New physics searches with 2-fermion final states

11 Oct. 2023

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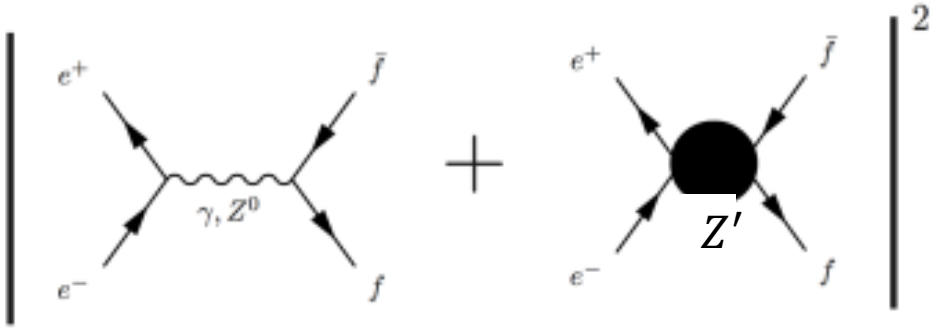
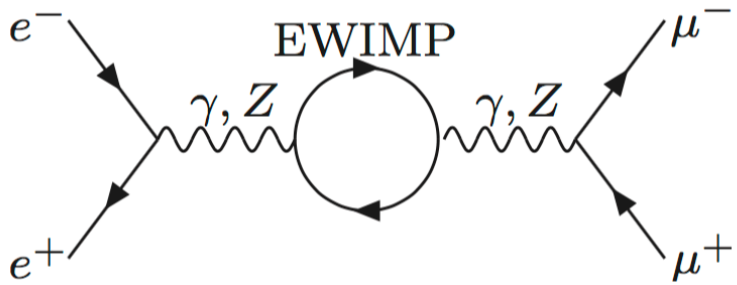
2-fermion $e^+e^- \to f\bar{f}$ event

$e^+e^- \to f\bar{f}$ (f: charged lepton or quark)

- Sensitive to Z' models
  - Interference with Z and γ
  - Total cross section, dependence on initial polarization, angular distribution
  - Model discrimination
- Loop effect with electroweak WIMP
  - Only dependent on EWIMP mass and spin
  - Sensitive to higher mass than direct search





Conditions of the study

ILD full simulation (ilcsoft v02-00-01), sqrt(s) = 500 GeV

Lepton channel ($\mu\mu$, $\tau\tau$ final states)

- Bhabha events to be done
- **Signal Events**:
  - $e^+e^- \to l^+l^-$ (Z^* true mass≥450 GeV)
- **Background Events**:
  - 2-fermion background
    $e^+e^- \to l^+l^-$ (Z^* true mass<450 GeV)
    other flavors
  - 4-fermion background
    leptonic events (mainly W/Z-derived)

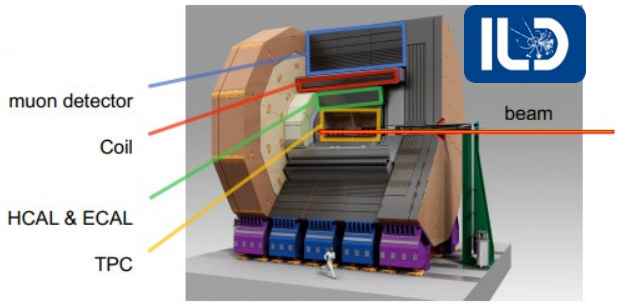
Quark channel (bb, cc final states)

- **Signal Events**:
  - $e^+e^- \to q\bar{q}$ (Z^* true mass≥450 GeV)
- **Background Events**:
  - 2-fermion background
    $e^+e^- \to q\bar{q}$ (Z^* true mass<450 GeV)
    other flavors
  - 4-fermion background
    hadronic events (mainly W/Z-derived)
    semileptonic events (mainly W/Z-derived)

- **Polarization**
- $e^-: \mp 80\%$, $e^+: \pm 30\%$

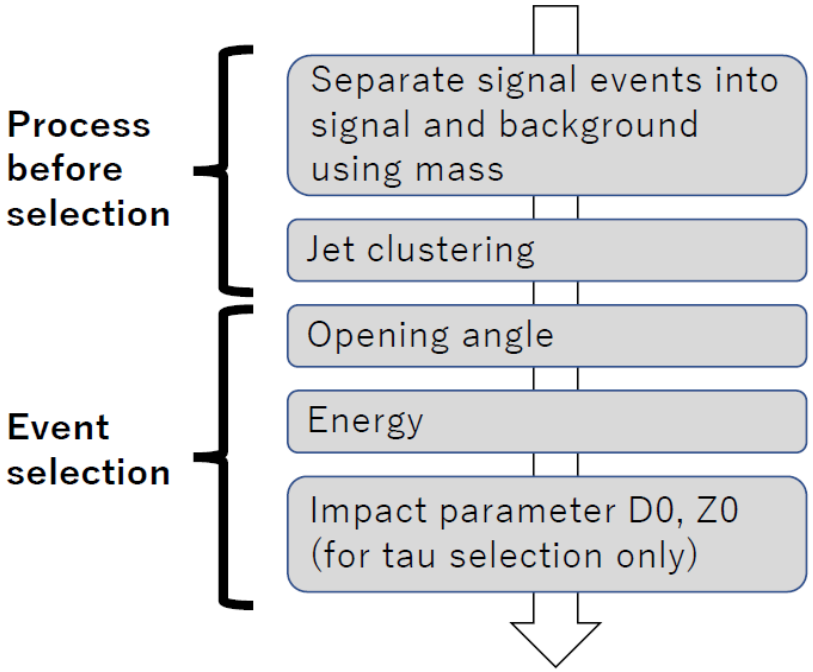
Luminosity

$1600\ \mathrm{fb}^{-1}$ each



Event selection for leptonic channel

Process chain Full simulation data



Dedicated tau jet clustering is applied for both μμ/ττ (μμ for FSR recovery)
Opening angle: reject hard ISR (low Q^2)
Energy: separate mu and tau events

Result of event selection for (e-,e+)=(-80%,+30%)

For mu

- Opening angle: $\cos(angle) \leq -0.95$
- Energy: $Energy \geq 450\ GeV$

efficiency in ()

Mu Event	2f signal	2f BG	4f BG
Original	781,215(100.00%)	4,249,717(100.00%)	10,089,686(100.00%)
Opening angle	758,658(97.11%)	1,061,907(24.99%)	1,729,938(17.15%)
Energy	716,569(91.72%)	21,776(0.51%)	50,082(0.50%)

For tau

- Opening angle: $\cos(angle) \leq -0.95$
- Energy: $Energy \leq 340\ GeV$
- Impact parameter: $D0\ significance \geq |2.0|$

efficiency in ()

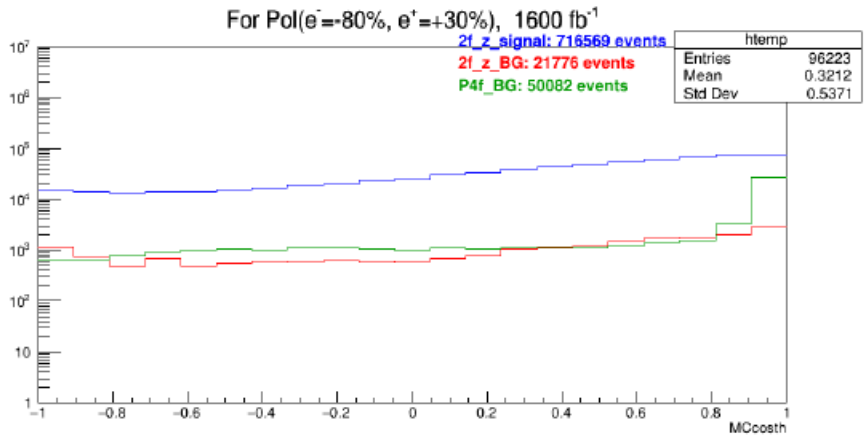
Tau Event	2f signal	2f BG	4f BG
Original	776,143(100.00%)	4,254,790(100.00%)	10,089,686(100.00%)
Opening angle	716,014(92.25%)	1,089,292(25.60%)	1,738,437(17.23%)
Energy	681,247(87.77%)	206,578(4.86%)	1,234,383(12.23%)
Impact parameter	559,438(72.08%)	121,159(2.85%)	177,527(1.74%)

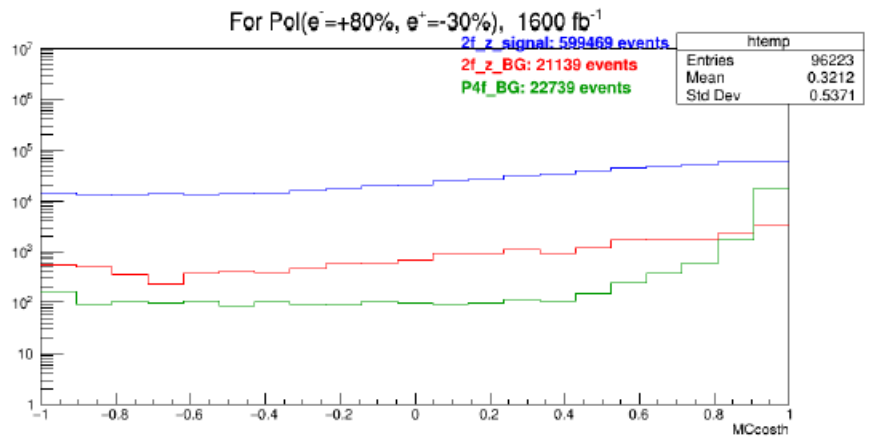
10

Efficiency: ~92% for μμ, ~72% for ττ
Background: significantly smaller than signal

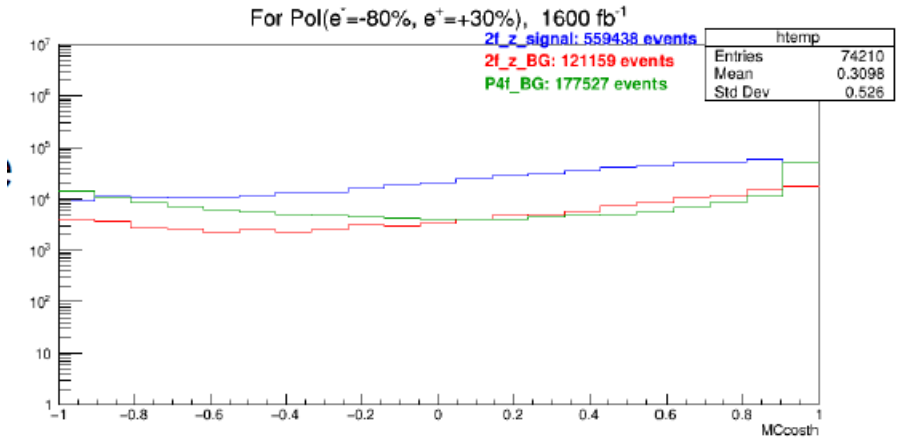
Angular distribution after selection

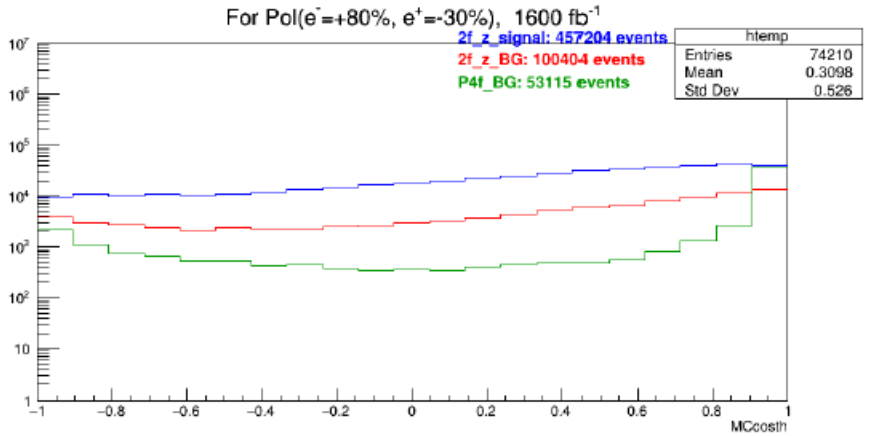
For mu



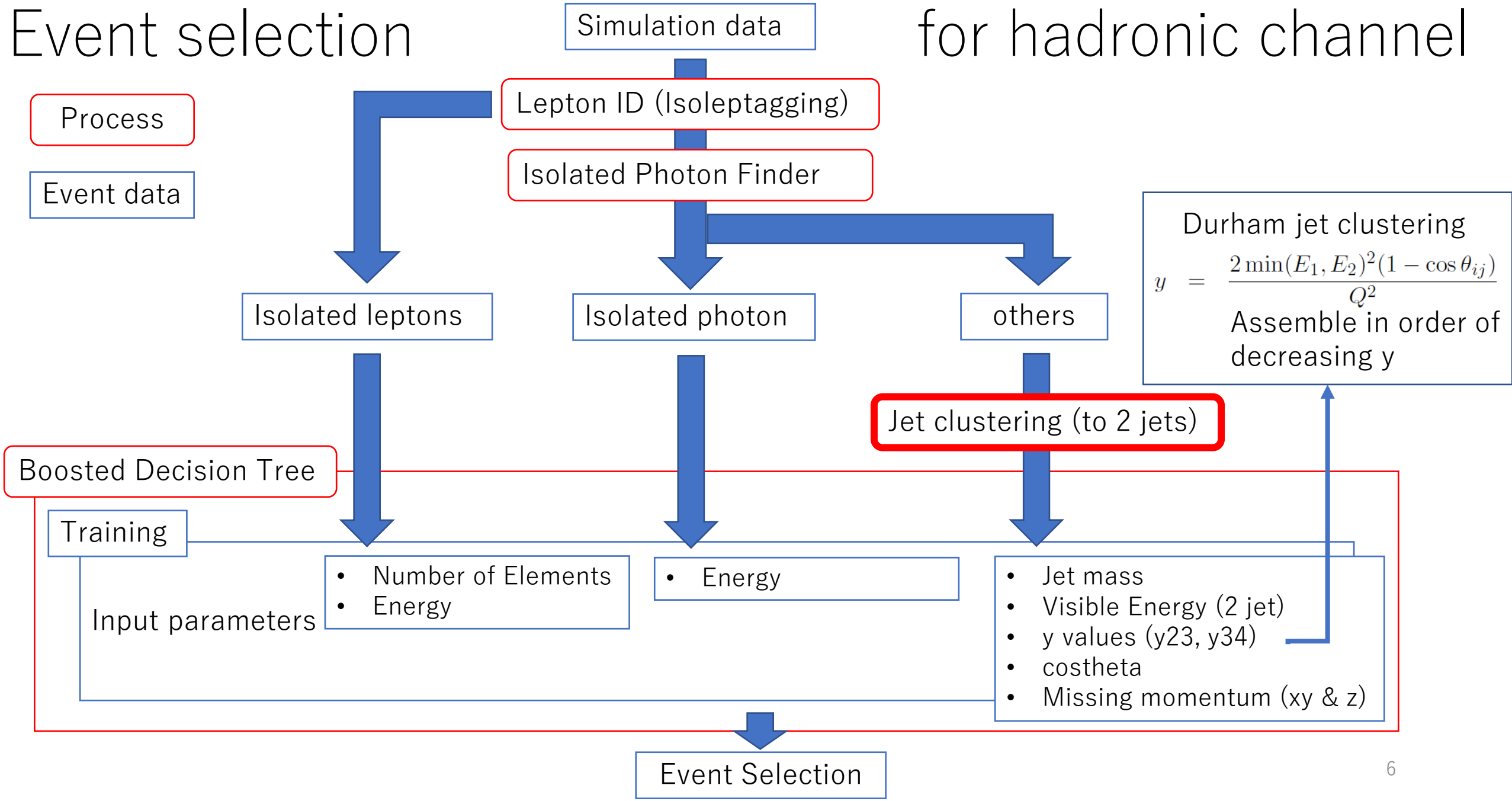


For tau





Event selection for hadronic channel

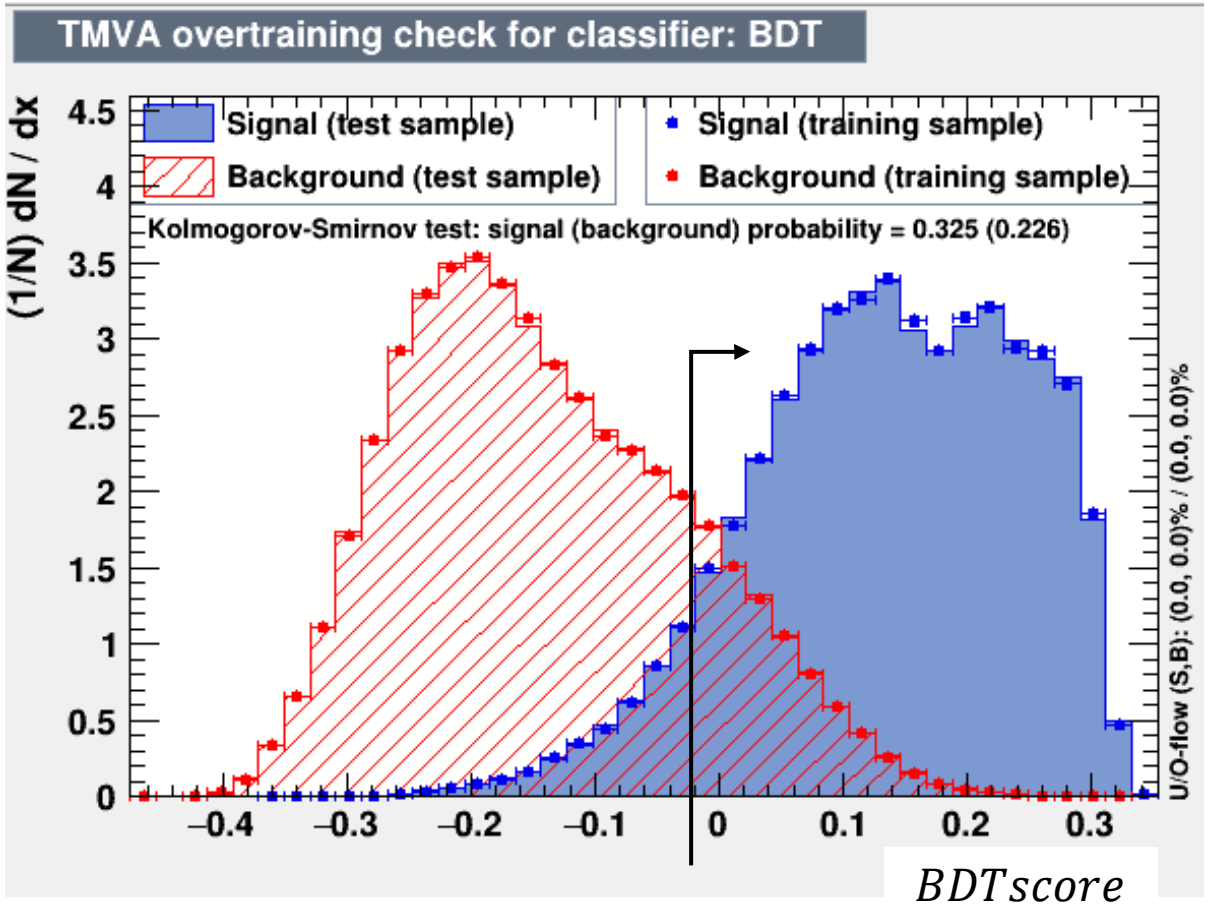


qq channel: BDT

- Input parameters
  - Isolated leptons
    - Number of Elements
    - Energy
  - Isolated photon
    - Energy
  - 2 jets
    - Jet mass
    - Visible Energy(2 jet)
    - y value(y23, y34)
    - costheta
    - Missing momentum (xy & z)

Conditions for remaining events

- Back-to-Back:
  - $\cos(op\_angle) \leq -0.95$
- $BDTscore \geq 0.0$



event selection result

	signal	2f BKG	4f hadronic BKG	4f semileptonic BKG
No cut	6,183,923 (100%)	25,197,014 (100%)	13,832,211 (100%)	19,630,562 (100%)
cut	**4,871,598 (78%)**	**502,037 (2%)**	**856,414 (6%)**	**95,682 (0.6%)**

quark flavor tagging

To evaluate the search for new physics, it is necessary to determine the cross-section for each flavor.

To do this, flavor tagging is performed, dividing events into b, c, q(u,d,s), and others.

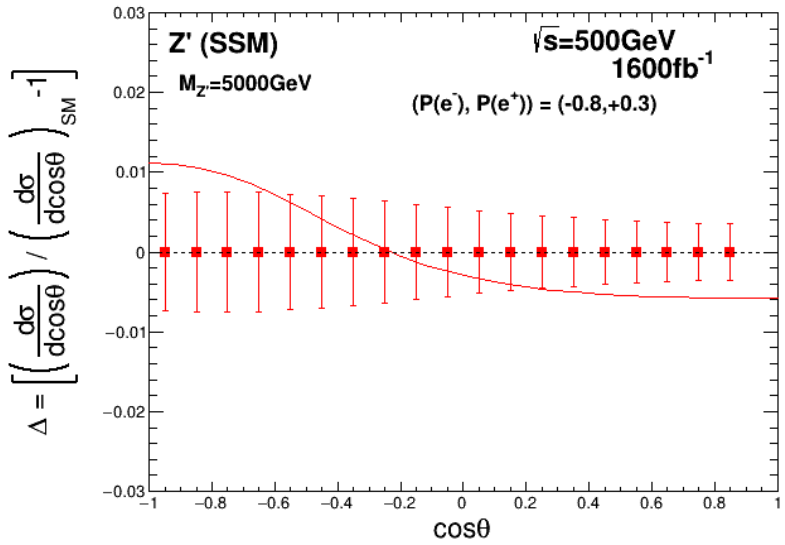
After event selection

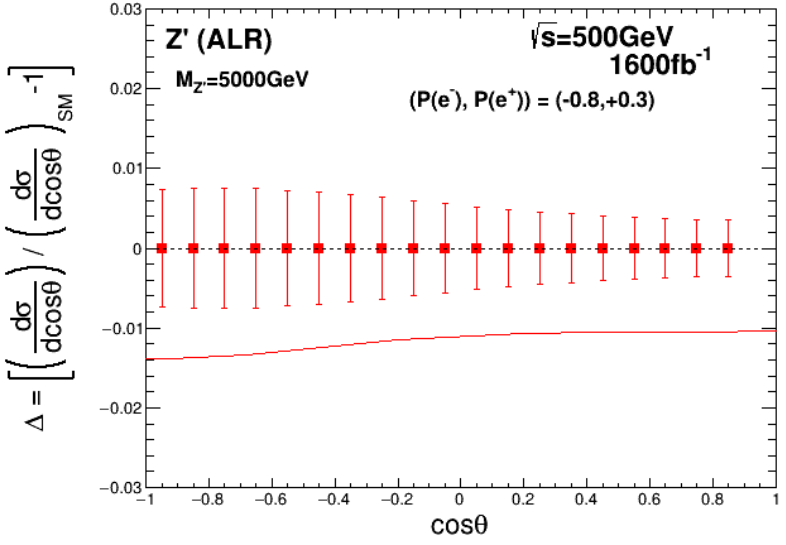
true flavor \ predicted flavor	q (u,d,s)	c	b	others
q (u,d,s)	**2,661,403**	83,956	36,887	34,311
c	266,296	**834,452**	89,949	10,348
b	13,535	21,423	**705,974**	5,104

Flavor tagging is applied to the two reconstructed jets.

- **If the flavors of both jets match, that event is classified as the tagged quark.**
- **Events that do not match are classified as the quark with the higher score.**
- **Events where the tagging fails for both jets are classified as 'others'.**

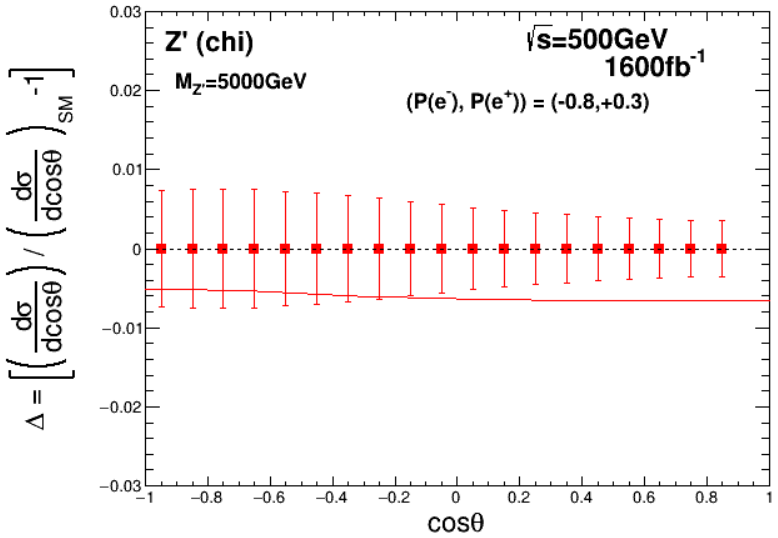
Deviation on angular distribution for μμ

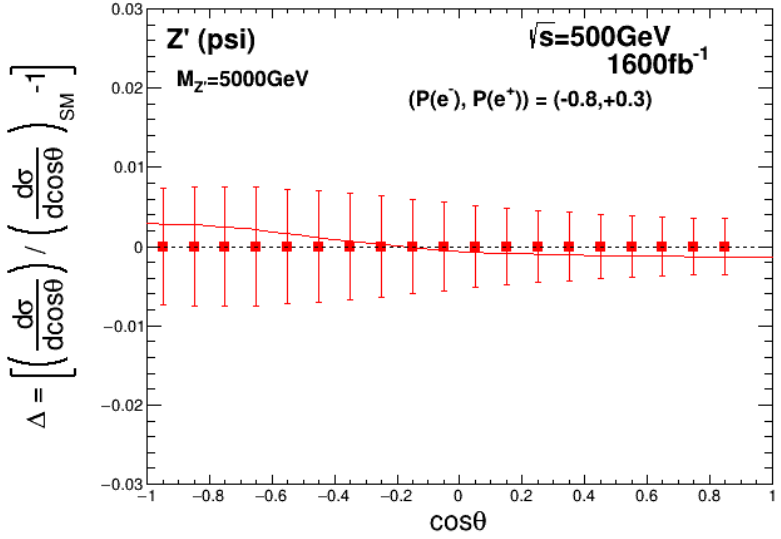


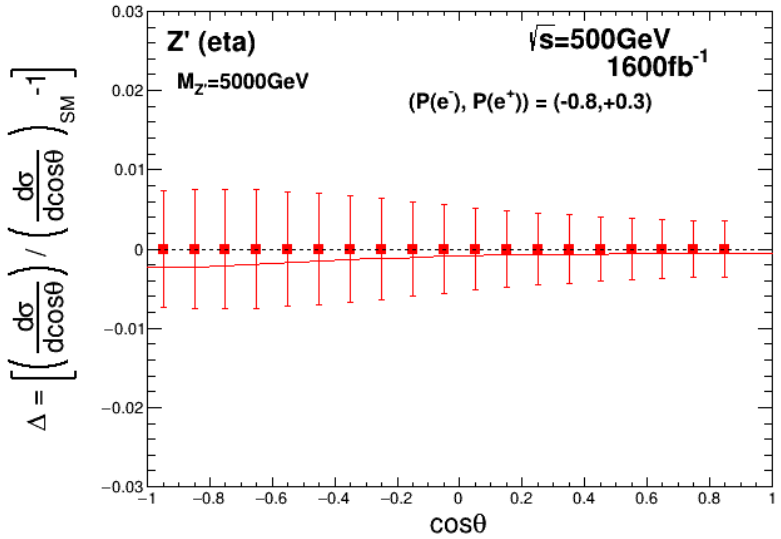


Z' models
(line: BSM effect, error bars: error on each bin)

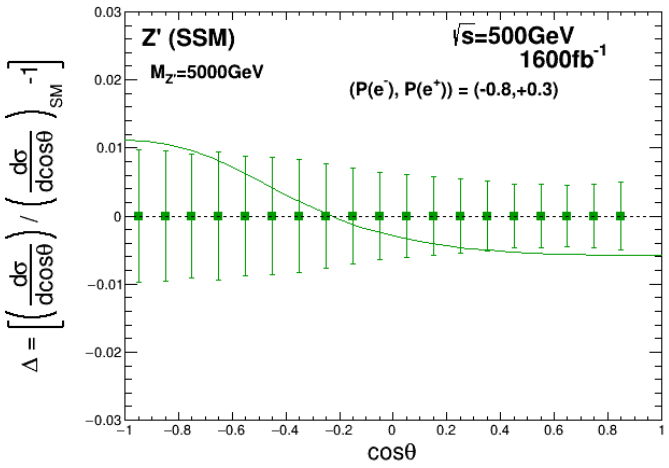
SSM: Sequential Standard Model
ALR : Alternative Left-Right symmetric
chi : E_6 χ *model* ($\beta = 0$)
psi : E_6 ψ *model* ($\beta = \pi/2$)
eta : E_6 η *model* ($\beta = \pi - \arctan\sqrt{5/3}$)

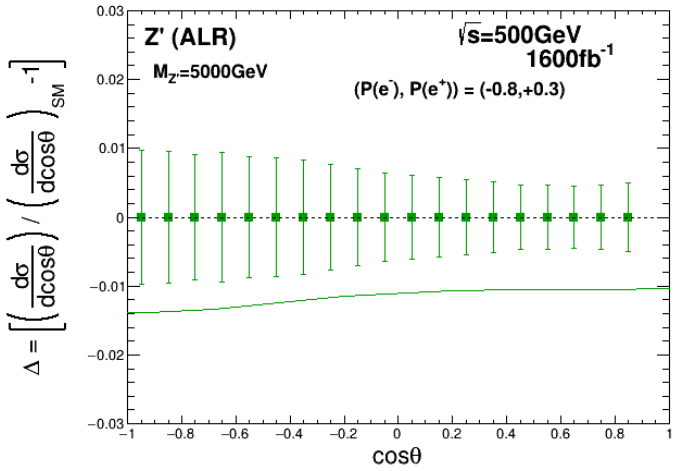


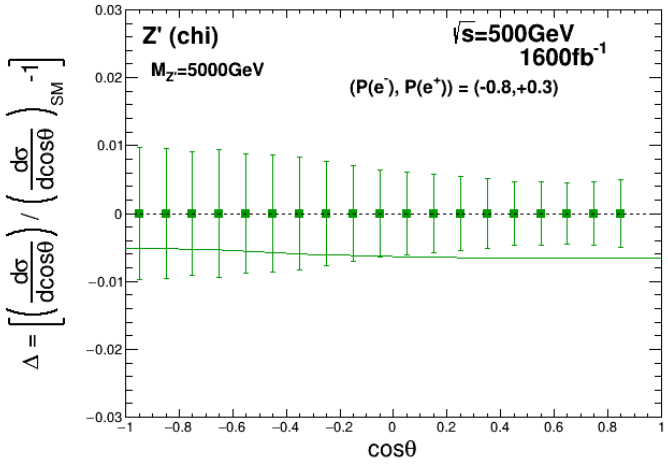


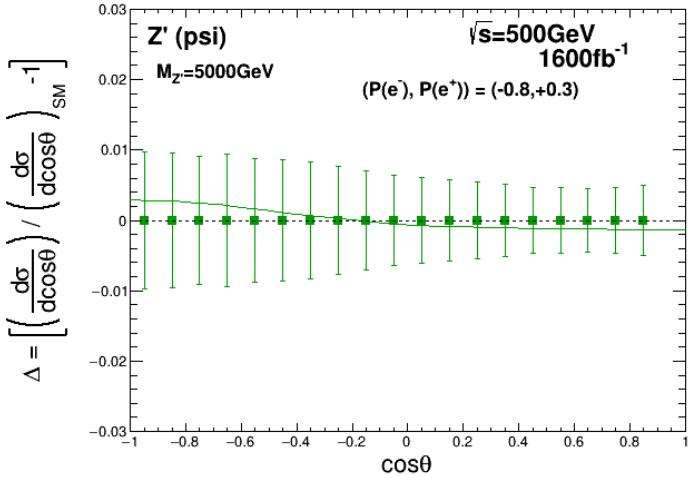


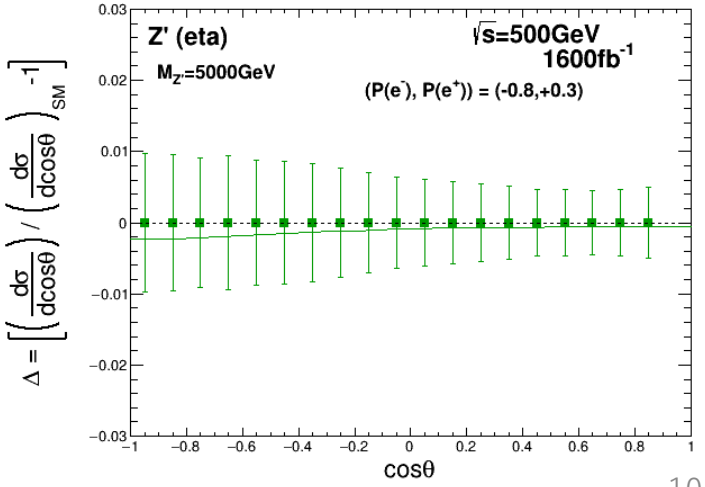
Deviation on angular distribution for $\tau\tau$











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(line: BSM effect, error bars: error on each bin)

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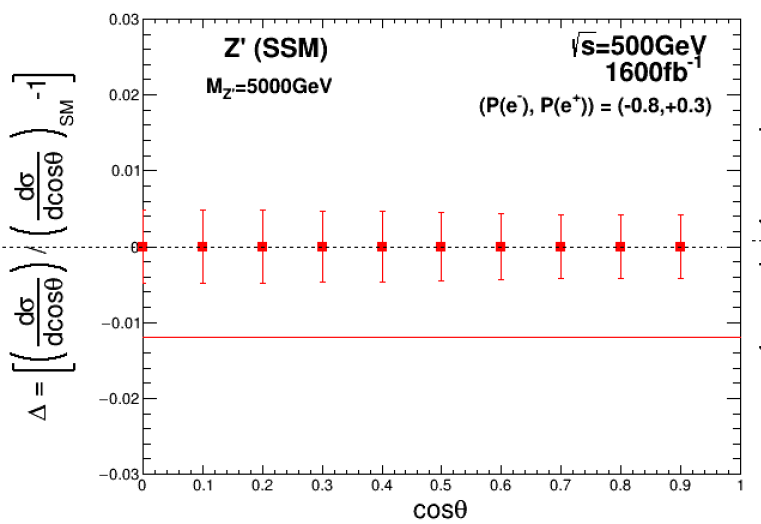
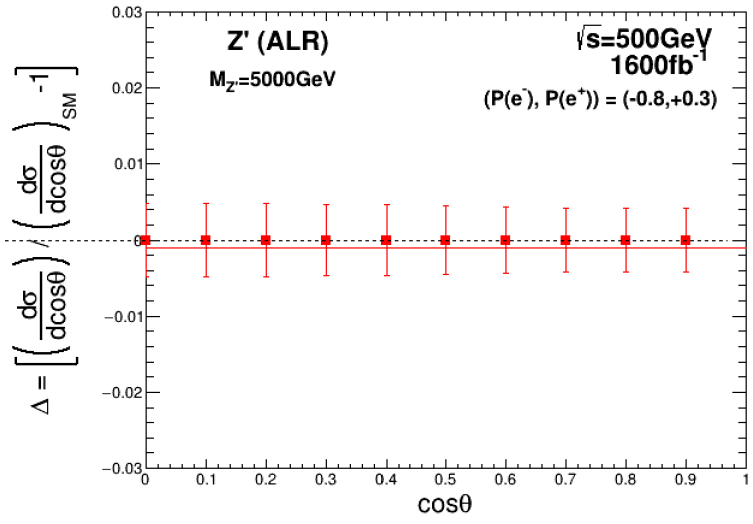
For bb

No charge ID assumed: absolute value of cosθ taken
No angular deviation seen on any Z' models → total cross section is used
(for both $e^-_L e^+_R$ and $e^-_R e^+_L$)





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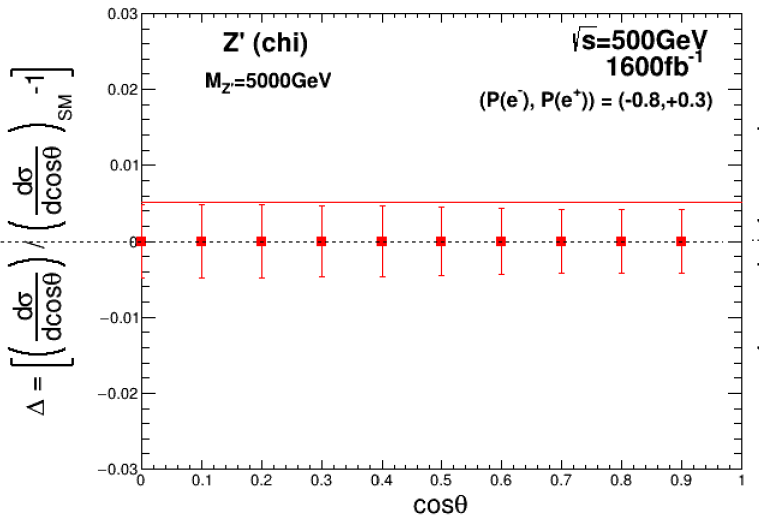
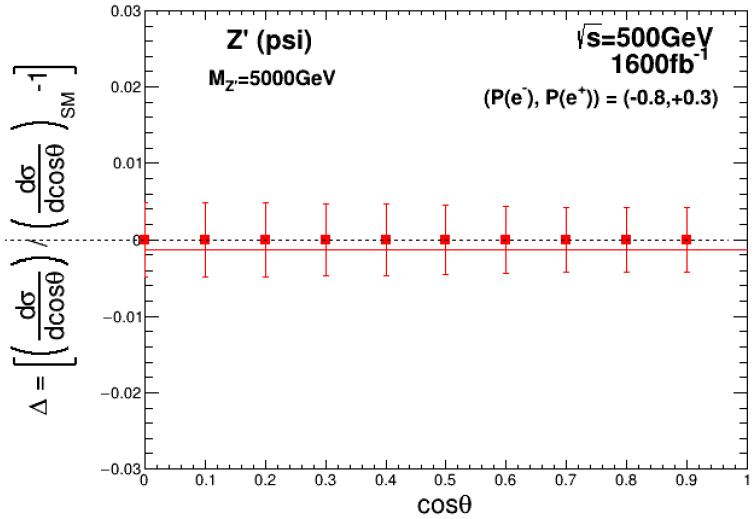
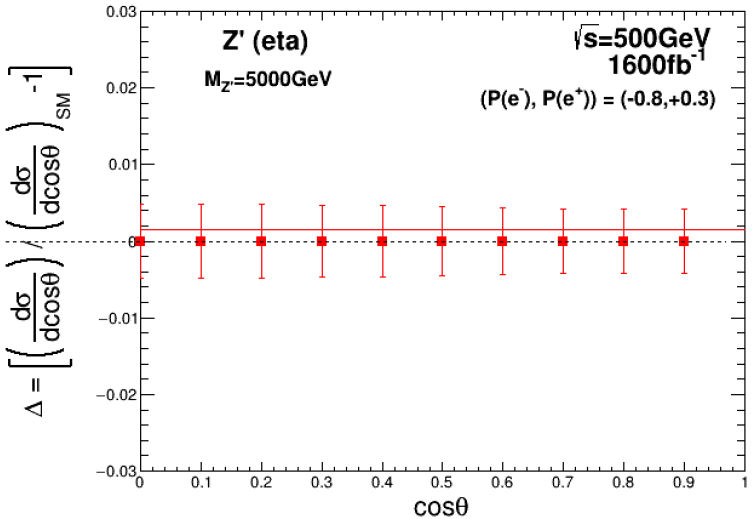
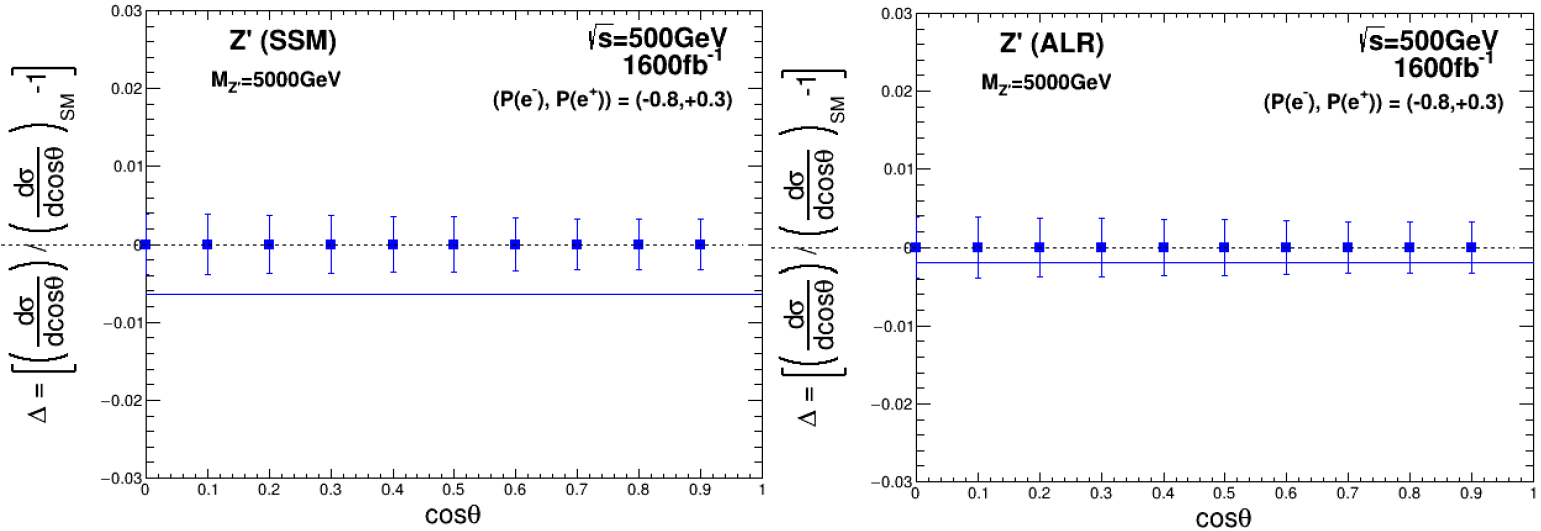






For cc

No charge ID assumed: absolute value of cosθ taken
No angular deviation seen on any Z' models → total cross section is used
(for both $e^-_L e^+_R$ and $e^-_R e^+_L$)



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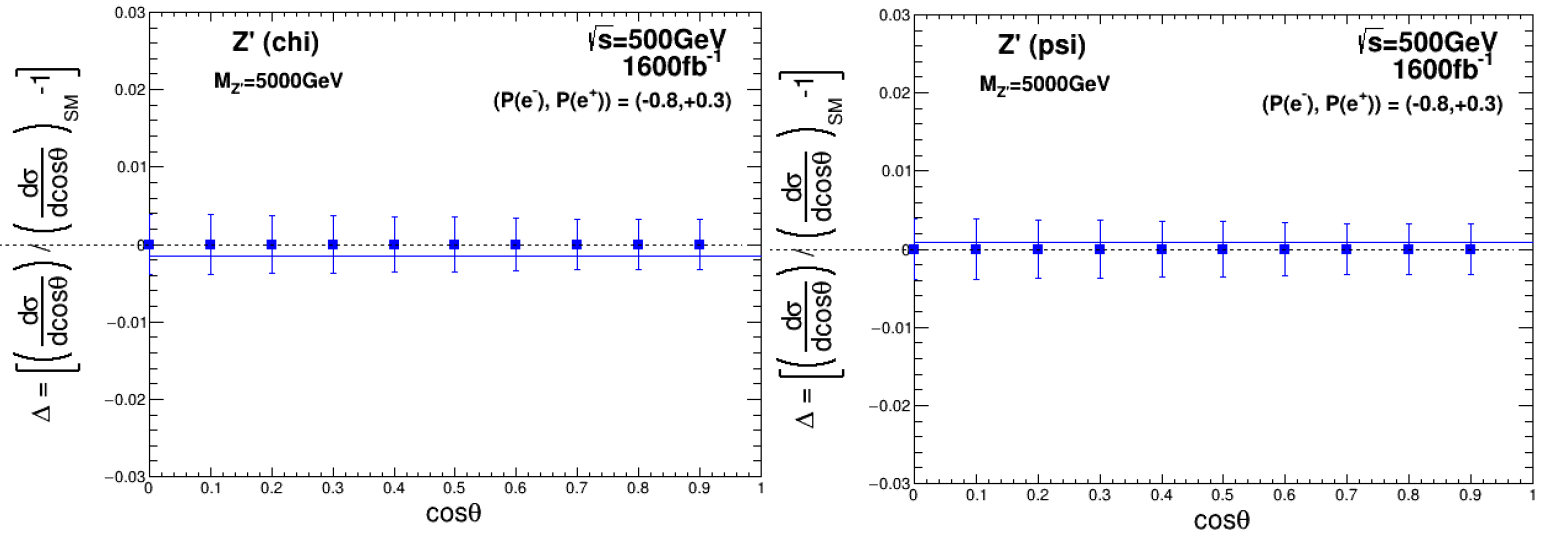
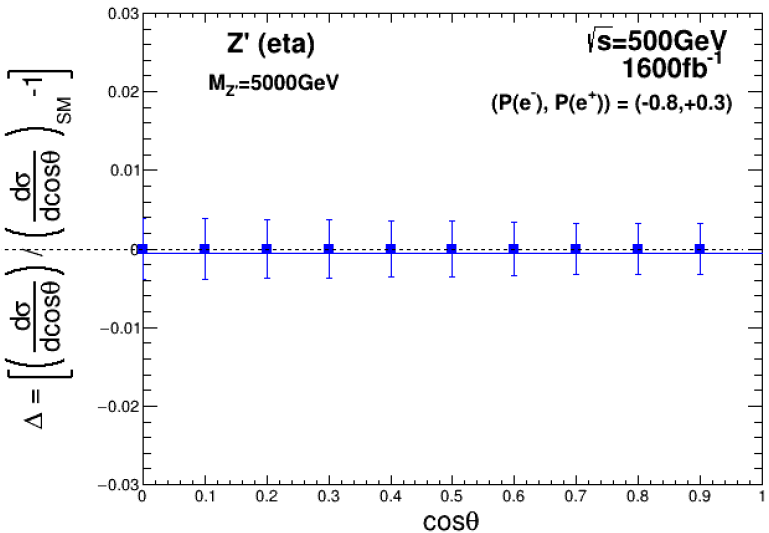




Evaluation of the discrimination performance of $\mathbf{Z'}$

- Accuracy of the i-th bin of the $\cos\theta$ distribution at ILC $(\delta\sigma_i/\sigma_i(SM))$

(It was divided into two bins: forward and backward).

$$\frac{\delta\sigma_i}{\sigma_i(SM)} = \sqrt{\left(\frac{\sqrt{S_i + N_i}}{S_i}\right)^2 + {\sigma_{syst}}^2}$$

S_i: the number of signal events
N_i: the number of background events **in each bin.**
In this evaluation, **systematic errors of 0.1% for μ and 0.2% for τ** are assumed. (For quarks it is not included.)

- The deviation of the differential cross-section between the Standard Model and each model for the i-th bin $(\delta\sigma_i(BSM)/\sigma_i(SM))$ is calculated and χ^2 is obtained.

$$\chi^2(BSM) = \sum_i \left\{\left(\frac{\delta\sigma_i(BSM)}{\sigma_i(SM)} \Big/ \frac{\delta\sigma_i}{\sigma_i(SM)}\right)^2\right\}$$

NDF = number of total bins

Probability for exclusion is calculated from χ^2 and NDF.
(Too pessimistic assumption? Under discussion…)

Results on leptonic channels (preliminary)

μμ channel

Z'model	SSM	ALR	χ	ψ	η
5-sigma	4.5 TeV	6.0 TeV	4.3 TeV	2.3 TeV	2.5 TeV
2-sigma	6.3 TeV	8.4 TeV	6.1 TeV	3.2 TeV	3.6 TeV

ττ channel

Z'model	SSM	ALR	χ	ψ	η
5-sigma	4.0 TeV	5.4 TeV	3.9 TeV	2.0 TeV	2.3 TeV
2-sigma	5.6 TeV	7.6 TeV	5.5 TeV	2.9 TeV	3.2 TeV

μμ + ττ combined

Z'model	SSM	ALR	χ	ψ	η
5-sigma	4.7 TeV	6.4 TeV	4.6 TeV	2.4 TeV	2.7 TeV
2-sigma	6.5 TeV	8.8 TeV	6.4 TeV	3.3 TeV	3.7 TeV

Mass limit for $b\bar{b}$, $c\bar{c}$ (preliminary)

$b\bar{b}$ channel

Z'model	SSM	ALR	χ	ψ	η
5-sigma	6.7 TeV	2.7 TeV	4.4 TeV	2.8 TeV	2.4 TeV
2-sigma	11.5 TeV	4.4 TeV	7.5 TeV	4.6 TeV	4.1 TeV

$c\bar{c}$ channel

Z'model	SSM	ALR	χ	ψ	η
5-sigma	5.3 TeV	4.6 TeV	2.6 TeV	2.4 TeV	2.5 TeV
2-sigma	9.1 TeV	7.9 TeV	4.4 TeV	3.8 TeV	4.3 TeV

$b\bar{b} + c\bar{c}$ combined

Z'model	SSM	ALR	χ	ψ	η
5-sigma	7.0 TeV	4.6 TeV	4.4 TeV	3.0 TeV	2.8 TeV
2-sigma	11.5 TeV	7.9 TeV	7.5 TeV	4.7 TeV	4.6 TeV

Comparison of Lepton and hadron results (preliminary)

$\mu\mu + \tau\tau$ combined

Z'model	SSM	ALR	χ	ψ	η
5-sigma	4.7 TeV	6.4 TeV	4.6 TeV	2.4 TeV	2.7 TeV
2-sigma	6.5 TeV	8.8 TeV	6.4 TeV	3.3 TeV	3.7 TeV

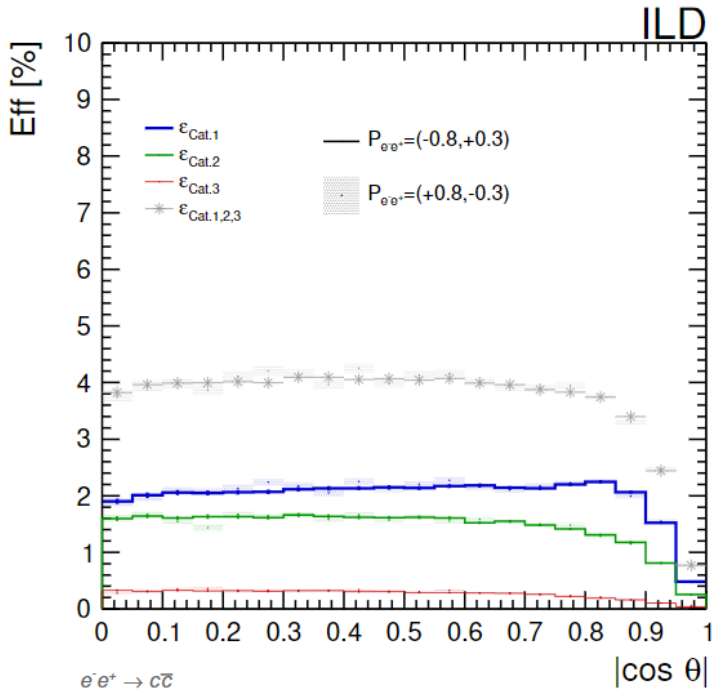
$b\bar{b} + c\bar{c}$ combined

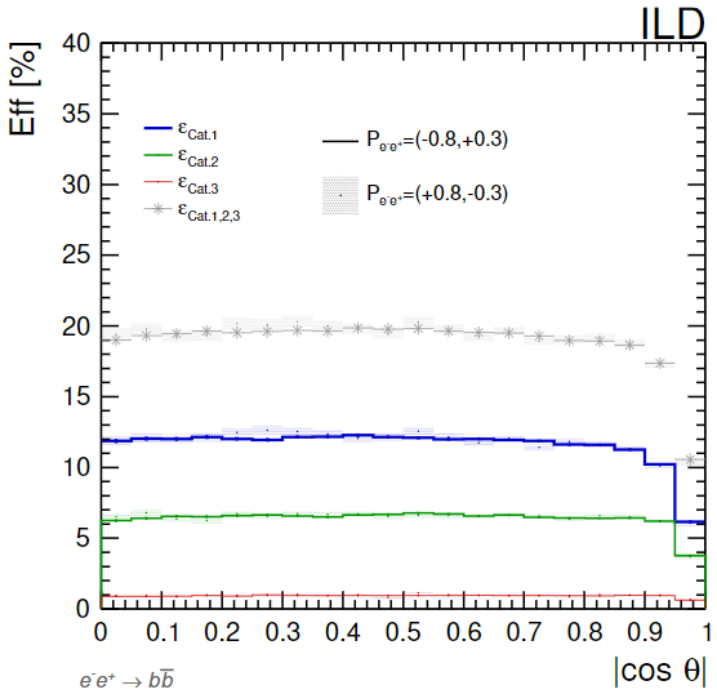
Z'model	SSM	ALR	χ	ψ	η
5-sigma	7.0 TeV	4.6 TeV	4.4 TeV	3.0 TeV	2.8 TeV
2-sigma	11.5 TeV	7.9 TeV	7.5 TeV	4.7 TeV	4.6 TeV

Absolute numbers to be confirmed
ALR tends to probe better **by leptonic channels**
SSM tends to probe better **by hadronic channels**

Effect of charge ID for b/c

ILD-PHYS-PUB-2023-001, June 2023





We tried Adrian's efficiency (in 250 GeV qq) applying to our sample to see the effect of charge ID.

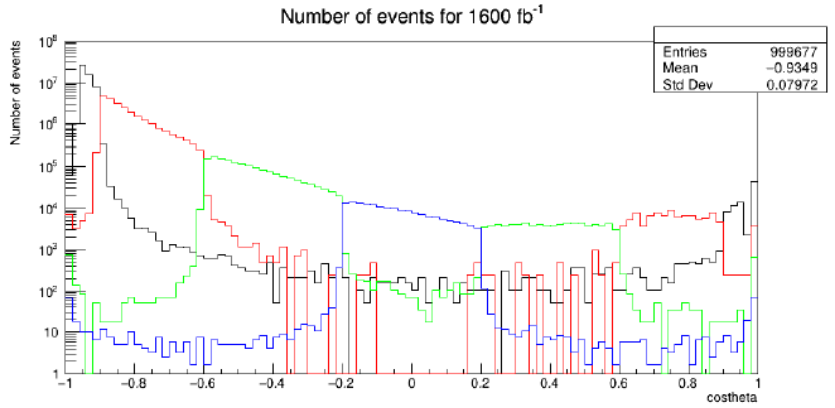
Since the efficiency is low as ~4% (cc) and ~19% (bb), significant improvements cannot be seen even if ignoring mis-tagging effects.

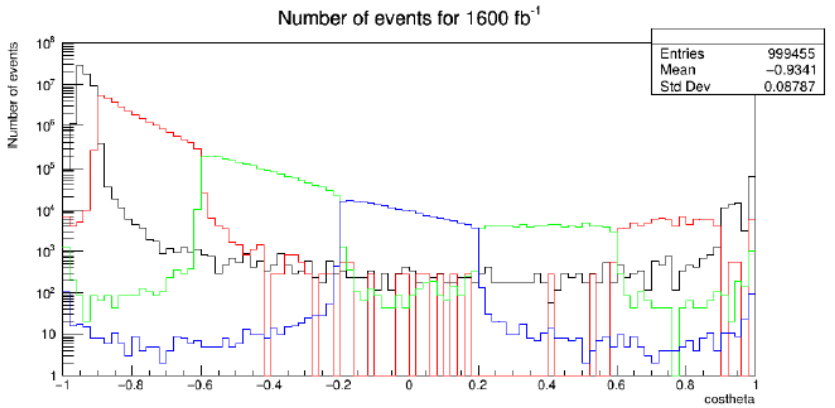
We are still investigating how to incorporate quark charge ID to our studies.

Bhabha sample

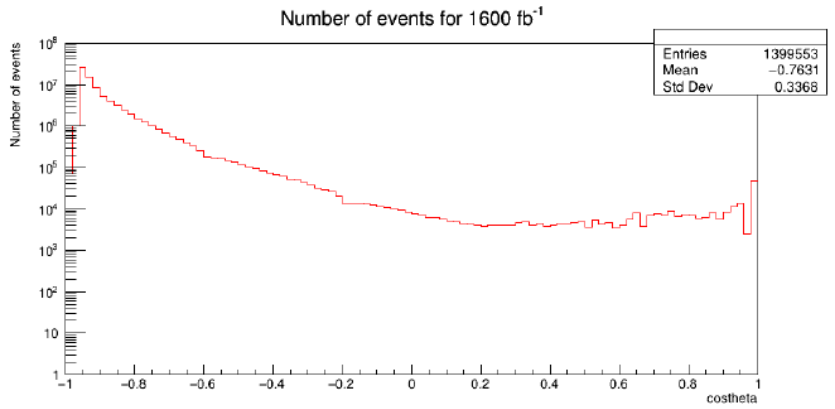
- We have requested high-q^2 Bhabha sample with different statistics on each angular region.
- Produced events have some issues → need to address

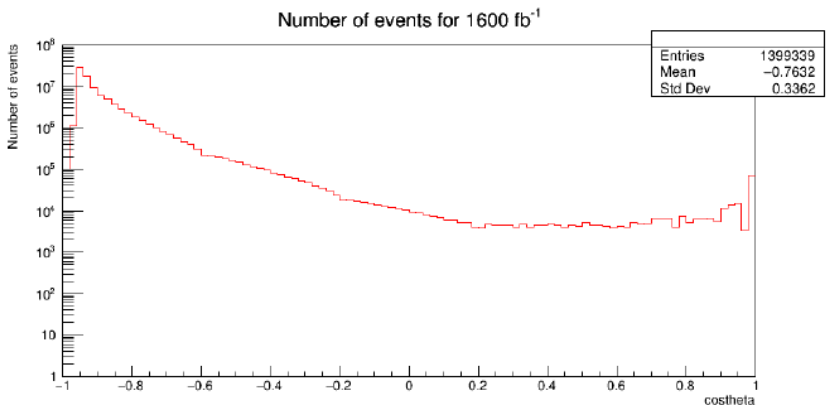
eRpL





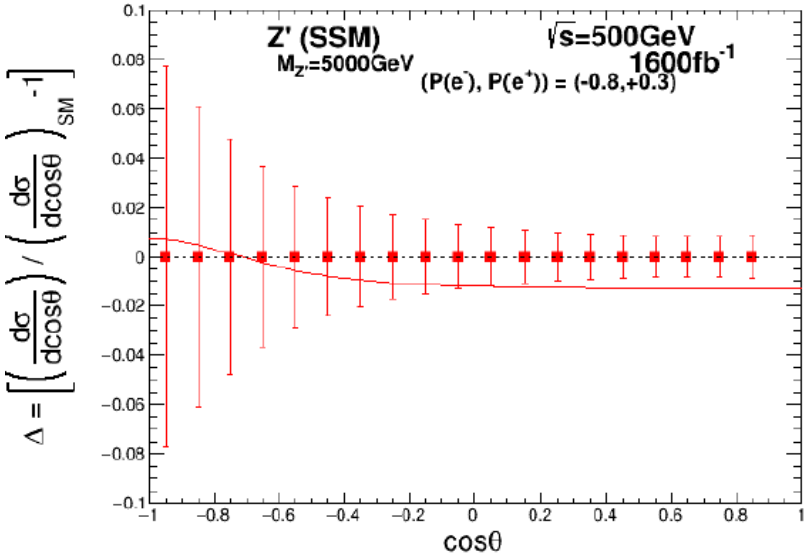
eLpR

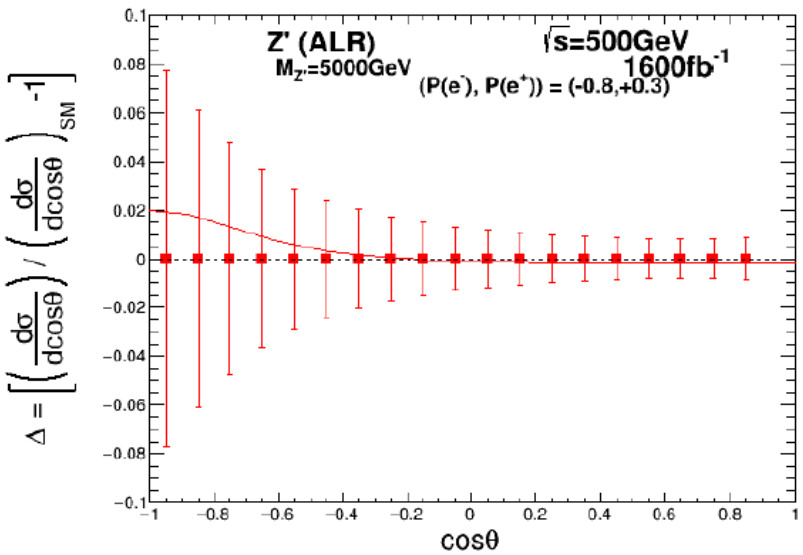




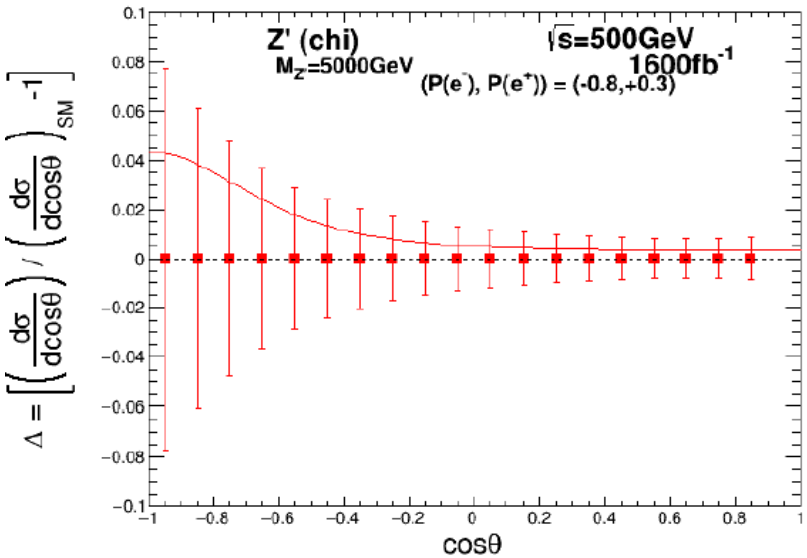
Summary

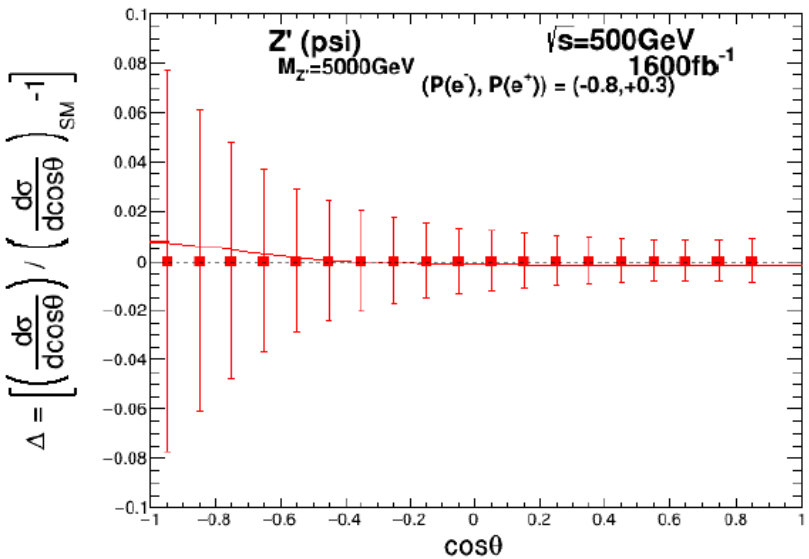
- We are evaluating the discovery potential of Z' at ILC 500GeV using leptonic and hadronic events.
- An evaluation was conducted for five Z’ models. Leptons and hadrons have different responses to each model: investigating both channels improve overall sensitivity.
- Final numbers to be given (we are fixing statistical issue).
- Charge ID is effective only if high efficiency is achieved.
- (tbc) ~10 TeV Z’ can be probed by 500 GeV ILC.

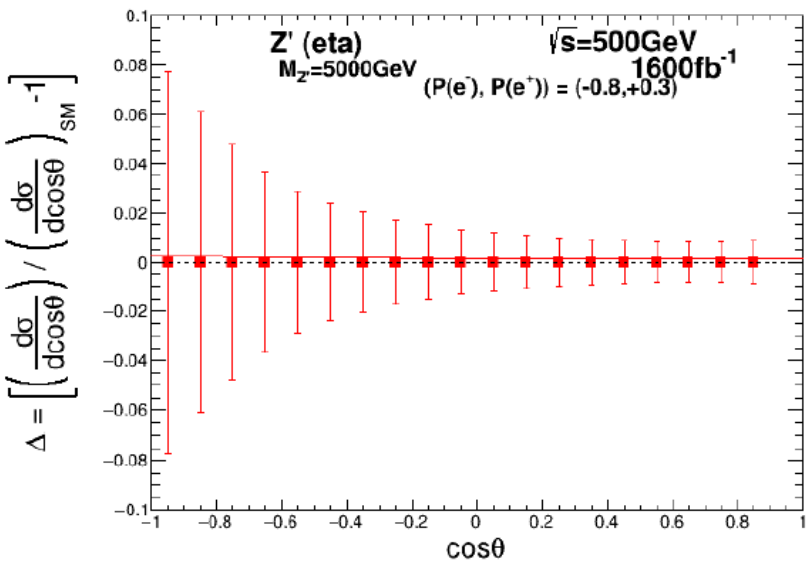

Z' (SSM)
√s=500GeV
M_Z'=5000GeV
1600fb^-1
(P(e^-), P(e^+)) = (-0.8,+0.3)
Δ = [(dσ/dcosθ) / (dσ/dcosθ)_SM - 1]
cosθ

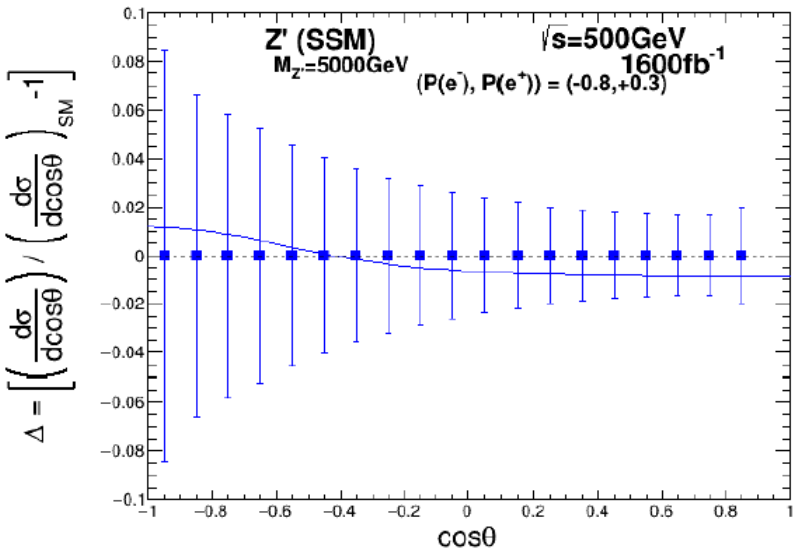

Z' (ALR)
√s=500GeV
M_Z'=5000GeV
1600fb^-1
(P(e^-), P(e^+)) = (-0.8,+0.3)
Δ = [(dσ/dcosθ) / (dσ/dcosθ)_SM - 1]
cosθ

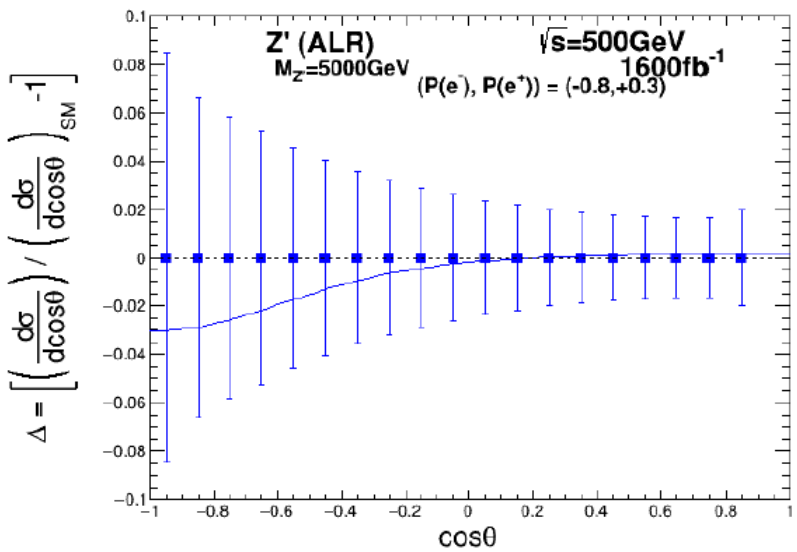
bb event


Z' (chi)
√s=500GeV
M_Z'=5000GeV
1600fb^-1
(P(e^-), P(e^+)) = (-0.8,+0.3)
Δ = [(dσ/dcosθ) / (dσ/dcosθ)_SM - 1]
cosθ

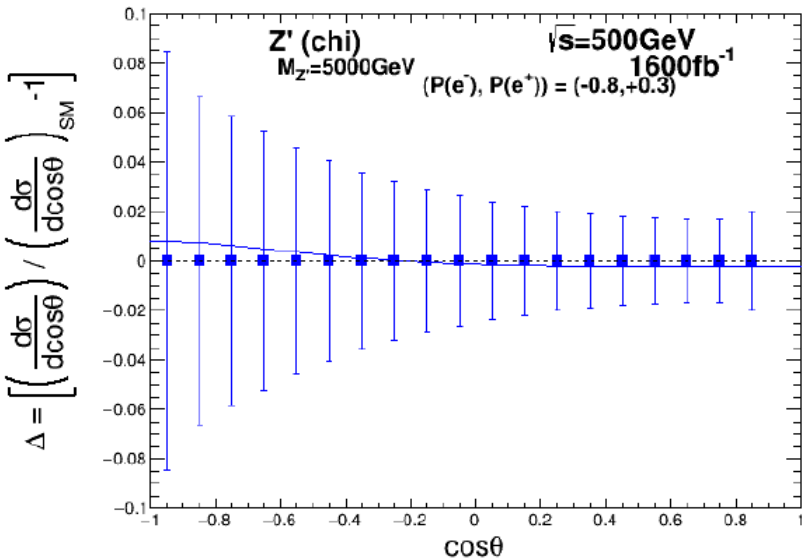

Z' (psi)
√s=500GeV
M_Z'=5000GeV
1600fb^-1
(P(e^-), P(e^+)) = (-0.8,+0.3)
Δ = [(dσ/dcosθ) / (dσ/dcosθ)_SM - 1]
cosθ

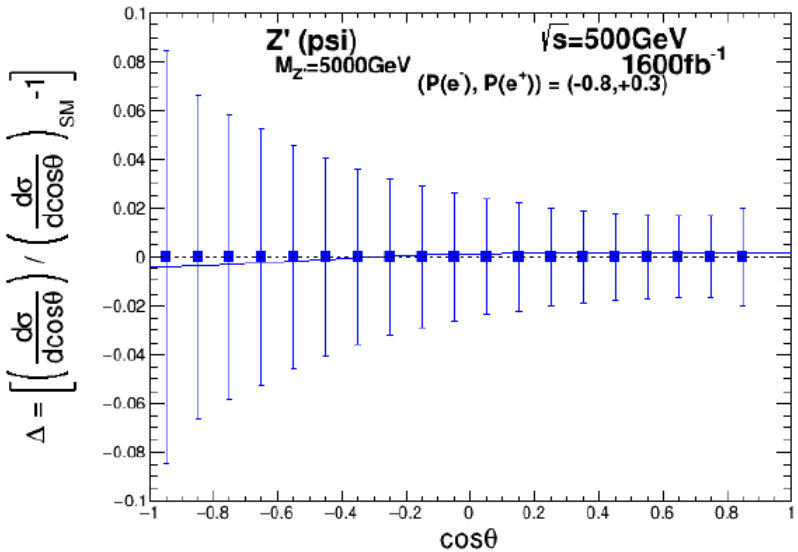

Z' (eta)
√s=500GeV
M_Z'=5000GeV
1600fb^-1
(P(e^-), P(e^+)) = (-0.8,+0.3)
Δ = [(dσ/dcosθ) / (dσ/dcosθ)_SM - 1]
cosθ

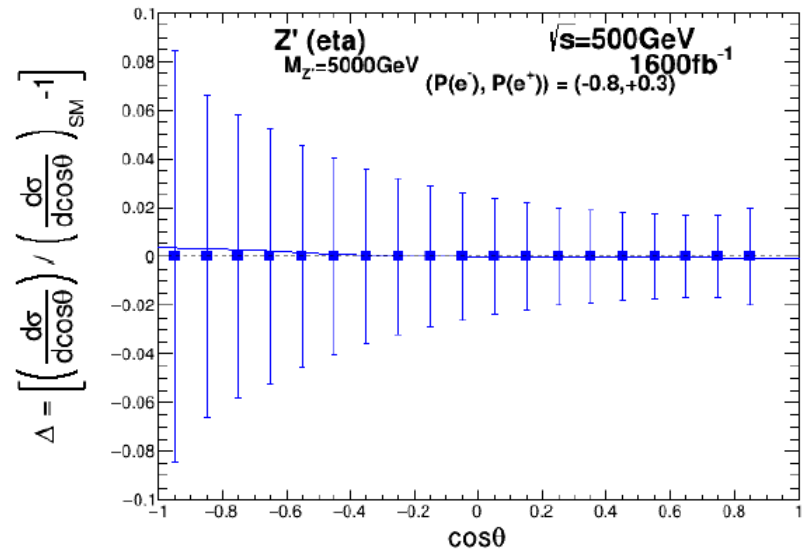

Z' (SSM)
√s=500GeV
M_Z'=5000GeV
1600fb^-1
(P(e^-), P(e^+)) = (-0.8,+0.3)
Δ = [(dσ/dcosθ) / (dσ/dcosθ)_SM - 1]
cosθ


Z' (ALR)
√s=500GeV
M_Z=5000GeV
1600fb^-1
(P(e^-), P(e^+)) = (-0.8,+0.3)
Δ = [(dσ/dcosθ) / (dσ/dcosθ)_SM - 1]
cosθ

cc event


Z' (chi)
√s=500GeV
M_Z'=5000GeV
1600fb^-1
(P(e^-), P(e^+)) = (-0.8,+0.3)
Δ = [(dσ/dcosθ) / (dσ/dcosθ)_SM - 1]
cosθ


Z' (psi)
√s=500GeV
M_Z'=5000GeV
1600fb^-1
(P(e^-), P(e^+)) = (-0.8,+0.3)
Δ = [(dσ/dcosθ) / (dσ/dcosθ)_SM - 1]
cosθ


Z' (eta)
√s=500GeV
M_Z'=5000GeV
1600fb^-1
(P(e^-), P(e^+)) = (-0.8,+0.3)
Δ = [(dσ/dcosθ) / (dσ/dcosθ)_SM - 1]
cosθ