Technical activities and random and not-so-random ideas

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KM3NeT Outing 2018

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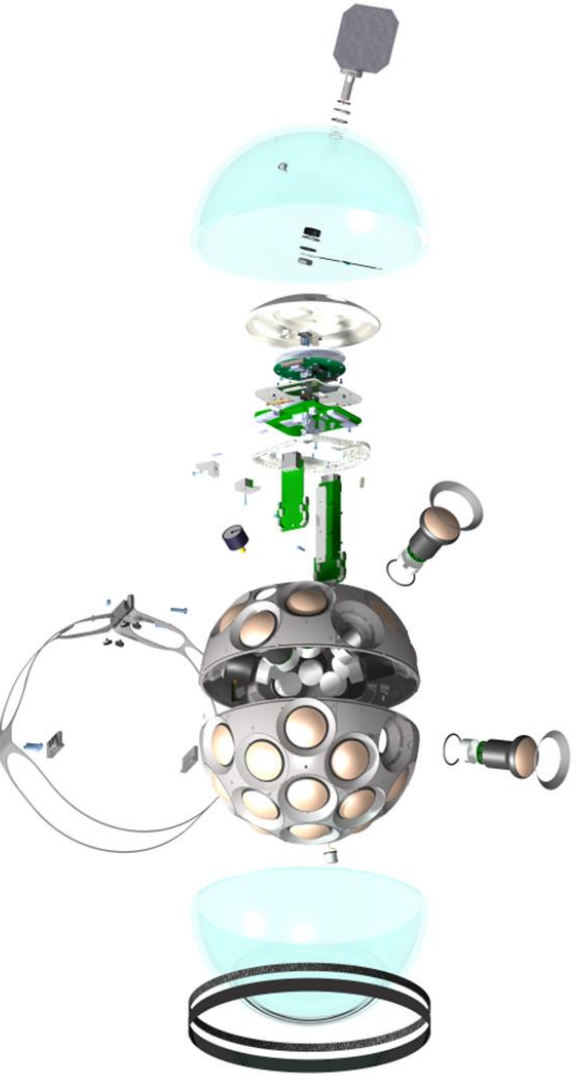
Contents

- Technical activities for KM3NeT at Nikhef
  - DOM and DU
  - Not too elaborate (see slides from Jamboree)
- Trigger & Reconstruction : hardware and algorithms
  - How to use computing hardware to improve performance
- Low-Energy Astophysics with ORCA
- Some ideas …

To inform (and discuss a bit)

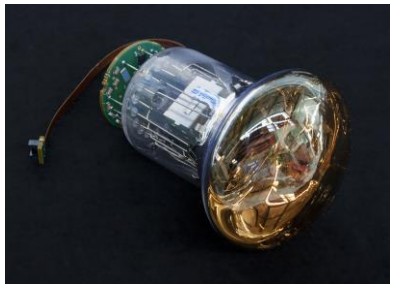
To expose and discuss

DOMs, DUs and related stuff



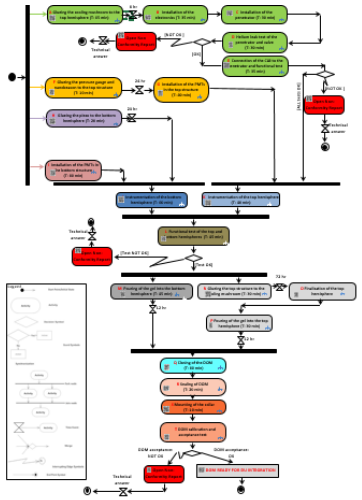
Technical activities at Nikhef related to DOMs and DUs

- DOM integration
  - Build DOMs from their components
  - Tool development
- DU integration
  - Attach DOMs & base penetrator to the VEOC
  - Tool development
- Firmware and software development
  - Control and read-out software on the CLB
  - White-Rabbit
  - DOM and base
- PMT bases
- DC/DC converters
- Base power protection
- Penetrators
  - Pressure Testing of DOM and base penetrators
  - Development (w/industry) of DOM and base penetrators
- DOM mechanics development
- DU mechanics development
- VEOC



DOM integration

71 <u>unique</u> components (in solid or liquid phase)



A procedure ….

Tools

People!

1.5 FTE mechanics
0.4 FTE electronics
0.4 FTE Testing (staff/students)
0.3 FTE administration/coordination

Time!

~4 Days/DOM

> 5 DOMs/week

A DOM !

Involved: Rene, Robin (MT), Jan, Jean-Paul (ET), Bruno, Lodewijk, Karel, Martijn …

DOM integration - Status

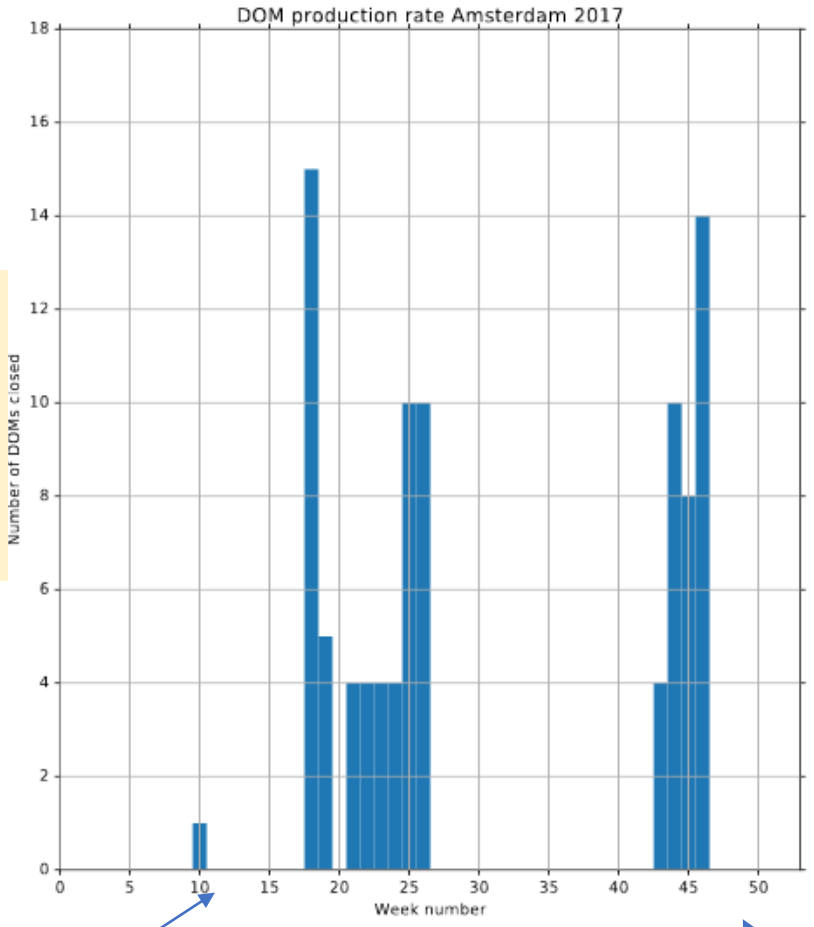
2017:
Two production runs of 36 DOMs
+ remnants of 2016

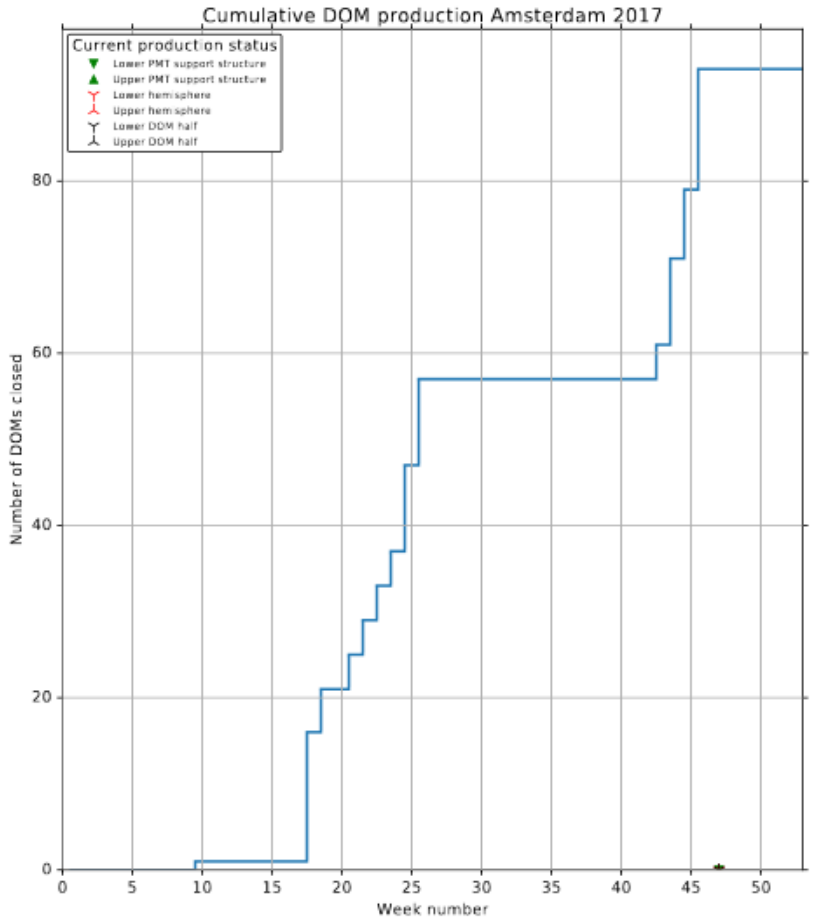
Cumulative numbers:

Nikhef : 200 DOMs built !
(excluding prototypes)

We can produce 8 (12) DOMs/week (un)comfortably with current setup

This is done by optimizing the order and timing of the procedures





2016 remnant

Summer production

Fall production

DOM integration issues

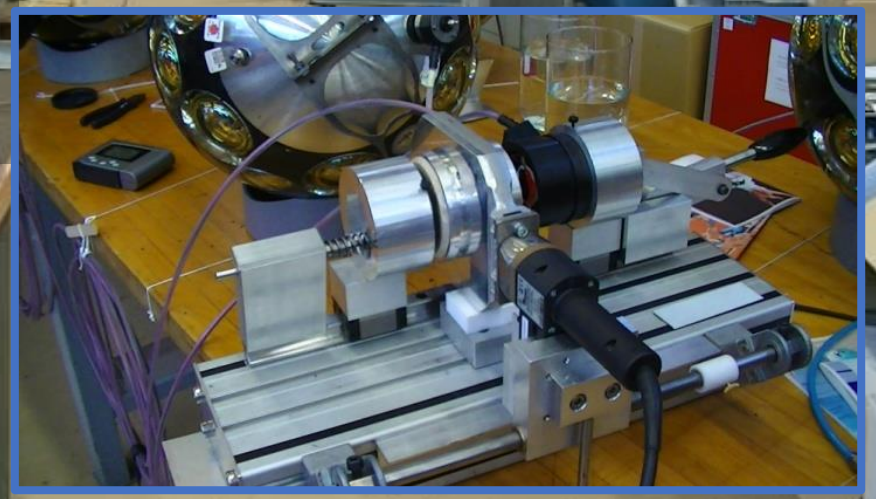
- Interface integration assistant, database and test software
  - Someone is working on it …
- Testing throughput never really tested
  - Testing room is being changed
  - Dedicated light-tight tables for testing
  - Also: NCR handling is not fluent
- Logistics and Storage
  - Components are needed (!)
  - Components need space
  - DOMs need space ..
- Almost single person failure risk

DU integration

Assembly of DOMs on to VEOC
- Electrical and optical connection of DOMs
- Filling the BOBs with oil and closure
- Leak tests
- Optical and electrical tests

~2 weeks work (if no issues)

Involved: Jan, Jean-Paul, Edward, Hans, Oscar



Plastic welding tool (also used in VEOC production)

DU Integration – issues

- Not all procedures are official and documented
  - Also: knowledge-transfer
- No proper acceptance criteria or tests defined
- Logistics and space
- Single person failure

Reconstruction & Trigger improvements through dedicated hardware

Improving the trigger efficiency and reconstruction accuracy will come at an improved computational cost (right??)

Trigger : Lower threshold is achieved by considering more hits – combinatorics!

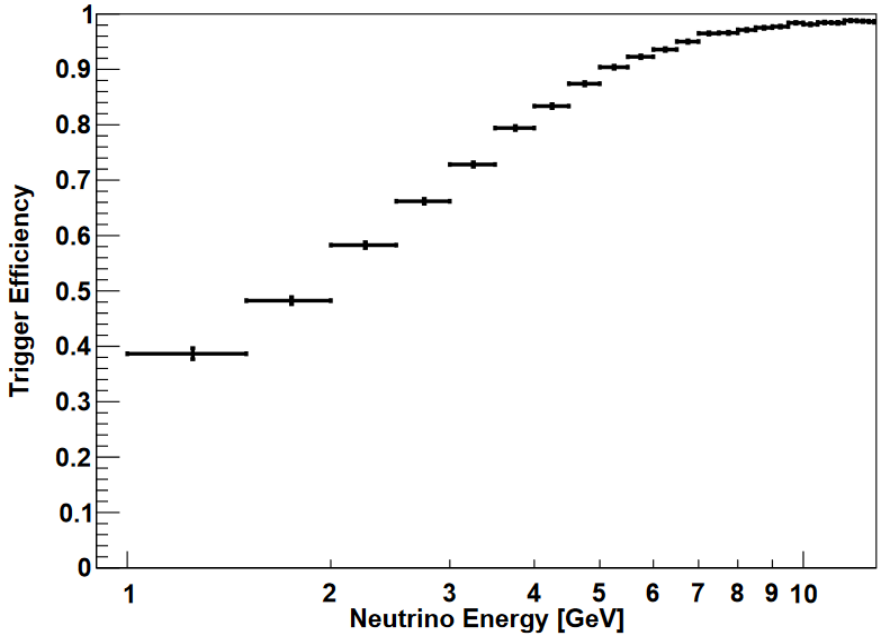
Lower trigger threshold requires fast online reconstruction to reduce noise

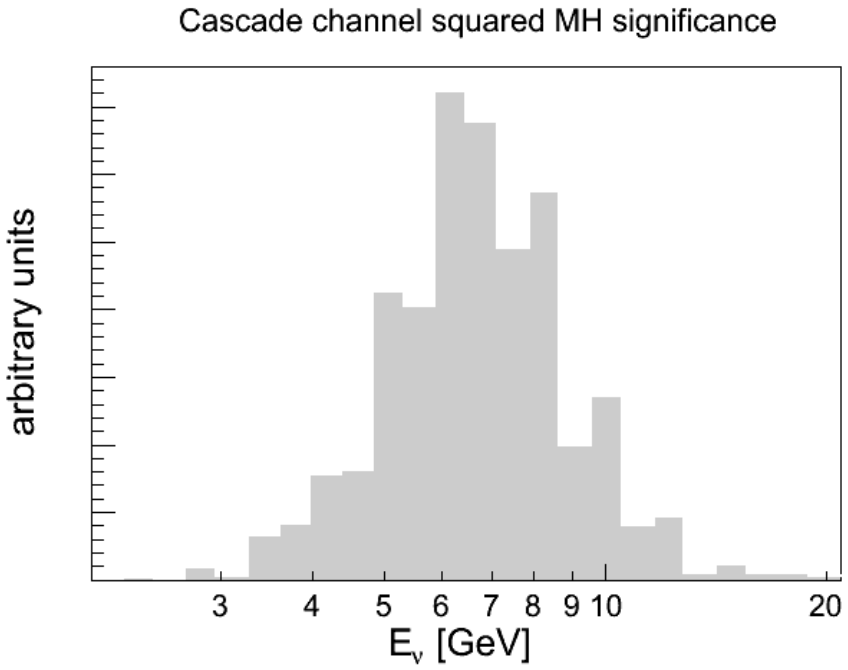
More complex event hypotheses (required to get more details) will require more complex likelihoods to be evaluated (to start, more dimensions to optimize in!)

More CPUs is likely not the answer

Let’s try (in no specific order):
- Dedicated hardware
- Smarter algorithms

ORCA: Motivation for lowering energy threshold





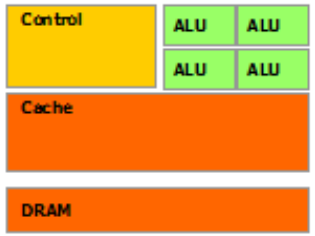
Efficiency of trigger with respect to ‘reconstructable events’ Nue

Note: pre improved trigger ….

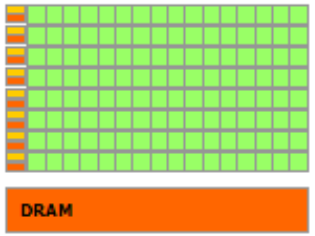
CPU, GPU and FPGA

CPU (Central Processing Unit)

Complex hardware, General purpose
Fixed instructions
Fixed hardware (logic) to execute these instructions
Program : list of instructions



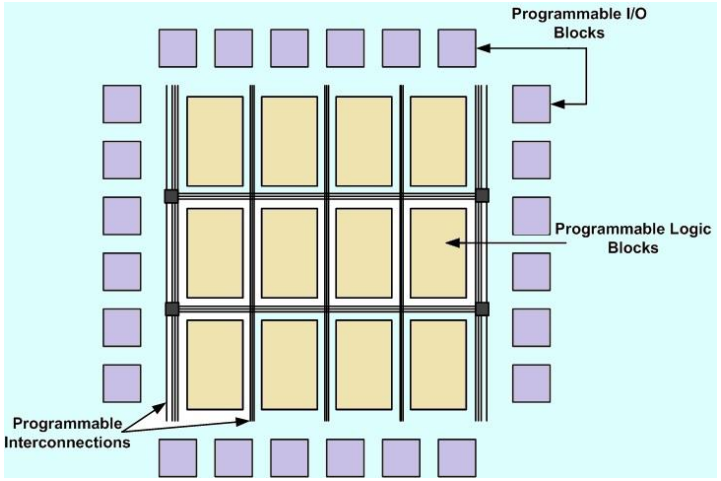
CPU



GPU

GPU (Graphiscs Processing Unit)

'Many small CPUs'
Limited instruction set/Limited complexity
Limited memory, shared by sets of cores
SIMD : single instruction multiple data
A collection of units executes same instruction on different data
Program: as CPU, but with restrictions



FPGA

'Configurable Hardware'

A collection of gates that can be configured to implement logic and connections

Program : define layout of the hardware
(e.g. a CPU can be implemented in an FPGA)

FPGA example: Sorting

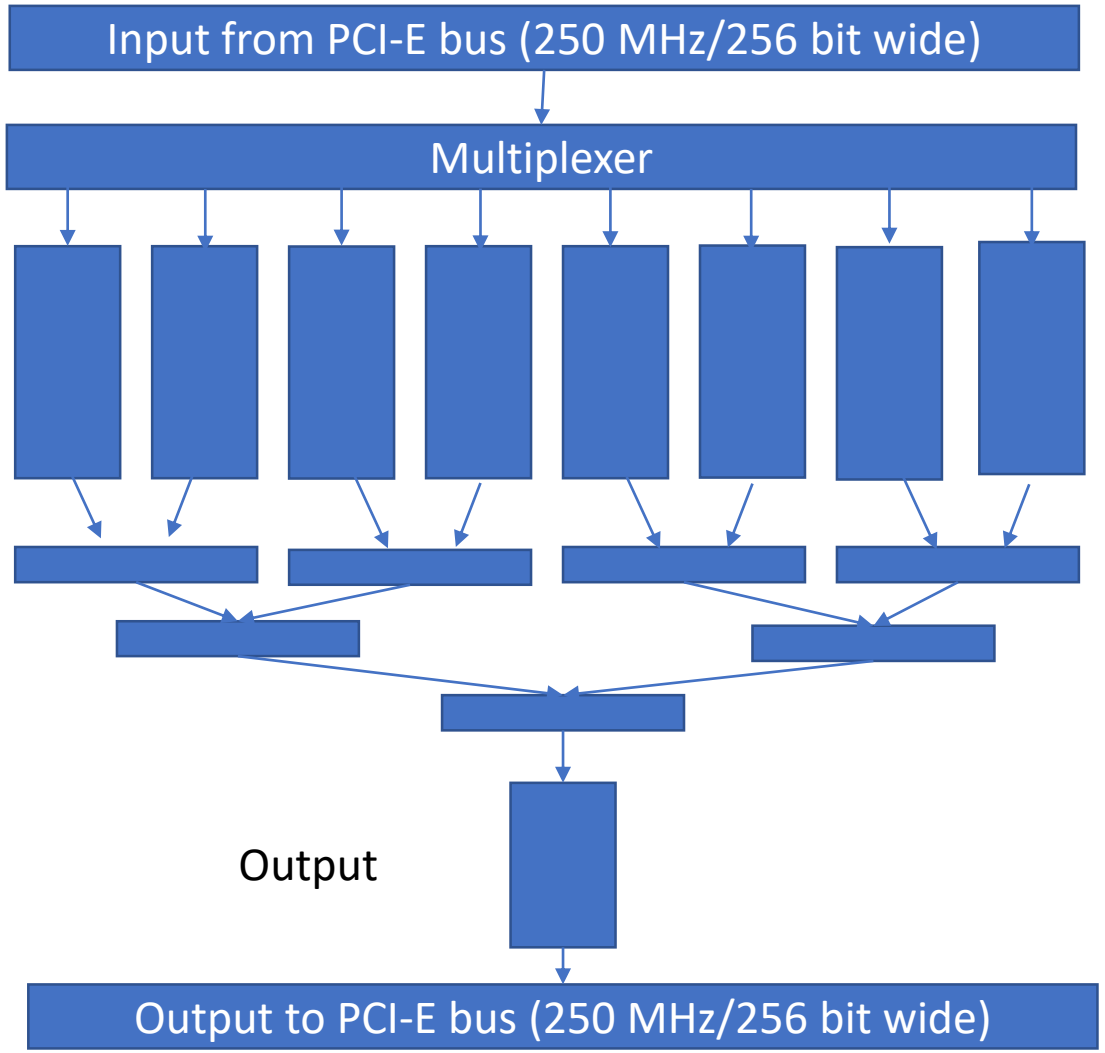
Datafilter:

70% of CPU power is used for sorting of L1 data

The L0 datavolume is ~400 times larger

Sorting time grows with n*log (n) *on a CPU*

FPGA : example



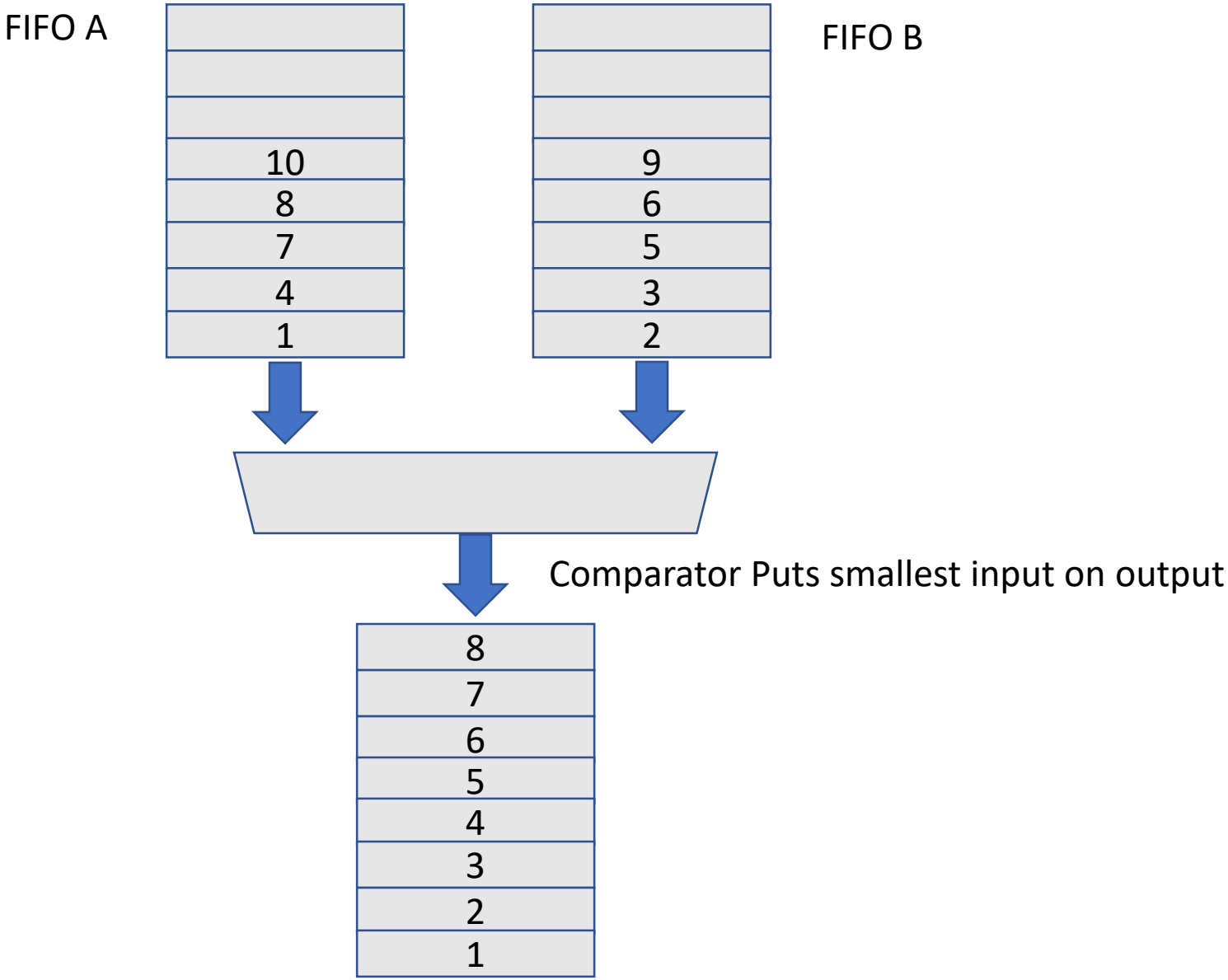
Sorting in CPU – program

- ….
- *Move datum A from memory to register I*
- *Move datum B from memory to register J*
- *Compare*
- *Move result to memory*
- *On to next in list …*
- ….

Theoretical throughput assuming PCI-E
64 Gbit/s = 8 Gbyte/s
1 hit, unpacked is 8 bytes

1 Billion hits sorted per second!

Note: 1) Data from single PMT is already sorted 2) Maximum internal clock of FPGA ~0.9 GHz



Every clock cycle, adds from input to buffer

Sorted hits?

- Required for trigger
- New things?
  - Time-sequence based trigger??
    - Let’s do some Fourier transforms!
    - Correlations?
  - Periodic sub-threshold signals??

GPU example : likelihood calculation

Event reconstruction involves maximizing the likelihood, e.g. :

$$L(\vec{y};\vec{\theta}) = \prod_{i=1}^{n} P(y_i;\vec{\theta})$$

Individual terms can be calculated separately!
Different hypotheses can be calculated separately!

Much room for parallelization

Probability density function:
Probability of datapoint i
Given event parameters ϑ

Currently the PDFs are summarized in large tables (GBs)
Tables are big and are not suitable for GPUs (e.g. local memory 64kB (shared….))
Global memory is slow and random lookups are very inefficient for GPUs

However, information on PMT position and direction and hit information may fit in small GPU cores

Multiple datapoints (hits/no hits) and possibly multiple hypotheses simultaneously

$P(y_i;\vec{\theta})$
$P(y_j;\vec{\theta})$
$P(y_k;\vec{\theta})$
$P(y_l;\vec{\theta})$
$P(y_m;\vec{\theta})$
$P(y_n;\vec{\theta})$
$P(y_o;\vec{\theta})$

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$P(y_l;\vec{\zeta})$
$P(y_m;\vec{\zeta})$
$P(y_n;\vec{\zeta})$
$P(y_o;\vec{\zeta})$

GP100, 3840 CUDA cores

GPU – other stuff

- Hit clustering in the trigger
  - Status: CUDA kernels for coincidence finding developed during eScience grant
  - Cluster finding to be done (e.g. ‘clique’)
- Neural networks/Deep-learning etc.
  - GPUs essential for this
  - Tensorflow installed on Schar & Schol (NVIDIA K80 GPUs)
  - See Maartens talk
- Photon tracking
- … (let’s see how we can benefit!)

Reconstruction with complex hypotheses

- Typically a track (shower) is described by position, direction, energy
- But it is essentially a sequence of energy loss events
  - Vertex shower
  - Track segments
  - Showers along track
- And quite often multiple particles
  - Muon bundles

Time-over-threshold

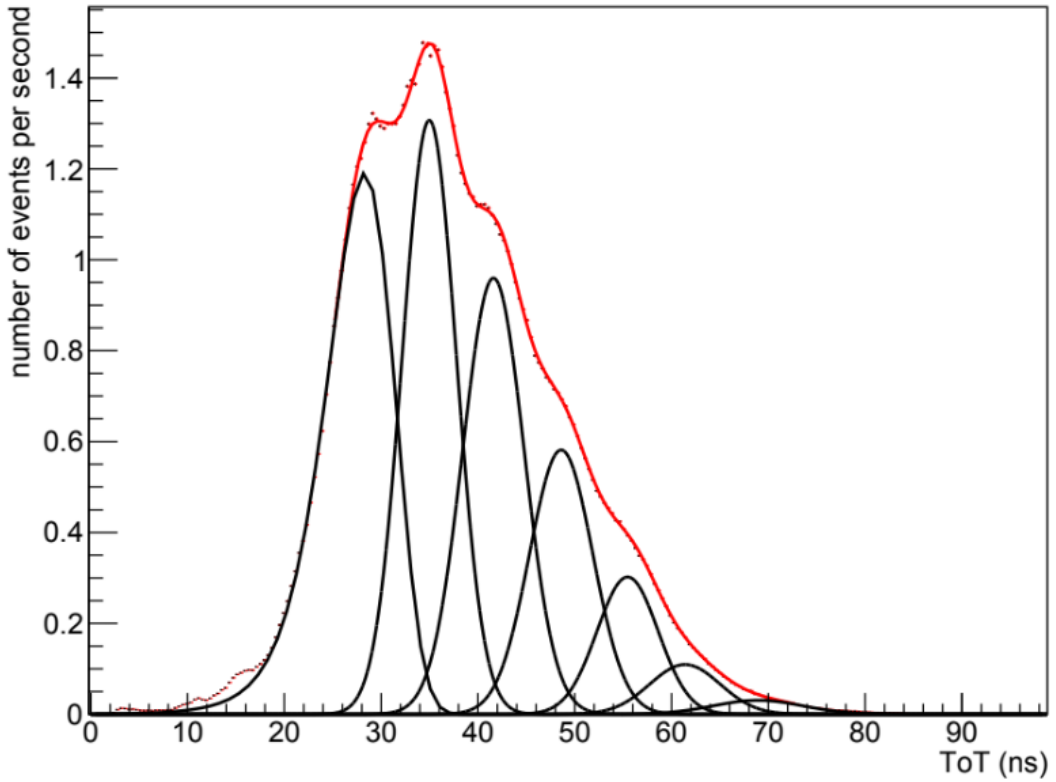
Hit arrival times are the main ingredients of the reconstruction

Currently, the ToT is not used to its maximum potential – basically not

Hit/No-Hit probability is used

Using the ToT has improved the shower reconstruction …

(What happened to this?)

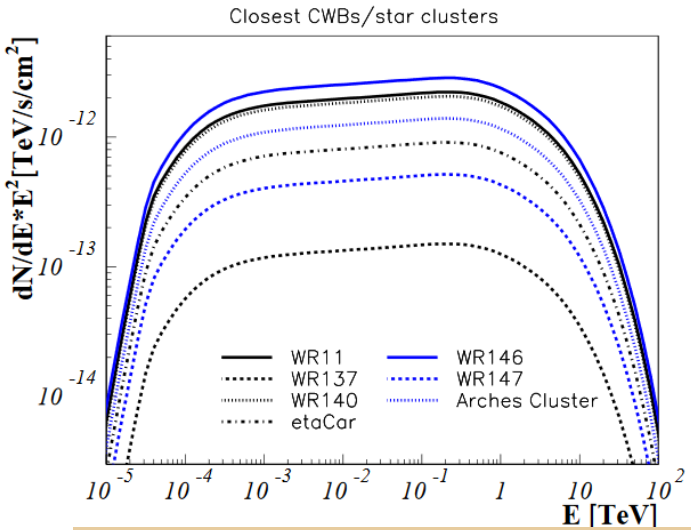


ORCA & Galactic Sources

(J. Becker Tjus, arXiv: 1405.0471)

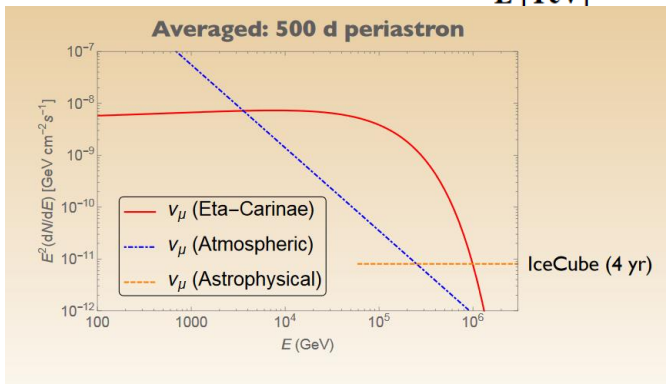
Neutrinos from colliding wind environments
(massive stars/binary systems)

Gamma-ray observations indicate possible hadronic acceleration for some candidates



They have a significant flux at low (=ORCA) energies

+ oscillation minimum at 25 GeV for atmospheric numu numu
+ known direction of candidates
+ Southern Hemisphere candidates

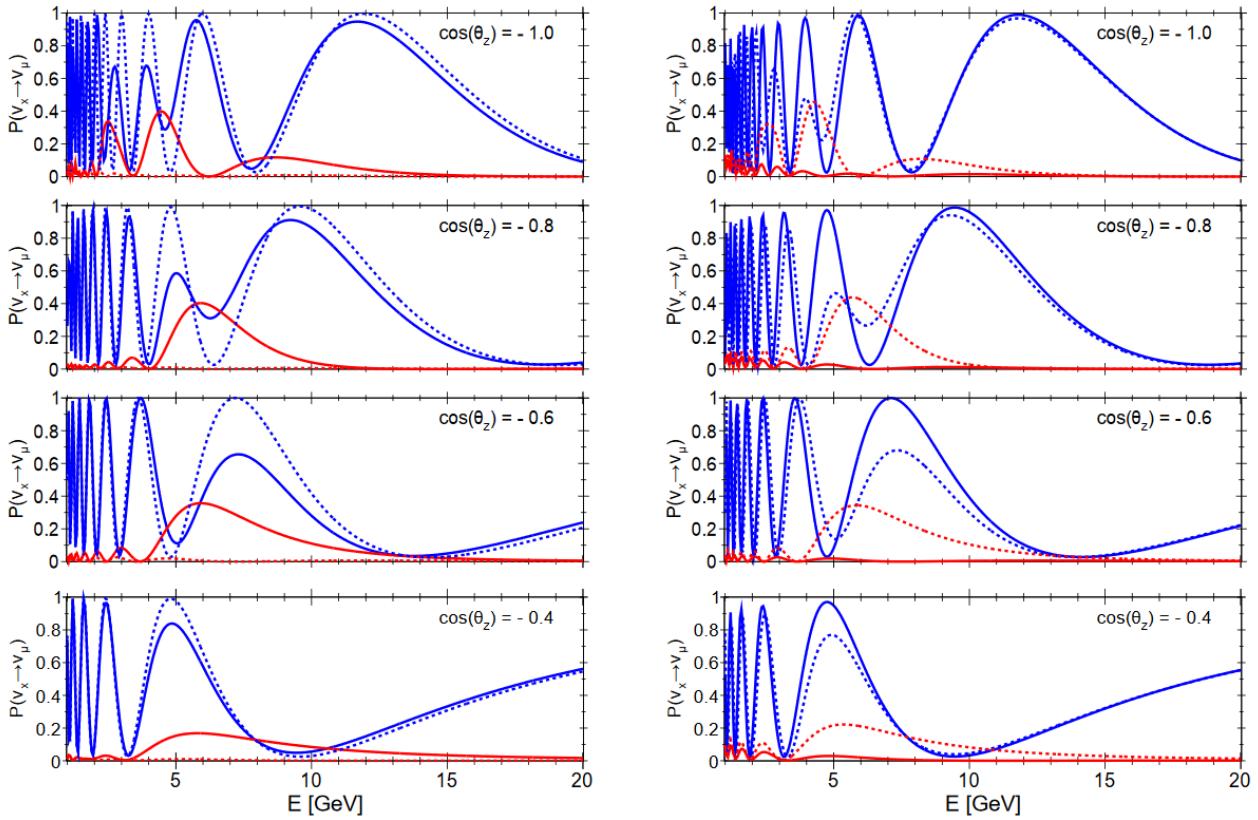


S. Razzaque
(Granada meeting, High-Energy)

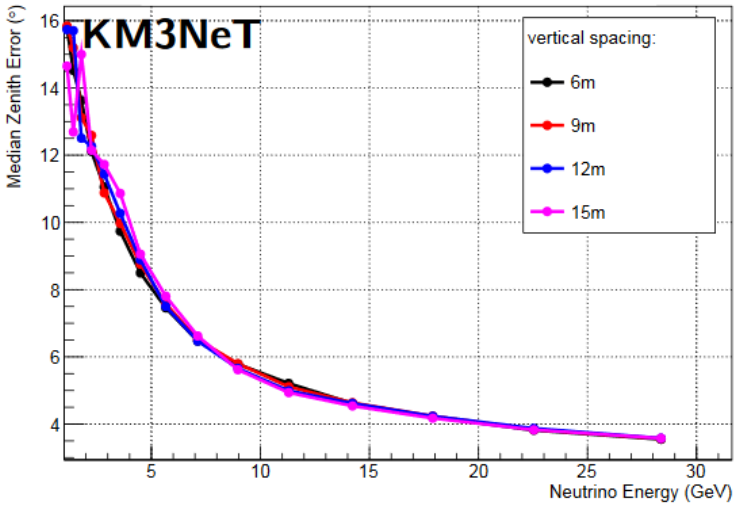
Uncertainties include
Atmospheric neutrino flux at GeV energies (requires low energy CORSIKA, and measurements)

ORCA : More general, are there windows we can exploit?

Atmospheric muon neutrino flux suppressed at energy dependent angles (angle dependent energies …)
+ known position



Zenith angle resolution – is it good enough?



Energy resolution ~30%

Event classification essential

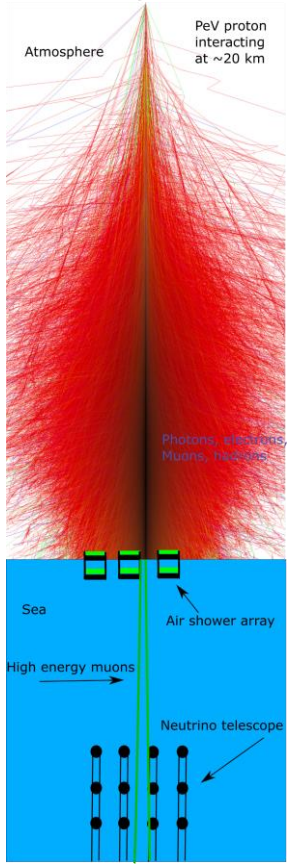
Let's investigate!

Some ideas (I) – surface array

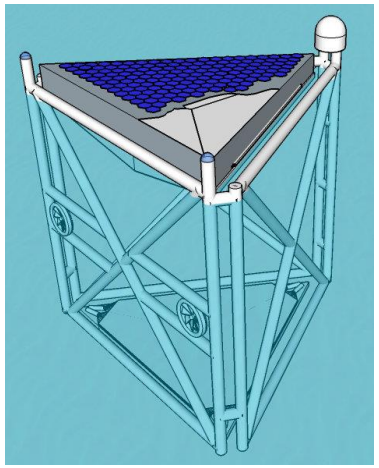
(Sea-) Surface array to complement KM3NeT

Motivations:
- Calibration of KM3NeT
- Cosmic-Ray research (see Lieselottes talk)
- Veto (?)

Conceptual design
(takes into account average current)
- 3 m2 solar panels
- 3 m2 scintillators
- Low power electrical engines
- DAQ and navigation electronics
- Satellite connection
- Plastic boat
- ~15 k euro each



~150-300 m separation



Energy, Direction
Possibly muon composition

Muon multiplicity, transverse energy

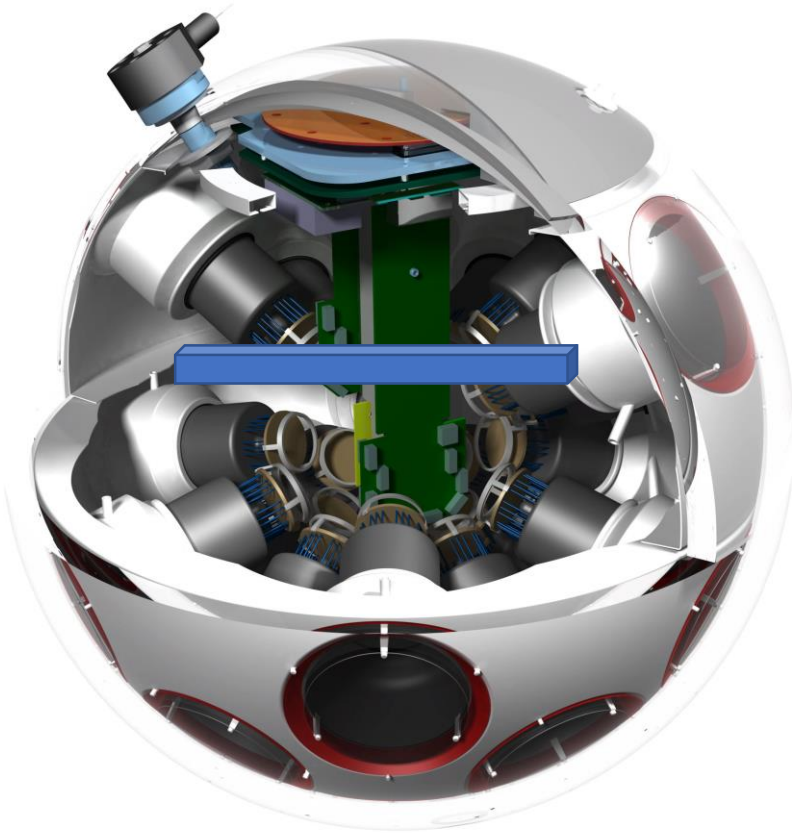
Moving boat tunes energy threshold!
… and angle w.r.t. detector

Some ideas (II) – scintillators in DOMs

Instrument DOMs with plastic scintillators

About 150-200 cm2 of scintillator fits in a DOM
Just remove top three rings…

Read-out can be done with our PMTs and
DAQ hardware – PMTs look inward



Why ?

- Scintillator localizes muon to ~10 cm
  - Calibration!!
- Threshold for muon energy much smaller than detector threshold
  - Sub-threshold measurement of muon flux
  - Anchors muon/neutrino flux models