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XVI International Workshop on Deep-Inelastic Scattering and Related Subjects

Early LHC Measurements to Check Predictions For Central Exclusive Production

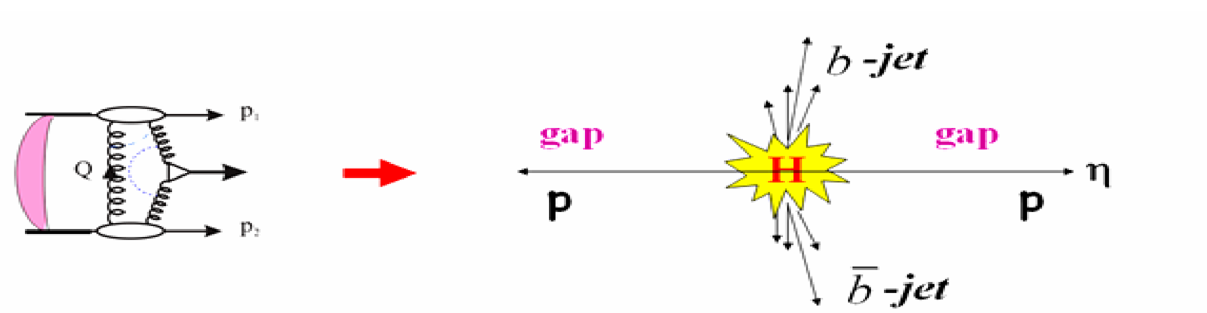
8^{th} April, 20008

Durham University

V.A. Khoze (IPPP, Durham & PNPI, St. Petersburg)

(based on works with A. Martin and M. Ryskin)

aim: to list & expose the main uncertainties in the theoretical expectations for CEP rates and to propose the measurements which will allow to cross- check the predictions



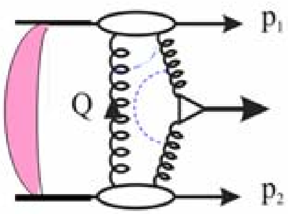
Higgs sector study- one of the central targets of FP420 physics menu

(Marek, Jeff, Pierre, Andy, Brian)

KMR pred^n of $\sigma(pp \to p + X + p)$ (symbolically)

$$L_{eff}^{PP} \sim \langle S^2 / b^2 \rangle * \left| N \int \frac{dQ_t^2}{Q_t^4} f_g(x_1, x_1', Q_t^2, \mu^2) f_g(x_2, x_2', Q_t^2, \mu^2) \right|^2,$$

contain Sudakov factor T_g which exponentially suppresses infrared Q_t region → pQCD



(High sens. to str. functs)

$$f_g(x, x', Q_t^2, \mu^2) = R_g \frac{\partial}{\partial \ln Q_t^2} \left[\sqrt{T_g(Q_t, \mu)}\, xg(x, Q_t^2) \right]$$

$\langle Qt \rangle_{SP} \sim M/2 \exp(-1/\bar{\alpha}_s)$, $\bar{\alpha}_s = N_c/\pi\ \alpha_s\ C_\gamma$

SM Higgs, $\langle Qt \rangle_{SP} \sim 2$ GeV >> Λ_{QCD}

$\langle S^2 \rangle$ - effect. quantity, character. prob. that rapidity gaps survive population by secondary hadrons → soft diffraction physics (model dependend.)

$\sigma(pp \to p + H + p) \sim 3$ fb at LHC for SM 120 GeV Higgs
(factor ~ 3 uncertainty after 'sanity checks')

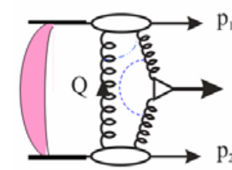
← reference. purposes, ExHume tuning

Implemented in ExHume MC with default $\langle S^2 \rangle_{Exh} \approx 0.03$, KMR- bt-space integration with exact ME

How reliable are the calculations ?

Are they well tested experimentally ?

- How well we understand/model soft physics ?
- How well we understand hard diffraction ?
- Is ‘hard-soft factorization’ well justified ?



✴ What else could/should be done in order to improve the accuracy of the calculations ?

So far the Tevatron diffractive data have been Durham-friendly) (Dino, Jim)

clouds on the horizon ?

or

?

Uncertainties in prediction of the CEP cross sections (exposed)

Saga about soft survival (1992-2008)

- Available data on soft diffraction at high energies are still rather fragmentary (CDF- high mass SD).
- Theoretical models contain various assumptions and many parameters.
- Durham models are tuned to describe available 'soft' diffractive data at high energies and predict the total, elastic, SD and DD dissociation cross sections which can be tested at the LHC.
- Durham models allowed to make predictions for the CEP jj and diphotons at the Tevatron which are broadly confirmed by the data , more tests to come.

SANITY CHECKS

- A way to compare the models : $< S^2(s,b) > / b^2$ with the same exponential slope b in ME

(an agreement within a factor of 2 is still a miracle!)

DATA

- MC model predictions should be confronted with the CDF data (e.g. proton spectra in SD)
- At the moment- no need to revise the Exhume default numbers, but we have to be opened-eyed. (note, on the theory side –downward tendency (stronger absorption effects), but CDF data rather favour upward)
- Survival factor is not universal (depends on the nature of the hard process, kinematics, selection criteria, acceptances….) recall : $S^2(A)/S^2(H) \sim 4$ (KKMR-03)

PDF's DEMOCRACY

- KMR08- global analyses gives a spread of up tp 3.

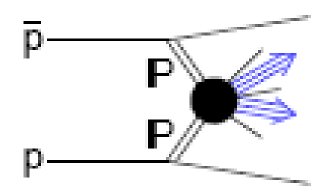
$$\sigma \sim (f_g)^4$$

- Here we are on the conservative side, but further studies and tests are needed

Higher-Order QCD effects

- Uncomfortably large higher-order QCD effects in the case of exclusive processes, exemplified by the Sudakov effect. Seen now in the new dijet exclusive data.

(Dino, Jim)

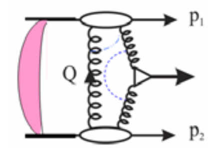


A killing blow to the wide range of theoretical models.

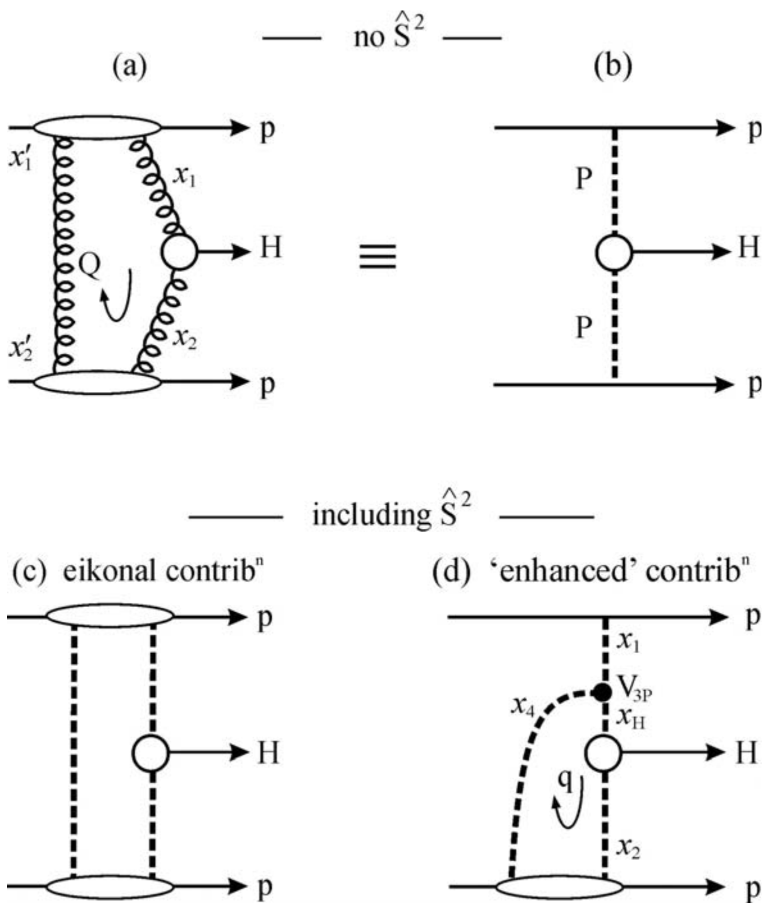
- Further detailed theoretical studies needed, NNLO Sudakov ?

- Self-consistent combined treatment of higher order effects in unintegrated struct. Functs. and in the hard cross-section – requires further detailed studies

Semi-enhanced hard rescattering and soft-hard factorization



"enhanced" correction to σ_H(excl)?



enhanced absorption, discussed first KKMR-01 in the diffractive dijet context

Bartels,Bondarenko,Kutak,Motyka-06
→used pert.thy.→corr^n could be large and→ σ_H(excl) modified ?
KMR-06 → arguments for small effect

Leading neutron prod. at HERA, Zeus, K(KMR)-06

Early LHC measurements to check predictions for central exclusive production

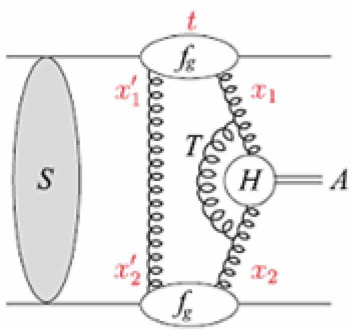
By popular demand (forward community)

V.A. Khoze[a,b], A.D. Martin[a] and M.G. Ryskin[a,b]

(arXiv: 0802.0177)

First data runs : L≈(0.1- 1) fb

DIVIDE AND CONQUER



A symbolic diagram for the central exclusive production of a system A.

Early LHC DATA

RP information, when

I ‘Worst-case’ scenario (proton tagging is still to come)

- Physics with rapidity gap trigger (ATLAS, CMS, ALICE) and comparatively low E_T thresholds (20-30 GeV) → probably for the first days
- Ratios of any sort are easier at the start (ADR & Orava). (CDF experience)

First, measuring the ratios of rates X + gap/ X inclusive (X=W,Z, dijets, dimuons…..)
Information on S^2

pp → RG +Z+ RG
pp → W +RG
pp → RG +W + RG
} probing quark distributions inside proton $*S^2$

pp → RG +jj+ RG (à la recent CDF studies) probing gluon distributions $*S^2$

pp → RG +Y + RG

pp → RG +central ’soft junk’ + RG ??

- Practically all rapidity range virtually covered ('holes' in rapidity are not v. essential)

Tests of absorption effects in the EW processes

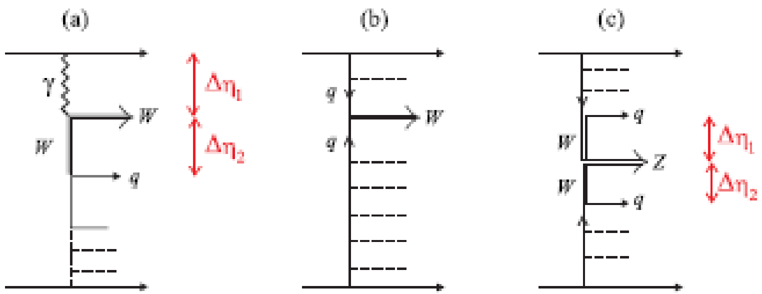
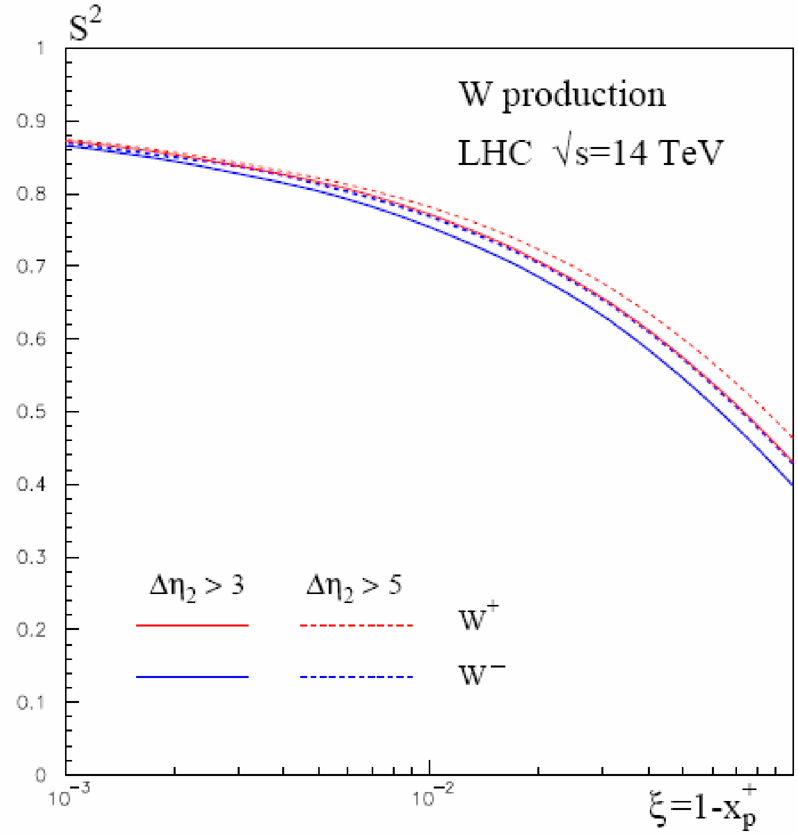


Figure 2: Diagrams for (a) W production with 2 rapidity gaps, (b) inclusive W production and (c) Z production with 2 rapidity gaps.



pp→ X+ RG+ W+ RG +Y ➲ photon exchange dominates

$$|t_{\min}| \simeq \frac{m_N^2 \xi^2}{1-\xi}$$

Early data runs:

Rapidity Gap veto trigger + high pt lepton or jet trigger

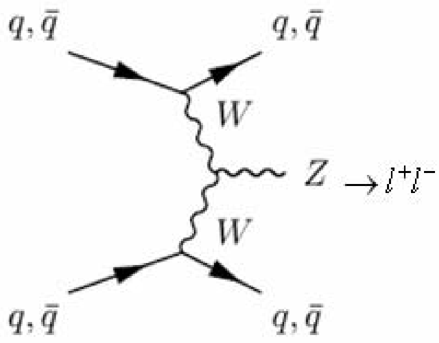
Figure 5: The rapidity gap survival factor S^2 as a function of ξ calculated using the global soft model of [15], assuming that the valence (sea) quarks are associated with the weak (strong) absorptive components. The small spread of the predictions arising from the different partonic content of the diffractive eigenstates mean that W+gaps events offer a meaningful test of the S^2 factor. Note that S^2 for the W^+ signal is larger since it has a bigger valence quark contribution.

The ratio (W+gaps/ W inclusive) will be measured first.

Z-monitor to gauge gap survival via VBF

KRSW-02

- q- pdfs- better accuracy, $\sim (f_q)^2$
- no Sudakov/ 'hard rescattering' effects,
- 'small size' component of the proton, $< S_Z^2 > \simeq 0.3$
- Track Counting Veto (recent CMS studies (A. Nikitenko et al)) DKS-91



- $pp \to Z + jj(p_t \geq 40 GeV)$ + further cuts to separate WWZ contribution

cautiously - after reasonable cuts $\sigma(Z \to ll + jj) \sim 100 - 200\, fb$

$\sigma(Z \to bb + jj) \sim 15\, fb$

more detailed analysis/optimisation needed

- CMS studies of hadron activity veto for the VBF H $\to \tau\tau$ searches with full detector simulation show robustness of the TCV method (e.g does not involve calorimeter scale uncertainties). $Z + jets, Z \to \mu\mu$ will be tested with the data. Current studies with the first 100 pb-1 at $L_{inst} = 2 * 10^{33}$

- Prospects of working at higher lumi (tracks from the single vertex only, e.g. defined by lept).

- May pave the way to study the VBF production of $H \to b\bar{b}$ (KRSW-02)

Exclusive Υ production as a probe of f_g

(Leszek, Graeme)

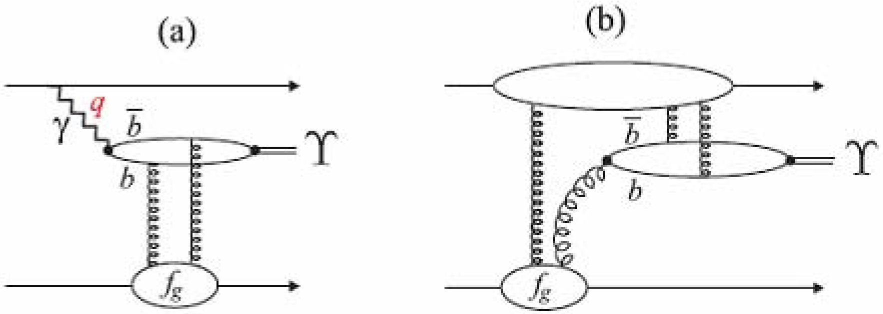


Figure 6: Exclusive Υ production via (a) photon exchange, and (b) via odderon exchange.

(CMS studies, S. Ovyn)

$$d\sigma / dy(pp \rightarrow p + \Upsilon + p) \sim 50\, pb$$

The cross section for γ +p→Y +p is given in terms of the same generalized gluon distribution fg that occurs in the CED Higgs production.

The odderon contribution (if it exists) can be separated and measured.

Tagging the lower proton will be very useful.

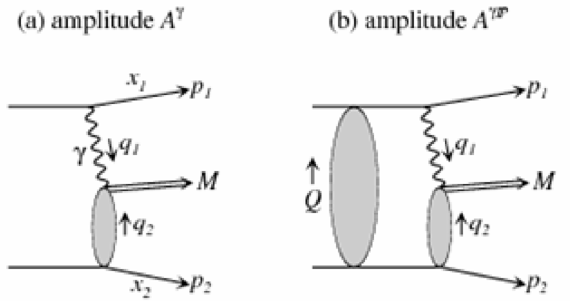
II When/if the proton tagging has come

Cleaner tests of dynamics of diffraction are provided by reactions where the bare amplitude is well known ('safe but more infrequent')

KMR-02

Tests of absorption effects in photon-exchange processes

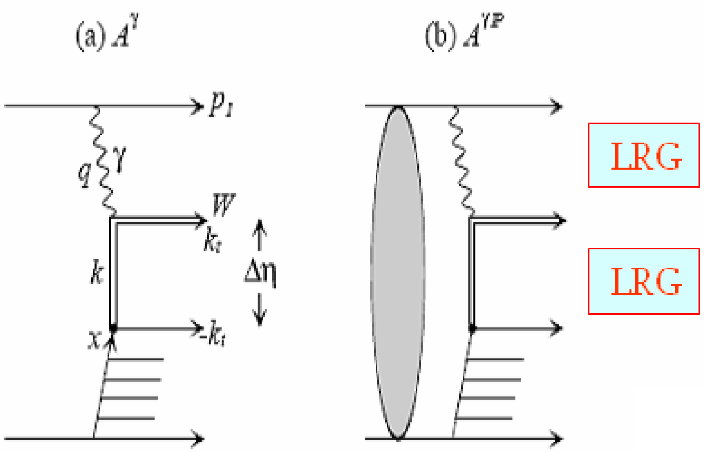
- pp→ p +Υ +p



$$M = (J/\psi), \Upsilon, W, \mu^+\mu^-$$

With proton tagging- detailed
studies performed only for
the J/ψ case at RHIC & Tevatron energies.
Υ- case at the LHC still to be investigated in details.

pt (t) –distributions demonstrate high sensitivity to the models for proton opacity;
photon polarizations plays an important role.
Rich diffractive structures in t and φ-distr



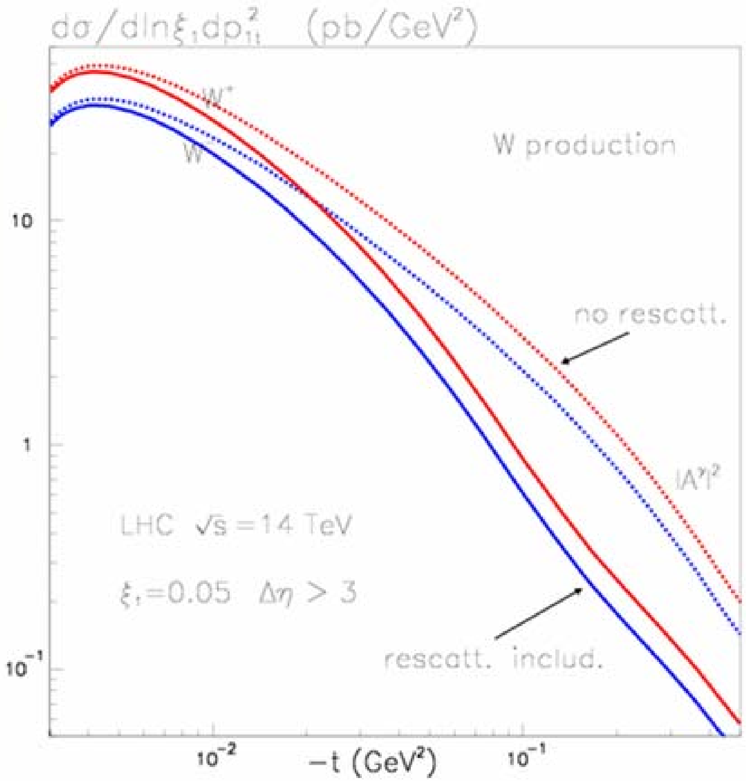
With proton tagging

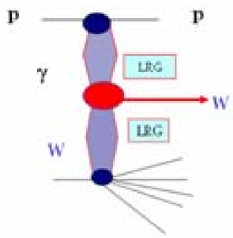
Without proton tagging

$$\sigma(RG+W+RG) \simeq 2*(0.2-1)\,pb*S^2$$

S^2 ~0.6-0.7

$t_{\min}(\xi_p)$ - effects





The differential cross section for $pp \to p + W^{\pm} + X$ at the LHC. The dotted and continuous curves correspond, respectively, to the predictions without and with the rescattering effects of Figs. 8(b,c). In each case W^+ production corresponds to the upper one of the pair of curves. The rapidity gap between the quark recoil jet and the W boson is taken to satisfy $\Delta\eta > 3$.

High rate soft diffraction physics programme

Early LHC data : TOTEM or/and ATLAS 240m, a special run

- $\sigma_{tot}, d\sigma_{el}/dt, \sigma_{SD}^{lowM}, \sigma_{DD}, d^2\sigma_{SD}/dtdx_L, d^2\sigma^{DPE}/d\ln\xi_1 d\ln\xi_2$

- Pt- correlations in soft DPE events
  universal (up to enhanced contributions.)

pt –spread, what about higher β (90m)- optics?

- Such measurements will:
  allow to tests the model assumptions,
  strongly restrict the soft survival factor,
  provide the valuable information on the 'enhanced absorption '

They are not sensitive to higher order pQCD (e.g. Sudakov) effects

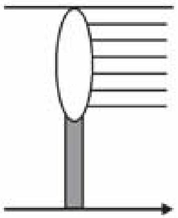
Low mass diffraction an important ingredient of models for soft diffraction (data are fragmentary)

- We need results on σ_{tot} and σ_{SD} simultaneously,

Larger (smaller) σ_{tot} and smaller (larger) σ_{SD}^{lowM} may lead to the same S^2

Up to the experimentalists to decide/define the priorities & timetable.
When the high β-optics is coming (2009-2010 ?) ?

SD



Available CDF data on proton spectra are well described by KMR model

(K.G.& Montanha-98)

If the effects of enhanced absorption are large, then the decrease could be much steeper,

$d\sigma_{SD}/dM^2 \sim 1/(M^2)^{1+\Delta}, \Delta \sim 0.3-0.6$

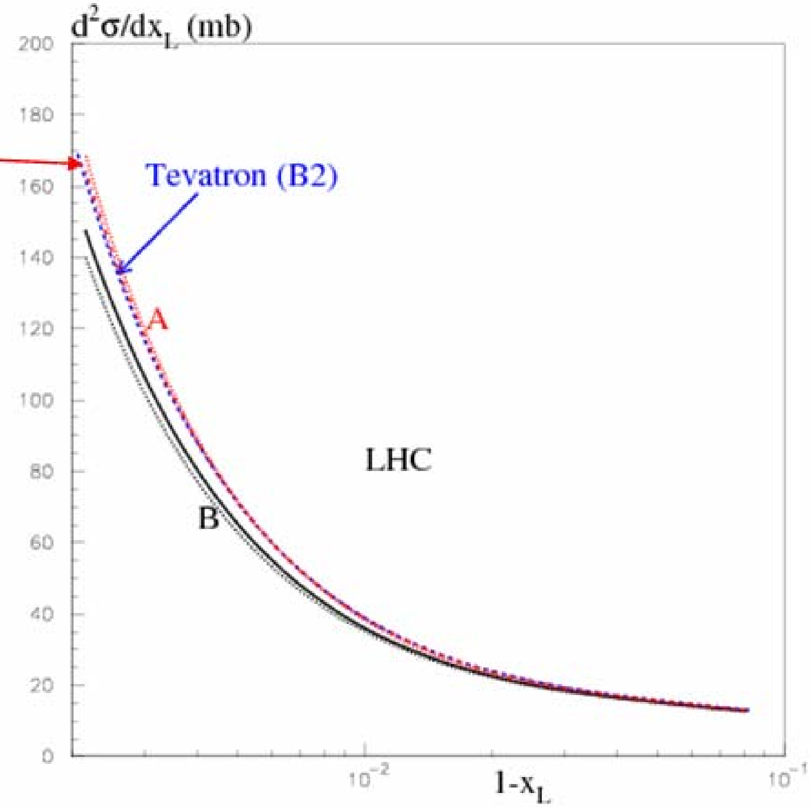
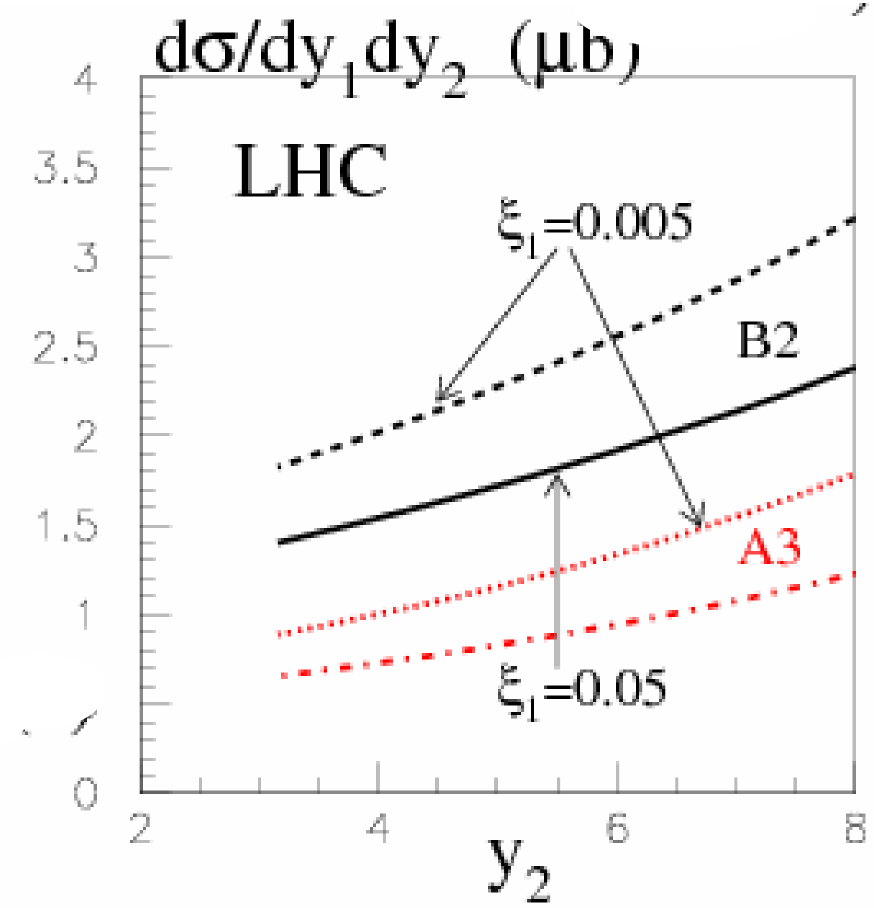


Figure 21: The cross section $d\sigma_{SD}/dx_L$ for single dissociation integrated over t at the LHC energy resulting from four models: the continuous (dotted) curves are due to the B2 (B3) models, while the upper (red) dotted and dot-dashed curves are for models (A3) and (A2) respectively. For comparison we also show by a dashed (blue) curve the cross section obtained from model (B2) at the Tevatron. The secondary Regge contribution is included in the same way as in Fig. 18(a); it is relatively very small for $(1-x_L) < 10^{-2}$.

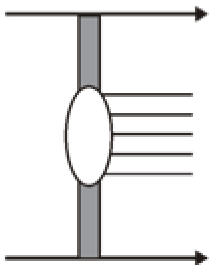
Governs the rate of the pile-up backgrounds.

MCs should be compared with/ tuned to the CDF data

Higher sensitivity to the parameters of models for Soft Diffraction



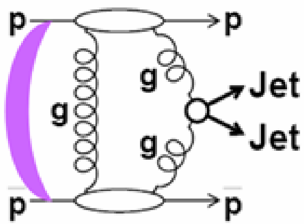
(d) the y_2 dependence of $d\sigma_{\rm DPE}/dy_1dy_2$ for $\xi_1 = 0.05$ and 0.005, corresponding, respectively, to proton taggers at 220 m and 420 m from the interaction point in the LHC experiments.



$y = -\ln \xi$, $\xi = (1-x)$

(also for calculations of the pile-up backgrounds)

Exclusive dijet Monitor & Interferometer



- CEP of diphotons (rate permitting) would provide an excellent combined test at M>10-20 GeV (better accuracy!)
- Dijet rate- combined effect of all basic ingredients (Surviv, Sudakov, pdfs, Enhanc. Absp) ($E_T > 10$ GeV)
- E_T-dependence -dominantly Sudakov (+anom dimens), weaker dependence on S^2.
  At low E_T- higher sensitivity to the Enhanced Absorption
- **When having the proton detectors operational**
  Correlations between proton transverse momenta, azimuthal distribts
  Practically insensitive to pdfs and Sudakov effects.
  High sensitivity to soft model parameters.
  Proton opacity scanner (KMR-02, also Kupco et al-05, Petrov et al -05)
- Comparing dijet signals in different rapidity intervals & pt → study of Sudakov suppression

Advantages

- Comparatively high rate (3 orders of magnitude higher than for the Higgs at the same E_T).

$$\sigma_{jj}^{DPE}(E_T > 20 GeV) \sim 10 nb, \quad \sigma(DPE) \sim 1-10 \mu b$$

- Possibility to separate different effects and to restrict different uncertainties by studying the same process

Possible dijet study strategy

❶ Measurement of E_T dependence of inclusive dijets (NLO DGLAP calculations).
Mainly tests of efficiencies etc

❷ Ratio of $\sigma_{jj}^{SD} / \sigma_{jj}^{incl}$ (similar to the CDF studies).

With known pdfs (HERA data) we test models for/measure the survival factor S^2

❸ Ratio $\sigma_{jj}^{DPE} / \sigma_{jj}^{incl}$ with different gap sizes allows to probe Sudakov effects and the possible role of 'enhanced absorption'
Variation of the gap size and jet E_T→ various quantitative tests
(e.g. absorption is higher for low-pt particles)

❹ When/if proton tagging is operational, then the studies of proton momentum correlation should come. pt-spread in the beams ?

Scanning of proton opacity.
Can also pave the way to direct measurements of CP violation
In the Higgs sector.

All these measurements are interesting on their own right: diffractive (soft QCD) physics is still not fully understood !

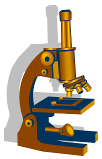
Main Tests at a glance

Soft Survival Factor **S^2** → W/Z + Rap Gap events

Generalized Gluon Distributions → Exclusive Y- production

Higher - Order Perturbative QCD Corrections to the Hard Amplitude → Exclusive two/three jet production

Soft diffraction program → Tests of models for soft diffraction

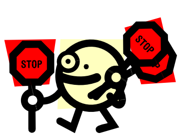


Conclusion

- We are now at the qualitatively new stage when the theoretical predictions for the CEP cross sections have reached the level of a factor of 3 accuracy.
- So far Durham group has been able to describe/predict the diffractive data.
- Essential improvement of the accuracy will require a lot of work and may not happen until the LHC experiments come FORWARD and produce the data (already) in the early runs. This will not be easy. It is not like a walk in the park.

LET THE DATA TALK !

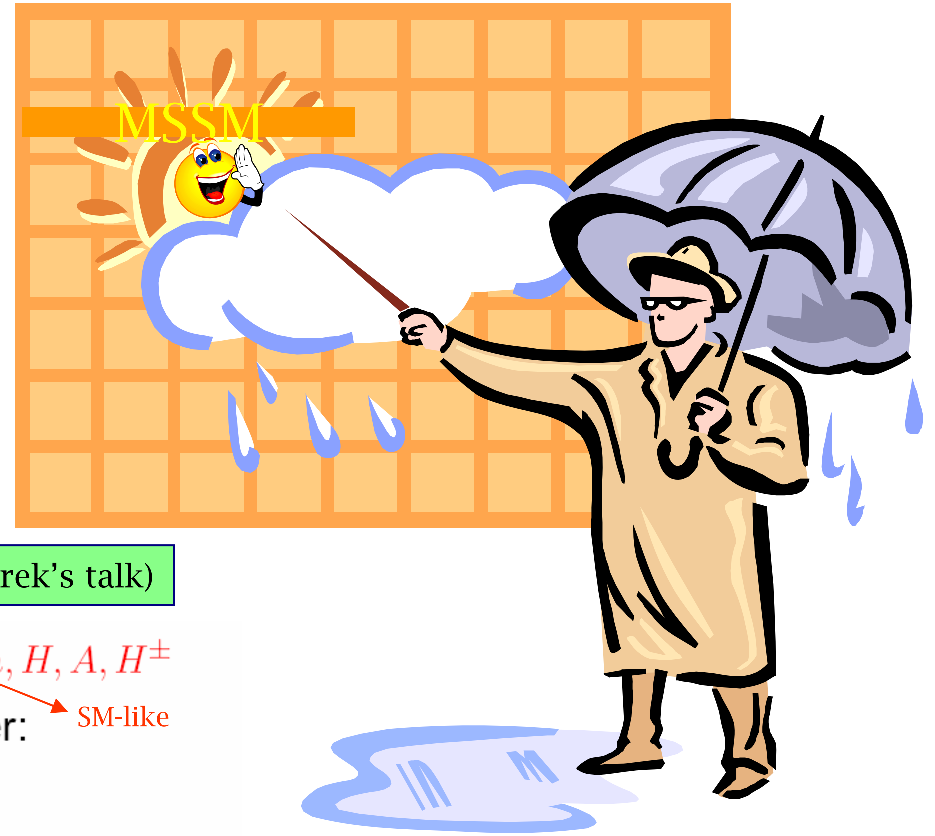
Only a large data set would allow to impose a restriction order on the theoretical models



BACKUP

without 'clever hardware':
for H(SM)→bb at 60fb-1 only
a handful of events due to
severe exp. cuts and low efficiencies,
though **S/B~1** .
But **H->WW** mode at M>135 GeV. (B.Cox et al-06)

enhanced trigger strategy & improved
timing detectors (FP420, TDR)



situation in the MSSM is **very different**
from the SM

(Marek's talk)

- Higgs sector of the MSSM: physical states $h, H, A, H^{\pm}$ (h → SM-like)

  Described by two parameters at lowest order:
  M_A, $\tan\beta \equiv v_2/v_1$

- Search for heavy MSSM Higgs bosons ($M_A, M_H > M_Z$):
  Decouple from gauge bosons
  $\Rightarrow$ no HVV coupling
  $\Rightarrow$ no Higgs production in weak boson fusion
  $\Rightarrow$ no decay $H \to ZZ \to 4\mu$

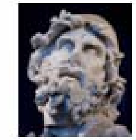
  Large enhancement of coupling to $b\bar{b}$ (and $\tau^+\tau^-$) in region of high $\tan\beta$

4 generations:→enhanced H→bb rate (~ 5 times)

Conventionally due to overwhelming QCD backgrounds, the direct measurement of Hbb is hopeless

The backgrounds to the diffractive H bb mode are manageable!

Uncertainties in prediction of the CEP cross sections (exposed)



- *qualitatively* new stage
  - orders of magnitude differences in theoretical expectations – are a history

    (not so long ago-  between Scylla and Charybdis)

  - new (encouraging) CEP Tevatron results available, more results to come
  - more theorists join the Exclusive CP club (*good & bad news*)
  - we are discussing now effects on the level of a factor of 3-4
- Absorption is only a part of a complex problem of evaluation the rates of CEP processes, $< S^2 >$ is just one of (averaged) characteristics.

  Centre of attention ?

  Difference on the level of only a factor of 2 is still a miracle!

- The models (model-builders) should demonstrate that they are able to describe the existing Tevatron/HERA data on soft / hard diffractive and CEP processes, better even to make some specific *predictions.*

  (*Durham group have performed various 'sanity checks'*, also $< S^2 >$ agrees with MC)

- One of the current limitations- not sufficient exp. information on low mass SD (DD)
- **Let the data talk** (yesterday, today & tomorrow (early LHC results))

EXPERIMENTAL CHECKS

☺ Up to now the diffractive production data are consistent with K(KMR)S results
Still more work to be done to constrain the uncertainties.

- Exclusive high-Et dijets NEW!
  CDF: data up to $(E_t)_{min}>35$ GeV (PRD, in press)

• 'Factorization breaking' between the effective diffractive structure functions measured at the Tevatron and HERA.

•The ratio of high Et dijets in production with one and two rapidity gaps

• Preliminary CDF results on exclusive charmonium CEDP.

•Energy dependence of the RG survival (D0, CDF).

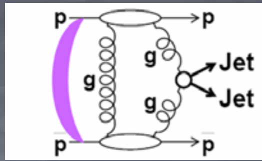
- Central Diffractive Production of $\gamma\gamma$ (….$\pi\pi$,$\eta\eta$) (**CDF**, PRL-07) NEW!
  (in line with the KMRS calculations)

- Leading neutrons at HERA NEW!

LET THE DATA TALK !

Only a large data set would allow to impose a restriction order on the theoretical models

Comparison with KMR

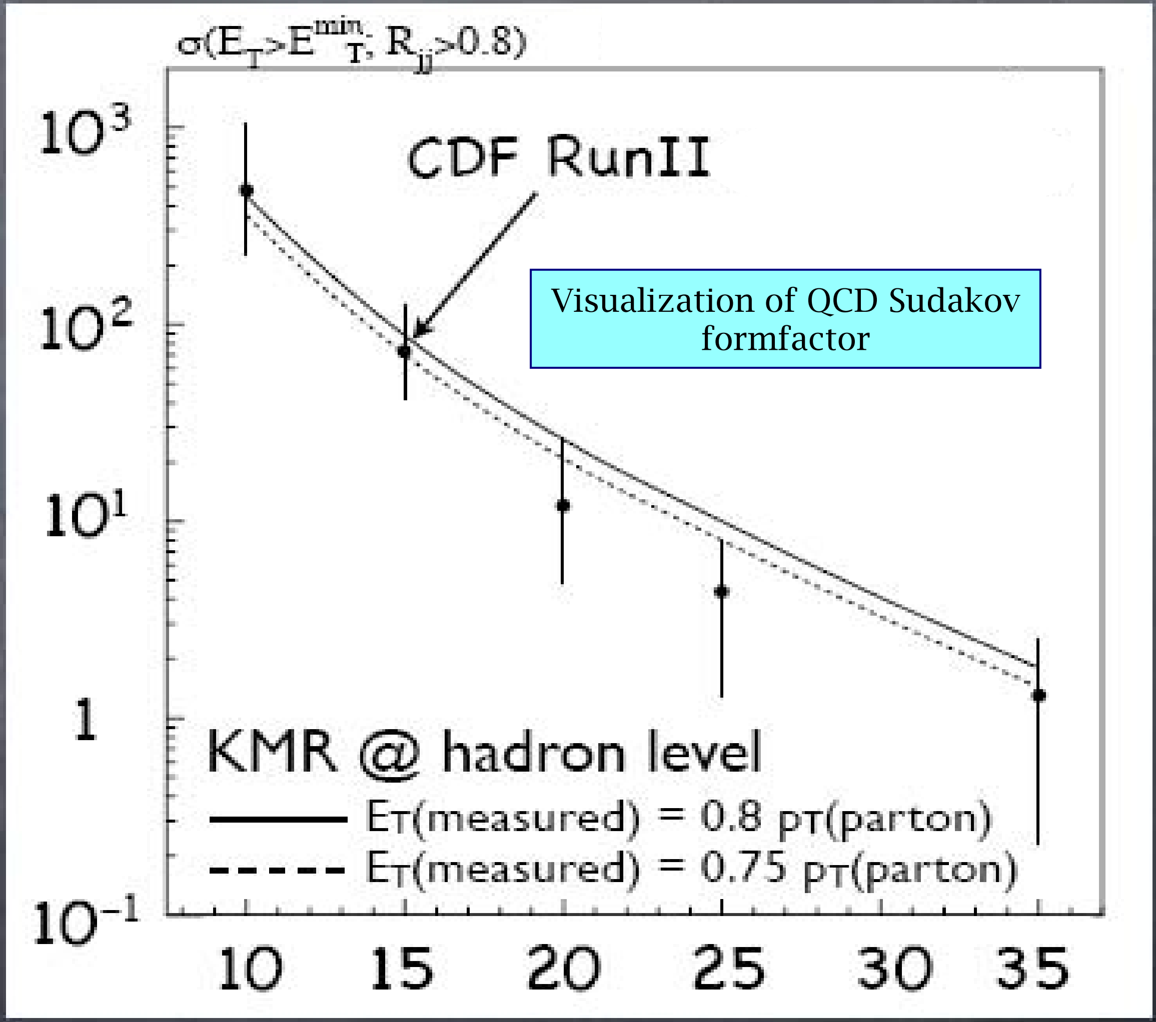


More direct comparison with KMR calculations including hadronization effects preferred

CDF out-of-cone energy measurement (cone R=0.7) :

- 20-25% at E_T^{jet}=10-20 GeV
- 10-15% at E_T^{jet}=25-35 GeV

Good agreement with data found by rescaling parton p_T to hadron jet E_T



Koji Terashi

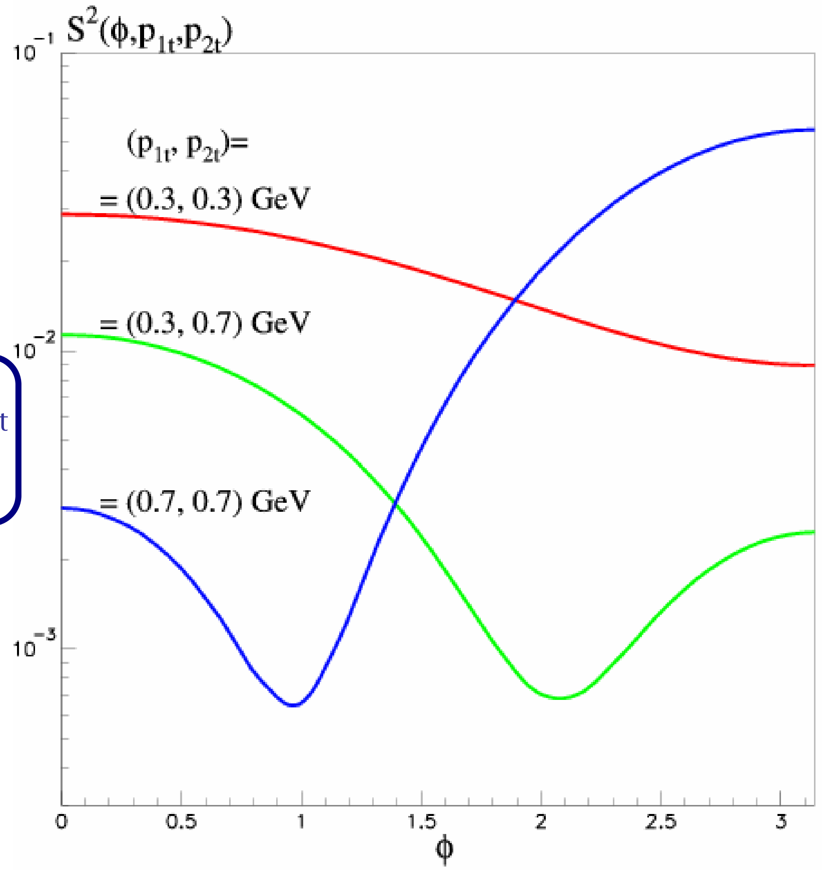
A killing blow to the wide range of theoretical models.

Dependence on jet E_T

$$\sigma_{jj}^{CEP}(E_T^{\min}) \sim 1/(E_T^{\min})^{5.3} \qquad \sigma_{jj}^{CIP}(E_T^{\min}) \sim 1/(E_T^{\min})^{2.4}$$

- Enhanced absorption effects (if essential) could change such behaviour;
  (sensitivity to the gap size, to lower E_T)

KMR-02



proton pt allows to sample different impact parameters bt
→Opacity Scanner

The dependence of the survival probability, S^2, of the rapidity gaps on the azimuthal angle ϕ between the transverse momenta $\vec{p}_{it}$ of the forward going protons in the process $pp \to p + M + p$, for typical values of p_{1t} and p_{2t}.

High ET central jets are not required (in principle)

Survival Probability

average over diff. estates i,k

over b

hard m.e. i k → X

survival factor w.r.t. soft i-k interaction

$$\overline{S^2} = \frac{\sum_{i,k} \int d^2b \, |a_{pi}|^2 \; |a_{p'k}|^2 \; |\mathcal{M}_{ik}|^2 \; \exp(-\Omega_{ik}(s,b))}{\sum_{i,k} \int d^2b \, |a_{pi}|^2 \; |a_{p'k}|^2 \; |\mathcal{M}_{ik}|^2}$$

If the outgoing protons are observed (with $p_T=0$), then average amps

$$\overline{S^2} = \left| \frac{\sum_{i,k} \int d^2b \, |a_{pi}|^2 \; |a_{p'k}|^2 \; \mathcal{M}_{ik} \; \exp(-\Omega_{ik}(s,b)/2)}{\sum_{i,k} \int d^2b \, |a_{pi}|^2 \; |a_{p'k}|^2 \; \mathcal{M}_{ik}} \right|^2$$