

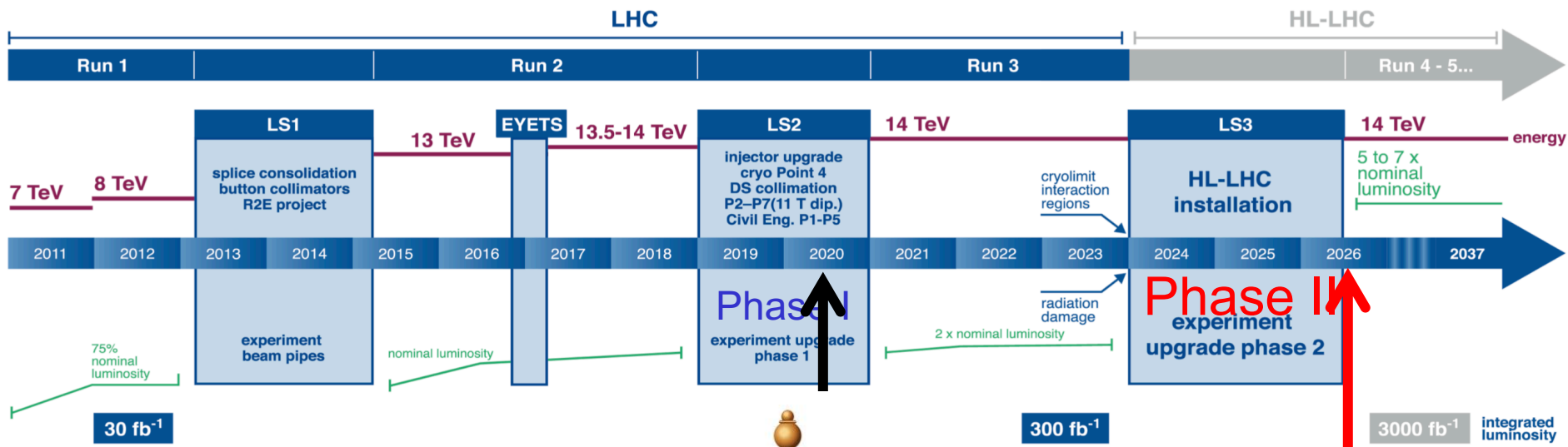


# 高粒度量能器进展



张华桥(高能所)





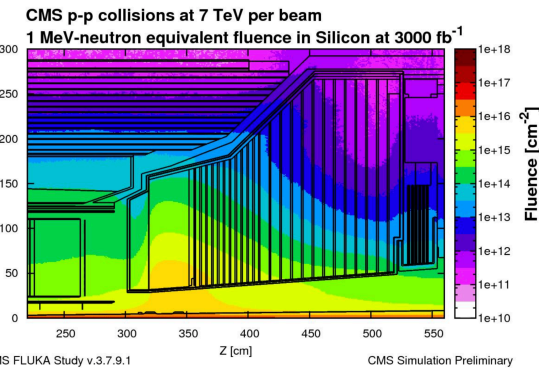
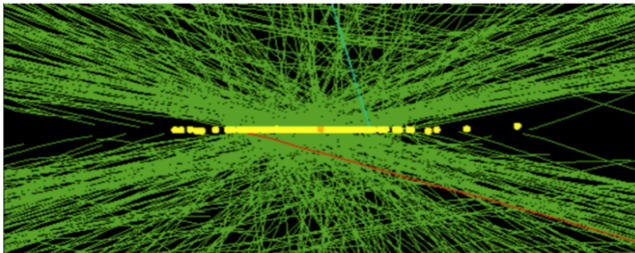
**Radiation damage:**  
 $10^{16}$  1 MeV  $n_{eq}/cm^2$



**Event rates capability:**  
 10 times int. lumi



**Pileup challenge: 200/BX**





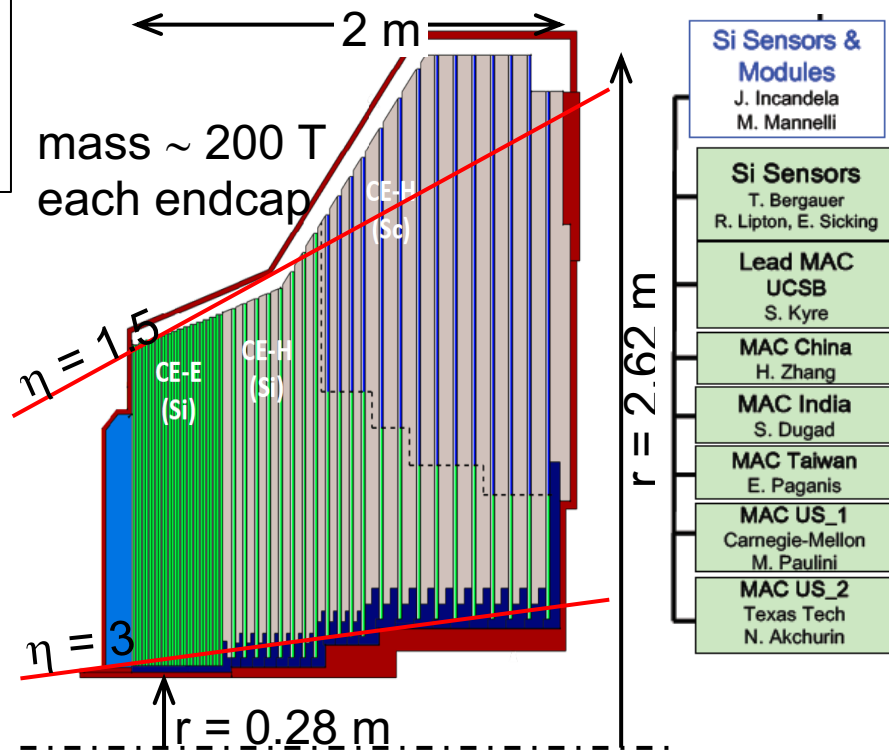
总材料造价69MCHF, 由CMS合作组中50余家单位共同设计建造  
高能所计划建立硅模块中心, 承担~5000硅模块(100平米)的集成

## Active Elements:

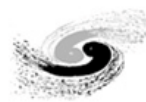
- Hexagonal modules based on Si sensors in CE-E and high-radiation regions of CE-H
- Scintillating tiles with SiPM readout in low-radiation regions of CE-H

## Key Parameters: (updated from TDR)

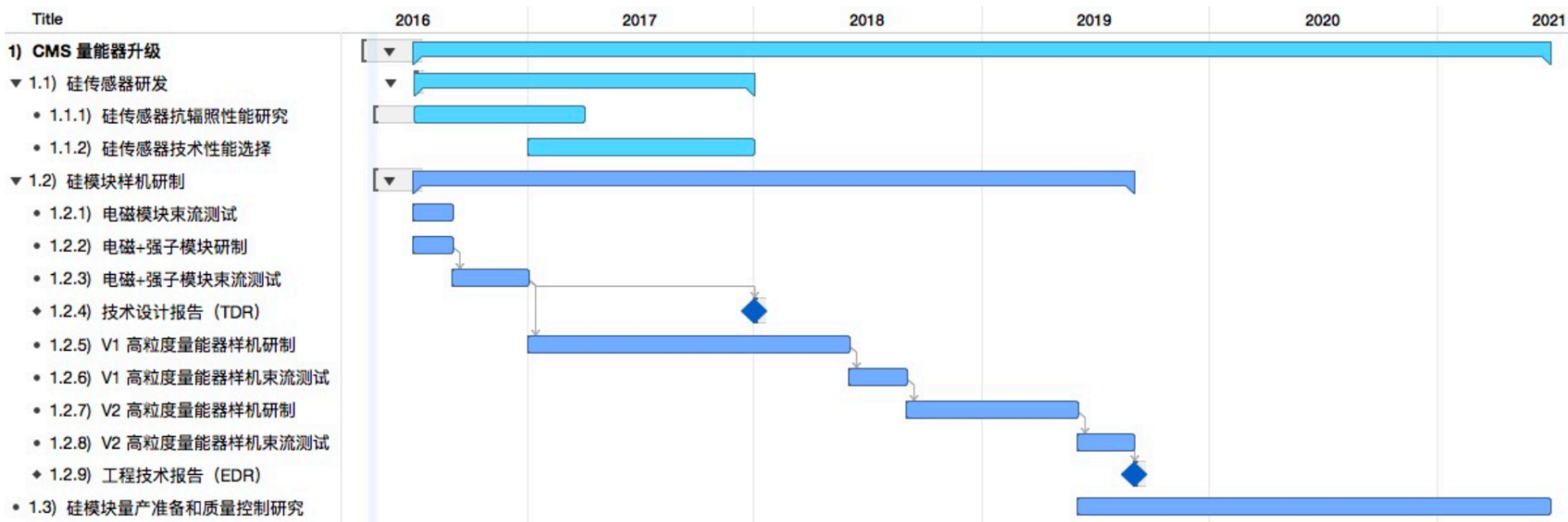
- HGCal covers  $1.5 < |\eta| < 3.0$
- Full system maintained at  $-30^{\circ}\text{C}$
- ~640m<sup>2</sup> of silicon sensors
- ~370m<sup>2</sup> of scintillators
- 6M Si channels, 0.5 or 1.1 cm<sup>2</sup> cell size
  - Data readout from all layers
  - Trigger readout from alternate layers in CE-E and all layers in CE-H
- ~31000 Si modules including spares



Electromagnetic calorimeter (CE-E): **Si**, Cu/CuW/Pb absorbers, 28 layers,  $25.5 X_0$  &  $\sim 1.7\lambda$   
 Hadronic calorimeter (CE-H): **Si** & **scintillator**, steel absorbers, 22 layers,  $\sim 9.5\lambda$

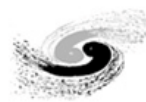


目标：部分掌握高粒度量能器设计、建造。  
跟进和填补空白，打破禁运。



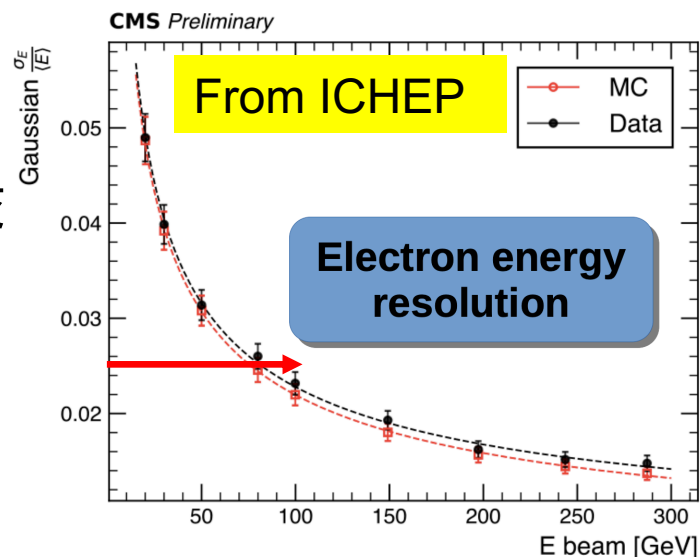
2019-2020: 高粒度量能器原型机的能量分辨率初步测试结果 ( $25\%/\sqrt{E}$ )  $\odot$  1%  
高粒度量能器组装流程图





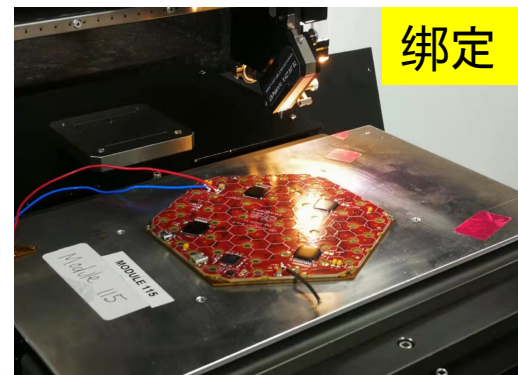
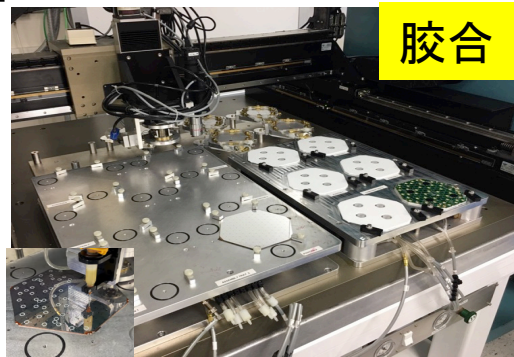
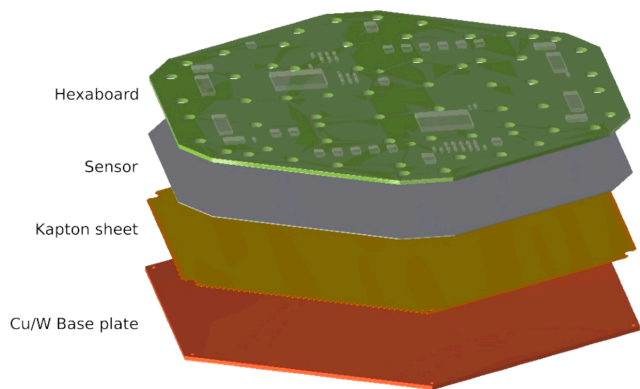
## 原型机电磁能量分辨率:

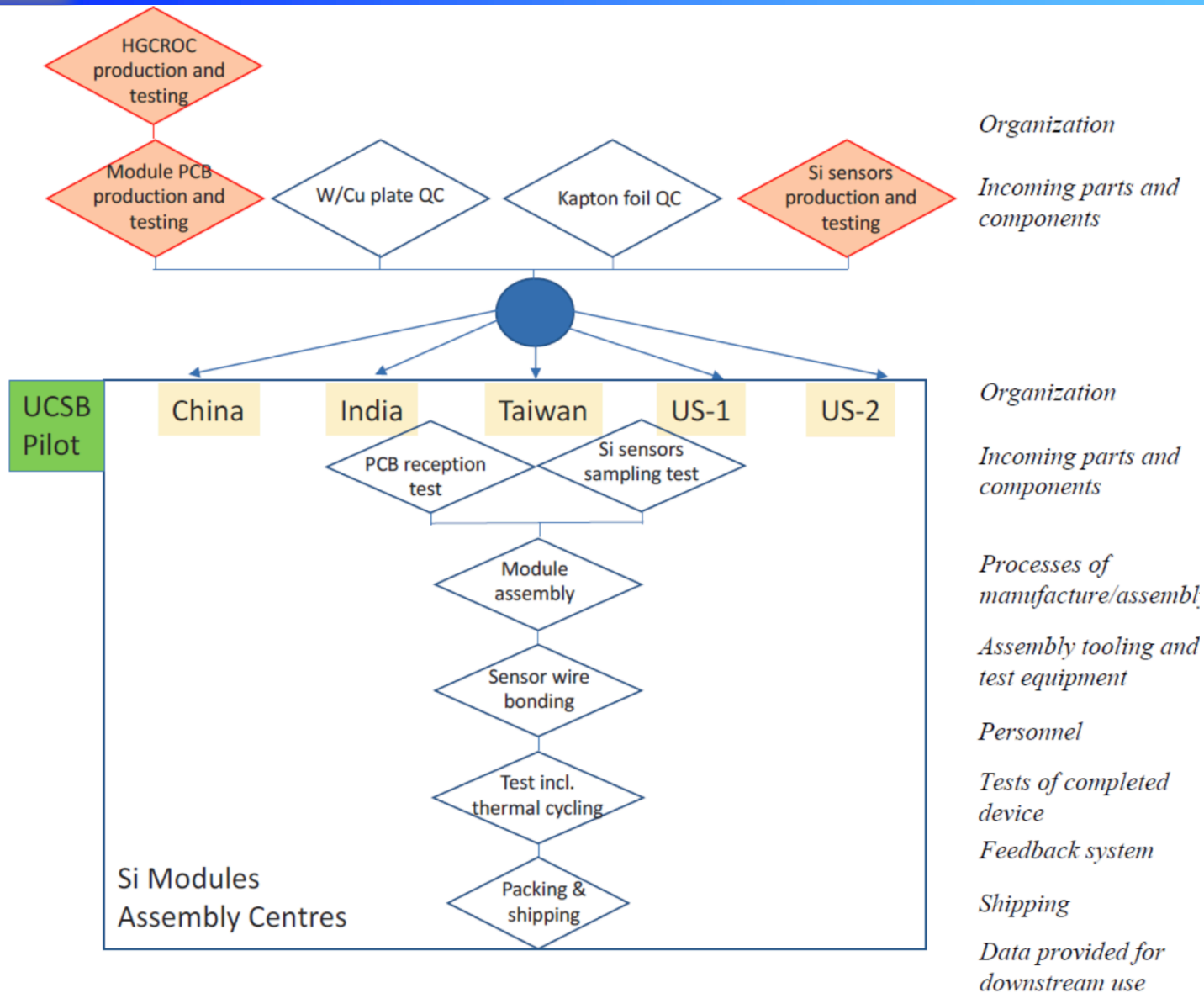
- 测试从1层到28层Ecal+51层HCal原型机
- 实验束测试得到的能量分辨率结果即将提交
- 能量分辨率好于:  $25\%/\sqrt{E} \odot 1\%$



## 模块建造流程

- 经原型机多次研究确定流程
- 高精度, 高速度, 自动化
- 正在确定量产工艺





### 2019年9月建成 140 m<sup>2</sup> 1000级洁净间:

- 温度: 20°C to 22°C; 湿度: 35% to 55%
- 长期温度/湿度和CCTV系统
- 空气压缩机, 真空机, 气体/真空管道系统



Room105



Room106



Control panel



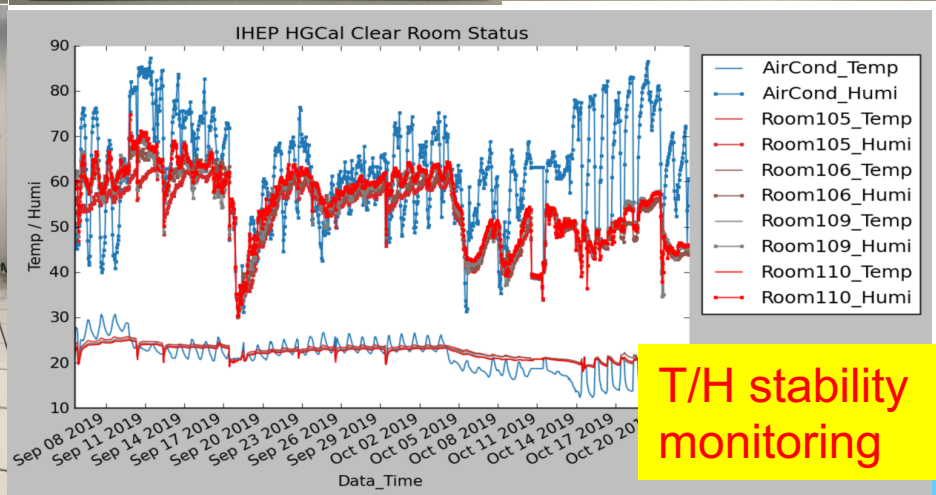
CCTV



Room109

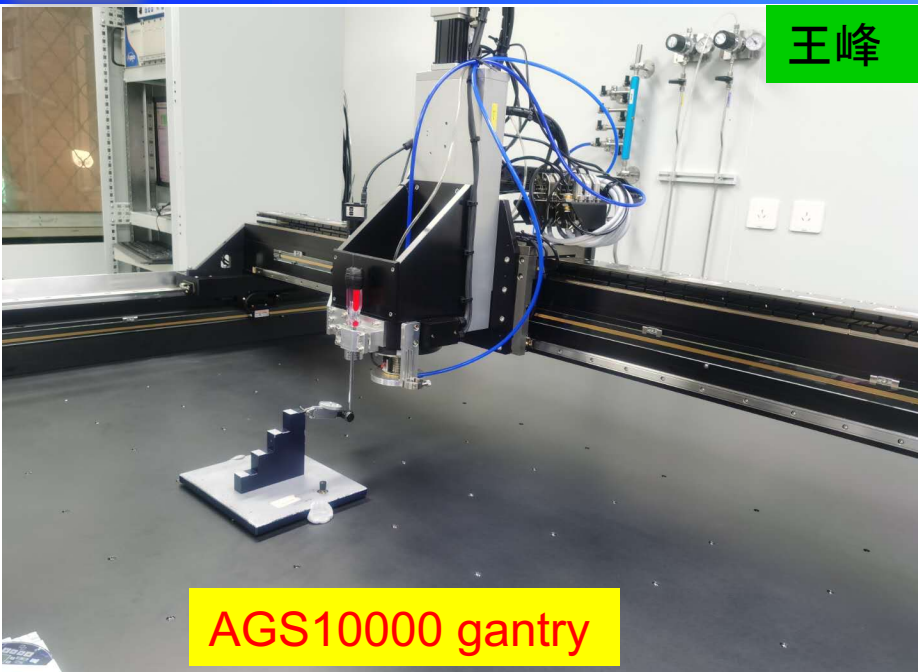


Room110



T/H stability  
monitoring

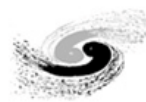




+Fisnar mini gantry, 离心机, 拉力测试仪, 温度循环系统, 电子学测试系统等

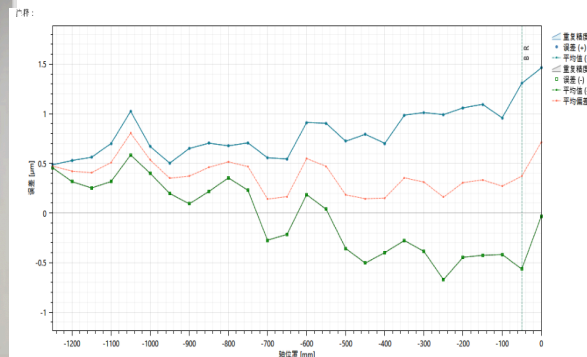
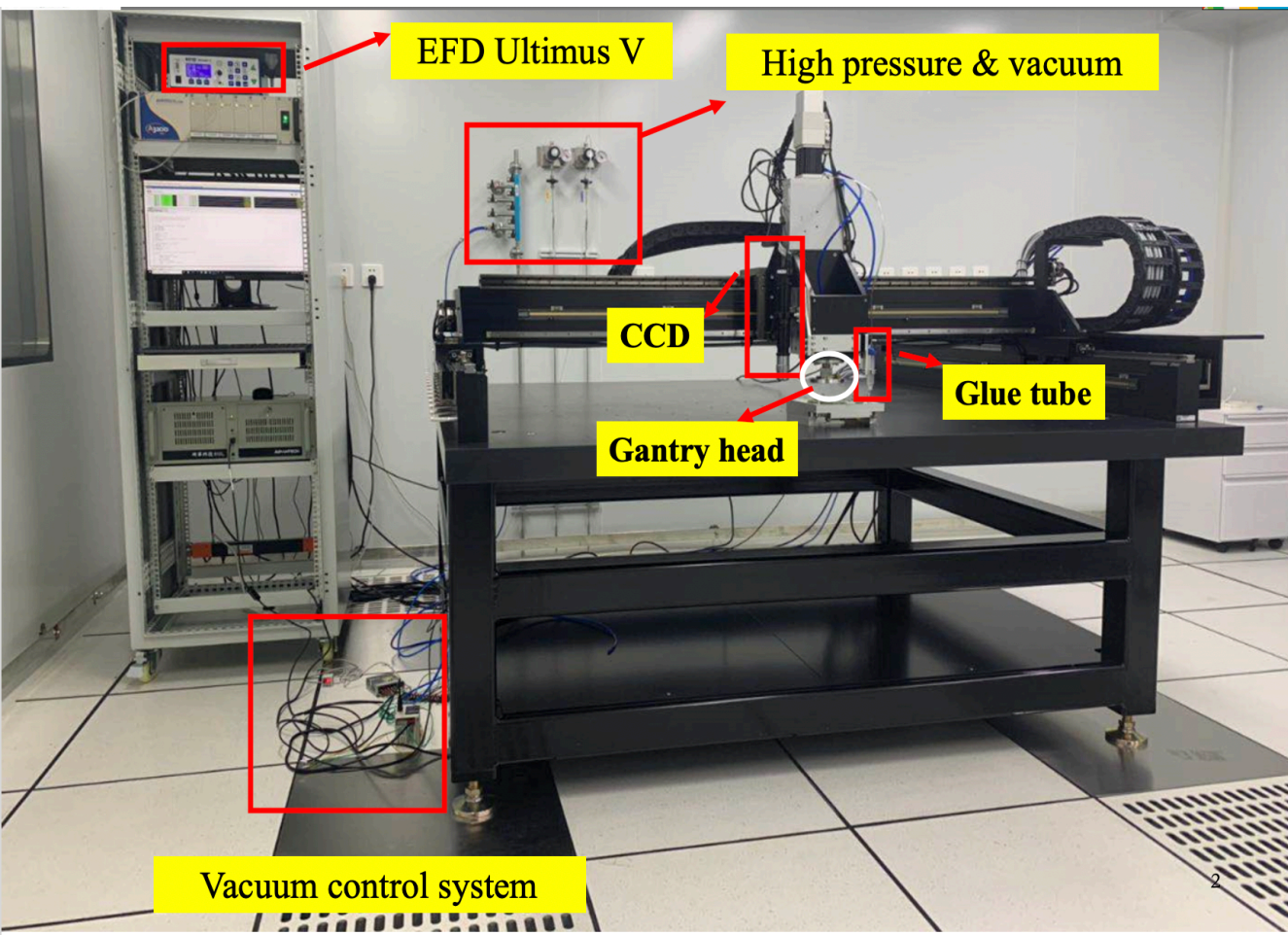
- 2019年开始主要仪器招标采购, 安装到位, 部分已经验收
  - 部分仪器受中美贸易战, 疫情影响较大
- 仪器使用初步培训完毕, 模块集成专用培训受疫情推迟
- 目前正进行仪器参数刻度, 专用工具设计制造, 安装, 联调





## 高粒度量能器硅模块集成

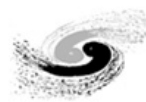
- 640平米, 6个MAC, 平均需要集成>100平米的硅探测器, 100万道读出
- 模块元件定位, 结构胶面积/厚度, 模块厚度, 稳定性, 抗辐照性, 集成速度
- 采用大行程高精度gantry+专用工具(1.25米\*1.25米\*0.1米 @ < +/-5微米)



精度和重复性, 详细见附表: 上页图

名称	(+) $\mu\text{m}$	(-) $\mu\text{m}$	(Bidir) $\mu\text{m}$	名称	值 ( $\mu\text{m}$ )
腔体 (A)				平均 (B)	1.87
底座腔体 (C)				平均 (D)	0.87
底座腔体 (E)	0.98	1.26	2.13	平均 (F)	0.66

详情见下午王峰的报告



- 单模块测试系统: 已经安装完毕, 测试6寸模块/8寸PCB

**Teststand**

RPI  
FPGA  
To module

**Module**

**Interposer**

**6" Module**

HG\_Pedestal [ADC counts]

Noise [ADC counts]

**8" PCB**

HG\_Pedestal [ADC counts]

Noise [ADC counts]

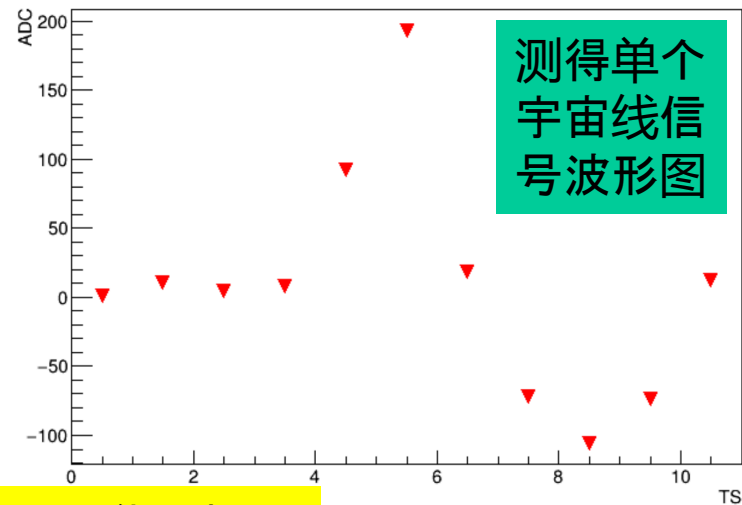
**Dark box**

详情见程华杰报告



- 宇宙线测试系统:

- 2套宇宙线测试系统: 2017年原型机系统和目前模块系统
- 均能够获得显著的宇宙线信号, 详情见程华杰报告



详情见程华杰报告

- 多模块测试系统:

- 供量产使用, 一次性测量12个模块, 目前还在设计中

- 高能所束流测试:

- 计划使用主束流测试模块饱和信号附近的线性
- 正开展前期准备工作





- 数据库系统保存模块集成过程中的重要信息
  - 模块元件的信息, 模块电学测试结果, 绑定结果, 温度循环测试结果等
- 将会大量使用: 自动化, 可视化, 同步, 备份, 本地化...

The screenshot displays the 'Module Assembly User Interface' with several key sections:

- Navigation:** Left sidebar with categories like 'Parts, tooling, supplies', 'Production steps and testing routines', and 'Shipping and receiving'.
- Module ID:** A central field set to '0' with 'New', 'Save', and 'Cancel' buttons.
- Configuration Panels:**
  - Pre-wirebonding qualification:** Includes fields for 'check edge contact', 'check glue spillage', 'Unbonded DAQ dataset', 'Unbonded DAQ user', and 'Unbonded DAQ OK?'.
  - Wirebonding:** Features checkboxes for 'Wirebonding performed', 'Is test bond module', 'Test bonds pulled', and 'Test bonds rebonded', along with user and OK? fields.
  - Encapsulation:** Includes 'Encapsulation done', 'Encapsulation user', 'cure start/stop' times, and 'Post-curing inspection'.
  - Finished module qualification:** Includes 'HV cables attached', 'HV cable attachment user', 'Unbiased DAQ dataset', 'Unbiased DAQ user', 'Unbiased DAQ OK?', 'IV dataset', 'IV user', 'IV OK?', 'Biased DAQ dataset', 'Biased DAQ voltage', and 'Biased DAQ OK?'.
- Tables:** 'IV datasets' and 'DAQ datasets' on the right side, each with an 'add selected to plotter' button.
- Comments:** A text area at the bottom left for 'Comments' with a 'delete selected' button and an 'add comment' button.

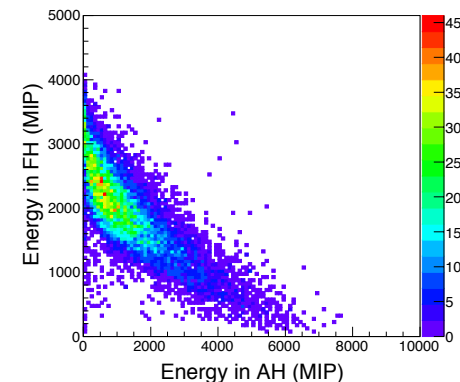
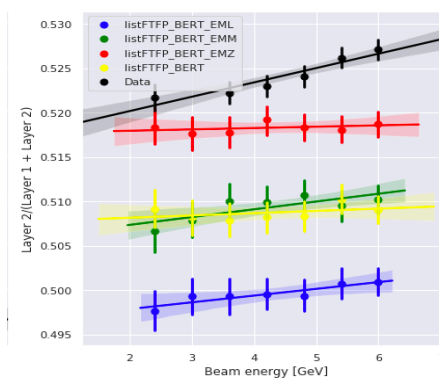
详情见下午王锦的报告



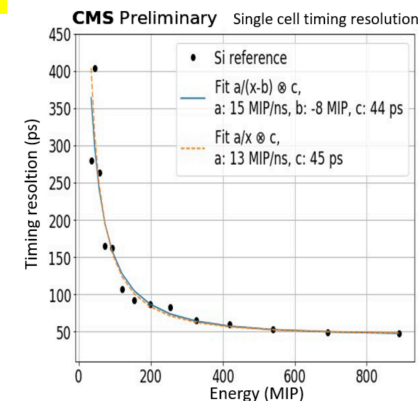
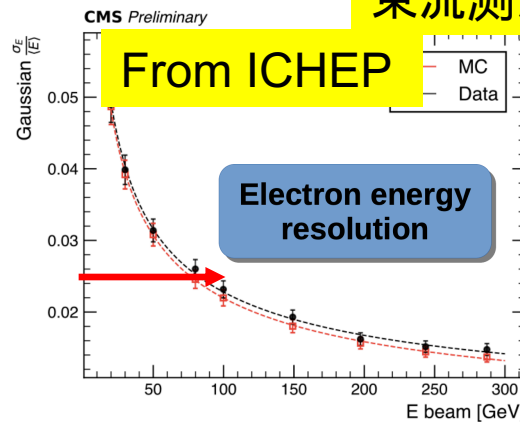


- 张华桥, 廖红波, Francesco, 李秉桓参与多次束流测试硬件准备, 实验束取数, 数据分析工作
- 伍灵慧2019/03-09在CERN半年, 从事实验束重建/分析工作

HGC束测时间	地点	IHEP参与
2016/03/21-04/12	FNAL	
2016/04/18-27	CERN	
2016/08/17-24	CERN	
2016/08/31-09/07	CERN	
2016/11/09-14	CERN	
2017/5/8-15	CERN	
2017/7/12-19	CERN	
2017/09/29-10/02	CERN	
2017/10/18-23	CERN	
2018/03/16-28	DESY	
2018/06/08-16	CERN	
2018/10/10-25	CERN	



## 束流测试分析结果



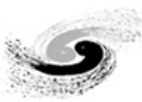
5 beam test paper in preparation



# Task list for site qualification (1)

<https://docs.google.com/spreadsheets/d/1vfSE06QK9bD--7gekQWap2C9huU5StMJjixXoj0PJ1U/edit#gid=1071353112>

A		L												M
1		TIFR (BARC)		CMU		IHEP		NTU		TTU		UCSB		
2		5/46 completed		15/46 completed		9/46 completed		14/46 completed		14/46 completed		24/46 completed		
3	Task	✓	Date	✓	Date	✓	Date	✓	Date	✓	Date	✓	Date	
4	<b>LAB INFRASTRUCTURE</b>	<input type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input type="checkbox"/>	3/1	
5	Establish cleanroom	<input type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	
6	Establish dry air cabinets	<input type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	
7	Establish particle count monitoring	<input type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	
8	Establish humidity monitoring	<input type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input type="checkbox"/>	3/1	
9														
10	<b>EQUIPMENT INSTALLED</b>	<input type="checkbox"/>	3/1	<input type="checkbox"/>	3/1	<input type="checkbox"/>	3/1	<input type="checkbox"/>	3/1	<input type="checkbox"/>	3/1	<input type="checkbox"/>	3/1	
11	Gantry	<input type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	
12	Wire Bonder	<input type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	
13	Pull Tester	<input checked="" type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	
14	Mini Gantry	<input checked="" type="checkbox"/>	3/1	<input type="checkbox"/>	3/1	<input type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	
15	Measuring Microscope	<input checked="" type="checkbox"/>	3/1	<input type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	
16	Work station	<input type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	<input checked="" type="checkbox"/>	3/1	
17	Test stand	<input type="checkbox"/>	8/1	<input type="checkbox"/>	8/1	<input type="checkbox"/>	8/1	<input type="checkbox"/>	8/1	<input type="checkbox"/>	8/1	<input type="checkbox"/>	8/1	
18														



5篇高粒度量能器量能器实验束测试文章正在准备中

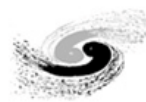
1. 张华桥, “CMS upgrade status”, CLHCP2019, 23 -27 Dec 2019, 大连
2. 张华桥, “半导体探测器在CMS高粒度量能器中的运用”, 中国材料大会, 2019年7月10-14, 成都
3. 王峰, “Recent progress of CMS HGCal at IHEP ”, CLHCP2019, 23 -27 Dec 2019, 大连
4. 刘勇, CMS HGCal beam test results, CLHCP2019, 2019.10.23-2019.10.25, 大连
5. 张华桥, “CMS HGCal status”, China CMS workshop, 2019.6.8-2019.6.9, 广州
6. 张华桥, 清华大学工物学术论坛: “5维量能器 — CMS实验高粒度量能器介绍”, 2020/6/11
7. 张华桥, 山东大学特邀讲座: “CMS希格斯物理最新进展与高粒度量能器介绍”, 2019/7/11



	Milestone Description	Duration	Finish by
1	Cleanroom lab space set up		
2	Have all equipment installed		Sep 11 <sup>th</sup> 2020
3	Train operators on all equipment		Sep 11 <sup>th</sup> 2020
4	Acquire all the necessary tooling		Oct 23 <sup>rd</sup> 2020
5	Acquire all dummy components and supplies		Oct 23 <sup>rd</sup> 2020
6	Qualify the gantry and wirebonder		Nov 6 <sup>th</sup> 2020
7	Develop glue patterns using acrylic dummies	2 weeks	Nov 20 <sup>th</sup> 2020
8	Build 10-15 dummies with blank silicon	4-6 weeks at one glue step per day	Jan 8 <sup>th</sup> 2021
9	Acquire all real components		Jan 15 <sup>th</sup> 2021
10	Build 4 dummies with HPK dummy sensors	2 weeks	Jan 22 <sup>nd</sup> 2021
11	Build 2 real modules!	1 week	Feb 1 <sup>st</sup> 2021

Milestone	WBS	Title	Date
<b>CE.MO.4</b>	<b>7.4.5</b>	<b>All Si module assembly sites &amp; procedures qualified (HL)</b>	<b>01 Feb 21</b>
CE.MO.7	7.6.2	Silicon Module components orders placed (HL)	2 DEC 21
CE.MO.9	7.6.4	Silicon Modules production 5% complete (HL)	26 OCT 22
CE.MO.10	7.6.6	Silicon Modules production 50% complete (HL)	21 OCT 23
CE.MO.11	7.6.8	Silicon Module production 100% complete (HL)	22 JUL 24





## Equipments responsables (设备负责人) :

Gantry: Wang Feng(王峰)

OGP: Sun Liang (孙亮, 顾煜栋)

Bonder: Gu Yudong (顾煜栋, 孙亮)

Electronics: Meng Bing, Li Xian (孟斌, 李鲜)

Silicon sensor R&D: 张万昌

Beam test at IHEP: 刘勇

数据分析/处理: 廖红波

实验室管理人: 待定

## 访问人员:

伍灵慧(高能所软件组): 2019/3-9

李郁博(北航/北大/复旦): 2019/7-12

程华杰(台湾大学) 2020/5/1-现在

- 王峰: 2019/9 博士后-->职工
- 沟通引进硅模块质量控制人才
- 新open一个联合博士后位置(刘勇, 张华桥)
- 吸引高能所CMS组投入学生到HGCal项目



- 高粒度量能器项目进展顺利
  - 实验束初步测试结果显示电磁能量分辨率好于 $25\%/\sqrt{E}$
  - 确定硅模块生产流程
  - 2019-2020年度建立硅模块集成实验室
    - 建成了140平米千级专用洁净间
    - 主要仪器设备到位, 正在调试培训等
- COVID对项目进度有一定的影响
  - 预计能够赶上调整之后的时间表
- 浙江大学计划参与高粒度量能器部分PCB的设计
- 复旦大学计划参与高粒度量能器模块中心建设
- 积极争取后续高粒度量能器批量集成经费
  - 2019基金委专项, 2020普通重点(失败), 2020NSFC专项(正在准备申请)



# backup





France/Prague/Japan/England

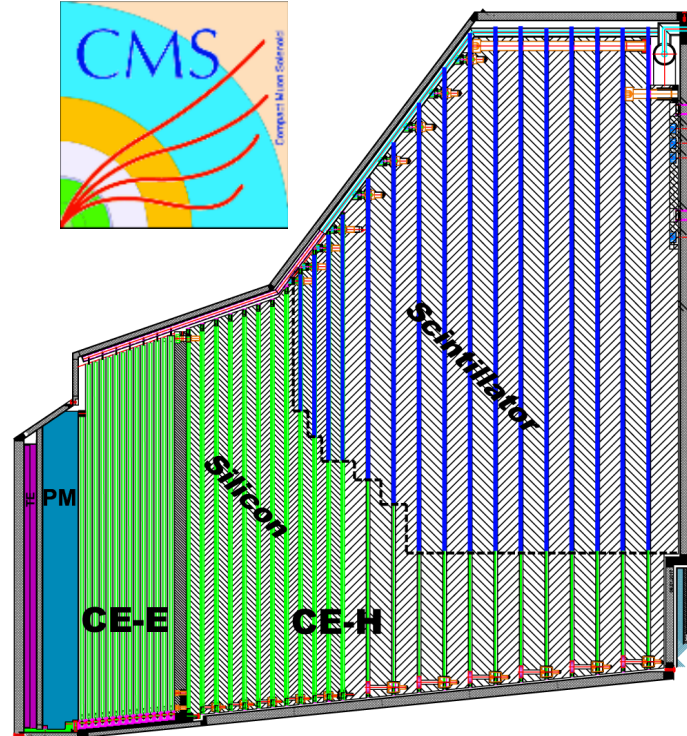


Years of R&D,  
Application Not yet approved

Similar idea



CMS HGC  
Approved to be built 2015-2023



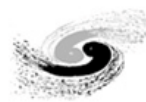
Other future HEP experiments

空间项目等



**优点: 可以达到1立方厘米一个探测读出  
很好的能量, 位置, 时间分辨率: 5D量能器**

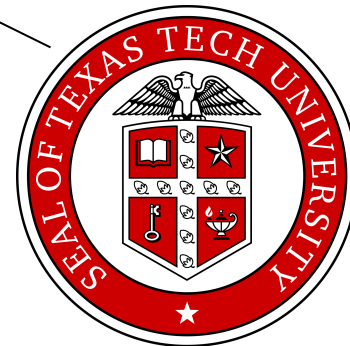
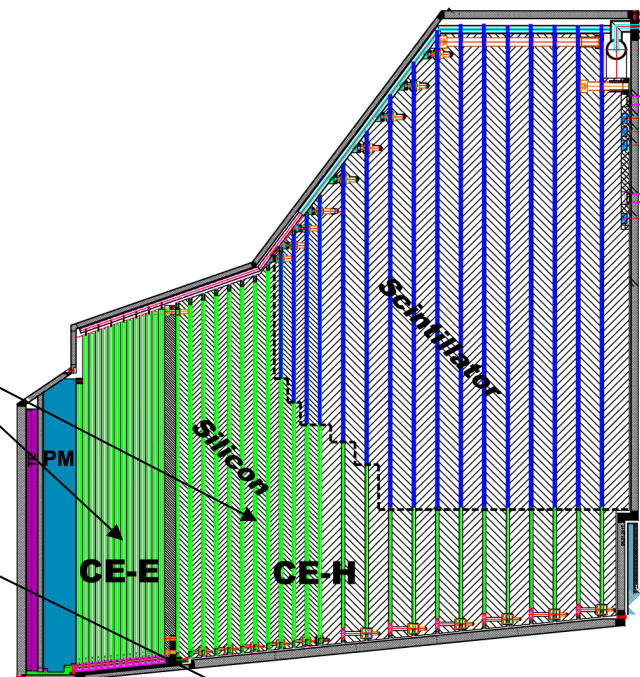
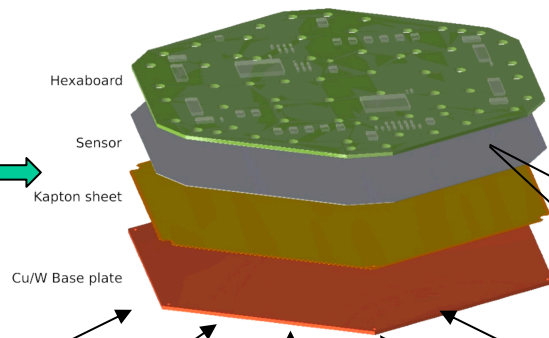




- Pilot MAC at UCSB



~27000 Si modules



MAC Taiwan

MAC Beijing

MAC Indian

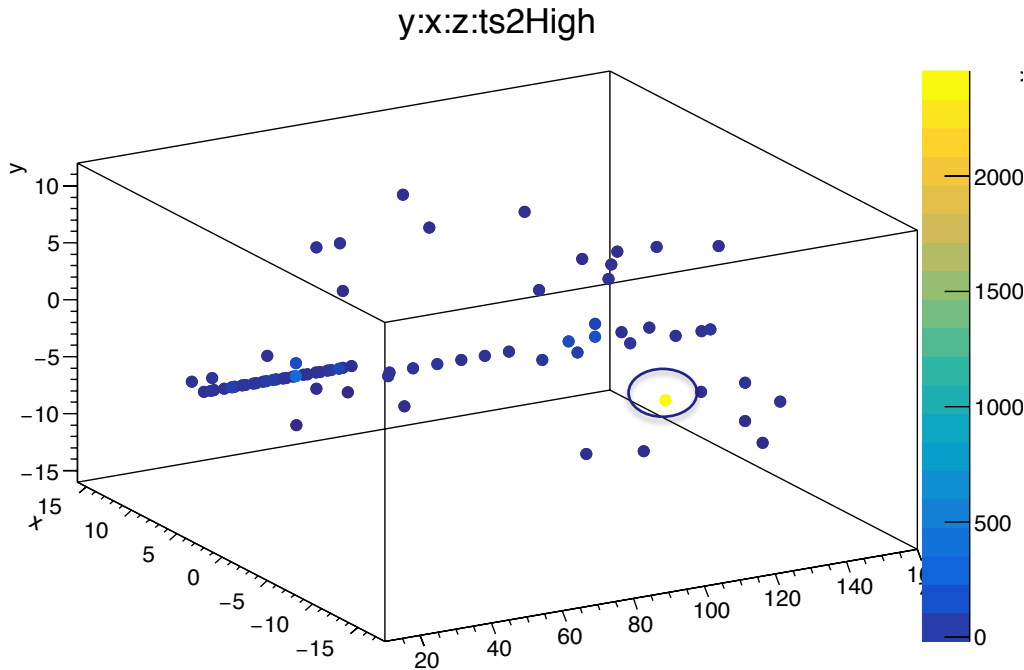
MAC CMU

MAC TTU

6 MACs, each MAC will produce 4500 Modules on average



- Look for “spikes”, i.e. some abnormal hits with extremely high signal
- Start the work on the clustering



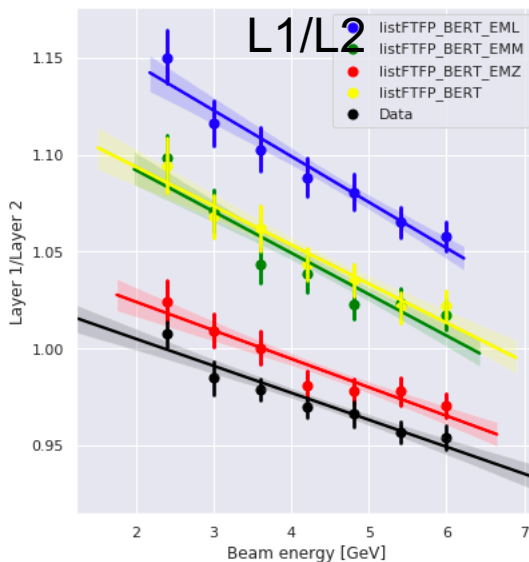
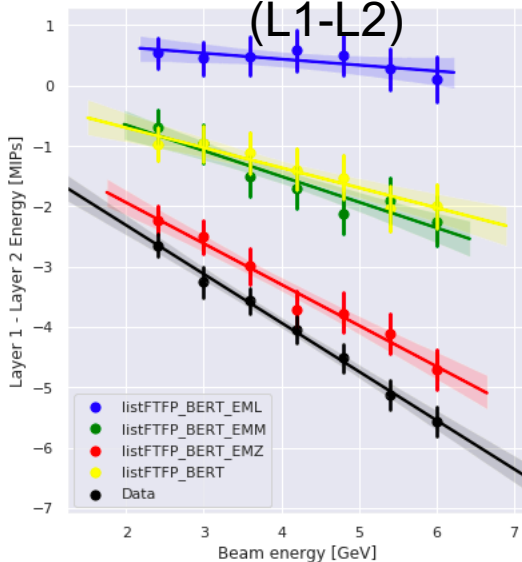
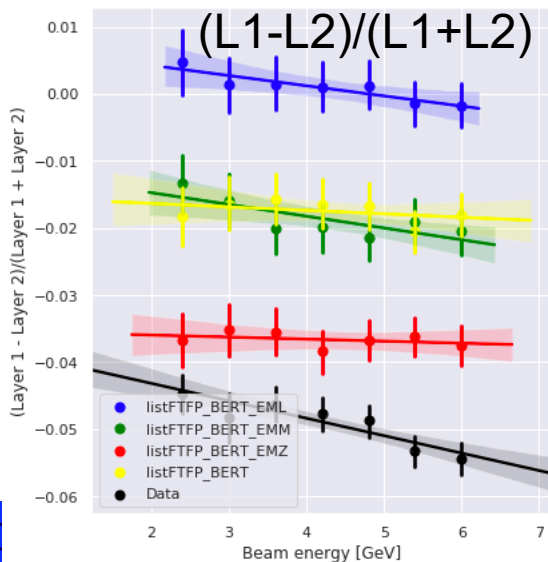
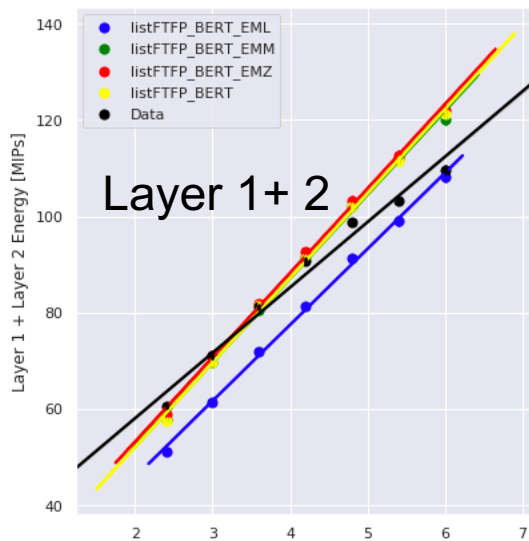
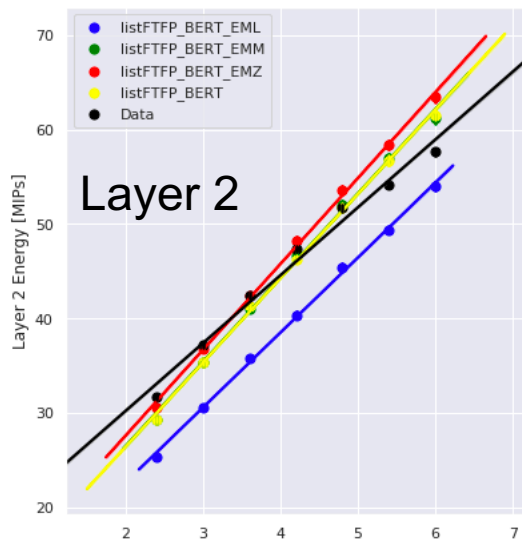
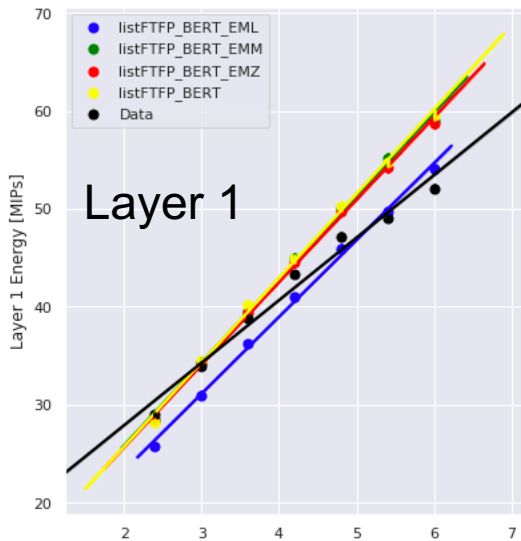
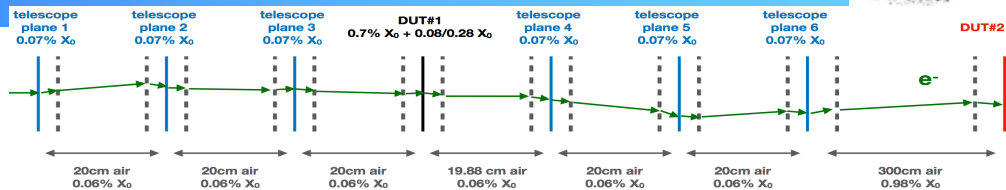
Offline simulation:  
new clustering Alg.

Science 27 Jun 2014:  
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Test beam data/simulation:  
simple clustering



- Energy correlation
- Back scattering (重新刻度)



not to scale :-)