Comparison of Tau-pair Performance with ILD ECAL candidates

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Motivation of This Study

- we want to estimate the performance of ECALs with the ILD bench mark process ee -> ττ.

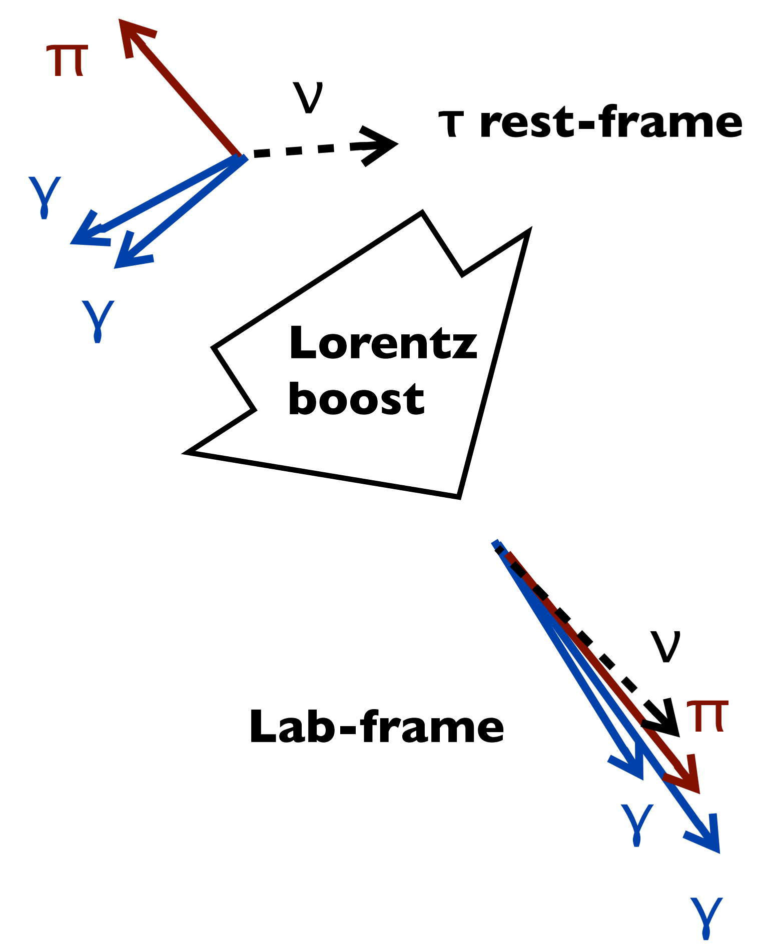
  - A potential criterion for ILC electromagnetic calorimeters (ECAL) is the ability to reconstruct gammas with a charged track near by.

  - Also, the full reconstruction of taus may be yet more challenging and the physics opportunities are potentially crucial. (Taus appear in many New Physics signatures)

- At high energy, daughters of τ decay are concentrated in a very narrow angle and a narrow area due to the Lorentz boost.

  - Identifying and measuring gammas (from πos) is difficult, because 2γs are very close.

  → ILD demands well segmented ECAL.



- We compare tau reconstruction performance (gamma separation) with some ILD ECAL candidates.

How precisely do ECALs reconstruct tau?

ILD ECAL Candidates

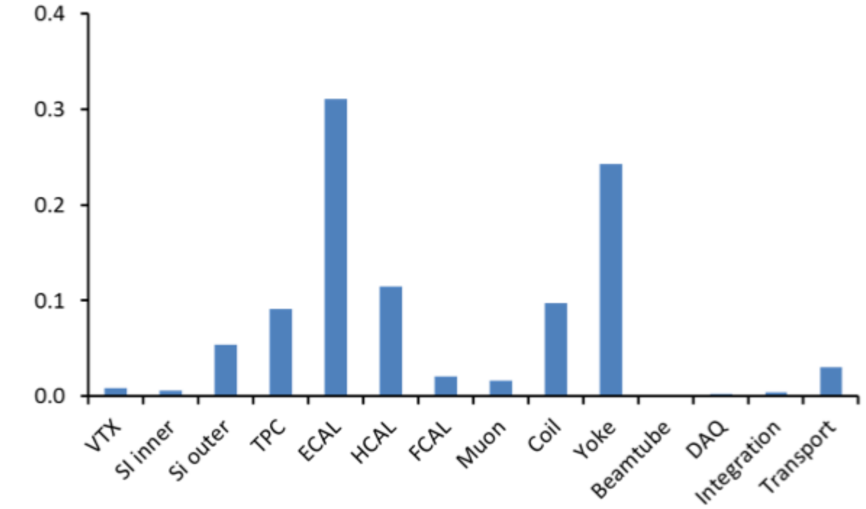
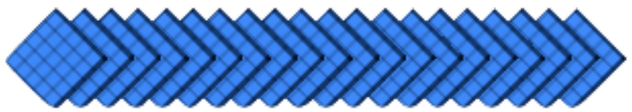


Figure 5.3.2: Summary plot of the relative contribution by the different sub-components to the total cost of the ILD detector.

- **ECAL is high cost.**
  - **We want to decrease the price without loosing performance as possible as we can.**
- **Basically, we examine with three types of ECALs**

- Si ECAL



- **Pure silicon ECAL.**
- **Silicon thickness = 0.5 mm**
- **Silicon cell size = 5x5 mm**
- **ECAL module thickness = 185.0 mm**

- DoubleLayer Hybrid

- **Si, Sci hybrid ECAL**
- **Silicon thickness = 0.5 mm**
- **Scintillator thickness = 1.0 mm**
- **ECAL module thickness = 190.796 mm**
- **Use Si 2-layer Sc 2-layer alternatively**
- **Apply SSA (strip split algorithm) at reconstruction step. → achieve 5x5 mm**

- Sci ECAL w/ SSA

- **Pure scintillator ECAL**
- **Scintillator thickness = 1.0 mm**
- **ECAL module thickness = 197.42 mm**
- **Scintillator size = 45x5 mm**
- **Apply SSA (strip split algorithm) at reconstruction step. → achieve 5x5 mm**
- **The cost is about half of pure Si ECAL**
- **The problem of ghost hit.**

- **And we think further configuration…**
  - **Single layer hybrid.**
  - **Scintillator strip + Scintillator tile**

※ Double - Hybrid cannot completely extract tail layer effect

Event sample

- Event sample

  e+ e- -> tau+ tau- √s = 500GeV (ISR-off to simplify event)

  Beam polarized : e-, e+ = -80%, +30%

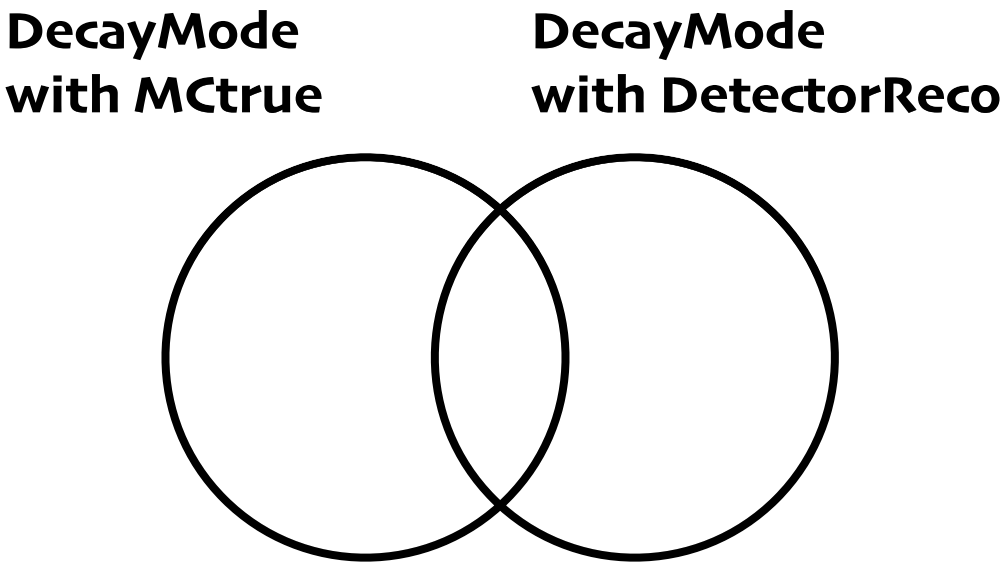
  e-, e+ = +80%, -30%

- Estimation

  - Reconstructed efficiency and purity at each tau decay.

$$efficiency = \frac{\begin{array}{c}\textbf{DecayMode}\\ \textbf{with MCtrue}\end{array} \cap \begin{array}{c}\textbf{DecayMode}\\ \textbf{with DetectorReco}\end{array}}{\begin{array}{c}\textbf{DecayMode}\\ \textbf{with MCtrue}\end{array}}$$

$$purity = \frac{\begin{array}{c}\textbf{DecayMode}\\ \textbf{with MCtrue}\end{array} \cap \begin{array}{c}\textbf{DecayMode}\\ \textbf{with DetectorReco}\end{array}}{\begin{array}{c}\textbf{DecayMode}\\ \textbf{with DetectorReco}\end{array}}$$



  - Physics observables : Afb, P(τ)(tau polarization)

Make tau jet and some Cut

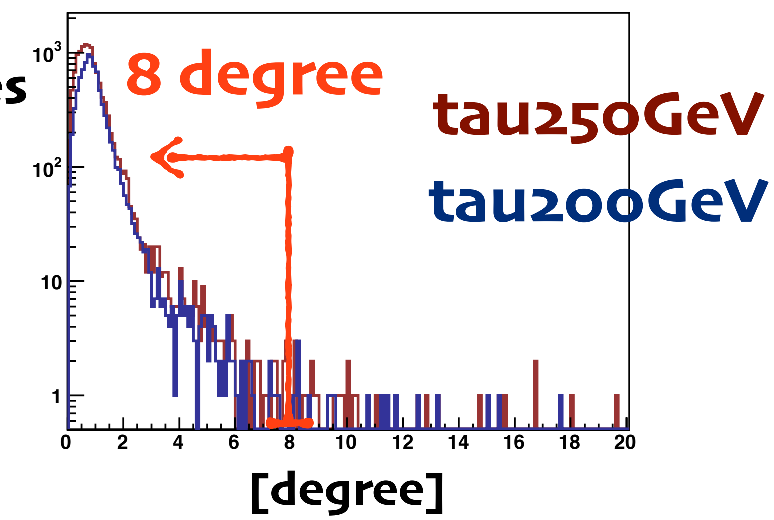
- Make tau jet

  1. Sort particles in energy order and select two energetic charged particles so as to satisfy back-to-back. → Charged daughter of tau.

  2. Gather particles around the charged daughter into the tau jet. and combine energy and momentum of associated particles.

     → Combine < 8 deg from charged track.

Angle between gamma and main Track
tau -> a1p1 mode
on MCtrue



- Applied cuts to suppress background.

main background :

e e -> Bhabha
e e -> W W -> 2l + 2ν
2-γ -> tau tau

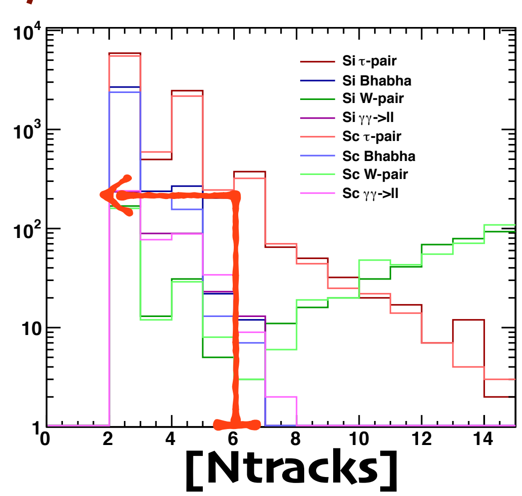
Pre-cut : demand Back-to-Back.

Cut / Signal(%)	Si ECAL	D-Hybrid	Sci w/SSA
No cut	100	100	100
Pre-cut	92.32	91.46	91.58
N of Tracks < 6	89.88	89.06	89.28
172 < Opening angle	87.22	86.42	86.68
-0.9 < Thrust angle < 0.9	87.22	86.42	86.68
70 < visible energy < 450	84.64	82.92	83.16

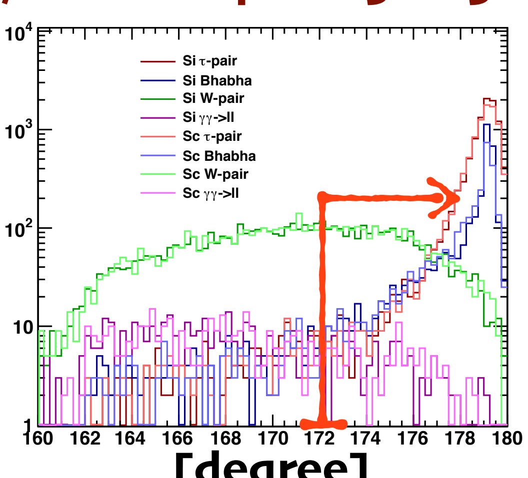
※ cuts applied to the whole event

Signal
Bhabha
W W -> 2l + 2ν
2-γ -> tau tau

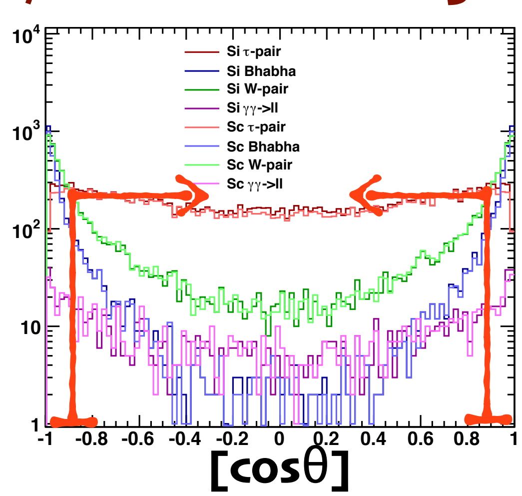
Si/ScECAL N of Tracks



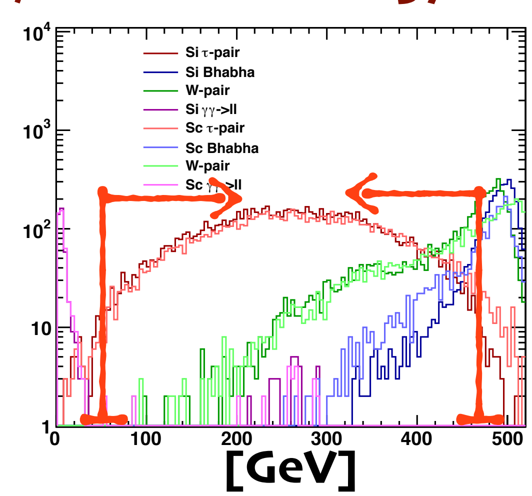
Si/ScECAL Opening Angle



Si/ScECAL Thrust Angle



Si/ScECAL Vis Energy



Selection of decay mode

- Applied two methods to distinguish decay modes of tau.

- Loose Cut : based on some cuts

1. Check whether track attached by Pandora is lepton or hadron.

2. Check energy of gammas.

Energy sum of gammas is less than 3.5GeV. → π mode.

Energy sum of gammas is more than 3.5GeV.

3. Check mass of gammas.

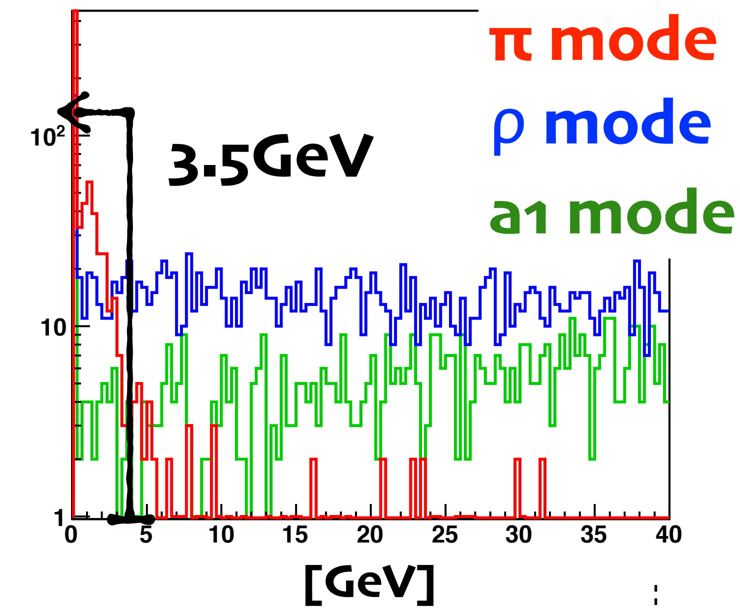
Mass of gammas (PiO) is less than 0.45GeV. → ρ mode.

Mass of gammas (PiO) is more than 0.45GeV. → a1 mode.

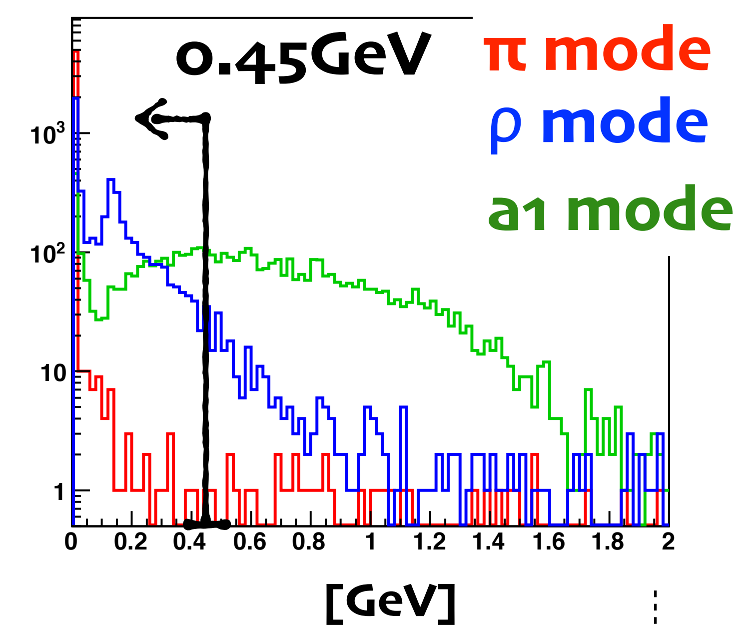
- MVA Cut : based on MVA method

→ Distinguish from MVA response on each ECAL.

Energy of Gammas
single tau 250GeV
Si ECAL Reconstruction



Mass of gammas
single tau 250GeV
Si ECAL Reconstruction



Efficiency & purity with Loose Cut

- Comparison of Detectors
  - √500GeV e-Le+R -> tau-tau+
  - Detectors

    Si ECAL,

    DoubleLayer Hybrid

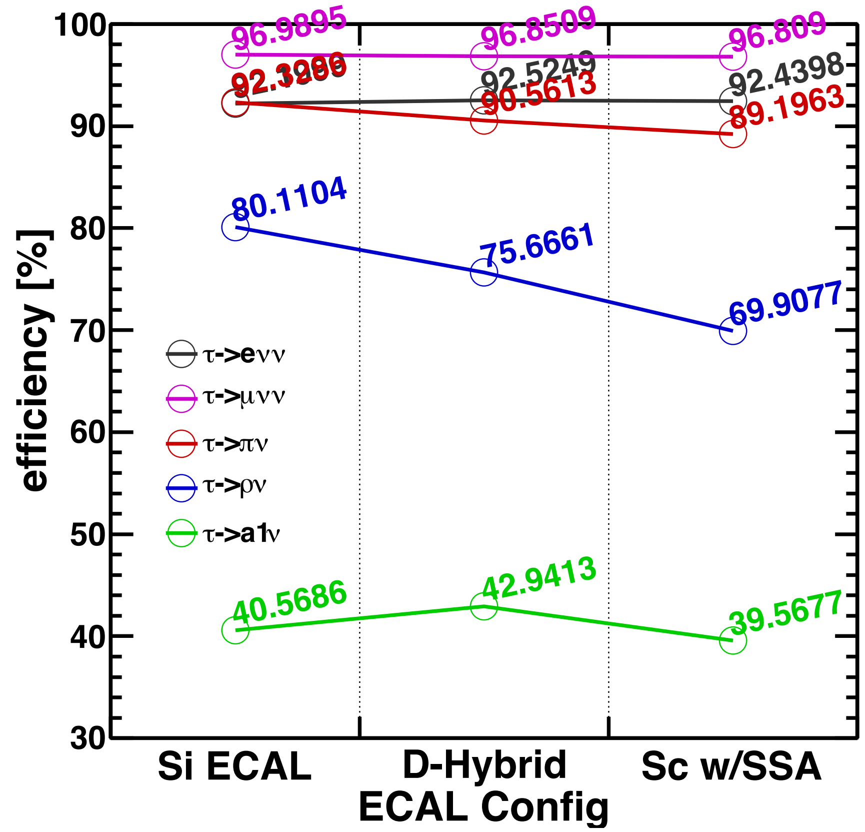
    Sci ECAL w/SSA
  - Cut

    Loose Cut
  - Efficiency & Purity
    - In reconstruction of leptonic decay, efficiency and purity are almost same.
    - In reconstruction of hadronic decay, efficiency and purity are difference.

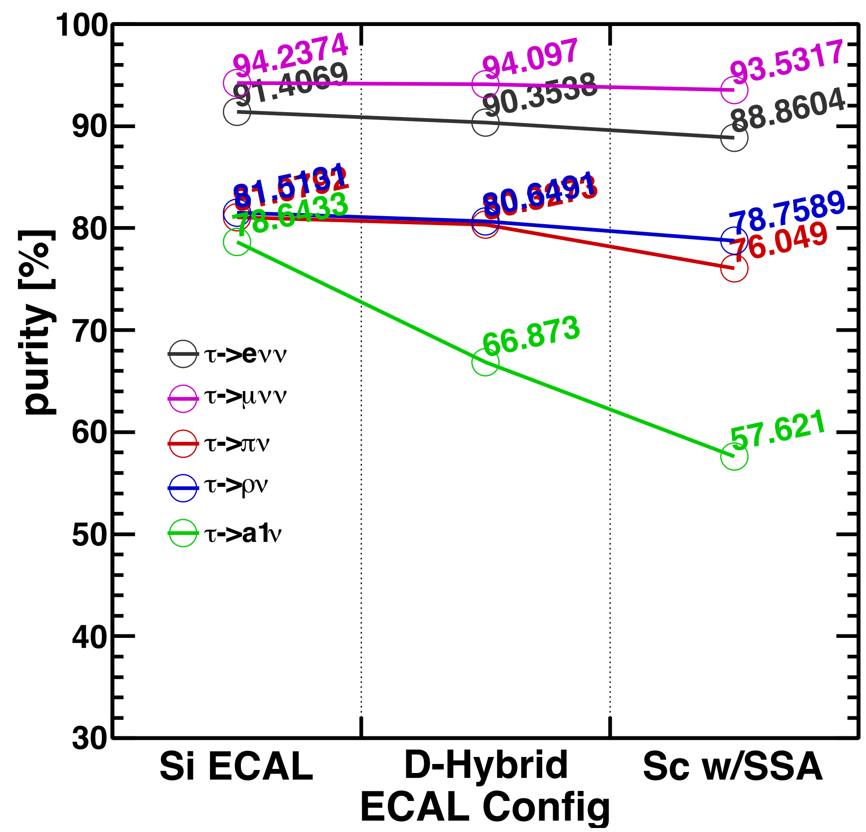
      (Good) Si ECAL > DoubleLayer Hybrid > Sci w/SSA (Not good)
  - Miss Selection
    - Also miss selection is difference.

      (Less) Si ECAL 16.54% > DoubleLayer Hybrid 18.97% > Sci w/SSA 20.39% (Not less)

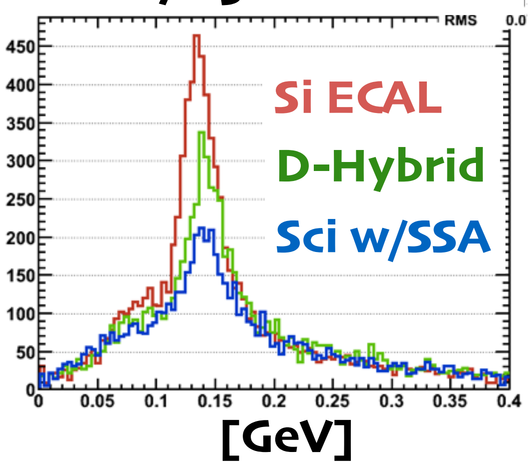
efficiency



purity



piO Mass at tau->rho
exactly 2gammas

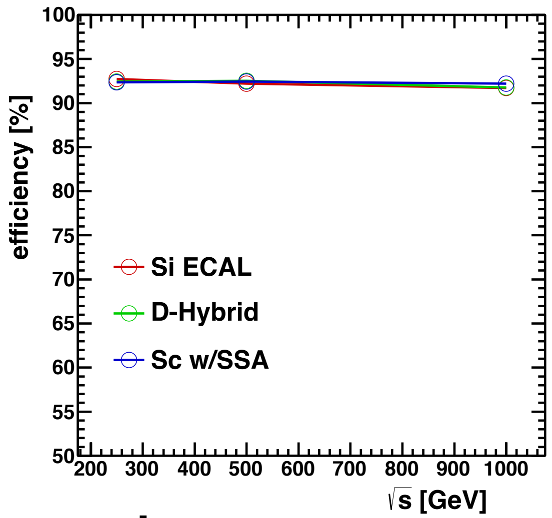


Efficiency & Purity with Loose Cut @ √s = 250, 500 & 1000 GeV

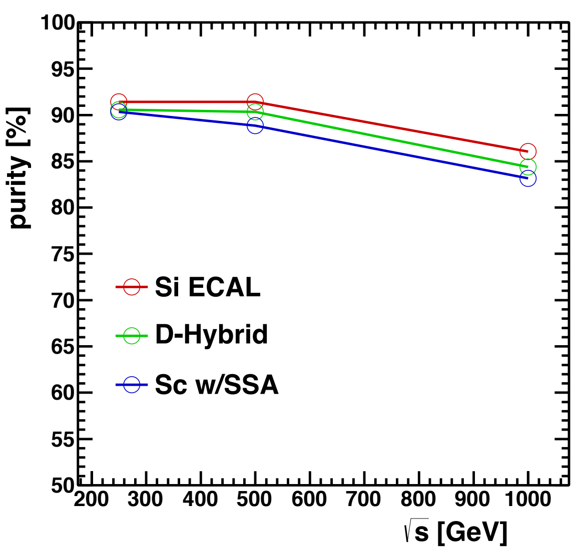
- Also simulated at some energy points 250, 500, 1000GeV.
- In e decay (leptonic decay), efficiency and purity are almost same.
- In pi decay, compared with Si ECAL, 2ECALs get a little bit worse.
- In rho and a1, with increasing energy they get worse, even Si ECAL.

e-mode

efficiency

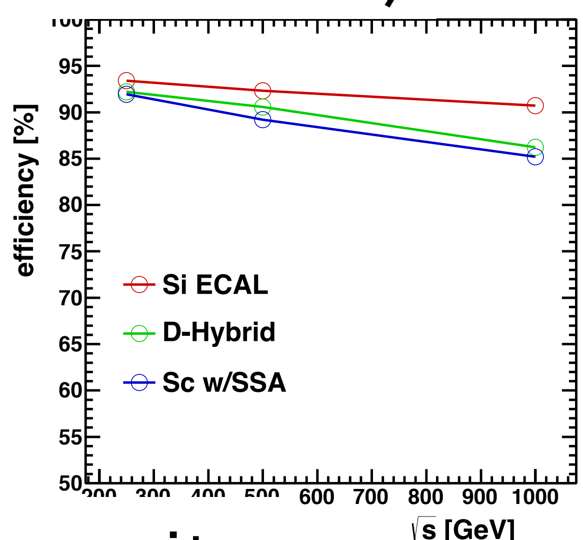


purity

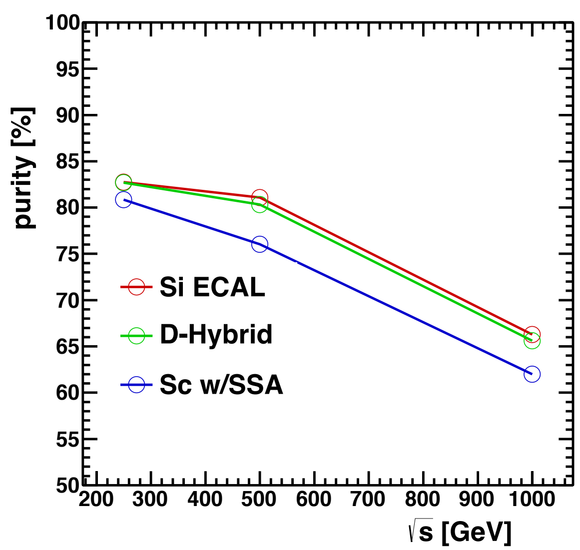


pi-mode

efficiency

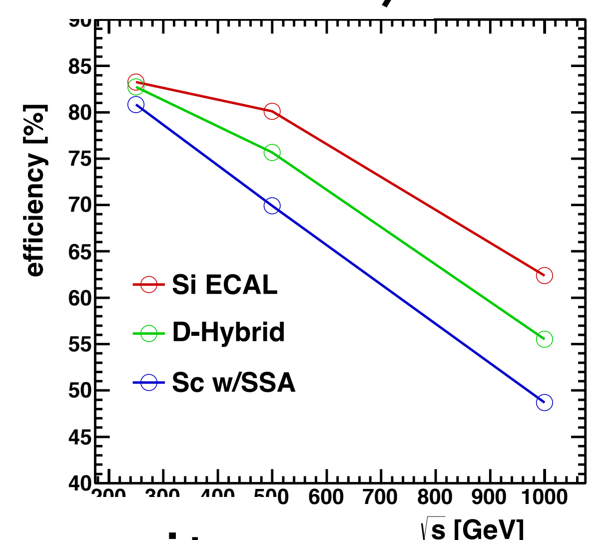


purity

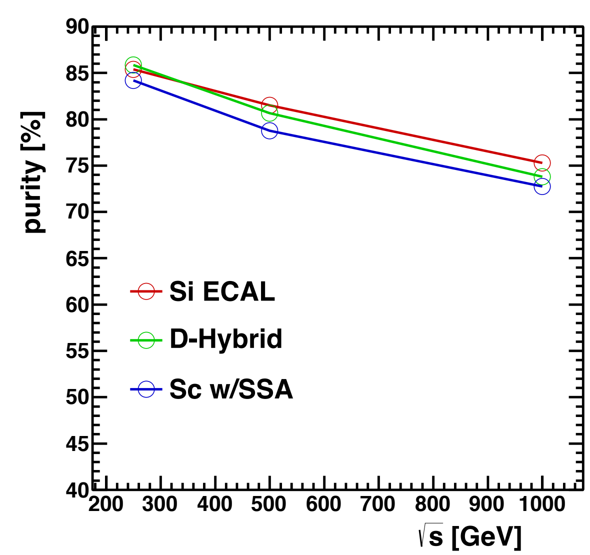


rho-mode

efficiency

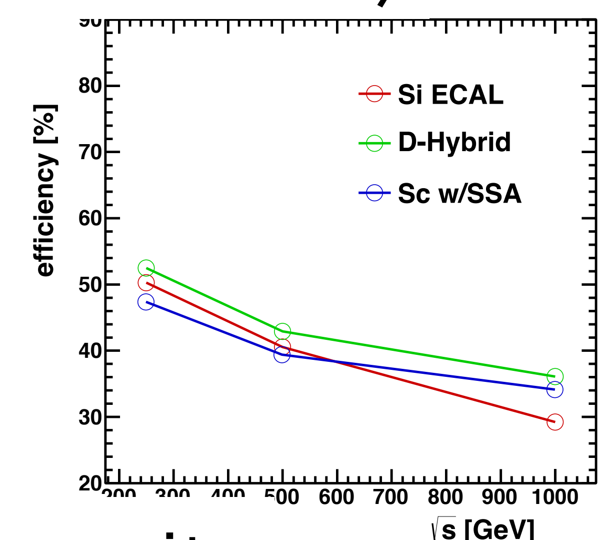


purity

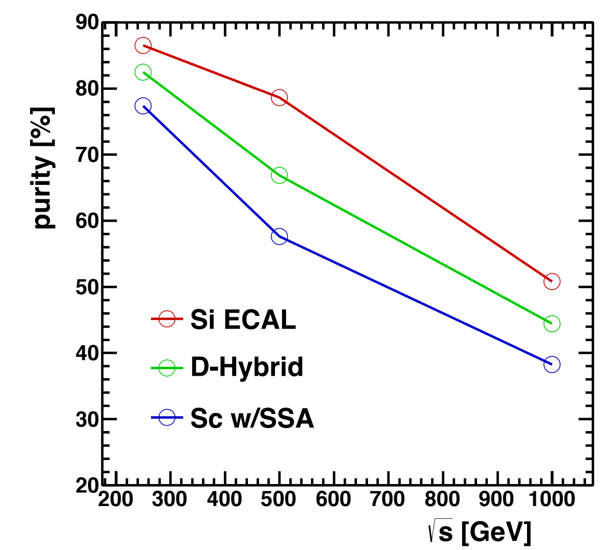


a1-mode

efficiency

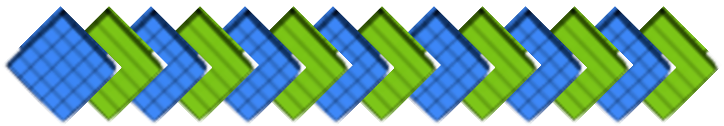


purity



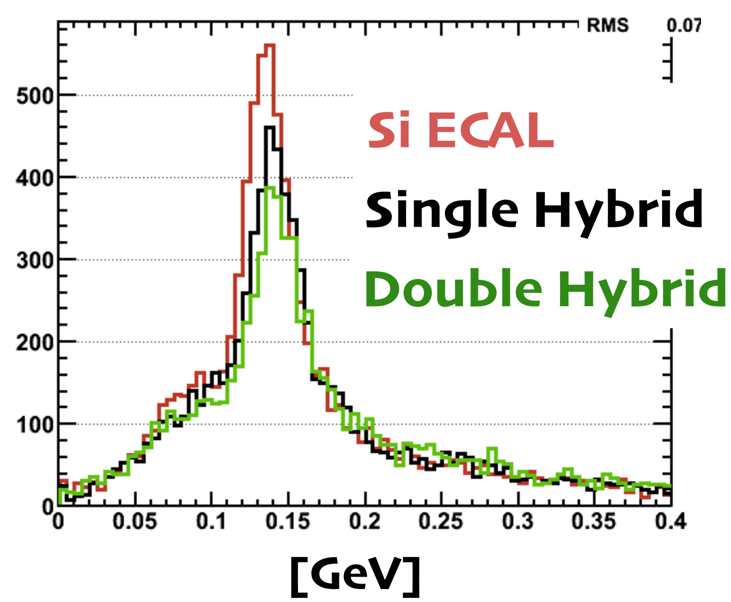
Further Configurations

- Configurations.
  - SingleLayer Hybrid



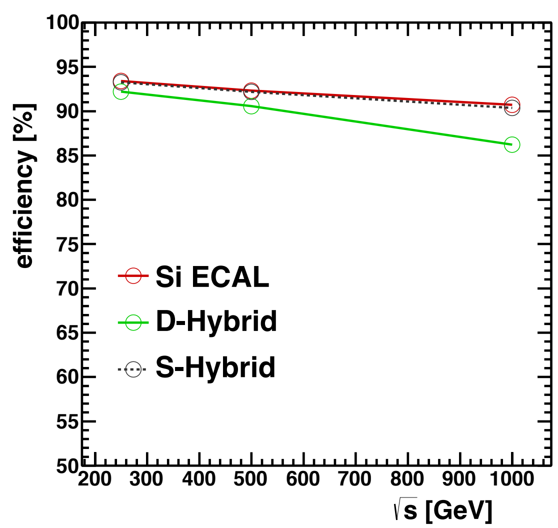
- Use Si 1-layer Sc 1-layer alternatively
- Can use precise information of Si layer and prevent ghost hit.
- Can expect almost the same performance of Si ECAL.

pi0 Mass at tau->rho
exactly 2gammas



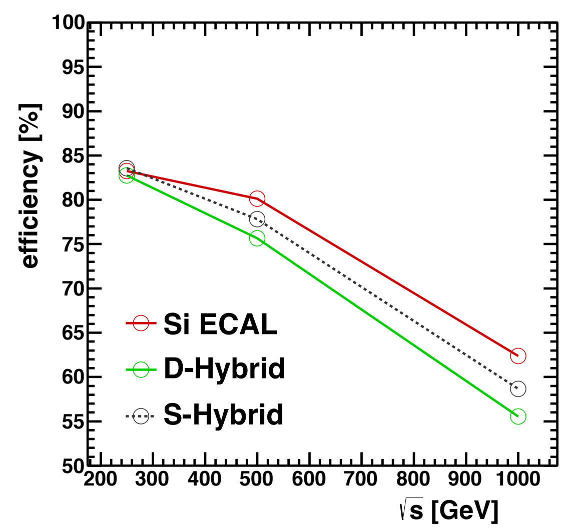
pi-mode

efficiency



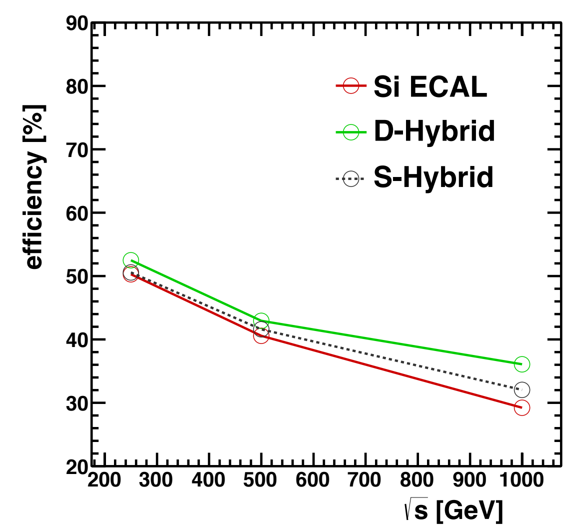
rho-mode

efficiency

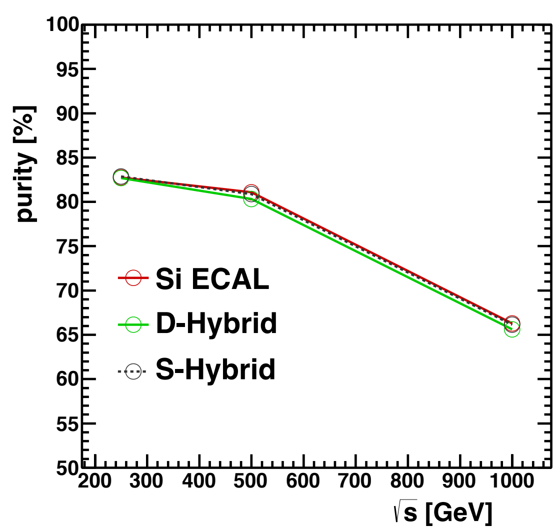


a1-mode

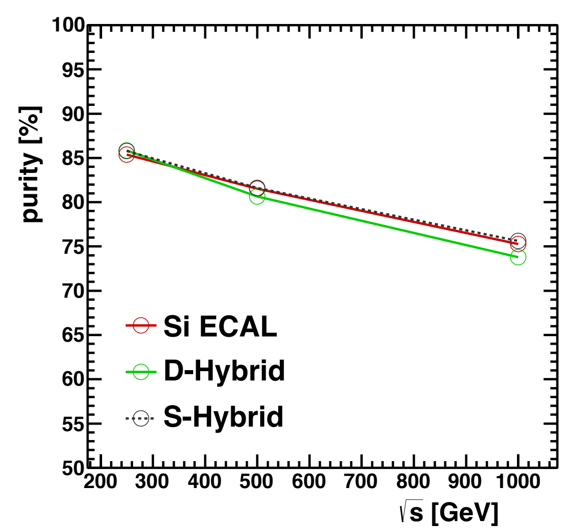
efficiency



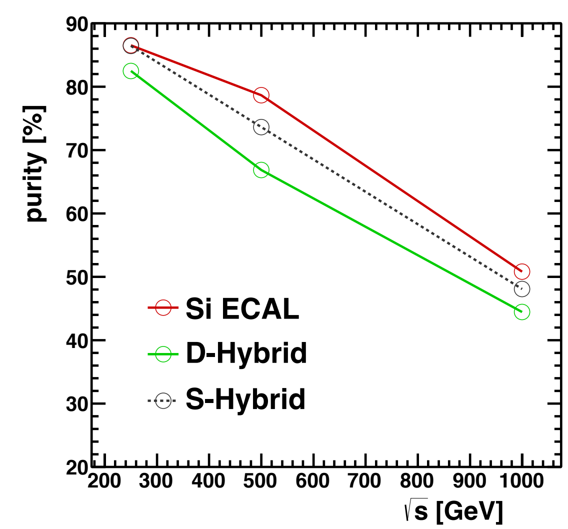
purity



purity



purity



- Under progress.
  - Scinti 45x5 + Scinti 10x10

Polarization and Optimal observable ω

- we can measure a polarization from the angular distribution of decay daughters.

  → the precise information of decay daughters is important

- The main observable are energies and angles of/between daughters in τ rest-frame.

  (- Since the neutrino is not observed, E and θ cannot be reconstructed completely.)

- Polarization calculation varies by decay modes.

- We can estimate by using optimal observable ω.

- Leptonic decay :

$$\omega_l = \frac{1 + x - 8x^2}{5 + 5x - 4x^2}$$

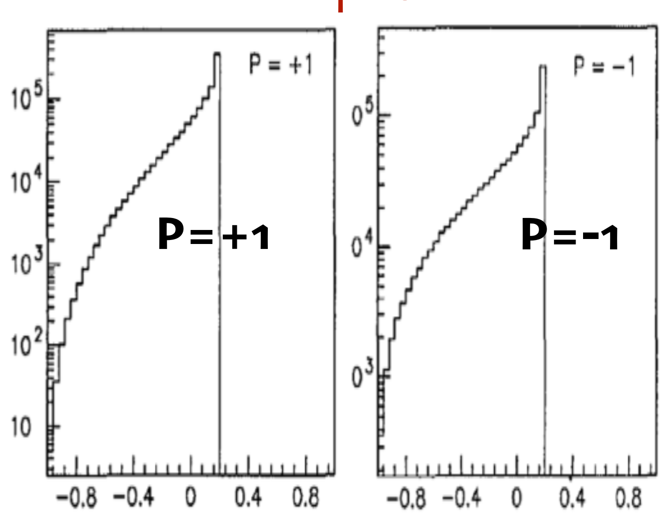
- Hadronic decay :

$$\omega_\pi = 2x - 1$$

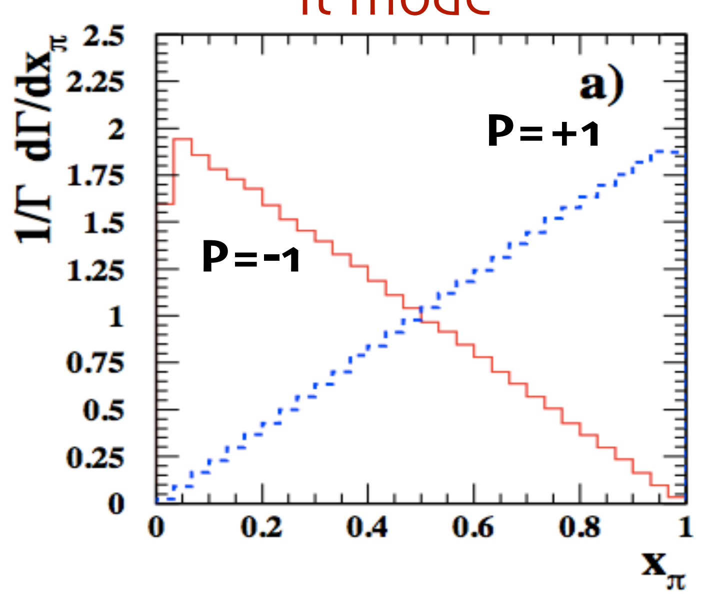
$$\omega_\rho = \frac{\left(-2 + \frac{m_\tau^2}{Q^2} + 2\left(1 + \frac{m_\tau^2}{Q^2}\right)\frac{3\cos\psi - 1}{2}\frac{3\cos^2\beta - 1}{2}\right)\cos\theta + 3\sqrt{\frac{m_\tau^2}{Q^2}}\frac{3\cos^2\beta - 1}{2}\sin 2\psi \sin\theta}{2 + \frac{m_\tau^2}{Q^2} - 2\left(1 - \frac{m_\tau^2}{Q^2}\right)\frac{3\cos\psi - 1}{2}\frac{3\cos^2\beta - 1}{2}}$$

$$\cos\psi = \frac{x(m_\tau^2 + Q^2) - 2Q^2}{(m_\tau^2 - Q^2)\sqrt{x^2 - 4Q^2/s}}$$

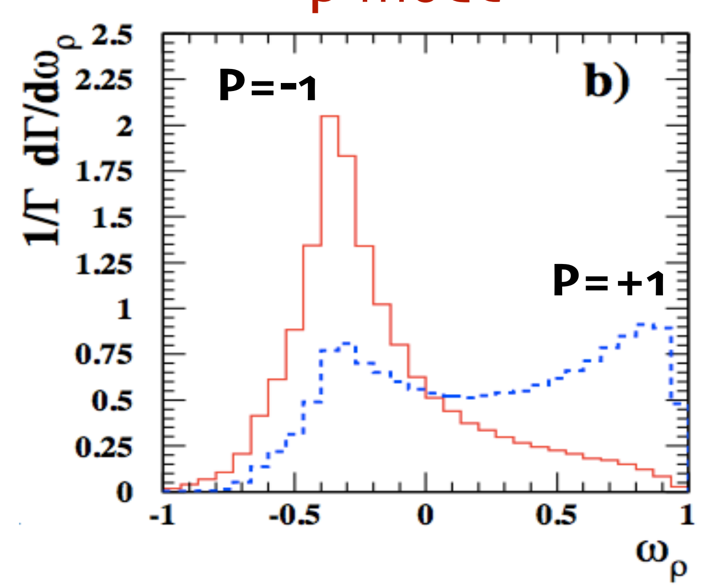
Leptonic



π mode



ρ mode



- So far, i do not consider a1 mode.

Polarization with 3Detectors

- Compared with 3 ECALs :
  Si ECAL, D-Hybrid, Sci w/SSA.

- Apply ω formula on sample
  after some cut applied.

- Loose cut is used for mode selection.

- Initial beam polarization.

Beam polarized : e-, e+ = -80%, +30%

e-, e+ = +80%, -30%

MCtrue

Si ECAL

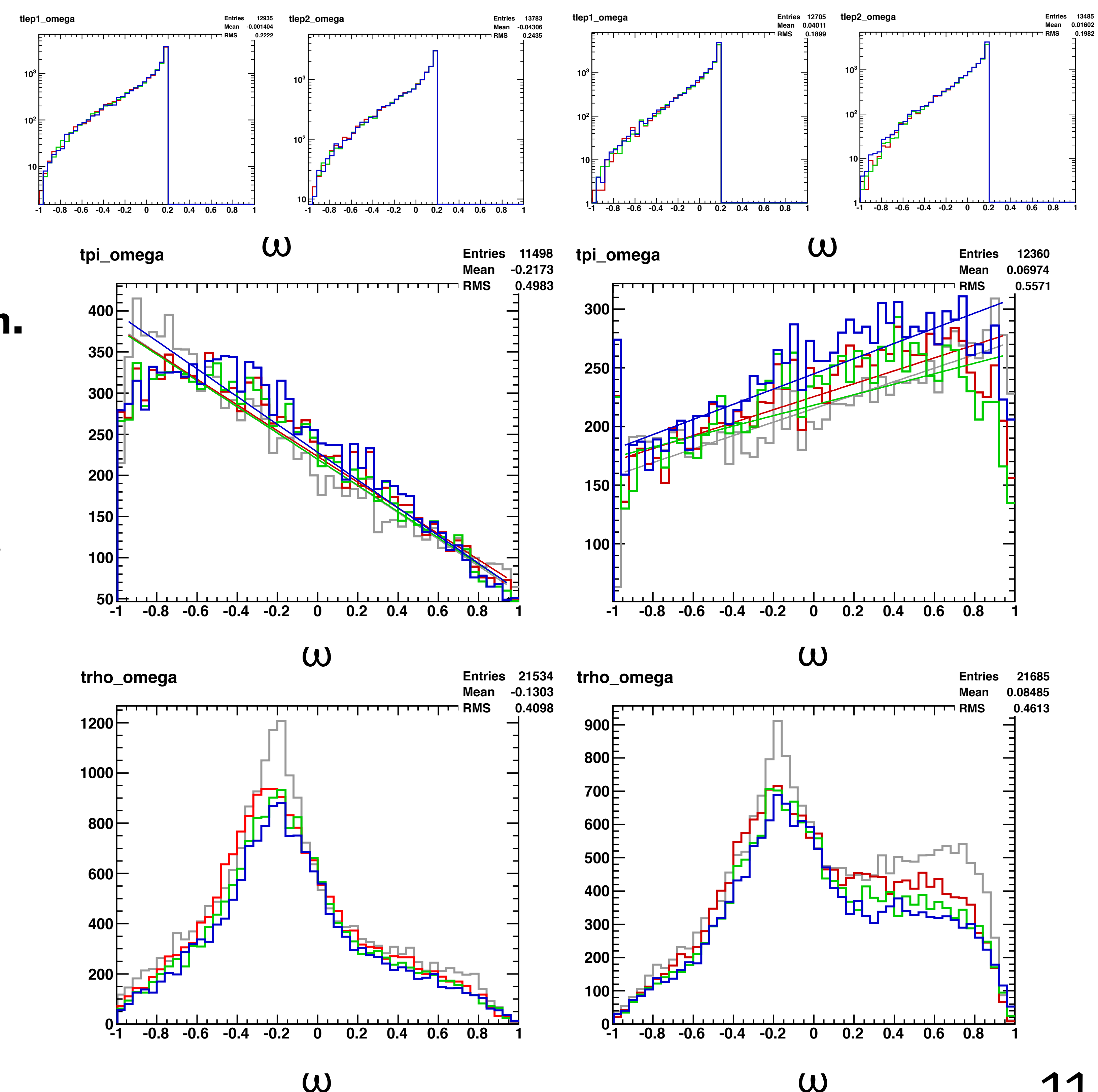
D-Hyvrid

Sci w/SSA

- difference appears
  at e-, e+ = +80%, -30%

e-, e+ = -80%, +30%

e-, e+ = +80%, -30%

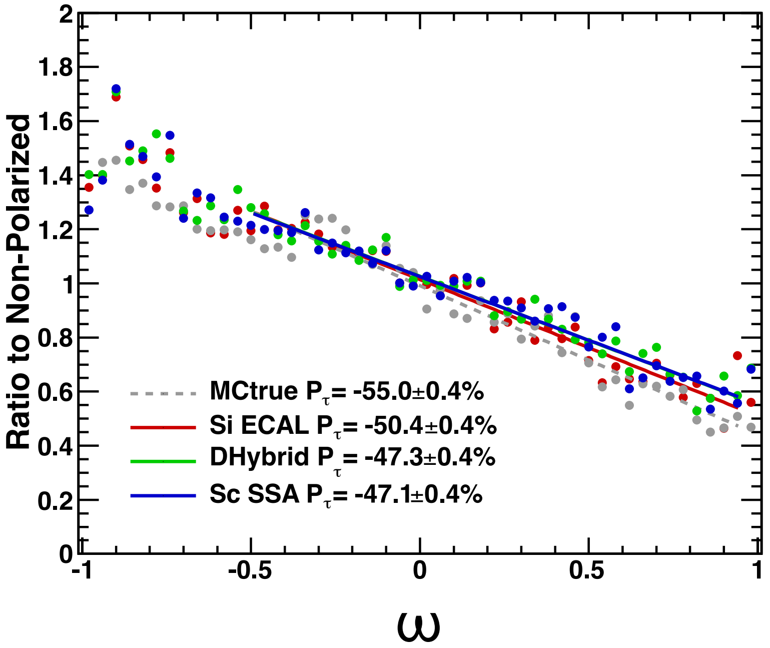


Polarization combined ω with 3Detectors

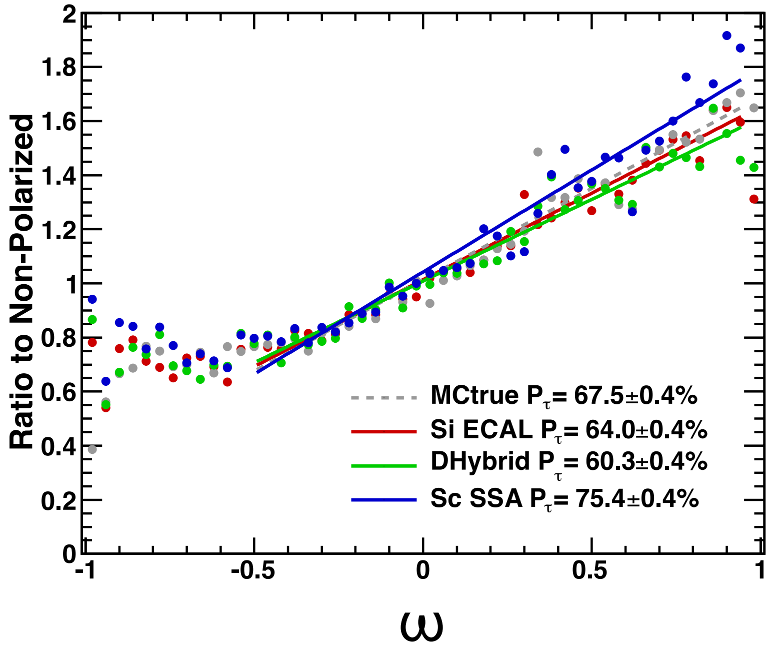
- Formula of ω differs by decay modes,
  but ω can be summed up through all decay modes.

  → Ratio to non-polarized sample.

e-L e+R = 80% 30%



e-R e+L = 80% 30%



- Obtained P(tau)

e-L e+R	e-R e+L
- MC true : 55.0%	- MC true : 67.5%
- Si ECAL : 50.4%	- Si ECAL : 64.0%
- DHybrid : 47.3%	- DHybrid : 60.3%
- Sc w/SSA : 47.1%	- Sc w/SSA : 75.4%

- estimated tau polarization and compared with 3ECALs.

- do not include error and need to analysis more precisely.

Summary & Outlook

- I simulated tau-pair events with some ILD ECAL candidates to test ECAL performance.

- Decay mode identified with Cut base.

  - For leptonic decay, performance is almost same between 3ECALs.

  - For hadronic decay mainly rho and a1 mode, performance is different between 3ECALs.

    rho mode : Efficiency of D-Hybrid and Sc w/SSA decrease 5% by 5% from one of Si ECAL.

    a1 mode : Efficiency of D-Hybrid and Sc w/SSA is almost same with one of Si ECAL.

    but purity decrease 10% by 10% from one of Si ECAL.

- With increasing √s the gammas are closer and it is more difficult for even Si ECAL to reconstruct them.

- Simulation with further configuration is under progress.

  Efficiency and purity of S-Hybrid is improved.

  we can expect S-Hybrid will be almost the same performance of Si ECAL

- And also, we compared tau polarization and the difference appears.

  → Including systematic error and need to analysis more precisely.

Backup

Comparison of Performance on Tau with ILD ECAL candidates

- we want to estimate the performance of ECALs with the ILD bench mark process ee -> ττ.

- Identifying and measuring gammas (from πos) in jets is already an important/crucial requirement.

- Also, the full reconstruction of taus may be yet more challenging and the physics opportunities are potentially crucial. (Taus appear in many New Physics signatures)

- At high energy, daughters of τ decay are concentrated in a very narrow angle and a narrow area due to the Lorentz boost.

→ it is difficult to separate particles with PFA (). → ILD demands well segmented ECAL. .

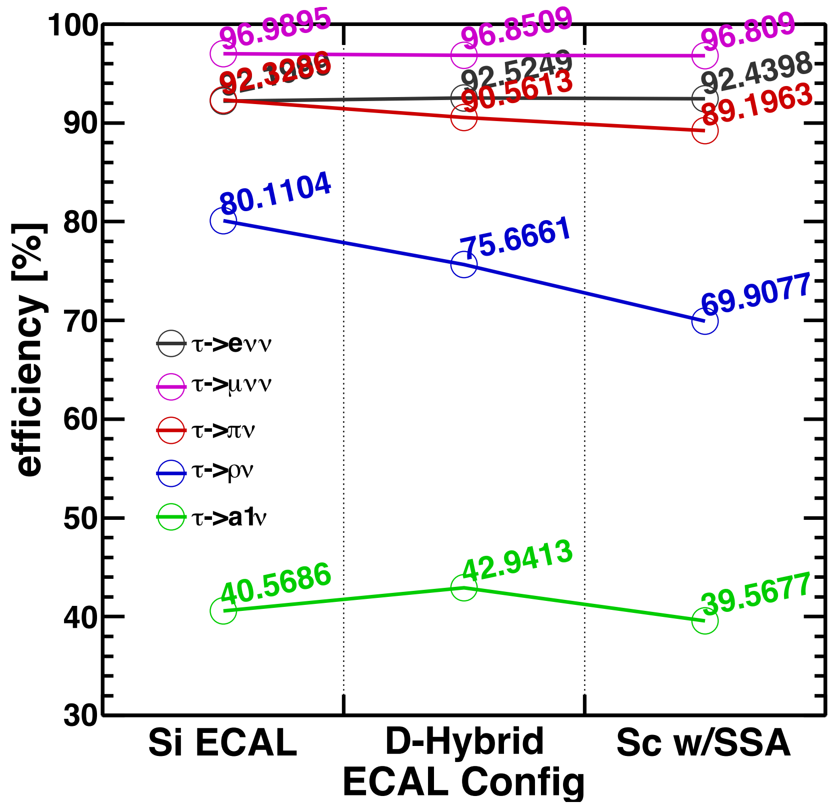
I compared tau reconstruction

1-prong decay
e, mu, pi, rho, a1

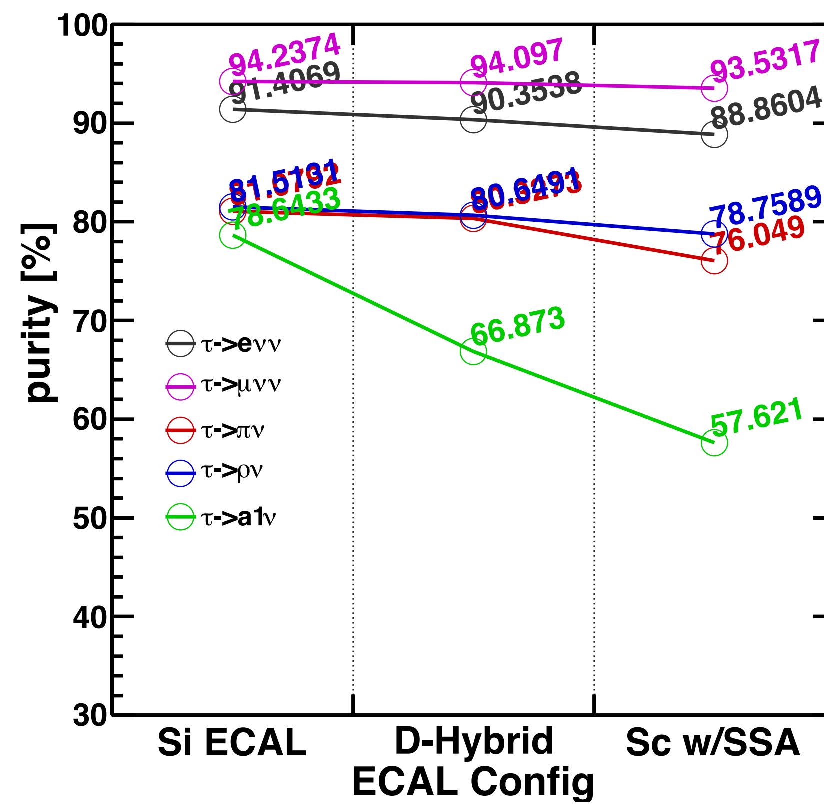
with some ECALs

Si ECAL, Hybrid, Sci ECAL

efficiency



purity



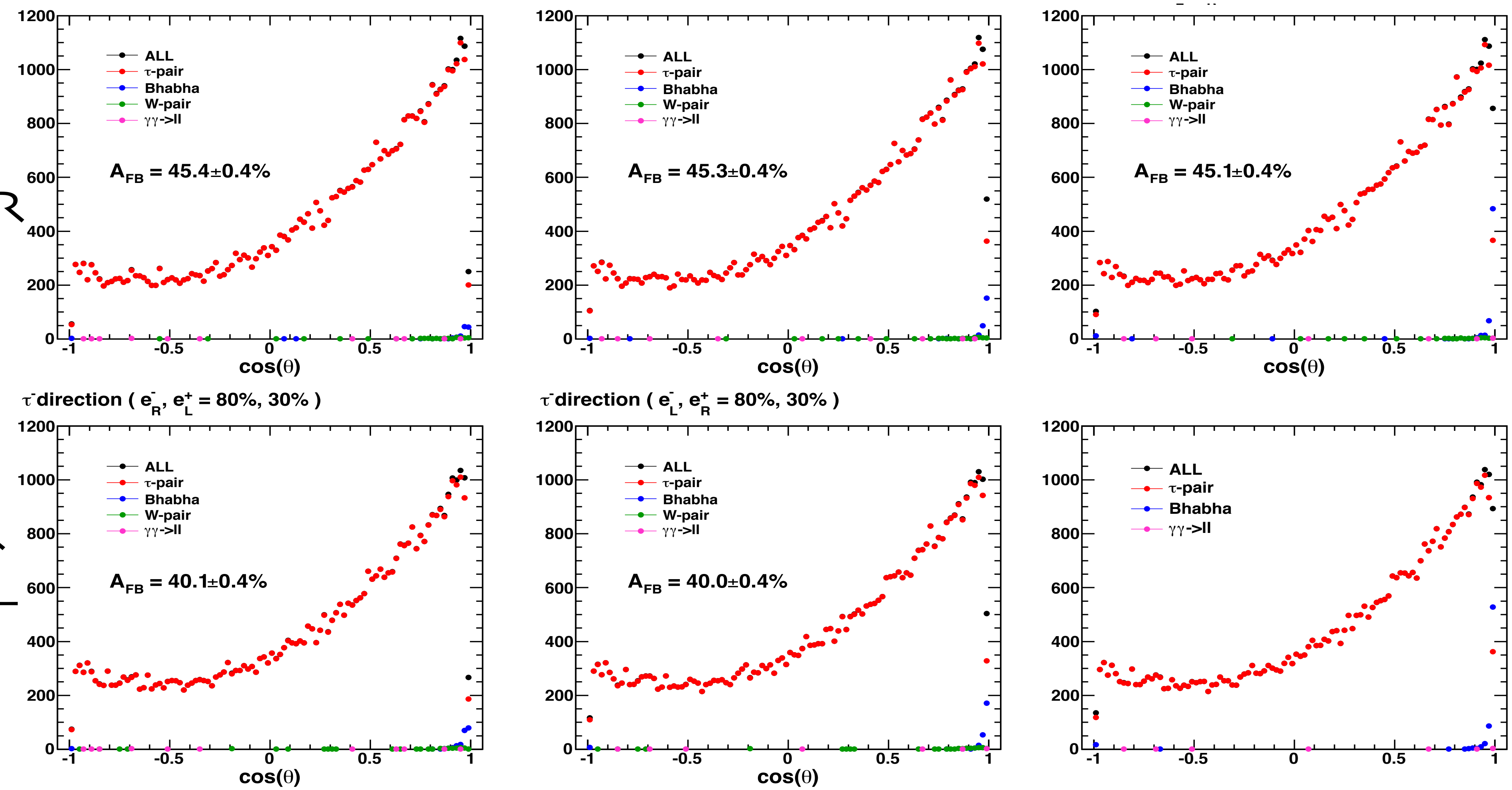
Forward-Backward Asymmetry

- **Angular distribution of tau- (-0.99 < cosθ < 0.99)**

- Si ECAL　　- DoubleLayer Hybrid　　- Sci ECAL w/SSA

e-L e+R

e-R e+L



→ Afb does not depend on ECal geometries.

But need to consider BG properly.

	e-L, e+R	e-R, e+L
Si Ecal	45.4±0.4%	40.1±0.4%
Hybrid	45.3±0.4%	40.0±0.4%
Sc SSA	45.1±0.4%	40.4±0.2%

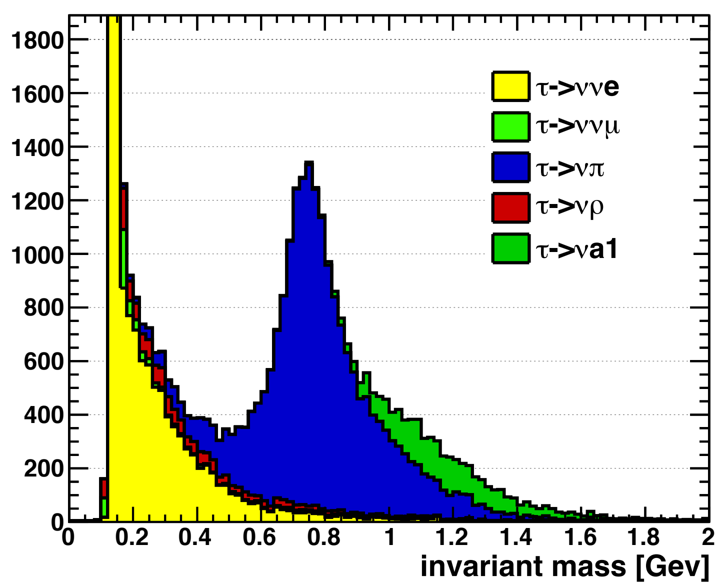
Miss Selection with Loose Cut

- Comparison of Detectors in each decay

- Si ECAL

Reconstructed mode (columns) / decay mode (rows)

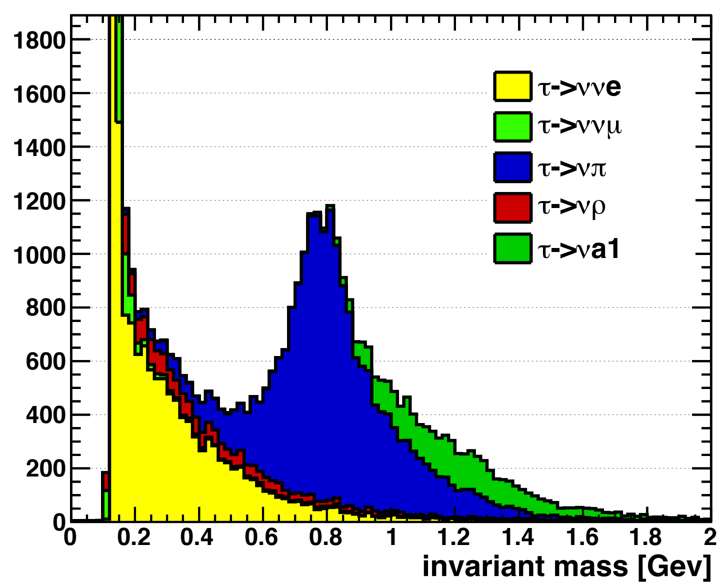
(%)	π	ρ	a1
e	1.27	2.53	3.98
μ	1.03	1.67	2.51
π	**92.30**	5.65	2.89
ρ	3.74	**80.11**	38.61
a1	0.30	3.49	**40.57**
×	1.36	6.55	11.47



- DoubleLayer Hybrid

Reconstructed mode (columns) / decay mode (rows)

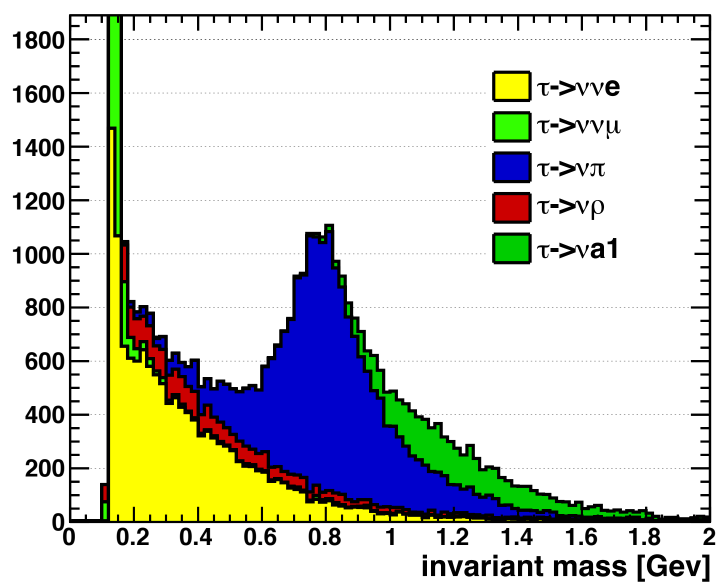
(%)	π	ρ	a1
e	1.25	3.05	4.21
μ	0.98	1.55	2.30
π	**90.56**	6.04	3.18
ρ	5.41	**75.67**	35.25
a1	0.44	6.98	**42.94**
×	1.36	6.71	12.12



- Sci ECAL w/SSA

Reconstructed mode (columns) / decay mode (rows)

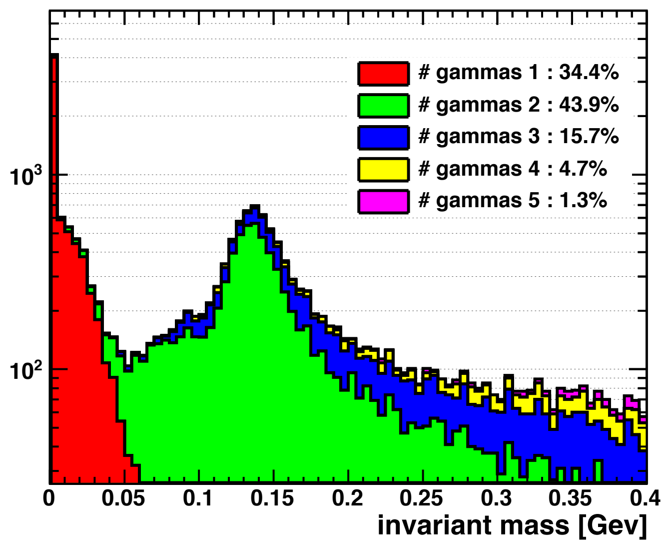
(%)	π	ρ	a1
e	1.53	3.45	4.90
μ	1.11	1.65	2.35
π	**89.19**	8.52	4.06
ρ	6.03	**69.90**	36.35
a1	0.76	9.68	**39.57**
×	1.38	6.80	12.77



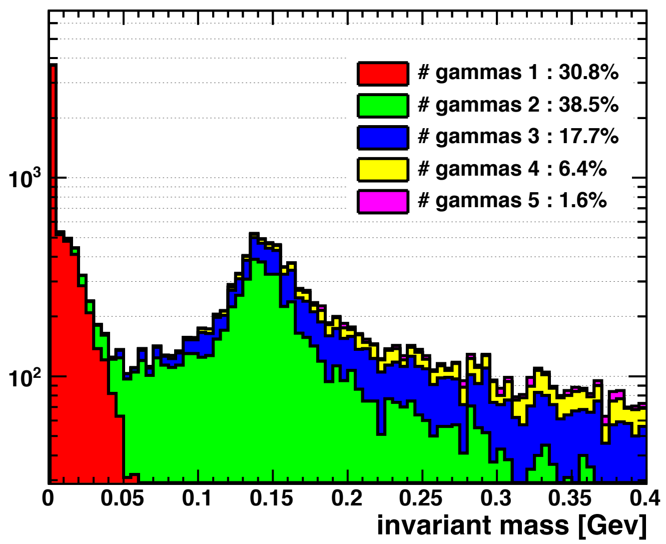
PiO at Rho mode with Loose Cut

- Comparison of Detectors.

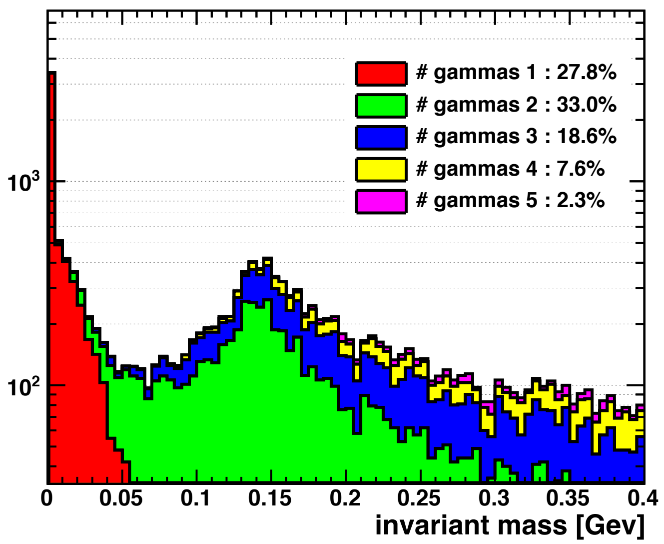
- Si ECAL



- DoubleLayer Hybrid

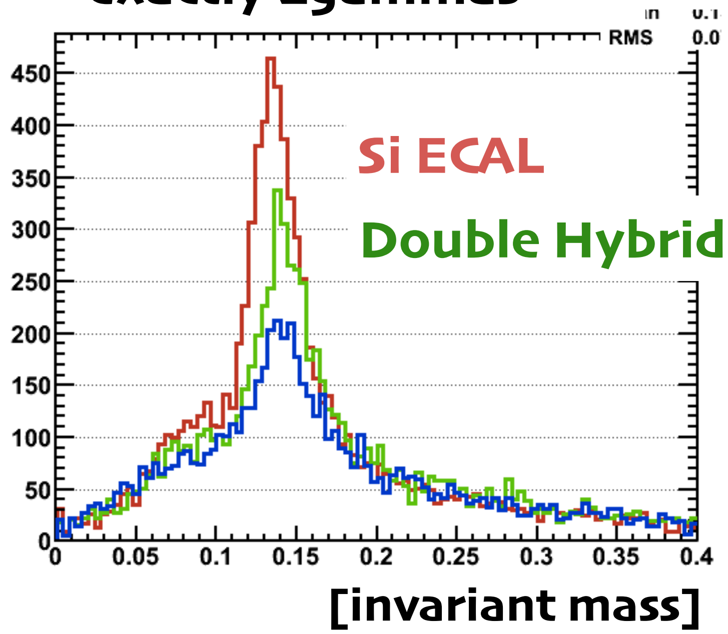


- Sci ECAL w/SSA



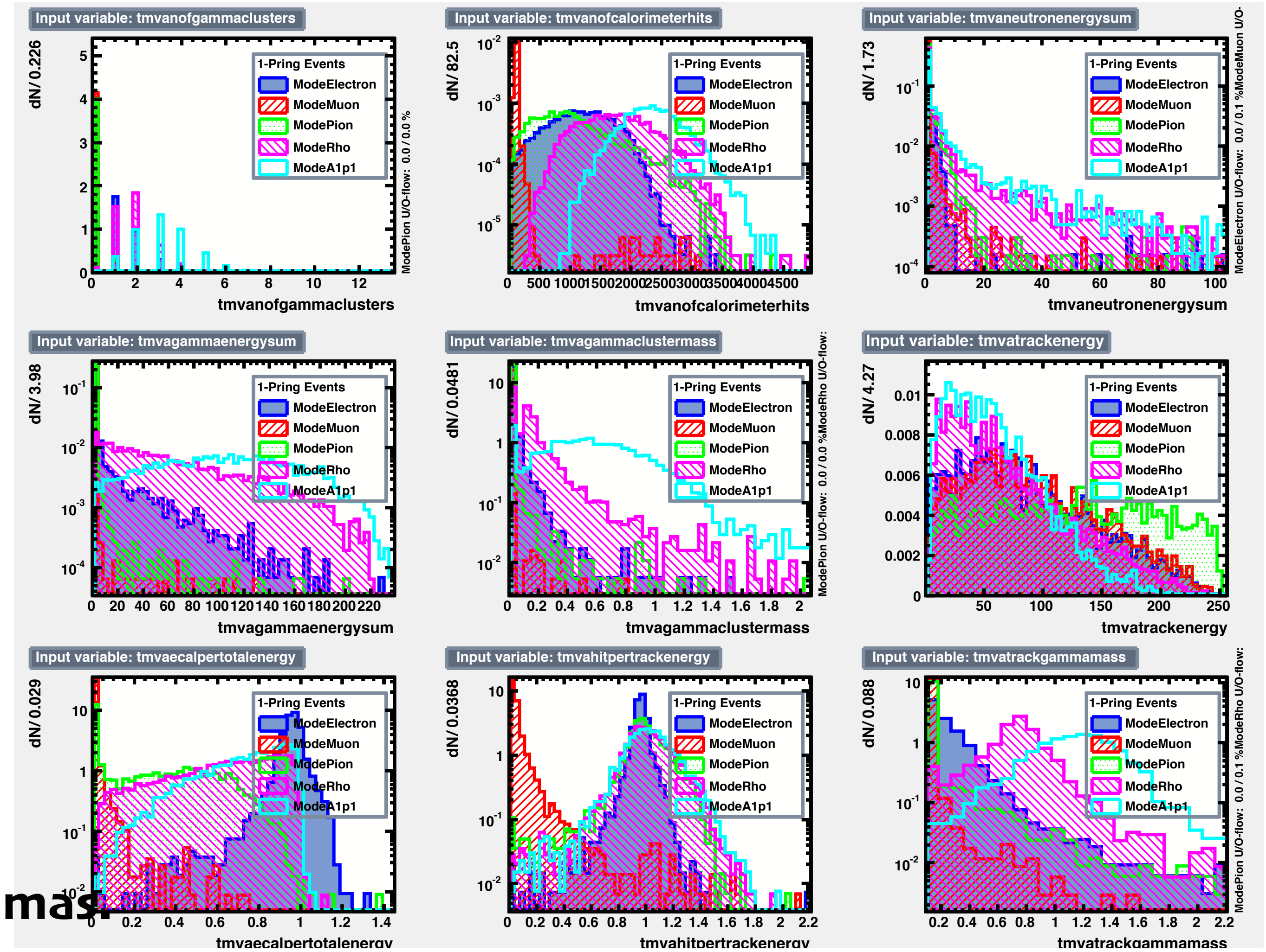
- Exactly 2-gammas.

piO Mass at tau->rho exactly 2gammas



MVA input Variables

Distribution of input variables (in case of Si ECAL)



- Training sample

Training on each mode

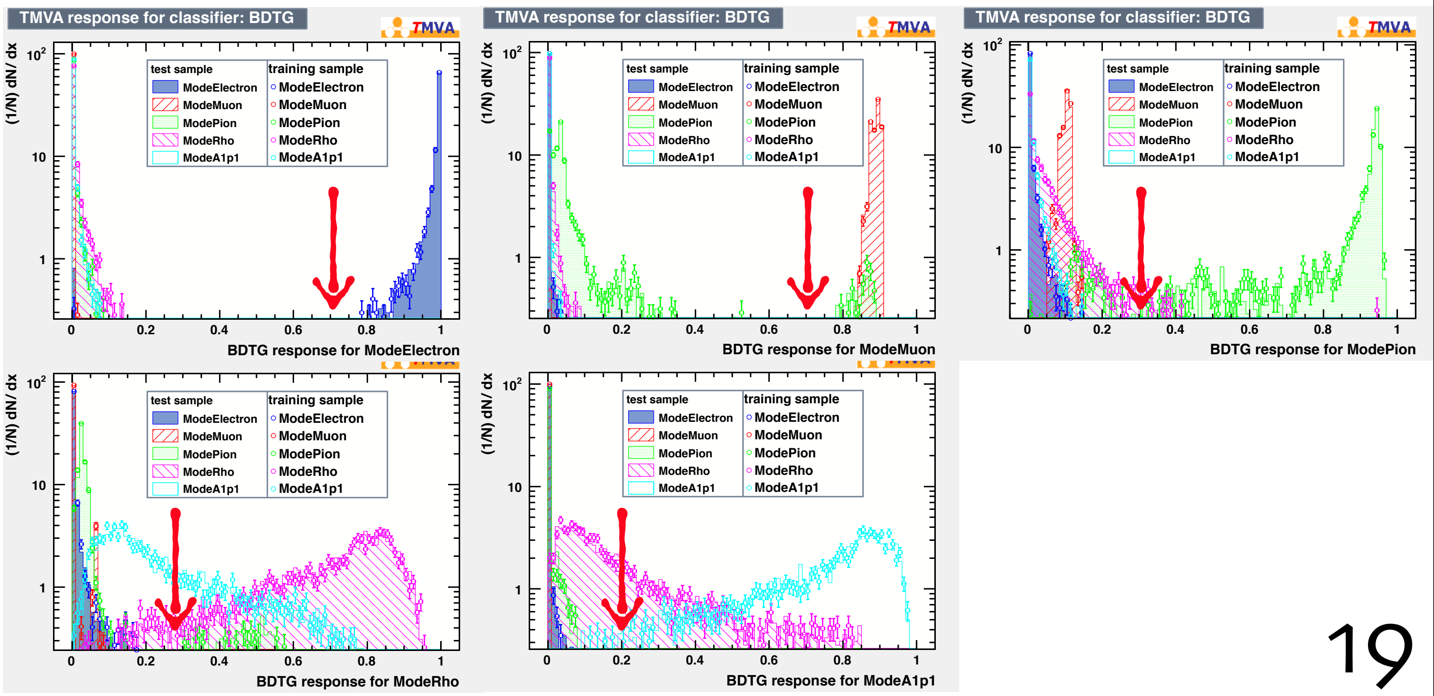
√500GeV e-Le+R -> tau-tau+

tau -> only e decay (mu, pi, rho, a1p1)

- MVA input 9variables.

1. #of gamma clusters.
2. Sum of gamma energy.
3. Mass of gamma clusters.
4. #of calorimeter Hits.
5. Sum of neutron energy.
6. Track energy.
7. ECAL E / Total E.
8. Hit E / Track E.
9. Mass of track+gammas.

MVA response (in case of Si ECAL)



- Method is BDT

Response : 0 (false) ~ 1 (true)

e mode Response > 0.7

μ mode Response > 0.7

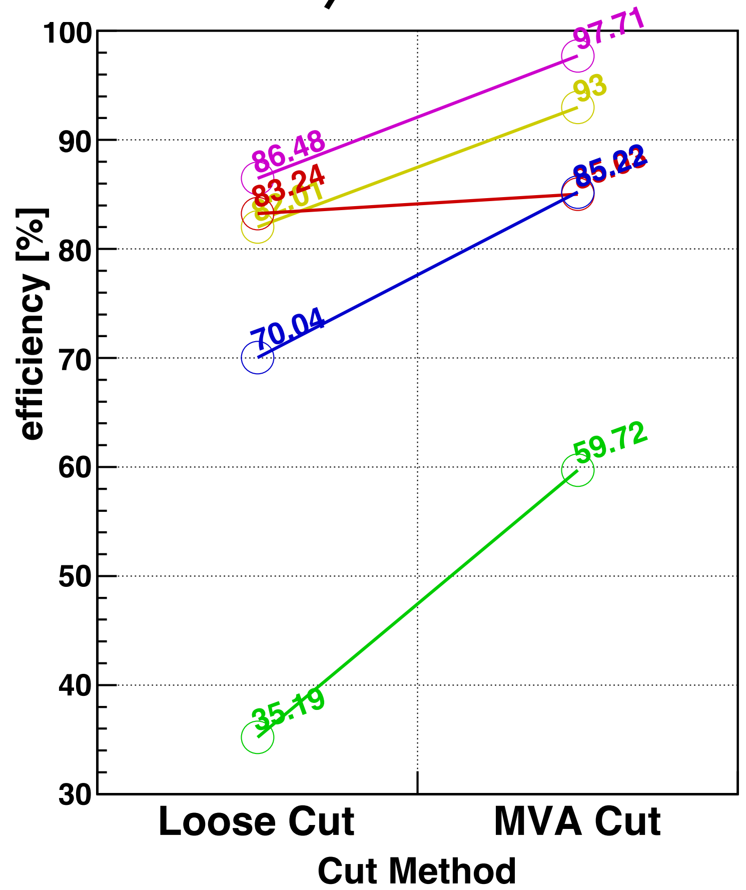
π mode Response > 0.3

ρ mode Response > 0.28

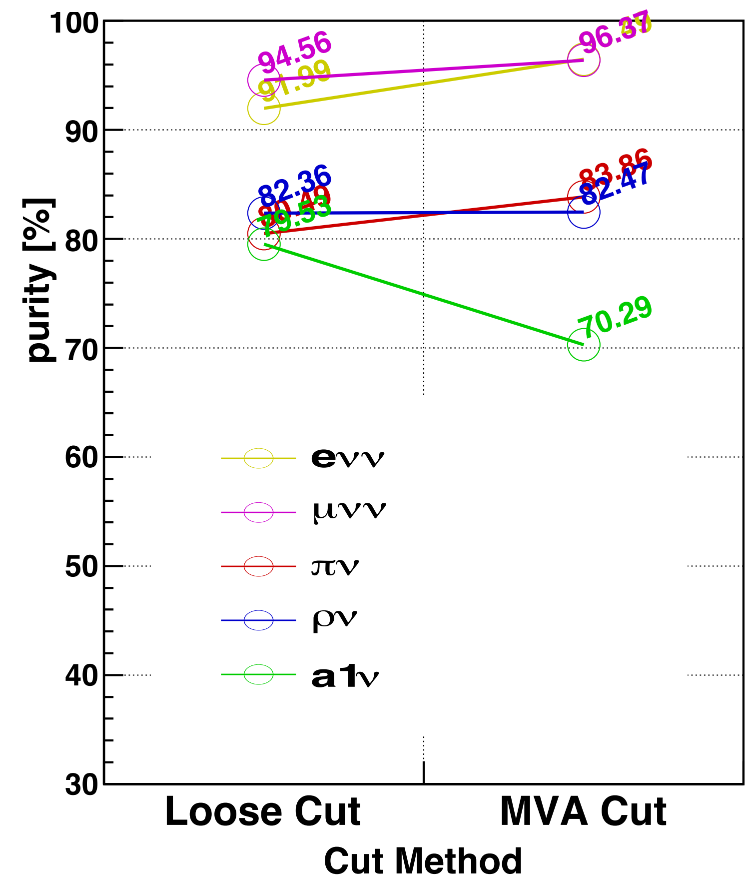
a1p1 mode Response > 0.2

Comparison of Cut Method in Si ECAL

efficiency



purity



- Comparison of Cut Method

  - √500GeV e-Le+R -> tau-tau+

  - Detector

    In case of Si ECAL.

  - Only 1-prong decay

    e, mu, pi, rho, a1p1

  - Cut

    Loose Cut, MVA Cut.

  - MVA Cut

    is over 80% on both efficiency and purity (except a1p1 decay).

  - Miss Selection

    In case of Loose Cut, ratio is 16.54%.

    In case of MVA Cut, ratio is 13.34%.

Efficiency & purity with MVA Cut

- Comparison of Detectors
  - √500GeV e-Le+R -> tau-tau+
  - Detectors

    Si ECAL,

    DoubleLayer Hybrid

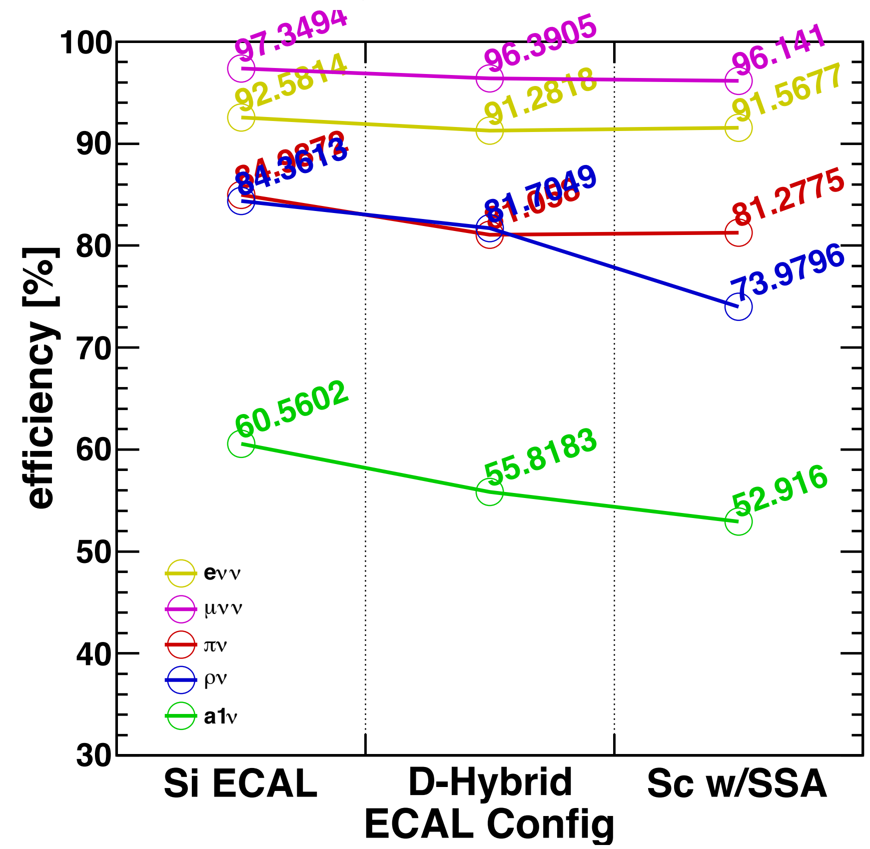
    Sci ECAL w/SSA
  - Cut

    MVA Cut
  - Efficiency & Purity
    - Improved generally by MVA
    - In reconstruction of leptonic decay, efficiency and purity are almost same.
    - In reconstruction of hadronic decay, efficiency and purity are difference.

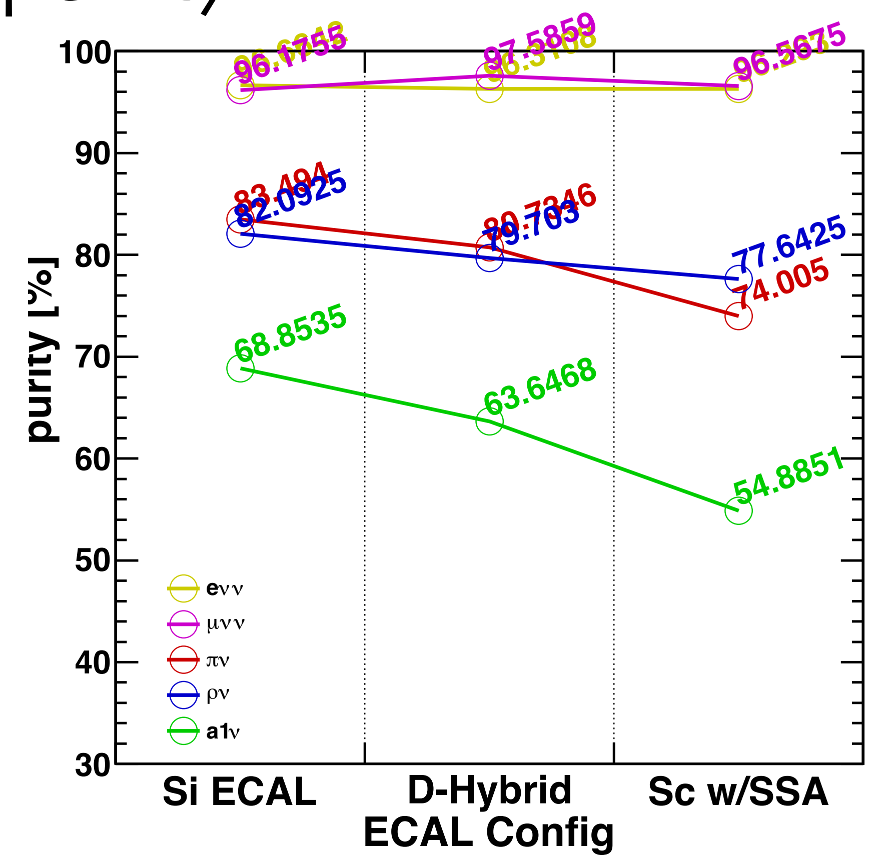
      (Good) Si ECAL > DoubleLayer Hybrid > Sci w/SSA (Not good)
  - Miss Selection
    - Also miss selection is difference.

      (Less) Si ECAL 13.34% > DoubleLayer Hybrid 15.19% > Sci w/SSA 18.23% (Not less)

efficiency



purity



Miss Selection with MVA Cut

- **Comparison of Detectors in each decay**

- Si ECAL

Reconstructed mode

decay mode

(%)	π	ρ	a1
e	1.25	0.95	0.74
μ	4.09	0.14	0.09
π	**84.99**	**5.53**	**1.20**
ρ	**5.98**	**84.36**	**37.24**
a1	**1.41**	**8.45**	**60.56**
×	2.28	0.57	0.17

- DoubleLayer Hybrid

Reconstructed mode

decay mode

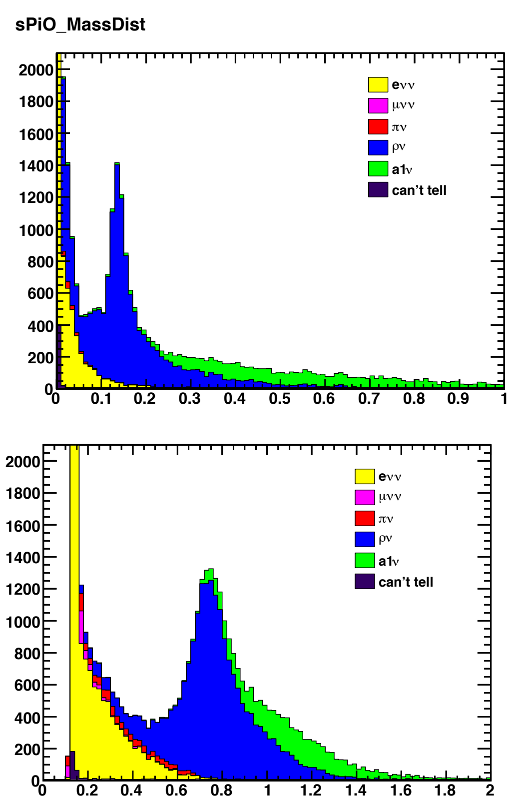
(%)	π	ρ	a1
e	1.52	1.01	0.65
μ	2.11	0.07	0.07
π	**81.06**	**6.96**	**1.27**
ρ	**6.95**	**81.70**	**42.02**
a1	**1.72**	**9.57**	**55.82**
×	6.11	0.69	0.17

- Sci ECAL w/SSA

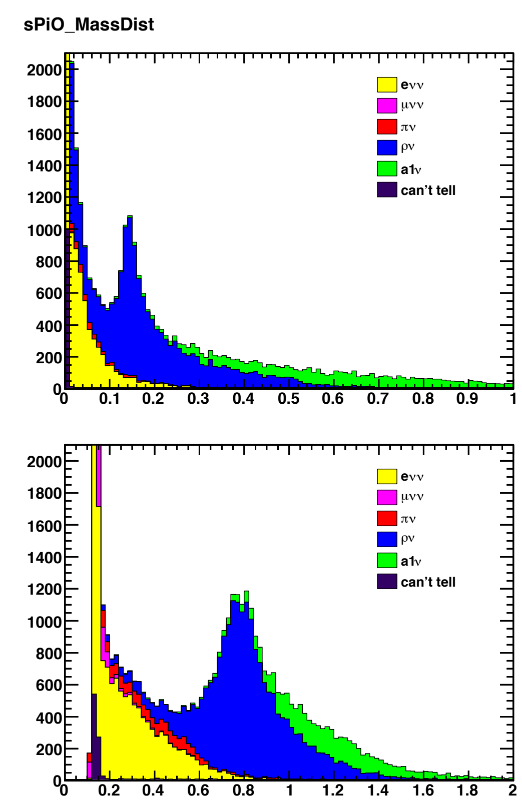
Reconstructed mode

decay mode

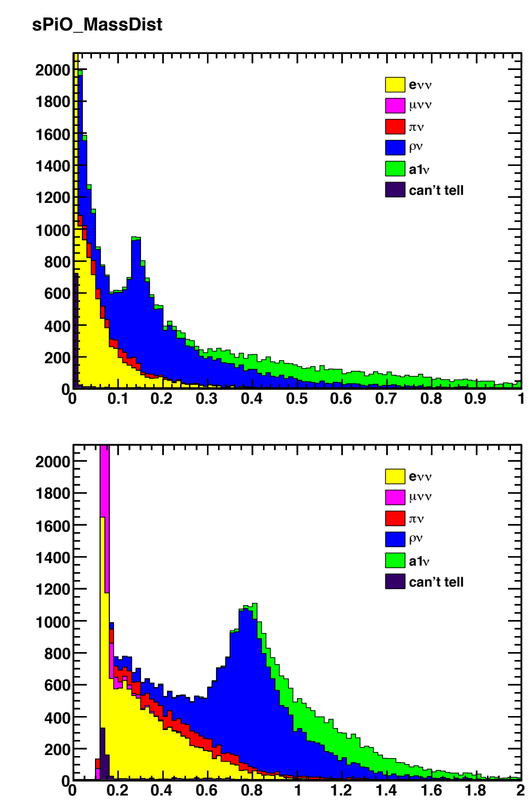
(%)	π	ρ	a1
e	1.71	0.97	0.60
μ	3.12	0.14	0.11
π	**81.28**	**10.76**	**2.54**
ρ	**7.35**	**73.98**	**43.71**
a1	**2.34**	**13.24**	**52.96**
×	4.2	0.91	0.08



[invariant mass]



[invariant mass]



[invariant mass]

3Detectors @ tautau with Loose Cut

Si ECAL thick0.5mm

Efficiency, Purity & Acceptance
(with **Loose Cut**)

Lepton1Mode Efficiency = 81.21
Lepton1Mode Purity = 91.99
Lepton1Mode Acceptance = 88.27

Lepton2Mode Efficiency = 86.48
Lepton2Mode Purity = 94.56
Lepton2Mode Acceptance = 91.46

PionMode Efficiency = 83.24
PionMode Purity = 80.49
PionMode Acceptance = 103.4

RhoMode Efficiency = 70.04
RhoMode Purity = 82.36
RhoMode Acceptance = 85.04

A1p1Mode Efficiency = 35.19
A1p1Mode Purity = 79.53
A1p1Mode Acceptance = 44.25

MissSelectionRatio = 16.54

ADoubleLayer Sci-thick1.0mm

Efficiency, Purity & Acceptance
(with **Loose Cut**)

Lepton1Mode Efficiency = 80.98
Lepton1Mode Purity = 91.13
Lepton1Mode Acceptance = 88.86

Lepton2Mode Efficiency = 86.05
Lepton2Mode Purity = 95.15
Lepton2Mode Acceptance = 90.44

PionMode Efficiency = 80.02
PionMode Purity = 78.47
PionMode Acceptance = 101.9

RhoMode Efficiency = 66.30
RhoMode Purity = 81.20
RhoMode Acceptance = 81.65

A1p1Mode Efficiency = 37.37
A1p1Mode Purity = 69.18
A1p1Mode Acceptance = 54.01

MissSelectionRatio = 18.97

Sci w/ SSA Sci-thick1.0mm

Efficiency, Purity & Acceptance
(with **Loose Cut**)

Lepton1Mode Efficiency = 81.10
Lepton1Mode Purity = 90.31
Lepton1Mode Acceptance = 89.79

Lepton2Mode Efficiency = 86.39
Lepton2Mode Purity = 94.78
Lepton2Mode Acceptance = 91.15

PionMode Efficiency = 79.29
PionMode Purity = 77.77
PionMode Acceptance = 101.9

RhoMode Efficiency = 63.58
RhoMode Purity = 80.25
RhoMode Acceptance = 79.22

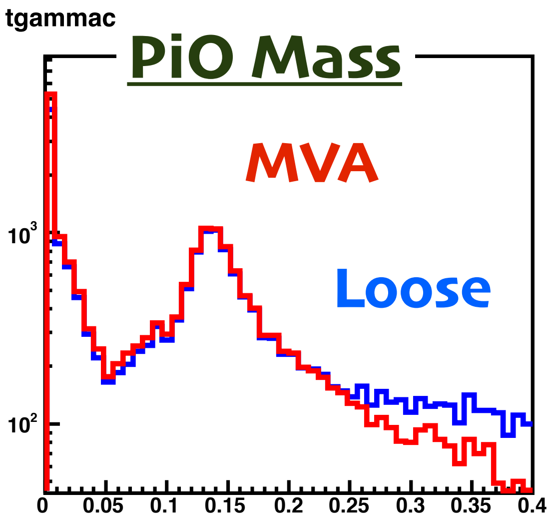
A1p1Mode Efficiency = 36
A1p1Mode Purity = 59.28
A1p1Mode Acceptance = 60.74

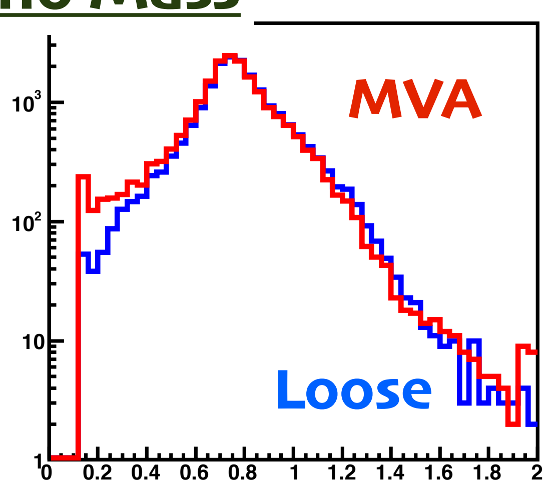
MissSelectionRatio = 20.39

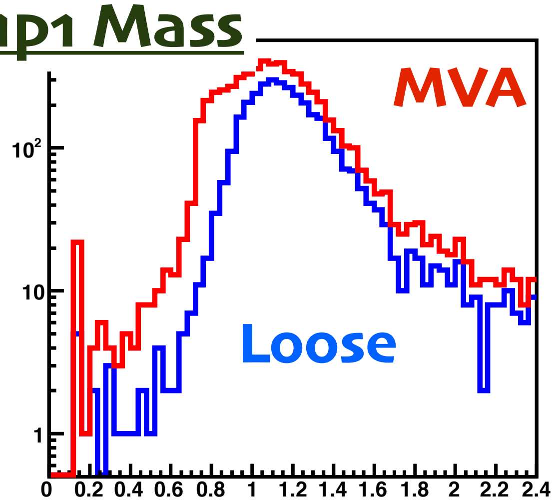
3Detectors @ tautau with MVA Cut

	Si ECAL thick0.5mm	ADoubleLayer Sci-thick1.0mm	Sci w/ SSA Sci-thick1.0mm
Efficiency, Purity & Acceptance (with **MVA Cut**)			
Lepton1Mode Efficiency	93.00	92.22	92.78
Lepton1Mode Purity	96.49	96.42	96.73
Lepton1Mode Acceptance	96.38	95.64	95.92
Lepton2Mode Efficiency	97.71	96.76	96.42
Lepton2Mode Purity	96.37	97.77	97.02
Lepton2Mode Acceptance	101.4	98.97	99.38
PionMode Efficiency	85.03	81.53	81.24
PionMode Purity	83.86	80.59	74.28
PionMode Acceptance	101.4	101.2	109.38
RhoMode Efficiency	85.22	82.96	74.33
RhoMode Purity	82.47	80.56	77.98
RhoMode Acceptance	103.3	102.9	95.32
A1p1Mode Efficiency	59.72	56.36	53.16
A1p1Mode Purity	70.29	65.63	54.96
A1p1Mode Acceptance	84.96	85.88	96.70
MissSelectionRatio	13.34	15.19	18.23

Si ECAL @ tautau







Efficiency, Purity & Acceptance (with **Loose Cut**)

Lepton1Mode Efficiency = 81.21
Lepton1Mode Purity = 91.99
Lepton1Mode Acceptance = 88.27

Lepton2Mode Efficiency = 86.48
Lepton2Mode Purity = 94.56
Lepton2Mode Acceptance = 91.46

PionMode Efficiency = 83.24
PionMode Purity = 80.49
PionMode Acceptance = 103.4

RhoMode Efficiency = 70.04
RhoMode Purity = 82.36
RhoMode Acceptance = 85.04

A1p1Mode Efficiency = 35.19
A1p1Mode Purity = 79.53
A1p1Mode Acceptance = 44.25

MissSelectionRatio = 16.54

Efficiency, Purity & Acceptance (with **MVA Cut**)

Lepton1Mode Efficiency = 93.00
Lepton1Mode Purity = 96.49
Lepton1Mode Acceptance = 96.38

Lepton2Mode Efficiency = 97.71
Lepton2Mode Purity = 96.37
Lepton2Mode Acceptance = 101.4

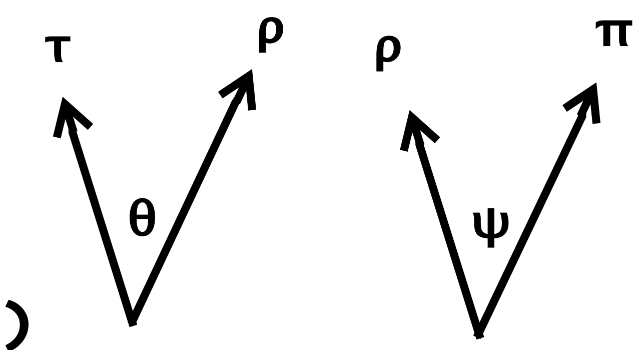
PionMode Efficiency = 85.03
PionMode Purity = 83.86
PionMode Acceptance = 101.4

RhoMode Efficiency = 85.22
RhoMode Purity = 82.47
RhoMode Acceptance = 103.3

A1p1Mode Efficiency = 59.72
A1p1Mode Purity = 70.29
A1p1Mode Acceptance = 84.96

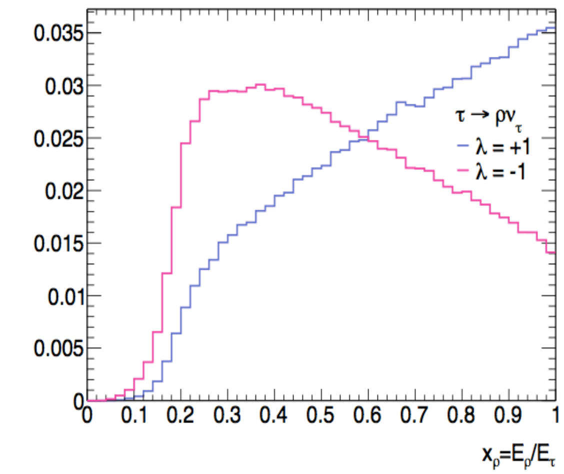
MissSelectionRatio = 13.34

Polarization observables ω



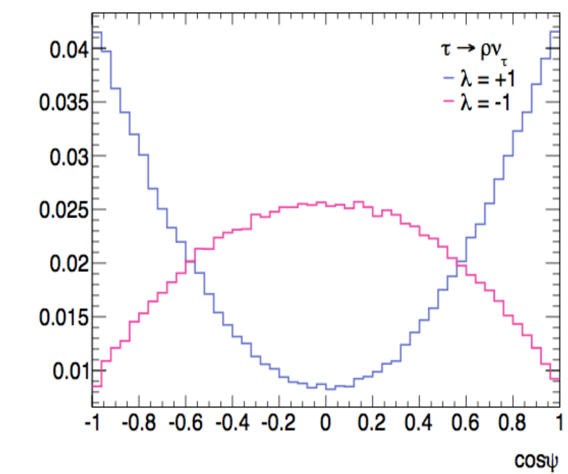
Recover optimal observable ω with cosψ* in ρ mode. **(BackUp Slides)**

A lot of sensitivity of the polarization is lost compared to the π decay.



→ due to the mixing of longitudinally and transversely polarized vector states.

Some of the sensitivity can be regained by considering other variables are sensitive to the tau helicity.

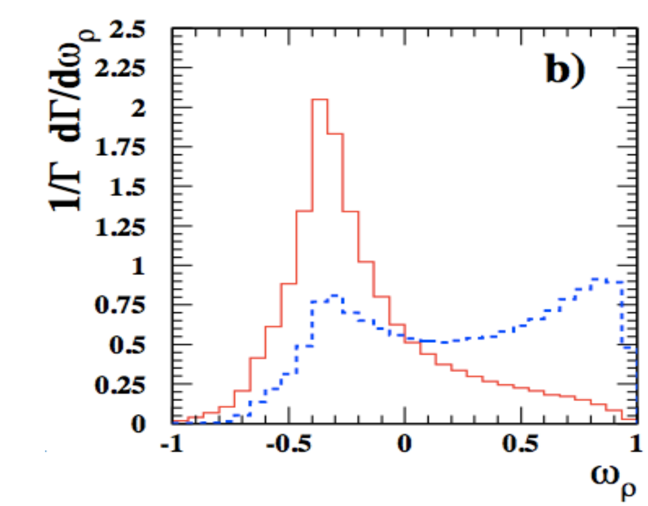


- **If one uses information of helicity of intermediate resonance, most of lost sensitivity can be regained.**

→ Define ψ as the angle between the charged π and the ρ initial direction

- **In terms of the laboratory frame**

$$\cos\psi^* = (E_{\pi\pm} - E_{\pi o}) / E_\rho$$

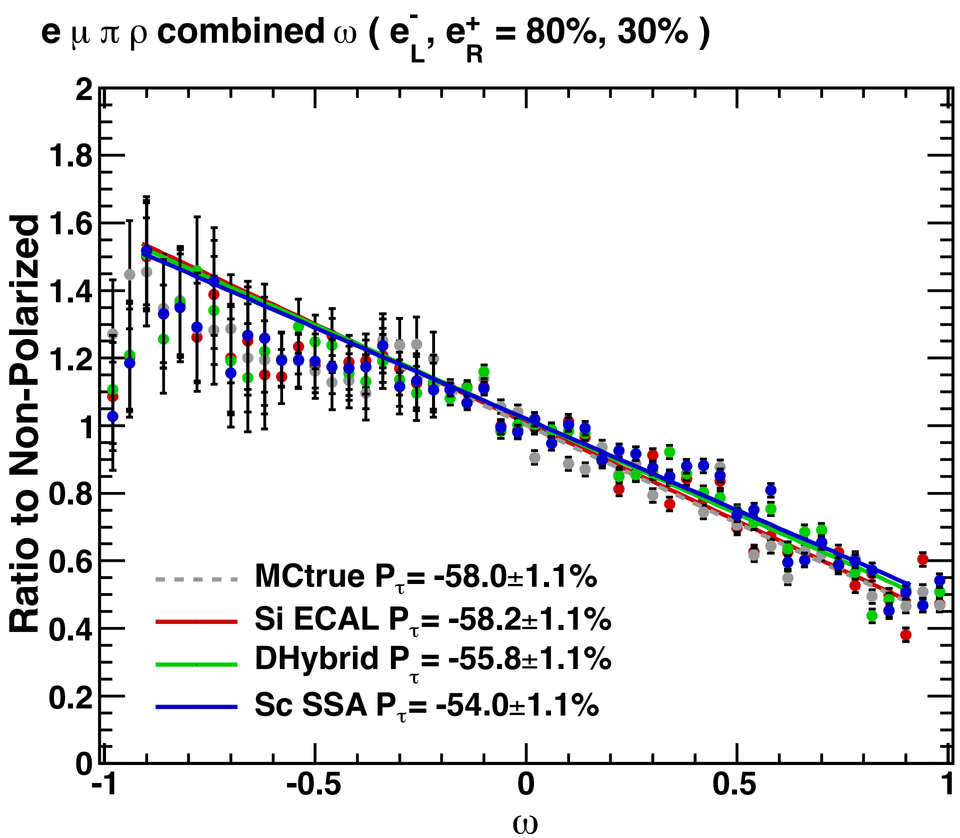


Polarization combined ω with 3Detectors

- Formula of ω differs by decay modes, but ω can be summed up through all decay modes.

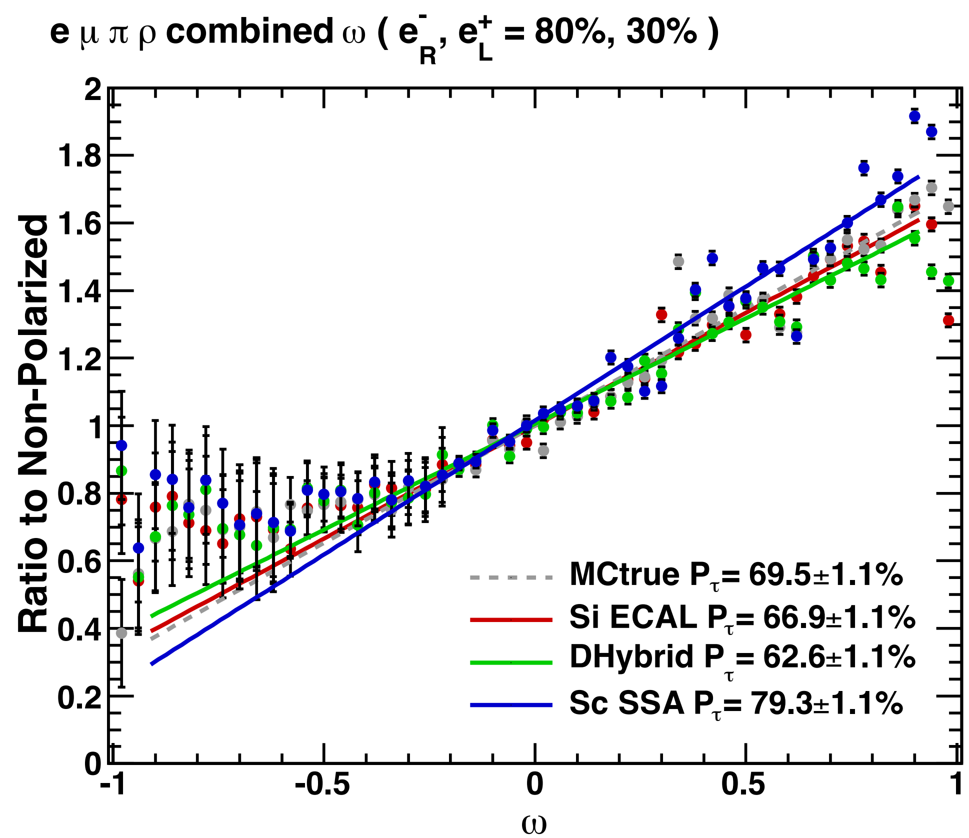
※ Include error forcibly

e-L e+R



- MC true : 58.0%
- Si ECAL : 58.2%
- DHybrid : 55.8%
- Sc w/SSA : 54.0%

e-R e+L



- MC true : 69.5%
- Si ECAL : 66.9%
- DHybrid : 62.6%
- Sc w/SSA : 79.3%