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

Samuel Wallon[1]

[1]Laboratoire de Physique Théorique
Université Paris Sud
Orsay

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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
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     - Detectors at ILC
   - $\gamma^*\gamma^* \to hadrons$ total cross-section
   - $\gamma^*\gamma^*$ exclusive processes

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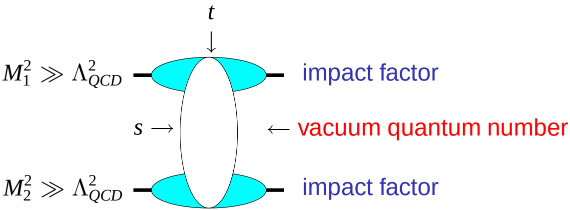
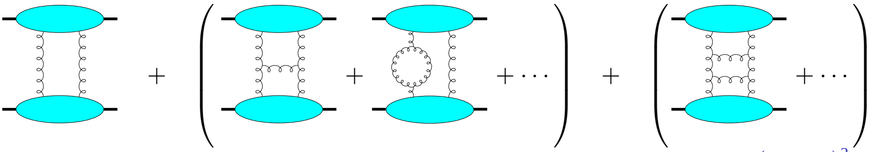
QCD in the Regge limit

LL BFKL Pomeron: basics

- At high energy $s \gg -t$, consider the elastic scattering amplitude of two IR safe probes.

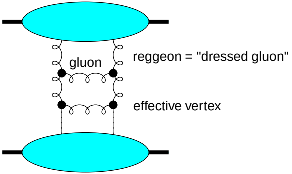


- Small values of α_S (perturbation theory applies due to hard scales) can be compensated by large $\ln s$ enhancements. $\Rightarrow$ resummation of $\sum_n (\alpha_S \ln s)^n$ series (Balitski, Fadin, Kuraev, Lipatov)



~ 1 $\qquad \sim \alpha_S \ln s$ $\qquad \sim (\alpha_S \ln s)^2$

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



- one gets, using optical theorem
$$\sigma_{tot} \sim s^{\alpha_P(0)-1}$$
with $\alpha_P(0) - 1 = C\,\alpha_S \qquad C > 0$
$\Rightarrow$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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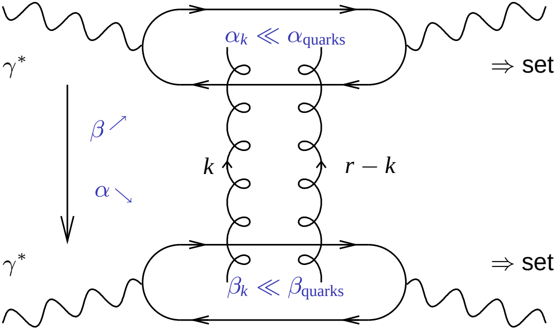
QCD in the Regge limit

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 $d^4k = \frac{s}{2}\, d\alpha\, d\beta\, d^2k_\perp$
- rearrange integrations in the large s limit:



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

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

$\Rightarrow$ impact representation note: $\underline{k}$ = Eucl. $\leftrightarrow$ $k_\perp$ = Mink.

$$\mathcal{M} = is \int \frac{d^2\,\underline{k}}{(2\pi)^4 \underline{k}^2\,(\underline{r}-\underline{k})^2} \mathcal{J}^{\gamma^*\to\gamma^*}(\underline{k}, \underline{r}-\underline{k})\; \mathcal{J}^{\gamma^*\to\gamma^*}(-\underline{k}, -\underline{r}+\underline{k})$$

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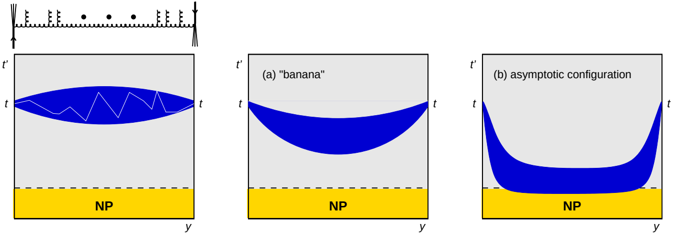
- how to fix the scale s_0 which enters in $\ln s/s_0$ resummation?
- α_S is fixed at LL how to implement running and scale?
- energy-momentum is not conserved in BFKL approach
  - note that this remains at any order: NLL, NNLL, ...
  - in the usual collinear renormalisation group approach (à la DGLAP), 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 α_S: gaussian diffusion of k_T : cigar-like picture (Bartels, Lotter)
  the more s increases, the larger is the broadness:
  define $l = \ln \frac{Q^2}{\Lambda^2_{QCD}}$ (fixed from the probes)
  and $l' = \ln \frac{k^2}{\Lambda^2_{QCD}}$ (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 cigare touches NP for $Y \sim b_{QCD} t^3$ ($b = 11/12$)
- while the center of the cigar approaches NP when $Y \sim bt^2$ ("banana structure")

A more involved treatment of LL BFKL with running coupling (Ciafaloni, Colferai, Salam, Sasto) showed that the cigare 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
  - $\gamma^* \to \gamma^*$ at $t = 0$ (Bartels, Colferai, Gieseke, Kyrieleis, Qiao)
  - forward jet production (Bartels, Colferai, Vacca)
  - $\gamma^* \to \rho$ in forward limit (Ivanov, Kotsky, Papa)

  $\Rightarrow$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 bellow) 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 α_S
  - back to the infrared diffusion problem, such a scheme enlarge the validity of perturbative QCD.
  - simplified version (Khoze, Martin, Ryskin, Stirling) at fixed α_S
    - $$\frac{1}{\underline{k}^3 \underline{k}'^3} \int \frac{d\omega}{2\pi i} \int \frac{d\gamma}{2\pi i} \left(\frac{\underline{k}^2}{\underline{k}'^2}\right)^{\gamma - 1/2} \frac{e^{\omega Y}}{\omega - \omega(\gamma)}$$

      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 γ
      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
$\Rightarrow$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
$\Rightarrow$Bartels, Jaroszewicz, Kwiecinski, Praszalowicz equation
  - looks like a 2-dimensional quantum mecchanical 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

- Color Glass Condensate and B-JIMWLK equation
  - JIMWLK: This effective field theory is a 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 bellow 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 correspondance 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 symetric
- toy models in 1+0 dimensions are under developpement (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 growths with Y
  - above this scale T is small (color transparency)
  - bellow 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

$\rightarrow$ this may solve the IR diffusion problem

Outline

onium-onium scattering as a gold plated experiment: $\gamma^{(*)}\gamma^{(*)}$ at colliders

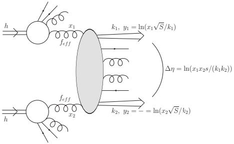
In order to test perturbative QCD in Regge limit, one should select peculiar observables

- no IR divergencies:
  - select external or internal probes with a given transverse size $\ll 1/\Lambda_{QCD}$
    - hard virtual photon
    - heavy meson: J/Ψ, Υ
    - 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

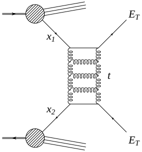
A process which satisfies such requirements is generically called onium-onium scattering

Outline

- Mueller-Navelet '87 jets: test of BFKLPomeron at $t = 0$
  - measure for two jets at large p_T (=hard scale) separated by a large rapidity, including possible activity between these jets



  - the signal would be a decorrelation of relative azimutal angle between emitted jets when increasing relative rapidity ΔY
  - measurement should be performed soon at CDF at large ΔY (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 Pomeron 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

Outline

Since the beginning of HERA in 1992, there have been much efforts in order to see the perturbative Regge dynamics.

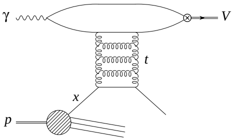
- DIS Peschanski, Navelet, Royon, S.W.; Golec Biernat, Kwiecinski (one hard scale = Q^2, model within the proton, either in term of coupling or in term of dipole densities)

  test of BFKL at $t = 0$

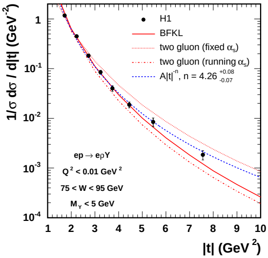
  both BFKL and DGLAP (NLL) can describe the data
- energetic forward jet production (hard scales = γ^* and jet energy) Mueller; Bartels, Loewe, De Roeck; Kwiecinski, Martin, Sutton; Bartels, Del Duca, Wüsthoff
  test of BFKL at $t = 0$

  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



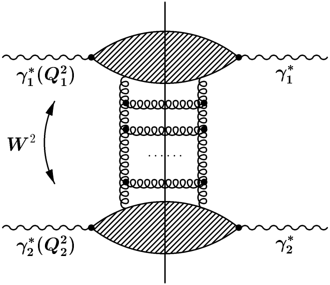
H1, ZEUS data seem to favor BFKL



Problems remains with spin density matrix (when considering all possible polarizations of ρ and γ)

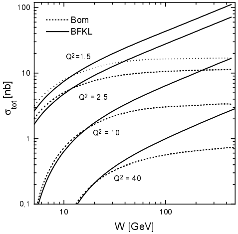
Outline

- 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

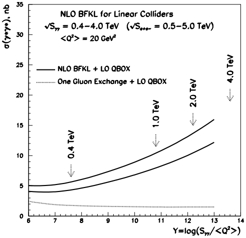


- Several groups investigated this process in LL BFKL (Bartels, Ewerz, Lotter, De Roeck, Staritzbichler; Brodsky, Hautmann, Soper), dipole model (Boonekamp, De Roeck, Royon, S.W.; Bialas, Czyz, Florkowski), modified LL BFKL(based on kinematical constraints) (Kwiecinski, Motyka), NLL BFKL(Brodsky, Fadin, Lipatov, Kim, Pivovarov).

Total cross-section at LEP: predictions for $\gamma^*\gamma^* \longrightarrow hadrons$



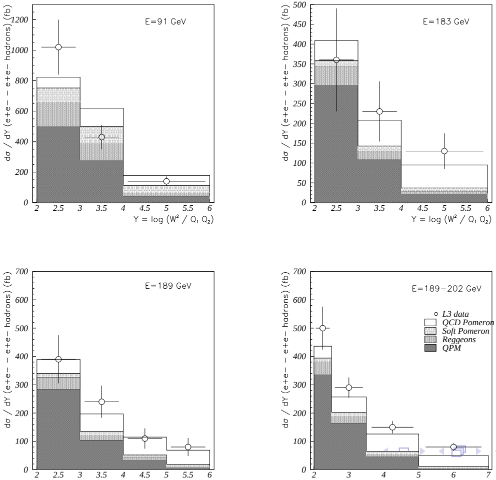
Modified LL BFKL compared to Born. Figure from Motyka, Kwiecinski



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 (incluiding 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

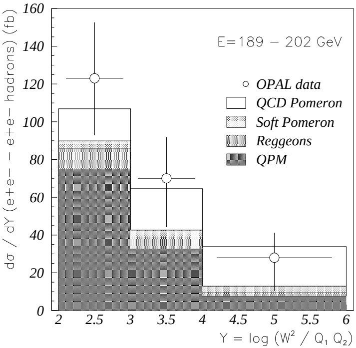


Figure: Comparison of the OPAL preliminary data on the differential cross-section for doubly tagged events $d\sigma(e^+e^- \to e^+e^- + hadrons)/dY$ with our predictions plotted as function of Y for the e^+e^- collision energies between 189 and 202 GeV. Figure from Motyka, Kwiecinski

- data seems to favour a BFKLscenario
  - Born 2 gluon exchange is too small
  - quark exchange is too small in the large Y set of the data
  - LL BFKLis to high
  - quark mass effects are important (Bartels, Ewerz, Staritzbichler)
  - a modified BFKLor a NLL BFKLwith 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 $\mathrm{pb}^{-1}$for DELPHI and energy limited:
    only 491 events at L3
    133 events for OPAL
    891 events for ALEPH

$\Rightarrow$no definite conclusion could be obtained

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The direct $\gamma\gamma$ cross-section is out of reach experimentally (from the box diagram)
ex: $\sigma^{\gamma\gamma\to\gamma\gamma} \sim 10^{-64}(\omega_\gamma/\mathrm{eV})^6 \mathrm{cm}^2$
$\Rightarrow$for visible light ($\omega \sim 1$ eV) $\sigma^{\gamma\gamma\to\gamma\gamma} \sim 10^{-65}\mathrm{cm}^2$!!
There are basically two ways for producting 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

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

$$P_{\gamma/Ze}(z, Q^2) \sim Z^2\, \alpha_{em} \frac{1}{z} \frac{1}{Q^2}$$

- 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 poluted by pure (soft) hadronic interactions between source of photons, since hadrons or nucleus are sentitive 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 comparared 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

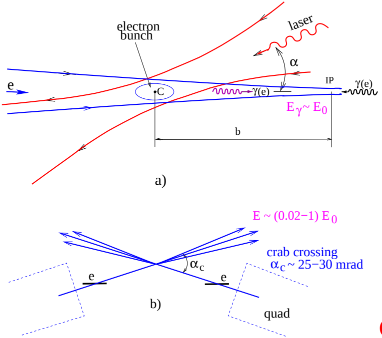
$$dn_\gamma \sim 0.03 \frac{d\omega}{\omega}$$

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

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

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 transfered to the outgoing photon (up to 82 % at ILC 500 GeV : the limit comes from the fact that one does not want to reconvert γ 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



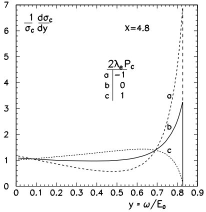
Cross-crab angle

- 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 γ mode:
  the distance b between conversion region and the Interaction Point is ~ 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

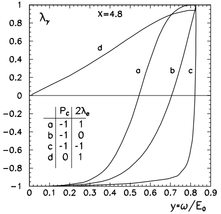
Onium-onium scattering at ILC collider

Photon colliders

- 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 proportionnal to the electron mass, which is helicity-flip, and dominates in the backward region
  $\Rightarrow$this provides a very elegant way of producing quasi monochromatic photons of maximal energy and given polarization:
  by using $\lambda_e P_c = -1$ (λ_e=mean electron helicity and P_c=mean laser photon circular polarization)



Spectrum of the Compton-scattered photons



Average helicity of the Compton-scattered photons

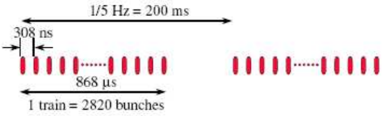
- WW distribution is sharply peaked around almost on-shell and soft photons.
- in γe or $\gamma\gamma$ mode, one or two photon are real
  $\Rightarrow$ In order to apply perturbative QCD, one needs to provide an hard scale.
  - either from the outgoing state: $J/Psi, \cdots$
  - either from the ingoing state: double tagged outgoing leptons

Outline

- 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.

Reference Design Report for International Linear Collider

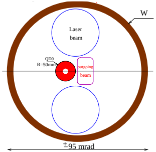
- $\sqrt{s_{e^+e^-}} = 2E_{lepton}$: nominal value of $500\,\mathrm{GeV}$
- high luminosity, with $125\,\mathrm{fb}^{-1}$ per year within 4 years of running at $500\,\mathrm{GeV}$
- possible scan in energy between $200\,\mathrm{GeV}$ and $500\,\mathrm{GeV}$.
- upgrade at $1\,\mathrm{TeV}$, with a luminosity of $1\,\mathrm{ab}^{-1}$ 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:
  - $\alpha_c > 25 =$ mrad last quadrupole ($\oslash$ =5cm) from IP: 4m and horizontal disruption angle=12.5 mrad $\Rightarrow$.0125+5/400=25 mrad
  - the mirors 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

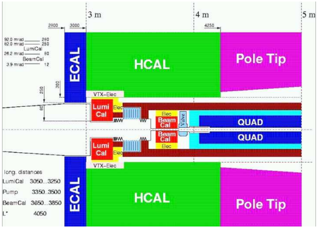
- Each design of detector for ILC project involves a very forward electromagnetic calorimeter for luminosity measurement, with tagging angle for outgoing leptons down to 5 mrad (design 10 years ago were considering 20 mrad as almost impossible!)
- This is an ideal tool for diffractive physics: cross-section 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

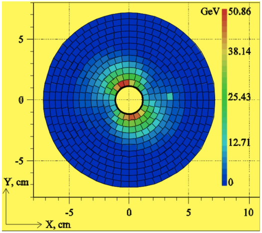
onium-onium scattering as a gold plated experiment: $\gamma^{(*)}\gamma^{(*)}$ at colliders

LDC detector

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
  $\Rightarrow$ in practice one can cut-off the cells for lepton tagging with

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

and to lower energies for higher angles.

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
   - $\gamma^*\gamma^* \to \textit{hadrons}$ total cross-section
   - $\gamma^*\gamma^*$ exclusive processes

- 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: $\theta_{min} \geq 25$ 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 $\theta_{min} \simeq 25$ 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 γe 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 mirors for the lasers).

Order of magitude of expected number of events per year, in a modified LL BFKLscenario

θ_{min} — θ_{max}	$\sigma(e^+e^- \to e^+e^- + hadrons)$ [fb] Born	Hard	Full (LS)	Events / year Full (LS)
10–20	134	365	450	56 000
20–30	16	41	46	5 700
30–40	3.5	8	9	1125
40–50	1.1	2.3	2.5	310
50–70	0.6	1.1	1.3	160
30–70	5.2	11	13	1 600

Predictions for TESLA at e^+e^- energy equal to 500 GeV. Cross-sections for $e^+e^- \to e^+e^- + hadrons$ with tagged electrons $E_{tag} > 30\text{GeV}$, $y_i > 0.1$, 2.5 GeV^2 $< Q_i^2 <$ 300 GeV^2, $2 < \ln[W^2/(Q_1Q_2)] < 10$, $\theta_{min} < \theta_{tag} < \theta_{max}$. Results of the calculation with the low scale of α_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 $\mathcal{L} = 125\text{fb}^{-1}$. Table modified from Kwiecinski, Motyka

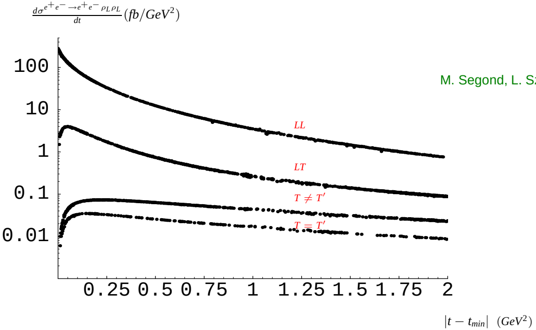
Outline

- in the case of $\gamma\gamma$ (e^+e^- without tagging or within $\gamma\gamma$ collider option), one can consider any diffractive process of type $\gamma\gamma \to J/\Psi J/\Psi$ 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
  $\gamma^*\gamma^* \to \rho_L^0\ \rho_L^0$ from $e^+e^- \to e^+e^-\rho_L^0\ \rho_L^0$ 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

Onium-onium scattering at ILC collider

$\gamma^{(*)}\gamma^{(*)}$ exclusive processes

Non-forward Born order cross-section for $e^+e^- \to e^+e^- \rho_L^0\ \rho_L^0$



M. Segond, L. Szymanowski, S. W.

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

$$\sigma^{LL} = 32.4 \text{ fb}$$
$$\sigma^{LT} = 1.5 \text{ fb}$$
$$\sigma^{TT} = 0.2 \text{ fb}$$
$$\sigma^{tot} = 34.1 \text{ fb}$$

which leads to $4.3\,10^3$ events per year with foreseen luminosity

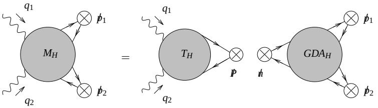
Onium-onium scattering at ILC collider

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

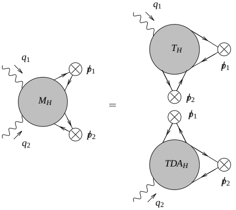
The moderate energy and the high energy factorizations (B. Pire, M. Segond, L. Szymanowski, S. W.)

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

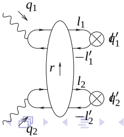
  - either a GDA for $s^2_{\gamma^*\gamma^*} \ll Max(Q_1^2, Q_2^2)$



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



- to be compared with the asymptotically large $s_{\gamma^*\gamma^*}$ mainly involved in this talk, treated using k_T factorization involving impact factors



Summary

- 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 $\gamma^{(*)}\gamma^{(*)} \to \eta_c\eta_c$ (Braunewell, Ewerz)
- production of C even resonances, such as π^0, η, η', 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 fonction with highly virtual photon (up to $Q^2 = 1000\,\mathrm{GeV}^2$
- 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 $\sqrt{s_{e^+e^-}} = 500$ GeV, $Q_{sat} \sim 1.1$ GeV
    saturation is at the border, almost negligible
  - at $\sqrt{s_{e^+e^-}} = 1$ TeV, $Q_{sat} \sim 1.4$ GeV
    saturation effects should start to be rather important (but still in the almost linear regime)