Search for Supersymmetry in the VBF 0-Lepton Channel at the CMS Experiment and Deep Learning-Based Particle Identification in the Calorimeter

YunJae Lee

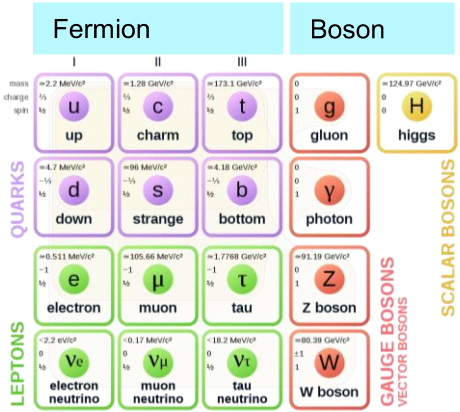
Supervisor: Jason Sanghun Lee

University of Seoul

E-mail: yunjae.lee@cern.ch

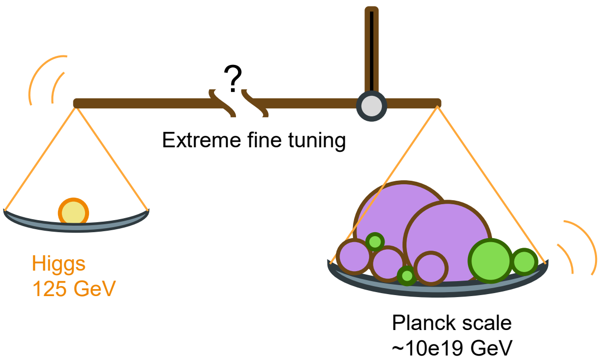
Contents

Introduction



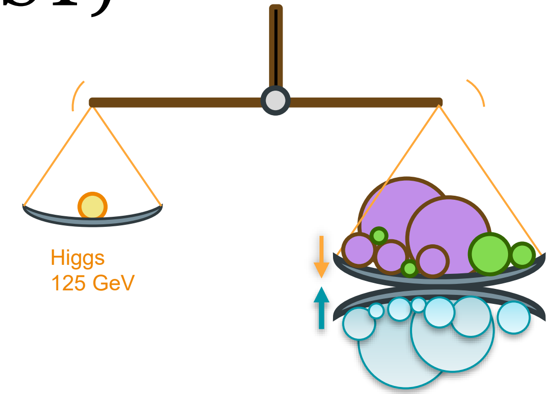
- The Standard Model describe universe with fermion and Boson.
  - Fermion as matter Boson as force carrier
- Electroweak force higgs mechanism

- There are limitation also,
  - Higgs mass can reach Planck scale 10^{19} GeV in the Standard Model.
    - Hierarchy problem
  - There is no Dark matter candidate
  - Neutrino mass is not zero

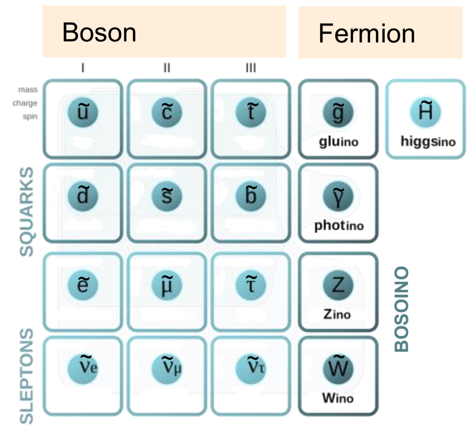


Supersymmetry (SUSY)

- Fermions (spin 1/2) → Bosonic Superpartners(spin 0)
- Bosons (in SM) → Fermionic Superpartners:
- W/Z Bosons (spin 1) → Wino/Zino (spin 1/2).
- Higgs Boson (spin 0) → Higgsino (spin 1/2).

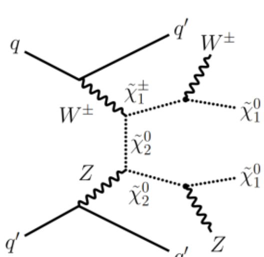


- SUSY propose light Higgs mass
  - quantum correction is cancelled by its superpartner particle
- Lightest Supersymmetric Particle as dark matter candidate
- Unifying forces at extreme energy.

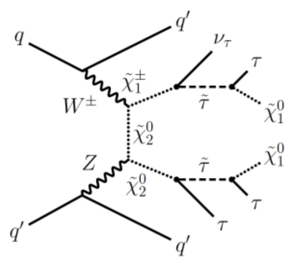


Supersymmetry (SUSY)

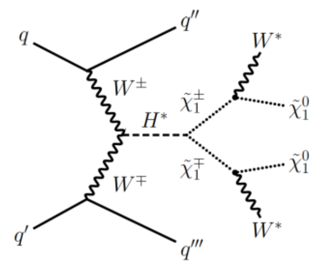
- Compressed mass spectrum: $\Delta m = m(\tilde{\chi}_2^0) - m(\tilde{\chi}_1^0)\ or\ m(\tilde{\chi}_1^{\pm}) - m(\tilde{\chi}_1^0)$
  - Soft final states particles
- Wino-Bino Model: Chargino-neutralino production (˜χ±1 ˜χ02) followedby decays through off-shell W and Z bosons
- Stau coannihilation Model
  - $\tilde{\tau}$ nearly degenerate with $\tilde{\chi}_1^0$, decays into low-energy τ
- Higgsino Model: Nearly mass-degenerate ˜χ±1 , ˜χ02, and ˜χ01 states
- background event. Z + jets, W + jets, QCD multijets, single top, top quark pairs, higgs and diboson events



Wino-Bino



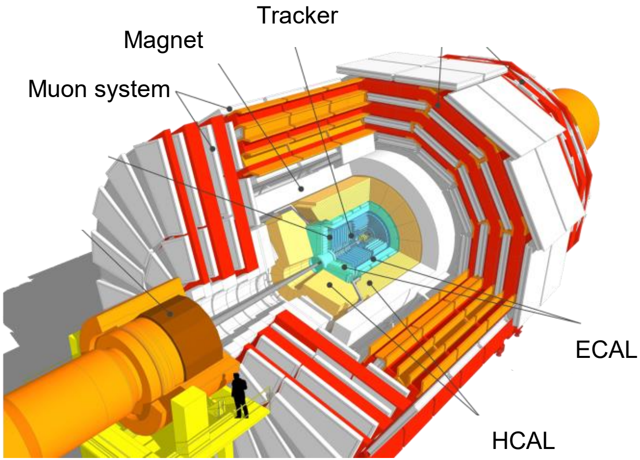
Stau coannihilation

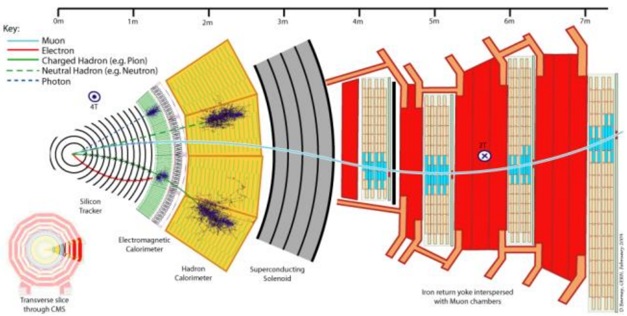


Higgsino

Compact Muon Solenoid (CMS)

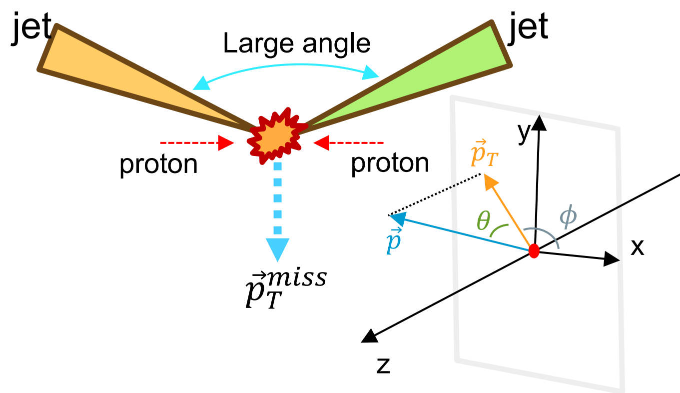
- Tracker
  - Reconstruct charged particle trajectories estimate momentum with magnetic field
  - Trajectory also reconstruct primary vertex and secondary vertex
- ECAL
  - Measure electron and photon energy.
- HCAL
  - Measure hadron energy to reconstruct jet
  - With tracker, electron photon charged hadron and neutral hadron identified
- Muon system
  - Muon track measured at outer detector
- Trigger
  - Data reduction 1/400 event which possibly having physical event.





SUSY search in VBF 0-lepton Ch.

- Event selection strategies
  - Quiet central region and large $\vec{p}_T^{miss}$.
  - VBF topology at jet selection.
  - 0-lepton channel suppress leptonic background
- Rely on jet kinematic variables
  - Dijet angle, dijet invariance mass, missing energy direction
  - Distinguished with QCD and top events



Step	Object	Selection Cuts
Central	Trigger	HLT_PFMETNoMu120_PFMHTNoMu120_IDTight
	e veto	$N(e)=0,\ p_T(e)>5$ GeV, $\lvert\eta(e)\rvert<2.1,\ I_{rel}<0.15$, medium cut-based ID
	μ veto	$N(\mu)=0,\ p_T(\mu)>3$ GeV, $\lvert\eta(\mu)\rvert<2.1,\ I_{rel}<0.15$, tight particle-flow ID
	τ veto	$N(\tau)=0,\ p_T(\tau)>20$ GeV, $\lvert\eta(\tau)\rvert<2.1$, tight anti-$e/\mu$ discrimination, prong = 1 or 3 (HPS)
	b-jet veto	$N(b)=0,\ p_T(b)>30$ GeV, $\lvert\eta(b)\rvert<2.4$, medium DeepCSV WP
	E_T^{miss}	$E_T^{miss}>250$ GeV
	QCD rejection	$\lvert\Delta\phi(E_T^{miss},j)\rvert_{min}>0.5,\ p_T(j)>30\ GeV,\ \lvert\eta(j)\rvert<4.7$, loose ID (2016)/ tight ID (2017–2018)
VBF	Jet selection	$N(j)\geq 2,\ p_T(j)>30$ GeV, $\lvert\eta(j)\rvert<4.7$, loose ID (2016) / tight ID (2017–2018)
	Dijet selection	$\Delta\eta(j_1,j_2)>3.8,\ \eta(j_1)\cdot\eta(j_2)<0,\ m_{jj}>500$ GeV

Data

- CMS Run 2 13 TeV pp collision luminosity(2016,2017,2018)
- Data samples
  - primary datasets MET, muon, electron, tau
- MC simulation
  - MADGRAPH, POWHEG, PYTHIA8
  - Background MC: Standard Model backgrounds which make $\vec{p}_T^{miss}$ and jets
    - Z + jets, W + jets, QCD multijets, single top, top quark pairs, diboson events.
  - Signal MC: minimal supersymmetric extension of the SM (MSSM)
    - Wino-bino, stau coannihilation, Higgsino

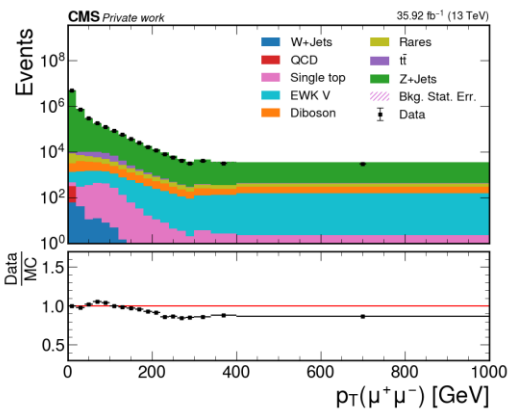
Z → υυ background

- Z boson modeling discrepancy at high p_T.
- Data/MC correction by p_T at Z+jet dominated control region and applied to Z+jet MC background.
- Transfer scale factor from each control region apply correction effect.

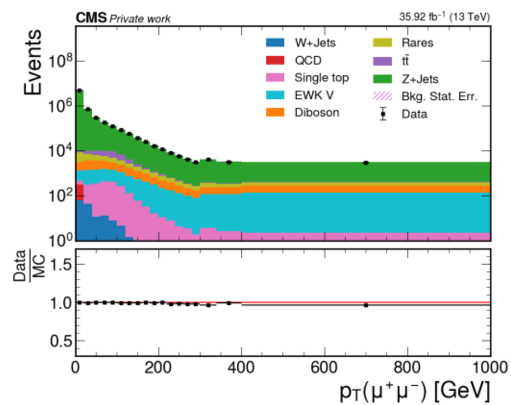
$$SF_{BG}^{Cut} = \frac{N^{Cut}(Data) - \sum N_{nonBG\ MC}^{Cut}}{N_{BG\ MC}^{Cut}}$$

$$N_{BG}^{SR} = N_{BG\ MC}^{SR}(central + VBF) \cdot SF_{BG}^{central} \cdot SF_{BG}^{VBF}$$

Step	Object	Selection Cuts
Central	Trigger	HLT_IsoMu24 (2016, 2018), HLT_IsoMu27 (2017)
	μ selection	$N(\mu) \geq 2$, $p_T(\mu) > 30$ GeV, $\lvert\eta(\mu)\rvert < 2.1$, $I_{rel} < 0.15$, tight particle-flow ID
	Additional μ veto	$N(\mu) = 0$, 3 GeV $< p_T(\mu) <$ 30 GeV, $\lvert\eta(\mu)\rvert < 2.1$, $I_{rel} < 0.15$, tight particle-flow ID
	e veto	$N(e) = 0$, $p_T(e) > 5$ GeV, $\lvert\eta(e)\rvert < 2.1$, medium cut-based ID
	τ veto	$N(\tau) = 0$, $p_T(\tau) > 20$ GeV, $\lvert\eta(\tau)\rvert < 2.1$, tight anti-$e/\mu$ discrimination, prong = 1 or 3 (HPS), $\Delta R(\tau_h, e/\mu) >$ 0.3, DeepTau2017v2p1, tight isolation
	b-jet veto	$N(b) = 0$, $p_T(b) > 30$ GeV, $\lvert\eta(b)\rvert < 2.4$, medium DeepCSV working point
	E_T^{miss}	$E_T^{miss} > 250$ GeV
	QCD rejection	$\lvert\Delta\phi(E_T^{miss}, j)\rvert_{min} > 0.5$, $p_T(j) > 30\ GeV$, $\lvert\eta(j)\rvert < 4.7$, loose ID (2016)/ tight ID (2017–2018)
VBF	Jet selection	$N(j) \geq 2$, $p_T(j) > 30$ GeV, $\lvert\eta(j)\rvert < 4.7$, loose ID (2016) / tight ID (2017–2018)
	Dijet selection	$\Delta\eta(j_1, j_2) > 3.8$, $\eta(j_1) \cdot \eta(j_2) < 0$, $m_{jj} > 500$ GeV



Correction applied



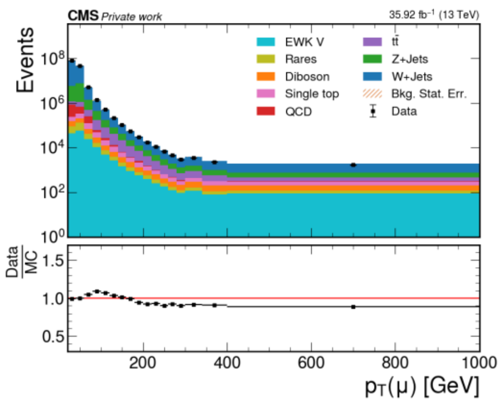
W → lυ background

- W boson modeling discrepancy at high p_T.
- Data/MC correction by p_T at Z+jet dominated control region and applied to W+jet MC background.
- Transfer scale factor from each control region apply correction effect.

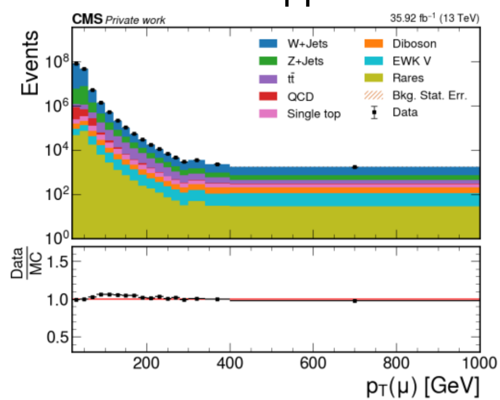
$$SF_{BG}^{Cut} = \frac{N^{Cut}(Data) - \sum N^{Cut}_{nonBG\ MC}}{N^{Cut}_{BG\ MC}}$$

$$N_{BG}^{SR} = N^{SR}_{BG\ MC}(central + VBF) \cdot SF_{BG}^{central} \cdot SF_{BG}^{VBF}$$

Step	Object	Selection Cuts
Central	Trigger	HLT_IsoMu24 (2016, 2018), HLT_IsoMu27 (2017)
	μ selection	$N(\mu) = 1$, $p_T(\mu) > 30$ GeV, $\lvert\eta(\mu)\rvert < 2.1$, $I_{rel} < 0.15$, $60\ GeV < m_T(\mu, p_T^{miss}) < 100\ GeV$, tight particle-flow ID
	Additional μ veto	$N(\mu) = 0$, 3 GeV $< p_T(\mu) < 30$ GeV, $\lvert\eta(\mu)\rvert < 2.1$, $I_{rel} < 0.15$, tight particle-flow ID
	e veto	$N(e) = 0$, $p_T(e) > 5$ GeV, $\lvert\eta(e)\rvert < 2.1$, medium cut-based ID
	τ veto	$N(\tau) = 0$, $p_T(\tau) > 20$ GeV, $\lvert\eta(\tau)\rvert < 2.1$, tight anti-$e/\mu$ discrimination, prong = 1 or 3 (HPS), $\Delta R(\tau_h, e/\mu) > 0.3$, DeepTau2017v2p1, tight isolation
	b-jet veto	$N(b) = 0$, $p_T(b) > 30$ GeV, $\lvert\eta(b)\rvert < 2.4$, medium DeepCSV working point
	E_T^{miss}	$E_T^{miss} > 250$ GeV
	QCD rejection	$\lvert\Delta\phi(E_T^{miss}, j)\rvert_{min} > 0.5$, $p_T(j) > 30\ GeV$, $\lvert\eta(j)\rvert < 4.7$, loose ID (2016)/ tight ID (2017–2018)
VBF	Jet selection	$N(j) \geq 2$, $p_T(j) > 30$ GeV, $\lvert\eta(j)\rvert < 4.7$, loose ID (2016) / tight ID (2017–2018)
	Dijet selection	$\Delta\eta(j_1, j_2) > 3.8$, $\eta(j_1) \cdot \eta(j_2) < 0$, $m_{jj} > 500$ GeV



Correction applied



QCD multijet background

- QCD background MC estimation performed by ABCD method at $Data - MC_{nonQCD}$

A:B=C:D

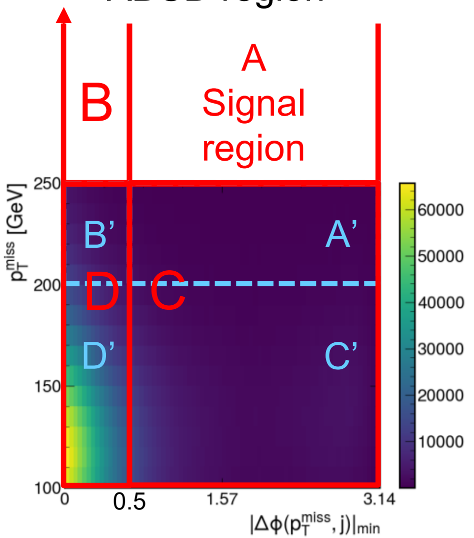
→ $A = B * \frac{C}{D}$

(While p_T^{miss} and $|\Delta\phi(p_T^{miss}, j)|_{min}$ are uncorrelated)

Inverted cut for BCD region

Closure test A'B'C'D' region inside C and D

ABCD region



2016 – transfer factor applied

$$A = \epsilon^{VBF} \frac{B^{pre} C^{pre}}{D^{pre}}, \epsilon^{VBF} = \frac{B^{VBF}}{B^{pre}}$$

QCD_A 2016 = 9699.121+/-64.478 2% error

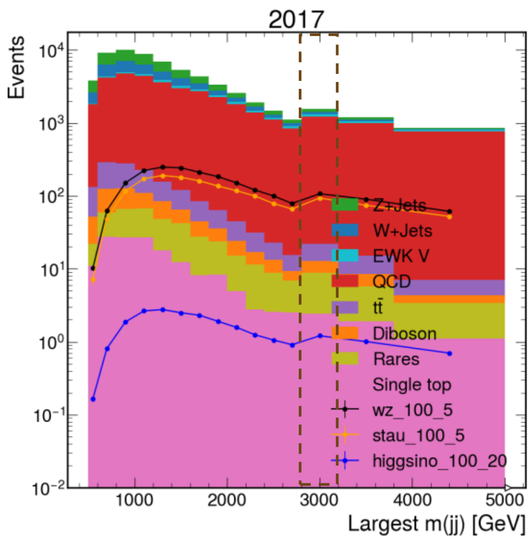
2017,2018

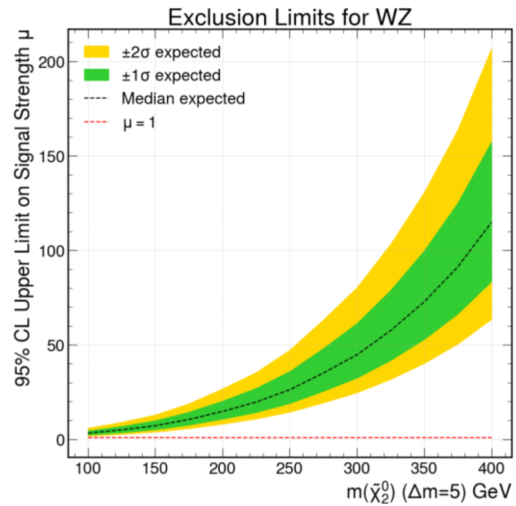
$$A = \frac{B^{VBF} C^{VBF}}{D^{VBF}}$$

QCD_A 2017 = 38553.26+/-167.53 9% error

QCD_A 2018 = 45529.63+/-138.39 13% error

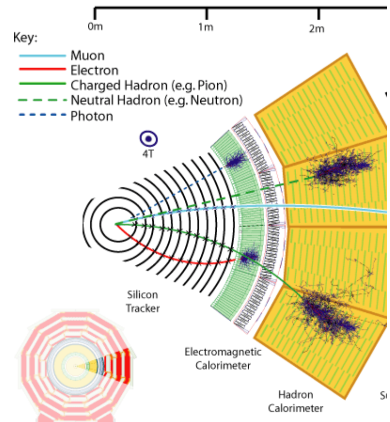
Signal strength





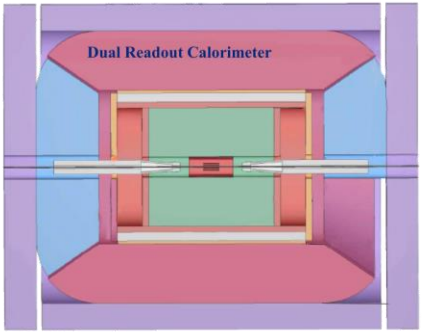
Particle identification in calorimeter

- Needs for advanced calorimeter precisely reconstruct jet energy and missing energy.
  - Calorimeter measuring particles energy through shower which is crucial to reconstruct properties.

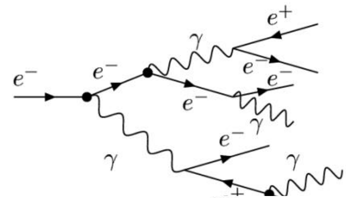


- Dual-readout calorimeter for future collider need accurate particle identification because it is unsegmented(not ECAL,HCAL).
  - charged particle need to be identified whether electron or hadron.

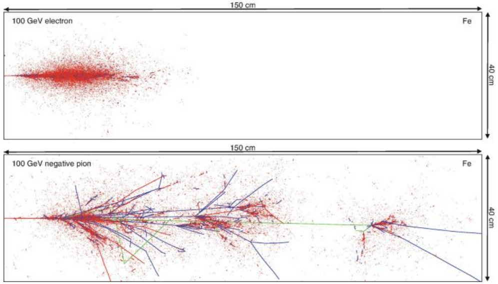
- Deep learning model is proposed for particle identification in the dual-readout calorimeter.
  - Expand PID for π^0 in addition to EM and hadron.
  - Better energy reconstruction based PID.

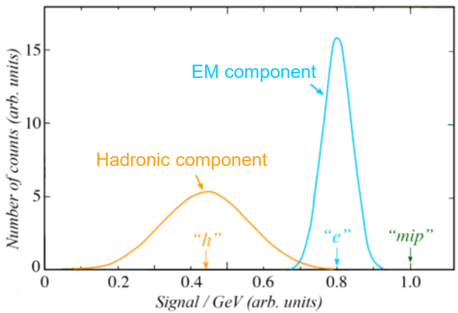


Particle Shower



- Cascade of particles produced when a high-energy particle interacts with the material
  - Electromagnetic (EM) shower - Braking radiation and electron pair production
  - Hadronic shower - Strong interaction between hadrons
- Fluctuation of Hadronic component and EM component
  - Nonlinearity in energy, nuclear binding energy, invisible particles(low momentum neutron, muon, neutrino)
  - Neutral pion increase at higher energy
- Shower shape helps to determine type of incident particle.
  - Shower profile of photon pair and other EM shower is different.
  - hadron and electron should be identified by shower shape and energy proportion.





Distributions of signal for shower components[1)]

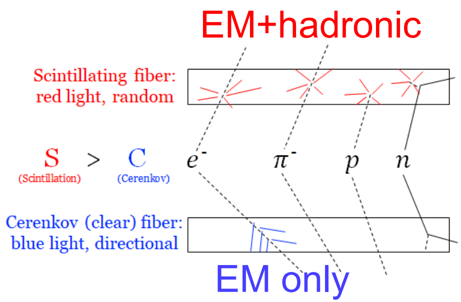
Dual-Readout Calorimeter

- Dual-readout calorimeter has two different, Scintillation and Cerenkov fibers components.
  - Scintillation fibers react to both EM and hadronic particle, Cerenkov fiber reacts to EM particle only.
- Dual-readout calorimeter propose great hadronic energy resolution.
  - Ratio of hadronic component and EM component $\boldsymbol{h/e}$ is differed by Scintillation part $(\boldsymbol{h/e})_S$ and Cerenkov part $(\boldsymbol{h/e})_C$.
  - $f_{em} = 1$ for EM shower, $f_{em} < 1$ for hadron shower

$$f_{\mathrm{em}} = \frac{(h/e)_C - (C/S)(h/e)_S}{(C/S)[1-(h/e)_S] - [1-(h/e)_C]}$$

  - Precise hadronic shower energy correction

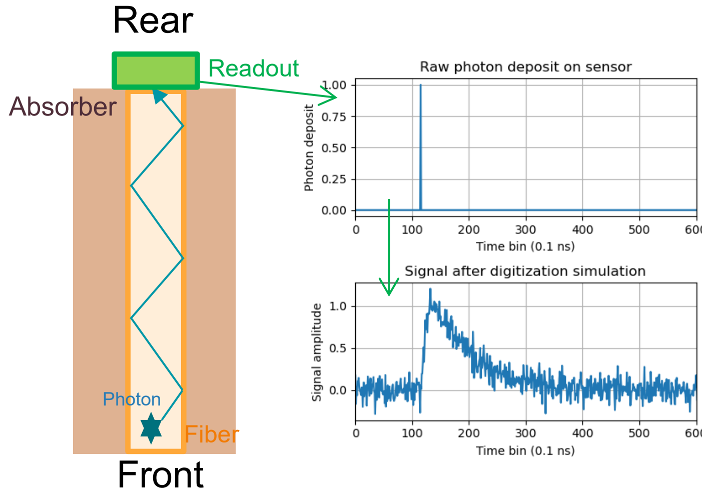
$$E = \frac{S-\chi C}{1-\chi}$$, (χ: dual-readout correction constant)

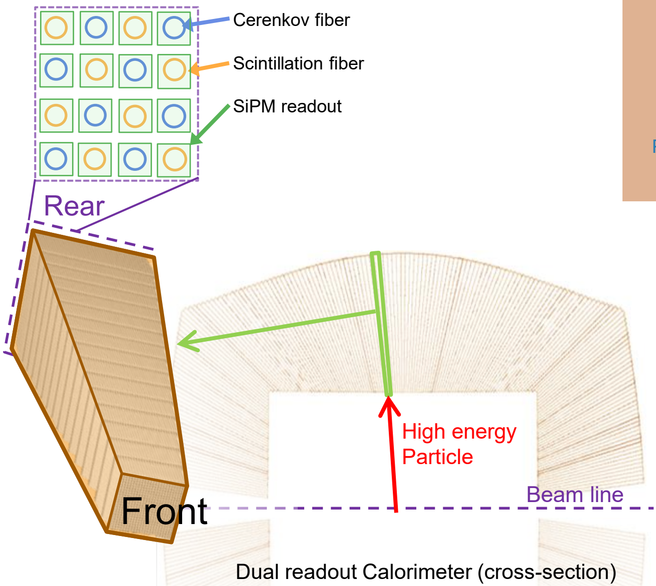


Signal is calibrated with electron of known Energy E. Cerenkov signal is smaller than scintillation signal with hadron showers.

Simulation setup

- Particle generated around interaction point toward calorimeter.
  - 2meter Copper absorber unit structure.
    - ~12 nuclear interaction length

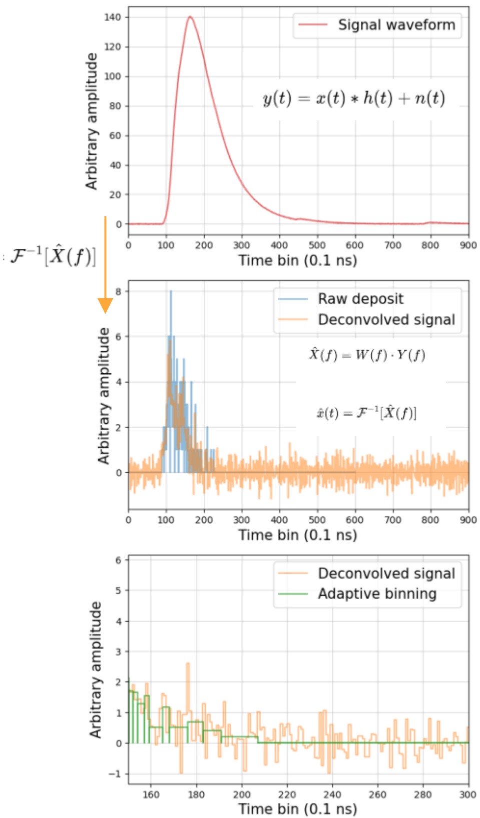




Dual readout Calorimeter (cross-section)

- Fibers are implanted longitudinally.
  - Readouts count light inside fiber
  - Signal is digitized by SiPM simulation.
- Simulation performed by GEANT4.

Preprocessing of waveform

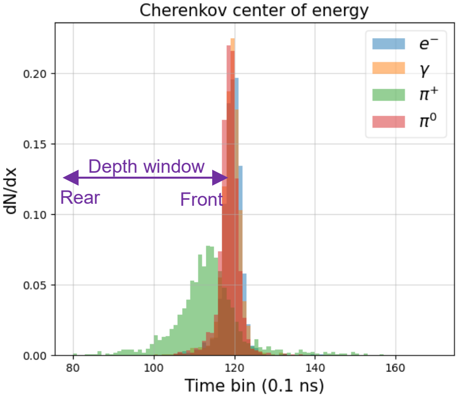


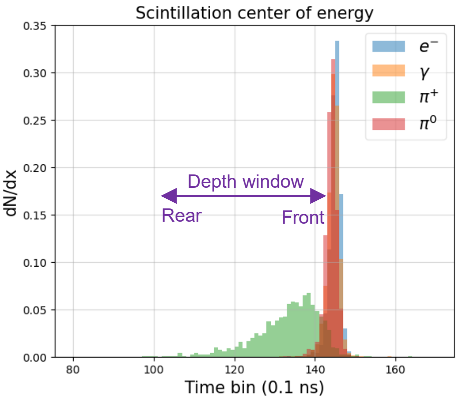
- Waveform output after SiPM signal simulation and digitization.
- Inverse Fourier transform to reconstruct raw deposit-x(t) from signal waveform-y(t).
  - Wiener filter to apply noise.
- Deconvolved signal follows shape of raw deposit.

$$W(f) = \frac{H^*(f)}{|H(f)|^2 + \frac{P_N(f)}{P_S(f)}}$$

- Adaptive binning to reduce noise.
  - Wide bin width for low amplitude.
  - Reduce size of data conserving timing resolution.
- Amplitudes by timing are reconstructed.

Timing analysis



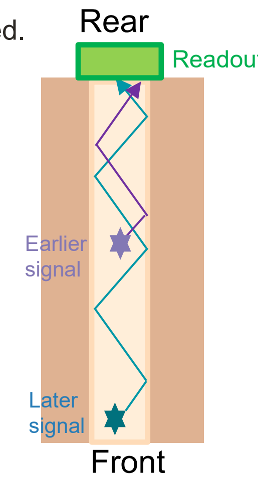


- Different signal timing by depth can be measured.
  - Earlier signal from rear side.
  - e^- peak timing as front signal timing
    - e^- shower appear just beneath.

T = $\frac{\sum N_{pe} * t}{\sum N_{pe}}$ (N_{pe}: photoelectron counts)

- Timing - depth window (gate for 5ns)
  - Cherenkov
    - Rear t_r^C : 7.6$_{+5\text{ns}}$ $= \frac{3.8}{c}$
    - Front t_f^C : 11.9$_{+5\text{ns}}$ $= \frac{1.8}{c} + \frac{2}{c_{eff}}$
  - Scintillation
    - Rear t_r^S : 10.4$_{+5\text{ns}}$ $= t_r^C + 2.8$
    - Front t_f^S : 14.7$_{+5\text{ns}}$ $= t_f^C + 2.8$

Scintillation delay: 2.8ns



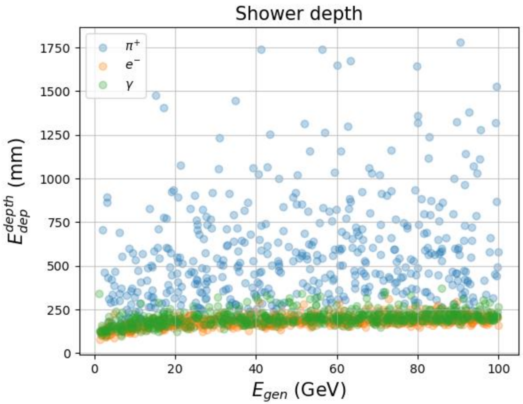
Speed of light in fiber
$c_{eff} = n * \cos(0.37\pi)\,c$
$(n = 1.5)$

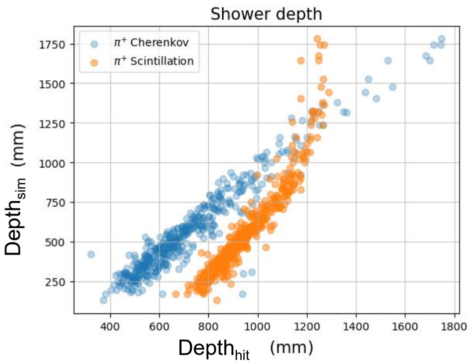
3D Shower reconstruction

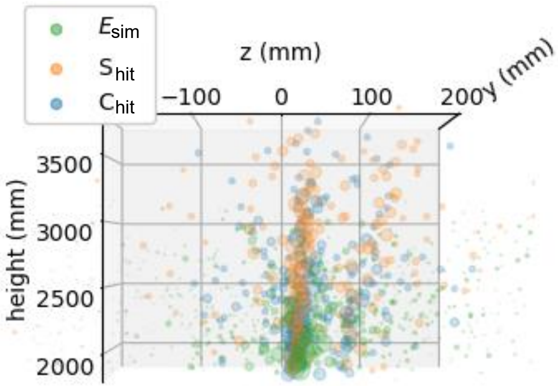
- Shower profile in depth gives more information which is not correlated with initial energy.

  E_{dep} = Energy deposit in simulation

- Energy deposit position reconstruction
  - $xyz_{hit} = xyz_{readout} - v_{eff}(t - t_r), \;\; v_{eff} = \frac{2\,m}{t_f - t_r}$







$$\mathrm{Depth_{hit}} = \frac{\sum N_{pe} * depth}{\sum N_{pe}}$$

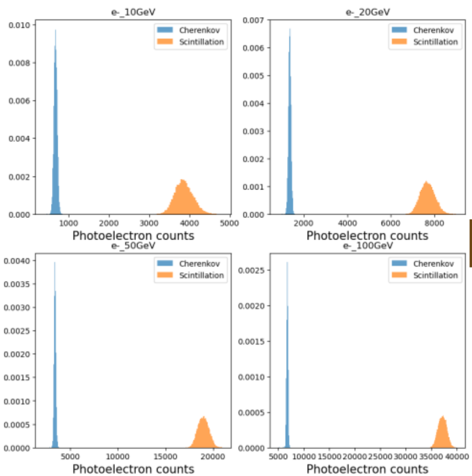
Calibration

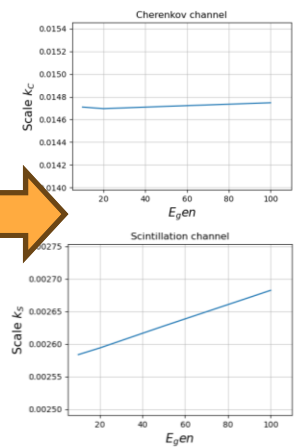
- Sum of signals S_raw and C_raw need to be calibrated to E_gen
  - k_C constant inside +-1%
  - k_S correlated with energy
    - Signal saturated at large amplitude
    - Energy dependent calibration

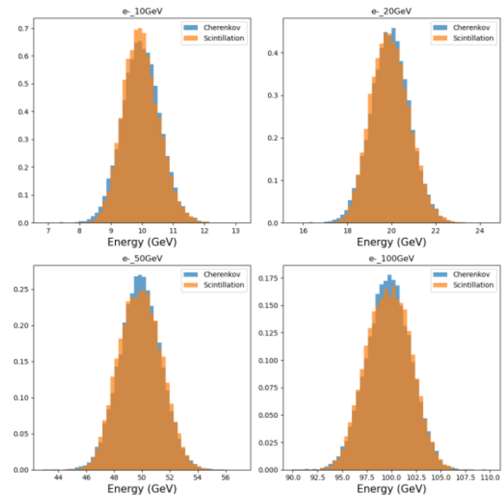
$$C = k_C * \sum C_{raw}$$

$$S = k_S * \sum S_{raw},\ k_S = a * E + b$$

$$\rightarrow S = \frac{b}{1 - a \sum S_{raw}}$$

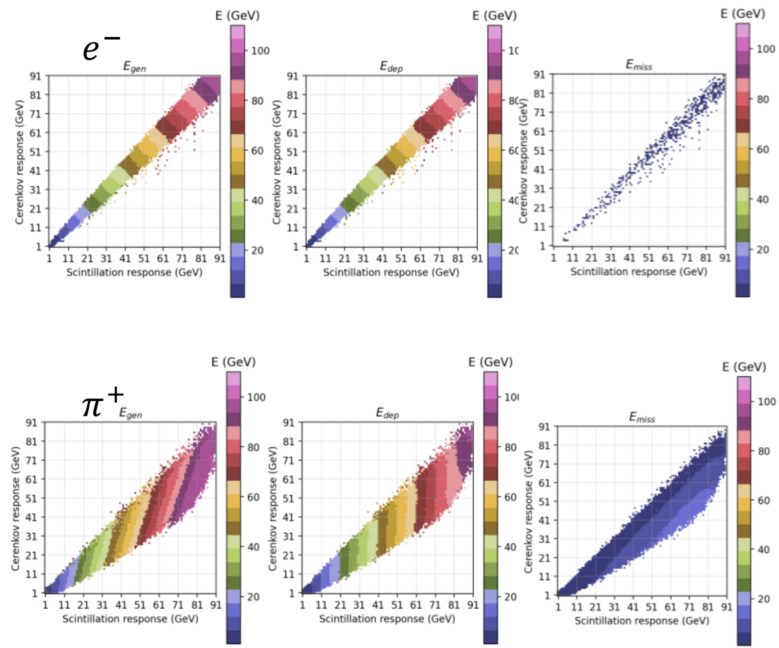






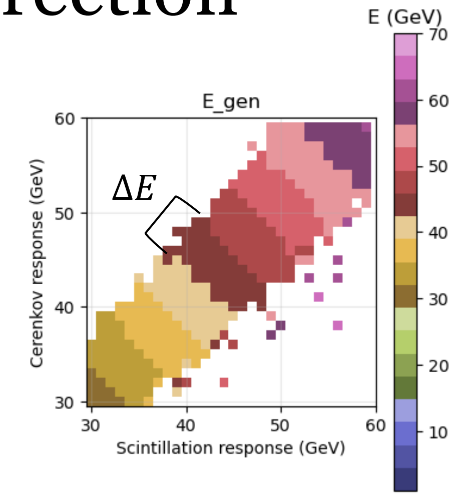
Energy distribution

- Initial energy E_{gen} (1-100 GeV)
  - Energy of incident particle before interaction with calorimeter.
- Deposit energy E_{dep}
  - The total energy transferred to the active material via ionization and excitation processes in GEANT4 simulation.
- Missing energy $E_{miss} = E_{gen} - E_{dep}$
  - includes non-ionizing energy, nuclear binding energy losses, leakage particles

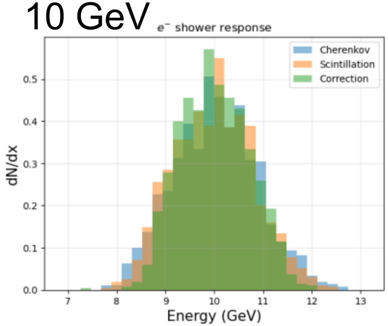


e^- shower energy correction

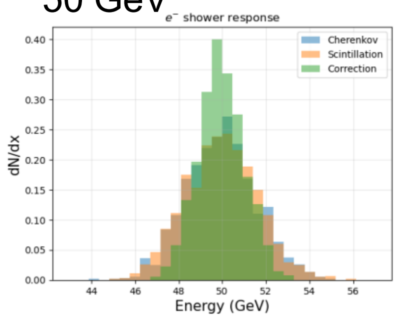
- C,S responses are linear to E_{gen}
- C,S combination improve precision
  - Energy reconstruction $E^{e}_{reco} = \frac{S+C}{2}$
- Linearity inside 0.5%

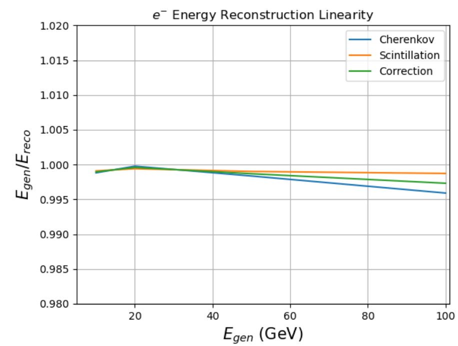


10 GeV



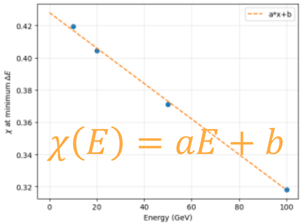
50 GeV





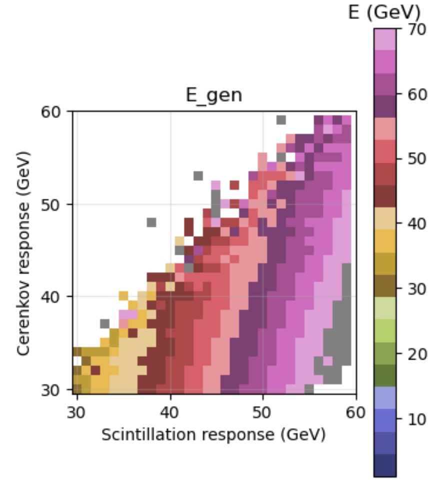
π^+ shower energy correction

- Both C and S responses reduced for π^+ than E_{gen}
- Energy reconstruction $E^{had}_{reco}(C,S) = \frac{S-\chi C}{1-\chi}$

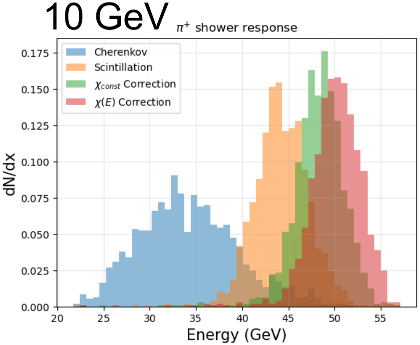


$$\Rightarrow aE^2 + \overbrace{(b-1-aC)}^{B}E + \overbrace{S-bC}^{C} = 0$$

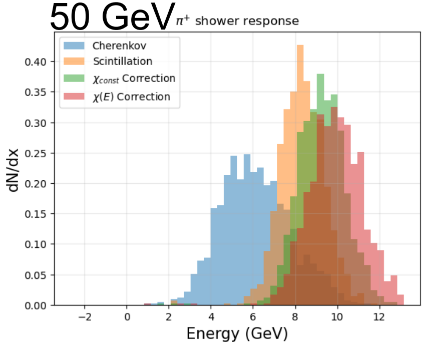
$$E^{had}_{reco}(C,S) = \frac{-B-\sqrt{B^2-4ac}}{2a}$$

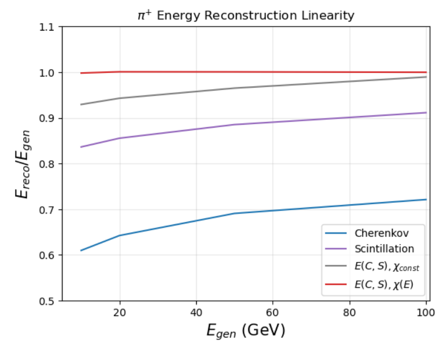


10 GeV



50 GeV





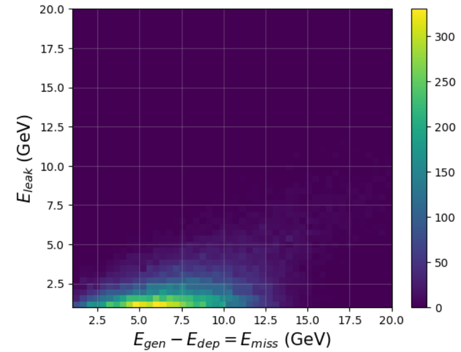
π^+ shower missing energy

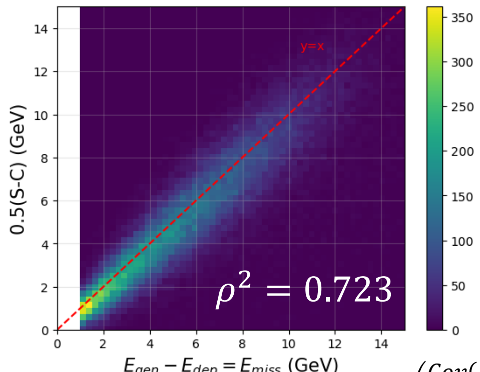
- E_{miss} mostly from nuclear binding energy losses
  - Proportional to hadronic component.

$$C = EM$$
$$S = EM + had$$
$$had = S - C$$

$$E_{miss} = a * had = a * (S - C)$$
(a: calorimeter variable)

- Missing energy can be modeling at 1 GeV <E_{miss}<20 GeV
  - a ~0.5 on current copper based dual-readout calorimeter.

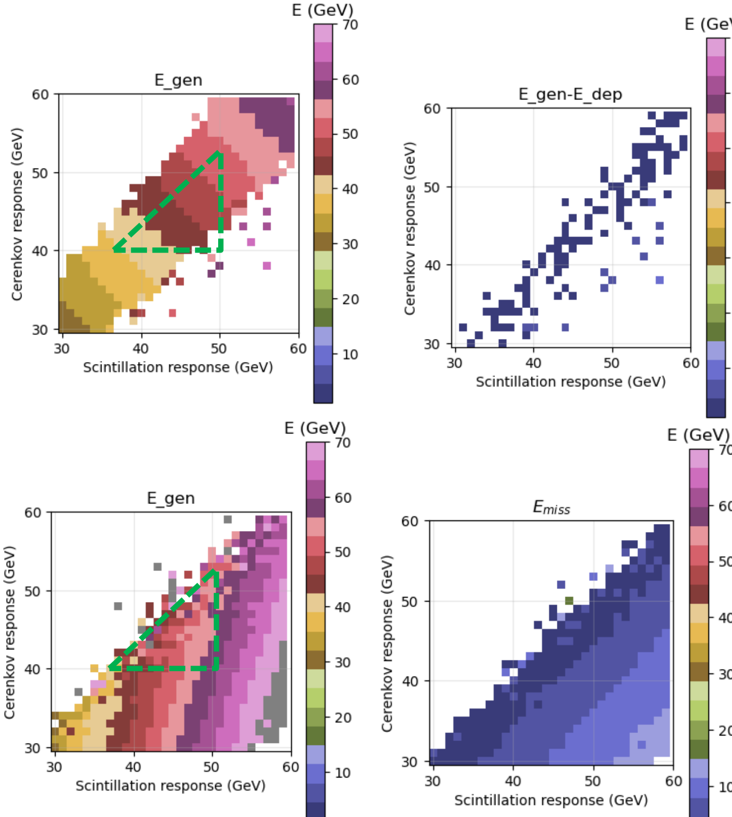




$$\rho^2 = \left(\frac{Cov(X,Y)}{\sigma_X \sigma_Y}\right)^2$$

Need for particle identification

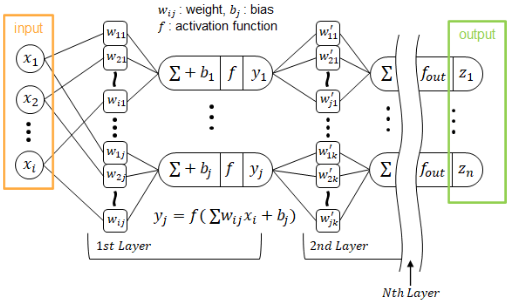
- Energy measurement differentiated by particle type.
  - Electromagnetic : e$^-$ γ π^0
    - $E^{EM}_{reco} = \frac{S+C}{2}$
  - Hadronic: π^+ K$^+$ K^0_L proton neutron
    - $E^{had}_{reco}(C,S) = \frac{S-\chi C}{1-\chi}$
- Overlapped C,S region but different energy profile.
  - Limitation on EM vs hadron discrimination.
- Shower shape also differentiated by particle type.
  - Readout positions project shape.
  - Signal timing gives depth profile.



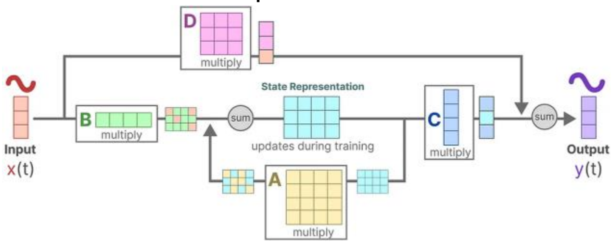
Deep learning model

- One of ML methods, which are based on neural networks
  - Neural networks model can fit arbitrary dataset to necessary output.
  - Multilayer Perceptron(MLP) is basic implementation.
- Mamba: Selective State Space model
  - State Space Models(SSMs) model local dynamics between inputs.
  - Selective gate enhance to catch relevant feature
  - Small complexity and faster than transformer.
- Model inputs
  - Cherenkov: $\sum_C N_{pe}$, $C_{raw}(xyz_{readout}, t, N_{pe})$, $C_{hit}(xyz_{hit}, N_{pe})$
  - Scintillation: $\sum_S N_{pe}$, $S_{raw}(xyz_{readout}, t, N_{pe})$, $S_{hit}(xyz_{hit}, N_{pe})$

Multilayer Perceptron

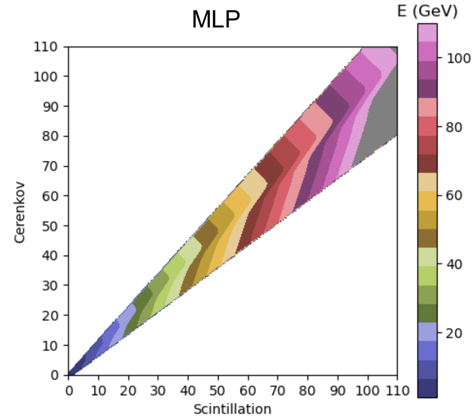


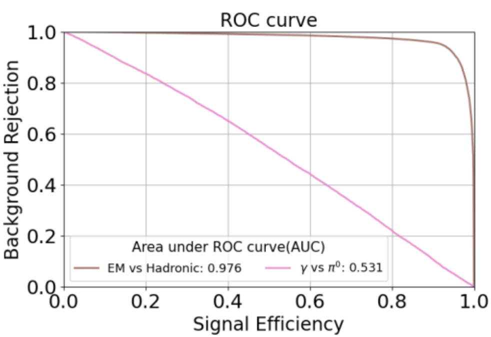
State Space Model

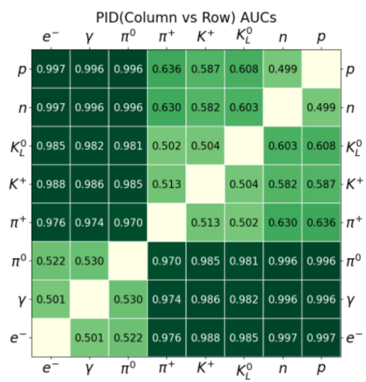


MLP without position, timing

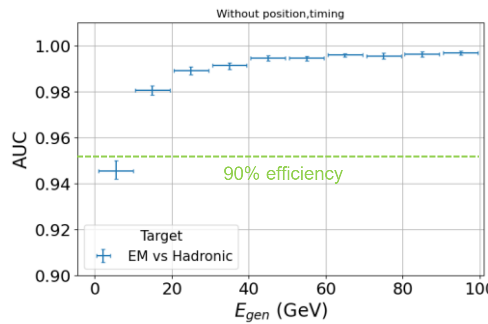
- Model: MLP($\sum_C N_{pe}$, $\sum_S N_{pe}$)
  - Model trying to mimic energy distribution of EM and hadronic shower.
  - AUC close to 1 at better performance.
- Performance limit of using only $\sum_C N_{pe}$ and $\sum_S N_{pe}$.
  - π^0 not discriminated.
  - EM vs hadron efficiency<90% under 10GeV






PID(Column vs Row) AUCs

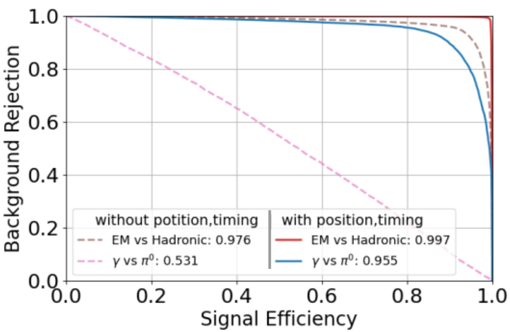
	e^-	γ	π^0	π^+	K^+	K_L^0	n	p
p	0.997	0.996	0.996	0.636	0.587	0.608	0.499	
n	0.997	0.996	0.996	0.630	0.582	0.603		0.499
K_L^0	0.985	0.982	0.981	0.502	0.504		0.603	0.608
K^+	0.988	0.986	0.985	0.513		0.504	0.582	0.587
π^+	0.976	0.974	0.970		0.513	0.502	0.630	0.636
π^0	0.522	0.530		0.970	0.985	0.981	0.996	0.996
γ	0.501		0.530	0.974	0.986	0.982	0.996	0.996
e^-		0.501	0.522	0.976	0.988	0.985	0.997	0.997

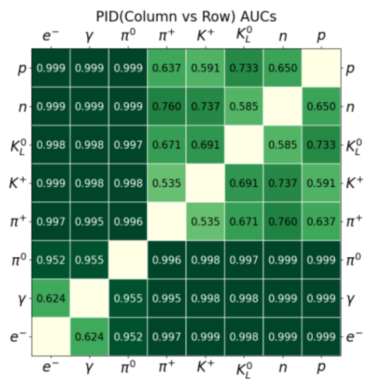


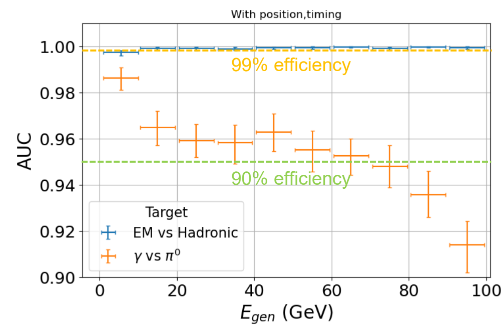
EM:e^-, γ , π^0
Hadronic:π^+, K^+, K_L^0, p, n

Model with position, timing

- Model: MLP(MLP($\sum_C N_{pe}$, $\sum_S N_{pe}$),Mamba(C_{raw}, S_{raw}),Mamba(C_{hit}, S_{hit}))
  - Model utilizes position, timing and energy.
- Position and timing improve overall performances
  - EM vs hadron efficiency>99% over 10GeV
  - π^0 shower discriminated with single γ shower.
    - Efficiency>90% under 70 GeV.



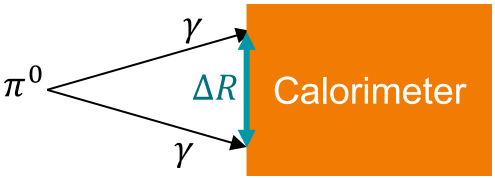


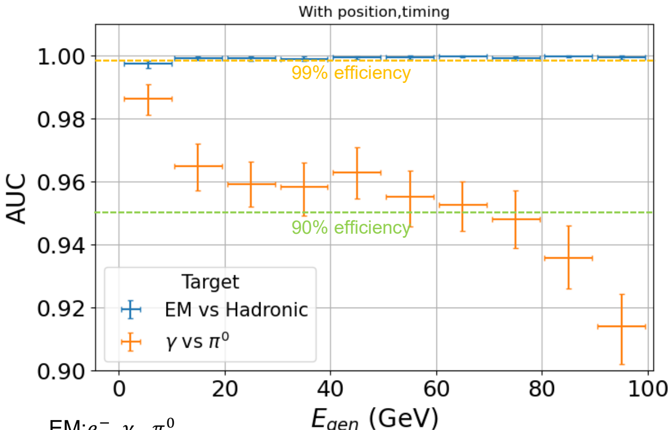


EM:e^-, γ , π^0
Hadronic:π^+, K^+, K_L^0, p, n

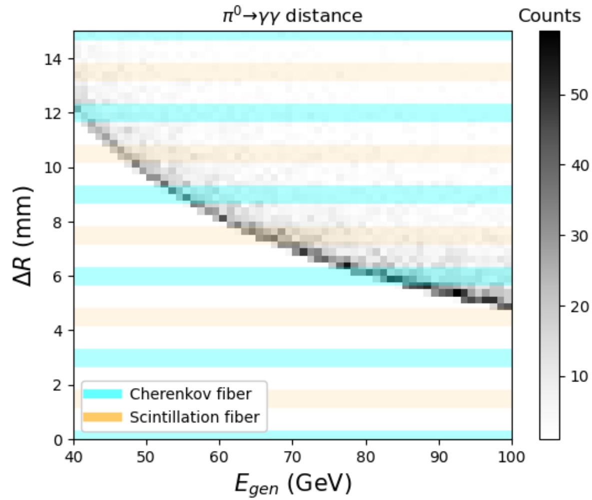
π^0 Identification performance

- π^0 vs γ performance decrease over 80 GeV.
  - Copper Molière radius $R_M = 15.68mm$
  - Gaussian radius $\sigma = \frac{R_M}{\sqrt{2\ln\frac{1}{0.1}}} \cong 7.3mm$ (5 fiber gap)
    - Two shower closer than radius are overlapped.

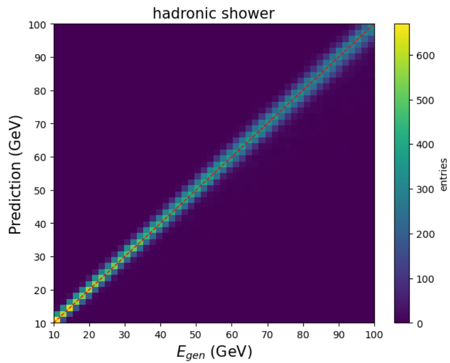


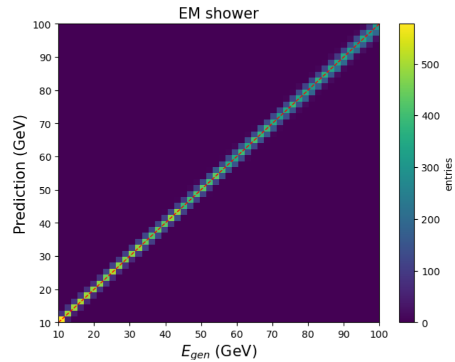


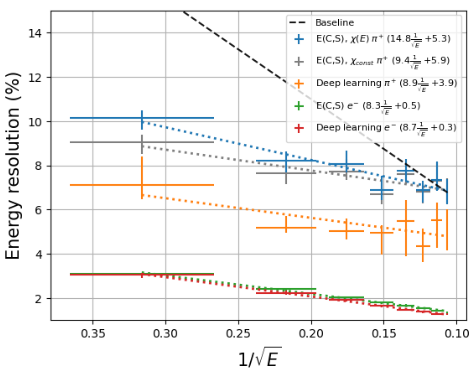
EM:e^-, γ , π^0
Hadronic:π^+, K^+, K_L^0, p, n

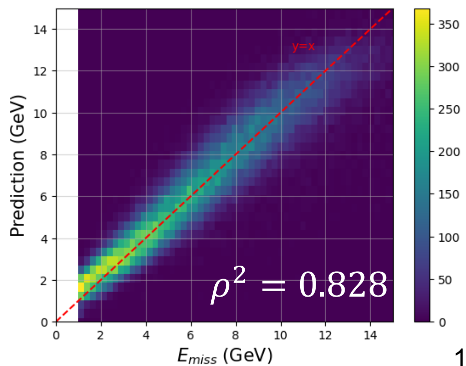


DL energy reconstruction









$0.5(S - C)$:0.723

1 GeV <E_{miss}<20 GeV

- Better energy reconstruction than dual-readout energy correction method

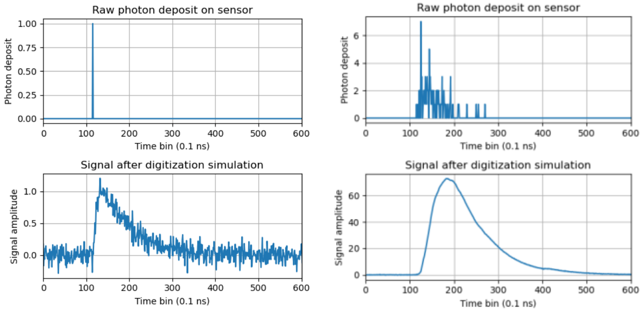
Summary

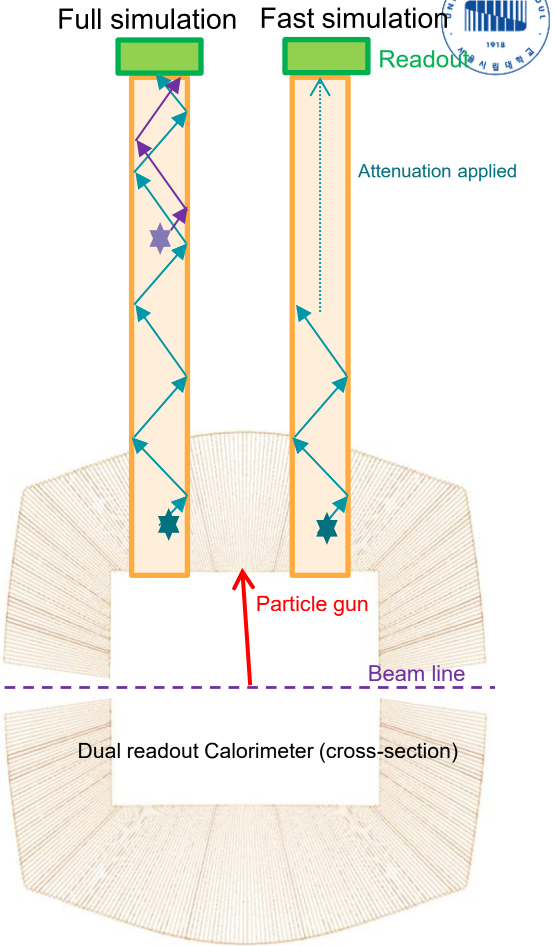
- SUSY search at VBF 0-lepton channel in CMS experiment study has performed.
- Separated energy reconstruction study has performed for electromagnetic shower and hadronic shower.
  - 3D shower profile is reconstructed timing analysis.
  - Energy dependent correction for better initial energy reconstruction.
- Deep learning implementation has been studied to extend particle identification.
  - Identification among EM(e^-, γ) and hadronic and π^0 shower.
  - Able to reconstruct initial energy and missing energy more accurately.

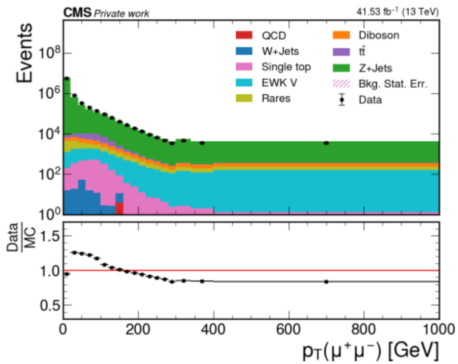
Backups

Simulation setup

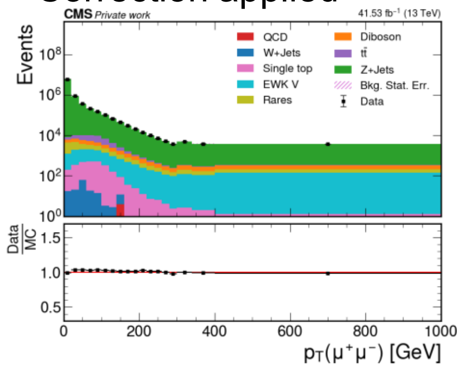
- SiPM(Silicon Photomultiplier) readouts count optical photon at end of each fiber.
  - Fast simulation algorithm for photon propagation inside fiber.
- Particle guns simulated at center of calorimeter
  - $e^-, \gamma , \pi^+, \pi^0, K^+, K_L^0, p, n$ are generated with random energy in 1 - 100 GeV.
  - Incident direction cover region of $2° \times 2°$ ($\Delta\phi$: 0.04, $\Delta\theta$: 0.04) on barrel and endcap.

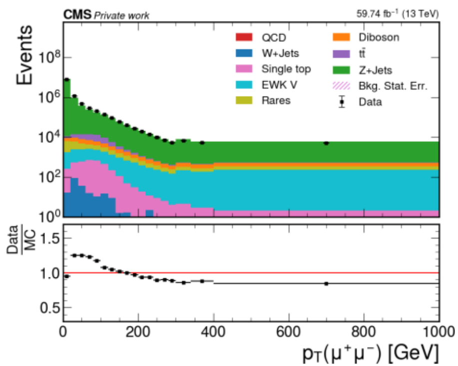


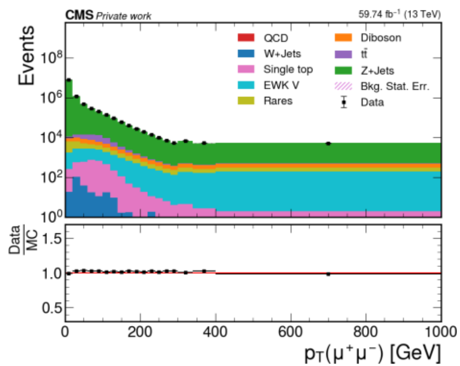




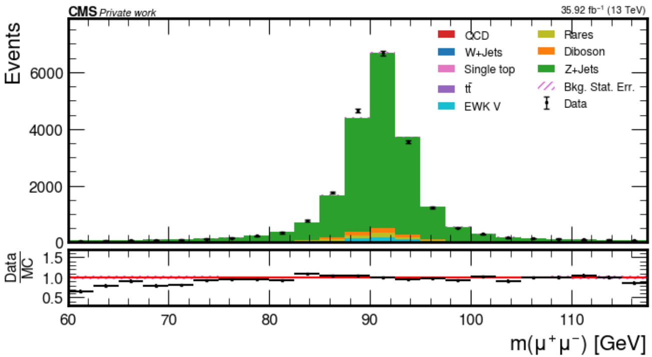
Correction applied

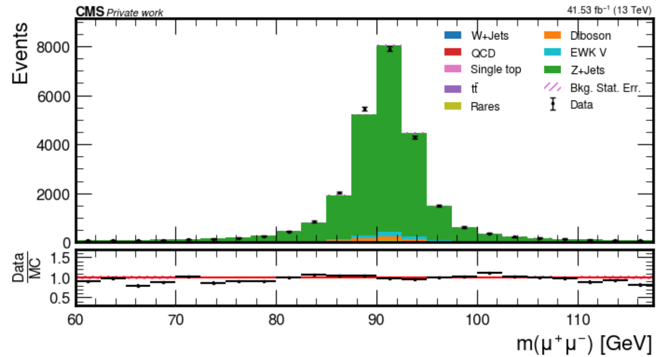


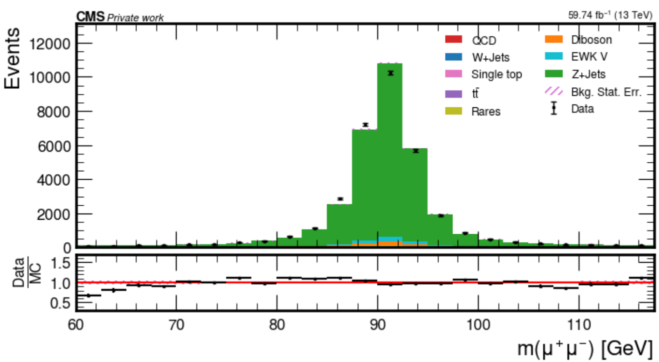




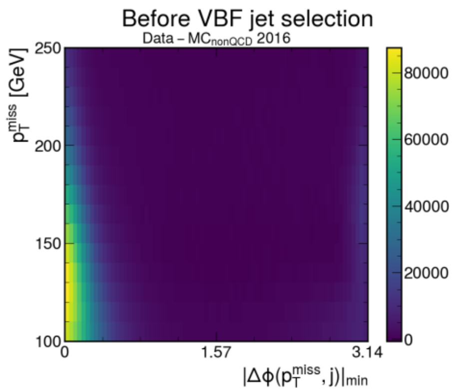
Kinematics plots – Z+Jet

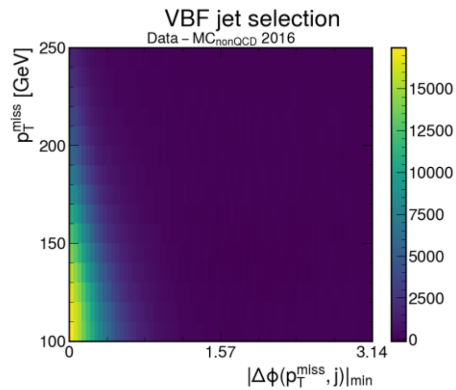


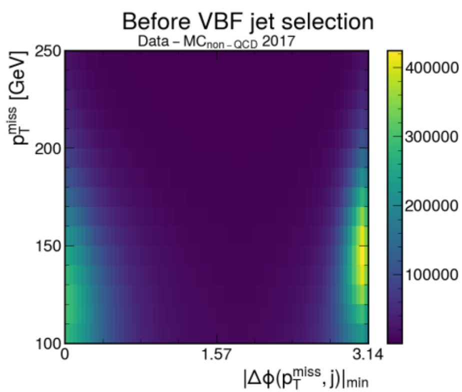


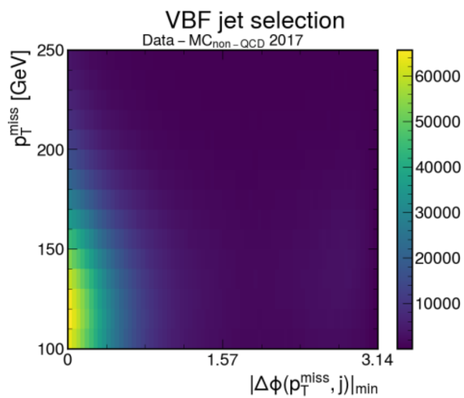


QCD multi jet background

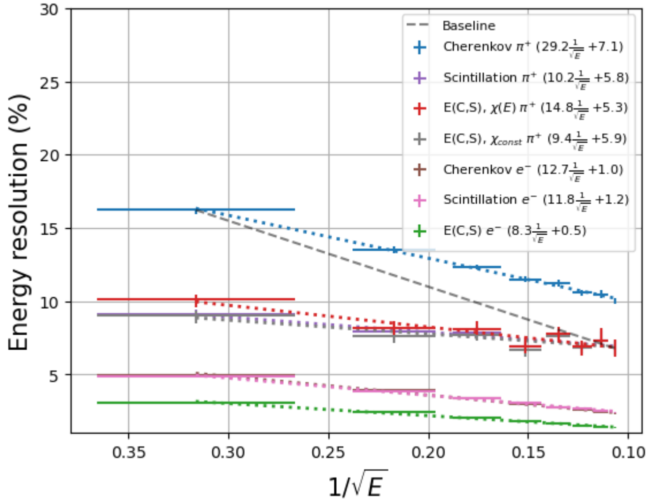








Dual-readout correction



Model

- MLP(Sraw,Craw), Mamba (readout position, signal timing, amplitude, fiber type), Mamba(hit position, amplitude, fiber type)
    - 3 model combined to MLP
    - 2M parameters

- 40k dataset each particle 50 train 20 validation 30 test
- Training time - 1 day(model is small mostly input lag) torch v2.5.1

MLP without position,timing

- Without position,timing

Deep learning without position,timing