The FP420 R&D Project

Motivation from KMR calculations (e.g. hep-ph 0111078)

• Selection rules mean that central system is (to a good approx) $0^{++}$
• If you see a new particle produced exclusively with proton tags you know its quantum numbers
• CP violation in the Higgs sector shows up directly as azimuthal asymmetries
• Proton tagging may be the discovery channel in certain regions of the MSSM
• Tagging the protons means excellent mass resolution ($\sim$ GeV) irrespective of the decay products of the central system

“The panel believed that this offers a unique opportunity to extend the potential of the LHC and has the potential to give a high scientific return.” - UK PPRP (PPARC)

R&D now fully funded: £500k from UK (Silicon, detector stations, beam pipe + LHC optics and cryostat design), $100k from US (QUARTIC), €100k Belgium (+Italy / Finland) (mechanics)
FP420 Schematic Outline

Spectrometer using LHC magnets to bend protons with small momentum loss out of the beam

$M \sim 30 \text{ GeV}$

$M \sim 200 \text{ GeV}$

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

$M^2 = \xi_1 \xi_2 S$
The 420m region at the LHC

Central Detector System

$M^2 = \varepsilon_1 \varepsilon_2 S$

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

<table>
<thead>
<tr>
<th>Line</th>
<th>T(K)</th>
<th>$\bar{\phi}_1 - \bar{\phi}_6$(mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1, M2, M3 Bus-bars</td>
<td>1.9</td>
<td>80-84</td>
</tr>
<tr>
<td>N Auxiliary bus-bars</td>
<td>1.9</td>
<td>50-53</td>
</tr>
<tr>
<td>X Heat exchanger</td>
<td>1.8</td>
<td>54-58</td>
</tr>
<tr>
<td>E Thermal shield</td>
<td>50-65</td>
<td>79-86</td>
</tr>
<tr>
<td>C Supports posts and beam screens</td>
<td>4.6</td>
<td>15-17.2</td>
</tr>
<tr>
<td>V1, V2 He jackets</td>
<td>1.9</td>
<td>50-53</td>
</tr>
</tbody>
</table>

420 m 308 m 215 m
DFB Arc Termination Modules

FP 420 Connection Cryostat Design
Keith Potter, Shrikant Pattalwar, Benoit Florin, Thierry Renaglia,
Thierry Colombet, Domenico Dattola
The FP420 Cryostat

FP 420 Connection Cryostat Design
Keith Potter, Shrikant Pattalwar, Benoit Florin, Thierry Renaglia, Thierry Colombet, Domenico Dattola
FP420 Tunnel Layout

FP420 detectors

FP 420 Connection Cryostat Design
Keith Potter, Shrikant Pattalwar, Benoit Florin, Thierry Renaglia, Thierry Colombet, Domenico Dattola
Movement Mechanism Designs

Louvain + INFN + Helsinki
FP420 Silicon Detector Stations

7.2 mm x 24mm (7.2 x 8 mm² sensors)

5 years at \(10^{35}\) cm\(^{-2}\) s\(^{-1}\)
FP420 Silicon Detector Stations

- Copper foil
- Carbon-carbon Frame
- 3D silicon + Readout chip
- Carbon-carbon Thined down to 0.5 mm
- Nominal Readout kaptions to control chip

Manchester / Mullard Space Science Lab
FP420 Silicon Detector Stations
• 1% events at LHC have diffractive proton track in FP420
• @ $2 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$, 7 interactions / bunch crossing
• -> 30% of FP420 events have an additional track
• Matching mass and rapidity of central system removes large fraction of these
• Of the remaining, 97.4% rejected by fast timing detectors with 10ps timing resolution (2.1 mm)
• Preliminary studies give $\sigma(\text{overlap}) = \sigma(\text{signal})$ for Higgs -> bb channel @ $2 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$.
FP420 Acceptance and Resolution

Glasgow / Manchester

Plots: P. Bussey using ExHuME / FPTrack

MB apertures
The intense coupling regime is where the masses of the 3 neutral Higgs bosons are close to each other and $\tan \beta$ is large.

$\gamma\gamma, WW^*, ZZ^*$ suppressed

$gg \rightarrow \phi$ enhanced

0+ selection rule suppresses $A$ production:

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

$M_A = 130$ GeV, $\tan \beta = 50$

$M_h = 124$ GeV: 71 signal / 10 background in 30 fb$^{-1}$

$M_H = 135$ GeV: 124 signal / 5 background in 30 fb$^{-1}$

$M_A = 130$ GeV: 1 signal / 5 background in 30 fb$^{-1}$

Well known difficult region for conventional channels, tagged channel may well be the discovery channel, and is certainly a powerful spin/parity filter.
This example shows that exclusive double diffraction may offer unique possibilities for exploring Higgs physics in ways that would be difficult or even impossible in inclusive Higgs production. In particular, we have shown that exclusive double diffraction constitutes an efficient CP and lineshape analyzer of the resonant Higgs-boson dynamics in multi-Higgs models. In the specific case of CP-violating MSSM Higgs physics discussed here, which is potentially of great importance for electroweak baryogenesis, diffractive production may be the most promising probe at the LHC.

J. Ellis et al hep-ph/0502251
• @ $1 \times 10^{33}$ cm$^{-2}$ s$^{-1}$ expect ~ 100 $\mu^+\mu^-$ events / fill with standard trigger thresholds

• Simulations (Louvain) indicate precision is better than necessary (theoretical limit is LHC beam energy uncertainty, $\sigma_0 = 0.77$ GeV $\sim$ 50 microns)

(also $\gamma\gamma$WW, $M_{\gamma\gamma} > 200$ GeV, $\sigma \sim 100$ fb -> very high sensitivity to anomalous quartic couplings)
The KMR Calculation of the Exclusive Process

\[ qg \rightarrow q + H + q \]

\[ q \rightarrow \text{Proton} \]

\[ \frac{d\sigma}{dy} = \frac{1}{2 \pi b^2} \frac{\alpha_s^2 G_F}{2} \left[ \frac{d^2 q_L}{q_L^2} \frac{f(x, q_L^2)}{q_L^2} \right]^2 \]

Dominant uncertainty: KMR estimate factor of 2-3.

Divergent: controlled by Sudakov

Power of \( Q_T \), 6 for pseudo-scalar

Jeff Forshaw, this workshop
Evidence for Exclusive Production

$10 \text{ GeV} < M_{\gamma\gamma} < 20 \text{ GeV}$

**Exclusive $e^+e^-$ pairs**

- 16 events observed

  - Estimated background = $2.1_{-0.3}^{+0.6}$
  - (mostly p-dissociation)
  - $\sigma_{\text{MEAS.}} = 1.6_{-0.3}^{+0.5}$ (stat) ± 0.3 (syst) pb
  - Poisson Prob. = $3 \times 10^{-8} \approx 5.5\sigma$

  - QED: LPAIR Monte Carlo
  - $\sigma_{\text{QED}} = (1.711 \pm 0.008) \text{ pb}$

**Exclusive $\gamma\gamma$ pairs**

- 3 events observed

  - Estimated background = $0.0_{-0.0}^{+0.3}$ events
  - (p-dissociation, exclusivity, fakes)
  - $\sigma_{\text{MEAS.}} = 0.14_{-0.04}^{+0.14}$ (stat) ± 0.03 (syst) pb
  - Poisson Prob. $(0.3 \rightarrow \geq 3) = 3.6 \times 10^{-3}$
    (conservative)
  - KMR (Durham) prediction = $0.04 \times + (3-5) \text{ pb}$

  - Note: $\sigma_{\text{MEAS.}} \approx 2 \times 10^{-12} \sigma_{\text{INEL}}$

  - It means exclusive H must happen (if H exists) and probably $\sigma \sim 10 \text{ fb}$ within factor $\sim 2.5$.
  - $\sigma$ higher in MSSM

Mike Albrow

Exclusive Diffractive Higgs

US-CMS Lincoln April 2006
Evidence for Exclusive Production

$J_z=0 \rightarrow$ for colour singlet bbar production, the born level contributions of a) and b) cancel in the limit $m_b \rightarrow 0$.
• We have built a strong international collaboration with the manpower and expertise to deliver forward proton tagging at high luminosity to the LHC

• FP420 adds real discovery potential to ATLAS / CMS.

• 12 month R&D study fully funded from UK, US and Belgium (~1000K CHF)

• Funding bids and significant manpower from Italy, Germany, Finland, Canada

• Agreed list of key R&D areas (with CERN) to address machine safety issues and physics goals.

• Technical design by Feb 2007 (Manchester 2006) and (if successful) TDRs to LHCC from ATLAS / CMS spring 2007.

• Physics returns potentially huge
• Trigger latency does not allow for 420m detectors to be included in L1 at ATLAS or CMS in standard running mode

• Problem for low-mass Higgs -> bb jets

• @ $1 \times 10^{32}$, no pile-up, isolation criteria allows L1 di-jet trigger
  (rate 2.6 KHz 2 jets $E_T > 40$ GeV reduced to < 1 KHz with isolation + topological cuts)

• @ $2 \times 10^{33}$, 7 pile-up events, tag at 220m + topological cuts OK

• @ $10^{34}$ require increase in trigger latency from 3.2 -> 4 $\mu s$ (SLHC ~ 6.4 $\mu s$)

• up to 20% bb events can be saved with $\mu$ triggers at all luminosities

• All other channels, e.g. WW(*), fine.
The benchmark: Standard Model Higgs Production

The benchmark: Standard Model Higgs Production

**Standard Model Higgs**

- **WW**: 
  - $M_H = 120$ GeV $\sigma = 0.4$ fb 
  - $M_H = 140$ GeV $\sigma = 1$ fb 
  - $M_H = 200$ GeV $\sigma = 0.5$ fb 

  $M_H = 140$ GeV : 5 (10) signal (1 (2) “gold platted” dl), negligible background in 30 fb$^{-1}$

- **b jets**: 
  - $M_H = 120$ GeV $\sigma = 2$ fb 
  - $M_H = 140$ GeV $\sigma = 0.7$ fb 

  $M_H = 120$ GeV : 11 signal, S/B $\sim$ 1 in 30 fb$^{-1}$

**QCD Background**

$QCD \sim \frac{m_b^2}{E_T^2} \frac{\alpha_S^2}{M_{bb}^2 E_T^2}$

**Selection rule**

$S/B \propto \frac{\Gamma(H \rightarrow gg)}{\Delta M} \propto G_F M_H^3 / \Delta M$

- The b jet channel is possible, with a good understanding of detectors and clever level 1 trigger
- The WW$^*$ channel is extremely promising: no trigger problems, better mass resolution at higher masses (even in leptonic/semi-leptonic channel)
- If we see Higgs + tags - the quantum numbers are 0++

Probing CP violation in the Higgs Sector

Azimuthal asymmetry in tagged protons provides direct evidence for CP violation in Higgs sector

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

<table>
<thead>
<tr>
<th>$M(H_1)$ GeV</th>
<th>cuts</th>
<th>30</th>
<th>40</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma(H_1)\text{Br}(\tau\tau)$</td>
<td>$a, b$</td>
<td>1.9</td>
<td>0.6</td>
<td>0.3</td>
</tr>
<tr>
<td>$\sigma_{\text{QED}}(\tau\tau)$</td>
<td>$a, b$</td>
<td>0.2</td>
<td>0.1</td>
<td>0.04</td>
</tr>
<tr>
<td>$A_{\tau\tau}$</td>
<td>$b$</td>
<td>0.2</td>
<td>0.1</td>
<td>0.05</td>
</tr>
</tbody>
</table>

(b) $p_t^+ > 300$ MeV for the forward outgoing protons

\[ \mathcal{M} = g_S \cdot (e_1^+ \cdot e_2^+) - g_P \cdot \epsilon^{\mu\nu\alpha\beta} e_{1\mu} e_{2\nu} P_{1\alpha} P_{2\beta}/(p_1 \cdot p_2) \]

Ongoing work - are there regions of MSSM parameter space where there are large CP violating couplings AND enhanced gluon couplings?

Evidence for Exclusive Production

5 \mu m will be possible - test bench under construction at CERN

Helene Mainaud-Durand, CERN
FP420 Collaboration

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


1. FNAL
2. The University of Manchester
3. University of Eastern Piedmont, Novara and INFN-Turin
4. The Cockcroft Institute
5. University of Antwerp
6. University of Texas at Arlington
7. The University of Glasgow
8. The University of Calabria and INFN
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. DESY
18. Institute for Particle Physics Phenomenology, Durham University
19. Helsinki Institute of Physics and University of Helsinki
20. University of Hawaii
21. University of Alberta
22. LAL Orsay
23. UC Louvain
24. Boston University
25. University of Nebraska
26. Institute of Physics, Academy of Sciences of the Czech Republic
27. Stony Brook University

Contacts:

Brian.cox@cern.ch (ATLAS)
Albert.deroeck@cern.ch (CMS)