The Askaryan Radio Array

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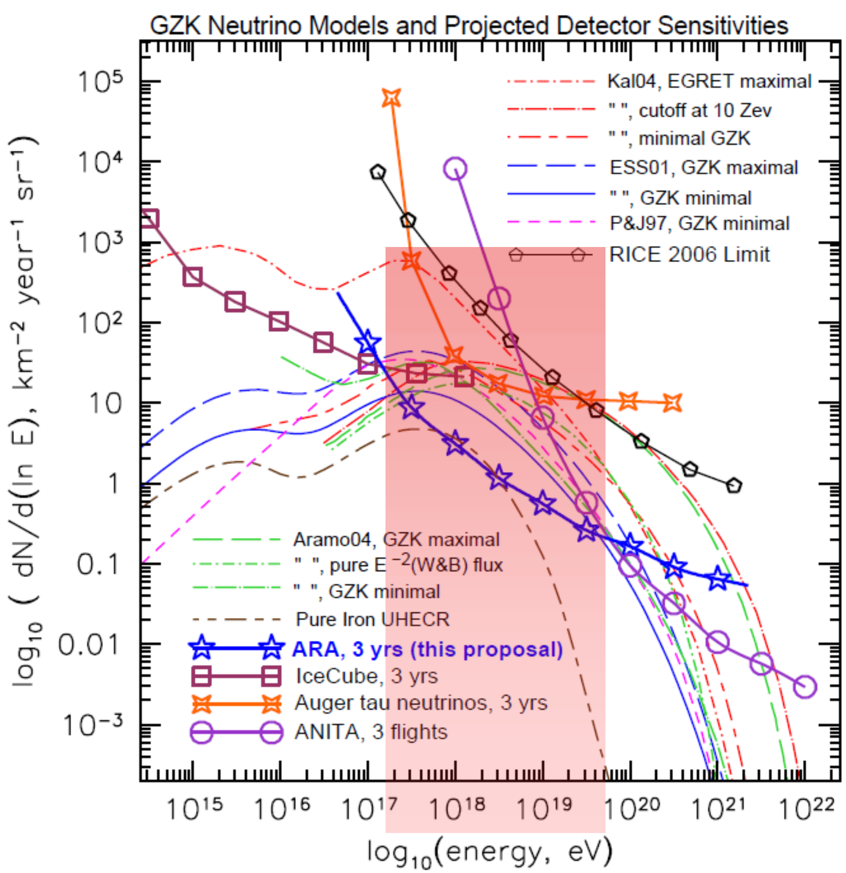
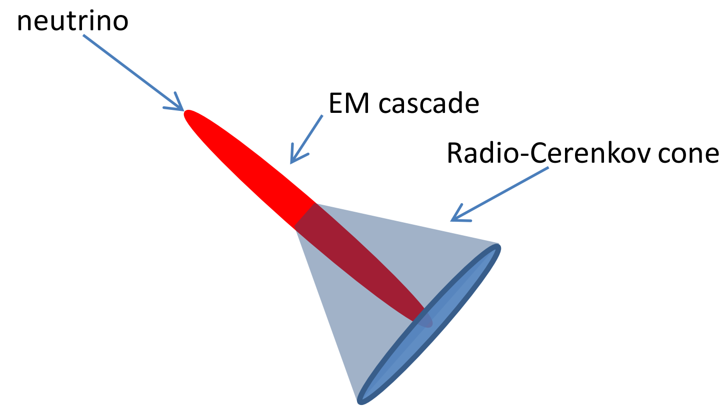
Outline

- ARA
  - Motivation/goal
  - Detector geometry
  - Event reconstruction
  - The test bed
  - Power supplies
- Current IIHE involvement
  - Digital data transmission system

The motivation/goal

- Expecting <1 GZK neutrino interaction per km^3 per year
  - ➢ **Big detector needed**





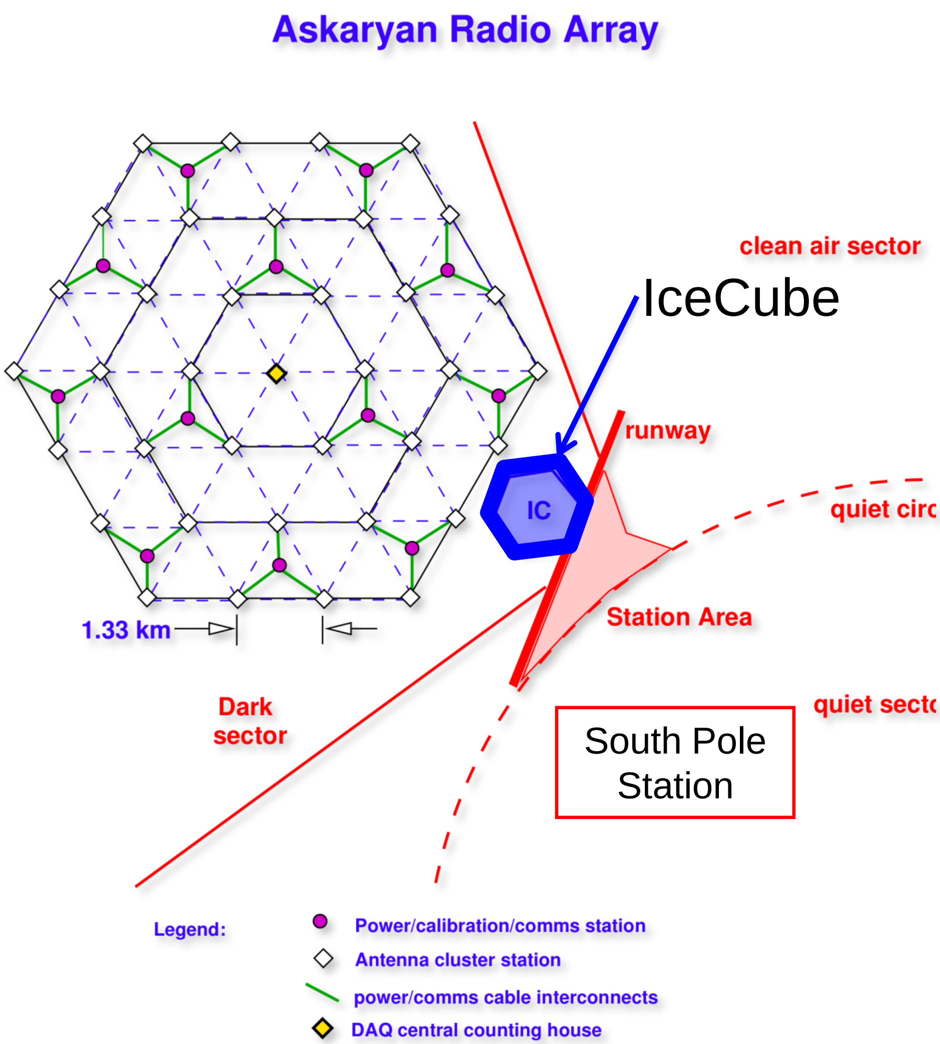
Want to detect neutrinos based on:

- Emission of coherent radio waves from neutrino-induced EM-cascades (predicted by Askar'yan, 1962)
- Verified at SLAC in 2000

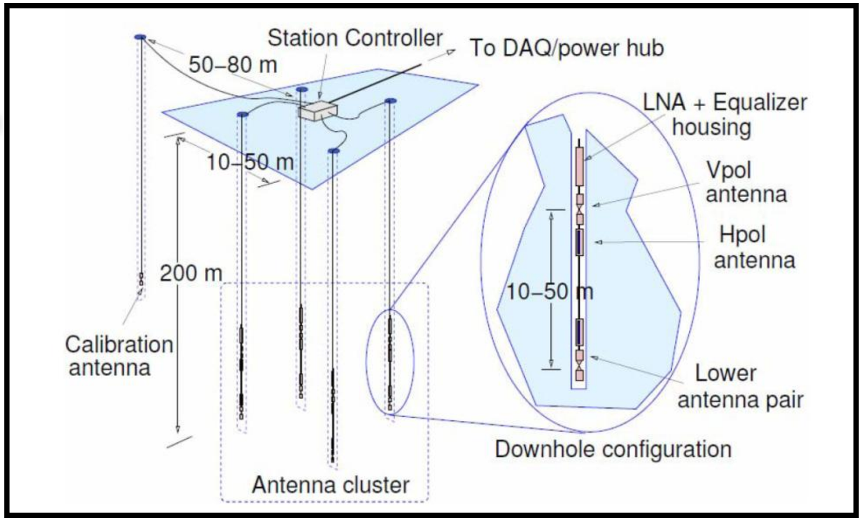
Why this detection method:

- Radio waves have high attenuation length in certain media (ex.: ~800m in ice)
- Radio antennas are cheap sensors compared to optical modules

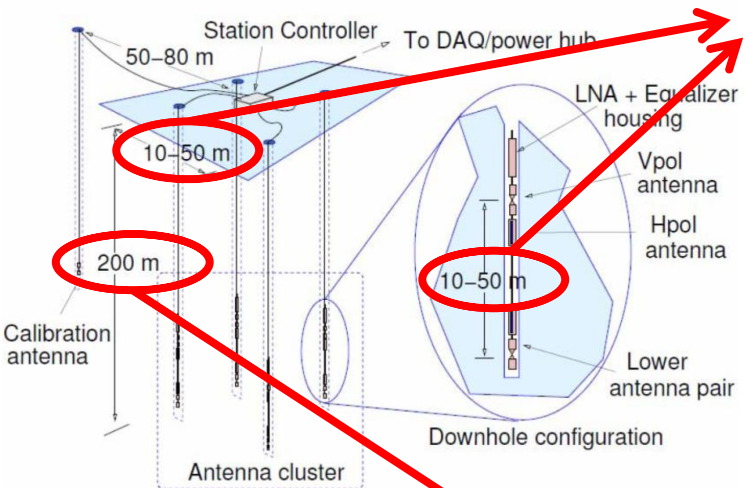
Detector geometry



- 37 stations
- 80km^2 coverage
- **One station:**
  - 16 + 2 antennas
    (8 h-pol., 8 v-pol., 2 cal. pulsers)



Detector geometry

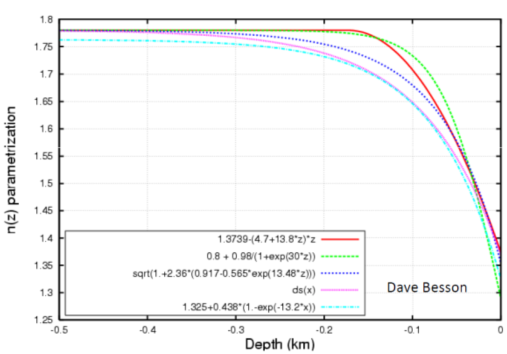


20 m - compromise between:

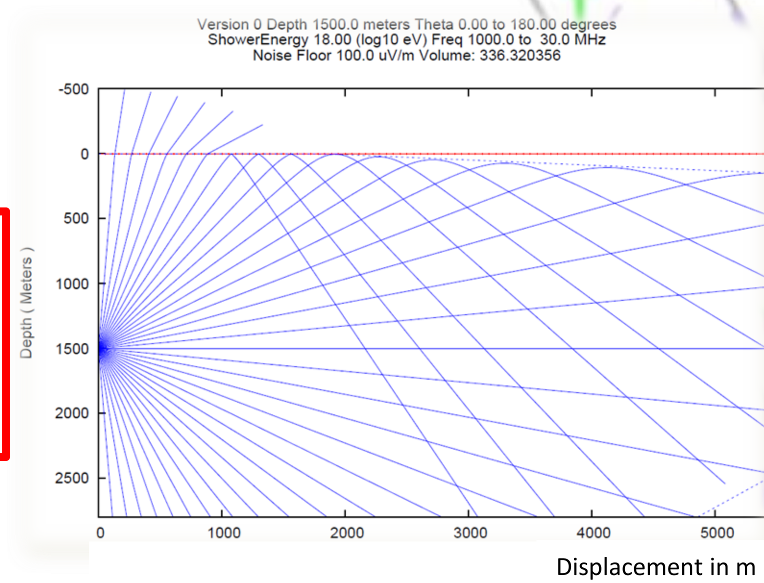
- Best angular resolution
- Maximum acceptable trigger rate

1.3 km station spacing:

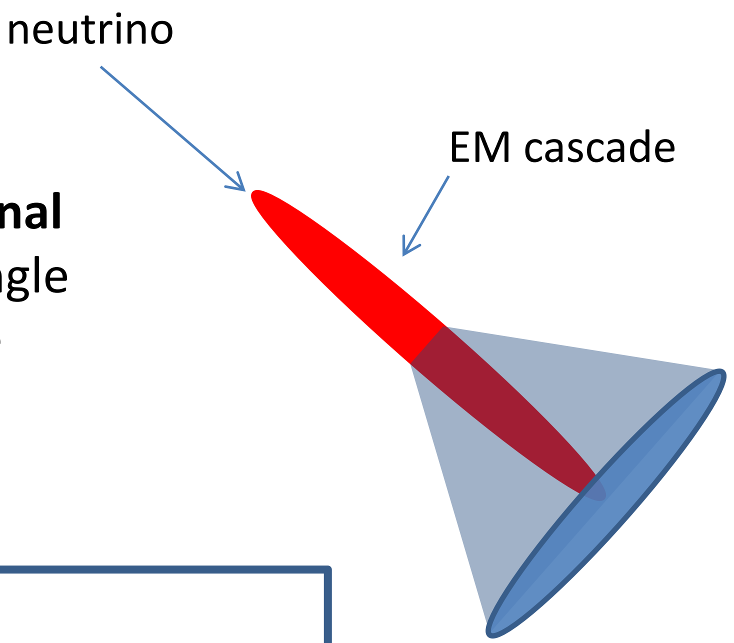
- Attenuation length for radio waves in ice ~800m



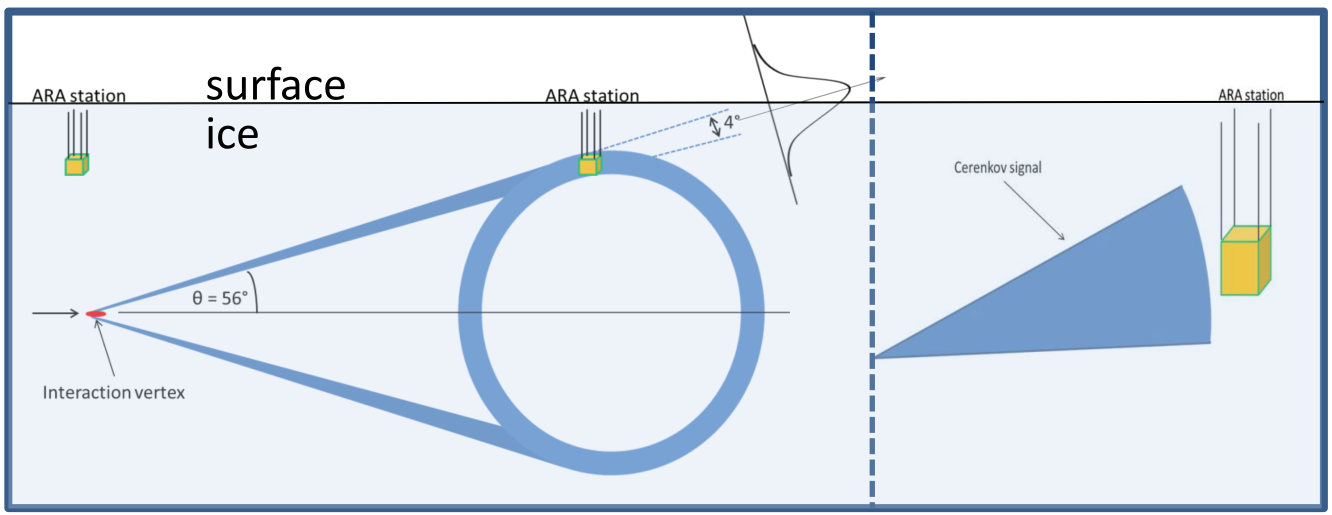
- Ray tracing: due to n(z) dependence radio signal is bent down in the firn
- **200m depth,** accounting for drilling costs



Event reconstruction



- **Fraunhofer diffraction of the emitted signal**
  - Signal is Gaussian distributed over angle Δθ around opening angle of the cone



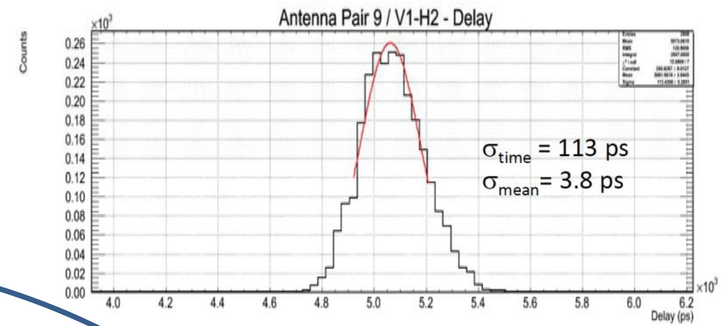
Reconstruction via grid search:

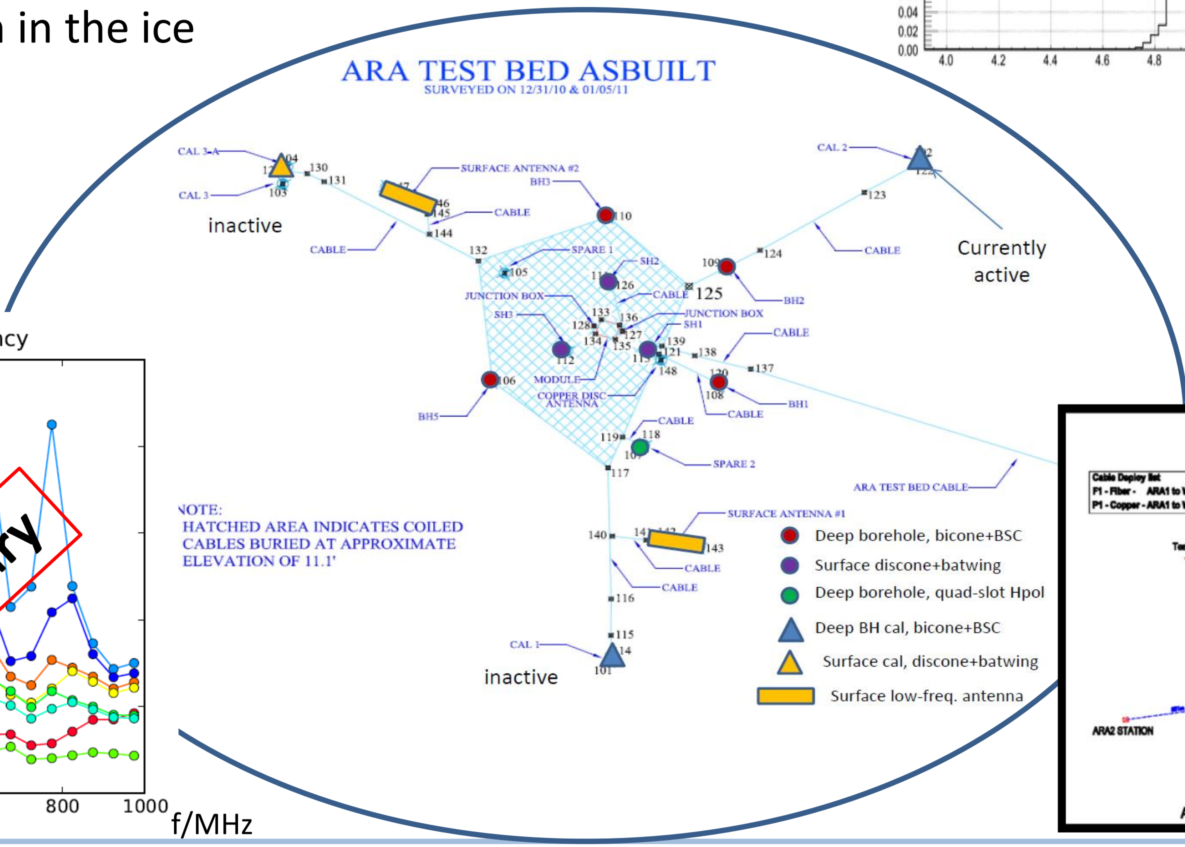
$$\chi^2 = \sum_i \frac{[\Delta t_i^{obs} - \Delta t_i^{hyp}(x_{sh}^{hyp})]^2}{\sigma_t^2}$$

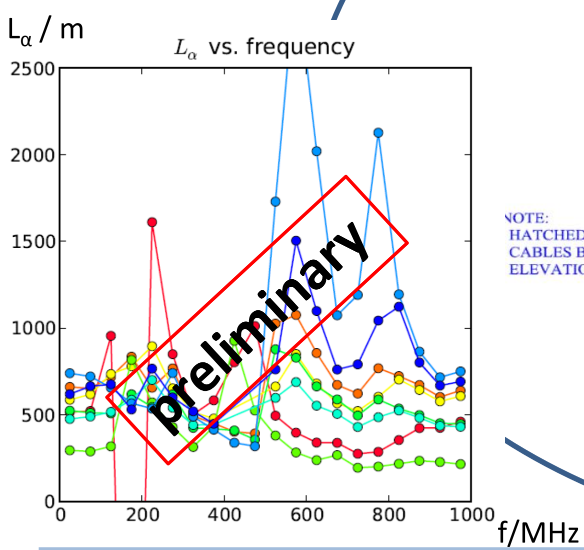
Δt = time difference between antenna triggers

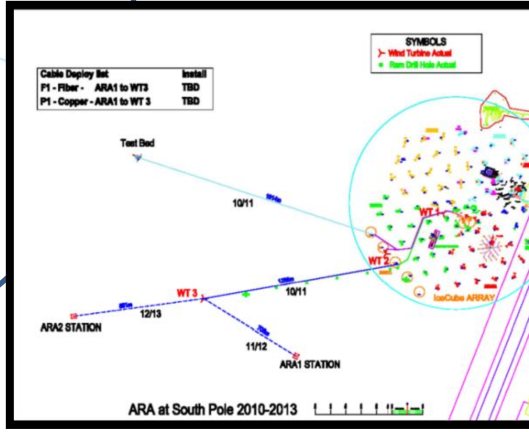
The test bed

Different goals:
- Study background noise
- Study reconstruction possibilities
- Measure frequency dependent attenuation in the ice









Power supplies

Move to "green" energy

Photos by Mark Dierckxsens

Estimated consumption: 300W / cluster (3 stations)
Future plan: Use only regenerative energies

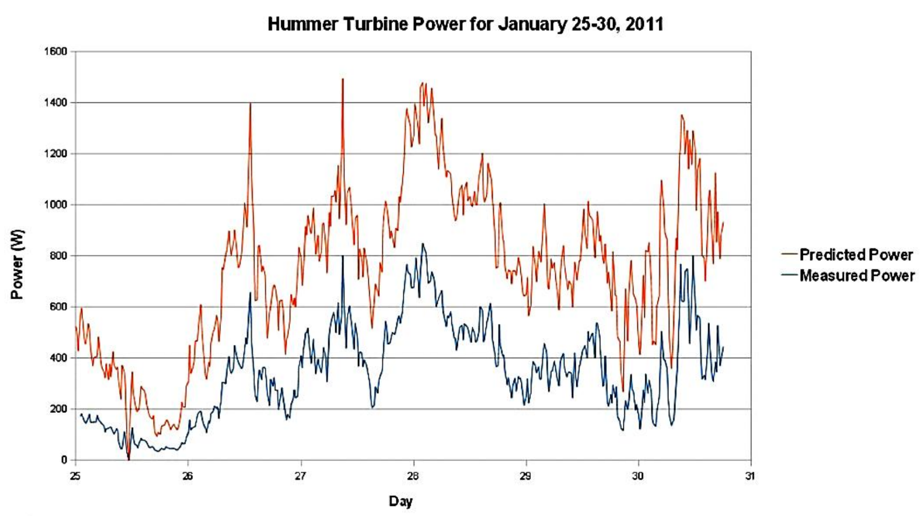
Why is it important:

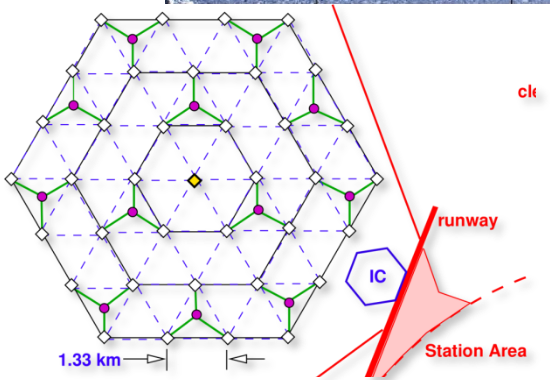
- To be autonomous
- Technically difficult to distribute all the power from the south pole station

Status:

- 3 wind turbines + batteries deployed for test measurements

Photo by Ken Ratzlaff, KU





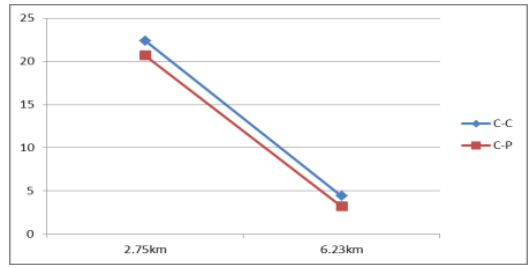
IIHE work

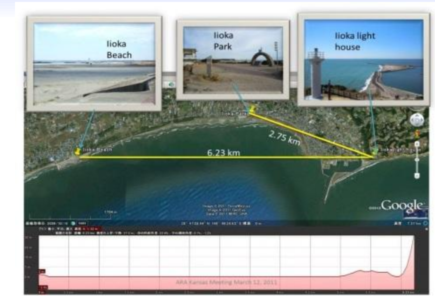
The IIHE involvement

1. **Long distant wireless network**
2. **GPS, Rubidium clock tests**

both together with Chiba university

[Mbps]

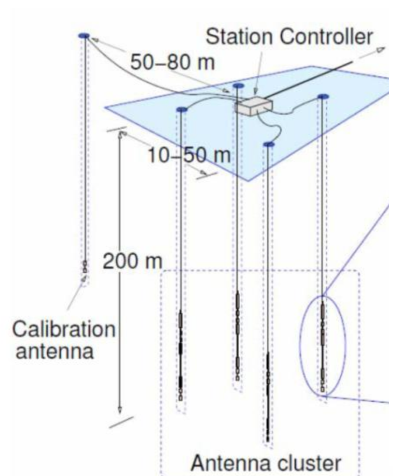


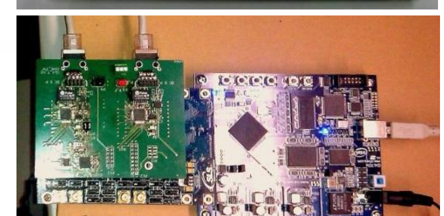


3. **Digital data and clock transmission for antenna data**

The challenge:

- **In general:**
  - data and clock transmission:
  - at highest speed
  - lowest power consumption possible
  - over a distance of >200m
  - Precise timing between holes
- **Specifically:**
  - Speed: O(100Mbits/s)
  - Transmission distance: 250m
  - Time precision in the hole: <50 ps





The motivation

Collaboration status in August 2010:

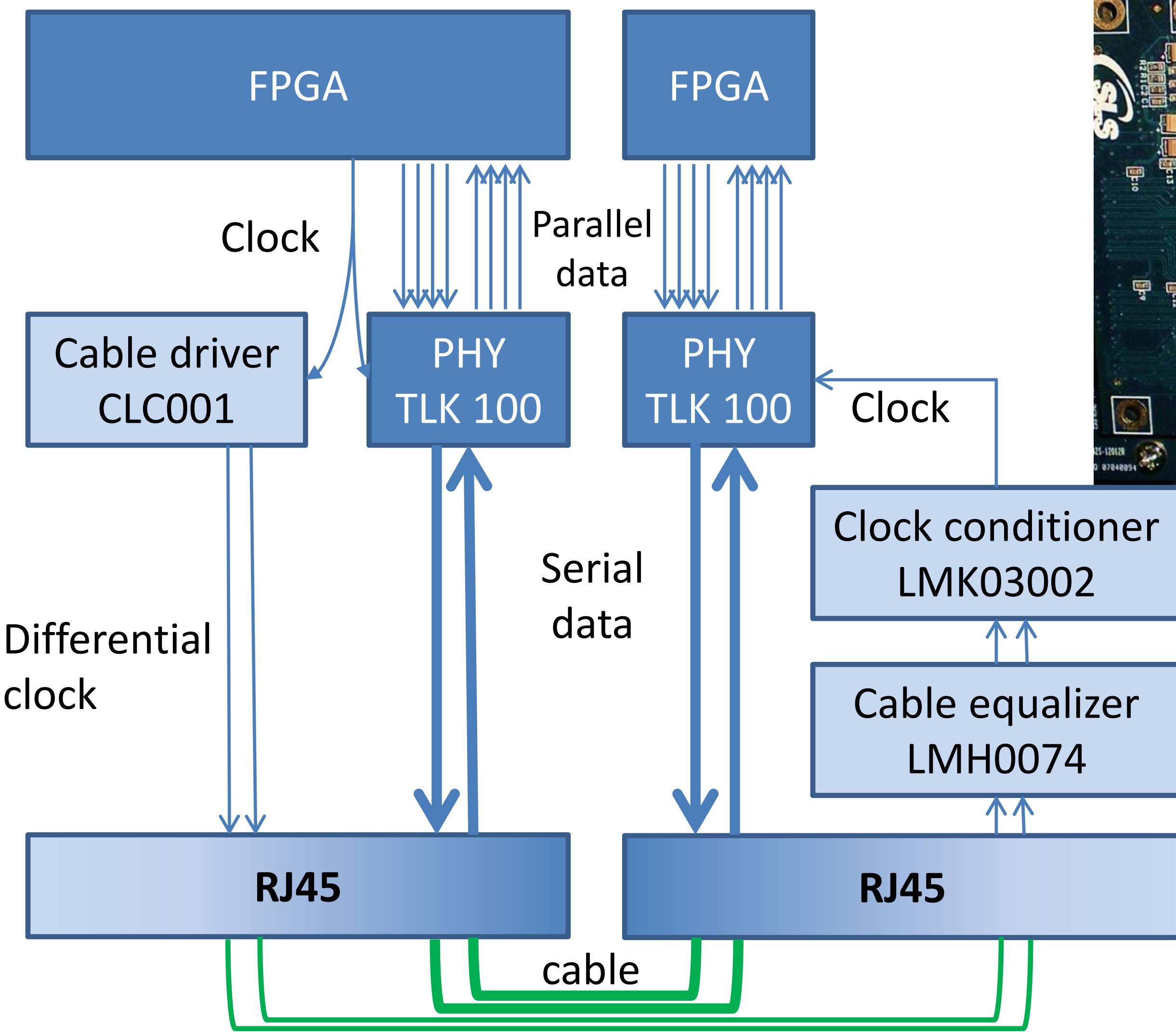
- analog data transmission via copper cable
- **But there are disadvantages:**
  - EMI problems
  - Bulky cables
  - Problems with timing calibration (high jitter)
  - Too much power needed for transmission

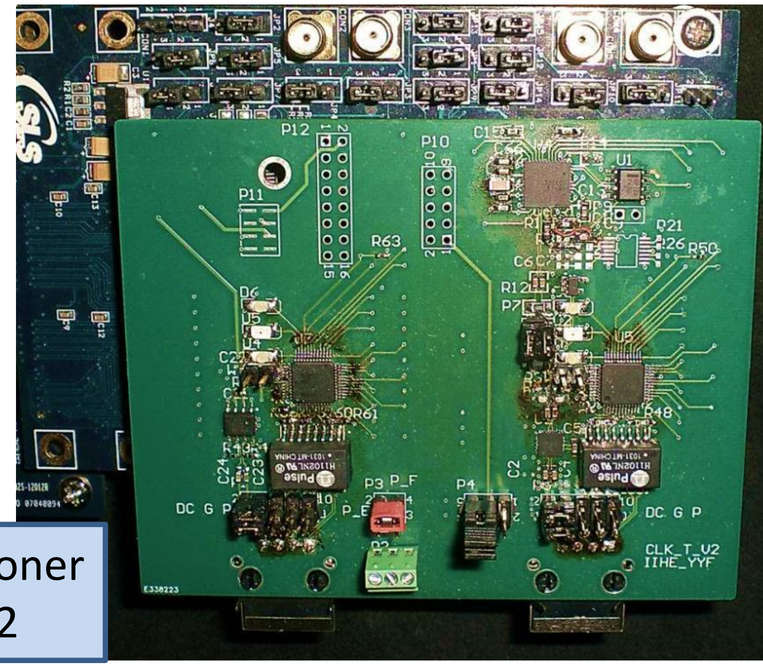
Proposed alternatives:

- Digital over optic fiber -> **rejected at that time because of high costs and fragility**
- Digital over copper:
  - Only small cable needed
  - Low power consumption possible

} **Developed in Brussels**

The setup



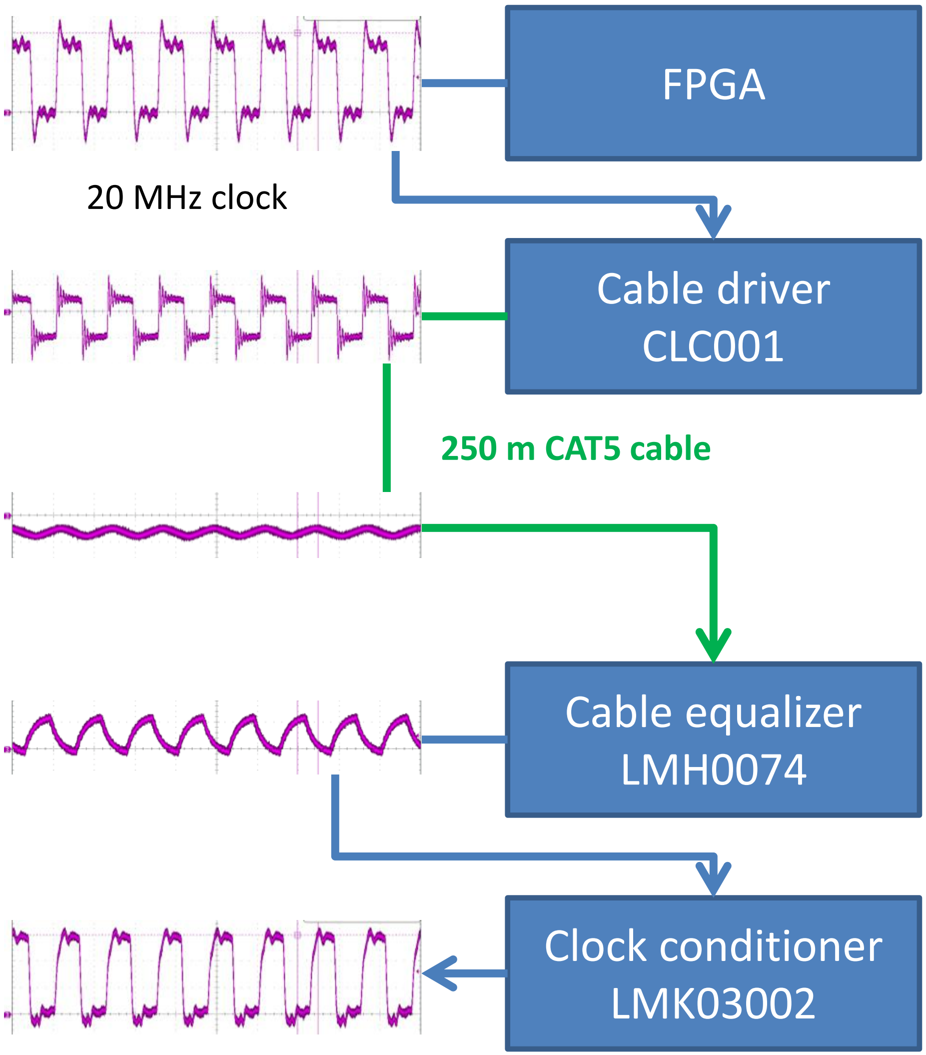


TLK100

- 10/100 Mbits/s Ethernet phy, 25MHz input clock
- **In current design:** driven by 20MHz clock
  - ➢ 8/80 Mbits/s
- Power consumption: 200 mW

The setup

Clock transfer system



Cable driver:

- Amplifying the incoming clock to transfer it
  - 400 ps rise time, 25 ps output jitter
  - 1 Vpp output
  - Power consumption: 520 mW

Cable equalizer:

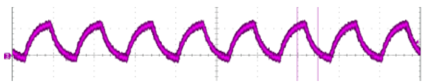
- equalization
- DC restoration
  - 750 mVpp output
  - Power consumption: 255 mW

Clock conditioner:

- Loop filtering
- Jitter cleaning
- Clock distribution
  - 200 fs output jitter
  - Power consumption: 578 mW

The setup

Clock conditioner

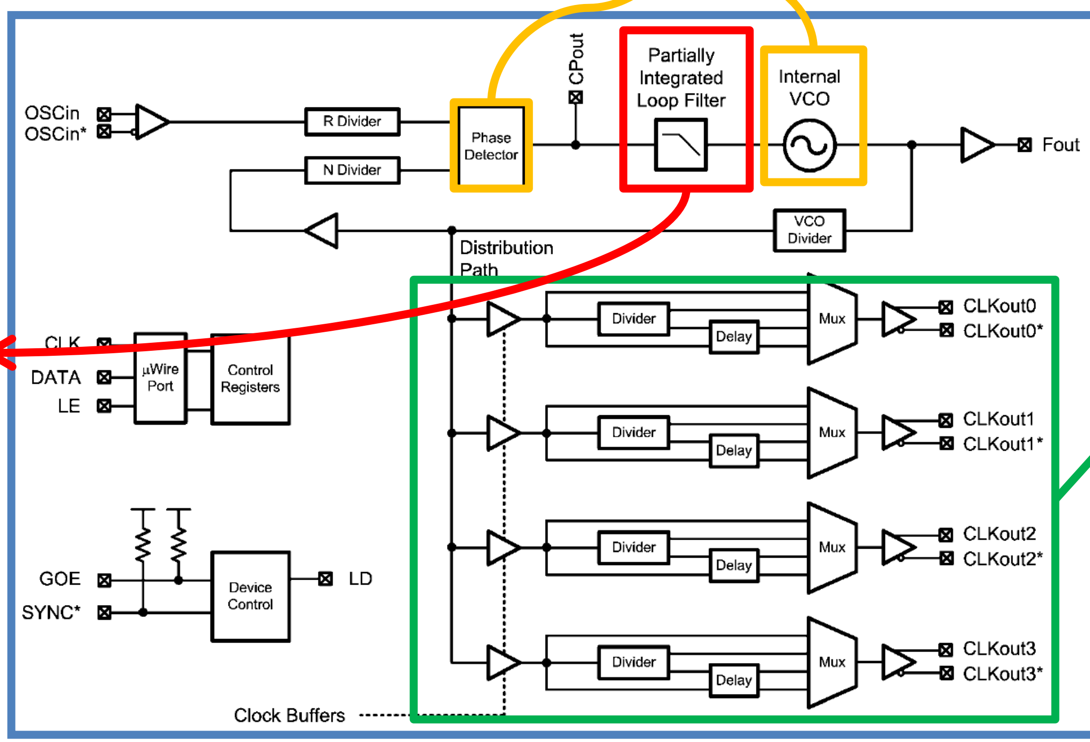


Makes clock detection easier for VCO

Voltage **C**ontrolled **O**scillator + phase detector

- **VCO** generates new clock
- Clock frequency is adjusted until phase detector doesn't find a difference to OSCin

"Fresh" clock with correct frequency supplied to PLL

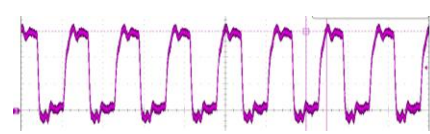


Loop filter:

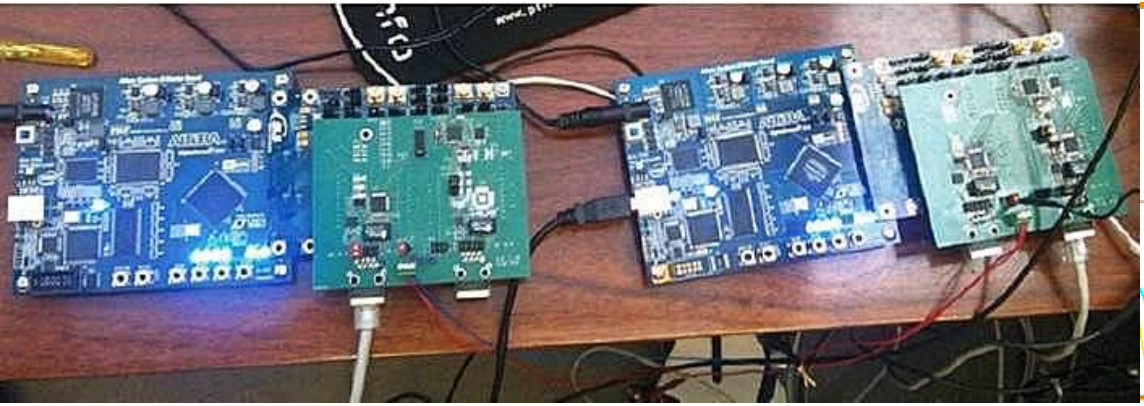
- 4 pole low pass, to remove high freqency noise

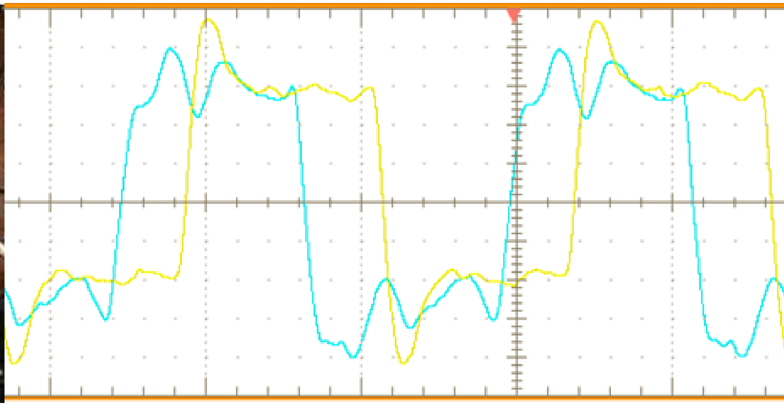
PLL:

- Clock distribution
- Frequency modulation
- Phase adjustment



Test results





Precision of period → Period1, Ch1; Period2, Ch2; TIE1, Ch1; TIE2, Ch2

shift between clocks → Skew1, Ch1, Ch2

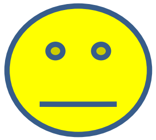
Description	Mean	Std Dev	Number of samples
Period1, Ch1	50ns	16ps	239988
Period2, Ch2	50ns	27ps	239976
TIE1, Ch1	0s	26ps	240000
TIE2, Ch2	0s	50ps	239988
Skew1, Ch1, Ch2	-8ns	52ps	239988
IP-failure rate (down to -40°C)	1.2E-8/32bits		4.3E11 (72 hours)
Power consumption	~2.3W		

Future plans

Presented system was not accepted by the ARA collaboration:

- Trigger rate raised from ~4MHz to ~40MHz
- Copper prizes raised (well shielded cable is very expensive)
- Power consumption got less important

- RF over fiber is the current choice
- **Digital system might still be interesting for other experiments**



Future plan:

Digital over optic fiber:

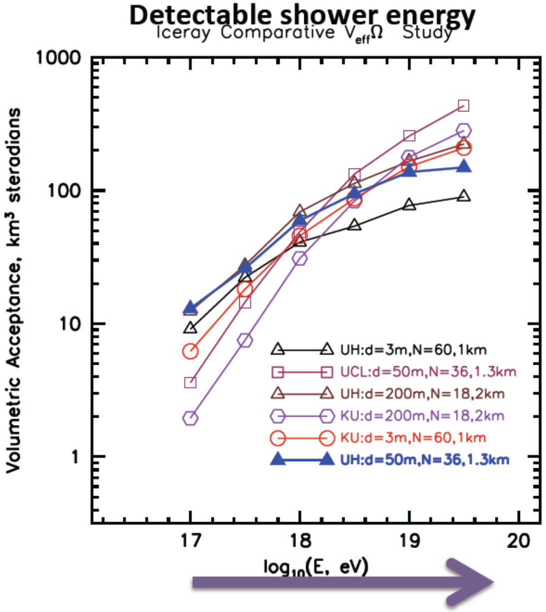
- One fiber cable for both directions carrying data and clock
- Speed: ~2GBits/s
- Clock recovered from the data (CDR – clock data recovery)
- Power consumption <700mW (for one system)

Summary

- ARA:
  - ARA detector will be able to efficiently detect GZK neutrinos
  - Test bed and power supplies are deployed to investigate possibilities
  - Future: Two ARA-stations will be ready this summer, to be deployed in the coming two years
- IIHE group
  - Currently involved in Wireless communication, GPS, rubidium clock
  - Digital data transmission system was assembled and successfully tested at the IIHE
- Future plans:
  - Digital data transmission via optic fiber
  - Firmware design for ARA electronics

Backup

Detectable shower energy



In Peter's code :

$$E(\omega, R, \theta) = E(\omega, R, \theta_C)\, e^{-\ln 2 \left[\frac{\theta - \theta_C}{\Delta\theta}\right]^2}$$

$$\Delta\theta = 2.7^{\circ} \left(\frac{500\mathrm{MHz}}{\nu}\right)\left(\frac{E_{LPM}}{0.14E_0 + E_{LPM}}\right)^{0.3}$$

$E_0 = 10^{17.5}$eV ~ $10^{19.5}$eV

where $E_{LPM} = 2$ PeV

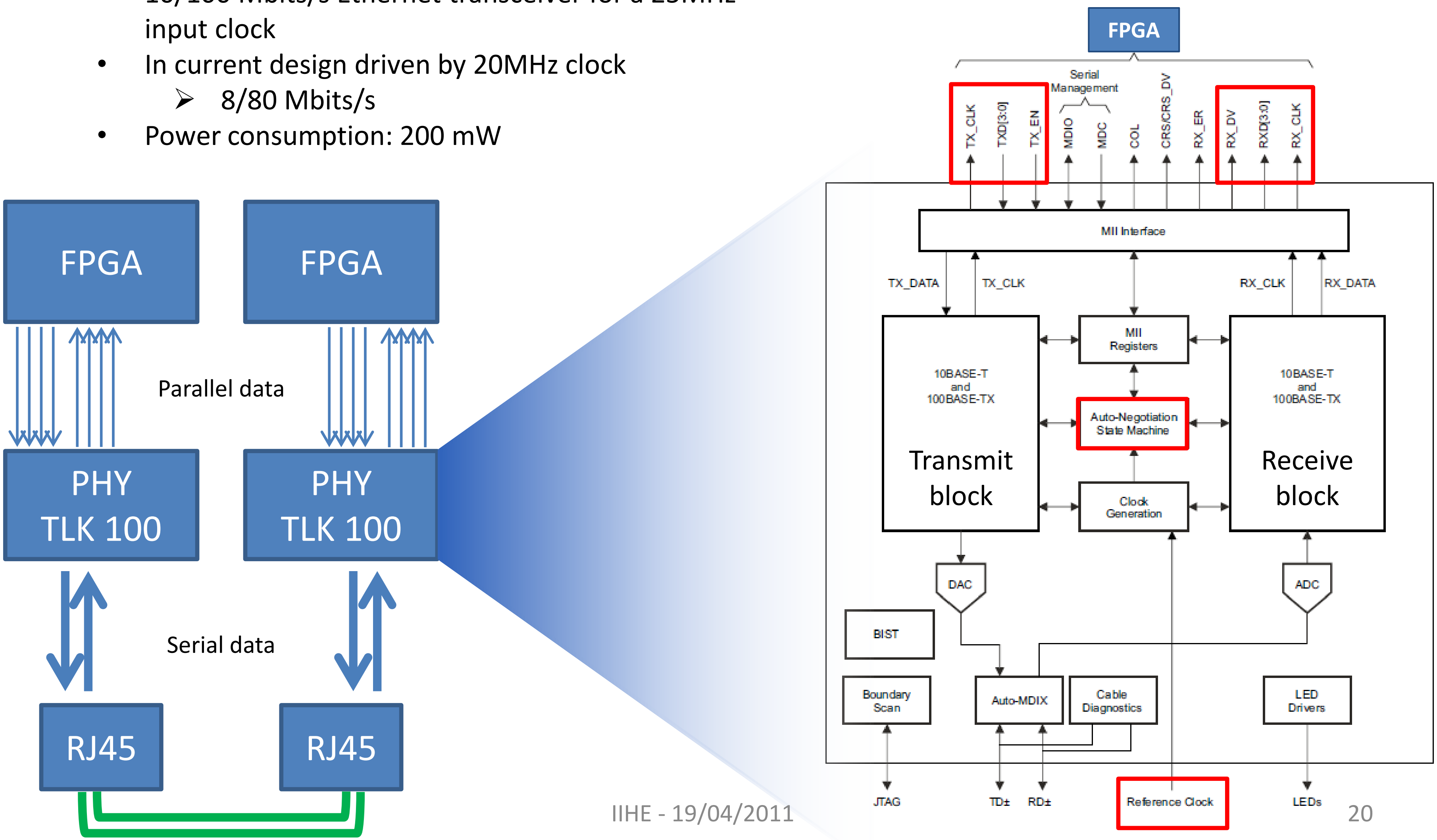
Cherenkov Radio Pulses from EeV Neutrino Interactions: The LPM Effect, J. Alvarez-Muniz and E. Zas (1997)

Hsin-Yi Tu ***13***

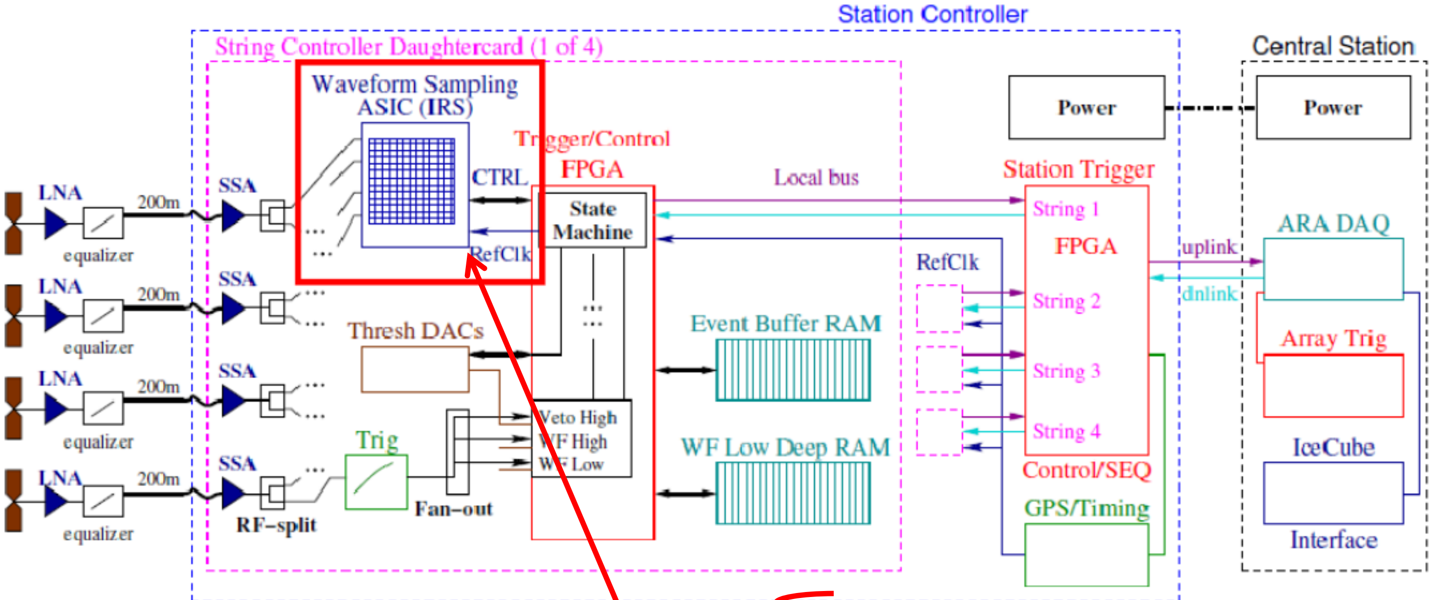
The setup

Data transfer system

- TLK100
  - 10/100 Mbits/s Ethernet transceiver for a 25MHz input clock
  - In current design driven by 20MHz clock
    - ➢ 8/80 Mbits/s
  - Power consumption: 200 mW



Station electronics



2 trigger levels:
- Coincidence: 5 of 16 antennas
- Pattern match:
  Can it be an RF signal?
- **Trigger rate: 10 – 50Hz**

32768	Samples/channel
8	channels
9	Bits resolution (12 bits logging)
Up to 4.5	GS/s
16	µs trigger latency (at 2 GS/s)
120	µs read-out time (512 samples)
1	kHz maximum trigger rate
250	ns blocked data **-> No dead time!**

Outline

- The setup
  - Data transfer system
  - Clock transfer system
- Operation, tests & results
  - Clock precision
  - Power consumption
  - IP-failure rate
  - Behaviour for low temperatures