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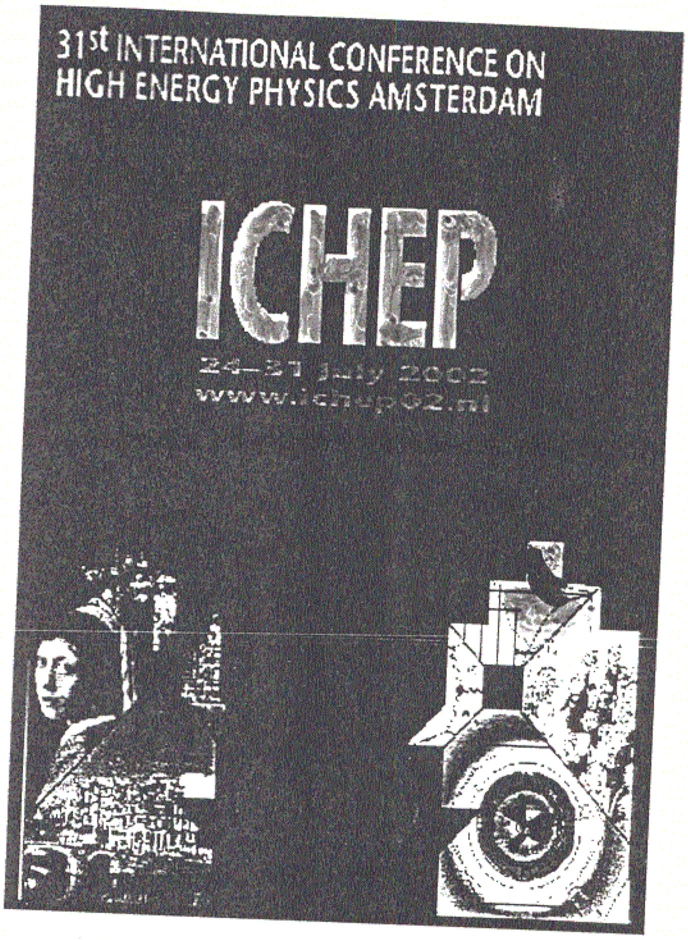
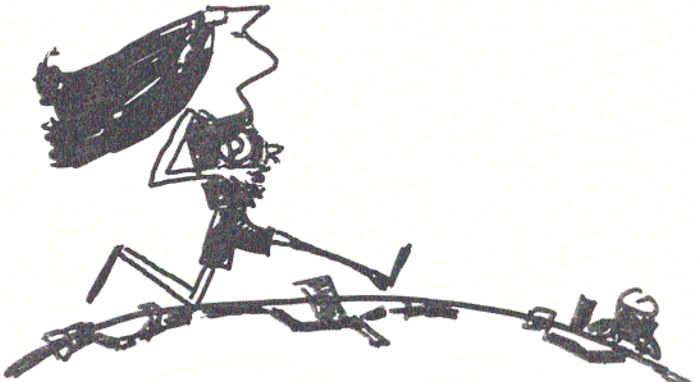


Physics with Forward Protons at Hadronic Colliders

V. A. Khoze (IPPP, DURHAM)

(in collaboration with A.D. Martin & M.G. Ryskin)



ATLAS & CMS – designed and optimised for DISCOVERY PHYSICS

- **How feasible are precision measurements at the LHC?**

- Main physics "goes forward" (not covered by the baseline design of ATLAS & CMS) of HIGH-P_T signature in the central region

- The accuracy of the precision measurements is limited by SYSTEMATICS.

ATLAS & CMS REQUIREMENT:

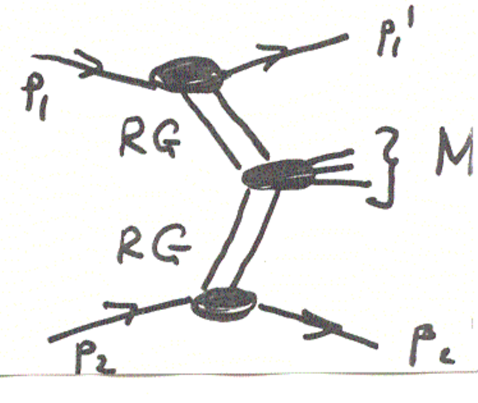
UNCERTAINTY IN THE LUMINOSITY

$\delta \mathcal{L} \leq 5\%$

- Lack of threshold scanning measurements (gold-mine of LC physics)

- Is there a way to solve these problems

- YES: Forward proton TAGGING



Rapidity Gap – "hadron-free" 'NO-FLIGHT' ZONE

Luminosity Monitors at the LHC

- Classic method based on the optical theorem

$$\left.\frac{d\sigma_{el}^{pp}}{dt}\right|_{t=0} = \frac{\sigma_{tot}^2}{16\pi}\left(1+\rho_{pp}^2\right)$$

↑ extrapolated

(at the LHC $\rho_{pp} = 0.1 \div 0.12$)

$N_{el} \sim \sigma_{tot}^2 \cdot L$

$N_{tot} \sim \sigma_{tot} \cdot L$

$$L \sim \frac{N_{tot}^2}{N_{el}}$$

The main challenge : to extrapolate elastic data from $|t| \gtrsim 0.01 - 0.02\ GeV^2$ to $t = 0$

(dedicated TOTEM programme , high β^* runs)

(Durham - KMR Group)

- A formalism developed for the description of high-energy soft processes , where multi-Pomeron effects are essential

- Global description of σ_{tot}, $\frac{d\sigma_{el}}{dt}$, ρ, σ_{SD}, σ_{DD} ISR - Tevatron

V. Khoze, A.D. Martin & M.G. Ryskin Eur. Phys JC 18 (2000) 167

(3% accuracy R. ORAVA + KMR)

• Forward Proton Taggers as Aladdin's Lamp

Recently much interest in central double-diffractive production in hadronic collisions

$p \overset{(-)}{p} \to p + M + \overset{(-)}{p}$ 'exclusive' reaction

'central inelastic'

$p \overset{(-)}{p} \to X + M + Y$ 'inclusive' reaction

$(+) \equiv$ Rapidity Gap - hadron-free zone

• VFTD - CDF LOI (M. Albrow et al) run 2A, Tevatron

$(1 - x_p \leq 0.1$, $\Delta M \simeq 250$ MeV, $M_H \lesssim 200$ GeV)

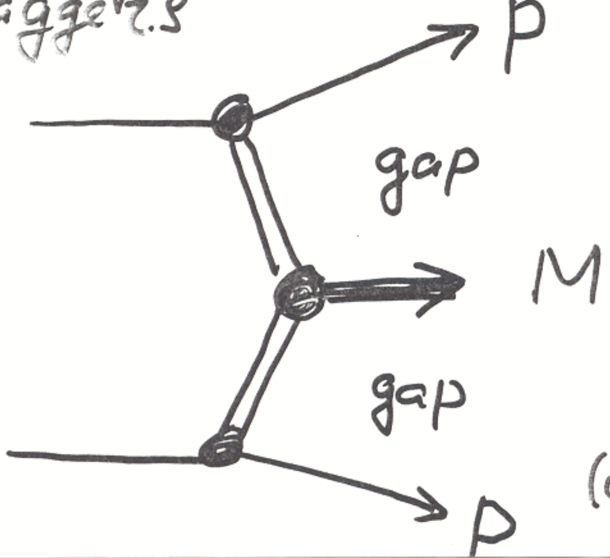
Roman Pots

• Microstations (R. Orava et al) for the LHC, $\Delta M \simeq 1$ GeV

$(M_H \simeq 120$ GeV)

Very rich physics menu

- Higgs - hunting
- 'Gluon Factory'
- χ_c, χ_b - central production
  glueballs (glueball filter a'la Close & Kirk)
- various aspects of diffractive physics
  Multi-gap event fraction
  (many outstanding questions of soft physics)
- $\gamma\gamma$ -physics
- $t\bar{t}$, $\tilde{g}\tilde{g}$, $\tilde{q}\bar{\tilde{q}}$ ... gluinoballs ...
- KK-gravitons, ... radions ...
- Good missing mass resolution provided by the proton taggers

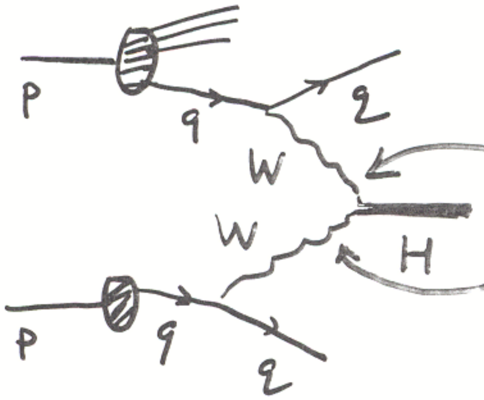


$M_{miss} = M$
(allowing for resolution)

● Diffractive Production Mechanisms

(within the Higgs context)

● 1987 – Yu. L. Dokshitzer, V.A. Khoze & S.I. Troian



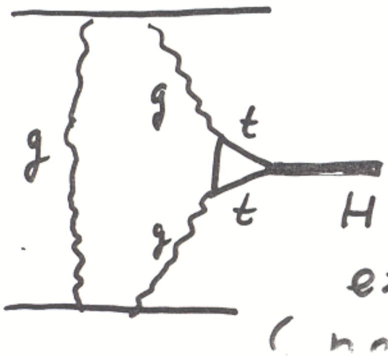
Rapidity Gaps –
– footprints of the pointlike colourless t-channel exchanges

(W, Z, γ .... "P")

NO colour transfer $\Longrightarrow$ No bremsstrahlung across the gap

● 1991 – A. Bialas & P. Landshoff

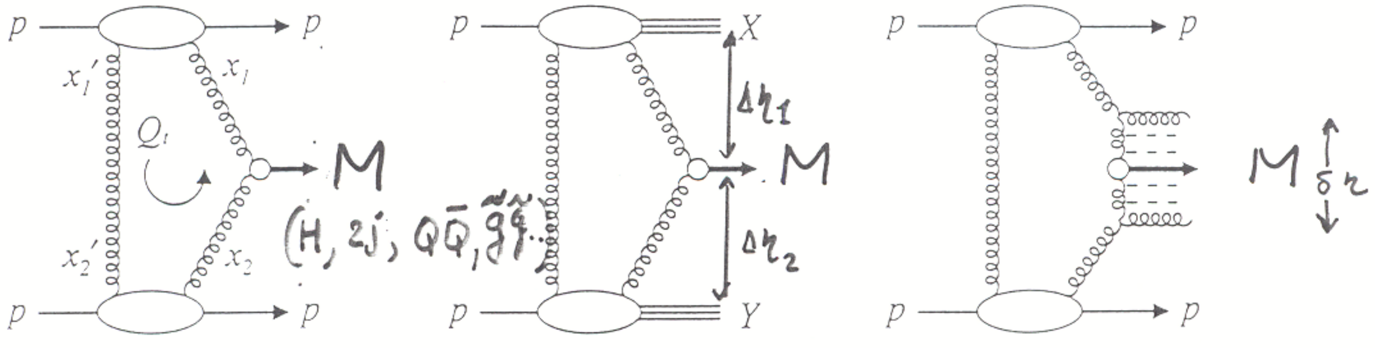
First QCD-based leading order calculation of double-diffractive Higgs production.



'accompanying' t-channel gluon screen's the colour

Left the possibility open for extra radiation and rescattering (not quantified) within perturbative framework

(a) exclusive (b) inclusive (c) central-inelastic



$M_{miss} = M$.	No M_{mis}	$M_{mis} > M$
$J_z = 0$ selection (P and C even states)	NO	NO
pile-up may be overcome	pile-up problems	pile-up may be overcome (M. Boonekamp et al)

- Truly exclusive production would allow to reconstruct the mass M from the two scattered protons.
  - ⇒ precise measurement of the scattered p momentum
- $M_{mis} = M$ (with allowance for resolution) of great value for reducing backgrounds + pile-up
- $J_z = 0$ selection ($gg \overset{PP}{\not\to} q\bar{q}|_{m_q\to 0}$, $2^{++}(Q\bar{Q})$....)
- Experimental issues A. De Roeck et al hep-ph/0207042
- Inclusive + Central inelastic — NO
  obvious advantages

'Unfortunate' diffractive production Physics

- Lack of dedicated interest from New Physics hunters
- Abundance of theoretical predictions ranging over many orders of magnitude

Interralated — discredit diffractive production mechanism
(viewed by many as a 'mucky lowland')

Some recent extremes (for σ_H^{excl}):

J.-R. Cudell & O.F. Hernandez, 1996 ('OPTIMISTS') — 300 fb LHC

Uppsala group (K. Enberg et al, 2002) ('PESSIMISTS') — $< 10^{-4}$ fb

$M_H = 120$ GeV

- Wide spread occurs either because different processes were considered or because important effects have been overlooked

ADM

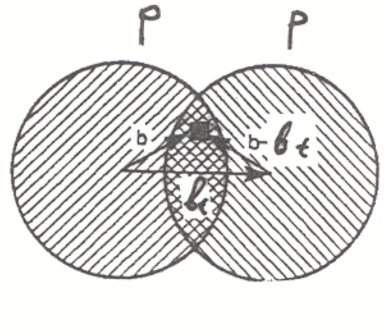
Survival of the Rapidity Gap

(in addition to the pile-up problems...)

RG – very promising, but quite a fragile tool

May be easily filled by secondaries from:

- Rescattering of spectator partons caused by the transverse overlap of the two incoming protons



Convolution of parton densities in impact plane.

$$S^2 = \frac{\int |M(s,b_t)|^2 e^{-\Omega(b_t)} d^2 b_t}{\int |M(s,b_t)|^2 d^2 b_t}$$

$\Omega(b_t)$ – 'optical density' of the interaction

Model dependence – the "Achilles heel"

Depends on : the nature of the colour-singlet exchange, spatial distribution of partons inside the proton, type of the process (SD, DD, CD)

First in the Higgs context:

Yu. Dokshitzer, V. Khoze, T. Sjöstrand – 1992

Bj – 1992 – SURVIVAL probability

Bj

- 'eikonal approach'

- E. Gotsman, E. Levin, U. Maor 1995–2000
  KMR – 1997–2001 – peaceful coexistence

- 'MC-approaches'

- M. Block, F. Halzen

$\boxed{\text{OFTEN OVERLOOKED}}$

I

(single-channel) traditional eikonal

$$\Omega(b_t) = \frac{\sigma_{pp}(s)}{4\pi B_p} e^{-b_t^2/4B_p}$$

- QCD-radiation induced by the 'active partons'

$\boxed{\text{RECOGNIZED}}$

Sudakov suppression phenomena

T^2

- QCD-radiation off the t-channel 'dipoles' ("P"-colour singlet digluon)

$\boxed{\text{PRACTICALLY ALWAYS NEGLECTED}}$

Symbolically

$$W = S^2 T^2$$

PROBABILITY for the RG's to survive in the hostile QCD-environment

- HIGH price to pay for the RADIATION DAMAGES
- Gluon spin correlations: $J_z = 0$ selection rule.

KMR

$pp \to p + H + p$

Survival prob. of rap. gaps

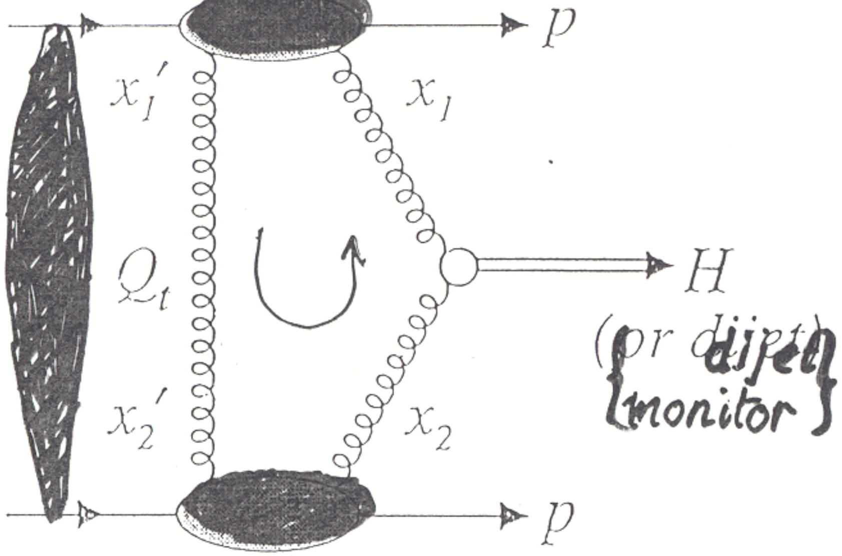
$$W = S^2 \, T^2$$

price for $\boxed{\text{no soft rescatt.}}$ $\boxed{\text{no } g \text{ rad}^n \text{ in } gg \to H}$

calc. using detailed 2-channel eikonal global analysis of soft pp data:

$S^2 = 0.02$ at LHC

$\quad = 0.045$ at Tevatron



$$\Lambda^2_{QCD} \ll Q_t^2 \ll M_H^2 \quad \to \text{pQCD}$$

$$\left(x' \sim \frac{Q_t}{\sqrt{s}}\right) \ll \left(x \sim \frac{M_H}{\sqrt{s}}\right) \ll 1$$

need uninteg. skewed gluons

$$\mathcal{M}_{\text{form}} = \underline{\frac{A}{M_H^2}\int \vec{Q}_{1t}\cdot\vec{Q}_{2t}\,\frac{d^2Q_t}{Q_t^6}}\; f\left(x_1, x_1', Q_t^2, \frac{M_H^2}{4}\right)\, f\left(x_2, x_2', Q_t^2, \frac{M_H^2}{4}\right)$$

where $f(x, x', Q_t^2, \mu^2) \approx R\,\frac{\partial}{\partial \ln Q_t^2}\left[\sqrt{T(Q_t,\mu)}\;xg(x, Q_t^2)\right]$

R is calculable
skewed effect
(R=1.2 at LHC)

$$\boxed{T(Q_t,\mu) = \exp\left(-\int_{Q_t^2}^{\mu^2}\frac{dk_t^2}{k_t^2}\frac{\alpha_s}{2\pi}\int_0^{1-k_t/\mu} dz\, z P_{gg} \cdots\right)}$$

strongly suppresses Q_t infrared region
+ anom. dimensions

$$\boxed{\sigma(p+H+p) \simeq \begin{cases} 3\text{ fb} & \text{at LHC} \\ 0.2\text{ fb} & \text{at Tevatron}\end{cases}}$$

mass 120 GeV

no emission when $\lambda \sim \frac{1}{k_t} > d \sim \frac{1}{Q_t}$

- $\tau_{\text{di-gluon}} \sim \frac{1}{\langle Q_t\rangle} \sim \frac{1}{Q_{\text{saddle}}} \sim 0.1\text{ fm}$

  $\tau_{\text{di-gluon}} \ll \tau_p \sim 1\text{ fm}$

- Single Log accuracy

Higgs

Summary

Detection of light Higgs is challenging
($M_H \lesssim 130\,\text{GeV}$)

A valuable process:

<u>exclusive DD Higgs production</u>

$$pp \to p + H + p$$
$$H \to b\bar{b}$$

$$M_H = \begin{cases} M_{b\bar{b}} & \sim 10\,\text{GeV resol}^{\underline{n}} \\ M_{miss} & \sim \underline{1\,\text{GeV resol}^{n}} \end{cases}$$

if p taggers installed at 420m

$\mathcal{L} = 30\,fb^{-1}$ $\quad M_H = 120\,\text{GeV}$

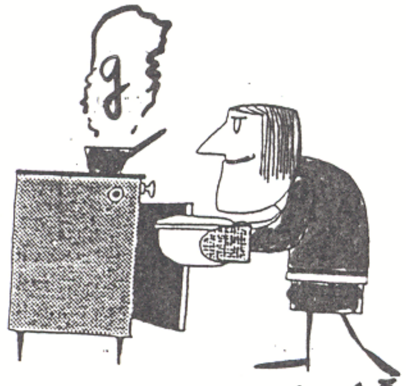
11 $\quad H \to b\bar{b}$ events seen
4 $\quad b\bar{b}$ background $\qquad$ bkgd suppressed

Can check predicted rate by observing
$$pp \to p + \text{dijet} + p$$

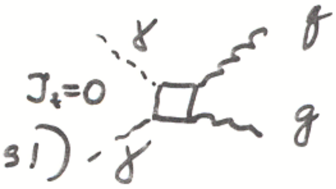
(so far consistent with CDF bound)
dijet monitor

	Process	Survival factor T^2	Survival factor S^2	Norm	σ_{Higgs} (fb) TEV	σ_{Higgs} (fb) LHC	
KMR	EXCL incl C-inel	+	+	pdf pdf	0.2 1 ~0.03	3 40 50	'skewed' gluons CDF-dijets – OK
B.Cox et al	C-inel	$T \simeq 1$	norm.	CDF dijets	0.02	6	
M. Boonekamp et al (ICHEP 02)	C-inel	$T \simeq 1$	norm.	CDF dijets	2,7	320	assume $S^2_{TEV} = S^2_{LHC}$

• **'Gluon factory'**



g - under-rated fundamental ingredient of the SM



$(\gamma\gamma)_{J_z=0} \to q\bar{q},\ gg$ (V. Khoze - 1991)

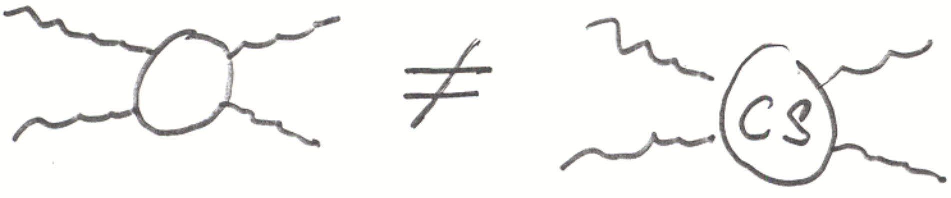
• Unique environment to perform very detailed studies of high energy gluon jets : $pp(\bar{p}) \to p + gg + p(\bar{p})$

purity ~ 1000 : 1 or better

• A real counterpart to $Z^0 \to q\bar{q}$ ($20 \cdot 10^6$ events)

variable E_g

• Long and checkered history



CS → $q\bar{q}$

CS → gg

No 'natural' purely gluonic sources

'environment-independent' detailed quantitative comparison of the perturbative and non-perturbative properties of q and g jets

SUSY Particle Production

- Probing the strong interaction sector of physics beyond the Standard Model

$\tilde{g}\tilde{g}$, $\tilde{q}\bar{\tilde{q}}$

'Light' sparticles
$M_{SUSY} < 400$ GeV

- Gluino studies cannot be easily achieved at LC's.

- In exclusive double-diffractive studies gluinos and squarks can be separated by their THRESHOLD BEHAVIOR

Parity conservation : $\sim \beta^3$ $(t\bar{t}, \tilde{g}\tilde{g})$
$\sim \beta$ $(\tilde{q}\bar{\tilde{q}})$

[+ standard modifications due to sparticle width and the QCD Coulomb interactions

{V. S. Fadin, VAK 1991
{I. I. Bigi, V. S. Fadin, VAK 1993]

For $m_{sp} \simeq 250$ GeV, $\beta \leq 0.6$

- $\Delta\sigma_{thr}(pp \to p + \tilde{g}\tilde{g} + p) \simeq 0.15$ fb

- $\Delta\sigma_{thr}(pp \to p + \tilde{q}\bar{\tilde{q}} + p) \simeq 0.04$ fb
(masses of the light squarks are likely to be degenerate, as are masses of $\tilde{q}_L$ and $\tilde{q}_R$)
- $\Delta\sigma(pp \to p + t\bar{t} + p) \simeq 0.1$ fb

(a potential template of the ability of the missing mass method)
(signal: jets $+ \not{E}_T +$ leptons) spartilles

$\Delta\sigma(pp \to X + \tilde{g}\tilde{g} + Y) \simeq 50$ fb
$\Delta\sigma(pp \to X + \tilde{q}\bar{\tilde{q}} + Y) \simeq 2$ fb

$\tilde{g} \sim$ LSP (NLSP) scenario

allowed mass window: 25–35 GeV

A. Mafi and S. Raby 2000

Gluinoball production !

Beyond the base (party) line

- CMS & ATLAS have been designed and optimised for discovery physics
- Is there anything else that should / can be done at the LHC ?
- ➔ YES, FORWARD PHYSICS
- Integration with central detector is mandatory

Conclusion

Triggering on forward going protons can provide us with a very rich physics menu.

This may allow not only to monitor the proton luminosity with high accuracy, but also to perform the high-resolution missing mass searches for New Physics.

In many aspects the physics programme with the tagged forward protons is complementary to the standard approaches at hadronic colliders and to the studies at a future linear e^+e^- collider.