KAVLI IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

東京大学 THE UNIVERSITY OF TOKYO

Status of Hyper-Kamiokande with hybrid PMT type

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T2K

Convener + meeting, 2019/05/27

Where we were at last HK TR meeting

- First HE results shows improvements of shape-resolution w/ mPMTs.

- FiTQun is now ready for 1 ring results for hybrid configuration
  → Indicates mPMT reduces E-bias near the edges of FV.

- Priority was therefore on HE results :
  1. Prepare a set of slides compiling all results @500MeV :
     vertex resolution & e/mu separation → Now.
  2. Repeat study w/ different momenta @T2HK energies.
  3. Check additional PID features : e/π0, e/γ separation.

- Your feedback (Itow-san and Shiozawa-san):
  → Test more ≠ configurations (Change mPMT 1,000 by 1,000).
  → Think about other arguments of mPMTs: if I add 1,000 mPMTs, this is what I can improve in calibration etc.

What I have done in reality

- 0. Intense debugging of the implementation → Took 10 days.
  → I will not present it to you (see next software meeting), but in short :
  a. Added more statistics to mu/e PDF used for fitting & checked the MC statistical fluctuations are negligible now.
  b. Solve numerous bugs in the code which affected the PID.
  c. Solve one bug in timing implementation that mainly affected the vertex resolution.

- 1. Prepare a set of slides compiling all results @500MeV : vertex resolution & e/mu separation.

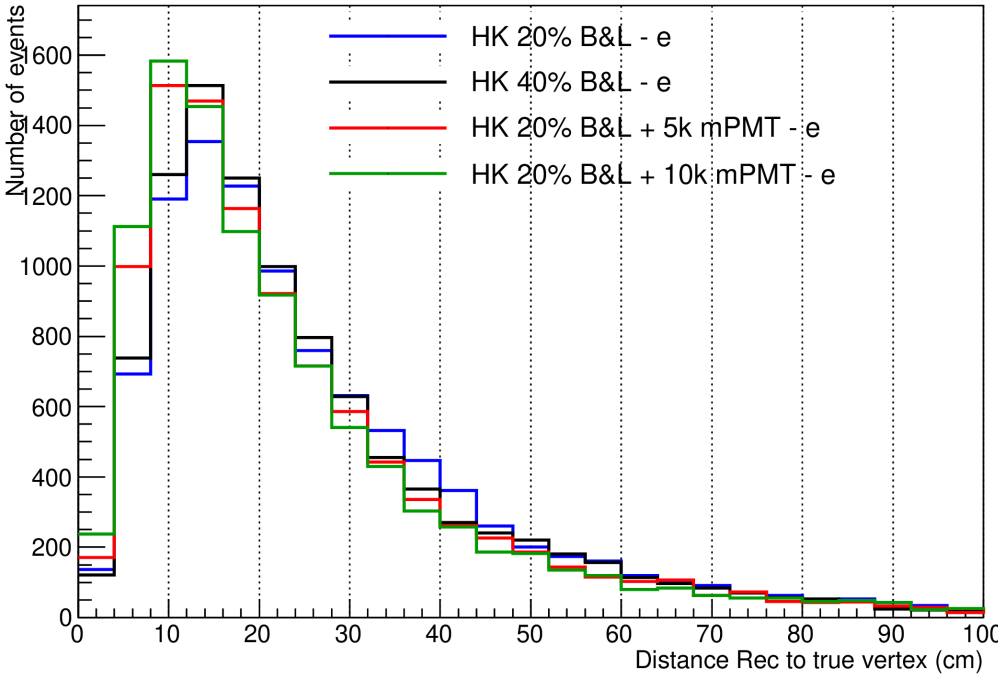
- 2. Check additional PID features : e/π0, e/γ separation.

- 3. Repeat study w/ different momenta @T2HK energies → Not done.

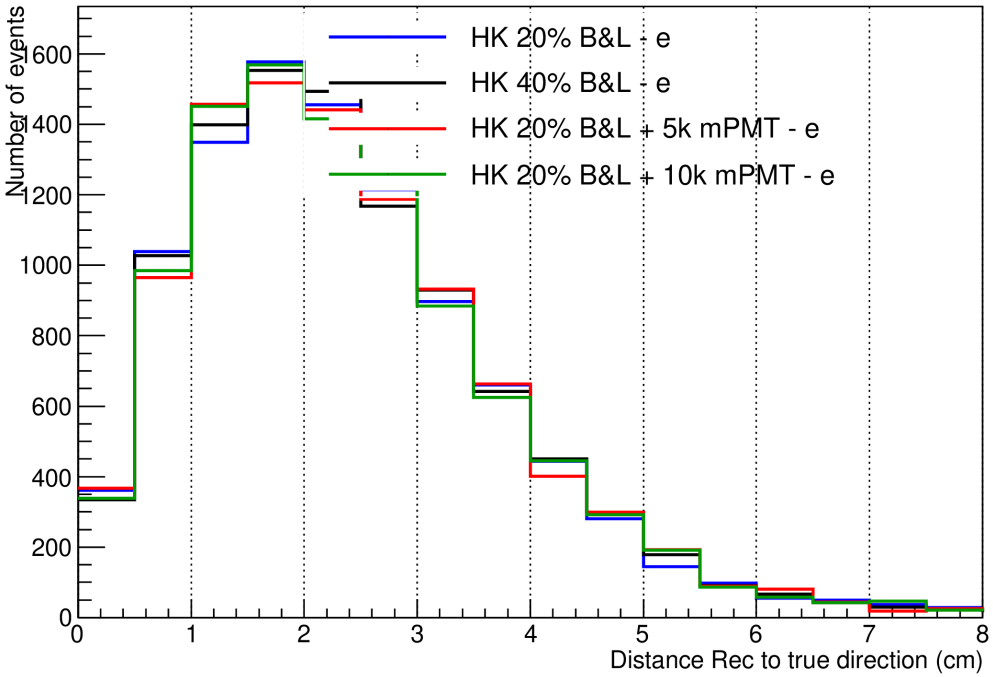
I. Vertex and momentum resolution

Results for 500 MeV e-

Vertex resolution



Direction resolution



- Vertex resolution seems slightly improved for 40 % B&L wrt 20 %.
- Vertex resolution seems improved with hybrid for both 5k & 10k cases
  → And seems significantly better even than 40 % B&L case.
- Direction resolution seems unaffected.

Results for 500 MeV e-

	20 % B&L	40 % B&L	Hybrid 5k mPMT	Hybrid 10k mPMT
Vertex res.	30 cm	28 cm	26 cm	25 cm
Direction res.	2.7°	2.7°	2.7°	2.7°
Momentum res.	7.0 %	6.2 %	6.7 %	6.8 %

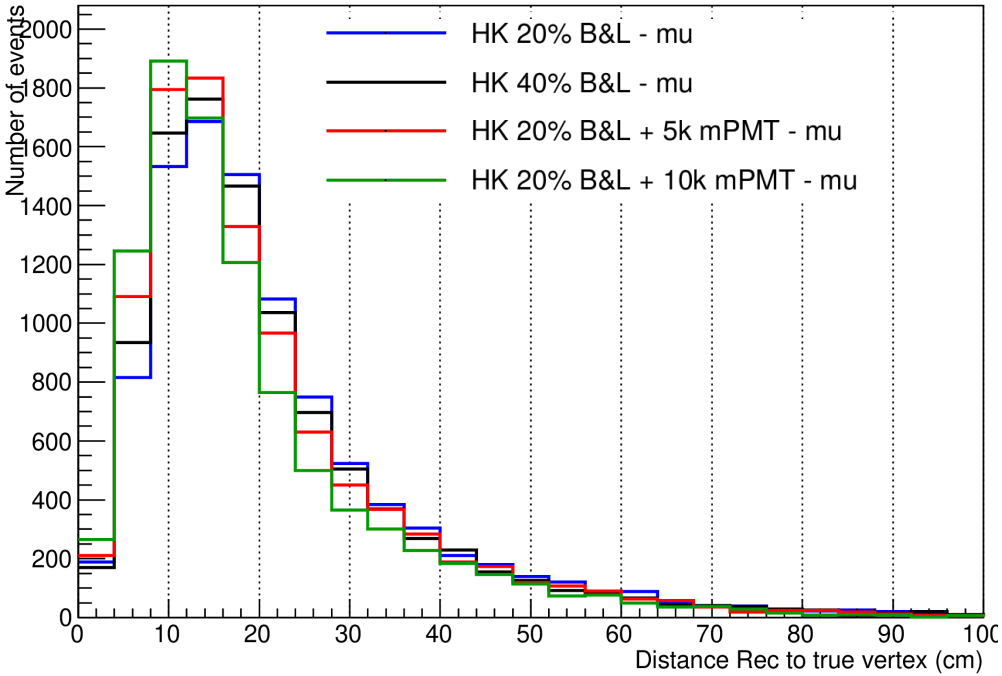
- Vertex resolution indeed improved with hybrid beyond 40 % B&L case
  → Better timing resolution.

- Direction is indeed unaffected.

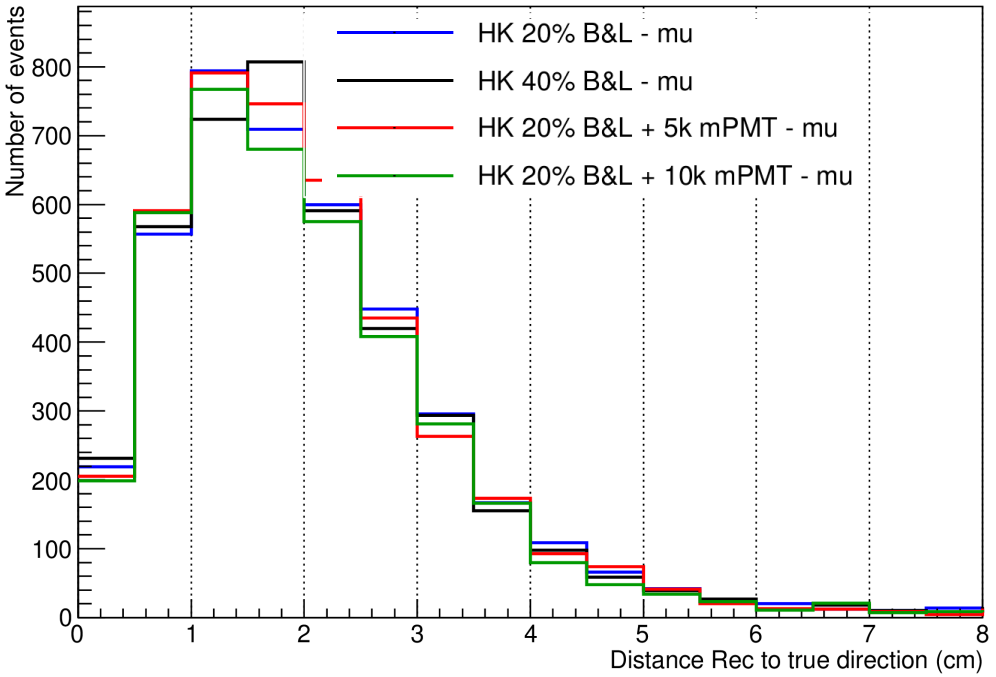
- Momentum resolution improved by 10 % from 20 % B&L to 40 % B&L
  → 5k & 10k mPMT allows to improve it by only 4 %.
  → Limited by photon collected : +20%BL double the p.e., while 5k mPMT only add 10 % more p.e.

Results for 500 MeV μ-

Vertex resolution



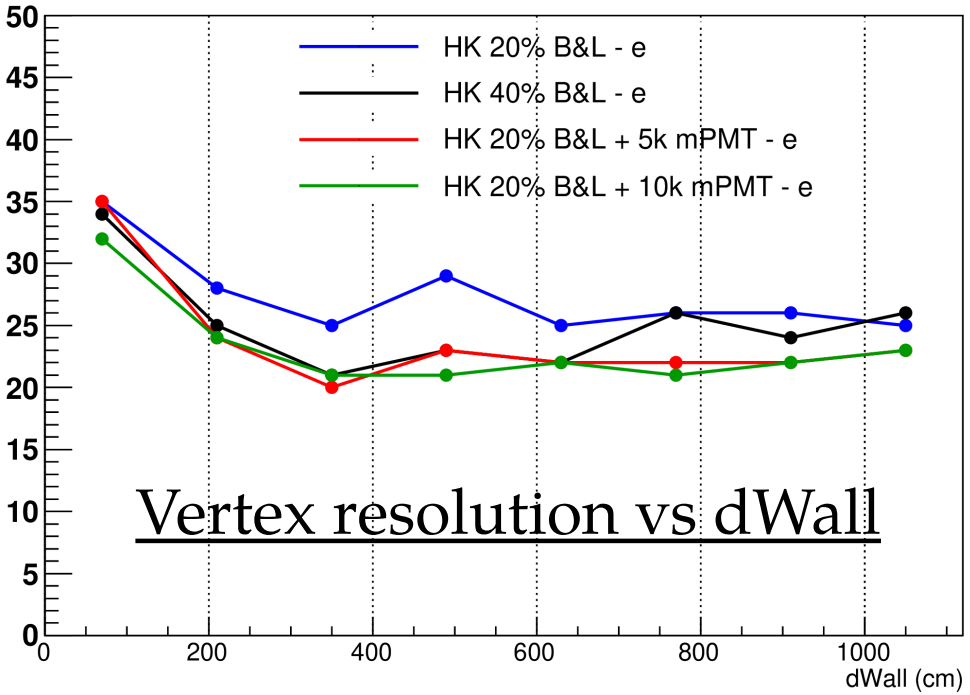
Direction resolution

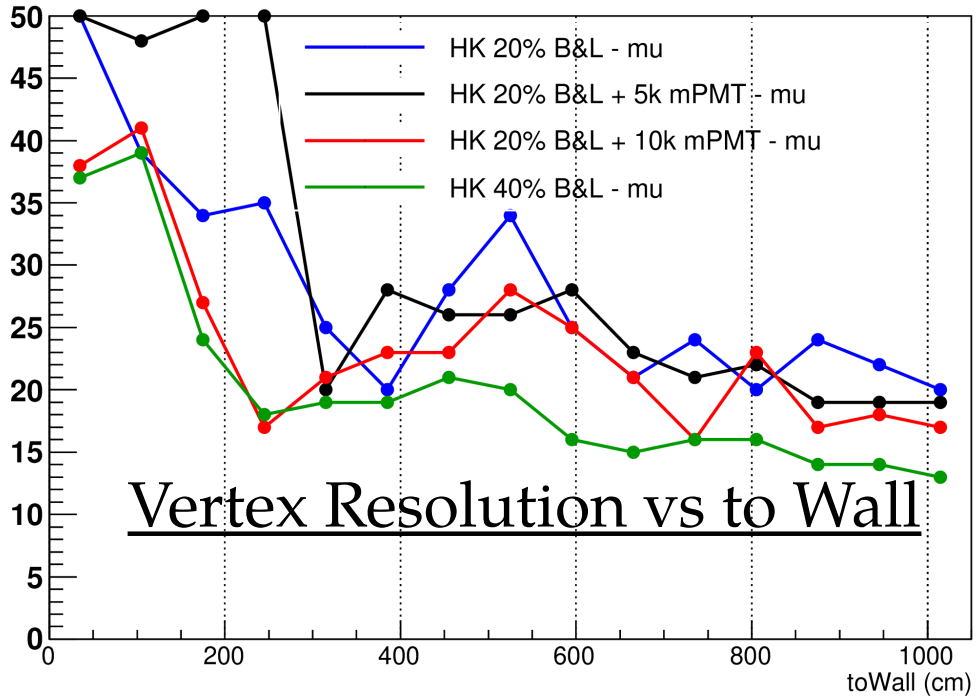


	20 % B&L	40 % B&L	Hybrid 5k mPMT	Hybrid 10k mPMT
Vertex res.	23 cm	22 cm	21 cm	20 cm
Direction res.	2.5°	2.5°	2.2°	2.2°
Momentum res.	5.6 %	5.3 %	5.4 %	5.2 %

- Similar conclusions than for electron case.

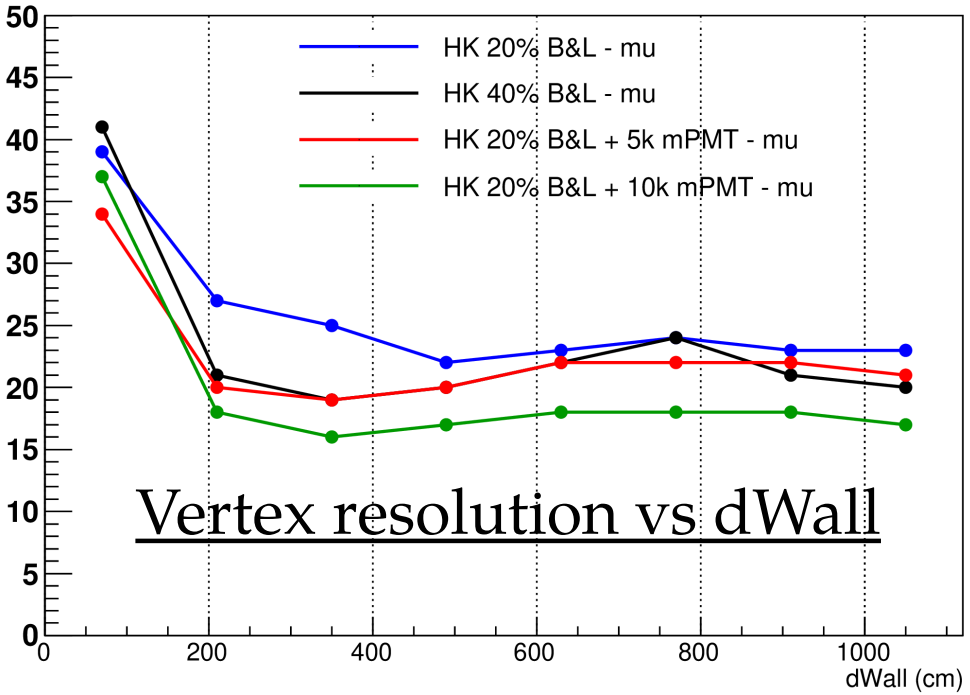
Dependency with dWall (500 MeV e)

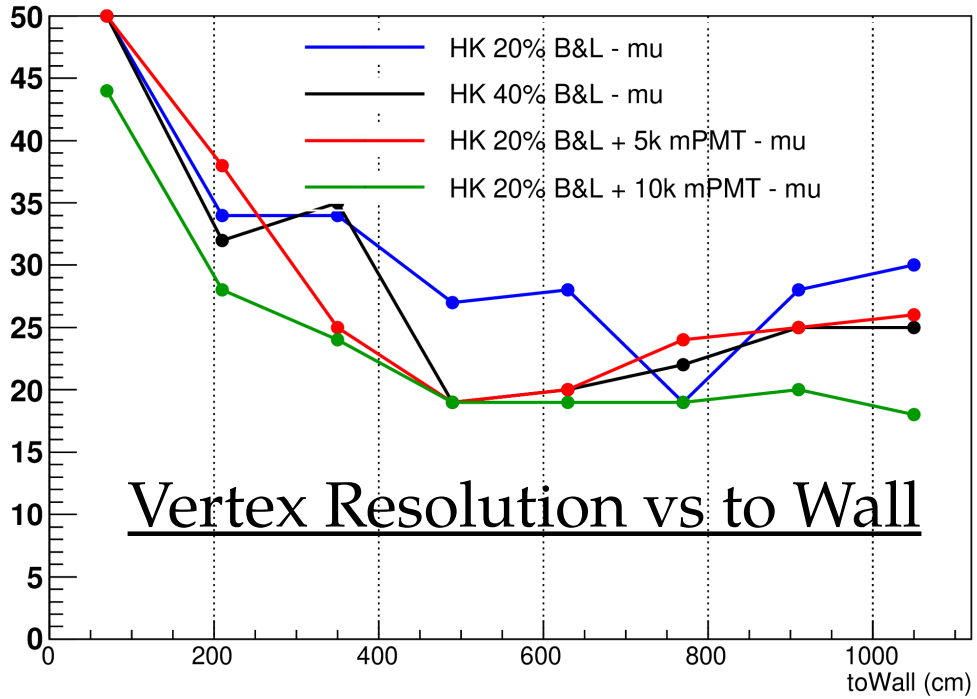




- Improvement with mPMT at small dWall, while B&L does not help.
- Keep in mind that fiTQun is written for 20'' : still imperfect for mPMT → Results are conservative.
- Temporary conclusions : as for vertex reconstruction abilities, 10k (and even 5k) mPMT helps more than +20 % B&L.

Dependency with dWall (500 MeV μ-)





- Same conclusions than for electrons.

- Can clearly see that small toWall lack of statistics
  → Event randomly generated in the tank with a random direction → Some of them are small dWall, but very few of them are small toWall.
  → I will check this with more stat. In future. Before that, I recommend to use dWall plot but be careful with toWall ones.

II. e/μ separation

e/μ separation @500 MeV in the whole tank

- What criterion to choose ?

  1. If we are statistically limited, we wish to determine how efficiency changes wrt PMT configuration.

  → For this purpose, we generally define a condition on bkg contamination (e.g. 2 % bkg contamination) and check efficiency.

  → I generated 50 % μ & 50 % e → Purity/contamination comparison with data (where ~80 % are μ) is meaningless, or should be scaled.

  → I defined my sample by requiring that background efficiency in the sample is same as T2K analysis (see next page).

  2. Alternatively, if we are systematics limited, we wish to determine the sample purity

e/μ separation @500 MeV in the whole tank

→ We generally determine a condition on efficiency of signal, and check how purity evolves wrt PMT configuration.

Runs 1-8	Expected						Data
	$\nu_\mu + \bar{\nu}_\mu$ CC	$\nu_e + \bar{\nu}_e$ CC	NC	BG Total	$\nu_\mu \to \nu_e$	$\bar{\nu}_\mu \to \bar{\nu}_e$	
FC	752.548	48.636	316.034	1117.218	97.355	0.865	1232
FCFV	546.921	35.219	195.225	777.365	67.656	0.615	842
Single ring	298.059	21.561	57.131	376.751	58.311	0.505	417
Electron-like PID	12.652	21.399	39.090	73.141	57.565	0.502	119
Evis >100 MeV							
No Decay-e							
E_ν^{rec}							
fiTQun π^0 cut							

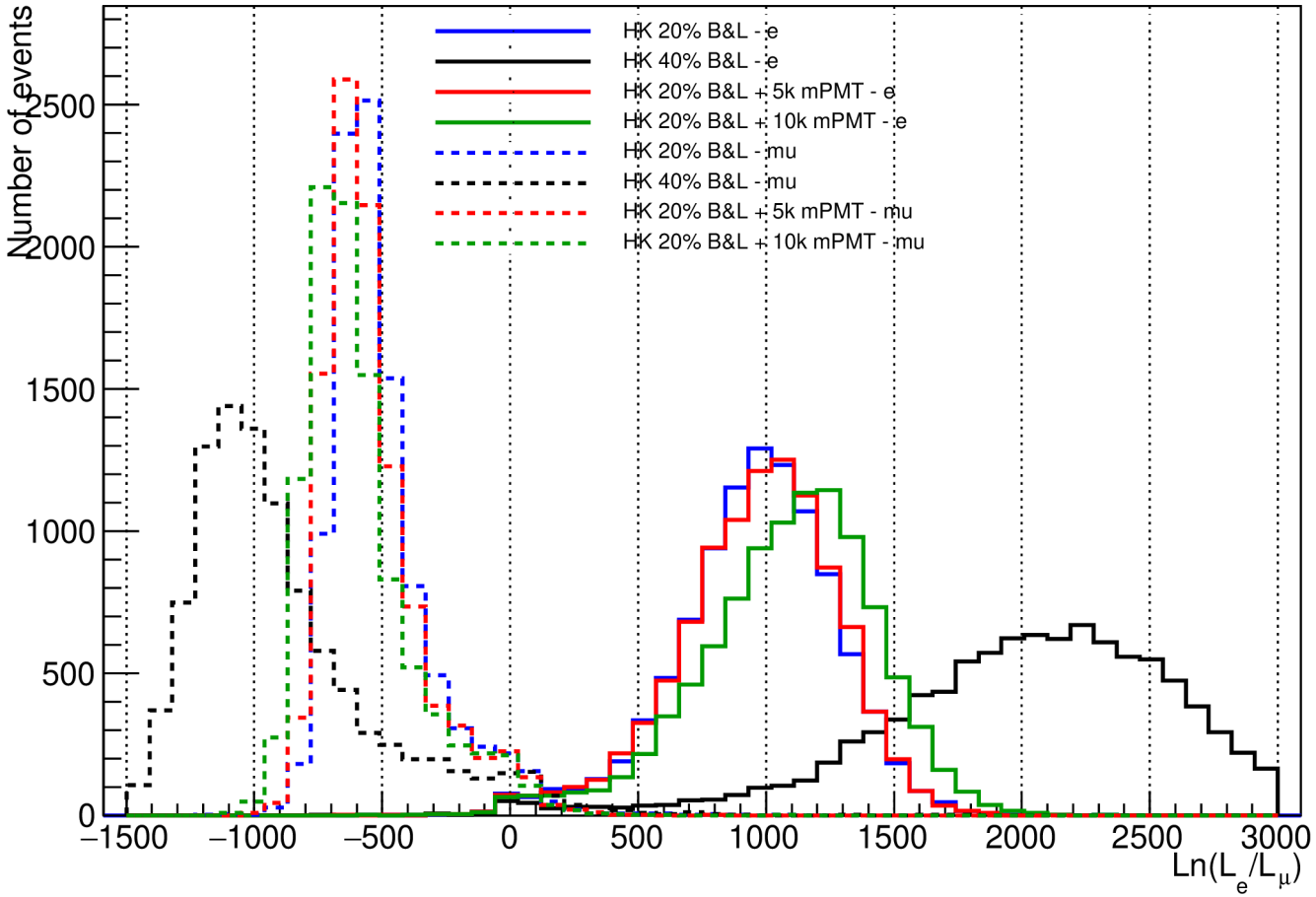
Bkg eff ~ 5 % signal eff ~ 99 %

T2K-SK provides us the following criteria :

1. Statistically limited type cut : check signal efficiency while requiring background contamination ≤ 5 %.

2. Systematic limited type cut : check signal purity while requiring background contamination ≥ 99 % → I took 95 % due to limited statistics at each dWall.

e/μ separation @500 MeV in the whole tank

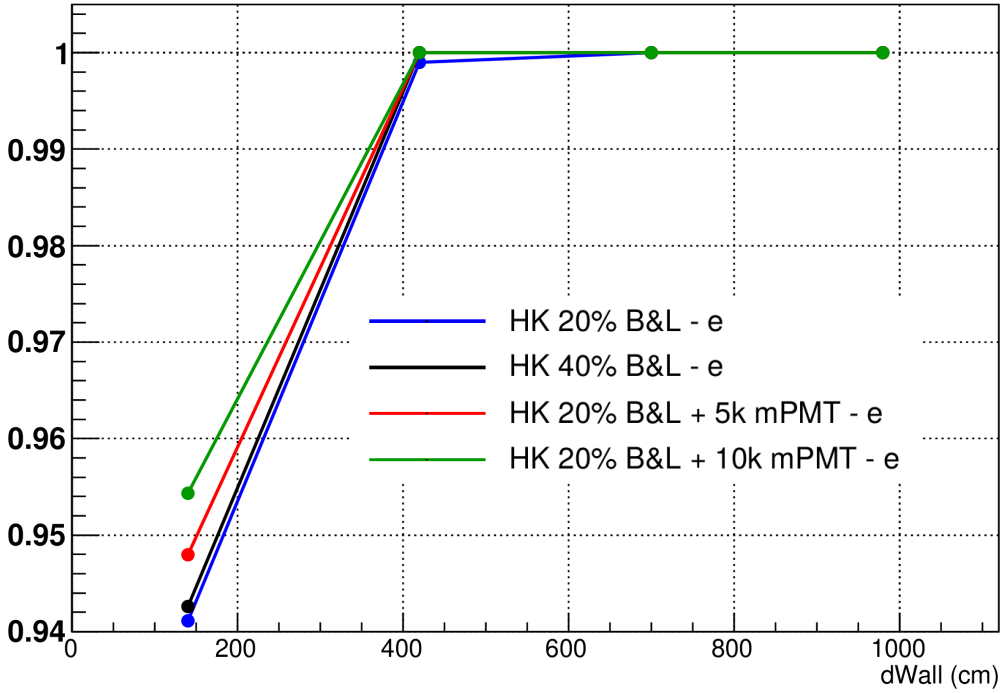


- E/μ separation in the detector : efficiency e ≥ 95 % for μ eff ≤ 5 %.
  → Overall separation already high and impact of more PMT is limited.

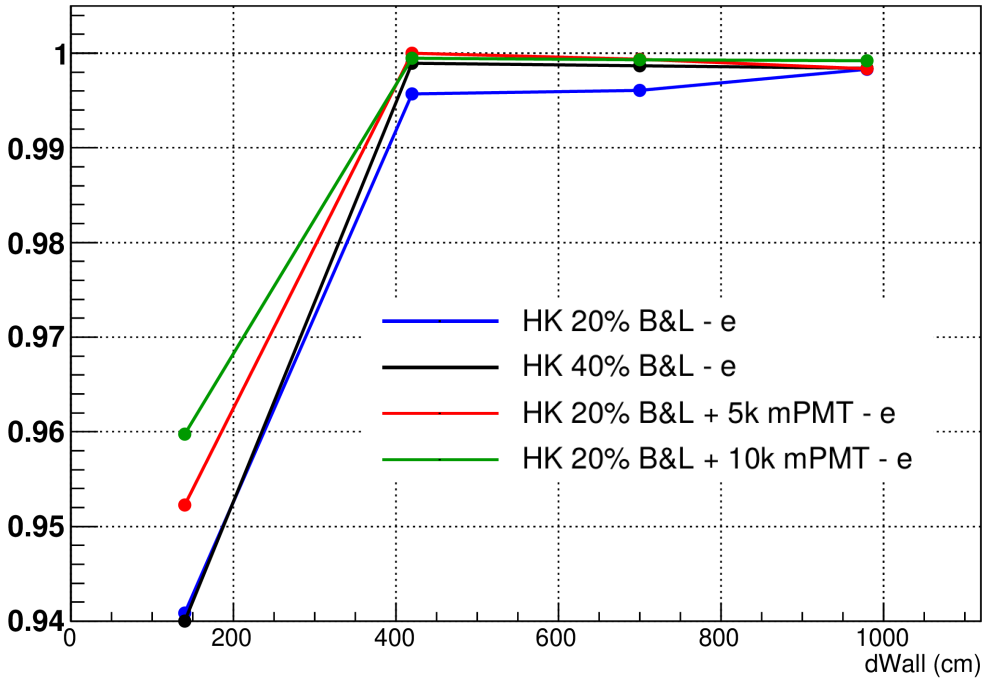
- But, how this separation evolves wrt to dWall/toWall ?

1Re-like sample wrt to dWall/toWall

1. e efficiency vs dWall (Requiring μ eff ≤ 5 %)



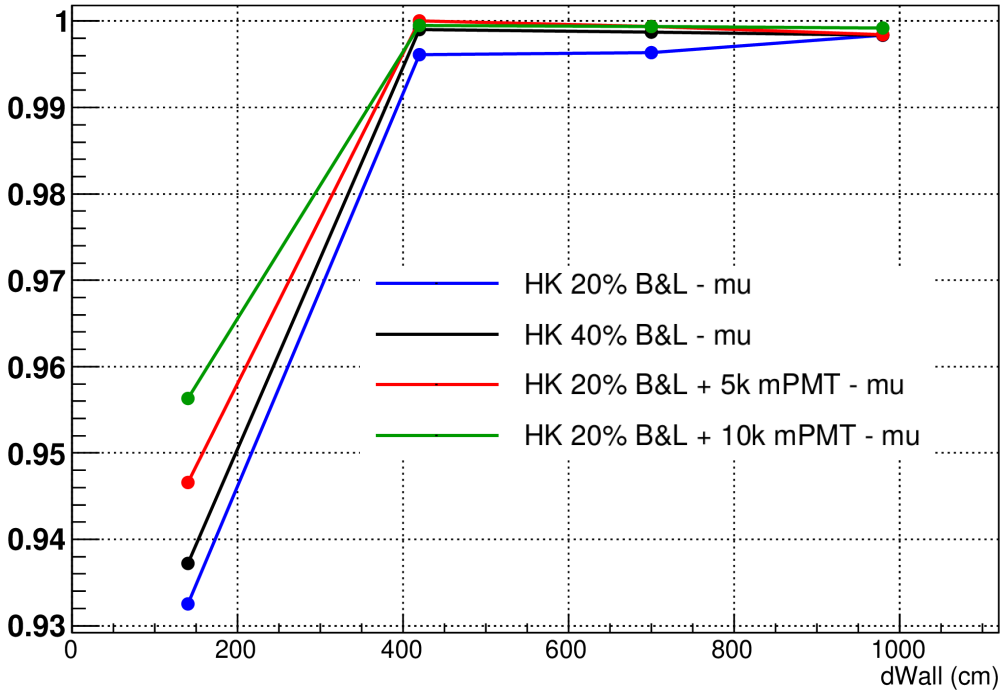
2. e-purity vs to Wall (Requiring e eff > 95%)



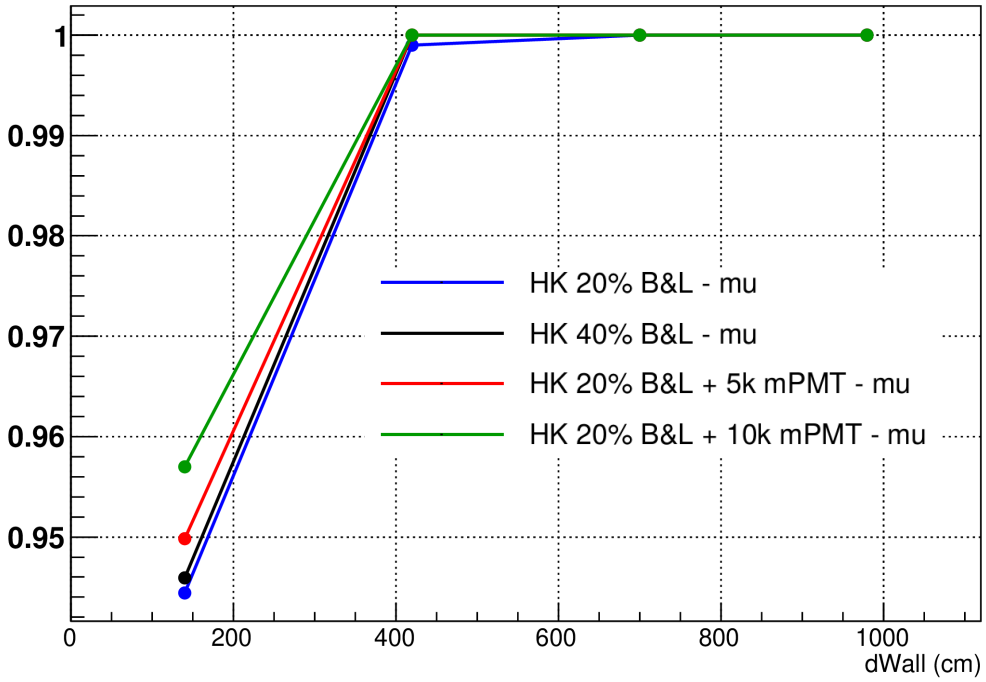
- No significant difference when going from 20 % → 40 % B&L.
- Impact of mPMT is clear at small dWall/toWall
  1. ↑ e-efficiency at a given μ-contamination.
  2. e-purity increases by 1-2 % using mPMT at dWall ≤ 2m
- Impact may be bigger for very small dWall (≤ 1.5m) → Needs more stat

1Rμ-like sample wrt to dWall/toWall

1. μ efficiency vs dWall (Requiring e eff ≤ 5 %)



2. μ-purity vs to Wall (Requiring μ eff > 95%)



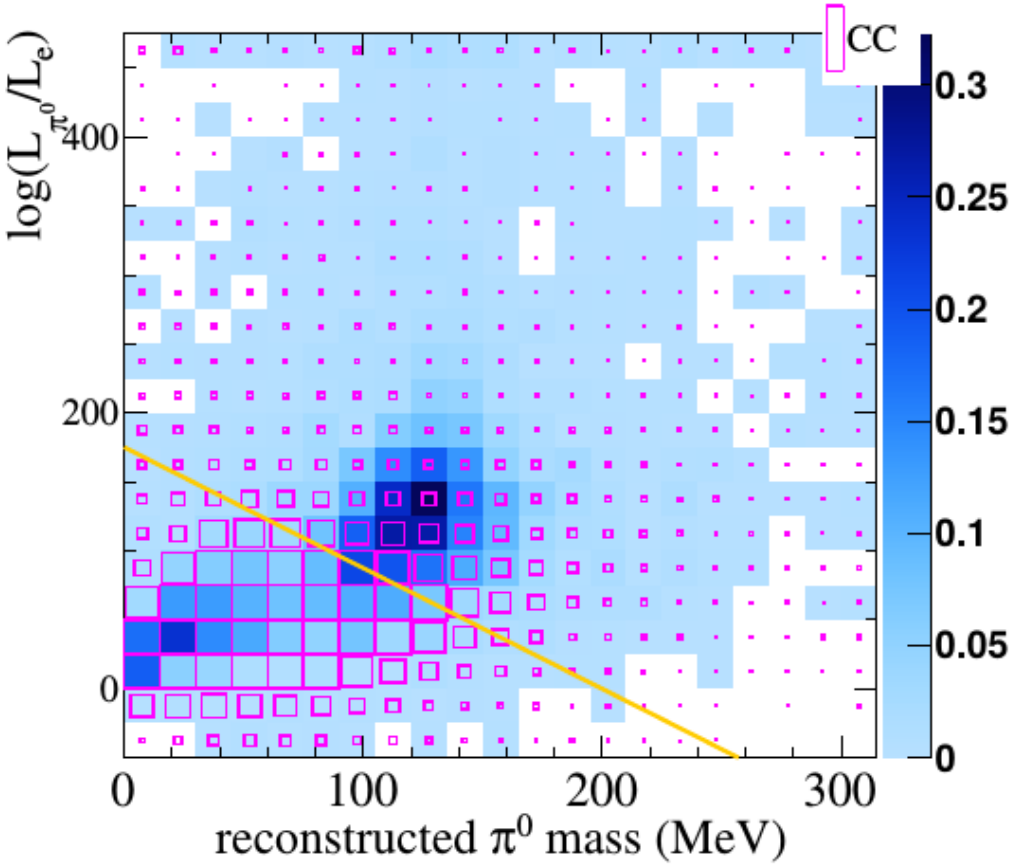
- Small (but non negligible) ≠ when going from 20 % → 40 % B&L.
- Impact of mPMT is clear at small dWall/toWall
  1. ↑ e-efficiency at a given μ-contamination (+2% at dWall ≤ 2m)
  2. e-purity increases using mPMT at dWall ≤ 2m
- Impact may be bigger for very small dWall (≤ 1.5m) → Needs more stat

III. e/π^0 separation

e/π^0 separation for CPV

- FV for beam-ν already very-optimized → small room for enhancement.

- Mesurement of δ_{CP} will be systematic limited → Focus on lowering syst.
  → Second dominant bkg → NCπ^0.



	fiTQun		
	$\nu_\mu + \bar{\nu}_\mu$	beam $\nu_e + \bar{\nu}_e$	signal $\nu_e + \bar{\nu}_e$
			C
FCFV	330.957	21.771	42.830
1ring	143.778	11.108	35.820
e-like	4.305	11.103	35.779
evis> 100MeV	1.617	11.023	35.080
0 Michel	0.439	9.383	31.696
Erec< 1.25GeV	0.278	4.953	30.560
not π^0	0.135	4.403	28.658

Efficiency of true ν_e: 94 %

→ Imposing 94 % efficiency → how much PD-coverage changes purity ?

e/π^0 separation

- Disclaimer #1:
  - First time I run fiTQun w/ π^0 fitter.
  - I modified & tuned the whole fiTQun by myself, but I am not a fiTQun expert.

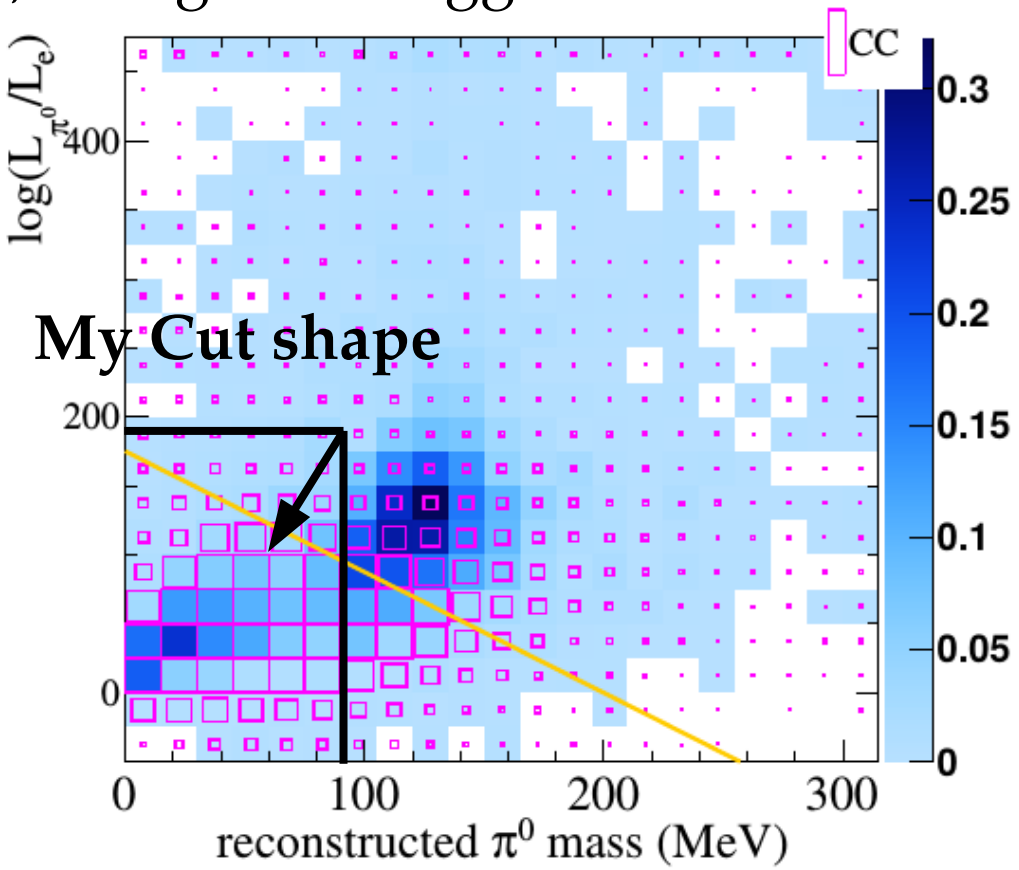
    → There may be tons of mistakes, though I debugged the main ones.

    → Your comments / questions will be very appreciated!

- Disclaimer #2 :

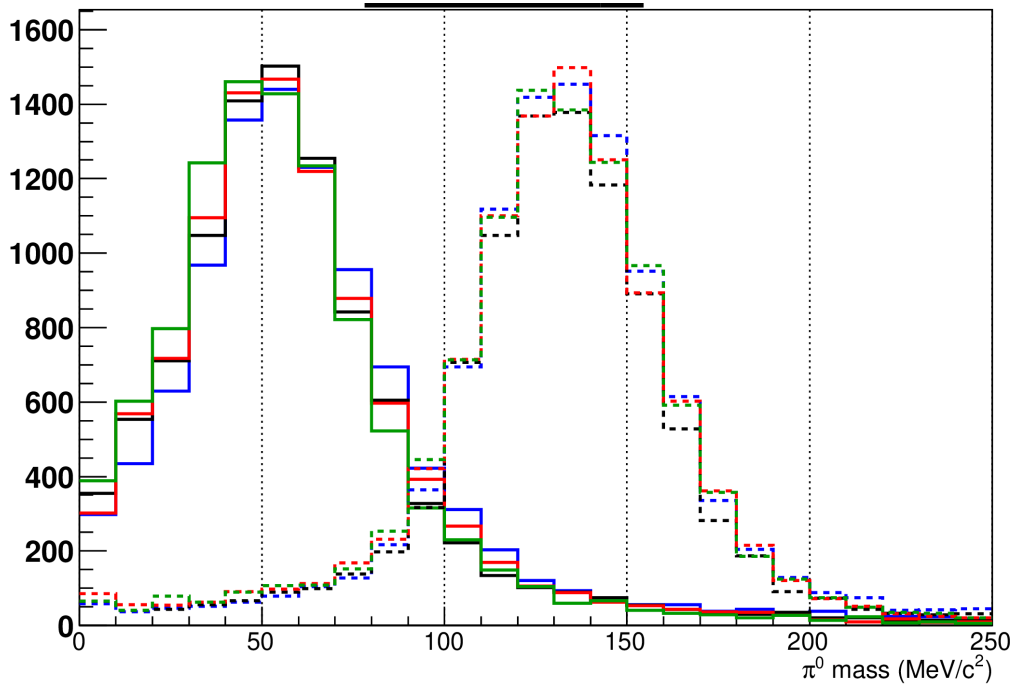
  For this first study, I didn't used a real 2D cut, but a rectangular cut

  → so the results are worse / conservative compared to our true performances.

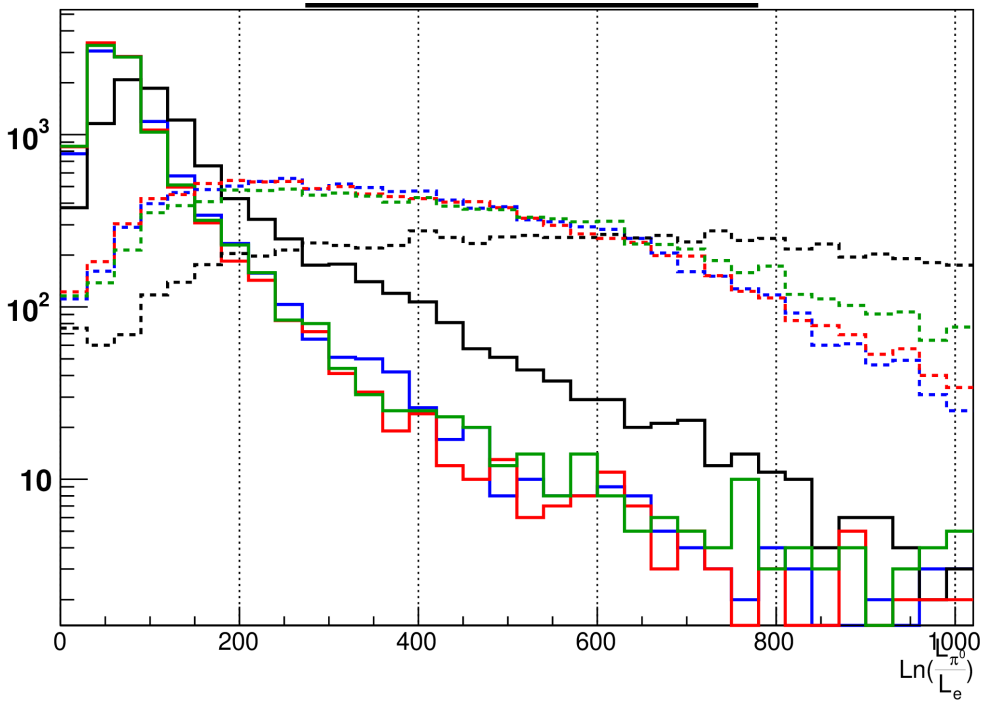


Projected results

Mass of π^0



Likelihood ratio



- Separation with π^0 mass seems slightly improved using mPMTs
  → Due to improved resolution in momentum ?

- As expected, the main impact of mPMT is seen in Ln(π^0 /e)
  → π^0 & e distributions are moved away from another adding mPMTs
  → What is the impact quantitatively ?

Summary of e/π^0 separation

π^0 contamination for various ν_e efficiencies (I can put this in a plot if you prefer)

π^0 contamination	20 % B&L	40 % B&L	Hybrid 5k mPMT	Hybrid 10k mPMT
ν_e eff = 80 %	8 %	7 %	8 %	7 %
ν_e eff = 90 %	18 %	13 %	15 %	12 %
ν_e eff = 94 %	25 %	22 %	23 %	21 %

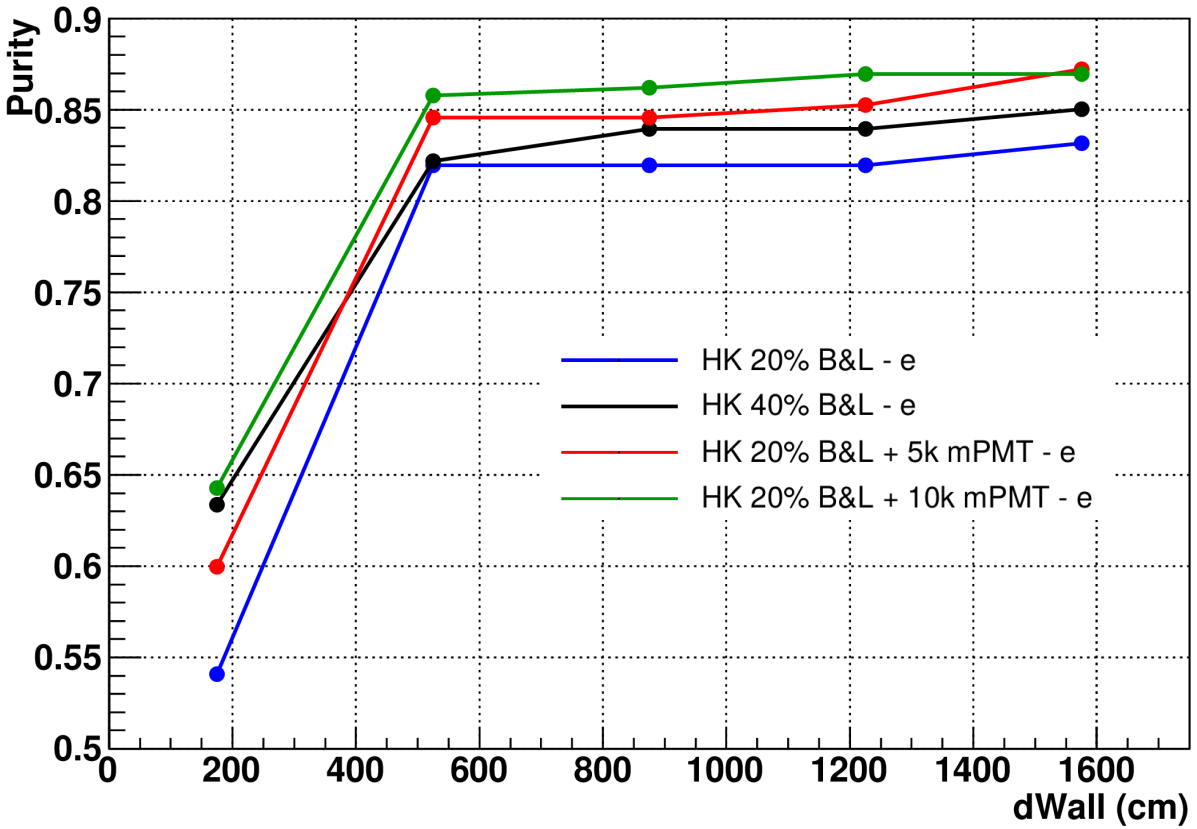
- @94 % ν_e eff : π^0 contamination reduced by 12 % from 20 → 40%B&L.

- 5kmPMT (resp. 10k) also helps for π^0 contamination reduction by 8 % (resp. 16%).
  → What I extracted is that 10k mPMT improvement is similar and slightly better than going to 40 % B&L.

- Similar reductions are seen consistently for ≠ efficiency cut values.

1Re-like sample wrt to dWall

e purity vs dWall (Requiring e eff ≥ 90 %, to avoid stat. fluctuation)



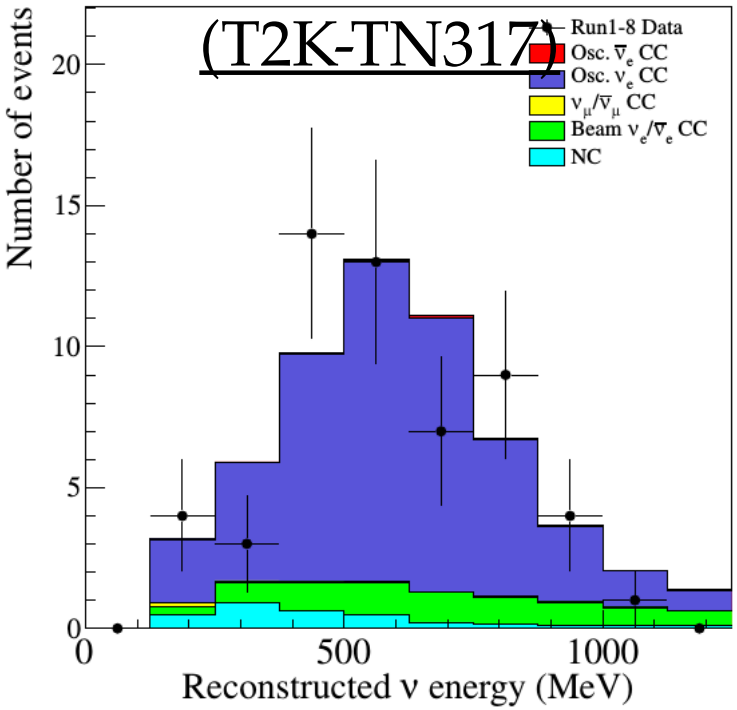
- ↑ PC 20 % → 40 % impacts e/π^0 separation, especially at dWall ≤ 4m.

- Impact of mPMT is clear over the whole detector, but especially at small dWalll : e-purity increases by 5 % (resp. 10%) using 5k mPMT (resp. 10k) at dWall ≤ 2m.

IV. e/γ separation

Motivations for e/γ separation

SK 1Re-like sample (T2K-TN317)



- NC is 2nd dominant background (30 % of the bkg i.e. 6 % of total Nevents).
- 1st source of NC : 50 % of NC are NCπ → Studied.
- 2nd source of NC : 26 % of NC are NCγ. → Can we separate e/γ ?

- The γ-ring is expected to be >99 % similar to e-ring (elm shower).
- Small differences are expected at the beginning of the Cherenkov emission → 2 e vs 1 e → Differences can be seen in outer ring part.
- Can the mPMT granularity & enhanced vertex resolution helps ?

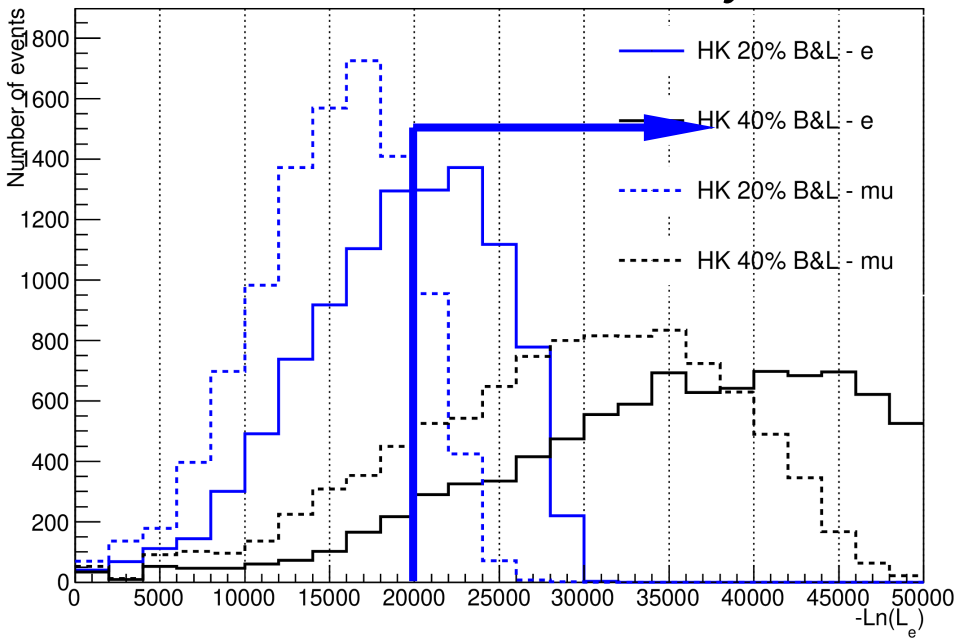
Limitations

- We do not have a γ-likelihood for now in fiTQun.

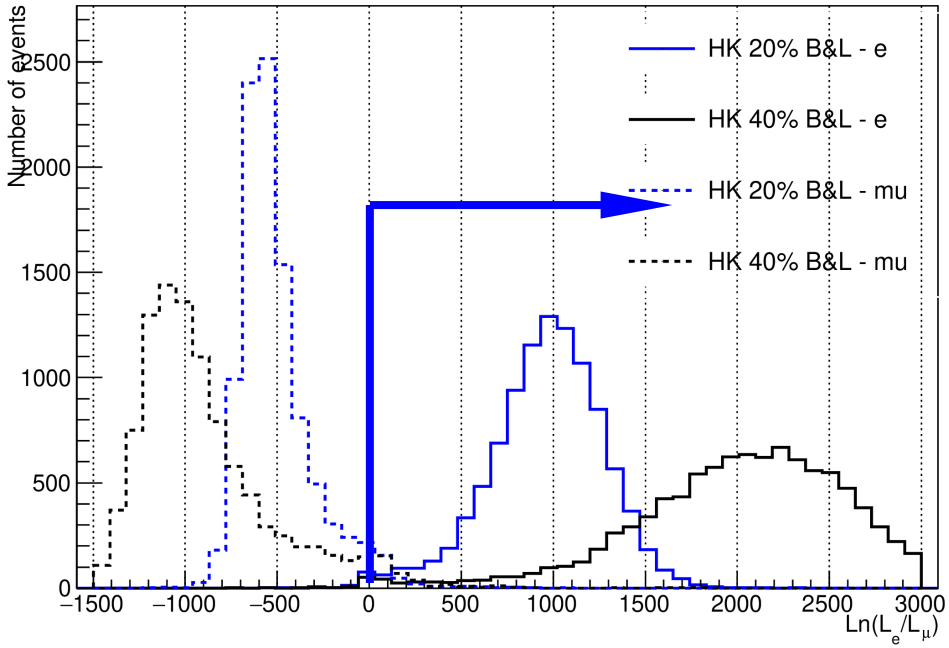
  → We will therefore only test how much particles are e-like.

  → Example of e vs μ : show how quantitatively how much likelihood ratio helps test can helps : e vs μ.

E-likelihood only



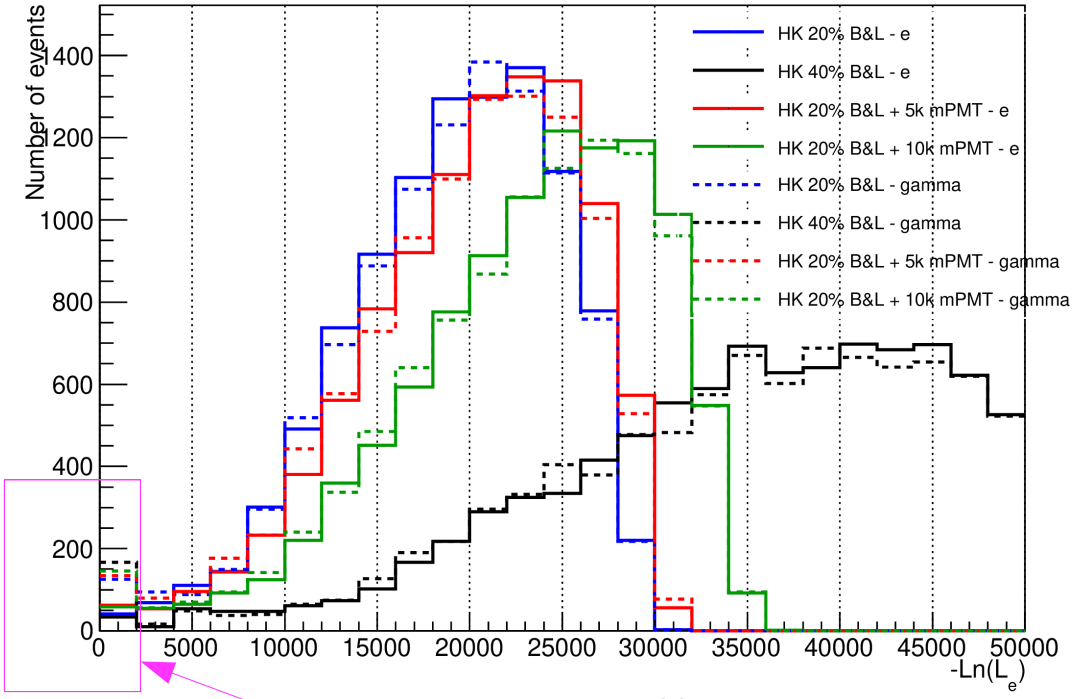
e vs μ-likelihood (NLL ratio)



- Separation is extremely improved using log-likelihood ratio

Results for e/γ separation

- Let's use the e-likelihood for e vs γ separation :



- e are slightly more e-like than γ & Differences seems slightly enhanced with mPMT in the low Ln(L) region.

- But separation is too small → Needs a proper γ -likelihood to have a realistic study !
  → Shall we/I can develop such a tool for Hyper-K and SuperK ?

Conclusions

- FiTQun has been largely debugged for the hybrid configuration.

- Produced all comparison results of e/μ separation @500 MeV/c^2.
  → mPMT enhances vertex resolution by 4cm (5k mPMT).
  → mPMT enhances e/μ separation, especially ≤ 4m from the wall.
  → These improvements surpass those with 40 % B&L.

- Produced first results of e/π^0 separation @500 MeV/c^2.
  → π^0 contamination in 1Re-like lower w/ +10k mPMT than 40 % B&L.
  → Bug that prevent me from showing you the π^0 result for small dWall.
  → Under investigation (you can see back-up slides).

Can we add this to TR ?

- Produced first results of e/γ separation @500 MeV/c^2.
  → mPMT or additional B&L seems to improves the separation.
  → But no quantitative conclusions before creating a γ-fitter.

Schedule

- Solve the π^0 – fitter bug for small dWall
  & Update the results w/ e/π^0 separation wrt dWall.

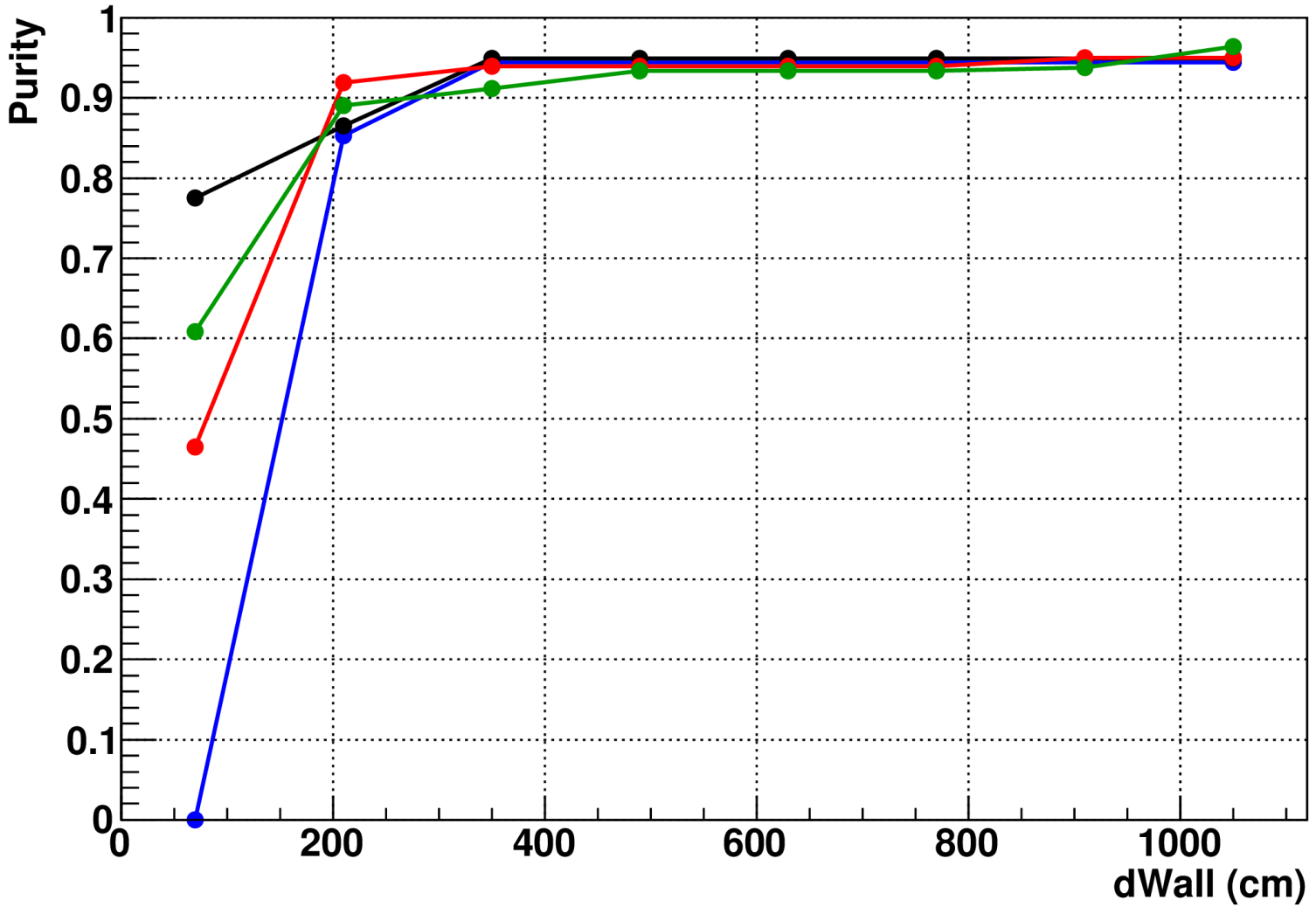
- Update the results w/ more stat (for towall) & at various momenta.

- Answer questions from Itow-san and Shiozawa-san :
  → Test more ≠ configurations (Change mPMT 1,000 by 1,000).
  → Think about other arguments of mPMTs: if I add 1,000 mPMTs, this is what I can improve in calibration etc.

- Bonus #1: Develop a new γ-fitter → can do it only if useful for SK also.
- Bonus #2 : Provides first results for ring counting.
  → To my knowledge, ring counting of fiTQun never been tuned for HK.
  → Quite challenging, and I have to focus more on the hardware now.
  → But we should try. Help from experts will be welcome.

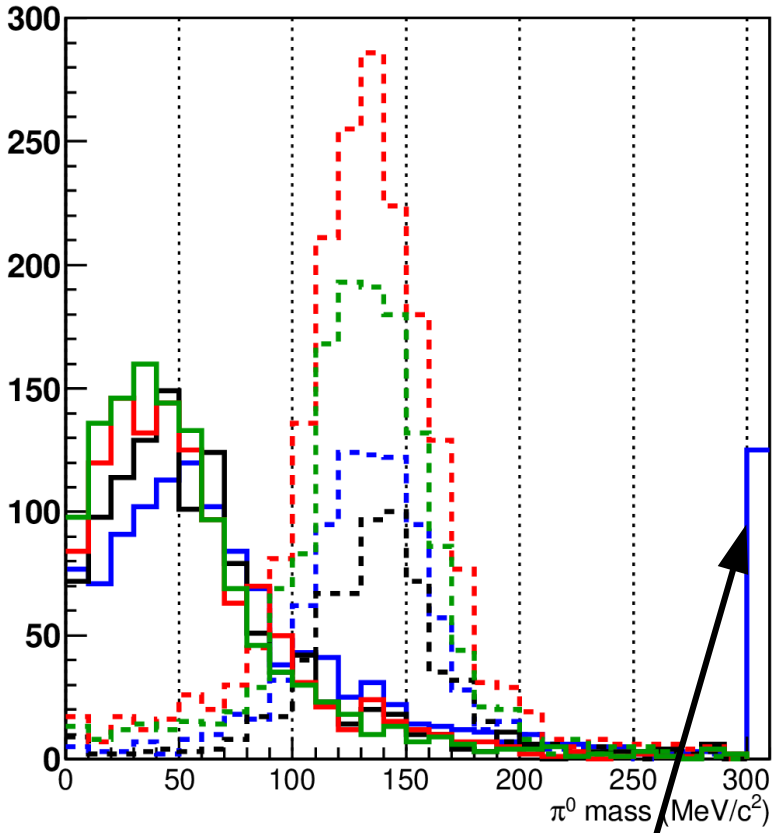
Additional slides

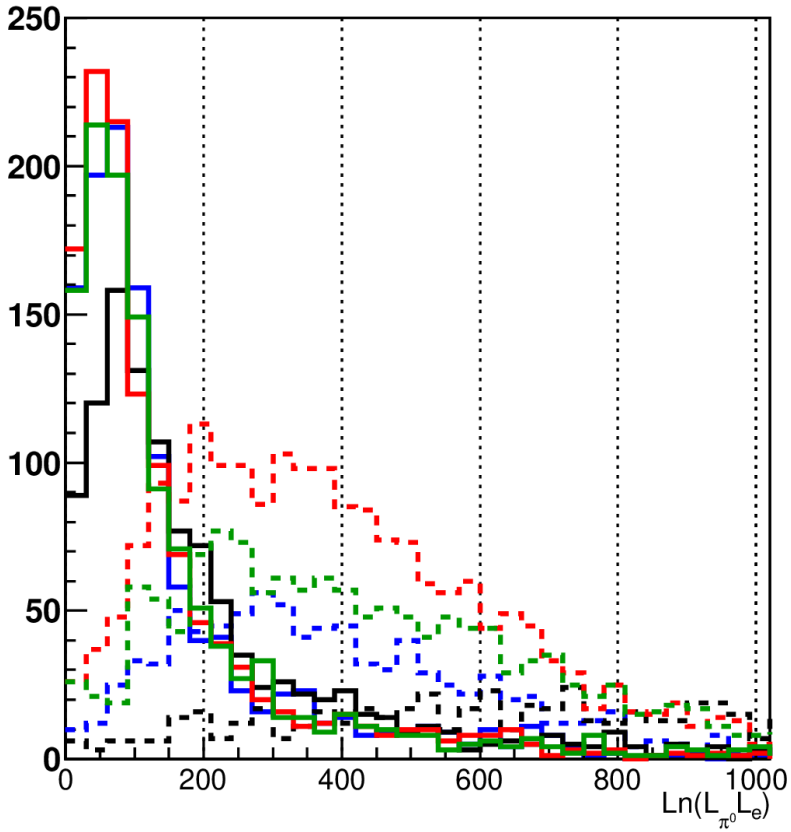
2. Debug de fiTQun avec les tables B&L



- Large improvement of the fitter close to the wall when adding mPMT.
- Improvements still smaller than 40 % B&L → To investigate.
- 0 % purity of nue if efficiency ≥ 90 % → Bug.

2. Debug de fiTQun avec les tables B&L





- <u>Why purity limited for small dWall, especially for 20%B&L ?</u>

→ E/pi0 are hidden here → Fit failure at small dWall ?

→ The e-fitter works → Vertex and momentum correctly fitted

→ So it is a pi0 fitter issue → Need more time to investigate & discriminate if it is a code issue or detector limitation.