



**IN2P3**  
Les deux infinis

I L  $\wedge$  N C E

International Laboratory for **A**strophysics,  
**N**eutrino and **C**osmology Experiments



東京大学  
THE UNIVERSITY OF TOKYO

# Introduction to HK reconstruction effort

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# Hyper-Kamiokande



HK reconstruction meeting, Take-off meeting, 2024/05/16

# Goals of this working group

- Main goal : Have the best working&validated reconstruction algorithm on Dec. 2027 to analyze the very first HK data !  
→ « Best » : 1.High physics performances, 2.High Speed & 3.Robustness against systematics ⇒ Optimisation + Validation on MC&Data.
- What do we have now :

	fiTQun	WatChMaL	GRANT
Descr.	Historical Likelihood-based SK fitter	CNN-based developed originally for IWCD	GNN-based developed for HK/SK
Pros	Powerful Robust (decades of SK)	Very powerful Can be extended beyond CNN	Very powerful Tested with HK MC
Cons	Very slow	Not final Not yet optimized for HK Not tested w/ data	Not final Not tested w/ data
Speed (500 MeV e-)	90s	??	< 1s

- For now the 3 communities are working mostly in parallel.

# Goals of this working group

- If HK were to start tomorrow, our only viable option is fiTQun.  
→ And will be anyway crucial to understand/compare our results wrt SK in the first years of HK ⇒ **Maintaining fiTQun is vital.**
- Based on this, my personal opinion is that we should aim for :
  1. Mandatory : A fiTQun-optimised algorithm for day-1 of HK.
  2. If possible : A ML-based algorithm for day-1
- It split our efforts... but maximize our creativity !  
→ This is essential now we are still 3.5 years before experiment starts.  
→ The ML-based algorithm might be hybrid between fiTQun/ML.

# The fiTQun algorithm

PMT unhit probability

PMT hit probability

PMT charge pdf

$$L(\mathbf{x}) = \prod_j^{\text{unhit}} \underbrace{P_j(\text{unhit}|\mu_j)}_{\text{PMT unhit probability}} \prod_i^{\text{hit}} \underbrace{\{1 - P_i(\text{unhit}|\mu_i)\}}_{\text{PMT hit probability}} \underbrace{f_q(q_i|\mu_i)}_{\text{PMT charge pdf}} \underbrace{f_t(t_i|\mathbf{x})}_{\text{PMT timing pdf}}$$

PMT timing pdf

- $X = (x, t, p, \theta, \varphi)$  : Particle hypothesis  $\rightarrow$  7 variables fit
- $\mu = \mu^{\text{dir}} + \mu^{\text{scat}}$  : Poisson mean of predicted charge detected by each PMT, which is also a function of  $X$

Normalization Integration along the particle track

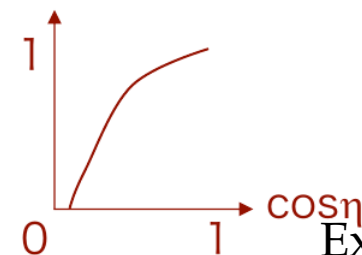
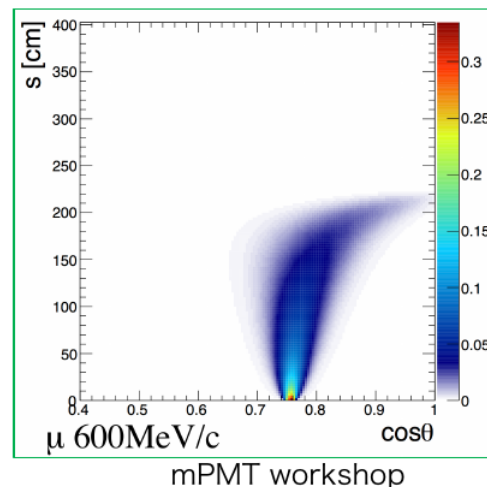
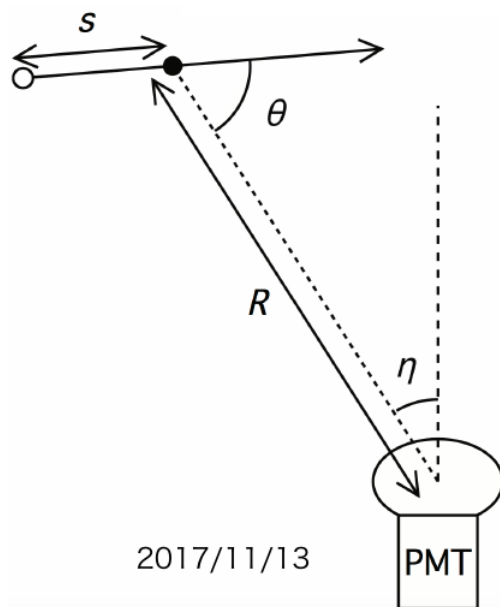
$$\mu^{\text{dir}} = \underbrace{\Phi(p)}_{\text{Normalization}} \int \underbrace{ds}_{\text{Integration along the particle track}} \underbrace{g(p, s, \cos \theta)}_{\text{Cherenkov emission profile}} \underbrace{\Omega(R)}_{\text{PMT solid angle at } \eta=0} \underbrace{T(R)}_{\sim R^{-2}} \underbrace{\epsilon(\eta)}_{\text{Light attenuation in water}}$$

Cherenkov emission profile

PMT solid angle at  $\eta=0$   
 $\sim R^{-2}$

Light attenuation in water  
 $\sim \exp(-R/L_{\text{attenuation}})$

PMT angular response



2017/11/13

Extracted from talk  
by T. Yoshida

# The fiTQun algorithm

PMT unhit probability

PMT hit probability

PMT charge pdf

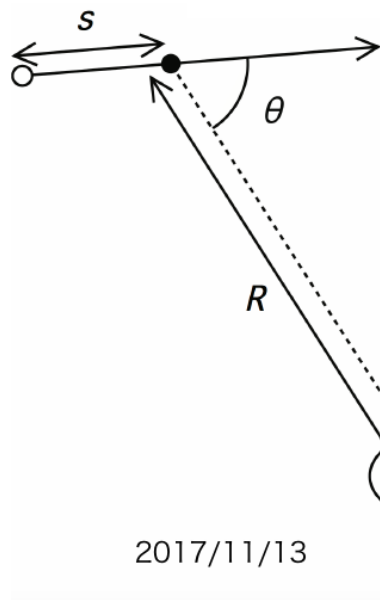
$$L(\mathbf{x}) = \prod_j^{\text{unhit}} \underline{P_j(\text{unhit}|\mu_j)} \prod_i^{\text{hit}} \{ \underline{1 - P_i(\text{unhit}|\mu_i)} \} \underline{f_q(q_i|\mu_i)} \underline{f_t(t_i|\mathbf{x})}$$

PMT timing pdf

- $X = (x, t, p, \theta, \varphi)$  : Particle hypothesis  $\rightarrow$  7 variables fit
- $\mu = \mu^{\text{dir}} + \mu^{\text{sct}}$  : Poisson mean of predicted charge detected by each PMT, which is also a function of  $X$

## Indirect light mean in a PMT

$$\mu^{\text{sct}} = \Phi(p) \int ds \frac{1}{4\pi} \underline{\rho(p, s)} \Omega(R) T(R) \epsilon(\eta) \underline{A(s)}$$



Cherenkov emission profile is integrates over angle, because indirect charge is predicted using the ratio to direct light

$$\rho(p, s) \equiv \int g(p, s, \cos \theta) d\Omega$$

Scattering tables

$$A(x_{\text{PMT}}, z_{\text{vtx}}, R_{\text{vtx}}, \varphi, \theta, \phi) = \frac{d\mu^{\text{sct}}}{d\mu^{\text{iso,dir}}}$$

# Goals for fiTQun

fiTQun goals :

1. Adapt it to HK → Done.
2. Run it on a whole HK production → On-going.
3. Reduce its processing time.
4. If possible, increase its physics performances.

How to make this happen : Make fiTQun accessible to new-comers.

- fiTQun tuning should be easier : On-going work by G. Diaz.
- Documentation should be improved : B. Quilain is preparing validation slides for HK CM.
- Hands-on tutorial : are preparing half-day tutorial for coming HK CM.  
→ Candidate date : Friday 06/09 morning (JST).

From now, interested people can already check task list :

<https://docs.google.com/spreadsheets/d/1AFbBV6cawTQoEkRpsrJJBHLXUP8Bz0igaUNuh83CTXY/edit?usp=sharing>

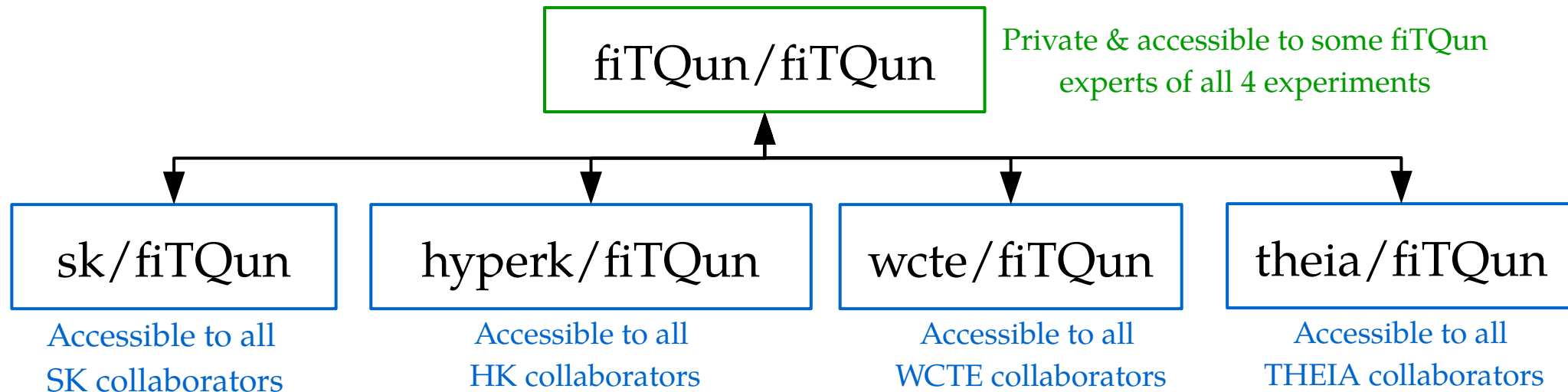


# Software organisation

- This meeting is aimed to discuss reconstruction algorithm mechanics, optimisation & physics.
  - We can always discuss software/policy, but it has to be presented ultimately in Software or Computing WG.
  - Today is the first meeting, so we should have this discussion.
- How to organize the fiTQun software effort ? Based on constraints :
  - fiTQun is used by 4 experiments → SK, HK, WCTE, THEIA
  - fiTQun provided by SK to HK w/ condition that improvements in one experiment should be made available for the other.
    - Joint development between SK&HK is ideal & necessary.
  - For now, I do not know the agreement with WTCE&THEIA to be honest.
  - THEIA being a potential FD for DUNE makes the situation a bit more complicated → But, they were actual fiTQun core developers (M. Wilking) & timeline is very long ⇒ No direct HK competitors.

# fiTQun software organisation

- Based on these constraints, my proposal would be ultimately:

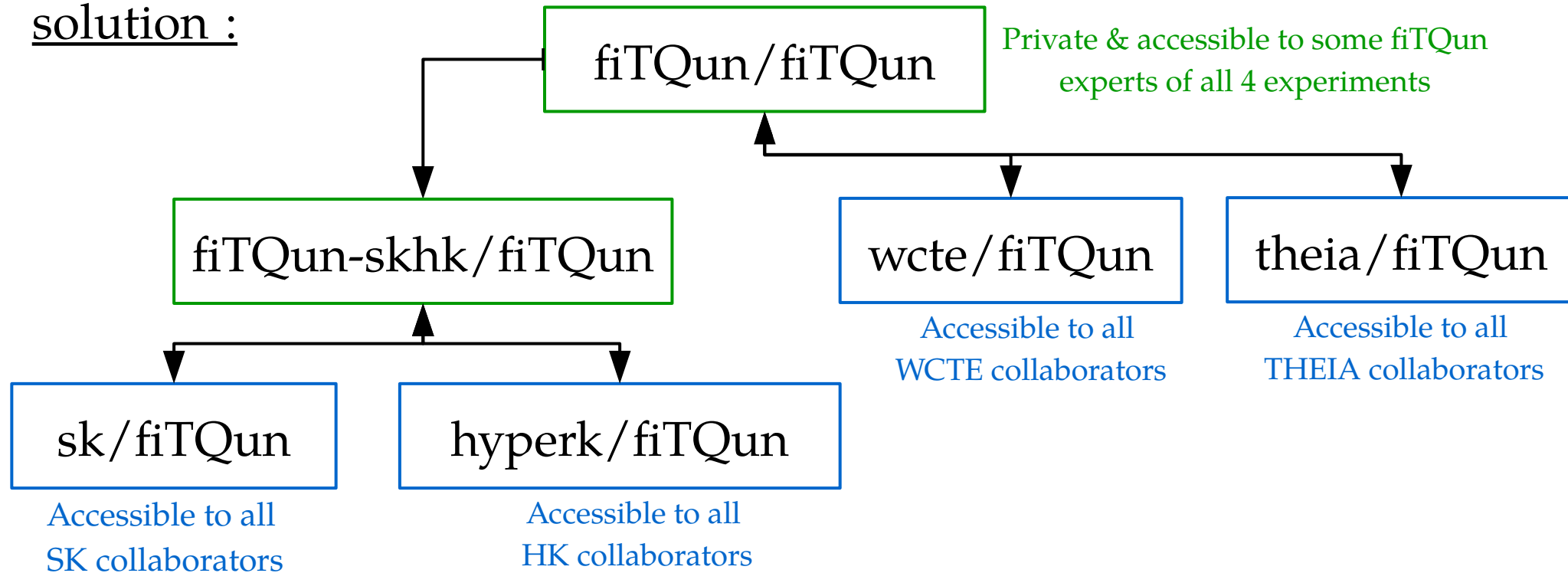


- Basically, all new features added by individual experiments will be made available to others.
- Until agreement between experiments is reached :
  - We have no choice but to keep our HK developments on the HK-branch only.
  - If our SK colleagues wish to use some of our tools → Shall we fork a repository from fiTQun / fiTQun to be available for SK / HK ?



# Intermediary fiTQun software organisation

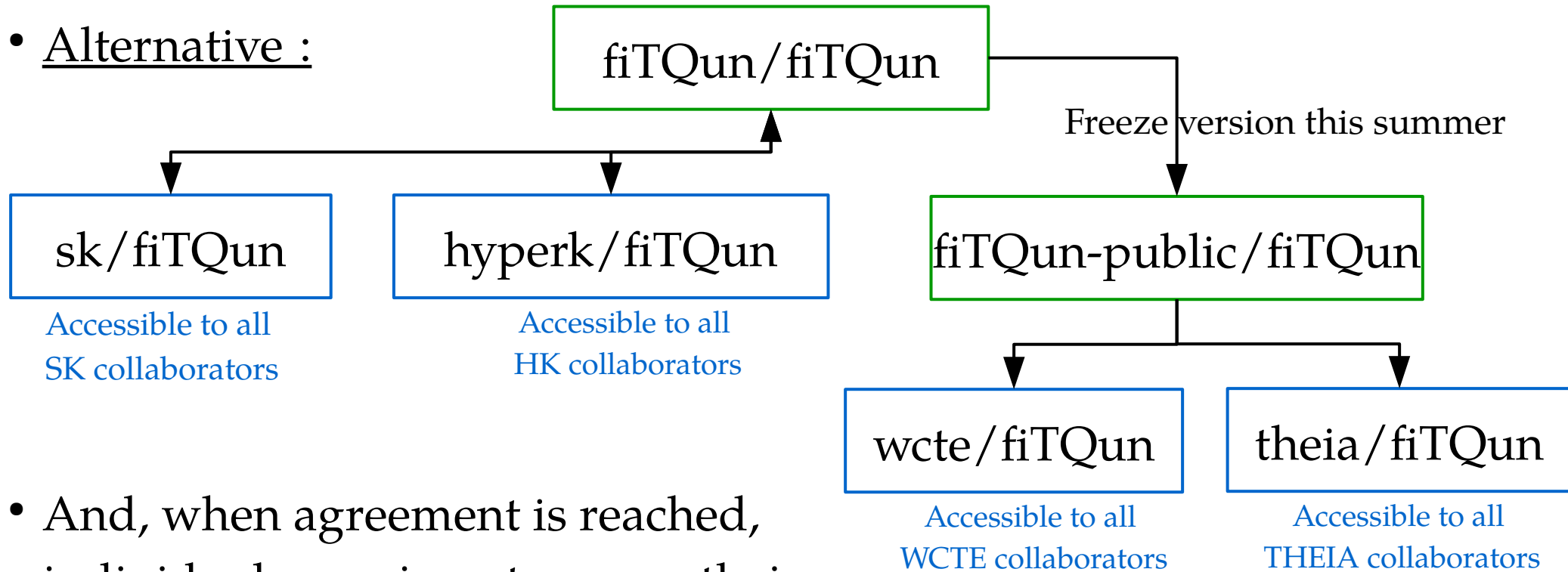
- Possible temporary solution :



- This structure makes it difficult to merge branches when agreement between experiments is reached. This situation happens basically because we need a joint repo. for SK&HK.
- Alternative : since there is no need for joint repo. for WCTE&THEIA, we can explore the opposite case...

# Intermediary fiTQun software organisation

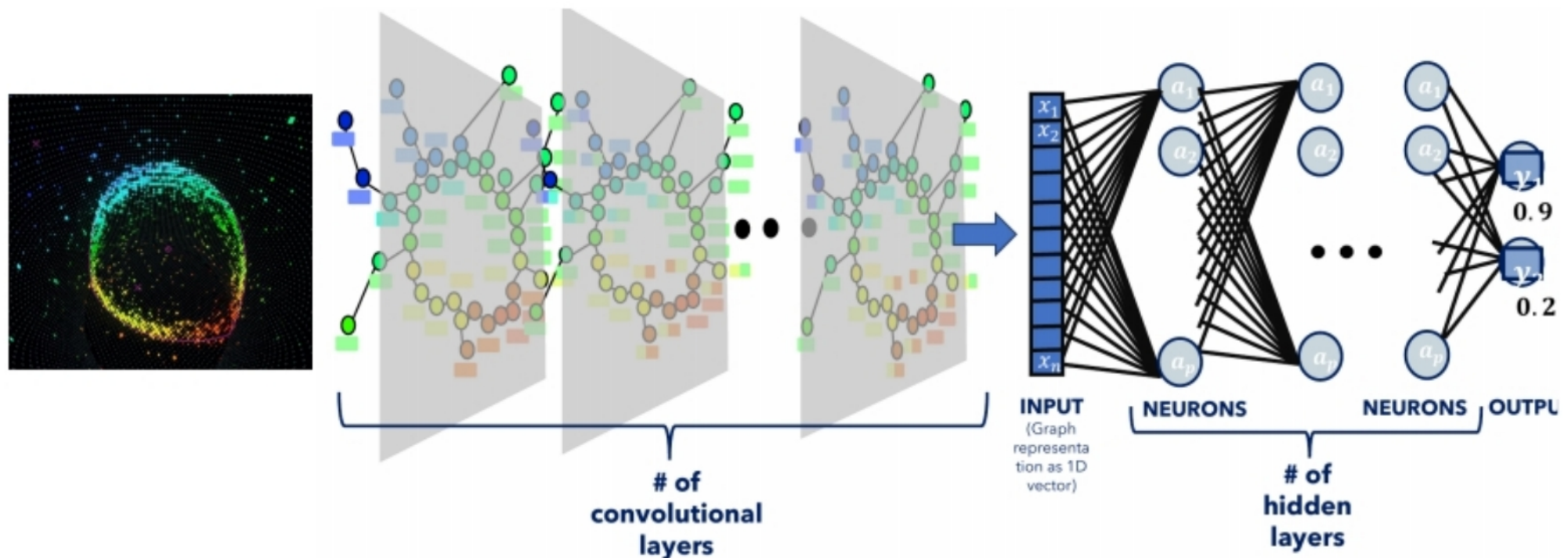
- Alternative :



- And, when agreement is reached, individual experiments merge their branches with fiTQun / fiTQun.
- If agreement found quickly → No need for this complicated situation.  
⇒ My proposal would be to receive your feedback today, and based on this, bring the situation to SK / HK managements.

# The GRANT & WatChMaL algorithms

- Detailed presentations have already been given several times.
  - I show here GRANT as an example (because I know better).
  - We are now finalizing GRANT&WatChMaL merging to extract best of both worlds  $\Rightarrow$  To be presented at HK-CM.
- GRANT : Graph-Neural Network algorithm  $\rightarrow$  Each PMT = a node

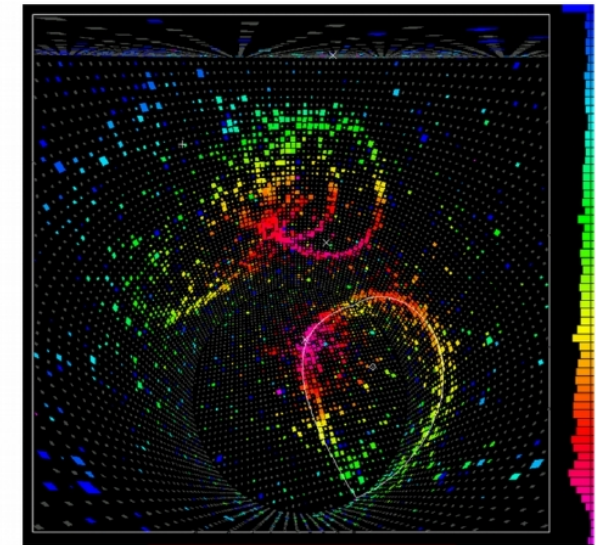


- Christine will show the updated performances in coming talk.

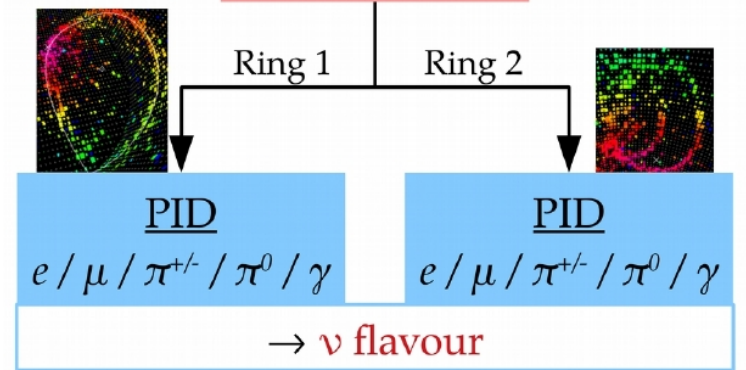
# The GRANT & WatChMaL algorithms

- Reminder of what was accomplished so far by GRANT :

	GNN	FitQun
e/mu	99% electron efficiency at 5% muon bg acceptance, Dwall, towall analysis: After 2 m, efficiency above 99.4% !	99% electron efficiency at 5% muon bg acceptance,
e/gamma	58% efficiency at 50% bg acceptance... [Fixed energy]	None
e/pi0	98% electron efficiency at 25% pi0 bg acceptance. [Fixed energy] 78% electron efficiency at 25% pi0 bg acceptance [Spectrum of energy]	94% electron efficiency at 25% pi0 bg acceptance
Energy reconstruction for e & mu	<ul style="list-style-type: none"> <li>Electron : 5% resolution at 500 MeV, energy bias at ~4%</li> <li>Muon : 7% resolution at 500 MeV, energy bias at ~7%</li> </ul>	<ul style="list-style-type: none"> <li>Electron : 7% resolution at 500 MeV</li> <li>Muon : 6% resolution at 500 MeV</li> </ul>
Vertex reconstruction for e & mu	<ul style="list-style-type: none"> <li>Electron : 91,7 cm longitudinal resolution, 153 cm transversal resolution,</li> <li>Muon : 103 cm longitudinal resolution, 181 cm transversal resolution,</li> </ul>	



Ring counting



- To be done in 2024 (priority) :
  - Improve the vertex/direction reco.
  - Create a ring-counting algorithm.
- Other developments :
  - e/γ separation.
  - μ/ π separation.
  - Improve memory usage → On-going.

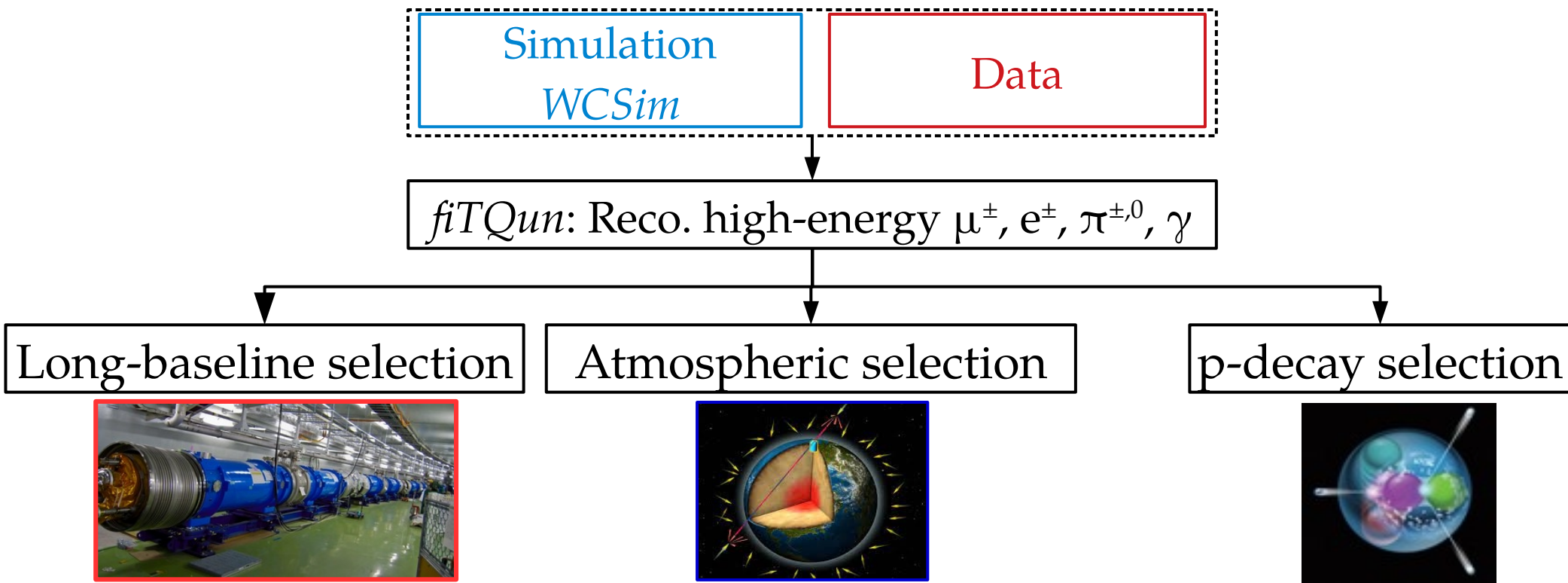
Kinematic variables

Vertex → **FV**  
 Direction → **L**  
 Momentum → **E**

Kinematic variables

Vertex → **FV**  
 Direction → **L**  
 Momentum → **E**

# How about event selections ?



Selection should be ultimately discussed in their associated physics working groups (LBL etc.). But :

- For now, no regular meeting for every groups except LBL.
- Selections also driven by algorithms (e.g.  $\mu/\pi$ ,  $e/\gamma$  separation...)
- Lots of selection/cuts common between analyses (e.g. p-decay & atmospheric...).

⇒ This meeting will be also **dedicated to selections**. When ready :



# Updated goals of this working group

- Main goals :
  - Have the best working&validated reconstruction algorithm on Dec. 2027 to analyze the very first HK data !
  - Have a LBL selection ready&validated for 2027.
  - Have an atmospheric selection ready&validated for 2027.
  - Have a p-decay selection ready&validated for 2027.
- Minimal goals for 2024 :
  - Validate fiTQun Gonzalo new tuning software.
  - Run&tune fiTQun on the LBL, atmospheric & p-decay productions.
  - Port the LBL, atmospheric & p-decay selections to HK.
  - Ideally, have GRANT/WatChMaL algorithms finalized → Basically, with all necessary reconstruction features, including ring-counting.
- Any additional development (fiTQun improvements...) is crucial and is extremely welcome.

# Conclusions & short-term steps

- Launching this WG&regular meetings to focus mainly on technical details, exchange reco. and physics ideas !  
→ Today's presentation was quite political as it is the first...
- There is a huge need of help in all activities :
  - fiTQun development.
  - GRANT/WatChMaL development.
  - Selection LBL, atmospheric and p-decay.⇒ Please do not hesitate to contact me if you are interested in any.
- To maximize our exchanges, we will :
  - Hold reco. meeting bi-weekly.
  - Have a hand-on fiTQun tutorial at the June HK-CM.
  - Create a fiTQun & GRANT/WatChMaL slack channels to encourage discussions → Please know I am not really checking slack, but you<sub>15</sub> can use it between you ⇒ Will add all people present at today's meeting.