ILC測定器研究会2005.3.4

Final Focous magnet Options

Y. Iwashita
Accelerator Laboratory,
Advanced Research Center for Beam Science,
Institute for Chemical Research, Kyoto University,
Gokanosho, Uji, Kyoto 611-0011, JAPAN
iwashita@kyticr.kuicr.kyoto-u.ac.jp
http://wwwal.kuicr.kyoto-u.ac.jp

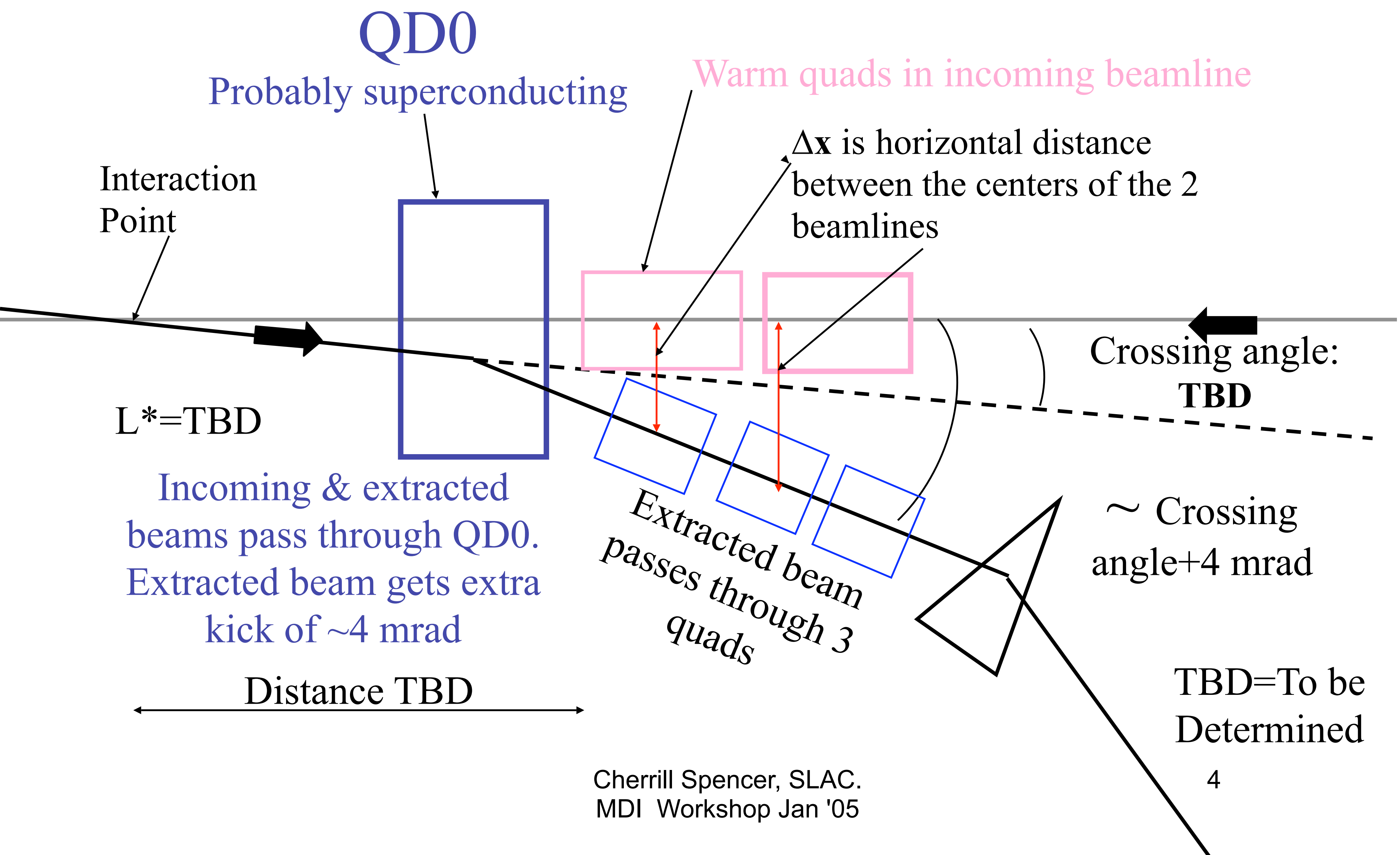
Contents

- FFQ options
  - Design choices
  - Technology choices
    - Normal magnet quadrupole
    - Superconducting magnet quadrupole
    - Permanent magnet quadrupole
    - Hybrid magnet quadrupole
  - R&D issues and Summary for FFQ
- RF kicker for head-on-collision
  - Rough idea
  - FINEMET
  - R&D issues

Design Choices

- It depends on
  - gradients for QD and QF
  - L* and, L** between QD and QF
  - crossing angle
- L* must be determined by detector interface
- L** can be very large
  - Pros : QF out of detector, shorter quads, smoother envelope, narrower SR
  - Cons : horizontal chromaticity (any other ?)
- Crossing angle?

Relative positions of the incoming & extraction magnets



QD0

Probably superconducting

Warm quads in incoming beamline

Interaction Point

Δx is horizontal distance between the centers of the 2 beamlines

Crossing angle: **TBD**

L*=TBD

Incoming & extracted beams pass through QD0. Extracted beam gets extra kick of ~4 mrad

Extracted beam passes through 3 quads

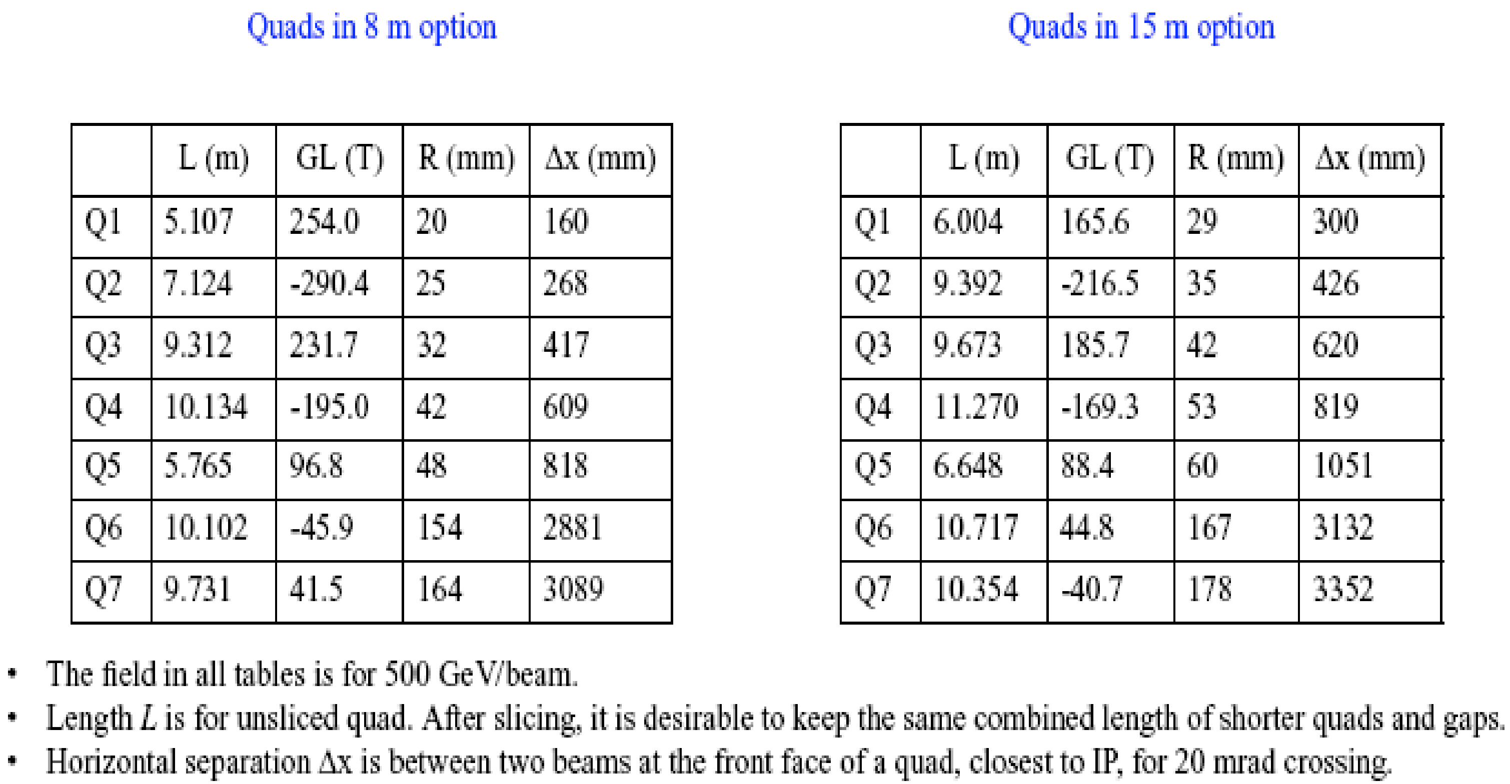
~ Crossing angle+4 mrad

Distance TBD

TBD=To be Determined

Extraction quad requirements with a 20mr crossing angle.

- To minimize beam size, quad apertures and dimensions in the extraction line, the quad focusing has to start soon after the IP. Even so the beam width gets very large.
- But, the first extraction quad has to be placed at sufficient distance from IP where it can realistically fit without interference with elements of the incoming beamline.
- Two options of extraction optics are compared below - with 8 and 15 m space between IP and the first extraction quad. Lattices from Yuri Nosochkov, SLAC



Quads in 8 m option

	L (m)	GL (T)	R (mm)	Δx (mm)
Q1	5.107	254.0	20	160
Q2	7.124	-290.4	25	268
Q3	9.312	231.7	32	417
Q4	10.134	-195.0	42	609
Q5	5.765	96.8	48	818
Q6	10.102	-45.9	154	2881
Q7	9.731	41.5	164	3089

Quads in 15 m option

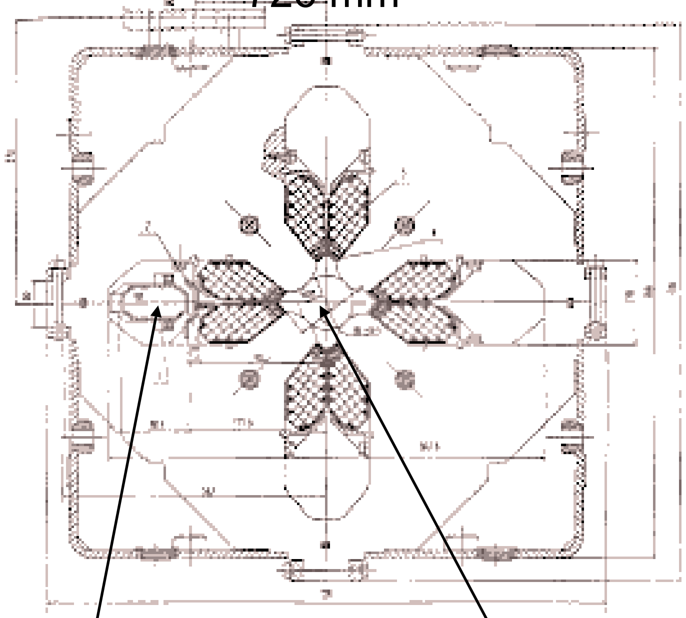
	L (m)	GL (T)	R (mm)	Δx (mm)
Q1	6.004	165.6	29	300
Q2	9.392	-216.5	35	426
Q3	9.673	185.7	42	620
Q4	11.270	-169.3	53	819
Q5	6.648	88.4	60	1051
Q6	10.717	44.8	167	3132
Q7	10.354	-40.7	178	3352

- The field in all tables is for 500 GeV/beam.
- Length *L* is for unsliced quad. After slicing, it is desirable to keep the same combined length of shorter quads and gaps.
- Horizontal separation Δx is between two beams at the front face of a quad, closest to IP, for 20 mrad crossing.

Unusual Quad Styles for areas with close adjacent beams

Quad for HERA Luminosity Upgrade.

726 mm

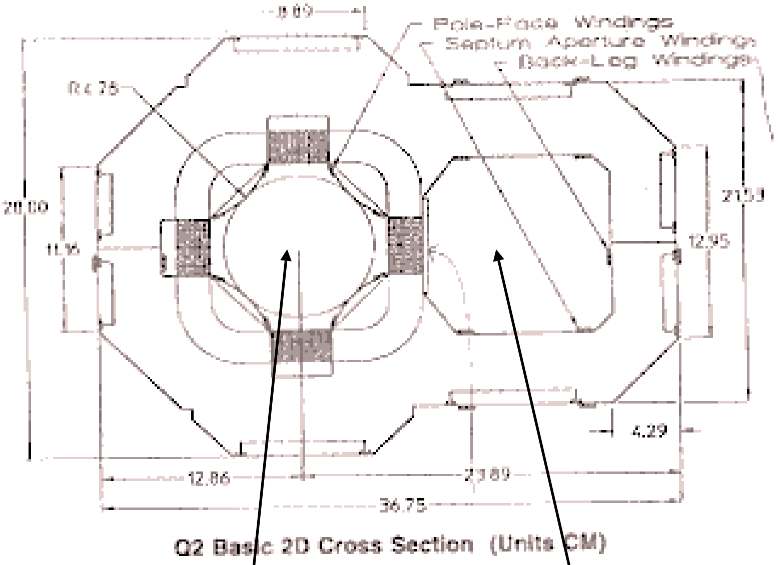


~221mm

Field-free region for secondary beam.
Primary beam passes through center of regular quad, bore radius=35mm

Q2 in PEPII

368mm



~142mm

Field-free region for secondary beam.
Primary beam passes through center of regular quad, bore radius=47.8mm

International Linear Collider
at Stanford Linear Accelerator Center

Extraction quad requirements with a 2mr crossing angle.

- If the crossing angle is only 2mr then the horizontal distance between the incoming and extracted beam, Δ**x**, becomes even smaller, forcing even stranger quadrupole designs.
- For example, based on a very preliminary and not fully-developed lattice with a 2 mr crossing angle and the first extraction quad at 10m from the IP (lattice from Yuri Nosochkov) these are the requirements on the first three extraction quads, for 250Gev/beam:

Quad	L (m)	GL(T)	R mm	Δx mm
QFEX1	4.143	127.9	56	21
QDEX2	4.161	-166.4	56	52
QFEX3	2.072	82.9	63	68

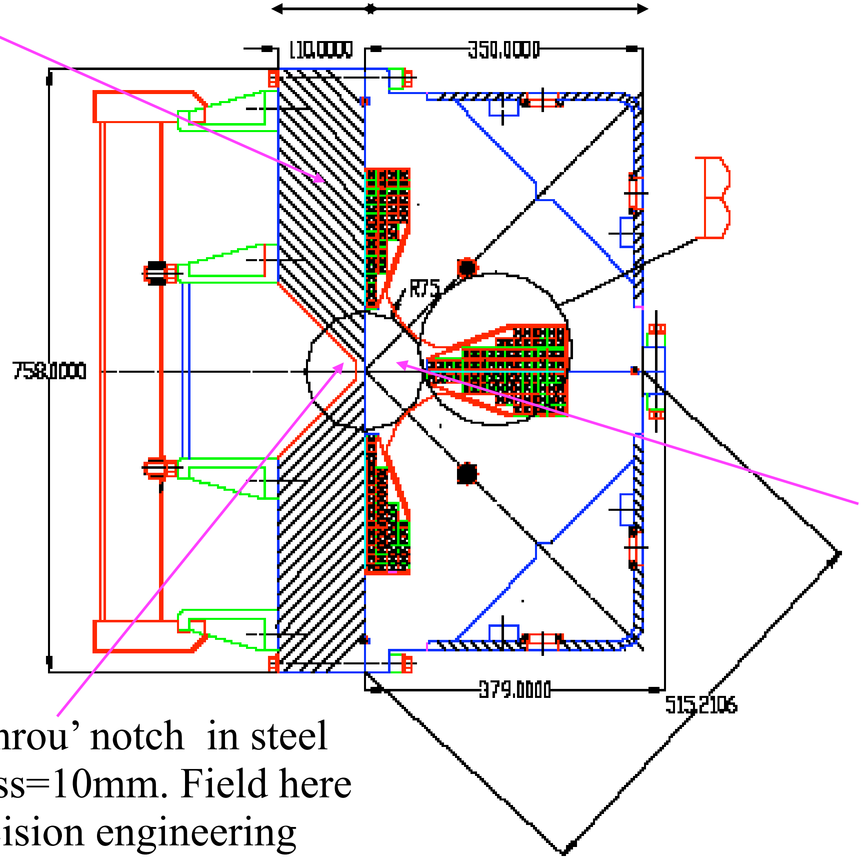
This set of magnet requirements is just one of many possible sets.

Septum Half Quad from TESLA TDR for 1st extraction quad

Steel septum

110mm

350mm



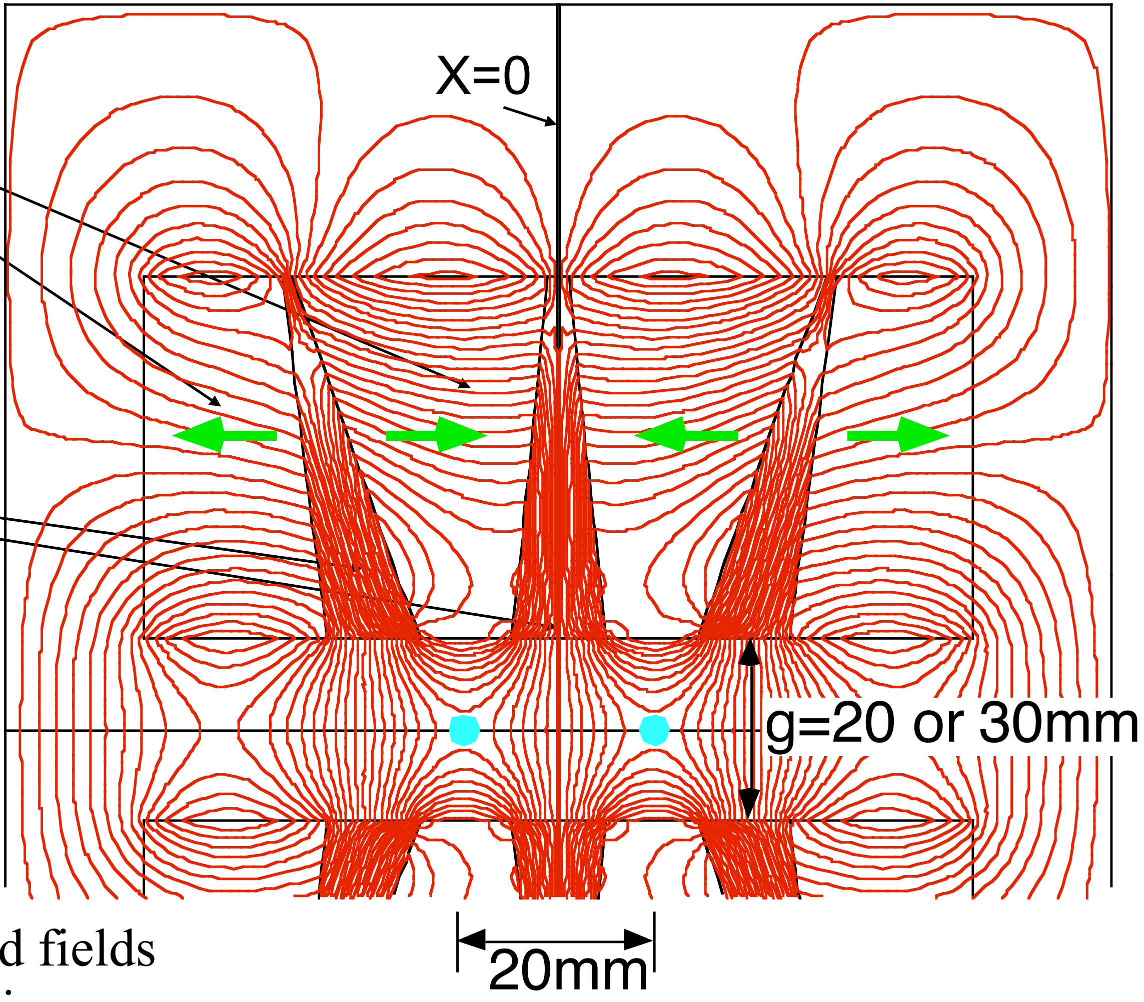
In my opinion one cannot satisfy Δx=21mm with such a design.

Extracted beam passes through HALF quad *to the right of its center* and so beam sees a dipole field on top of the quad field. The magnet's effect on the beam shape has to be modelled using some field data from a magnet simulation program.

Incoming beam passes throu' notch in steel septum. Septum thickness=10mm. Field here needs to be <~20G. Precision engineering needed to achieve this. Design is based on a HERA luminosity upgrade quad. Bore radius = 75mm.

Extracted beam horizontal profile is NOT Gaussian, nevertheless outlying particles will hit face of magnet if half-aperture is too small.

Side-by-side Quads: a different approach, using permanent magnets



NEOMAX46
pm bricks

Permendur,
soft mag
material

Sides are open

Have full quad fields
in both beamlines.

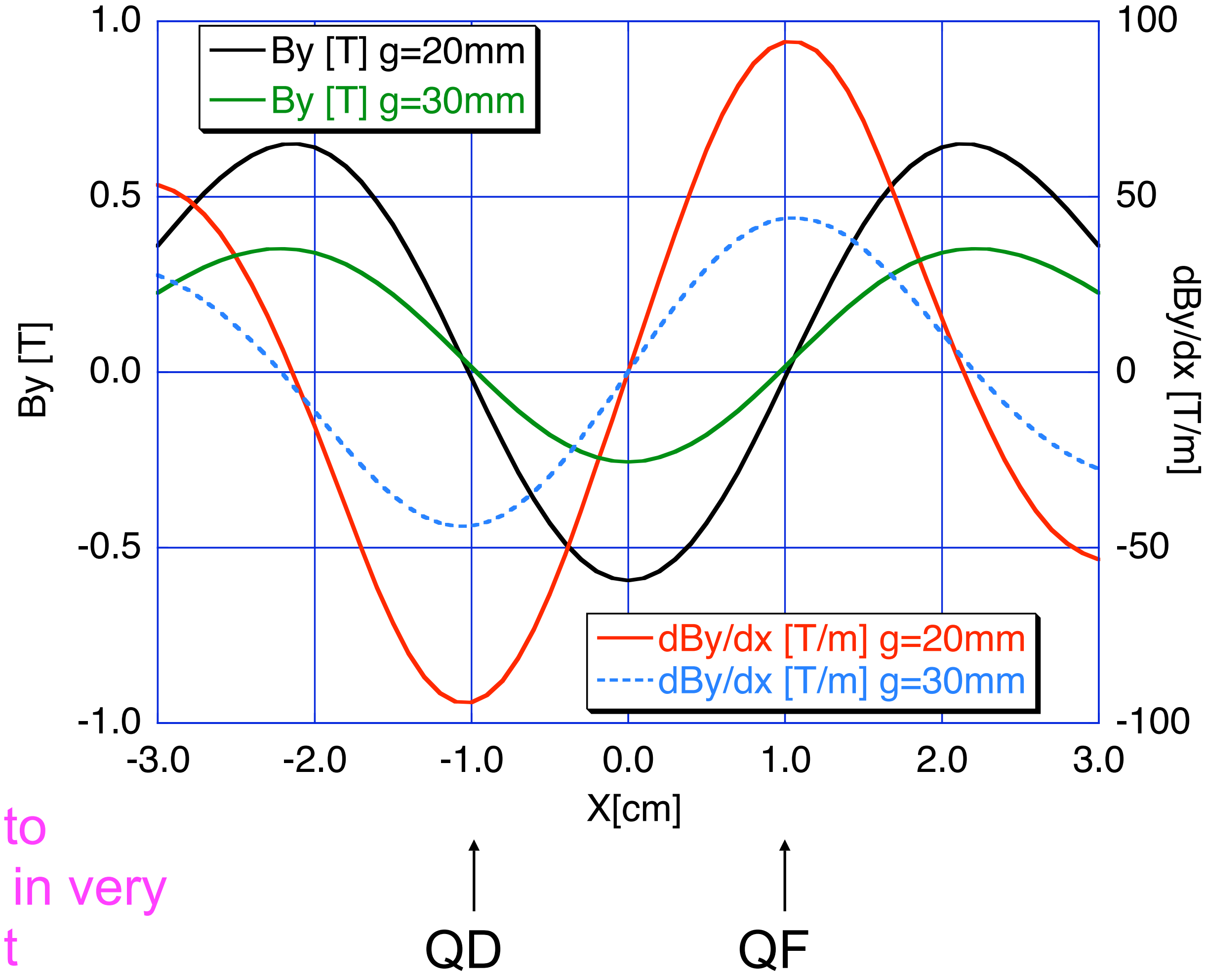
Beam offset =±10mm
QD QF

Idea from
Y.Iwashita,
Kyoto
University

Conceptual figure.
Very preliminary.

Vary gap height to
vary gradient

Gradient variation with x for side-by-side quads

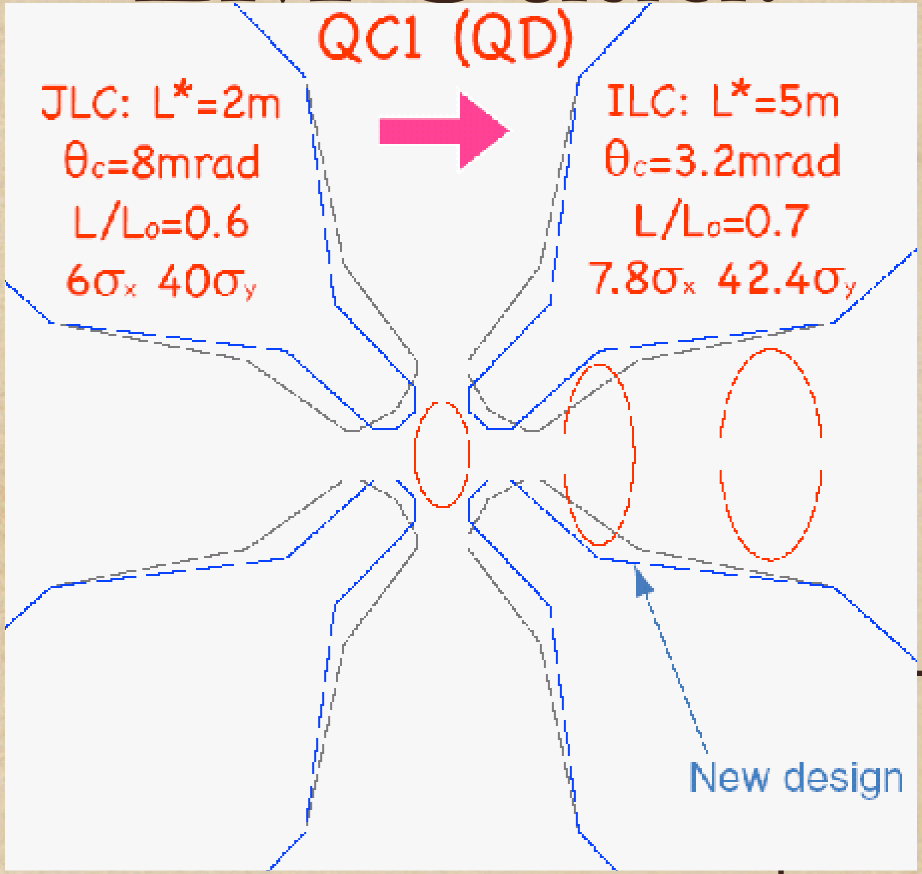


Gradient varies along x : has sextupole component.

Maximum value of ~100T/m at x=+-10mm

Possible way to have 2 quads in very close adjacent beamlines.

EM Quad.



Advantages

Well known techonology

Disadvantages

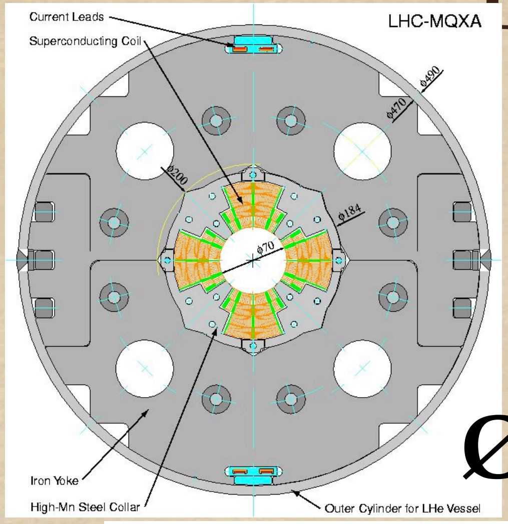
Heat Load (cooling)

	Bore radius (mm)	Effective Length(m)	Gradient (T/m)
QF1	5	3.996	44.83
QD0	1.8	3.353	-128.8

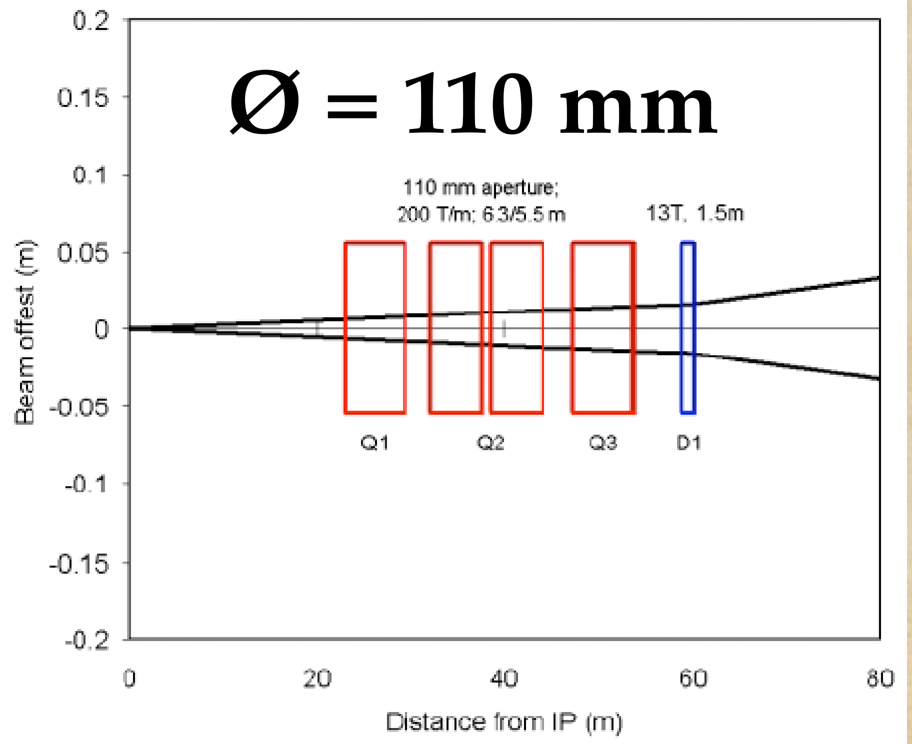
http://acfahep.kek.jp/subg/ir/bds/jlc-bds.html#ffocus

Larger Bores for SC quad

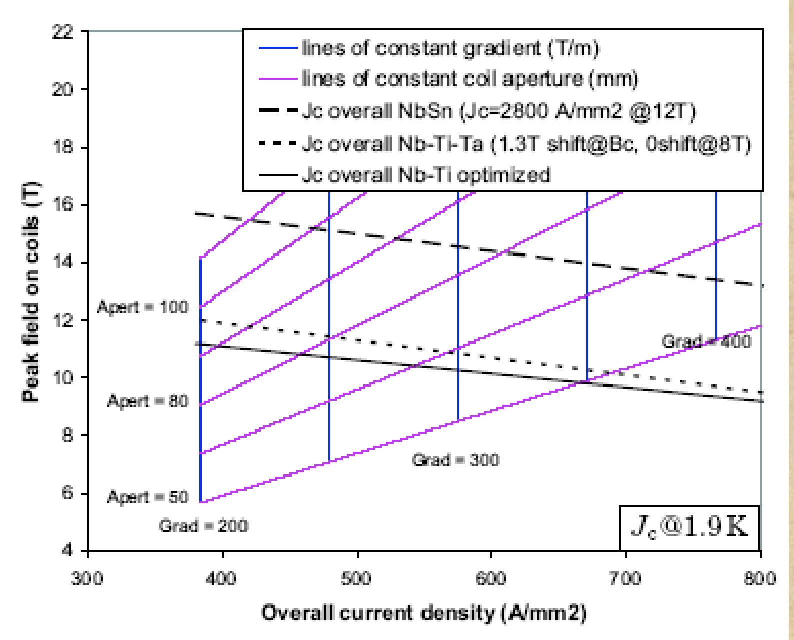
- LHC low beta quad
- LHC upgrades using Nb_3Sn



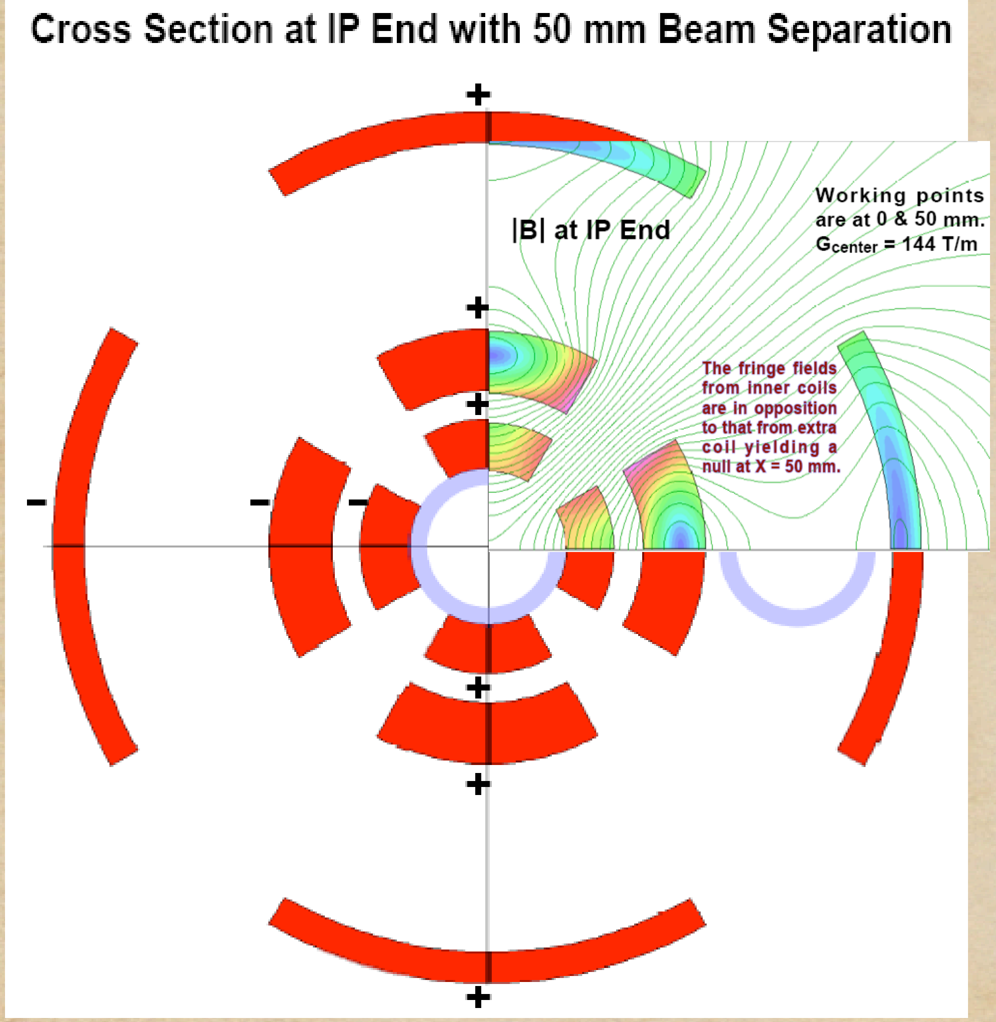
Ø = 70 mm



Ø = 110 mm



Small bore double aperture SC quad


Cross Section at IP End with 50 mm Beam Separation

|B| at IP End

Working points are at 0 & 50 mm.
$G_{\mathrm{center}} = 144$ T/m

The fringe fields from inner coils are in opposition to that from extra coil yielding a null at X = 50 mm.

Xing angle = 50 mm / L*

$G_{\mathrm{in}} = 144$ T/m, $\varnothing_{\mathrm{in}} = 20$ mm
$G_{\mathrm{out}} = 50$ T/m, $\varnothing_{\mathrm{out}} = 20$ mm

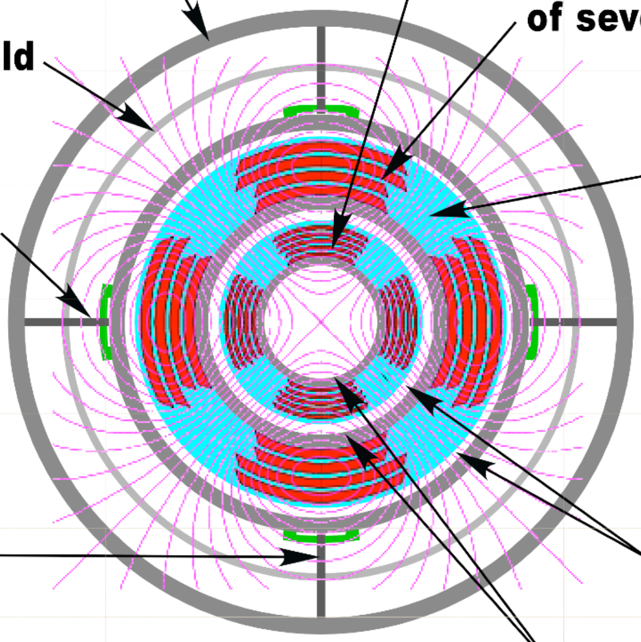
Outer coil (single strand) is tapered to follow the exit trajectory

Outer coil can accomodate a skew quad layer

Compact SC Quad.

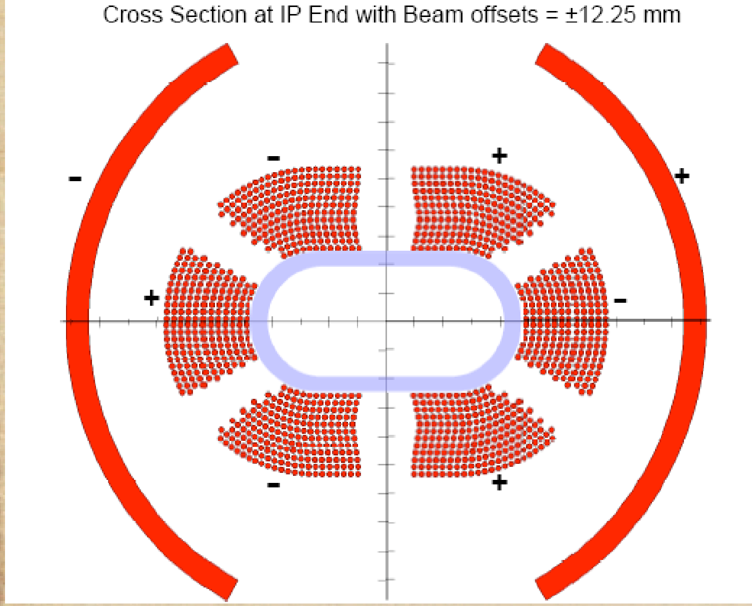
Inner Beam Tube	**20 mm ID**
Outer Cryostat Tube	**114 mm OD**

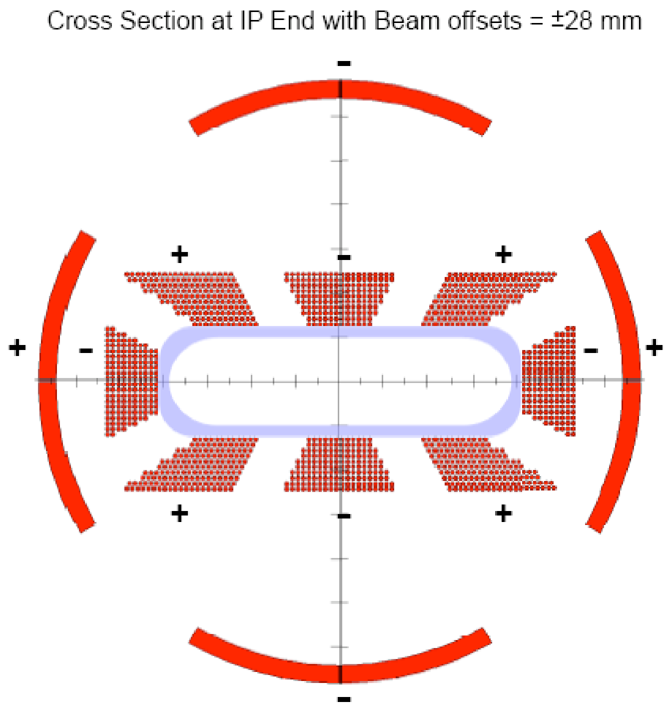
QDO Coil Parameters	
Inner Quad	**63 T/m**
Outer Quad	**81 T/m**
Total Quad	**144 T/m**



Design Concept: Two independent coil windings. Integrated helium flow. Copper inside inner coil support tube.

Small bore single aperture SC quad





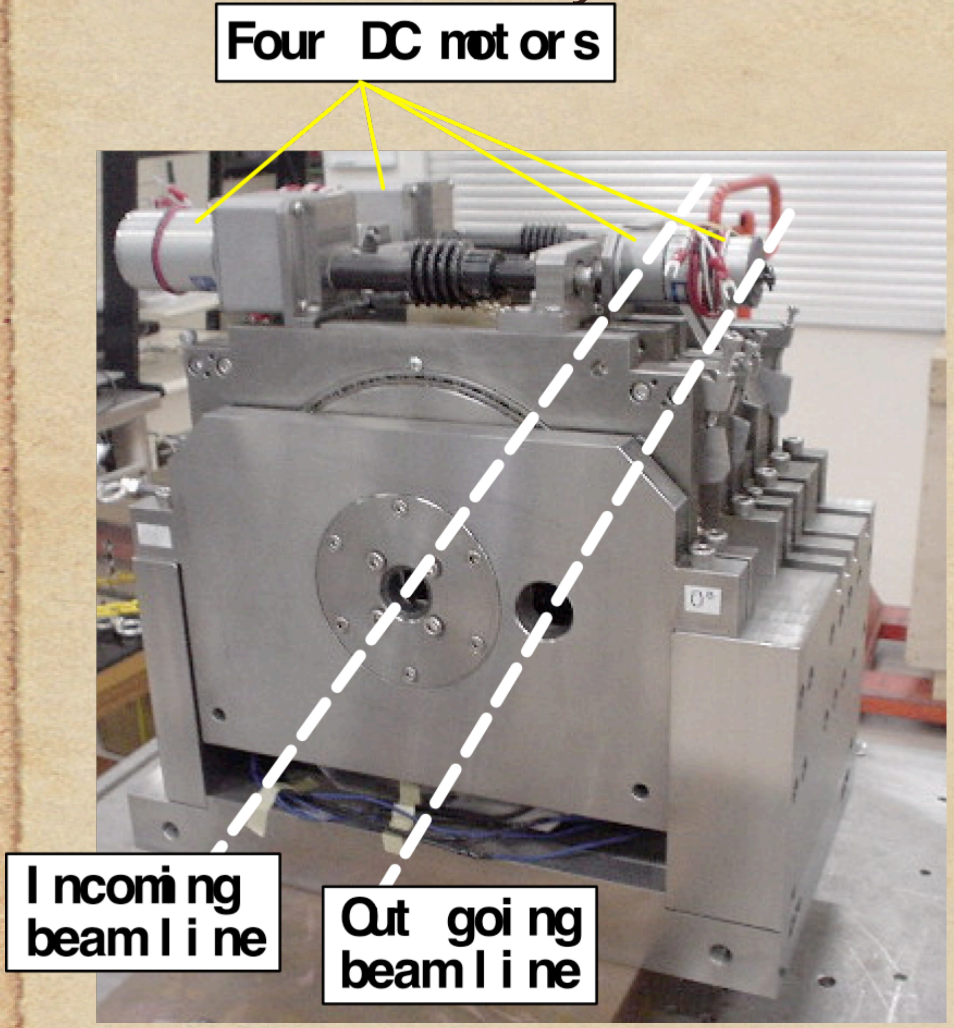
Sextupole-like : Xing = 7 mrad
G = 140 T/m

Octupole-like : Xing = 10 mrad

Common features :

- same gradient in and out
- large non-linearities

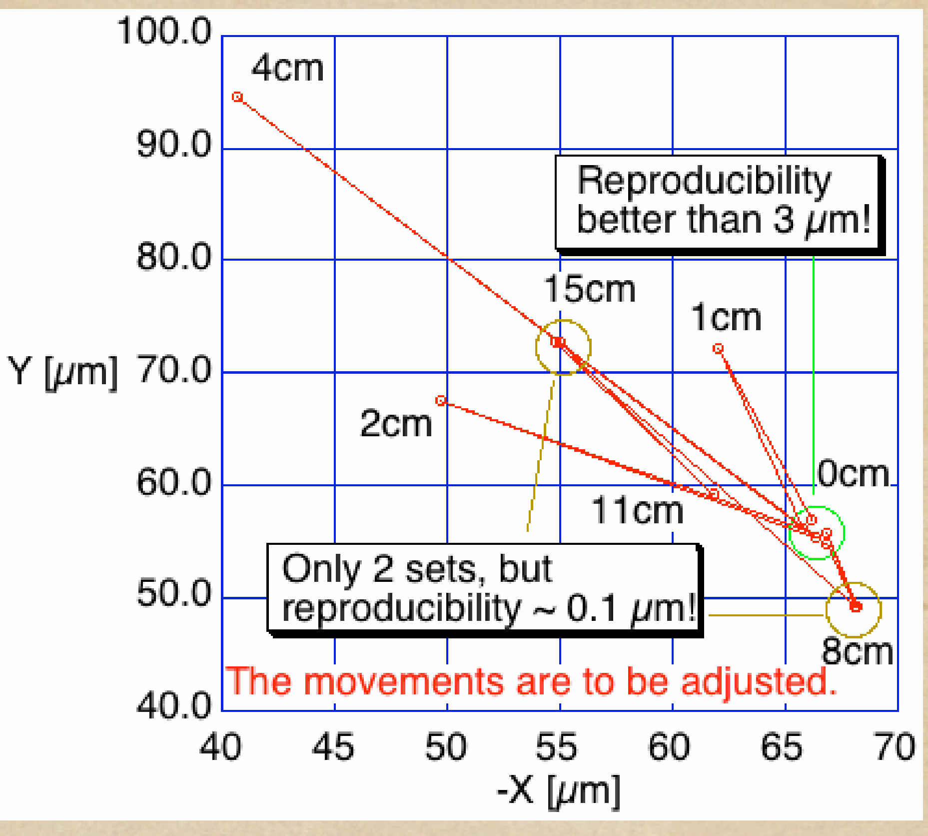
Adjustable PM Quad.



Four DC motors

Incoming beamline

Outgoing beamline



Reproducibility better than 3 μm!

Only 2 sets, but reproducibility ~ 0.1 μm!

The movements are to be adjusted.

Max. Grad.	125T/m(140T/m)
Min. Grad	23T/m(35T/m)

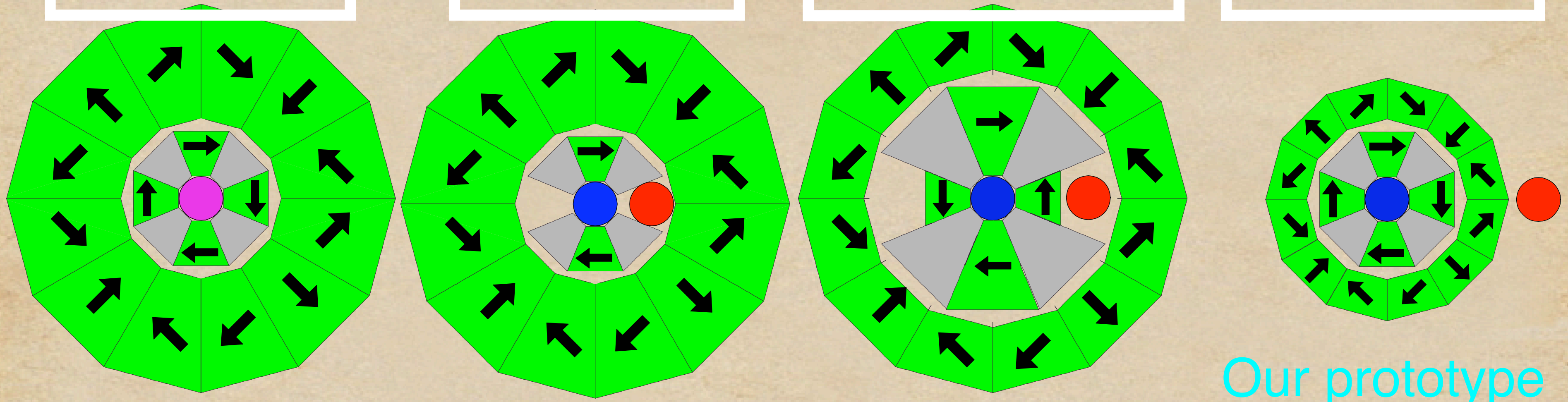
PM Quad for Various L* & X-ing Angles

NBS
(Head on)

SBS
(2mrad?)

MBS
(7,13mrad?)

LBS
(20mrad?)

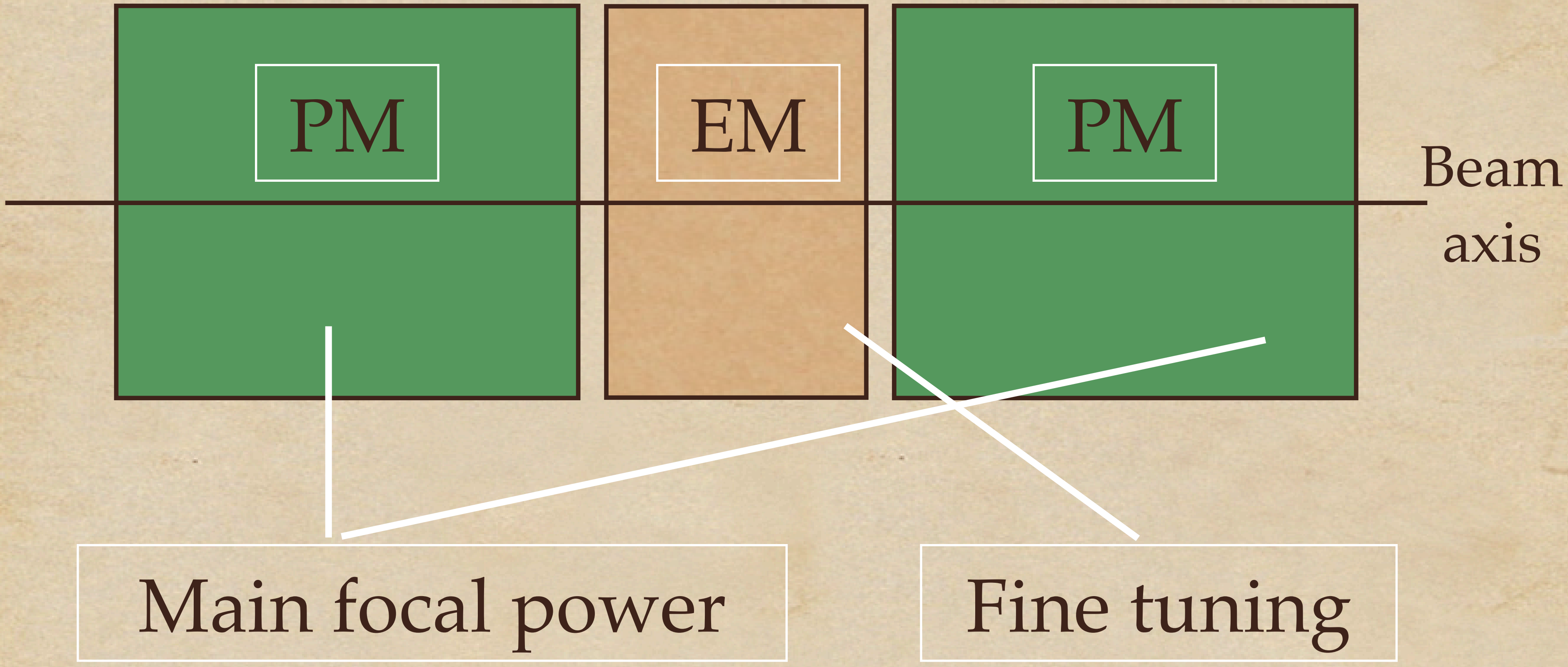


Our prototype

Q-size	ϕ160mm	ϕ160mm	ϕ160mm	ϕ100mm
ϕ20mm	212T/m(max) -23T/m (min)	175T/m (max) -77T/m (min)	208T/m(max) 26T/m (min)	186T/m(max) 31T/m(min)
ϕ14mm	296T/m	242T/m	282T/m	272T/m

NBS=No Beam Separation, SBS=Small Beam Separation
MBS=Medium Beam Separation, LBS=Large Beam Separation

Hybrid Quad. (practical option)



Main focal power

Fine tuning

→ Strong tunable quadrupole!

Technology Choice

	Head on 0.3mrad	2mrad	7mrad	>13mrad
EM	○		○	
SC	○	○		○
PM	○	○	○	○

R&D

EM
- Power dissipation.
- Cooling.

SC
- Study of axis vibration
- Nb3Sn technology
- Beam-beam losses and quad cooling

PM
- Study of radiation damage effect (PS?)
- Study of thermal effect (now preparing)
- Hybrid Q

All Qs
- Optimizing the design for each L* , Crossing angle and bore radius.
- Optics study for optical design.
- BEAM-BEAM LOSSES
- Support and stabilisation

Summary

	EM	SC	PM
Pros.	• Off the shelf for usual shape	• Large Gradient • Large bore radius	• Strong in small bore • Low power consumption
Cons.	• Large power consumption • Lengthy	• Axis Vibration •Beam-beam losses and quad cooling (Heat load?)	• Stability (radiation damage, temperature coef.)

RF Kicker for Head-on-Collision

Background:

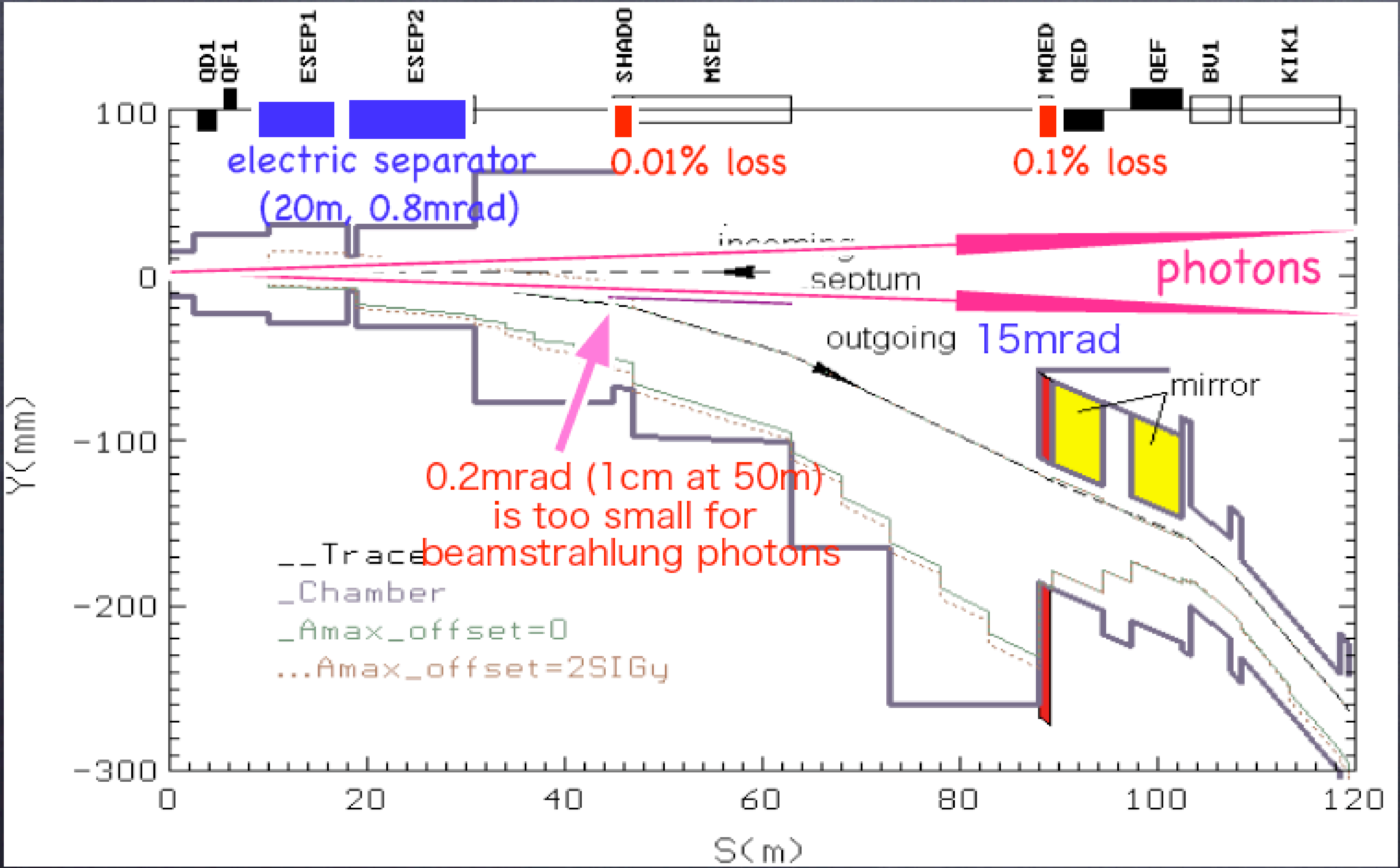
Head-on is desirable for physics,

BUT

e^+ and e^- cannot be separated by

STATIC magnet

Extraction line (head-on) at TESLA-TDR



electric separator

(20m, 0.8mrad)

0.01% loss

0.1% loss

photons

15mrad

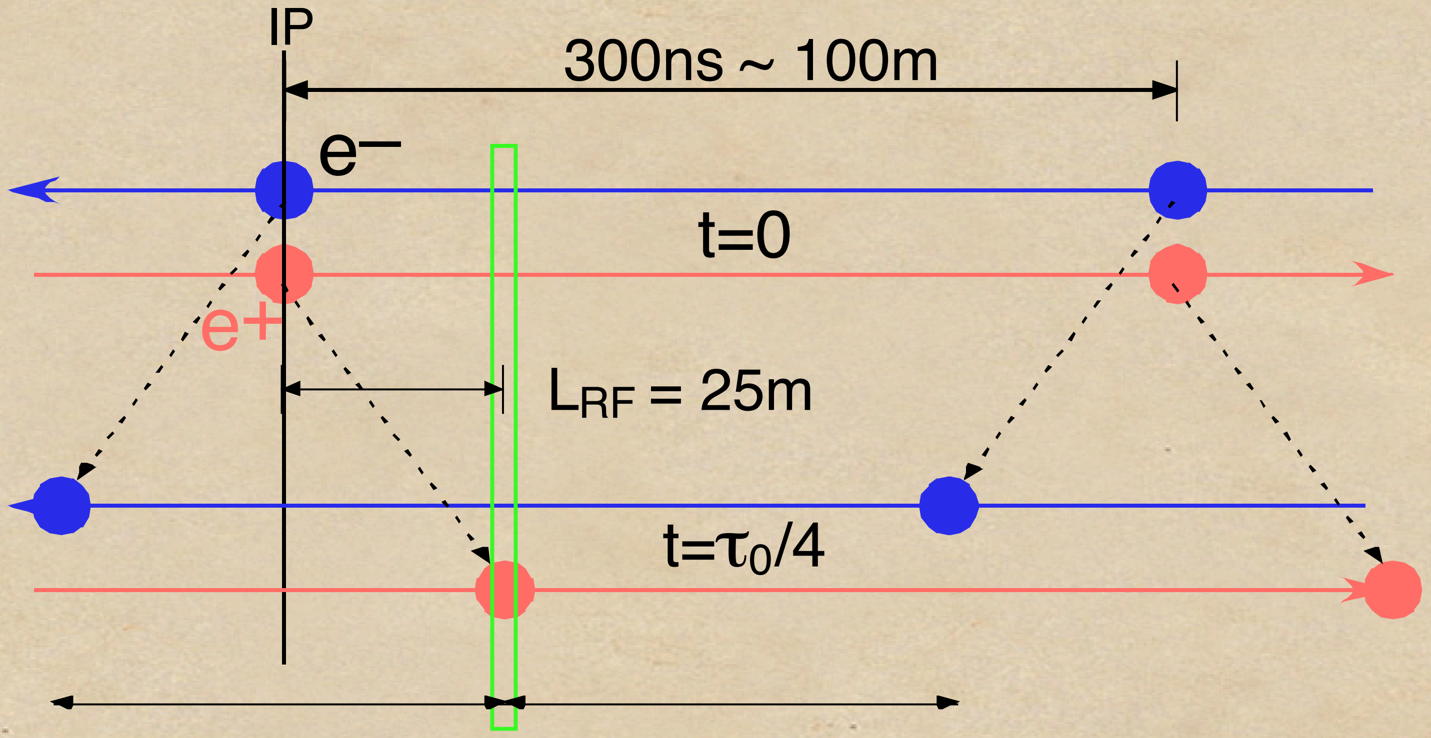
mirror

0.2mrad (1cm at 50m)

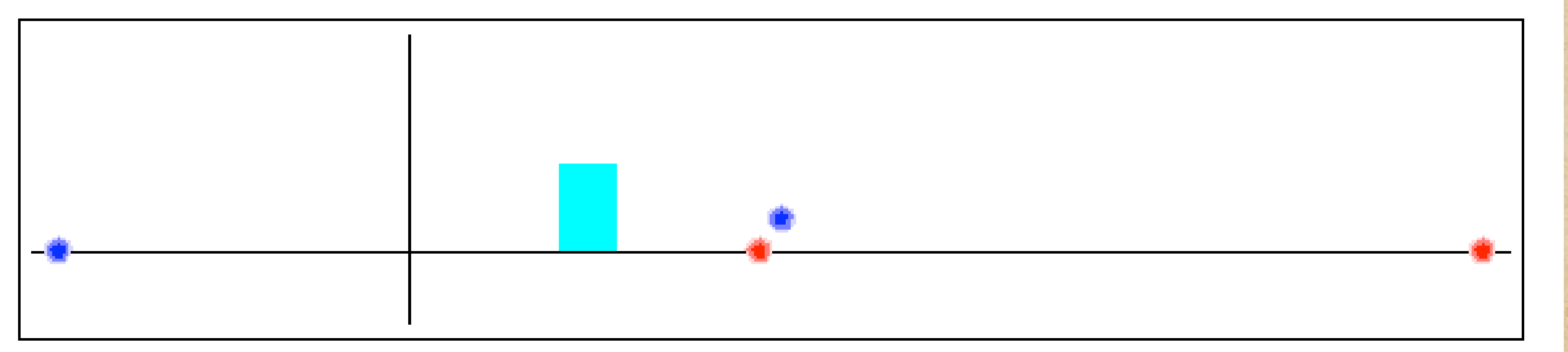
is too small for

beamstrahlung photons

Time Structure of Beams

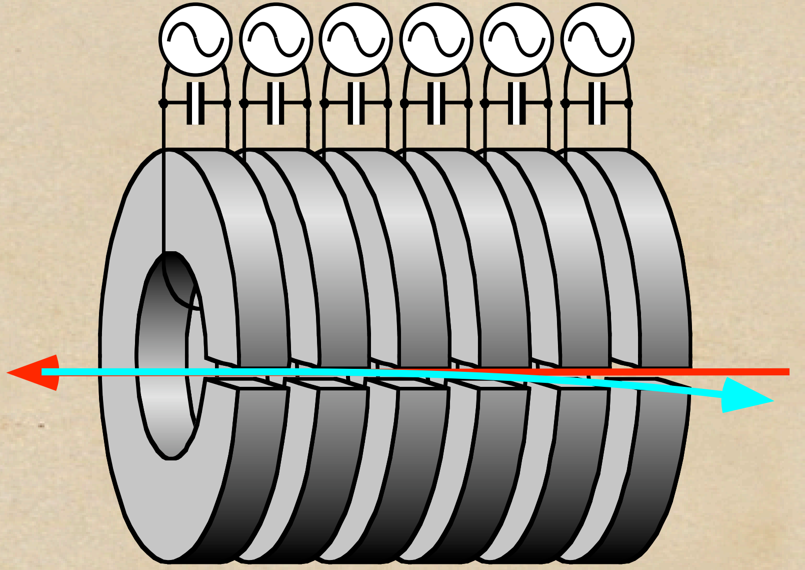


Out-bunch at the Center of In-bunch



Sketch of a Kicker

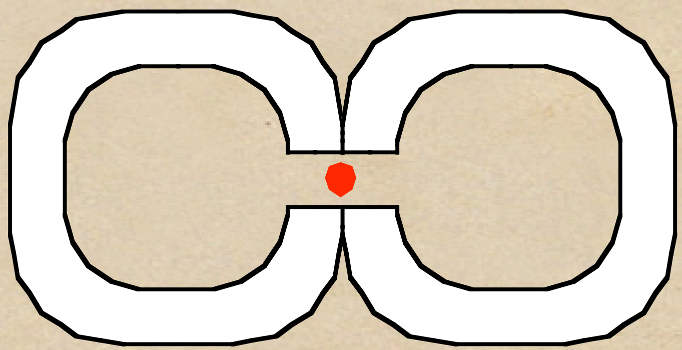
DC+3MHz (+6MHz)



0.25T x L=4m

1 mrad

Variant



Double C-type

Better shielding

Step at center?

Advantage and Disadvantage

Advantage

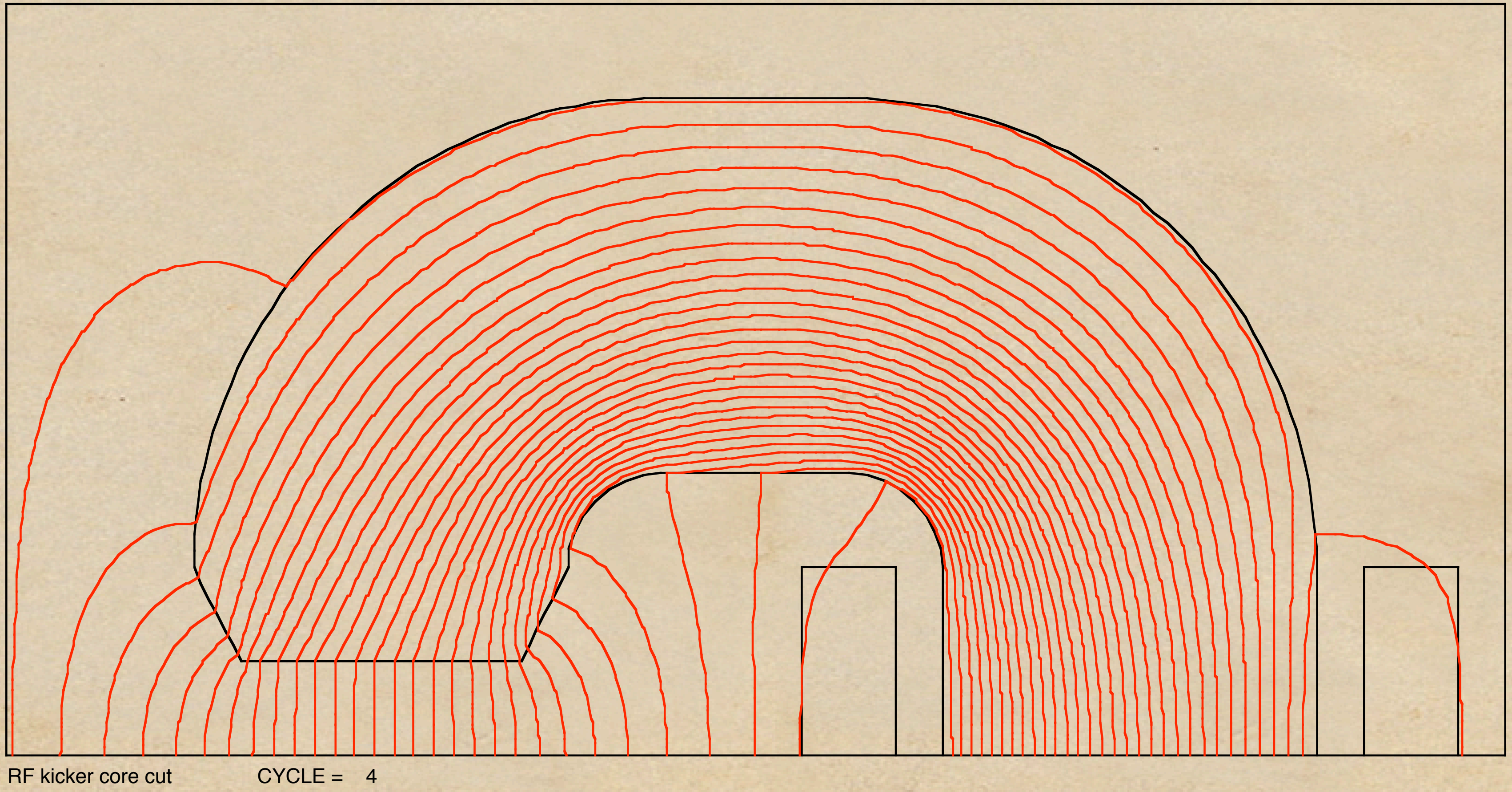
- Can attain Head-on collision.
- Easier than Crab Cavity.

Disadvantage

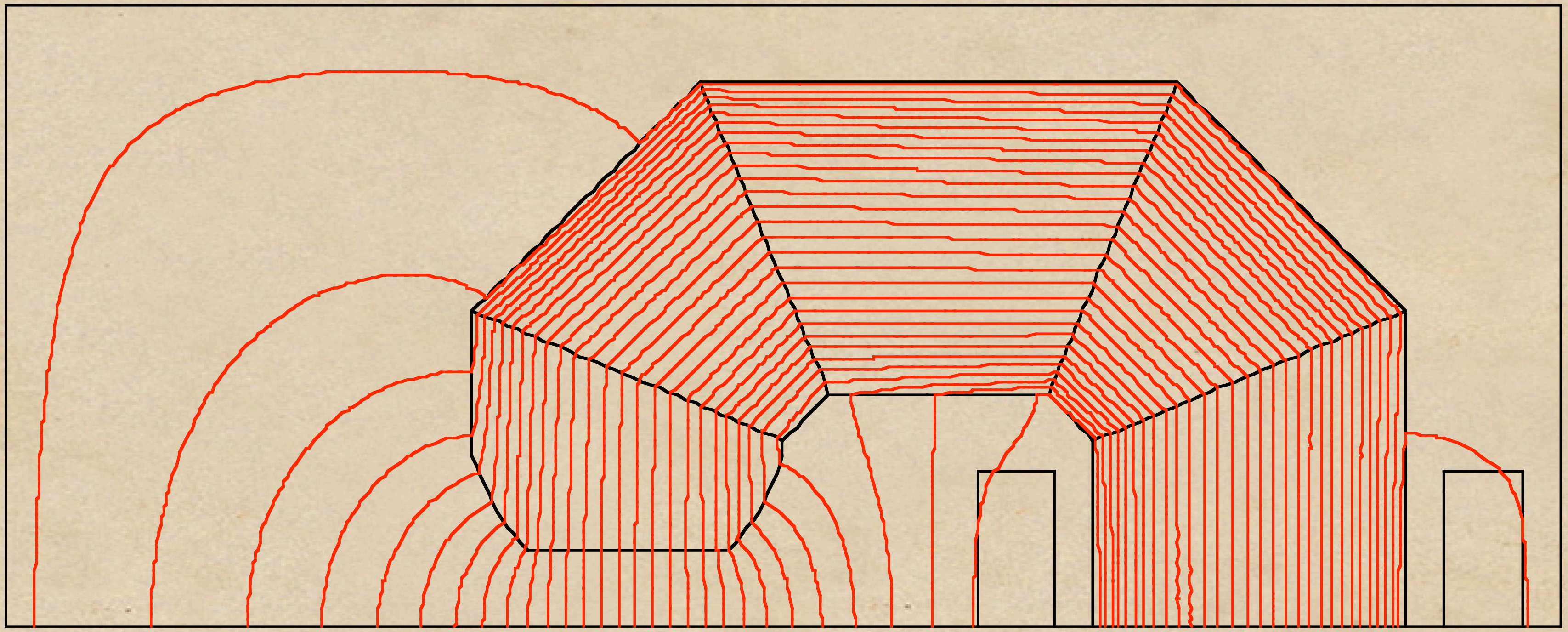
- If stopped, beam will hit the other side. (Failure of all the 133 units does not likely happen.)
- It may kick the incoming beam.

RF kicker

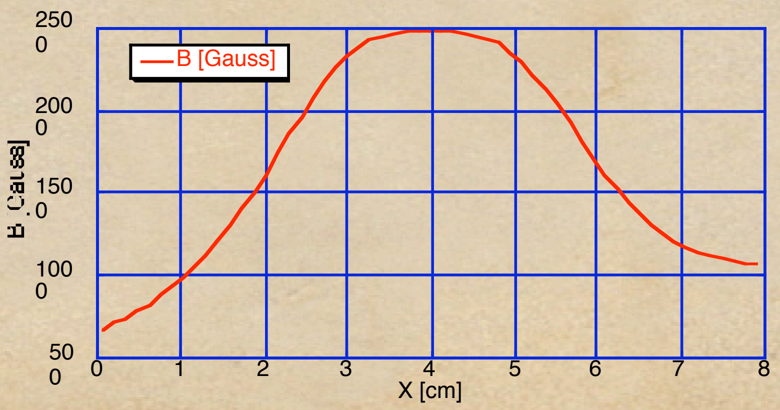
Flux plot (isotropic material)



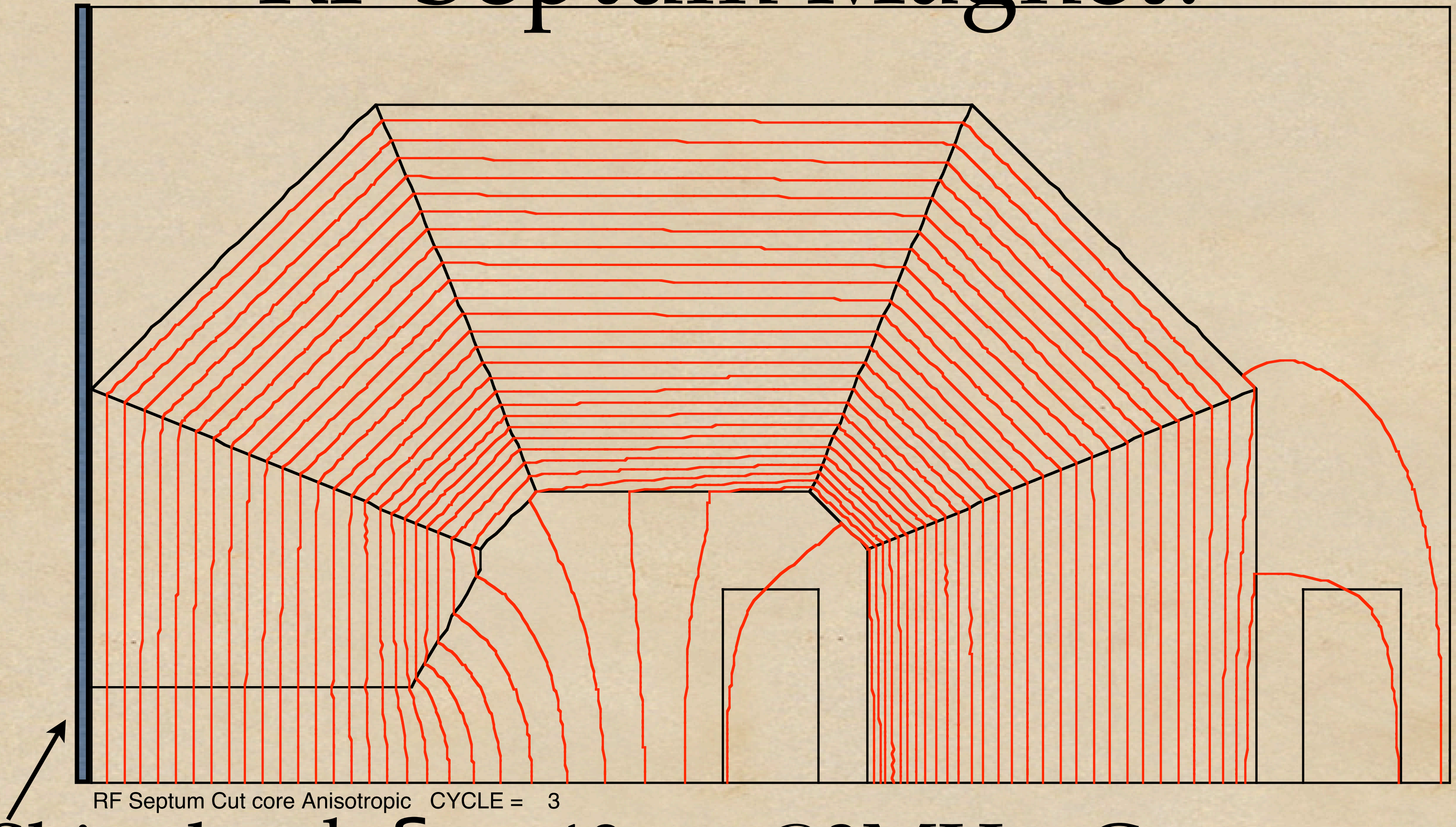
Anisotropic core (cutcore)



RF kicker Cut core Anisotropic   CYCLE =   3



RF Septum Magnet?

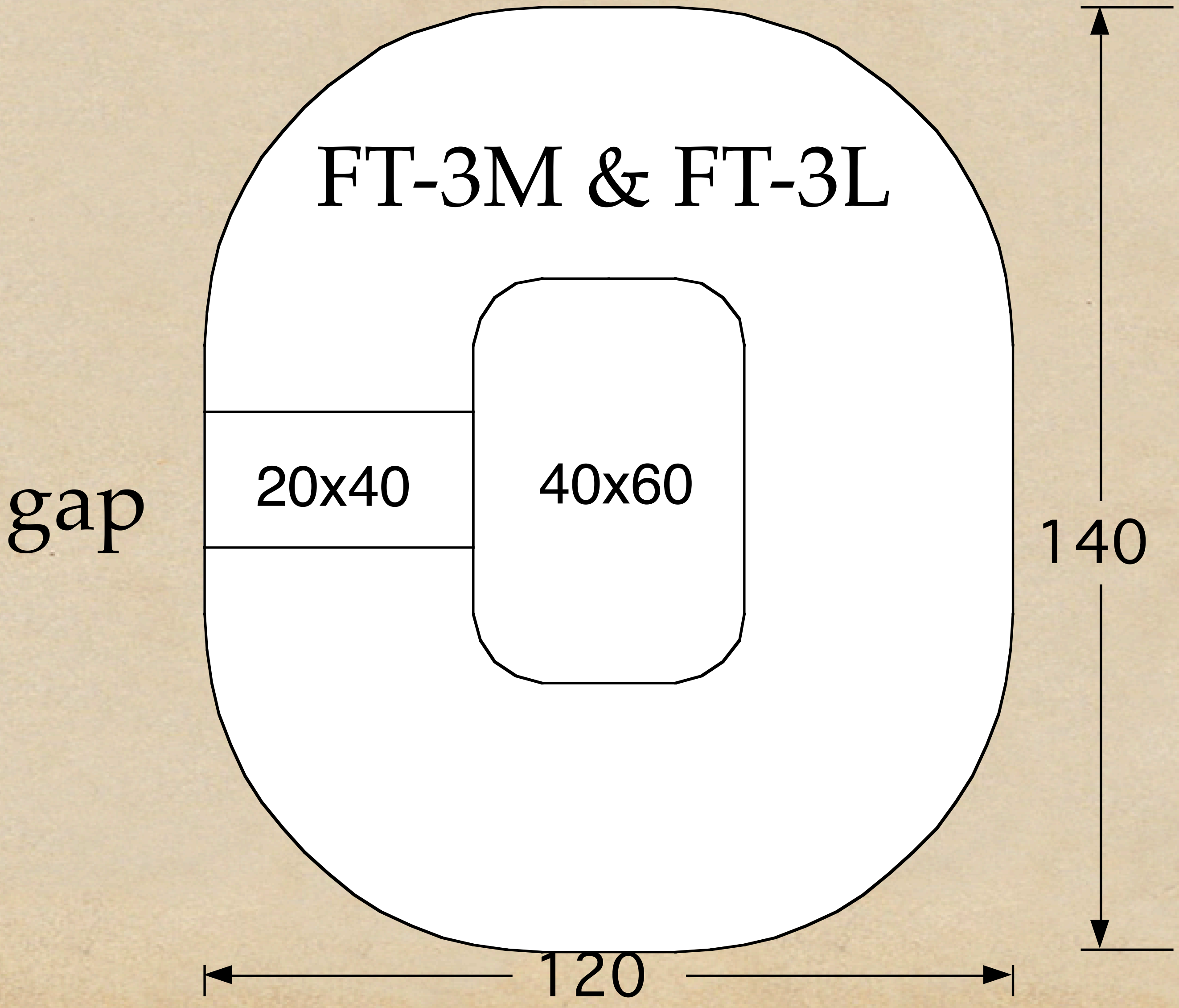


Skin depth δ : ~40μm @3MHz, Cu

σ_{Cu}=58 MS/m, R~2mΩ, H=0.25/μ_0=0.2MA/m

P=80MW/m^2 , 4m x 2cm=8x10^{-2} m^2 –> 6.4MWpk

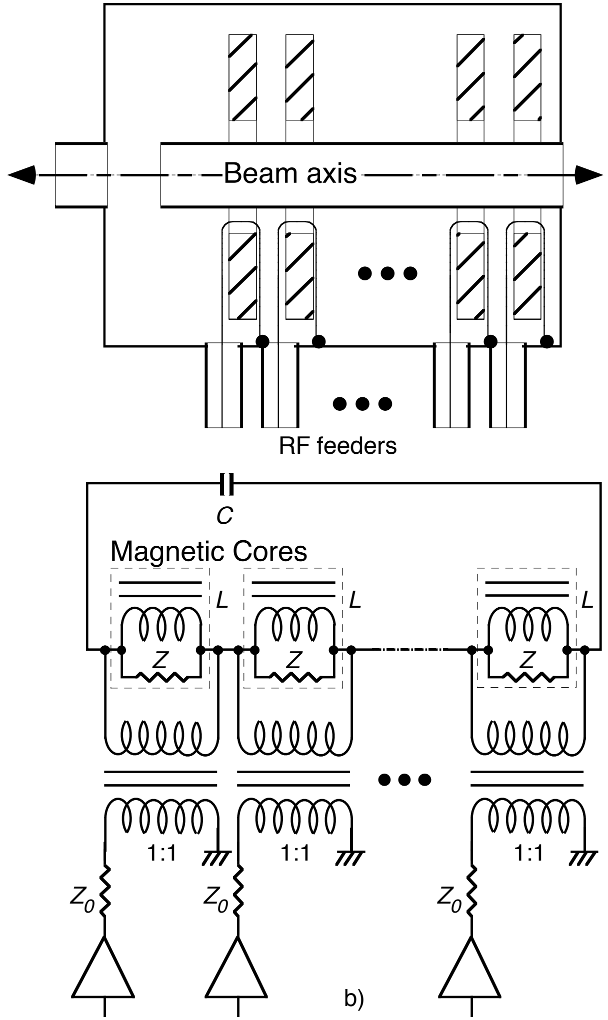
Two sample cores are ordered



Fabricated FINEMET core
（Ready 3/1）

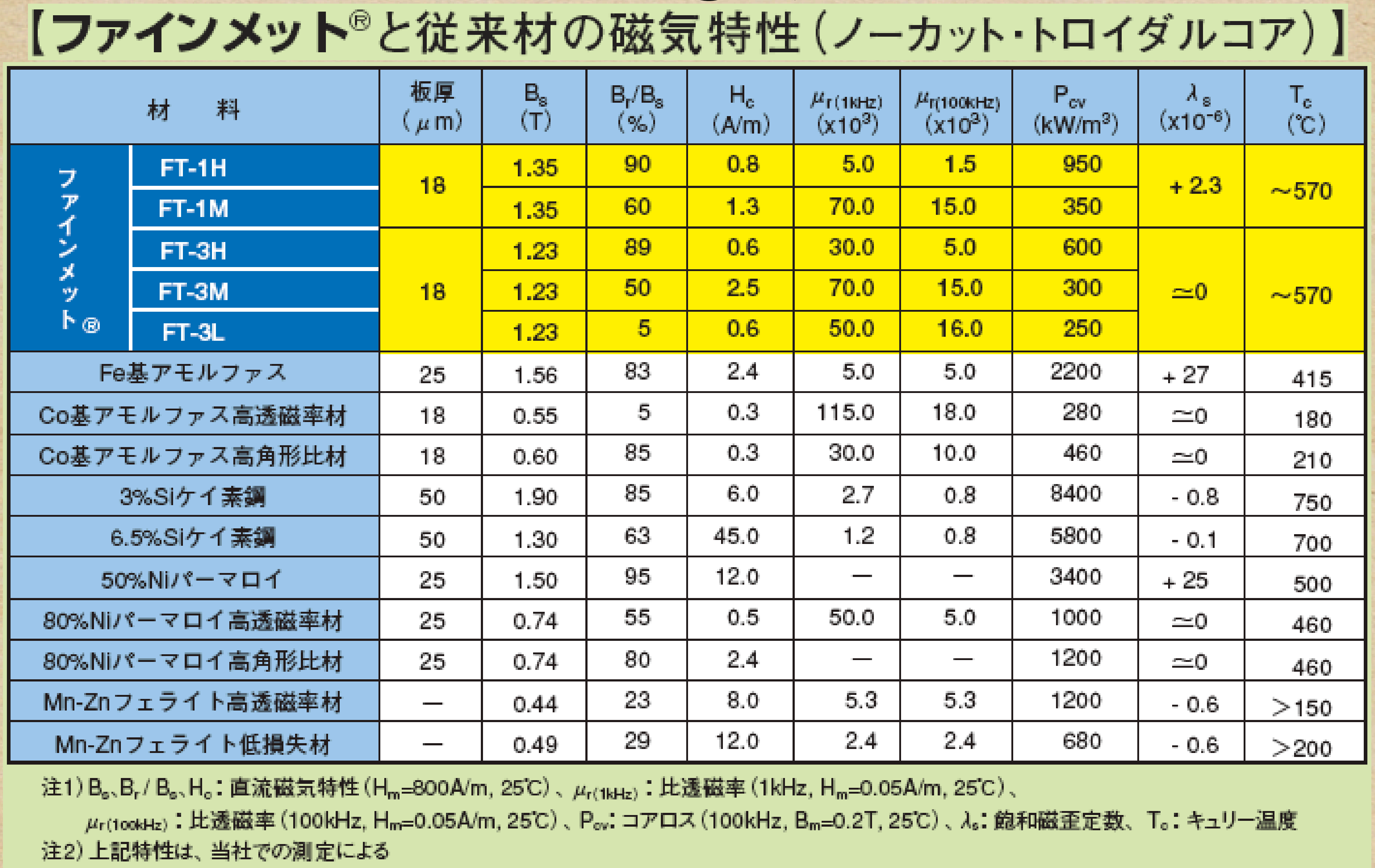
Untuned cavity at Kyoto U.

Led to the excavation of FINEMET



Multi-Feed Technique

FT-3L



【ファインメット®と従来材の磁気特性（ノーカット·トロイダルコア）】

材料		板厚 (μm)	B_s (T)	B_r/B_s (%)	H_c (A/m)	$\mu_{r(1kHz)}$ ($x10^3$)	$\mu_{r(100kHz)}$ ($x10^3$)	P_{cv} (kW/m³)	λ_s ($x10^{-6}$)	T_c (℃)
ファインメット®	FT-1H	18	1.35	90	0.8	5.0	1.5	950	+ 2.3	~570
	FT-1M		1.35	60	1.3	70.0	15.0	350		
	FT-3H	18	1.23	89	0.6	30.0	5.0	600	≃0	~570
	FT-3M		1.23	50	2.5	70.0	15.0	300		
	FT-3L		1.23	5	0.6	50.0	16.0	250		
Fe基アモルファス		25	1.56	83	2.4	5.0	5.0	2200	+ 27	415
Co基アモルファス高透磁率材		18	0.55	5	0.3	115.0	18.0	280	≃0	180
Co基アモルファス高角形比材		18	0.60	85	0.3	30.0	10.0	460	≃0	210
3%Siケイ素鋼		50	1.90	85	6.0	2.7	0.8	8400	- 0.8	750
6.5%Siケイ素鋼		50	1.30	63	45.0	1.2	0.8	5800	- 0.1	700
50%Niパーマロイ		25	1.50	95	12.0	—	—	3400	+ 25	500
80%Niパーマロイ高透磁率材		25	0.74	55	0.5	50.0	5.0	1000	≃0	460
80%Niパーマロイ高角形比材		25	0.74	80	2.4	—	—	1200	≃0	460
Mn-Znフェライト高透磁率材		—	0.44	23	8.0	5.3	5.3	1200	- 0.6	>150
Mn-Znフェライト低損失材		—	0.49	29	12.0	2.4	2.4	680	- 0.6	>200

注1）B_s、B_r / B_s、H_c：直流磁気特性（H_m=800A/m, 25℃）、$\mu_{r(1kHz)}$：比透磁率（1kHz, H_m=0.05A/m, 25℃）、
$\mu_{r(100kHz)}$：比透磁率（100kHz, H_m=0.05A/m, 25℃）、P_{cv}：コアロス（100kHz, B_m=0.2T, 25℃）、λ_s：飽和磁歪定数、T_c：キュリー温度
注2）上記特性は、当社での測定による

High B, low core loss, high Tc

Power Estimation

Stored Energy for a core : $W=0.75$ [J]

Coil current for 0.25T : $I = 4$ [kA]

Inductance ($L I^2/2=W$) : $L= 94$ [nH]

Capacitance ($L C=\omega^{-2}$) :$C= 30$ [nF]

Voltage ($C V_c^2/2=W$) : $V_c= 7$ [kV]

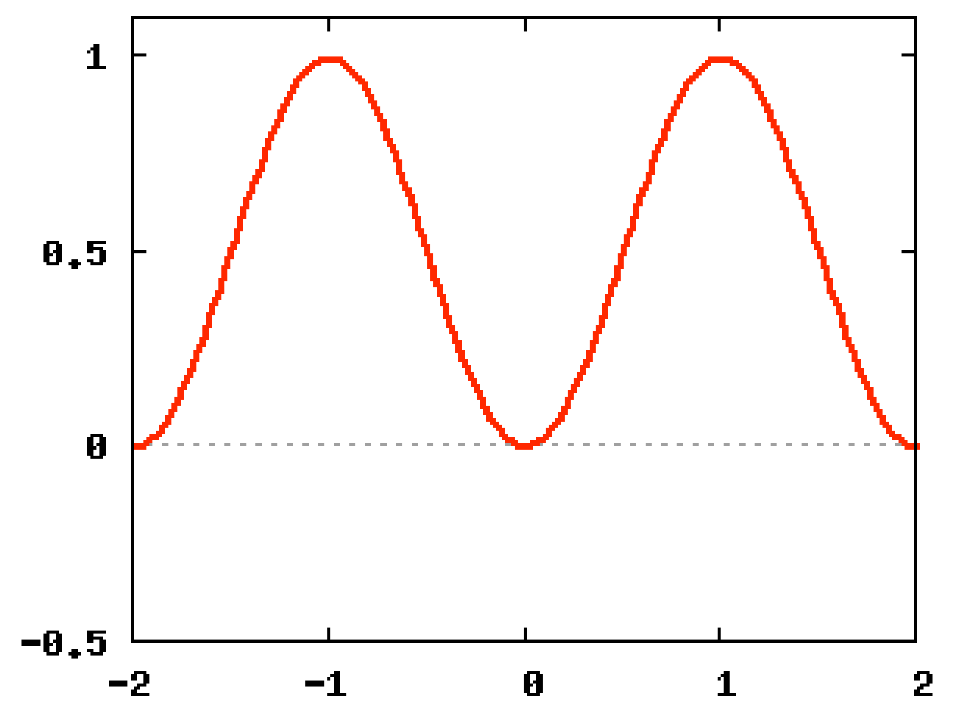
Core Volume :$C_v=300$ [cc]

Core Loss Pcv (3MHz, 0.2T) : $P_{cv}=10^8 W/m^3$

Core Loss P (3MHz, 0.25T) : $P = 45 kW/core$

Waveform 1: simple cosine

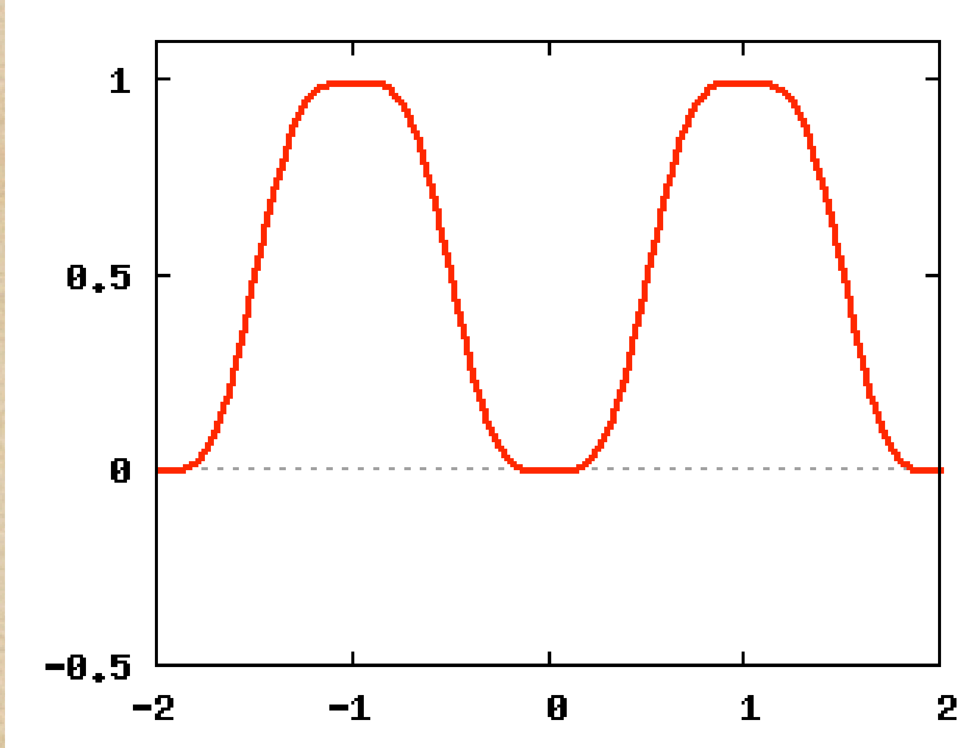
$$f(t) = 1 - \cos(\omega t)$$



- Phasing division≧4
- 1 Section=1.0m
- Both end x = 0.50m
- θ = 2.47×10-7

Waveform 2: two cosines

$$f(t) = \frac{8}{9} - \cos(\omega t) + \frac{1}{9}\cos(3\omega t)$$



Phasing division≧1

$x = 2.0\mathrm{m}$

$\theta_x = 4.65\times10^{-8}$

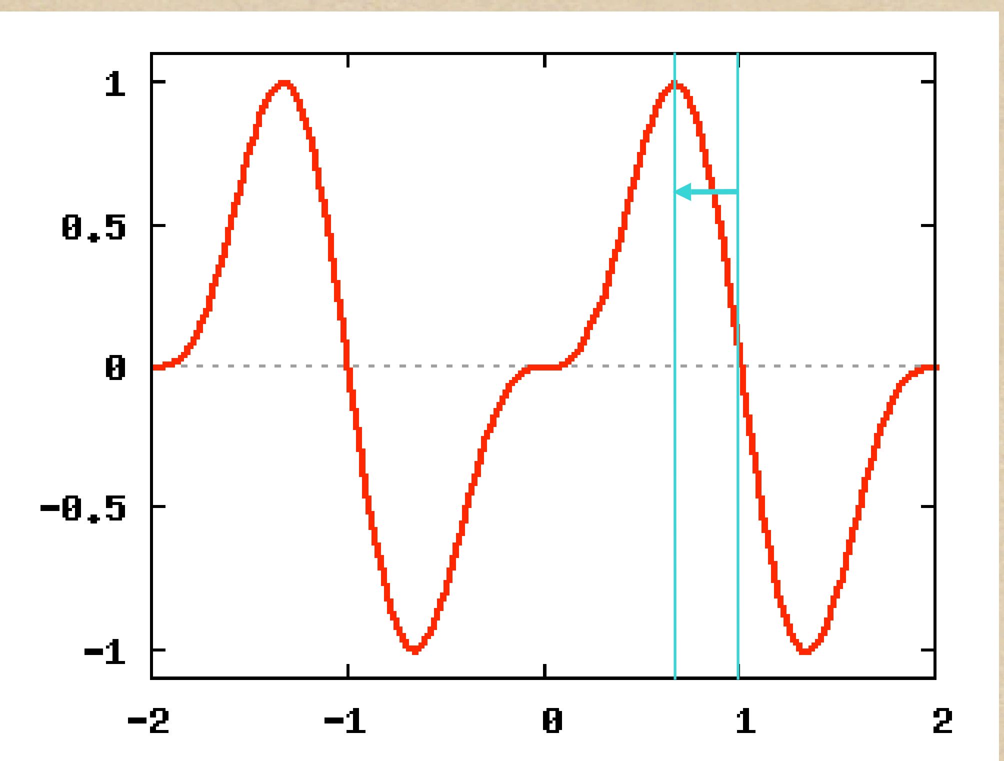
$< 3.0\times10^{-7}$

Very flat base.

But difficult?

Waveform 3: sines

$$f(t) = -\sin(\omega t) + \frac{1}{2}\sin(2\omega t)$$



Phasing division≧2

$x = 1.0\text{m}$

$\theta_x = 9.54\times10^{-8}$

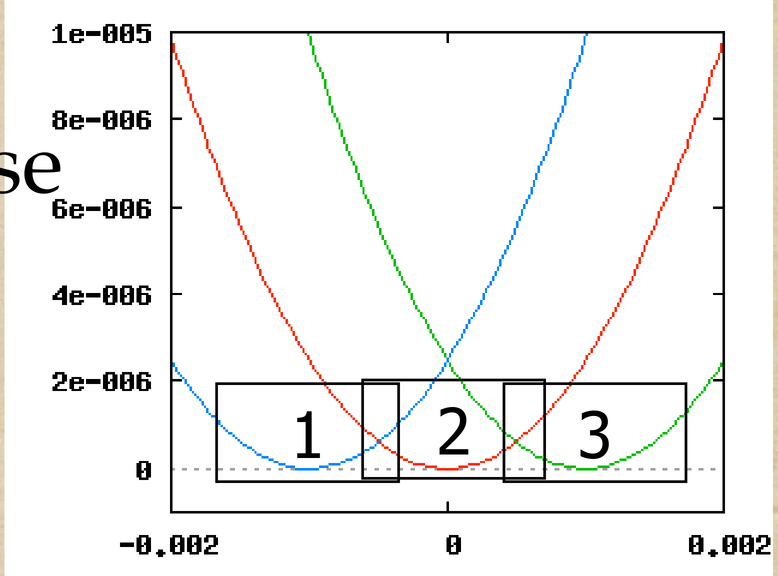
$< 3.0\times10^{-7}$

No DC System.

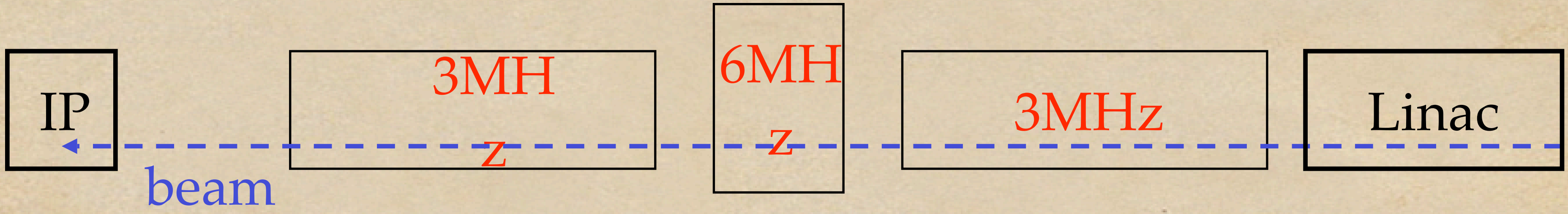
Not at the center

Compensation by Phasing

- Phasing = different phase at each section.
- Apply each bottom to incoming beam
- No need for 133 division
  → divide into some group



Advantage of sine option

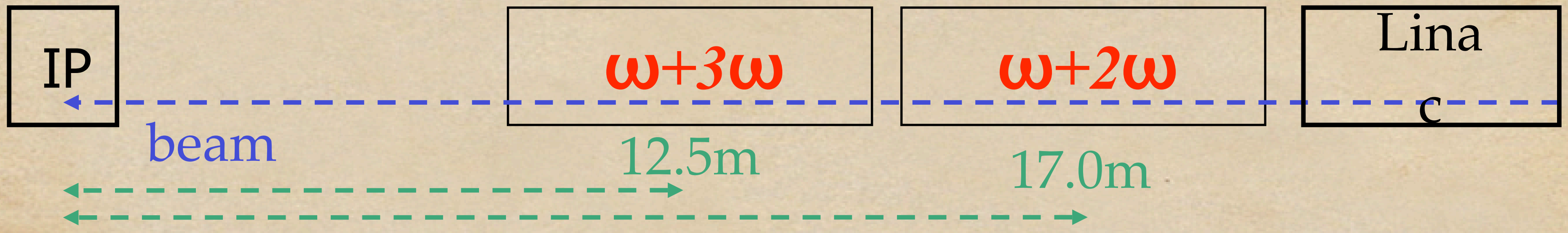


- Can apply the harmonics separately.
- Waveform **ω+2ω** needs 2 groups

  → Separate RF's are useful for

  Easier construction & Phasing

Expansion: 500GeV→1TeV



IP

ω+3ω

ω+2ω

Linac

beam

12.5m

17.0m

- Kicker's location depends on the harmonics.
  → multiple kickers can distribute.
- Operate 1 kicker for 500GeV
- Operate 2 kickers for 1TeV

RF Stability

- Amplitude jitter ～10^{-2} has little effect
- Phase fluctuation is dominant.

for 2 grouped separate RF system,

phase	1×10^{-3}	4×10^{-3}	1×10^{-2}	3×10^{-2}	[rad]
ω+2ω	1.00	1.15	1.50	3.16	$\times10^{-7}$[rad]
ω+3ω	2.59	2.99	3.89	8.20	$\times10^{-7}$[rad

Phase stability within 10^{-3} rad is desirable.

Issues on RF kicker

- More investigation on material for kicker core (FINEMET)
- Investigate for vertical kick by fringing field
- Beam chamber has to be made of insulator. <Shield by thin metal(copper)?>
- Estimated RF power: 45kWpk/core, (0.25Tx4m, 1mrad) x (133 cores, 133 Amp's)
- Dark current issue
- Abort kicker (MPS)
- Septum Magnet ?
- BPM? (directional BPM?)