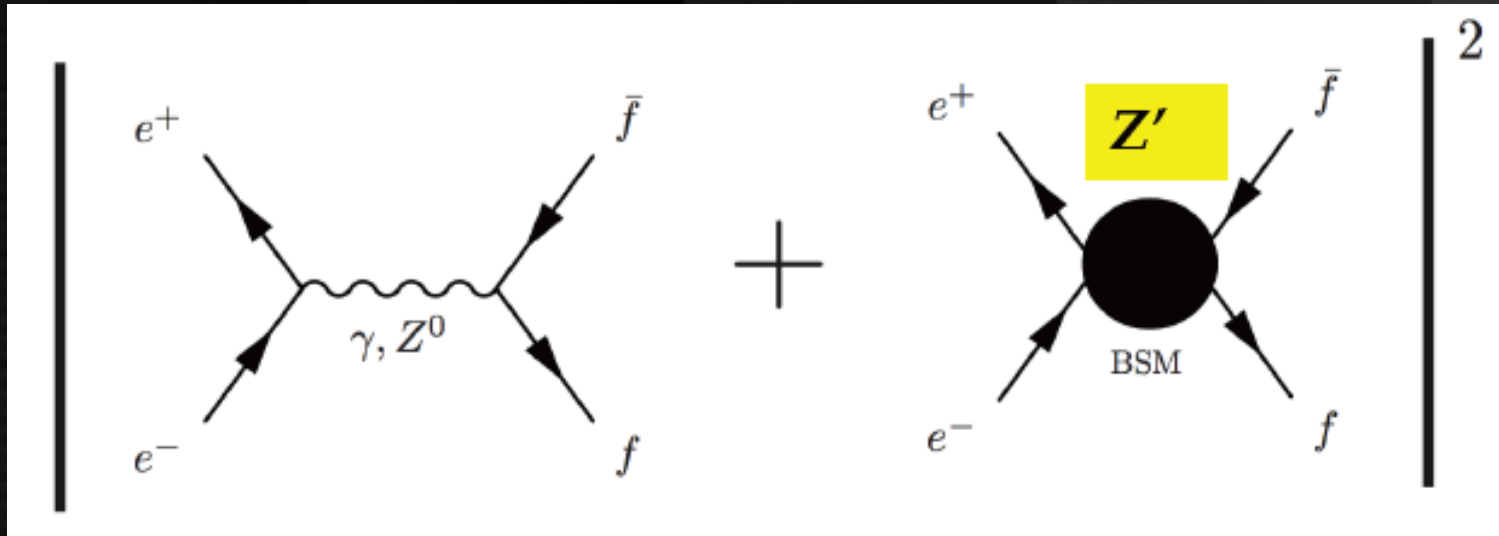




Two-fermion final states at International Linear Collider

Taikan Suehara (Kyushu Univ.)

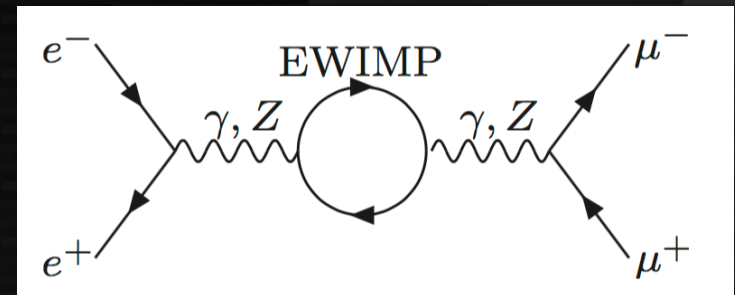
2-fermions in e^+e^- collider



Effect of virtual BSMs (Z 's, WIMPs, ...) **as interference**

Observables for detection:

- Cross section
- Production angle
- Dependence on polarization
- Polarization (τ)



See arXiv:1504.03402

$e^+e^- \rightarrow ff$: basics

SM Cross section (80/30% polarization assumed)

Whizard 1.95

Sqrt(s)	Process	$\sigma (e^-_L e^+_R)$	$\sigma (e^-_R e^+_L)$	σ (No pol.)
250 GeV	$e^+e^- \rightarrow qq$	79 pb	46 pb	50 pb
	$e^+e^- \rightarrow ll (\mu, \tau)$	13 pb	10 pb	9.3 pb
500 GeV	$e^+e^- \rightarrow qq$	19 pb	4.3 pb	9.4 pb
	$e^+e^- \rightarrow ll (\mu, \tau)$	10 pb	3.1 pb	5.6 pb
1 TeV	$e^+e^- \rightarrow qq$	5.6 pb	1.3 pb	2.8 pb
	$e^+e^- \rightarrow ll (\mu, \tau)$	3.1 pb	0.9 pb	1.6 pb

Effect of polarization (incl. $Z\gamma \rightarrow ff\gamma$)

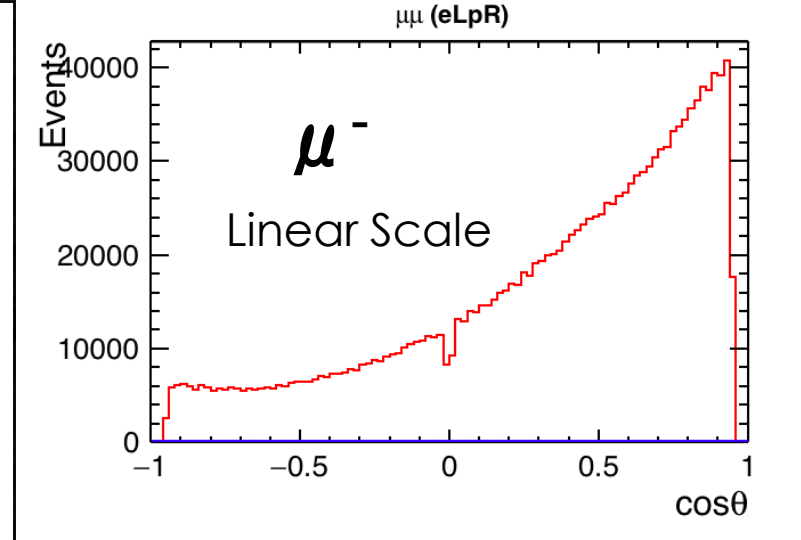
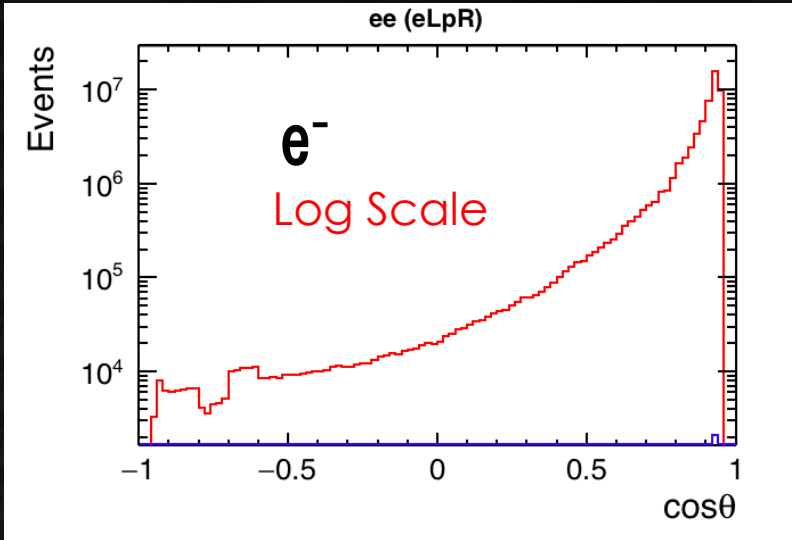
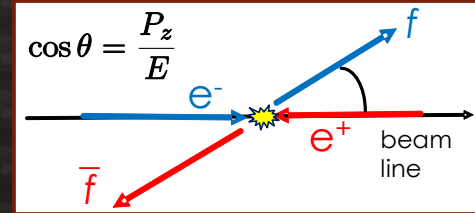
- 1.5 – 2 times more cross section at $e^-_L e^+_R$
- Independent observables with two polarization setup

Statistical power

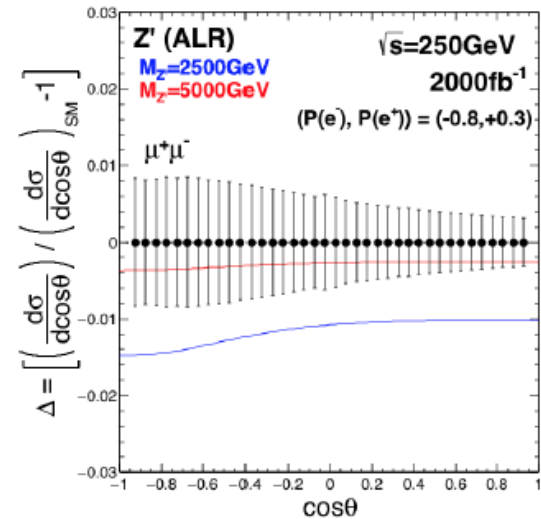
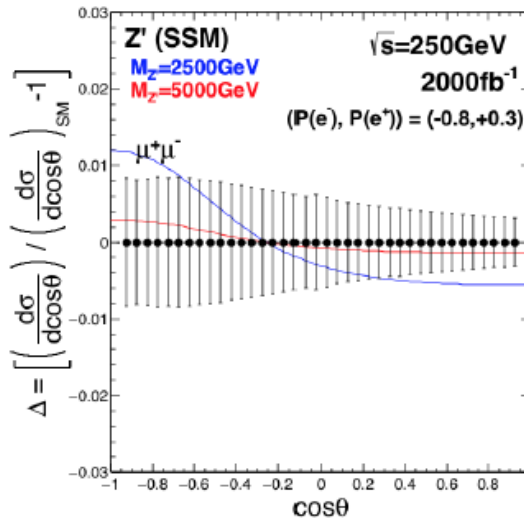
10 pb \rightarrow 10^7 events / 1 ab⁻¹ \rightarrow 0.03% ultimate statistics

Angular distribution with Z'

SM angular distribution (250 GeV, full sim)

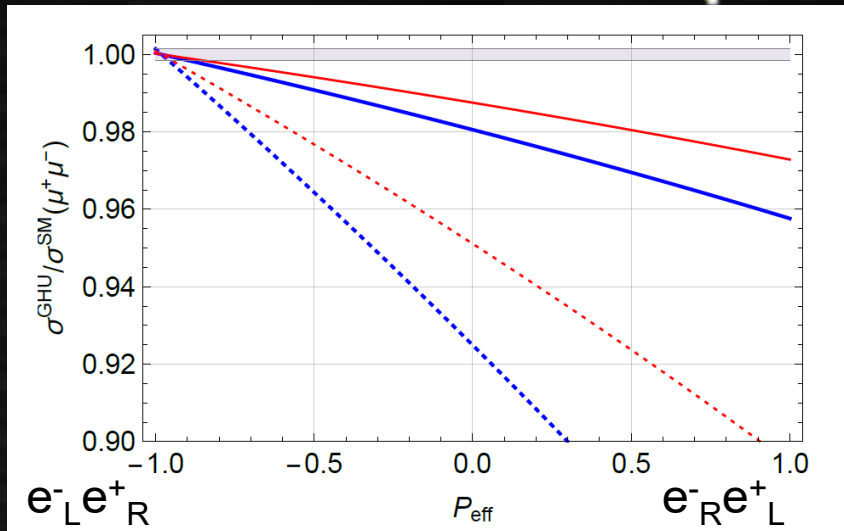


Deviation from SM by Z' models (SSM, ALR) for $ee \rightarrow \mu\mu$



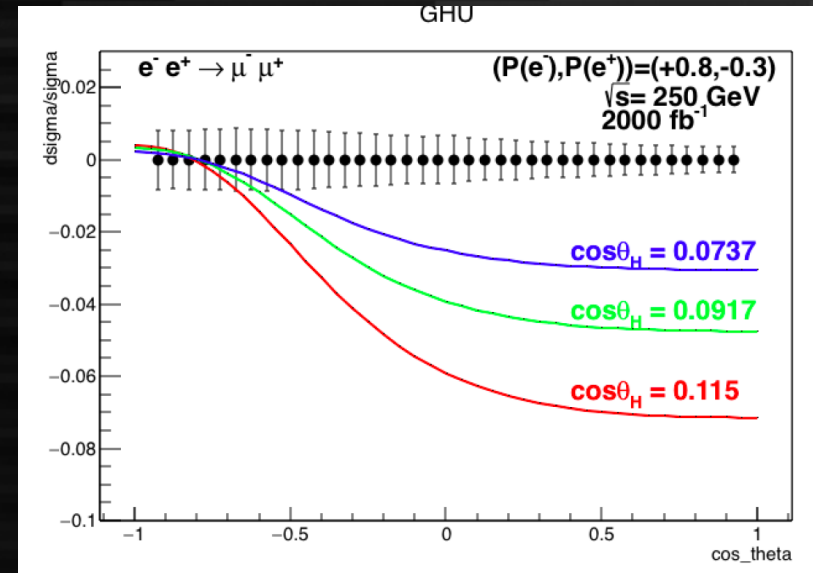
arXiv:1801.04671
arXiv:1902.05245

Polarization power: an example



Gauge-Higgs unification (GHU) predicts Z' only couples to right-handed electrons (solid: 250 GeV, dotted: 500 GeV, red: $\phi_H = 0.0917$, blue: $\phi_H = 0.0737$)

arXiv:1705.05282
arXiv:1801.04671



250 GeV ILC easily identifies Z' from GHU with right-handed polarization

Exclusion / discovery for Z' models

Exclusion (95%CL) / discovery (5σ) reach at ILC

arXiv:1908.11299

Model	250 GeV, 2 ab ⁻¹ excl.	disc.	500 GeV, 4 ab ⁻¹ excl.	disc.	1 TeV, 8 ab ⁻¹ excl.	disc.
SSM	7.8	4.9	13	8.4	22	14
ALR	9.5	6.0	17	11	25	18
χ	7.0	4.5	12	7.8	21	13
ψ	3.7	2.4	6.4	4.1	11	6.8
η	4.2	2.7	7.3	4.6	12	7.9

TeV

- e, μ , τ , b combined (without full consideration of systematics)
- Phenomenological model
 - SSM: Sequential Standard Model
- Theory-motivated model
 - ALR: Alternative Left-Right model
 - χ , ψ , η : E₆ group models
- 500 GeV / 1 TeV: extrapolated from 250 GeV study

ee \rightarrow ff: Summary

- e^+e^- can probe Z' with comprehensive way
 - Can use ee , $\mu\mu$, $\tau\tau$, bb , (cc) , (qq)
 - Z' with weak coupling to lepton can be probed
 - Beam polarization helps a lot on some models
 - Tau polarization to 1% - can be a new probe?
- 250 GeV – 5-10 TeV Z' can be in reach
 - Depending on models
 - Can expect to exceed HL-LHC reach
- 1 TeV – more powerful than FCChh in indirect search
 - Comparison in EPPSU physics briefing book

Remaining topics

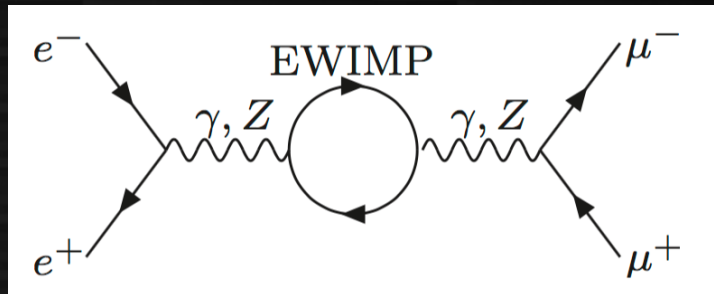
- Full simulation study with > 500 GeV
 - Current results based on simple extrapolation
- Uncertainty of the production angle by detector effect
 - Not considered now
- Realistic estimation of the systematic effects
 - Luminosity, efficiency, charge ID etc.
- More Z' models
- Better jet charge assignment (eg. by deep learning)

Remaining topics

- Precise estimation of systematic effects
 - To total cross section
 - To differential cross section
 - To polarization, charge assignment, tau pol etc.
 - Combine channels with (partially correlated) systematics
- Broader models to examine
 - Different couplings to generations
 - Different couplings to lepton/quark
 - Different effects to polarization

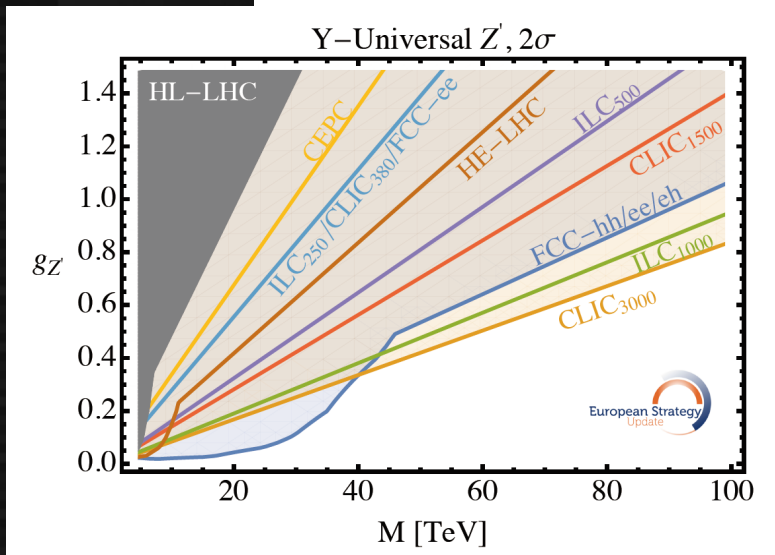
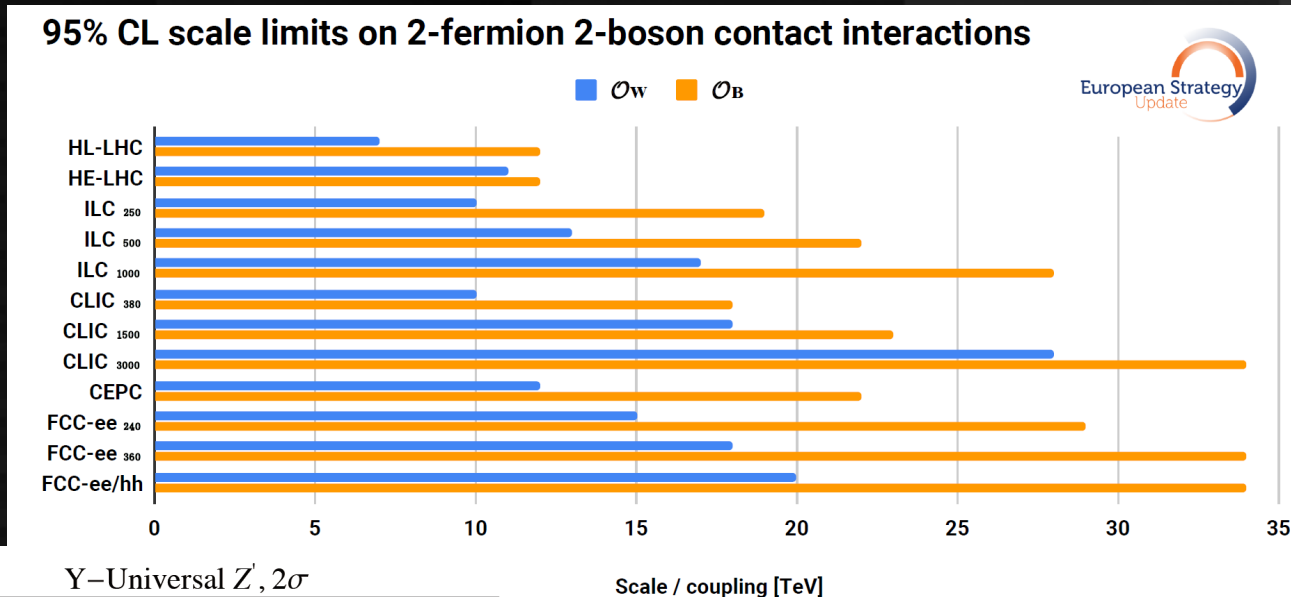
BSM models

- Z' models
 - SSM
 - ALR (Alternative Left-Right model)
 - E_6 models (motivated from string theory)
 - Gauge Higgs Unification (Hosotani model)
- General WIMP search
 - Determined by spin of EWIMP



ee → ff: EPPSU

“Y-universal Z” model is considered



For universal-type Z':

- 250 GeV e^+e^- can exceed HL-LHC reach
- ~TeV e^+e^- is comparable to 100 TeV hh