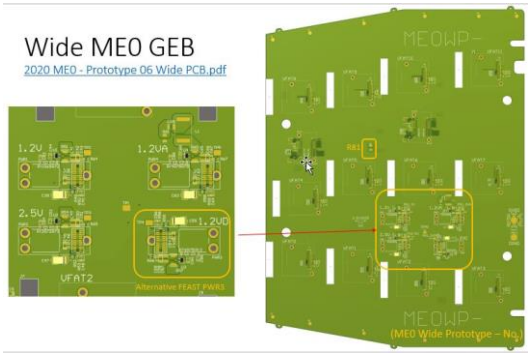


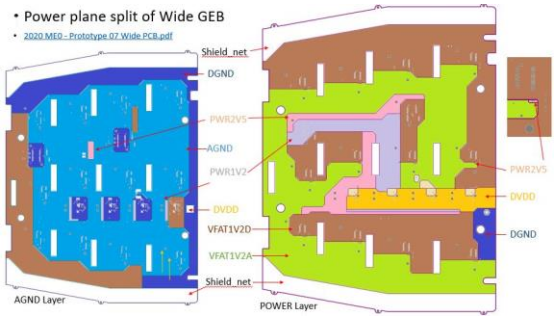



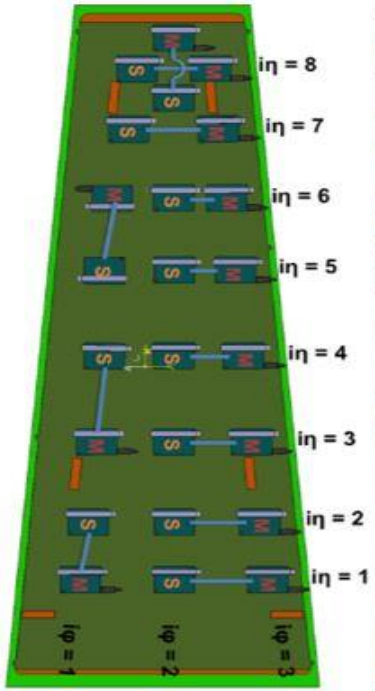



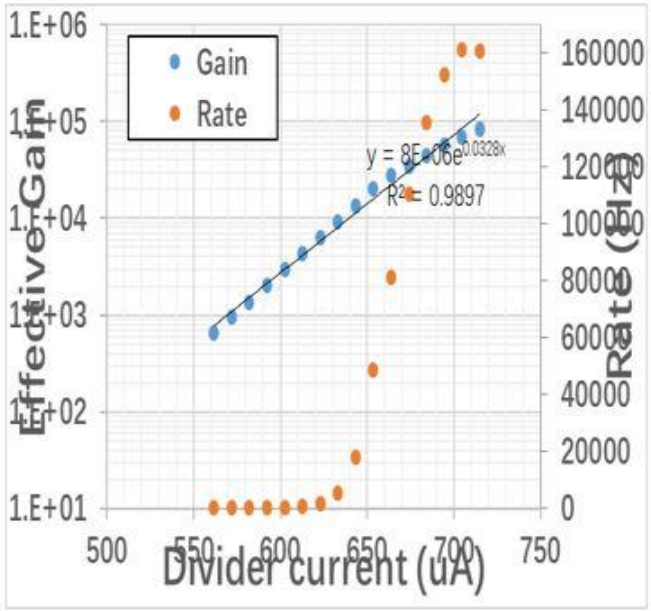



# CMS-GEM升级进展： CERN X射线测试(QC5)

## QC5测试情况：有效增益（王大勇、卢梦、陈诚等）：

探测器数据读出部分分为24个区域。对每个工作电流点，记录200个读出板信号电流值，最后取平均。有效增益定义为：（有源信号电流-无源信号电流）/（电子电荷×初级放大×（有源计数率-无源计数率）。

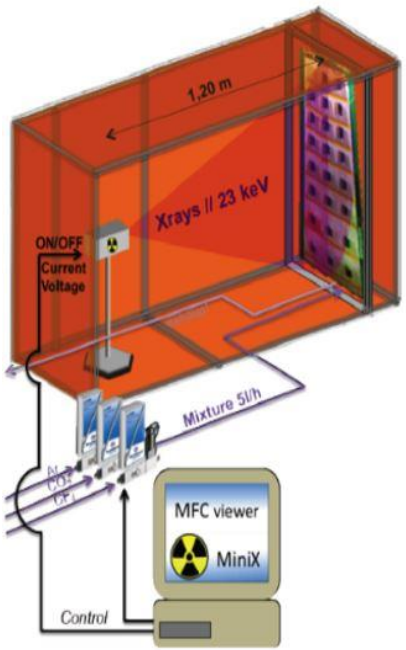


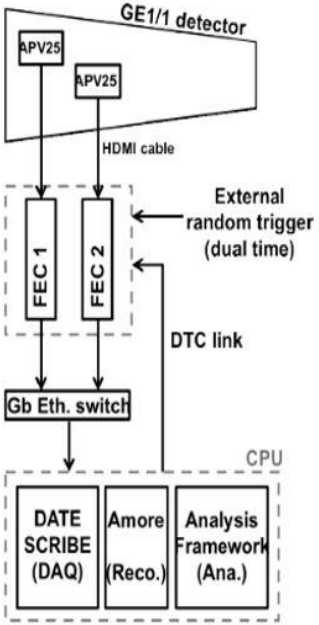



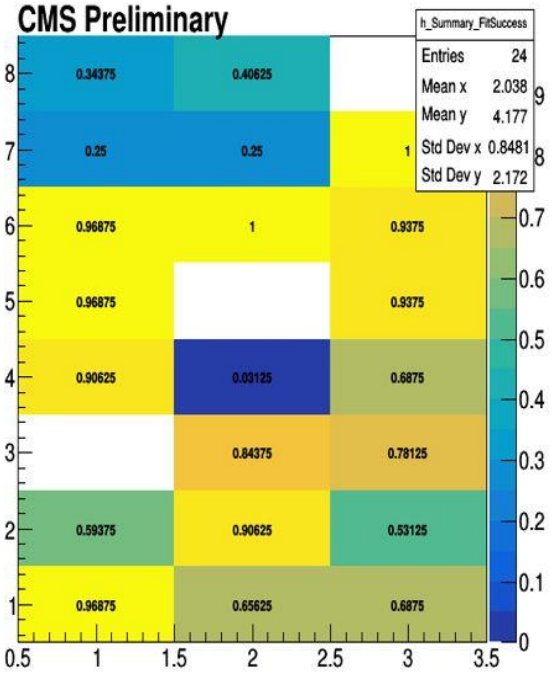
# CMS-GEM升级进展： CERN X射线测试(QC5)

## QC5测试情况：响应均匀性（王大勇、卢梦、陈诚、吕旭东等）：

对所有24个读出区域的信号都进行测量。从APV25芯片出来的信号通过HDMI线传输到前端电子学板，数据获取是由Alice实验设计的软件DATE来控制。整套SRS寄存器的配置通过由FIT的S. Colafranceschi设计的网页接口SCRIBE来实现。最终的数据分析是利用CMS GEM的分析框架来完成。



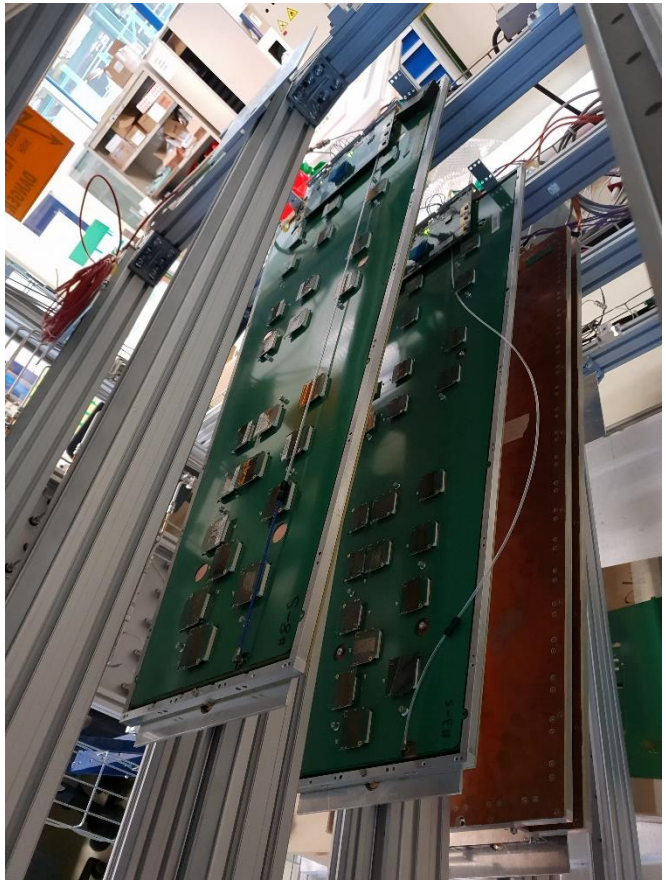



# CMS-GEM升级进展： CERN宇宙线测试(QC8)

## 性能扫描和分析工具研发（Andrew Levin）

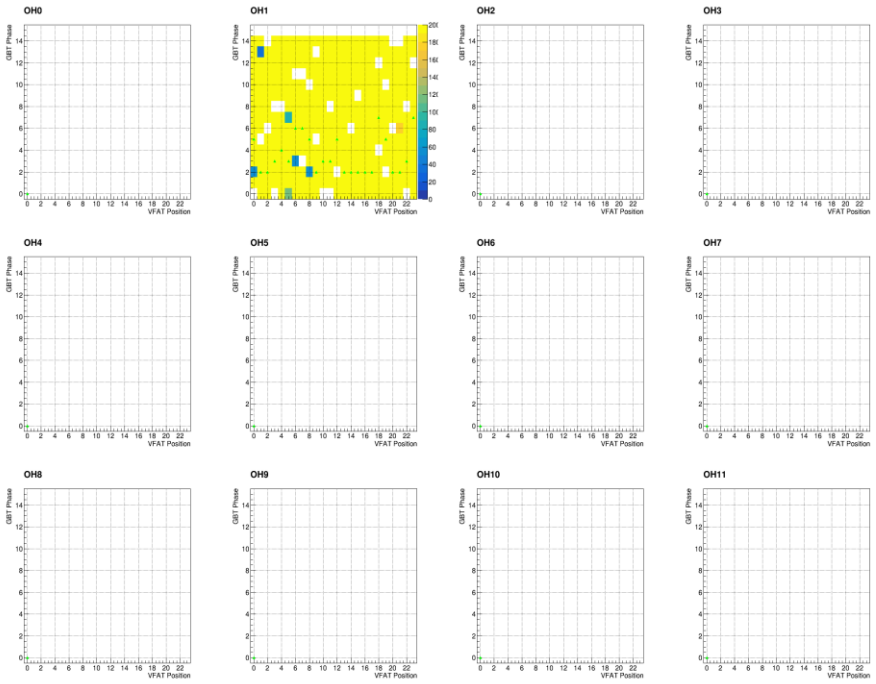
- Supporting the QC8 team using the data taking and analysis scripts
  - GBT phase scans
  - DAC scans
  - Scurve scans
  - S-bit rate scans
  - Iterative trimming
- Added several improvements to the iterative trimming, such as parallel processing, scurve quality criteria, and the possibility to align the mean + an offset instead of just the mean
- Currently, we are working on the migration to a new framework for Run 3



  - Take calibration scan data from within XDAQ instead of a separate python framework
  - Perform analysis of calibration scans using scipy python package instead of ROOT
  - Use a more exact solution to the trimming problem instead of the iterative trimming algorithm

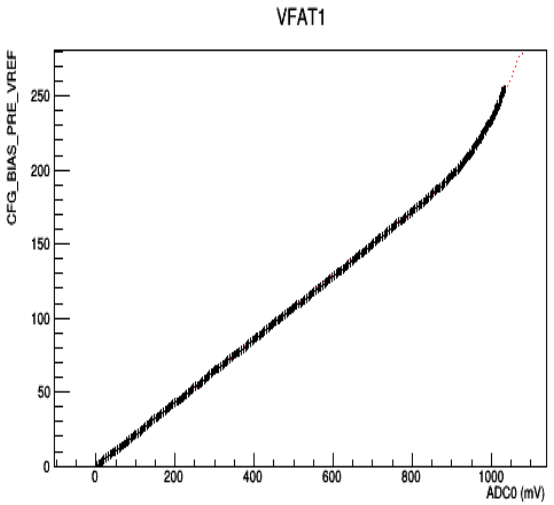
# CMS-GEM升级进展： CERN宇宙线测试(QC8)

## GBT phase scans




- x-axis: VFAT
- y-axis: GBT phase
- z-axis: number of successes (SYNC_ERR_CNT, CFG_RUN, HW_ID_VER, and HW_ID can be read)

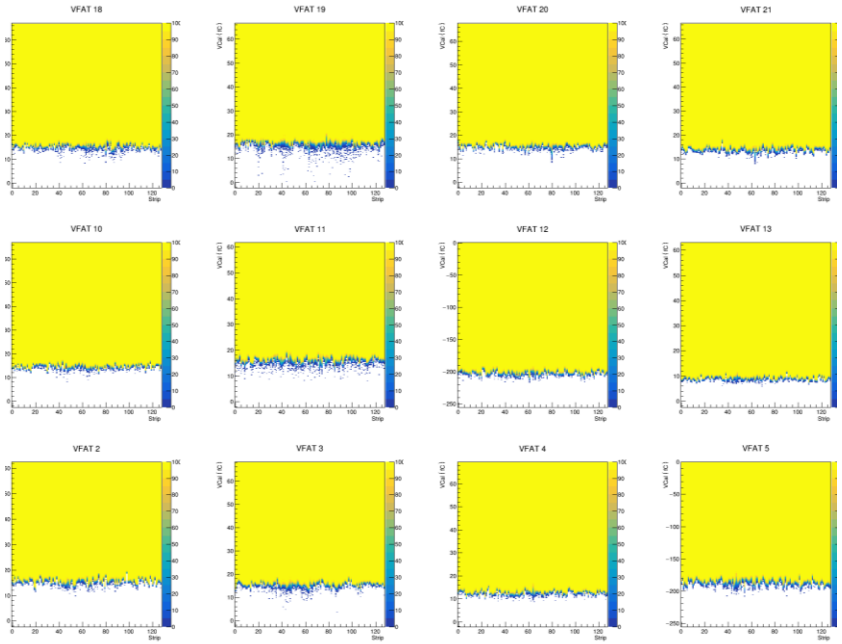
## DAC scan




- Due to radiation, the appropriate DAC settings may change
- Record the ADC value for each possible value of the DAC register
- ADC is converted to a voltage or a current using calibration information provided by the VFAT3 designers
- DAC vs ADC plot can be fit with a $5^{th}$ degree polynomial
- From this plot, we can determine the DAC register setting that corresponds to the nominal value of the ADC, which is also provided by the VFAT3 designers

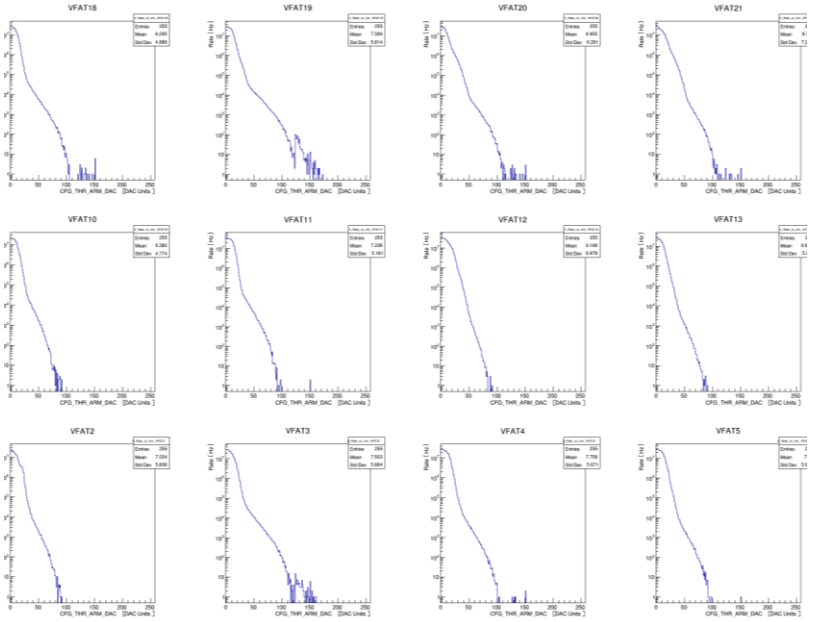
# CMS-GEM升级进展： CERN宇宙线测试(QC8)

## S-curve scan or trimming scans




- Send a calibration pulse to an individual channel and record whether a hit is register
- Vary the calibration pulse strength
- Provides a useful overview of the performance of the readout electronics
- Can be used to determine which channels are dead or which channels are hot and therefore should be masked
- Can also be used to characterize the noise
- x-axis: strip number; y-axis: injected charge; z-axis: number of hits out of 100

## S-bite rate scan

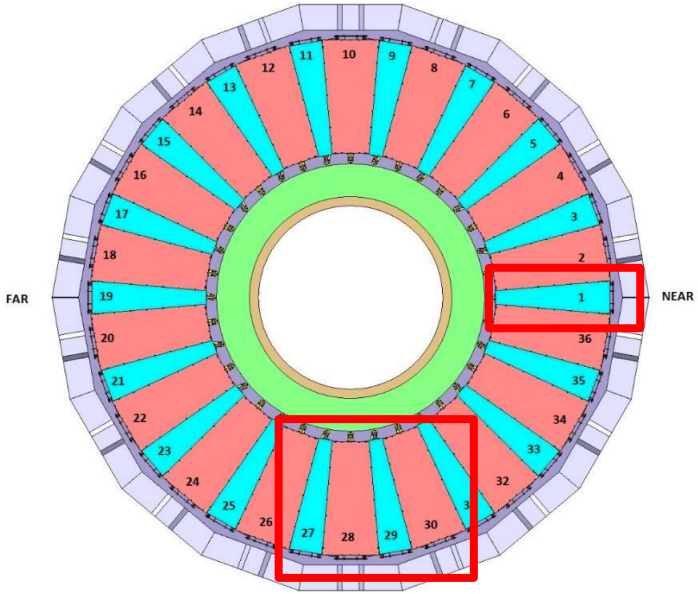



- S-bit is a clustered data format for the trigger
- 14 bits: 11 bits for the cluster address and 3 bits for the cluster size
- Neighboring strips, up to 16, grouped together
- Plot shows rate as a function of global threshold register

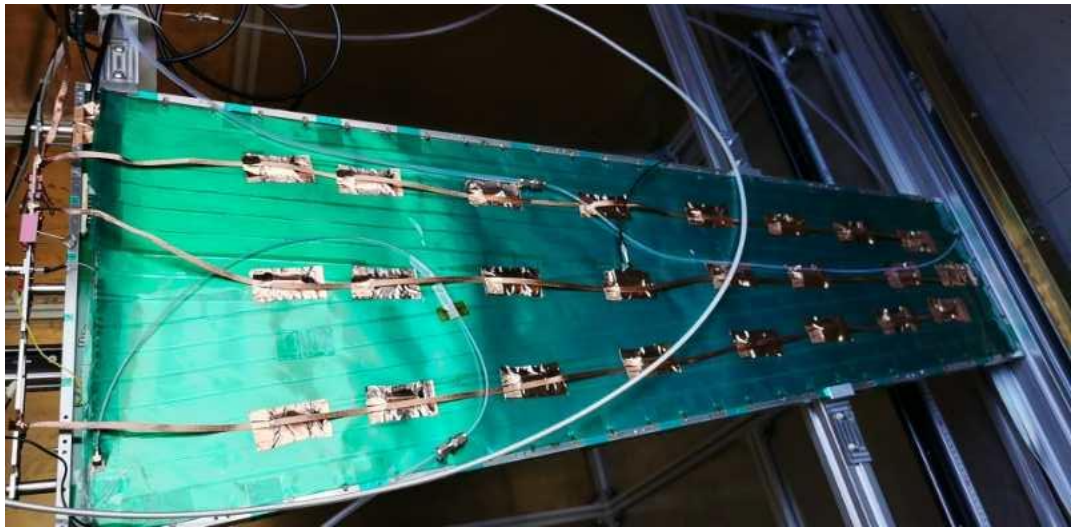
# CMS-GEM升级进展：组装测试准备

**北大GEM探测器组装测试实验室建设（马宏骥、Aera Jung、蒋楚翘等）：**

- 组装完成的小尺寸GEM测试（Q3-Q5)基本完成；
- 一个全尺寸GE1/1探测器（参加了CMS对撞束测试后）2020年1月被卸下来，运到北大，进行质量控制流程测试。




5个GE1/1探测器安装到CMS上（位置1,27,28,29,39,30）进行对撞束测试



完成对撞束测试后，卸下运到北大的其中一个GE1/1

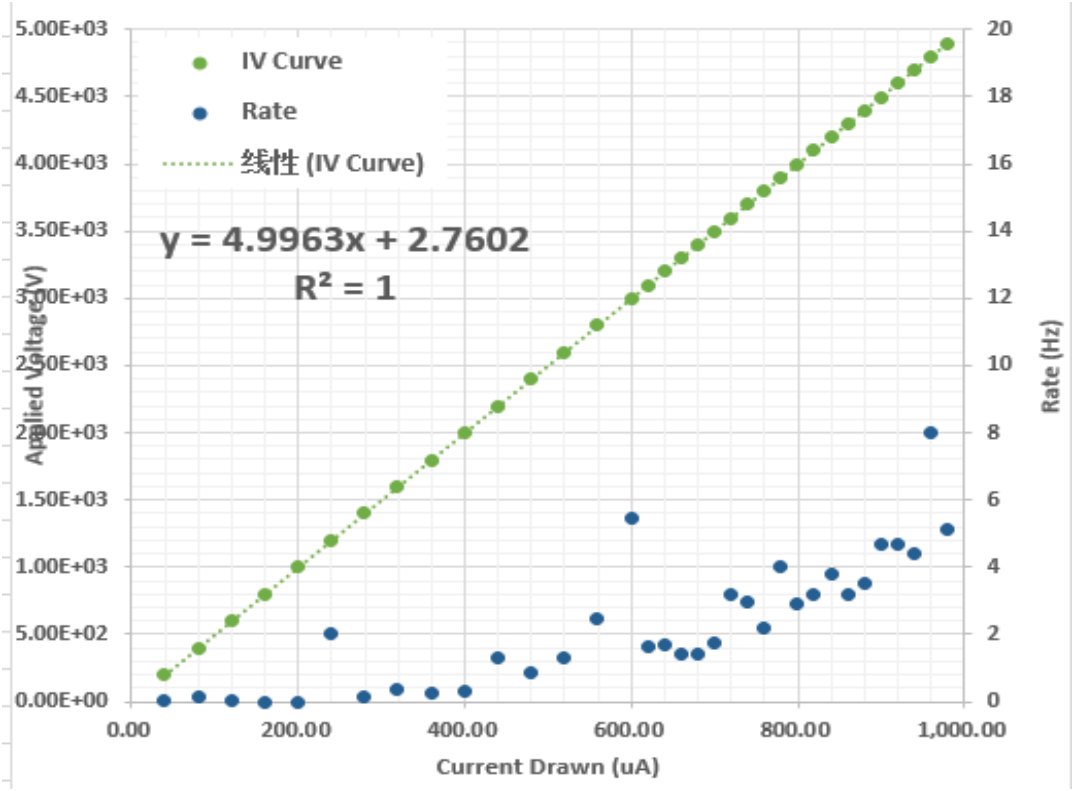
# CMS-GEM升级进展：全尺寸GE1/1探测器测试

- 目前对全尺寸GEM　GE1/1探测器测试正在进行；

QC4测试情况（探测器高压测试-电流电压曲线）：

- Ortec 142PC
- Ortec 474
  - Coarse Gain: 4
  - Fine Gain: 4
  - Diff. Time: 500ns
  - Int. Time: 500ns
- Caen N844
  - Threshold: 140mV
- Ortec 974
  - Acquisition Time: 60s

(Note: same as QC-instruction)

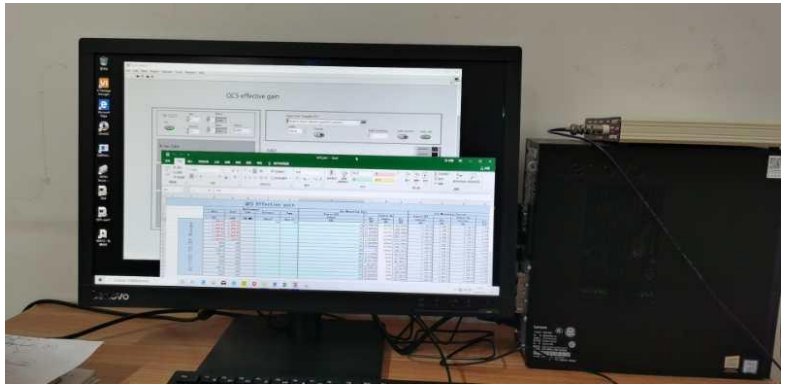


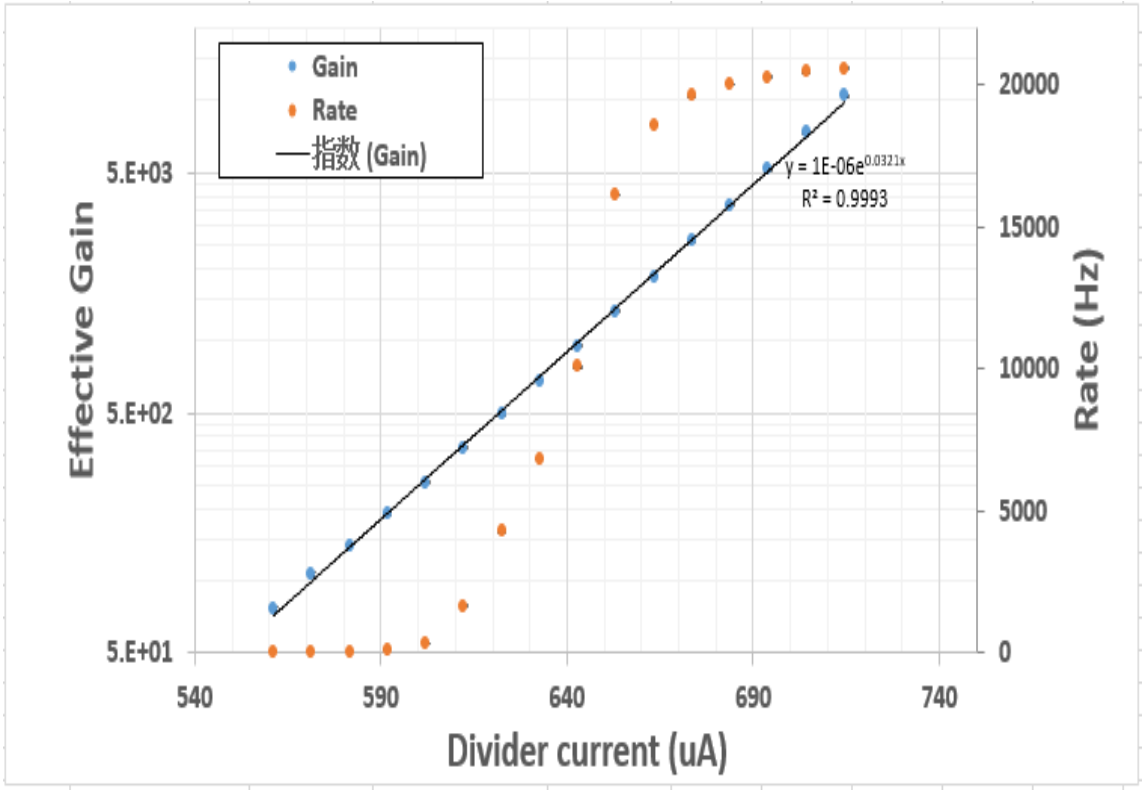
# CMS-GEM升级进展：全尺寸GE1/1探测器测试

QC5测试情况（用X射线进行探测器增益和均匀性测试）北大：

- Ortec 142PC
- Ortec 474
  - Coarse Gain: 4
  - Fine Gain: 4
  - Diff. Time: 500ns
  - Int. Time: 500ns
- Caen N844
  - Threshold: 255mV
- Ortec 974
  - Acquisition Time: 60s
- Keithley 6482
- Ag X-ray
  - HV: 40kV
  - Current: 50uA

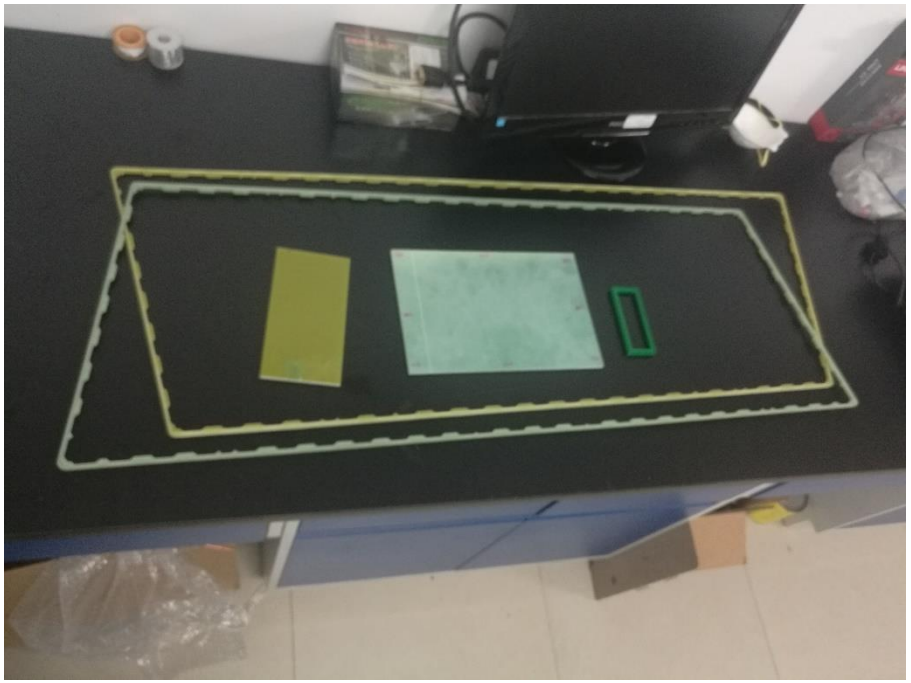
- Note: noise is high!





# CMS-GEM升级进展：结构部件研发与采购

- GEM探测器内框架在国内研制：第一批两个FR34框架2019年9月运到CERN进行了测试；第二批四个框架（M1-M4）2019年12月运到CERN进行了测试；各项指标满足要求。2020年6月召开了最后Review会议，确定在中国的生产细节。
- 其它探测器组装配件在中国的生产、采购基本完成，将分批运往CERN。




# CMS-GEM升级进展：FR4内框架研发与生产

## GE2/1 GEM探测器内框架在中国生产内部Review会议 （2020年6月2日）

### R&D and prototyping of GEM external frame in China

**Apr. 2019**: factories contacted for the frame production: Machining Workshop of PKU, Axicomb etc... . downsized frame prototype were produced, to study:

- FR4 material characteristics,
- thickness tolerance control,
- coating technique ...,

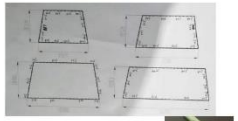
concluded that thickness tolerance control is very challenging, conventional machining is not enough, need special technique or tooling.

**Jul.-Aug. 2019**: full size GE2/1 frame prototypes (without coating) were produced in both factories, tested at PKU, and were brought to CERN.

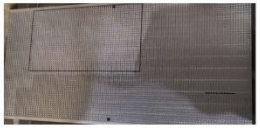
- Thickness tolerance control was promising, although improvement needed,
- Axicomb's product was preferred.

### R&D and prototyping of GEM external frame in China

**Dec.-Jan. 2020**: a set of full size GE2/1 M1-M4 frame prototypes (with coating) were produced in Axicomb, tested at PKU, and brought to CERN for test.



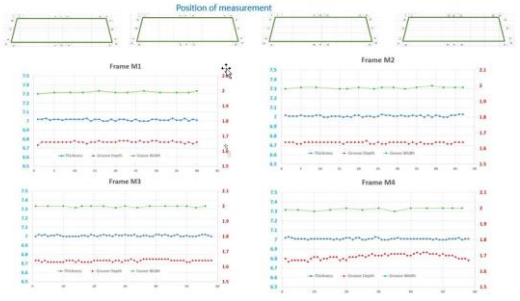
Axicomb improved machining technique, developed a tolling of vacuum sucking device to fix the FR4 panel during the milling process.



tolling for frame milling

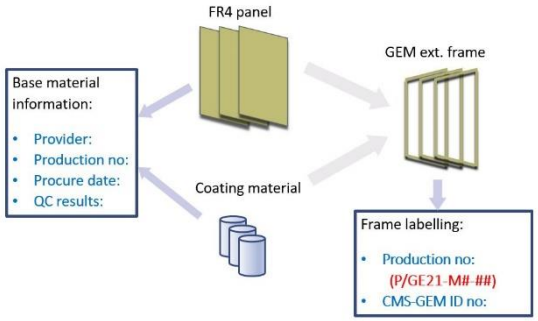
### R&D and prototyping of GEM external frame in China

CERN test results:




**Conclusion:** thickness tolerance control and coating satisfactory.

### Labelling:




### 工艺流程

**Production Process for GE2/1 Ext. Frame**

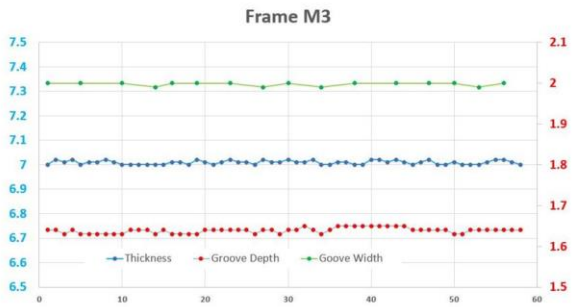
此VMC1680设备加工GE21 M3 / M4 / M7 / M8 共4款框架。加工外形尺寸，厚度及背面尺寸。

This VMC1680 machine processes GE21_ M3 / M4 / M7 / M8 frames。Processing overall dimension, thickness and slot dimension.

● 铣加工 Milling

### GEM Frame QC Check list (draft)

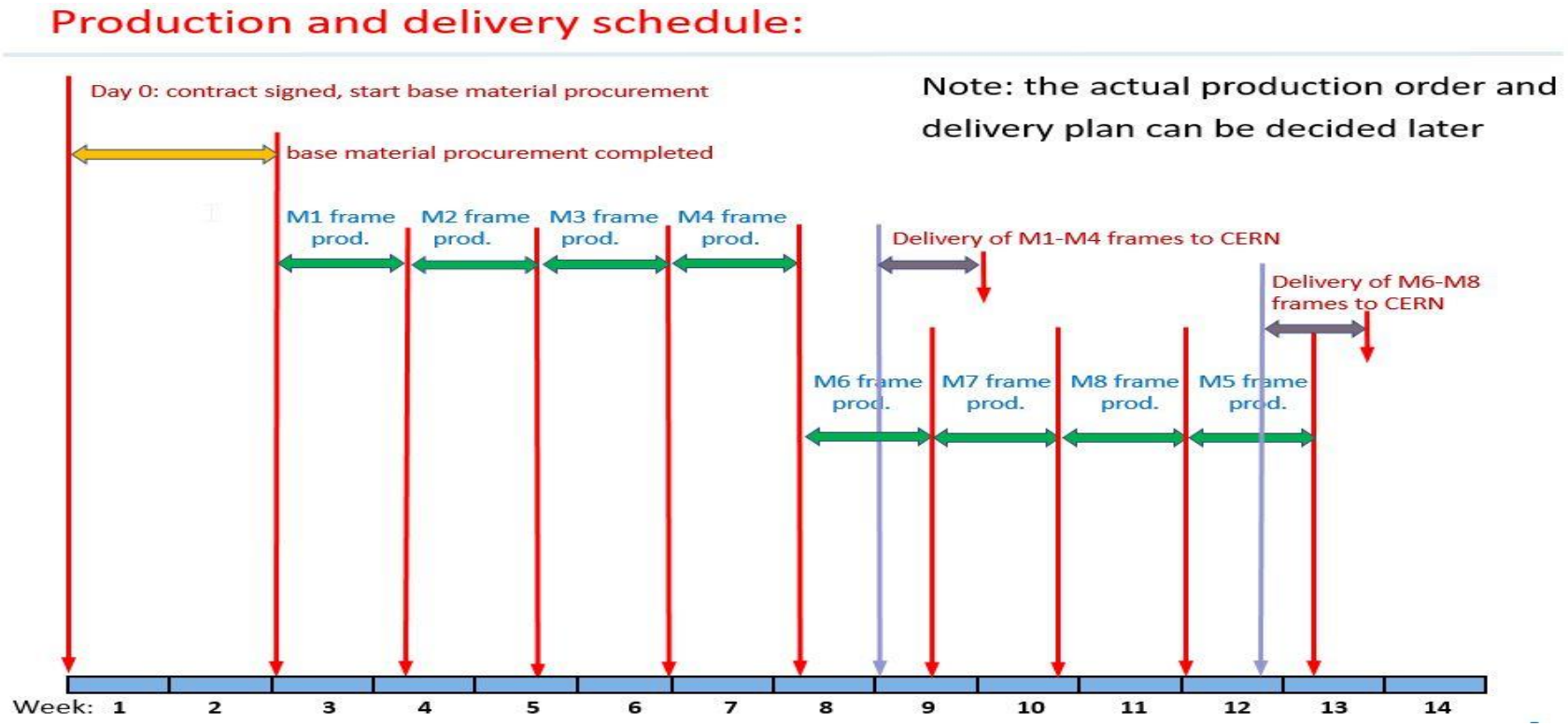
Plot of QC result for each frame (e.g.: from Jeremie's test at CERN)



# CMS-GEM升级进展：FR4内框架研发与生产

## GE2/1 GEM探测器内框架在中国生产内部Review会议结论：

- 中国生产的全尺寸内框架样品结果两轮测试，Axicom公司生产的样品各项指标符合CMS-GEM要求；
- 对第一站GEM框架的改进：外表面将进行聚氨酯漆喷涂处理；
- 近期需建立具体质控、database等流程指标。



# CMS-GEM升级进展：GEM探测器模拟研究

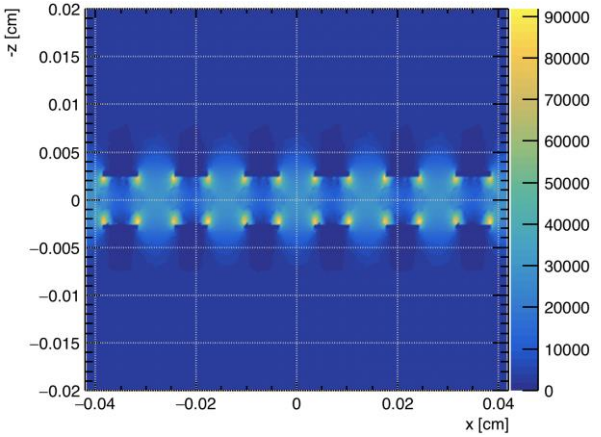
## 四层GEM探测器模拟研究（Aera Jung，章立诚，王玥等）

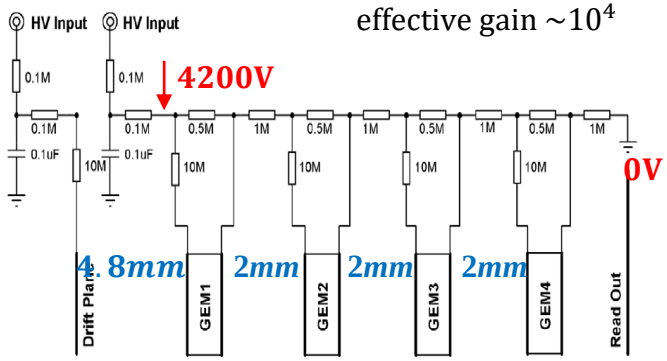
**Plan**

Simulation of Quadruple-GEM detector (compare with Triple-GEM detector)

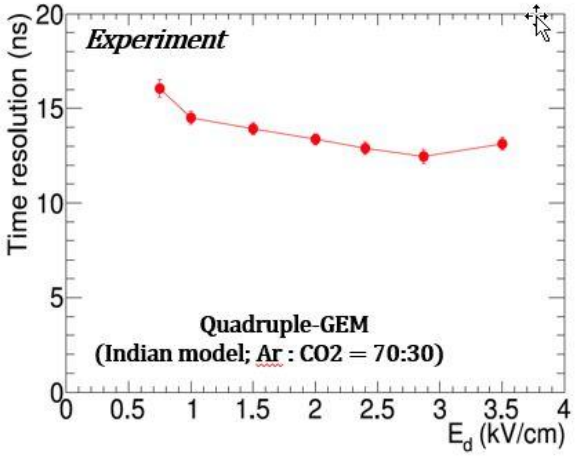
| | | | | |
|---|---|---|---|---|
| Effective Gain | On 3(4)-GEM | Misalignment | Comparison | Conclusion |
| | Signal strength spectrum | | Energy Resolution | Transparency |
| Time Resolution | On 3(4)-GEM | Misalignment | Comparison | Conclusion |
| | Different Condition | | Change GEM Distance | |
| Spatial Resolution | On 3(4)-GEM | Misalignment | Comparison | Conclusion |
| | Different Condition | | Change GEM Distance | |
| Others | On 3(4)-GEM | Misalignment | Readout Capacity | Conclusion |
| | | IBF | Charging up | ..... |

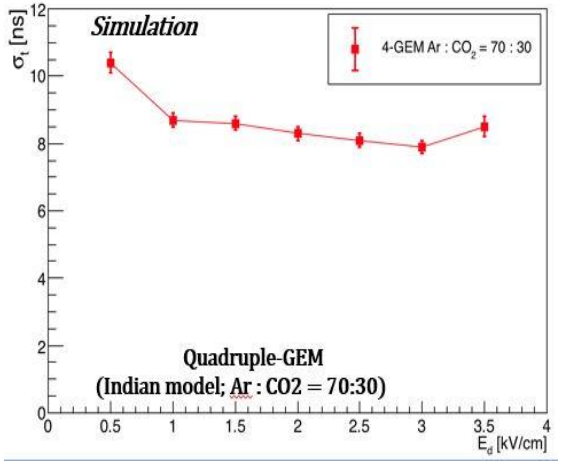
Simulation of GEM foils




effective gain ~$10^4$

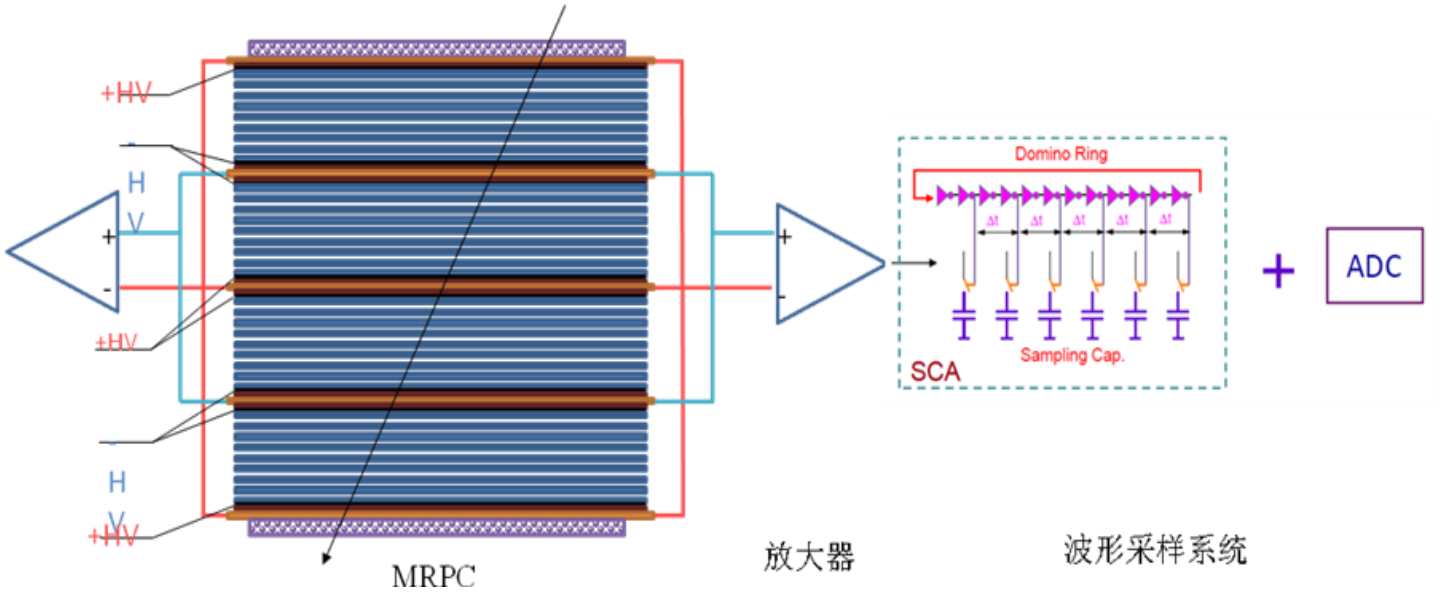


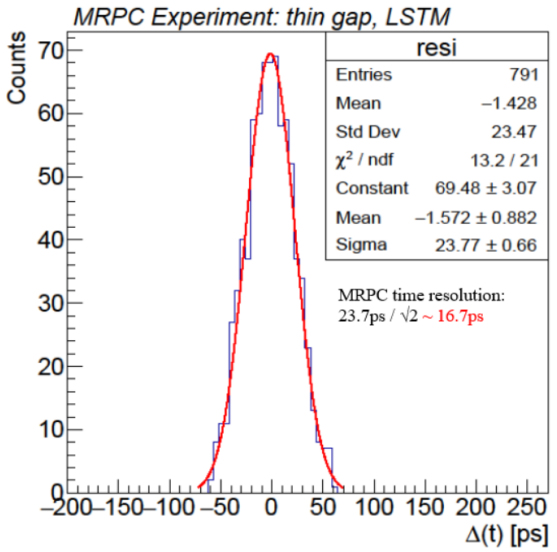
# CMS-MRPC研发进展

- 针对高亮度物理实验（如Jlab-SoLID)高计数率，超高时间分辨的需求，研制出时间分辨优于20ps 的MRPC
- 将深度学习方法应用于MRPC时间重建，提高了MRPC的时间分辨率，最好时间分辨达到16ps
- 研究寻找适合于高计数率MRPC的新型环保气体
- 密封型MRPC研制

# CMS-MRPC研发进展：超高时间分辨MRPC

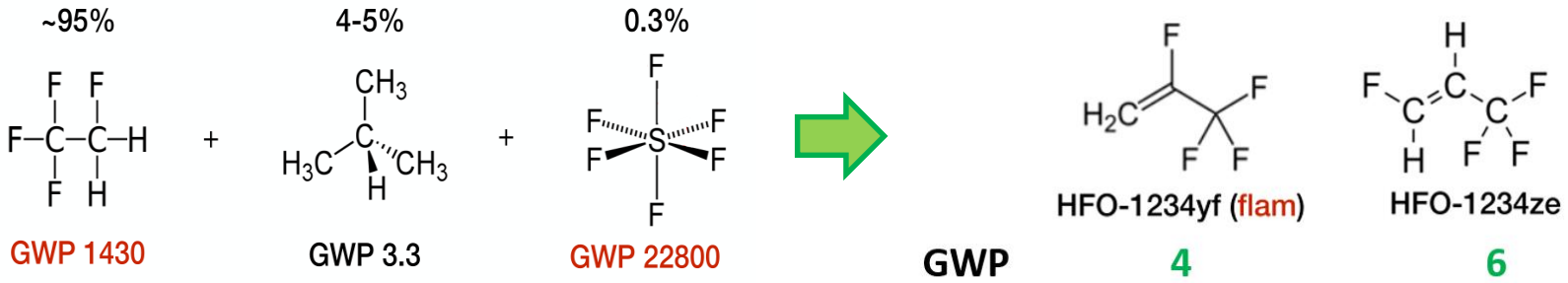



- MRPC结构：气隙宽度105微米，4个Stack共32个气隙，
  玻璃厚度：0.5mm，差分读出
- 读出电子学采用高速前放+SCA高速波形采样
- 时间分析方法：神经网络
- 宇宙线测试得到时间分辨达16ps

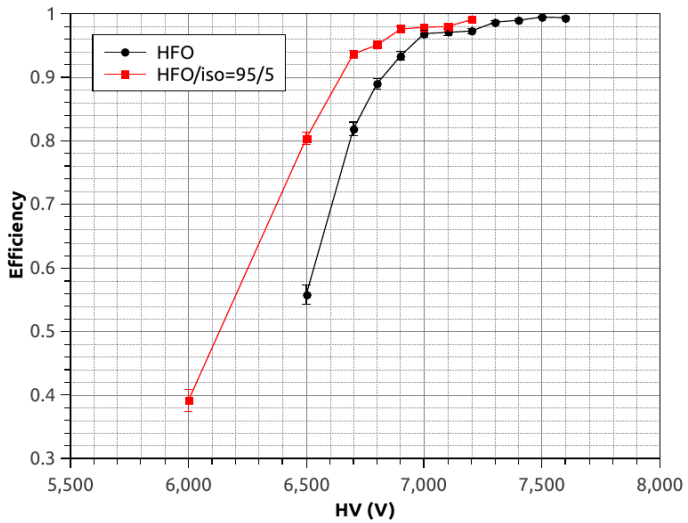


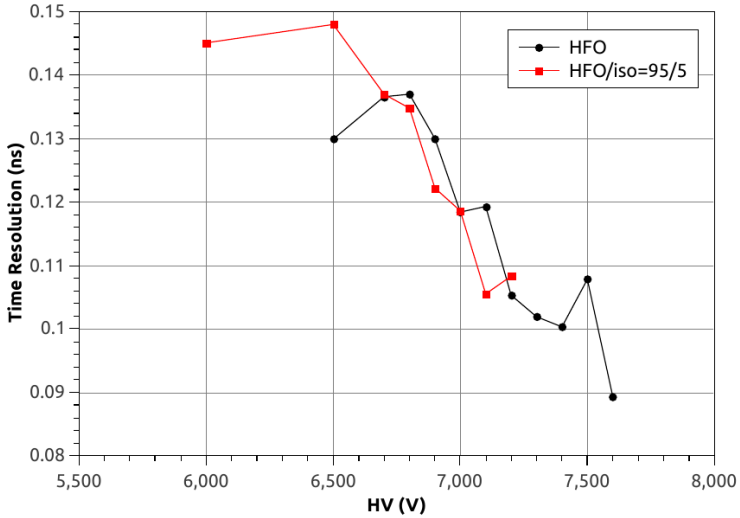
# CMS-MRPC研发进展：环保工作气体研究

在国际上对含氟气体管制的背景下，寻找低GWP值工作气体势在必行：




现有工作气体的GWP　　环保工作气体的GWP



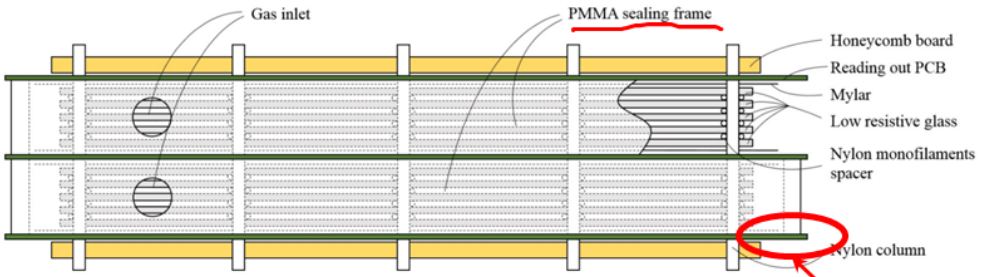

高计数率MRPC在两种环保气体下的效率坪

# CMS-MRPC研发进展：密封型MRPC研制

除了研究采用环保气体外，研究更加节能环保运行的MRPC也很重要。密封型MRPC可以达到节能环保的目标。

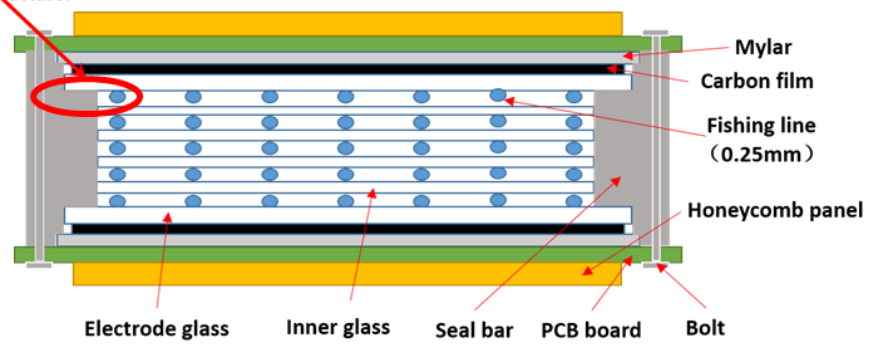
## New thought for sealing

Using outermost glass plates and sealing frame



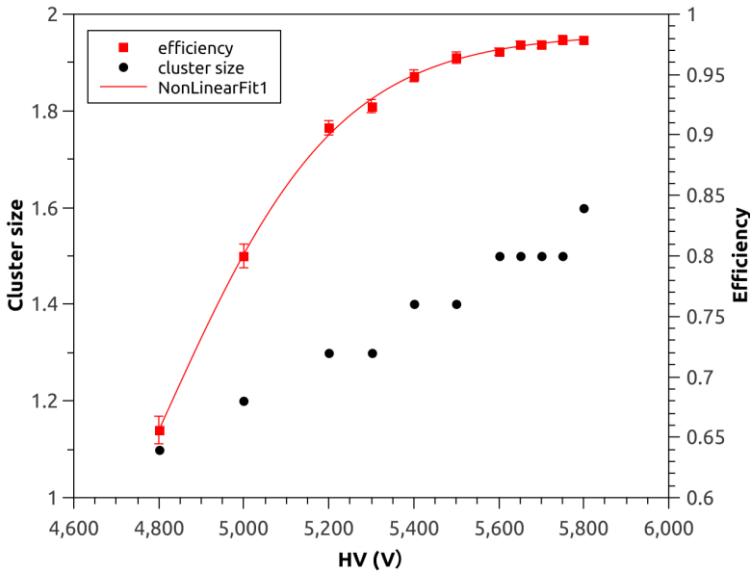

Lyu, P., et al. "Development and performance of **self-sealed MRPC**." *JINST.* 12.03 (2017).

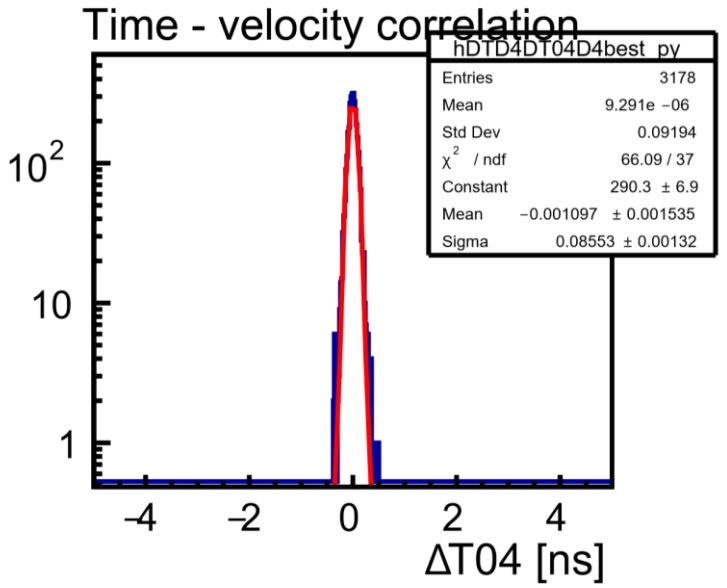
**Figure 3**. The sectional sketch of the double-stack MRPC prototype with the self-sealed structure.



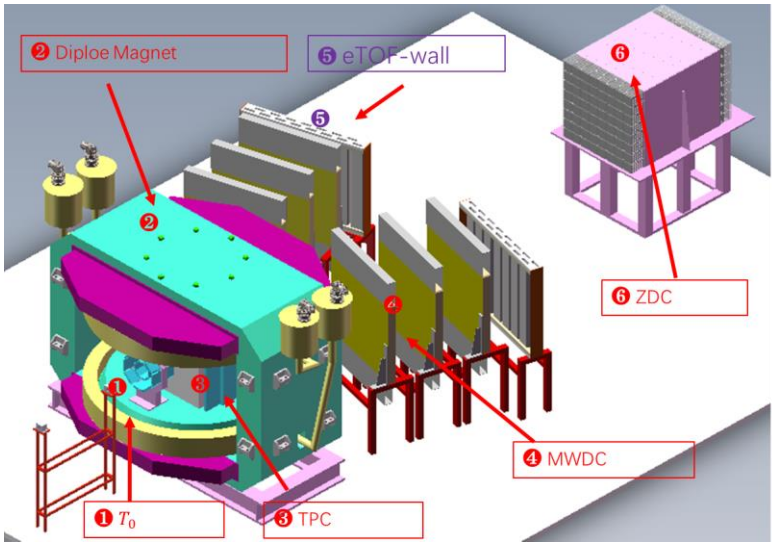

Different thoughts:
**PCB or glass plate as sealing panel.**

# CMS-MRPC研发进展：密封型MRPC性能



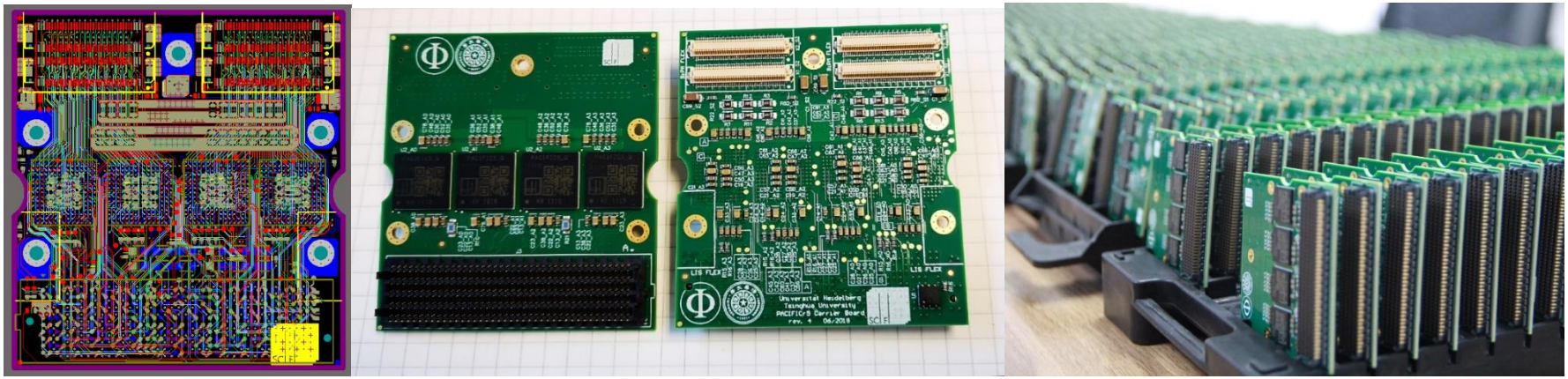




- 气体流量：< 1SCCM
- 效率：>95%
- 时间分辨：~60ps
- 用于建造兰州外靶实验CEE的端部 飞行时间谱仪



# LHCb-Sci-Fi升级进展

**2018-2019：Redesign of PACIFIC Frontend Board & Mass Production**



**2018.09 - First 250 PACIFIC Frontend Boards finished !**
**(for first C-Frame of SciFi)**

**2019.09 – Finished all 2,528 PACIFIC Frontend Boards !**
**(647,168 channels)**

# LHCb-Sci-Fi升级进展

## 2019： QA System for PACIFIC chips & PACIFIC Frontend Board

test automatically update result to DB

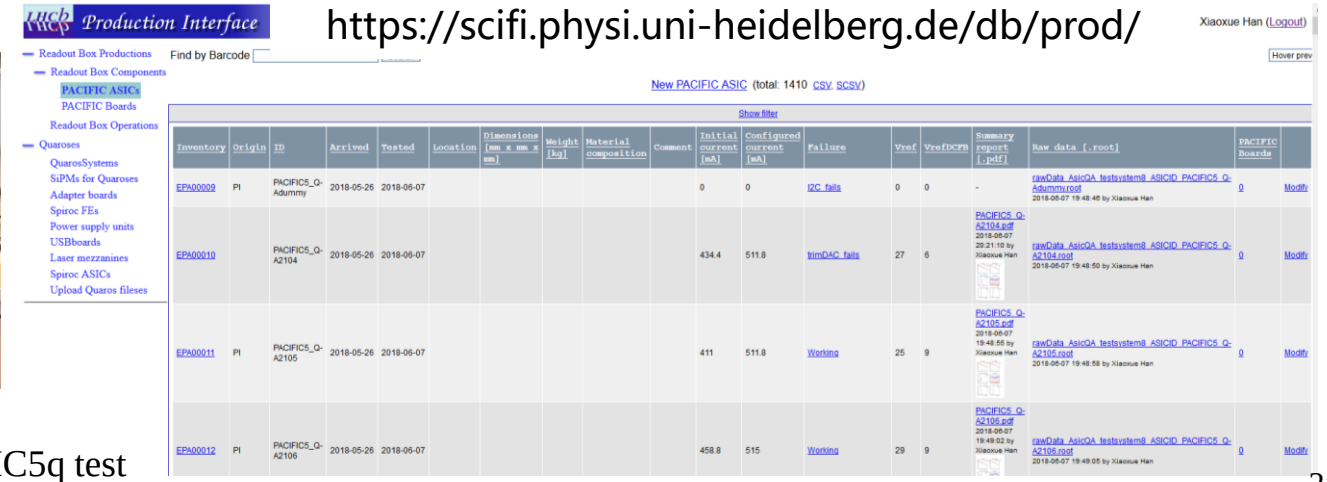
final check the QA test routine

QA test running : 10 ASICs/run ， ~100ASICs/hour

**全部测试结果存入Sci-Fi Production数据库**

https://scifi.physi.uni-heidelberg.de/db/prod/

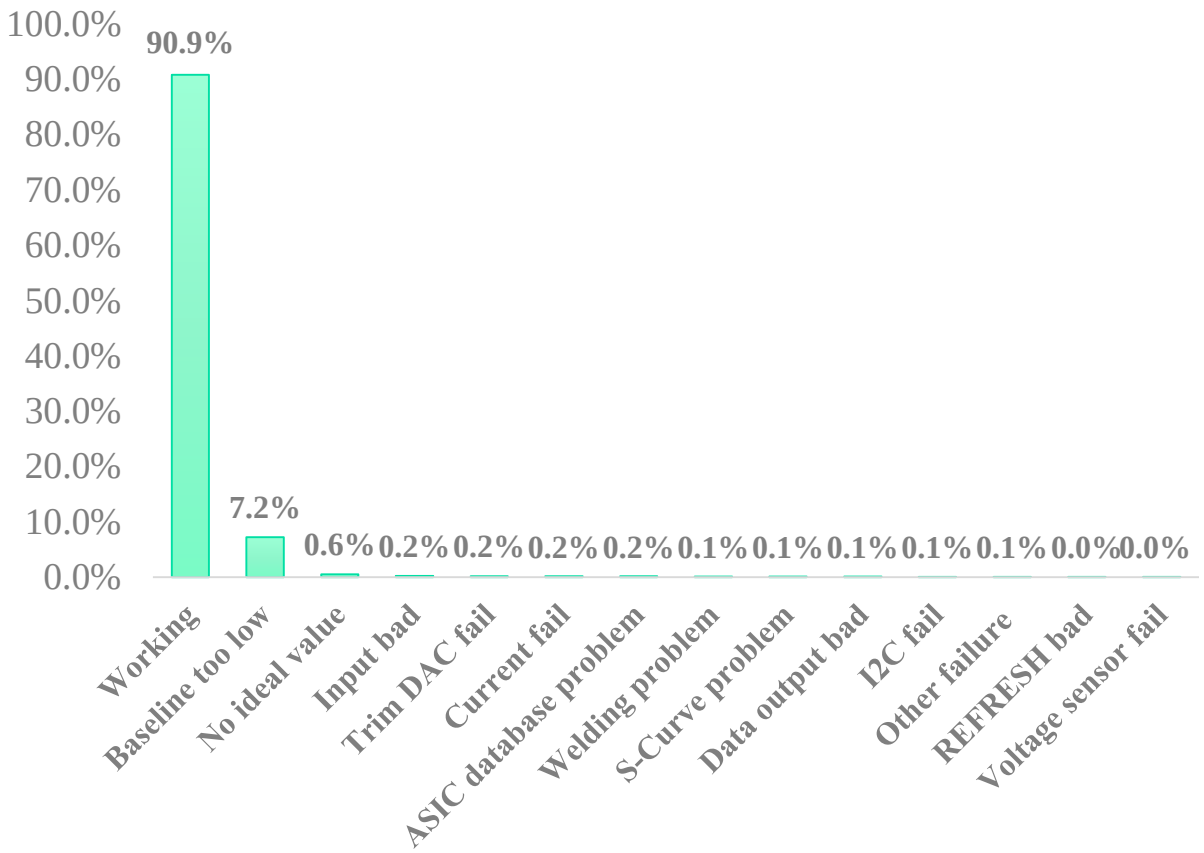
finish all 1st batch 1420 PACIFIC5q test



# LHCb-Sci-Fi升级进展

## 2019.09： Final test result for all in Tsinghua and Valencia

- 2528 boards:
  - Working: 2297
  - Baseline too low: 183
  - No ideal value: 14
  - Input bad: 6
  - Trim DAC fail: 5
  - Current fail: 4
  - ASIC database problem: 4
  - Welding problem: 3
  - S-Curve problem: 3
  - Data output bad:3
  - I2C fail: 2
  - Other failure: 2
  - REFRESH bad: 1
  - Voltage sensor fail: 1



# LHCb-Sci-Fi升级进展

2019年9月，清华大学完成全部2528套（647,168通道）SciFi前端电子学板，并交付CERN。

Production:

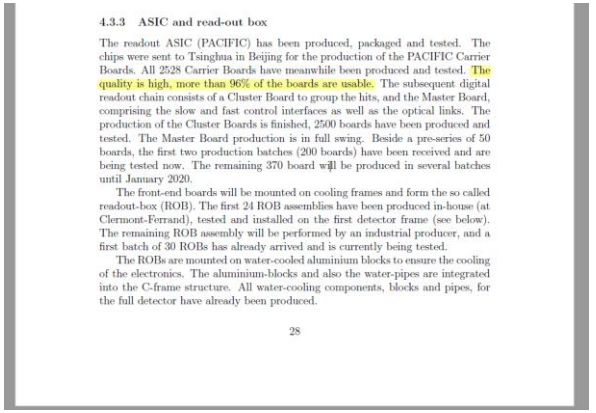
| | |
|---|---|
| PACIFIC Chip | 100% produced and tested |
| PACIFIC Board | 100% produced and tested |
| Cluster Board | 100% prodcued and tested |
| Master Board | Preseries 50 MBs: ok<br>Main production (570 boards):<br>Batch 1: 96 MBs in July<br>Batch 2: 104 MBs in Aug<br>Batch 3: 100 MBs in Sep<br>Next batches: 08 Nov, 06 Jan |
| Mechanical Parts | 100% produced |
| Front-end boxes | Preseries (23) ready → frame1<br>Batch 1: 30 boards at CERN |

Congratulations to
- Tsinghua, Valencia, HD
- Clermont-Ferrand

FEB finishing determined by MB schedule: Significant

2019年10月15日的SciFi Institution Board会议上，SciFi的Group Leader Prof. Ulrich Uwer专门就SciFi前端电子学板研制的全部顺利完成，向清华大学表示祝贺和感谢。

2019年10月30日，CERN-RRB-2019-108中评价清华大学完成的SciFi前端电子学板“质量很高，良率超过了96%”



4.3.3 ASIC and read-out box

The readout ASIC (PACIFIC) has been produced, packaged and tested. The chips were sent to Tsinghua in Beijing for the production of the PACIFIC Carrier Boards. All 2528 Carrier Boards have meanwhile been produced and tested. The quality is high, more than 96% of the boards are usable. The subsequent digital readout chain consists of a Cluster Board to group the hits, and the Master Board, comprising the slow and fast control interfaces as well as the optical links. The production of the Cluster Boards is finished, 2500 boards have been produced and tested. The Master Board production is in full swing. Beside a pre-series of 50 boards, the first two production batches (200 boards) have been received and are being tested now. The remaining 370 board will be produced in several batches until January 2020.

The front-end boards will be mounted on cooling frames and form the so called readout-box (ROB). The first 24 ROB assemblies have been produced in-house (at Clermont-Ferrand), tested and installed on the first detector frame (see below). The remaining ROB assembly will be performed by an industrial producer, and a first batch of 30 ROBs has already arrived and is currently being tested.

The ROBs are mounted on water-cooled aluminium blocks to ensure the cooling of the electronics. The aluminium-blocks and also the water-pipes are integrated into the C-frame structure. All water-cooling components, blocks and pipes, for the full detector have already been produced.

28

# 课题三 CMS 端盖谬子探测器升级项目进展小结

- 北京大学组前端电子学板GE2/1 GEB研制按计划顺利进行，今年下半年可以批量生产。在国内质控的升级也在进行（自动化连通性、误码率、眼图测试等等）；已经开始着手前端电子学板ME0 GEB研制，初步设计已经完成；
- CMS-GEM组装测试基地准备工作进展顺利，成功测试了全尺寸探测器。由于疫情推迟了基地审核步骤，具体时间待定。GEM探测器内框架生产计划下半年开始。
- 清华大学组继续进行高性能MRPC研发，将深度学习方法应用于时间重建，得到最好时间分辨达到16ps。成功研制了密封型MRPC。
- 清华大学完成了LHCb-SciFi 读出电子学前端板的设计及全部生产和测试（2500块板），得到了合作组的高度评价。
- 人员：本项目本年度北京大学组毕业一名博士生（部分工作）和一名硕士生。Aera Jung（韩国）进入北大组做博士后，全职从事GEM探测器组装测试工作。

谢谢！