Asymptotic pion and kaon production in gamma gamma collisions

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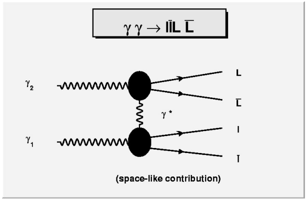
Outline

Two fermions pair production ($\gamma\gamma \to l\bar{l}L\bar{L}$) : a little history (starting in $\simeq$ 1970) and motivation for PLC, ILC and LHC.

- **Pseudo Pair Configurations (peripheral diagrams)**



- **Total cross section computation**
  Two identical lepton pair production at infinite energy in $\gamma\gamma$ center of mass : L.N. Lipatov et al (1969),$\cdots$
  Two identical pion pair production : Chen et al. (1970)
- **Total and differential cross section.**
  Different pairs produced - main logarithmic approximation- gamma polarisation : V. G. Serbo et al. (1970 - 1985-1998 - $\cdots$)
- **Factorisation Formulae**
  cf. Kessler and C. Carimalo thesis (1974)
  Provide also powerful tools to calculate Helicity Amplitudes (Use of Helicity Coupling, $\cdots$)
- **Motivation Today**
  -Reference process for luminosity measurement at PLC
  - Can be a noise for low angle detector at ILC
  - Can be a background source to rare processes
  $\Rightarrow$ Only a realistic Monte-Carlo can give a correct answer (at low and high angle).
  $\Rightarrow$ have analytical formulas to test the validity of the Monte Carlo on some distributions

Our goal : obtain analytical formulas without mass approximation in order to have the accuracy of old formulas

We use the Factorisation Formulae : including all diagrams where the exchanged photon is space-like : Cf Kessler, Carimalo, $\cdots$ ($\gamma\gamma$ group of Collège de France)

$$\sigma = \int_{u_{min}}^{u_{max}} \int_{u'_{min}}^{u'_{max}} \int_{t_{min}}^{t_{max}} \frac{d\sigma}{dt du du'} du\, du'\, dt$$

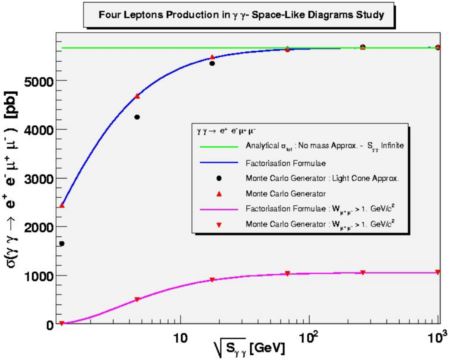
$$\frac{d\sigma}{dt du du'} = \frac{uu'}{8\pi^3 s^2 t^2} \Big((1 + ch^2\theta)\sigma_T \sigma'_T + sh^2\theta(\sigma_T\sigma'_L + \sigma_L\sigma'_T) + ch^2\theta\sigma_L\sigma'_L \Big)$$

with $$sh^2\theta = \frac{4st(t - t_{min})(t_{max} - t)}{(u + t)^2(u' + t)^2}$$

$$\sigma_T^{\gamma\gamma^\star \to l^+ l^-} = \frac{4\pi\alpha^2\beta u}{(u+t)^2} \left(\beta^2 - 2 + 2\frac{2t}{u} - \frac{t^2}{u^2} + \frac{3 - \beta^4 + 2t^2/u^2}{2\beta} L \right)$$

$$\sigma_L^{\gamma\gamma^\star \to l^+ l^-} = \frac{16\pi\alpha^2\beta t}{(u+t)^2} \left(1 - \frac{1-\beta^2}{2\beta} L \right)$$

$$L = \ln\left(\frac{1+\beta}{1-\beta}\right), \quad \beta = \sqrt{1 - \frac{4m^2}{u}}$$



- Blue line : Factorization Formula without cuts
- Pink line : Factorization Formula with cuts on muons
- Other results explain later in talk

Analytic formula for two fermion Pair production in $\gamma\gamma$ at infinite energy

We obtain finally (green line in the right figure) :

$$\sigma = \frac{4\alpha^4}{9\pi m m'}\left\{\frac{19}{16}\left[2\left(\frac{1}{u}-u\right)\ln(u)-\left(\frac{1}{u}+u\right)\left(2+\ln^2(u)\right)\right]+\left[\frac{25}{4}+\frac{19}{32}\left(\frac{1}{u}-u\right)^2\right]Poly(u)\right\}$$

where $Poly(u) = Poly(1/u) = \Lambda_3(u) - \Lambda_3(-u)$, $\quad \Lambda_n(z) = \int_0^z \frac{\ln^{n-1}|t|}{1+t}\,dt$ (Kummer function)

cf PLB B718-2012-577

When the two masses are very different ($m \gg m'$), we obtain :

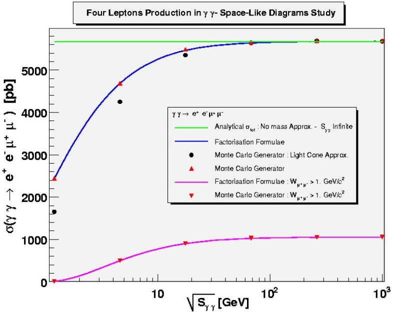
$$\sigma \simeq \frac{28\alpha^4}{27 m^2 \pi}\left(\ln^2(u^2) - \frac{103}{21}\ln(u^2) + \frac{485}{63}\right)$$

in agreement with Serbo et al. computation.
$ee\mu\mu$ Serbo et al production agrees with the exact expression within a relative accuracy of 10^{-5}.

When masses are equal ($m = m'$) we get :

$$\sigma = \frac{\alpha^4}{m^2\pi}\left(\frac{175}{36}\zeta(3) - \frac{19}{18}\right)$$

in agreement also with the well-known formula for identical pair production.



Factorization Formulae is used to compute the $\gamma\gamma \to \pi^+\pi^- l^+ l^-$ total cross section : $l^+ \equiv e^+, \mu^+, \tau^+$ - charged pions are depicted as scalar point-like particles in QED (Born Approximation, cf Cheng, Serbo, $\cdots$)

$$\sigma = \int_{u_{min}}^{u_{max}} \int_{u'_{min}}^{u'_{max}} \int_{t_{min}}^{t_{max}} \frac{d\sigma}{dtdudu'} du\, du'\, dt$$

$$\frac{d\sigma}{dtdudu'} = \frac{uu'}{8\pi^3 s^2 t^2} \Big((1 + ch^2\theta)\sigma_T \sigma'_T + sh^2\theta(\sigma_T\sigma'_L + \sigma_L\sigma'_T) + ch^2\theta\sigma_L\sigma'_L \Big)$$

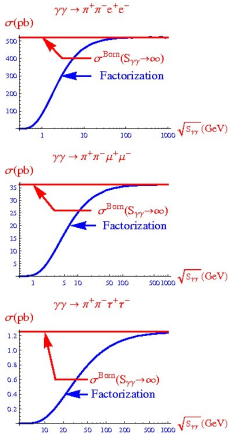
with $\quad sh^2\theta = \dfrac{4st(t - t_{min})(t_{max} - t)}{(u+t)^2(u'+t)^2}$

$$\sigma_T^{\gamma\gamma^\star \to \pi^+\pi^-} = \frac{2\pi\alpha^2\beta u}{(u+t)^2} \left[3 - \beta^2 + \frac{-3 + 2\beta^2 + \beta^4}{2\beta} \ln\left(\frac{1+\beta}{1-\beta}\right) \right]$$

$$\sigma_L^{\gamma\gamma^\star \to \pi^+\pi^-} = \frac{4\pi\alpha^2\beta t}{(u+t)^2} \left[-3 + \frac{3 - \beta^2}{2\beta} \ln\left(\frac{1+\beta}{1-\beta}\right) \right]$$

$$L = \ln(\frac{1+\beta}{1-\beta}), \quad \beta = \sqrt{1 - \frac{4m_\pi^2}{u}}$$

$$\sigma'_{T,L} = \sigma_{T,L}^{\gamma\gamma^\star \to l^+ l^-} \quad \text{(already defined)}$$



- Blue line : Factorization Formula
- Other results explain later in talk

Analytic formulae for $\gamma\gamma \to \pi^+\pi^- l^+ l^-$ cross section at Infinite Energy

We obtain finally (red line in the right figure) :

$$\sigma = \frac{\alpha^4}{72\pi m_\pi m_l}\left[-2\left(\frac{19}{u}+5u\right)\ln(u)+\left(\frac{19}{u}-5u\right)\left(2+\ln^2(u)\right)+\left(\frac{5u^2}{2}+27-\frac{19}{2u^2}\right)Poly(u)\right]$$

where $Poly(u) = Poly(1/u)$ (already defined), and $u = \frac{m_l}{m_\pi}$

When the two masses are very different ($m_\pi \gg m_e$), we obtain :

$$\sigma \simeq \frac{16\alpha^4}{27\pi m_\pi^2}\left[\ln^2\left(\frac{m_e}{m_\pi}\right)-\frac{8}{3}\ln\left(\frac{m_e}{m_\pi}\right)+\frac{163}{72}\right]$$

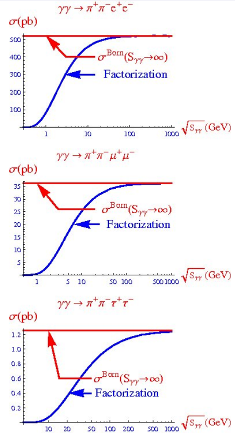
in agreement with Serbo et al. computation.

$\pi^+\pi^- e^+ e^-$ ($\pi^+\pi^-\mu^+\mu^-$)Serbo et al production, agrees with the exact expression within a relative accuracy of $5\ 10^{-6}$ ($9\ 10^{-2}$).

If we make $m_\pi \simeq m_\mu$ and $m_\pi \ll m_\tau$ we get :

$$\sigma \simeq \frac{7\alpha^4\left(5\zeta(3)+2\right)}{36\pi m_\pi^2}\left[1+\frac{62-7\zeta(3)}{7\left(5\zeta(3)+2\right)}\left(1-\frac{m_\mu}{m_\pi}\right)\right]$$

$$\sigma \simeq \frac{252\alpha^4}{243\pi m_\tau^2}\left[\ln^2\left(\frac{m_\tau}{m_\pi}\right)+\frac{20}{21}\ln\left(\frac{m_\tau}{m_\pi}\right)+\frac{247}{126}\right]$$



Factorization Formulae is used to compute the $\gamma\gamma \to \pi^+\pi^- K^+K^-$ total cross section : charged pions and kaons are depicted as scalar point-like particles in QED (Born Approximation, cf Cheng, Serbo, $\cdots$)

$$\sigma = \int_{u_{min}}^{u_{max}} \int_{u'_{min}}^{u'_{max}} \int_{t_{min}}^{t_{max}} \frac{d\sigma}{dtdudu'} du\, du'\, dt$$

$$\frac{d\sigma}{dtdudu'} = \frac{uu'}{8\pi^3 s^2 t^2} \Big((1 + ch^2\theta)\sigma_T \sigma'_T + sh^2\theta(\sigma_T\sigma'_L + \sigma_L\sigma'_T) + ch^2\theta\sigma_L\sigma'_L \Big)$$

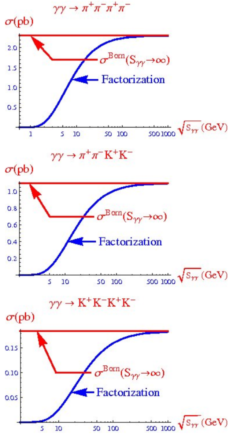
with $\quad sh^2\theta = \dfrac{4st(t-t_{min})(t_{max}-t)}{(u+t)^2(u'+t)^2}$

$$\sigma_T^{\gamma\gamma^\star \to \pi^+\pi^-} = \frac{2\pi\alpha^2\beta u}{(u+t)^2} \left[3 - \beta^2 + \frac{-3 + 2\beta^2 + \beta^4}{2\beta} \ln\left(\frac{1+\beta}{1-\beta}\right) \right]$$

$$\sigma_L^{\gamma\gamma^\star \to \pi^+\pi^-} = \frac{4\pi\alpha^2\beta t}{(u+t)^2} \left[-3 + \frac{3-\beta^2}{2\beta} \ln\left(\frac{1+\beta}{1-\beta}\right) \right]$$

$$L = \ln\Big(\frac{1+\beta}{1-\beta}\Big), \quad \beta = \sqrt{1 - \frac{4m_\pi^2}{u}}$$

$$\sigma'_{T,L} = \sigma_{T,L}^{\gamma\gamma^\star \to K^+K^-}$$

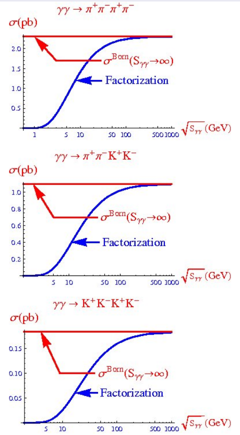


- Blue line : Factorization Formula
- Other results explain later in talk

We obtain finally (red line in the right figure) :

$$\sigma = \frac{5\alpha^4}{144\pi m_\pi m_K}\left[2\left(u - \frac{1}{u}\right)\ln(u) + \left(\frac{1}{u} + u\right)\left(2 + \ln^2(u)\right) + \left(\frac{4}{5} - \frac{1}{2}\left(\frac{1}{u} - u\right)^2\right) Poly(u)\right]$$

where $Poly(u) = Poly(1/u)$ (already defined), and $u = \frac{m_\pi}{m_K}$



If masses are equal (i.e. put $m_K \to m_\pi$) we get :

$$\sigma^{\rm Born}_{\gamma\gamma\to\pi^+\pi^-\pi^+\pi^-} = \frac{\alpha^4}{144\pi m_\pi^2}\left(7\zeta(3) + 10\right)$$

in agreement with H. Cheng and T. T. Wu.

If we put $u = \frac{m'}{m} \ll 1$ we get :

$$\sigma \simeq \frac{36\alpha^4}{243\pi m^2}\left[\ln^2(u) - \frac{7}{6}\ln(u) + \frac{77}{36}\right]$$

Inclusive cross section in $\gamma\gamma$ collisions at infinite energy :$\pi^+\pi^-K^+K^-$, $\pi^+\pi^-e^+e^-$, $\pi^+\pi^-\mu^+\mu^-$

Using the impact factor method the energy distribution of particles moving along the momentum of one photon is given by E.A. Kuraev, A. Schiller and V. G. Serbo

$$\frac{d\sigma_a}{dx_+ dx'_+} = \frac{4\alpha^4}{\pi} \int_0^\infty f(t, X, x_+) f'(t, X', x'_+) dt$$

with $f(f')$ function depends on lepton or scalar nature of the particle pair produced at one vertex :

$$f(t, X, x_+) = \begin{cases} \frac{x_+ x_-}{t} F_s(X) & \text{(scalar)} \\ \frac{-2x_+ x_-}{t} F_s(X) + \frac{X}{t} \ln \frac{1+X}{1-X} & \text{(lepton)} \end{cases}$$

$$F_s(X) = -1 + \frac{1}{2}\left(X + \frac{1}{X}\right) \ln \frac{1+X}{1-X}$$

where $x_+(x_-) \in [0,1]$, with $x_+ + x_- = 1$, is the incoming first photon energy fraction carried by the positive (negative) particle of the pair produced at one vertex. The function f' and the variables $x'_+(x'_-)$ are similarly defined for particle pair produced by the second incoming photon at the other vertex.

After integration without any mass approximation we have $\Rightarrow$

$$\frac{d\sigma_a^{\gamma\gamma\to S^+S^-S'^+S'^-}}{dx_+ dx'_+} = 18 x_+ x_- x'_+ x'_- \times \sigma^{\gamma\gamma\to S^+S^-S'^+S'^-}$$

$$\frac{d\sigma_a^{\gamma\gamma\to S^+S^-l'^+l'^-}}{dx_+ dx'_+} = 3x_+x_- \left[\sigma^{\gamma\gamma\to S^+S^-l'^+l'^-} + 2\left(1 - 6x'_+x'_-\right) \sigma_{\text{scal.}(l')}^{\gamma\gamma\to S^+S^-l'^+l'^-}\right]$$

$$\frac{d\sigma_a^{\gamma\gamma\to S^+S^-l'^+l'^-}}{dx_+} = 3x_+x_- \sigma^{\gamma\gamma\to S^+S^-l'^+l'^-} \simeq \frac{4\alpha^4}{9\pi m_\pi^2} x_+x_- \left[\ln^2 u^2 - \frac{16}{3}\ln u^2 + \frac{163}{18}\right]$$

$(u = \frac{m_e}{m_\pi} \ll 1)$, in agreement with Serbo et al. computation, $\pi^+\pi^- e^+e^-$ Serbo et al production agrees with the exact expression a relative accuracy lower than $5\ 10^{-6}$.

Inclusive cross section in $\gamma\gamma$ collisions at infinite energy :$ee\mu\mu$

$$\frac{d\sigma_a^{\gamma\gamma\to l^+l^-l'^+l'^-}}{dx_+dx'_+} = \frac{1}{2}\sigma^{\gamma\gamma\to l^+l^-l'^+l'^-}$$

$$+(1-6x_+x_-)\,\sigma_{\rm scal.(1)}^{\gamma\gamma\to l^+l^-l'^+l'^-}$$

$$+(1-6x'_+x'_-)\,\sigma_{\rm scal.(1')}^{\gamma\gamma\to l^+l^-l'^+l'^-}$$

$$+2\,(1-6x_+x_-)\,(1-6x'_+x'_-)\,\sigma_{\rm scal.(1,1')}^{\gamma\gamma\to l^+l^-l'^+l'^-}$$

$$= a - x_+x_-b - x'_+x'_-c + x_+x_-x'_+x'_-d$$

$$a \simeq \frac{8\alpha^4}{\pi m_\mu^2}\left(\frac{1}{8}\ln^2 u^2 - \frac{1}{2}\ln u^2 + 1\right)$$

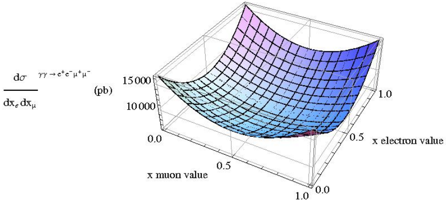
$$b \simeq \frac{8\alpha^4}{\pi m_\mu^2}\left(\frac{1}{6}\ln^2 u^2 - \frac{13}{18}\ln u^2 + \frac{40}{27}\right)$$

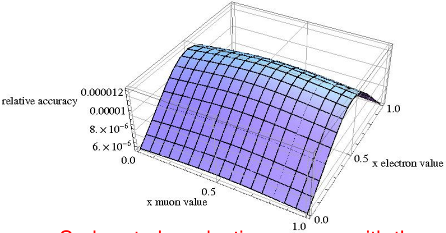
$$c \simeq \frac{8\alpha^4}{\pi m_\mu^2}\left(\frac{1}{4}\ln^2 u^2 - \frac{1}{2}\ln u^2 + 2\right)$$

$$d \simeq \frac{8\alpha^4}{\pi m_\mu^2}\left(\frac{1}{3}\ln^2 u^2 - \frac{7}{9}\ln u^2 + \frac{77}{27}\right)$$

$$(u = \frac{m_e}{m_\mu}) \ll 1$$

(a,b,c,d, in agreement with Serbo et al. computation)





$ee\mu\mu$ Serbo et al production, agrees with the exact expression within a relative accuracy lower than 2 10^{-5}.

- **Monte-Carlo generator : Old Status** :
  Fully integrated in ROOT (cf R. Brun et al)
  Event Generation with FOAM (cf S. Jadach)
- **Computation : first method (very fast).** Computation of the squared of the Helicity Amplitudes in the Impact Factor Method approximation which gives us the dominant term at low angle and high energy (black points in the right figure) .

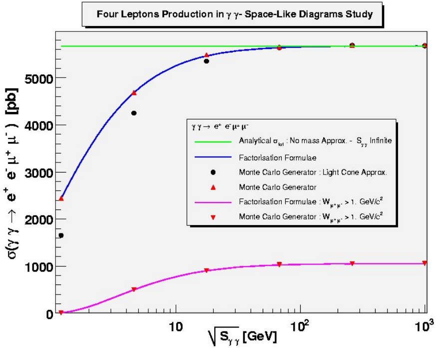
$$|M|^2 \sim L_{++} R_{--}$$

$$L_{++} = 4k_+^2 \left[\{(1-\bar{x}) P_{l/\gamma}(x) + l \leftrightarrow \bar{l}\} + 2\frac{\vec{l}_\perp . \vec{\bar{l}}_\perp}{ab} (x(1-\bar{x}) + \bar{x}(1-x)) - 2\frac{m^2}{ab} \right]$$

$$P_{l/\gamma}(x) = \frac{2m^2 x}{a^2} + \frac{x^2 + (1-x)^2}{a}$$

where $P_{l/\gamma}(x)$ is the lepton spectrum distribution, $l_+, l_-, \vec{l}_\perp$ are the lepton light cone variables, $x = 1 - \frac{l_+}{k_+}$ is the fraction of the photon energy taken by the quasi-real lepton l, $a = k_+ l_-$, $b = k_+ \bar{l}_-$ and $k_+ = \sqrt{S_{\gamma\gamma}}$

- **Computation : second method.** We compute the Helicity Amplitudes without approximation (red triangles in the right figure) in perfect agreement with the numerical integration of the factorization formulae (blue and pink (invariant mass cut)) lines.



$\gamma\gamma \to \pi^+\pi^- l^+ l^-, K^+K^- l^+ l^-, \pi^+\pi^-\pi^+\pi^-, K^+K^-K^+K^-, \pi^+\pi^-K^+K^-$ processes included in Monte-Carlo Generator (Born Term)

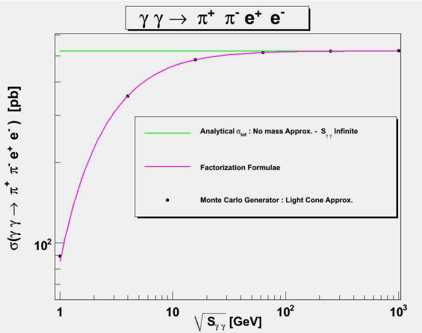
- Monte-Carlo generator : New Status :
- Fully integrated in ROOT (cf R. Brun et al)
- Event Generation with FOAM (cf S. Jadach)
- Fully integrated with Pythia 6 inside ROOT (cf T. Sjostrand)

- Computation : Impact Factor Method (black points in the right figure) .

$$|M|^2 \sim L_{++}^{\pi^+\pi^-} R_{--}$$

$$L_{++}^{\pi^+\pi^-} = 2k_+^2 \left\{ \left[\left(\frac{(1-x)}{a} - \frac{m_\pi^2}{a^2} \right) (1+x-\bar{x})^2 + l \leftrightarrow \bar{l} + \right] + \frac{2\vec{l}_\perp . \vec{\bar{l}}_\perp \,(1+x-\bar{x})\,(1+x-\bar{x})}{ab} \right\}$$

where $l_+, l_-, \vec{l}_\perp$ are the lepton light cone variables, $x = 1 - \frac{l_+}{k_+}$ is the fraction of the photon energy taken by the quasi-real lepton l, $a = k_+ l_-$, $b = k_+ \bar{l}_-$ and $k_+ = \sqrt{S_{\gamma\gamma}}$



Study mechanisms of pion pair production at ILC in $\gamma\gamma \to \pi^+\pi^- l^+ l^-$

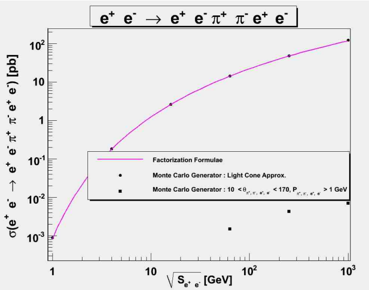
Lepton pair of $\gamma\gamma \to \pi^+\pi^- e^+ e^-$ $(\mu^+\mu^-)$ processes can be used for tagging pion pair

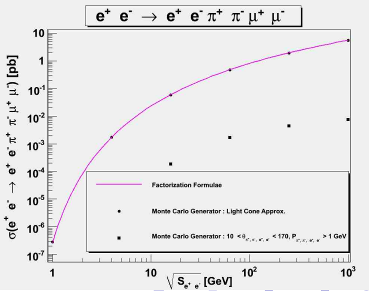
Cross Section Computation :

$$\sigma = \int_{z_{min}}^{z_{max}} dz\, 2z \int_{\frac{z^2}{z_{max}}}^{z_{max}} \frac{dy}{y} f_{\gamma/e}(y) f_{\gamma/e}\left(\frac{z^2}{y}\right)$$

$$\times\, \sigma^{\gamma\gamma \to \pi^+\pi^- l^+ l^-}\left(z\sqrt{S_{e^+e^-}}\right), \quad y = \frac{E_\gamma}{E_{beam}}$$

- Potential background for detectors at very low angle never taken into account (Need more studies with our Monte Carlo)
- Strong dependence of the visible cross section with angular and energy cuts applied
- $\sigma^{ILC}_{Visible} \simeq 0.1 - 10$ fb (black square in the right figure)
- $N_{evt} \simeq 10^2 - 10^4$ if $L(ILC) = 1\ \mathrm{ab}^{-1}$
- Need realistic simulation for bgk rejection (pion decay in flight background to $\gamma\gamma \to \pi^+\pi^-\mu^+\mu^-$,· · ·)





Study mechanisms of pion pair production at ILC in $\gamma\gamma \rightarrow \pi^+\pi^- l^+ l^-$

- Pseudorapidity Distribution (η)

Figure (right-top) :

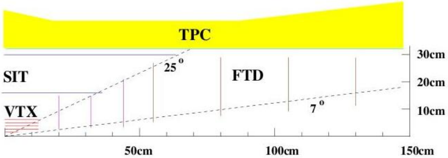
- Pion : $|\eta_{\mathrm{MAX.}}| \simeq 4$, but can be seen in FTD/VTX (blue line)
- Electron $|\eta_{\mathrm{MAX.}}| \simeq 6.5$, mostly in bean pipe but can be seen in FTD/VTX (red line)

Figure (right-midle) :

- Muon : $|\eta_{\mathrm{MAX.}}| \simeq 4$, but can be seen in FTD/VTX(red line)

Figure (right-bottom) :

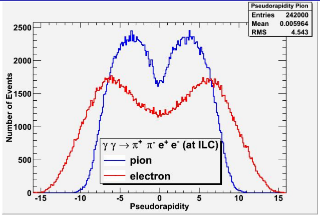
- $\gamma\gamma \rightarrow \pi^+\pi^-$ (blue line)$u\bar{u}$ (blue line), photon exchanged beetween $\pi^+\pi^-$ pair and $u\bar{u}$ pair. Products of $u\bar{u}$ fragmentation (green line)

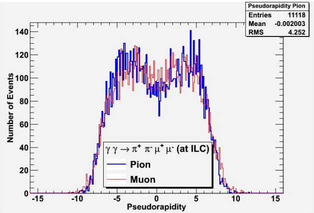


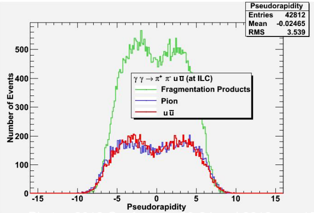
Vertex Detector (VTX) $-1.9 \lesssim \eta \lesssim 1.9$

Forward Tracker (FTD) $-3 \lesssim \eta \lesssim 3$

$\Rightarrow$ Many particles are produced in the beam pipe, but a significant fraction can be seen at low angle.







Study mechanisms of pion pair production at LHC in $\gamma\gamma \rightarrow \pi^+\pi^- l^+ l^-$

- **Cross Section Computation :**

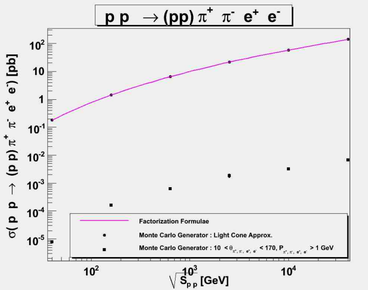
$$\sigma = \int_{z_{min}}^{z_{max}} dz 2z \int_{\frac{z^2}{z_{max}}}^{z_{max}} \frac{dy}{y} f_{\gamma/p}(y) f_{\gamma/p}(\frac{z^2}{y})$$

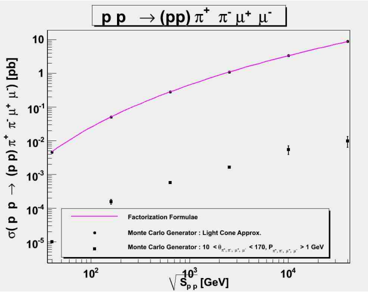
$$\sigma^{\gamma\gamma \rightarrow \pi^+\pi^- l^+ l^-}(W_{\gamma\gamma})$$

$$f_{\gamma/p}(y, \mu^2) = f_{\gamma(el)/p}(y) + f_{\gamma(inel)/p,Q^2}(y)$$

$y = \frac{E_\gamma}{E_{beam}}$ and Q^2 is the resolution scale at which the proton is probed.

- **Photon content of proton used :**
  -elastic contribution (Bernd A. Kniehl)
  -inelastic comtribution (M. Glück et al),
- **Few events but clear signature**
  $\sigma^{LHC}_{Visible} \simeq 0.1 - 1$ fb (depending strongly on CUTS)
  if $L(LHC) = 100 \text{ fb}^{-1} \rightarrow \text{N}_{\text{evt}} \simeq 10 - 100$
  (need realistic simulation for bgk rejection ⇒ conclusion)
- **Use Roman pot** to tag proton(s) ?





Study mechanisms of pion pair production at LHC in $\gamma g \rightarrow \pi^+\pi^- Q\bar{Q}$

- **Central Cross Section :**
  Photon exchanged beetween pion pair and quark pair

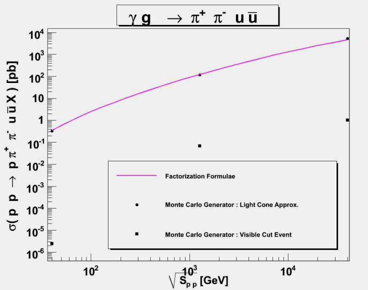
$$\sigma^{\gamma g \rightarrow \pi^+\pi^- Q\bar{Q}} = \frac{1}{8} 4 e_Q^2 \frac{\alpha_s}{\alpha} \frac{1}{2} \sigma^{\gamma\gamma \rightarrow l\bar{l} Q\bar{Q}}$$

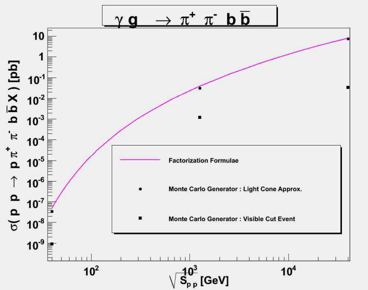
- **PDF :**
  Gluon content of the proton used : CTEQ6
  Photon content of the proton used : elastic (Bernd A. Kniehl) and inelastic (M. Glück et al).
- **Pion pair and $Q\bar{Q}$ pair inside detector**

$$\sigma_{Visible}^{LHC : \gamma g \rightarrow \pi^+\pi^- u\bar{u}} \simeq 100 \text{ fb} - 1000 \text{ fb}$$

$$\sigma_{Visible}^{LHC : \gamma g \rightarrow \pi^+\pi^- b\bar{b}} \simeq 1 \text{ fb} - 10 \text{ fb}$$

- Need realistic LHC estimation of background (simulation, pile-up $, \cdots$) to see if we can extract the signal
- Remember : pseudo pair configuration can give some "strange" events
  pion pair and $Q\bar{Q}$ are back to back in γg center of mass and are produced at low angle $\Rightarrow$ After boost some pion pair are not visible and $Q\bar{Q}$ pair is visible from one side of the detector $\Rightarrow$ strange events

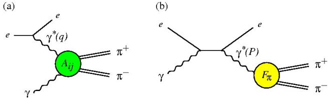




A Monte-Carlo for Exclusive production of pion pairs in $\gamma^*\gamma$ collisions at large Q^2

INPUT : M. Diehl, T. Gousset and B. Pire (Phys.Rev.D62:073014,2000)

- $e\gamma \rightarrow e\pi\pi$



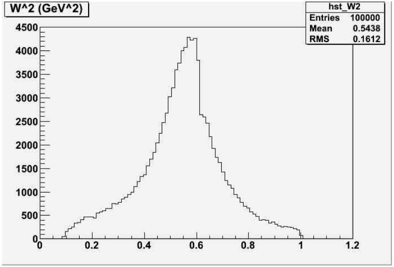
(a) $\gamma^*\gamma$ scattering and (b) bremsstrahlung.
Green blob denotes the two-pion generalized distribution amplitudes (GDAs)

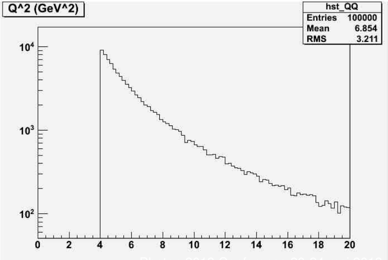
- C program differential cross section (M. Diehl)

OUTPUT : Monte-Carlo generator :

- Fully integrated in ROOT (cf R. Brun et al)
Event Generation with FOAM (cf S. Jadach)

BABAR simulation example :
$e^-e^+ \rightarrow e^-(Q^2)e^+\ \pi^+\pi^-(W^2)$





Summary

- Monte-carlo for Pseudo pair production is ready (fully integrated in ROOT software).
- Provide analytical formulas without mass approximation for the total and inclusive cross section of the process $\gamma\gamma \to \pi^+\pi^- + \text{ 2 leptons}$ and $\gamma\gamma \to \pi^+\pi^- K^+ K^-$.
- Monte-Carlo for two pion exclusif production in $\gamma^*\gamma$ collisions at large Q^2 is ready.(fully integrated in ROOT software)

- Outlook
  - Need to continue the study of each process if we want the error on the number of events computed (validity range of Born approximation, contributions of other process with same final state, $\cdots$)
  - Include “ILC photon fluxes” and simulate theses events at ILC
  - LHC :Include more realistic photon fluxes in our Monte-Carlo in p p case (Q^2 and angulaire dependence for photons)
  - Belle 2 simulation for two pion exclusif production in $\gamma^*\gamma$ collisions at large Q^2