Particle ID in ILD

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Calorimeter Workshop

IAS program

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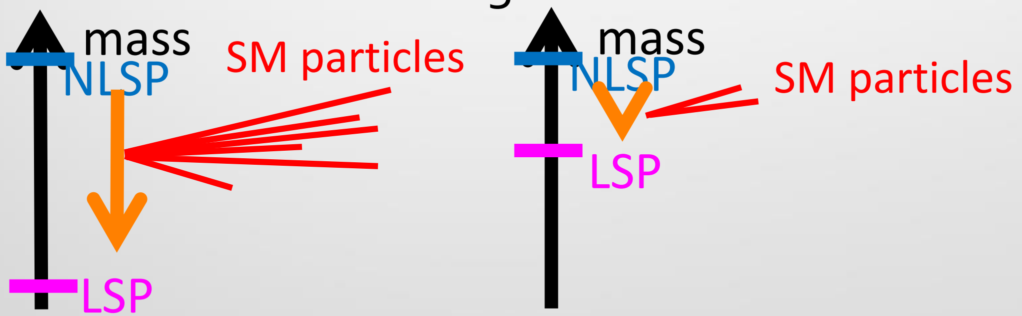
Outline

- Introduction
- Requirement of the TPC for the ILD
  - dE/dx of ILD TPC
- Requirement of the Calorimeters for the ILD
  - Shower profiles of ILD Calorimeters
- Particle Identification
  - LeptonID & μ/π separation
  - Charged hadrons(especially Kaon ID)
  - Neutrals(Photons)
- Some applications for physics analyses
- Future plans(on going study)
- Summary

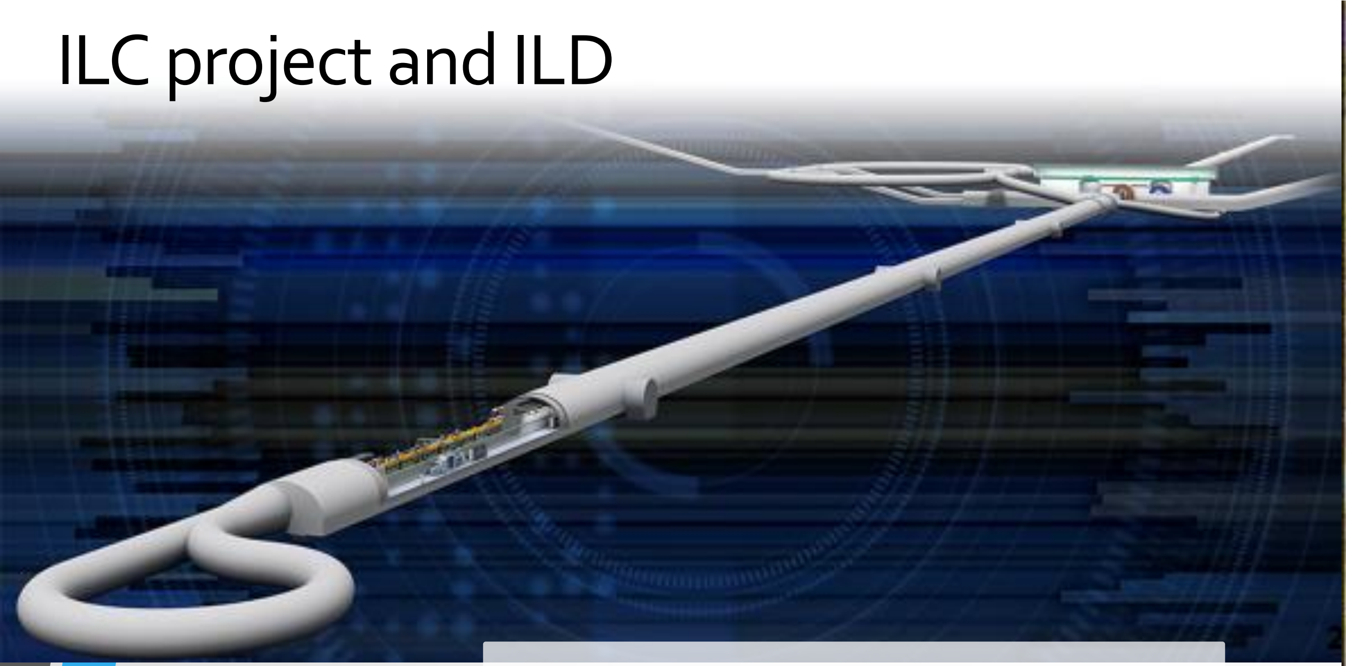
Introduction

- Even if energy frontier, flavor physics is important!
  - e.g. Higgs→ bb, cc, gg: separation with jet flavor is crucial
- We have to realize extensive efficiency for all the analysis components and tools
- PID is one of the good tools which make higher level reconstruction tools better
- PID itself (will) help analyses in many cases
  - e.g. $e^+e^- \rightarrow \chi_1^+\chi_1^- \rightarrow \chi_1^0\chi_1^0$+SM
  - Higgsino with mass difference degenerate



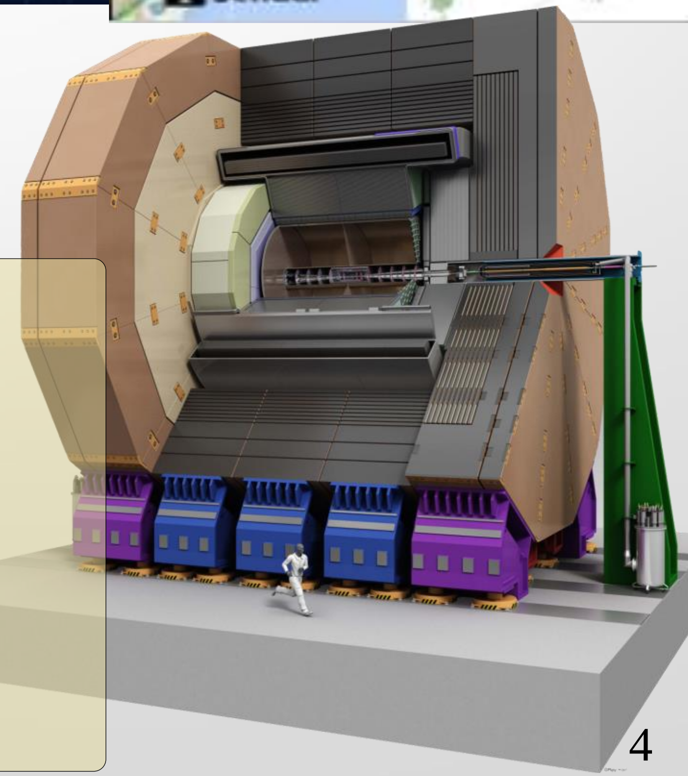
- We have to construct a PID tool and to explore the possibility of better physics results

ILC project and ILD



- **International Linear Collider**
  - **The Higgs & top factory at √s= 250-500 GeV** (upgradable to multi-TeV).
  - Linac e^+e^- ~ 11+11 km for 500 GeV

- **International Large Detector**
  - The main tracker is the **Time Projection Chamber** **(TPC)**
    - Large number of measured points
      → continuous tracking
      → track separation and pattern recognition
    - **Particle identification**
    - Low material budget before the calorimeters



Requirements of the TPC for the ILD

○ Requirements of the TPC from the physics point of views

[1] Momentum resolution

$\sigma_{pt}/pt \sim 1\times10^{-4}\ pt$ [GeV]

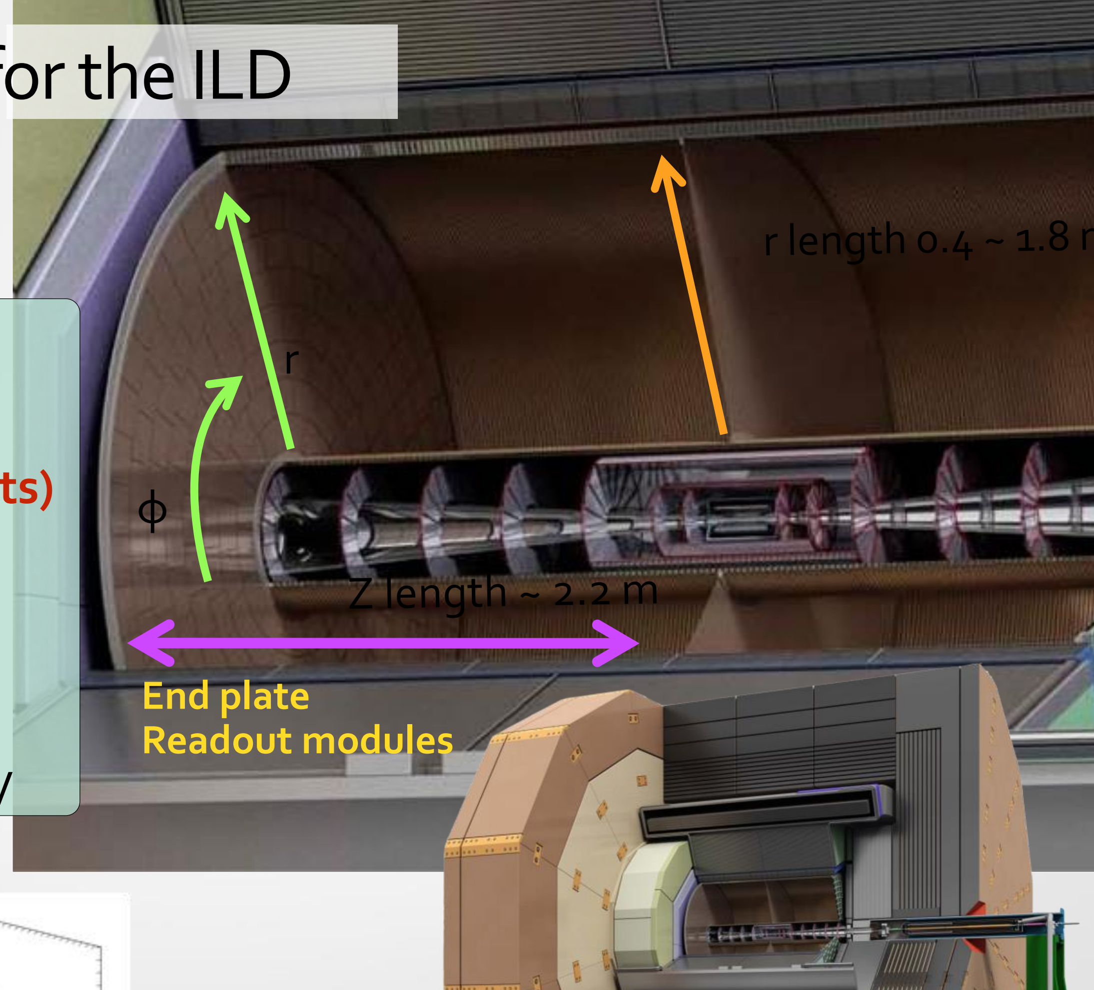
[2] Single hit resolution (200 points)

$\sigma_{r\phi} < 100$ [μm] (over the TPC)

$\sigma_{Z} < 400 \sim 1400$ [μm] (Z=0 ~ full)

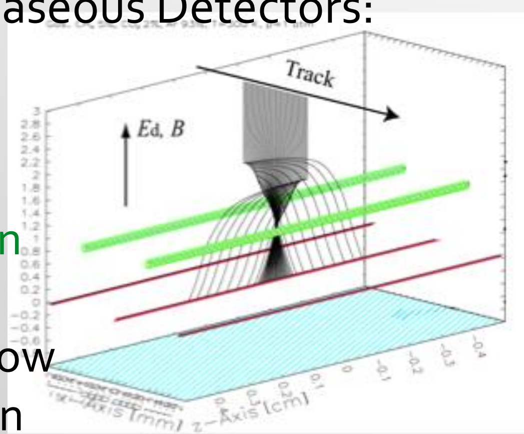
[3] dE/dx resolution : ~ 5%

for particle identification 1 ~ 10 GeV

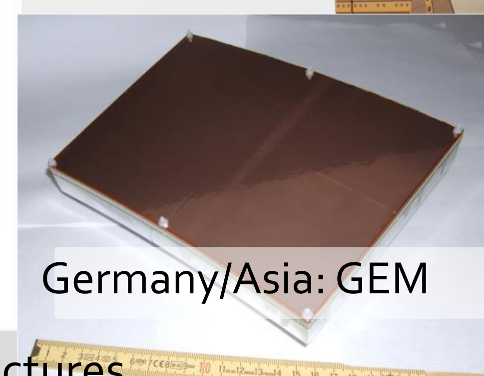


○ MicroPattern Gaseous Detectors:

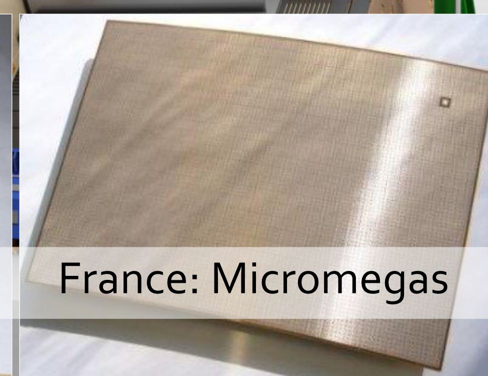
- No ExB effect
- Improve point resolution



- Low ion back-flow
- Stable operation
- Easier to manufacture + Thin support structures



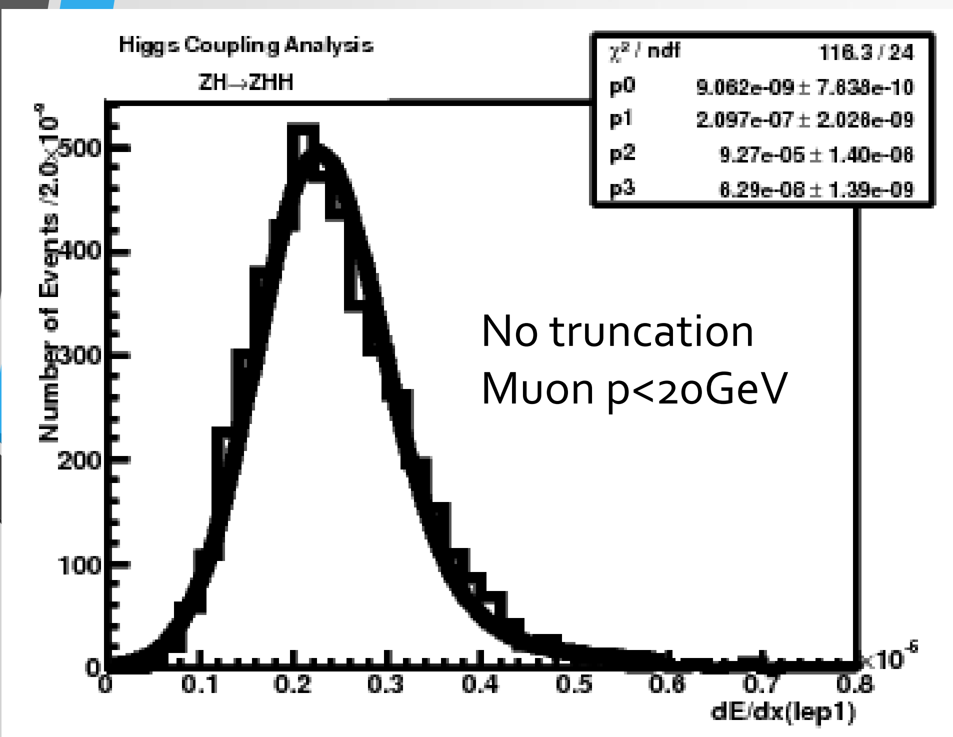
Germany/Asia: GEM

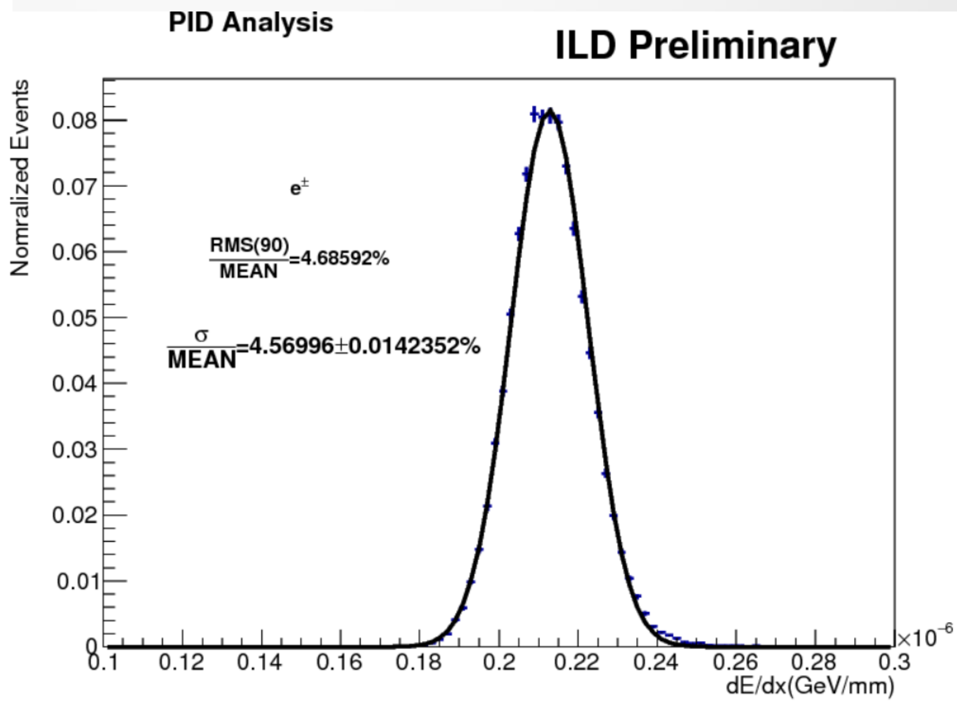


France: Micromegas

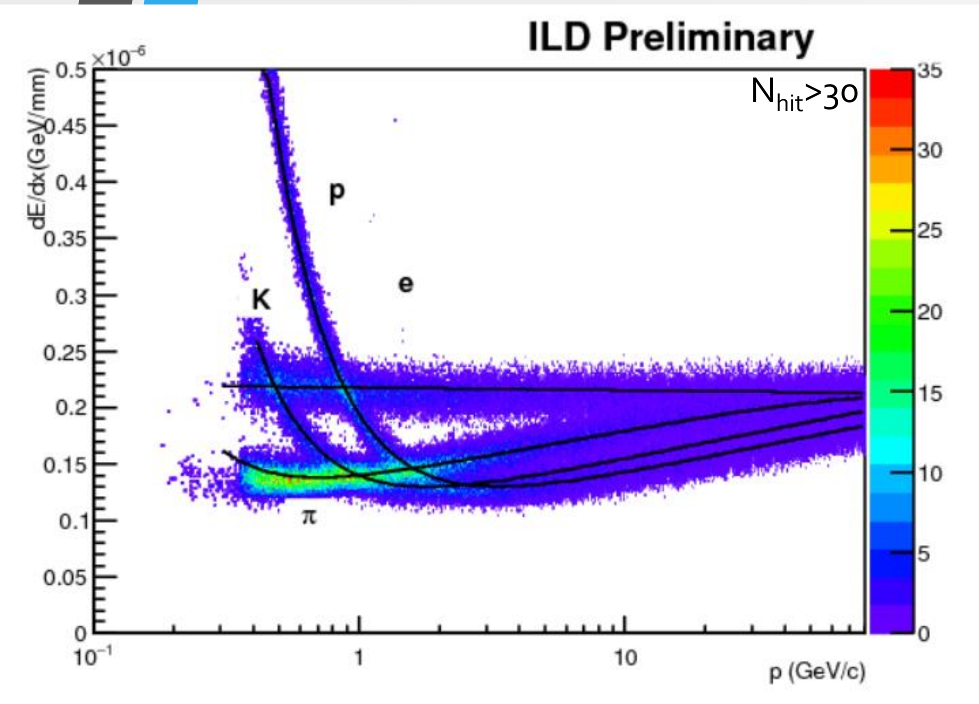
Calculation of track dE/dx

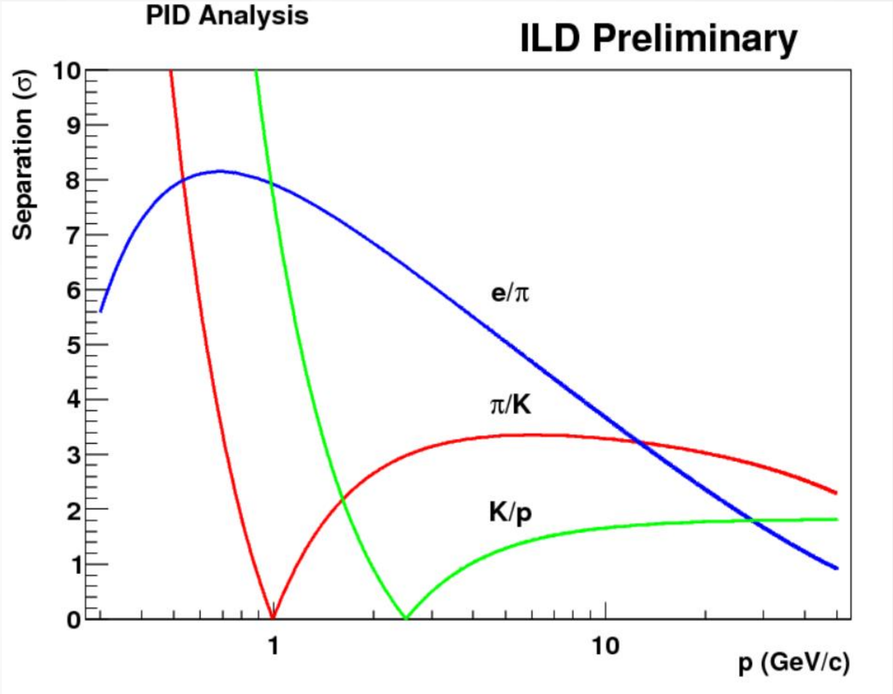
- $\frac{dE}{dx} = \frac{energy\ deposit}{flight\ path\ in\ the\ hit(TPC)}$
- Track dE/dx is calculated using truncation method
  - Arrange dE/dx value of each hit in descending order
  - Upper 30% and lower 8% are discarded take mean over rest
- Going to good gaussian shape





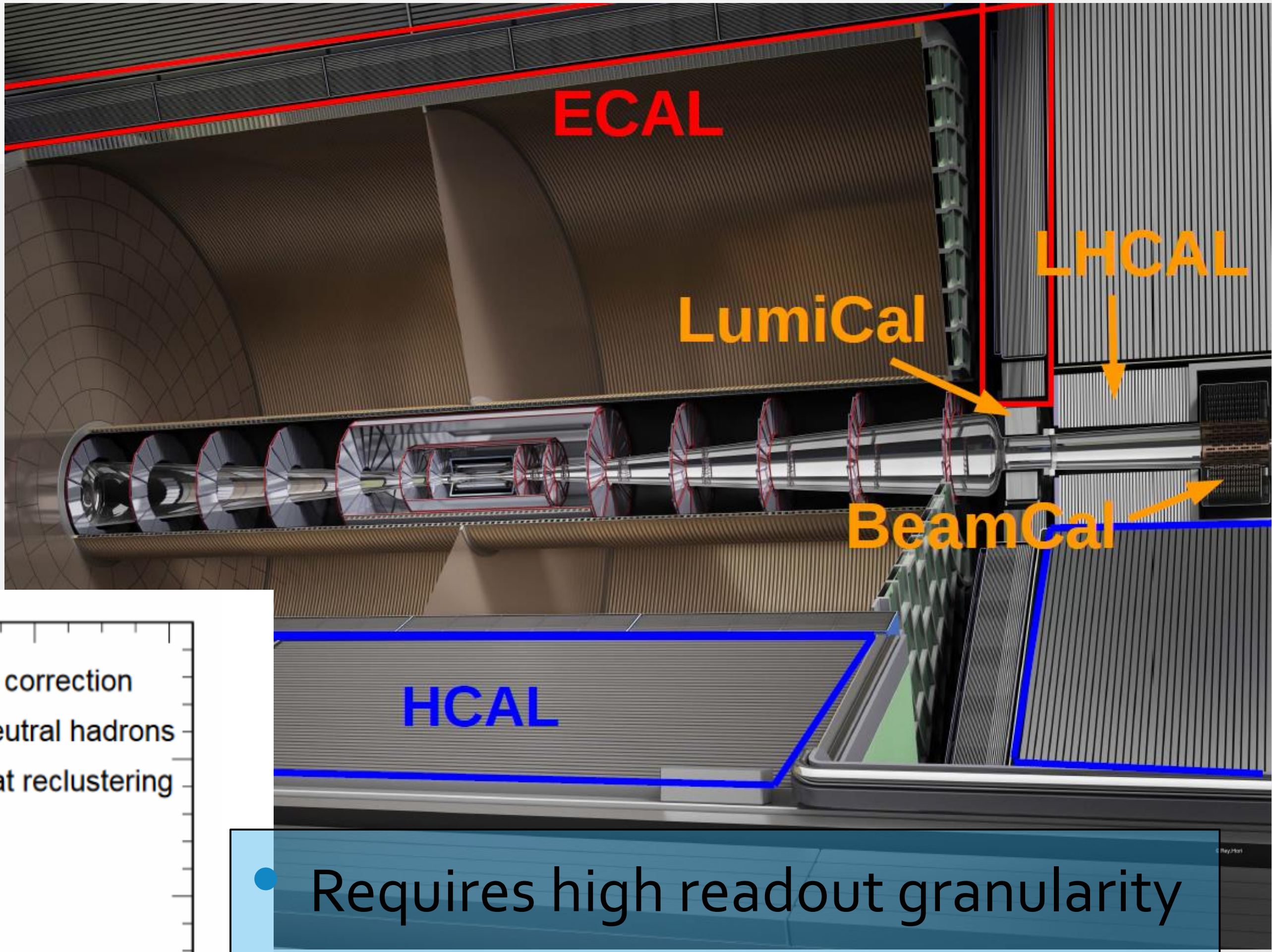
dE/dx of ILD TPC



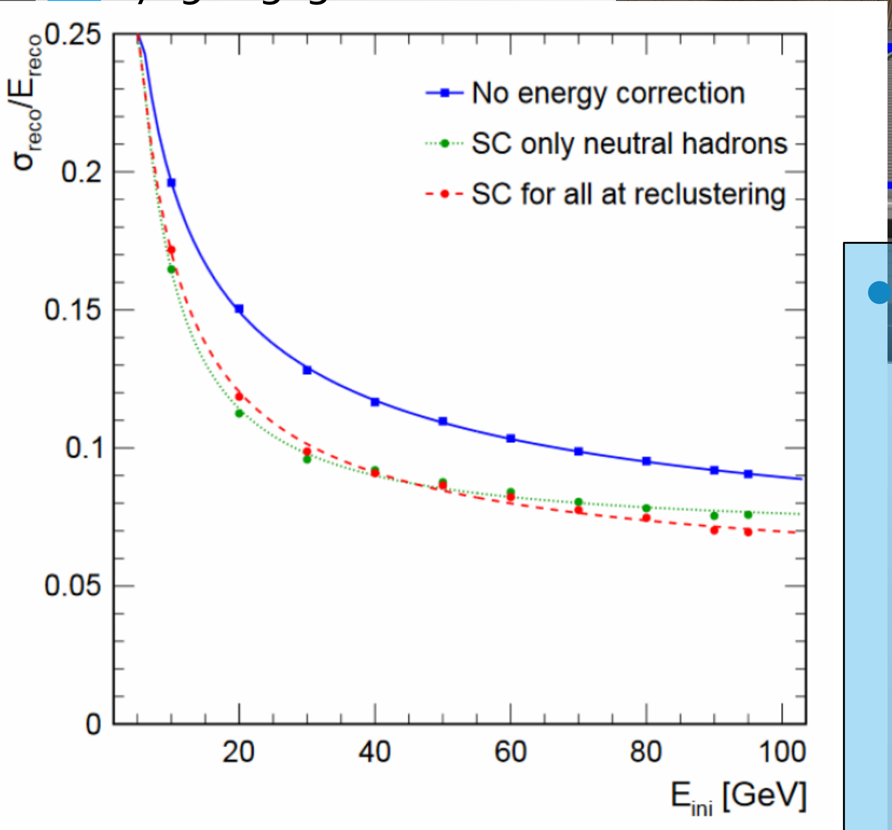


- Momentum dependence of dE/dx in ILDTPC
  - Good separation for each particle type
- Separation power of each particle
  - ~3σ for π/K separation

Calorimeters



arXiv:1705:10363



- Requires high readout granularity
  - To obtain maximum performance from particle flow reconstruction
  - Ecal: ～30layers, cellsize 10～25mm²
  - Hcal: ～40layers, cellsize 10～100mm²

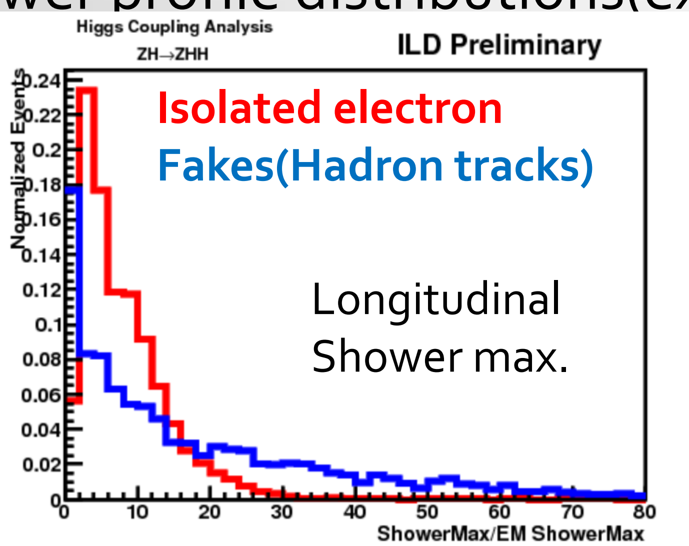
Shower profile

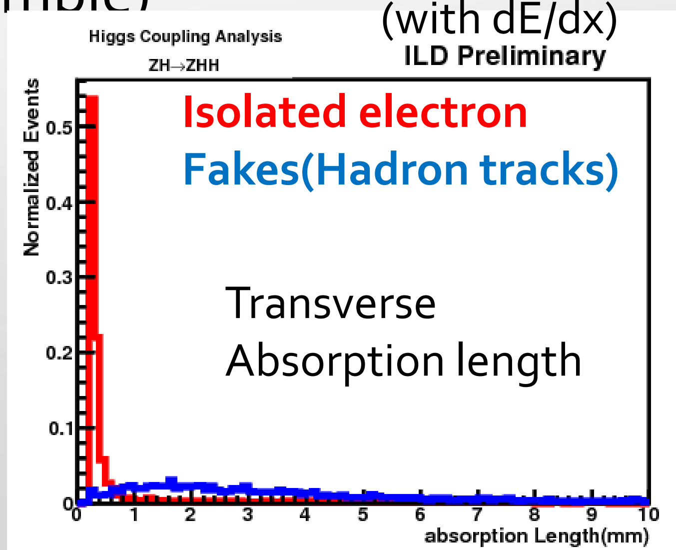
- Shower shapes in the calorimeter are different between electron/photon/muon/hadrons
- Information extraction is based on fitting to cluster hits:
  - Well-known EM shower profile

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

- In addition, hit based variable is also used(to identify shower start)
  - To identify shower start position
  - To create variables for low momentum μ/π separation
- Shower profile distributions(example)

30% improve for fake rejection (with dE/dx)





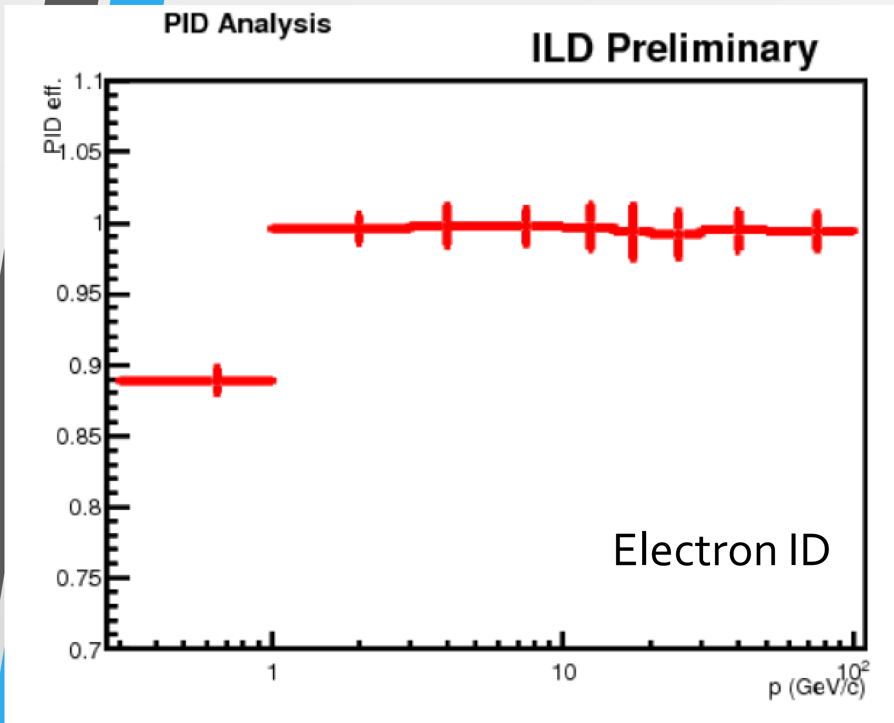
Construct PID

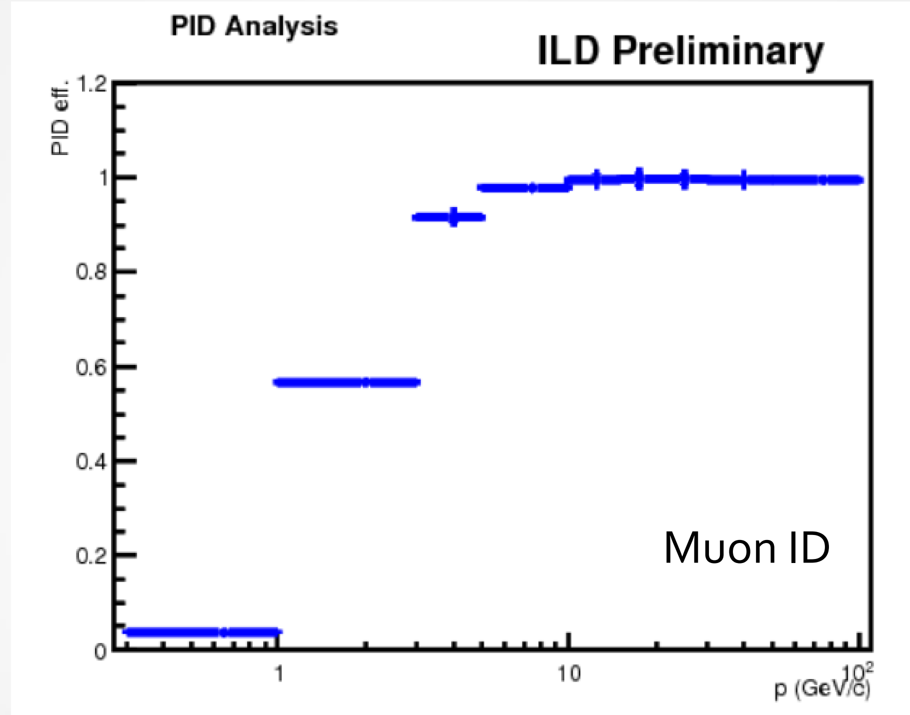
- Construct PID to identify 5 fundamental particles
  - e, μ, π, K, p
- Based on Bayesian Classification
  - Estimate posterior probability:

$$\mathrm{P}(C|x) = \frac{P(x|C) \cdot P(C)}{P(x)}$$

- Combine information from each sub-detector
  - Basic variables: Calorimetry and Tracking (E/p, Ecal/(Ecal+Hcal), mucal, etc.)
  - dE/dx information
  - Shower profile information
- Include special μ/π separation algorithm for low momentum tracks
  - p<2.0GeV/c μ/π tracks
  - Use cluster hits distribution
  - Based on BDT using TMVA

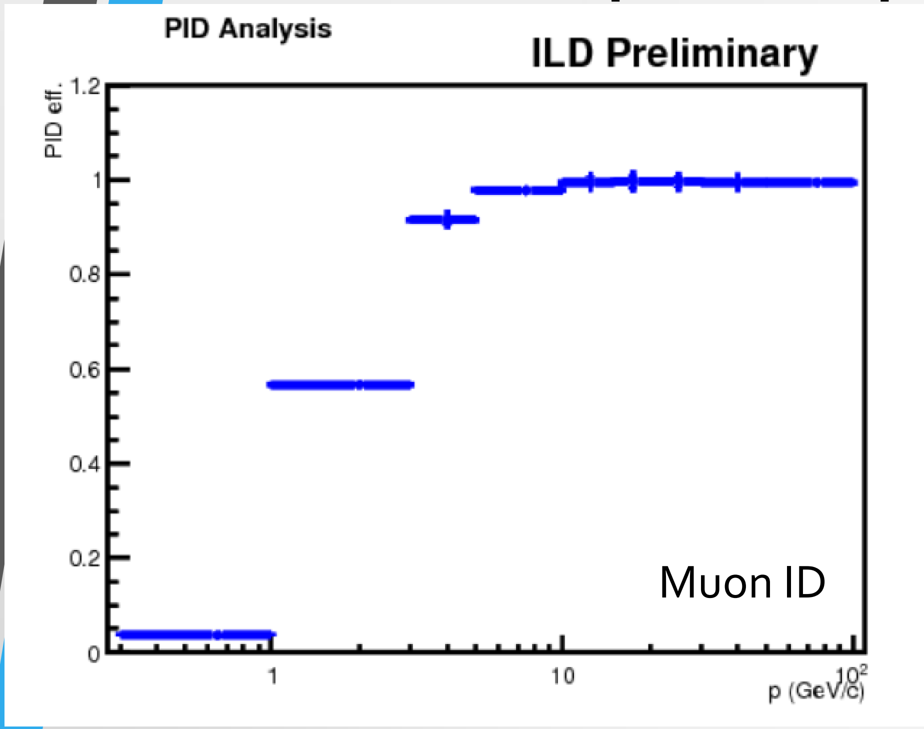
LeptonID

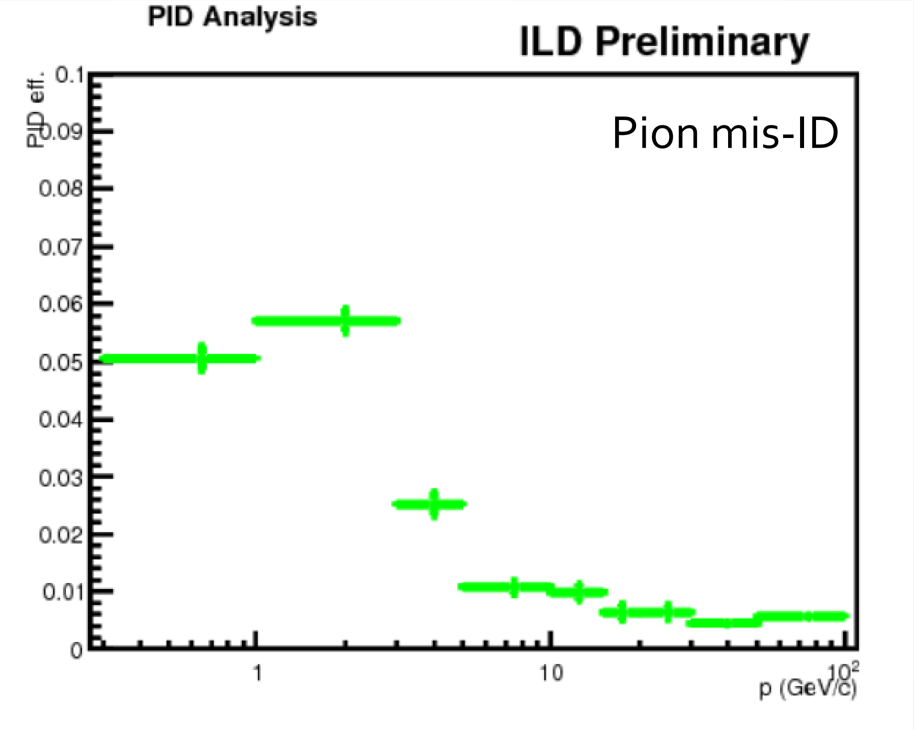




- Both leptons can be identified well
  - >99% efficiency for electron @ p>1.0GeV/c
  - >98% efficiency for muon @p>3.0GeV/c

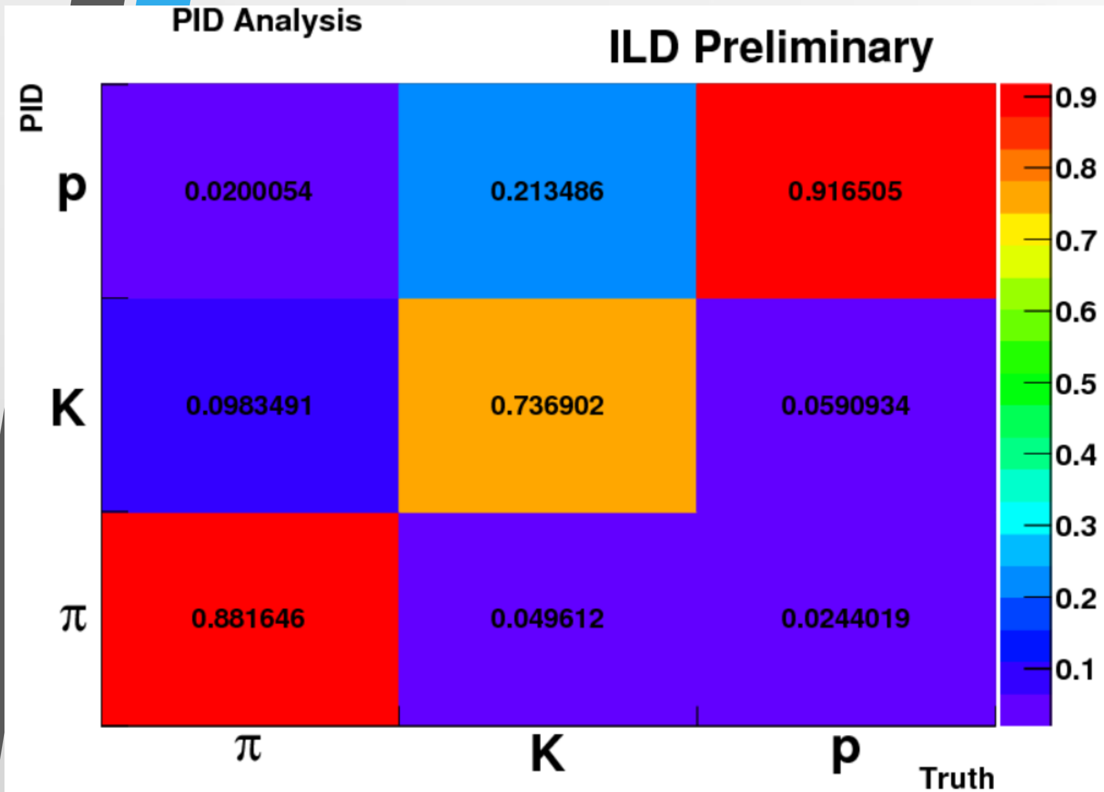
μ/π separation

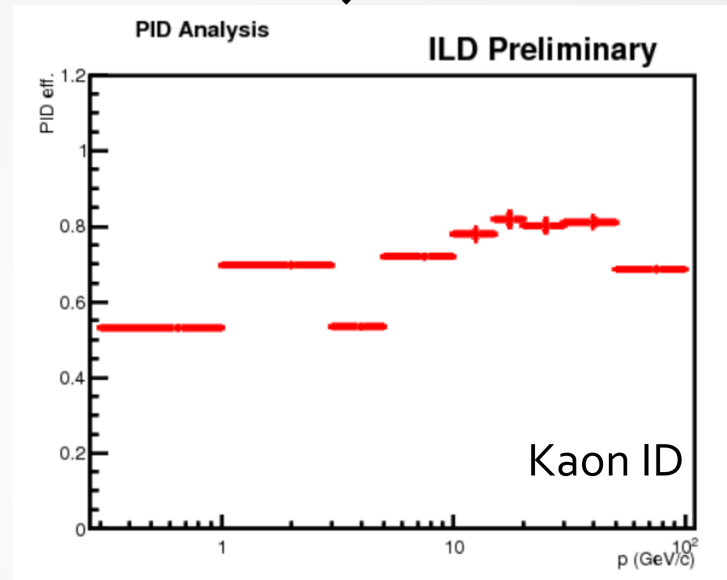


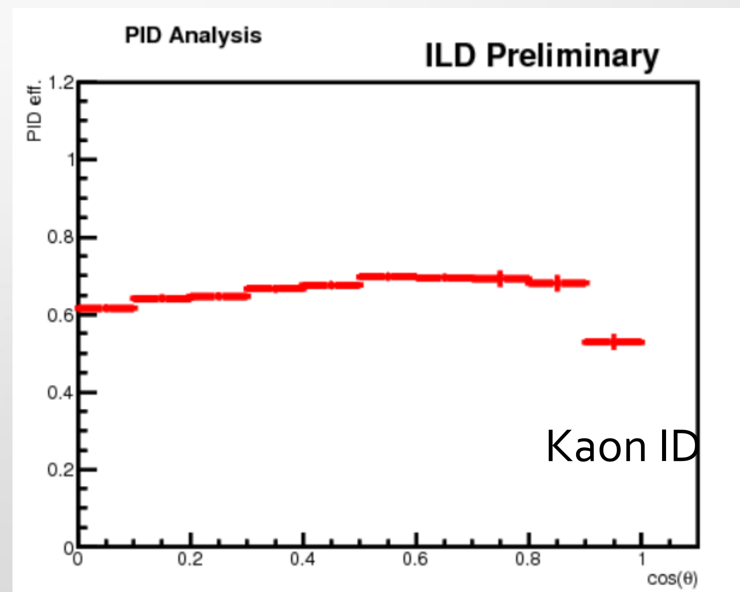


- Good pion suppression @ p>5.0GeV/c
  - Pion mis-ID is ～1.0%
- Pion mis-iD efficiency is <2.6% @ p>3.0GeV/c

Charged hadrons(Kaon ID)





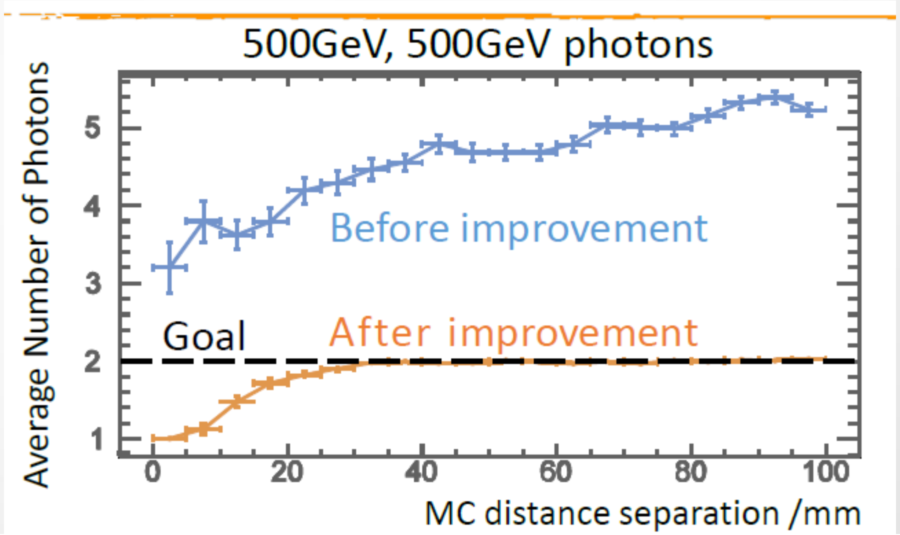


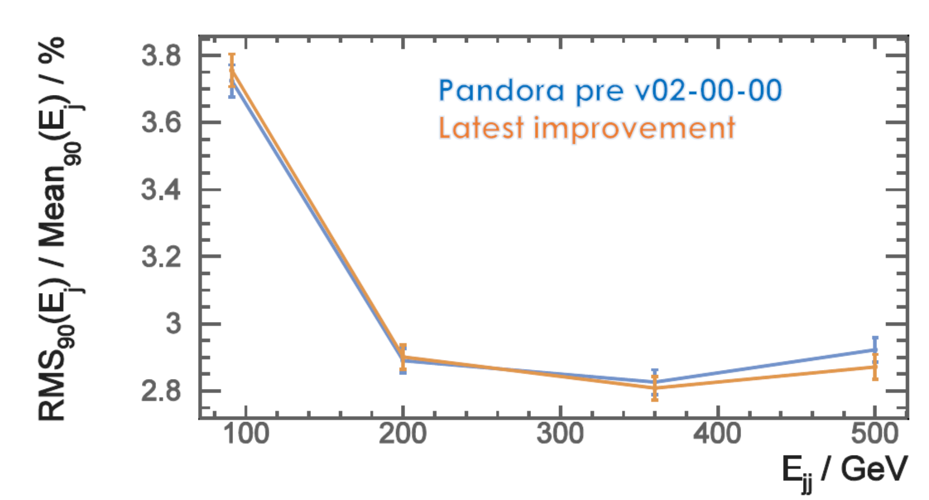
- Good Kaon ID for physics analysis improvement
  - talk about that later
- Momentum & angle dependence looks weak
  - except very forward region

neutrals

- Good photon reconstruction is important
  - π(η) and τ reconstruction is based on photon reconstruction
- There are some difficulties to be resolved:
  - Recover photon energy in Hcal
  - Remove fragments
  - Separation of very nearby photons
  - Etc.
- Pandora PFA has made such efforts
  - Good separation of both photons nearby
- Going to better jet energy resolution!

Boruo Xu

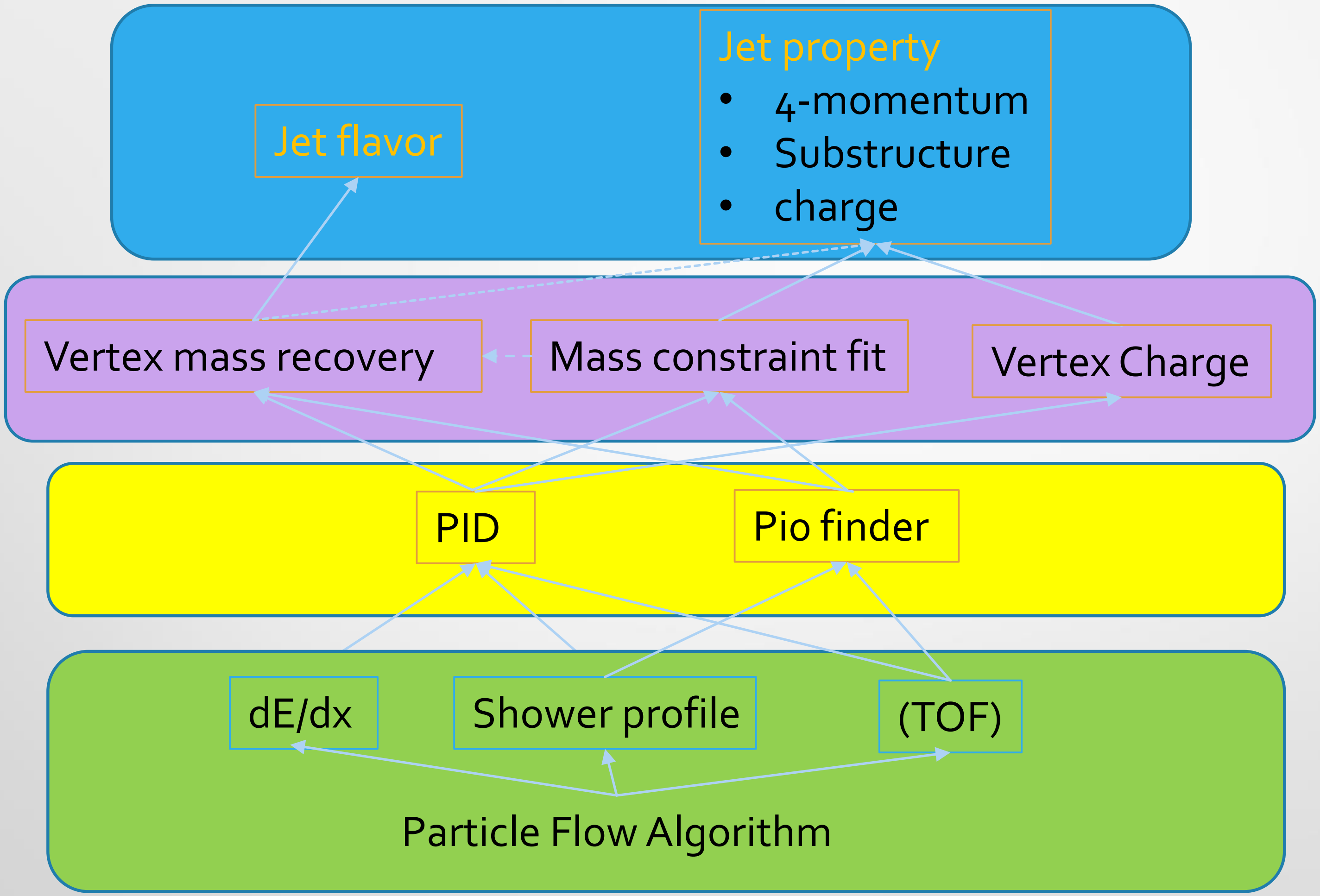




Applications for Physics Analyses

Towards higher level reconstruction

- Everything is related with each other

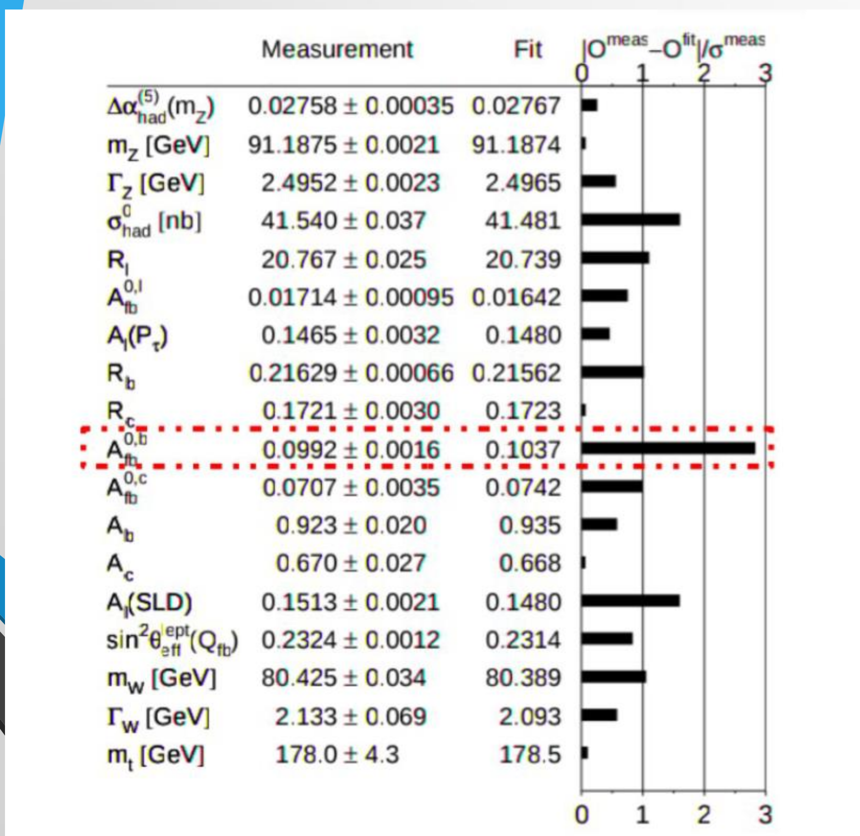


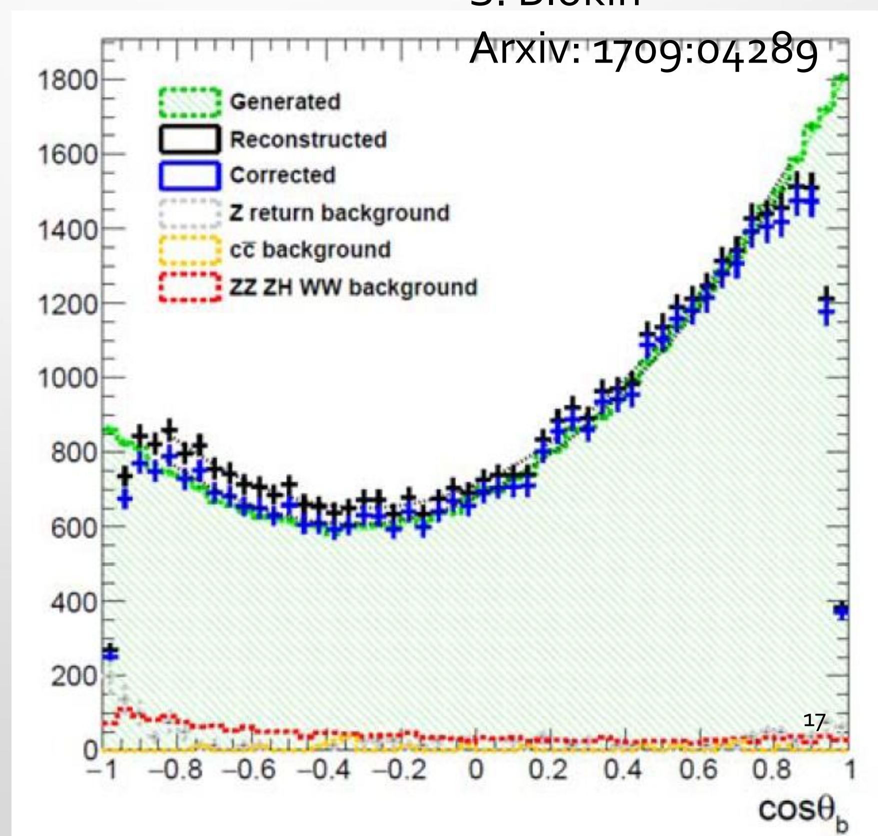
- Reconstruct each jet as correct as possible is one of the most important task for ILC physics analyses

Vertex charge measurement

- Forward-backward asymmetry of 3[rd] generation quark production is sensitive to new physics
- Need to identify b-jet charge for A_{fb} measurement
- We can use Kaon coming from secondary/tertiary vertices to determine b-jet charge!

S. Blokin
Arxiv: 1709:04289





Kaon ID for Afb measurement

- Use dE/dx information
  - Selecting Kaon region on momentum dependence
  - Kaon can be selected 97% purity with 87% efficiency @p>3GeV
- Choose vertices using Kaon status
  - Vertices on which Kaons carry the charge accepted
    - K^-K^-, $K^-K^-K^+$: OK
    - K^+K^-: rejected
- Events with opposite Kaon charge bjets accepted

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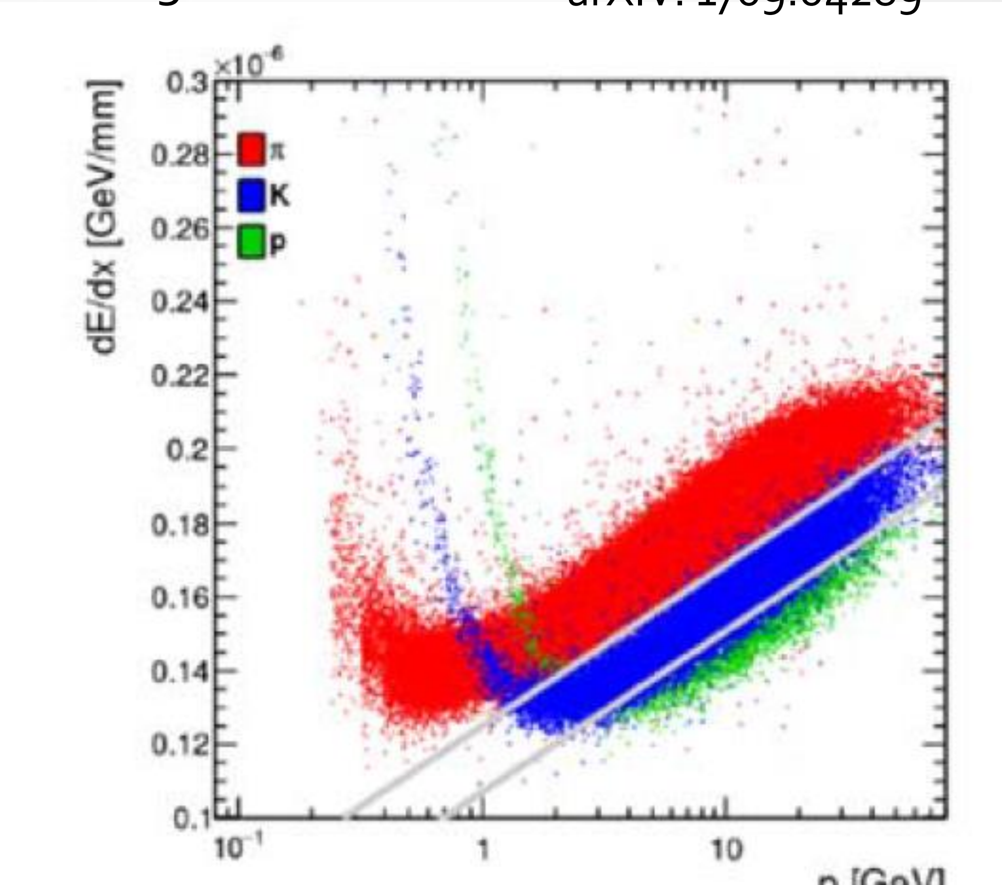

Jet reconstruction improvement using Particle ID

- With particle-flow based jet reconstruction, we have to tackle to reconstruct as well as possible each jet
- Using particle ID, we can apply mass constraint fit to improve jet energy resolution
  - Both neutral and charged particles possible
  - e.g.) $\pi^0 \rightarrow \gamma\gamma$, $J/\psi \rightarrow \mu\mu$

    $\eta \rightarrow \pi^+\pi^-\gamma$
- One example: $\pi^0 \rightarrow \gamma\gamma$
  - Tested with 10GeV π^0s
  - $\sigma_{fit}/\sigma_{meas}$=0.76

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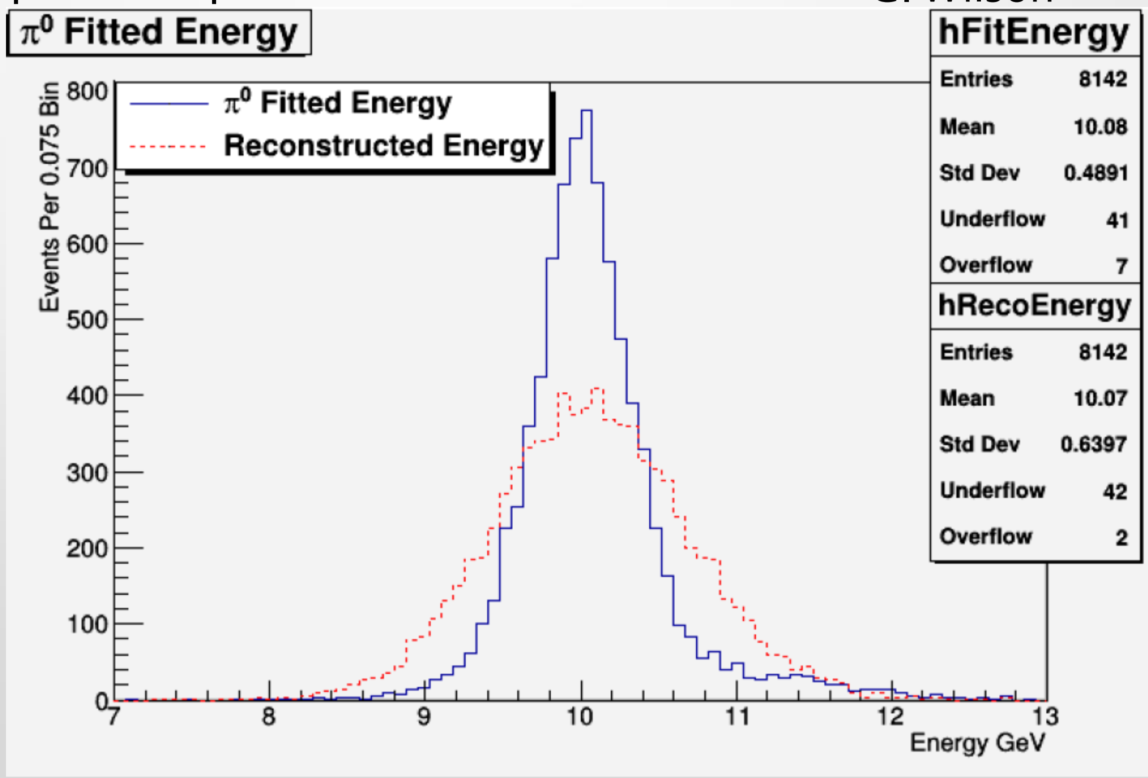
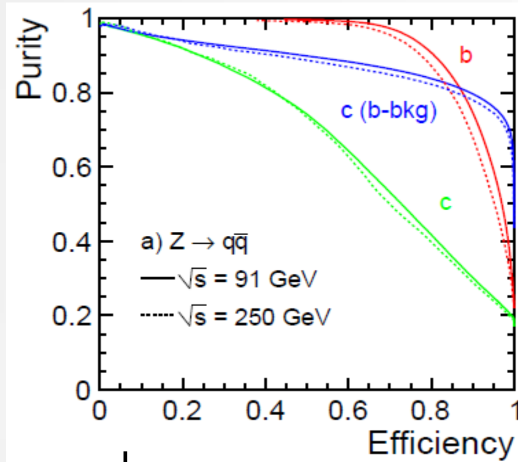
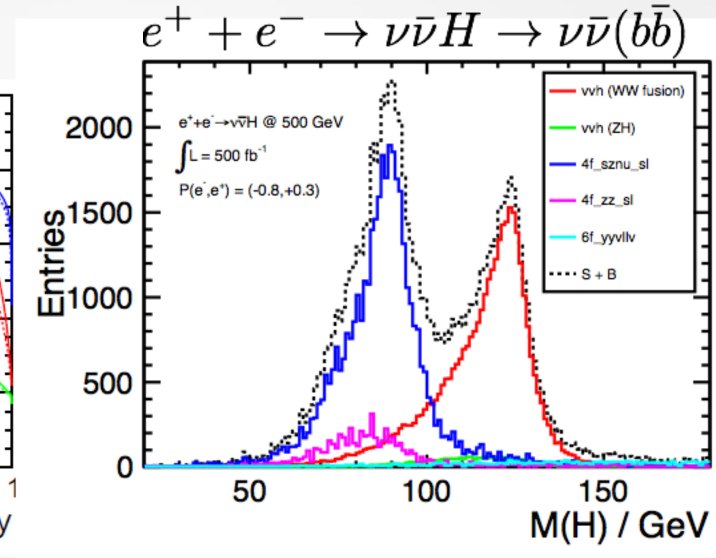


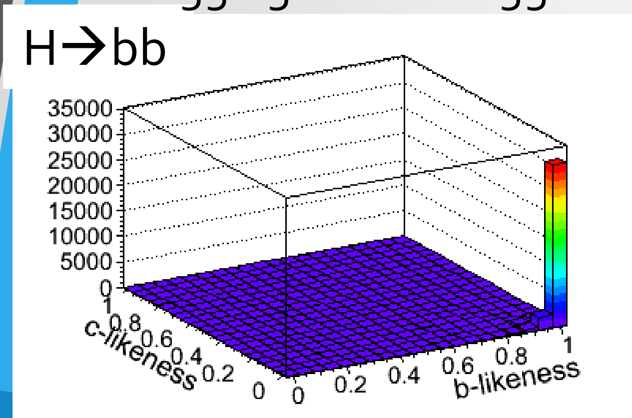
Flavor Tagging

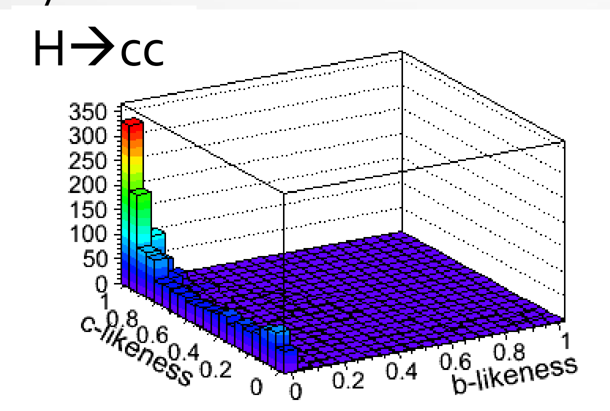
- Crucial for any kinds of analyses in ILC!
- e.g.) Higgs coupling
- Very important for Higgs coupling measurement
  - c-tagging available

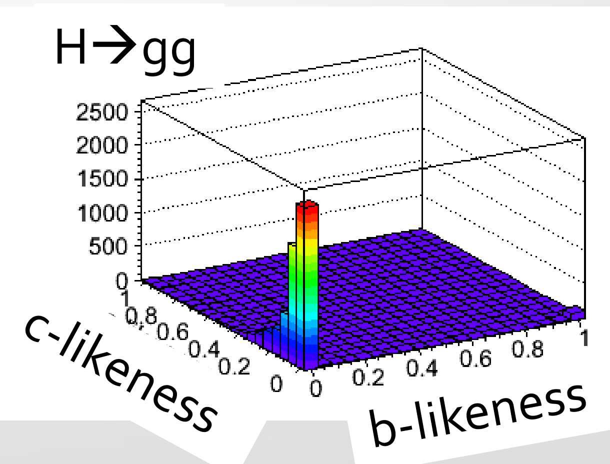




Flavor tagging of each Higgs decay mode





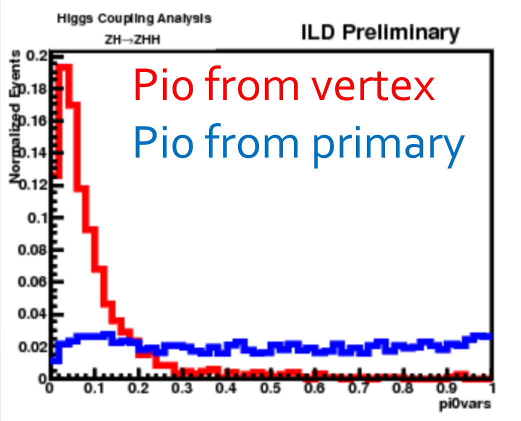


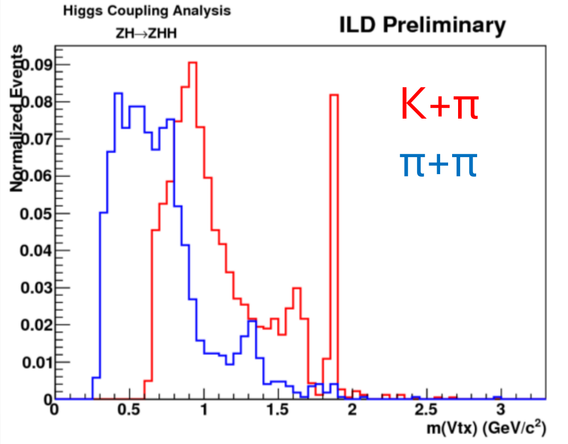
Precision of Higgs couplings (250+350+500GeV)

Runtime	H→bb	H→cc	H→gg
8yrs.	1.5%	2.7%	2.3%
20yrs.	0.7%	1.2%	1.0%

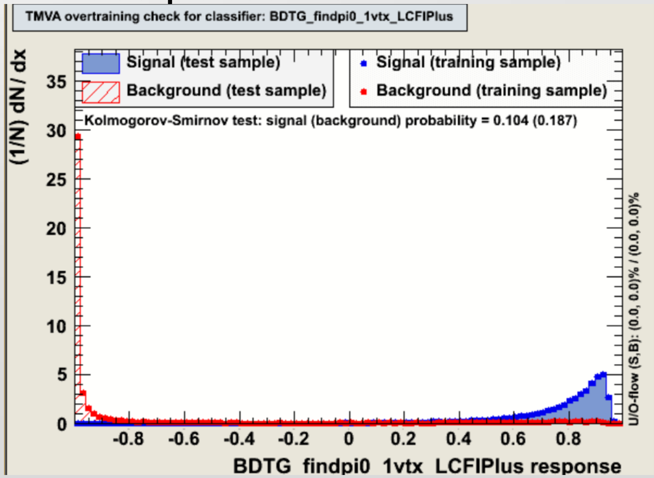
Vertex mass recovery

- Using pios which escape from vertices
  - Need to choose good pio candidates –construct pio vertex finder
  - Key issue –pio kinematics, very collinear to vertex direction



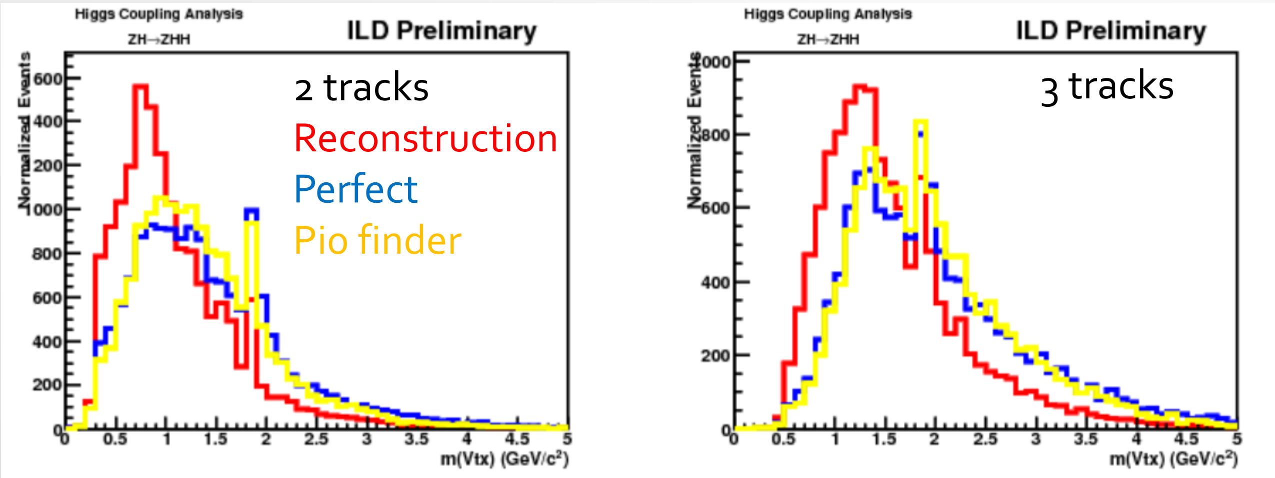


- Particle ID is the other key to classify vertices
  - Different particle patterns have different vertex mass patterns
- Construct Pio Vertex finder using MVA
  - Identify which vertex pios are coming from

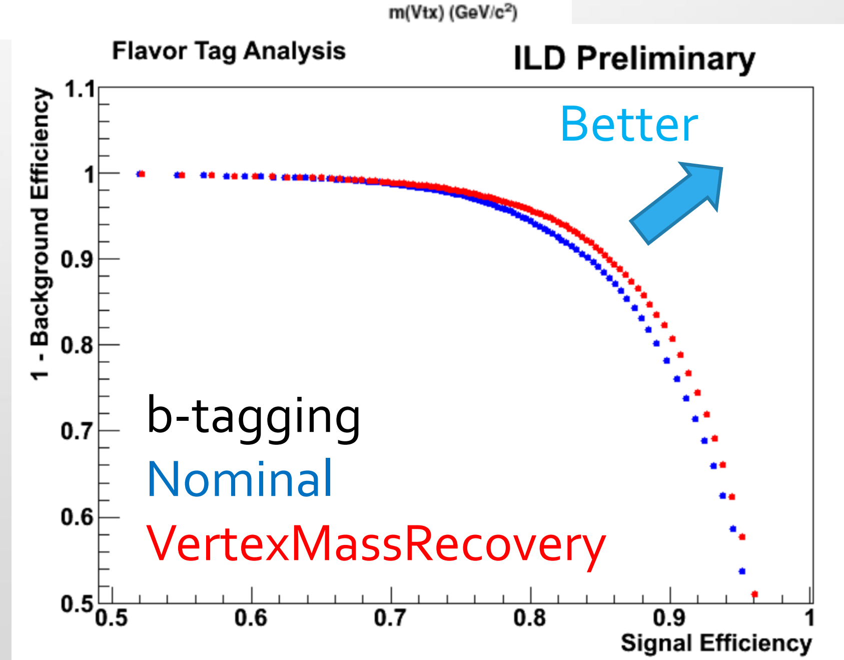


Effect on vertex mass recovery

- Vtx mass distributions for each vertex pattern(ntrk)
  - Difference is coming from mis-pairing of gammas(eff. ～50%) and mis-attachment of π^0s



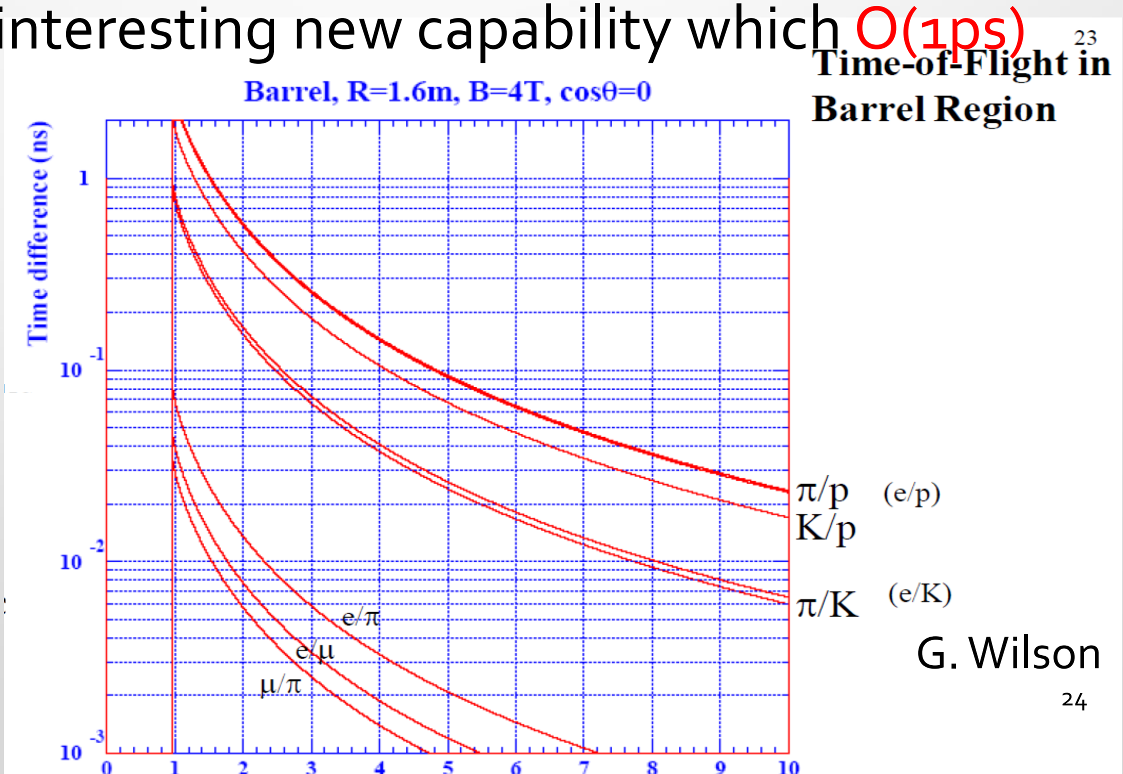
- Effect on Flavor Tag performance
  - ZZZ events@500GeV
  - Compare with ROC curve



On going study

Timing and Particle flow

- Using timing information of Calorimeter will have some benefits:
  - Using timing information at the cell and cluster level to resolve mis-assignment of particle energy deposit
  - Particle TOF for particle ID
- Good possibility to have better separation of K/π & K/p with O(10-100ps) TOF resolution
  - Suffer from K->p mis-ID using dE/dx for K/p separation
- Low momentum μ/π is an interesting new capability which O(1ps) TOF could address
- Tracks with p<0.96GeV/c
  - Endcap TOF?



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PID for neutrals

- Photon: γ/π by TOF will be possible if O(100ps) resolution
- Neutral hadrons: can help to obtain better resolution by combining hadron TOF and calorimetry

TOF helps neutral hadron ID

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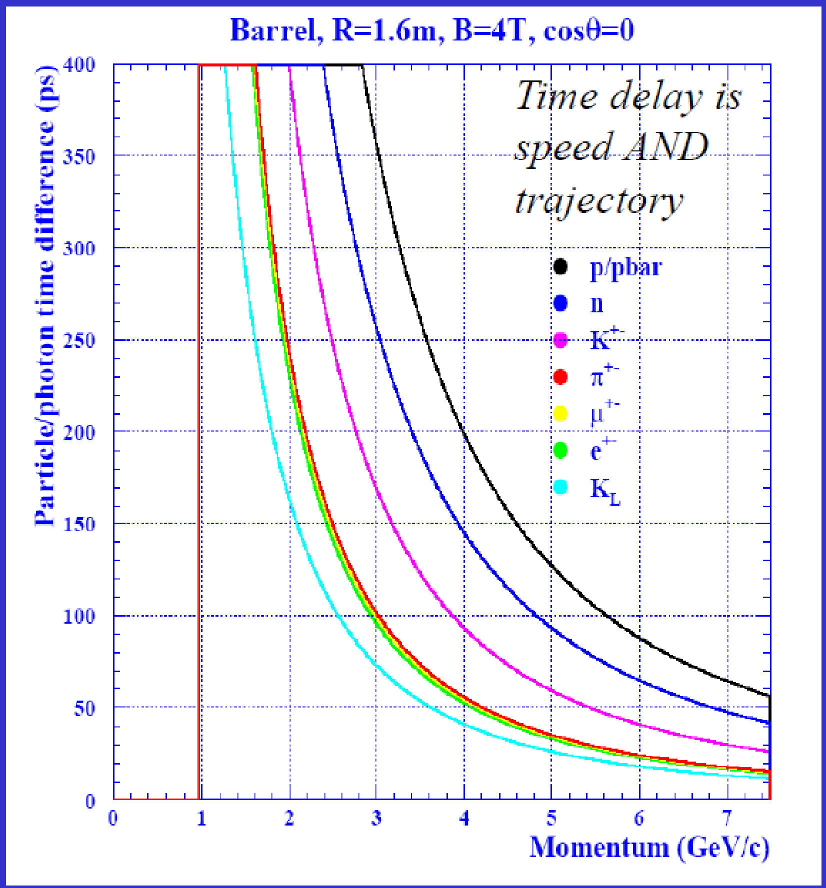

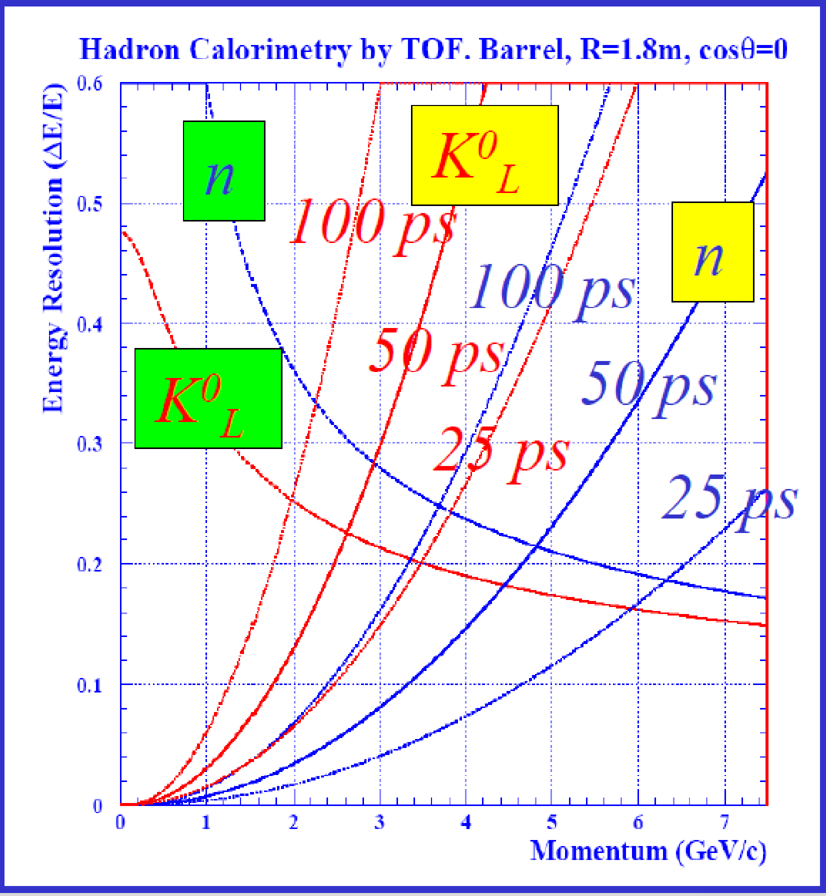

Summary

- Even if energy frontier, flavor physics is very important!
  - It is very important to identify heavy flavor properties
    - Jet flavor
    - Jet charge
  - Such cases, PID will help for better performance!
  - In some cases, PID is directly used
    - e.g. Higgsino study with mass difference degenerate
- In ILD, PID is good as a tool which helps those tasks
  - Thanks to TPC and high granularity calorimeters!
- We need to construct PID with better efficiency
  - Include timing information of calorimeter
  - Use Deep Learning to integrate all the information for better PID efficiency
    - Directly estimate posterior probability with each particle hypothesis

Back ups