Optimal Collimators for the ILC

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Overview

- Calculations of prototype collimator wakefields
  - Geometric
  - Resistive
- Numerical calculation
  - GdfidL calculations & technique
  - Comparison with other tools
- Design of the complete Collimator Assembly
  - RF design & optimisation
  - Overview of general characteristics

Analytical calculations: Summaries:

- Tenenbaum et. al. Direct measurement of the transverse wakefields of tapered collimators PRST-AB (2007) 10 034401-1-8

$$y' = \frac{y_0 Q \kappa}{E} \qquad \kappa \approx (1.35) \frac{Z_0 c}{4\pi b_1^2} \alpha^{1/2} \qquad \alpha \equiv \theta_T b_1 / \sigma_z$$

- Tenenbaum & Onoprienko Direct measurement of the resistive wakefields in tapered collimators. SLAC-PUB-10578 (2004)

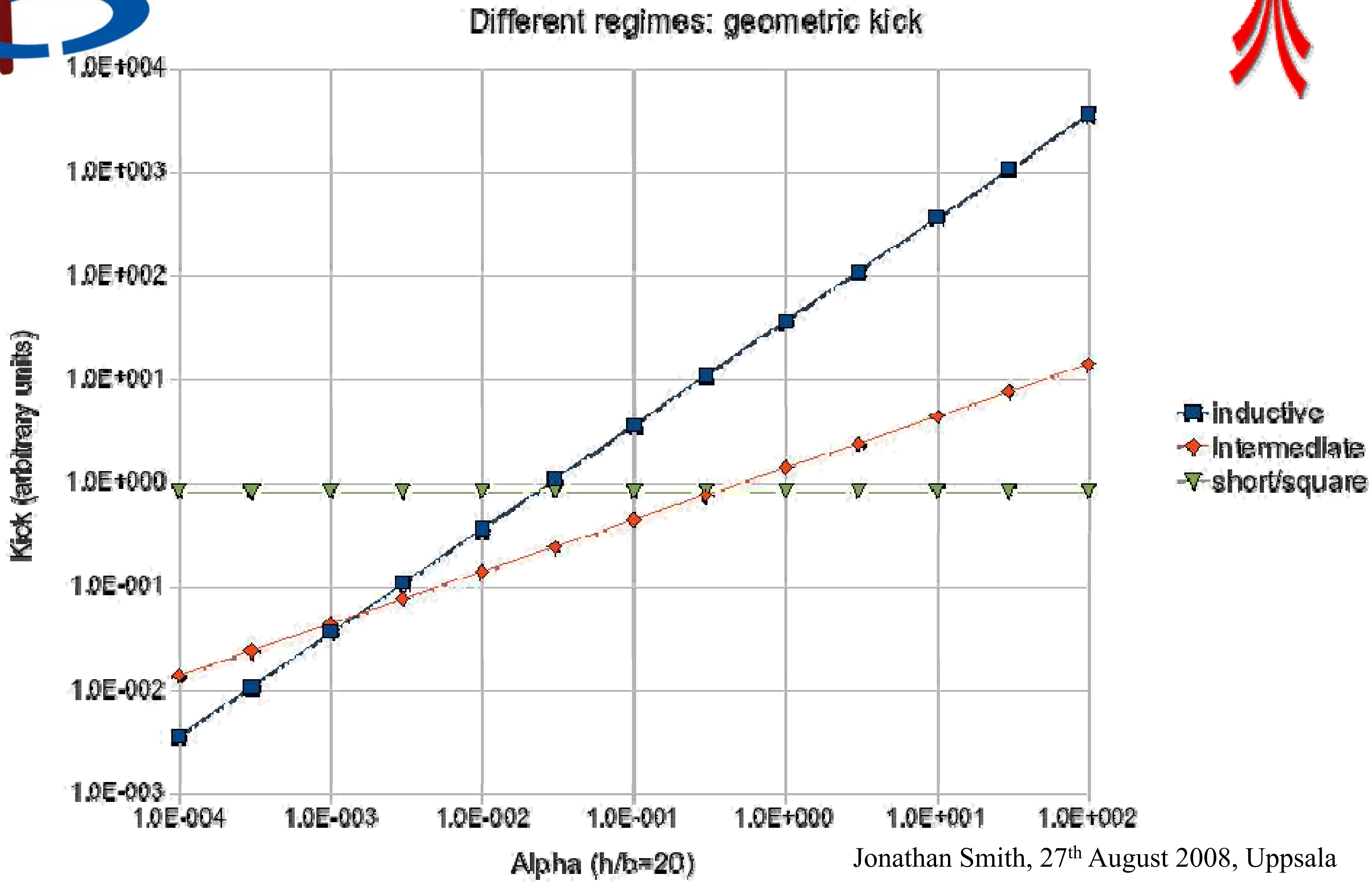
- Surface roughness effects?

$$\kappa = F_G \frac{\sqrt{2}}{\pi} \frac{r_e m_e c^2}{e^2} \frac{L}{r^3} \sqrt{\frac{1}{Z_0 \sigma \sigma_z}}$$

$$\kappa = F_G \frac{\sqrt{2}}{\pi} \frac{r_e m_e c^2}{e^2} \frac{1}{r_1^2 \tan\alpha} \sqrt{\frac{1}{Z_0 \sigma \sigma_z}}$$

Theory Advances

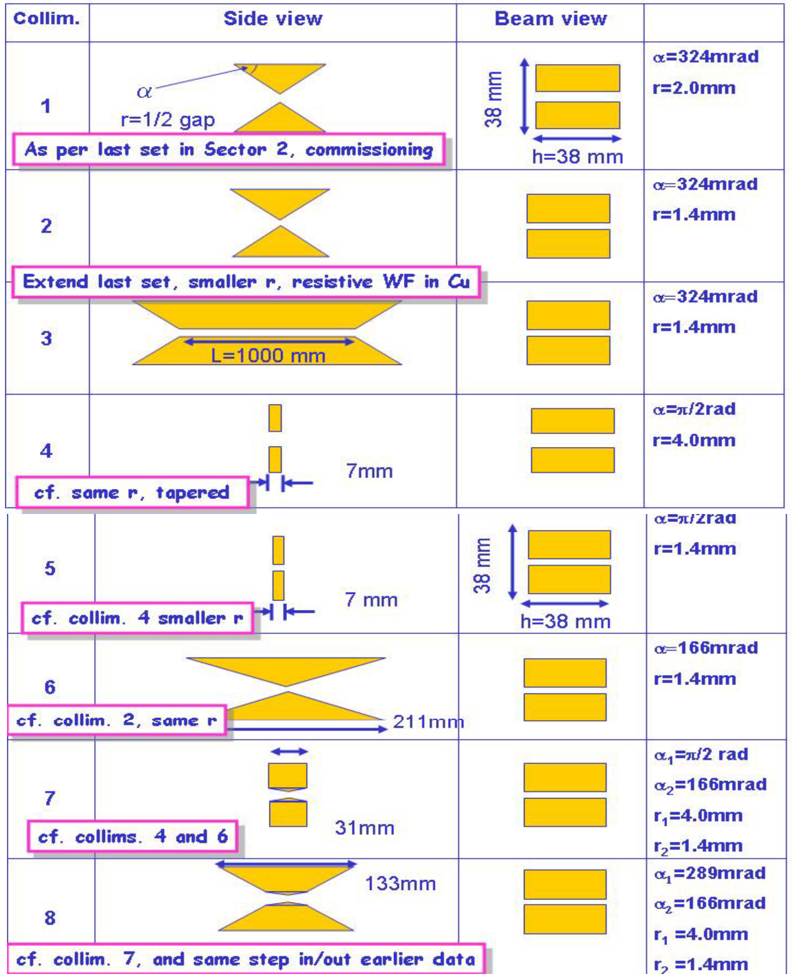
- K. Bane, G. Stupakov (SLAC) expressed an interest in the project: offered to derive any further formulae that may be necessary
- Results starting to flow from Mathematical Physics Group at Lancaster, with improved scheme for ‘smooth’ tapers, and resistive wakefield work in Manchester HEP group
- Results using ‘optimal’ design, as derived by Yokoya (1990) and used in the inductive regime by B. Podobedov (PAC07 etc)
- Accurate theoretical prediction requires knowledge of high frequency conductivity. Electro-optic measurements at THz frequencies in progress at Daresbury



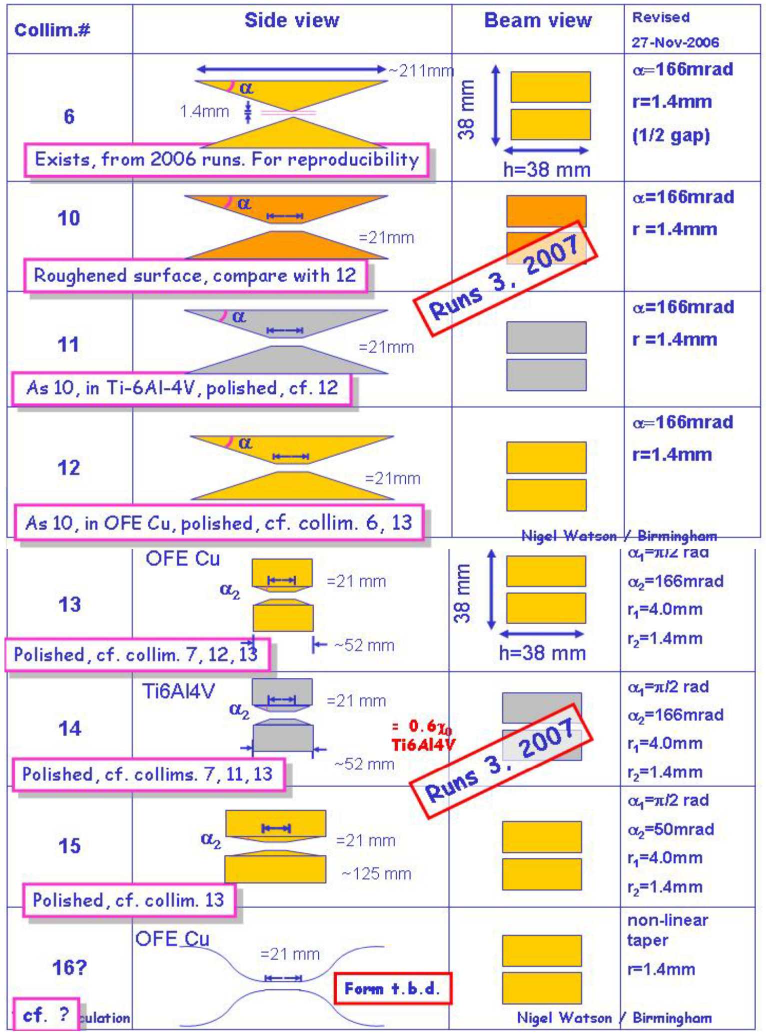
Different regimes: geometric kick
1.0E+004
1.0E+003
1.0E+002
1.0E+001
1.0E+000
1.0E-001
1.0E-002
1.0E-003
Kick (arbitrary units)
1.0E-004
1.0E-003
1.0E-002
1.0E-001
1.0E+000
1.0E+001
1.0E+002
Alpha (h/b=20)
inductive
intermediate
short/square

Prototype collimators (2006): Analytic calculations (V/pC/mm)

Col. #	Res.	Geom.	Total
1	0.001	2.246	2.247
2	0.003	5.894	5.896
3	0.628	5.894	6.522
4	0.000	0.561	0.562
5	0.004	4.584	4.588
6	0.005	4.219	4.224
7*	0.005	4.244	4.249
8*	0.006	4.219	4.224



More collimators from 2007…



Col. #	Res.	Geom.	Total
6	0.005	4.219	4.224
10	0.018	4.219	4.237
11	0.183	4.219	4.401
12	0.018	4.219	4.237
13*	0.005	4.219	4.224
14*	0.052	4.219	4.271
15*	0.018	2.315	2.333
16	Num.	Calc.	Only.

GdfidL calculations of these prototype collimators

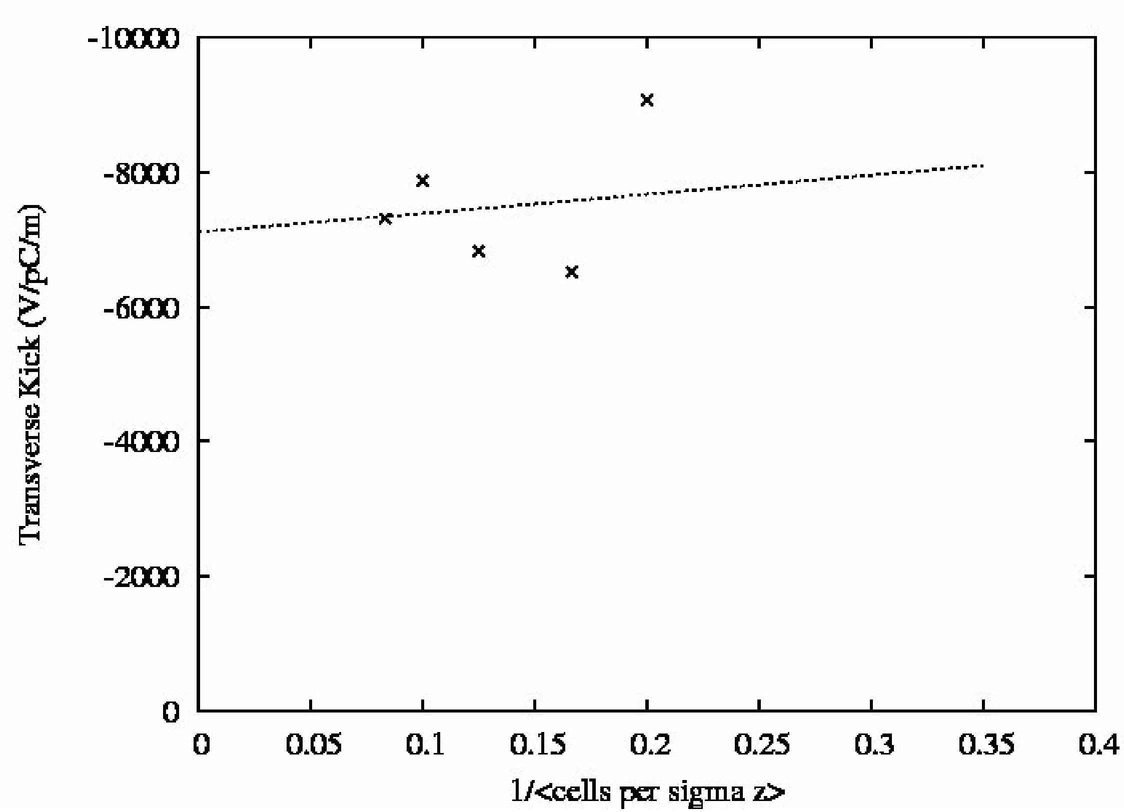
- Goal: Validate tools as being able to reliably calculate wakefields from collimator structures
- Results must be mesh stable, calculated with a well defined process, in the minimum time possible to allow iterations
- Determine sensible resolution.
- We are interested in more than just dipole kick.
- We would like to understand the uncertainty in the result!
- $\Delta_z < 5$ cells/σ_z results no good. Gaussian not well resolved.
- Use window-wake, (aka moving mesh, frame travels with bunch) if possible.

Set of scripts for GdfidL calculations.

- For each collimator
  - For each bunch length of interest
    - For each offset of the bunch from the axis
      - For each resolution
        - Run simulation in GdfidL
      - End for loop & Calculate resolution independent value
    - End for loop & Calculate dipole, and other kicks
  - End for loop & Compare with experimental data
- End for loop

Determining a resolution stable result

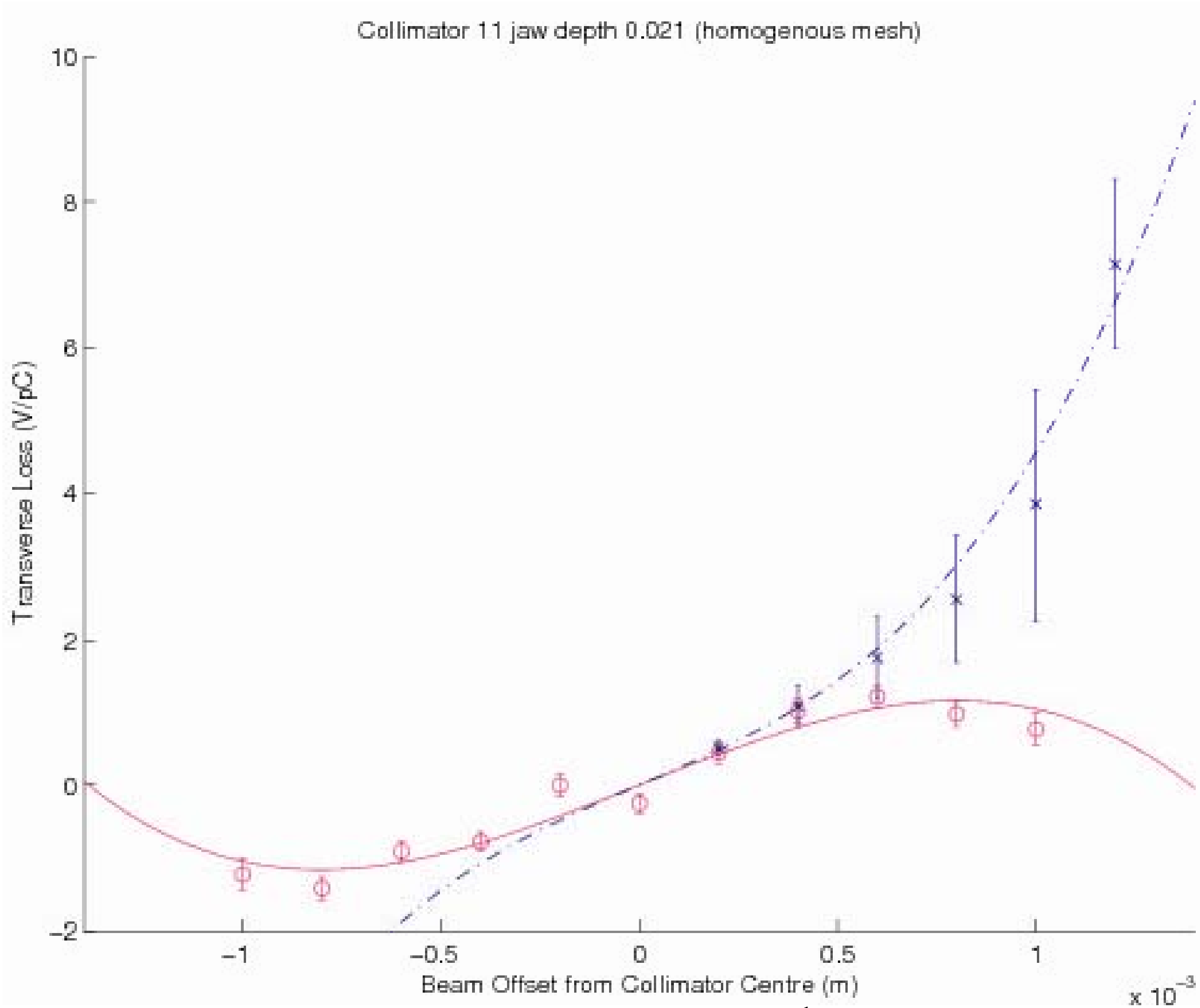
- Linear, exponential, weighted linear, weighted exponential, skipping outliers, etc.
- Error from quality of fit?
- Chose difference between highest res point and extrapolation to zero mesh size.



Podobedov & Krinsky "Transverse impedance of axially symmetric tapered structures" PRST-AB 9 055401 (2006)

Comparing with experimental data

- Polynomial fit
- Use central points only
- Ignore measured value at zero offset or force this as constraint?
- What about errors?



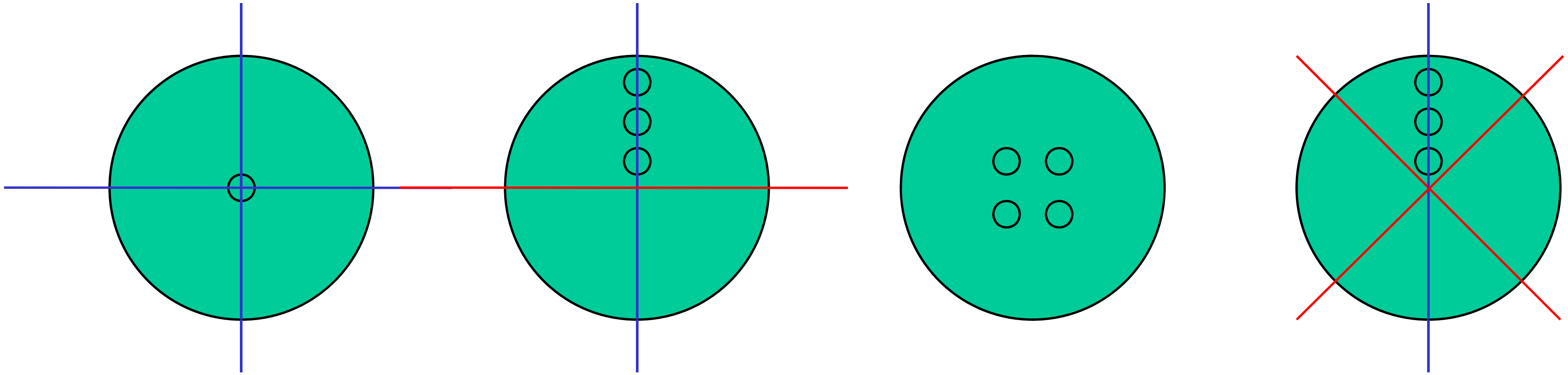
Other Codes…

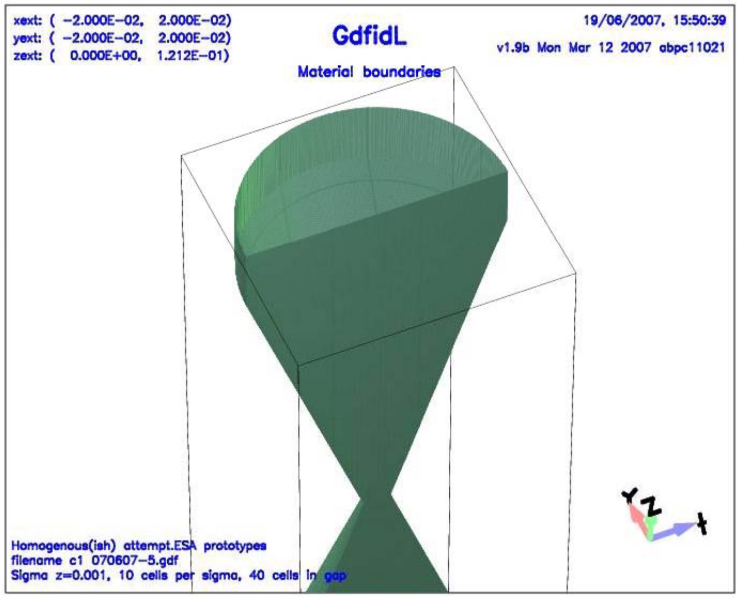
- A number of schemes presented at Wakefest '07 (SLAC)
- PBCI: http://www.temf.de/unmaintainable/downloads/pdfs/SLAC_PBCI_TEMF.pdf
- ECHO-3D
- Zagorodnov & Bane "Wakefield Calculations for 3D Collimators" EPAC 2006.
- What about 2D for optimisation?

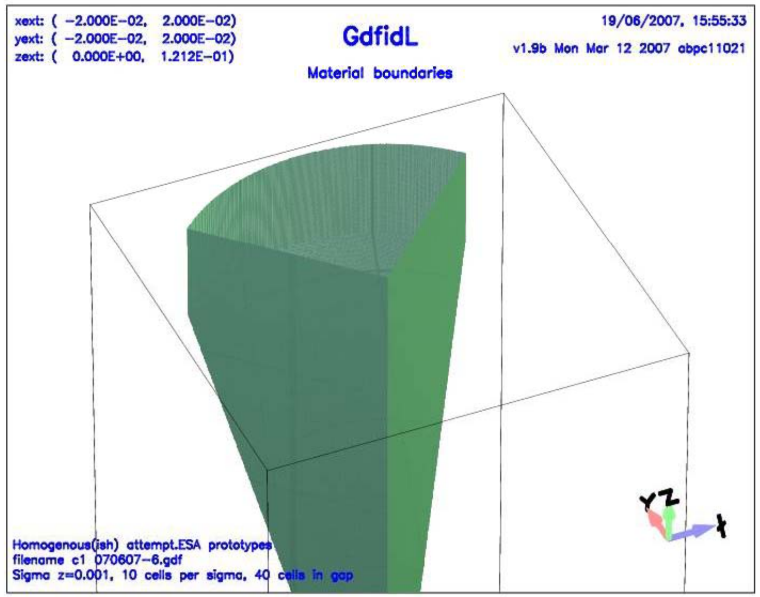
ECHO-3D & GdfidL (Trans. kick/0.5mm bunch)

Collimator	GdfidL	(err?)	GdfidL (err!)	ECHO
1	1.39	0.29	0.01	1.7
2	3.06	0.02	0.03	3.1
3	5.57	0.15	0.30	5.1
4	0.78	0.00	0.00	0.77
5	6.07	0.30	0.20	6.8
6	1.64	0.50	0.21	2.3
7	2.80	0.09	0.15	2.7
8	2.62	0.01	0.01	2.4

Extracting modal values

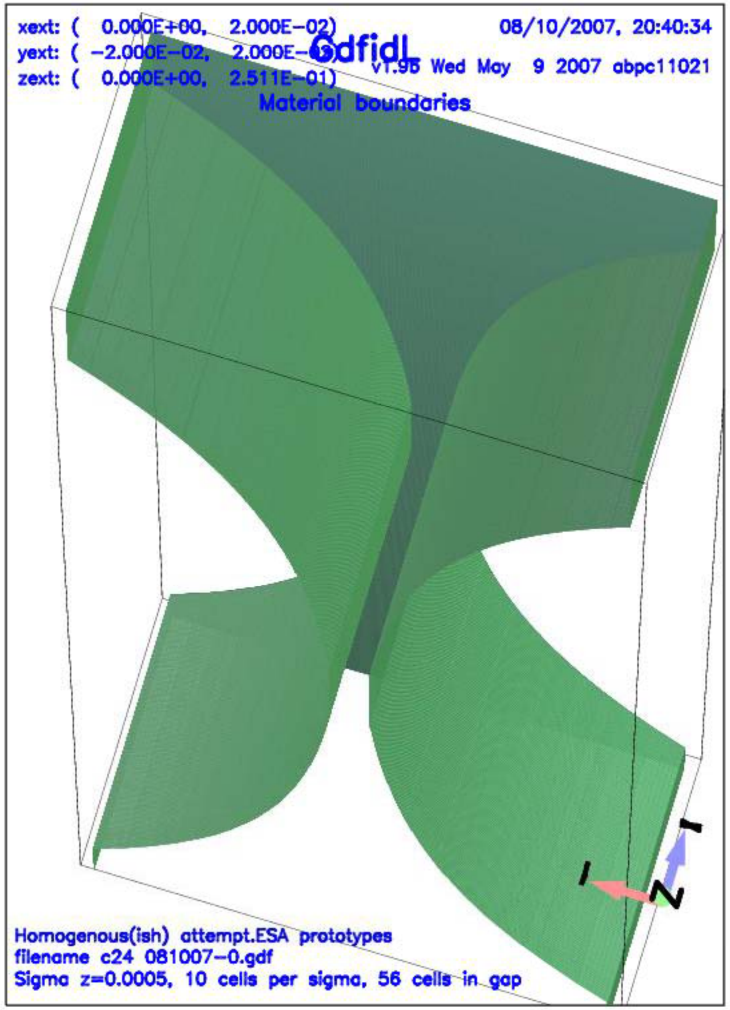






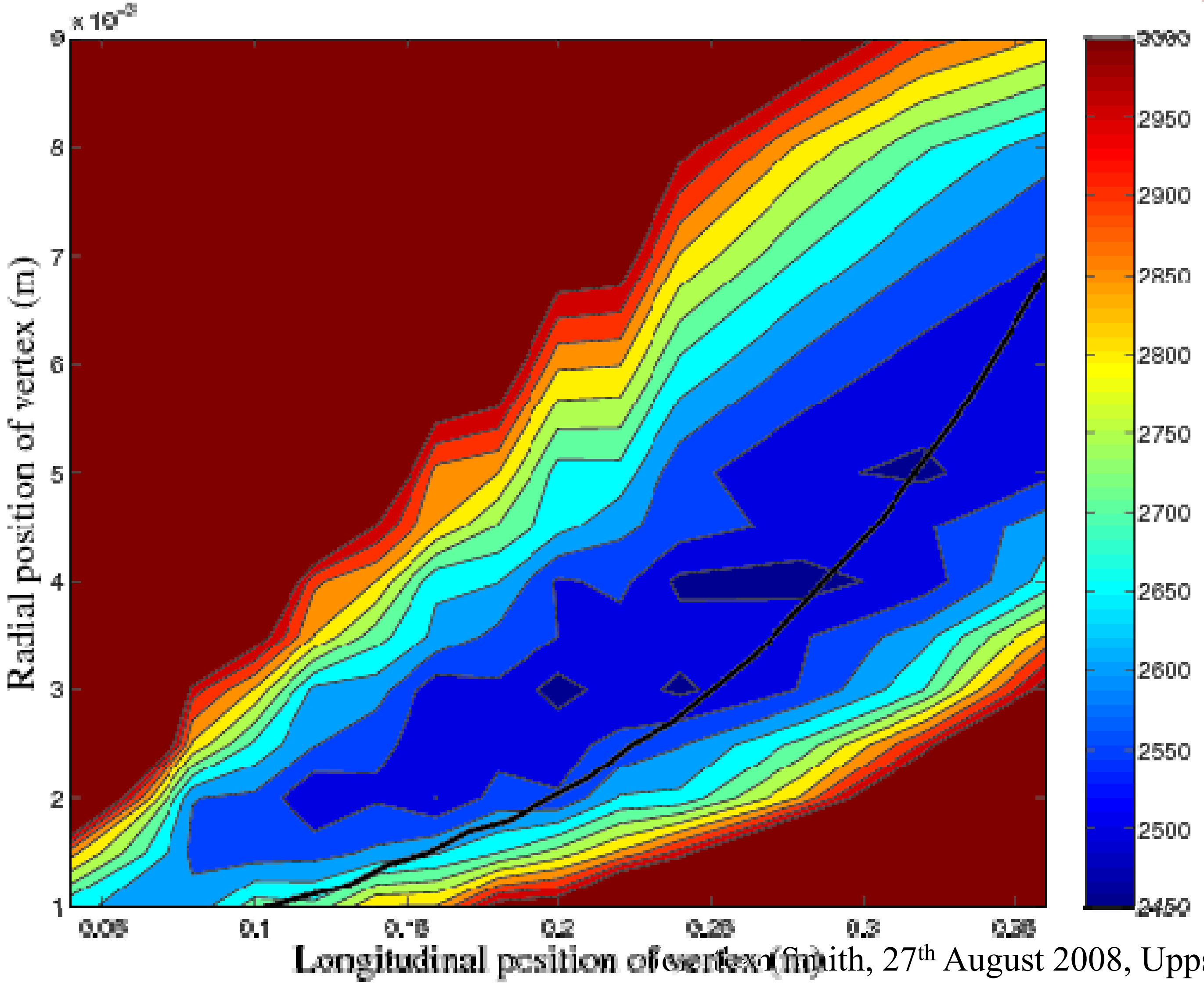
Final Collimator Design

- 2 Step design
- Baseline from RDR & optics simulations
- Calculation of optimal point for vertex cf Yokoya "Impedance of slowly tapered structures 1990 (Podobedov)
- Investigation of trapped modes

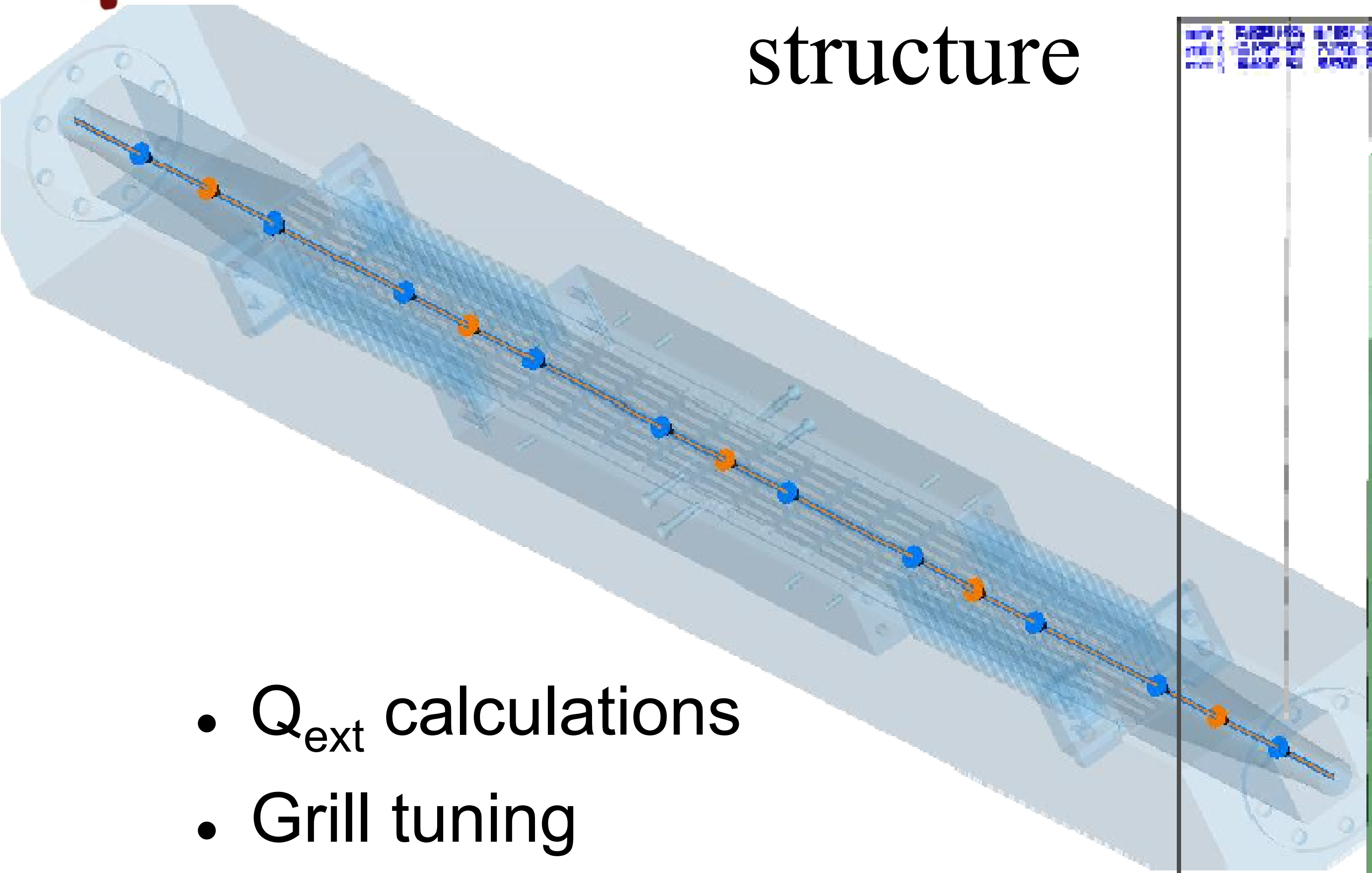


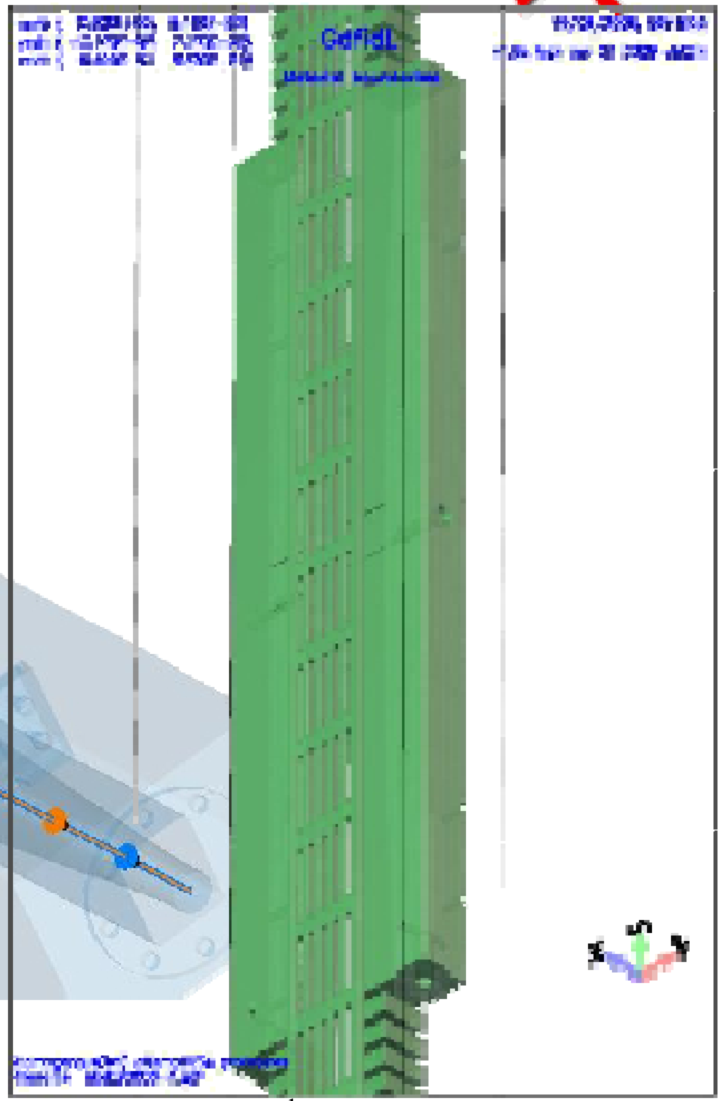
Optimisation of taper angles

- Minimise kick & minimise length

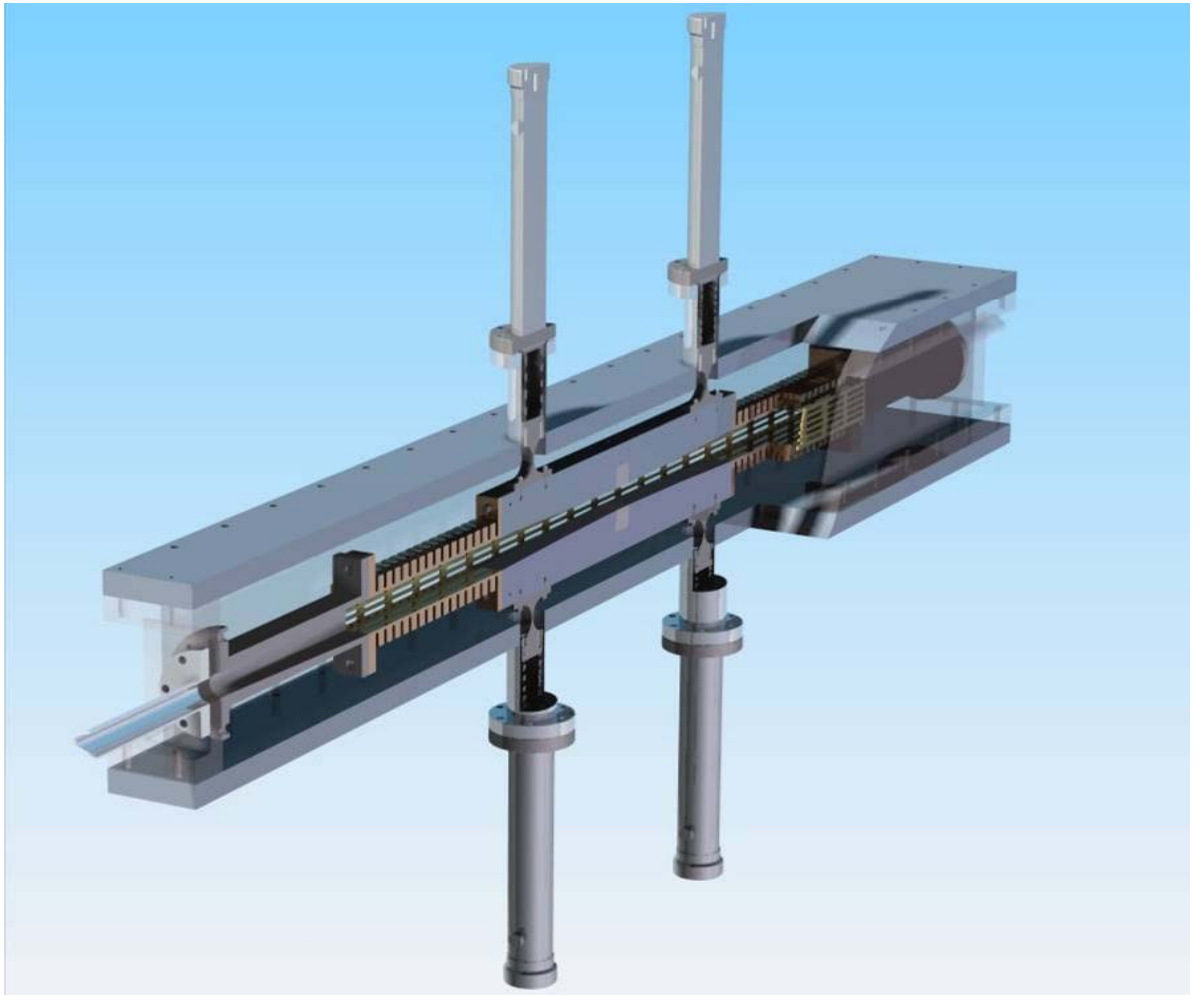


RF simulations of complete structure





- Q_{ext} calculations
- Grill tuning
- Damping requirements



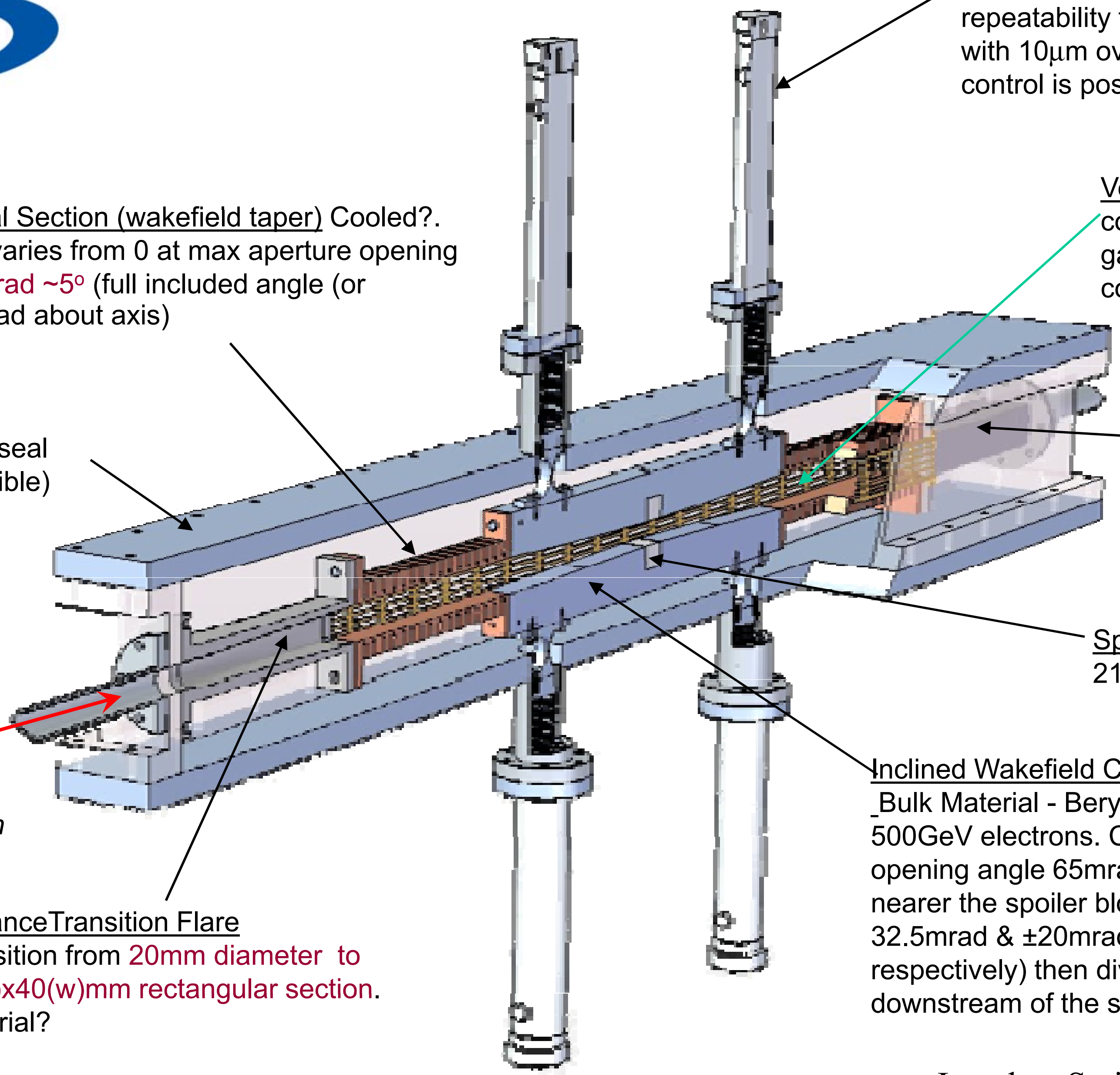
ILC-Collimator Initial Design Scheme

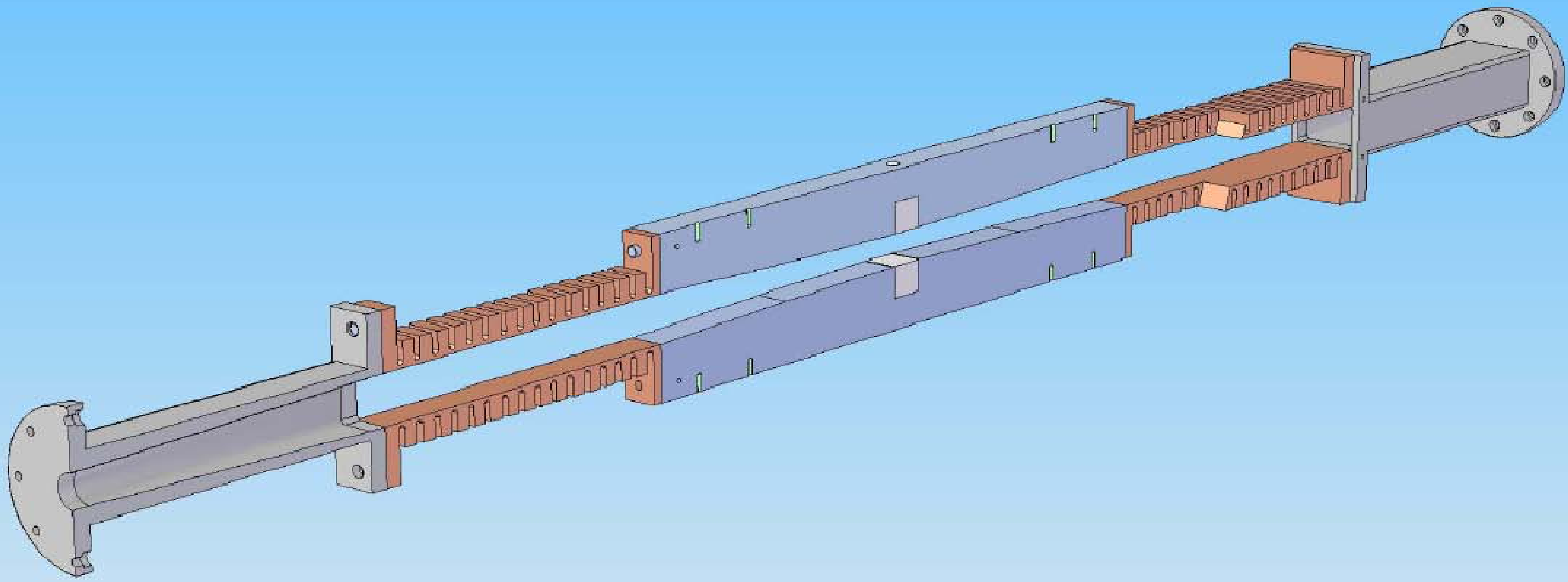
Simon Appleton/Barry Fell, May 08

Jonathan Smith, 27th August 2008, Uppsala

Operational Overview

Side Cross-Section Through Beam Centre Line





Click in powerpoint slideshow to disassemble

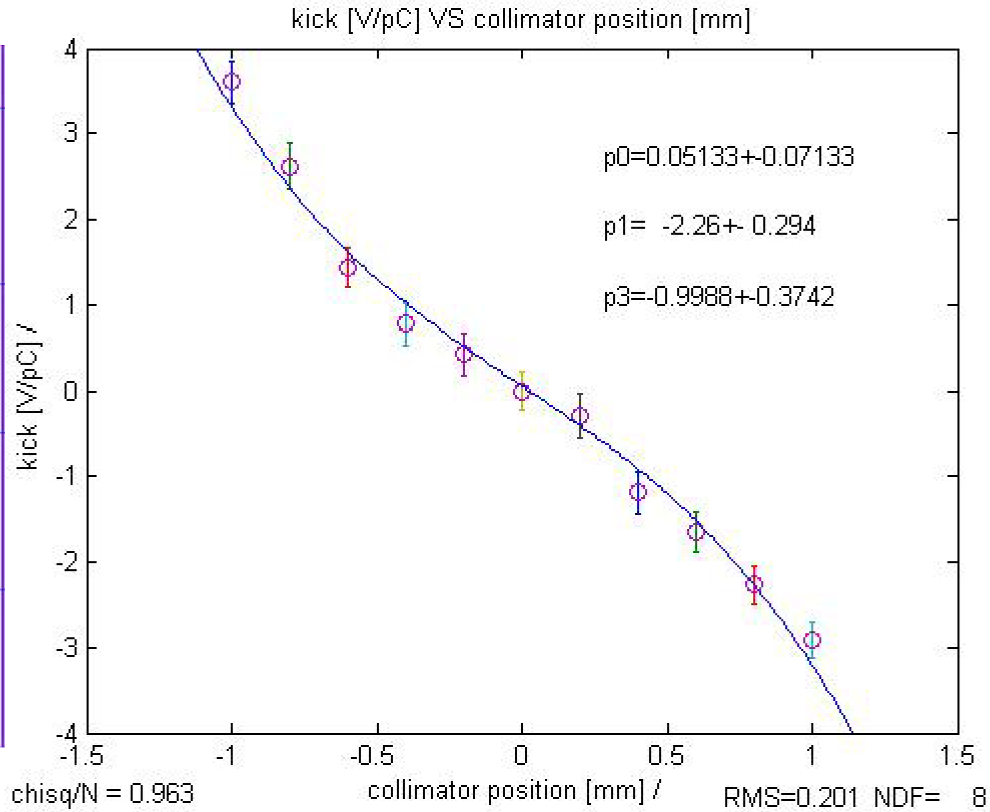
3D 'Strip Down' Views

What's new at ESA?

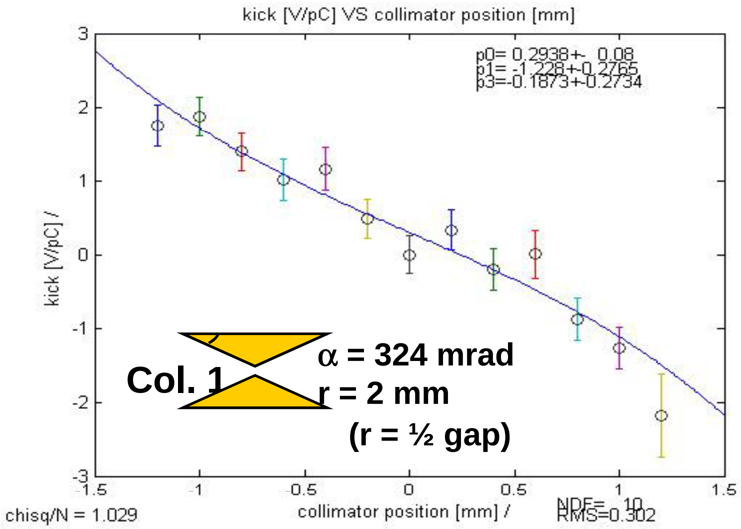
- Successful July run with improved measurements/resolutions on some existing collimators
- Some results not fully understood – identical Titanium alloy collimator produced less wake when more was expected.
- Still limited by BPM resolution.

Collimator 14 – new results

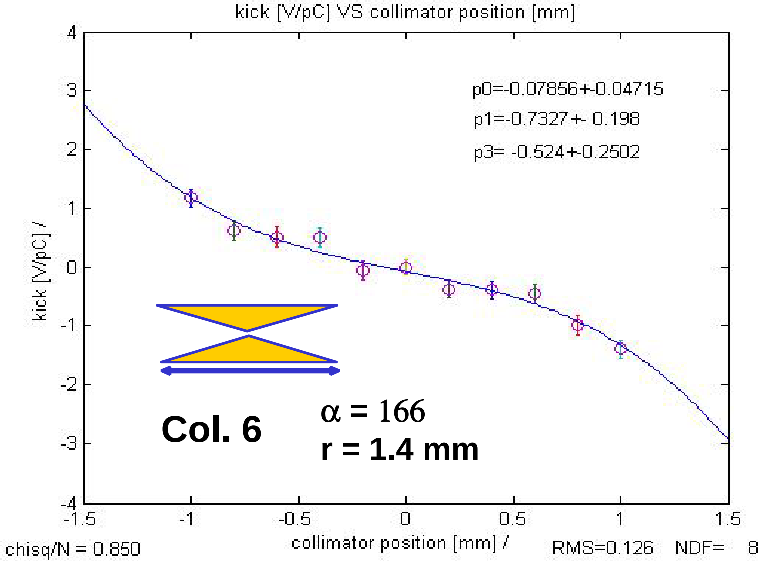
Collim.#	Side view	Beam view	Revised 27-Nov-2006
13	OFE Cu, α_2, =21 mm, ~52 mm	38mm, h=38 mm	$\alpha_1=\pi/2$ rad, α_2=166mrad, r_1=4.0mm, r_2=1.4mm
14	Ti6Al4V, α_2, =21 mm, ~52 mm		$\alpha_1=\pi/2$ rad, α_2=166mrad, r_1=4.0mm, r_2=1.4mm
15	α_2, =21 mm, ~125 mm		$\alpha_1=\pi/2$ rad, α_2=50mrad, r_1=4.0mm, r_2=1.4mm
16	OFE Cu, =21 mm		non-linear taper, r=1.4mm



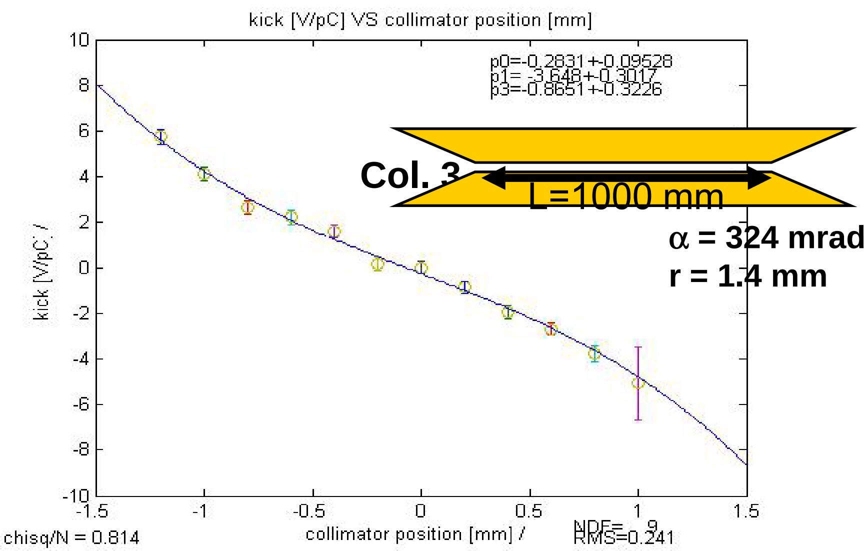
Also at SLAC…



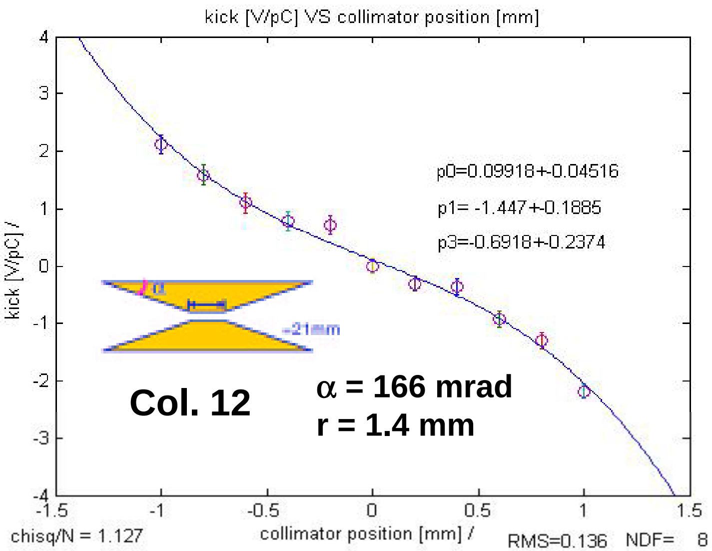
kick [V/pC] VS collimator position [mm]
p0= 0.2938+- 0.08
p1= -1.228+-0.2765
p3=-0.1873+-0.2734
Col. 1
α = 324 mrad
r = 2 mm
(r = ½ gap)
kick [V/pC] /
collimator position [mm] /
chisq/N = 1.029
NDF= 10
RMS=0.302



kick [V/pC] VS collimator position [mm]
p0=-0.07856+-0.04715
p1=-0.7327+- 0.198
p3= -0.524+-0.2502
Col. 6
α = 166
r = 1.4 mm
kick [V/pC] /
collimator position [mm] /
chisq/N = 0.850
RMS=0.126
NDF= 8

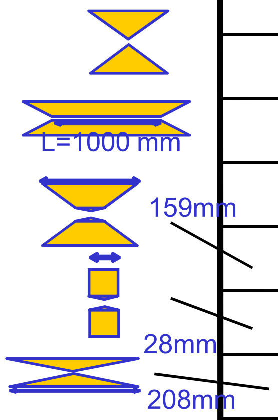


kick [V/pC] VS collimator position [mm]
p0=-0.2831+-0.09528
p1= -3.648+-0.3017
p3=-0.8651+-0.3226
Col. 3
L=1000 mm
α = 324 mrad
r = 1.4 mm
kick [V/pC /
collimator position [mm] /
chisq/N = 0.814
NDF= 9
RMS=0.241



kick [V/pC] VS collimator position [mm]
p0=0.09918+-0.04516
p1= -1.447+-0.1885
p3=-0.6918+-0.2374
Col. 12
α = 166 mrad
r = 1.4 mm
kick [V/pC] /
collimator position [mm] /
chisq/N = 1.127
RMS=0.136
NDF= 8

Preliminary results:



Collimator	Measured[4] Kick Factor V/pc/mm (χ^2/dof) **Linear fit**	Measured[4] Kick Factor V/pc/mm (χ^2/dof) **Linear + Cubic Fit**	Analytic Prediction[1] Kick Factor V/pc/mm	ECHO3D Modelling Prediction[2] Kick Factor V/pc/mm
1	1.4 ± 0.1 (1.0)[3]	1.2 ± 0.3 (1.0)	1.1	1.7
2	1.4 ± 0.1 (1.3)	1.2 ± 0.3 (1.4)	2.3	3.1
3	4.4 ± 0.1 (1.5)	3.7 ± 0.3 (0.8)	6.6	7.1
4	0.9 ± 0.2 (0.8)	0.5 ± 0.4 (0.8)	0.3	0.8
8	1.7 ± 0.3 (2.0)	1.7 ± 0.3 (2.2)	2.3	2.4
7	1.7 ± 0.1 (0.7)	2.2 ± 0.3 (0.5)	2.4	2.7
6	0.9 ± 0.1 (0.9)	0.9 ± 0.3 (1.0)	2.3	2.4
5	3.7 ± 0.1 (7.9)	4.9 ± 0.2 (2.6)	2.3	6.8

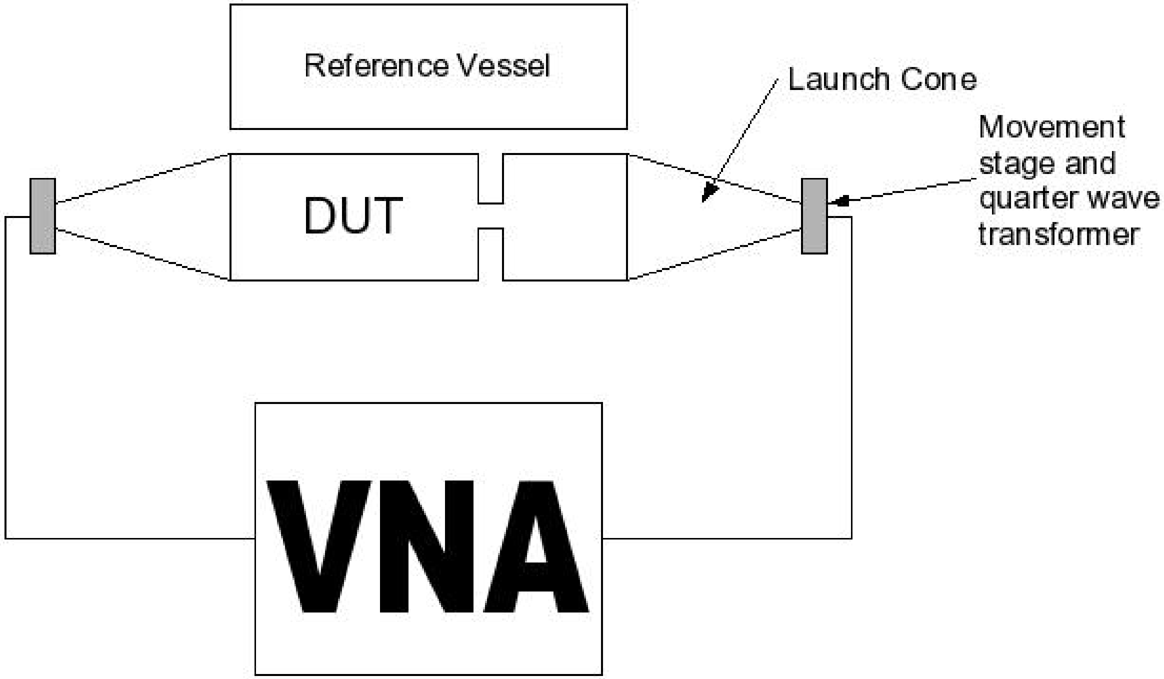
[1]Assumes 500-micron bunch length
[2]Assumes 500-micron bunch length, doesn't include analytic resistive wake; modelling in progress
[3]Kick Factor measured for similar collimator described in SLAC-PUB-12086 was (1.3 ± 0.1) V/pc/mm
[4]Still discussing use of linear and linear+cubic fits to extract kick factors and error bars

→ Goal is to measure kick factors to 10%

Data as at PAC07

Coll.	Measured Kick Factor / V/pC/mm (Linear Fit)	Measured Kick Factor / V/pC/mm (Linear & Cubic Fit)	Analytic Prediction Kick Factor V/pC/mm	3-D Modeling Prediction Kick Factor V/pC/mm
1	1.4 ± 0.1 (1.0)	1.2 ± 0.3 (1.0)	2.27	1.63 ± 0.37
2	1.4 ± 0.1 (1.3)	1.2 ± 0.3 (1.4)	4.63	2.88 ± 0.84
3	4.4 ± 0.1 (1.5)	3.7 ± 0.3 (0.8)	5.25	5.81 ± 0.94
4	0.9 ± 0.2 (0.8)	0.5 ± 0.4 (0.8)	0.56	0.8
5	3.7 ± 0.1 (7.9)	4.9 ± 0.2 (2.6)	4.59	6.8
6	0.9 ± 0.1 (0.9)	0.9 ± 0.3 (1.0)	4.65	2.12 ± 1.14
7	1.7 ± 0.1 (0.7)	2.2 ± 0.3 (0.5)	4.59	2.87 ± 0.53
8	1.7 ± 0.3 (2.0)	1.7 ± 0.3 (2.2)	4.59	2.39 ± 0.89
13		4.1 ± 0.4 (0.8)		3.57 ± 0.98
14		2.6 ± 0.4 (1.0)		3.57 ± 0.98
15		2.0 ± 0.3 (1.8)		2.51 ± 1.16
16		1.3 ± 0.3 (1.0)		2.35 ± 1.50

Wire measurement: Theory

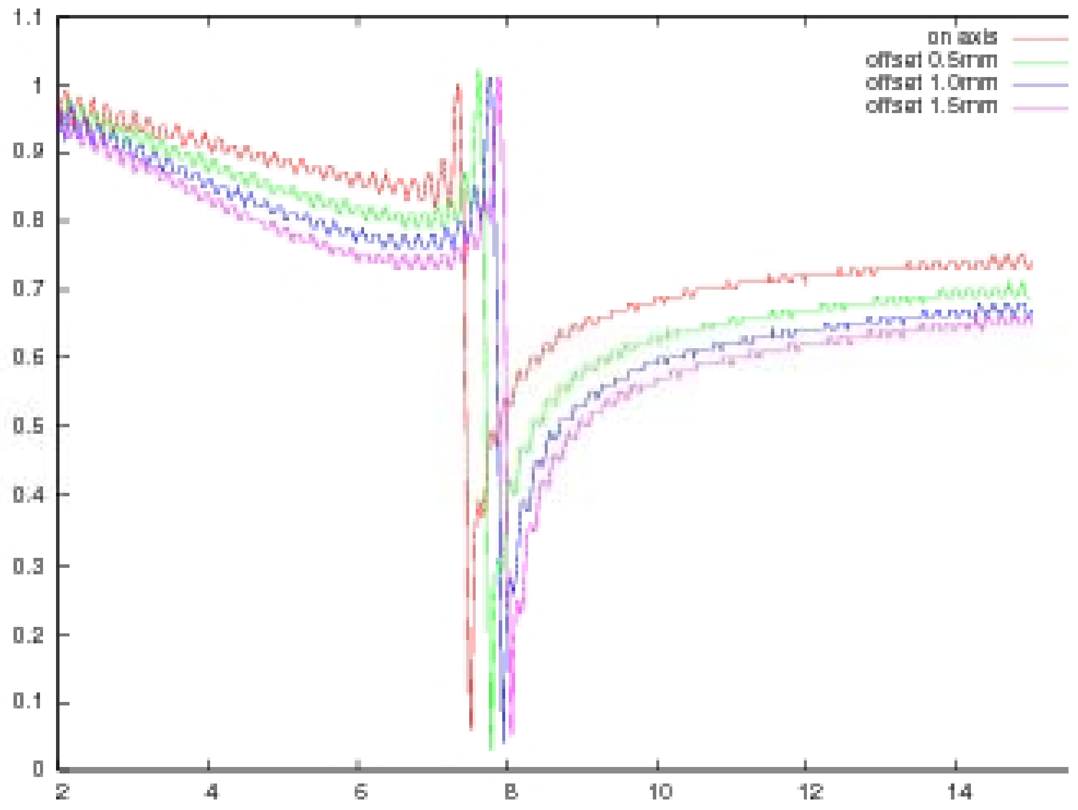


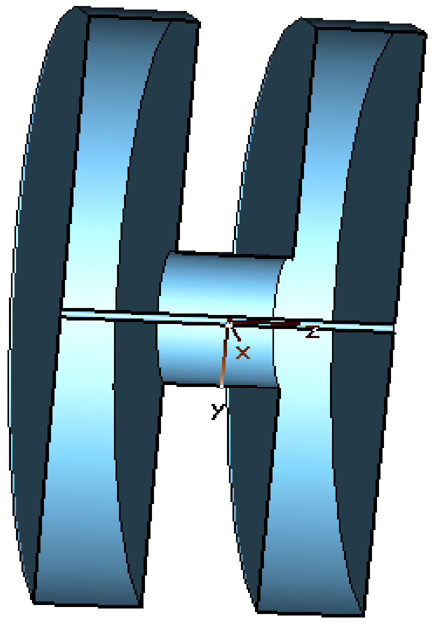
$$\frac{S_{21,DUT}}{S_{21,ref}} = \frac{e^{j\theta}}{\cos(\xi\theta) + \frac{j}{2}(\xi + \frac{1}{\xi})\sin(\xi\theta)}$$

$$\xi = \sqrt{1 - \frac{jZ_{||}}{\theta Z_0}}$$

$$Z_{||} = -2Z_0 \ln\left(\frac{|S_{21,DUT}|}{|S_{21,ref}|}\right)$$

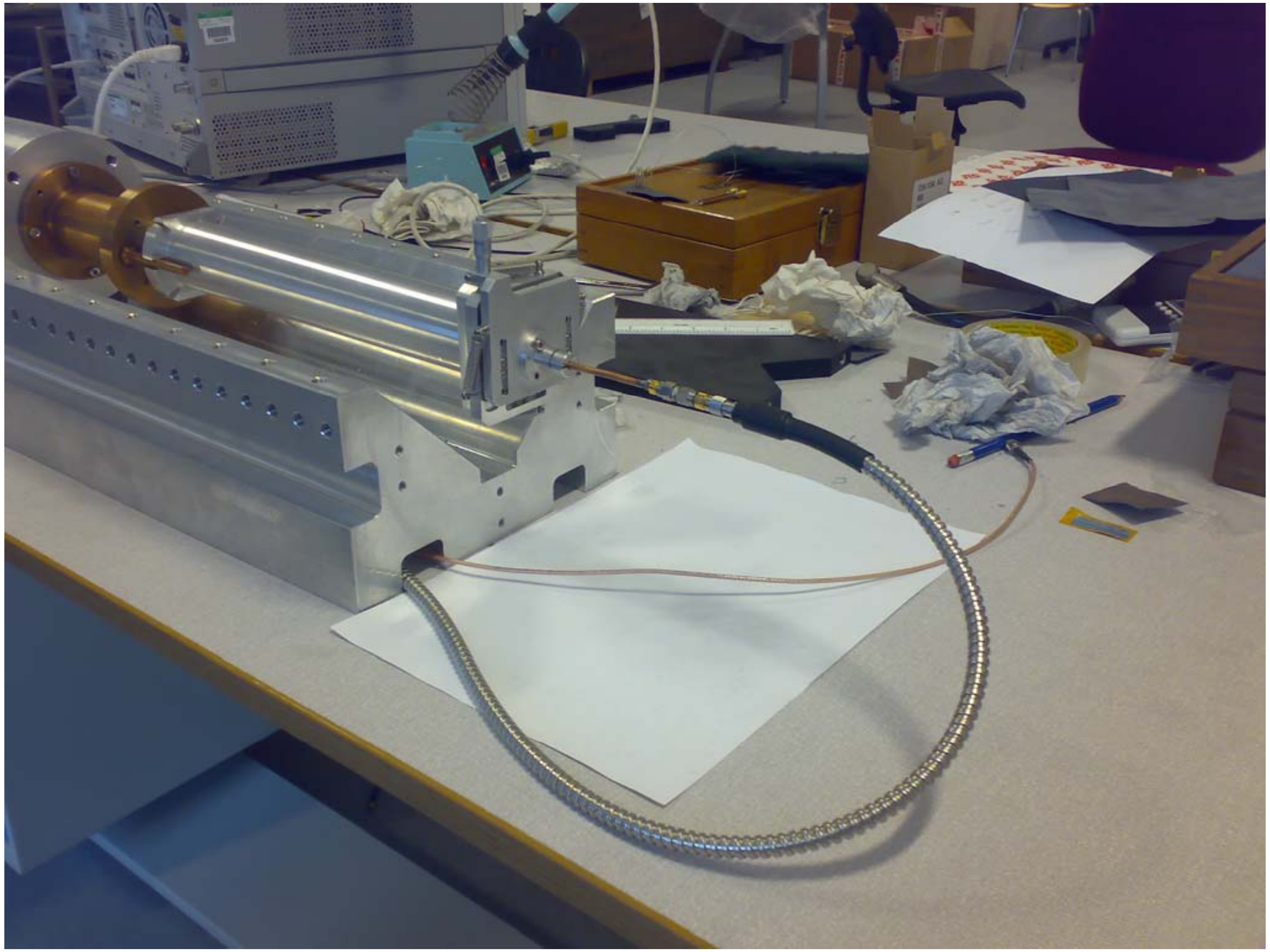
Wire measurements
Mock-up in Microwave Studio



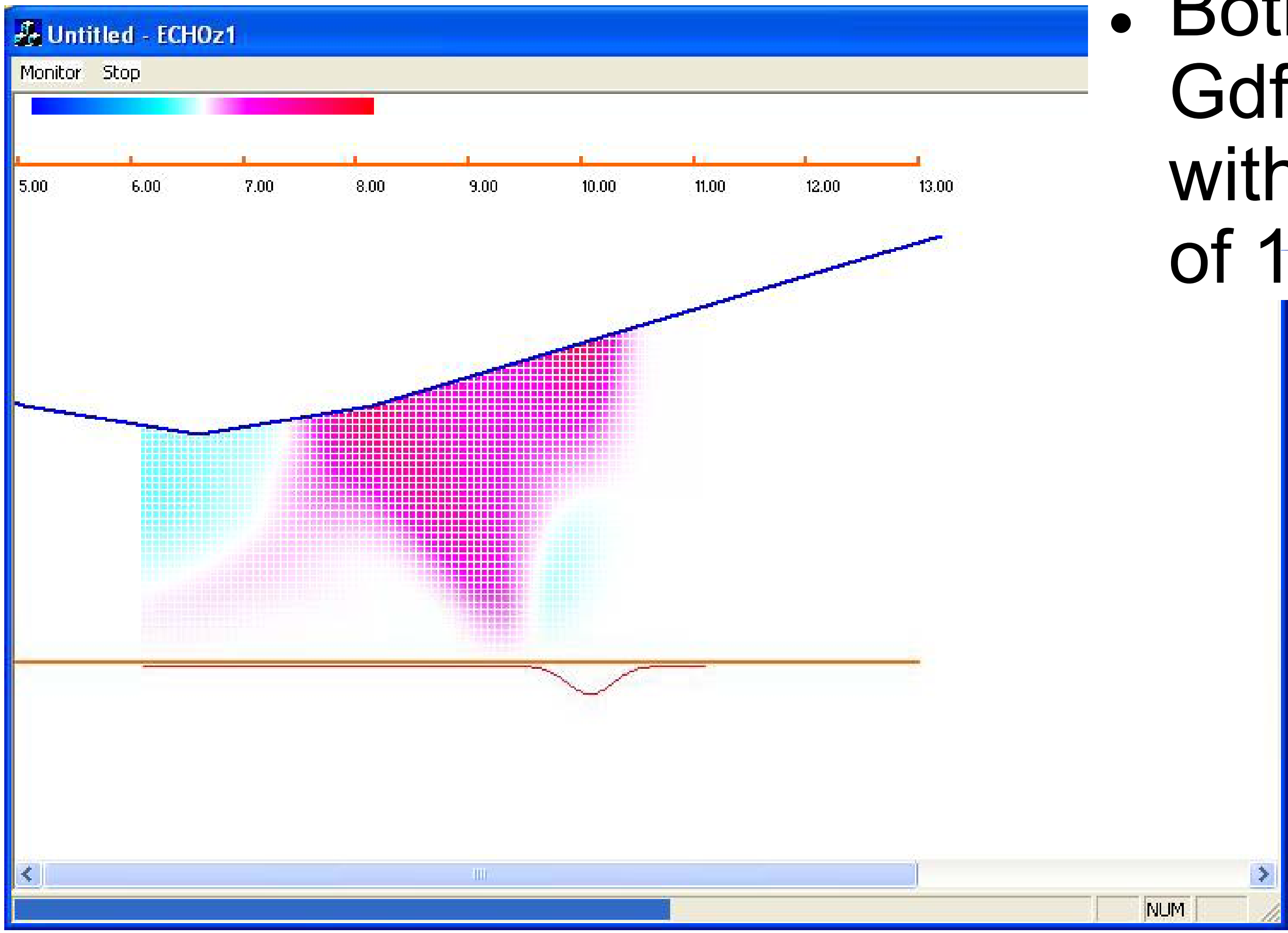


Jonathan Smith, 27th August 2008, Uppsala

Wire measurement: Experiment

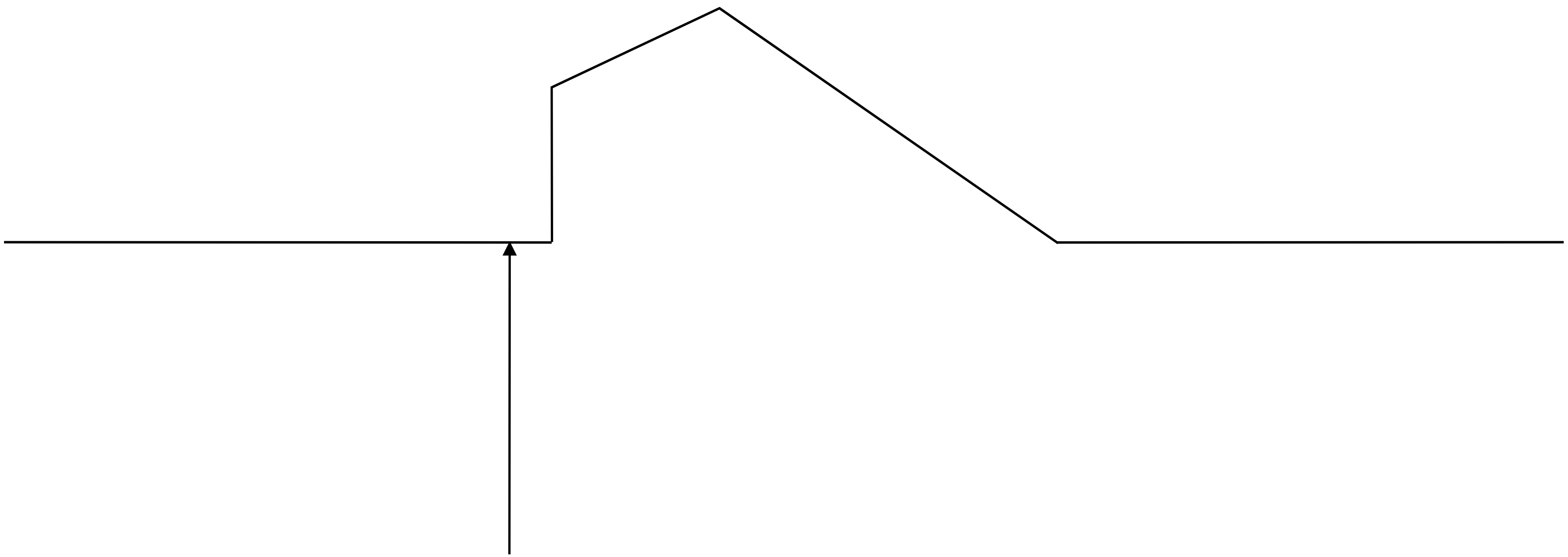


Benchmarking against ECHO



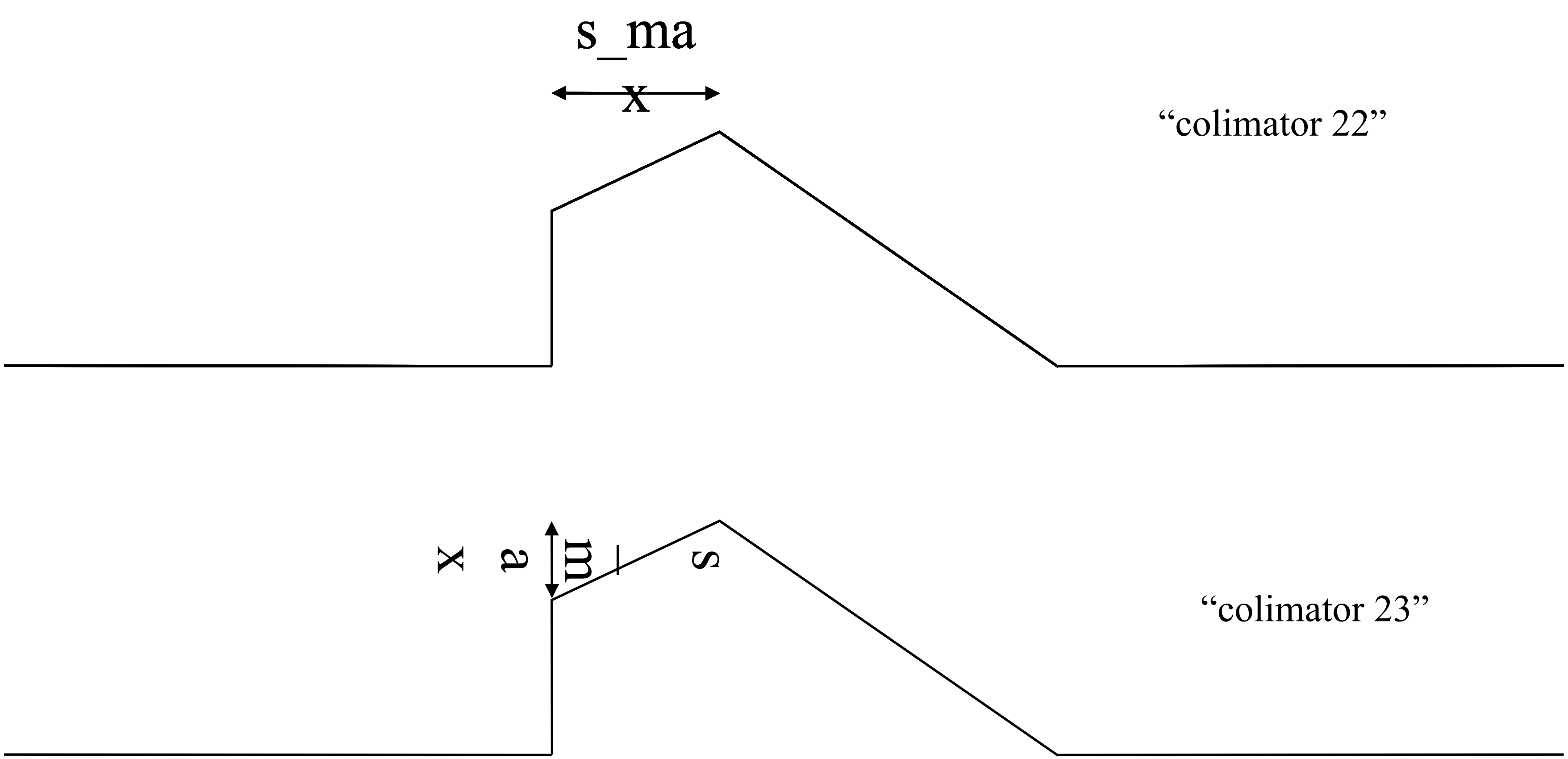
- Both ECHO & GdfidL giving output within 0.01V/pC/mm of 1.36V/pC/mm!

WB's suggestion:

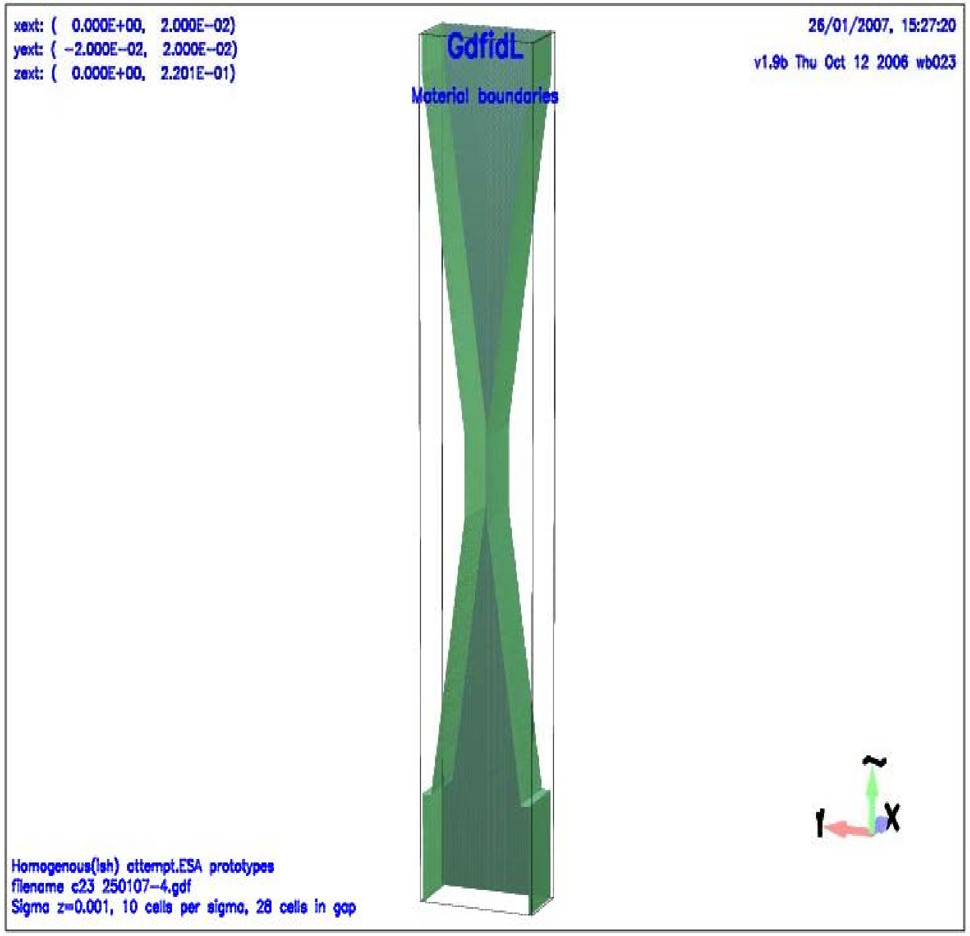


Chop this bit off as beam will never see wake that has travelled this far from the bunch

Two possibilities:



Longitudinally Asymmetric?



Results...

Setup Date (Estimate	collima	alpha1	jaw_r1	jaw_r2	sigma_z	z cells p	y_positio	Longitudinal lo	Kick fact	(V/pC/m)
290107	22	3.24E-001	1.40E-003	3.42E-003	5.00E-004	6	4.00E-004	-39.17	-4586.03	
290107	23	3.24E-001	1.40E-003	7.40E-003	5.00E-004	6	4.00E-004	-37.64	-4508.15	
271006	2	3.24E-001	1.40E-003	undef	5.00E-004	6	4.00E-004	-37.41	-4466.48	

Setup Date (Estimate	collima	alpha1	jaw_r1	jaw_r2	sigma_z	z cells p	y_positio	Longitudinal lo	Kick fact	(V/pC/m)
290107	22	3.24E-001	1.40E-003	5.43E-003	1.00E-003	10	4.00E-004	-14	-2904.78	
290107	23	3.24E-001	1.40E-003	1.34E-002	1.00E-003	10	4.00E-004	-12.76	-2851.28	
271006	2	3.24E-001	1.40E-003	undef	1.00E-003	10	4.00E-004	-12.66	-2855.48	

Summary

- Experimental programme to measure collimator wakefields at SLAC-ESA.
- Numerical simulations to provide direction to the collimator design programme.
- Alternative numerical/analytical techniques under development, which will provide useful comparison.

Unfinished business

- Checking dependence on bunch profile
- Final numbers for trapped modes
- Validation with results from other codes

Project deliverables

- Development of validated methods for simulating the wakefields in tapered collimating structures generated by the passage of specified bunches (but excluding the dynamics of the electron motion in the wakefields). Achieved in full
- Investigation of the design of short collimators with low wakefield effects leading to the proposal of designs for cold and hot testing Achieved in full
- Cold test measurements on selected designs in both time and frequency domains to provide validating data for the simulations. Determined results were not relevant.
- Participate in spoiler wakefield beam tests and analyse results. Achieved in full
- Propose optimal colliamtor design. Achieved in full

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  - Overview of general characteristics