Prospects at ILC
A gold place for QCD in the perturbative Regge limit

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Outline

1. QCD in the Regge limit: theoretical status
   - LL BFKL Pomeron
   - $k_T$ factorization
   - LL BFKL Pomeron: limitations
   - Higher order corrections
   - Non-linear regime and saturation
   - Onium-onium scattering as a gold plated experiment: $\gamma^{(*)}\gamma^{(*)}$ at colliders

2. Inclusive and Exclusive tests of BFKL dynamics
   - Hadron-hadron colliders
   - HERA
   - Total cross-section at LEP

3. Onium-onium scattering at ILC collider
   - Sources of photons
   - ILC project
     - cost
     - ILC collider
     - Detectors at ILC
   - $\gamma^*\gamma^* \rightarrow \text{hadrons}$ total cross-section
   - $\gamma^*\gamma^*$ exclusive processes
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At high energy $s \gg -t$, consider the elastic scattering amplitude of two IR safe probes.

\[ M_1^2 \gg \Lambda_{QCD}^2 \]
\[ M_2^2 \gg \Lambda_{QCD}^2 \]

Small values of $\alpha_s$ (perturbation theory applies due to hard scales) can be compensated by large $\ln s$ enhancements. \( \Rightarrow \) resummation of \( \sum_n (\alpha_s \ln s)^n \) series (Balitski, Fadin, Kuraev, Lipatov)
QCD in the Regge limit

QCD in the Regge limit

this results in the effective BFKL ladder, called Leading Log hard Pomeron.

one gets, using optical theorem

\[ \sigma_{\text{tot}} \sim s^{\alpha_P(0) - 1} \]

with \( \alpha_P(0) - 1 = C \alpha_S \quad C > 0 \)

\( \Rightarrow \) Froissart bound violated at perturbative order

equivalent approach at large \( N_c \): dipole model (Nikolaev, Zakharov; Mueller)

based on perturbation theory on the light-cone

equivalence between BFKL and dipole model proven at the level of diagrams

(Chen, Mueller) and at the level of amplitude (Navelet, S.W.)
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**QCD in the Regge limit**

$k_T$ factorization: illustration for $\gamma^*\gamma^* \to \gamma^*\gamma^*$ case

- Use Sudakov decomposition $k = \alpha p_1 + \beta p_2 + k_\perp$ and write $d^4k = \frac{1}{2} d\alpha d\beta d^2k_\perp$.

- Rearrange integrations in the large $s$ limit:

  $\Rightarrow$ set $\alpha_k = 0$ and $\int d\beta$

  $\Rightarrow$ set $\beta_k = 0$ and $\int d\alpha$

- Impact representation note: $k = \text{Eucl.} \leftrightarrow k_\perp = \text{Mink.}$

\[
\mathcal{M} = is \int \frac{d^2k}{(2\pi)^4 k^2 (r - k)^2} \mathcal{J} \gamma^* \to \gamma^* (k, r - k) \mathcal{J} \gamma^* \to \gamma^* (-k, -r + k)
\]
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how to fix the scale $s_0$ which enters in $\ln s/s_0$ resummation?

$\alpha_S$ is fixed at LL how to implement running and scale?

energy-momentum is not conserved in BFKL approach

- note that this remains at any order: NLL, NNLL, ...
- in the usual collinear renormalisation group approach (à la DGLAP), this is naturally implemented in the usual renormalisation group approach (vanishing of the first moment of splitting function):
  technically, from the very beginning, one starts with non local matrix elements. The energy-momentum tensor corresponds to its first moment, which is protected by radiative corrections
IR diffusion along the BFKL ladder: (for t-channel gluons, $k^2 \sim -k_T^2$)

- at fixed $\alpha_S$: gaussian diffusion of $k_T$ : cigar-like picture (Bartels, Lotter)
- the more $s$ increases, the larger is the broadness:
  
  define $l = \ln \frac{Q^2}{\Lambda_{QCD}^2}$ (fixed from the probes)
  
  and $l' = \ln \frac{k^2}{\Lambda_{QCD}^2}$ ($k^2$ = virtuality of an arbitrary exchanged gluon along the chain)

  then the typical width of the cigar is given by a diffusion picture: $\Delta t' \sim \sqrt{\alpha_S Y}$

  $\Rightarrow$ non-perturbative domain (NP) touched when $\Delta t' \sim \sqrt{\alpha_S Y} \sim t$

- using a simple running implementation tell that the border of the cigar touches NP for $Y \sim b_{QCD} t^3$ ($b = 11/12$)

- while the center of the cigar approaches NP when $Y \sim b t^2$ ("banana structure")

A more involved treatment of LL BFKL with running coupling (Ciafaloni, Colferai, Salam, Sasto) showed that the cigar is “swallowed” by NP in the middle of the ladder: one faces tunneling when $Y \sim t! \Rightarrow$ IR safety doubtless
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Higher order corrections to BFKL kernel are known at NLL order (Lipatov Fadin; Camici, Ciafaloni), now for arbitrary impact parameter
\[ \alpha_s \sum_n (\alpha_s \ln s)^n \] resummation

impact factors are known in some cases at NLL
- \( \gamma^* \rightarrow \gamma^* \) at \( t = 0 \) (Bartels, Colferai, Gieseke, Kyrieleis, Qiao)
- forward jet production (Bartels, Colferai, Vacca)
- \( \gamma^* \rightarrow \rho \) in forward limit (Ivanov, Kotsky, Papa)

⇒ this leads to very large corrections with respect to LL

rem: the main part of these corrections can be obtained from a physical principle, based on a kinematical constraint along the gluon ladder (which is subleading with respect to LL BFKL (Kwiecinski) However it is rather unclear whether this has anything to do with NLL correction: in principle this constraint would be satisfied when including LL+NLL+NNLL+NNNLL+....
Such a constraint is more related to in the mproved collinear resummed approach (see below) for which the vanishing of the first moment of the splitting function is natural.

These perturbative instabilities means that an improved scheme is desirable
either use a physical motivation to fix the scale of the coupling
- running should be implemented at NLL
- scale is fixed starting from NNLL
- it has been suggested to use BLM scheme in order to fix the scale: cf $\gamma^*\gamma^* \to X$ total cross-section (Brodsky, Fadin, Lipatov, Kim, Pivovarov) and $\gamma^*\gamma^* \to \rho\rho$ exclusive process (Enberg, Pire, Szymanowski, S.W; Ivanov,Papa)

either one uses a resummed approach inspired by compatibility with usual renormalization group approach
- (Salam; Ciafaloni, Colferai): in $\gamma^*(Q_1)\gamma^*(Q_2)$
  - takes care of full DGLAP LL $Q_1 \gg Q_2$
  - takes care of full anti-DGLAP LL $Q_1 \ll Q_2$
  - fixes the relation between rapidity $Y$ and $s$ is a symmetric way compatible with DGLAP evolution
  - implement running of $\alpha_s$

back to the infrared diffusion problem, such a scheme enlarge the validity of perturbative QCD.
- simplified version (Khoze, Martin, Ryskin, Stirling) at fixed $\alpha_s$

\[
\frac{1}{k^3 k'^3} \int \frac{d\omega}{2\pi i} \int \frac{d\gamma}{2\pi i} \left( \frac{k^2}{k'^2} \right)^{\gamma^{-1/2}} e^{\omega Y} \left( \omega - \omega(\gamma) \right)
\]

at LL is replaced by simply performing

\[
\frac{1}{\omega - \omega(\gamma)} \Rightarrow \frac{1}{\omega - \omega(\gamma, \omega)}
\]

$d\omega \Rightarrow$pole: one then solves $\omega = \omega(\gamma, \omega)$
$d\gamma$ at large $Y$ approximation $\Rightarrow$Saddle point in $\gamma$
takes into account the main NLL corrections (within 7 % accuracy)
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Froissart bound should be satisfied at asymptotically large $s$ and for each impact parameter $b$, $T(s, b) < 1$ should be satisfied

⇒ various unitarization and saturation models

- **Generalized Leading Log Approximation** in this approach one takes into account any fixed number $n$ of $t$-channel exchanged reggeons

  ⇒ Bartels, Jaroszewicz, Kwiecinski, Praszalowicz equation

  - looks like a 2-dimensional quantum meccanical problem with time $\sim \ln s$ involving $n$ sites
  - it is an integrable model in large $N_c$ limit (Lipatov; Faddeev,Korchemsky): XXX

Heisenberg spin chain
solution of BJKP (i.e. energy spectrum \( \Rightarrow \) intercept) exists for arbitrary \( n \)

- gives access to both Pomeron \( P = C = +1 \) and Odderon \( P = C = -1 \)
- for Odderon \( \alpha_O < 1 \) (Janik, Wosiek, Korchemsky, Kotanski, Manashov; Lipatov, de Vega)
- but only couples to non-leading impact factor
- for Odderon, the solution which couples to leading impact factor satisfies \( \alpha_O = 1 \):
  - either from perturbative Regge approach Bartels, Lipatov, Vacca
  - or from dipole model Kovchegov, Szymanowski, S.W.
Extended Generalized Leading Log Approximation

- in EGGLA (Bartels; Bartels, Ewerz) the number of reggeon in $t$–channel is non conserved. It satisfies full unitarity (in all sub-channel)
  $\Rightarrow$ effective 2-d field theory: realize the Gribov idea of Reggeon field theory in QCD
  simplest version: Balitski-Kovchegov equation which basically involves fan-diagrams
  (with singlet sub-channels)
- loops (in terms of Pomerons) corrections are unknown

- multipomeron approach: this makes contact with AGK cutting rules of pre-QCD
  (Bartels, Wüsthoff; Bartels, Vacca, Salvatore)
  In the large $N_c$ limit, this is the dominant contribution when coupling to physical impact factors (leading with respect to BJKP coupling) $\Rightarrow$ unitarization through multipomeron resummation
QCD in the Regge limit
non-linear regime and saturation: CGC

- **Color Glass Condensate** and B-JIMWLK equation
  - **JIMWLK**: This effective field theory is based on a scattering picture of a probe off the field of a source, which is treated through a renormalisation group equation with respect to longitudinal scale, with an explicit integration out of modes below this scale.
  - **Balitski**: Scattering of Wilson loops and computation of interaction of one loop on the field of the other (related to the eikonal phase approach à la Nachtmann (see also Kogut, Soper in QED).
  - **BK** equation is a simplified version corresponding to the mean field approximation: one neglect any multi-particle correlation except the two gluon one.
  - There is at the moment no clear one-to-one correspondence between EGLLA and CGC.
  - Loops (in terms of Pomerons) corrections are also unknown, although there is a claim that CGC could take into account an infinite set of loops by guessing the way to make the picture more symmetric.

- Toy models in 1+0 dimensions are under development (Reggeon field theory) to understand these corrections.
- Very interesting links exist between saturation models and statistical physics (reaction-diffusion models of the FKPP class) (Peschanski, Munier; Iancu, Mueller, Munier).
- The main feature of these saturation models is that they provide a saturation scale $Q_s(Y)$ which grows with $Y$.
  - Above this scale $T$ is small (color transparency).
  - Below this scale it saturates.
  - Due to this scale, the contribution of gluons with $k^2 < Q_s^2$ in a BFKL ladder is strongly reduced.
  - This may solve the IR diffusion problem.
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In order to test perturbative QCD in Regge limit, one should select peculiar observables:

- no IR divergencies:
  - select external or internal probes with a given transverse size \( \ll 1/\Lambda_{QCD} \)
    - hard virtual photon
    - heavy meson: \( J/\Psi, \Upsilon \)
    - energetic forward jets
  - or impose \( t \) to provide the hard scale

- observable dominated by the "soft" (but still perturbative) dynamics of QCD (BFKL and extensions) and not by its collinear dynamics (DGLAP, ERBL): probes should have comparable transverse sizes

- give the opportunity to control the spread in \( k_T \) of the partons: transition from linear to non-linear (saturated regime) This has to do with the increase of \( s \) for a given transverse size of the probes

- it should give access both to forward (i.e. inclusive) and non-forward (i.e. exclusive processes) dynamics

A process which satisfies such requirements is generically called onium-onium scattering.
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Inclusive and Exclusive tests of BFKL dynamics
hadron-hadron colliders

- **Mueller-Navelet ’87** jets: test of BFKLPomeran at $t = 0$
  - measure for two jets at large $p_T$ (=hard scale) separated by a large rapidity, including possible activity between these jets
  
  \[ k_1, y_1 = \ln(x_1 \sqrt{S/k_1}) \]
  \[ k_2, y_2 = -\ln(x_2 \sqrt{S/k_2}) \]
  \[ \Delta \eta = \ln(x_1 x_2 s / (k_1 k_2)) \]

  - the signal would be a decorrelation of relative azimuthal angle between emitted jets when increasing relative rapidity $\Delta Y$
  - measurement should be performed soon at CDF at large $\Delta Y$ (up to 12)
  - studies at NLL BFKL: Sabio Verra, Schwennsen; and resummed NLL BFKL: Marquet, Royon
  - more to come at LHC if CMS or ATLAS could allows measurement in the very forward region

- **diffractive** high energy (=hard scale) jet production: measure two jets with a gap in rapidity
  - **Mueller-Tang ’92**: test of BFKL Pomeran at $t \neq 0$ (Enberg, Ingelman, Motyka); involves non perturbative gap survival rapidity
high $p_T$ jet production at LL and NLL (Bartels, Sabio-Vera, Schwennsen) relies
- on computation of impact factors, kernel and Green function at LL and NLL order
- on the precise definition of emitted jet (made of one or two $s$–channel emitted particle which occurs at NLL (matters for the effective jet vertex)
- on a modeling of proton impact factor:
  The only hard scale is $p_T^2$ of the jet
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Since the beginning of HERA in 1992, there have been much efforts in order to see the perturbative Regge dynamics.

- **DIS** Peschanski, Navelet, Royon, S.W.; Golec Biernat, Kwiecinski (one hard scale = $Q^2$, model within the proton, either in term of coupling or in term of dipole densities)
  test of BFKL at $t = 0$
  both BFKL and DGLAP (NLL) can describe the data

- **energetic forward jet production** (hard scales = $\gamma^*$ and jet energy) Mueller; Bartels, Loewe, De Roeck; Kwiecinski, Martin, Sutton; Bartels, Del Duca, Wüsthoff
  test of BFKL at $t = 0$
  data seem to favor BFKL
exclusive vector meson production at large $t$ Forshaw, Ryskin; Bartels, Forshaw, Lotter, Wüsthoff; Forshaw, Motyka, Enberg, Poludniowski test of BFKL at large $t$

\[ \gamma p \rightarrow V \]

H1, ZEUS data seem to favor BFKL

Problems remains with spin density matrix (when considering all possible polarizations of $\rho$ and $\gamma$)
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At LEP, in particular at LEP2, the available energy in $s$ channel (from $\sqrt{s_{e^+e^-}} = 183$ to 202 GeV) was sufficient to expect a reasonable test of the total cross-section

Several groups investigated this process in LL BFKL (Bartels, Ewerz, Lotter, De Roeck, Staritzbichler; Brodsky, Hautmann, Soper), dipole model (Boonekamp, De Roeck, Royon, S.W.; Bialas, Czyz, Florkowski), modified LL BFKL (based on kinematical constraints) (Kwiecinski, Motyka), NLL BFKL (Brodsky, Fadin, Lipatov, Kim, Pivovarov).
Inclusive and exclusive tests of BFKL dynamics
Total cross-section at LEP: predictions for $\gamma^*\gamma^* \rightarrow \text{hadrons}$

Modified LL BFKL compared to Born. Figure from Motyka, Kwiecinski

BLM scale-fixed NLO BFKL predictions compared to Born. Figure from Brodsky, Fadin, Lipatov, Kim, Pivovarov
Motyka, Kwiecinski ’99 and ’00:
Amplitude evaluated in the modified LL BFKL approach (including kinematical constraints). Quark box (simulating usual DGLAP for $Q_1 \sim Q_2$, soft Pomeron and reggeon contributions where also evaluated.
comparison with L3 data
Inclusive and exclusive tests of BFKL dynamics
Total cross-section at LEP: comparison with data

Figure: Comparison of the OPAL preliminary data on the differential cross-section for doubly tagged events $d\sigma(e^+e^- \rightarrow e^+e^- + \text{hadrons})/dY$ with our predictions plotted as function of $Y$ for the $e^+e^-$ collision energies between 189 and 202 GeV. Figure from Motyka, Kwiecinski
data seems to favour a BFKL scenario

- Born 2 gluon exchange is too small
- quark exchange is too small in the large $\mathcal{Y}$ set of the data
- LL BFKL is too high
- quark mass effects are important (Bartels, Ewerz, Staritzbichler)
- a modified BFKL or a NLL BFKL with BLM scale fixing is plausible

however

- the minimal detection angle was limited to 30 mrad
- luminosity (eg: L3 617 pb$^{-1}$, 592.9 pb$^{-1}$ for OPAL, 640 pb$^{-1}$ for ALEPH, 550 pb$^{-1}$ for DELPHI) and energy limited:
  - only 491 events at L3
  - 133 events for OPAL
  - 891 events for ALEPH

⇒ no definite conclusion could be obtained
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Onium-onium scattering at ILC collider

Sources of photons

The direct $\gamma\gamma$ cross-section is out of reach experimentally (from the box diagram)

ex: $\sigma_{\gamma\gamma\to\gamma\gamma} \sim 10^{-64} (\omega_{\gamma}/\text{eV})^6 \text{cm}^2$

$\Rightarrow$ for visible light ($\omega \sim 1 \text{ eV}$) $\sigma_{\gamma\gamma\to\gamma\gamma} \sim 10^{-65} \text{cm}^2$ !

There are basically two ways for producing photons

- one can use a high luminosity collider of charged particle as a source of photons: $Ap, pp, e^+p, e^+e^-$ colliders.
  idea of Fermi, Weizsäcker, Williams: field of a charged particle = flux of equivalent photon (which are almost real)
- one can use Compton backscattering to pump the energy of electron of a storage ring or of a collider in order to produce high luminosity and high energy photons
Onium-onium scattering at ILC collider
Sources of photons: Hadron and Nucleus colliders

This is based on Fermi-Weizsäcker-Williams equivalent photon approximation:

\[ P_{\gamma/e}(z, Q^2) \sim Z^2 \alpha_{em} \frac{1}{z} \frac{1}{Q^2} \]

- one can use a high energy and high luminosity hadron collider (LHC, Tevatron)
- or a colliders with heavy nucleus (large Z) can in principle give a good source of photon (RHIC, LHC: see Nystrand’s talk): the lower luminosity can be compensated by the enhancement factor \( Z^2 \).

At LHC, both modes would give comparable fluxes of photons
however, the $\gamma\gamma$ events are polluted by pure (soft) hadronic interactions between source of photons, since hadrons or nucleus are sensitive to strong interaction:

- one needs to select peculiar ultraperipheral events for which the typical impact parameter $b$ between hadrons (nucleus) exceeds $1/\Lambda_{QCD}$.
- this is possible experimentally with very forward detectors, with (anti)tagging protons:
  - forward detector at CDF: data are coming
  - LHC: detectors (Roman pots) suggested at 420 m (FP420 at CMS and ATLAS) and 220 m (RP200 at ATLAS) from IP at LHC
    - very interesting proposition for both $\gamma\gamma$ diffractive physics and for hadronic diffractive physics (ex: Higgs exclusive production, MSSM, QCD)
    - non trivial problems with fast time trigger (due to long distance from IP to the detector to be compared with rate of events at high luminosity) combining both detectors increases acceptance

- cutting in $b$ would reduce dramatically the luminosity in the case of $\gamma\gamma$ physics. Survival probability have to be taken into account (non-perturbative ingredient).

$e^\pm$ is not affected by strong interaction

$\Rightarrow e^+e^-$ colliders are the cleanest solution in principle for $\gamma^{(*)}\gamma^{(*)}$ physics, both from a theoretical point of view and from an experimental point of view
In the $e^+e^-$ case, from Fermi-Weizsäcker-Williams

$$dn_\gamma \sim 0.03 \frac{d\omega}{\omega}$$

The number of equivalent photons is thus rather small and their spectrum is soft:

$$L_{\gamma\gamma}(W_\gamma/(2E_e) > 0.1) \sim 10^{-2} L_{e^+e^-}$$
$$L_{\gamma\gamma}(W_\gamma/(2E_e) > 0.5) \sim 0.410^{-3} L_{e^+e^-}$$

Novosibirsk group (Ginzburg, Kotkin, Serbo, Telnov ‘80):
use Compton backscattering of a laser on a high energy electron beam of a collider

- due to $u$-channel diagram, which has an almost vanishing propagator, the cross-section has a peak in the backward direction
- in this backward direction, almost all the energy of the incoming electron is transferred to the outgoing photon (up to 82% at ILC 500 GeV: the limit comes from the fact that one does not want to reconvert $\gamma$ in $e^+e^-$ pairs!)
- the corresponding number of equivalent photons is of the order of 1 if the beam has a small size, with laser flash energy of $1 - 10$ J
Onium-onium scattering at ILC collider

Photon colliders: cross-crab angle

Cross-crab angle

- the photon beam follows the direction of the incoming electron beam with an opening angle of $1/\gamma_e$
- due to the very good focussing of electrons beams which is expected at ILC, this is the main effect which could limit the luminosity in $\gamma$ mode: the distance $b$ between conversion region and the Interaction Point is $\sim 1.5$ mm!
- it is thus impossible to use a magnet to deflect the low energy outgoing electron beam $\Rightarrow$ cross-crab angle between the two incoming beams to remove the outgoing beams
the luminosity which can be obtained is $0.17 L_{e^+e^-}$

this is a very interesting luminosity since the cross-section in $\gamma\gamma$ are usually one order of magnitude higher that for $e^+e^-$

the matrix element of the Compton process is helicity-conserving except for the term proportional to the electron mass, which is helicity-flip, and dominates in the backward region

⇒ this provides a very elegant way of producing quasi monochromatic photons of maximal energy and given polarization:
by using $\lambda_e P_c = -1$ ($\lambda_e$=mean electron helicity and $P_c$=mean laser photon circular polarization)
WW distribution is sharply peaked around almost on-shell and soft photons.

In $\gamma e$ or $\gamma \gamma$ mode, one or two photon are real

$\Rightarrow$ In order to apply perturbative QCD, one needs to provide an hard scale.
  - either from the **outgoing state**: $J/\Psi$, · · ·
  - either from the **ingoing state**: double tagged outgoing leptons
Outline

1. QCD in the Regge limit: theoretical status
   - LL BFKL Pomeron
   - $k_T$ factorization
   - LL BFKL Pomeron: limitations
   - Higher order corrections
   - Non-linear regime and saturation
   - Onium-onium scattering as a gold plated experiment: $\gamma(\ast)\gamma(\ast)$ at colliders

2. Inclusive and Exclusive tests of BFKL dynamics
   - Hadron-hadron colliders
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   - Total cross-section at LEP

3. Onium-onium scattering at ILC collider
   - Sources of photons
     - ILC project
       - cost
       - ILC collider
       - Detectors at ILC
   - $\gamma^\ast\gamma^\ast \rightarrow$ hadrons total cross-section
   - $\gamma^\ast\gamma^\ast$ exclusive processes
ILC cost:
1.78 G $ site-dependent costs (tunnelling in a specific region, ...)
4.87 G$ for shared values of the high technology and the conventional components

This estimate is comparable to the cost for the Large Hadron Collider (LHC) at CERN when costs for pre-existing facilities are included.
Onium-onium scattering at ILC collider

ILC project: collider

Reference Design Report for International Linear Collider

- $\sqrt{s_{e^+e^-}} = 2E_{lepton}$: nominal value of 500 GeV
- high luminosity, with $125 \text{ fb}^{-1}$ per year within 4 years of running at 500 GeV
- possible scan in energy between 200 GeV and 500 GeV.
- upgrade at 1 TeV, with a luminosity of $1 \text{ ab}^{-1}$ within 3 to 4 years
- to reach such a high luminosity, the paquets should have a rather intricate structure

- non trivial technological problem for extracting the outgoing beam
  - at the moment, 3 options are considered: 2 mrad, 14 mrad and 20 mrad, with in each case a hole in the detector at that angle to let the outgoing beam get through toward the beam dump (this means that the acceptance in the forward calorimeter is reduced)
  - in order to compensate the potential lost luminosity when scattering at non zero scattering angle, crab-cross scattering is studied (the paquet is not aligned with the direction of its propagation, like a crab)
two interaction regions are highly desirable:

- one which could be at low crossing-angle
- one compatible with $e\gamma$ and $\gamma\gamma$ physics (through single or double laser Compton backscattering)

$\gamma\gamma$ constraint:
- $\alpha_c > 25 = \text{mrad}$ last quadrupole ($\varnothing = 5\text{cm}$) from IP: 4m and horizontal disruption angle=12.5 mrad $\Rightarrow 0.0125+5/400=25$ mrad
- the mirrors could be placed either inside or outside the detector, depending on the chosen technology

Layout of the quad and electron and laser beams at the distance of 4 m from the interaction point

thus in $e\gamma$ and $\gamma\gamma$ modes, almost no space for any forward detector in a cone of 95 mrad

$\Rightarrow$ if the option suggested by Telnov (single detector + single interaction point + single extraction line) would be chosen (this solution without displacement of the detector between 2 interaction points is much cheaper) it could become very difficult to make diffractive physics
Each design of detector for ILC project involves a very forward electromagnetic calorimeter for luminosity measurement, with tagging angle for outgoing leptons down to 5 mrad (design 10 years ago were considering 20 mrad as almost impossible!)

This is an ideal tool for diffractive physics: cross-section are sharply peaked in the very forward region

luminosity is enough to give high statistics, even with exclusive events

there are 4 concepts of detectors at the moment:
  - GLD
  - Large Detector Concept (LDC)
  - Silicon Design Detector Study (Sid)
  - 4th
We focus specifically on the LDC project

- The **BeamCal** is an electromagnetic calorimeter devoted to luminosity measurement, located at 3.65 m from the vertex

- It can be used for diffractive physics

- The main background is due to **beamstrahlung photons**, which leads to energy deposit in cells close from the beampipe

  ⇒ in practice one can cut-off the cells for lepton tagging with

  \[
  E_{\text{min}} = 100 \text{ GeV} \\
  \theta_{\text{min}} = 4 \text{ mrad}
  \]

  and to lower energies for higher angles.
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Onium-onium scattering at ILC collider
\[ \gamma^* \gamma^* \rightarrow \text{hadrons} \] total cross-section

- In comparison to LEP
  - the luminosity would be much higher (a factor \( \sim 10^3 \))
  - detector given access to events closer to the beampipe (LEP: \( \theta_{\text{min}} \geq 25 \) to 30 mrad)
  - higher \( s \)

One can thus hope to get a much better access to QCD in perturbative Regge limit
to have enough statistics in order to see a BFKL enhancement, it was considered
to be important to get access down to \( \theta_{\text{min}} \sim 25 \) to 20 mrad (Boonekamp, De Roeck, Royon, S.W.).

- Probably this could be extended up to 30 mrad due to the expected luminosity (factor 2
to 3 luminosity higher then TESLA project)
- detectors down to 4 mrad now (20 mrad was considered to be almost impossible 10 years ago)

\[ \Rightarrow \] not a so critical parameter, except within a \( \gamma e \) and \( \gamma \gamma \) option with (single detector + single interaction point + single extraction line) scenario (proposed by Telnov): in that case it would be very difficult to have a forward detector bellow 100 mrad (due to the presence of mirrors for the lasers).
Onium-onium scattering at ILC collider

$\gamma^*\gamma^* \rightarrow \text{hadrons}$ total cross-section

Order of magnitude of expected number of events per year, in a modified LL BFKL scenario

<table>
<thead>
<tr>
<th>$\theta_{\text{min}} - \theta_{\text{max}}$</th>
<th>$\sigma(e^+e^- \rightarrow e^+e^- + \text{hadrons})$ [fb]</th>
<th>Events / year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Born</td>
<td>Hard</td>
</tr>
<tr>
<td>10–20</td>
<td>134</td>
<td>365</td>
</tr>
<tr>
<td>20–30</td>
<td>16</td>
<td>41</td>
</tr>
<tr>
<td>30–40</td>
<td>3.5</td>
<td>8</td>
</tr>
<tr>
<td>40–50</td>
<td>1.1</td>
<td>2.3</td>
</tr>
<tr>
<td>50–50</td>
<td>0.6</td>
<td>1.1</td>
</tr>
<tr>
<td>30–70</td>
<td>5.2</td>
<td>11</td>
</tr>
</tbody>
</table>

Predictions for TESLA at $e^+e^-$ energy equal to 500 GeV. Cross-sections for $e^+e^- \rightarrow e^+e^- + \text{hadrons}$ with tagged electrons $E_{\text{tag}} > 30$GeV, $y_i > 0.1, 2.5$ GeV$^2 < Q_i^2 < 300$ GeV$^2$, $2 < \ln[W^2/(Q_1Q_2)] < 10$, $\theta_{\text{min}} < \theta_{\text{tag}} < \theta_{\text{max}}$. Results of the calculation with the low scale of $\alpha_s$ in impact factors: two-gluon exchange (Born approximation), hard and full (hard+soft) contributions and the expected number of events per year, assuming the integrated luminosity per year to be $\mathcal{L} = 125$fb$^{-1}$. Table modified from Kwiecinski, Motyka
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in the case of $\gamma\gamma (e^+e^- \text{ without tagging} \text{ or within } \gamma\gamma \text{ collider option})$, one can consider any diffractive process of type $\gamma\gamma \rightarrow J/\Psi J/\Psi$ or other heavy produced state. The hard scale is provided by the mass of the charmed quark mass (Kwiecinski, Motyka).

Expected number of events for ILC: around 75 000

due the small detection angle offered by Beamcal, one has the possibility to investigate processes of type $\gamma^*\gamma^* \rightarrow \rho_0^0 \rho_0^0$ from $e^+e^- \rightarrow e^+e^- \rho_0^0 \rho_0^0$ with double tagged out-going leptons.

This gives access to
- arbitrary $t$ BFKL exchange
- one play with $s$ cuts and with $Q_1$ and $Q_2$ to get access to a full figure of collinear (ERBL, DGLAP) physics as well as of BFKL physics, with perturbative control
Non-forward Born order cross-section for $e^+ e^- \rightarrow e^+ e^- \rho_L^0 \rho_L^0$

We obtain, at $\sqrt{s_{e^+ e^-}} = 500$ GeV

\[
\begin{align*}
\sigma^{LL} & = 32.4 \text{ fb} \\
\sigma^{LT} & = 1.5 \text{ fb} \\
\sigma^{TT} & = 0.2 \text{ fb} \\
\sigma^{tot} & = 34.1 \text{ fb}
\end{align*}
\]

which leads to $4.3 \times 10^3$ events per year with foreseen luminosity
Onium-onium scattering at ILC collider

\( \gamma^(*) \gamma^(*) \) exclusive processes: contact with low energy processes

The moderate energy and the high energy factorizations (B. Pire, M. Segond, L. Szymanowski, S. W.)

- at moderate \( s_{\gamma^* \gamma^*}^2 \gg \Lambda_{QCD}^2 \), we perform the direct calculation.
  We then show that it can be presented in a QCD factorized form involving

  - either a GDA for \( s_{\gamma^* \gamma^*}^2 \ll \text{Max}(Q_1^2, Q_2^2) \)

  \[
  M_H \rightarrow T_H \rightarrow GDA_H
  \]

  \[
  q_1 \rightarrow p_1 \quad q_2 \rightarrow p_2
  \]

  \[
  T_H = \frac{q_1}{p_1} \frac{q_2}{p_2}
  \]

  \[
  GDA_H = \frac{q_1 q_2}{M_H} \frac{p_1 p_2}{T_H}
  \]

  - or a TDA for \( Q_1^2 \ll Q_2^2 \) or \( Q_1^2 \gg Q_2^2 \)

  \[
  M_H \rightarrow T_H \rightarrow TDA_H
  \]

  \[
  q_1 \rightarrow p_1 \quad q_2 \rightarrow p_2
  \]

  \[
  T_H = \frac{q_1}{p_1} \frac{q_2}{p_2}
  \]

  \[
  TDA_H = \frac{q_1}{p_1} \frac{q_2}{p_2}
  \]

  to be compared with the asymptotically large

  \( s_{\gamma^* \gamma^*} \) mainly involved in this talk,
  treated using \( k_T \) factorization involving impact factors
ILC would offer excellent facilities for clean tests of QCD in the perturbative Regge limit as well as of collinear QCD in both $e^+e^-$, $e\gamma$ and $\gamma\gamma$, it offers very high luminosity and energy.

Detectors under study could measure very forward particle. The $e\gamma$ and $\gamma\gamma$ give the possibility of making polarized photon physics (eg.: Sievers effect).

The $\gamma^(*)\gamma^(*)$ channel is interesting for many exclusive reactions, including the odderon exchange through $\gamma^(*)\gamma^(*) \rightarrow \eta_c\eta_c$ (Braunewell, Ewerz).

Production of $C$ even resonances, such as $\pi^0$, $\eta$, $\eta'$, $f_2$ as well as exotic states $q\bar{q}g$ like $J^{PC} = 1^{++}$, (Anikin, Pire, Szymanowski, S.W.)

$\gamma^(*)\gamma^(*)$ gives the chance to investigate photon structure function with highly virtual photon (up to $Q^2 = 1000 \text{ GeV}^2$).

There is a potential very interesting possibility of entering smoothly into the non-linear saturation regime when the machine would be upgraded up to 1 TeV:

- at $\sqrt{s_{e^+e^-}} = 500 \text{ GeV}$, $Q_{sat} \sim 1.1 \text{ GeV}$
  - saturation is at the border, almost negligible
- at $\sqrt{s_{e^+e^-}} = 1 \text{ TeV}$, $Q_{sat} \sim 1.4 \text{ GeV}$
  - saturation effects should start to be rather important (but still in the almost linear regime)