FFA@CEBAF Working Group | MINUTES

Meeting date | time *06/13/2025 | 11 AM EST* | Meeting location https://jlab-org.zoomgov.com/j/1614898082?pwd=TnUzMS81M2sxbDZIbERJU01tYkJCQT09

Meeting called by	Alex B
Type of meeting	Weekly Meeting
Facilitator	Alex B
Note taker	Salim
Timekeeper	Alex B

Attendees

Alex B, Donish, Salim, Dejan, Sadiq, Volker, Kirsten, Randy, Vasiliy, Edy

INTRO DISCUSSION

AGENDA TOPICS

Time allotted | *30 mins* | Agenda topic *CEBAF Design Steps* | Presenter *Dejan*

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS 8, 050101 (2005)

Design of a nonscaling fixed field alternating gradient accelerator

D. Trbojevic, E. D. Courant, and M. Blaskiewicz, BNL, Upton, New York 11973, USA*

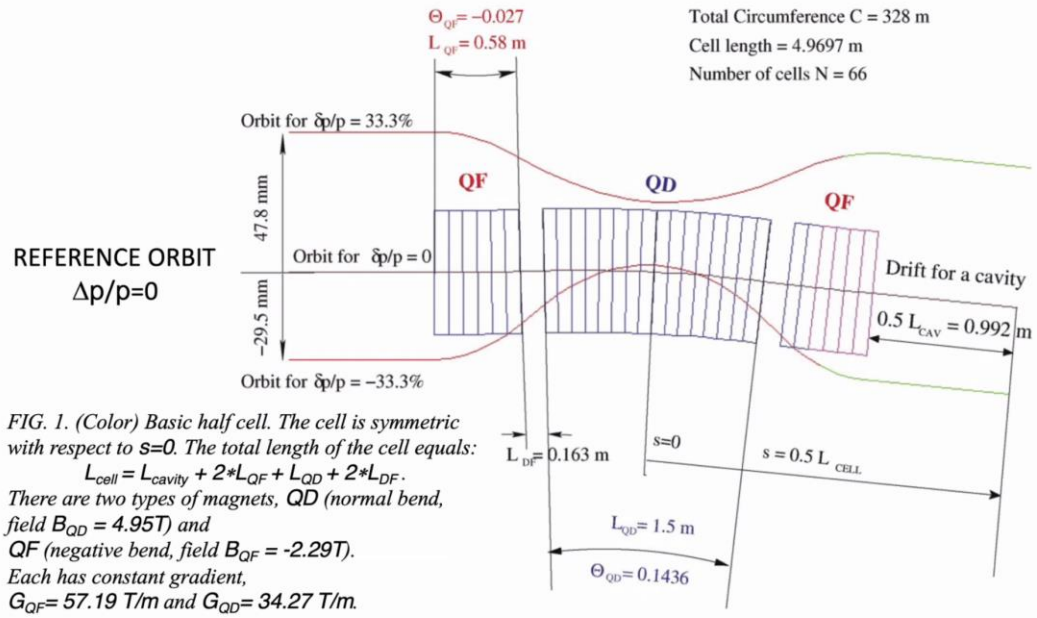

FIG. 1. (Color) Basic half cell. The cell is symmetric with respect to s=0. The total length of the cell equals: $L_{cell} = L_{cavity} + 2*L_{QF} + L_{QD} + 2*L_{DF}$. *There are two types of magnets, QD (normal bend, field B_{QD} = 4.95T) and QF (negative bend, field B_{QF} = -2.29T). Each has constant gradient, G_{QF}= 57.19 T/m and G_{QD}= 34.27 T/m.*

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- Dejan: many ways to do this; I design the lattice and ten tune the fields after (Scott and Stephen do it different).

We consider a particle of momentum p and a reference particle with momentum p_0 and charge q; the momentum offset is $\delta = \frac{p-p_0}{p_0}$. The magnetic rigidity of the reference particle is:

$(B\rho)_0 = \frac{p_0}{q}$ *; the reference particle is on a reference orbit (assumed planar) with local radius of curvature ρ_0 and vertical field $B_0(s) = (B\rho)_0 / \rho_0(s)$. In the cases considered here the field $B_0(s)$ and with it the radius of curvature $\rho_0(s)$ are constant in each magnet, so that the reference orbit consists of circular arcs in the magnets and straight sections between the magnets. We assume that the magnetic field in the dipole magnets is linear:*

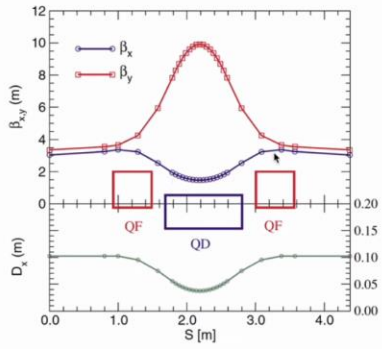

FIG. 2. (Color) Betatron functions and dispersion in the basic cell at the central energy.

$$B_y = B_0 + Gx,$$

How do we find the closed reference orbit in the CEBAF basic cell?

*To have the **same dipole field for the reference circular orbit** a parameter named RATIO is introduced as: RATIO=QLF/BL, where the QLF is length of the focusing magnet and BL is the length of the defocusing magnet and the bending angle of the magnets are connected by the relationship:*

ANG_{TOT}=NDIP(ANGBD+RATIO*ANGBD)=*

*ANG_{TOT}=NDIP*ANGBD (1 + RATIO)) Reference orbits bending fields are the same in both magnets $BD_0=BQF_0$*

- Dejan: These designs were intended for light sources; work came from trying to get the lowest emittance. Stephen contributed to longitudinal varying bending magnets.
- Stephen: The concept was not mine, but I did help design some.

Selection of the the tunes at the reference orbit NUX and NUY

NUX = 0.22208
NUY = 0.0801

The range in the focusing and defocusing tunes must be within the orbit stability region:

$nux_{max} < 0.38$ and $nuy_{min} > 0.05$

The reference energy for the FFAG lattice for electrons is quite different than for other cases like muons, protons, heavy ions as they do not have large synchrotron radiation energy loss. As we do not know what is the best reference energy, we can select the one closer to the highest energy. The final reference energy in the WEST ARC case was: E_{CENT}=20.45 GeV but this will be explained in more detail later.

The momentum dependence loop can be set-up in any code knowing the maximum and minimum energy, the gain by the linac:

These are two examples for PTC and BMAD:

```
EMAX=22.65D0;
EMIN=11.65D0;
ELIN=2.2D0;
ECEN=20.50D0;
DLTP=-1.0D0*(PLIN/PCEN);
DPMAX=(PMAX-PCEN)/PCEN;
```

```
do I=0,5,1
    x(5)=I*DLTP+DPMAX;
    Calculate orbits,
    betatron functions etc.
enddo
```

Momentum dependence loop in the Bmad can be done few different ways by using *tao*

Scott Berg's way:

1. There is a main bmad lattice file with element definitions
2. 06_05_2025.tao the loop file

```
set global plot_on=f
    do i = 1, 13
      set sym ke= 10e6 + 20e6*([[i]])
      set particle_start [[i]]@pz = (sqrt(ke*(2*m_proton+ke))-ele::0[p0c])/ele::0[p0c]
    enddo
set global lattice_calc_on=t
set global plot_on=t
```

3. The tao.init file

I prefer to define the energies and make the loop using "universes"

- Dejan: Scott has a different approach which only requires 3 files whereas mine requires 7 files; for a new-comer it may be more convenient to follow Scott's approach.

I define the energies by using files like:
energy1.lat

```
parameter[p0c] = 16099999991.8906855 ! central energy 16.1 GeV
beam_start[pz] = -0.37888197       !corresponds 10 GeV  miminum energy
! pz = (p - poc)/poc

!! For arc only
 beam_start[x]     = -8.03028059e-3
 beam_start[px]    = 0.0
 beginning[beta_a]  = 0.22281250
 beginning[alpha_a] = 0.0
 beginning[beta_b]  = 5.07769173
 beginning[alpha_b] = 0.0
 beginning[eta_x]   = -0.06240713
 beginning[etap_x]  = 0.0
```

The dp/p loop is using universes in the tao.init file

```
&tao_start
  plot_file = 'tao_plot.init'
  startup_file = 'tao.startup'
/
!Beam Initialization
!-----------------------------------------------------------
&tao_design_lattice
  n_universes = 5
    design_lattice(1)%file = "cell1.lat"
    design_lattice(2)%file = "cell2.lat"
    design_lattice(3)%file = "cell3.lat"
    design_lattice(4)%file = "cell4.lat"
    design_lattice(5)%file = "cell5.lat"
/
```

The cell.lat files
call, file = Dec8_2020_CEBAF.bmad
call, file = energy1.bmad

Summary of the steps in the CEBAF lattice design

1. Start by the finding the reference orbit by selecting the reference energy
2. Run the dp/p loop and see if all momenta have stable orbits with tunes conforming the set-up limits $nux_{max}<0.38$ at the lowest energy and $nuy_{min}>0.05$ at the highest energy
3. Check the orbit offsets at both ends of the energy spectrum
4. Calculate the maximum fields in both magnets using previous orbits by $B_{max}=B_o+G*x_{max}$
5. If the field is larger than Stephen's limits either change the total number of cells and try again, or readjust the tunes at the reference energy
6. If everything is stable and the maximum fields are within the magnet limits calculate the synchrotron radiation loss for each energy
7. Adjust the central energy such that the total synchrotron radiation loss is minimum. This is shown in the next slide

Optimization of the synchrotron radiation loss

23-Jun-22epsD (F/m)	1e	ERM	CLIGHT	C_GAMMA	ECENT	BD	QLF	LBD	LCELL	GF	GD (T/m)	BF	
	8.8542E-12	1.60218E-19	5.10999E+05	2.99792E+08	8.85419E-05	20.800000	-0.570870	1.600000	0.840756	2.094395	-61.105246	78.471935	-1.17479

BF_middle	BF_END	BF_AVG	XF_END	XF_MIDDLE	XD_MID	XD_END	BD_END	BD_MIDDLE	BD_AVG	BRHO	GAMMA
21.90	-1.334648	-1.306607	-1.320627	2.157133	2.616031	1.772985	2.025665	-0.411912	-0.431740	-0.421826	7.30505E+01	4.28572E+0
19.70	-0.951314	-0.994010	-0.972662	-2.958584	-3.657301	-2.377589	-2.759468	-0.787410	-0.757444	-0.772427	6.57121E+01	3.85519E+0
17.50	-0.595169	-0.716756	-0.655963	-7.495890	-9.485694	-5.855244	-6.932623	-1.114886	-1.030342	-1.072614	5.83737E+01	3.42466E+0
15.30	-0.270653	-0.480973	-0.375813	-11.354528	-14.796462	-8.547495	-10.388631	-1.386086	-1.241608	-1.313847	5.10353E+01	2.99414E+0
13.10	0.016858	-0.294363	-0.138752	-14.408452	-19.501648	-10.315755	-12.995912	-1.590684	-1.380367	-1.485525	4.36969E+01	2.56361E+0

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Ncells	I(mA)	constant	barleta									
	86.000000	0.000000	9.59976E-10	1.40800E+01								

R_QF	R_BD	beta	Tau_QF	tau_QD	tau_total	QF energy of one electron	QD	POWER from QF	power of QF+BD	power of QD
-55.315024	-173.176988	1.00000E+00	4.58984E-07	2.41184E-07	7.00168E-07	9.15920E-01	1.17607E-01	1.45643E+08	1.53451E+08	7.80810E+0
-67.559053	-85.072280	1.00000E+00	4.58984E-07	2.41184E-07	7.00168E-07	1.97392E-01	1.56757E-01	6.39288E+07	8.51143E+07	2.11855E+0
-88.989375	-54.421925	1.00000E+00	4.58984E-07	2.41184E-07	7.00168E-07	9.33174E-02	1.52590E-01	2.29443E+07	5.51812E+07	3.22369E+0
-135.799602	-38.844182	1.00000E+00	4.58984E-07	2.41184E-07	7.00168E-07	3.57286E-02	1.24907E-01	5.75662E+06	4.27278E+07	3.69711E+0
-314.927605	-29.415112	1.00000E+00	4.58984E-07	2.41184E-07	7.00168E-07	8.27986E-03	8.86469E-02	5.75258E+05	3.52245E+07	3.46492E+0
								2.38848E+08	3.71699E+08	1.32851E+0

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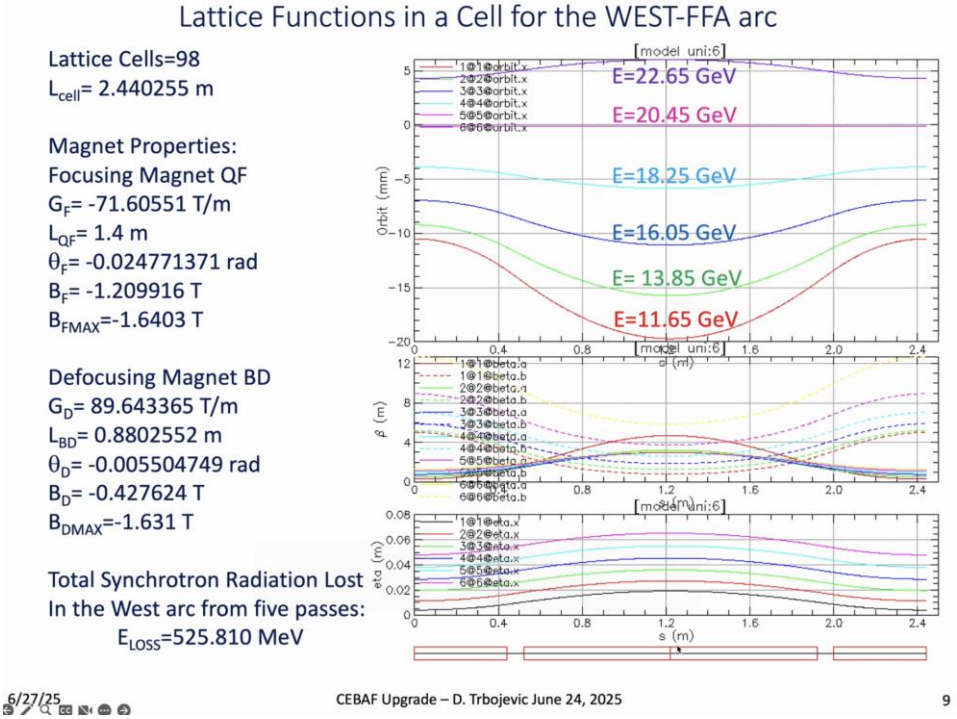
								2.38848E+08	3.71699E+08	1.32851E+0

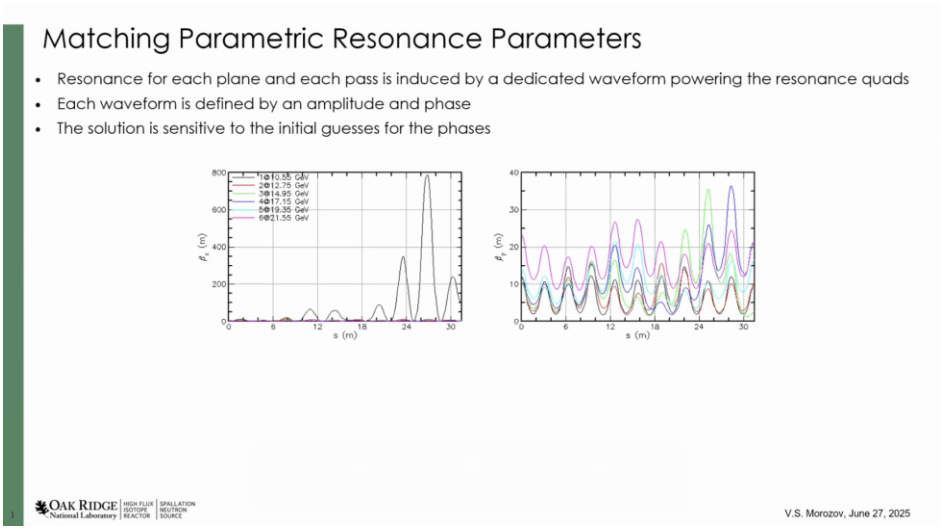
- Dejan: Many parameters to look at. One of the more important parameter to look at is the maximum magnetic field.



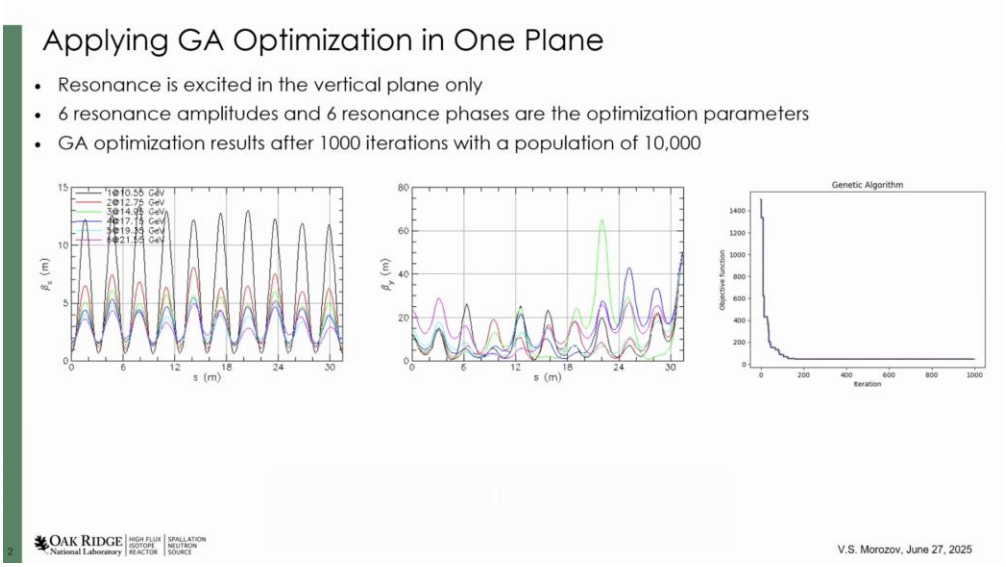
- Dejan: Stephen can discuss how they designed it.
- Stephen: The reference orbitin Bmad is confusing; not a real physical thing, but central orbit is.
- Alex: I put these files and presentation in the sharepoint.
-

AGENDA TOPICS

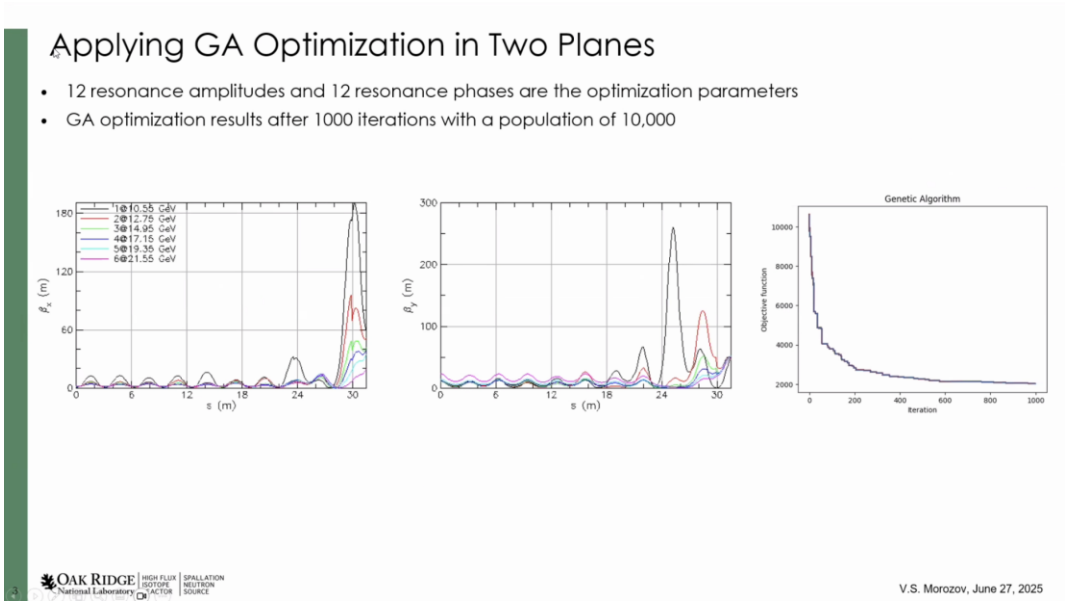
Time allotted | *30 mins* | Agenda topic Matching Parametric Resonance Presenter *Vasiliy*



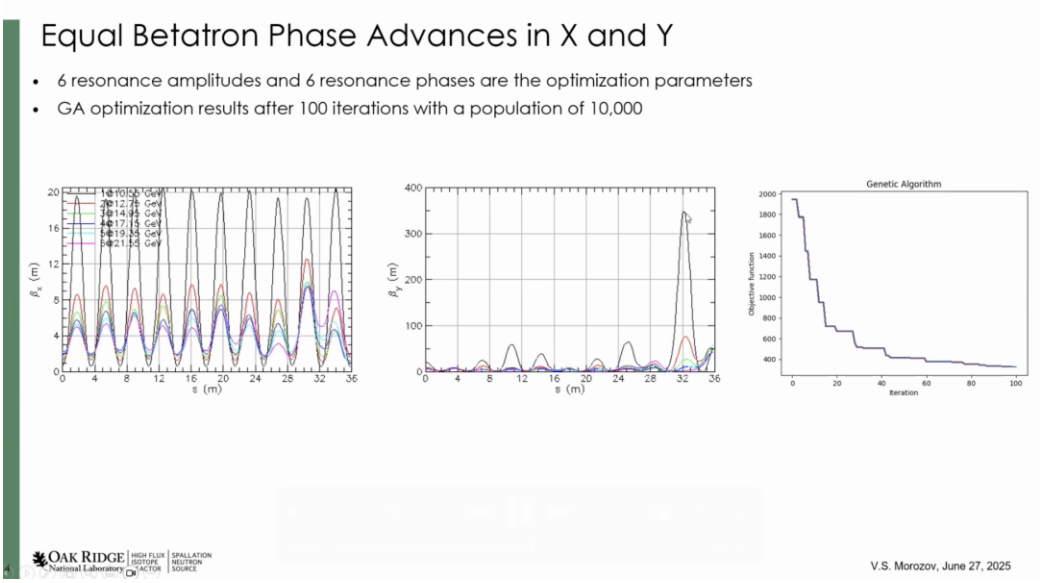
- Vasiliy: Each pass is defined by an amplitude and phase; very sensitive to initial guesses of phases.



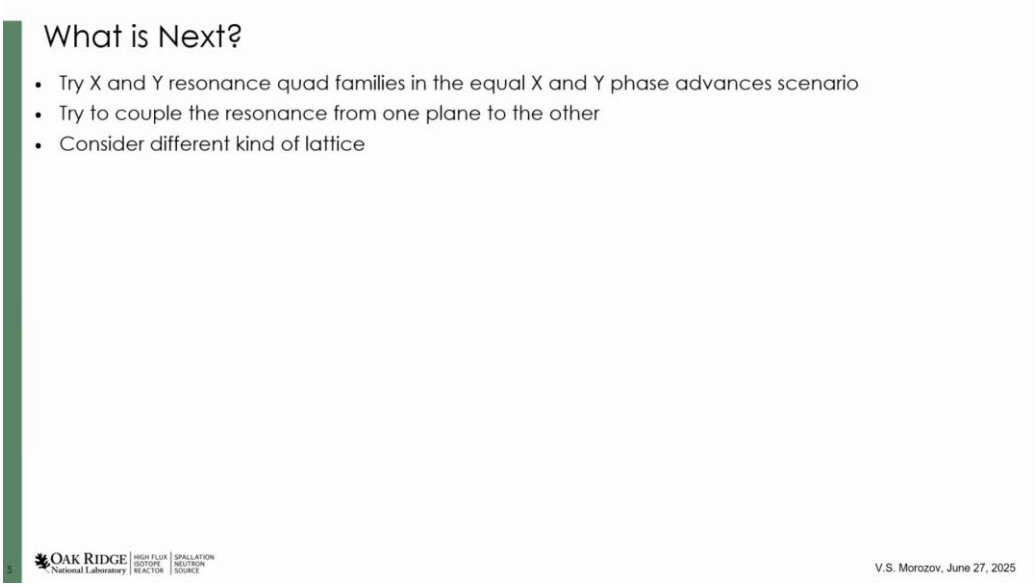
- Vasiliy: Very complex system, so started with one place initially (vertical). Did provide "decent" results.



- Vasiliy: Followed same approach but in both planes this time. Performed better than I expected.



- Vasily: Wanted to try a "naive" example but had very littler effect in the horizontal beta functions.



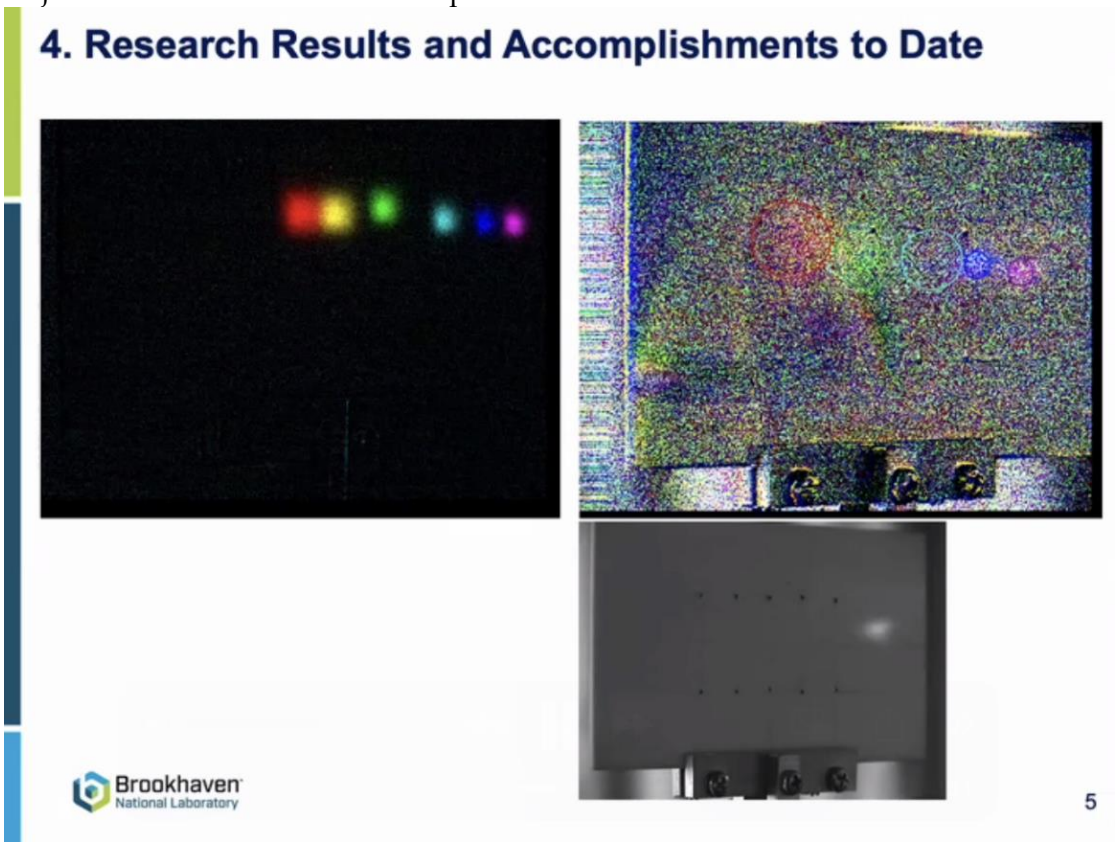
- Stephen: In terms of percentage, how good is the match?
- Vasiliy: Definitely within (or better) than 20%.
- Stephen: Possible to put a different gradient in every magnet or allow the length of the magnet to vary as well. This will give you some more parameters to vary.
- Dejan: What is very good in this exercises is that the length is only 30m.
- Stephen: It would be interesting to see how does your solution scale with the number of cells.
- Alex: Please put these slides in the FFA sharepoint.

AGENDA TOPICS

Time allotted | *10 mins* | Agenda topic General

- Dejan: We did an experiment at the ATF very similar to your LDRD, changed initial conditions to get the transfer matrix by rotating our assembly.
- Stephen: Much easier to rotate and move the assembly than to bend a 22 GeV beam.

- Alex: Our range we will be looking is between 5-11 GeV. If you could send us additional stuff for the set up that would be great. What were the energy of your ions?
- Dejan: From 50 MeV to 250 MeV protons.



Action Items	Person responsible	Deadline

Special notes

Pathway to Repository: https://jeffersonlab-my.sharepoint.com/:f:/g/personal/tristan_jlab_org/EqZ5MeS-nipCgPfZB5p0oS4B9Is67d3nQb9sLJI3Zyev9g