INGRID
pile-up problem

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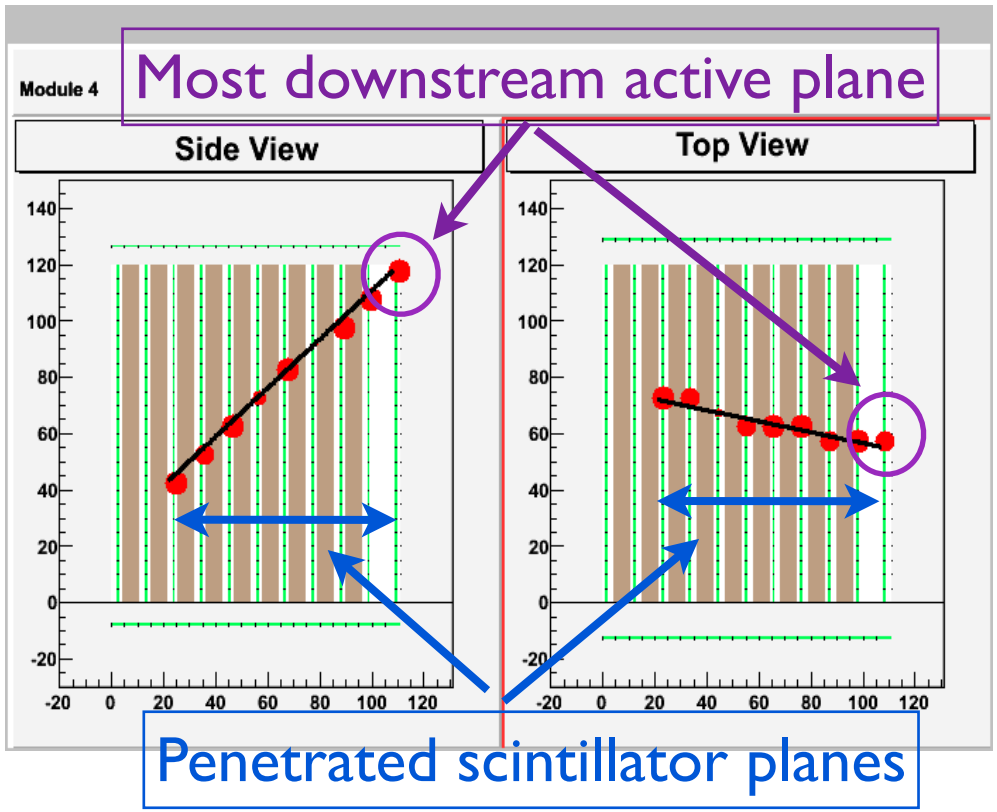
The pile-up problem

- At the current INGRID tracking code, can select only one track when there are more than two tracks at one module in per one bunch.
  - The track selection is depend on the most downstream plane# (MD#) and penetrated scintillator planes (=track length)
    - Select the track with larger MD# and track length



- Especially at high power beam, possible to miss the track from neutrino events → neutrino events loss (pile-up problem)

Rough estimation

- Want to estimate of the effect of the pile-up on the # of observed events at INGRID roughly.
  - Want to estimate the correction factor to current observed neutrino events of Data.
- At first step, review of some event pile-up cases by cartoons.

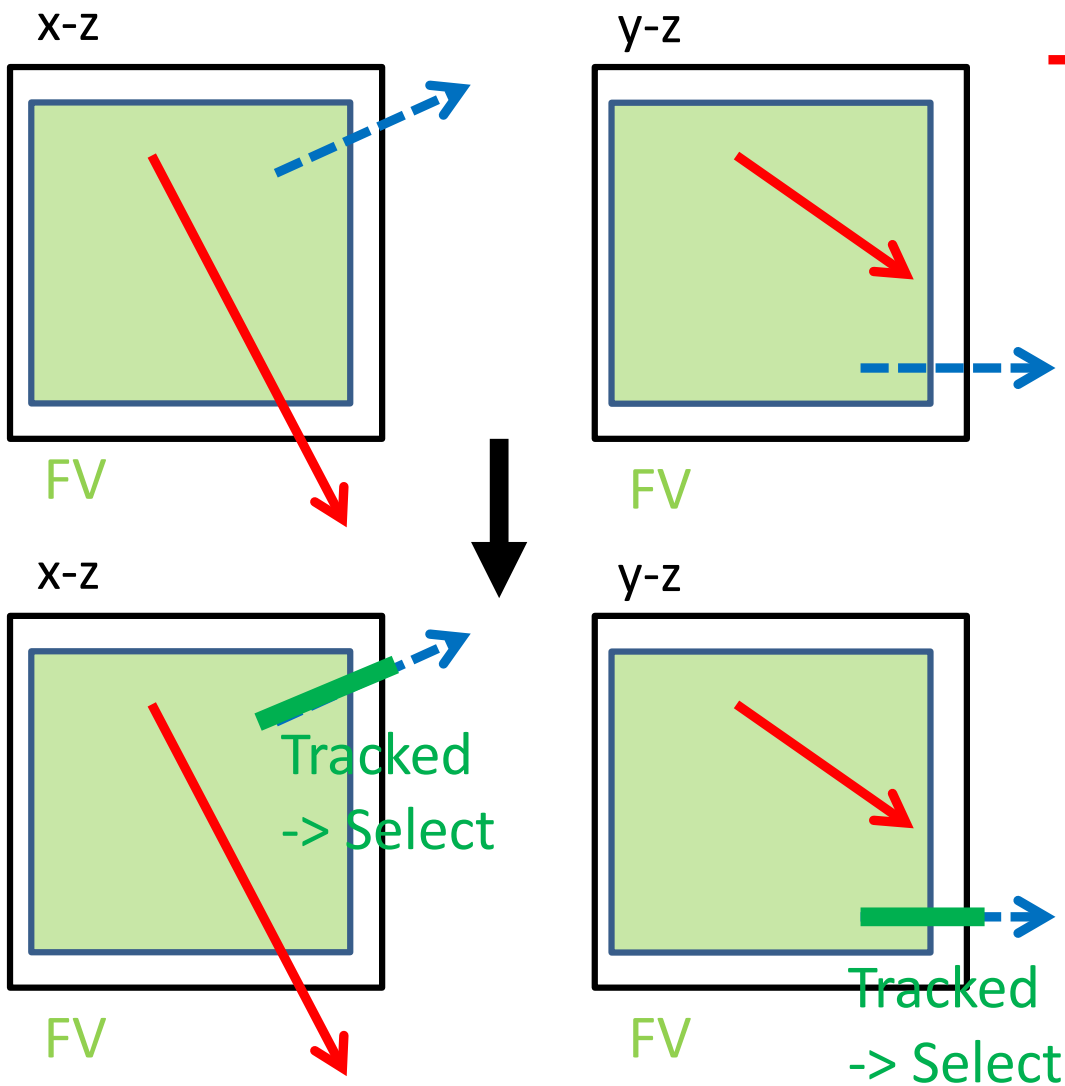
Define the following name for each event type:

NuFv = Remain after FV cut = neutrino event candidate

NuOV = Reject w/ FV cut

BG = Reject w/ Upstream VETO cut

Pileup-1 : NuFV + NuFV



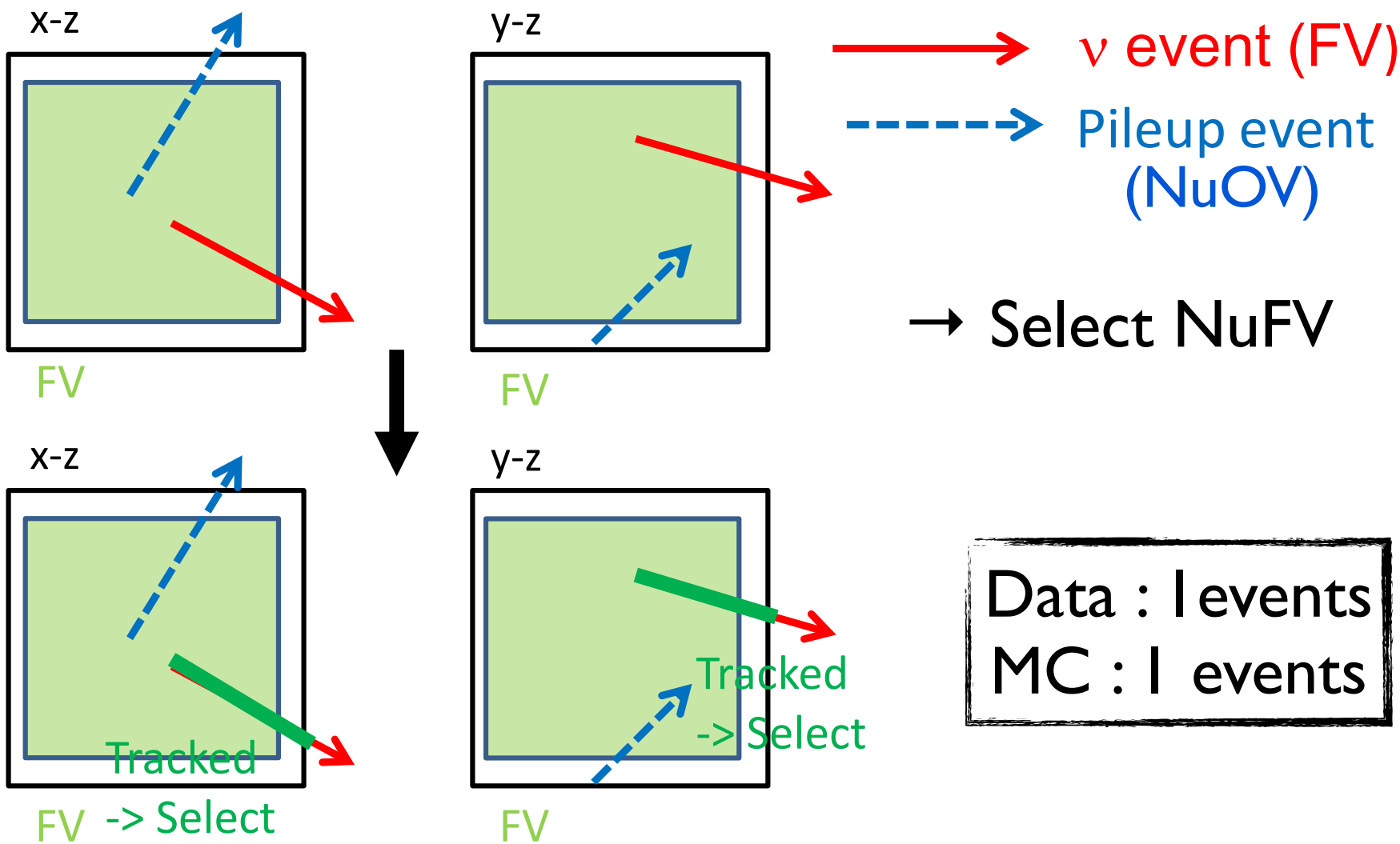
ν event (FV)

Pileup event (NuFV)

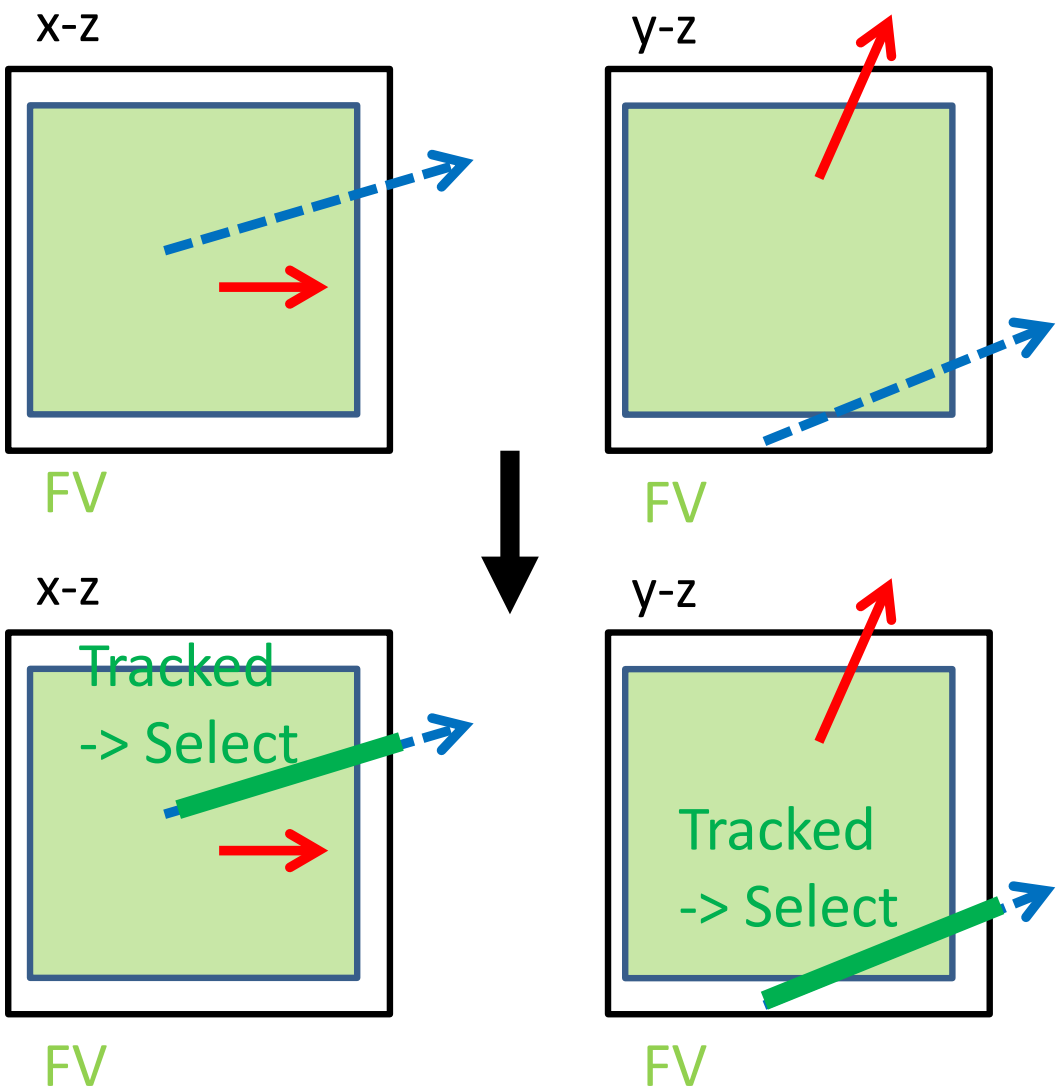
→ At current MC, generate neutrino events one-by-one. So event pileup not happen.

Data : 1 events
MC : 2 events

Pileup-2A NuFV + NuOV



Pileup-2B NuFV + NuOV



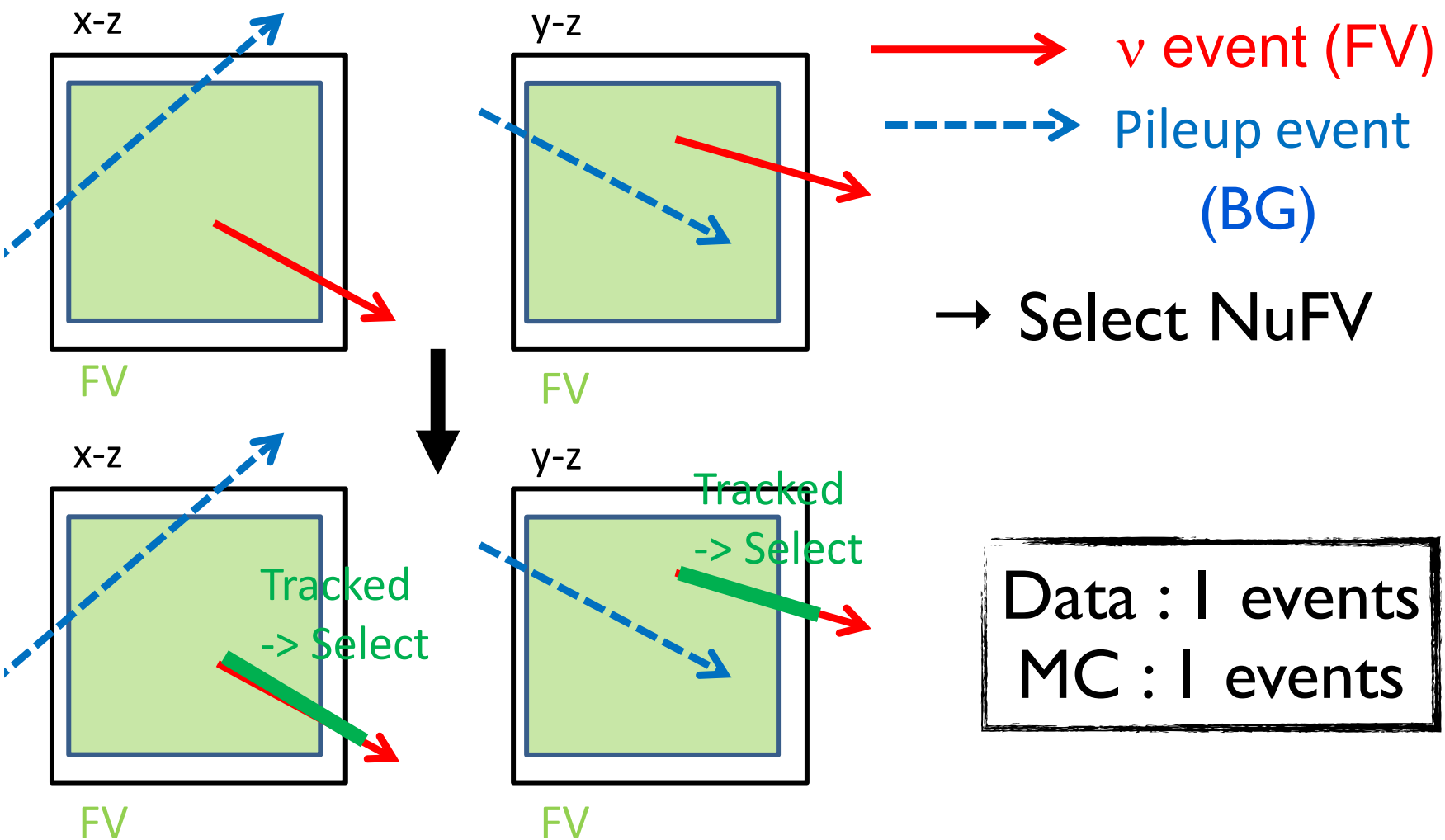
ν event (FV)

Pileup event (NuOV)

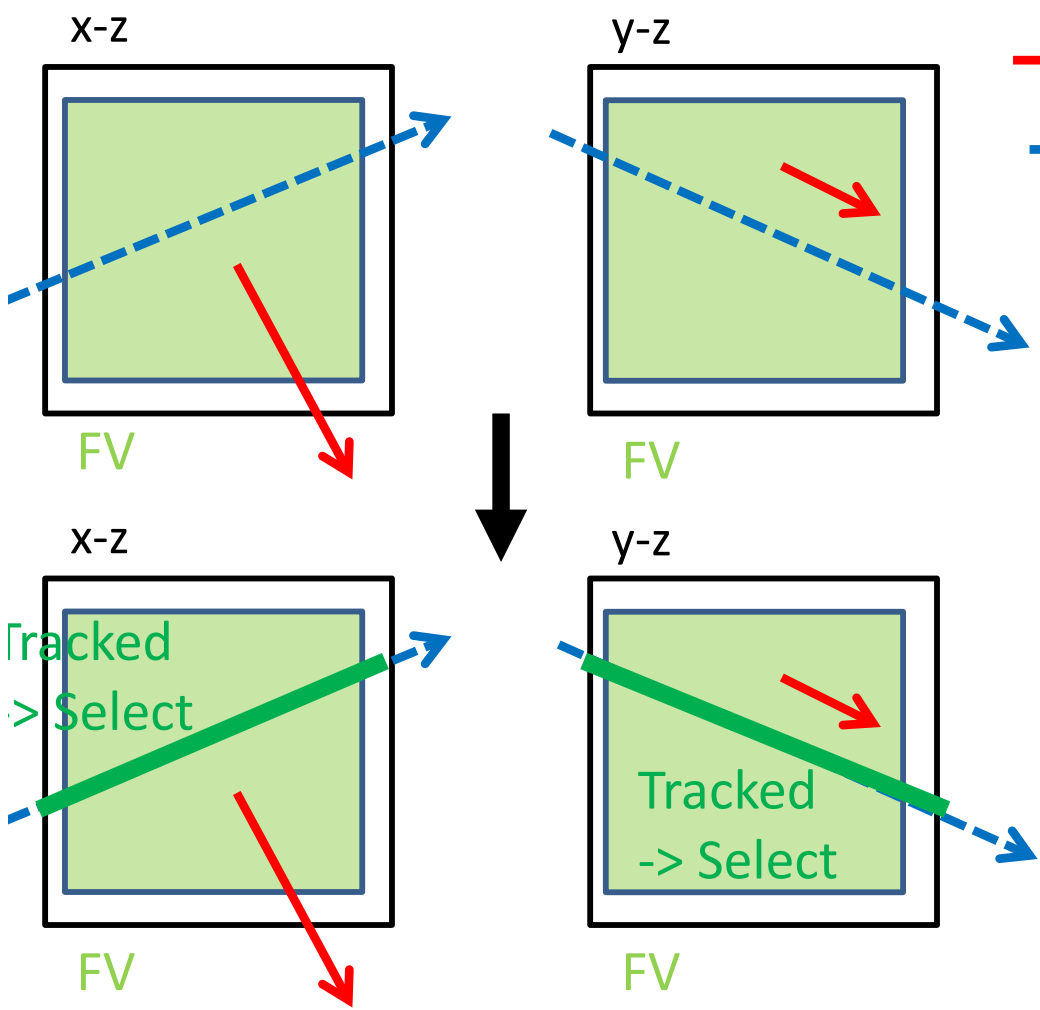
→ Select NuOV

Data : 0 events
MC : 1 events

Pileup-3A NuFV + BG



Pileup-3B NuFV + BG



ν event (FV)

Pileup event (BG)

→ Select BG

Data : 0 events
MC : 1 events

Pile-up event loss case

Event loss = (# of events counted at Data) - (# of events counted at MC)

	Event loss
pile-up 1 (NuFV-NuFV)	-1
pile-up 2A (NuFV-NuOV)	0
pile-up 2B (NuOV-NuFV)	-1
pile-up 3A (NuFV-BG)	0
pile-up 3B (BG-NuFV)	-1

→ Need to consider the case of pile-up1, pile-up 2B, and pile-up 3B to estimate the effect of pile-up event loss.

Probability of pile-up event loss

Probability of event loss from pile-up to
= Rate(pileup-1) + Rate(pileup-2B) + Rate(pileup-3B) [/ppb]

→ **Probability of event loss divided by neutrino event rate**
= Rate(NuFV) + Rate(NuOV)*Prob(pileup-2B) + Rate(BG)*Prob(pileup-3B) [ppb]

* Each event rates → Estimated from data.
* Probability of whether 2A or 2B (3A or 3B) happen → Estimated by toy MC with PDF estimated from data.

Note

- Good to assume that the pile-up probability is proportional to # of proton per bunch (ppb) at MR RunI&II beam power (max~100kW, relatively low beam power).
- At higher beam power, this response will be saturated to beam power. Need other estimation.

Each event rate (Data)

- Use data in MR Run29-30
  - Beam power ~ 2e12 ppb → Prob(BG-NuFV)~0.5% → pile-up negligible
- Estimate each event rates to calculate the ratio of # of each events to POT.

Each event rate in MR Run29&30 [**/1e14 pot**]

module#	0	1	2	3	4	5	6	7	8	9	10	11	12	13
BG	1.69E-01	2.17E-01	2.42E-01	2.51E-01	2.45E-01	2.12E-01	1.68E-01	1.75E-01	2.15E-01	2.61E-01	2.74E-01	2.62E-01	2.26E-01	1.75E-01
NuOV	3.76E-02	5.07E-02	6.08E-02	7.08E-02	6.09E-02	5.56E-02	4.47E-02	4.39E-02	5.79E-02	6.58E-02	7.26E-02	6.64E-02	6.05E-02	4.38E-02
NuFV	7.30E-02	1.06E-01	1.30E-01	1.30E-01	1.27E-01	1.06E-01	7.33E-02	8.52E-02	1.10E-01	1.31E-01	1.35E-01	1.32E-01	1.08E-01	8.44E-02

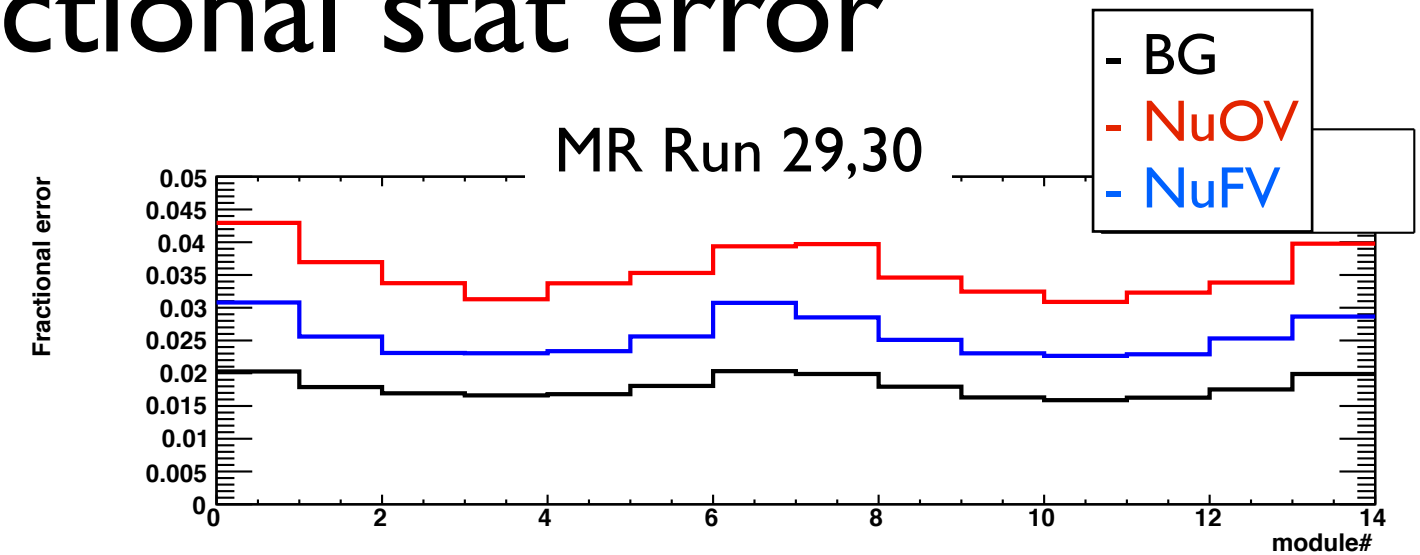
This table not include stat error.
→ Stat error shown at next page.

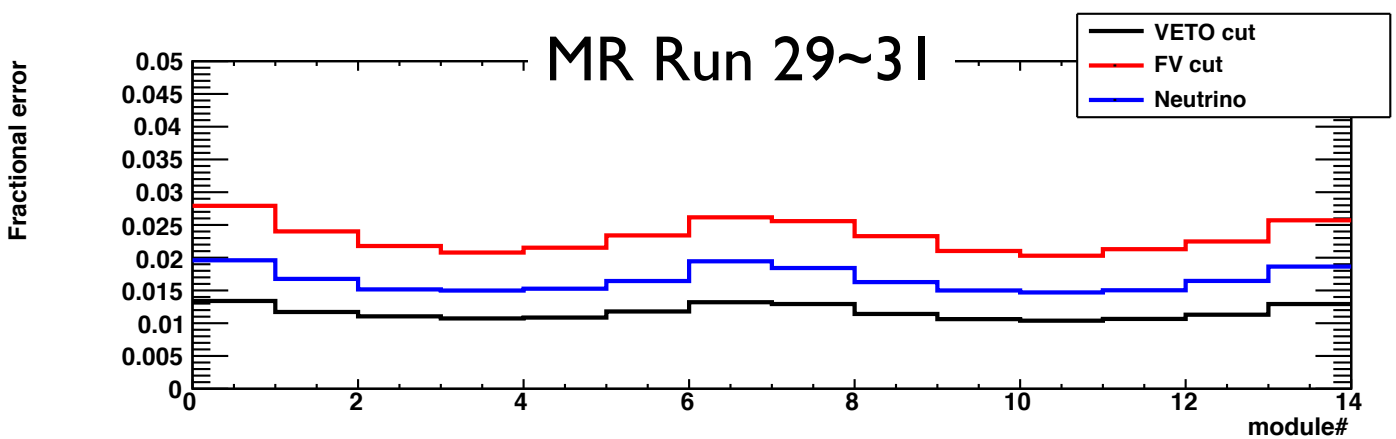
Fractional stat error

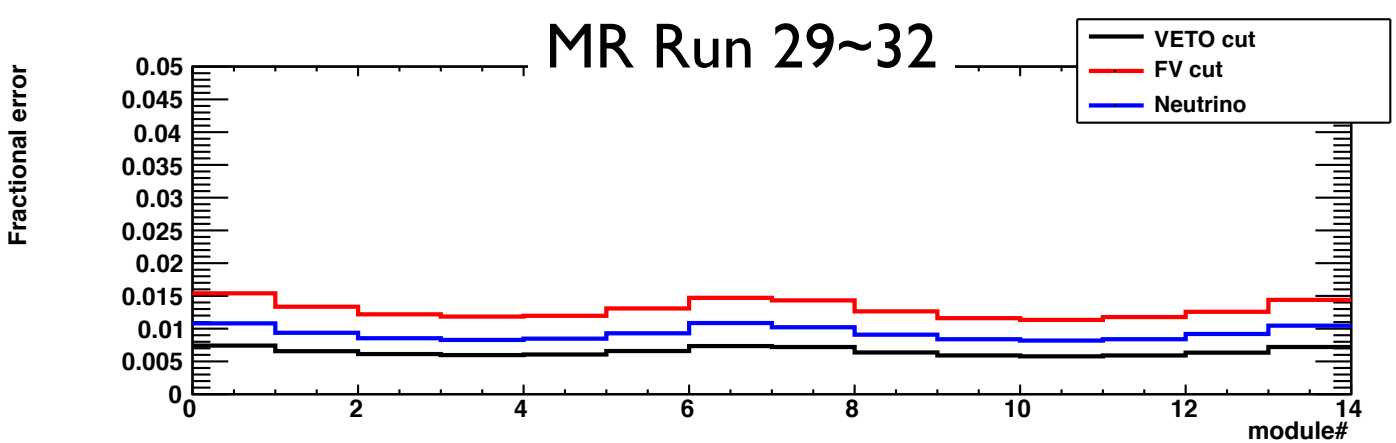
2~4% stat error by using only Run 29&30

By using Run29~32 data, stat. error reduce 1% level.

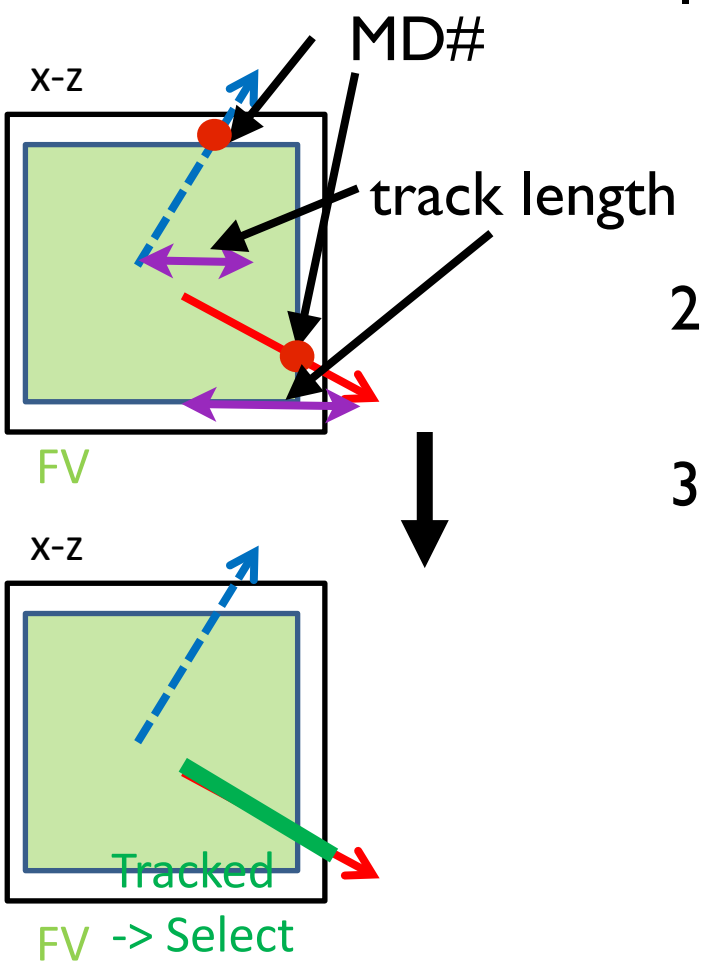
Check this error size to neutrino even rate after estimation of pile-up event loss.
→ If small, I think not need to use Run31,32 data.





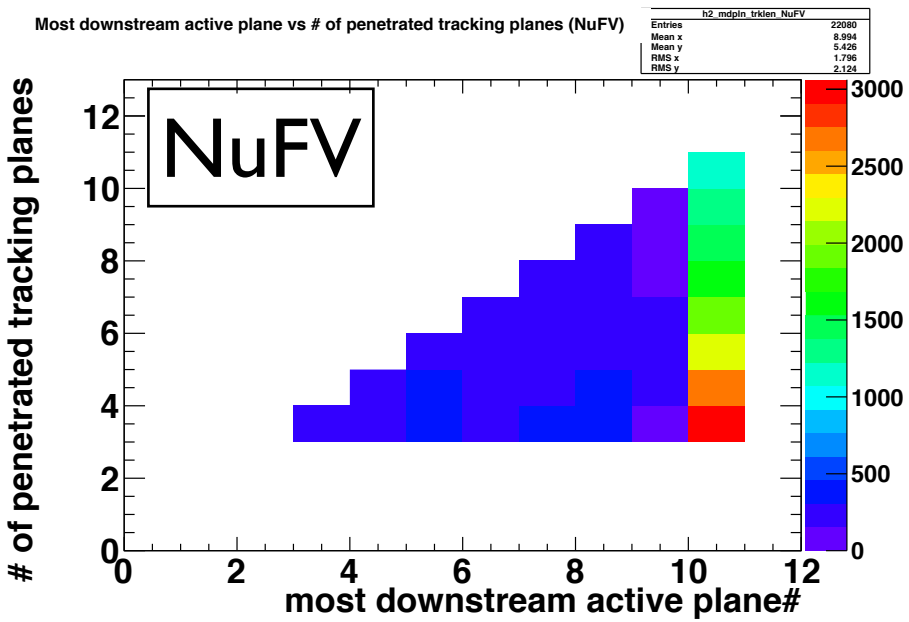


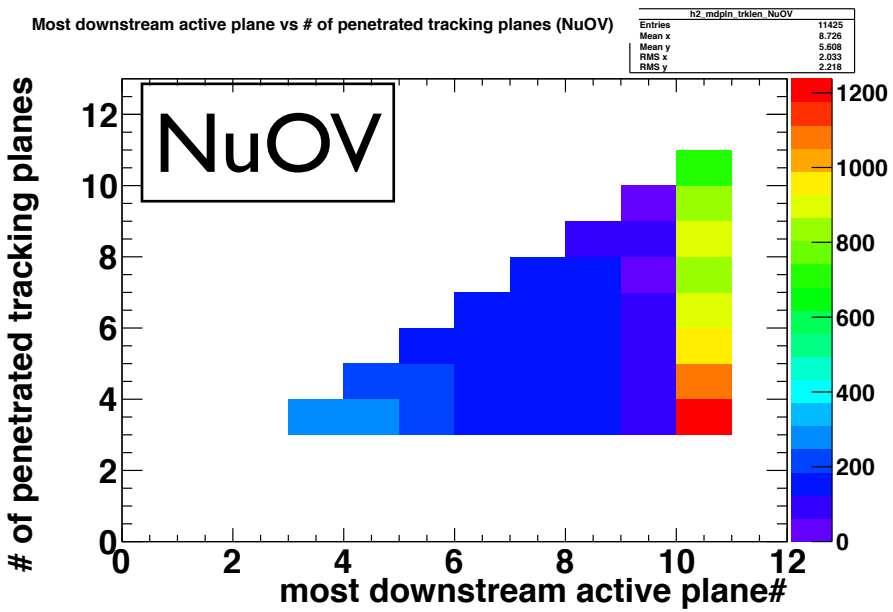
Toy MC

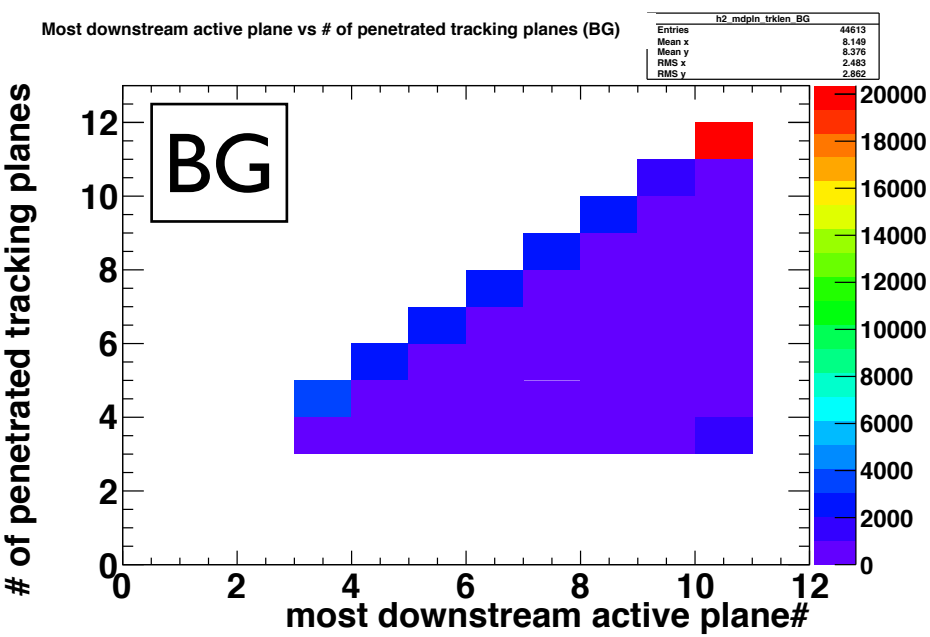


1. Make the 2D-PDF of "most downstream plane (MD#) vs penetrated scintillator planes (track length)" by Data in Run29-30 for NuFV, NuOV, BG event cases
2. Define MD# and CH planes for each event cases according to 2D-PDF
3. For pile-up 2 case, compare the MD# between NuFV and NuOV and select larger MD# track, and then categorize pile-up 2A or 2B.
    1. If MD# same, compare track length and select longer track .
    2. For pile-up 3 case, compare between NuFV and BG.
4. Repeat 1~3 process 1e6 times and estimate the probability of 2A and 2B (3A and 3B) case.

MD# vs track length distribution in MR Run29-30 data (of whole modules)







Track length = End plane# - Start plane# +1

→ Make PDF to normalize these distribution by total # of each events

Result of 10^6 toy MC

	Probability
Pileup 2A(NuFV-NuOV)	0.4758
Pileup 2B(NuOV-NuFV)	0.4605
Same MD# and CH planes	0.0637

	Probability
Pileup 3A(NuFV-BG)	0.4107
Pileup 3B(BG-NuFV)	0.5773
Same MD# and CH planes	0.0120

Plan to deal with # of events of same MD# as the syst. error

→ Assign the half of same MD# as the systematic error

Calculation of the pile-up effect

ex) the effect of the pile-up at module#10 (largest neutrino event rate)

The ratio of event loss to one neutrino event
= Rate(NuFV)
+Rate(NuOV-2B)*Prob(NuOV-2)+Rate(BG-3B)*Prob(BG-3B)
= 1.35e-2 + 7.26e-2*0.4605 + 2.74e-2*0.5773
= **0.033 [/1E+13 ppb]**

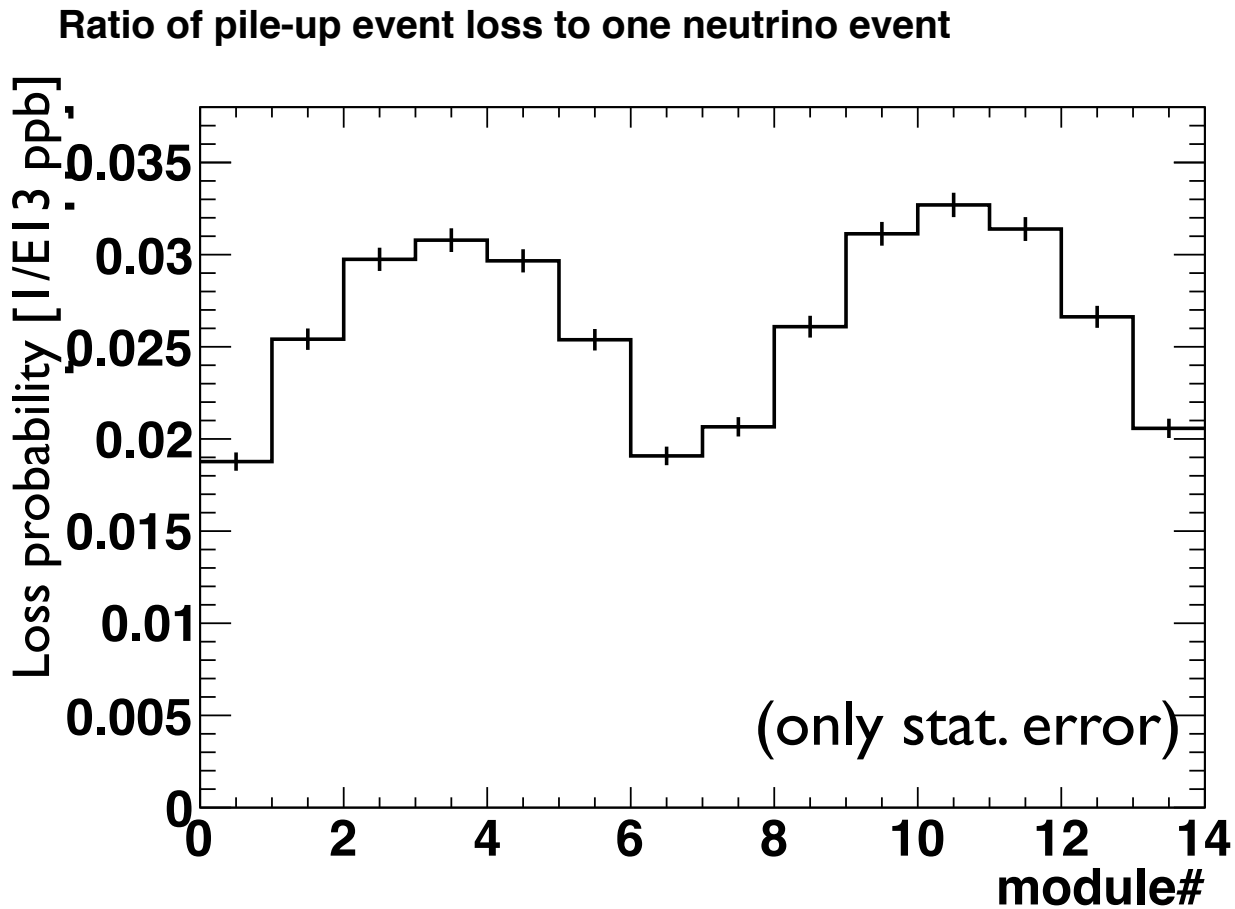
Stat error
= 7.0e-4 → **2.0%**

Syst. error from toy MC
= 7.26e-2*0.0637/2 + 2.74e-1*0.0120/2 = 5.0e-4 → **1.5%**

Event loss ratio to one neutrino event = **3.3e-2 ± 7.0e-3 ± 5.0e-3**
→ Stat. and syst. error are small (<1%) (Off course, there are other syst. error source needed to be estimated, but expected to few% level)

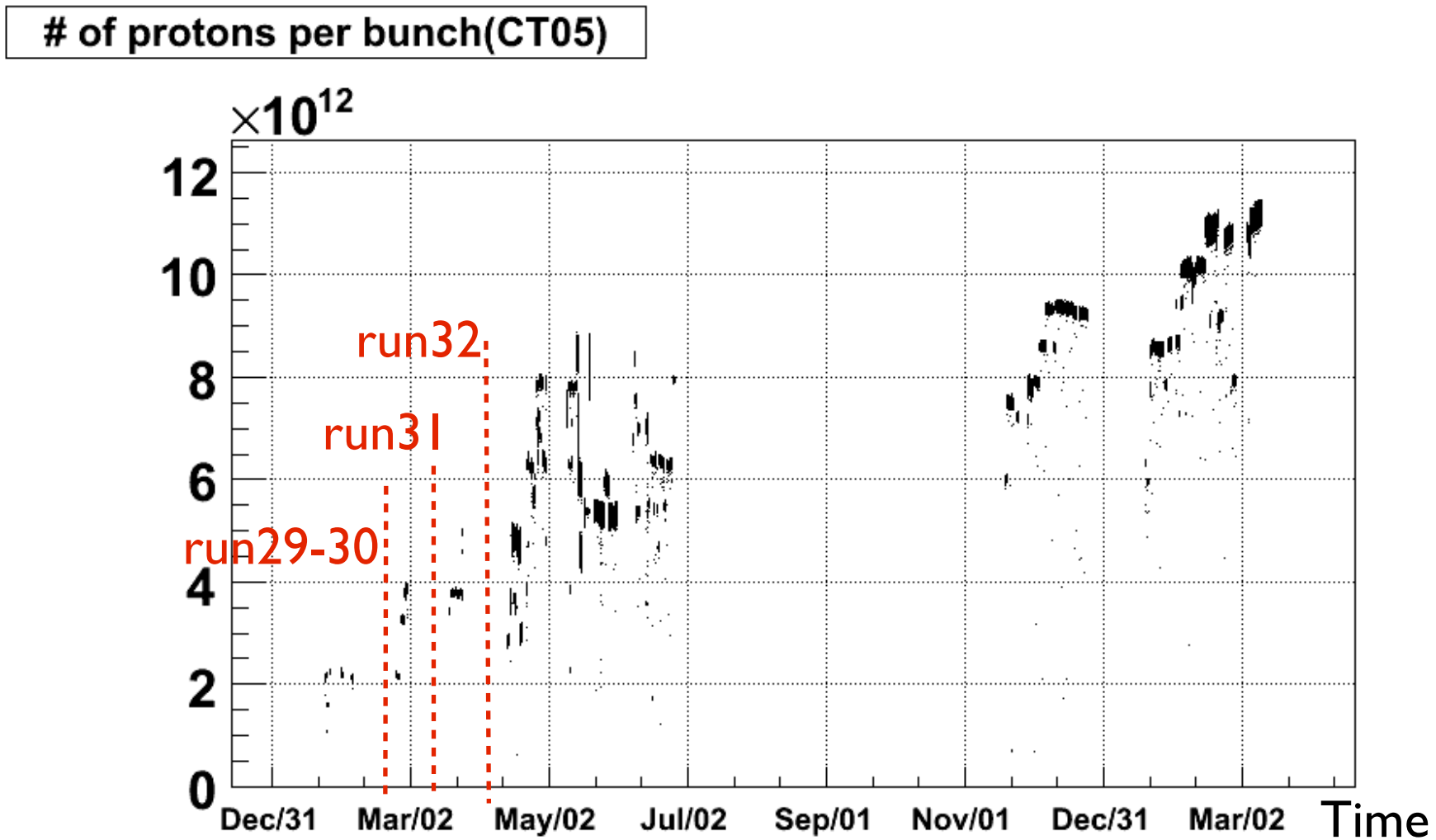
Event loss probability at each module

Event loss probability is 2~3% [/1E13 ppb]



mod#	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Loss prob [/1E13ppb]	0.019	0.025	0.030	0.031	0.030	0.025	0.019	0.021	0.026	0.031	0.033	0.031	0.027	0.021
Fractional Stat. error	0.0265	0.0229	0.0212	0.0209	0.0212	0.0229	0.0264	0.0254	0.0227	0.0207	0.0202	0.0206	0.0224	0.0254
Fractional Syst. error	0.0118	0.0115	0.0114	0.0122	0.0115	0.0120	0.0127	0.0119	0.0120	0.0118	0.0121	0.0117	0.0123	0.0119

History of protons/bunch



Run period	Avg. proton/bunch	pile-up loss prob. (mod#10)
run29&30	~2e12	6.8e-3
run31,32	3.5~4e12	1.2e-2~1.4e-2
run 38	~1e13	3.40E-02

Summary

- Roughly check the pile-up effect by using the low intensity beam data and toy MC
  - Probability of pile-up event loss divided by neutrino event rate = 0.033 [/1e13 ppb] (at module#10)
- At March 2011 beam power = 145 ~ 1e13 protons/bunch → 3.3% event loss at maximum (assuming linearity of pile-up loss) → Not negligible, need to consider !
- Can estimate the correction factor spill-by-spill to observed neutrino event in Data by using this results → Will do it
- In parallel to this study, estimate the pile-up effect bunch-by-bunch by using Detector MC properly (by kikawa-san).