Tau lepton reconstruction by using SiECAL, ScECAL with SSA, and Hybrid ECAL

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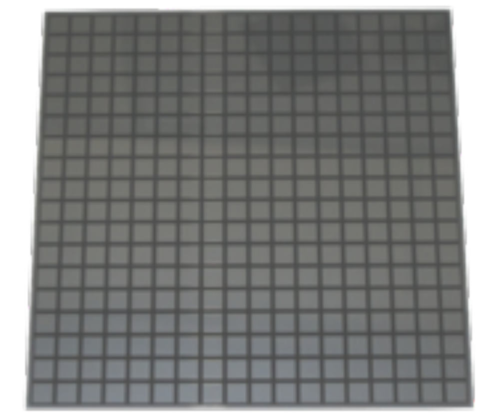
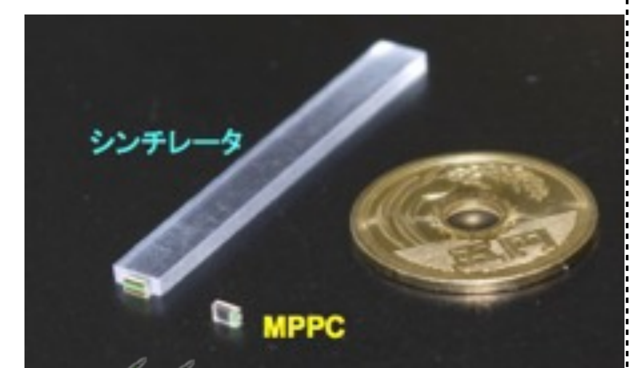
Introduction

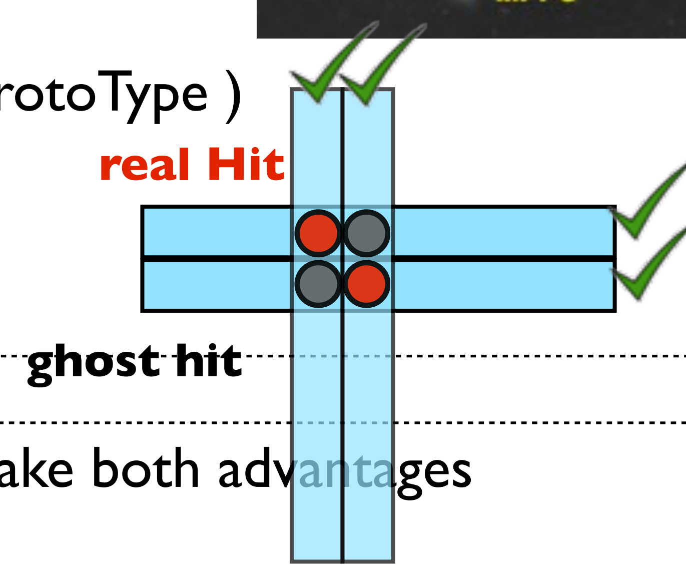
ILD ECAL

- Si ECAL : - 5 mm x5 mm lateral granularity with Si-Pad
  - Easy to make fine granular ECAL
  - Intrinsic energy resolution: ~ 16% /√E (2006 PhysicsProtoType)
  - Expensive



- Sc ECAL : - 45 mm x 5 mm plastic scintillator strip.
  - layer-layer orthogonal alignment → 5 x 5 mm^2 granularity.
    Special algorithm (SSA) is developed as yesterday's my talk .
  - ghosts might appear
  - Intrinsic energy resolution: ~ 13% /√E (2009 PhysicsProtoType)
    note 10 x 45 x 3 mm strip
  - less expensive than half as SiECAL.





- Hybrid ECAL : - Si layers and Sc layers are piled up alternatively to take both advantages
  - ghosts are almost disappeared.
  - in this talk, not real alternative Hybrid .... study of real alternative one is ongoing

Motivation of this study

- $ee \rightarrow \tau\tau$ is one of the ILD bench mark process to study the ECAL performance
  Seeing:
  - event selection ability : Efficiency & Purity
  - Physics observables : σ, AFB, tau polarization,

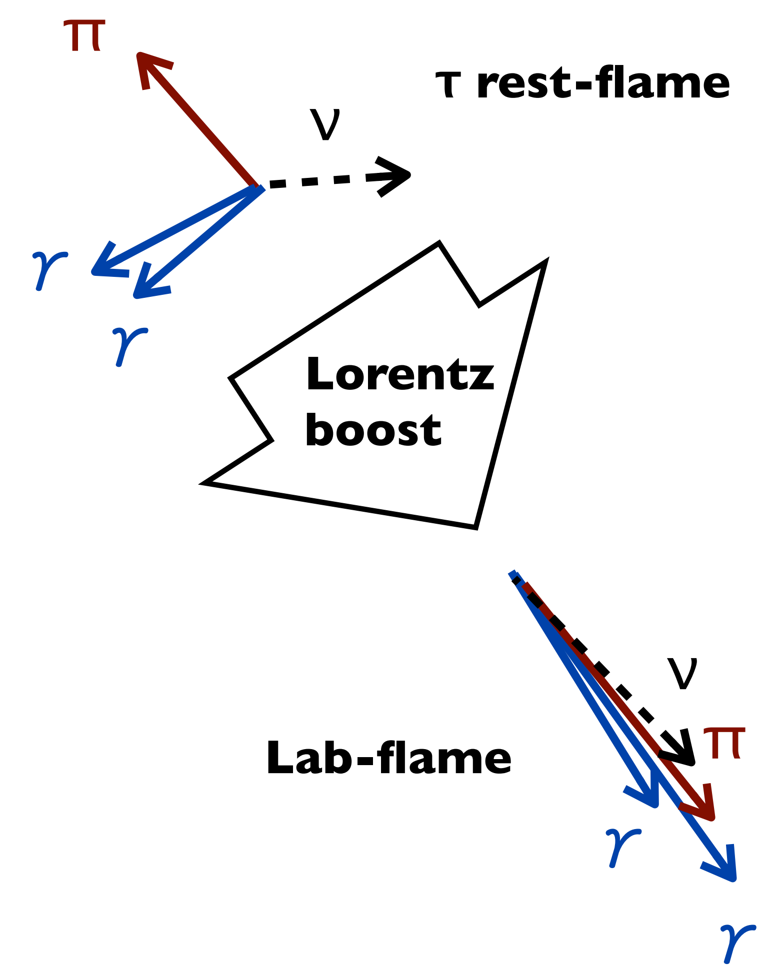
- High Lorentz boost of τ jet ($\sqrt{s}$ = 500 GeV)

  → Challenge of particle separation by using PFA.

- Angular distribution provides the polarization of τ

  → requires precise four momentum measurements.

  - including π^0 reconstruction → 2-γ separation ability.



τ decay reconstruction is good examination of performance of ECALs with PFA and Strip Splitting Algorithm for strip ECAL.

Event samples

- Event generation : Whizard.

- Beam condition $\sqrt{s}$ = 500GeV (ISR-OFF)
- Beam polarization : e- e+ = -80% +30%, e- e+ = +80% -30%,
- Signal : e- e+ → τ τ
- BackGround (Temporary) : e- e+ → Bhabha
  2-γ → τ τ
  e- e+ → WW

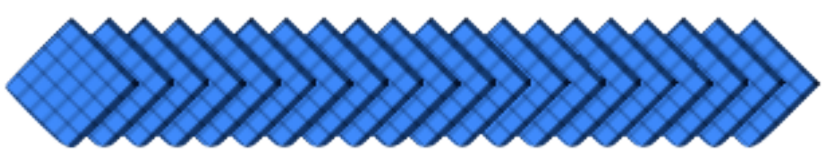
- τ's branching ratio

τ->eνν	17.8%
τ->μνν	17.4%
τ->πν	11.3%
τ->ρν	24.9%
τ->a1ν (1p)	9.0%
τ->a1ν (3p)	10.0%

- Detector : Mokka (ECAL Configuration)

SiECAL :

0.5 mm of thickness of Si



ScECAL : w/o SSA, w/ SSA

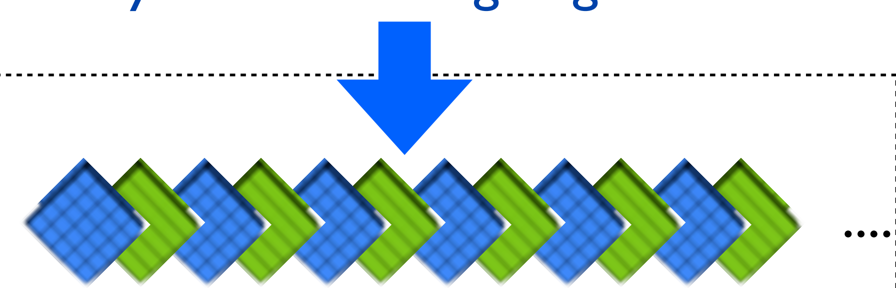
1.5 mm of thickness of Sc

Analysis with more suitable thickness is under going

Hybrid : Alternative Double Layer

Si+Si+Sc+Sc+Si+Si+..... (w/ SSA)

Analysis with complete alternative Hybrid is under going



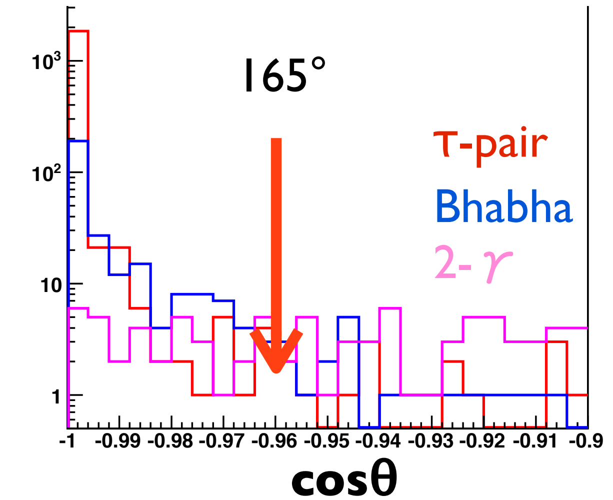
- Event reconstruction : Marlin.

- Reconstruction by using PandoraPFA.
- Mode Selection : cut base.

Reconstruction of τ jet

1. Sort particles in energy order.

2. Select two of the most energetic charged particles (tau candidates) with larger than165° of their opening angle.



→ This set of cuts is called the pre-cuts

BG rejection ratio of the pre-cuts

e-L, e+R	τ-pair	Bhabha	2-γ → ττ	W-pair
Si Ecal	3.5%	67.8%	95.5%	47.3%
Hybrid	3.5%	67.9%	95.3%	48.2%
Sc SSA	3.4%	67.9%	95.4%	49.1%
Sc w/o SSA	9.9%	72.4%	95.4%	49.8%

※ In order to make it simple ISR is off. in this study
2/3 events are rejected with ISR.

3. Merge the four momenta of particles around main candidates

→ particles in 15 deg cone are merged

※ considering Cone of 250 GeV τ, it might be better to set 10 deg cone (we know now).

Background Suppression

- done after pre-cut

1. The number of tracks <= 6.

2. 70 < E_{vis} < 450GeV. E_{vis} : charged energy

   70GeV > to reject $\gamma\gamma \to \tau\tau$ Cut, 450GeV < to reject Bhabha.

3. 172° < Opening angle between 2jets.

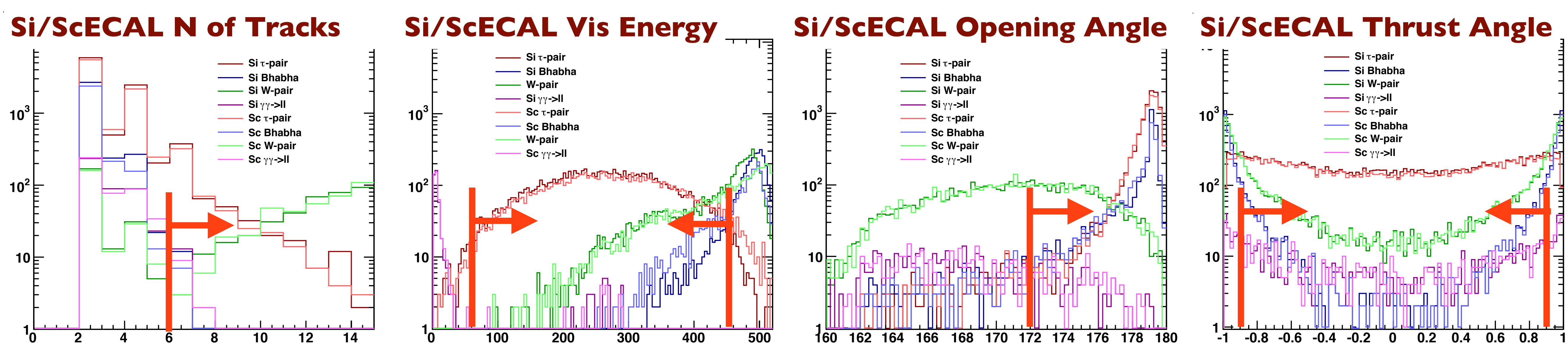
   → some BG Cut.

4. |cosθ| < 0.9 for both jets.

   →WW → lνlν Cut.

- effect of the background suppression

Cuts	tautau	bhabha	ww	2-γ
No-Cut	100%	100%	100%	100%
Pre-Cut	96.4%	32.2%	50.9%	4.5%
#Tracks	94.1%	32.2%	2.3%	4.5%
Evisible	91.4%	8.3%	2.3%	3.7%
OpenAngle	89.7%	2.1%	0.6%	0.1%
cos(Thrust)	89.7%	2.1%	0.6%	0.1%



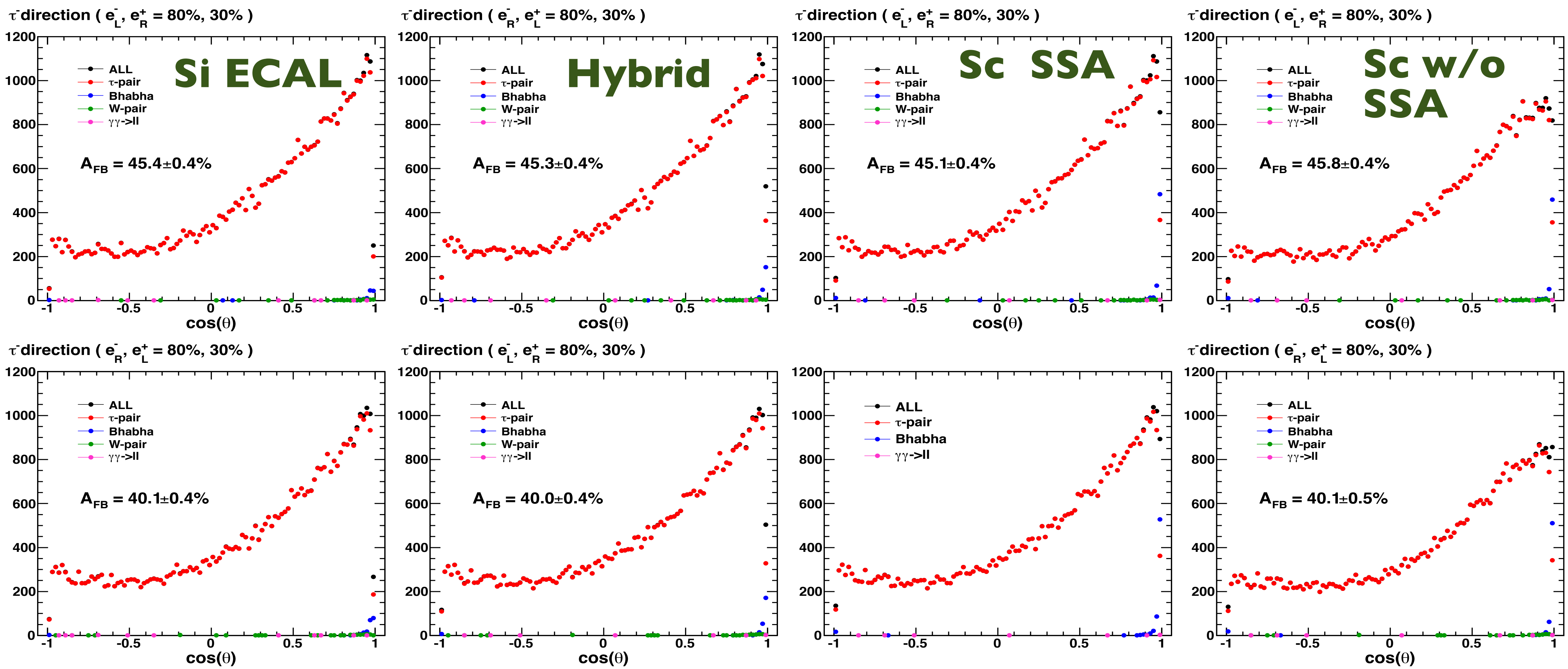
Forward-Backward Asymmetry

$$\frac{N_F - N_B}{N_F + N_B}$$

N : # of τ^-

e-L e+R

e-R e+L



- Forward-Backward Asymmetry

	Si Ecal	Hybrid	Sc SSA	Sc w/o SSA
e-L, e+R	45.4±0.4%	45.3±0.4%	45.1±0.4%	45.8± 0.4%
e-R, e+L	40.1±0.4%	40.0±0.4%	40.2±0.4%	40.1±0.5%

→ No diff. among ECAL types, ... but Sc w/o SSA fails to reconstruct a part of events at very forward.

Mode selection with a set of trial cuts

- Selection whether leptonic or semi-leptonic and 1 prong or 3 plong

  - Lepton ID by PandoraPFA
  - The number of charged particle in τ jet → 1-prong or 3-prong.

- separation π, ρ, a1 mode in 1 prong event

  - Cut by using γ information :
    - Eγ > **5.0Gev** → **Hard - γ**
    - Eγ > **0.8Gev** → γ

→ π mode : the number of Hard - γ == 0 && Eγs < 5GeV

π Reconstruction → charged four momentum with only track information

→ ρ mode : the number of Hard - γ = 1 && γ <= 2 or γ <= 4 && Mass γs (π0) < 0.4GeV

ρ reconstruction → charged + γs

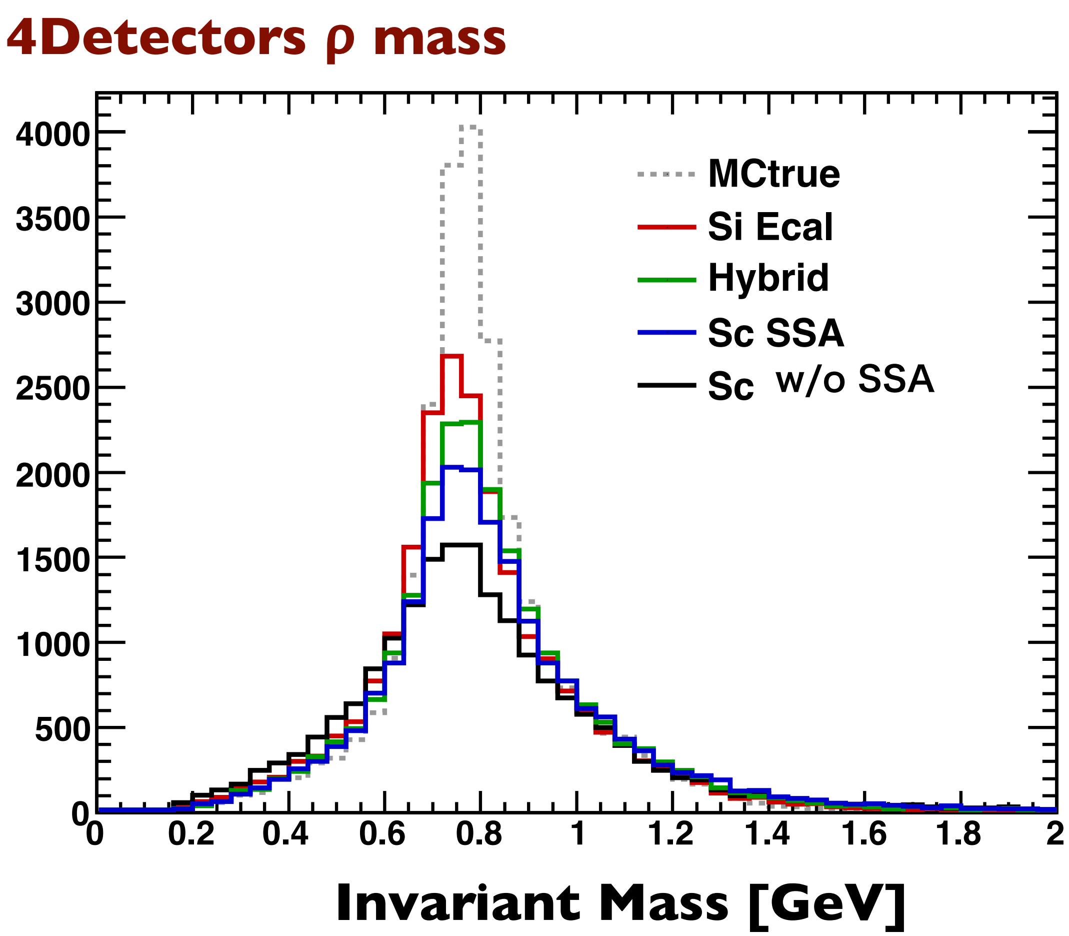
⟶ π^0 Reconstruction

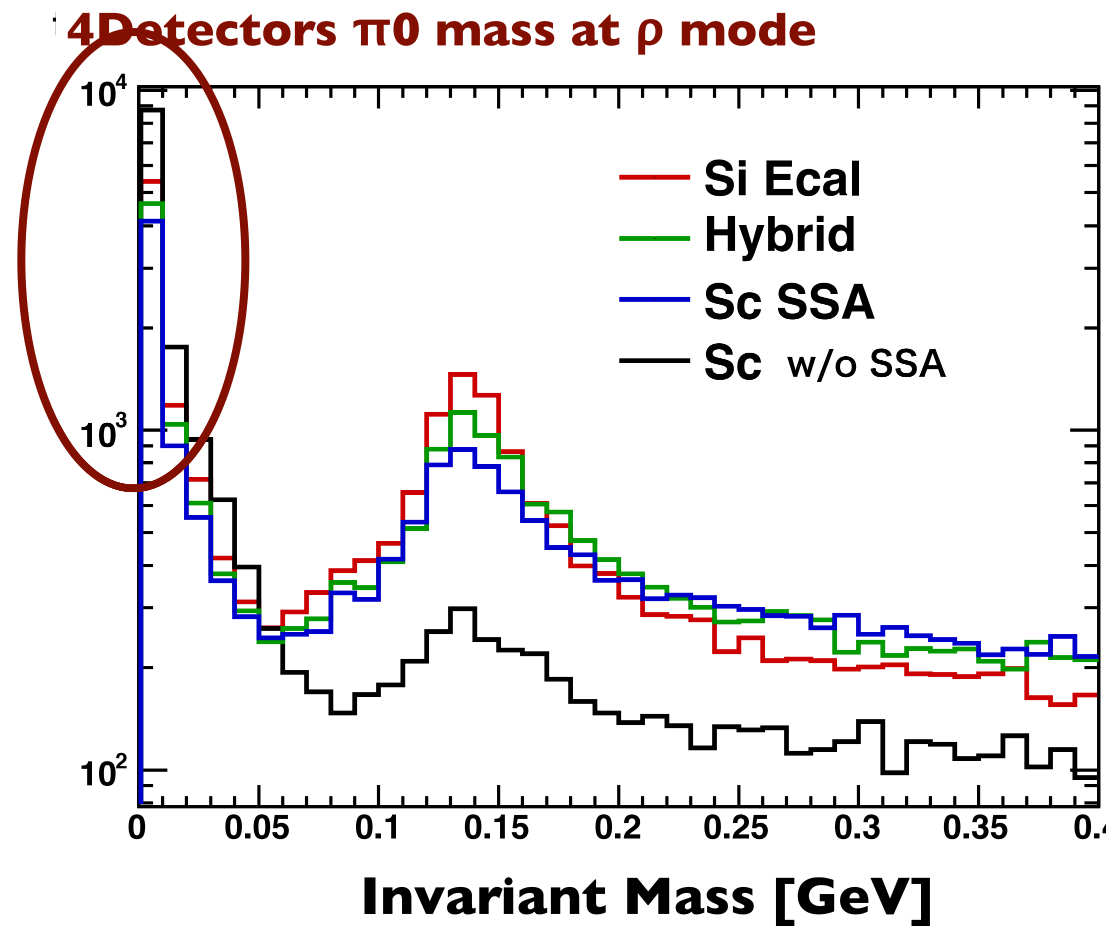
→ a1 mode : the other events

a1 reconstruction → charged + γs

ρ reconstruction including π^0 reconstruction

- Mass of ρ and π^0





- ρ reconstruction

  performance of reconstruction: Si ECAL > Hybrid Sc w/ SSA > Sc w/o SSA

  0.89±0.01, 0.86±0.01, 0.82±0.01, 0.77±0.01

  note: PandoraPFA is not best tuned for ScECAL (see recent study by John Marshall)

- π^0 reconstruction

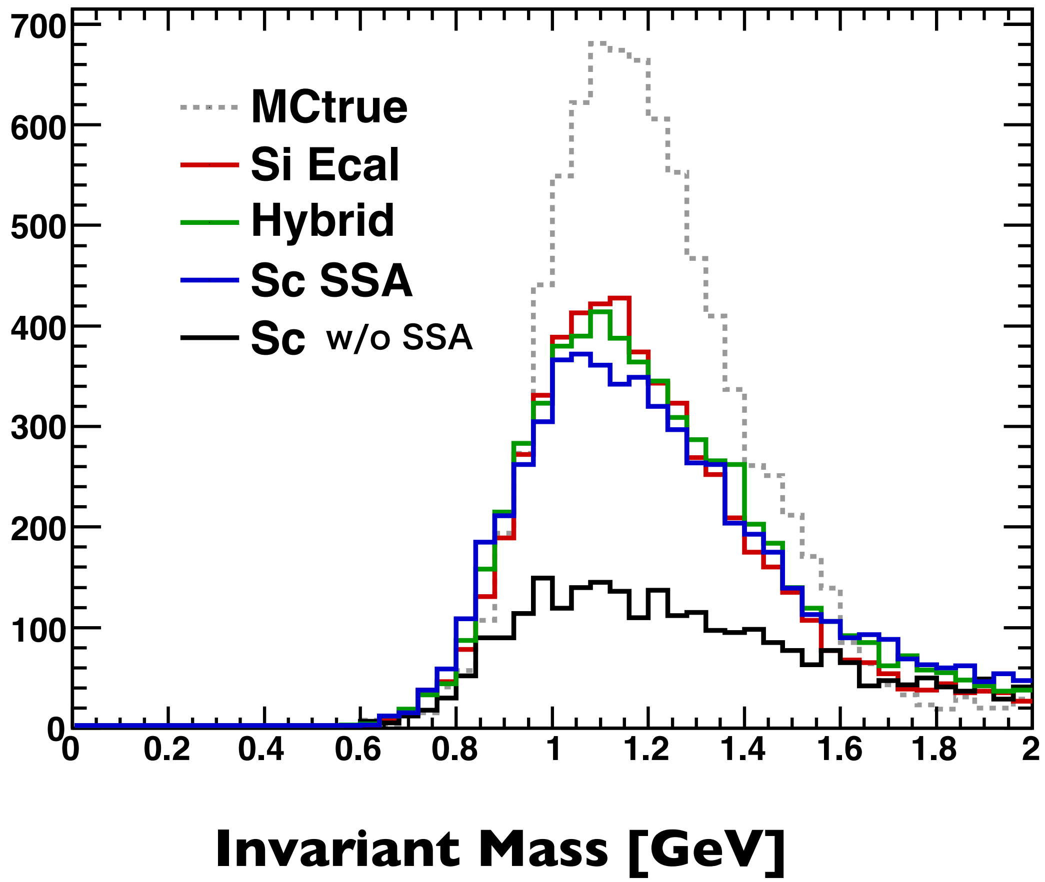
  SSA drastically improve π^0 reconstruction

  Single photon events are also used in ρ reconstruction

a1 reconstruction in 4ECALs

- Mass of a1

4Detectors a1 mass



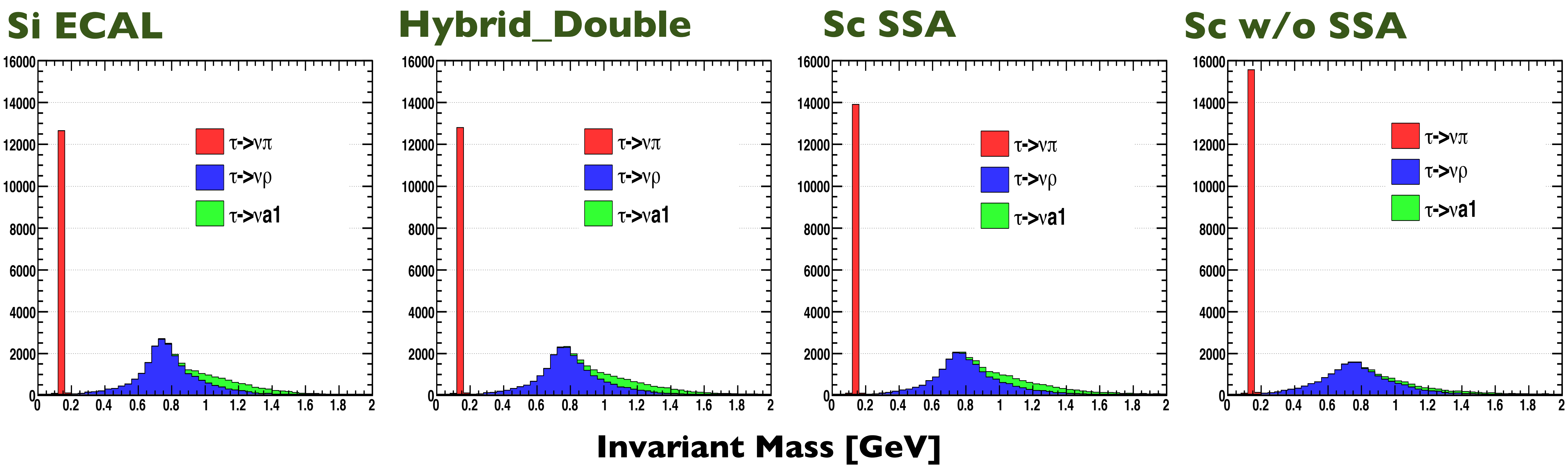
Ecal type	Acceptance
SiECAL	0.796±0.015
Hybrid	0.780±0.012
Sc SSA	0.756±0.012
Sc w/o ssa	0.421±0.008

- a1 reconstruction

SSA drastically improve a1 reconstruction

There is no large difference between Ecal types except Sc w/o SSA.

π, ρ, & a1 mass in 4ECals



- $\pi^{\pm}$ identified events increase with ScECAL
  ➡Some $\rho^{\pm}$ events misidentified as $\pi^{\pm}$ with ScECAL ➡ "Hard - γ" is missed by fragmentation of "Large-γ" into small γ. ➡ need to try special cone size for ScECAL

Summary

- Performances of four types of ILD-ECAL are compared in τ-pair reconstruction

  - Strip ECAL reconstruction method "SSA" works well to reconstruct ρ and a1 although some fragmentation of gamma lead to misidentify ρ as π event.

  - Alternative double layer Hybrid improves the situation, not complete.

    ➡ need study with real alternative Hybrid ECAL

Outlook

- need study with background events

- need study of real alternative hybrid ECAL

- introduce PandoraPFA tune for ScECAL

- Polarization study.

Angular dist (ω) : π mode

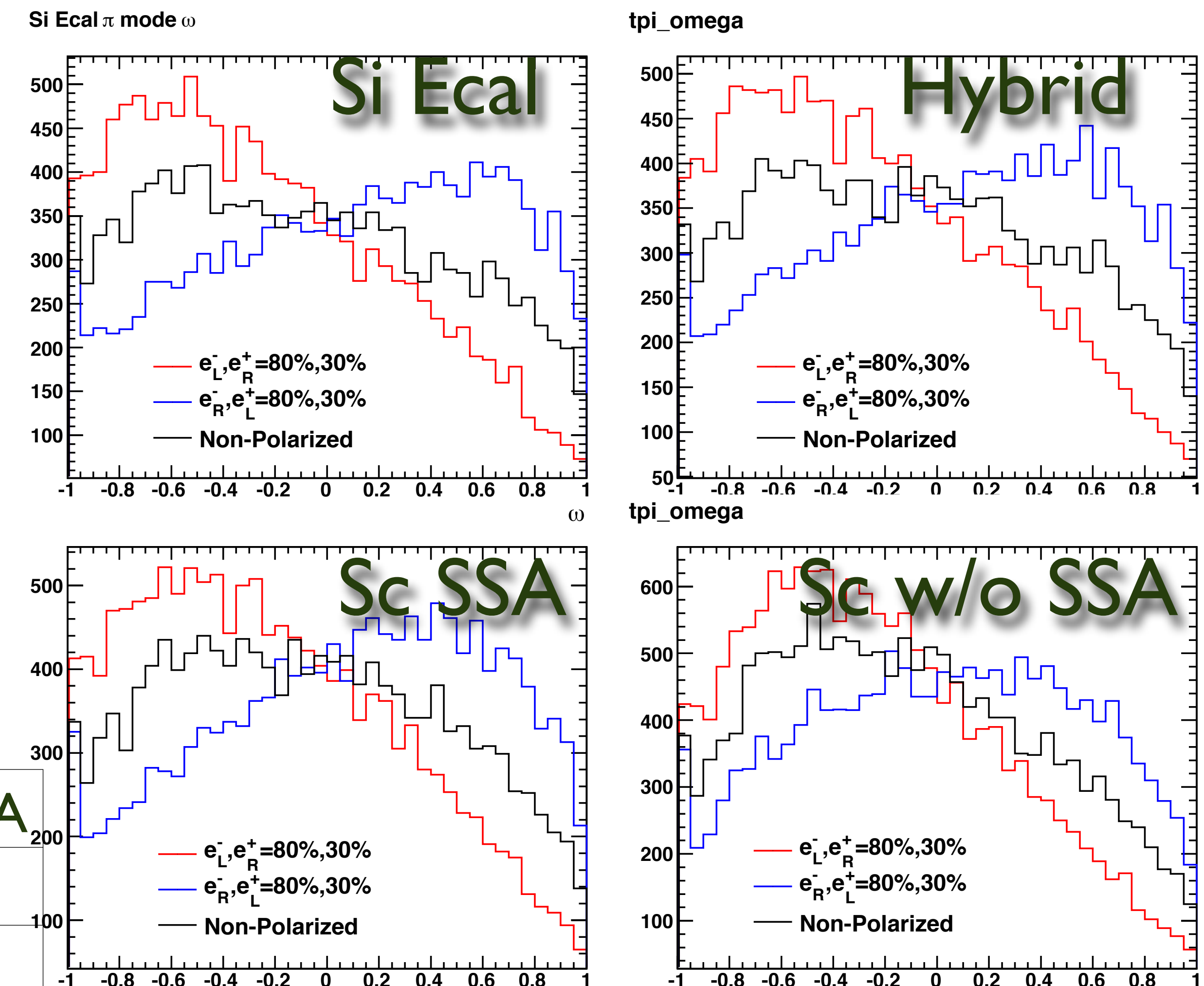
- Since this channel is the simplest,
  this exhibit the highest sensitivity to polarization.

- Because of no large dependence on γ separation if threshold of counting γ is sufficient, τ's visible polarity is near about 50% in 4 ECals.

- P(τ) Result at π

P(τ)	MCtrue	Si Ecal	Hybrid	Sc SSA	Sc w/oSSA
e-L e+R	48%	47%	49%	48%	45%
e-R e+L	57%	51%	50%	52%	46%

- ω distribution

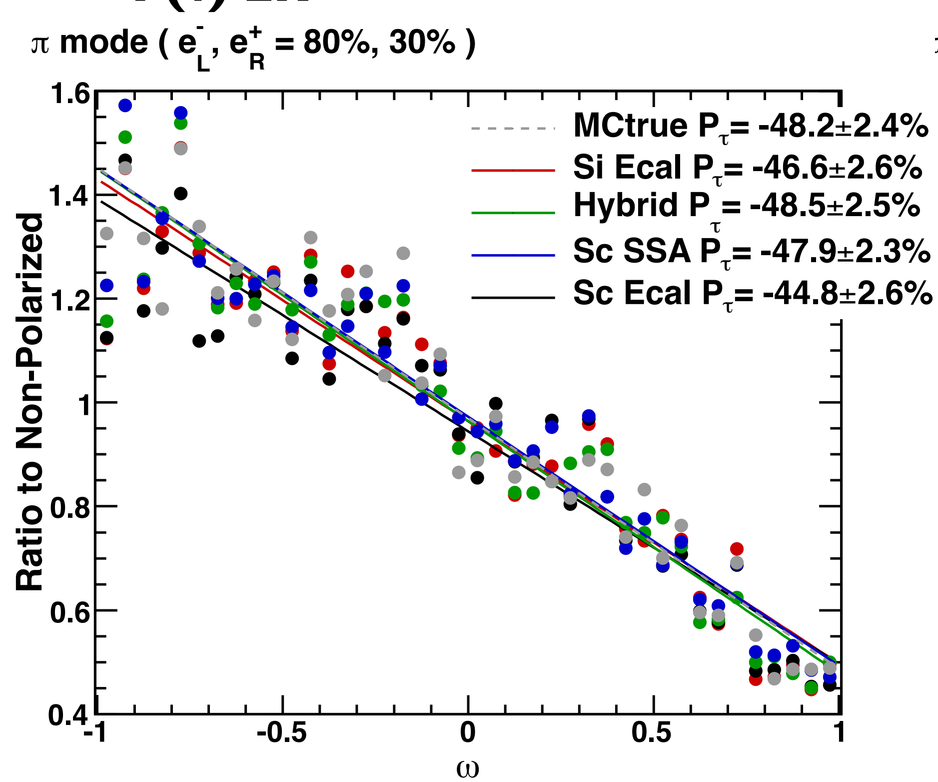


- ω distribution

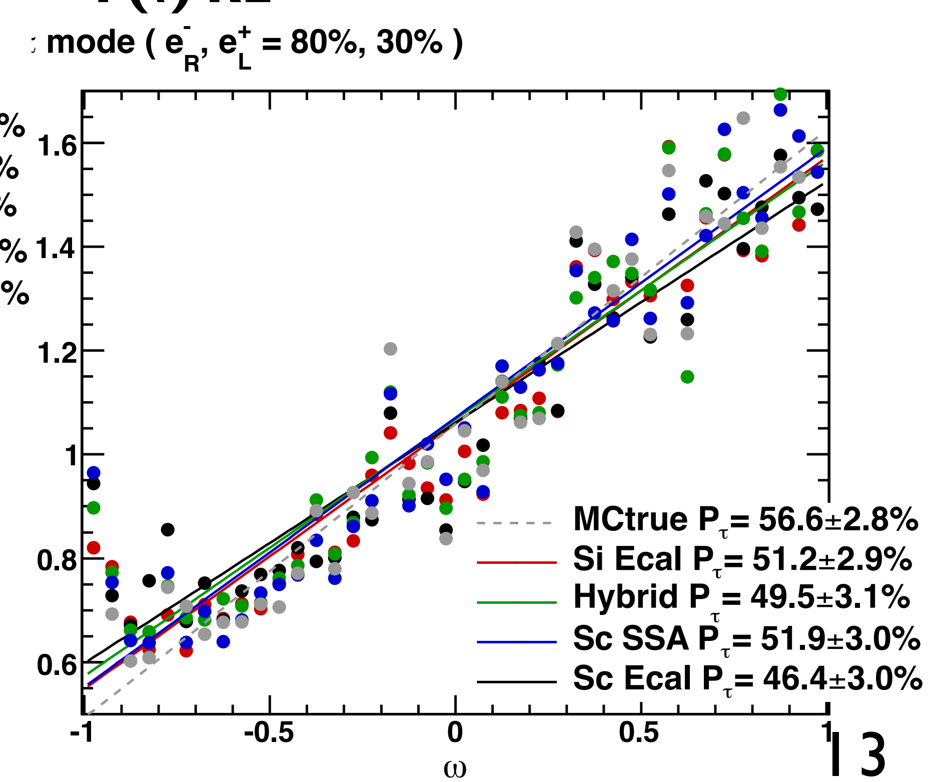
  → ω distribution divided by non-polarizing sample

  and Linear fit is applied to obtain P(τ) value.

- P(τ) LR



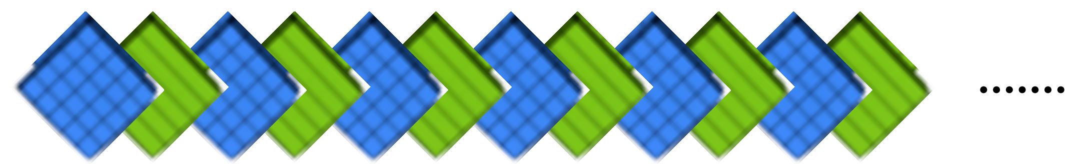
- P(τ) RL



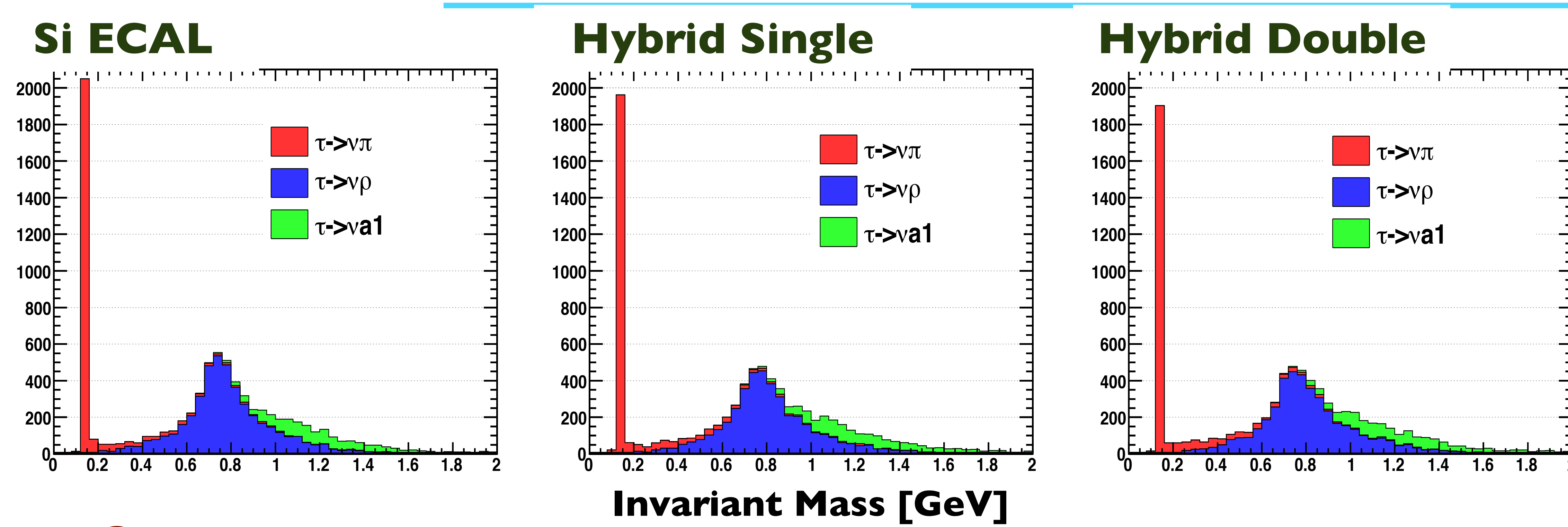
Hybrid Single Alternative

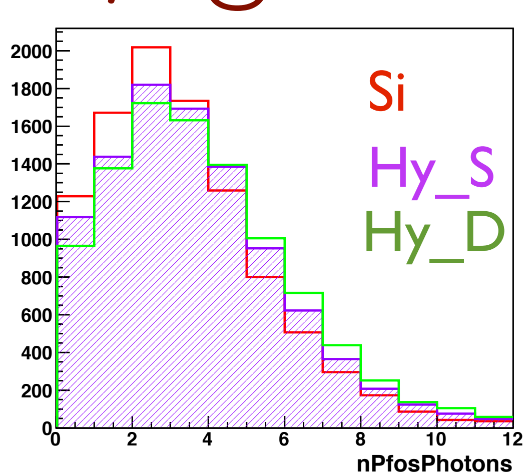
- Hybrid Single Alternative　　(※πはγを含ませてReconstruction)

シンチTile 5mmx5mm
シンチStrip 45mmx5mm



- Alternative Single layer Hybridならゴーストヒットは生じないはずだが、



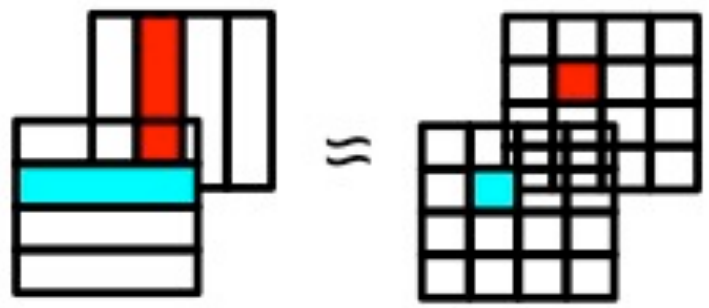


πモードの広がりは (余計なγ) 少し抑えられたが、
まだ、π ρ ともにSi ECALくらいの精度には達していないように思われる。

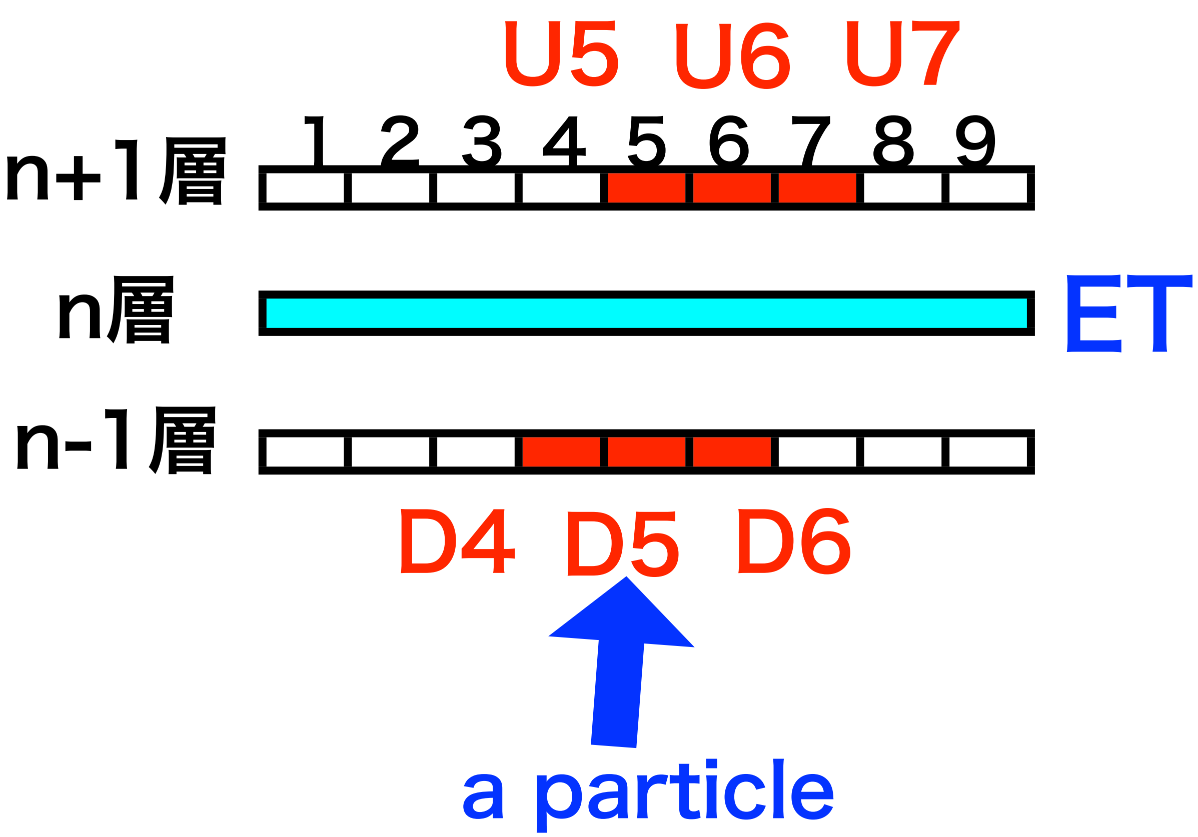
→ SSAが上手く動いていない？

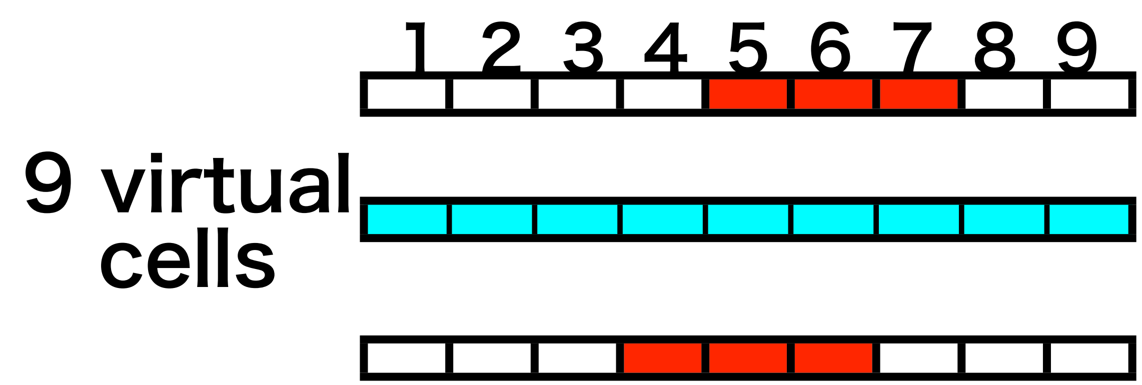
Back Up

Strip Ecal reconstruction with the strip splitting algorithm



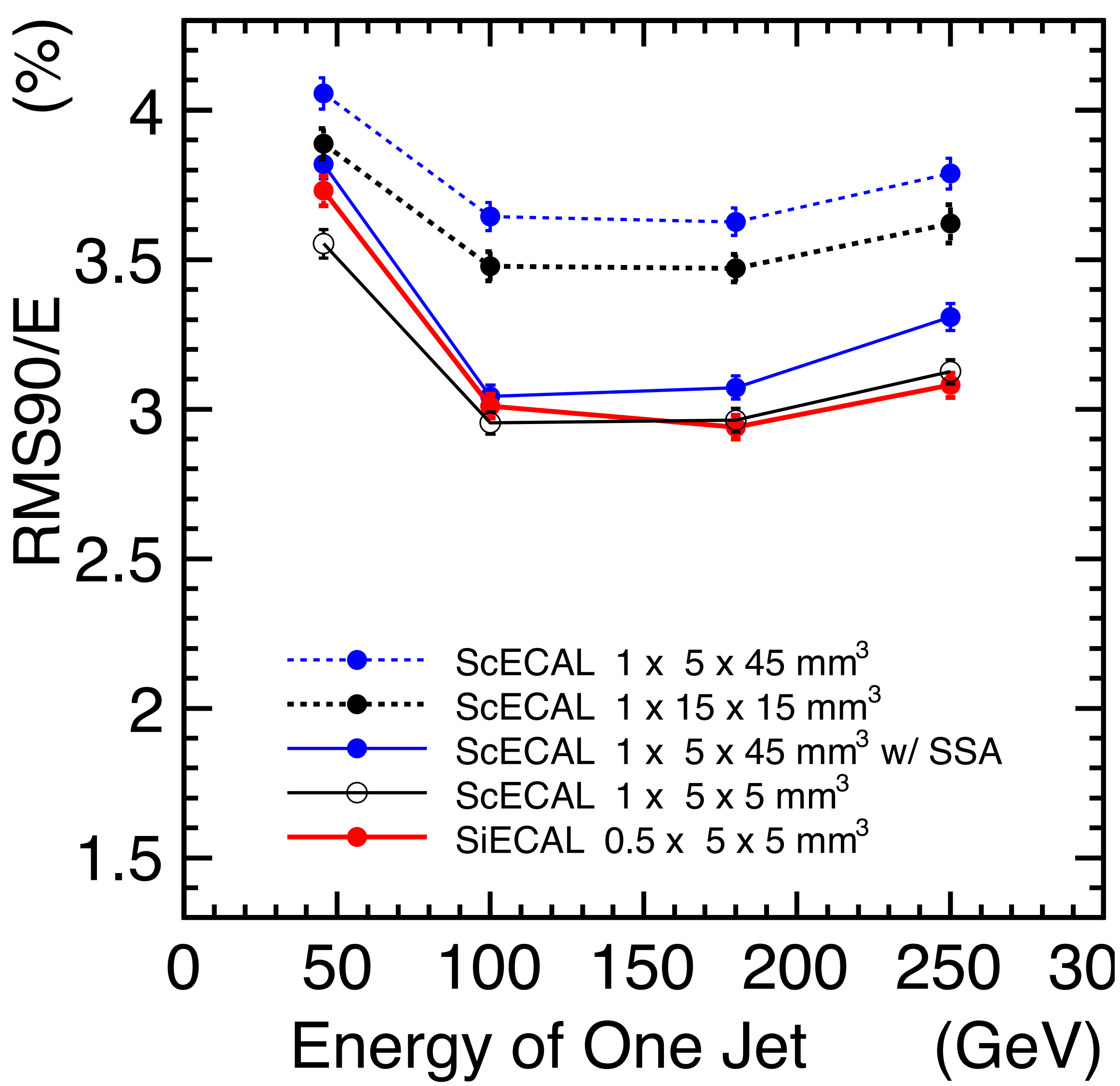
deposited energy on a strip
delivered into virtual square cells

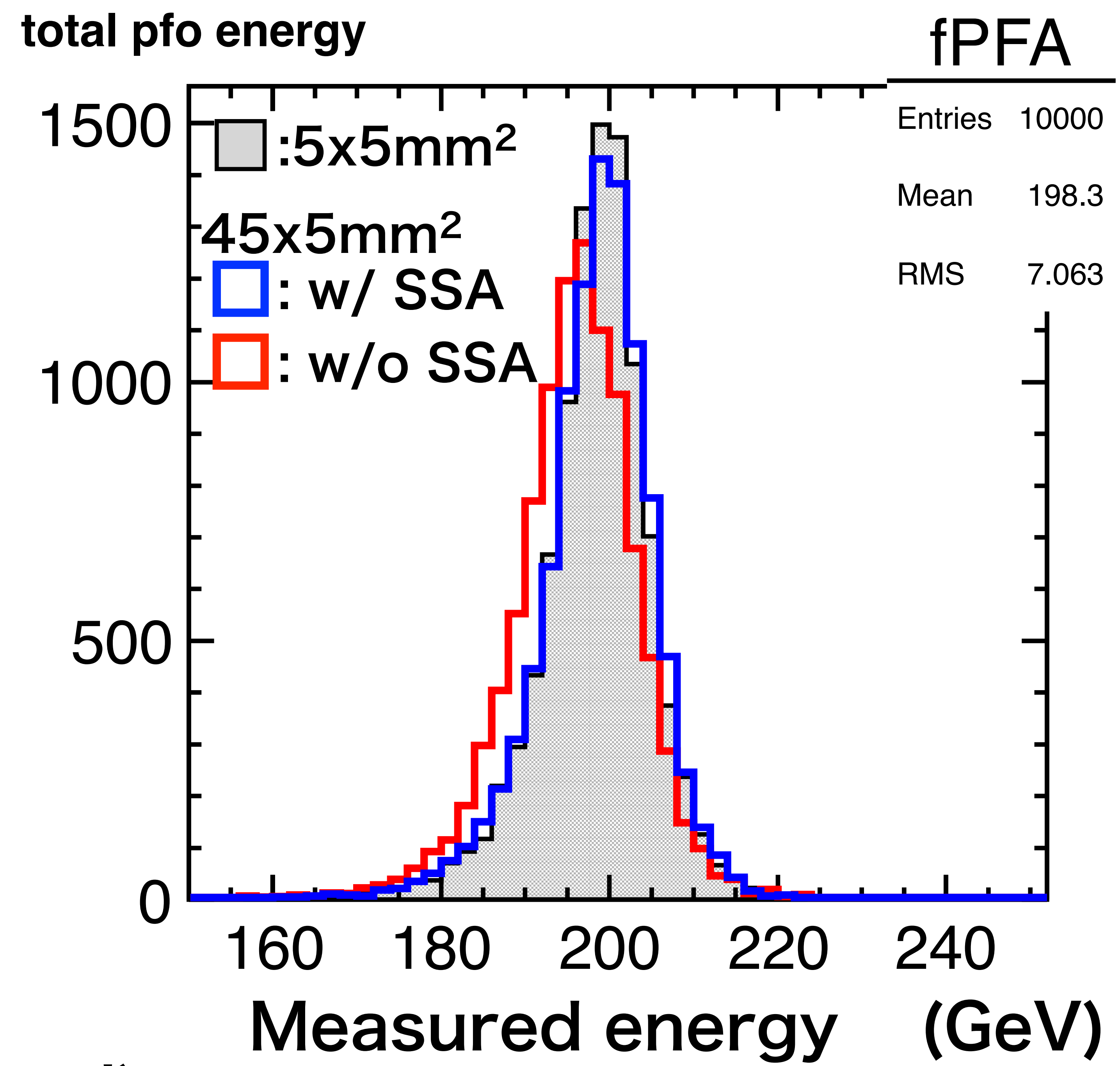




Effect of SSA

$Z' \rightarrow q\bar{q} \quad q = u, d, s$





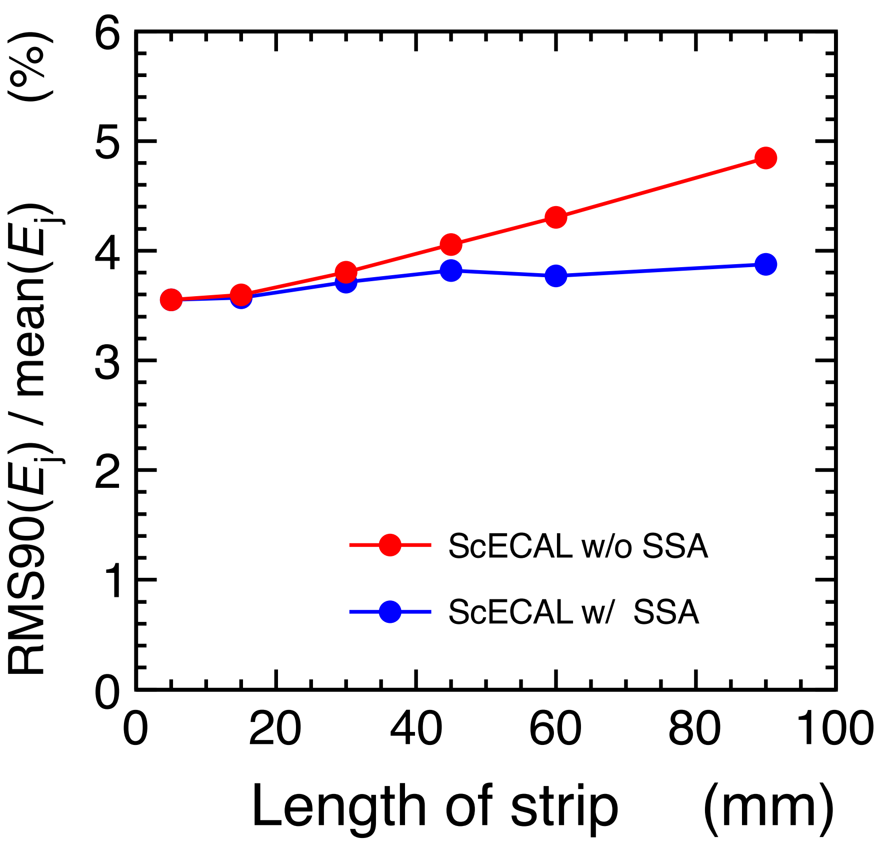
cos(θ_Thrust) < 0.7 (Barrel)

RMS90: RMS of 90% of center events

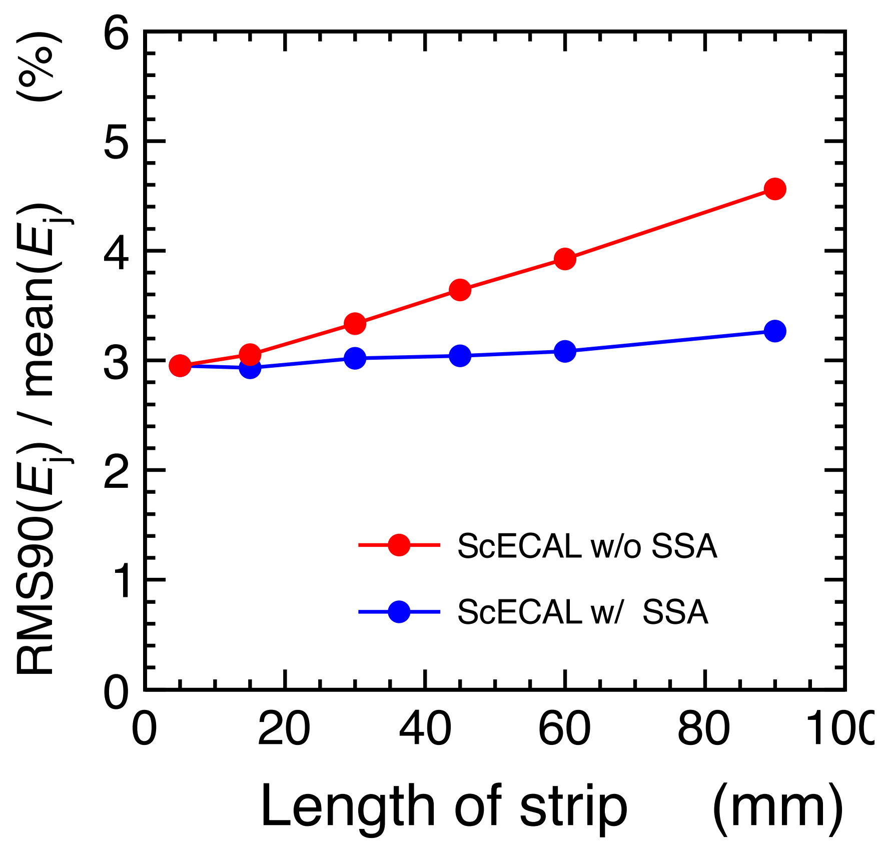
SSA makes JER of strip ECAL close to 5 x 5 mm² tile ECAL

uds two Jet Energy Resolution
depending on the strip length

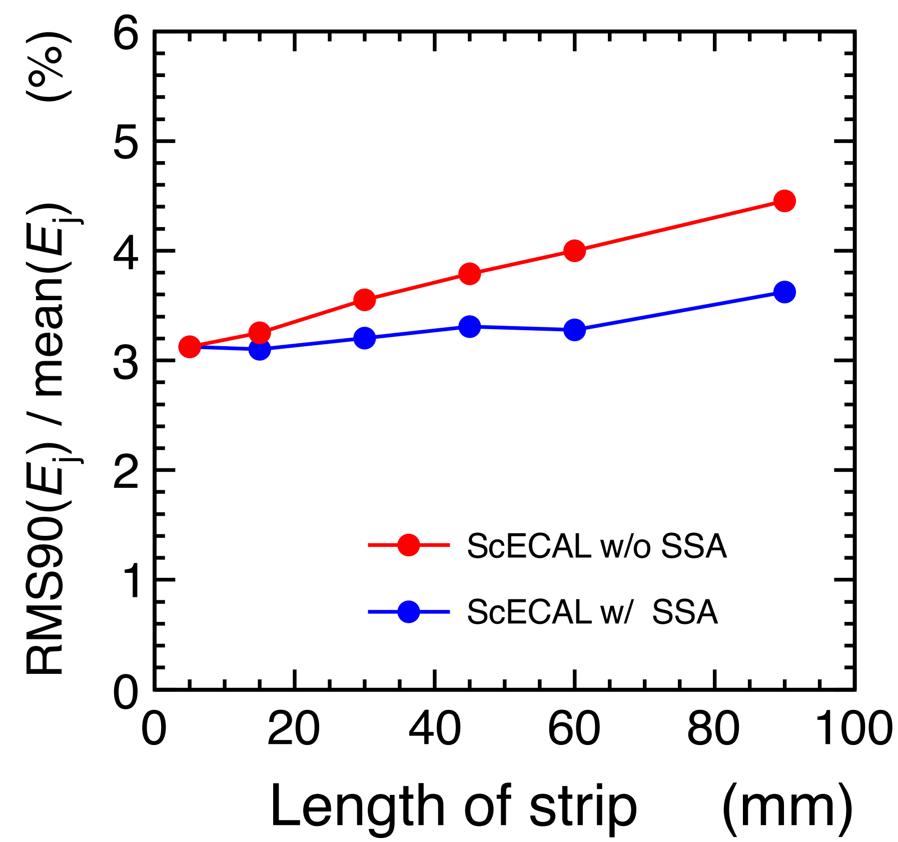
45 GeV



100 GeV

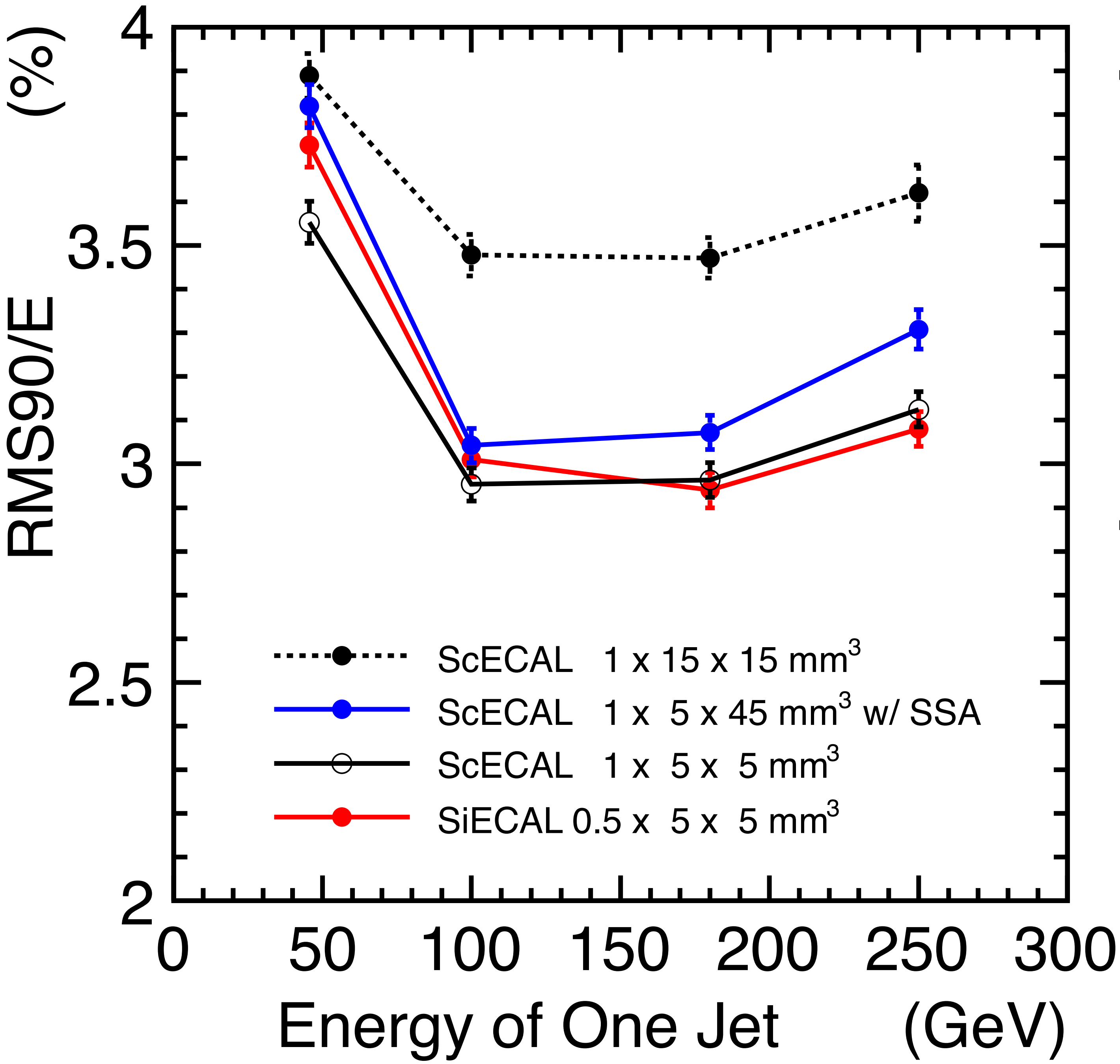


250 GeV



- No large deterioration with increasing the strip length up to 60 mm after applying SSA.

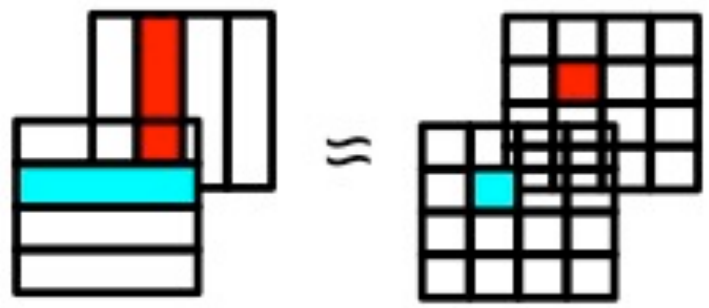
a little more detail



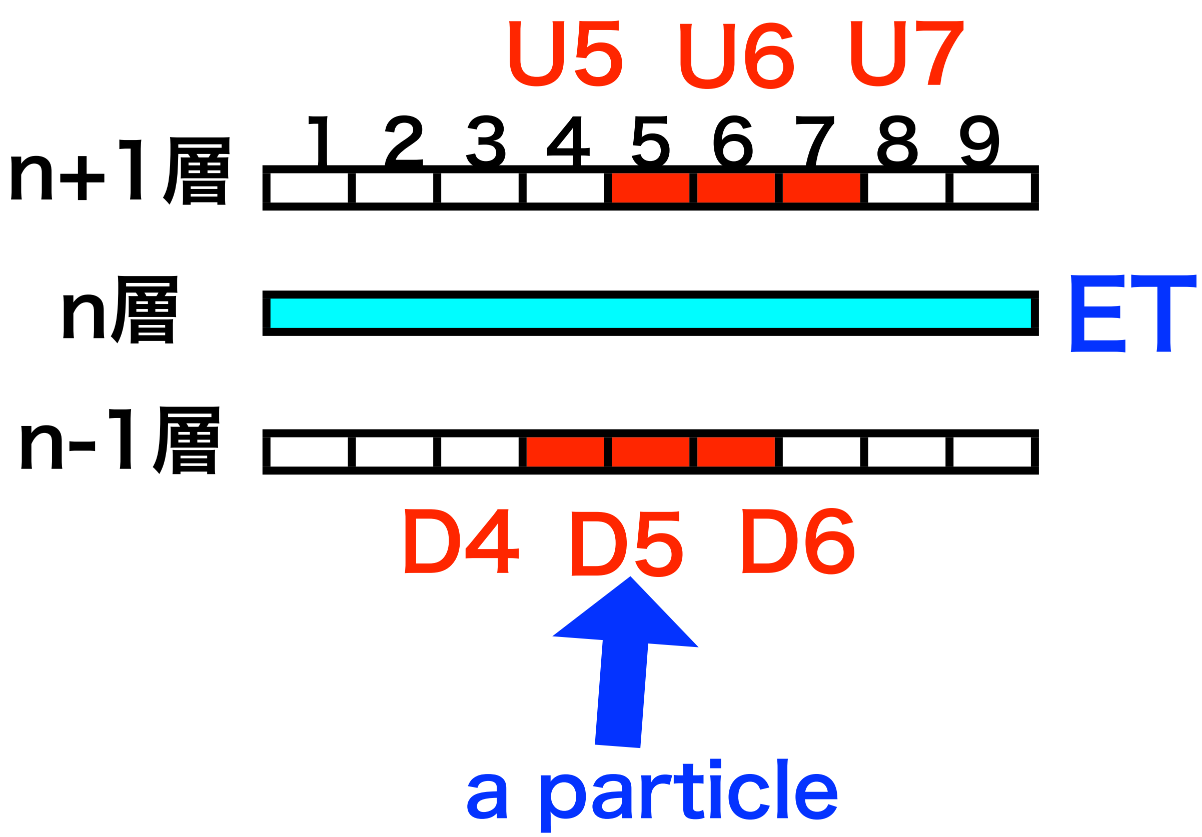
- 5 x 5 mm² tile ScECAL and SiECAL are comparable with each other by John's study.
- difference between 5 x 5 mm² ScECAL and 45 x 5 mm² + SSA ScECAL are 0.3% maximum at 45 GeV jet and 0.1-0.2% up to 250 GeV jet.

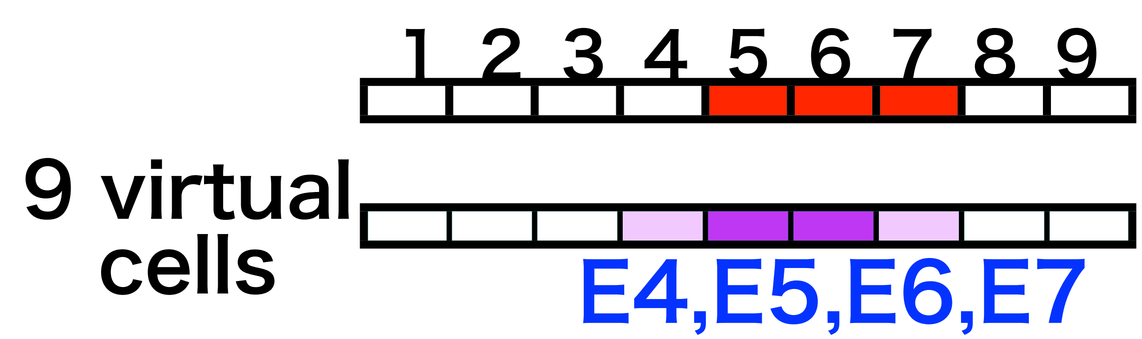
What happens at 45 GeV and high energy jets?

Strip Ecal reconstruction with the strip splitting algorithm



deposited energy on a strip
delivered into virtual square cells



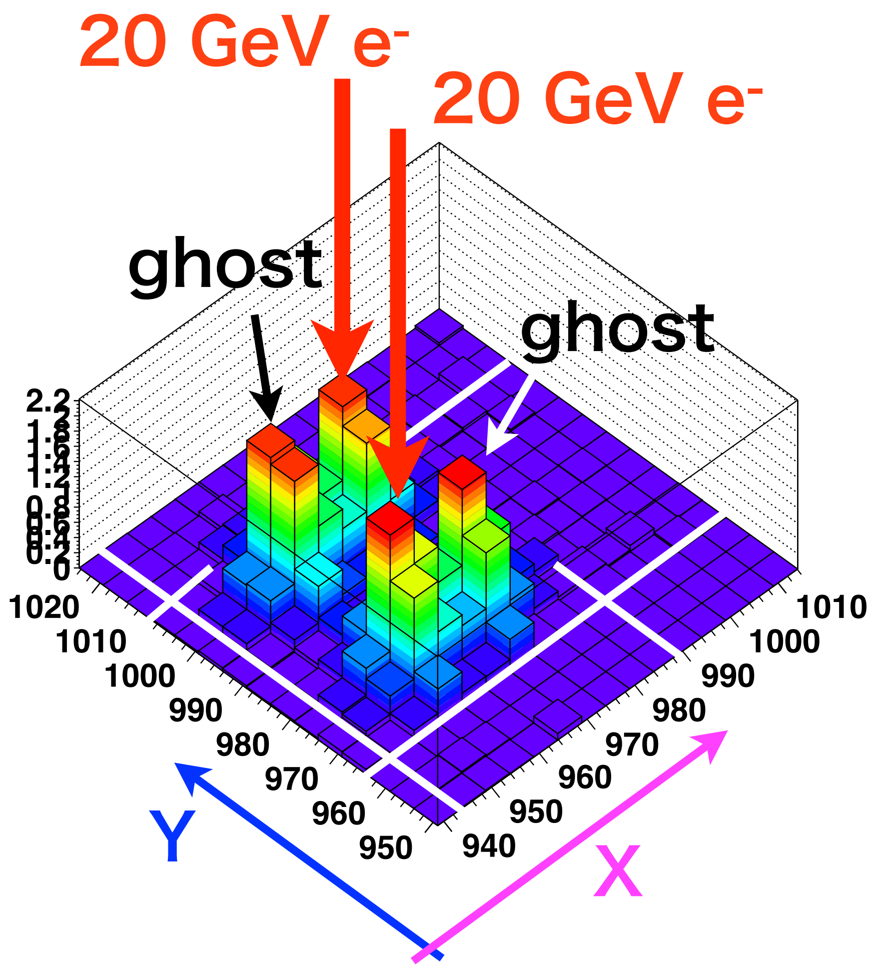


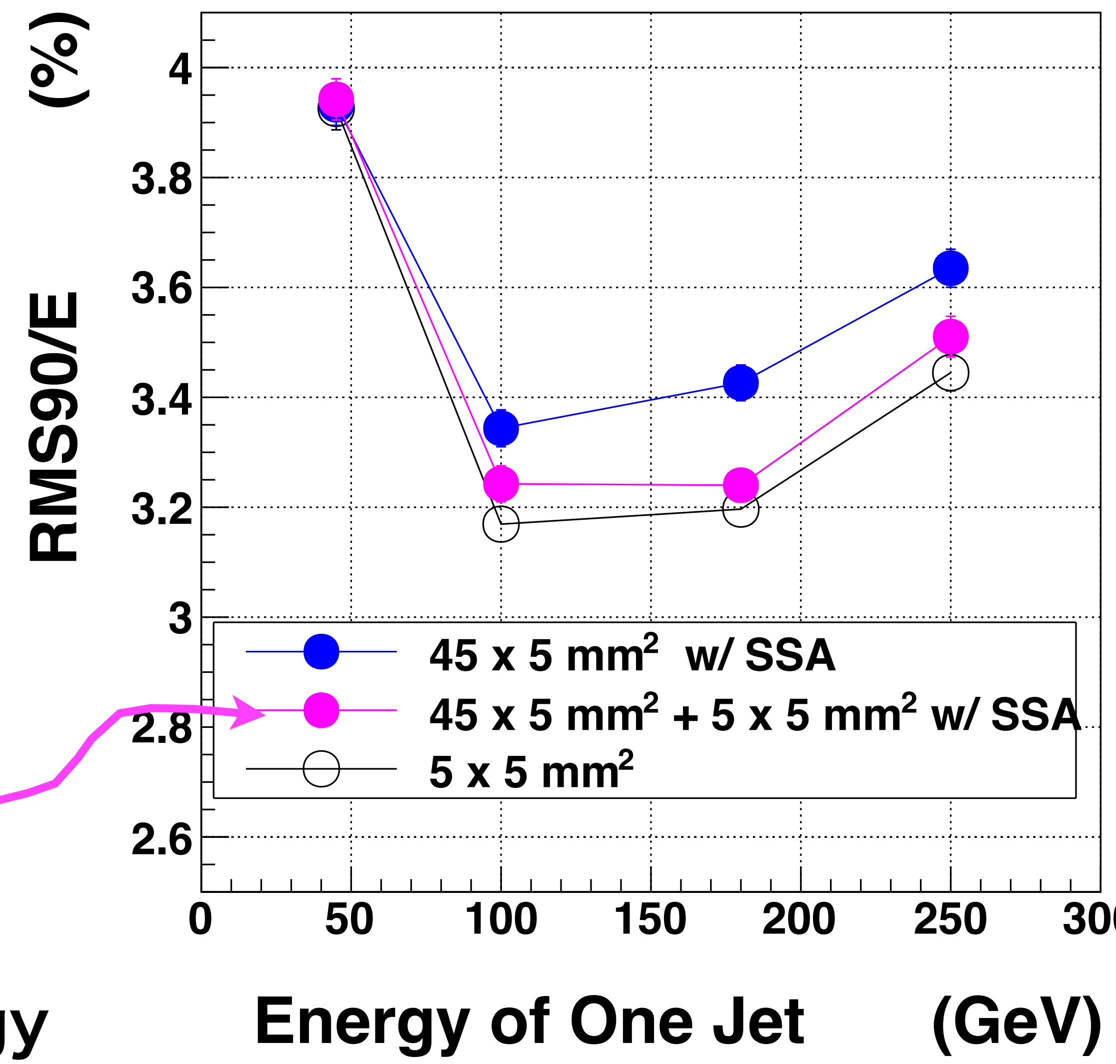
example

$$E5 = ET \times \frac{U5 + D5}{\sum^{9} Uj + \sum^{9} Dj}$$

positions and energies of all virtual cells are fed into the PandoraPFA program

ghost problem and its solution(1)





Solution

5 x 5 mm^2 interleaved between strip layers

too small for current technology

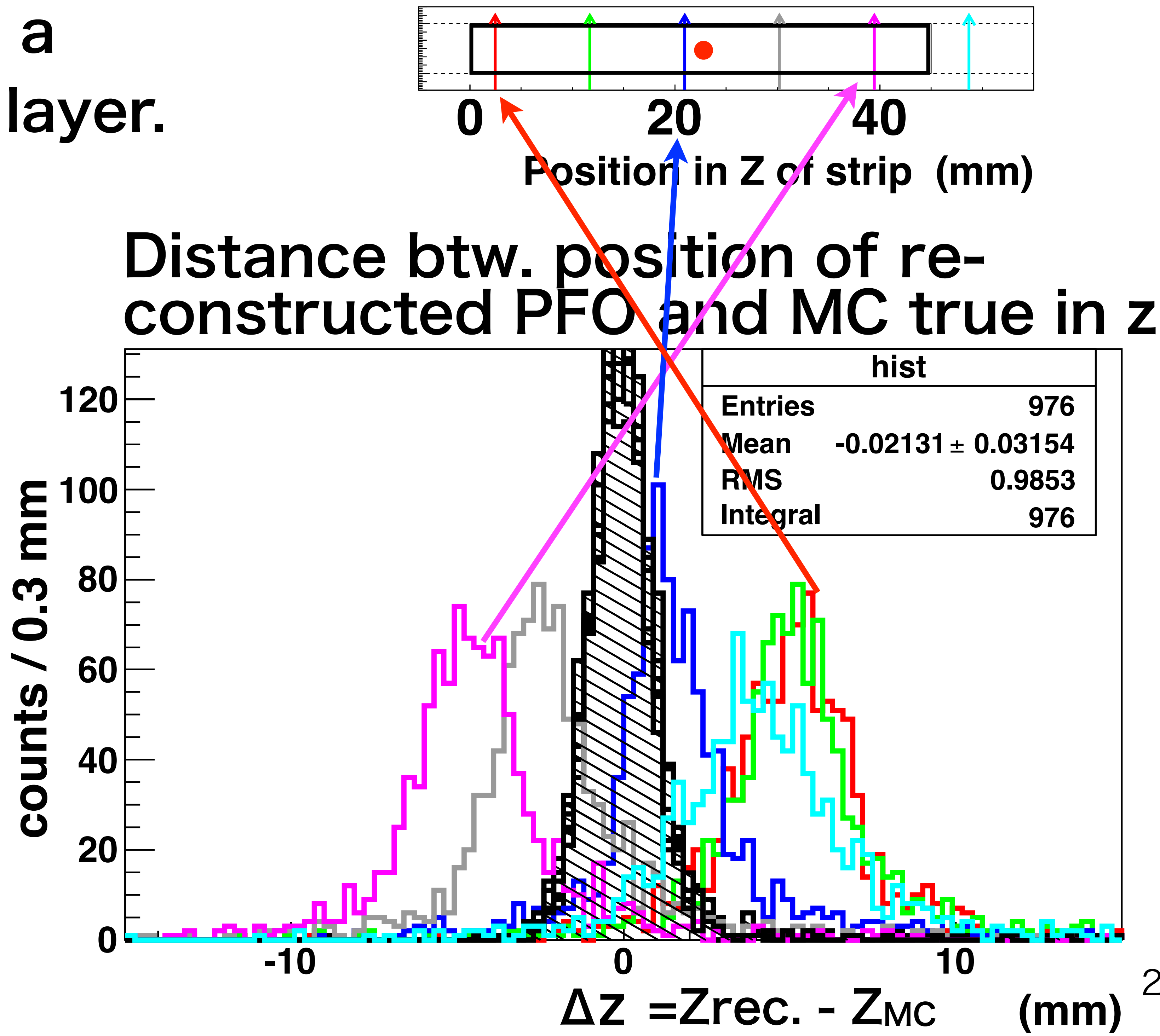
Use Si - layers for 5 x 5 mm^2 layers

= Hybrid ECAL

Position
Gravitational center of energy

10 GeV photons are injected on the ScECAL of ILD, changing injection position w.r.t. a scintillator of the first layer.

Side view of a scintillator of the first layer and injection point of photons



Black hatched: reconstructed PF object with SSA, not depend on injection position.

Position resolution is ~1 mm

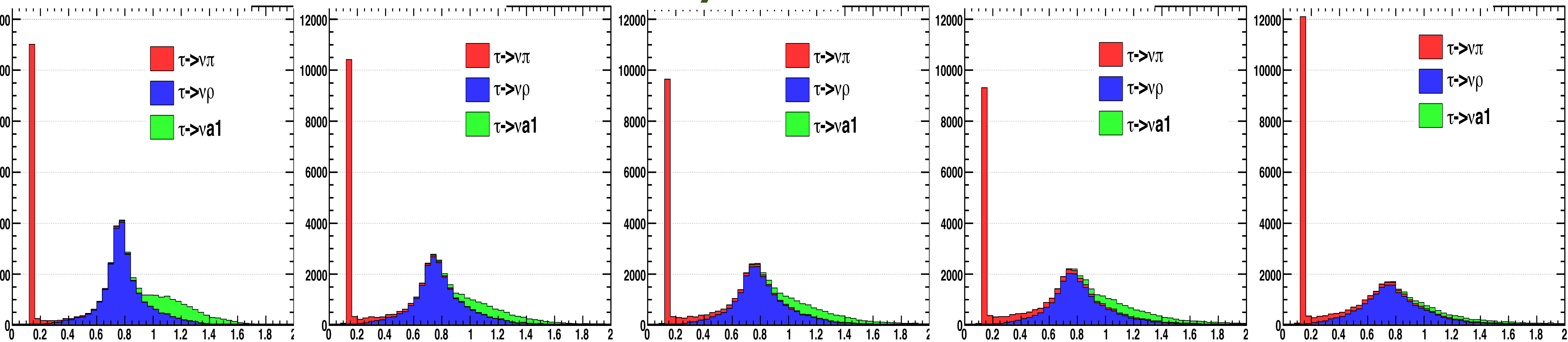
Color lines: without SSA

Systematic shift is removed by the SSA

π, ρ, & a1 mass in 4ECals with MyCut

- それぞれのECALにおいて、τのモードの質量分布。(※πはγを含ませてReconstruction)

MC Truth **Si ECAL** **Hybrid** **Sc SSA** **Sc ECAL**



Invariant Mass [GeV]

- SSAによりπのピークが減り、横に広がった。

  → SiECALでは、πの質量でそんなに広がっていない。
  SSAのゴーストヒットによる、γフラグメントを含んだと思われる。

- Alternative double layer Hybridでも、まだゴーストヒットによるγのフラグメントが生成しているように思われる。

  → PFA Cone-Clusteringの拡張により、性能改善の必要。

  → Alternative single layer Hybridを用いればSiECALと同じ分割能力が期待できる。

Mode selection with MyCut

- The efficiency and the purity

$$\text{efficiency} = \frac{\text{カットベースで選ばれたモード}}{\text{イベント数} \times \tau \times \text{Bratio}}$$

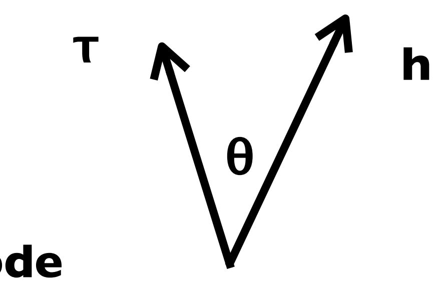
- Efficiency with MyCut

e-L, e+R	MCtrue	Si Ecal	Hybrid	Sc SSA	Sc Ecal
τ->eνν	98%	89%	90%	90%	67%
τ->μνν	99%	93%	93%	92%	89%
τ->πν	105%	113%	115%	125%	140%
τ->ρν	102%	91%	88%	84%	78%
τ->a1ν(1p)	102%	78%	82%	80%	43%

→ MCtrueでの Efficiencyは100%近い、Cutに大きな問題なし。

- purity with MyCut

Polarization observable I



- The main observable is angle θ in τ rest-flame.
  - Since the neutrino is not observed,
    the angle θ cannot be reconstructed completely.
  - In the lab frame the angle θ is related to energy fraction x carried by ....
  - Hadronic system : linear function

cosθ* (=ω) ≈ 2x - 1 → **this is an optimal observable ω**

π mode : x = Eπ / Eτ

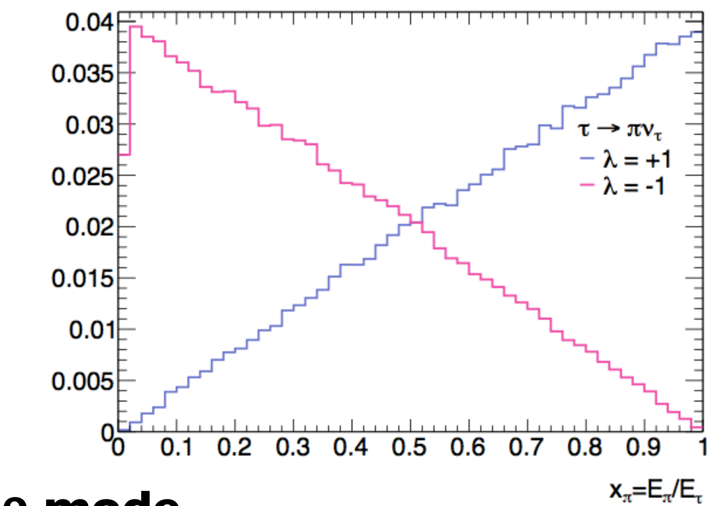
ρ mode : x = Eρ / Eτ

  - leptonic system :

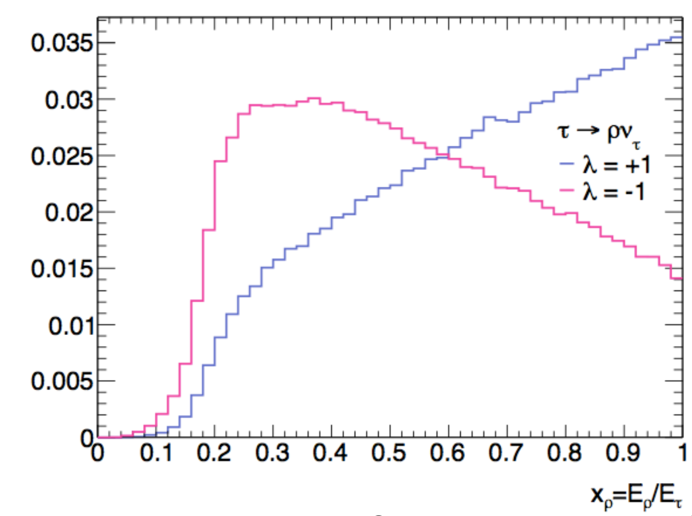
- there are two neutrinos in the final state which makes this decay channel less sensitive to the tau helicity than the hadronic channels.

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

• π mode

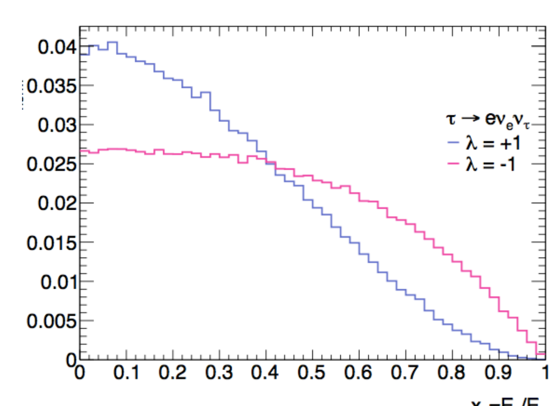


• ρ mode



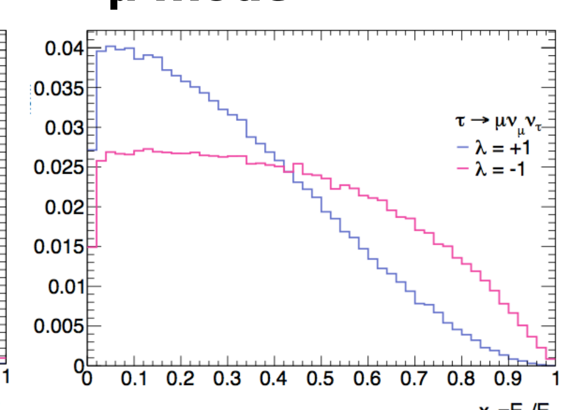
-1 0 1(ω)

• e mode

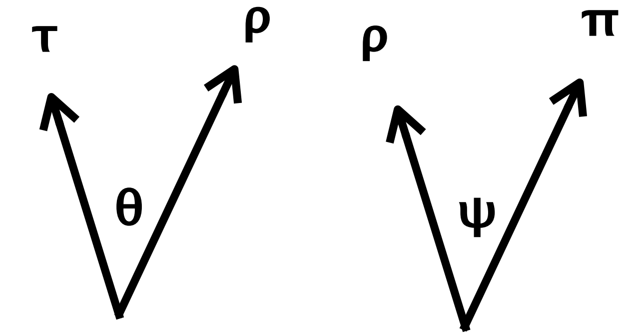


-1 0 1(ω)

• μ mode



Polarization observable 2 (ρ mode)



- 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.

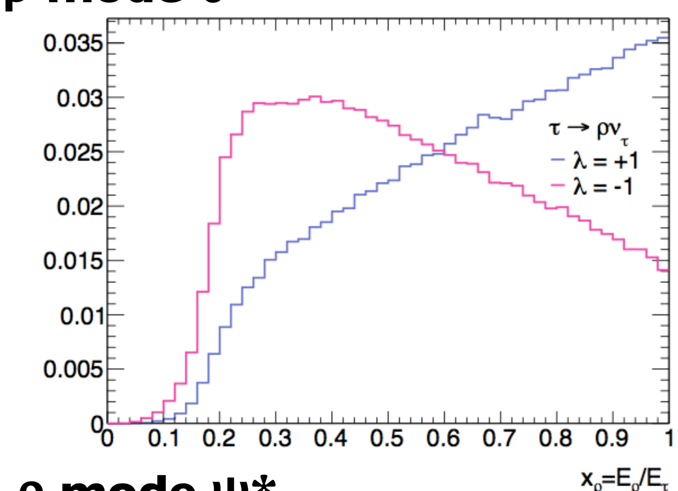
  - If one uses information of helicity of intermediate resonance, most of lost sensitivity can be regained.

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

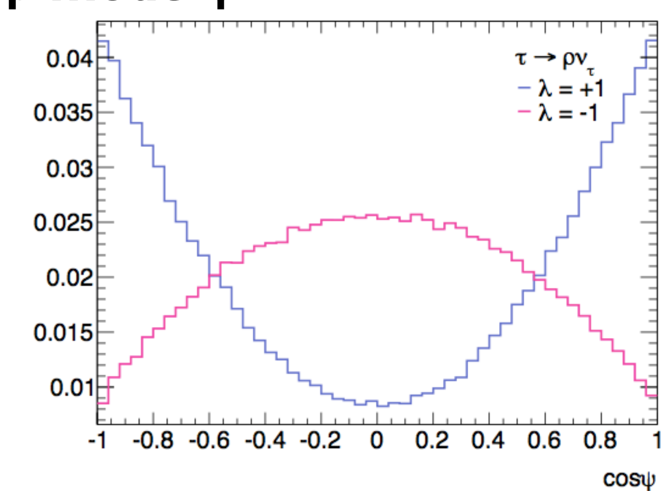
- In terms of the laboratory frame

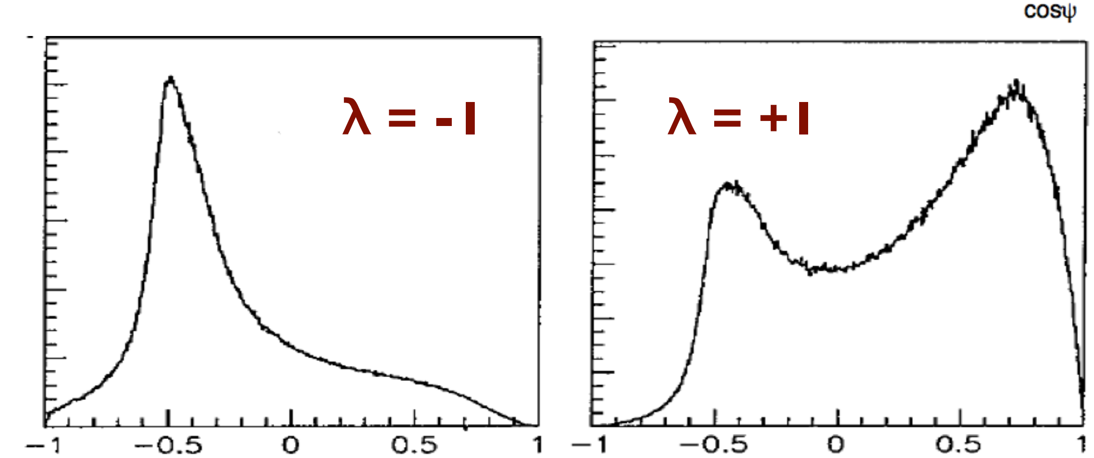
  cosψ* = (Eπ± - Eπ0) / Eρ

- ρ mode θ*



- ρ mode ψ*



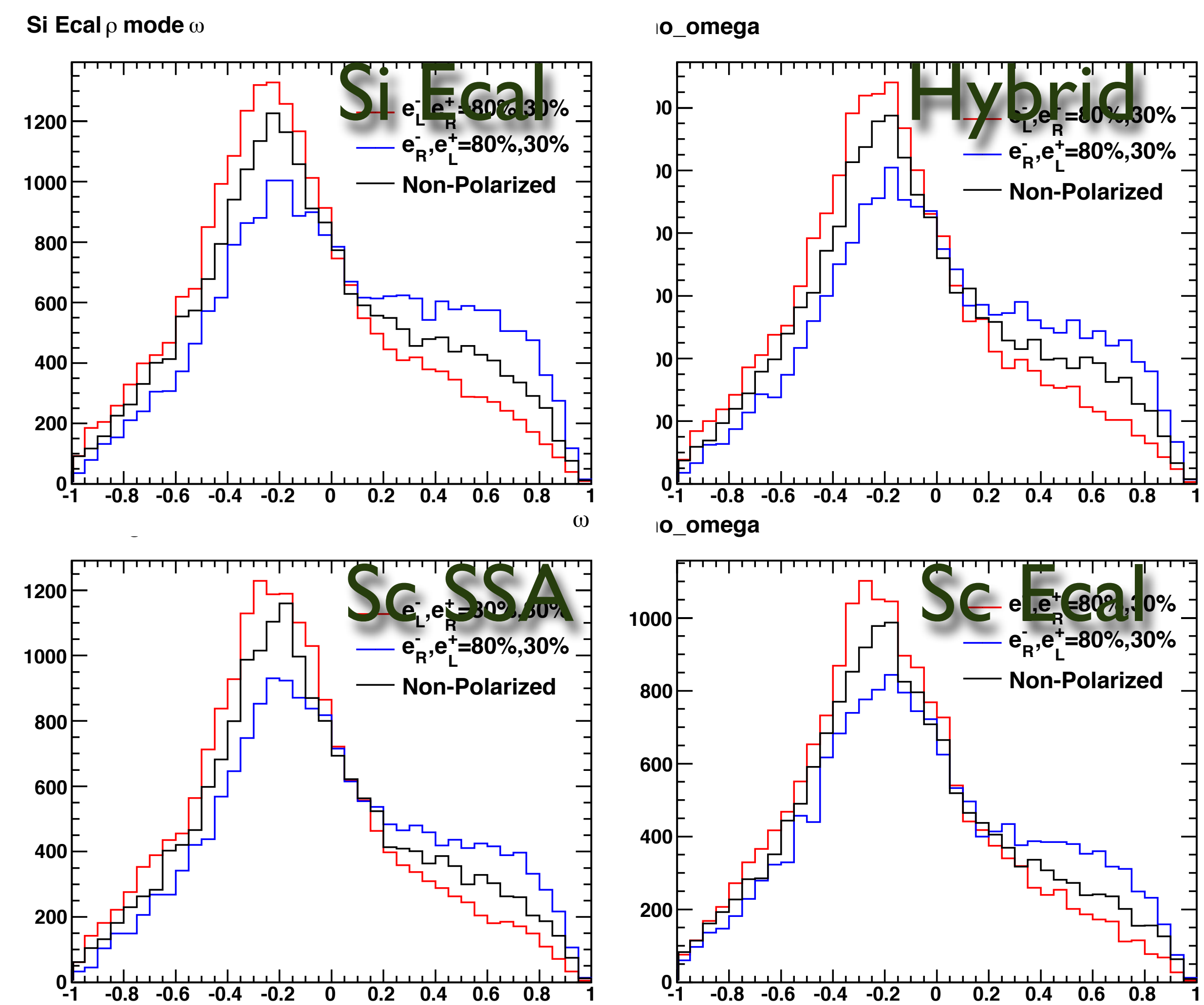


-1 0 1(ω)

Angular dist (ω) : ρ mode

- In case of recovering ω with cosψ*.

- ω distribution



- P(τ) Result

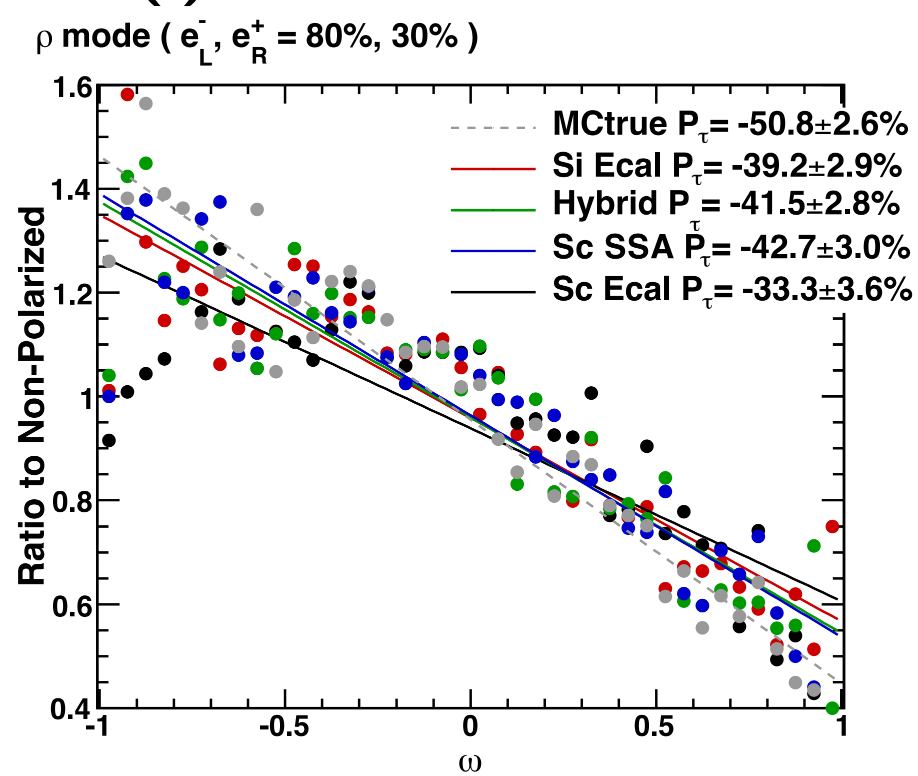
P(τ)	MCtrue	Si Ecal	Hybrid	Sc SSA	Sc Ecal
e-L e+R	51%	40%	42%	43%	33%
e-R e+L	52%	52%	47%	47%	38%

- ω distribution

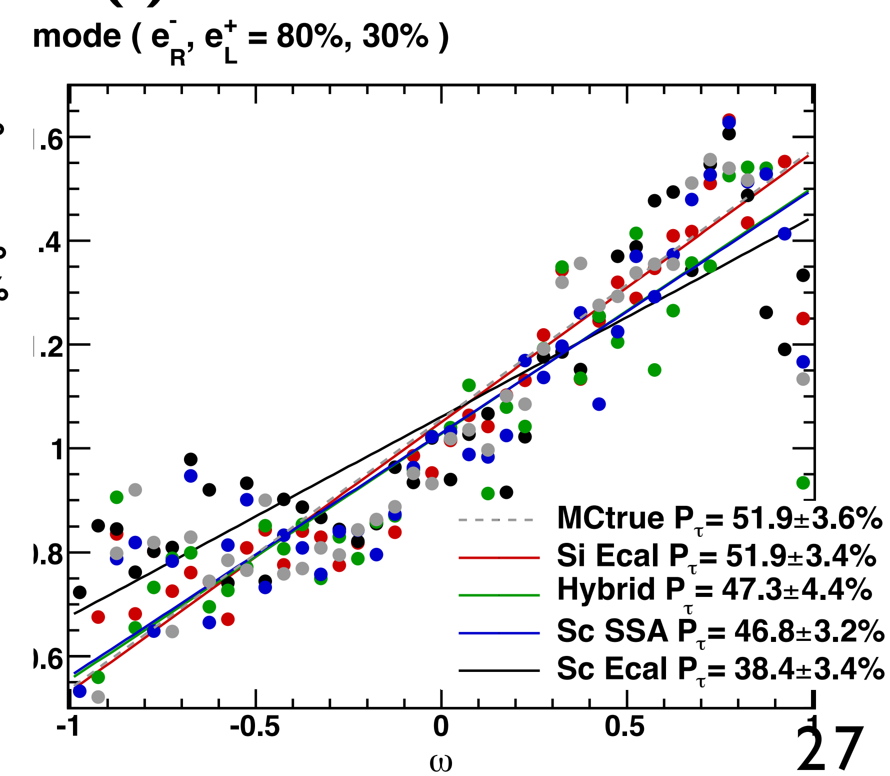
→ ω distribution divided by non-polarizing sample

and Linear fit is applied to obtain P(τ) value.

- P(τ) LR



- P(τ) RL

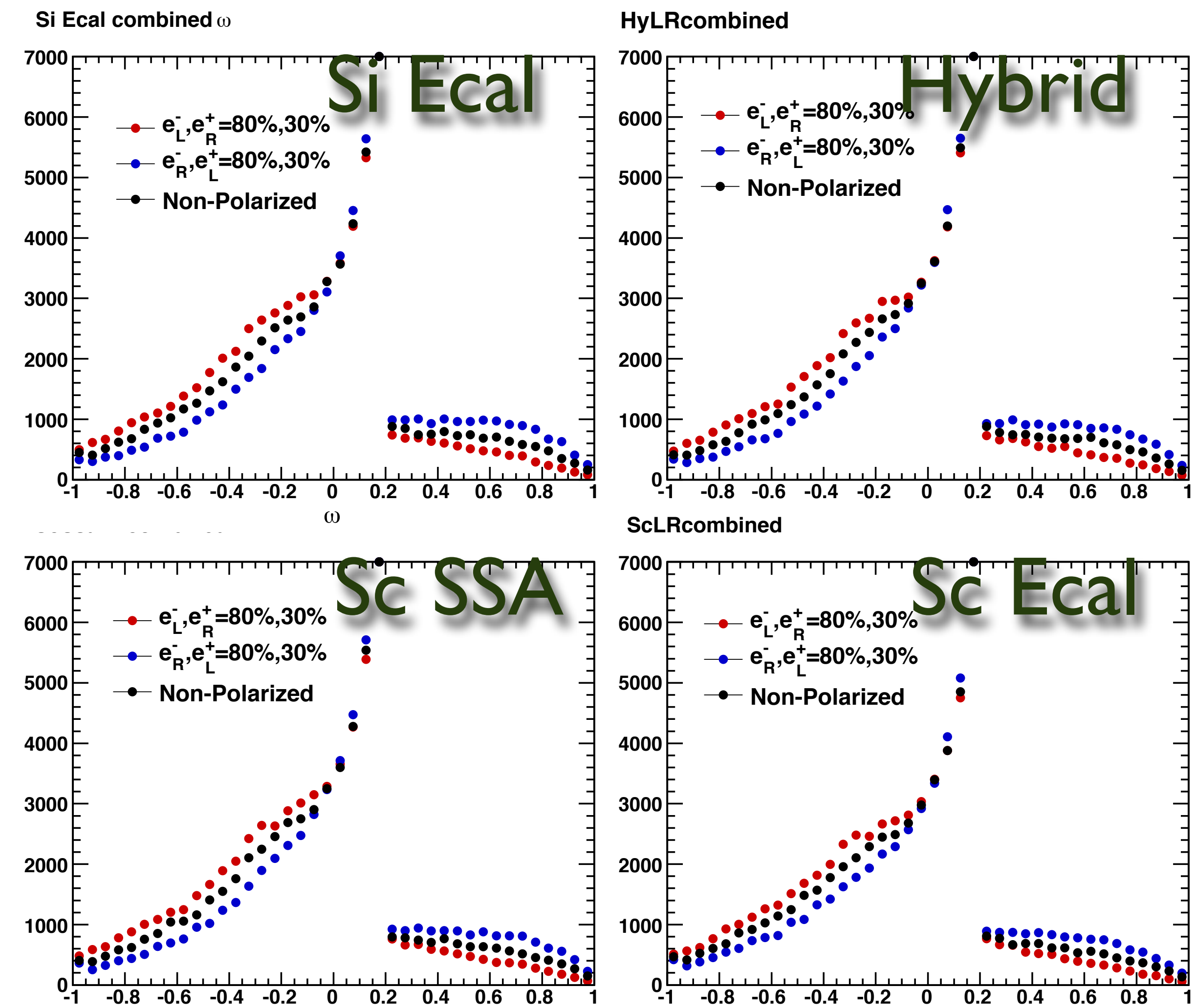


Angular dist (ω) : combined ω

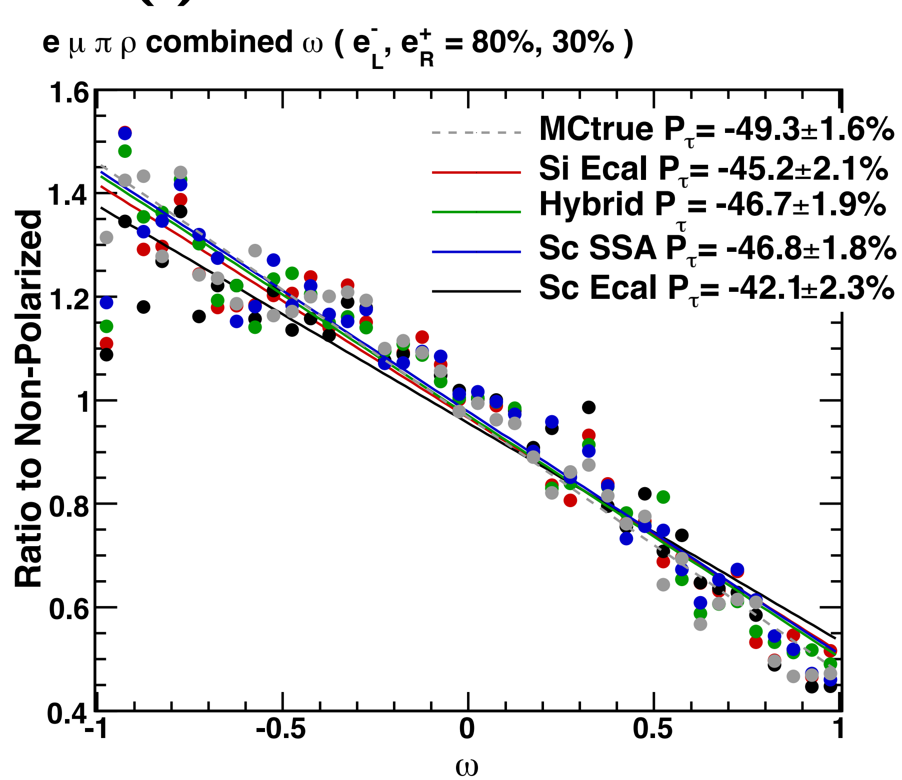
- Distribution of the polarization observable after summing up all decay modes.
- ω distribution divided by non-polarizing sample.
- P(τ) Result

P(τ)	MCtrue	Si Ecal	Hybrid	Sc SSA	Sc Ecal
e-L e+R	49%	45%	47%	47%	42%
e-R e+L	57%	52%	50%	51%	45%

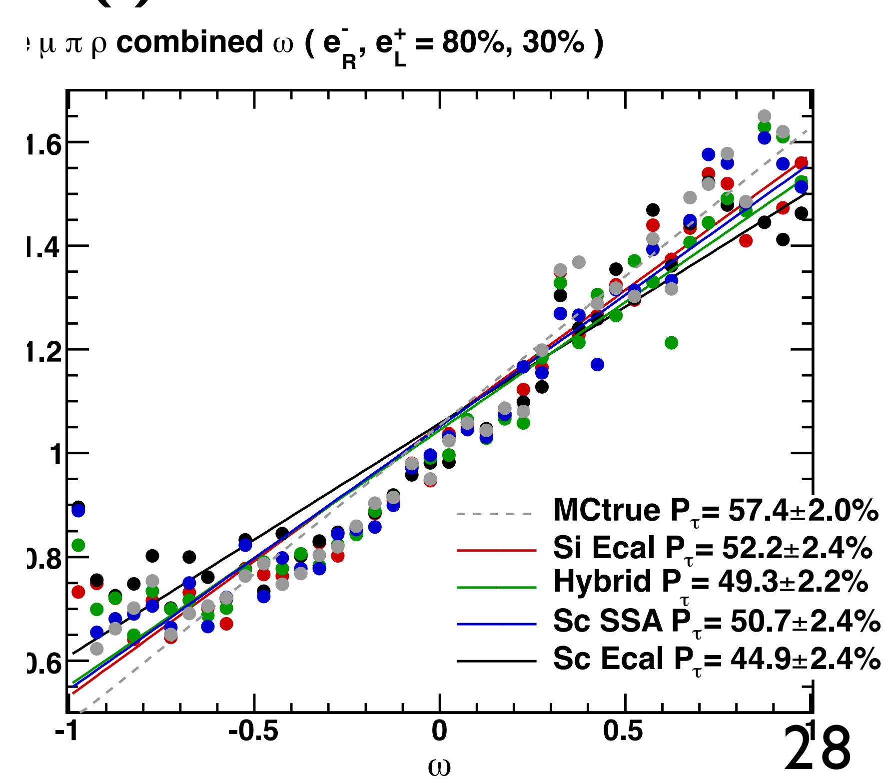
- ω distribution



- P(τ) LR



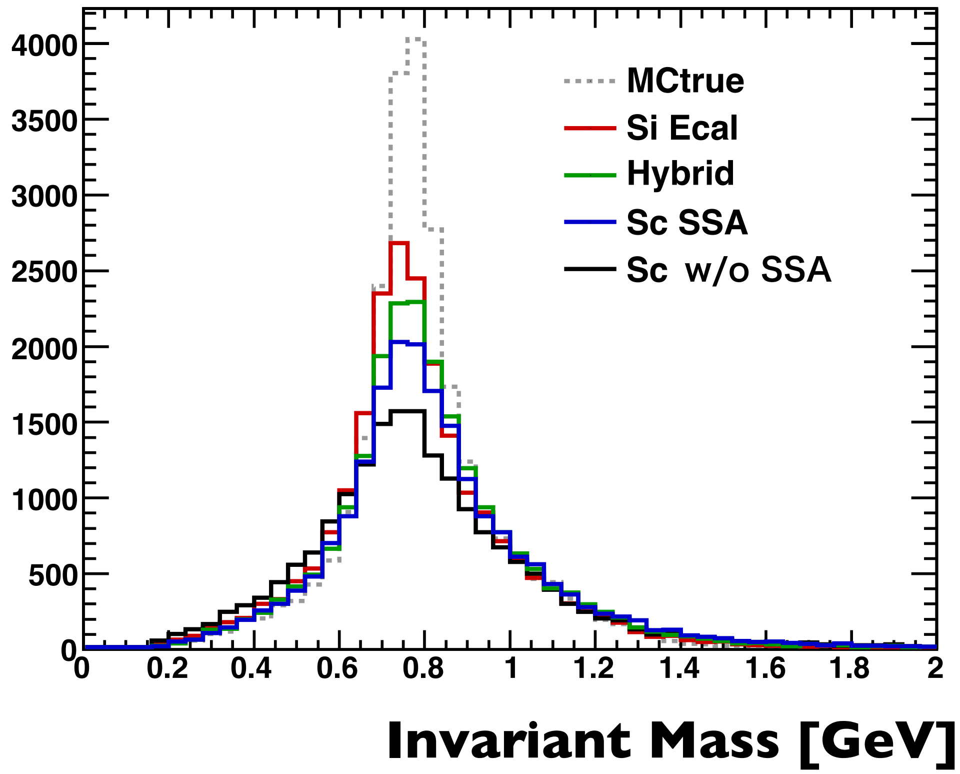
- P(τ) RL



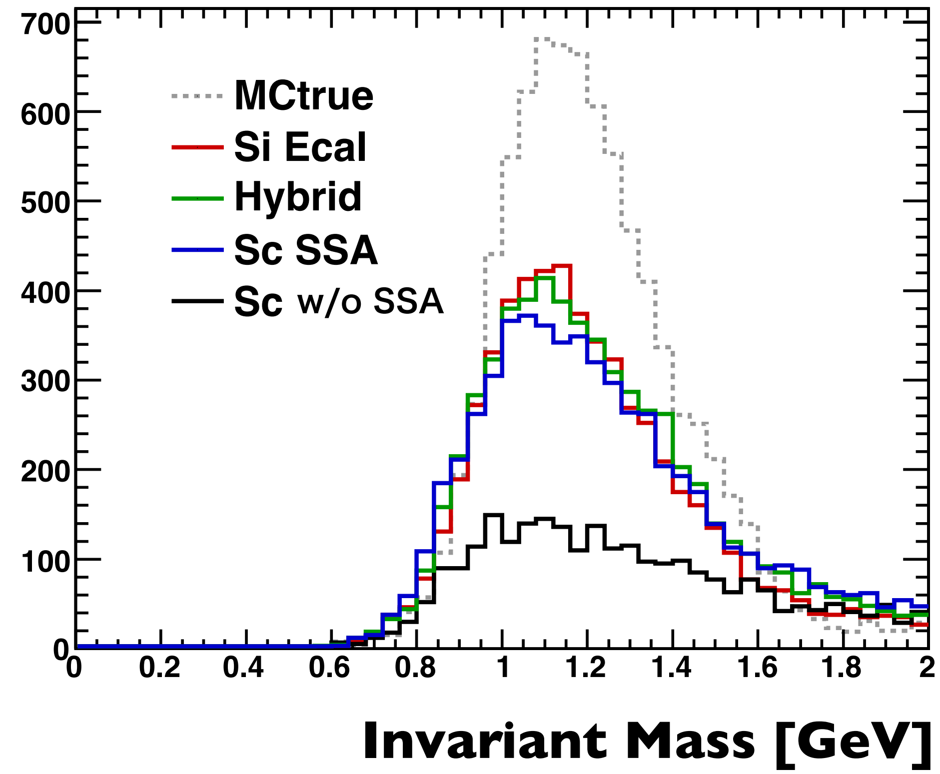
ρ, π0 & a1 Mass in 4ECALs with MyCut

- Mass of ρ and a1

4Detectors ρ mass



4Detectors a1 mass



- ρ reconstruction

  performance of reconstruction: Si ECAL > Hybrid Sc w/ SSA > Sc w/o SSA

- a1 reconstruction

  SSA drastically improve a1 reconstruction

  There is no large difference between Ecal types except Sc w/o SSA.

Introduction (ILD ECAL)

- PFAを用いて最高の性能を目指す

  Jetを構成する粒子のうち、荷電粒子はtrackerで、

  γはEMCALで、中性ハドロンはHCALで測定する

- Jet Energy Resolution

  終状態は、ほぼジェット：

  ee -> ννWW / ννZZ の4jet eventにおいて、

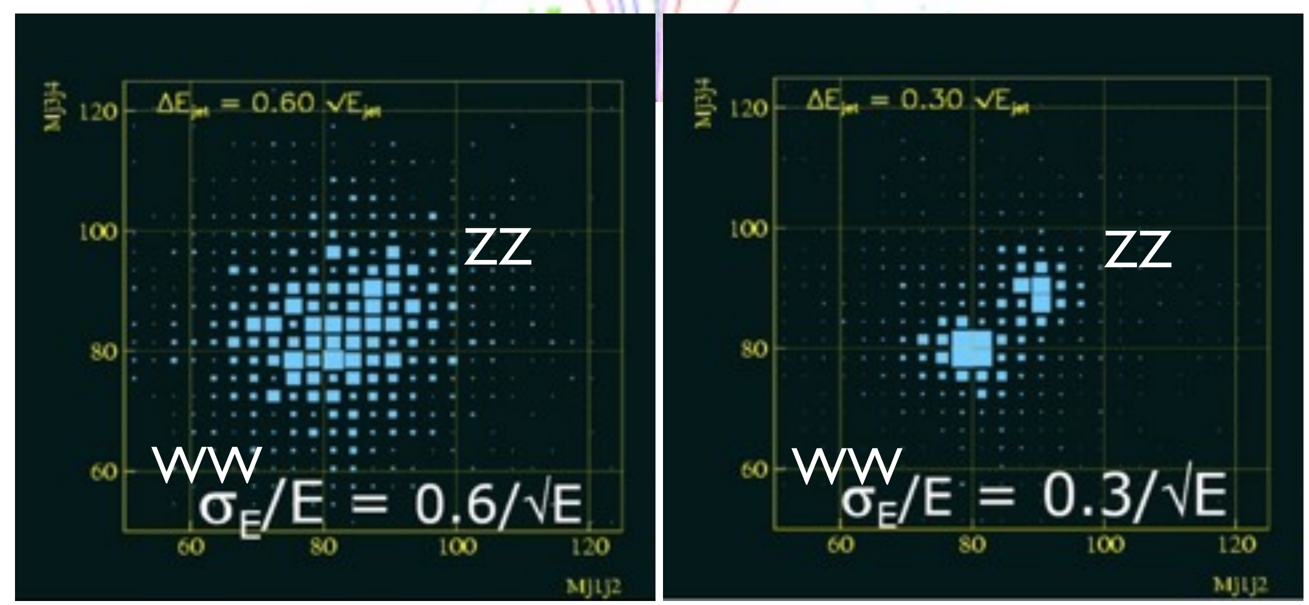
  質量分解能が、自然幅(~2GeV)程度になること

  → $\sigma_{E_{jet}}$ / Ejet = 3~4%

  (30% / $\sqrt{E_{jet}}$ below 100GeV)

  - カロリメータの非常に細かいセグメント化

  (- 粒子間隔を拡げるための大きな半径と強い磁場 ($d \sim BR^2$))



- ILD ECAL測定器への要求

  - 要求されるGranularity :

    1cm^{2}またはそれ以下のセグメント化 → PFAへの最適化

  - 要求されるEnergy Resolution (単粒子に対して) : 15% / $\sqrt{E}$