The University of Manchester

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The FP420 Project

The Challenge of Measuring Forward Protons at the LHC

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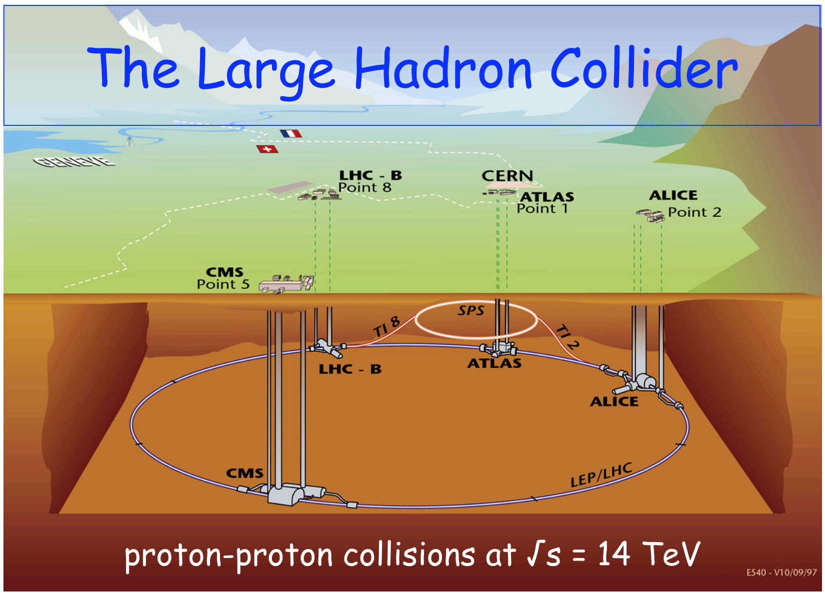
On behalf of the FP420 Collaboration*

*~30 institutes from Europe and North America

My name is Jo Pater, I work here at the University of Manchester, and I'm going to tell you about the FP420 project. The FP420 Collaboration is a collection of people from about 30 institutes in the US, Canada and Europe. We are proposing to install very low-angle tracking detectors on either side of ATLAS and/or CMS at the Large Hadron Collider….



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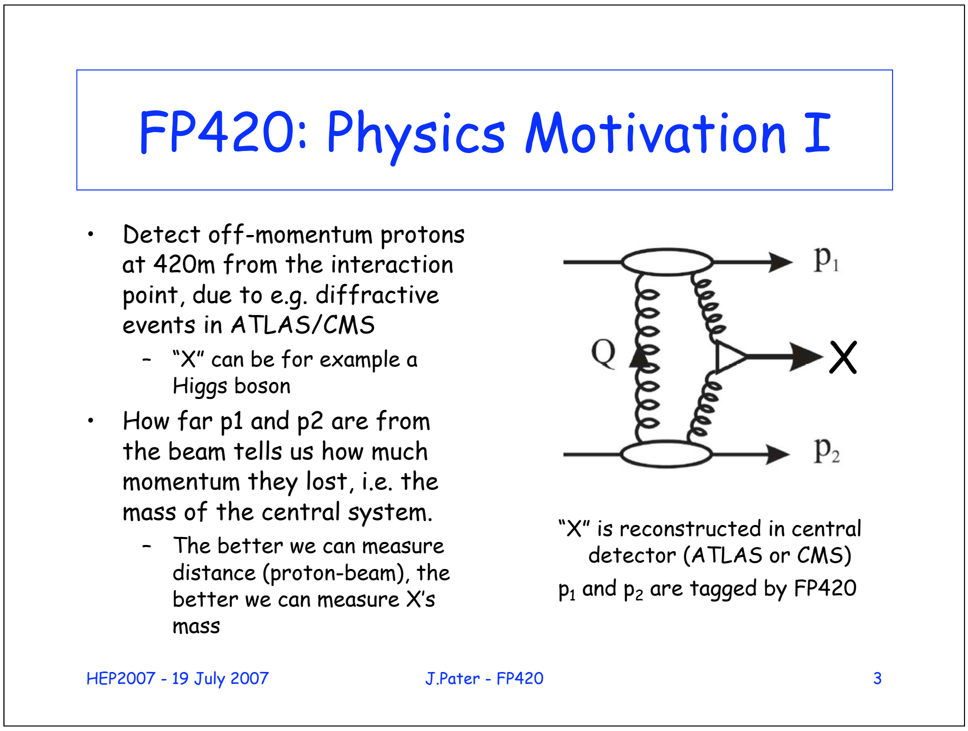
Most of you know what the Large Hadron collider is Iexpect, but here’s a picture of it anyway. It’s a proton-proton collider being constructed udnerground at CERN near Geneva, Switzerland. The proton beams will be accelerated to 7 TeV each for a centre-of-mass energy of 14 TeV, which we expect, or at least hope, to be enough to create any new particles that might be lurking out there.

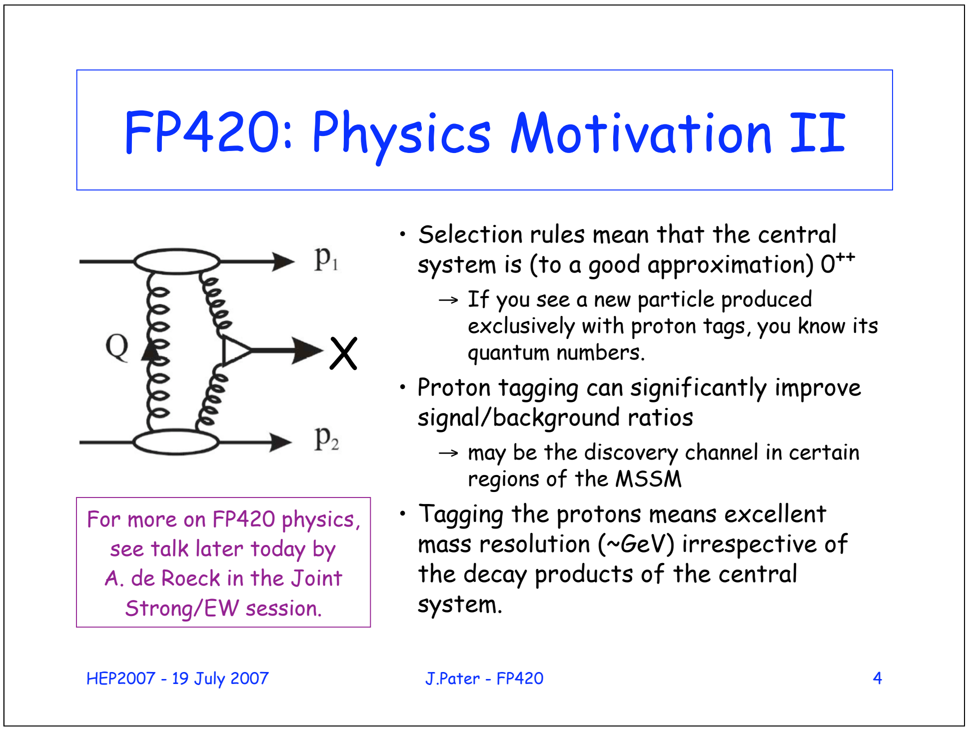
There will be quite a few experiments around the LHC ring. The ones of primary interest to the FP420 collaboration are ATLAS, located here, and CMS and Totem across the way.



FP 420 is being proposed as an extension or upgrade to these large experiments.

The idea behind FP420 is to detect off-momentum protons from diffractive events like the one pictured here, where two beam protons each radiate a gluon which then combine to produce …something, a Higgs boson perhaps…in the central detector (ATLAS or CMS), and the original beam protons continue on, having lost some, but not much, of their momentum.

How much momentum they have lost determines how far out of the beam the two protons are at 420m, after passing through various bits of the LHC optics.

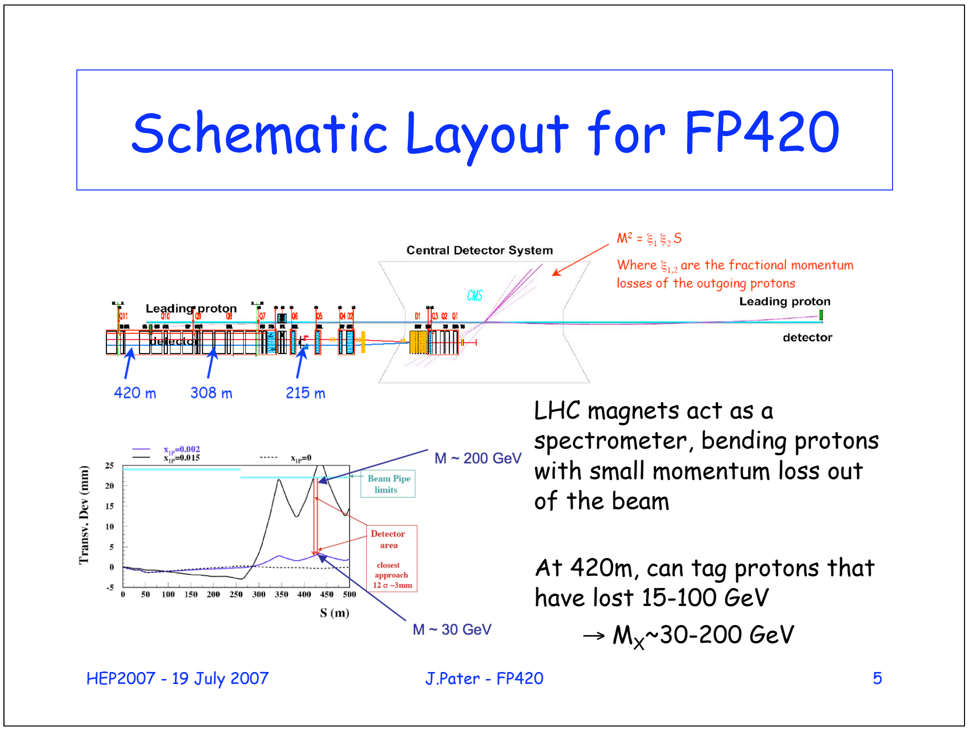


There are several reasons why this is an interesting way to do physics.

Firstly, selection rules mean that the central system has (to a very good approximation) quantum numbers 0++.

Secondly, proton tagging can significantly improve signal to background ratios, and in some cases such as in certain regions of the minimal supersymmetric standard model, it can even make a signal potentially visible above background levels when it could not be seen in any other way.

Lastly but very importantly, if done properly, proton tagging can mean excellent mass resolution (on the order of a few GeV) for the centrally-produced state, irrespective of how it decays in the central detector.



Here is a schematic view of how FP420 would fit into the LHC. Her ein the middle is a box representing the central detector system (in this case labeled CMS). The various bits of beam optics are only shown on one side, and the ‘leading proton detector’ is only shown on the other, for clarity, but of course you would have both these things on both sides of the central system.

Basically what you’ve got here is the LHC magnets acting as a spectrometer, bending protons with small momentum losses out of the beam.

This graph shows the expected transverse deviation of protons out of the LHC beam as a function of the distance from the interaction point. The dotted line is the path followed by a proton that hasn’t lost any energy; the purple line is for a proton that has lost 0.2% of its energy, or about 15 GeV, and the black line is for a proton that has lost 1.5% of its energy, or about 100 GeV. The red lines show where the FP420 detectors will be positioned, and demonstrate that we should be able to see protons that have lost energy in this region, in other words to creating a central state with mass between 30 and 200 GeV.

I should mention that if FP420 is combined with a similar detector at 220m from the interaction point (such as TOTEM in CMS, or the proposed FP220 detector at ATLAS), considerably higher mass states could be detected.

FP420 Requirements

- Must get as close as possible to the beam
  - 3mm is ~12σ
  - Detectors need to be edgeless
- Severe environment! Detectors must be:
  - very radiation-hard
  - moveable to garage position during beam filling/tuning
- Must know beam-detector distance precisely
  - 50μ position uncertainty at 420m due to energy spread in beam
  - Keep alignment precision around ~10μ to avoid degrading this further
- Precision timing needed to beat pileup

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On this slide I outline the main requirements for using a forward detector to investigate diffractive physics in this mass range.

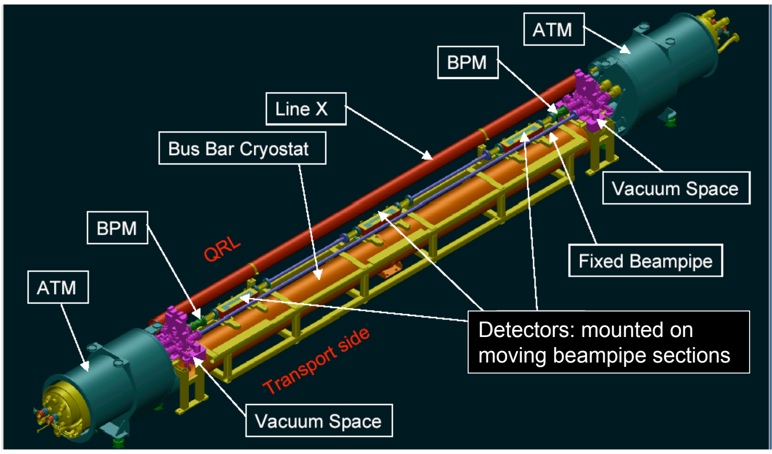
First of all, we must be able to get very very close to the beam. 3mm of beam envelope is the 12-sigma point,in other words almost all of the beam particles that haven't lost momentum are within 3mm of the nominal beam line, and we need to get in about that close to maximise our sensitivity. Our detectors also need to be essentially edgeless, for the same reason.

Now getting this close to the LHC beam means entering a pretty severe environment, radiation-wise, so our detectors have to be very radiation hard and they also have to be moveable so we can get them out of the way during filling and beam tuning when most of the beam isn't necessarily inside that 3mm radius.

We also have to know our beam-to-detector distance very precisely. There is a 50-micron position uncertainty already on the off-momentum protons simply due to the energy spread in the beam, after they've propagated through the LHC optics to 420 meters.

The last big requirement is that we need some precision timing detectors, to beat backgrounds due to pileup; I'll go into this in a little more detail on a later slide.

FP420 Integration



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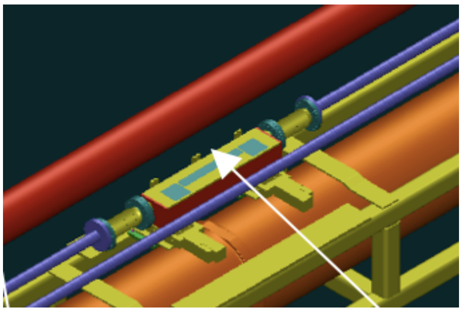
Here is a sketch of what the 420m region would look like with FP420 installed. 420m is a region where a cold section meets a warm section, and at the moment in LHC, there is a ‘connection cryostat’ that makes this transition. We are propsing to replace this connection cryostat with a modified version with our detector integrated into it as shown here.

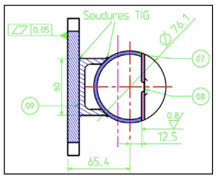
The main features are of course the two beampipes, shown in dark blue. Note that one beampipe is an ordinary fixed LHC beampipe while the other has some special features upon which the FP420 detectors will be mounted.

ATM stands for Asynchronous Transfer Mode and is a proposed telecommunications standard for broad band ISDN. The word "asynchronous" actually means "asynchronous in time” and "asynchronous time division multiplexing" might be a more appropriate term to describe the ATM technology. (For beam control)

QRL = cryogenic distribution line

"Hamburg Pipe"

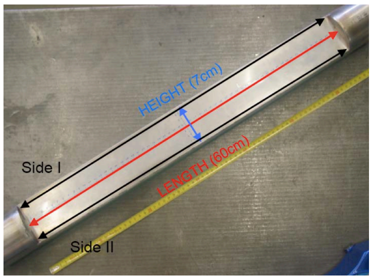




"Hamburg pipes" position detectors

~ 3cm from beam during fill/tune

~ 5mm from beam during operation



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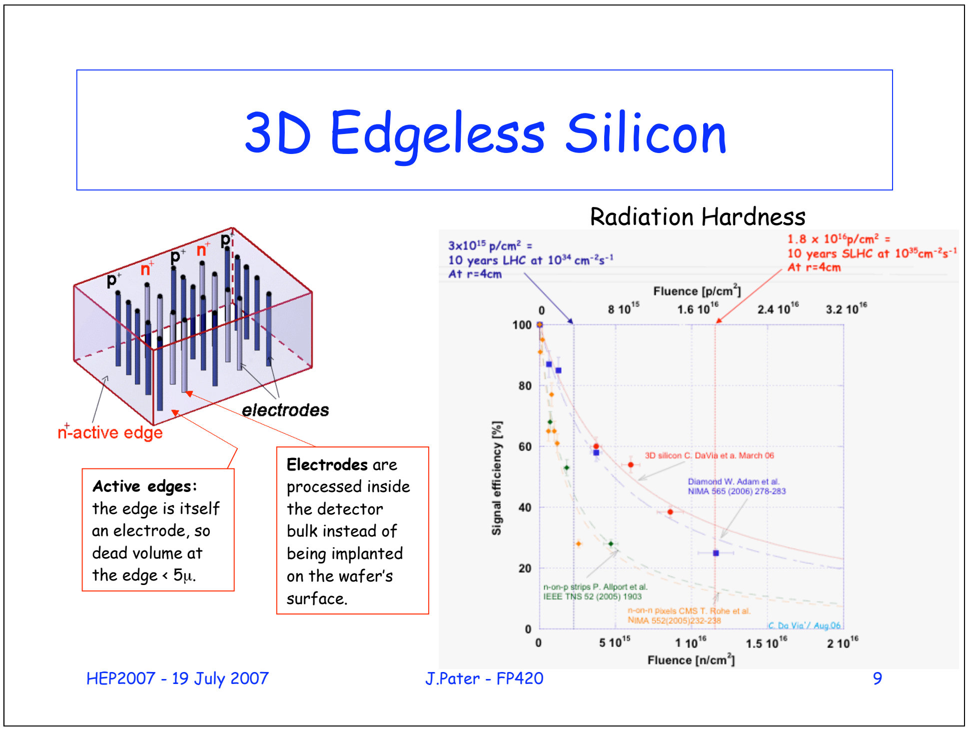
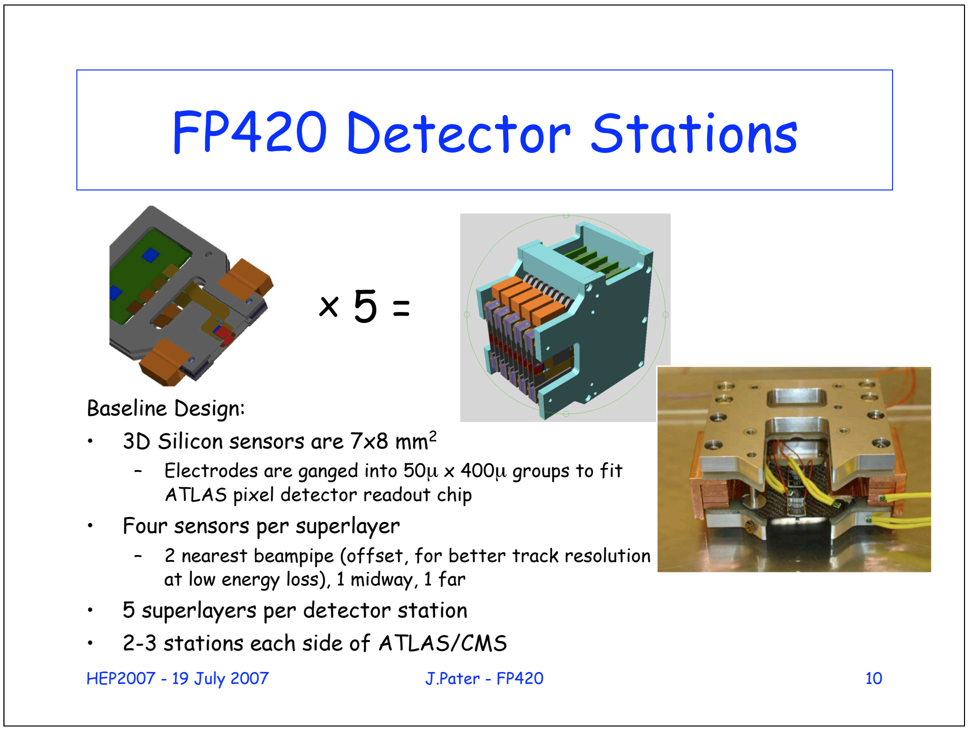
Here's a closer view of that special beampipe: some sections of it move so that the detectors can be positioned well out of the beam during filling and tuning but very close to the beam during operation. We call these moveable beampipes 'Hamburg beampipes' because they have been successfully used at DESY on the HERA collider.

The schematic shows a cross-section of what the moveable pipe looks like, and here is a photo of a prototype. Under the red double-headed arrow is a very thin metal window that allows the off-momentum protons through to hit our detector which will be mounted on top (outside the moving beampipes)



We are proposing to make our detectors from 3D Edgeless Silison. 3D silicon differs from 'ordinary' planar silicon in that the electrodes go all the way through the detector bulk rather than being implanted on the surface. This geometry makes the detectors much faster than planar silicon detectors, and also allows for good performance even close to the edge; turning the edges themselves into electrodes ('active edges') makes the detectors virtually edgeless, making them ideal for forward detector applications like FP420.

These detectors are much more radiation-hard than other choices, as has been demonstrated in test-beam experiments as as is illustrated in this plot, showing signal efficiency as a function of how much radiation the detector has been exposed to. The vertical blue line here represents ten years at LHC design luminosity; the detectors are as you see expected to still be functioning well after receiving this dose. In fact they are expected to still be operating, although at rather reduced efficiency, after ten years' worth of super LHC luminosity.



Here I show the baseline design for FP420 detector stations using edgeless 3D silicon sensors. The sensors themselves are 7mm by 8mm; the electrodes are ganged into 50-micron by 400-micron groups, to fit ATLAS pixel detector readout chips which are bump-bonded onto the sensors.

We arrange four such sensors into a superlayer; 2 of the 4 are in the position nearest to the beampipe, but offset to one another to allow better track resolution for low-energy-loss protons. One sensor is further away from the beam and the fourth is in the farthest position, covering out to about 75mm from the beam centroid.

Five of these superlayers are then arranged into a frame as shown here, and this is a detector station, of which we expect to have 2 or possibly 3 on each side of the central detector.

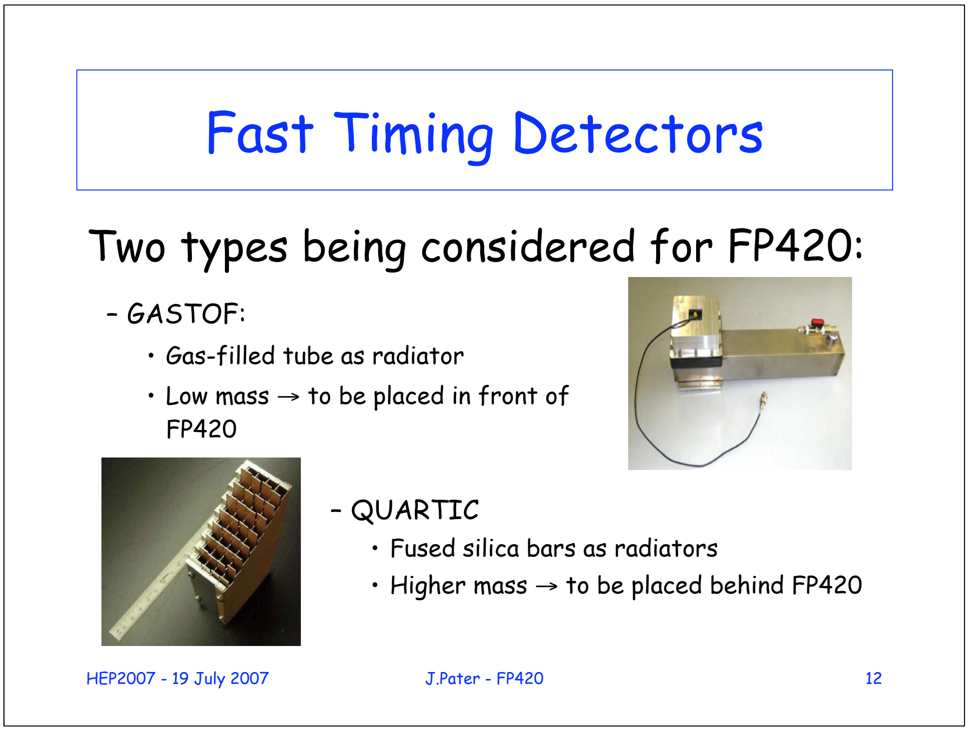
Background Rejection

Main backgrounds in FP420 are from single-diffraction pileup events

- Some can be removed by kinematic cuts (e.g. matching mass measured in FP420 and central detector)
- Almost all of what is left can be rejected by fast timing detectors:
  - Measure relative arrival time Δt of protons on the two sides ($\pm$420m)
    - $\rightarrow$ z position of interaction point = $(c\Delta t)/2$
  - Match this with measured vertex position from central detector.

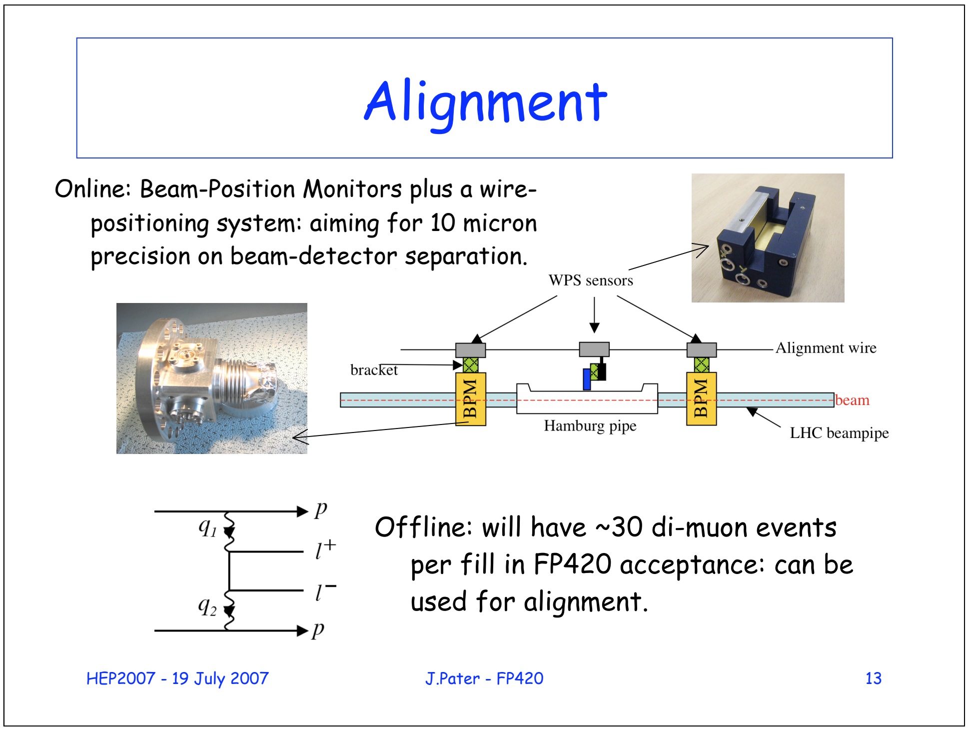
What about backgrounds in FP420? Our main backgrounds are expected to come from single-diffraction pileup events; in other words events where two incoming protons exchange energy and one of them carries on intact, slightly deflected and the other one breaks up creating a splash of uninteresting particles in the central detector.

Some of this background can be removed by kinematic cuts, for example by matching the 'mass' measured in FP420 with that measured in the central detector, but this is not terribly effective as the resolutions can be quite poor. We will have to rely upon fast timing detectors to reject the rest, and fortunately that is possible provided the detectors have good enough resolution. The way to do it is to measure the relative arrival time of the protons on the two sides I.e. at plus and minus 420meters from the central detector; given this relative arrival time, the position of the z vertex is just c-delta-t over 2; this can be matched with the measured vertex postion from the central detector



We're investigating two different types of fast timing detectors for FP420. Both are Cerenkov detectors; the first is called GASTOF which uses a tube full of gas as the radiator. This is a very low-mass detector and so it can be placed in front of FP420 without causing too much multiple scattering.

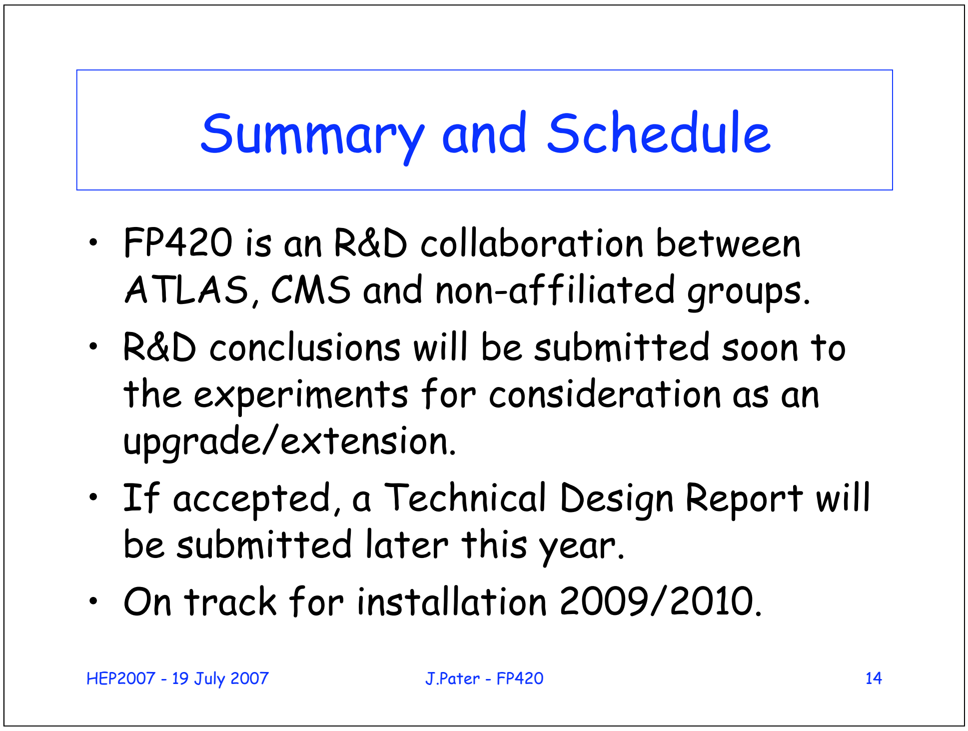
The other is called QUARTIC which uses fused silica bars as radiatiors. This is a higher mass option and so will have to be placed behind FP420 so as not to produce too much background in the detectors.



As I said earlier, one of the real beauties of FP420 is that we ought to be able to measure the mass of the centrally-produced system better than the central detector can. This requires of course measuring how much energy the protons have lost, as precisely as possible, and that requires knowing exactly where our detectors are in relation to the beam. We propose to align FP420 with two complementary techniques.

Our proposed online alignment system, all in hardware, is shown here. It is based upon Beam position monitors, shown in yellow, and a wire positioning system, shown here. The wire-positioning sensors are capacitive devices that can very accurately tell you their position relative to the alignment wire; they are attached to the detectors and to the beam position monitors to allow relative alignment between these components.

We can also align using tracks from a well-understood process such as di-muon events which we should have enough of to be useful.



To summarise:

FP420 is a reasearch-and-development collaboration with members from Atlas, CMS and also some groups with no affiliation to either experiment. We intend to submit our R&D conclusions very soon so that FP420 can be considered for an upgrade or extension to the detectors.

If we're accepted, we will submit a TDR later this year, and are looking to install and start taking data in 2009 or 2010.

Thanks for your attention!