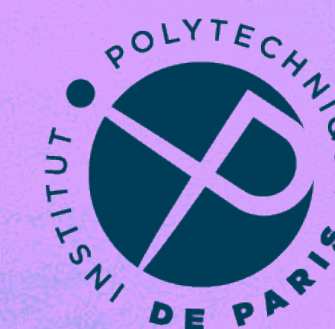
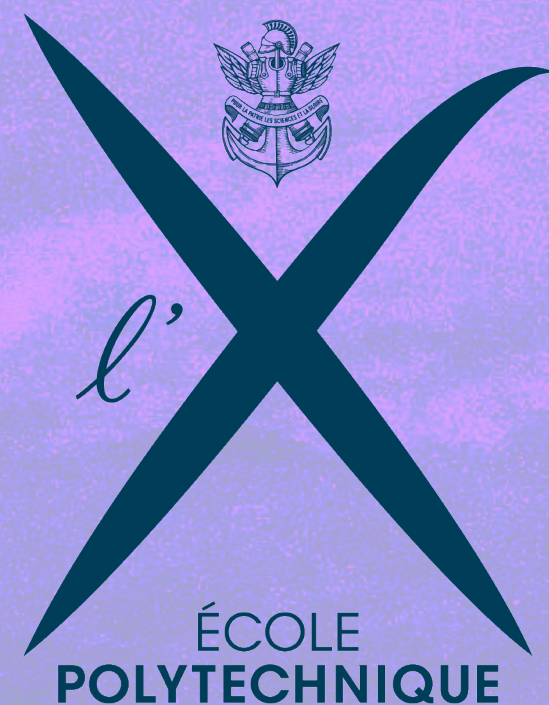




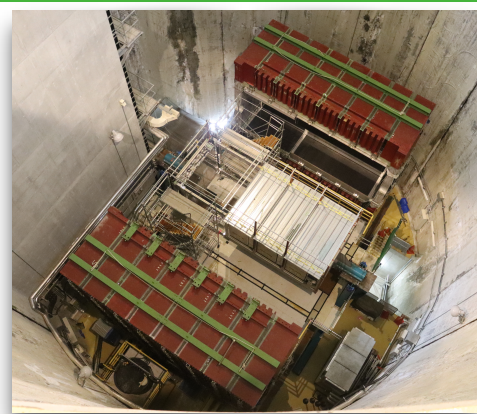
First results with upgraded near detector and flux of T2K

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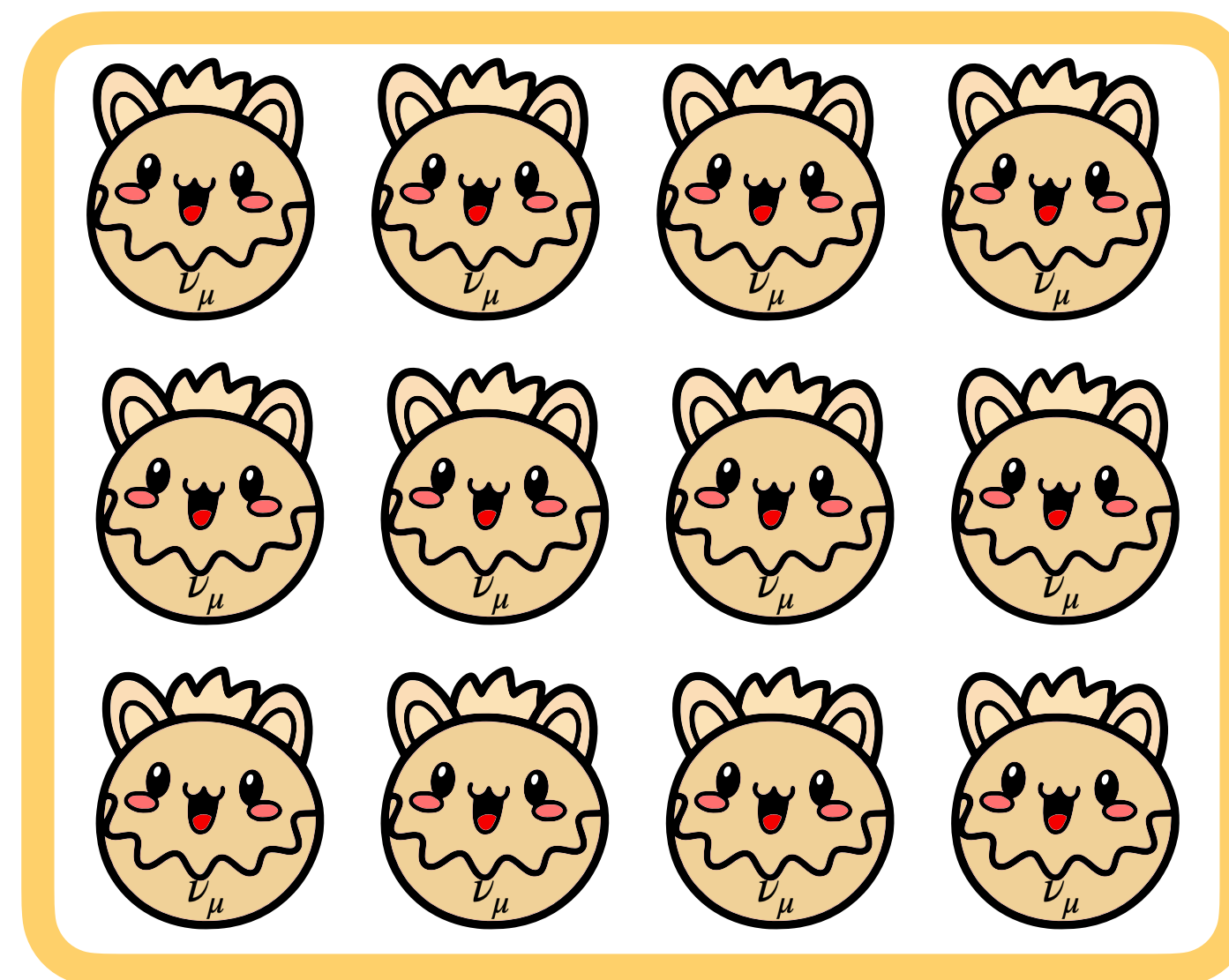


IP PARIS

Neutrino Oscillation

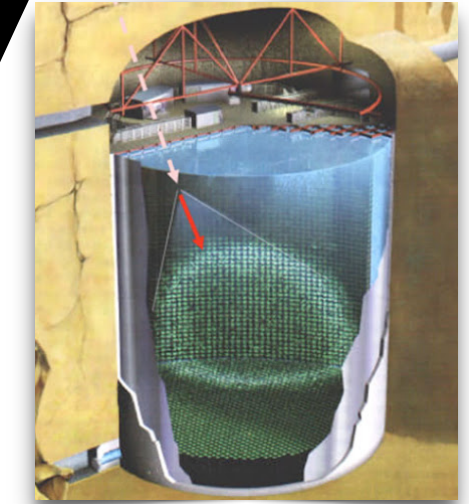
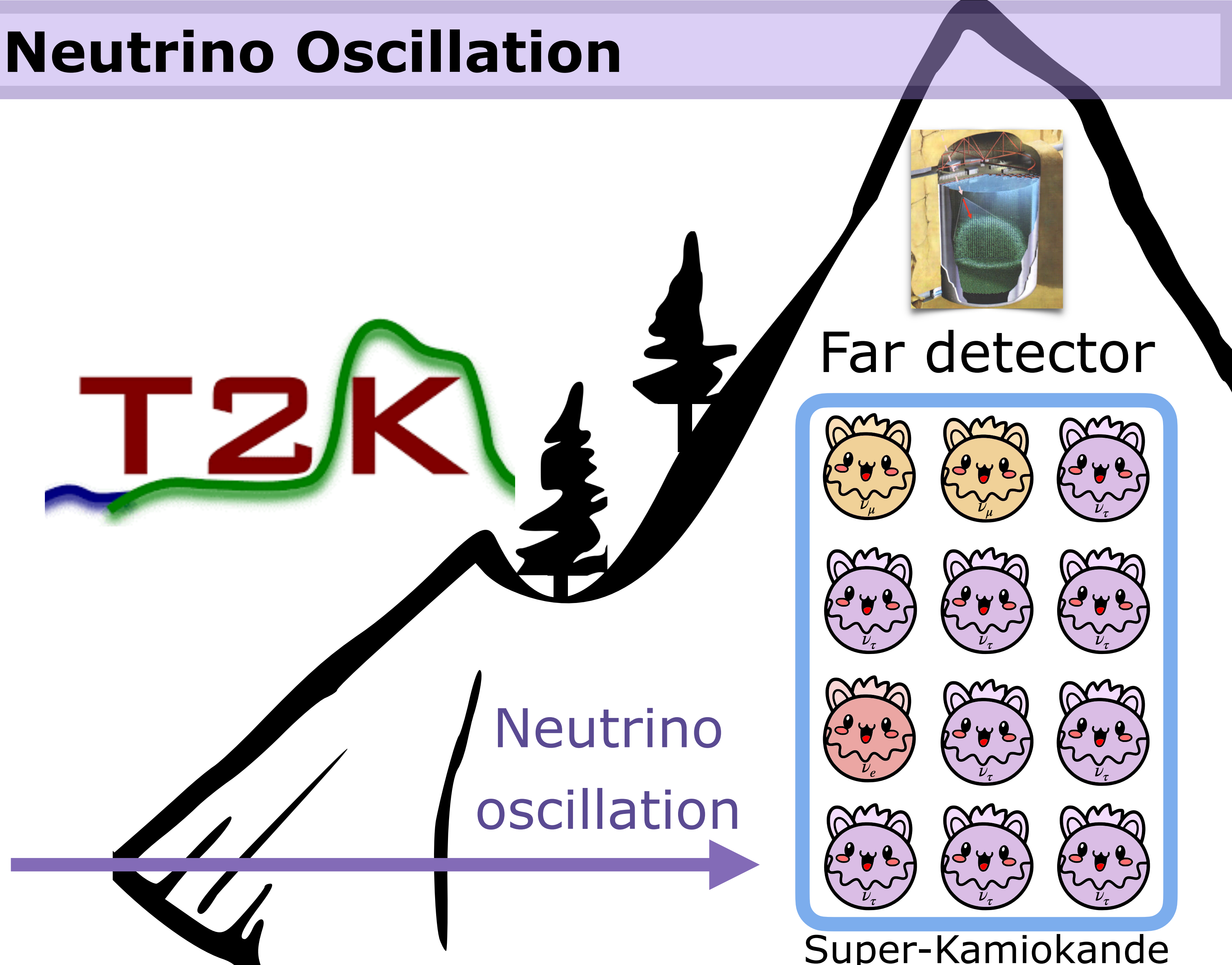


Near detector

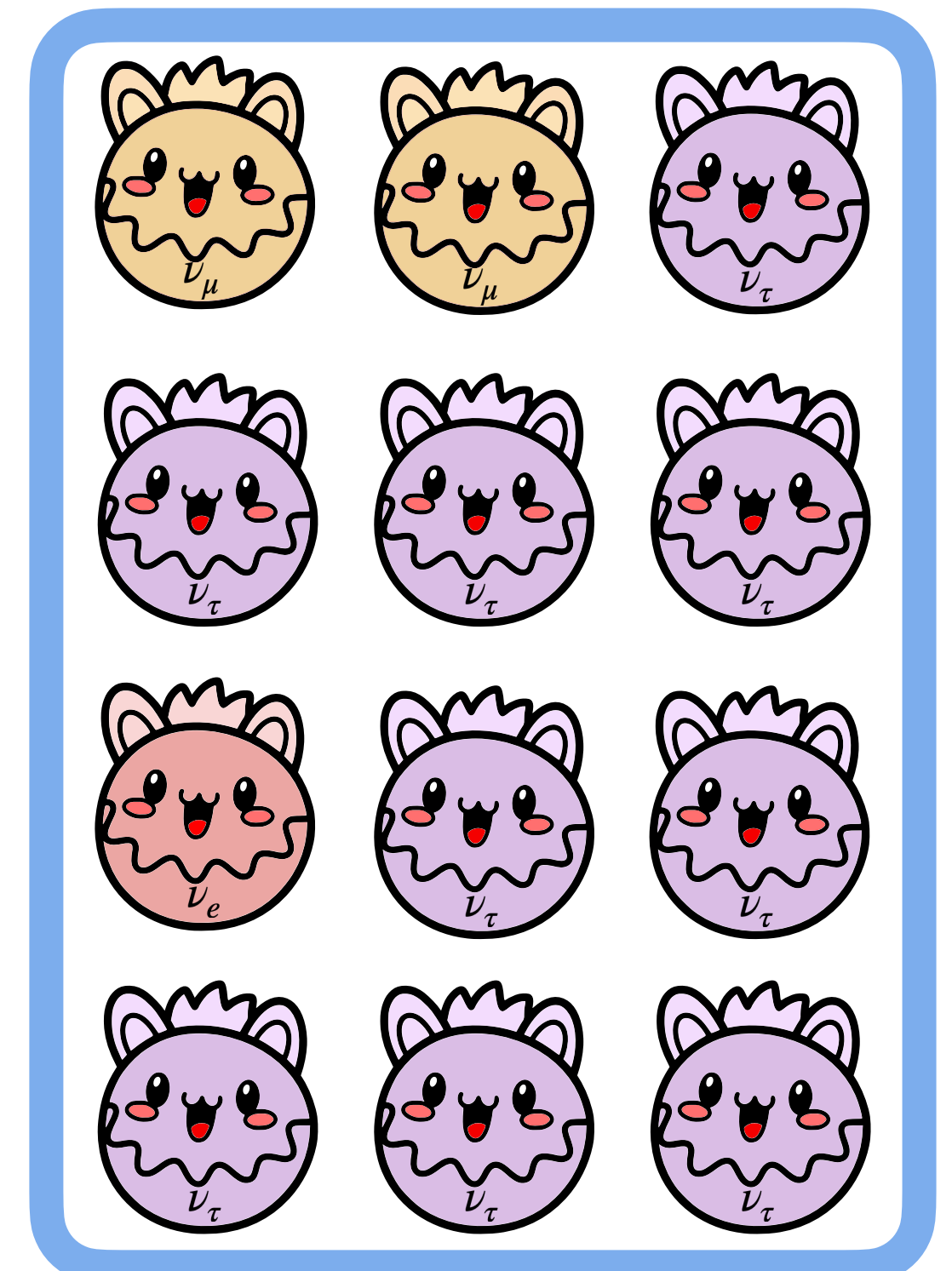


ND280

T2K

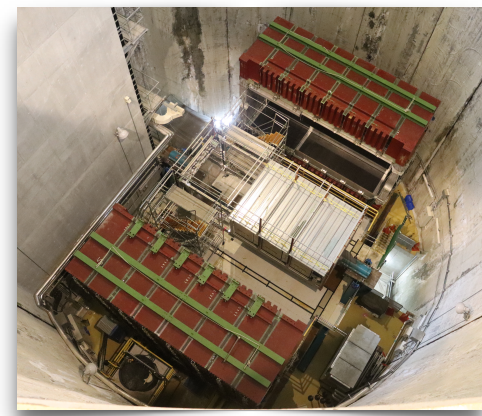


Far detector

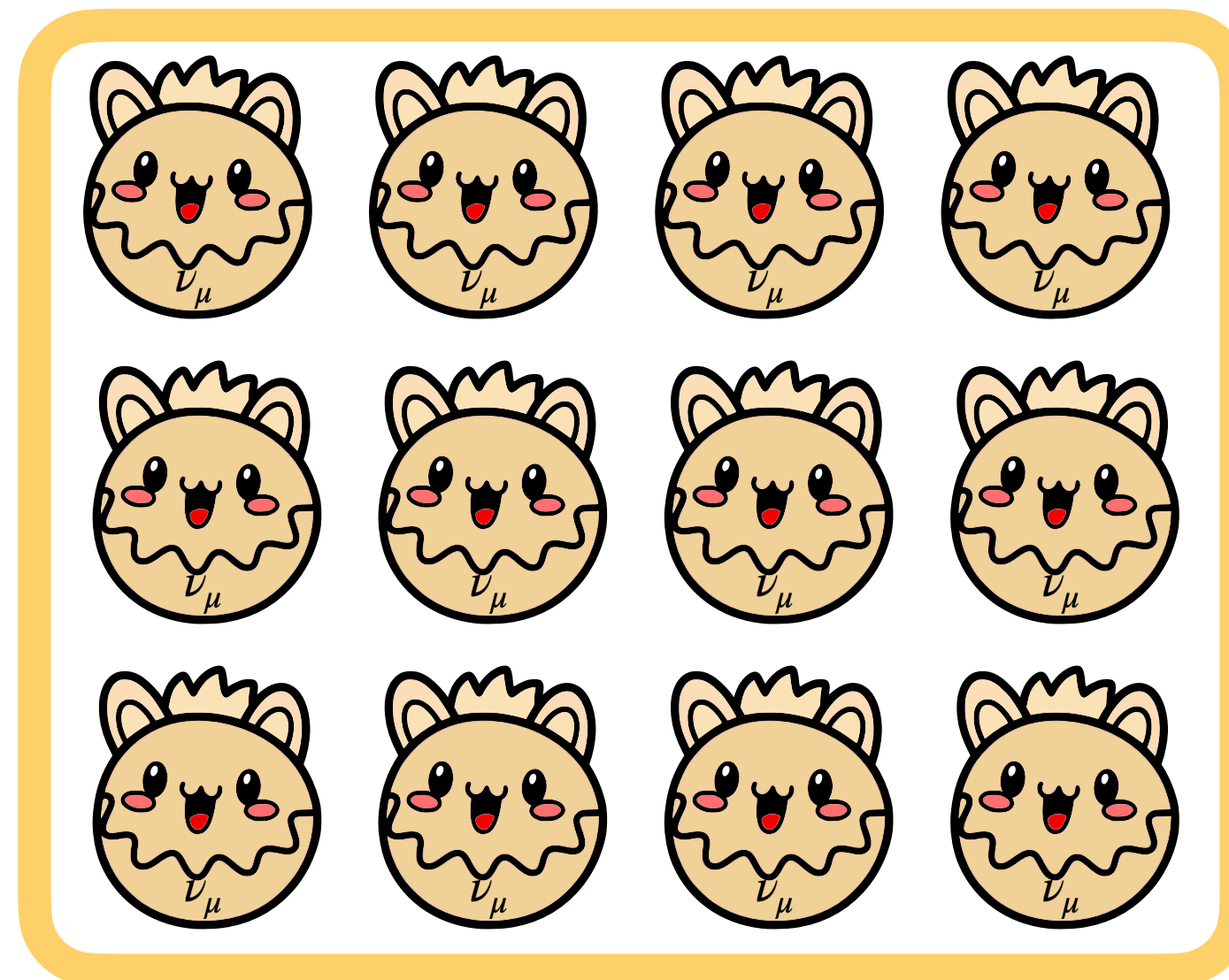


Super-Kamiokande

Neutrino Oscillation



Near detector



ND280

T2K

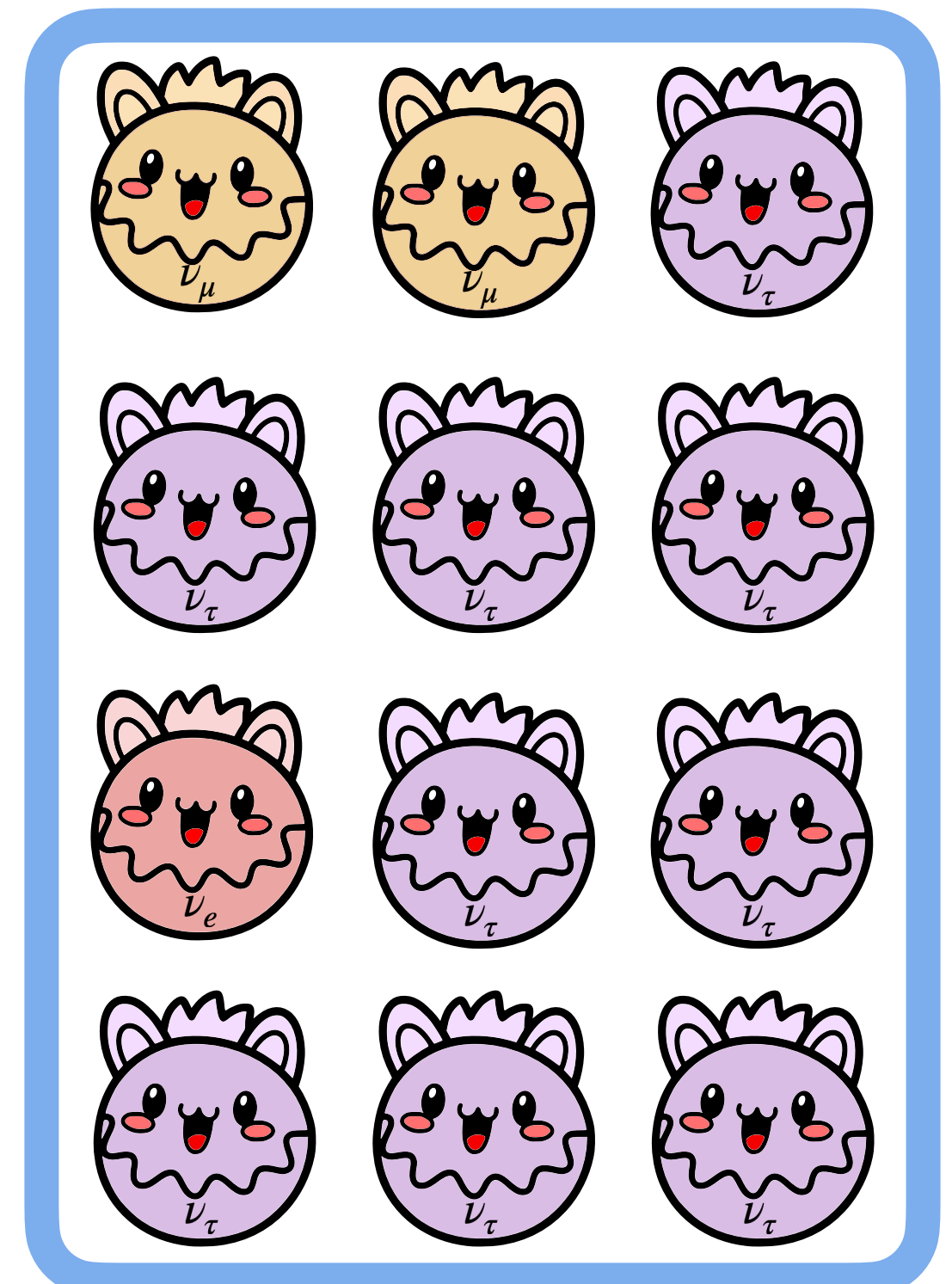


Details on
oscillation
analysis (OA) in
Nico's
presentation!

Neutrino
oscillation

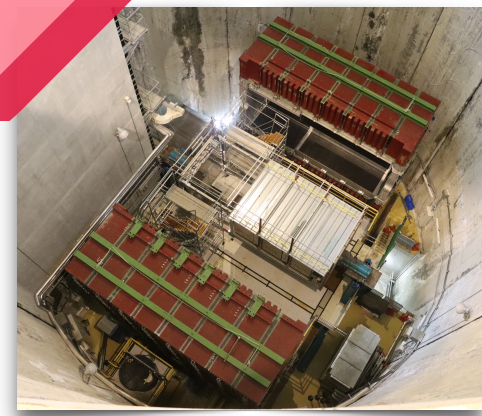


Far detector



Super-Kamiokande

Neutrino Oscillation

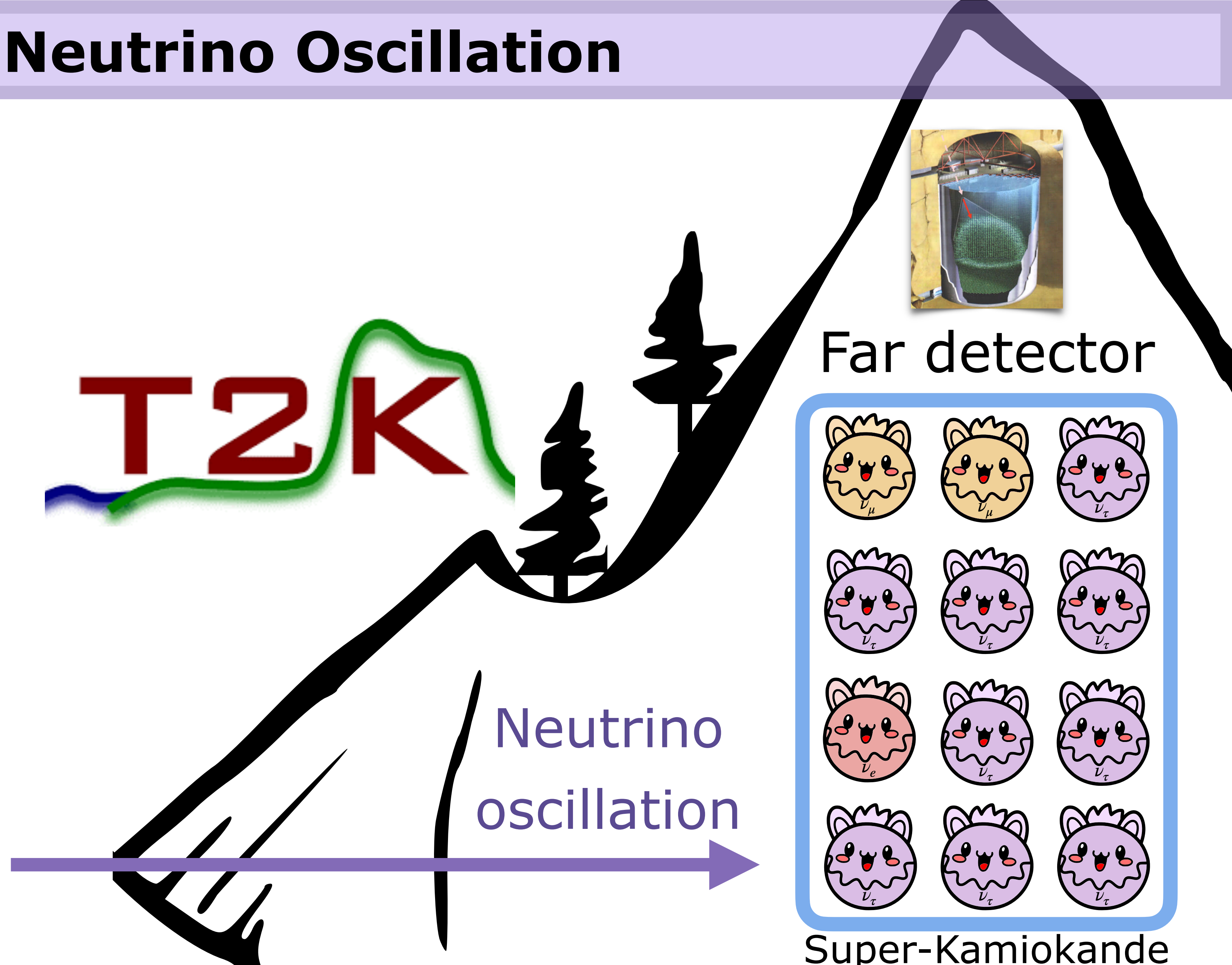


Near detector

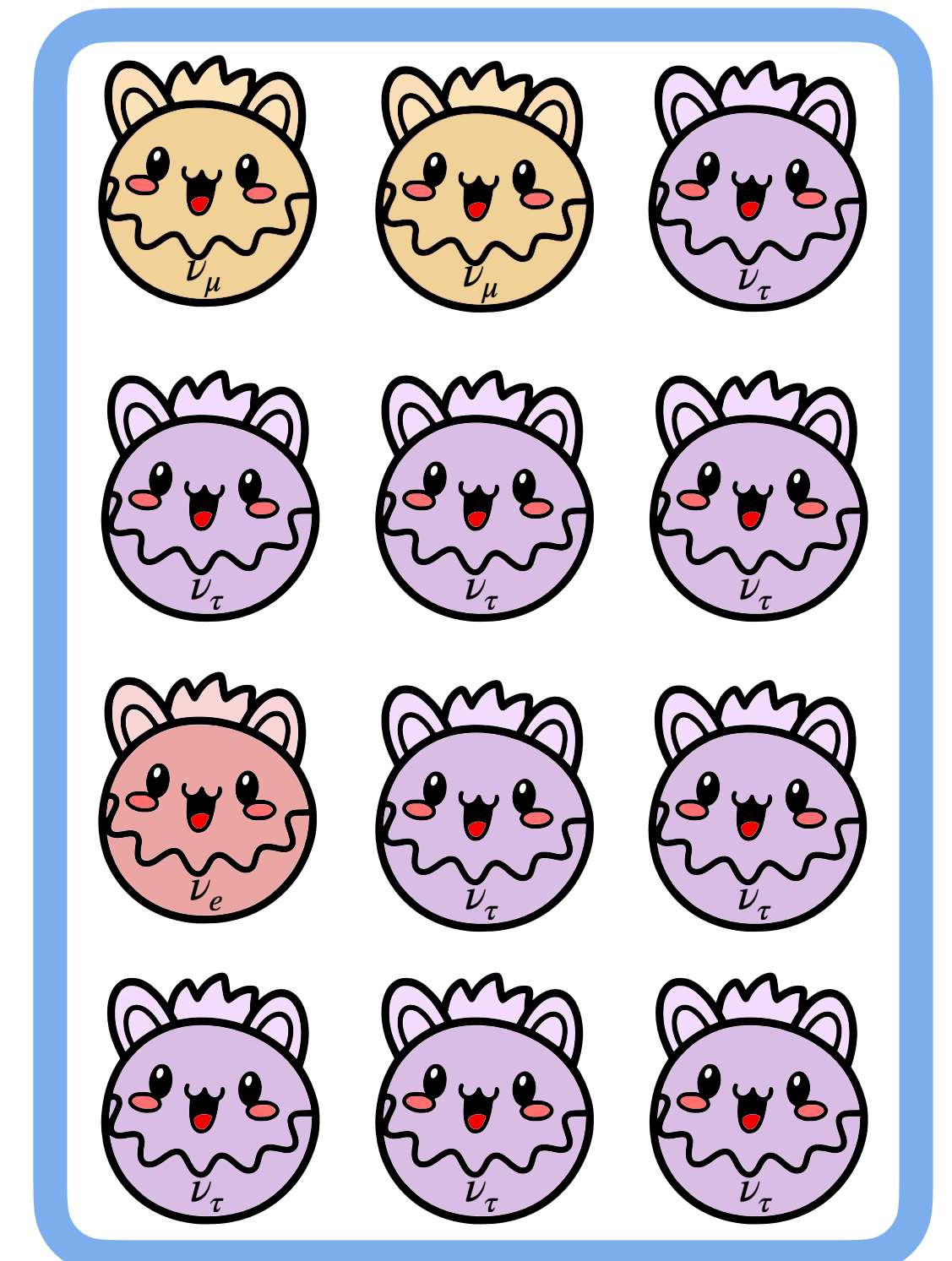


ND280

T2K



Far detector



Super-Kamiokande

Neutrino Oscillation

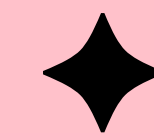


Near detector



ND280

T2K



Outline:

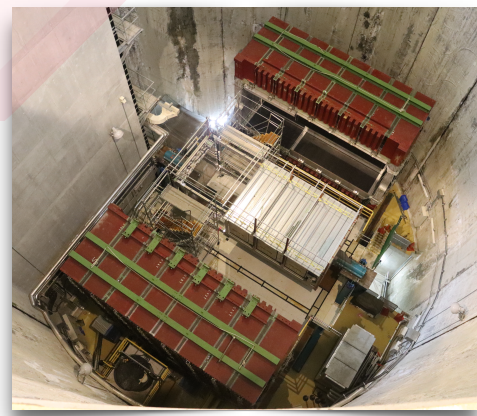
Flux upgrade

Neutrino
oscillation



Super-Kamiokande

Neutrino Oscillation



Near detector



ND280

T2K

Outline:

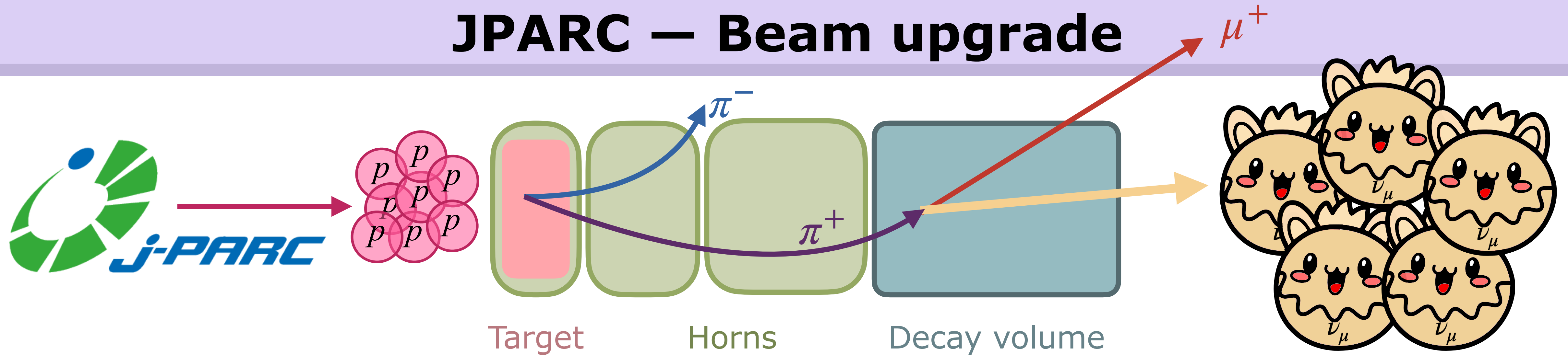
- ◆ Flux upgrade
- ◆ Near Detector upgrade

Neutrino
oscillation



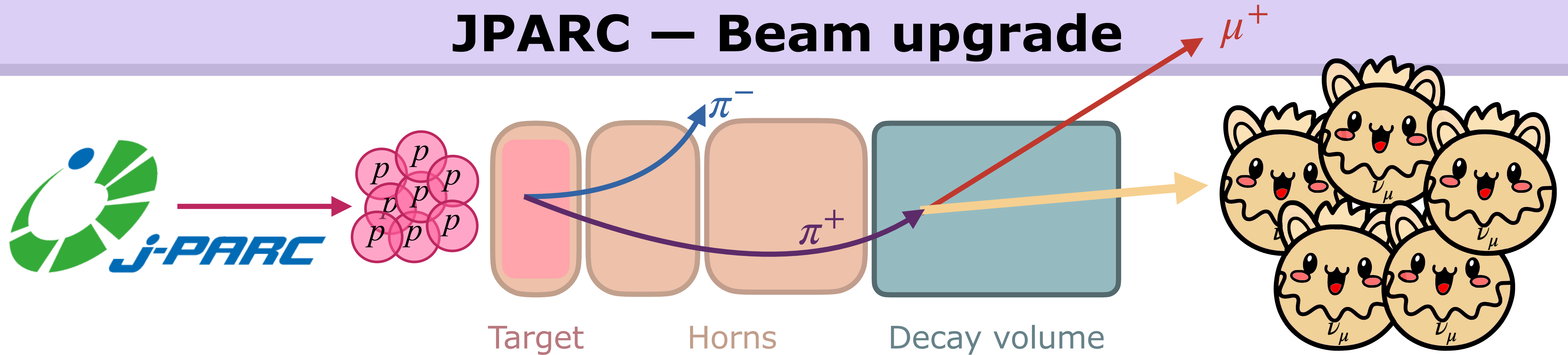
Super-Kamiokande

JPARC — Beam upgrade



Pre-upgrade
Current: 250kA

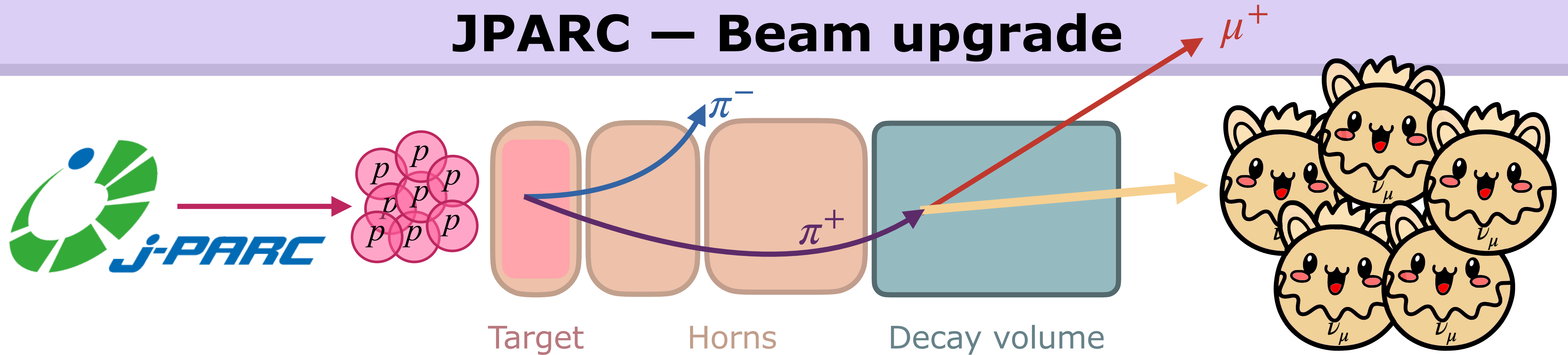
JPARC — Beam upgrade



Pre-upgrade
Current: 250kA

Post-upgrade
Current: 320kA

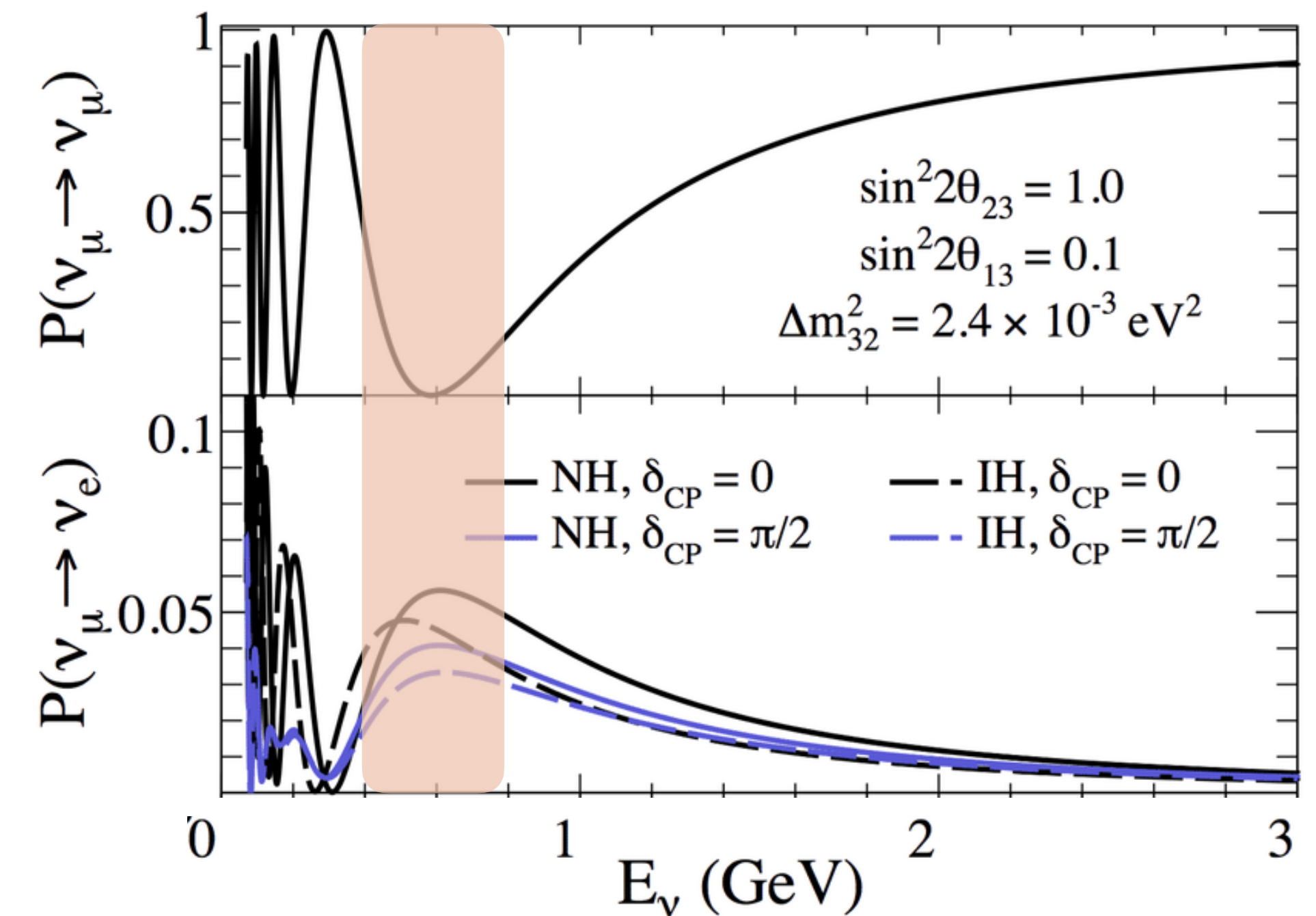
JPARC — Beam upgrade



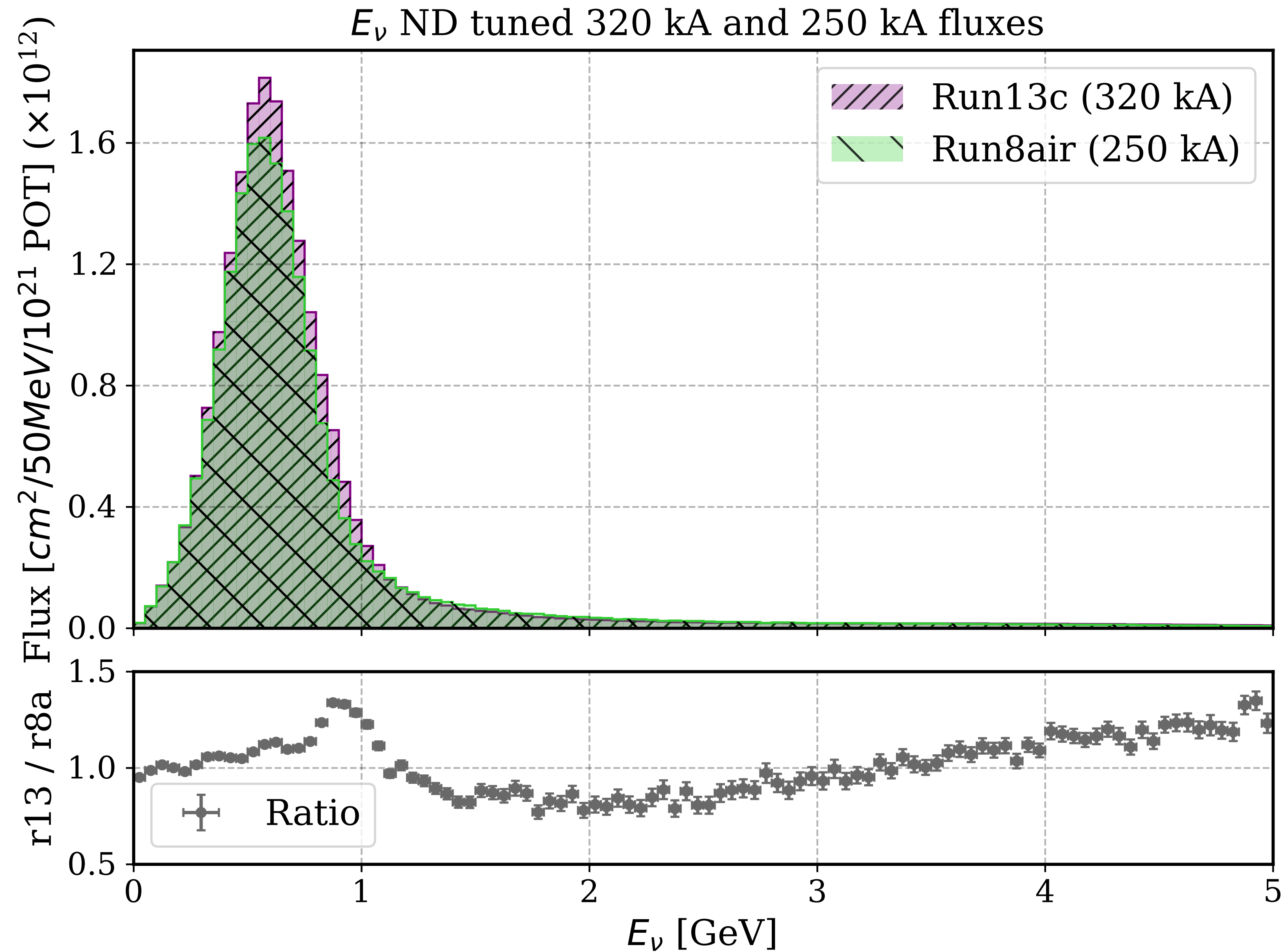
Pre-upgrade
Current: 250kA

Post-upgrade
Current: 320kA

More events
at peak neutrino
energy
(Highest oscillation
probability)



Neutrino flux at ND



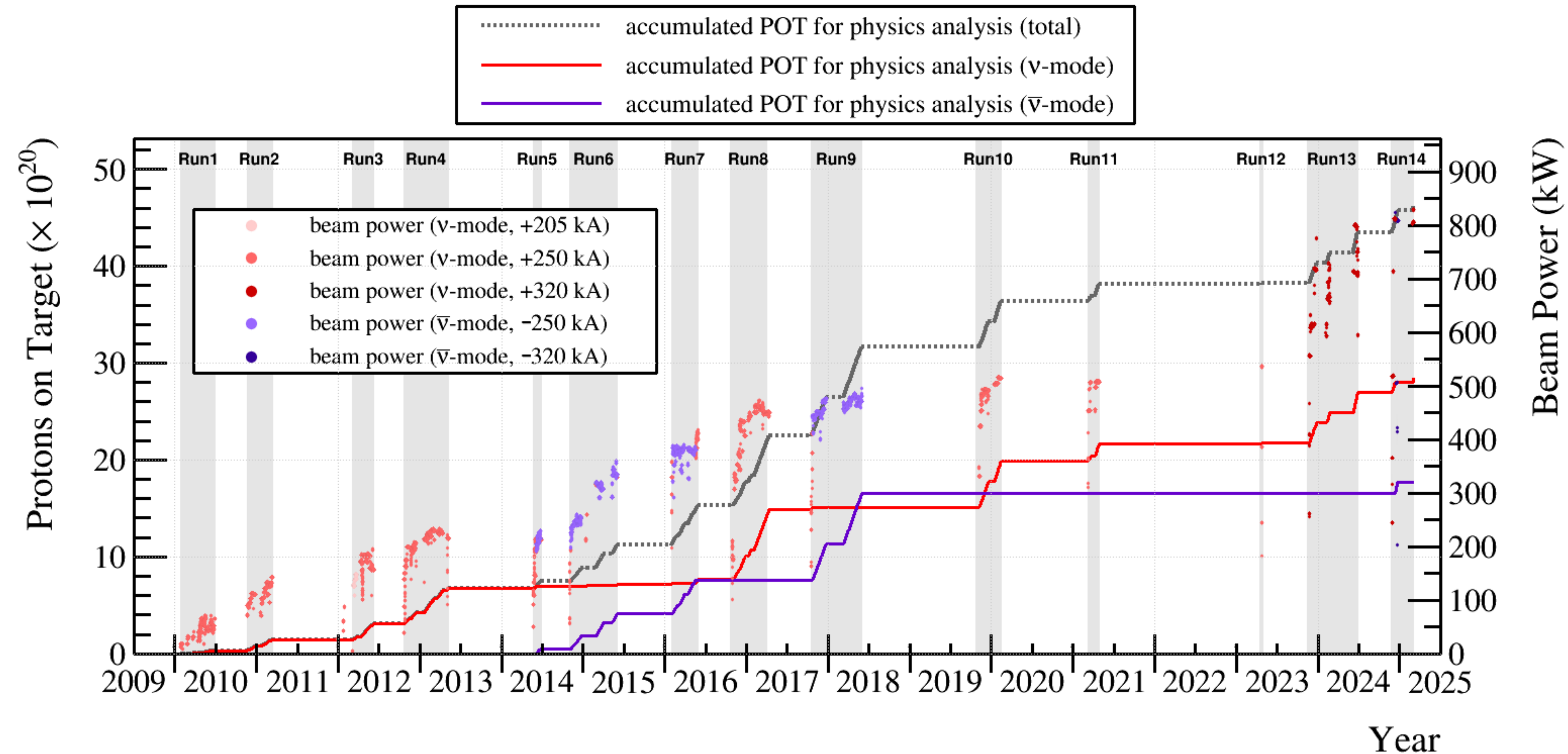
320 kA (new flux)

250 kA (old flux)

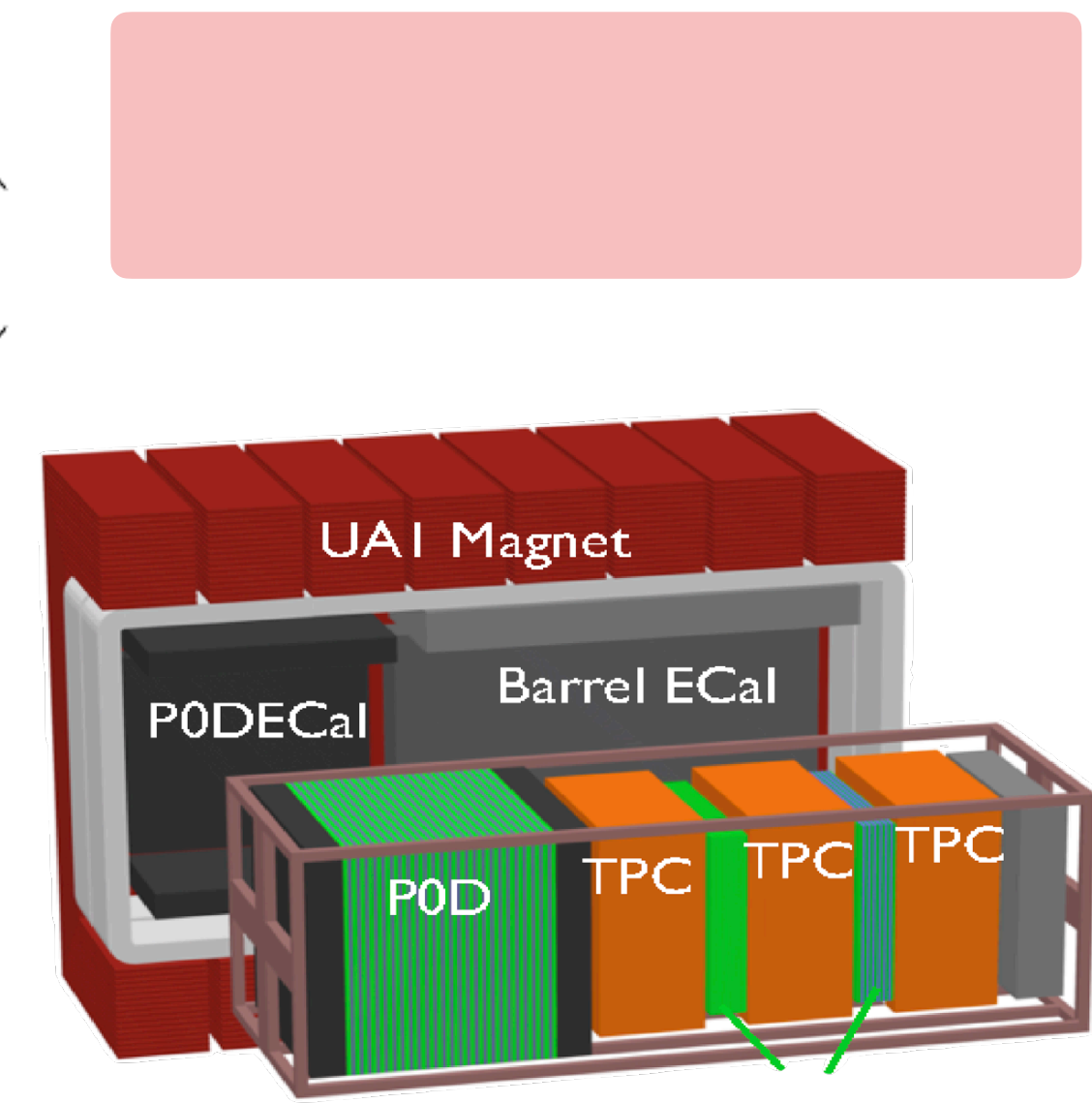
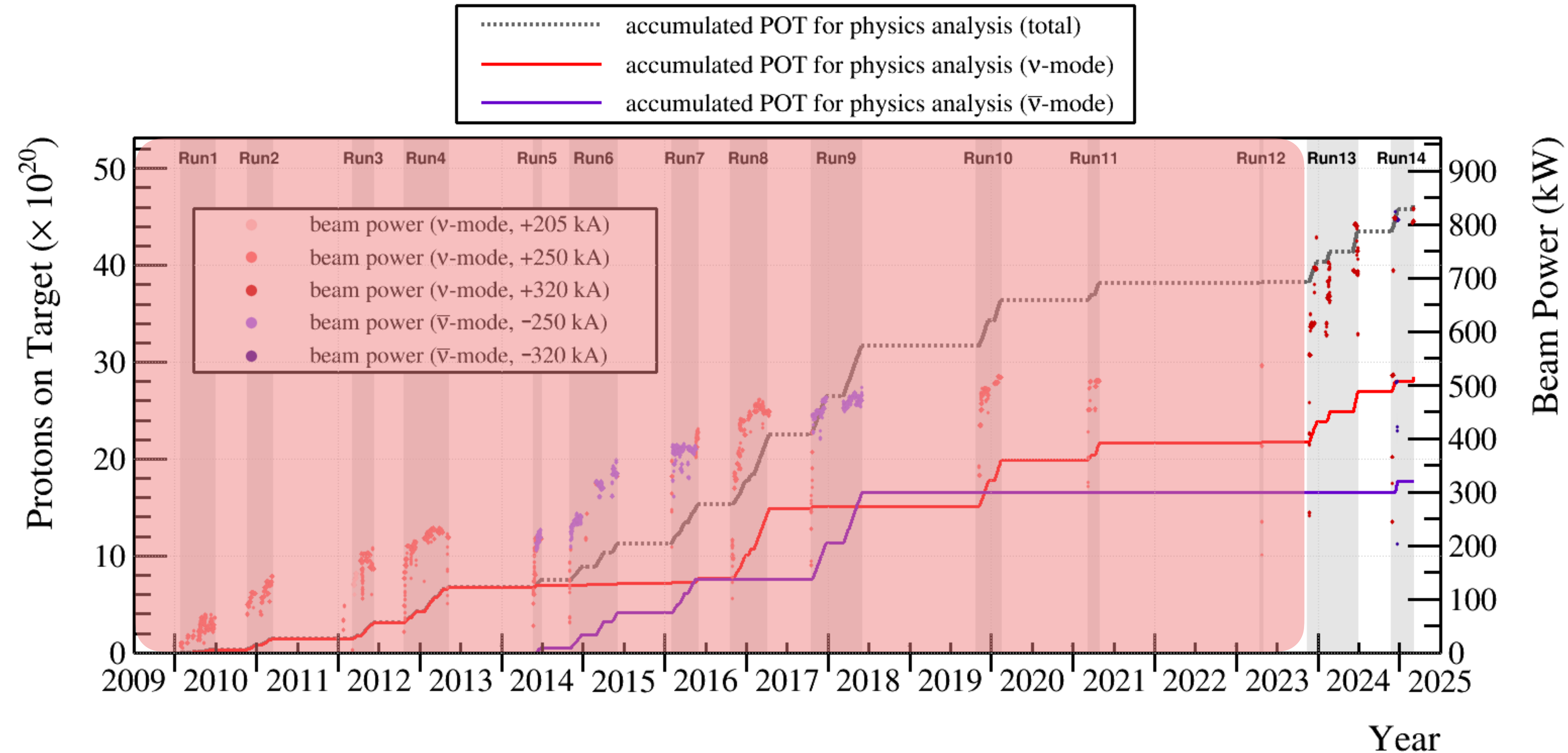
~10% increase
at the peak

Flux FHC (ν_μ)

Accumulated POT over time

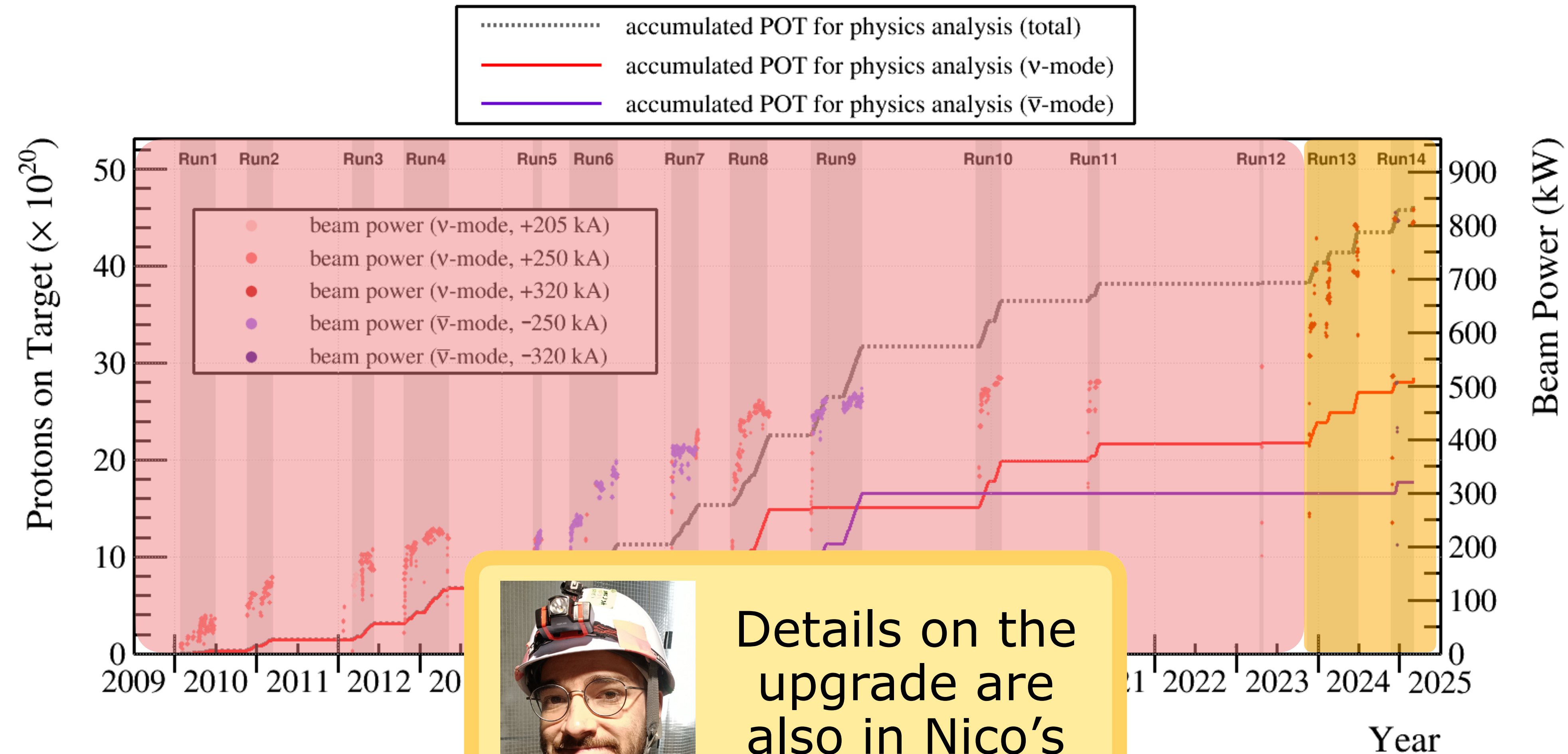


Data in pre-upgrade era

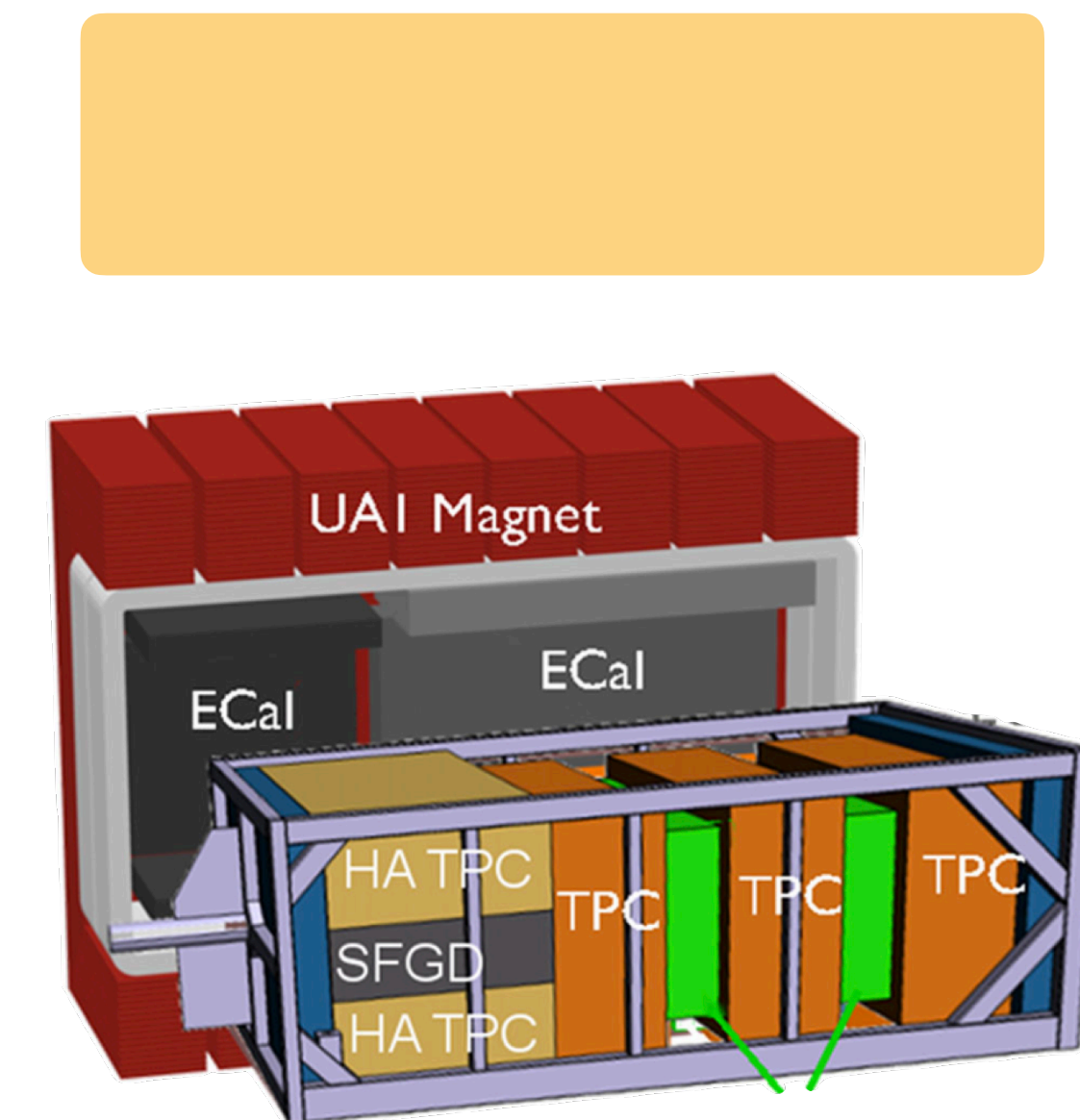


Current:
 $\pm 250\text{kA}$

Detector and beam upgrade

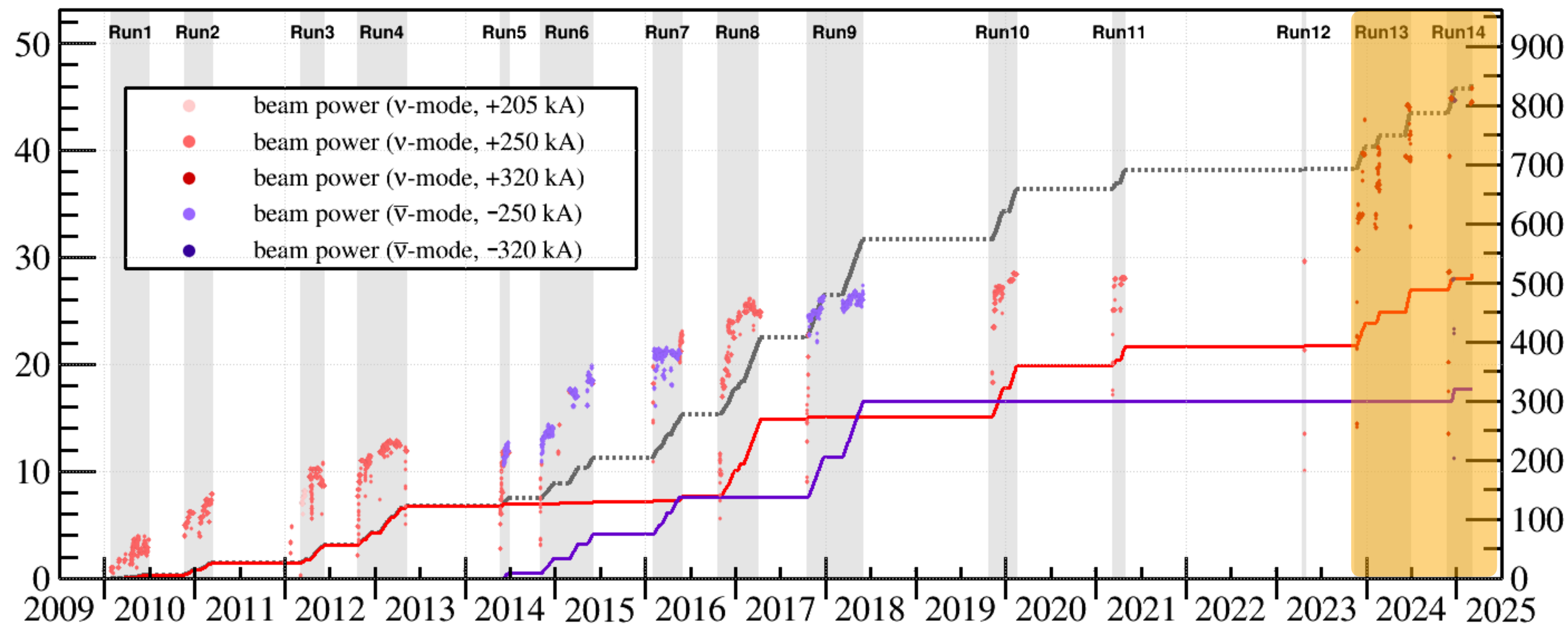


Details on the upgrade are also in Nico's presentation!



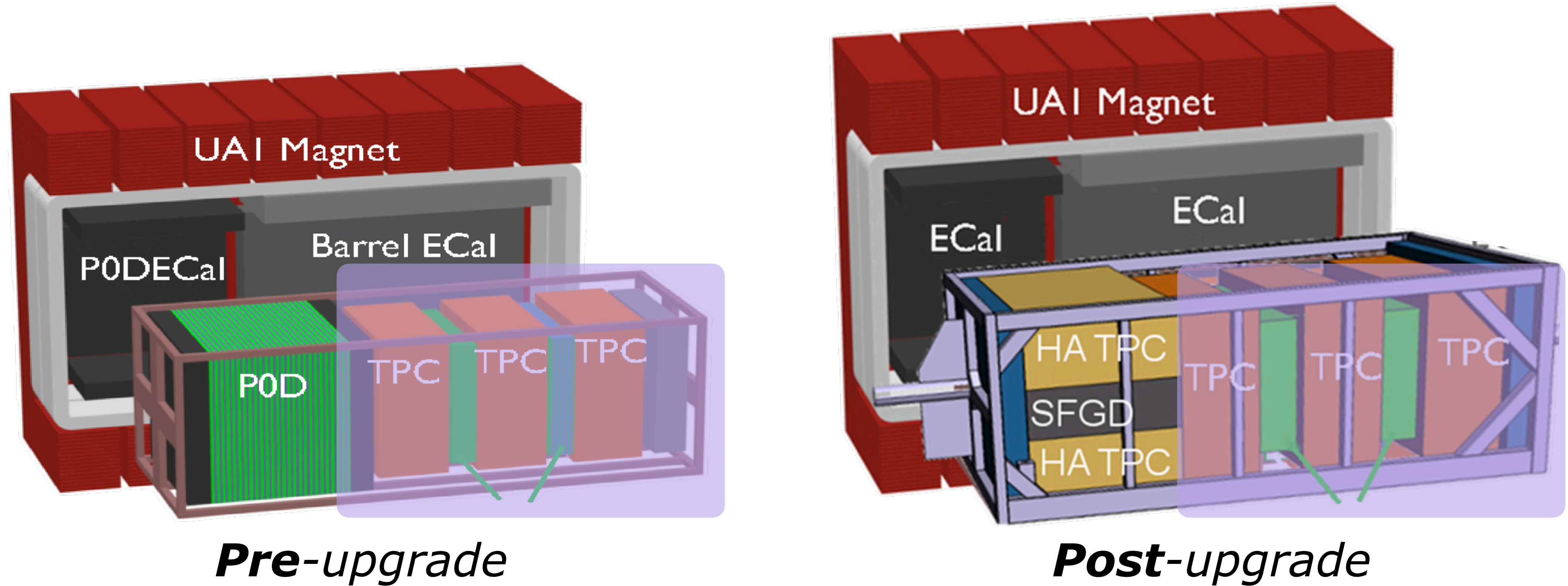
Current:
 $\pm 320\text{kA}$

Two upgrades



Two upgrades were made at the same time (ND and flux), we want to disentangle their effects. I will focus on the upgrade of the beam.

Pre and post upgrade comparisons



Compare the physics variable in the sub-detectors that stayed the same before and after the upgrades.

Full plan

Plan:

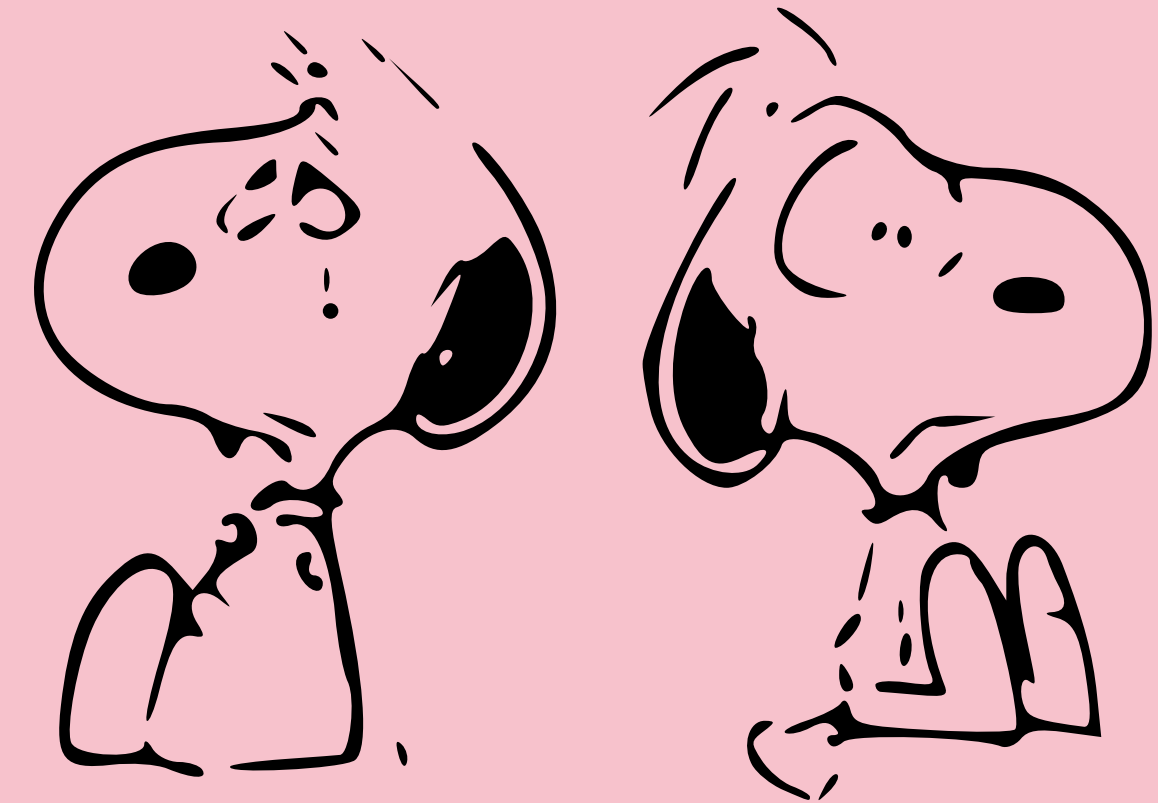
- Check MC & data distribution of 320kA & 250 kA of outgoing muon kinematics
- Study the data/MC agreement of 320kA vs 250kA (accounting for errors)



320kA **consistent** with 250kA, OK



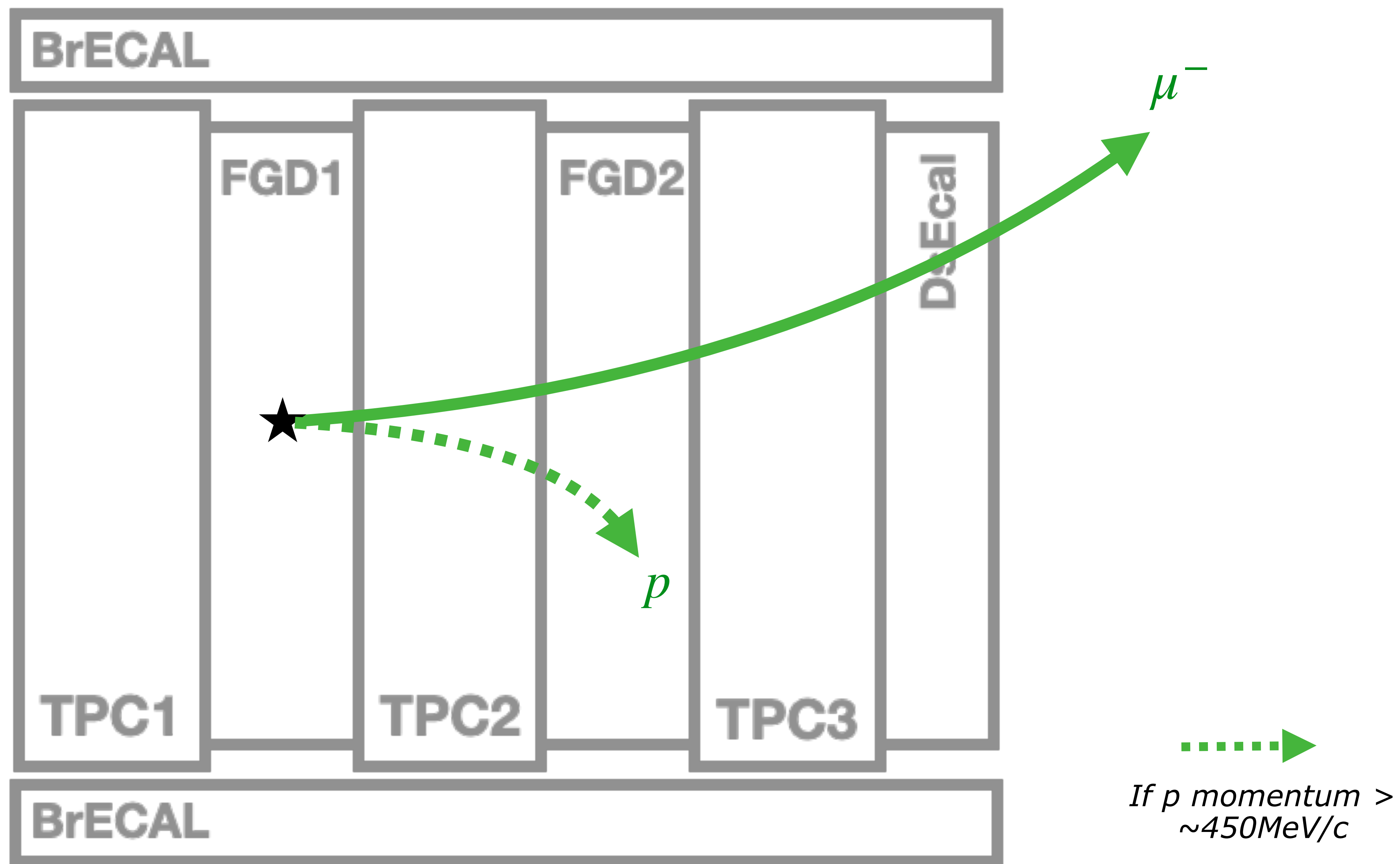
Not consistent, not OK



Using legacy detectors FGD1 CC0 π



As
detailed
in Nico's
slides!
:D



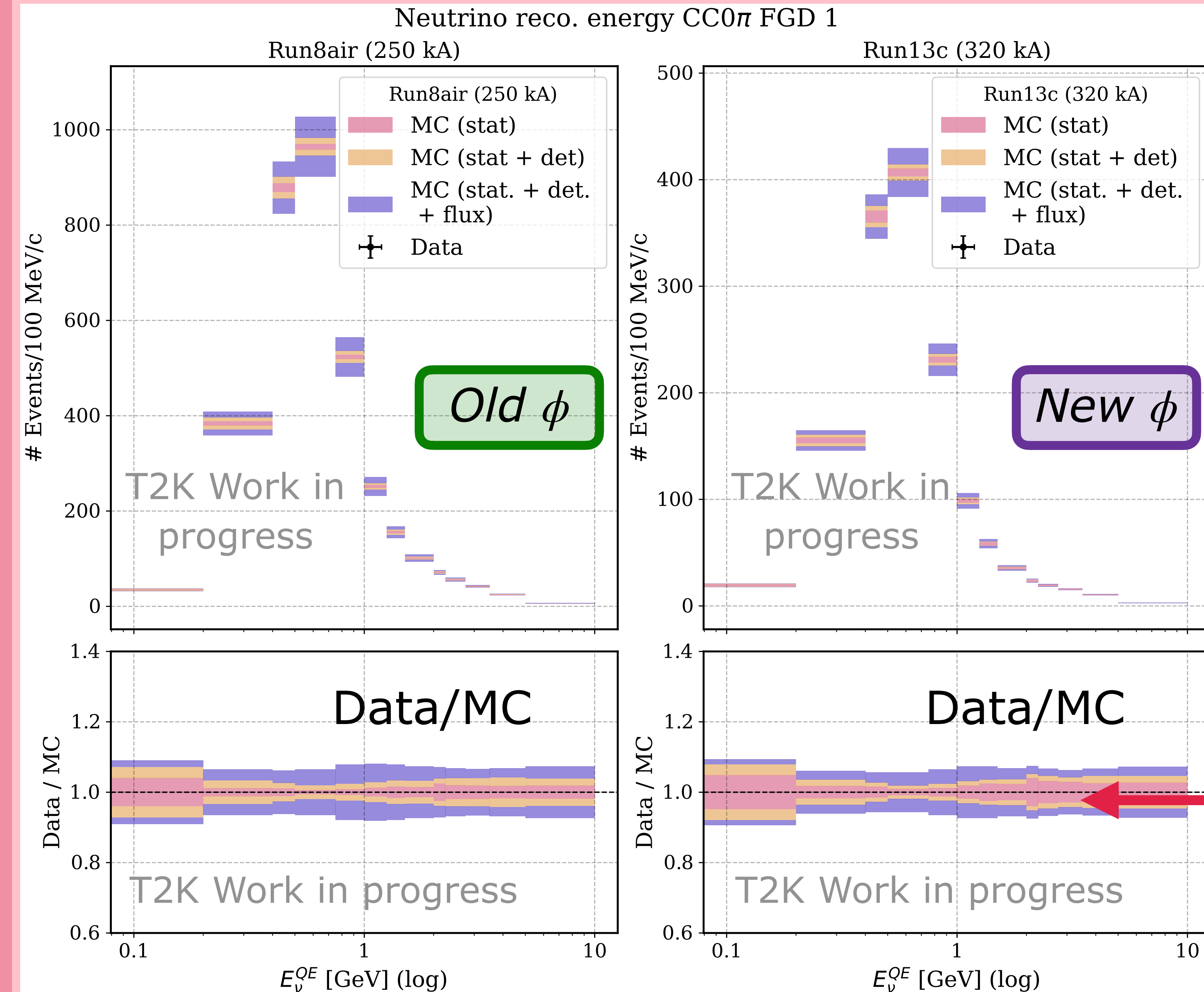


Validation of the new flux

CC0Pi sample FGD1 reco neutrino energy



Centred around unity
for visualisation purposes



CC0Pi sample FGD1 reco neutrino energy

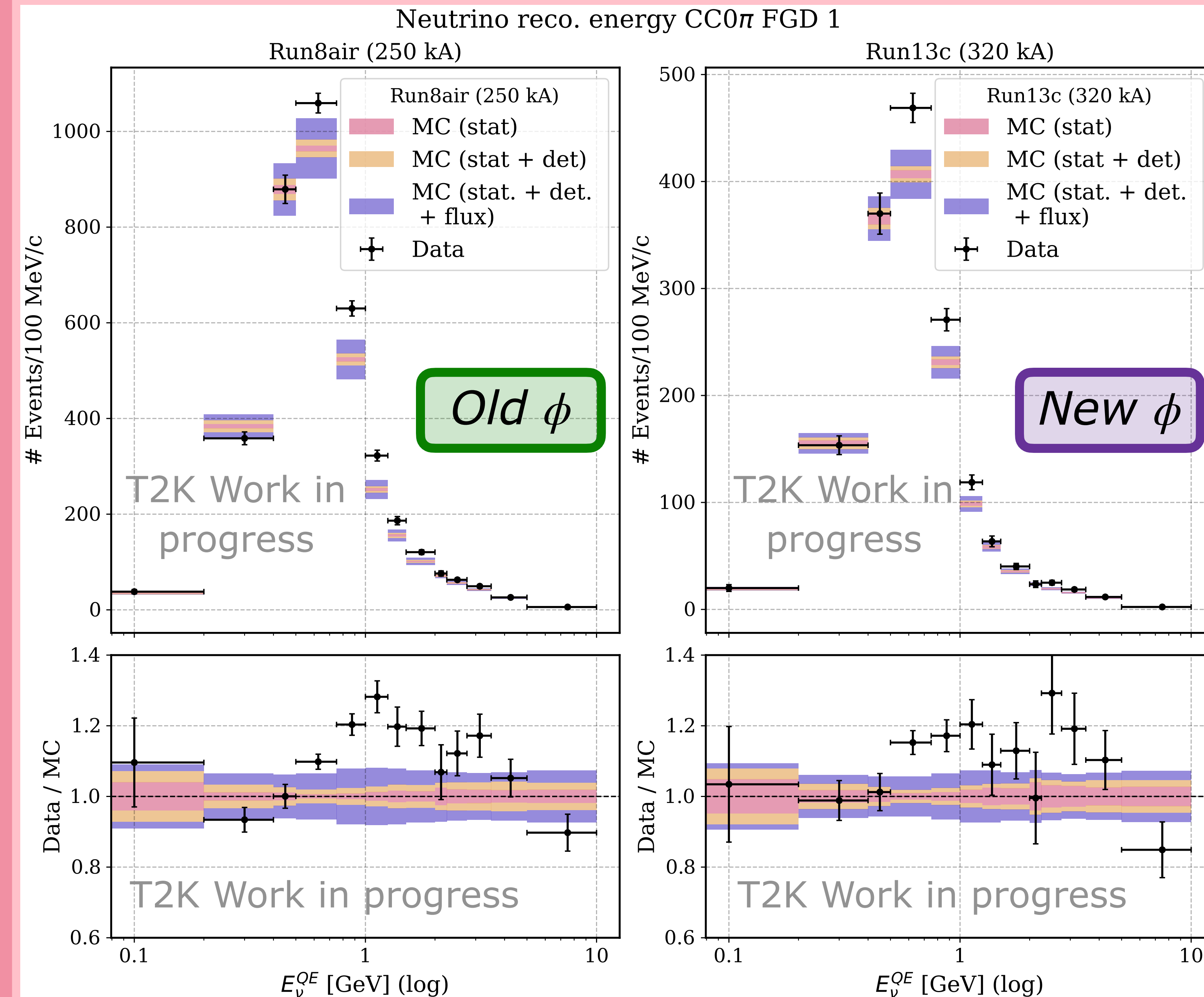
* Pre-fit MC not following data is expected*

* "By-eye" similar trend in the Data/MC ratios



Details on
oscillation
analysis (OA) in
Nico's
presentation!

*Tuning needed before oscillation analysis



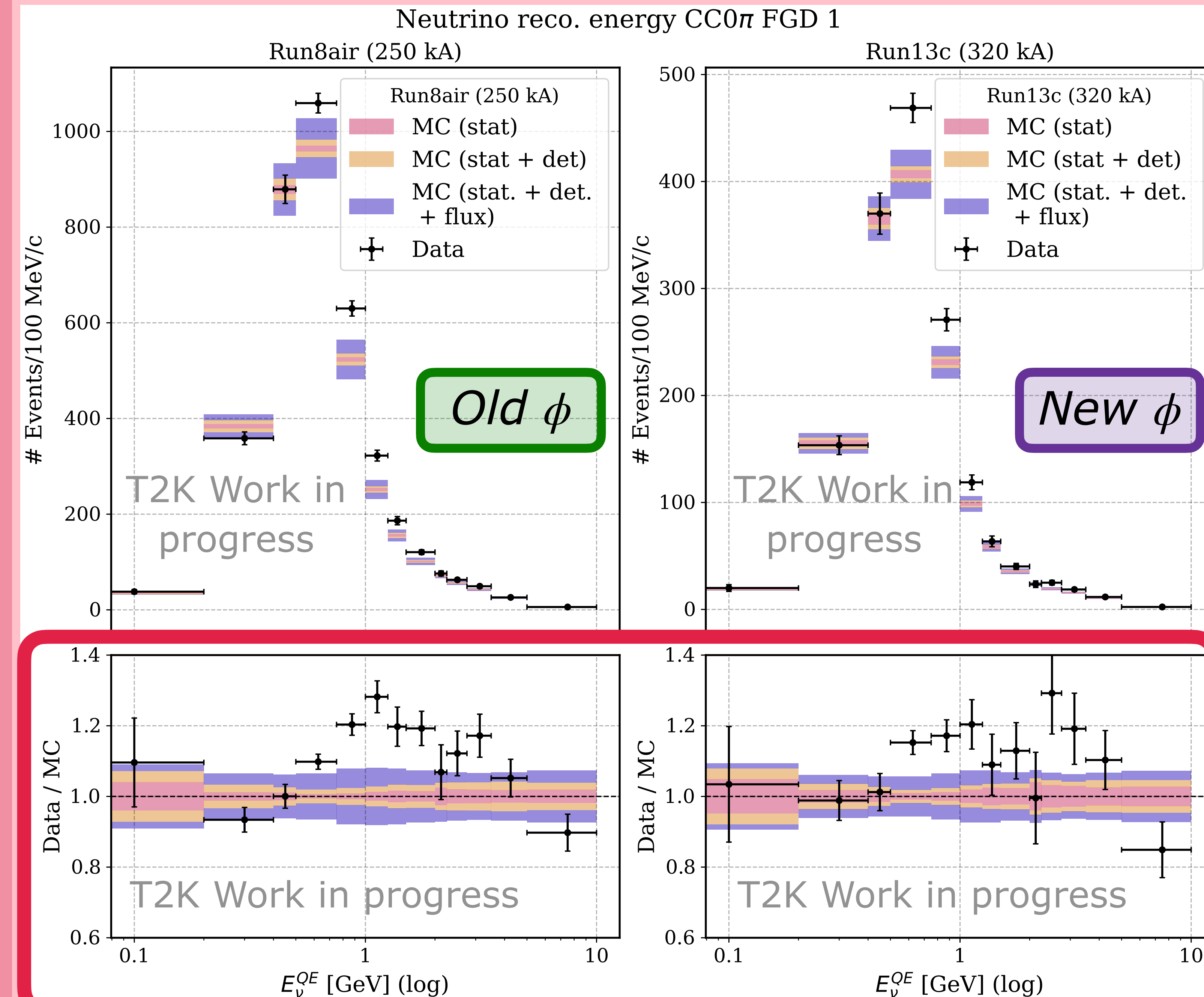
CC0Pi sample FGD1 reco neutrino energy

* Pre-fit MC not following data is expected*

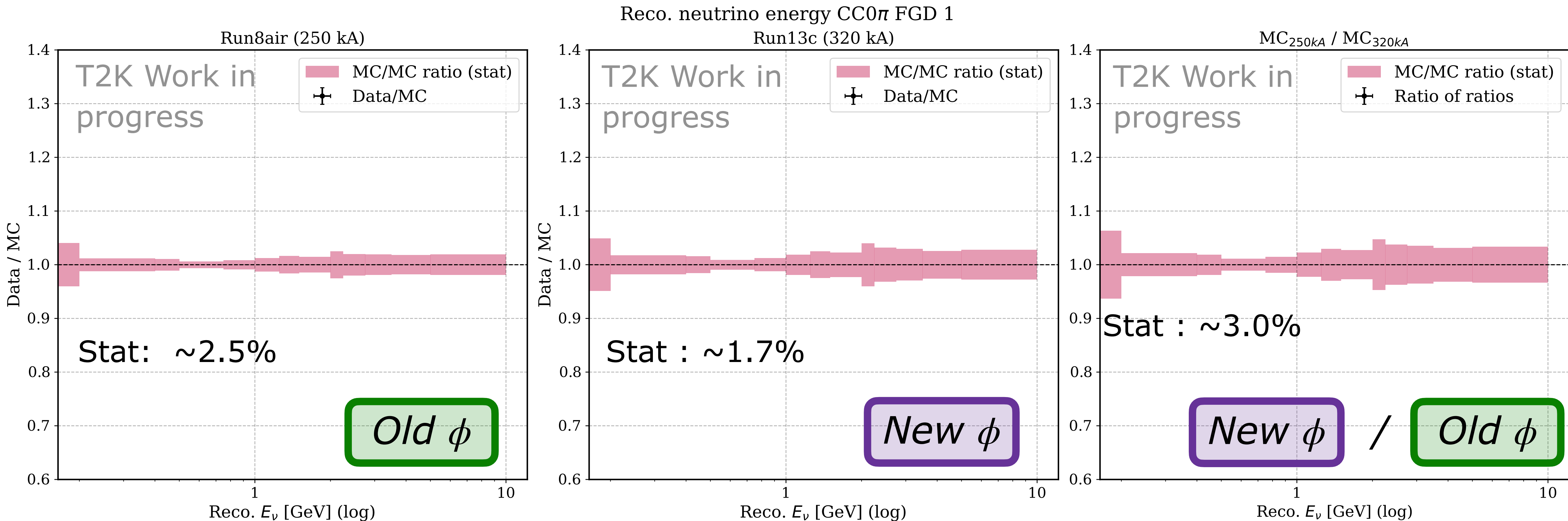
* "By-eye" similar trend in the Data/MC ratios

* Focus on the ratios :
need to compute the
320 kA / 250 kA ratio

*Tuning needed before oscillation analysis

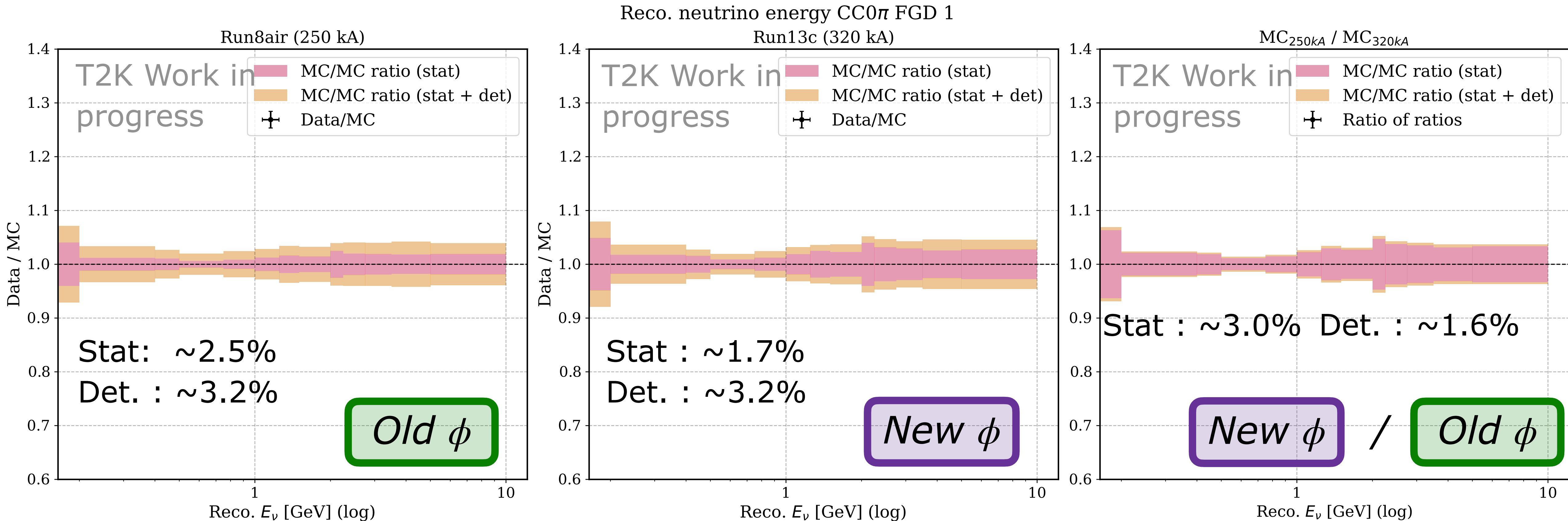


Neutrino reconstructed energy: stat only



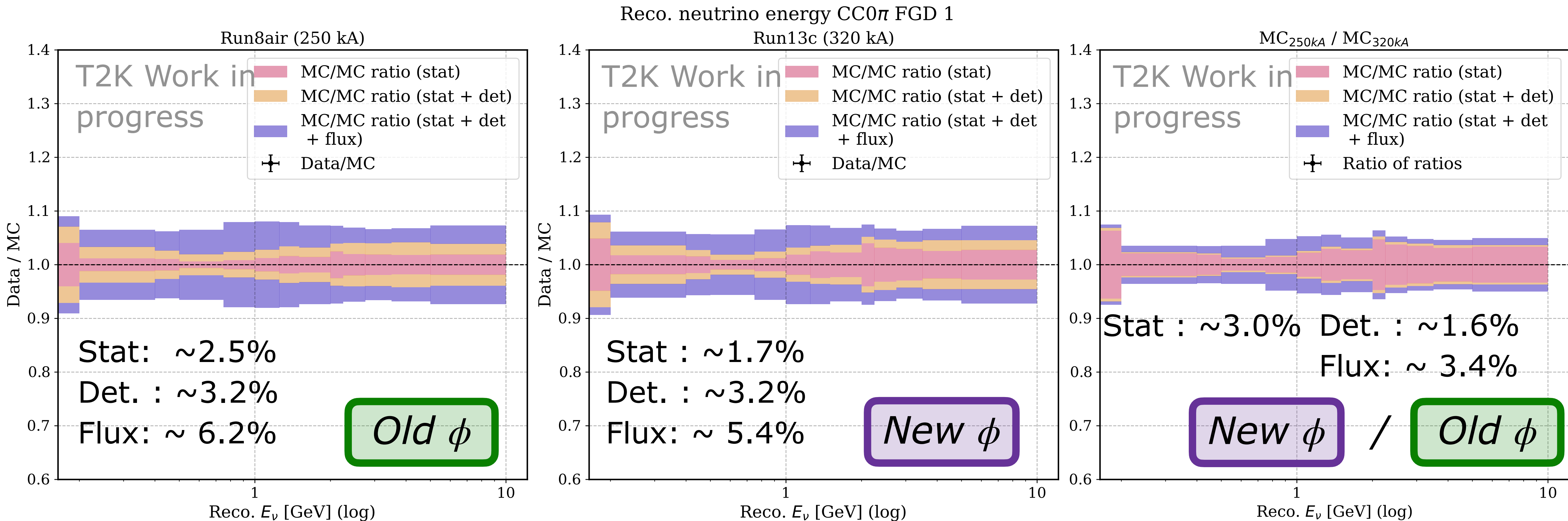
MC statistical uncertainty are added quadratically.

Neutrino reconstructed energy: stat + det



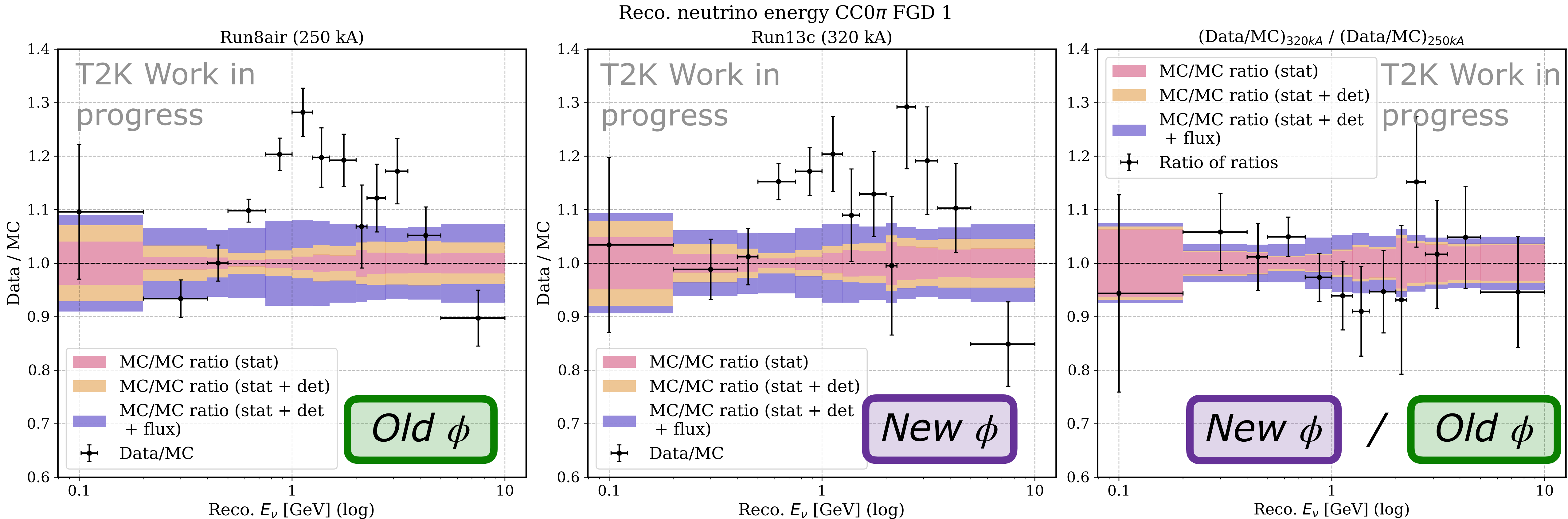
Detector uncertainties are re-computed. Much lower in case of ratios as most detector components are the same.

Neutrino reconstructed energy: stat + det + flux



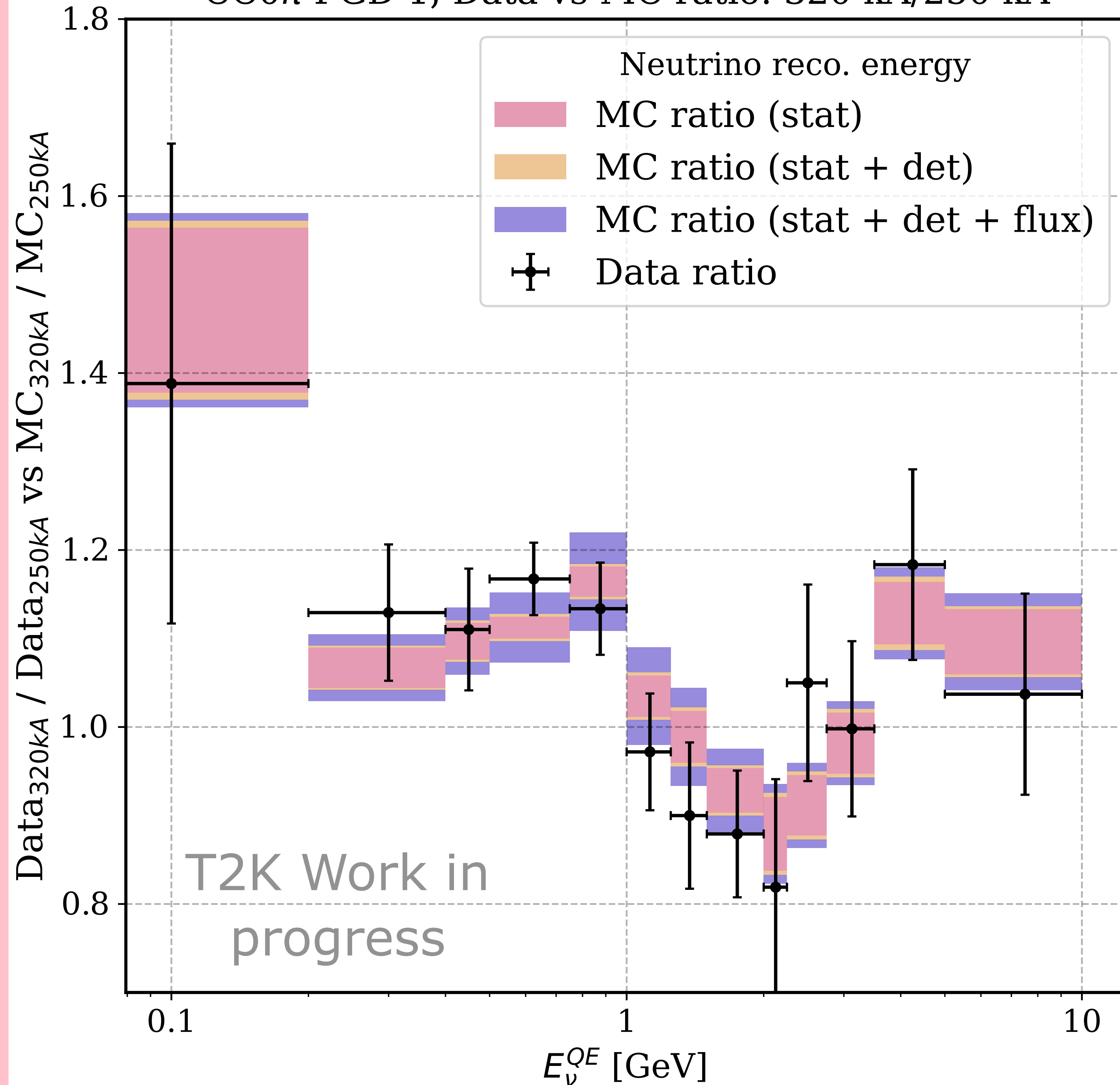
Flux uncertainties are re-computed. Lower in case of ratios as most flux components are the same.

Muon momentum: stat + det + flux + data



Uncertainties are added quadratically. All data point for ratio of ratios fall within uncertainties i.e. we model in a **similar** way both flux.

CC0 π FGD 1, Data vs MC ratio: 320 kA/250 kA



CC0Pi sample FGD1 reco neutrino energy

What is plotted:

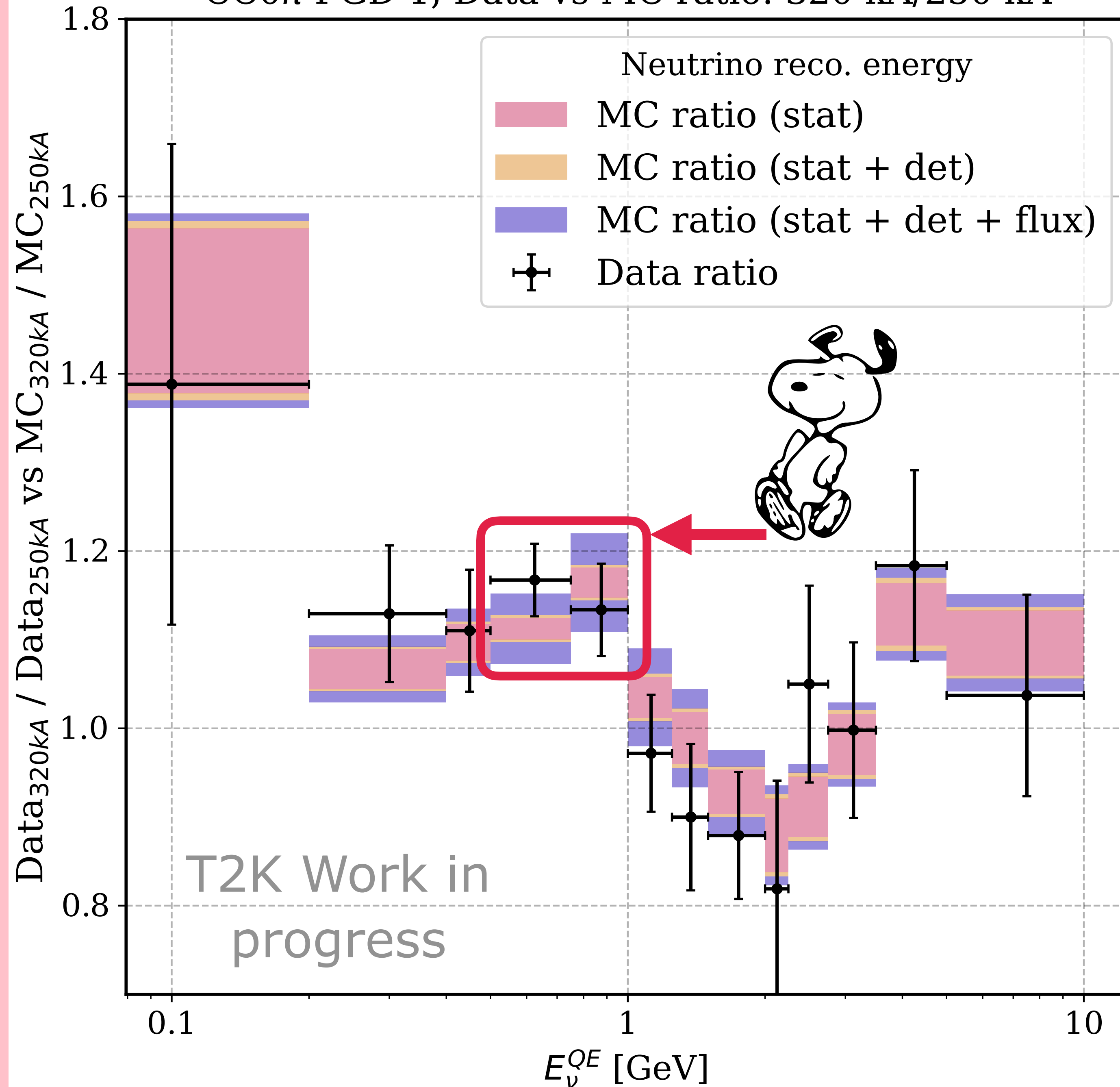
$$\frac{\text{Data}_{320\text{kA}}}{\text{Data}_{250\text{kA}}} \text{ against } \frac{\text{MC}_{320\text{kA}}}{\text{MC}_{250\text{kA}}}$$

~10% increase at the peak
Less events in the queue (>1GeV)

Here accounting for exposure differences.

P-value = 0.932

CC0 π FGD 1, Data vs MC ratio: 320 kA/250 kA



CC0Pi sample FGD1 reco neutrino energy

What is plotted:

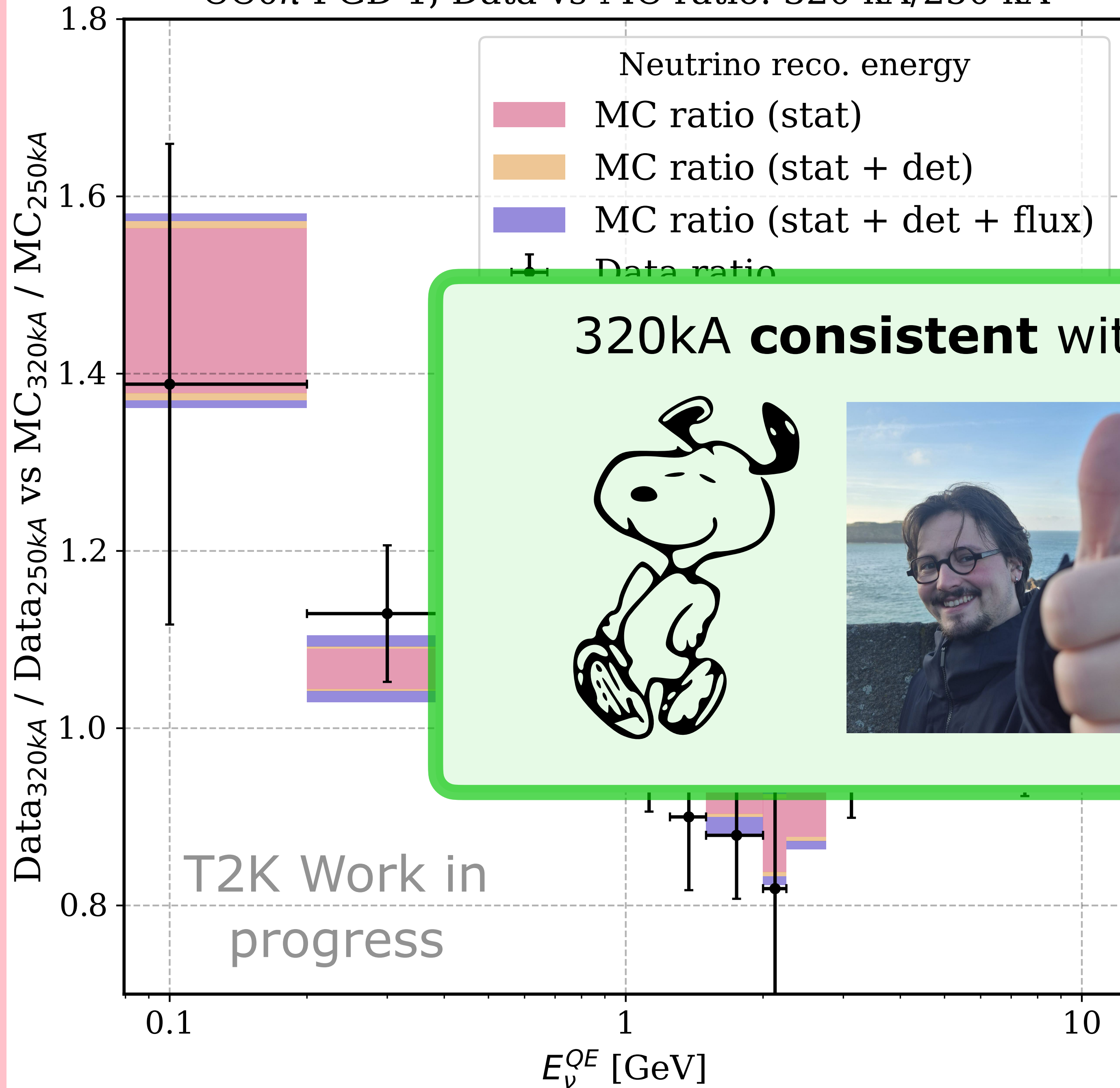
$$\frac{\text{Data}_{320\text{kA}}}{\text{Data}_{250\text{kA}}} \text{ against } \frac{\text{MC}_{320\text{kA}}}{\text{MC}_{250\text{kA}}}$$

~10% increase at the peak
Less events in the queue (>1GeV)

Here accounting for exposure differences.

P-value = 0.932

CC0 π FGD 1, Data vs MC ratio: 320 kA/250 kA



CC0Pi sample FGD1 reco neutrino energy

What is plotted:

320kA **consistent** with 250kA, OK



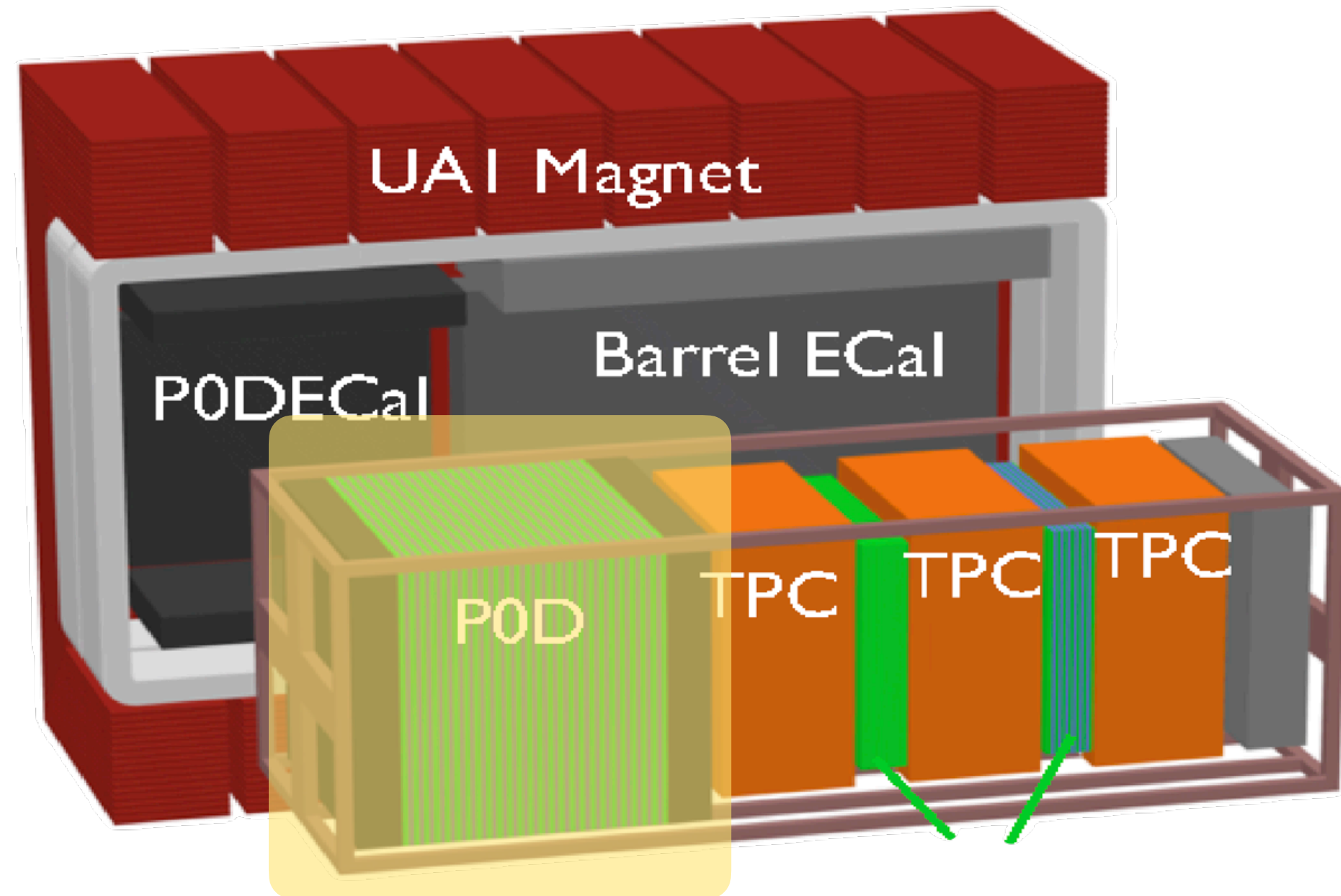
against $\frac{MC_{320kA}}{MC_{250kA}}$

at the peak
neutrino queue (>1GeV)

Here accounting for exposure differences.

P-value = 0.932

Pre and post upgrade comparisons



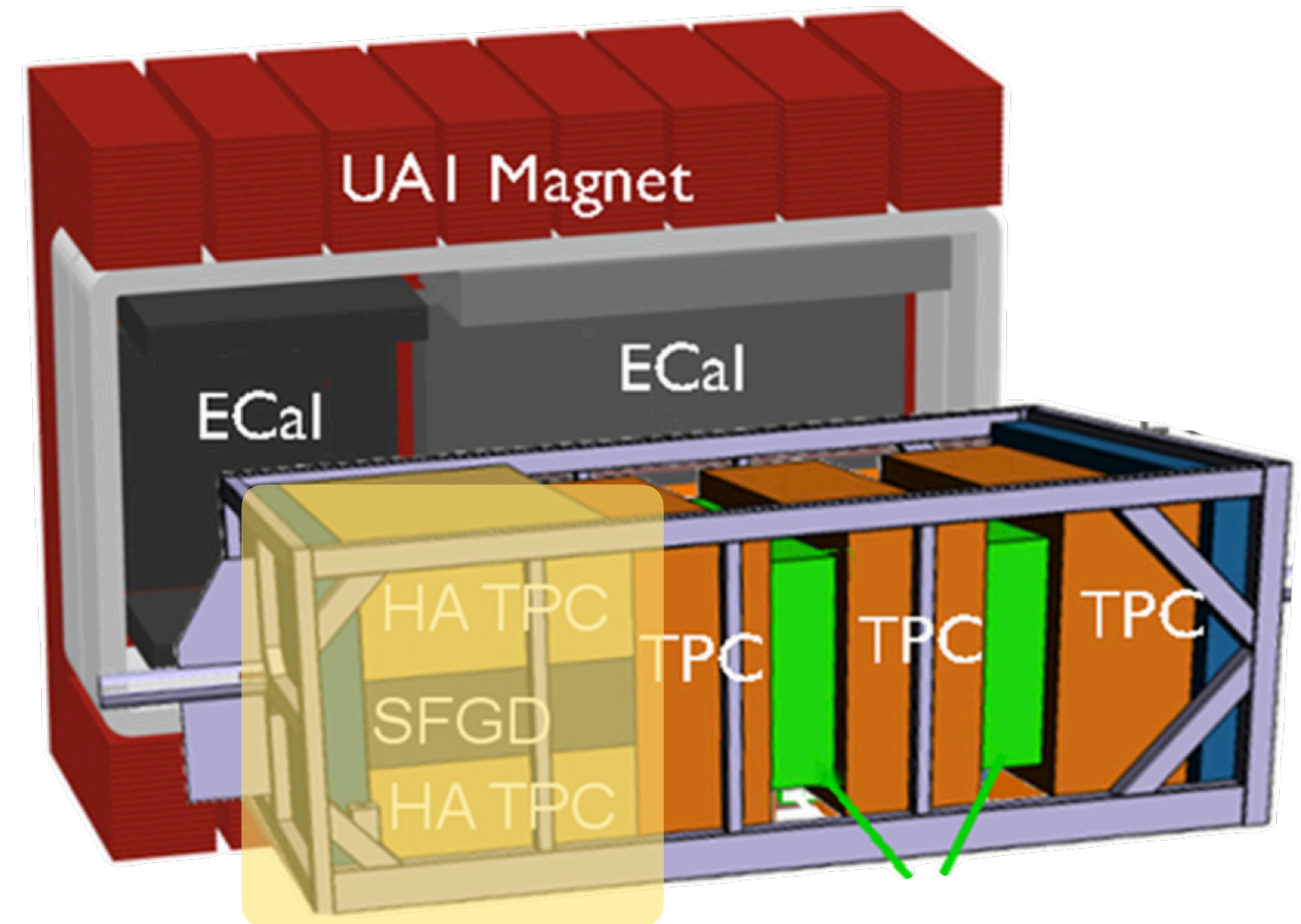
Pre-upgrade

TPC: Time Projection Chamber

HA TPC: High Angle TPC

FGD: Fine Grained Detector

SFGD: Super FGD



Post-upgrade

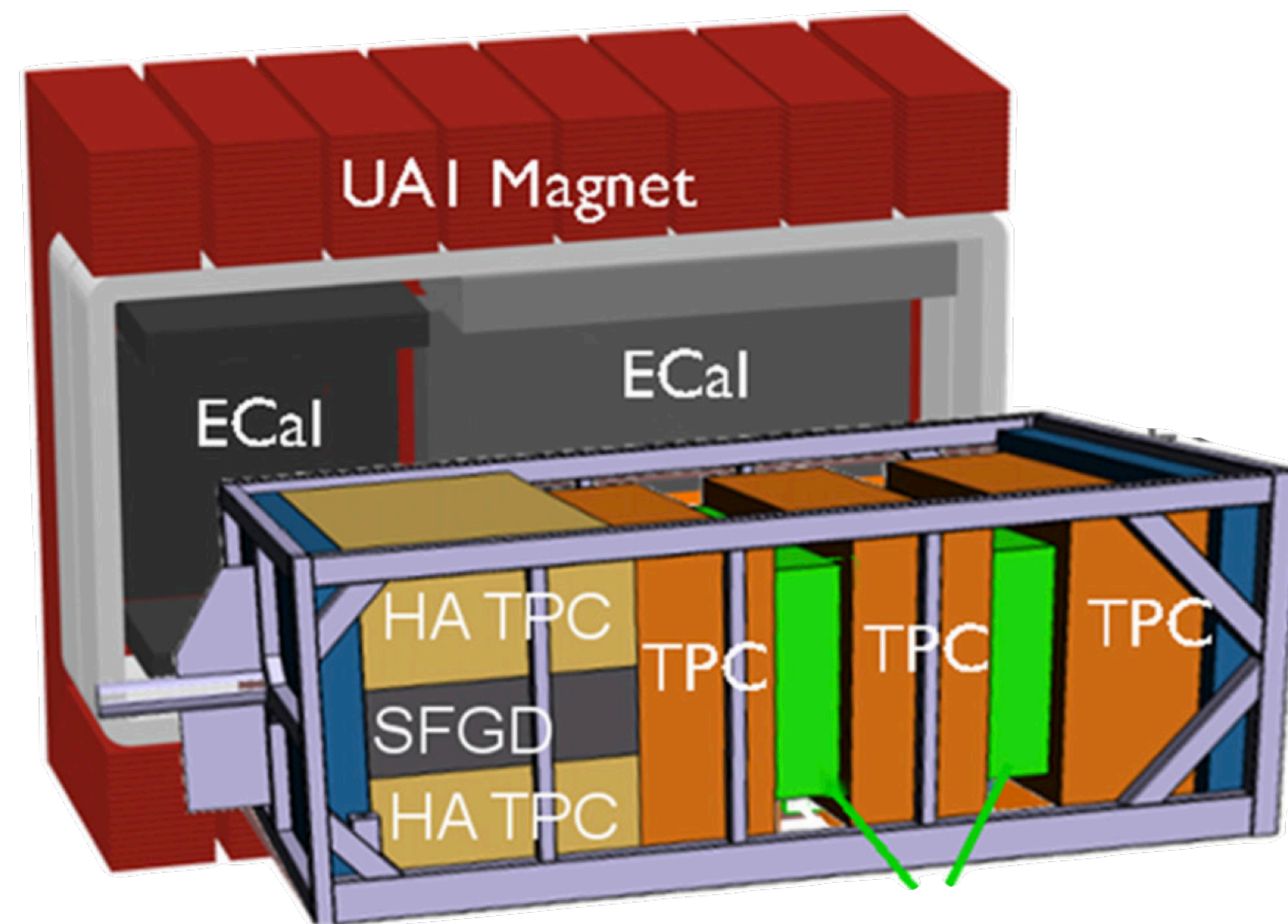
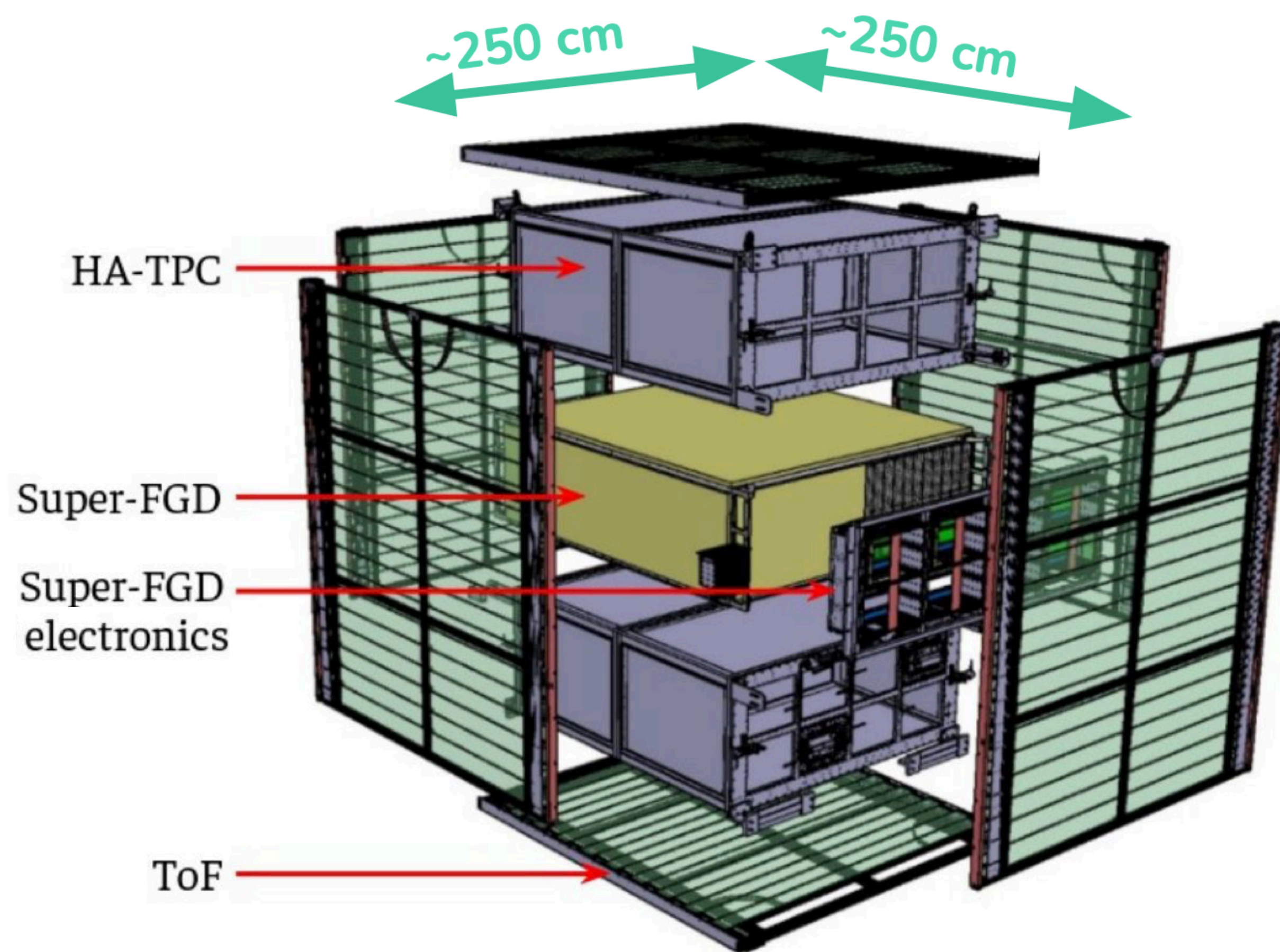
Upgrade:

Improved 4π acceptance

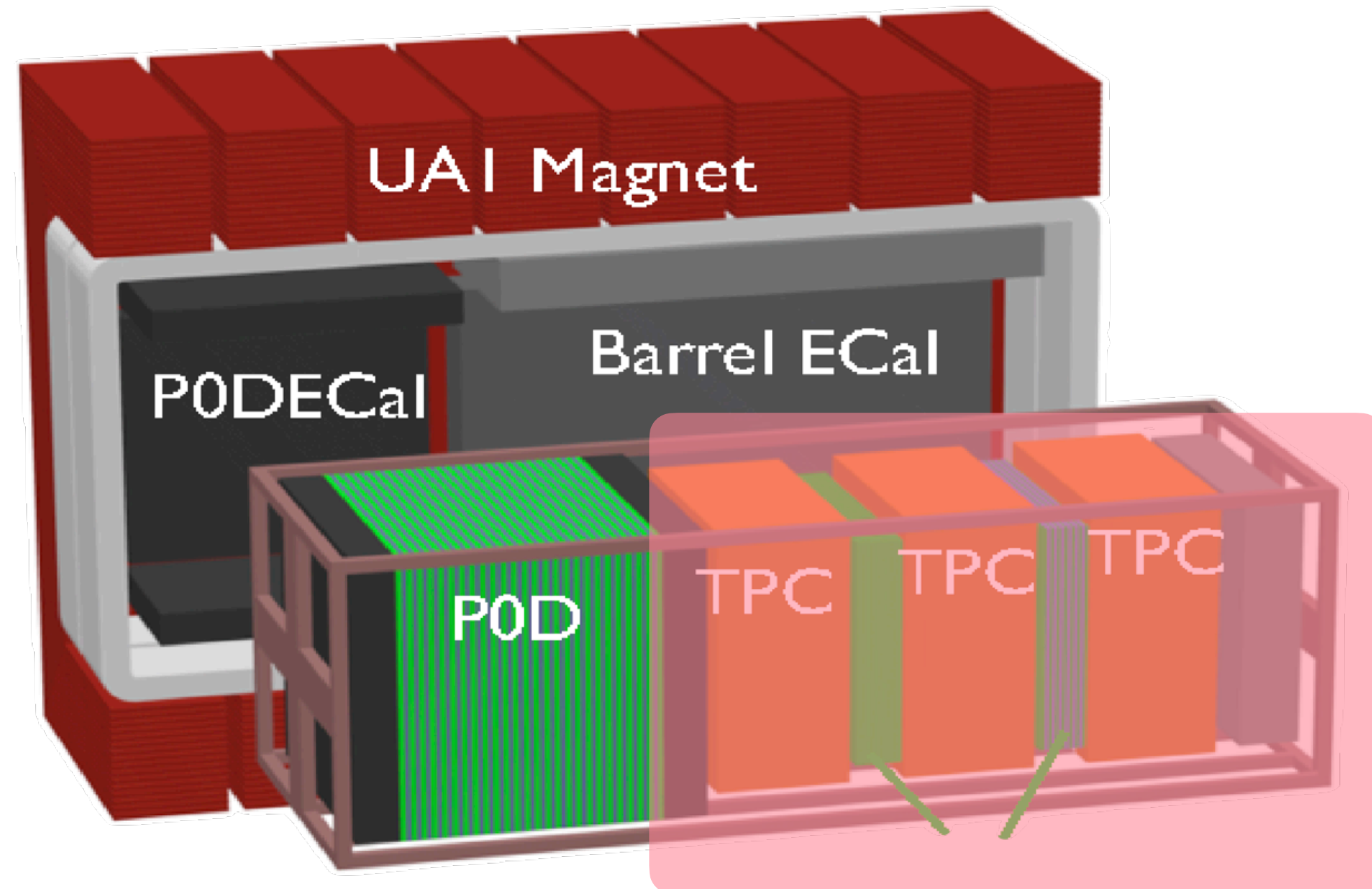
Improved protons detection threshold

Improved neutron detection

New detectors in post upgrade



Pre and post upgrade comparisons



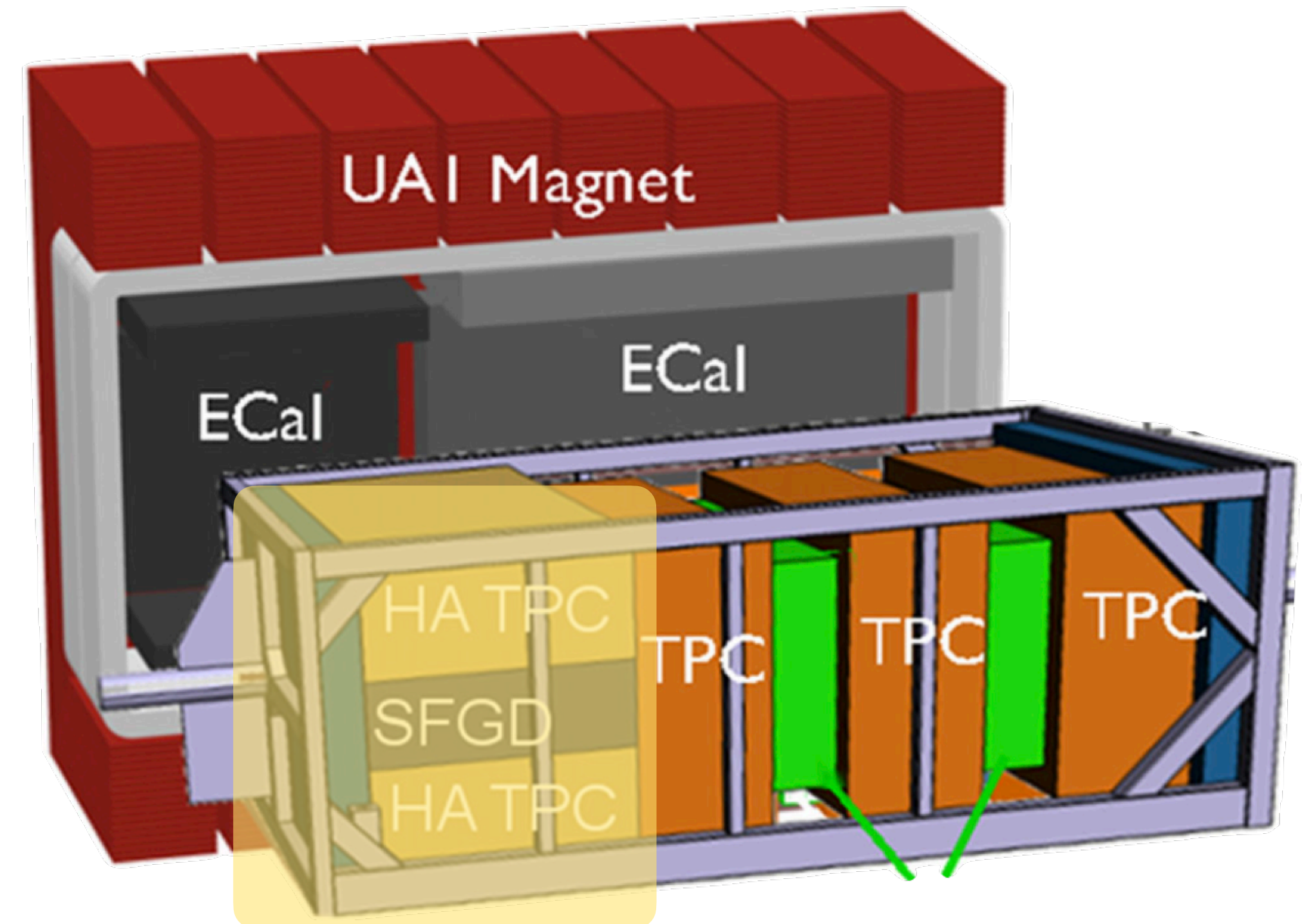
Pre-upgrade

TPC: Time Projection Chamber

HA TPC: High Angle TPC

FGD: Fine Grained Detector

SFGD: Super FGD



Post-upgrade

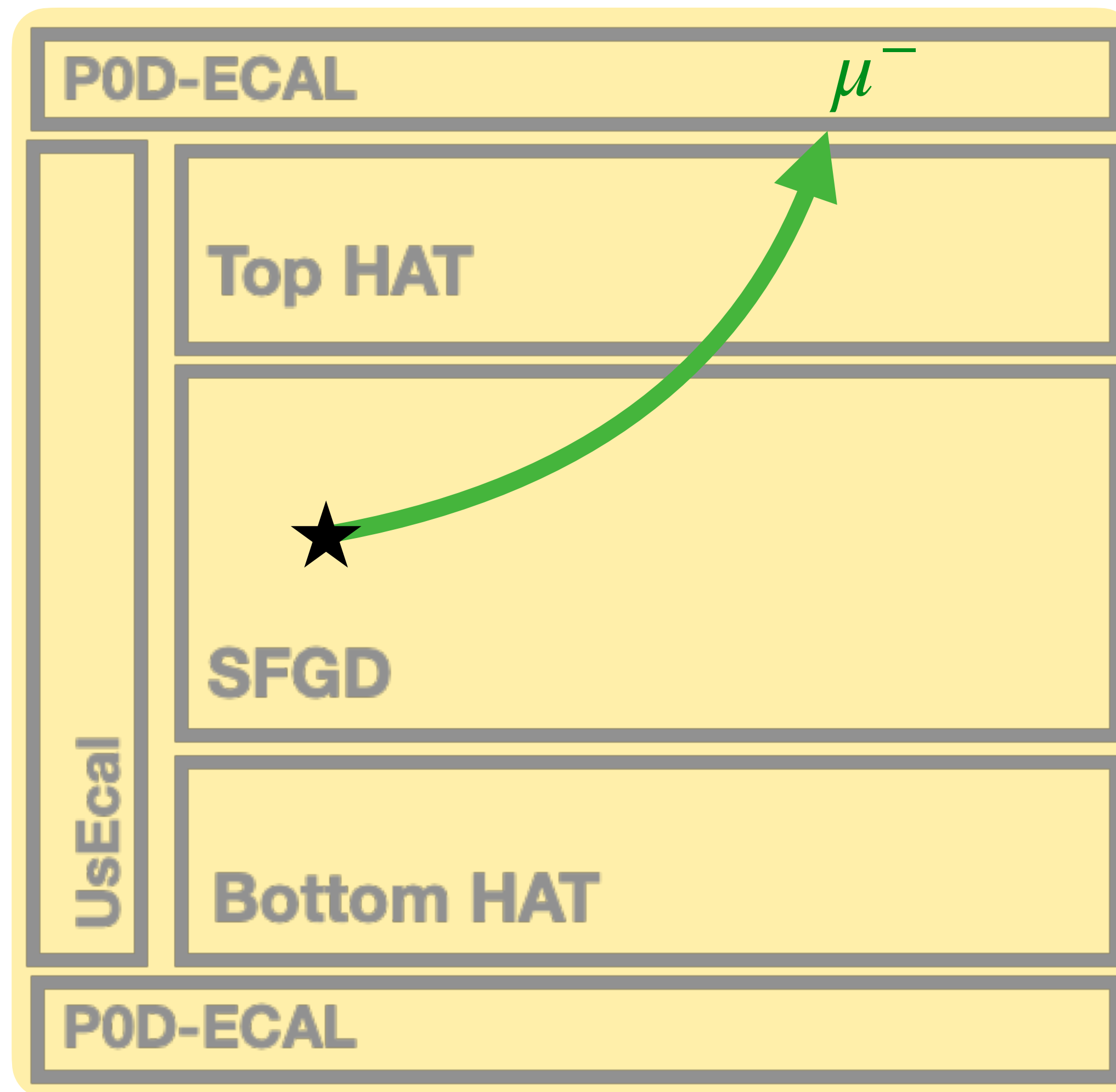
Upgrade:

Improved 4π acceptance

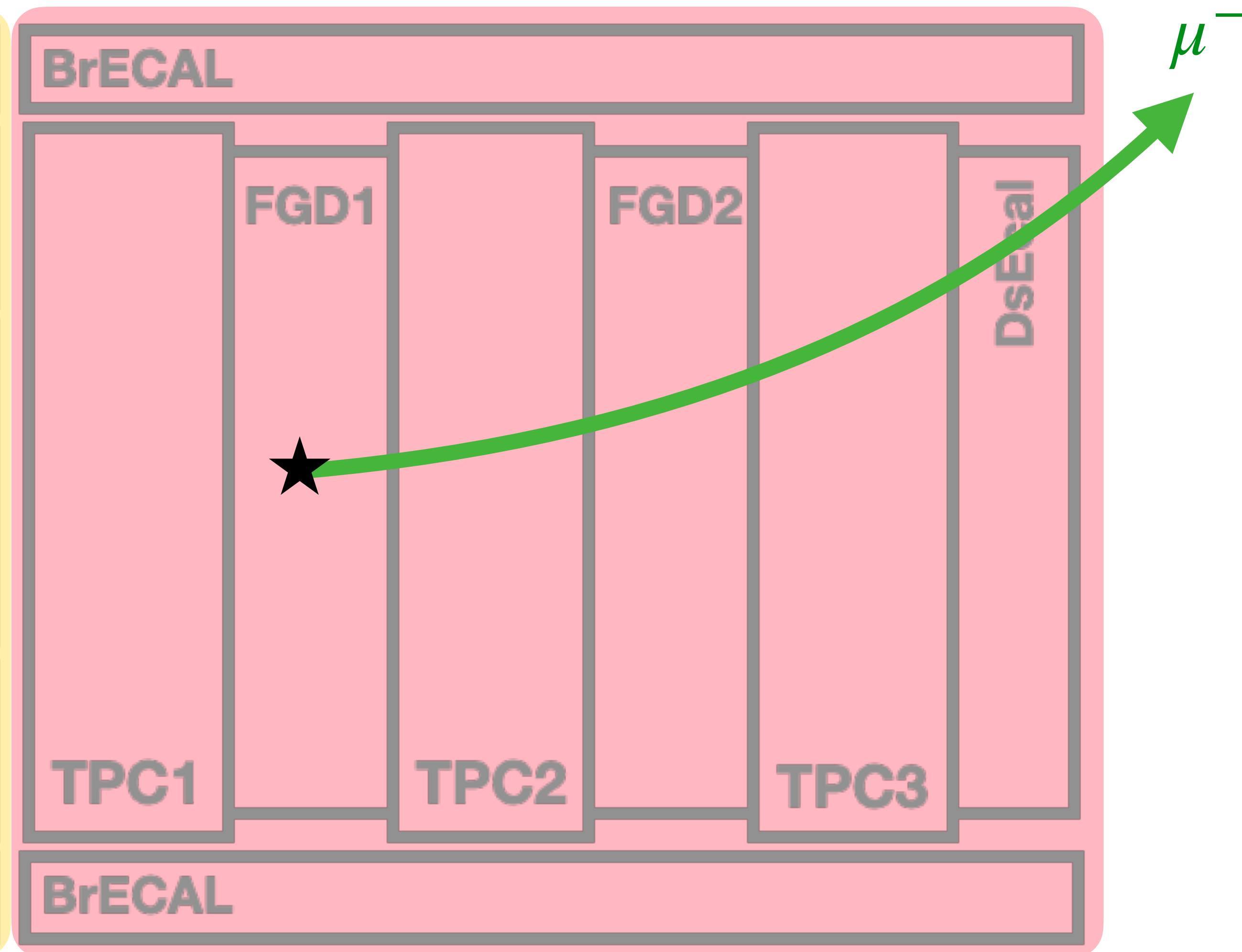
Improved protons detection threshold

Improved neutron detection

Upgrade selection against classic selection



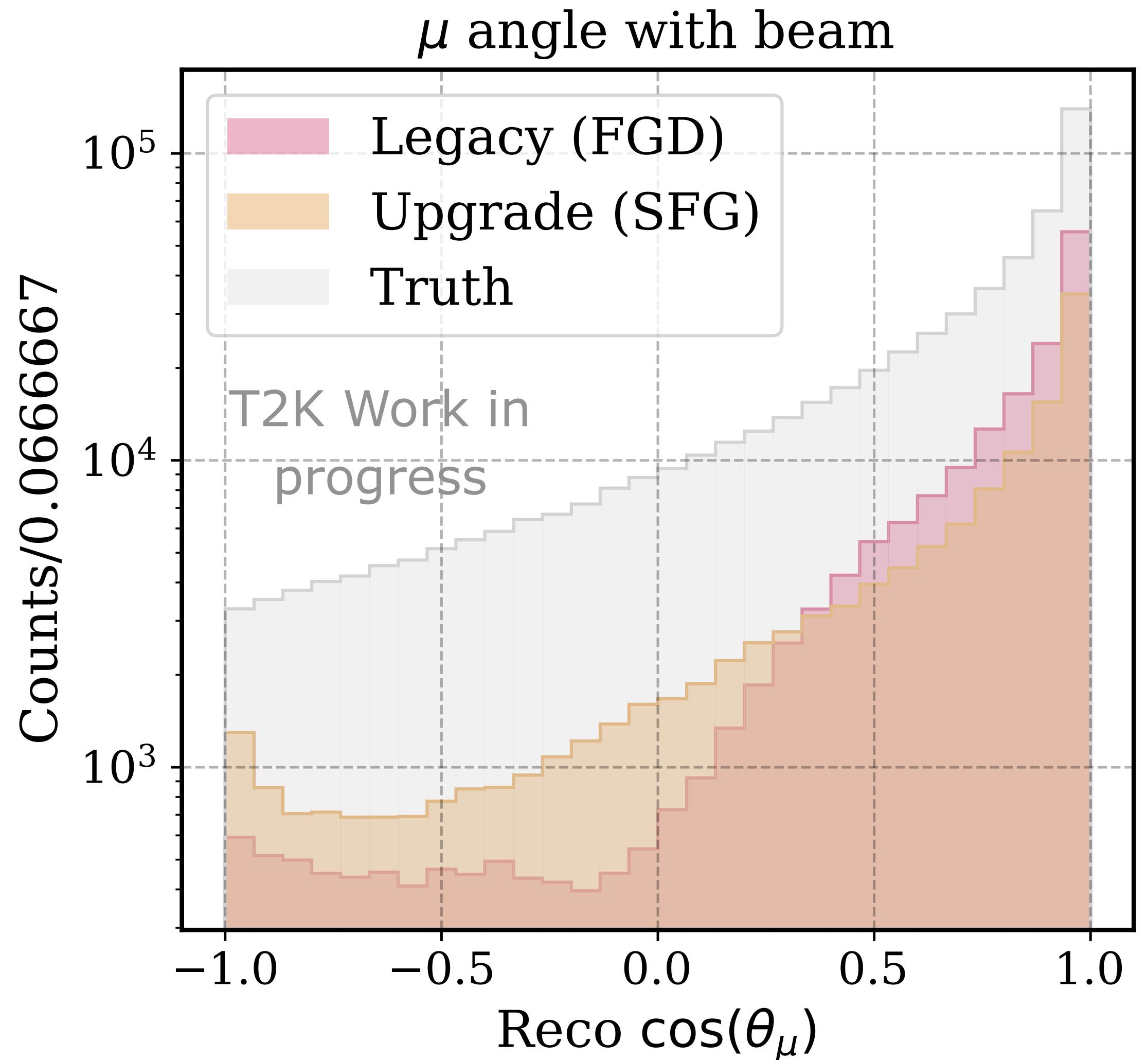
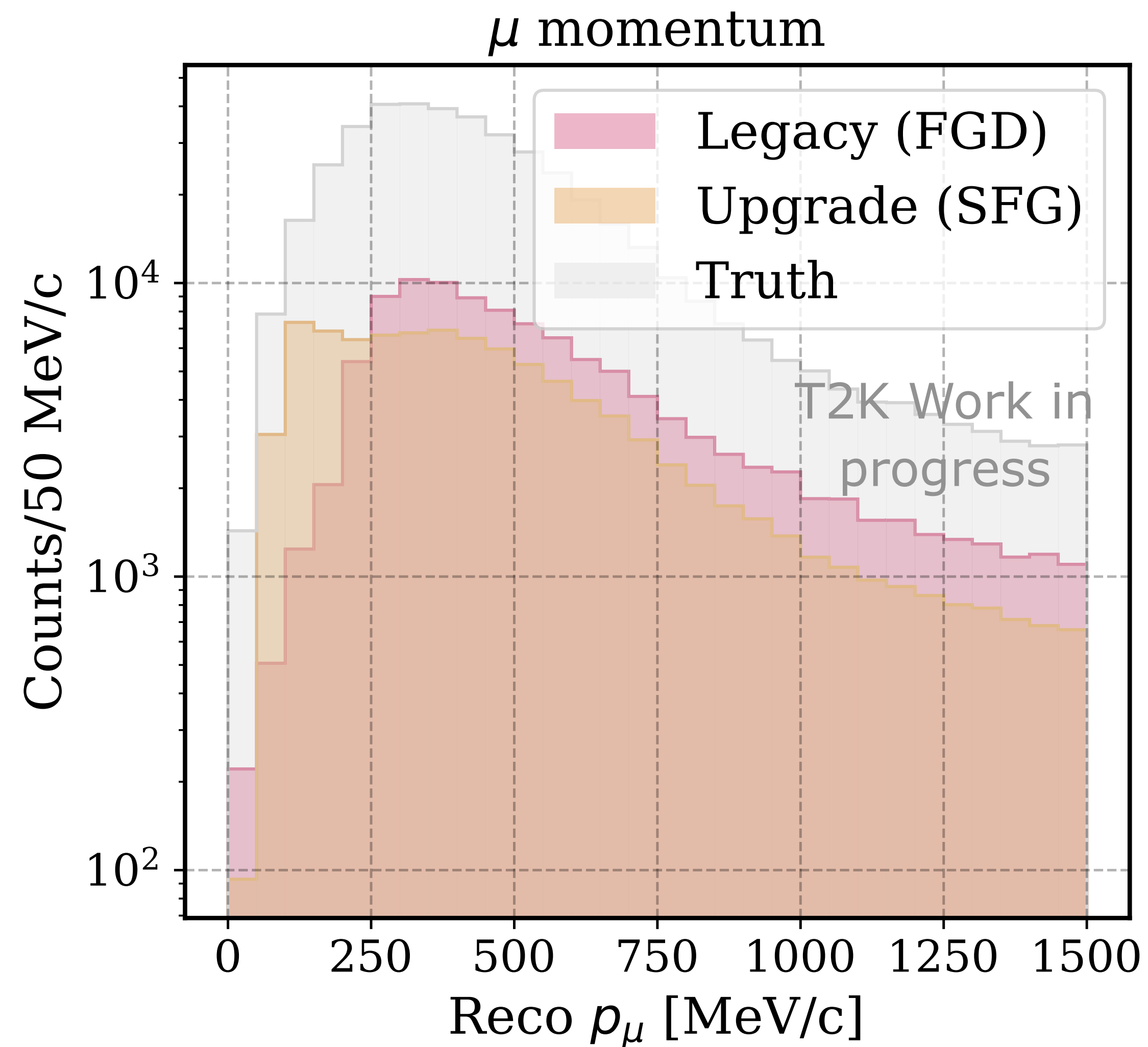
Upgrade selection



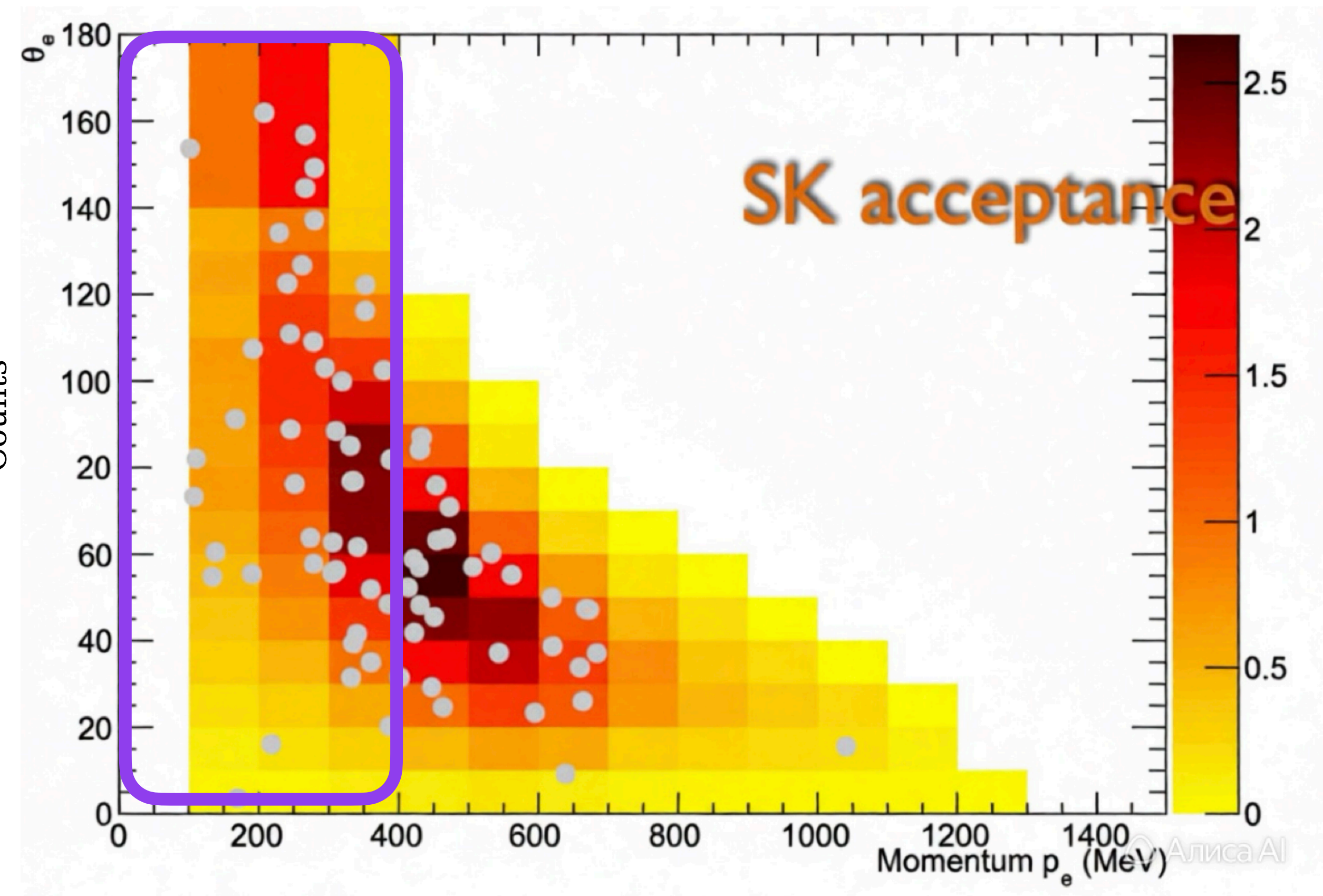
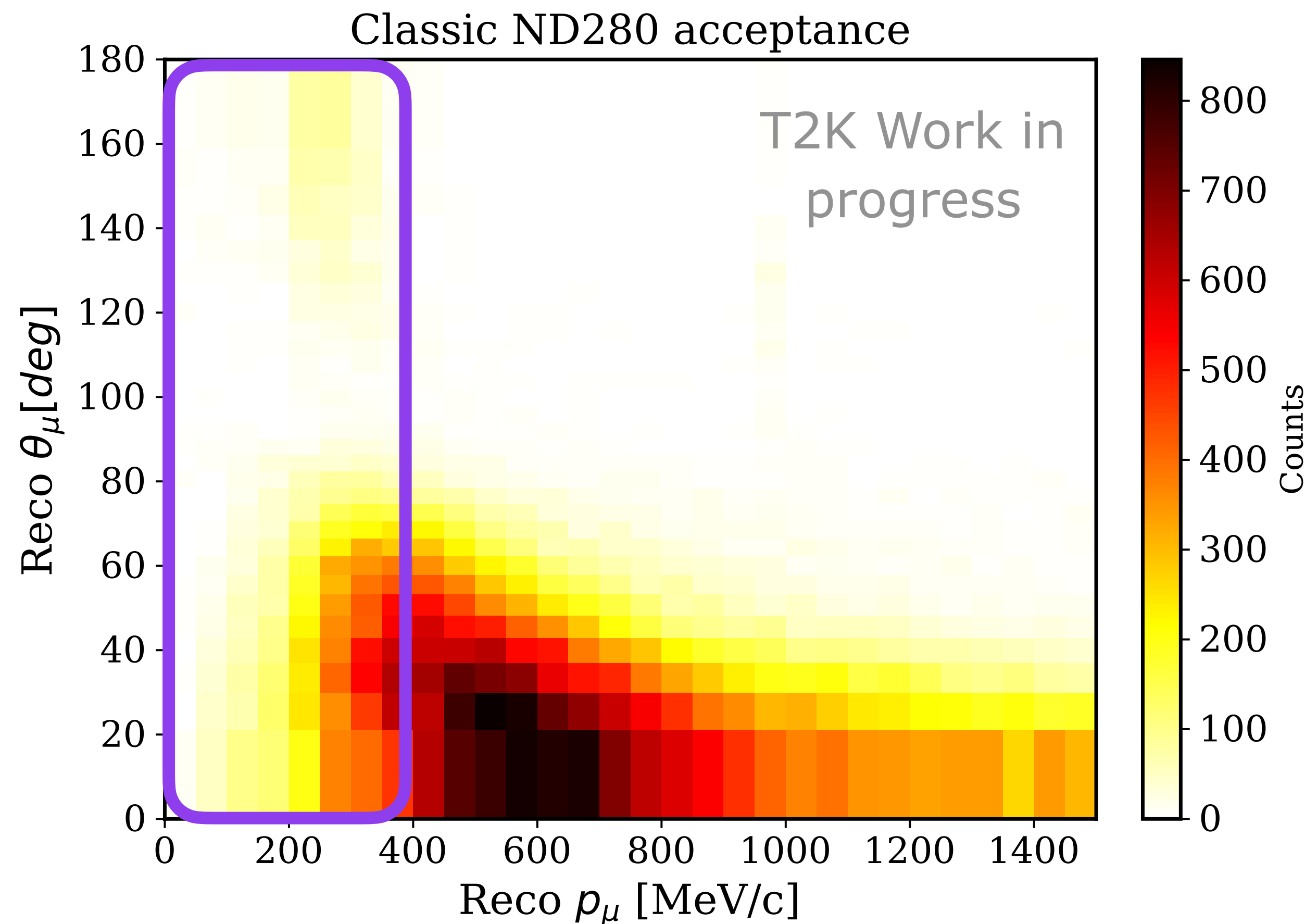
Classic selection

Upgrade selection against classic selection

Momentum and angle CC Inclusive

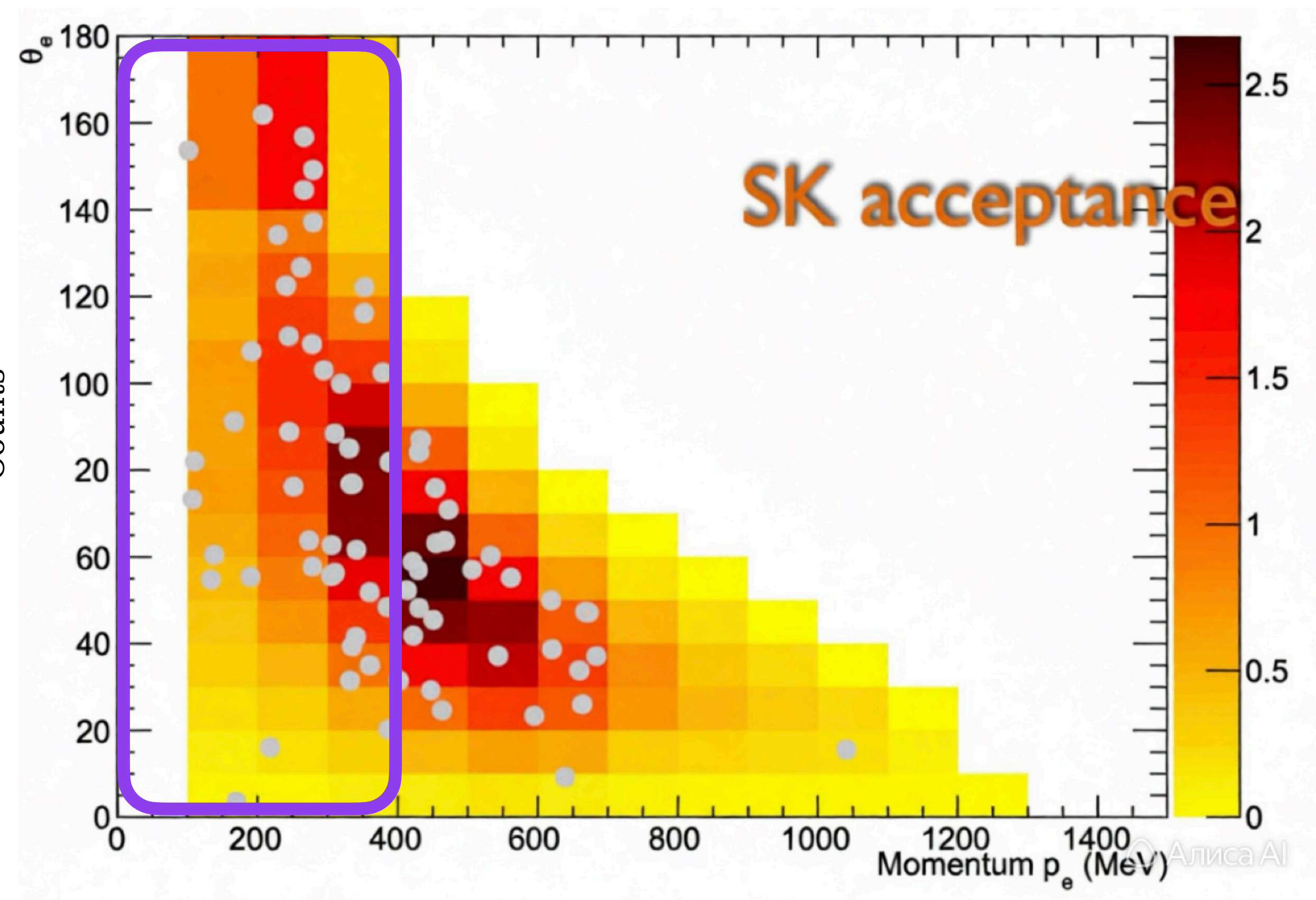
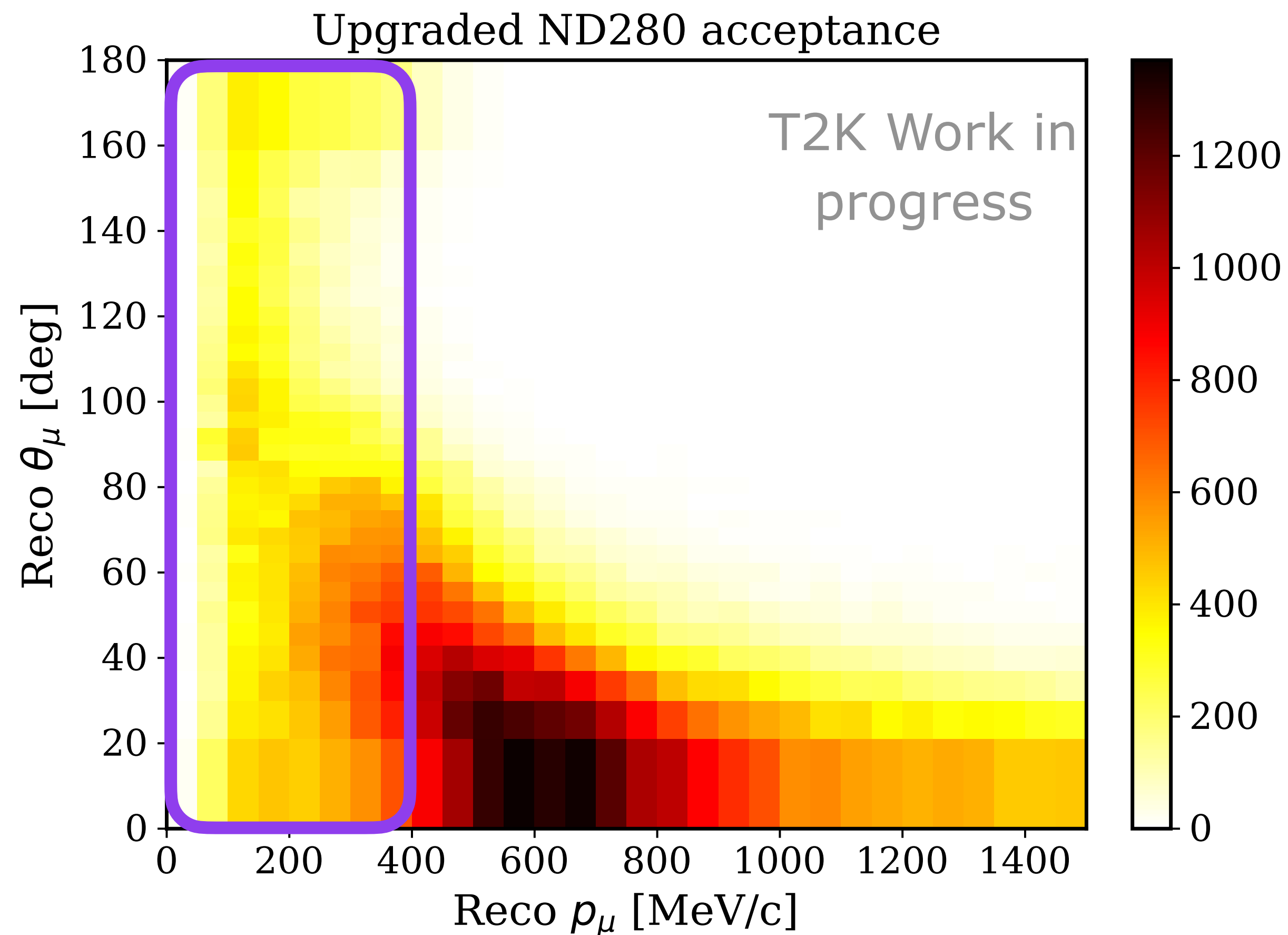


Classic ND280 acceptance



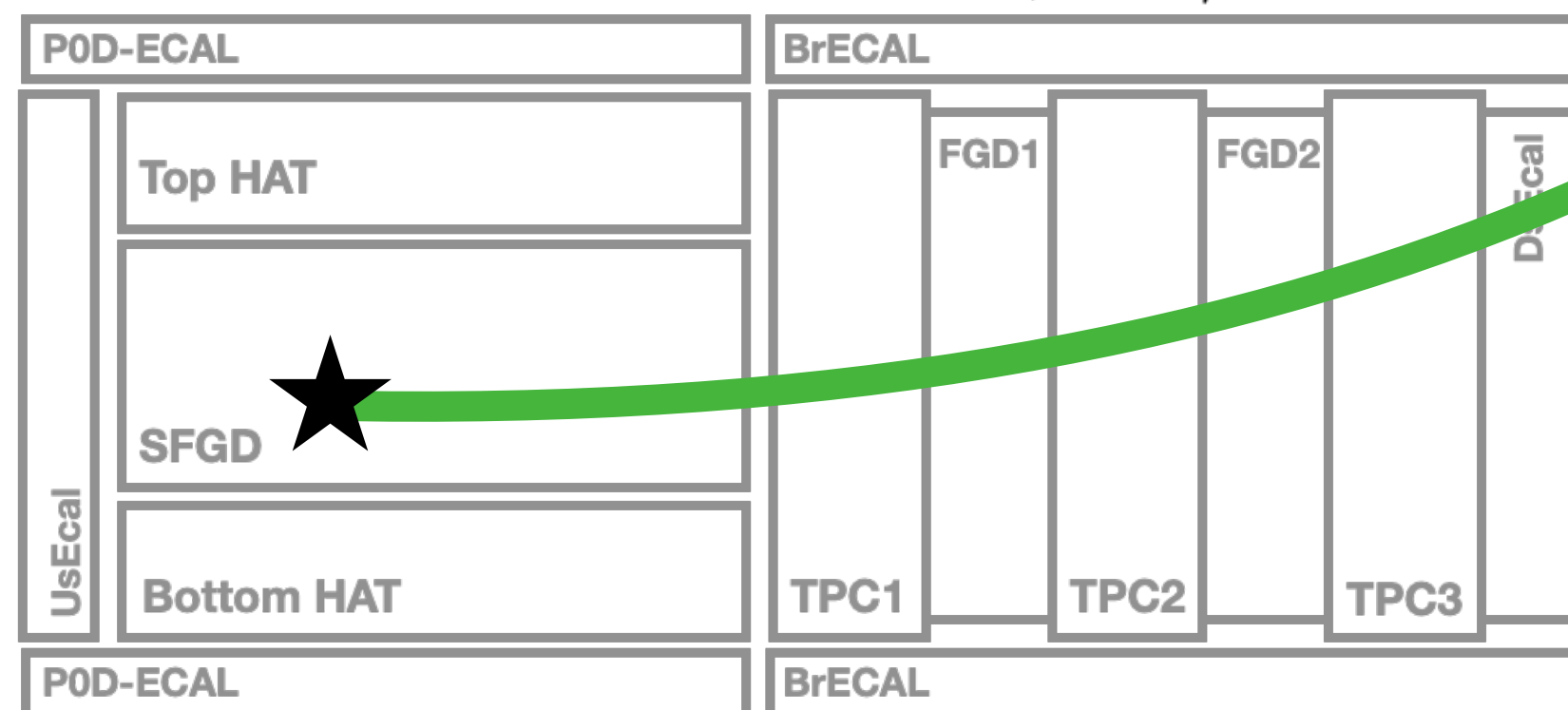
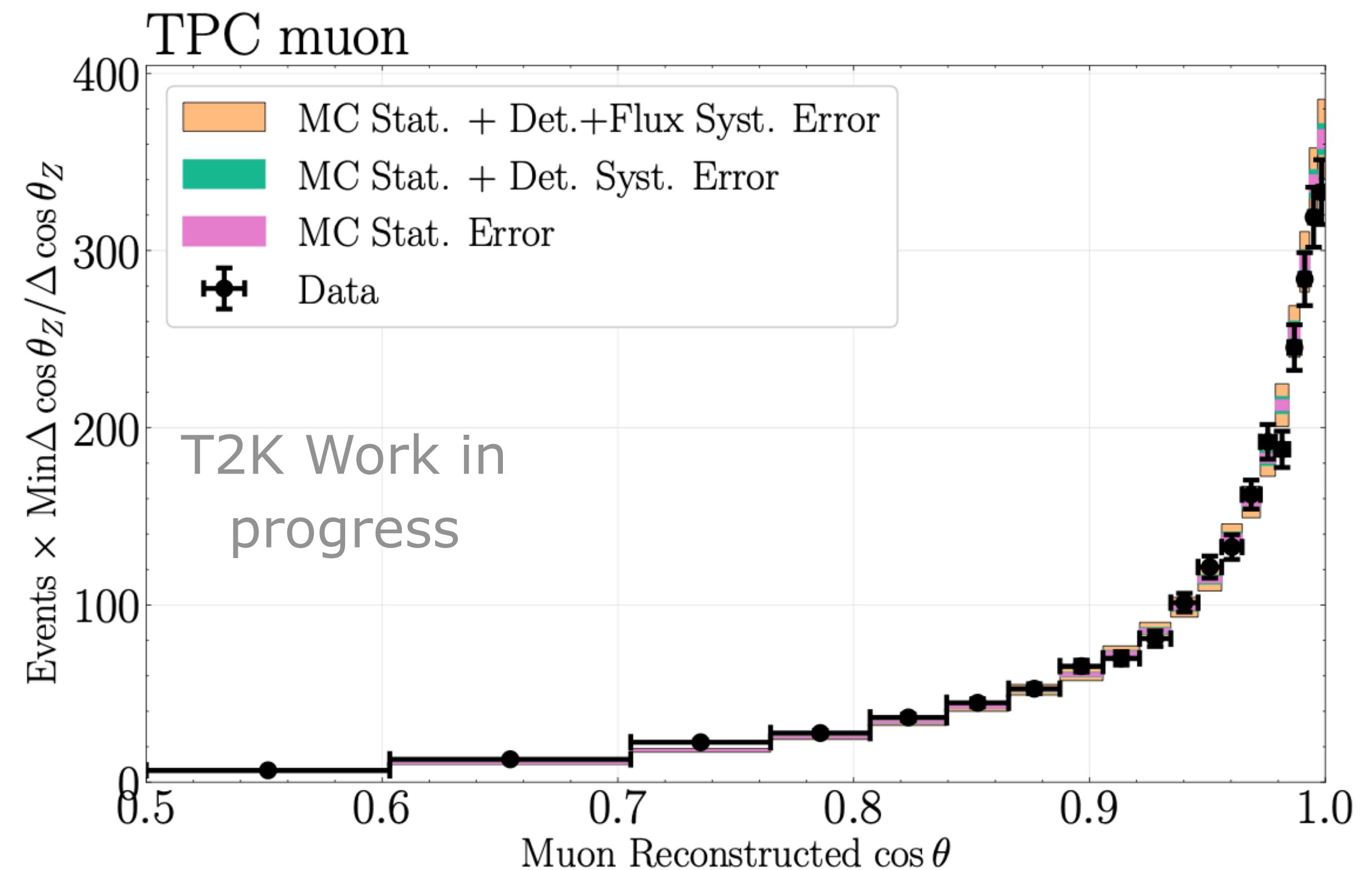
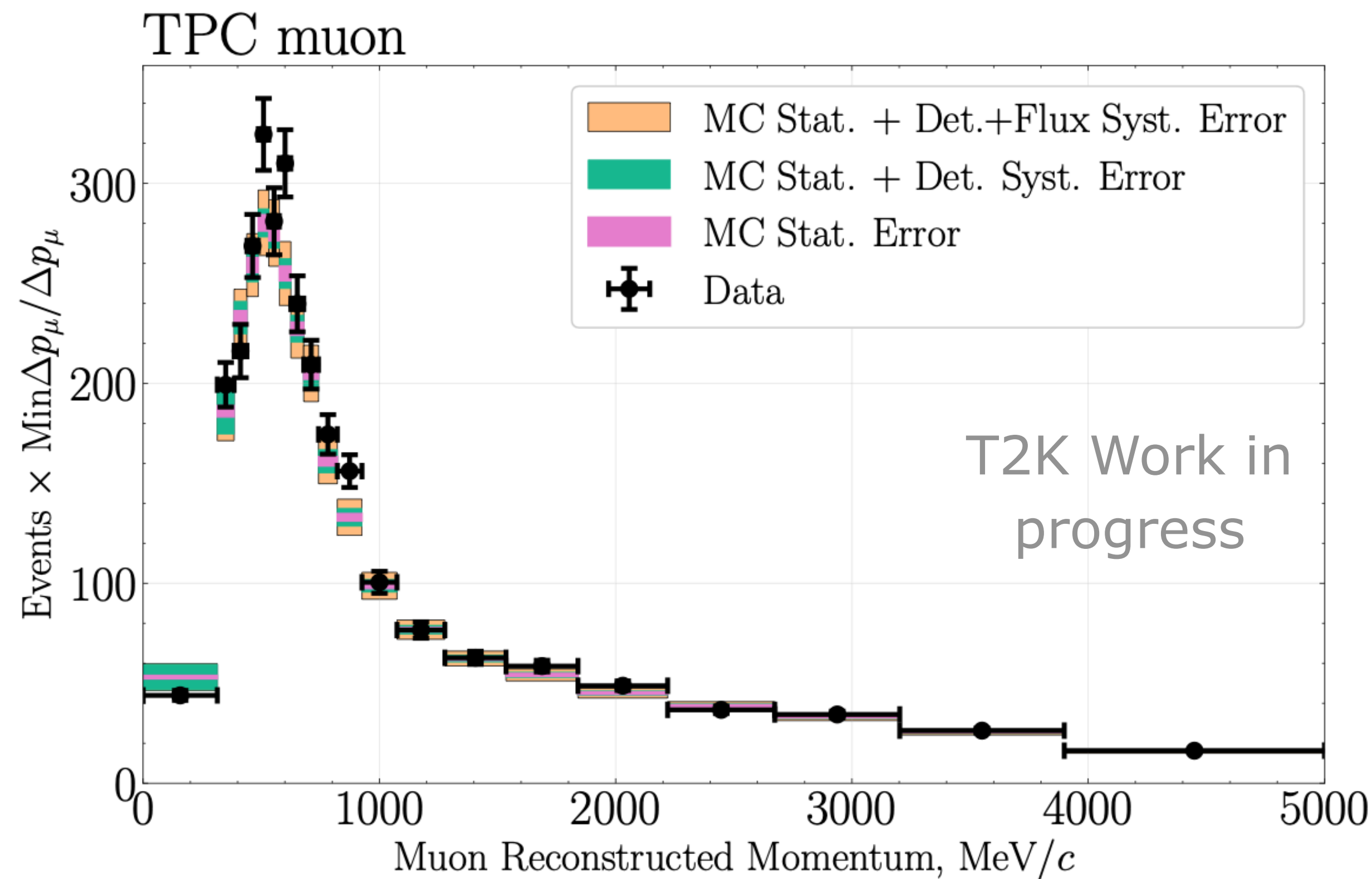
Classic ND280 less sensitive to backward and low momentum tracks

Upgraded ND280 acceptance



Upgraded ND280 has increased acceptance in phase-space: more overlap in the phase space of ND and FD.

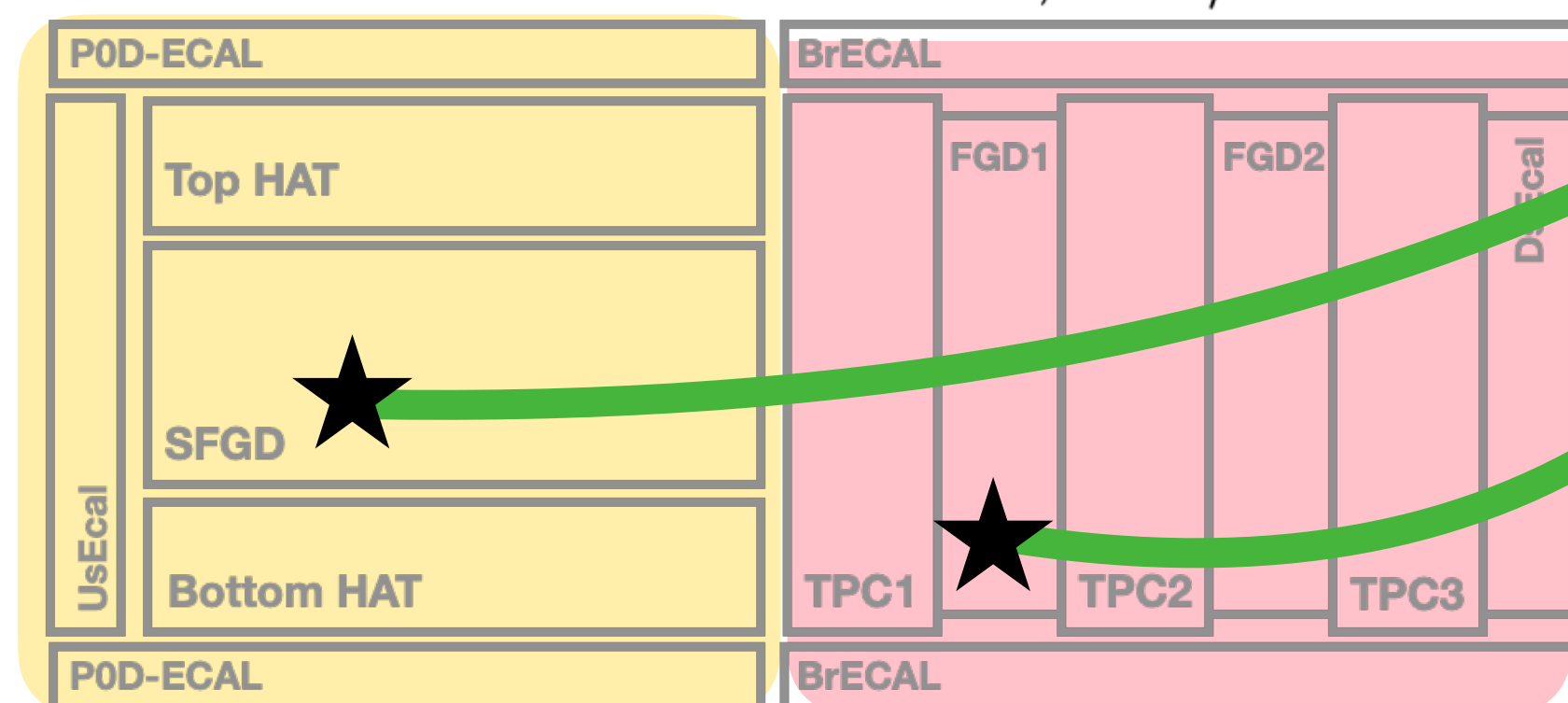
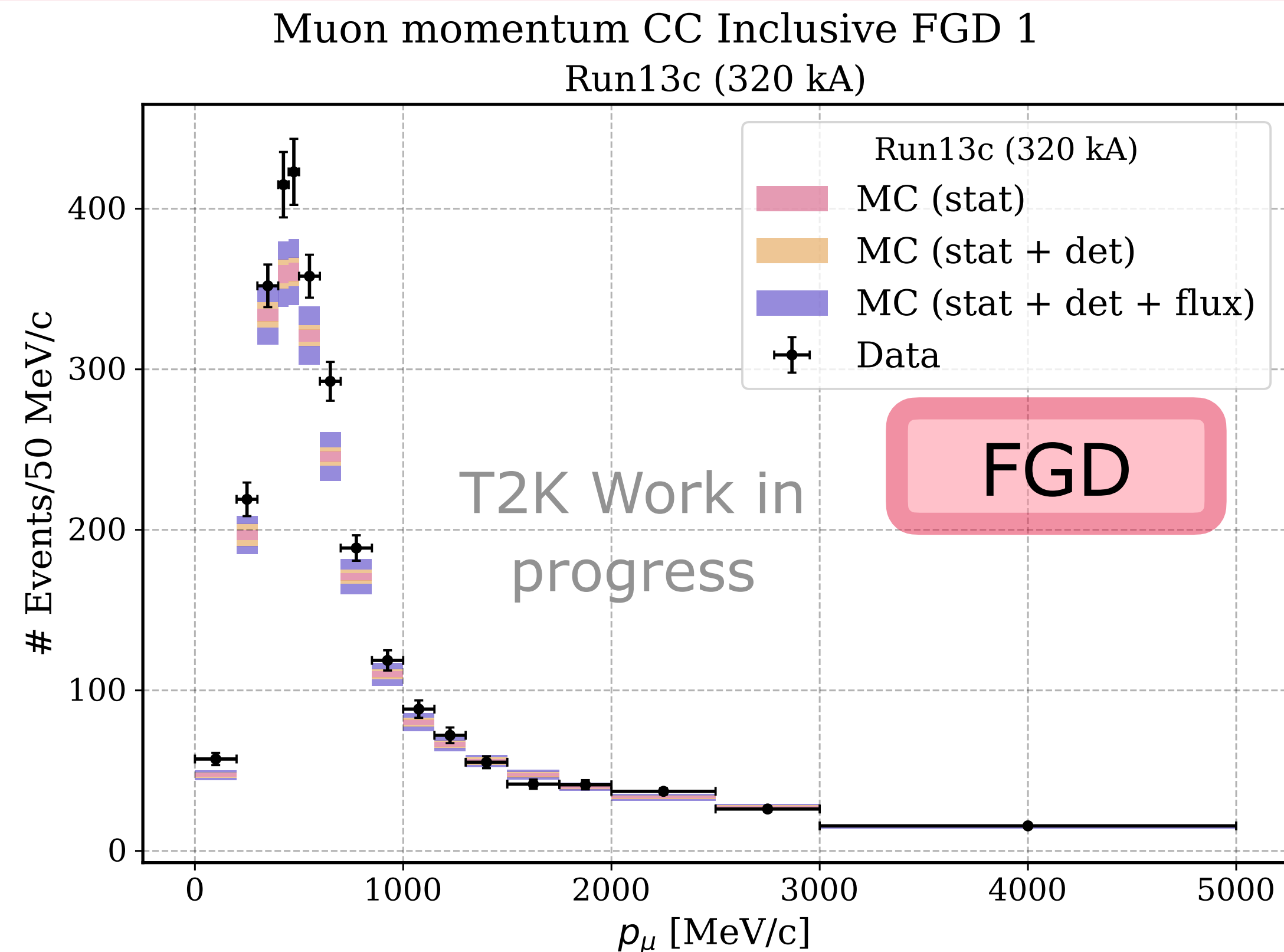
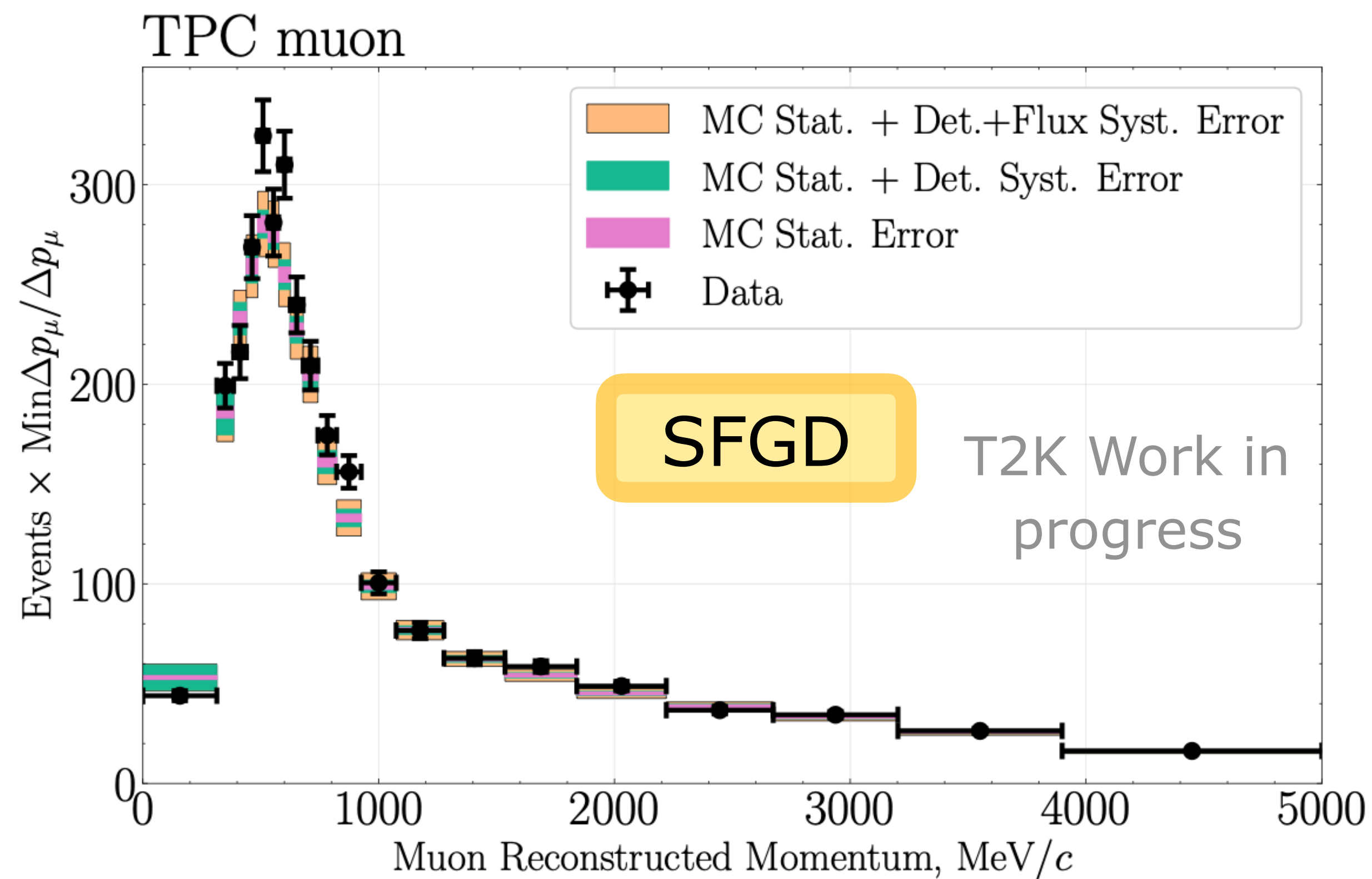
Upgrade selection with data



μ^-

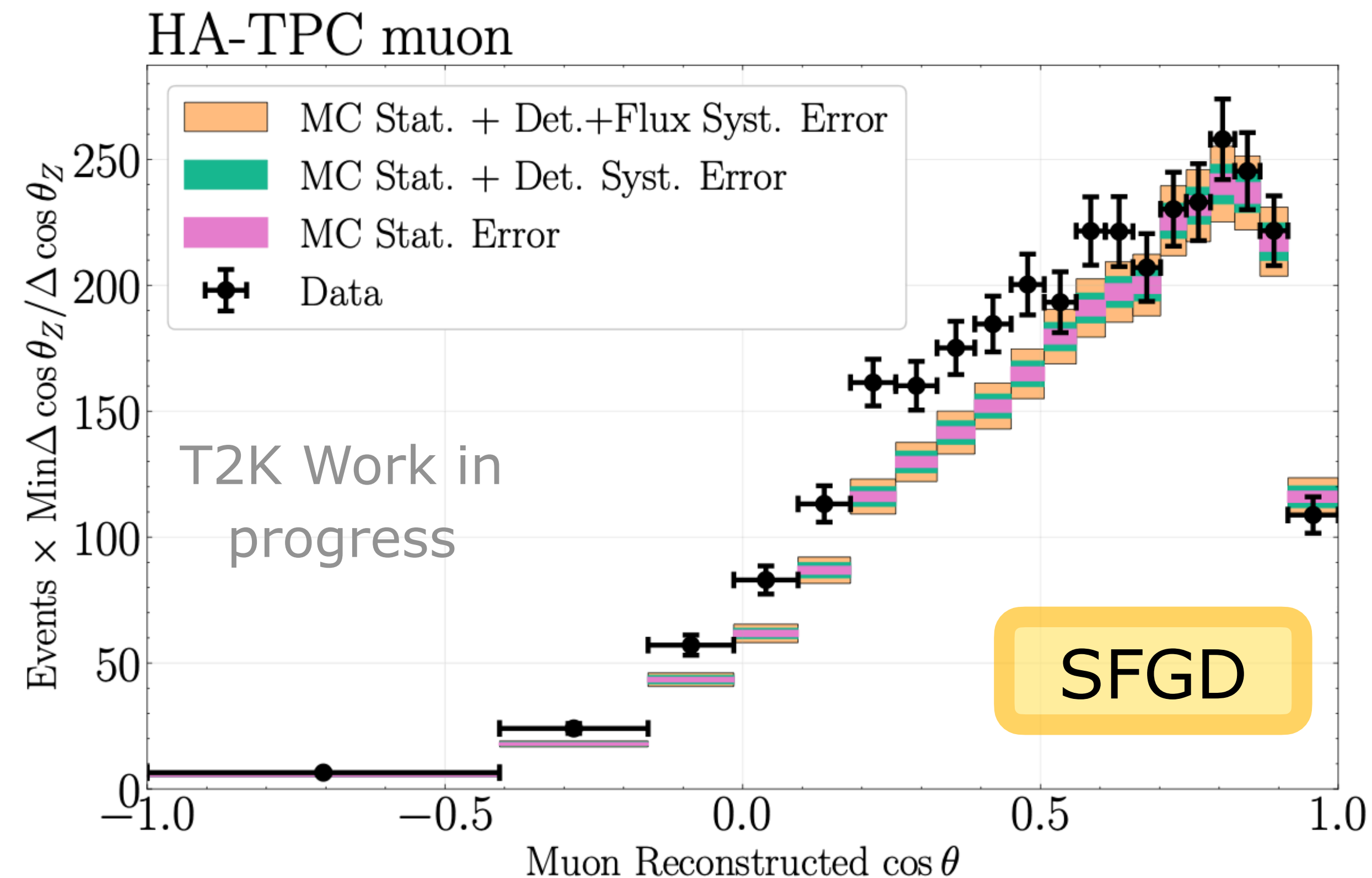
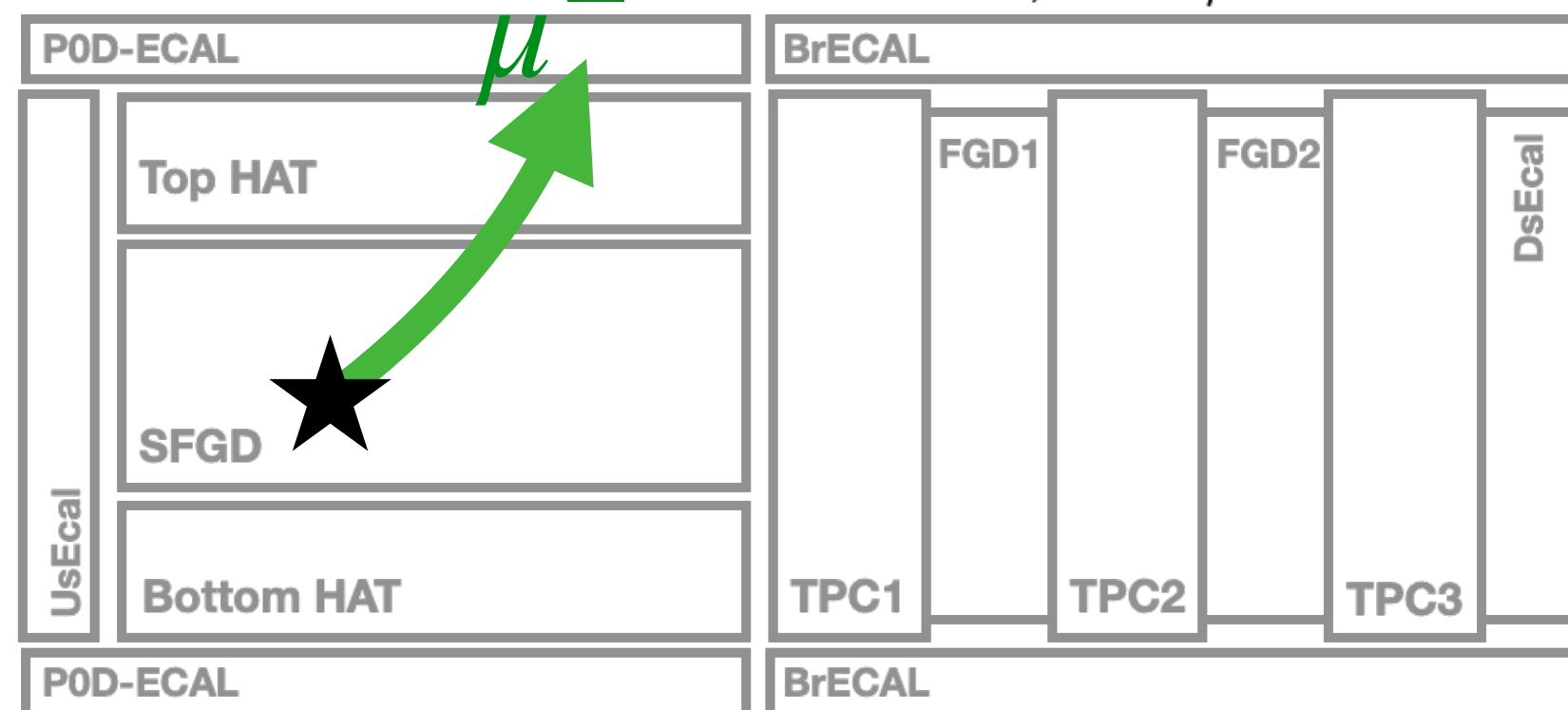
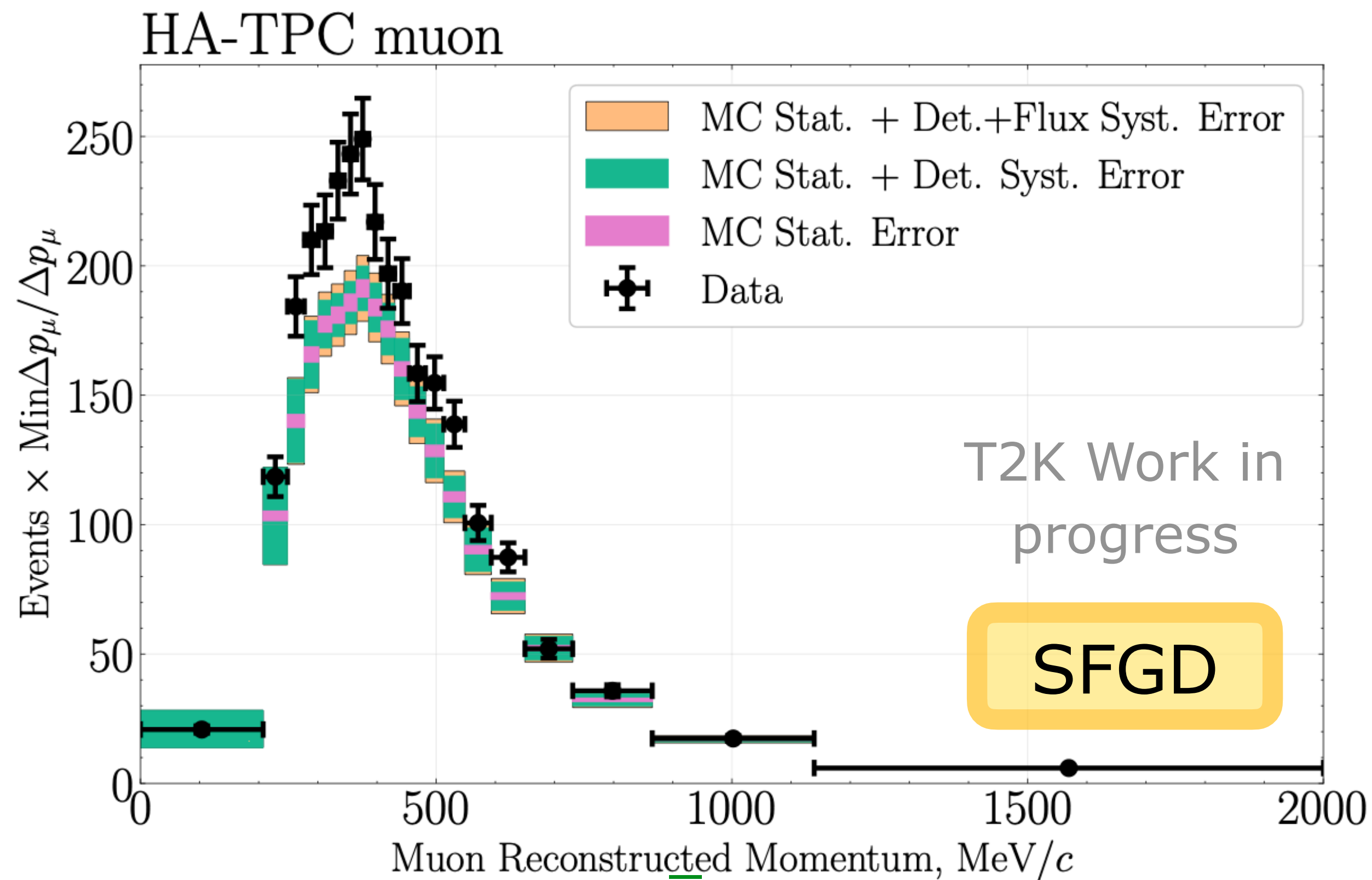
Comparable agreement between data and pre-fit MC to what we saw in classic ND280!

Upgrade selection with data

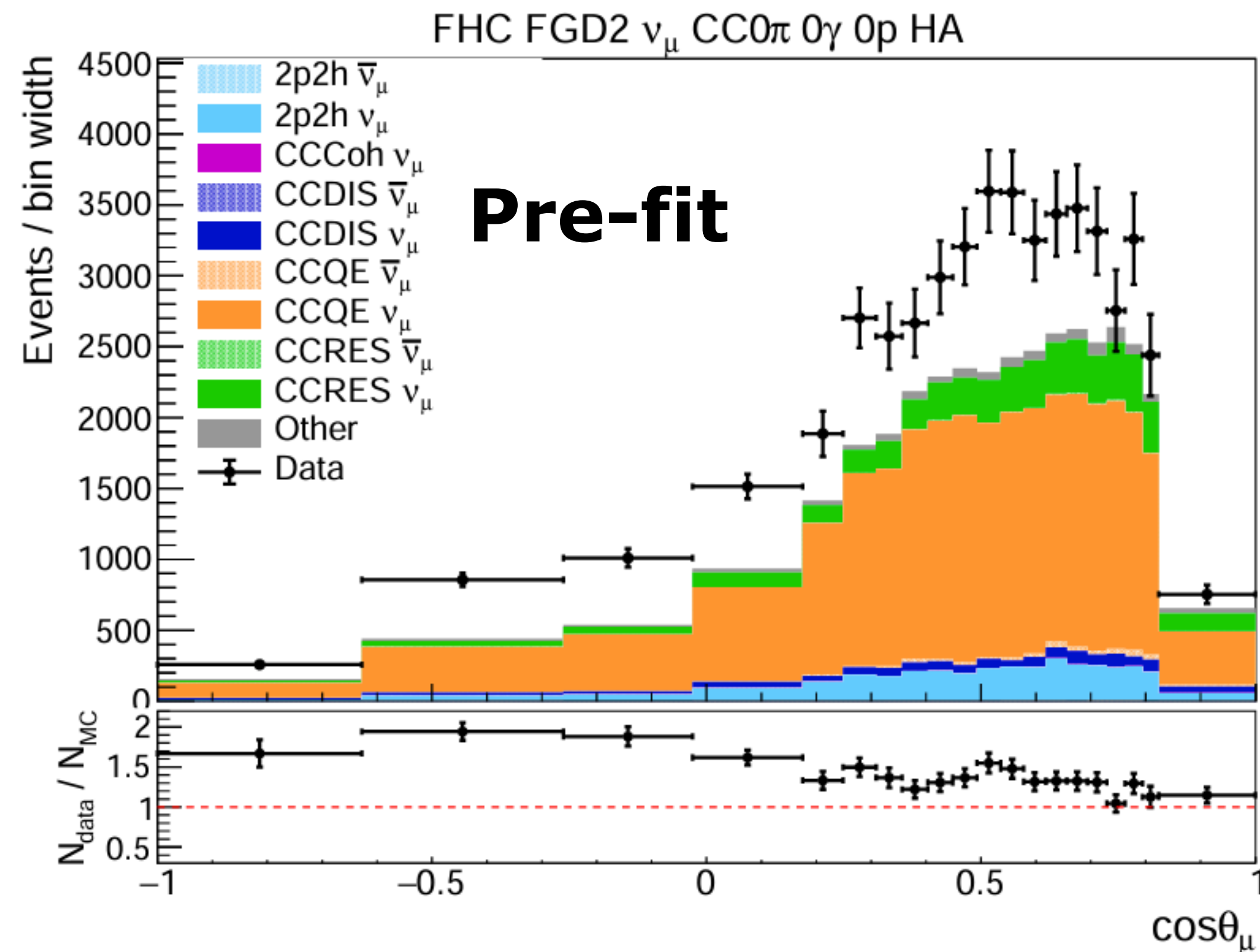


Comparable agreement between data and pre-fit MC to what we saw in classic ND280!

Upgrade selection with data

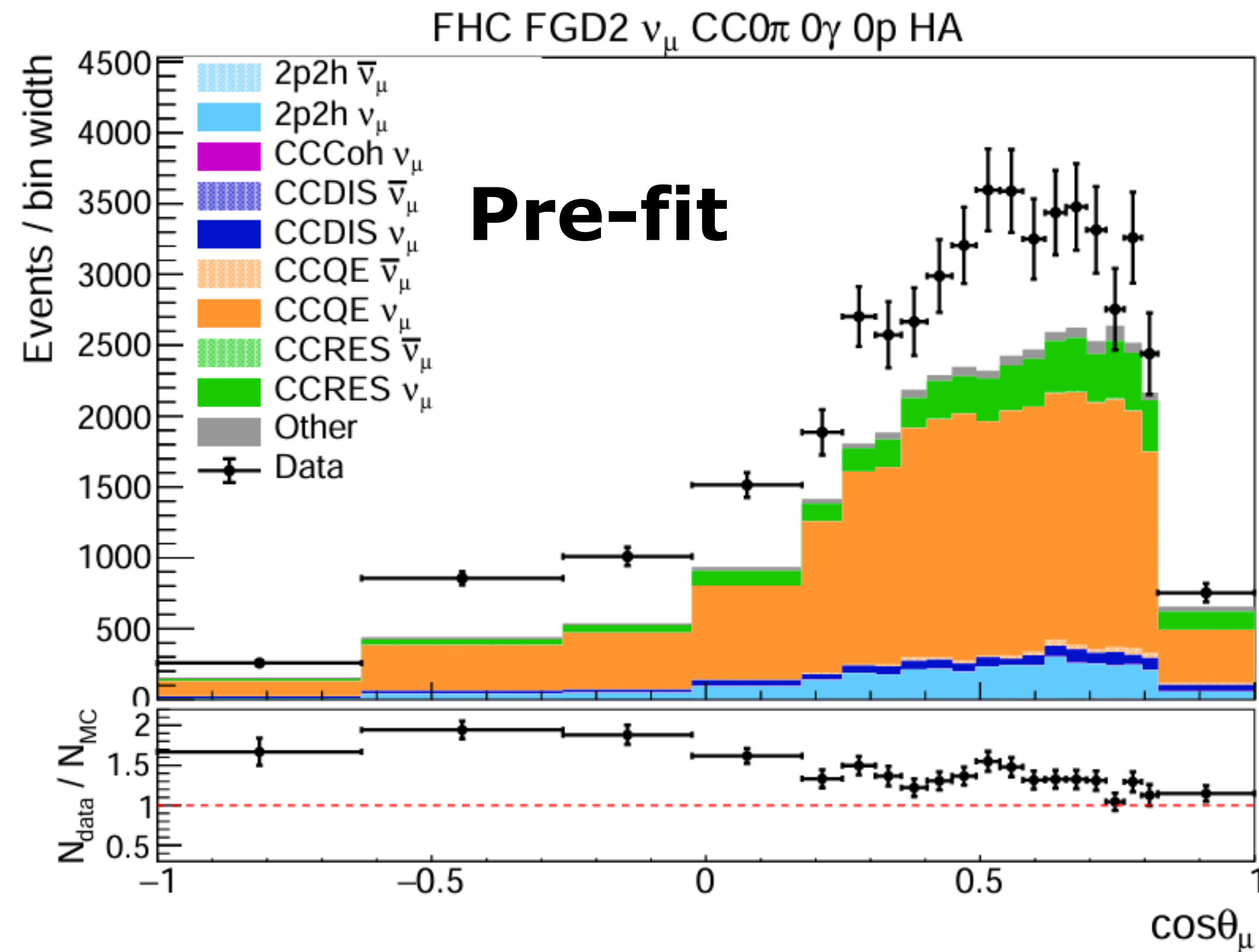


Tuning of MC at the near detector

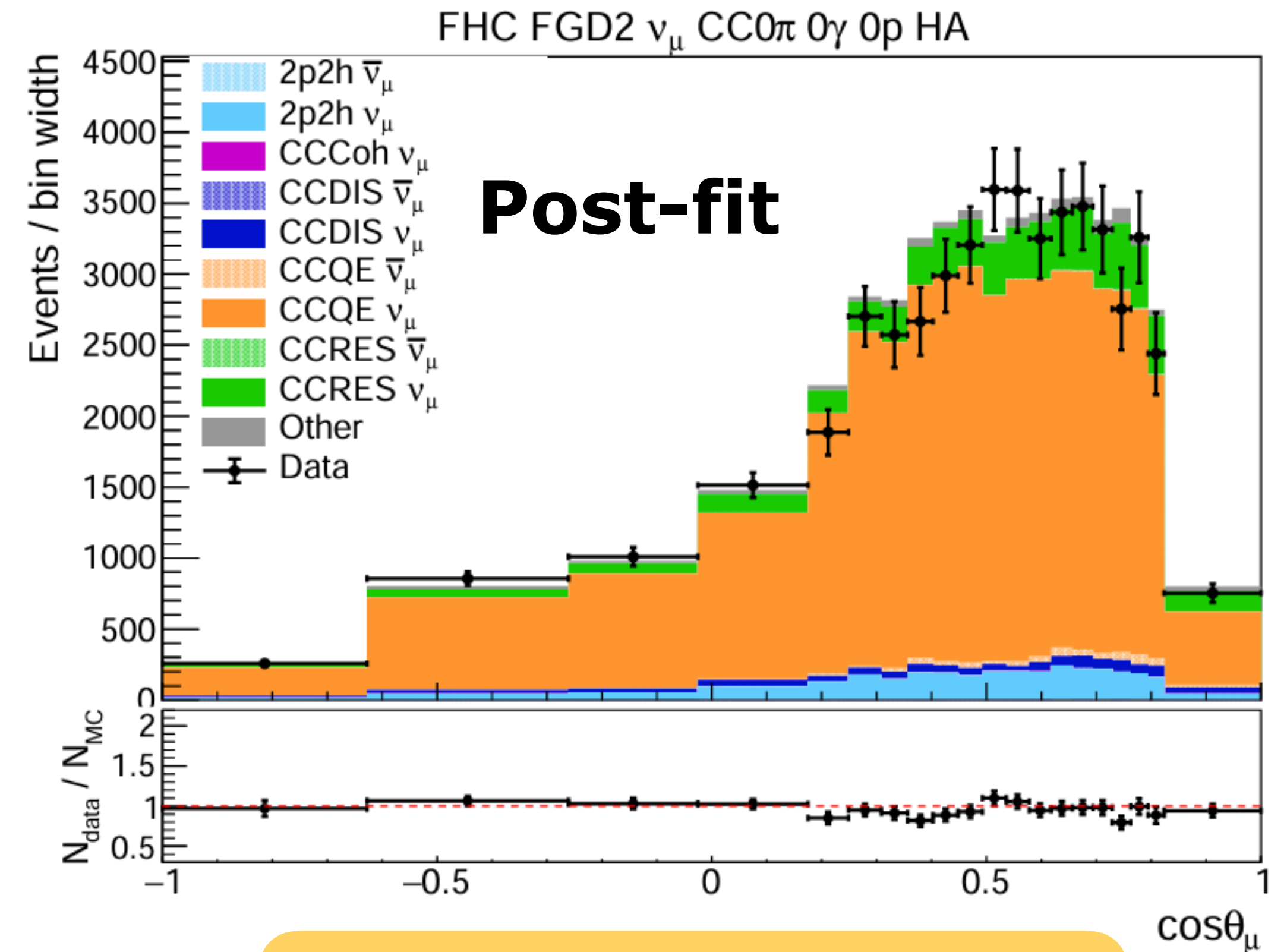


Comparable agreement
between data and pre-fit MC to
what we saw in classic ND280!

Tuning of MC at the near detector

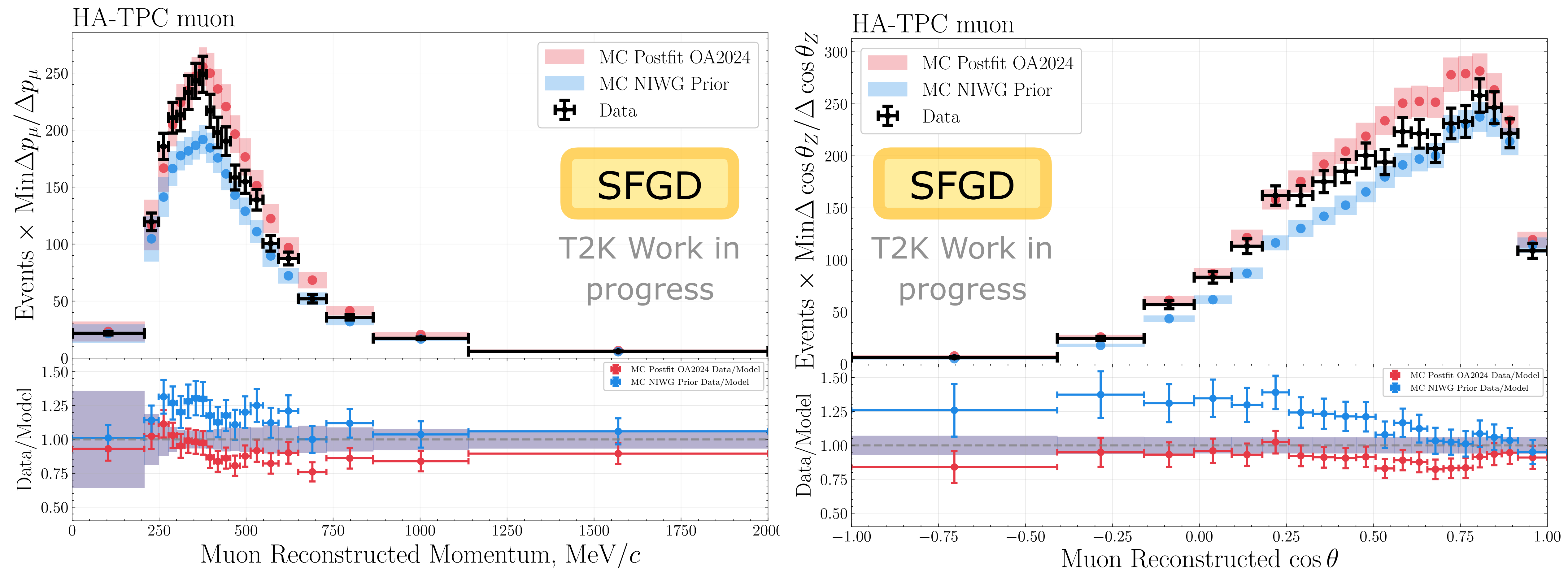


Comparable agreement
between data and pre-fit MC to
what we saw in classic ND280!



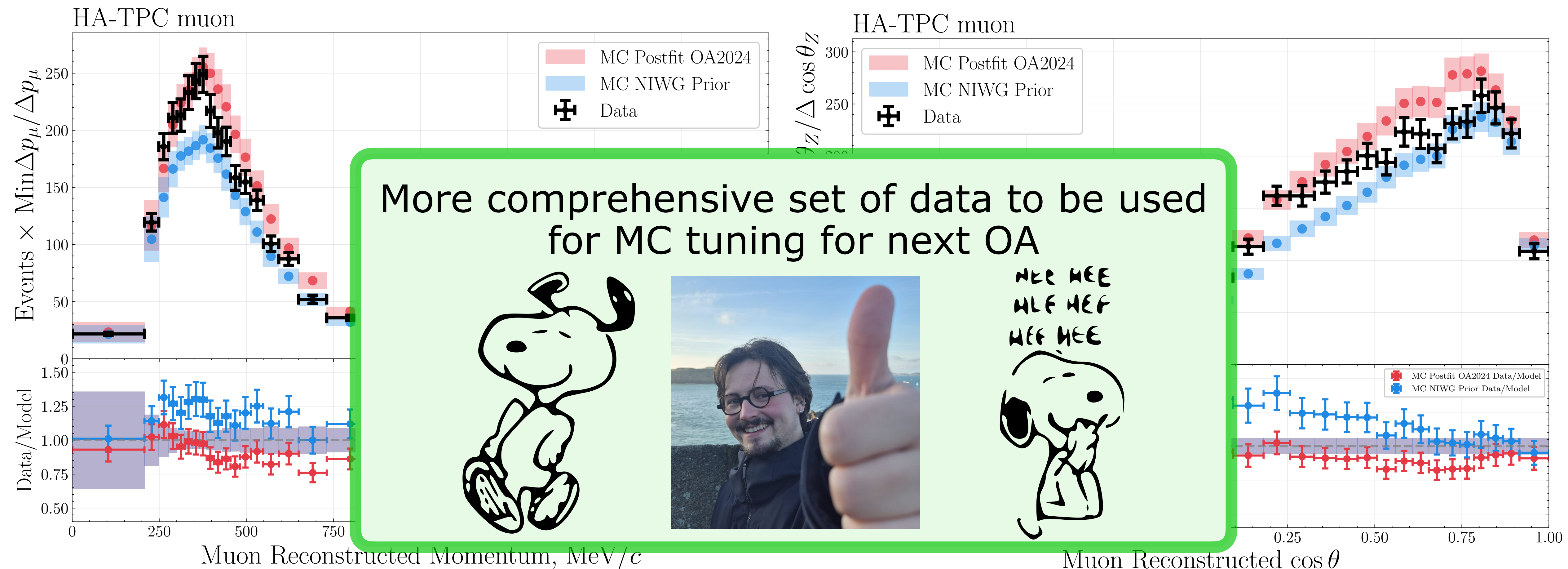
Details in Nico's
presentation!

Upgrade selection with data



Here also compared to the **post-fit MC model** as obtained in the most recent analysis using only FGDs data (see Nico's slide): shows **extrapolation** from forward to high angle phase space regions is robust!

Upgrade selection with data



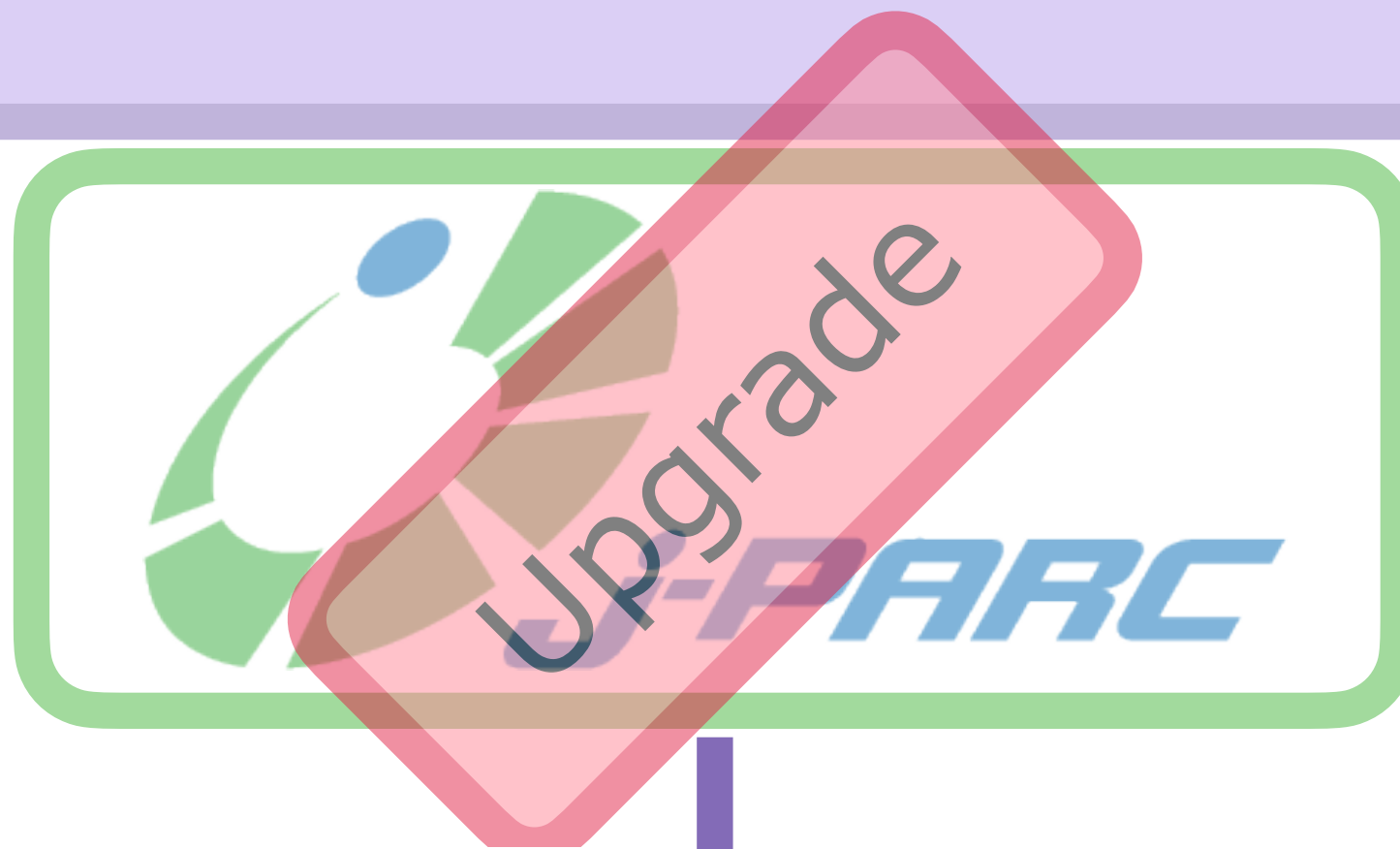
Here also compared to the **post-fit MC model** as obtained in the most recent analysis using only FGDs data (see Nico's slide): shows **extrapolation** from forward to high angle phase space regions is robust!

Conclusion

Important and encouraging
results for oscillation
analysis in upgrade era!

T2K

Neutrino oscillation



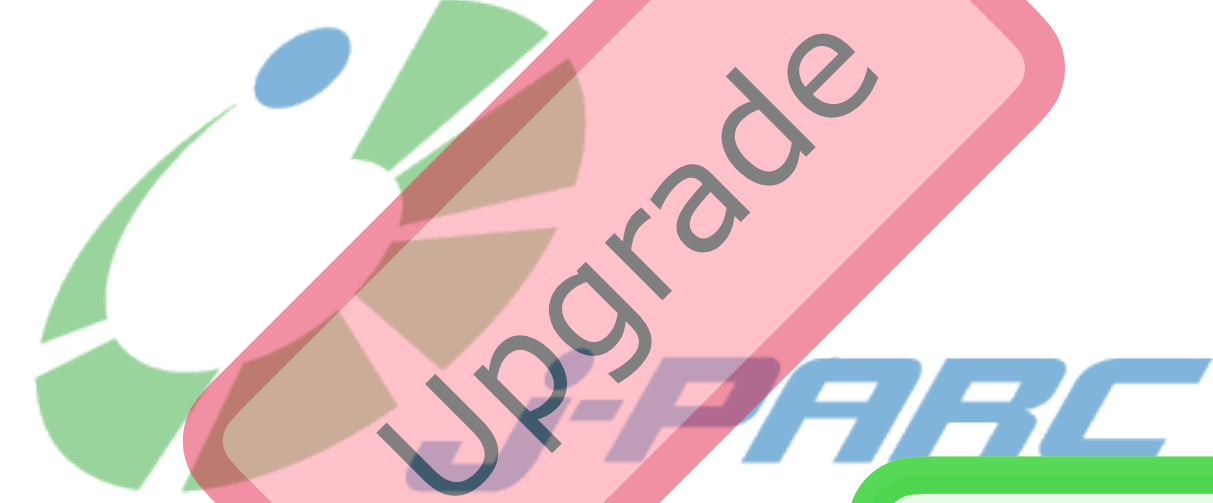
Conclusion

Important and encouraging
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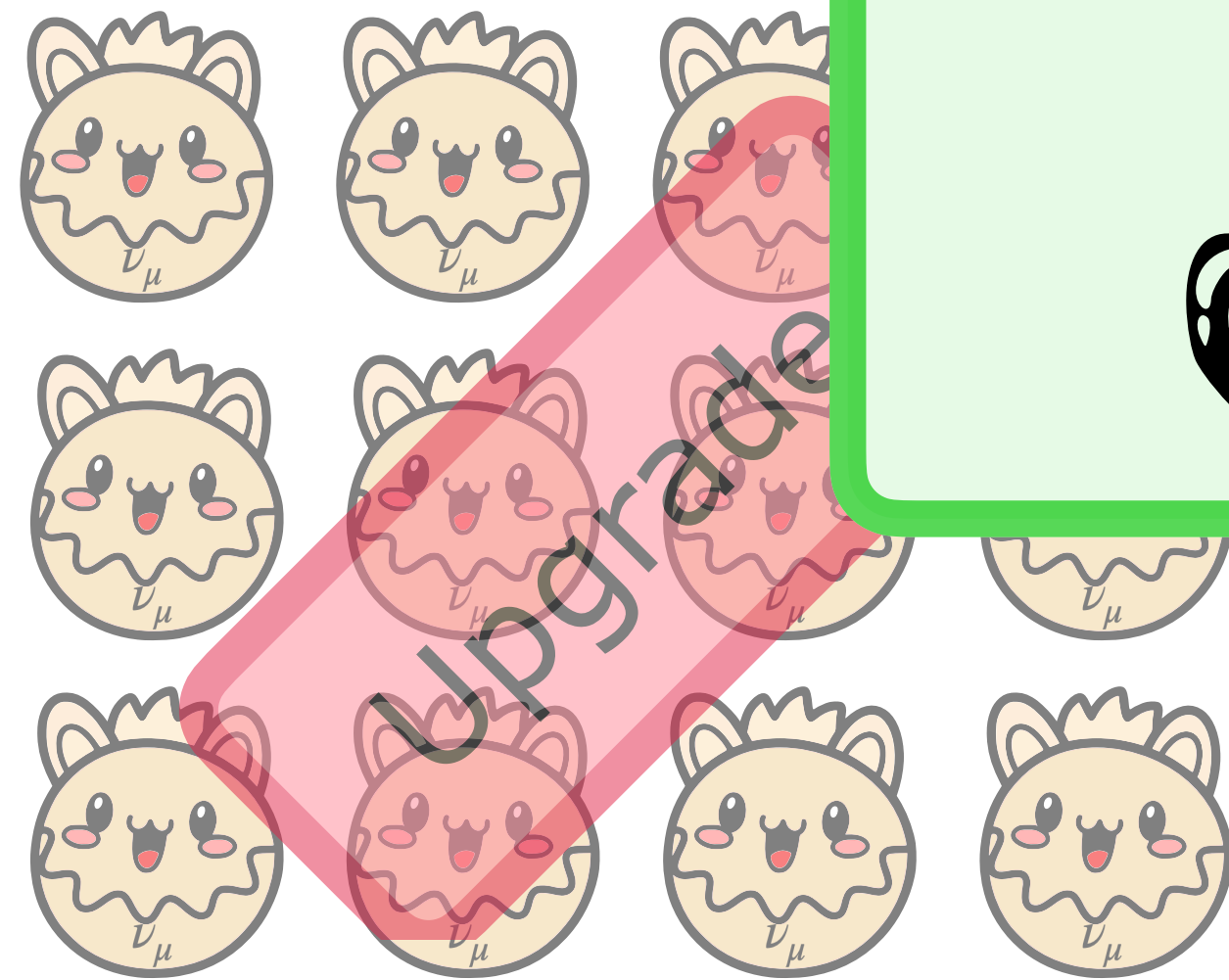
Stay tuned for next **ND fit** including
upgrade data!



Neutrino oscillation



Upgrade

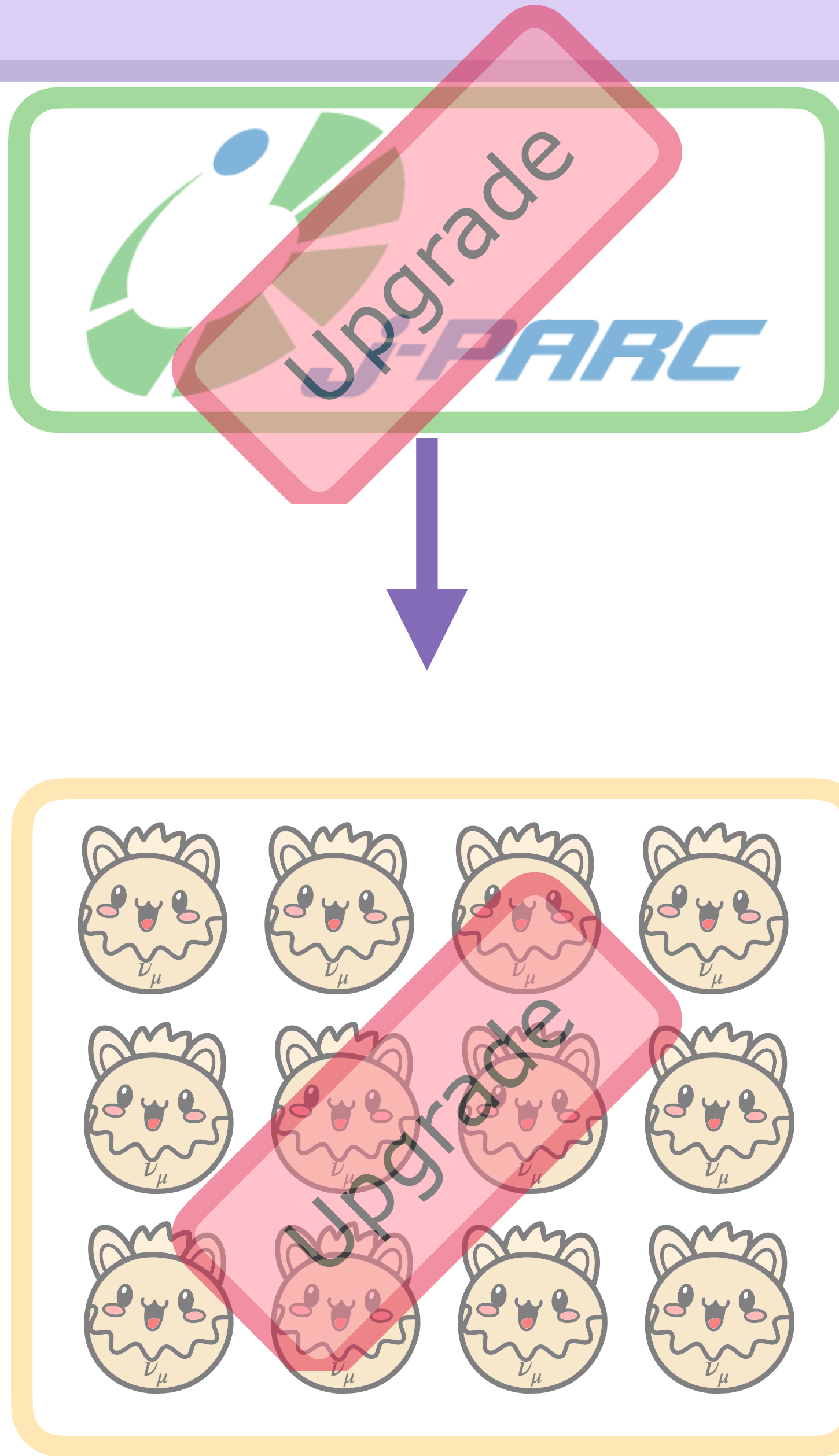


Upgrade



Conclusion

Important and encouraging
results for oscillation
analysis in upgrade era!

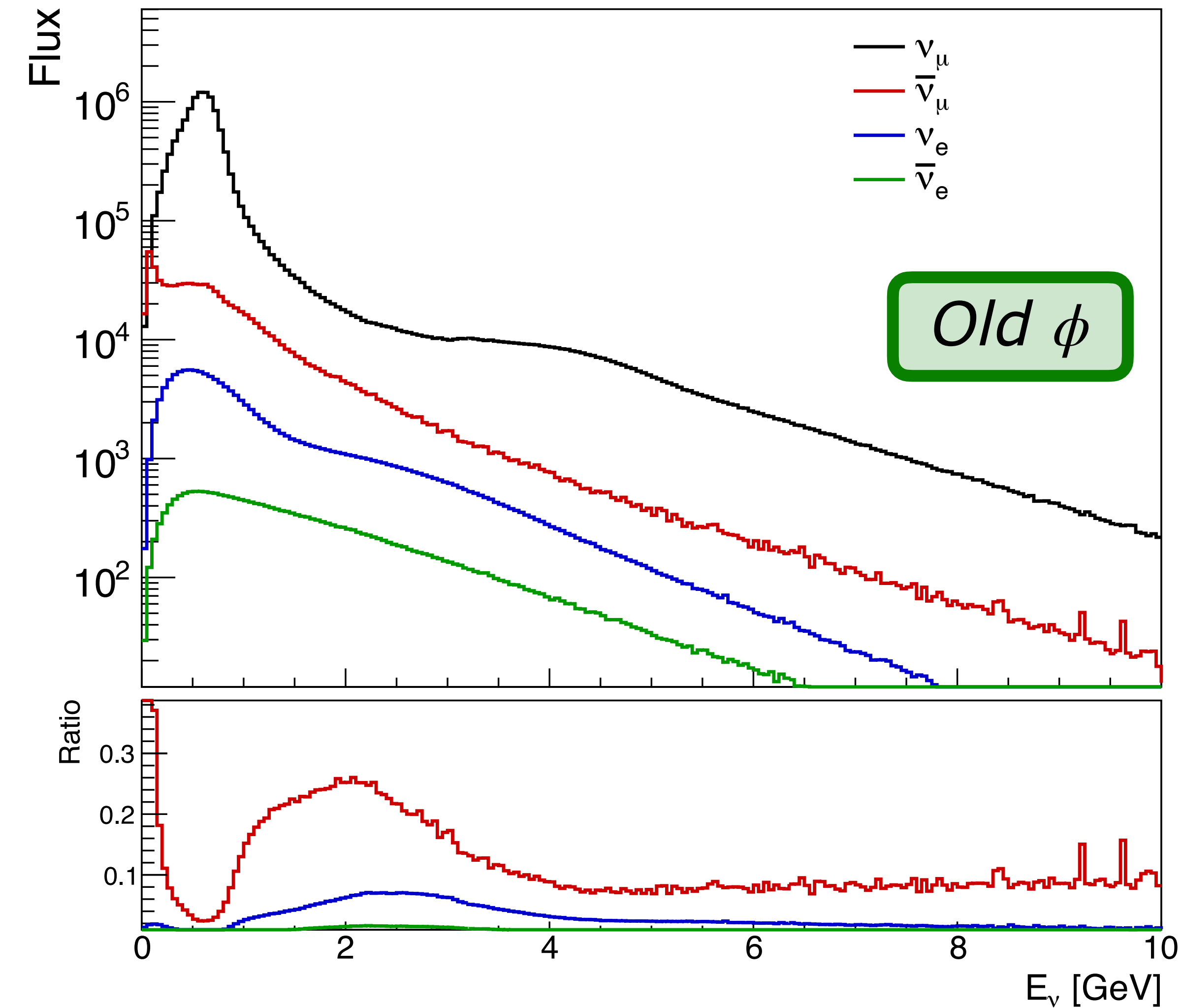


Thanks!

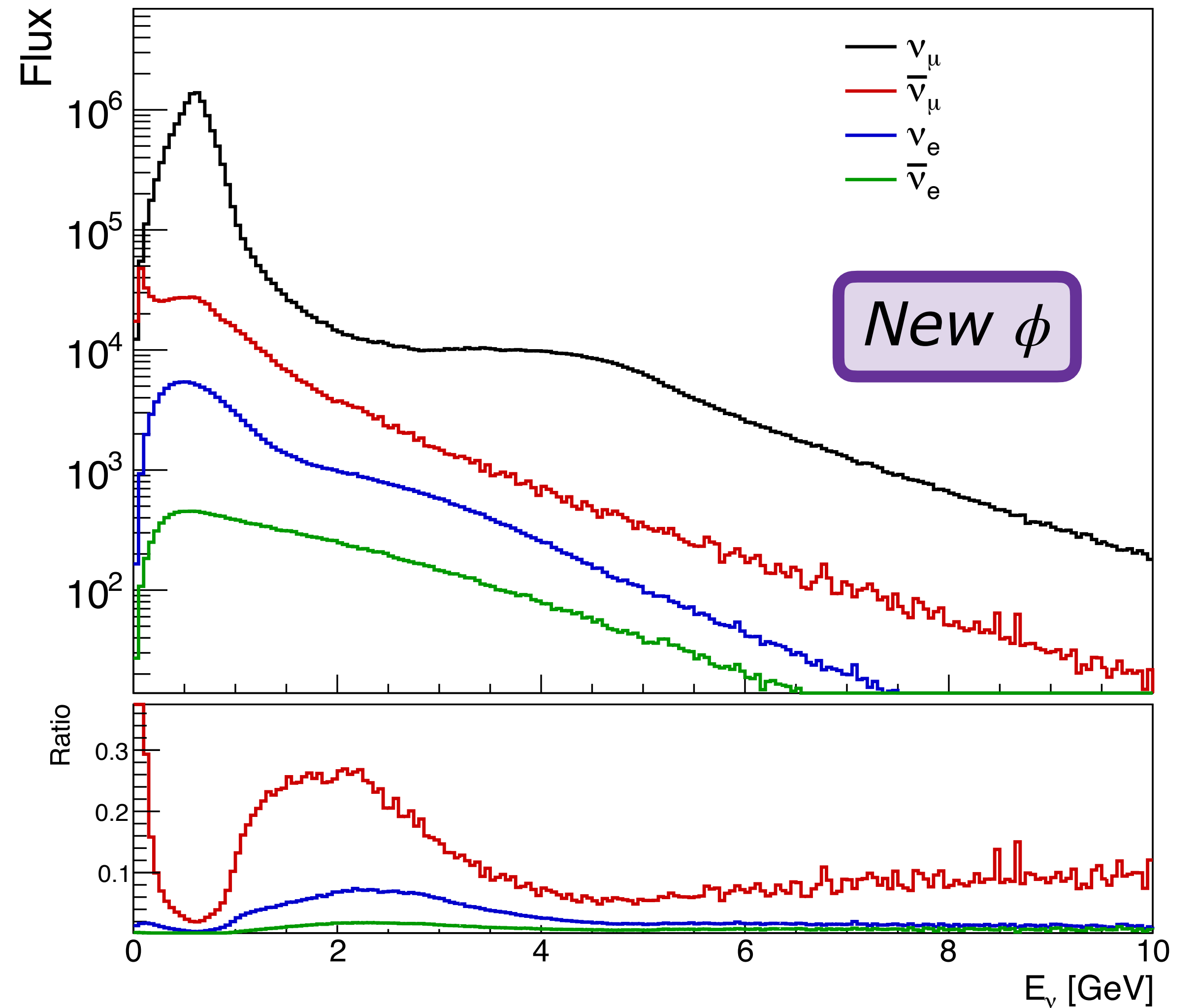
2026/06/02 - Jean-Baptiste Plançon

Neutrino flux at SK

25a tuned flux (run1-11_ndto9)



25a tuned flux (run12-15_ndto15)



Sources of detector uncertainty

TPC related

B Field distortions
TPC momentum scale
TPC momentum resolution
TPC PID
TPC clustering
TPC tracking
TPC charge ID

FGD-TPC related

TPC-FGD Matching

FGD related

FGD PID
FGD Hybrid Tracking
Michel electron tagging

ECal related

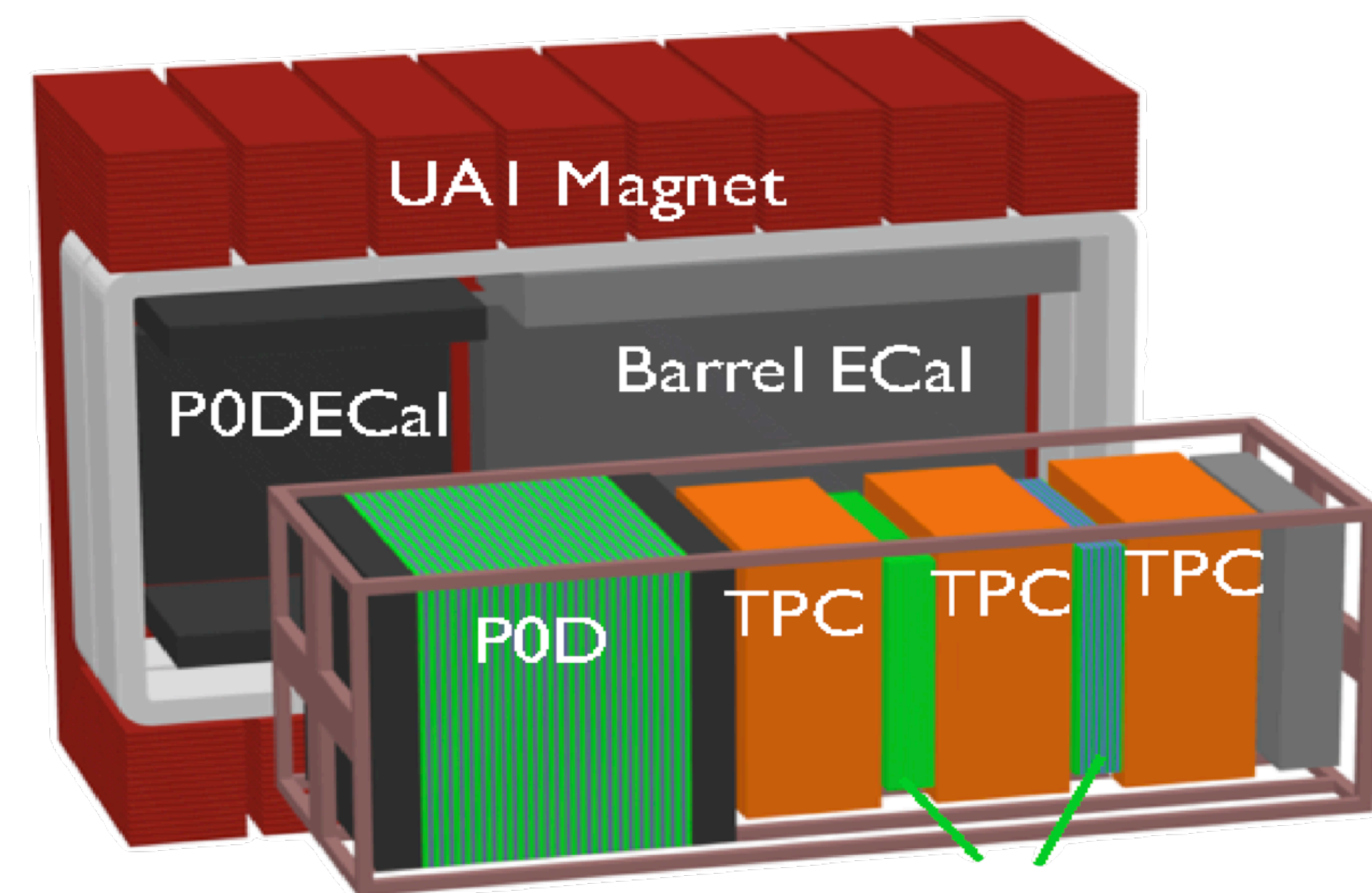
ECal tracking efficiency
TPC-ECal matching efficiency
ECal PID EmHip
ECal photon pile-up

Background related

OOFV background
Sand muon background
Pile-up

MC modeling related

Pion secondary interactions
Proton secondary interactions
FGD mass



Flux uncertainty

A Review of relevant physics

A.1 Proton beam optics and Twiss parameters

A.2 Neutrino Production

A.3 Off-axis method

A.4 Isospin symmetry

A.5 Inclusive cross sections and multiplicities .

A.6 Interaction types

A.7 Feynman scaling hypothesis

