Tau analysis (A_{FB} and A_{pol})

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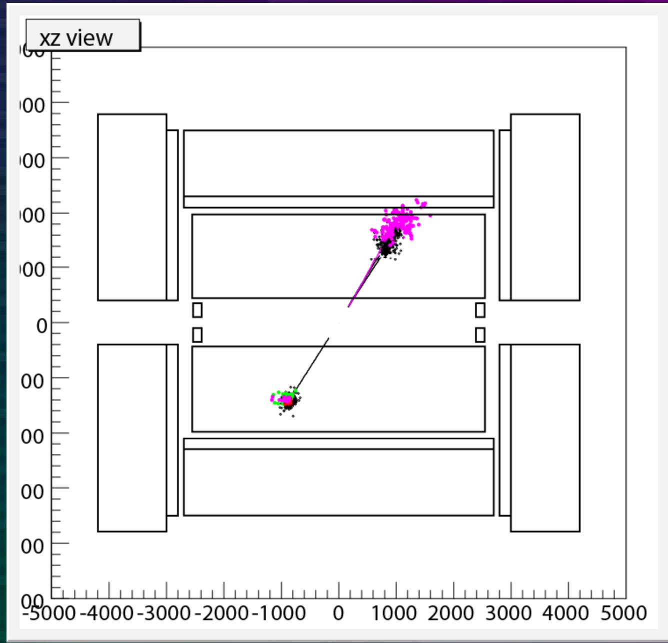
Physics process for optimization

Benchmark processes:

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.
$Z^* \rightarrow \tau^+\tau^-$	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, $m\chi$	Point 5 of Table 1 of BP report. W/Z separation by PFA

Tau-pair issues

- PFA performance in high-γ (140) τs
  - 1 or 3 energetic $e\mu\pi^{\pm}$ + 0-several π^0s (rarely Ks)
  - Concentrated in narrow angles, not easy to separate in PFA
- Cross section and A_{FB} meas.
  - Background suppression
    - Bhabha & $\gamma\gamma$ -> $\tau\tau$
- Polarization measurements
  - Decay mode identification
    - Mode separation cuts
    - Invariant mass cuts of ρ/π_0 in $\rho\nu$ mode
  - Obtaining A_{pol} by angular dist. of decay products



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)
    - 50pb preselected: $|\cos\theta| < 0.92$, jet angle < 170deg
    - 0.2 fb^{-1} in GLD' with Jupiter
    - Good $e\pi$ separation is essential
  - $\gamma\gamma \to \tau\tau$ (1500 pb)
    - Separation cut by generator info.
    - Cut by angular & energy information

BG suppression cuts

1. Specialized jet clustering (TaJet)
   - Njet=2 durham is not worked due to ISR/FSR
2. 1 positive & 1 negative jets required
3. Opening angle > 170deg
4. |cos(theta)| < 0.9 for both jets
   - Bhabha is much larger in the edge region
5. Number of track <= 6
   - Veto hadronic events
6. 2-electron and 2-muon veto
   - For bhabha and ee->μμ veto
   - E-ID by Ecal/total deposit, μ-ID by hit/track energy
7. Visible energy > 40 GeV

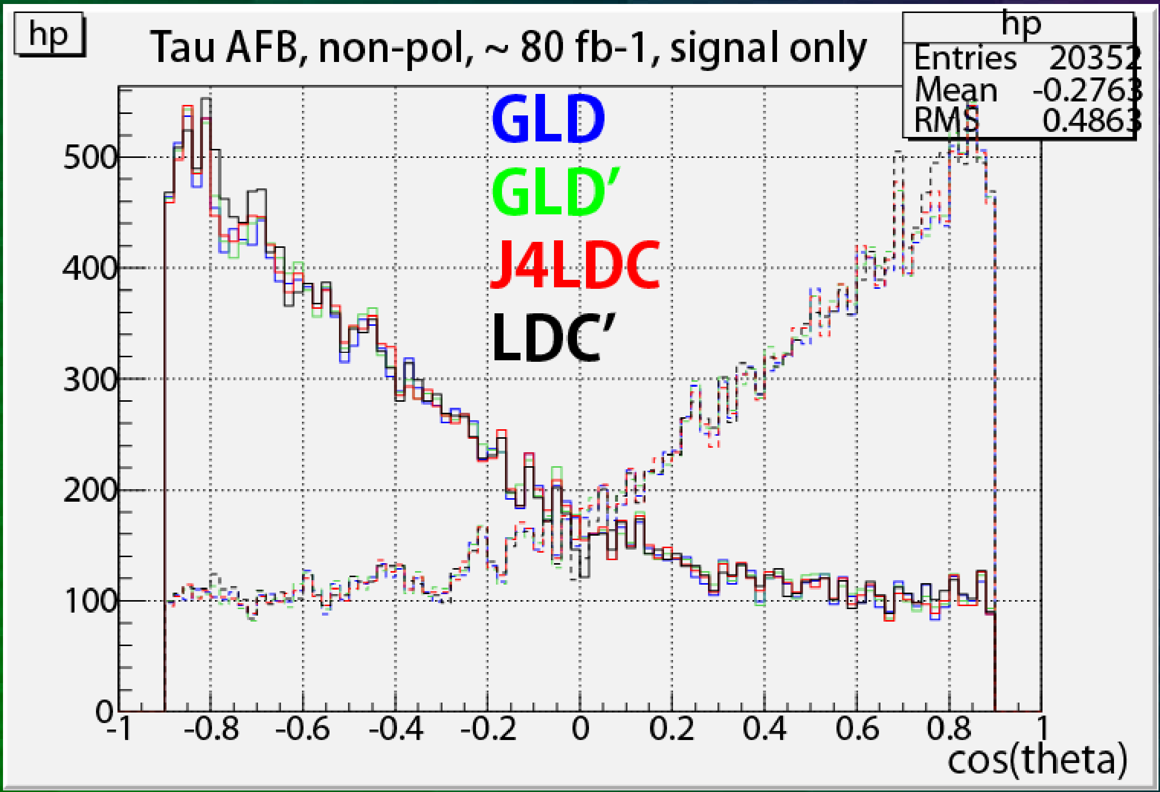
   γγ->ττ rejection

BG suppression cuts results

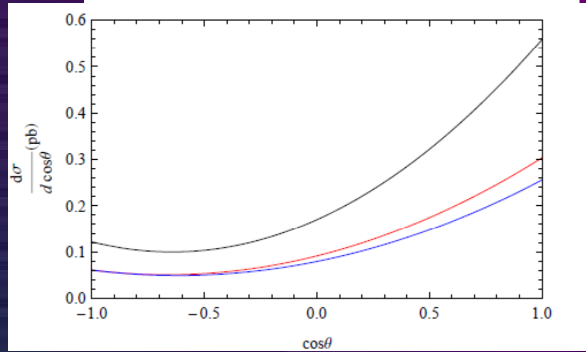
Process	Tautau (non-pol)				Bhabha	ggtt
Geometry	GLD	GLD'	J4LDC	LDC'	GLD'	stdhep
Cross section (pb)	2.3	2.3	2.3	2.3	34000	1500
Luminosity (fb-1)	77.28783	78.41826	78.46696	79.13043	0.2	0.7
All events	88881	90181	90237	91000	13M	1M
1+1 jet	59352	58919	62489	64159	-	-
jet angle > 170 deg	26266	26476	26873	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%

Tau A_{FB} result



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



SM calculation
(Red: left, Blue: right)

No difference between geometries

	AFB cut eff	AFB value	AFB error in 500 fb-1
GLD	22.90%	46.63% ± 0.62%	0.24%
GLD'	22.77%	46.69% ± 0.62%	0.24%
J4LDC	22.72%	46.69% ± 0.62%	0.24%
LDC'	22.65%	46.83% ± 0.62%	0.24%

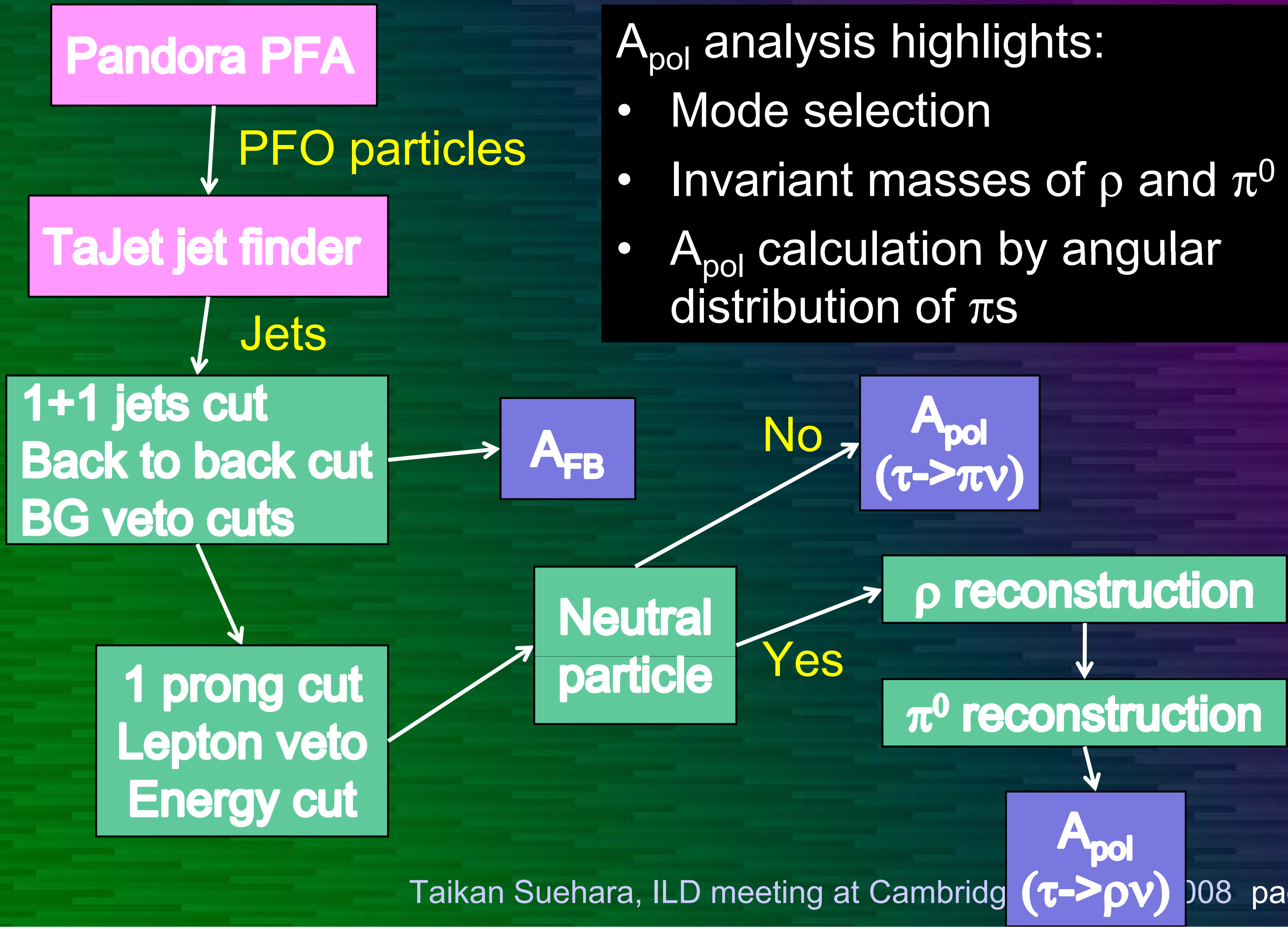
Decay modes in A_{pol} analysis

$\tau \rightarrow e\nu\nu$	• 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



$\tau \to \pi\nu$ 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.

$\tau \rightarrow \pi\nu$ 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%

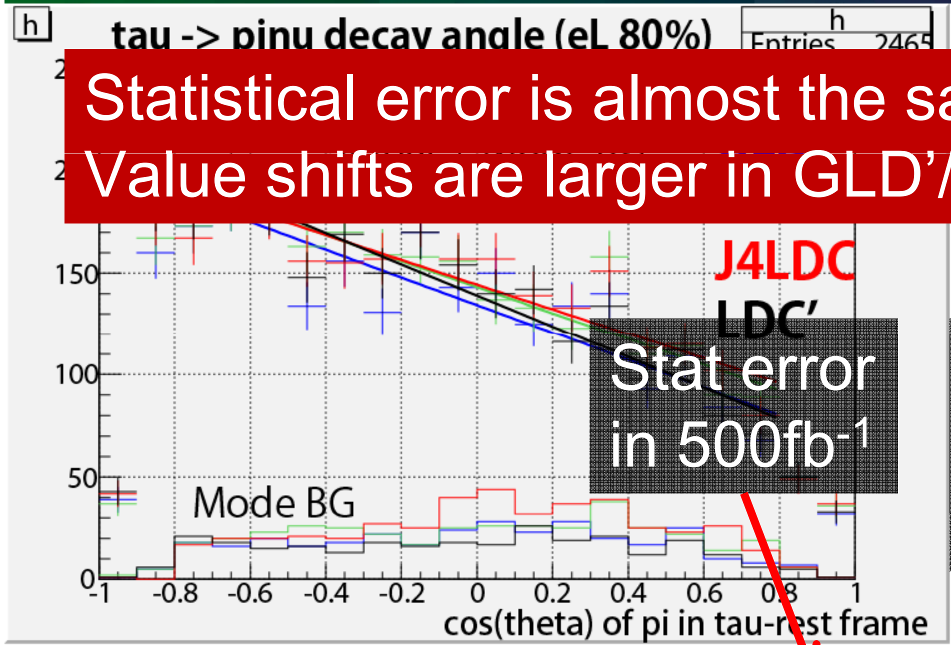
Selection performance between geometries

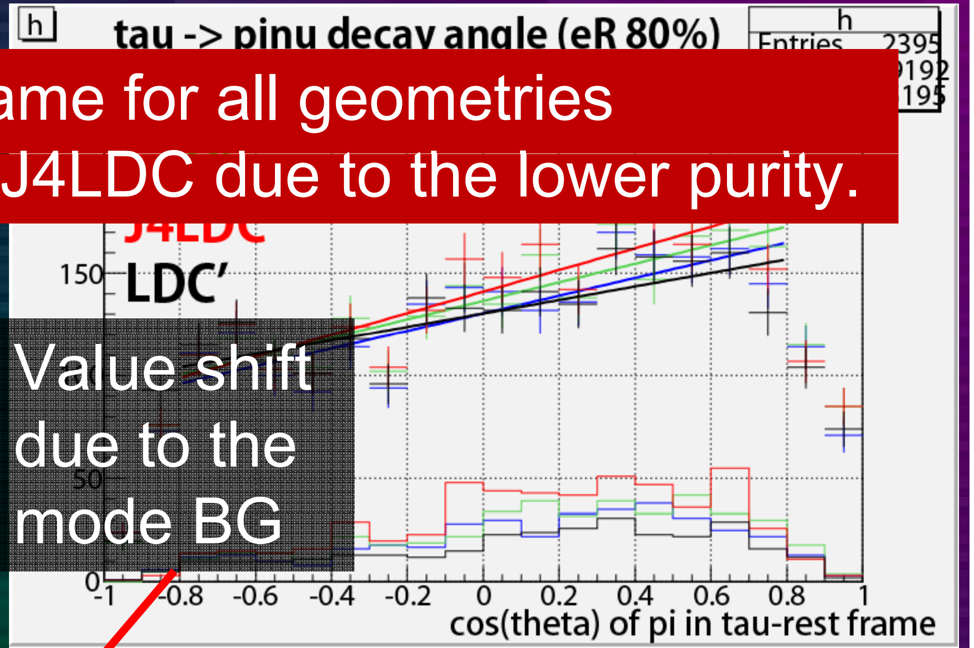
(look at the 2nd row from the bottom)

- Efficiency: not so different
- Purity: LDC' > GLD > GLD' > J4LDC
  - $\tau \rightarrow \rho\nu$ 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 500fb^{-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!

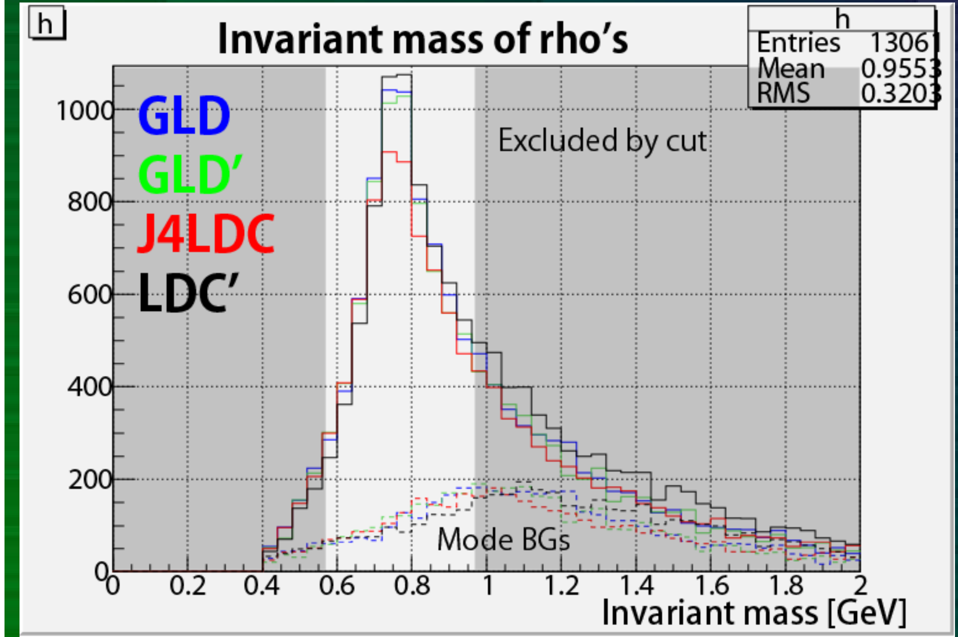
τ -> $\rho\nu$ selection cuts

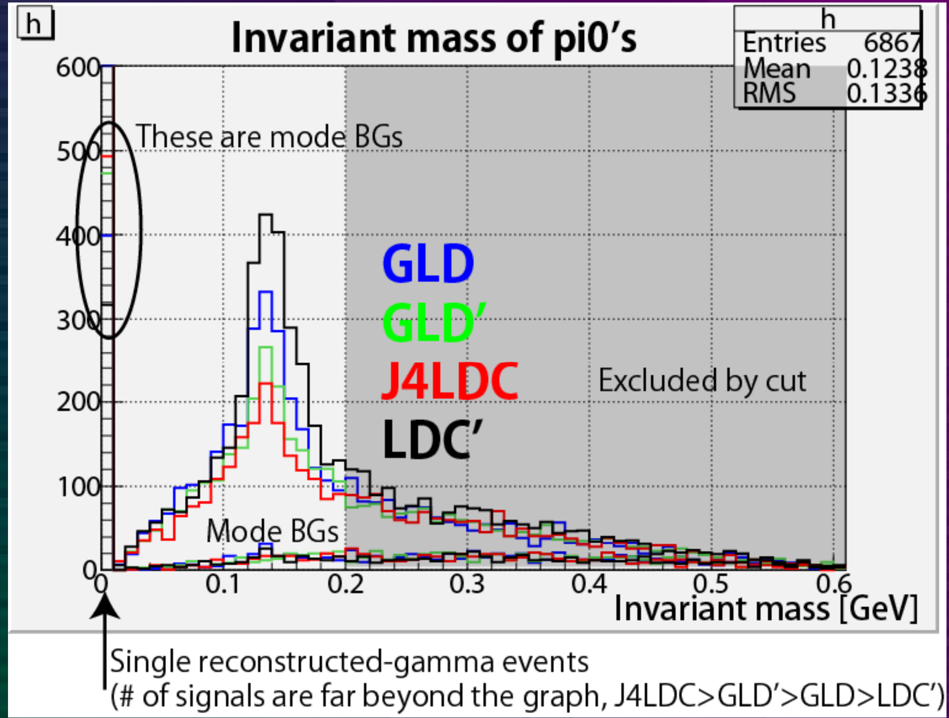
1. 1 prong cut
2. Lepton veto
3. Energy cut (jet energy must be > 10 GeV)

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





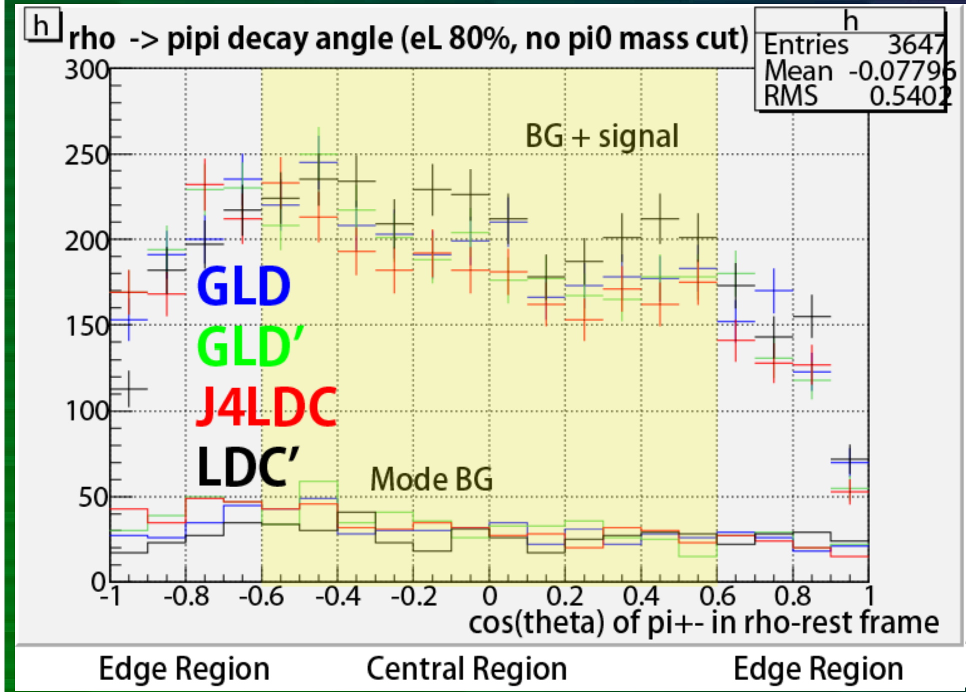
- Clear difference observed in invariant mass distributions.
  - LDC's best, larger is better in Jupiter geometries.
  - Mark confirmed the granularity affects the mass distributions.
- Three candidates in $\rho\nu$ mode selection
  - No π^0 mass cut, π^0 cut with left edge included / excluded

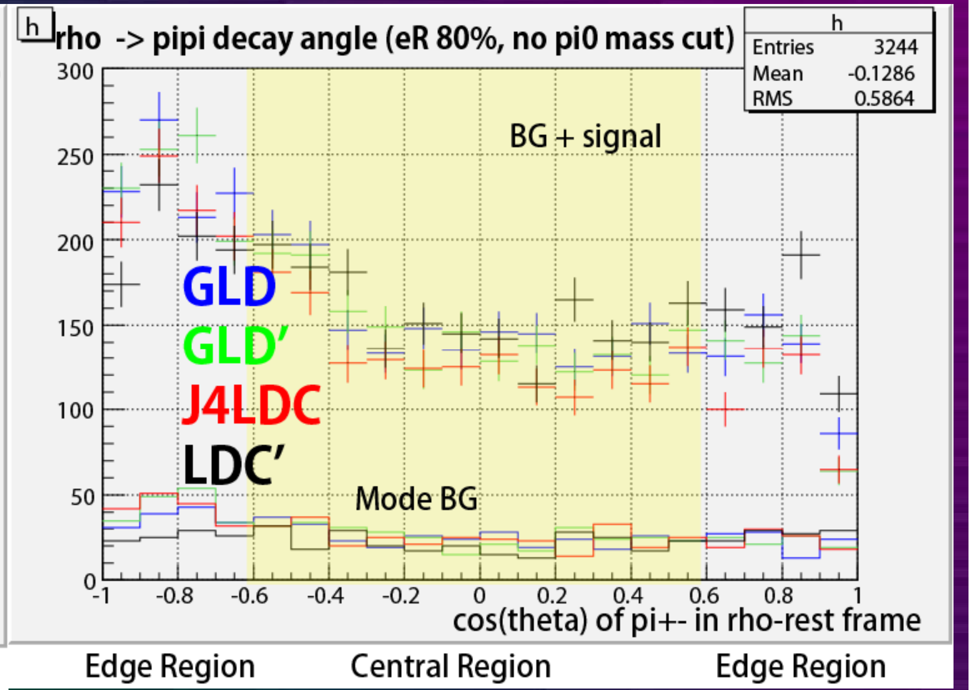
ρ -> πν selection results

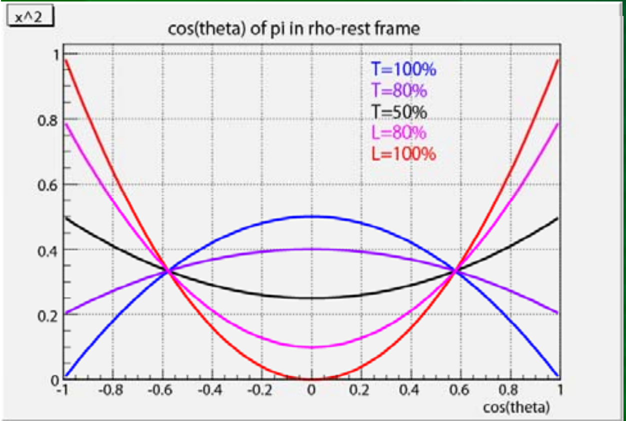
Geometry	GLD		GLD'		J4LDC		LDC'	
	eff.	purity	eff.	purity	eff.	purity	eff.	purity
NO cut	100.00%	25.36%	100.00%	25.35%	100.00%	25.35%	100.00%	25.26%
1+1 jet	66.69%	25.33%	65.54%	25.43%	69.26%	25.35%	70.31%	26.30%
opening angle>170deg	29.46%	25.28%	29.29%	25.29%	29.65%	25.24%	29.63%	25.28%
AFB cut	24.63%	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%
>1GeV 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



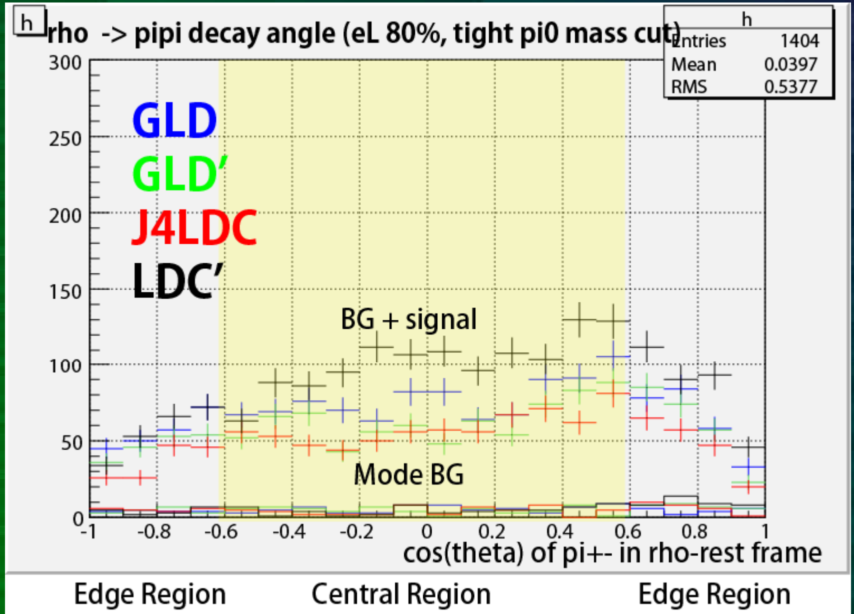


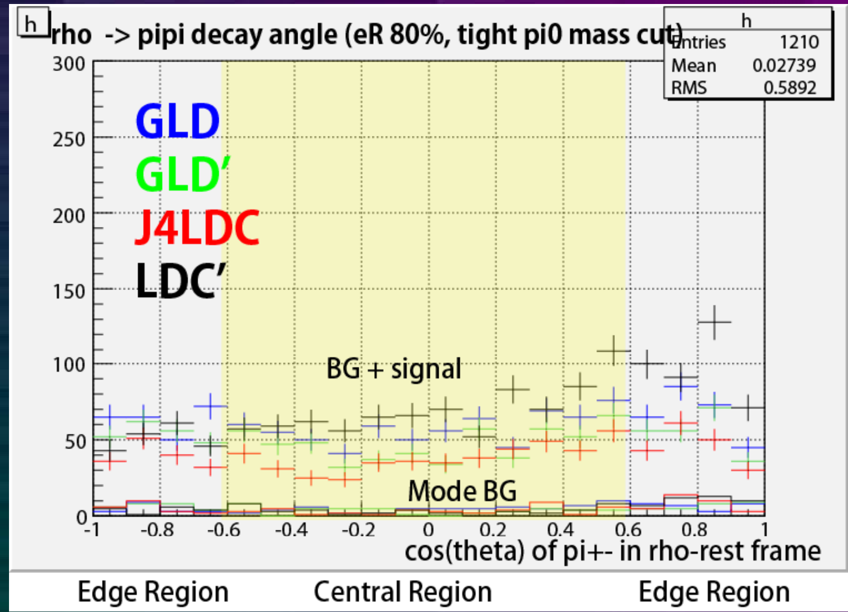


P_{pol} vs dist. calc

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

τ -> $\rho\nu$, ρ->$\pi\pi$ 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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$$y = \frac{|E_{\pi^0} - E_{\pi^-}|}{E_{\text{beam}}}, \qquad (23)$$

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

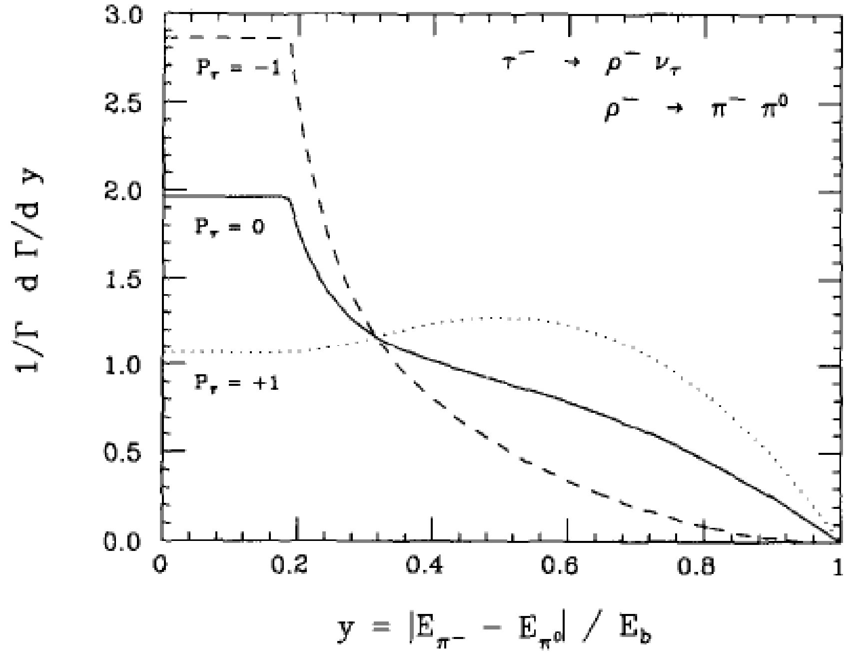
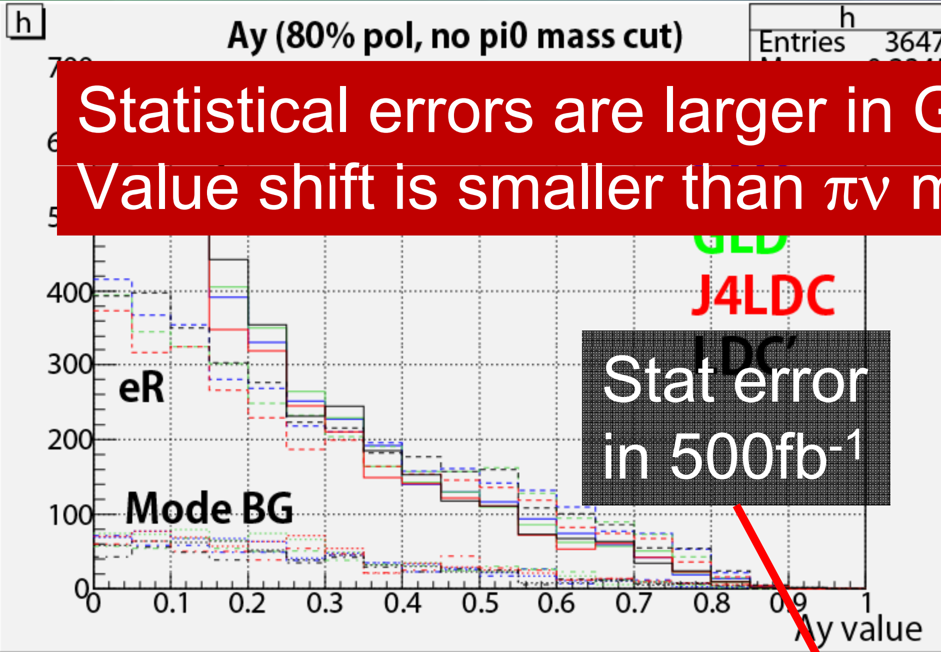
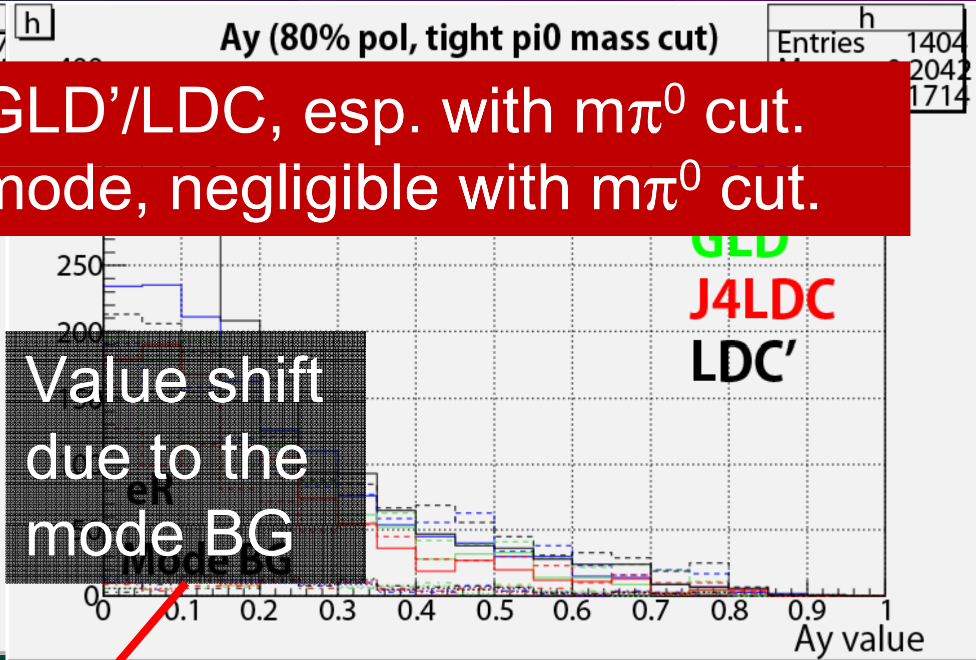


Fig. 2. Distribution of the energy difference of the two decay pions in the process $\tau^- \to \rho^- \nu_\tau$, $\rho^- \to \pi^- \pi^0$ for three values of the τ^- polarization. The common crossover point of the curves at $y_c = 0.316$ is due to the linear dependence of $d\Gamma/dy$ on the τ polarization.

- Combined information of $\tau \to \rho\nu$ and $\rho \to \pi\pi$ 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 (nopi 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!

Performance Summary

Geometry	GLD	GLD'	J4LDC	LDC'	Related to
A_{FB}	○	○	○	○	BG cut
$A_{pol}(\pi\nu,stat)$	○	○	○	○	Selection efficiency
$A_{pol}(\pi\nu,shift)$	○	△	×	◎	Selection purity
$A_{pol}(\rho\nu,stat)$	○	△	×	◎	Selection efficiency
$A_{pol}(\rho\nu,shift)$	○	○	○	○	Selection purity
Overall	○	△	×	◎	

- Difference comes from ρ/π^0 reconstruction
  - Shift of $\pi\nu$ comes from ρ with missing photon.
  - Stat error of $\rho\nu$ comes from worse ρ/π^0 reconstruction.
- Larger/higher granularity geometry preferred.
- But anyway the difference might be not critical…

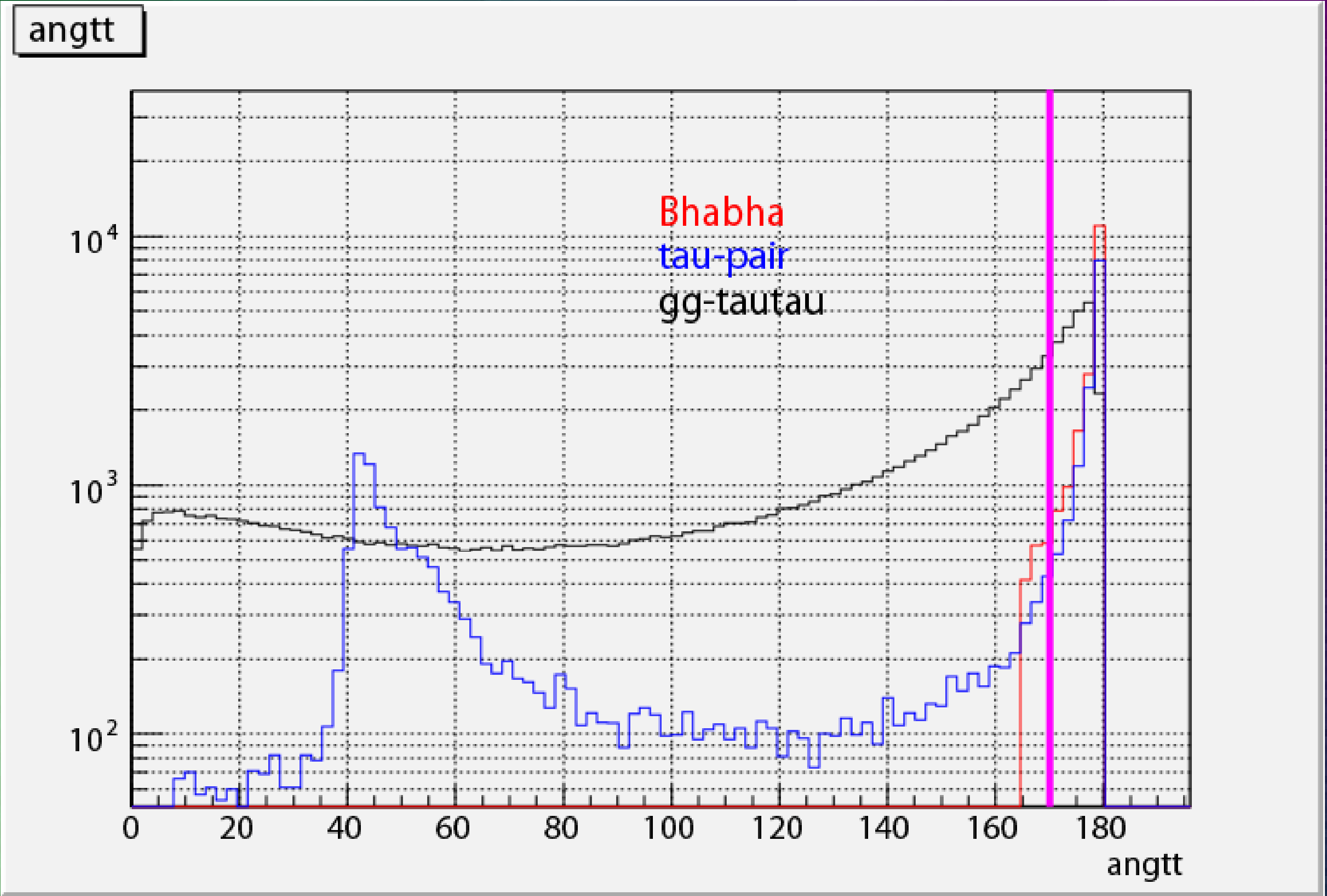
Comments

- A_{FB} calculation includes no backgrounds.
  - All backgrounds can be suppressed to <10% of signal in generator level.
  - Accidental (on-flight decay, etc.) background is very difficult to estimate.
- For A_{pol} study statistics is not sufficient.
- Obtained A_{pol} is deviated from expectation: need to check systematic effects further.
- Performance should be checked on high-granualized GLD-size detector (might be optimal).

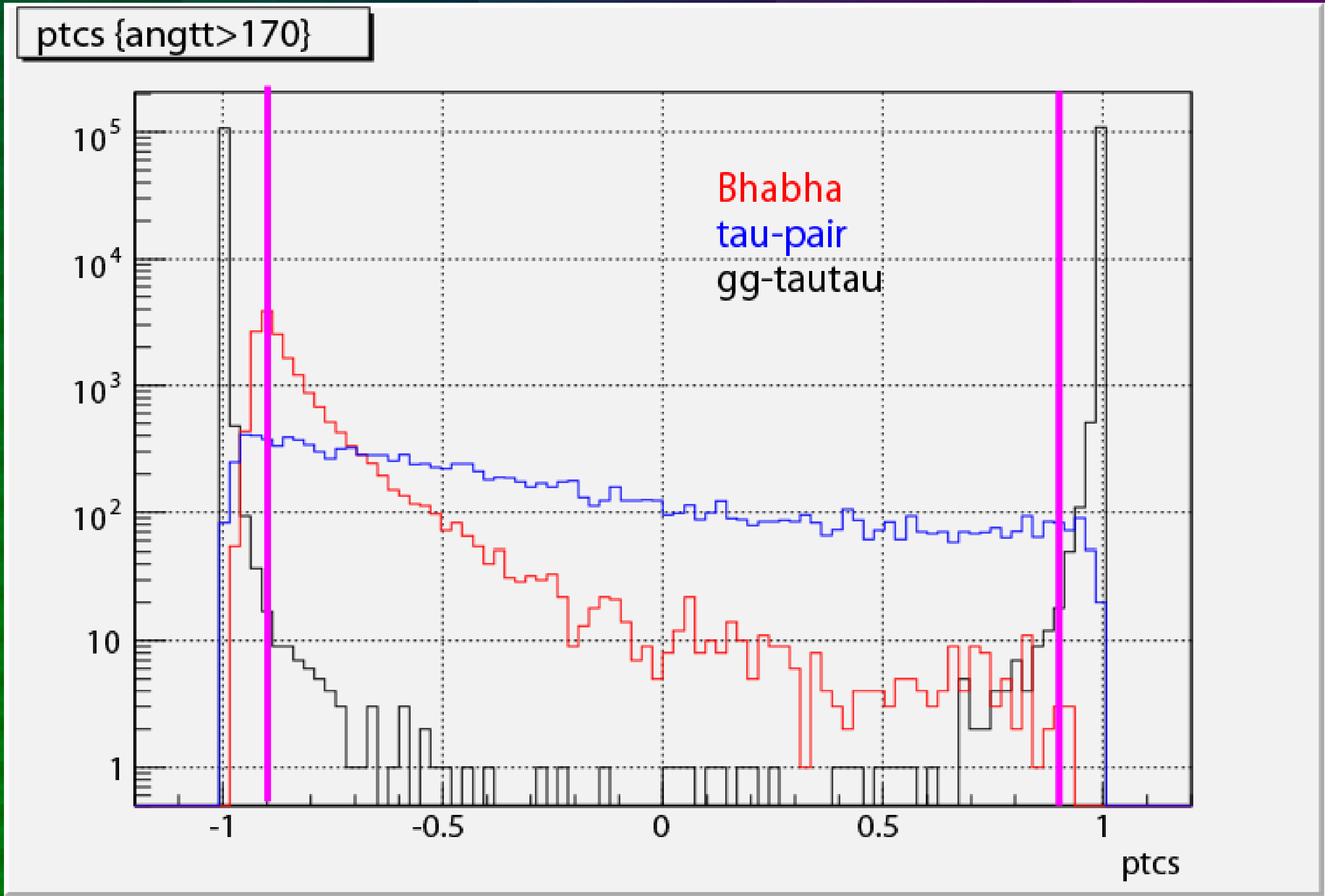
Thank you for your attention.

Backup

Opening angle cut



Costheta cut



Visible energy cut