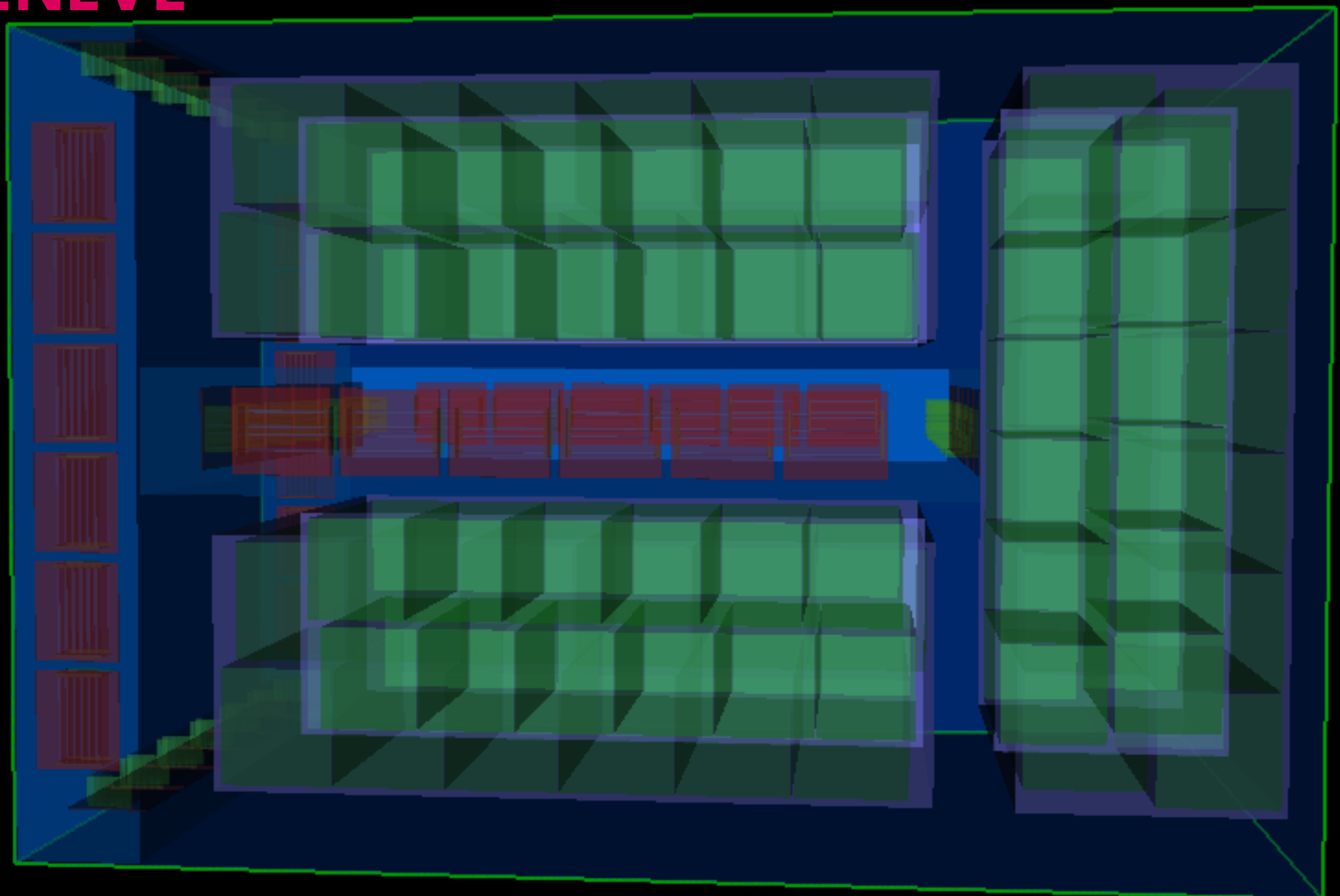
UNIVERSITÉ DE GENÈVE



Simulation:
Y. Karadzhov
(U. Geneva)

Thoughts about T2K and Hyper Kamiokande

Near Detector Upgrades

16.07.2015

Mark Rayner, University of Geneva / High Pressure TPC Meeting, Barcelona

Bibliography

T2K NIM paper

ND280 TPC NIM paper

Alain Blondel, ND280 upgrades, HK-EU meeting

— https://indico.cern.ch/event/378508/contribution/12

Alain and Yokayama-san, Upgrade talks at June T2K CM

Raj Shah and Mark Hartz' talks at this meeting

— http://indico.ipmu.jp/indico/contributionDisplay.py?contribId=29&confId=67

— http://indico.ipmu.jp/indico/contributionDisplay.py?contribId=60&confId=67

Federico's HP-TPC talks at the ND280 upgrade sessions

and thanks to:

Alain, Yordan Karadzhov, Leila Haegel, Lorena Escudero, Jeanne, Mark Hartz, Emilio, Raj Shah and Sandro Bravar for their input

What do the sensitivity studies say?

What are the most important things for the near detector(s) to constrain?

- Intrinsic ν_e background has potential to limit sensitivity

  →how can we get nue with high precision?
- Wrong sign background and High E have equal contribution to sensitivity (at 10% error)

  →magnetic field
- Intrinsic ν_e - <10% uncertainty required, <5% ideal

  →how can we get nue with high precision?
- High E (>1GeV) - < 5% would be an improvement

  →high-E information important due to interplay of systematics
- Wrong sign background - Ideal constraint below 5%, 20%-50% much worse

  →magnetic field

Raj Shah, VALOR sensitivity studies
1st Hyper-Kamiokande Proto Collaboration Meeting

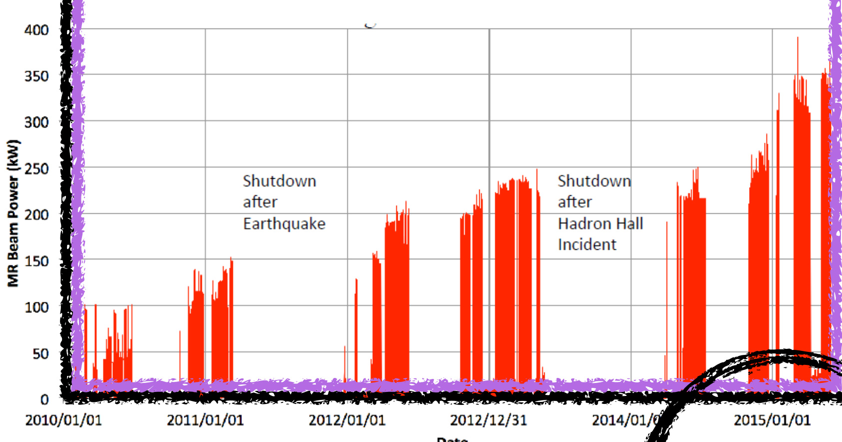
Strong motivation to upgrade ND280

next steps: double rep. rate with new power supplies, fast kickers and higher gradient RF improve loss controls further with more feedbacks

Main ring beam power

750 kW

original request



365 kW

1 MW ???

Hyper-K

Can achieve 2–3 times the requested T2K POT by 2025 when Hyper-K begins taking data

What's more, we surely want to **keep ND280 for Hyper-K** as it provides unique information.

If we want to keep ND280 alive, we should **update/upgrade**

2010 2015 2020 2025 time

Foreseen ND280 tracker TPC statuses in 2025

Must refurbish gas system

—Drives operation cost, not negligible

Must upgrade the DCC back end readout electronics

—However the rate of channel failures is small so Micromegas and front end electronics would not need major work

Possible upgrades

—Reduce the DCC front end readout latency

—Increase robustness against high occupancy events

TPCs look sustainable

Foreseen P0D/FGD detector statuses in 2025

Likely degradation of scintillator light output

— ~5% / year in MINOS, MINERVA

—*Serious problem over the long term*

Big question mark over scintillator detectors

Expect all DAQ components to fail at some level over the next 5–15 years

—Continuing backend board connector availability?

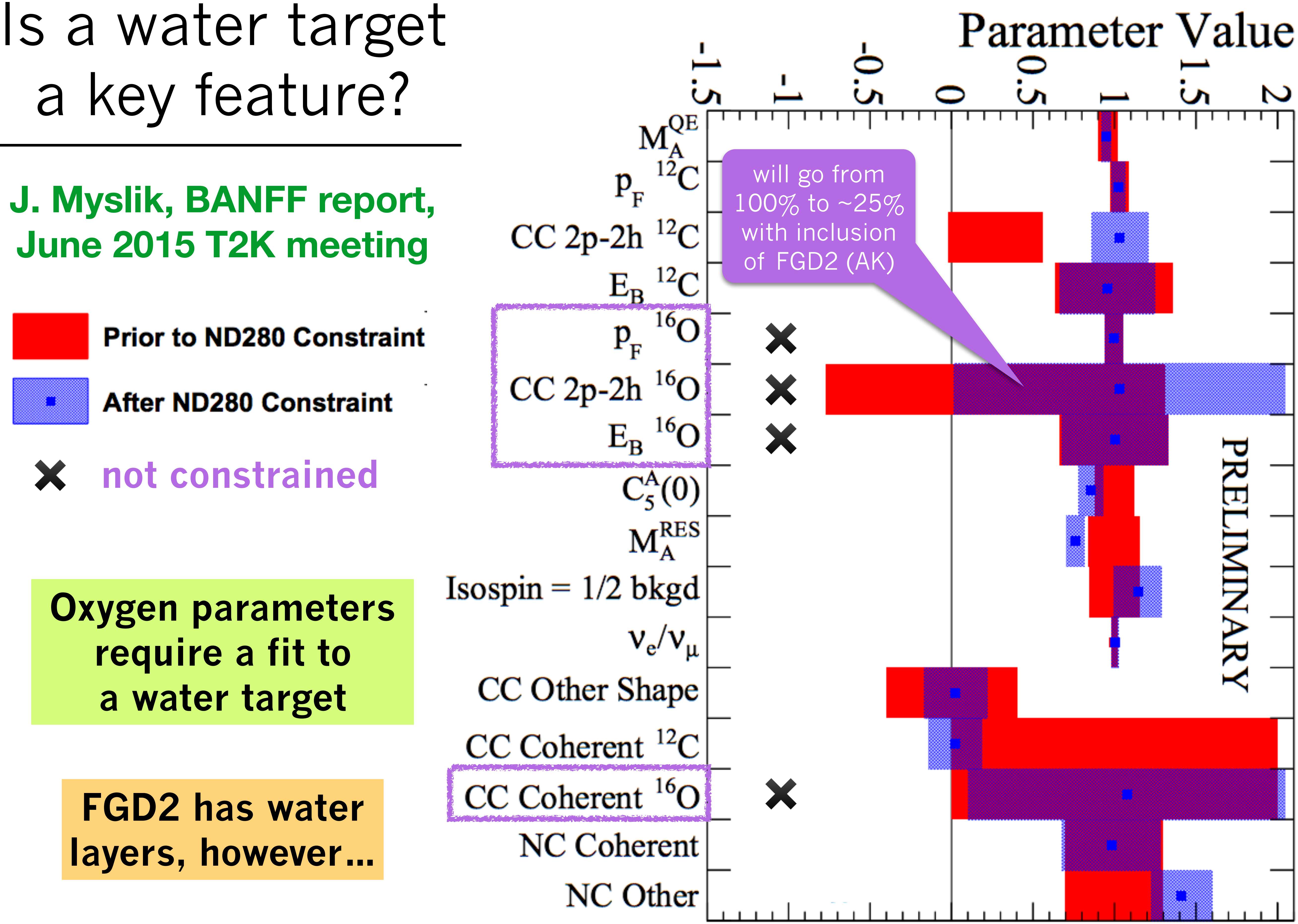
—The electronics is obsolete: impossible to build spares

<1% of TRIPt frontend board have failed: *>10% spares*

5% of the backend board have failed: *20% spares*

Is a water target a key feature?

J. Myslik, BANFF report, June 2015 T2K meeting



Oxygen parameters require a fit to a water target

FGD2 has water layers, however…

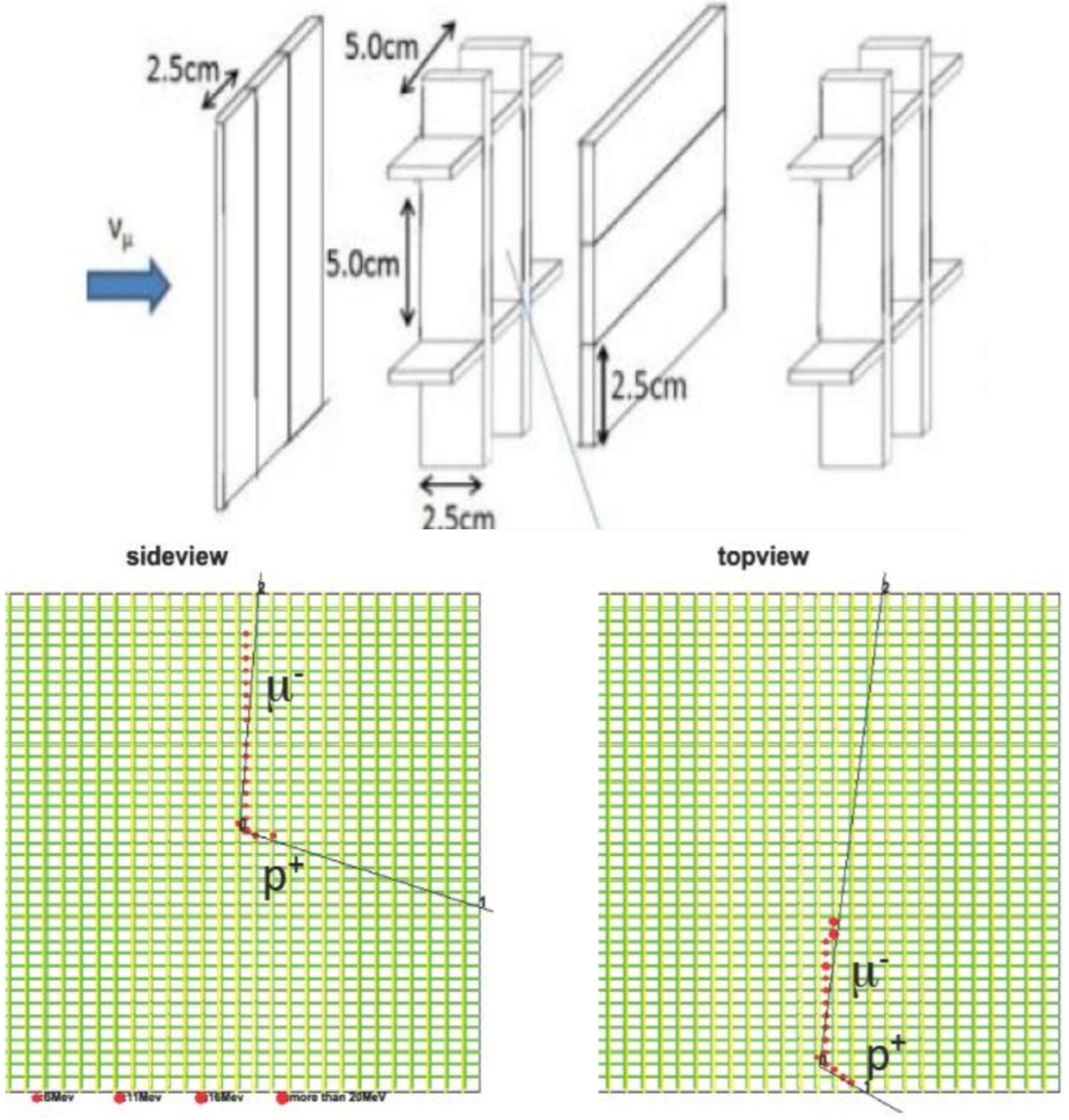
A limitation of the current detector:

FGD2 is only 40% water, short track reconstruction is difficult

Two solutions have been proposed…

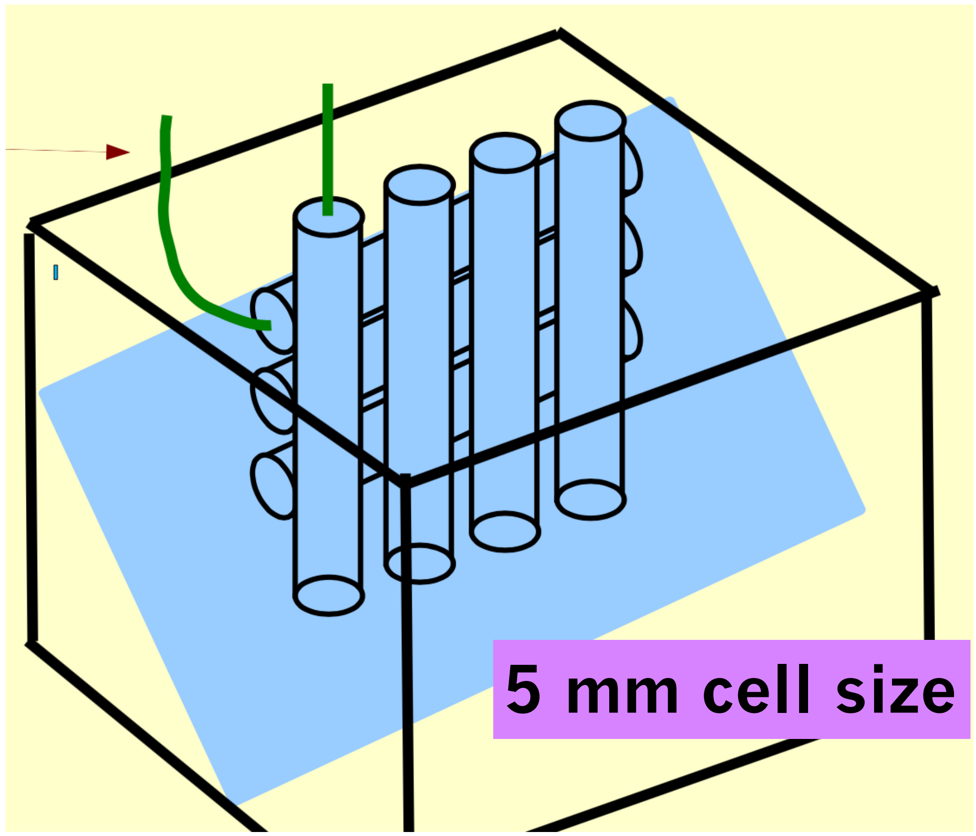
80% and 70% water respectively, and can reconstruct short 3D tracks

A Wagasci style scintillator grid



Water-based liquid scintillator

Mylar straws painted with reflective paint on the outside, WLS fibres strung inside the straws



Stanley Yen *et al.*, TRIUMF

Aside: Can such a target be big enough?

FGD1 is 1.07m³ or ~1 ton

far/near flux ~ 0.6 — 0.8 x 10^{-6}

→statistics at 280 m in 1 ton is equivalent to ~1.4 Mton at HK

More than enough for HK

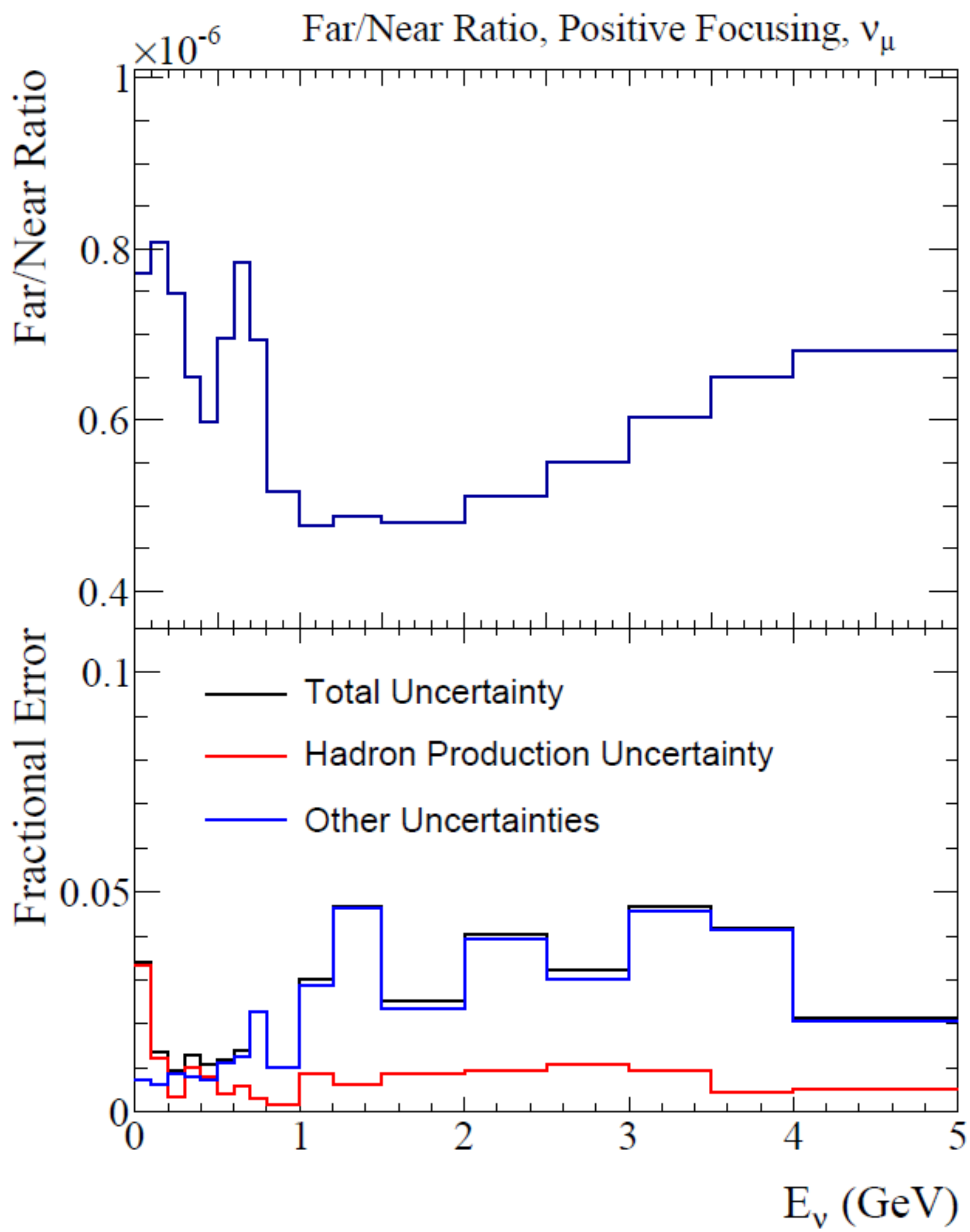
(particularly as the disappearance is almost complete and appearance is small)

Aside: Is L = 280 m << 1 km limiting?

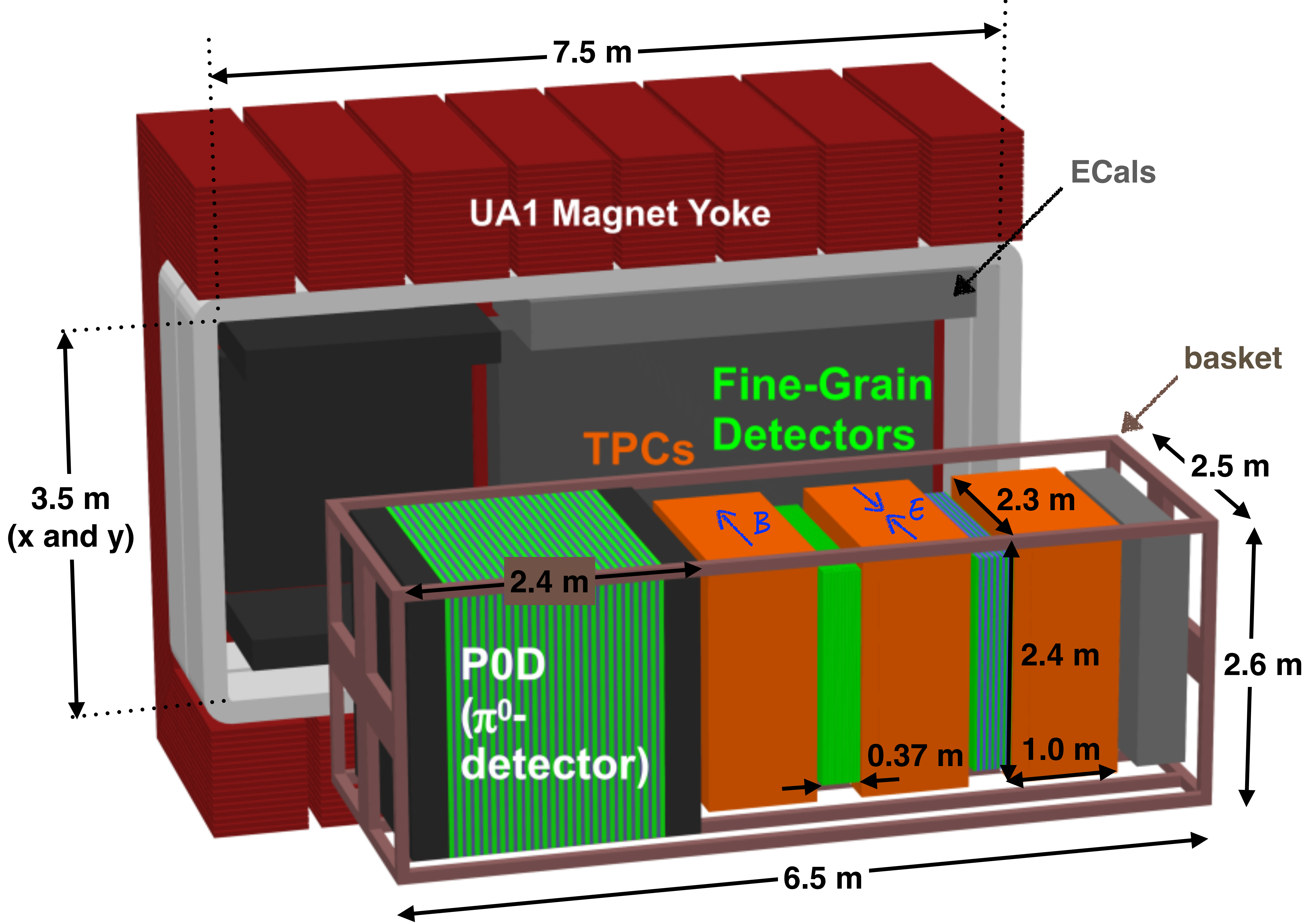
Uncertainty on FD/ND flux is ≤ 2%

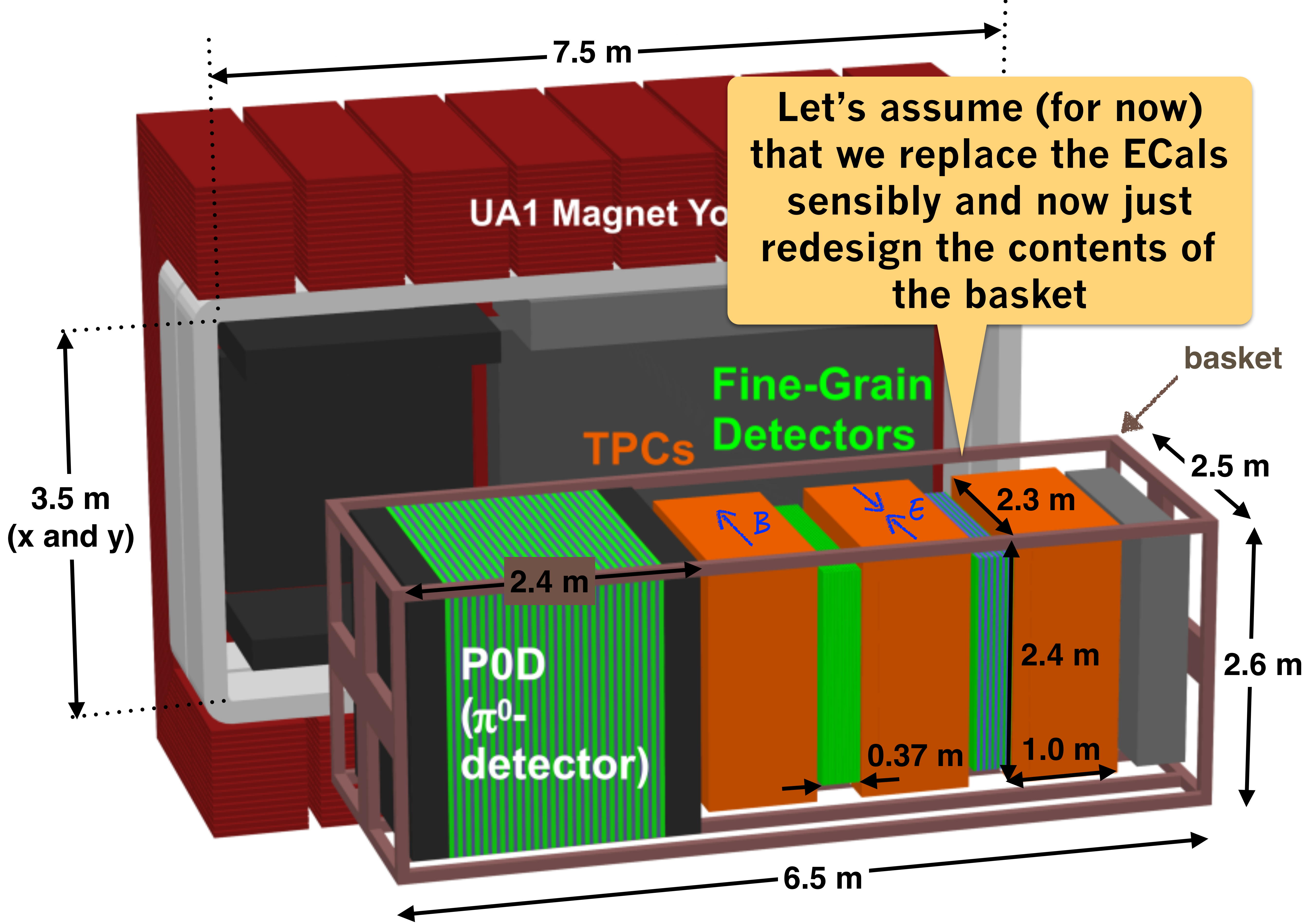
The detector being close to the target is probably not a fundamental limitation

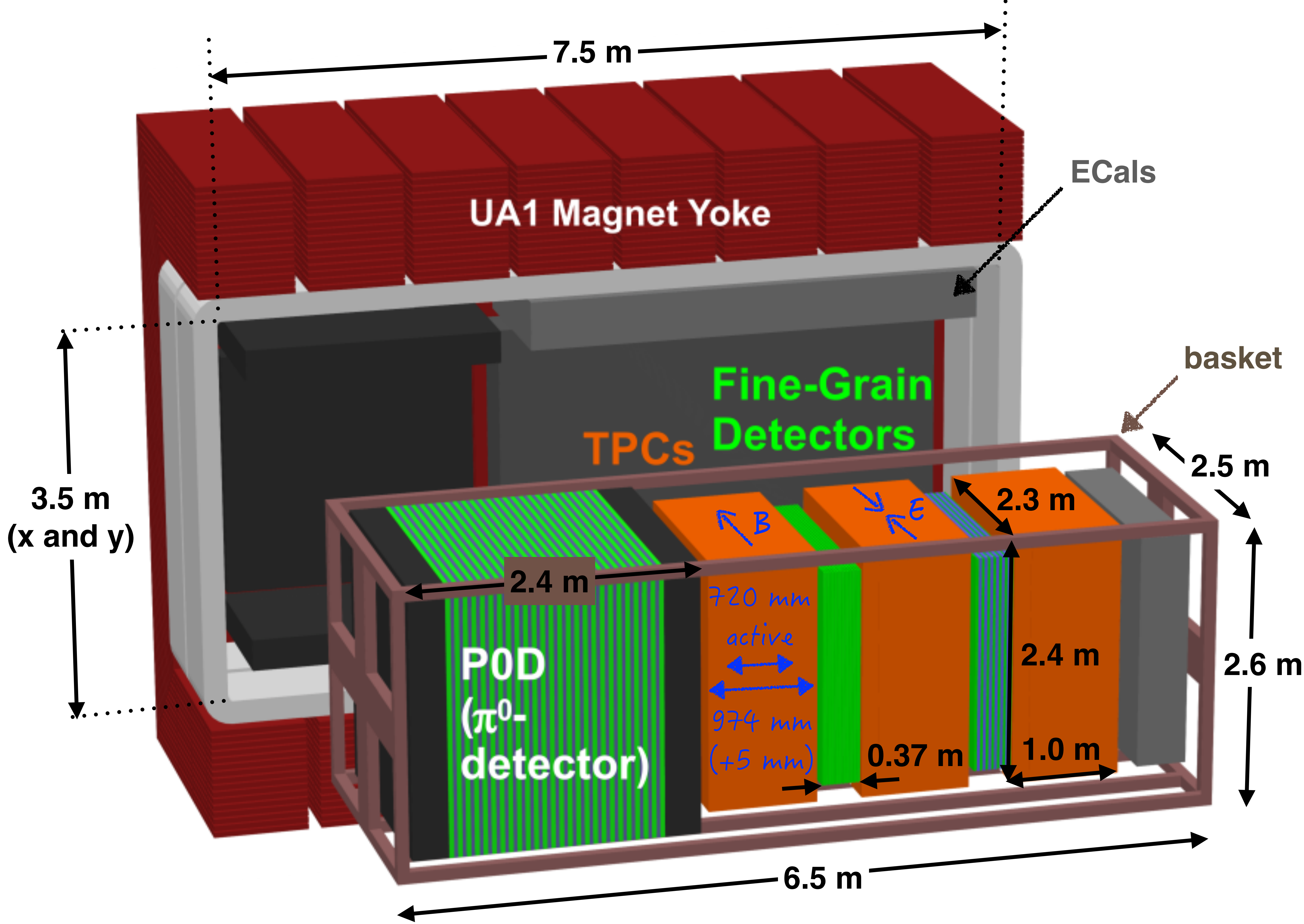
(quantitative study is envisaged)



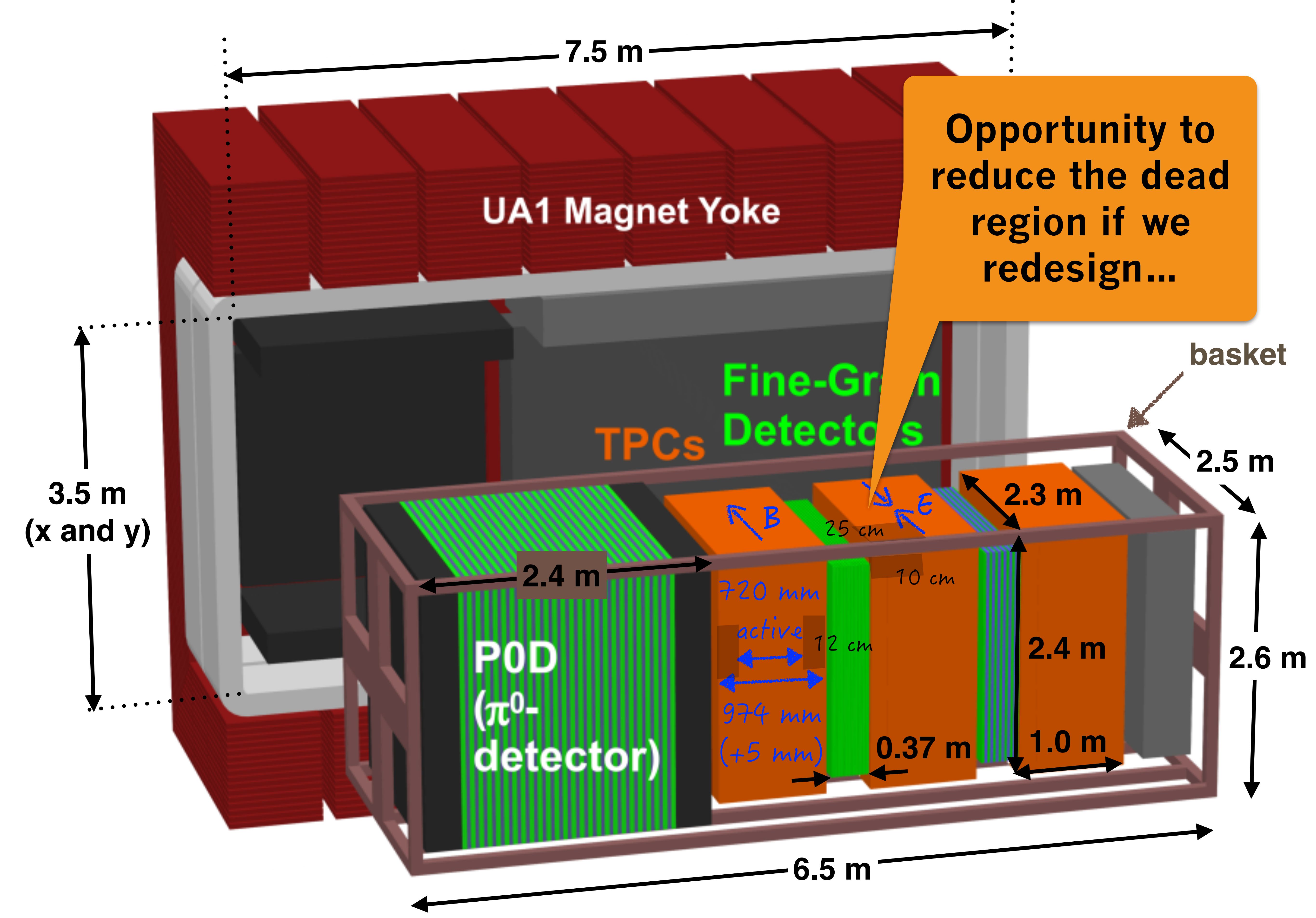
2015 analysis with 2009 NA61 data
further improvements are possible

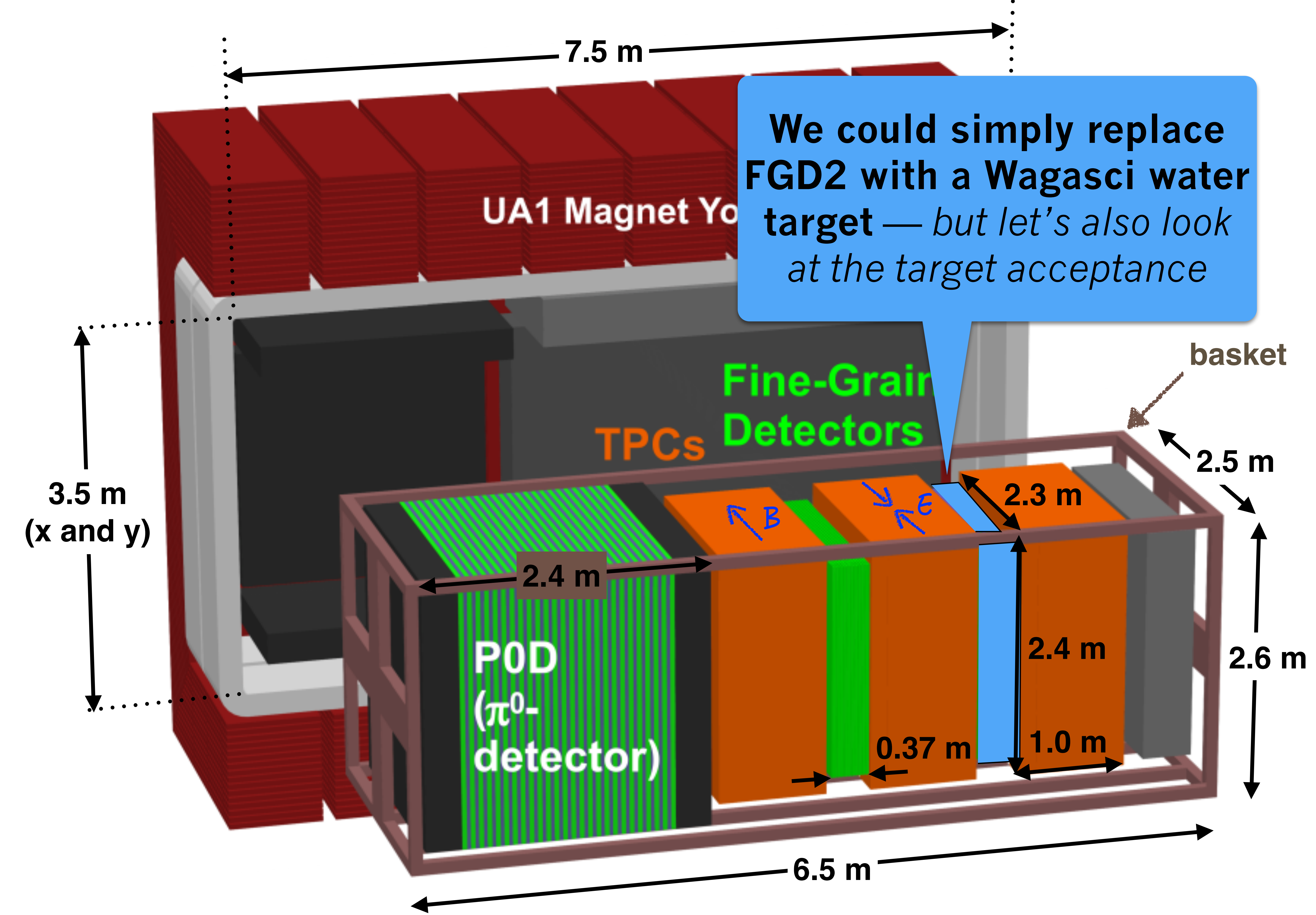

7.5 m
UA1 Magnet Yoke
ECals
basket
Fine-Grain
Detectors
TPCs
3.5 m
(x and y)
2.5 m
2.3 m
B
E
2.4 m
P0D
(π⁰-
detector)
2.4 m
2.6 m
0.37 m
1.0 m
6.5 m


7.5 m
UA1 Magnet Yo
Let's assume (for now) that we replace the ECals sensibly and now just redesign the contents of the basket
basket
Fine-Grain Detectors
TPCs
3.5 m (x and y)
2.5 m
2.3 m
2.4 m
2.4 m
2.6 m
P0D (π^0-detector)
0.37 m
1.0 m
6.5 m



7.5 m
UA1 Magnet Yoke
ECals
basket
Fine-Grain
Detectors
TPCs
3.5 m
(x and y)
2.5 m
2.3 m
2.4 m
B
E
720 mm
active
974 mm
(+5 mm)
P0D
(π[0]-
detector)
2.4 m
0.37 m
1.0 m
2.6 m
6.5 m


7.5 m
UA1 Magnet Yoke
Opportunity to reduce the dead region if we redesign…
Fine-Grain Detectors
TPCs
basket
3.5 m (x and y)
2.5 m
2.3 m
B
E
25 cm
2.4 m
10 cm
720 mm active
12 cm
974 mm (+5 mm)
P0D (π^0-detector)
2.4 m
2.6 m
0.37 m
1.0 m
6.5 m


7.5 m
UA1 Magnet Yo
We could simply replace FGD2 with a Wagasci water target — *but let's also look at the target acceptance*
basket
Fine-Grain
Detectors
TPCs
2.5 m
2.3 m
3.5 m
(x and y)
2.4 m
B
E
2.4 m
2.6 m
P0D
(π⁰-
detector)
0.37 m
1.0 m
6.5 m

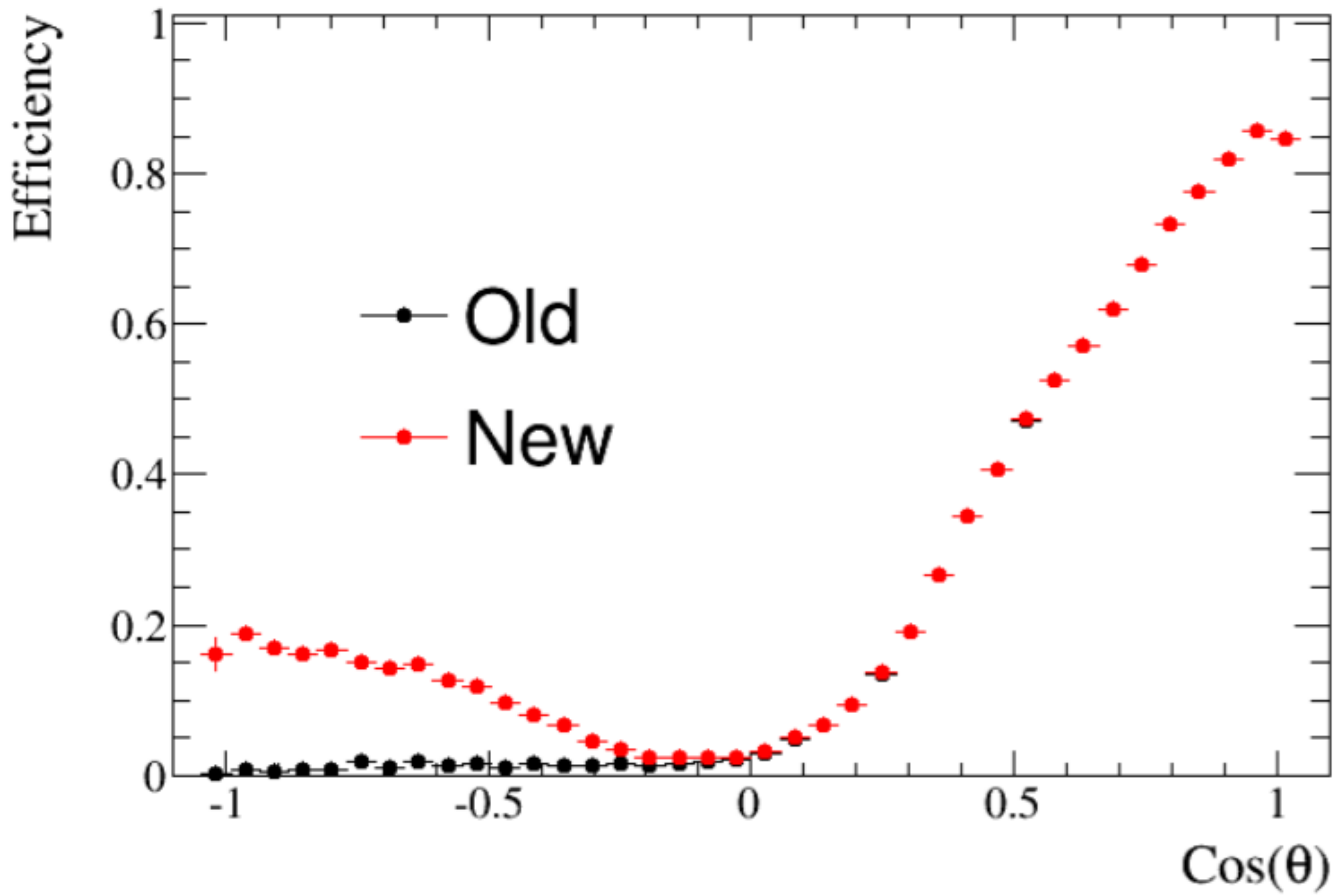
Another limitation:

Different energy resolution and acceptance to Hyper-K

- Acceptance is currently limited to ± 53° (forward) for muons
- Extrapolation leads to model dependent error
- *Needs to be quantified: concerns ~30% of cross-section?*

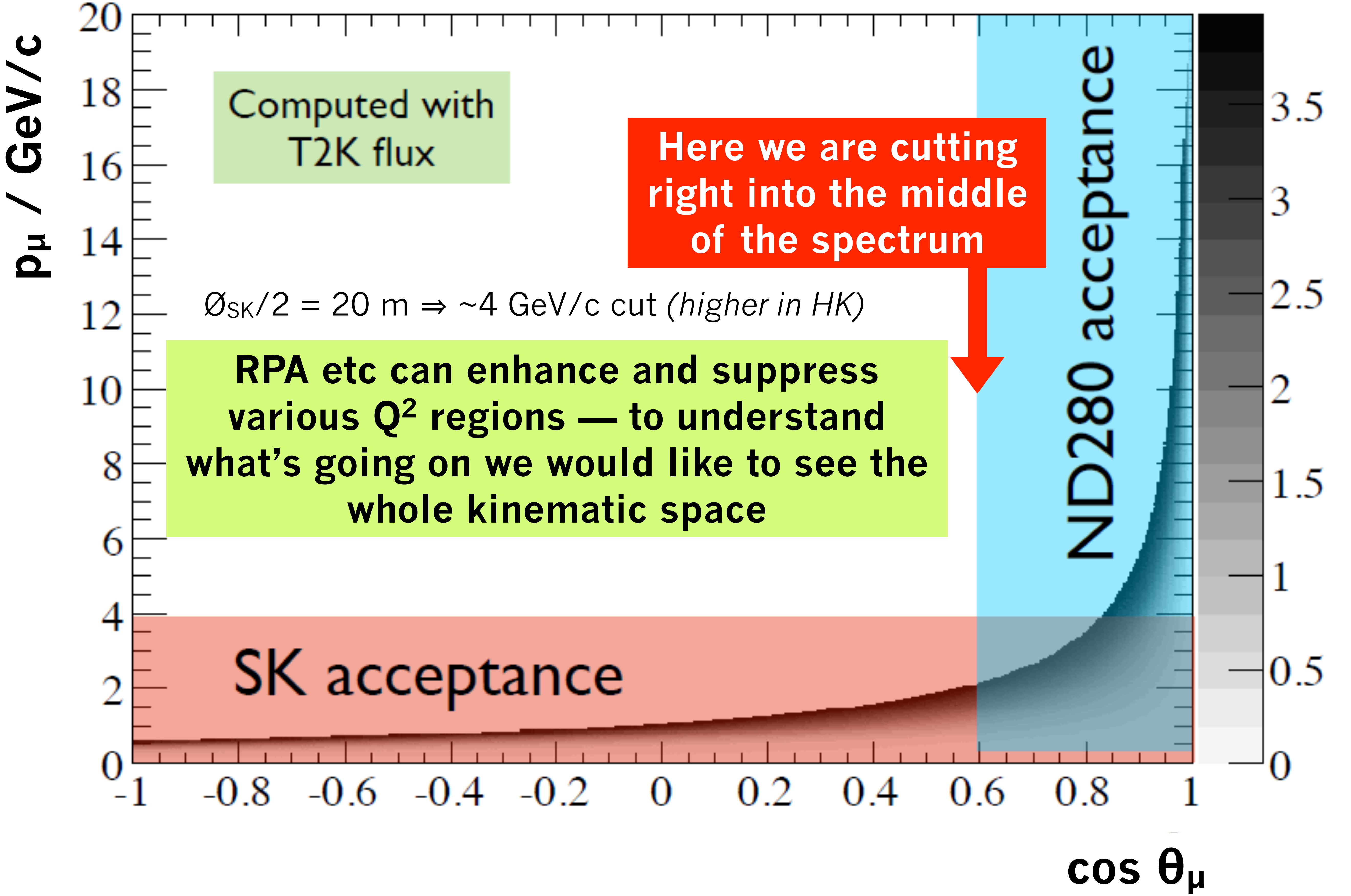
Improvements can only go so far with the present geometry

Momentum and sign determination are unclear

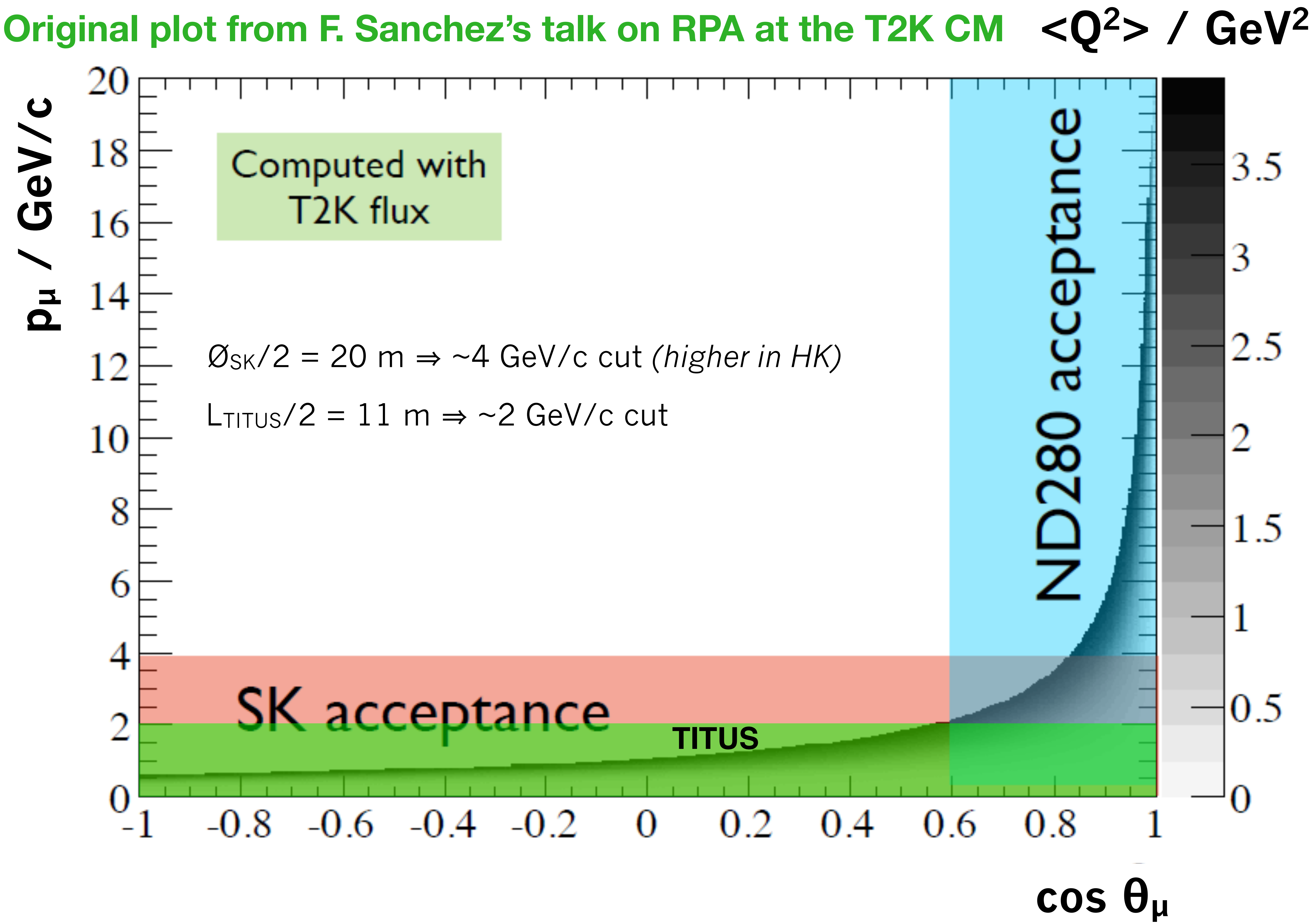


Even with the same detector, ambiguities remain, hence the benefit of nuSTORM or nuPRISM

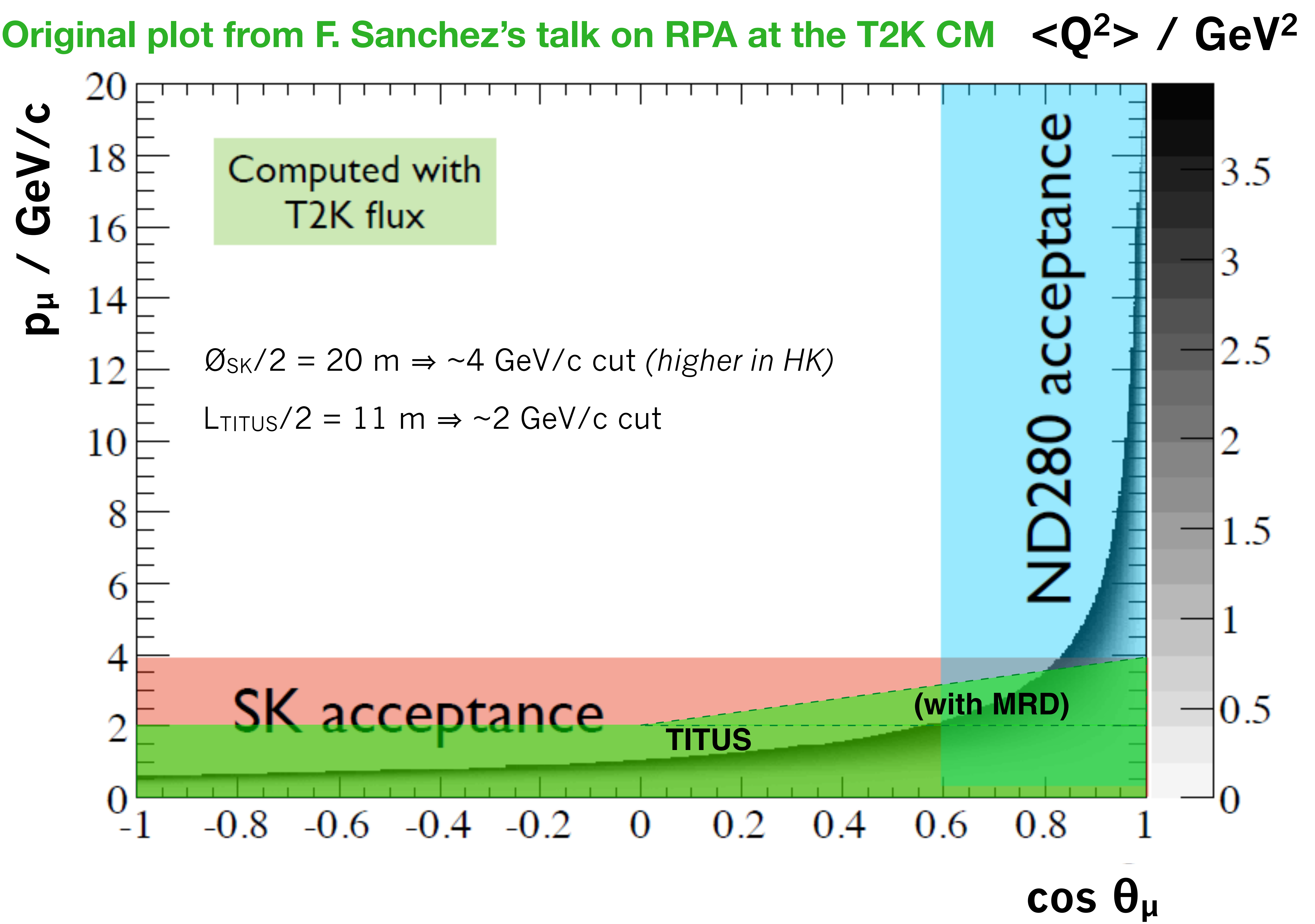
Original plot from F. Sanchez's talk on RPA at the T2K CM



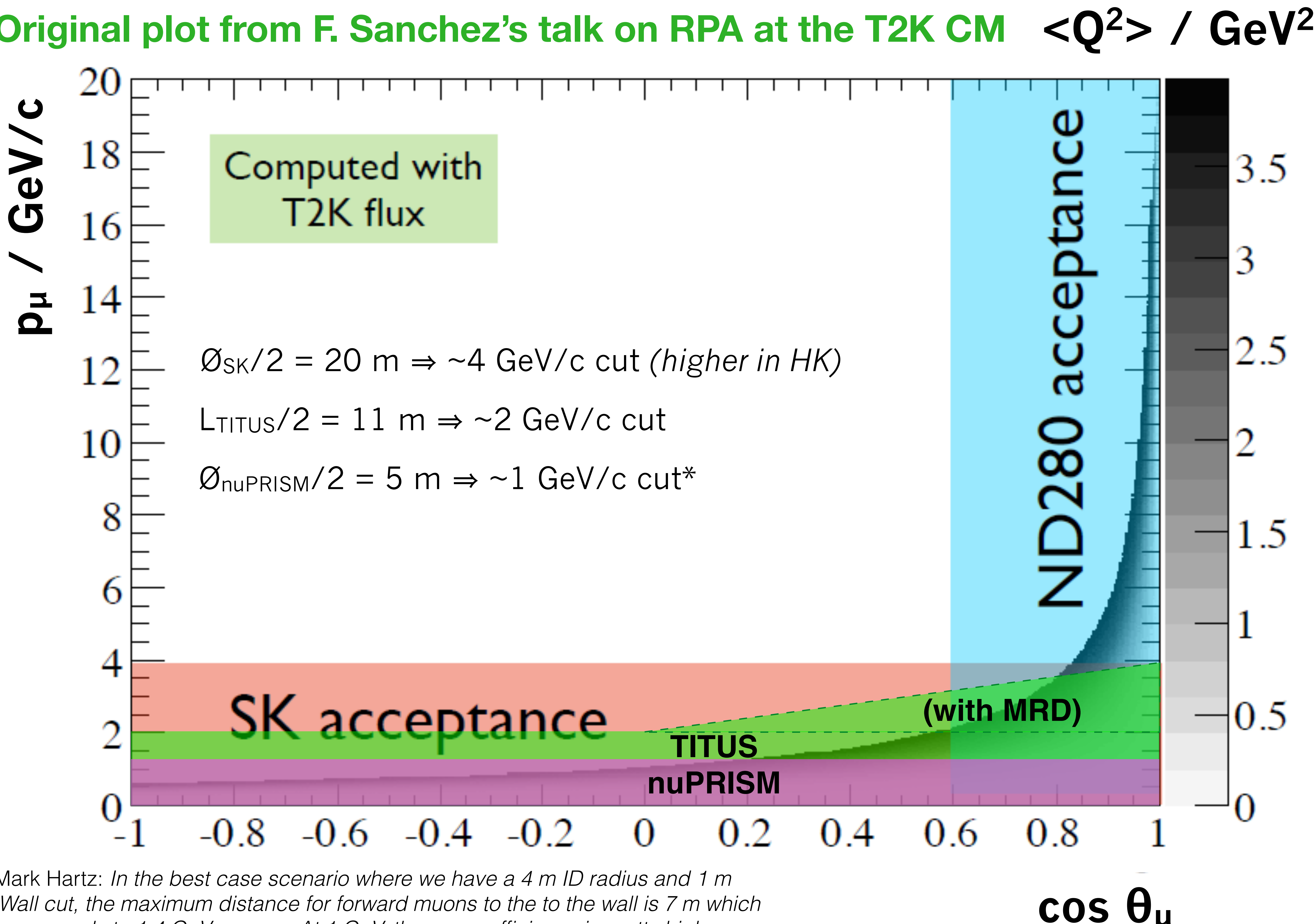
Original plot from F. Sanchez's talk on RPA at the T2K CM



Original plot from F. Sanchez's talk on RPA at the T2K CM

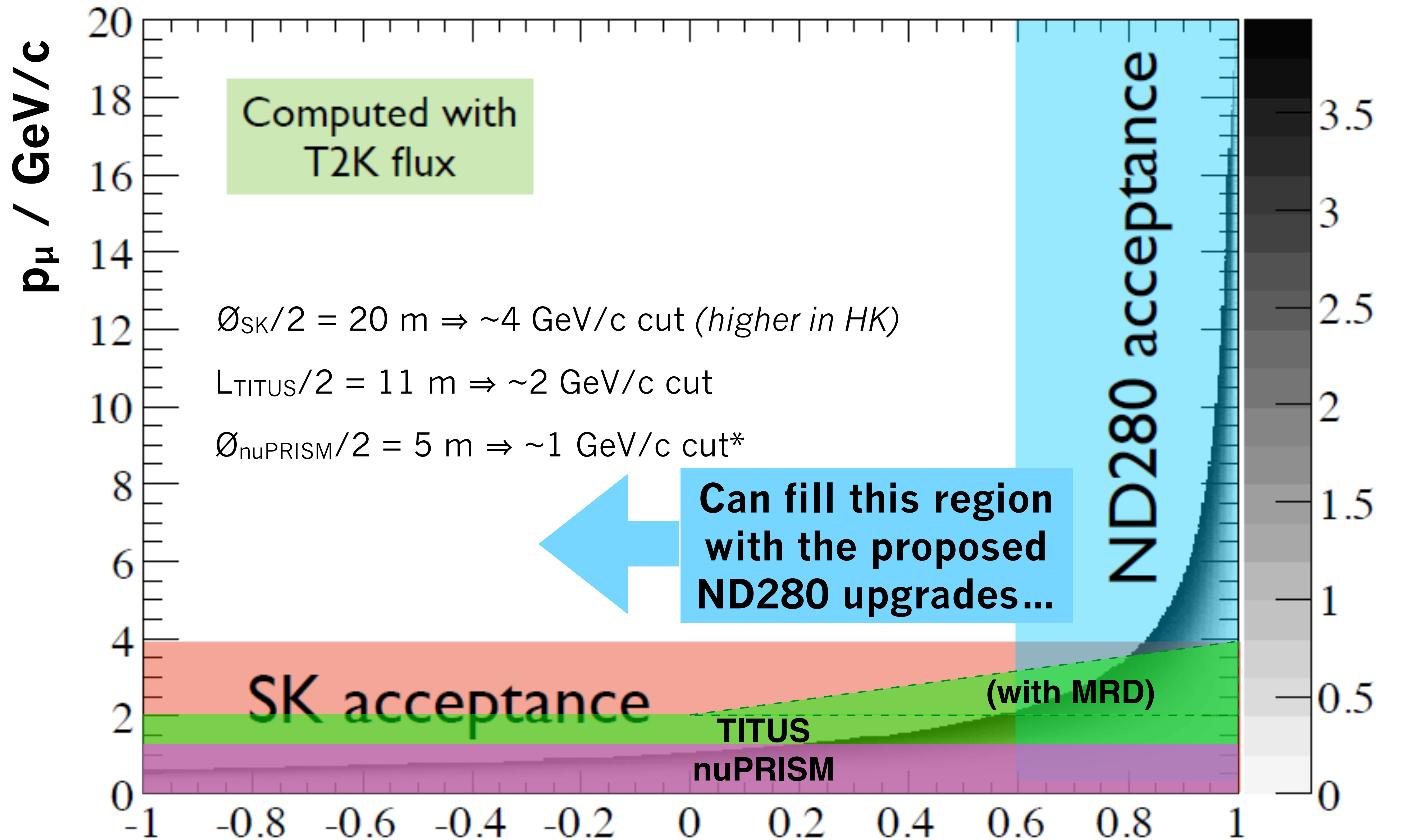


Original plot from F. Sanchez's talk on RPA at the T2K CM



*Mark Hartz: *In the best case scenario where we have a 4 m ID radius and 1 m dWall cut, the maximum distance for forward muons to the to the wall is 7 m which corresponds to 1.4 GeV muons. At 1 GeV, the muon efficiency is pretty high.*

Original plot from F. Sanchez's talk on RPA at the T2K CM



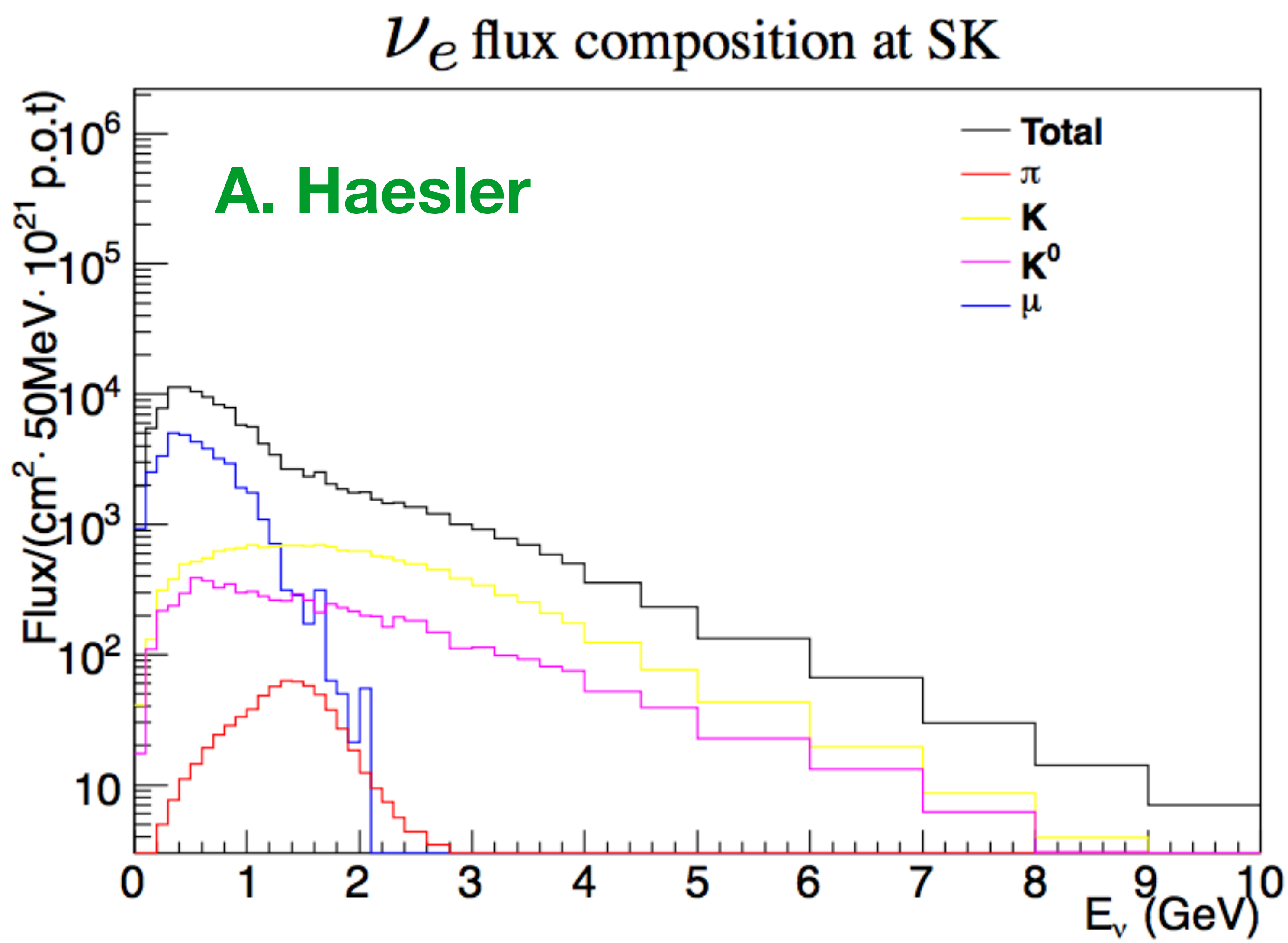
*Mark Hartz: *In the best case scenario where we have a 4 m ID radius and 1 m dWall cut, the maximum distance for forward muons to the to the wall is 7 m which corresponds to 1.4 GeV muons. At 1 GeV, the muon efficiency is pretty high.*

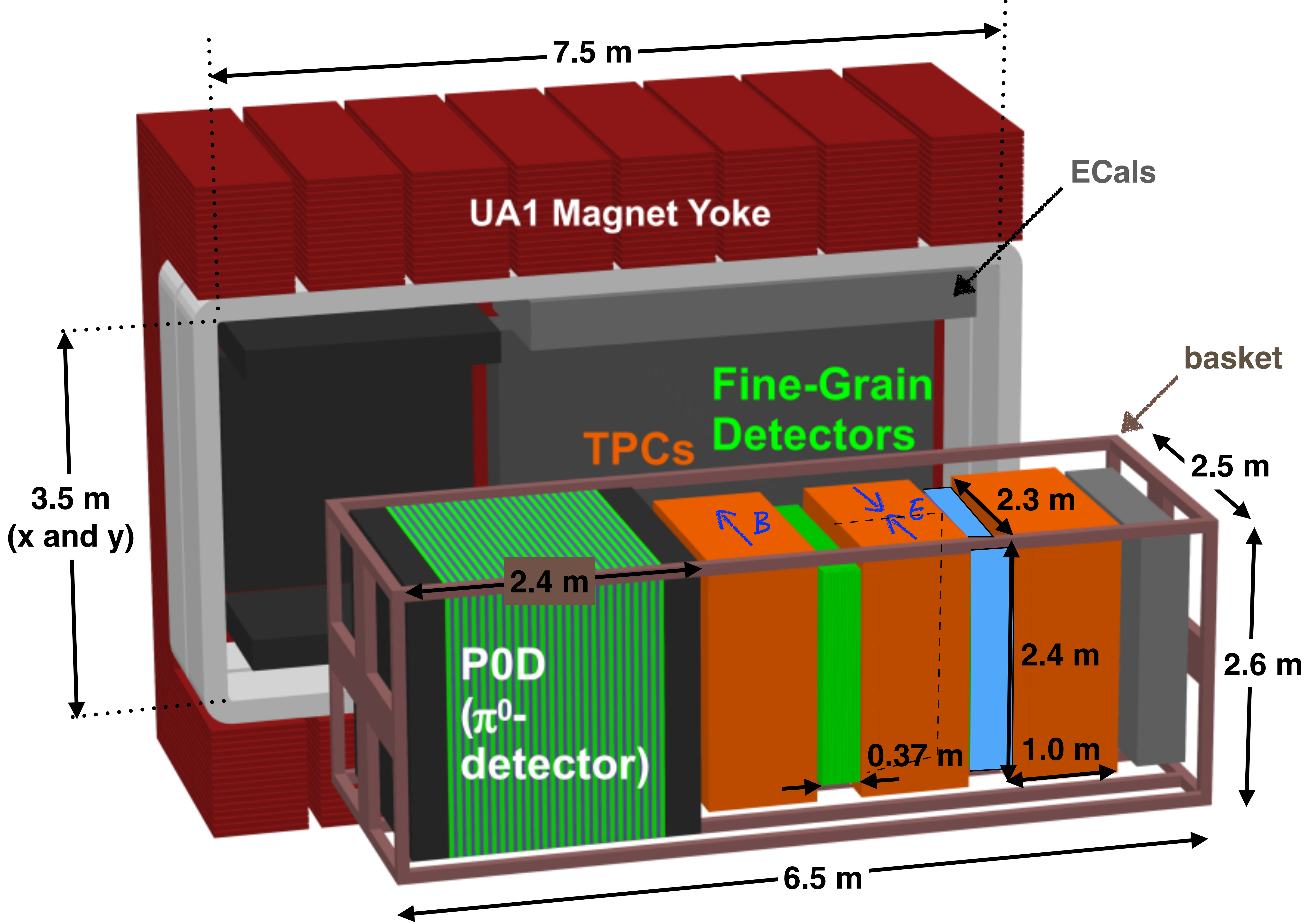
It is good to measure the full kinematic space for muons and even better to do it for electrons

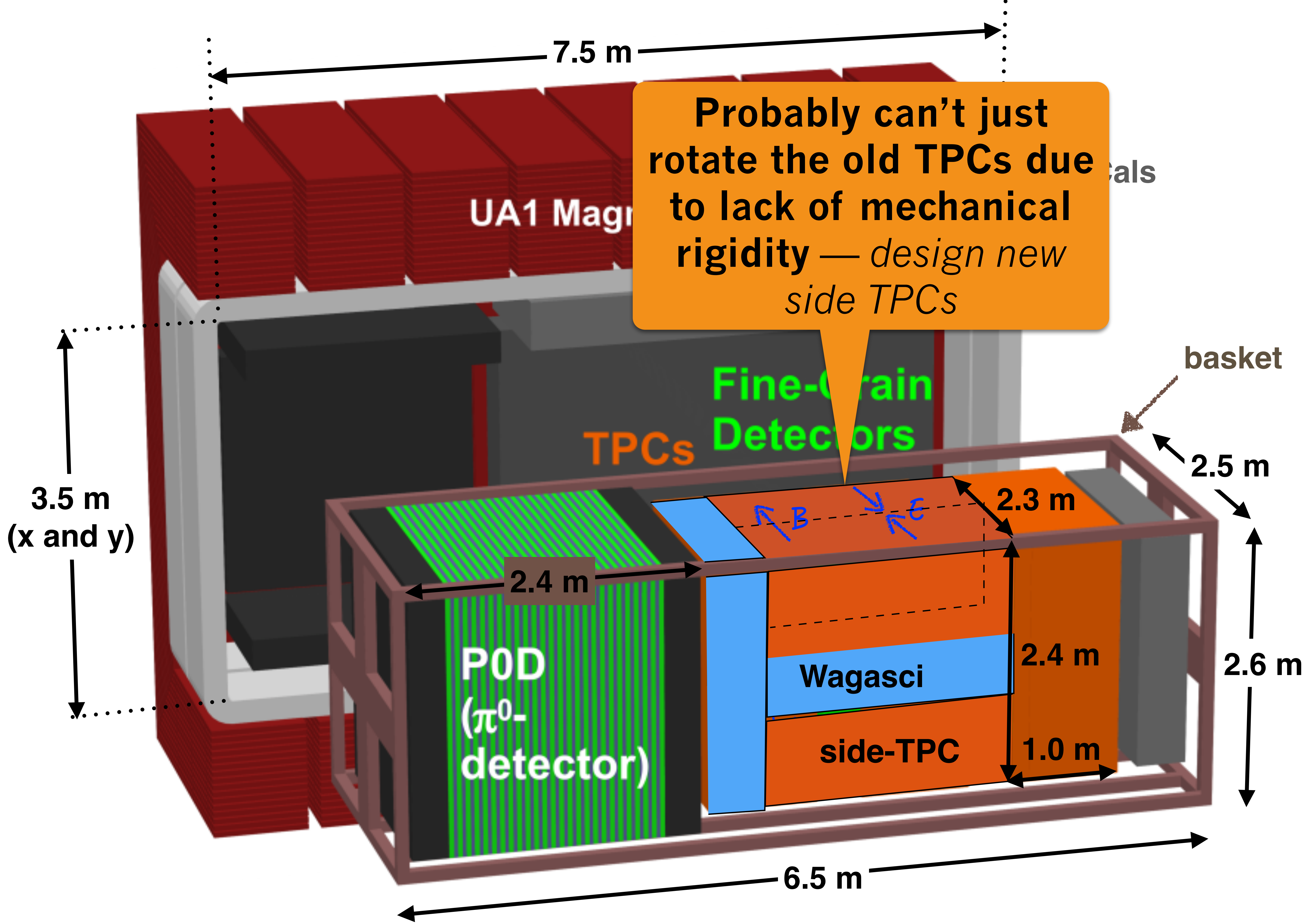
Upgraded ND280 is the only proposed solution to have this ability

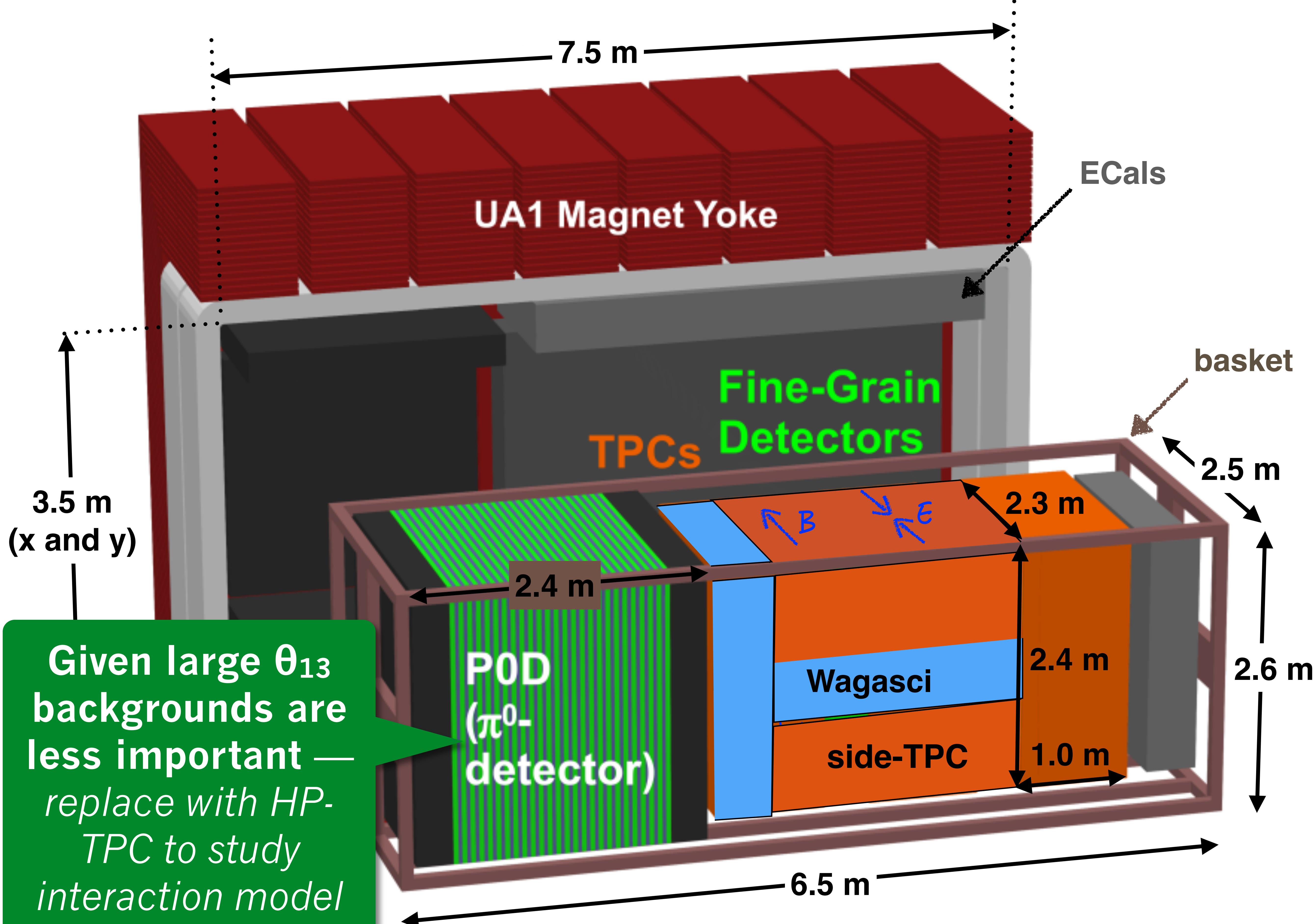
High energy electrons and muons can be well measured in the ND280 magnetic field, we should quantify the precision needed and achievable — it is only a matter of the space we leave in the forward direction for TPCs.

The ν_e flux in the low energy (E<1GeV) region is intimately tied with that of the ν_μ, as it is produced by muon decays, the muons being themselves being produced by the decays of pions which produce the same low-energy part of the neutrino spectrum

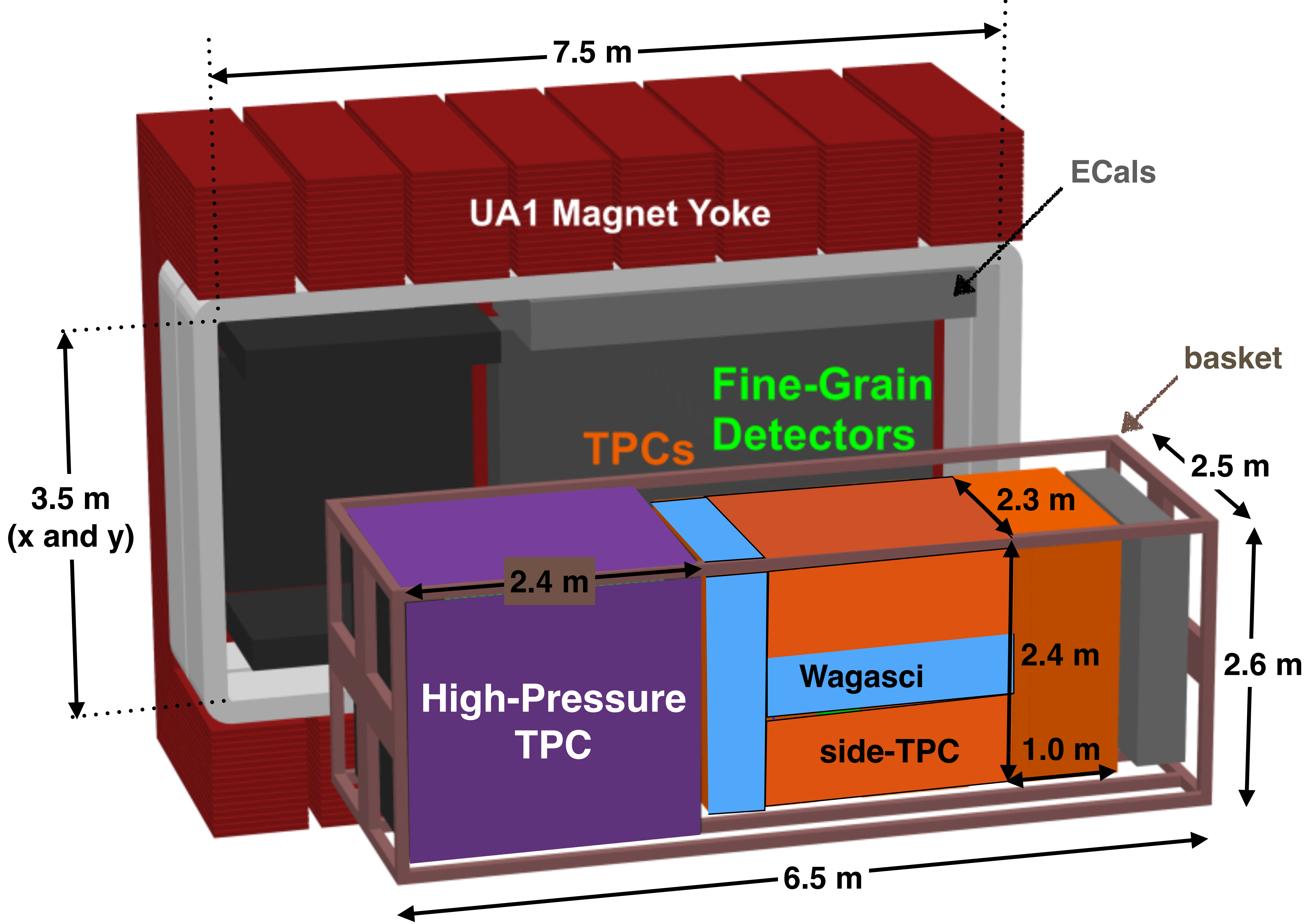


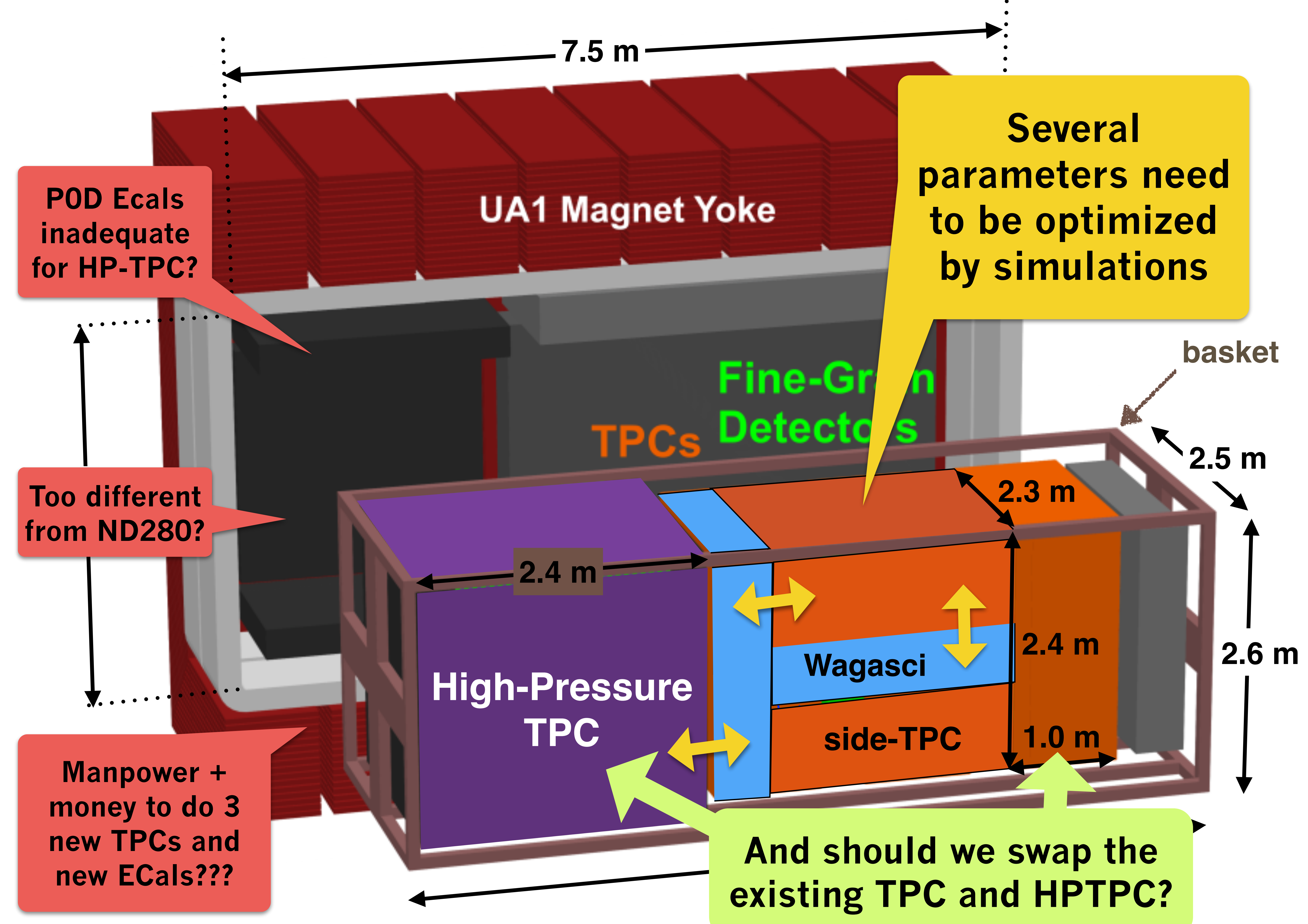

7.5 m
UA1 Magnet Yoke
ECals
basket
Fine-Grain
Detectors
TPCs
2.5 m
3.5 m
(x and y)
2.3 m
B
E
2.4 m
2.4 m
2.6 m
P0D
(π0-
detector)
0.37 m
1.0 m
6.5 m


7.5 m
UA1 Magn
cals
Probably can't just rotate the old TPCs due to lack of mechanical rigidity — *design new side TPCs*
basket
Fine-Grain Detectors
TPCs
2.5 m
2.3 m
3.5 m (x and y)
2.4 m
P0D (π^0-detector)
B
E
Wagasci
2.4 m
2.6 m
side-TPC
1.0 m
6.5 m



Given large θ_{13} backgrounds are less important — *replace with HP-TPC to study interaction model*


7.5 m
UA1 Magnet Yoke
ECals
basket
Fine-Grain
Detectors
TPCs
3.5 m
(x and y)
2.5 m
2.3 m
2.4 m
2.6 m
2.4 m
Wagasci
High-Pressure
TPC
side-TPC
1.0 m
6.5 m

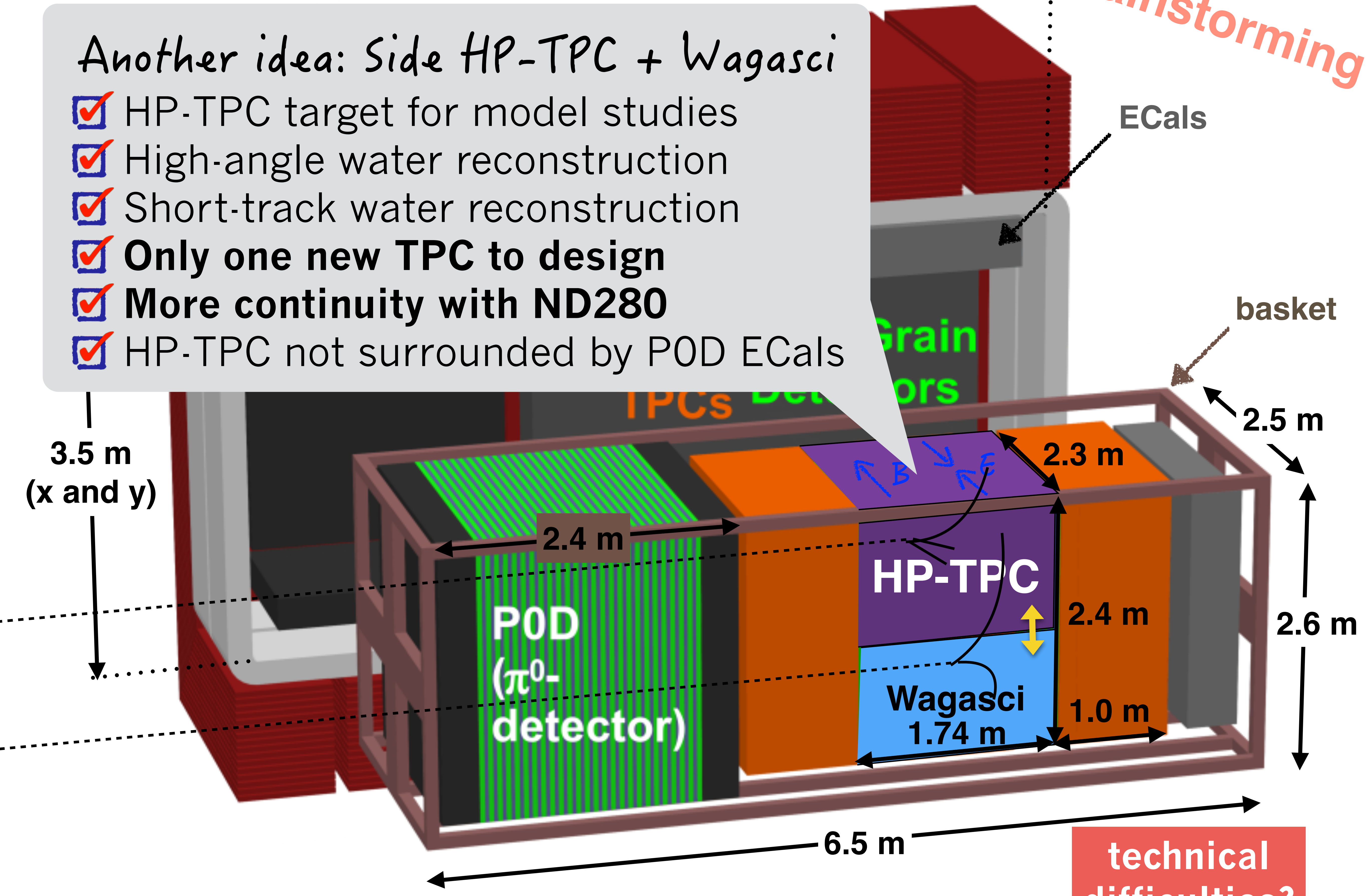


7.5 m
UA1 Magnet Yoke
P0D Ecals inadequate for HP-TPC?
Several parameters need to be optimized by simulations
Fine-Grain Detectors
TPCs
basket
2.5 m
2.3 m
Too different from ND280?
2.4 m
2.4 m
Wagasci
2.6 m
High-Pressure TPC
side-TPC
1.0 m
Manpower + money to do 3 new TPCs and new ECals???
And should we swap the existing TPC and HPTPC?

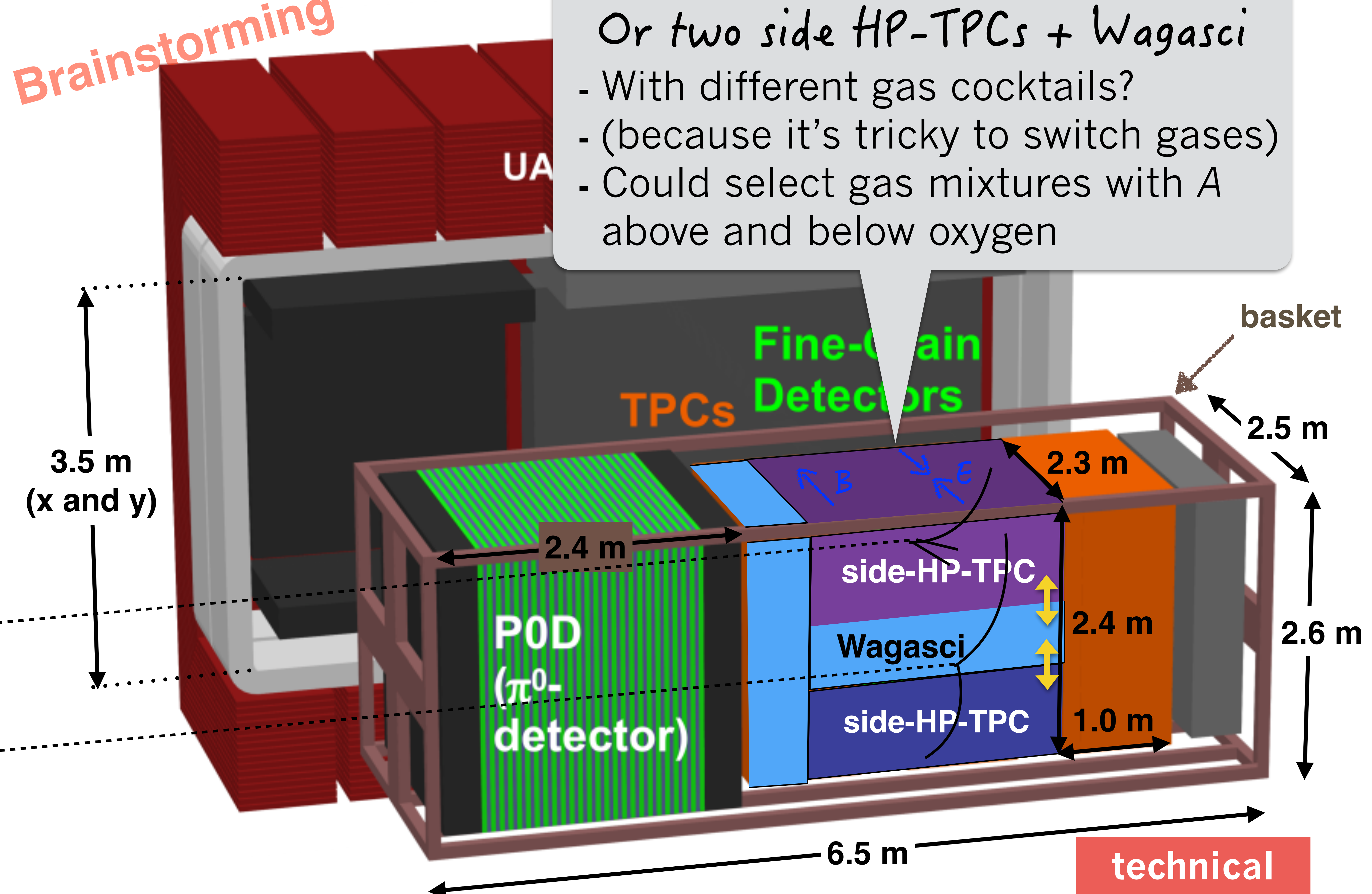
Can we eliminate side-TPC = HP-TPC?

Another idea: Side HP-TPC + Wagasci

- ☑ HP-TPC target for model studies
- ☑ High-angle water reconstruction
- ☑ Short-track water reconstruction
- ☑ **Only one new TPC to design**
- ☑ **More continuity with ND280**
- ☑ HP-TPC not surrounded by P0D ECals



Can we eliminate side-TPC = HP-TPC?



Or two side HP-TPCs + Wagasci

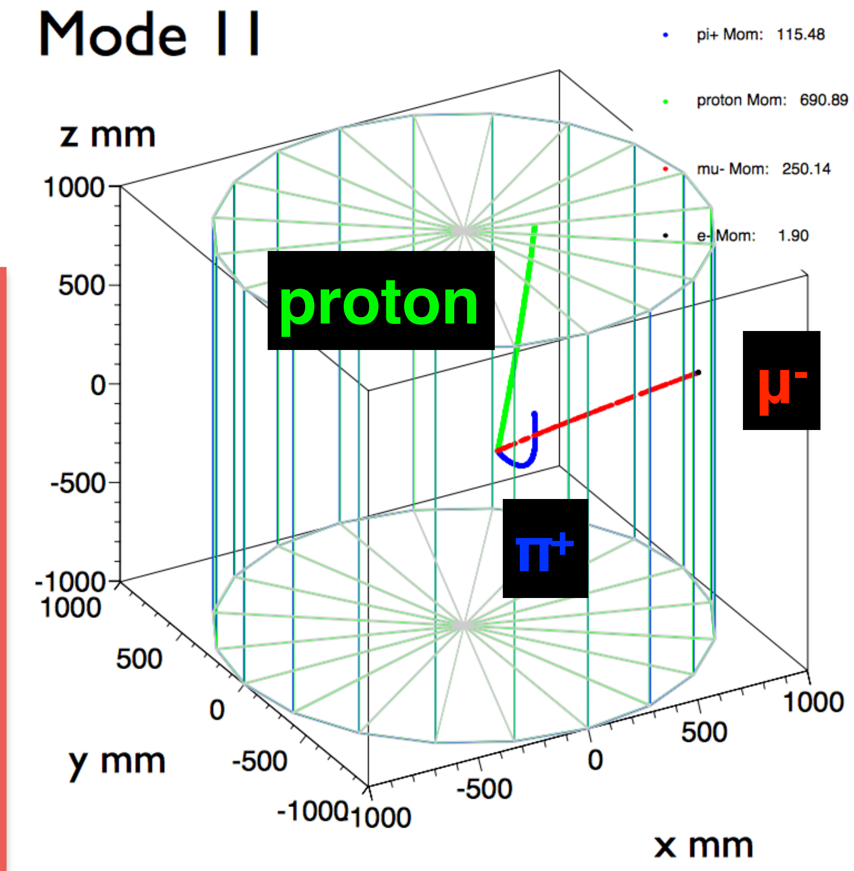
- With different gas cocktails?
- (because it's tricky to switch gases)
- Could select gas mixtures with *A* above and below oxygen

technical difficulties?

F. Sanchez, M. Ravonel

Low threshold detector to pin down nuclear model

High Pressure Time Projection Chamber



Advantages

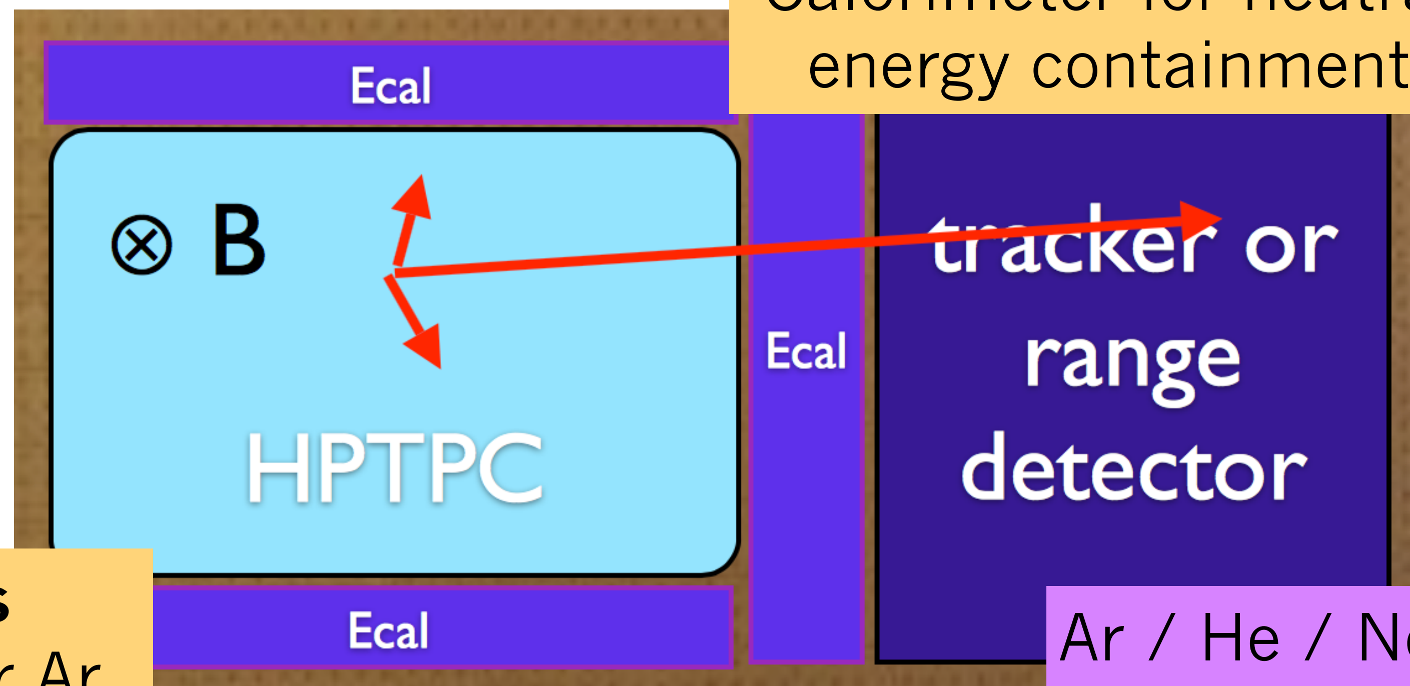
- Target = detector.
- 3D reconstruction capabilities
- Possibility to exchange targets
- low density → low thresholds
- excellent PID capabilities
- Almost uniform 4π acceptance

Key point: these proposed basket HP-TPCs are big enough to get a good number of events

Disadvantages

- low number of interactions → requires high pressure and large volume
- requires in addition a magnet or range detectors to measure momentum

Calorimeter for neutral energy containment



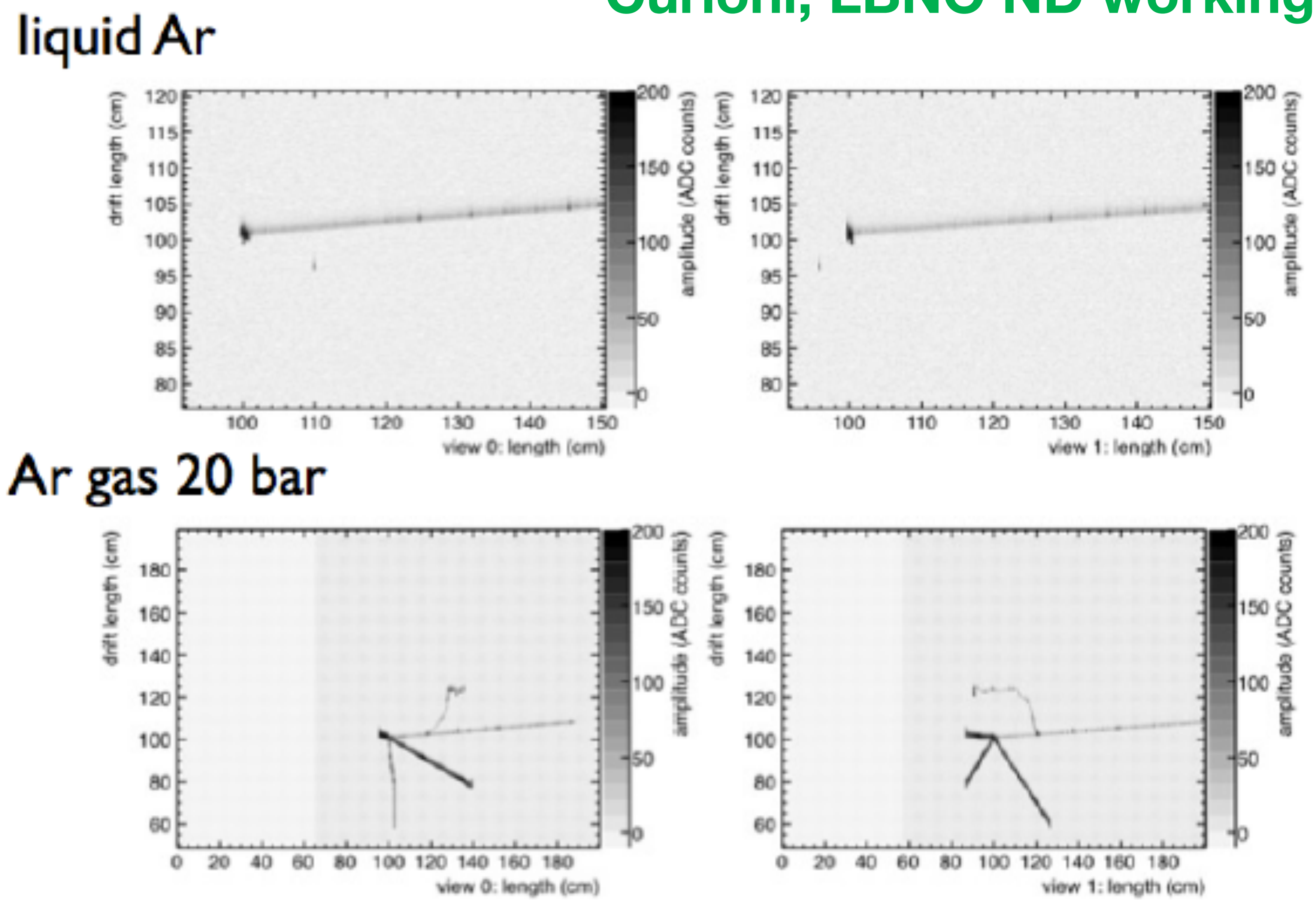
Ar / He / Ne target

~30,000 CC events in He at 5 bars
A factor x5 for Ne and a factor x10 for Ar
(8m^3 detector, 4 years, 1.6 x 10^{21} POT/year)

http://www.t2k.org/meet/nd280/meet/NDupgrade/ NDWS-Jan14/NDWS

Comparing liquid vs gas argon

Curioni, LBNO ND working group, 2012



Beautiful and interesting, but how would we use these short tracks?

(If the MC is perfect, we don't need to fret about energy reconstruction…)

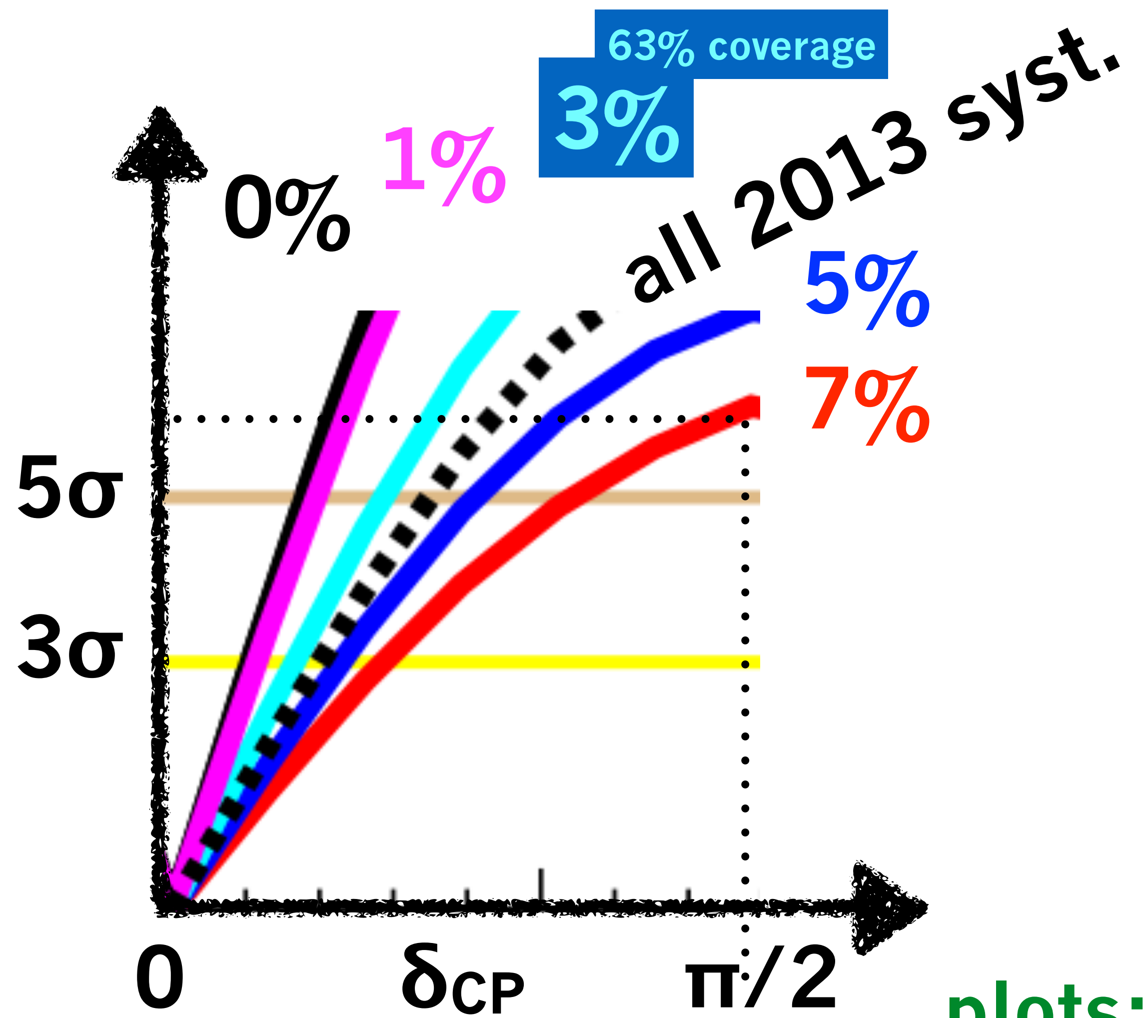
something must be done!

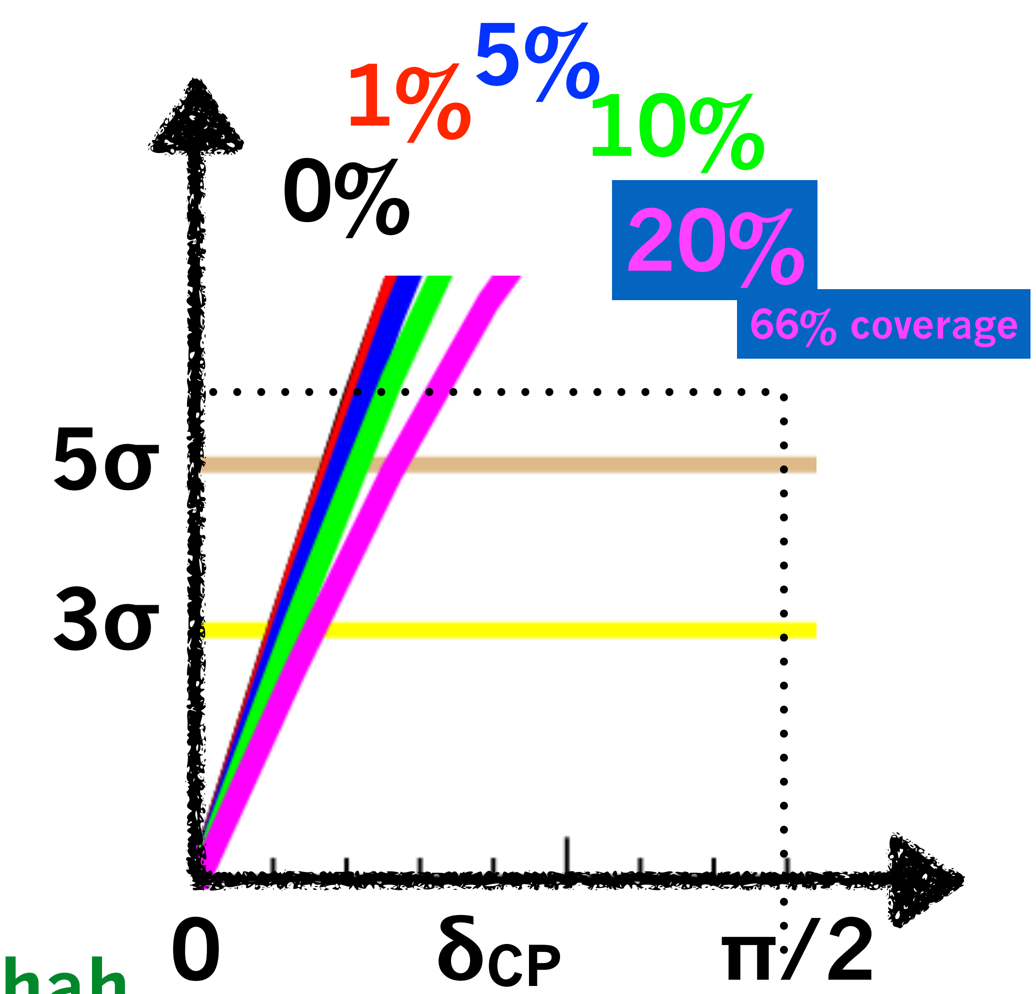
Two tricky issues with big sensitivity ramifications:

Oscillating ν_e and intrinsic ν_e

Effect of prior uncertainty on $\sigma(\nu_e)$ and (independently) $\sigma(\bar{\nu}_e)$

Effect of prior uncertainty on intrinsic ν_e flux below E = 1 GeV



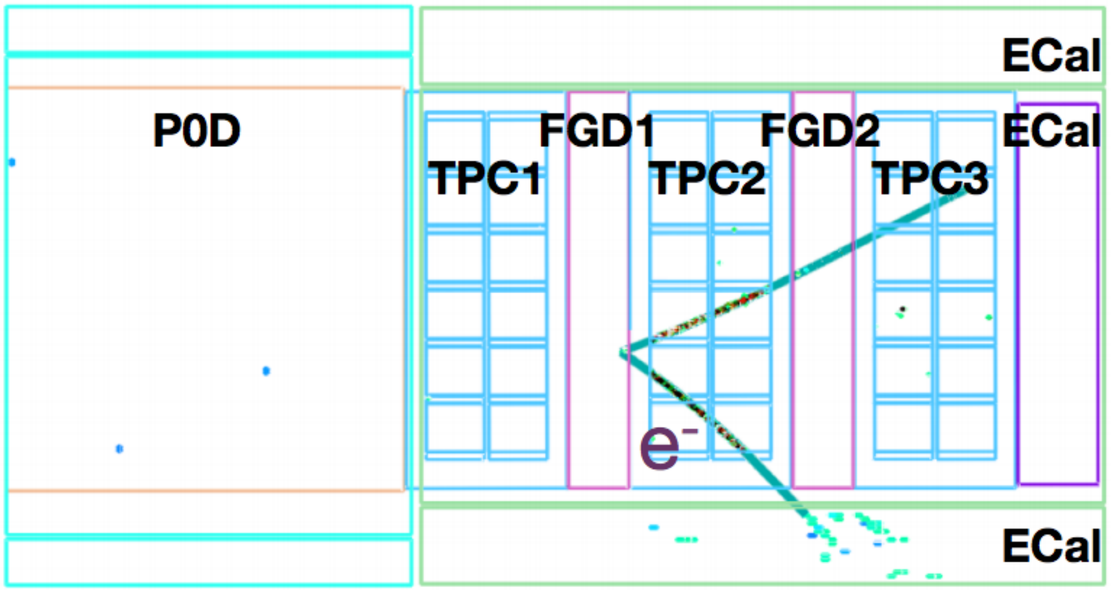


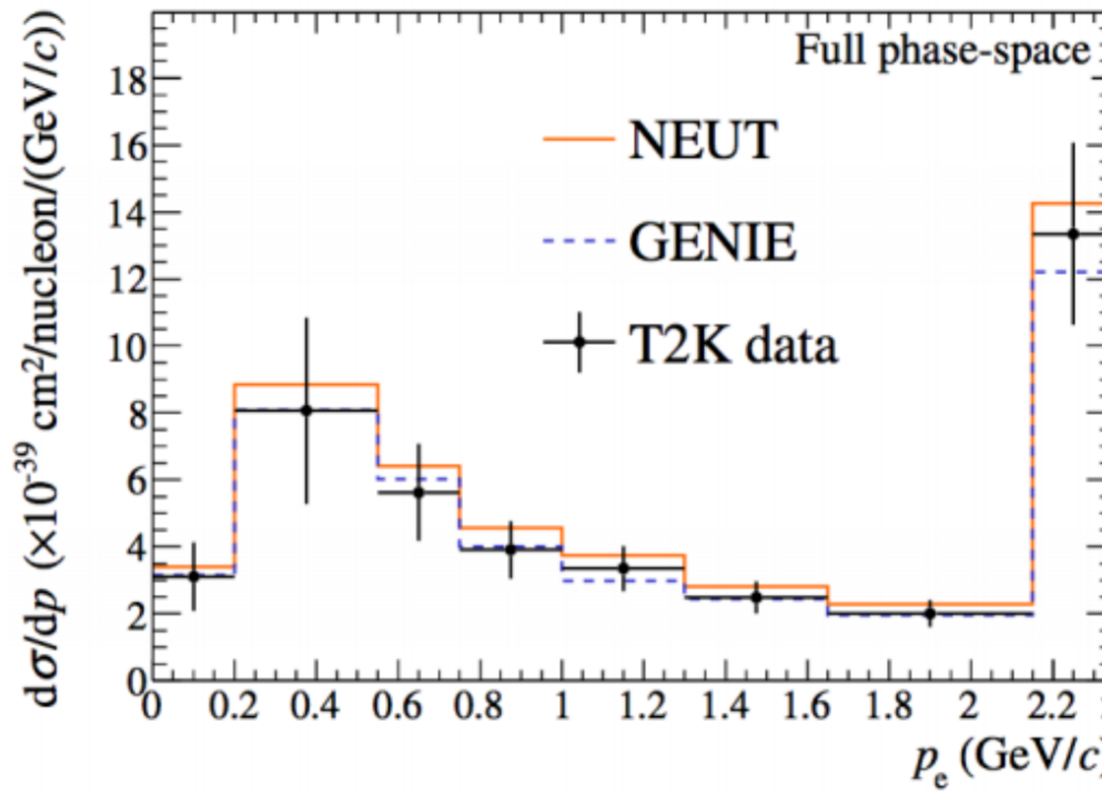
plots: Raj Shah

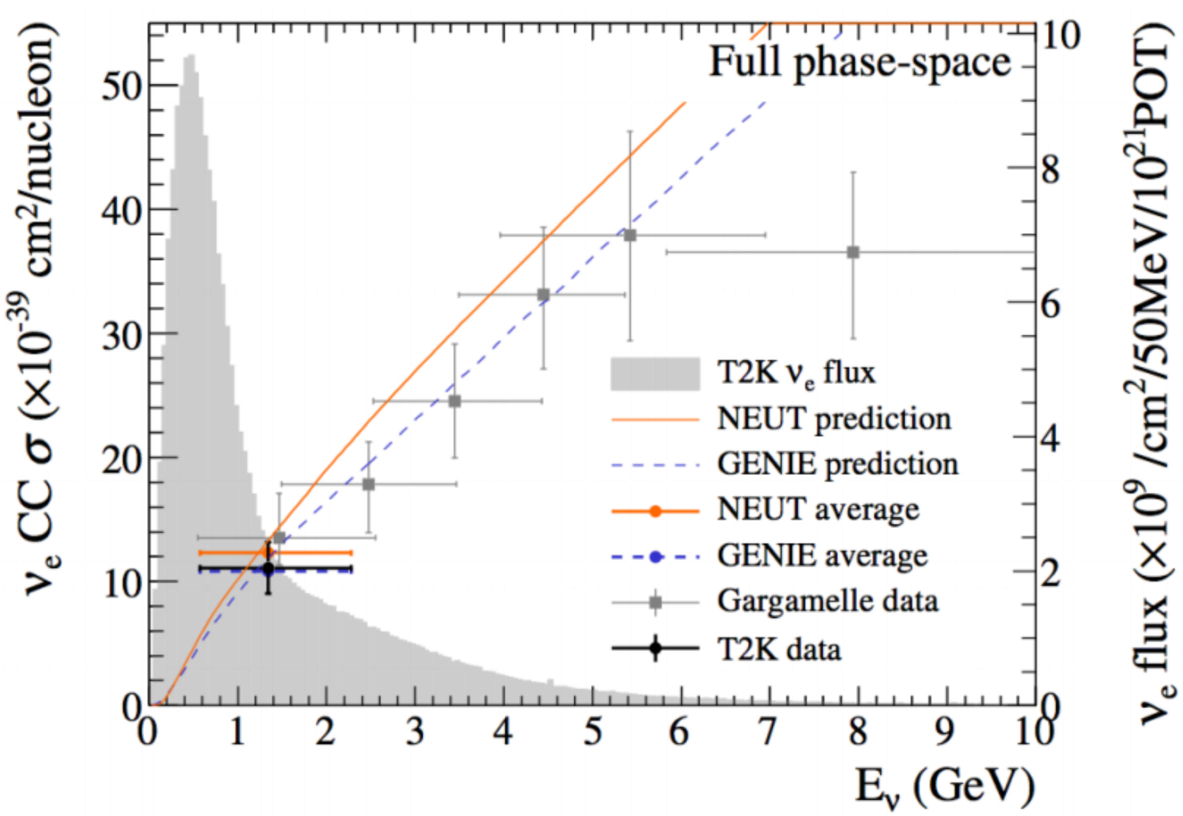
(max [zero systematics] δ_{CP} coverage for 5σ observation of CPV is 77%)

3% prior uncertainty on the cross section does as much damage to CPV sensitivity (~10% coverage of δ_{CP}) **as 20% uncertainty on the intrinsic flux**

Ben Smith has already done an ND280 tracker analysis of the nue x-sect.







- Sample is 65% pure CC ν_e
- Non-uniform acceptance
- Large BG from $\gamma \rightarrow e^+e^-$
- Largest uncertainties are:
  - *Flux (12.9%)*
  - *Statistics (8.7%)*
  - *Detector (8.4%)*

Also cf. Mark H's talk from the HK proto CM for a nice discussion

How might we best improve on this in an ND280 upgrade?

The importance of the ν_e / ν_μ x-section ratio

Theoretically, the CP asymmetry is : $A_{CP}^{th} = \frac{P_{\nu_\mu \to \nu_e} - P_{\bar{\nu}_\mu \to \bar{\nu}_e}}{P_{\nu_\mu \to \nu_e} + P_{\bar{\nu}_\mu \to \bar{\nu}_e}} \propto \frac{\sin \delta_{CP}}{\cos \delta_{CP}}$

What we measure is : $A_{CP}^{meas} = \frac{N_{\bar{e}} - N_e}{N_{\bar{e}} + N_e} = \frac{1 - r}{1 + r}$

where $N_e = \frac{\varphi_\mu}{L_{SK}^2} P_{\nu_\mu \to \nu_e} N_{target}^{SK} \sigma_e \epsilon_e^{SK} = N_\mu^{ND} \frac{L_{ND}^2}{L_{SK}^2} \frac{N_{target}^{ND}}{N_{target}^{SK}} \frac{\sigma_e}{\sigma_\mu} \frac{\epsilon_e^{SK}}{\epsilon_\mu^{ND}} P_{\nu_\mu \to \nu_e}$

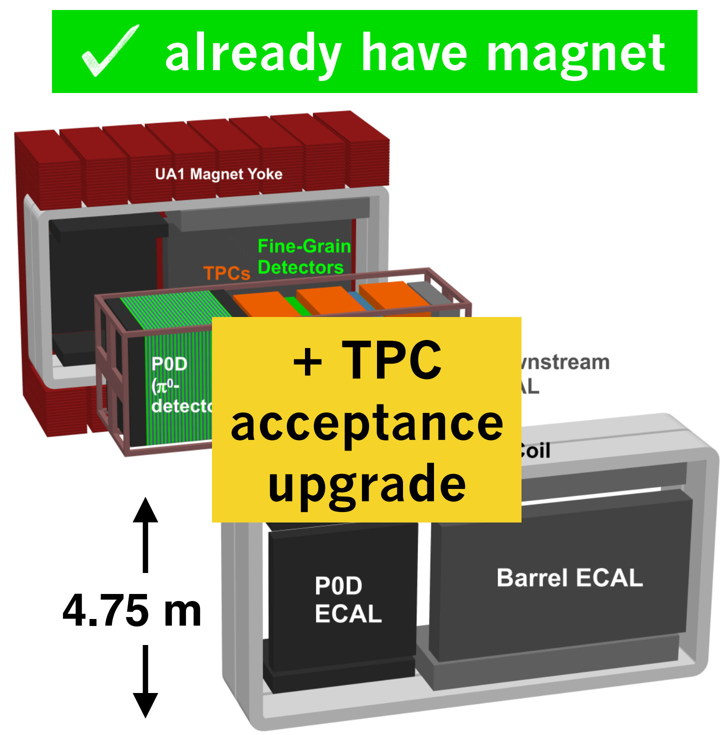
so : $r\left(P_{\nu_\mu \to \nu_e}, P_{\bar{\nu}_\mu \to \bar{\nu}_e}, N_\mu, N_{\bar{\mu}}, R_\sigma\right) = \frac{N_\mu^{ND}}{N_{\bar{\mu}}^{ND}} \frac{\epsilon_{\bar{\mu}}}{\epsilon_\mu} \frac{\epsilon_e}{\epsilon_{\bar{e}}} \frac{P_{\bar{\nu}_\mu \to \bar{\nu}_e}}{P_{\nu_\mu \to \nu_e}} R_\sigma$

with : $R_\sigma = \frac{\left(\frac{\sigma_e}{\sigma_\mu}\right)}{\left(\frac{\sigma_{\bar{e}}}{\sigma_{\bar{\mu}}}\right)}$

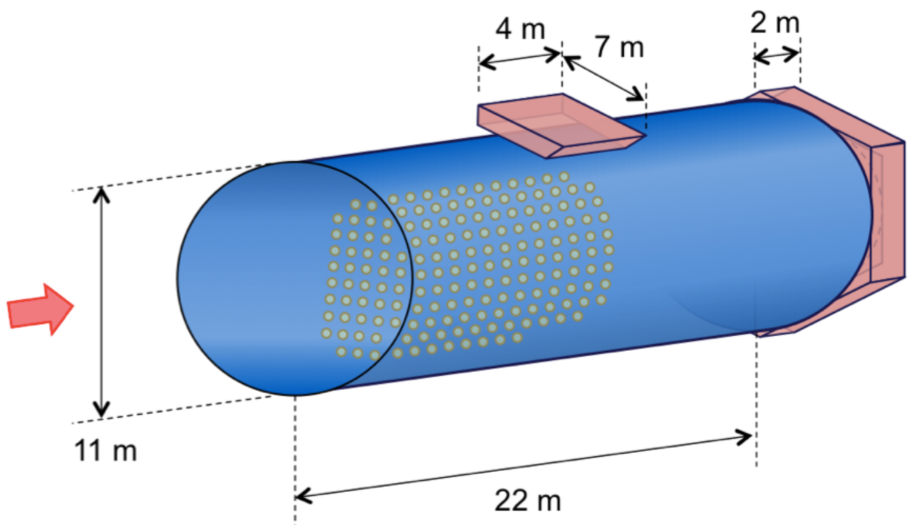
L. Haegel

NOT AN EXHAUSTIVE LIST!

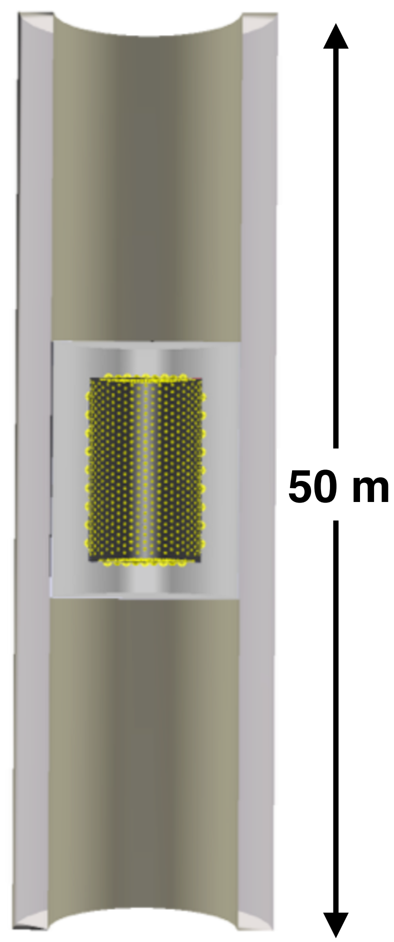
naively favour TITUS or ND280+nuPRISM?



- ☑ **Constrain wrong-sign BG** *(B-field+TPCs)*
- ☑ **High-E constraints***
- ☑ **Wagasci-style water target with short-track resolution**



- ☑ **Constrain wrong-sign BG** *(Gd & magnetized MRD)*
- ☑ **Same detection method**
- ☑ **Higher-E sample with MRD***



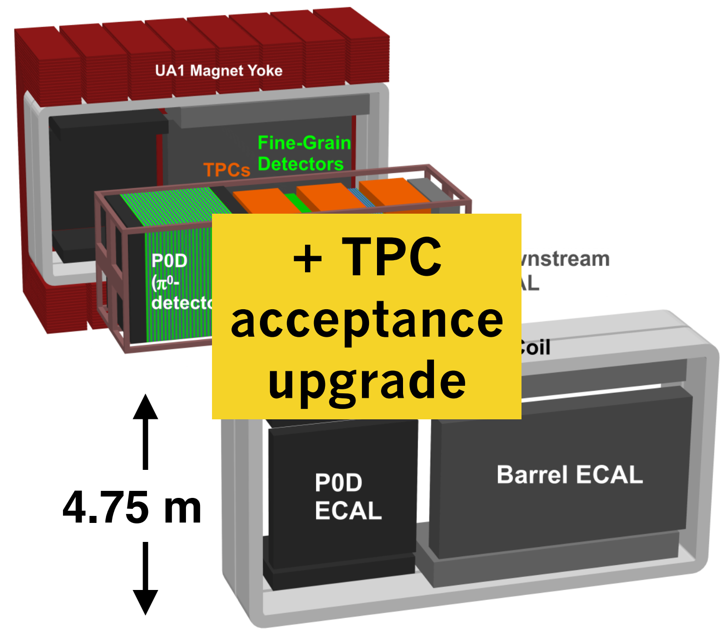
- ☑ **Interaction model independence**
- ☑ **Same detection method**
- ☑ **Sterile neutrinos**

**seems important for CPV sensitivity, cf. Raj's talk*

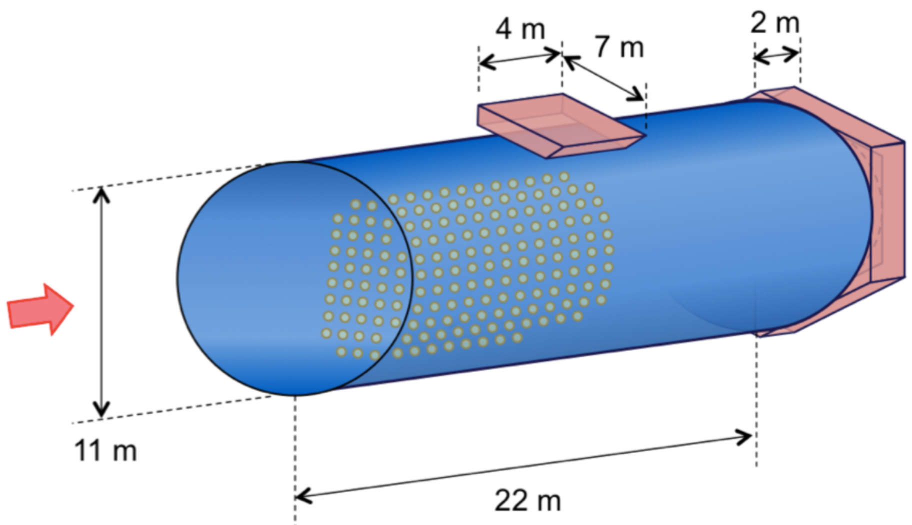
NOT AN EXHAUSTIVE LIST!

naively favour TITUS or ND280+nuPRISM?

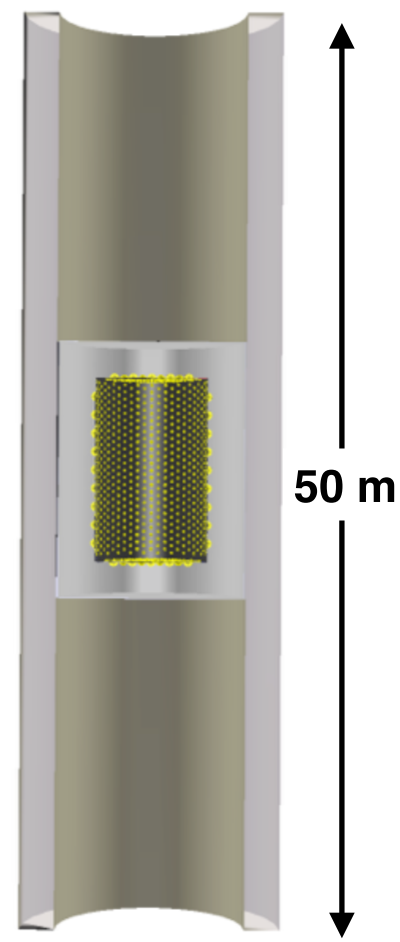
✓ already have magnet



- ☑ **Constrain wrong-sign BG** *(B-field+TPCs)*
- ☑ **High-E constraints***
- ☑ **Wagasci-style water target with short-track resolution**
- **And what about a HP-TPC?**
  - *Do we need a clear measurement of small recoil nuclei?*
  - *Also: ν_e cross section and a constraint on intrinsic ν_e (excellent kinematics)*



- ☑ **Constrain wrong-sign BG** *(Gd & magnetized MRD)*
- ☑ **Same detection method**
- ☑ **Higher-E sample with MRD***



- ☑ **Interaction model independence**
- ☑ **Same detection method**
- ☑ **Sterile neutrinos**

*seems important for CPV sensitivity, cf. Raj's talk

Conclusion

Do we need a water target?

80% water, 5cm-grid 3D-tracking *Wagasci target*

After taking 10% or our original POT request in 5 years, we can achieve 2-3 times our request by 2025 — and then follows Hyper-K

It may be advantageous to *upgrade the acceptance* of the target to match Super-K/Hyper-K's by introducing *new side-TPCs*

POD is less strongly motivated given large θ_{13}

—There is space for a *High Pressure TPC*

—What better tool to study interaction model effects in detail?

Other issues

—Probably need to replace ECAL — expensive

—Introduce a range detector in the basket?

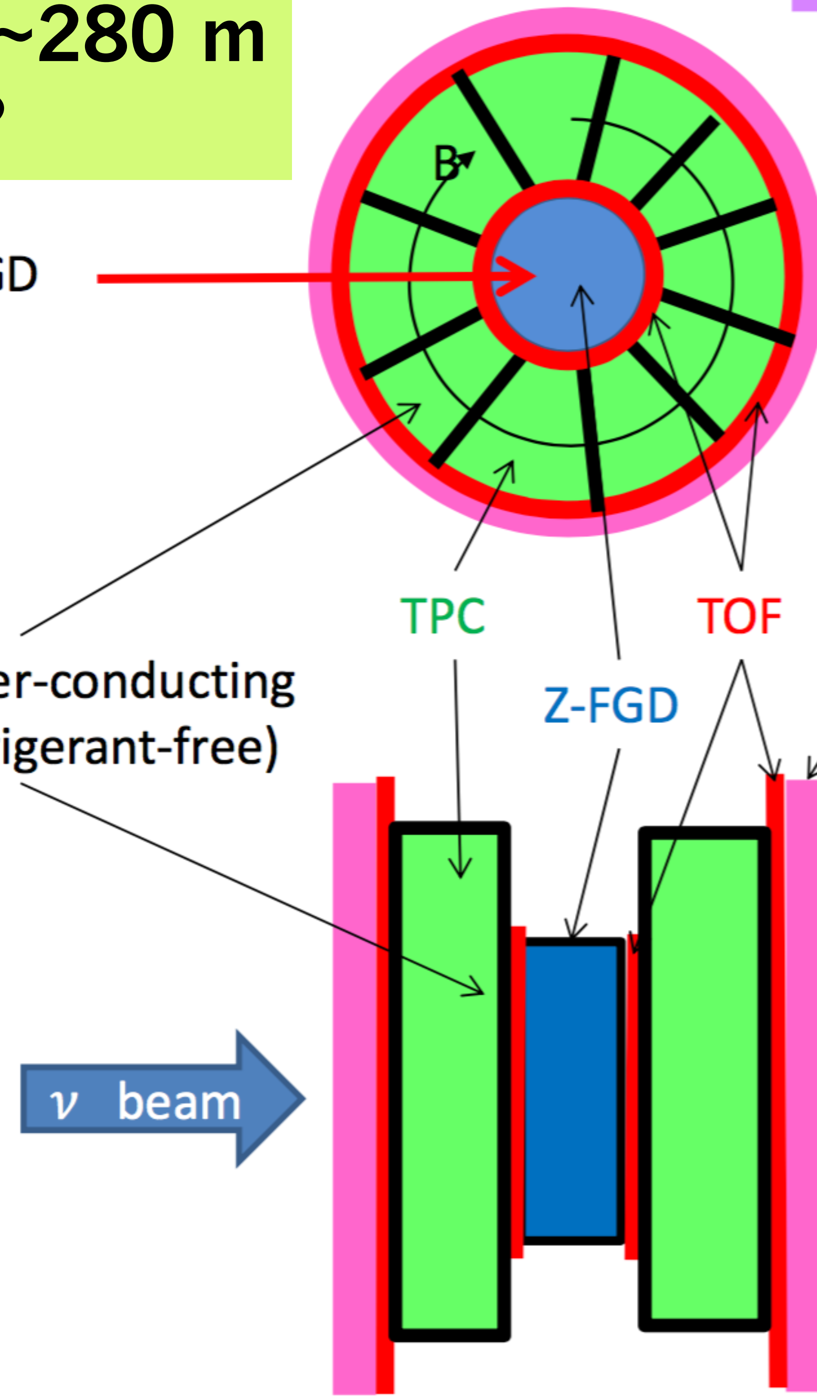
Simulations and quantitative predictions are underway

Backup slides follow

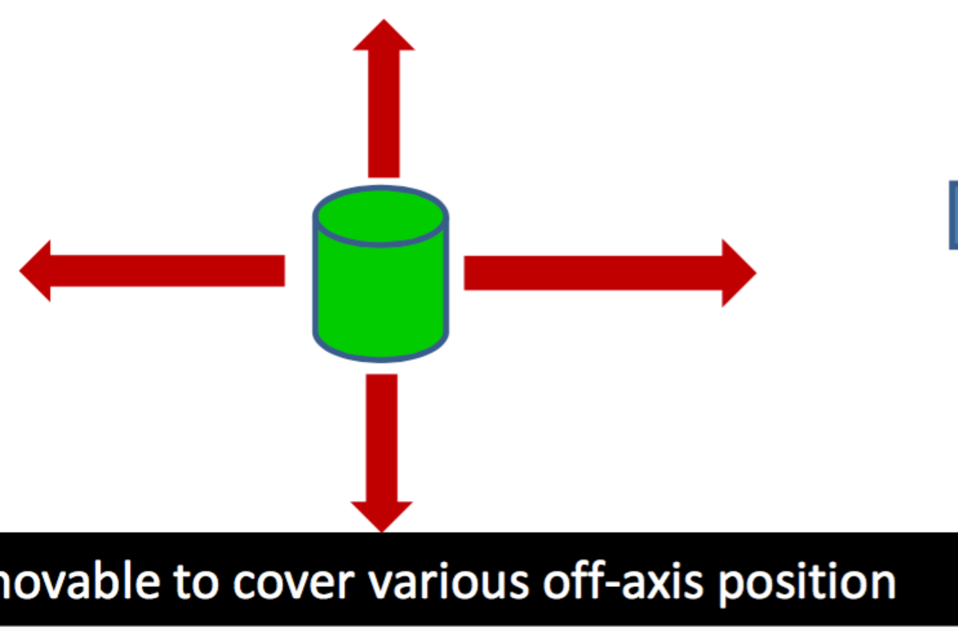
"a toy to have a brainstorm for the future"

Could we use the nuPRISM concept at ~280 m with an FGD-TPC type detector?

A.Ichikawa



This TPC design isn't practical, but the idea is rather ingenious...

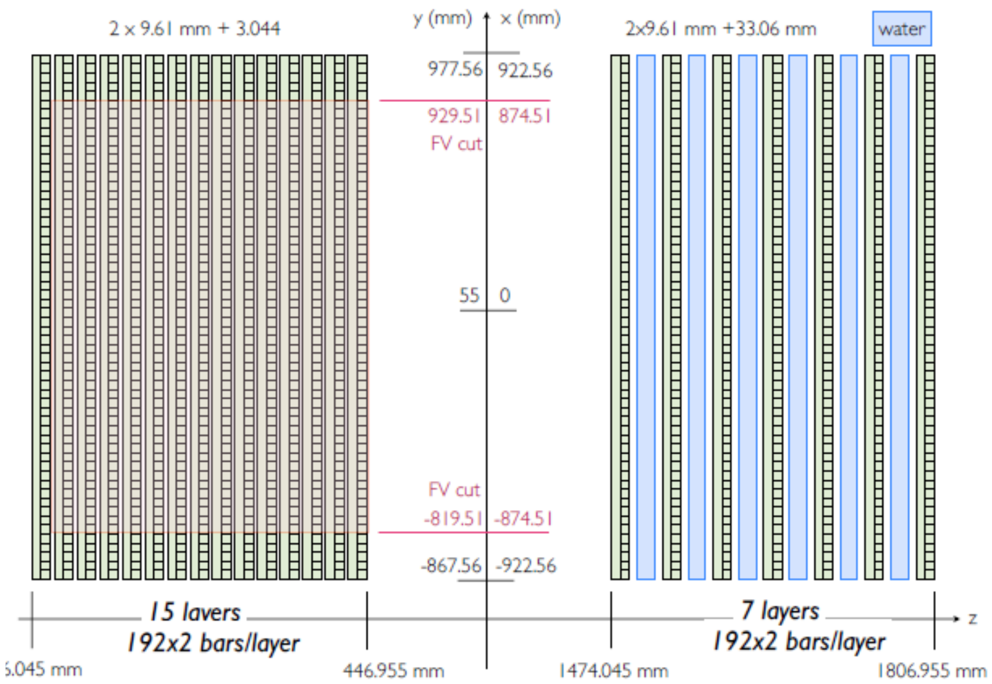


cf. upgrade session at last T2K CM

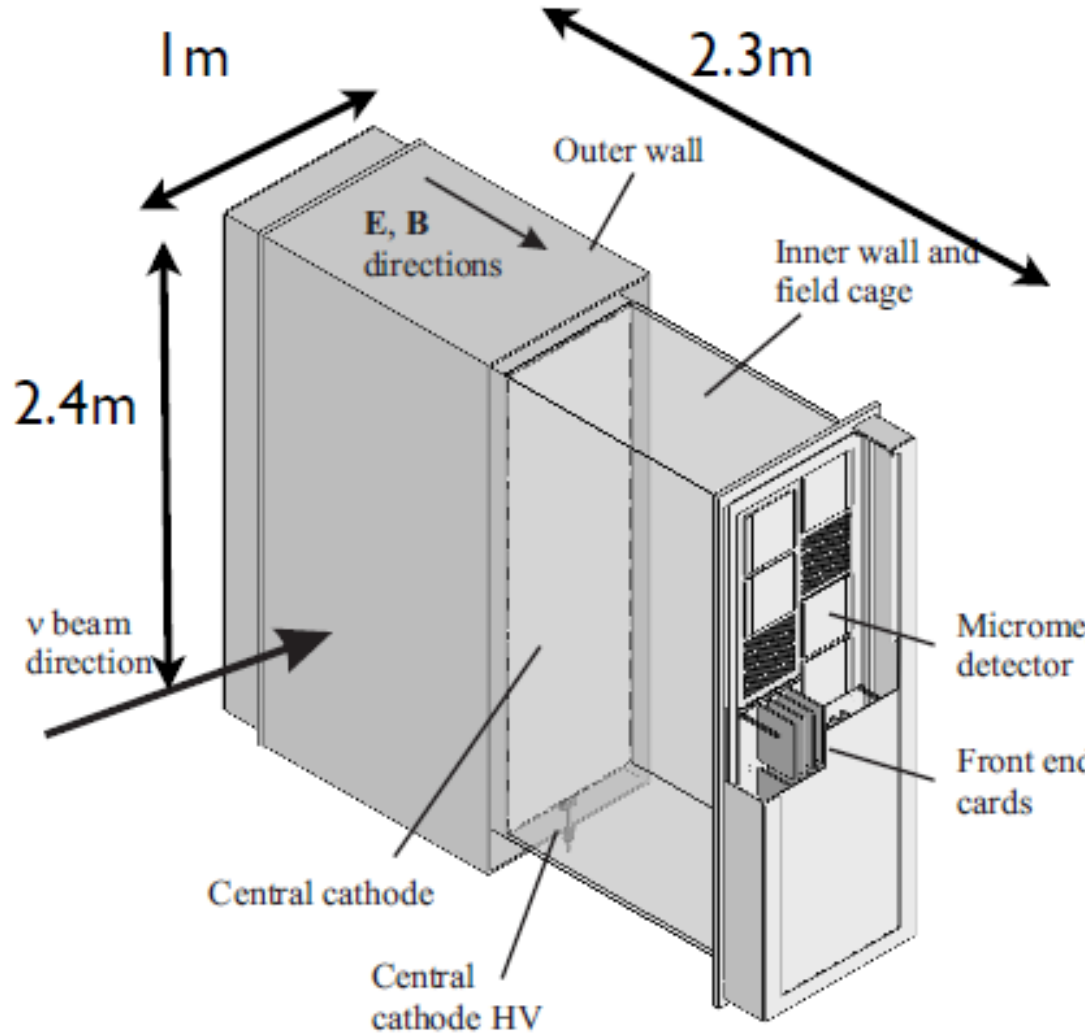
Or more simply, a magnetized MRD behind a Wagasci/PM-style target?

informal chat, MH

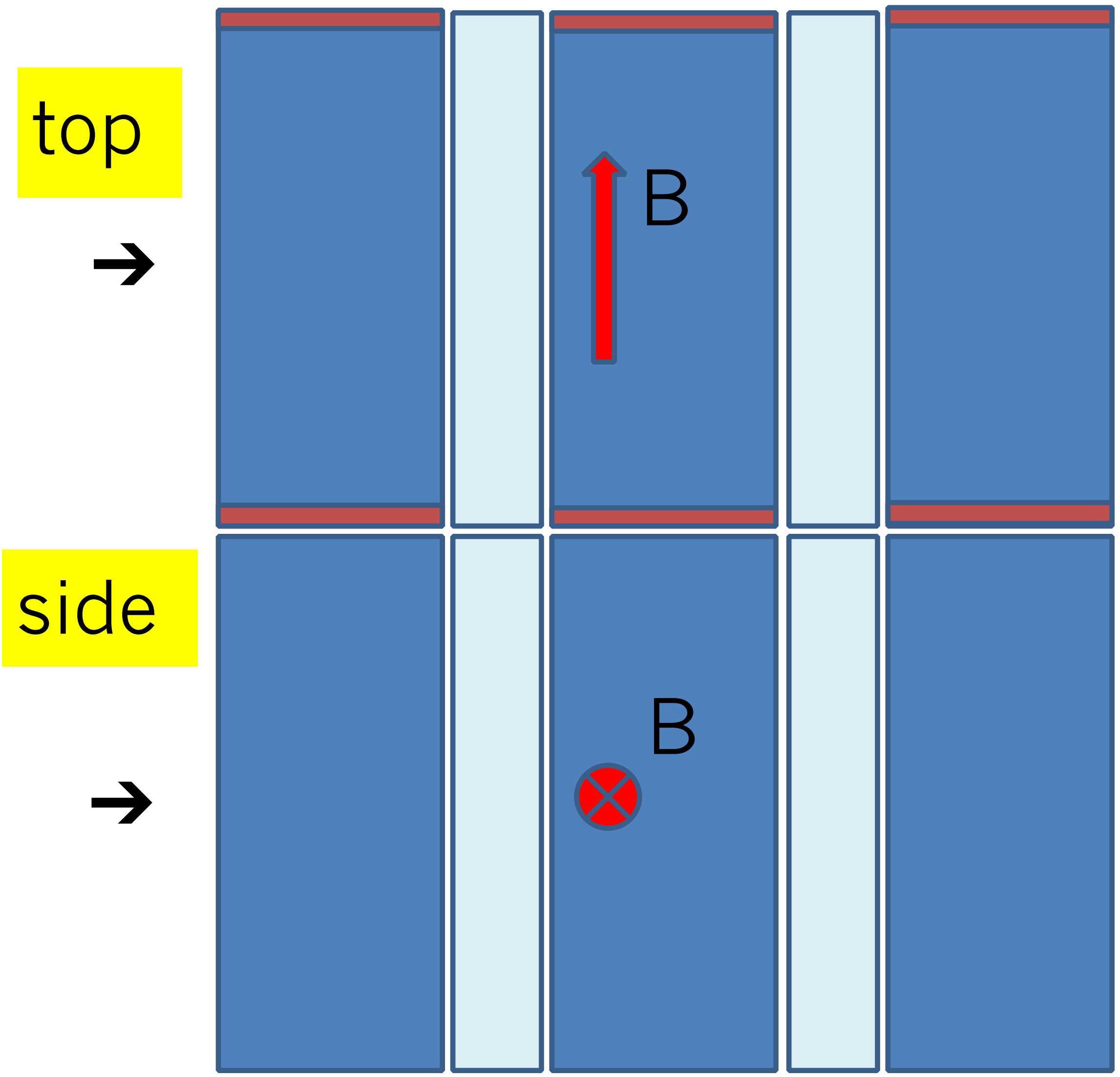
What about a simpler suggestion for increasing the acceptance, using the existing TPCs…



FGDs: $2300 \text{ mm} \times 2400 \text{ mm} \times 365 \text{ mm}$



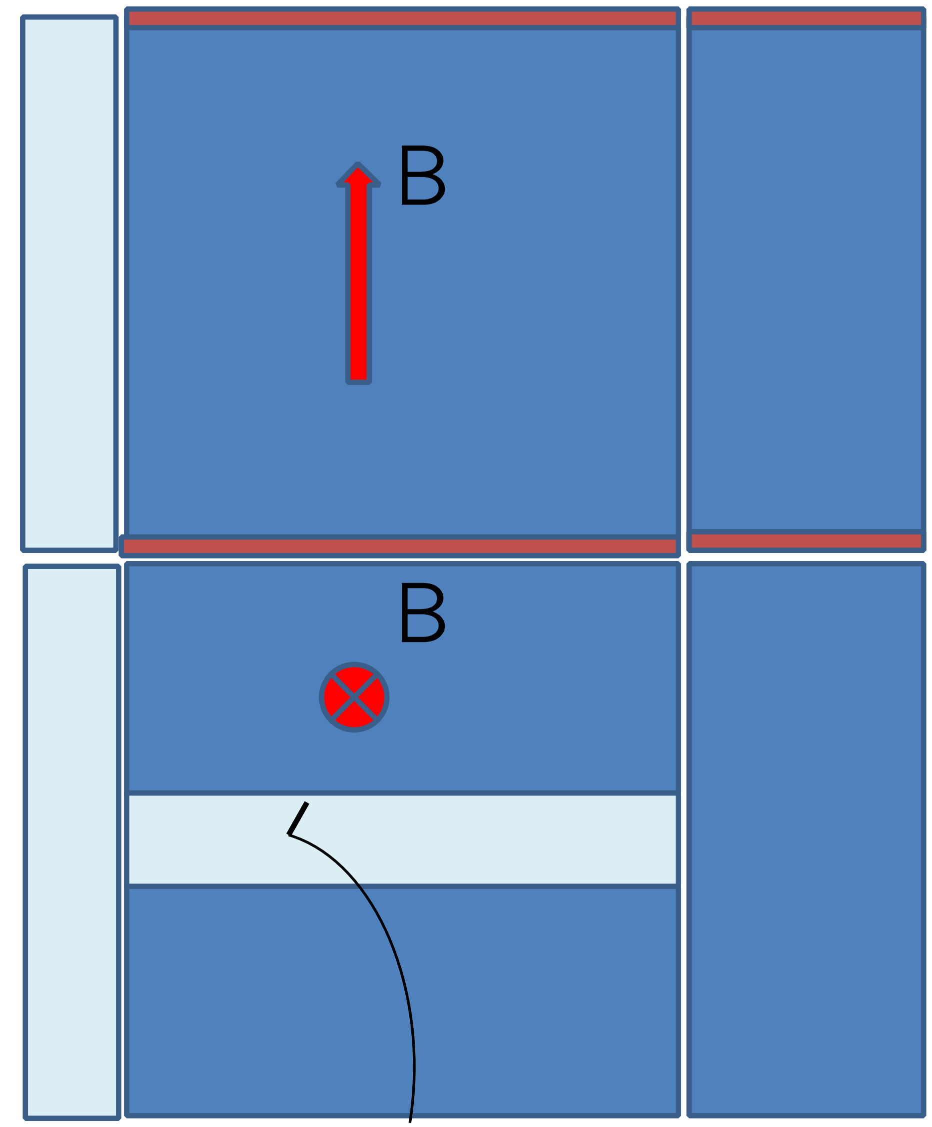
present configuration



dark blue= TPC drift volume
dark red= TPC micromegas
light blue = FGD

scale approximate

Alain's suggested re-configuration

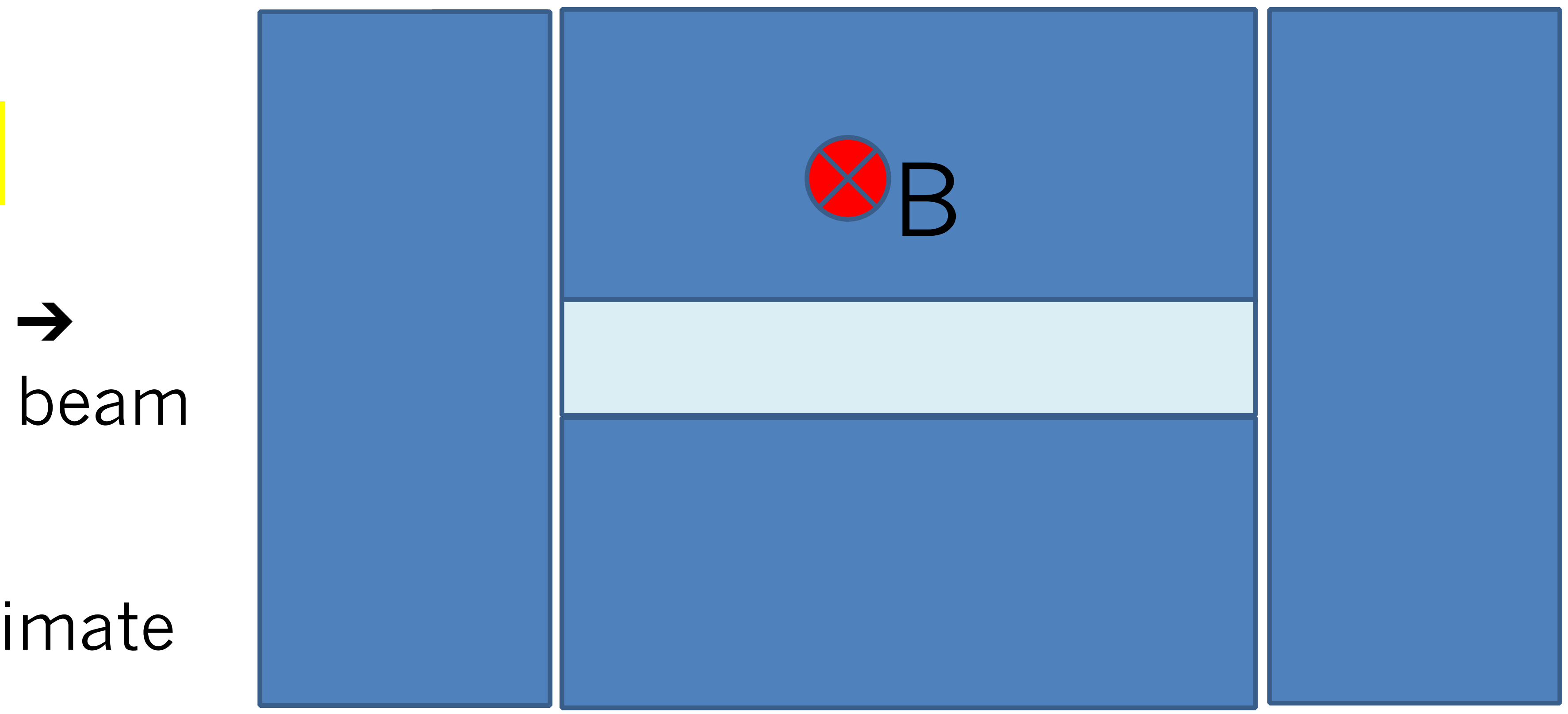


B and E still parallel

Unfortunately rotating the TPCs might be unfeasible mechanically

<u>ideally</u>: add a 4th TPC

side view:



scale approximate

fiducial volume: 2.4 m long x 1.7 m wide x 0.35 m high= 1.4 m^3

could be increased by improved design of TPC field cage

A more feasible plane could be to keep the current TPCs in place, and build new "side-TPCs", made to measure

More leeway in deciding how to use the rest of the space in the magnet

Should be led by simulations
These are underway in Geneva

Foreseen detector statuses in the Hyper-K era

Jeanne solicited answers to several questions concerning the maintainability of the detector components

—Detailed information is in the backup slides
—A summary is presented here

General point:

Both our *ease in maintaining experts* and the *likelihood of continued financial and technical support by institutions* would be reduced by any gap between T2K and HK running

DAQ and electronics

If UK institutions stay in T2K and Hyper-K, we would expect to continue supporting the system

Expect all components to fail at some level over the next 5-15 years

—Continuing backend board connector availability?

—The electronics is obsolete: impossible to build spares

<1% of TRIPt frontend board have failed: *>10% spares*

5% of the backend board have failed: *20% spares*

The major source of instability is the optical trigger link

—Can be improved changing the firmware of the existing boards

—In progress; a big job!

P0D

For use >2025, consider modest improvements

—Better MPPC's

—Leak proof bags

—Water based soluble liquid Scintillator (cf. backup slide)

Likely degradation of scintillator light output

— ~5% / year in MINOS, MINERVA

—*Serious problem over the long term*

TPCs

Need several institutions

—Already difficult to fill the expert shifts with 7

—Interest in HK growing (Canada, some European groups...)

Must refurbish gas system

—Drives operation cost, paid from the common fund, not negligible

Must upgrade the DCC back end readout electronics

—However the rate of channel failures is small so Micromegas and front end electronics would not need major work

Possible upgrades

—Reduce the DCC front end readout latency

—Increase robust against high occupancy events.

FGDs

Not clear to what extent the Canadian group could continue to support the FGDs into Hyper-K

Difficult to predict how the detector components might age

—Possibility of failures with time

— electronics, water system...

Suggestion of an FGD3 to replace the P0D

SMRDs

Probably no problem to continue INR support

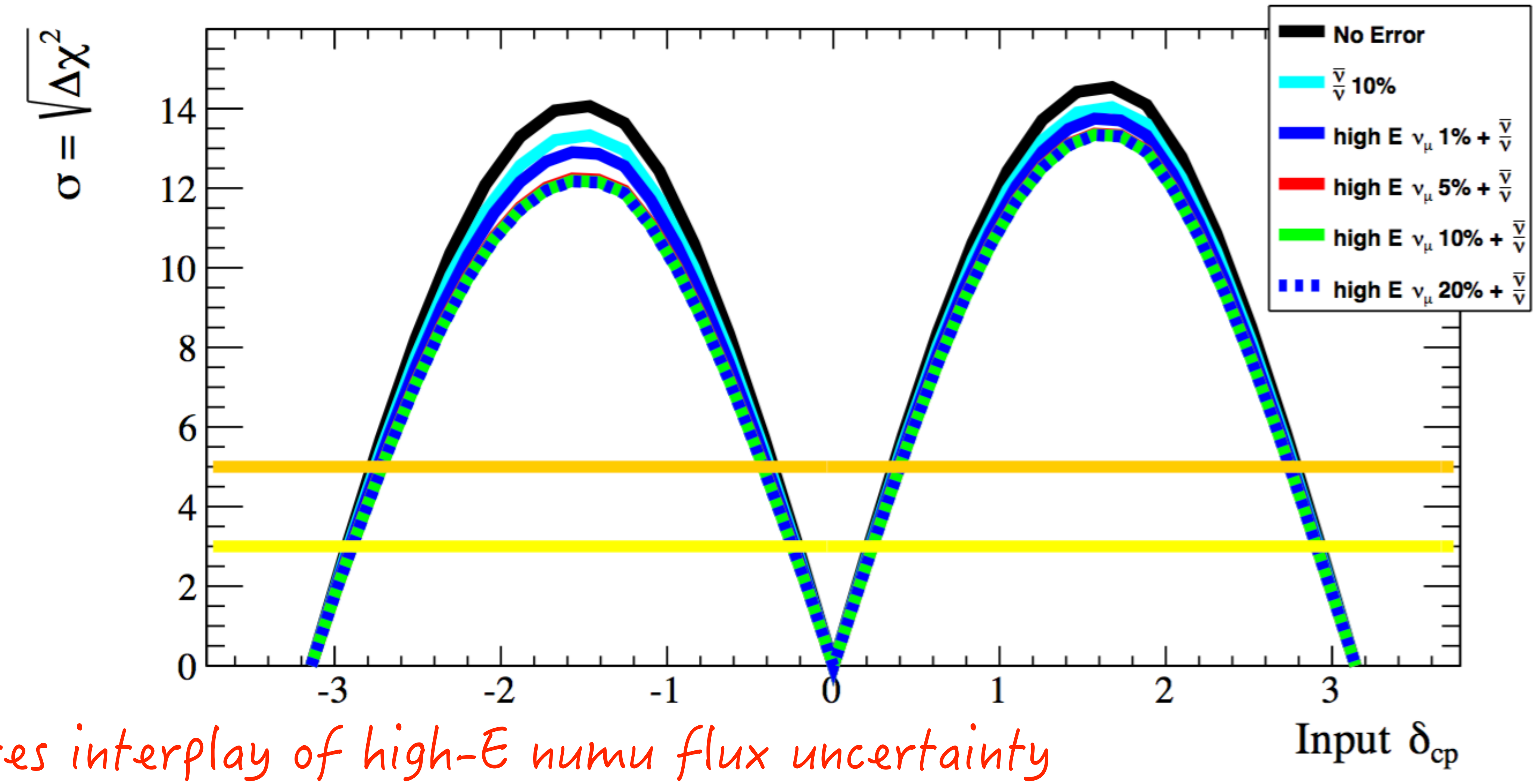
Possible upgrades

—Some *MPPCs* and and *electronic channels* should probably be replaced

—Upgrade electronics to achieve better timing?

—Need more detectors in the area close to POD and FGD1?
(Only 2 magnet gaps there are filled with detectors)

Additional effect of High E(> 1GeV) uncertainty



Illustrates interplay of high-E numu flux uncertainty and antineutrino cross-section unceratinty on CPV sensitivity

Up to 2x reduction in sensitivity when high E error considered with $\frac{\bar{\nu}}{\nu}$

Increase error beyond 5% makes no difference

Constraint between 1%-5% necessary to improve sensitivity

Raj Shah, VALOR sensitivity studies, this meeting

Raj Shah (Oxford) VALOR HyperK Studies June 30, 2015 8 / 68

Notes

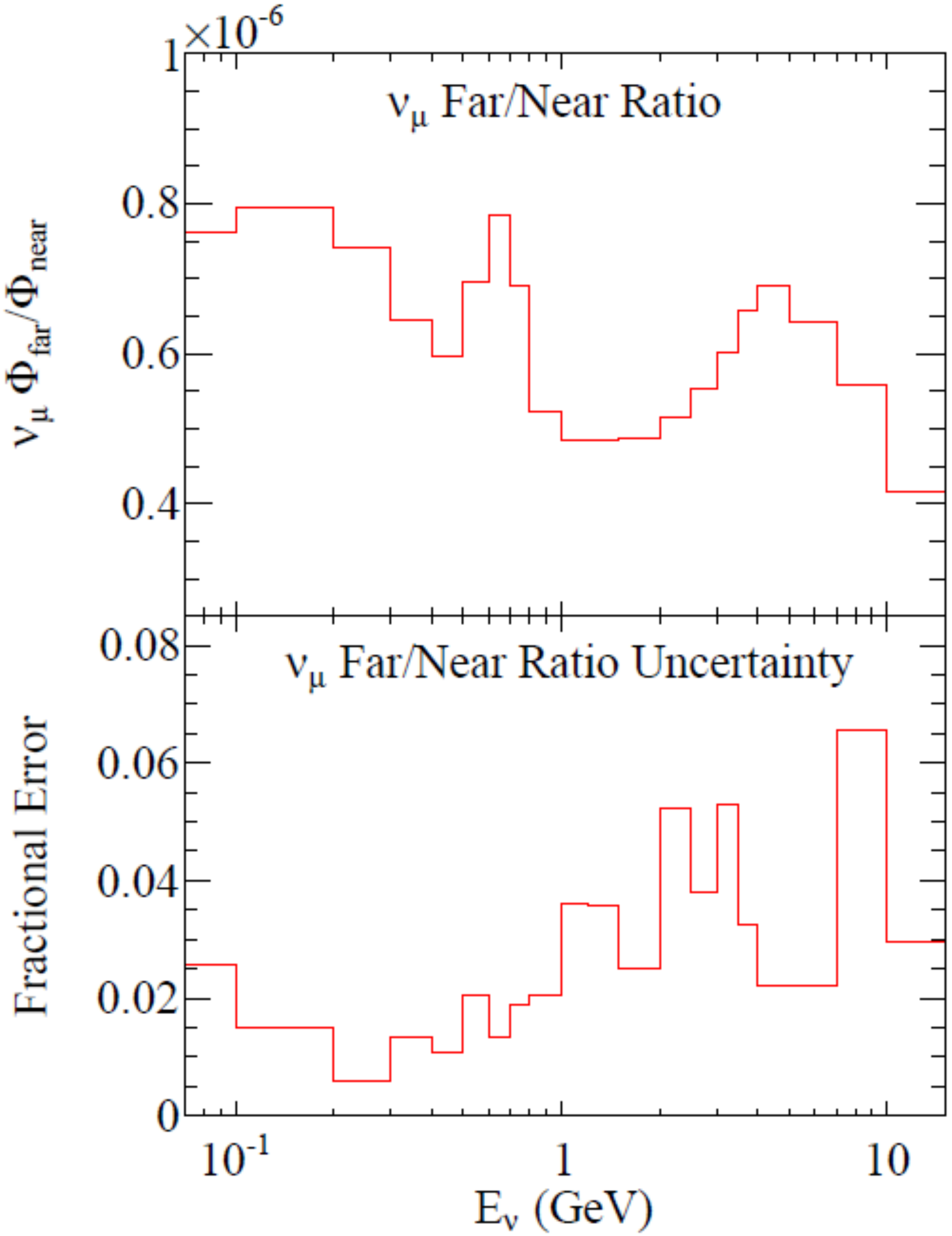
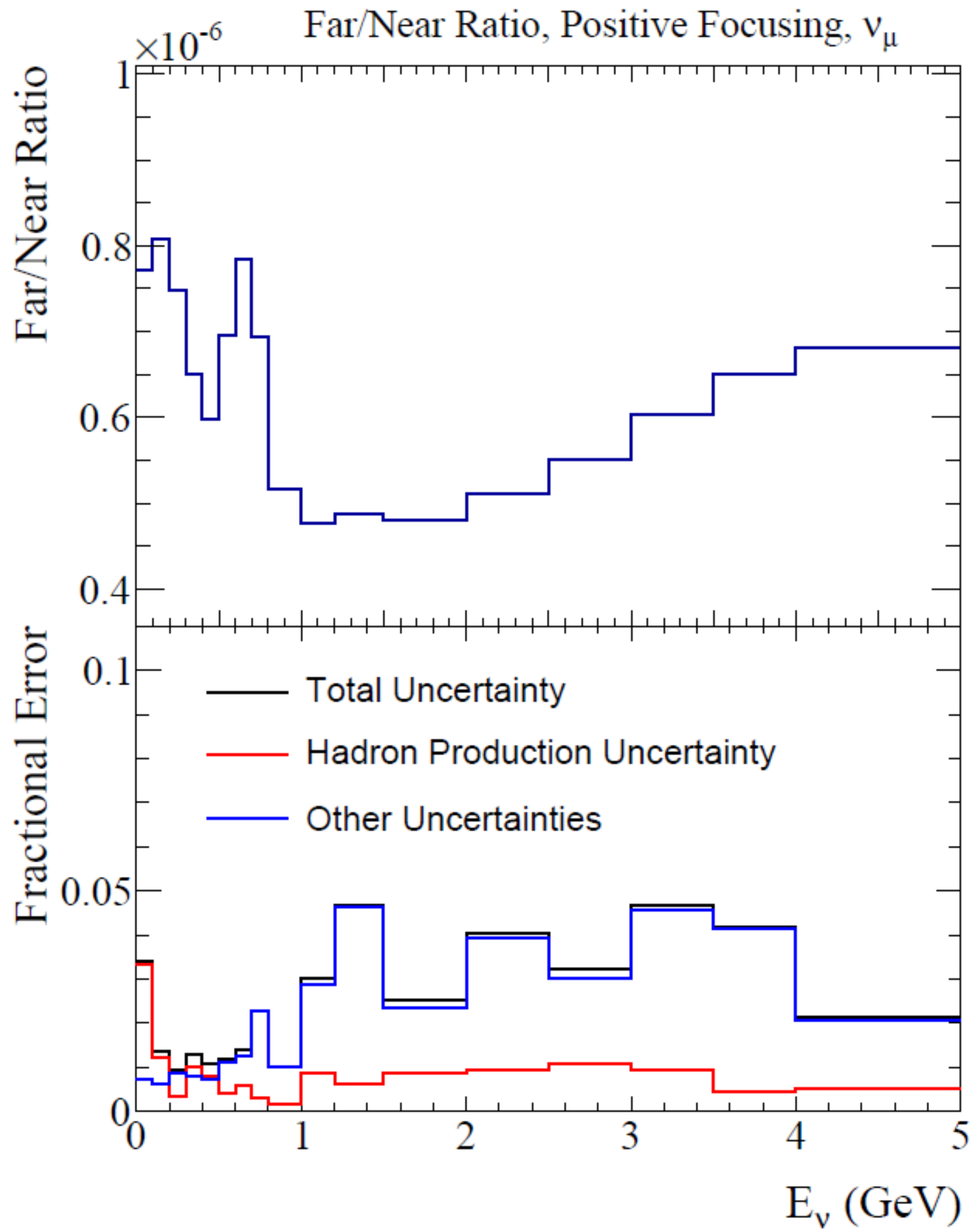


FIG. 45: The far/near ratio for the ν_μ flux prediction (top) and the uncertainty on the ratio (bottom).

2012 with 2007 NA61 data



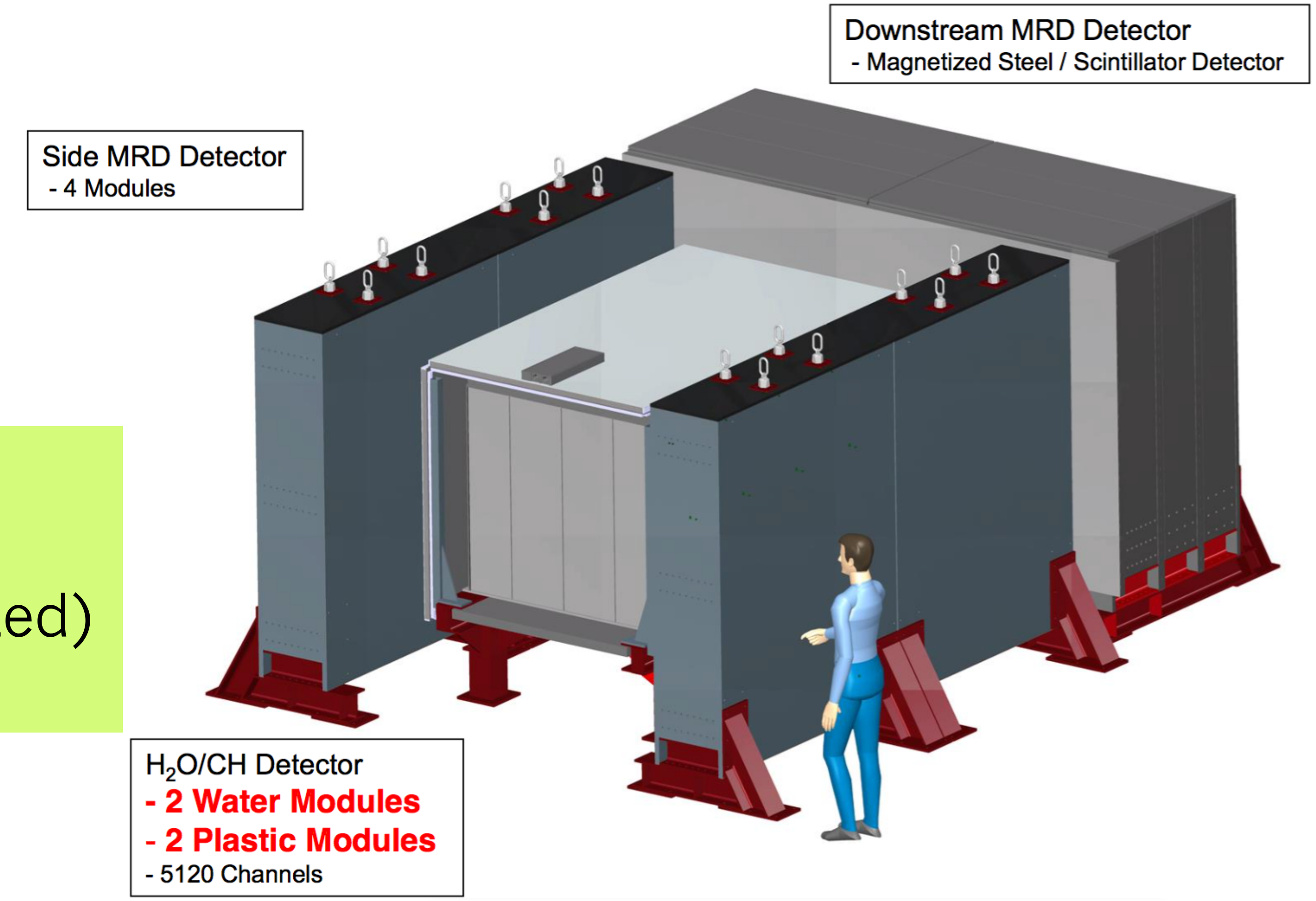
2015 version with 2009 NA61 data

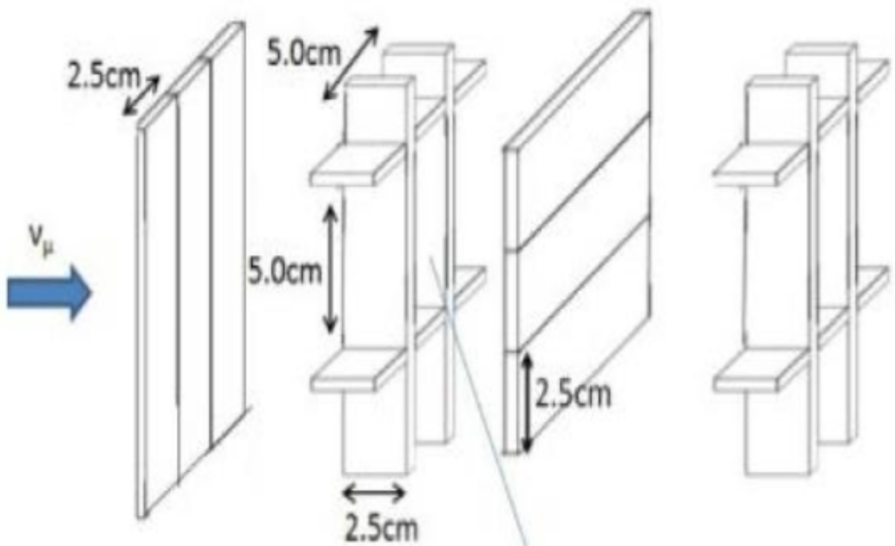
3% precision H_2O / CH x-section ratio

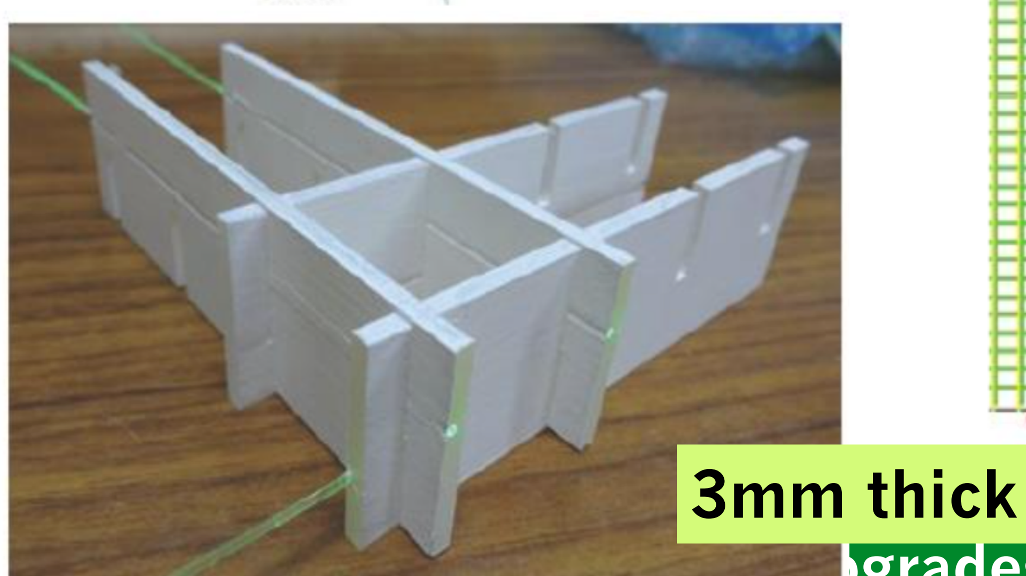
Wagasci

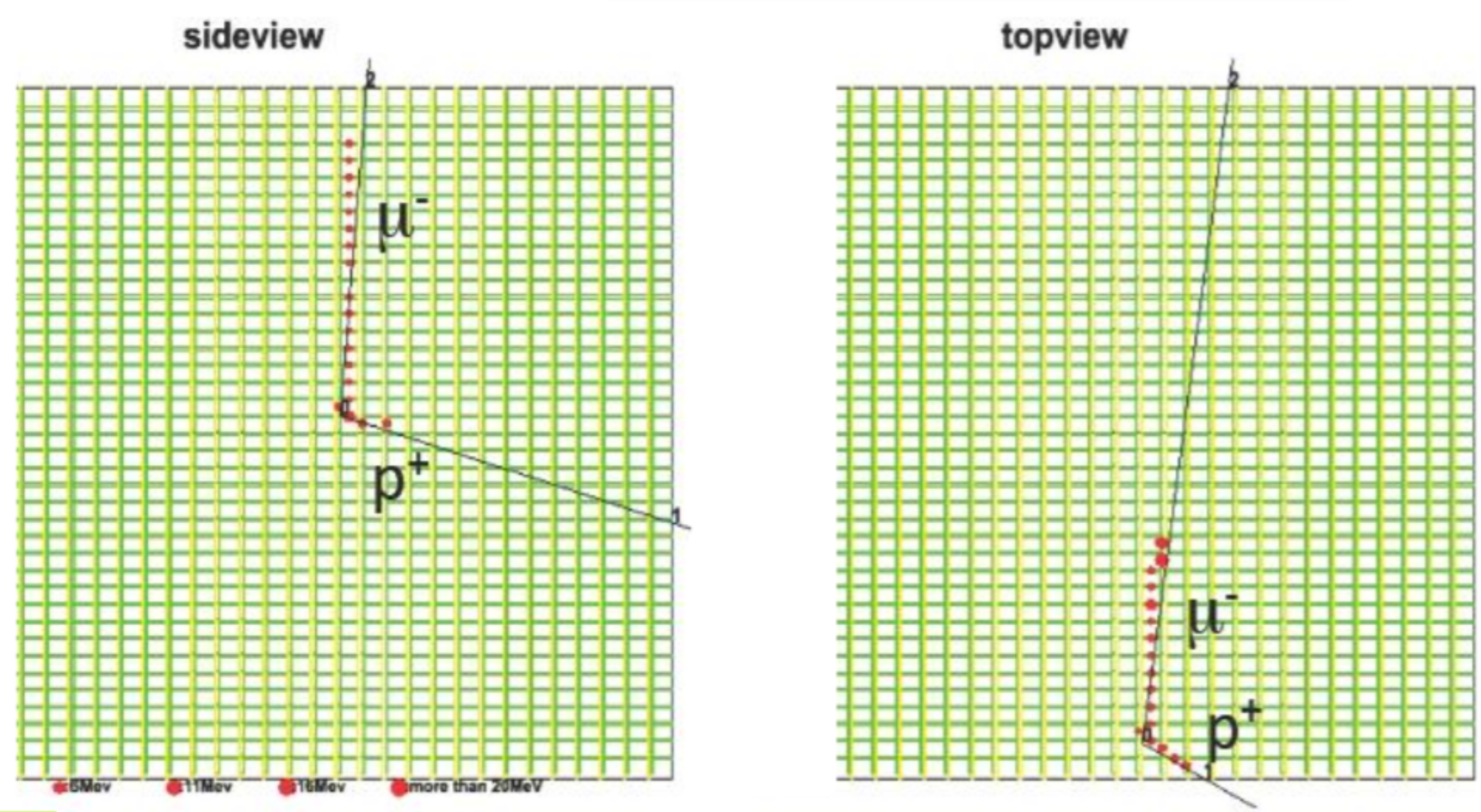
Wagasci collaboration

'The B2 experiment'
- 3D scintillator grid filled with water
- Side MRDs and end MRD (magnetized)
- Excellent phase space coverage





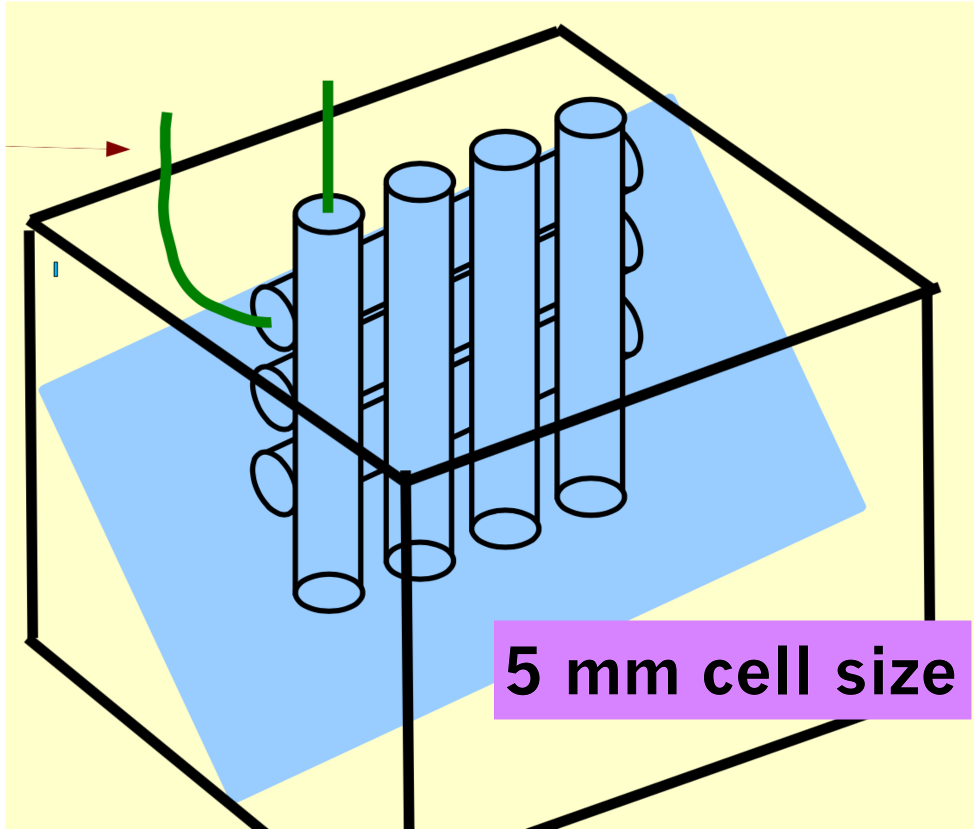




Straws and WBLS - a better target for ND280?

Water-based liquid scintillator

Stanley Yen, TRIUMF



Current FGD2
- Dead regions
- Low energy recoil protons produce no signal in passive water

mylar straws painted with reflective paint on the outside, WLS fibres strung inside the straws

Water-Based Liquid Scintillator (WbLS) at Brookhaven National Lab
- WbLS-1 70% water **1000** optical photons/MeV
- WbLS-2 70% water **1500** optical photons/MeV

compared with pure liquid scintillator (BC408) **10,000** photons/MeV

Currently measuring light output using TRIUMF cyclotron

http://www.t2k.org/ndup/ general/meetings/ 20150203/

Questions for people responsable for the component detectors

Jeanne

1. Required manpower? (operation, including maintenance, on call experts and calibration)
2. Would any of the supporting institutes for T2K be able to maintain the operation for Hyper-K? If not, is there potential to donate the hardware to HK at the end of T2K? and who currently owns it?
3. Are there any components that would be expected to fail on the timescale of Hyper-K?
4. Are there any obvious upgrades that could be made to improve the ease of the detector operation or the performance?
5. Operation costs, including for replacement parts

DAQ and Electronics

1. During running DAQ expert has to be available all the time. -> at least 3 people during any extended running period. This on-call DAQ expert currently has a back-up of real system experts who originally designed, built and commissioned the DAQ/electronics. Calibration -> job of detector experts
2. Most of the hardware (DAQ/electronics) has been donated to KEK and the UK is not expecting to get any of this back. If the UK institutions stay in T2K and continue their involvement in HyperK, we would expect that we would continue supporting the system. However, it is very difficult to say if this also true in 5 years from now. I assume an important question would be if T2K runs until HyperK comes online. This will also depends on the overall decision of the T2K-UK groups and if STFC continue to fund us.
3. **We expect all components to fail at some level over the next 5-15 years**
   - The **commercial PCs** will have to be replaced every ~5 years. Not clear if the hardware to connect to the backend boards (optical GBit Ethernet) will still be available over the lifetime of the experiment.
   - **Uninterruptable power supplies** need new batteries every ~3 years.
   - **The electronics is already obsolete and it will be impossible to build any new spares.**
   - **Less than around 1% of TRIPt frontend board have failed over the last years and we do have at least 10% spares**. Additionally 5% of the backend board have failed for which we have 20% spares.
   - Could easily imagine failure rate to double -> problems with the backend boards.
   - Power supplies or similar are essentially commercial components for which replacement of similar functionality will always be available.
4. **The major source of instability is the optical trigger link.** Could be improved changing the firmware of the existing boards, but major work required. In progress. We are also moving into the direction of having **remote experts**, which may require **additional hardware interlocks** to be installed.

5. Cost estimates: Replacement of commercial PC every 5 years: £50k — £100k?, Replacement batteries every 3 years: £5k

TPCs

Need several institutions

—Already difficult to fill the expert shifts with 7

—Interest in HK growing (Canada, some European groups...)

Must refurbish gas system

—Drives operation cost (open circuit)

—Paid from the common fund, not negligible

Must upgrade the DCC back end readout electronics

—However the rate of channel failures is small so Micromegas and front end electronics would not need major work

Possible upgrades

—Reduce the DCC front end readout latency

—Increase robust against high occupancy events.

FGDs

1. Manpower:
   - 1 on site expert during beam
   - 1-2 weeks of maintenance per year for the water system and electronics
   - 1 person-hr per week to check the calibration
   - 1 person-week per year of data vs. MC tuning
2. It isn't clear to what extent the Canadian group could continue to support the FGDs into Hyper-K. If they can't, there would be the potential to donate them to whichever institutes could support them.
3. Can't predict how the detector components might age, but there is the possibility of failures with time (electronics, water system).
4. Scott also thought that if an FGD type design was used (and the P0D was removed) it might be better to make a third FGD

P0D

- P0D provides a complementary measurement ofCCinc, NCpi0 etc. where you can do a water subtraction which is foolproof. The measurements w/o a subtraction have difficulties knowing exactly where the vertex originates (in water or Scintillator).
- Also if you measure very accurately neutrino and antineutrino water xsec ratios vs Enu (important for future HyperK/DUNE Physics), we know that the angular distributions of neutrino and antinu are very different due to the antinu helicity, so the backward tracks and vertex migration can be very different.

- One related aspect is if one wishes to continue to use the P0D beyond T2K (after ~2025), it might be useful to consider modest improvements in the medium term. These could include
  1) Better MPPC's
  2) Leak proof bags, turnkey water filling/draining
  3) Water based soluble liq. Scintillator.
- Of course, there are likely degradation issues such as the P0D scintillator light output. We know that MINOS and MINERVA have problems with their light output dropping per year (~5% I think), which can be serious problem over the long term.

Stop water vertices migrating between p0dules - two methods with WBLS

http://www.t2k.org/meet/ndup/general/meetings/ 20141005/NDup-20141005

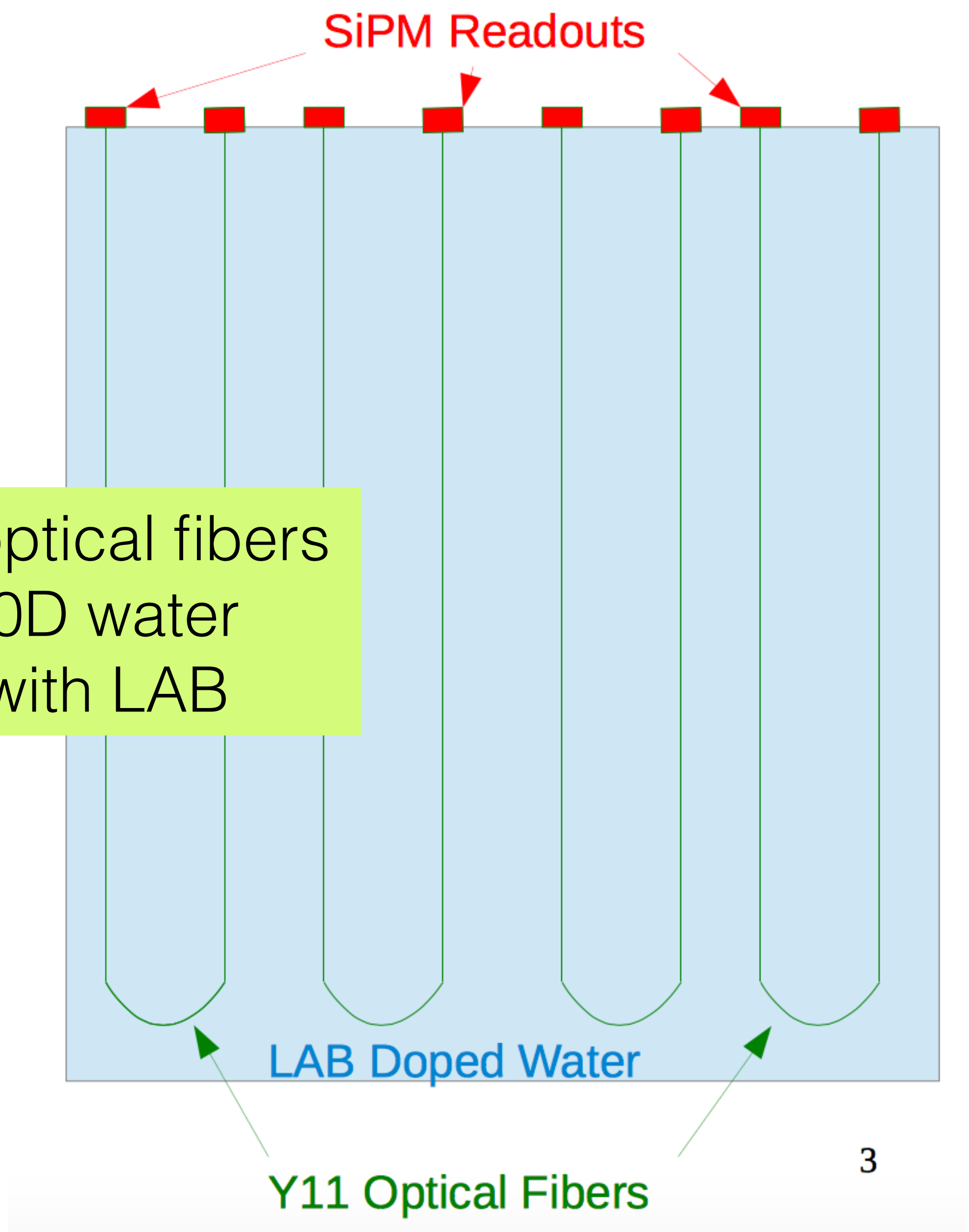
P0D Water Bag Upgrades

Ryan Wasserman, Norm Buchanan, Walter Toki, Colorado State University

liquid scintillator linear alkylbenzene (LAB)

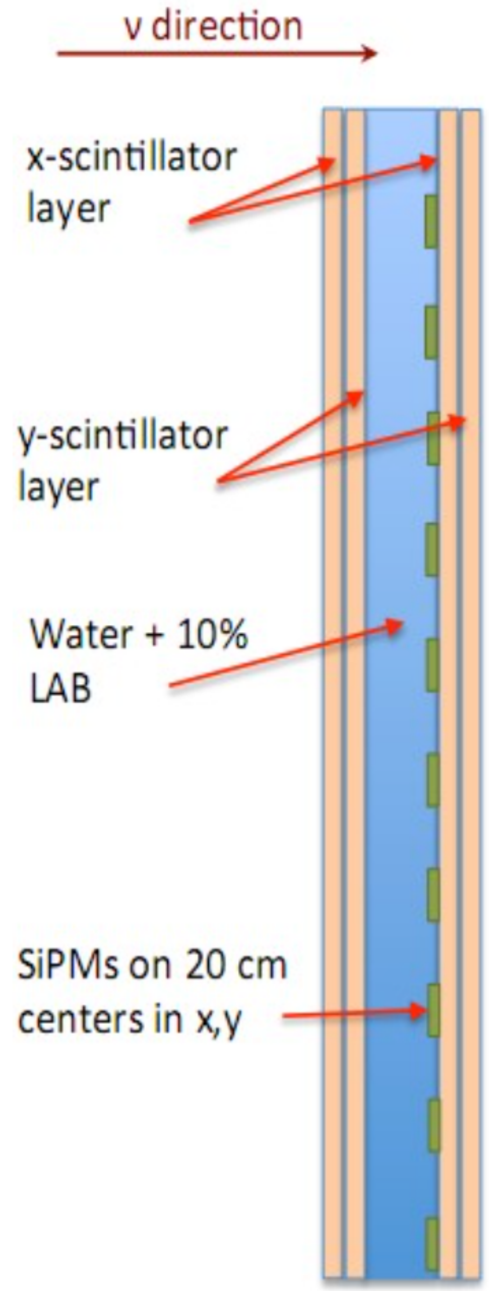
option 1

Curved Y11 optical fibers placed into P0D water bags doped with LAB



option 2

SiPMs and LAB inside P0D water modules



Plans to create a 1m x 1m scale prototype detector in HEP lab at CSU

SMRDs

1. 1 person is needed for calibration work, 1 should be in Tokai as an expert during the running time.
2. INR is involved in HK, do not see a problem with the SMRD at the HK time.
3. Maybe some MPPC's and and some electronic channels should be replaced.
4. SMRD detectors have good time resolution of 1 ns but electronics we use now allows us to obtain only about 2-3 ns. If better timing will be needed then we have to upgrade the electronics. The second point – we probably need more detectors in the area close to POD and FGD1 where only 2 magnet gaps are filled with detectors.
5. It depends on what should be done. From the installation experience, the driving cost is the labor if all detectors are manufactured and shipped to Tokai. I do not know the operational cost but suggest it is a small fraction of the ND280 operational cost

Neutrino beam mode $\nu_\mu \to \nu_e$ uncertainties:

Error source [%]	$\sin^2 2\theta_{13} = 0.1$	$\sin^2 2\theta_{13} = 0$
Beam flux and near detector	2.9	4.8
(w/o ND280 constraint)	(25.9)	(21.7)
ν interaction (external data)	7.5	6.8
Far detector and FSI+SI+PN	3.5	7.3
Total	8.8	11.1

What are the limitations?

A. Near detector and far detector are different

A quantitative re-projection of these causes of errors is necessary in order to understand better what to improve.

A0. flux at near detector and far detector are different.

The FD/ND ratio is however quite well known

A1. Near dector is scintillator not water

However cross-sections on water are being measured using FGD2 (40% water), by subtraction from FGD1 with proper weighting, or by identification of events in water

➔ it would be better to have fractionally more water in target.

A2. Near detector has different E_ν resolution and acceptance than far detector.

Acceptance is presently limited to ± 53° (forward) for muons, extrapolation leads to model dependent error. *Needs to be quantified -- concerns 30% of cross-section?*

We can now get larger angle muons but momentum and sign determination are unclear.

Efficiency for photons is different? (is it sufficient to estimate correction?)

Improve angular acceptance
-- two solutions were proposed

-- High pressure TPC

very nice vision of vertex

(but what do we learn from that?)

good solution for near detector in case far detector is LArg TPC

(this is why we proposed it for the ND of LBNO!)

photon and neutron detection remains to be addressed

need pressure vessel around photon detector (LBNO prototype)

In principle could reconstruct H2O cross-section by combination of gases

e.g. $0.5\ CO_2 + 13/6*CH_4 - 2/3\ C_4H_{10} = H_2O$

However high P CO_2 captures electrons heavily (capture ↑ more than P)

(Rob Veenhof)