SAPPHiRE Physics Case: Experiment e-e-, eγ and γγ colliders

Mayda M. Velasco

SAPPHiRE Day

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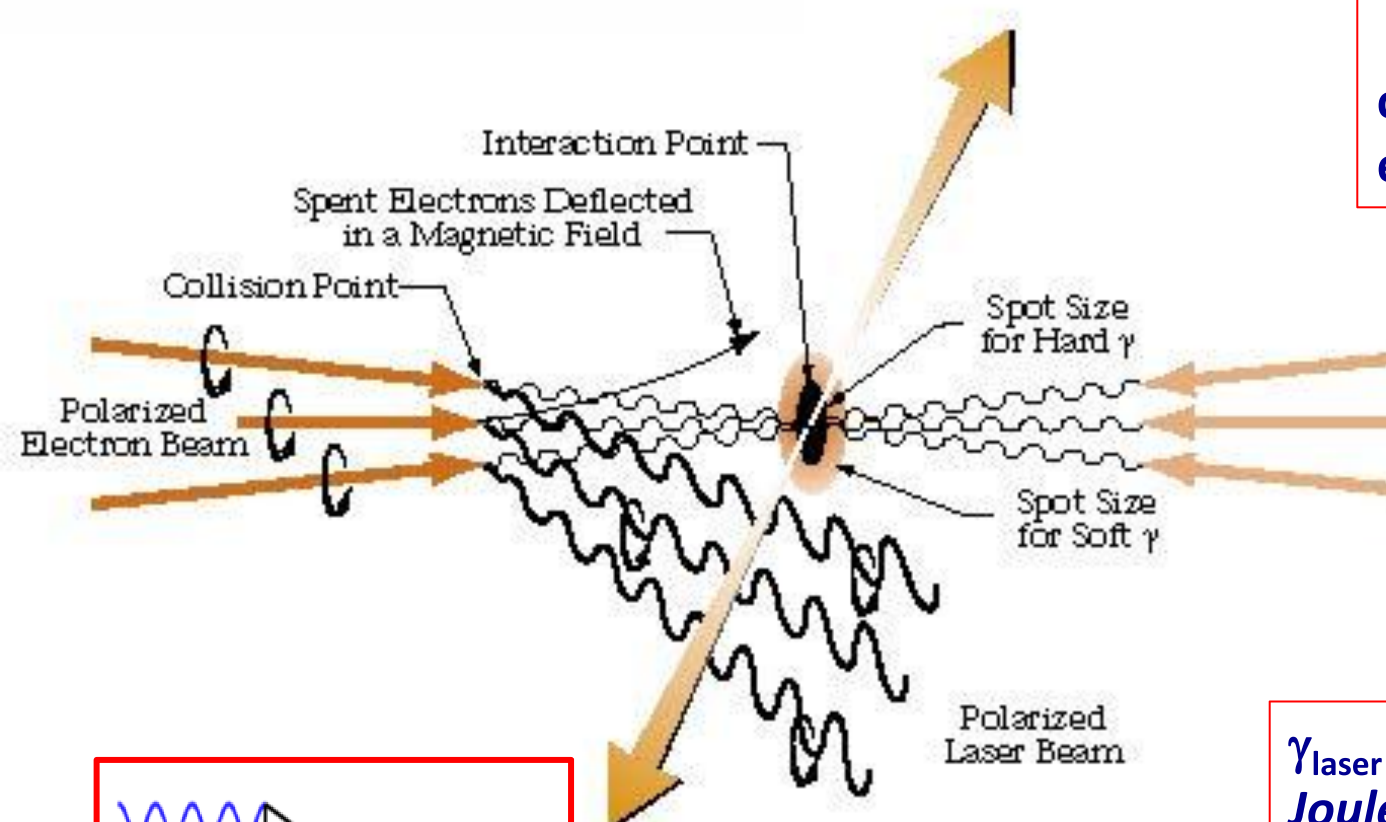
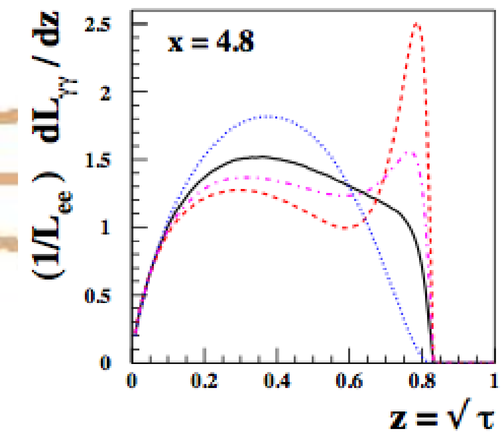
Technical facts and assumptions

- Starts from $e^- e^-$
  - Both beam can be polarized
  - We have never built a high energy e-e- collider
- Will need high power laser or FEL to generate high energy γ-beam ($e^{\square}\gamma_{laser} \rightarrow e^{\square}\gamma$) .
  - Main questions from our community, can this be done?
    ➔*Main topic of today's meeting*
  - Polarization of photon controlled from the polarization of the γ_{laser}
- Performance of the detector and beam environment not more difficult that what we are experiencing at the LHC

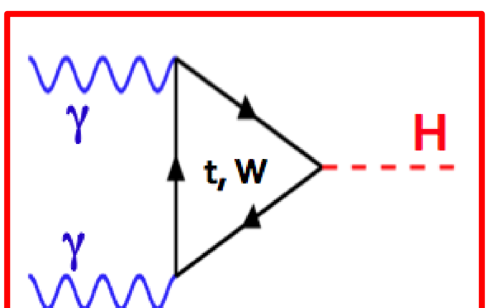
$\gamma\gamma$ collider based on $e^{-}e^{-}$



Compton scattering:
$e^{-}\gamma_{laser} \rightarrow e^{-}\gamma$
can transfer 80% of e- energy to γ



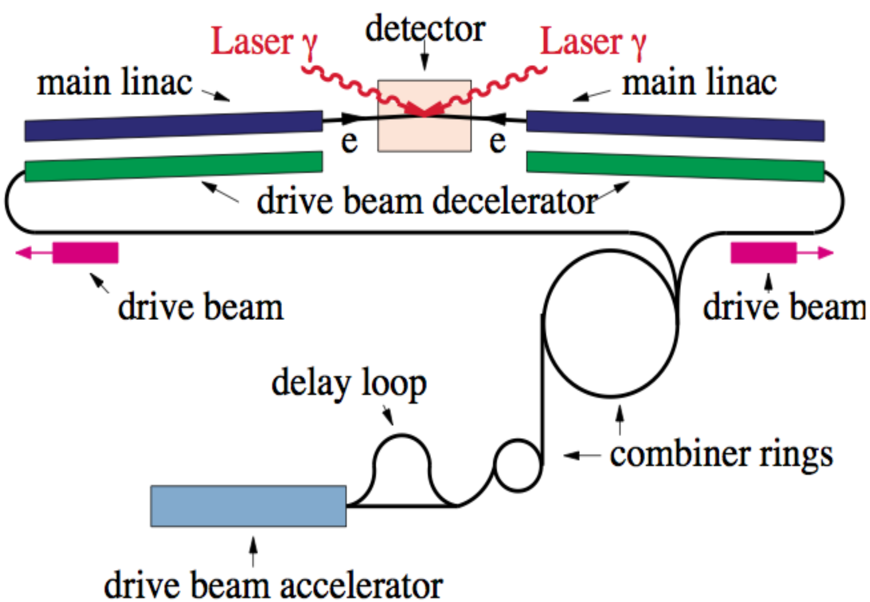
γ_{laser}: Pulses of a several *Joules* with a λ~350nm (3.53 eV) for E_{e-} ~ 80 GeV

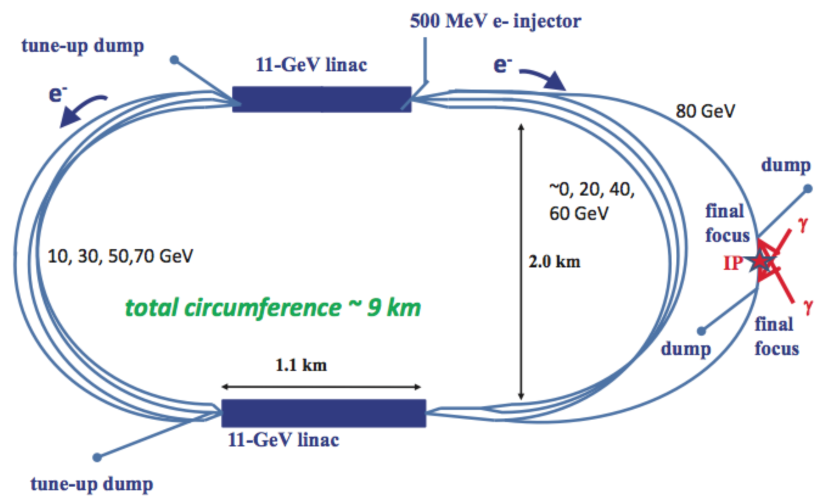


Initial designs

#1 Light Higgs Factory: CLICHE, ILC (TESLA) & SAPPHiRE

Machine	$E_{e^+e^-}$ (GeV)	$M_{h_{SM}}$ (GeV)	Yield/year	Ref.
CLICHE	150	115	22.5k	hep-ex/0110056
CLICHE	160	120	23.6k	Correct for $\Gamma_{\gamma\gamma}$
TESLA	160	120	21.0k	hep-ex/0101056
SAPPHiRE	160	125	20.0k	1208.2827
e^+e^-	$350_{TESLA}(500_{NLC})$	120	3.5k(20k) Tag(Raw)	hep-ph/0101165





Why built a low energy $\gamma\gamma$ collider as a light Higgs Factor?

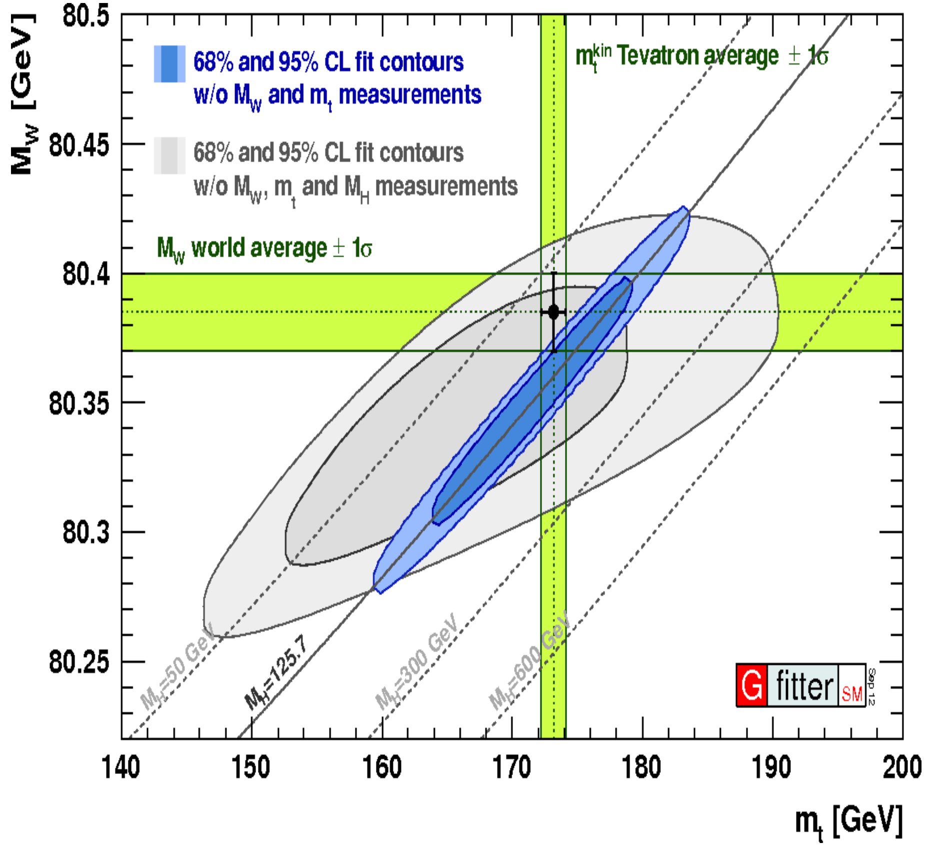
In my opinion: To search for the unexpected properties of the Higgs in a model independent way… that is,

Higgs CP Mixing and Violations

CP asymmetries at the 1% level accessible with ½ a year with current designs

Why complement the physics program with e-e- and e-γ collisions?

- Test consistency in EW sector requires precise measurements of parameters like:
  - $\sin^2 \theta_W$
    - $e^- e^- \rightarrow$ e-e-
  - $M_W = M_Z \cos \theta_W$
    - $e^- \gamma \rightarrow W\nu$
  - $M_H, \Gamma_{\gamma\gamma}$: $\gamma\gamma \rightarrow H$

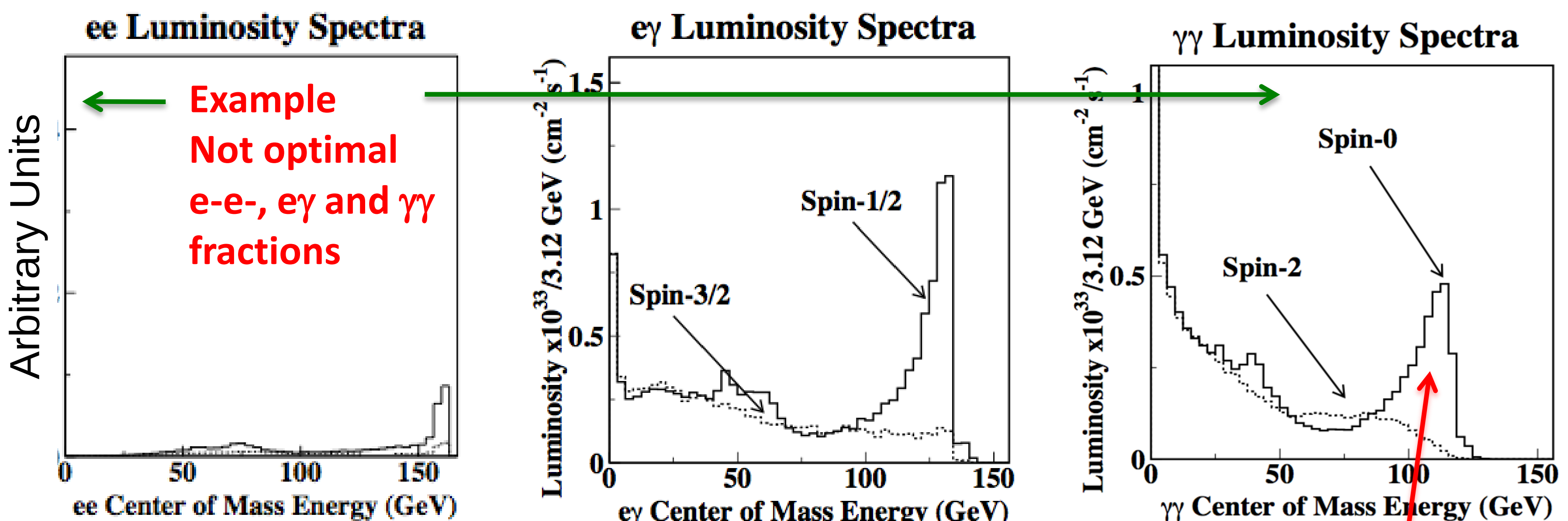


SAPPHiRE Beam Configuration needed for full experimental program

Assumptions and run recommendation:

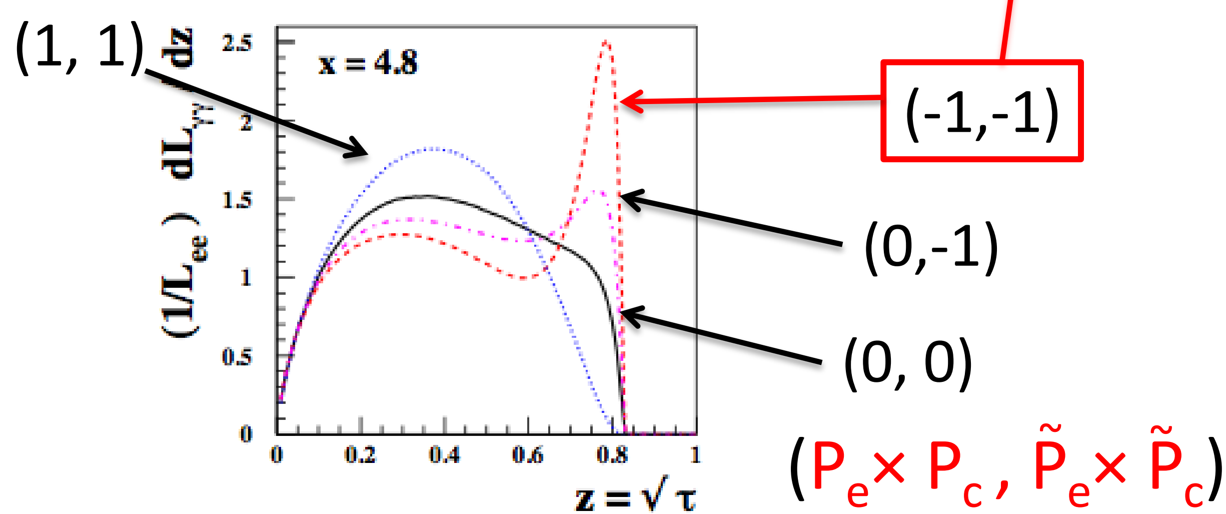
- Start running each mode separately (ee, eγ, $\gamma\gamma$):
  - $e^{-}e^{-}$ first:
    - Physics
    - Understand L_{ee} luminosity
    - e^{-} beam polarization
  - $e^{-}\gamma$ second:
    - Physics
    - commission e□ γ_{laser} → e□γ
  - Finally $\gamma\gamma$
- Optimize SAPPHiRE $\gamma\gamma$ paramaters
  - Highest yields for Higgs for both linear and circular polarization
  - Reduce backgrounds in H → bb and H → $\gamma\gamma$
  - Minimizing amount of ee and eγ, while keeping enough event to monitor polarization and luminosity.

Beam optimization depends on conversion efficiency of $e^{□}\gamma_{laser} \rightarrow e^{□}\gamma$

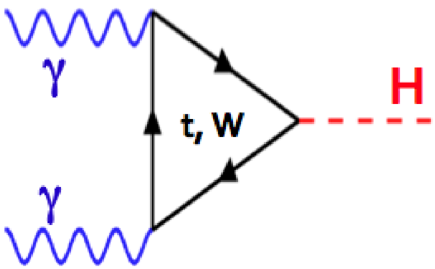


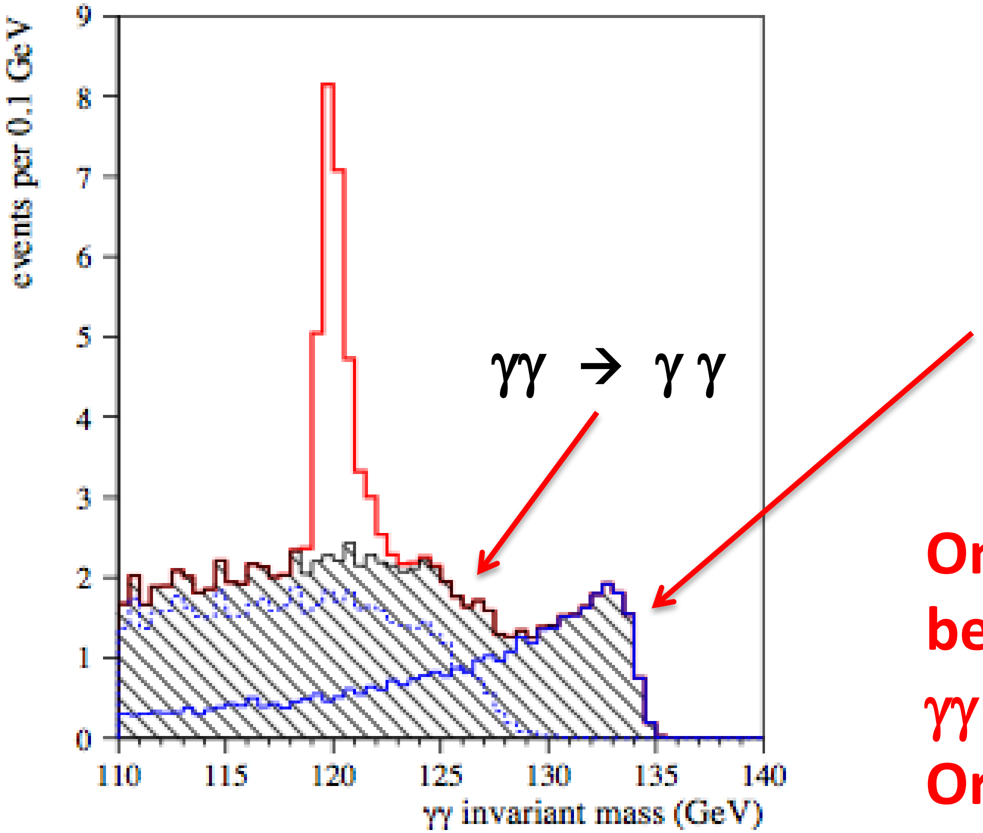
$\gamma\gamma \rightarrow 4\,\mu$ can be used to monitor luminosity σ ~ pb

J=0 and J=2 component might be understood from $\gamma\gamma \rightarrow$ ll γ σ ~ pb



Beam composition affects our Signal/Background





One reason to reduce $e^- \gamma$ beam component and use $\gamma\gamma \rightarrow ll\gamma$ for luminosity Or $\gamma\gamma \rightarrow 4l$

1^{st} : e-e- collider mode @ SAPPHiRE

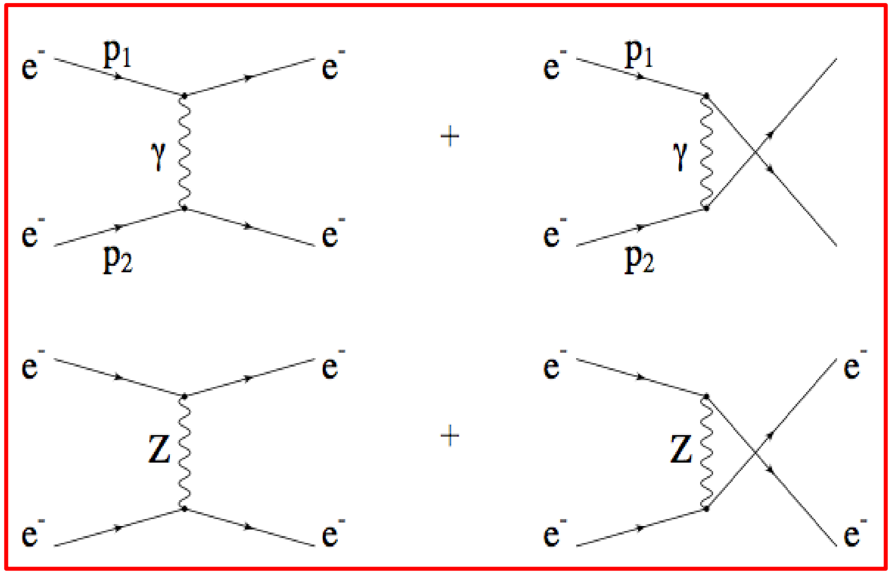
- $e^- e^-$ geometric luminosity: $\mathcal{L}_{ee} = 2 \times 10^{34}\ cm^{-2}s^{-1}$
- 10^7 s per year: 200 fb^{-1} or 200,000 pb^{-1}
- Moller scattering $e^- e^- \rightarrow e^- e^-$
  - E_{cm} = 160 GeV ; Scatt. angle > 5 degree ; P_T > 10 GeV for outgoing e-

$P_{1e} \times P_{2e} = 0 \rightarrow \sigma = 2981$ pb

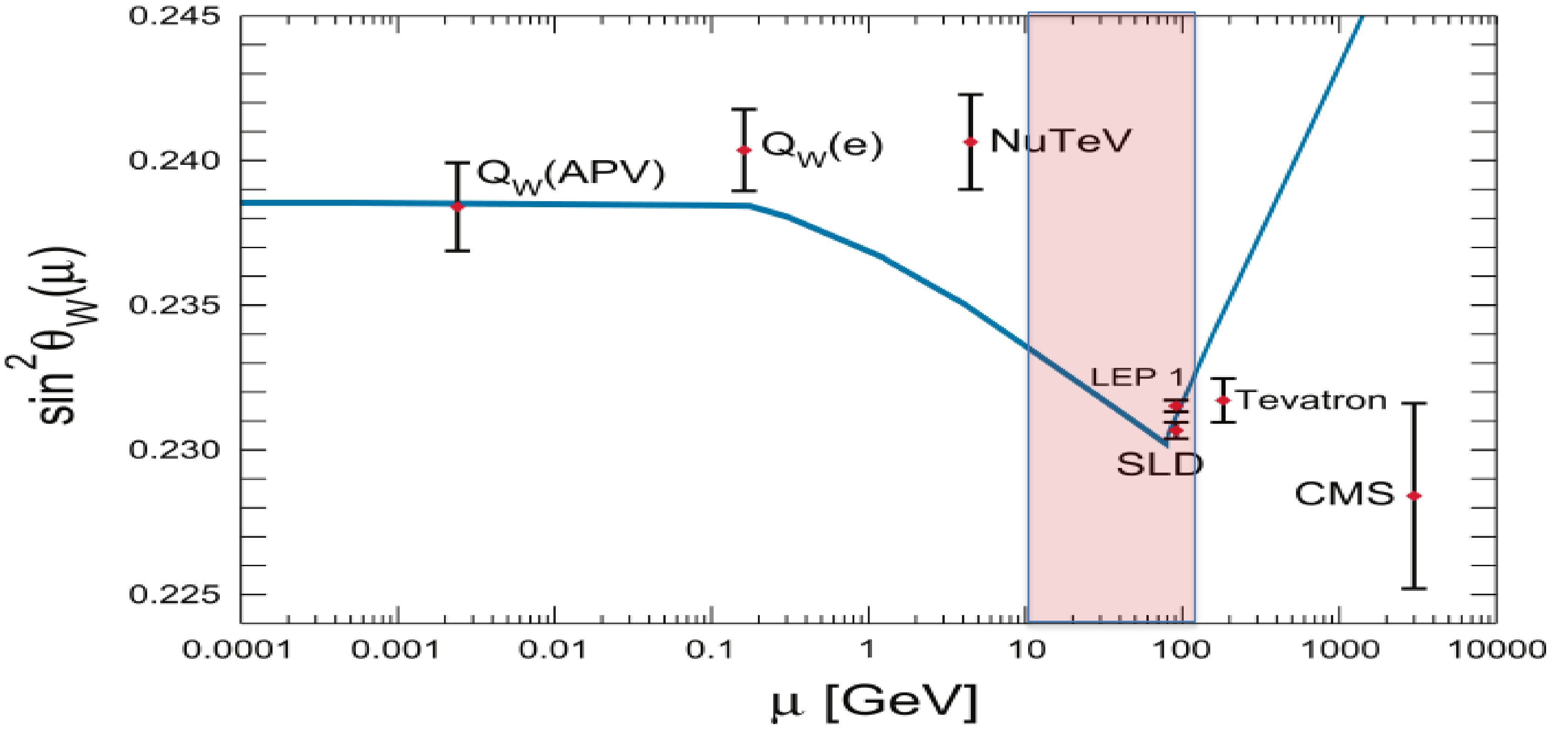
$P_{1e} \times P_{2e} = -1 \rightarrow \sigma = 3237$ pb

$P_{1e} \times P_{2e} = +1 \rightarrow \sigma = 2728$ pb

$\rightarrow N_{ev} \sim 6 \times 10^8$



Interested in running of $\sin^2 \theta_W$ and measurement at the Z-pole



At SAPPHIRE $\mu = E_{cm}$ sqrt{ ½ (1-cos θ)}

θ = scattering angle → Maximum μ~113 GeV

e⁻e⁻: Moller Scattering to get running of $\sin^2 \theta_W$

@ SAPPHiRE

$$A_{\rm LR}^{(2)} \equiv \frac{d\sigma_{\rm LL} - d\sigma_{\rm RR}}{d\sigma_{\rm LL} + d\sigma_{\rm RR}}$$

$$\frac{N_{\rm LL} - N_{\rm RR}}{N_{\rm LL} + N_{\rm RR}} = P_{\rm eff} A_{\rm LR}^{(2)}(y) \left(\frac{1}{1 + \frac{1-P_1 P_2}{1+P_1 P_2} \frac{\sigma_{\rm LR}+\sigma_{\rm RL}}{\sigma_{\rm LL}+\sigma_{\rm RR}}} \right)$$

$$P_{\rm eff} = \frac{P_1 + P_2}{1 + P_1 P_2}.$$

$$A_{\rm LR}^{(2)}(y = 1/2) \approx (1 - 4 \sin^2 \theta_W) \frac{2x}{3 + 2x}, \qquad x \equiv \frac{s}{m_Z^2}.$$

~5%

$$y = \frac{1 - \cos\theta}{2}, \qquad 0 \le \theta \le \pi$$

@ SLC (e+e-)

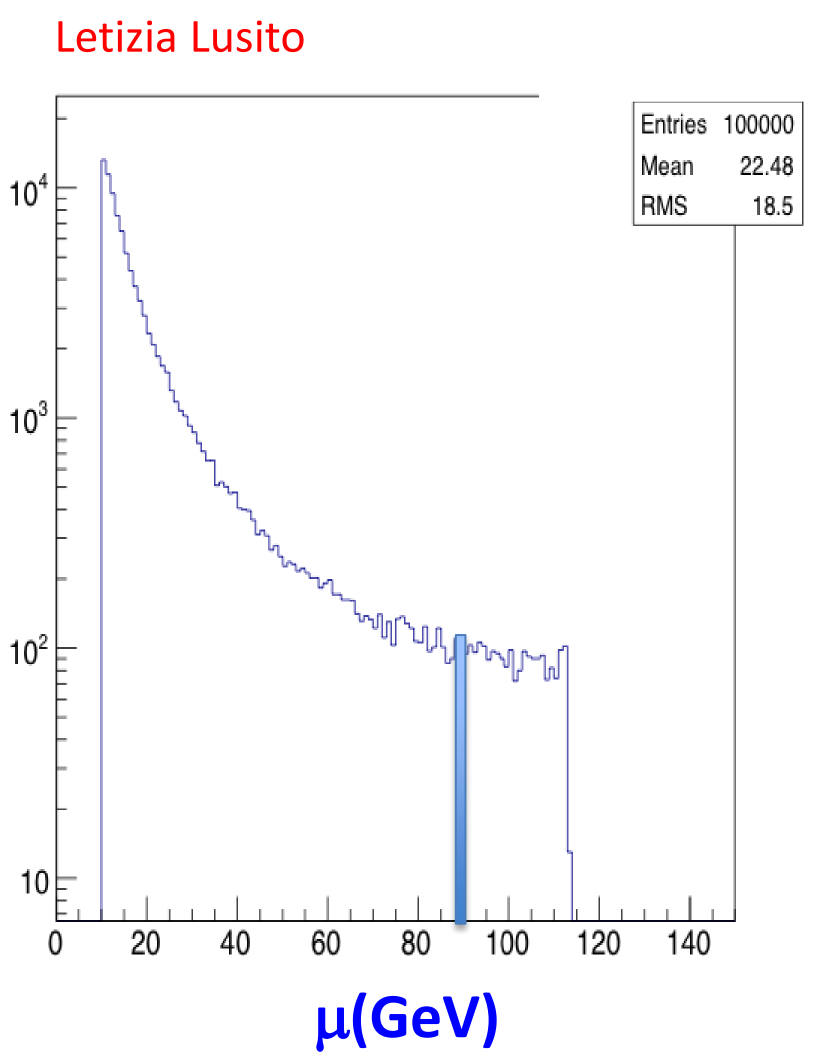
$$A_{\rm LR} \equiv \frac{\sigma(e^+ e_L^- \to \text{hadrons}) - \sigma(e^+ e_R^- \to \text{hadrons})}{\sigma(e^+ e_L^- \to \text{hadrons}) + \sigma(e^+ e_R^- \to \text{hadrons})}$$

$$\frac{N_L - N_R}{N_L + N_R} = P_{e^-} A_{\rm LR},$$

$$A_{\rm LR} = \frac{2(1 - 4\sin^2\theta_W)}{1 + (1 - 4\sin^2\theta_W)^2}$$

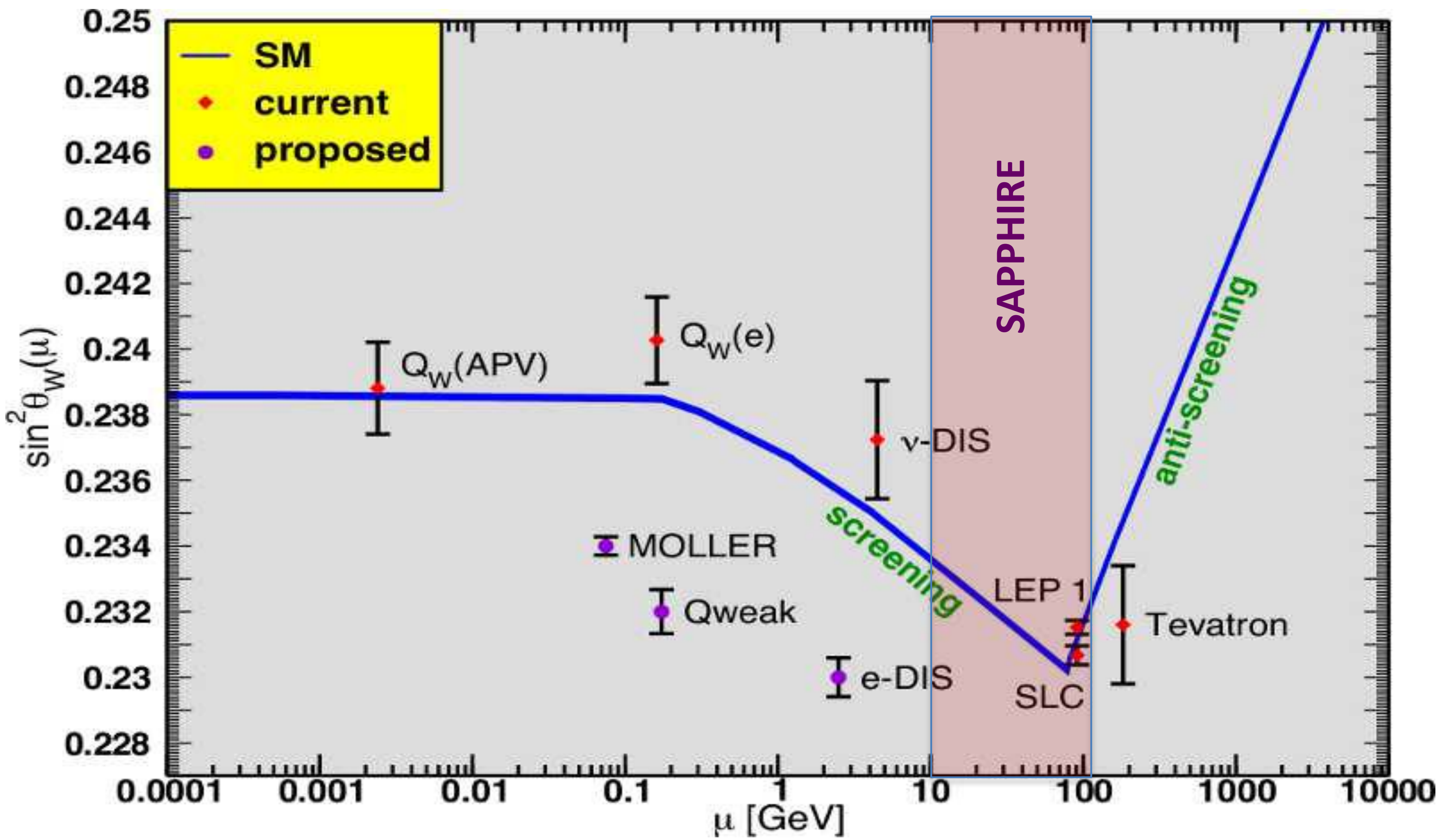
~15%

Precision on $\sin^2 \theta_W$ at SAPPHIRE



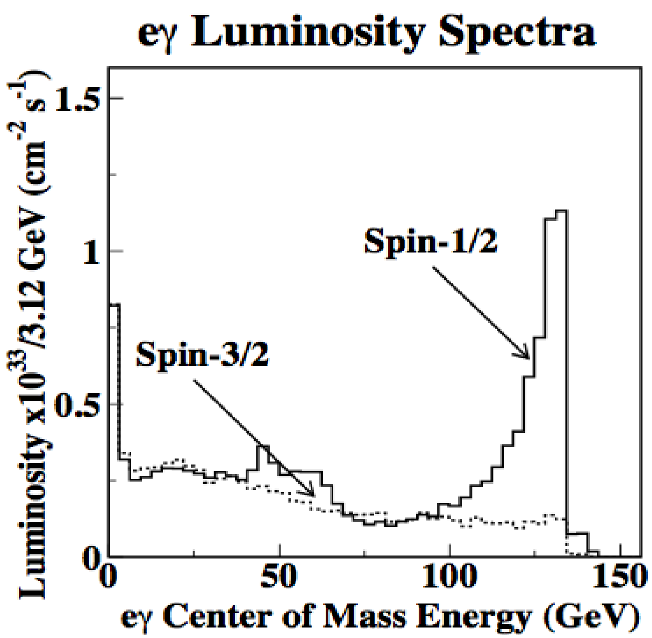
- **Like SLAC-SLC (& LEP) at M_Z**
  - **A_{LR} based on 150K event**
  - **$\delta A_{LR} \sim 0.003$**
  - **$\delta \sin^2 \theta_W \sim 0.0003$**
- **SAPPHiRE at highest μ**
  - **A_{LR} based on 10^6 event**
  - **$\delta A_{LR} \sim 0.001$**
  - **$\delta \sin^2 \theta_W \sim 0.0004$**
- **In addition to precise measurement of running down to 10 GeV**

e⁻e⁻: Moller Scattering to get running of $\sin^2\theta_W$

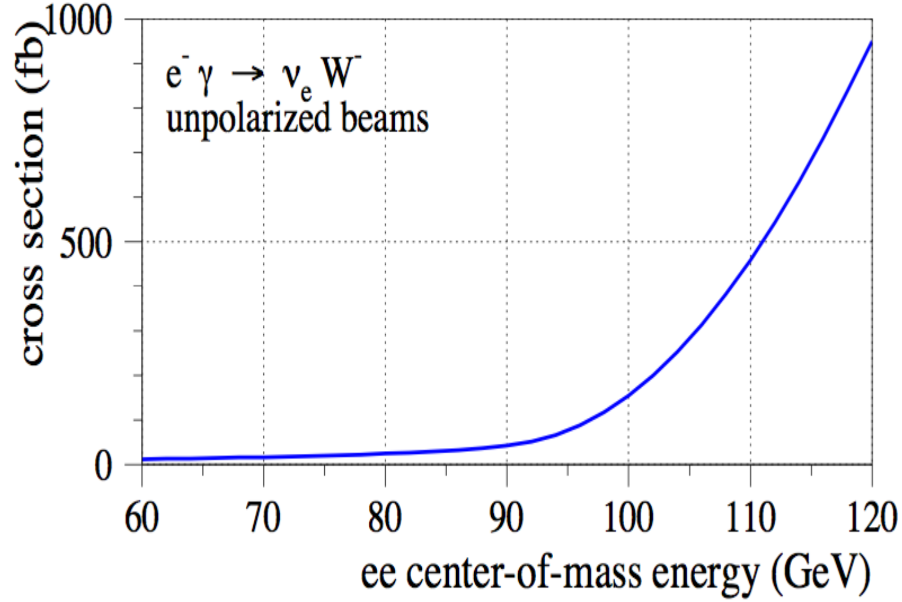


➔ **Complements future programs**

2nd $e^-\gamma$: M_W from $e^-\gamma \rightarrow W^-\nu$



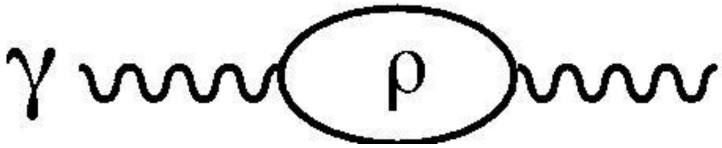
- Mass measurement scanning might be better than from W → hadron events? To be checked.
- Pileup dependent, beam composition dependent…



- As part of understanding produces photon spectra, would like to keep on energy of e- beam producing the γ beam fixed, while increasing the energy of 2nd e- beam only

$e^- \gamma \rightarrow e^-$ *hadrons* & $e^- \gamma \rightarrow \nu$ *hadrons*

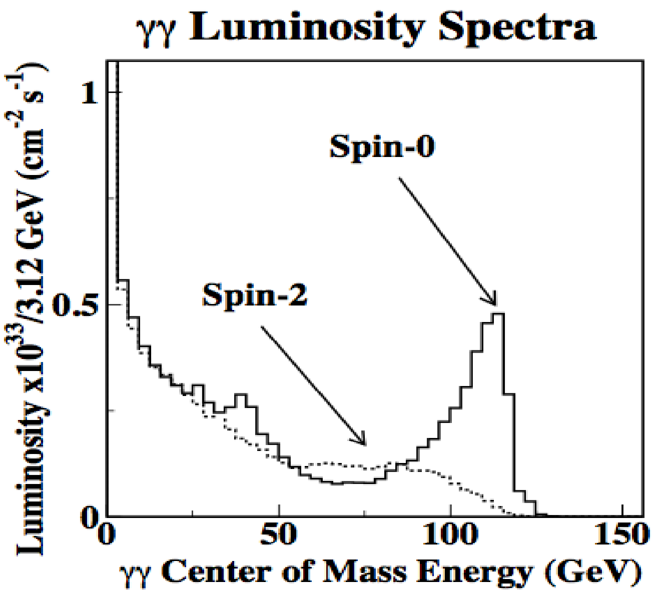
- **Also useful to understand early on the hadron structure of the photon**

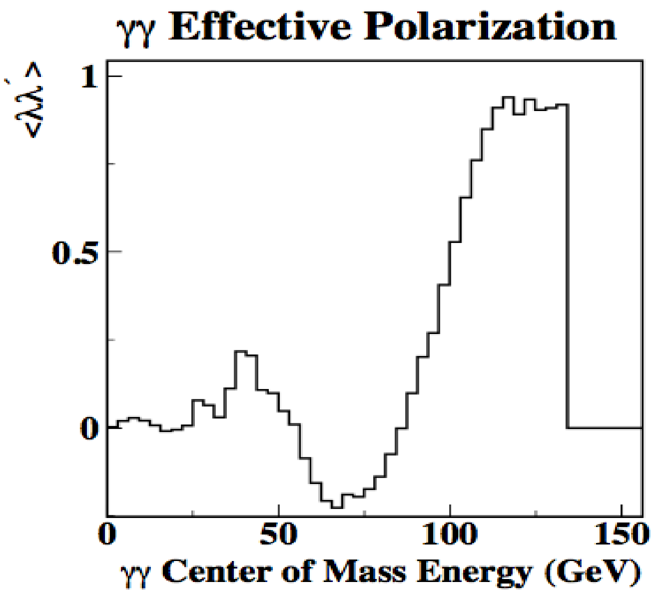


  - **Needed for proper estimate of the background in channels like $\gamma\gamma \rightarrow H \rightarrow bb$**

3[rd]: $e^-e^- \rightarrow \gamma\gamma$ Spectrum tuned for a Higgs-factory

- Well defined $J = 0, 2$ final states,
  when starting with *circularly* $(\lambda = \pm 1)$ polarized γ's



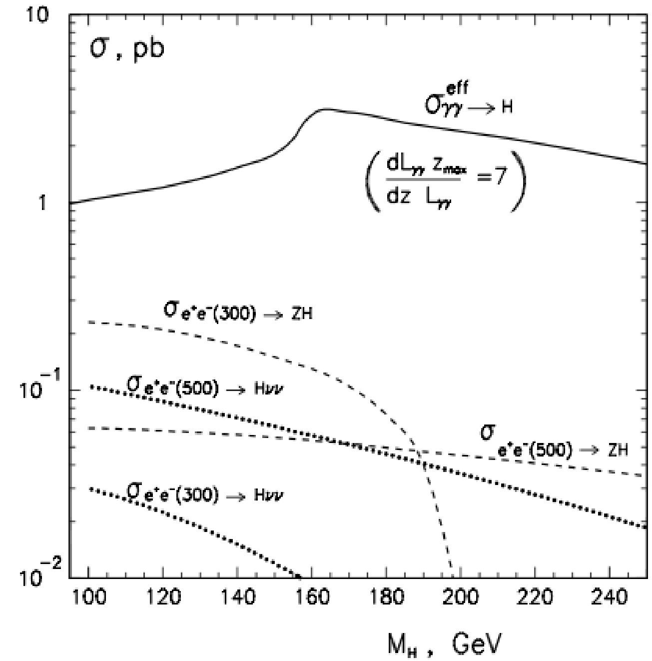


γγ: H production in γγ → H

- Large cross section
  ⇒ Neutral Higgs ($Y = h_{SM}, H, A$)

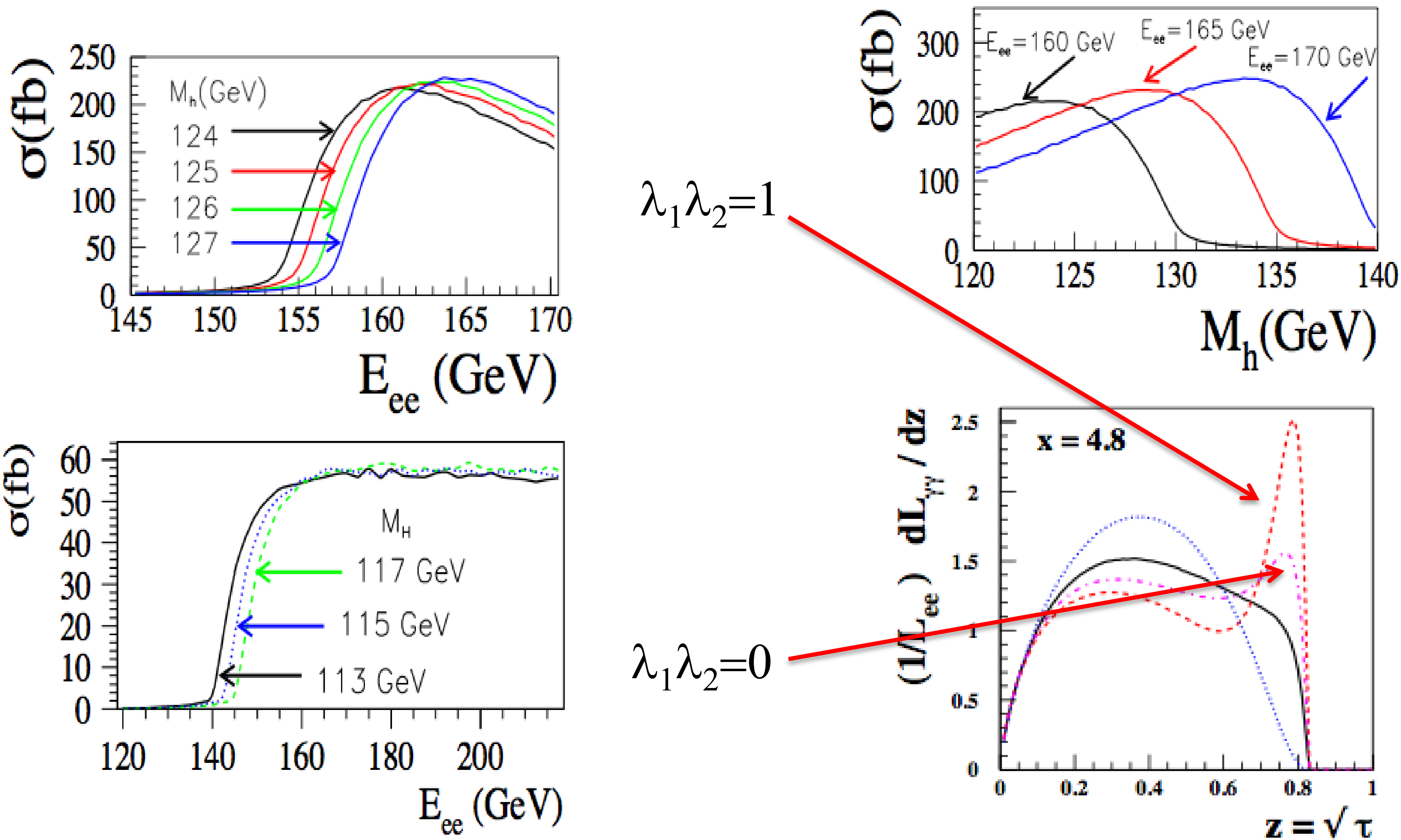
$$\sigma(\gamma\gamma \to Y \to XX') \propto \Gamma^{Y}_{\gamma\gamma} Br(Y \to XX')(1 + \lambda_1\lambda_2)$$

Photon beam polarization

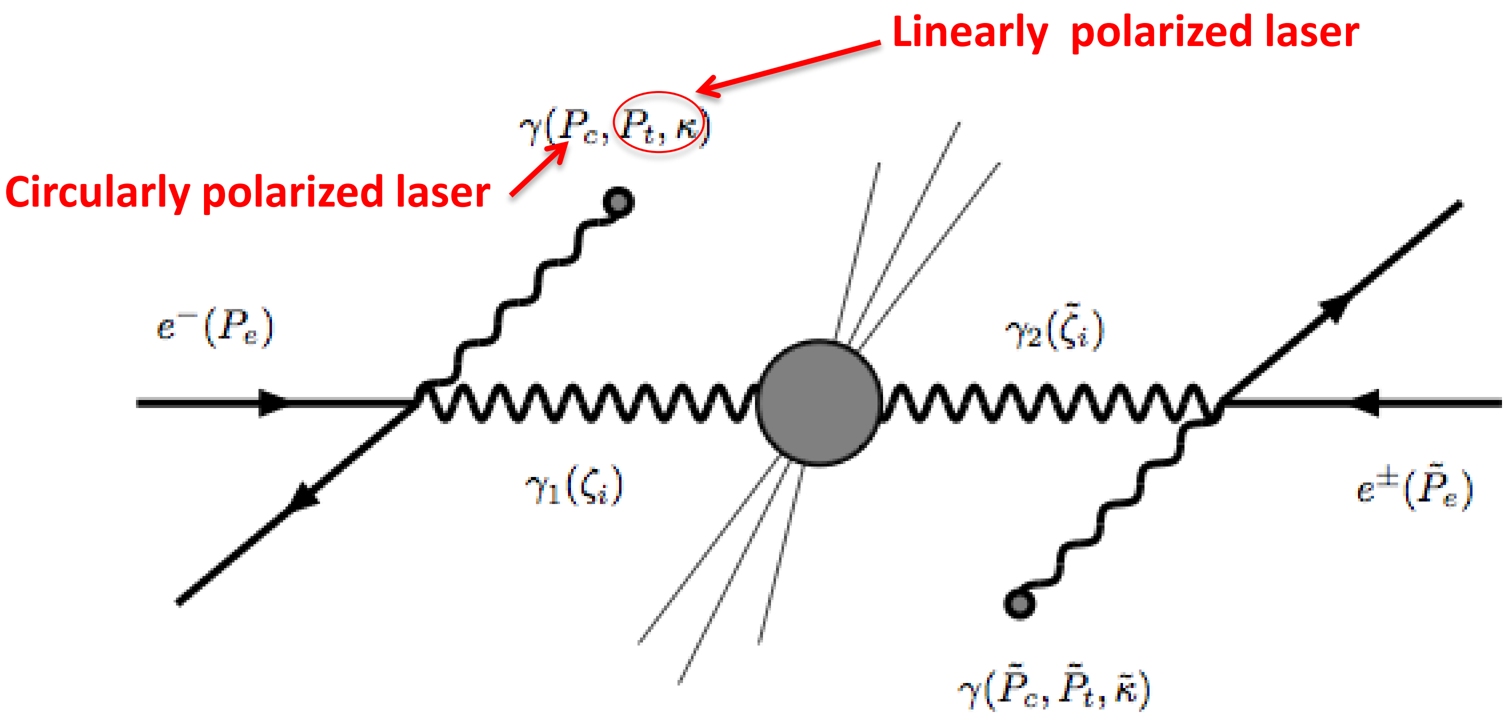


- Well defined CP-states, with *linearly* ($\lambda = 0$) polarized γ's
  ⇒ $(\gamma_{\|} \parallel \gamma_{\|})$ ⇒ CP-even
  ⇒ $(\gamma_{\|} \perp \gamma_{\|})$ ⇒ CP-odd

Cross sections convoluted with the expected beam profile



$\gamma\gamma$ Ideal To Measure CP Mixing and Violation



ζ_2 is the degree of circular polarization

(ζ_3, ζ_1) are the degrees of linear polarization

ζ_2 is the degree of circular polarization

(ζ_3, ζ_1) are the degrees of linear polarization

Only with $\gamma\gamma C$

<u>In s-channel production of Higgs:</u>

$$\overline{|\mathcal{M}^{H_i}|^2} = \overline{|\mathcal{M}^{H_i}|_0^2} \left\{[1+\zeta_2\tilde{\zeta}_2] + \mathcal{A}_1\left[\zeta_2+\tilde{\zeta}_2\right] + \mathcal{A}_2\left[\zeta_1\tilde{\zeta}_3+\zeta_3\tilde{\zeta}_1\right] - \mathcal{A}_3\left[\zeta_1\tilde{\zeta}_1-\zeta_3\tilde{\zeta}_3\right]\right\}$$

== 0 if CP is conserved ($\mathcal{A}_1$, $\mathcal{A}_2$)

== +1 (-1) for CP is conserved for A CP-Even (CP-Odd) Higgs ($\mathcal{A}_3$)

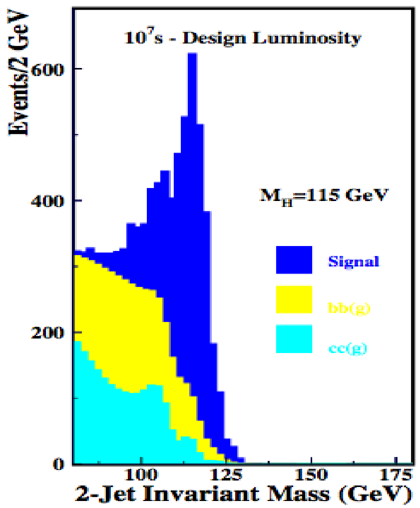
If $\mathcal{A}_1 \neq 0$, $\mathcal{A}_2 \neq 0$ and/or $|\mathcal{A}_3| < 1$, the Higgs is a mixture of CP-Even and CP-Odd states

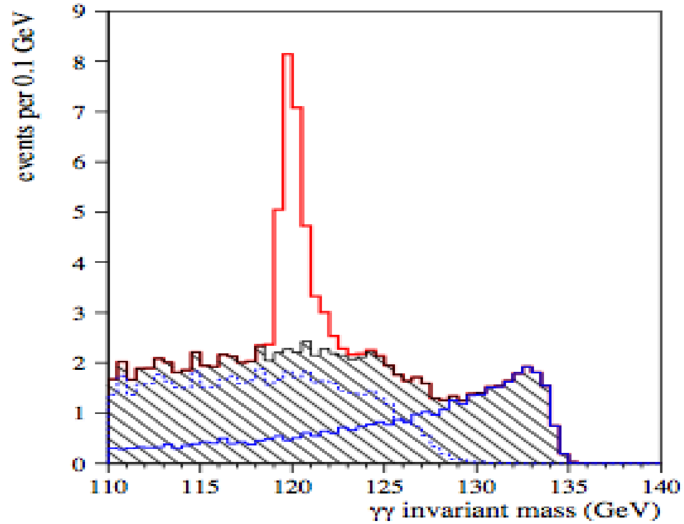
Possible to search for CP violation in $\gamma\gamma \to$ H $\to$ fermions without having to measure their polarization

In bb, a ≤1% asymmetry can be measure with 100 fb^{-1} that is, in 1/2 years

arXiv:0705.1089v2

$h^0 \longrightarrow b\bar{b}$ and $h^0 \longrightarrow \gamma\gamma$ hep-ex/0110056





2% measurement of $\{\Gamma_{\gamma\gamma} \times Br(h \longrightarrow b\bar{b})\}$ within a year!

21% measurement of $\{\Gamma_{\gamma\gamma} \times Br(h \longrightarrow \gamma\gamma)\}$ within a year!

150 MeV mass measurement in 0.5 year!

Only with γγC

Ultimately Model independent:

→ %2 Measurement of $\Gamma_{\gamma\gamma}$ and 10% on Γ_{Total}

→ Assuming a 2% uncertainty on Br(H to bb)

→ Results in 4% constrain in the Htt Yukawa coupling

Short term plan

- In the next few month we need to optimize the SAPPHIRE machine parameters that could give us the best physics program
  - Including staging for e^-e^- and $e^-\gamma$ with respect to $\gamma\gamma$
- Need to
  - make quantitative estimates of how well we could measure $\sin^2\theta_W$ in e^-e^- and M_W in $e^-\gamma$
  - Redo all 125 GeV Higgs estimated with realistic conditions
  - Determine accuracy at which the various CP asymmetries could be measured

Forming Working Groups

- Electro Weak
- Higgs
- QCD
- Flavor Physics
  - Interest from the tau community
- Luminosity and polarization

➔ *Workshop around May or June*

BACKUP

Summary for Light Higgs

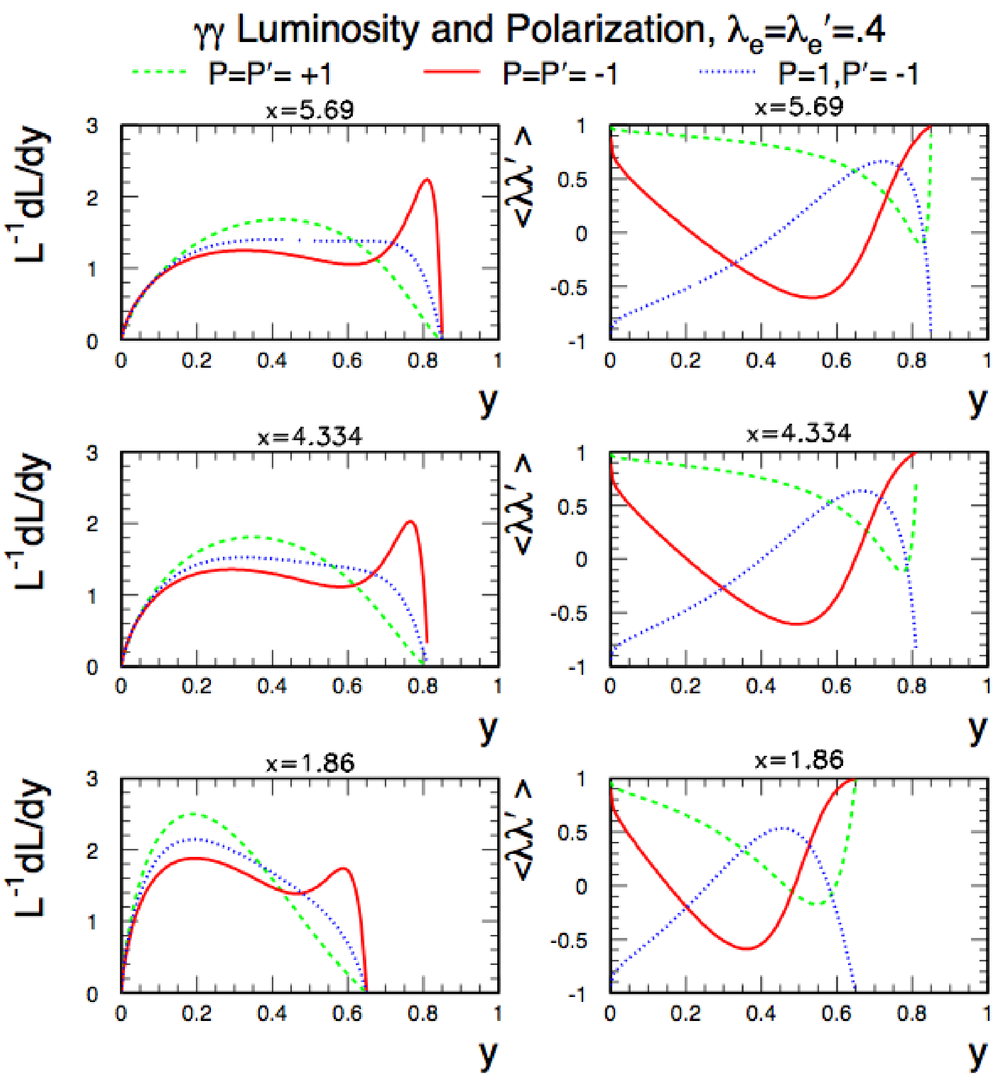
After three years of data taking at nominal conditions for CLICHE $M_h = 120$ GeV.

Measurement	Precision
$\Gamma_{\gamma\gamma} \times Br(h \to bb)$	0.012
$\Gamma_{\gamma\gamma} \times Br(h \to WW)$	0.035
$\Gamma_{\gamma\gamma} \times Br(h \to \gamma\gamma)$	0.121
$\Gamma_{\gamma\gamma} \times Br(h \to ZZ)$	0.064
$\Gamma_{\gamma\gamma} \times Br(h \to \gamma Z)$	0.20
$\Gamma_{\gamma\gamma}$ * ×	0.021
Γ_{Total} *	0.13
Mass ($\gamma\gamma$ decay)	61 MeV
CP asymmetry (WW decay)	0.035-0.040

* Take $Br(h \to bb)$ from LC

× 19% measurement at TESLA in 500 fb^{-1}

Compton Laser Backscattering Facts



$$E_e + w_o \rightarrow E_{e'} + E_\gamma$$

$$x_{max} = \frac{4E_e w_o}{m_e^2}$$

$$E_\gamma = \frac{x}{x+1} E_e$$

$$y_{max} = \frac{E_\gamma}{E_e}$$

Available:

$$w_o = 3.53\ eV$$
$$= 0.351 \mu m\ laser$$