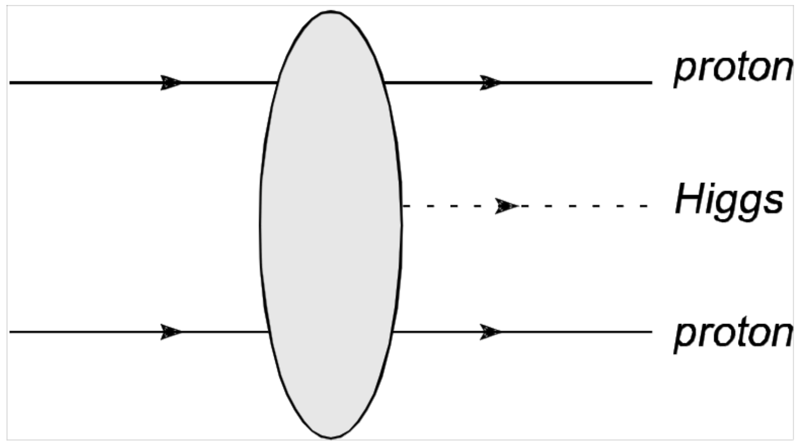
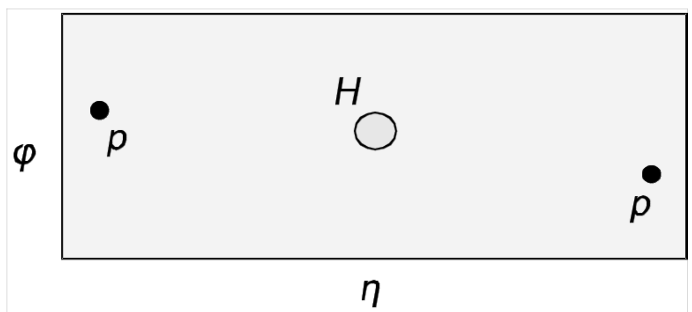
Central Exclusive Higgs Production

- Theory
- SM Higgs
- SUSY Higgs
- Gluino pair production
- Tevatron
- Other opportunities
- FP420

Jeff Forshaw
UC Davis 2007

Exclusive Higgs production





Detect the four-momenta of the protons using detectors situated 220m and 420m from the interaction point

Why?

- Excellent mass resolution 2-3 GeV
- Spin-parity analyser
  Possibility to investigate CP structure of Higgs system
- Reduced backgrounds
  Especially in b-bbar channel

Challenges

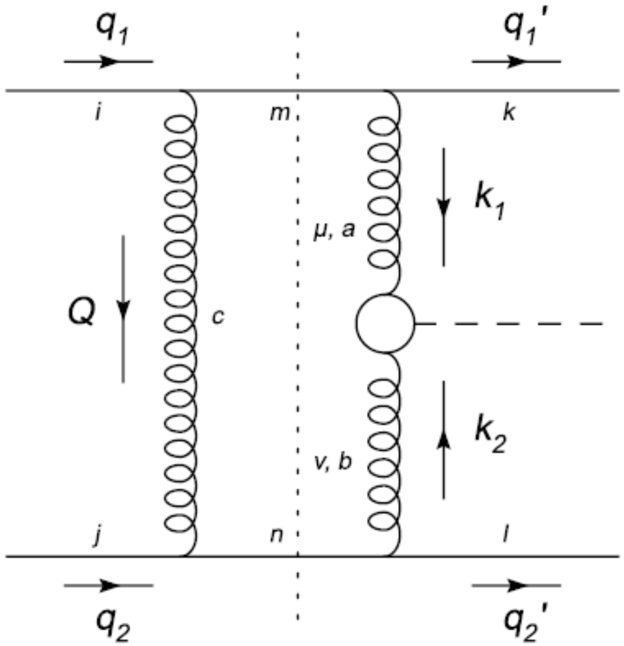
- Theory
- Requires new detectors
- Triggering
- Small signal rates

Calculating the cross-section

- **Durham approach**
  perturbative QCD
  Khoze, Martin, Ryskin, Kaidalov
  Monte Carlo: ExHuME (Monk & Pilkington)
- **Saclay approach**
  non-perturbative QCD
  Peschanski, Boonekamp, Royon, Kúcs
  Monte Carlo: DPECM
- **Hybrid approaches**
  Bzdak; Petrov & Ryutin
  Monte Carlo: EDDE

This talk is short on references: see my review on hep-ph/0508274

Start by computing the quark level amplitude…..



$$\mathrm{Im}A^{ik}_{jl} = \frac{1}{2} \times 2 \int d(PS)_2\, \delta((q_1 - Q)^2)\delta((q_2+Q)^2)$$
$$\frac{2gq_1^\alpha\, 2gq_{2\alpha}}{Q^2}\, \frac{2gq_1^\mu}{k_1^2}\, \frac{2gq_2^\nu}{k_2^2}\, V^{ab}_{\mu\nu}\, \tau^c_{im}\tau^c_{jn}\tau^a_{mk}\tau^b_{nl}\,.$$

$$d(PS)_2 = \frac{s}{2}\int \frac{d^2\mathbf{Q_T}}{(2\pi)^2}\, d\alpha d\beta \qquad Q = \alpha q_1 + \beta q_2 + Q_T.$$

$$V^{ab}_{\mu\nu} = \delta^{ab}\left(g_{\mu\nu} - \frac{k_{2\mu}k_{1\nu}}{k_1 \cdot k_2}\right) V$$ Scalar Higgs

$$q_1^\mu V^{ab}_{\mu\nu} q_2^\nu \approx \frac{k^\mu_{1T}}{x_1}\frac{k^\nu_{2T}}{x_2} V^{ab}_{\mu\nu} \approx \frac{s}{m_H^2} k^\mu_{1T} k^\nu_{2T} V^{ab}_{\mu\nu}$$
$$k_i = x_i q_i + k_{iT}$$

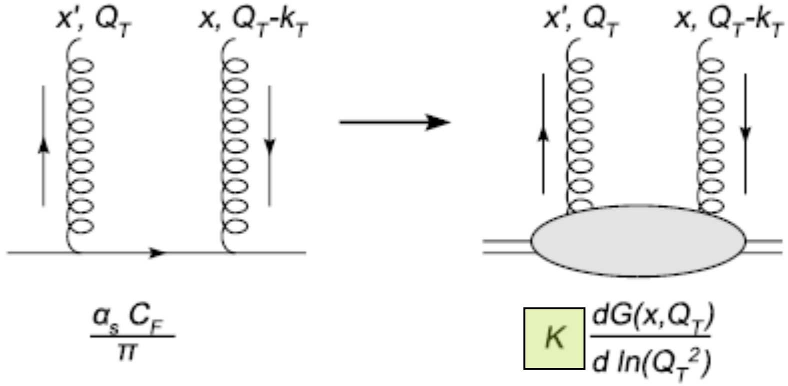
$Q_T \approx -k_{1T} \approx k_{2T}$

i.e. colliding gluons must have equal helicity

$$\frac{d\sigma}{d^2\mathbf{q_{1T}}'d^2\mathbf{q_{2T}}'dy} \approx \left(\frac{N_c^2-1}{N_c^2}\right)^2 \frac{\alpha_s^6}{(2\pi)^5}\frac{G_F}{\sqrt{2}}\left[\int \frac{d^2\mathbf{Q_T}}{2\pi}\frac{\mathbf{k_{1T}}\cdot\mathbf{k_{2T}}}{\mathbf{Q_T}^2\mathbf{k_{1T}}^2\mathbf{k_{2T}}^2}\frac{2}{3}\right]^2$$

$$\frac{\mathbf{k_{1T}}\cdot\mathbf{k_{2T}}}{\mathbf{Q_T}^2\mathbf{k_{1T}}^2\mathbf{k_{2T}}^2} \approx -\frac{1}{\mathbf{Q_T}^4}$$

Need to replace the quarks by protons…..



If $x' = x$ and $k_T = 0$ then $K = 1$.

We have $x' \ll x$ and $k_T^2 \ll Q_T^2$ in which case

$$\boxed{K \approx e^{-bk_T^2/2}\,\frac{2^{2\lambda+3}}{\sqrt{\pi}}\,\frac{\Gamma(\lambda+5/2)}{\Gamma(\lambda+4)}}$$

(assuming $xg(x,Q^2) \sim x^{-\lambda}$)

Since $\langle Q_T \rangle \sim 1.5$ GeV expect $b \approx 4$ GeV^{-2} (J/Ψ data from HERA).

≈ 1.2 for a 120 GeV Higgs at LHC, i.e. $(1.2)^4 \approx 2$ in cross-section.

Hence quark level….

$$\frac{d\sigma}{d^2\mathbf{q_{1T}}'d^2\mathbf{q_{2T}}'dy} \approx \left(\frac{N_c^2-1}{N_c^2}\right)^2 \frac{\alpha_s^6}{(2\pi)^5}\frac{G_F}{\sqrt{2}}\left[\int \frac{d^2\mathbf{Q_T}}{2\pi}\frac{\mathbf{k_{1T}}\cdot\mathbf{k_{2T}}}{\mathbf{Q_T}^2\mathbf{k_{1T}}^2\mathbf{k_{2T}}^2}\frac{2}{3}\right]^2$$

Becomes hadron level…

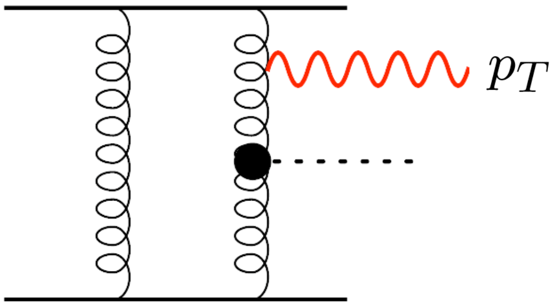
$$\boxed{\frac{d\sigma}{dy} \approx \frac{1}{256\pi b^2}\frac{\alpha_s G_F\sqrt{2}}{9}\left[\int \frac{d^2\mathbf{Q_T}}{\mathbf{Q_T}^4} f(x_1,Q_T)f(x_2,Q_T)\right]^2 \times (1.2)^4}$$

After integrating over the proton transverse momenta

$$f(x,Q) \equiv \partial G(x,Q)/\partial \ln Q^2$$

The apparent infra-red divergence is regulated: as $Q_T \to 0$ the two gluons which fuse to produce the Higgs radiate freely and spoil the gap. We need to forbid such radiation.

Sudakov suppression…..



The probability of emitting a gluon off a fusing gluon is logarithmically enhanced:

$$\frac{C_A\alpha_s}{\pi}\int_{Q_T^2}^{m_H^2/4}\frac{dp_T^2}{p_T^2}\int_{p_T}^{m_H/2}\frac{dE}{E}\sim\frac{C_A\alpha_s}{4\pi}\ln^2\left(\frac{m_H^2}{Q_T^2}\right)$$

Emission below Q_T is forbidden: the gluon's wavelength is too long to resolve the individual gluons.

Summing the large logarithms to all orders gives an exponential for the probability NOT to emit:

$$e^{-S}=\exp\left(-\frac{C_A\alpha_s}{\pi}\int_{Q_T^2}^{m_H^2/4}\frac{dp_T^2}{p_T^2}\int_{p_T}^{m_H/2}\frac{dE}{E}\right)$$

We must include this non-emission probability in the amplitude:

$$\int\frac{dQ_T^2}{Q_T^4}f(x_1,Q_T)f(x_2,Q_T)\boxed{e^{-S}}$$

Since the suppression factor vanishes faster than any power of Q_T the integral is rendered finite.

A bit more work needed to get the single logarithms right…..

$$e^{-S} = \exp\left(- \int_{Q_T^2}^{m_H^2/4} \frac{dp_T^2}{p_T^2} \frac{\alpha_s(p_T^2)}{2\pi} \int_0^{1-\Delta} dz \, [zP_{gg}(z) + \sum_q P_{qg}(z)] \right)$$

$\Delta = 2p_T/m_H$

Want the distribution of gluons in Q_T with no emission up to m_H:

$$\tilde{f}(x, Q_T) = \frac{\partial}{\partial \ln Q_T^2} \left(e^{-S/2} \, G(x, Q_T) \right)$$

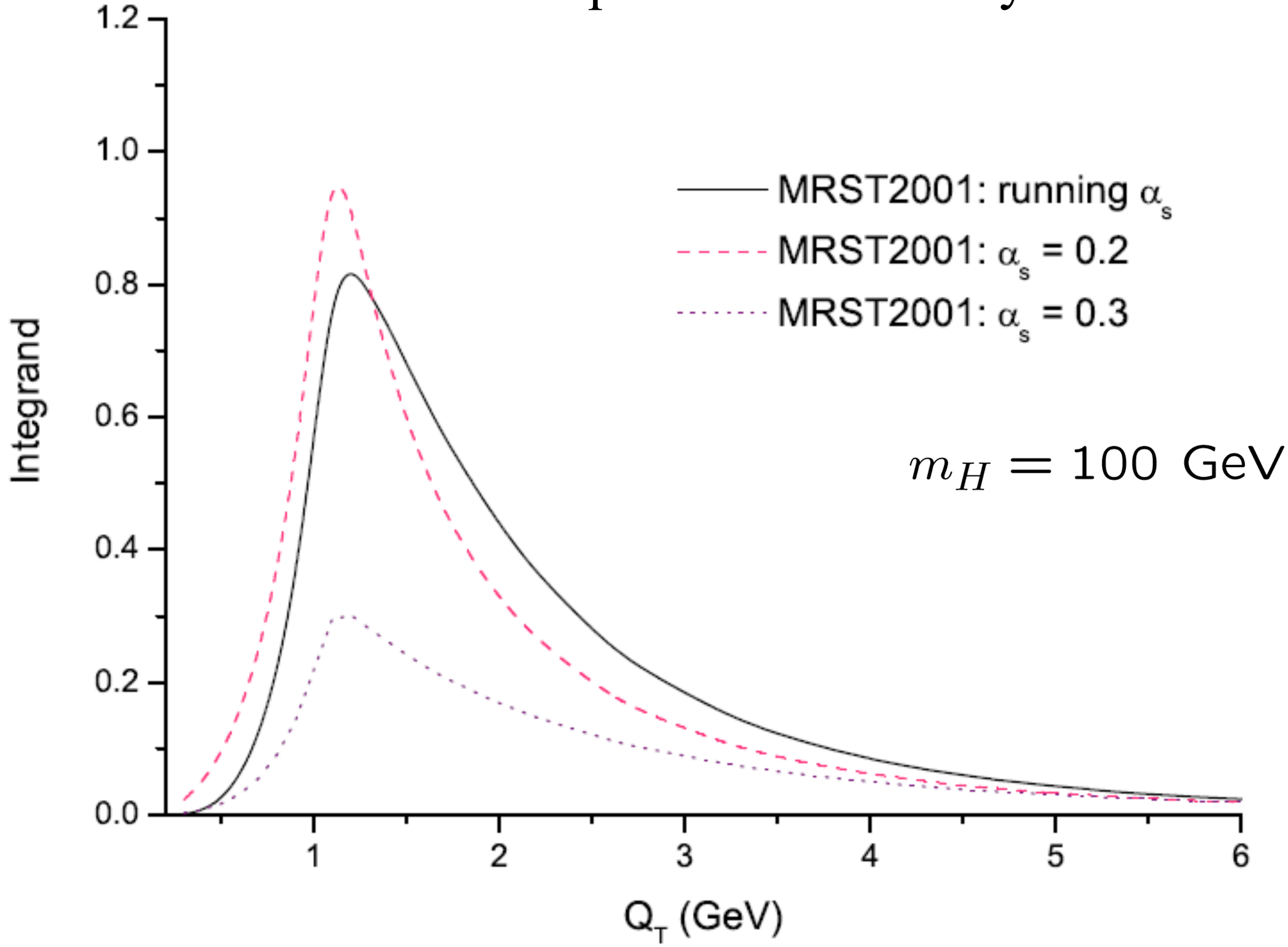
which means we must make the replacement

$$\int \frac{dQ_T^2}{Q_T^4} f(x_1, Q_T) f(x_2, Q_T) \, e^{-S} \longrightarrow \int \frac{dQ_T^2}{Q_T^4} \tilde{f}(x_1, Q_T) \tilde{f}(x_2, Q_T)$$

DLLA LLA

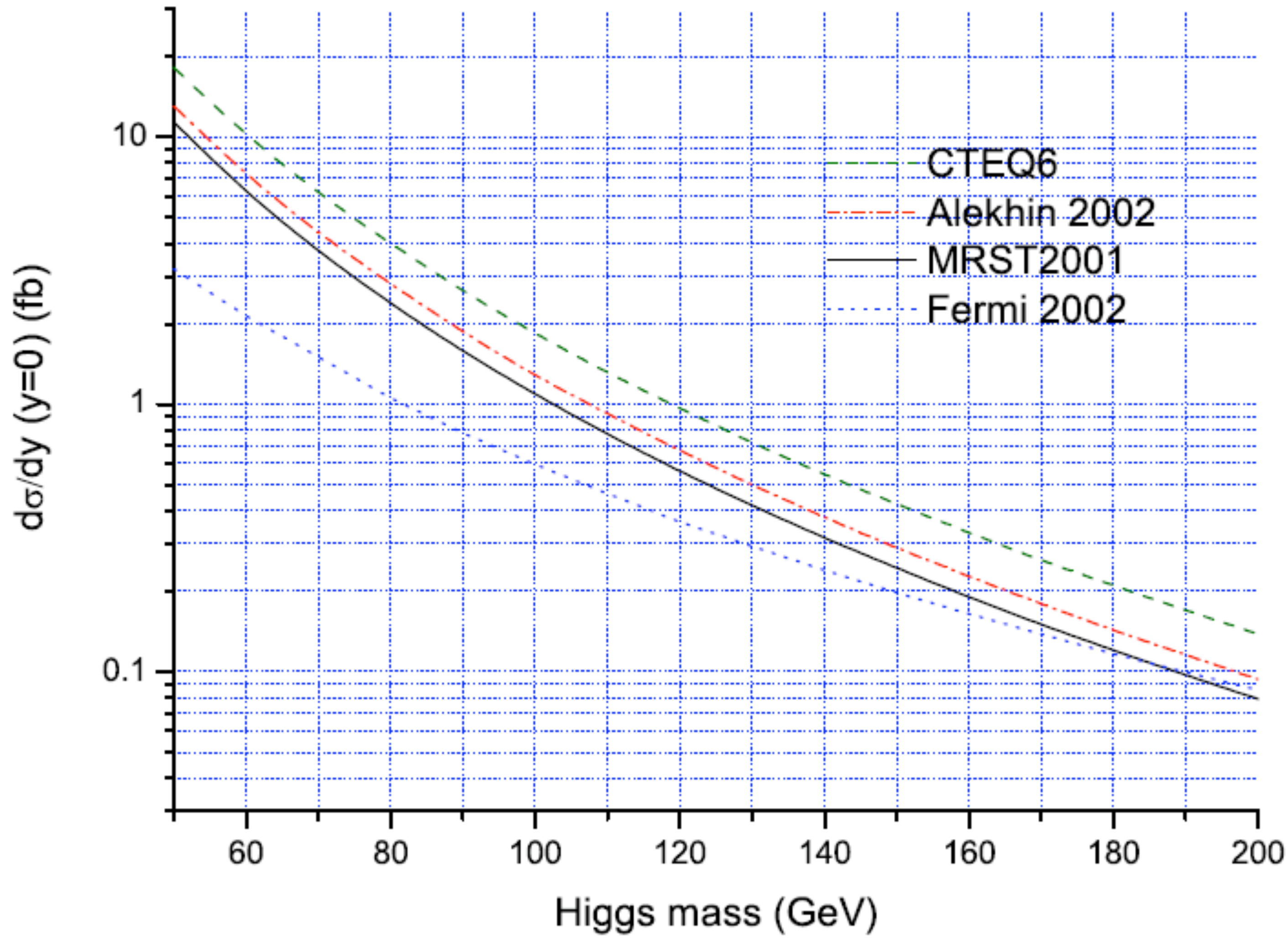
It is crucial to sum to LLA accuracy: factor ~10 enhancement

It’s ok to use perturbation theory…



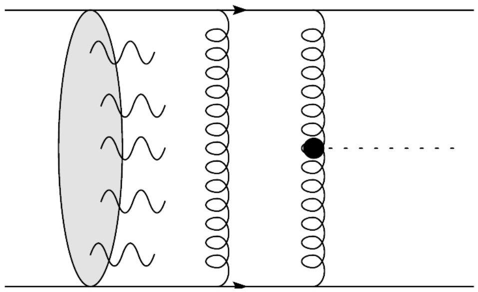
$$\exp(\langle \ln Q_T \rangle) \sim \frac{m_H}{2} \exp\left(-\frac{c}{\alpha_s}\right) \quad \boxed{\sim 2\ \text{GeV}}$$

Factor ~2 uncertainty from choice of gluon



And finally….gap survival (slightly oversimplified)

We want $P(pHp|\text{nothing else})$.



Assume that there is a single mechanism which fills gaps ("an inelastic scatter") and assume that it is independent of anything else in the event.

$$P_n(r) = \frac{\chi(r)^n}{n!}\exp(-\chi(r))$$

Can be extracted from, e.g. elastic scattering and total cross-section data.

$$d\sigma(p+H+p|\text{no soft emission}) = d\sigma(p+H+p) \times \boxed{S^2}$$

$$\boxed{S^2 = \frac{\int dr\ \ d\sigma(r)\ \ \exp(-\chi(r))}{\int dr\ \ d\sigma(r)}}$$

$$d\sigma(r) \propto [(\int d^2\mathbf{q_1}'\, e^{i\mathbf{q_1}'\cdot\mathbf{r}/2}\ \exp(-b\mathbf{q_1}'^2/2)) \times (\int d^2\mathbf{q_2}'\, e^{-i\mathbf{q_2}'\cdot\mathbf{r}/2}\ \exp(-b\mathbf{q_2}'^2/2))]^2$$

$$\propto \exp\left(-\frac{r^2}{2b}\right)$$

Same b as before: partial cancellation of uncertainty in total rate.

Typical values are ~3% at the LHC (bigger at Tevatron)

We need to figure out the "eikonal" factor….

$$\sigma_{\rm inelastic} = \int d^2\mathbf{r}(1 - \exp(-\chi(r)))$$

Combined with the optical theorem this implies that

$$\begin{aligned}\sigma_{\rm elastic} &= \int d^2\mathbf{r}(1 - \exp(-\chi(r)/2))^2, \\ \sigma_{\rm total} &= 2\int d^2\mathbf{r}(1 - \exp(-\chi(r)/2)).\end{aligned}$$

Hence one can fit the eikonal factor using data.

This model is the basis behind the underlying event generation in PYTHIA and also the "JIMMY" underlying event model in HERWIG. Both have been tested successfully against data (from HERA and Tevatron). [Sjostrand & Skands; Borozan & Seymour; Odagiri; Butterworth; Field.]

More sophisticated eikonal models: Kaidalov, Khoze, Martin, Ryskin; Gotsman, Levin, Maor et al.

Standard Model Higgs

b quark decay channel

- It is possible (due to 0^+ selection rule)
- 6 signal after all cuts (S/B > 1) with 100/fb for 120 GeV Higgs
- Hard to trigger at level 1 but can be done.

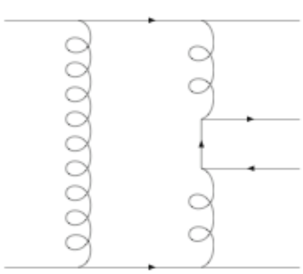
low lumi: muon $p_T \geq 6$ GeV trigger and/or gap trigger

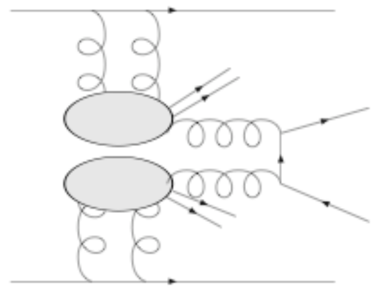
high lumi: muon plus jet trigger and/or fixed jet rate trigger (e.g. 25 kHz)

Backgrounds (also for SUSY Higgs)

1. Central exclusive dijet production (and now three parton final states)
2. "Double pomeron exchange"
3. Overlap events from pile-up (at high luminosity)

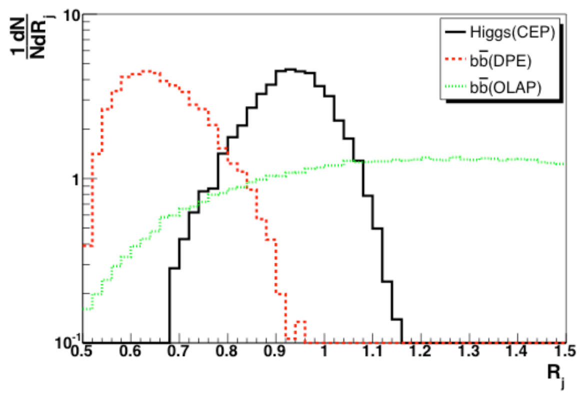
$$\begin{array}{lcl} pp & \to & p + X \\ pp & \to & p + X \\ pp & \to & jj + X \end{array}$$

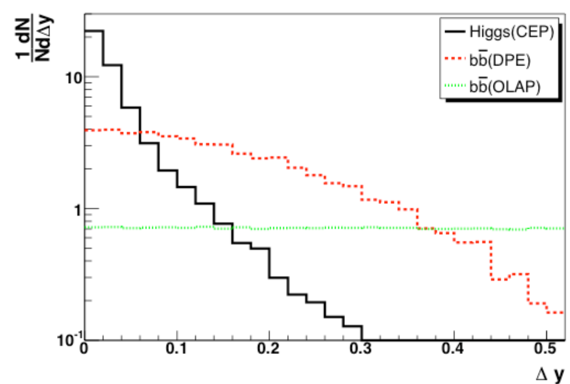




Eliminating dijet backgrounds
(same strategy for SUSY analyses)

$\Delta M = \pm 4$ GeV
$E_T > 40$ GeV
b-tagging

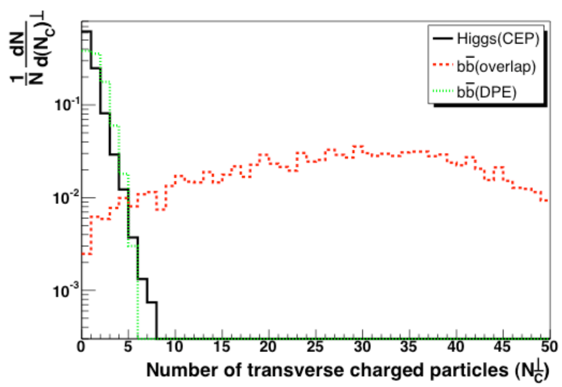




$0.82 < R_j < 1.1$
$\Delta y \leq 0.6$

$N_c^{\perp} \leq 1, N_c \leq 5$

Effective at killing overlap background. And still works at high lumi (50%).

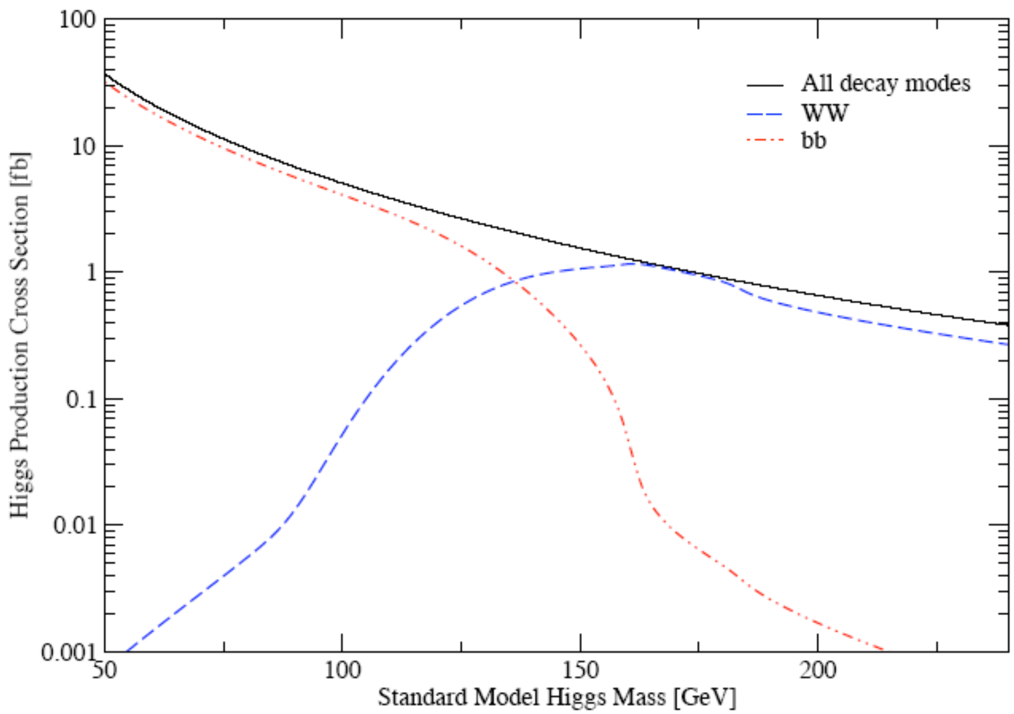


Timing from pots locates primary vertex to 2.1mm. Pile-up vertices spread over 5.6cm.

Andy Pilkington 2007

The WW decay channel is easier to trigger (require at least one W to decay leptonically)

Rate is still large enough….



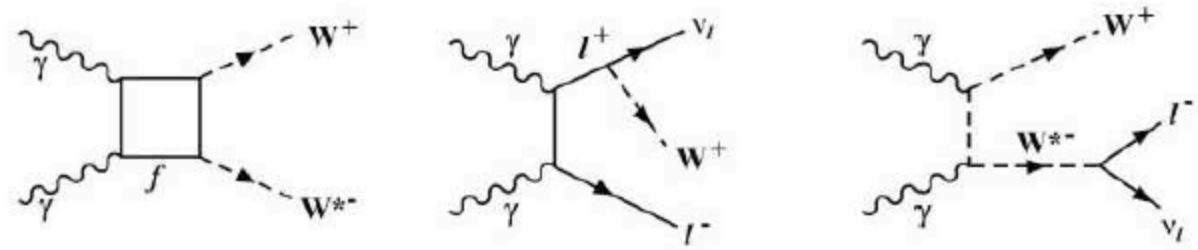
Cox, de Roeck, Khoze, Pierzchala, Ryskin, Stirling, Nasteva, Tasevsky

Selection cuts	Higgs Mass (GeV)	Efficiency	Signal σ (fb)	Events / 30 fb^{-1}
Generated $H \to WW$	120	100%	0.40	12
	140	100%	0.93	28
	160	100%	1.16	35
	180	100%	0.84	25
	200	100%	0.48	15
Acceptance of proton taggers (420m + 220m)	120	61 %	0.25	7
	140	67 %	0.63	19
	160	71 %	0.83	25
	180	74 %	0.62	19
	200	77 %	0.37	11

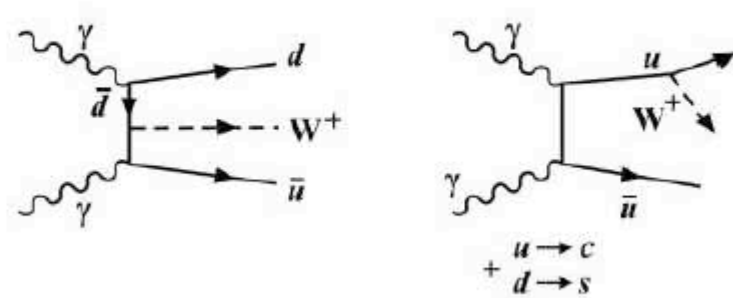
- Single electron p_T > 25 GeV or single muon p_T > 20, $|\eta|$ < 2.5 ~ 25% efficiency
- If thresholds could be reduced to 15 GeV, (e.g. combination with 2 central jets) then efficiency rises to ~ 40%

Small numbers of events (low lumi) but backgrounds under control

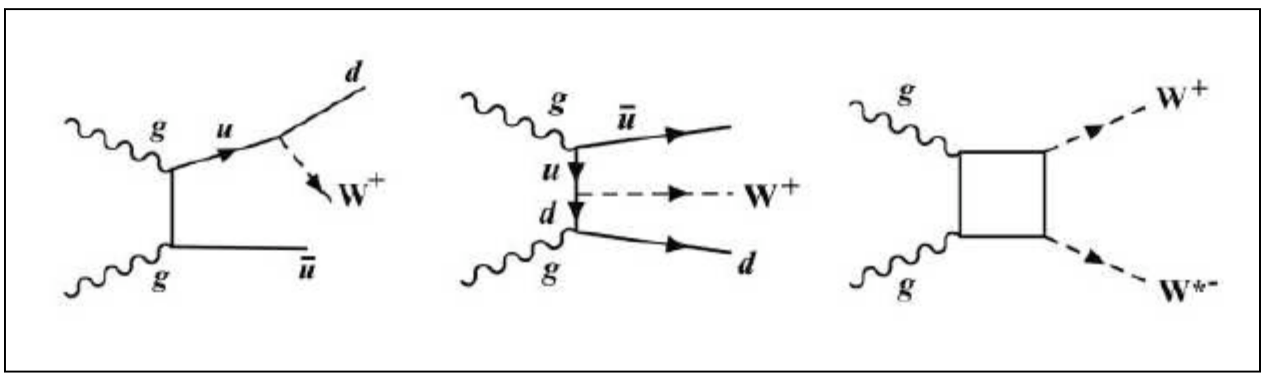
Don't need many events to measure the mass and establish cleanly that Higgs is a scalar particle.



(a) **(b)** **(c)**



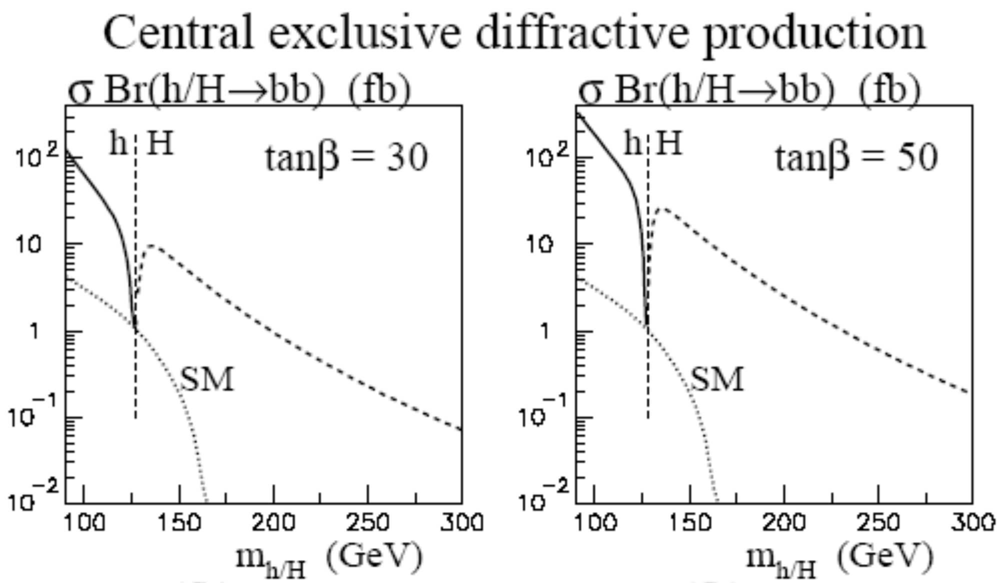
(d) **(e)**



Intense coupling region of MSSM

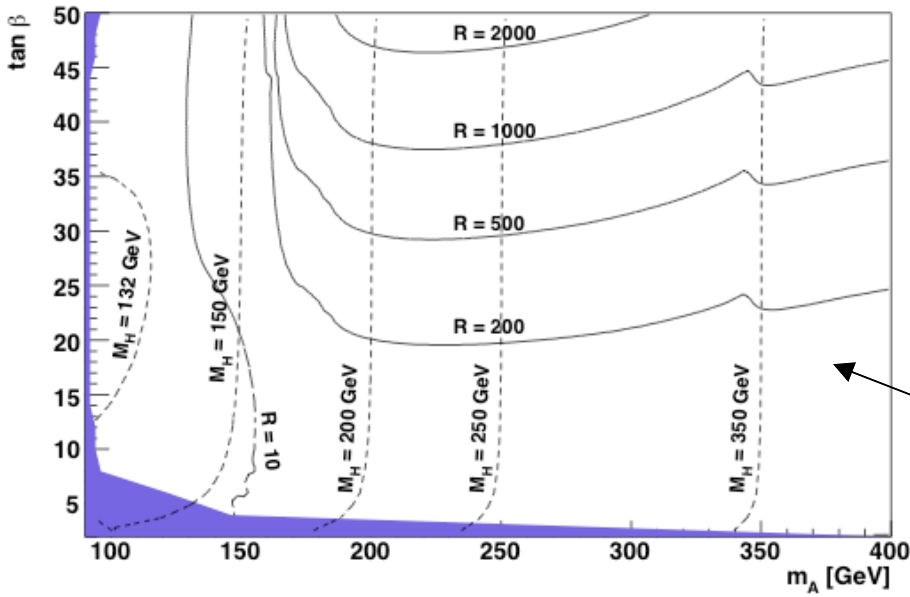
- All three Higgses have similar mass
- tan β large
- coupling to $b\bar{b}$ enhanced
- very challenging to study via conventional methods
- ….big central exclusive cross-section

Boos, Djouadi, Muhlleitner, Vologdin, Nikitenko



Very large cross-sections
and can detect in the
b-quark decay channel

Kaidalov, Khoze, Martin, Ryskin

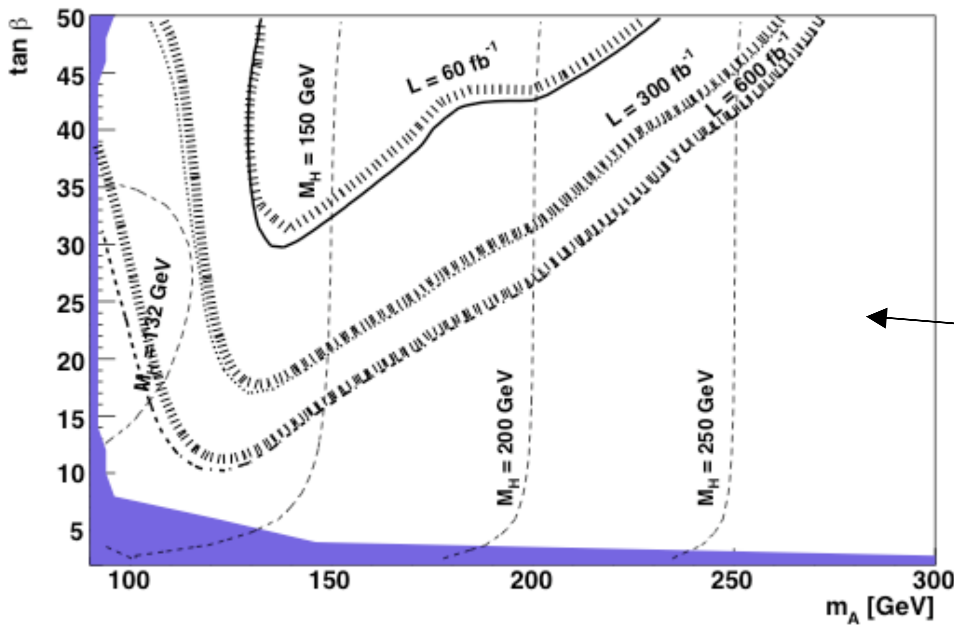


$$m_H^{\max} \text{ scenario}$$

$$\mu = -500 \text{ GeV}$$

Carena, Heinemeyer, Wagner, Weiglein

Ratio of MSSM (H production) to SM (h) production.



Assumes that the overlap background can be neglected (definitely ok at low lumi, may also be possible at high lumi).

From Marek Tasevsky

CPV MSSM “Tri-mixing”

$$\begin{pmatrix} \phi_1 \\ \phi_2 \\ a \end{pmatrix} = O \begin{pmatrix} H_1 \\ H_2 \\ H_3 \end{pmatrix}$$

- Radiatively induced explicit CP violation mixes CP even and CP odd higgses.

- It is possible for all three Higgs bosons to have similar masses for a charged Higgs mass 140-170 GeV and large tan β > 40.

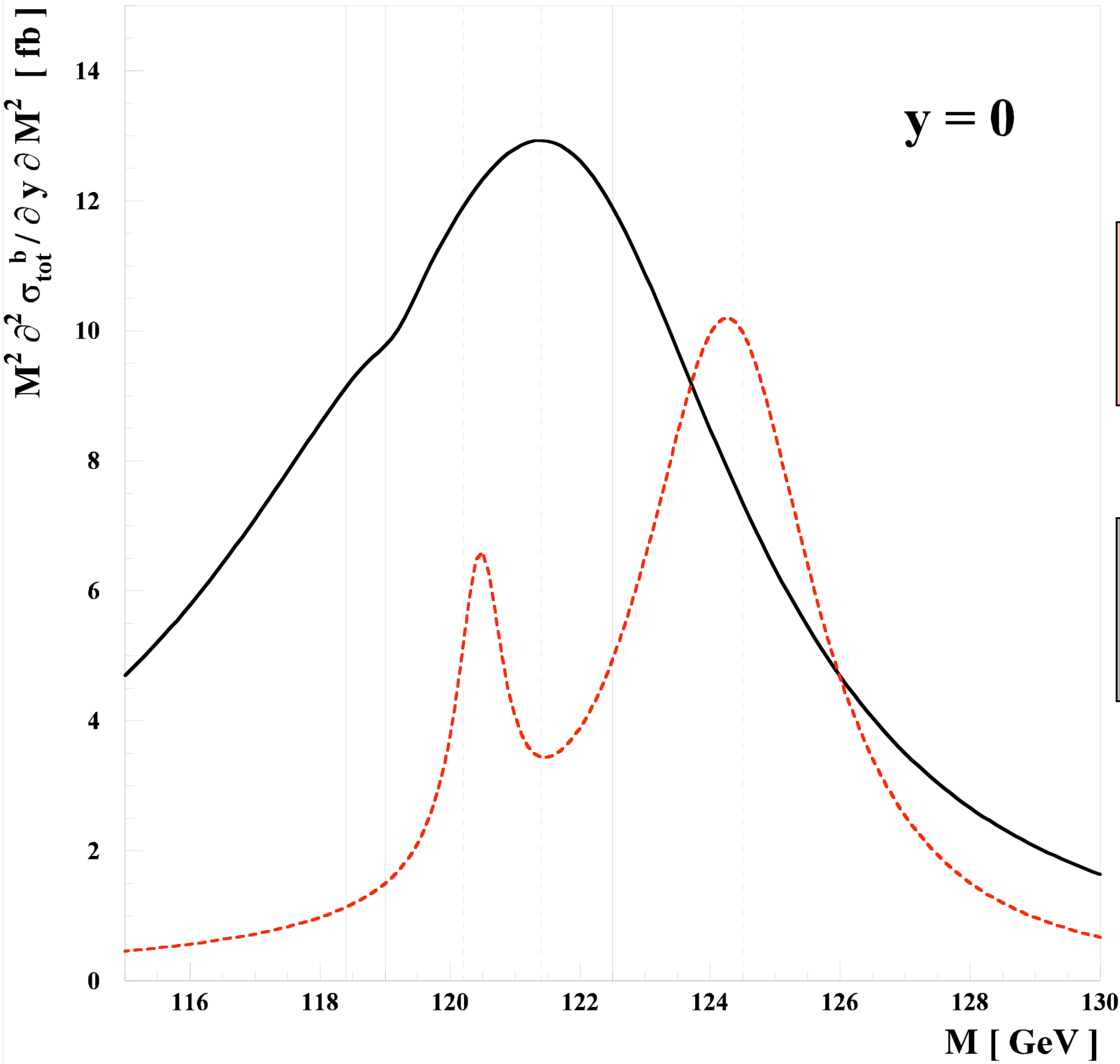
  Full coupled channel analysis performed by J. Ellis, J-S. Lee, Pilaftsis

$$\begin{aligned}
&\tan\beta = 50, \quad M_{H^\pm}^{\mathrm{pole}} = 155 \quad \mathrm{GeV}, \\
&M_{\tilde{Q}_3} = M_{\tilde{U}_3} = M_{\tilde{D}_3} = M_{\tilde{L}_3} = M_{\tilde{E}_3} = 0.5 \quad \mathrm{TeV}, \\
&|\mu| = 0.5 \quad \mathrm{TeV}, \quad |A_{t,b,\tau}| = 1 \quad \mathrm{TeV}, \\
&|M_{1,2}| = 0.3 \quad \mathrm{TeV}, \qquad |M_3| = 1 \quad \mathrm{TeV},
\end{aligned}$$

J-S.Lee, Pilaftsis, J. Ellis, Carena, Wagner, Mrenna, Choi, Hagiwara, Drees

CPsuperH

J. Ellis, J-S. Lee, A. Pilaftsis



$\Phi_\mu = 0^\circ$, $\Phi_{A_t,A_b,A_\tau} = 90^\circ$, $\Phi_{1,2} = 0^\circ$, $\Phi_3 = -10^\circ$,

$M_{H_1} = 120.2$, $M_{H_2} = 121.4$, $M_{H_3} = 124.5$,
$\Gamma_{H_1} = 1.19$, $\Gamma_{H_2} = 3.42$, $\Gamma_{H_3} = 3.20$,

$\Phi_\mu = 0^\circ$, $\Phi_{A_t,A_b,A_\tau} = 90^\circ$, $\Phi_{1,2} = 0^\circ$, $\Phi_3 = -90^\circ$,

$M_{H_1} = 118.4$, $M_{H_2} = 119.0$, $M_{H_3} = 122.5$,
$\Gamma_{H_1} = 3.91$, $\Gamma_{H_2} = 6.02$, $\Gamma_{H_3} = 6.34$,

Cross-sections are much bigger than SM case.

Higgs tri-mixing scenarios with $\Phi_3 = -90^\circ$ (solid lines) and $\Phi_3 = -10^\circ$ (dotted lines). The vertical lines indicate the three Higgs-boson pole-mass positions. ($b\bar{b}$ decay channel)

NMSSM Higgs

Natural to extend MSSM to include a singlet superfield:

$$W \sim \lambda \hat{S}\hat{H}_1\hat{H}_2 + \frac{\kappa}{3}\hat{S}^3 \qquad \langle S \rangle \neq 0$$

Solves the "μ problem" but has potentially troublesome phenomenology…

Possible to have a lightest higgs which decays predominantly (90%) to two light pseudo-scalars:

$$h_1 \longrightarrow a_1 a_1$$

where the light pseudo-scalar has a mass below the threshold for b-bbar pair production,

e.g. $$m_{h1} = 90 \text{ GeV}$$
$$m_{a1} = 10 \text{ GeV}$$

Hence would want to observe the decay to four taus.

Gunion, Ellwanger, Hugonie, Dermisek

Very preliminary…..[Gunion, Hodgkinson, Papaefstathiou, Pilkington, JRF]

$$\begin{array}{ccccc} pp \to p + & h_1 & + p & & \\ & \downarrow & & & \\ & a_1 & a_1 & & \\ & \downarrow & & \searrow & \\ & \tau^+\tau^- & & & \tau^+\tau^- \end{array}$$

Signal after cuts around 0.5 fb with manageable background.

Trigger on $p_T > 6$ GeV muon.

Force 3 jets and cut on number of charged tracks and on energy profile of jets.

Utilize measurement of proton momenta and assume missing momentum for neutrinos is collinear to the out going pseudoscalar to overconstrain the kinematics.

Stable gluinos

- Stable gluinos, e.g. as in split SUSY, pair-produced with a "large" cross-section.
- May bind into gluinonium or decay into distinctive final state (R-hadrons).
- Gluinonium decay to gluons is at too low a rate.
- R-hadrons look like slow muons good for triggering

Peter Bussey, Tim Coughlin, Andy Pilkington, JRF.

Not many events are needed for a clean extraction of the gluino mass

• Essentially background free

Cut on the speed of the R-hadron and use pots to constrain kinematics of central system.

• Collect events at high luminosity

Pile-up can be handled using pots to locate primary vertex (3mm) and to constrain kinematics of central system.

• Mass of gluino can be extracted event-by-event

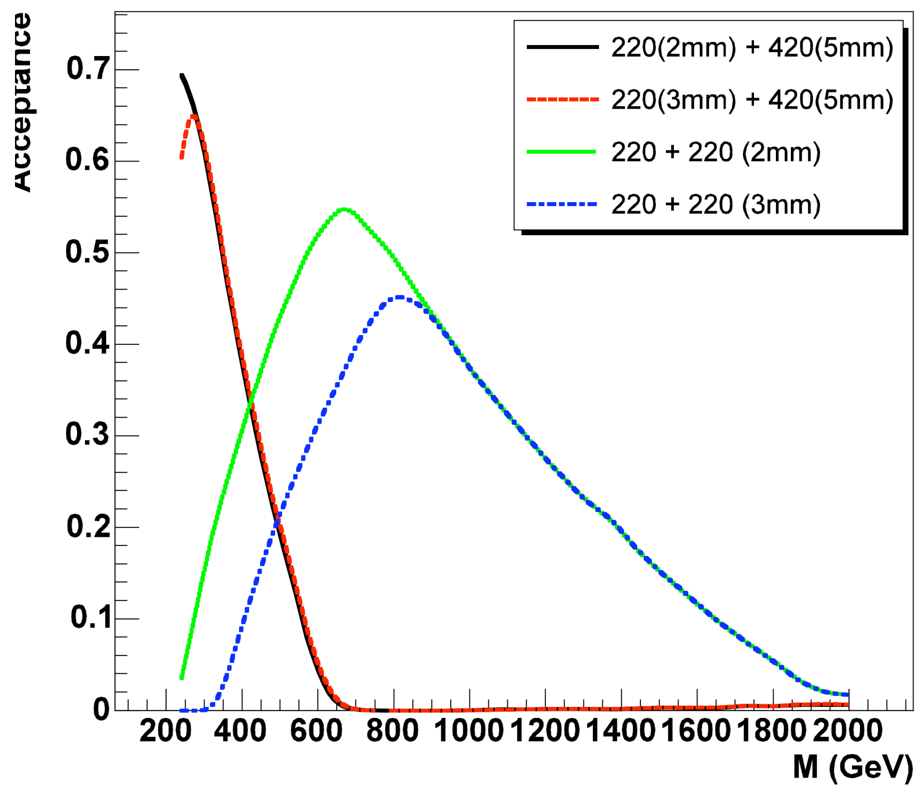
Using pots in conjunction with the pseudo-rapidity of the R-hadrons (from the muon detectors).

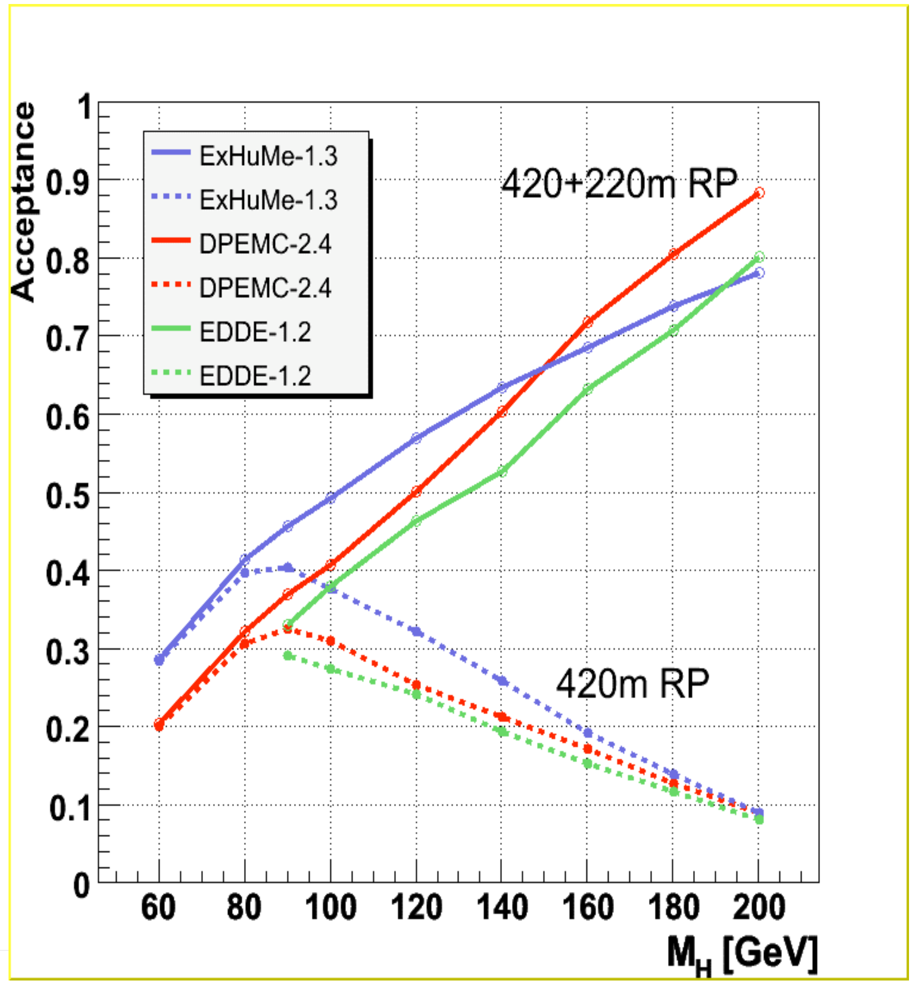
Gluino mass (GeV)	No. of events (300/fb)	Error on mass (GeV)
200	145	0.2
250	35	1.1
300	10	1.5
350	4	2.5

Advert: these estimates use new estimates for acceptance and resolution of forward detectors.

Acceptance of various pot combinations

M = invariant mass of central system

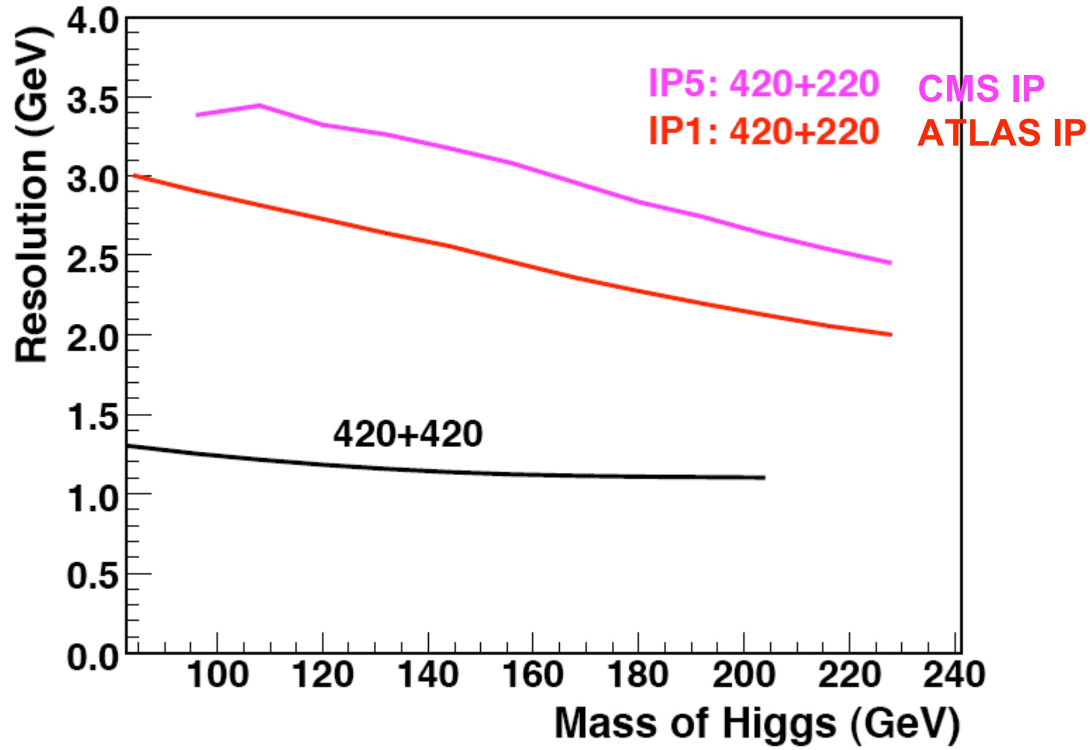




FPTRACK: P.J. Bussey & W. Plano

M. Grothe: ICHEP06

Mass resolution:

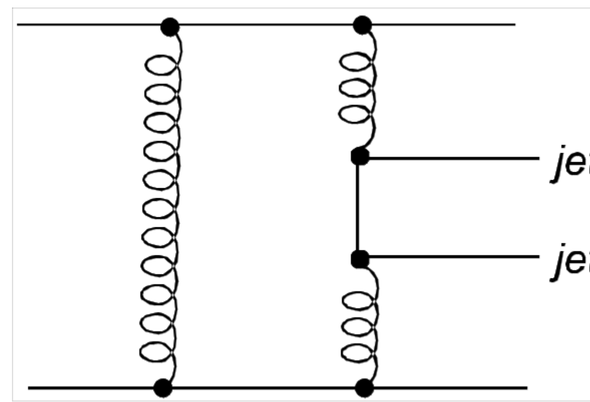


Glasgow-Manchester

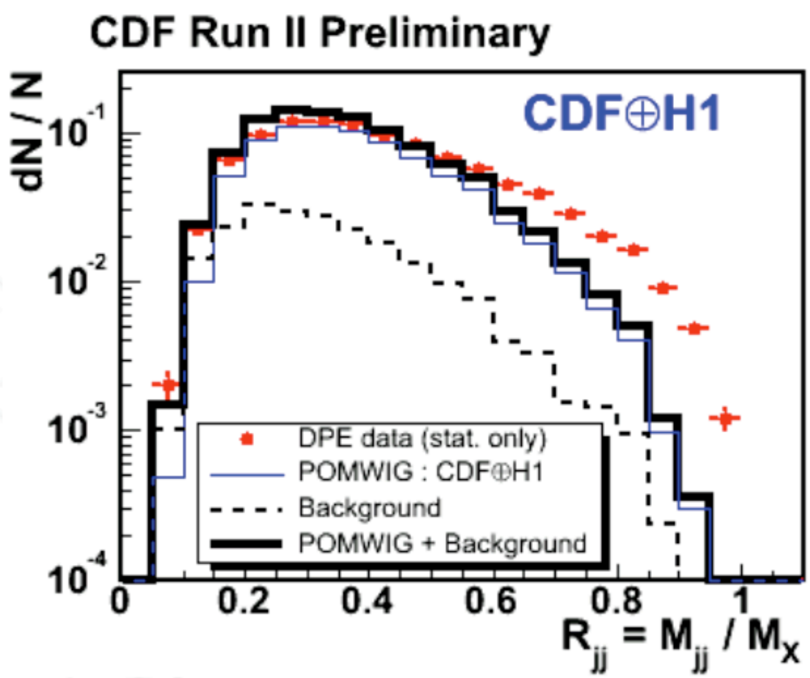
Role of the Tevatron

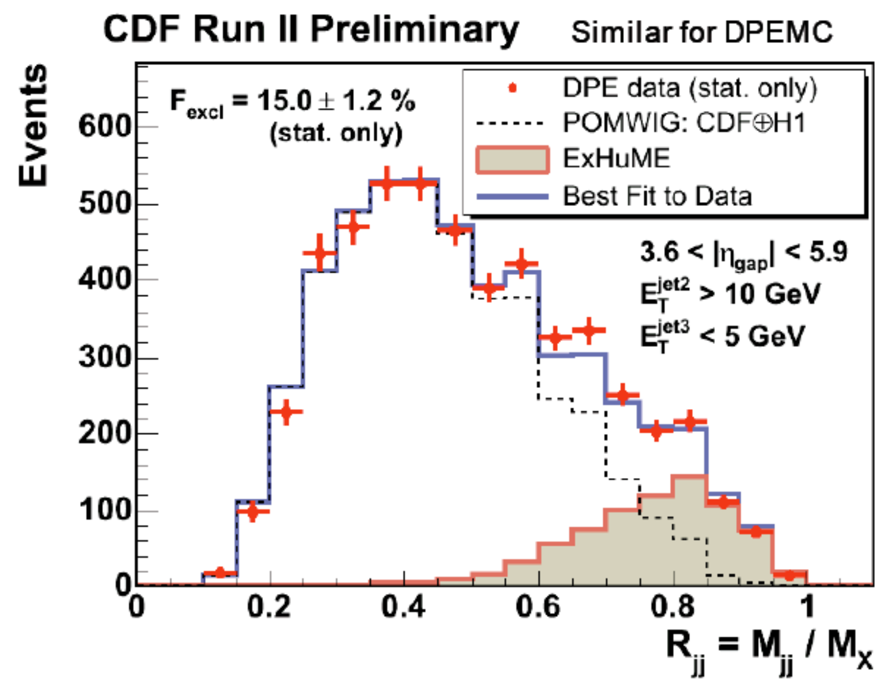
Central dijet production can be used to test the theory :

$$pp \to p + \text{jet} + \text{jet} + p$$



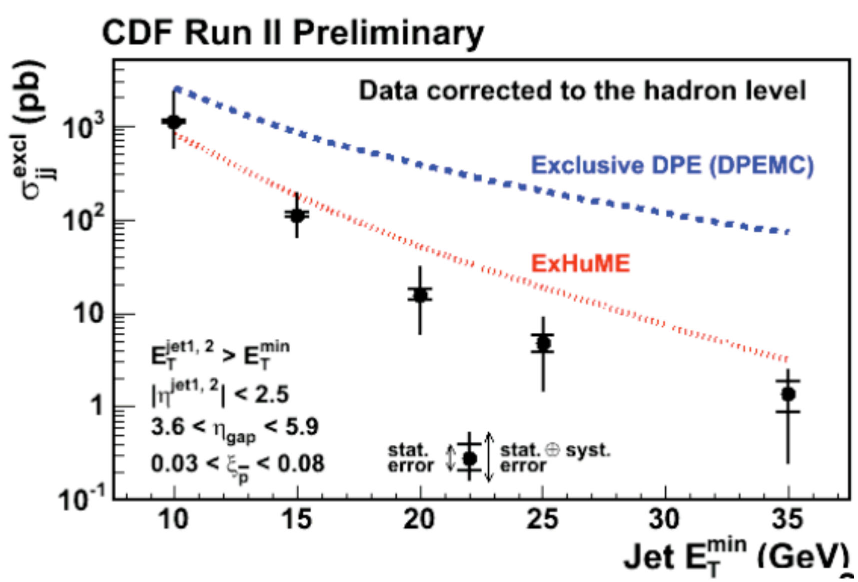
$R_{jj} = M_{jj}/M_X =$ fraction of central mass in the dijets





POMWIG (Cox & JRF) simulates INCLUSIVE production, i.e. p+jj+X+p, central systems and its parameters are fixed by the HERA data on diffractive deep inelastic scattering.

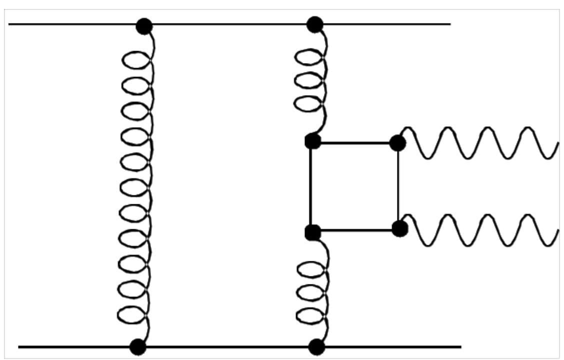
CDF also sees a suppression of quark jets in the "exclusive" region in accord with the expectations of ExHuME.

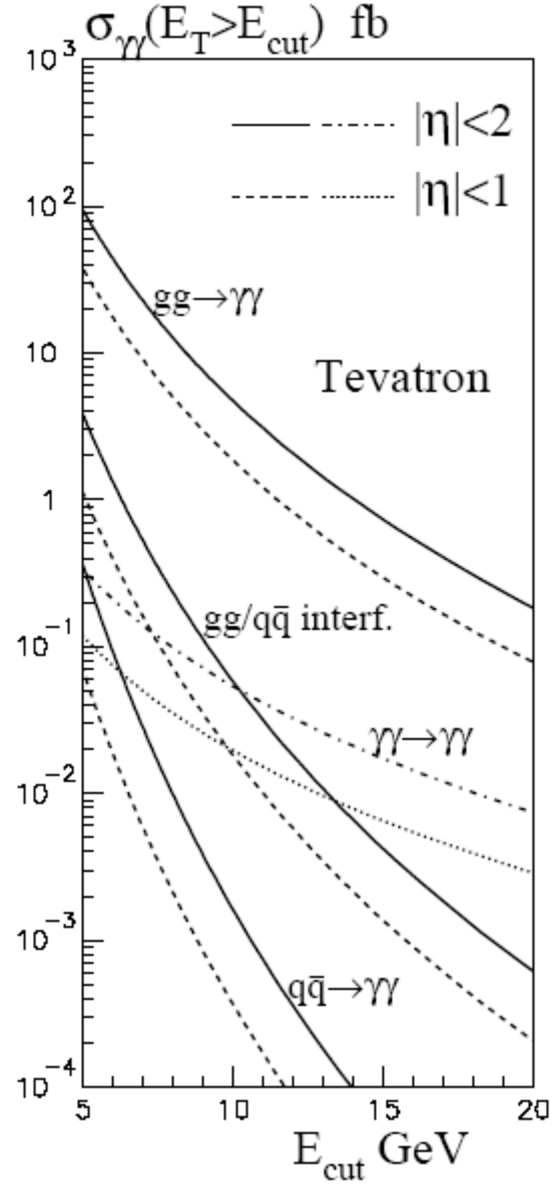


A “standard candle” at the Tevatron

$$p\bar{p} \to p + \gamma\gamma + \bar{p}$$

Analysis underway on CDF:
3 events seen and expect 1



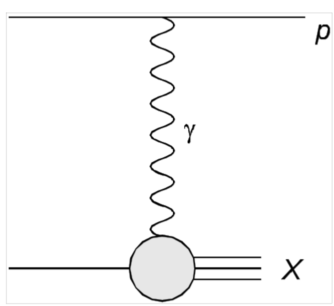


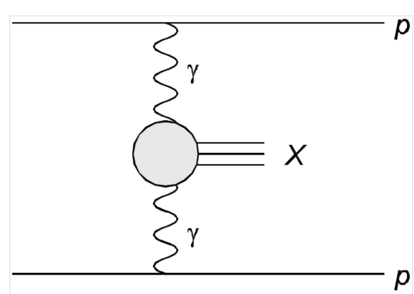
Khoze, Martin, Ryskin, Stirling

$[\ p\bar{p} \to p + \chi_c + \bar{p}\ ]$

Other possibilities with forward proton detection

- QCD and diffractive physics
- High energy photon-proton and photon-photon physics
    - $\gamma\gamma WW$ quartic coupling 10000 better the LEPII.
    - Photoproduction of sparticles (~ HERA)
    - Gamma-gamma mode (~ Photon collider)
    - Luminosity measurement at LHC: $pp \to p + l^{+} + l^{-} + p$





FP420

- International collaboration ~32 institutions from 11 countries

- “*The LHCC acknowledges the scientific merit of the FP420 physics program and the interest in its exploring its feasibility*.”

CERN-LHCC-2005-025
LHCC-I-015

FP420 : An R&D Proposal to Investigate the Feasibility of Installing Proton Tagging Detectors in the 420m Region at LHC

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1. FNAL
2. The University of Manchester
3. University of Eastern Piedmont, Novara and INFN-Turin
4. The Cockcroft Institute
5. University of Antwerpen
6. University of Texas at Arlington
7. The University of Glasgow
8. University of Calabria and INFN-Cosenza
9. Bristol University
10. Brunel University
11. CERN
12. Lawrence Livermore National Laboratory
13. University of Turin and INFN-Turin
14. University of Lund
15. Rutherford Appleton Laboratory
16. Molecular Biology Consortium
17. Institute for Particle Physics Phenomenology, Durham University
18. DESY
19. Helsinki Institute of Physics and University of Helsinki
20. UC Louvain
21. University of Hawaii
22. LAL Orsay
23. University of Alberta
24. Stony Brook University
25. Boston University
26. UCLA
27. University of Nebraska
28. Institute of Physics, Academy of Sciences of the Czech Republic
29. Brookhaven National Laboratory

Now also UCL, MSSL and Cambridge

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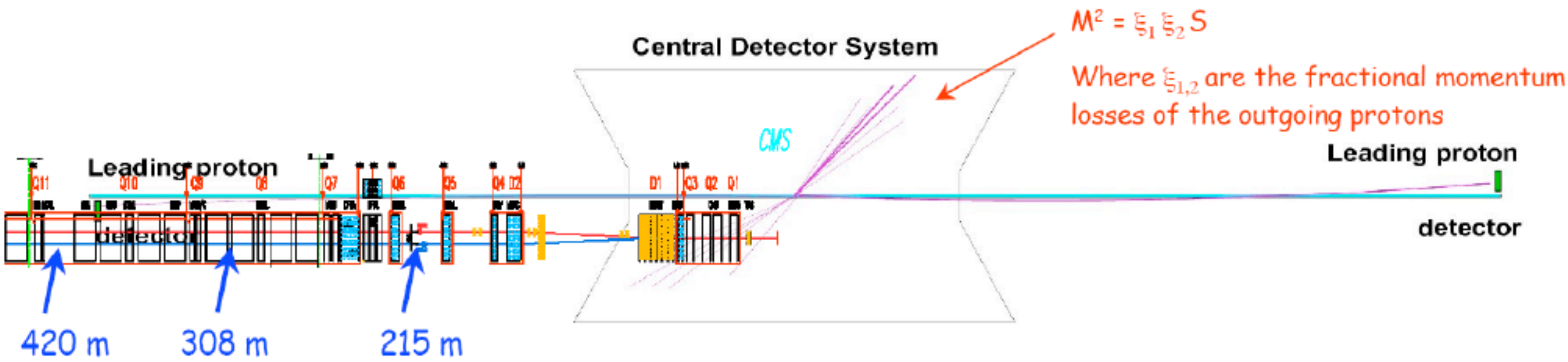

•Moving detectors into beam: Helsinki, Louvain, Turin

•Integrating into the cold region: CERN, Cockcroft Institute, Turin

•3D edgeless silicon detectors: Manchester & Stanford

•Silicon detector stations: Manchester & Mullard SSI

•Fast timing detectors: U Texas Arlington (QUARTIC) & UC Louvain (GASTOF)
aim to beat down pile up backgrounds (z vertex res < 3mm)

•220m at ATLAS: Saclay, Prague, Cracow, Stony Brook

•220m at CMS: TOTEM but high lumi programme unclear (rad hard detectors needed)

Summary

- Central production of new physics is a real and very exciting possibility for the LHC
- It may be the best/only way to examine some physics
- Theory predictions known to an accuracy ~ x 3
- Good progress on simulation/study of backgrounds (ExHuME)
- Can learn already from Tevatron data – measurements will reduce theoretical uncertainty for LHC
- Experimental collaboration: FP420 TDR to ATLAS & CMS in Aug 2007 (LHCC later). Installation could take place during 1st major shutdown