Lepton Reconstruction & H→ττ Measurement at CEPC

IAS 2020

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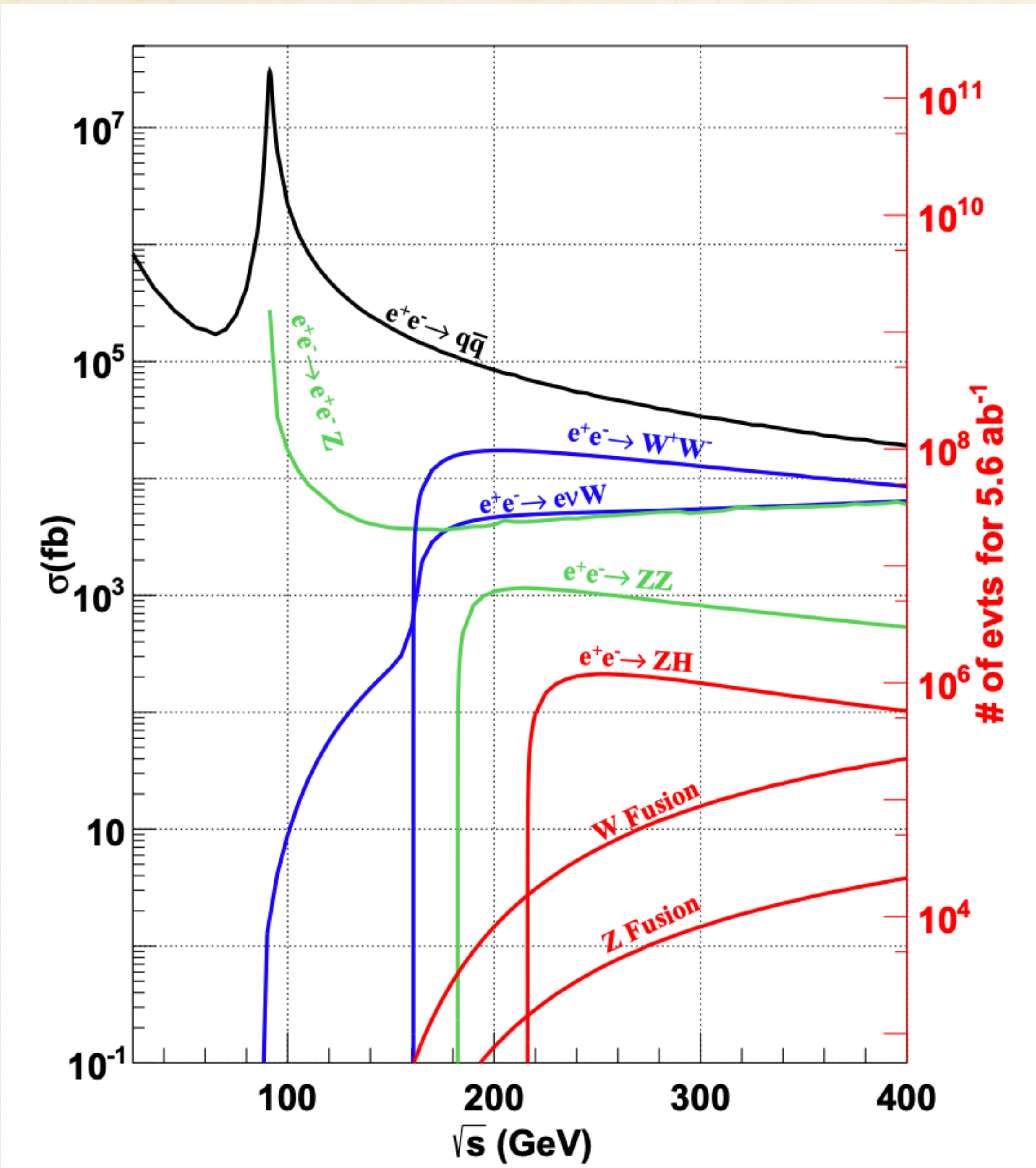
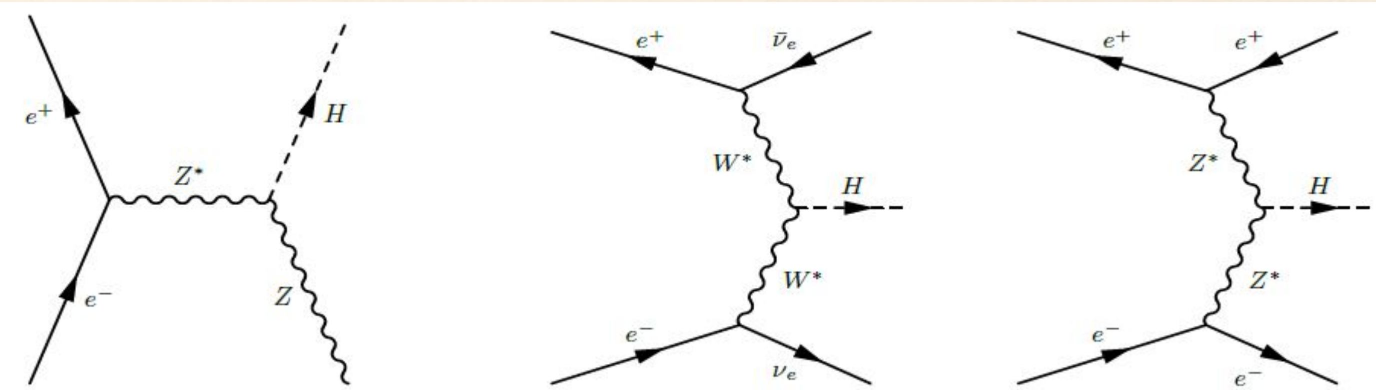
CEPC

Plan

- Introduction
- Lepton Identification
    - Single lepton
    - Lepton in jets
- τ Identification
- Summary

CEPC





- Higgs factory: 240 GeV, 10^6 Higgs,
  - Advantage: Clean, Known initial states
  - Measurements: Higgs boson mass, cross section, decay modes, branching ratio
- Z factory: 91 GeV, 6×10^{11}
  - EW precision physics
- WW threshold runs, ~160GeV, 10^8
  - W mass/width measurement
- PFA Oriented detector

Light Lepton (Isolated)

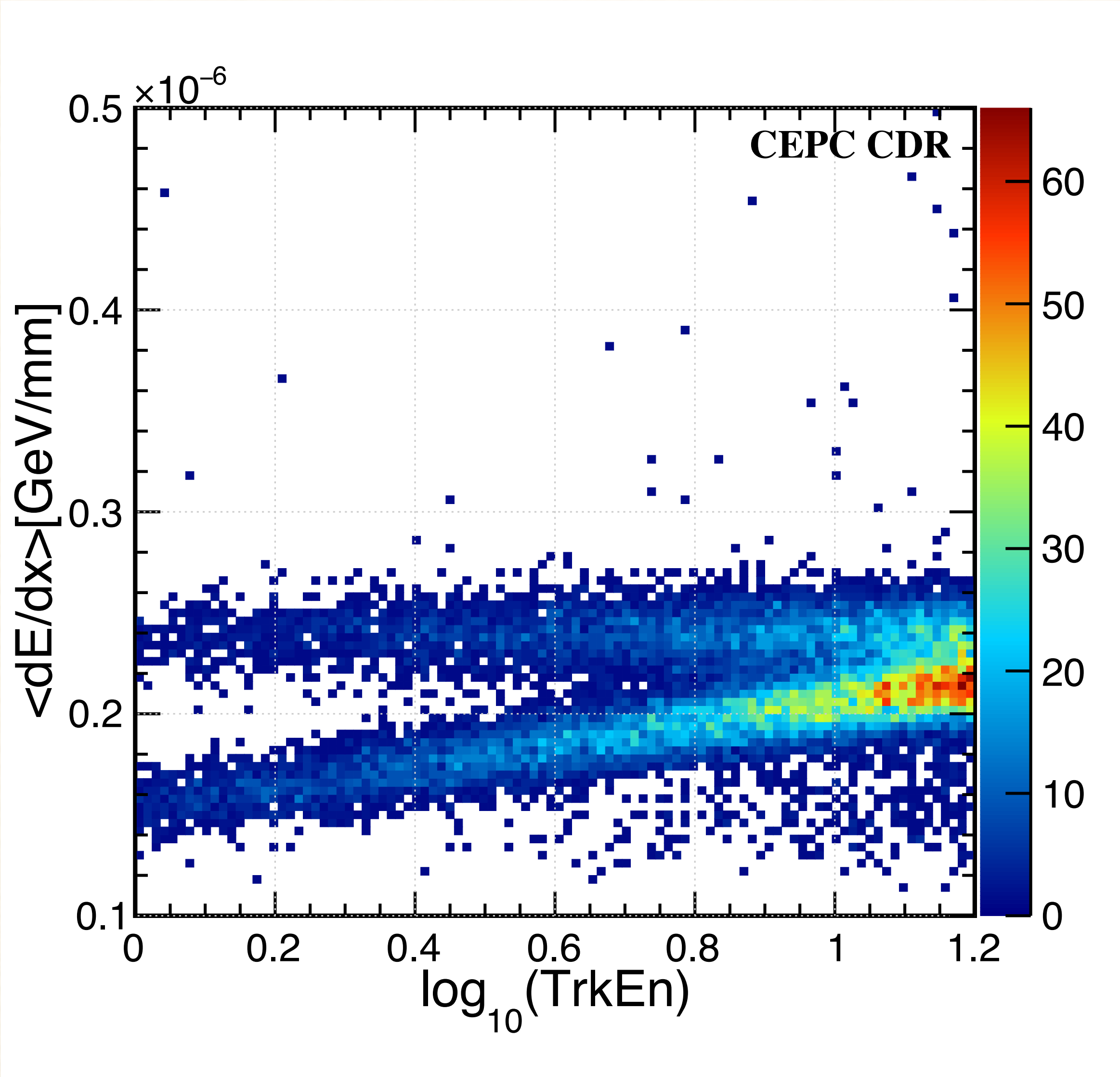
Essential to the precise Higgs measurements
jet flavor tagging and the jet charge measurement

Sample

- LICH (Lepton Identification for Calorimeter with High granularity)
  - Input: 24 variables from reconstructed charged particle
  - Tool: TMVA
  - Training samples: Single particle: e, μ, π (1 GeV ~ 120 GeV) at different regions (endcap, barrel, overlap)
  - Output: likelihood

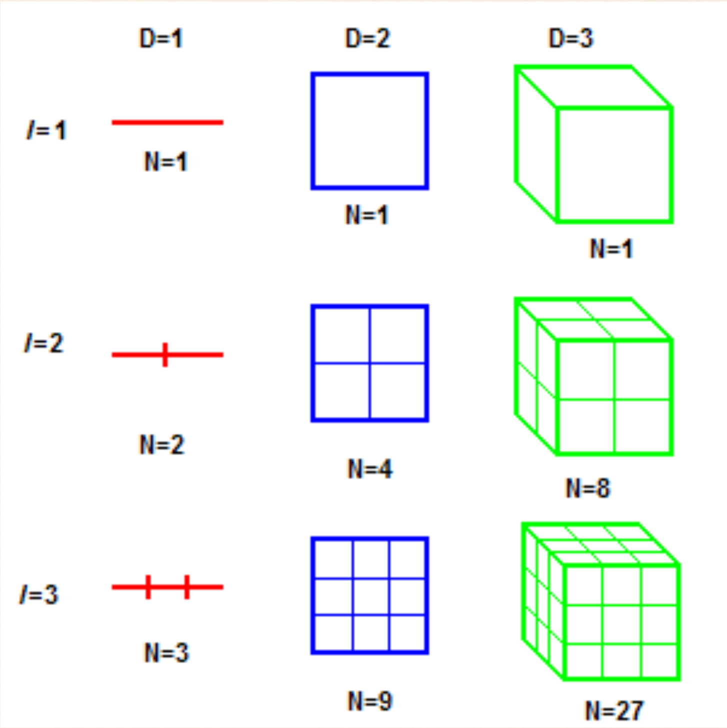
dE/dx

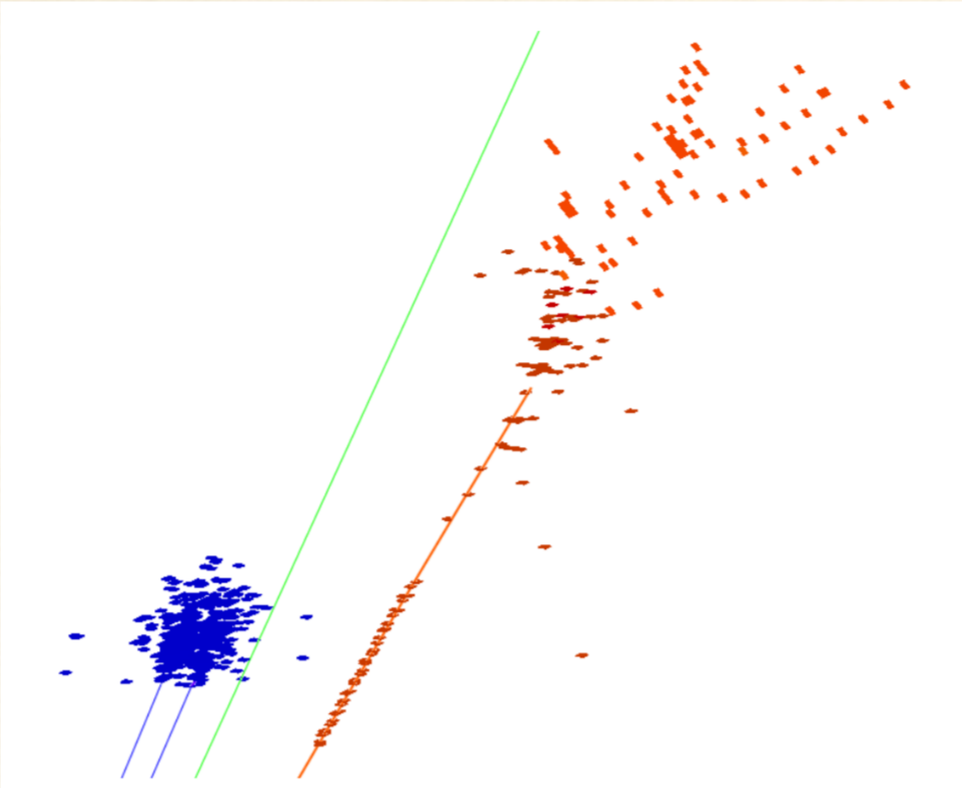
- For a track in TPC, the distribution of energy loss per unit of depth follows an approximately Landau distribution.

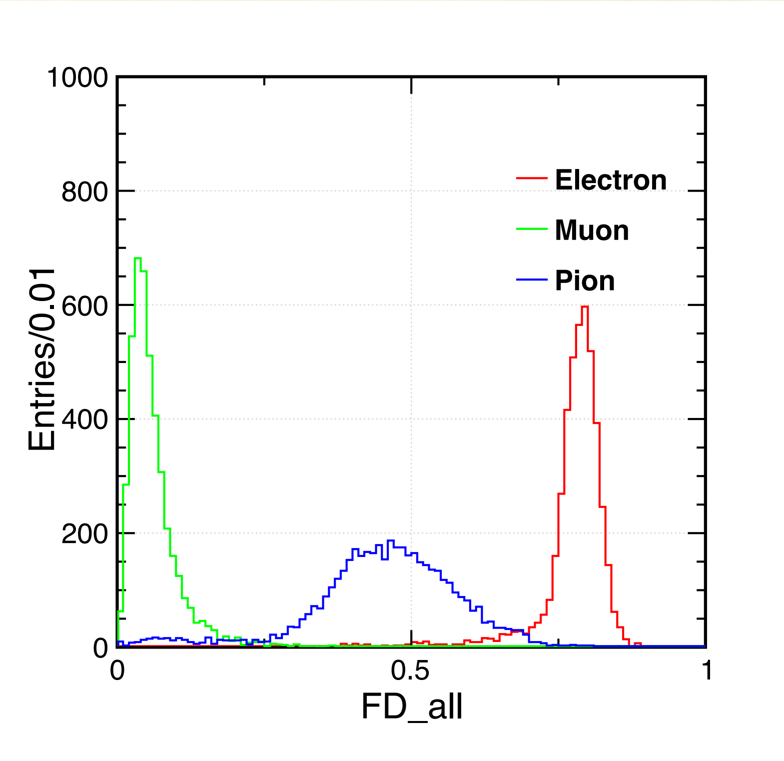


Fractal Dimension

- Describe the self-similar behavior of shower spatial configurations (compactness of the particle shower)
  - $FD_\beta = \langle \log(R_{\alpha,\beta})/\log\alpha \rangle + 1$
    where $R_{\alpha,\beta} = N_\beta / N_\alpha$, α and ß are scales at which the shower is analyzed.
  - Average over range: 1cm - 120cm

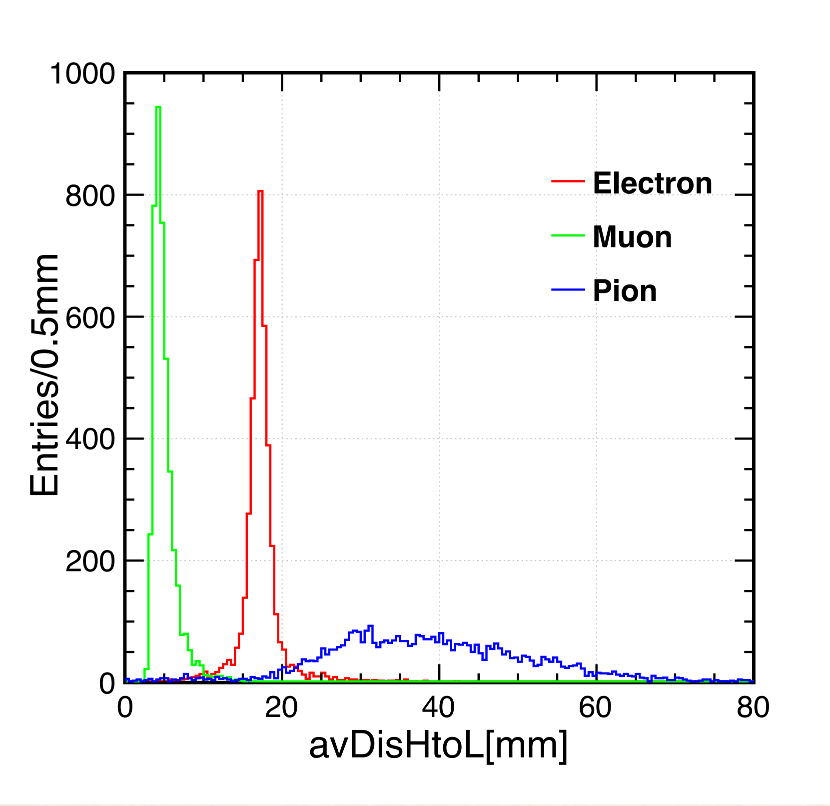


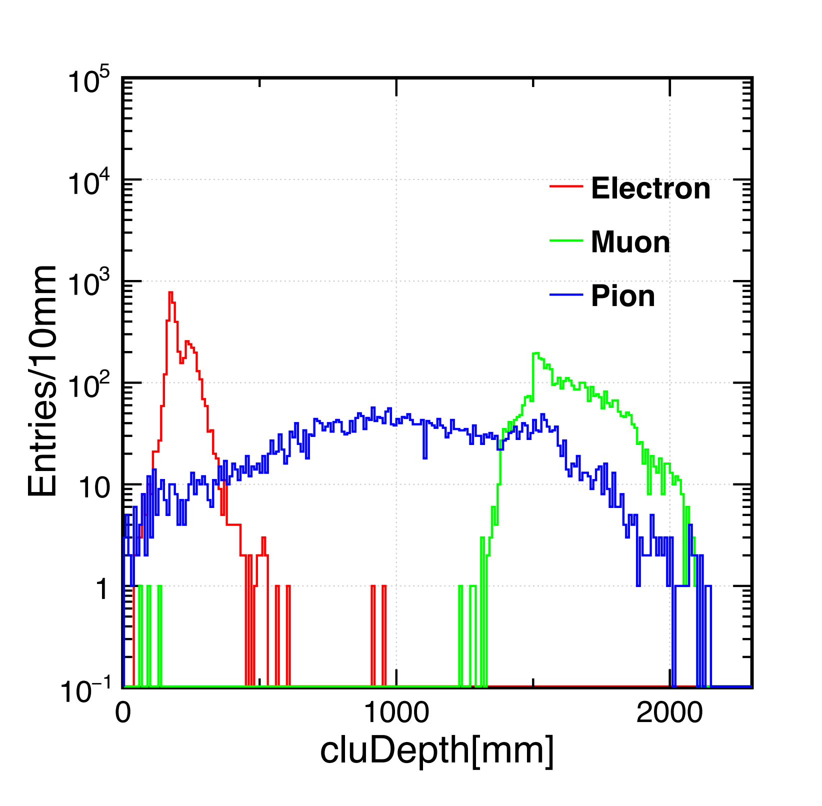


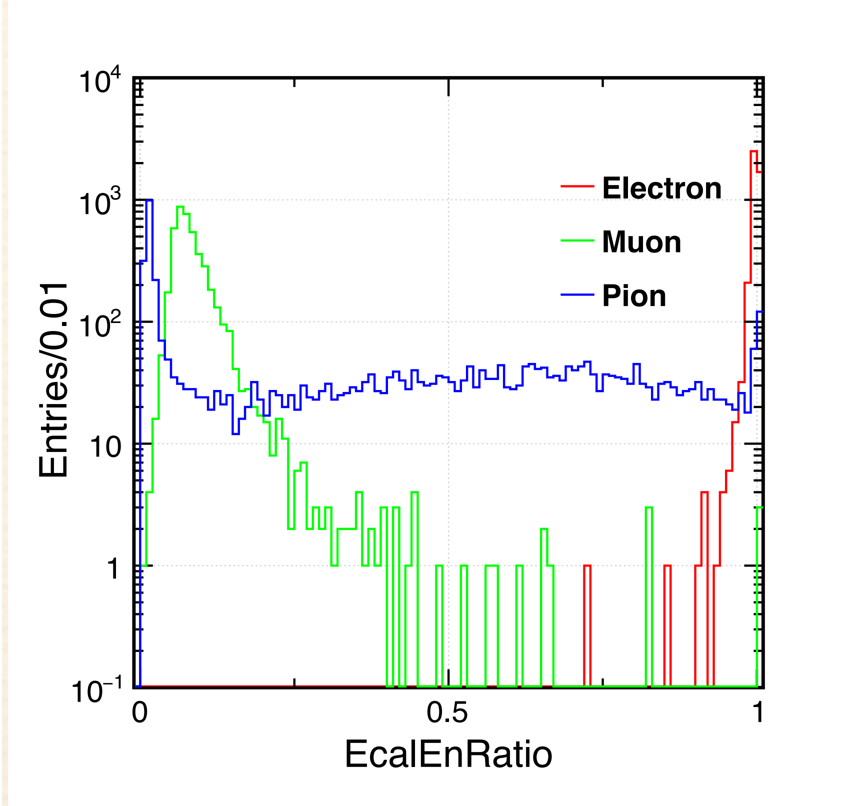


Other Parameters

- Proportion of energy: Energy deposit in the first 10 layers in ECAL to the entire ECAL, or the energy deposit in a cylinder around the incident direction with a radius of 1 and 1.5 Moliere radius.
- Distance(max, min, avr) between hit and track / axis
- Number of hits / number of layers hit by the shower
- Depth
- …

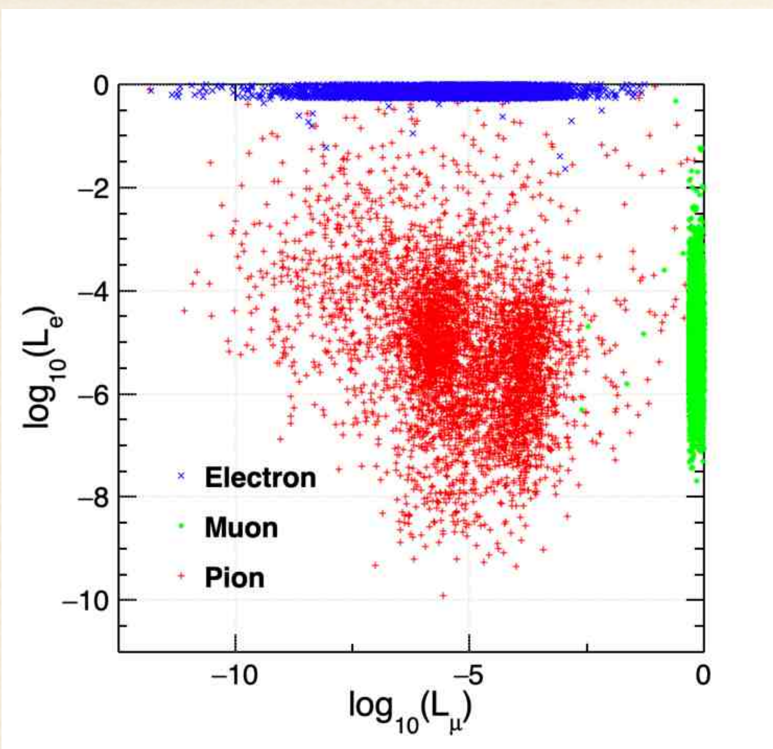


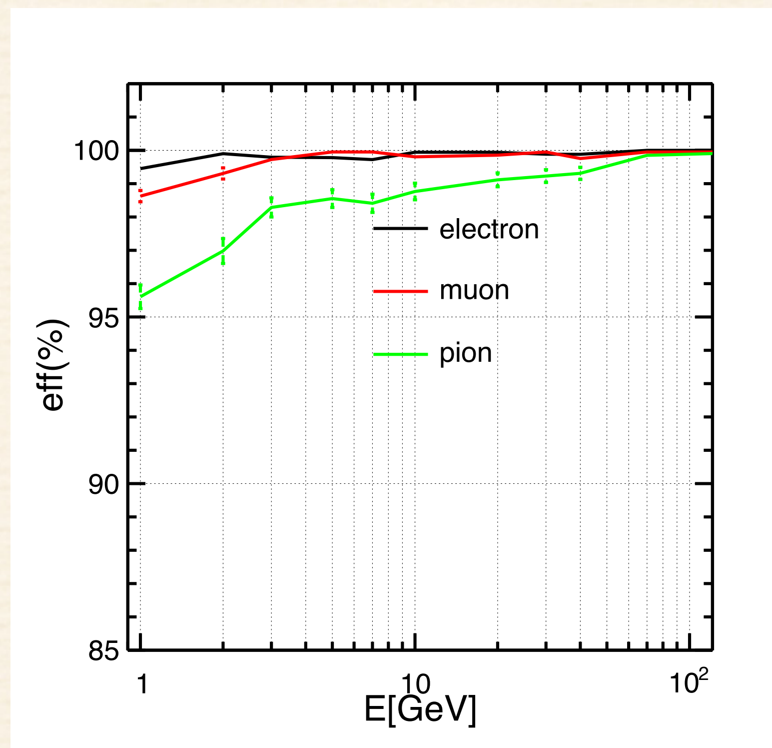


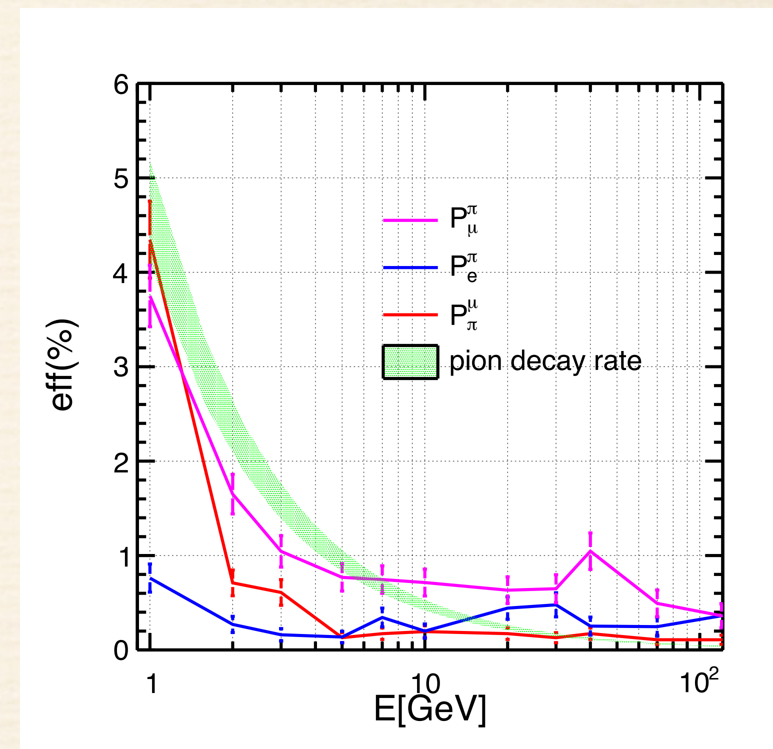


Result

- LICH uses TMVA methods to summarize 24 input variables into two likelihoods, corresponding to electrons and muons.
- The efficiency for electron and muon is higher than 99.5% (E>2 GeV). Pion efficiency ~ 98%.







Migration Matrix at 40GeV (LICH)

Type	e^- *like*	μ^- *like*	π^+ *like*
e^-	99.71 ± 0.08	< 0.07	0.21 ± 0.07
μ^-	< 0.07	99.87 ± 0.08	0.05 ± 0.05
π^+	0.14 ± 0.05	0.35 ± 0.08	99.26 ± 0.12

Migration Matrix for ALEPH PID ($> 2GeV$)(*Eur.Phys.J.C20:401-430,2001*)

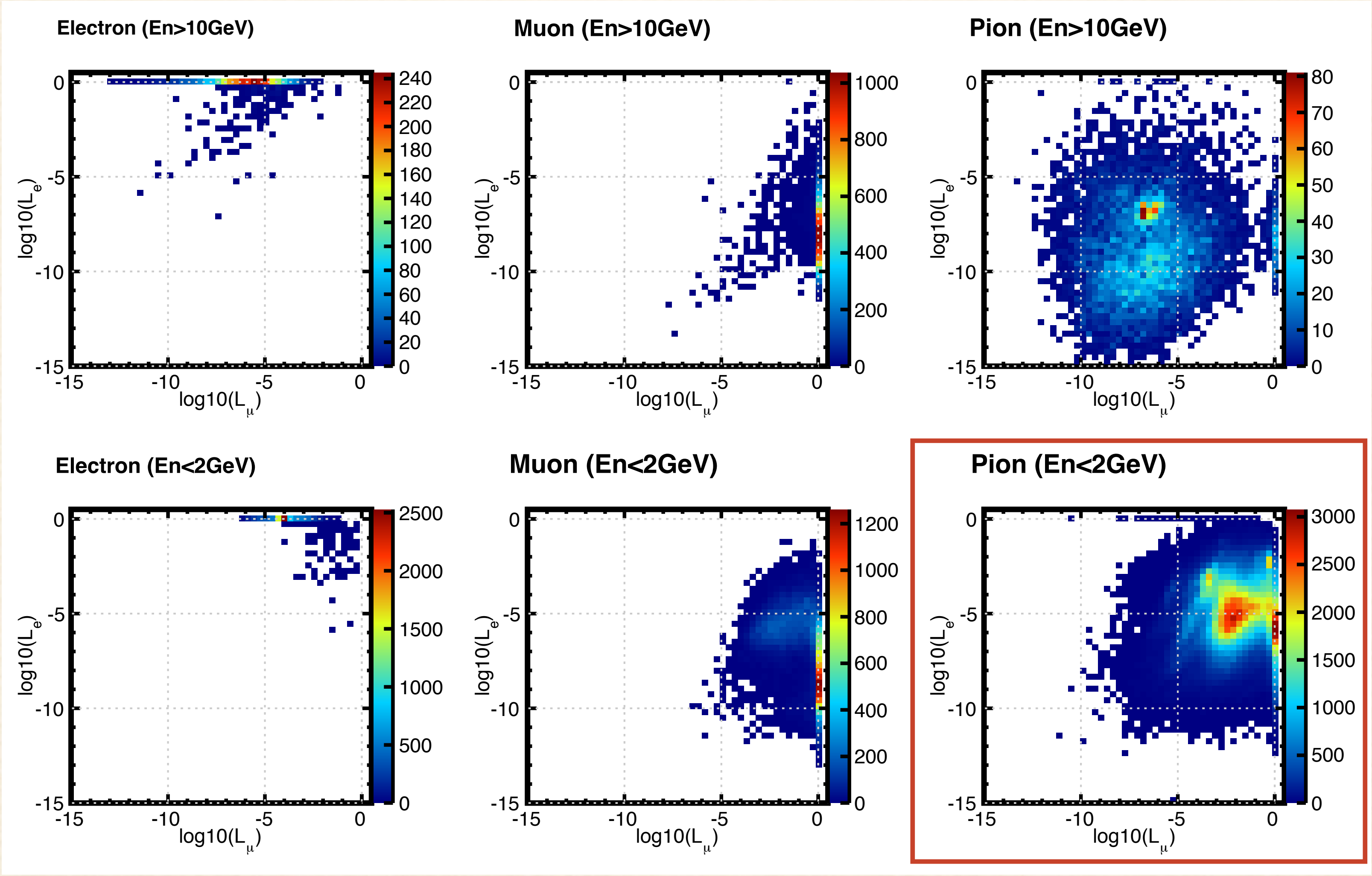
Type	e^- *like*	μ^- *like*	π^+ *like*	undefined
e^-	99.57 ± 0.07	< 0.01	0.32 ± 0.0	0.09 ± 0.04
μ^-	< 0.01	99.11 ± 0.08	0.88 ± 0.08	0.01 ± 0.01
π^+	0.71 ± 0.04	0.72 ± 0.04	98.45 ± 0.06	0.12 ± 0.03

Light Lepton (in Jets)

The performance for lepton in jets degrades
comparing to the single particle results
because of the high statistics of background
and the cluster overlap

Likelihood vs Energy

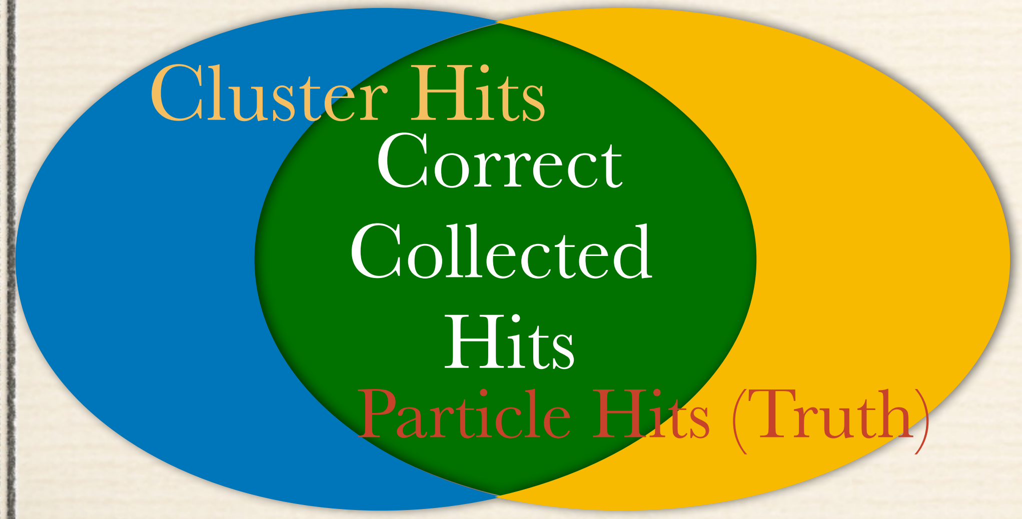
- For higher energy, still nice separation
- For lower energy, pion mixed with muon

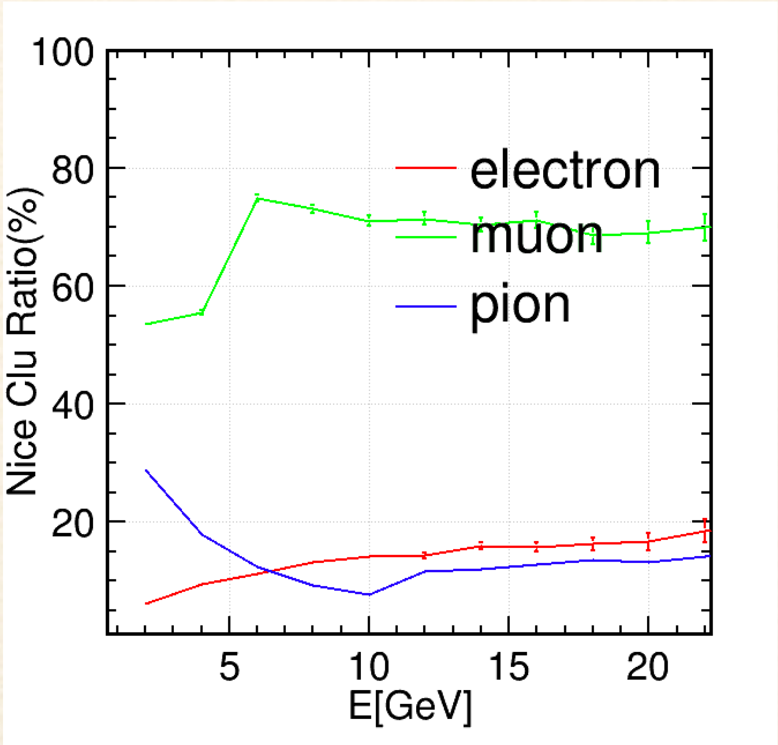


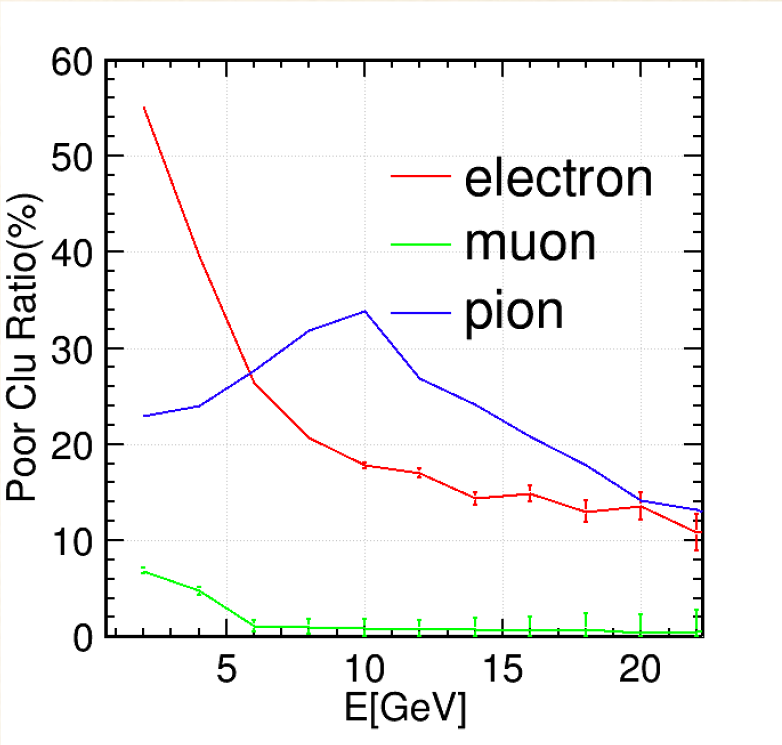
Clustering Performance

- Use clustering
  - efficiency (correct collected hits/particle hits)
  - purity (correct collected hits/cluster hits)

  to characterize clustering performance
- We look into "nice" clusters (efficiency*purity>0.92) and "poor" clusters (efficiency*purity<0.44)

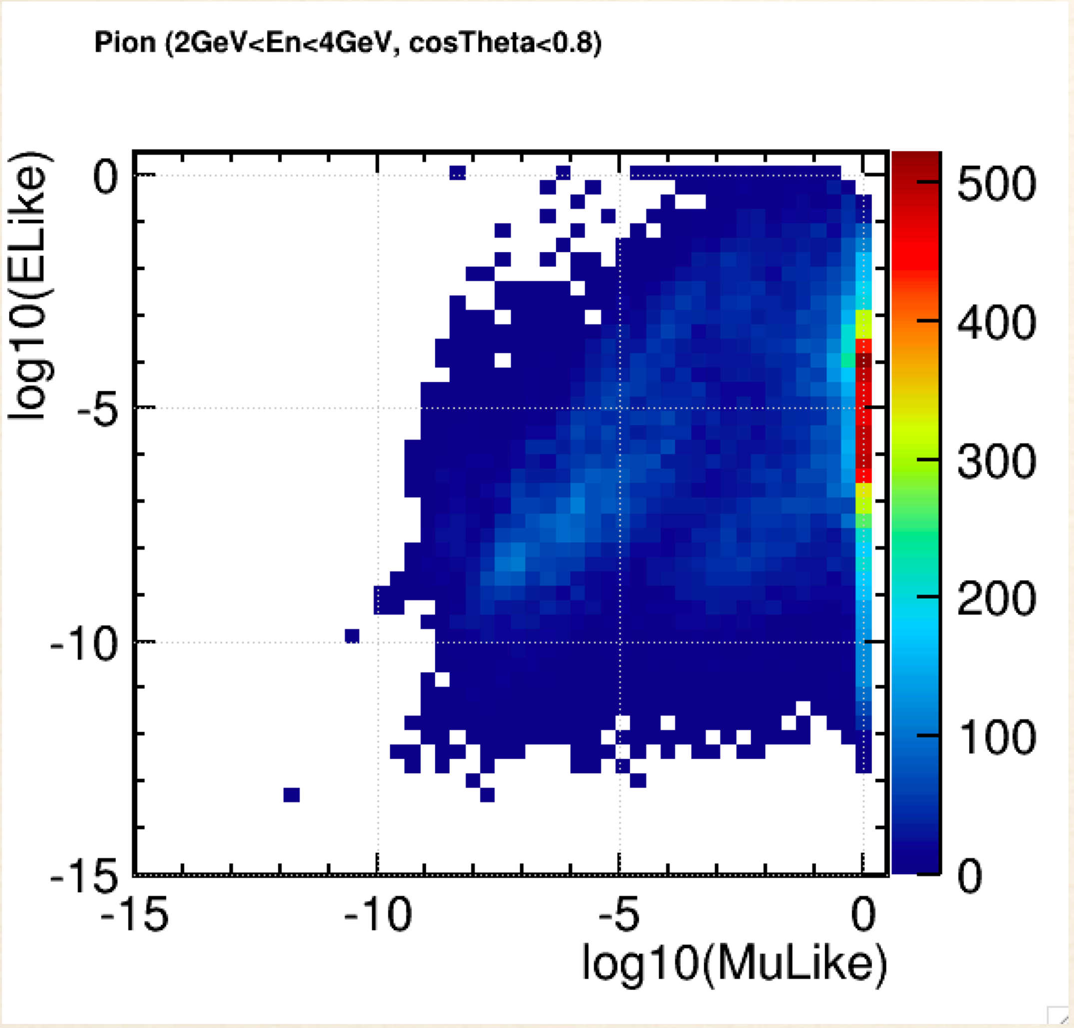


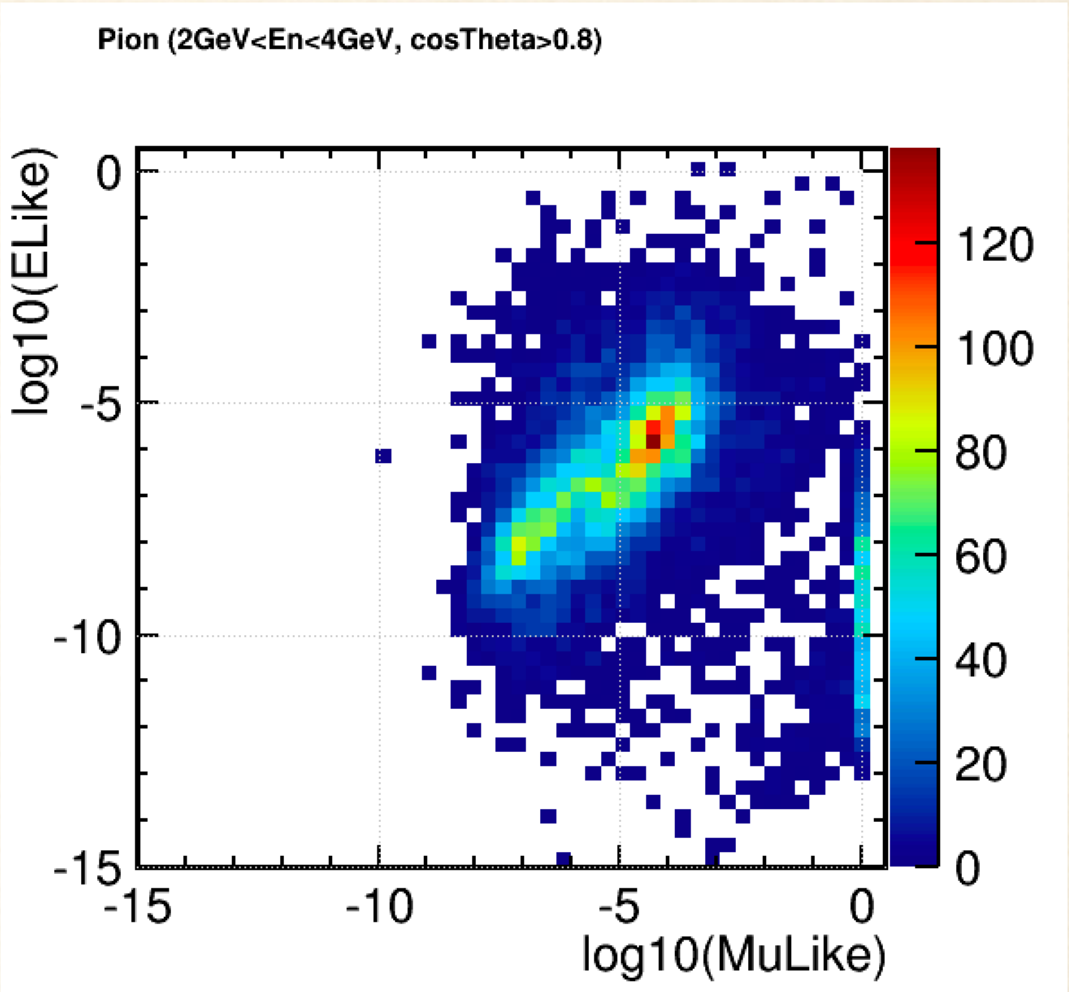




Angular Dependence

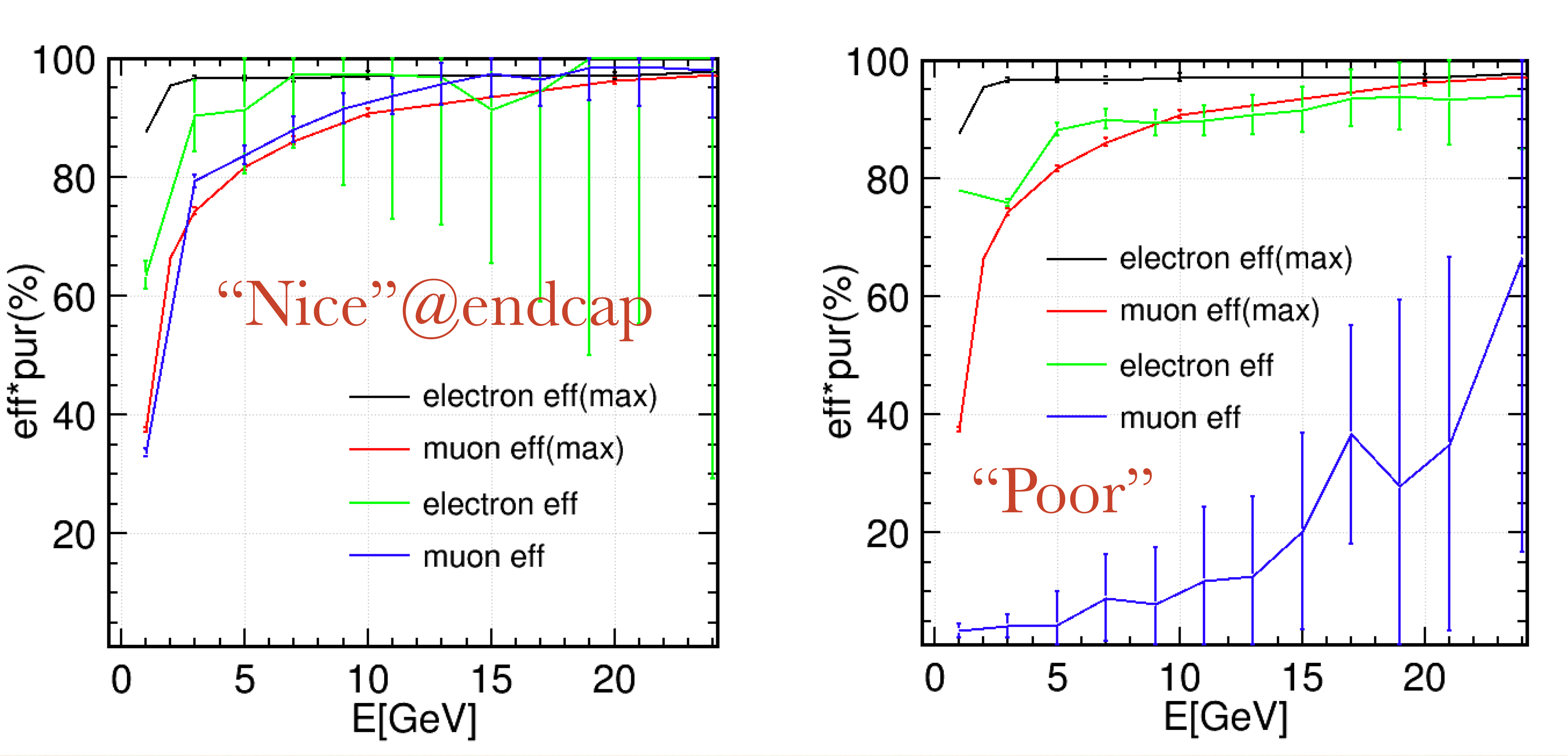
- Low energy pions mixed with muons: better on endcaps





Result

- Comparison of lepton identification performance for "nice"/"poor" clusters and the extrapolated performance using single particle results and the statistics (up limit to be achieved)



τ Identification

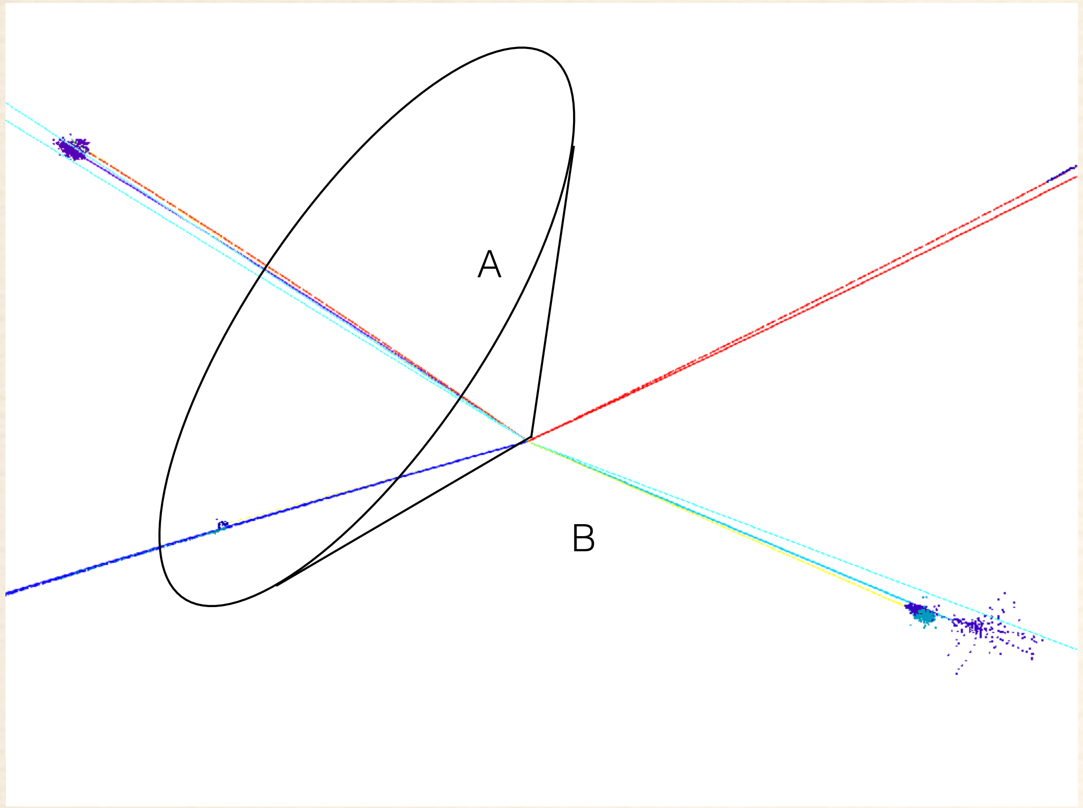
Tau is the heaviest SM lepton - large coupling to Higgs boson Br($H \rightarrow \tau\tau$): 6.27%

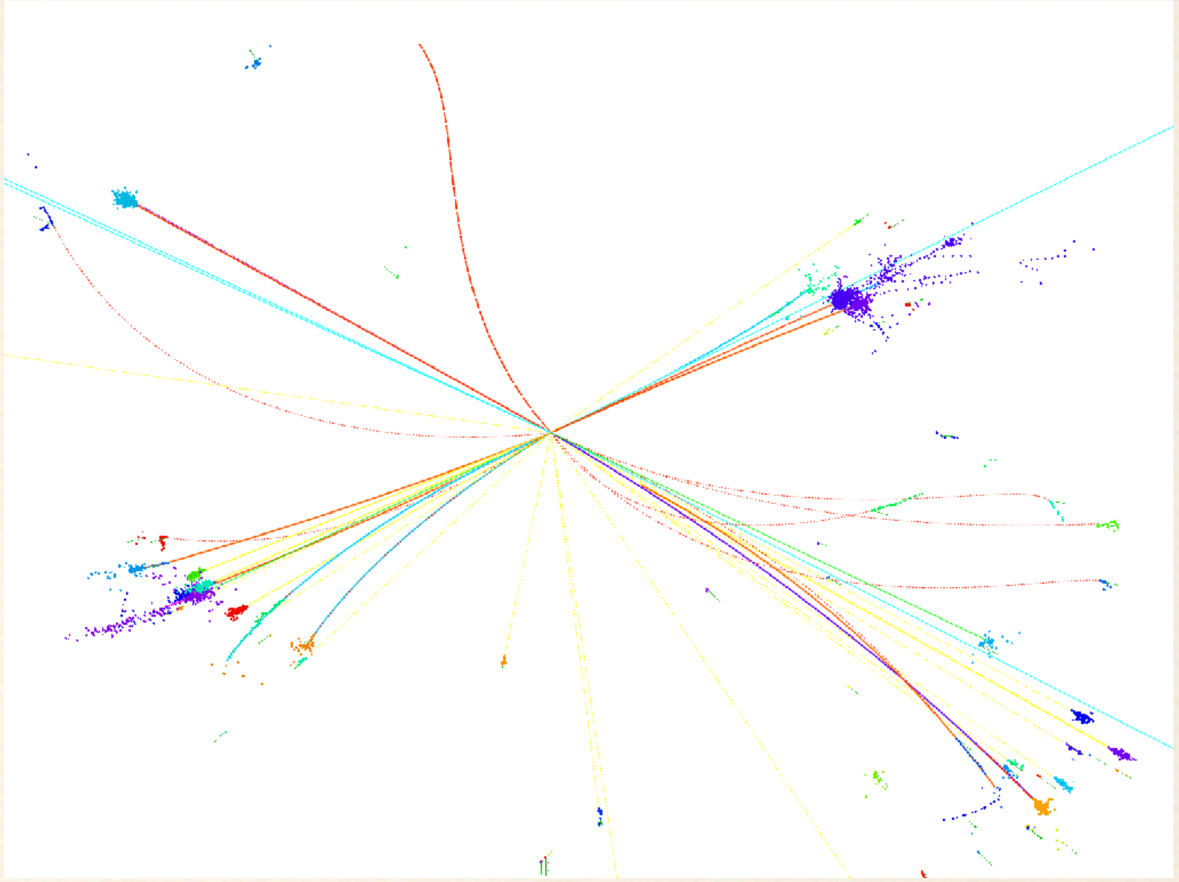
Rich relevant physics

Performance rely on particle separation

Testbed for PFA/Objectives for detector optimization

Event topology



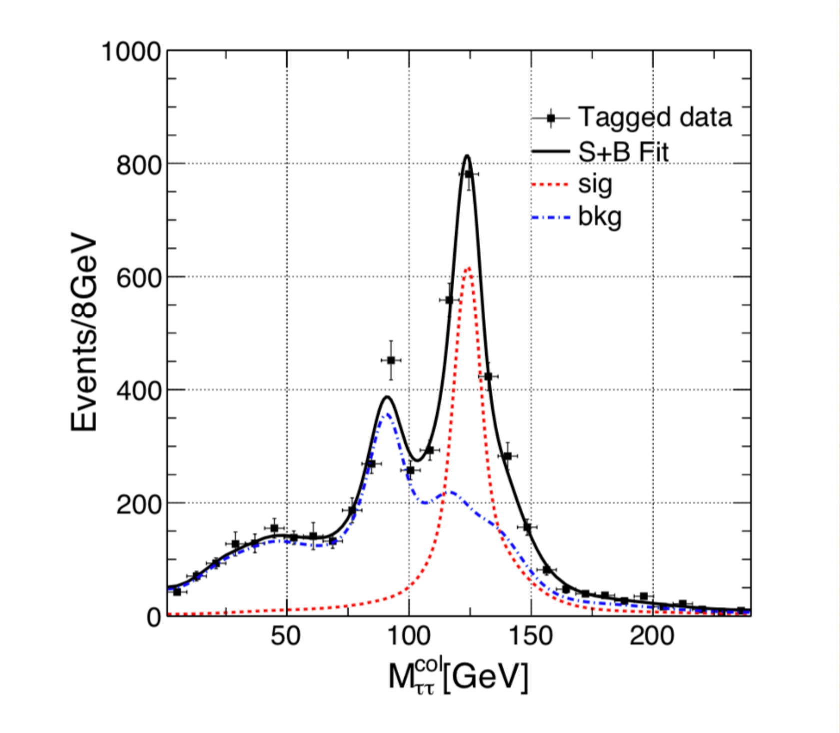


- Veto the two isolate lepton
- Divide the whole space into 2 part
- Use the **multiplicity** and **impact parameter** for ττ event selection.
- Fit the ττ mass for signal and background statistics

- qq events selection
- Tau jet reconstruction package: **TAURUS**
- τ pair selection
- Jet system information
- Fit on impact parameter

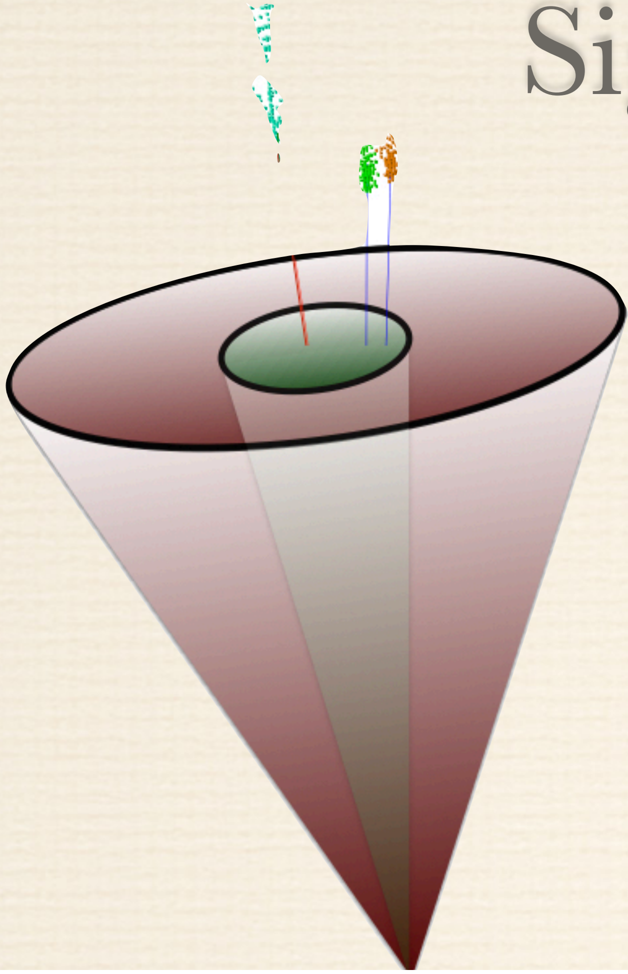
Signal Strength Analysis (without jets)

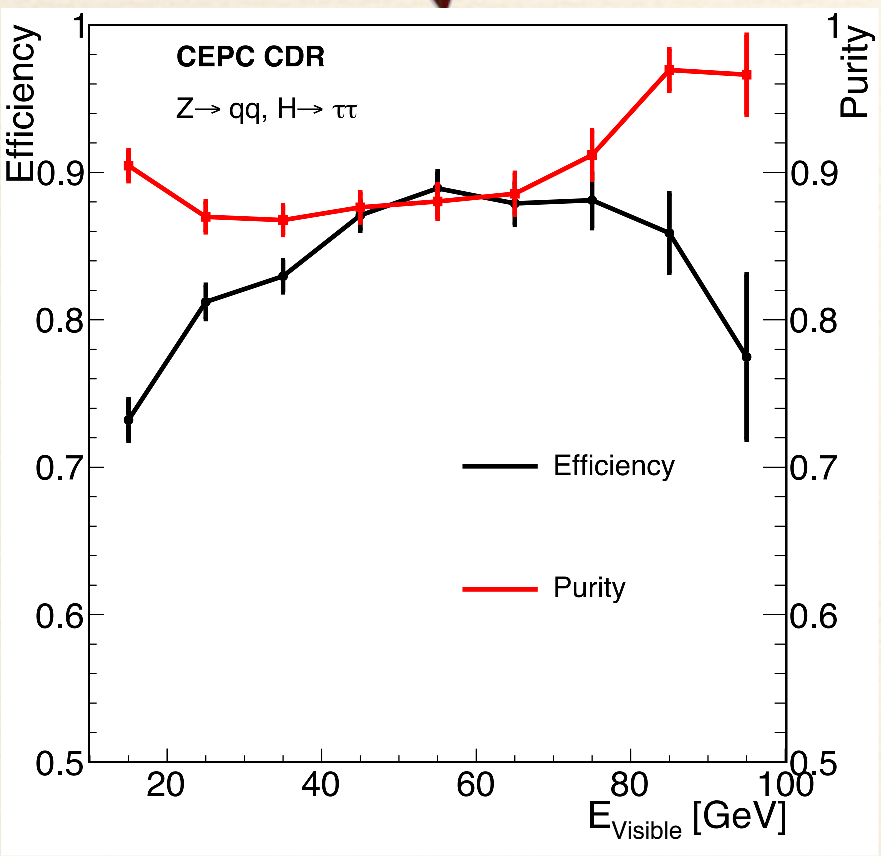
- Veto the two isolate lepton
- Divide the whole space into 2 part
- Use the multiplicity and impact parameter for ττ event selection.
- Fit the collinear mass for signal and background statistics



	$\mu\mu H\tau\tau$	$2f$	SW	SZ	WW	ZZ	mixed	ZH	total Bkg	$\sqrt{S+B}/S(\%)$
total generated	2388	801152078	19517399	9072946	50826211	6389424	21839941	1102582	909900581	1263.17
$N_{\mu^+} > 1, N_{\mu^-} > 1$	2341	22894549	37923	720547	1335231	831861	1251657	567636	27639404	233.56
$115GeV < M_{recoil} < 160GeV$	2186	864849	154	155502	396485	112837	164225	3114	1697166	61.75
$60GeV < M_{invariant} < 105GeV$	2118	662042	0	31145	111376	56642	99874	987	962066	48.08
$E_{Le} < 65GeV$	2101	658199	0	17760	111340	56516	99822	957	944594	48.02
$N_{Trk}(A/B) < 6$ & $N_{Ph}(A/B) < 7$	1977	78	0	996	2576	8019	29	105	11803	6.16
BDT>0.78	1891	0	0	264	231	3682	9	39	4225	4.26
$M_{\tau\tau}^{col} > 0$	1853	0	0	259	88	3099	9	35	3490	4.07
$\tau\tau$ collinear mass fit result										2.75

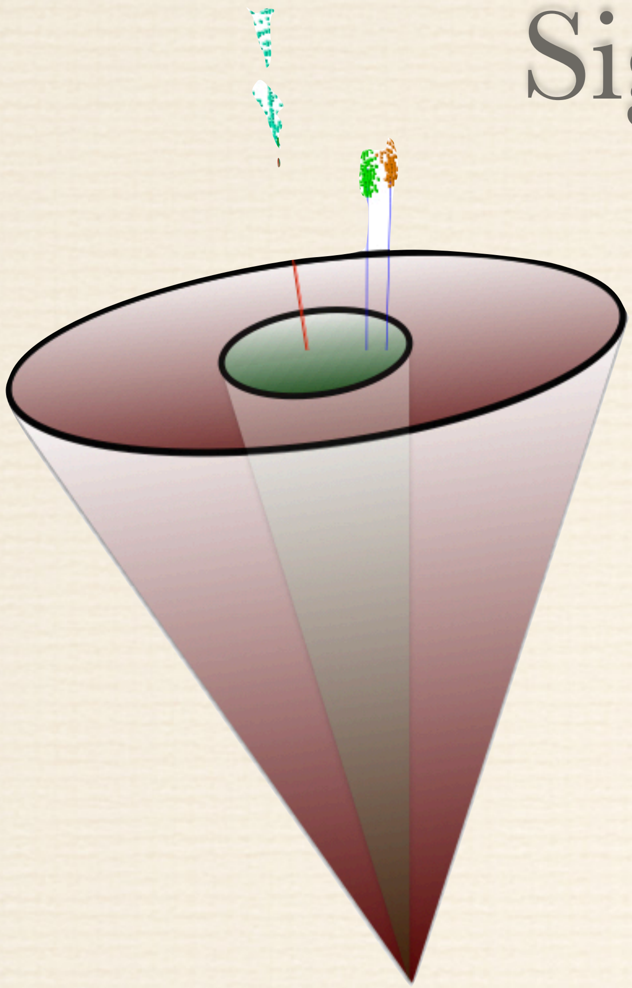
Signal Strength Analysis (with jets)

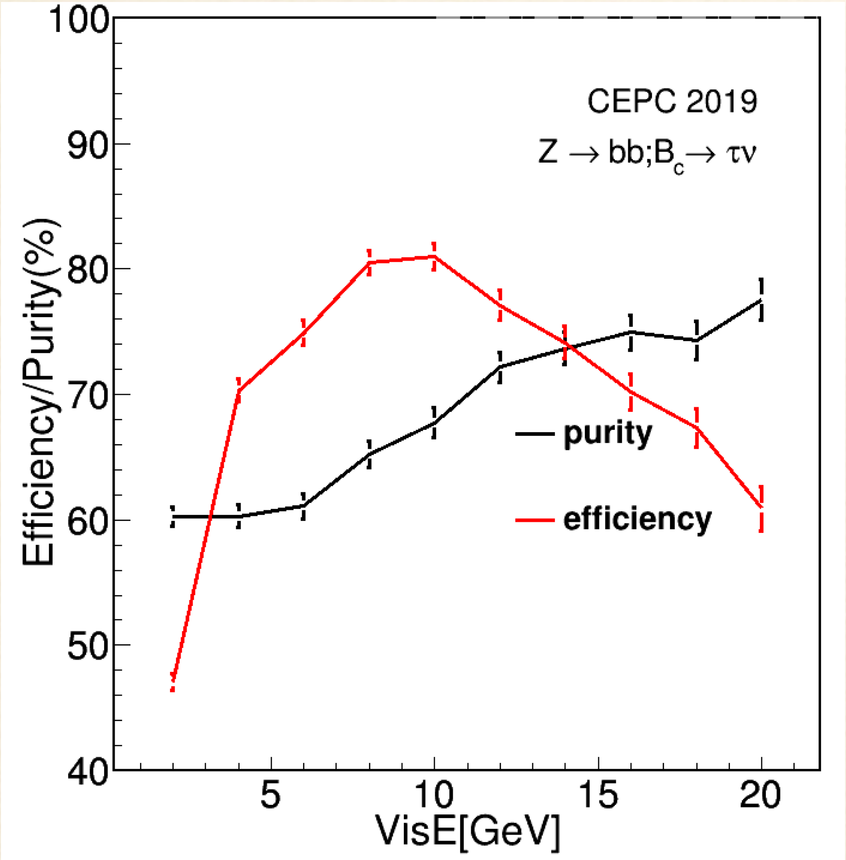




- Double cone based algorithm
  - Find seeds(Tracks with enough energy)
  - Collect particle in two cones
  - Use the multiplicity, energy ratio between two cones, invariant mass for τ tagging
- Event efficiency ~ 60%

Signal Strength Analysis (with jets)





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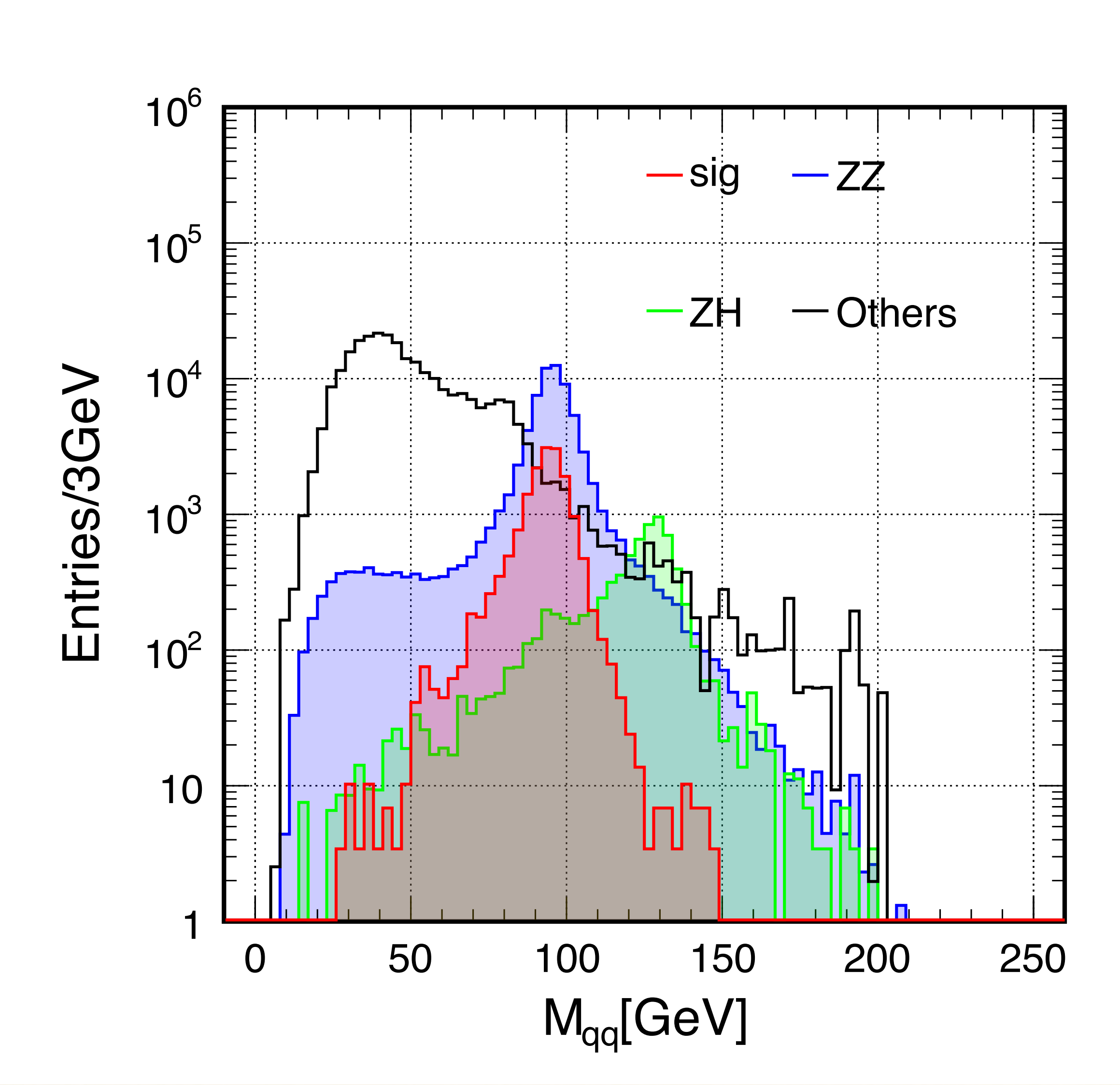
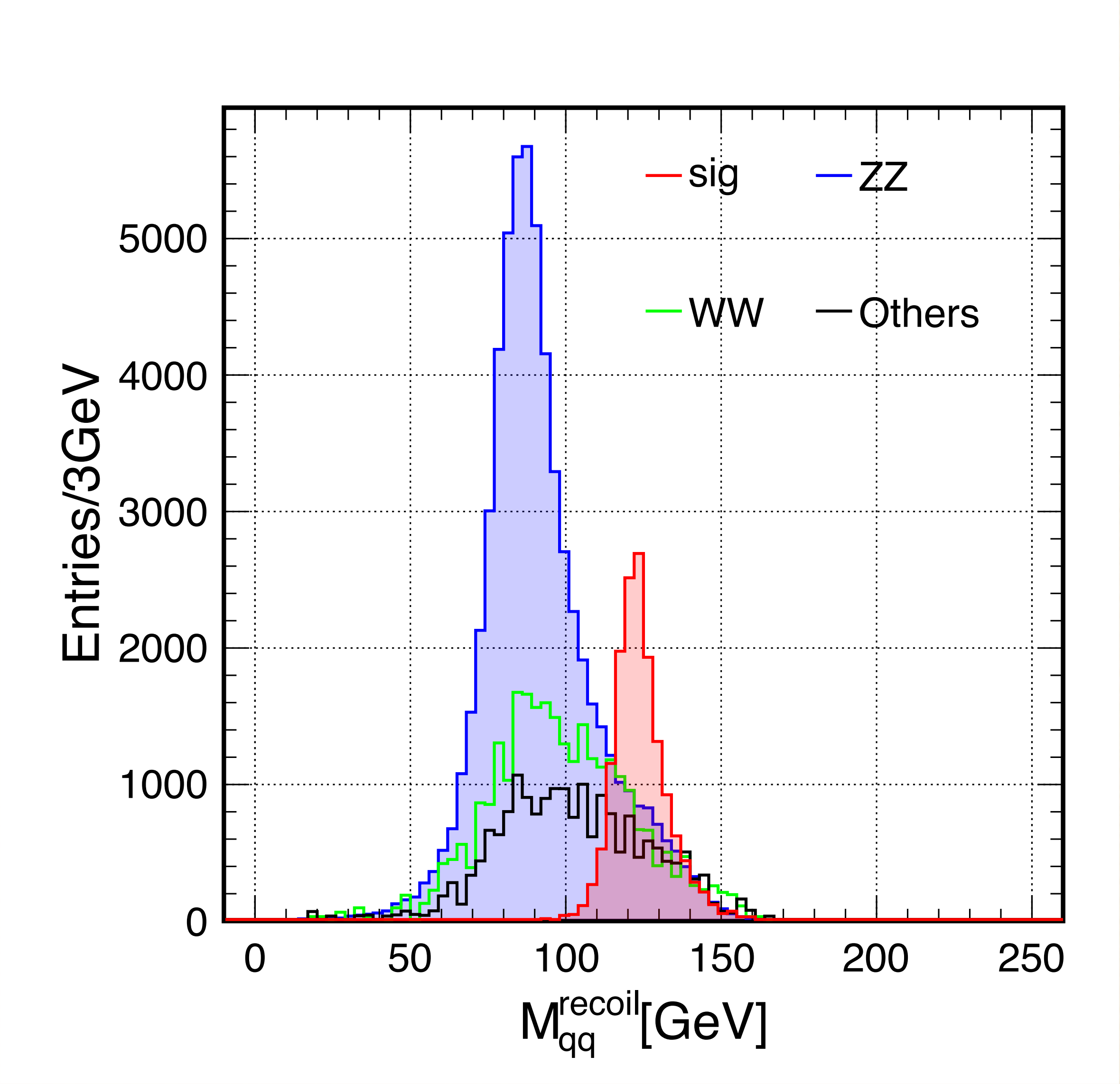
Signal Strength Analysis (with jets)

- Event selection: qq system information





Signal Strength Analysis (with jets)

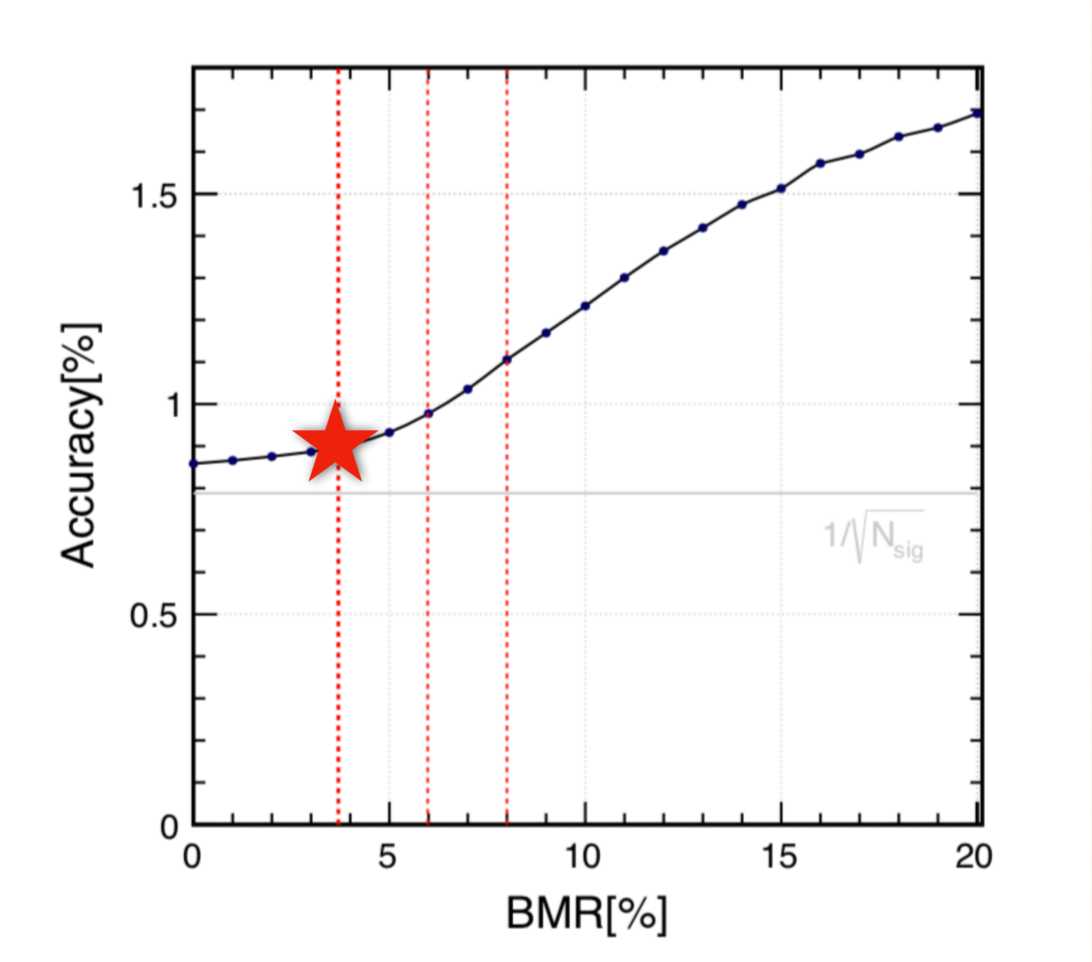
- Event selection: qq system information

	$qqH\tau\tau$	$2f$	SW	SZ	WW	ZZ	mixed	ZH	total Bkg	$\sqrt{S+B}/S$ (%)
Total Statistic	48266	801152078	19517399	9072946	50826211	6389424	21839941	374357	909679268	62.43
NCh>10	47347	272992986	13765307	1969972	47052263	5756249	18020636	331843	359889260	40.07
$110GeV < E_{tot} < 235GeV$	46183	173589861	13159096	942644	31297172	3239464	5154115	264535	227646887	32.67
$E_{Le} < 45GeV, E_{L\mu} < 65GeV$	44093	169589868	3413790	707027	22428227	2911836	4985026	237240	204273014	32.41
$N_{\tau^+} > 0, N_{\tau^-} > 0$	24214	401147	212183	13999	1129502	171380	193055	16821	2138087	6.55
$90GeV < M_{\tau\tau}^{col} < 160GeV$	17176	9717	21483	1689	135538	62721	7722	5305	244175	2.97
$70GeV < M_{qq} < 110GeV$	16257	1596	4119	1012	26823	52307	1818	717	88392	1.98
$M_{qq}^{rec}(GeV) > 100GeV$	16211	0	1463	637	11071	13814	1265	647	28897	1.31
2-D impact parameter fit result										0.93

Results & BMR Dependency

- Combined Accuracy: 0.8%
- BMR: boson mass resolution, Separate W/Z/H in hadronic decays
- 3.8% for the current Detector+PFA
- qqH signal strength accuracy degrades by 20% if the boson mass resolution degrades from 3.8% to 8%.

	$\delta(\sigma\times BR)/(\sigma\times BR)$
$\mu\mu H$	2.8%
eeH	5.1%
$\nu\nu H$	7.9%
qqH	0.9%
combined	0.8%



Tau decay mode analysis

	No Trk	1-prong(l)	1-prong(h)	1prong + 1photon	1prong + 2photon	1prong + 3photon	1prong + 4photon	1prong + 5photon	3prong	3prong+ 2photon	other
1-prong(l)	3.58	88.42	3.17	2.58	0.04	0	0	0	0.35	0	Ntrk>1
1-prong(h)	5.90	5.76	78.17	4.49	0.82	0.20	0.06	0	1.16	0	Ntrk>1
1prong + 2photon	2.47	1.31	0.88	29.01	58.34	3.27	0.21	0.01	0.03	1.59	Ntrk>1
1prong + 4photon	1.93	1.23	0.17	1.78	9.75	31.07	45.01	3.24	0	0.19	Ntrk>1
3prong	1.34	1.93	0.34	0.15	0.05	0	0	0	88.44	0.24	Ntrk=2
3prong + 2photon	1.12	1.68	0.14	0.10	0.33	0.10	0.02	0.01	1.08	63.94	Nph=1

Summary

- TMVA based lepton identification has been developed with high efficiency
  - For >2GeV isolate lepton: 99.5%
  - For leptons in jets, degrade due to high statistics, mis-clustering and angular effects
  - “Nice” clusters performance ~ isolate case
- Inclusive τ identification developed with efficiency ~ 80%
  - PFA plays important role in Higgs to ττ analysis (final relative accuracy: 0.8%)
  - Decay modes identification ongoing
  - Better photon/π0 reconstruction needed (ongoing)
- Plan
  - τ in jets
  - CP
  - Exotic decay

Thank you for your attention!