Small *x* and Diffraction 2003

September 17-20, 2003 FNAL

Looking Forward to Forward physics at the LHC

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In collaboration with A.B. Kaidalov, A.D. Martin & M.G. Ryskin

(KKMR)

The main aim – to illustrate how the LHC physics potential can be enlarged if the Forward-Proton Taggers are installed

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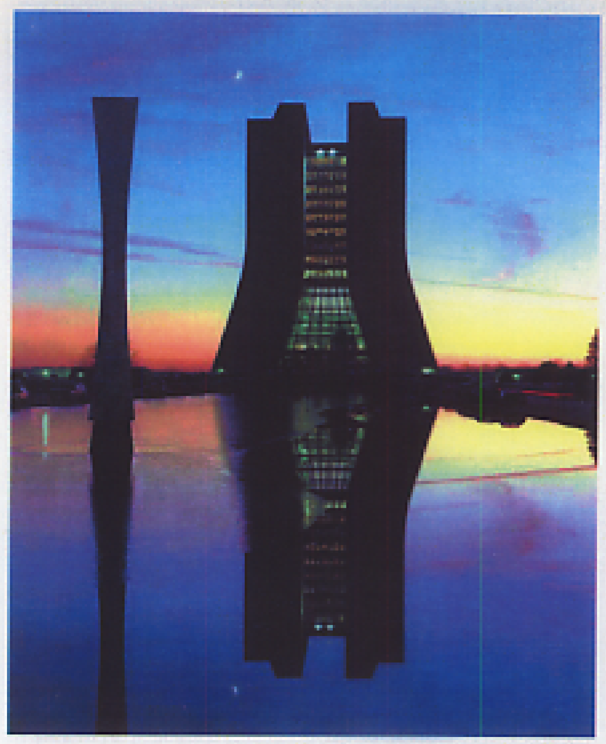


PLAN

- Is there anything else that should/can be done at the LHC beyond the base (party) line ?

- Forward Proton Taggers as Aladdin's Lamp

- Special offers:
  - Central Exclusive Diffractive Production as a Spin-Parity Analyser
  - Extending the potential of Higgs study
  - Gluon Factory, SUSY, ...

- Conclusion

CMS & ATLAS - designed and optimised to look beyond the SM

High-p_T signatures in the central region

But ...

- Main physics "goes Forward"
- The precision measurements are limited by systematics

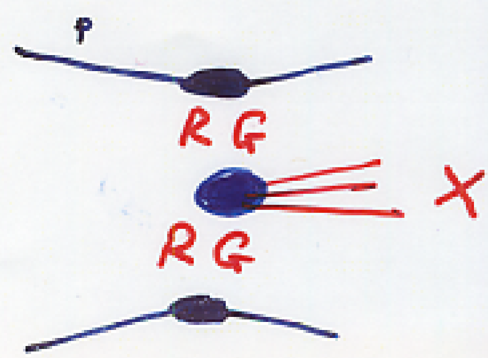
Luminosity goal of $\delta\mathcal{L} \leq 5\%$

- Lack of threshold scanning (gold-mine of a LC)
- Quantum number analysing ?
- Photon beams ?

LC chartered territory

Is there a way out ?

- Yes, Forward Proton Tagging



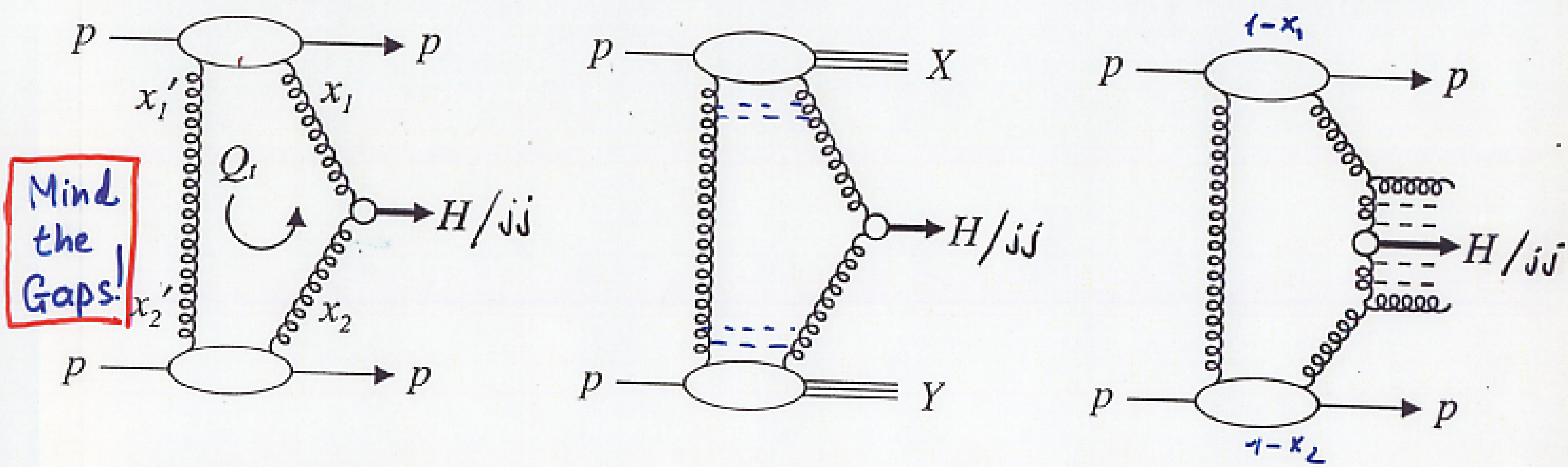
Rapidity Gaps – 'Hadron-free' (no-flight) zones

ΔM_x (central det.) $\simeq \Delta M_{missing}$ (protons)

A. Bialas & P. Landshoff, 91

Diffractive Higgs / dijet signal at LHC

CEDP



(a) exclusive	(b) inclusive	(c) central-inelastic
$M_{\text{miss}} = M_H$	no M_{miss}	$M_{\text{miss}} > M_H$
$J_z = 0$ rule for background	no rule	no rule
$S/B \sim 3$	$S/B \sim 0.01$	$S/B \sim 0.001$
pile-up may be overcome	pile-up problems	pile-up may be overcome

0^+

precise measurement of the scattered p momentum

$(0^-/0^+ \sim 10^{-2})$

Northen English alliance

(Experimental gain not yet fully explored) as Aladdin's Lamp

Forward Physics Program

- Soft & Hard diffraction
  - Total cross section and elastic scattering
  - Gap survival dynamics, multi-gap events, proton light cone ($pp \to 3jets+p$)
  - Diffractive structure: Production of jets, W, J/ψ, b, t, hard photons
  - ✓ Double Pomeron exchange events as a gluon factory
  - ✓ Diffractive Higgs production, (diffractive Radion production)
  - ✓ SUSY & other (low mass) exotics & exclusive processes
- Low-x Dynamics
  - Parton saturation, BFKL/CCFM dynamics, proton structure, multi-parton scattering
- New Forward Physics phenomena
  - New phenomena such as DCCs, incoherent pion emission, *Centauro's*
- Strong interest from cosmic rays community
  - Forward energy and particle flows/minimum bias event structure
- Two-photon interactions and peripheral collisions
- Forward physics in pA and AA collisions
- Use QED processes to determine the luminosity to 1% ($pp \to ppee$, $pp \to pp\mu\mu$)

Many of these studies can be done best with L ~10^{33} (or lower)

- not my cuppa tea

KMR studies

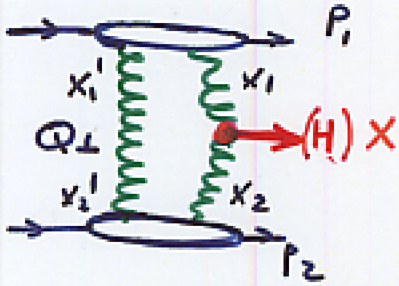
VFPD - rich physics menu

- Higgs - hunting
- $\gamma\gamma$ - physics (complementary to a LC) $L_{\gamma\gamma} \sim 10^{-2} L_{pp}$
- 'light' SUSY, $\tilde{q}\bar{\tilde{q}}$, $\tilde{g}\tilde{g}$ (mass scanning)
- various aspects of diffractive physics; χ_b, χ_c, 'exotic' states...
- 'Gluon Factory'
- KK-gravitons, radions, ... gluinoballs ...

- Very good missing mass resolution provided by the proton taggers

- Valuable additional tool to complement the 'conventional' strategies at hadron and $\mathcal{L}$-e^+e^- colliders

Main features of the KMR formalism



Mind the gap → Soft survival factor $\hat{S}^2$

$$T_{Born} = \mathcal{N} \int \frac{d^2 Q_\perp \, V_h}{Q_\perp^2 (\vec{Q}_\perp - \vec{p}_{1\perp})^2 (\vec{Q}_\perp + \vec{p}_{2\perp})^2} f_g(x_1, x_1'; Q_{1\perp}^2, t_1) f_g(x_2, x_2'; Q_{2\perp}^2, t_2)$$

- Skewed unintegrated gluon densities f_g embody Sudakov-like form factor T

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

- Normalization is fixed by the global parton analysis

- T- factor provides the infrared stability for 0^+ (+ effective anomalous dimensions of f_g)

  $$\tau_{digluon} \sim \frac{1}{\langle Q_T \rangle} \sim \frac{1}{(Q_\perp)_{SP}} \sim 0.1\,fm \ll \tau_p \sim 1\,fm$$

- Soft survival factor is calculated in terms of a two-channel eikonal model (tuned to describe all existing pp, $p\bar{p}$ data)

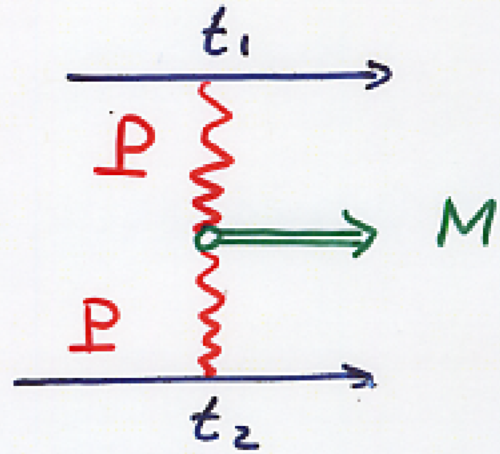
  $(\hat{S}^2_{CEDP}) = 0.026$ (LHC)

- $V_{0^+} \sim Q_\perp^2$, $V_{0^-} \sim p_{1\perp} p_{2\perp}$

  ↳ Sudakov suppression is not sufficient

CEDP as a spin-parity analyser

General rules of Regge-theory



$$\gamma^{J_z}_{m_1 m_2} = P(-1)^{J+J_z}\,\gamma^{-J_z}_{-m_1,-m_2}$$ P conservation

$$m_1 + m_2 = J_z$$

$$\gamma^{J_z}_{m_1 m_2} \sim (-t_1)^{|m_1|/2}(-t_2)^{|m_2|/2}$$

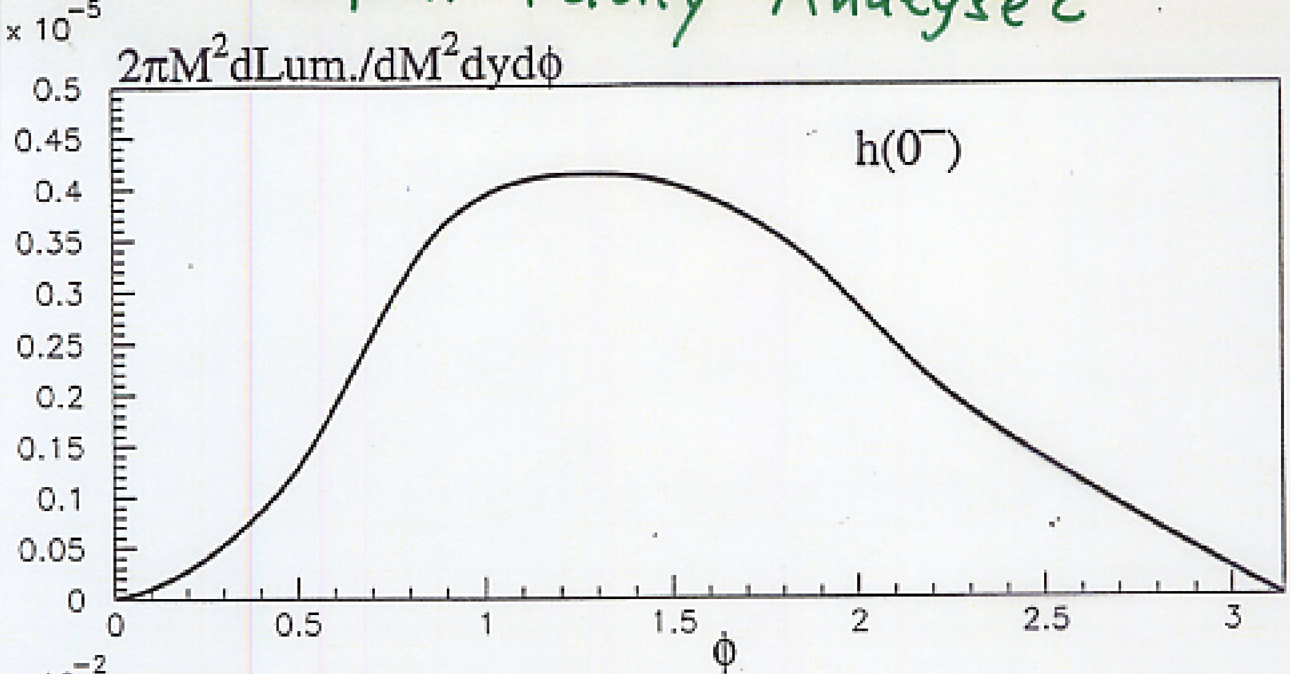
(K. Boreskov 1968)

- $J_z = 0$, parity even selection rule for the forward DPE processes
- Resurrected in the box-diagram ('di-gluon P', QED) picture, KMR 2000

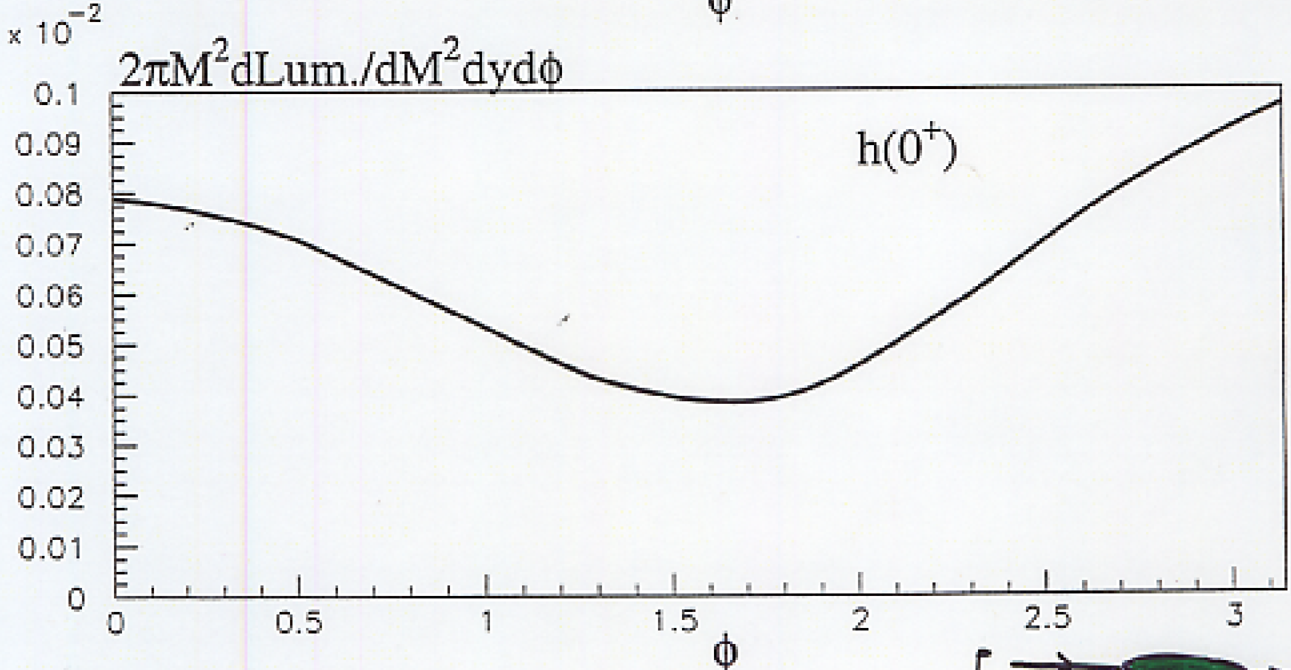
$$\varepsilon^{(1)}_j\,\varepsilon^{(2)}_k \sim (Q_\perp - p_{1\perp})_j\,(Q_\perp + p_{2\perp})_k \sim \delta^{(2)}_{jk}\frac{Q_\perp^2}{2} - (p_{1\perp})_j(p_{2}$$

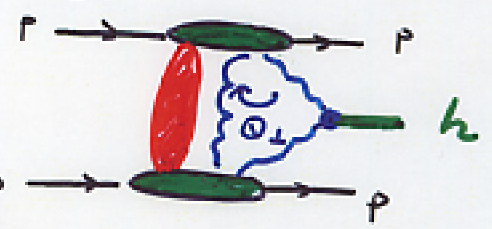
→ P-even, $J_z = 0$

Spin-Parity Analyser



M=120GeV,
y=0



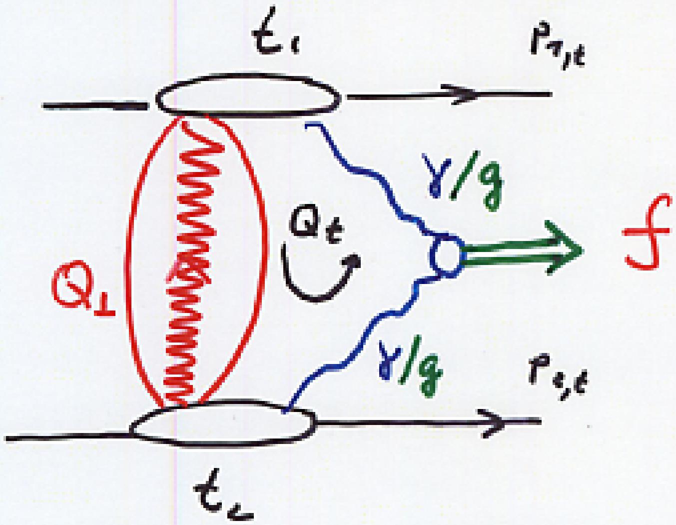


- ϕ-distribution as a unique way to distinguish between the natural $(P=(-1)^J)$ and unnatural $(P=(-1)^{J+1})$ parity states
- Absorptive effects enhance the difference
- $p_\perp$ and ϕ cuts ($P_t > 0.4$ GeV, $40° < \phi < 140°$) increase the $0^-/0^+$ ratio by a factor of 5.

but .... infrared sensitivity of the 0^- signal

VF ℙT as a spin-parity filter

(Gauge invariance, symmetry relations)



$(p_{1,2})_t \ll Q_t$

(LO) box diagram

selection rule

spin correlations

$\gamma\gamma$ } ℙ even

gg (colour singl.) ℙℙ } $J_z = 0$

KMR - 2001

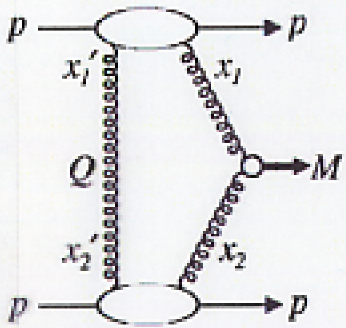
Applications :

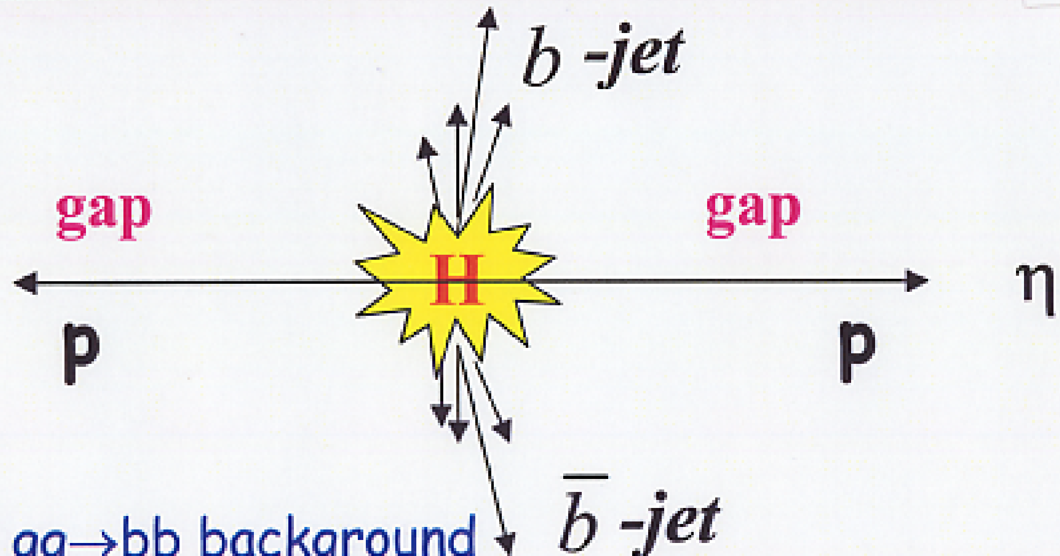
- $\gamma\gamma \rightarrow \mu^+\mu^-$, e^+e^- (luminometry)
- $gg^{ℙℙ} \rightarrow H \rightarrow b\bar{b}$ (BG suppression)
  H- spin analyser ('for free')
- $gg^{ℙℙ} \rightarrow \tilde{q}\bar{\tilde{q}}$ (β), $\tilde{g}\tilde{g}$ (β^3) threshold behaviour (discriminator)
- $gg^{ℙℙ} \rightarrow$ (KK) gravitons
- glueball filter ... non-$Q\bar{Q}$ states

~~2^{++}~~ ~~1^{++}~~

Diffractive Higgs Production

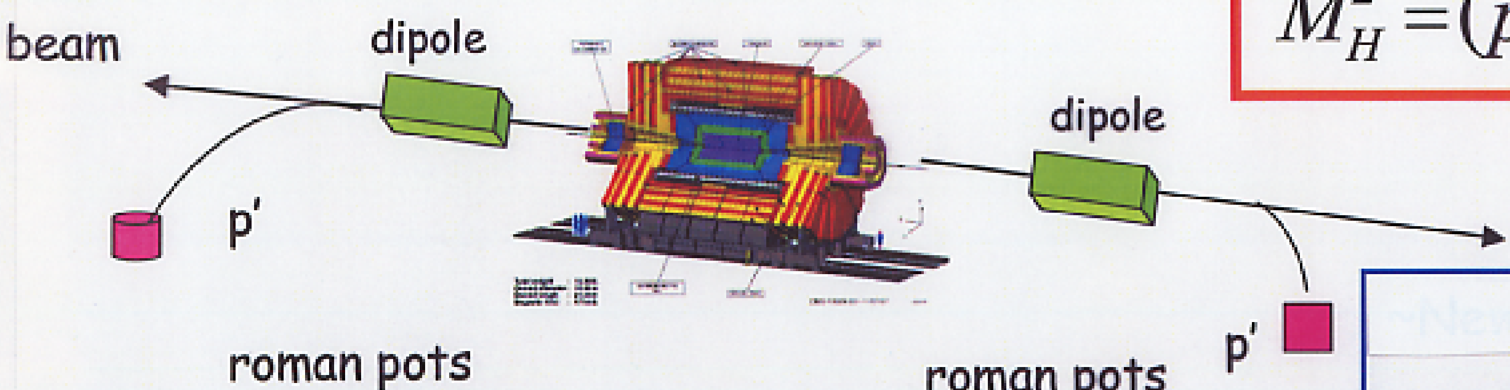
Exclusive diffractive Higgs production pp→ p H p :CEDP
Inclusive diffractive Higgs production pp → p+X+H+Y+p :





Advantages:
- Jz=0 suppression of gg→bb background
- Mass measurement via missing mass

$$M_H^2 = (p + \bar{p} - p' - \bar{p}')^2$$



studied by many groups

SM Higgs, $m_H = 120$ GeV

σ_H^{CEDP}	uncertainties SL accuracy MRST99 pdf's
Tevatron 0.15	factor of 4
LHC 2.2 fb	factor of 2.5

- 'Natural' lower limit

$$\sigma_{\gamma\gamma}(p\bar{p} \to p + H + \bar{p}) = 0.01 \text{ fb} \quad \text{Tevatron}$$

$$\sigma_{\gamma\gamma}(pp \to p + H + p) = 0.1 \text{ fb} \quad \text{LHC}$$

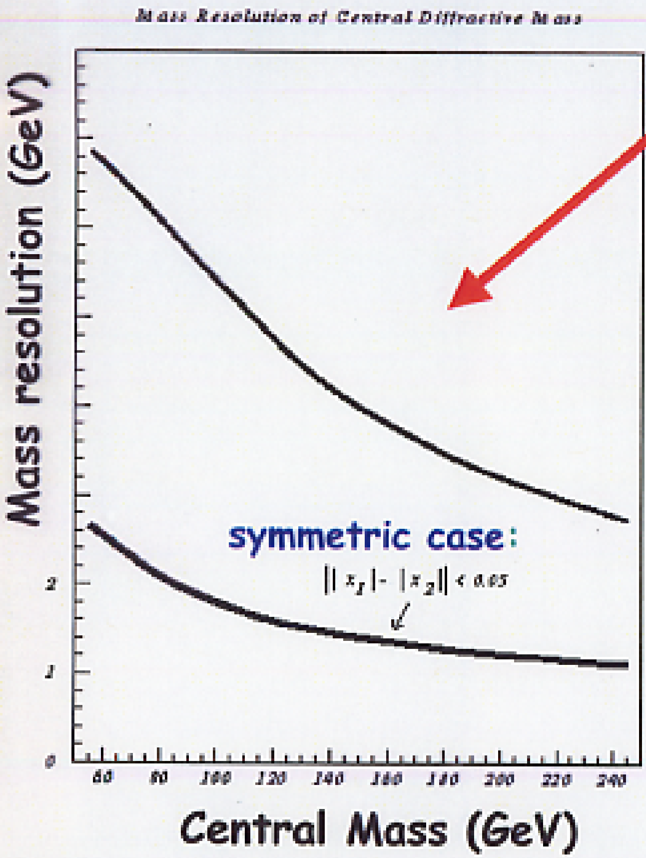
- Can be significantly improved by measuring the CEDP of dijets with $M_{jj} \simeq 120$ GeV

- PDF's democracy – further uncertainties (can be brought under control) $\sigma_H \sim (f_g)^4$

- CDF & DØ hard diffraction data are KKMR-friendly

- 0^- – infrared sensitive rate (Pandora's box)

Diffractive Higgs Production (SM)



(Helsinki group)

Mass resolution vs. central mass
from protons measured in roman pots
Assuming proton beam spread of 10^{-4}

Exclusive channel pp→ p H p advantages
Good mass resolution thanks to missing mass method: $M_H^2 = (p + \bar{p} - p' - \bar{p}')^2$

ΔM = O(1.0 - 2.0) GeV (including systematics)

After taking into account
- Cuts for B-tagging efficiency
- Experimental acceptance in central detector
- Cuts to suppress HO contributions
- Experimental acceptance in proton tagger

⇒ left with 11 events for 30 fb^{-1}
3-20 (~~6-25~~ events with uncertainties)
for a SM Higgs with 120 GeV
1-7 background ~~~3-4~~ events $\frac{S}{B} \sim 3$

* NLO uncertainties in the Background estimates

Could be a competitive channel.

DeRoeck, Khoze, Martin, Orava, Ryskin E. Phys. J (2002) 391

30 fb^{-1} at LHC (accounting for the experimental cuts & efficiencies)

SM Higgs → 'Nightmarish' scenario

Higgs signal (SM) 120GeV		number of events: signal	number of events: background	S/B	significance $S/\sqrt{S+B}$
a) $H \to \gamma\gamma$	CMS	313	5007	$0.06\left(\frac{1\,\text{GeV}}{\Delta M_{\gamma\gamma}}\right)$	4.3σ *) K-factor
	ATLAS	385	11820	$0.03\left(\frac{2\,\text{GeV}}{\Delta M_{\gamma\gamma}}\right)$	3.5σ
b) $t\bar{t}H$, $H \to b\bar{b}$		26	31	$0.8\left(\frac{10\,\text{GeV}}{\Delta M_{bb}}\right)$	3σ
c) $gg^{PP} \to p + H + p$, $H \to b\bar{b}$		11	4	$3\left(\frac{1\,\text{GeV}}{\Delta M_{\text{missing}}}\right)$	3σ
DKMRO cuts		8.1	2.9		2.5σ
MSSM, $\tan\beta = 30$, $M_h = 115$ GeV		100	3	$33\left(\frac{1\,\text{GeV}}{\Delta M_{\text{missing}}}\right)$	10σ

Conventional Higgs folklore (arrow pointing to rows a) and b))

Incredible significance for a Higgs signal!

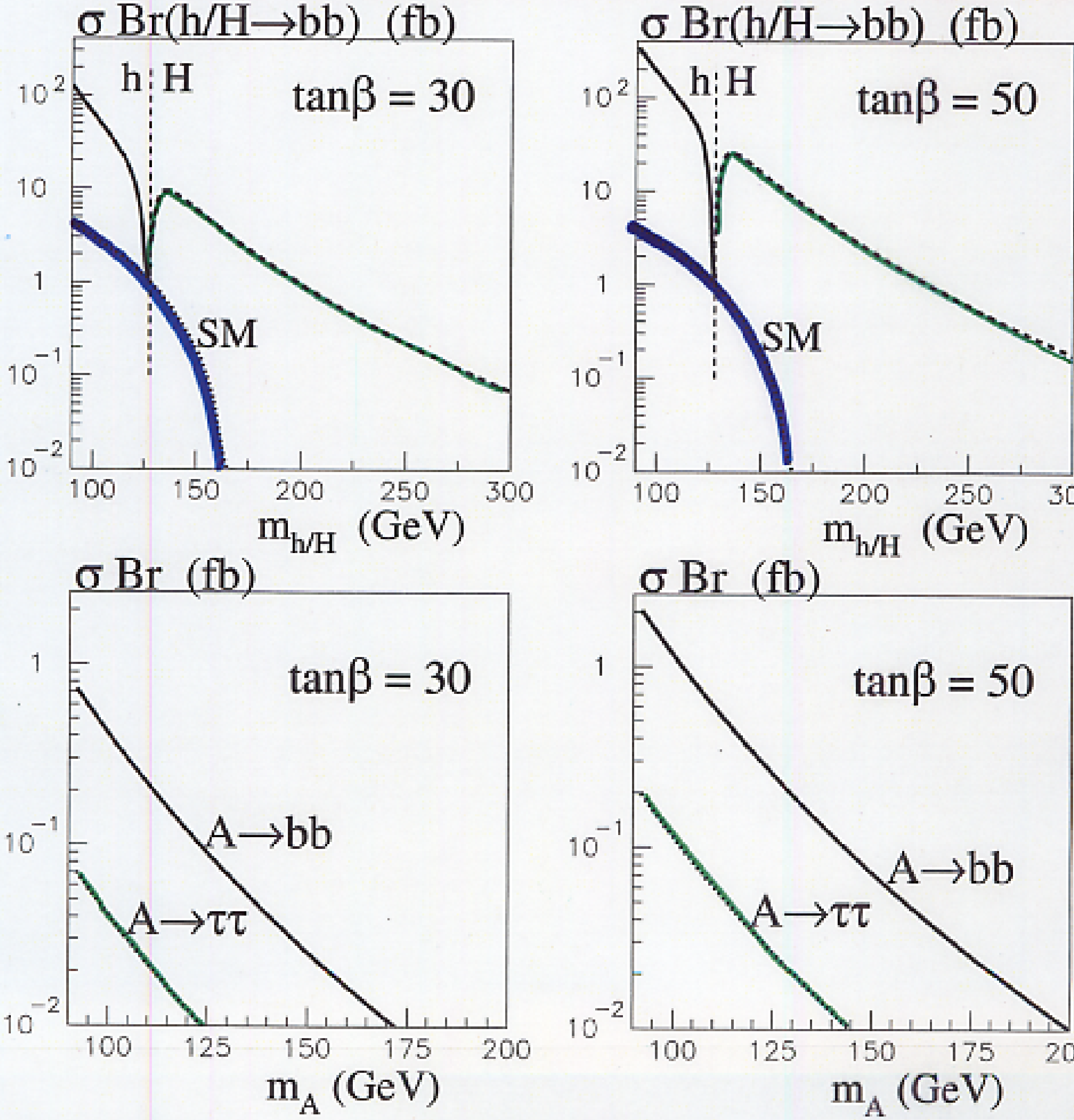
MSSM Higgs

KKMR hep-ph/0307064

for $\tan\beta = 30(50)$ the signal is $\sim 10\,(40)$ larger than in the SM

Incredible significance ($\sim 10\sigma$) for a Higgs signal!

Central exclusive diffractive production



Higgs-Hunter's Headaches

- Troublesome regions in the Higgs parameter space

  Conventional searches at the LHC may face difficulties (.. h, H, A separation)

- After discovery stage

  Establishing the nature of the newly discovered heavy state

  - signal separation
  - spin-parity determination
  - proving the Higgs interpretation

- The CEDP can play a decisive role in solving these vital problems

  Especially advantageous

  - $\Gamma(\text{Higgs} \to gg)\, Br(\text{Higgs} \to \bar{b}b) \gg \Gamma(SMH \to gg)\, Br(SMH \to \bar{b}b)$
  - $\Gamma_{tot} \gtrsim \Delta M_{missing} \sim \mathcal{O}(1\ \text{GeV})$
  - Scalar-Pseudoscalar mass degeneracy

$m_H \lesssim 250$ GeV $\longrightarrow$ statistics

Probing the Troublesome Regions in the MSSM parameter space

◉ The Intense Coupling Regime

$m_h \sim m_H \sim m_A \sim \mathcal{O}(100\ \text{GeV})$,

large $\tan\beta$

$\Delta m_{h,H,A} \simeq \mathcal{O}(1\ \text{GeV})$

$\Gamma_{h,H,A} \simeq \mathcal{O}(1\ \text{GeV})$

Marked difference with the SM Higgs

- Traditional detection modes ($\gamma\gamma$, WW^*/ZZ^*) are strongly suppressed

  WW-fusion – weak signal

- The CEDP cross sections are significantly enhanced

◉ The decoupling limit

$m_A > 2m_Z$, $\tan\beta \geq 5$

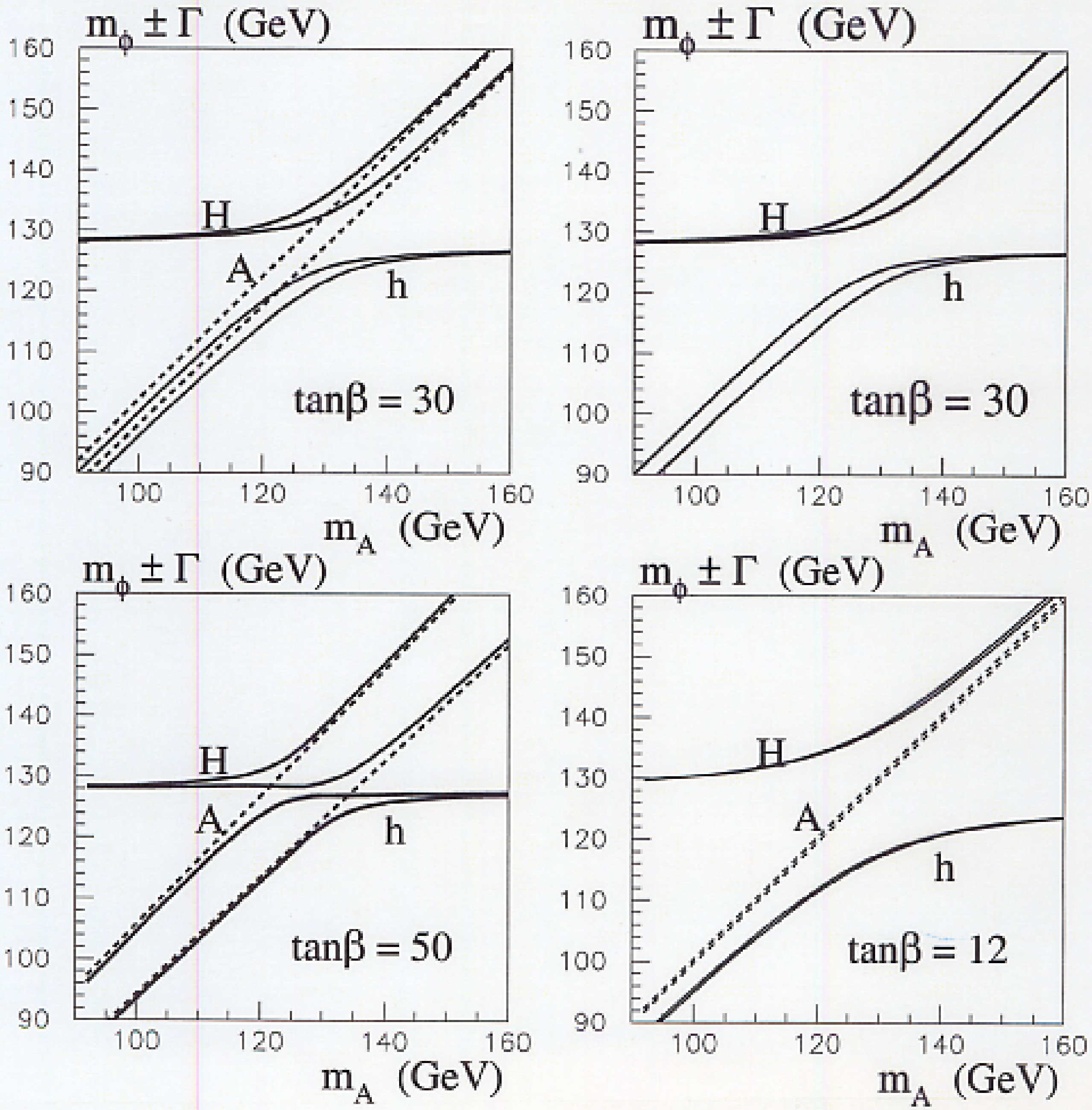
- h becomes indistinguishable from the SM Higgs
- H and A are comparatively heavy and approximately degenerate

  a NIGHTMARISH SCENARIO

MSSM resonance Higgs peaks

- The h and H are clearly identifiable if 0^- production is suppressed (even around $m_A \sim 130$ GeV).
- Outside the range $m_A = 130 \pm 5$ GeV the widths of the h and H are quite different.

The intense coupling regime



● The notorious 'holes' regions

at present understanding of the LHC detectors will plague the intervals $m_A \gtrsim 200\,\text{GeV}$, $\tan\beta \sim 4-7$

$130 \lesssim m_A \lesssim 170\,\text{GeV}$, $\tan\beta \simeq 4-6$

The hole up to $m_H \sim 160\,\text{GeV}$ can be covered by CEDP ! (at $300\,fb^{-1}$)

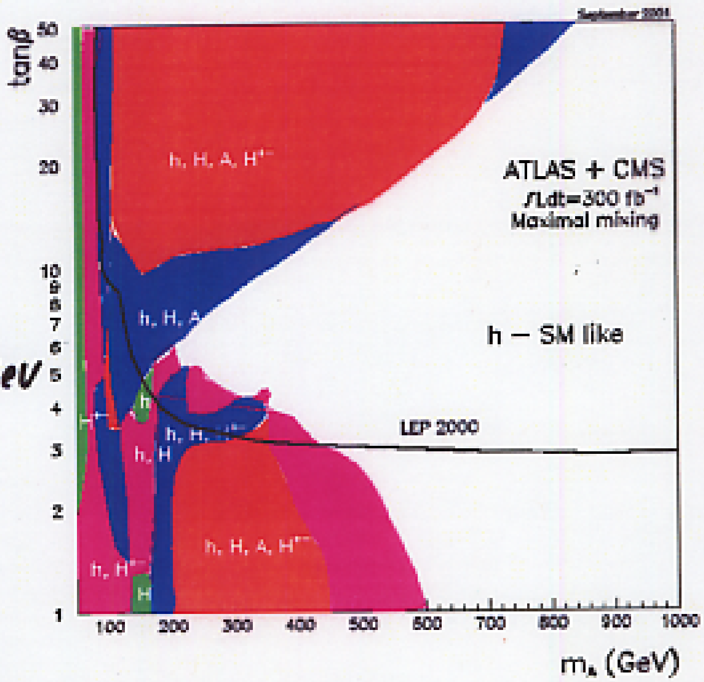


Figure 28: Regions in the m_A–$\tan\beta$ plane in the maximal mixing scenario in which up to four Higgs boson states of the MSSM can be discovered at the LHC with 300 fb^{-1} of data, based on a simulation that combines data from the ATLAS and CMS detectors. Taken from ref. [87].

are: $A, h \to \tau^+\tau^-$ (where the τ is detected either via its leptonic or hadronic decay) and $A, h \to \mu^+\mu^-$, which yield promising signals if $\tan\beta$ is large. The $\tau^+\tau^-$ channel provides the largest discovery reach in the heavy Higgs mass. Other possible neutral Higgs decays: $A, H \to t\bar{t}$; $H \to ZZ^* \to 4\ell$; $H \to hh$ and $A \to Zh$ are significant in regions of the parameter space that are (nearly) ruled out by the LEP Higgs search. For the charged Higgs boson, we must again consider whether $H^\pm$ can be produced in (on-shell) top-quark decays. If this decay is forbidden, the positively charged Higgs boson will be produced primarily by $gb \to H^+t$ (see Section 3.5.1). In either case, the observation of the charged Higgs boson is possible if $\tan\beta \gg 1$ or $\tan\beta \lesssim \mathcal{O}(1)$ [221]. For large $\tan\beta$, the decays $H^+ \to \tau^+\nu$ and $t\bar{b}$ (if kinematically allowed) provide the most favorable signatures. In particular, the $\tau\nu$ decay mode, followed by the hadronic decay of the τ provides the largest discovery reach for large $m_{H^\pm}$. The ultimate charged Higgs mass reach can depend significantly on the choice of MSSM parameters that control the radiative corrections to the Higgs-bottom quark Yukawa coupling [196] [see, *e.g.*, eq. (70)].

Putting all of the above results together, it may be possible at the LHC to either *exclude* the entire m_A–$\tan\beta$ plane (thereby eliminating the MSSM Higgs sector as a viable model), or achieve a

Idenifying the pseudoscalar

- If the cross sections σ_H, σ_A were comparable
  - missing mass scan
  - azimuthal correlations between $\vec{p}_{\perp 1}, \vec{p}_{\perp 2}$

But ....

CEDP selection rules

With some luck

$m_A = 90-100$ GeV, $\tan\beta \sim 10-15$

at $300\, fb^{-1}$ at the edge of observability

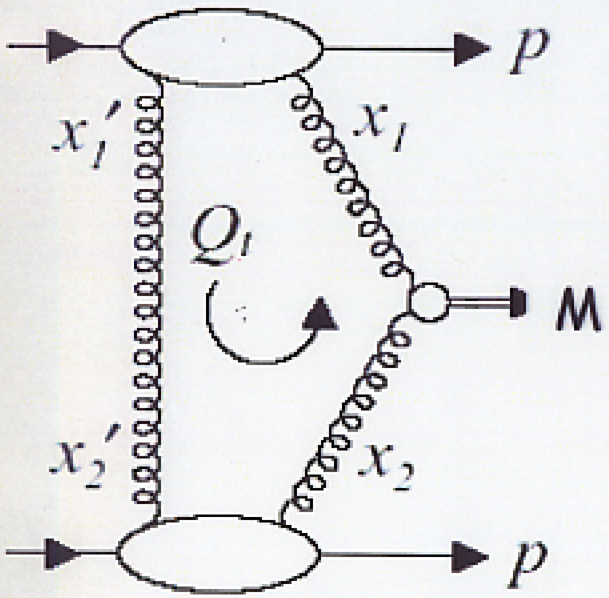
mind the large uncertainties in σ_A

Current progress

$pp \to p + \{H/A\} + p$

Note in passing

- Incoming particles are gluon
  $\Rightarrow$ Gluon factory!



- 100,000 high purity ($q/g = 1/3000$) gluon jets with $E_T > 50$ GeV in 1 year

- Possible new resonant states, glueballs, quarkonia 0^{++} (χ_b),gluinoballs, background free environment (bb, WW & t+t- decays)

- Squark & gluino threshold scans?
  - thresholds are well separated (β^3 or β)
  - practically background free signature: multijets & missing transverse energy
  - model independence (missing mass!)
  - expect 10-15 events for gluino/squark masses of 250 GeV
  - interesting scenario: gluino as the LSP with mass window 25-35 GeV (S.Raby et al.)

Forward Detectors

Forward physics needs forward detectors

- TOTEM – TDR - end of 2003
- CMS common study group with TOTEM to study detectors and Physics (& luminosity) of forward detectors
- ATLAS: Interest in Roman Pot detectors/starting-up activity
- All projects still need approval

...Common meetings

- VFTD – CDF LOI (M. Albrow et al)
- DØ – two-arm tagging

HERA, CDF, DØ diffractive experience

Conclusions

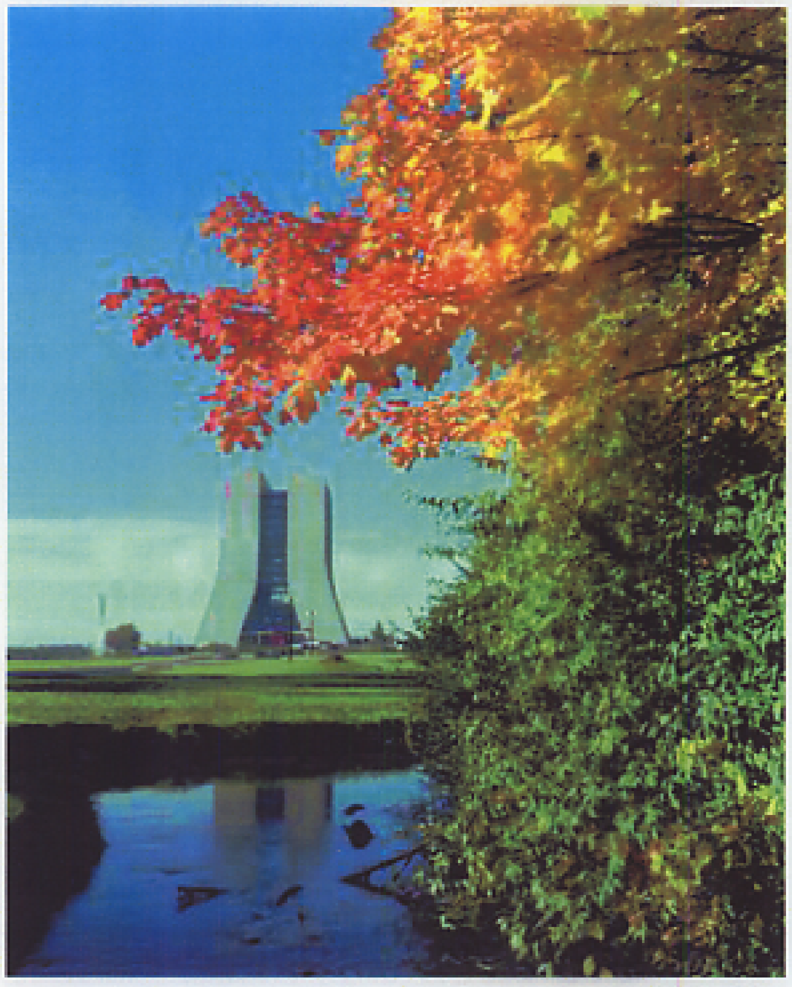
- The physics menue of the proton colliders might be appreciably enlarged provided suitable **proton taggers** are installed.

- **C**entral **E**xclusive **D**iffractive production is well suited to study some of the troublesome regions of the Higgs parameter space and to establish the identity of the newly discovered object.

- The implementation of the proton taggers would complement the physics programmes of both, the hadronic colliders, and a future LC. This would allow to perform some studies which, otherwise, have to await the construction of a LC.

Purpose

The purpose of this workshop is to present and discuss experimental, phenomenological and theoretical progress in high energy diffractive interactions. Small-x phenomena in the nucleon and large rapidity gaps in general will be covered, as well as relevant cosmic ray interactions.



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Konstantin Goulianos

Though .... nothing would happen unless the experimentalists come Forward and do REAL WORK