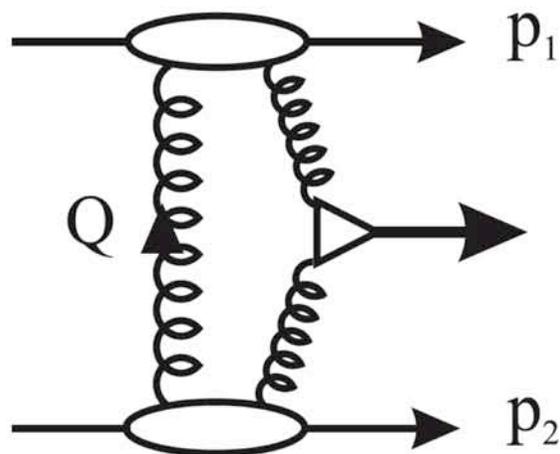


The FP420 R&D Project



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

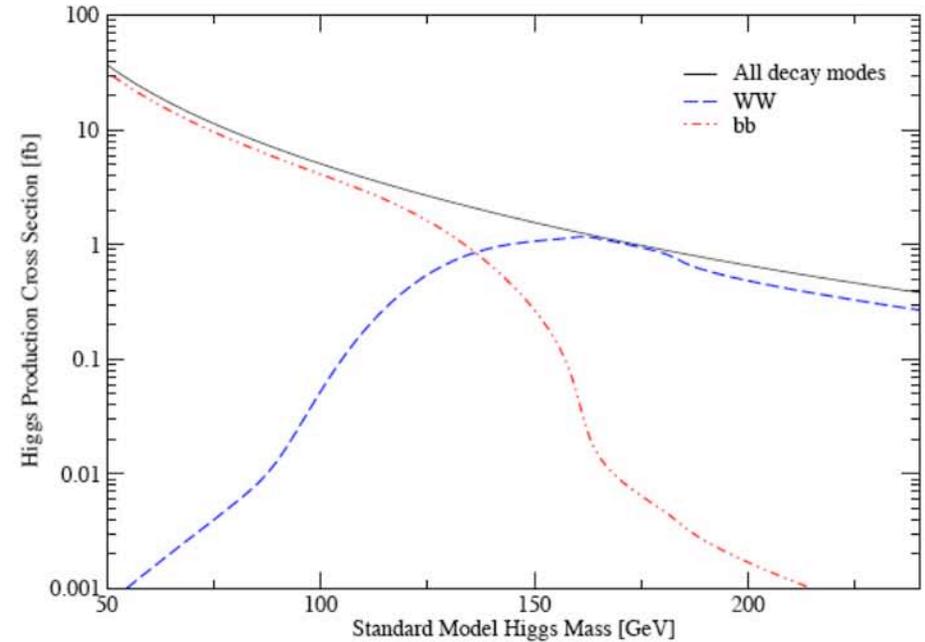
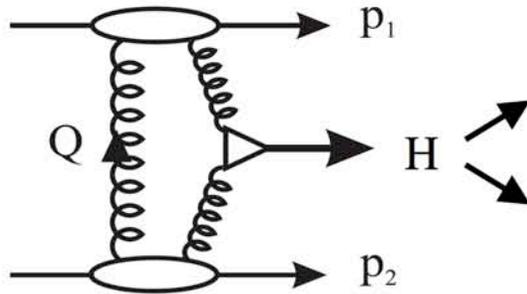
- Selection rules mean that central system is (to a good approx) 0^{++}
- If you see a new particle produced exclusively with proton tags you know its quantum numbers
- Proton tagging may be the discovery channel in certain regions of the MSSM
- Tagging the protons means excellent mass resolution ($\sim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

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

"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), €100 Belgium (+Italy / Finland) (mechanics)

The benchmark : Standard Model Higgs Production



Higgs Quantum Numbers / mass resolution

WW^* : $M_H = 120 \text{ GeV } \sigma = 0.4 \text{ fb}$
 $M_H = 140 \text{ GeV } \sigma = 1 \text{ fb}$
 $M_H = 200 \text{ GeV } \sigma = 0.5 \text{ fb}$

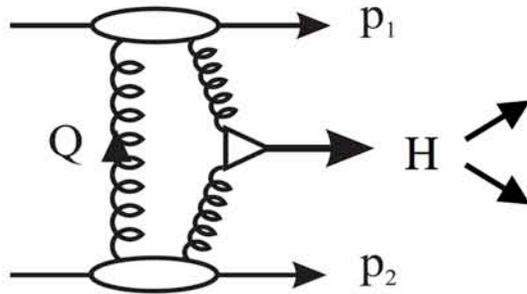
$M_H = 140 \text{ GeV}$: 5 (10) signal (1 (2) "gold plated" dl),
 very small backgrounds in 30 fb^{-1}

Higgs b-decay channel

b jets : $M_H = 120 \text{ GeV } \sigma = 2 \text{ fb}$
 $M_H = 140 \text{ GeV } \sigma = 0.7 \text{ fb}$

0^{++} Selection rule \rightarrow
 QCD Background $\sim \frac{m_b^2}{E_T^2} \frac{\alpha_S^2}{M_{bb}^2 E_i}$

The benchmark : Standard Model Higgs Production



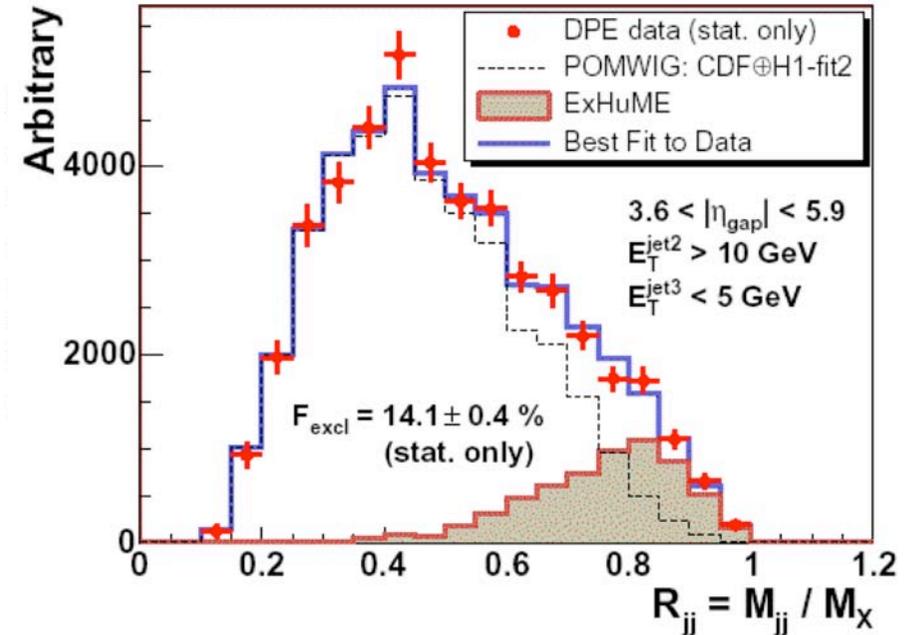
Higgs Quantum Numbers / mass resolution

WW^* : $M_H = 120 \text{ GeV } \sigma = 0.4 \text{ fb}$
 $M_H = 140 \text{ GeV } \sigma = 1 \text{ fb}$
 $M_H = 200 \text{ GeV } \sigma = 0.5 \text{ fb}$

$M_H = 140 \text{ GeV}$: 5 (10) signal (1 (2) "gold plated" dl),
 very small backgrounds in 30 fb^{-1}

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

CDF Run II Preliminary

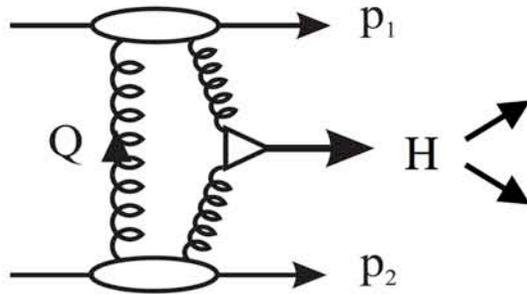


Higgs b-decay channel

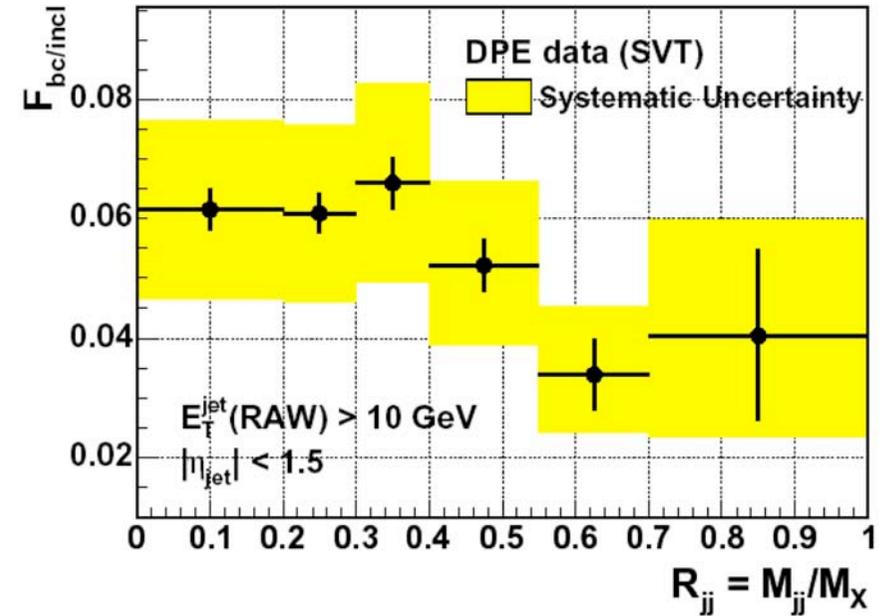
$b \text{ jets}$: $M_H = 120 \text{ GeV } \sigma = 2 \text{ fb}$
 $M_H = 140 \text{ GeV } \sigma = 0.7 \text{ fb}$

0^{++} Selection rule \rightarrow
 QCD Background $\sim \frac{m_b^2}{E_T^2} \frac{\alpha_S^2}{M_{bb}^2 E_T}$

The benchmark : Standard Model Higgs Production



CDF Run II Preliminary



Higgs Quantum Numbers / mass resolution

WW^* : $M_H = 120 \text{ GeV } \sigma = 0.4 \text{ fb}$
 $M_H = 140 \text{ GeV } \sigma = 1 \text{ fb}$
 $M_H = 200 \text{ GeV } \sigma = 0.5 \text{ fb}$

$M_H = 140 \text{ GeV}$: 5 (10) signal (1 (2) "gold plated" dl),
 very small backgrounds in 30 fb^{-1}

Higgs b-decay channel

b jets : $M_H = 120 \text{ GeV } \sigma = 2 \text{ fb}$
 $M_H = 140 \text{ GeV } \sigma = 0.7 \text{ fb}$

O^{++} Selection rule \rightarrow
 QCD Background $\sim \frac{m_b^2}{E_T^2} \frac{\alpha_S^2}{M_{bb}^2 E_T}$

FP420 Discovery scenarios

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

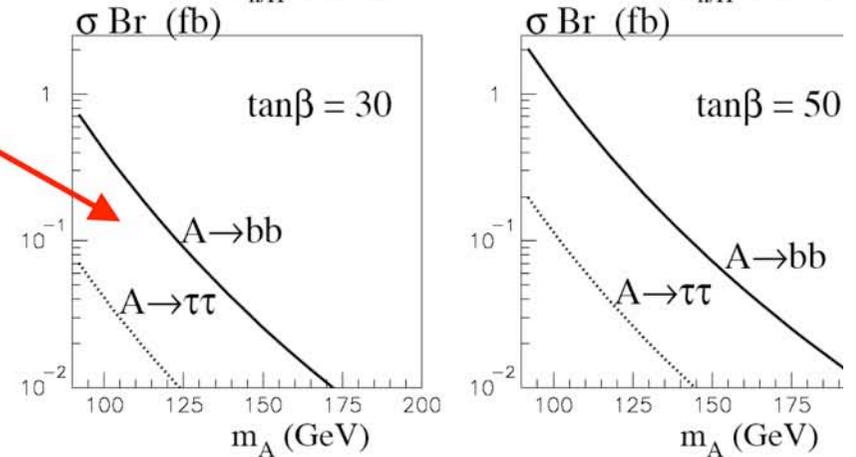
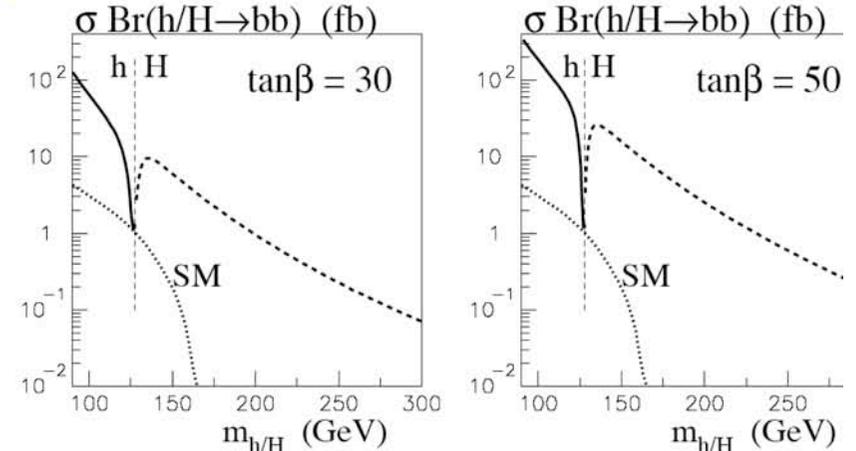
$M_A = 130 \text{ GeV}, \tan \beta = 50$

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

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

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

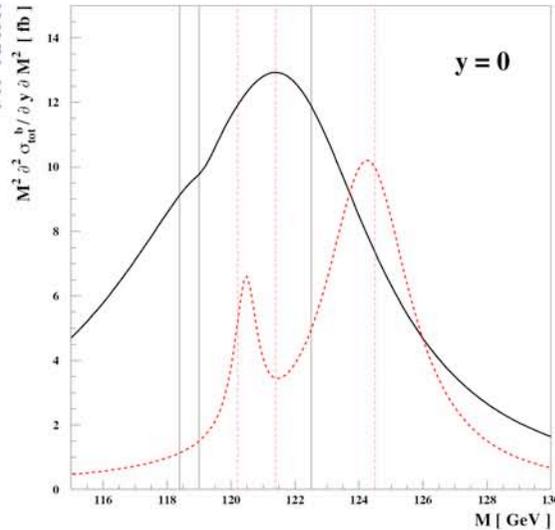
Central exclusive diffractive production



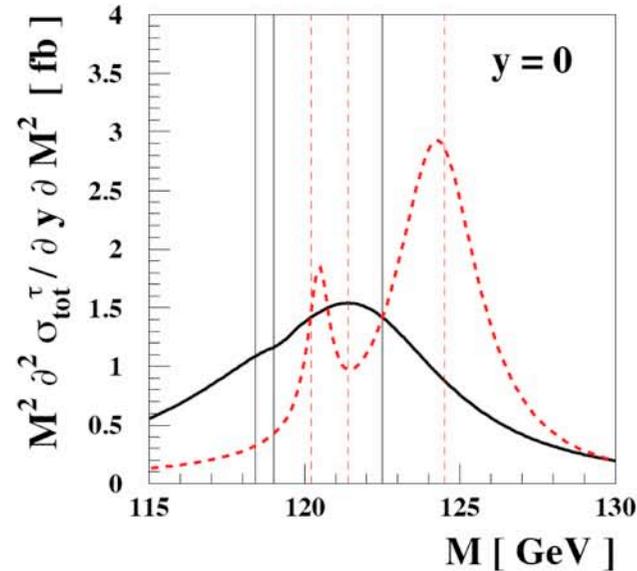
Well known difficult region for conventional channels, tagged channel may well be the discovery channel, and is certainly a powerful spin/parity filter



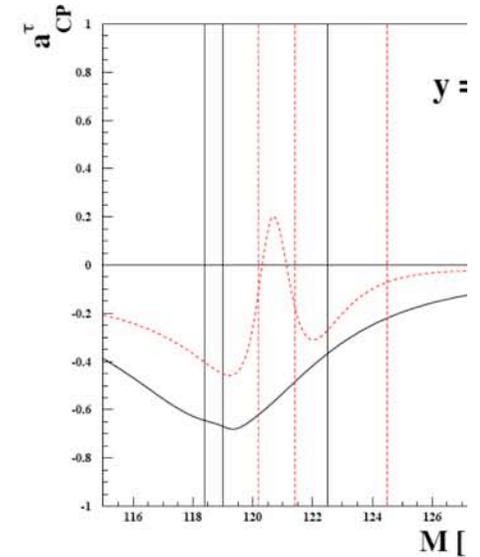
bb decay



$\tau\tau$ decay



$\tau\tau$ 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.

FP420 R&D Collaboration

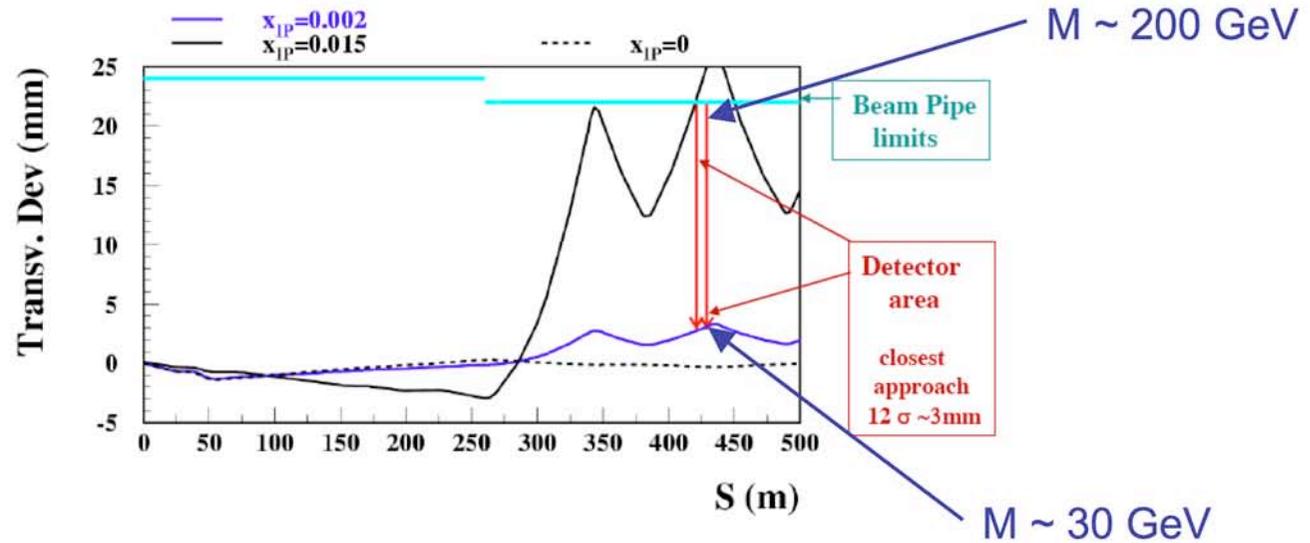
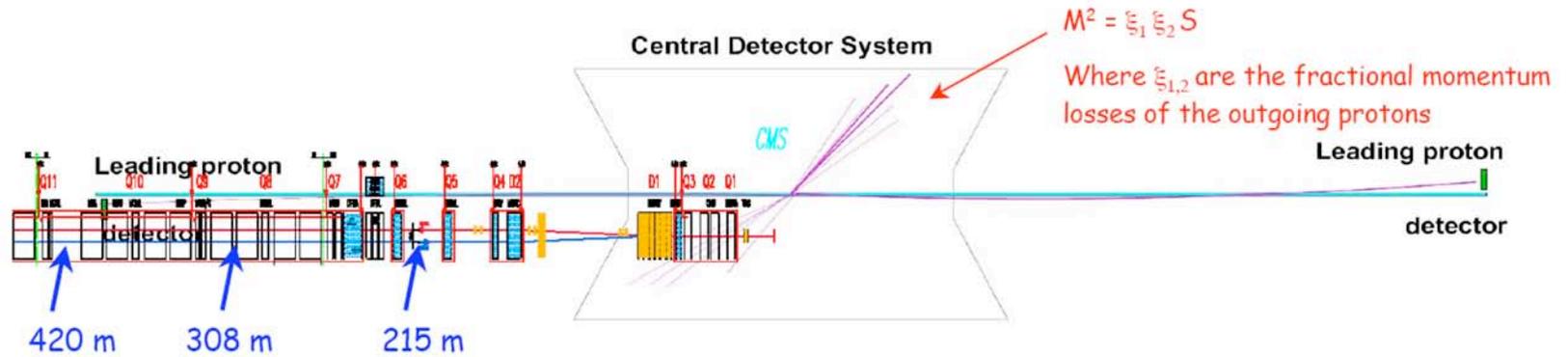
- **Spokes** : Brian Cox (Manchester, ATLAS) and Albert DeRoeck (CERN,CMS)
- **Technical Co-ordinator** : Cinzia DaVia (Manchester)

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

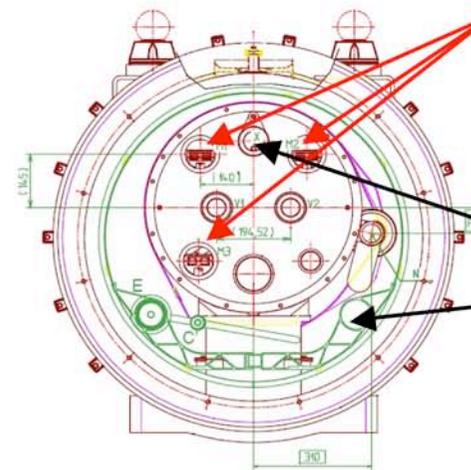
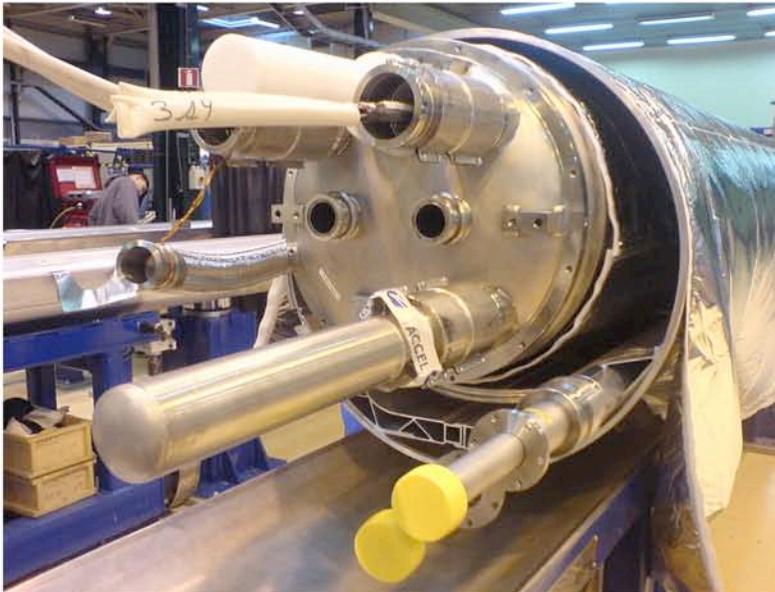
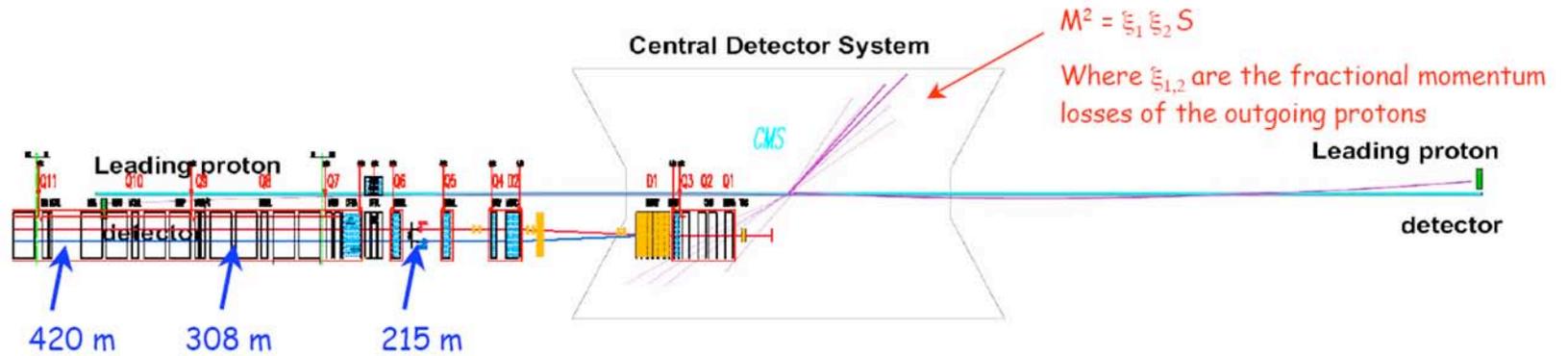
FP420 Schematic Outline



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



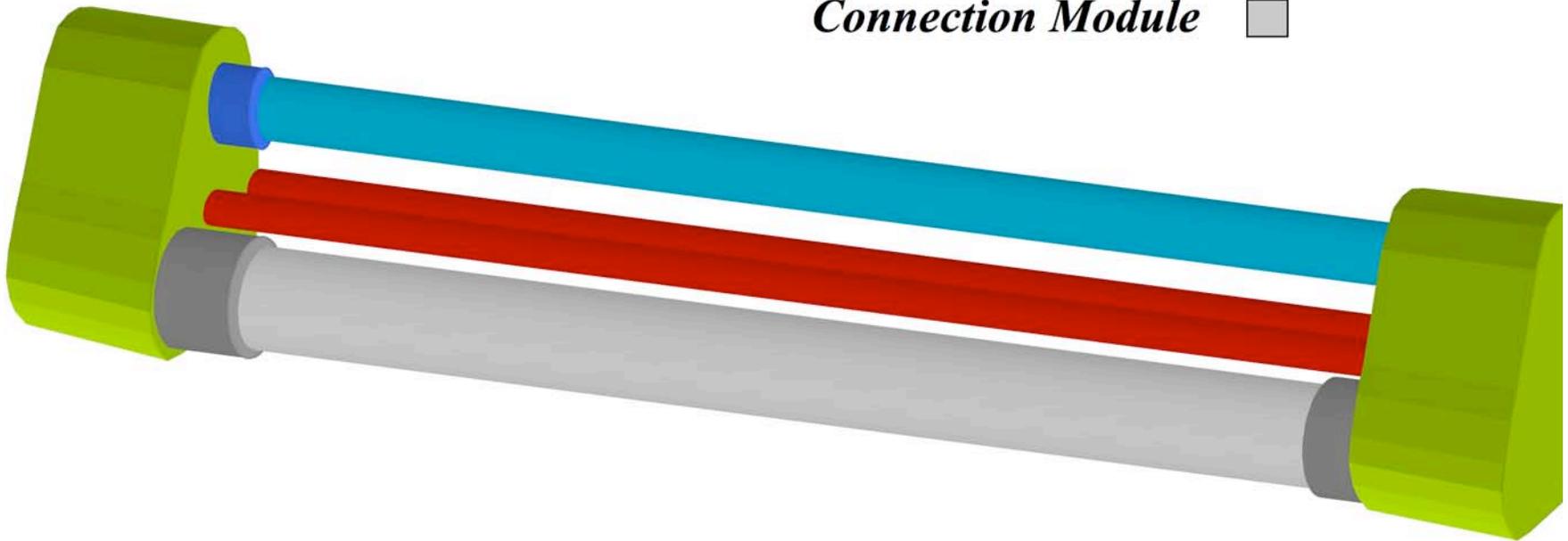
The 420m region at the LHC



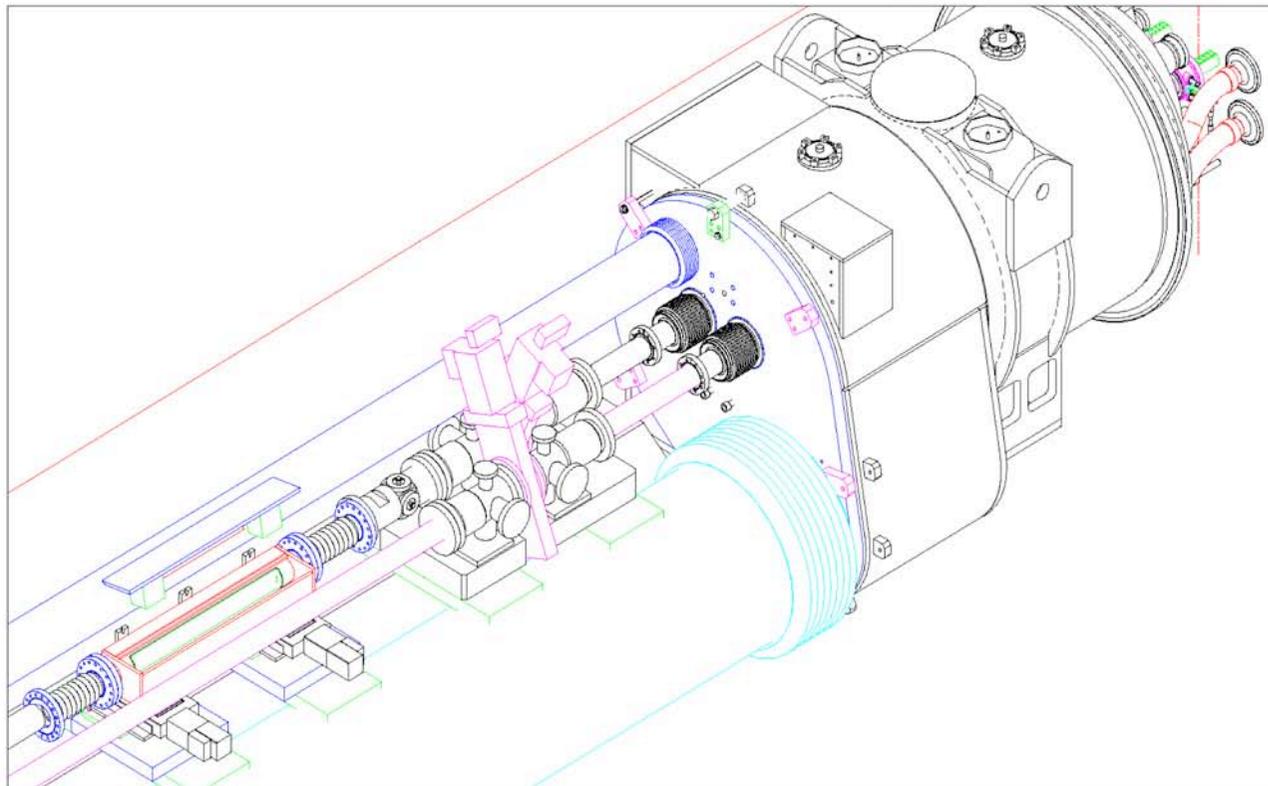
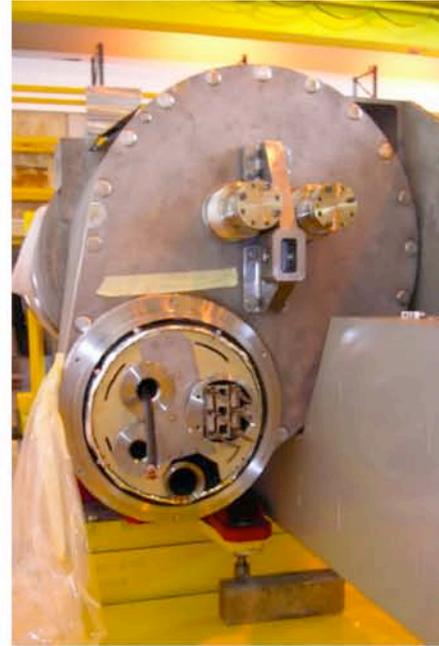
Line	T(K)	$\phi_i - \phi_e$
M1, M2, M3 Bus-bars	1.9	80-8
N Auxiliary bus-bars	1.9	50-5
X Heat exchanger	1.8	54-5
E Thermal shield	50-65	79-8
C' Supports posts and beam screens	4.6	15-17
V1, V2 He jackets	1.9	50-5 66-7

The FP420 connection cryostat :

- ATM module* ■
- Beam tubes* ■
- Line X vacuum vessel* ■
- Connection Module* ■

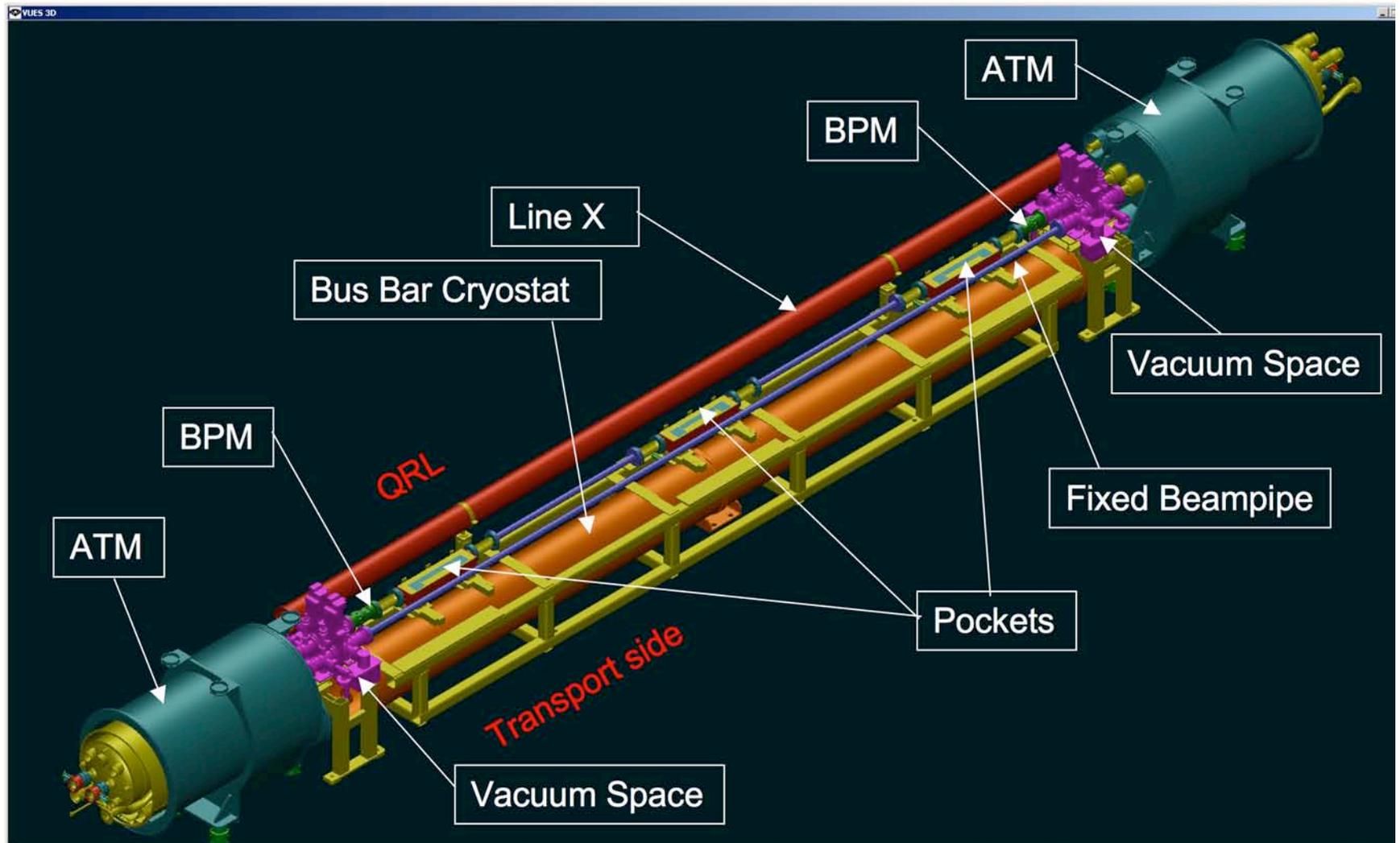


FP420 ATMs

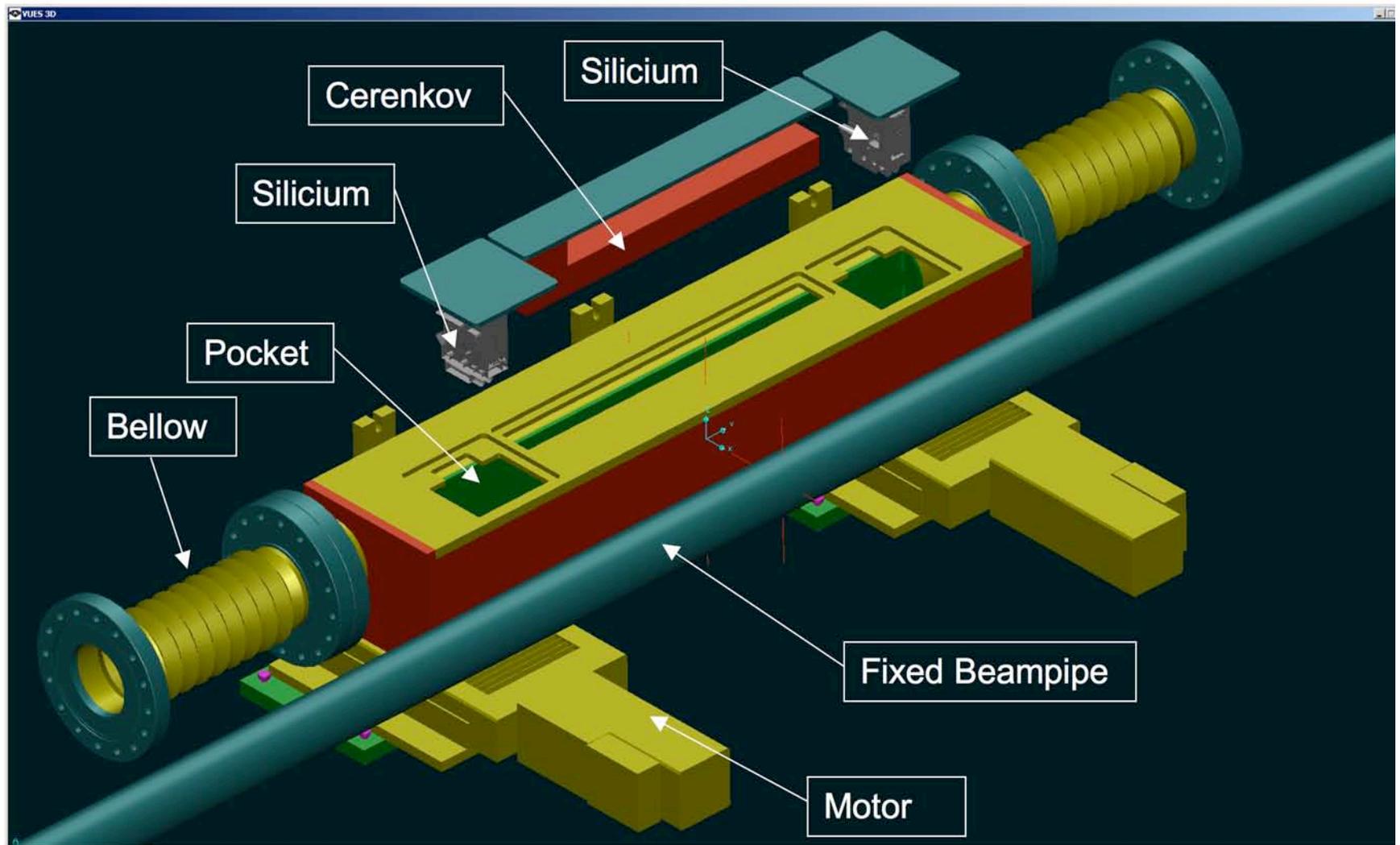


T. Colombet,
T. Renaglia,
R. Folch

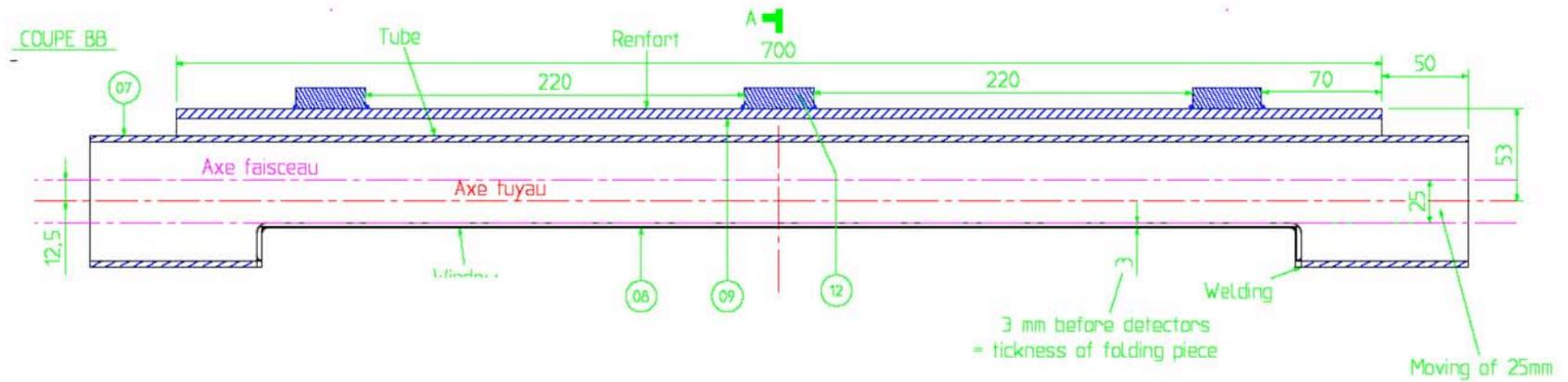
Integration of the moving beampipe and detectors



Integration of the moving beampipe and detectors

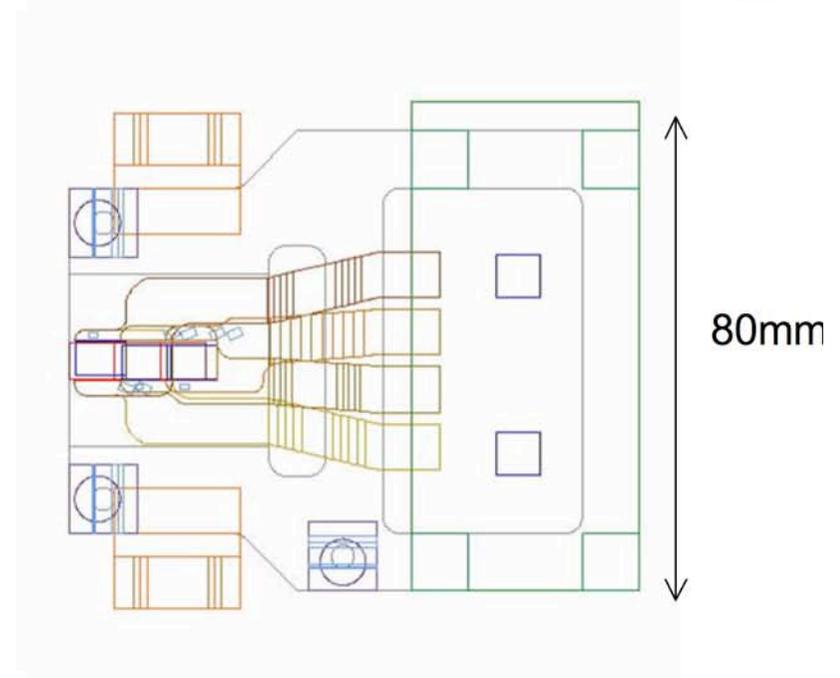
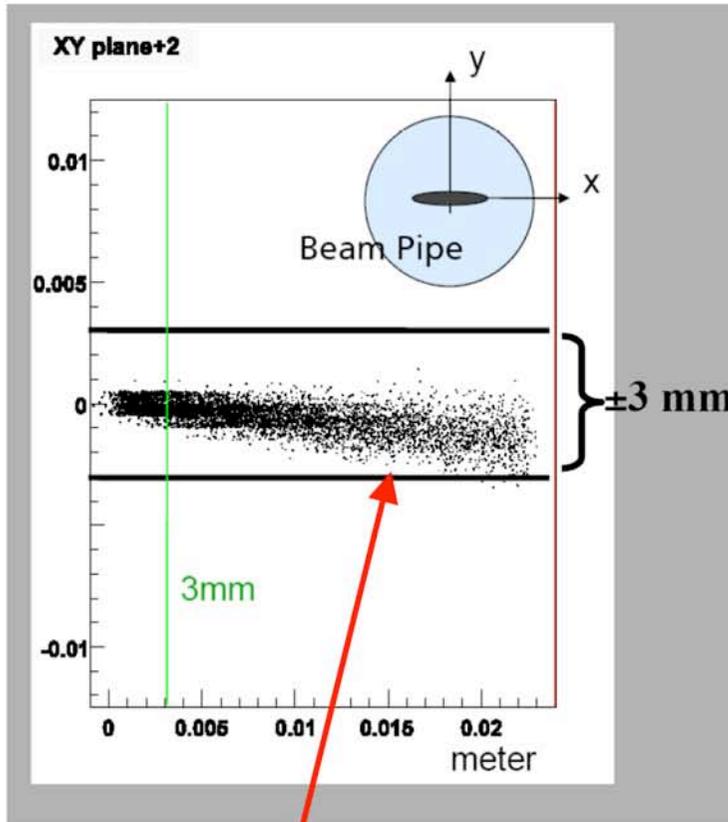


Prototype FP420 Pocket



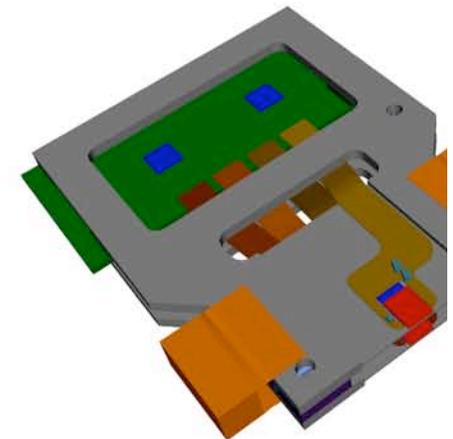
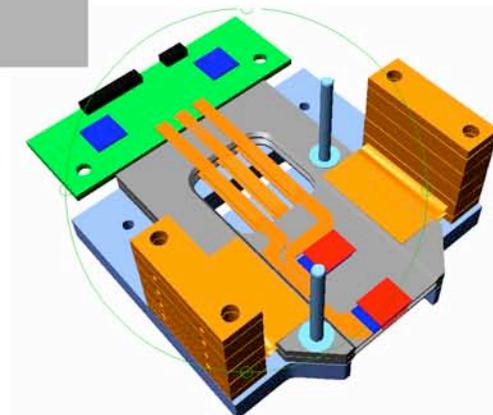
Pocket prototype constructed at Louvain and undergoing simulation and wire-testing at Cockcroft Institute for trapped modes, beam stability etc.

FP420 Silicon Detector Stations

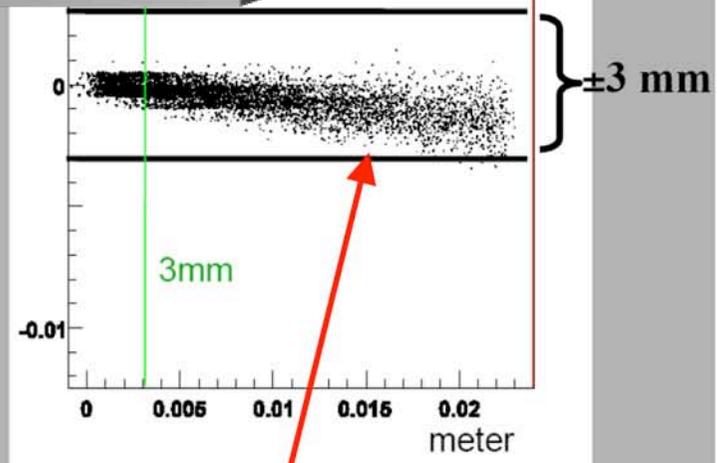
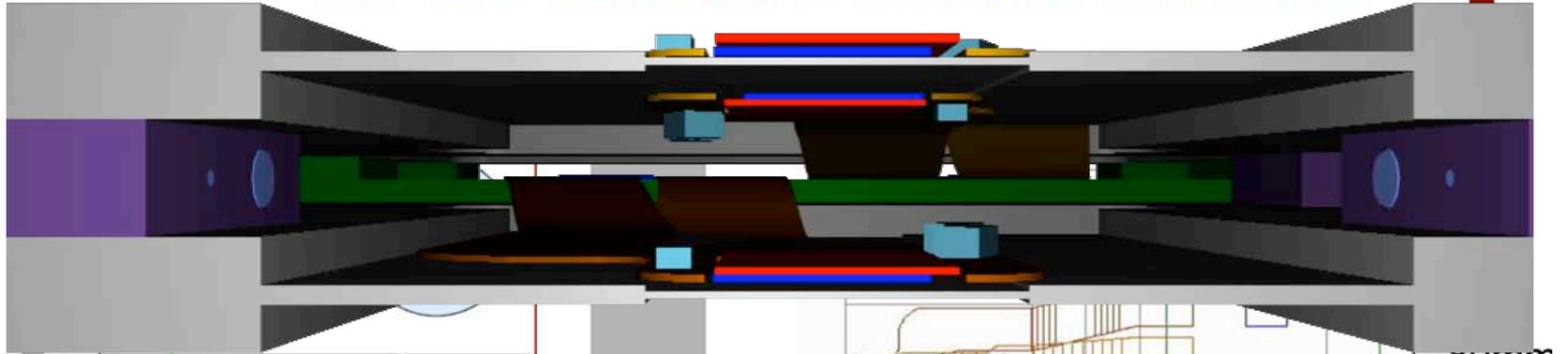


7.2 mm x 24mm (7.2 x 8 mm² sensors)

FP420 Mask



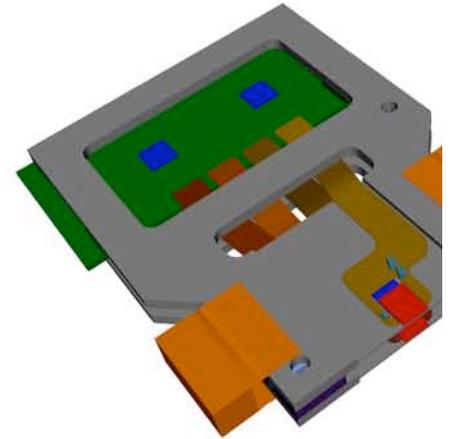
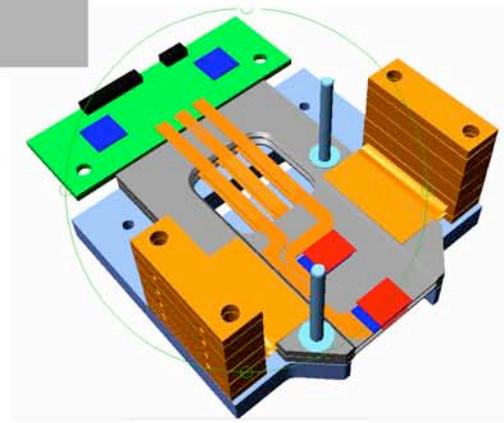
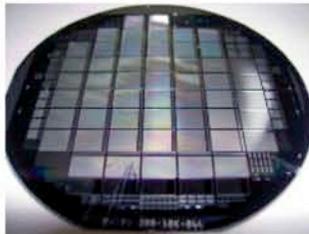
FP420 Silicon Detector Stations

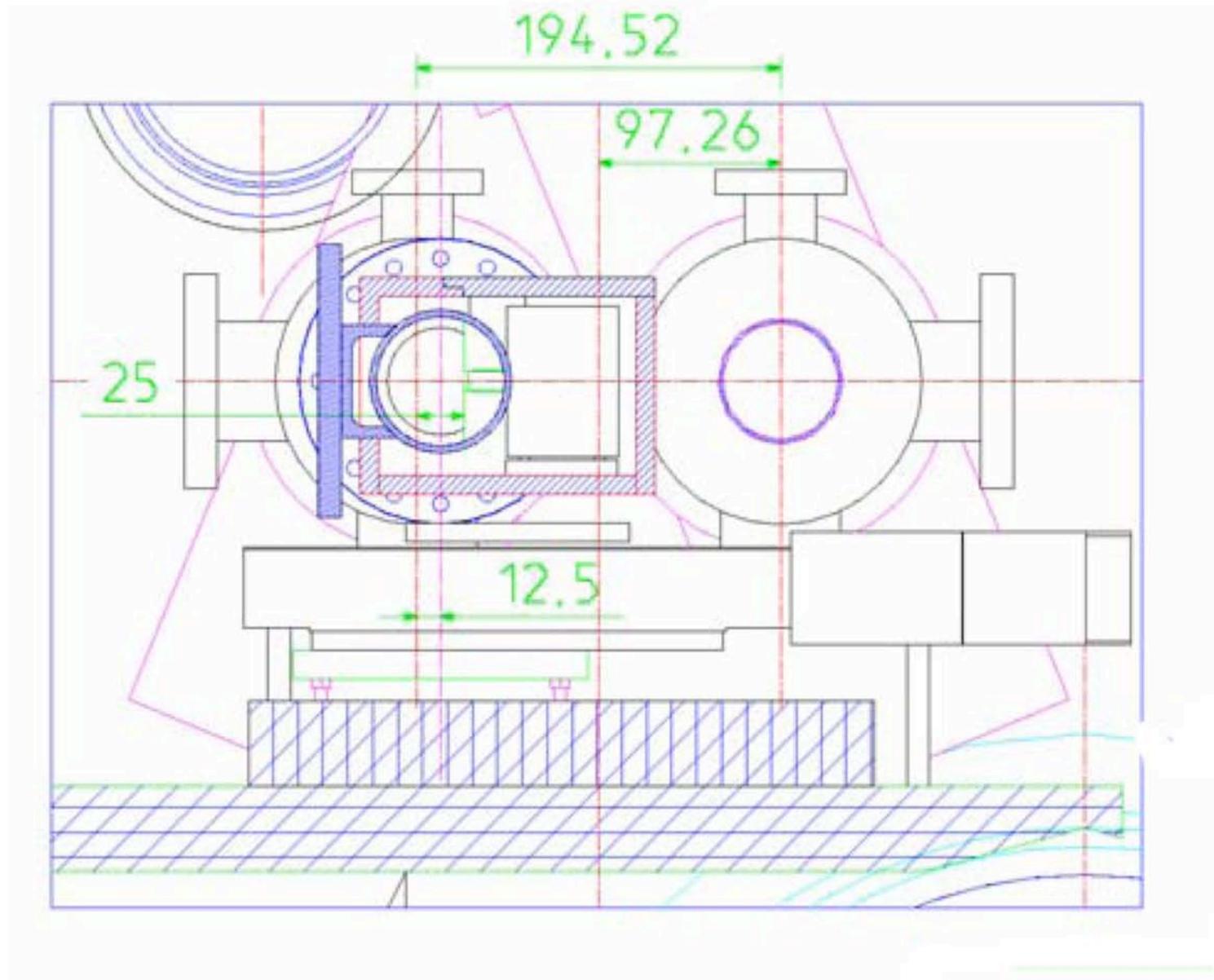


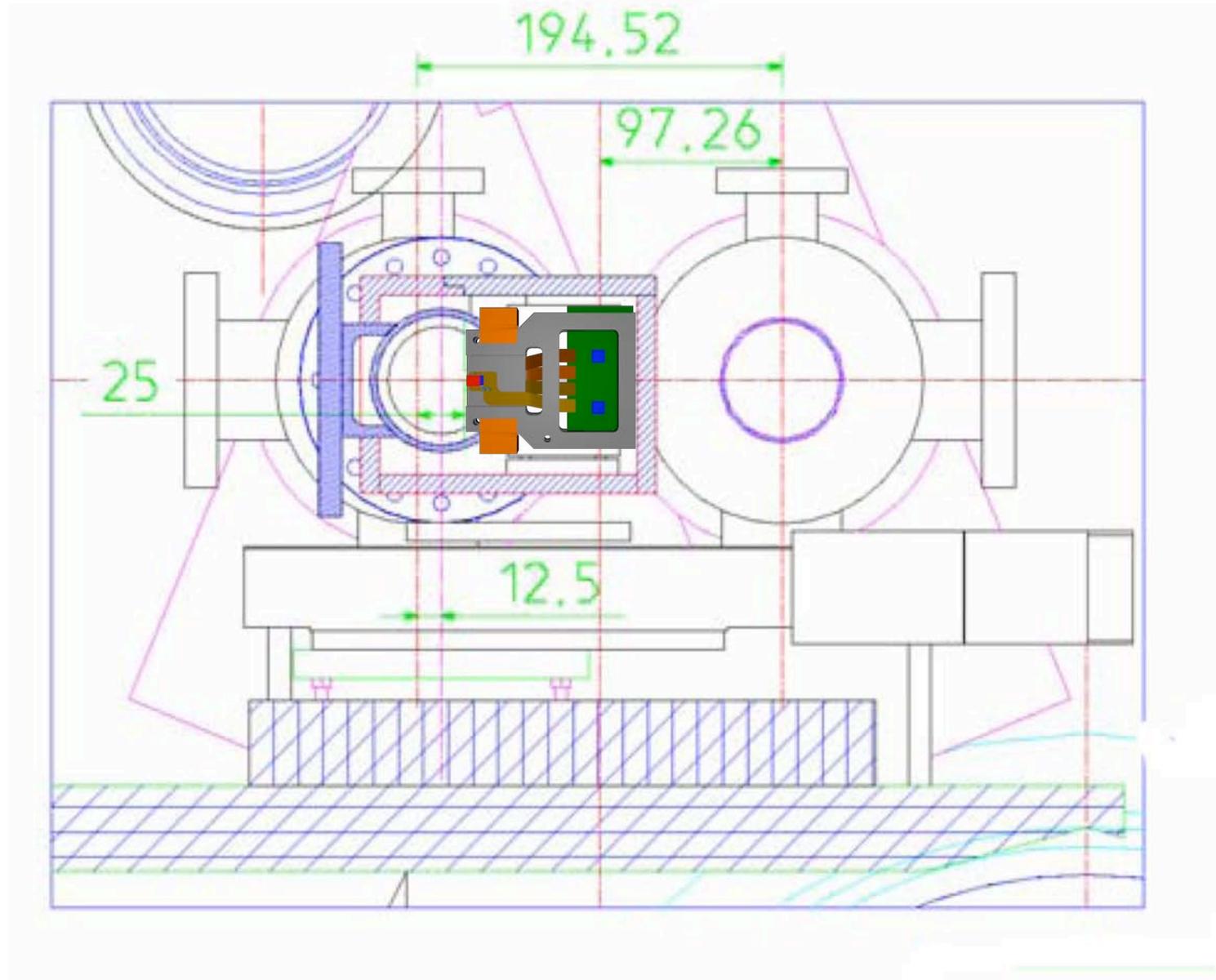
80mm

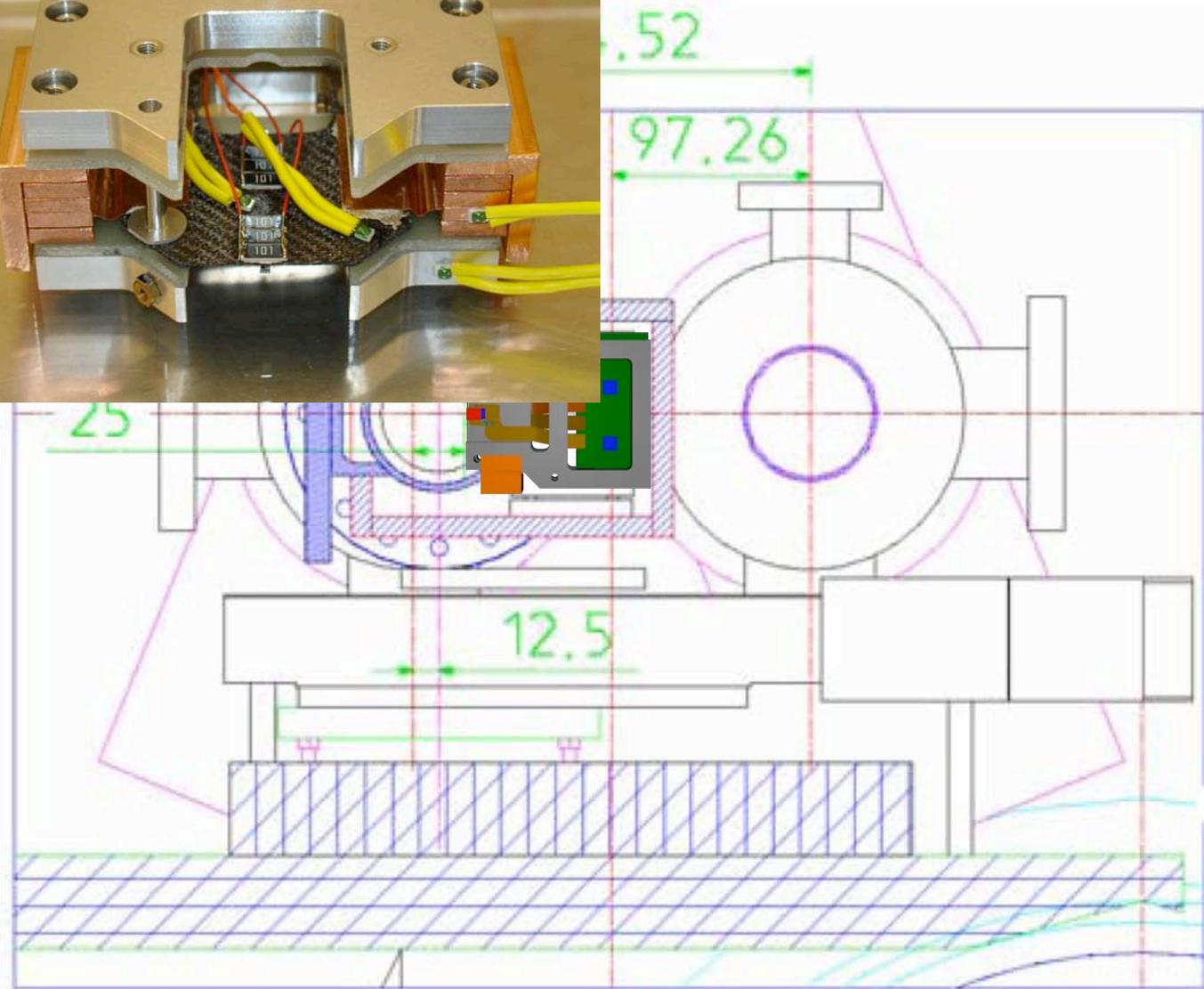
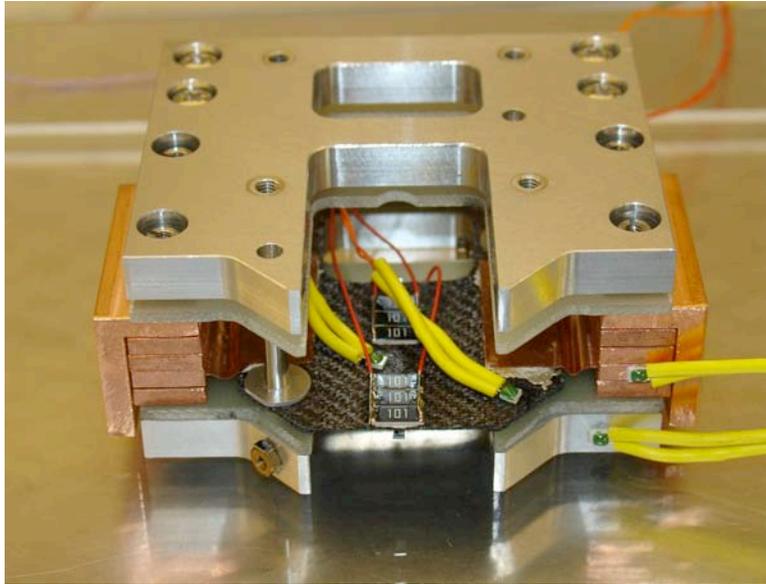
7.2 mm x 24mm (7.2 x 8 mm² sensors)

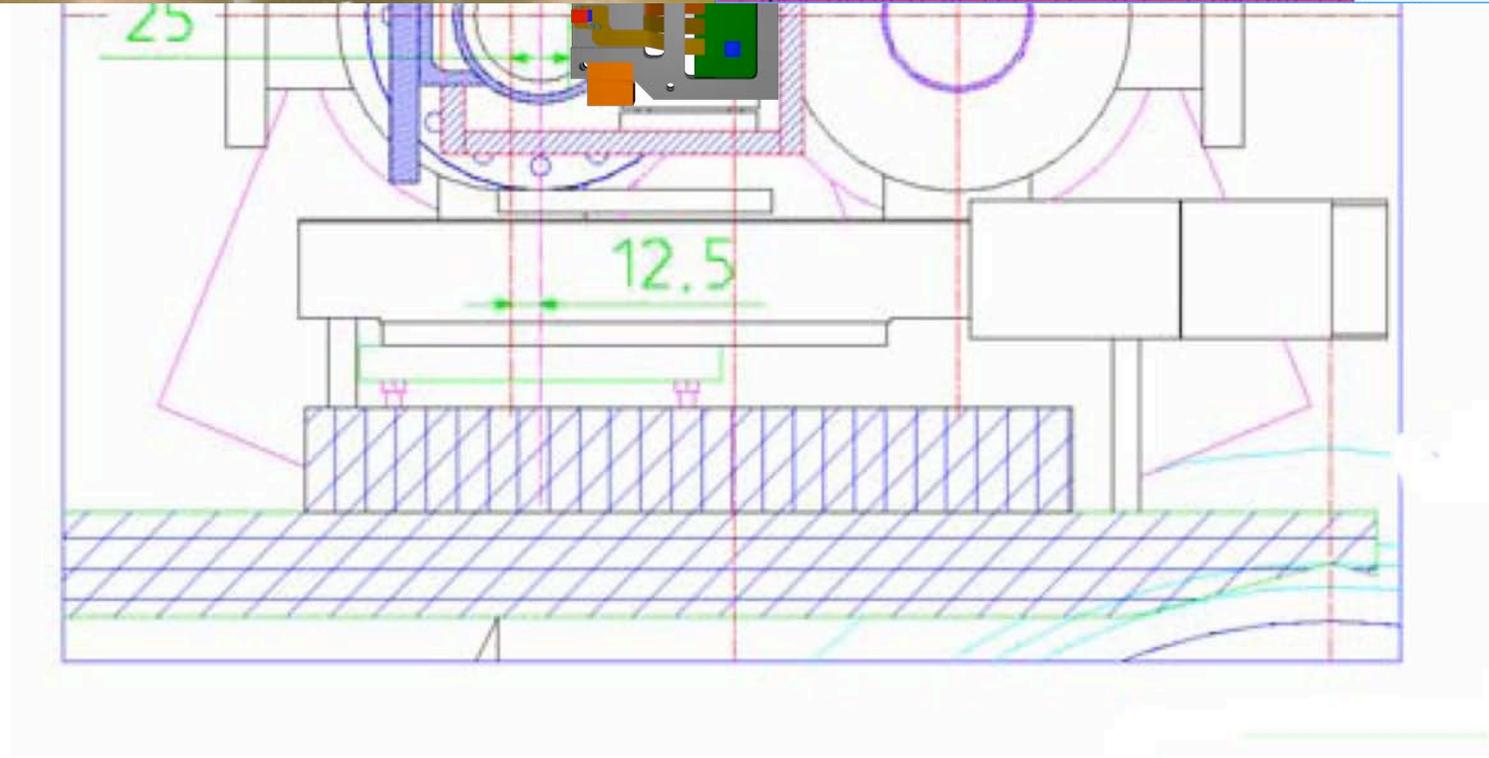
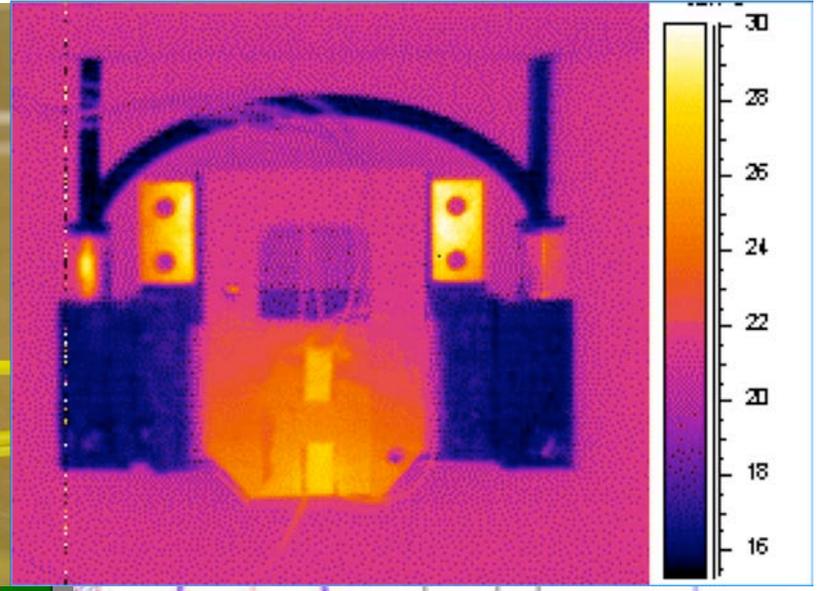
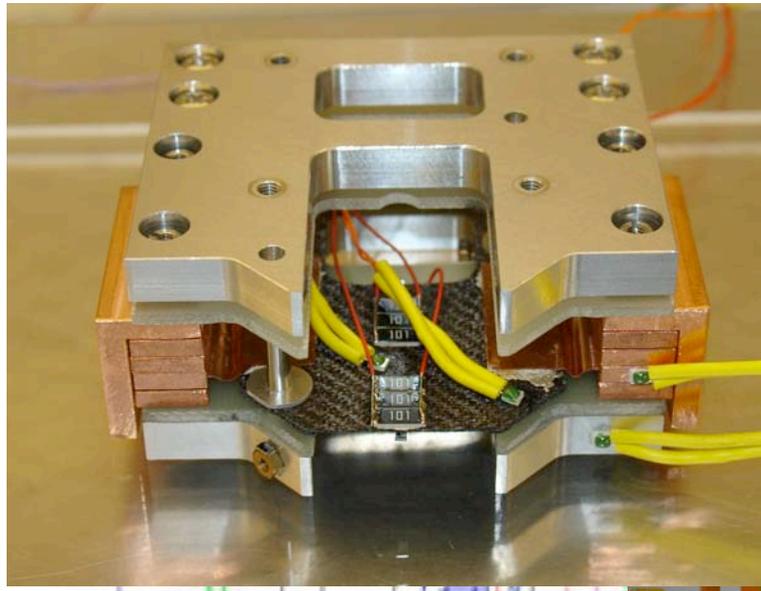
FP420 Mask

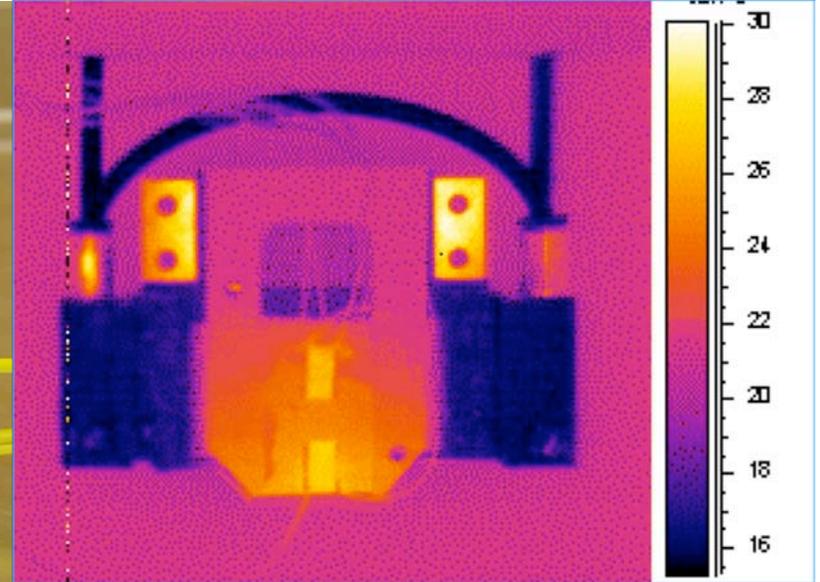
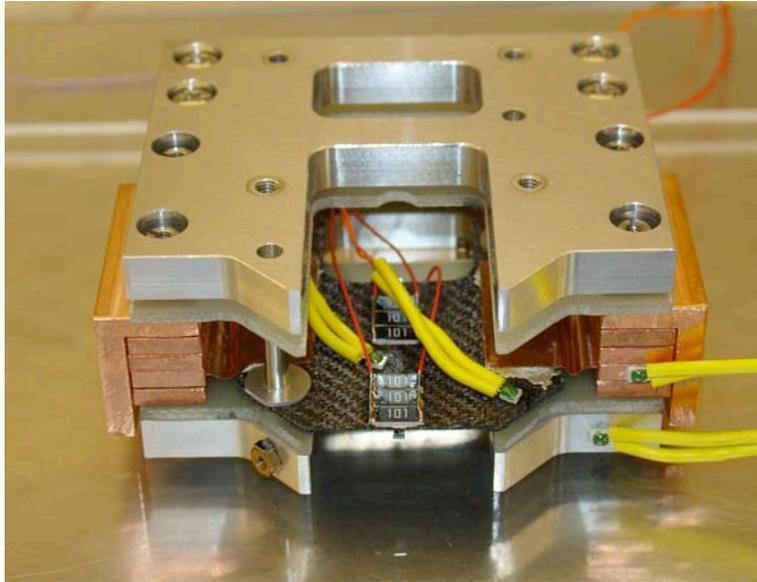








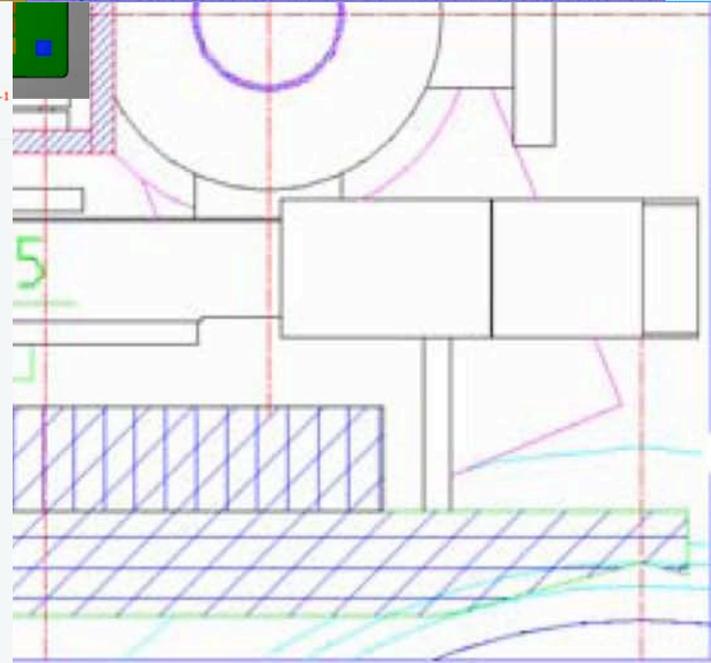
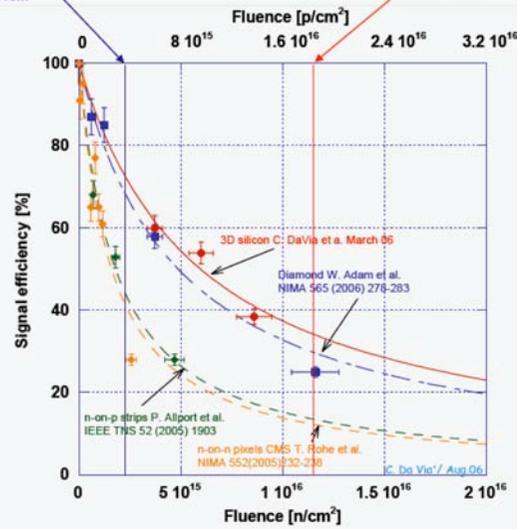


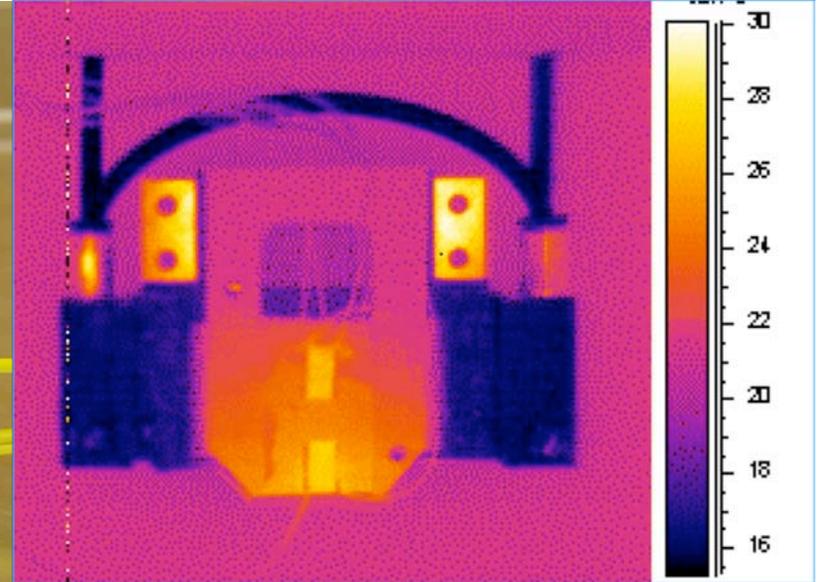
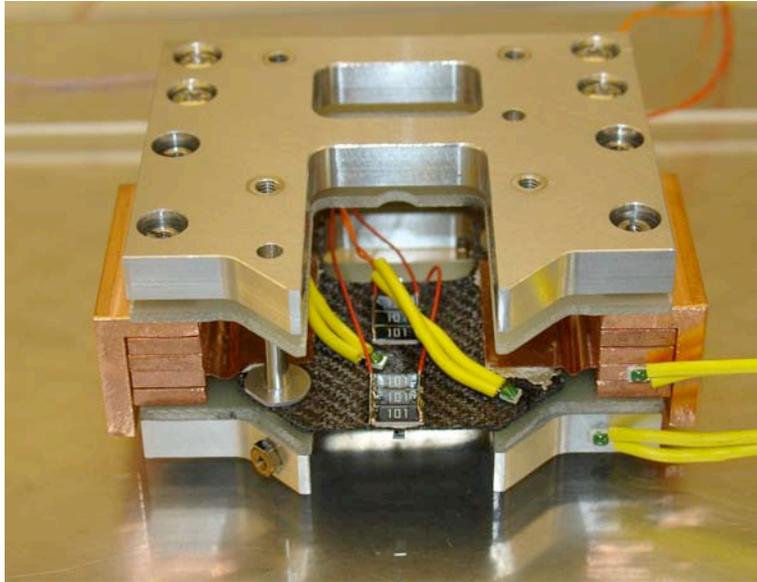


Radiation Hardness

$3 \times 10^{15} \text{ p/cm}^2 =$
10 years LHC at $10^{34} \text{ cm}^{-2}\text{s}^{-1}$
At $r=4\text{cm}$

$1.8 \times 10^{16} \text{ p/cm}^2 =$
10 years SLHC at $10^{36} \text{ cm}^{-2}\text{s}^{-1}$
At $r=4\text{cm}$

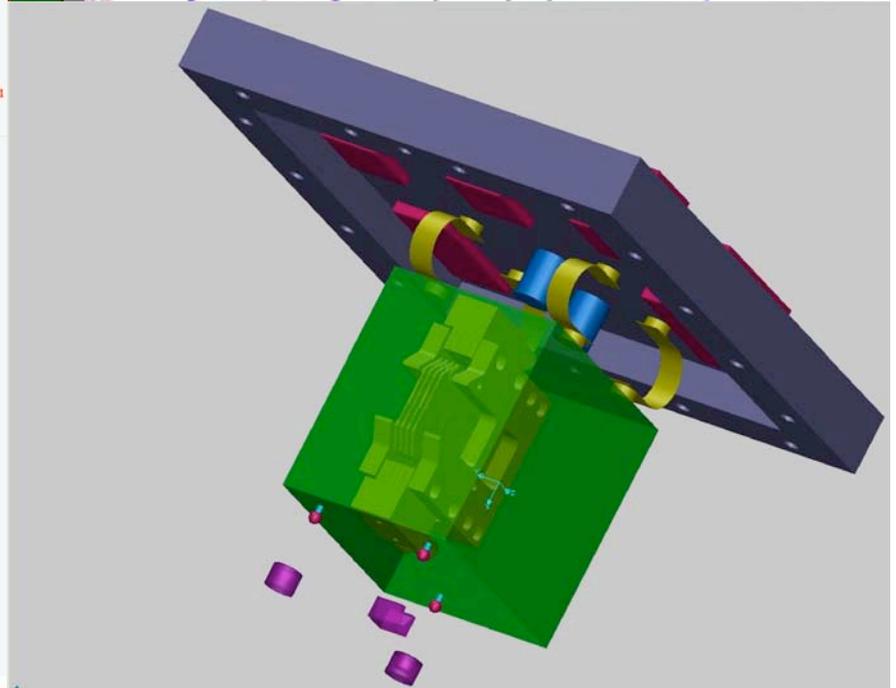
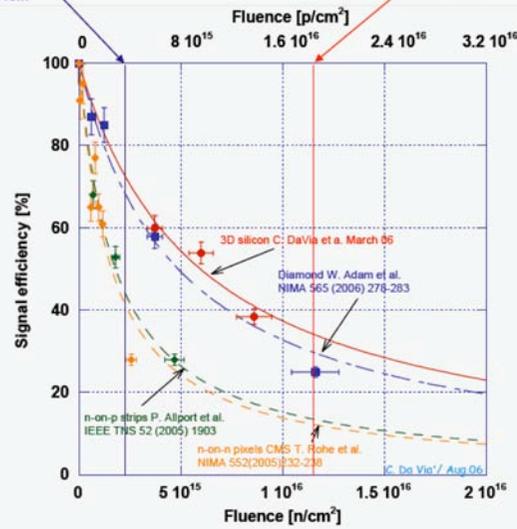




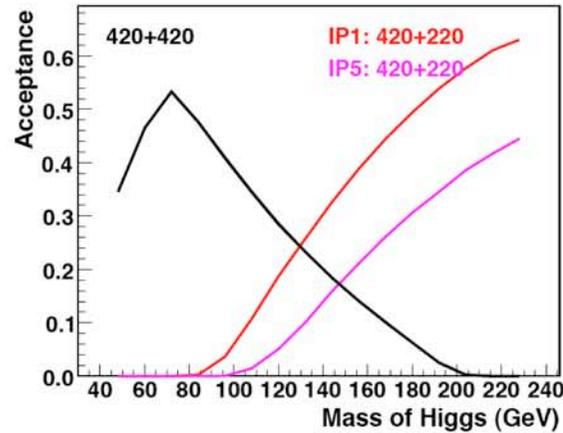
Radiation Hardness

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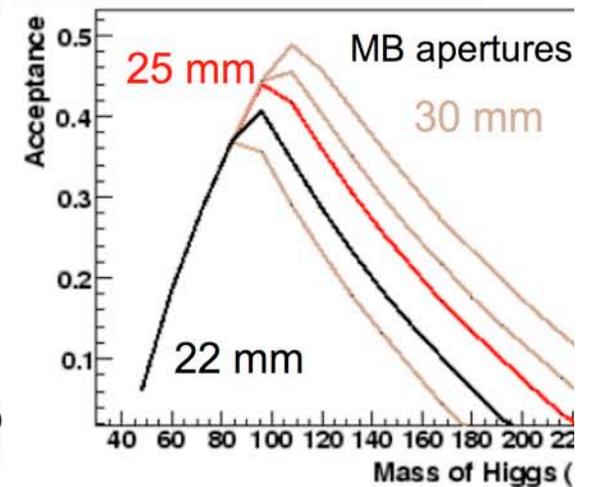
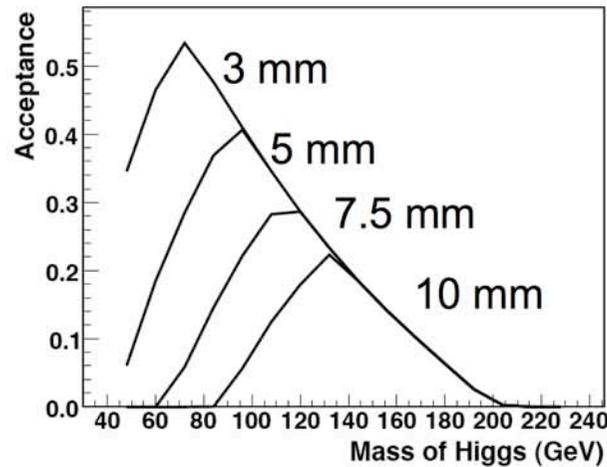
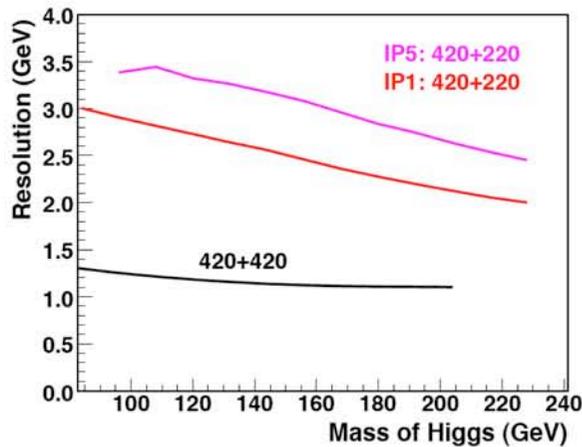
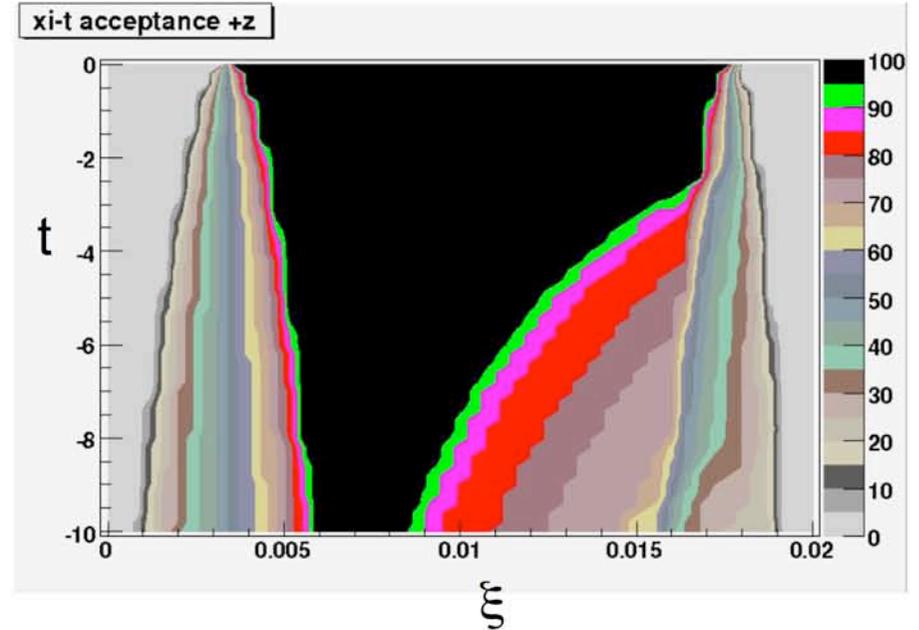
$1.8 \times 10^{16} \text{ p/cm}^2 =$
10 years SLHC at $10^{36} \text{ cm}^{-2}\text{s}^{-1}$
At $r=4\text{cm}$



FP420 Acceptance and Resolution

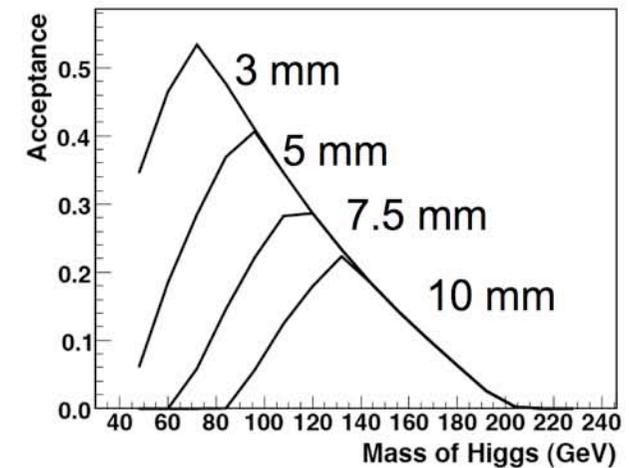
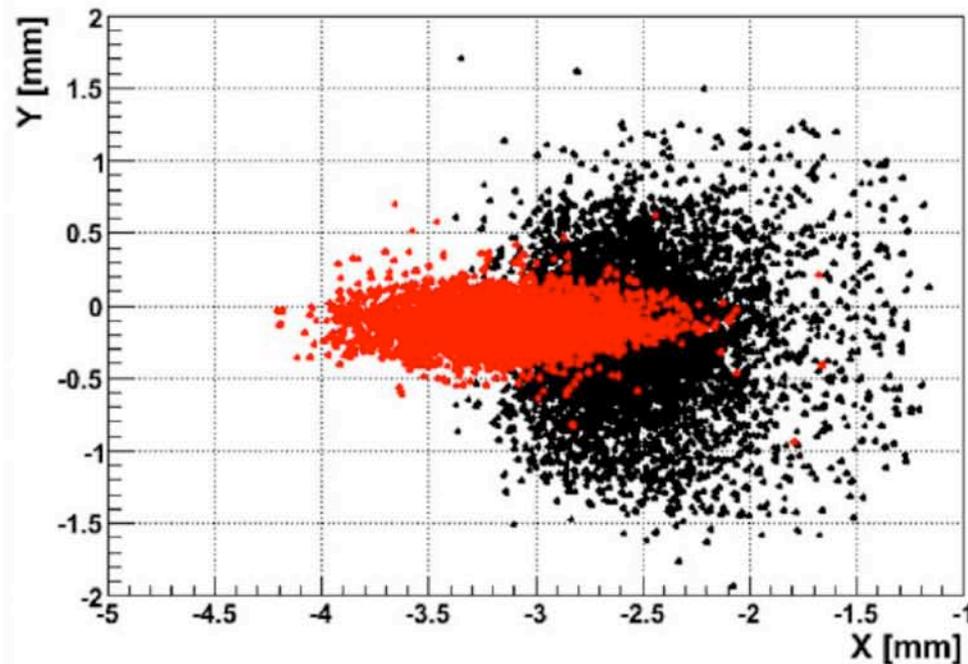


3 mm + 3 mm



Machine Induced Backgrounds

- 20000 momentum cleaning events at IR3 collimators
- Track emerging off-momentum halo protons
- Count hits at FP420 location in $x, x', y, y', dp/p$ until when all protons are absorbed at collimators or other aperture limits (NOT FP420)
- I'll show plots for FP420 IP5



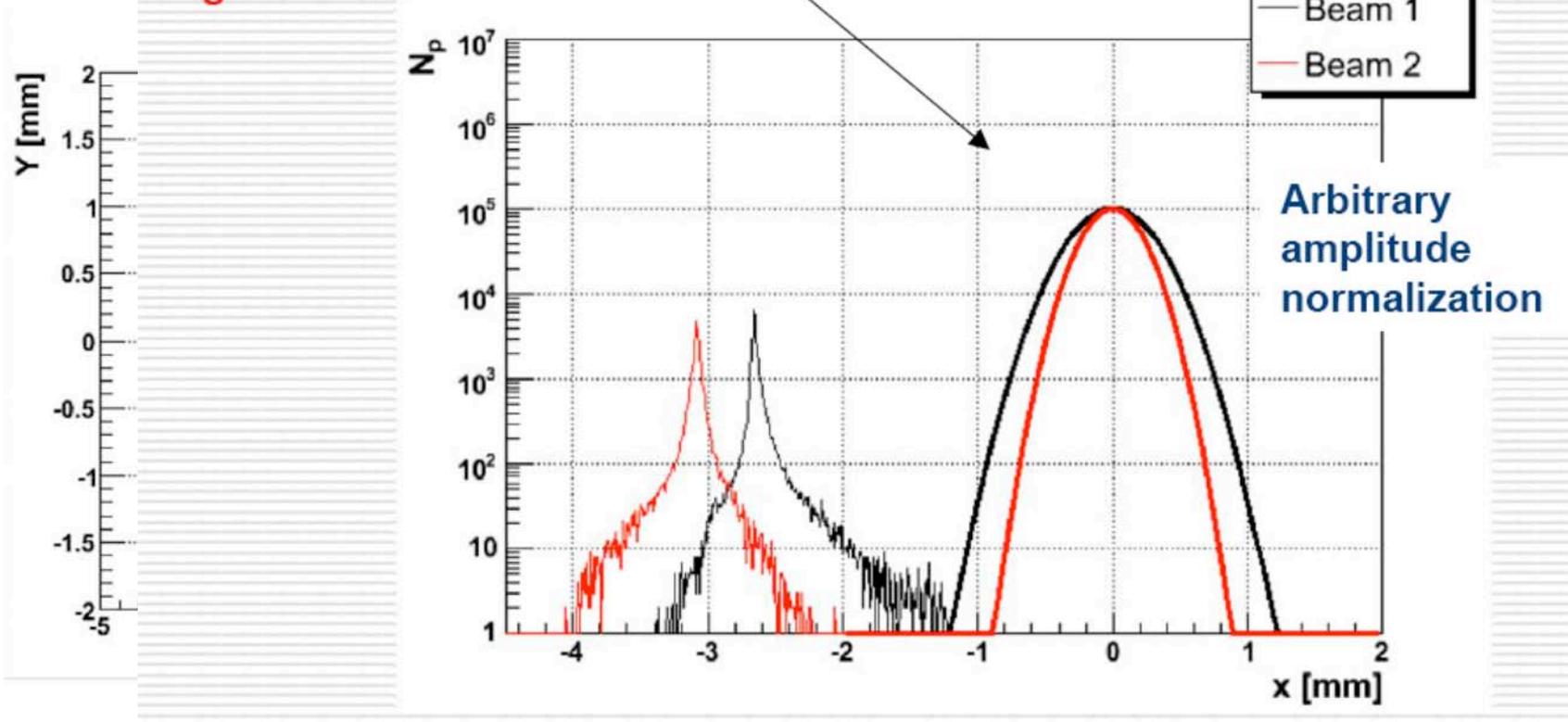
Machine Induced Backgrounds

Hor beam profiles with **nominal optics** and **momentum spread**

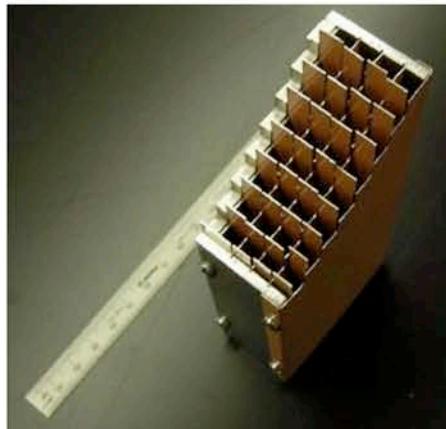
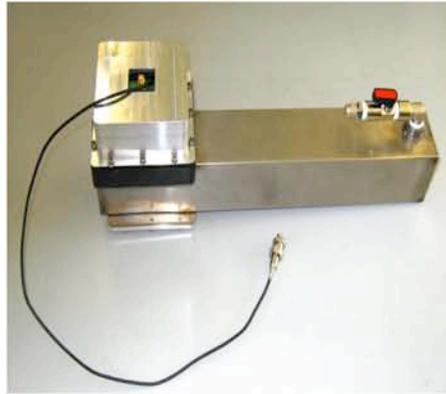
Physical beam sizes:

Sigma1=250um

Sigma2=180



FP420 Fast timing Detectors



Why ? Pileup Background Rejection

E.g., Two protons from SD interactions, and two b-jets from another

How? Compare z-vertex for SVX with TOF

$$z = c(TR - TL) / 2$$

$$\delta z \text{ (mm)} = 0.21 \delta t \text{ (psec)}$$

(2.1 mm for $\delta t = 10$ psec)

10 psec -> x40 rejection

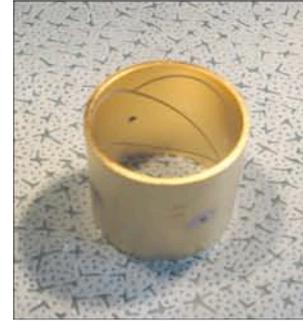
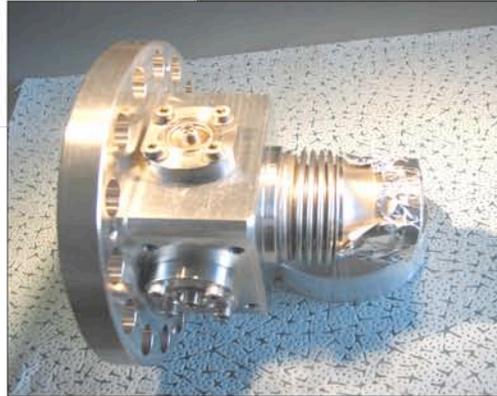
- 1% events at LHC have diffractive proton track in FP420
- @ $2 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$, 7 interactions / bunch crossing
- -> 30% of FP420 events have an additional track
- Matching mass and rapidity of central system removes large fraction of these
- Of the remaining, 97.4% rejected by fast timing detectors with 10ps timing resolution (2.1 m)

Upgrade for T958 Phase II

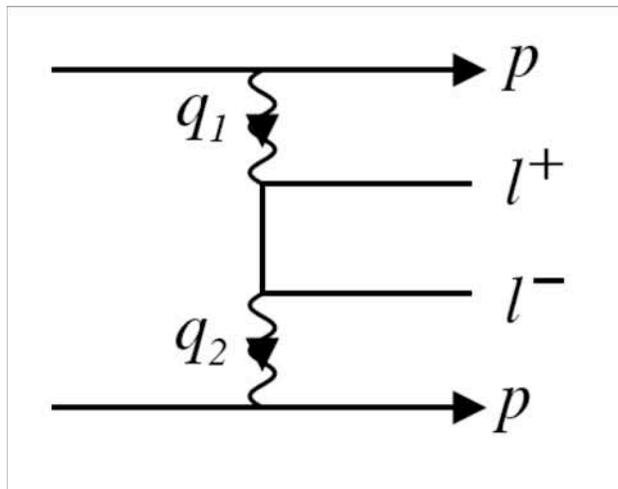
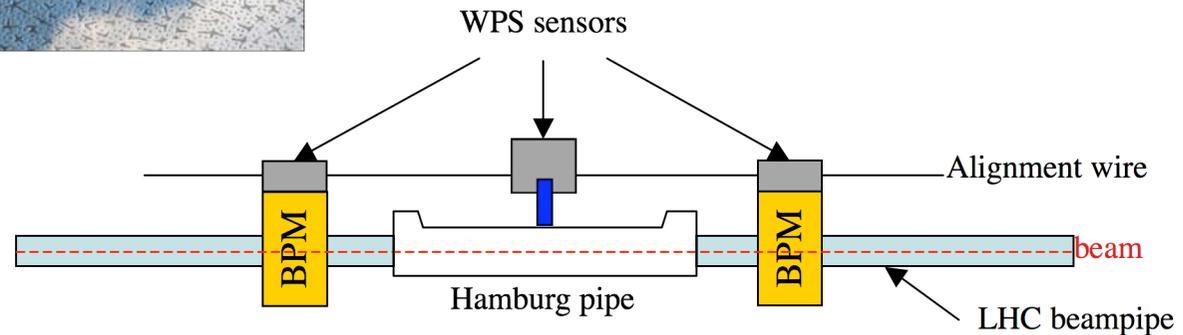
Planned for March 7-20

- New detector prototypes
- New electronics
- Improved DAQ
- Improved alignment
- Automated analysis and database routines, to allow instant and easier analysis
- Improved tracking
- **At present, full QUARTIC + GASTOF would give 40ps. Upgrade expected to give ~ 20ps. Ultimately, with phase 3 improvements expect 11ps. Increase to 2 x QUARTICS would give < 10ps.**

FP420 Alignment



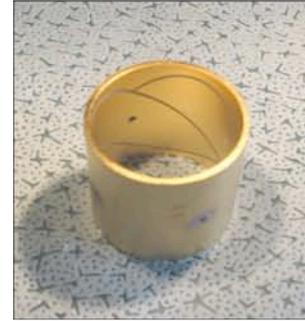
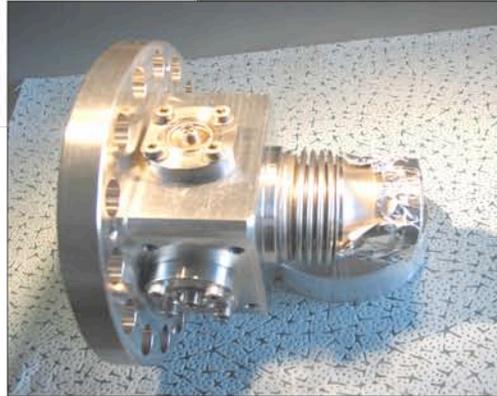
CLIC BPMs + wire positioning system : aim for 10 microns relative to beam



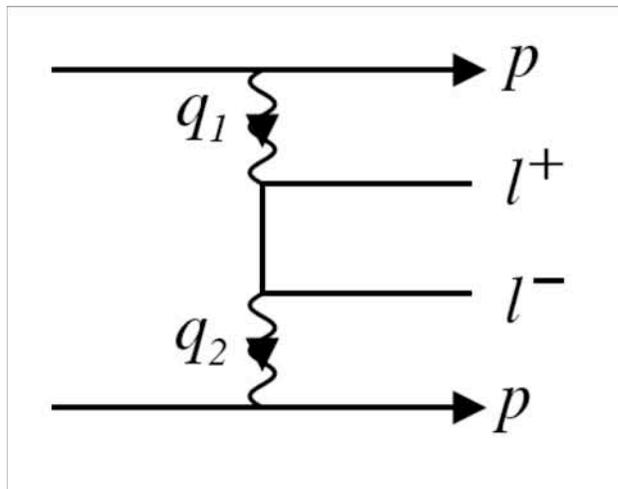
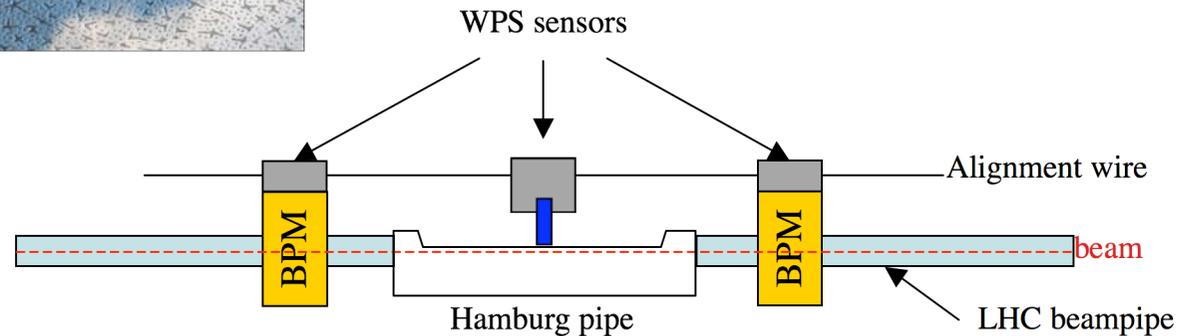
@ $10^{33} \text{ cm}^{-2}\text{s}^{-1}$ with standard ATLAS triggers, have ~ 30 di-muon events / fill in FP420 acceptance

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

FP420 Alignment



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



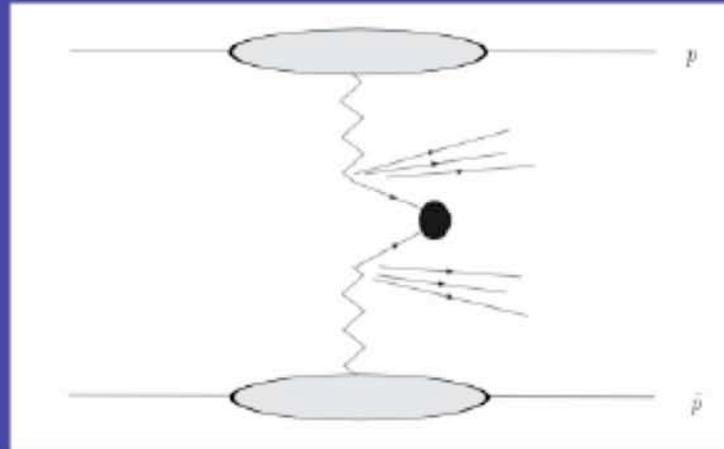
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Thanks to Lars Soby, Rhodri Jones, Helene Mainaud-Duran, Andreas Herty and Robert Boudot

Backgrounds 1: CEP

- Backgrounds are:
 - $pp \rightarrow p + bb + p$ and
 - $pp \rightarrow p + gg + p$ (where both gluons are misidentified as b quarks).
- Quark production is suppressed by m_q^2 / M^2 . This means that bb production is suppressed, but also that light quark backgrounds are negligible.
- These are also produced by ExHuME.

Backgrounds 2: DPE



This type of background is generated using the POMWIG MC.

$$pp \rightarrow p + A + bb + p$$
$$pp \rightarrow p + A + jj + p$$

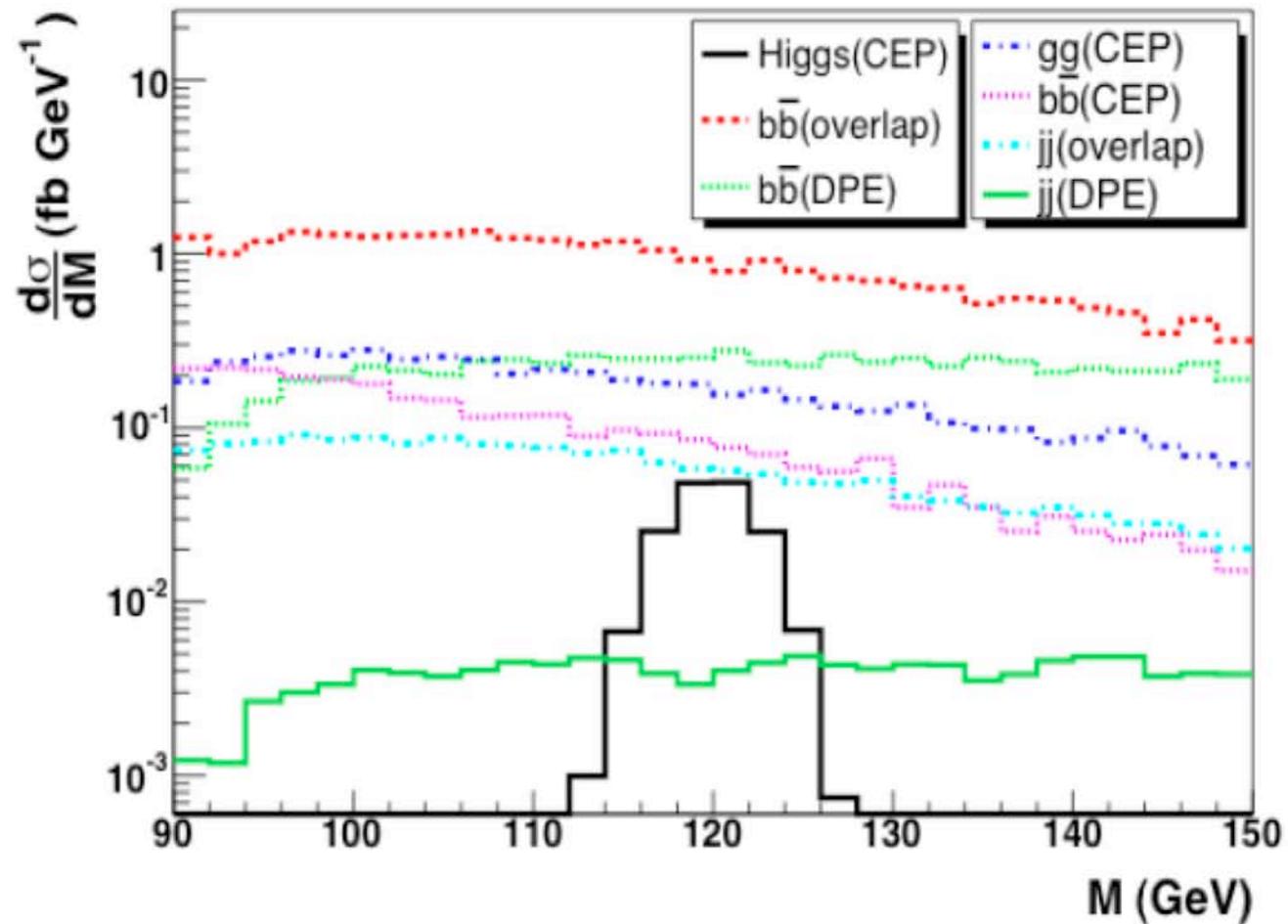
A = other activity in the central system. i.e pomeron remnants.
j = light quark and gluon jets.

Note: $M \neq M_{bb}$

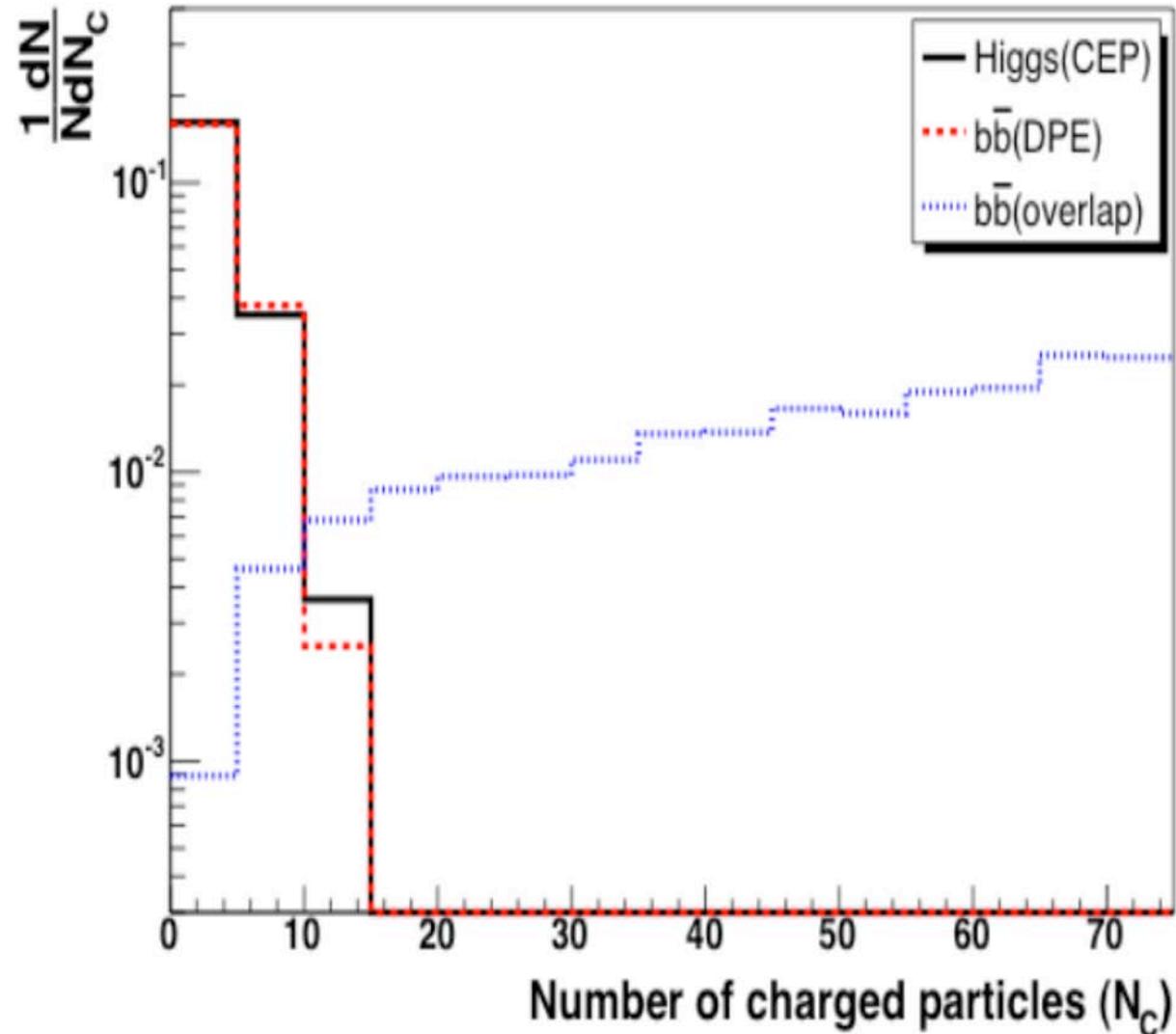
Backgrounds 3: Overlap

- The overlap background is a normal QCD (bb or jj) event + 2 single diffractive events in the same bunch crossing.
- $\sigma_{\text{new}} = (N-1)(N-2) P_i^2 Q \sigma$
 - σ_{new} = observed cross section (fb)
 - N = no. of pile up events (luminosity dependent).
 - Q = quartic rejection factor (Q=0.025)
 - P_i = probability of pile up event being single diffractive which produces a proton and causes a hit in FP420 .
 - σ = input cross section for the QCD event.

After basic cuts, smearing according to ATLAS TDR and FP420 beam simulation, with overlap calculated at $2 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$



After basic cuts, smearing according to ATLAS TDR and FP420 beam simulation, with overlap calculated at $2 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$



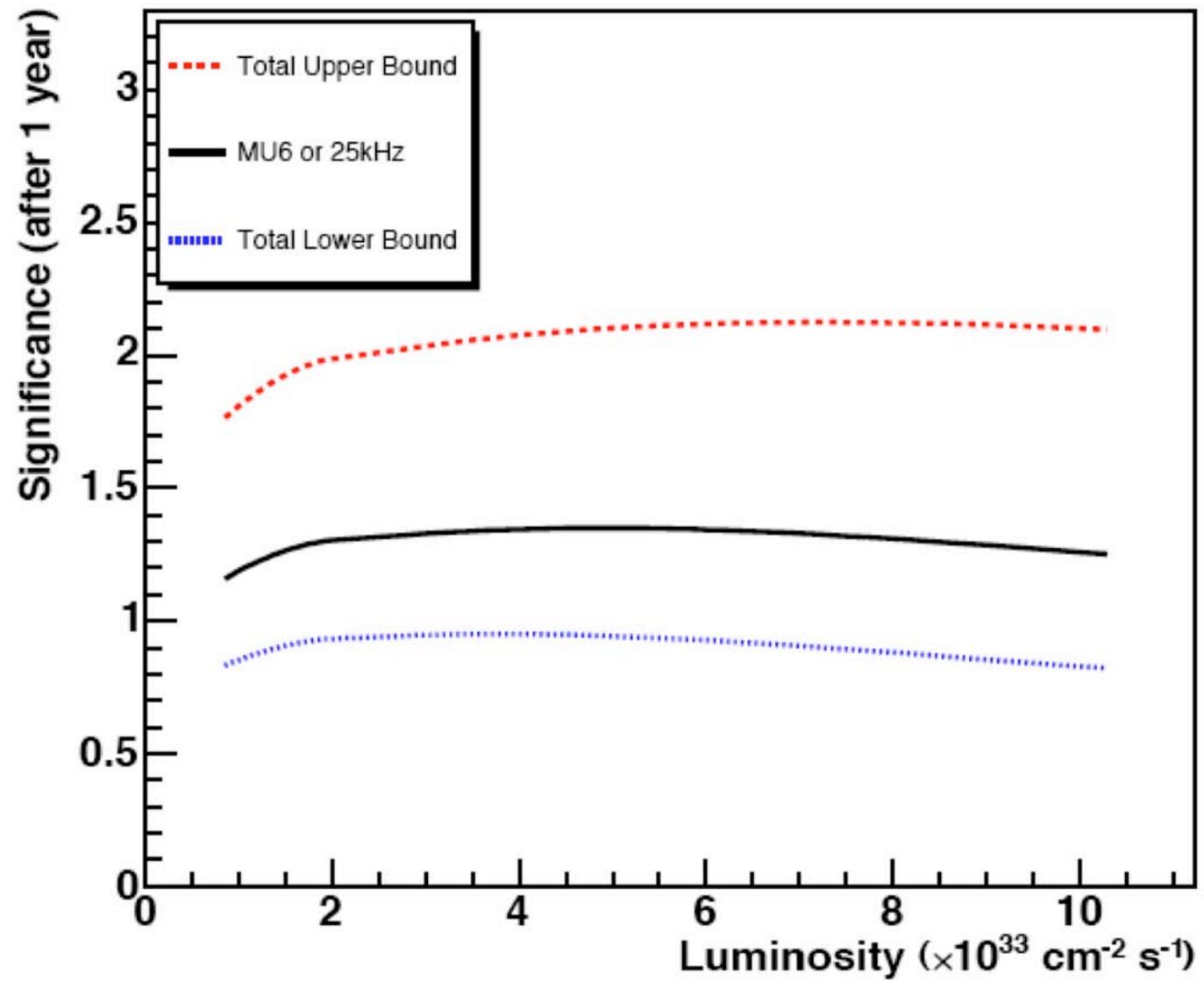
Preliminary Results for full analysis (ATLFAST)

SM 120 GeV Higgs \rightarrow bb after all cuts and acceptances, but excluding trigger**Final Cross Section**

Process	σ_{K_T} (fb)	σ_{cone} (fb)
H \rightarrow bb (CEP)	0.058	0.054
bb (CEP)	0.12	0.10
gg (CEP)	0.18	0.08
bb (DPE)	0.14	0.08
jj (DPE)	0.002	0.0005
bb (OLAP)	0.032	0.03
jj (OLAP_)	0.001	<0.001

How to keep those events

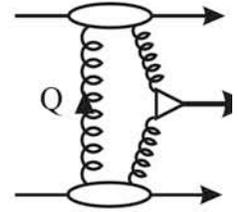
- Cannot use current jet triggers so.....
- Use low p_T muon triggers (as the b can decay to muon)
 - At ATLAS $p_T > 6\text{GeV}$
 - Retains 11% of events
- New Jet trigger?
 - Possible in principle to have large rate at level 1 and veto at level 2 using FP420. Level 2 rate of 20Hz (1%).
 - Veto on level 2 is 2 proton hits in FP420.
 - Additional veto on vertexing could be possible using QUARTIC TOF.
 - So choose $E_T > 40\text{GeV}$ and prescale to a fixed jet rate at level 1. i.e 1kHz, 5kHz or larger?



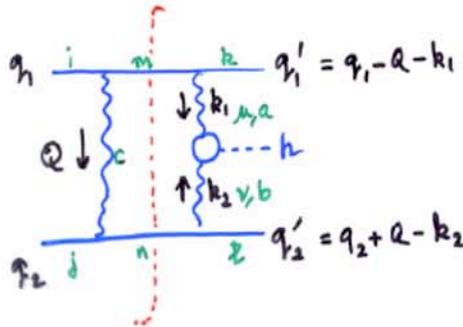
FP420 Timetable

- FP420 is an R&D collaboration between ATLAS, CMS and non-affiliated groups
- Aim is to build 420m proton taggers as upgrades to both experiments
- FP420 will produce a design report in Spring 2007
- If accepted by ATLAS and / or CMS, this will lead to TDR from experiments to LHCC in early summer 2007
- There will be no formal FP420 collaboration after this time, although we envisage creating some framework for continued co-operation in construction and installation phase
- The proton taggers will be operated and maintained like any other sub-detector component of ATLAS and CMS
- FP420 has 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
- FP420 is strongly supported by large physics groups with extensive experience in building and installing LHC detectors

The KMR Calculation of the Exclusive Process



$$qq \rightarrow q + H + q$$



$q \rightarrow$ Proton

$$\frac{d\sigma}{dy_H} \approx \frac{1}{256\pi b^2} \frac{\alpha_s^2 G_F \sqrt{2}}{9} \left[\frac{d^2 Q_1}{Q_1^4} f(x_1, Q_1^2) f(x_2, Q_1^2) \right]$$

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

Dominant uncertainty: KMR estimate factor of 2-3.

Divergent: controlled by Sudakov

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

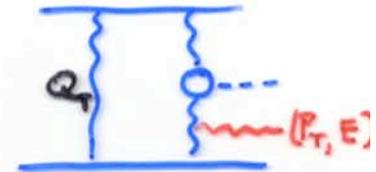
$$Q \sim \frac{M_H}{2} \exp\left(-\frac{2\pi}{N_c \alpha_s} \left[\frac{n}{2} - 1 - 2\delta\right]\right)$$

$\alpha_s = 0.2, M_H = 100 \text{ GeV}, n = 4, \delta = 0.2$

\rightarrow **2 GeV**

Power of Q_T , 6 for pseudo-scalar

As $Q_T \rightarrow 0$ 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

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