

Also see: A. Faus-Golfe, M.A. Valdivia , F. Zimmermann, “*The challenge of monochromatization: Direct s-Channel Higgs Production:  $e^+e^- \rightarrow H$* ”, [Eur. Phys. J. Plus 137 \(2022\) 31](#)

Frank Zimmermann, CERN

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## FCC Physics Workshop, Liverpool

### 8 February 2022



# monochromatization - history

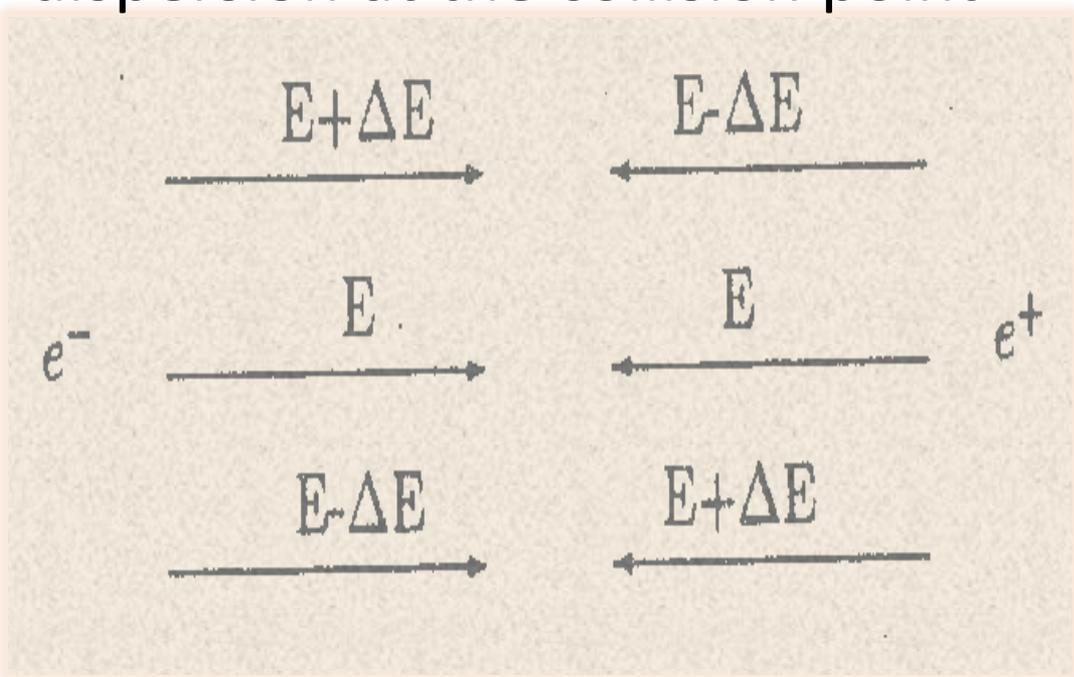
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- V. Telnov, "Monochromatization of e+e- colliders with a large crossing angle" 31.08. 2020

never used in any real machine;  
new feature for FCC: beamstrahlung

# mono-chromatization for direct Higgs production

## $e^+e^- \rightarrow H$ at FCC-ee

one concept: introduce antisymmetric dispersion at the collision point



rel. collision energy spread for standard conditions

$$\left(\frac{\sigma_W}{W}\right)_{\text{standard}} = \frac{\sigma_\delta}{\sqrt{2}}$$

rel. collision energy spread w. mono-chromatization

$$\left(\frac{\sigma_W}{W}\right)_{\text{m.c.}} = \frac{\sigma_\delta}{\sqrt{2}} \frac{1}{\lambda}$$

mono-chromatization factor

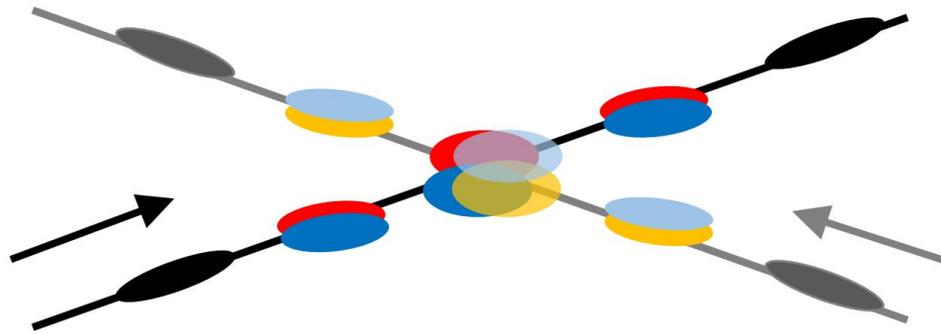
$$\lambda = \sqrt{\frac{D_x^{*2} \sigma_\delta^2}{\epsilon_x \beta_x^*} + 1}$$

in LEP(-1) bunch train operation created unwanted antisymmetric vertical dispersion (G. Wilkinson, Rome),  
 $\epsilon_y \sim 400 \text{ pm}$ ,  $\beta_y^* = 50 \text{ mm}$ ,  $\sigma_\delta = 0.07\%$ ,  $D_y^* \sim 2 \text{ mm} \rightarrow \lambda \sim 1.05$

# three scenarios for FCC

baseline  
with  
crab  
cavities

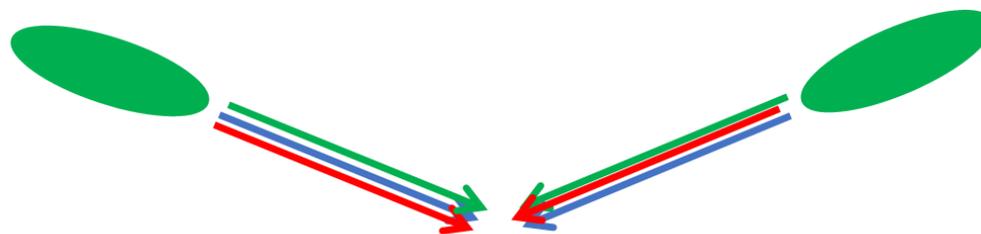
1.



$$D_x^* \neq 0$$

optimized  
by Alan

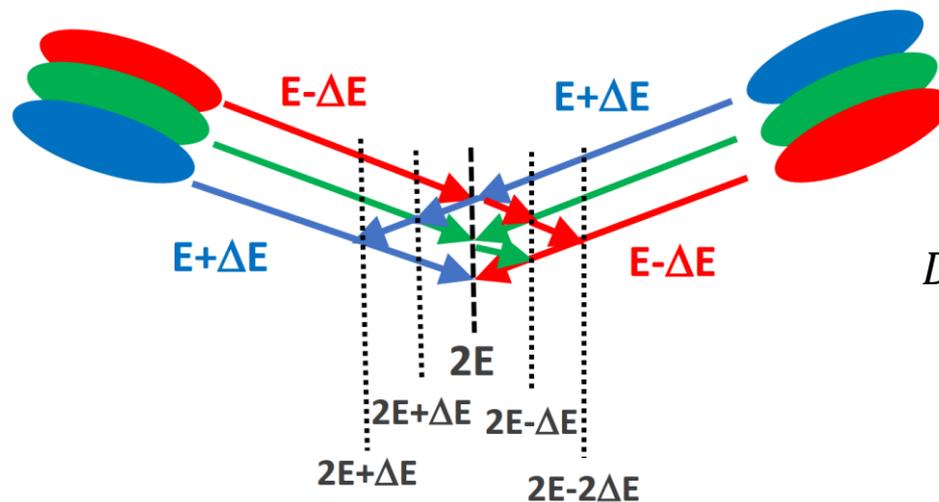
2.



$$D_x^* = 0$$

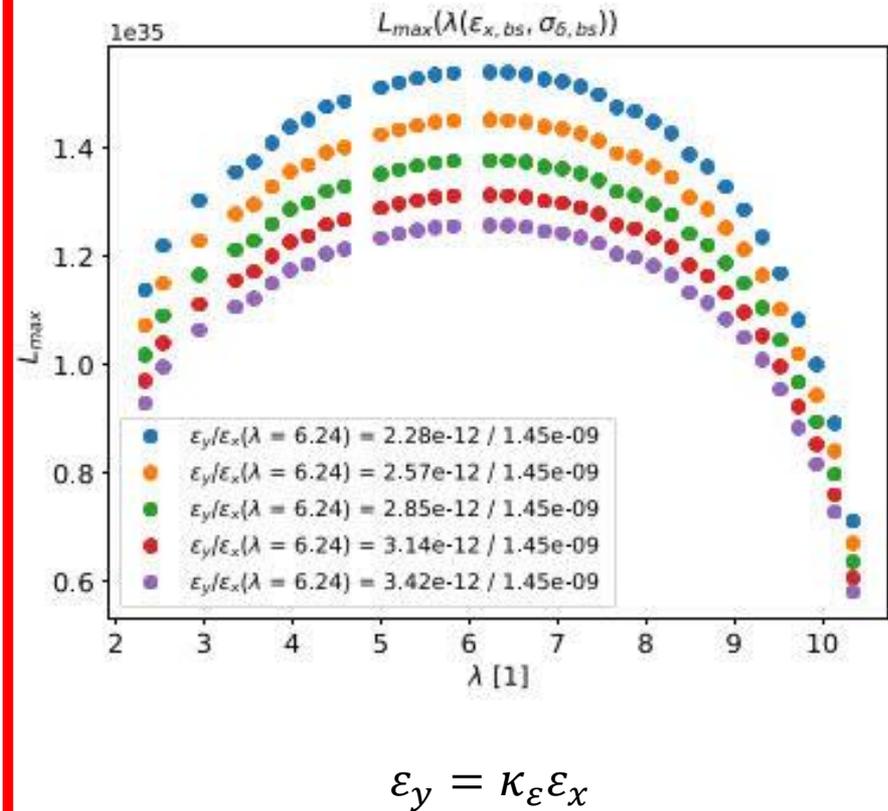
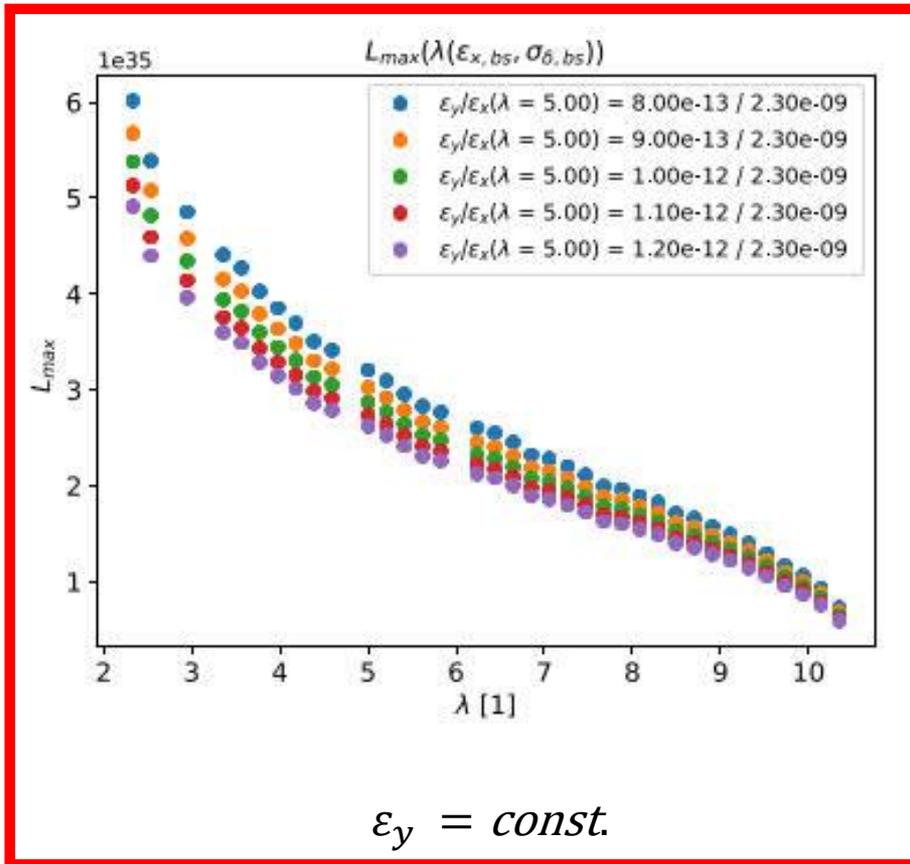
alternatives  
with  
crossing  
angle

3.



$$D_x^* \neq 0$$

# two cases for scenario 1



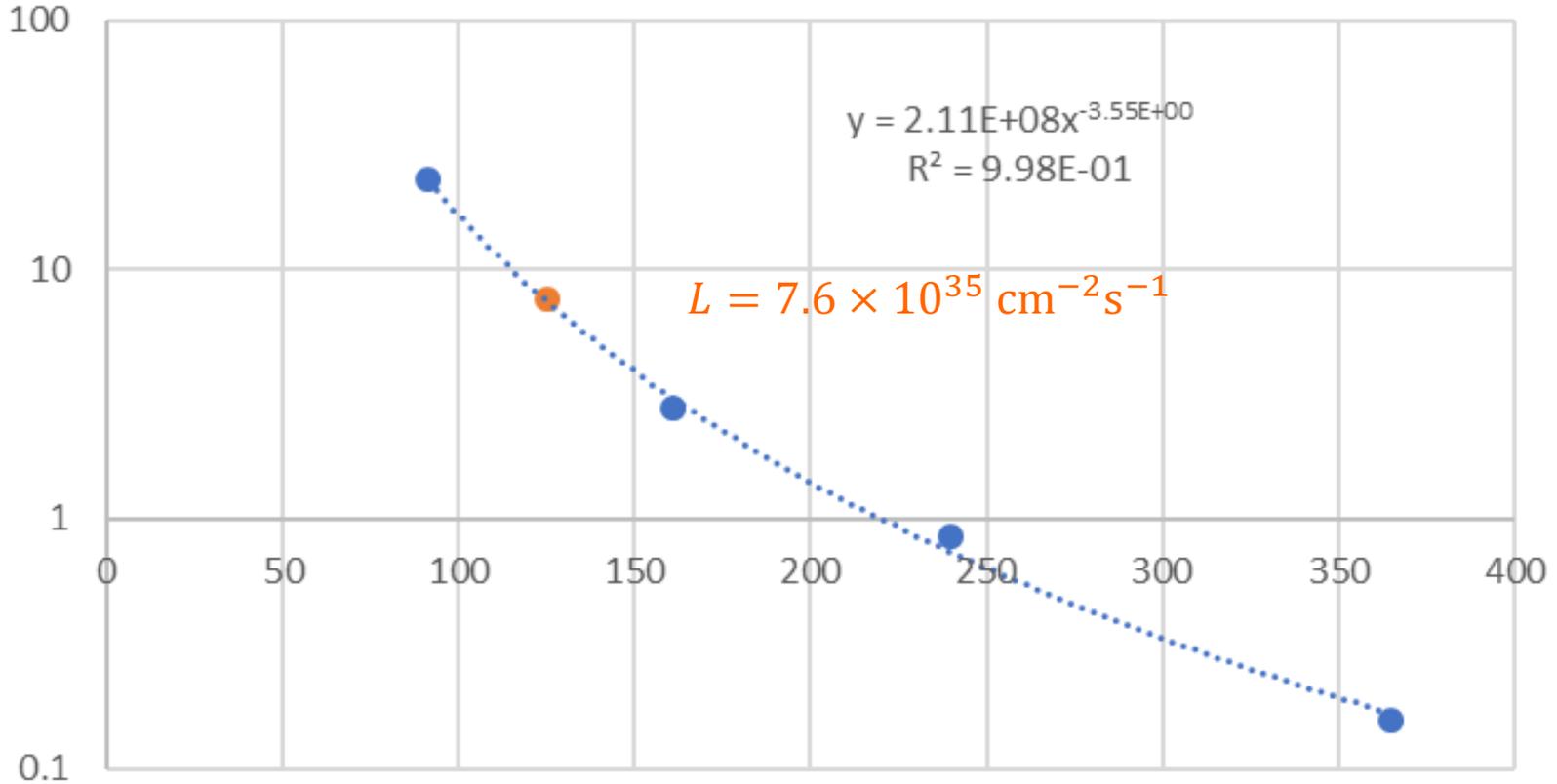
example: pick  $\lambda \sim 5$ ,  $\sigma_W \approx 6$  MeV

**assume optimum case**

# optimum case for scenario 2

peak luminosity  
[ $10^{35} \text{ cm}^{-2} \text{ s}^{-1}$ ]

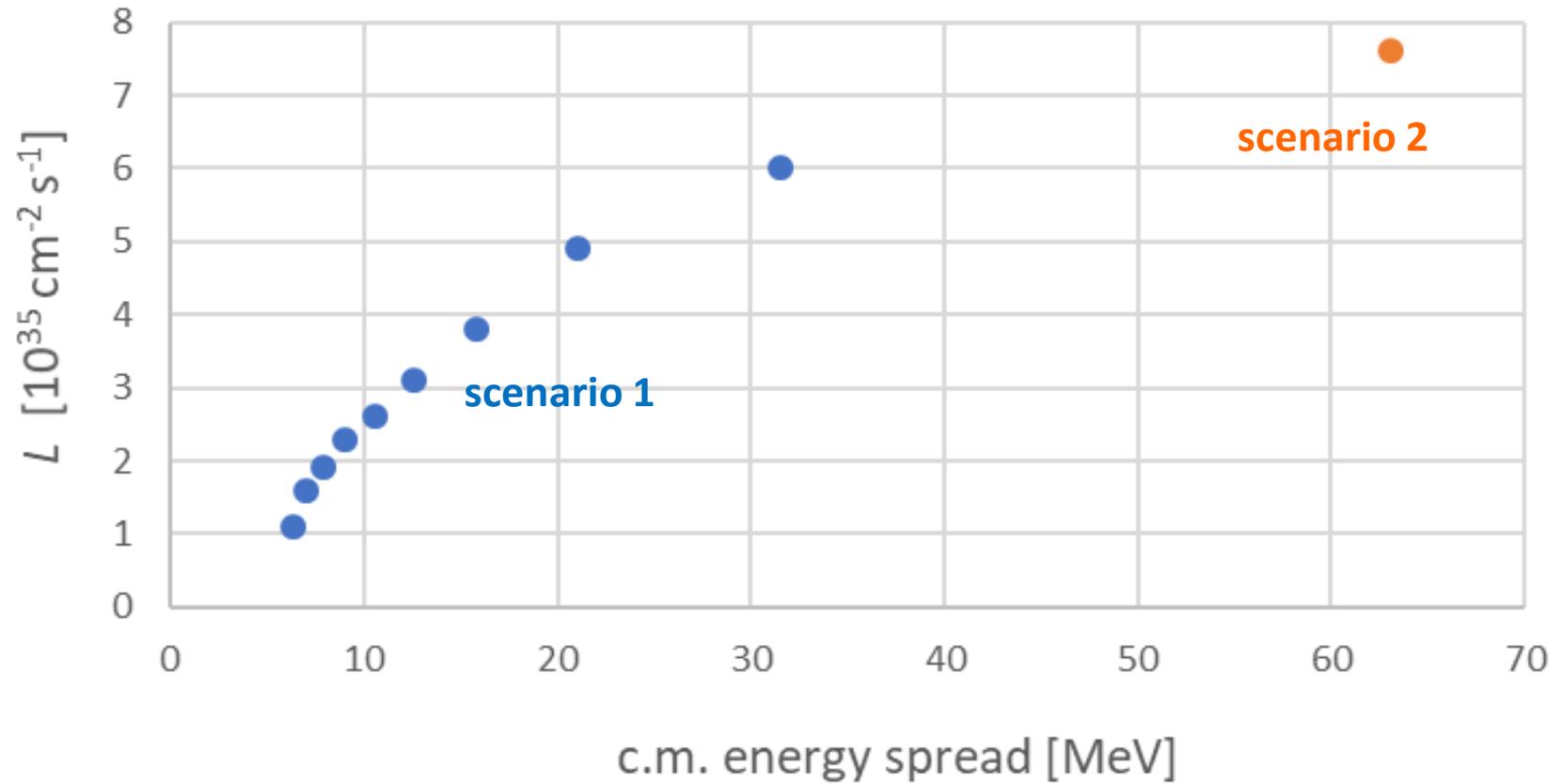
lumi-fit



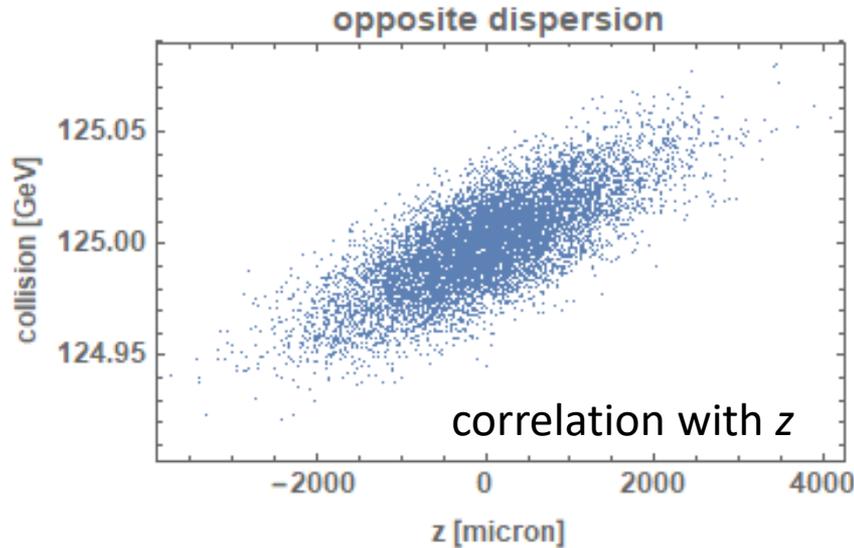
c.m.  
energy  
[GeV]

# peak luminosity versus $\sigma_W$ - 1

luminosity versus c.m. energy spread



# scenario 3: $z$ - $E_{cm}$ correlation of luminosity events



**built-in  
energy scan**

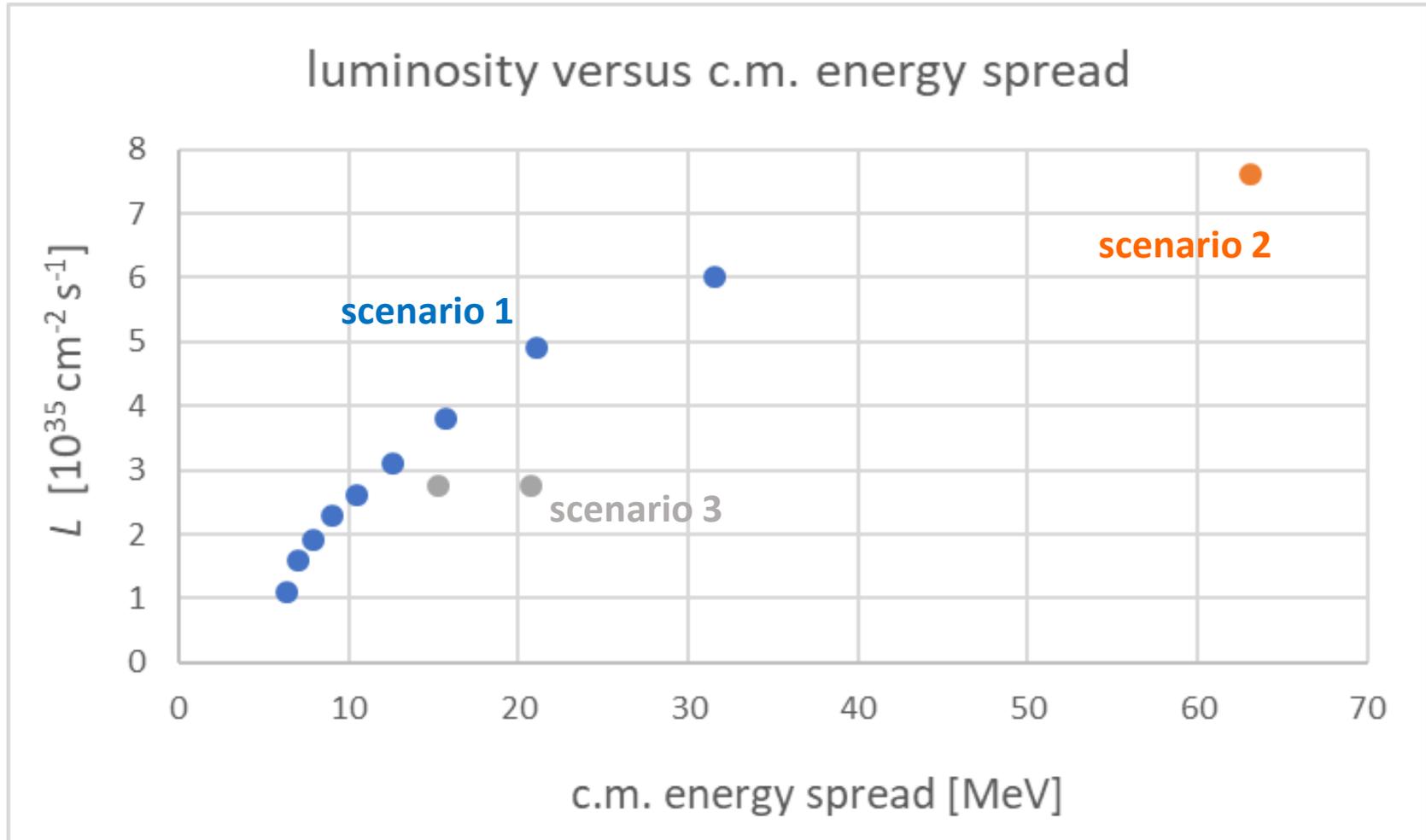
$$\sigma_w \sim 20.7 \text{ MeV}$$

$$\sigma_w \sim 15.3 \text{ MeV over } 3 \mu\text{m}$$

Guinea-Pig simulation  
with equilibrium beam  
distribution

tentative parameters at 62.5 GeV		self-consistent simulation w $\theta_c=30$ mrad (total)	
$D_x^*$	0.105 m	$\sigma_x^*$	80 $\mu\text{m}$ (with dispersion)
$\beta_x^*$	9 cm	$\sigma_{x,\beta}^*$	15 $\mu\text{m}$
$\sigma_\delta$	0.0715%	$\sigma_{\delta,\text{tot}}$	0.075 %
$\epsilon_{x,SR}$	0.51 nm	$\epsilon_{x,\text{tot}}$	2.5 nm
$\sigma_y$	45 nm ( $\epsilon_y = 2 \text{ pm}$ , $\beta_y^* = 1 \text{ mm}$ )	$L$	$2.75 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}$
$N_b$	$6 \times 10^{10}$	$\xi_y$	0.061
$n_b$	14170		

# peak luminosity versus $\sigma_W$ - 2



# integrated luminosity

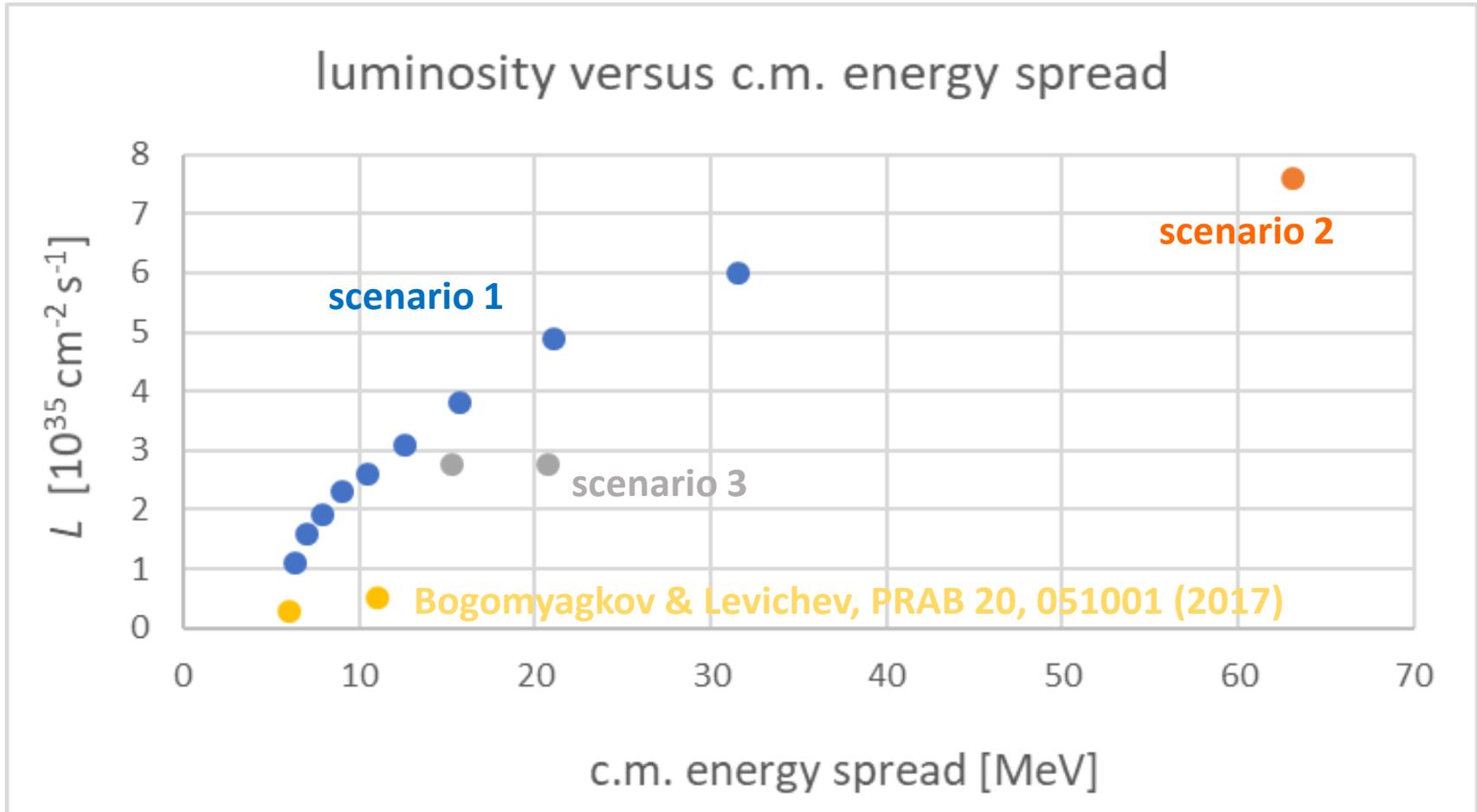
CDR assumptions:

185 physics days per year,  
physics efficiency of 75%

$$10^{35} \text{ cm}^{-2}\text{s}^{-1} \rightarrow 1.2 \text{ ab}^{-1}/\text{year/IP}$$

$$7.6 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1} \rightarrow 9.1 \text{ ab}^{-1}/\text{year/IP}$$

# peak luminosity versus $\sigma_W$ - 3



are our scenarios too optimistic?

# A "4<sup>th</sup> scenario": SC cavity upstream of IP

TM<sub>210</sub> cavity

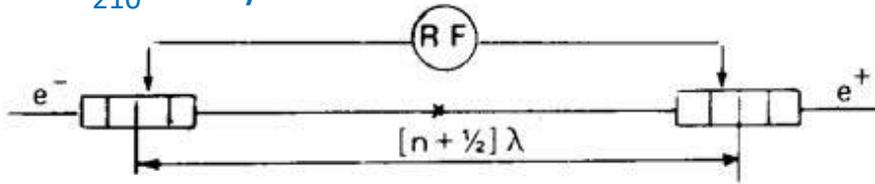


Fig. 4. Schematic view of the two superconducting accelerating rf structures relative to the interaction point used for monochromatization.

$$E_s = -E_{s0} \sin k_x x \cdot \cos k_z z \cdot \cos(\omega t + \phi),$$

$$H_x = \frac{k_z}{k} E_{s0} \sin k_x x \cdot \sin k_z z \cdot \sin(\omega t + \phi), \quad (1)$$

$$H_z = -\frac{k_x}{k} E_{s0} \cos k_x x \cdot \cos k_z z \cdot \sin(\omega t + \phi),$$

where  $E_{s0}$  is the amplitude of electric field;  $\omega$ ,  $\phi$  are the frequency and phase of oscillations;  $k_x = 2\pi/a_x$ ,  $k_z = \pi/a_z$ ,  $k^2 = k_x^2 + k_z^2$ .

dispersion at RF cavity;  
**true reduction of beam energy spread at IP**

can crab cavities be used?  
 RF voltage? side effects?

A. Zholents, NIM A 265 (1988) 179

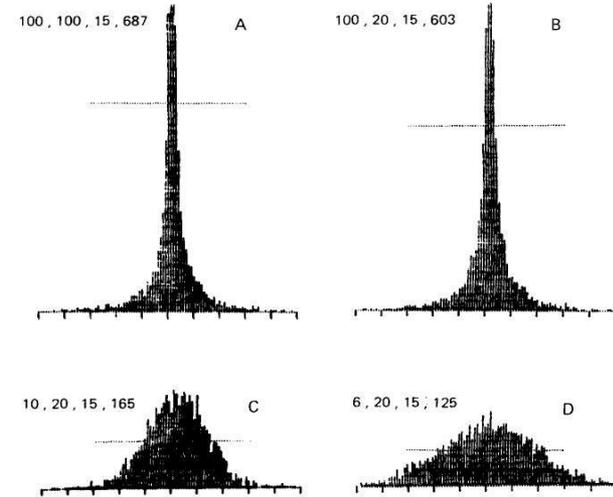


Fig. 5. Histograms of the luminosity distribution in the total energy of electron and positron collisions. The step of the histograms is  $0.01 \sigma_t$ , where  $\sigma_t = \sqrt{2} \sigma_{\Delta E/E}$  and there are 10 steps between two graduation lines. The parameters of the rf-monochromatization scheme, used in the numerical simulation, are given on each plot in the following order:  $\kappa_0$ ,  $a_x/\sigma_{x1}$ ,  $\lambda/\sigma_1$ . The fourth number shows the number of particles in the peak. The upper parts of the first two histograms lying above a certain level are not shown on the plot. An additional horizontal line on all the plots shows the half height of the peak.

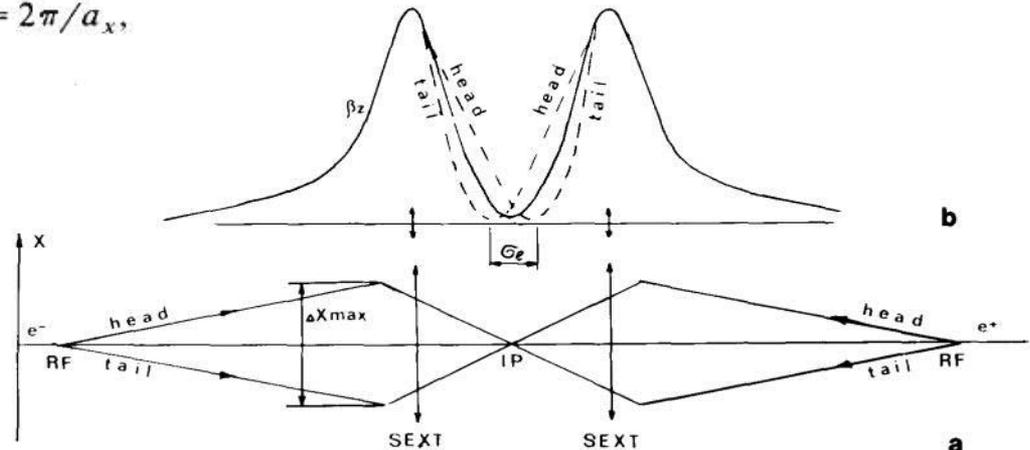


Fig. 6. a) The trajectories of the head and the tail of the bunch in the region between AS. b) The behaviour of  $\beta_z$ -function.

# Snowmass2021 Letter of Interest

## Monochromatized direct s-channel Higgs production in $e^+e^-$ at $\sqrt{s}=125$ GeV

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### Abstract

The FCC-ee could allow the measurement of the electron Yukawa coupling,  $k_e$ , in a dedicated run at  $\sim 125$  GeV center-of-mass (CM) energy, provided that the CM energy spread,  $\sigma_{\text{ecm}}$ , can be made comparable to the width of the standard model Higgs boson itself  $\Gamma_H \approx 4.2$  MeV, and that enough luminosity is integrated under such conditions. The natural collision-energy spread at 125 GeV, due to synchrotron radiation, is about 50 MeV. Its reduction to the desired level can be accomplished by means of monochromatization, e.g., through introducing nonzero horizontal dispersion of opposite sign at the interaction point (IP), for the two colliding beams. Such nonzero IP dispersion leads to an increase of the transverse horizontal emittance from beamstrahlung. Self-consistent IP parameters need to be determined and optimized for maximum sensitivity to the  $k_e$  coupling. Modifications of the standard final-focus optics are required for generating the required IP dispersion and for the possible accommodation of crab cavities. Alternative monochromatization scenarios, as well as improvements of the (simulated) data analysis, can also be explored. This effort addresses the only known pathway to measure an important property of the Higgs boson and to understand the origin of the electron mass.

# a few conclusions

several approaches exist to achieve monochromatized s-channel Higgs production at FCC-ee, with e.g.  $L \sim 10^{35} \text{ cm}^{-2}\text{s}^{-1}$ , or higher, at  $\sigma_W \sim 6 \text{ MeV}$  - is this of interest for physics? how should we optimally trade off luminosity and energy spread?

there are quite a number of monochromatization approaches – in addition to those presented, there also is a scheme based on angular IP dispersion (Telnov), another one with strong RF focusing (Bogomyagkov & Levichev), and of course  $D_y^* \neq 0$ .

crab cavities needed in the monochromatization baseline could also be used for the Zholents scheme; perhaps a combination of these schemes would be optimum

we are assembling a stronger team (**CNRS IJCLab**, CERN, ANL, SLAC, BINP, Guanajuato, ...) to address open questions – notice great interest from the particle-physics community