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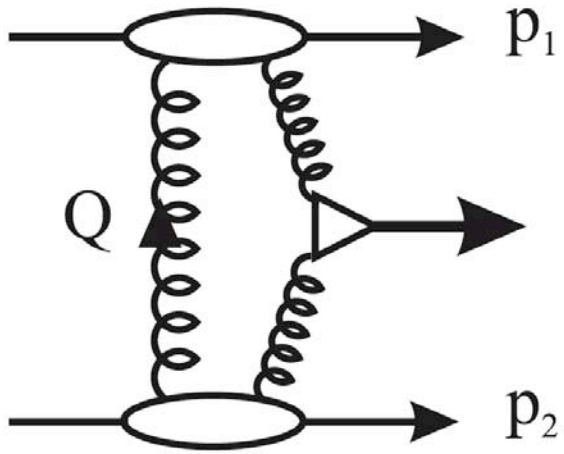
# Forward Proton Tagging at the LHC

1. Can we detect outgoing protons in interesting range of momentum loss ?
2. Can we use these protons to enhance the discovery potential of ATLAS and CMS ?




FP420 R&D Funding (ATLAS & CMS) :

"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 funding : £500k from UK (Silicon, detector stations, beam pipe + LHC optics and cryostat design), $100k from US / Canada (QUARTIC, UTA/FNAL/Alberta), €100k Belgium (+Italy / Finland) (mechanics)

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# FP420 R&D Collaboration

- Spokes : Brian Cox (Manchester, ATLAS) and Albert DeRoeck (CERN,CMS)
- Technical Co-ordinator : Cinzia DaVia (Manchester, ATLAS)

Collaboration : FNAL, The University of Manchester, University of Eastern Piedmont, Novara and INFN-Turin, The Cockcroft Institute, University of Antwerpen, University of Texas at Arlington, The University of Glasgow, University of Calabria and INFN-Cosenza, CERN, Lawrence Livermore National Laboratory, University of Turin and INFN-Turin, University of Lund, Rutherford Appleton Laboratory, Molecular Biology Consortium, Institute for Particle Physics Phenomenology, Durham University, DESY, Helsinki Institute of Physics and University of Helsinki, UC Louvain, University of Hawaii, LAL Orsay, University of Alberta, Stony Brook University, Boston University, University of Nebraska, Institute of Physics, Academy of Sciences of the Czech Republic, Brookhaven National Laboratory, University College London, Cambridge University

## ATLAS Roman pot upgrade at 220m with additional horizontal pots

France : Saclay, Paris 6

Czech Republic : Prague

US : Stony Brook

Poland : Cracow

Germany : Giessen

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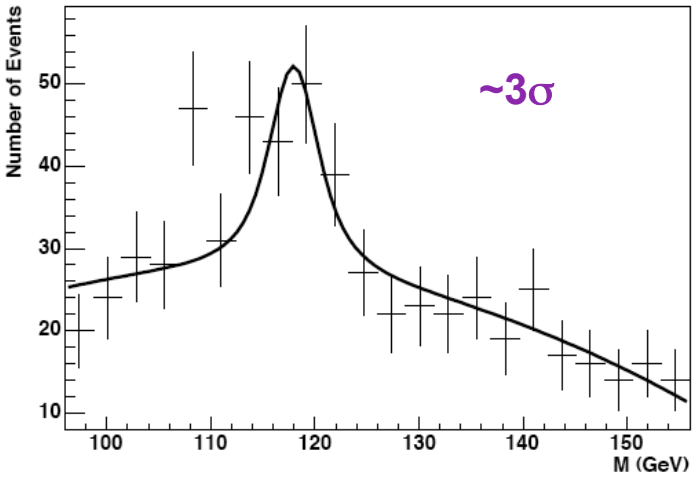
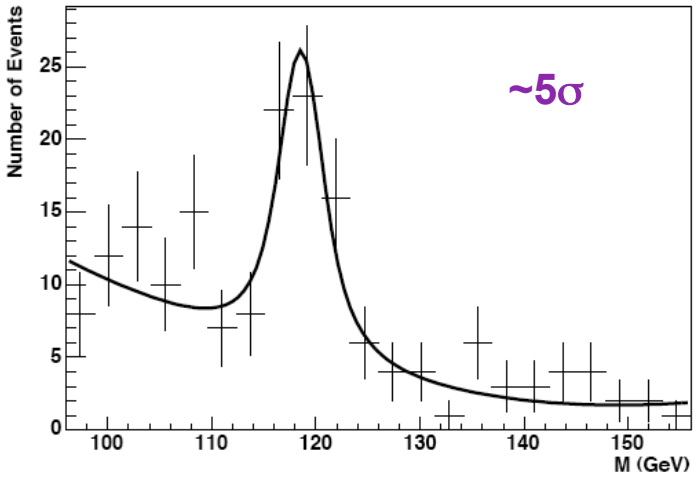
# An example of what forward proton tagging could do

$M_h^{max}$ MSSM scenario, b-jet channel, standard ATLAS L1 trigger hardware, 420m only, 5mm from beam, 10ps timing (left) or ~2ps / 10ps central (right):

($m_A$=120 GeV, tanβ = 40, 300fb$^{-1}$ @ $10^{34}$ cm$^{-2}$s$^{-1}$, $\sigma_{h\to bb}$ = 17.9fb)




The critical challenge:

- Fast timing resolution: To operate at $10^{34}$ cm$^{-2}$s$^{-1}$ we must achieve 10ps

Bottom line : Higgs -> b-jets can be detected if $\sigma > 10$ fb

Better than 1 GeV mass resolution in certain MSSM scenarios

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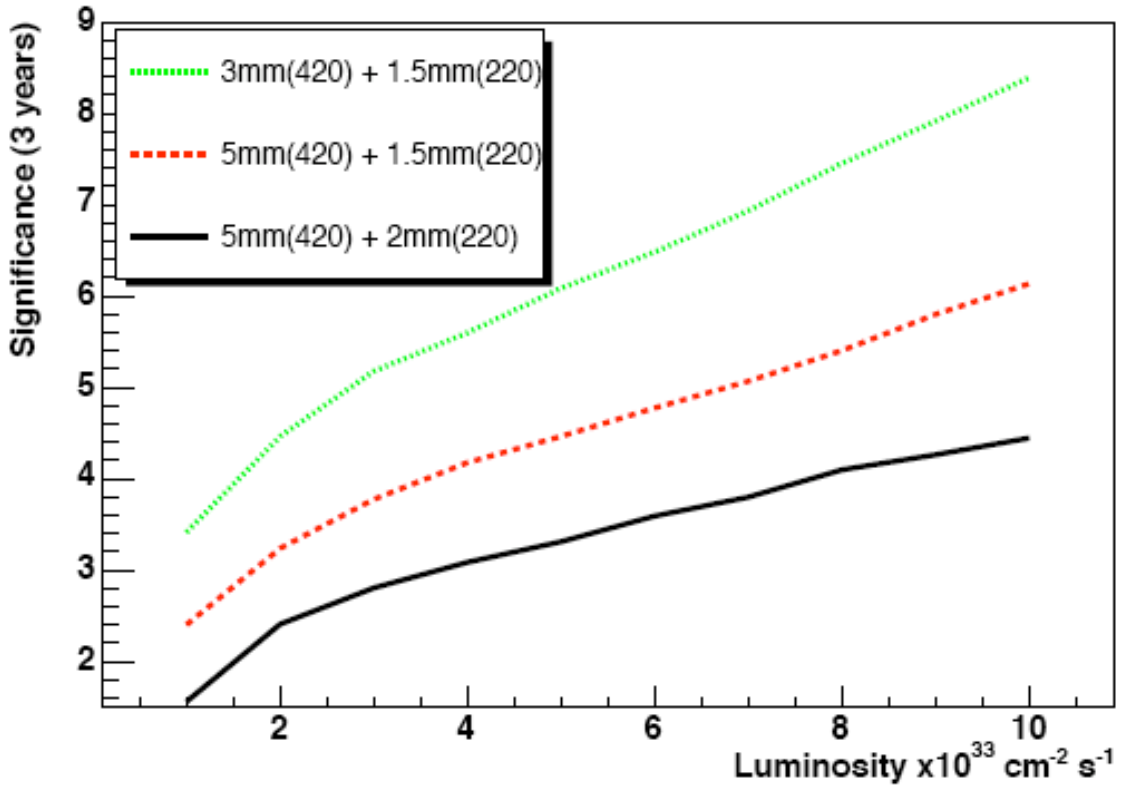
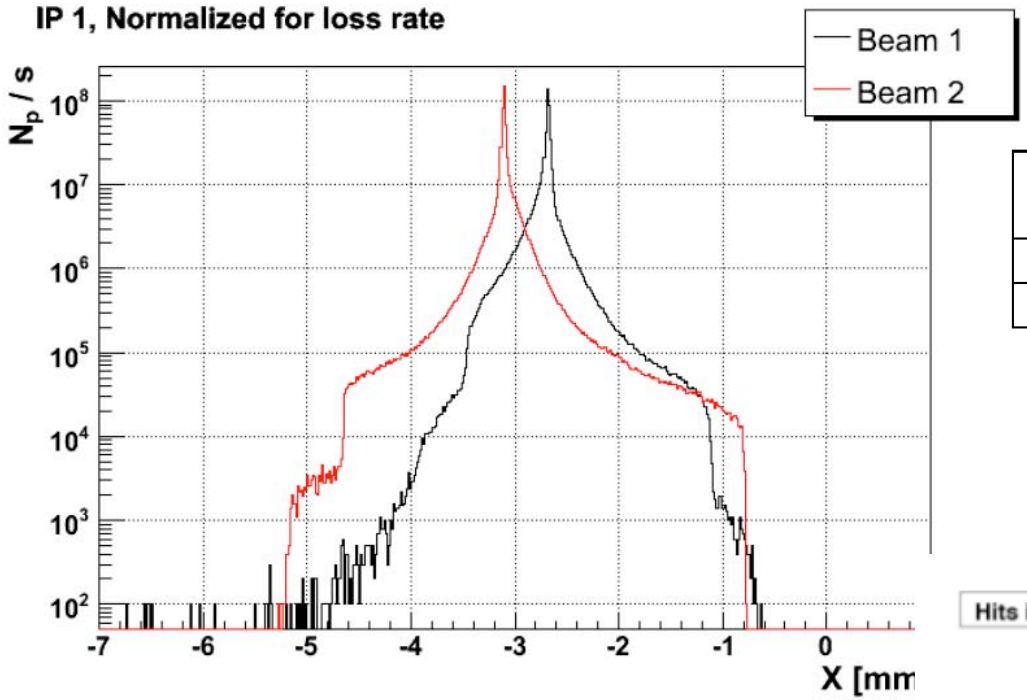
# An example of what forward proton tagging could do

Also important at 220m is the distance of approach to the beams :

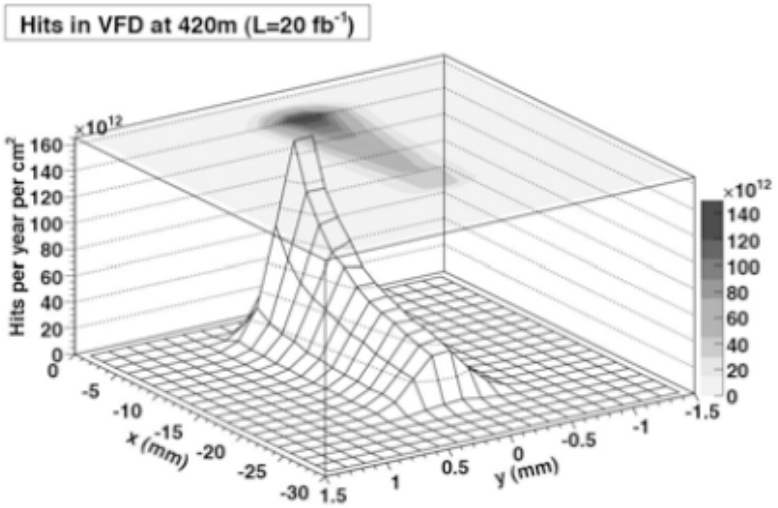
If assume 220m pots at L1, combined analysis achieves very high significance IF silicon can approach close to beam



# Backgrounds and distance of approach



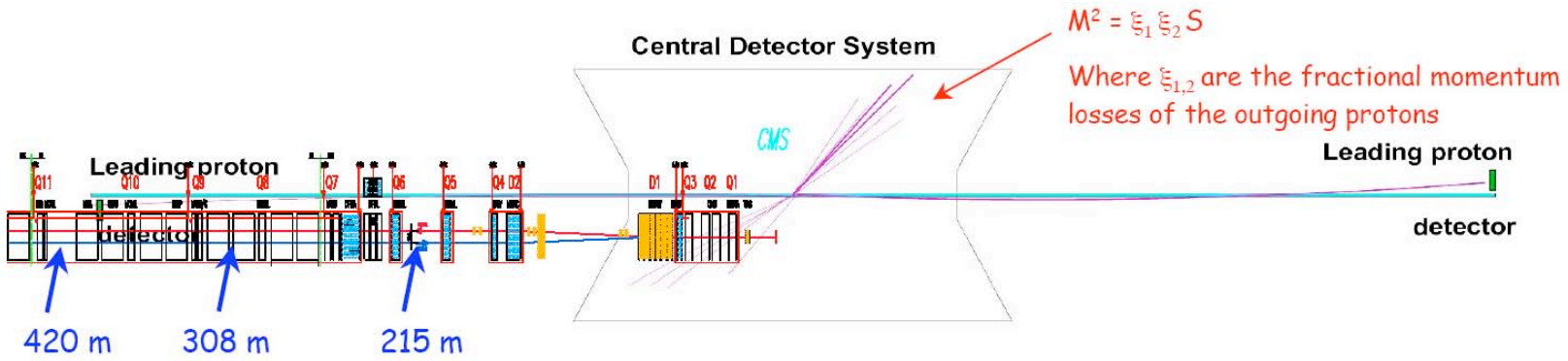

| System | n1 $[\sigma_{\beta x}]$ | n2 $[\sigma_{\beta x}]$ |
|---|---|---|
| Betatron Cleaning | 6 | 7 |
| Momentum Cleaning | 15 | 18 |

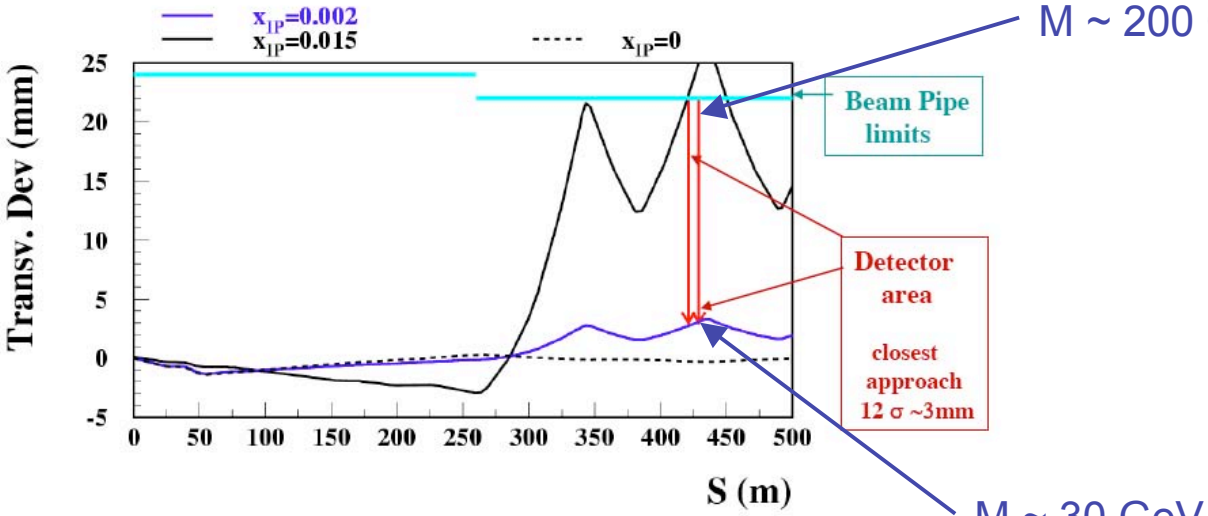



pp -> pX

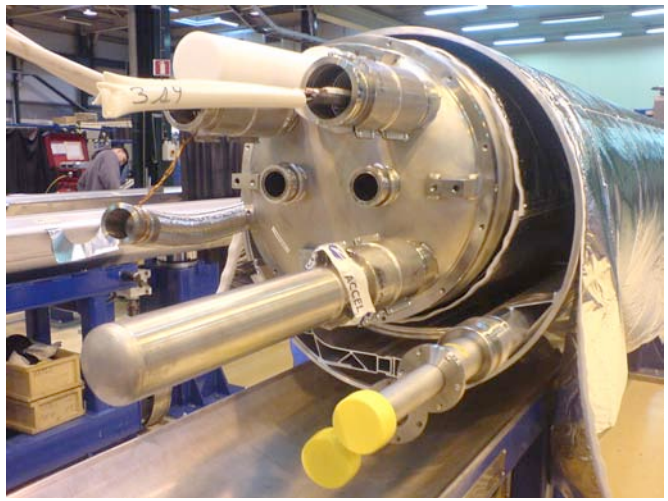
# Schematic Outline

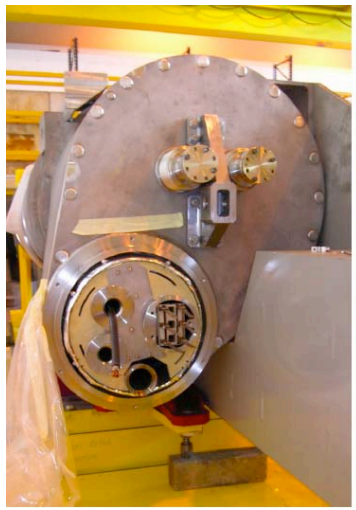
Spectrometer using LHC magnets to bend protons with small momentum loss out of the beam

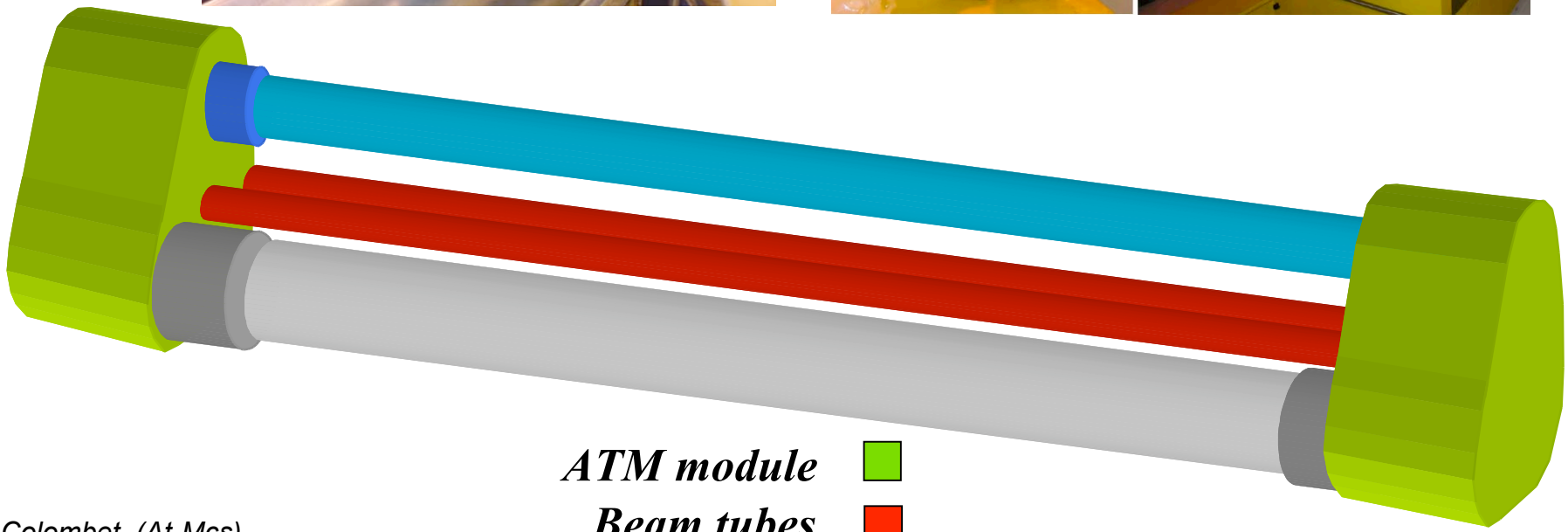


# FP420 Connection Cryostat







*ATM module*

*Beam tubes*

*Line X vacuum vessel*

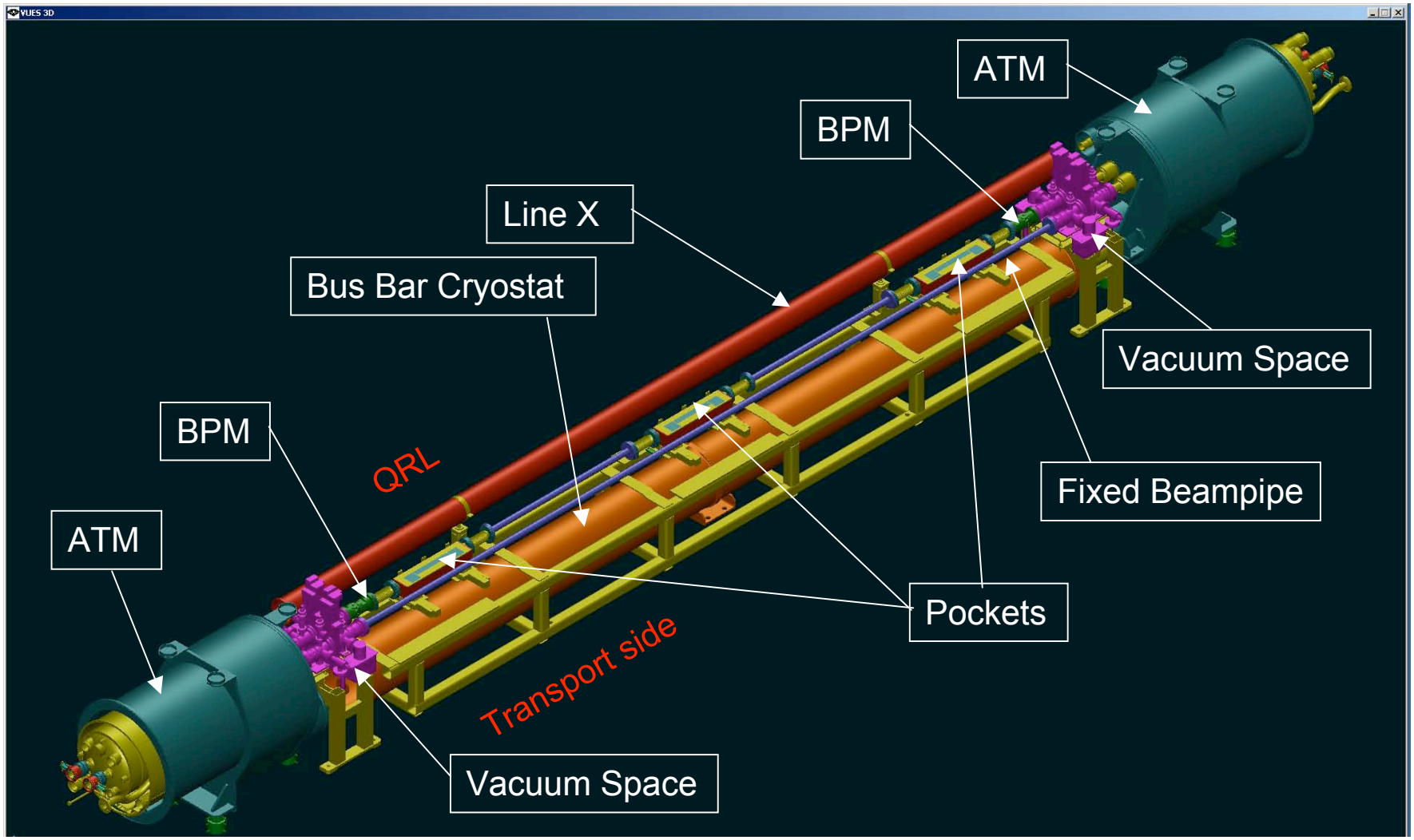
*Connection Module*

*T. Colombet (At-Mcs)*

*T. Renaglia,*

*R. Folch*

# Integration of the moving beampipe and detectors




Benoît Florins, Krzysztof Piotrzkowski, Guido Ryckewaert

CRC
Louvain-la-Neuve

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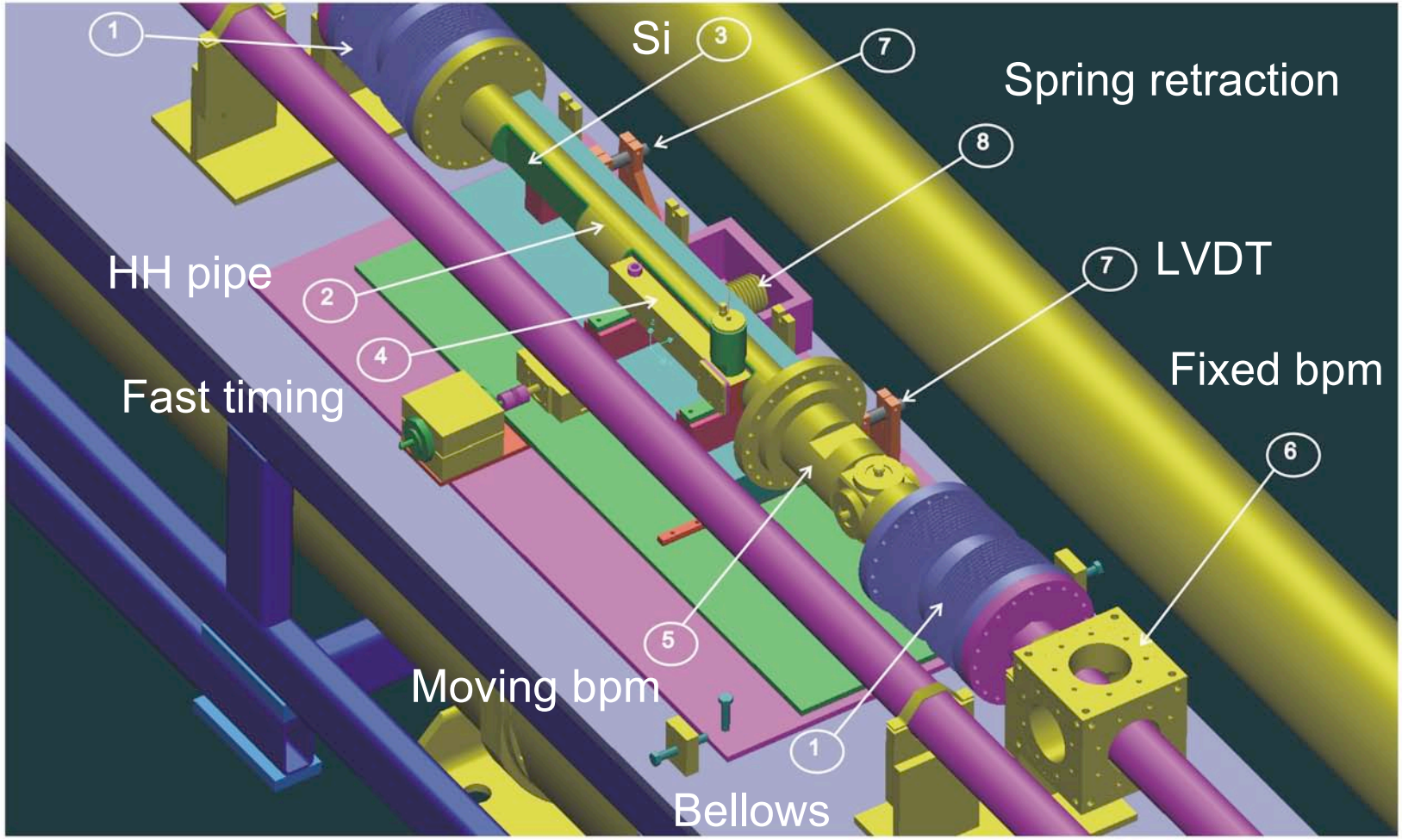
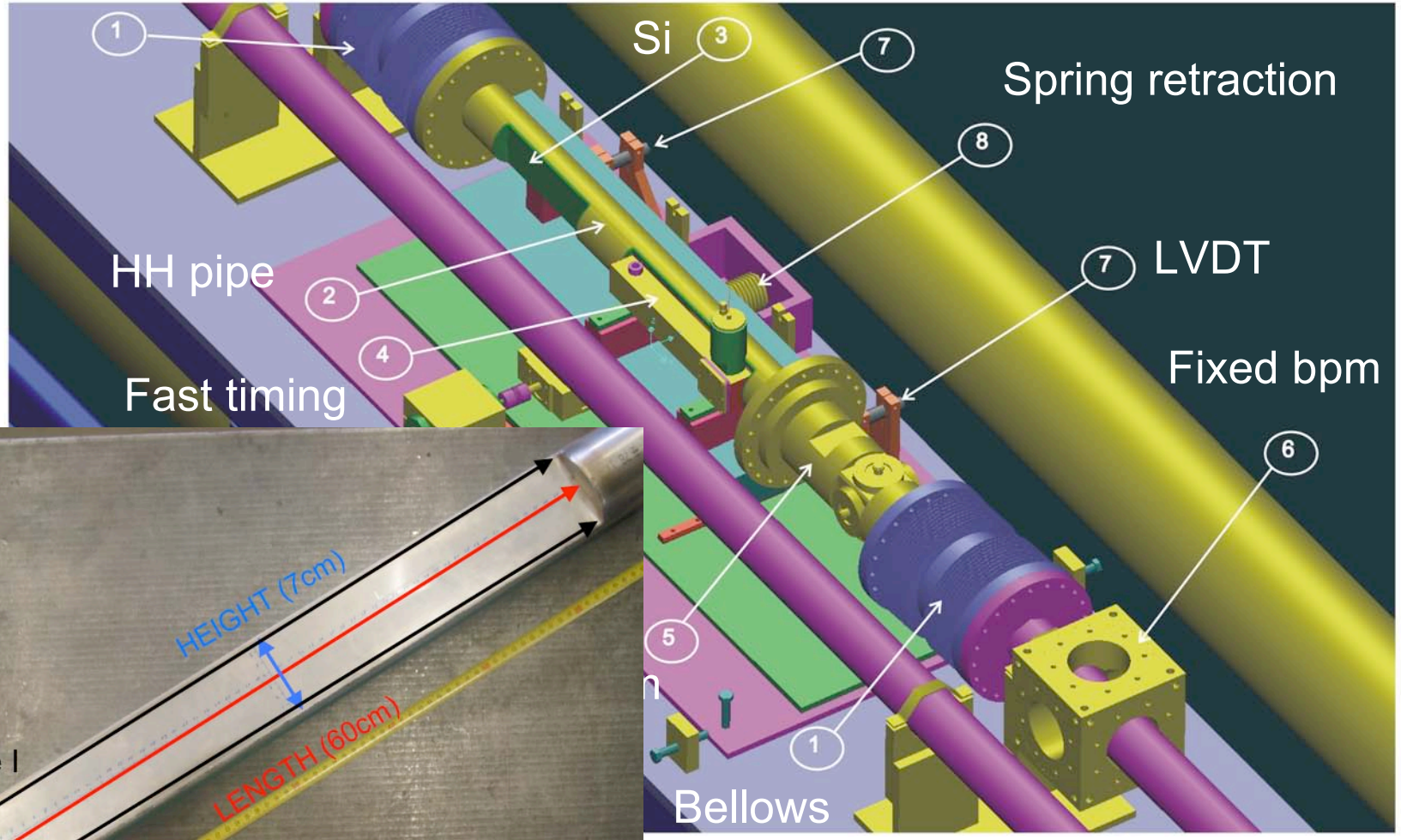
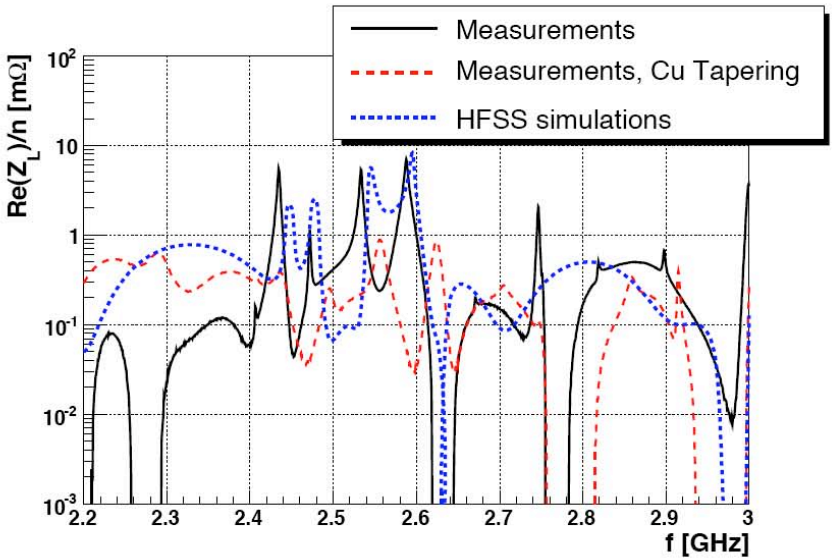
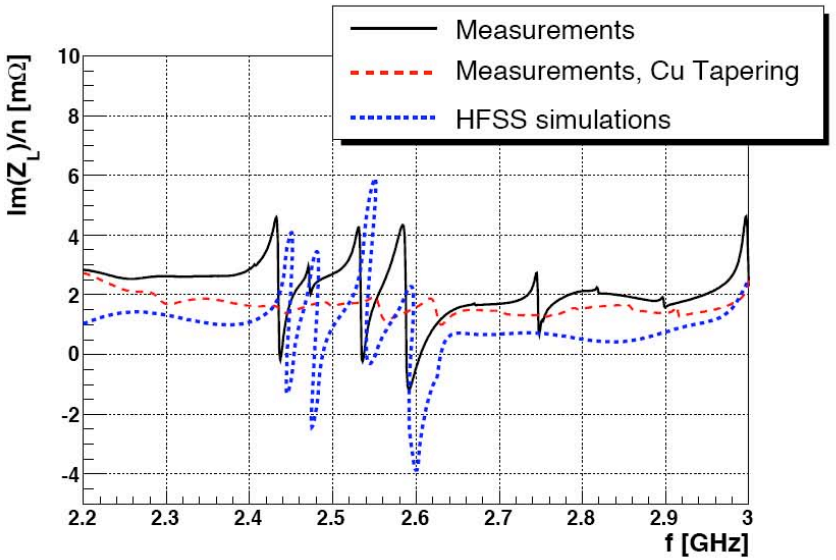
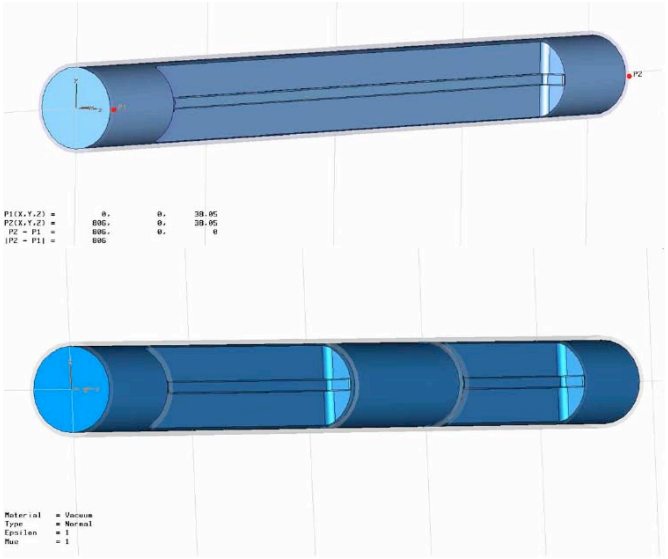




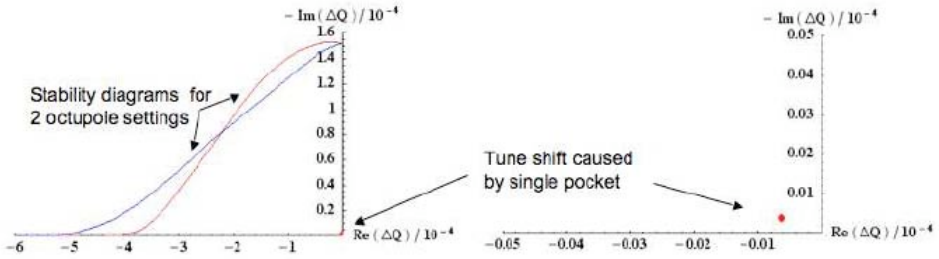
# Impact of FP420 on LHC



Ran simulations and measurements for 2 geometries - very small impact on LHC impedance budget



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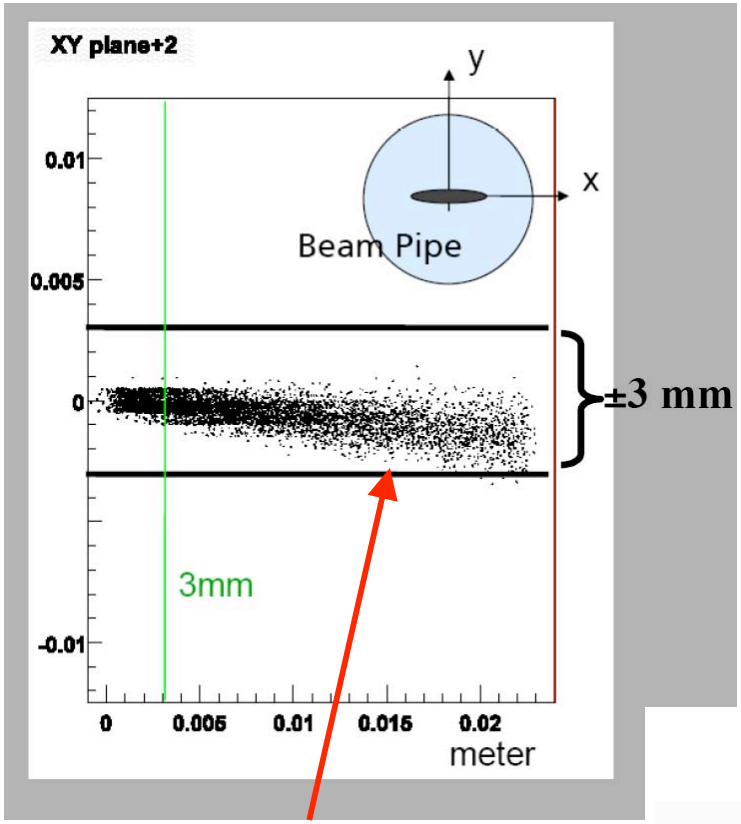
# Installation Schedule

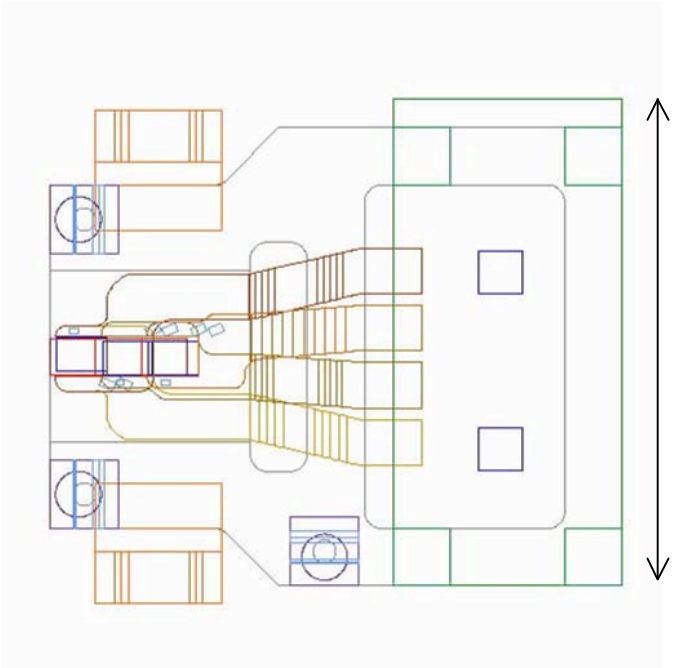
| | Normal Days |
|---|---|
| Warmup from 1.9K to 4.5 K | 1 |
| Warmup from 4.5K to 300 K | 15 |
| Venting | 2 |
| Dismantling interconnection | 10 |
| Removal of the connection cryostat | 2 |
| Installation of the FP420 cryostat | 5 |
| Realization of the interconnections | 15 |
| Leak test and electrical test | 4 |
| Closing of the vacuum vessel | 1 |
| Evacuation/repump | 10 |
| Leak test | 2 |
| Pressure test | 4 |
| Cooldown from 300 K to 4.5 K | 15 |
| Cooldown from 4.5K to 1.9 K | 3 |
| Total [days] | 89 |

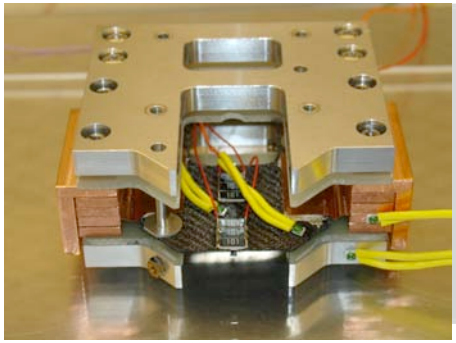
**Table 4:** The estimated time in days required to install one NCC

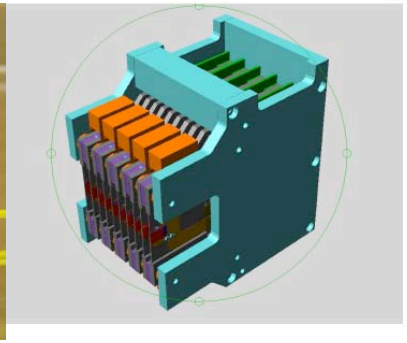
# FP420 Silicon Detector Stations

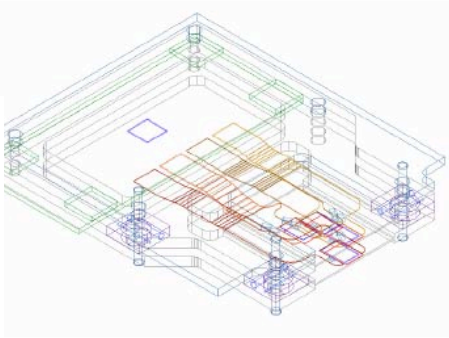


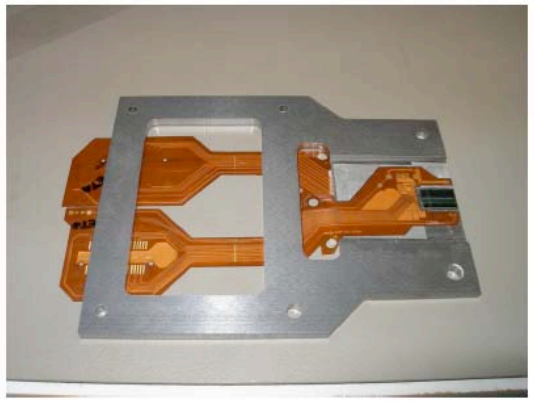

7.2 mm x 24mm (7.2 x 8 mm$^2$ sensors)



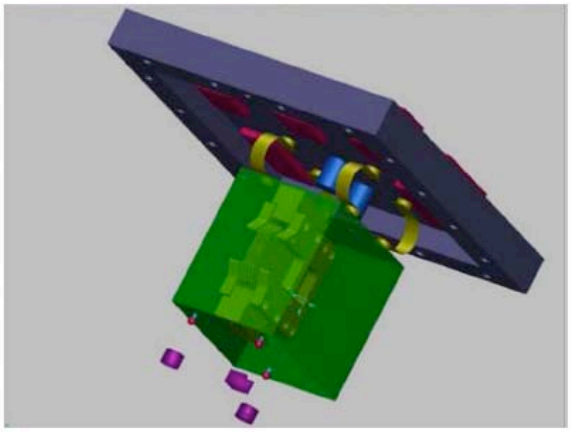



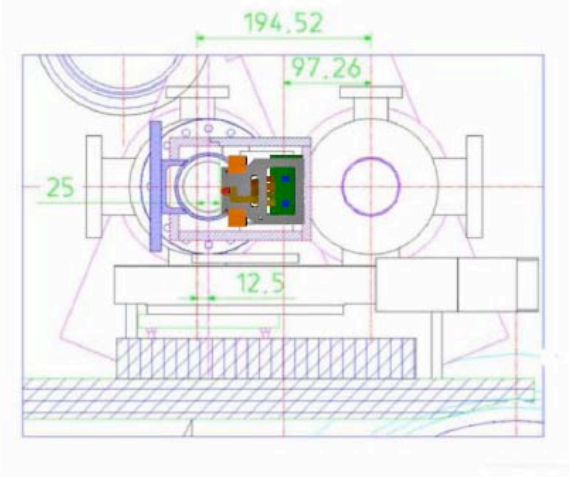


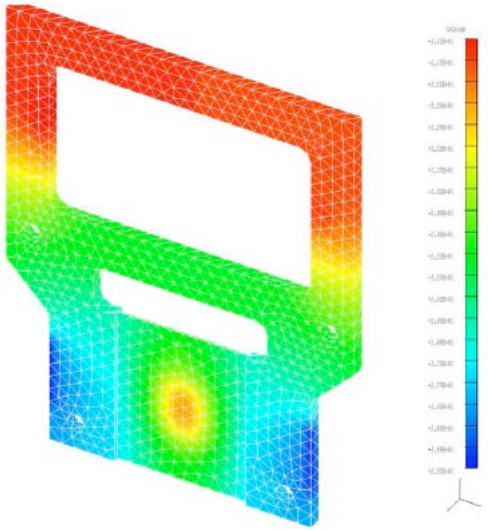


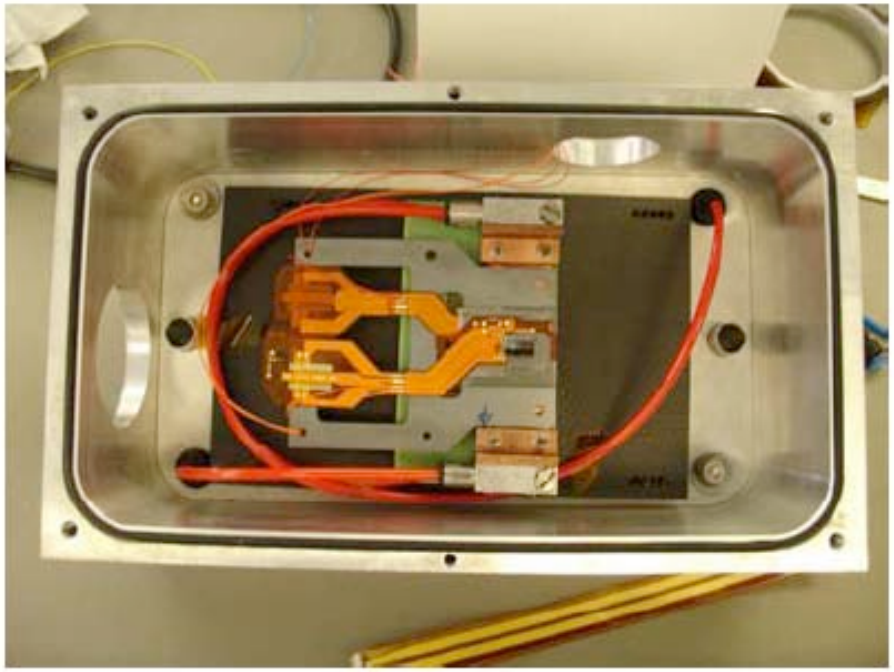


# Silicon detector housings





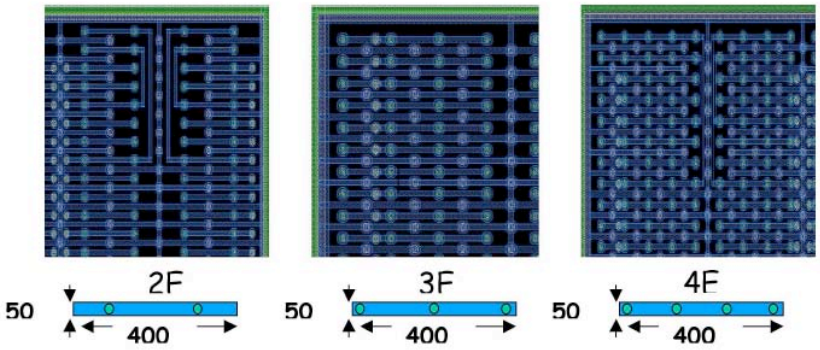


CE7 alloy (70 / 30 Si / Al)

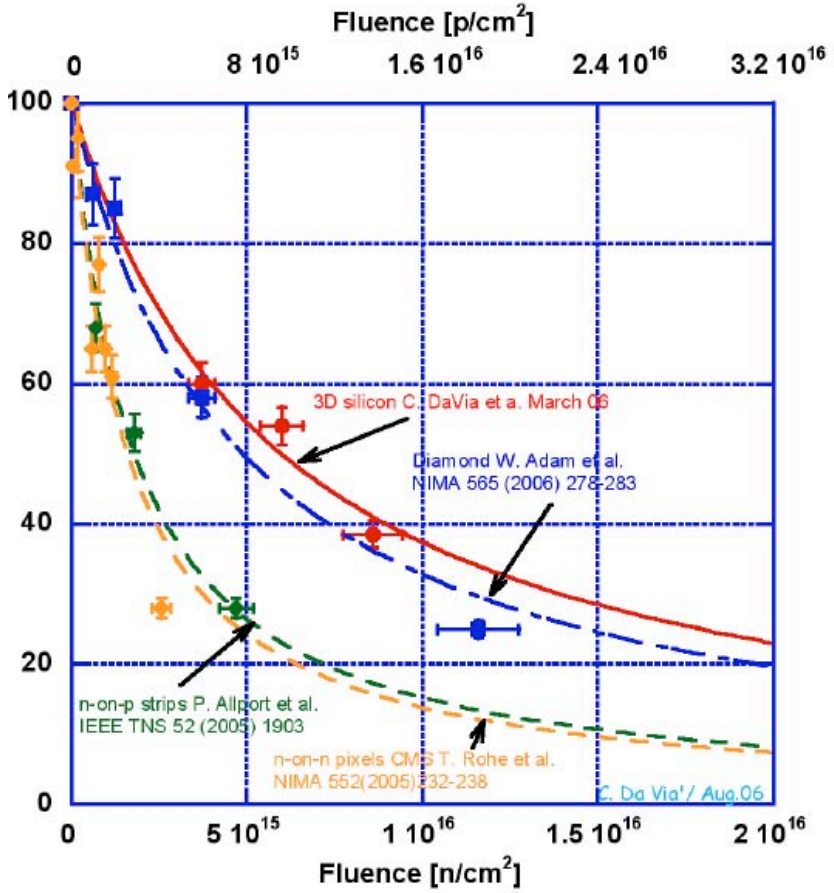
Peltier cooling probable solution

Achieved thermal + mechanical stability @ 10 microns in thermal tests

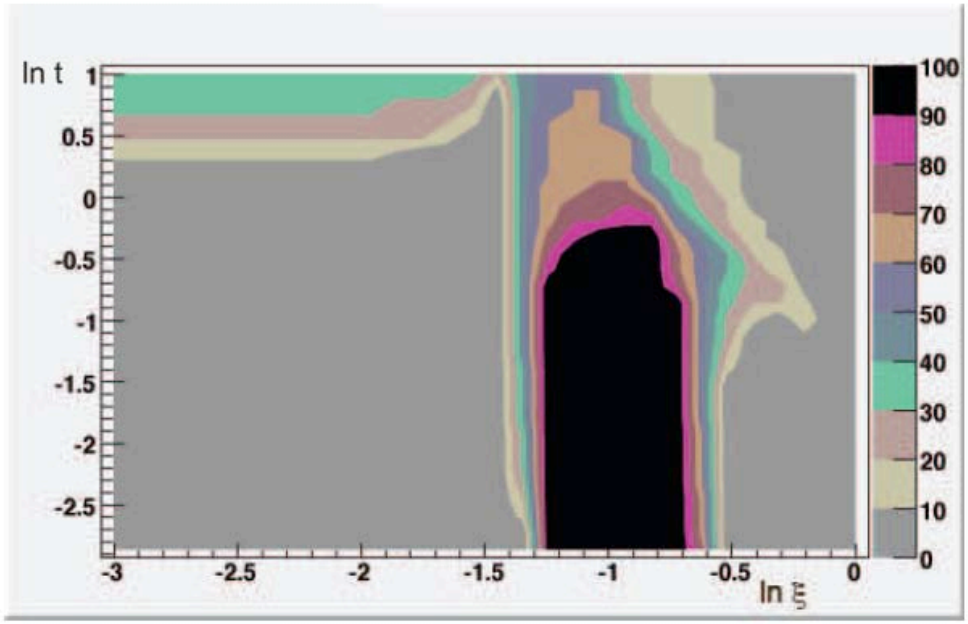
# 3D Silicon Sensors

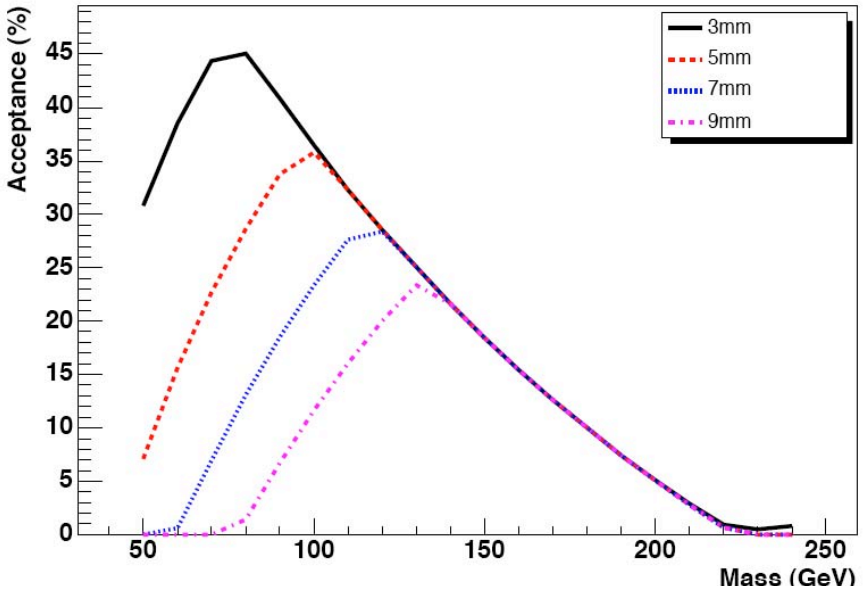


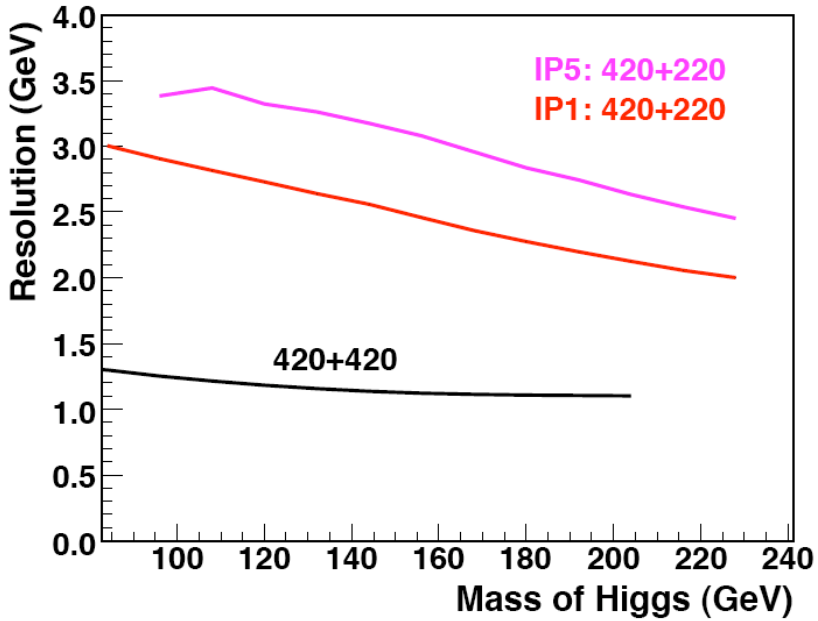

- 3D extremely rad-hard
- Successfully tested in TOTEM pot in SPS in 2004 + H8 (CERN) 2006
- Sensors bump-bonded onto ATLAS pixel readout chips
- Standard ATLAS pixel DAQ

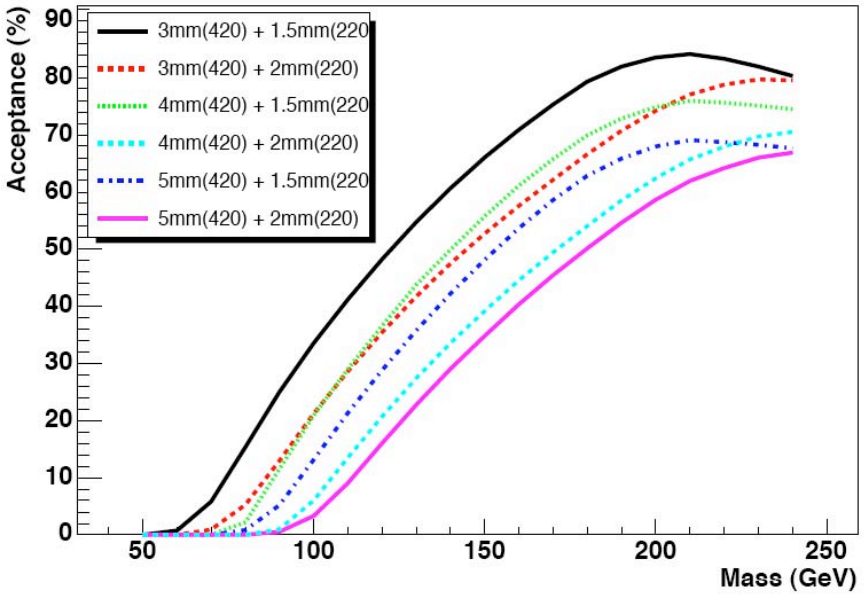


# Acceptance and Resolution

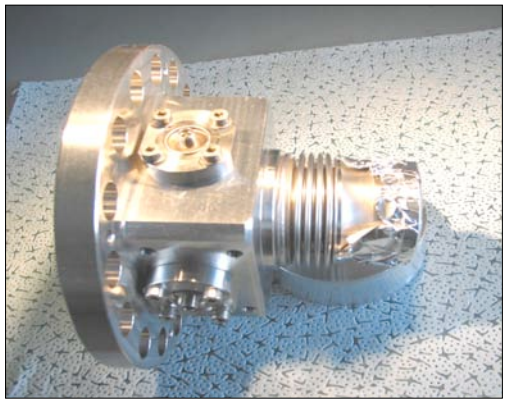


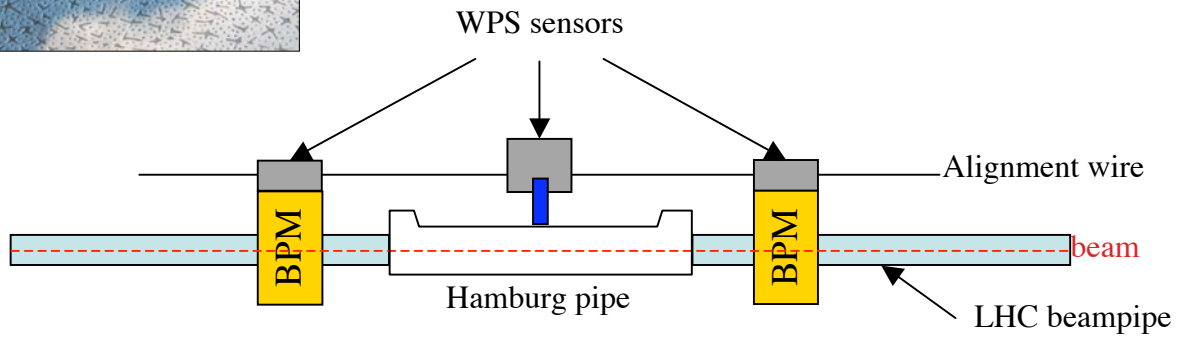



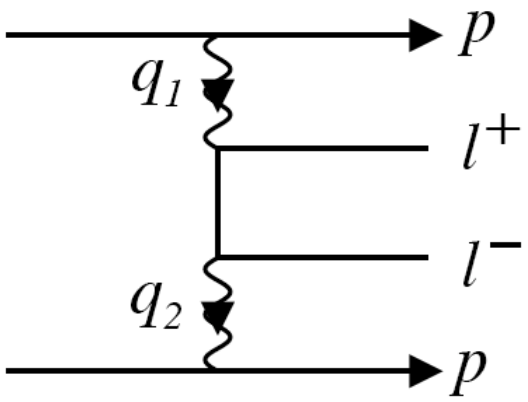



# FP420 Alignment



CLIC BPMs + wire positioning system : aim for 10 microns relative to beam

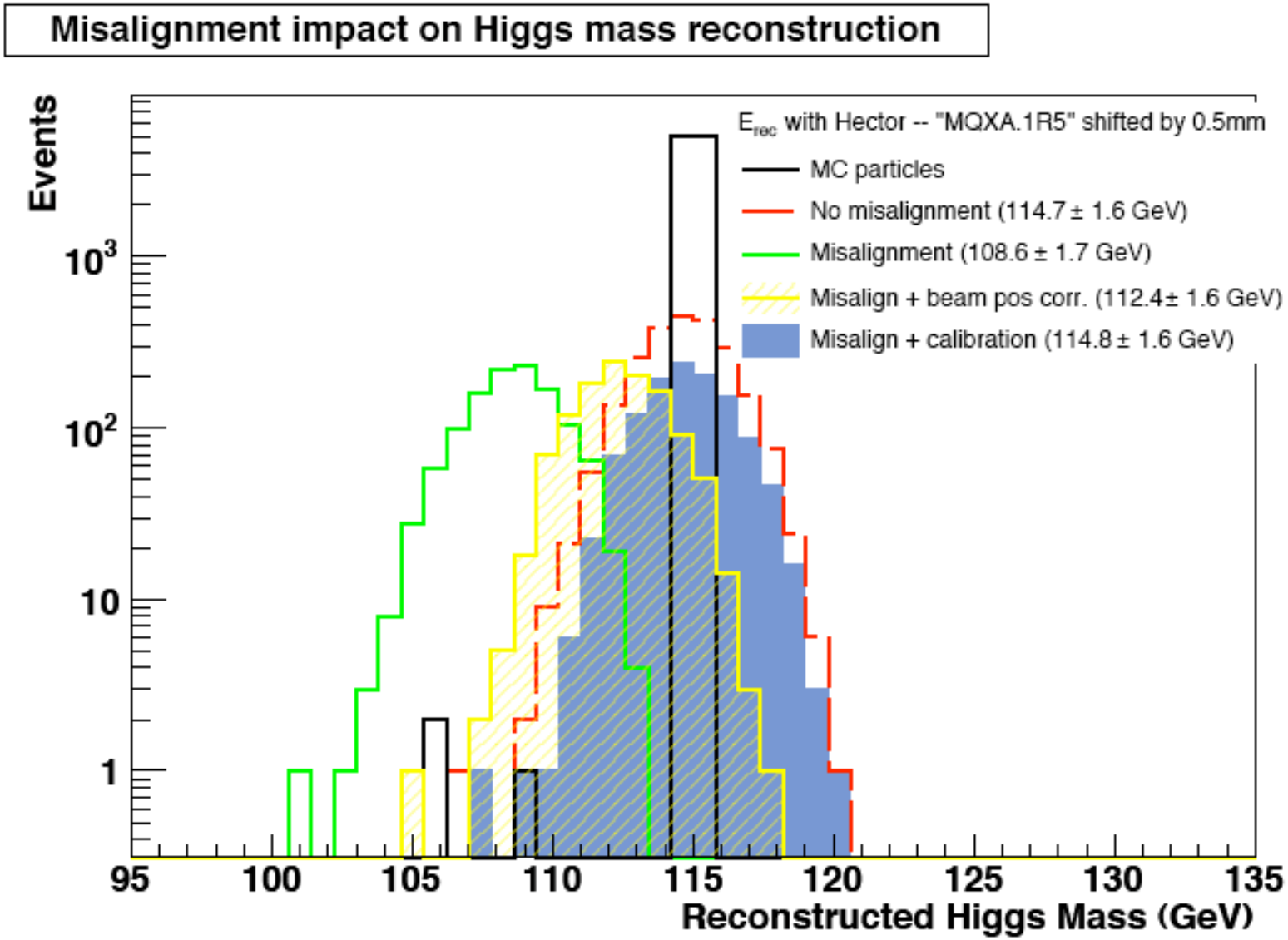



@ $10^{33}$ $cm^{-2}s^{-1}$ with standard ATLAS triggers, have ~ 30 di-muon events / fill in FP420 acceptance ($\sigma$ ~ 7pb)

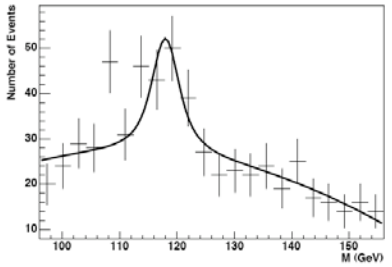
Thanks to Lars Soby, Rhodri Jones, Helene Mainaud-Durand, Andreas Herty and Robert Boudot

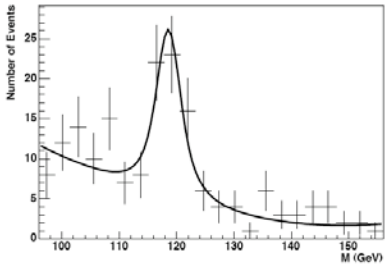
# Mass reconstruction

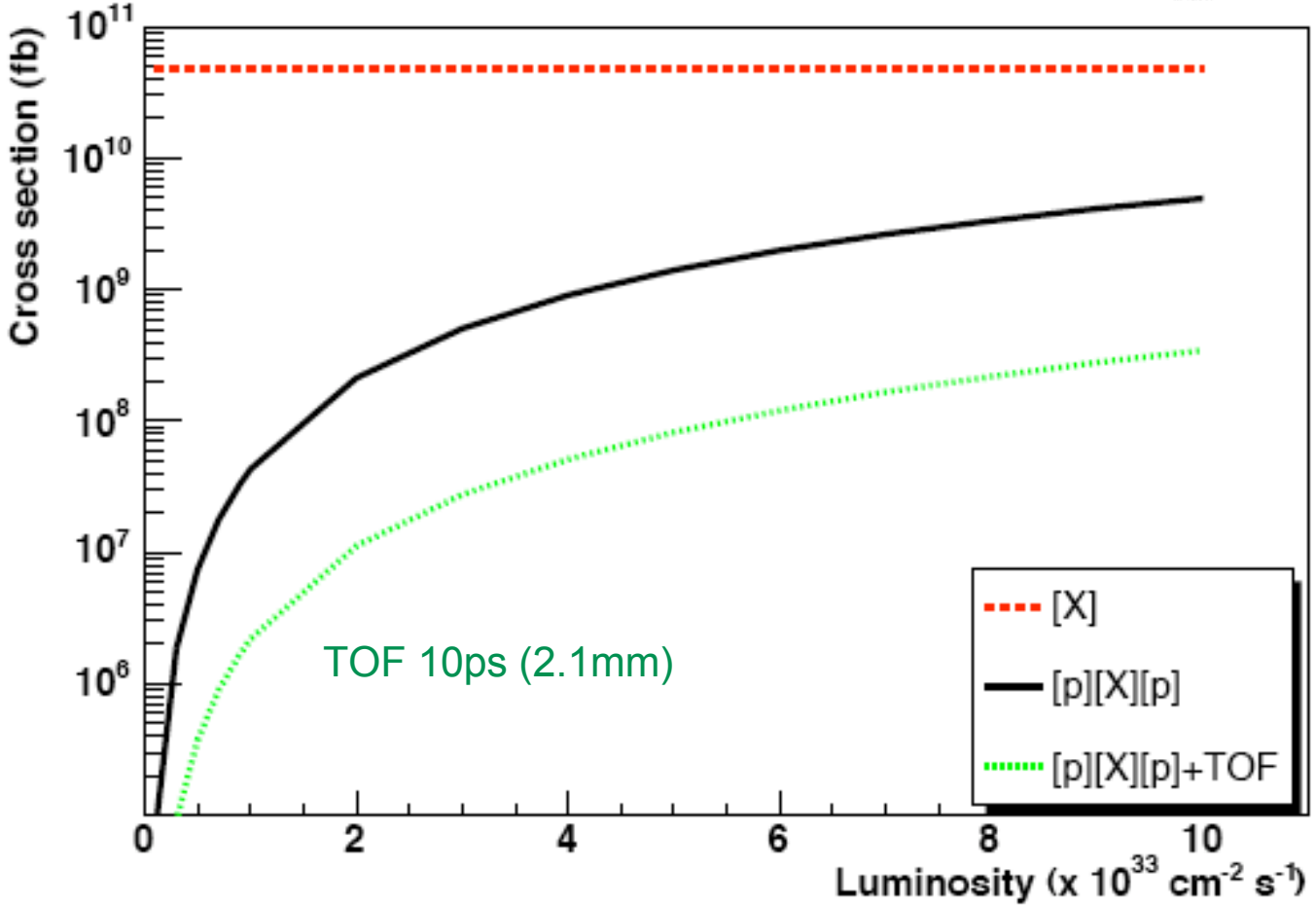


# FP420 Fast timing Detectors

Dijet cross sections, $E_T$ > 40 GeV

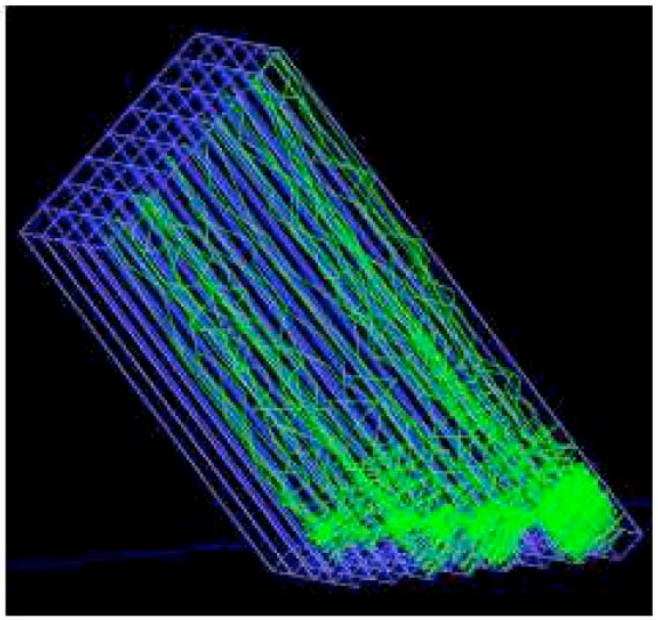


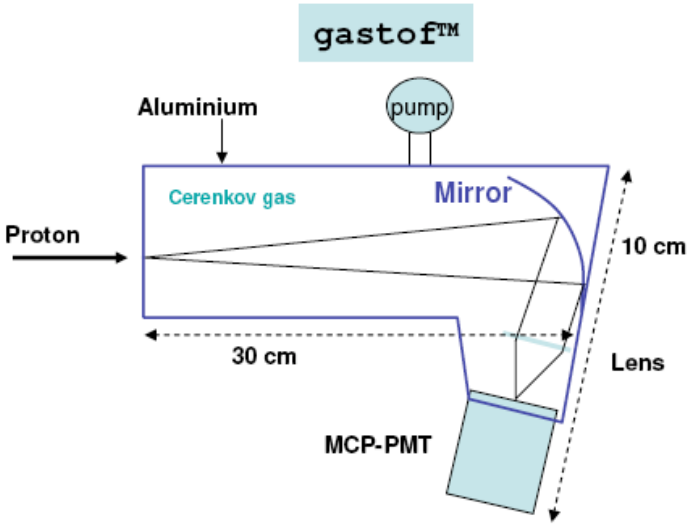
# Fast timing detectors

## Quartic (FNAL, Alberta, UTA)



More than 50% of the photons arrive within the first 5 ps.

## GASTOF (Louvain)




all the photons arrive within $\approx 3$ ps

Burle 85011-501 with 25 $\mu$m pores

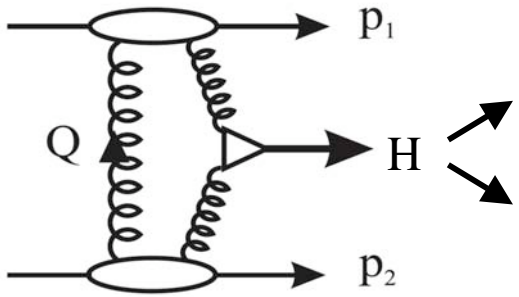
Hamamatsu R3809U-50 with 6 $\mu$m pores

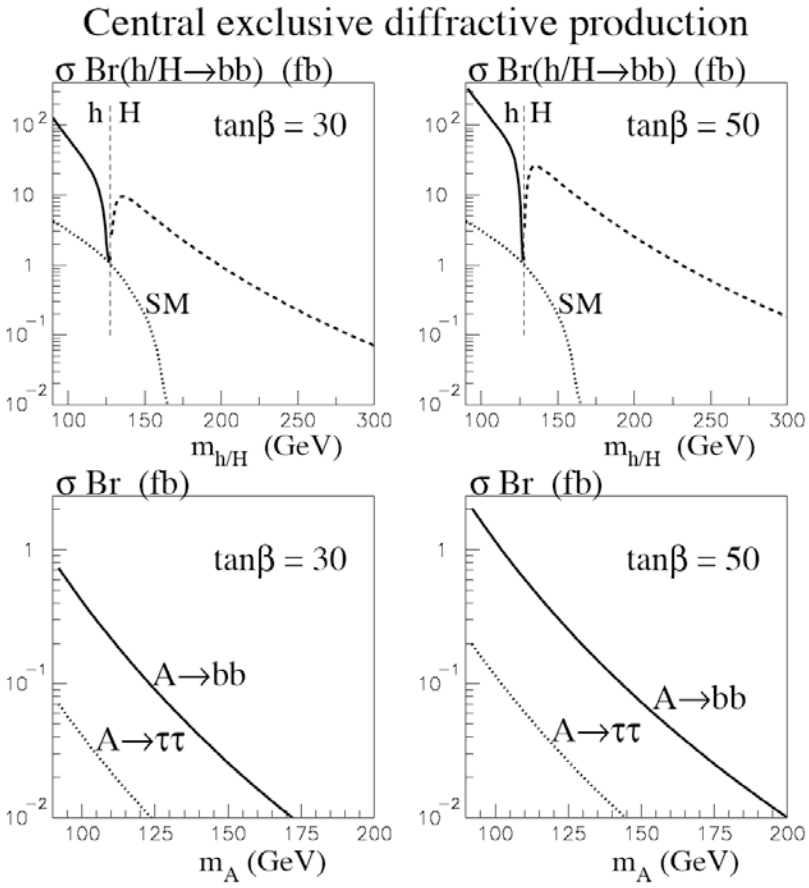
Test beam FNAL:

$$\delta t(G1) = 42 \text{ ps and } \delta t(G2) = 24 \text{ ps}$$

$\delta t(\text{QB4}) = 40$ ps ← Burle 85011-501 with 10 $\mu$m pores

# CEP production - many other interesting channels




- **SM Higgs -> WW**

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), very small backgrounds in 30 fb$^{-1}$

- **NMSSM Higgs -> ττττ**

Looks very promising, results from Forshaw, Gunion, Pilkington et al. next month

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

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

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

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

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

A. B. Kaidalov. et al, Eur.Phys.J. C33 (2004) 261-271

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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 |
|---|---|---|---|---|
| $\sigma(H_1)\mathrm{Br}(\tau\tau)$ | $a, b$ | 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 |

'CPX' scenario 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

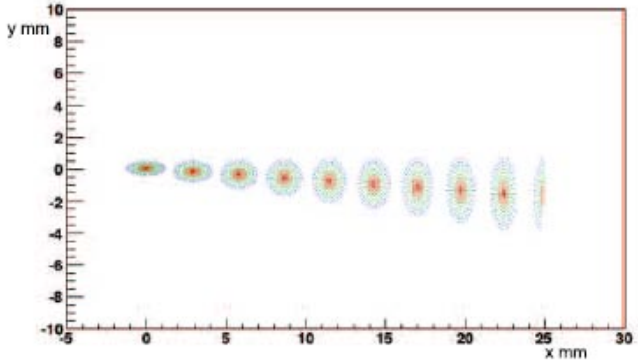
CP odd active at non-zero t

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

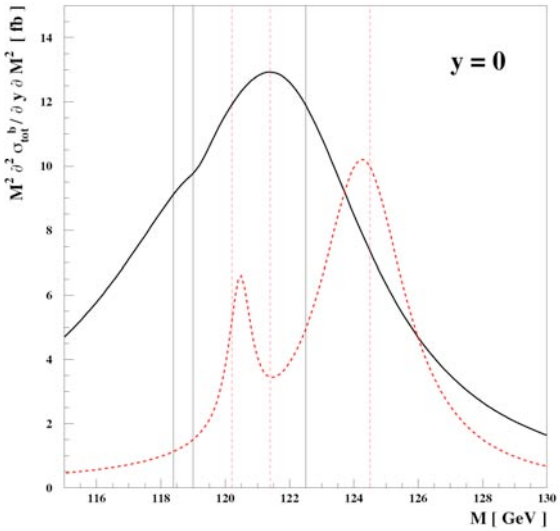
# Measuring the ϕ distribution



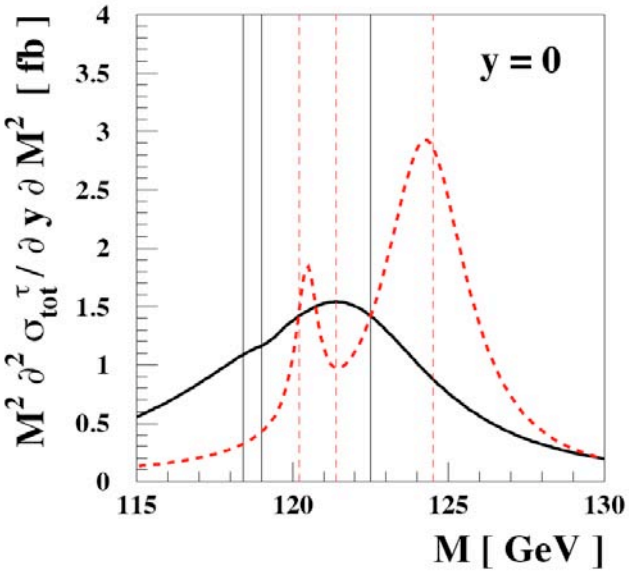

**Chromaticity grid at 420 m**

# CP violation in the Higgs Sector

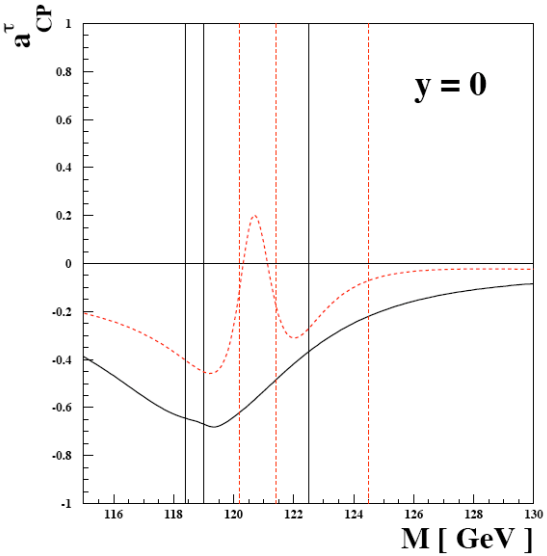
bb decay




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

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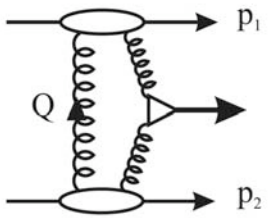
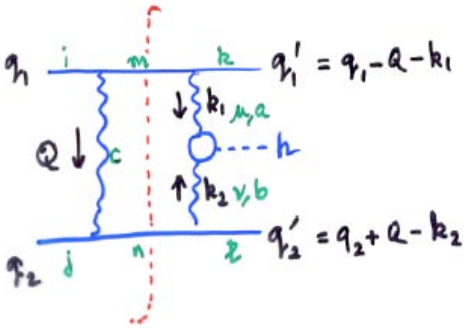
# Forward Physics upgardes at the LHC

- FP420 is currently an R&D collaboration between ATLAS, CMS and non-affiliated groups.
- In addition, there is a strong, complementary program to upgrade the 220m region which adds value to 420m program
- Aim is to submit proposal for a sub-detector upgrade this year for 420m and 220m upgrades
- If accepted by ATLAS and / or CMS, this would lead to TDR from experiments late 2007 / early 2008
- The FP420 design phase is fully funded, and will be completed in summer 2007
- If funding is secured, cryostats (built by TS-MME) and baseline detectors could be ready for installation in Autumn 2008.
- However, more likely goal is autumn 2010
- 220m and 420m tagging detectors have the potential to add significantly to the discovery reach of ATLAS and CMS for modest cost, particularly in certain regions of MSSM parameter space
- There is a rich QCD and electroweak physics program in parallel with discovery physics

# The KMR Calculation of the Exclusive Process




$qq \to q+H+q$




q -> Proton

$$\frac{d\sigma}{dy_H} \simeq \frac{1}{256\pi \underline{b}^2} \frac{\alpha_s^2 G_F \sqrt{2}}{9} \left[\int \frac{d^2\underline{Q}_1}{\underline{Q}_1^4} f(x_1, \underline{Q}_1^2)\, f(x_2, \underline{Q}_1^2)\right]^2$$

$$f(x_i, Q_1^2) = \frac{\partial G(x_i, Q_1^2)}{\partial Q_1^2} \quad (x_i = \alpha_i)$$

Dominant uncertainty: KMR estimate factor of 2-3.

Divergent: controlled by Sudakov

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

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

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

→ 2 GeV

Power of $Q_T$, 6 for pseudo-scalar

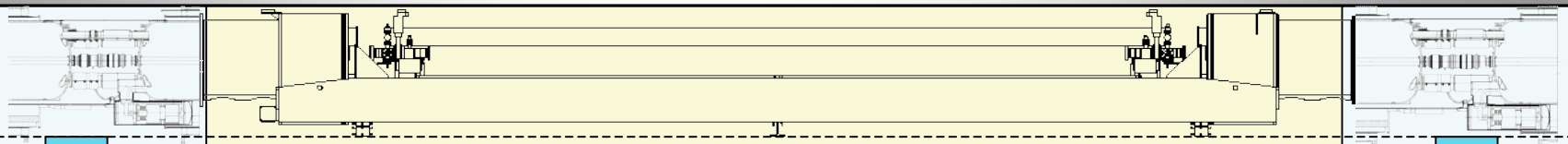
As $Q_T \to 0$ so the screening gluon fails to screen and $P_T \neq 0$ emission is allowed. Hence $e^{-S}$ vanishes faster then any power of $Q_T$.


exponentiating generates a factor in amplitude of

$$\exp(-S) = \exp\left(-\frac{C_A}{\pi}\int_{Q_T^2}^{\frac{1}{4}M_H^2} \alpha_s \frac{dP_T^2}{P_T^2} \int_{P_T}^{M_H/2} \frac{dE}{E}\right)$$ ← double logs

Jeff Forshaw, this workshop

# Preliminary planning of interconnection:



Days
1
3
5
7
9
11
13
15
17
19
21
23
25

Dismantling of interconnection

Removal of C.C.

Reconditioning of interconnection

Installation of FP420 cryostat.

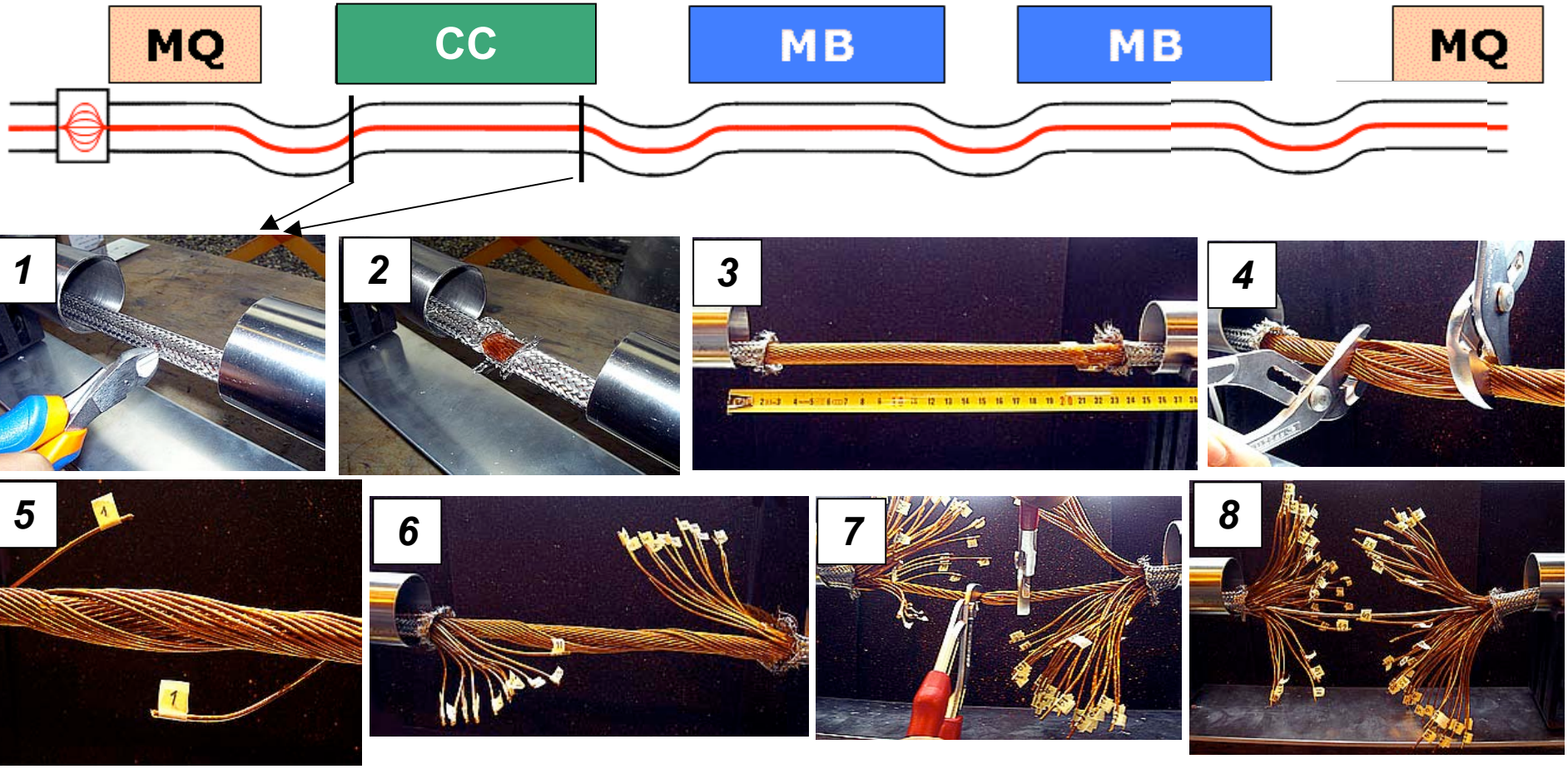
Interconnection

Last operation & commissioning.

T. Colombet (At-MCS)

# Dismantling of interconnections :

## Line N dismantling :




*T. Colombet (At-MCS)*

| | |
|---|---|
| 2 peoples | 12 hours + previous (4 hours) = 2 days |