Design of Fixed/Perm IMSE for ASDEX Upgrade (2014-2015)

Basic design
View geometry
Optics optimisation
Magnetic field considerations
....

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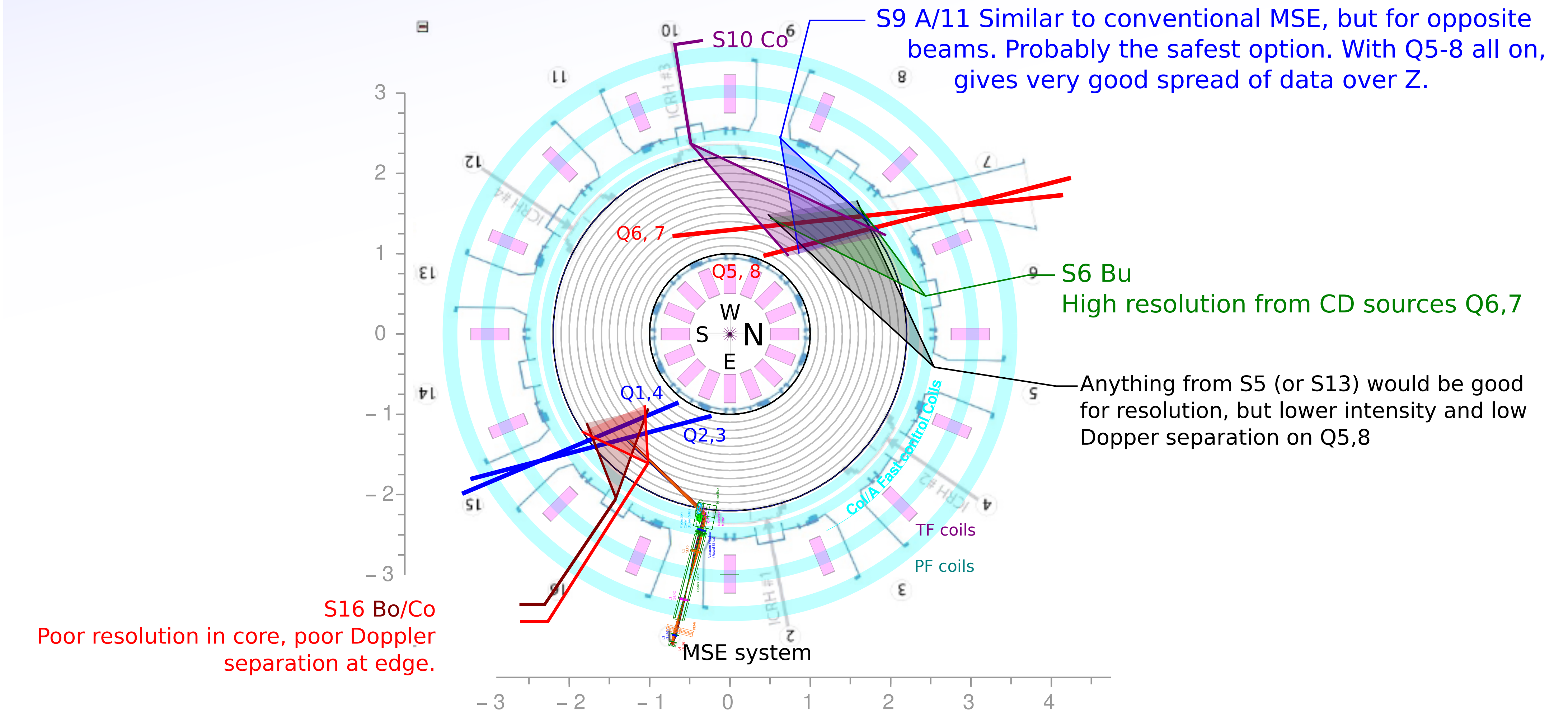
Port Options

Things to consider:

1) View obstruction (Limiters, tiles etc) - How much of the beam/plasma can we actually see?
2) Spatial resolution - View should be as toroidal as possible in beam area.
3) Doppler separation - As accuate angle to the beam as possible so MSE is Doppler shifted away from Dα BG.
   (Blue shift (towards) is better than Red to avoid C impurity line)
4) Contrast from σ - Horizontal view gives better contrast as view is more perp' to Stark E field.
5) Polarisation vs Pitch - Measurement is more sensitive with view not toroidal.



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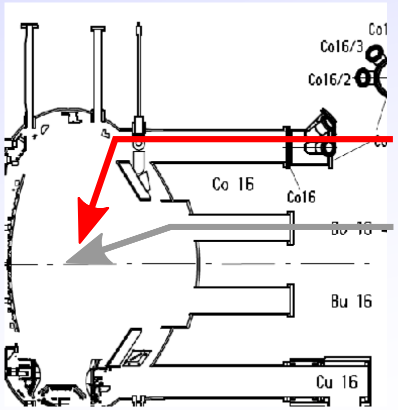
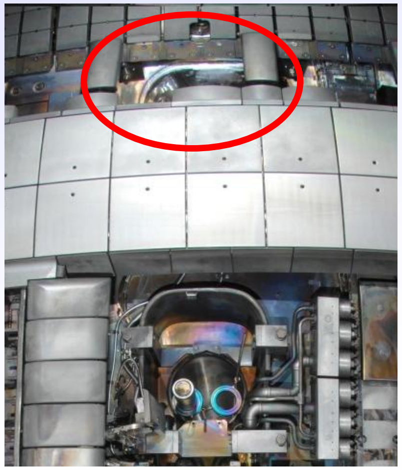
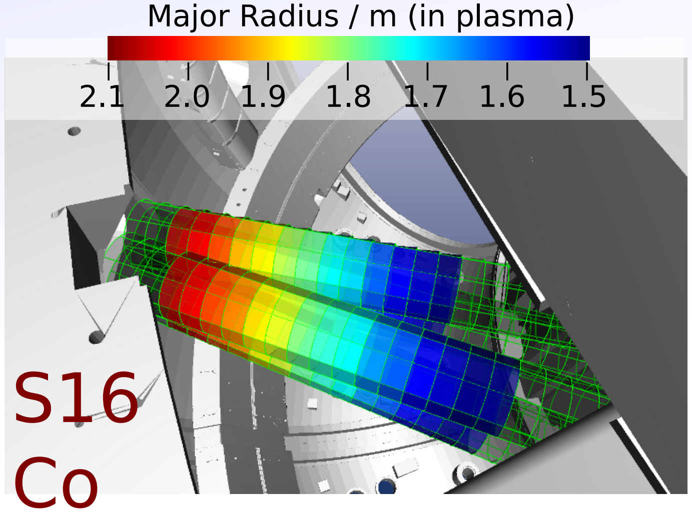
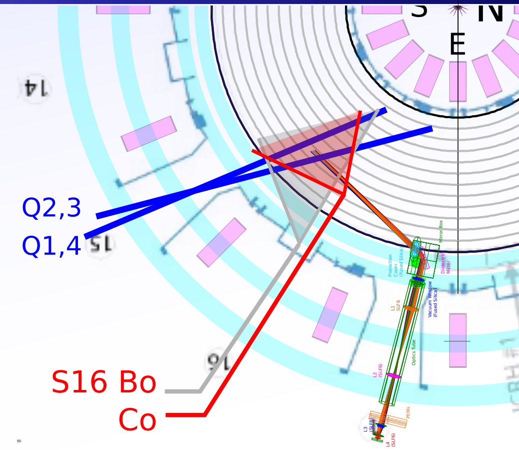
S16 Co

S16 Co, Using same beams as existing MSE. Q3+4 are blue shifted and marginal, Q2 is unusable, Q1 is red shifted and marginal.





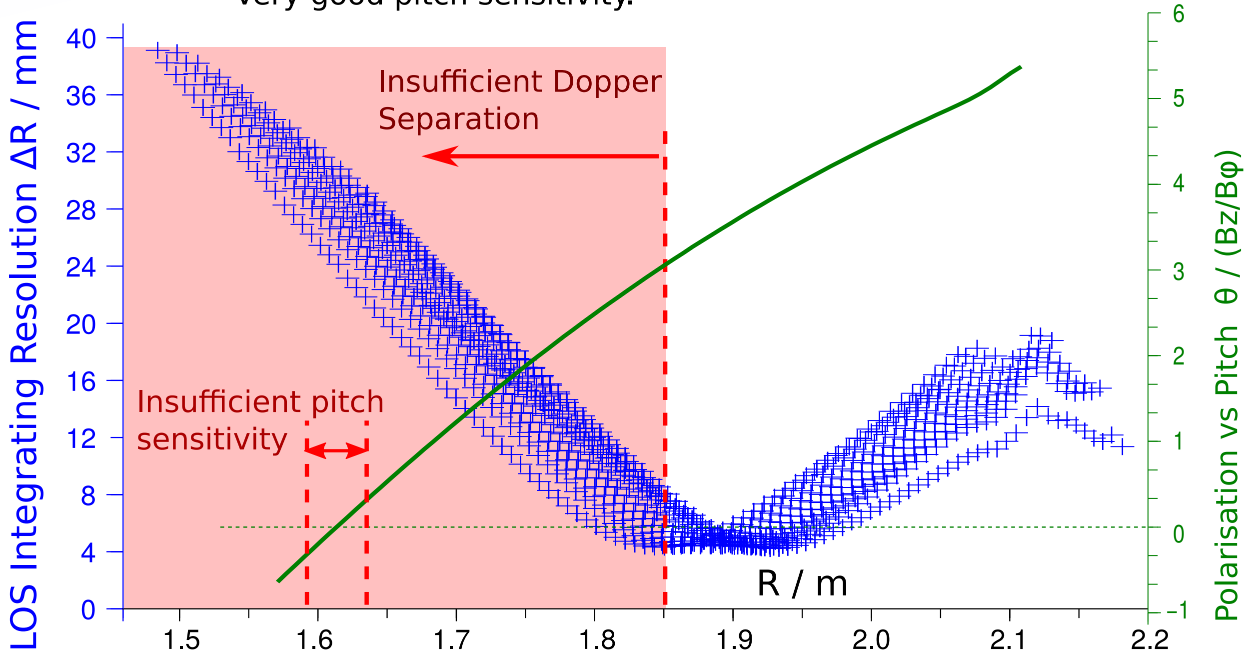




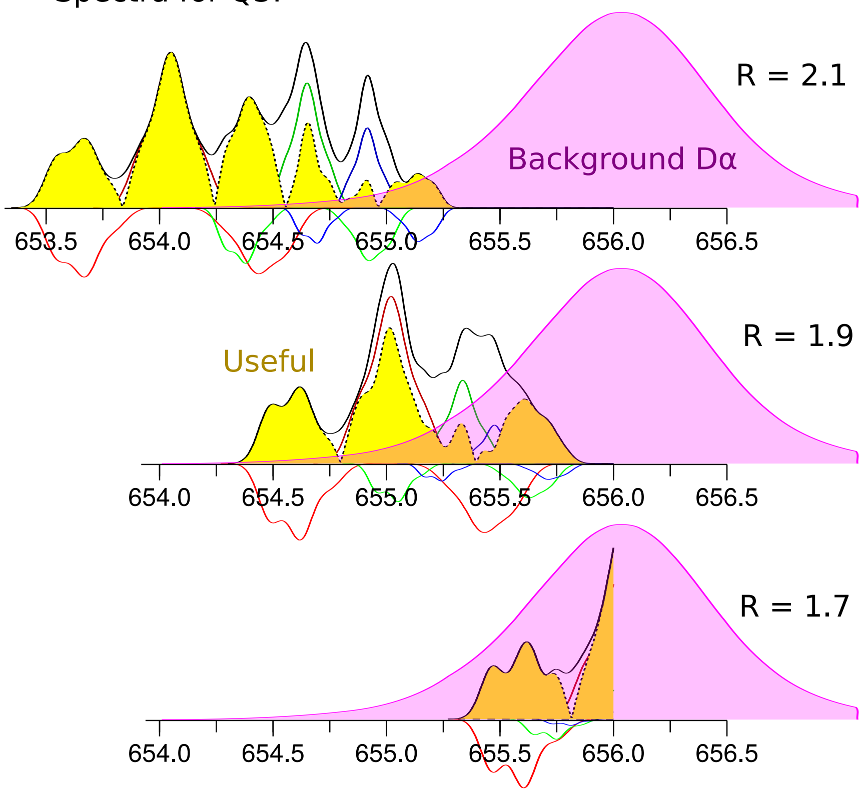
Modeling from coordinate = (-1.023, -1.661, 1.141)

CAD 1925.9458, -308.41736, 1140.9631

Not sure if it will be able to see all of plasma/beam region past tiles and structure.
Looking very vertically downwards so integrated downward over beam
--> 10cm Z resolution --> lose the advantage of having 2D.
Very poor Doppler separation - unusable for R < 1.85m.
Very good pitch sensitivity.



Spectra for Q3:



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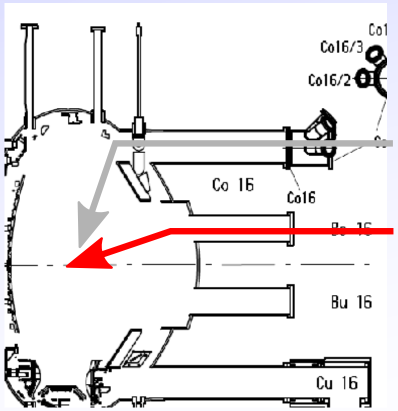
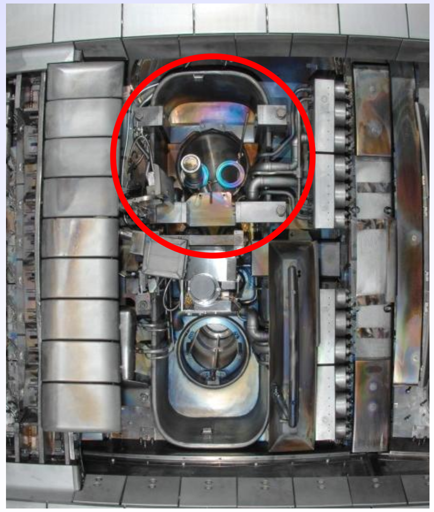
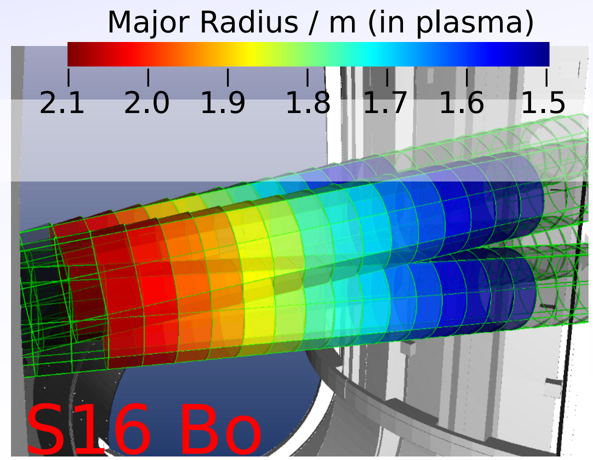
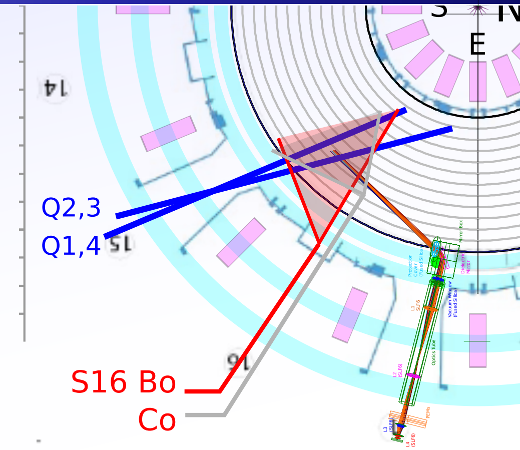
S16 Bo

All beams are red-shifted.





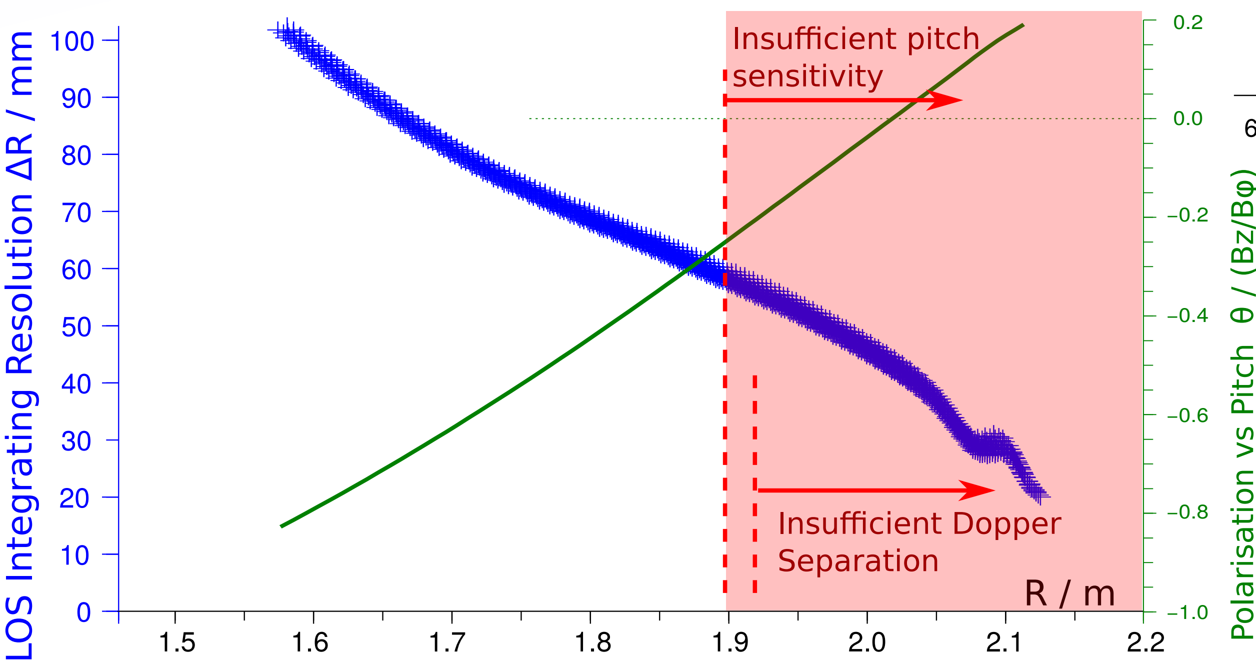




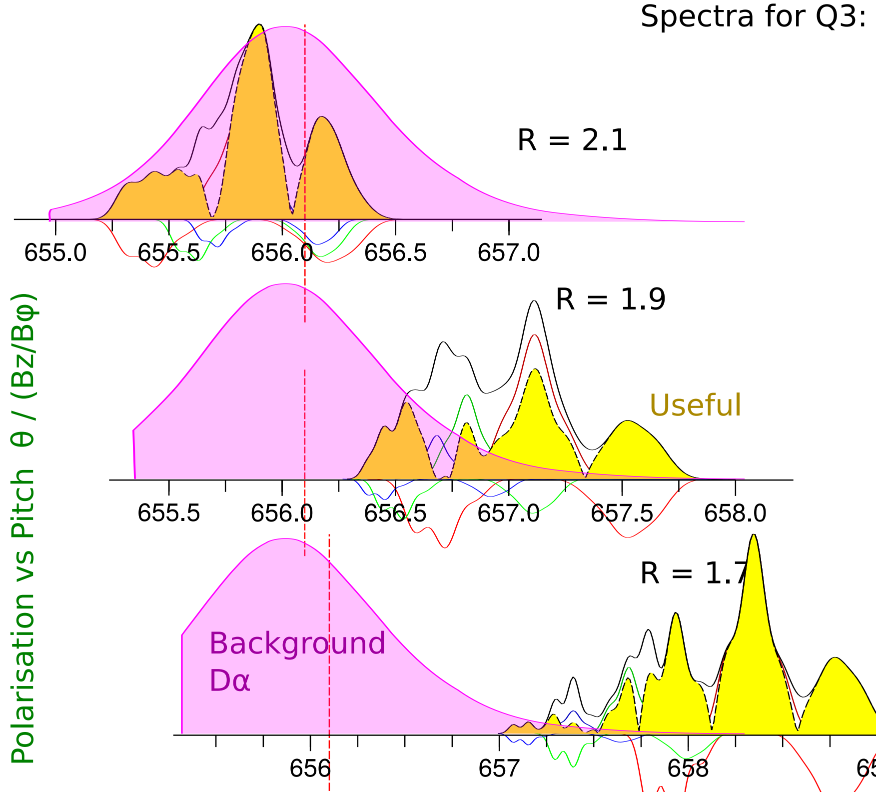
Modeling from coordinate
= (-1.339, -2.146, 0.421)

CAD 2495.5706 -414.9472 421.38983

Good full view of beams. Good Z resolution (~4cm), not great R resolution.
Still poor Doppler separation - unusable for R < 1.8m
LOS Integrating Resolution is quite good, pitch sensitivity is very good.



Spectra for Q3:



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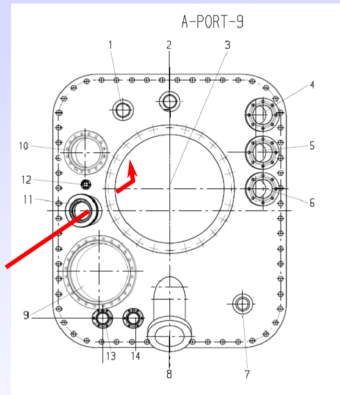
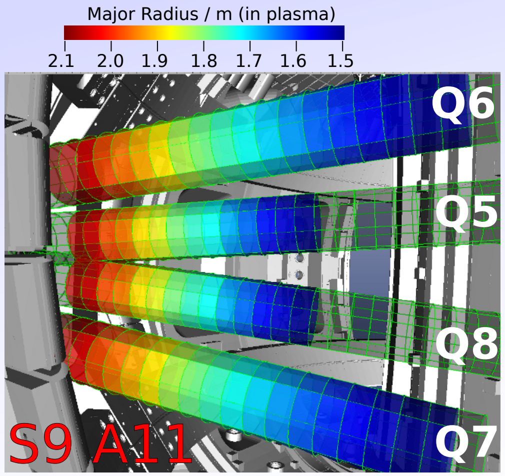
S9 A11

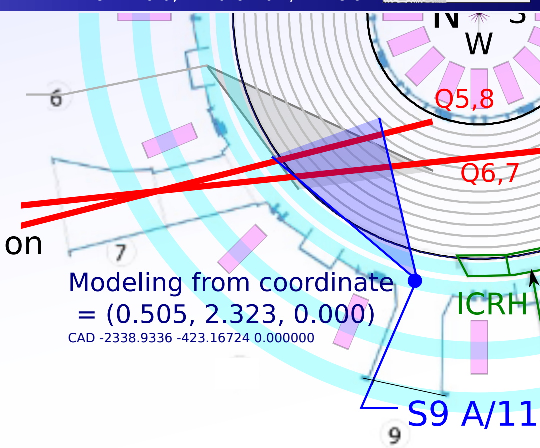




Good full view of beams covering a lot of the plasma Z - good for 2D tomography.

Limiter might cut off view of edge, depending on how far out optical head can be.

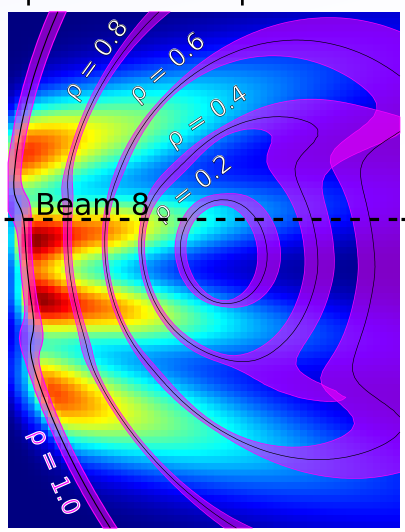
Beams 6, 7 and 5/8 should be well separated and together would give a lot of information.



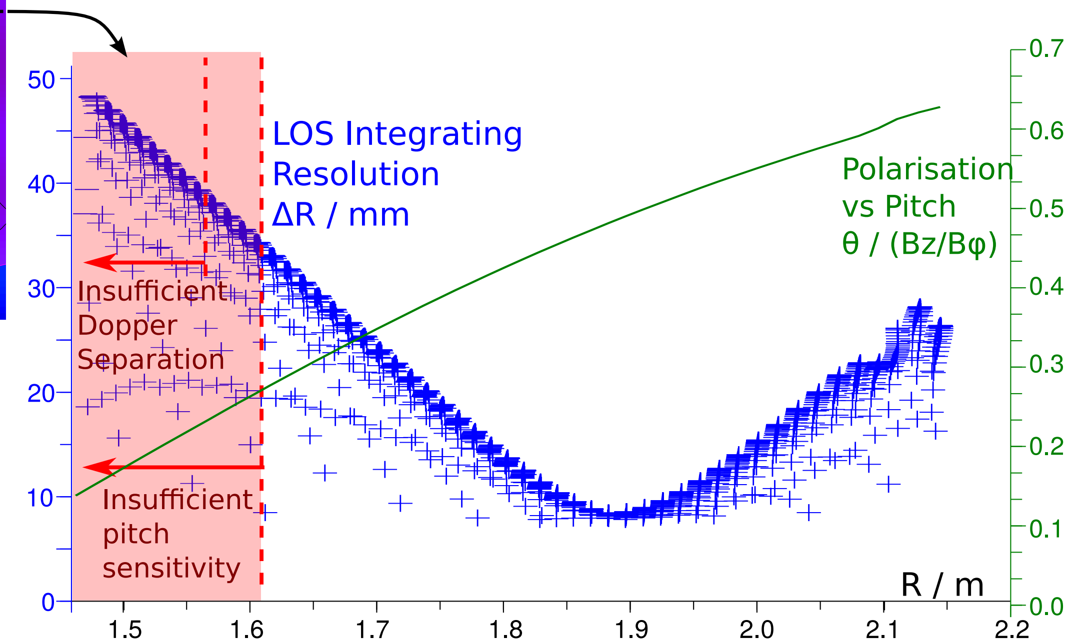
Beam 5/8 (Normal / non-NBCD)

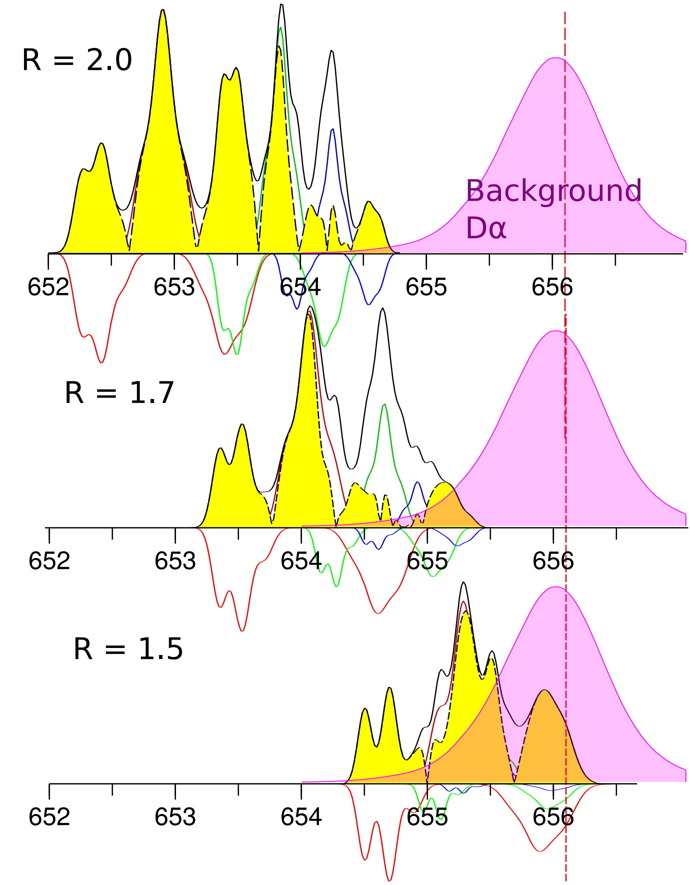
For Beam 8 (5 should be the same):
Doppler shift is ok as far as magnetic axis but not past it, as is the pitch sensitivity. Both would be improved by moving the head to the RHS of the port, with the head behind the ICRH grill. Spatial resolution is good in both R and Z, especially in ρ > 0.4.

ρ Moments of pixels



Q6+7 Only illuminate ρ > 0.4





ipx=15

ipx=34

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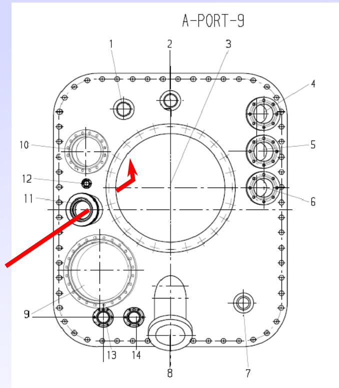
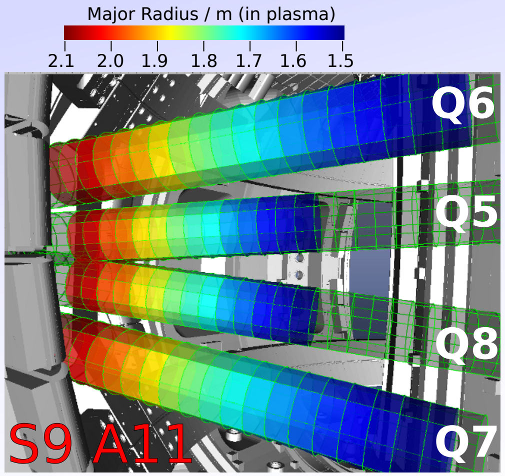
ASDEX Upgrade

S9 A11





Good full view of beams covering a lot of the plasma Z - good for 2D tomography.

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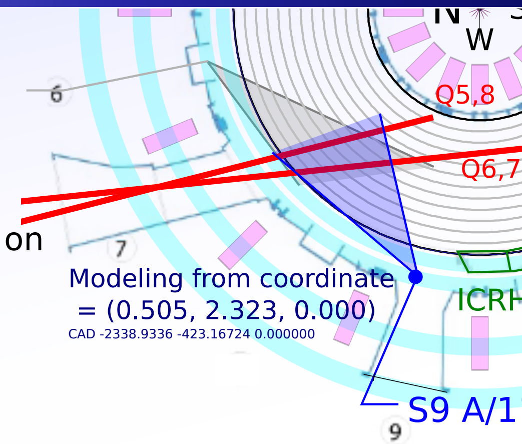
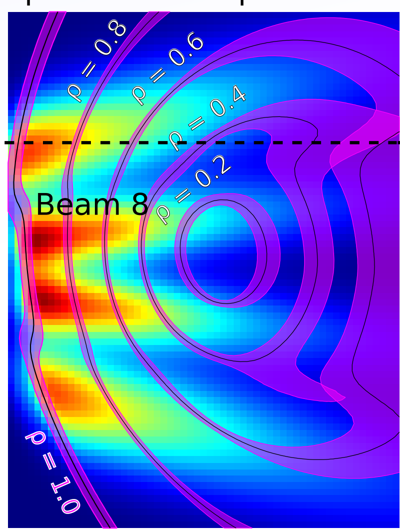


Beam 6/7 (Tangential / NBCD)

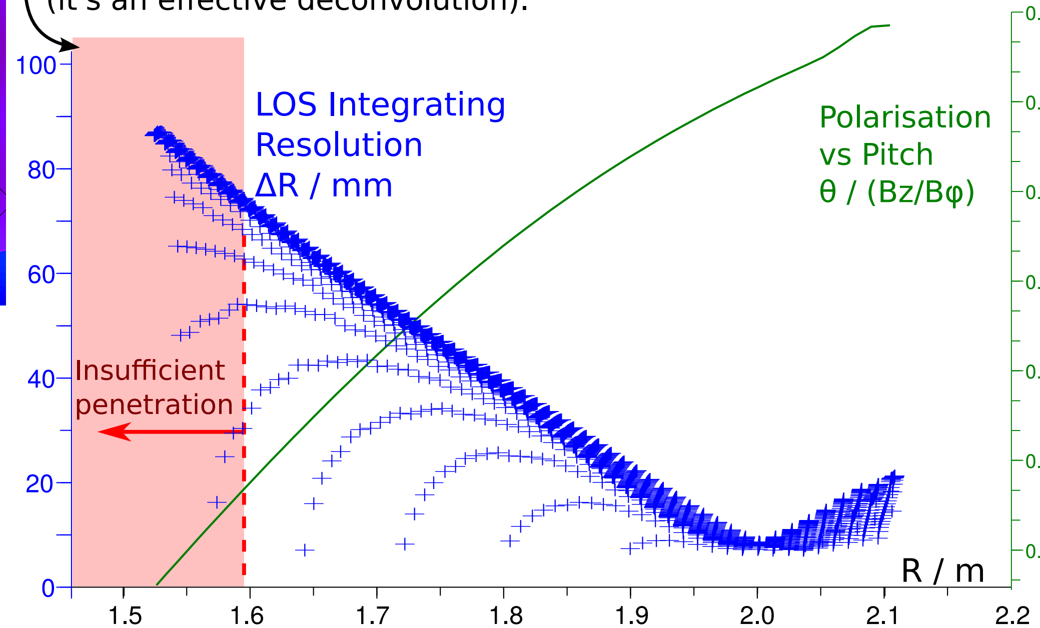
For Beam 6 (7 should be the same):
Beam only penetrates to ρ ~0.5 but Dopper separation is very good for this range. At the edge it even separates the energy components so Er images should be possible.

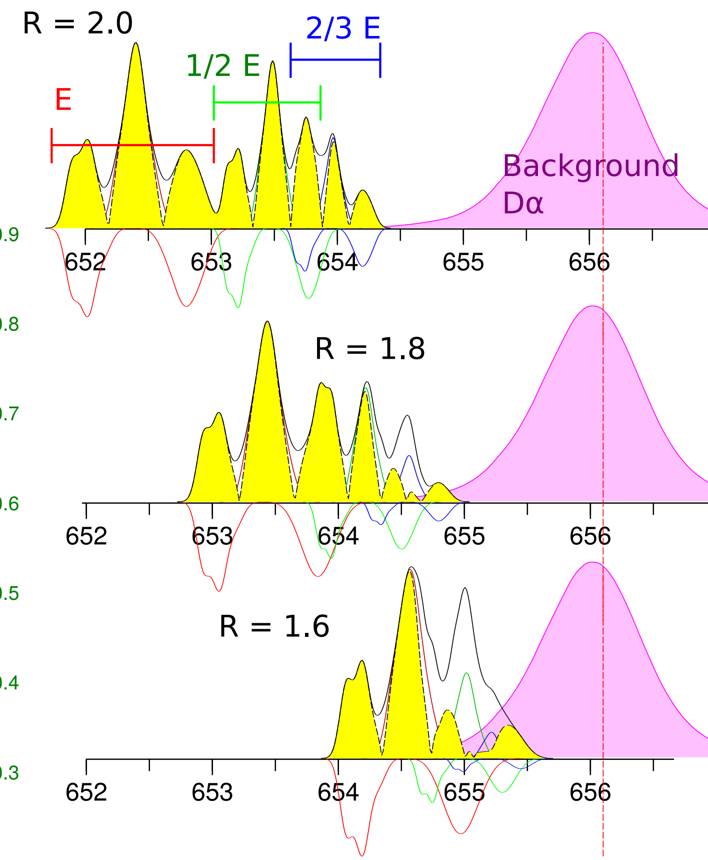
Pitch sensitivity is good. Spatial resolution is good at edge and not so good near centre. However, the large quantity of data for ρ ~ 0.5 should overcome this in the current tomography (it's an effective deconvolution).

ρ Moments of pixels



Q6+7 Only illuminate ρ > 0.4





ipx=15

ipx=34

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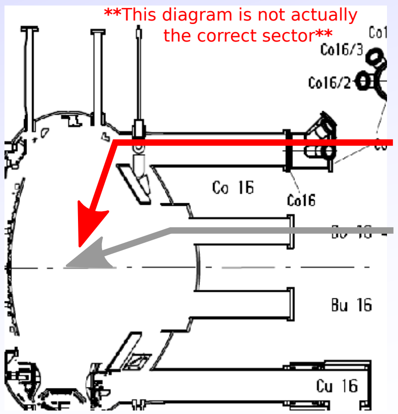
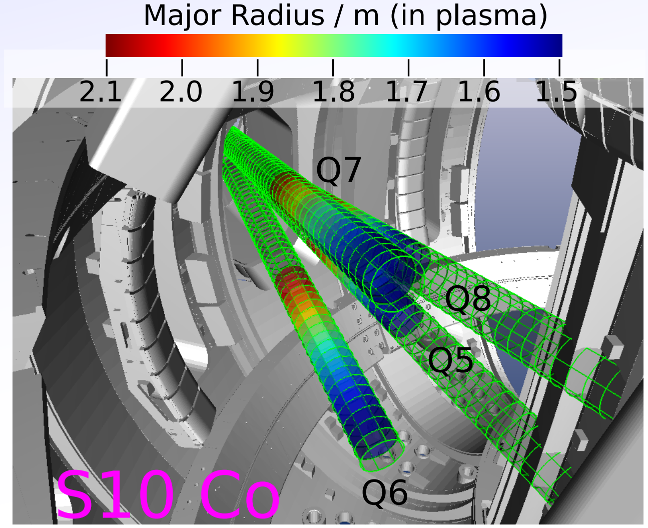
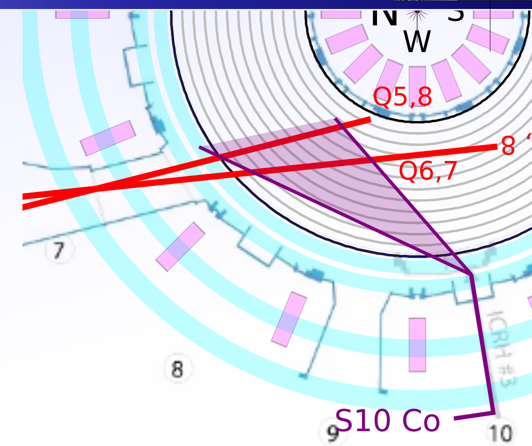
S16 Co

S10 Co, on box2 beams, above the ICRH grill. Generally, a very complicated setup.
Doppler shift is well clear of Dα for all radii of all beams.
Q7 completely overlaps Q5 and Q8.





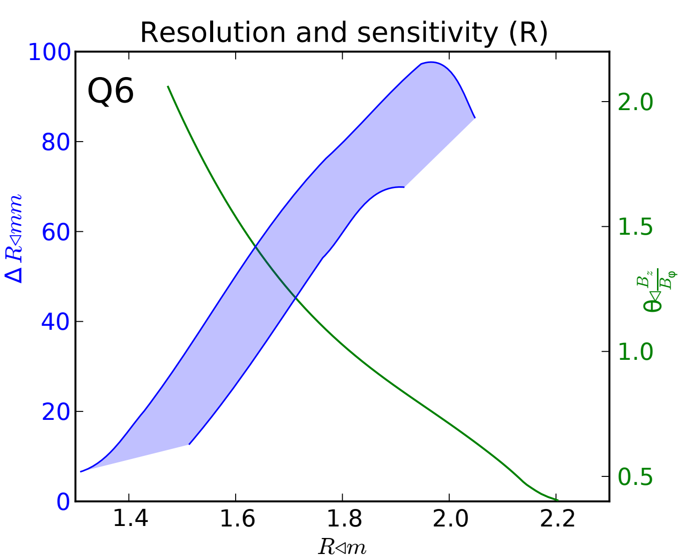


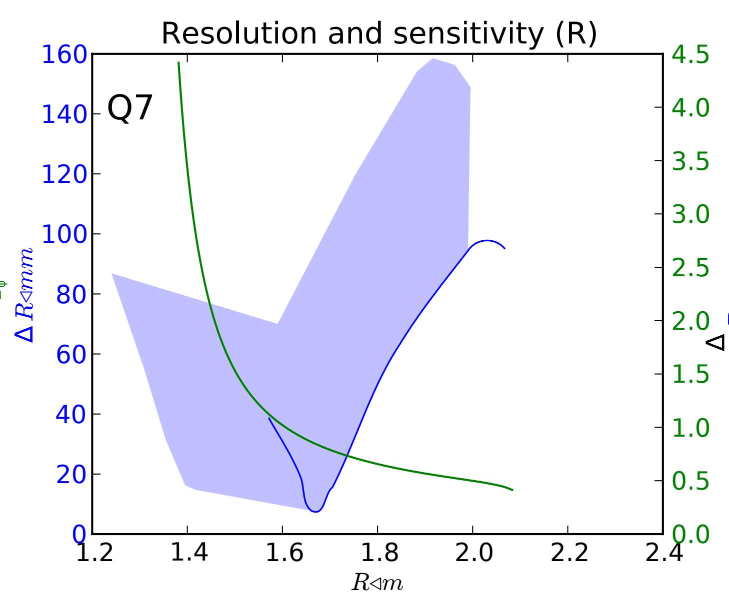
Modeling from coordinate
= (-0.385, 1.853, 1.015)

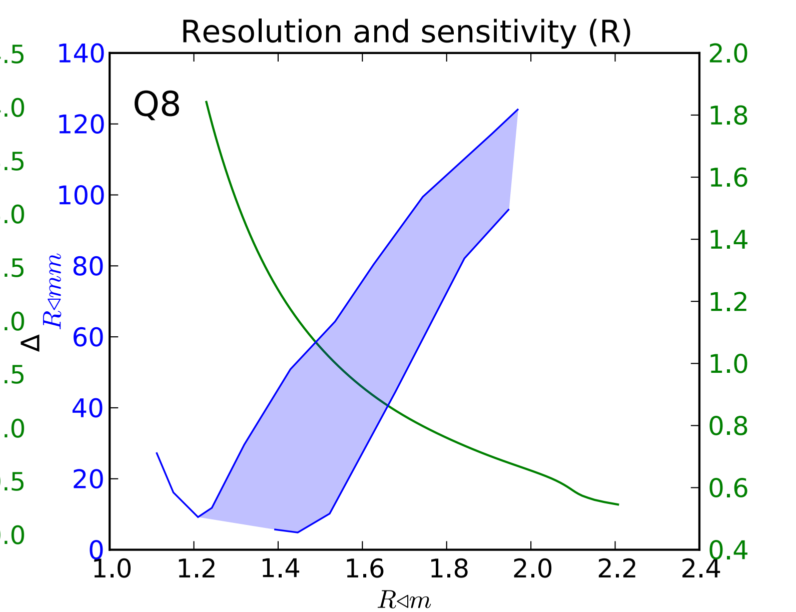
CAD -1564.379 -1065.5983 1015.1467

Not sure if it will be able to see all of plasma/beam region past tiles and structure.
Looking quite steep downwards, so Z integrated on Q6.
Excellent resolution for Q7 in the core, ok for Q5+8 at core and past, but signal probably will be too weak.
Angle projection very good for core R, but remember, Q6 and Q7 are still at ρ ~ 0.5 at R~1.5.
So Q6/7 (NBCD) give good info on the mid-radius and Q8 gives good info on the core only.
All regions of all beams are good pitch sensitivity and good Doppler shift.

Spectra for Q5:

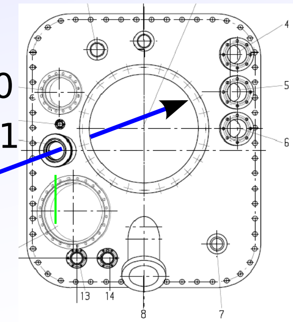


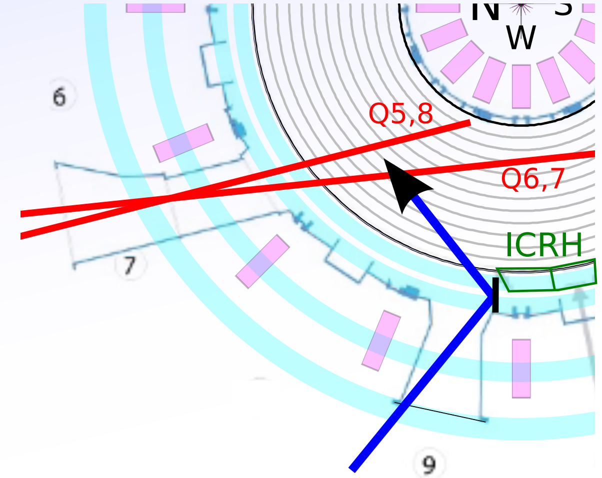




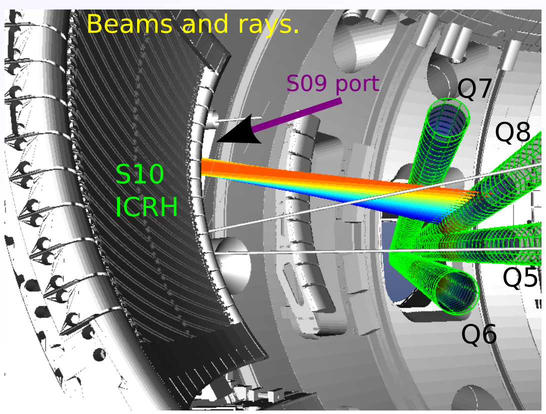
S9 A11 - across ECE - concave mirror

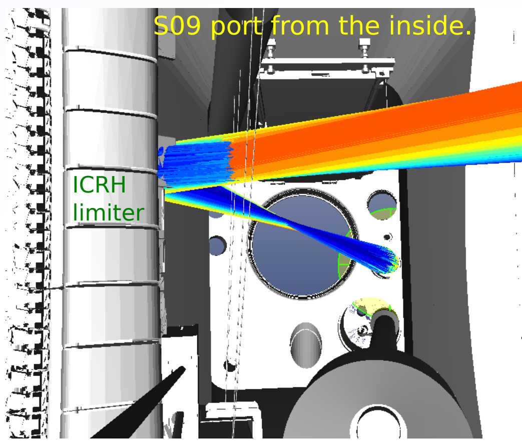
We think there might be space to put the mirror in behind the ICRH limiter in S09 and view it from A11 on the other side. (A10 would also work). This means having no optics tube, so we can cross the ECEI lines of sight.

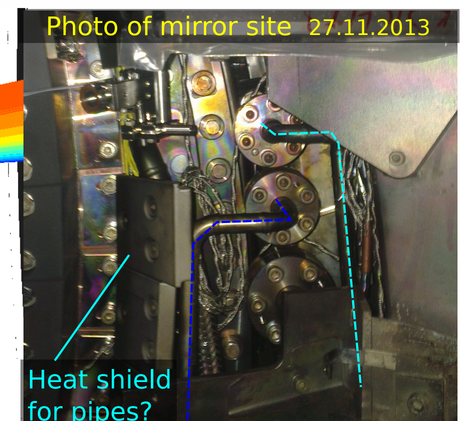


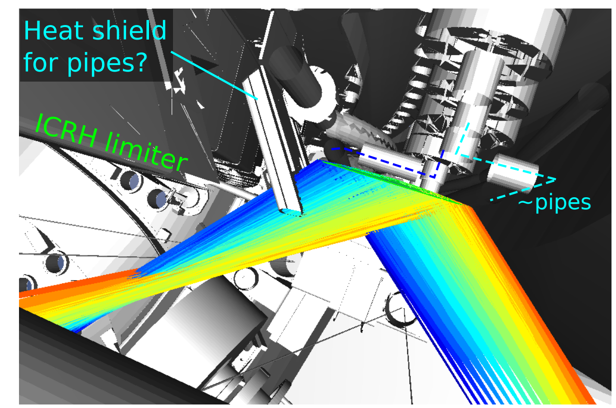


The MSE system has its first lens (L1) in the tube near the mirror.
Andreas had the idea to use a curved mirror to do both jobs in one.
Throwing together a quick optics design in my ray tracer, this could look something like:









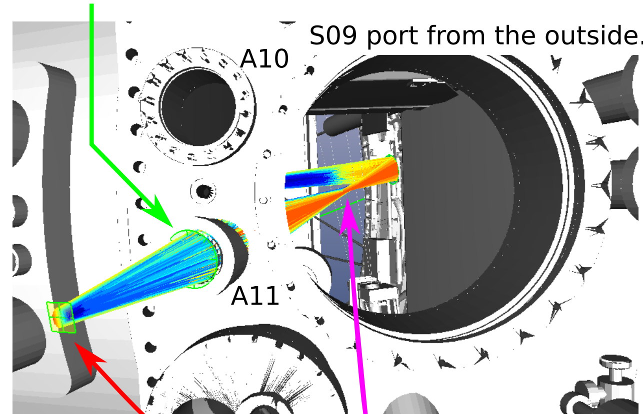
First normal lens (L2) just inside port flange.

This pipe seems to only connect back into the antenna. Can it be re-routed?

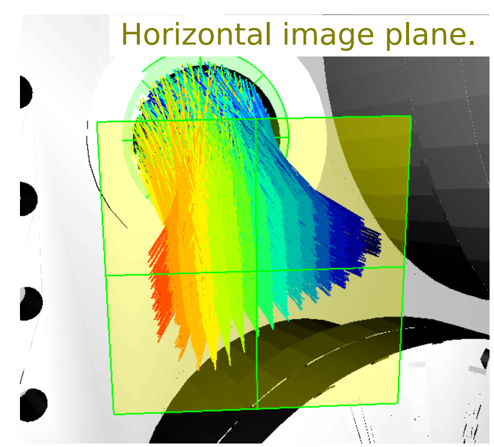
Looking at emission from just Q8 to start.

Using a curved mirror in behind the ICRH antenna to keep it clear of the ECE imaging sight lines (next page). There should be enough space if we can reroute the ICRH cooling pipe(s).

The curved angled mirror splits the image into one focal plane for the vertical and one for the horizontal. It would require anisotropic optics (i.e. ~cylindrical lenses) to fix this further down the optical system.



Split horizontal and vertical image planes



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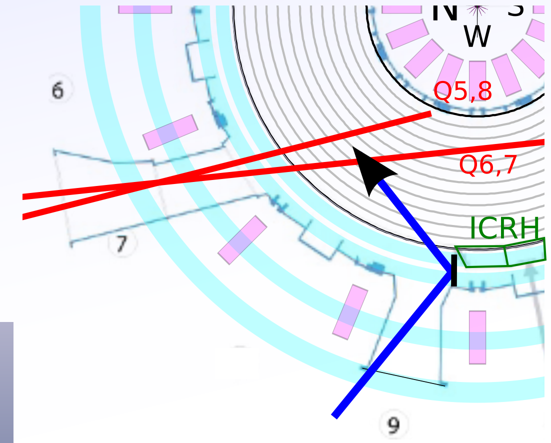
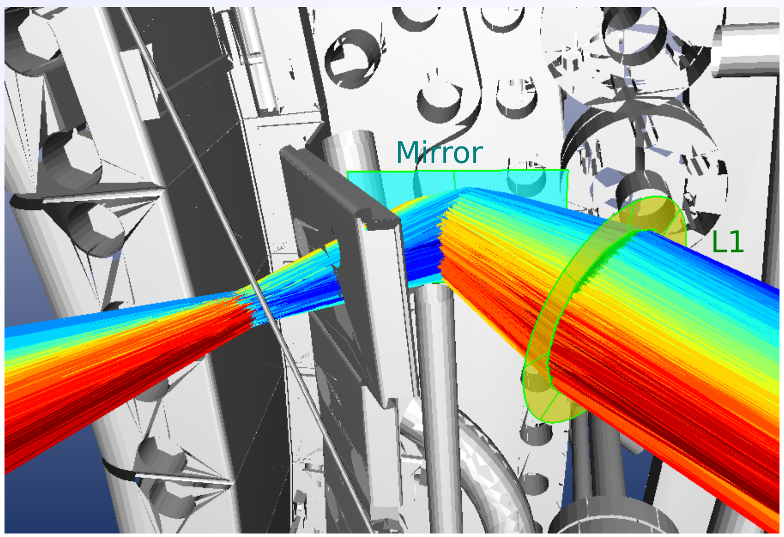
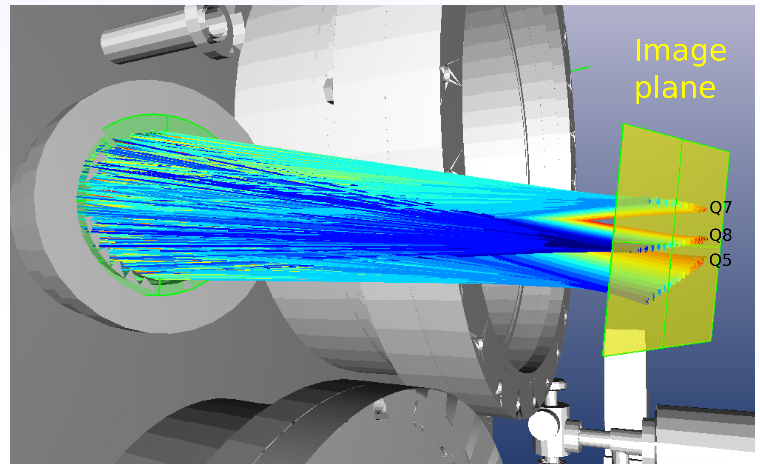
S9 A11 - L1 & Flat mirror.



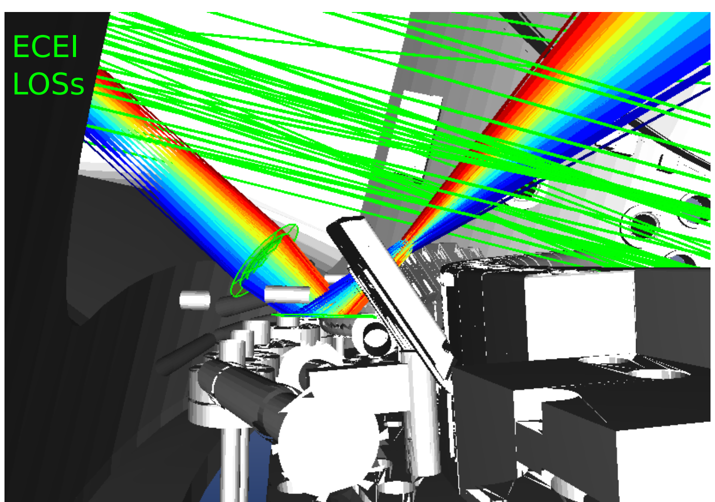
The curved mirror might work - we have to work out how curved mirrors at glancing angles behave. Currently, I can only see Q8 with it, and not the other 3.

Using a flat mirror and the primary imaging lens (L1) in the mirror box together might also work. It's optically much simpler and there could be just enough space for it.
Something like:





I set up the imaging arbitrarily, and optimised focus by hand.
Q5, Q7 and Q8 all image nicely. Q6 probably would if magnification is was reduced a bit.



The collection aperture size is ~16mm and by chance all the viewing lines cross near the existing cooling pipe heat shield. We can probably optimise for this too and have only a very small shutter and protection over (~20mm).

This 16mm spot gives 50% of the light of the MSE (~25mm collection spot) but I only ever coupled 10% of the MSE light to the camera, so we can beat the prototype IMSE by optimising the whole optical system together, and still have a small aperture (~20mm).
This does keep all our surfaces ~perp to the rays, which helps, but we now need a shutter for the L1 lens as well.
Also, we have to think about how we might align (only roughly) the mirror, since the IMSE won't be there during in-vessel access.

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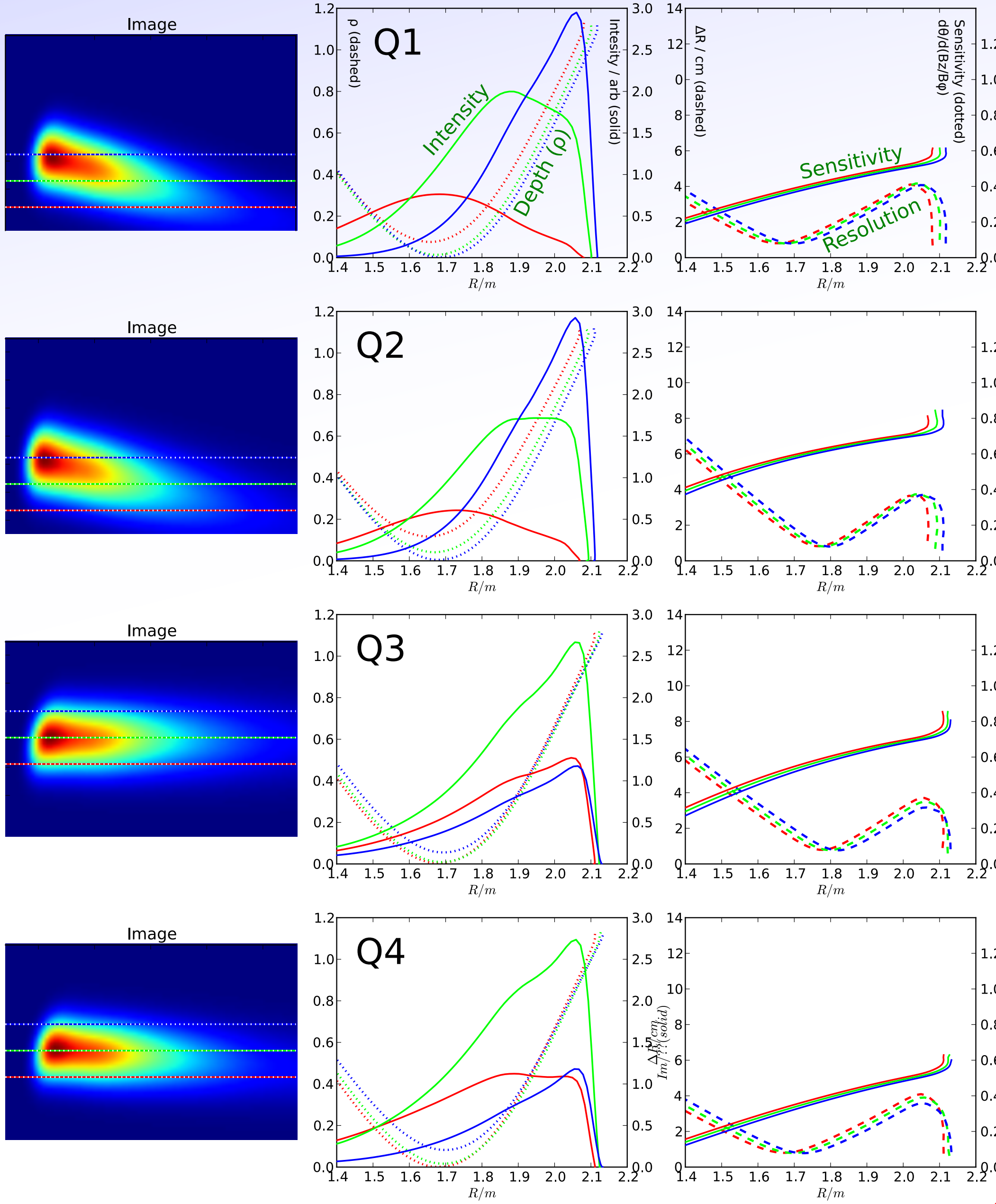
S9 A11 Review

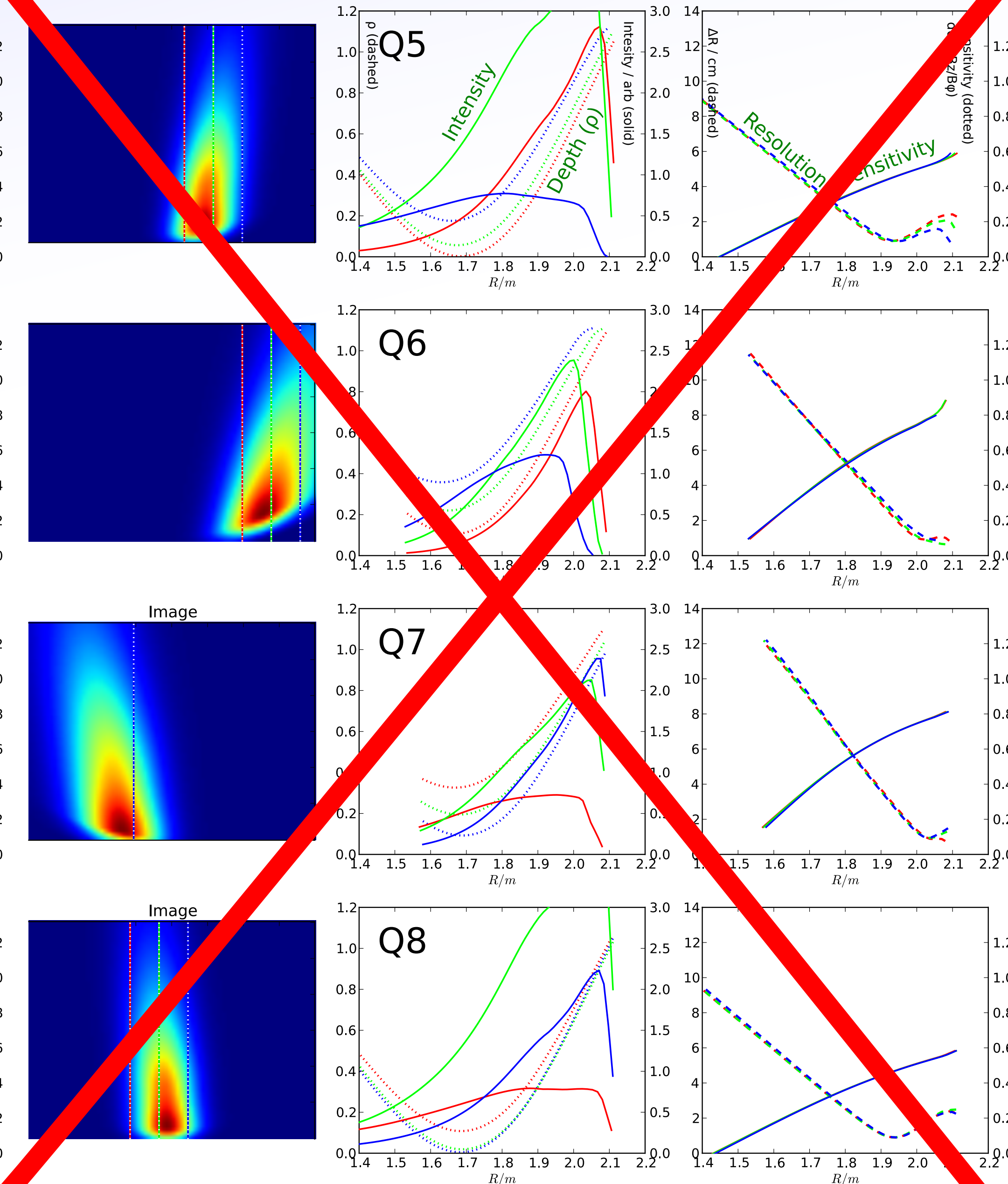
Reviewing S9 A11, viewing from just inside ICRH limiter, and comparing to existing MSE:

MSE:



Wrong view position

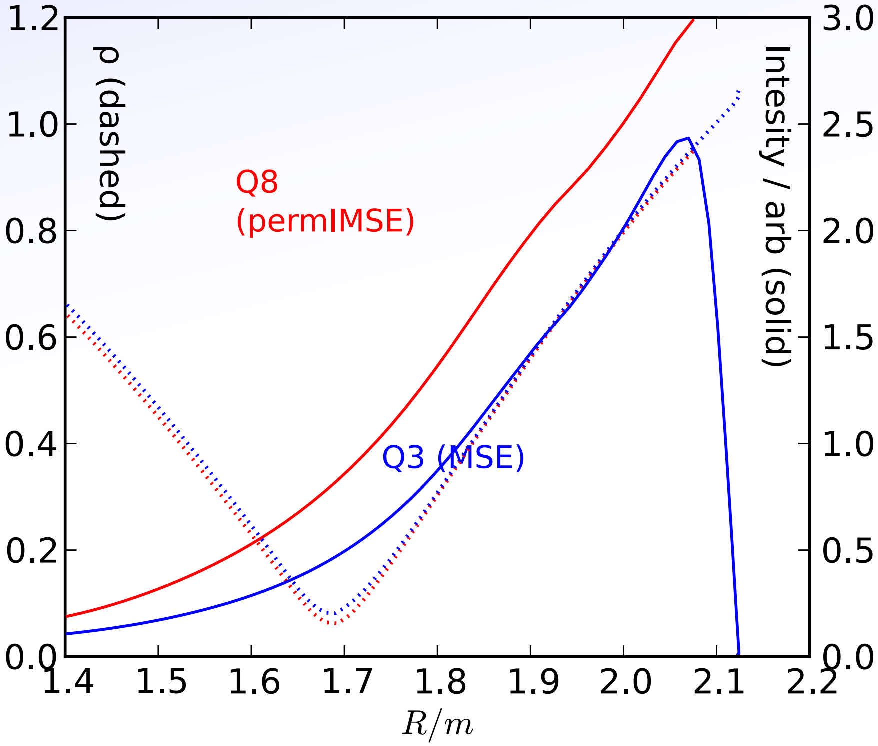
PermIMSE:

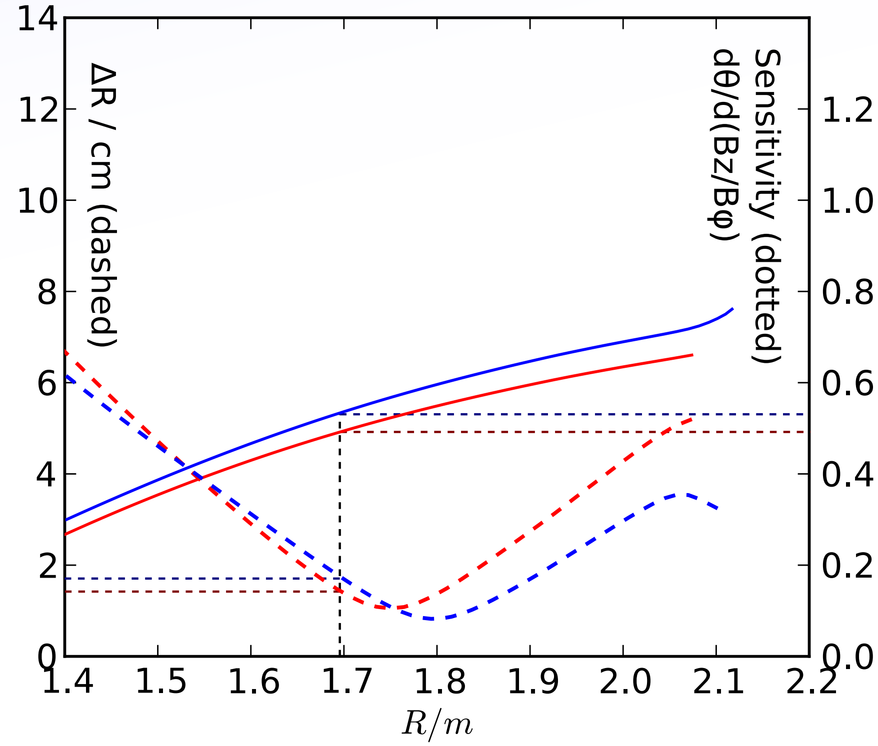


S9 A11 Review

Looking specifically at the 'usual' Q3(MSE) and Q8(permIMSE):

MSE:





So, the permanent IMSE system on Q8, should about the same resolution and the sensitivity with slightly more light as the prototype IMSE system does on Q3.

The main advantage is that we can probably view a bit deeper down to R=1.6. The sensitivity and resolution are very poor, but there might be enough light to localise the magnetic axis which makes the whole equilibrium solving easier.

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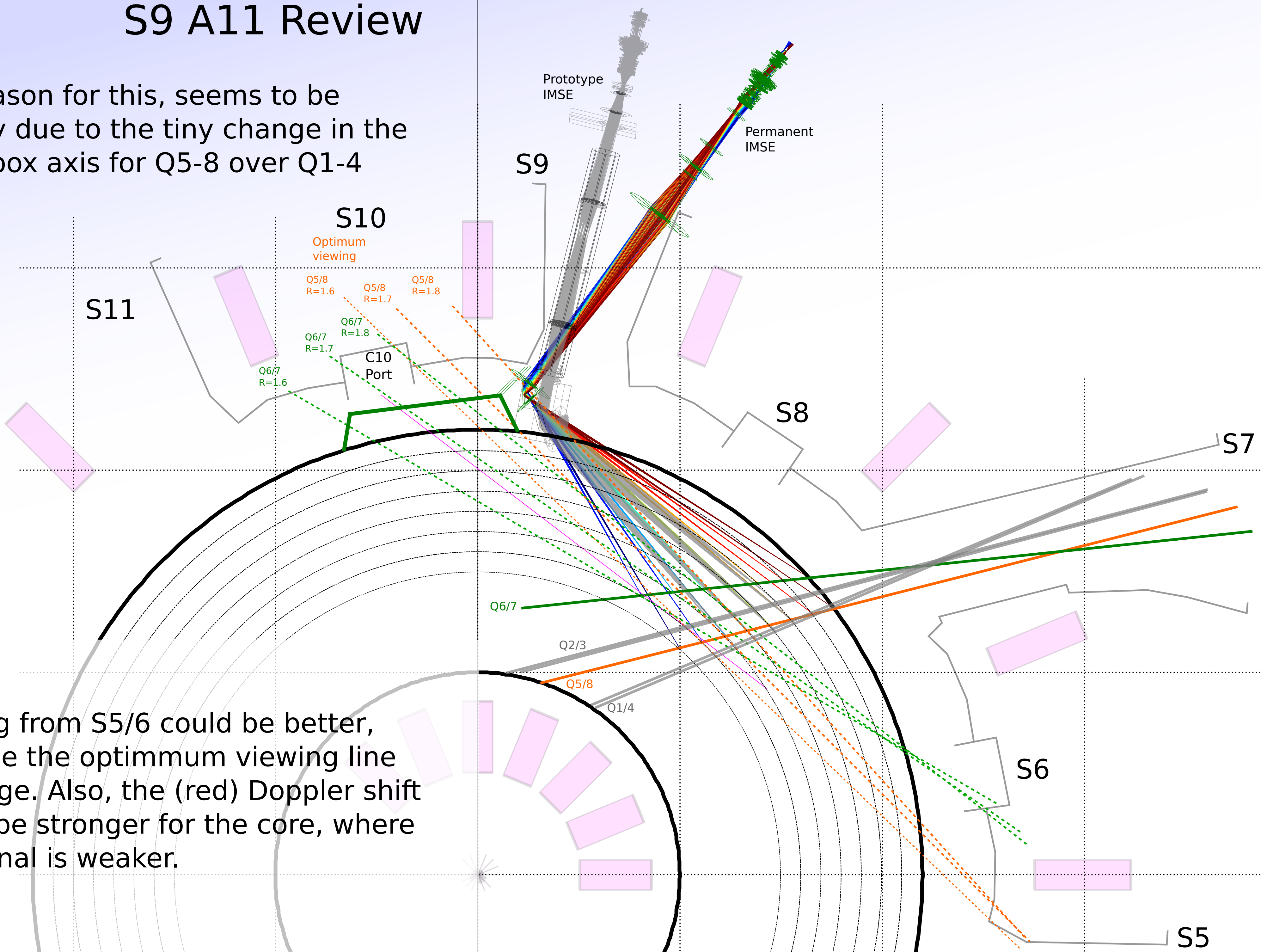
S9 A11 Review

The reason for this, seems to be entirely due to the tiny change in the beam box axis for Q5-8 over Q1-4



Viewing from S5/6 could be better, because the optimmum viewing line converge. Also, the (red) Doppler shift would be stronger for the core, where the signal is weaker.

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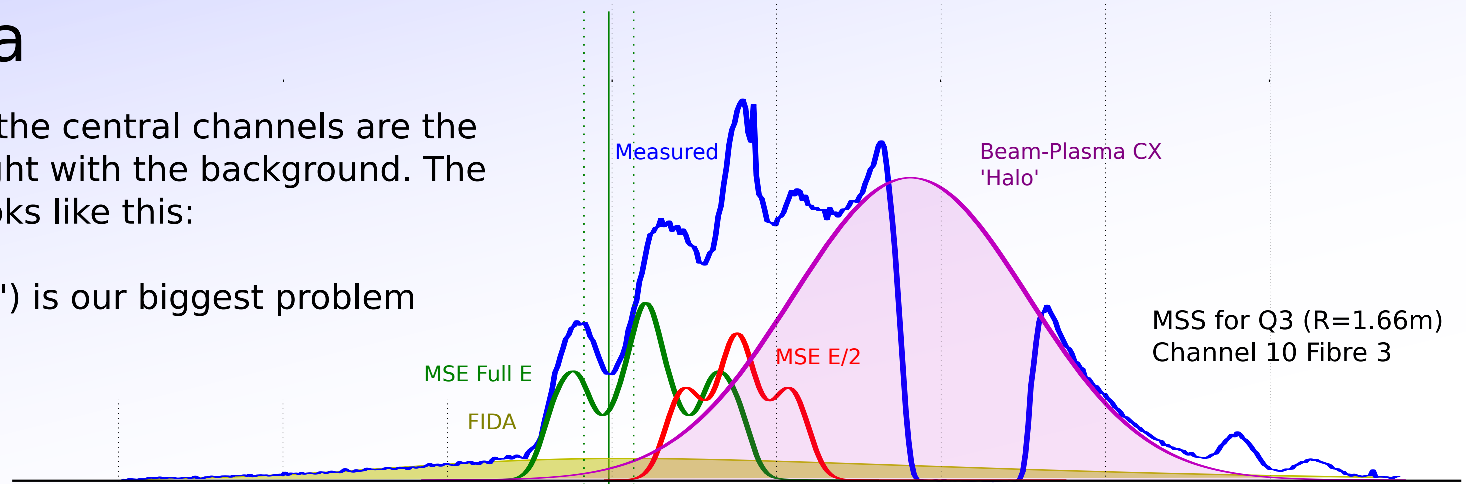
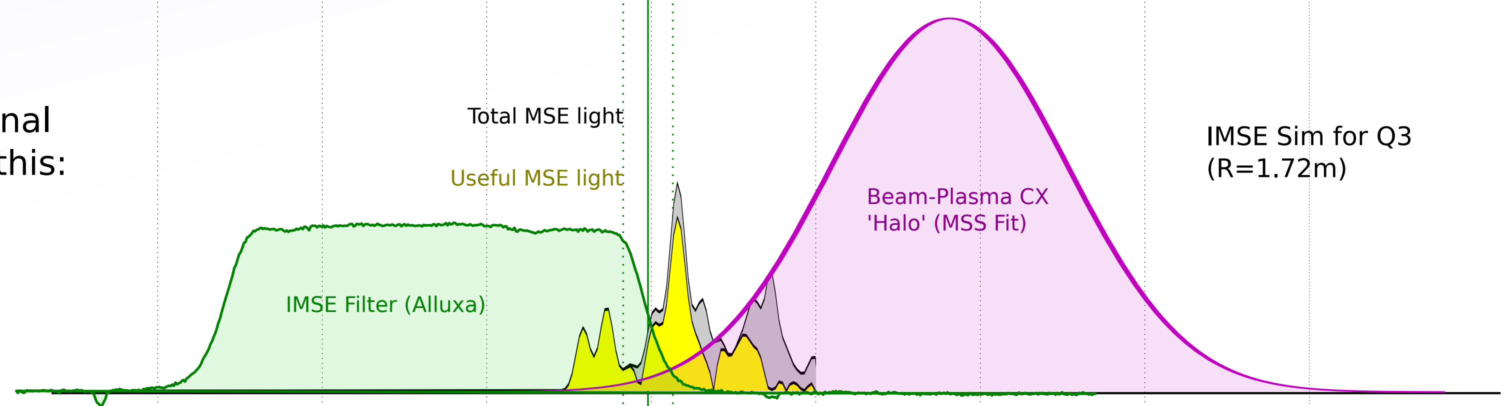
S9 A11 Spectra

For all the blue-shifted MSE systems, the central channels are the least shifted and most likely to mix light with the background. The fit to the MSS spectrum (B.Geiger) looks like this:

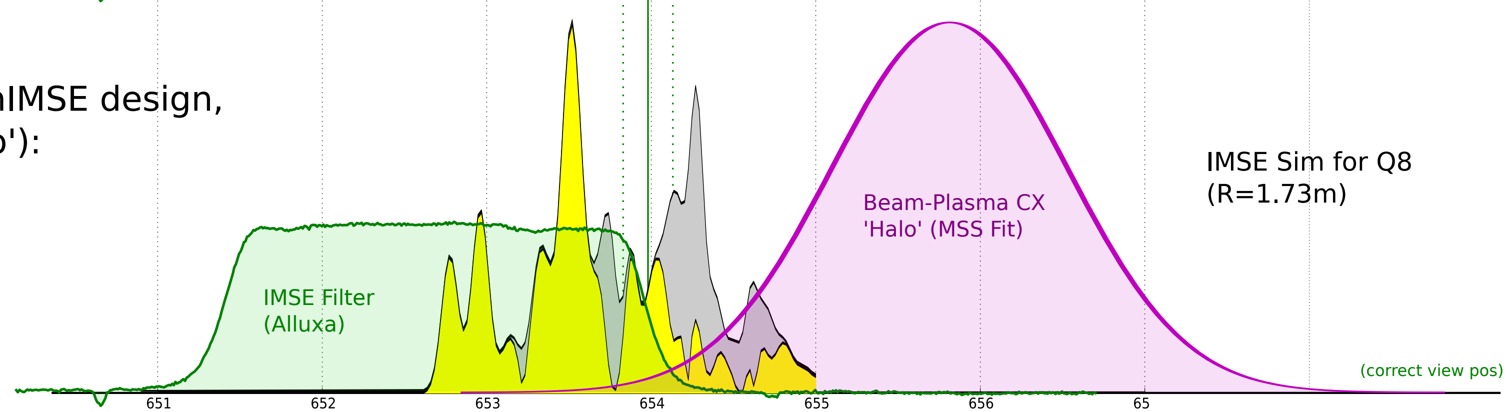
The Plasma-Beam CX (Ben call's 'halo') is our biggest problem for the core signal/noise.



My simulation of the useful MSE signal
and the best IMSE filter, looks like this:

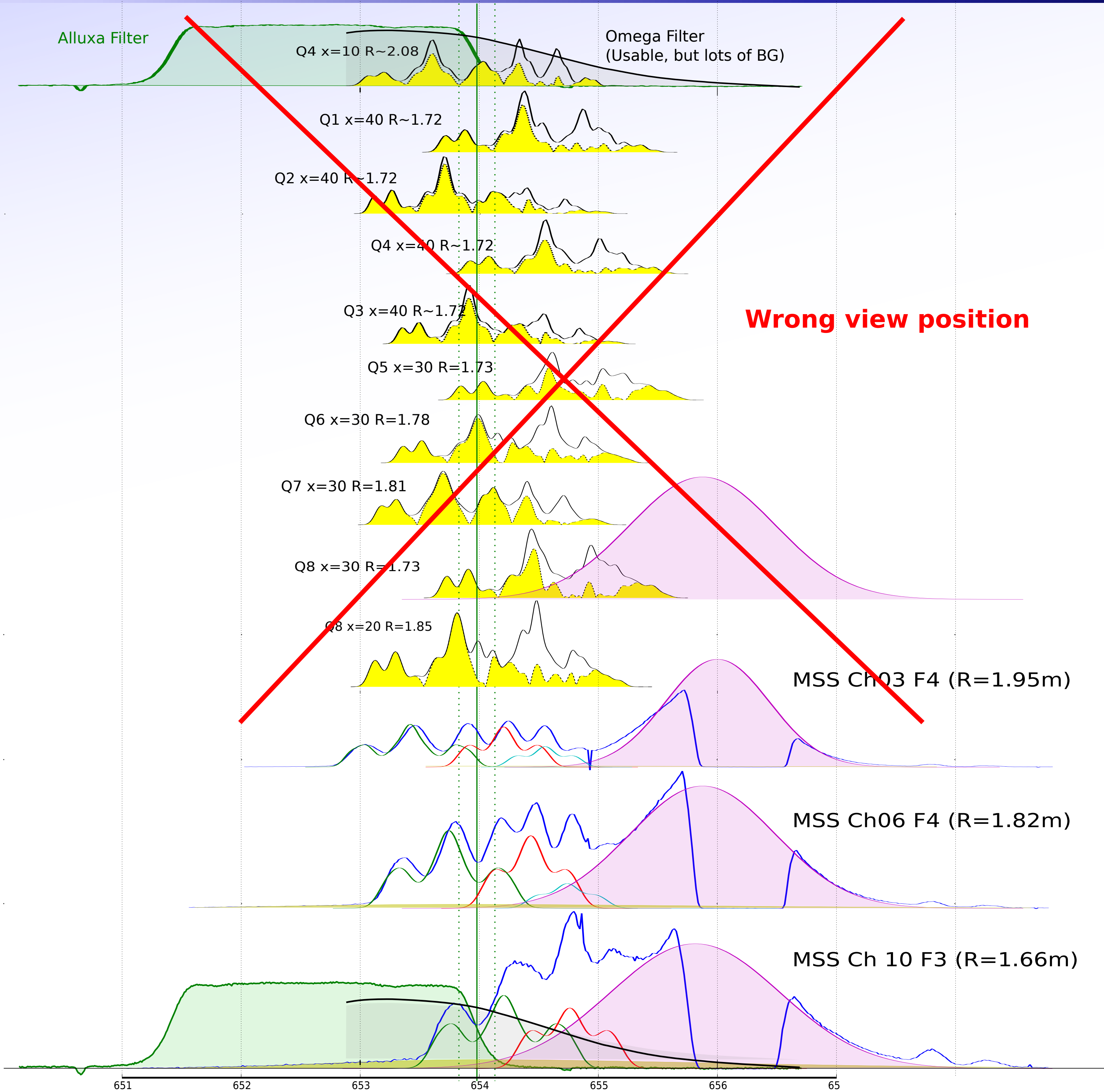


What we expect for Q8 on the permIMSE design,
looks like this (nicluding MSS's 'halo'):



Even at R=1.55m, π and σ light is collected for Q8. It drops to only π at R=1.50 but we can in principle still see that deep into plasma. Coupled with the extra light due to better beam penetration, it will be very good for mag axis position inference and sawteeth studies.

Lots of spectra:



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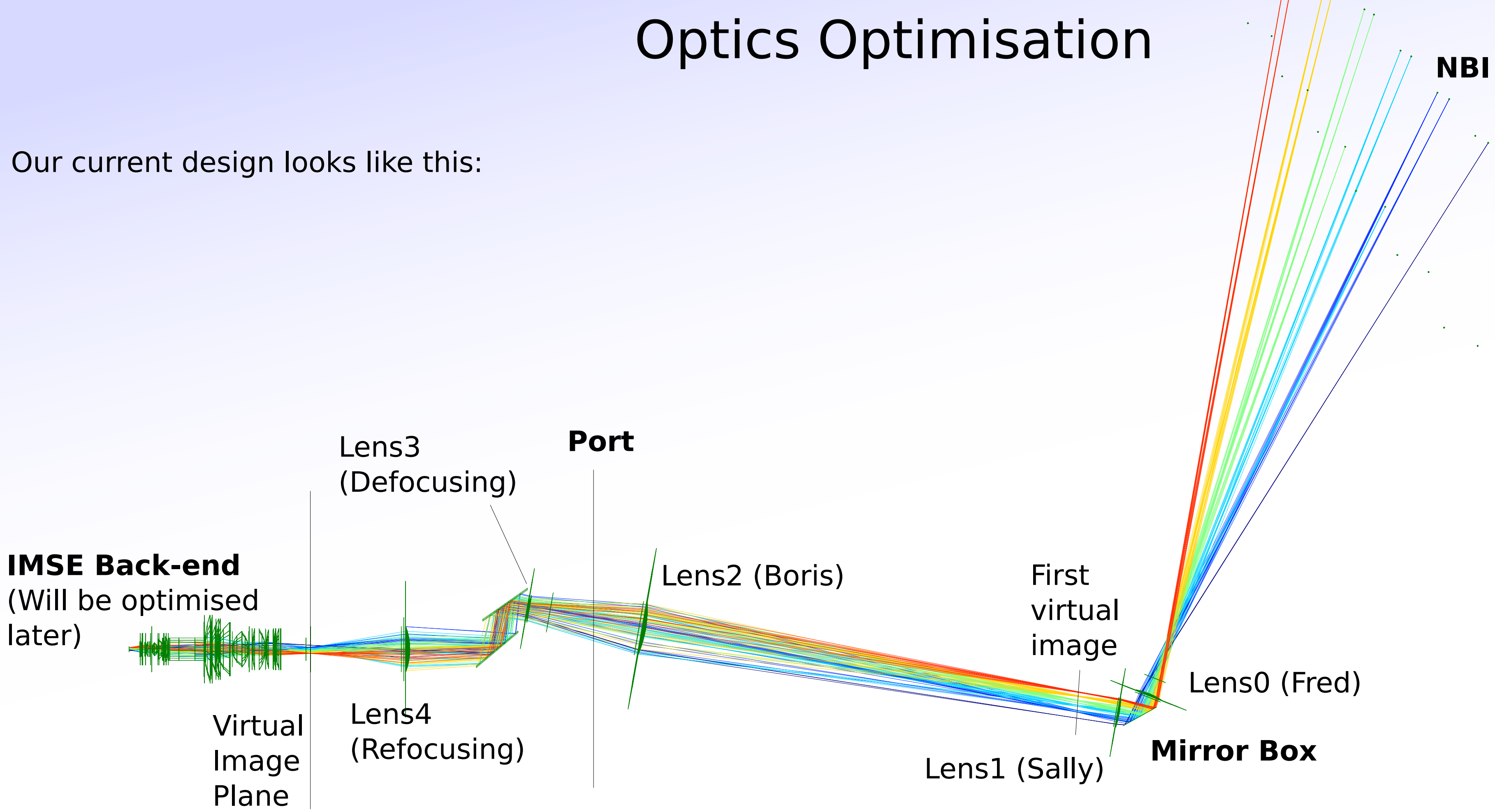
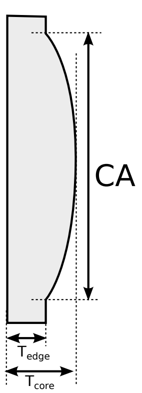
Optics Optimisation

Our current design looks like this:



Spherical Lenses in this are:

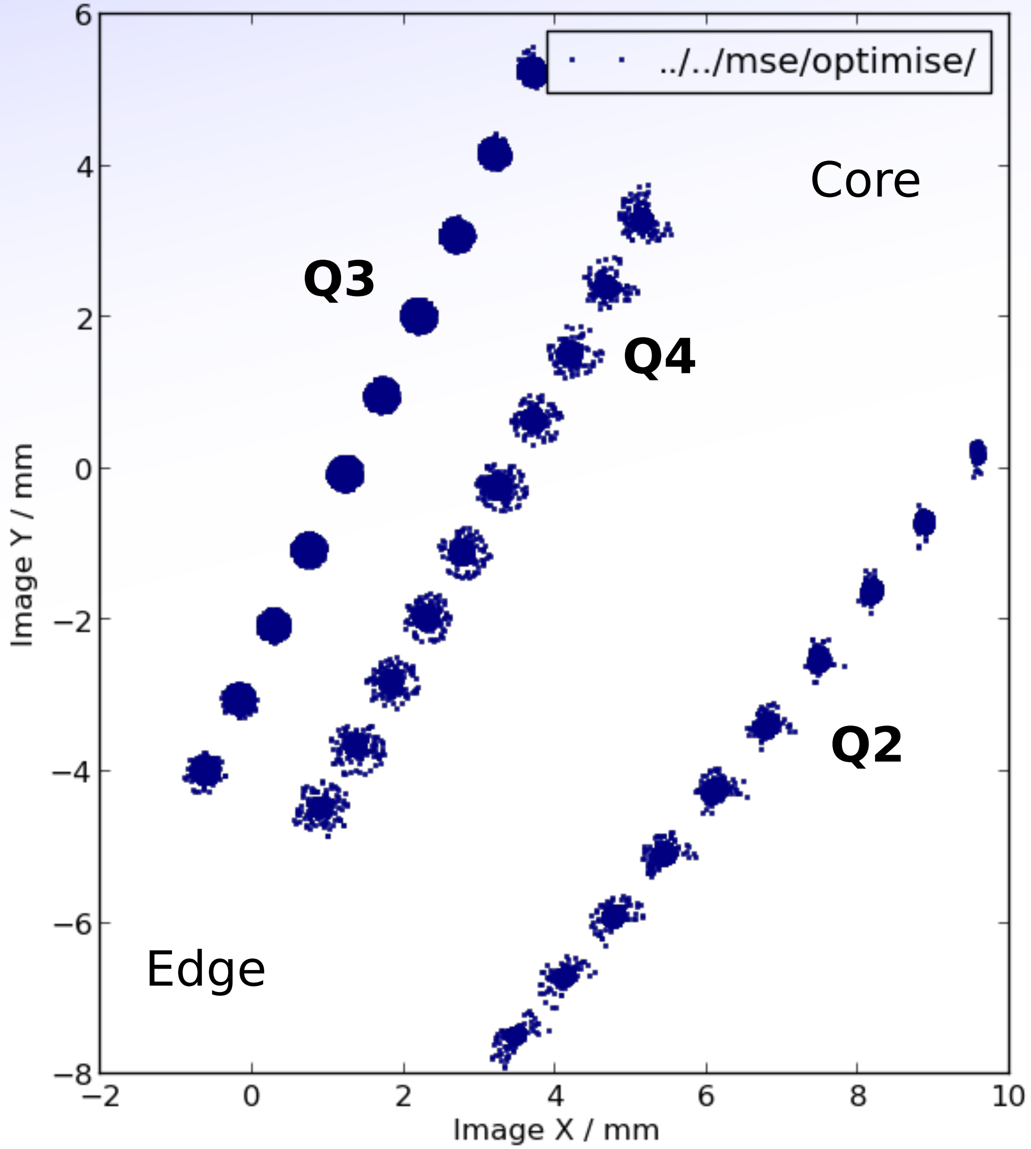
All: Ohara S-TIH6 n(λ=653nm) = 1.796469



	Lens0 (Fred)	Lens1 (Sally)	Lens2 (Boris)	Lens3 (Defocus)	Lens4 (Refocus)
f	198.000mm	334.000mm	329.000mm	-182.000mm	182.000mm
R	157.701mm	266.021mm	262.038mm	-144.957mm	144.957mm
CA	60mm	66mm	120mm	60mm	100mm
T_{edge}	5.000mm	5.000mm	8.000mm	5.000mm	10.000mm
T_{centre}	7.880mm	7.055mm	14.962mm	1.862mm	18.896mm

Optics Optimisation

Prototype best focus (moving image plane)



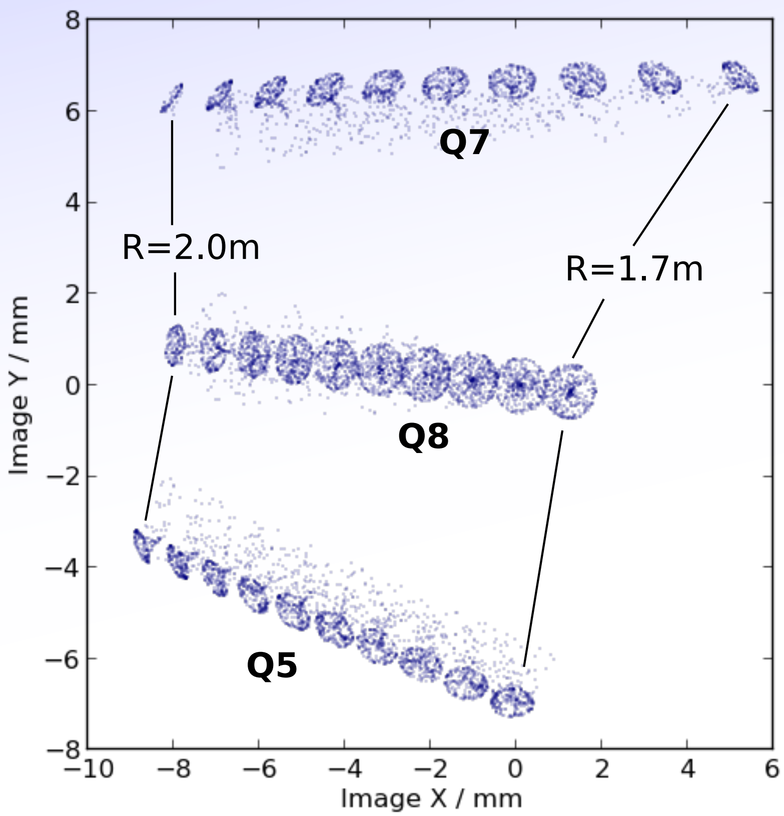
For comparison, optimising focal plane of MSE system (fibre plane), the best we get is an average blur spot that corresponds to **FWHM = 2.3cm** at the beam (Q3).

The real focus using the MSE optics looks good on the backwall but might have always been this bad for the beam itself (how would we have known?)

We'd like to do at least a little better than this for the permIMSE.

Optics Optimisation

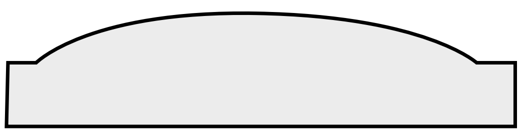
Best focus with no modification to lens shapes:



Best FWHM on image, rescaled to beam plane equivalent:

Image plane only:	FWHM = 8.4cm
+Shift all lenses along normal:	FWHM = 8.3cm
+Pan/Tilt all lenses:	FWHM = 8.1cm
+Shift/Pan/Tilt all lenses:	FWHM = 8.2cm

--> With planar convex spherical lenses we will have very poor resolution.



Spherical Lenses in this are: All: Ohara S-TIH6 n(λ=653nm) = 1.796469

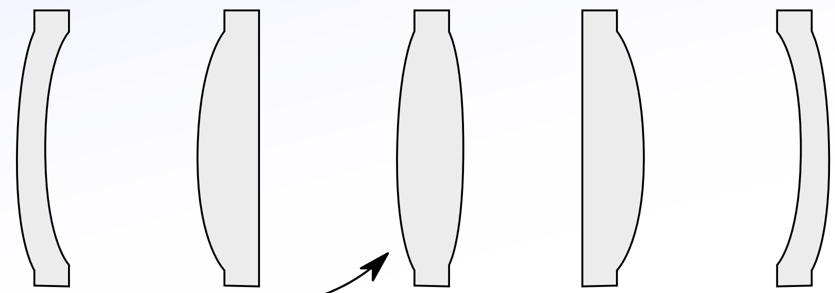
Lens0 (Fred)	Lens1 (Sally)	Lens2 (Boris)	Lens3 (Defocus)	Lens4 (Refocus)
f = 198.000mm	f = 334.000mm	f = 329.000mm	f = -182.000mm	f = 182.000mm
R = 157.701mm	R = 266.021mm	R = 262.038mm	R = -144.957mm	R = 144.957mm
CA = 60mm	CA = 66mm	CA = 120mm	CA = 60mm	CA = 100mm
T_{edge} = 5.000mm	T_{edge} = 5.000mm	T_{edge} = 8.000mm	T_{edge} = 5.000mm	T_{edge} = 10.000mm
T_{centre} = 7.880mm	T_{centre} = 7.055mm	T_{centre} = 14.962mm	T_{centre} = 1.862mm	T_{centre} = 18.896mm

Lens Bending

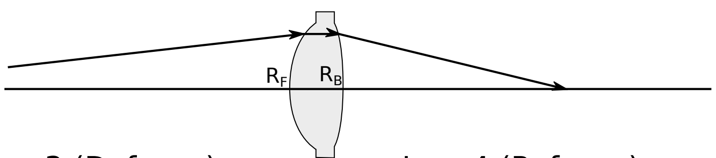
The different focus at slightly different points. We will be able to refocus the bacnk-end objective before ach pulse depending on beam configuration, so we can treat the focusing of each beam separately, i.e. use a different image plane for each beam and let them independently vary.

Best FWHM for Planar-Convex is now **7.8cm**

Now, can we optimise it by changing the lens bending?



Optimise: Pan + Tilt + Bend all lenses.
They start at the very sub-optimal equal double convex and work their way towards a more planar back.
Best FWHM = 6.95cm - a bit better but probably not worth the effort.
Focal lengths changed a little bit too.



All: Ohara S-TIH6 n(λ=653nm) = 1.796469

Lens0 (Fred)

f = 198.000mm
CA = 60mm
T_{edge} = 5.000mm
T_{centre} = 7.880mm

R_{PC} = 157.701mm
R_F = 366.398mm
R_B = 507.954mm
f_{DC} ~ 268mm

Lens1 (Sally)

f = 334.000mm
CA = 66mm
T_{edge} = 5.000mm
T_{centre} = 7.055mm

R_{PC} = 266.021mm
R_F= 326.360mm
R_B = 520.066mm
f_{DC} ~ 253mm

Lens2 (Boris)

f = 329.000mm
CA = 120mm
T_{edge} = 8.000mm
T_{centre} = 14.962mm

R_{PC} = 262.038mm
R_F = 532.655mm
R_B = 525.427mm
f_{DC} ~ 334mm

Lens3 (Defocus)

f = -182.000mm
R = -144.957mm
CA = 60mm
T_{edge} = 8.000mm
T_{centre} = 4.862mm

R_{PC} = -144.957mm
R_F = 276.834mm
R_B = 359.141mm
f_{DC} ~ -197mm

Lens4 (Refocus)

f = 182.000mm
R = 144.957mm
CA = 100mm
T_{edge} = 8.000mm
T_{centre} = 16.896mm

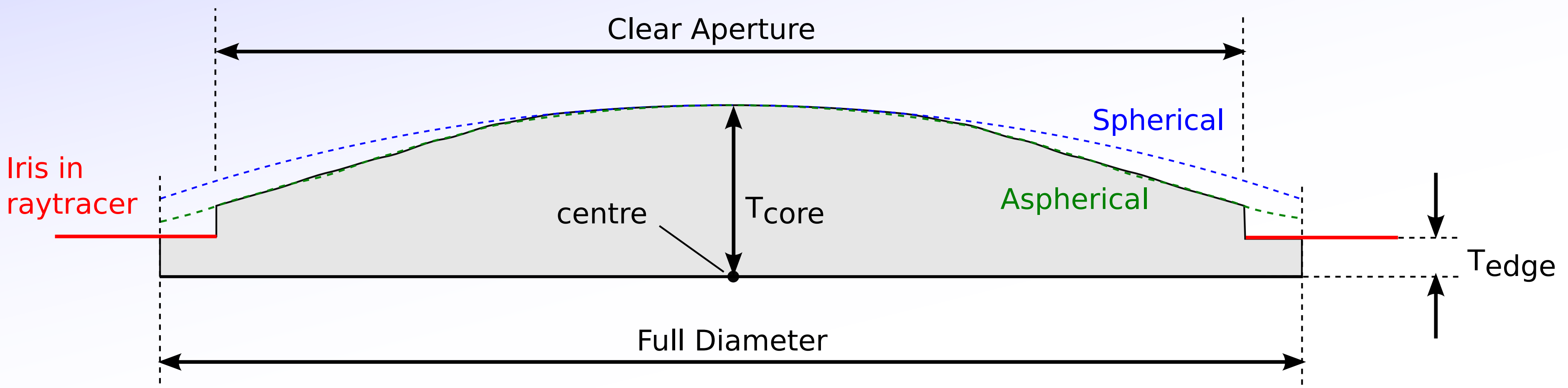
R_{PC} = 144.957mm
R_F = 242.004mm
R_B = 369.453mm
f_{DC} ~ 186mm

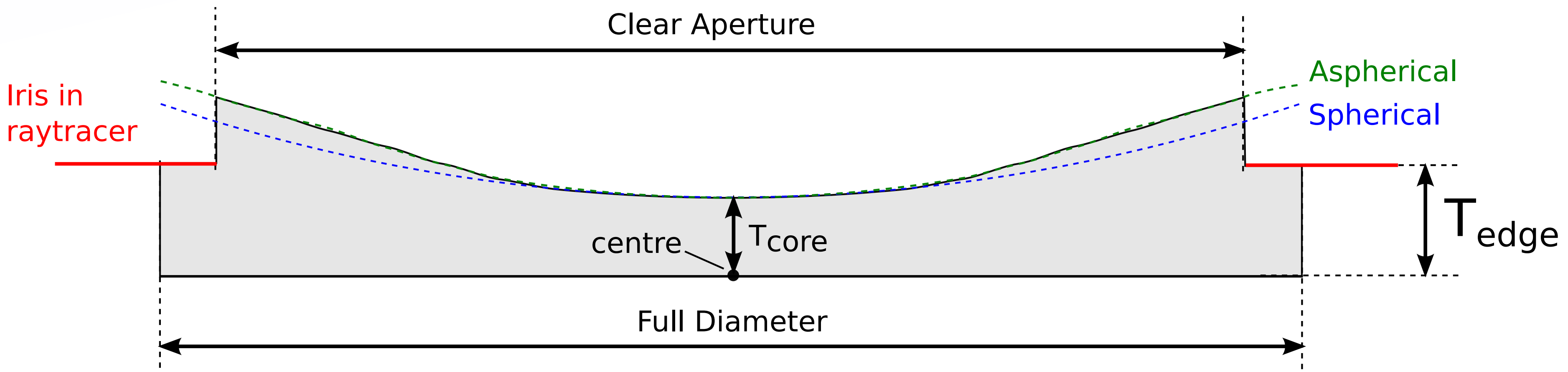
This doesn't seem to help much and certainly isn't enough. If we're going to have to use Aspherics anyway, there isn't much point in doing this.

Pan/Tilt: With planar-convex lenses, allowing pan/tilt of all lenses improves by only 2%.

Lens Definition

The optimisation changes the curvature without moving surfaces, so it's useful to have a fixed centre thickness.
We need to specify a fixed thickness for the mounting:

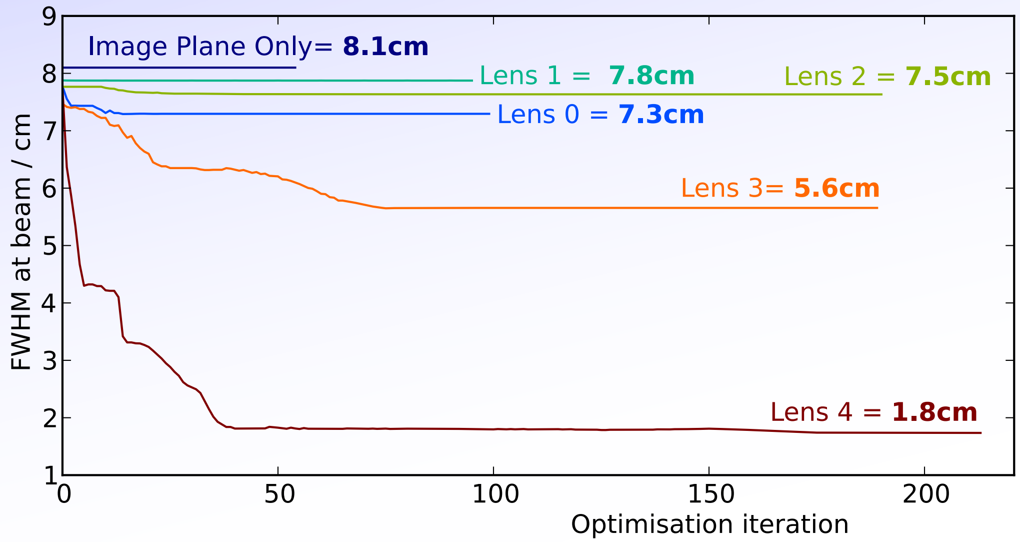


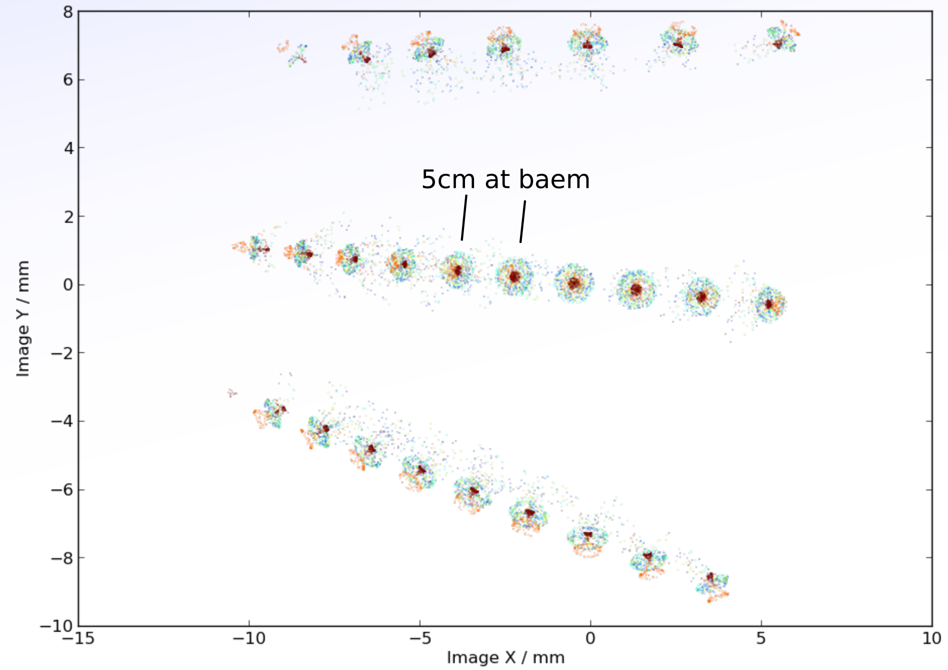


Surfaces need to be ground/polished to the spherical/aspheric surface and then the edges cut, so T_{edge} must be less than the thickness from planar to (a)spherical surface at the full diameter.

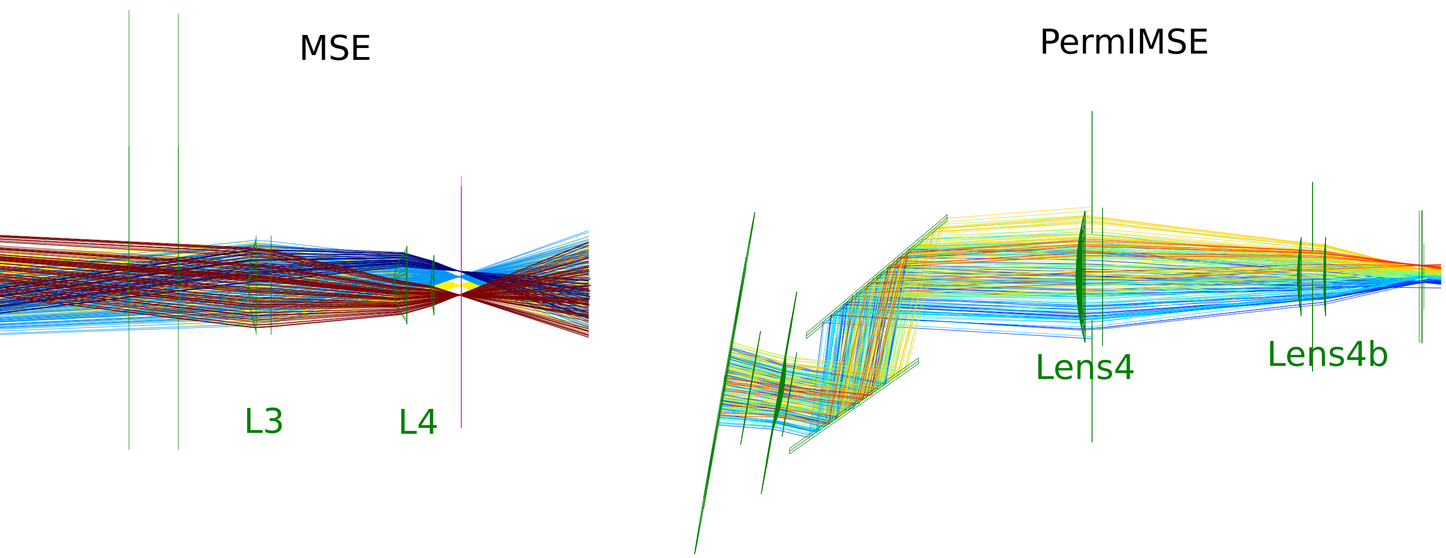
Lens Definition

Optimising each lens as the only aspheric (independently):





Lens4 definitely needs to be aspheric, but it depends on how big we want the virtual image.
Out of interest, we can also see how well we could solve this with spherical lenses, like the MSE system does:



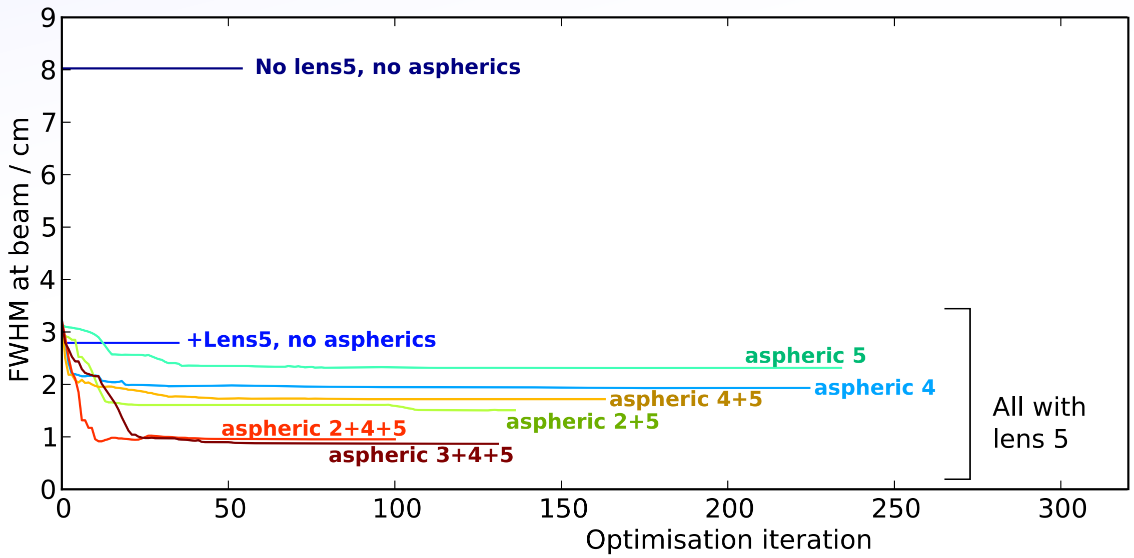
Optimisation of L4b	Best FWHM
Curv. Radii	**3.9cm**
Curv. Radii + Pos	**3.7cm**
Aspheric Front	**2.5cm**

The smaller aspheric 4b isn't as good the large aspheric lens4 without 4b, so 4b is absolutely no use to us :(

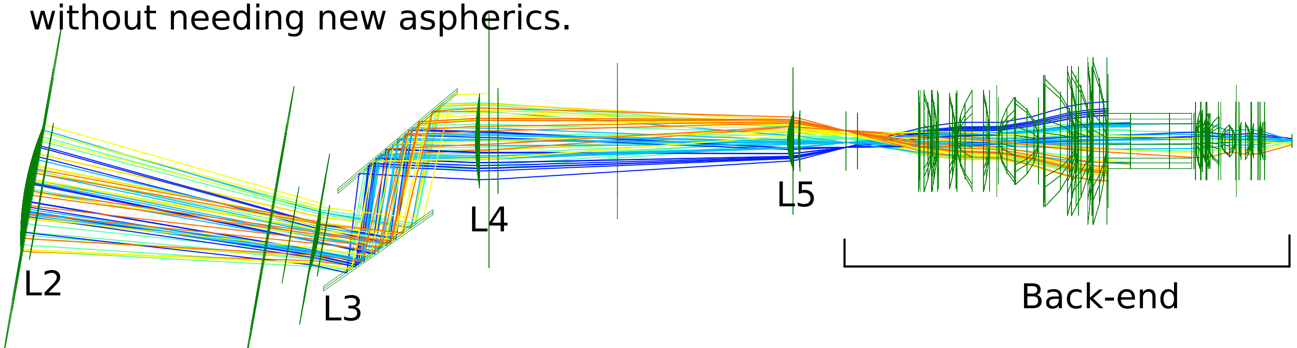
Lenses++

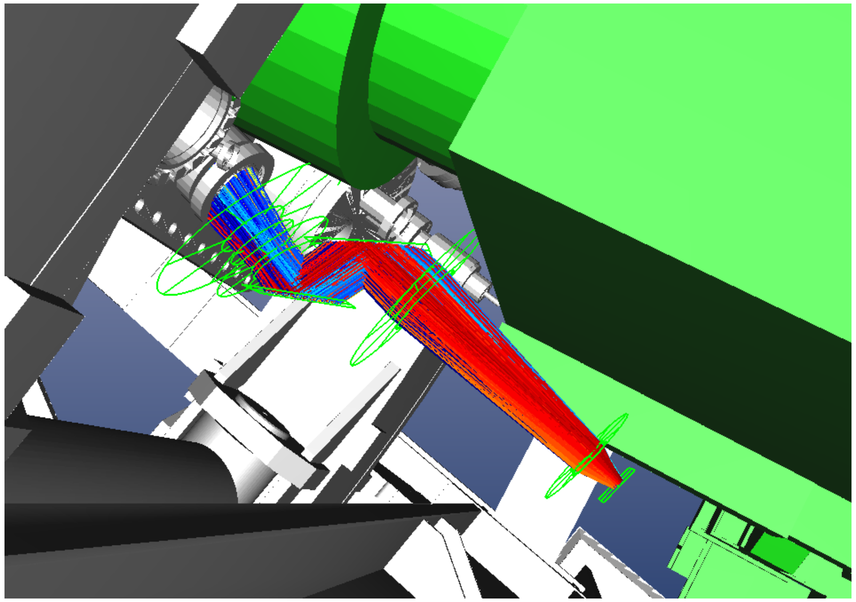
Well, actually... there is some advantage to this set-up.
Lens 4 gets weaker and we add a small short focal length lens5 bolted to the back-end.

1) Since we move lens4 back towards the mirrors, it doesn't need to be quite as big.
2) The mirror box will be smaller and can avoid being in the way of the ECE people. (and less likely to get knocked)
3) There is natually less abberation so it might require less aspherics
4) It should be less sensitive to PF support vs vessel movements since a lot of the final imaging power is now moving with the back-end.



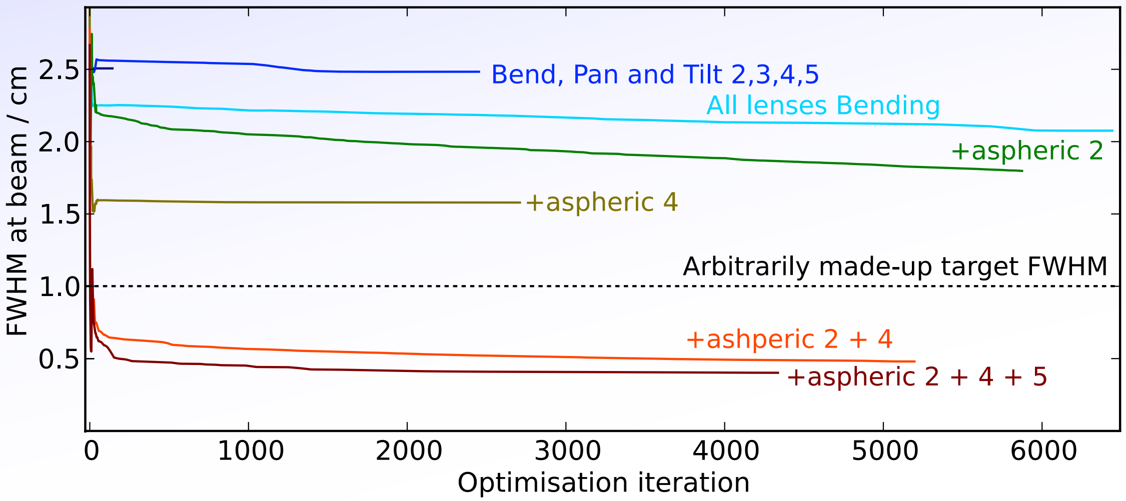
5) We should be able to change L5 later to suit the new back-end without needing new aspherics.





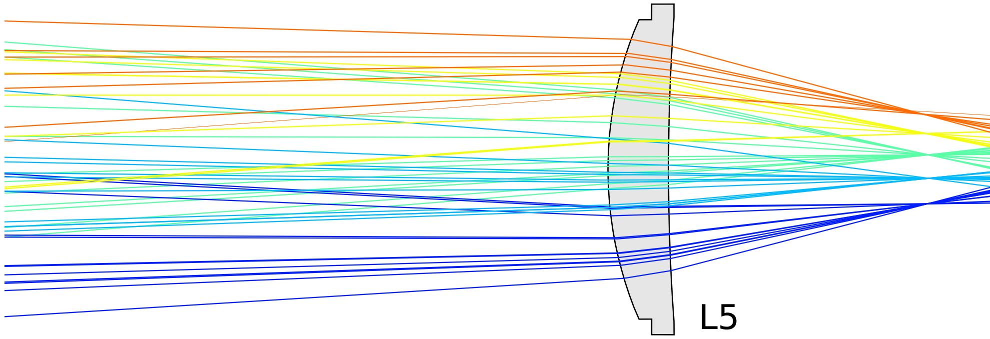
Bending

We can now examine specific aspheric lens combinations with this configuration, optimising the bending of all the other lenses (particularly lens5) at the same time:



Again, aspheric 2 + 4 make the most difference and takes us below the desired 1cm resolution.
Aspheric 5 makes a small difference but not enough to warrant it considering that we might change it later.

Since it's not aspheric, lens 5 does need to be significantly 'bent' away from PlanarConvex:



For the aspheric 2+4 case, the optimiser didn't bend the planar surface of lenses 0, 1 or 3 much, but it extend the focal length of 0 and 1 to improve both the light throughput and the spot size. Unfortunately, this removes our contingency on the field of view.

Original was R = 160mm, and optimised is R = 200mm, so I choose R=180mm as a comprimise. This improves the throughput in the mid-radius by 5-10% and makes almost no difference to the vignetting at the core and edge.

So, now we put that in, fix all the other lenses and optimise again just the aspheric surfaces of 2 and 4...

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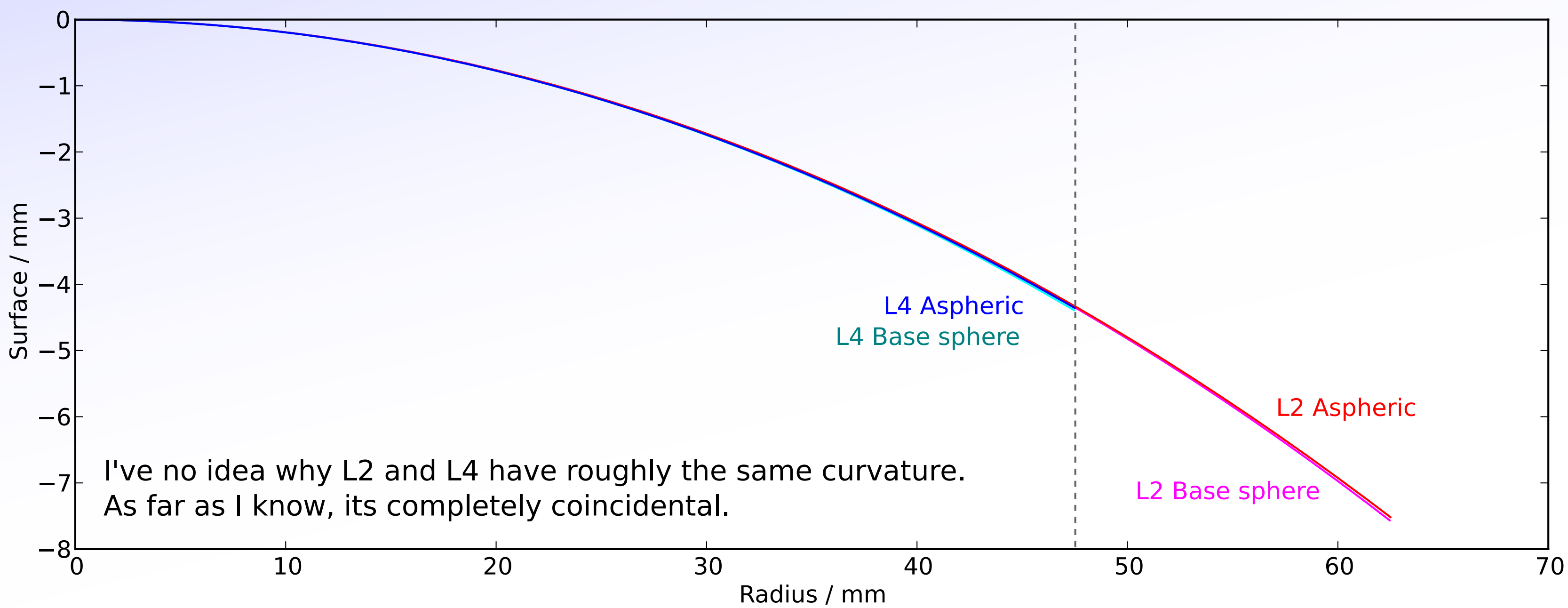
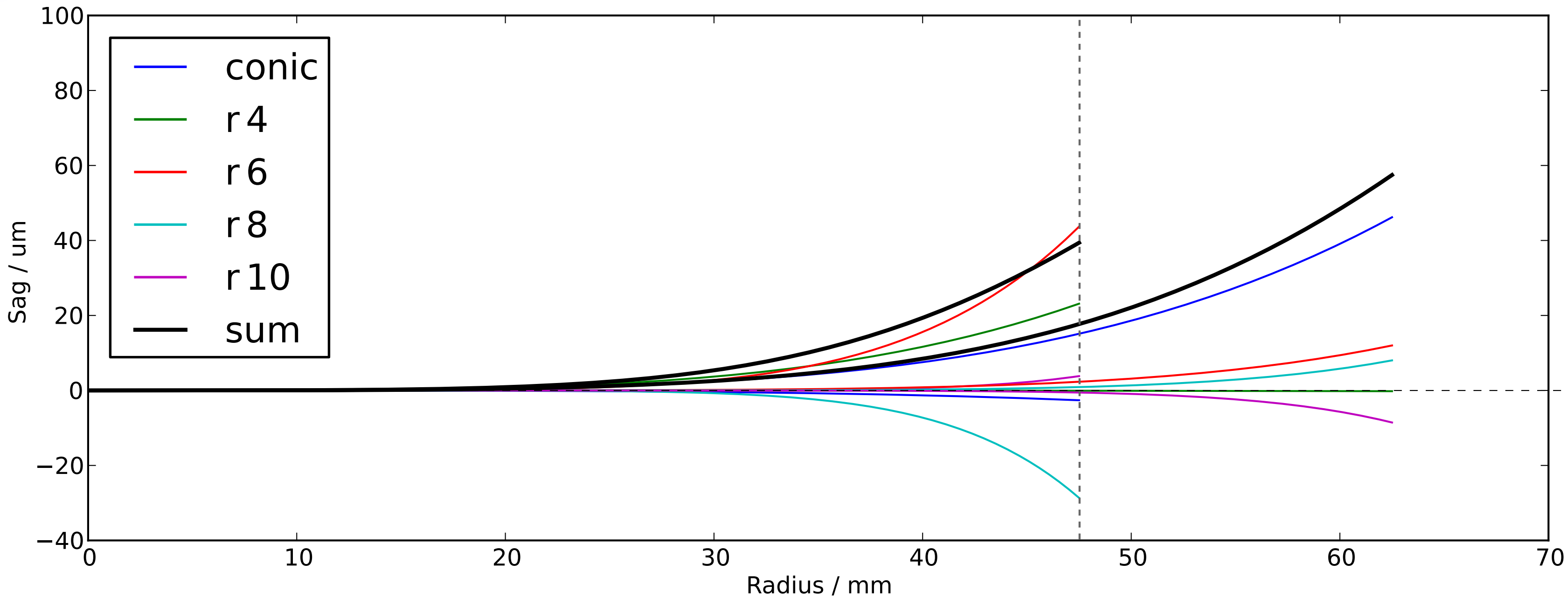
Aspheric 2 and 4

After re-optimising aspheric surfaces for 2 and 4, the **<FWHM> ~ 0.40mm** and the aspherics look like this:





Stage6:

Lens 2:
R = 261.639mm
d = 125mm
CA = 120mm
cc = -0.414132
A4 = 0.001308 x 10^{1} / m
A6 = -0.201269 x 10^{3} / m
A8 = -0.344317 x 10^{5} / m
A10 = 0.939706 x 10^{7} / m

Lens 4:
R = 258.737mm
d = 95mm
CA = 85mm
cc = 0.068652
A4 = -0.454567 x 10^{1} / m
A6 = -3.805416 x 10^{3} / m
A8 = 11.058227 x 10^{5} / m
A10 = -6.536800 x 10^{7} / m

Curvature in **opposite** direction to base sphere.

Curvature in **same** direction as base sphere.

Final(ish) State

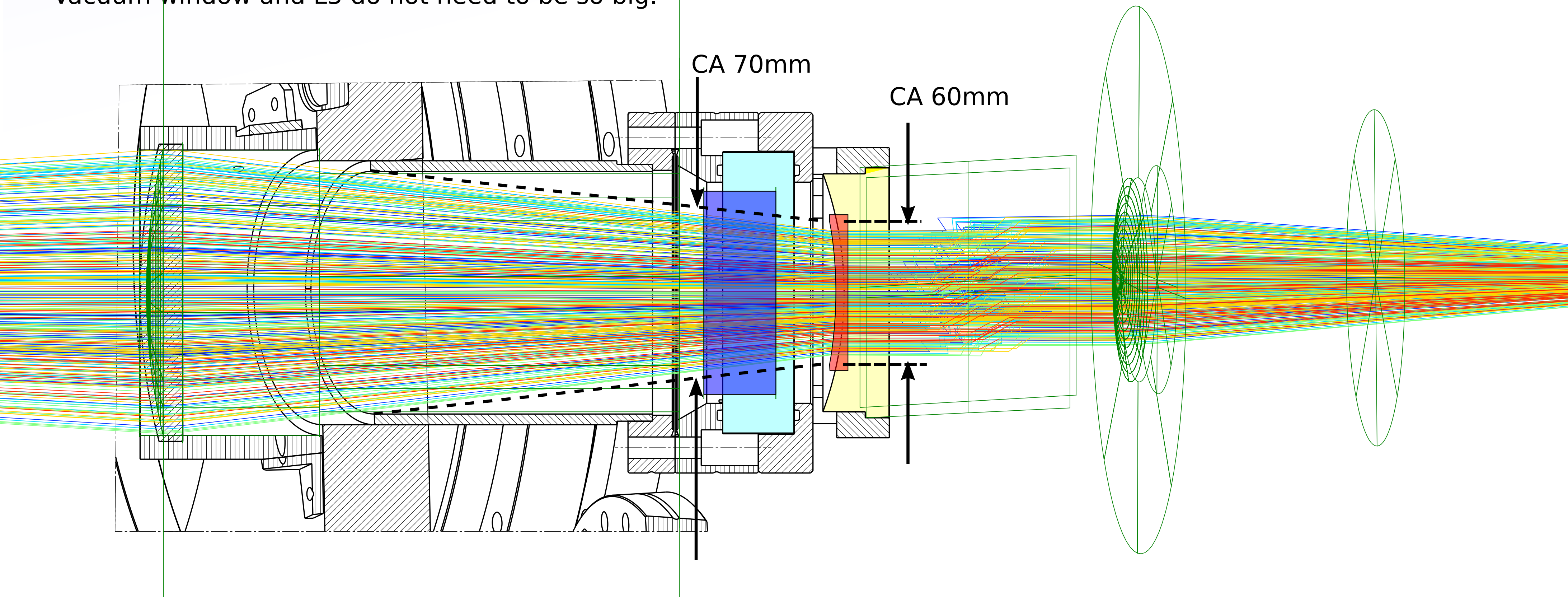
Now moved vacuum window further out and made it thicker.
This required moving L3 further out which changed everything so now everything has been reoptimised.

L5 now 2cm thick minicus, could this be an issue with Faraday??

Saved as linear system in ZMX to check in winLens and an old version of Zeeman.
These do not show good focus at the same plane for different spatial positions, and don't agree with each other in how far out it is. This could be due to the process of making the system 2D.

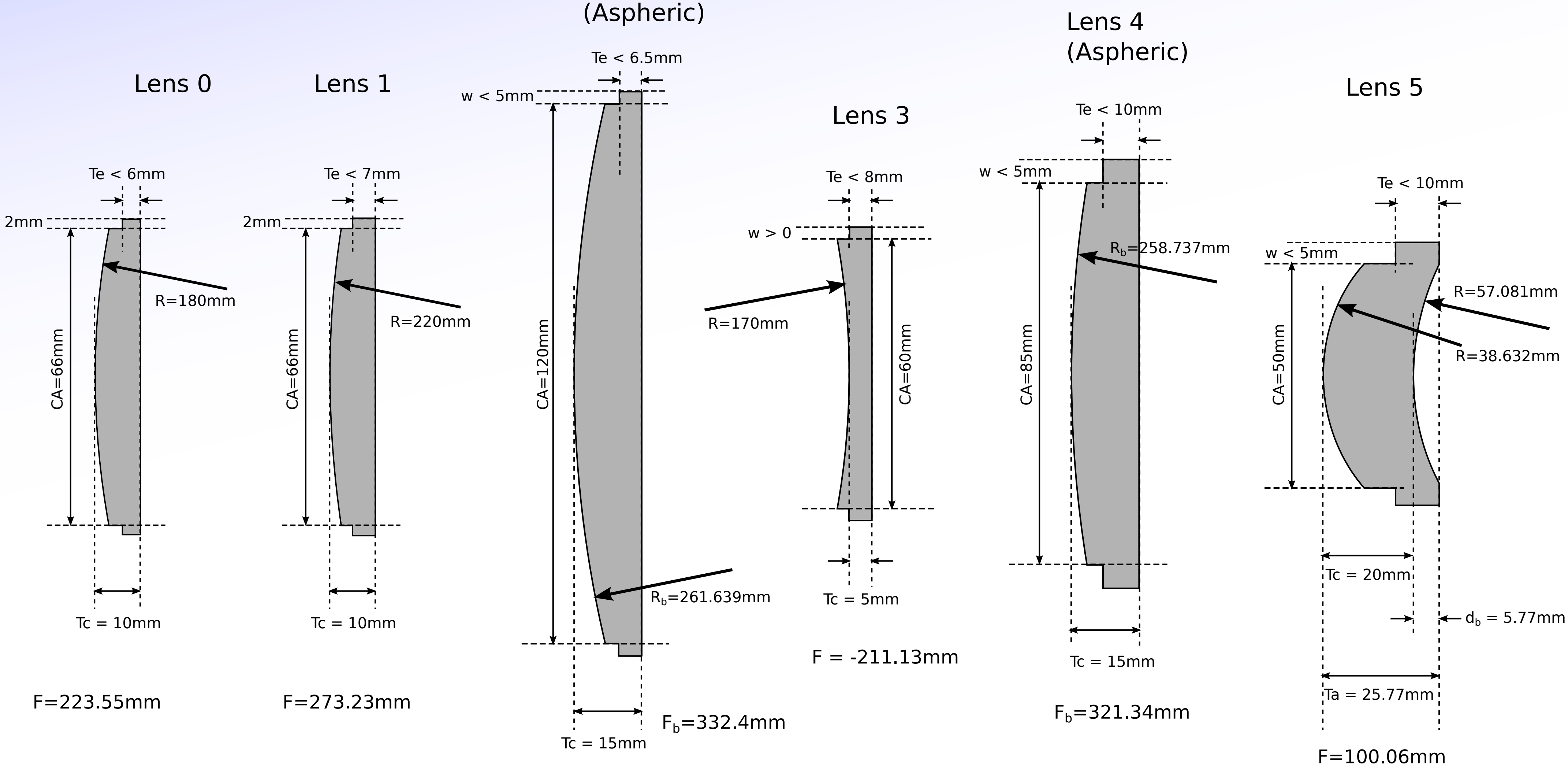
They do seem to agree that the my aspherics fix the focusing for each point individually.
The Sag data from the previous slide matches the sag data in winLens, so I believe I am using the coeffs correctly.

Everything doesn't match designers port diagram. L3 is smaller than he thinks and needs to get 1cm closer to L2.
Vacuum window and L3 do not need to be so big.



Final(ish) State

The optical requirements of the lenses are now:



Mounting edges are OK within the given bounds. The can be made wider or smaller as long as they don't go through the curvature radii.

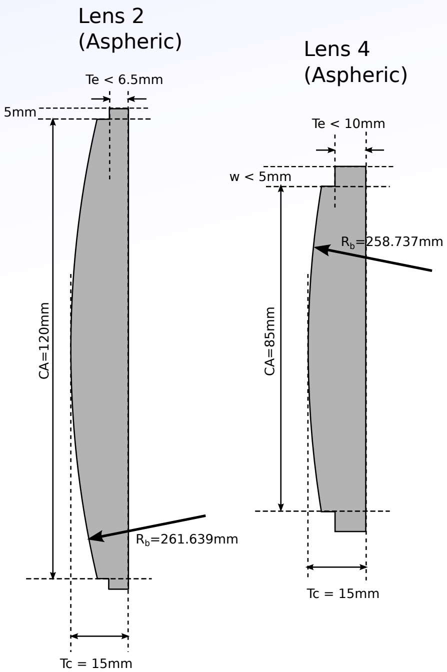
For lenses 1-4, the back side (flat side) should be mounted at the specific positions to match the ray-tracing.

Lens 5 should also be mounted with it's back side, but some adjustment here would be useful.

Specifications for the aspherics follow.

Aspheric Definitions

The aspheric lenses (L2 and L4) are defined in terms of their radius of curvature, conic constant and polynomial terms.
The coefficients (which are not unitless) and are in meters in FusionOptics.
In mm, they are:




```
Lens 2:
R = 261.639 mm
k = -0.414132
A4 =  1.30800e-11
A6 = -2.01269e-13
A8 = -3.44317e-17
A10 = 9.39706e-21
```

Rad/mm,	From plane/mm,	From sphere/mm
0.000	-0.0000	-0.0000
5.000	0.0478	-0.0000
10.000	0.1911	-0.0000
15.000	0.4302	-0.0001
20.000	0.7651	-0.0005
25.000	1.1960	-0.0012
30.000	1.7231	-0.0025
35.000	2.3468	-0.0048
40.000	3.0673	-0.0085
45.000	3.8849	-0.0140
50.000	4.7999	-0.0221
55.000	5.8128	-0.0334
60.000	6.9242	-0.0484

```
Lens 4:
R = 258.737 mm
k =  0.068652
A4 = -4.54567e-09
A6 = -3.80542e-12
A8 =  1.10582e-15
A10 = -6.5368e-20
```

Rad/mm,	From plane/mm,	From sphere/mm
0.000	-0.0000	-0.0000
5.000	0.0483	-0.0000
10.000	0.1933	-0.0000
15.000	0.4349	-0.0002
20.000	0.7733	-0.0009
25.000	1.2083	-0.0023
30.000	1.7397	-0.0054
35.000	2.3675	-0.0107
40.000	3.0913	-0.0194
45.000	3.9115	-0.0318

Partial Aspherics

The aspheric lenses might take too long to order so here's some options with spheical in-vessel optics:

<FWHM> at beam plane (i.e. actual resolution):

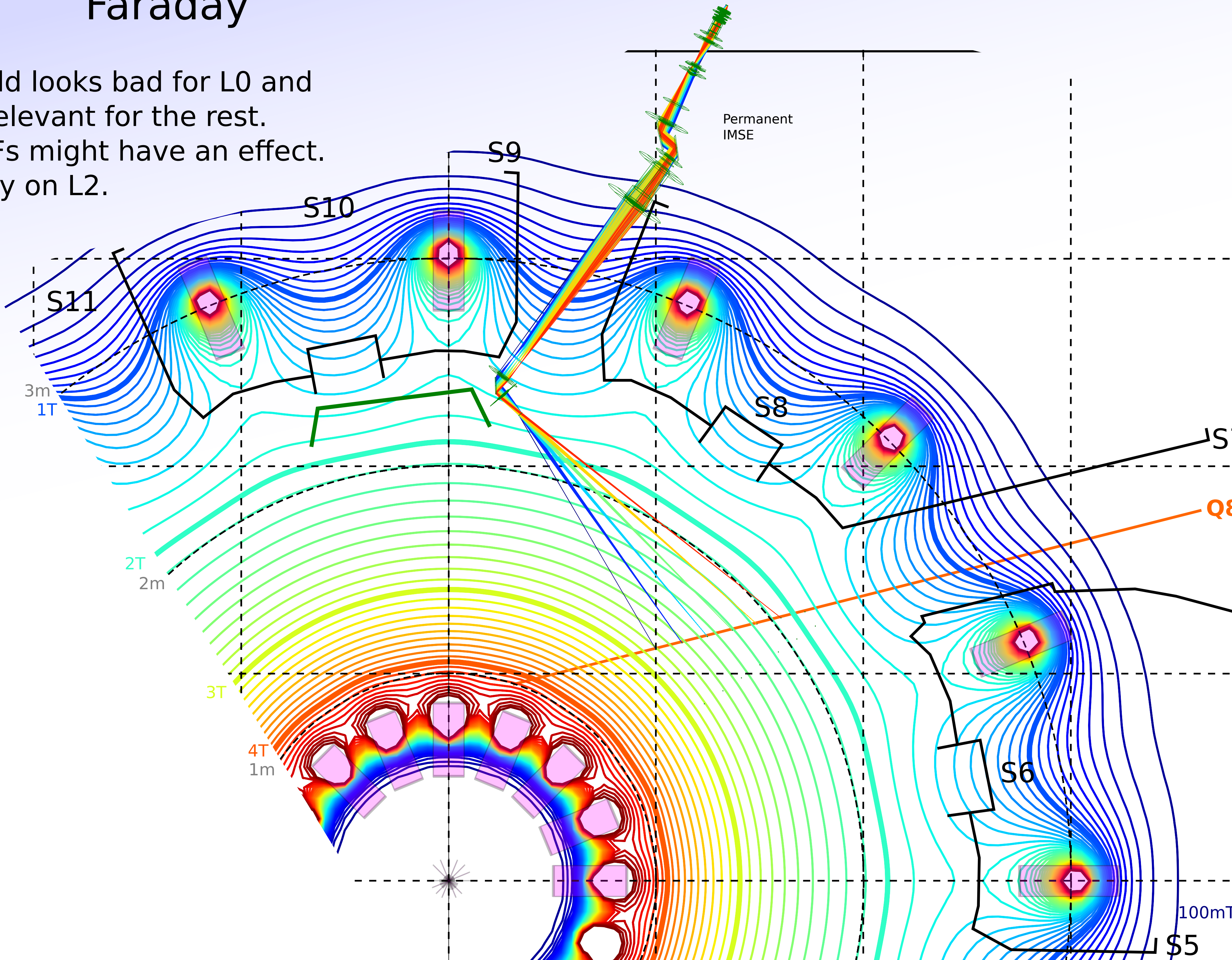
Original aspheric Boris, for comparison = 3.0mm
Best Spheric Boris, no changes to the rest = 24.4mm
Best Spheric Boris, re-optimised L4 = 24.2mm
Split Spheric Boris, no changes to the rest = 8.0mm
Split spheric Boris, re-optimised L4 = 4.5mm

So, if time constraints say we must have a spherical Boris to get the in-vessel stuff done in time, I would say split boris and use the reoptimsed L4, keeping it like that forever.

If we think we have a good change to order the aspheric in time, or can't split Boris for mechanic reasons, then we should buy a spherical Boris now and replace it later, leaving the L4 optimised ready for having the asphercial Boris late but accepting 2.5cm resolution for the first campaign.

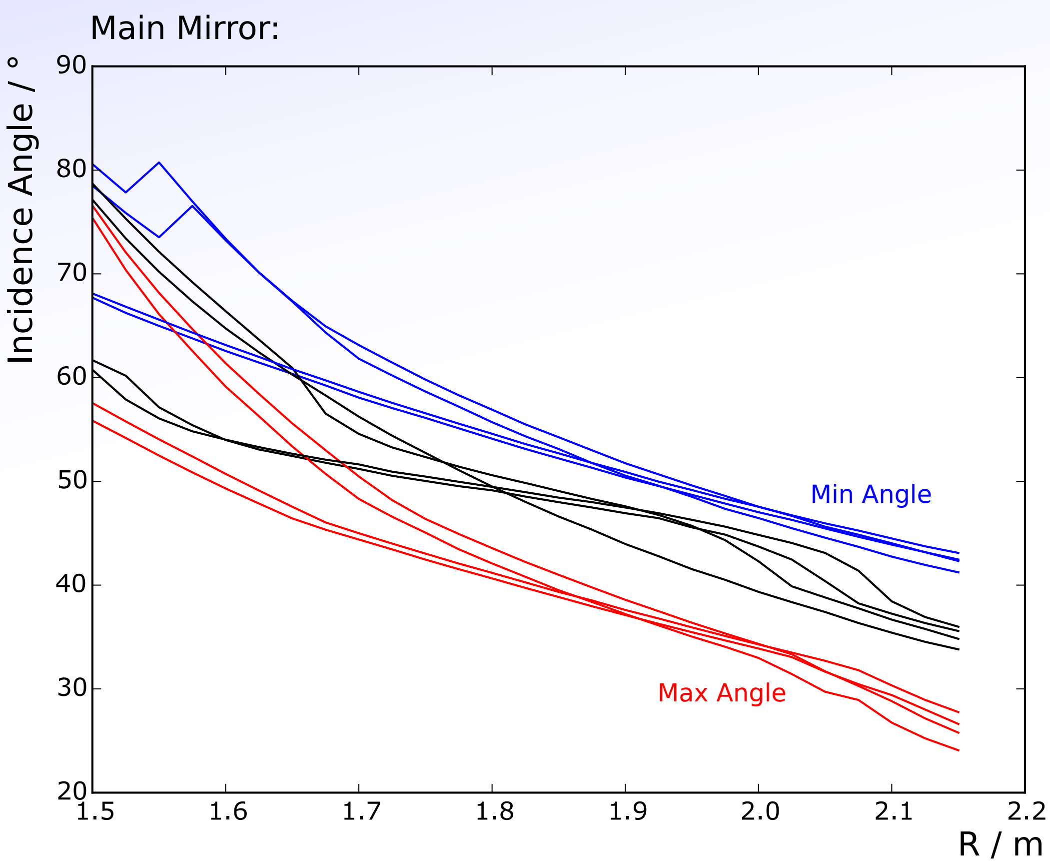
Faraday

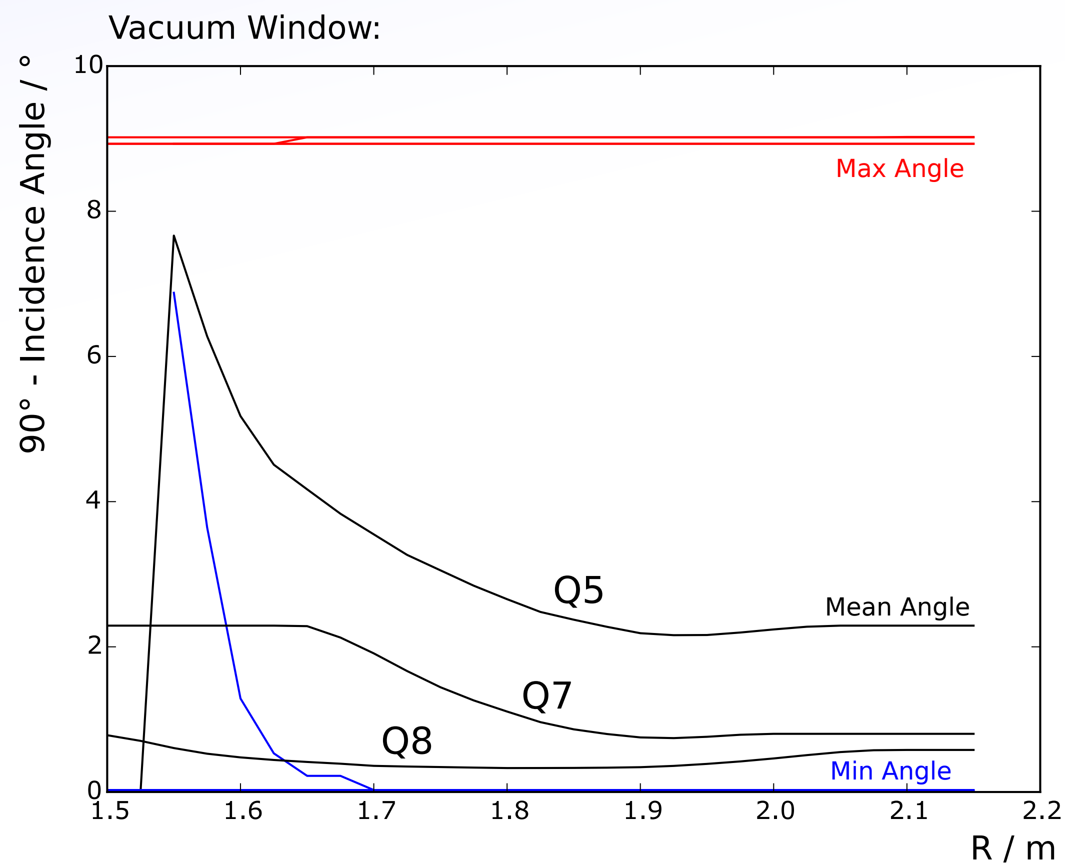
The TF field looks bad for L0 and almost irrelevant for the rest. Vertical PFs might have an effect. Particularly on L2.



Incidence Angles

Incidence angles on interesting surfaces calulated by LightAssessment





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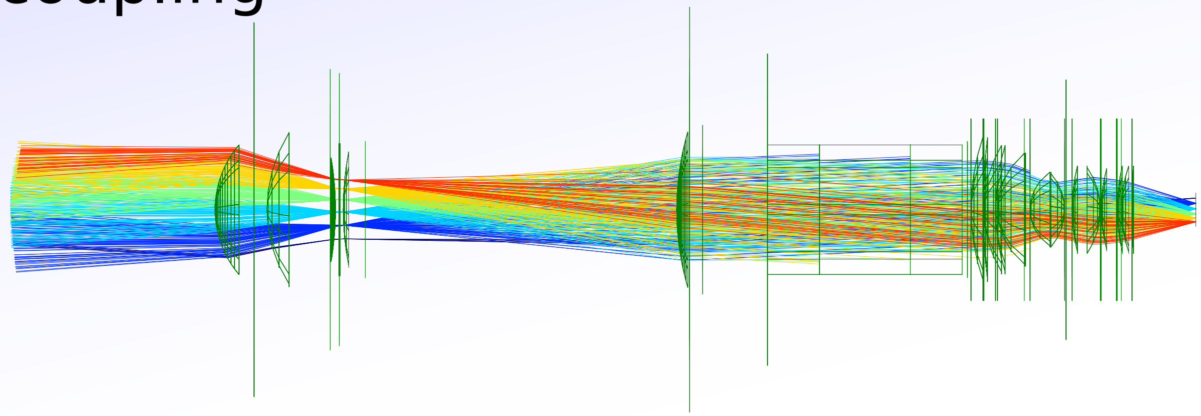
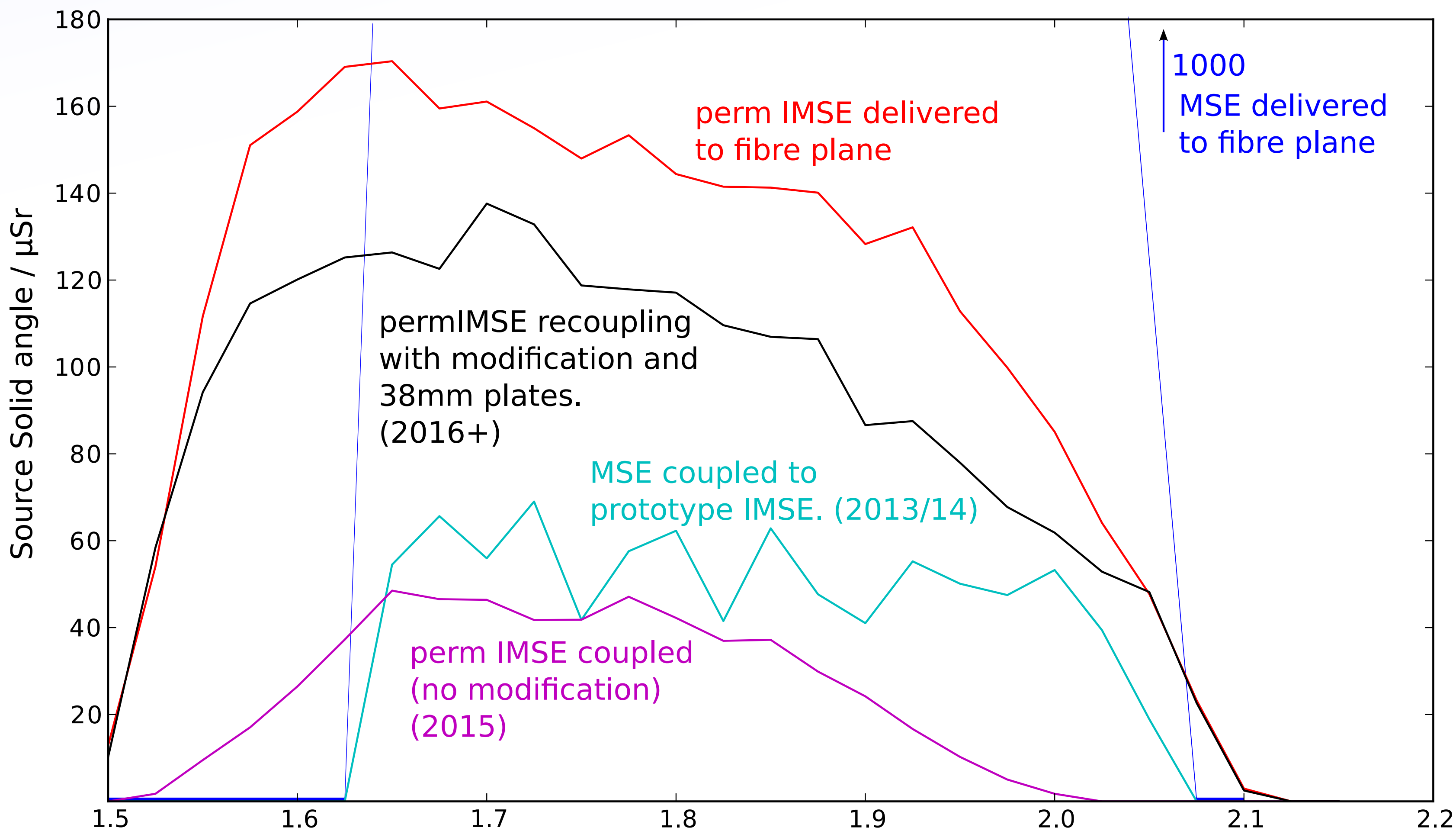
Recoupling

For the later redesign of the back-end, we can probably build our own (aspheric) objective lens to better couple the IMSE to the forward optics. With this and 38mm plates and clear aperture through the whole system, we should be able to couple all the light we deliver to the virtual image, beating the 2013/14 IMSE/MSE set-up.





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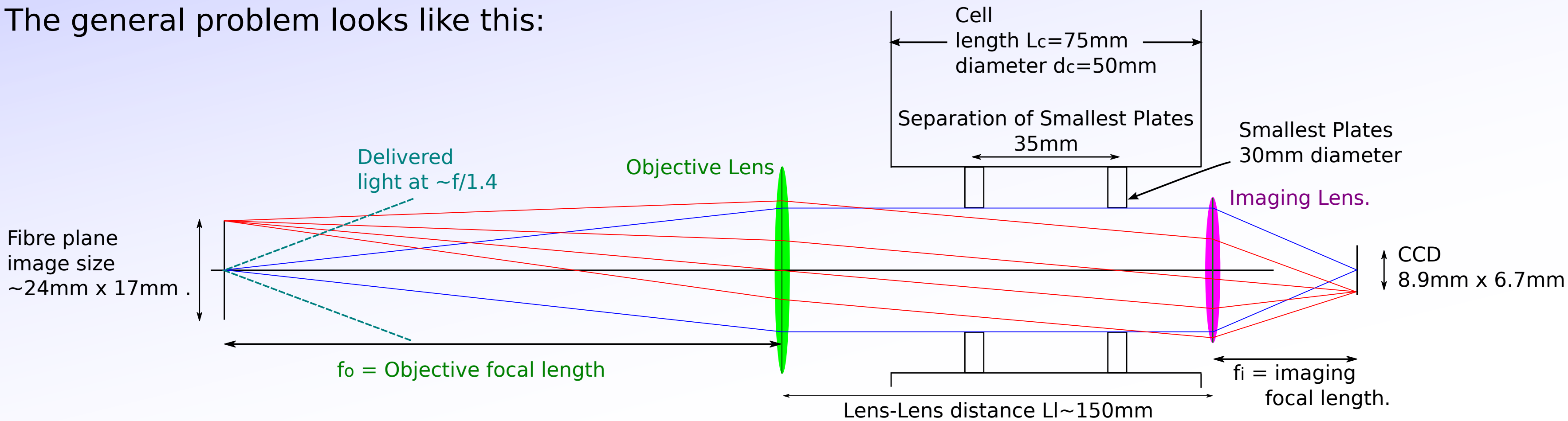
IPP Greifswald

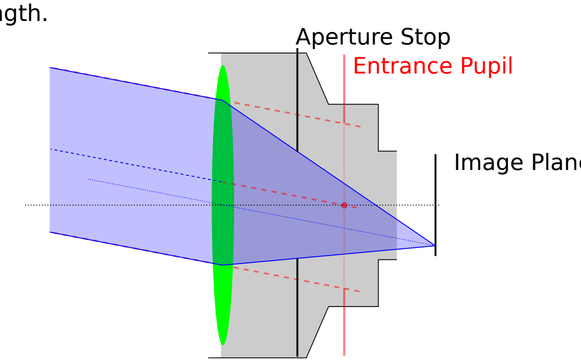
Imaging Lens

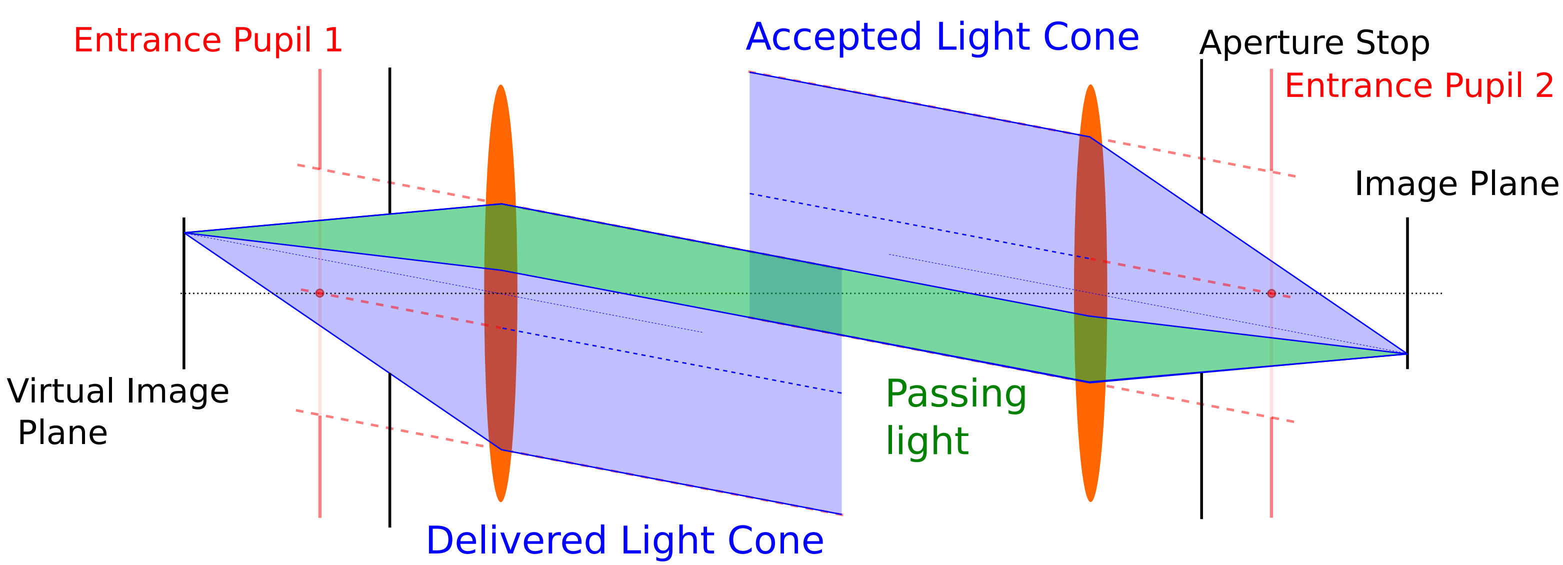
The general problem looks like this:



If we assume the delivered light is always much bigger than the objective lens' acceptance cone, and correctly targeted with a field lens, the light throughput, vignetting and coverage of the crystal it determined by the aperture and entrance pupils of the two lenses. Camera objectives generally seem to have their entrance pupil inside the lens body, not too far from the mount plate

This is rather sub-optimal for out objective-objective setup:





Need to measure the entrace pupil locations in the lab.

Although, that would imply lots of vignetting, which we don't really have.

Backend Redesign

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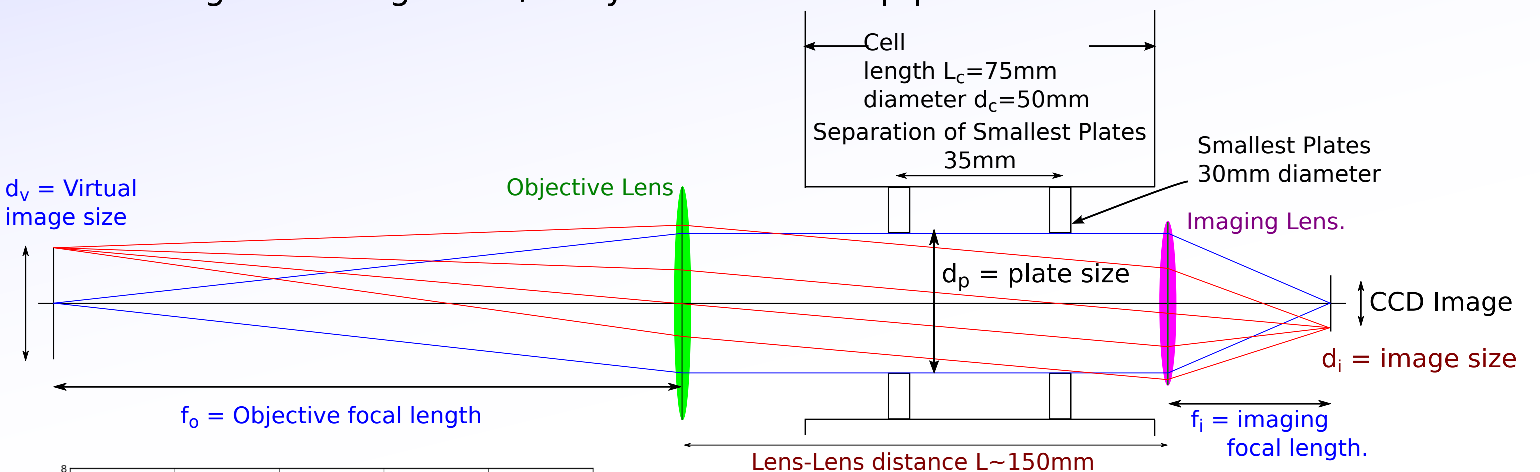
Redesign back-end because:
- We can now modify the end of the forward optics (L5 and hence the virtual image size).
- We can make the objective ourselves.
- I understand optics much better and have the ray-tracer now.
- We can get more light and/or try to restrict the μ problems.



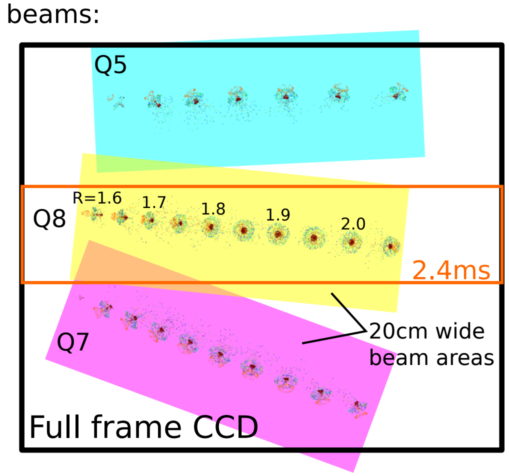
CCD Size

Andor Zyla CMOS chip is:
2560 x 2160 6.5μm pixels
16.64 x 14.04 mm

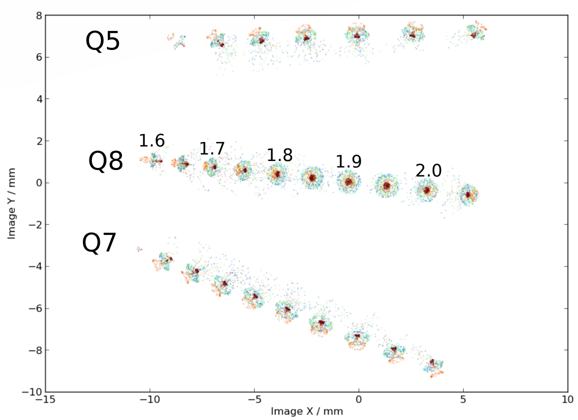
The less lines of the CCD we use, the faster we can go, and we get more light per pixel.

Lines	Frame Time
2160	10ms
2048	9.5ms
1920	5ms
512	2.4ms
128	0.6ms

And we want to be able to see all the beams:



So, to see all of Q8 (R=1.5 to R=2.0), we need an 'image size' of:
di = 11mm.



dp = 38mm fixes the maximum light circle that we'll pass coming out of the objective. As long as the objective is faster, the passed light cone angle goes as A = dp/fo. So, we want fo as short as possible.

A = dp . di /fi /dv

fi can't be much shorter than 50mm, because the filter angles will be too steep. We are already using a wider angle range than the MSE system did, although the Doppler shift is stronger this time too.

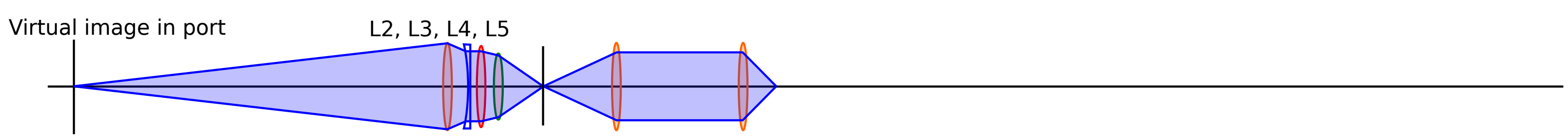
Keeping the same throughput, we can vary *fi* and *dv* together:

dv = dp. di / fi / A

For a longer fi, we would need a smaller dv, which increases the light makes the light arriving at dv wider angle, so we collect less of it with the objective. arg...

dv/di = fo/fi
dv = di.fo/fi
fo = dv.fi/di

d_p = 38mm
L = 150mm
dv = ???
fi >= 40mm
di = 11mm



Backend Redesign

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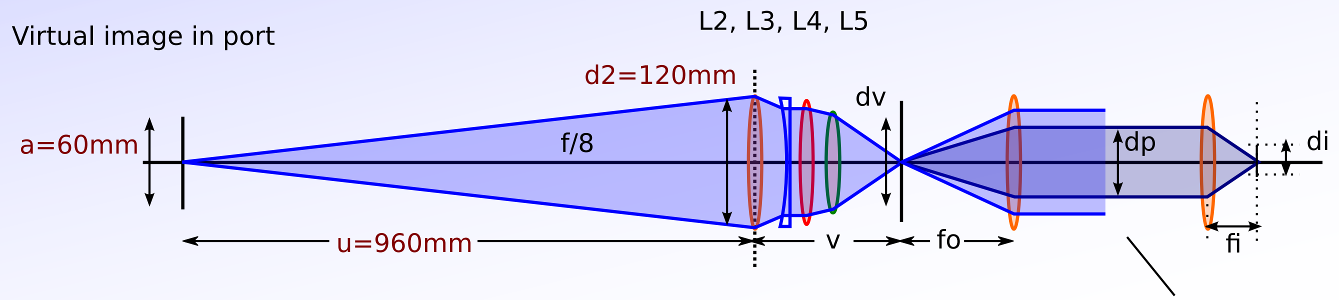
IPP Greifswald

Light is delivered to the virtual image plane by the L2 - L5 group. All of the light that L2 collects from the virtual image created in the port by L0,L1 is delivered to the back-end virtual image. L2 is 120mm diameter and ~960mm from the image, giving the whole system f/8.



Effective focal length of L2-5 group:
$1/u + 1/v = 1/f$
$a / u = dv / v$

Currently dv = 20mm, so
$v = dv\, u / a = 320$
f = 240mm
and delivery to virt img is f/2.7

More generally:
$a / u = dv / v$
$dv = v\, a/u$
dv and v are both still flexible.

From last slide:
$A = dp\,.\,di\,/fi\,/dv$
$A = dp\,.\,di\,/\,(a/u)\,/\,fi\,/\,v$

Max throughput we can get to CCD is:
$= di * dp / fi$

Max througput delivered from front end is:
$= a/u * d2$
So we need a fi that allows this much
$di * dp / fi > a * d2/u$

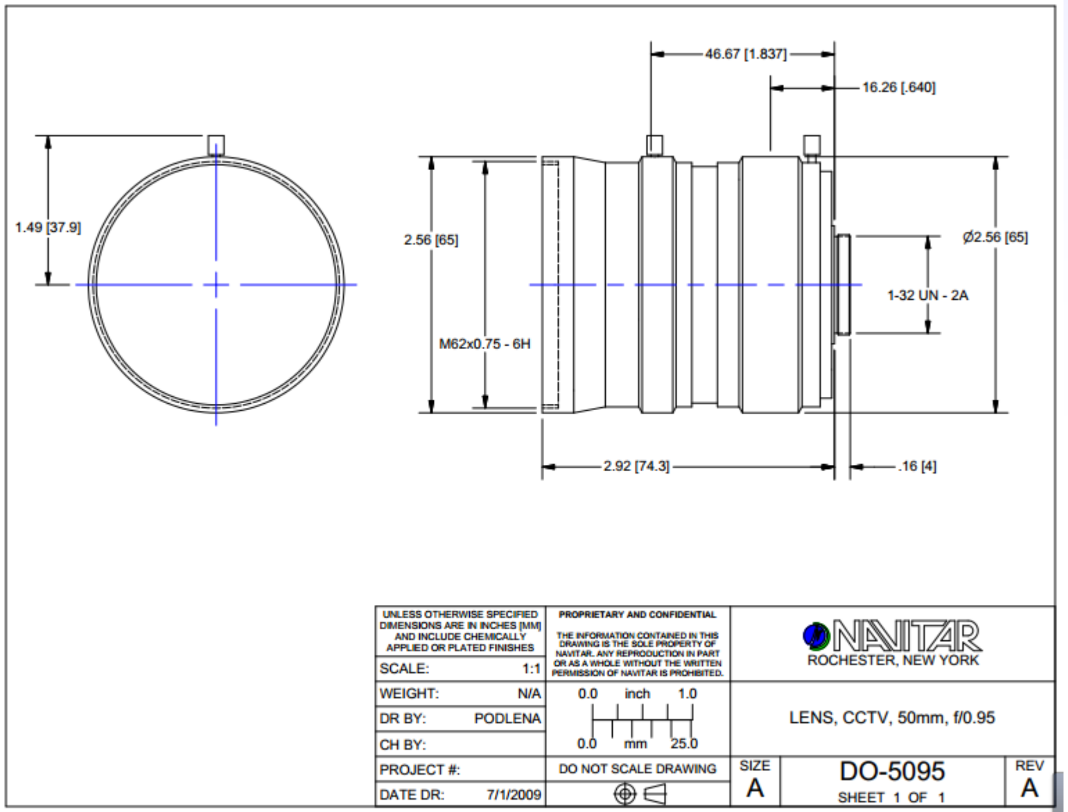
$fi < di * dp * u / a / d2$
fi < 55mm
fi = 50mm

We don't want to go any faster than this, because the filter angles will be a problem.
In fact, they already are really.
$di/2 / fi = 6.3°$!!
Assuming we want the core flat to the filter, we will have 12° AOI, giving a lot of λ shift at the low field side.

Navitar DO-5095

Oliver Ford
IPP Greifswald

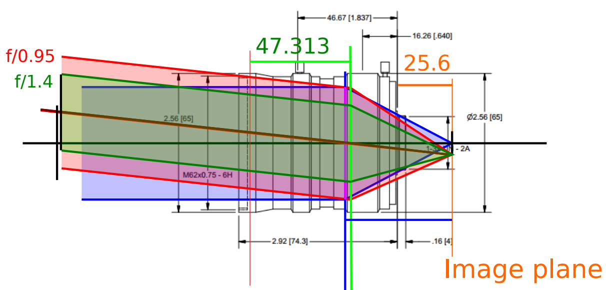
Candidate Imaging lens:






Back Focal Length: 25.62
EFL (mm): 50
Exit Pupil Position: -101.77
Field Angle 1/2 (HxV): 7 18' x 5 30'
Field Angle 1/3 (HxV): 5 30' x 4 12'
Field Angle 1/4 (HxV) : 2 54' x 2 45'
Field Angle 1 (HxV): 14 36' x 11 00'
Field Angle 2/3 (HxV) : 10 06' x 7 36'
Filter Diameter: ?2 P=0.75
Focus Control : Manual
Focusing range from front of lens (m): 0.6 - inf.
Format: 1"
F Stop: 0.95-16
Iris Control: Manual
Mount : C
Object Area at M.O.D. (HxV) 1: 140 x 105
Object Area at M.O.D. (HxV) 1/2: 70 x 53
Object Area at M.O.D. (HxV) 1/3 : 53 x 40
Object area at M.O.D. (HxV) 1/4 : 35 x 26
Object Area at M.O.D. (HxV) 2/3: 97 x 72
Zoom Control: Fixed
Cost ~ $1k

E-mail from Navitar: "The entrance pupil is 47.313 mm from the vertex of the front (glass) surface inside the lens (towards the iris)".



The Fujinon 50mm/1.4 seems to have it's entrance pupil ~52mm behind the front of the lens housing. Which is probably about the same as this.

Alternatives:

KOWA 55mm/0.75 - No focus, hard to find.
Canon 50 / 1.0 - Not great image quality. $4k
Canon 50 / 0.95 - Apparently not great image quality. Hard to find.
Leica Noctilux-M 50mm f/0.95 ASPH - Very good quality, $10k
Handevision IBELUX 40mm f/0.85 - $2k

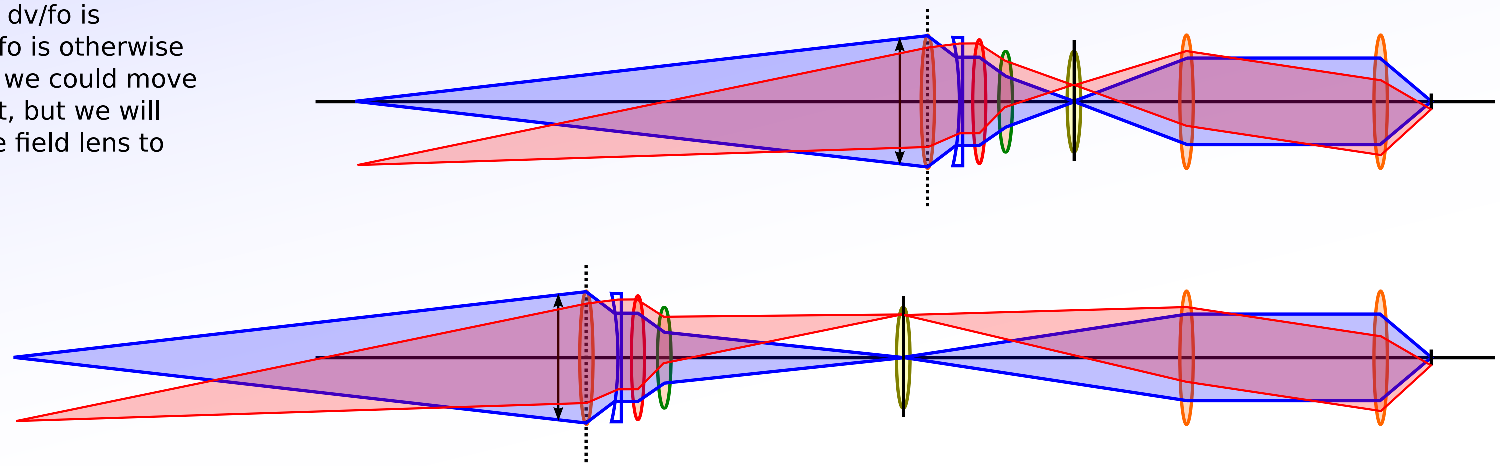
Backend Redesign - Imaging Lens

Oliver Ford
IPP Greifswald

For the object lens...
Magnification sets:
dv / fo = di / fi

and matching throughput:
dp / fo = d2 / v
v = dv u / a
dp / fo = d2 a / dv / u
dv / fo = d2 a / dp / u

So, it seems that dv/fo is determined, but fo is otherwise free. This means we could move the system in/out, but we will need a difference field lens to collect the light:



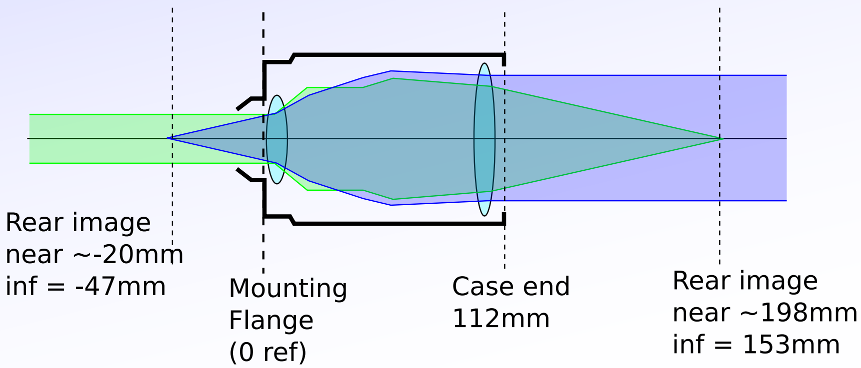
Is there any reason not to just use the L5 we already have?

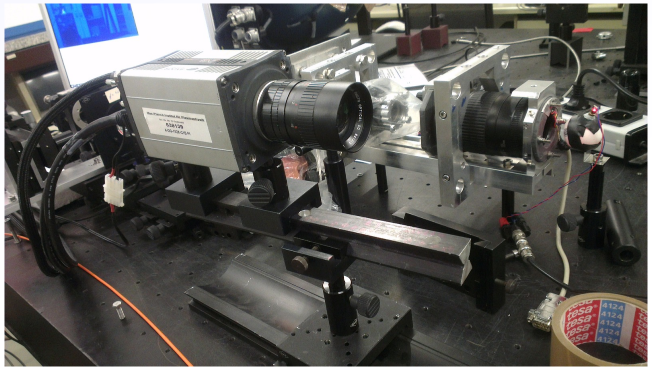
Lens characterisation

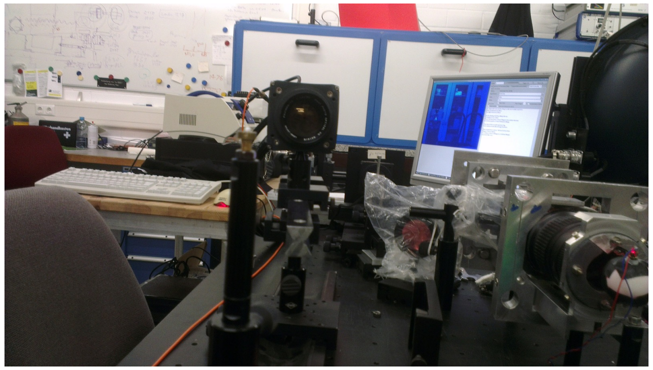
Oliver Ford
IPP Greifswald

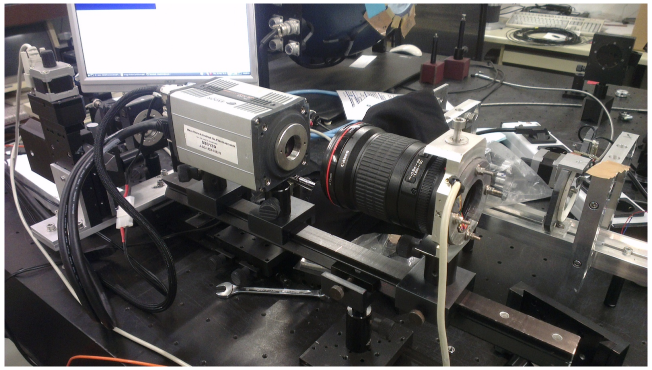
We want to know how the object lens behaves, but can't get the full optical model (Canon, proprietary, grumble grumble)
So, measuring the Canon 135mm USM f/2 in the lab:

1) Measure front and back focus position from infinity at full span of focus adjustment.

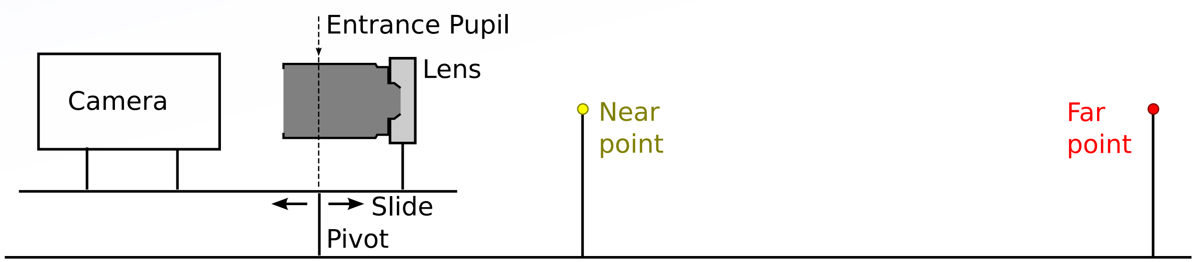






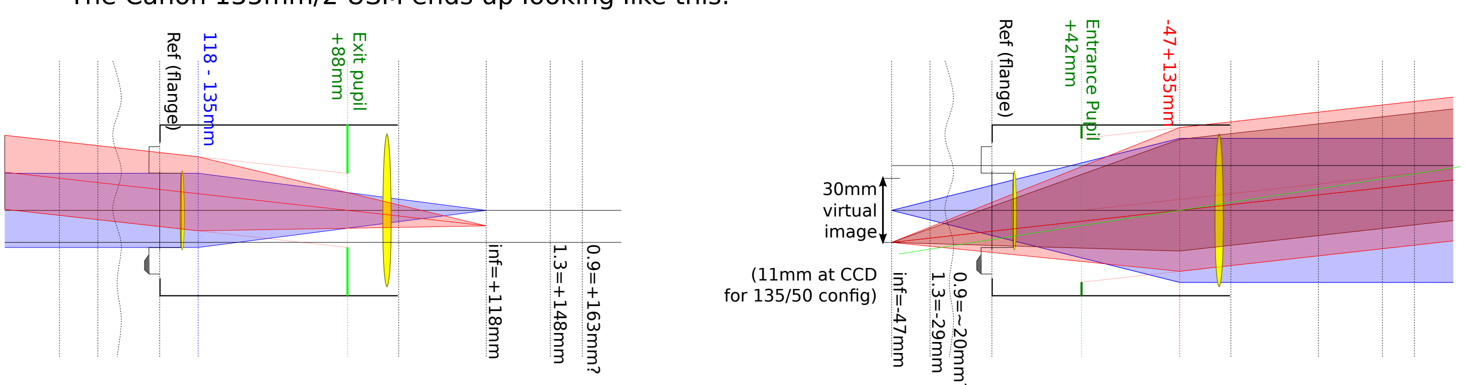


2) Set-up lens in each direction on a mount rotating about an adjustable point.



Mount a near and far light source.
Slide camera+lens to find the position where there is no parallax error when pivoting the camera.
The pivot point is the entrance pupil.

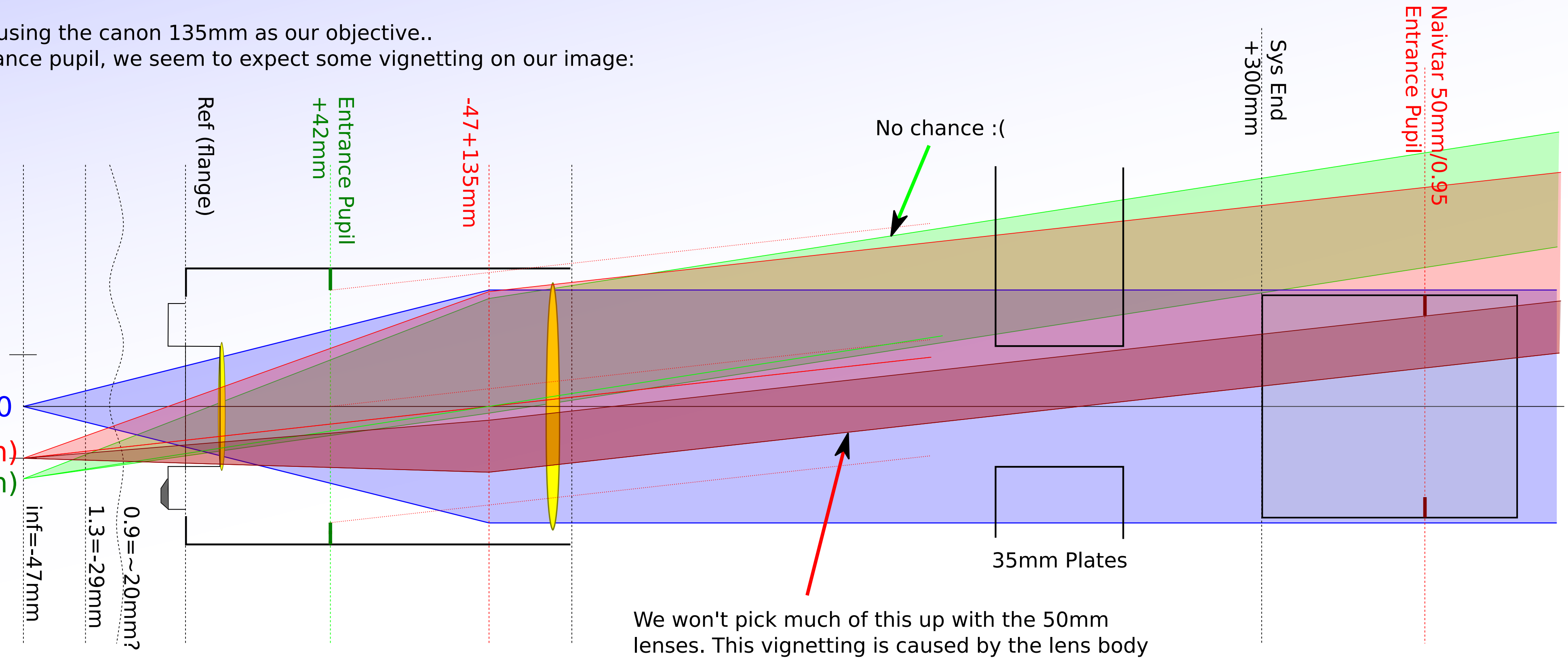
The Canon 135mm/2 USM ends up looking like this:



Canon 135mm Vignetting

Oliver Ford
IPP Greifswald

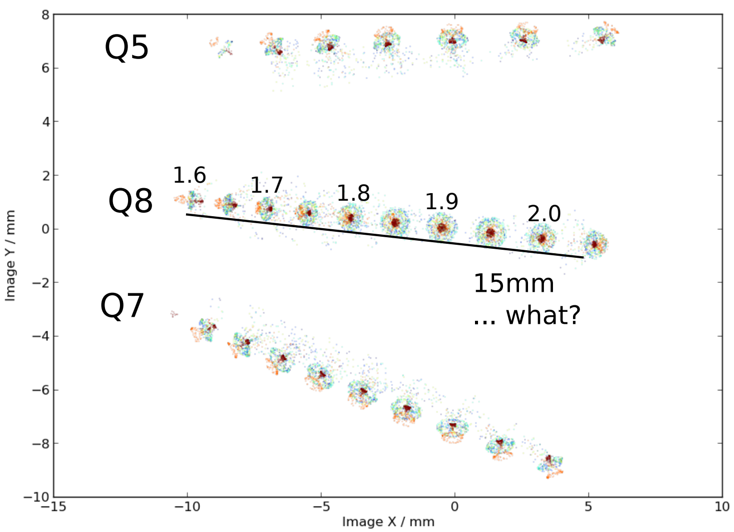
We'll start out using the canon 135mm as our objective..
Using the entrance pupil, we seem to expect some vignetting on our image:



We won't pick much of this up with the 50mm lenses. This vignetting is caused by the lens body and will be the limit no matter what we do with the field lens.

Specs claim 18° diag (42mm), 16° horiz (37mm), 10° vert (23mm)
And photography reviews show significant vinetting above f/2.8 setting.
[http://kenrockwell.com/canon/lenses/135mm-f2.htm]
So yea, that's reasonble. Bad news for us since it vignets on the bad edge

Raytracing seems to show R=1.6 to R=2.05 as 15mm at virtual image.



Wait.... what??

Oh, I've been working with 30mm virtual image size. The final optimisation seems to have ended up with ~18mm as our absolute max no the virtual image.

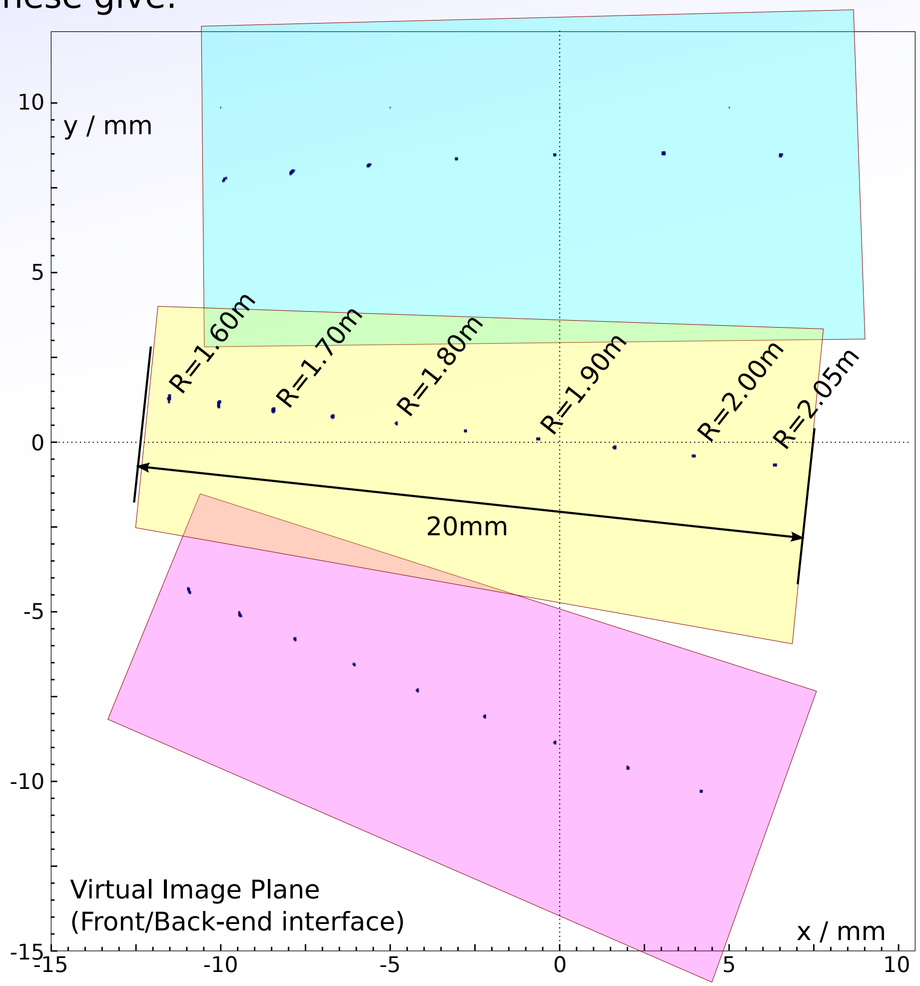
So we really want a 18 * 50 / 11 = 80mm object lens.
So actually, out CCD image will be 6mm, instead of 11 :(
With the cannon 100mm one we have, we would get 9mm, which might be ok.

Setup 2015

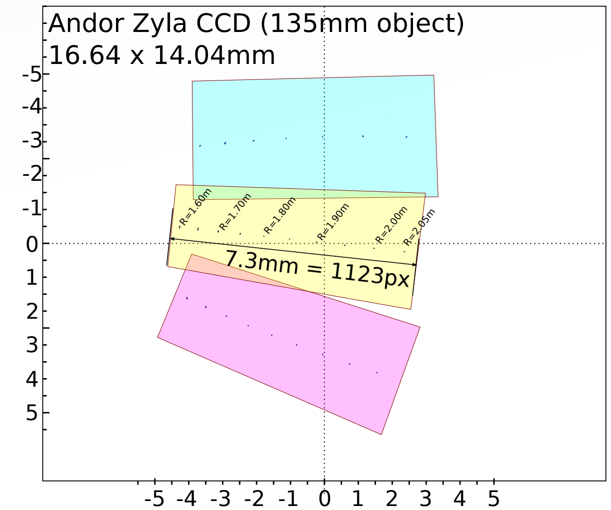
Oliver Ford
IPP Greifswald

Investigating what we can do with 'setup 2015' - the new front-end with the old back-end optics.
We've ordered L5 so, for now we're stuck with the current *dv*. However, we can modify the back-end with the new Navitar 50mm/0.95 imaging lens and whatever object lenses we have in the lab. So, what do we have?

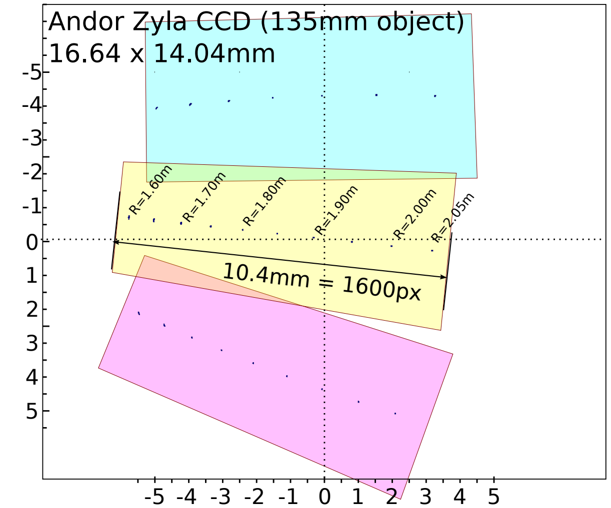
We have both 135mm and 100mm f/2 canon autofocus lenses which can easily we switch.
These give:



135 / 50 →



100 / 50 →

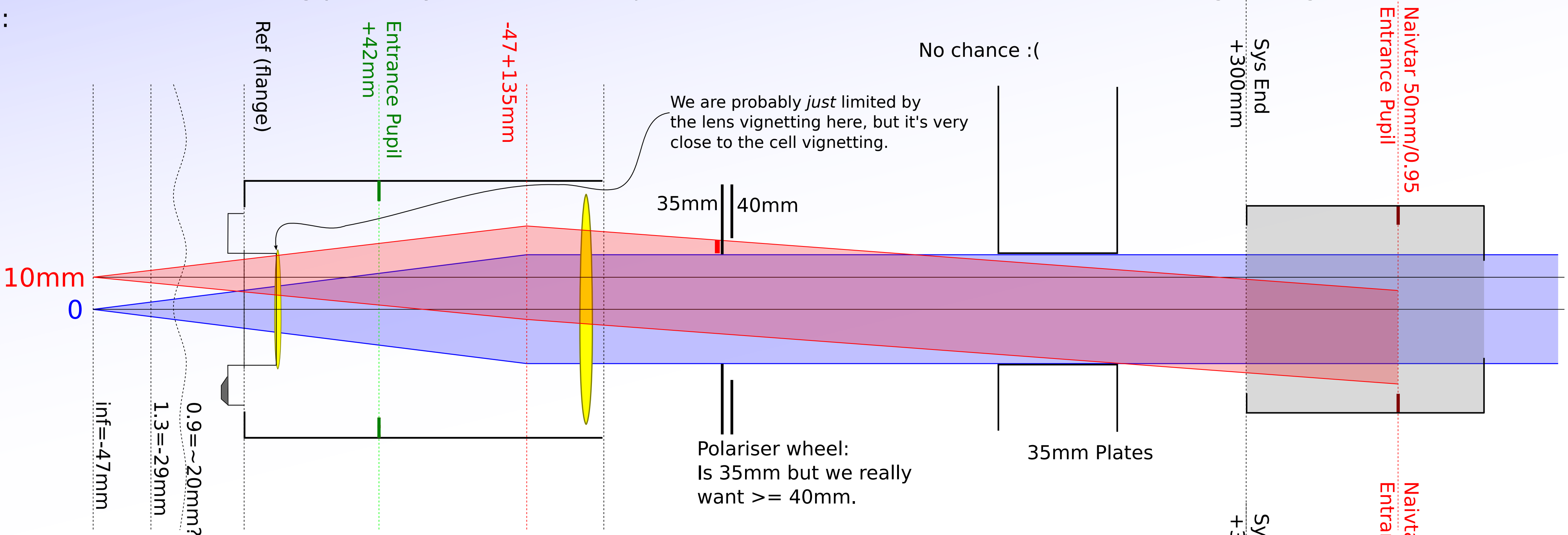


The second case might be useful if we need the resolution, and might pick up a bit more light.
The first case will use less of the CCD and less angle, which means more light per pixel.
Since we use less angle, we have less fringes but that also means less dramatic μ effect within FOV.
--> Stick with the 135mm objective and take the 100mm along with just in case.

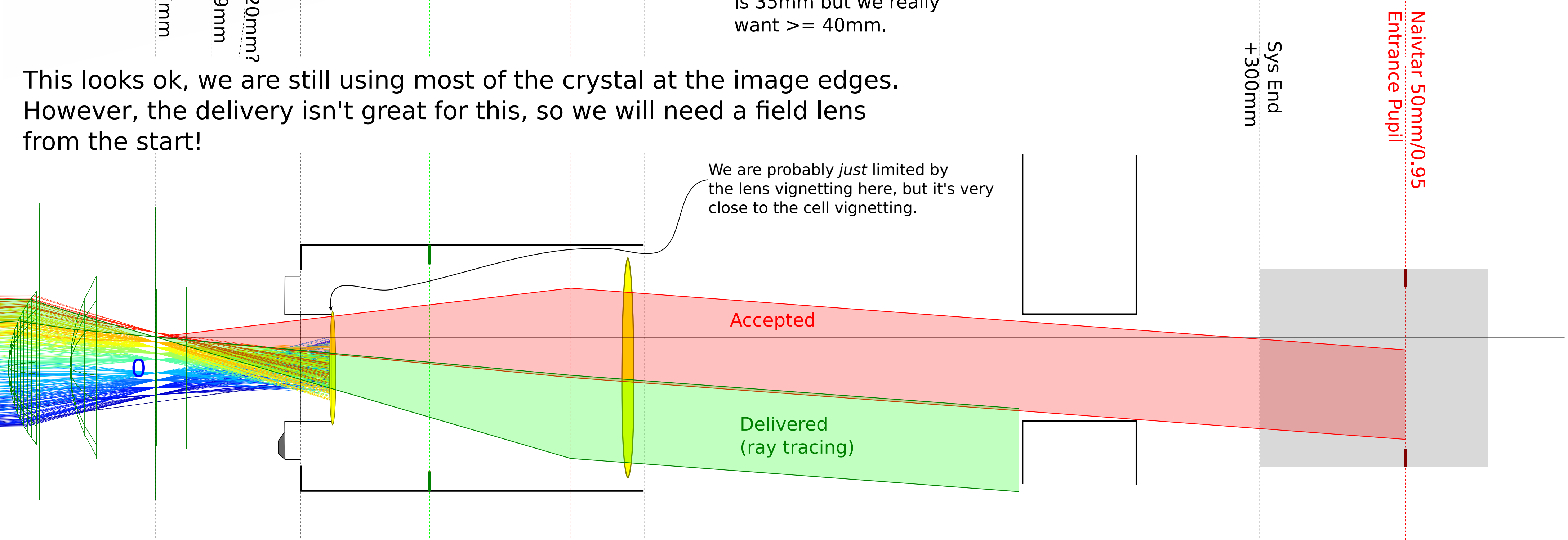
Setup 2015

Oliver Ford
IPP Greifswald

We now know we'll be using primarily the 135mm objective, with dv = 20mm (not 30!). So, our vignetting now looks like this:



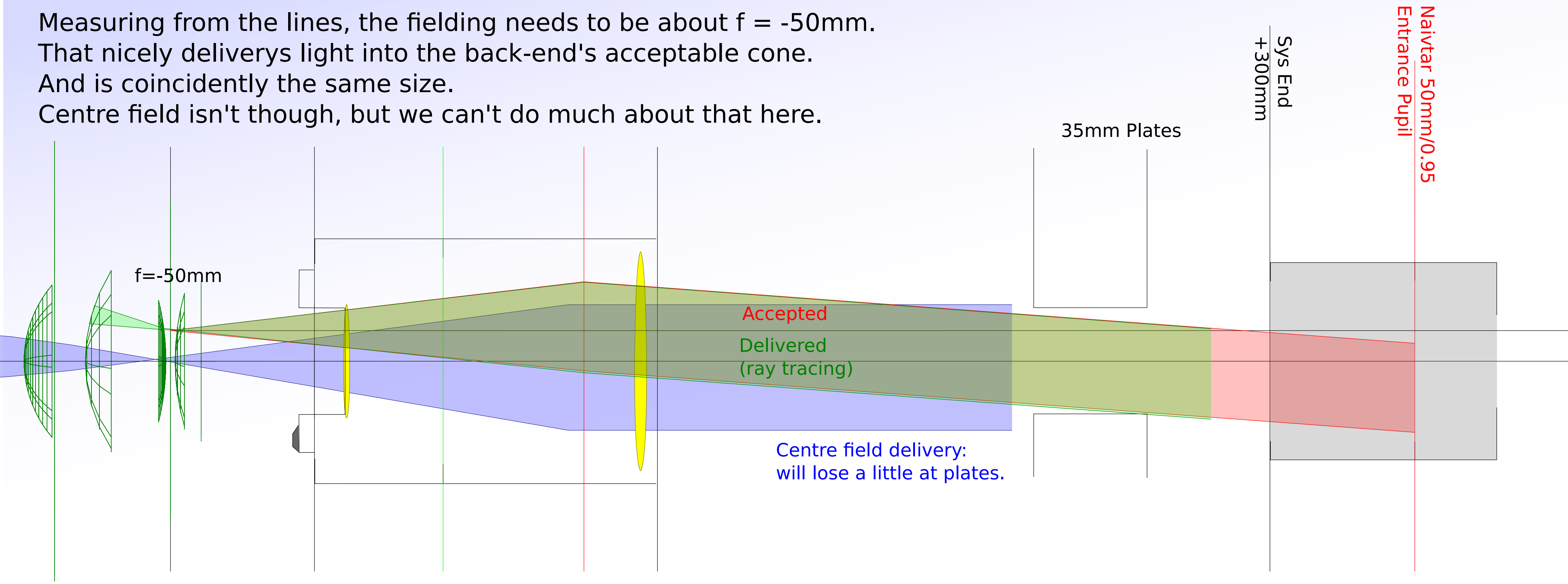
This looks ok, we are still using most of the crystal at the image edges. However, the delivery isn't great for this, so we will need a field lens from the start!



Setup 2015 - field lens

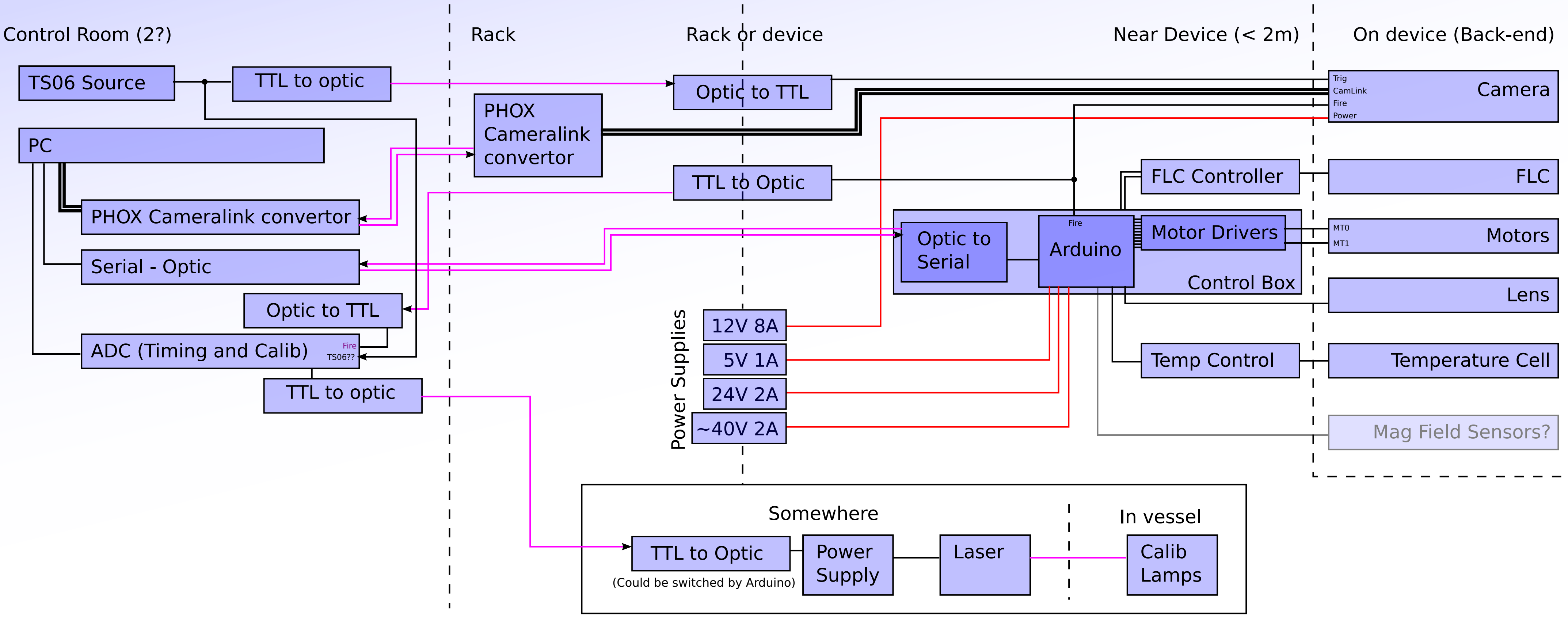
Oliver Ford
IPP Greifswald

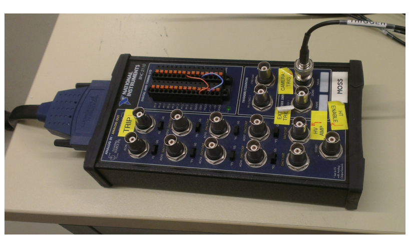
Measuring from the lines, the fielding needs to be about f = -50mm.
That nicely deliverys light into the back-end's acceptable cone.
And is coincidently the same size.
Centre field isn't though, but we can't do much about that here.



Electronics and Comms for 2015

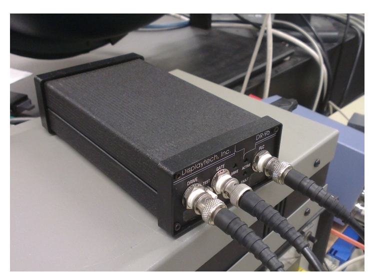
Oliver Ford
IPP Greifswald





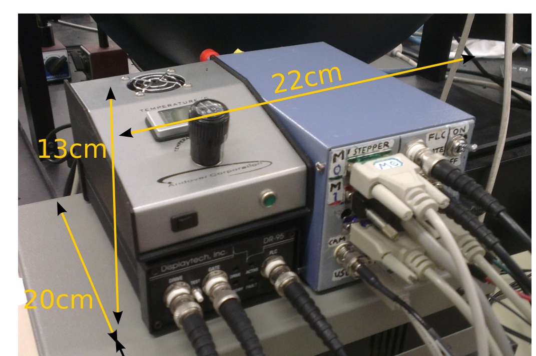
DAC/ADC Head
Generally useful for
calibration and control

Temp controller
200 x 110 x 80mm



FLC controller
Must be shielded
from mag field
200 x 110 x 50mm

Control box
- Arduino
- Motor controllers
- Optic - Serial
200 x 110 x 110mm

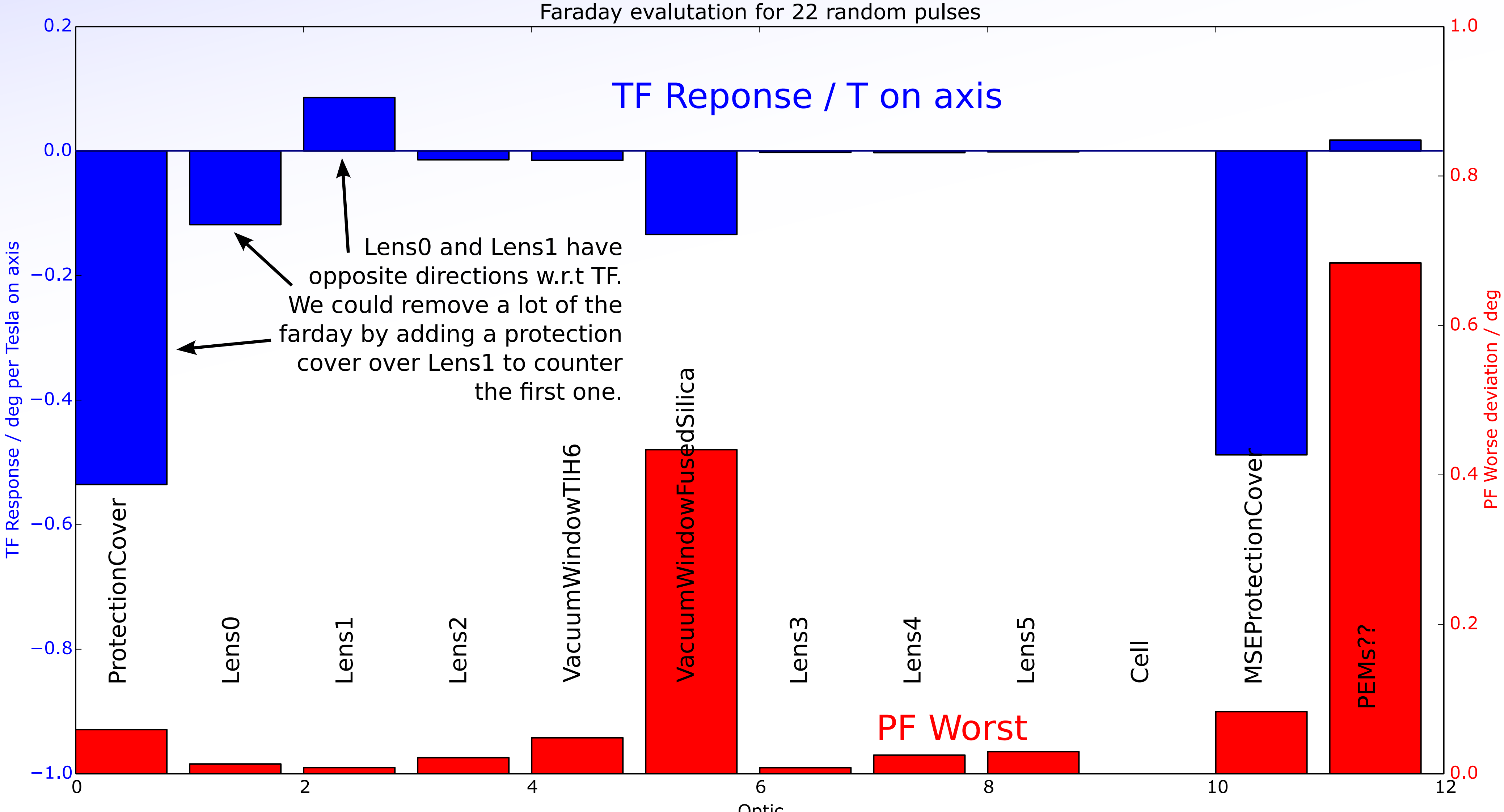


10cm (without power supplies)

Oliver Ford
IPP Greifswald

Faraday response of optics

Calculated full faraday rotation response to all coils for 22 pulses.
Model: Full PF + simple 3D model of 16 circular filament TFs. Currents from sig/MAI/...
TIH6 Verdet assumed 0.4 rad/T/m (worst case)



Seems ok for everything except the Fused Silica components. The Vacuum window PF response (and the PEMs????) are a significant problem.