

## Idea

Osservare TM a Belle-II, con la photon-photon fusion, come proposto per il TT

Reference TT a Belle-II, BES-III e FCC-ee: PhysRevD.105.093008

$$\sigma(ab \rightarrow ab + X) = 4\pi^2 (2J+1) \frac{\Gamma_{\gamma\gamma}(X)}{m_X^2} \frac{d\mathcal{L}_{\gamma\gamma}^{(ab)}}{dW_{\gamma\gamma}} \bigg|_{W_{\gamma\gamma}=m_X}, \quad (2) \quad dL/dW \text{ effective photon lumi}$$

Sigma TM / TT = (M\_TT/M\_TM)^2 Gamma\_gg(TM)/Gamma\_gg(TT) dLgg/dWgg (TM)/dLgg/dWgg (TT)

| Resonance | $J^{PC}$ | $m_X$ (MeV)          | $\Gamma_{\text{tot}}$ (MeV) | $\Gamma_{\gamma\gamma}$ (MeV) | $\mathcal{B}_{\gamma\gamma}$ |
|-----------|----------|----------------------|-----------------------------|-------------------------------|------------------------------|
| $T_0$     | $0^{-+}$ | $3553.696 \pm 0.240$ | $2.28 \times 10^{-8}$       | $1.83 \times 10^{-8}$         | $\sim 80\%$                  |

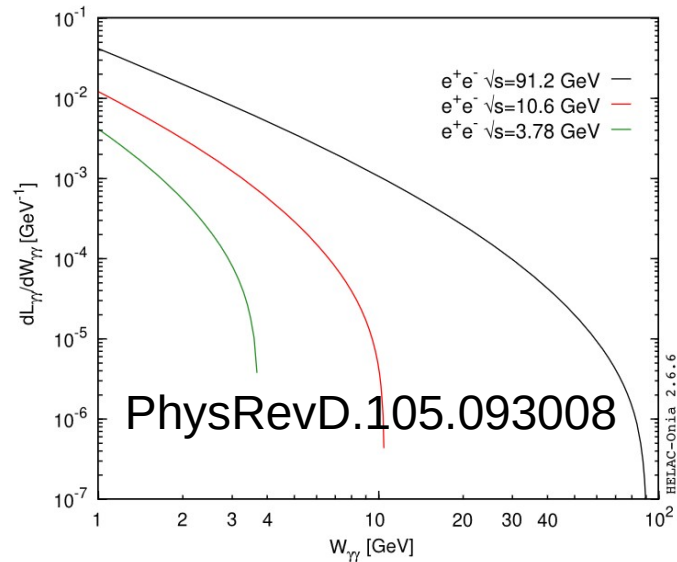
TT(para-1S) Gamma\_gg = 1.83e-8 MeV

TM(para-1S) Gamma\_gg = 3 Gamma\_ee (ortho-1S) = 3 hbar c / (c 1.8 ps) = 1.0945e-9 MeV (arxiv.org/abs/2309.11683)

Sigma TM / TT = 16.95 \* dLgg/dWgg(TM)/dLgg/dWgg (TT)

Necessaria stima di dL/dW → prossima slide

The factor  $\frac{d\mathcal{L}_{\gamma\gamma}^{(ab)}}{dW_{\gamma\gamma}}|_{W_{\gamma\gamma}=m_X}$  is the value of the effective two-photon luminosity function at the resonance mass, determined from the convolution of the incoming photon EPA fluxes. For  $e^+e^-$  beams, the  $\gamma$  flux is estimated with the Weizsäcker-Williams approximation [30] (also cf. Eq. (3) of [31]), with the maximum virtuality set to  $Q_{\max}^2 = 1 \text{ GeV}^2$  as we focus on quasireal EPA scatterings,

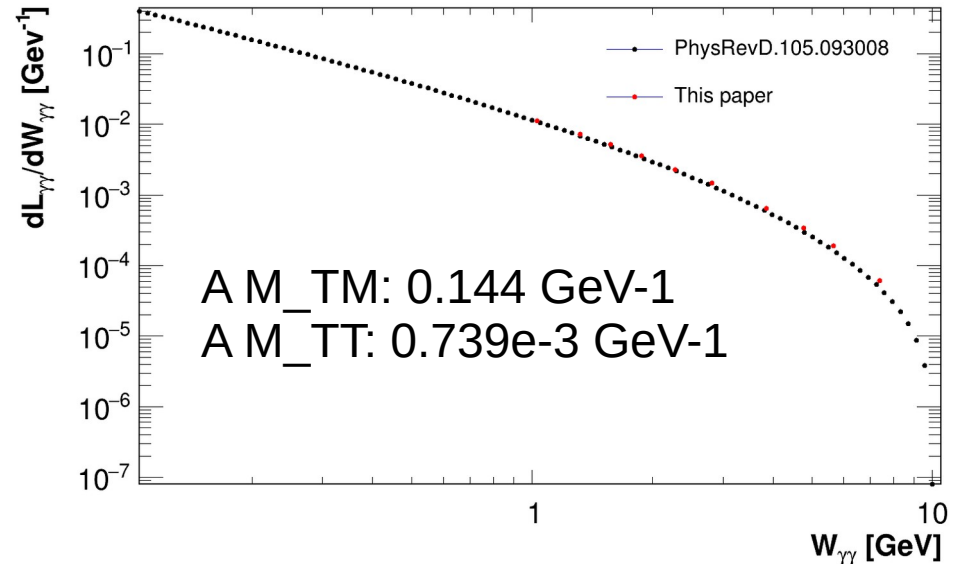


The  $\gamma\gamma$  luminosity, normalized to  $\mathcal{L}_{ee}$ , [arxiv.org/pdf/2301.07089](https://arxiv.org/pdf/2301.07089)

$$dL_{\gamma\gamma} = \int dn_1 dn_2 = 2zdz \int f(x)f\left(\frac{z^2}{x}\right) \frac{dx}{x}, \quad (2.2)$$

where  $z = W_{\gamma\gamma}/2E_0$  and  $z^2 = xy$ . The distribution of luminosity on  $z$  is obtained by integration on  $x$  from  $x = z^2$  to  $x = 1$ . However, if we restrict the maximum value of

$$f_{\gamma/e}(x_\gamma, Q_{\max}^2) = \frac{\alpha}{2\pi} \times \text{j.physletb.2020.135926} \left[ \frac{1 + (1 - x_\gamma)^2}{x_\gamma} \ln \frac{Q_{\max}^2}{Q_{\min}^2(x_\gamma)} + 2m_e^2 x_\gamma \left( \frac{1}{Q_{\max}^2} - \frac{1}{Q_{\min}^2(x_\gamma)} \right) \right]$$



# XS TM

Sigma TM / TT = 16.95 \* dLgg/dWgg(TM)/dLgg/dWgg (TT) (slide 1)

dL/dW (slide 2): W=M\_TM: 0.144 GeV-1 - W=M\_TT: 0.739e-3 GeV-1

Sigma TM / TT = 16.95 \* dLgg/dWgg(TM)/dLgg/dWgg (TT) (slide 1)

Moltiplicando per 0.015fb (vedi sotto) viene 49.5 fb

PhysRevD.105.093008

TABLE II. Photon-fusion production cross sections  $\sigma \times \mathcal{B}_{\gamma\gamma}$  for para-ditauonium signal and backgrounds ( $C$ -even charmonium states, and LbL scattering over  $m_{\gamma\gamma} \in (m_{T_0} \pm 100 \text{ MeV})$ , and  $|\eta_\gamma| < 5$ ) decaying to diphotons, at various  $e^+e^-$  facilities and in UPCs at the LHC. The last column lists the total produced  $T_0$  and dominant irreducible  $\chi_{c2}$  yields for the integrated luminosities quoted at each collider (those for the LHC correspond to LHCb). Uncertainties (not quoted) are around  $\pm 10\%$  (except for  $\eta_c(2S)$ , see text).

| Colliding system, c.m. energy, $\mathcal{L}_{\text{int}}$ , exp. | $\sigma \times \mathcal{B}_{\gamma\gamma}$ |              |                  |                  |        |          | $N \times \mathcal{B}_{\gamma\gamma}$ |                  |
|--|--|--------------|------------------|------------------|--------|----------|---------------------------------------|------------------|
|  | $\eta_c(1S)$                               | $\eta_c(2S)$ | $\chi_{c,0}(1P)$ | $\chi_{c,2}(1P)$ | LbL    | $T_0$    | $T_0$                                 | $\chi_{c,2}(1P)$ |
| $e^+e^-$ at 3.78 GeV, 20 fb <sup>-1</sup> , BES III              | 120 fb                                     | 3.6 ab       | 15 ab            | 13 ab            | 30 ab  | 0.25 ab  | ...                                   | ...              |
| $e^+e^-$ at 10.6 GeV, 50 ab <sup>-1</sup> , Belle II             | 1.7 fb                                     | 0.35 fb      | 0.52 fb          | 0.77 fb          | 1.7 fb | 0.015 fb | 750                                   | 38 500           |

Facendo il conto usando solo la formula generale in slide 1, viene 53fb per il TM, quindi valore molto simile ai 49.5fb ottenuti  
Per il TT viene 0.0169fb, molto simile ai 0.015fb del paper

$$d\sigma/dW = \frac{\sigma_{\gamma\gamma\rightarrow\gamma\gamma}(W)}{2E_0} \frac{dL_{\gamma\gamma}}{dz}.$$

Light by light (e+e- → e+e- 2gamma) con 1 loop di fermioni

Alla massa del TM (0.2 GeV) e al sqrt(s) di Belle-II il backgrou dominante è light-by-light

Ref. per XS gamma gamma → gamma gamma:

<https://arxiv.org/pdf/0911.5634>

da dove arxiv2301... ha preso plot

Usando i valori digitizzati dal paper viene  
sigma\_gg\_gg (W=M\_TM) = 490 pb  
Idem per TT = 9.92 pb

Moltiplicando per dL/dW ottengo:  
dXS/dW = 70.56 pb per W=M\_TM  
dXS/dW = 7.33 fb per W = TT

Se sul TT integro su 200 MeV (come in PhysRevD.105.093008)  
Ottengo XS=1.46fb, molto simile allo 0.17fb che ottengono loro

Se sul TM suppongo una risoluzione del 10% sulla massa  
invariante della coppia di fotoni, integrando in 2 sigma (80 MeV)  
ho XS = 5.6pb

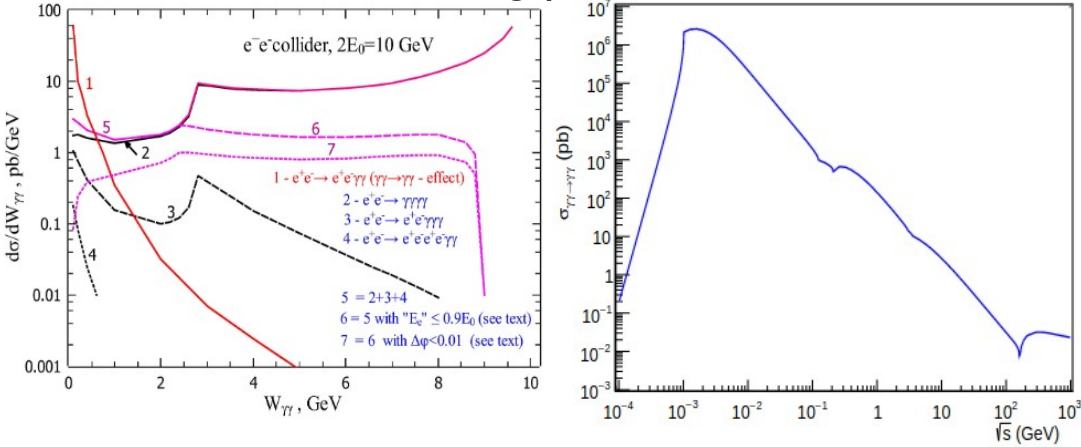


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|  | $\eta_c(1S)$                               | $\eta_c(2S)$ | $\chi_{c,0}(1P)$ | $\chi_{c,2}(1P)$ | LbL    | $T_0$    | $T_0$                                 | $\chi_{c,2}(1P)$ |
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Segnale XS = 53 fb, LbL bkg XS = 5.6 pb, assumiamo 500 fb-1 di int. lumi.

Sono 26.5k eventi di segnale e 2.8e6 di bkg –  $S/B = 0.94\%$  -  $s/\sqrt{b} = 15$  sigma

Con una sistematica sull'integrale di  $dXS/dW$  del LbL sotto il segnale dell'1% non si vede nulla

Con una sistematica del per mille si fanno comunque 15 sigma

La verità è nel mezzo

I LbL alla massa di  $2\mu$  ha dei balzi brutti (vedi slide precedenti) –  $dXS/dW$  del LbL si fitta dalle sideband e in principio (abbiamo  $\sim 1M$  eventi di LbL lì intorno) si fa al per mille quindi OK

Nel dubbio vanno simulati evento per evento LbL e TM e fatta una reiezione del fondo sensata per poter essere più laschi sulla sistematica

Simulare photon photon fusion del para-TM come un ALP, hanno gli stessi numeri quantici

La teoria effettiva dell'ALP va bene anche per il para-TM

L'accoppiamento effettivo (che si calcola imponendo le due gamma uguali) è piccolo rispetto alla scala (massa TM), quindi la teoria effettiva è OK

$$\mathcal{L} = \frac{1}{2} \partial^\mu a \partial_\mu a - \frac{1}{2} m_a^2 a^2 - \frac{1}{4} g_{a\gamma\gamma} a F^{\mu\nu} \tilde{F}_{\mu\nu},$$

SuperChic simula un ALP fatto da photon photon fusion  
e simula anche il LbL

$g_{a\gamma\gamma}$  is the ALP-photon coupling and  $(\tilde{F}_{\mu\nu}) F^{\mu\nu}$  is  
photon width is given by <https://arxiv.org/html/2310.17270v2>

$$\Gamma_a = \frac{g_{a\gamma\gamma}^2 m_a^3}{64\pi}.$$

$g_a$  del TM =  $1.512 \times 10^{-4} \text{ GeV}^{-1}$

$g_a$  del TT =  $9.05 \times 10^{-6} \text{ GeV}^{-1}$

Con SuperChic sul TM senza tagli viene esattamente 53fb, cioè quella calcolata “a mano” sul TM  
Sul TT viene 0.027 fb, molto diverso dallo 0.017fb ottenuto prima “a mano” e allo 0.015fb del paper  
Ma inserendo gli stessi tagli di PhysRevD.105.093008 ( $|\eta| < 5$ ) viene esattamente 0.015fb come a loro

SuperChic validato per TM/TT production → le sezioni d'urto per TM si prendono da lì  
Fare stesso giochino per LbL.

Guardare qua per coverage angolare, tagli ecc. <https://arxiv.org/html/2406.14614v1>

Una volta che ci sono tutti i fondi e il segnale simulato con la cinematica, fare il plot  $m_{gg}$  e calcolare  
significanza con tot fb $^{-1}$

Poi trainare un BDT a discriminare segnale/fondo e ricalcolare significanza