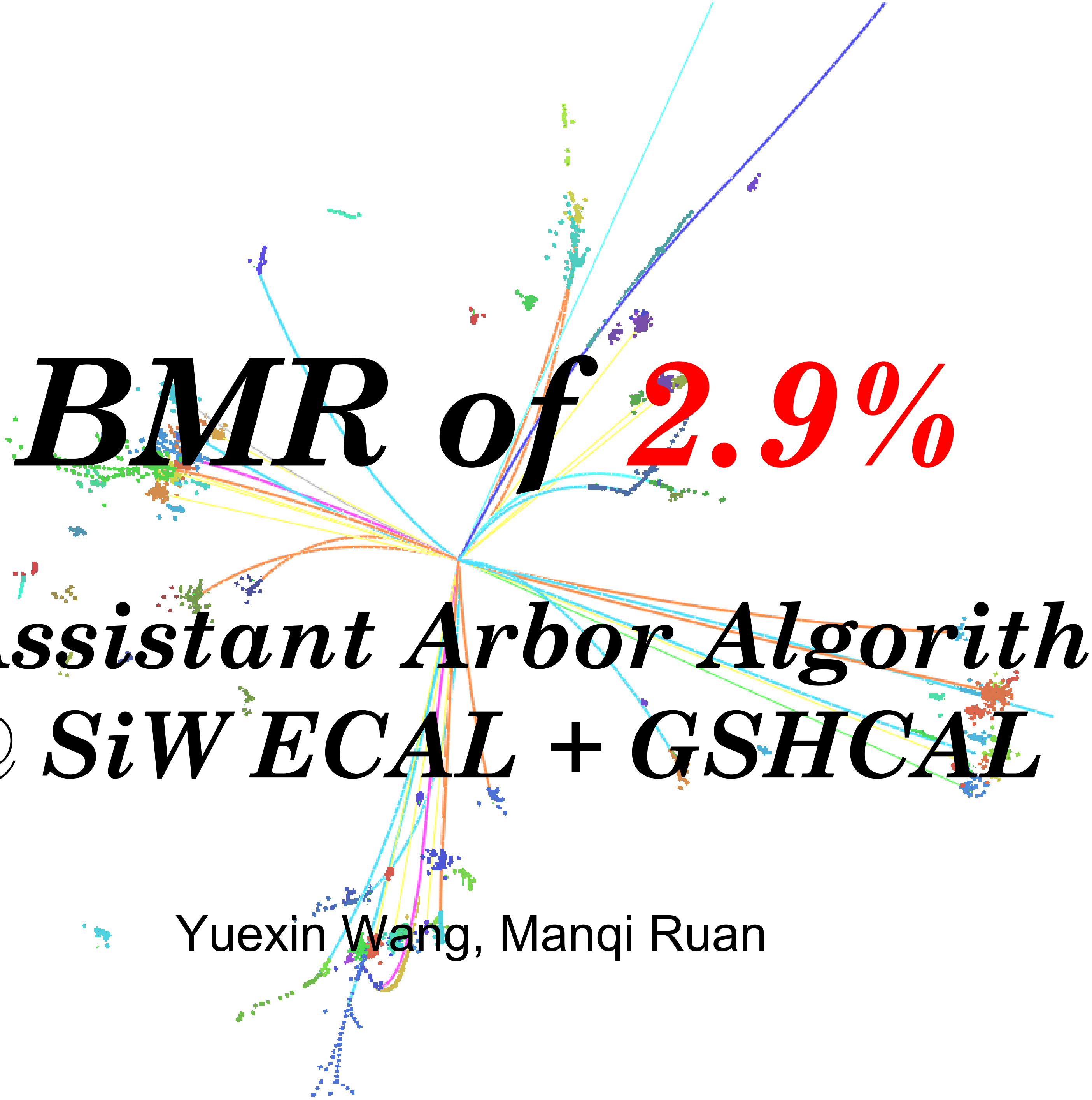
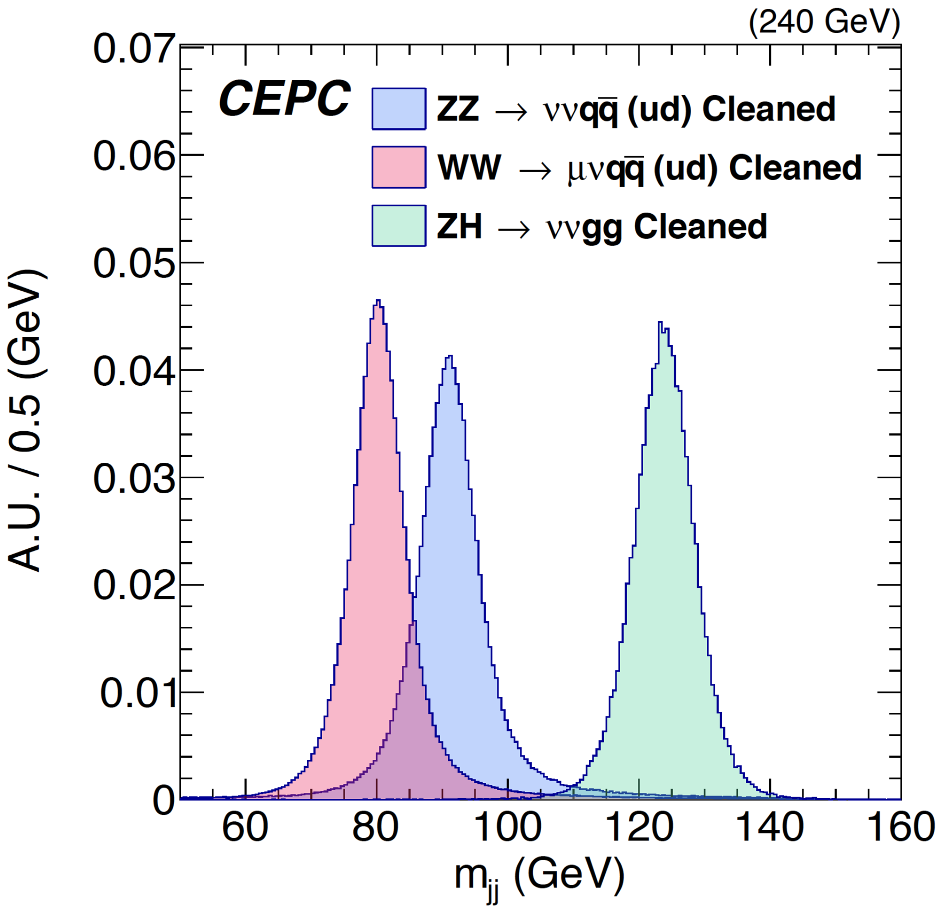


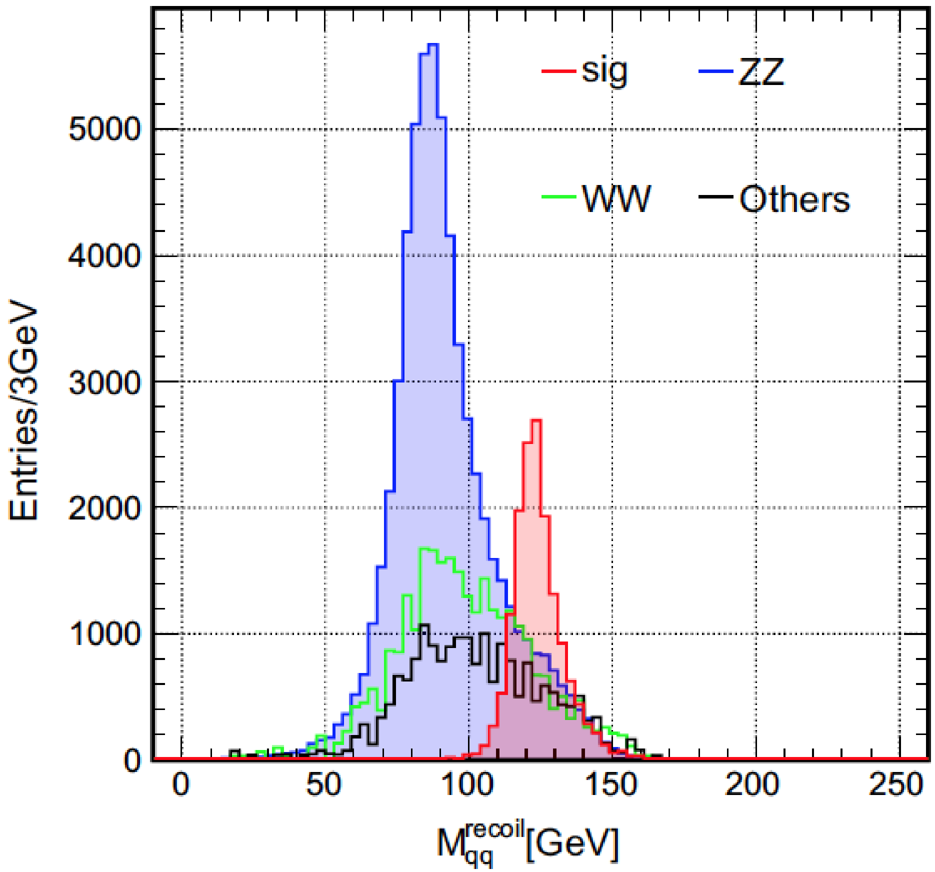
BMR of 2.9%

AI Assistant Arbor Algorithm
@ SiW ECAL + GSHCAL

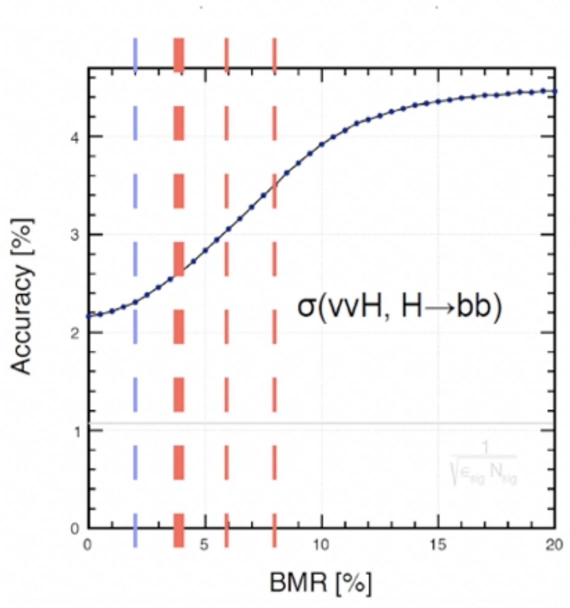
Yuexin Wang, Manqi Ruan

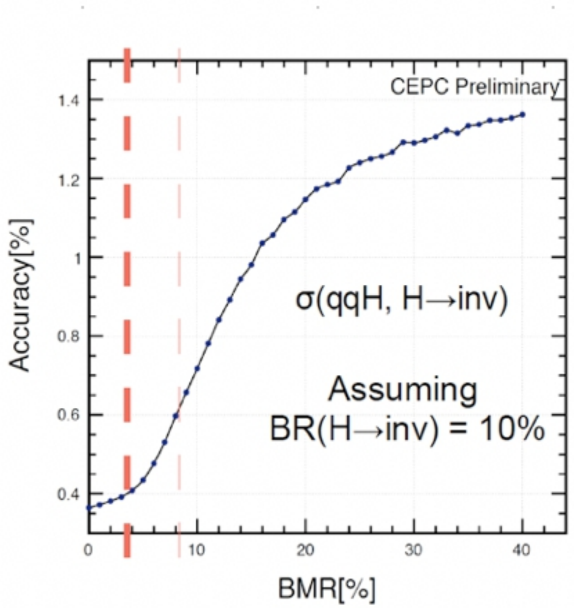
Boson Mass Resolution: Key Per. Para

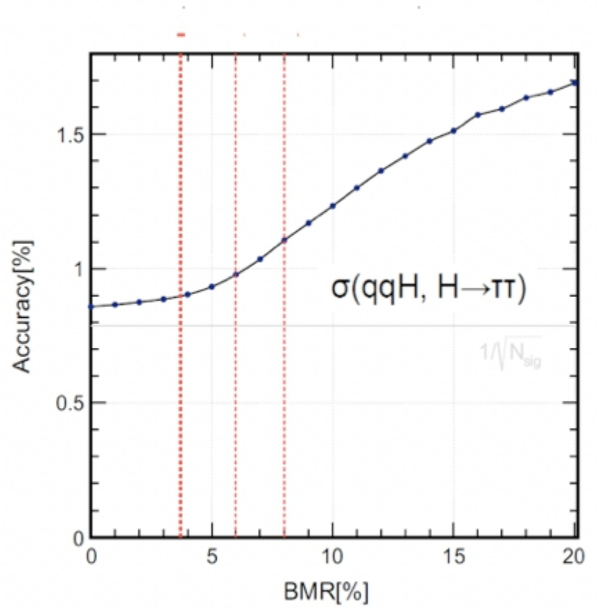


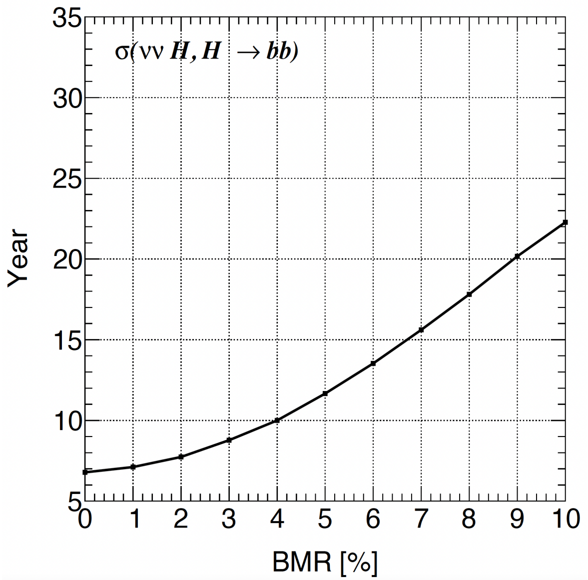


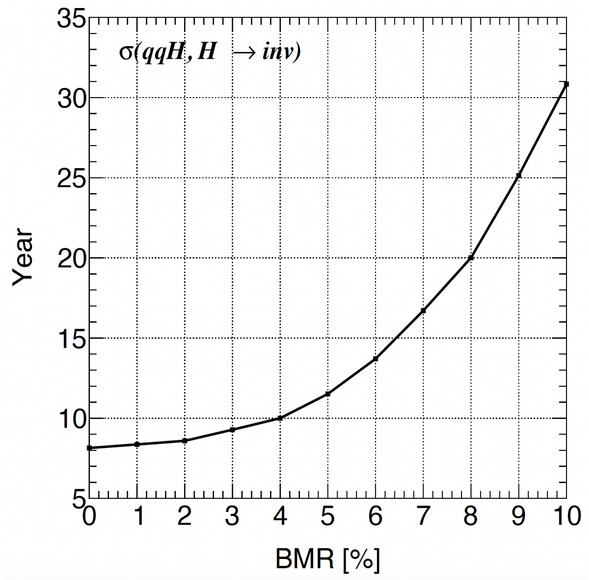
BMR: impact on critical measurements

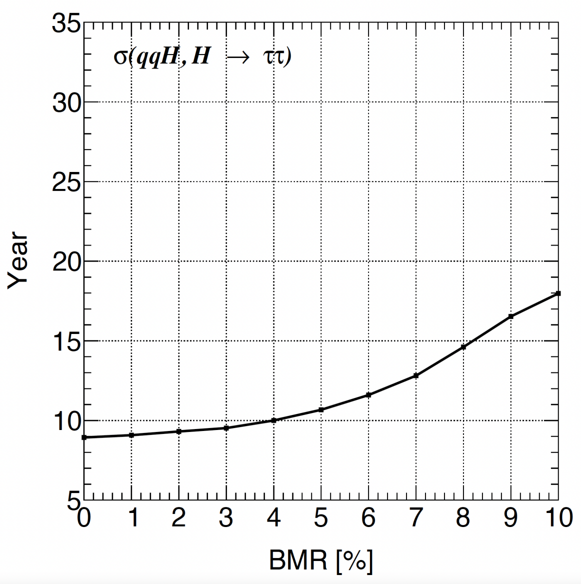




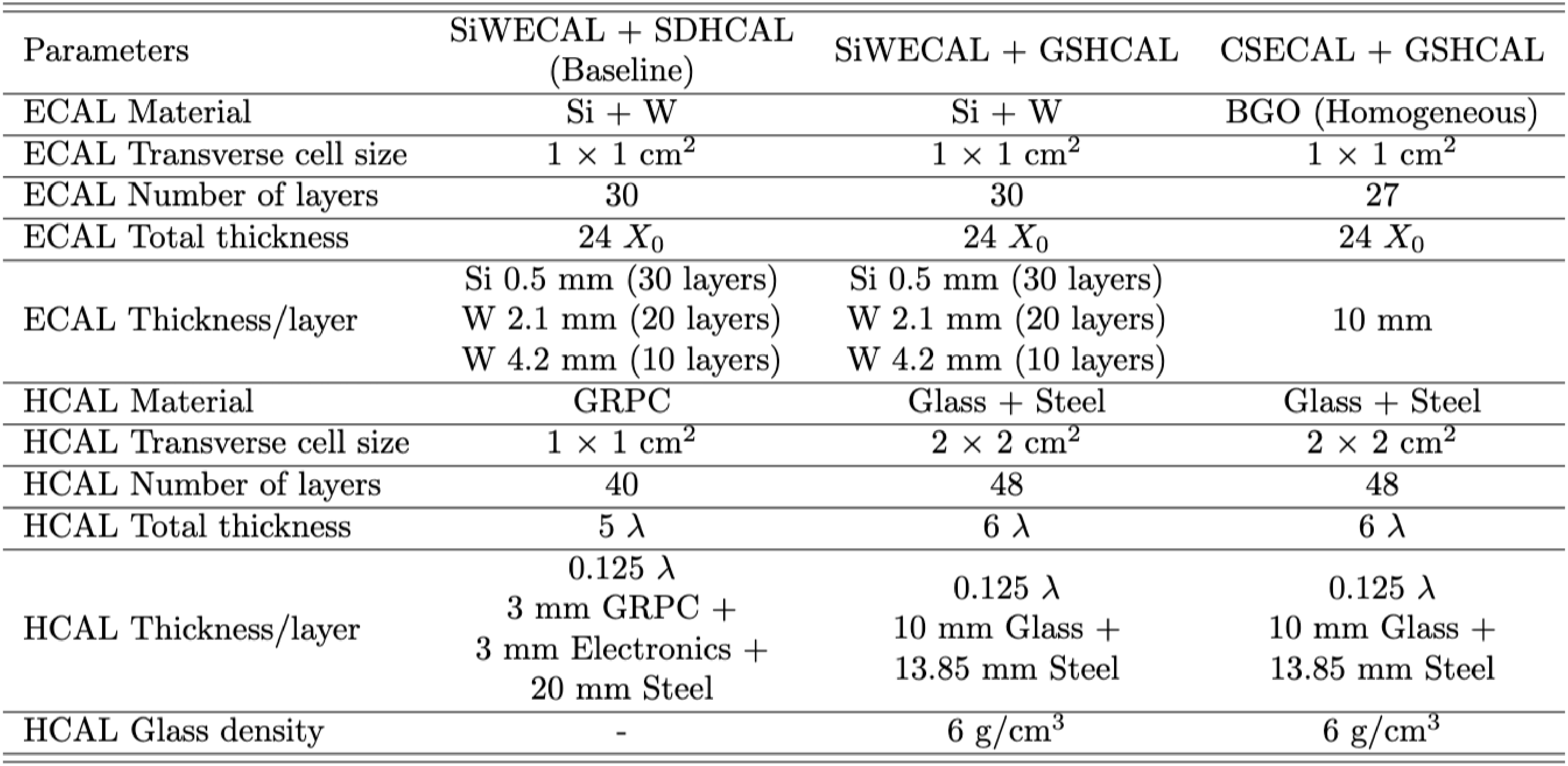






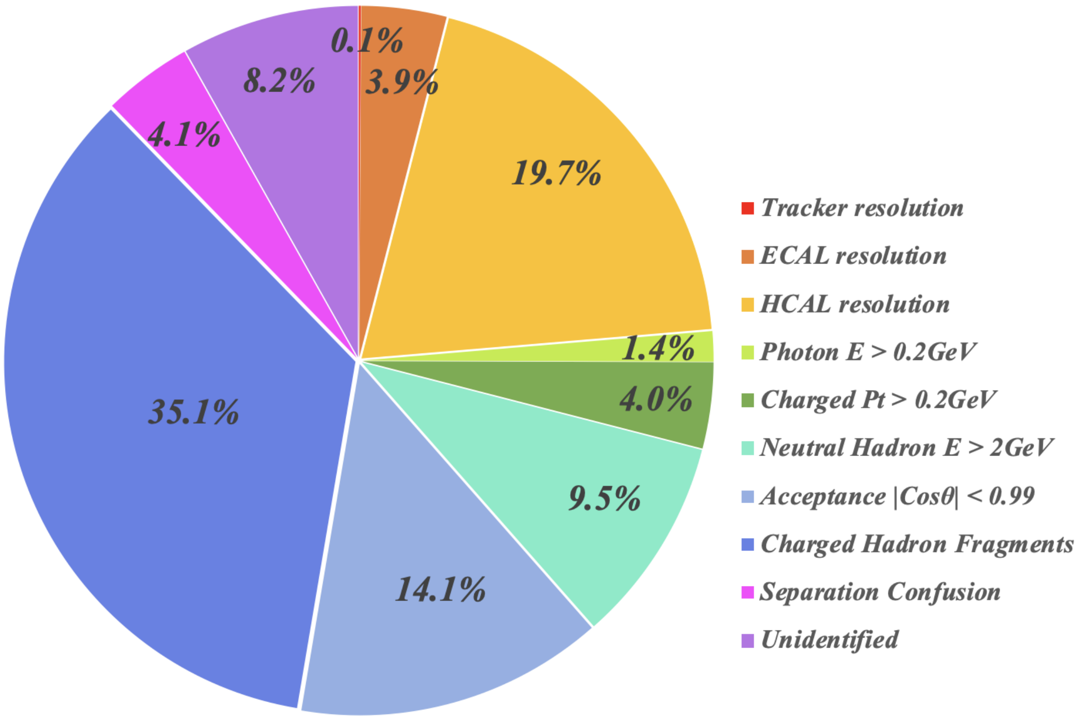


Three detector models



Parameters	SiWECAL + SDHCAL (Baseline)	SiWECAL + GSHCAL	CSECAL + GSHCAL
ECAL Material	Si + W	Si + W	BGO (Homogeneous)
ECAL Transverse cell size	1×1 cm^2	1×1 cm^2	1×1 cm^2
ECAL Number of layers	30	30	27
ECAL Total thickness	24 X_0	24 X_0	24 X_0
ECAL Thickness/layer	Si 0.5 mm (30 layers) W 2.1 mm (20 layers) W 4.2 mm (10 layers)	Si 0.5 mm (30 layers) W 2.1 mm (20 layers) W 4.2 mm (10 layers)	10 mm
HCAL Material	GRPC	Glass + Steel	Glass + Steel
HCAL Transverse cell size	1×1 cm^2	2×2 cm^2	2×2 cm^2
HCAL Number of layers	40	48	48
HCAL Total thickness	5 λ	6 λ	6 λ
HCAL Thickness/layer	0.125 λ 3 mm GRPC + 3 mm Electronics + 20 mm Steel	0.125 λ 10 mm Glass + 13.85 mm Steel	0.125 λ 10 mm Glass + 13.85 mm Steel
HCAL Glass density	-	6 g/cm^3	6 g/cm^3

BMR decomposition @ CDR baseline



- *1st, Ultimate Precision ~ 2.8 with CDR baseline3rd, HCAL*

- *2nd, HCAL resolution dominant the uncertainties from intrinsic detector resolution: need better HCAL*

- *3rd Leading contribution: Confusion from shower Fragments (fake particles), need better Pattern Reco.*

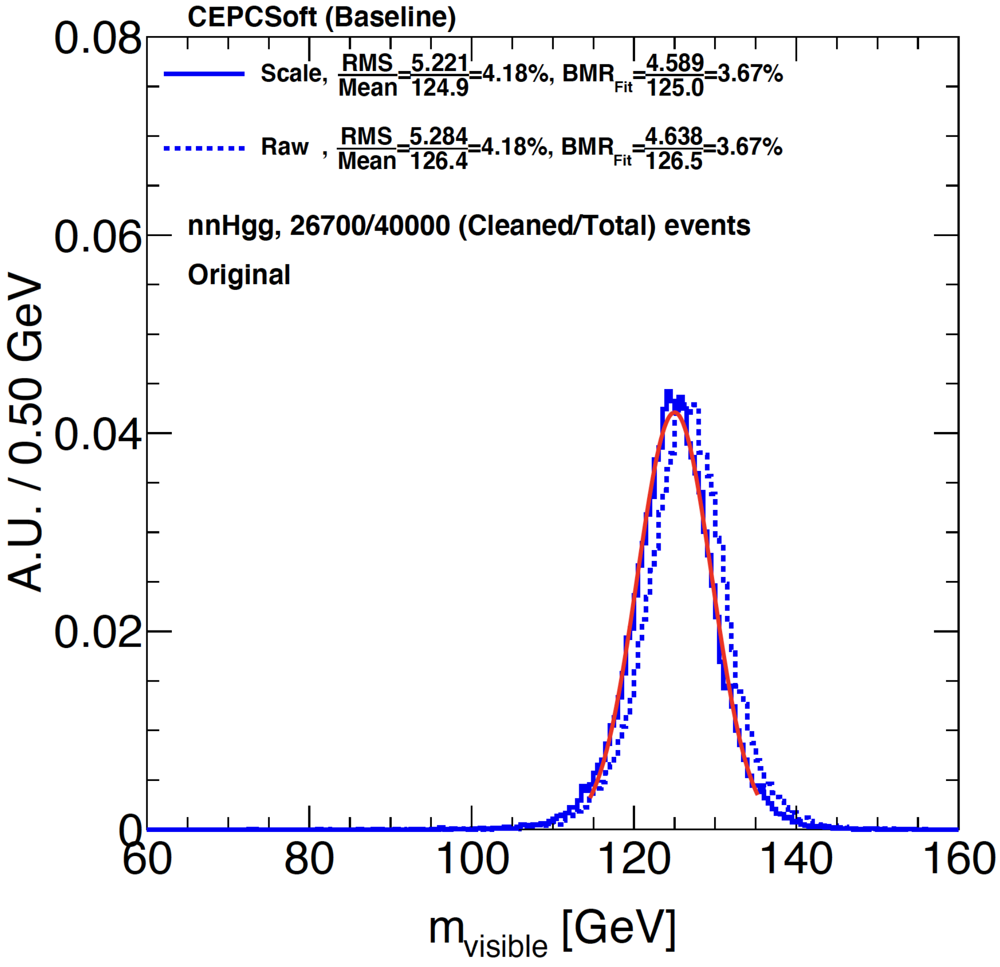
Improving HCAL:

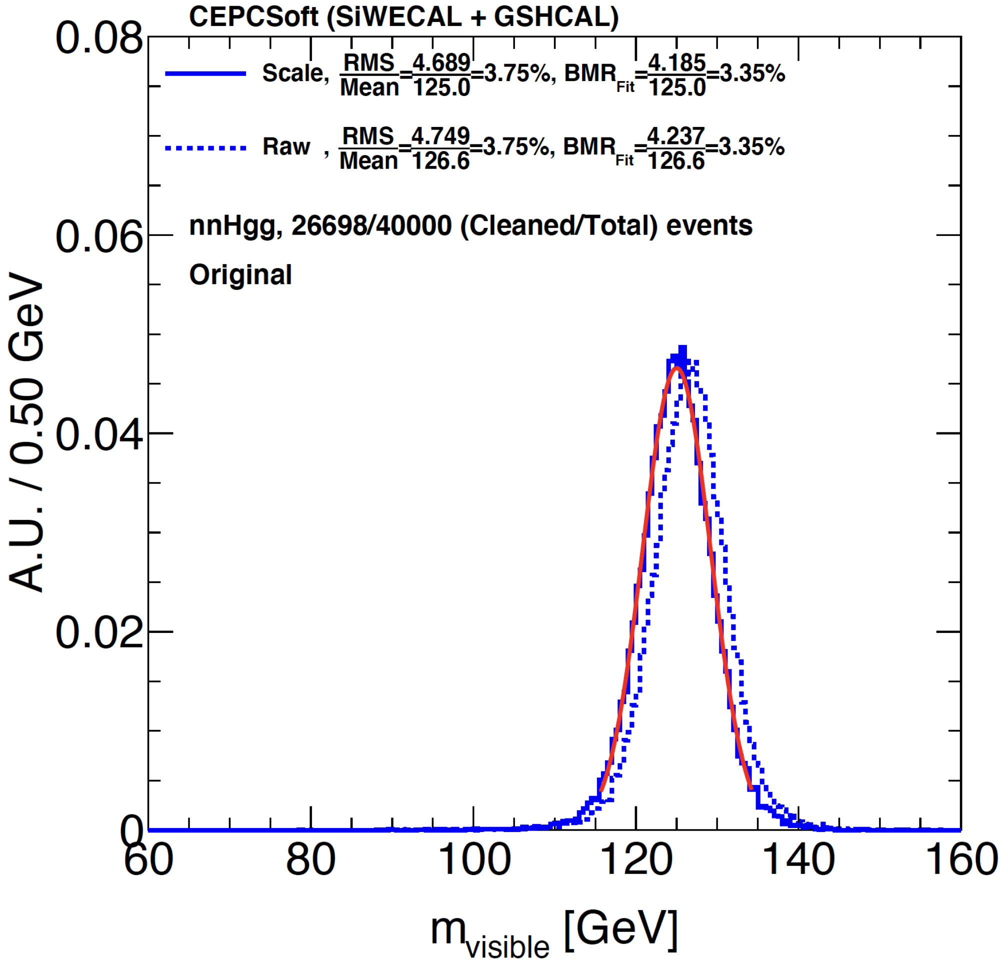
RPC Digital HCAL → GSHCAL

Remarks:

- *1st, what matters is not only intrinsic HCAL resolution... but hadron resolution at ECAL + HCAL: Dedicated development towards shower energy estimator is needed*
- *2nd, performance dependents on Energy threshold, timing cut, etc: digitization study need to be enhanced*

Baseline → M1: BMR 3.67% → 3.35%



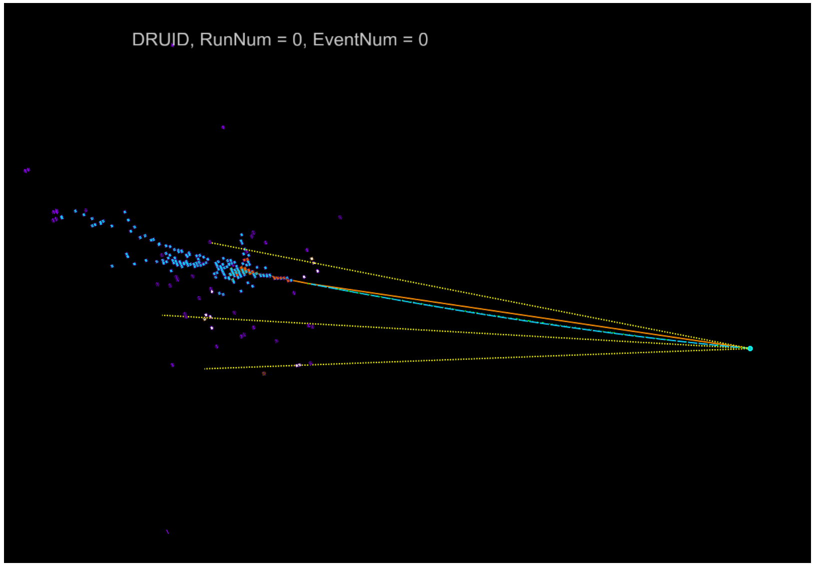


Reminder: Not only larger sampling (0.2)... but also thicker (0.1)!

Shower Fragment Veto

1, Touch base study using MC Truth

2, Realistic id using Transformer



Charged fragment veto at Truth level

Baseline (SiWECAL + SDHCAL)

0: BMR ~3.70%, original

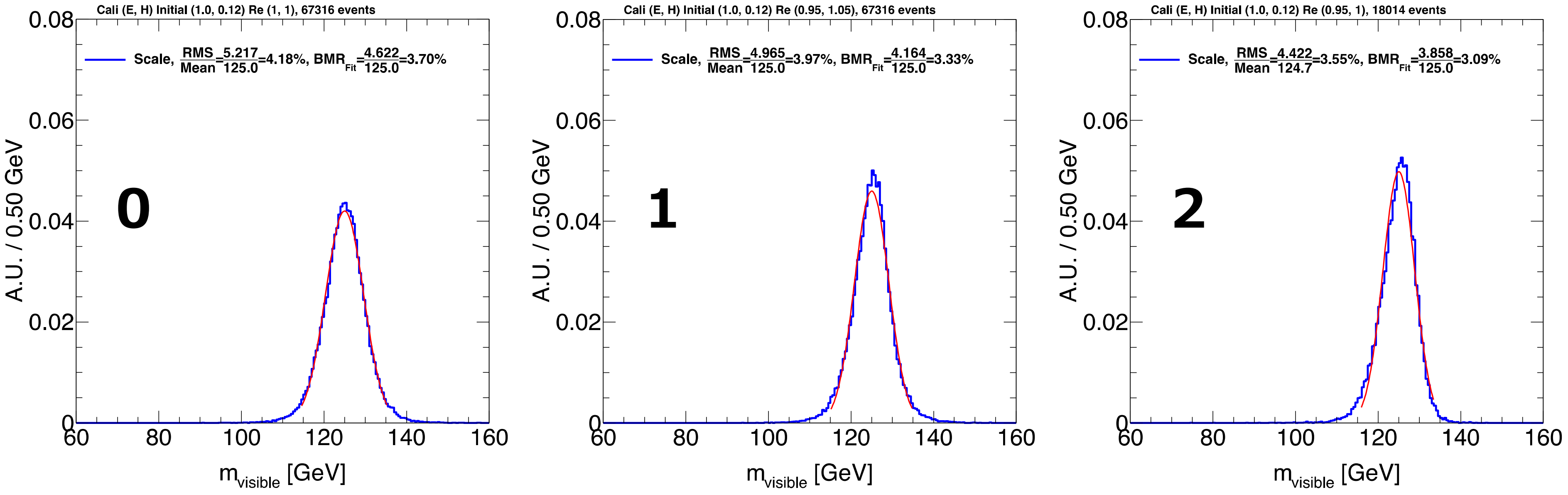
1: BMR ~3.33%, remove charged fragments

2: BMR ~3.09%, remove charged fragments + “Null MCP” event cut

PS: Two cases of “Null MCP” (fail to link to MCTruth Particle)

- PFO reconstructed by Energy Flow
- PFO caused by LumiCal Hits

Null MCP Cut eff ~ 25%



Charged fragment veto at Truth level

SiWECAL + GSHCAL (ideal parameter)

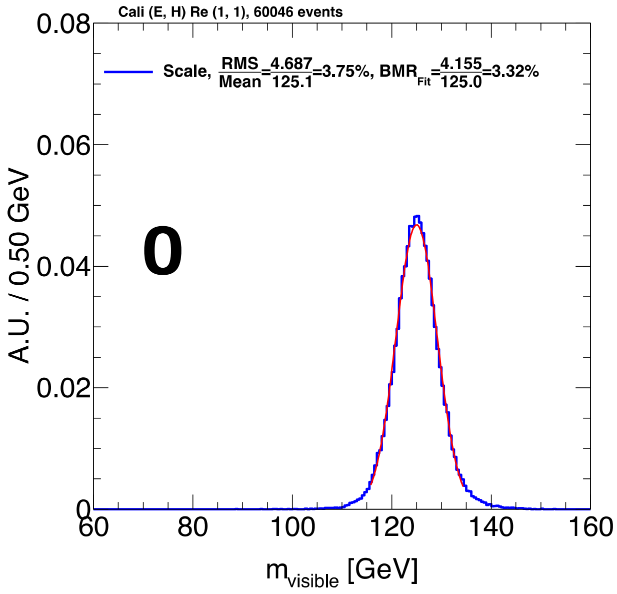
0: BMR ~3.32%, original

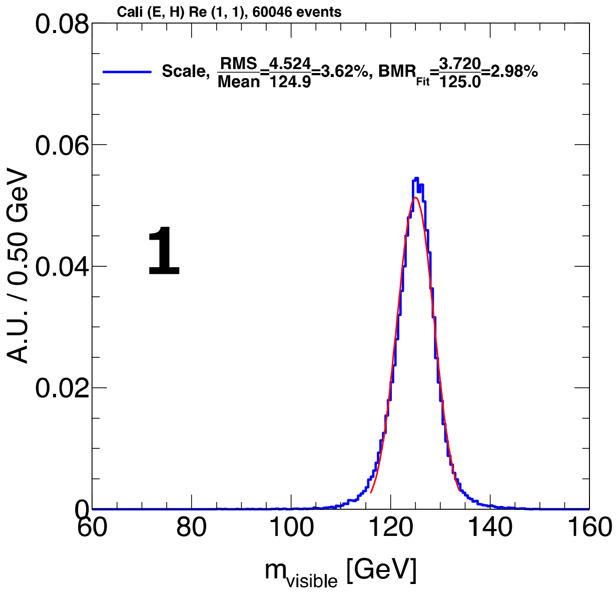
1: BMR ~2.98%, remove charged fragments

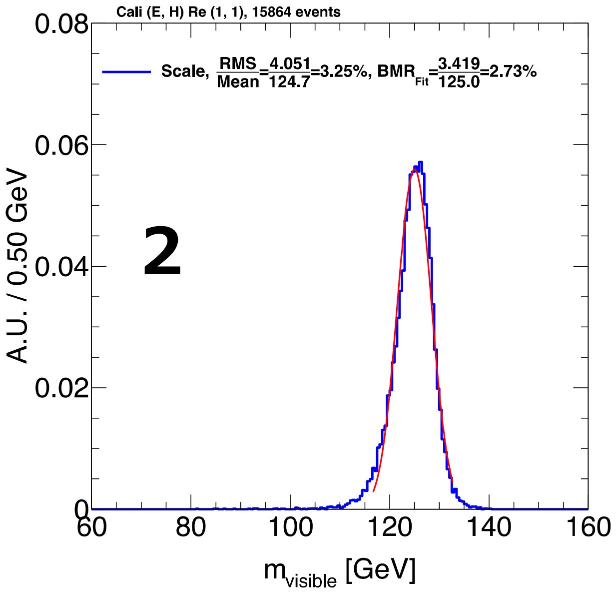
2: BMR ~2.73%, remove charged fragments + “Null MCP” event cut

PS: Two cases of “Null MCP” (fail to link to MCTruth Particle)

- PFO reconstructed by Energy Flow
- PFO caused by LumiCal Hits







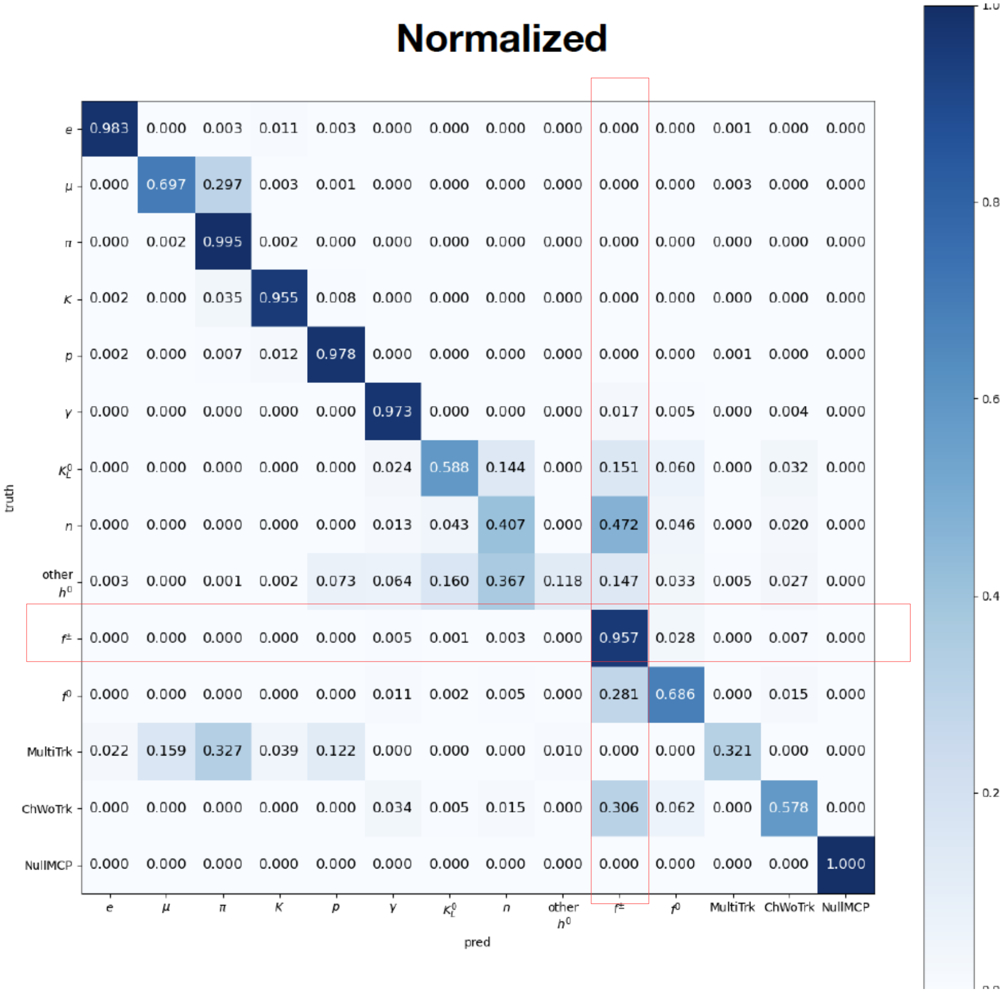
Realistic Fragment Veto:

AI Assistant Arbor Algorithm

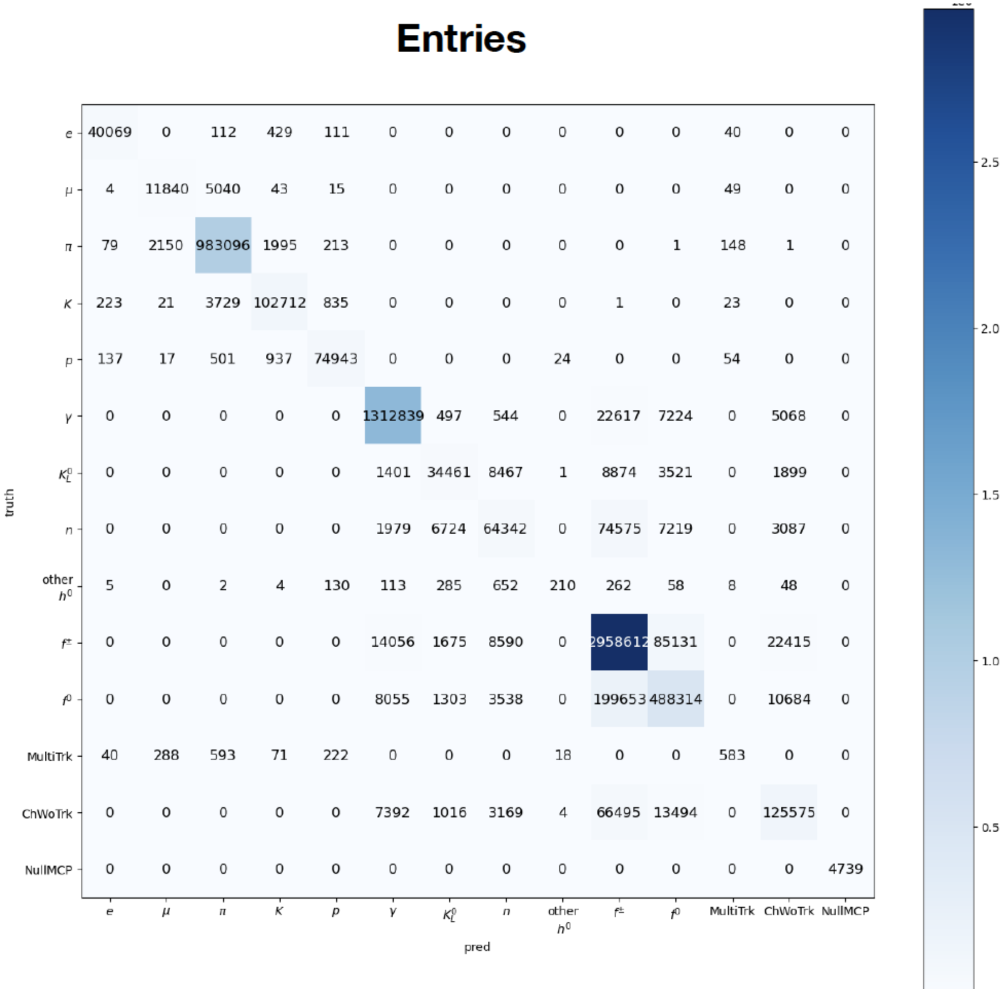
Cluster

Full species PID using ParticleTransformer

Inclusive

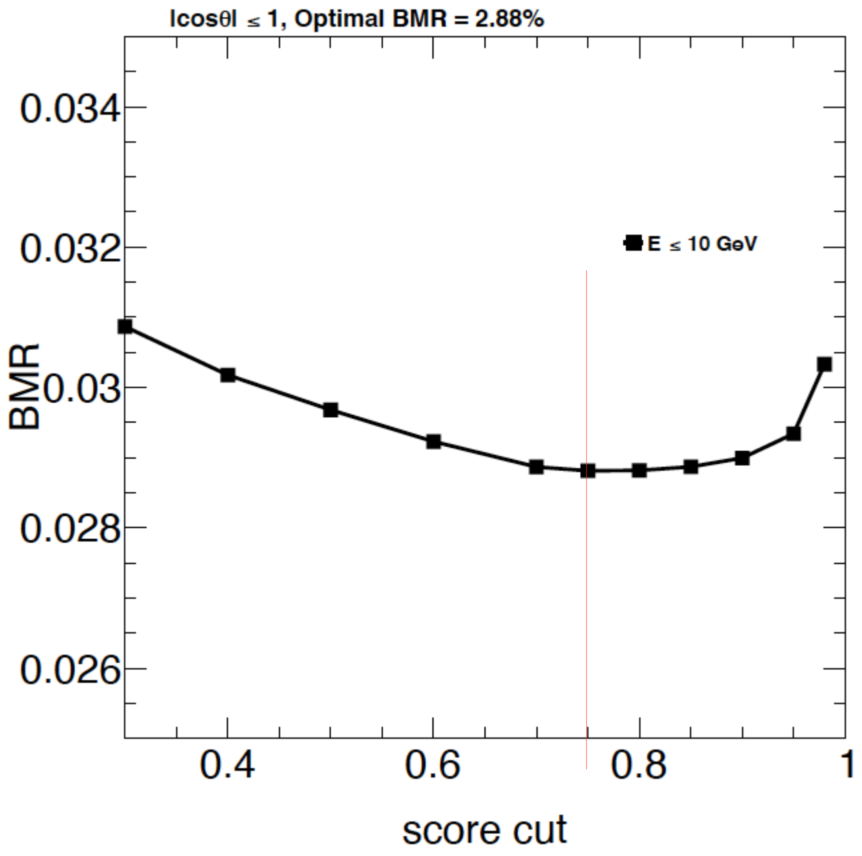


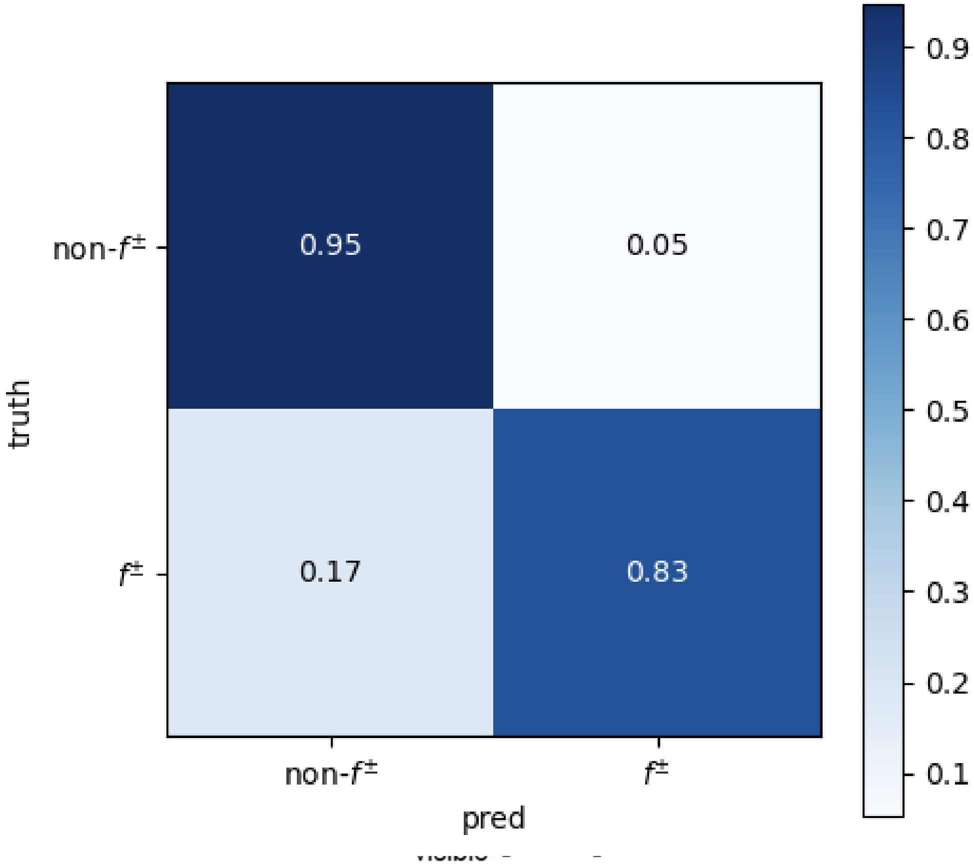
	e	μ	π	K	p	γ	K_L^0	n	other h^0	$f^\pm$	f^0	MultiTrk	ChWoTrk	NullMCP
e	0.983	0.000	0.003	0.011	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000
μ	0.000	0.697	0.297	0.003	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000
π	0.000	0.002	0.995	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
K	0.002	0.000	0.035	0.955	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
p	0.002	0.000	0.007	0.012	0.978	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000
γ	0.000	0.000	0.000	0.000	0.000	0.973	0.000	0.000	0.000	0.017	0.005	0.000	0.004	0.000
K_L^0	0.000	0.000	0.000	0.000	0.000	0.024	0.588	0.144	0.000	0.151	0.060	0.000	0.032	0.000
n	0.000	0.000	0.000	0.000	0.000	0.013	0.043	0.407	0.000	0.472	0.046	0.000	0.020	0.000
other h^0	0.003	0.000	0.001	0.002	0.073	0.064	0.160	0.367	0.118	0.147	0.033	0.005	0.027	0.000
$f^\pm$	0.000	0.000	0.000	0.000	0.000	0.005	0.001	0.003	0.000	0.957	0.028	0.000	0.007	0.000
f^0	0.000	0.000	0.000	0.000	0.000	0.011	0.002	0.005	0.000	0.281	0.686	0.000	0.015	0.000
MultiTrk	0.022	0.159	0.327	0.039	0.122	0.000	0.000	0.000	0.010	0.000	0.000	0.321	0.000	0.000
ChWoTrk	0.000	0.000	0.000	0.000	0.000	0.034	0.005	0.015	0.000	0.306	0.062	0.000	0.578	0.000
NullMCP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000



	e	μ	π	K	p	γ	K_L^0	n	other h^0	$f^\pm$	f^0	MultiTrk	ChWoTrk	NullMCP
e	40069	0	112	429	111	0	0	0	0	0	0	40	0	0
μ	4	11840	5040	43	15	0	0	0	0	0	0	49	0	0
π	79	2150	983096	1995	213	0	0	0	0	0	1	148	1	0
K	223	21	3729	102712	835	0	0	0	0	1	0	23	0	0
p	137	17	501	937	74943	0	0	0	24	0	0	54	0	0
γ	0	0	0	0	0	1312839	497	544	0	22617	7224	0	5068	0
K_L^0	0	0	0	0	0	1401	34461	8467	1	8874	3521	0	1899	0
n	0	0	0	0	0	1979	6724	64342	0	74575	7219	0	3087	0
other h^0	5	0	2	4	130	113	285	652	210	262	58	8	48	0
$f^\pm$	0	0	0	0	0	14056	1675	8590	0	2958612	85131	0	22415	0
f^0	0	0	0	0	0	8055	1303	3538	0	199653	488314	0	10684	0
MultiTrk	40	288	593	71	222	0	0	0	18	0	0	583	0	0
ChWoTrk	0	0	0	0	0	7392	1016	3169	4	66495	13494	0	125575	0
NullMCP	0	0	0	0	0	0	0	0	0	0	0	0	0	4739

Preliminary: Identify & veto charged shower fragments using AI





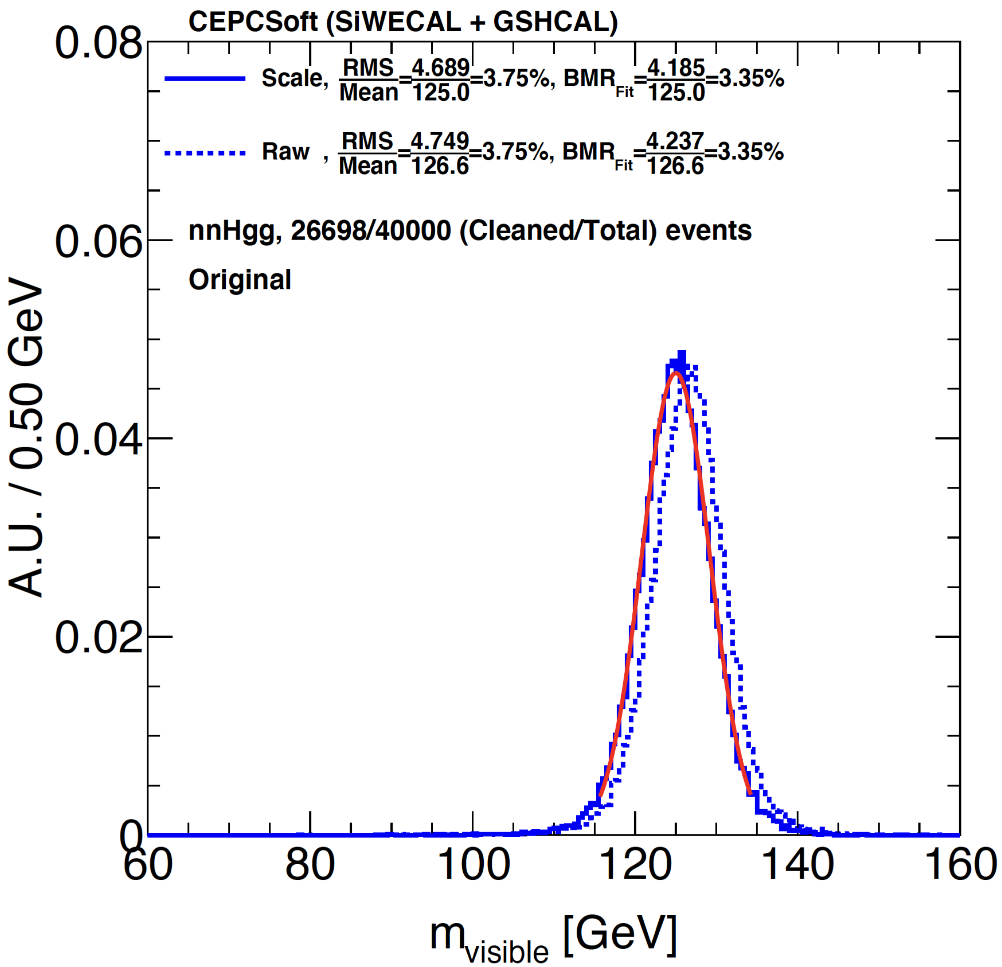
	non-$f^\pm$	$f^\pm$
non-$f^\pm$	0.95	0.05
$f^\pm$	0.17	0.83

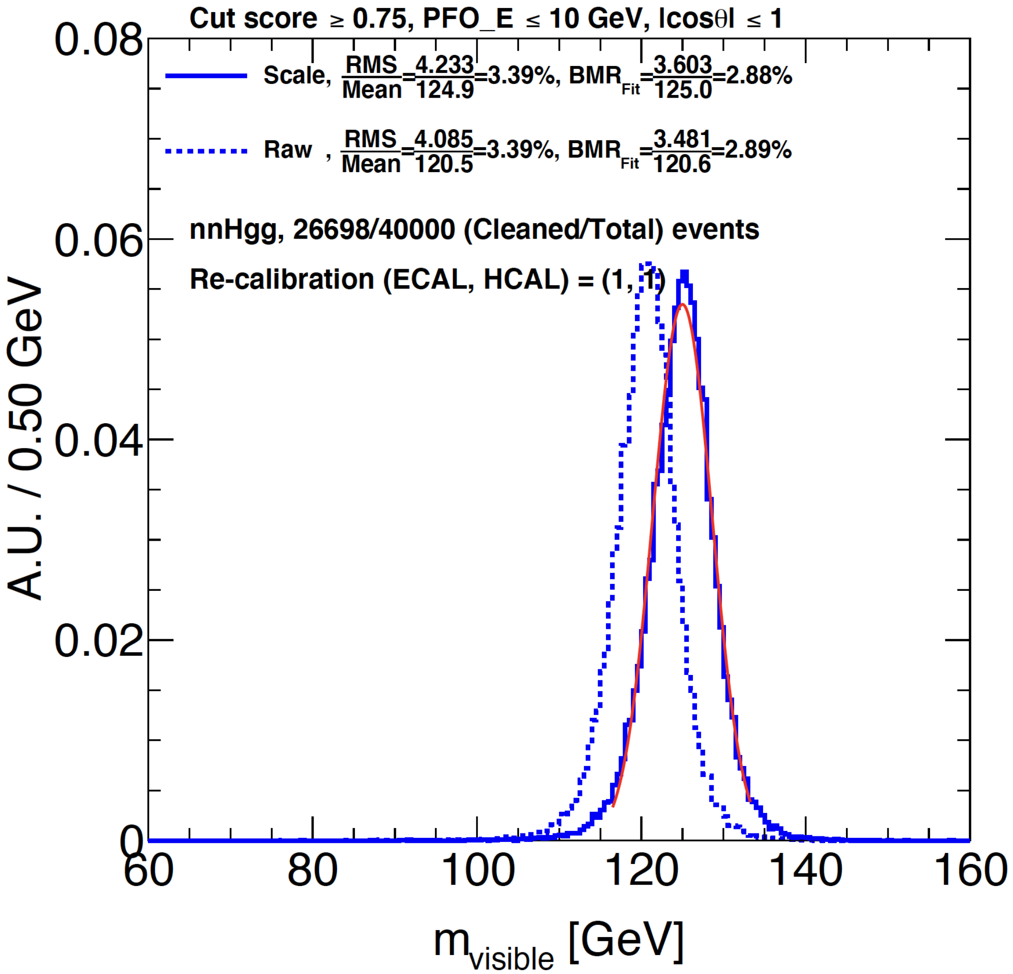
Trained at 12E4 events,

Test & Applied at 4E4 events

score > 0.75
efficiency ~83%
purity ~95%

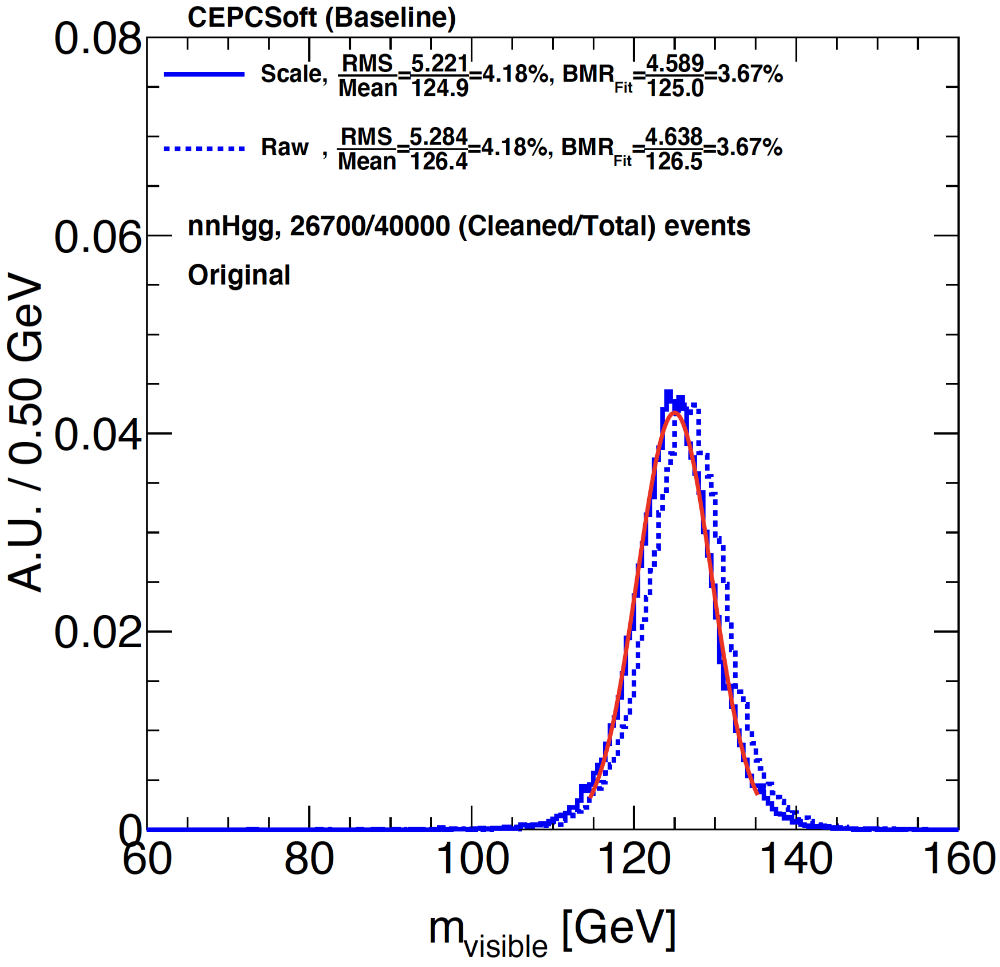
M1(SiW + GS): BMR 3.35 → 2.89%

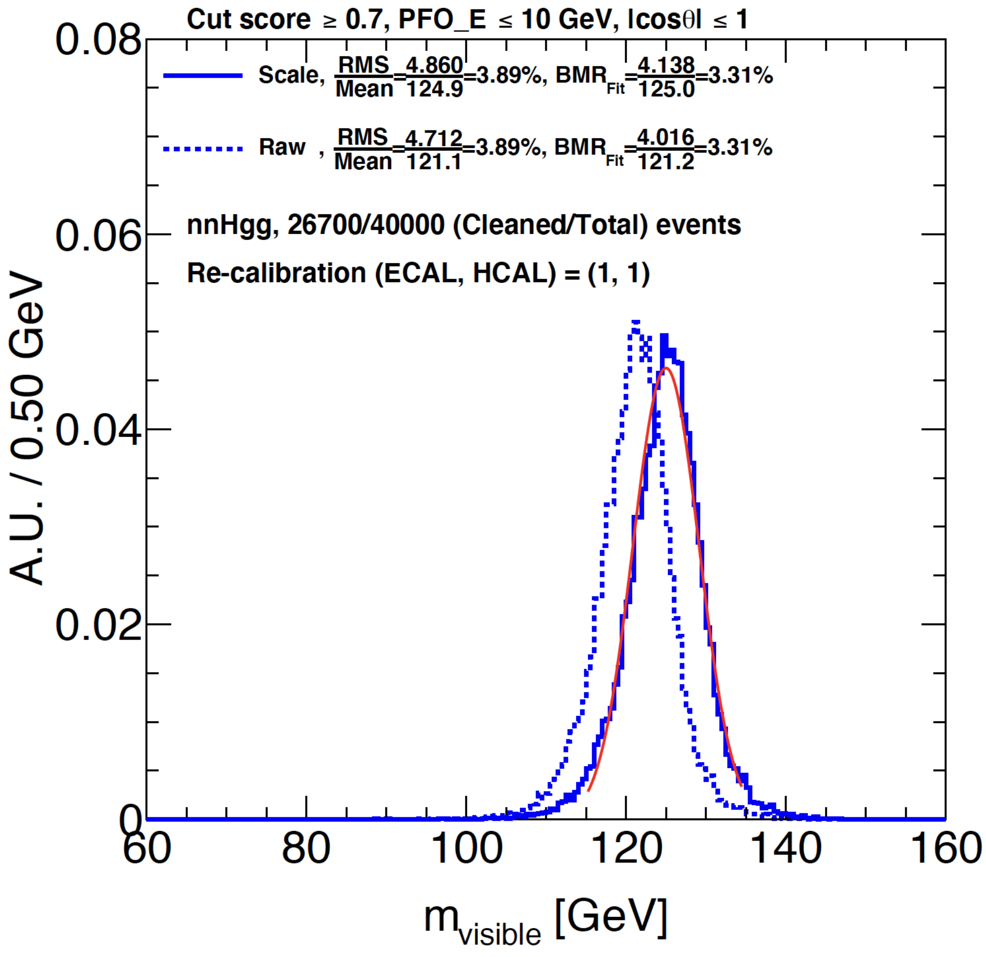




Truth level veto prediction: 3.32 -> 2.98%

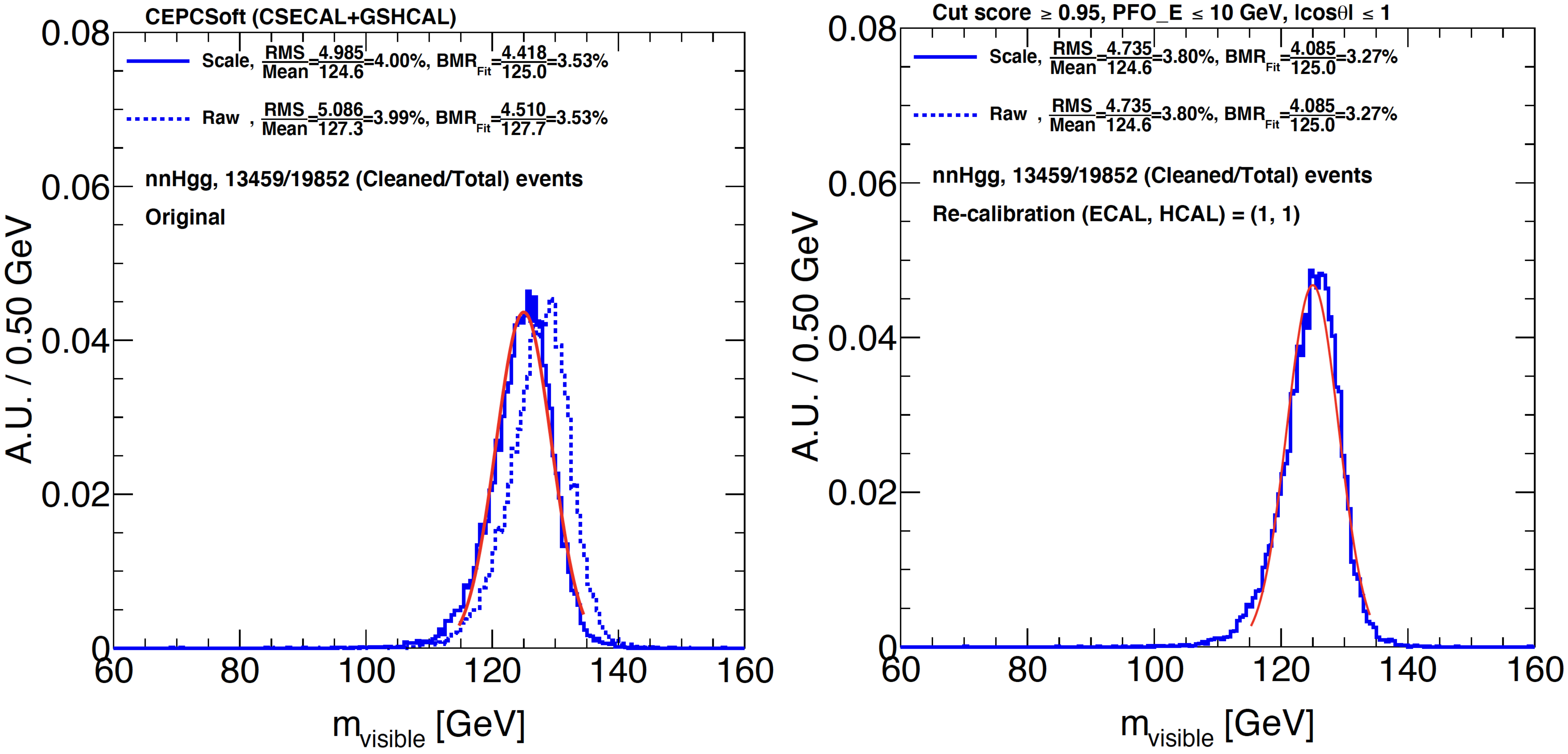
CDR baseline (SiW + RPC): BMR 3.67 → 3.31%



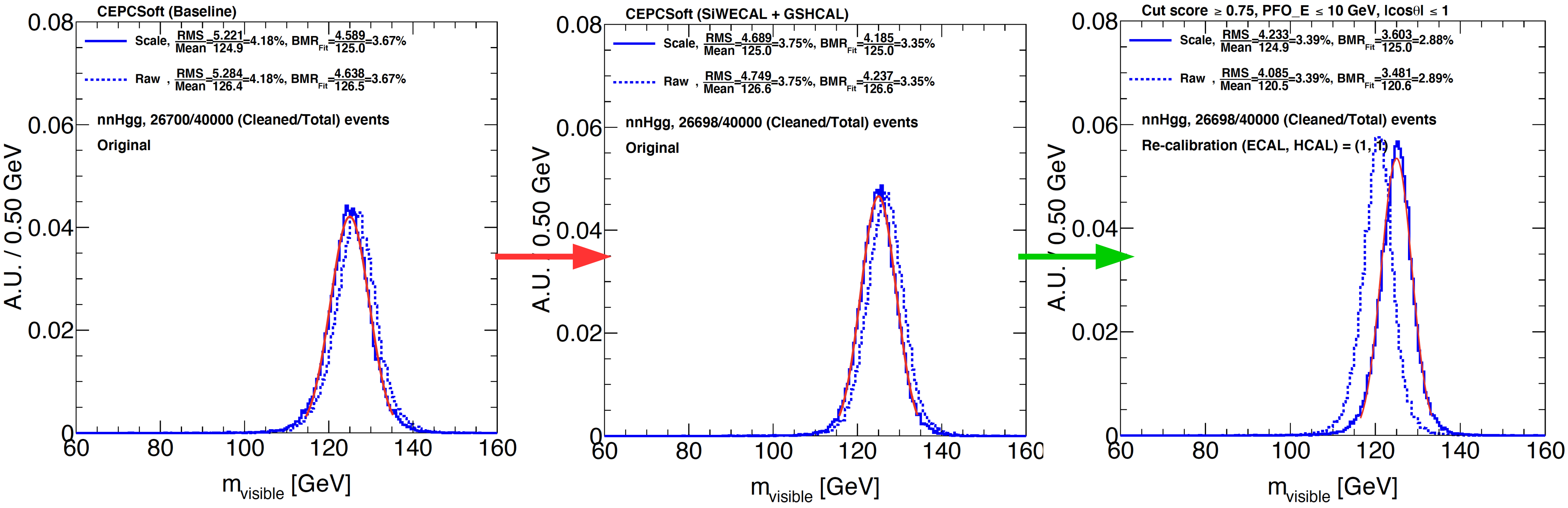


Truth level veto prediction: 3.70 -> 3.33%

M2(Xstal + GS): BMR 3.53 → 3.27%



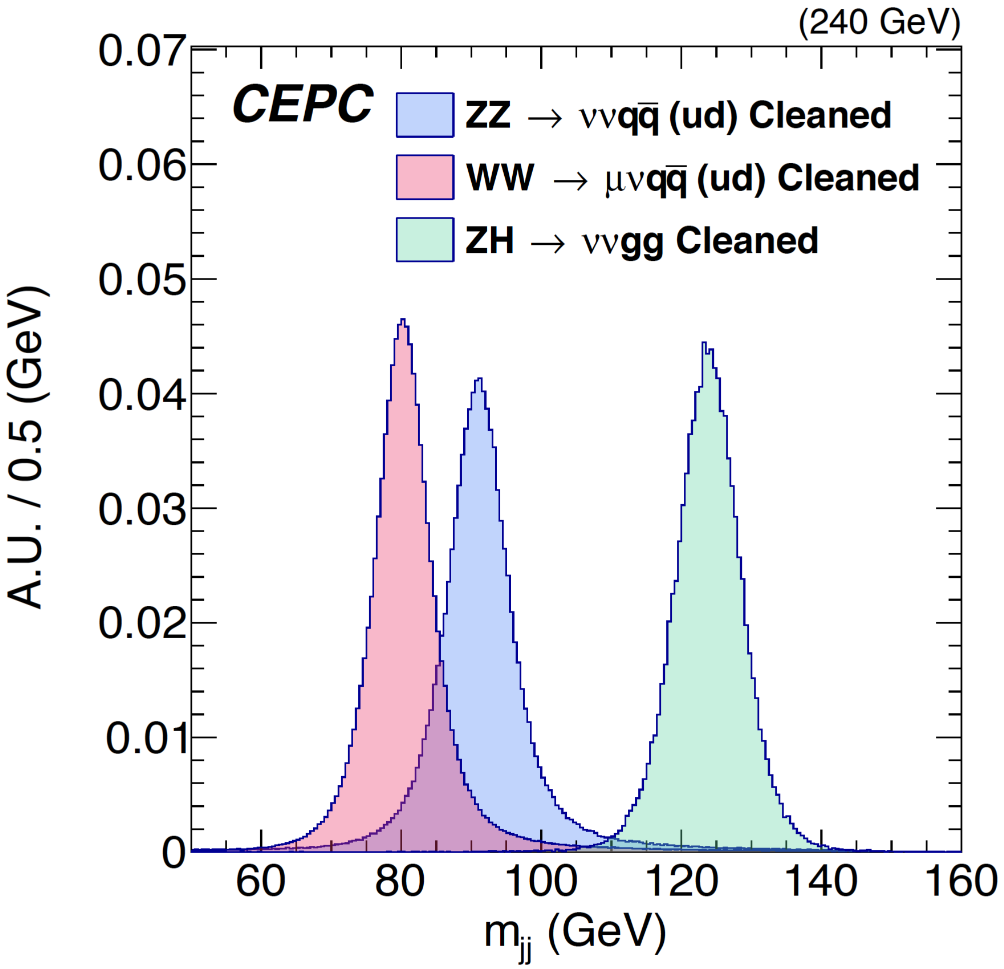
BMR Comparison

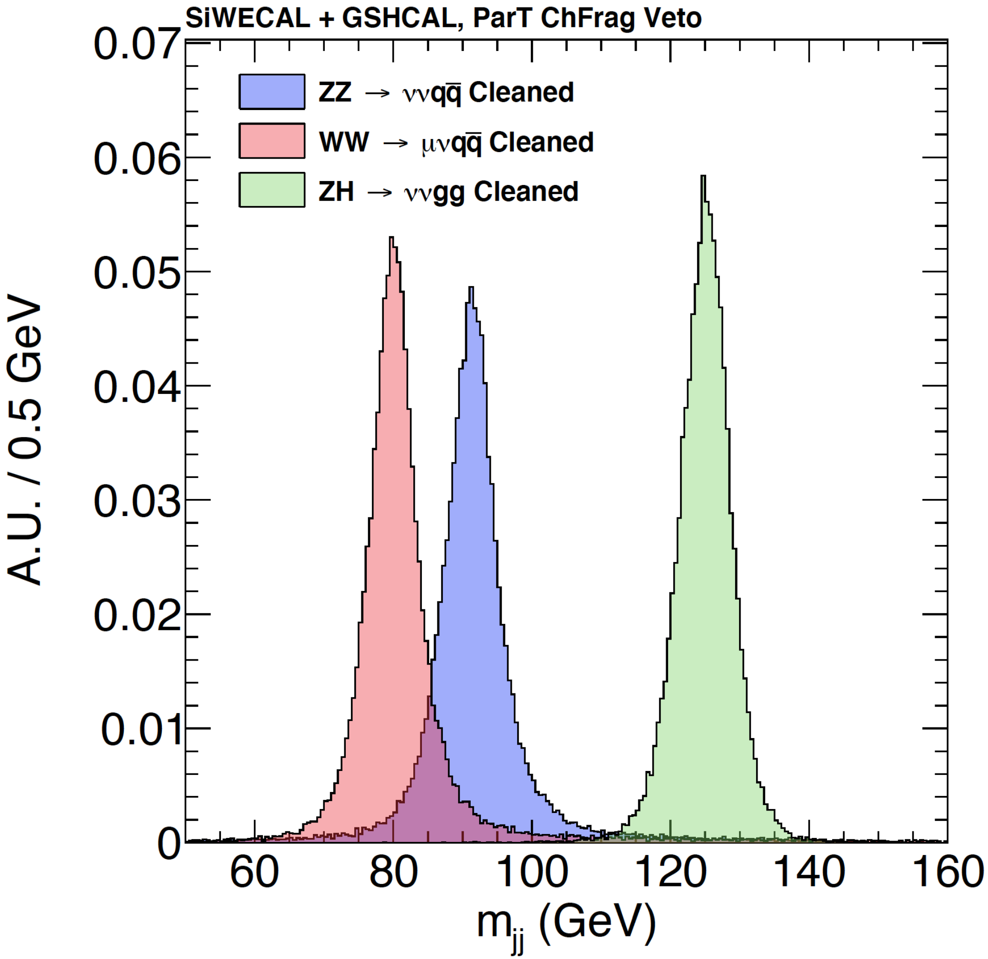


Detector	Arbor	A4: AI Assistant Arbor	Improvement
SiW ECAL + RPC DHCAL	3.67	3.31	0.4
SiW ECAL + GSHCAL	3.35	2.88	0.5
Xstal ECAL + GSHCAL	3.53	3.27	0.3

@ Xstal ECAL: ...to be optimized...

... At Bosons ...


(240 GeV)
CEPC
ZZ → ννqq̄ (ud) Cleaned
WW → μνqq̄ (ud) Cleaned
ZH → ννgg Cleaned
A.U. / 0.5 (GeV)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
60
80
100
120
140
160
m_jj (GeV)


SiWECAL + GSHCAL, ParT ChFrag Veto
ZZ → ννqq̄ Cleaned
WW → μνqq̄ Cleaned
ZH → ννgg Cleaned
A.U. / 0.5 GeV
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
60
80
100
120
140
160
m_jj (GeV)

Summary

- BMR of 2.9% reached
  - Using A4 (AI Assistant Arbor Algorithm) + SiW ECAL + GS HCAL
  - Compared to 4% BMR, BMR ~ 3% saves ~ 10% luminosity for key physics benchmarks

- A4 significantly eliminates the shower fragment confusions: Transformer provides unprecedented identification capability (same methodology as Jet Origin ID)
  - SiW ECAL + GS HCAL: BMR ~ 2.5% @ no confusion limit
  - Similar improvements observed at other geometry

- Towards Toolkits of One To One correspondence RecOnstruction: TOTORO

To do

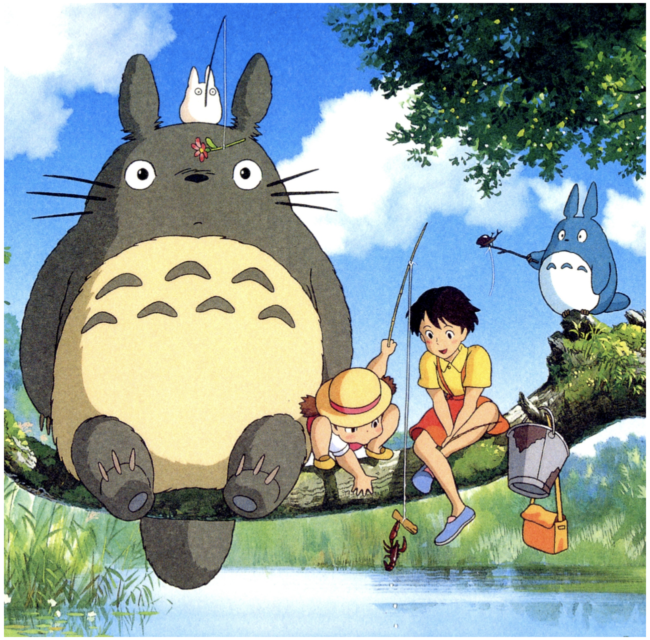
- To better understand the performance & dependence... especially to investigation further into usage of Hit Time info

- To improve the neutral hadron reco.

- Energy estimator development

- Digitization development & Validation

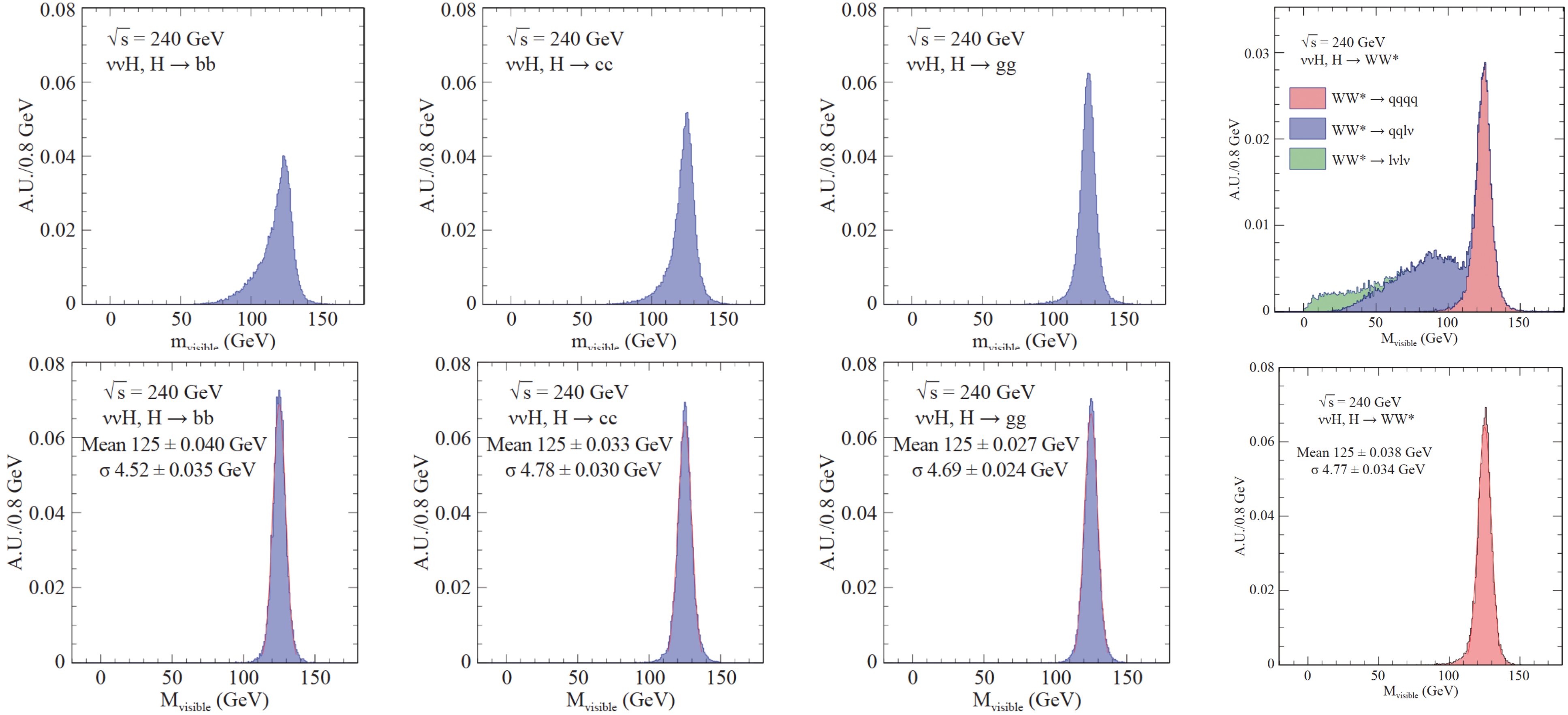
- Geometry Optimization



- Simu. realistic beam background & DAQ scenario - event time interval... or recon. In Space Time

Back up

BMR: no significant dependence on #jets...



Fi

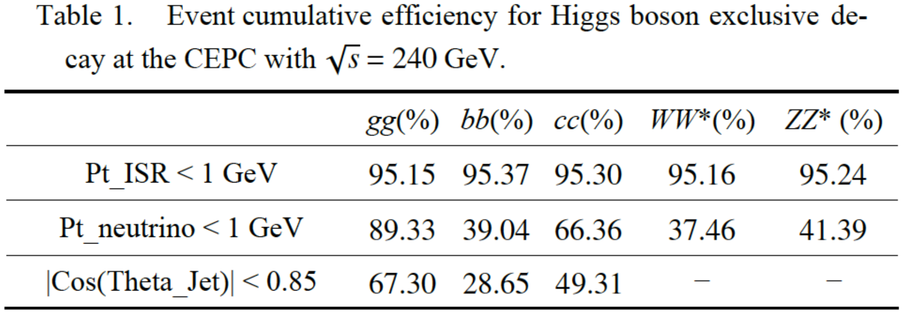


Table 1. Event cumulative efficiency for Higgs boson exclusive decay at the CEPC with $\sqrt{s} = 240$ GeV.

	gg(%)	*bb*(%)	*cc*(%)	*WW**(%)	*ZZ** (%)
Pt_ISR < 1 GeV	95.15	95.37	95.30	95.16	95.24
Pt_neutrino < 1 GeV	89.33	39.04	66.36	37.46	41.39
|Cos(Theta_Jet)| < 0.85	67.30	28.65	49.31	–	–

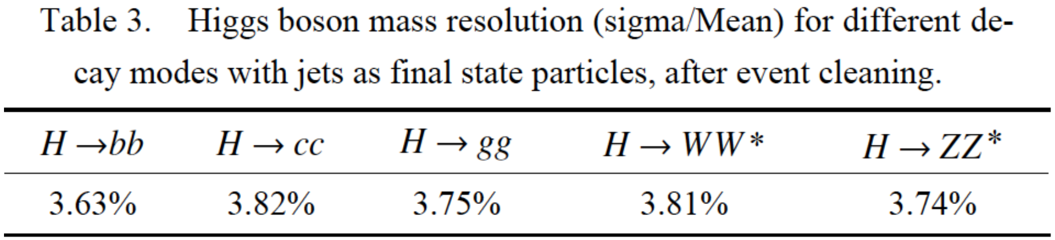


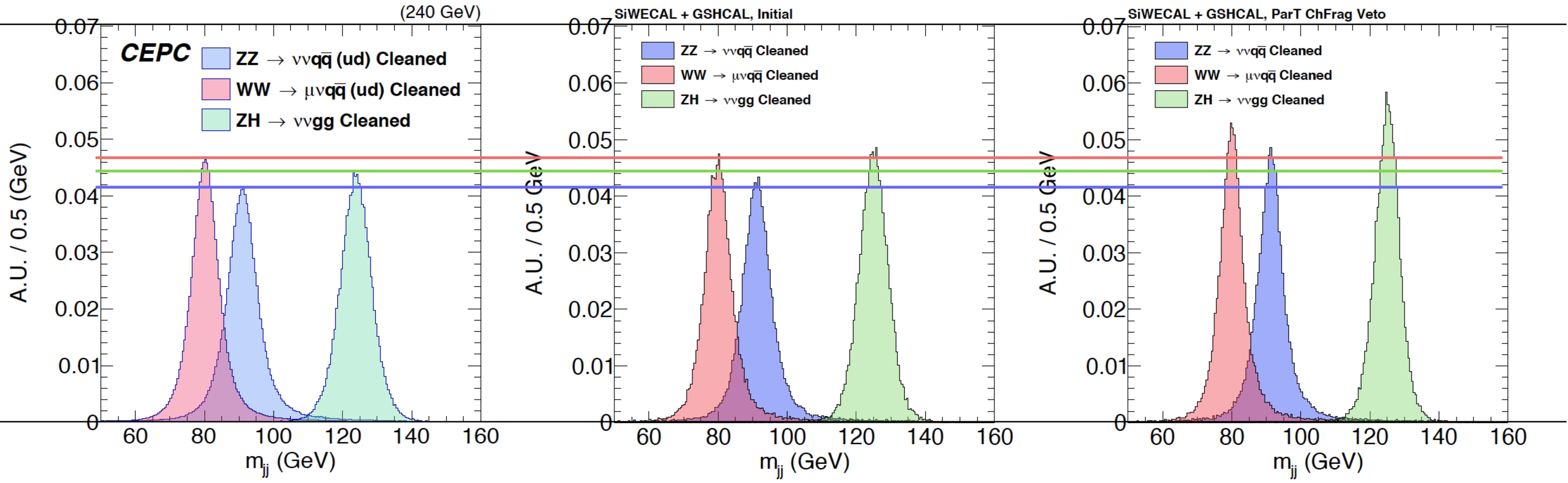
Table 3. Higgs boson mass resolution (sigma/Mean) for different decay modes with jets as final state particles, after event cleaning.

$H \to bb$	$H \to cc$	$H \to gg$	$H \to WW^*$	$H \to ZZ^*$
3.63%	3.82%	3.75%	3.81%	3.74%

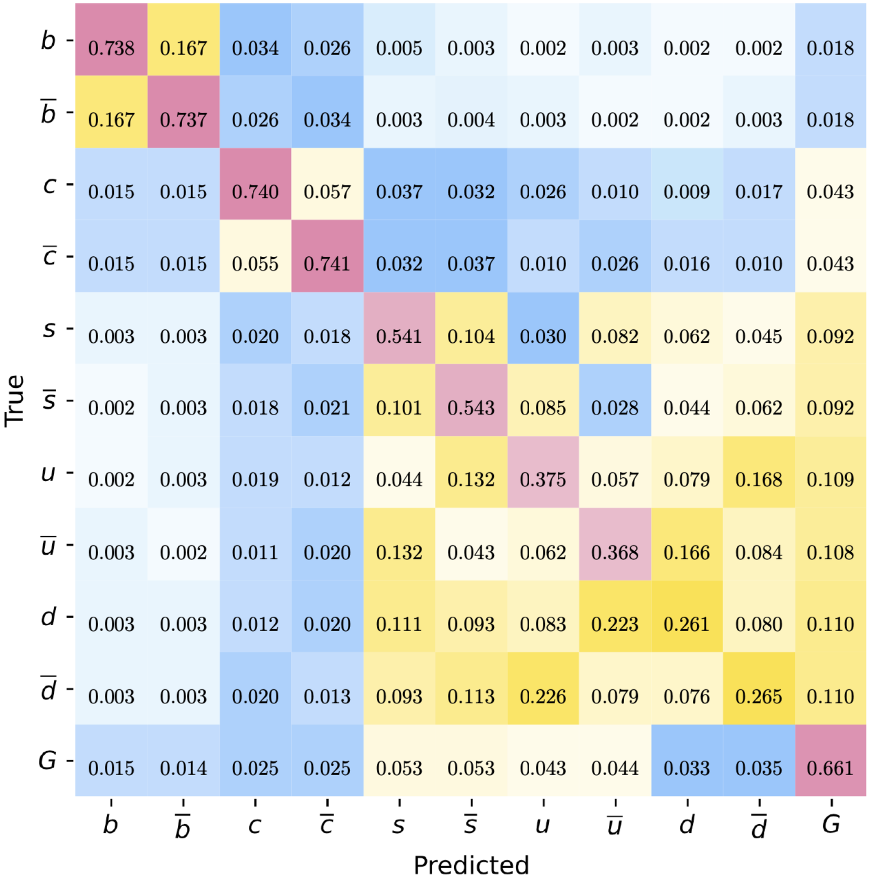
WHZ

Baseline

SiWECAL + GSHCAL

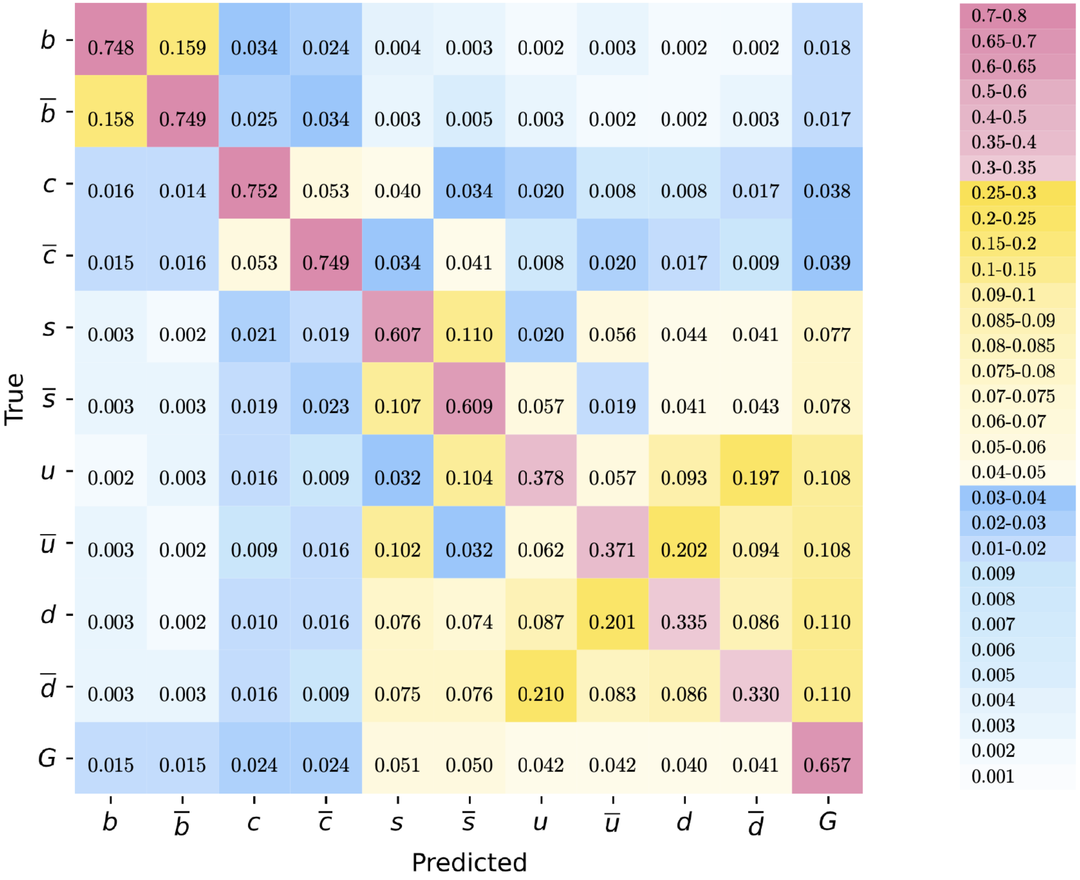


M11 2 with charged hadron



	b	$\bar{b}$	c	$\bar{c}$	s	$\bar{s}$	u	$\bar{u}$	d	$\bar{d}$	G
b	0.738	0.167	0.034	0.026	0.005	0.003	0.002	0.003	0.002	0.002	0.018
$\bar{b}$	0.167	0.737	0.026	0.034	0.003	0.004	0.003	0.002	0.002	0.003	0.018
c	0.015	0.015	0.740	0.057	0.037	0.032	0.026	0.010	0.009	0.017	0.043
$\bar{c}$	0.015	0.015	0.055	0.741	0.032	0.037	0.010	0.026	0.016	0.010	0.043
s	0.003	0.003	0.020	0.018	0.541	0.104	0.030	0.082	0.062	0.045	0.092
$\bar{s}$	0.002	0.003	0.018	0.021	0.101	0.543	0.085	0.028	0.044	0.062	0.092
u	0.002	0.003	0.019	0.012	0.044	0.132	0.375	0.057	0.079	0.168	0.109
$\bar{u}$	0.003	0.002	0.011	0.020	0.132	0.043	0.062	0.368	0.166	0.084	0.108
d	0.003	0.003	0.012	0.020	0.111	0.093	0.083	0.223	0.261	0.080	0.110
$\bar{d}$	0.003	0.003	0.020	0.013	0.093	0.113	0.226	0.079	0.076	0.265	0.110
G	0.015	0.014	0.025	0.025	0.053	0.053	0.043	0.044	0.033	0.035	0.661

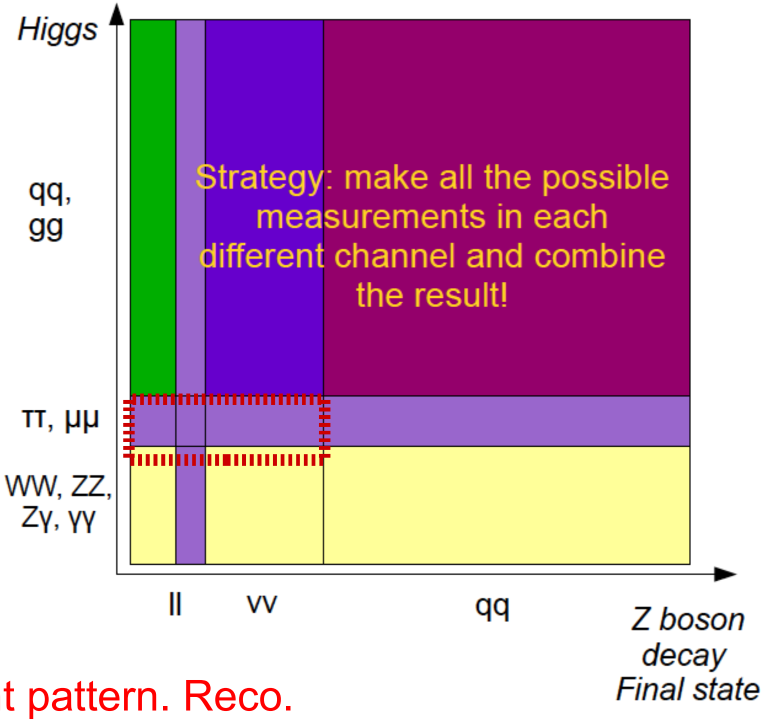
M11 3 with charged hadron and K_L K_S



	b	$\bar{b}$	c	$\bar{c}$	s	$\bar{s}$	u	$\bar{u}$	d	$\bar{d}$	G
b	0.748	0.159	0.034	0.024	0.004	0.003	0.002	0.003	0.002	0.002	0.018
$\bar{b}$	0.158	0.749	0.025	0.034	0.003	0.005	0.003	0.002	0.002	0.003	0.017
c	0.016	0.014	0.752	0.053	0.040	0.034	0.020	0.008	0.008	0.017	0.038
$\bar{c}$	0.015	0.016	0.053	0.749	0.034	0.041	0.008	0.020	0.017	0.009	0.039
s	0.003	0.002	0.021	0.019	0.607	0.110	0.020	0.056	0.044	0.041	0.077
$\bar{s}$	0.003	0.003	0.019	0.023	0.107	0.609	0.057	0.019	0.041	0.043	0.078
u	0.002	0.003	0.016	0.009	0.032	0.104	0.378	0.057	0.093	0.197	0.108
$\bar{u}$	0.003	0.002	0.009	0.016	0.102	0.032	0.062	0.371	0.202	0.094	0.108
d	0.003	0.002	0.010	0.016	0.076	0.074	0.087	0.201	0.335	0.086	0.110
$\bar{d}$	0.003	0.003	0.016	0.009	0.075	0.076	0.210	0.083	0.086	0.330	0.110
G	0.015	0.015	0.024	0.024	0.051	0.050	0.042	0.042	0.040	0.041	0.657

Introduction

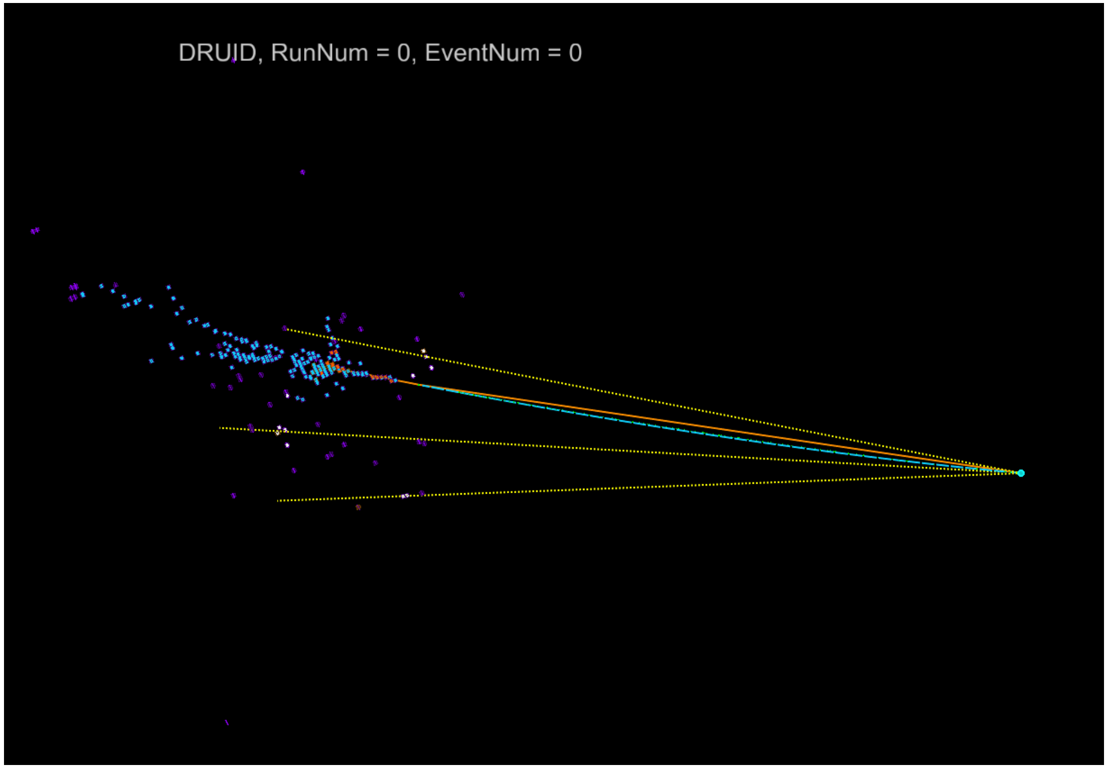
- Massive Four in Standard Model:
  - Z & W: ~ 70% goes to a pair of jets
  - Higgs: ~90% goes to jet final states (ZH events)
  - Top: t → W + B
- To reconstruct all kinds of Physics Object
  - Identification & Measurements
  - Objects:
    - Lepton, Photons, Kaon,
    - pi-0, Tau, Lambda, Kshort,
    - Heavy flavor hadrons,
    - Jets
    - Missing energy/momentum
    - Exotics...

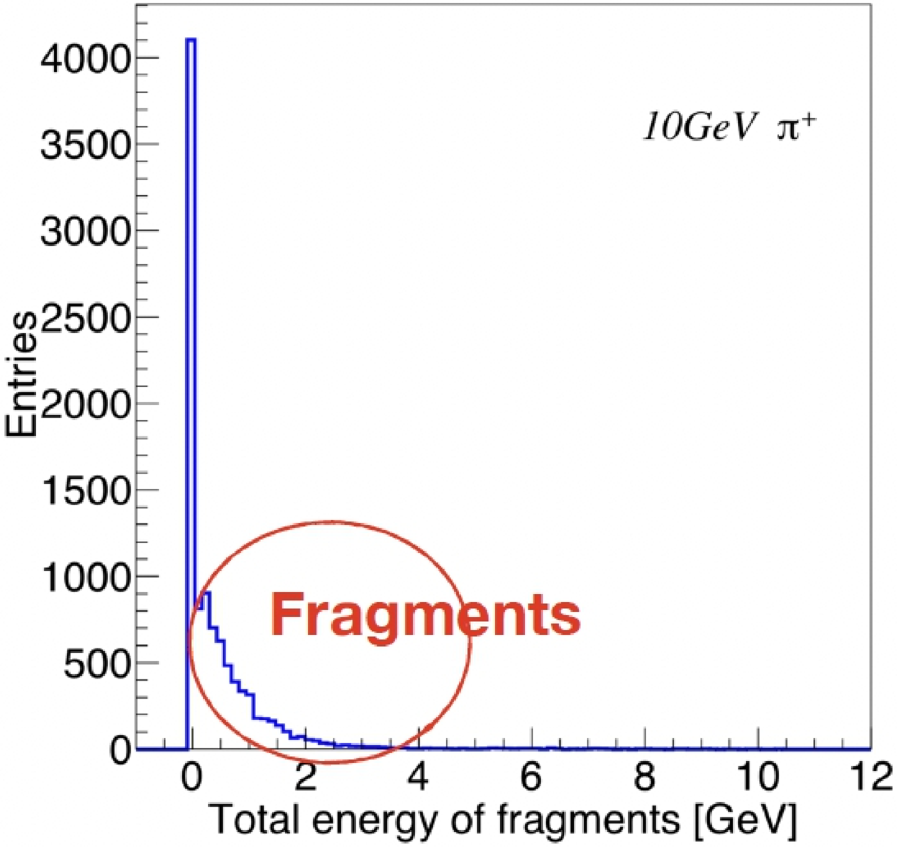


Strategy: make all the possible measurements in each different channel and combine the result!

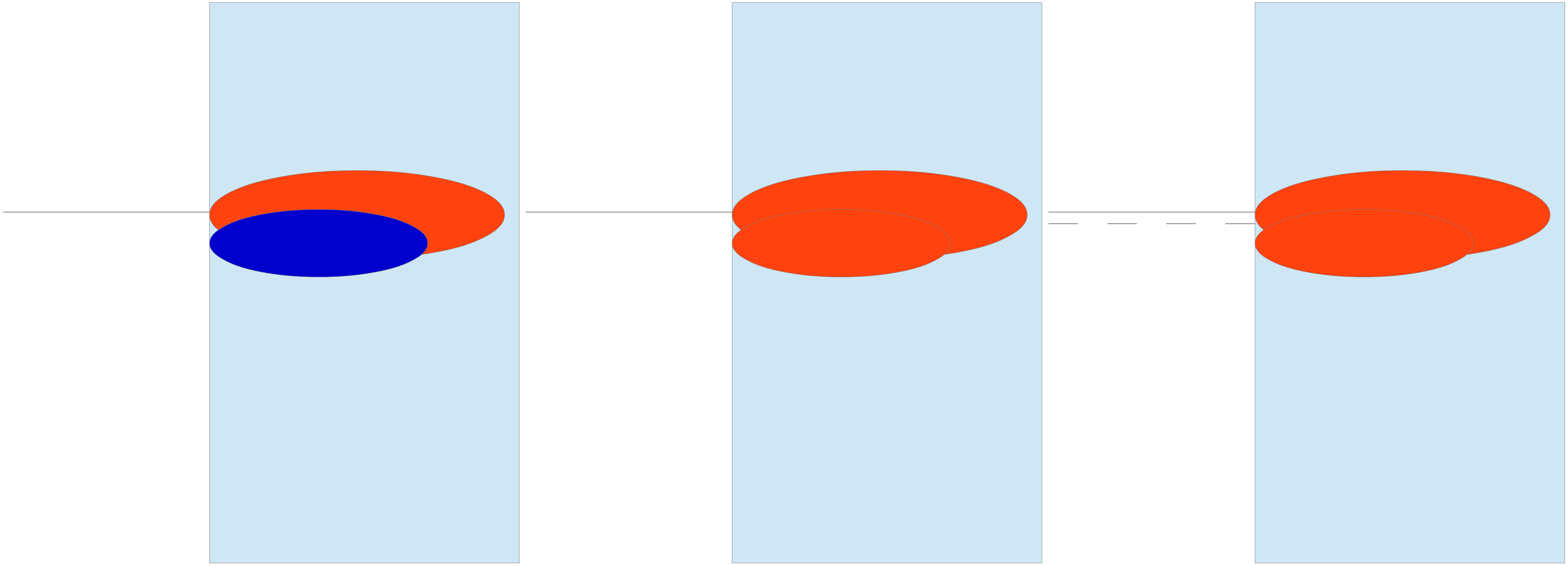
- Excellent pattern. Reco.
- Larger acceptance... in solid angle, energy threshold, and time.
- Excellent intrinsic resolutions
- Extremely stable...
- Be addressed by state of art detector design, technology, and reconstruction algorithm!

Confusion-1: charged fragments





Pattern-compensation: neutral cluster merged into charged



- If Cluster Energy be significantly larger than associated track (E >> P): reconstructed as a Charged PFO with E = P, and a Neutral one with energy of E-P
- However due to the failure and uncertainty of tracking, ... exist mis-id