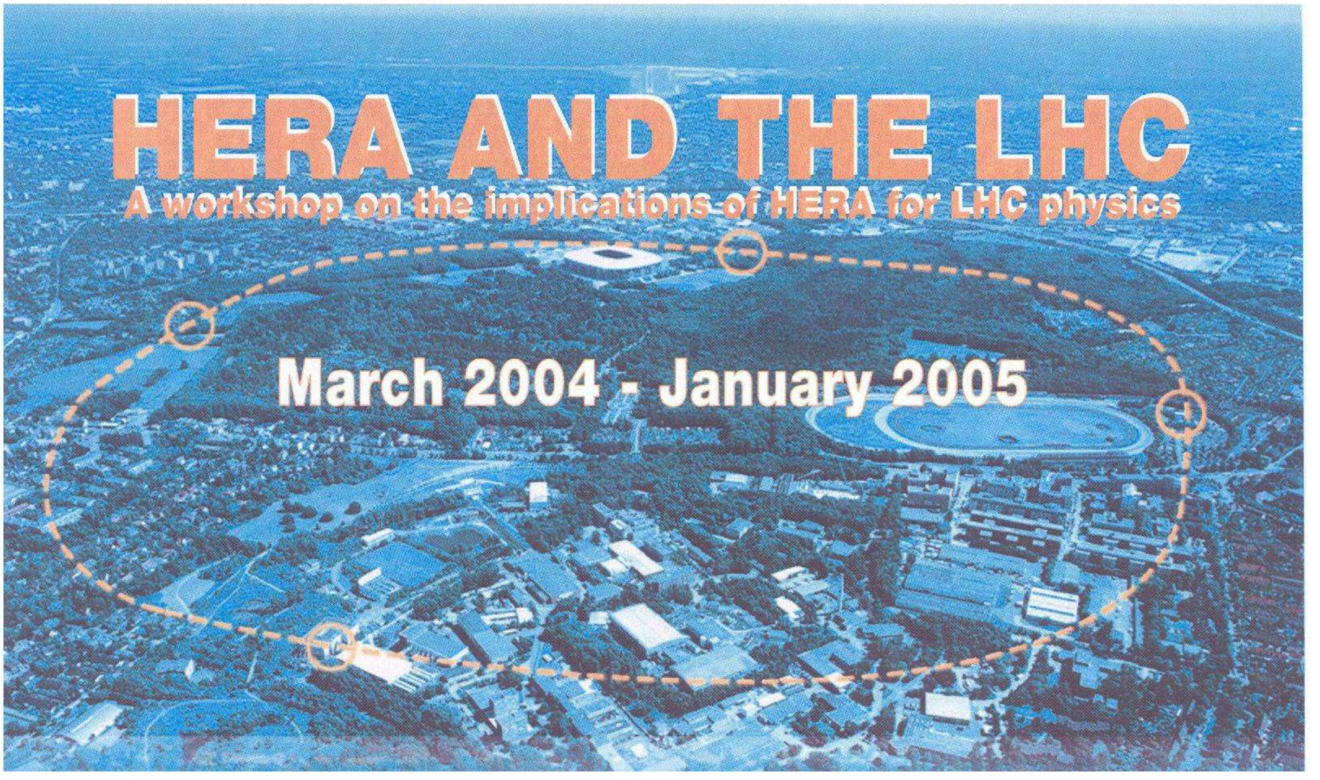

Midterm Meeting, 11-13 October, 2004

Exclusive Diffractive Higgs Production and Related Processes

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In collaboration with
A.B.Kaidalov, A.D.Martin ,M.G.Ryskin, W.J.Stirling

Main Aims:

- to illustrate how the Higgs physics reach of the LHC can be significantly extended by addition of Forward Proton Taggers.
- to discuss the Standard Candles for testing the theoretical predictions.

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PLAN

1. Introduction
   (a gluonic Aladdin's lamp)

2. The key selling points of the Central Exclusive Diffractive processes.

3. Basic elements of the KMR approach
   (a brief guide)

4. Prospects for CED Higgs production.

- the SM case
- MSSM Higgses in the troublesome regions
- MSSM with CP-violation

5. Experimental checks (today and tomorrow)

6. New recent development

7. Conclusion

Forward Proton Taggers as a gluonic Aladdin's Lamp

Rich Old and New Physics menu

- Higgs Hunting (currently key selling point).
- Photon-Photon Physics.
- 'Light' SUSY (sparticle 'threshold' scan).
- Various aspects of Diffractive Physics (strong interest from cosmic rays people).
- Luminometry.
- High intensity Gluon Factory.
(lower lumi run, RG trigger…)
- Searches for new heavy gluophilic states (radions ,gluinonia,….), KK gravitons..

Would provide a unique additional tool to complement the conventional strategies at the LHC and ILC.

Not as 'either the Higgs or nothing'

The advantages of CED Higgs production

- Prospects for high accuracy mass measurements (width in some MSSM cases)

mass window $\Delta M = 3\sigma \sim 1$ GeV (wishlist)

~4 GeV(currently feasible, Helsinki Group)

- Valuable quantum number filter/analyser.

(0++ dominance ;C,P-even)

No obvious way to establish the Higgs CP at LHC conventionally.

(an important ingredient of pQCD approach, otherwise, large $|J_z|=2$ …effects, $\sim(pt/Qt)^2$)

- H ->bb 'readily' available

$(gg)_{CED} \not\to b\bar{b}$ LO (NLO,NNLO), BG-studied

SM Higgs S/B~3(1GeV/ΔM)

complimentary information to the conventional studies(also tau tau)

- H->WW*,especially for SM Higgs with M~135GeV

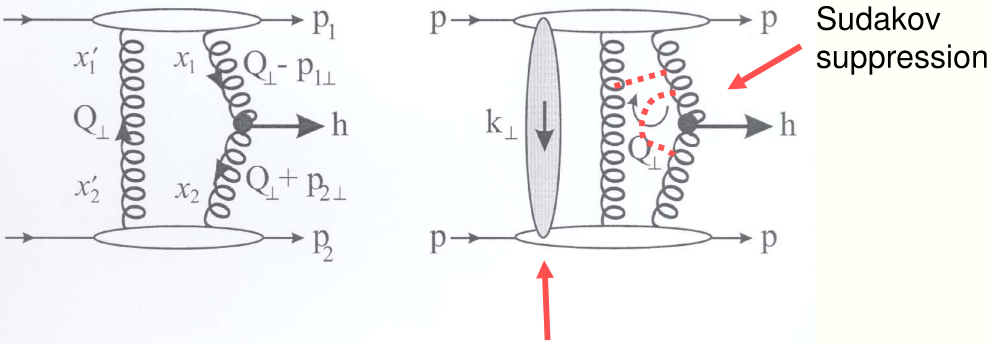
- New leverage –proton momentum correlations

(probes of QCD dynamics, pseudoscalar ID, CP violation effects.)

The basic ingredients of the KMR approach (1997-2004)

J.Forshaw(June-04.)

Interplay between the soft and hard dynamics



Bialas-Landshoff-91
(Born -level)

rescattering/absorptive
effects

Main requirements:

•inelastically scattered protons remain intact

•active gluons do not radiate in the course of evolution up to the scale M

•<Qt> >>Λ_{QCD} in order to go by pQCD book

MIND THE GAP

h price to pay for such a clean environment

$\sigma(\mathrm{CEDP}) \sim 10^{-4}\, \sigma(\mathrm{INCL})$

Rapidity Gaps should survive hostile hadronic Radiation Damages & 'partonic pile-up'

$W = S^2\ T^2$

Colour charges of the 'digluon dipoles' are screened only at r> 1/<Qt>

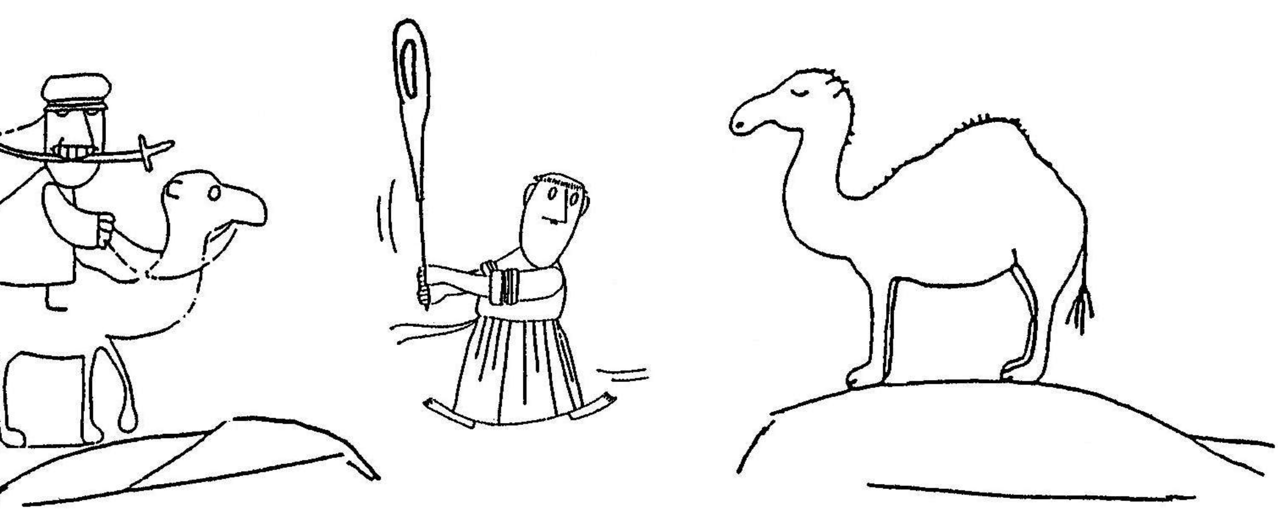
GAP KEEPERS (survival factors),

protecting RG against:

the products of QCD radiation with M>kt>Qt (T)

soft rescattering effects (necessitated by unitarity) (S)

Forcing two (inflatable) camels to go through the eye of a needle



$$\sigma = \mathcal{L}(M^2, y)\,\hat{\sigma}(M^2) \qquad M^2 \frac{\partial \mathcal{L}}{\partial y\,\partial M^2} = \hat{S}^2 \quad L$$

(SHCEMATICALLY)

$$L_F^{\rm excl} = \left(\frac{\pi}{(N_C^2-1)b} \int \frac{dQ_t^2}{Q_t^4} f_g(x_1, x_1', Q_t^2, \mu^2)\, f_g(x_2, x_2', Q_t^2, \mu^2) \right)^2$$

$$\frac{d^2\sigma}{dt_1 dt_2} \propto e^{b(t_1+t_2)},$$ where b is the t-slope

(x, x', Q_t^2, μ^2) are the skewed unintegrated structure functions (suPDF)

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

the simplified form

$$f_g(x, x', Q_t^2, \mu^2) = R_g \frac{\partial}{\partial \ln Q_t^2}\left[\sqrt{T(Q_t, \mu)}\, xg(x, Q_t^2)\right]$$

ccounts for the single log Q^2 skewed effect (1.2 at the LHC)

$T(Q_t, \mu)$ is the survival probability that a gluon with transverse momentum Q_t untouched in the evolution

T (+ a.d.) –an **IR filter**

the apparent divergency in the Qt-integration nullifies

$$\langle Q_t \rangle_{SP} \sim \frac{M}{2} \exp\left(-\frac{1}{\bar{\alpha}_s}\right), \qquad \bar{\alpha}_s = \frac{N_C \alpha_s}{\pi}$$

SM Higgs

$$M \gg \langle Q_t \rangle_{SP} \simeq 2\ \mathrm{GeV} \gg \Lambda$$

1. An important role of subleading terms in $f_g(x, x', Q_t^2, \mu^2)$ – SL accuracy

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

(PDF-democracy)

SM Higgs at LHC

3. $\hat{S}^2_{KMR} = 0.026\ (\pm 50\%)$ at LHC

detailed (two-channel eikonal) analysis of soft data

• good agreement with other 'unitarizer' approaches and MC

U. Maor.

4. $\hat{S}^2/b^2$ quite stable (within 10–15%)

$\hat{S}^2 \sim s^{-0.16}$ (the Tevatron - LHC range)

$dL/d\ln M^2 \sim \frac{1}{(16+M)^{3.3}}$

$\sigma_H \sim \frac{1}{M^3}$, $(\sigma_B)_{ch} \sim \frac{\Delta M}{M^6}$

7. $J_z = 0$, P-even selection rule for

is justified only if

$\langle p_t^2 \rangle / \langle Q_t^2 \rangle \ll 1$

Current consensus on the LHC Higgs search prospects

(e.g, A.Djouadi, Vienna, G.Weiglein, CMS, 04)

•SM Higgs : detection is in principle guaranteed for any mass.

•In the MSSM h-boson most probably cannot escape detection ,and in large areas of parameter space other Higgses can be found.

•But there are still troublesome areas of the parameter space:

intense coupling regime,
MSSM with CP-violation…..

•More surprises may arise in other SUSY non-minimal extensions

• After discovery stage (Higgs identification):

The ambitious program of precise measurements of the mass, width, couplings, and, especially of the quantum numbers and CP properties would require an interplay with a *ILC*

SM Higgs, CEDP
LHC, L=30fb-1
KMR-00,KKMR-03

M(GeV)	120	140	comments
xsect	3fb (1 -5.5fb)	1.9fb (0.6 -3.5fb)	accuracy could be improved (th. exp. CEDP dijets Mjj~M)
Sbb	11	3.5	cuts +effis
(S/B)bb	3(1GeV/ΔM)	2.4(1GeV/ ΔM)	cuts +effis. LO,NLO Bgd
Sww*	3.6	8.4 . 6 (MC+det. stim) ADR & MS	LH,LL domin. detailed MC needed
(S/B)ww* Needed	>>1	>>1	detailed MC studies

ZZ*+tau tau

- ‘Natural’ low limit - 0.1fb (photon fusion)

- An added value of the WW*

‘less demanding’ experimentally
(trigger and mass resolut. requirements..)

high acceptance and efficiencies

an extension of well elaborated conventional program,
(experience, MC’s………)

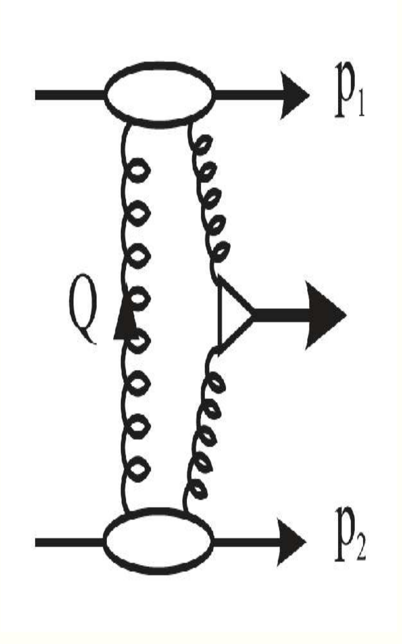
Note in passing:

mass resolution is rising with M

prospects of accurate H mass measurements ,
0+ assignment ,spin-parity analyzing
- still hold

The MSSM and more exotic scenarios

$$pp \to p + \phi + p$$



If the coupling of the Higgs-like object to gluons is large, double proton tagging becomes very attractive

- The intense coupling regime of the MSSM

(E.Boos et al, 02-03)

- The MSSM with explicit CP violation

(A.Pilaftsis,98;M.Carena et al.,00-03,B.Cox et al 03)

(a)The intense coupling regime

M_A < 120-150GeV, tan beta >>1 (E.Boos et al,02-03)

- h,H,A- light, practically degenerate
- large wdths, must be accounted for
- the 'standard' modes WW*,ZZ*, gamma gamma …- strongly suppressed v.s. SM
- the best bet –mu mu channel,

In the same time – especially advantageous for CEDP:

(KKMR 03-04)

- (Higgs->gg)Br(Higgs->bb) - significantly exceeds SM. Thus ,much larger rates.
- widths~ mass window,
- 0- is filtered out, and the h/H separation may be possible
- (b) The intermediate regime: M_A 500 GeV, tan beta $\lesssim$ 5-10

(the LHC wedge, windows)

(c) The decoupling regime

(in reality, M_A>140 GeV, tan beta $\gtrsim$10)

h is SM-like, H/A -heavy and approximately degenerate

CEDP may allow to filter A out

The intense coupling regime of the MSSM

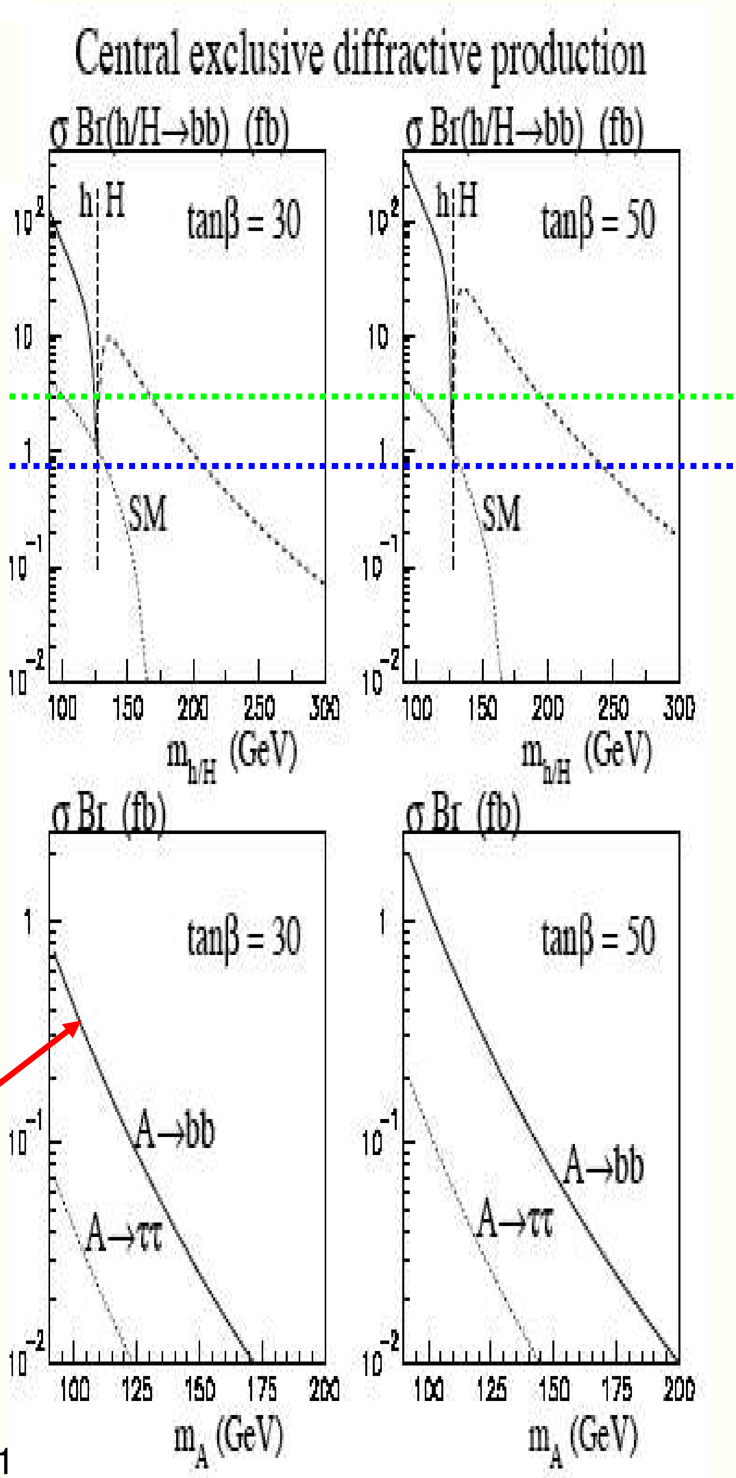
The intense coupling regime is where the masses of the 3 neutral Higgs bosons are close to each other and tan β is large

$\gamma\gamma, WW^{\star}, ZZ^{\star}$ suppressed

$gg \to \phi$ enhanced

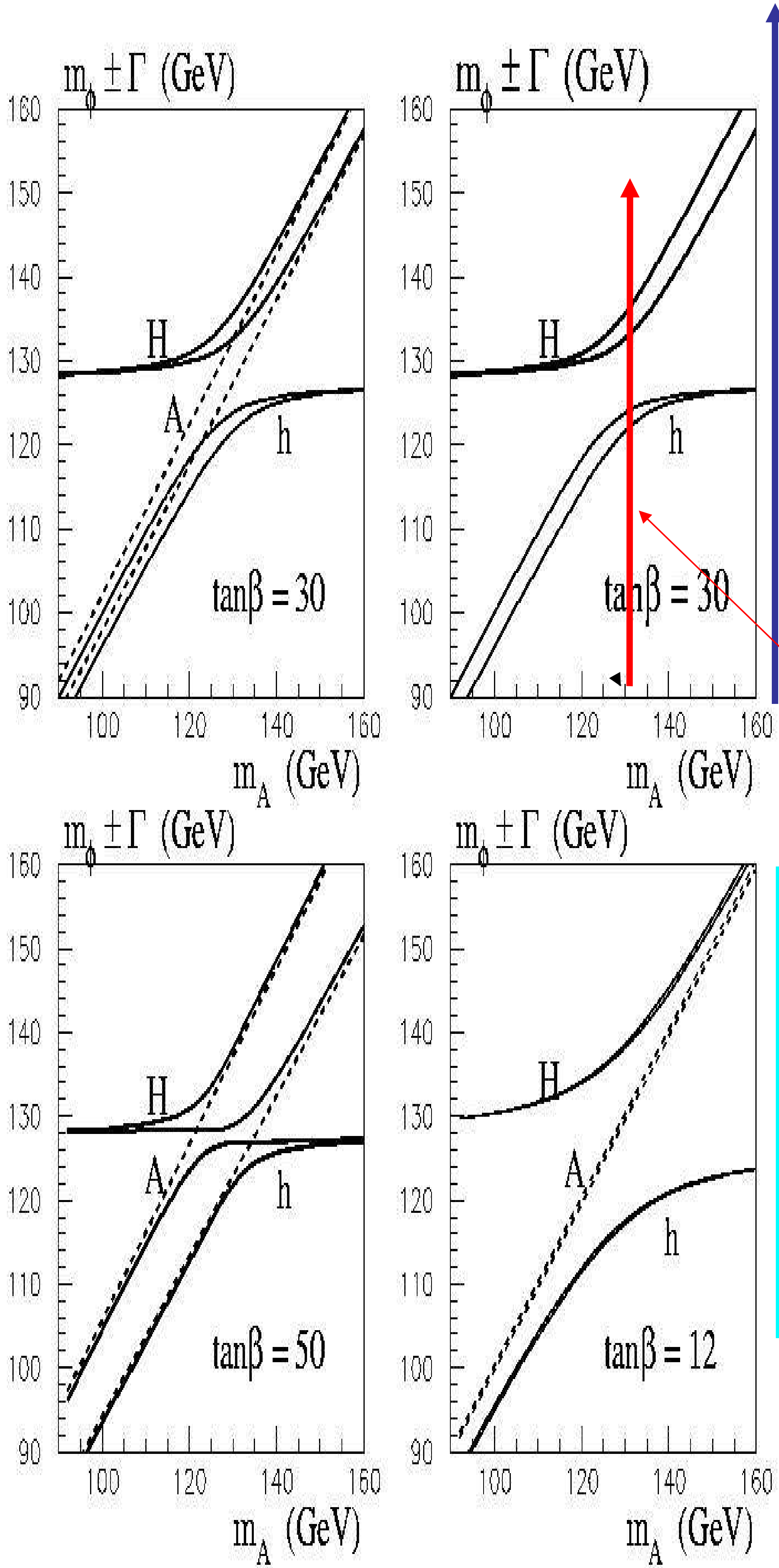
0^{++} selection rule suppresses A production:

CEDP 'filters out' pseudoscalar production, leaving pure H sample for study



for 5 σ with 300 (30) fb^{-1}

$$\mathrm{Br}(b\bar{b}) \cdot \sigma > 0.7\ \mathrm{fb}\ (2.7\ \mathrm{fb})$$



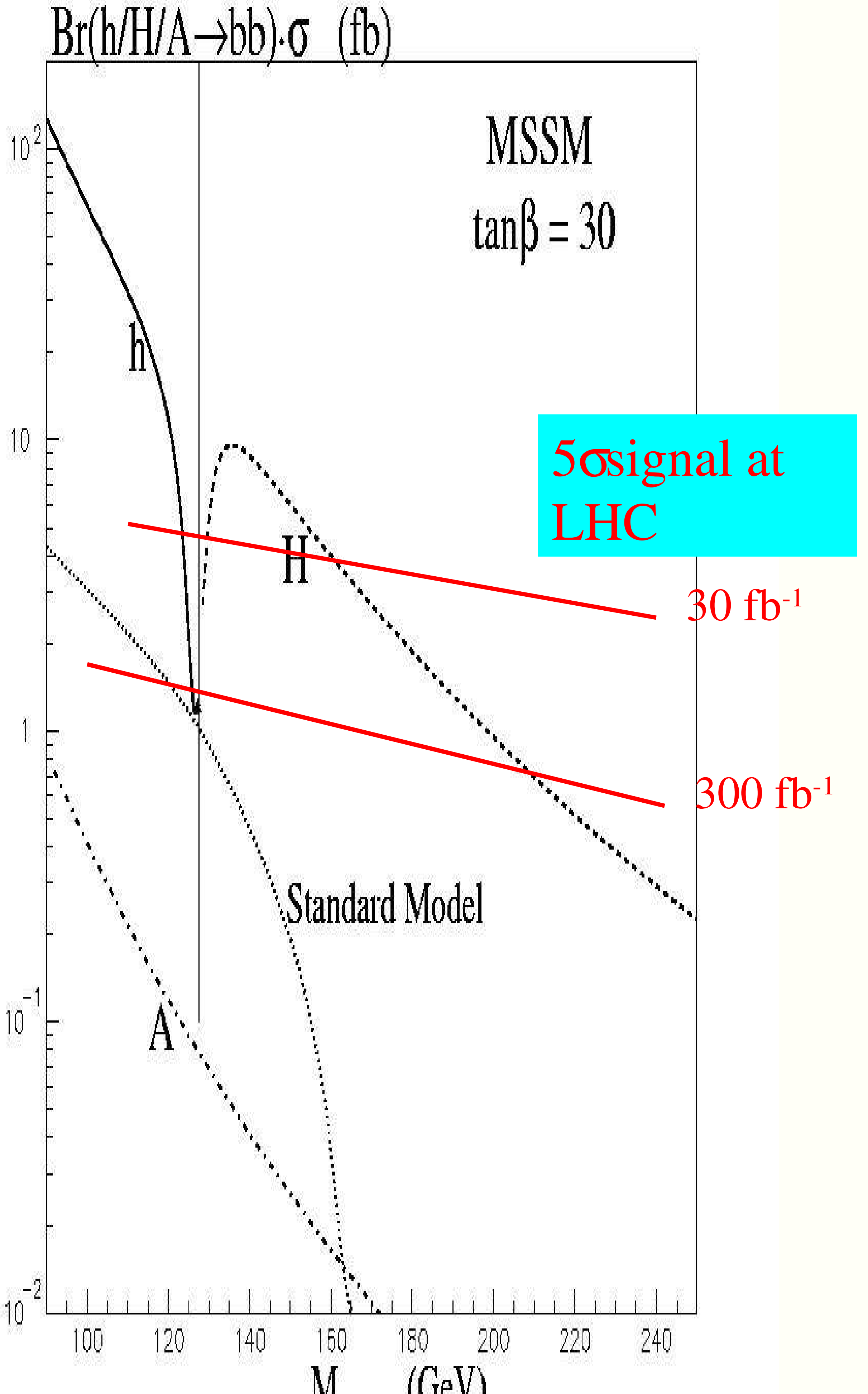
decoupling regime:
$m_A \sim m_H$ large
h = SM

intense coup:
$m_h \sim m_A \sim m_H$
$\gamma\gamma$,WW.. coup. suppressed

with CEDP:

- h,H may be clearly distinguishable outside130+-5 GeV range,
- h,H widths are quite different

Central exclusive diffractive production



SM pp → p + (H → bb) + p

S/B~11/4(ΔM)

with ΔM (GeV) at LHC with $30\ fb^{-1}$

e.g. m_A = 130 GeV, tan β = 50

(difficult for conventional detection, but CEDP favourable)

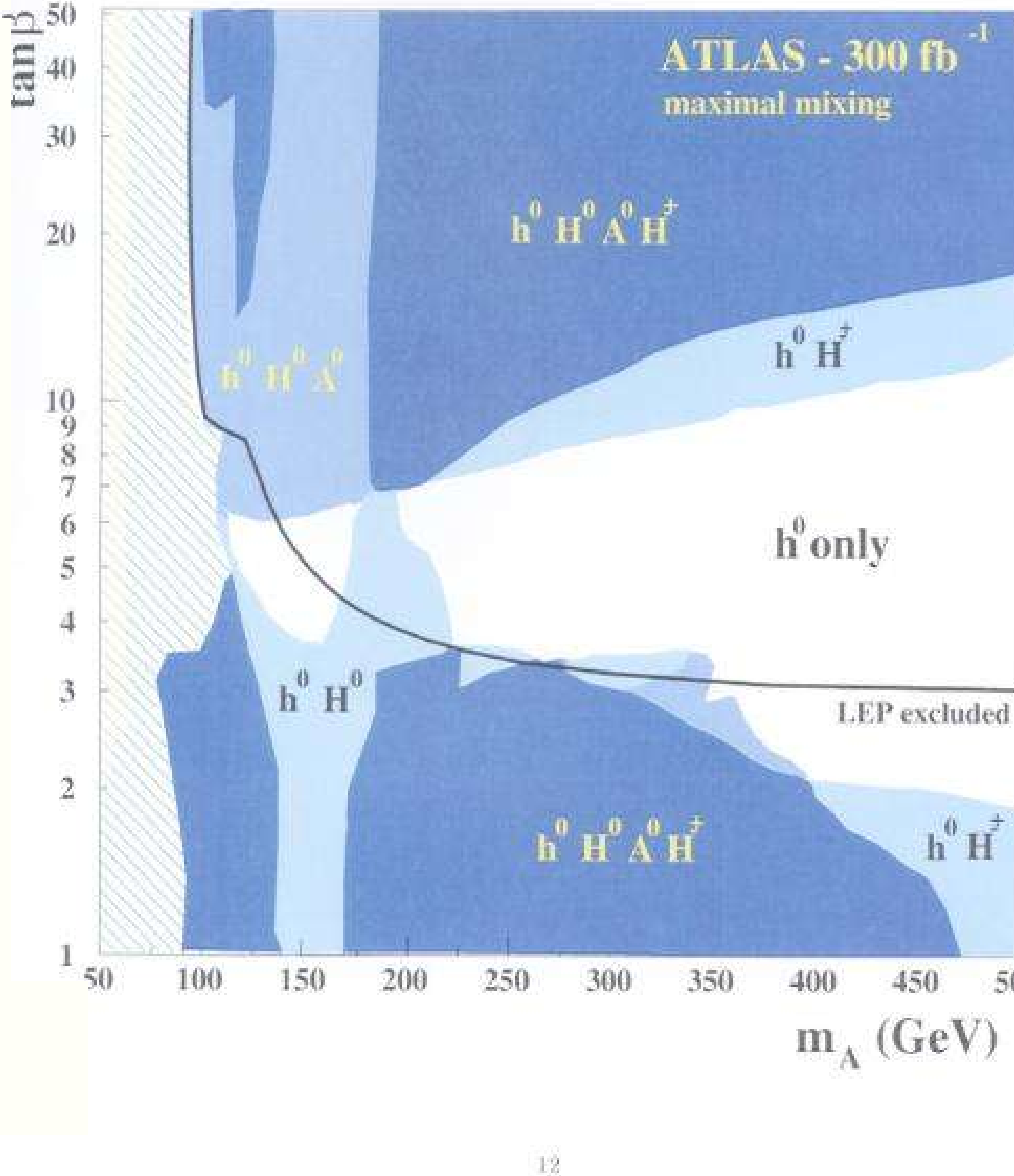
	S	B
m_h = 124.4 GeV	71	3
m_H = 135.5 GeV	124	2
m_A = 130 GeV	1	2

$\times \frac{\Delta M}{1\ \text{GeV}}$

incredible significance(10 s.d.) for Higgs signal even at 30 fb -1

The intermediate regime

The ‘LHC window’

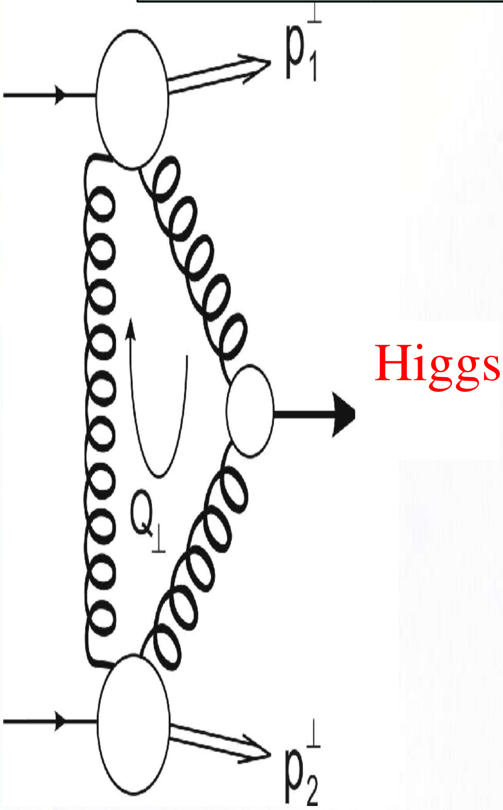


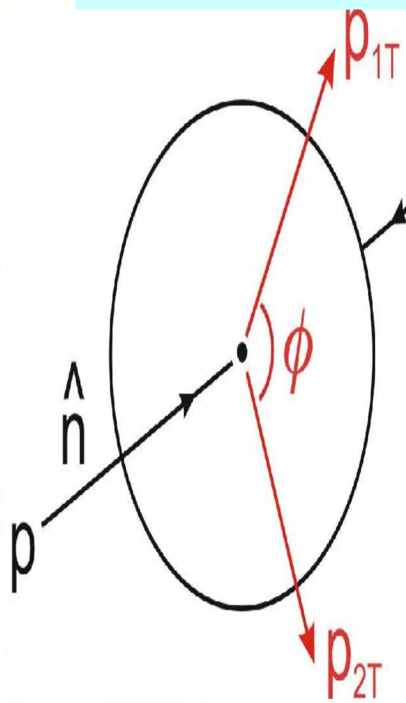
With CEDP the mass range up to 160-170 GeV can be covered at 300 fb-1

An additional valuable tool

A(0-), CPX

pp->p+H+p





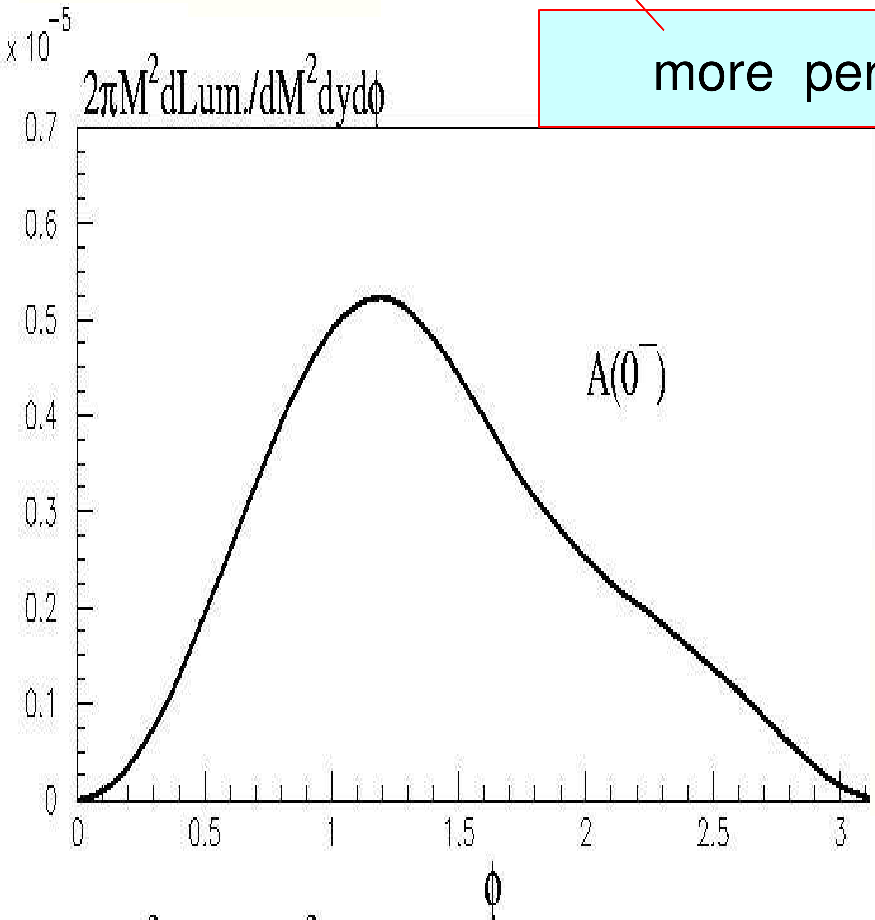
$$V(0^+) \sim \text{const.}, \qquad V(0^-) \sim (\vec{p}_{1T} \times \vec{p}_{2T}) \cdot \hat{n} \sim |t_1|^{1/2} |t_2|^{1/2} \sin\phi$$

$$\int \frac{d^2 Q_T}{Q_T^4} \text{ for } 0^+ \quad \rightarrow \quad p_{1T}\, p_{2T} \int \frac{d^2 Q_T}{Q_T^6} \text{ for } 0^-$$

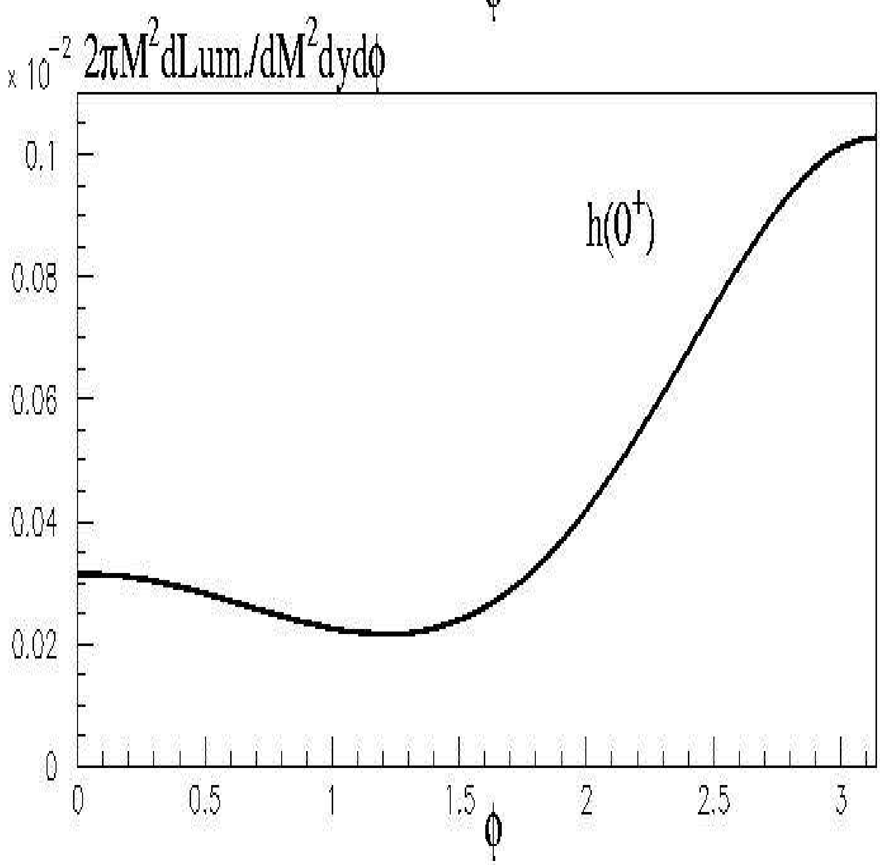
More IR-sensitive

$$\langle S^2(0^-)\rangle \sim 3\text{-}4\,\langle S^2(0^+)\rangle$$

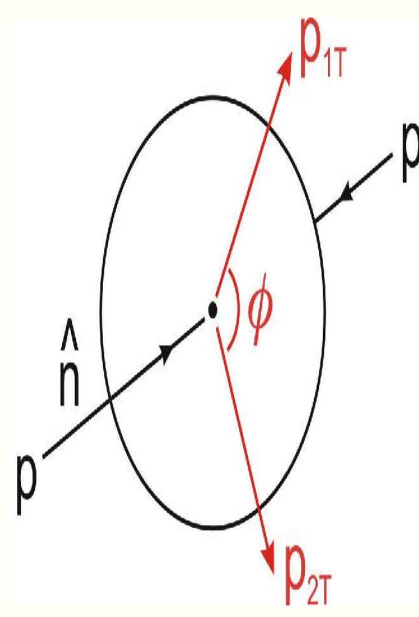
more peripheral



p_{1T},p_{2T} correlations reflect spin-parity of central system: can distinguish 0^- from 0^+



pp->p1+H+p2



CPX MSSM Higgs (KMR-03)

$$A = \frac{\sigma(\varphi < \pi) - \sigma(\varphi > \pi)}{\sigma(\varphi < \pi) + \sigma(\varphi > \pi)}$$

$$M = g_S \cdot (e_1^{\perp} \cdot e_2^{\perp}) - g_P \cdot \varepsilon^{\mu\nu\alpha\beta} e_{1\mu} e_{2\nu} p_{1\alpha} p_{2\beta} / (p_1 \cdot p_2)$$

CP even

CP odd active at non-zero t

$M(H_1)$ GeV	cuts	30	40	50
$\sigma(H_1)\mathrm{Br}(b\bar{b})$	a	45	14	6
$\sigma^{\mathrm{QCD}}(b\bar{b})$	a	16000	1400	200
$A_{b\bar{b}}$		0.14	0.07	0.04
$\sigma(H_1)\mathrm{Br}(\tau\tau)$	a, b	1.9	0.6	0.3
$\sigma^{\mathrm{QED}}(\tau\tau)$	a, b	0.2	0.1	0.04
$A_{\tau\tau}$	b	0.2	0.1	0.05
$M(H_2)$ GeV		103.4	104.7	106.2
$\sigma\mathrm{Br}(H_2 \to 2H_1 \to 4b)$	c	0.5	0.5	0.5
$\sigma\mathrm{Br}(H_2 \to 2b)$	a	0.1	0.1	0.2
$M(H_3)$ GeV		141.9	143.6	146.0
$\sigma\mathrm{Br}(H_3 \to 2H_1 \to 4b)$	c	0.14	0.2	0.18
$\sigma\mathrm{Br}(H_3 \to 2b)$	a	0.04	0.07	0.1

(b) $p_i^{\perp} > 300$ MeV for the forward outgoing protons

$$H_2, H_3 \to H_1 + H_1$$

many other possibilities , e.g. $H_3 \to H_1 + Z$

Summary of CEDP

- *The missing mass method may provide unrivalled Higgs mass resolution*
- *Real discovery potential in some scenarios*
- *Very clean environment in which to identify the Higgs,for example, in the CPX scenario*
- *Azimuthal asymmetries may allow direct measurement of CP violation in Higgs sector*
- *Assuming CP conservation, any object seen with 2 tagged protons has positive C parity, is (most probably) 0^+, and is a colour singlet*

e.g. m_A = 130 GeV, tan β= 50

(difficult for conventional detection, but exclusive diffractive favourable)

$\mathcal{L}$ = 30 fb^{-1}

	S	B	
m_h = 124.4 GeV	71	3	events
m_H = 135.5 GeV	124	2	
m_A = 130 GeV	1	2	

$\times \frac{\Delta M}{1\ \text{GeV}}$

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

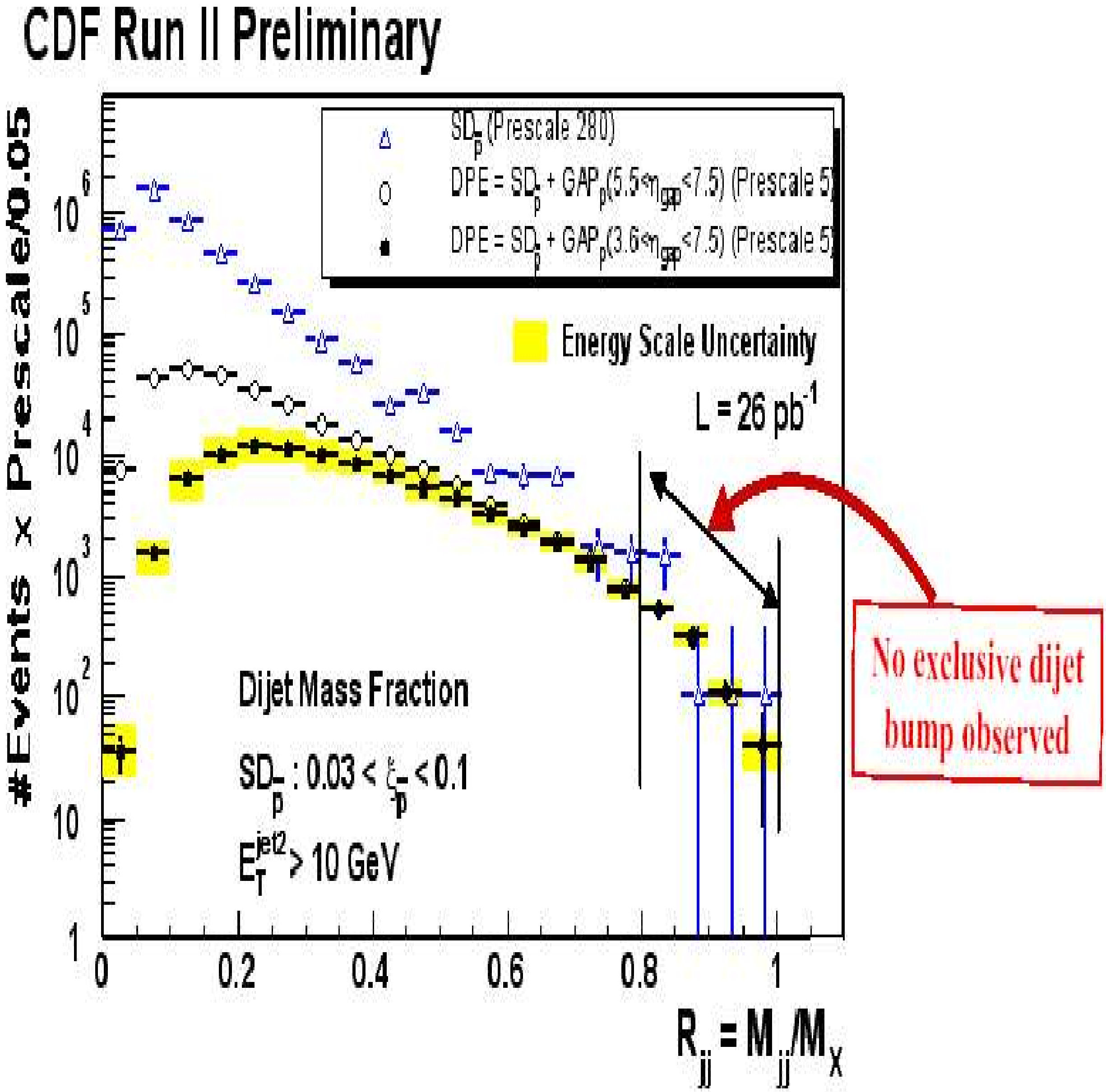
•Very low rate of CED high-Et dijets ,observed yield of Central Inelastic dijets.
(CDF, Run I, Run II)

'Factorization breaking' between the effective diffractive structure functions measured at the Tevatron and HERA.
(KKMR-01 ,a quantitative description of the results, both in normalization and shape of the distribution)

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

•The HERA data on diffractive high Et dijets in Photoproduction.
(Klasen& Kramer-04 NLO analysis)

•Preliminary CDF results on exclusive charmonium CEDP. Higher statistics is on the way.
•Energy dependence of the RG survival (D0, CDF)



$|\eta_{jet1,2}|<2.5$, $0.03<\xi_{\bar{p}}<0.1$, $3.6<\eta_{gap}<7.5$, $R = 0.7$

Minimum E_T^{jet1}	Cross Section : $\sigma_{DPE}^{excl.\,jj}(R_{jj}>0.8)$
10 GeV	970 ± 65(stat) ± 272(syst) pb
25 GeV	34 ± 5(stat) ± 10(syst) pb

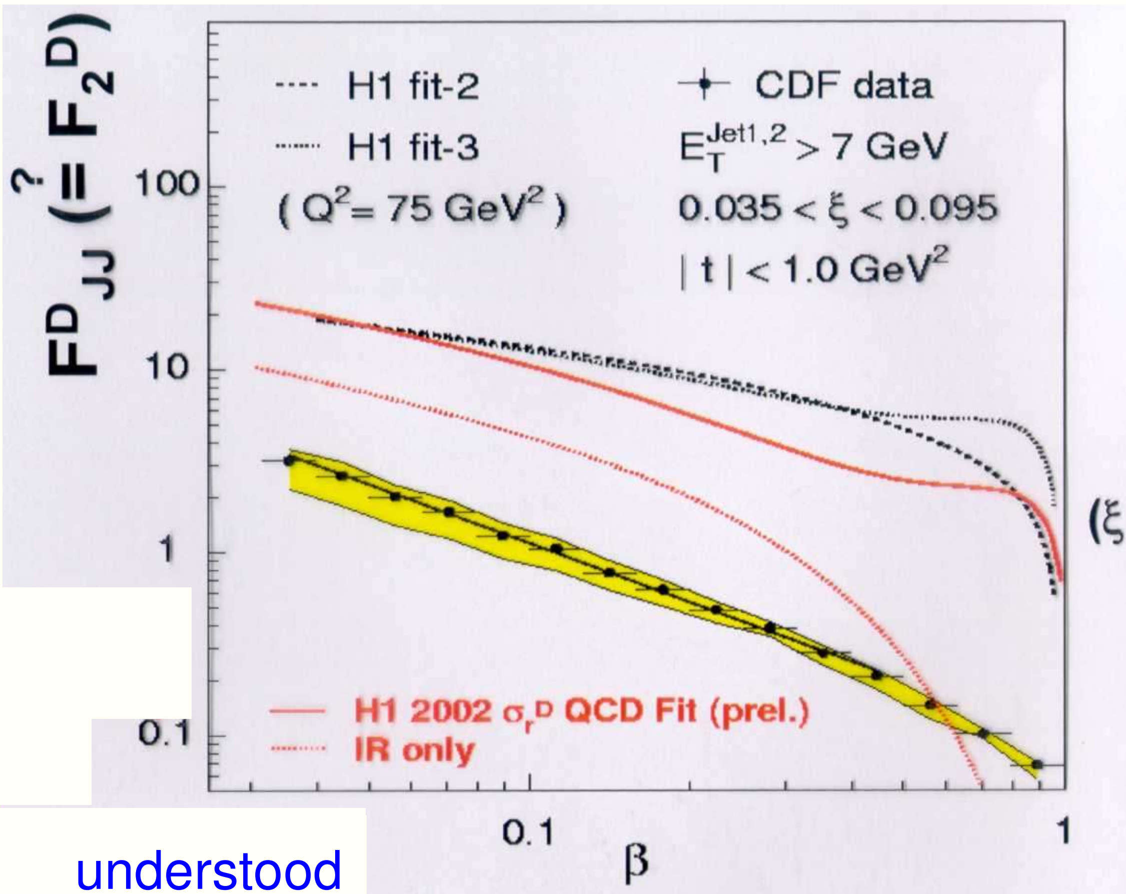
KMR-00
CEDP
~ 1 nb

KMR-04
~40pb

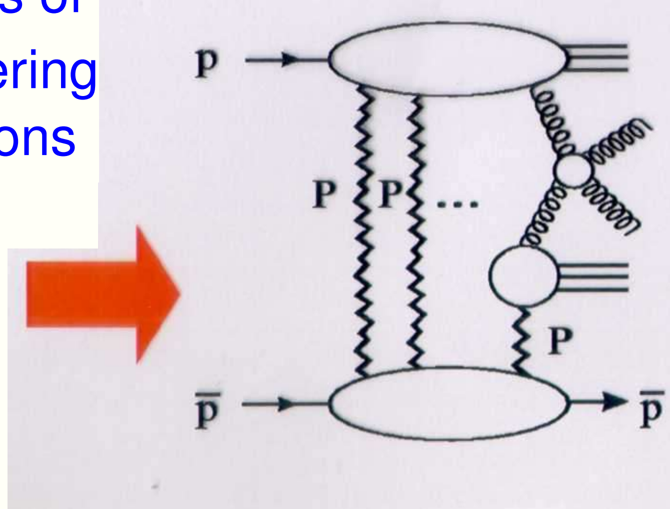
'OPTIMISTIC ' models ruled out experimentally
(Run I-published , Run II, prelim)

More tests with upcoming
Tevatron run-II data

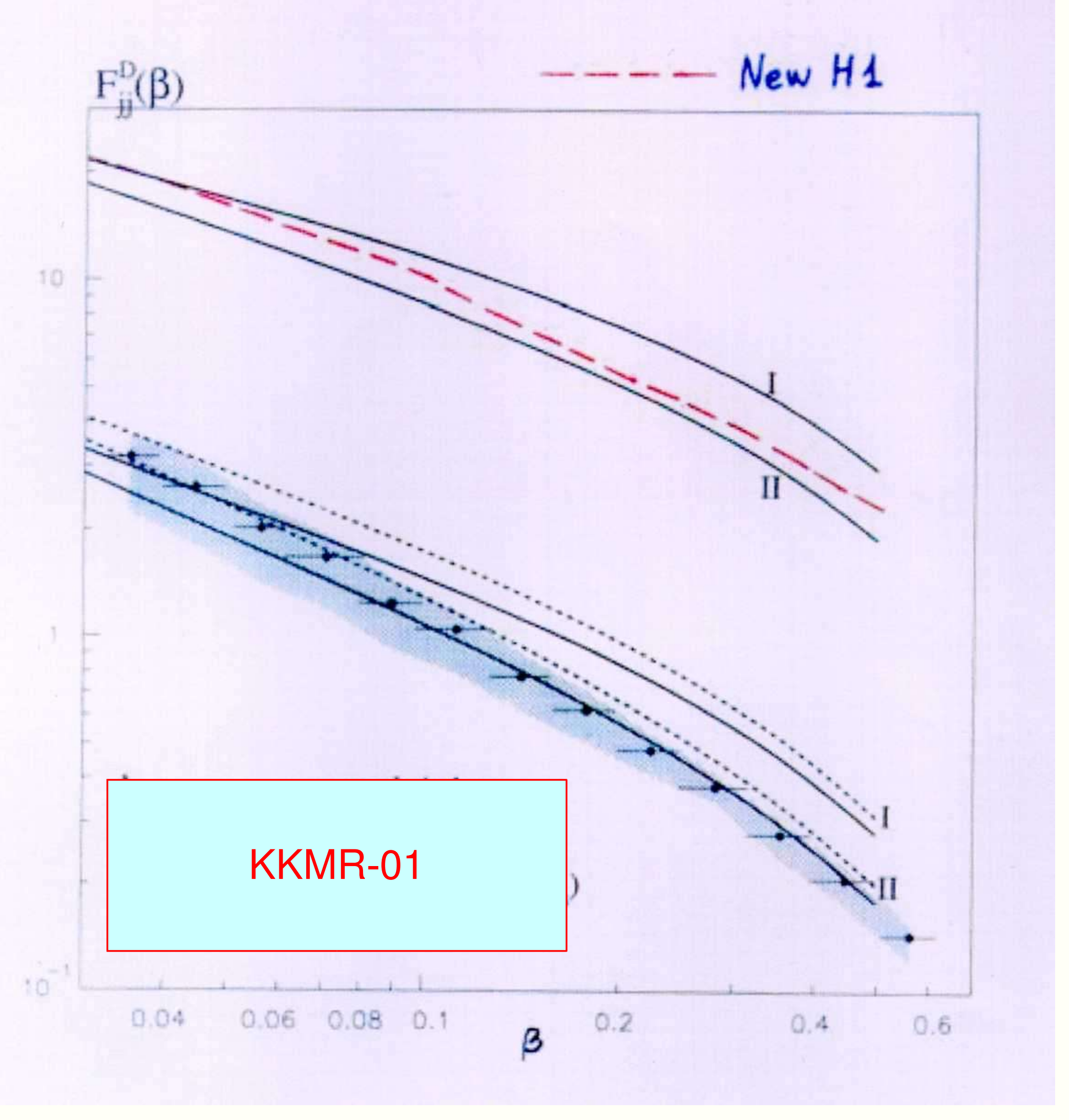
Test of factorization



understood
in terms of
rescattering
corrections



CDF-00



The measured CDF dijet diffractive distribution compared with KKMR predictions

Soft survival factors for RG

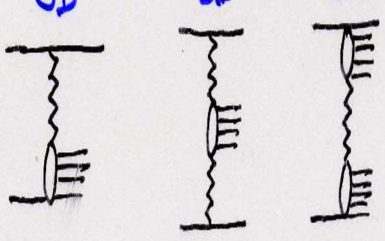
prob. of p to be in diff. estate ϕ_n

prob. of producing heavy system from ϕ_n

no inelastic interaction.

$$S^2 = \frac{\sum_n \int d^2b \, |a_{pn}|^2 \, |\mathcal{M}_n|^2 \, e^{-\Omega_n}}{\sum_n \int d^2b \, |a_{pn}|^2 \, |\mathcal{M}_n|^2}$$

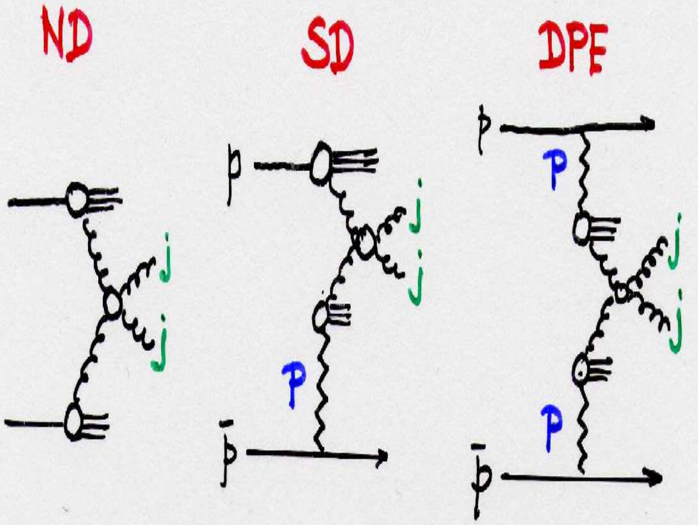
Values of S^2



	SD	CD	DD
Tevatron	0·10	0·05	0·15
LHC	0·06	0·02	0·10

Diffractive dijet production ,Tevatron
KKMR-03

KMR-00, prediction



Multi-IP effects → $S_1 = 0.10$ $S_2 = 0.05$

A.Bialas& R.Pecshanski 03

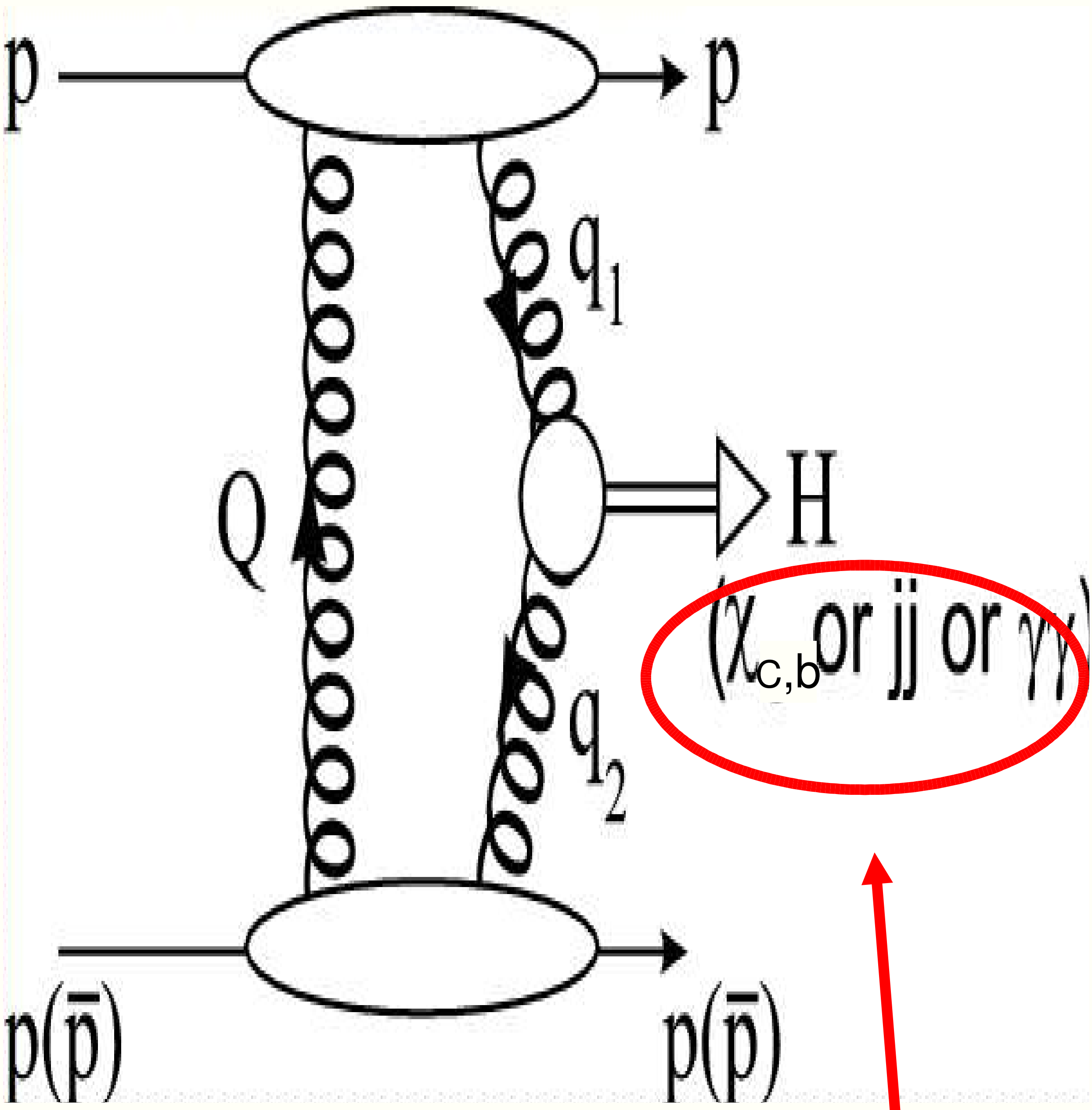
$$R_1 \equiv \frac{\sigma_{jj}^{SD}}{\sigma_{jj}^{ND}} = \frac{F_P\, f_P}{f_{\bar{p}}} |S_1|^2$$

K.Goulianos

$$R_2 \equiv \frac{\sigma_{jj}^{DPE}}{\sigma_{jj}^{SD}} = \frac{F_P\, f_P}{f_p} \frac{|S_2|^2}{|S_1|^2}$$

$$D = \frac{R_1}{R_2} = \frac{|S_1^2|^2}{|S_2|^2} \simeq \frac{(0.10)^2}{(0.05)} \simeq 0.2$$

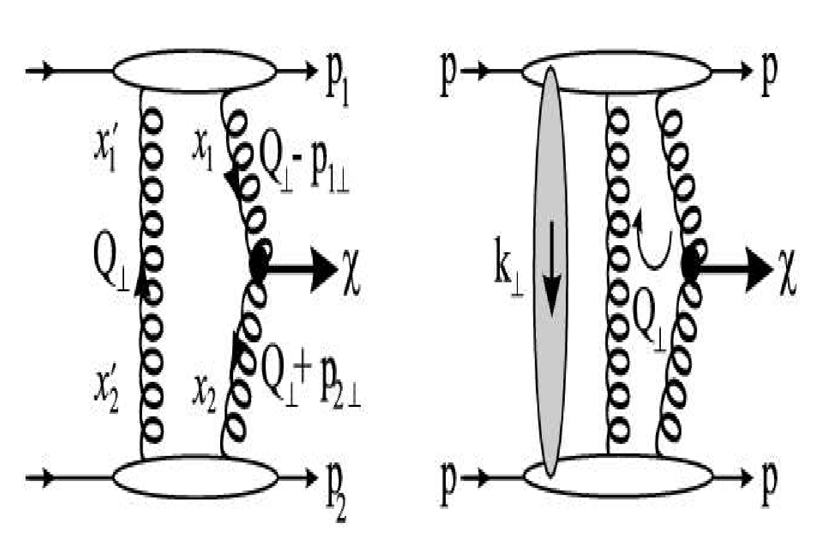
CDF: $D = 0.19 \pm 0.07$



Possible
"standard candles"

Diffractive χ production

(KMR-01,KMRS-04)
also Petrov &R.Ryutin-04



	Tevatron $\sqrt{s} = 2$ TeV		LHC $\sqrt{s} = 14$ TeV	
	χ_c	χ_b	χ_c	χ_b
$d\sigma_{\rm excl}/dy\|_{y=0}$	130	0.2	340	0.6
$\sigma_{\rm excl}$	650	0.5	3000	4
$d\sigma_{\rm incl}/dy\|_{y=0}$	13	0.06	30	0.2
$\sigma_{\rm incl}$	70	0.3	200	2

only (order-of-magnitude) estimates possible for
charmonium production

"Standard Candles"

at Tevatron to test excl. prod. mechanism

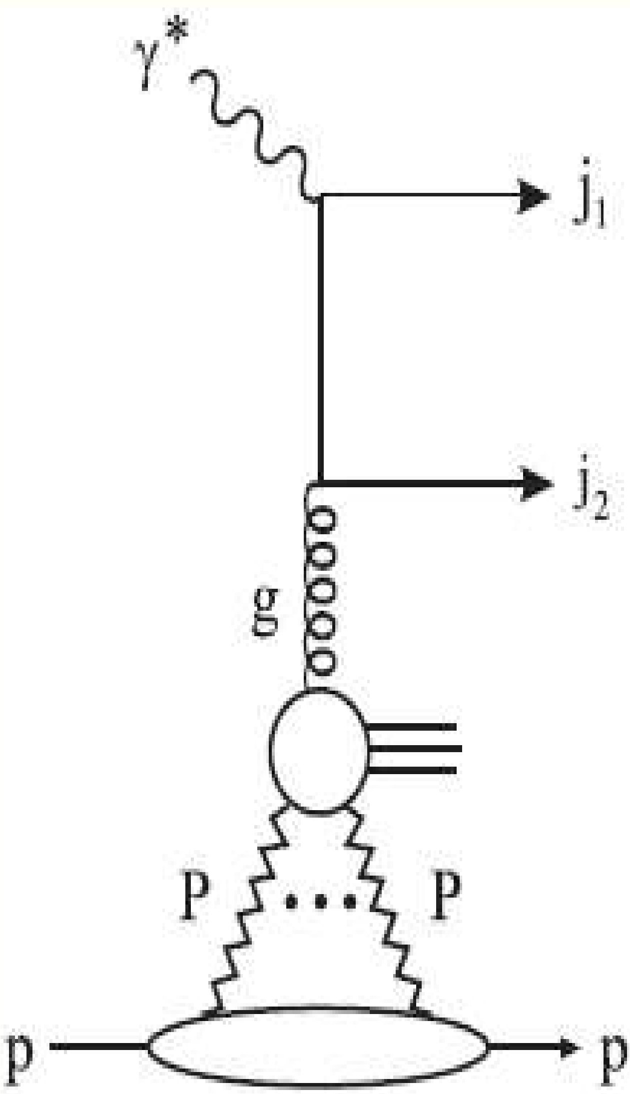
pp p + χ+ p high rate, but only an order-of-magnitude estimate

pp p + jj + p rate OK, but excl. peak washed out

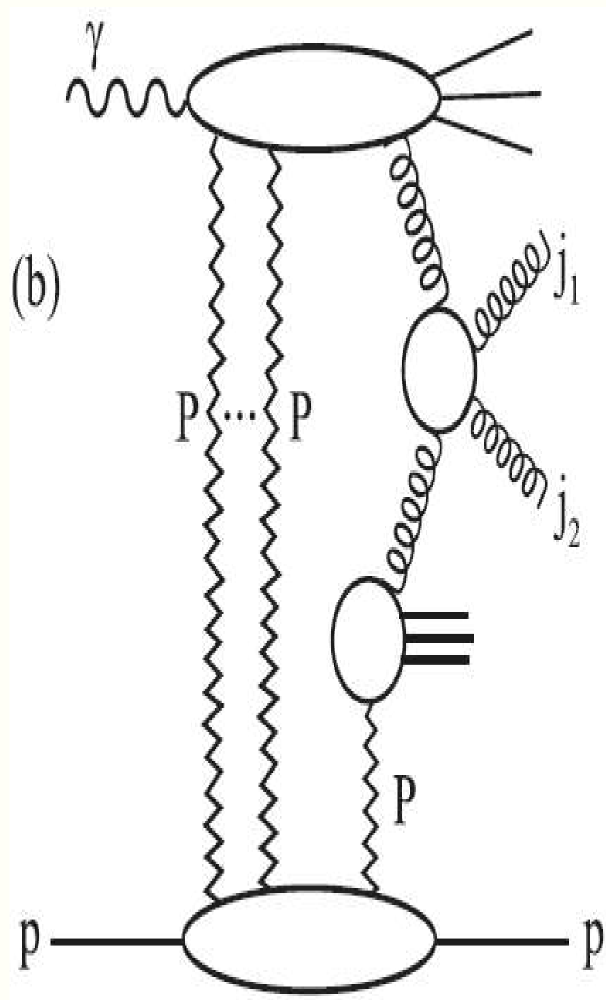
pp p + $\gamma\gamma$+ p low rate, but cleaner signal

Factorization breaking in diffractive dijet photoproduction

Direct photoproduction:



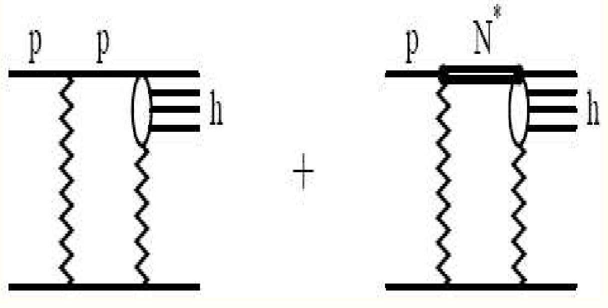
Resolved photoproduction:



→Factorization breaking

Two-Channel Eikonal Model

Hadronic collisions:



Survival probability:

$$|S|^2 = \frac{\int d^2b \left(|M_v|^2 e^{-\Omega_v(s,b)} + |M_{sea}|^2 e^{-\Omega_{sea}(s,b)} \right)}{\int d^2b \left(|M_v|^2 + |M_{sea}|^2 \right)}$$

$$\Omega_i = K_i \frac{(g_{pp}^{I\!P})^2 (s/s_0)^{\Delta}}{4\pi B} e^{-b^2/4B}$$

KMR 00, KKMR 01

Photoproduction:

Generalized vector meson dominance:

Survival probability:
R ≡$|S|^2$ ≈0.34

KKMR-03

Some recent development

•Sensitivity studies of the uPDFs to the details of the gluon kt-distribution

(L.Lonnblad & M.Sjodalh,03 ,H.Jung)

The bottom line: currently - mainly kt- integrated gluon densities are tested.

•The PYTHIA MC result for the soft Gap Survival factor (LHC)=0.026.

(L.Lonnblad, March 04) DKS-92

bj, KKMR, GLM, M.Strikman et al -analytical results

•Correlations between the proton pt's - a way to probe the dynamics of diffraction (unitarity effects) and the properties
of the central system
(K(KMR) 02-04; A. Kupco et al 04;
V.Petrov et al, 04).

• A (simple) model for CEDP with gluon uPDF fitted to HERA elastic data.
(DL Sudakov and unitarization included)
(V.Petrov & R.Ryutin,04)

- MC and detector simulation studies
  (Manchester, Saclay groups, V.Petrov et al).

- Studies of the possibility to observe
  an ‘Invisible Higgs‘
  (KMR, 04)
  Even more severe background and
  trigger conditions

- Fashion takes its toll
  gluinonia in split SUSY scenarios
  (Durham group…)

depends on survival

HERA Experiments:

(what we would like to have for Xmas)

Thanks to Aliosha, Leif, Michael and Misha

main aim: to constrain un(integrated) gluon at HERA

- Reanalyze dijets in photoproduction at higher E_{T}.
- Measure ratios of diffractive/inclusive cross sections at HERA at high E_T (KMR-03)

→ Photon PDF uncertainties cancel

→ Hadronization corrections cancel

- Measure FL at x=0.005-0.03, Q2=3-30GeV2
- Exclusive charmonium production (possible handle on the suPDF)
- Inclusive photoproduction of high Et (~20-40 GeV) jets in the current fragmentation region (pt-distribution)

CONCLUSION

- Forward Proton Tagging proves to be a promising valuable tool to study the Higgs physics at the LHC.

- *Exclusive Diffractive Higgs Production* may provide a unique possibility to cover the troublesome domains of the MSSM and to verify the identity of the Higgs-like candidates.

- So far Durham approach has survived the experimental tests.

- The predicted rates for New Physics signals can be checked experimentally by the proposed Standard Candle processes.

- *...still a lot of studies to be done....*

FORWARD PHYSICS NEEDS FORWARD DETECTORS

Nothing would happen unless the experimentalists come FORWARD and do REAL WORK