Tau-pair performance in ILD detectors

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Menu

- Motivation for tau-pair study
  - For LOI
  - For ILD detector optimization
  - For Z' search
- Analysis on SM background suppression
- Analysis on polarization

Motivation of this study

- For LOI:
  - ILC detector concepts should make a Letter-Of-Intent (LOI) by March 2009.
  - The LOI should contain analyses of specified benchmark physics processes based on full MC to show performance of the detector concept.
  - Tau-pair is one of the benchmark process, and it is a good analysis sample for reconstruction of π_0 to 2γ.
- For detector optimization:
  - Using results of the analyses of different detector models can illuminate difference of the performance.
- For physics:
  - Precise measurement of tau-pair cross section and angular distribution can detect a Z' boson whose mass is up to several TeV.

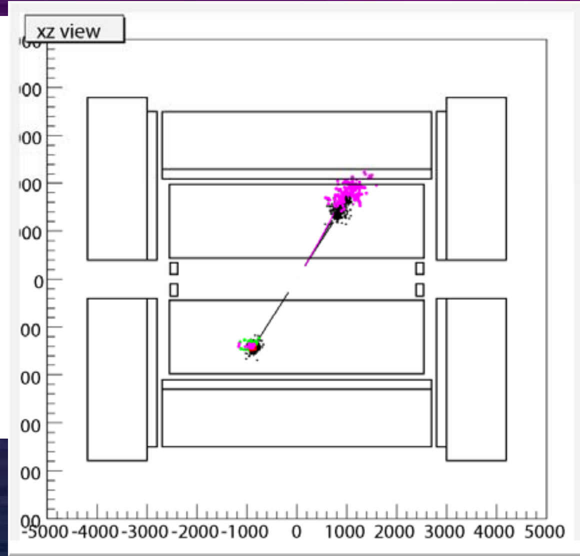
LOI: Benchmark process list

Processes ($e^+e^- \rightarrow$)	$\sqrt{s}$ (GeV)	Observables	Comments
ZH, ZH→e^+e^-X,	250	σ, m_H	m_H=120GeV, test materials and γ_{ID}
→$\mu^-\mu^+X$	250	σ, m_H	m_H=120GeV, test $\Delta P/P$
ZH, H→cc, Z→$\nu\nu$	250	Br(H→cc)	Test heavy flavour tagging and anti-tagging of light quarks and gluon
, Z→qq	250	Br(H→qq)	Same as above in multi-jet env.
Z* → $\tau^+\tau^-$	500	σ, A_{FB}, Pol(τ)	Test π^0 reconstruction and τ rec. aspects of PFA
tt, t→bW, W→qq'	500	σ, A_{FB}, m_{top}	Test b-tagging and PFA in multi-jet events. m_{top}=175GeV
$\chi^+\chi^-$, $\chi_2^0\chi_2^0$	500	σ, m_χ	Point 5 of Table 1 of BP report. W/Z separation by PFA

LOI: Charge of tau-pair analysis

4. $e^+e^- \rightarrow Z \rightarrow \tau^+\tau^-$ (Ecm=500 GeV)
   a. tau reconstruction, aspects of particle flow
   b. π^0 reconstruction
   c. tracking of very close-by tracks

   Tau reconstruction is a very challenging topic at the ILC. It will stress the tracking system and the clustering in the calorimeter. In addition selecting π^0 mesons will probe the photon reconstruction ability of the detector. Observables are the efficiency and purity. Physical observables are σ, A_{FB} and Ptau (tau polarization)



Description of LOI benchmark, from ILC-MEMO-2008-001

- Themes
  - Tracking and calorimetry of concentrated particles
    - Gamma factor is around 140 for 250 GeV τs
  - π_0 to 2γ decay reconstruction
    - 2γs are very closed, difficult to separate
- Observables
  - Cross section, A_{FB}, $P(\tau)$
  - Event selection and π_0 reconstruction performance (efficiency and purity)

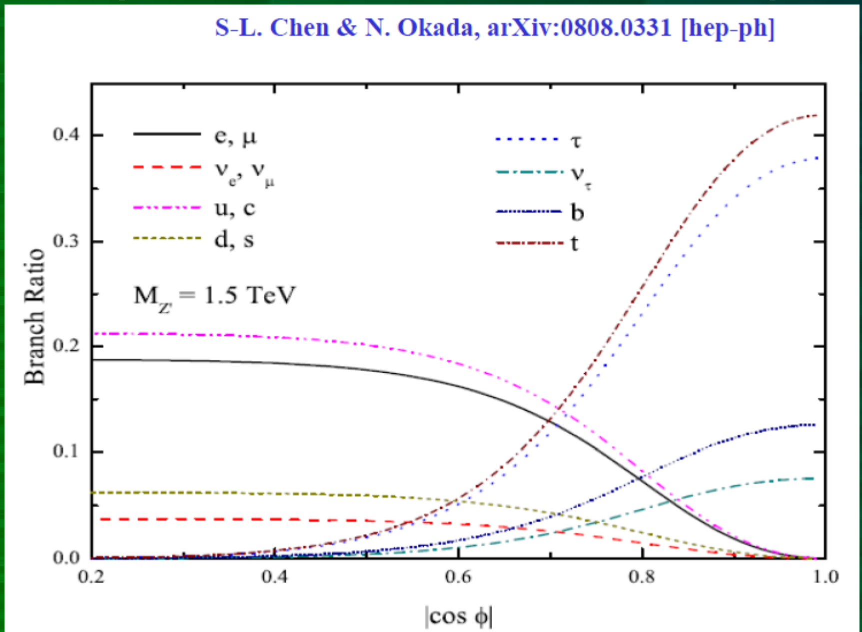
Opt: Comparing detector models

Geometry	GLD	GLD’	J4LDC	LDC’
Software	Jupiter	Jupiter	Jupiter	Mokka
Magnetic field	3 Tesla	3.5 Tesla	4 Tesla	3.5 Tesla
TPC Rmin	43.7 cm	43.5 cm	34 cm	37.1 cm
ECAL Rmin	210 cm	185 cm	160 cm	182.5 cm
ECAL thickness	19.8 cm	19.8 cm	19.8 cm	17.2 cm
HCAL thickness	120 cm	109 cm	96 cm	127.2 cm
ECAL granularity	1x1 cm	1x1 cm	1x1 cm	0.5x0.5 cm

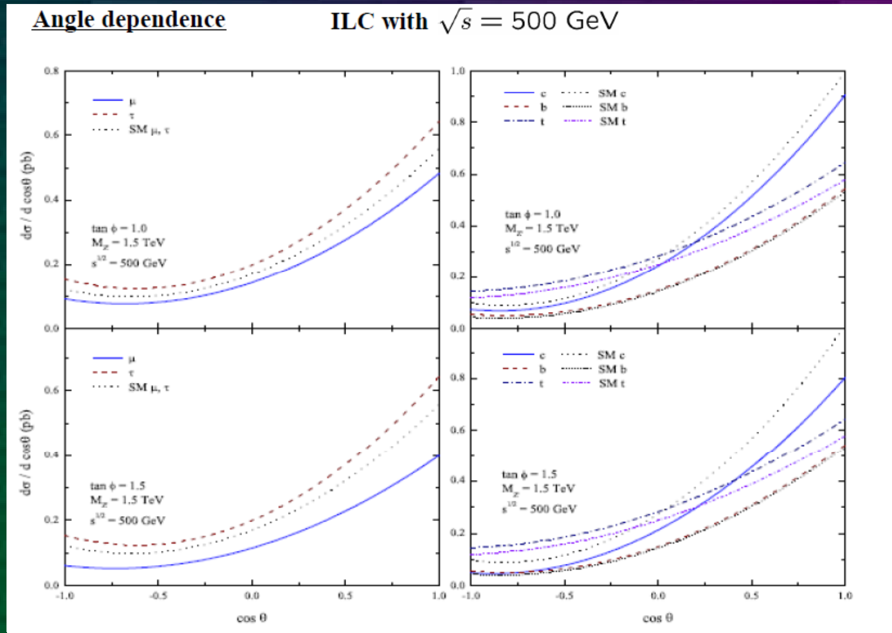
- We generate event samples for detectors with different size and B field. (signal only for Jupiter geometries)
- Compare difference of performance.

Phys: Flavor dependent Z' model

- Additional Z' boson can make tau-pair production cross section and angular distribution deviated from SM.
- If the coupling to Z' (-> Z' decay branching ratio) is flavor dependent, measuring tau-pair production can be the main process to measure Z' properties.

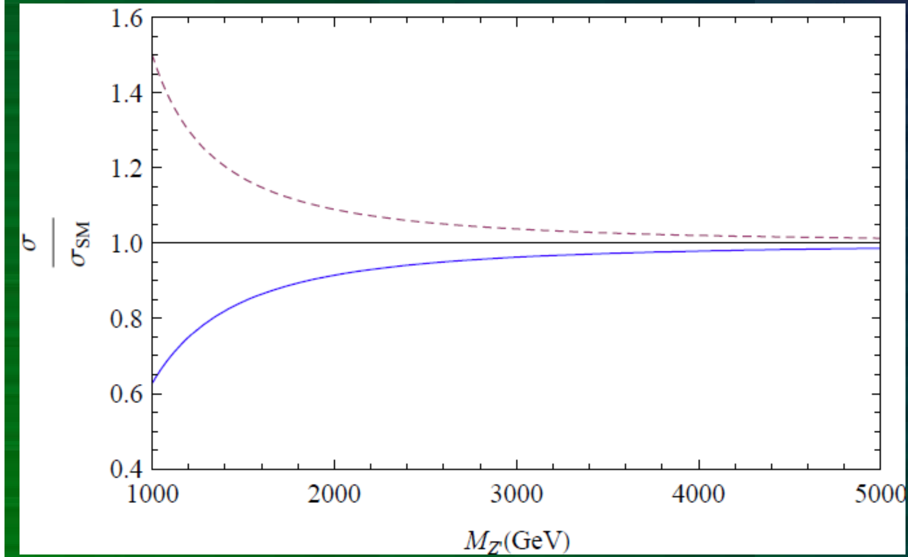


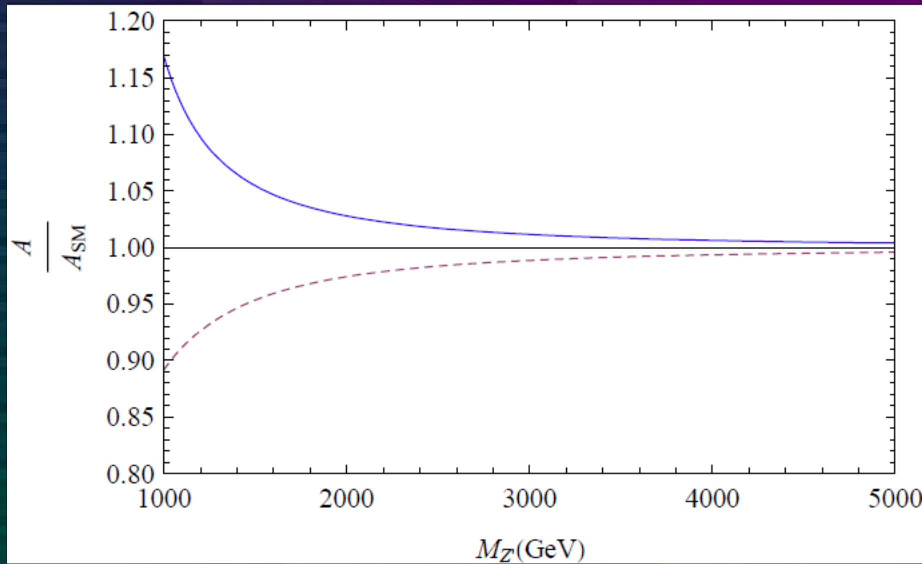
Branching ratio of Z'
with a model parameter ϕ



Deviation of angular dependence by Z'

Required precision for σ and A_{FB}





- 1% precision for cross section and A_{FB} can detect ~5 TeV Z'

Event samples (sig. & bg.)

- Signal cross sections: 2.6 pb (e_L), 2.0 pb (e_R)
- Simulated events:
  - ~80 fb^{-1} in GLD, GLD' and J4LDC with Jupiter
  - ~80 fb^{-1} in LDC' with Mokka
  - Reconstructed by MarlinReco/PandoraPFA (ilcsoft v01-04)
- Backgrounds:
  - Bhabha (35000 pb)
    - Good $e\pi$ separation is essential
  - $\gamma\gamma$ -> $\tau\tau$ (1500 pb)
    - Cut by angular & energy information
  - WW -> $l\nu l\nu$ (~1 pb)
    - Cut by opening angle

BG suppression by full SM sample

- For LOI, background study should be done by a MC sample of full processes of specific (least) integrated luminosity.
  - 2f: 50fb^{-1}, 4f: 20fb^{-1}, Bhabha: 0.1 fb^{-1} $\gamma\gamma$: 1fb^{-1} etc.
- MC sample of LDC' detector model has been generated.
  - LDC' is slightly different from ILD reference model.
  - Generation for ILD reference model is in preparation.

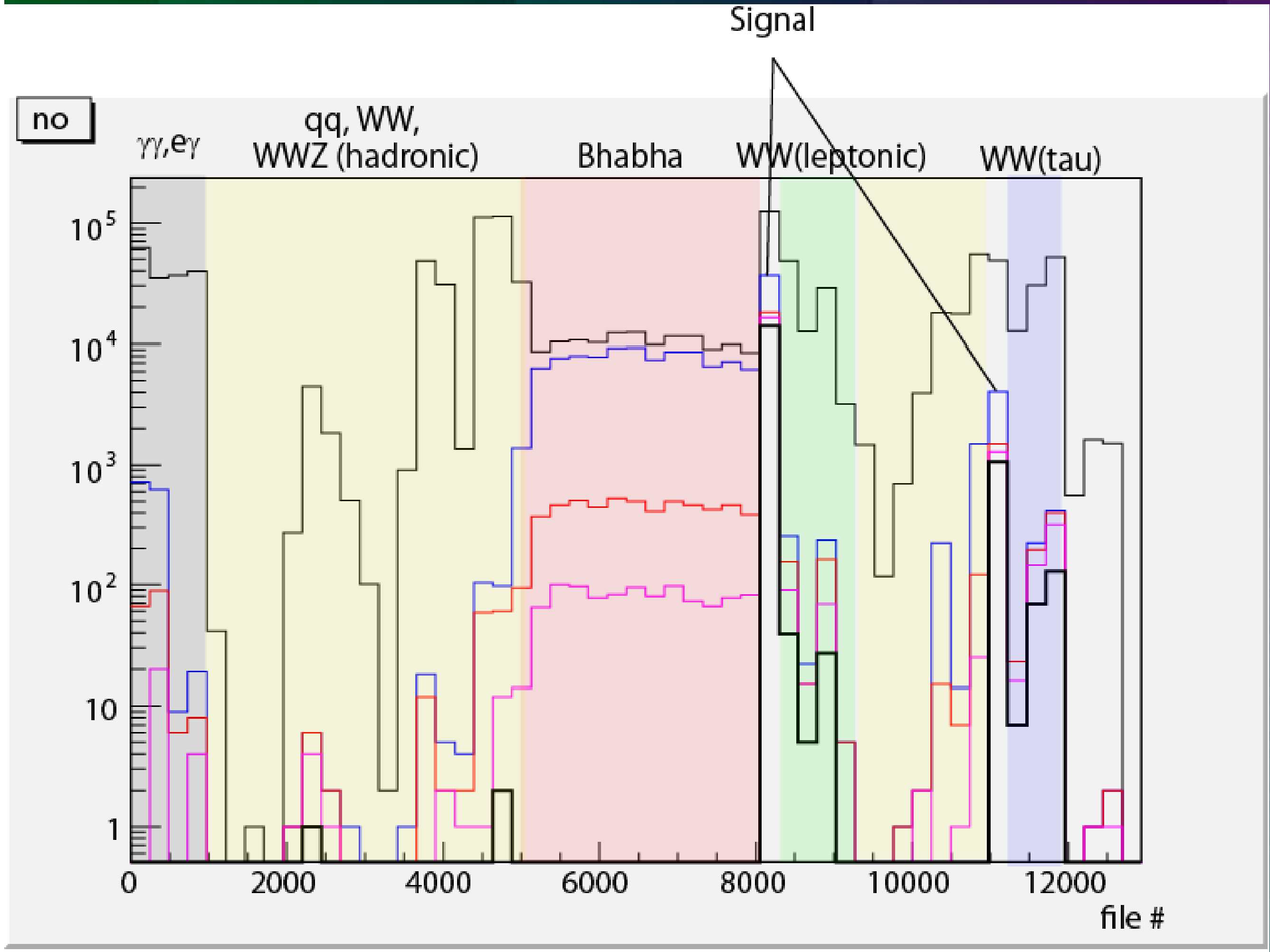
LDCPrime_02Sc			
EventType	NEvent	L[1/fb]	delta_L
2f	1092584	19.89	0.15
4f	2666806	48.88	2.69
6f	446028	471.36	66.21
aa_X	181408	0.28	0.02
ee	6931010	0.1	0
eaea	344270	0.19	0
nnNa	806700	17.45	3.93
aaNa	261954	9.42	0.82
hX	276728	465.86	75.74
other	120000	0	0
Zh_ee_mu[illegible]	20000	1332.98	0
Zh_qqnn	10000	223.26	0
Zh_qqqq	25000	158.73	0
tautau	100000	22.03	2.8
6f_bbqqqq	450217	486.37	5.42
sp5_ch_ne	82305	464.01	112.54
sp5_x	78570	692	248.26
sps1ap	1617133	891.37	195.94
ZZ	50000	74.59	39.59
total	15560713		

Number of events produced in LDC' (from Frank's slide)

BG suppression cuts

1. Number of track <= 6
   – Veto hadronic events
2. Specialized jet clustering (TaJet)
   – Customized to taus (several particles within narrow angle)
   – 1 positive & 1 negative jets required for further analyses
3. Opening angle > 178deg
   – Suppress WW to $l\nu l\nu$ background
4. $40 < E_{vis} < 450$ GeV
   $\gamma\gamma \to \tau\tau$ and Bhabha rejection
5. 2-electron and 2-muon veto
   – For bhabha and $ee \to \mu\mu$ veto
   – E-ID by Ecal/total deposit, μ-ID by hit/track energy
6. $|\cos\theta| < 0.9$ for both jets
   – Bhabha is completely suppressed by this cut

Result of SM suppression cut



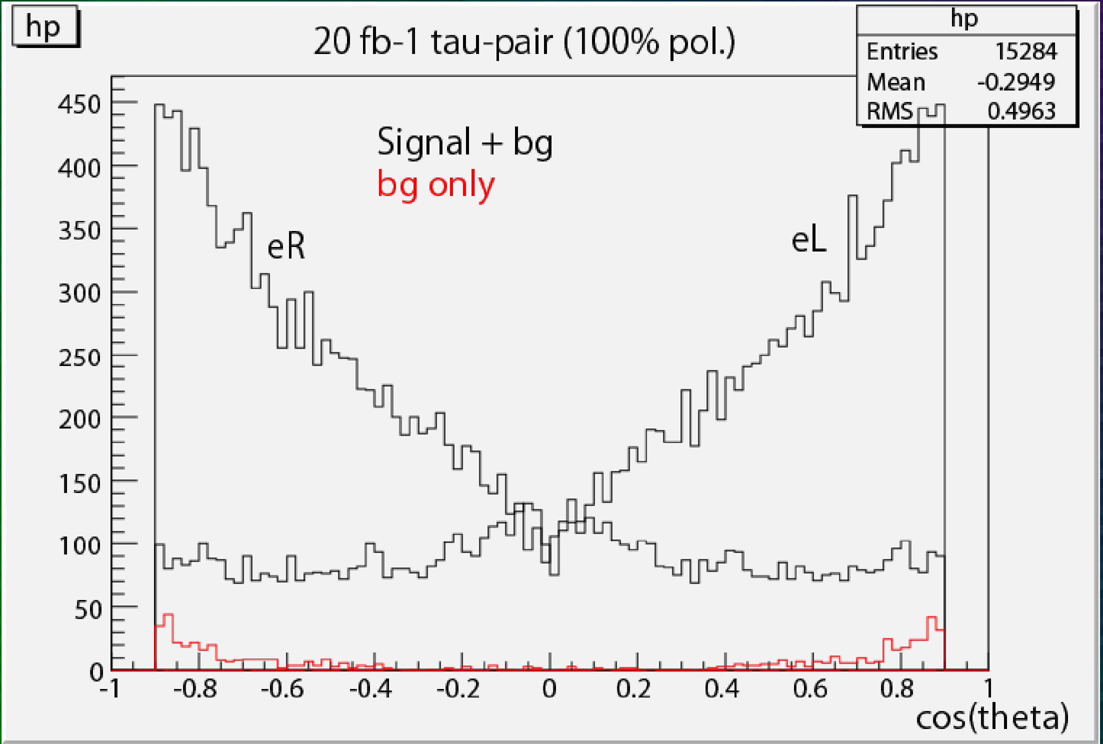
track # cut only, opening angle cut, visible energy cut, ee,μμ cut, cosθ cut

	All	Tau
#tr cut only	1108578	69489
Angle cut	139499	19504
Evis cut	26589	18996
ee, μμ cut	19403	17378
cosθ cut	15284	14808

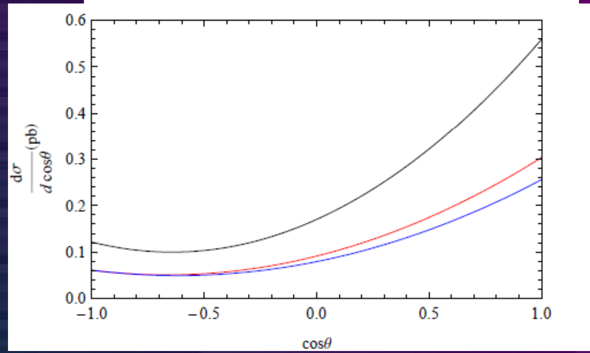
Remaining bhabha is 0 in 0.1 fb^{-1}
-> Bhabha background is < 10% of signal
(Need more events for precise estimation)

Preliminary: luminosity not normalized,
γγ–ττ not contained.

Forward-backward asymmetry



$$A_{FB} = \frac{N_F - N_B}{N_F + N_B}$$



SM calculation
(Red: left, Blue: right)

- # of bg events is much smaller than signal events
  - If we precisely estimate bg amount, statistical error of signal only concerns to σ and A_{FB} measurements
- Effective cross section after cut is 490 fb (21.3% acceptance)
  - Corresponds to 0.2 % error in σ and 0.28% error in A_{FB} at 500 fb^{-1}

Decay modes in A_{pol} analysis

$\tau \rightarrow e\nu\nu$	• Branching ratio: 17.8% • 3 body decay; pol. info is smeared
$\tau \rightarrow \mu\nu\nu$	• Branching ratio: 17.4% • 3 body decay; same as $e\nu\nu$ mode
$\tau \rightarrow \pi\nu$	• Branching ratio: 10.9% • Pol. can be directly observed by π distribution
$\tau \rightarrow \rho\nu$, $\rho \rightarrow \pi\pi$	• Branching ratio: 25.2% • Pol. of ρ can also be obtained by π distribution in ρ-rest frame (pol. of ρ is connected to pol. of τ)
$\tau \rightarrow a_1\nu$, $a_1 \rightarrow \pi\pi\pi$	• Branching ratio: 9.3% • Currently not used because statistics is low

Analysis flow

A_{pol} analysis highlights:

- Mode selection
- Invariant masses of ρ and π^0
- A_{pol} calculation by angular distribution of πs

Pandora PFA

↓ PFO particles

TaJet jet finder

↓ Jets

1+1 jets cut
Back to back cut
BG veto cuts

→ **A_{FB}**

↓

1 prong cut
Lepton veto
Energy cut

→ **Neutral particle**

No → **A_{pol} ($\tau \to \pi\nu$)**

Yes → **ρ reconstruction** → **π^0 reconstruction** → **A_{pol} ($\tau \to \rho\nu$)**

$\tau \rightarrow \pi\nu$ selection cuts

1. 1 prong cut
   Jets with >2 charged particle rejected.
2. Lepton veto
   Events containing e/μs are rejected.
   (criteria is the same as A_{FB} lepton-pair veto)
3. Energy cut
   Jets with energy < 10 GeV rejected.
   (e/μ/π separation is inefficient in low energy)
4. Events with > 1 GeV neutral particles are rejected.
   In “tight cut” event with any neutrals are rejected.

τ -> $\pi\nu$ selection results

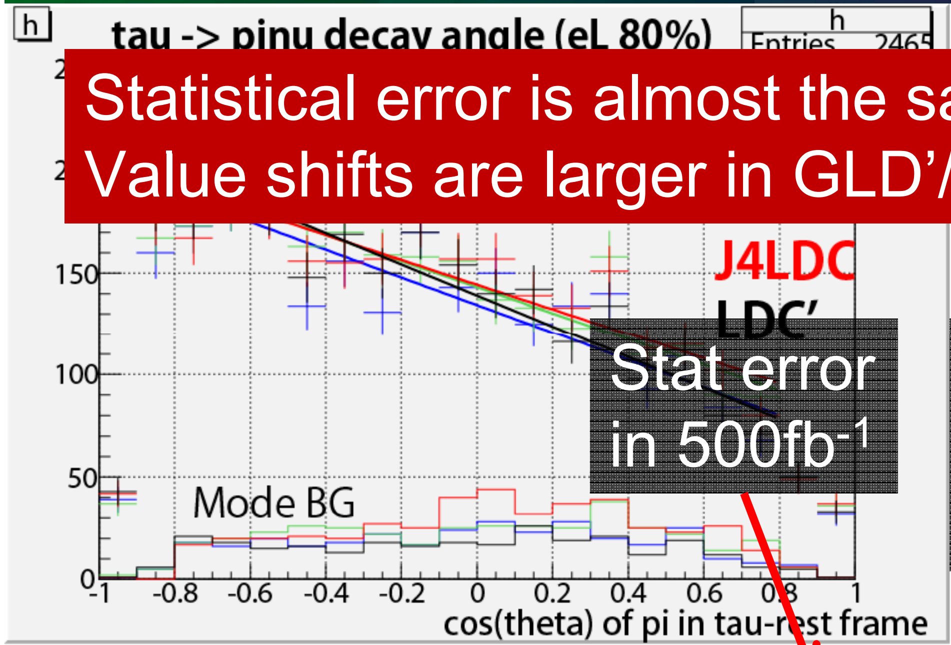
Geometry	GLD		GLD'		J4LDC		LDC'	
	eff.	purity	eff.	purity	eff.	purity	eff.	purity
NO cut	100.00%	10.89%	100.00%	10.88%	100.00%	10.90%	100.00%	10.90%
1+1 jet	67.87%	11.06%	66.49%	11.07%	71.39%	11.23%	72.50%	11.70%
opening angle>170deg	30.01%	11.05%	29.83%	11.05%	30.38%	11.12%	30.43%	11.20%
AFB cut	25.20%	11.98%	25.07%	11.98%	25.23%	12.10%	25.17%	12.11%
1 prong	25.17%	14.55%	25.06%	14.57%	25.22%	14.69%	25.16%	14.61%
Jet energy cut	24.32%	14.50%	24.24%	14.54%	24.36%	14.66%	24.34%	14.58%
e,mu veto	23.32%	24.26%	22.88%	24.02%	23.00%	24.53%	23.59%	23.98%
No gamma cut	21.29%	85.73%	21.37%	83.58%	21.43%	80.84%	21.16%	88.50%
No gamma cut (tight)	20.54%	86.89%	20.56%	84.57%	20.66%	81.95%	20.42%	89.22%

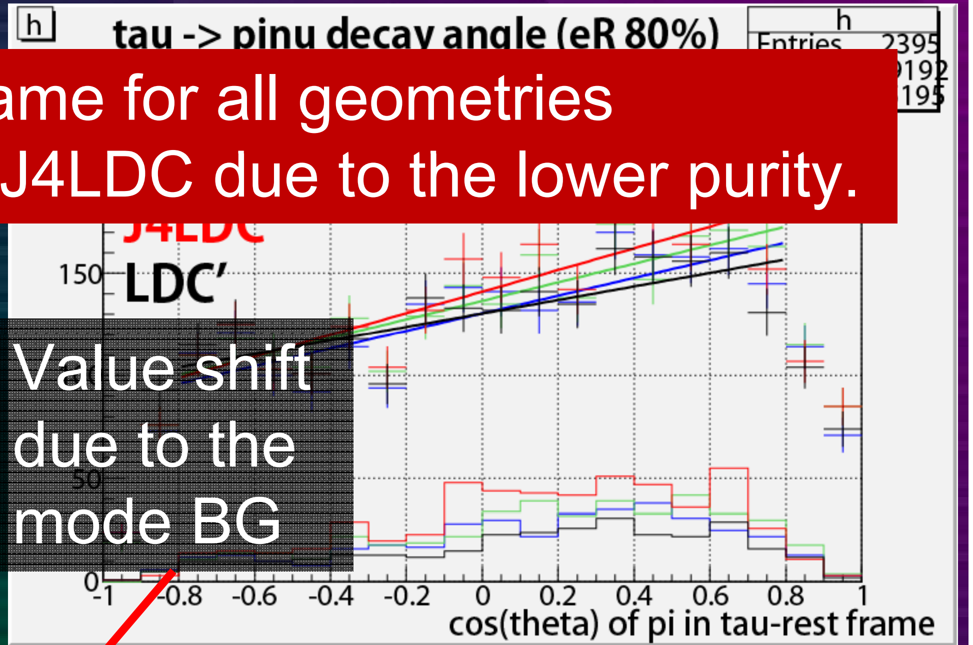
Selection performance between geometries

(look at the 2nd row from the bottom)

- Efficiency: not so different
- Purity: LDC' > GLD > GLD' > J4LDC
  - τ -> $\rho\nu$ mode (decay 2π is mis-reconstructed as single) might be the reason (larger is better)
  - LDC' has advantage due to high CAL granularity.

A_{pol} calculation ($\pi\nu$ mode)





Statistical error is almost the same for all geometries
Value shifts are larger in GLD'/J4LDC due to the lower purity.

Stat error in $500 fb^{-1}$

Value shift due to the mode BG

	Pol	Apol (count)	estat	shift	Apol (linear fit)	estat	shift
GLD	eL (80%)	47.17% ± 4.54%	1.25%	−7.01%	54.89% ± 4.67%	1.28%	−4.49%
GLD'		49.45% ± 4.52%	1.25%	−9.76%	52.11% ± 4.64%	1.28%	−7.65%
J4LDC		49.14% ± 4.60%	1.28%	−12.41%	52.20% ± 4.68%	1.30%	−10.28%
LDC'		52.72% ± 4.30%	1.22%	−5.46%	57.95% ± 4.49%	1.27%	−3.25%
GLD	eR (80%)	−25.62% ± 4.77%	1.35%	−6.20%	−25.41% ± 5.23%	1.48%	−7.58%
GLD'		−24.04% ± 4.79%	1.36%	−9.23%	−23.33% ± 5.18%	1.47%	−9.81%
J4LDC		−28.57% ± 4.88%	1.38%	−7.58%	−27.73% ± 5.22%	1.48%	−9.63%
LDC'		−18.93% ± 4.63%	1.33%	−6.57%	−19.11% ± 5.12%	1.48%	−6.15%

Values obtained by signal-only events!

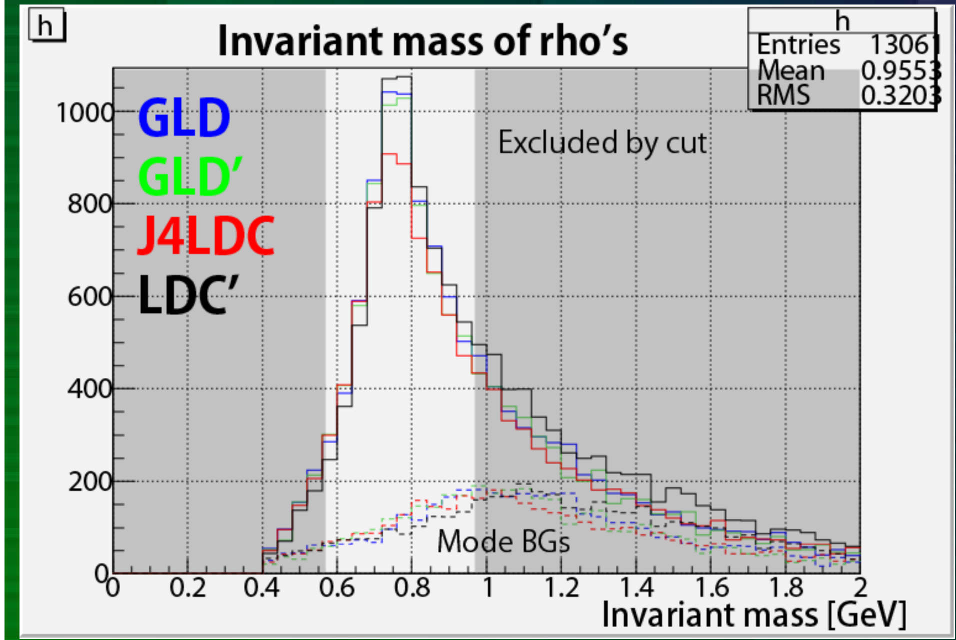
τ -> $\rho\nu$ selection cuts

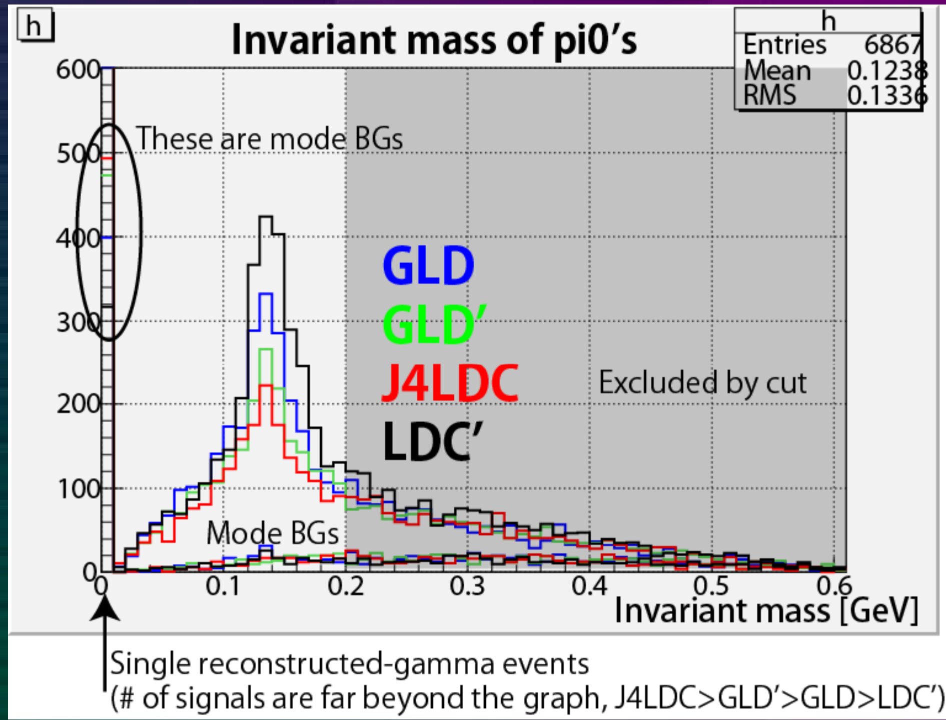
1. 1 prong cut
2. Lepton veto
3. Energy cut (jet energy must be > 10 GeV)

Above are same as τ->$\pi\nu$ cuts

4. Events with > 10 GeV from neutrals (in total) are selected.
5. Mass of ρ is reconstructed, must be within 200 MeV from actual mass (770 MeV).
6. Mass of p0 is reconstructed with neutral particles.
   If # of neutrals >=3, nearest (in angle) two are combined until 2 particles are left.
   Application of this cut is discussed later.

ρ and π^0 reconstruction





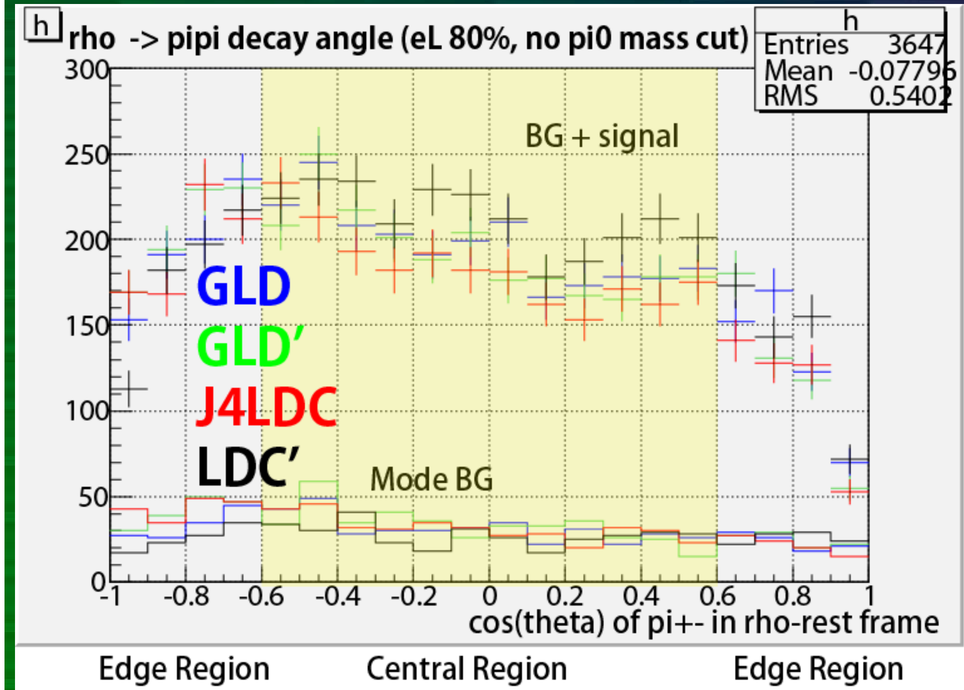
- Clear difference observed in invariant mass distributions.
  - LDC's best, larger is better in Jupiter geometries.
  - Mark confirmed the granularity affects the mass distributions.
- Three candidates in ρν mode selection
  - No π^0 mass cut, π^0 cut with left edge included / excluded

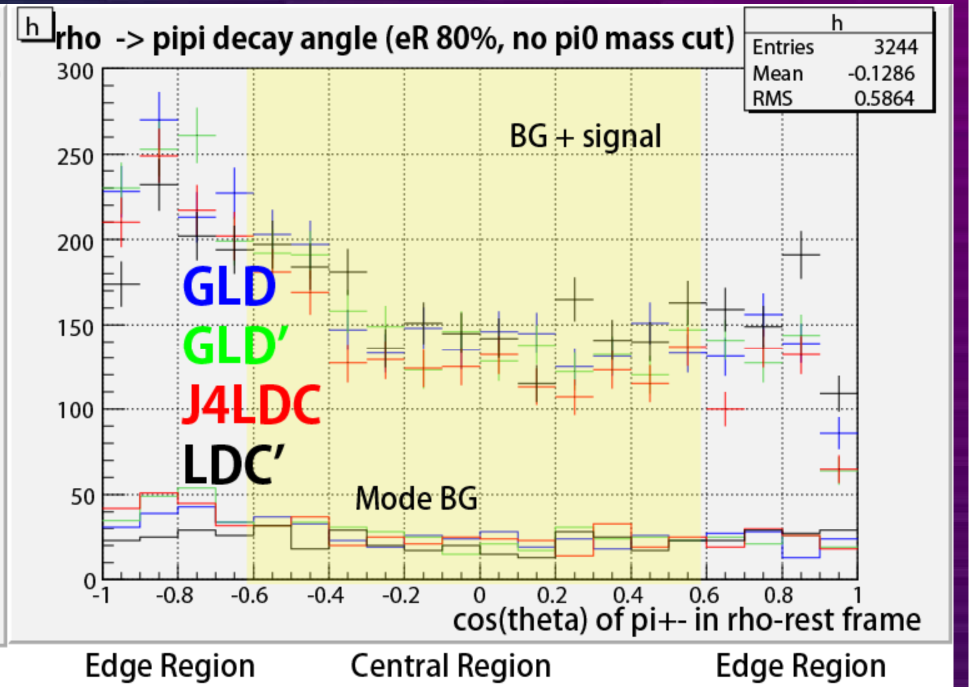
$\rho \to \pi\nu$ selection results

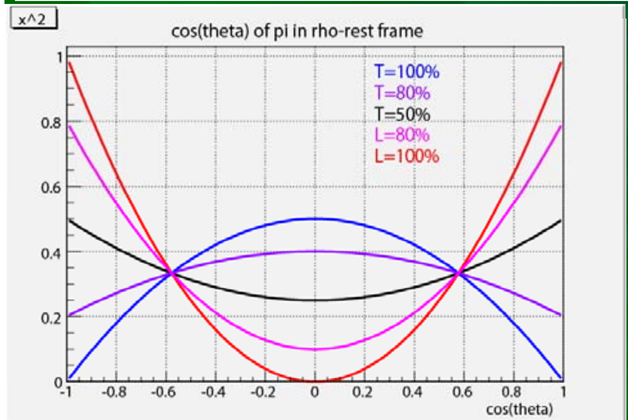
Geometry	GLD		GLD'		J4LDC		LDC'	
	eff.	purity	eff.	purity	eff.	purity	eff.	purity
NO cut	100.00%	25.36%	100.00%	25.35%	100.00%	25.35%	100.00%	25.26%
1+1 jet	66.69%	25.33%	65.54%	25.43%	69.26%	25.35%	70.31%	26.30%
opening angle>170deg	29.46%	25.28%	29.29%	25.29%	29.65%	25.24%	29.63%	25.28%
AFB cut	24.63%	27.28%	24.45%	27.22%	24.30%	27.11%	24.43%	27.25%
1 prong	23.30%	31.38%	23.10%	31.30%	23.02%	31.19%	23.07%	31.06%
Jet energy cut	23.14%	32.15%	22.96%	32.10%	22.87%	32.00%	22.95%	31.87%
e,mu veto	22.08%	51.22%	21.86%	51.14%	21.67%	51.14%	21.97%	50.64%
> 1 GeV gamma	19.07%	65.83%	18.49%	65.44%	17.96%	65.19%	19.69%	65.54%
570<mRho<970	12.70%	83.38%	12.05%	81.80%	11.26%	81.39%	12.77%	85.71%
mPi0<200	10.41%	88.71%	9.81%	86.77%	8.95%	85.90%	9.73%	89.84%
0<mPi0<200	5.31%	92.30%	4.32%	90.32%	3.72%	90.48%	6.38%	93.88%

- 3rd row from bottom: used as “no π^0 mass cut”.
- 2nd row from bottom: used as “π^0 mass cut”.
  - Events with single neutral are survived with this cut.
- Most bottom row: used as “tight π^0 mass cut”.
  - Events with single neutral are eliminated with this cut.
- Clear difference by geometries:
  LDC’s the best, bigger is better in Jupiter’s.

τ -> $\rho\nu$, ρ->$\pi\pi$ distribution (1) no π^0 cut



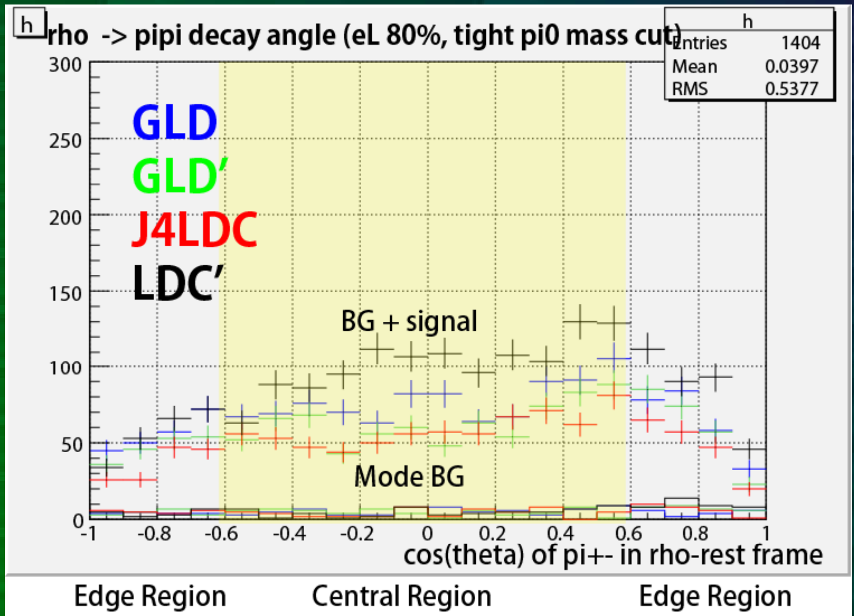


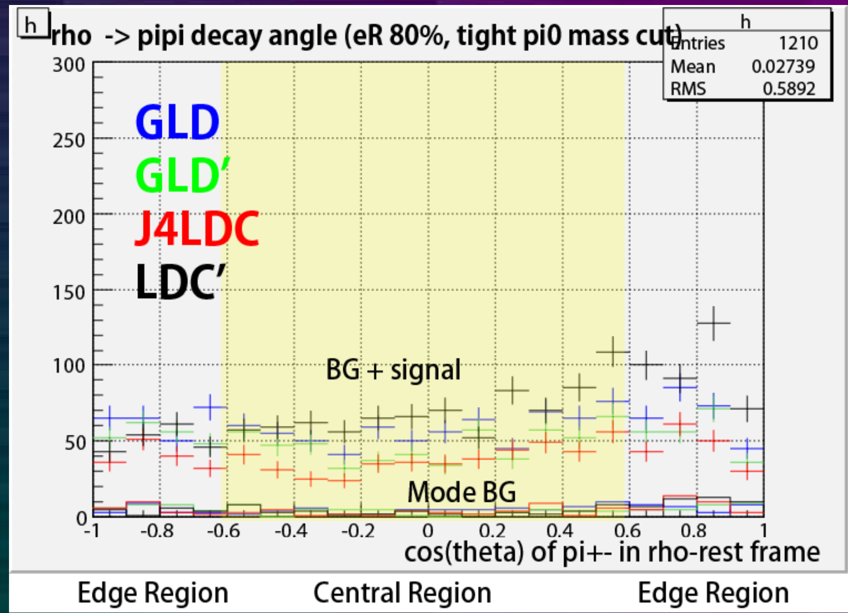


P_{pol} vs dist. calc

- Clear difference between e_L and e_R observed.
- Distribution is degraded due to the cut effects.

$\tau \to \rho\nu$, $\rho \to \pi\pi$ distribution (2) tight π^0 cut





- Number of signal is about a half.
- Difference between geometry enhanced.
  - J4LDC is not realistic with this cut?
- Background is quite low, negligible level.

Obtaining P(τ) value

τ POLARIZATION MEASUREMENTS AT LEP AND SLC

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$$y = \frac{|E_{\pi^0} - E_{\pi^-}|}{E_{\mathrm{beam}}}, \qquad (23)$$

to be a good τ polarization analyzer. The y distribution is shown in fig. 2 for three values of the τ^- polarization: $P_\tau = -1$, 0 and +1. Indeed a large sensitivity to the τ polarization is found.

In order to quantify this sensitivity we consider the y symmetry

$$A_y(P_\tau) = \frac{\Gamma(y>y_c; P_\tau)}{\Gamma(y>y_c; P_\tau=0)} - \frac{\Gamma(y<y_c; P_\tau)}{\Gamma(y<y_c; P_\tau=0)} \qquad (24)$$

with respect to the crossover point at $y_c = 0.316$. One

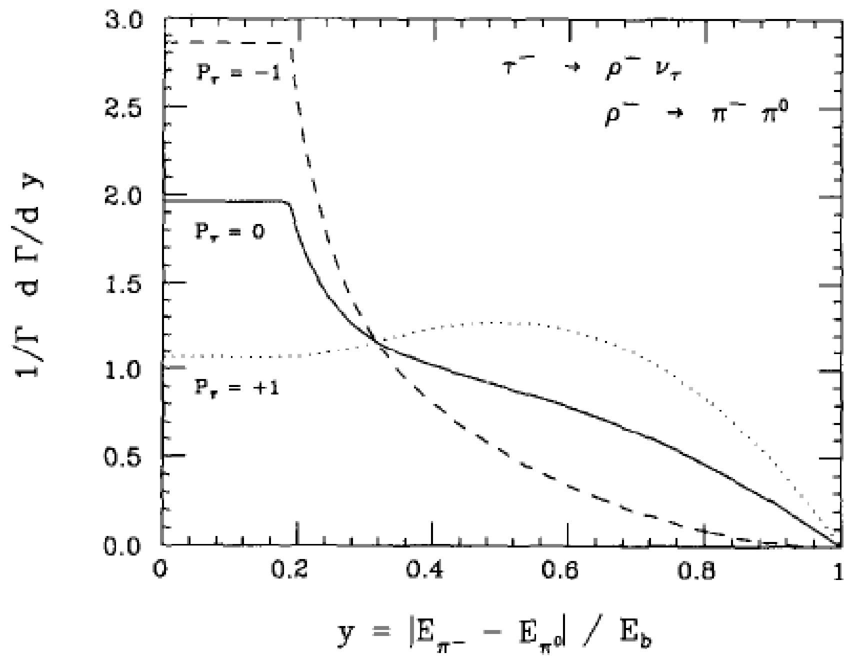
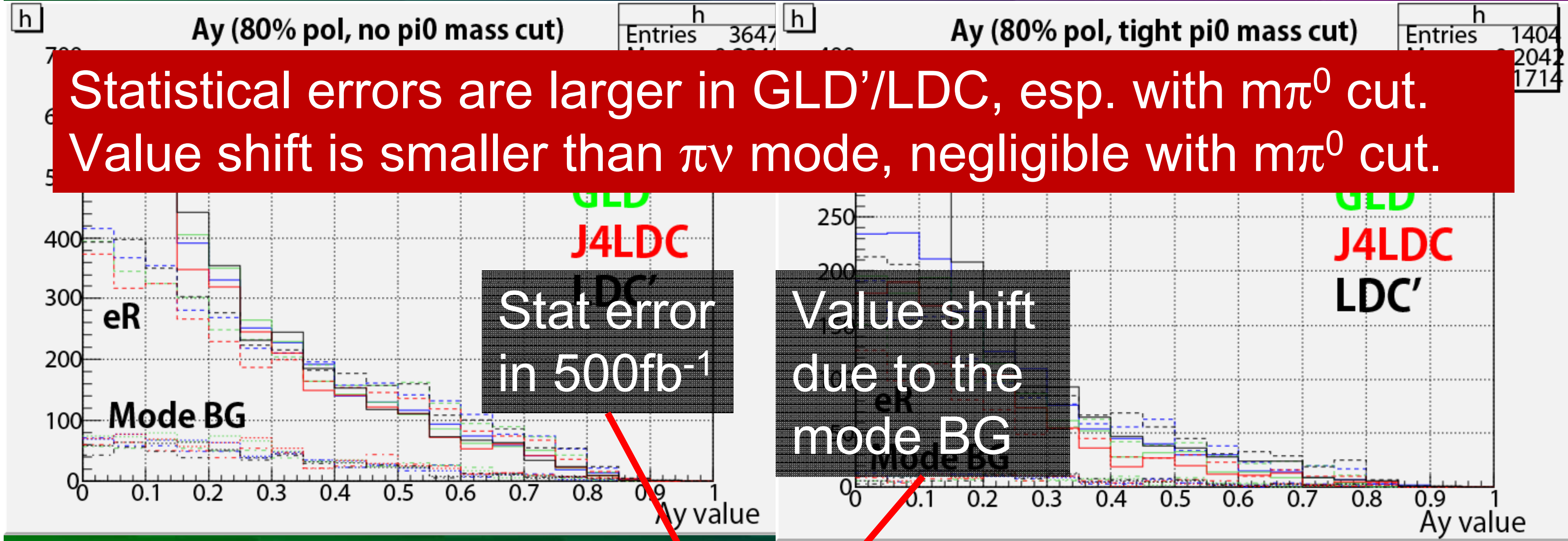


Fig. 2. Distribution of the energy difference of the two decay pions in the process $\tau^- \to \rho^- \nu_\tau$, $\rho^- \to \pi^- \pi^0$ for three values of the τ^- polarization. The common crossover point of the curves at $y_c = 0.316$ is due to the linear dependence of $d\Gamma/dy$ on the τ polarization.

- Combined information of τ -> ρν and ρ -> ππ decay can be used in this method.

A_{pol} calculation ($\rho\nu$ mode)



Statistical errors are larger in GLD'/LDC, esp. with $m\pi^0$ cut.
Value shift is smaller than $\pi\nu$ mode, negligible with $m\pi^0$ cut.

Stat error in 500fb^{-1}

Value shift due to the mode BG

	Pol	Apol (no pi mass cut)	estat	shift	Apol (w pi mass cut)	estat	shift
GLD	eL (80%)	34.06% ± 4.26%	1.17%	-2.68%	34.53% ± 6.78%	1.86%	-1.66%
GLD'		38.66% ± 4.30%	1.19%	-3.59%	42.62% ± 7.36%	2.04%	-1.10%
J4LDC		34.86% ± 4.47%	1.24%	-4.24%	36.30% ± 8.24%	2.29%	0.79%
LDC'		35.62% ± 4.13%	1.17%	-3.36%	36.81% ± 6.05%	1.72%	-0.99%
GLD	eR (80%)	-28.33% ± 4.87%	1.37%	4.91%	-30.89% ± 8.32%	2.35%	3.70%
GLD'		-30.87% ± 5.00%	1.42%	3.67%	-34.26% ± 9.36%	2.66%	0.88%
J4LDC		-35.34% ± 5.38%	1.52%	2.53%	-36.45% ± 11.18%	3.16%	-1.90%
LDC'		-32.70% ± 4.89%	1.41%	2.89%	-32.46% ± 7.86%	2.27%	-0.49%

Values obtained by signal-only events!

Summary

- Tau-pair events are analyzed in ILD framework.
- SM background can be efficiently removed by appropriate cuts.
  - Bhabha statistics is short -> need pre-selection
  - No $\gamma\gamma\tau\tau$ events
  - Weighting of background is needed

  -> All will be performed in ILD reference detector for LOI
- A_{pol} analysis is implemented, showing larger and highly granulated detectors give better performance.
- Up to 5 TeV Z' boson can be measured by measuring anomaly to the tau-pair production.

Thank you for your attention.

Backup

Updates from ECFA08

- SM background suppression cut and its study was fully developed after ECFA08
- Polarization treatment of tau-generator was fixed, and obtained polarized distribution was analyzed.
- A criterion for tau->rhonu decay mode is developed.

BG suppression cuts results

Process	Tautau (non-pol)				Bhabha	ggtt
Geometry	GLD	GLD'	J4LDC	LDC'	GLD'	stdhep
Cross section (pb)	2.3	2.3	2.3	2.3	34000	1500
Luminosity (fb-1)	77.28783	78.41826	78.46696	79.13043	0.2	0.7
All events	88881	90181	90237	91000	13M	1M
1+1 jet	59352	58919	62489	64159	-	-
jet angle > 170 deg	26266	26476	26873	26944	-	217431
|cos(theta)| <0.9	22867	23176	23179	23202	11171	130
# of track <= 6	22828	23127	23131	23153	11171	-
ee veto	21504	21733	21713	22041	13	-
mumu veto	20629	20816	20771	21123	13	-
40 GeV < Evis < 450 GeV	20352	20531	20502	20609	5	0
AFB cut efficiency	22.90%	22.77%	22.72%	22.65%	0.4 ppm	0.00%

- Backgrounds are suppressed to negligible level.
- Signal efficiency is ~23%, quite low but…
  - Most cut events in first 2 cuts are with hard-photons
  - Practical signal efficiency is considered ~75%