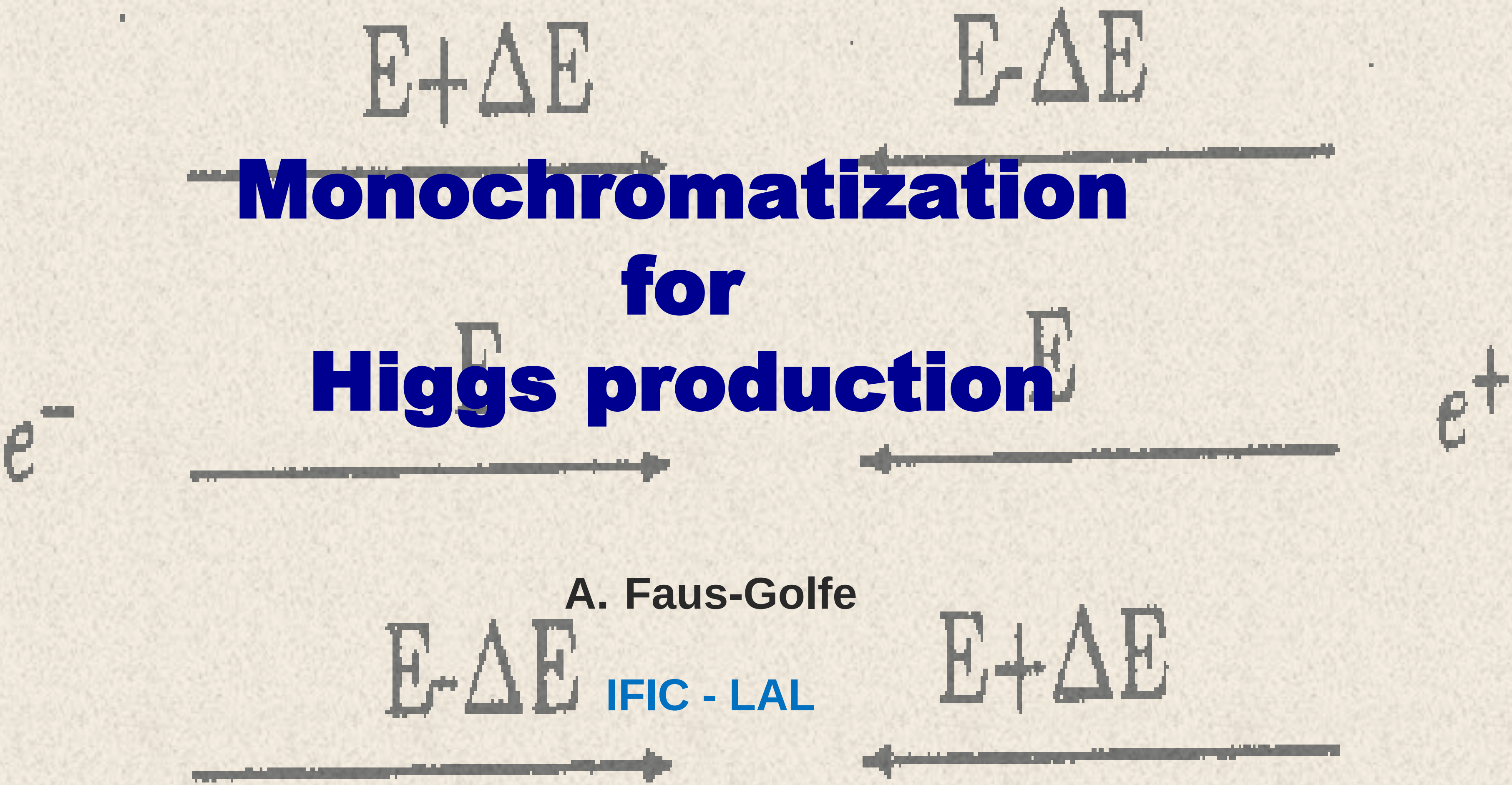

Monochromatization for Higgs production

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IFIC - LAL

Outline

- Objectives
- Monochromatization principle
  - Energy Resolution and Monochromatization
  - Monochromatization factor
  - Standard scheme
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- Monochromatization implementation in FCC-ee Higgs production
  - Standard and Optimized scheme implementation
- Conclusions and Further studies

Objectives

- The aim is to monochromatize the FCC-ee beams at E_{CM} = 125.2 GeV for the production of e+e ---> H(125.2) in the s-channel, just like a muon collider, but with hopefully much higher luminosity -- and lower cross-section. The Higgs width is 4.2 MeV and the FCC-ee energy spread is about $5x10^{-4}$ at these energies, so one needs to gain a factor 10 in energy spread. We also need to keep the beams polarized to keep track of the beam energy precisely.

- From previous study we could conclude that there is no fundamental reason against monochomatization, but given the FCC-ee optics configuration (IP dispersion can be generated independently for the two beams since there are two separate e+ / e- channels) horizontal dispersion at the IP (opposite sign) is the more natural option. Based on this option and the related trade-off between horizontal focusing and horizontal dispersion, we have studied the impact on luminosity and the options to avoid losses.

Monochromatization principle

Energy Resolution: $s_w = \sqrt{2} E_0 s_e$

energy spread

$$\sigma_\varepsilon^2 = \frac{55 \hbar c E_0^2}{32\sqrt{3}(mc^2)^3} \frac{I_3}{I_2} \frac{1}{J_\varepsilon}$$

$$s_w \mu \frac{1}{\sqrt{r J_e}}$$

To increase S_w

$r >>>$ bending radius

$0.5 £ J_e = 3 - J_x £ 2.5$ longitudinal partition number

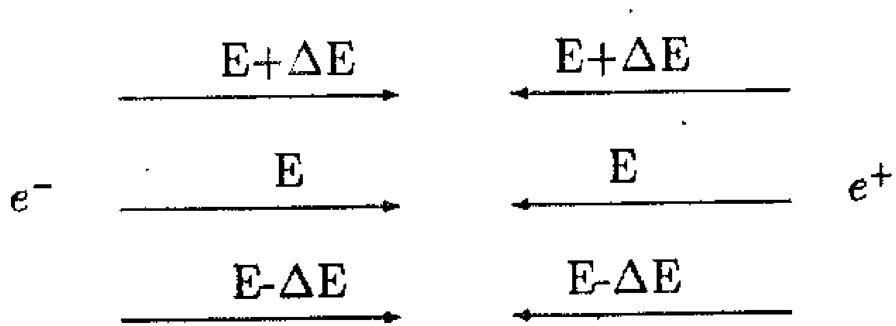
Monochromatization [7]

Monochromatization principle

Standard collision:

dispersion has the same sign in the IP

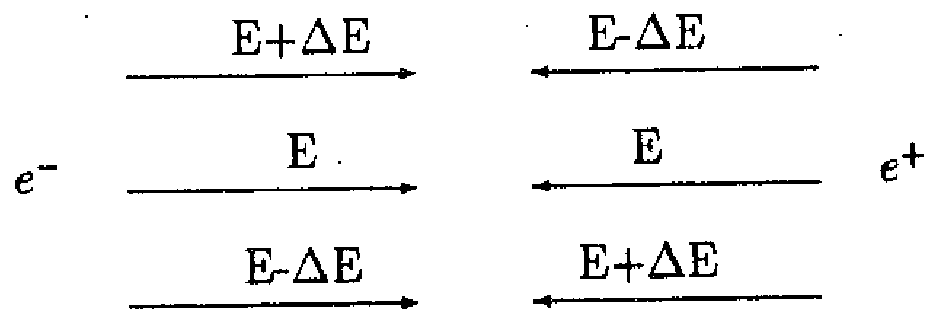
$$w = 2\left(E_0 + e\right)$$



Monochromatization:

dispersion has opposite sign in the IP

$$w = 2E_0 + 0(e)^2$$



Enhancement of energy resolution, and sometimes increase of the relative frequency of the events at the centre of of the distribution.

Monochromatization principle   Monochomatization factor

1) Case with: $D^*_{x,y}=0$

$$L_0 = \frac{k_b f_r N_+ N_-}{4\pi \sigma^*_{x\beta}\sigma^*_{y\beta}}$$

2) Case with: $D^*_{x+} = - D^*_{x-} = D^*_x$

$D^*_{y+} = - D^*_{y-} = D^*_y$

Monochromatization factor

$$\lambda = (1 + \sigma_\varepsilon^2 (\frac{D_x^{*2}}{\sigma_{x\beta}^{*2}} + \frac{D_y^{*2}}{\sigma_{y\beta}^{*2}}))^{1/2}$$

$$L = \frac{L_0}{\lambda}$$

$$\Sigma_w = \frac{\sqrt{2} E_0 \sigma_\varepsilon}{\lambda}$$

- Opposite dispersions at the IP enhance energy resolution without detriment of the differential luminosity while dispersion which have the same sign degrade both differential and total luminosity

- When $\sigma^*_y <<< \sigma^*_x$ is more efficient to produce dispersion in the vertical plane trying to keep it zero horizontally

Monochromatization principle "Standard" Scheme

$\sigma^*_y <<< \sigma^*_x$ → $D^*_{x+} = D^*_{x-} = 0$
$D^*_{y+} = - D^*_{y-} = D^*_y$

Implementations historical Studies:

- VEPP4: one ring, electrostatic quads [3][12]
- SPEAR: one ring, electrostatic quads, λ~8 [9]
- LEP: one ring, electrostatic quads (limited strength) and alternative RF magnetic quads, λ~3 (optics limitations) [2] [10]
- Superconducting RF resonators [33]
- Tau-Charm factory: two rings, vertical dipoles, , λ~7.5 [3] [4] [6]]8] [11] [13] [32]

Never tested experimentally !!!!!!

Higgs factory:

$$E_0 = 120\ GeV$$
$$N_b = 0.46\ 10^{11}$$
$$I = 30\ mA$$
$$\epsilon_x = 0.94\ nm$$
$$\epsilon_y = 1.9\ pm$$
$$\beta_x^* = 0.5\ m$$
$$\beta_y^* = 1.0\ mm$$
$$\sigma_x^* = 22\ \mu m$$
$$\sigma_y^* = 0.044\ \mu m$$
$$\sigma_\varepsilon = 0.001$$
$$\sigma_b = 1.17\ mm$$
$$L_0 = 6.0\ 10^{34}\ cm^{-2}s^{-1}$$

choosing

$$D_x^* = 0.1\ m$$
$$D_y^* = 0.0$$

Monochromatization factor

$$\lambda = (1 + \sigma_\varepsilon^2 \frac{D_x^{*2}}{\sigma_{x\beta}^{*2}})^{1/2} = 4.65$$

Luminosity

$$L = \frac{L_0}{\lambda} = 1.29\ 10^{34}\ cm^{-2}s^{-1}$$

Standard deviation of w

$$\Sigma_w = \frac{\sqrt{2}E_0\sigma_\varepsilon}{\lambda} = \frac{0.17}{4.65} = 0.036\ GeV$$

Monochromatization principle "Optimized" Scheme

Optimizing the beam parameters we could **gain** in **energy resolution keeping** the **luminosity** constant and the beam-beam in the standard limits !!!!!!

Rewriting some formulas:

$$\sigma_y^* << \sigma_x^* \Rightarrow$$

$D^*_{y+} = D^*_{y-} = 0$
$D^*_{x+} = - D^*_{x-} = D^*_x$

$$\frac{\sigma_\varepsilon^2 D_x^{*2}}{\sigma_{x\beta}^{*2}} >> 1$$

$$\Sigma_w \simeq \sqrt{2} E_0 \sqrt{\frac{\epsilon_x}{H_x^*}}$$ with $$H_x^* = \frac{D_x^{*2}}{\beta_x^*}$$ horizontal invariant dispersion

$$\xi_{xy} = \frac{N_b r_e \beta_{xy}^*}{2\pi\gamma\sigma_{xy}^*(\sigma_x^* + \sigma_y^*)} \Rightarrow L = \frac{I\gamma}{2er_e}\left(\frac{\xi_x}{\beta_x^*} + \frac{\xi_y}{\beta_y^*}\right)$$

with $\sigma_x^* \simeq \sigma_\varepsilon D_x^*$ $\Rightarrow$

$$\xi_x << \xi_y \simeq \xi_{max}$$

$$\frac{\xi_y}{\beta_y^*}$$ dominant term

The new condition for an **optimized scheme** with:

$$\beta_y^* << \beta_x^* \qquad \sigma_y^* << \sigma_x^* \qquad \xi_x < \xi_y$$

$$L \simeq \frac{I\gamma}{2er_e}\frac{\xi_y}{\beta_y^*} \qquad\qquad \frac{2\pi\gamma}{N_b r_e}\epsilon_y \xi_y \frac{\beta_x^*}{\beta_y^*} \leq 1$$

The beam-beam parameter could be maximized in the plane where dispersion is zero, keeping lower value in the plane where dispersion is different from zero

Monochromatization principle "Optimized" Scheme for FCC-ee

Higgs factory:

$$E_0 = 120\ GeV$$
$$\sigma_\varepsilon = 0.001$$
$$\sigma_b = 1.17\ mm$$

choosing

$$D_x^* = 0.1\ m$$
$$\beta_y^* = 0.001,\ 0.005,\ 0.05,\ 0.01\ m$$
$$\beta_x^* = 0.5,\ 0.1,\ 0.05,\ 0.01\ m$$

keeping

$$L_0 = 6.0\ 10^{34}\ cm^{-2} s^{-1}$$
$$\xi_y = 0.09$$

→

Monochromatization principle "Optimized" Scheme for FCC-ee

$L = 6.0\ 10^{34}\ cm^{-2}s^{-1}$	$\xi_y = 0.09$			
$\beta_y^*[m]$	0.001	0.005	0.01	0.05
N_b	$3.8\ 10^{10}$	$1.95\ 10^{11}$	$3.8\ 10^{11}$	$1.95\ 10^{12}$
$\beta_x^*[m]$	0.5	0.5	0.5	0.5
$\epsilon_y[m\ rad]$	$1.6\ 10^{-12}$	$4.1\ 10^{-12}$	$1.6\ 10^{-10}$	$4.1\ 10^{--9}$
$\sigma_y^*[m]$	$4.0\ 10^{-8}$	$1.4\ 10^{-7}$	$1.3\ 10^{-6}$	$1.4\ 10^{-5}$
$\sigma_x^*[m]$	$1.02\ 10^{-4}$	$1.02\ 10^{-4}$	$1.02\ 10^{-4}$	$1.02\ 10^{-4}$
ξ_x	0.007	0.018	0.069	0.151

Monochromatization principle "Optimized" Scheme for FCC-ee

$L = 6.0\ 10^{34}\ cm^{-2}s^{-1}$ $\xi_y = 0.09$				
$\beta_y^*[m]$	0.001	0.005	0.01	0.05
N_b	$3.8\ 10^{10}$	$1.95\ \ 10^{11}$	$3.8\ 10^{11}$	$1.95\ \ 10^{12}$
$\beta_x^*[m]$	0.1	0.1	0.1	0.1
$\epsilon_y[m\ rad]$	$8.1\ 10^{-12}$	$2.1\ 10^{-11}$	$8.1\ 10^{-10}$	$2.1\ 10^{--10}$
$\sigma_y^*[m]$	$9.0\ 10^{-8}$	$3.2\ 10^{-7}$	$2.8\ 10^{-6}$	$3.2\ 10^{-5}$
$\sigma_x^*[m]$	$1.0\ 10^{-4}$	$1.0\ 10^{-4}$	$1.0\ 10^{-4}$	$1.0\ 10^{-4}$
ξ_x	0.0007	0.0037	0.007	0.028

$L = 6.0\ 10^{34}\ cm^{-2} s^{-1}$ $\xi_y = 0.09$				
$\beta_y^* [m]$	0.001	0.005	0.01	0.05
N_b	$3.8\ 10^{10}$	$1.95\ \ 10^{11}$	$3.8\ 10^{11}$	$1.95\ \ 10^{12}$
$\beta_x^* [m]$	0.05	0.05	0.05	0.05
$\epsilon_y [m\ rad]$	$1.6\ 10^{-11}$	$4.1\ 10^{-11}$	$1.6\ 10^{-9}$	$4.1\ 10^{--8}$
$\sigma_y^* [m]$	$1.3\ 10^{-7}$	$4.5\ 10^{-7}$	$4.0\ 10^{-6}$	$4.5\ 10^{-5}$
$\sigma_x^* [m]$	$1.0\ 10^{-4}$	$1.0\ 10^{-4}$	$1.0\ 10^{-4}$	$1.0\ 10^{-4}$
ξ_x	0.0004	0.0019	0.004	0.012

Monochromatization principle “Optimized” Scheme for FCC-ee

$L = 6.0\ 10^{34}\ cm^{-2}s^{-1}$ $\xi_y = 0.09$				
$\beta_y^*[m]$	0.001	0.005	0.01	0.05
N_b	$3.8\ 10^{10}$	$1.95\ 10^{11}$	$3.8\ 10^{11}$	$1.95\ 10^{12}$
$\beta_x^*[m]$	0.01	0.01	0.01	0.01
$\epsilon_y[m\ rad]$	$8.1\ 10^{-11}$	$2.1\ 10^{-10}$	$8.1\ 10^{-9}$	$2.1\ 10^{--7}$
$\sigma_y^*[m]$	$2.8\ 10^{-7}$	$1.0\ 10^{-6}$	$9.0\ 10^{-6}$	$1.0\ 10^{-4}$
$\sigma_x^*[m]$	$1.0\ 10^{-4}$	$1.0\ 10^{-4}$	$1.0\ 10^{-4}$	$1.0\ 10^{-4}$
ξ_x	0.00007	0.0004	0.0007	0.002

Conclusions

- There is no fundamental reason against monochomatization.
- Implementation of a “standard” and even an “optimized” scheme seems not so difficult.
- But monochomatization has never been tested experimentally these means a flexible lattice with two modes of operation with/without is mandatory.

Further studies

Drawbacks:

- D_x^* gives rise quantum excitation which increase horizontal emittance
- Residual coupling
- Aperture limitation
- Dynamic Aperture reduction
- Beam-Beam including parasitic crossings
- Estimations of the broad band and the narrow band impedances and the current limits
- Touschek lifetime
- Polarization ring
- Background and masking

References

[1] R. Eichler et al., Proposal for an electron–positron collider for heavy flavor particle physics and synchrotron radiation (PSI PR 88-09, 1988).

[2] J.M. Jowett, CERN LEP-TH 87-56 (1987).

[3] A.A. Zholents, CERN SL/AP 92-27 (1992).

[4] P.F. Beloshitsky, A magnet lattice for a Tau-Charm factory suitable for both standard scheme and monochromatization scheme (LAL-RT 92-09, July 1992).

[5] SLAC linear collider conceptual design report, SLAC report 229 (1980).

[6] J. Gonichon, J. Le Duff, B. Mouton and C. Travier, Preliminary study of a high luminosity e^+e^- storage ring at a CM energy of 5 GeV (LAL-RT 90-02, January 1990).

[7] A Renieri, Possibility of achieving very high energy resolution in e^+e^- storage rings, Frascati Preprint INF/75/6(R) (1975).

[8] A.A. Advienko et al., The project of modernization of the VEPP-4 storage ring for monochromatic experiments in the energy range of Ψ and Υ mesons, Proc. 12th Int. Conf. on High Energy Accelerators, Batavia (1983).

[9] K. Wille and A.W. Chao, SLAC/AP-32 (1984).

[10] M. Bassetti and J.M. Jowett, Proc. IEEE Part. Accel. Conf., Washington (1987) p. 115 and CERN/LEP-TH/87-09 (1987).

[11] A. Faus-Golfe and J. Le Duff, A versatile lattice for a tau-charm factory that includes a monochromatization scheme (LAL-RT 92-01, February 1992).

[12] A.L. Gerasimov and A.A. Zholents, Proc. 13th Int. Conf. on High Energy Accelerators, Novosibirsk (1986) and Preprint INP 86-85, Novosibirsk (1986).

[13] A.L. Gerasimov, D.N. Shatilov and A.A. Zholents, Nucl. Instr. and Meth. A 305 (1991) 25.

[14] DESY Storage Ring Group, Proc. 9th Int. Conf. on High Energy Accelerators, Stanford (1974) p. 43.

[15] A.L. Gerasimov, D.N. Shatilov and A.A. Zholents, Proc. 9th Int. Conf. on High Energy Accelerators, Stanford (1974).

[16] K.W. Robinson, Phys. Rev. 111 (2) (1958) 373.

[17] A. Hoffman, LEP Note 192, October 1979.

[18] Workshop 4th Generation Light Sources SSRL 92/02 (1992).

[19] M. Sommer, Optimization of the emittance of electron–positrons storage rings, LAL-RT 83-15, November 1983.

[20] G. Wüstefeld, The minimization of the natural emittance in the Triple Bend Achromat, Technischer Bericht BESSY TB 108-87 (1987).

[21] A Jackson, A comparison of the Chasman–Green and Triple Bend Achromat, LBL 21279 (1986).

[22] H. Kung, C. Travier and C.C. Kuo, Emittance calculation for a TBA storage ring, SRRC/BD 87-04 (1987).

[23] L. Farvacque, J.L. Laclare and A. Ropert, BETA User's Guide, ESRF-SR LAT-88-08, Grenoble, March 1987, revised in February 1989.

[24] H. Grote and F. Christoph Iselin, CERN SL/AP 90-13 (Rev. 3) (1993).

References

[25] M. Donald and D. Schofield, A User's guide to the HARMON program, LEP Note 420 (1982).

[26] F. Iazzourene, C.J. Bocchetta, R. Nagaoka, L. Tosi and A. Wrulich, RACE-TRACK User's guide Version 4.01, ST/M 92-7, July 1992.

[27] R.P. Walker, Proc. IEEE Part. Accel. Conf., Washington, vol. 1 (1987) p. 491.

[28] U. Völkel, Particle Loss by Touschek Effect in a Storage Ring, DESY 67-5 (1967).

[29] J. Haissinski, Rapport technique 52.63 bis Rubriques: Problèmes Théoriques généraux (1963).

[30] Y. Alexahin, Calculation of the Touschek lifetime JINR Dubna, private communication.

[31] J. Haissinski, RT 5-64 Anneaux de stockage, Laboratoire de l'Accélérateur Linéaire, Orsay (1964).

[32] A. Faus-Golfe and J. Le Duff, *Versatile DBA and TBA lattices for a Tau-Charm Factory with and without beam Monochromatization*. NIM A 372 (1996) 6-18.

[33] A. Zholents, *Shopisticated Accelerator Techniques for Colliding Beam Experiments*. NIM A 265 (1988) 179-185.

Thanks for your attention