KAVLI IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

東京大学 THE UNIVERSITY OF TOKYO

The Hyper-Kamiokande experiment : a thought about our contributions

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Note : I did not had the chance to discuss with some of you, especially at CEA.

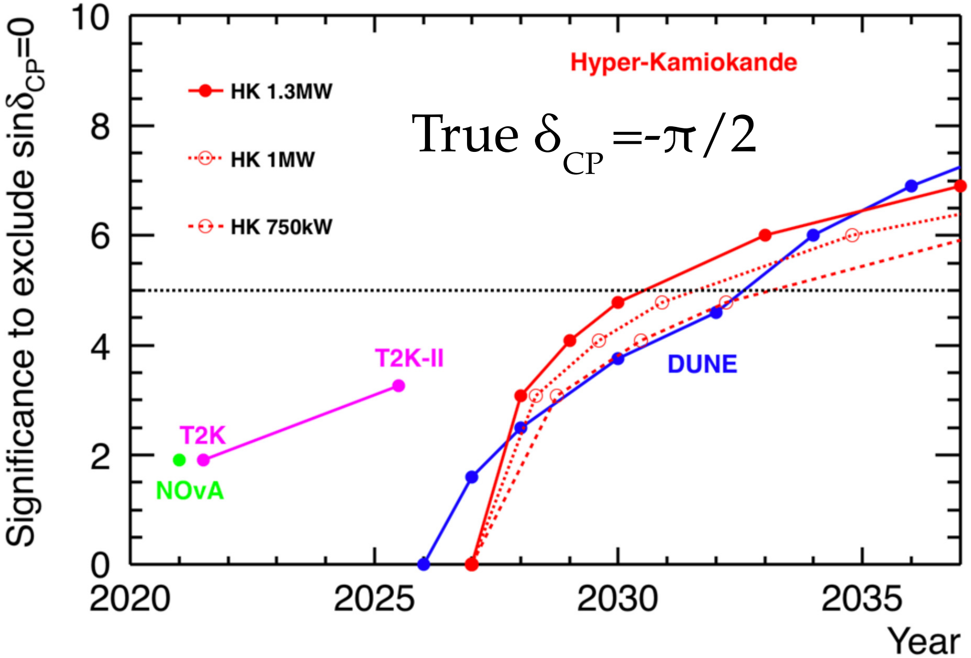
→ Please forgive that I may have not integrated your priorities here and interrupt me anytime to mention them or correct me.

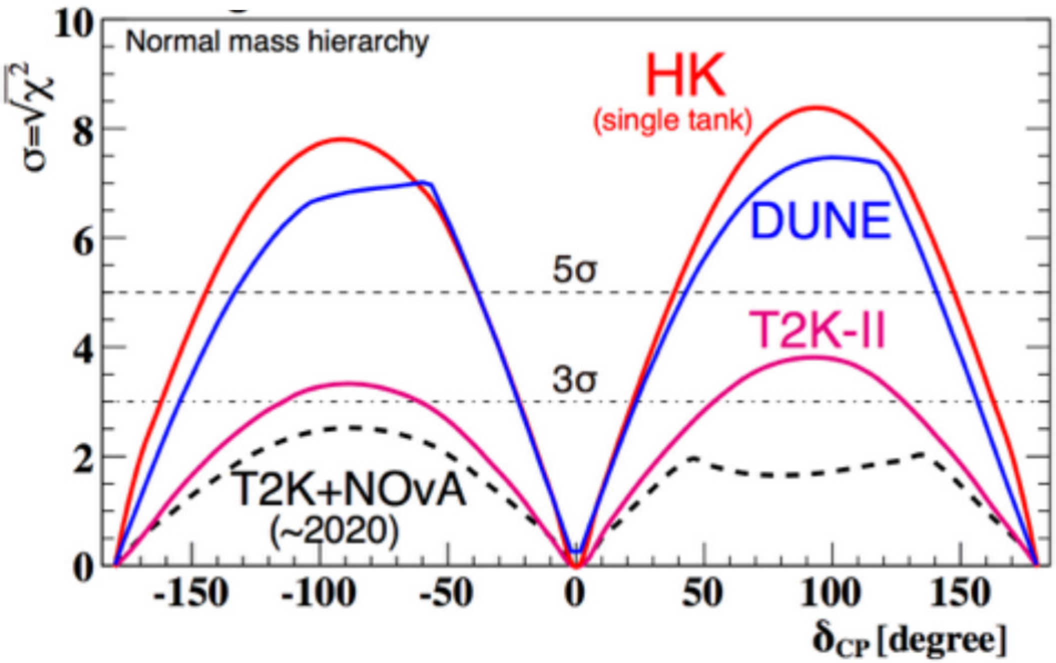
Meeting de preparation LLR/LPNHE/CEA/Omega, 2019/10/17

I. Reminder of Hyper-K goals and timeline

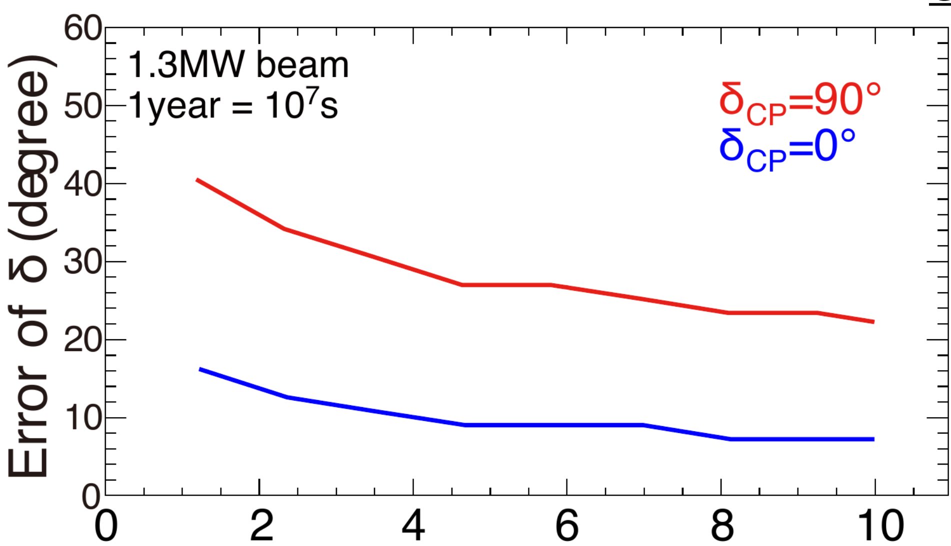
The Hyper-Kamiokande experiment

1. Observe CPV violation in lepton sector : if maximal, takes ≤ 3 years.





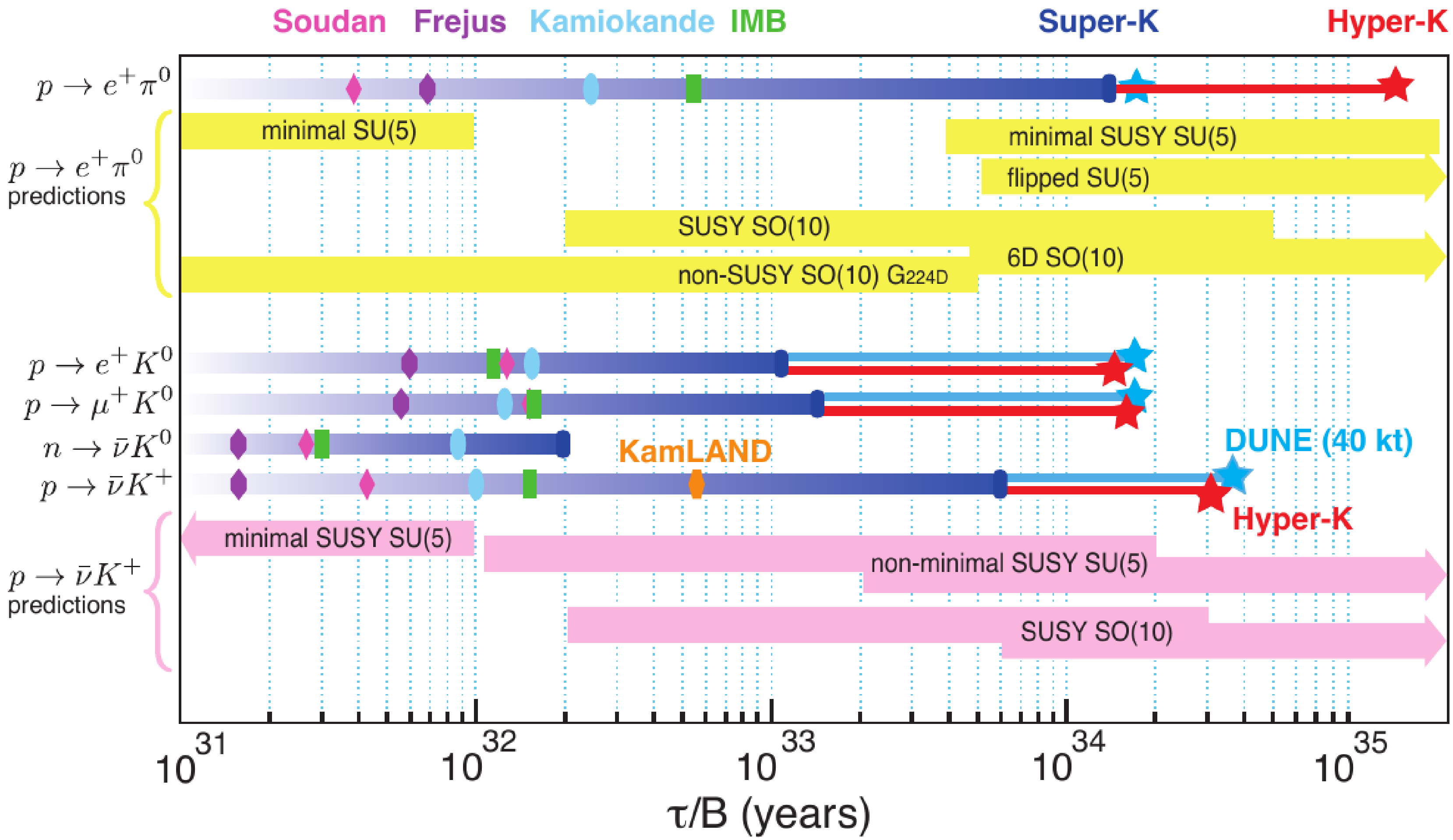
- Then, precise measurement of δ_{CP} measurements :



- Test some leptogenesis models.
- Test maximal CPV : hidden symetry ?
- Test symetries in lepton generation.

GUT and proton decay

2. Probe Grand Unified Theories at a new scale through proton decay.



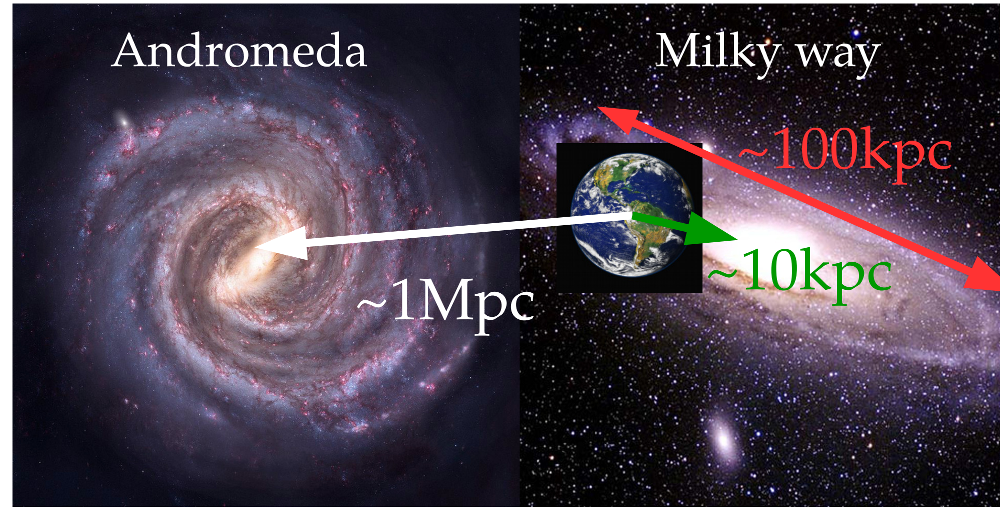
- HK will be able to probe Minimal SUSY-SU(5) & SUSY-SO(10) almost completely with the world highest sensitivity !

- This analysis is essentially limited / statistics → Crucial to increase FV.

Supernovae neutrinos

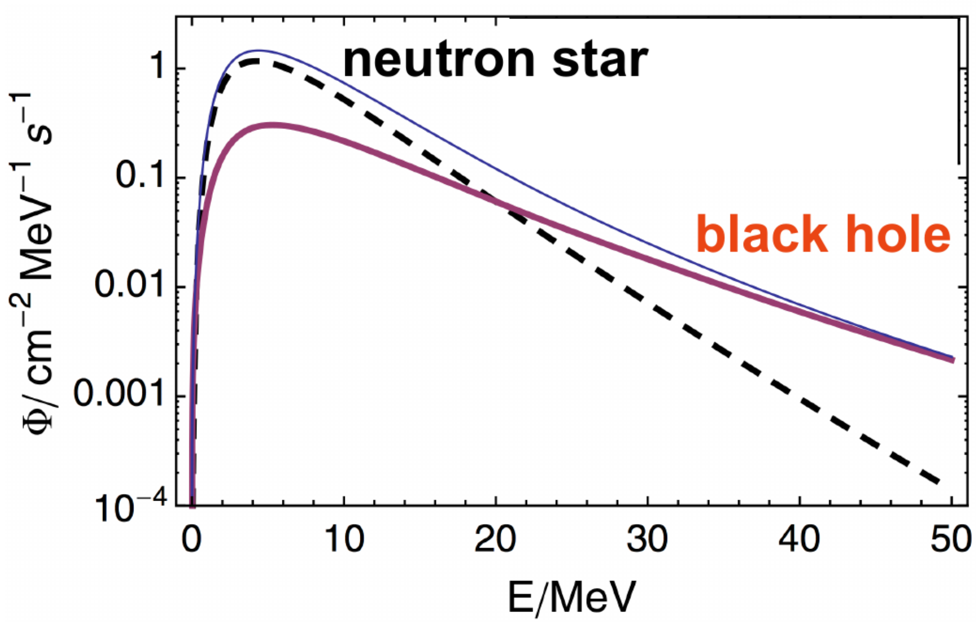
<u>3. Probe supernovae ν :</u> 99 % of SN energy → ν.

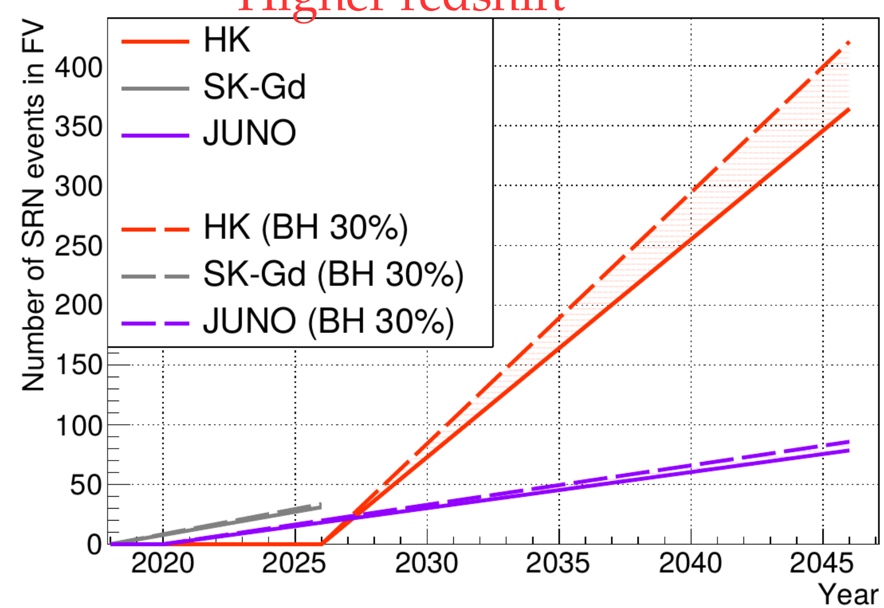
- But direct ν detection very rare.
- HK sensitive also extra-galactic SNν from Andromeda !



- SN-relic neutrino → new constraints on cosmic star history → May be first detected in SK-Gd.
  <u>→ The spectrum determined by HK :</u> Low energy ↔ Probe older stars

Higher redshift

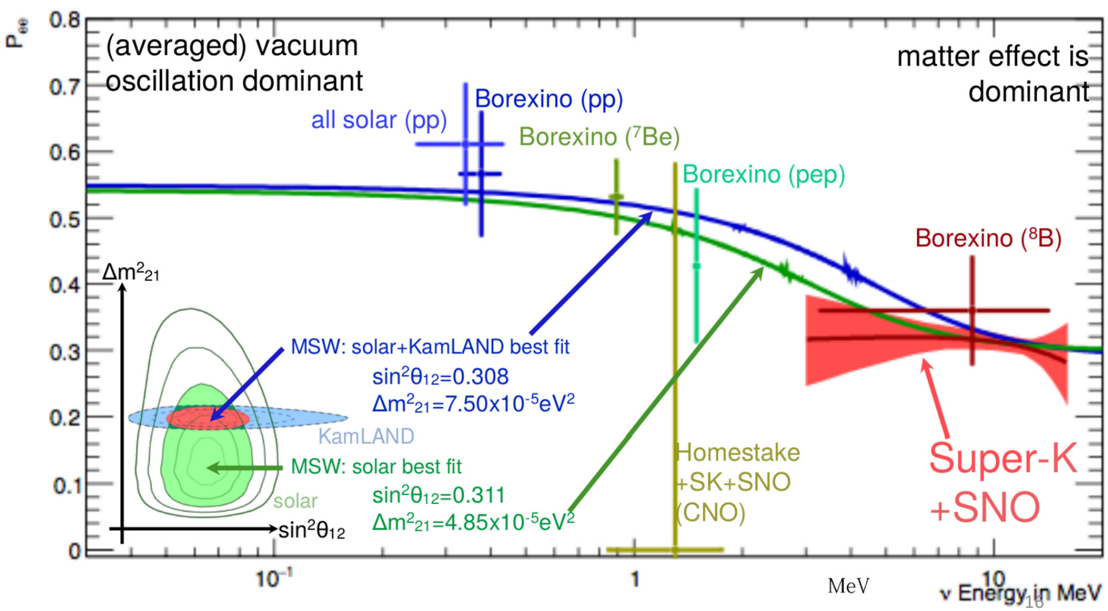


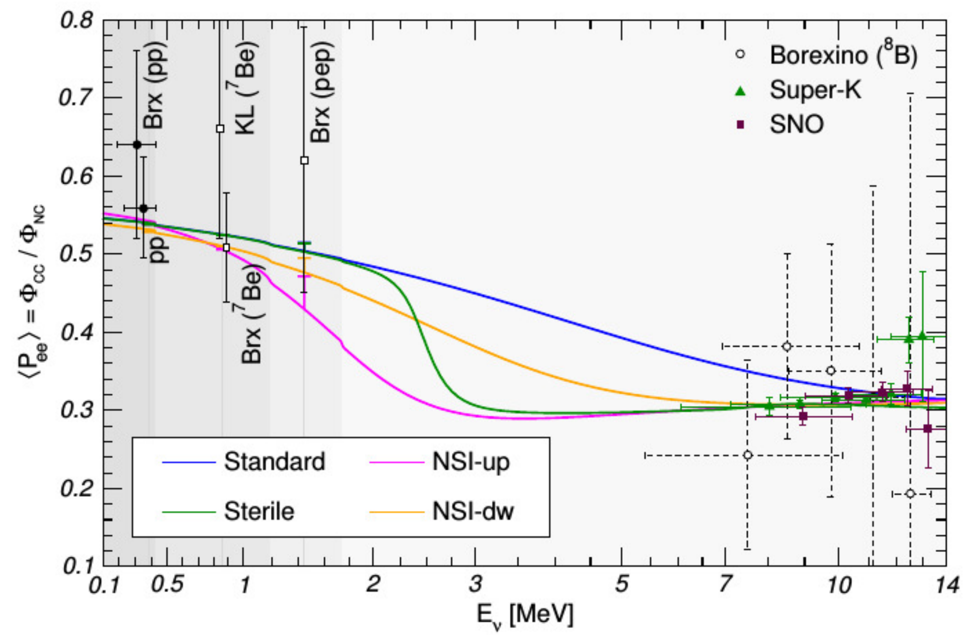


Solar neutrinos : upturn

<u>4. Probe solar ν :</u> SK/SNO found a high matter effect in the Sun

↔ Solar upturn shifted to lower energies





- <u>Displacement of the upturn can be explained by :</u>
  - Statistical fluctuation ?
  - Light sterile neutrino ?
  - Non Standard Interaction in the dense Sun ?

The Hyper-Kamiokande experiment

Jan. 2018	Approved in the MEXT « top 7 » most important scientific projects
Sept. 2018	Approved by University of Tokyo w/ promise to start construction in April 2020 + Seed funding by MEXT (as for SK)
Aug. 2019	Cost approved by MEXT : budget sent to Ministry of Finance !
Dec. 2019	Approved by Ministry of Finance ?
Apr. 2020	Construction start
2027	First data taking !

- Funding approval method similar to Super-K.
- When approved, the budget in Japan is fully guaranteed (not yearly).
- Construction starts in 5 months !

What is approved ?

- Budget approved by MEXT :

Components	Japan	Overs
Cavern	246	-
Tank and	125	-
Photo-detection	70	147
Water system	37	-
Management,	24	-
Total	502	147

Components	Japan	Overs
J-PARC upgrade	33	-
ND/IWCD facility	10	-
ND/IWCD	-	30
Total	43	30

20 % coverage of 20'' B&L PMTs.

- What is not covered :

1. Additional 20 % photocoverage to reach same 40 % as SK.
→ Fund additional/complementary/different PMTs ?

2. Price for electronics is not included → If Japan funds it, PC ↓.
→ Fund component of the PMTs electronics ?

3. 75 % of the price of IWCD (everything apart from excavation).
→ Fund mechanics/PMT/electronics/water system of IWCD ?

II. Thoughts about the 3 proposals

Where to start ?

- Before talking about $ and expertize : which physics do we wish to do ?
  → Near or/and far detector ? Low or/and high energies ?

- Consensus from LLR and LPNHE : far detector !
  → Already contribute to T2HK near detector with ND280-upgrade.
  → LLR contribution in Super-Kamiokande, esp. low energies.
  → LPNHE contribution in T2K/SK joint fit, i.e. high energies.
  → So, we can exclude contributions from IWCD.

1. Then, what are the criteria at lab level:

a. Synergy between physics interest and hardware → done.

b. Expertize of our engineers: no public engineer in Japan !

c. Involves also students/physicsts.

d. Contribution as visible & standalone as possible : easily advertized.

Where to start ?

2. At France level :

a. Synergy of contributions between labs : LPNHE/LLR/CEA/Omega.

b. Synergy with existing French-funded experiments : JUNO/ KM3NeT…

3. Needs to be convoluted to budget allocated by IN2P3.

a. Seems to be clear that it will be ≤ 10 million euros…

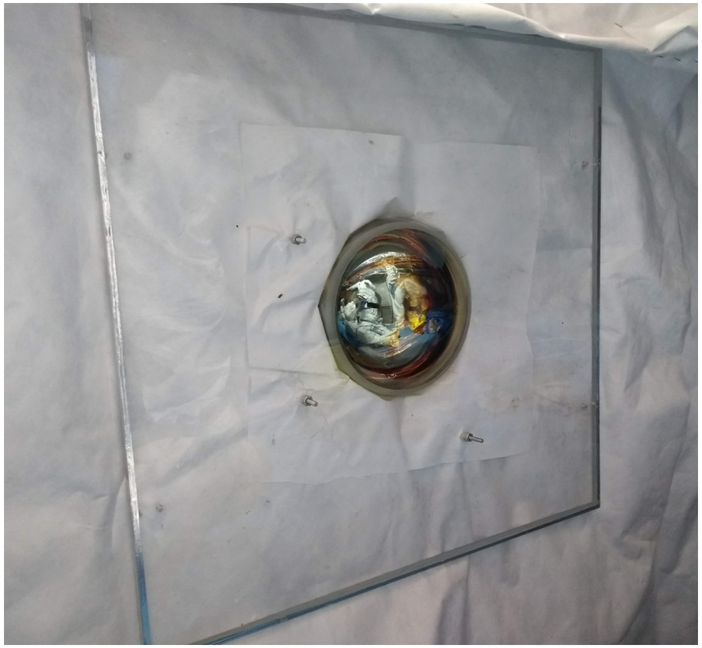
b. More seriously : totally not clear for now → So I prepared several scenarios for budgets : 1, 3 , 5, > 5 million cases.

c. I personally think we should avoid requesting a standalone 1 million case → Too negligible.

III. The 20′′ PMTs

What is taken for photosensors in FD

- For OD : Task handled by UK → 3′′ PMT with WLS plates



- For inner detector :

a. Japan order of 20,000 B&L PMTs.

b. Spain should take care of cover.

c. Main and only item left is electronics or electronic boxes

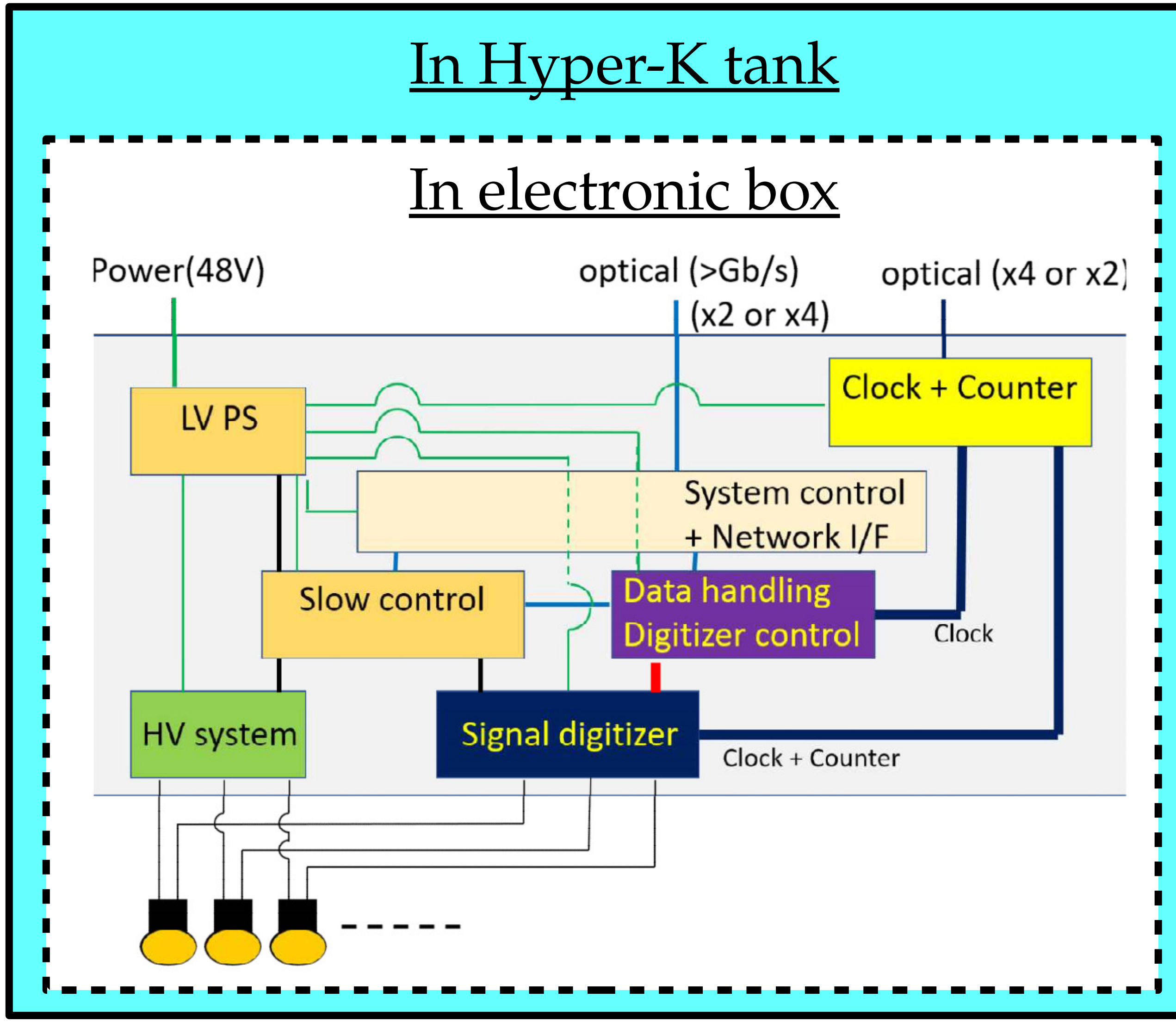
→ Japan has a back-up solution for every items.

→ But no budget : any proposal from us will lead to ↑ photocoverage : impact low energy, Mass hierarchy and potentially p-decay.

Contributions opened for 20'' PMTs

- Front end located under water : in boxes attached to structure !
  → 24 channels/PMTs read in one box.

- There are 7 parts :
  1. Digitizer for Q/T.
  2. Digitizer control system
  3. Clock.
  4. Slow control.
  5. LV PS for board.
  6. HV PS for PMTs
  7. System control & network.



- So far, only the DAQ PC has been taken by UK. Otherwise, everything is opened (told by Hayato-san).

20'' PMTs

- <u>Grades :</u> 2 = very important, 1 = important, 0 = limited.

	Expertize of engineers	Visible & standalone	Involves students & physicsts	Synergy w/ other French exp.	Price
Digitizer	2	2	1	1 : w/ Ω	1 box = 1k Total = 1M
Digitizer control board	2	2	1	0	1 box = 0.78k Total = 0.78M
Slow Control	2	2	2	0	??
Clock system	1	1	1	1 : for LPNHE w/ ATLAS ?	1 box = 0.5 k (w/ master clock etc.) Total = 0.5 M
HV	0	1	0	0	1 box = 2.4 k Total = 2.4 M

- I classified from ↓ order of overall importance regarding our criteria.
  → Other contributions (GPS etc.) are minor and shown in back-up.
  → Prices does not take into account R&D costs.

Some proposal for electronics

1. Maximal visibility package : the Front-End electronics of B&L

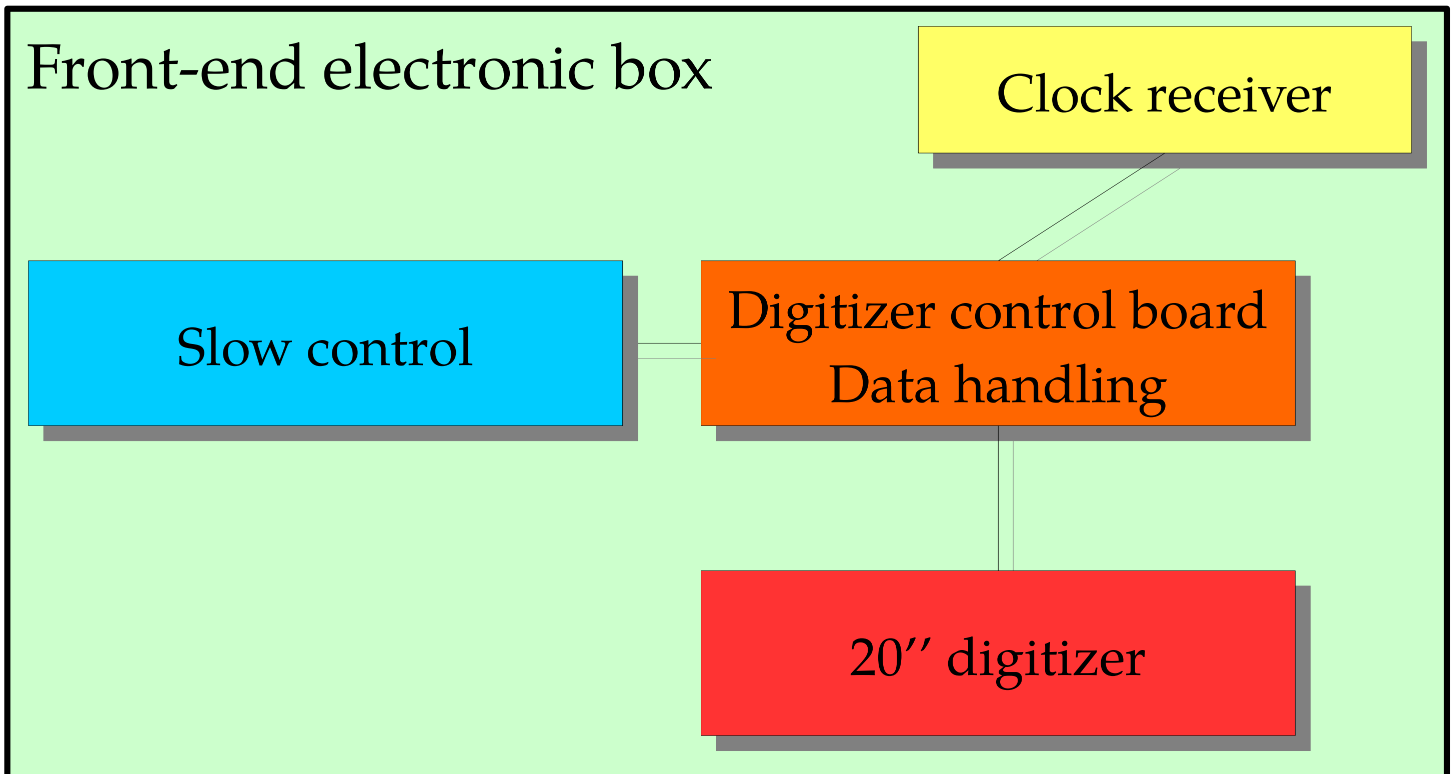
a. Develop digitizer & digitizer control board & clock system.

b. Could involve LLR & LPNHE & CEA & Omega (chip).

c. Maximal visibility & maximal synergies between groups.

d. If we have a software engineer, we could also add slow control.

→ Total cost : 2.3 million euros for production only.



→ Note : control board is the key for synergies between contributions !

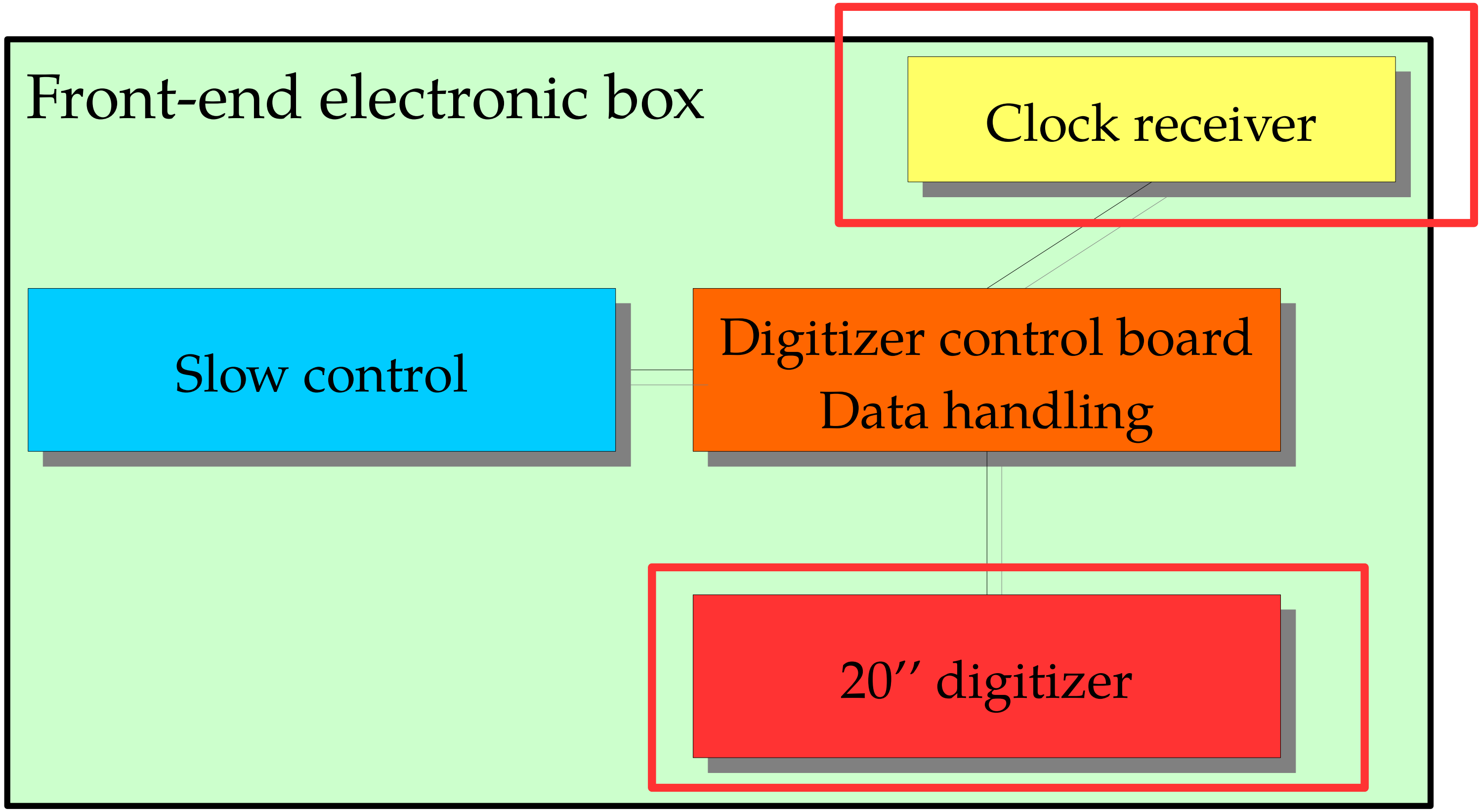
Some proposal for electronics

2. Semi-maximal visibility package : clock receiver & digitizer.

a. Could involve LLR & LPNHE & CEA & Omega (chip).

b. Synergy reduced due to missing control board

→ Total cost : 1.8 million euros for production only.



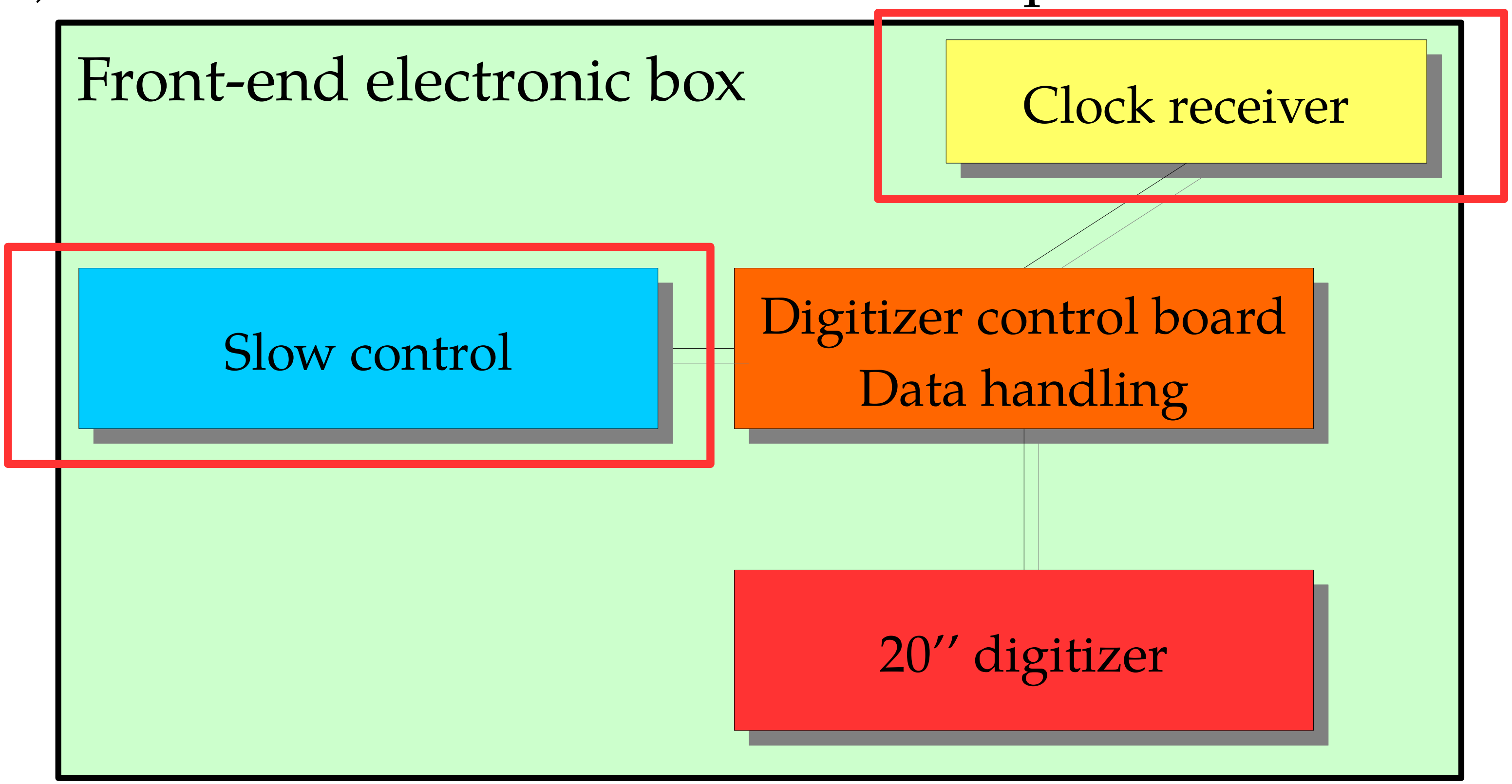
Some proposal for electronics

3. <u>Low cost package :</u> clock receiver & slow control.

→ Visibility, but very minimal funding help for Hyper-K.

→ Total cost : ~ 1 million euros for production only.

4. I did not cited all packages where clock receive is not used (LPNHE choice) → If this constraint can be release, please let me know.



III. Proposals for multi-PMT at Far Detector

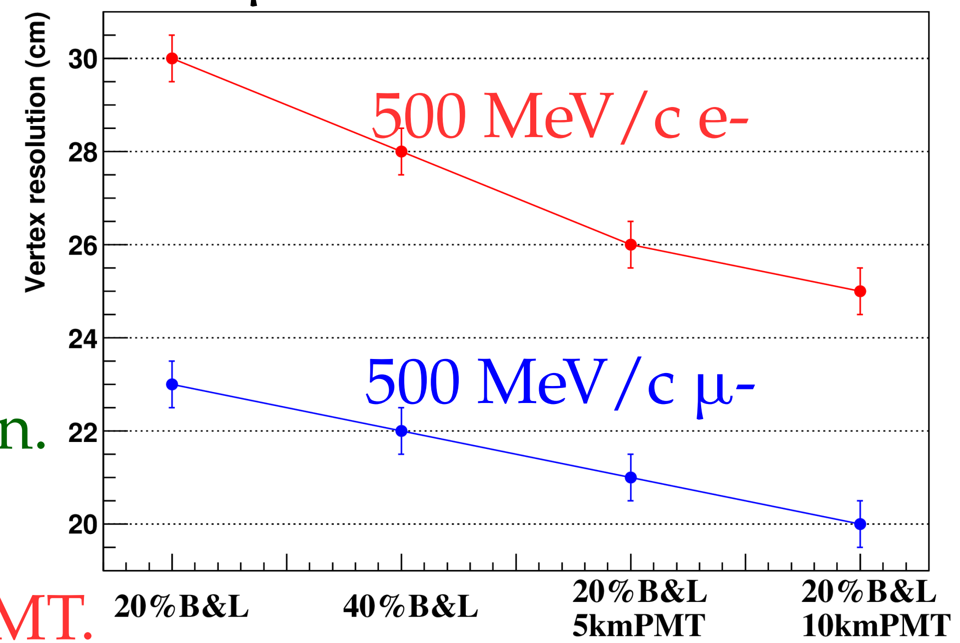
Multi-PMT impact at high energy

Multi-PMTs allows at high energy :

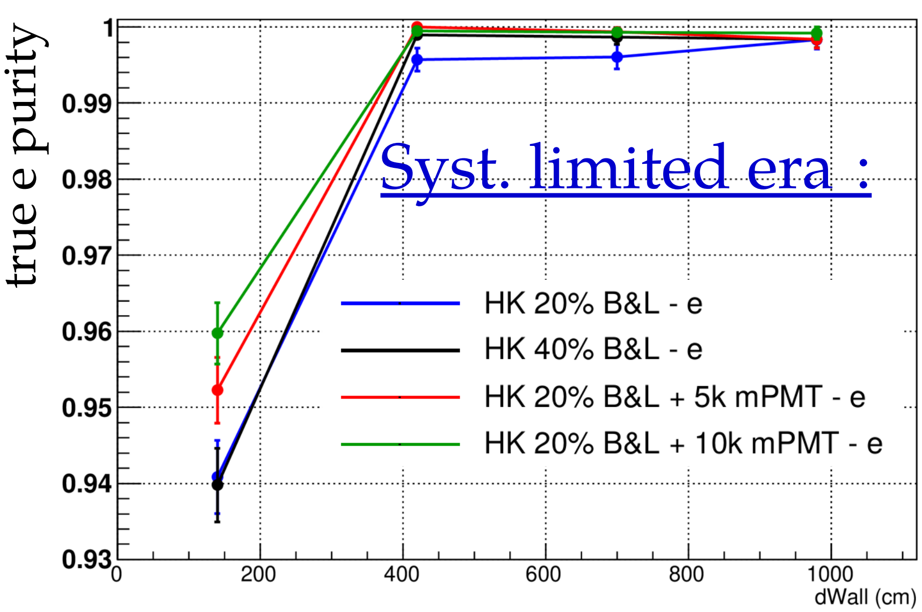
- ↑ vertex resolution, esp. near wall.
- ↑ e/μ separation, esp. near wall.
- ↑ e/π^0 separation, esp. near wall.
  → CPV & p-decay.
- ↑ E-bias calibration ? → δ_{CP} resolution.
- ↑ ring counting → MH, p-decay.

→ Even only +5k mPMT > +20k 20''-PMT.

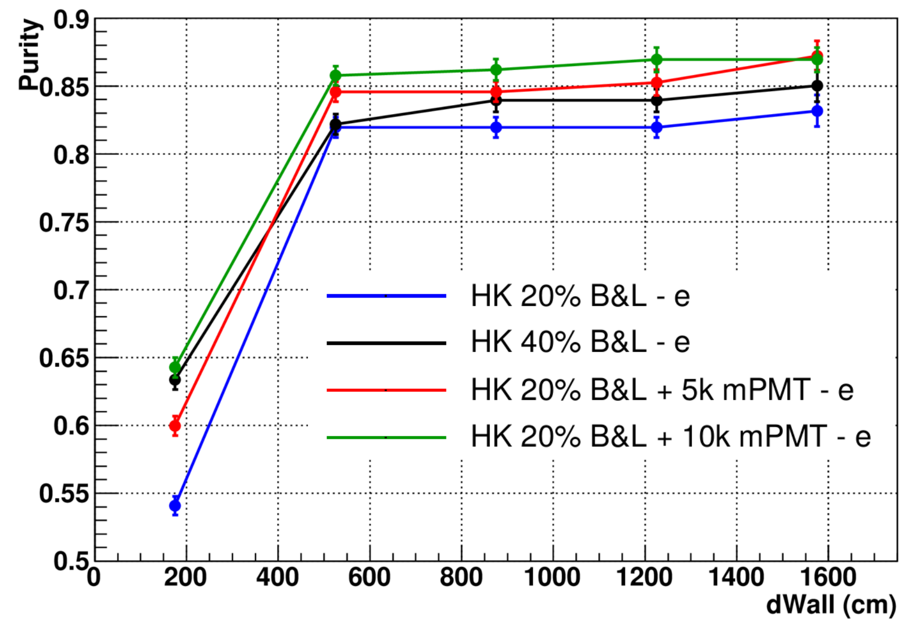
e/μ vertex resolution



e/μ separation : 1R e-like sample



e/π^0 separation : 1R e-like sample

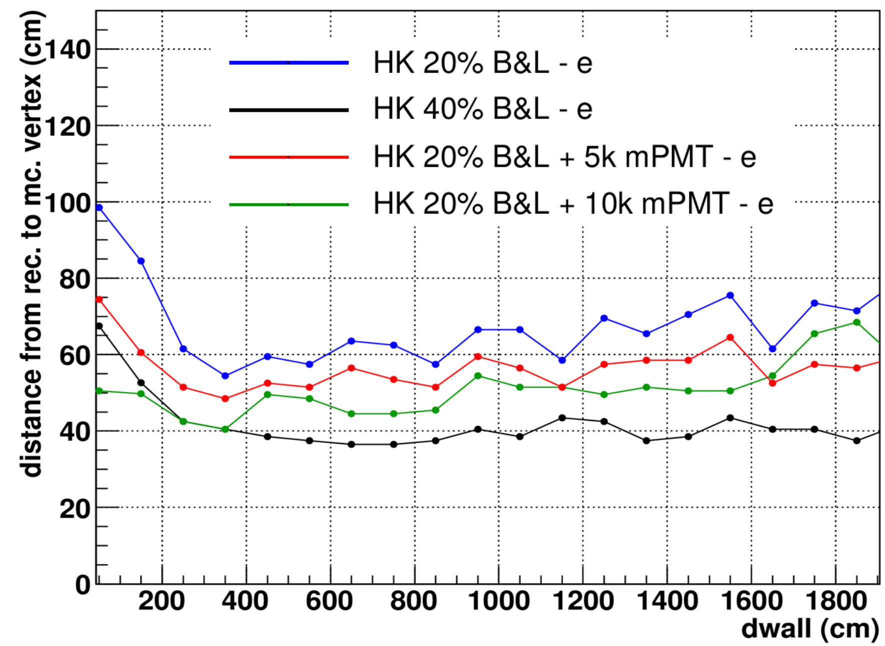


Multi-PMT impact at low energy

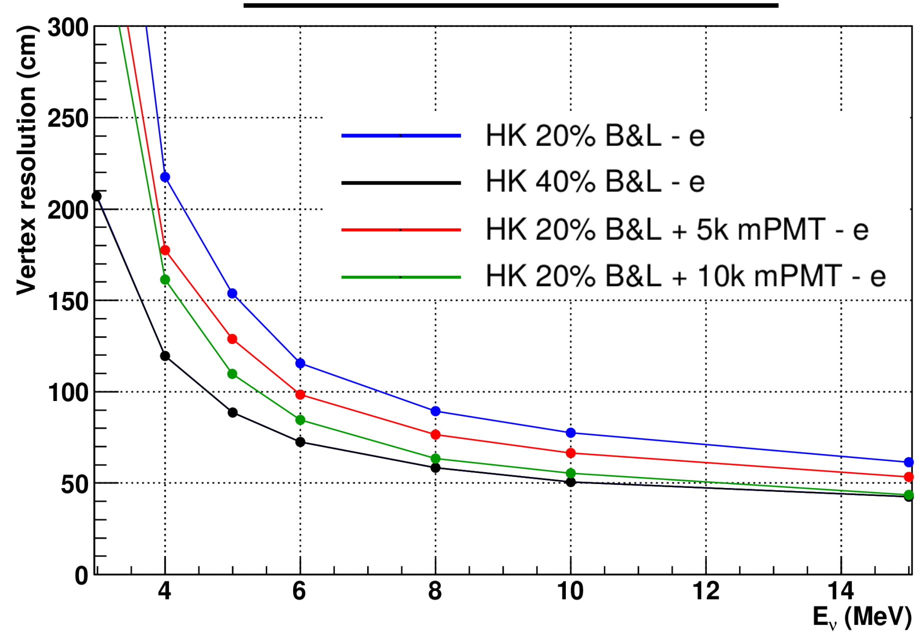
<u>Multi-PMTs allows at low energy :</u>

- ↑ vertex resolution, esp. near wall
- Larger ↑ vertex resolution for Low E.
- In any case, large impact at low E
  → Solar, SRN.
  → Could impact also n-tagging fo p-decay and MH.
  → Depends if we reach 100Hz/PMT.
- Impact 5k mPMT < +20k 20''-PMT
  → But price is not the same
  (aim for 1 mPMT price ~ 1 20''-PMT)

<u>10 MeV electrons</u>



<u>3-15 MeV electrons</u>



Advantages of multi-PMT

- Advantages for us to go for Multi-PMTs :

  All same advantages as 20'' PMT contributions (see before).

  + Synergy w/ 2 experiments France participates : JUNO (3''), KM3NeT.

  + Synergy w/ CERN w/ test beam experiment & MEMPHYNO.

- What are the possible contributions :

Front-end electronic box

Clock receiver

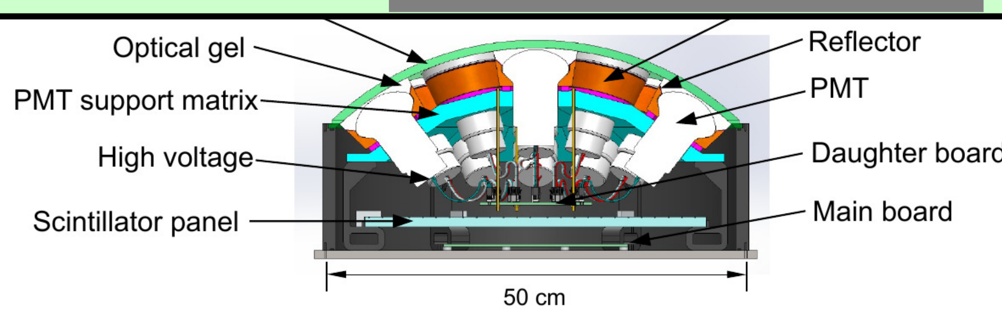
Slow control

Digitizer control board
Data handling

MCC

20'' digitizer

In Multi-PMT



Multi-PMT digitizer

Proposal for mPMTs

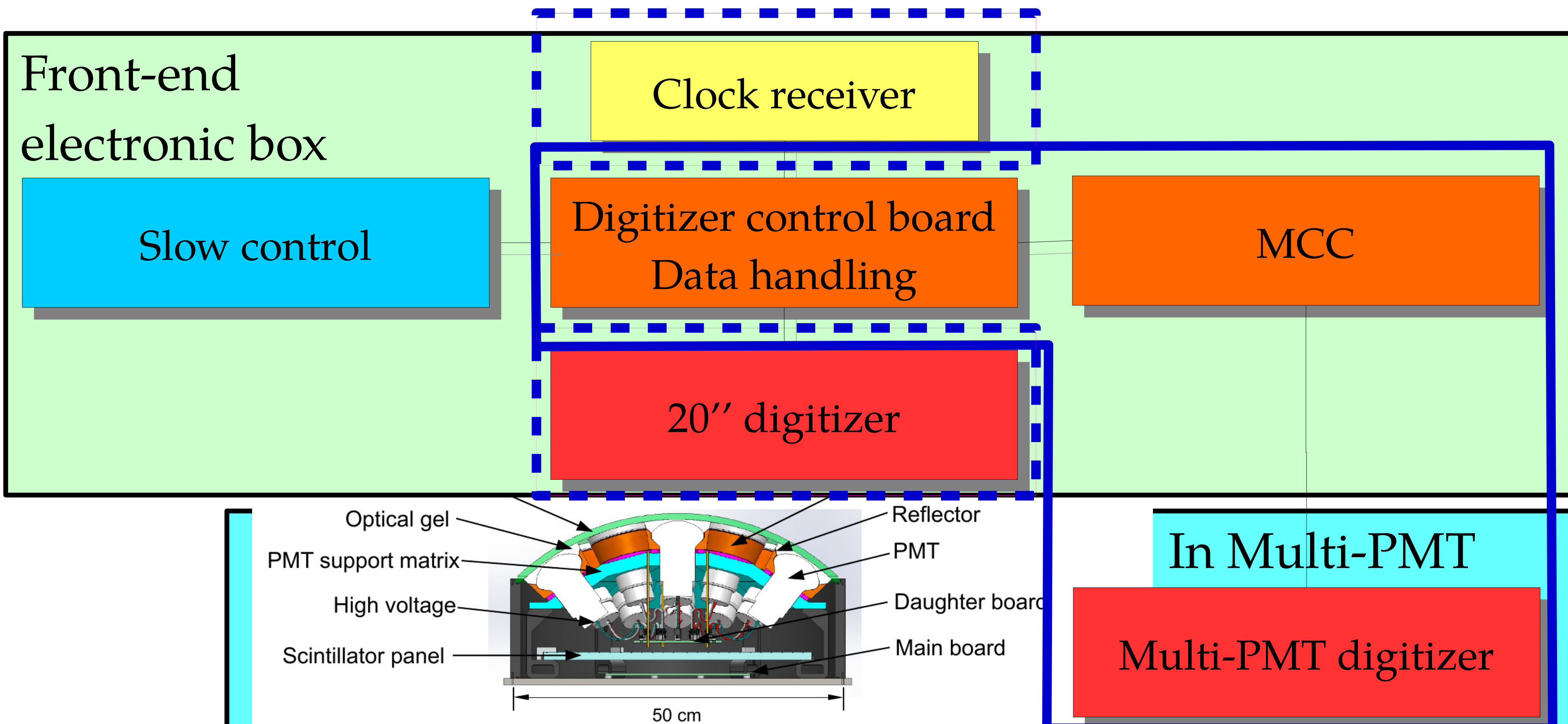
1. mPMT digitizer & control board (20″ and mPMT) (+ clock receiver)

1.a. Synergic, involves Omega. Price for production is ~ 1.8 million euros.

1.b. If add clock receiver : ~2.3 million euros for production-only.

1.c. If the chip can be similar (board will be different) : add 20″ digitizer.

→ 3.3 million euros for production only.

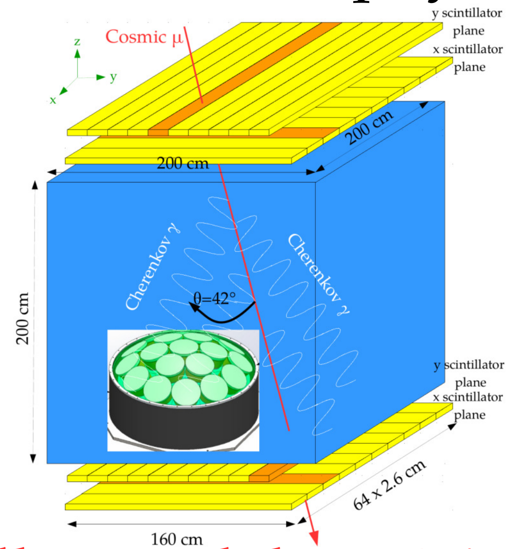


Proposal for mPMTs

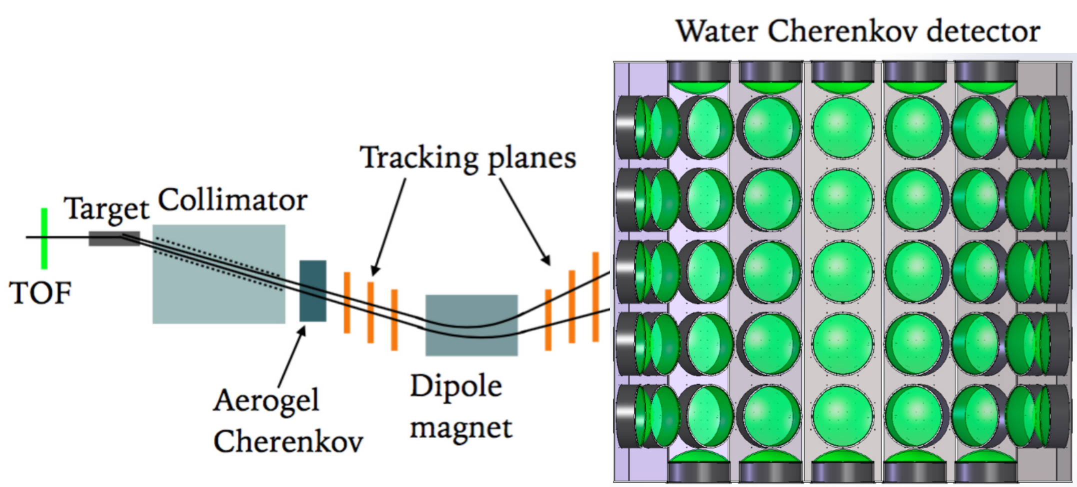
- In that option, we would not have to fund any multi-PMT.
  → Will develop and fund the electronics of mPMTs for FD.

- <u>We will have however to test our electronics :</u>
  1. We have MEMPHYNO !
  2. We will have the test beam experiment at CERN → Can put mPMT, but also 20′′ PMTs

<u>W/ cosmics : Memphyno tank</u>



<u>In test beam at CERN</u>



→ Totally standalone ! And relies on our strengths.

→ Ask Christophe about possibilities (technical and timeline).

Smaller proposal for mPMTs

2. Digitizer for mPMT and 20″

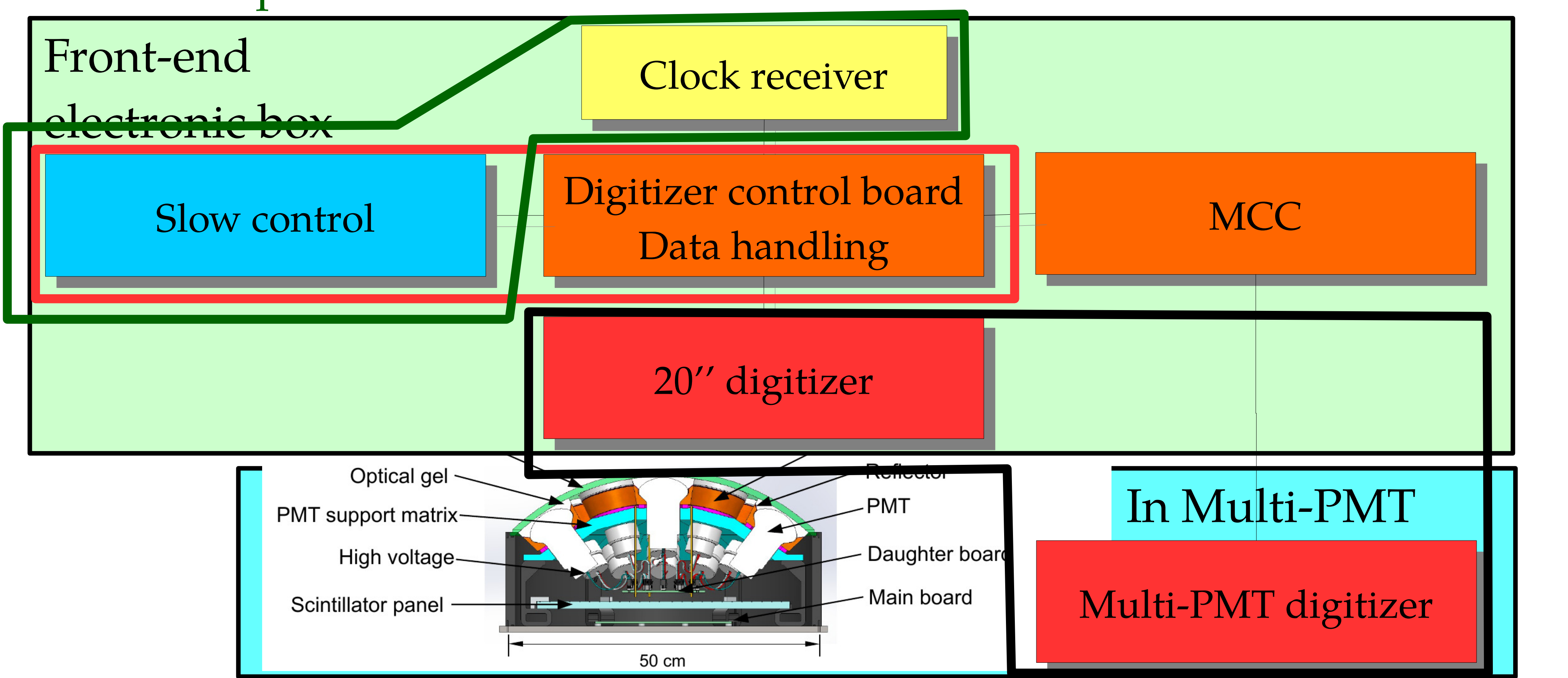
→ Totally synergic, if chip can be same. Price for prod ∼ 2 million euros.

3. Clock distribution (20″ & mPMT) + Control board (for 20″ & mPMT)

→ Totally synergic, price for production is ∼ 1.5 million euros.

4. Clock distribution and slow control (for 20″ & mPMT).

→ Price for production is 0.5 million euros.



Personal opinion about mPMTs

- mPMT are still not sure to be funded for FD.
  → So, extremely dangerous to for an mPMT-only contribution without paying&assembling mPMTs.

- <u>We therefore have two options :</u>

1. Have a transversal/synergic contribution for 20''-PMT and mPMTs :
→ This is what I tried to do in the options I proposed before !
→ Already presented.

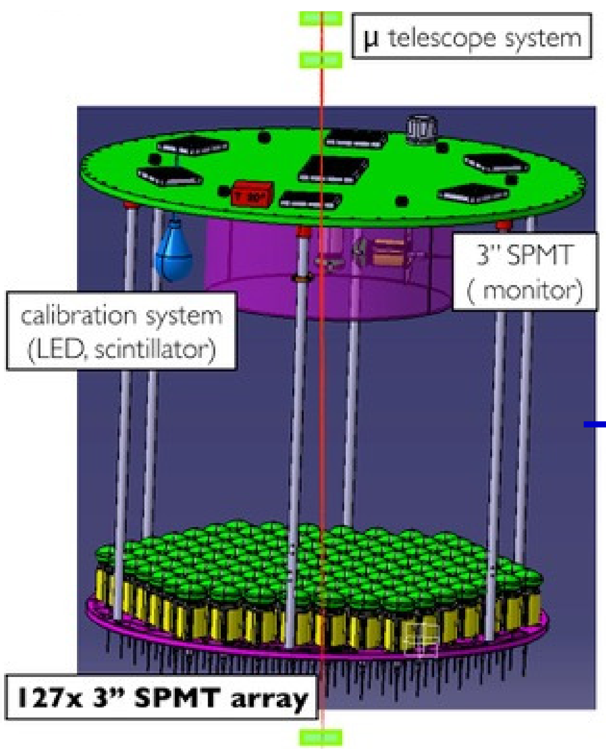
2. Go for mPMT-only but pay/assemble/test mPMTs in France.
→ Could be coupled to a low cost development before : slow control, clock distribution.

A test bench proposal

- <u>Our hardware contribution can be :</u>
  → Clock distribution & slow control (transversal to mPMT/20″) : 0.5ME
  → Digitizer & clock distribution : 1.5 ME.

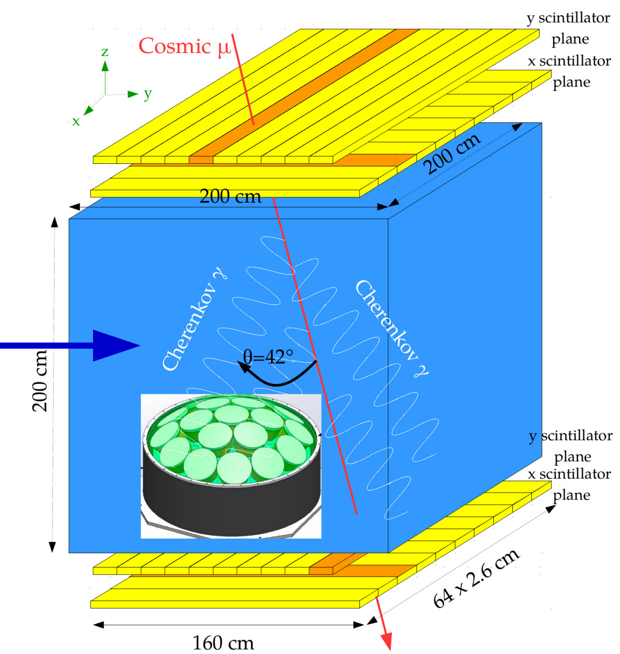
- + Considering all material to build 1,000 mPMTs → 5 million euros.
  → <u>Example :</u> 30 for test beam, 970 for FD.

<u>Test 3″ PMT at LLR</u>



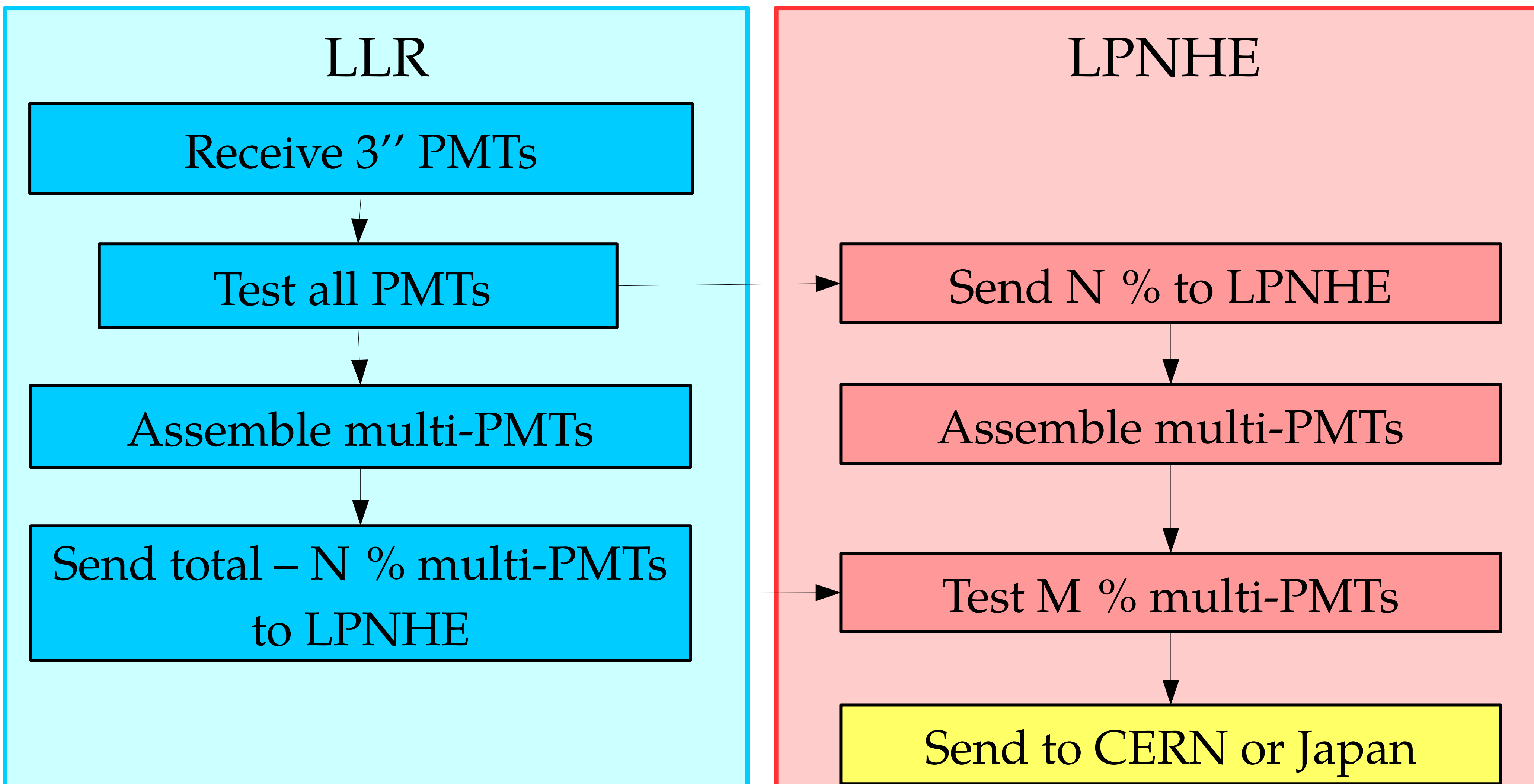
<u>Assembly mPMT at LLR & LPNHE</u>

<u>Testing mPMTs at LPNHE</u>



A large scale proposal

- Our strong points :
  - Expertize of 3'' PMTs and PMT calibration: Benjamin,Thomas ?Alice ?
  - MEMPHYNO tank & Mathieu's grant to improve it.
  - May have a basis for 3'' test with JINO (discussed w/ Anatael).



IV. Conclusions

Conclusions

- We should not forget, is how good and vast will be HK physics
  → The world-leading program in various area of physics !
  → Based on decades of hard work, but also lots of learning by failures, from all of us for SK & T2K : expertize of physicists & engineers.
  → T2K and SK are the world-leading experiments in their area. It is not a promise, it is a fact.
  → We should not be ashamed to request a budget at the level of this belief in our experiment.

- Based our potential contributions on physics we aim → Far Detector.

- Potential contributions are :
  1. 20'' PMT electronics → If we do, more 20'' PMTs ?
  2. mPMT electronics → If we do, more mPMTs.
  3. mPMT test/assembly → If we do, more mPMTs.
  → Could be combined to some extend.

Conclusions

- For each contributions, we tried to rank them by :

a. Expertize of our engineers: no public engineer in Japan !

b. Involves also students/physicsts.

c. Contribution as visible & standalone as possible : easily advertized.

d.Synergy of contributions between labs : LPNHE/LLR/CEA/Omega.

e. Synergy with existing French-funded experiments : JUNO/ KM3NeT…

f. Schedule → Asked Hayato-san, but still waiting.

- I prepared personal thoughts about workpackages and rank them w/ the above criteria
  → Please treat it only as my opinion, and a starting point for discussion.

- I tried to show you results from impact of mPMT
  → Seems very beneficial for HK, above adding 20'' PMTs (TBC).
- You can find more details in back-up.

Conclusions

- <u>Some conclusions after thinking about mPMT of our discussions :</u>

1. Assembling mPMT in France may be complicated both for manpower issue, but also, hightlighting a standalone contribution.
→ For us, it would make more sense not to pay for a part of the whole mPMTs and assemble them, but to pay for the whole production of a small component of mPMTs (e.g. electronics).

2. At the same time, I know we have very good engineers / technical potential developments, while other countries have more students /physicists (Japan, Canada…).
→ It was assumed that each countries participating to mPMT will assemble them → I do not know how much thoughts were put in it.
→ We should definitely re-discuss how to fund mPMT, and use strenghts of every countries.

Conclusions

- It would remove test/assembly of mPMTs as a potential requests…
  … To my point of view, it is dangerous to for an mPMT-only contribution without paying&assembling mPMTs.

- <u>So, 2 solutions :</u>
  a. Contribution to 20'' electronics only.

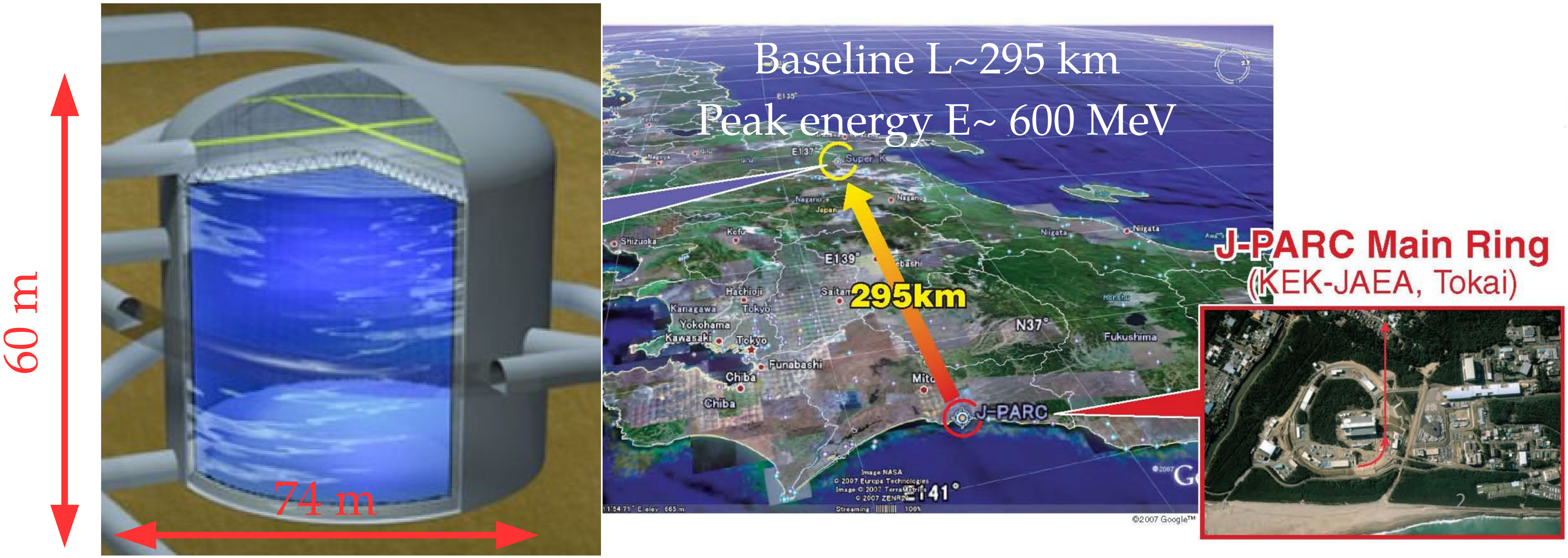
  b. Tranverse contribution to 20'' and mPMT electronics.
  → Would be ideal, if we have enough manpower & funds.
  → Should clearly tell IN2P3 that w/ a bit more funds : can extract much more physics (non proportional) using our synergies in France.

<u>Advantages for us to go for Multi-PMTs :</u>
Enhanced physics beyond 20'' PMTs for same price (for LE, TBC).
All same advantages as 20'' PMT contributions
+ Synergy w/ 2 experiments France participates : JUNO (3''), KM3NeT.
+ Synergy w/ CERN w/ test beam experiment & MEMPHYNO.

Additional slides

The Hyper-Kamiokande experiment

- Next generation of neutrino observatory in Japan→ construction 2020-26
  → A 260 kton water Cherenkov detector → <u>FV mass ~ 8 x SK.</u>



- <u>Rich & vast physics program :</u>

1. Observe CP violation in lepton sector.
2. Probe Grand Unified Theories at a new scale through proton decay.
3. Direct Supernovae detection not only in our galaxy, but in Andromeda.

& New constraints on cosmic star history using SRN background.

4. Probe solar neutrino up-turn and day/night asymetry.

My personal wishes

- I personally think that we cannot propose :
  - To participate to Far Detector.
  - And to work on a sub-part of mPMT w/o buying / testing / assembling some of the modules (e.g. just develop electronics).

→ Because there is a too large risk that mPMT does not happen for FD if we do so.

→ So we should decide to step-in or not (personal point of view only).

- Of course, on top of mPMT testing / assembly, we could focus on an additional R&D work.

  → Not pay for production, just R&D.

  → <u>Example :</u> calibration test bench.

A large scale proposal

- <u>Our contributions could cover :</u>

  - Ordering 2,000 mPMTs → 10M$.

  - Construction of a large scale test bench for 3′′ PMTs & mPMT :
    - For 3′′ PMTs → Use LAL test bench for JUNO ? Construct one at LLR ?
    - For mPMT → Use MEMPHYNO.

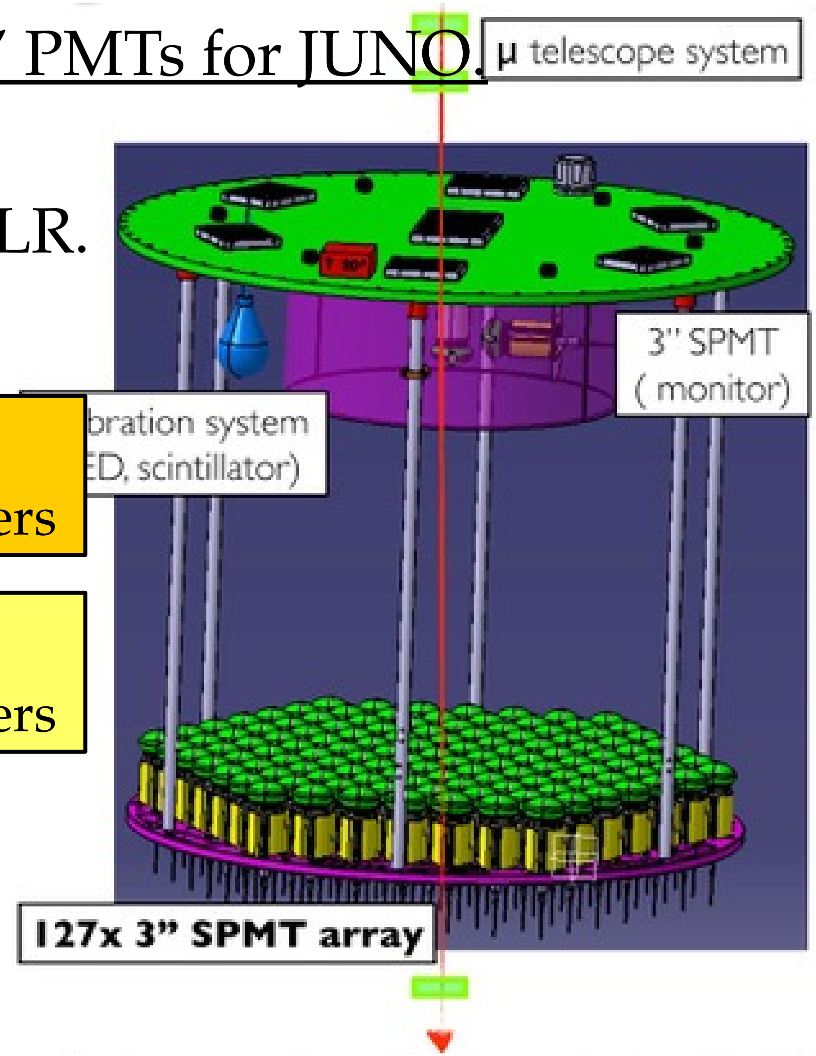
  - Assembly of mPMTs at LLR available for both LPNHE & LLR → Have 2 persons every day ↔ 1 mPMT/day.

  - Send some of the mPMTs at MEMPHYNO for tests w/ calibration sources and cosmics.

  - LLR&LPNHE may/could also take care of slow control for PMTs.

The test bench for 3′′ PMTs

- Here is the test bench forecast for testing 3′′ PMTs for JUNO.
  - → When could it be available for us ?
  - → If not soon enough, could build one at LLR.



Receive 3′′ PMTs at LLR

Test N %

Expert shifts for LLR / LNPHE members

Assemble multi-PMTs

Shifts for LLR / LNPHE members

Test M % at MEMPHYNO

Send at CERN / Japan

- To realize this, we need :
  - A working test bench from end of 2020 → Electronics etc.
  - MEMPHYNO instrumented with same calibration sources than test bench to test same properties (on top of cosmics).

If we do not have all this money

- Our contributions could cover testing and assembling mPMTs only → But who would buy them and send them to us ?

- <u>Development of calibration sources that could be deployed :</u>
    - In MEMPHYNO.
    - In Test experiment.
    - In IWCD.
    - In FD.

→ LPNHE could e.g. focus on high energy calibration source deployment. LLR could focus on low energy ones.

- <u>Electronics : Front-end board already taken in charge.</u>
  → Work on a low cost front end to install PMT in HyperK FD.
  → Back-end boards of mPMTs (not small). What strikes me is that Poland claim to ask for 2,000 mPMT + do all back-end-board + take care of B&L PMTs: realistic ? → Ask Marcin and Mark.

If we do not have all this money

- My personal feeling for LLR :
  - Have a contribution in FD.
  - If France does not buy mPMT, it is likely we won't have them in FD.
  - So to me, we should focus on asking budget to ask for mPMT on our side.
  - Or move to another project, different from mPMTs.

- If we manage to reduce the cost of a mPMT, it would be really brilliant.

  → Low cost electronics ? How much this is already done by Italy ?

  → Ask Gianfranca.

- We could also focus on HV power supplies :

  → LPNHE for mPMTs.

  → LLR for B&L PMTs → Could require few B&L in test beam.

Alternative 2 : mPMT FE or power supplies

- If we manage to reduce the cost of a mPMT, it would be really brilliant.
  → Low cost electronics ? How much this is already done by Italy ?
  → Ask Gianfranca.

- We could also focus on HV power supplies :
  - → LPNHE for mPMTs.
  - → LLR for B&L PMTs → Could require few B&L in test beam to test them in-situ.

- Or focus on the monitoring / slow control for FD of mPMTs and B&L.

If we renunce of synergy with FD

- Focus on IWCD instead of FD.

- <u>In that case, here are the additional contributions :</u>

- **Detector tank**
- **multi-PMT support structure**
- multi-PMTs (including HV, electronics)
- HV and electronics collector cards
- DAQ & Slow Control
- Calibration
- **Water system**
- Beam line monitors (provided by CERN?)
- Computing

So far, nobody has taken ownership

Potential CERN/CENF participation?

After meeting with LPNHE

- 10 millions will be almost impossible
  → I think we all agree. It is only our goal.

- Whatever the budget requested, we need a clear description of how to use it.
  → The best would be to have some « packages » with a corresponding budget and all advantages it gives to HyperK.
  → E.g. : Slow control ↔ 500kEuros etc.

- LPNHE would also like to be on FD. Their contribution to ND is the ND280 upgrade, and they wish to argue that their new contribution is FD.

After discussion with Mark

- We could produce a Japan/Canadian prototype. For this, we need :
  - Clean PVC → Investigate on my side.
  - Order PMT → I could do in October.
  - Assembly with Gel → Wait for feedback from Canada.

- For Front End of the mPMT :
  - On the Italian side (so for FD), the leading engineer has just left
    → What will it becomes ?
    → The electronics may not really adapted to our needs for HK → Would like to have a simple Q/T digitizer, like QBEE.

  - On the Canadian side (so for IWCD), one of the leading engineer has just left, but it will only delay the project.

  - As for the back-end board → Ask Marcin.
  - As for HV → Ask Marcin

Reading the TR

The basic requirements of the front-end electronics are to provide and monitor HV for each photosensor, to collect all the hit data without loss, to transfer data to the readout system and to keep the collected data until they are read out. All the front-end electronics have to be synchronized and there should be no large phase shift at a level of a few hundreds of ps or larger even after a power recycling. Further details are described in each sub-section.

What does it mean to be synchronized ?

→ Electronics (Front end) have an inner clock. With it, they can register the time of the signal.

→ Every front end could be slightly asyncronized. We could correct for their shift with calibration afterwards, precisely measuring their t0.

→ However, we need all signals to be synchronized enough for trigger for example. But, triggers are based on number of hits in few 10ns → Why do we need ~100ps synchronization ?

At this moment, there seems to be no technical reason to differentiate the inner and outer detector electronics and DAQ system. However, if there are groups that would like to provide only ID or OD system components, we would ask the group to develop components which satisfy the requirements documented here and are compatible (if applicable) with the other relevant components. There are differences in the readout electronics for the mPMTs, and it is not clear how to integrate the detailed description into this section, so this has been included as a separate

Question to Hayato-san :

→ Has UK group volunteered for OD electronics ? DAQ ? Slow control ?

→ If not : should consider integrating both ID/OD in our development.

Reading the TR to do better

In designing the electronics and the DAQ system, it is necessary to estimate the amount of data to be processed. $\boxed{\text{At the moment, all the signals from PMTs above 0.33PE,}}$ including the dark noise, are expected to be recorded by the electronics and transferred to the DAQ, which then reduces unnecessary noise in the data by applying software triggers. One of the most important roles of the front-end electronics and the DAQ system $\boxed{\text{is to not lose information from a nearby supernova}}$ burst if one occurs. We evaluate the amount of data for this case using some assumptions that have been discussed with the photosensor and neutrino astrophysics groups.

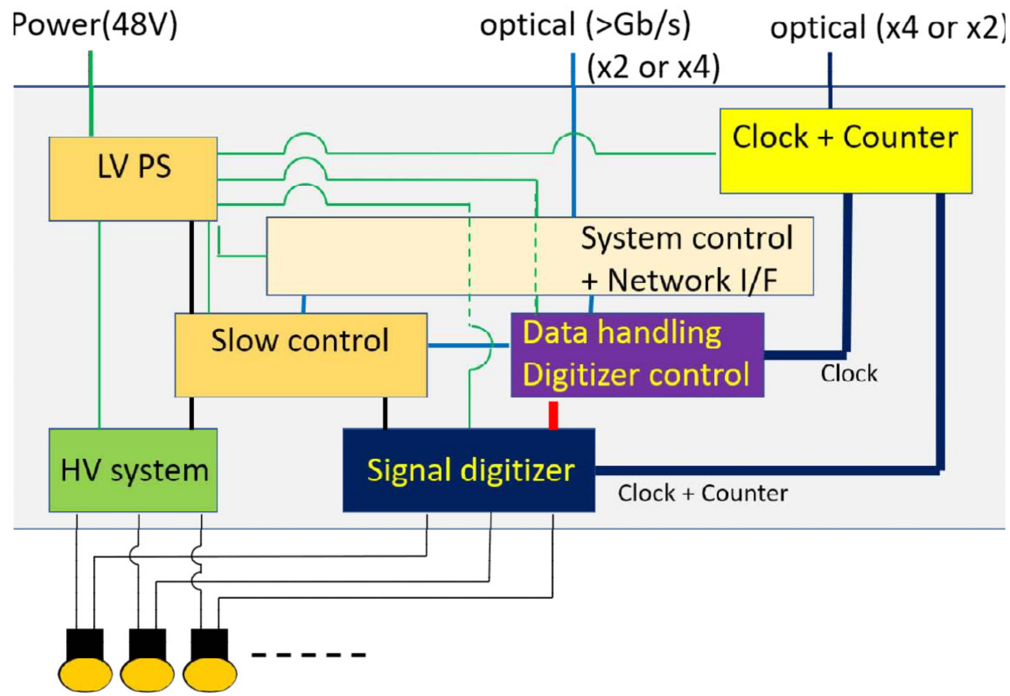
- For now, the trigger is set at 0.33 PE → How much is it for SK ?
- When a SN happens, shall we take only signal > 0.33 p.e, or the whole signal for each PMT ? → It seems only signal > 0.33 p.e.
- For HE, it is clear in the table that the main broadband is requested when signal arrives (not when Dark rate).
- For SN, we expect 75M hits / s → 125 GB/s for the first 1s.
- For LE, if we set the threshold at 6 MeV and have a DR 7 times higher than SK (in reality, 5 times??)
  → LE trigger : 350 Hz.
  → 1 trigger contains ~ 80 MB/s data for 60 micro-sec.

Item	Assumptions and estimates
Number of ID PMTs	40,000
Dark rate/PMT	10 kHz
Noise rate	3.2 GB/s
Noise rate (per board)	2.0 MB/s
Event rate	75M events (0 to 1 s) 105M events (1 to 10 s)
Data rate (10 s)	327 GB
Data rate (10 s per board)	0.17 GB

Reading the TR

- Front end will be located under water, in some boxes attached to structure somewhere → Where ?

- There are 7 parts :
  1. Digitizer for Q/T.
  2. Digitizer control system
  3. Clock.
  4. Slow control.
  5. LV power supplies for board.
  6. HV power supplies for PMTs
  7. System control & network interface.



- One box gathers 24 PMT signals → Charge and ti

- 1. First, for digitization, both charge and time are digitized.
  → Characteristics/requirements are shown on the right.
  → TDC and QDC.
  → When threshold is crossed : QDC and TDC registered, and stored on a 32 bits chip (4 x 10^9 slots).

Trigger	self triggering for each channel
PMT impedance	50 Ω
Signal reflection	<0.1%
Discriminator threshold	<0.25PE (well below 1PE)
Processing speed/hit (channel dead time)	<1 μs
Maximum hit rate	>1 MHz for each channel
Charge dynamic range	0.1 to 1250PE (0.2 to 2500 pC)
Charge resolution	RMS 0.05PE for signals below 25PE
Timing LSB	<0.5 ns
Timing resolution	RMS <0.3 ns at 1PE RMS <0.2 ns for signals above 5PE
Power consumption	<1 W per channel

- 3. Clock :
  a. Slow clock (61 kHz so every 16 microsec):
     - Read out stored QDC/TDC on the 32 bit chip.
     - Reset the fast clock counter and the 32 bit chips.
  b. Fast clock : (125 MHz ↔ every 8 ns) → Launch a new TDC ramp.

1. The digitizer

There are two kinds of technologies that have been proposed for the ID (and OD) readout. The first approach is to use a charge to time converter chip together with a TDC. The charge to time converter chip integrates the charge in a pre-defined gate time when the signal pulse height exceeds the threshold. Then, a single square shape pulse is output, whose rising edge indicates the signal timing and whose width is proportional to the input charge. Because of these characteristics of the output pulse, there will be a dead time during the signal pulse output but this dead time can be smaller than 1 μs, which satisfies our requirements.

1. QTDC : This is basically a spiroc2D like chip. We integrate charge and start a TDC ramp to measure Q/T.
→ Japan + US are collaborating to design this chip. I believe this spot is already taken → Ask Hayato-san.
→ Ask Omega : what could be our minimal dead-time ?

2. Waveform digitizer : Based on Flash-ADC
→ Record shape of the pulse in charge/time → Could be used to discriminate signal from noise using shape ?
→ No dead-time
→ Poland is working on it. My personal guess is that this option cost much more, so could be used for mPMT and dominantly, for IWCD.

2. The clock module

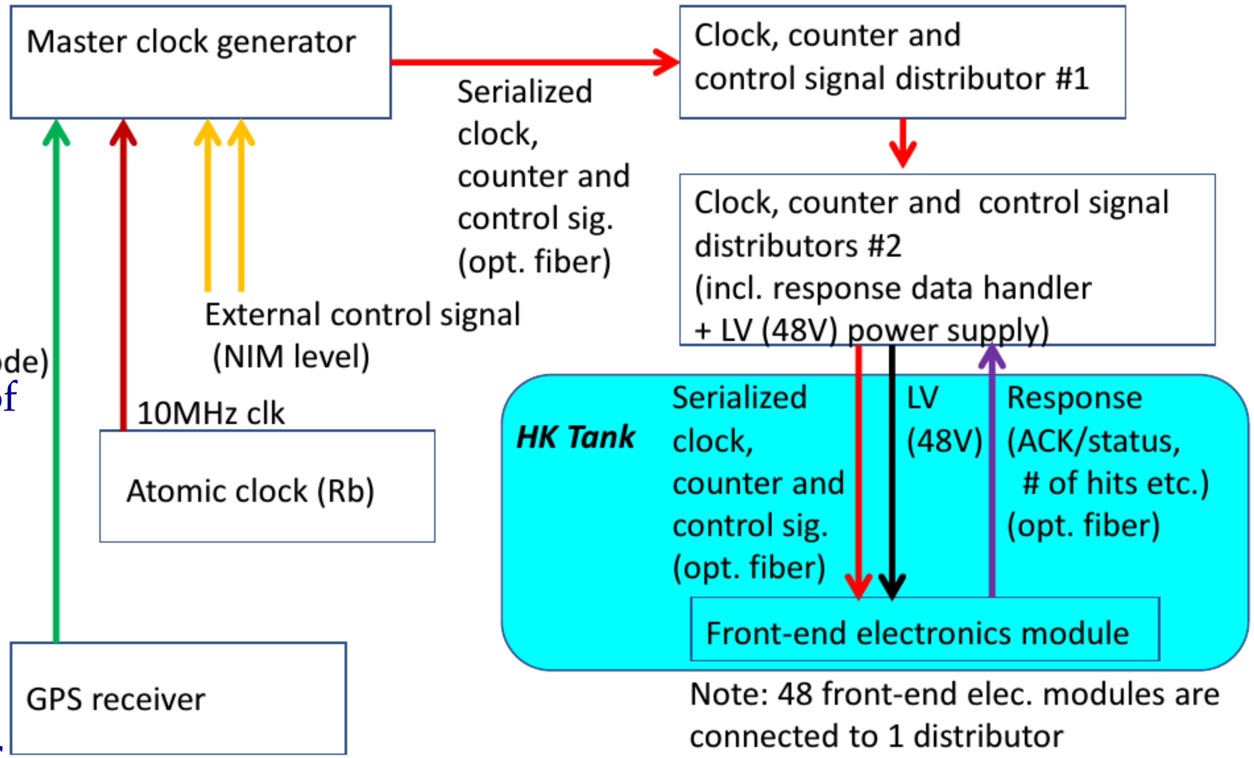
There are 5 components :

1. One master clock for the whole HK which generates the clock.

2. Two clock counter distributor #1 which decodes the clock
→ Cascade (two?) to reduce the number of outputs on a single Distributor.

3. Receivers in each Front End board

4 & 5. Atomic clock and GPS to correct for shifts of the master clock.



- Difference between clock time, time received by the counter generator and the output of the receiver in the TFB has to be stable, and < 100 ps.

- Basically, how the master clock is generating a « tic », a clock count ?

- How atomic clock and GPS receivers impact the master clock ?

- What/which/how the GPS signal is provided to the master clock ?

2. The master clock module

The master clock generator provides a 125 MHz clock, a 61 kHz clock, a 32-bit counter, a GPS based timestamp and additional bits to control the blocks in the front-end electronics (Fig. 175).

The 125 MHz clock is generated using external inputs from an atomic clock. The frequency of most atomic clocks is set to 10 MHz which we assume is fine, but we may need to be capable of accepting other frequencies. The 61 kHz clock is generated every 2048 counts of the 125 MHz clock. It is used to increment the 32-bit counter, which is distributed to the front-end electronics. Both the 125 MHz and the 61 kHz clocks need to be accessible from an external output by configuration.

The generator module has to have at least 4 external signal inputs, which are transmitted with the 32-bit counter to control the front-end electronics module. It has to accept three independent GPS 1 pps inputs, which are associated with a serialized timecode. There are various timecode protocols available, so the module has to be configurable to accept them. The relative time differences between the latest 61 kHz clock and the most recent GPS 1 pps pulse has to be recorded with the data for each GPS. For this it is necessary to have at least one ethernet port to send out the information. The same information is also embedded within the 32-bit counter and sent to each of the front-end modules.

- Atomic clock is what generates the 125MHz clock ? → Check this with Hayato-san.
- Slow clock is derived from the fast clock → Every 2048 counts.
- GPS timing is used to check if atomic clock has not been mistaken.

2. The transmitter & receivers clock module

- Transmitter : basically decodes clock from master and transmit it to receiver.

- Receivers (in Front end) : receive the clock information (slow and fast) from the transmitter to :
  - a. Send data to digitizer control system and reset the 32 bit chips (slow clock).
  - b. Generate a TDC ramp.

3. The digitizer handler / data processing

- This is basically the function we call « Back-end board » for ND280 → Integrated here in the front end.

- Unlike digitizer which only digitizes, the digitizer control system :

    1. Can receive command from extermal user and transmit to digitizer → distribute clock information to digitizer for example.

    2. Receive data from digitizer and send it to readout.

- Secondary importance :

    3. Also, it could perform pedestal data taking, or other calibration data taking → Periodic trigger launched ?

    4. Could do a data reduction if needed.

- Important note : the high / low / SLE triggers are clearly not at this level, but higher in the chain, as we need data from all PMT (so all Front Ends)
→ In what we call « readout level »

- Who is taking care of the digitizer control system ?

6. The HV board

This block is expected to provide a stable and low noise (ripple) high voltage power to each of the 24 PMTs associated with a front-end electronics module. It needs to have the capability to turn on and off individual channels, to monitor the voltage and the current of each channel and to cut the power supply of each channel if the current or the voltage are different from the expected values. The basic requirements are summarized in Table LII.

1. Provide HV up to 2500 V for each of the 24 PMT.

2. Should have a slow control to switch on/off PMT individually → Use the slow control described after.

Could have :

1 HV power supply / electronic module + divider between 24 channels.

Or

2. 24 small HV power supplies

- How is it done for SK ?

Question to Hayato-san :

→ Who is taking care of this ? No one from now.

Item	Requirements
Output voltage	0 to 2500V
Accuracy	$< 0.2\%$ (1500 to 2500V) < 3V (0 to 1500V)
Output current	> 0.5 mA/channel
Output stability	$< 0.2\%$ /year
Accuracy of voltage monitor	$< 0.2\%$
Accuracy of current monitor	$< 0.5\%$
Ramp up/down speed	Tunable from 100 to 500V/s
Ripple noise level	< 10 mV at 10 kHz
Temperature dependence	50 ppm/K
Failure rate (per channel)	$< 1\%$ /10 years
Power consumption	< 1 W/channel

4. The slow control

- Slow control could be used for :

  1. Changing settings of the module → Here, of the digitizer (e.g. change trigger mode to periodic trigger instead of when it > threshold) or the HV supplies (and LV).

  2. Monitoring the module items → Checking digitizer bits used, checking connections between all components of the boards communicates, check HV values for each of 24 channels. Also monitores LV.

- What needs to be monitored (2.) :
  - Temperature to better than 0.5°C.
  - Humidity to better than 10%.
  - Low Voltage to better than 0.1V and 10mA.
  - High Voltage to better than 0.2% for the voltage and 0.5% for the current.

- So far, who is taking part of this ?

7. The system control and network interface

- It is basically responsible of sending information from the digitizer control system to external « readout level » and vice vera (for monitoring).
- Use a protocol TCP/IP.
- Sent through an optical fiber.
- <u>On top of that :</u>
- The optical fiber is quite a work → Should have durable material for > 20 years.
- GPS system → Should work on the GPS system similar to the one from SK for the master clock.

And what about mPMTs

- Unlike B&L PMT, the front end electronics of mPMT is already integrated in the module.

- <u>But, we obviously cannot have one cable / mPMT to go to surface</u>

  → In fact we could, as in SK.

  → But propose to install MPMT Concentrator Card (MCC) located in some electronic box → Use one from B&L ? → Yes, this is our goal

  → As for B&L, will received signal from 24 mPMT, and can control HV from 24 of them.

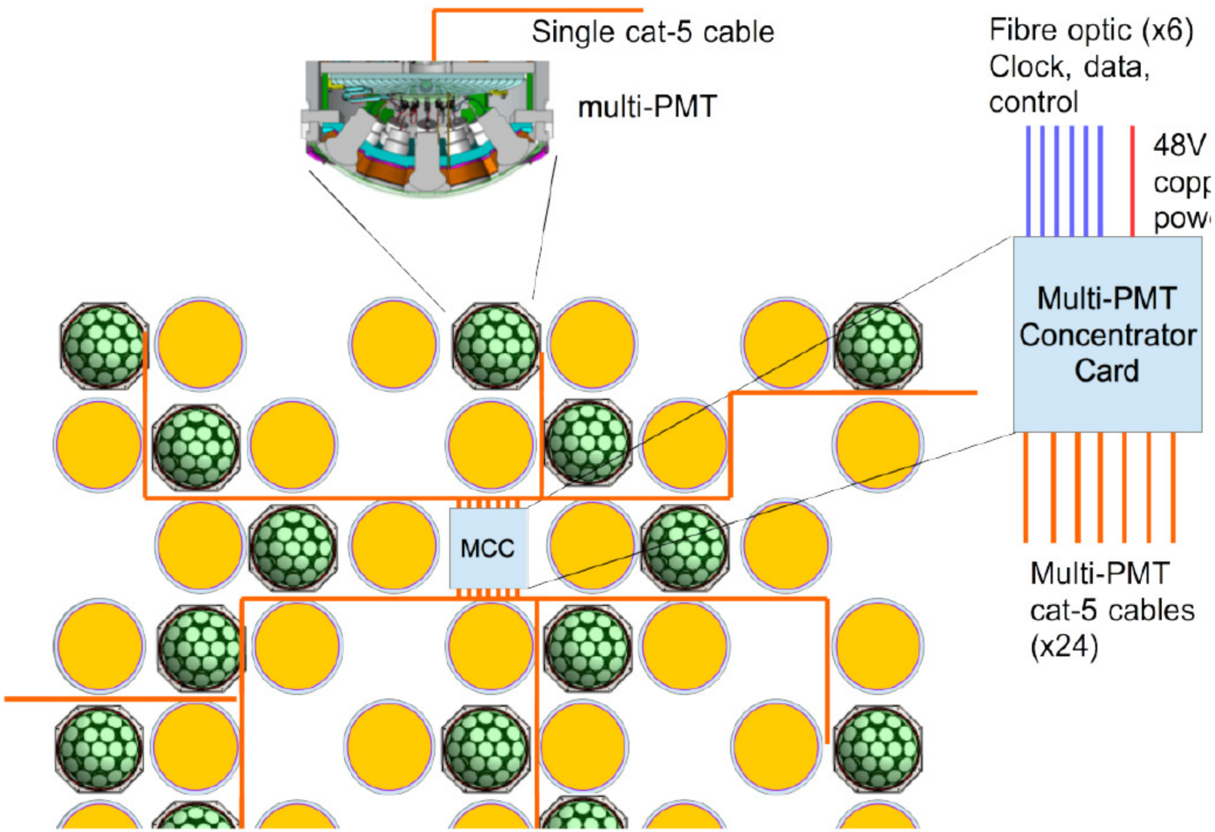
  → Our goal would be to use the same optical link for both B&L electronic modules and this MCC, to:
  a. Use same clock for both PMT types.
  b. Therefore, send data at the same time.
  c. Control both the HV from the mPMT and B&L.

- As a notice, the slow control would be then shared for both B&L and mPMT → Very good development.

- <u>What would be different between B&L and mPMT :</u>
  1. The digitizer obviously, as one is in the mPMT, the other in the electronic module.
  2. The HV → an mPMT needs another voltage + is the HV in the mPMT or in the electronic module ?
  Answer : It seems in the mPMT. Is it necessary ?
  3. What about the digitizer controller ? Can it be common ?
  Answer : for now, it is separated. Can it be common ?

And what about mPMTs

- <u>The MCC :</u>

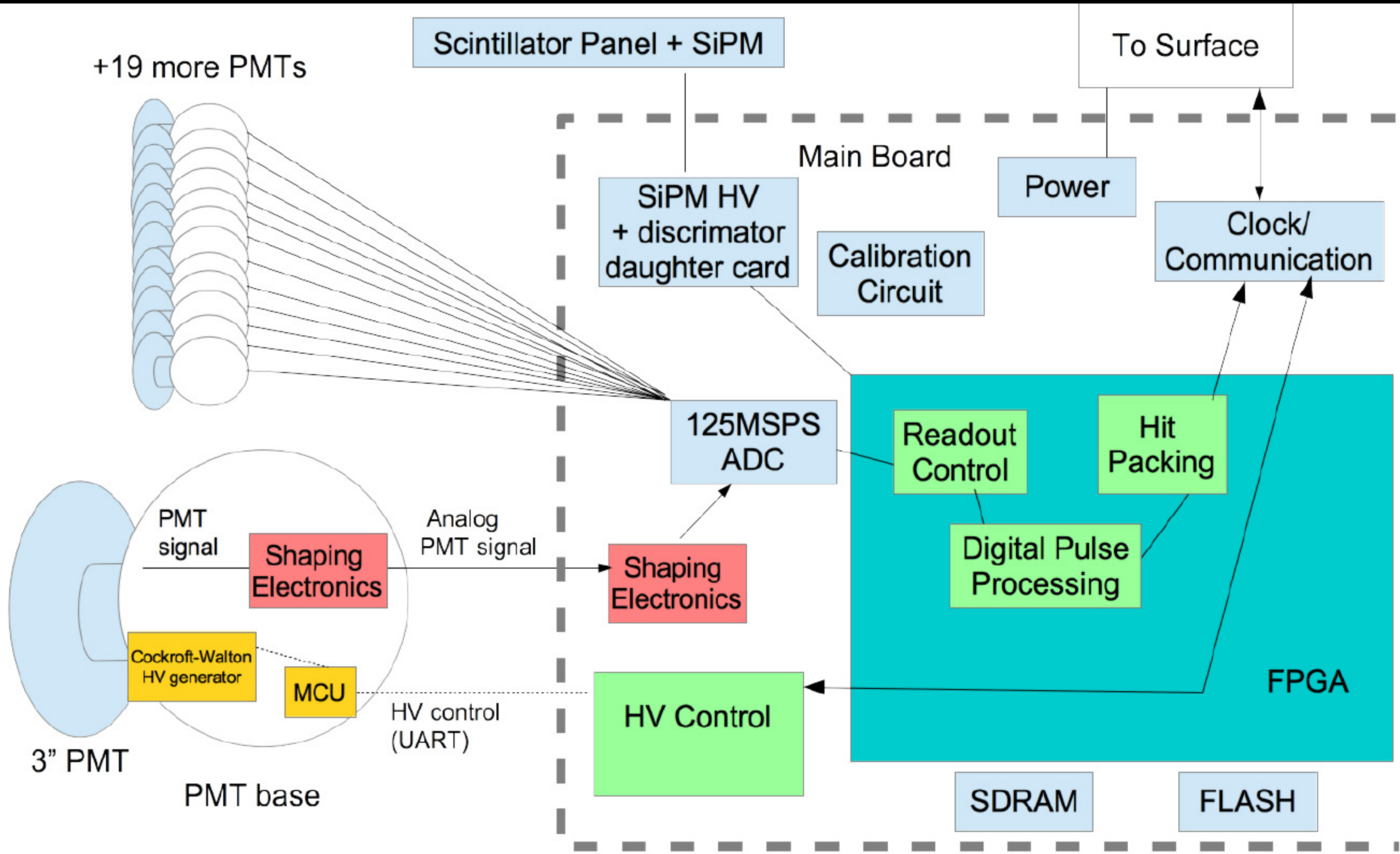


- <u>There are 2 available digitizers :</u>

- 1. The Italian one → I naively thought it was basically like the B&L digitizer (Q/T digitizer) but seems no. Let's check in next slides.

- 2. The Canadian/Polish one → Based on FADC → No dead time & noise/signal discrimination based on pulse shape
  → But much more expansive : how much ?
  → Maybe too expansive for FD.

The Italian electronics

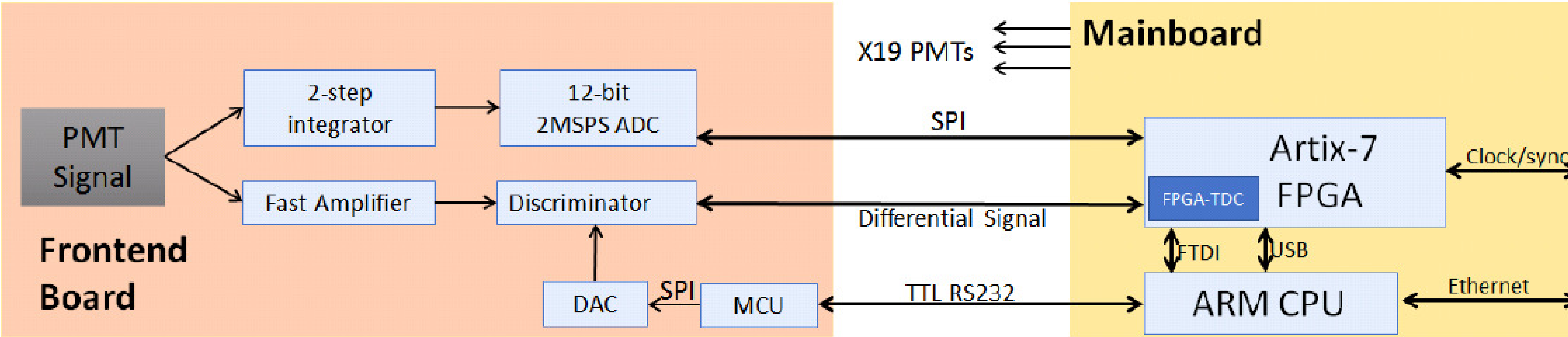


- First, it seems that HV control (Slow Control) is in the MCC → But HV generation is in the mPMT → May be too hard to send a stable HV over long distance ? Check this.

The Q/T digitization proposed for the mPMT is different from the Q/T digitization proposed for the ID PMTs. The mPMT solution uses discrete components to make the Q/T digitization, whereas the ID electronics uses the QTC ASIC + an FPGA-based TDC.

- So, the Italian solution is the real one like a spiroc 2d → ADC digitizer of 12 bits by the way for Italian one.

The Italian electronics



The mPMT electronics can be divided into two parts: a set of single channel Front End boards (FEB), and a Main Board (MB). The FEB are mechanically connected to HV boards that are placed very close to the individual PMTs. The MB is mounted in the centre of the module on the electronics support structure as described in section III.6 C 4. The outputs of the single channel FEB are merged into the MB through individual flat cables. A very low power MCU is embedded on the Front End to control both the HV board and the FEB itself, and only one connector for both boards is needed. The overall scheme is shown schematically in Figure 157.

The time measurement circuit consists of a fast high gain amplifier and a discriminator. The output of the amplifier is compared with a threshold set by the DAC and the output of the discriminator is sent to the main board using a differential signal. There it is used by the FPGA to produce a time stamp and generate a hold signal for the ADC. For the charge measurement the input signal is shaped with a three stage integrator and acquired with a 2 Msps 12-bit ADC. An energy resolution of 0.1% FWHM and a time resolution of 100 ps have been measured for this digitization system, with a power consumption of 40.5 mW per channel.

Mark's main worry : energy resolution may be not linear with energy, as pulse shape varies.

Wait, if it is just pulse shape changes, we could calibrate this with an LED…
→ Check with Mark

The mPMT HV board

The positive voltage supply has a lower dark count rate, and the cathode of the PMT is connected to ground, so there is no possibility of glass discharges. On the other hand the pedestal shifts with the event rate, and it is not possible to use voltage multipliers to generate the power supply. To read out the anode signal at high voltage it is necessary to have a decoupling capacitor with a very high insulation tension. The negative voltage supply has a higher dark count rate and the glass of the PMT is connected to the high voltage supply, but the pedestal does not shift with the event rate and the anode signal is read out relative to the ground.

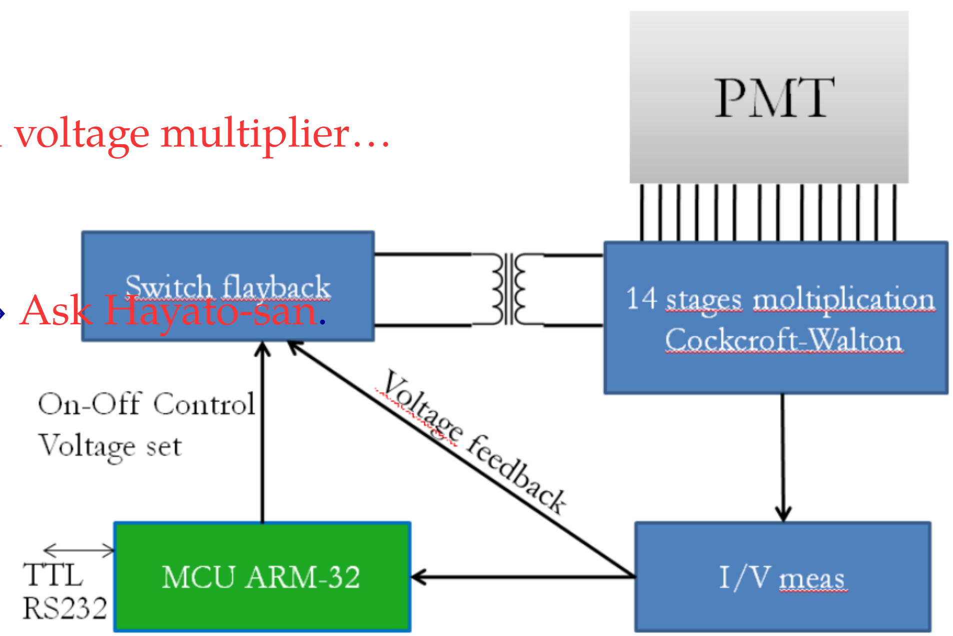
There is one per mPMT, in the module itself → Need large power to be send from MCC to mPMT.
→ Simpler to send smaller V but higher A ? If no, investigate the power supplies to be in the electronic module with the MCC .

HV >0 :

- Why couldn't we use voltage multipliers ? → What is a voltage multiplier…
- Why pedesal would shift with the event rate ?

- For B&L PMTs, what is the status of the HV generator? → Ask Hayato-san.

- For mPMT, using resistive base will increase the power consumption too much
  → So, go for a Cockroft-Walton.
  → Check what are the 2 circuits.



The mPMT HV board

The layout of the HV system is shown in Figure 159. To cope with the limited budget for power consumption, we cannot simply use a standard HV supply and a resistive voltage divider. Instead we have developed an active power supply based on the Cockcroft-Walton voltage multiplier, similar to the solution adopted in the KM3NeT PMT base design. The HV board has a single 5 V supply and needs one analogue input, namely a reference voltage in the range 0–2 V, and one digital on/off bit. The outputs of the boards are the high voltages for the PMTs and two analogue values in the range 0–3.3V corresponding to the anode voltage and the current. Two HV board prototypes have been built and tested. Figure 160 shows the measured power consumption of the two prototypes compared with the expectation. A power consumption of 12.5 mW per channel has been achieved, corresponding to a 237.5 mW power consumption for the HV board for a full mPMT.

- Are the 2 prototypes built for <0 or > 0 HV ?
- What is more difficult for HV > 0 → Cannot use the voltage multipliers.
- What is the status of the HV >0 board measurement ?

Reading the TR

Question to Hayato-san :

→ Has UK group volunteered for OD electronics ? DAQ ? Slow control ?

→ If not : should consider integrating both ID/OD in our development.

To do from now :

1. Go through all my questions, and try to answer them.
2. Ask the un-answered ones to Hayato-san and Marcin.
3. Try to organize the work in workpackages.
4. Associate workpackages with a cost estimation and a timeline.

Costs by Hayato-san

Calendar for October 2019 for Benjamin :

a. Prepare slides & scenario for all possible contributions for France.
b. Evaluate costs of workpackages.
c. Propose coherent scenarios for France with synergy between groups and with other existing experiments (KM3NeT, JUNO) / experience.

For this, I need :

a. Reading a re-reading TR.

b. Discussing with experts
→ mPMT (Mark/Gianfranca/Marcin/Benjamin).
→ Electronics & DAQ (Hayato-san/Marcin).

c. Discussing multiple time with
→ LPNHE → Done once, and redo.
→ LLR → Next week.
→ Anatael, who may have access to a facility for small PMT testing → Mail sent.
→ Meeting CNRS/IN2P3 and Utokyo → Send email to Shiozawa-san → sent → He will discuss directly with Michel.

Updates after discussing with Hayato-san

- None of the packages in the whole electronics have been really taken, apart from the DAQ and network (basically, the PCs) by UK.

- In this DAQ, the slow control is not taken into account → Available.

- Japan has a back-up solution for all items, in case other countries cannot pay. If other countries pay, this money can be re-invested on other items (i.e. more PMTs?).

- Each electronics package cost, in total ≤ 1 million euros.
  → Good : this amount can be asked independently by a group/country.

- Japan is not against (in principle) that a country does the R&D and Japan pay for the production, or share its cost:
  → But should not be our goal, as we wish Japan's money to go to PMT.
  → Needs a joint agreement (so check if it is ok for external country)

Updates after discussing with Hayato-san

- For digitizer :
  - Can be developed by an external country.
  - Need QDC and TDC. For now, TDC is on an external FPGA as the chip did not have TDC → having QDC/TDC on the same chip is welcome in future → Omega chips ?
  - From omega, the issue is that it seems their product does not have the small dead-time compatible with HK requirements
    → To investigate.
    → For this purpose : need summary of the requirements for chips.
    → Can add the cost as an issue.
  - Issue with i.e. spiroc → The dynamic range is too small.

Updates after discussing with Hayato-san

- Slow control → Needs a new one, with an interlock.

- Fiber and connectors
  → 100m cables assumed in Hayato-san estimation.
  → Connector prices have been investigated from 2 companies : LEMO and a German company.
  → Estimation based on same technologies as KM3NeT.

- Signal connectors and feedthrough
  → Estimation based on same technologies as KM3NeT.

- Water tight boxes for electronics
  → One candidate is Baikal-style boxes : glass of 3cm thickness.
  → Advantage is that it is quite cheap (5,000 dollars) : German company
  → Disadvantage can be radioactivity for LE in the glass.

Updates after discussing with Hayato-san

- Very cheap solutions :
- Clock system → Master clock, transmitters and Front-End receivers.
- GPS system :
    - System at HK → Same than Tokai.
    - System at Tokai is getting old, and has been constructed by the US for T2K. It needs update for T2K-II and HK, but US won't be part of the experiment
      → Could be an upgrade for T2K and Hyper-K

Updates after discussing with Hayato-san

- Same board (digitizer control) can be used for both mPMT and B&L
  $\rightarrow$ In that case, one should integrate the MCC in this board.

- Poland would like to work on this digitizer control system for both B&L and mPMT $\rightarrow$ But so far, no real promise $\rightarrow$ So open for us, but should be discussed with Poland.

- Check with Gianfranca about status of the Italian electronics for mPMT.

- EGADS/Test beam/Memphyno could be used for every tests of PMTs, electronics etc.

Initial cost estimates of ID electronics. (OD part is not included.)

1 electronics box handles 24 PMTs.
Initial estimate of 1 electronics box was @720,000 yen

We need at least 834 boxes for ID, assuming 20,000 PMTs for ID.

Therefore, 834 x @720,000 yen ~ 600,000,000 yen (total)

However, several components could be more expensive than initially assumed.

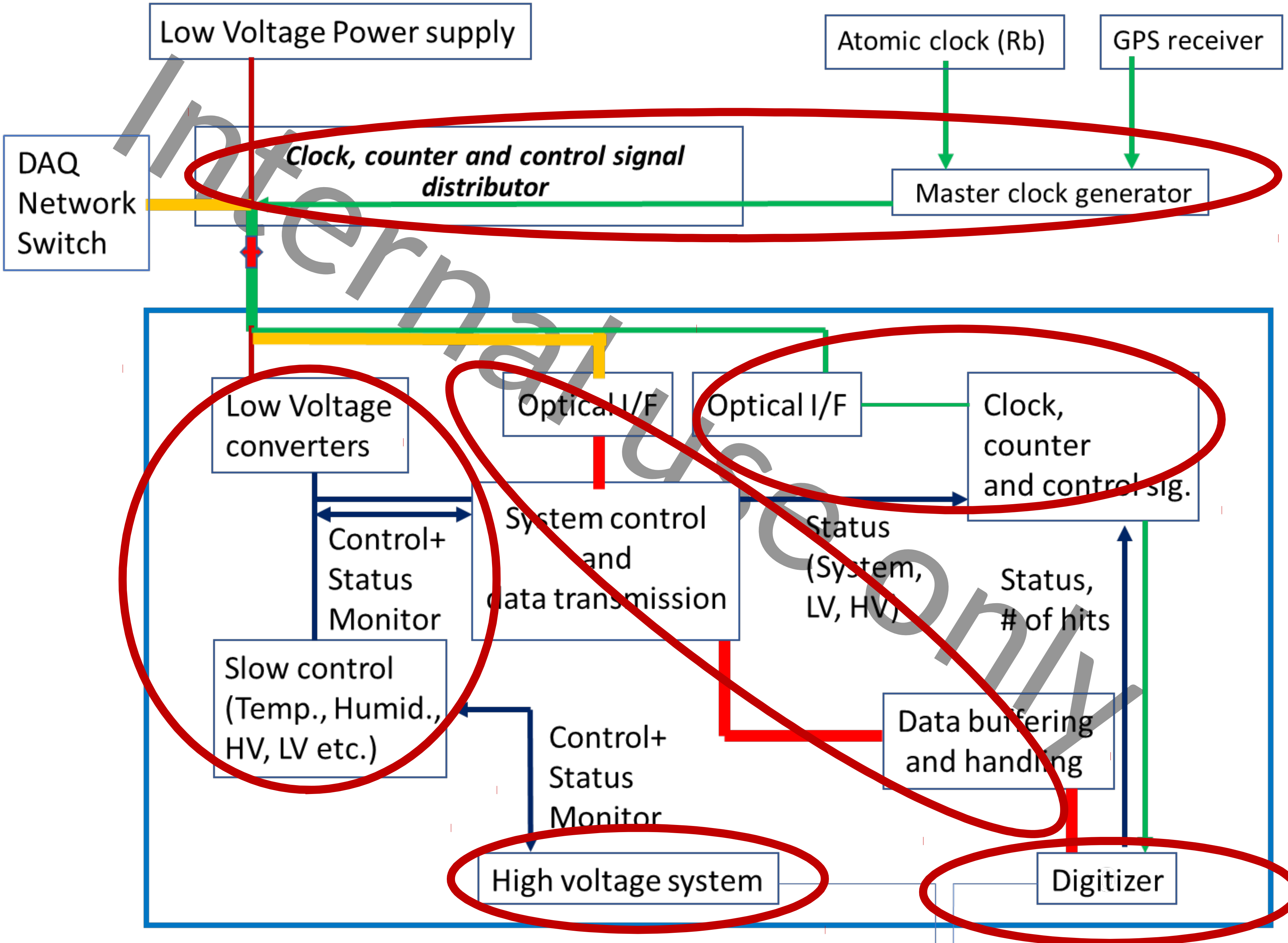
R&D cost of components is roughly O(10,000,000) yen per each.
This only includes costs to make proto-types and do evaluation.
Cost of case and feed-through R&D may be different,
and it may cost more. (It depends on the contractors.)

Breakdown of the cost for 1 board.

Digitizer (QTC + TDC)
Target cost [100,000 yen]
Main board
Target cost [78,000 yen] *)Need revision (Could be more expensive.)
*)Expect large discount for FPGA cost (Xilinx FPGA)
Clock/timing system (generator, distributors, receivers incl. Optical I/F)
target cost [50,000 yen]
High voltage system (including control and monitor systems)
Target cost [180,000] *)Current estimate is higher than ~240,000 yen
Fiber + Cable (timing & power)
Target cost [100,000 yen] *)Current estimate is ~200,000 yen
Signal connector + Feed through + Cable
Target cost [72,000 yen] *)Current estimate is ~150,000 yen
LVPS
Target cost [5,000 yen] *)Current estimate is ~ higher than 10,000 yen
Case
Target cost [135,000 yen] *)Need revision. (Could be more expensive)

100,000 + 78,000 + 50,000 + 180,000 + 100,000 + 72,000 * 5,000 + 135,000 = 720,000

Block diagram (20inch PMT readout electronics)



Updates after discussing with Marcin

- Andrea, the Italian engineer workin on the Front End electronics for mPMT, has really left.

- But Italy still have the engineer who work on the HV.

- HV < 0 of Italy works very well, and they seem to have an idea for the HV>0 → Would be for Italy.

- France could contribute to Front-End of mPMT
  → The full electronic of mPMT for Italy has been sent to Marcin.
  → We could focus on the Front-End, as HV is already taken.
  → Note that so far, there is no ASICS. The QDC/TDC is done independently by some commercial independent boards → Meaning ?
  → We may do better with an Omega chip, or cheaper.

- MCC is currently designed by Krakow (Poland) → May welcome help !

Updates after discussing with Marcin

- France could also work on designing a test facility of PMTs.
  + if needed, buying one for each countries → Will be specialized in 3″ PMT testing.
  → Need to test 3″ PMTs after soldering the HV basis, as it may very well break the PMT or damage it. In that case, we should test every PMTs, which is not possible I think.
  → The soldering and testing after soldering could be done by Hamamatsu → Investigate price.
  → We could design a facility to test n % of the 3″ PMTs for all European + Canadian group → One facility / site where you assemble (and therefore, buy) mPMT. We may also pay for every facilities.

  → We should also be responsible of some test of some of the assembled mPMTs.

  → Test of PMT response in TTS, charge etc. aging test etc.

Updates after discussing with Marcin

- The key is to understand :
  - which characteristics shall we check and which Hamamatsu does.
  - How many % of PMTs has to be checked ?
  - Note that KM3NeT relied on Hamamatsu for that.

Notes for the estimations / proposal

- I did not talked about items that seemed taken → PC and output DAQ by UK, HV for mPMT by Italy etc.

- There will be ~20,000 PMTs
  → Let's count 24,000 PMTs, so 1,000 electronic boxes.

- I applied 100 yens ↔ 1 euros

20'' PMTs

	Pros	Cons	Price	Ressources
20 '' digitizer	-Crucial for HK → Central role -May use Ω expertize -At LLR, expertize on board digitizers -Physicists can also work on this	-Have always one expert in Japan during data taking in future. - ?	24 channels = 1k Total = 1M	-Electronic engineers → Franck ?
20 '' digitizer control board	-Same as above, w/o Omega expertize -Physicists can also work on this	-Have always one expert in Japan during data taking in future. - ?	24 channels = 0.78k Total = 0.78M	-Electronic engineers → Franck ?
20 '' Slow control	-Very cheap while crucial -Physicists can also work on this	-Not a huge « Price » contribution for HK → May need another contribution	??	-Software engineers → ?
20 '' HV	-Centrak for HK.	-Not super fascinating for physicist → Only engineer project -Do we have the expertize ?	24 channels = 2.4 k Total = 2.4 M	
HK clock system	-Relatively cheap.	- ?	24 channels = 0.5 k (w/ master clock etc.) Total = 0.5 M	-Electronic engineer → Stefano

Multi-PMTs

	Pros	Cons	Price	Ressources
MPMT digitizer	-Crucial for MPMT in FD. -Same as for 20″	-Italy working on it… But their engineer has left one just now $\rightarrow$ May need help, or taking over	Same as 20″ ?	Same as 20″
MPMT digitizer control board	-Same as for 20″ -Can be common in some parts w/ 20″ (firmware will be different)	-University of Krakow already working on it. -But might be ok to share work (Marcin said).	Same as 20″ ?	Same as 20″
MPMT Slow control	Could / Should be common with 20″	Same as 20″	Same as 20″ ?	Same as 20″
MPMT clock system	-Relatively cheap. -Common w/ 20″	Same as 20″	Same as 20″ ?	Same as 20″
MPMT test bench 3″ PMT test bench	-Crucial for mPMTs. -Involves both engineers / physicists / students.	?	?	1 software engineer 1 mechnical engineer 1 Physcist at least (could be Benjamin)

Additional items

	Pros	Cons	Price	Ressources
Fiber + cable connecting electronic box to readout	-Crucial for HK	-Just buying material ?	24 channels = 2k Total = 2M	?
Signal connector + Feedthrough	-Crucial for HK	-Just buying material ?	24 channels = 1.5k Total = 1.5M	?
LVPS	-Crucial for HK	-Not so many R&D ?	24 channels = 1k Total = 1M	-Electronic engineer $\rightarrow$ Franck-san ?
GPS system	-Crucial for HK -If also take care of Tokai GPS, could be an upgrade for T2K-II -Quite cheap	-Engineer-only work ?	?	-Electronic engineer $\rightarrow$ Franck-san ?
Box/case for electronics	-Crucial for HK	-Engineer-only work	1 box = 1.4k Total = 1.4M	Mechanical engineer $\rightarrow$ Alain & Oscar ?

Now, try to build conherent scenarios

- MPMT → We should buy some of them
  + Design calibration bench ?
  + Digitizer ?
  + Slow control ?
  + MCC (control board for mPMT) ?

- If electronics only → I think we should focus on 20′′ as we wish to work on FD
  → LLR takes care of digitizer and LPNHE of control board ?
  → Or LLR takes care of control board, Omega of digitizer & LPNHE of clock system and slow control ? → Package of readout electronics !!

- Super low budget → Take care of slow control for both mPMT and 20′′
  → I do not think we should present this option as acceptable for us.

- Add JINO informations → Start data taking from beginning 2020.

- Anatael seems ok for collaboration.

- I asked if we could dominantly use it after 2021/2022 when assemblig all modules for HKFD.

From now on

- Each of us should consider what she/he wishes to do, and many have many more ideas than I had.

- Could you investigate our engineer/student ressources in next 7 years ?

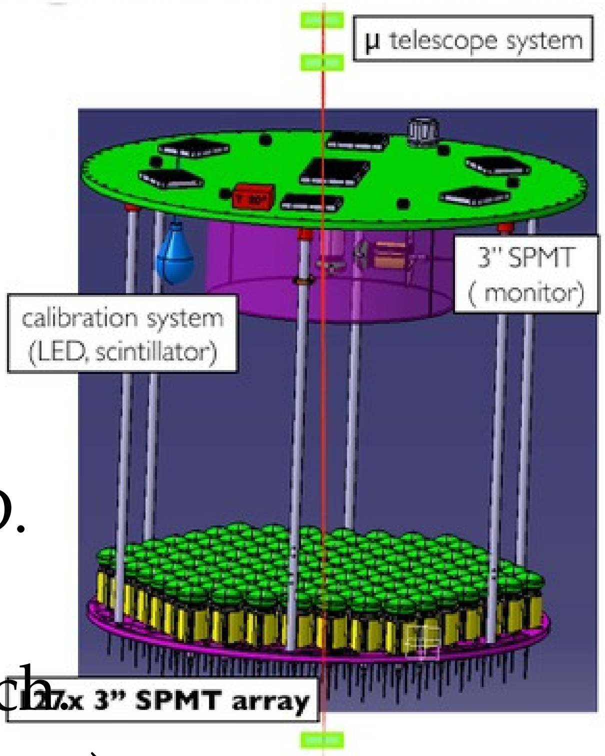
- <u>On my side :</u>
  - Had 4 meetings with LPNHE, Hayato-san, Mark, Marcin last week.
  - Have 2nd meeting w/ LPNHE next week.
  - <u>Goal :</u> discuss most of the important items before meeting on 17th, to have efficienct&qualitative discussions on that day.

- Will prepare for next meeting a plot to show an impact of 1,000 mPMTs vs 1,000 20″, as it does not really exists → Motivation for Multi-PMTs.

- I would like to propose we set a monthly Hyper-K France meeting from now on ? → How do you think ?

From now on

Test 3″ PMT



- If we go for mPMT :
  - I started discussions about JINO with Anatael :
  - Would be ready by beginning of 2020.
  - Could be used for Hyper-K.
  - My wish : use it ~20-30 % of time before end 2021 to construct mPMT for test beam/IWCD.
  - From 2022 → Use it ~100 % of time for mPMT FD.
  - Anatael said it should work, as JUNO will start taking data from 2022 → No more use of test bench.
  - Clarify if we could add calibration sources (laser etc.)

- Need to clarify exactly which characteristics of PMTs we wish to check :
  - Gain, TTS etc. for all PMTs.
  - QE, Dark rate for some reference PMTs.

→ I am now working on this list w/ Gianfranca → When finished, check if I can improve JINO to match our needs, or should re-design a test bench.