Muon neutrino disappearance update

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What's new since last CM

- First NC/CC analysis
  - shown at the Neutrino 2016, as a plot only, without systematics, simple statistical treatment
  - systematics will certainly dilute the result
- Better statistical treatment
  - in progress
- Systematics study
  - in progress

First NC/CC analysis

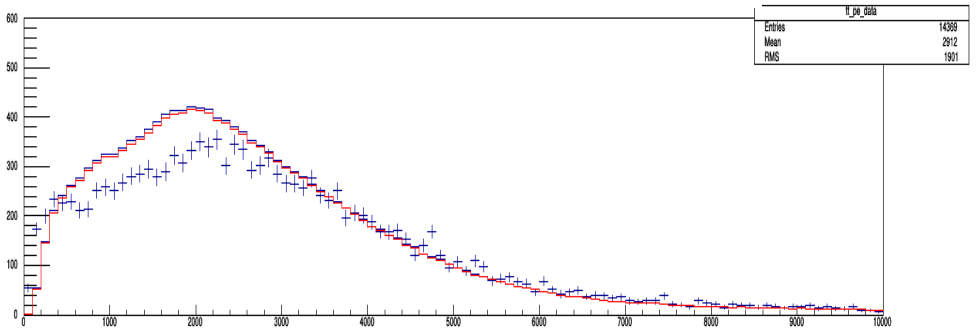
Event selection

- CC-like selection
  - n_mu_tracks > 0 && bending_topology && p_mu_good != 0
- NC-like selection
  - n_mu_tracks = 0 && !bending_topology && p_mu_good = 0
  - note that this is **different** from NOT(CC-like selection)
- Global selection
  - CONTAINED && TT_digits >= 10
  - must be either CC-like or NC-like
    - gets rid of the mess in the middle
  - TT photoelectrons > 400

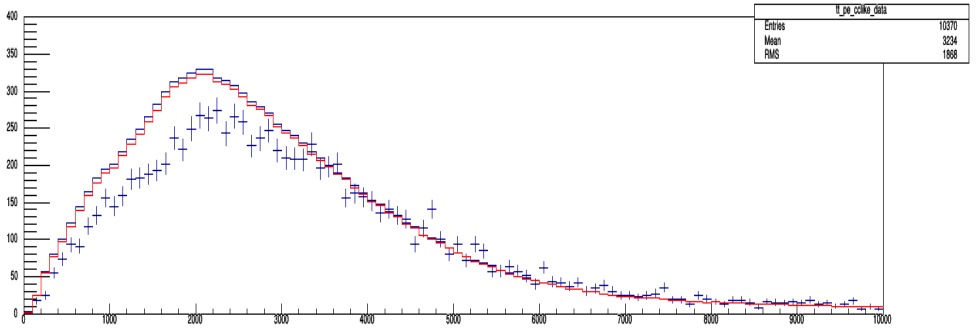
Additional cut

- Additional global cut
  - total TT photoelectrons per event > 400
  - this comes by comparing tt_pe between MC and data and cutting where they diverge
  - I believe this is detector noise

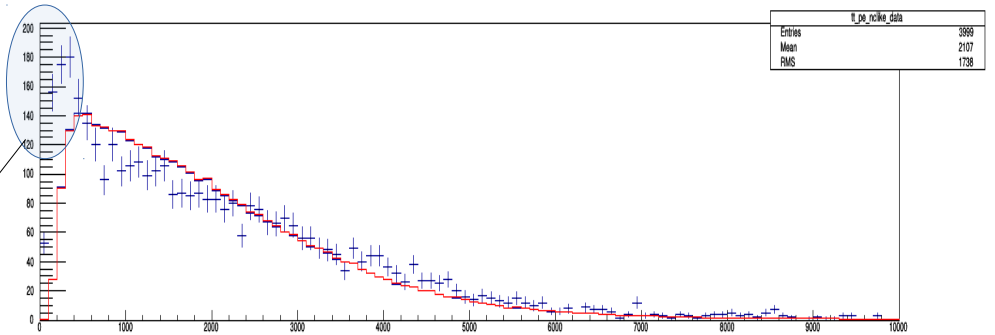
NC-like and CC-like events



CC-like events



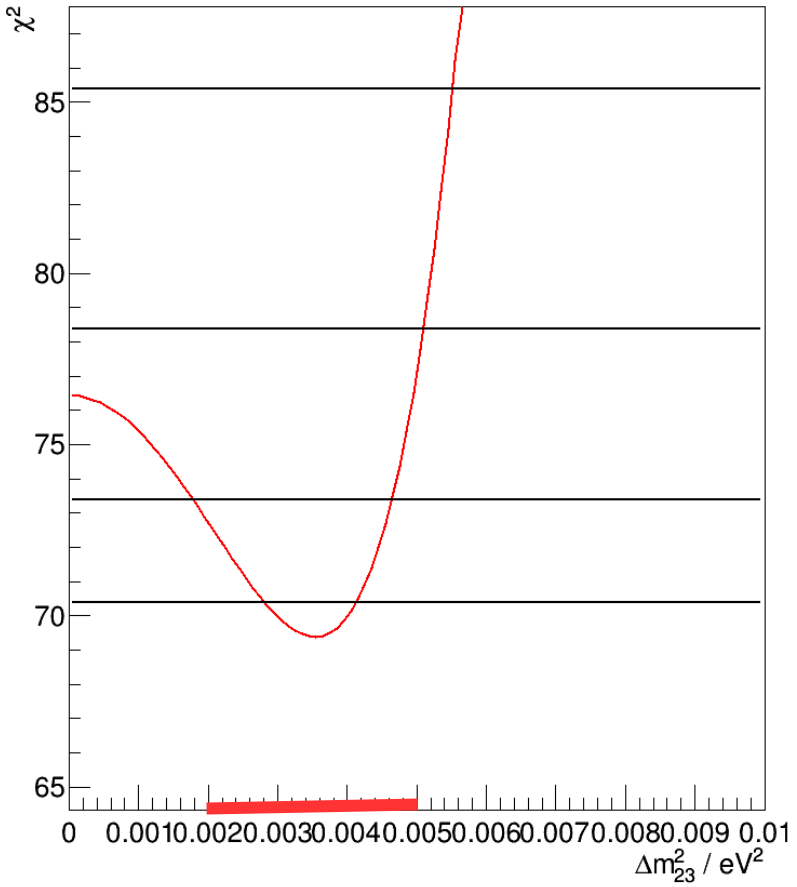
NC-like events



cut these away

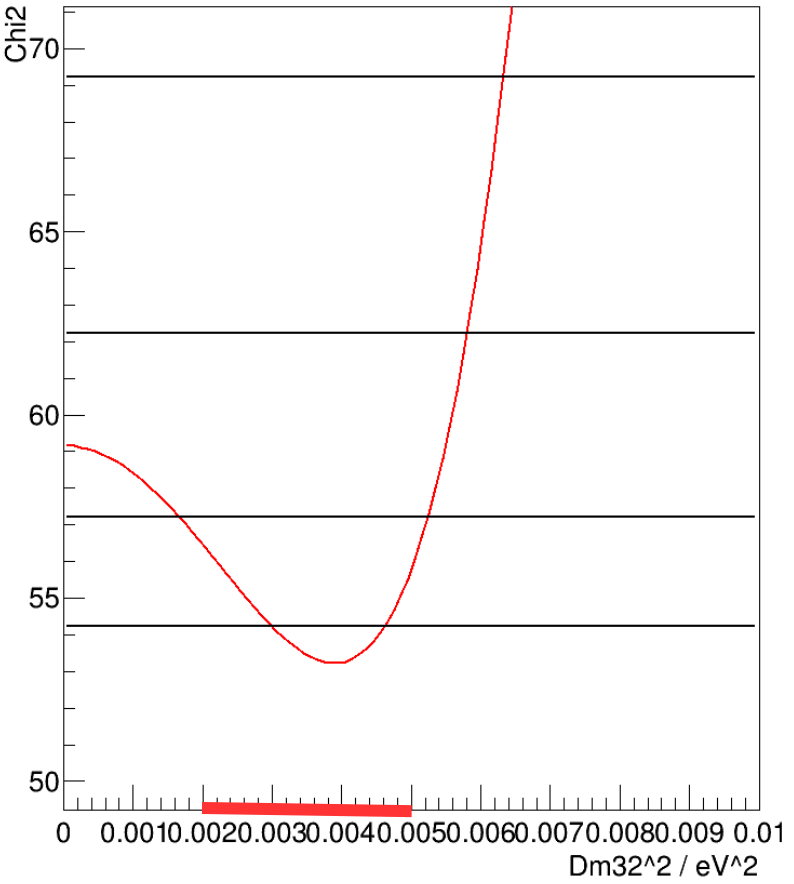
Fit results, mixing angle fixed

χ^2 in NC/CC ratio fit, $M_{\mu\mu}$ = 0.99997



chi2_min=69.377971 ndof=71
chi2_min/ndof=0.977155
(m2_low, m2_best, m2_high)
(0.002812, 0.003538, 0.004129) @ 1s
(0.001786, 0.003538, 0.004640) @ 2s
(0.000000, 0.003538, 0.005096) @ 3s
(0.000000, 0.003538, 0.005510) @ 4s

NC/All ratio, M_mu_mu = 0.99997



chi2_min=53.222128 ndof=72
chi2_min/ndof=0.739196
(m2_low, m2_best, m2_high)
(0.002997, 0.003892, 0.004616) @ 1s
(0.001663, 0.003892, 0.005241) @ 2s
(0.000000, 0.003892, 0.005802) @ 3s
(0.000000, 0.003892, 0.006317) @ 4s

appearance
90% CL

Further work

- This analysis looks OK, but needs to be improved to make sure it's correct
- We need:
  - better statistical treatment – to be sure
  - inclusion of systematics - mandatory
  - better proxy variable than E_tt - optional

Better statistical treatment

Statistics

- We are using NC/CC ratio to reduce systematics coming from the beam uncertainty
  - statistics of a ratio is different than statistics of a counting experiment (Poissonian or Gaussian)
  - therefore, we think Chi2 statistics might not be entirely appropriate for our analysis
  - we are investigating this effect and trying to construct a proper statistical treatment for our problem

Bayesian approach

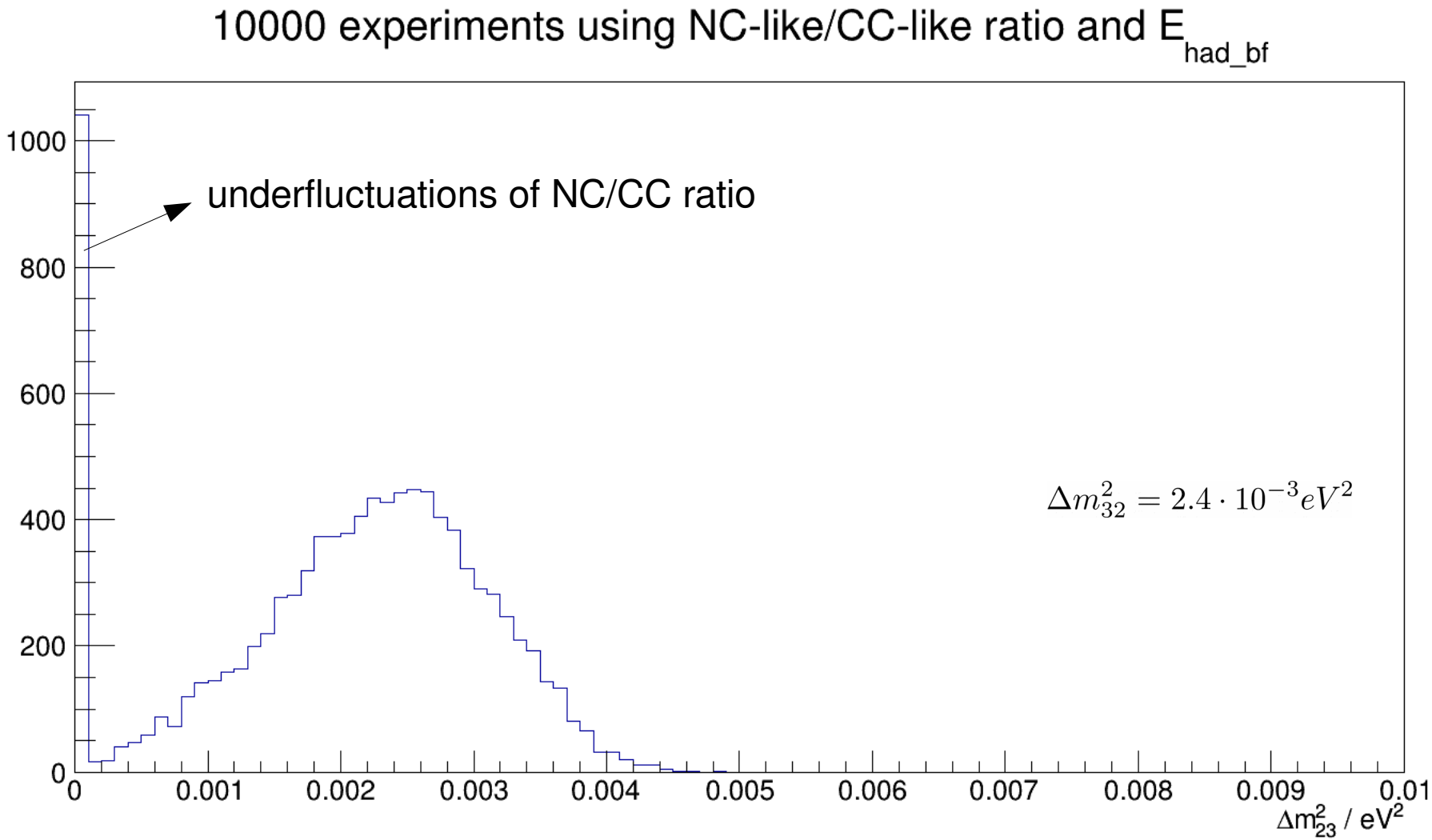
- Bayesian approach seems better for this problem because:
  - easier to marginalize unknown beam uncertainty coefficients
  - easier to combine with other measurements
    - can be used as prior to tau appearance measurement
- Actually, we are currently using the *maximum a posteriori estimation*, but are thinkng to construct full bayesian pdf

  $P(\Delta m^2_{32}|\mathrm{data})$
- An internal note will be available with all the details

Pseudoexperiments

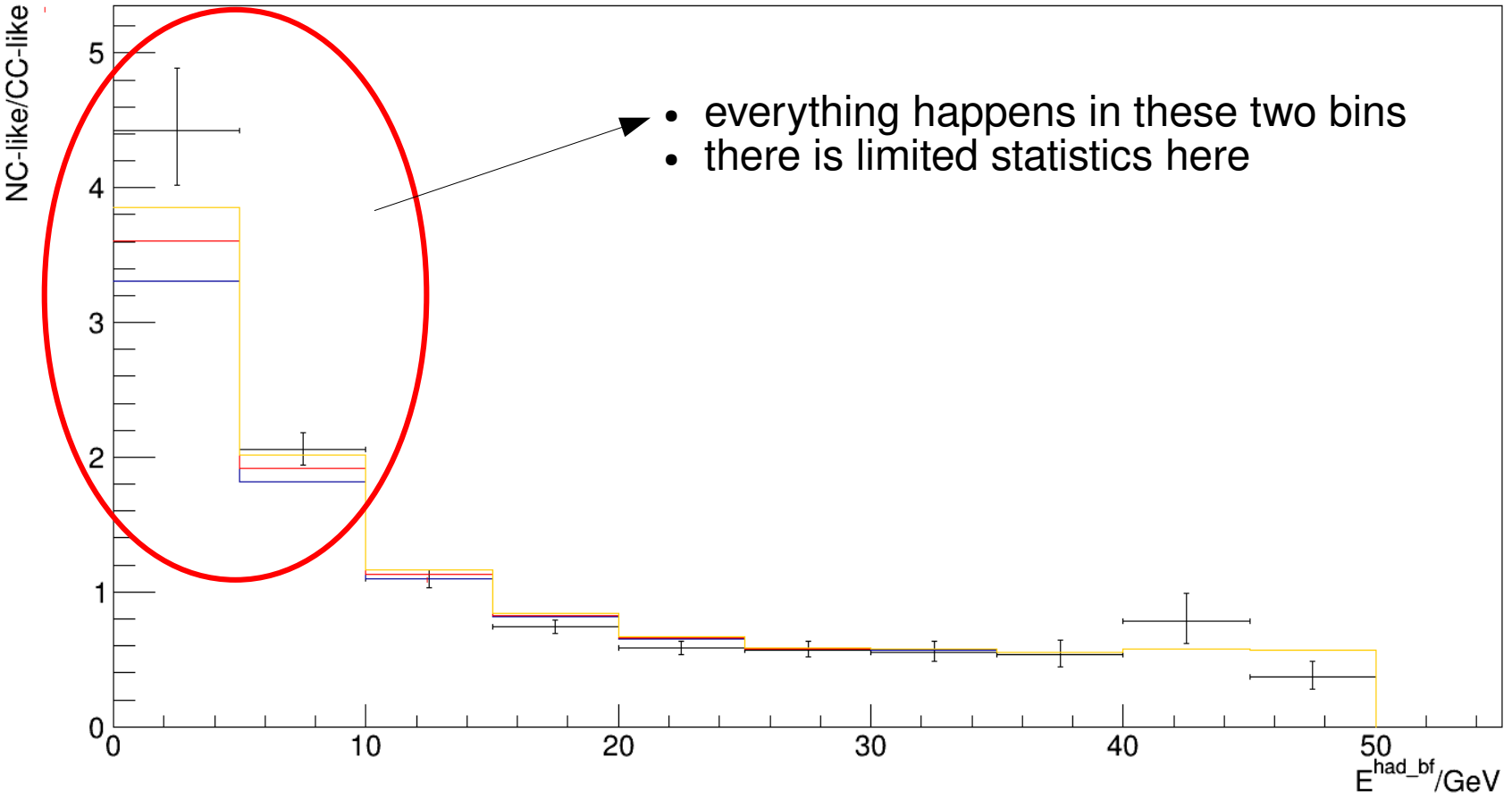
- Since we have a large MC sample (~100 times data), we can use it to construct simulated experiments
  - data is simulated by randomly choosing MC events, according to their weight
  - number of chosen events is roughly equal to number of data we have
- We have used such pseudoexperiments to test the statistical procedures in our analysis, and it will be further used to study systematic effects
  - for systematics - modify beam normalization and shape and see how it affects the result of simulated experiments

Simulated experiment sample, bayesian statistics



Bayesian MAP estimation, no systematics

Example of one pseudoexperiment

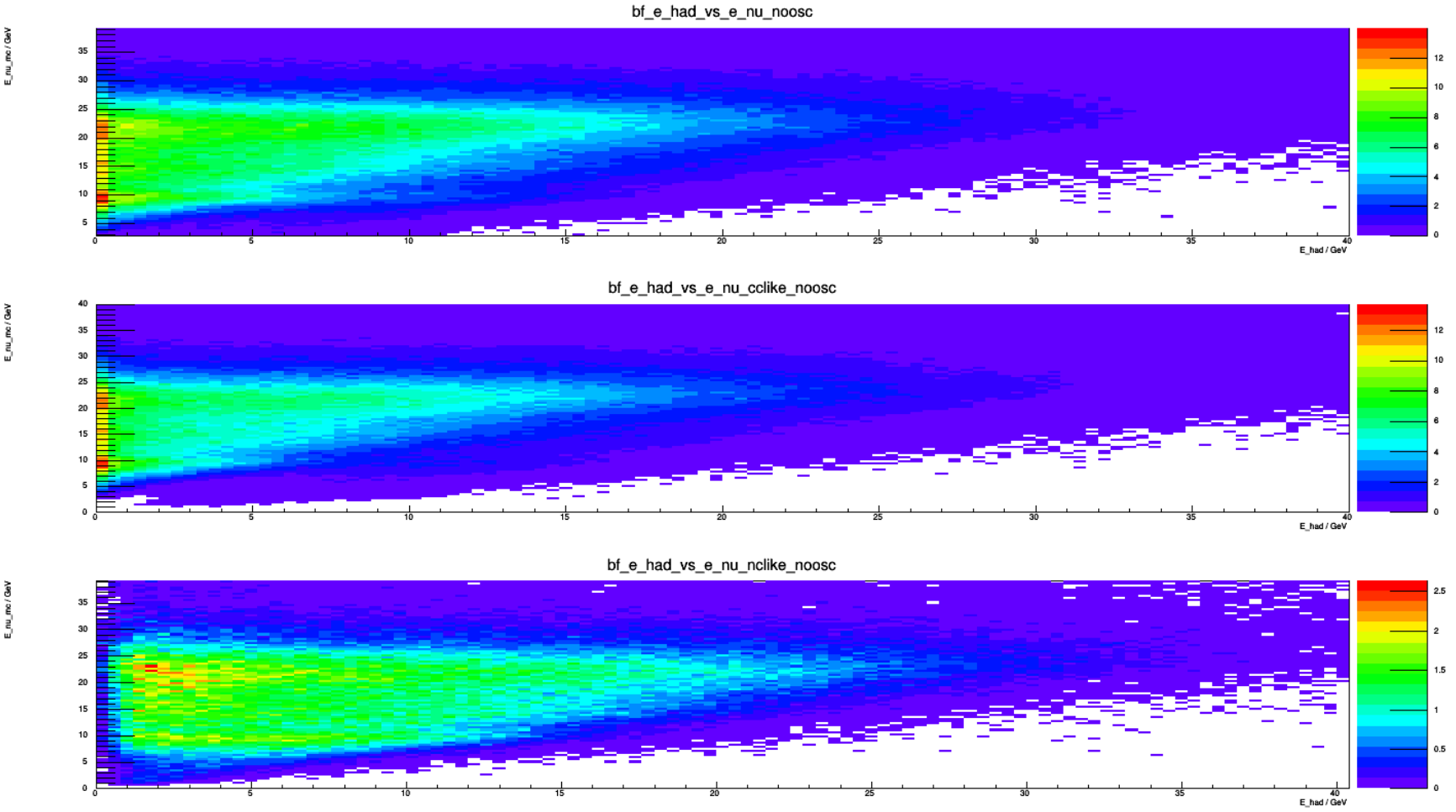


Beam systematics

Beam systematics

- NC/CC ratio should decrease the systematics coming from the beam
  - BUT this will work if dependence of true nu energy on a proxy variable (E_tt, E_had, …) is similar for NC and CC samples
    - this similarity is not the best in our case
- Idea to improve this was to use TMVA regression to train the various MVA systems to reconstruct true nu energy, wich would be our new proxy variable for E_nu

BF hadronic energy vs. true nu energy



TMVA energy reconstruction

- we tried using TMVA regression to reconstruct energy on event-by-event basis
  - separately trained for CC-like and NC-like events
  - MLP (neural network) gave the best results

Variables used for MVA training

	CC-like	NC-like
BF hadronic energy	yes	yes
TT deposited energy	yes	yes
Good muon momentum	yes	no
First brick center X	yes	yes
First brick center Y	yes	yes
First brick wall	yes	yes
BF predicted SM	yes	yes
TT planes	yes	yes
RPC planes	yes	yes
Non-mu tracks	yes	yes
Angle between hadronic jet and beam direction	no	yes

TMVA energy reconstruction

- results reasonable for CC-like events, useless for NC-like events
  - CC-like events have closed kinematics
- it seems we are stuck with leftover systematics of the beam, even when using NC/CC ratio

TMVA NC/CC classification – a possibility

- an additional possibility is to train MVAs to make a better NC/CC classification
- however, pseudoexperiments show that there would be no gain in the sensitivity
  - we compared pseudoexperments using true NC/CC information and the ones using NC-like/CC-like classification
- could be done, as an acaemic exercise sometime along the line, but it's not a priority now since time is critical

Conclusions

Conclusions

- We are working towards the end of disappearance analysis
  - in worst case scenario we will get only the upper limit on square mass difference
- Bayesian approach will make it easier to combine disappearance result with results from other channels
  - it can be used as a prior, but it might be technically difficult
- As suggested by the PC, we will have a single paper containing disappearance and other channels
  - I completely agree with this

The end