Particle ID study and its application at ILD (towards flavor tagging improvement)

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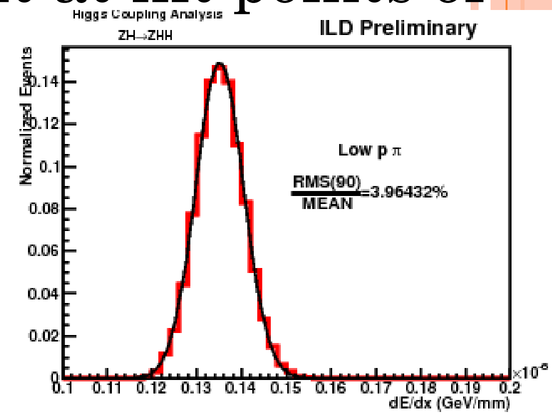
For analysis improvement

- All the analyses are saturated within the present framework
  - Needs new idea
  - Especially, need to improve the results of Higgs self-coupling
- Fundamental new variables might provide improvements of analysis tools @ILD, but not yet used well
  - dE/dx in TPC
  - Shower profiles in the calorimeters
- Particle ID will be available using those variables
- Will those variables give improvements to other analysis components?
  - Isolated lepton ID → of course!
  - Energy correction using PID → it is OK!
  - Flavor tagging using PID? → looks hopeful!
  - Hope for jet clustering?

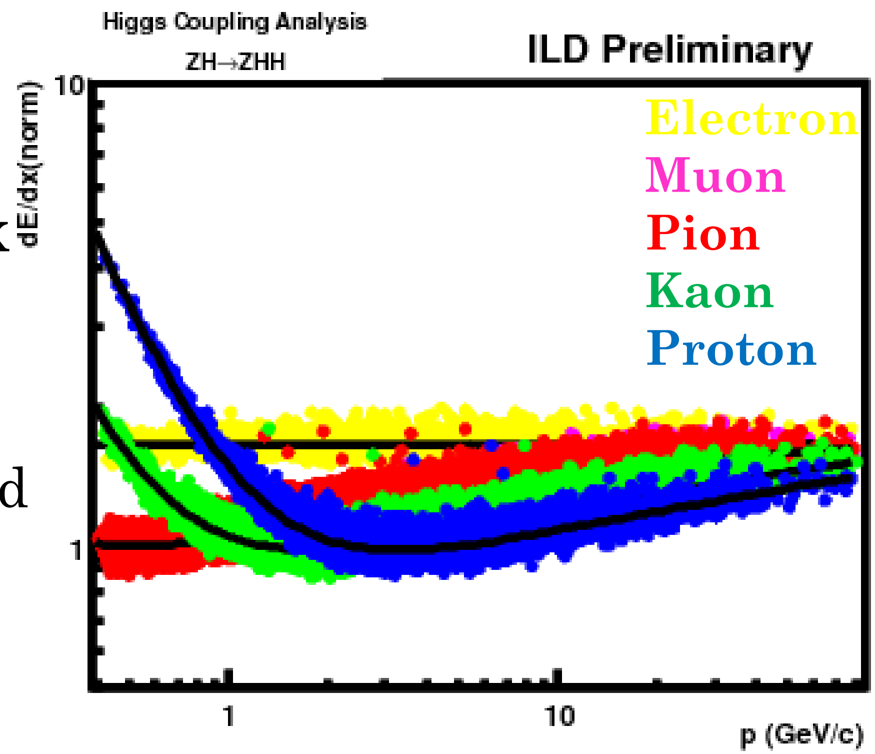
→it is necessary to study them

dE/dx from TPC @ILD

- dE/dx can be calculated using energy deposit at hit points of TPC
- Fluctuation of dE/dx is important: TDR 5%
  - Check using various type of tracks
  - Fluctuations of each particle/each momentum range: **3 – (<5)%!!**
  - Including detector effect is necessary



- Momentum dependence of dE/dx for each particle
  - Polar angle dependence corrected
  - Num. of Hits dependence corrected
  - Scale to $\left\langle \frac{dE}{dx} \right\rangle = 1.0$ for MIP pion



Shower profile @ILD

- Shower shapes in the calorimeter are different between electron/photon/muon/hadrons
  - So characters of the clusters will be a good tool to distinguish tracks
  - Especially, electromagnetic shower shape is well known
  - Grabbing those information will boost leptonID efficiency/fake rejection efficiency

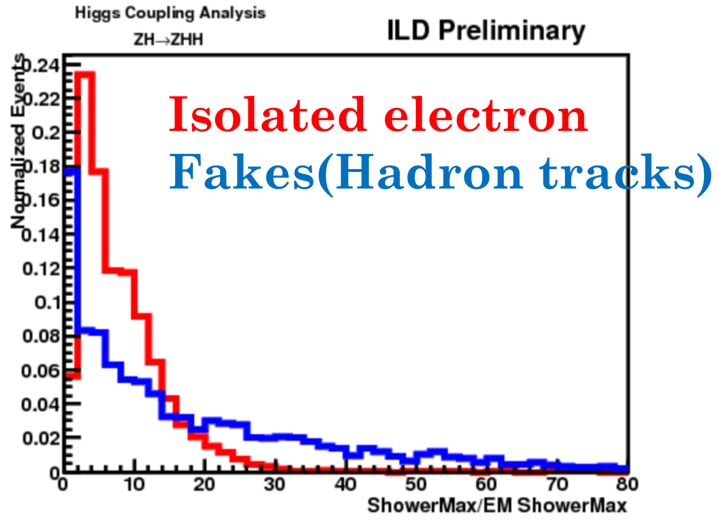
- Information extraction is based on fitting to cluster hits:
  - Well-known EM shower profile

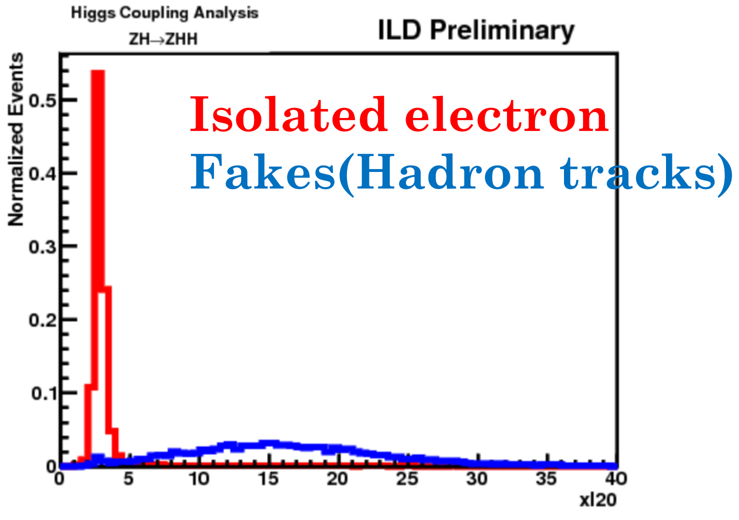
$$f(x_l, x_t) = ac\frac{(c(x - x_{l0}))^{b-1} \cdot \exp(-c(x - x_{l0})) \cdot \exp(-dx_t)}{\Gamma(b)}$$

- In addition, hit based variable is introduced to identify shower start
  - Xl20 – length from cluster start to 20% of total energy deposit

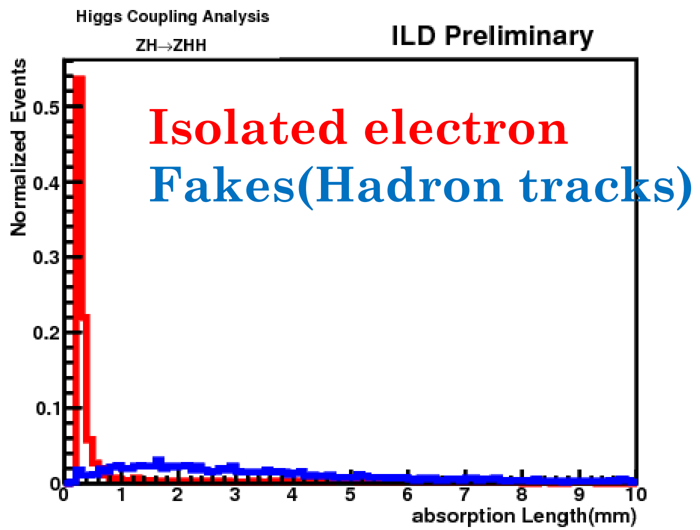
Shower profile @ILD

- Longitudinal information – shower Max, & shower start position





- Transverse information – Absorption length



First Application – Lepton ID

- Lepton ID for single lepton – using likelihood method
  - Lepton likeliness: $L = \frac{\prod s}{\prod s + \prod b}$,
  - Variables: traditional variables(Ecal/(Ecal+Hcal), E/P, D0, Z0, cone energy)
  - And using dE/dx(convert to χ^2) & shower profiles
- Signal detection efficiency – set almost same efficiency
- Signal is HH→(bb)(WW*)→(bb)(lvjj)

method	Cut based	Likelihood_old	Likelihood_new
Signal(%)	98.1	98.1	97.8

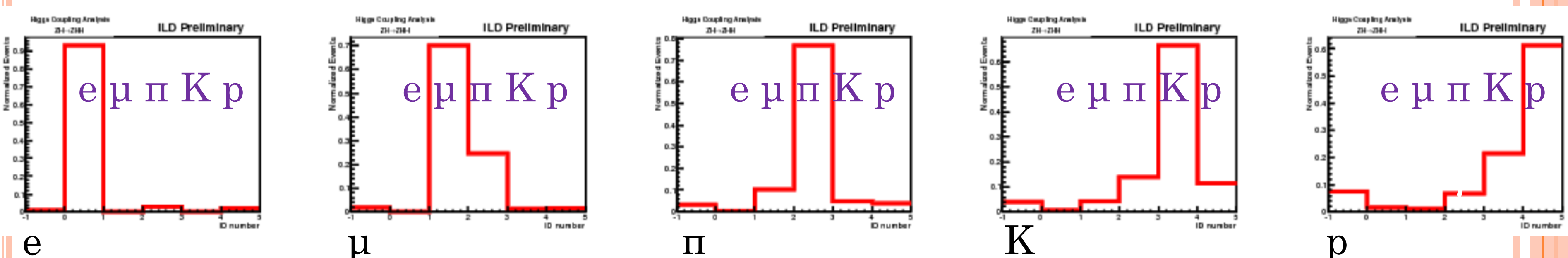
- Background rejection efficiency:

Single lepton ID	Cut based	Likelihood_old	Likelihood_new
Signal(%)	98.1	98.1	**97.8**
ttbar – all hadronic(%)	7.9	3.1	**2.3**

  - Improvement of all hadronic event rejection: ～30%
  - Note: lepton energy threshold is loosened on likelihood_new
    - From E(lep)>15GeV → E(lep)>10GeV

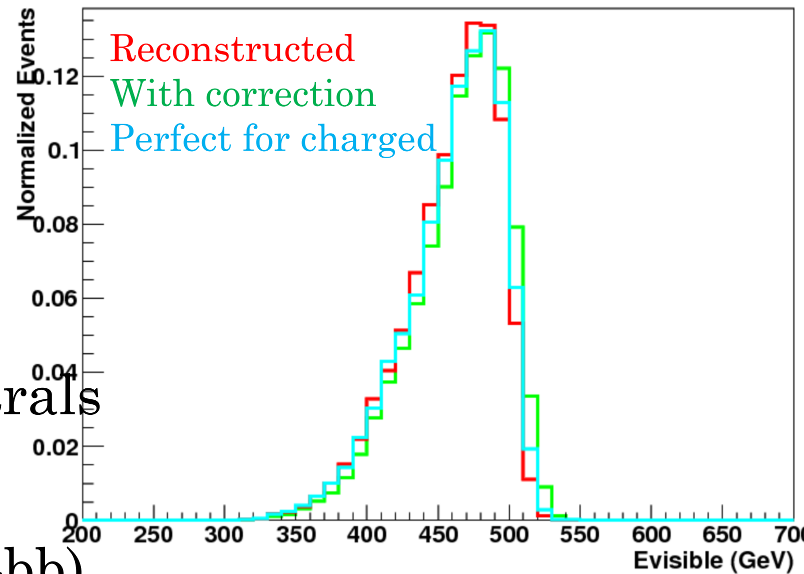
Particle ID @ILD

- New variables make Particle ID available
  - How are particles identified as each particle type?
- Construct Particle ID algorithm:
  - Based on Bayesian approach: define posterior probability
  - Make "rejected" category:
    - Track is rejected if its posterior probability is below threshold
    - Those tracks are moved to pions
- Overall ID efficiency – no energy threshold required:
  - Electron can be identified almost perfectly(>90%)
  - Muon ID eff. is ~70% →due to low energy muons(μ/π separation)
  - Hadron ID effs. are 62%~75%

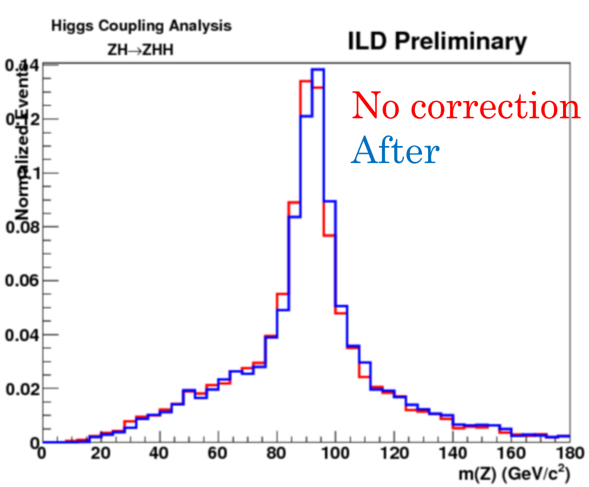


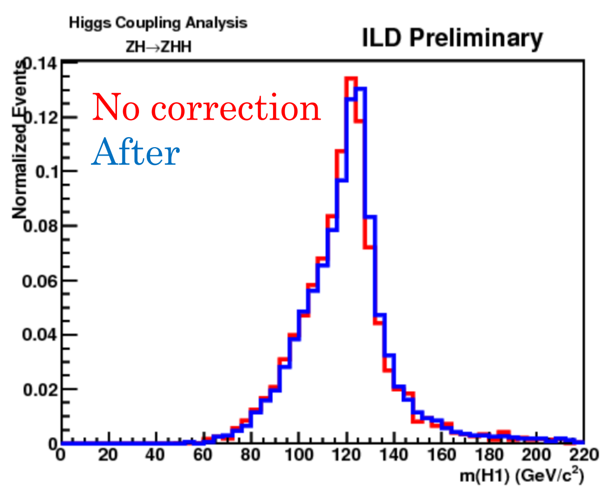
Track energy correction

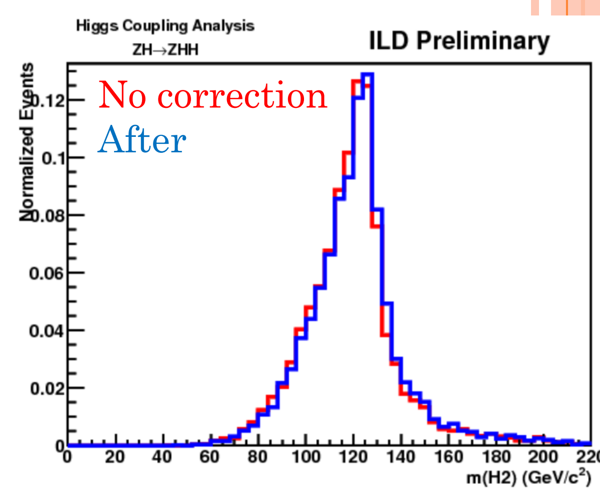
- Track energies are corrected using those momentum & mass
  - Using particle ID to identify tracks
- Visible energy
  - Using qqHH→qq(bb)(bb)
  - So far, overestimated due to misID
  - Correction effect is small due to neutrals



- Mass distribution
  - Check Z(Z→qq, q is light) and H(H→bb)
  - Jet matching with MC truth is applied
  - Effect is small too due to neutrals







Hope for flavor tagging improvement

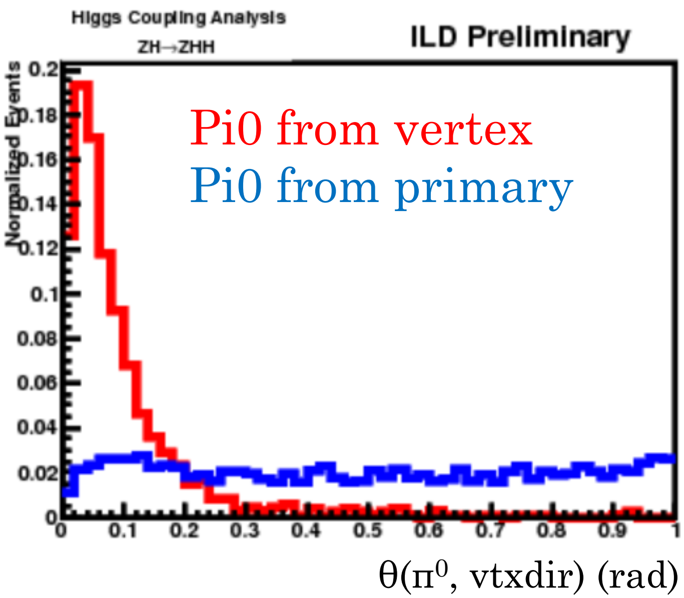
- For flavor tagging improvement
  - Vertex mass is the key to separate heavy/light flavor vertex
  - Many pi0s will escape from B/D vertex → checked that using MC truth
  - Mass resolution will be degrade due to escaping neutrals
  - Is there possibility to recover pi0s which escape from vertices?

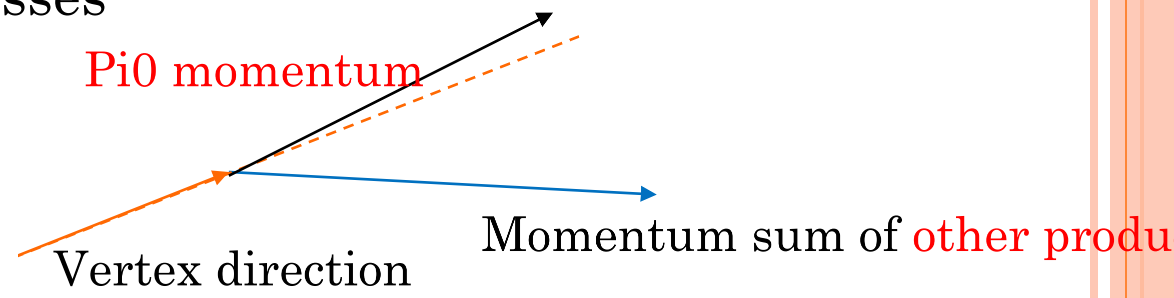
- We are studying the possibility of vertex mass recovery using pi0s
  - Pi0 vertex finder – which vertex is the π^0 coming?
- Finding vertex of pi0s
  - Very difficult to identify vertex – depends on detector configuration
  - Making the best of decay kinematics
  - Using TMVA to find pi0 candidates from the vertex
  - Comparing vertex mass distribution
  - Sample: using qqHH@500GeV samples(so many tracks & pi0s in events)

- Goal: flavor tagging efficiency improvement!

KEY ISSUES

- Pi0s from (secondary, third) vertices are very collinear to vertex direction
  - due to their small masses



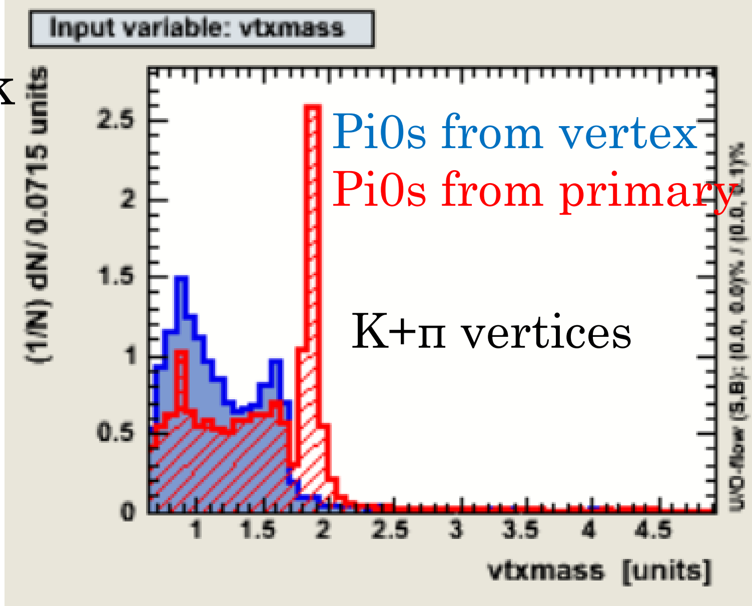


- But, there are many pi0s which come from primary vertex & are accidentally collinear to the vertex direction!
  - Ref.) In qqHH events, 50～60 pi0s will be produced!!

Key issues

- To avoid attaching too many pi0s:
  - Don't add pi0s in specific conditions →using vertex mass for MVA input

    e.g.) no pi0s will come on D meson peak



  - **Generality can't keep due to this variable!**

    →but, this is a hint

    ※Particle pattern on vertex has different vertex mass pattern!

  - Making wrong mass shift effect smallest
    - Checking pi0s from large energy to small energy
      - Arrange pi0s in descending order of those energies
    - Update vertex momentum when a pi0 candidate is found

      →add pi0 4-momentum to vertex momentum, and use it for next pi0 candidate check

Input variables to construct a general classifier

- Getting general - num. of particles are used as input variables
  - Num. of e/μ/π/K/p in the vertices – using particle ID
  - Those variables are not variables for background rejection, but are variables for vertex classification

  → Do those variables work as variables for vertex classification in the MVA classifier?

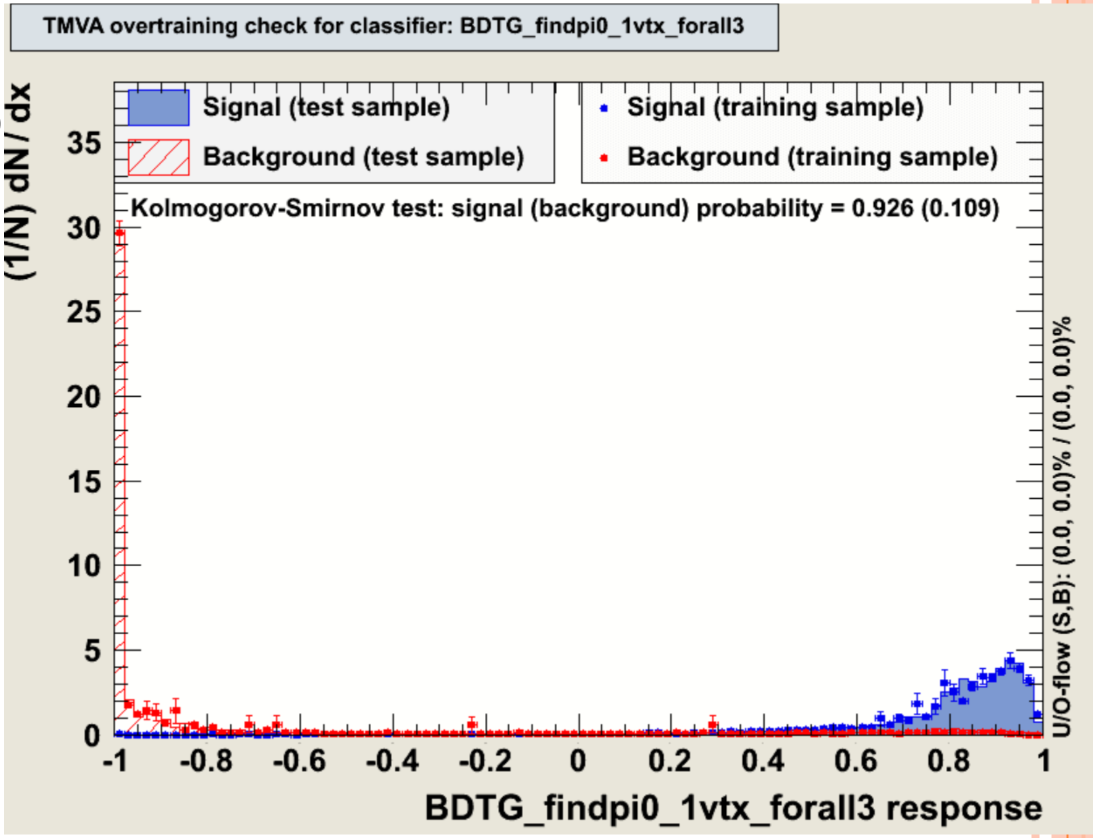
- Num. of tracks in vertices must not be a variable
  - Don't need the bias from num. of tracks in vertices
  - weighting samples to erase such bias

- I have constructed 3 types of MVA classifiers:
  - For third vertices
  - For secondary vertices which have third vertices
  - For secondary vertices which don't have third vertex
  - Using b jets

MVA output example

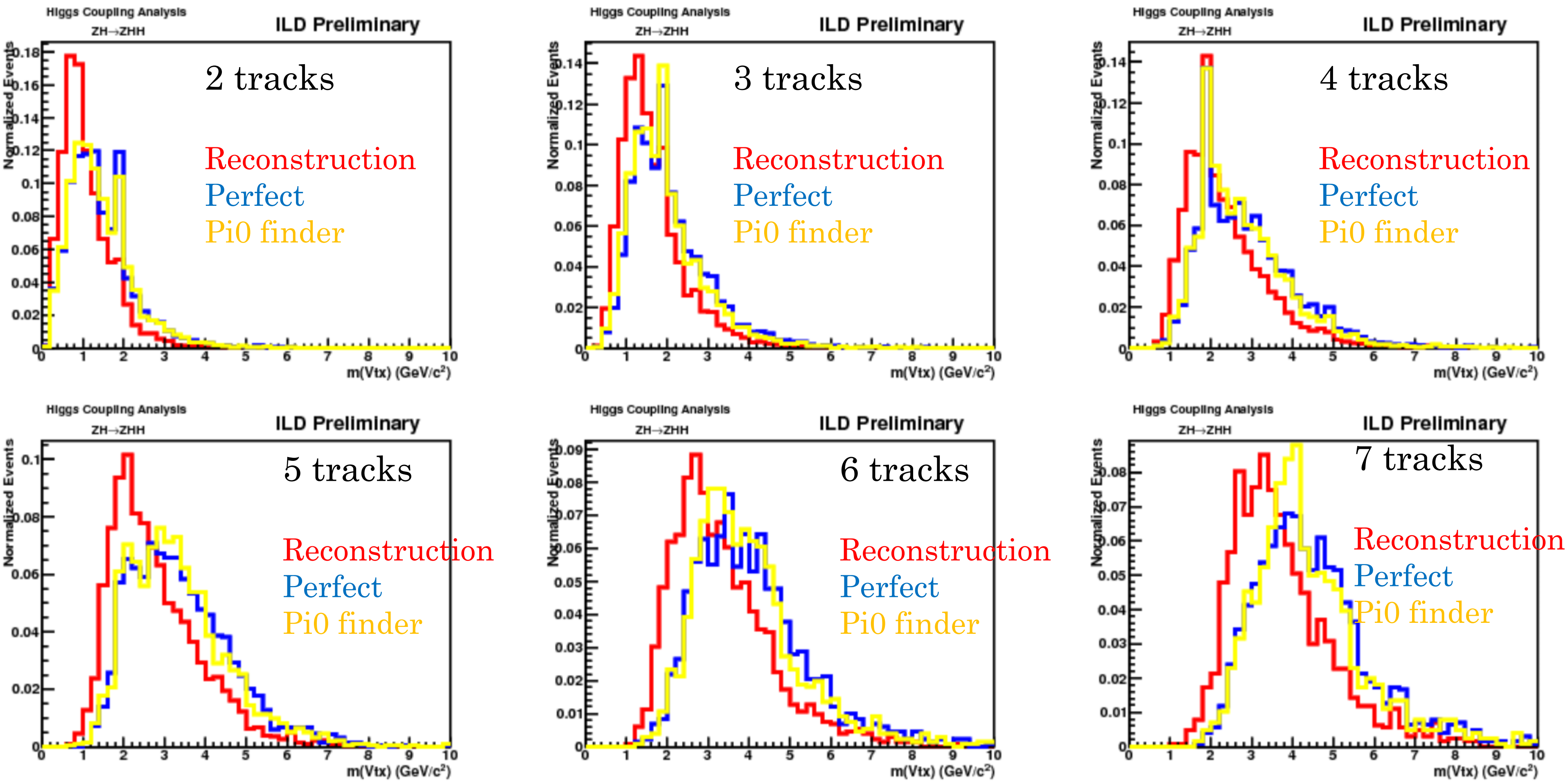
- Signal: pi0s from secondary vertices which don't have third vertex
- Background: pi0s from primary(L_{decay} from IP <0.3mm)
- All the pi0s are assumed to come from secondary vertex
  - Correct gammas & pi0 momentum
- Using Gradient BDT
- MVAcut>0.79(ntrk>=3)

  >0.69(ntrk==2)



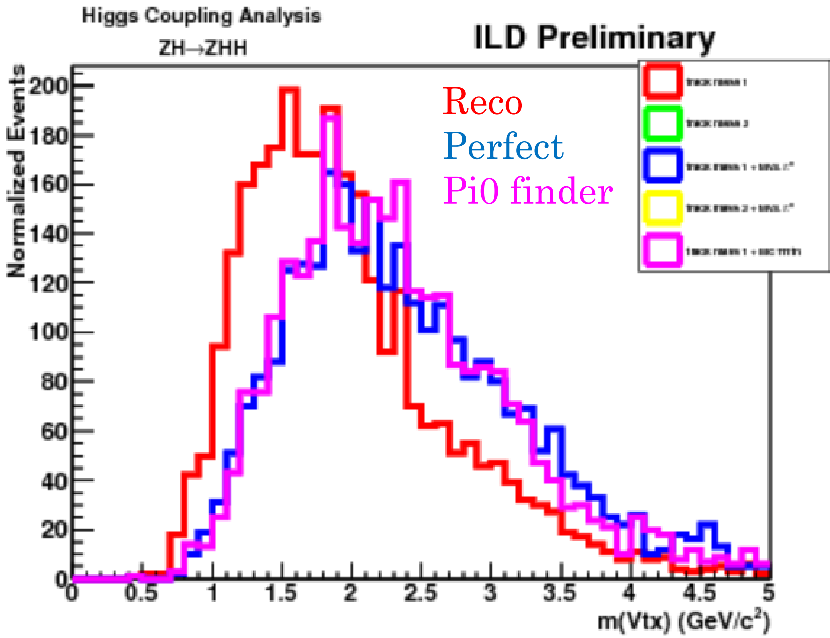
VTX MASSES

- Vtx mass distributions for each vertex pattern(classified with ntrk)
  - not so bad
  - 2track case has bias…

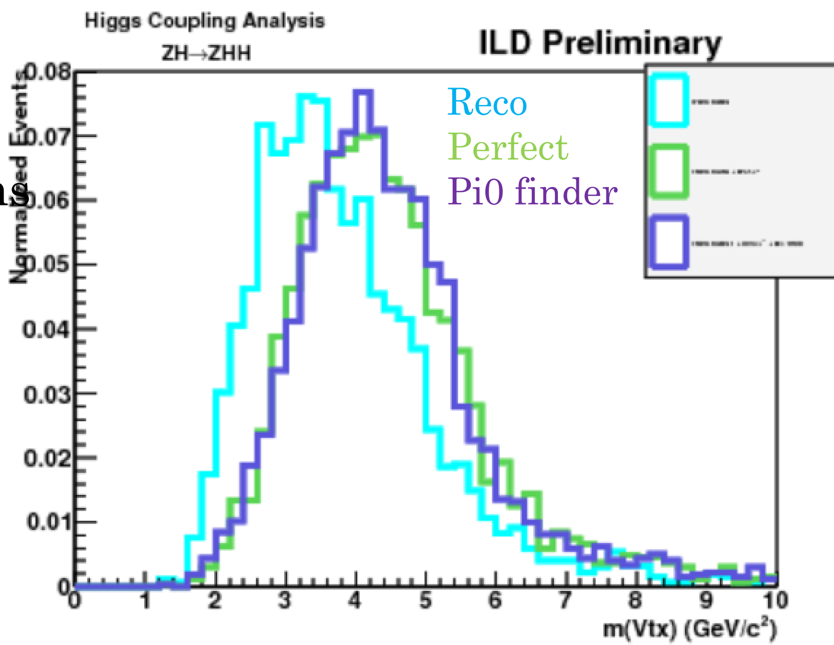


Glance at other case

- 2 vertices in bjet
  - Secondary vertex - 4tracks case

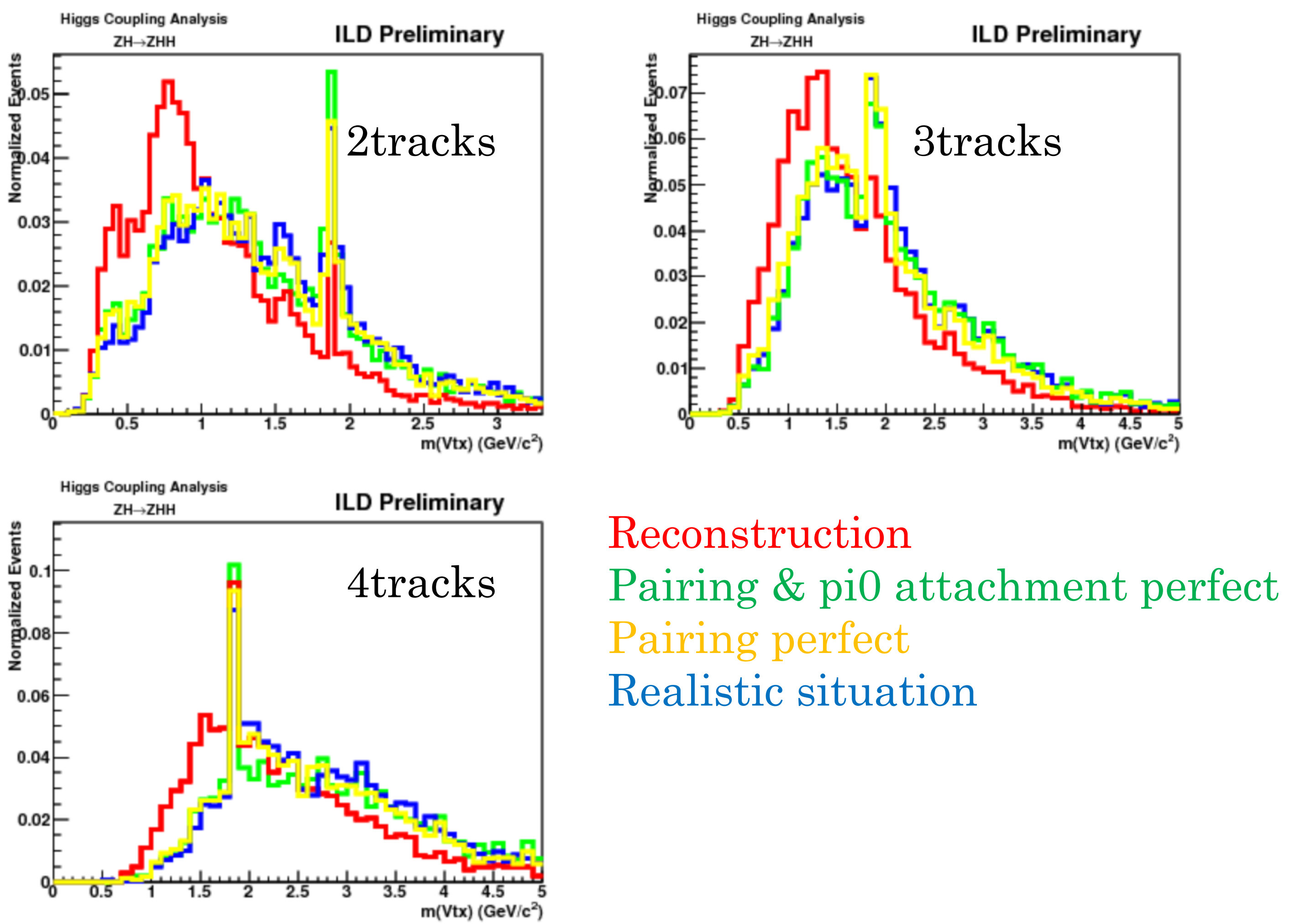


  - Merging with third vertex
    - Third vertices allow all the track patterns
    - Attach pi0s to both of the vertices using pi0 vertex finder



MOST REALISTIC SITUATION

- Pi0s are reconstructed from neutral PFOs
  - Using gamma finder – distinguish gammas from neutral hadrons
  - Using pi0 reconstruction – pairing of 2 gammas
  - Using pi0 vertex finder – pi0 candidates to be attached



Vertex mass recovery effect on flavor tagging

- **Can vertex mass recovery really improve flavor tagging?**
  - Try to construct flavor tagger using recovered vtx mass!
  - Note: this flavor tagger is very "toy" flavor tagger!
- First, checking single variable separation power $\langle S^2 \rangle$:

$$\langle S^2 \rangle = \frac{1}{2} \int \frac{(S(y) - B(y))^2}{S(y) + B(y)} dy$$

  - $\langle S^2 \rangle$ is from 0 to 1: 0 is no separation and 1 is perfectly separated

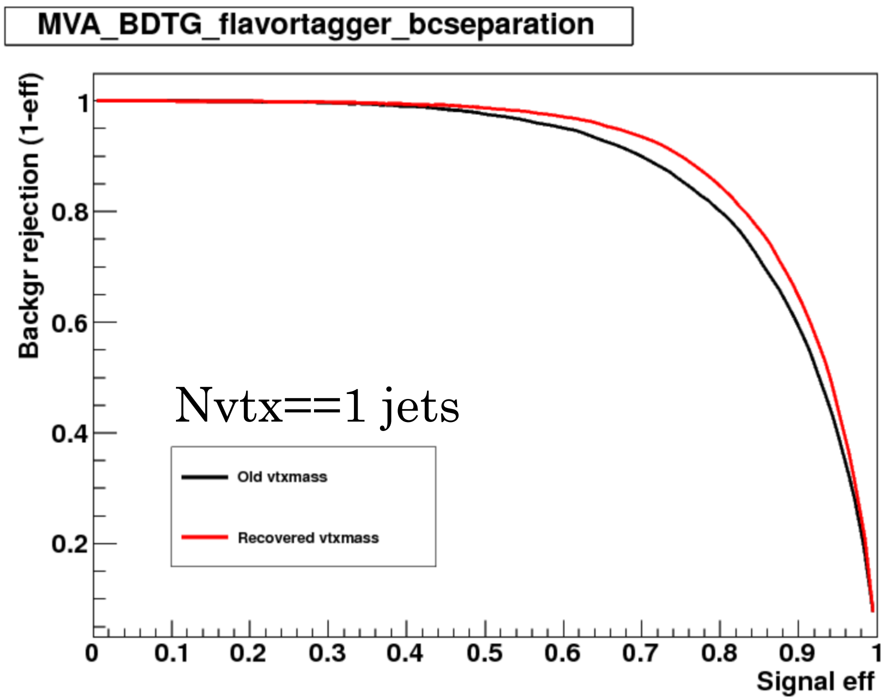
bc separation	Old vtxmass	Recovered vtxmass
2nd vtx (use 1vtx jet)	0.1654	**0.2756**
2nd vtx (use 2vtx jet)	0.2660	**0.2870**
3rd vtx (use 2vtx jet)	0.2714	**0.3211**

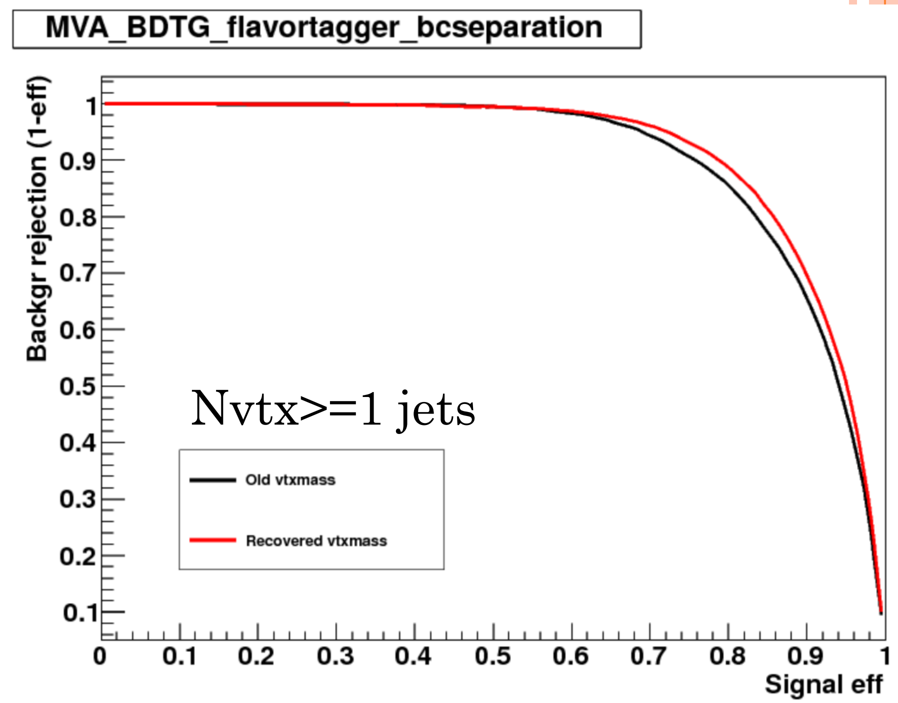
bl separation	Old vtxmass	Recovered vtxmass
2nd vtx (use 1vtx jet)	0.1652	**0.1618**

  - In b jet vs. l jet case, l jet statistics is too low

Vertex mass recovery effect on flavor tagging

- Construct a "toy" flavor tagger
  - Input variables are obtained from LCFIPlus
  - Input variable selection is too primitive!
  - Only vertex mass is replaced to recovered vertex mass
  - Compare with ROC curve





- For more precise study, need to step into LCFIPlus

Summary, Problems and Prospects

- Fundamental new variables provide improvement @ILD
  - Lepton ID – give improvement for background rejection
- Particle ID @ILD has great hope for analysis improvement
  - Track energy correction – effect is small, but mass distribution shifts to good direction
  - There seems hope for attaching pi0s to vertices using PID
    - Vertex mass recovery is reasonable
    - Of course, many checks are necessary
    - More optimization is necessary
  - In realistic situation, pi0 vertex finder has robustness
    - pi0 gamma mis-pairing effect is small
    - Neutral hadron contamination effect is small

- Vertex mass recovery will provide better separation on b/c jets!
  - Single variable separation power improves well
  - Recovered vertex mass seems to bring better flavor tagger!
  - Need precise study in LCFIPlus – finally, check flavor tagging effs.!

- Prospects: Particle ID has possibility of wider application
  - Next: Is there room in 0 vertex jet flavor tagging improvement?
  - b quark charge can be identified?

BACKUPS

dE/dx

- For improvement, using dE/dx is one of the powerful tools
  - Particle ID for each track will give a large impact to the analysis
  - Application to general analysis component is very wide
    - Lepton ID
    - Track energy correction
    - B-tagging?
    - Jet clustering?
- Important factor to use dE/dx is: fluctuation
  - TDR: measurement resolution is **5%**
  - So, fluctuation from simulation is within 5% without detector effect

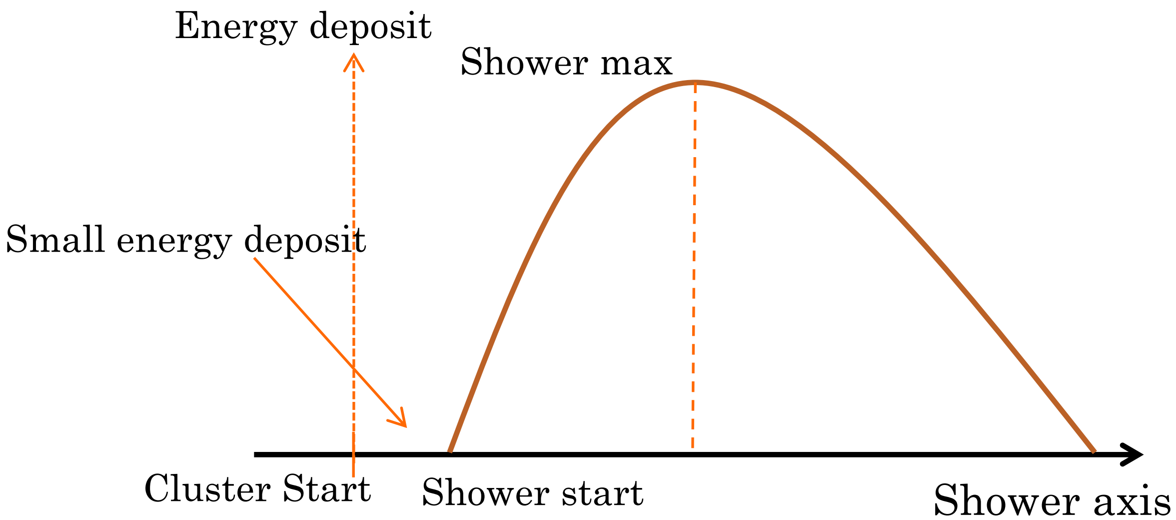
- dE/dx definition:
  - $\frac{dE}{dx} = \frac{energy\ deposit}{flight\ path\ in\ the\ hit(TPC)}$
  - dE/dx can be calculated at any hit point
  - Truncated mean is calculated as track dE/dx

  $\left\langle\frac{dE}{dx}\right\rangle = \frac{1}{n}\sum_i^n \frac{dE_i}{dx_i}$ upper 30%, lower 8%(important!) hits are discarded to avoid Landau tail(next slide)

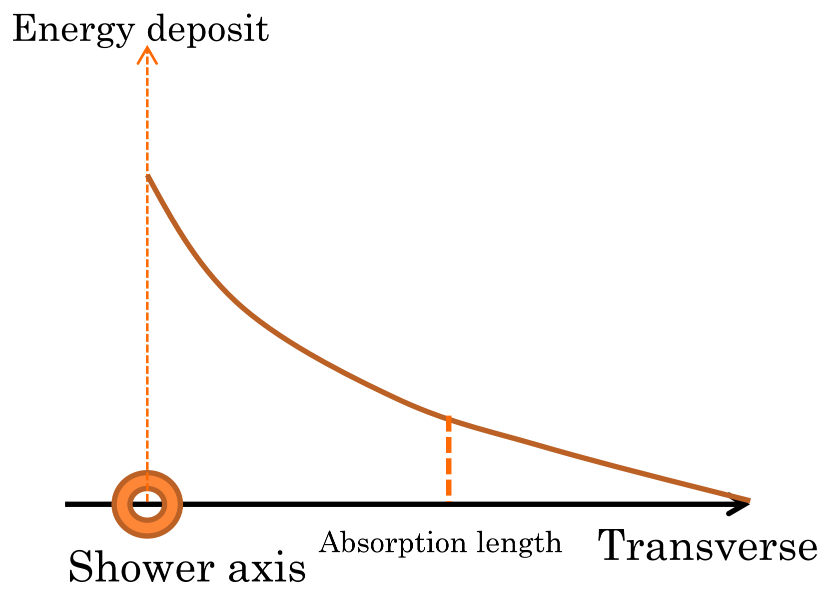
  →optimization is necessary

Shower profile –structure in the cluster

longitudinal

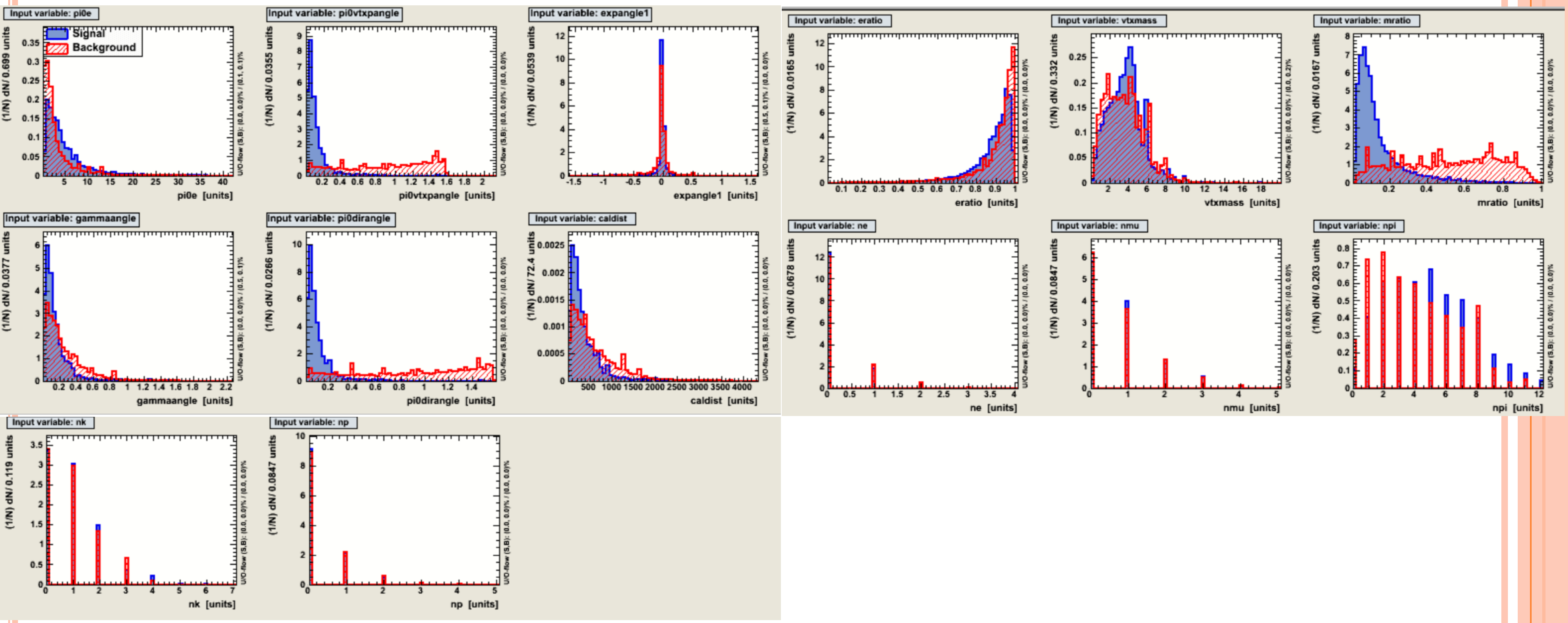


transverse



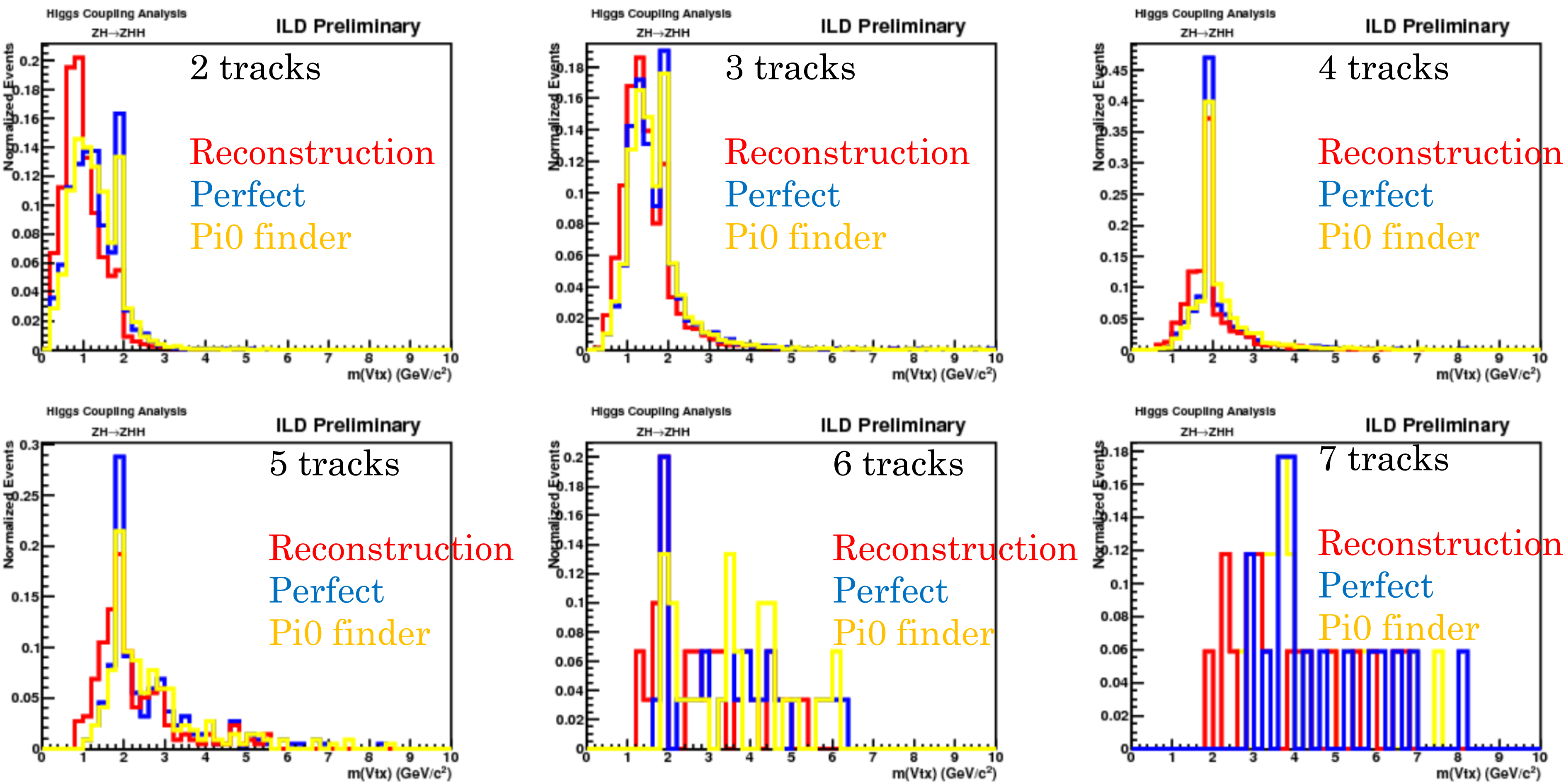
MVA – USING TMVA

- Input variables to be used
  - Secondary vertices which don't have third vertex



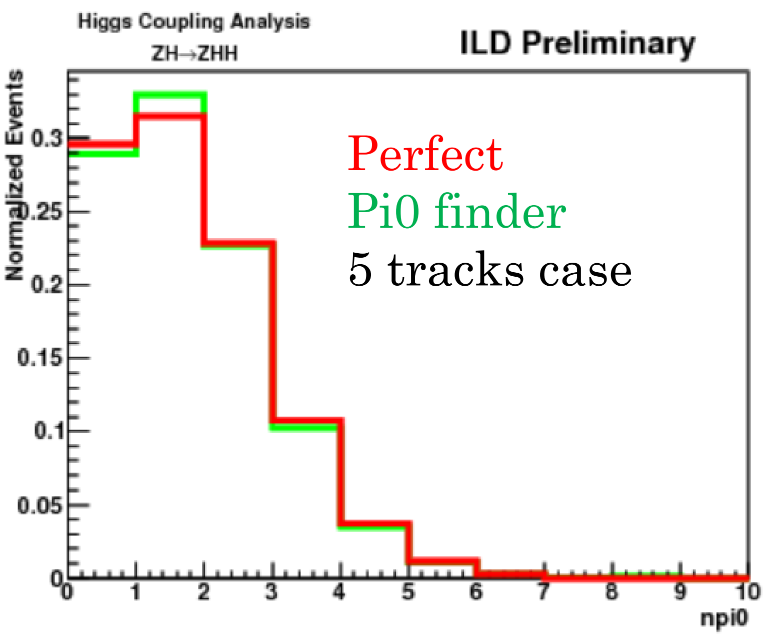
Testing of c vertex case

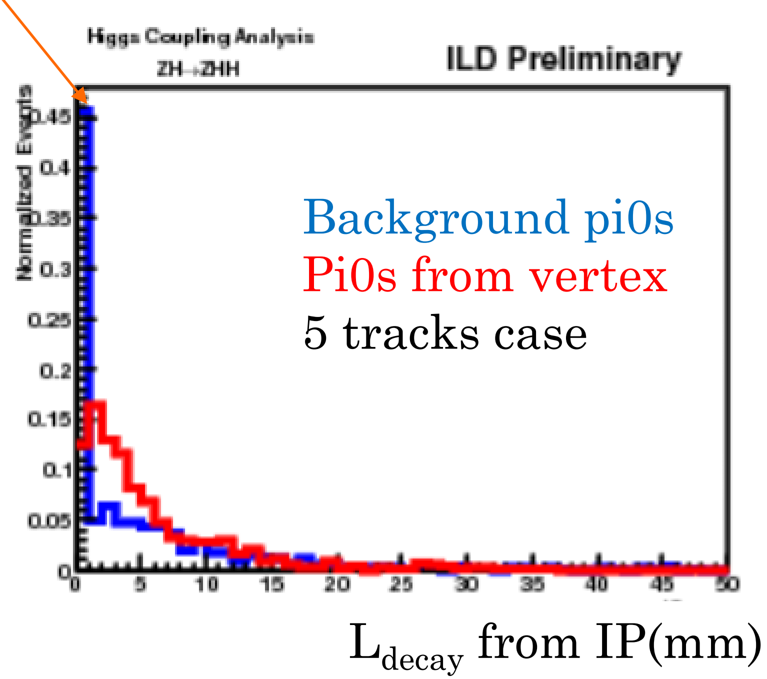
- Attaching pi0s to c vertex using same classifier
  - So far, no strange behavior



Some plots

- Num. of pi0s to be attached →determine MVAcut by it
- Where do pi0s really come from?
  - Many pi0s from primary are mis-attached to the vertices
  - Now, that is limited by detector configuration(can't determine exact gamma direction)
  - To some extent, an idea to catch gamma direction is necessary





THE MOST REALISTIC SITUATION

- After an event occurs, we only measure:
  - Charged particle information – 4-momentum, and particle type(PID)
  - Neutral particle information – 4-momentum of gamma or stable hadrons
  - We have no direct information of pi0s
- We need to get pi0 information from gammas!
  - Gamma finder – choosing gamma candidates from neutral particles
  - Pi0 reconstruction – gamma pairing from gamma candidates
- In such situation, how is the vertex mass recovery?
  - How is neutral hadron contamination effect?
  - How is gamma mis-pairing effect?
- About pi0 reconstruction, I have already talked at previous talk
- By using that pi0 reconstruction, attaching pi0 candidates and compare the vertex mass