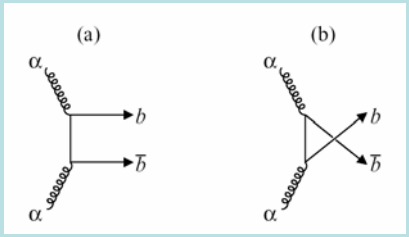
Brian Cox

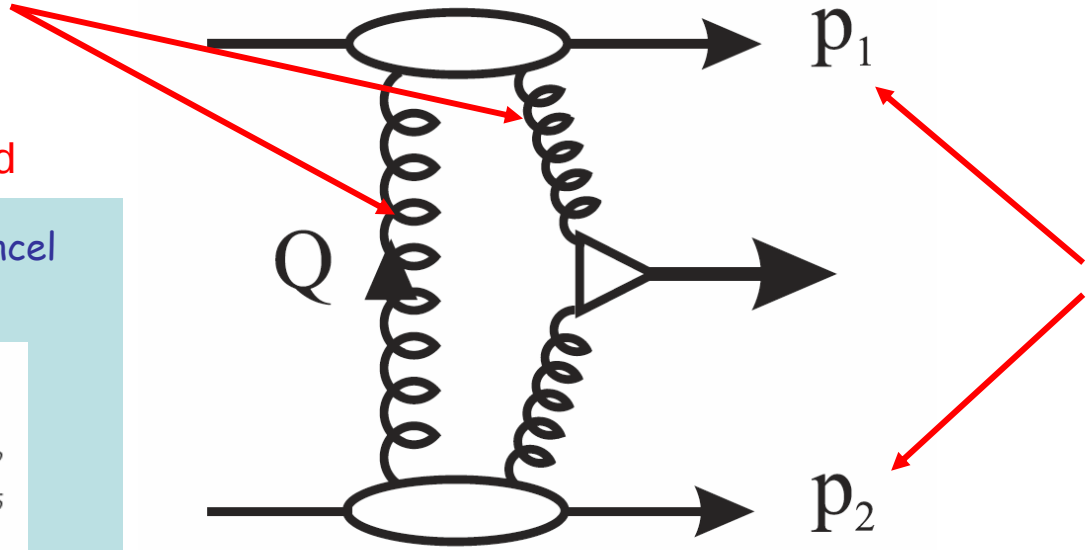
Double proton tagging at the LHC and predictions from HERA and Tevatron

Only 0^{++} (or 2^{++}) systems produced

$b\bar{b}$ background strongly suppressed

$s \gg M^2, t$, (a) & (b) cancel in limit $m_b \to 0$

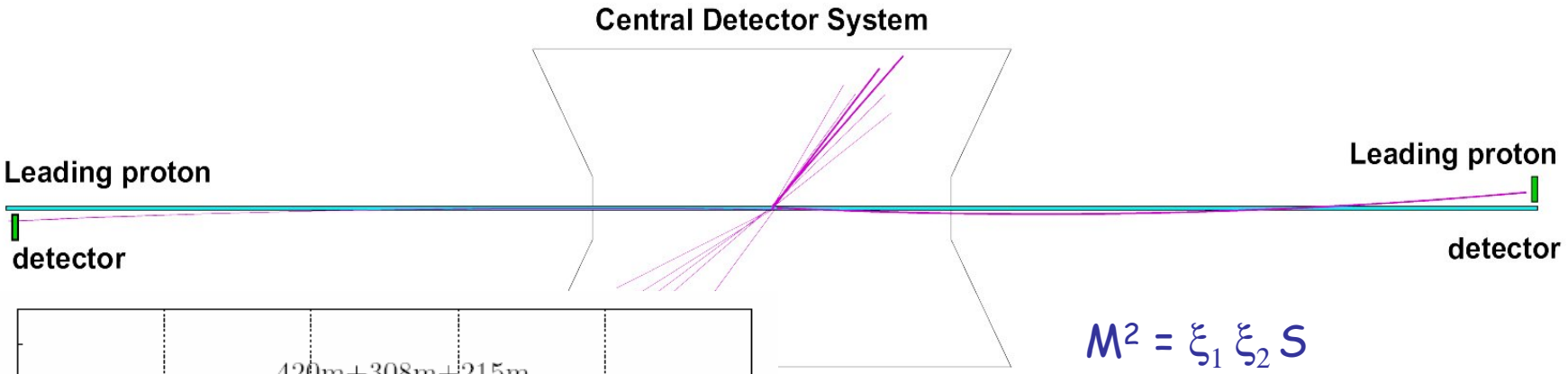


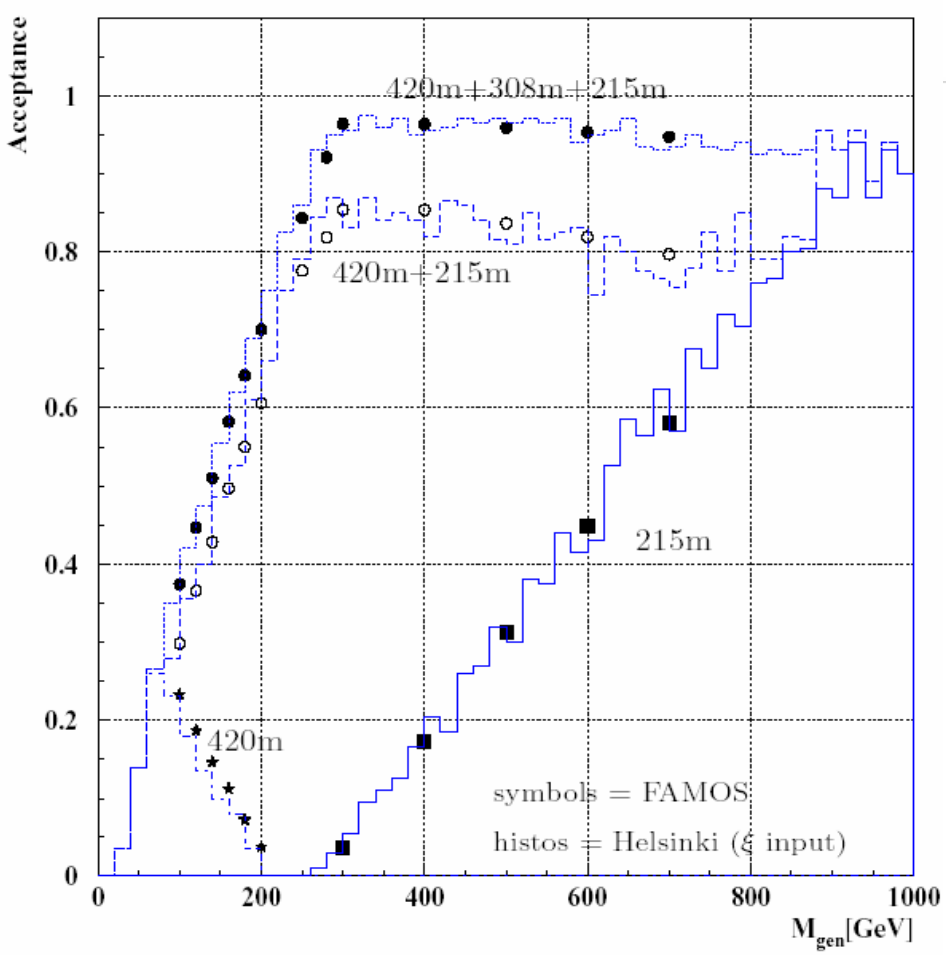


Improved mass resolution

Very schematically it's a glue – glue collider where you know the beam energy of the gluons …

Double Proton Tagging ('CEDP')





$M^2 = \xi_1 \xi_2 S$

Where $\xi_{1,2}$ are the fractional momentum losses of the outgoing protons

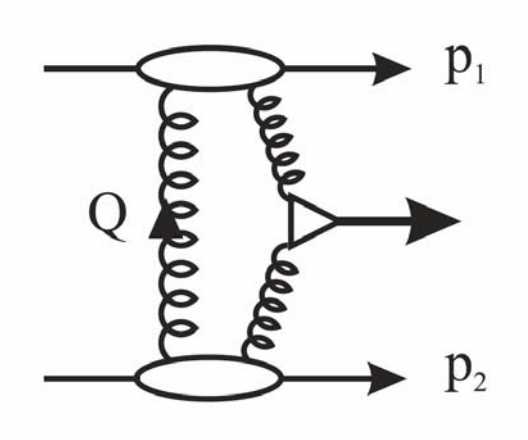
Curves:
Helsinki
Group

Dots
FAMOS
simulation

A. DeRoeck

Particularly promising scenarios for CEDP

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



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

- 'Difficult' regions of the MSSM
- The MSSM with explicit CP violation (CPX)
- Radions ("graviscalar" of Randall-Sundrum models)

• Even if a Higgs-like signal is seen in conventional channels, how can one discriminate between different models?

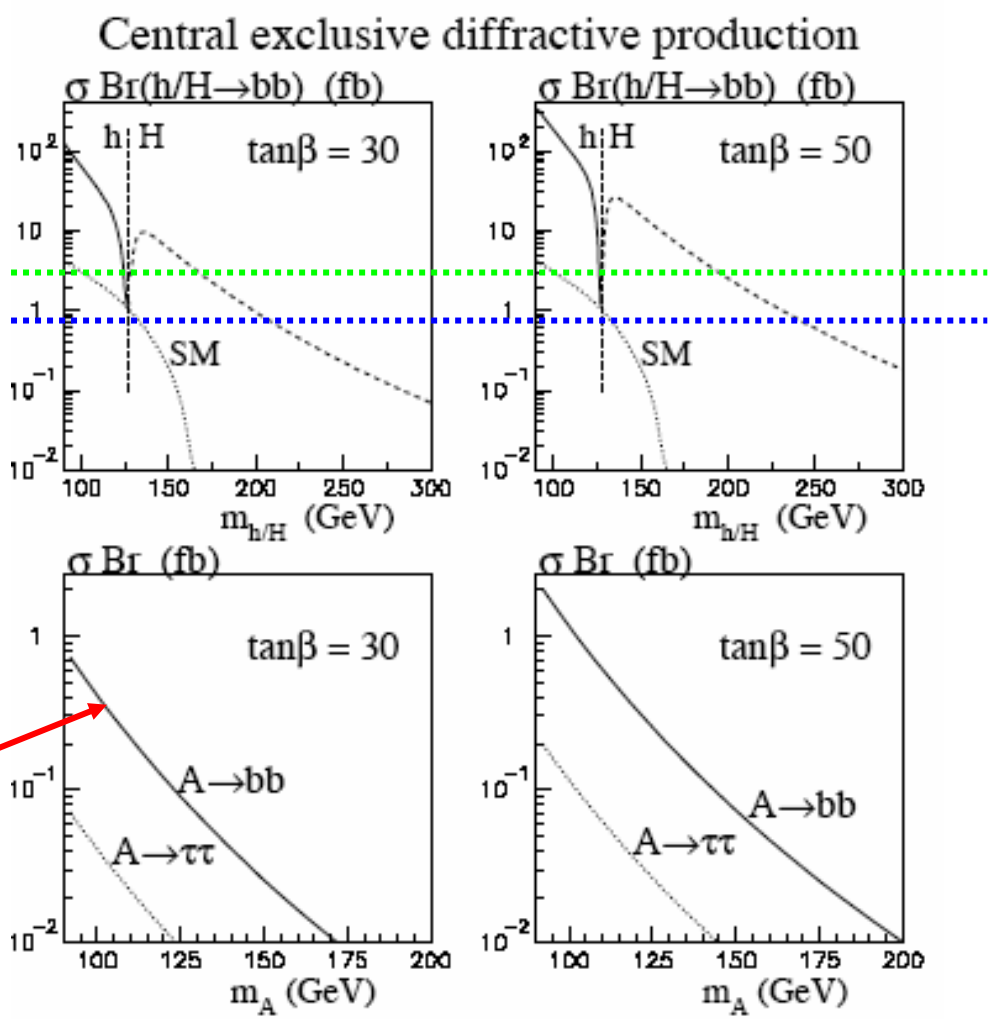
• Measuring the widths, the b (and possibly τ) couplings and spin-parity and will be important tools

An example : The intense coupling regime of the MSSM

e.g. $m_A = 130$ GeV, $\tan\beta = 50$
(difficult for conventional detection,
but exclusive diffractive favourable)
$L = 30$ fb^{-1}, $\Delta M = 1$ GeV

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

Alan Martin Manchester Dec 2003



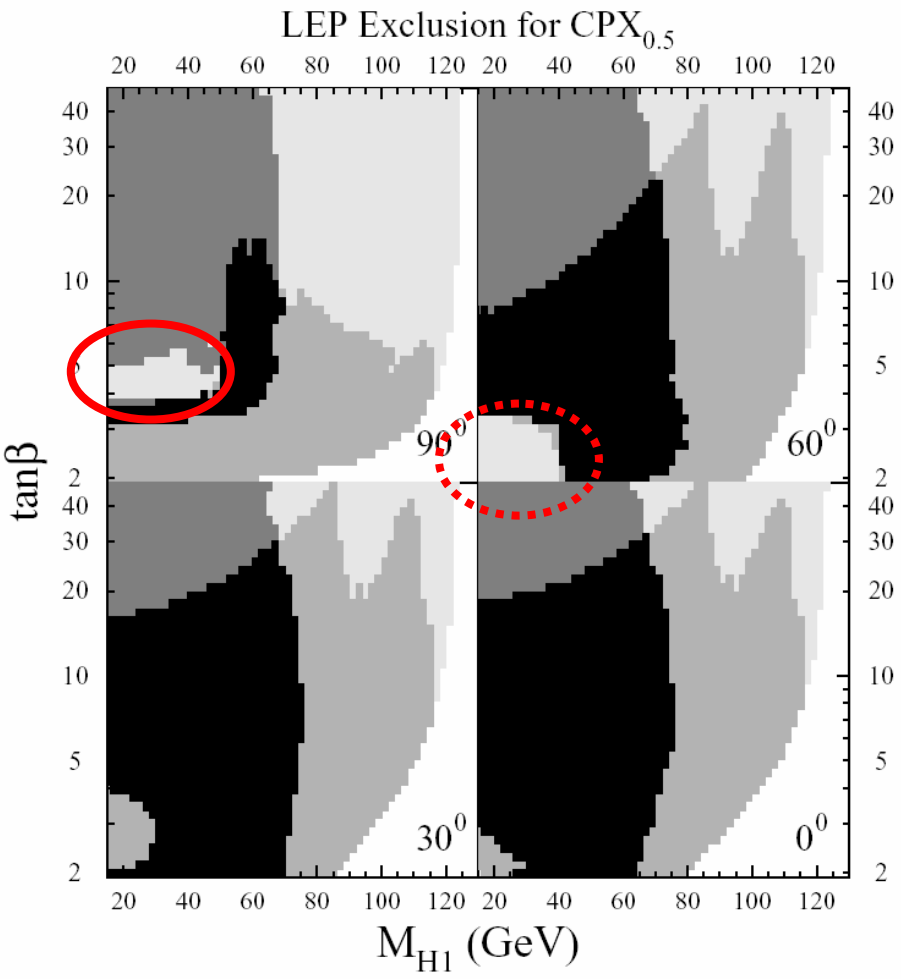
0^{++} selection rule suppresses A production:

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

For 5 σ with 300 (30) fb^{-1} $\mathrm{Br}(b\bar{b}) \cdot \sigma > 0.7$ fb $(2.7$ fb$)$

Kaidalov, Khoze, Martin, Ryskin hep-ph/0311023

Another example : CPX MSSM Higgs



Medium grey $e^+e^- \to ZH_i$

Dark grey $Z^* \to H_iH_j \to 4b$

"there are small regions of parameter space in which none of the neutral Higgs bosons can be detected at the Tevatron and the LHC"

Plot from M. Carena, J. Ellis, S. Mrenna, A. Pilaftsis and C. E. M. Wagner, hep-ph/0211467

CPX MSSM Higgs

b bbar very difficult because of large background:

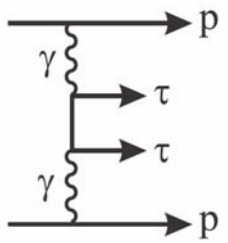
0^{++} Selection rule

QCD Background ~ $\frac{m_b^2}{E_T^2}\frac{\alpha_S^2}{M_{b\bar{b}}^2 E_T^2}$

Also, since resolution of taggers > Higgs width:

$$S/B \propto \Gamma(H \to gg)/\Delta M \propto G_F M_H^3/\Delta M$$

But ττ mode has only QED background



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

$M(H_1)$ GeV	cuts	30	40	50
$\sigma(H_1)\mathrm{Br}(\tau\tau)$	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

σ in fb

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

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

CP even

CP odd active at non-zero t

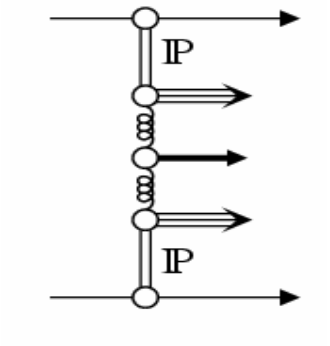
Direct evidence for CP violation in Higgs sector

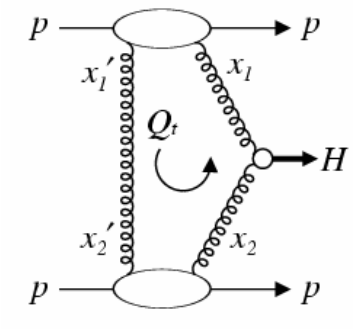
B.C., Forshaw, Lee, Monk and Pilaftsis hep-ph/0303206

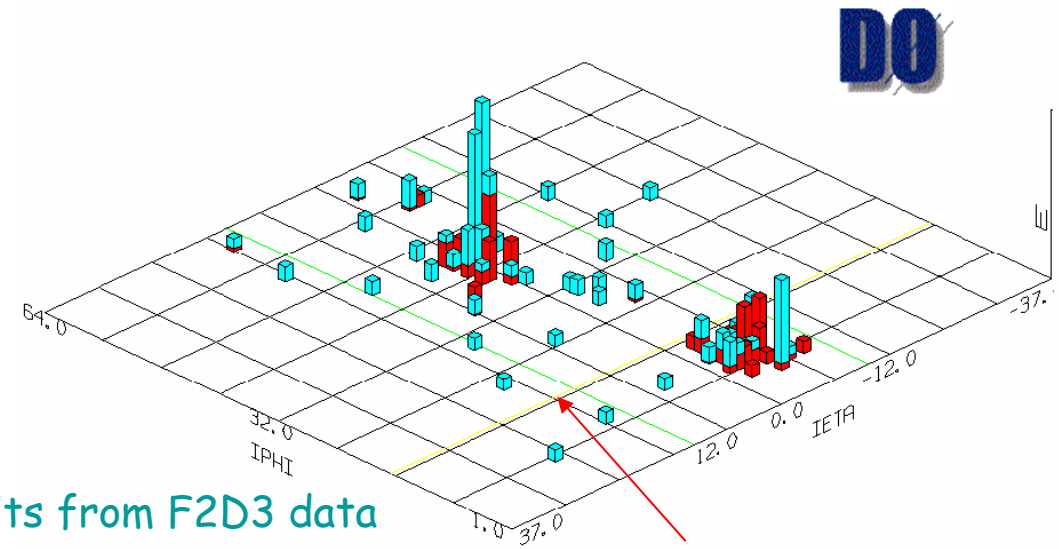
Khoze, Martin and Ryskin hep-ph/0401078

How reliable are the predictions?

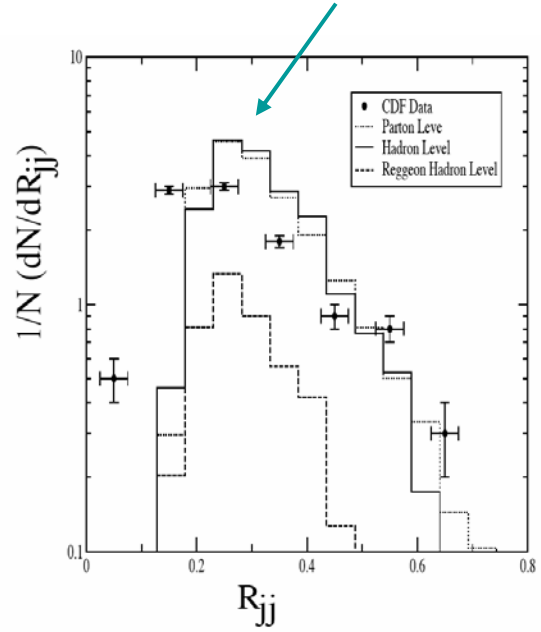
Double pomeron of any kind is EXPERIMENTALLY poorly understood

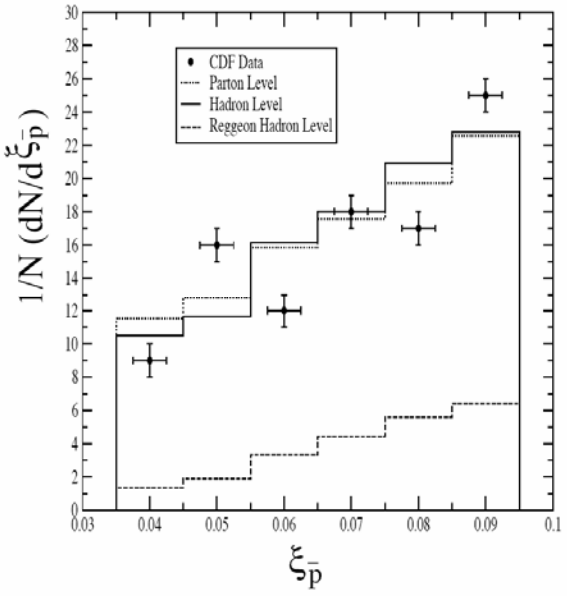






Predictions from POMWIG, i.e. H1 QCD fits from F2D3 data





This is a background to CEDP !

Exclusive limit (CDF) 3.7 nb

KMR prediction ~ 1 nb

Appleby and Forshaw Phys.Lett.B541:108-114,2002

CDF Phys. Rev. Lett. 85, 4215 (2000)

CDF FERMILAB-PUB-03/043-E

Khoze, Martin & Ryskin, hep-ph/0111078, 0006005

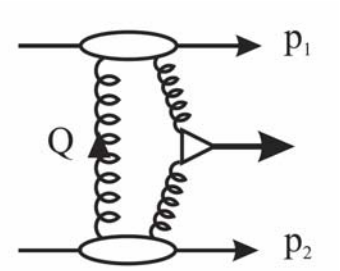
How reliable are the predictions?

- The cross section ~ factorises …

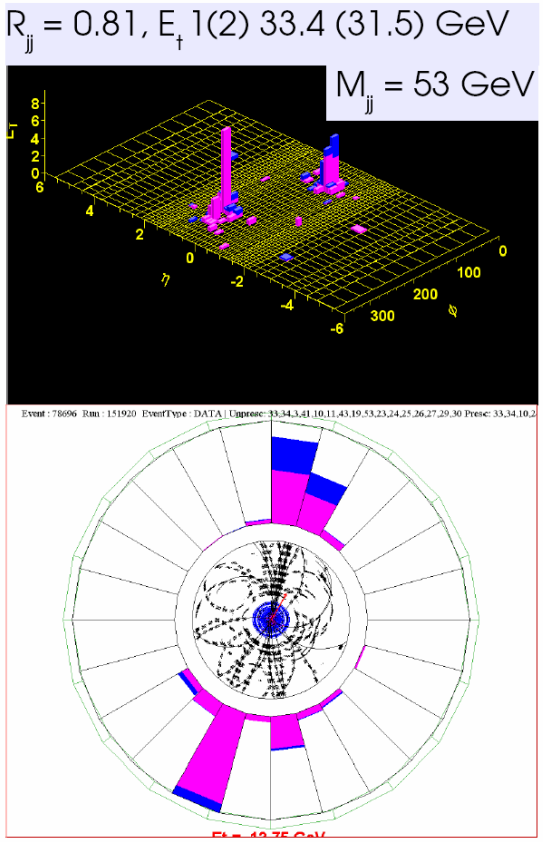
Hard subprocess cross section

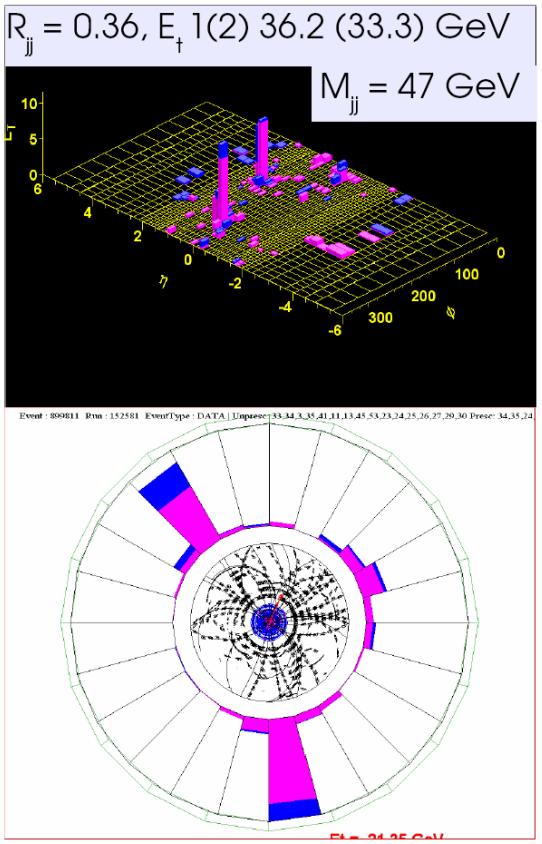
$$\sigma = \mathcal{L}(M^2, y)\,\hat{\sigma}(M^2)$$

Effective luminosity for production of mass M at rapidity y



… so can be checked by measuring higher rate processes at Tevatron and LHC





Exclusive χ_c production cross section from at CDF

$gg \to M(M^2)$

If all candidate events are exclusive $J/\psi + \gamma$,

$\sigma =$ 0.8 nb ± 0.3 (stat) ± 0.7 (syst)) pb

Estimate from Khoze, Martin Ryskin, Eur Phys J. C19, 477 (2001)

$\left(\frac{M^2}{4}\right)^2$

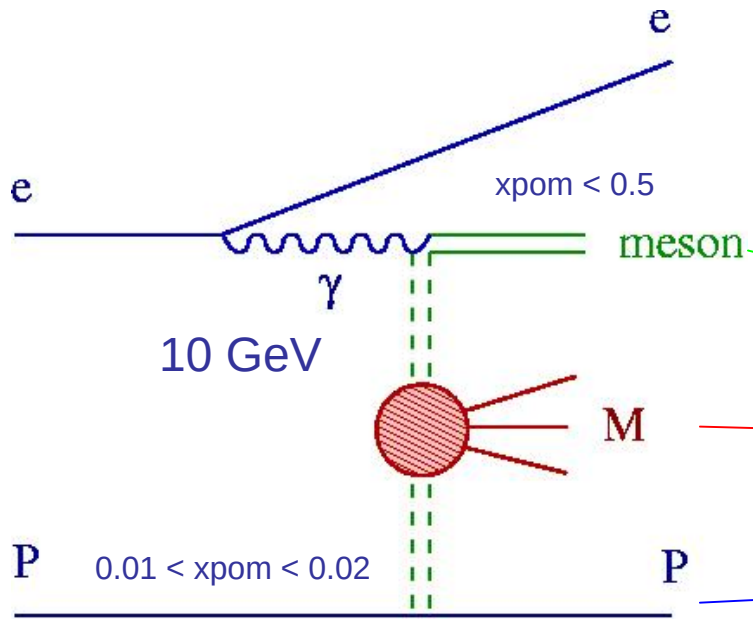
al gluon

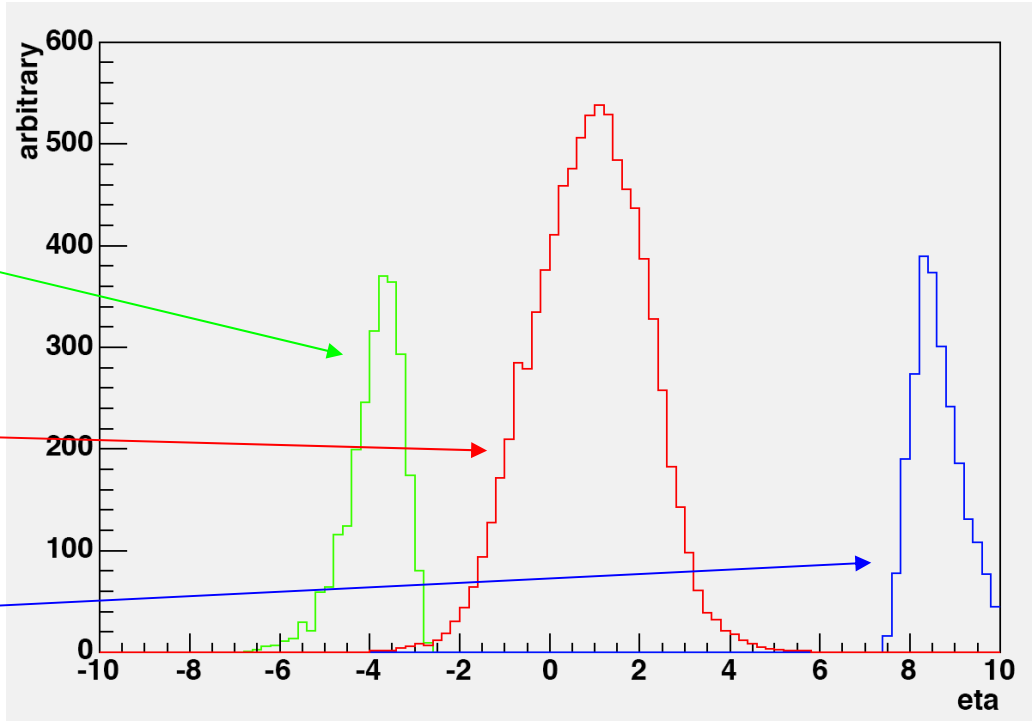
$\sigma \approx$ 1.2 nb

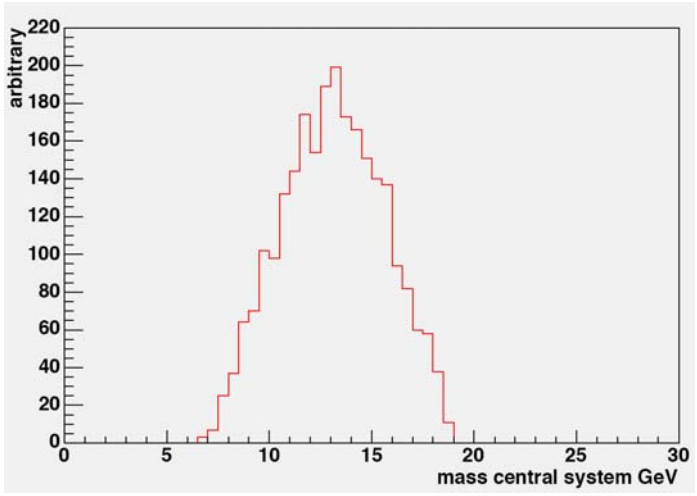
! Very preliminary, assumes all events are χ_c and exclusive, and calculation unreliable because of low mass of χ_c

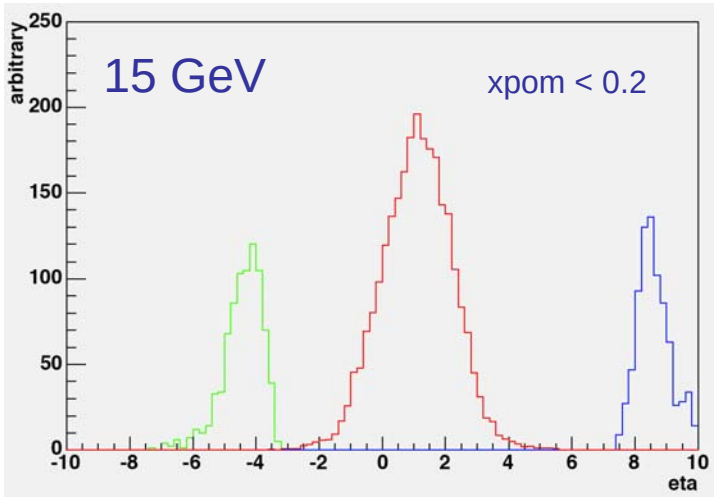
CDF plots and results from Angela Wyatt

Could anything be done at HERA?









Summary of CEDP physics

- The missing mass method gives unrivalled mass resolution
- There are regions of e.g. MSSM which (might) not be seen in any other way
- Complementary information to standard search channels :

  Azimuthal asymmetries 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

  Measurements of branching ratios into e.g. $\tau\tau$

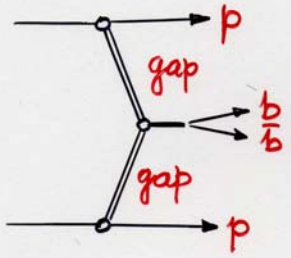
- Any measurements of double pomeron will help constrain models (of underlying production process and / or gap survival probability
- More work to be done, but it may be possible (and very valuable) to see double pomeron at HERA.

The Standard model Higgs

Khoze, M, Ryskin

Exclusive Diffractive Higgs Production

$pp \to p + H + p$



- $M_H = \begin{cases} M(b\bar{b}) \\ M_{missing} \end{cases}$ if p's tagged $\Delta M_{miss} \sim 1$ GeV

+ De Roeck, Otawa

- LO background $gg \to b\bar{b}$
  V. suppressed (by $J_z = 0$ selection rule)
  ($= 0$ for $m_q = 0$ and forward p's)

- The 'price' of the gaps ?

LHC $\mathcal{L} = 30\ fb^{-1}$ 120GeV Higgs

$\sigma(pp \to p + H + p) = 3fb$

90 events
↓ efficiency of p taggers
54
↓ BR($H \to b\bar{b}$)
36
↓ b, $\bar{b}$ tag efficiency
22
↓ polar angle cut
11 events

See K. Osterbergs talk for details

Higgs signal		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
	ATLAS	385	11820	$0.03\left(\frac{2\text{ GeV}}{\Delta M_{\gamma\gamma}}\right)$	3.5σ
b) $t\bar{t}H$ $\hookrightarrow b\bar{b}$		26	31	$0.8\left(\frac{10\text{ GeV}}{\Delta M_{b\bar{b}}}\right)$	3σ
c) $gg^{PP} \to p + H + p$ $\hookrightarrow b\bar{b}$		11	4	$3\left(\frac{1\text{ GeV}}{\Delta M_{\text{missing}}}\right)$	3σ

Alan Martin

Signal to Background

A detailed study for 120 GeV Standard model Higgs at LHC (De Roeck et. al.)

$\Delta M_{\text{missing}} = 1\ \text{GeV}$

- Leading order ‘bbbar’ backgrounds
  - misidentification of large glue – glue subprocess

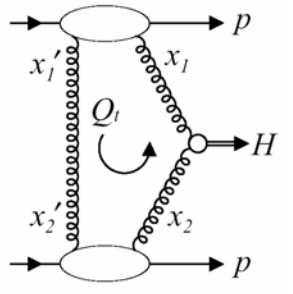
    Assuming 1% b misidentification probability B/S ~ 0.06

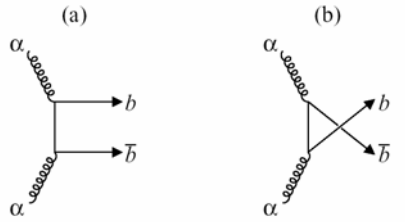
  - non-forward (i.e. non-zero t) $J_Z = 2$ admixture

    B/S ~ 0.08

  - order m_b^2/E_T^2 contribution from massive b quarks

    B/S ~ 0.06





- NLO backgrounds
  - bbar glue in which gluon goes undetected down beam pipe

    Removed by requiring $M_{\text{missing}} = M_{b\bar{b}}$

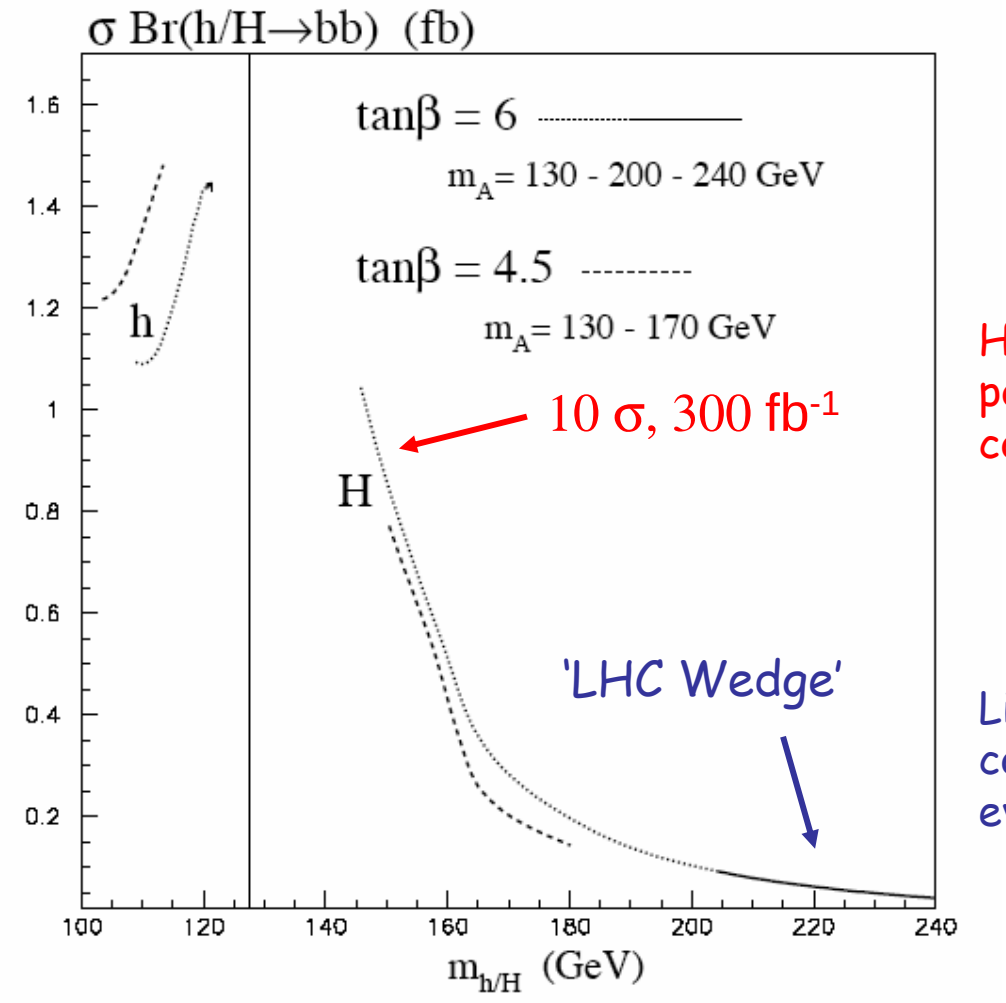
  - bbar glue in which gluon co-linear with b jet

    B/S ~ 0.06

  - NNLO shown to be negligibly small

A. De Roeck, V. A. Khoze, A. D. Martin, R. Orava and M. G. Ryskin Eur.Phys.J. C23 (2002) 311-327

The 'Window' regions and the decoupling limit



H scalar at 5σ may not be possible with 300 fb^{-1} in conventional channels

Lightest higgs only in conventional channels even with 300 fb^{-1}

Also useful in 'decoupling' limit (m_A and m_H ~ degenerate) - e.g. m_A = 185 GeV and tanβ = 7 : $\mathrm{Br}(H \to b\bar{b})\sigma_H = 0.17$ fb.

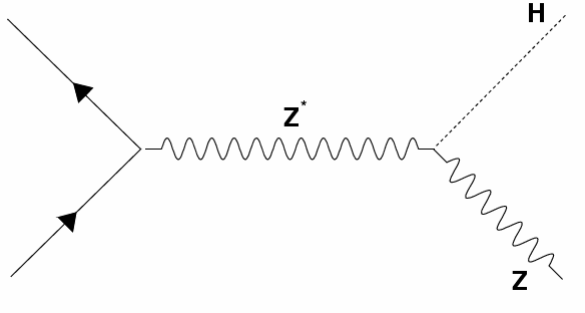
MSSM with explicit CP violation

Imagine a light scalar which couples predominantly to glue, and decays to b jets … would we see it at LEP, Tevatron or LHC?

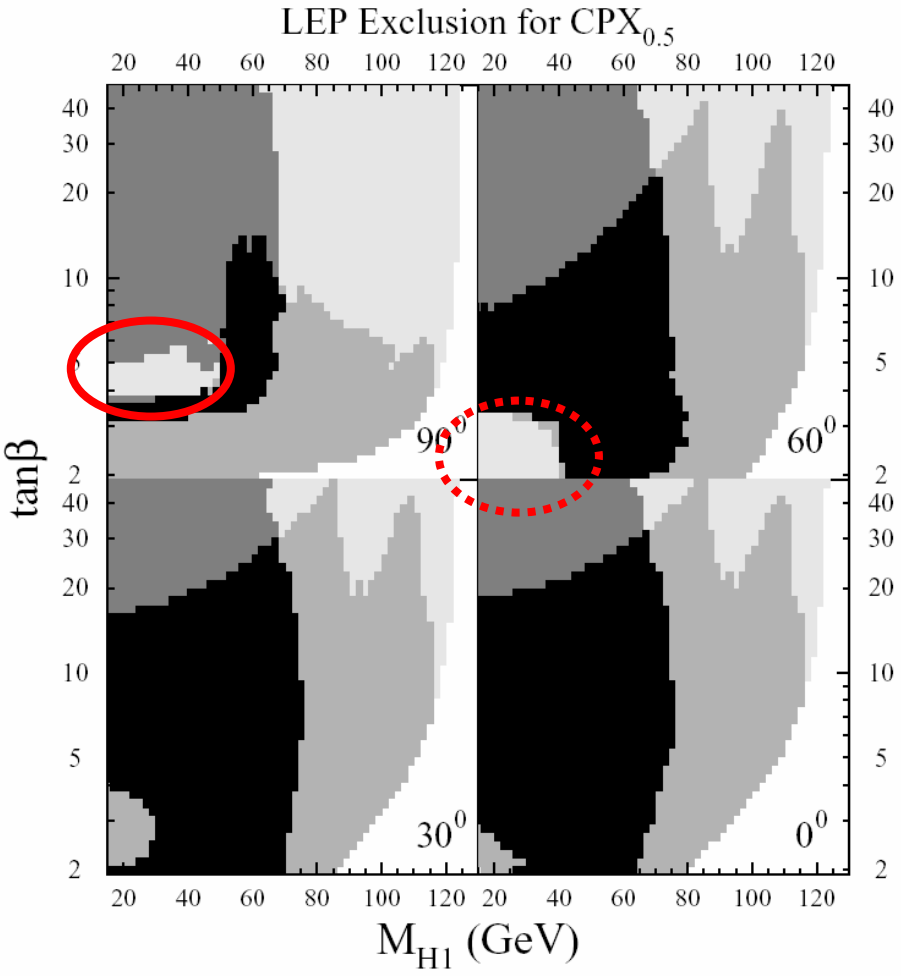
$$H_u = \begin{pmatrix} \phi_1^+ + i\phi_1^- \\ \phi_1 + ia_1 + v_u \end{pmatrix}, \quad H_d = \begin{pmatrix} \phi_2^+ + i\phi_2^- \\ \phi_2 + ia_2 + v_d \end{pmatrix}$$

In the CPX scenario, the three neutral MSSM Higgs bosons, (CP even) h^0 and H^0, and (CP odd) a mix to produce 3 physical mass eigenstates H_1, H_2 and H_3 with mixed CP

Then, (very schematically), the lightest Higgs could be predominantly CP odd, and not couple strongly to the Z.



Light neutral Higgs bosons in the CPX scenario



Medium grey $e^+e^- \to ZH_i$

Dark grey $Z^* \to H_iH_j \to 4b$

"there are small regions of parameter space in which none of the neutral Higgs bosons can be detected at the Tevatron and the LHC"

Plot from M. Carena, J. Ellis, S. Mrenna, A. Pilaftsis and C. E. M. Wagner, hep-ph/0211467

Radions in Randal Sundrum Models

$$ds^2 = e^{-2kry} ds'^2 - r^2 dy^2$$

- Fluctuations in 4-d metric give rise to gravitons
- Fluctuations in r give rise to 'radions'

Dimensionless mixing term

$$\Delta\mathcal{L} = -\frac{1}{2}\left(1+6\gamma^2\xi\right)\phi_r\Box^2\phi_r - \frac{1}{2}\phi_r m_{\phi_r}^2\phi_r - \frac{1}{2}h_0\left(\Box^2 + m_{h_0}^2\right)h_0 - 6\gamma\xi\phi_r\Box^2 h_0$$

$$\gamma = v/\Lambda_\phi$$

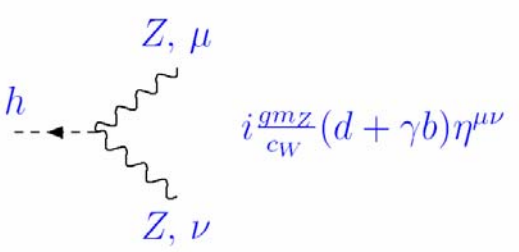
Radion guage field doesn't couple to Z, BUT mixing can occur

$$\begin{pmatrix} h_0 \\ \phi_r \end{pmatrix} = \begin{pmatrix} d & c \\ a & b \end{pmatrix}\begin{pmatrix} h \\ \phi \end{pmatrix}$$

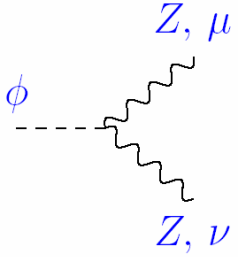
Standard model coupling of Higgs to Z

$$g_{zzh} = g_{sm}\left(d+\gamma b\right), \quad g_{zz\phi} = g_{sm}\left(c+\gamma a\right)$$

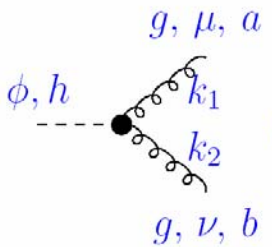
a = *c* = 0, no mixing and radion does not couple to z



$i\frac{gm_Z}{c_W}(d+\gamma b)\eta^{\mu\nu}$

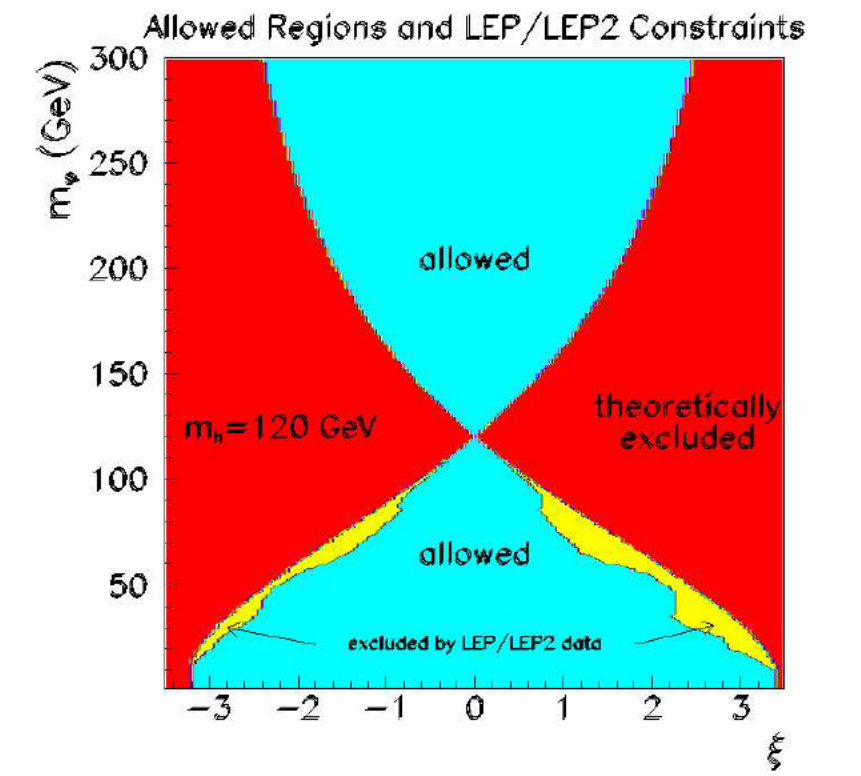


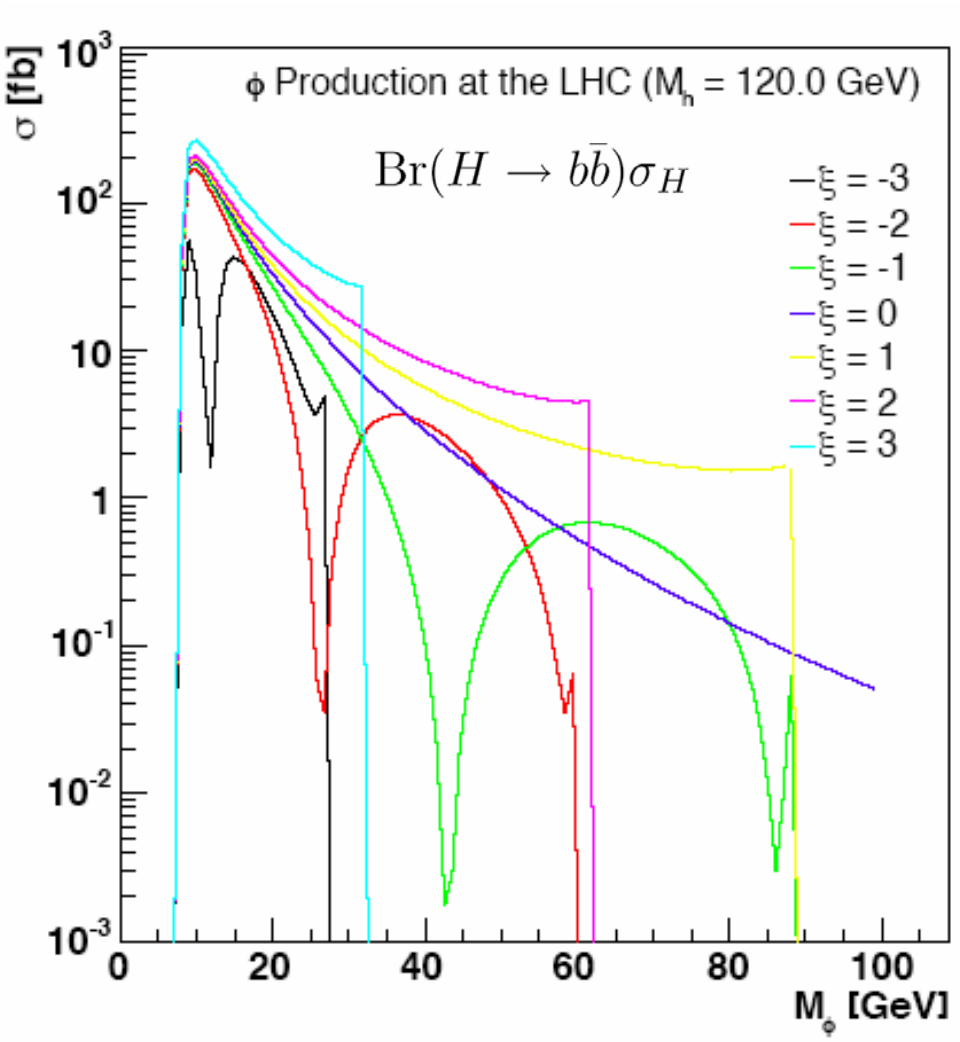
$i\frac{gm_Z}{c_W}(c+\gamma a)\eta^{\mu\nu}$



$ic_g\delta^{ab}[k_1\cdot k_2\eta^{\mu\nu} - k_1^\nu k_2^\mu]$

Radions





Preliminary Plot from James Monk

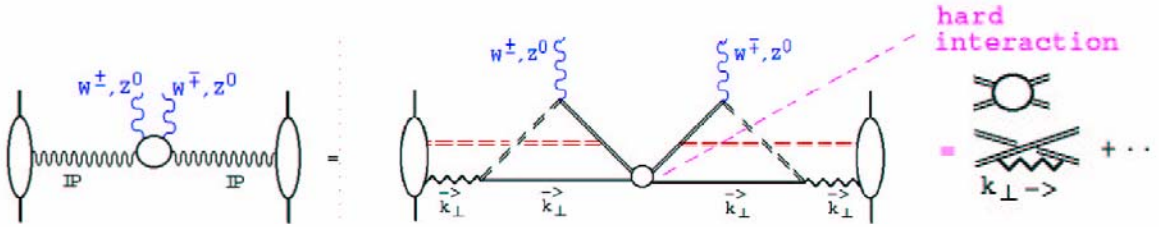
Plot from D. Dominici et. al. hep-ph/0206192

More exotic models of EWSB

Alan White

If each $\mathbb{P}$ can be "cleanly isolated", double $\mathbb{P}$ exchange at the LHC should maximally expose the "new physics" of Π production.

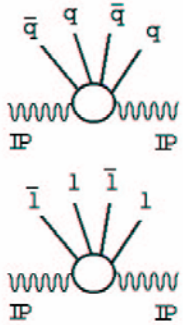
Π's can be pair-produced directly via the anomaly mechanism -



Order-of-magnitude arguments say that the large $k_\perp$ production of W^+W^- and Z^0Z^0 pairs should produce jet cross-sections that are at least as large as (and could be considerably larger than) the inclusive cross-sections predicted by standard QCD.

There should also be additional top quark production via a "background" anomaly vertex -

If new leptons exist, with electroweak scale masses, then there will similarly be large $k_\perp$ anomaly vertices for their production.



Double $\mathbb{P}$ exchange should be the most definitive and may be spectacular !!

The GTeV experiment

Mike Albrow

• Proposal for a new forward physics experiment to run 2009 - 2014 in parallel with BTeV at the Tevatron

• Complimentary physics menu to the LHC (because lower mass central systems accessible)

glueballs, new hadronic states such as X(3872), Pentaquarks …

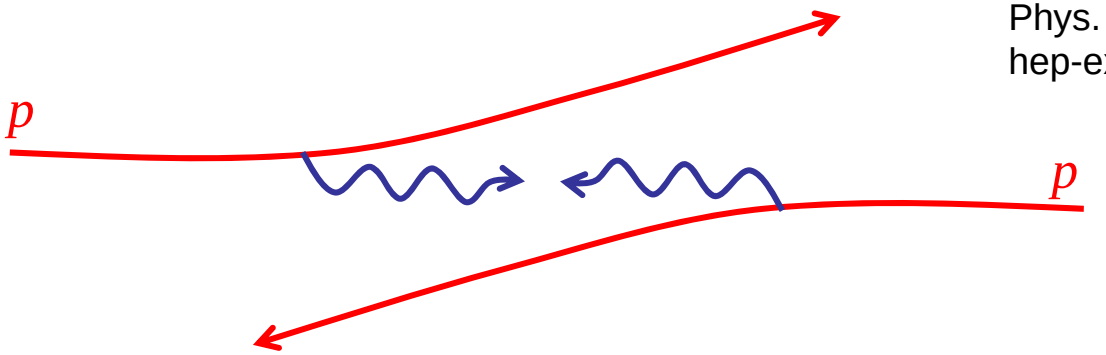
• As for LHC, missing mass resolution and quantum number determination are key ingredients for a unique physics program

• Workshop on 'The Future of QCD at B0 and D0' at Fermilab May 20th - 21st 2004. For details contact Mike Albrow or Andrew Brandt

LHC as a High Energy γγ Collider

K. Piotrzkowski

Phys. Rev. D63 (2001) 071502(R)
hep-ex/0201027

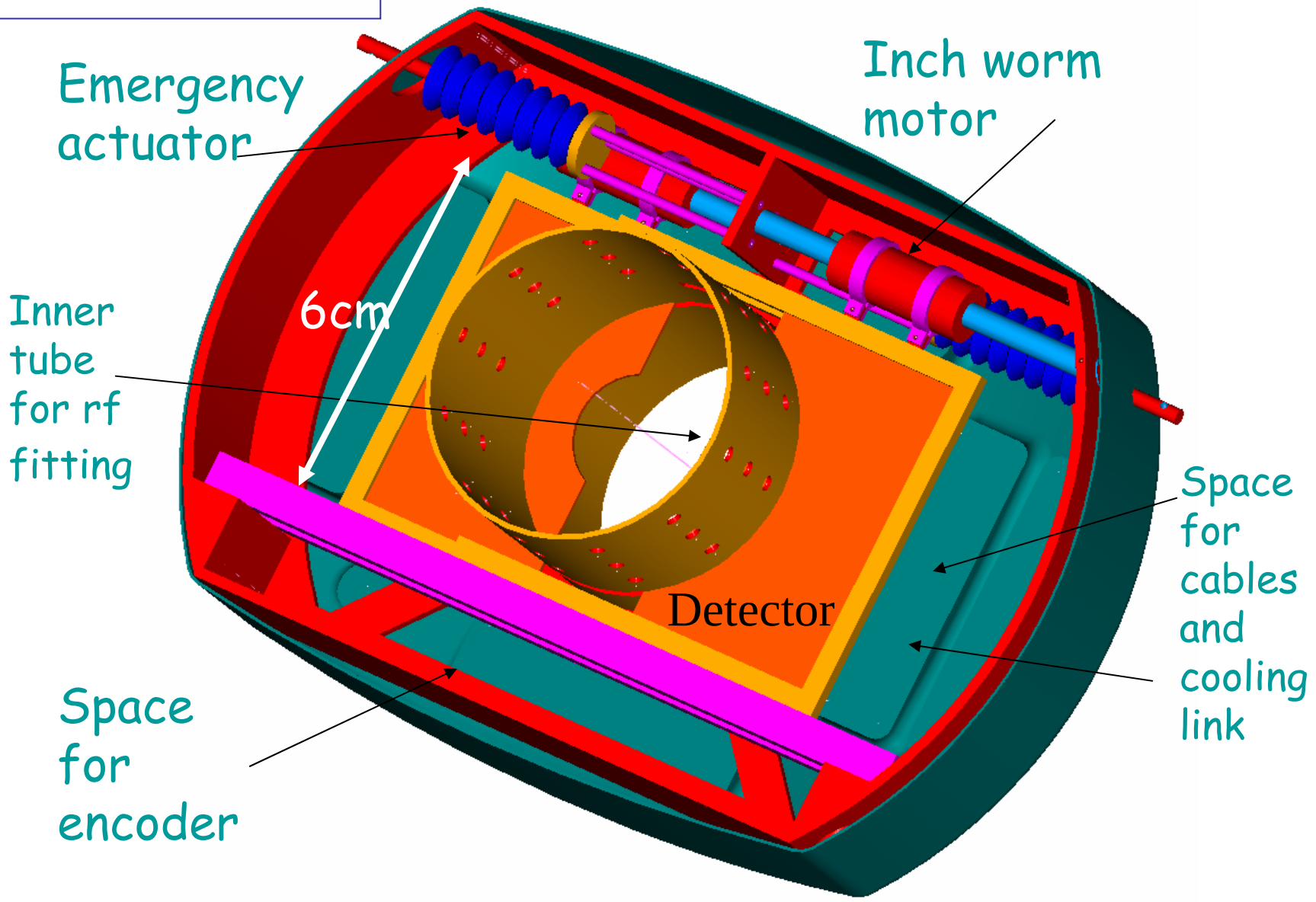


Observation:
Provided efficient measurement of forward-scattered protons one can study high-energy γγ collisions at the LHC

Highlights:
- **γγ CM energy *W* up to/beyond 1 TeV (and under control)**
- **Large photon flux *F* therefore significant γγ luminosity**
- **Complementary (and clean) physics to *pp* interactions, eg studies of exclusive production of heavy particles might be possible ➡ opens new field of studying very high energy γγ (and γp) physics**

Hardware

Microstation



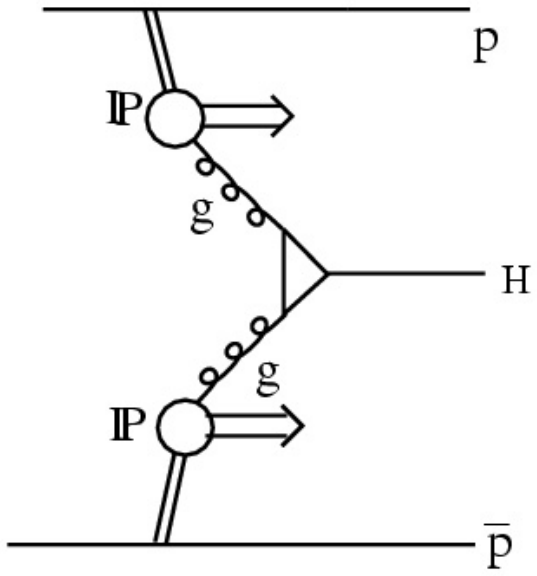
Detectors at 300m/400m

Some Major Concerns:

Detectors in this region requires changes in the machine

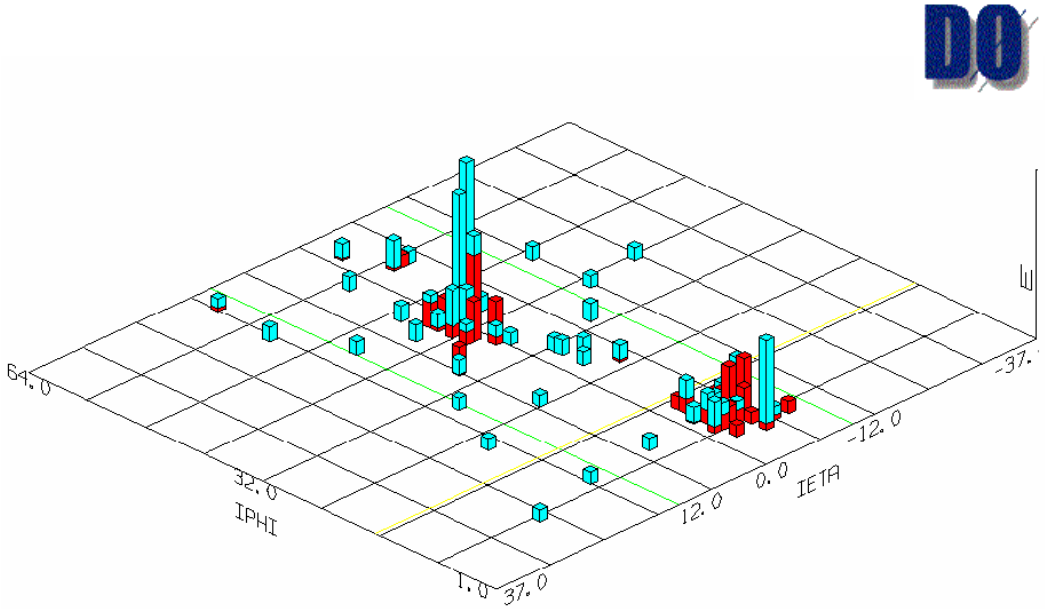
- Physics Case
  - Can we expect to see a good signal over background?
    ⇒ Signal understood (cross section)
    ⇒ Needs good understanding of the background (inclusive!)
    ⇒ Needs more complete simulations (resolutions, etc.)
- Trigger
  - 300m/400m signals of RPs arrive too late for the trigger
    ⇒ Can we trigger with the central detector only for L1?
    Note: L1 2-jet thresholds E_T > ~150 GeV
- Machine
  - Can detectors (RPs or microstations) be integrated with the machine? Technically there is place available at 330 and 420 mç

Soft pomeron – pomeron background



"Inclusive" (Central-inelastic) process

$p+p \rightarrow p + \text{gap} + H + X + \text{gap} + p$



Removed by requiring $M_{\text{missing}} = M_{b\bar{b}}$