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Workshop on Photon—Photon Collider
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New Physics in the Intermediate-energy e^-e^- collider in $\gamma\gamma$ Higgs Factory

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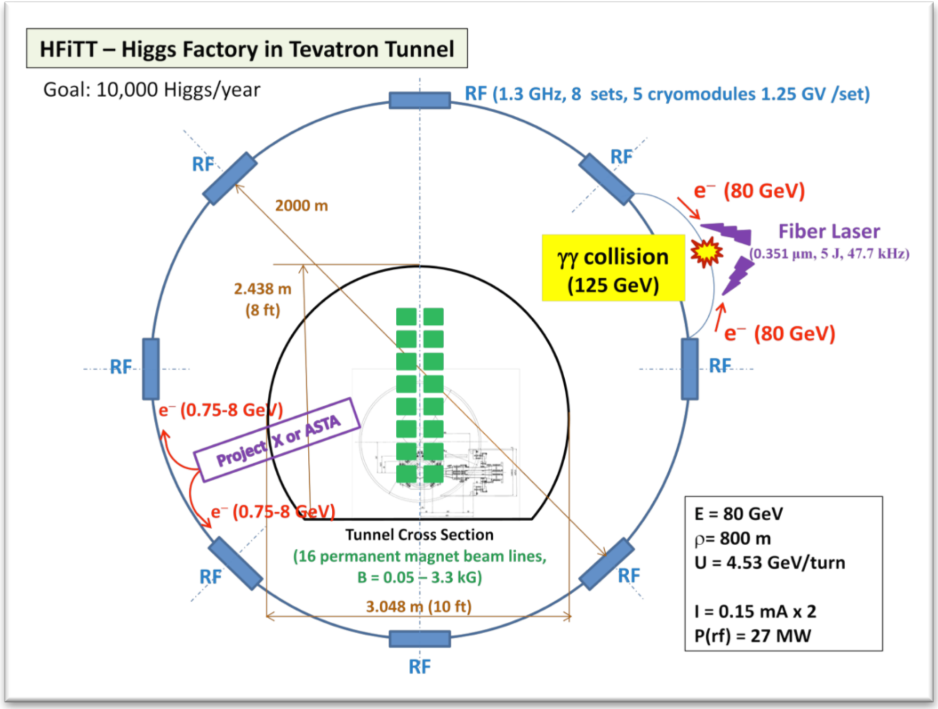
Q: How e-e- beams Push Physics?



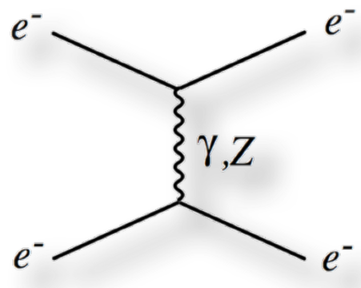
Parameters of Electron Beams[12]	
Beam Energy	80 GeV ×2
CoM Energy	160 GeV
Current	0.15 mA ×2
Polarization	80 %
Luminosity	3.2×10^{34} cm^{-2} s^{-1}
Run time	1Mo= 2.63×10^{6} s^{-1}
Accu Lumin in a month	84 fb^{-1}

Question:

Before electron beams interacting with lasers in the future *γγ* collider, how can we take advantage of primary electron beams to test SM and explore new physics?

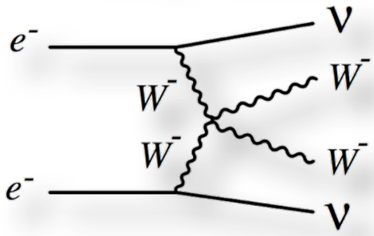
Outline

1. $\sin^2(\theta_W)$ in Moller Scattering
   - **Precise Measurement of $sin^2(\theta_W)$**
   - Probe Interaction with Dark Photon



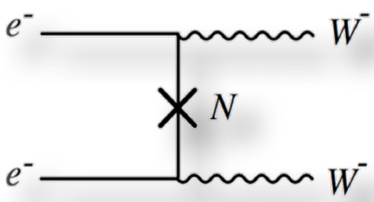
Parity Violation

2. SM Boson Production in ee collision
   - **cross section of WZ and H production**
   - Search heavy Higgs via $W_L^- W_L^-$ scattering

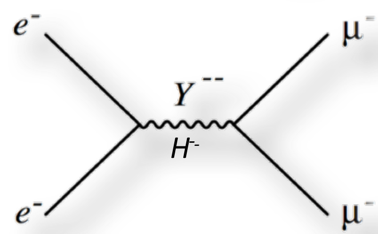


WW scattering

3. Majorana Neutrinos
4. Doubly Charged Boson



Majorana Neutrino



Bilepton

1. $\sin^2(\theta_W)$ in Moller Scattering

Fundamental Parameters in SM

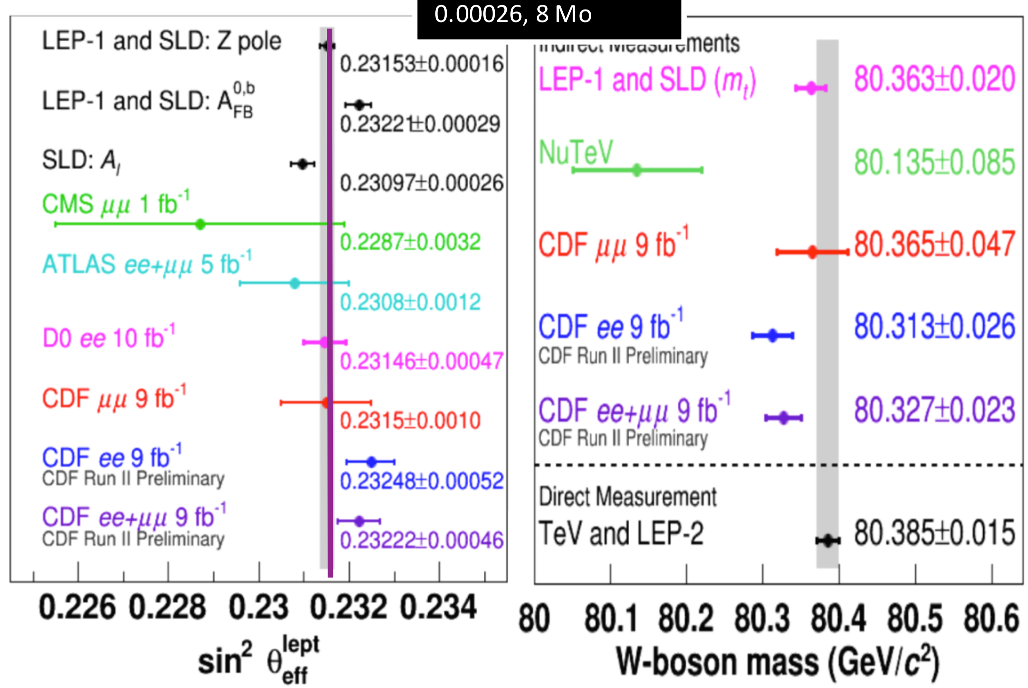
Symbol, equation	Value	Uncertainty (ppb)
c	299 792 458 m s^{-1}	exact*
h	6.626 070 040(81)$\times 10^{-34}$ J s	12
	…3)$\times 10^{-34}$ J s	12
	…4(40)$\times 10^{-22}$ MeV s	6.1
e	…98)$\times 10^{-19}$ C = 4.803 204 673(30)$\times 10^{-10}$ esu	6.1, 6.1
	… fm	6.1
	…V^2 mbarn	12
	…V/c^2 = 9.109 383 56(11)$\times 10^{-31}$ kg	6.2, 12
	…$/c^2$ = 1.672 621 898(21)$\times 10^{-27}$ kg	6.2, 12
	…91) u = 1836.152 673 89(17) m_e	0.090, 0.095
	…$/c^2$	6.2
	…$/c^2$ = 1.660 539 040(20)$\times 10^{-27}$ kg	6.2, 12

2.2×10^5
1.9×10^5

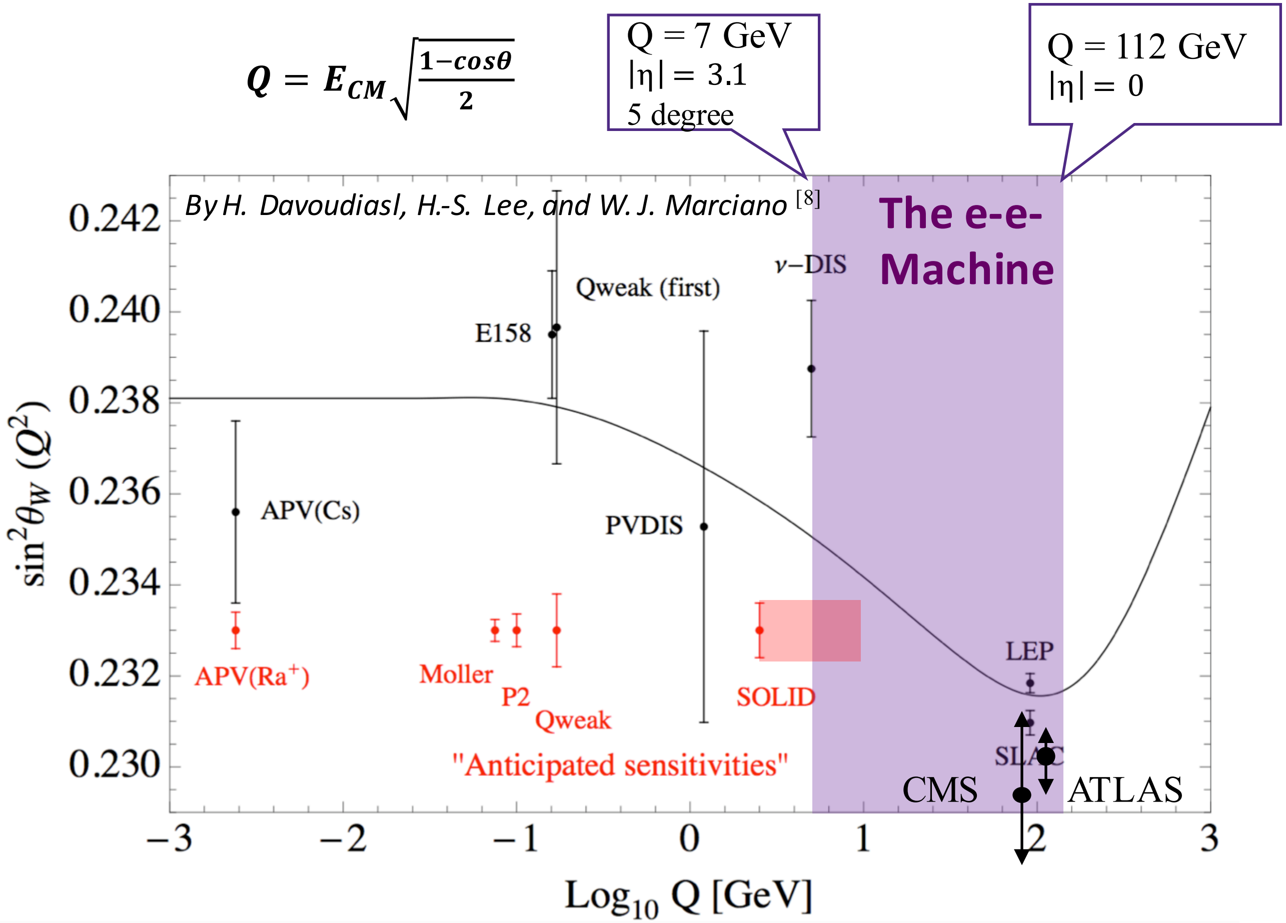
10^5ppb

Measurement of $\sin^2(\theta_W)$ at Z-pole [16]

Raw Stat Uncertainty
0.0005, 2 Mo
0.00026, 8 Mo



1. $\sin^2(\theta_W)$ in Moller Scattering



Coverage in the range from 7-112 GeV[8]. Complements future lower energy programs. Exellent to precise measurement of $sin^2(\theta_W)$ and observe the running of $sin^2(\theta_W)$ in SM.

1. $\sin^2(\theta_W)$ in Moller Scattering

V-A structure of weak interaction gives rise to L-R parity violation in Moller scattering. The EW Lagrangian is [5]

$$\mathfrak{L} = eA_\mu\bar{\psi}\gamma^\mu\psi - gZ_\mu\bar{\psi}\gamma^\mu(c_V + c_A\gamma_5)\psi$$

Aa a result, helicity amplitude squared for certain polarized initial and final state takes the following structure, where $\beta = \frac{\sqrt{2}G_F}{e^2}$ and $c_{R,L} = c_V \pm c_A$ [6]

$$|\mathfrak{M}^2| = 4e^4 \times$$

$I \backslash F$	RR	RL	LR	LL
RR	$\frac{s^4}{u^2t^2} + \beta\frac{4s^3}{ut}c_{RR}$	0	0	0
RL	0	$\frac{u^2}{t^2} - \beta\frac{2u^2}{t}c_{RL}$	$\frac{t^2}{u^2} - \beta\frac{2t^2}{u}c_{RL}$	0
LR	0	$\frac{t^2}{u^2} - \beta\frac{2t^2}{u}c_{RL}$	$\frac{u^2}{t^2} - \beta\frac{2u^2}{t}c_{RL}$	0
LL	0	0	0	$\frac{s^4}{u^2t^2} + \beta\frac{4s^3}{ut}c_{LL}$

σ_{RR}, σ_{LL} → A_{RR-LL}; σ_R, σ_L → A_{R-L}

By measuring the L-R parity violation in Moller scattering, one can precisely measure the electroweak mixing angle $sin^2(\theta_W)$[6]

$$A_{R-L} = \frac{d\sigma_R - d\sigma_L}{d\sigma_R + d\sigma_L} = \frac{s}{\sqrt{2}\pi}\frac{G_F}{\alpha}\cdot\left[\frac{s^2ut}{u^4 + t^4 + s^4}\right]\cdot(4sin^2\theta_W - 1)$$

$$A_{RR-LL} = \frac{\sigma_{RR} - \sigma_{LL}}{\sigma_{RR} + \sigma_{LL}} = \frac{s\,G_F}{\sqrt{2}\pi\alpha}\left[\frac{ut}{s^2}\right](4sin^2\theta_w - 1)$$

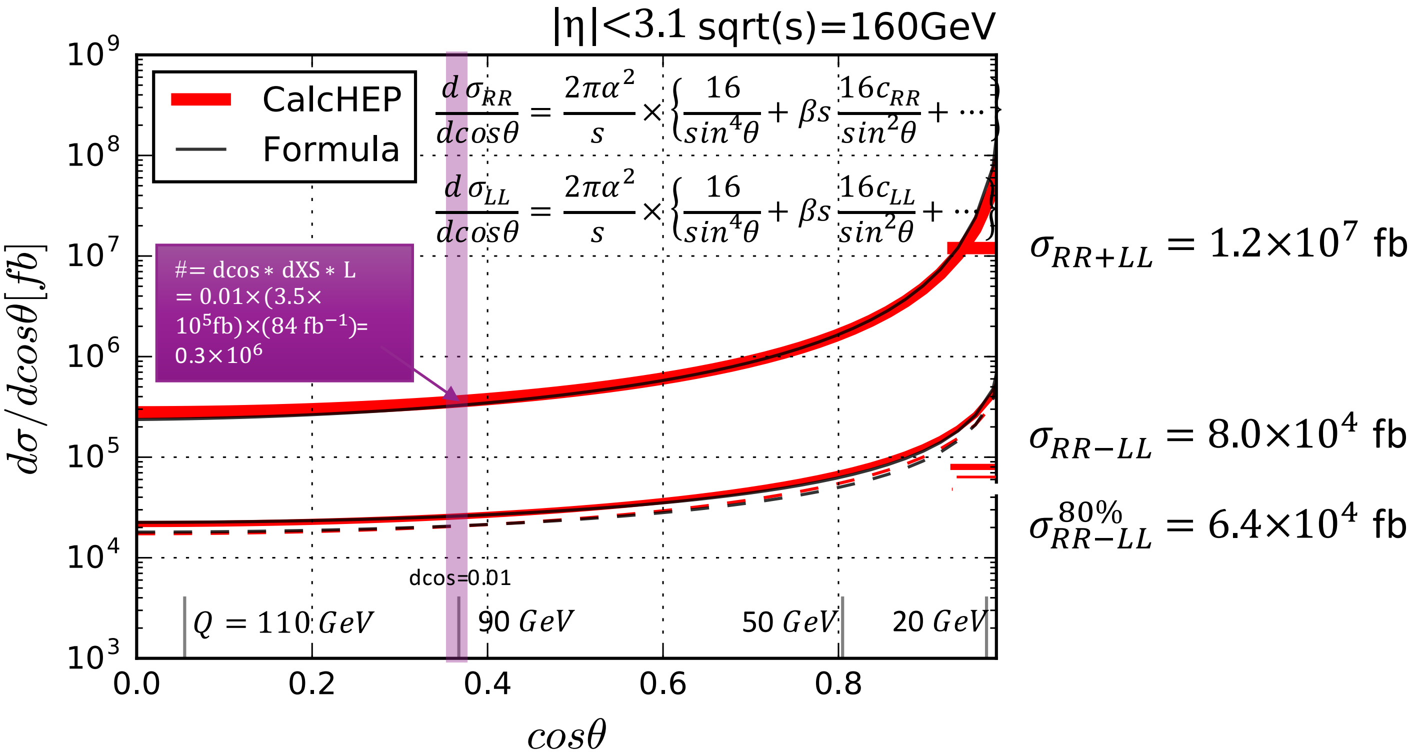
1. $\sin^2(\theta_W)$ in Moller Scattering

$$\frac{d\sigma}{d\cos\theta} = \frac{2\pi\alpha^2}{s} \times$$

$I \backslash F$	RR	RL	LR	LL
RR	$\frac{s^4}{u^2t^2} + \beta\frac{4s^3}{ut}C_{RR}$	0	0	0
RL	0	$\frac{u^2}{t^2} - \beta\frac{2u^2}{t}C_{RL}$	$\frac{t^2}{u^2} - \beta\frac{2t^2}{u}C_{RL}$	0
LR	0	$\frac{t^2}{u^2} - \beta\frac{2t^2}{u}C_{RL}$	$\frac{u^2}{t^2} - \beta\frac{2u^2}{t}C_{RL}$	0
LL	0	0	0	$\frac{s^4}{u^2t^2} + \beta\frac{4s^3}{ut}C_{LL}$

	$\lvert\eta\rvert<3.1$, 5 degree	
σ_{RR}	6.20×10^6 fb	$\sigma_R \sim$ 5.90×10^6 fb
σ_{RL}	$5.60.\times10^6$ fb	
σ_{LR}	$5.60.\times10^6$ fb	$\sigma_L \sim$ 5.86×10^6 fb
σ_{LL}	6.12×10^6 fb	
$\sigma_{RR} + \sigma_{LL}$ $\sigma_R + \sigma_L$	1.23×10^7 fb	1.18×10^7 fb
# total evt *(L=84 fb^{-1} for RR,LL)*	1.03×10^9	0.99×10^9
σ_{RR}-σ_{LL} σ_R-σ_L	8.0×10^4 fb	4×10^4 fb
# A_{PV} evt *(L=84 fb^{-1} for RR,LL)*	6.7×10^6	3.4×10^6

1. $\sin^2(\theta_W)$ in Moller Scattering



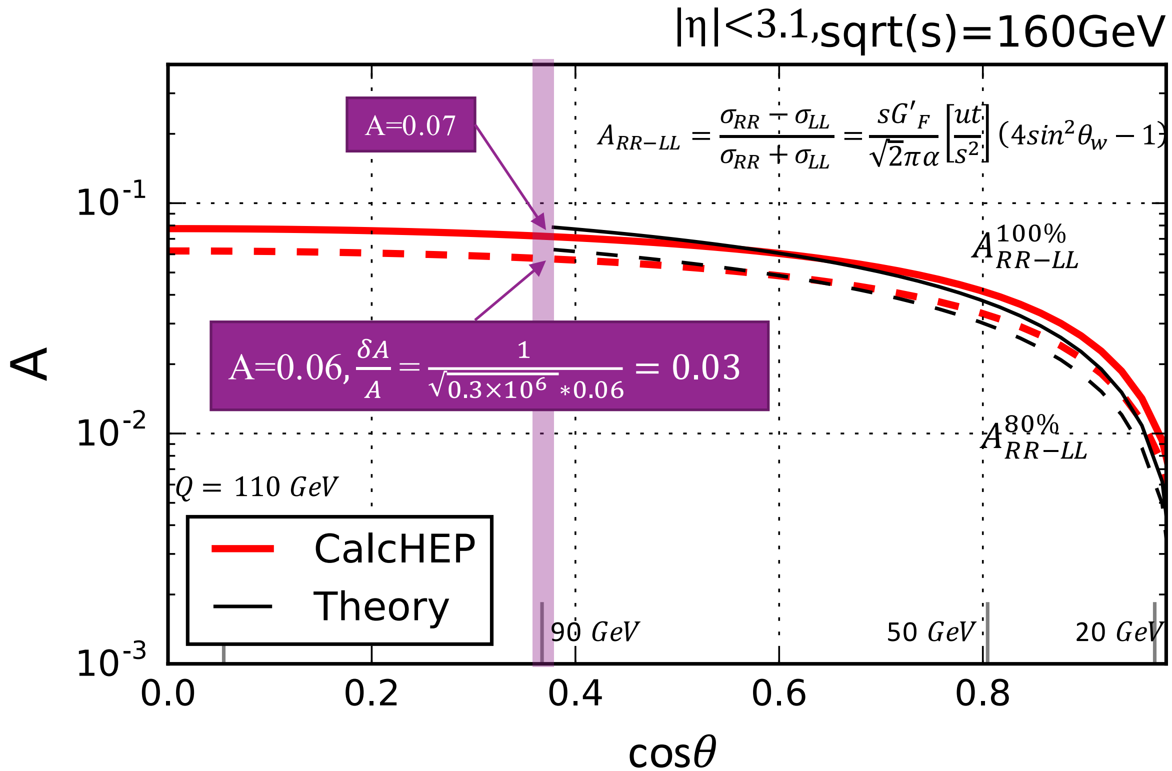
Using both polarized beam allows direct measurement of σ_{RR-LL} which doubles the # of asymmetric events, comparing with single polarized beam ($\sigma_R - \sigma_L$)

$\sigma_{RR-LL} = \sigma_{RR} - \sigma_{LL} = 2(\sigma_{RR} + \sigma_{RL})/2 - 2(\sigma_{LR} + \sigma_{LL})/2 = 2(\sigma_R - \sigma_L)$

Considering polarization efficiency, a right hand beam has actually Q right-hand component, polarization efficiency P=Q-(1-Q)=2Q-1. the observable asymmetric has a **factor of P** comparing with perfect polarization

$\sigma^P_{RR-LL} = (Q^2\sigma_{RR} + 2Q(1-Q)\sigma_{RL} + (1-Q)^2\sigma_{LL})-(Q^2\sigma_{LL} + 2Q(1-Q)\sigma_{RL} + (1-Q)^2\sigma_{RR}) = P\sigma_{RR-LL}$

1. $\sin^2(\theta_W)$ in Moller Scattering



Estimate the uncertainty of A

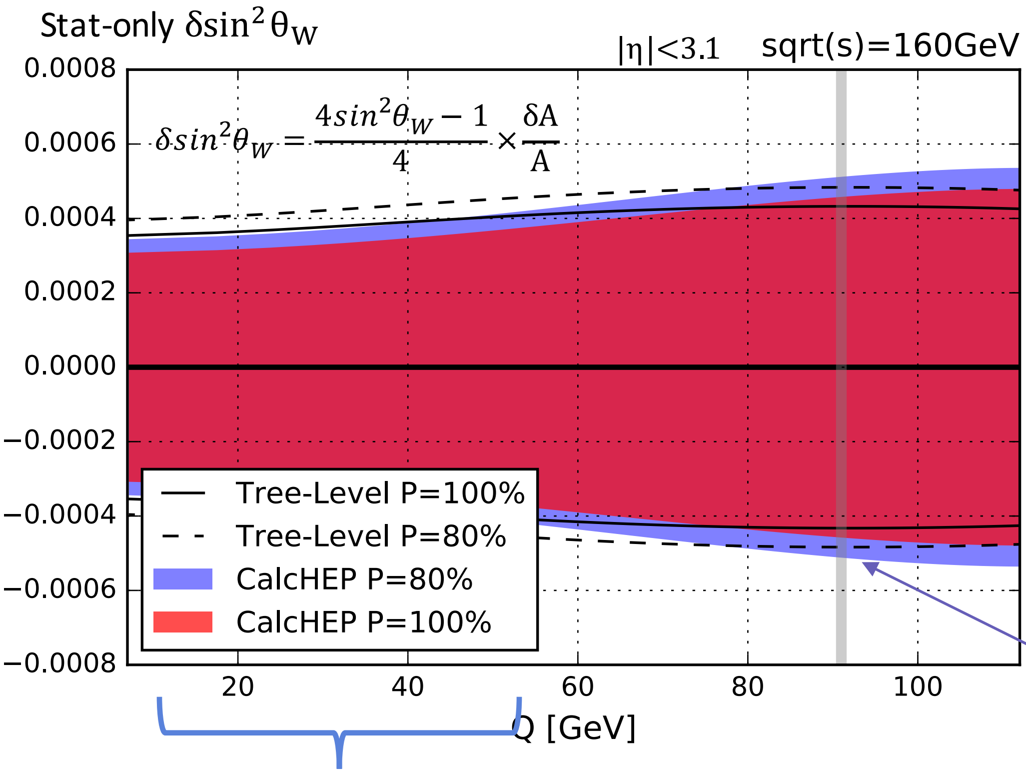
Twice larger oberserved Asymmetry: $A_{RR-LL} = \frac{N_{RR}-N_{LL}}{N_{RR}+N_{LL}} \sim 2A_{R-L} = 2*\frac{N_R-N_L}{N_R+N_L}$

Estimate the uncertainty of A:

$$(\delta A)^2 = \left(\frac{\partial A}{\partial N_{RR}}\right)^2 N_{RR} + \left(\frac{\partial A}{\partial N_{LL}}\right)^2 N_{LL} = \frac{4N_{RR}N_{LL}}{(N_{RR}+N_{LL})^3} = A\frac{1}{N_{RR}-N_{LL}}$$

$$\frac{\delta A}{A} = \frac{1}{\sqrt{N_{RR}-N_{LL}}}\frac{1}{\sqrt{A}} = \frac{1}{A\sqrt{\#}}$$

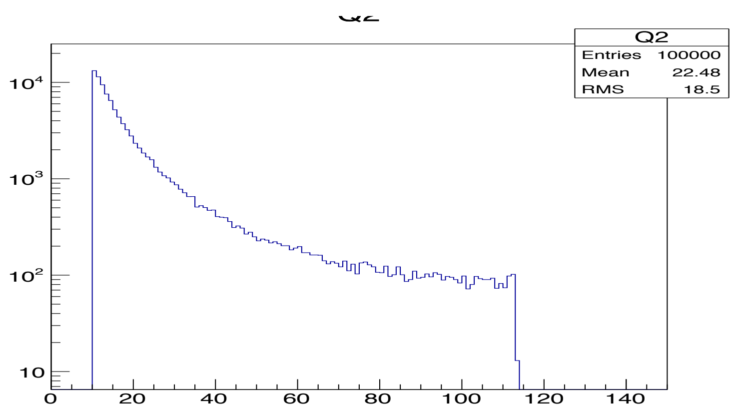
1. $\sin^2(\theta_W)$ in Moller Scattering



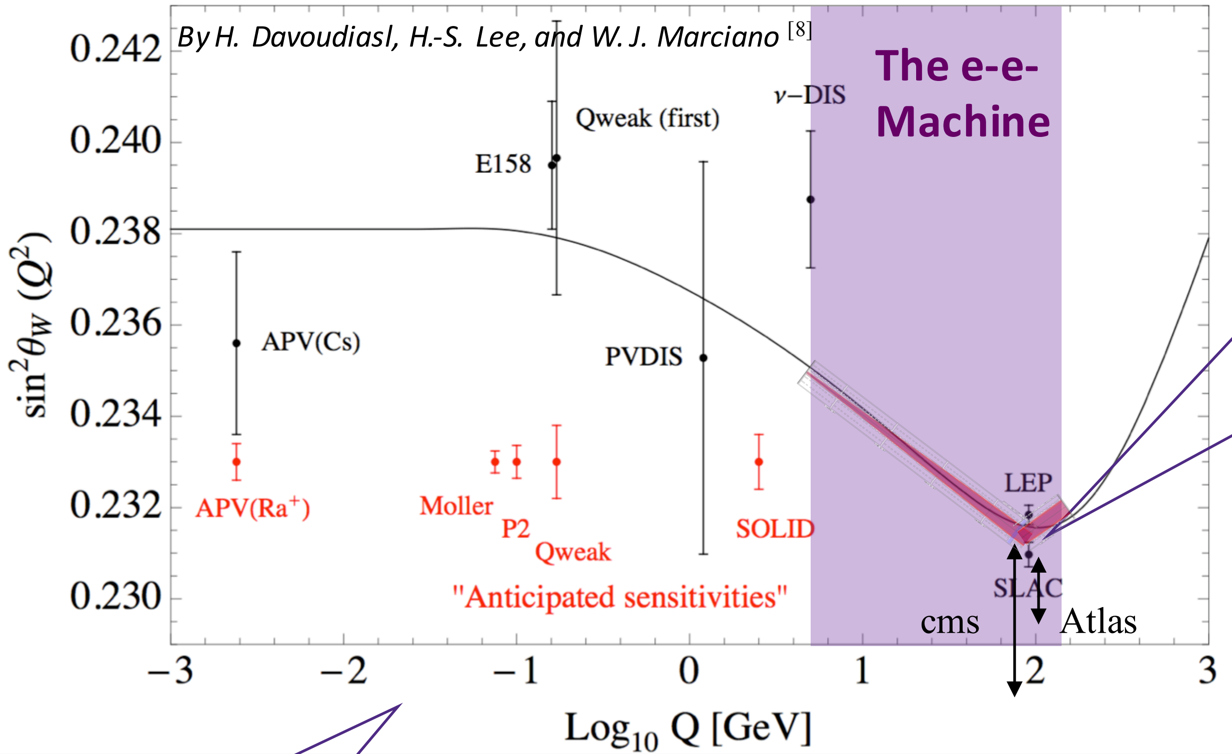
Considering Polarization, with $L = 84\ fb^{-1}$ for both LL-RR and $|\eta|<3.1$. At Z-pole the statistical uncertainty for mixing angle $\sin^2\theta_W$ can be estimated

- Number of events $\# = dcos * dXS * L = 0.01\times(3.5\times10^5 fb)\times(84\ fb^{-1}) = 0.3\times10^6$ and left-right asymmetry $A=\frac{\sigma_{RR}-\sigma_{LL}}{\sigma_{RR}+\sigma_{LL}}=0.06$:
  - $\frac{\delta A}{A}=\frac{1}{A\sqrt{\#}}=0.03$
  - **Stat**: $\delta\sin^2\theta_W = \frac{4\sin^2\theta_W-1}{4}\times\frac{\delta A}{A}=$**0.0005**
  - If $\# = 1.2\times10^6$, $\delta\sin^2\theta_W=$**0.00025**

Small stat-uncertainty in low-Q due to high cross section



1. $\sin^2(\theta_W)$ in Moller Scattering



LEP A_{FB} 0.23193(29)
SLAC A_{RL} 0.23070(26)
3-sigma deviates ?

Good Average
Ex 0.23125(15)
Th 0.23124(12)
Constrain New physics

1.8-sigma discrepancy between experiements and theory. Why?

1. $\sin^2(\theta_W)$ in Moller Scattering

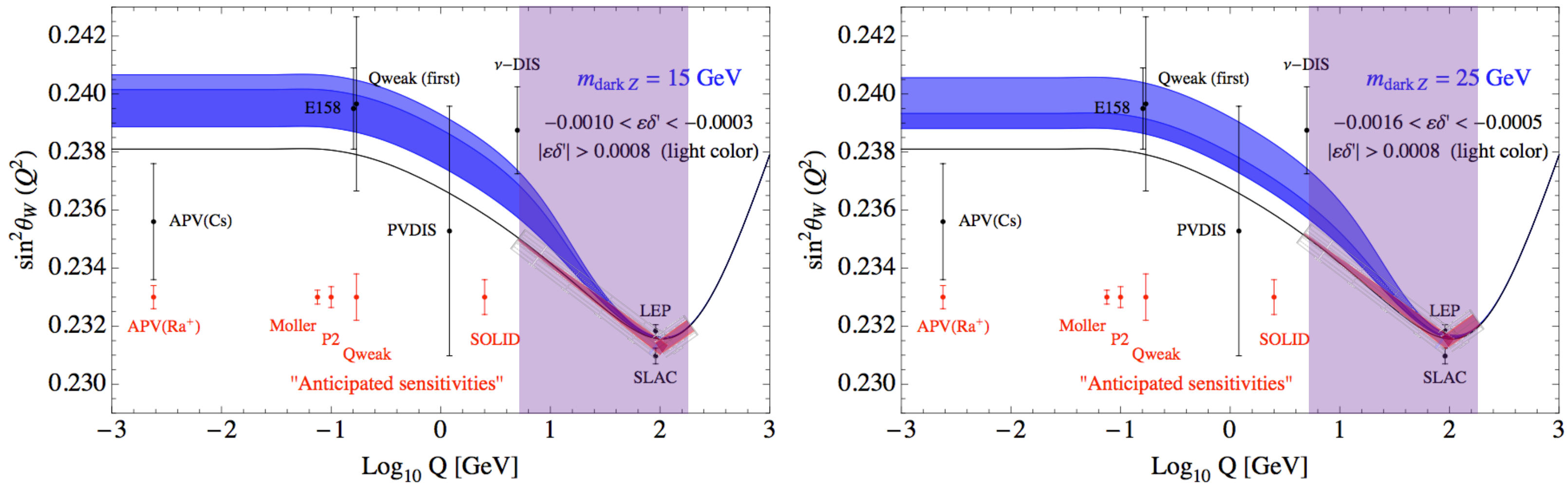
A possible new physics fitting the constrain and fixing the 1.8-sigma discrepancy is coupling between dark photon Z' with fermion via kinematic and mass mixing[8]

$$\mathcal{L}_{\text{int}} = (-e\varepsilon J^{em}_{\mu} - \frac{g}{2\cos\theta_W}\frac{m_{Z_d}}{m_Z}\delta' J^{NC}_{\mu} + \ldots)Z^{\mu}_{d}$$

Where constrain on kinematic mixing from Br(Z'→ll) is $|\epsilon| < 0.04$

And constrain on mass mixing is $|\delta'| < 0.02$ [8]

By H. Davoudiasl, H.-S. Lee, and W. J. Marciano[8]



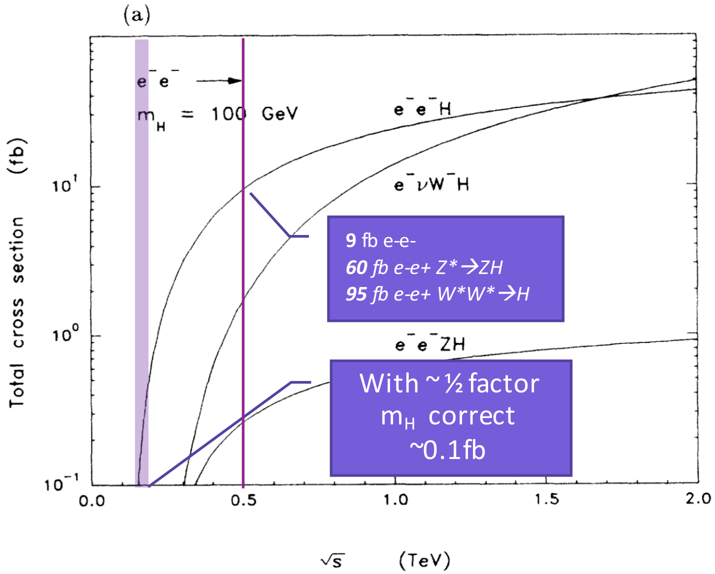
(a) (b)

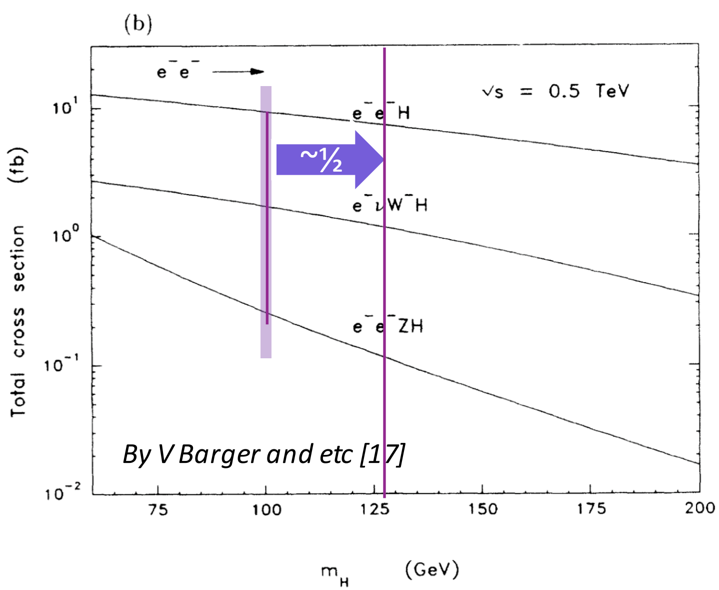
Blue -- 1-sigma region indicated by experiments.

Dark Blue -- constrain allowed region in Z' model while 1-sigma region of experiments.

Black line -- SM prediction

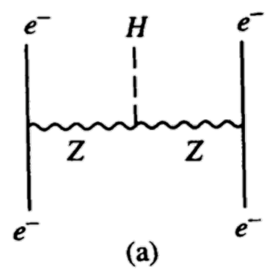
2. SM Boson Production and WW Scattering





What if particles other than e- are observed?

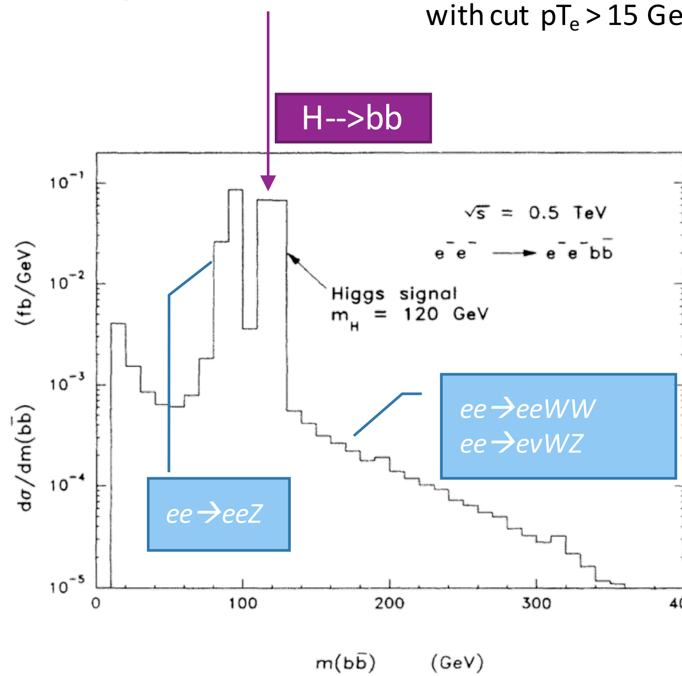
SM production of Higgs boson in e-e- collider



The Higgs production with m_H=125GeV is about

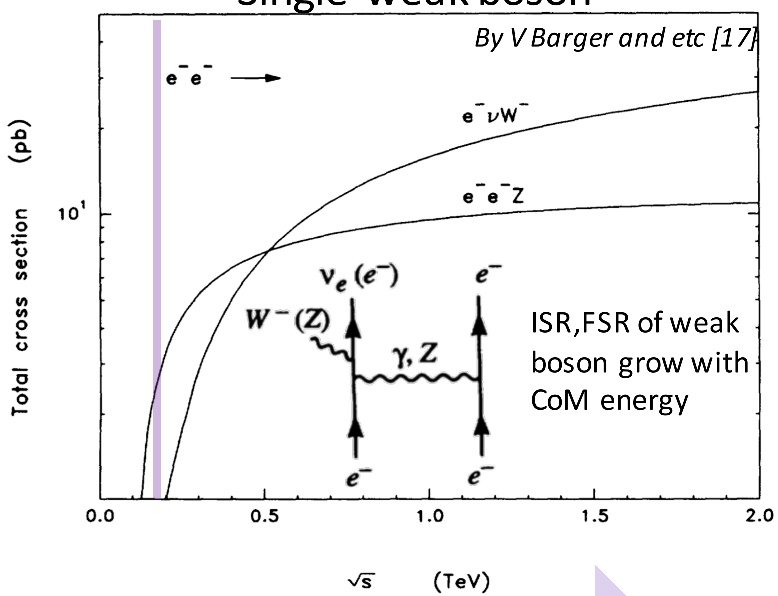
- 0.2/2 fb at $\sqrt{s} = 160$ GeV,
- 9/2 fb at $\sqrt{s} = 500$ GeV
- 1.4/2 fb at $\sqrt{s} = 500$ GeV

with cut $pT_e > 15$ GeV, $|\cos\theta_e| < 0.966$



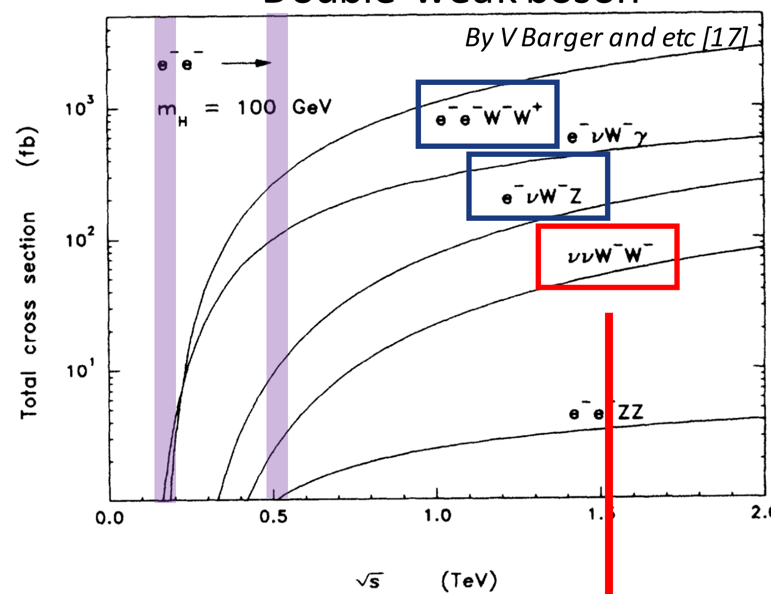
SM production of weak boson in e-e- collider

Single weak boson

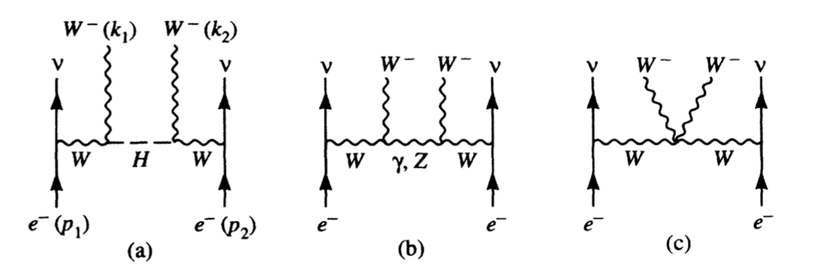


ISR,FSR of weak boson grow with CoM energy

Double weak boson

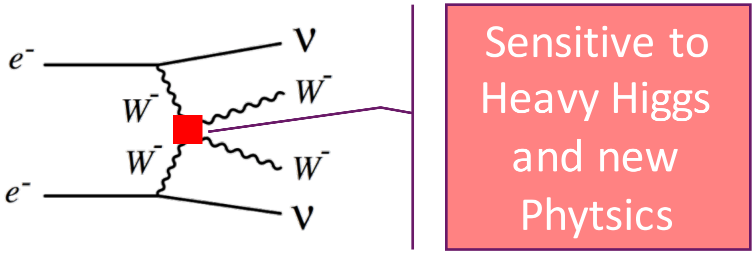


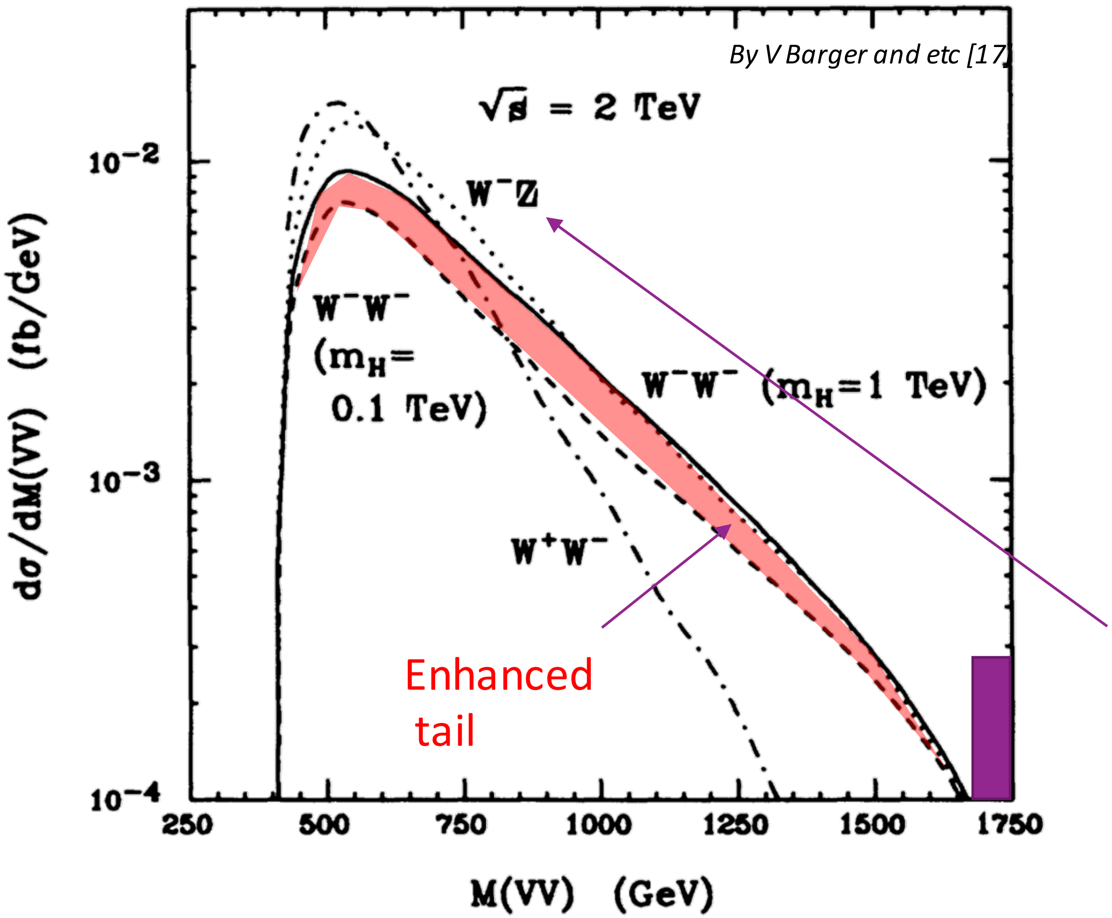
Heavy TeV Higss → Enhance WW scattering → Enhance cross section ee→vvWW



This process are interesting!

2. SM Boson Production and WW Scattering





- **Study by V. Barger shows**

$$\Delta\sigma = \sigma_{WW}^{m_H=1\ TeV} \text{-} \sigma_{WW}^{SM}$$
$$= 2.7\ fb \text{ at } \sqrt{s} = 1.5\ TeV$$
$$= 4.5\ fb \text{ at } \sqrt{s} = 2.0 TeV$$

- **Kinematic Cut**

$p_T W > 150$GeV, $|\cos\theta w| < 0.8$
$E_e > 50$ GeV, $|\cos\theta e| < 0.989$
50GeV < $p_T VV$ < 300 GeV
$\Delta p_T VV > 400$ GeV

- Observe TeV level Higgs via W-W- scattering. The mass spectrum of two vector boson VV will have an enhanced tail.

- This enhancement can be better observed if Z background can be separated from W, which allows lower CoM energy $\sqrt{s}$

3. Majorana Neutrino

Why neutrino have mass? Why left-handed only?

Massive self-conjugate Right-handed neutrinos do not talk to other SM particles but only left handed partners . Adding them breaks L symmetry and generate mass.

$$L_{\nu}^{mass} = -\overline{\nu_L} m_D \nu_R - \frac{1}{2}\overline{\nu_R^c} m_M \nu_R + h.c$$

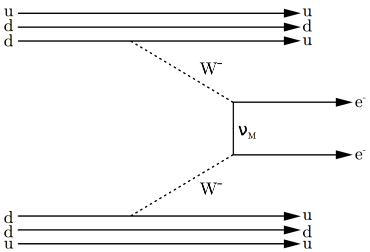
Mass eigenstates gives 3 lighter and 3 heavier Majorona neutrinos, [3]

$$M_{\upsilon} = \frac{m_D^2}{m_M}, \quad M_N = m_M$$

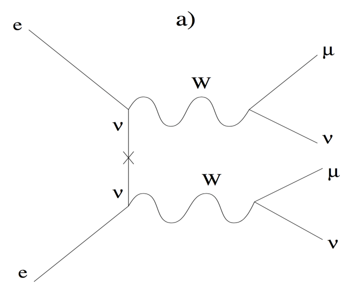
Expressing the weak eigenstates in the charged current by the corresponding mass eigenstates *e-e- → W-W- or W-W- →e-e-* is governed by the interaction Lagrangian, where the weak interaction coeff $U_{eN} = \frac{m_D}{m_M}$

$$L_{W e\nu, W eN} = \frac{g}{\sqrt{2}} \left(\sum_{\nu} \bar{e}\gamma_{\mu} L U_{e\nu} \nu + \sum_{N} \bar{e}\gamma_{\mu} L U_{eN} N \right) W^{\mu}$$

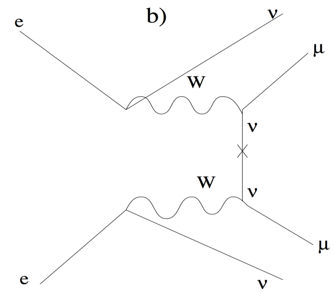
3. Majorana Neutrino



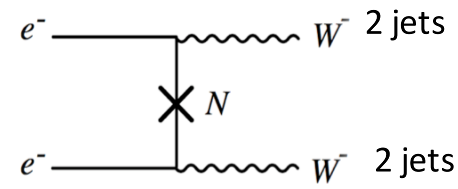
$0\nu\beta\beta$



Two On-shell W



Virtual W



Two On-shell W to 4 jets

Radioactive Isotope | Lepton Channel | Hadron Channel

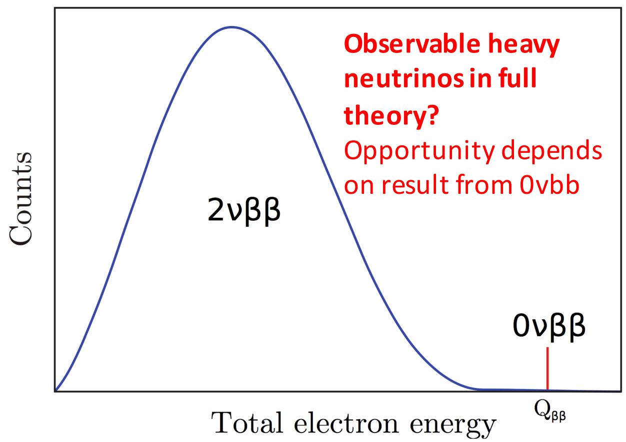
Cross section of LNV $\sigma \propto \left[\frac{U_{eN}^2}{M_N}\right]^2 \propto \left[m_{\beta\beta}\right]^2$, the larger M_N is, the smaller cross section get suppressed. Constrain on the two parameters m_D and m_M (or U_{eN}^2 and M_N) comes from [3]

- No left-handed Majorana term in theory: $\sum M_\upsilon U_{e\nu}^2 + \sum M_N U_{eN}^2 = 0$
- Charged current universality $U_{eN}^2 < 0.004$
- The non-observation of neutrinoless double beta decay, neutrino oscillation and cosmological survey constrain effective majorana mass [3]

$$m_{\beta\beta} = \sum_\nu U_{e\upsilon}^2 M_\upsilon < eV$$

3. Majorana Neutrino

by C. Greub and etc [3]



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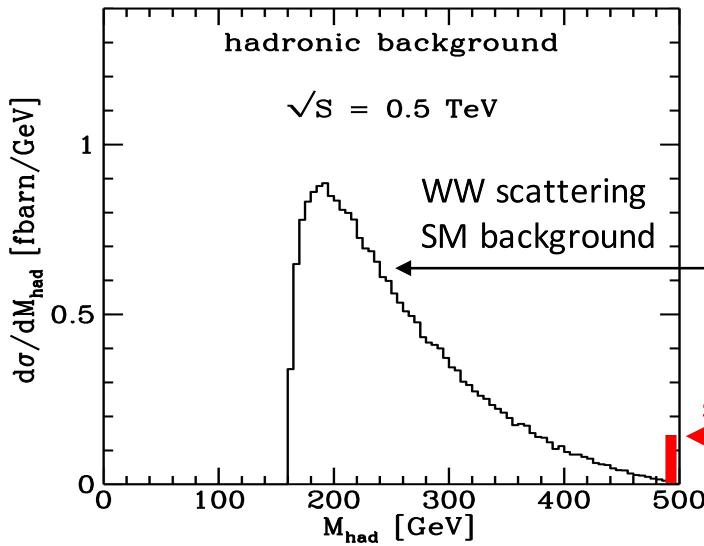
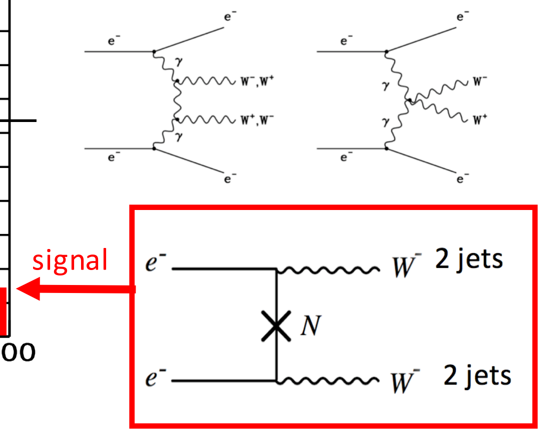
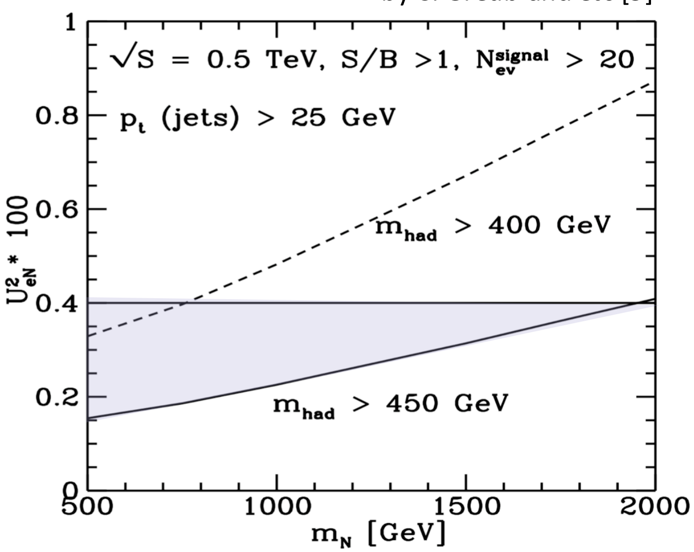


Hadron Channel



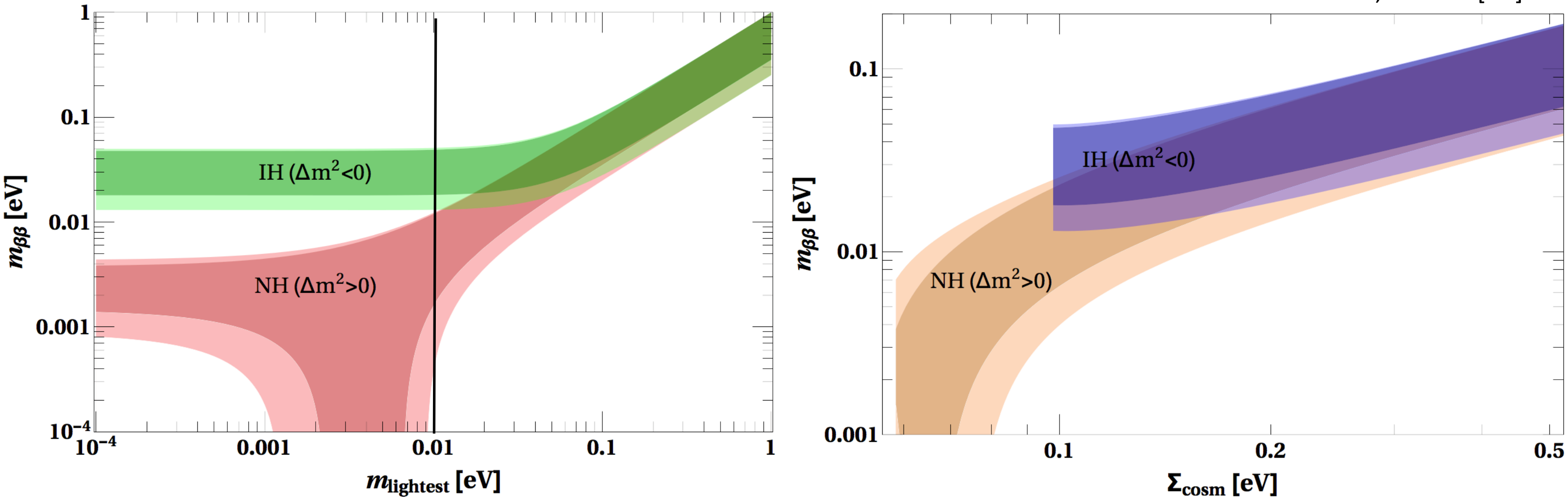
by C. Greub and etc [3]



- Search few TeV level m_N
- Similar to neutrinoless double beta decay, in hadron channel one can search for a bump on tail of Mass_4jets .
- Signal can be observed with 500 GeV CoM energy, if M_N <2 TeV [3] . But not sensitive enough for heavier mass scale.
- Note that the shape of WW scattering SM background can be used to probe new physics too

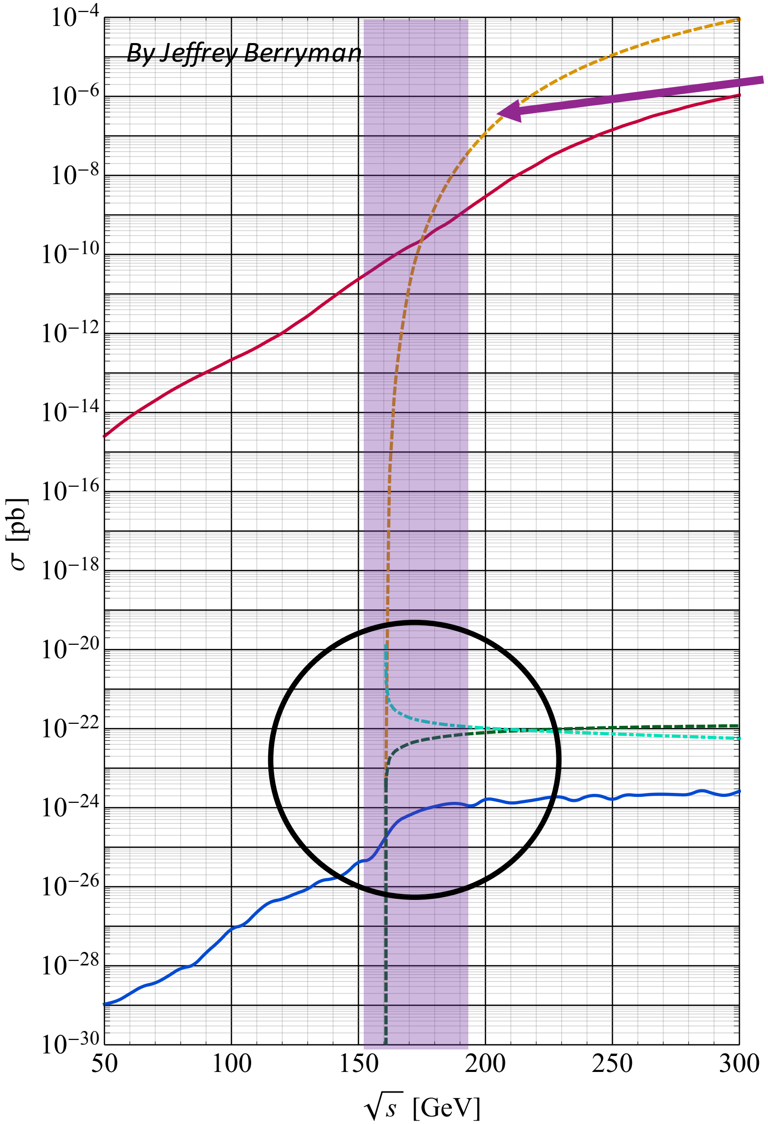
3. Majorana Neutrino

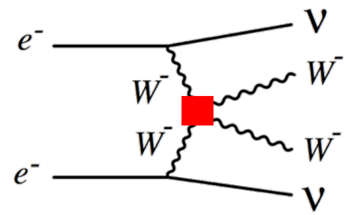
Stefano Dell'Oro, and etc [18]



Constrain on $m_{\beta\beta}$ from neutrino oscillation and cosmological survey. [18] Assuming $m_{linghtest} = 0.01\ eV$ and taking the max of $m_{\beta\beta} = 0.01\ eV$, choosing a mass scale for heavy neutrino M_N, one can calculate the cross section for LNV weak process. In order to calculate cross section with effective lagrangian (0.1 eV seasaw light neutrino but heavy neutrino is integrated out), one need to take $m_D \sim$ weak scale and $m_M \sim 10^9$ TeV. This significantly suppresses NLV

3. Majorana Neutrino



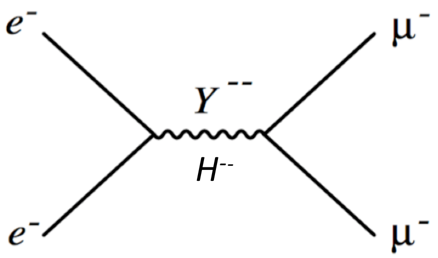


Lepton Channel

- ❖ BSM model assumption
  - Effective theory, N is integrated over.
  - $m_D \sim M_Z$. The lightest neutrino mass is 0.1 eV
  - The hierarchy is normal. Best fit the oscillation result.
  - The PMNS and Majorana CP-violate phase are zero.
- ❖ Around CoM = 160 GeV, two on-shell W threshold, Muon channel is very clean.
- ❖ SM: With luminosity of 84 fb^{-1}, one gets #=8×10^{-6} evet ~ 0 SM event.

4. Doubly Charged Boson

- In muon channel, SM predicts a relatively small background at $\sqrt{s}$=160 GeV. However Bilepton hypothesis predicts an observable cross section for dimuon production $e^-e^- \rightarrow \mu^-\mu^-$.No missing energy. Muons are both energetic. Dimuon mass = $\sqrt{s}$.

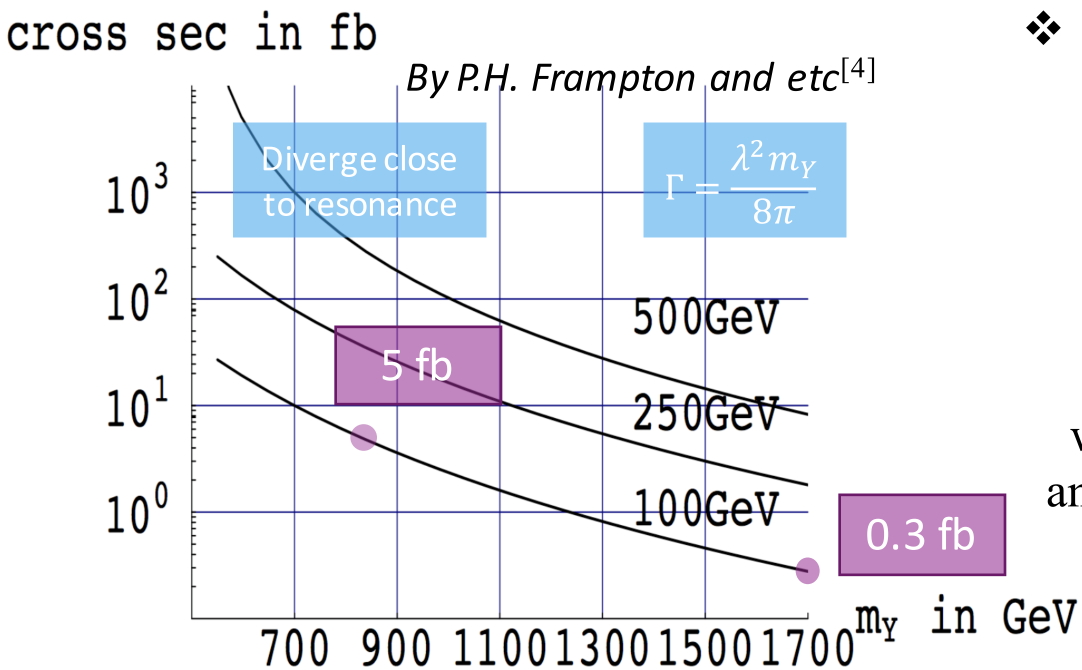


- A boson with lepton number ± 2, exists in a few models.
  - **Vector like** 3-3-1 model and SU(15) Grand Unification Model. Lower limit on $M(Y^{--})$ is ≥850 GeV [11]
  - **Scalar like** extended Higgs model.
    - T3=0: >438GeV ATLAS search for H++H−− production in 20.3 fb−1 of pp collisions at Ecm = 8 TeV. [15]
    - T3=+/-1: >551GeV ATLAS search for H++H−− production in 20.3 fb−1 of pp collisions at Ecm = 8 TeV[15]
    - The Lagrangian for Yukawa Coupling

$$L_Y = h_{R,ij} l^T_{iR} C\sigma_2 H_R l_{j,R} + h_{L,ij} l^T_{iL} C\sigma_2 H_L l_{j,L} + h.c.$$

    - The cross section is $\sigma = \frac{8\pi^2}{m_{H^{--}}} B_{ee} B_{ll} \Gamma_{H^{--}} \delta(s - m^2_{H^{--}})$
    - Requiring Higher energy ee collider, TeV levet to produce resonance. Depends on mass and mass width if off shell.

4. Doubly Charged Boson



- In 3-3-1 bilepton couples with leptons via the following Larangian [4]

$$\mathfrak{L}_Y = \lambda Y_\mu^{++} e^T C \gamma^\mu P_L e + \lambda^\dagger Y_\mu^{--} \bar{e} \gamma^\mu P_L C \bar{e}^T$$

The cross section for $e^- e^- \to \mu^- \mu^-$

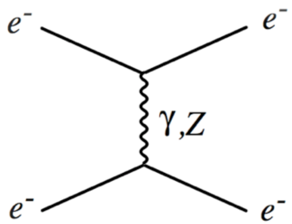
$$\frac{d\sigma}{dcos\theta} = \frac{\lambda^4}{32\pi}(1 + cos^2\theta)\frac{s}{(s - m_Y^2)^2 + m_Y^2 \Gamma_Y^2}$$

where coupling strength model is $\lambda = \frac{g}{\sqrt{2}}$
and total cross section is

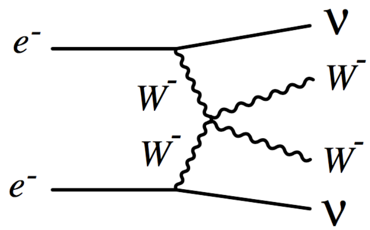
$$\sigma = \frac{\lambda^4}{24\pi} \frac{s}{(s - m_Y^2)^2 + m_Y^2 \Gamma_Y^2}$$

- If $m_Y = 1.7$ TeV, with luminosity=84 fb^{-1}, one expects 84 fb^{-1} x 0.3 fb = 25 events.
- If $m_Y = 850$ GeV, with luminosity=84 fb^{-1}, one expects 84 fb^{-1} x 5 fb = 420 events.
- One can reduce background by cutting off dimuon mass somewhere below CoM energy and only focus on the hard dimuon mass.

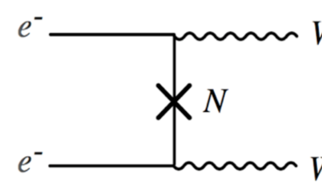
Conclusion



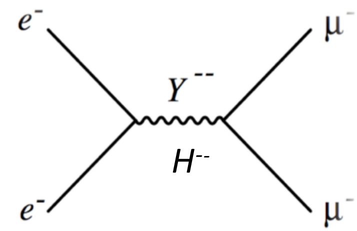
Parity Violation



WW scattering



Majorana Neutrino



Bilepton

- **Parity Violation** Moller scattering on electron-electron collider offers excellent chance to test the running of $\sin^2(\theta_W)$ from 7 GeV < Q < 112 GeV. Precise measuring the running of EW mixing angle to ~0.0002 offers good probe to Z' interaction.
- **WW scattering** Measuring the SM cross section for W,Z production in ee collider offers a good test of standard model. In addition, WW scattering provide an access to heavy Higgs. However ideal if higher energy 500 GeV.
- **Majorana Neutrino** If $M_N = m_M$ < 2 TeV, there can be a chance to observe a signal of Majorana neutrino. If m_D ~ 100 GeV, we do not have sensitivity.
- **Bilepton:** Even though 160 GeV ee machine does not produce a resonance of Y with >850 GeV or H >551 GeV, good news is the enhancement of muon pair production can be observable. Say 331 predicts 0.3 fb more cross section in $e^-e^- \to \mu^-\mu^-$

Thanks to Jeffrey Berryman, Andre Gouvea, Wei-Yee Keung, Jianping Chen

Reference

[1] W.-Y. Keung and L. Littenberg, "Test of supersymmetry in e- e- collisions," *Physical Review D*, vol. 28, no. 5, p. 1067, 1983.

[2] J. L. Feng, "Physics at ee-colliders," *International Journal of Modern Physics A*, vol. 15, no. 16, pp. 2355–2364, 2000.

[3] C. Greub and P. Minkowski, "Heavy majorana neutrinos in ee-collisions," *International Journal of Modern Physics A*, vol. 13, no. 14, pp. 2363–2381, 1998.

[4] P. H. Frampton and A. Rašin, "Seeking gauge bileptons in linear colliders," *Physics Letters B*, vol. 482, no. 1, pp. 129–133, 2000.

[5] M. E. Peskin, D. V. Schroeder, and E. Martinec, "An introduction to quantum field theory," 1996.

[6] E. Derman and W. J. Marciano, "Parity violating asymmetries in polarized electron scattering," *Annals of Physics*, vol. 121, no. 1-2, pp. 147–180, 1979.

[7] W. J. Marciano and A. Sirlin, "Precise su(5) predictions for $sin^2 \theta_W{}^{exp}$, m_W, and m_Z," *Phys. Rev. Lett.*, vol. 46, pp. 163–166, Jan 1981.

[8] H. Davoudiasl, H.-S. Lee, and W. J. Marciano, "Low q 2 weak mixing angle measurements and rare higgs decays," *Physical Review D*, vol. 92, no. 5, p. 055005, 2015.

[9] K. Kumar, S. Mantry, W. Marciano, and P. Souder, "Low-energy measurements of the weak mixing angle," *Annual Review of Nuclear and Particle Science*, vol. 63, pp. 237–267, 2013.

[10] C. Heusch and P. Minkowski, "Lepton-flavour violation induced by heavy majorana neutrinos," *Nuclear Physics B*, vol. 416, no. 1, pp. 3–45, 1994.

[11] L. Willmann, P. Schmidt, H. Wirtz, R. Abela, V. Baranov, J. Bagaturia, W. Bertl, R. Engfer, A. Grossmann, V. Hughes, *et al.*, "New bounds from a search for muonium to antimuonium conversion," *Physical Review Letters*, vol. 82, no. 1, p. 49, 1999.

[12] Chou, Weiren, Gerard Mourou, Nikolay Solyak, Toshiki Tajima, and Mayda Velasco. "HFiTT-Higgs Factory in Tevatron Tunnel." *arXiv preprint arXiv:1305.5202* (2013).

[13] J.F Gunion, Probing Lepton-Number-Violating Gouplings of Dobuley charged higss bosons at an e-e- cllider. Hep-hp/9510350, 1995

[14] Orhan Cakir, Production of Doubly charged Higgs Bosons at Linear e-e- colldiers., arXiv:hep-ph/0604183v3

[15] Particle Data Group, http://pdg.lbl.gov/2016/listings/contents_listings.html

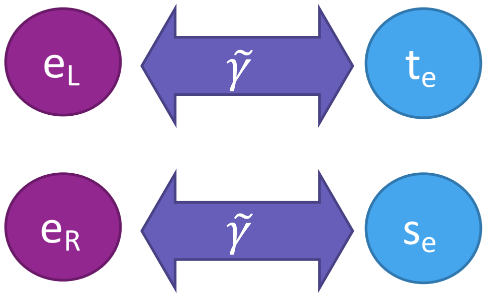
[16] A. Bodek ,Standard Model Precision Electroweak Measurements at HL-LHC and Future Hadron Colliders

[17] V Barger, J.F. Beacom, Kingman Cheung, T.Han, Production of weak bosons and Higgs bosons in e-e- collisions. 1994.

[18] Stefano Dell'Oro and etc, Neutrinoless double beta decay: 2015 review , 2016

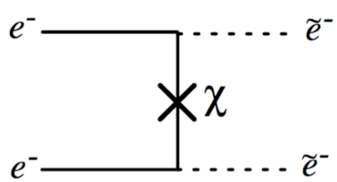
- backups

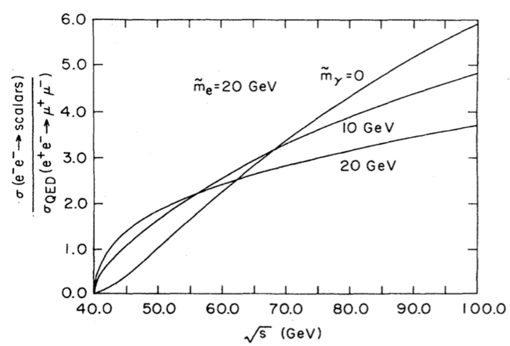
4. Selectron Pair production



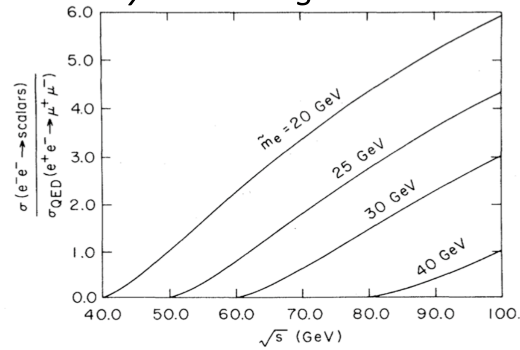
- Electron and selectron are connected by Majorana photino via interaction Lagrangian on the left.
- Selectron pair are produced on-shell via exchanging Majorana photino. Depends on the mass of photino and selectron. [1]

$$\mathscr{L}_{\text{int}} = -\sqrt{2}(\bar{e}_R t_e + \bar{e}_L s_e)\tilde{\gamma} + \text{H.c.}$$





By W.Y. Keung and etc [1]

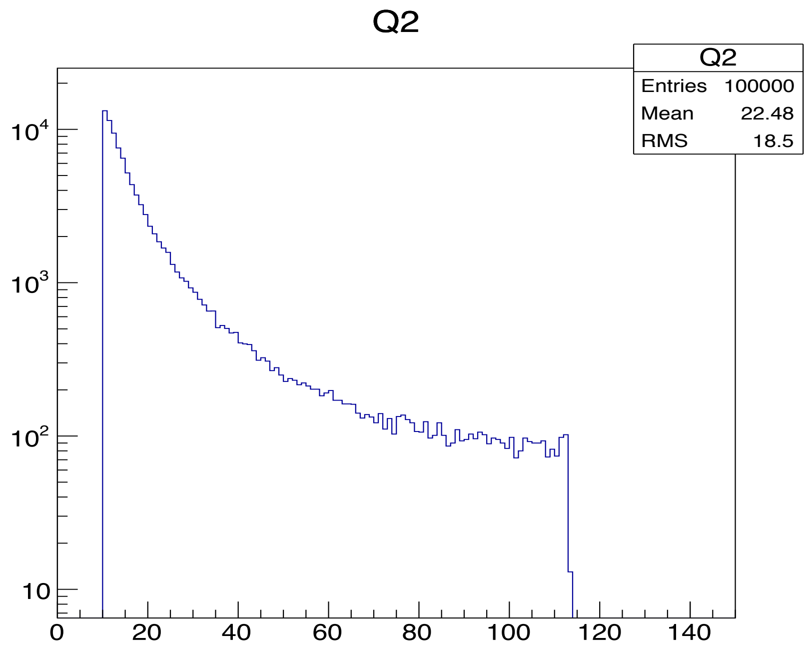


$$d\sigma(e_L^- e_R^- \to s_e t_e)/dt = 4\pi\alpha^2 s^{-2}(ut - \tilde{m}_e^{\,4})(t - \tilde{m}_\gamma^{\,2})^{-2},$$

$$d\sigma(e_R^- e_L^- \to s_e t_e)/dt = 4\pi\alpha^2 s^{-2}(ut - \tilde{m}_e^{\,4})(u - \tilde{m}_\gamma^{\,2})^{-2}.$$

$$d\sigma(e_L^- e_L^- \to s_e s_e)/dt = d\sigma(e_R^- e_R^- \to t_e t_e)/dt = (1/2!)4\pi\alpha^2 s^{-1}\tilde{m}_\gamma^{\,2}[(t - \tilde{m}_\gamma^{\,2})^{-1} + (u - \tilde{m}_\gamma^{\,2})^{-1}]^2.$$

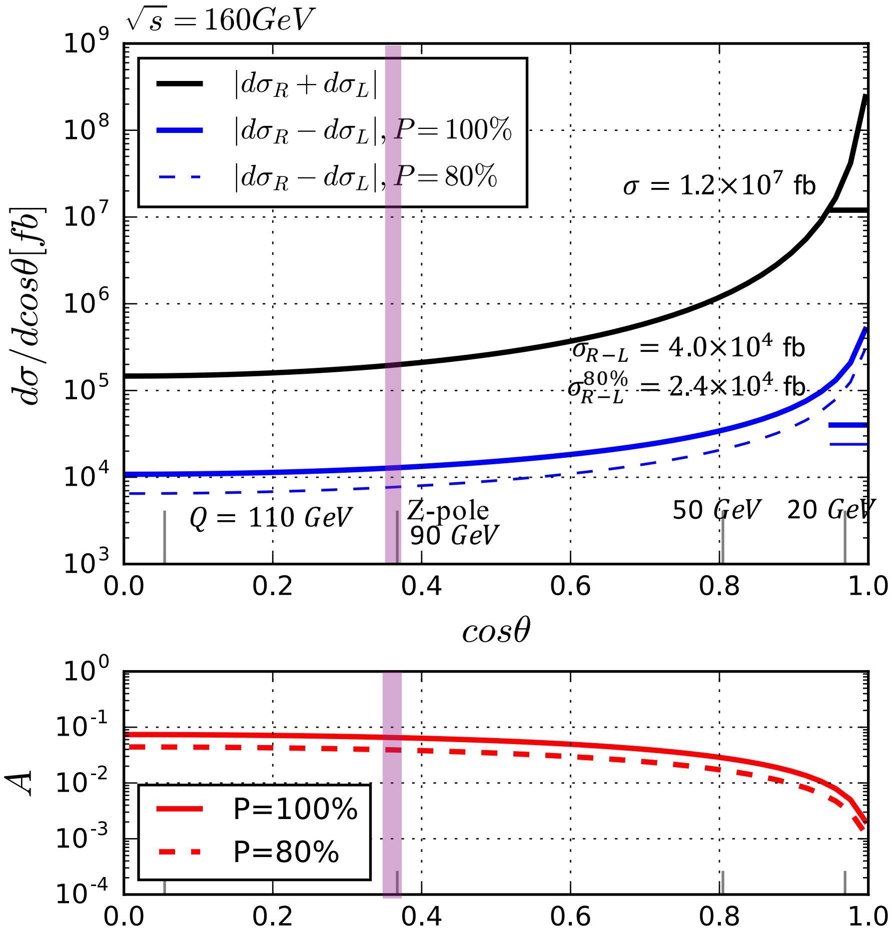
At SAPPHIRE



- **This machine at highest μ**
  - **A_{LR} based on 10^6 event**
  - **$\delta A_{LR} \sim 0.001$**
  - **Stat: $\delta \sin^2 \theta_W \sim 0.0002$**

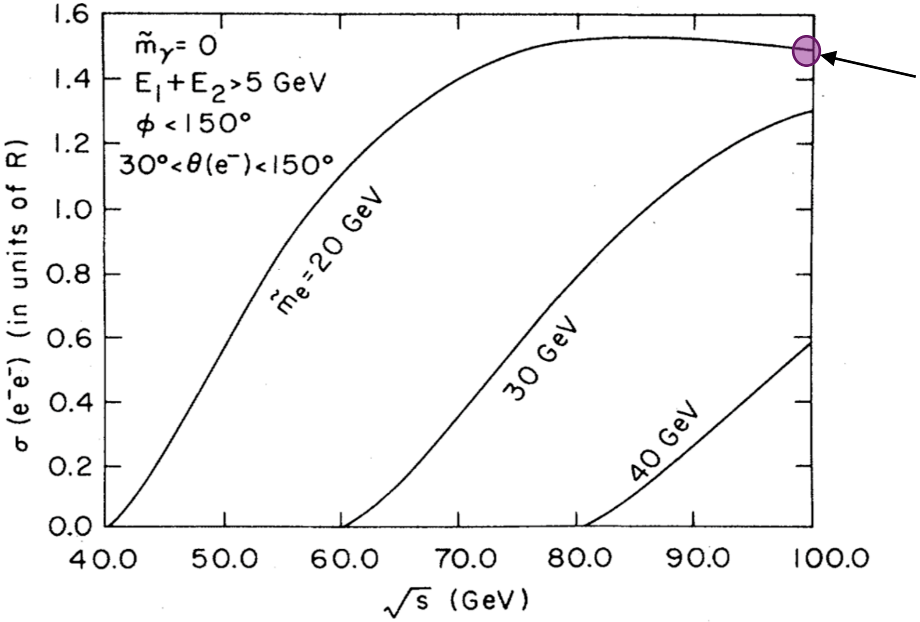
- **In addition to precise measurement of running down to 10 GeV**

1. A_{RL} and $\sin^2(\theta_W)$ in Moller Scattering

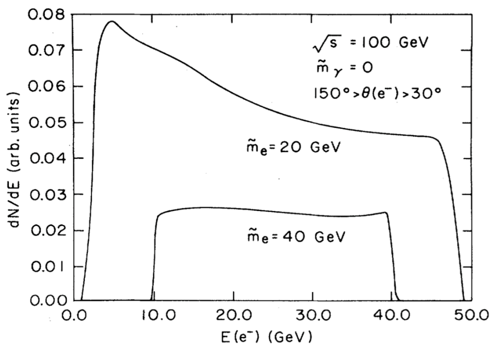


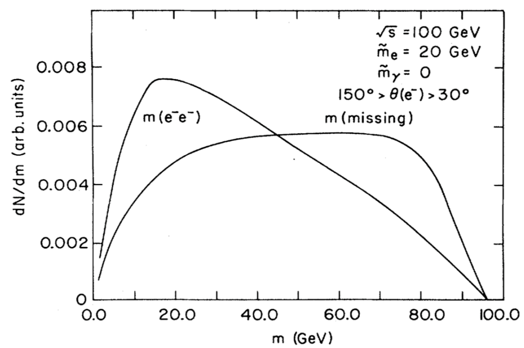
4. Selectron Pair production

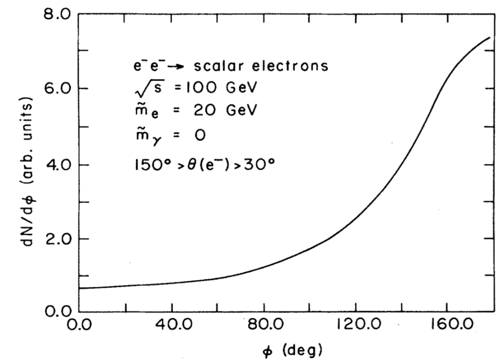
By W.Y. Keung and etc [1]



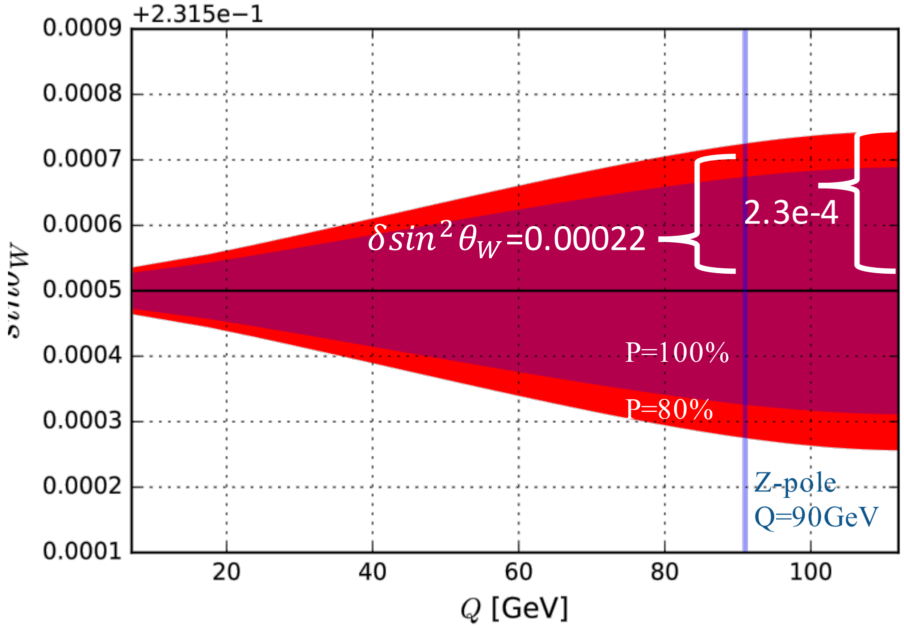
- Where $1R = 8.7\times10^3$ fb at CoM energy = 100 GeV
- With kinematic cut on the left σ=1.5R = 13.05×10^3 fb. 84 fb^{-1} luminosity gives #event = $\sigma\times L = 1.1\times10^6$
- Selectron decays into SM electrons and the lightest SUSY particles. The energy, Imass and $\Delta\phi$of these signel electrons from selectrons is distinct from background Moller electron.



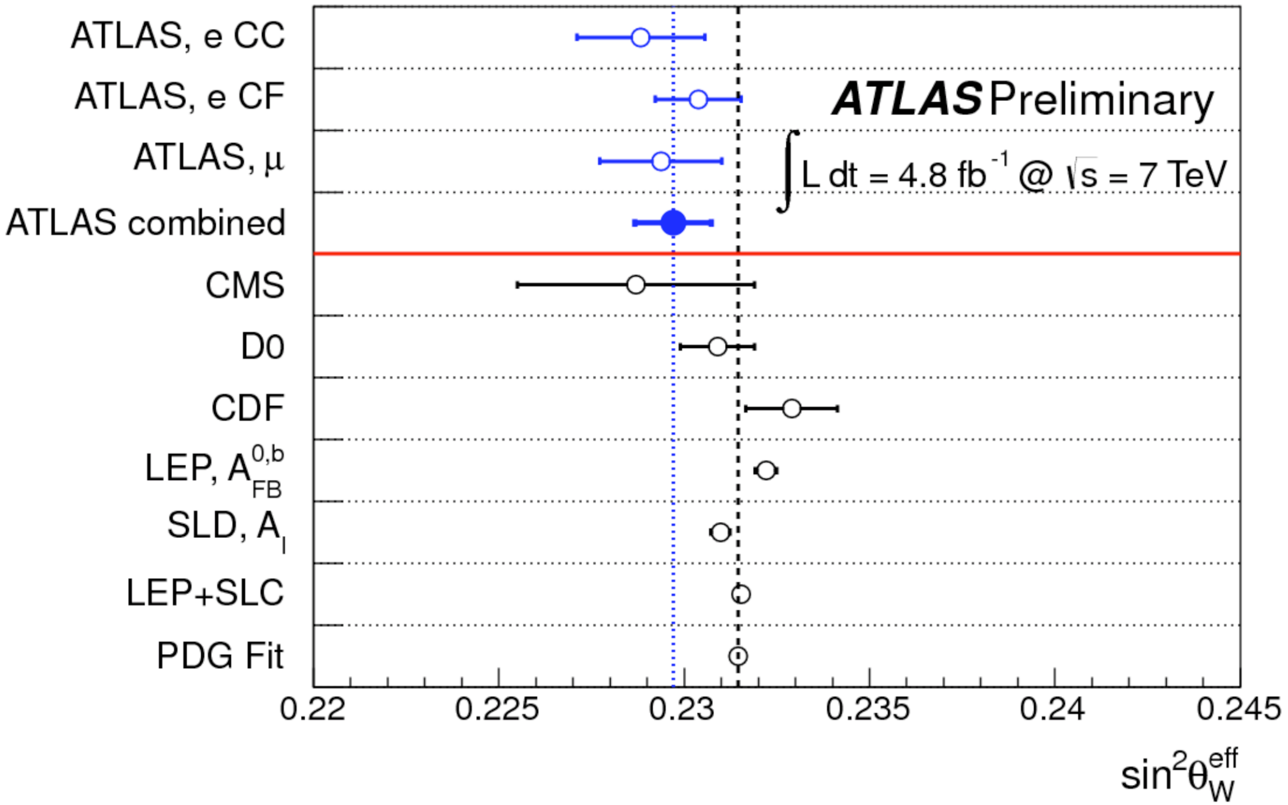




At Z-pole the statistical uncertainty for mixing angle $\sin^2\theta_W$ can be estimated.

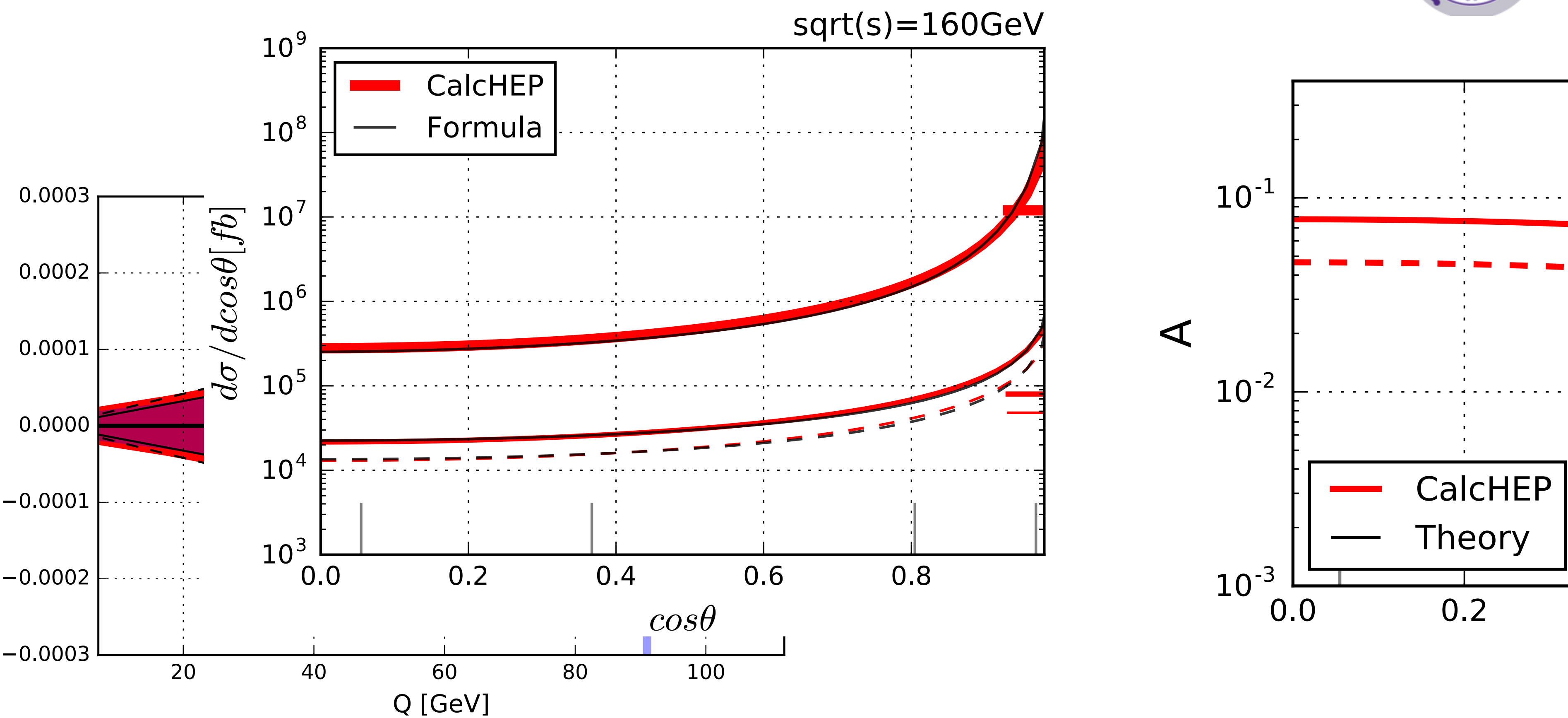


- Number of events $\# = dcos * dXS * L = 0.01\times(2.4\times10^5\,fb)\times(84\,fb^{-1}) = 0.2\times10^6$ and left-right asymmetry A=0.14:
  - $\frac{\delta A}{A} = \frac{1}{\sqrt{\#*A}} = 0.013$
  - $\delta\sin^2\theta_W = \frac{4\sin^2\theta_W - 1}{4} \times \frac{1}{\sqrt{\#*A}} = 0.00022$
- Number of events $\# = 1\times10^6$, and left-right asymmetry A=0.14:
  - $\frac{\delta A}{A} = \frac{1}{\sqrt{\#*A}} = 0.0057$
  - $\delta sin^2\theta_W = \frac{4sin^2\theta_W - 1}{4} \times \frac{1}{\sqrt{\#*A}} = 0.00010$
- Number of events $\# = 0.15\times10^6$, and left-right asymmetry A=0.14:
  - $\delta A = \frac{A}{\sqrt{\#*A}} = 0.0026$
  - $\delta sin^2\theta_W = \frac{4sin^2\theta_W - 1}{4} \times \frac{1}{\sqrt{\#*A}} = 0.00027$



CMS :
$\sin^2\theta_{eff}$ = 0.2287 ± 0.0020 (stat) ± 0.0025 (syst)

ATLAS :
$\sin^2\theta_{eff}$ = 0.2297± 0.0004(stat) ± 0.0009(syst)



sqrt(s)=160GeV
CalcHEP
Formula
$d\sigma/dcos\theta[fb]$
$cos\theta$
0.0003
0.0002
0.0001
0.0000
−0.0001
−0.0002
−0.0003
20
40
60
80
100
Q [GeV]
10^9
10^8
10^7
10^6
10^5
10^4
10^3
0.0
0.2
0.4
0.6
0.8
A
10^{-1}
10^{-2}
10^{-3}
CalcHEP
Theory

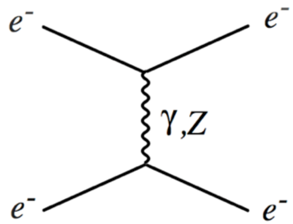
1. $\sin^2(\theta_W)$ in Moller Scattering

$$\frac{d\sigma}{dcos\theta} = \frac{2\pi\alpha^2}{s} \times$$

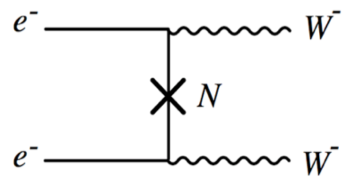
$I \backslash F$	RR	RL	LR	LL
RR	$\frac{s^4}{u^2 t^2} + \beta \frac{4s^3}{ut} c_{RR}$	0	0	0
RL	0	$\frac{u^2}{t^2} - \beta \frac{2u^2}{t} c_{RL}$	$\frac{t^2}{u^2} - \beta \frac{2t^2}{u} c_{RL}$	0
LR	0	$\frac{t^2}{u^2} - \beta \frac{2t^2}{u} c_{RL}$	$\frac{u^2}{t^2} - \beta \frac{2u^2}{t} c_{RL}$	0
LL	0	0	0	$\frac{s^4}{u^2 t^2} + \beta \frac{4s^3}{ut} c_{LL}$

	|η|<3.1, 5 degree		&& *pT>20 GeV*	
σ_{RR}	**6.20x10^6 fb**	$\sigma_R \sim$ 5.90x10^6 fb	**3.25x10^6 fb**	$\sigma_R \sim$ 2.99x10^6 fb
σ_{RL}	**5.60.x10^6 fb**		**2.73.x10^6 fb**	
σ_{LR}	**5.60.x10^6 fb**	$\sigma_L \sim$ 5.86x10^6 fb	**2.73.x10^6 fb**	$\sigma_L \sim$ 2.97x10^6 fb
σ_{LL}	**6.12x10^6 fb**		**3.21x10^6 fb**	
$\sigma_{RR} + \sigma_{LL}$ $\sigma_R + \sigma_L$	1.23x10^7 fb	1.18x10^7 fb	0.65x10^7 fb	0.60x10^7 fb
# total evt *(L=84 fb^{-1} for RR,LL)*	1.03x10^9	0.99x10^9	5.37x10^8	5.01x10^8
σ_{RR}-σ_{LL} σ_R-σ_L	8.0x10^4 fb	4x10^4 fb	~4.2x10^4 fb	2.1x10^4 fb
# A_{PV} evt *(L=84 fb^{-1} for RR,LL)*	6.7x10^6	3.4x10^6	~3.5x10^6	1.8x10^6

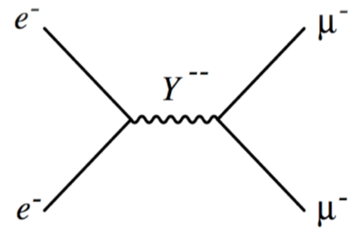
Outline



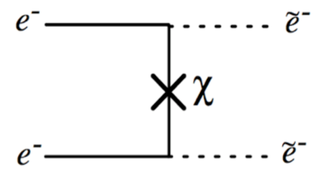
Parity Violation



Majorana Neutrino



Bilepton



SUSY

	LR Asymmetry	Majorana Neutrino	Bilepton	Selectron
Energy	$\sqrt{s}$ = 160 GeV	$\sqrt{s}$ = 160 GeV	$\sqrt{s}$ = 100 GeV	$\sqrt{s}$ = 100 GeV
Cross section	1.2×10^{7} fb	1×10^{-22} fb	5×10^{0} fb [4]	1.3×10^{4} fb [1]
Lunimosity	84 fb^{-1}	84 fb^{-1}	84 fb^{-1}	84 fb^{-1}
Signal	$\Delta\sigma_{R-L}= 2.4\times10^{4}$ fb	0 evt	420 evt	1.1×10^{6} evt
Search Channel	2-electron	2-muon, 4-jet (2 on-shell Ws)[3]	2-muon	2-electron
Model and Estimation Asumpiton	7 GeV<Q<112GeV $\lvert\eta\rvert < 3.1$ P=80%	Coupling mass mixing m_N = ? TeV m_υ = 0.1 eV	3-3-1 model Coupling $\lambda = \frac{g}{\sqrt{2}}$ m_Y = 850 GeV w/o phase cut for mu	$m_{\tilde{e}}$ = 20 GeV $m_{\tilde{\gamma}}$ = 0 GeV Coupling e with phase cut for e