

宇宙线热中子探测阵列的搭建

崔树旺¹，马欣华²，陈天禄³，刘茂元³，周荣⁴

1. 河北师范大学 ， 2. 中科院高能物理研究所

3. 西藏大学 ， 4. 四川大学

内容摘要

- 宇宙线热中子探测器工作原理简介
- 热中子探测器阵列(16个探测器构成1CLUSTER)
- 进展
- 正在进行的工作与未来计划
 - 探测器模拟
 - 数据分析

宇宙线全粒子能谱：膝区

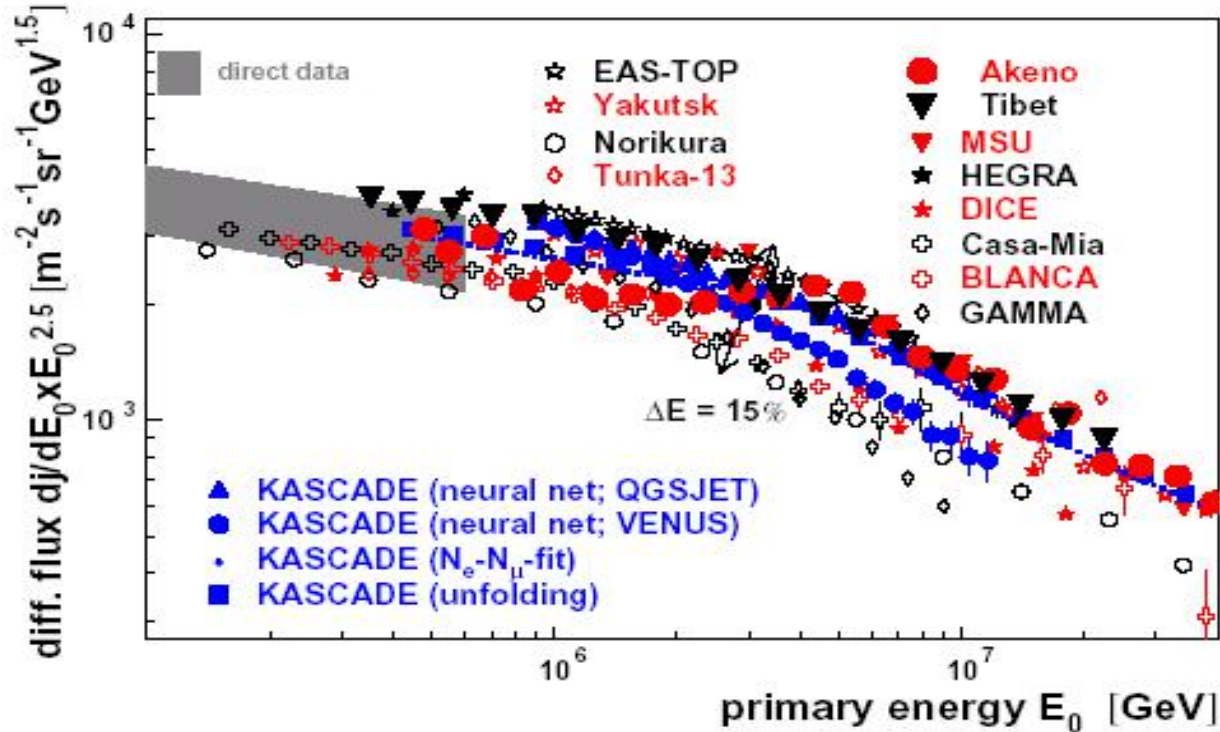
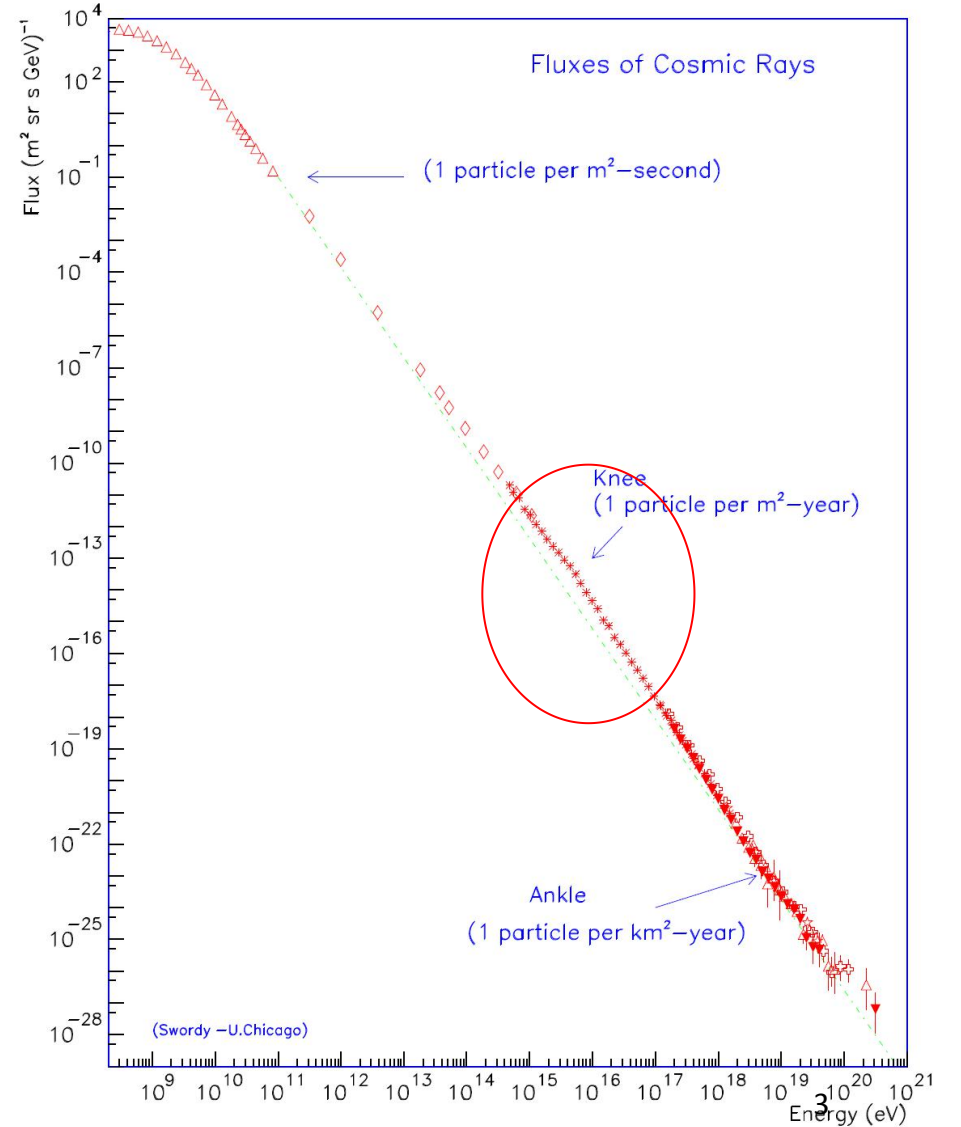
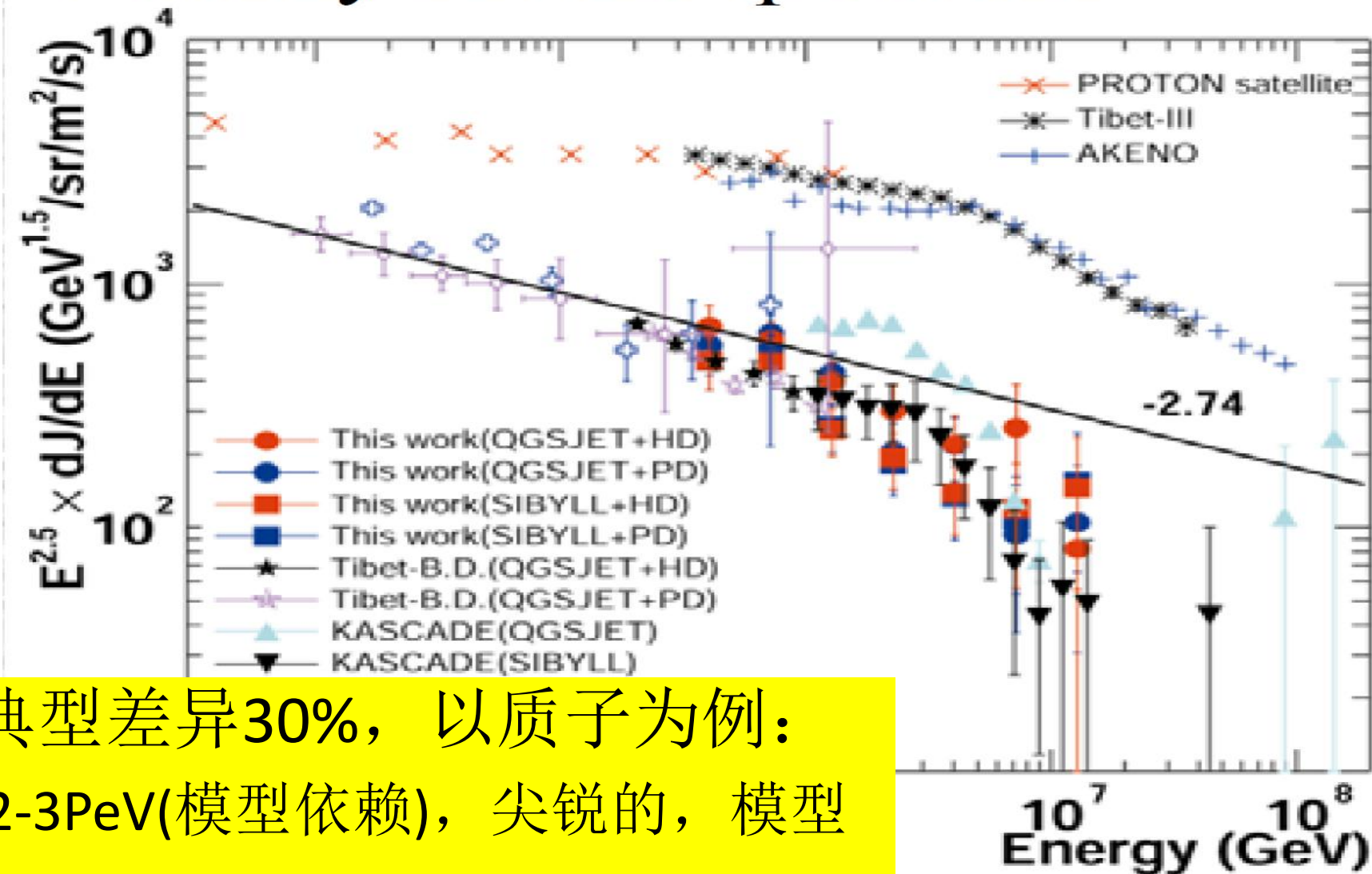


Figure 1. Compilation of different experimental results on the cosmic ray all-particle energy spectrum around the knee. The effect of a 15% uncertainty in energy reconstruction is indicated. (Refs.: Akeno [16], Tibet [17], MSU [18], HEGRA [19], DICE [20], Casa-Mia [21], Blanca [22], Gamma [23], EAS-TOP [24], Yakutsk [25], Norikura [26], Tunka [27], KASCADE [28, 29, 30], compilation of direct data by Watson [31].)



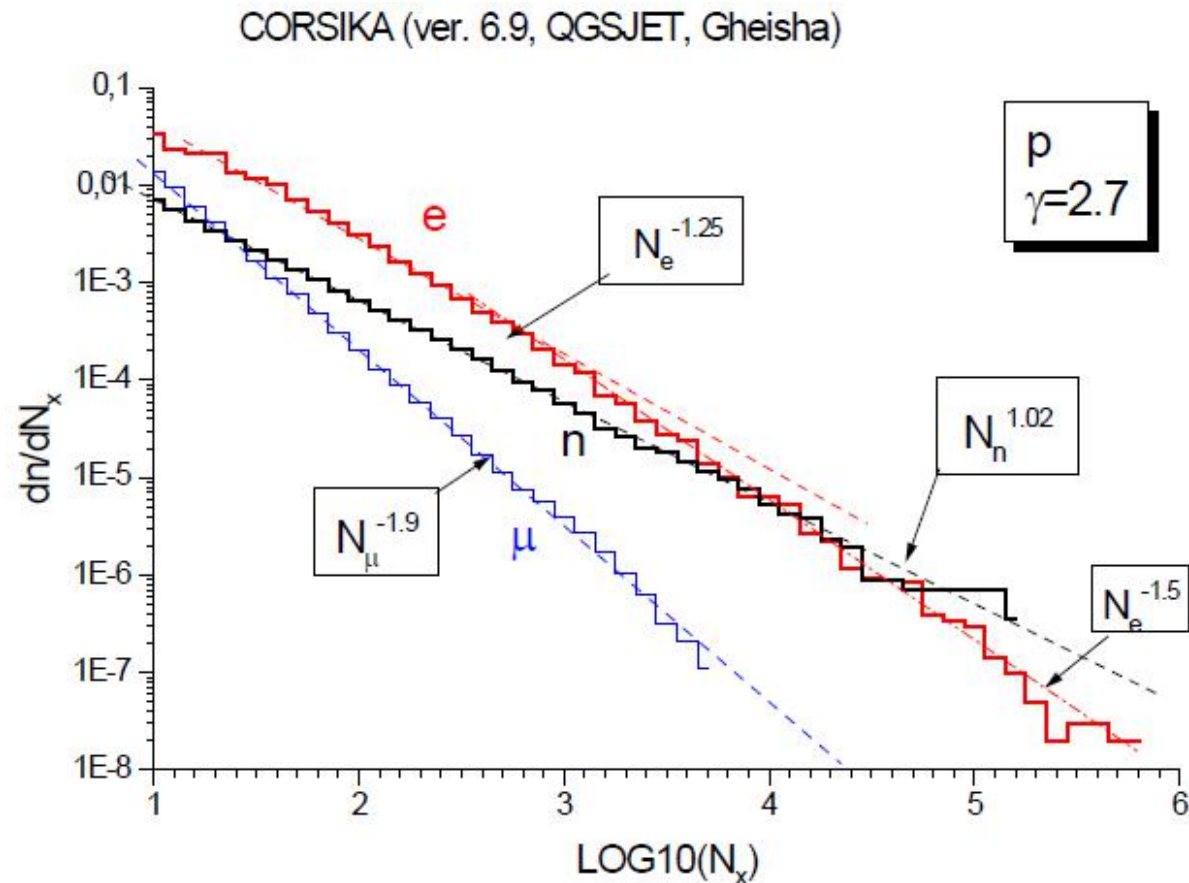
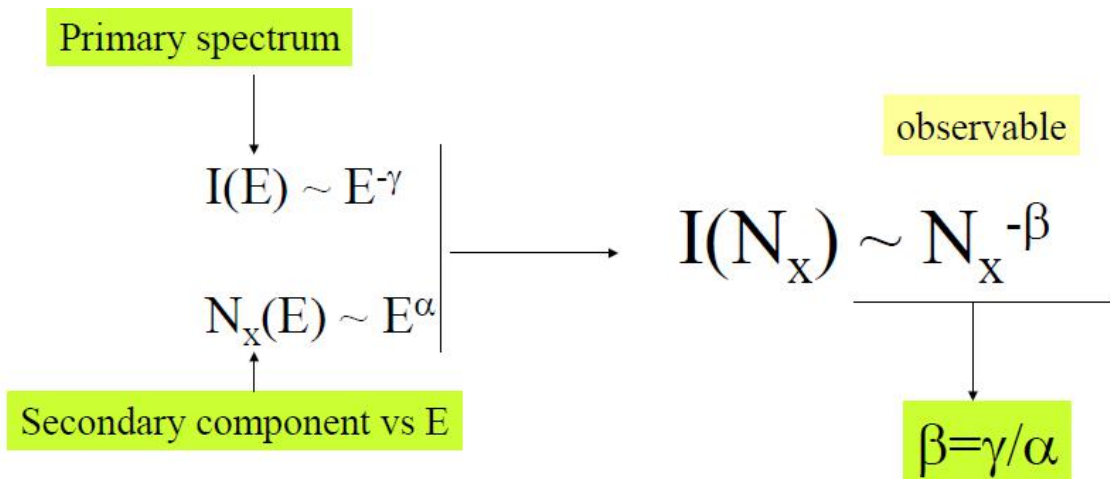
Primary Proton spectrum



现有探测结果的典型差异30%，以质子为例：

◆KASCADE: 拐折在2-3PeV(模型依赖)，尖锐的，模型依赖

◆ASgamma: 拐折在~400TeV，缓慢的

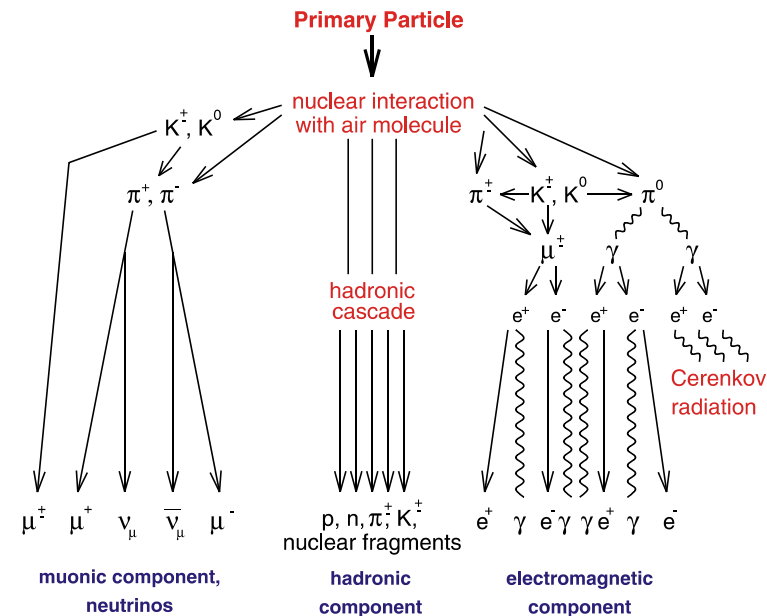
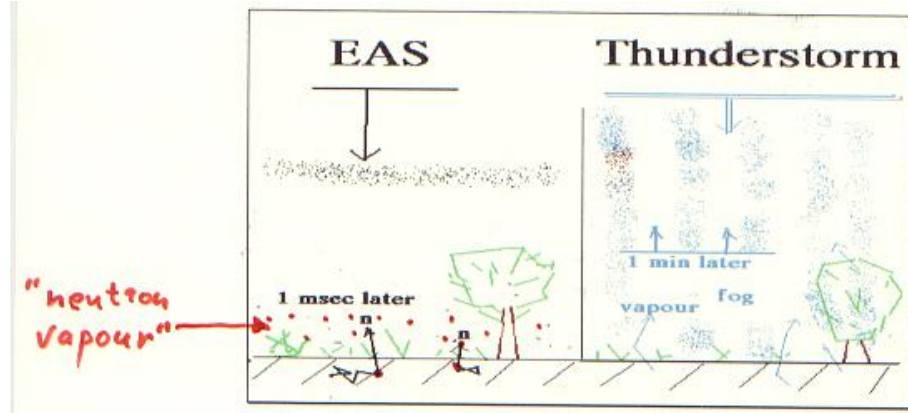


探测技术问题：

不同的次级粒子得到不同的能谱拐折?!

探测不同的次级粒子是十分必要的!

强子是宇宙线簇射的“骨架”，对成份十分敏感。



- 簇射中少量的强子与**周围环境中的物质**（土壤、建筑物、探测器材料、空气等）发生核反应产生大量MeV量级的**蒸汽中子**，蒸汽中子经过周围环境中的物质的慢化而产生**热中子**
- EAS热中子探测器可以确定EAS芯区强子，比昂贵的**强子量能器**有更强的规模优势，有更高的**性能-价格比**。

EAS热中子探测技术的优势

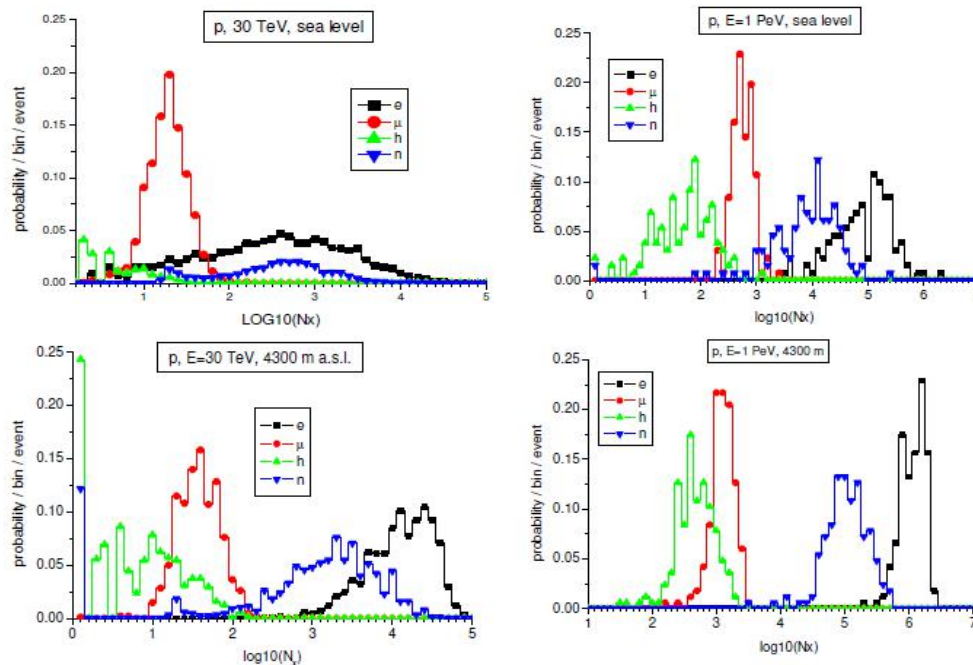
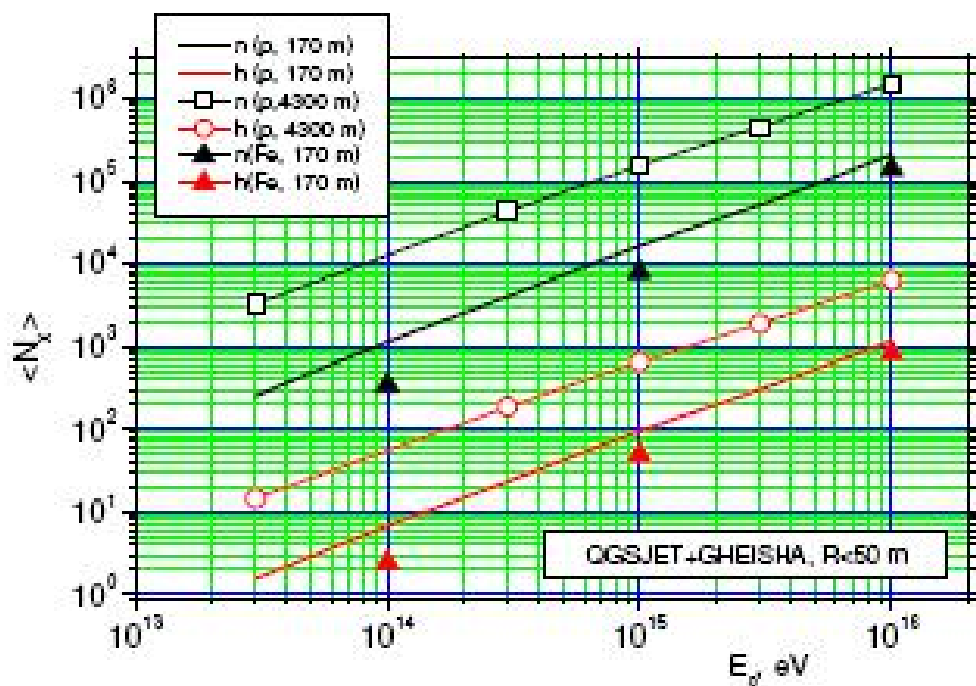
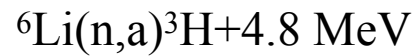
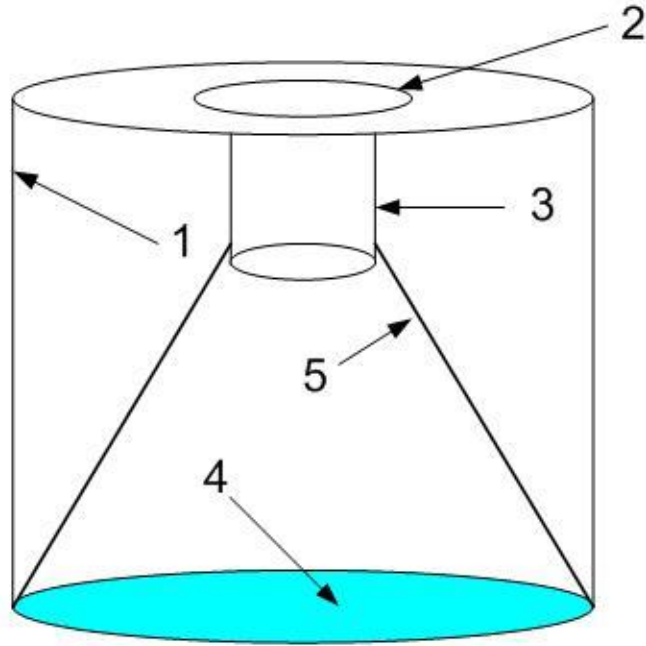


Fig. 2. Different EAS components size distributions for primary protons and primary energies equal to 30 TeV (left panel) and 1 PeV (right panel) for sea level (upper panel) and for 4300 m a.s.l.(bottom panel)

河北师大、高能所、俄罗斯合作发表的文章 **Thermal neutron flux produced by EAS at various altitudes**, Yu.V. Stenkin, V.V. Alekseenko, D.M. Gromushkin, LIU Ye ,MA Xin-Hua, ZHAO Jing, Chinese Physics C Vol. 37, No. 1 (2013) 015001

EAS中少量的强子成分能够产生大量的热中子，其数量比强子多2-3个数量级。高海拔要比海平面高1-2个数量级

en-detector design



Scintillator: $\text{ZnS}(\text{Ag}) + {}^6\text{LiF}$

or

$\text{ZnS}(\text{Ag}) + \text{natural B}$

1 - PE water tank, $\varnothing=72 \text{ cm}$, $h=57 \text{ cm}$

2 - lid $\varnothing=30 \text{ cm}$

3 - 6" PMT

4 - scintillator, $s=0.36 \text{ m}^2$

5 - reflecting cone

n-efficiency - 20%

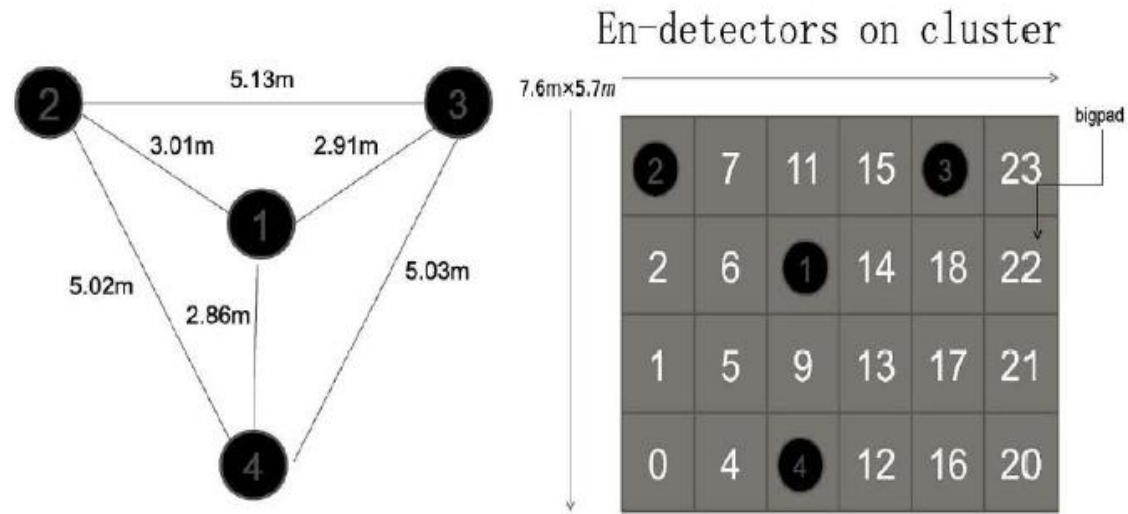
thickness - 30 mg/cm^2



$\text{ZnS}(\text{Ag})$ is a unique scintillator for heavy particles detection:

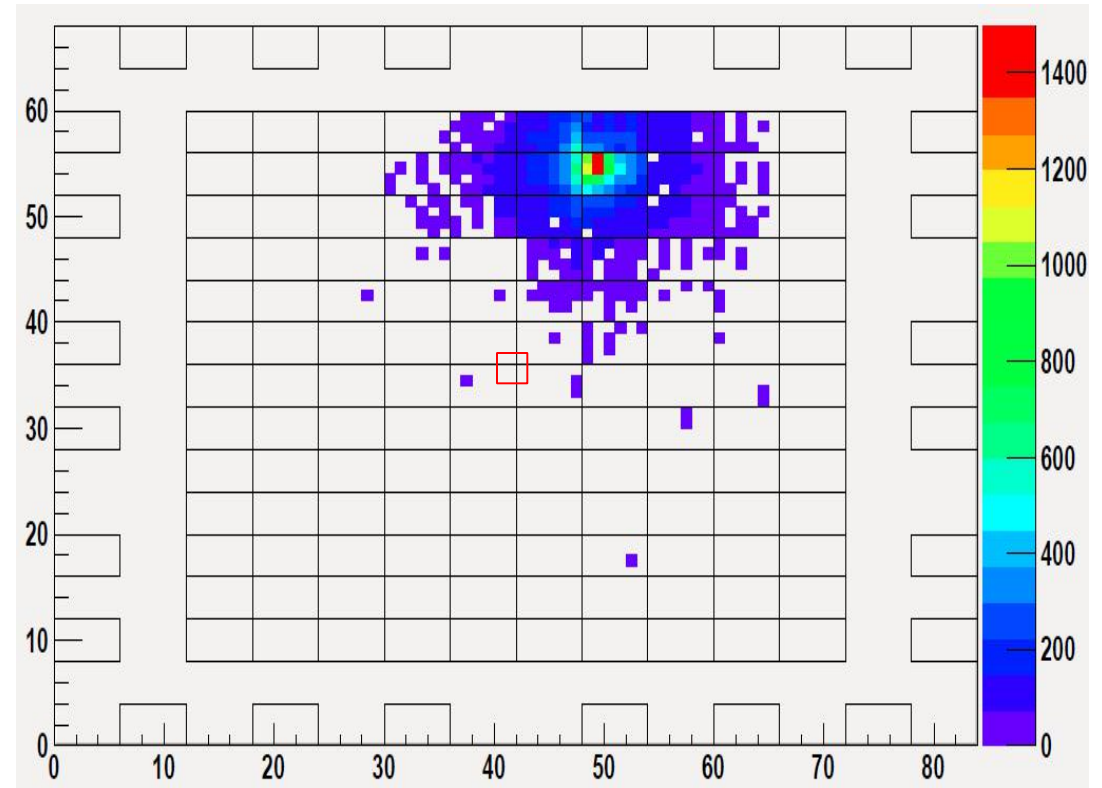
160,000 photons per capture

PRISMA-YBJ



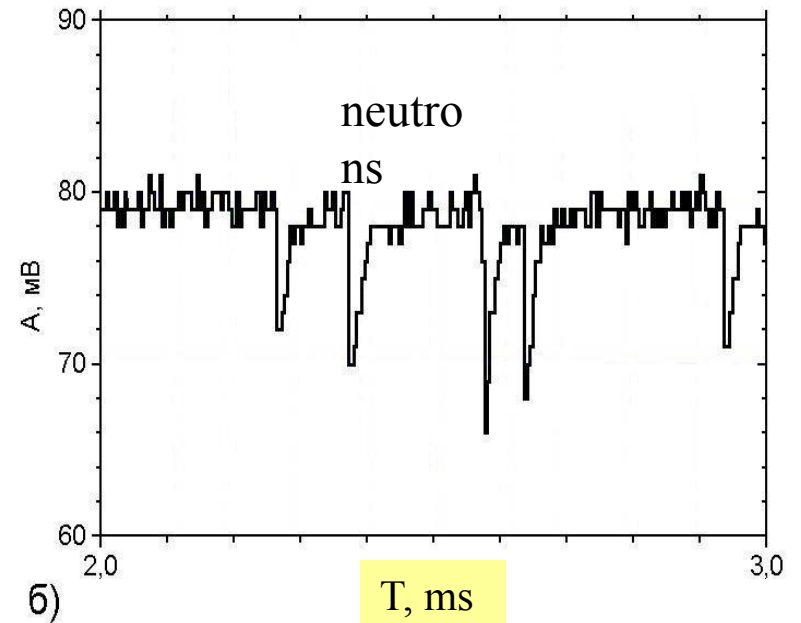
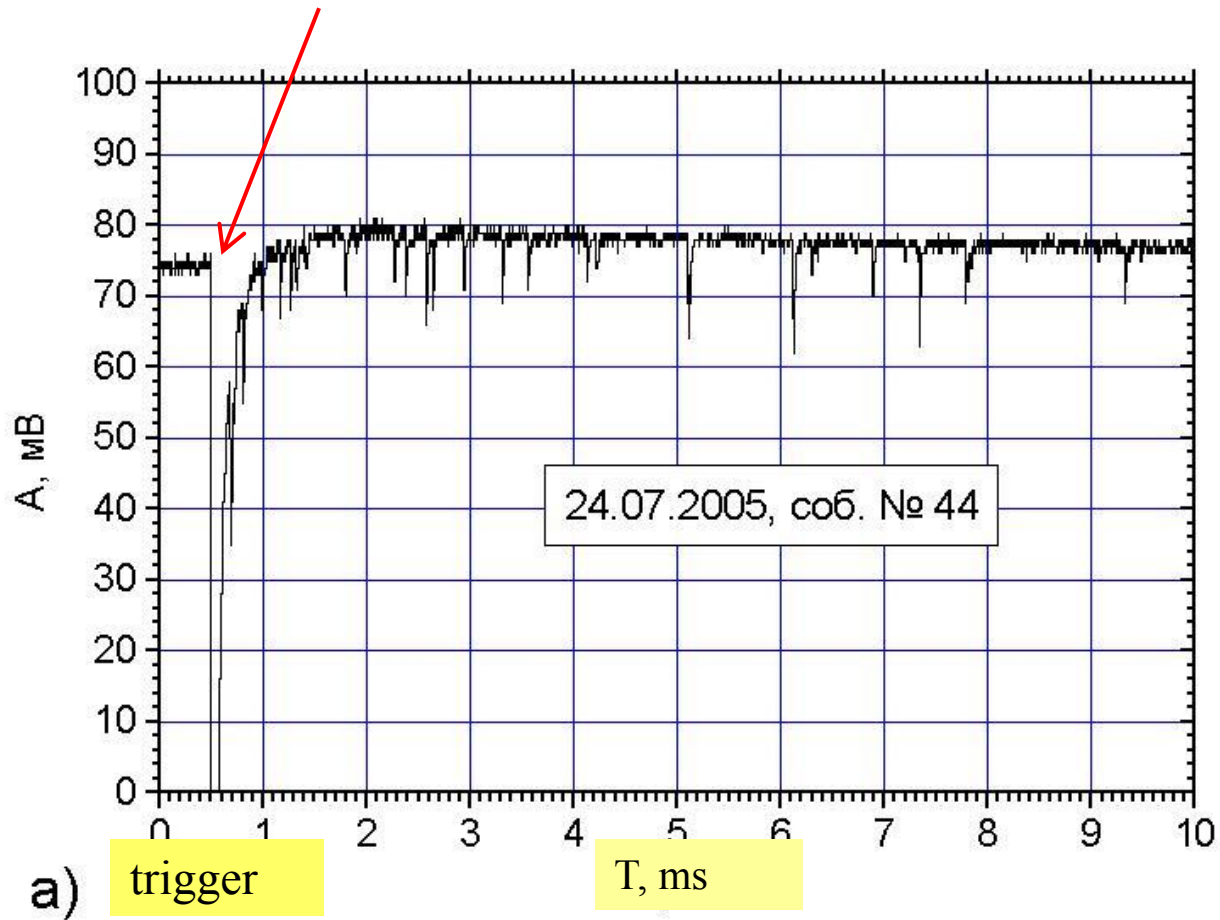
Running time: 2013.11—?

PRISMA-YBJ+ARGO-YBJ: 高海拔联合观测



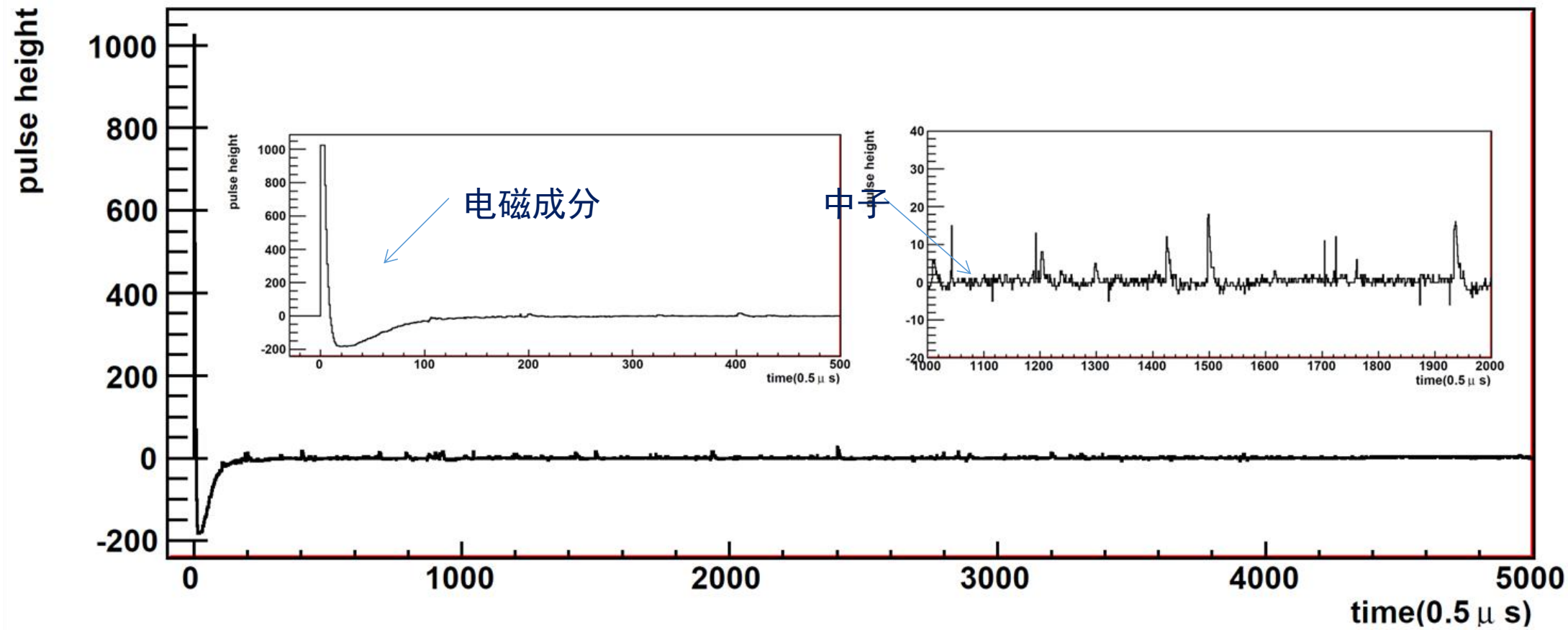
Oscillogram of the en-detector signal in a case of EAS

e-n - component pulse



Detail of the oscillogram with neutron pulses

宇宙线簇射事例：得到电磁成分和中子，包含时序



前期工作研究

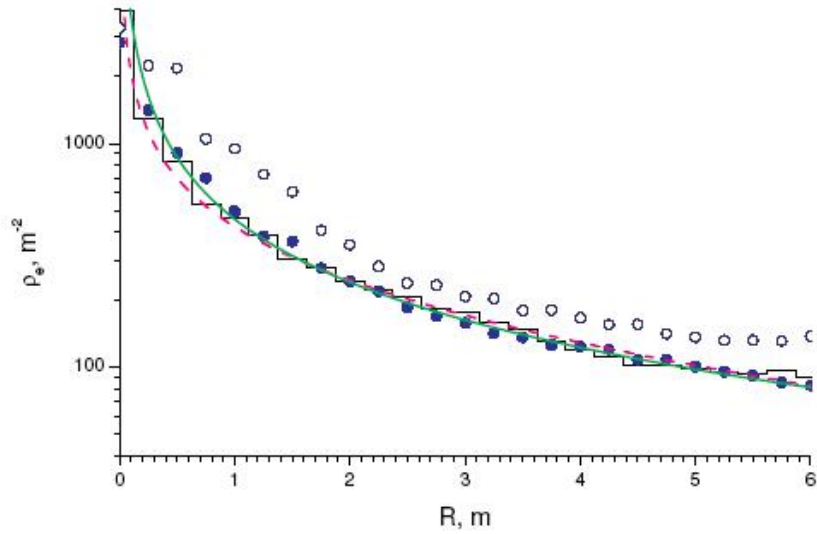


Figure 3. Lateral distribution of electromagnetic component of EAS at 4300 m a. s. l. altitude. Histogram - experimental data, ● - simulation for protons, ○ - simulation for iron, — NKG function (4), - - - ARGO-YBJ experimental fit (3).

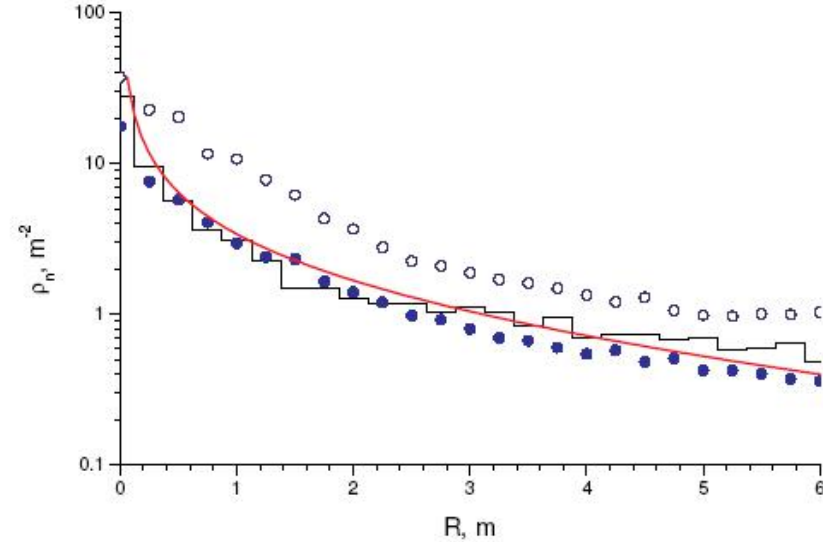
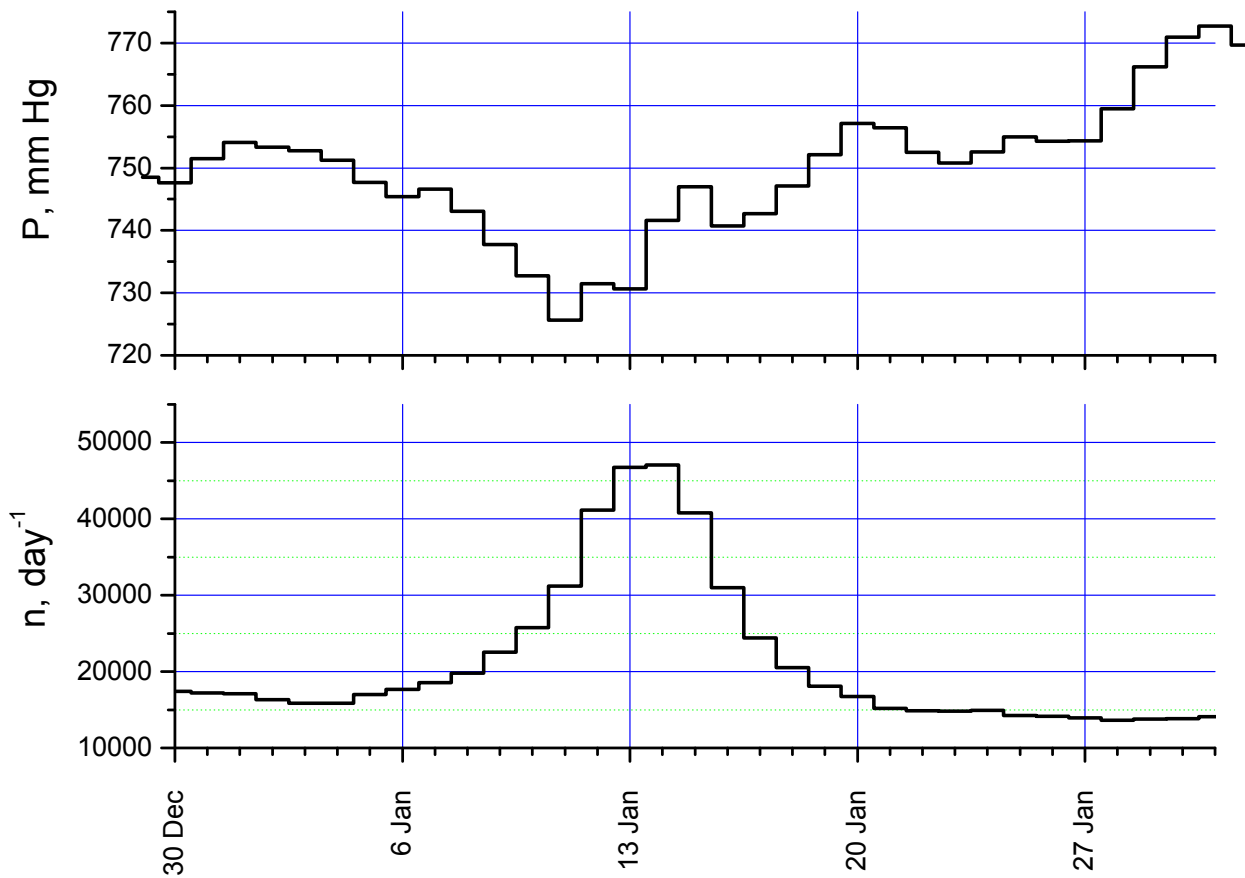
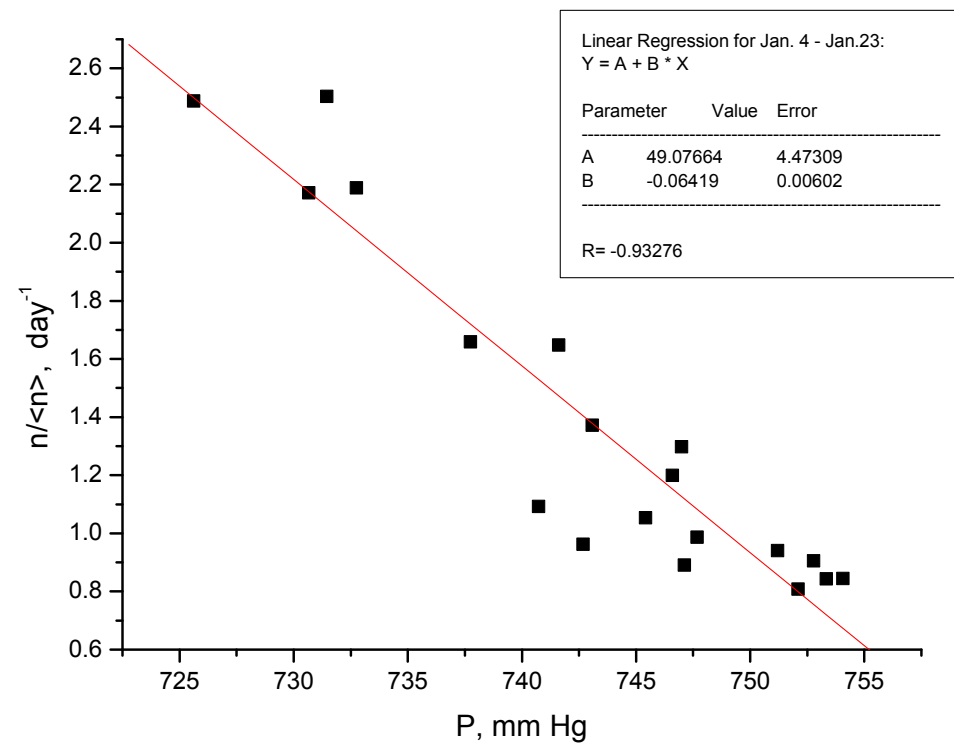


Figure 4. Lateral distribution of secondary thermal neutrons in EAS at 4300 m a. s. l. altitude. Histogram experimental data, ● - simulation for protons, ○ - simulation for iron, — KASCADE function for hadrons with ρ_h raised to 20m (5).

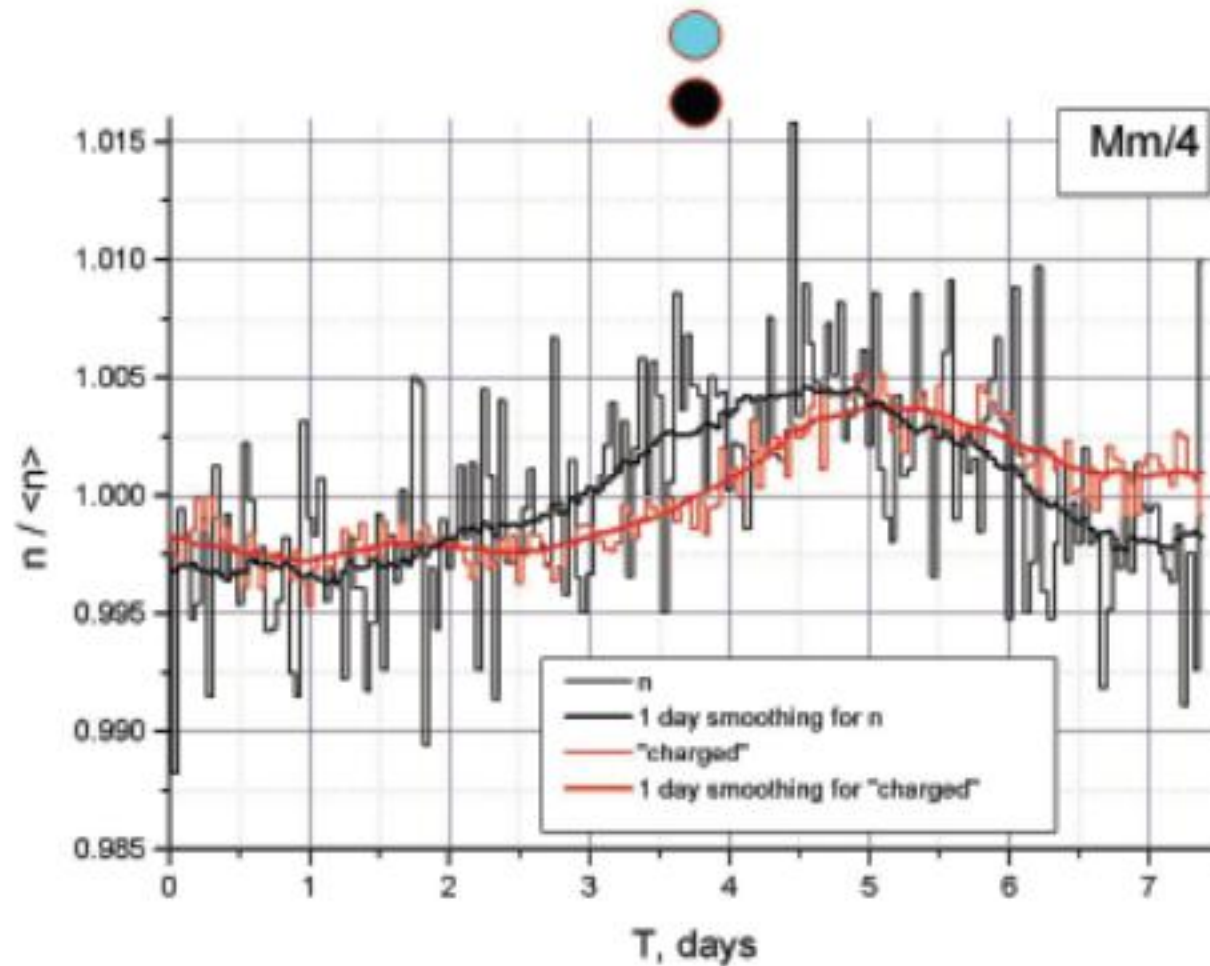


气压日变化和中子数平均值
反相关关系 Jan. 4 – Jan. 23.

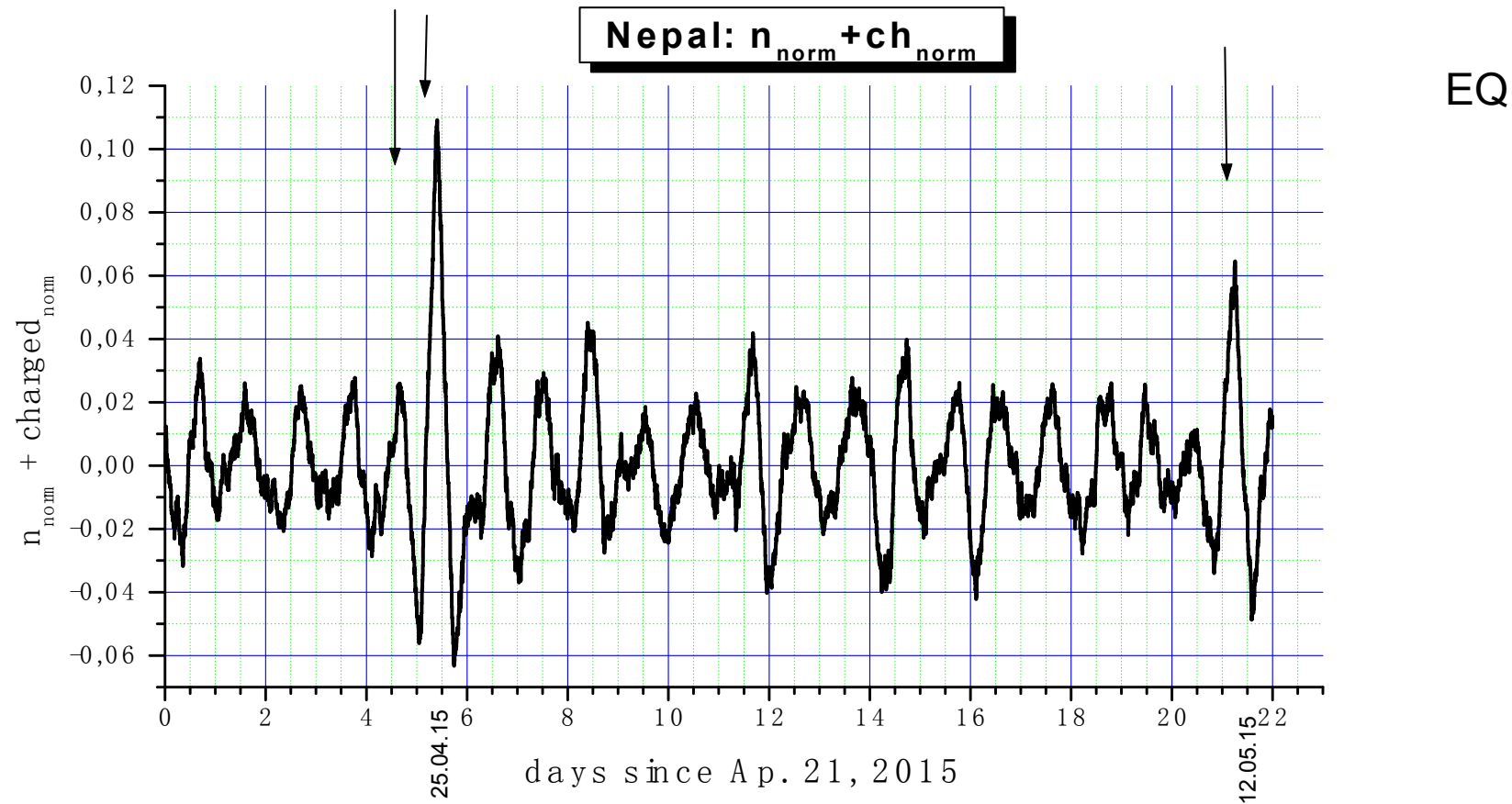


4th harmonic of Moon month in neutrons and “charged” (1 week wave)

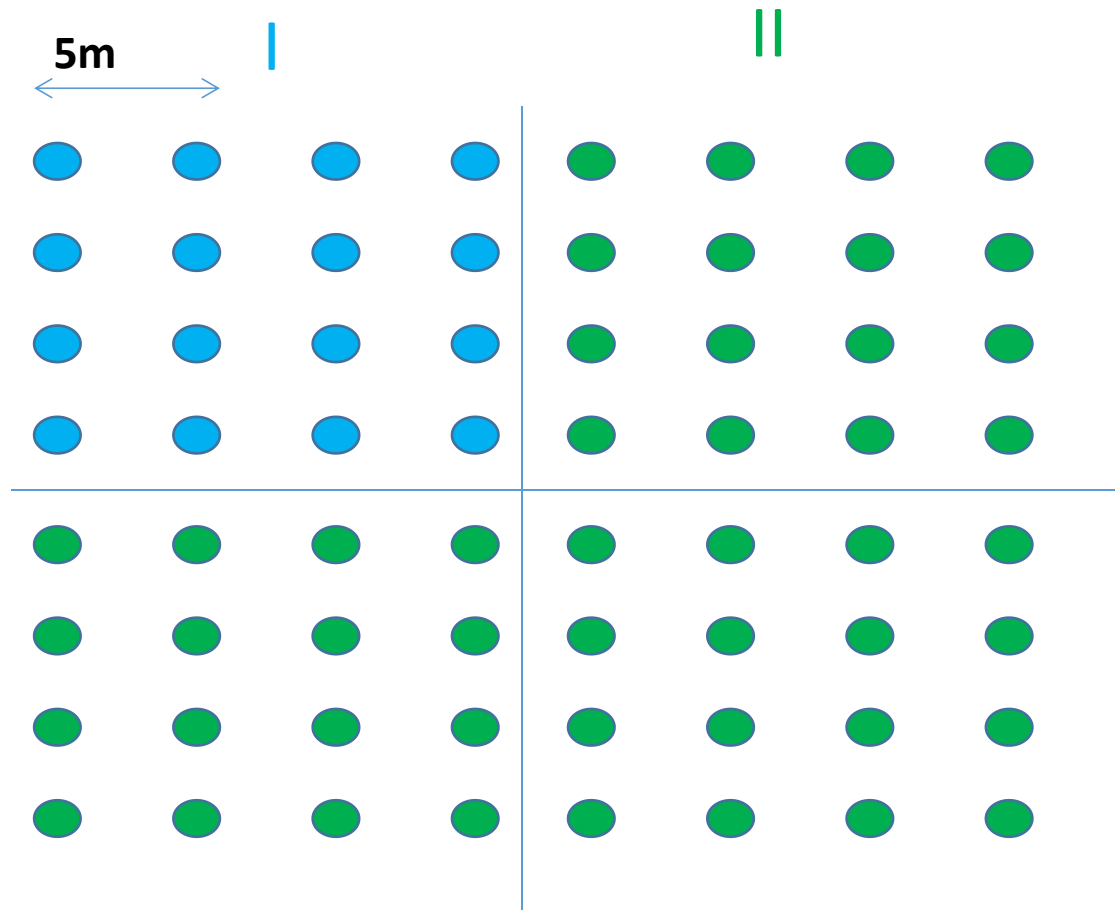
PRISMA-YBJ
4300 m a.s.l.



4th harmonic of Moon month ($T=7.38d$) observed at Tibet level. Positions of moon syzygies are marked by circles.



April 25 when the strongest earthquake occurred (M=7.8), but only next day (April 26) when aftershock quake with M=6.7 was observed. After 2 weeks, another strong aftershock was observed and again we saw a significant peak of $\sim 6\%$ amplitude

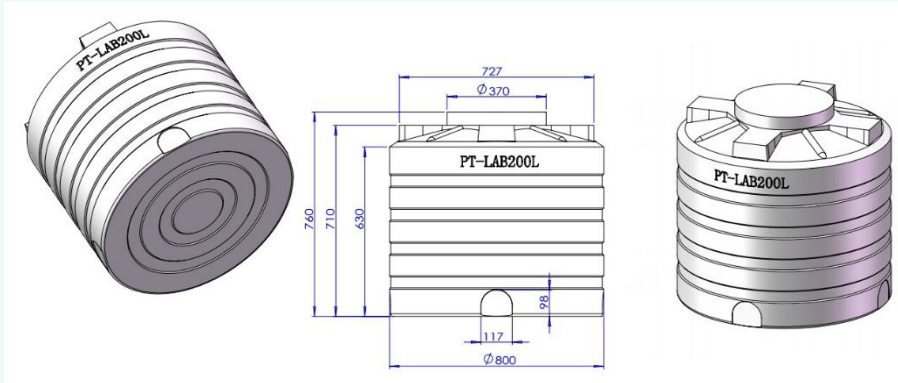


64台探测器(4 clusters)组成EAS观测阵列, $35\text{m} \times 35\text{m} = 1225\text{m}^2$

16个探测器1个CLUSER(2016)

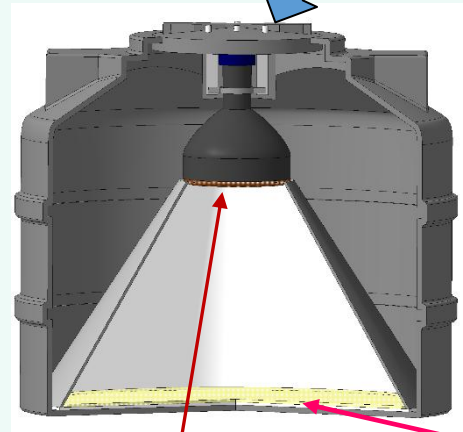
64个探测器4个CLUSER(2017-2018)—— **目标**

未来目标PRISMA-LHAASO
建设400个探测器构成的10000
平米阵列(20??)

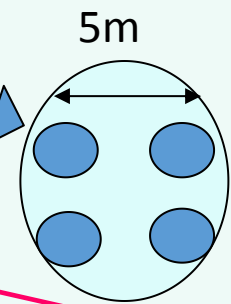


探测器单元

100m



16 en-detectors in cluster,
25 clusters,
400 en-detectors



4" PMT CR165 (Beijing Hamamtsu)

100m

Boron scintillator
 $ZnS(Ag)+B_2O_3$



项目进展过程

- 2015年6月提议
- 2015年10月22日西藏大学，确定资助建设16个热中子探测器项目
- 2015年12月初采购
- 2015年12月18日开始陆续到货

低压电源DH1718-4(2)，2015.12.18

电缆、插座、插头（17套），信号插头（68），2015.12.30

工控机服务器MR-g45，三星显示器SZZC330HW，2015.12.30

光电倍增管CR165及附件15套，2016.01.08

塑料桶（样品），2016.5.16

塑料桶（16个），2016.07.07

高压电源（2块），2016.07.29

转换插头（I型50个，II型25个），光电倍增管BASE（17个）2016.07.29

闪烁体（16片），Boron scintillator ZnS(Ag)+B₂O₃，2016.09.25

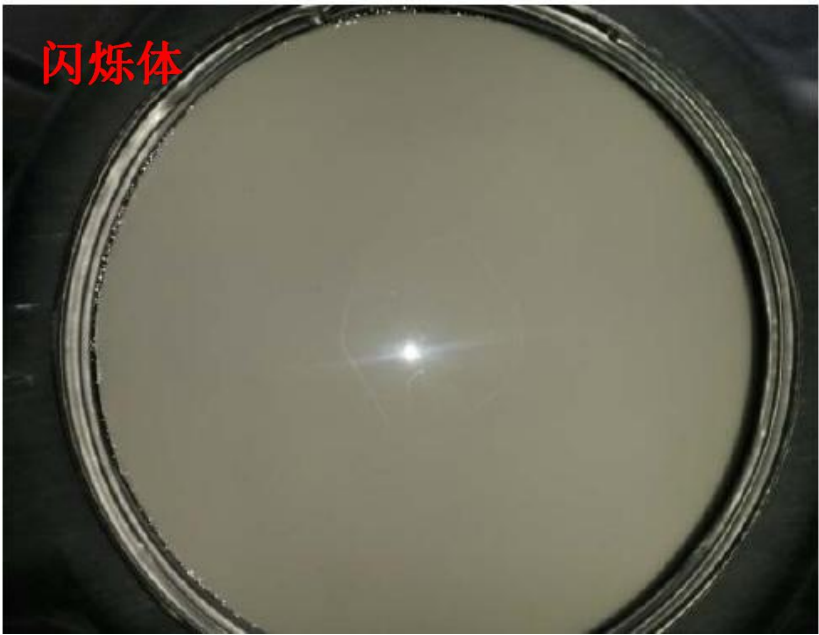
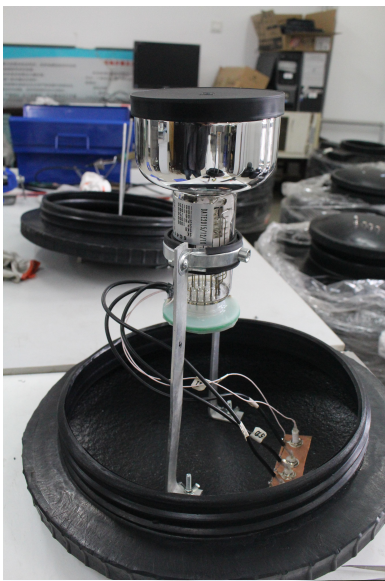
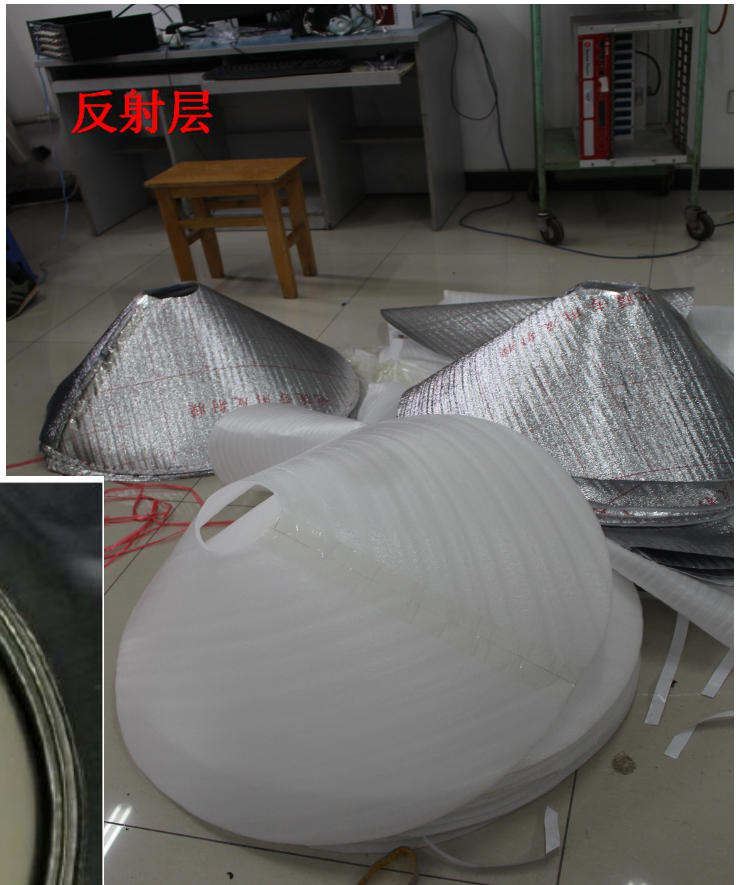
FADC（四川大学），2016.09.27

- 2016.05.07, 低压电源测试 (李兵兵, 刘帅)
- 2016.08.04, 高压电源测试 (李兵兵, 贾谊堃)
- 2016.09.08, 光电倍增管测试 (贺亚运, 李兵兵, 高博) 河北师大
- 2016.09.19, 初步安装调试探测器 (马欣华)
- 2016.10.07, 光电倍增管测试 (贺亚运, 李兵兵, 高博) 高能所
- 2016.10.12, YURI, OLEG俄罗斯科研人员进驻河北师范大学
- 2016.10.13, 四川大学三个研究生 (黄启昌等,) 进驻河北师范大学
- 2016.10.15, 现场协调会议
- 2016.10.18, 16台热中子探测器安装结束 (避光、取样、高压调节问题解决)
- 2016.10.19, 决定将探测器摆放 (研究室外五楼) 楼顶, 防雨和电源箱购买
- ~~2016.10.26, FADC出现问题, 原四路FADC, 四台探测器类似羊八井ARGO实验大厅模式摆放~~于2016年12月初解决部分问题。
- 2016.10.27, 运行

现场工作和讨论场景



探测器安装掠影

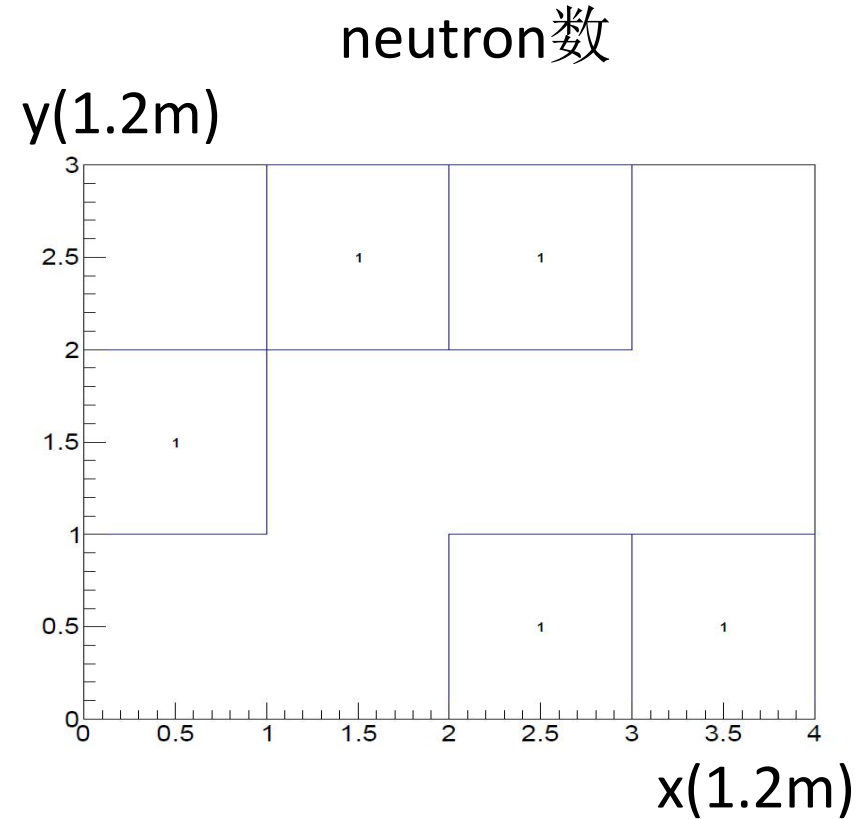
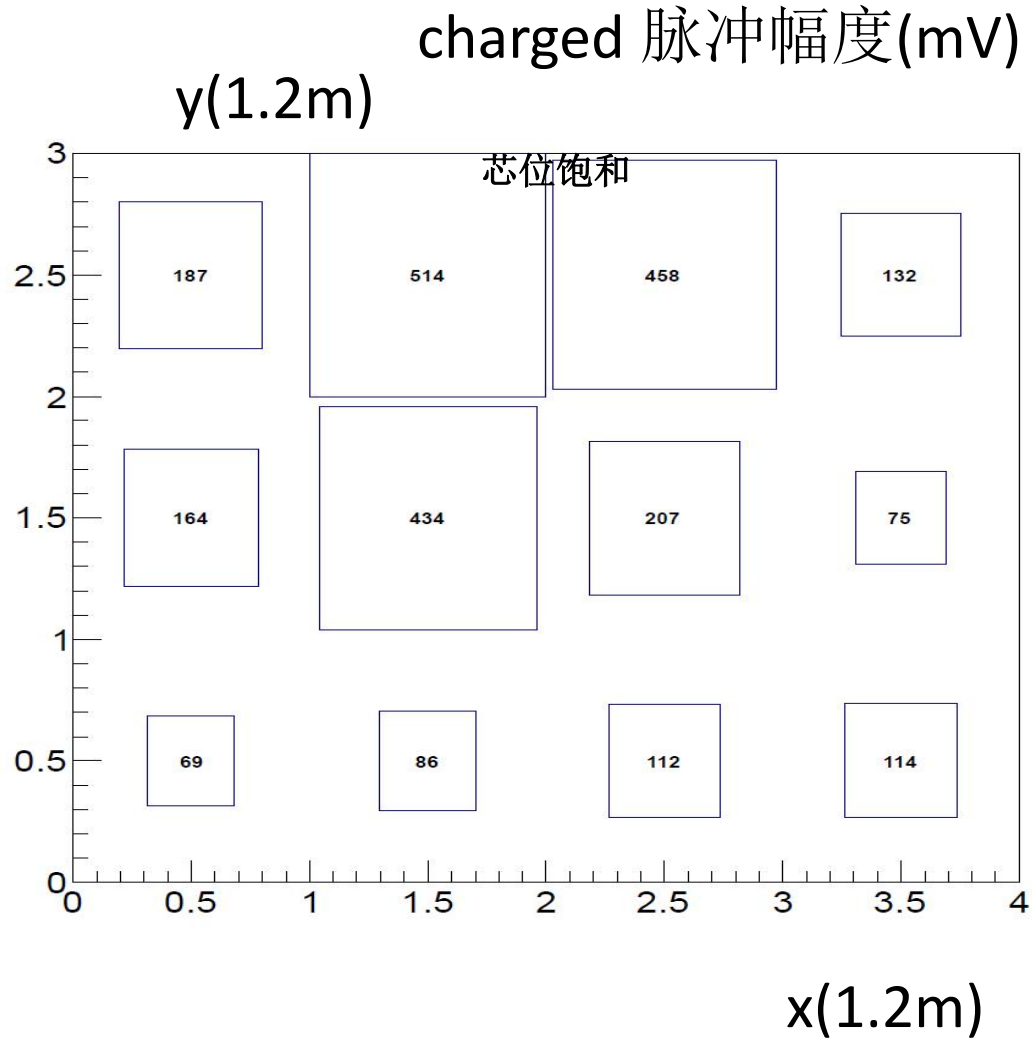


室外四个探测器阵列 和室内安装好的探测器



one EAS event

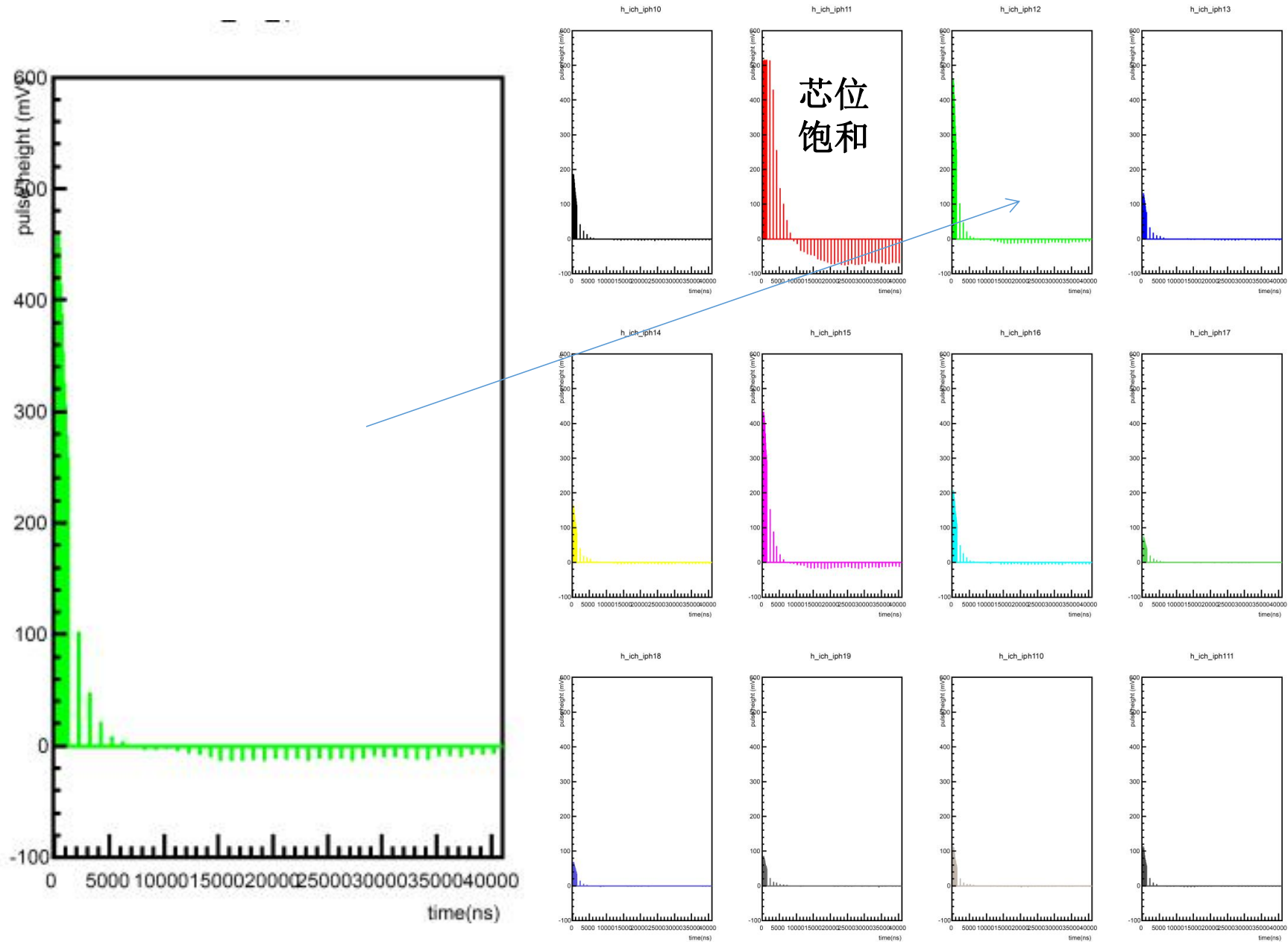
2017/01/01, 12:46:58.055, event 1001#, 5 neutrons



中子数少的可能原因:

- 1) 低海拔
- 2) 在室内

charged 脉冲

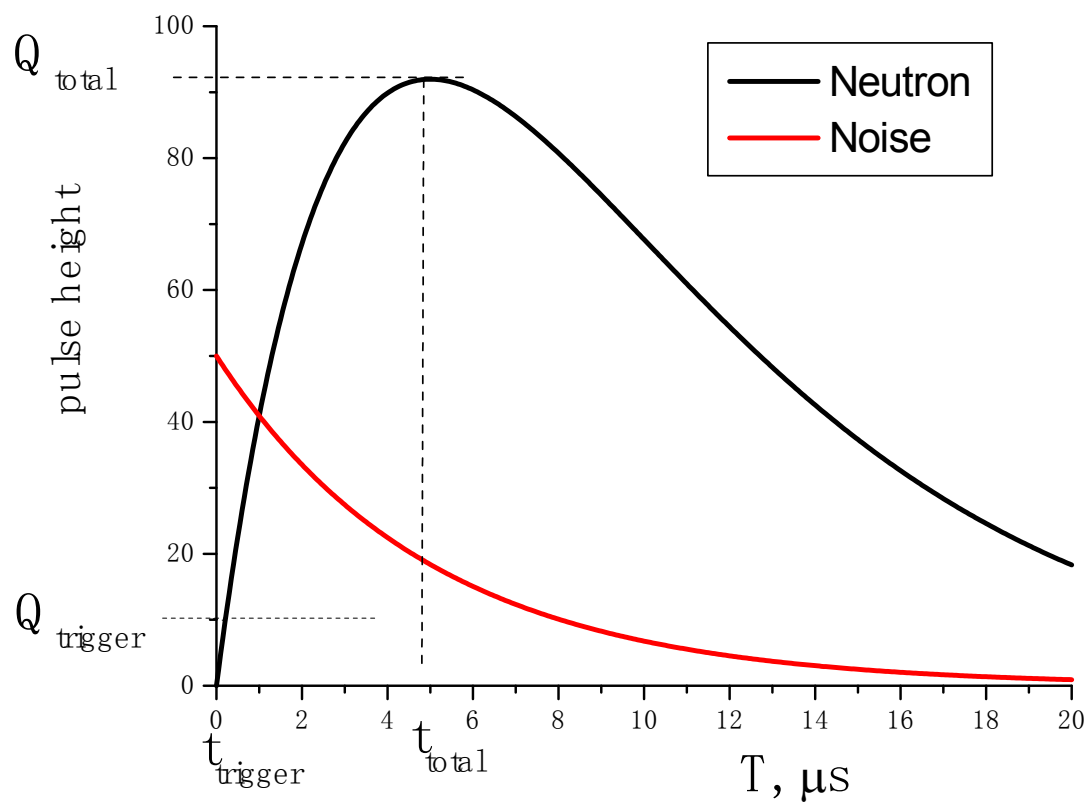


正在做的工作——

1. FADC还是稍微有点问题，正在调试解决
2. 探测器模拟——河北师大和俄罗斯
3. 数据重建——河北师大和俄罗斯
4. 热中子探测器数据分析——EEMD经验模态分解方法
5. 下一轮探测器设备订货招标测试和安装

谢谢！

中子/噪音区分



Q_{trigger}

