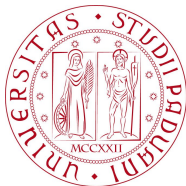


JUNO PMT Electronics State of Art

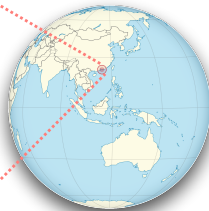
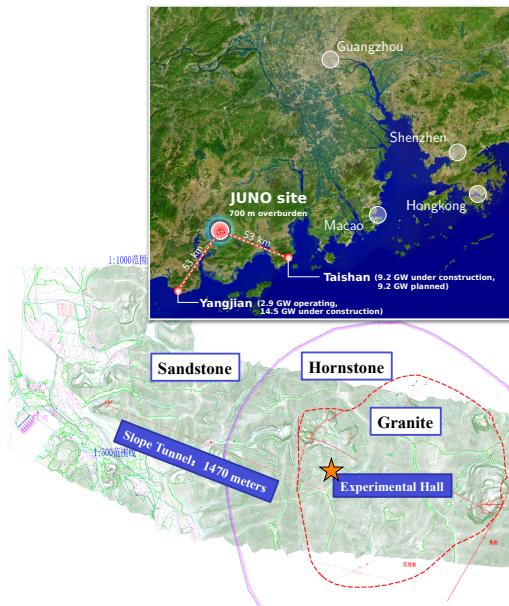
Alberto Garfagnini
on behalf of the JUNO Electronics Group

Università di Padova and INFN, Italy

VII International Open Working Group Meeting for Hyper-Kamiokande,
10 - 11 July 2016, London, UK



The JUNO Experiment



Nice granite structure
at right distance from
reactors (very lucky!)

Jiangmen City
Guandong province

JUNO Physics Programme

Reactor Neutrinos

- ✓ First **combined observation** of solar and atmospheric oscillation
- ✓ **mass hierarchy** via solar-atmospheric interference
- ✓ vacuum oscillation $\rightarrow$ not relying on matter enhancement (and related uncertainties)
- ✓ no θ_{23} or δ_{CP} ambiguities $\rightarrow$ **Complementary** to NO ν A, Pingu and DUNE
- ✓ Most precise measurement of **solar parameters** (θ_{12} , Δm_{12}^2)

Supernova Neutrinos

- ✓ a unique opportunity for Particle Physics and Astrophysics

Geoneutrinos

- ✓ JUNO alone might detect more geo- ν than all other world's experiments

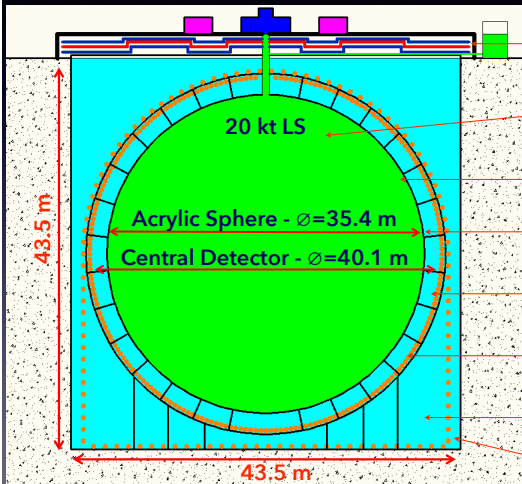
Solar Neutrinos

- ✓ address open issues in Solar Physics : MSW turn on, metallicity

$\rightarrow$ JUNO Yellow Book on Physics : J.Phys. G43 (2016) 3, 030401

JUNO Detector Design

- The experiment consists of a very large 20 kton liquid scintillator detector.



Top muon veto: plastic scintillator strips

LS: 20 kton LAB based

LS container: acrylic. The maximum stress should be <35 MPa.

Buffer: water

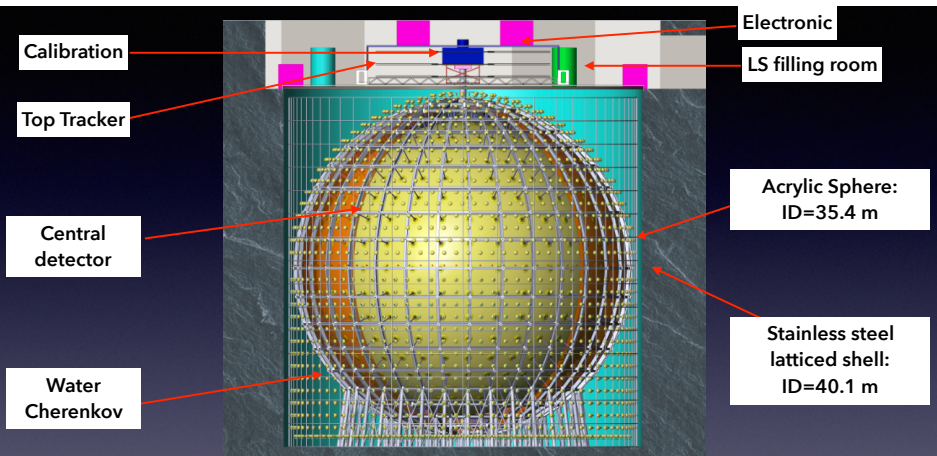
PMTs: 17000 20" PMTs + 34000 3" PMTs for a $\sim 77.8\%$ coverage

Buffer/PMT support: Stainless steel structure

Water Cherenkov veto: 20 kton water

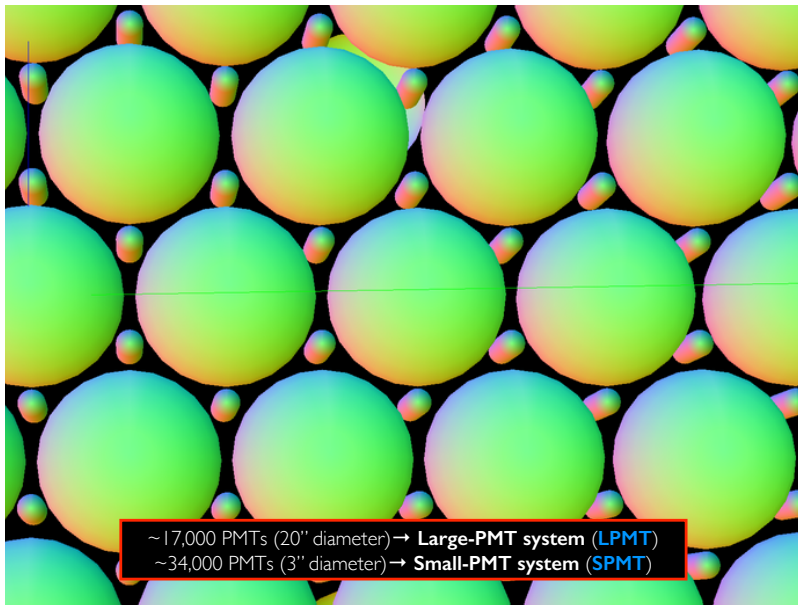
PMTs: 2000 20" veto PMTs

JUNO Detector Challenges



Experiment	Daya Bay	BOREXINO	KamLAND	JUNO
LS mass	20 ton	~300 ton	~1 kton	20 kton
Coverage	~12%	~34%	~34%	~80%
Energy resolution	~7.5%/√E	~5%/√E	~6%/√E	~3%/√E
Light yield	~ 160 p.e. / MeV	~ 500 p.e. / MeV	~ 250 p.e. / MeV	~ 1200 p.e. / MeV

The JUNO Double Calorimetry Approach



JUNO Double Calorimetry

Additional readout system (~36,000 3" PMTs): **2 independent readouts embedded within same detector**. Many purposes...

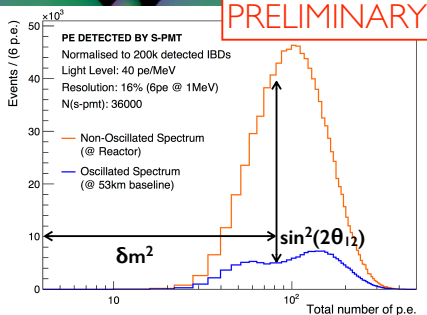
- **(high precision calorimetry for $\pm\Delta m^2$)** response aid to 20" PMTs for non-stochastic systematics ($\leq 3\%$ @ 1 MeV).
Main goal **control of response non-linearities**.
- **($\theta_{12} \oplus \delta m^2$)** internal redundancy oscillation parameter measurement: **systematics cross-check** ($< 1\%$ precision)
- **(^9Li background)** enhanced 4π - μ -tracking for cosmogenic ion production on C tagging/vetoing: $^{12}\text{B}/^9\text{Li}/^8\text{He}$.
- **(supernova readout complementarity)** double-readout to ensure unbiased both energy and rate measurement
- **(readout $\oplus$ trigger complementarity)** complementary time resolution, dynamic range & trigger (position) information $\rightarrow$ **further empower event reconstruction**



3" PMT

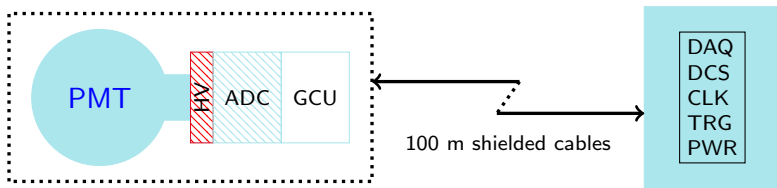
(several options)

- MELZ (RU)
- HZC (CH)
- ETL (UK)
- Hamamatsu (JP)



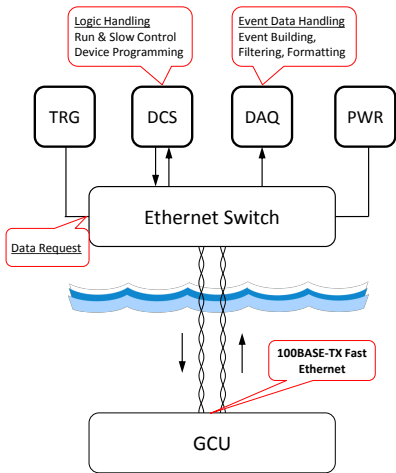
complementary ($\theta_{12}, \delta m^2$) measurement

JUNO Large PMT Electronics Layout

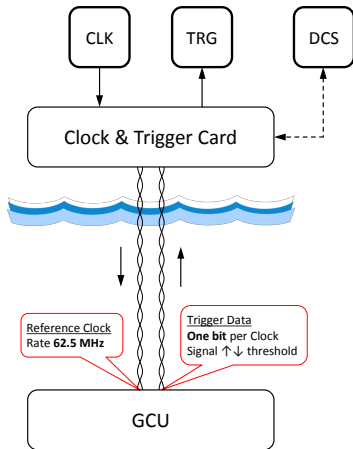


- ✓ The PMT readout electronics will be installed underwater (wet) , very close to the PMT :
 - ➔ PMT Voltage Divider and High Voltage
 - ➔ Front-End electronics: analog and digital electronics
- ✓ The BackEnd/Trigger/Timing electronics will be placed outside (dry)
- ✓ Long cables (~ 100 m) will transfer all signals and bring power to the electronics

JUNO Electronics Communication Scheme



Async Comm (2 pairs)

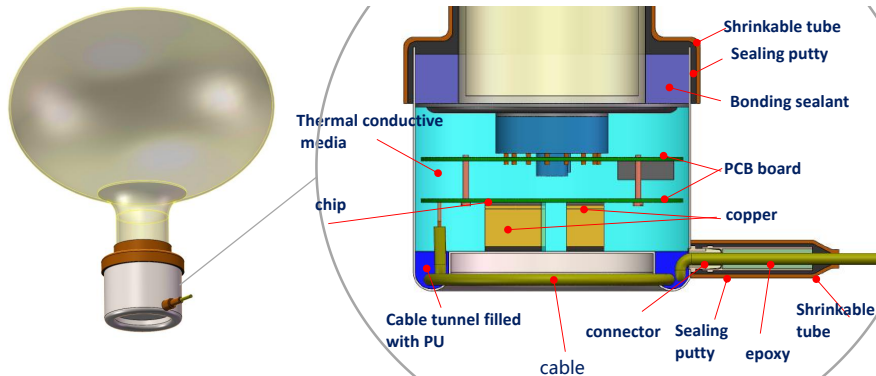


Sync Comm (2 pairs)

JUNO Electronics Overview

Front-End electronics split into 3 boards

- 1) Voltage Divider (closer to PMT)
 - 2) Global Control Unit
 - 3) Power Board (further from PMT)
- + HV module in between



The Large (20") PMTs

- JUNO (Central Detector and Water Cherenkov Veto) will be equipped with
- ~ 15000 MCP PMT, (20", produced by North Night Vision Technology)
- ~ 5000 R12860 PMT, (20", produced by Hamamatsu Photonics)
- an extensive **PMT acceptance** and **characterization program** has been developed
- PMT potting and **integration with readout electronics** validation tests will be performed, early 2017



Photograph of MCP-PMT



Hamamatsu R12860

Parameters of 20-inch PMT

List of the Parameters	Minimum requirement
Detection efficiency @420nm (QE * CE)	27% in average, all >24%
TTS of SPE (FWHM)	<12 ns
Rise time and fall time	<8ns, < 16ns
Gain	10^7
Non-linearity @ 10^7 gain	<10% (0-1000pe)
Dark rate @ 0.25 SPE, 10^7 gain	<50kHz
non-uniformity of QE	<15%
Operating High voltage @ 10^7 gain	<3000 V
P/V ratio of SPE	>2.5
Pre-pulse ratio (80ns time windows) and after-pulse ratio (20us time windows)	<5%, <5%
Spectral response range (nm)	300-650
Geomagnetic field sensitivity (@450mG)	SPE variation < 20%; TTS variation < 15%
Long-term stability	Gain variation < 5% for 3 week, and <10% for 1 year; Anode current variation < 1% / $^{\circ}$ C

High Voltage

- ✓ Original idea : **convert** a **low AC** voltage to **high DC** voltage
- ✓ using a cascade of half-wave doublers (**Cockroft-Walton multipliers**)

PROS :

- HV generation close to the PMT
- small intrinsic power dissipation (< 0.05 W/channel)
- small heat loss
- high stability of HV (better than 0.05%)
- reduced cost

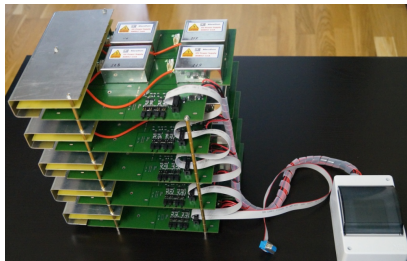
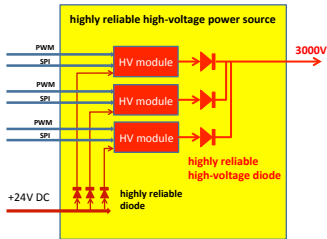
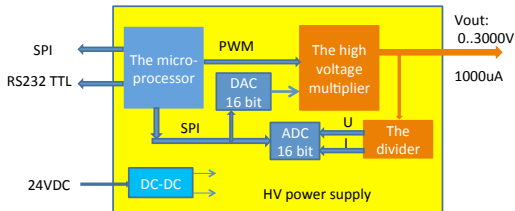
CONS :

- **reliability is crucial : no more access to underwater modules**

Parameter	Specs
Output voltage	0 - 3000 V
Maximum current	100 μ A (@ 3 kV)
Stability of V	0.05%
Output voltage ripple	60 mV (Peak2Peak)
Output voltage temperature coeff.	100 ppm/ $^{\circ}$ C
Long Term stability	$< 0.01\%$
Input Voltage	24 V
Control	SPI, RS-485

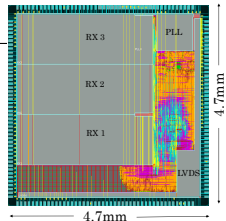
HV prototyping and testing

- Two companies, **HVSYS (Dubna)** and **Marathon (Moscow)** have designed and developed prototype modules
- All specs have been successfully met
- Long term tests are colorbluegoing on for both series of prototypes
- Discussion on reliability is ongoing: the possibility to employ more than one module/PMT is under investigation



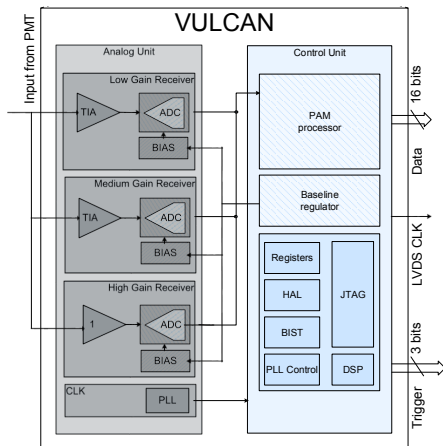
The Vulcan ADC (baseline option)

- an ASIC capable of **fast data sampling** and processing for signal reconstruction
- employs **three 8-bit ADCs** with highly configurable operating modes
- capable of generating a **fast trigger** while processing data
- provides an optional **compensation** for **signal overshoot**



Vulcan Specs

- **Sampling rate** : 1 GHz
- **Bandwidth** : 500 MHz
- **Input impedance** : $< 10 \Omega$
- **Dynamic range** : $1/16 \cdot 2000$ pe
- **ADC resolution** : 8 bit $[3 \times]$
- **High gain** : 0.06 pe/bit
- **Medium gain** : 0.4 pe/bit
- **Low gain** : 8 pe/bit
- **Power consumption** : 1 W



Vulcan chip features

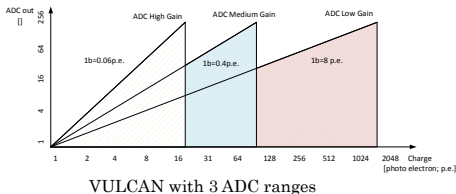
Programmable Adaptive Memory

- allows to perform **data reduction** and **compression**

IN : 24 bit $\times$ 1 GHz = 3 GB/s

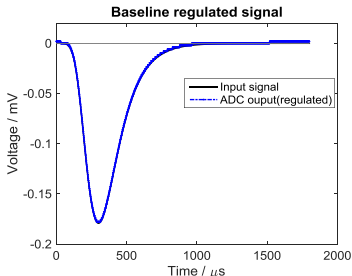
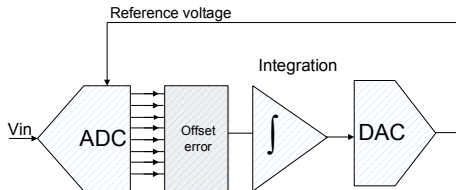
OUT : 16 bit $\times$ 500 MHz = 1 GB/s

- allows to **select ADC gain mode** (for best precision)



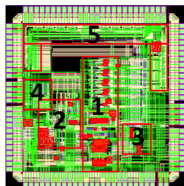
Baseline regulation

- ADC output $\propto$ number of photoelectrons
- biasing fluctuations may shift the baseline
- a **$\Sigma\Delta$ method** allows to **compensate** for these effect



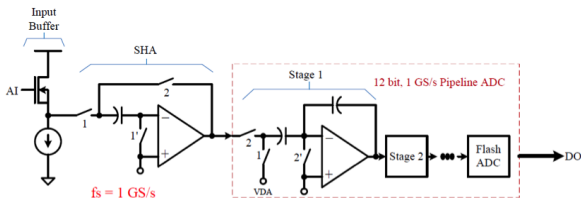
The Tsinghua ADC (alternative option)

- an ASIC capable of fast data sampling and processing for signal reconstruction
- employs two 12-bit ADCs with highly configurable operating modes
- capable of generating a fast trigger while processing data



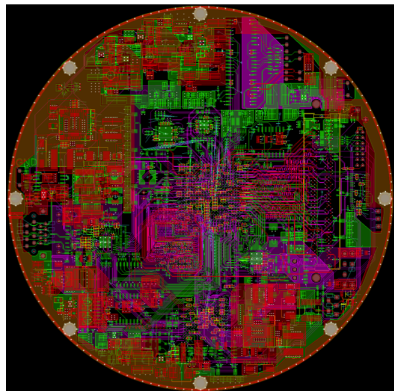
Tsinghua ADC Specs

- Sampling rate : 1 GHz
- Input Bandwidth : 500 MHz
- DNL : < 0.5 LSB
- INL : < 2 LSB
- SNR : ~ 61 dB
- ADC resolution : 9 bit (ENOB) @ 1 GHz
- Power consumption : < 800 mW



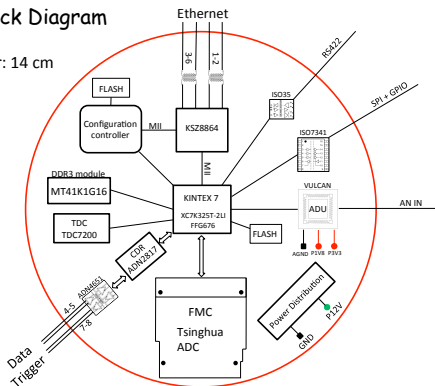
The Global Control Unit

- it's the PMT interface to the DAQ and DCS
- it allows to control the HV, ADU or FEC/ADU, and performs the first online digital analysis of the signal.
- it incorporates a dedicated fast memory (2GB) for data storage before transmission to BackEnd electronics (essential in case of supernova neutrinos)

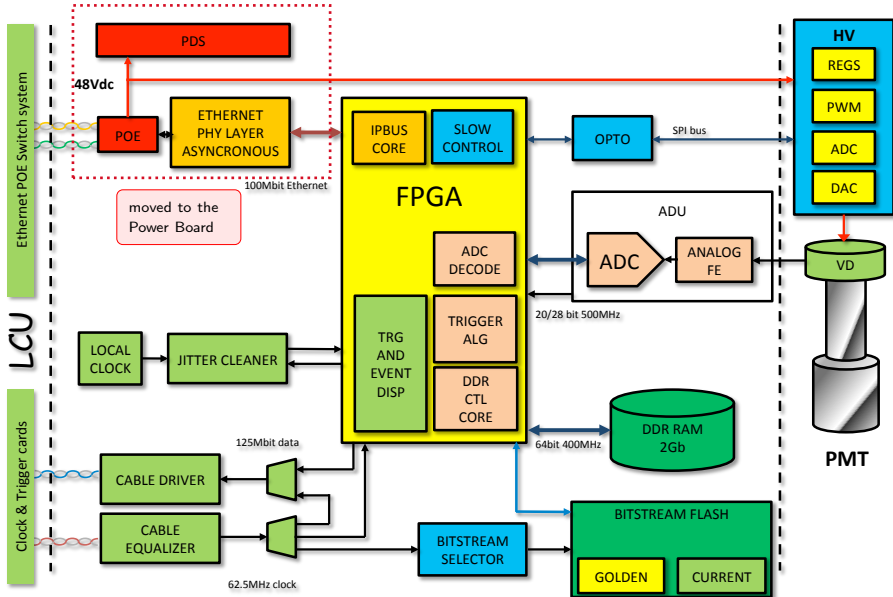


GCU Block Diagram

Diameter: 14 cm

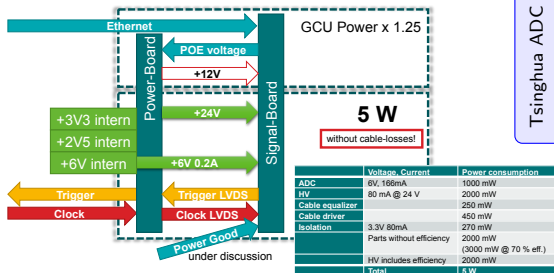


The GCU block diagram

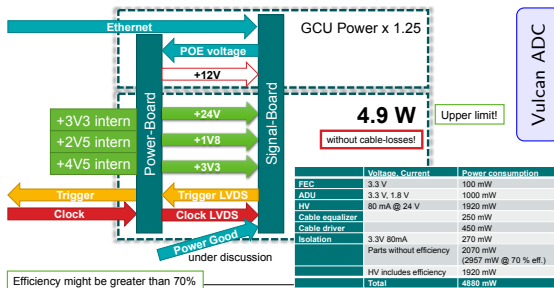


Power Transmission

- power is transmitted over Ethernet cables
- a dedicated board, on the PMT back side, receives power through the CLK line and provides regulated DC power to all components: HV, ADC (Vulcan or Tsinghua ADC) and GCU



Tsinghua ADC



Vulcan ADC

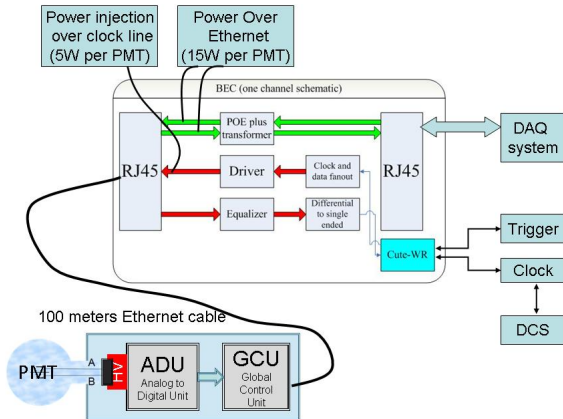
Efficiency might be greater than 70%

The BackEnd electronics

- allows to **connect each PMT** readout electronics with the **DAQ, DCS and Trigger** electronics :
- **split signals** to different destinations
- guarantee **high speed data transfer** over **100 m CAT5 cables**
- perform some concentration, if possible

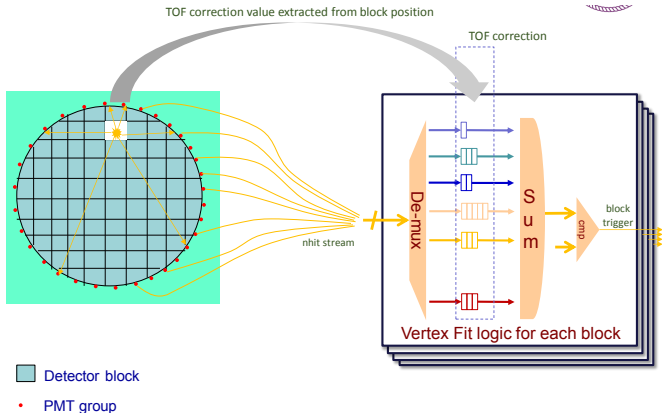
Distributed signals

- event data
- detector status and control
- trigger request and accept
- global reset
- system clock
- power for LV
- power for HV



The Trigger electronics

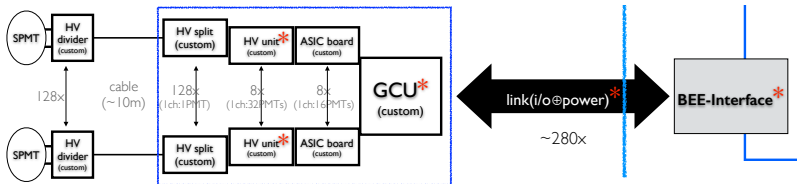
- all the PMT send out a trigger signal, synchronous with the reference clock
- if a decision is taken by the Global Trigger Electronics (dry) a data request is sent to the fired PMTs on the async lines. The PMTs reply by sending the requested waveform data, in a specific time window, through the async lines.
- special topological trigger is under development for online vertex fitting



small PMT electronics

- a large number (~ 36 k) of small, 3", PMT will be installed in JUNO
- despite the high number of channels, a **much lower rate is expected** (no waveform) $\rightarrow$ we can afford **major multiplicity (128x)** allowing **36 k PMTs over < 300 readout channels**
- **synergies**, between the large and small PMT system electronics are foreseen
- a readout card with **$8 \times$ CatiROC System On Chip** is being designed by **APC + OMEGA LAB (IN2P3)** and **CAEN**

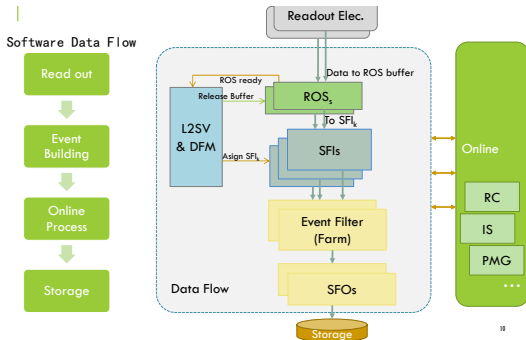
($\rightarrow$ C. De La Taille's talk on CatiROC)



- Large PMT (Central Detector + Water Cherenkov), 20 k PMTs :
 - each PMT is read out directly : 16 Mbit/s (with 1 kHz physics rate)
 - using the BackEnd electronics schema, i.e. Ethernet switch (48 PMT/switch), data rate = 768 Mbps
 - Total CD data rate 2GB/s (CDR), 36GB/s without zero suppression or data compression

- Small PMT system, 34 k PMTs :

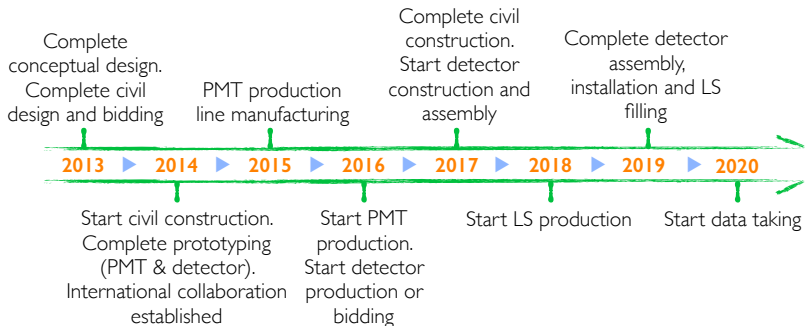
- data readout in blocks of 128 channels
- total sPMT data rate : 1 MB/s



Reliability of Electronics

- it is one of the **main concern** → the **PMT and electronics** will not be accessible once the detector has been filled with LS and water
- our goal is : **$\leq 1\%$ PMT failure**, including electronics, **over 6 years**
- **several strategies** are being followed :
 - **calculations** are being carried on based on **MIL-STD-756B** and **MIL-HDBK-217F** (for components)
 - an **external review and certification** for the GCU will be soon performed by a **Space-Certified Company**, (thermal and MTBF analysis, and PCB layout)
 - a **dedicated laboratory** has been setup to perform **reliability and aging tests** on components
 - **redundancy on critical components** is under investigation
- ➔ in early 2017, **100 PMTs** will be equipped with **close-to-final electronics** and, **after potting, reliability and long term tests** will be performed

JUNO Schedule



The JUNO Electronics Group

- **large PMT electronics L2 coordinators** :
Achim Stahl (RWTH, Aachen) and Xiaoshan Jiang (IHEP Beijing)
 - **High Voltage Unit** : Andrei Sadovski (JINR Dubna)
 - **ADC Unit 1** : Christian Grewing (FZ Jülich)
 - **Front End Chip** : Xiongbo Yan (IHEP, Beijing)
 - **ADC Unit 2** : Wei Wei (Tsinghua Univ, Beijing)
 - **Global Control Unit** : Alberto Garfagnini (INFN Padova)
 - **Data Link Unit** : Yifan Yang (ULB, Brussel)
 - **Trigger** : Guanghua Gong (Tsinghua Univ, Beijing)
 - **Power and Clock Distribution** :
Jochen Steinmann (RWTH, Aachen), Jun Hu (IHEP, Beijing)
- **small PMT L2 coordinator** : Anatael Cabrera (APC, Paris)
- **DAQ and DCS L2 coordinator** : Kejun Zhu (IHEP, Beijing)