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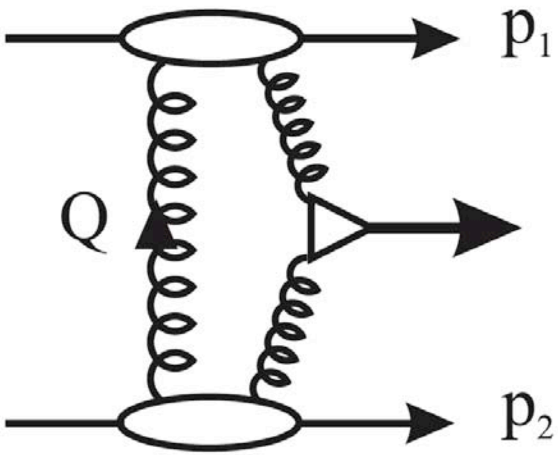
The FP420 R&D Project



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 (~ 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)

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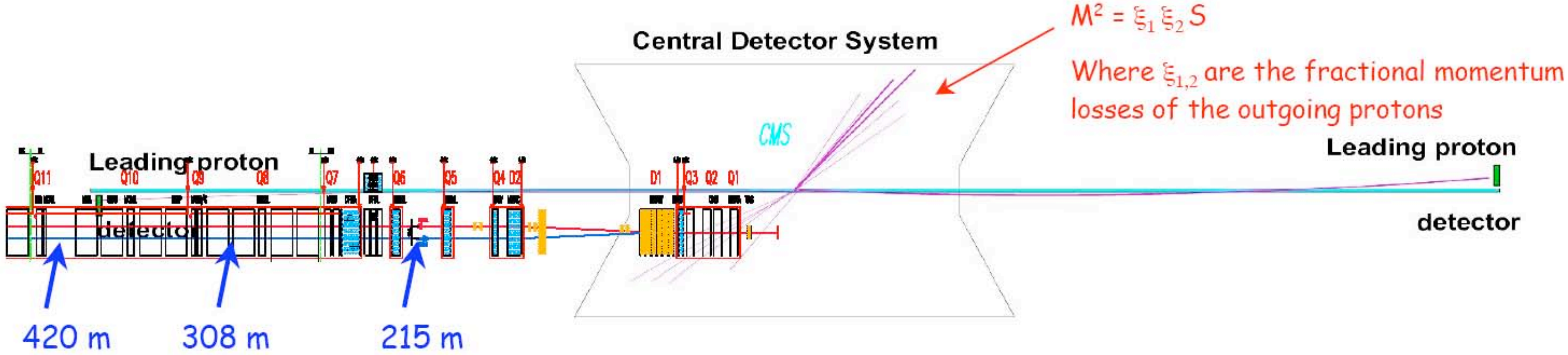
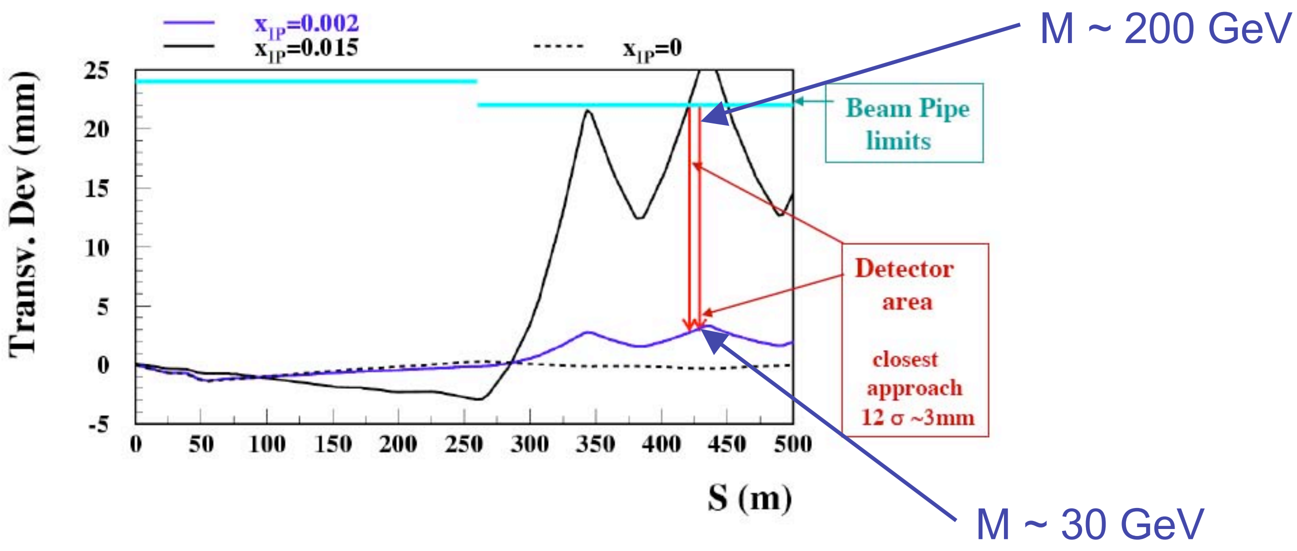
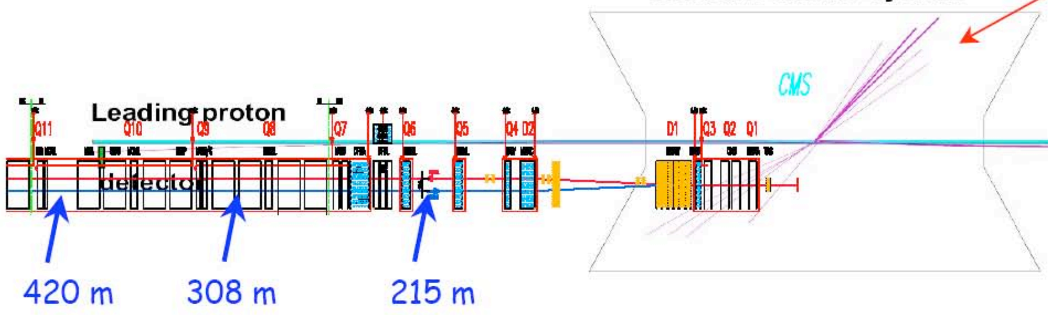
FP420 Schematic Outline

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



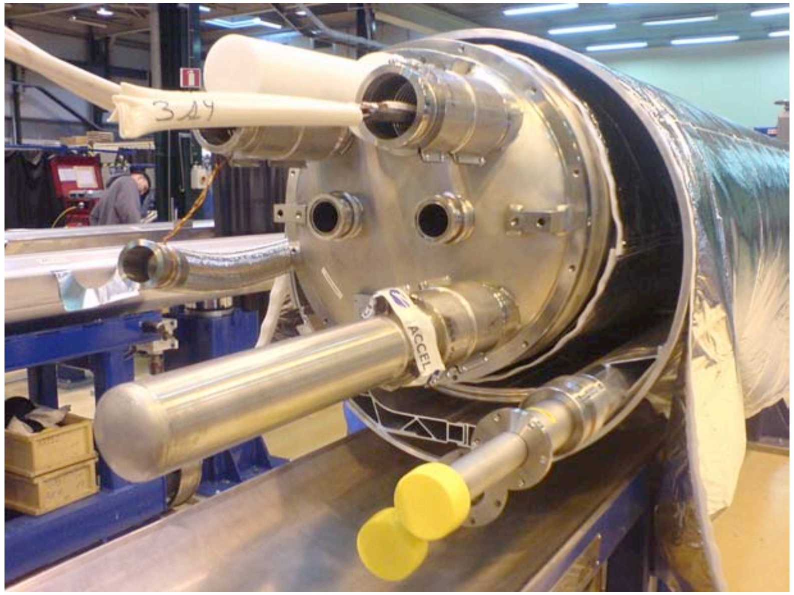


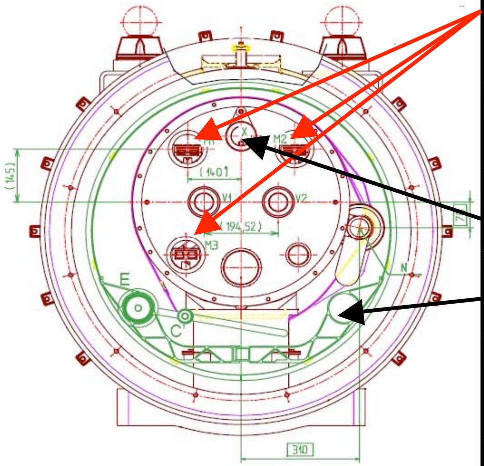
The 420m region at the LHC



$M^2 = \xi_1 \xi_2 S$

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





Line	T(K)	$Ø_i - Ø_e$(mm)
M1,M2,M3 Bus-bars	1.9	80-84
N Auxiliary bus-bars	1.9	50-53
X Heat exchanger	1.8	54-58
E Thermal shield	50-65	79-86
C' Supports posts and beam screens	4.6	15-17.2
V1,V2 He jackets	1.9	50-53 66-70

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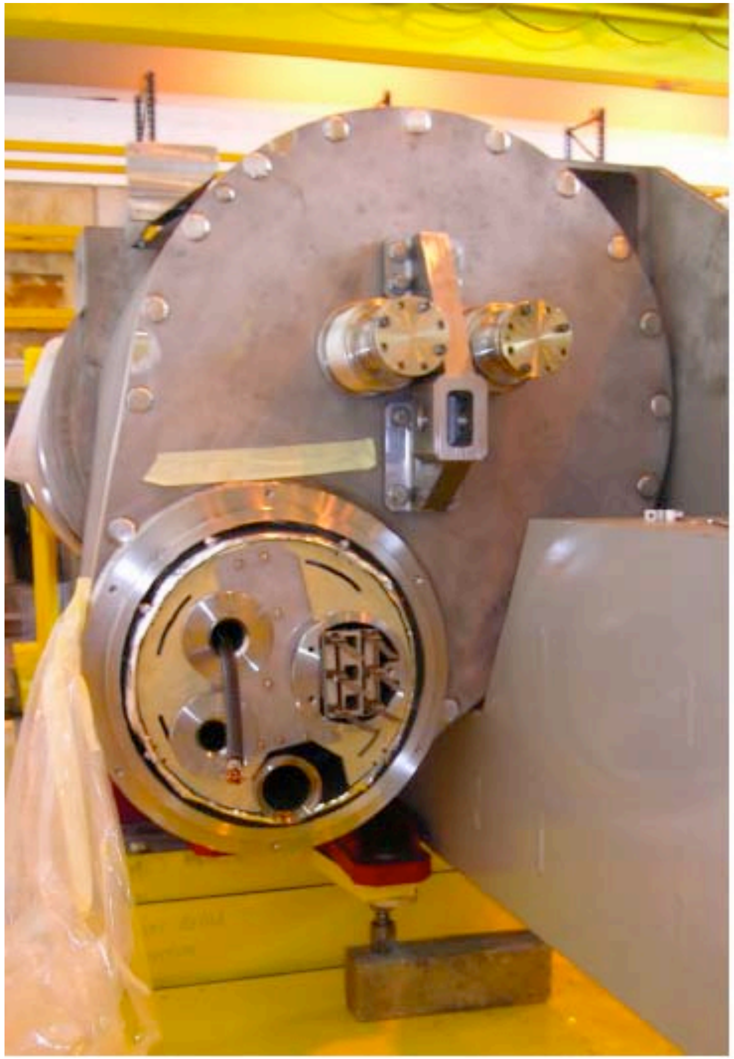
DFB Arc Termination Modules



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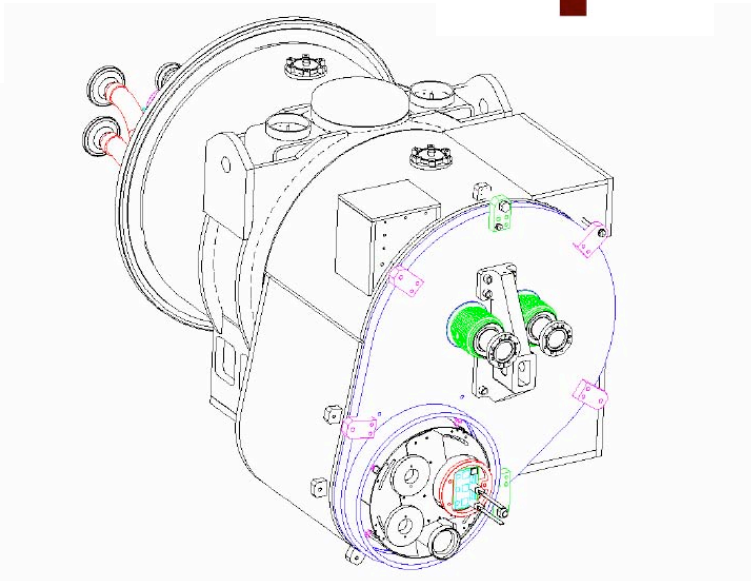
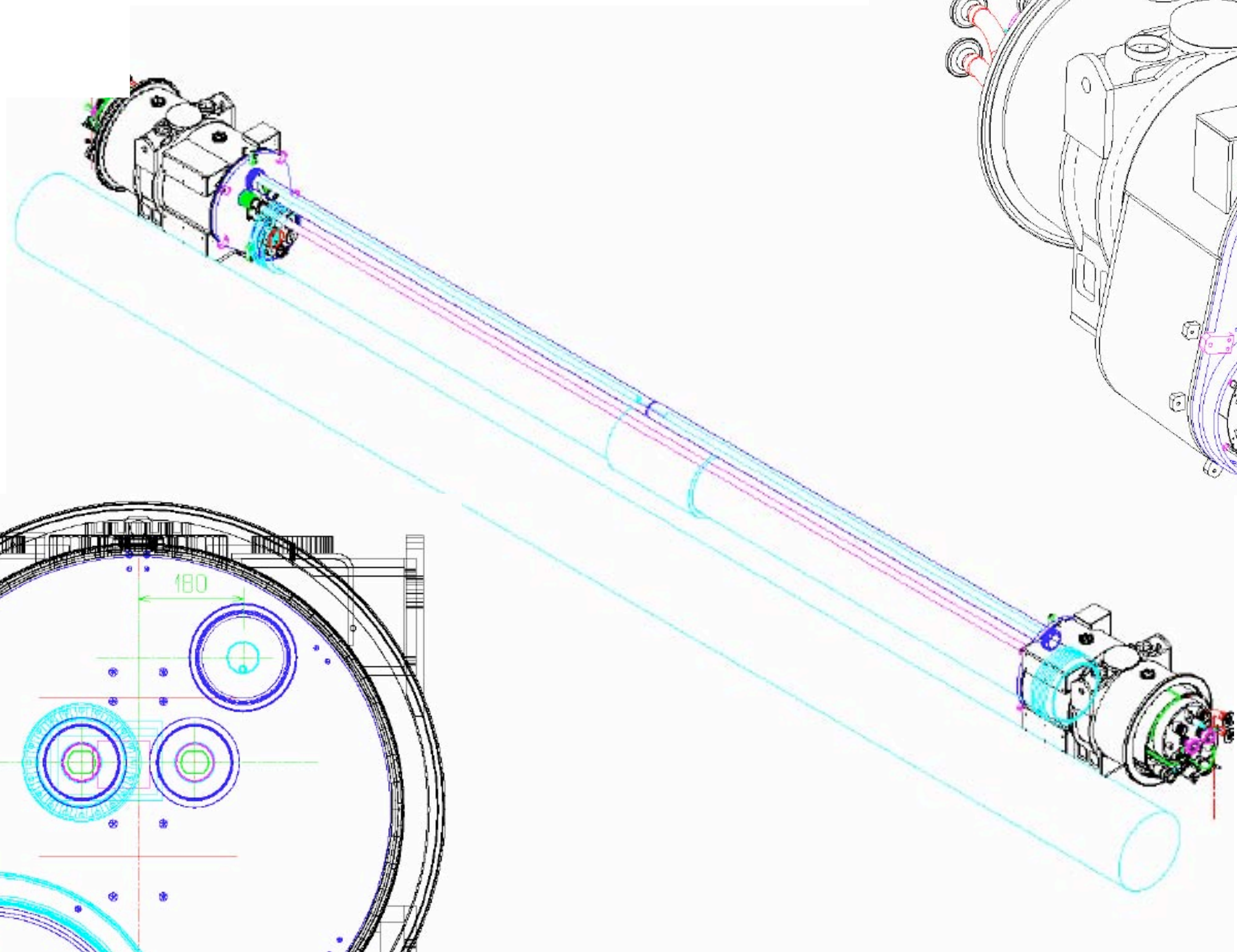
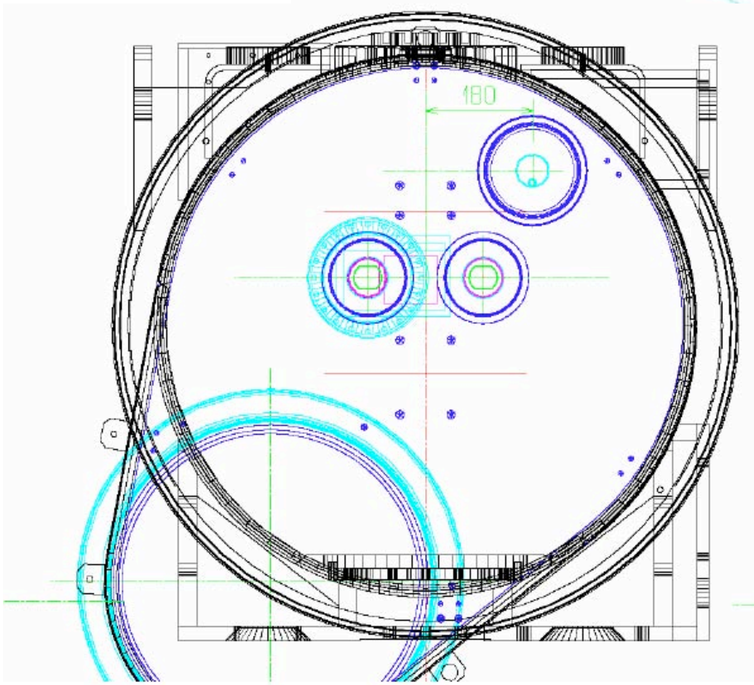
Cockcroft Institute / CERN / INFN

The FP420 Cryostat







FP 420 Connection Cryostat Design

Keith Potter, Shrikant Pattalwar, Benoit Florin, Thierry Renaglia,
Thierry Colombet, Domenico Dattola

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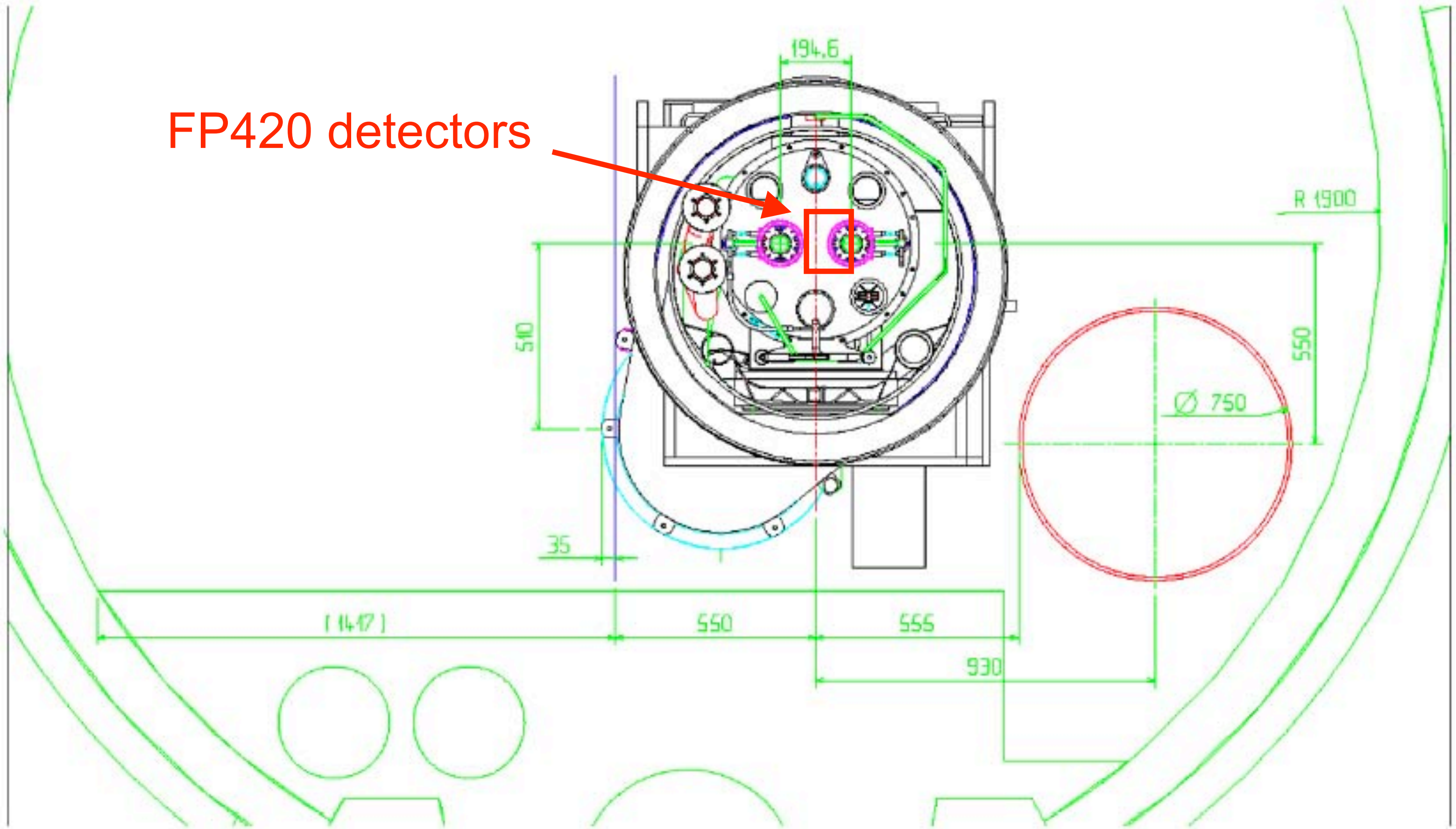
FP420 Tunnel Layout



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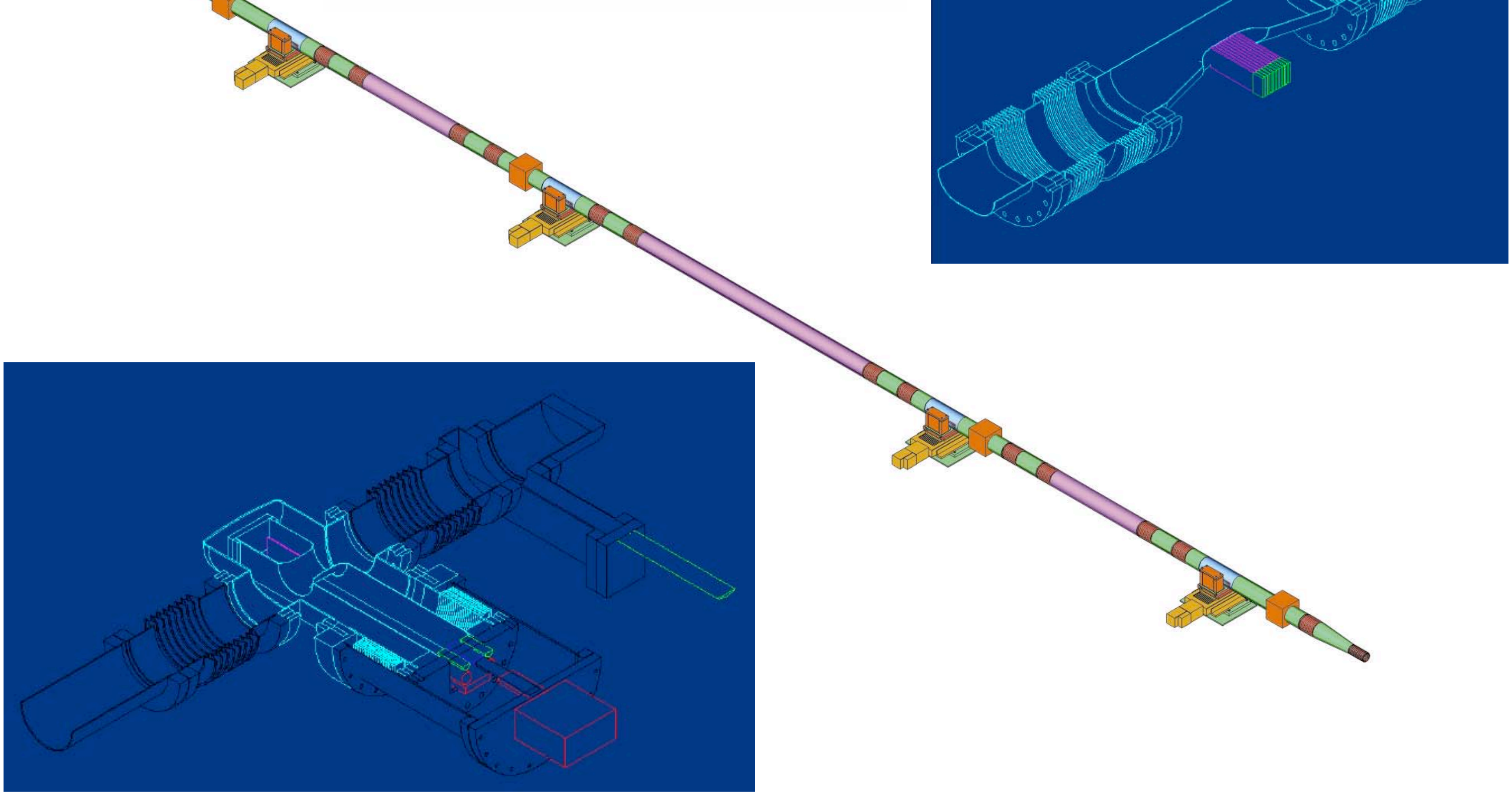
Louvain + INFN + Helsinki

Movement Mechanism Designs



Brunel / Stanford

FP420 Silicon Detector Stations

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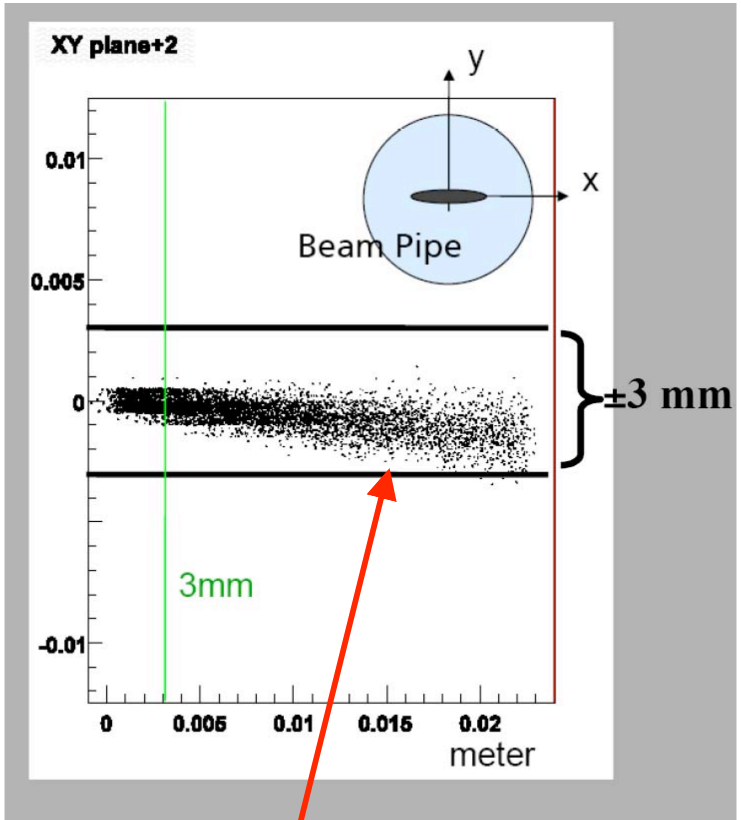
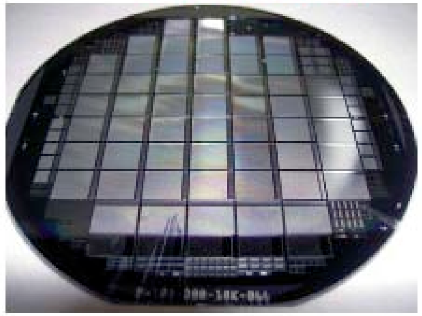
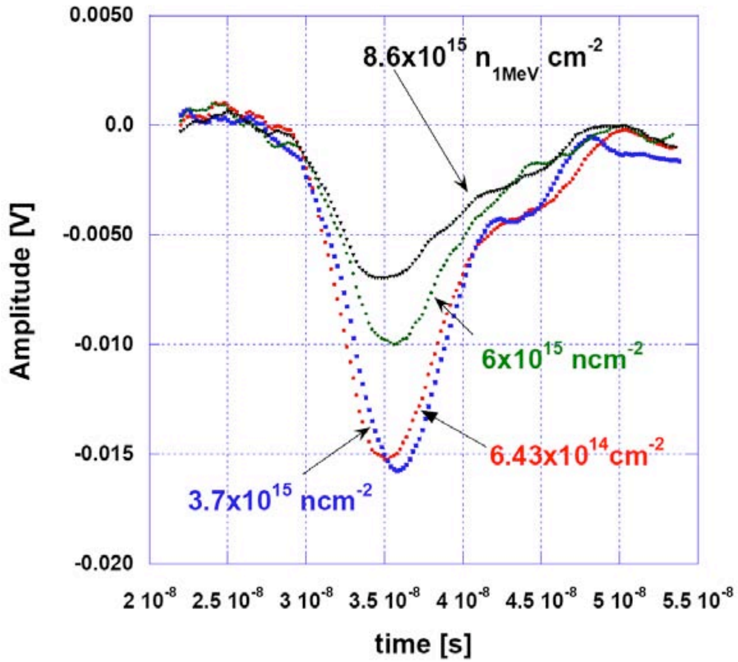


7.2 mm x 24mm (7.2 x 8 mm^2 sensors)

FP420 Mask

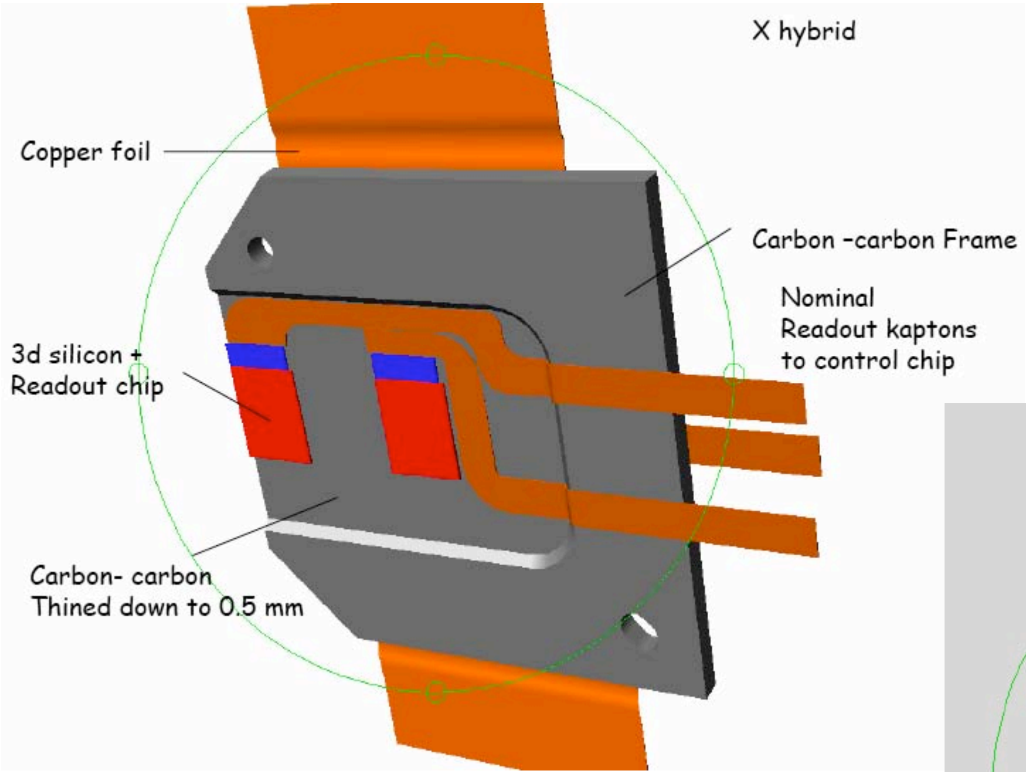


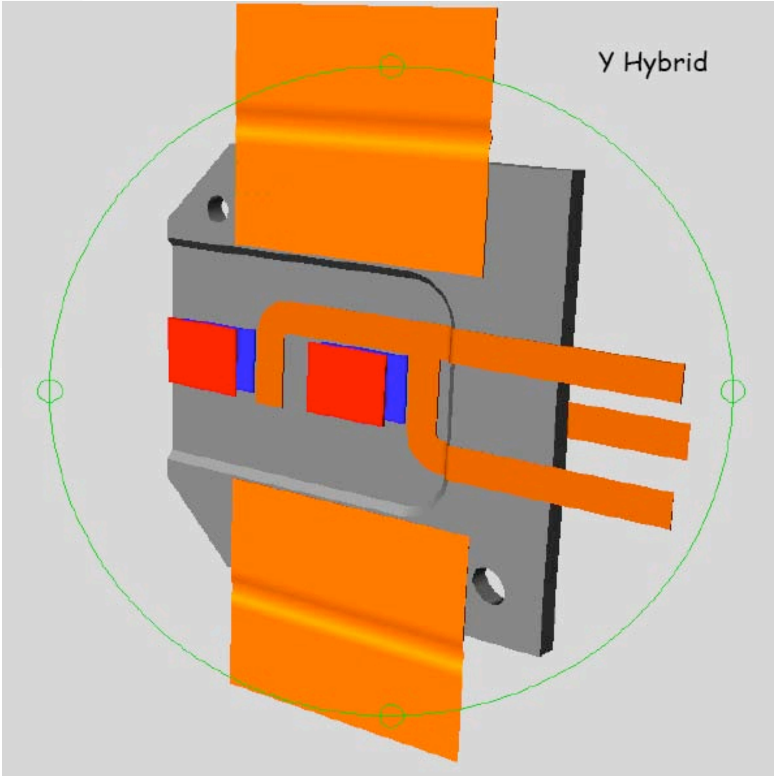


5 years at 10^{35} cm^{-2} s^{-1}

Manchester / Mullard Space Science Lab

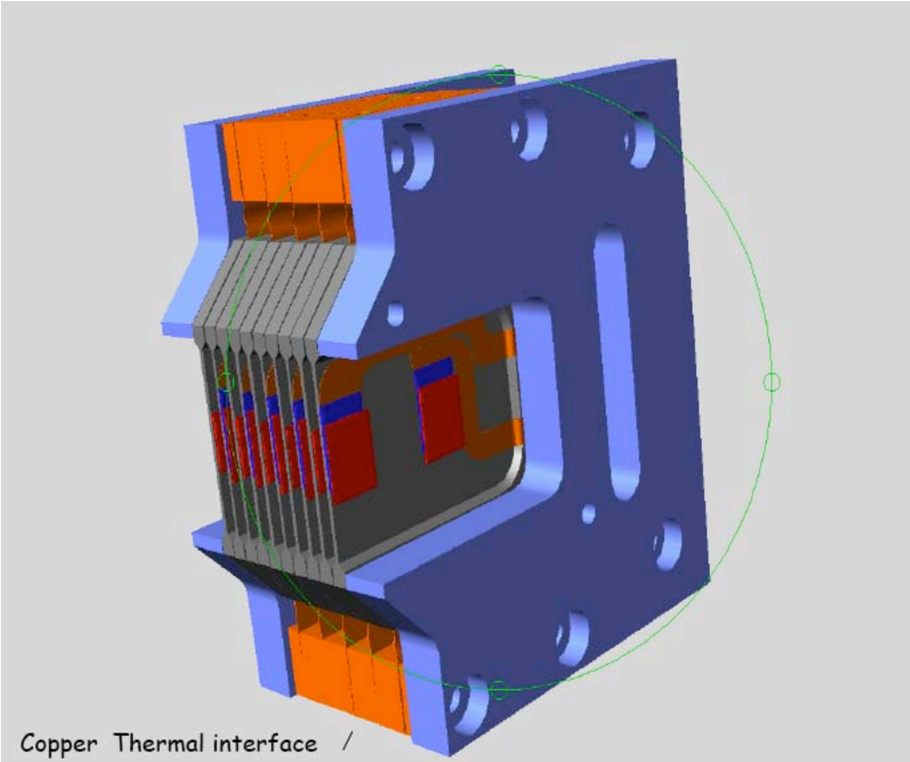
FP420 Silicon Detector Stations

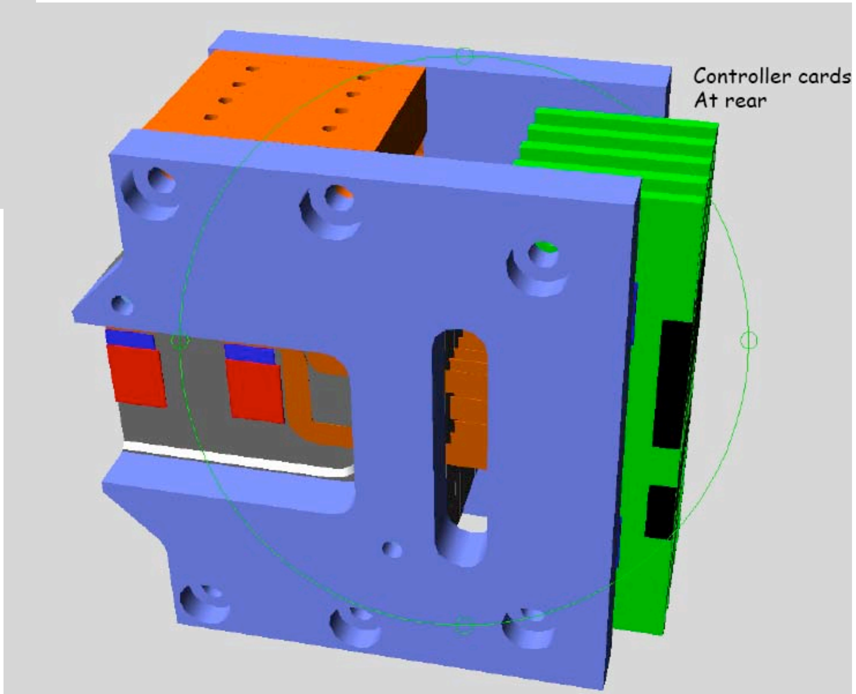




Manchester / Mullard Space Science Lab

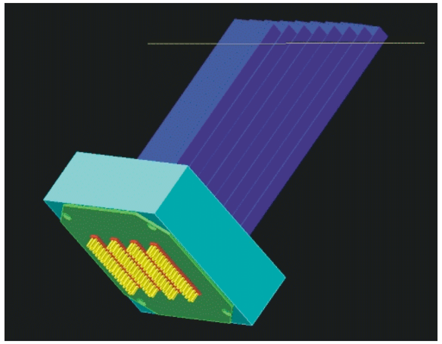
FP420 Silicon Detector Stations

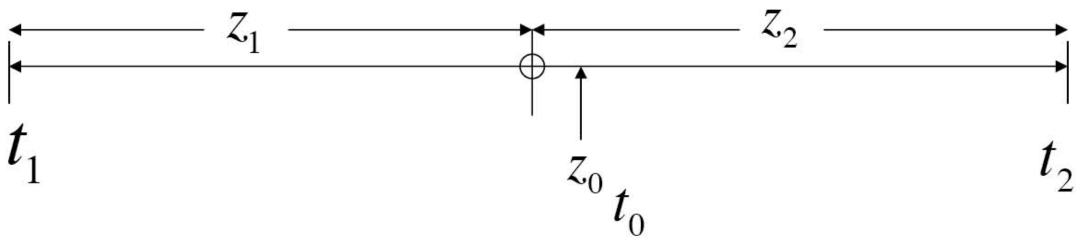




UTA / Alberta / FNAL / Louvain

FP420 Fast timing Detectors





$$t_1 - t_0 = \frac{c}{|z_1| + z_0}; \quad t_2 - t_0 = \frac{c}{|z_2| - z_0}$$

($|z_i|$ are distances but z_0 is signed)

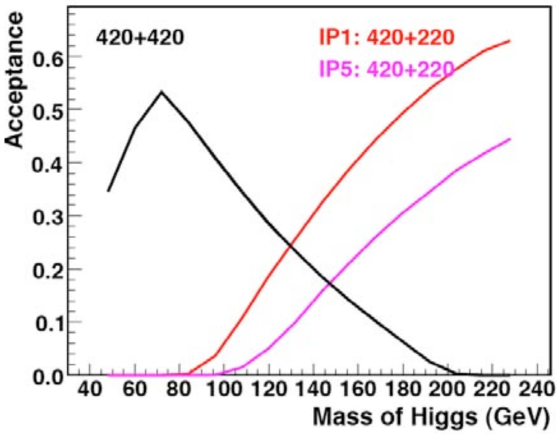
Stating the obvious, but → $z_0 = \left(\frac{c}{2}\right) \times \left(\frac{1}{t_1 - t_0} + \frac{1}{t_2 - t_0}\right)$

if $z_1 = z_2$

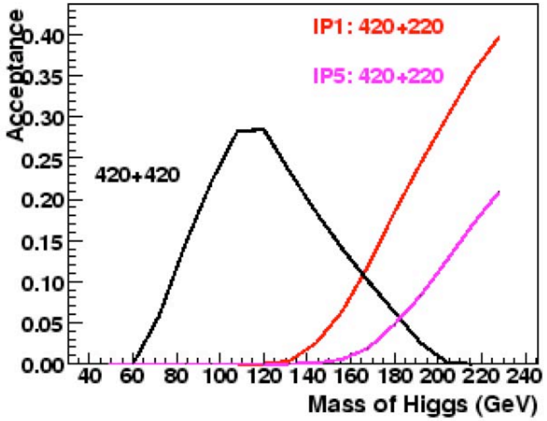
- 1% events at LHC have diffractive proton track in FP420
- @ 2 x 10^{33} $cm^{-2}s^{-1}$, 7 interactions / bunch crossing
- -> 30% of FP420 events have an additional track
- Matching mass and rapidity of central system removes large fraction of these
- Of the remaining, 97.4% rejected by fast timing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

Glasgow / Manchester

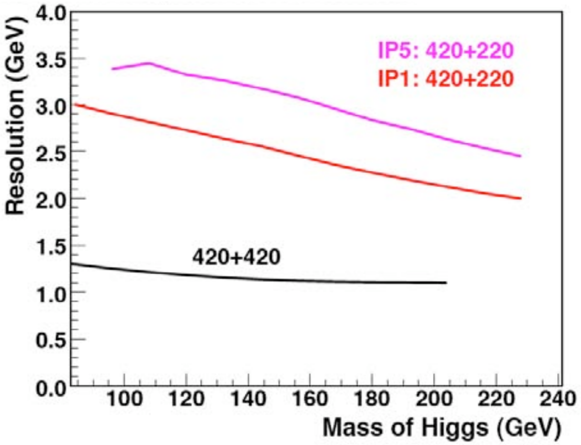
FP420 Acceptance and Resolution

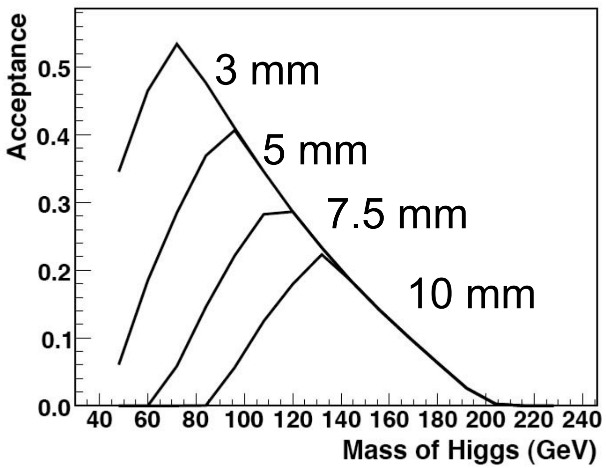


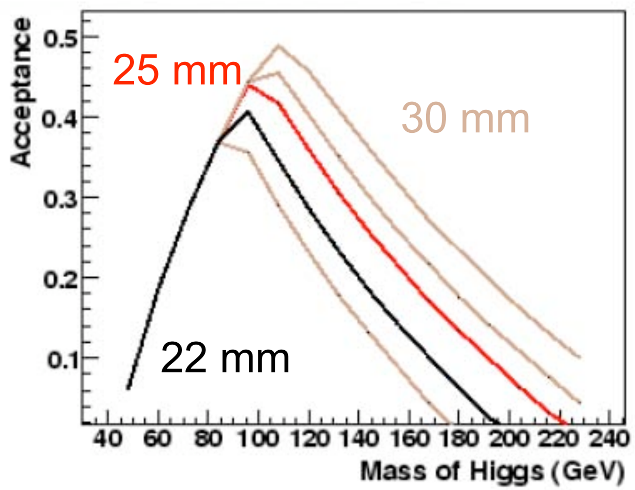
3 mm + 3 mm



7.5 mm + 3 mm







MB apertures

Plots : P. Bussey using ExHuME / FPTrack

FP420 Physics Highlights

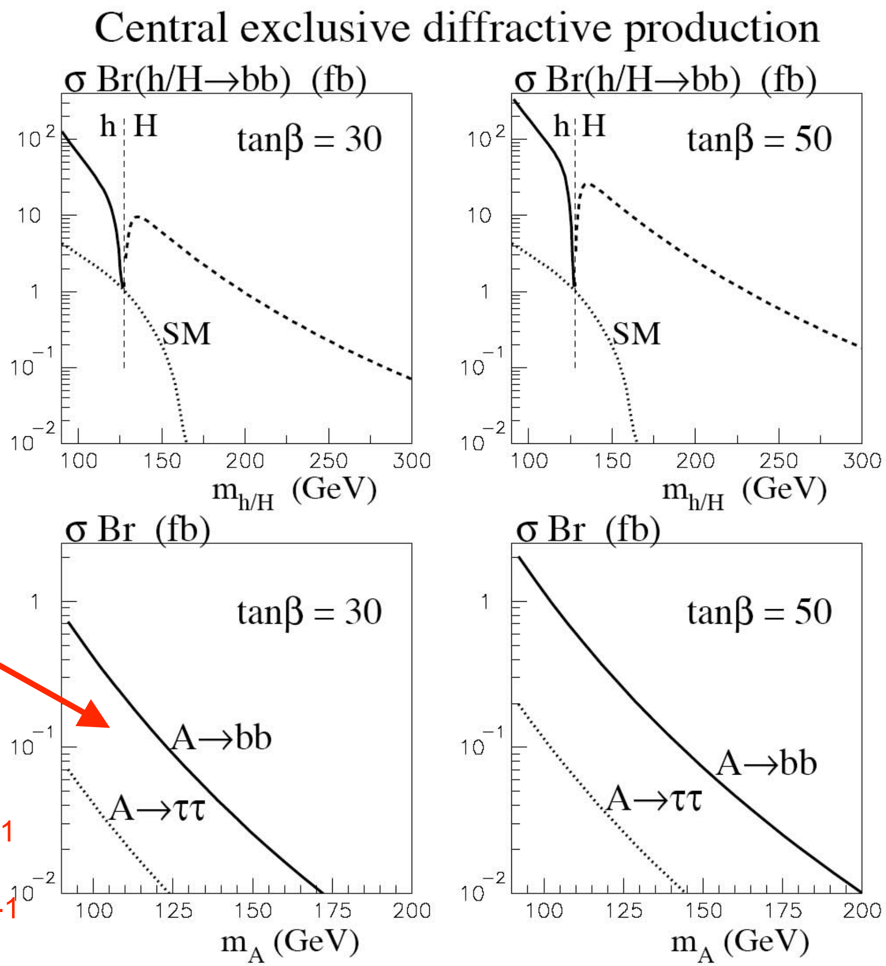
The intense coupling regime is where the masses of the 3 neutral Higgs bosons are close to each other and tan β is large

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

$gg \rightarrow \phi$ enhanced

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

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



M_A = 130 GeV, tan β = 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

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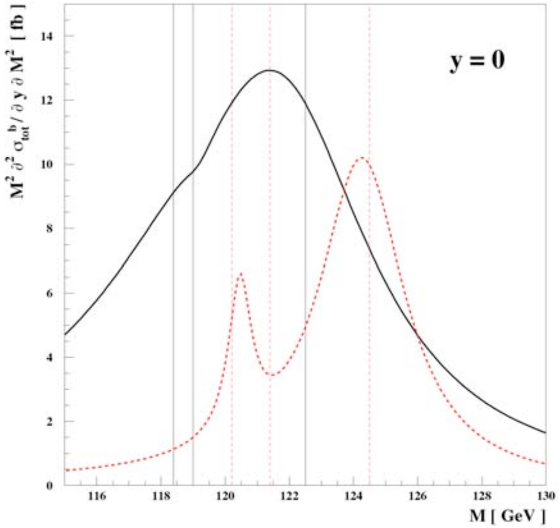
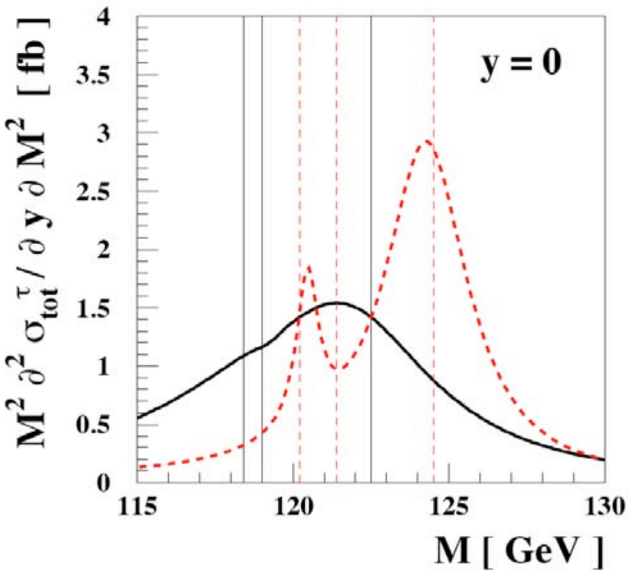
CP violation in the Higgs Sector

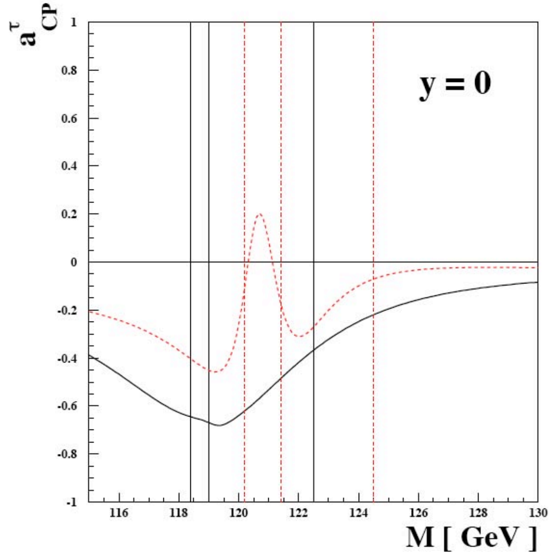
bb decay



ττ decay



ττ decay

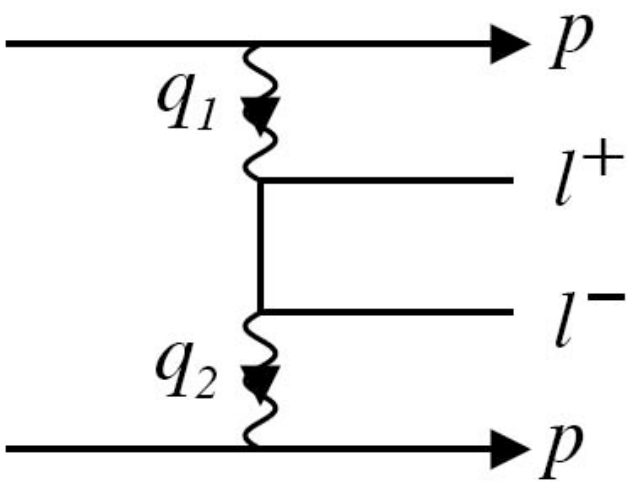


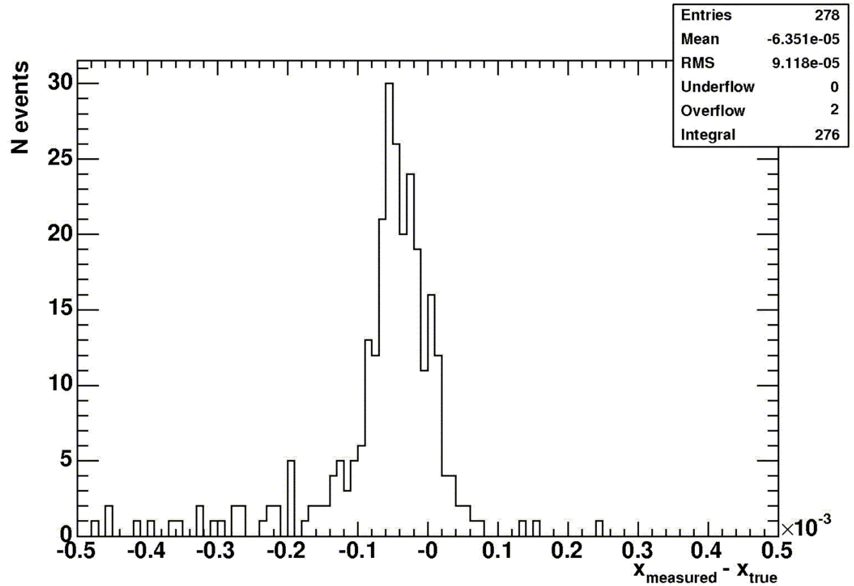
This example shows that exclusive double diffraction may offer unique possibilities for exploring Higgs physics in ways that would be difficult or even impossible in inclusive Higgs production. In particular, we have shown that exclusive double diffraction constitutes an efficient CP and lineshape analyzer 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

Louvain

FP420 alignment





- @ 1 x 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 , σ_0 = 0.77 GeV ~ 50 microns)

(also $\gamma\gamma WW$, $M_{\gamma\gamma} > 200$ GeV, $\sigma \sim$ 100 fb -> very high sensitivity to anomalous quartic couplings)

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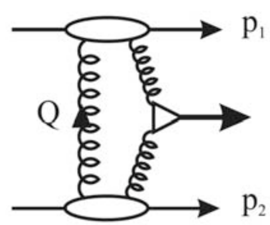
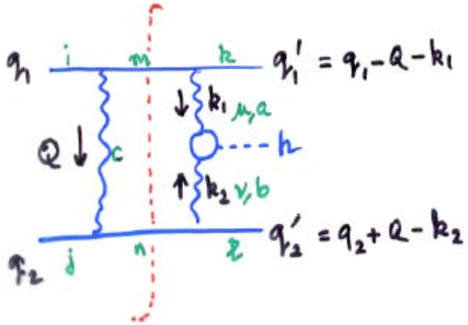
IPPP Durham

The KMR Calculation of the Exclusive Process



qq → q+H+q



→ q -> Proton

$$\frac{d\sigma}{dy_H} \simeq \frac{1}{256\pi \underline{\underline{b^2}}} \frac{\alpha_s^2 G_F \sqrt{2}}{9} \left[\int \frac{d^2 Q_\perp}{Q_\perp^4} \underline{\underline{f(x_1, Q_\perp^2)}} \; \underline{\underline{f(x_2, Q_\perp^2)}} \right]^2$$

$$f(x_i, Q_\perp^2) = \frac{\partial G(x_i, Q_\perp^2)}{\partial Q_\perp^2} \quad (x_i = \alpha_i)$$

Dominant uncertainty: KMR estimate factor of 2-3.

Divergent: controlled by Sudakov

assuming $f \sim (Q^2)^\gamma$

$$Q \sim \frac{M_H}{2} \exp\left(- \frac{2\pi}{N_c \alpha_s} \frac{\left[\frac{n}{2} - 1 - 2\gamma\right]}{2} \right)$$

$\alpha_s = 0.2, \; M_H = 100$ GeV, $n = 4$, $\gamma = 0.2$

→ 2 GeV

Power of Q_T, 6 for pseudo-scalar

As $Q_T \to 0$ so the screening gluon fails to screen and $P_T \approx 0$ emission is allowed. Hence e^{-S} vanishes faster than any power of Q_T.

exponentiating generates a factor in amplitude of

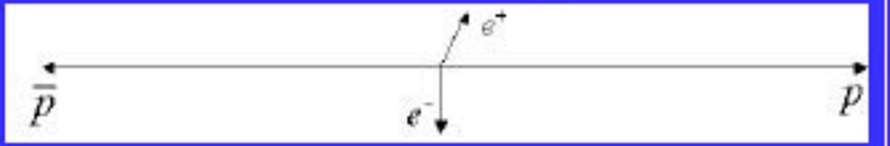
$$\exp(-S) = \exp\left(- \frac{C_A}{\pi} \int_{Q_T^2}^{M_H^2/4} \alpha_s \frac{dP_T^2}{P_T^2} \int_{P_T}^{M_H/2} \frac{dE}{E} \right) \quad \leftarrow \text{double logs}$$

Jeff Forshaw, this workshop

CDF Blessed this morning!

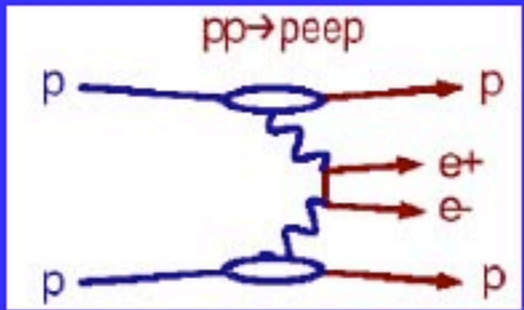
10 GeV $< M_{\gamma\gamma} <$ 20 GeV

Exclusive e^+e^- pairs



16 events observed

Estimated background = $2.1^{+0.6}_{-0.3}$
(mostly p-dissociation)
$\sigma_{MEAS.} = 1.6\ ^{+0.5}_{-0.3}$ (stat) $\pm$ 0.3 (syst) pb
Poisson Prob. = $3\times10^{-8} \approx 5.5\sigma$



QED: LPAIR Monte Carlo

$\sigma_{QED} = (1.711 \pm 0.008)$ pb

Exclusive $\gamma\gamma$ pairs

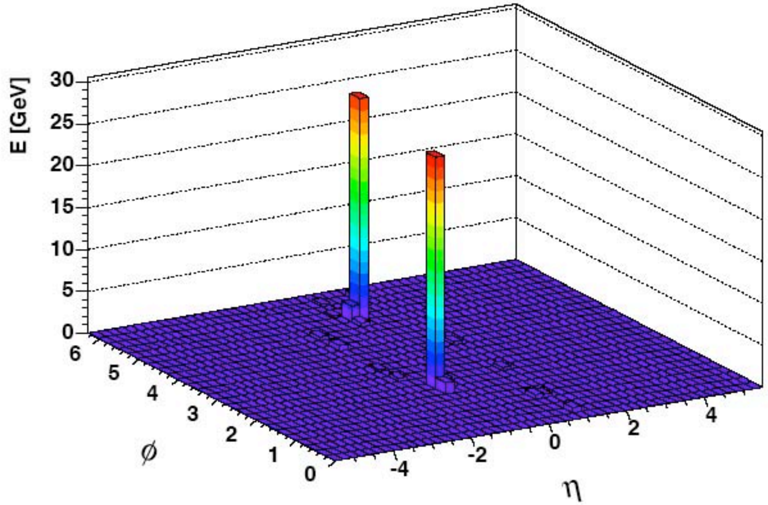
3 events observed

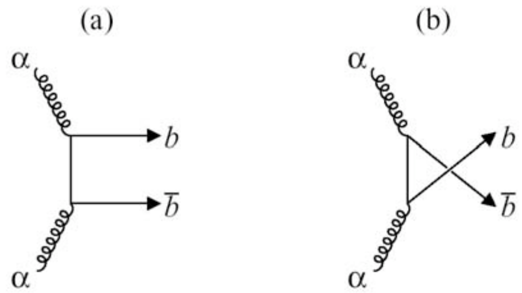
Estimated background = $0.0\ ^{+0.3}_{-0.0}$ events
(p-dissociation, exclusivity, fakes)
$\sigma_{MEAS.} = 0.14\ ^{+0.14}_{-0.04}$ (stat) $\pm$ 0.03 (syst) pb
Poisson Prob.$(0.3 \rightarrow \geq 3) = 3.6\times10^{-3}$
(conservative)
KMR (Durham) prediction = $0.04 \times\!\div$ (3-5) pb

Note: $\sigma_{MEAS} \approx 2\times10^{-12}\sigma_{INEL}$!

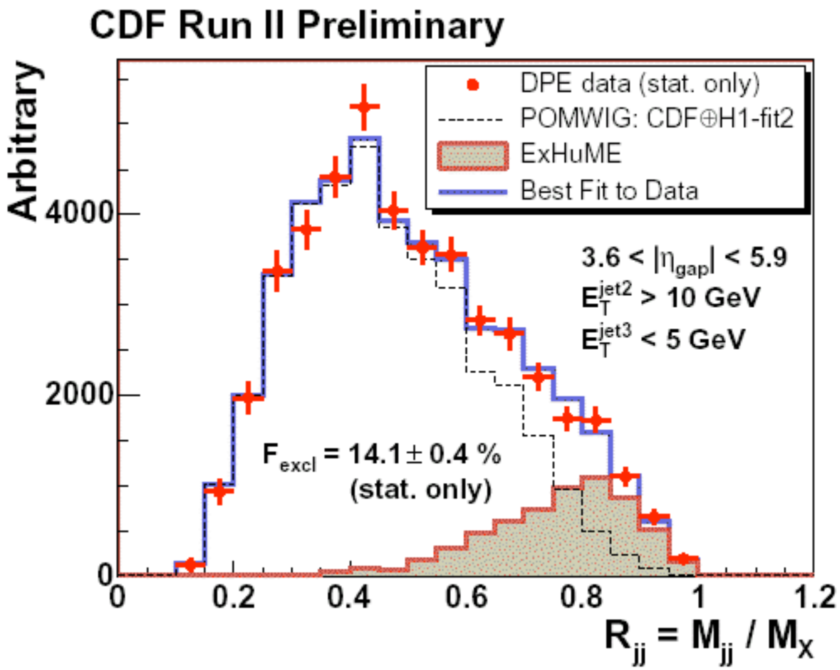
It means exclusive H must happen (if H exists) and probably $\sigma \sim$ 10 fb within factor ~ 2.5.
σ higher in MSSM

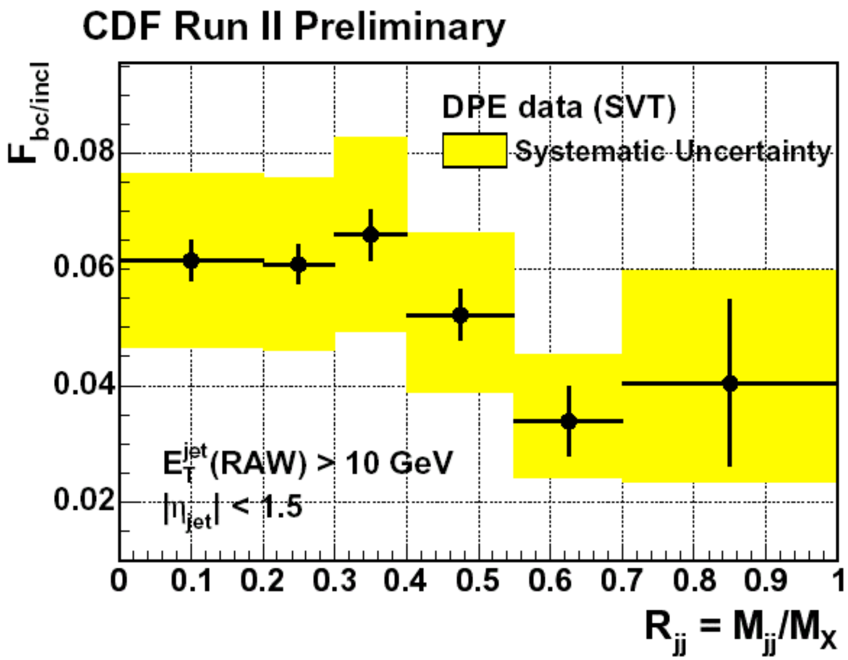
Evidence for Exclusive Production





J_Z=0 -> for colour singlet bbar production, the born level contributions of a) and b) cancel in the limit m_b -> 0





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FP420 Summary

• 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

FP420 L1 Trigger

• 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 x 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)

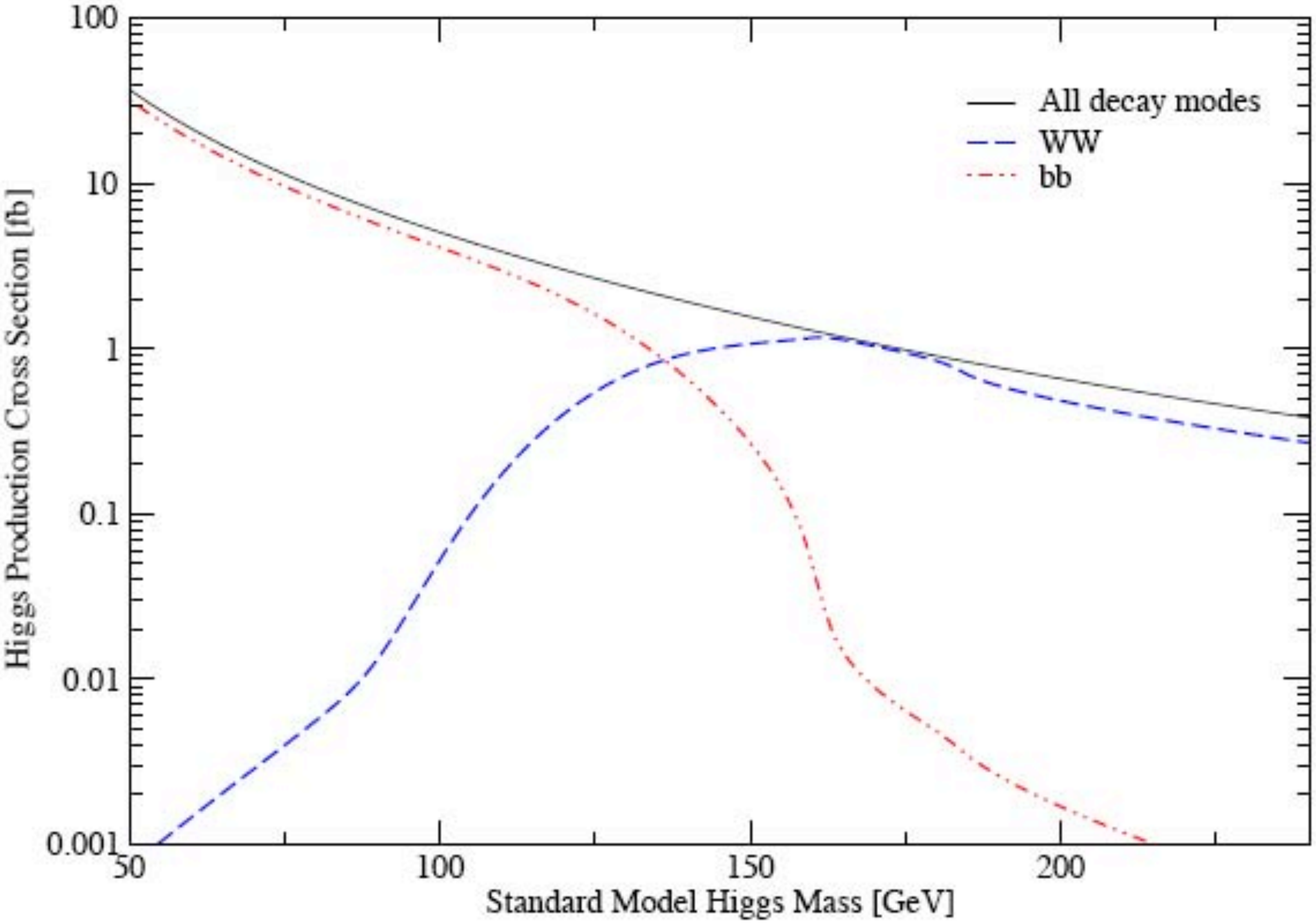
• @ 2 x 10^{33}, 7 pile-up events, tag at 220m + topological cuts OK

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

• up to 20% bb events can be saved with μ triggers at all luminosities

• All other channels, e.g. $WW^{(*)}$, fine.

The benchmark : Standard Model Higgs Production



B.E. Cox. et al, Eur. Phys. J. C 45, 401-407 (2006)

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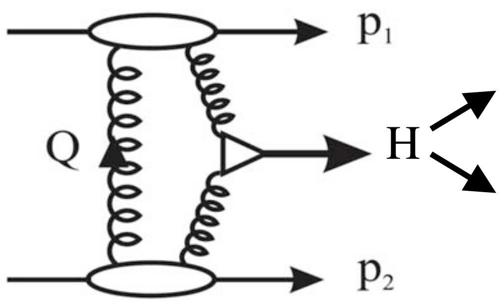
The benchmark : Standard Model Higgs Production

Standard Model Higgs



WW* : M_H = 120 GeV σ = 0.4 fb

M_H = 140 GeV σ = 1 fb

M_H = 200 GeV σ = 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 σ = 2 fb

M_H = 140 GeV σ = 0.7 fb

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

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:

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

- 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^{++}

B.E. Cox. et al, Eur. Phys. J. C 45, 401-407 (2006)

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Probing CP violation in the Higgs Sector

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

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

$M(H_1)$ GeV	cuts	30	40	50
$\sigma(H_1)\text{Br}(\tau\tau)$	a, b	1.9	0.6	0.3
$\sigma^{\text{QED}}(\tau\tau)$	a, b	0.2	0.1	0.04
$A_{\tau\tau}$	b	0.2	0.1	0.05

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

'CPX' scenario σ in fb

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

CP even

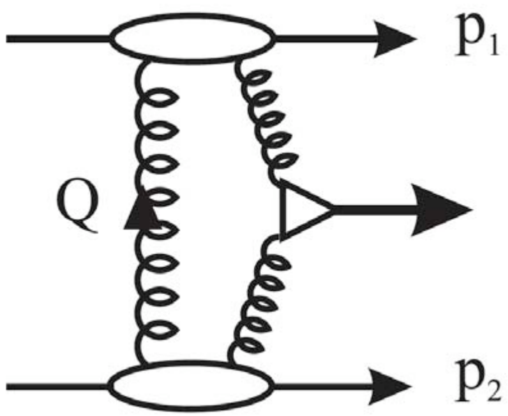
CP odd active at non-zero t

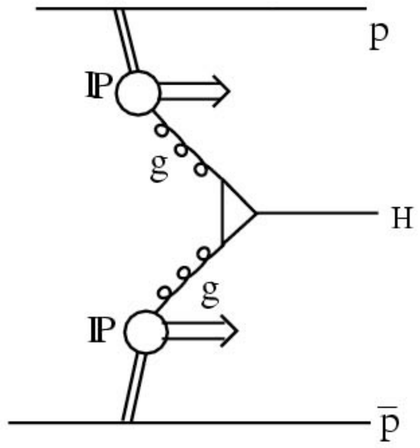
Ongoing work - are there regions of MSSM parameter space where there are large CP violating couplings AND enhanced gluon couplings?

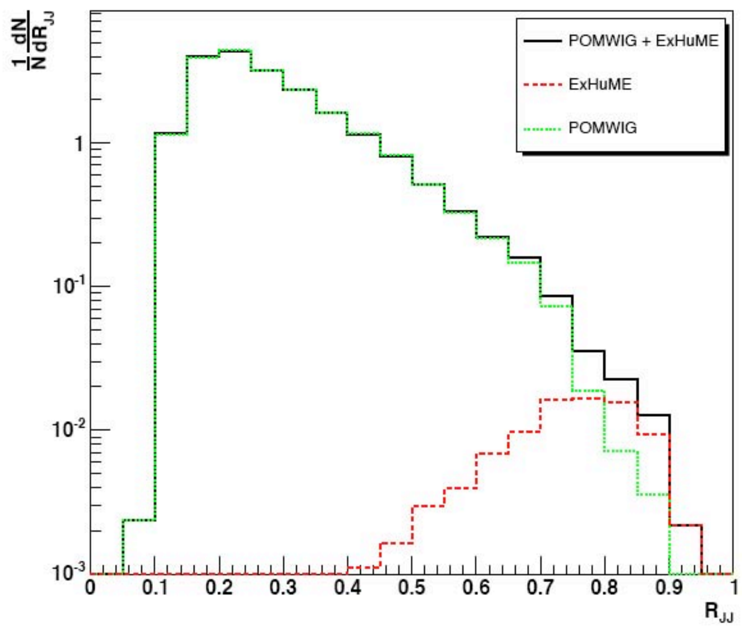
B.C., Forshaw, Lee, Monk and Pilaftsis Phys. Rev. D. 68 (2003) 075004

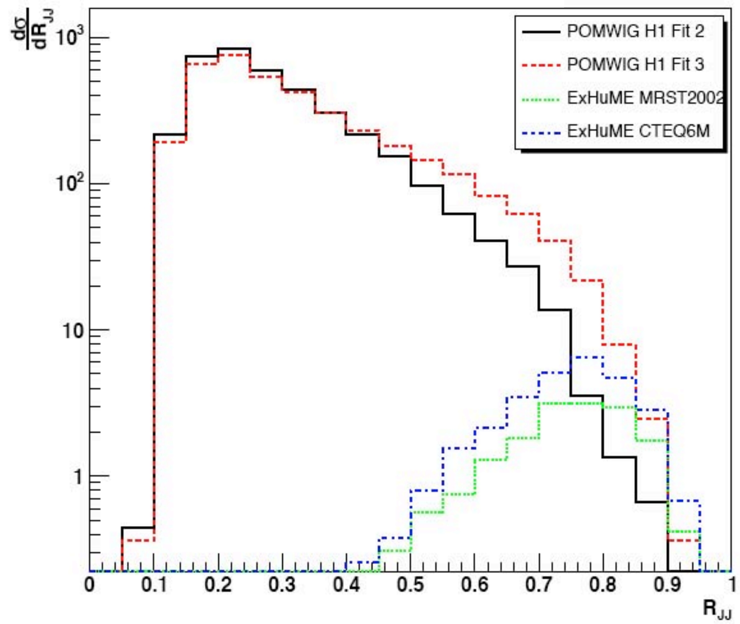
Khoze, Martin and Ryskin Eur. Phys. J. C 24 (2004) 327

Evidence for Exclusive Production









B. C. and A. Pilkington, Phys.Rev.D72:094024,2005

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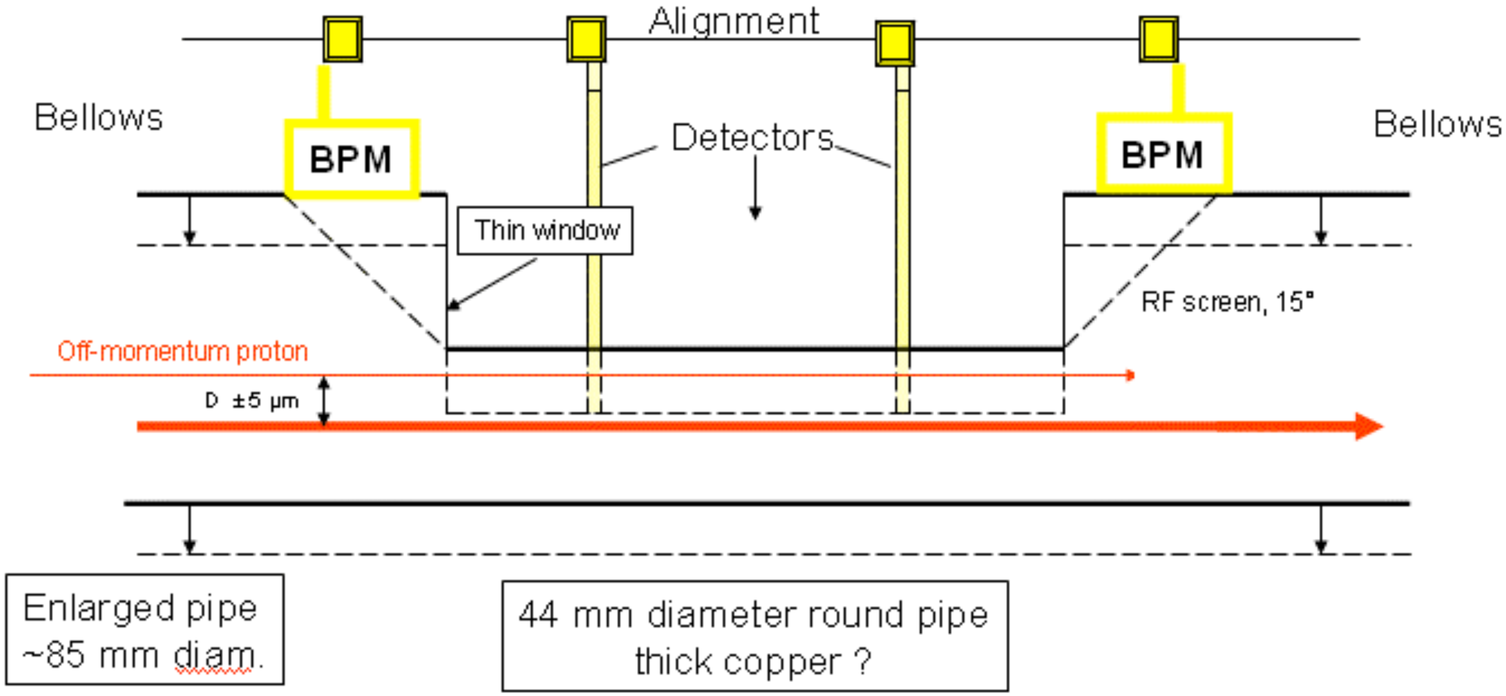
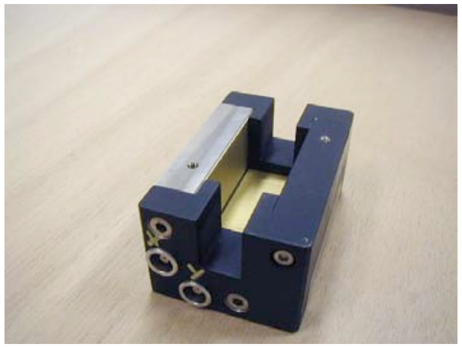
FP420 alignment





5 μm will be possible - test bench under construction at CERN

Helene Mainaud-Durand, CERN

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FP420 Collaboration

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

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