大型中微子射电探测望远镜 GRAND原型阶段 数据获取系统设计

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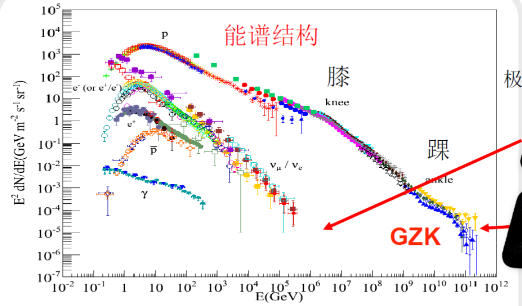
中国物理学会高能物理分会第十一届全国会员代表大会暨学术年会

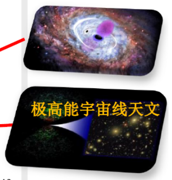
2022/08/11

大型中微子射电探测望远镜GRAND

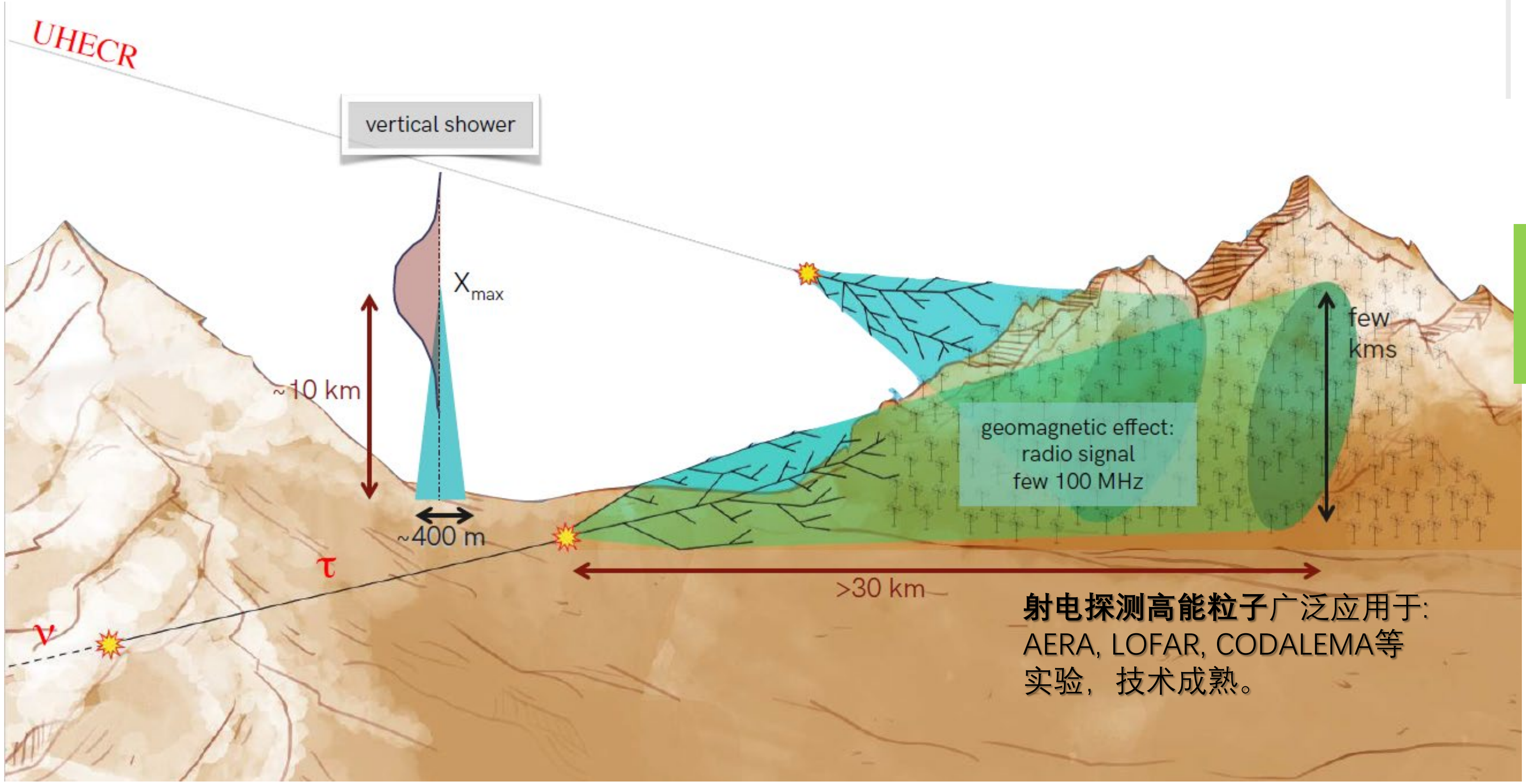
Giant Radio Array for Neutrino Detection

极高能宇宙线研究：起源，加速与传播





最高能量达3×10²⁰eV，已知物理学基本规律还成立？



射电探测高能粒子广泛应用于: AERA, LOFAR, CODALEMA等实验，技术成熟。

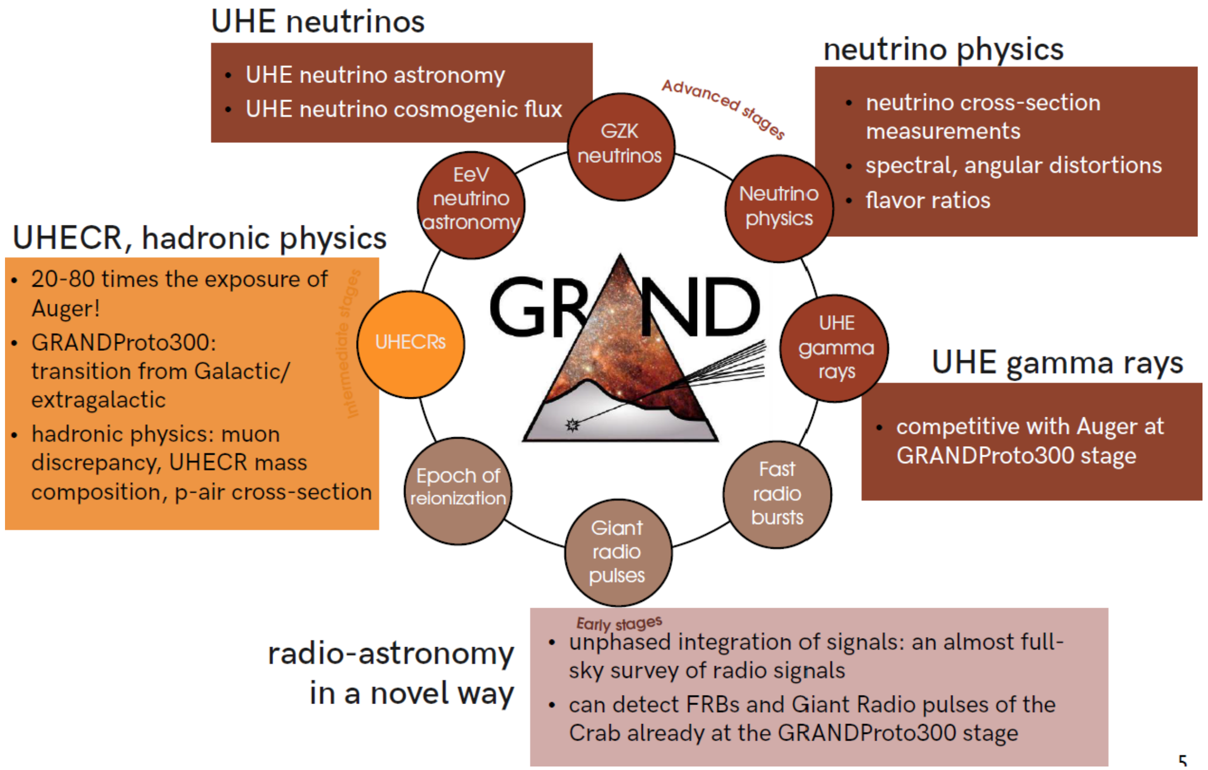
地磁场作用

在地磁场中，相对论性的正负粒子drift变化的电势差

优点：

- 射电天线价格较低，安装调试简单，易大规模扩展
- 可以收集到簇射的整个演化过程
- 相比较大气荧光探测技术，几乎可以在任何天气条件下运行(雷电除外)

GRAND科学目标和实施计划



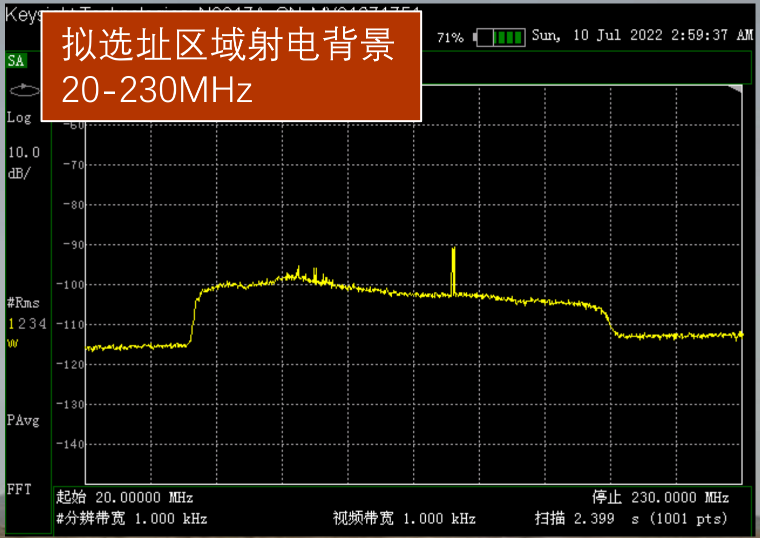
当前

2022：GRANDProto300，验证射电自触发探测技术，实现对超大倾角宇宙线的观测

2025：GRAND10k，发现EeV中微子的踪迹

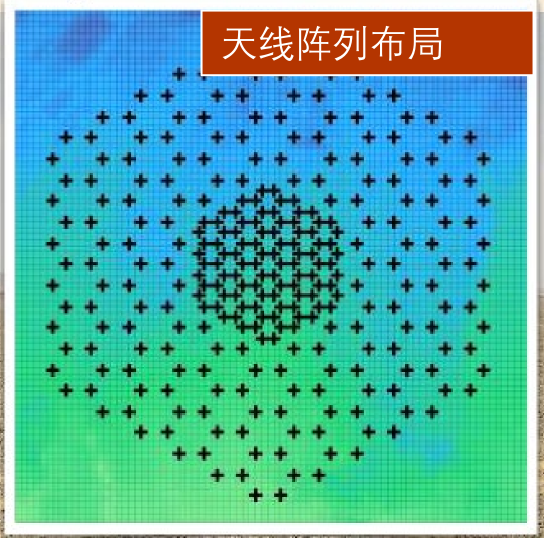
203x：GRAND200k，20组10k阵列，世界最大的中微子射电观测实验

GrandProto300

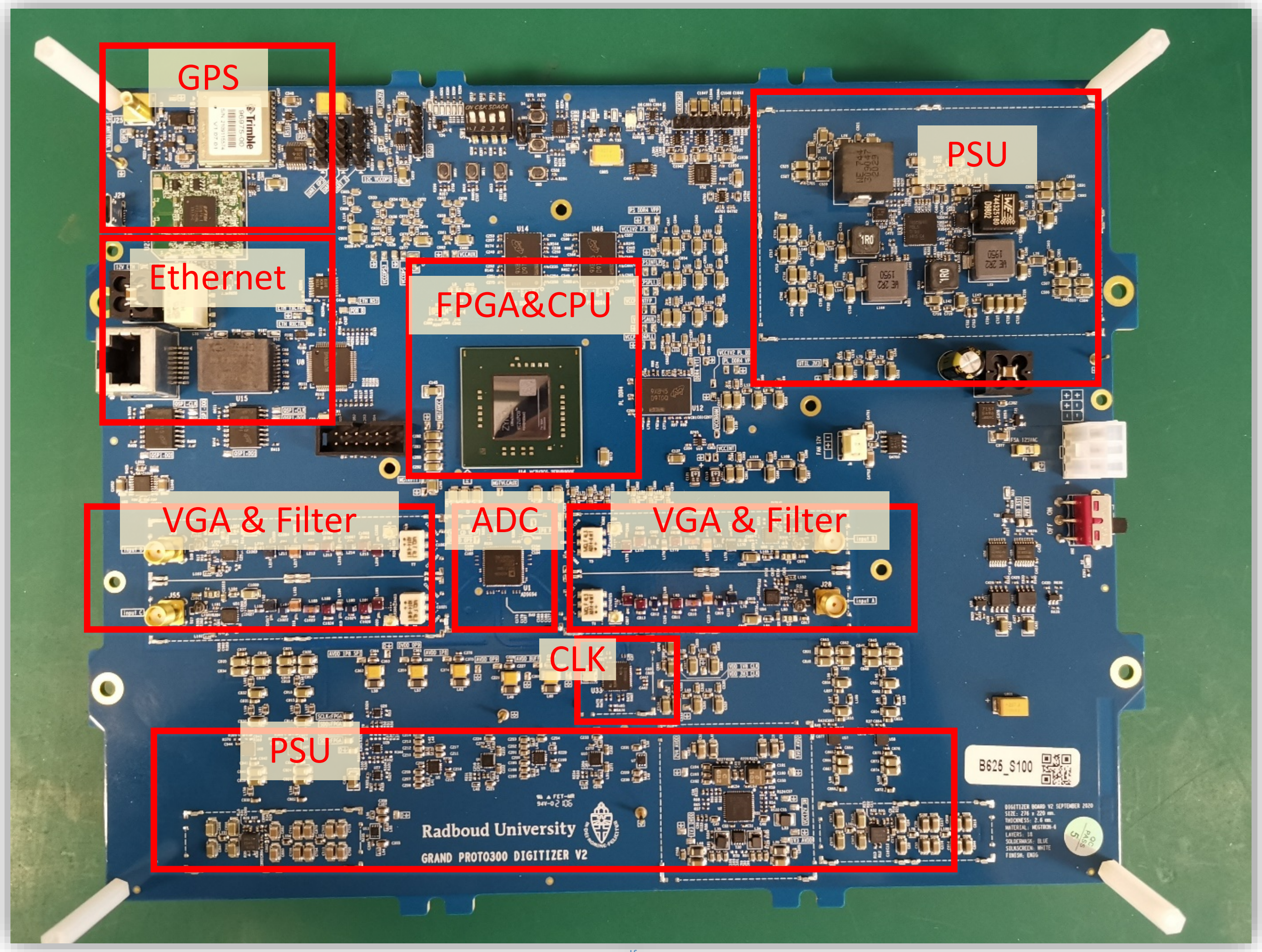


Layout: 300 antennas, 200km^2, 1km step size with denser infill

Erange = $10^{16.5}$-10^{18}eV ~EeV

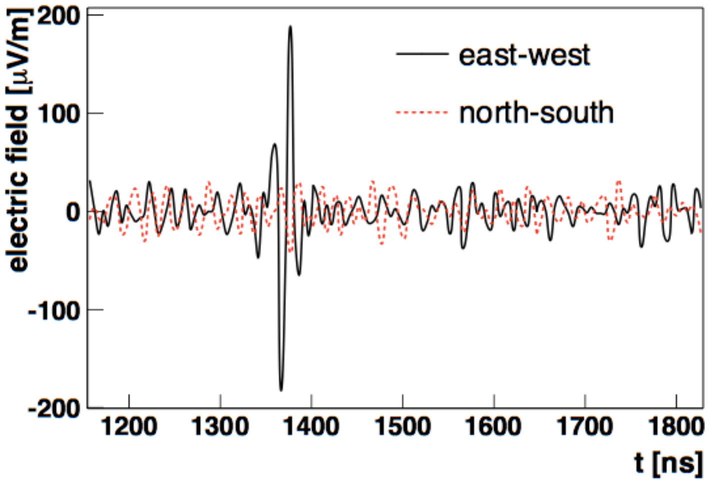


GP300电子学板

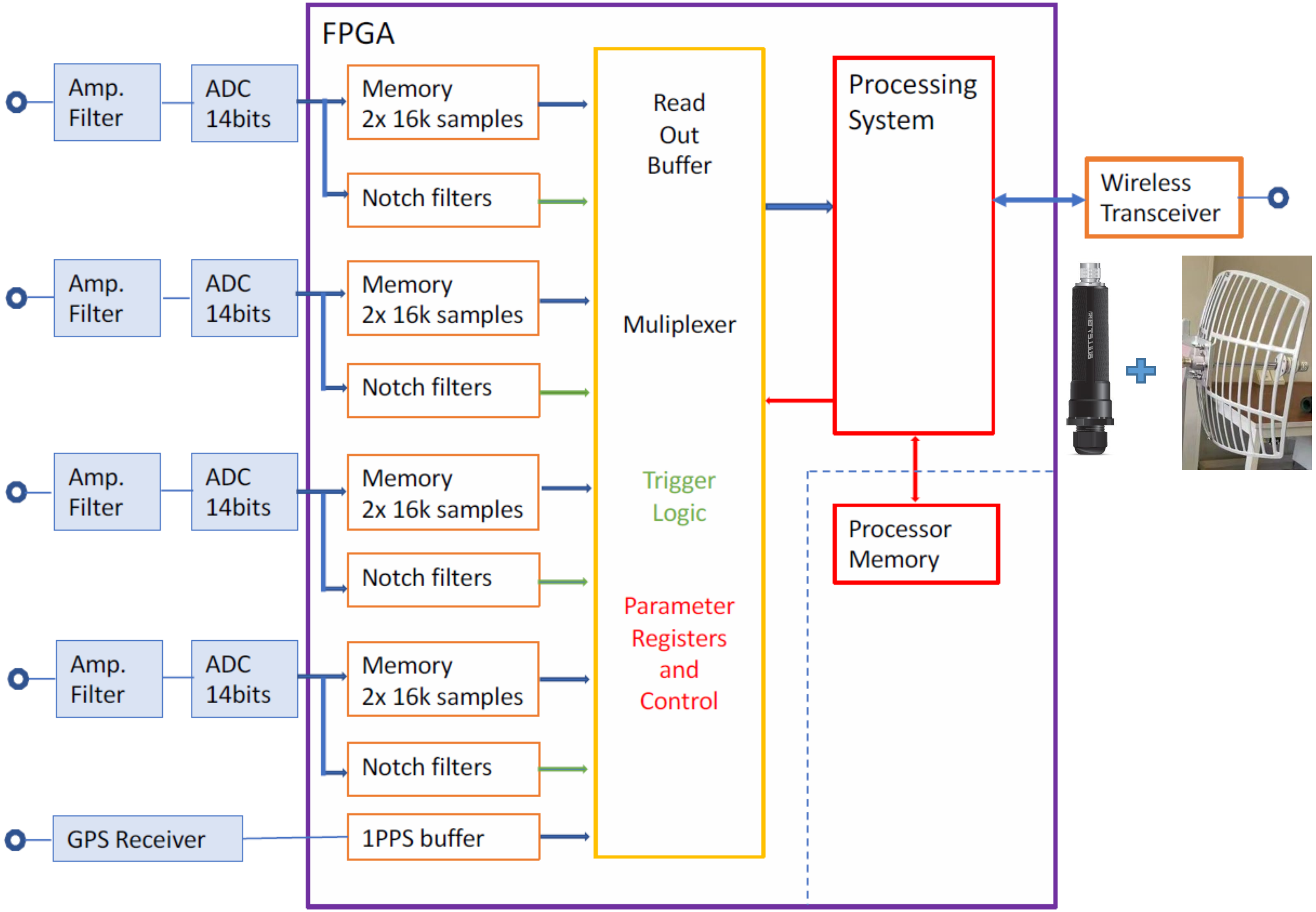


- Sampling 4 channels at **500MHz**
- Time stamping using GPS (or Galileo or Beidou) up to **10 ns**
- Advanced FPGA for digital trigger algorithms
- Powerful CPU running the DAQ software
- Wireless 5 GHz connection to central DAQ
- ~**15W，** 5 days when battery alone

GP300固件逻辑



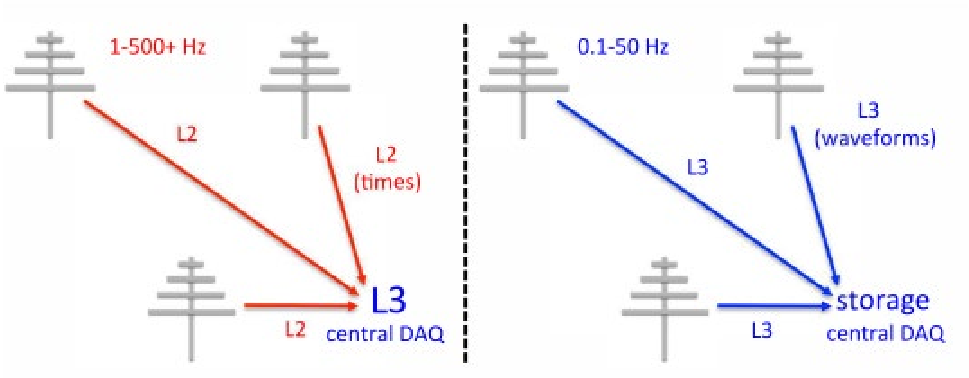
electric field [μV/m]
200
100
0
-100
-200
1200
1300
1400
1500
1600
1700
1800
t [ns]
east-west
north-south

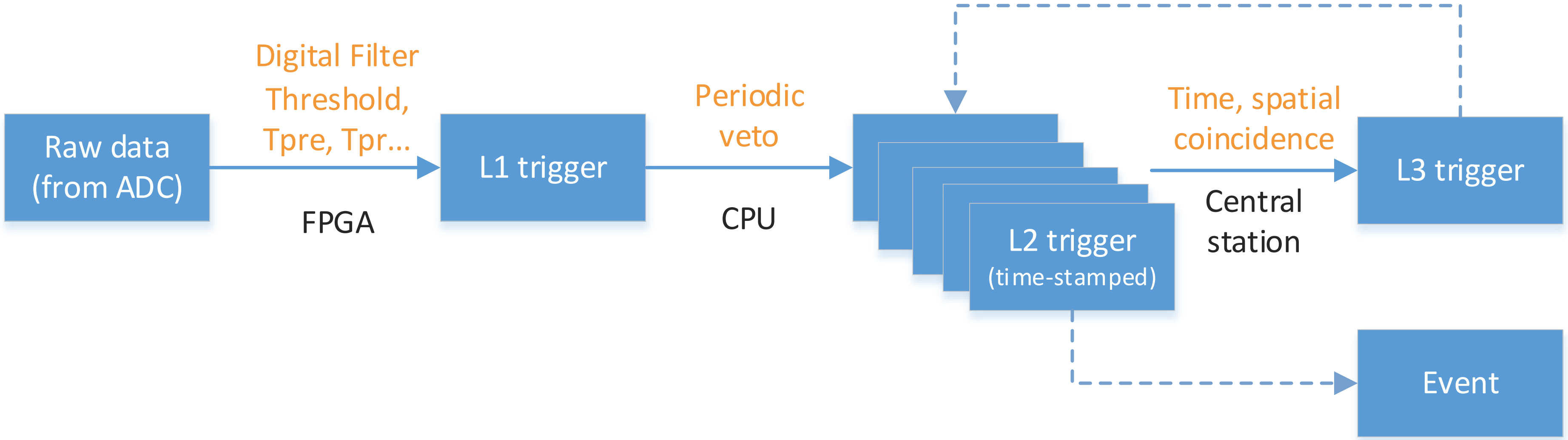


FPGA
Amp. Filter
ADC 14bits
Memory 2x 16k samples
Notch filters
Amp. Filter
ADC 14bits
Memory 2x 16k samples
Notch filters
Amp. Filter
ADC 14bits
Memory 2x 16k samples
Notch filters
Amp. Filter
ADC 14bits
Memory 2x 16k samples
Notch filters
GPS Receiver
1PPS buffer
Read Out Buffer
Muliplexer
Trigger Logic
Parameter Registers and Control
Processing System
Processor Memory
Wireless Transceiver

*10.1016/j.nima.2012.11.153

GP300数据链路(三级触发)



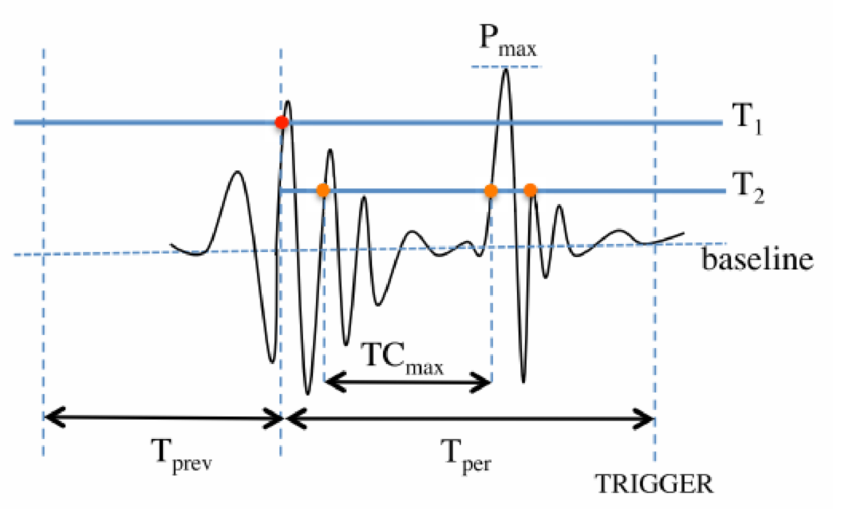


Triggered data:
1 DU trace： 1024pts * 2B(14bits) * 4 Channel = 8kB

For **10Hz** L3 trigger rate(design), **20** detector units(DUs) triggered, Throughput 8kB * 10Hz * 20 * 8 = **12.8Mbps** required.

With **Ubiquity** bullet and airFiber, **300Mbps** over 50km+

GP300硬件触发算法(L1)

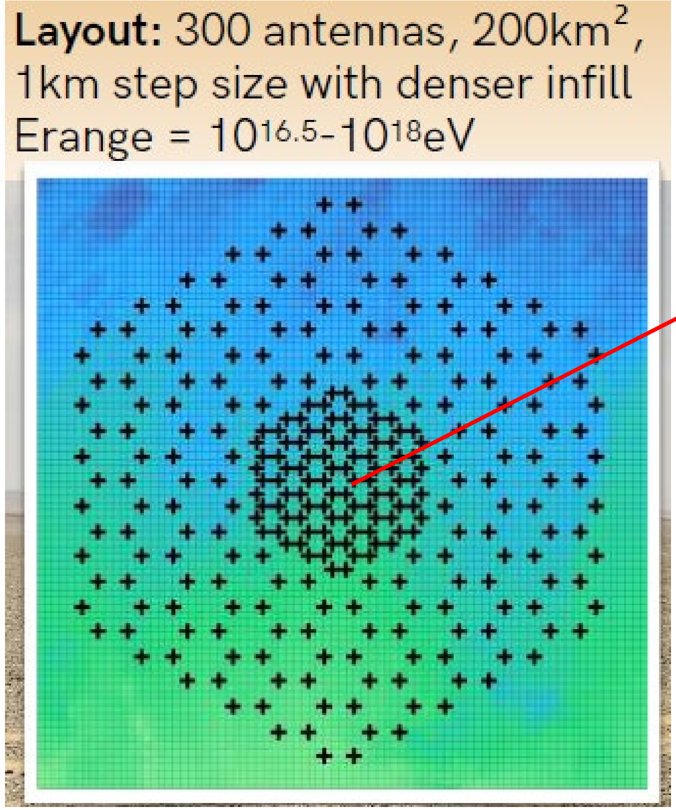


T1 = 5 σ, T2 = 3.75 σ, NC (1-8),
Tprev=1.25us，Tper = 6.25us,   TC = 130ns

1. the voltage rising edge crosses the primary threshold T_1;
2. before the T_1 crossing, no other T_1 crossings occur during the previous time period T_{prev};
3. after the T_1 crossing, the signal rising edge crosses a secondary threshold T_2, where normally $T_2 < T_1$;
4. the number of rising-edge T_2 crossings NC within a time period T_{per} falls within a specified range $NC_{min} < NC < NC_{max}$;
5. the time TC between successive T_2 crossings is less than a maximum value TC_{max};
6. the quotient Q of the pulse maximum P_{max} divided by the number of T_2 crossings NC falls within the range $Q_{min} < Q < Q_{max}$.

GRAND需要根据仿真和实验数据，自定义L1触发策略。
实验的第一阶段，考虑设置宽松触发条件，获取较长时间的原始数据。
闪烁探测器外触发

GP300 数据中心

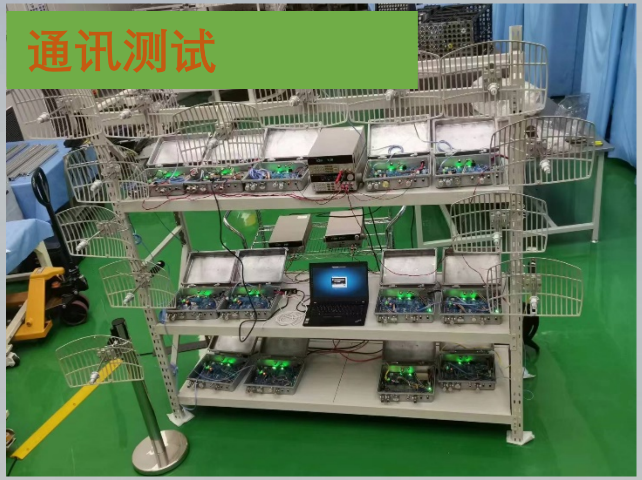


1 中心站，太阳能供电，位于阵列中心, L3触发和slow control。**微波中继（1Gbps）**连接到数据机房(市电)。

日均数据量 12.8Mbps/8*24*3600 = **140GB(max)**,
绝大多数是噪声，根据模拟，一天大概2700个事例，需要**数据离线处理。**

总结和计划

- 100组探测器单元已完成生产(天线, LNA, 太阳能面板, 电池, 机械结构, 电子学板)
- 电子学板测试完成
  - 高低温, 老练, 信号采集
- 项目选址初步确定→**甘肃敦煌**
- 计划**9月份**开始首批13组探测器单元的安装和试运行



相关报告:

(Poster) Introduction of DAQ System`s Firmware of Giant Radio Array for Neutrino Detection　许行

(Poster) “GRAND”数据获取电子学板的测试研究　陈义仁

项目重要参与单位(国内):

西安电子科技大学, 高能物理研究所, 国家天文台等