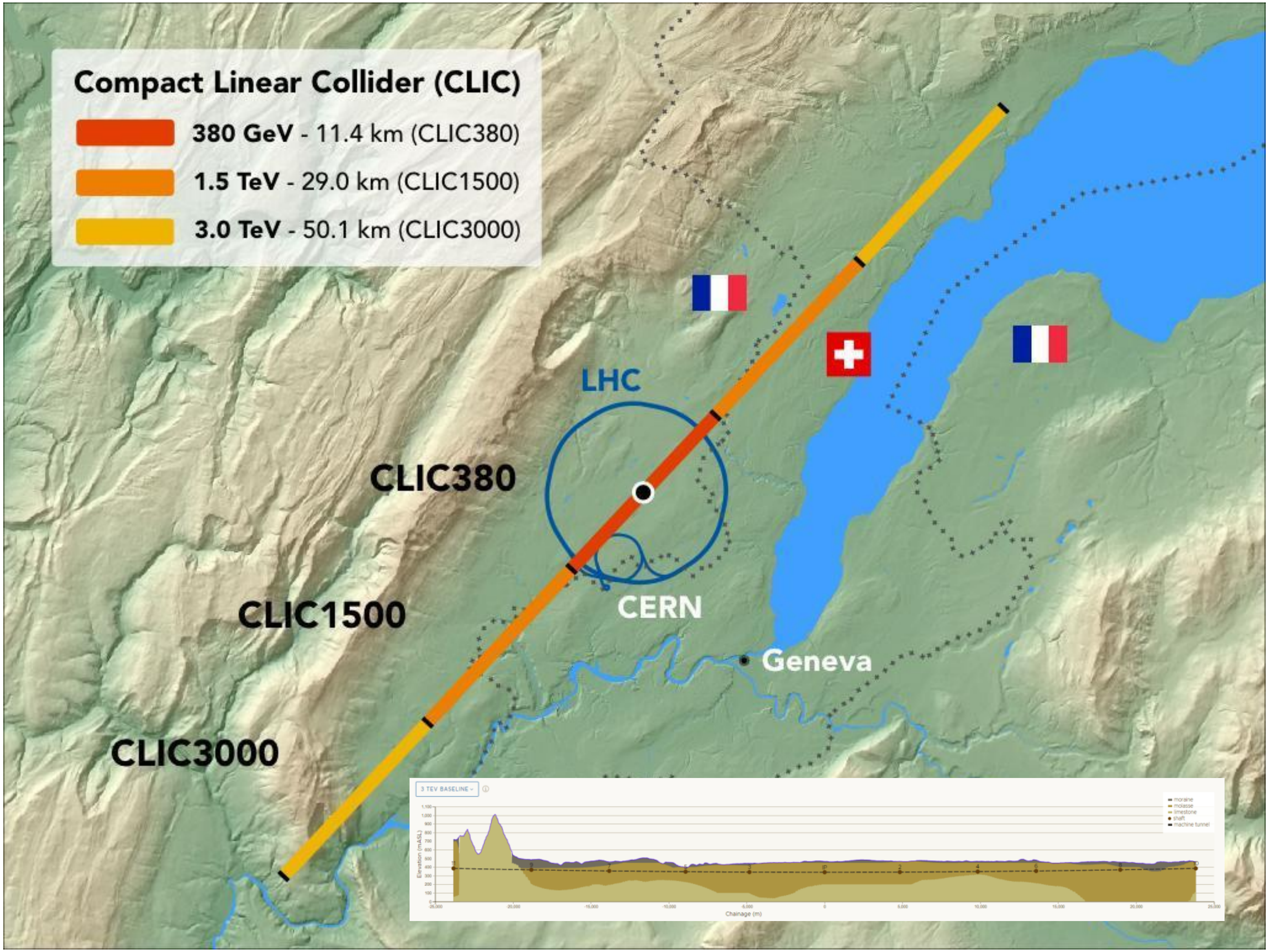
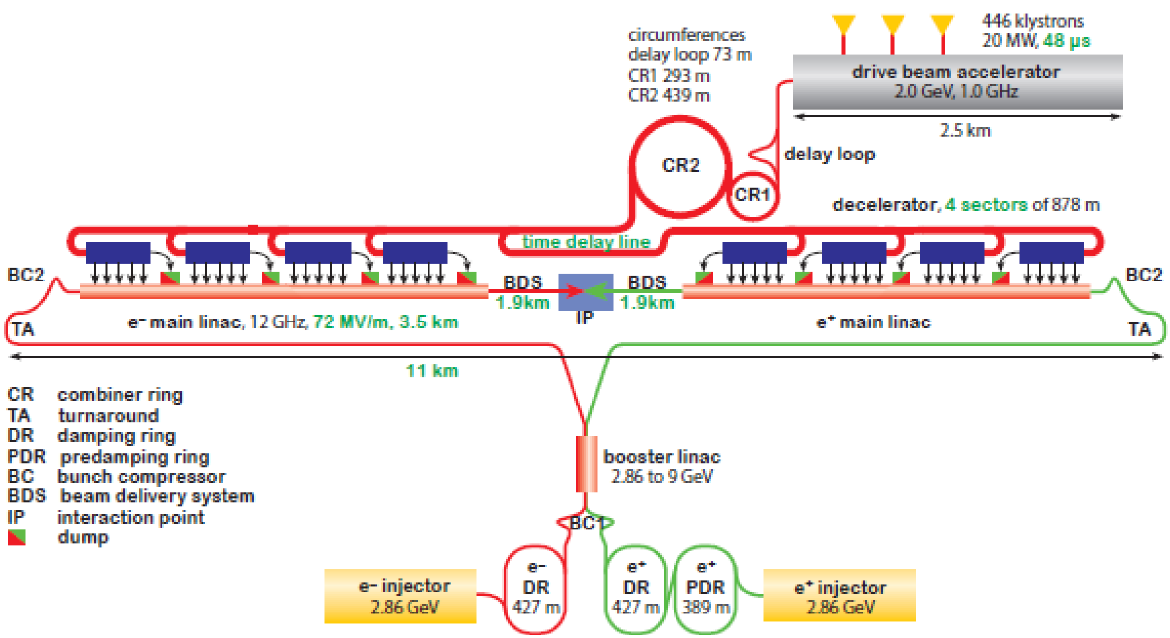
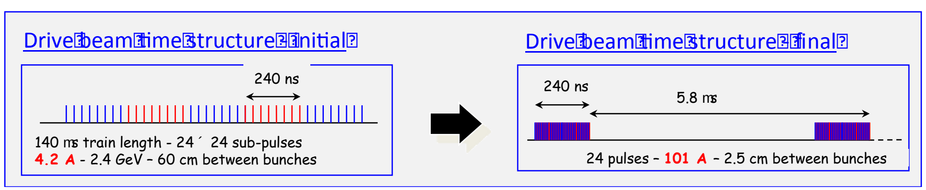


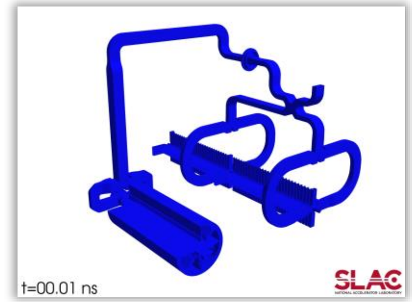
Compact Linear Collider (CLIC)
380 GeV - 11.4 km (CLIC380)
1.5 TeV - 29.0 km (CLIC1500)
3.0 TeV - 50.1 km (CLIC3000)
LHC
CLIC380
CLIC1500
CLIC3000
CERN
Geneva

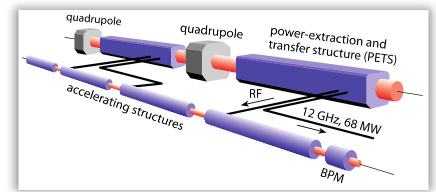
CLIC layout, power generation

Drive-beam (low energy, high intensity, long pulses) created by klystrons



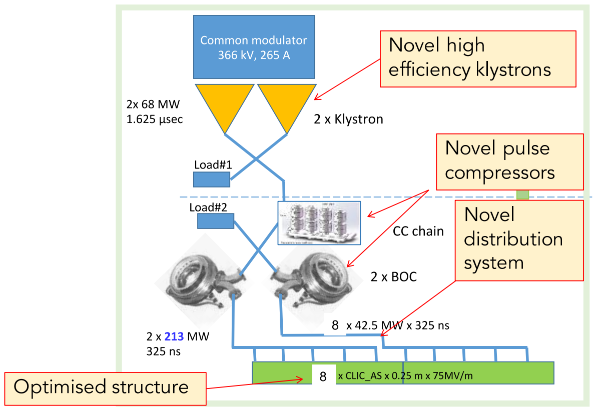






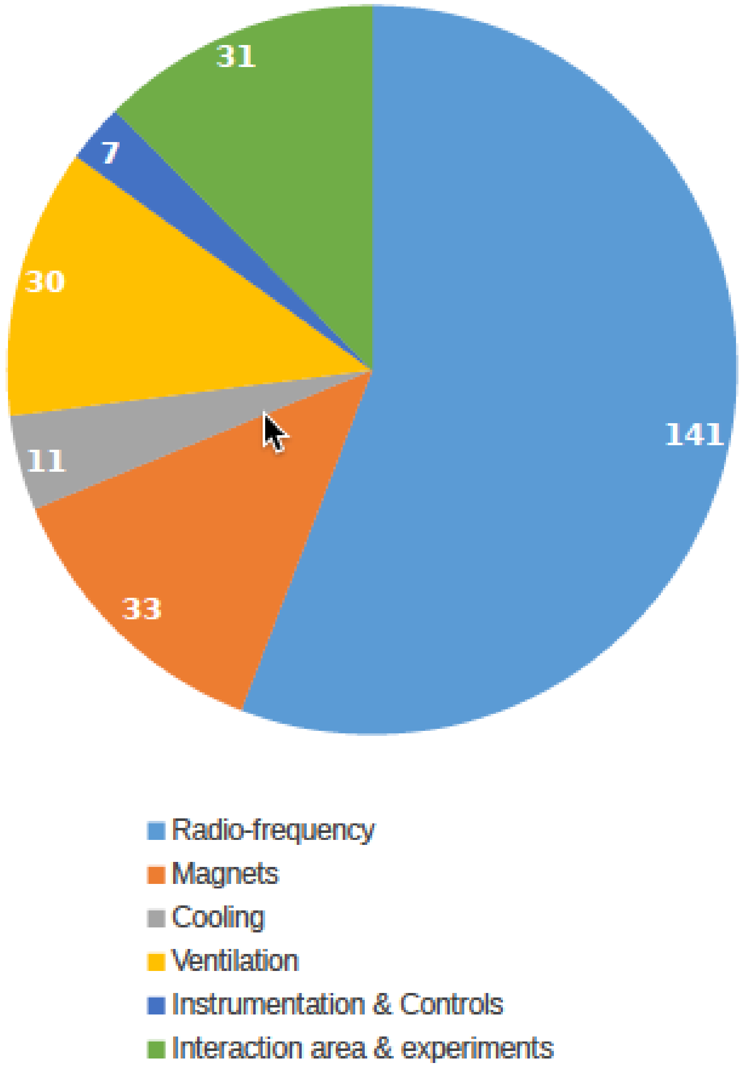
First stage energy ~ 380 GeV

Parameter'	Unit'	380'GeV'	3'TeV'
Centre&of&mass,energy,	TeV,	0.38,	3,
Total,luminosity,	10^{34}cm&2s&1,	1.5,	5.9,
Luminosity,above,99%,of,√s,	10^{34}cm&2s&1,	0.9,	2.0,
RepeEEon,frequency,	Hz,	50,	50,
Number,of,bunches,per,train,		352,	312,
Bunch,separaEon,	ns,	0.5,	0.5,
AcceleraEon,gradient,	MV/m,	72,	100,
Site,length,	km,	11,	50,



Note: We also study a klystron driven 380 GeV version – replacing the drive-beam complex on the surface with modulators, klystrons in the tunnel

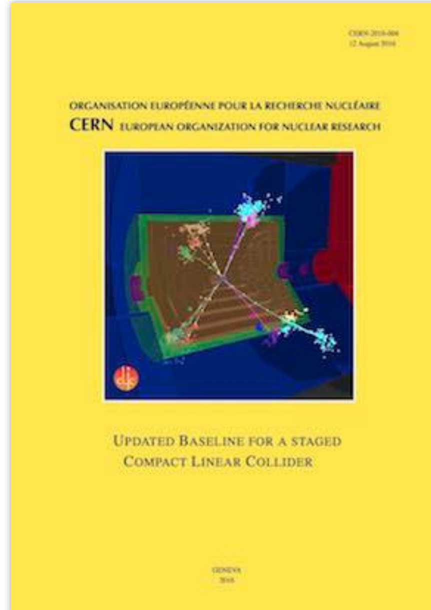
Power and energy



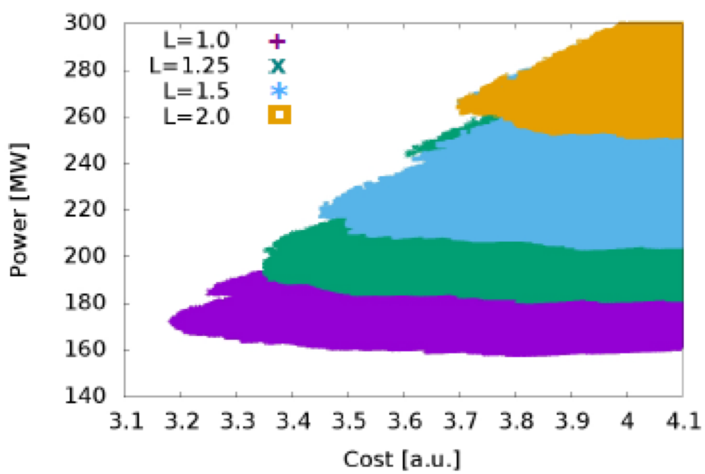
CLIC cost and power optimisation

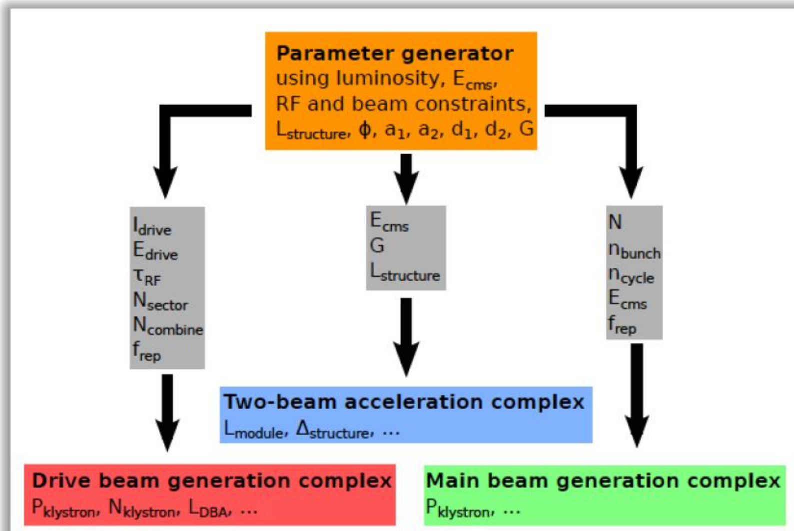
- CDR 2012: Cost and power estimated (bottom up, WBS based, reviewed – led by Lyn Evans, including ILC cost experts)
- 2013: Useful document comparing ILC and CLIC cost and performance (among others) (link) – still valid in most respects

- 2016: Cost and power update for 380 GeV drivebeam based machine made
- Still a very limited exercise:
  - Optimize accelerator structures, beam-parameters and RF system -> defines machine layout for 380 GeV
  - Remove pre-damping ring for electrons, scale DB better, some other minor changes
  - Largely scaling from 500 GeV

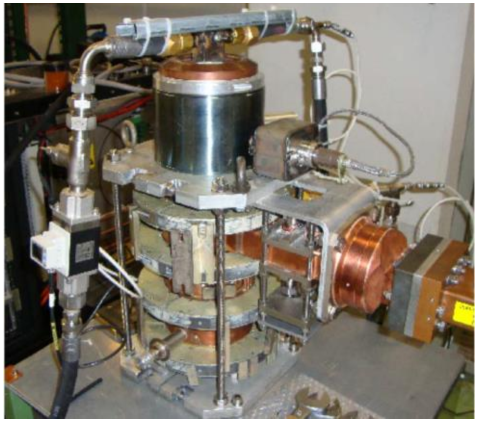


Yellow report: New reference plots for power, costs, luminosities, physics, etc





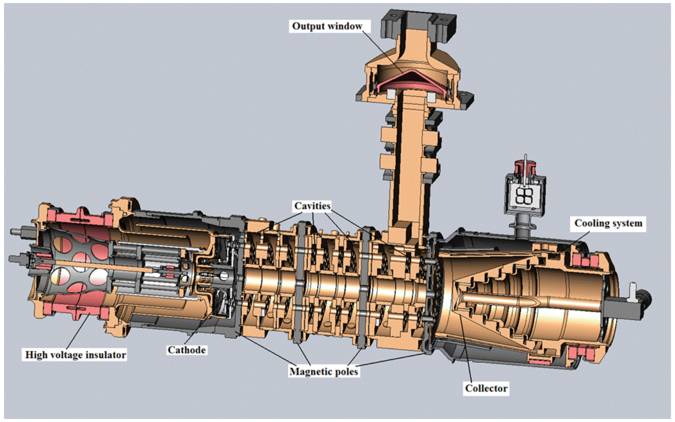
New ideas on klystron efficiency



Commercial Prototype of High Efficiency S-band Pulsed BAC MBK

Igor Guzilov[1], Roman Egorov[1], Gerard Mcmonagle[2], Igor Syratchev[2], Ben Woolley[2]
[1]JSC "Vacuum device's basic technologies", Moscow, 117342, Vvedenskogo str.,3,k.1
RUSSIAN FEDERATION,
[2]CERN, CH-1211, Geneva 23, Switzerland

"To minimise the development risks and fabrication cost of the first BAC MBK prototype, we have decided to facilitate a retrofit design of an existing klystron; MBK KIU-147. It has been in production in Russia (FSUE "Toriy") for almost 15 years and operates at 60 kV, 290 A with **42% RF power production efficiency**."



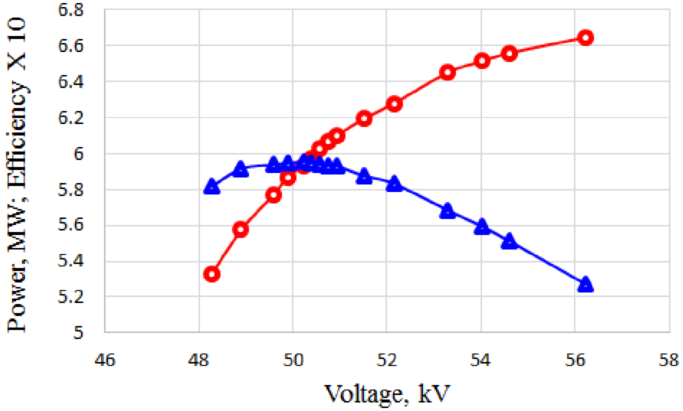
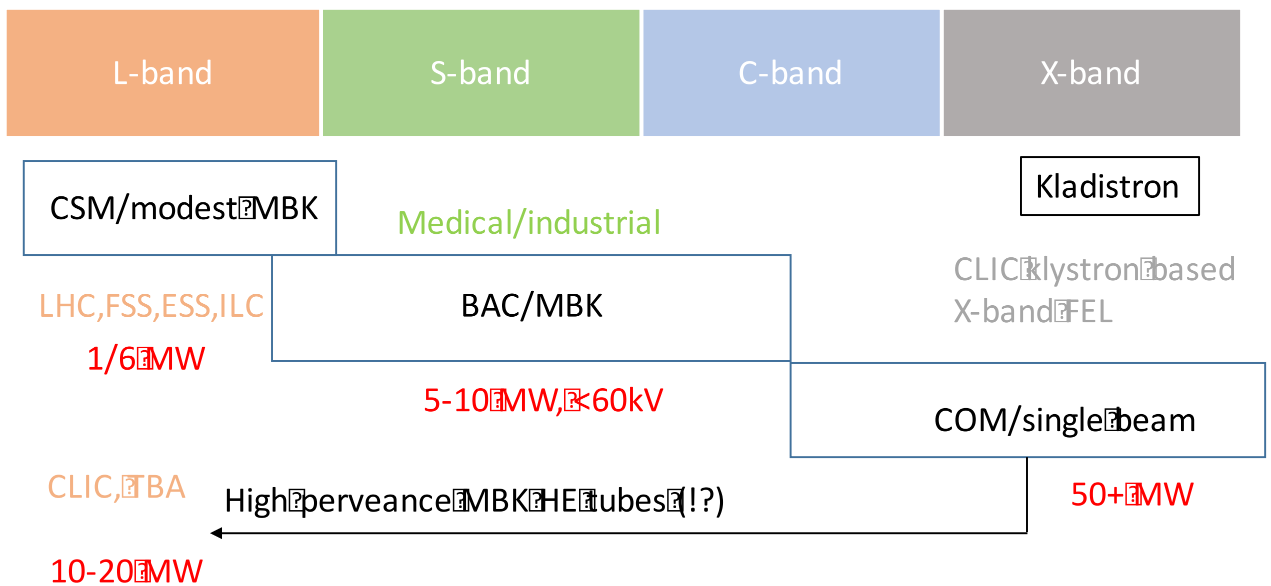


Figure 5: The efficiency (triangular) and RF power production (circle) in saturation at 3.003 GHz as functions of high voltage.

The choice of bunching technology may drive the applicable frequency range and multi-beam options (cost/performance):



I. Syratchev

Observations on power consumption, X-band

- **Electronic efficiency** – Current tube only about 45%. We have launched with SLAC a design study tube which incorporates the latest ideas about high efficiency. Should result in higher efficiency tube, >65% or so and lower modulator voltage, below 400 kV (from 430 kV).
- **Solenoid** – Current normal conducting solenoid consumes 20 kW, same average power as klystron itself. Going to superconducting solenoid has the potential to reduce this consumption by an order of magnitude. Low field application so conductor of choice is MgB2. We look towards order demonstrator unit. PPM (Periodic Permanent Magnet) also potential solution but not clear if this is compatible with high-efficiency

From W.Wuensch

Superconducting klystron solenoid

A SC Solenoid Design applicable for X-band Klystrons

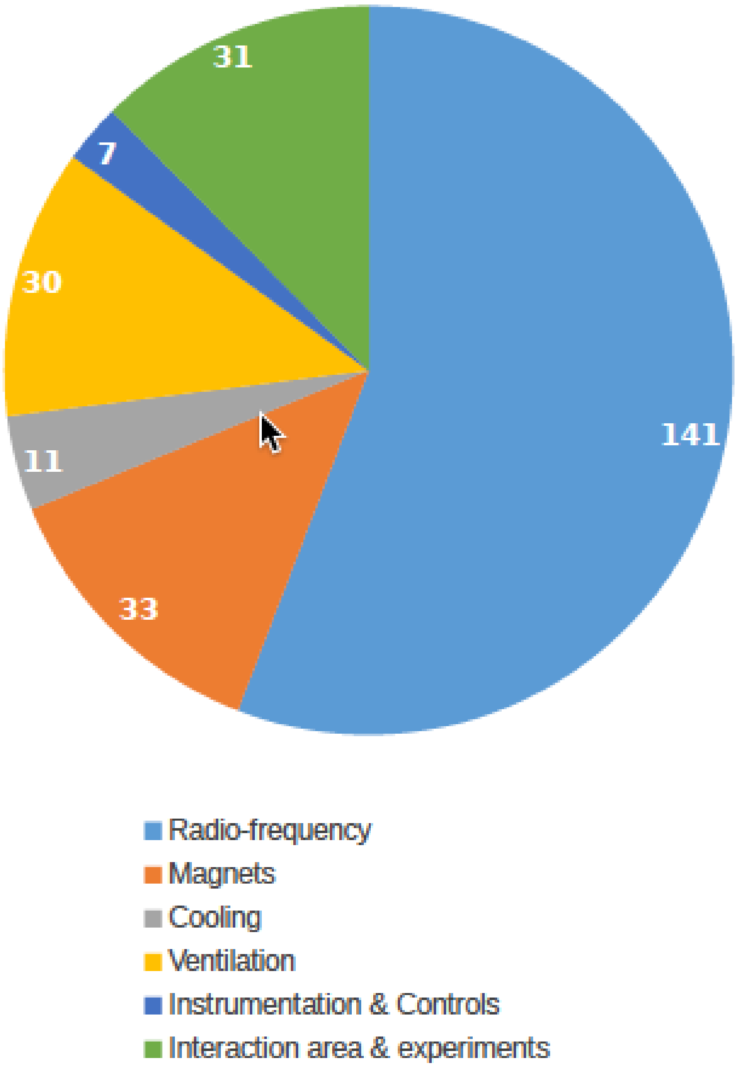
Akira Yamamoto (KEK and CERN)

Discussed with the CLIC RF team: 2017-8-25
Updated: 2017-9-5a
Updated: 2017-10-5
Summary updated: 2017-10-25

Background and Objectives

- The CLIC-380 staging scenario is being studied at CERN, and the X-band (12 GHz) klystron-based accelerating scheme may be a cost-effective option.
- The klystron requires a solenoid magnet field for beam focusing with
  - Bc = **~ 0.6** T in a bore-diameter of 0.48 m
- A Cu-based solenoid magnet, currently used, is consuming
  - AC-plug power of **~20 kW** per Klystron,
- The superconducting magnet option will result in
  - Total AC-plug power saving of **> ~80 MW** for ~4,500 klystron in CLIC-380.

Magnets



ZEPTO (Zero Power Tuneable Optics) project is a collaboration between CERN and STFC Daresbury Laboratory to save power and costs by switching from resistive electromagnets to permanent magnets.

Potential targets

DRIVE BEAM

Type	Magnet type	Total	Effective Length [m]	H	V	Strength	Units	Min field	Max field	Rel Field Accuracy	Higher Harmonics [Tm]	per magnet [kW]	total [MW]
DBQ	Quadrupole	41400	0.194	26	26	62.78	T/m	10%	120%	1E-03	1.0E-04	0.5	17.0
MBTA	Dipole	576	1.5	40	40	1.6	T	10%	100%	1E-03	1.0E-04	21.6	12.4
MBCOTA	Dipole	1872	0.2	40	40	0.07	T	-100%	100%	1E-03	1.0E-03	0.3	0.5
QTA	Quadrupole	1872	0.5	40	40	14	T/m	10%	100%	1E-03	1.0E-04	2.0	3.7
SXTA	Sextupole	1152	0.2	40	40	85	T/m^2	10%	100%	1E-03	1.0E-03	0.1	0.1
MB1	Dipole	184	1.5	80	80	1.6	T	10%	100%	1E-03	1.0E-04	42.0	7.7
MB2	Dipole	32	0.7	80	80	1.6	T	10%	100%	1E-03	1.0E-04	25.0	0.8
MB3	Dipole	236	1	80	80	0.26	T	10%	100%	1E-03	1.0E-04	4.5	1.1
MBCO	Dipole	1061	0.2	80	80	0.07	T	-100%	100%	1E-03	1.0E-03	0.4	0.4
Q1	Quadrupole	1061	0.5	80	80	14	T/m	10%	100%	1E-03	1.0E-04	5.9	6.3
SX	Sextupole	416	0.2	80	80	85	T/m^2	10%	100%	1E-03	1.0E-03	0.5	0.2
SX2	Sextupole	236	0.5	80	80	360	T/m^2	10%	100%	1E-03	1.0E-04	3.3	0.8
QLINAC	Quadrupole	1638	0.25	87	87	17	T/m	No data	100%	No data	No data	6.3	10.3
MBCO2	Dipole_CO	880	1	200	200	0.008	T	-100%	100%	2E-03	2.8E-05	0.3	0.3
Q4	Quadrupole	880	1	200	200	0.14	T/m	10%	100%	2E-03	2.8E-05	0.5	0.5

Obvious targets

Likely targets

Possible targets

To be updated and agreed in collaboration with beam dynamics team…

Potential targets

MAIN BEAM

Type	Magnet type	Total	Effective Length [m]	H	V	Strength	Units	Min field	Max field	Rel Field Accuracy	Higher Harmonics [Tm]	per magnet [kW]	total [MW]
D1	***Dipole***	***6***	***1***	***30***	***30***	***0.4T***		***100%***	***100%***		***1.0E-04***	***1.8***	***0.0***
D2 Type 1	***Dipole***	***12***	***1.5***	***30***	***30***	***0.7T***		***100%***	***100%***		***1.0E-04***	***5.8***	***0.1***
D2 Type 2	***Dipole***	***666***	***1.5***	***30***	***30***	***0.5T***		***100%***	***100%***		***1.0E-04***	***3.8***	***2.5***
D3	Dipole	16	1.5	500	30	0.5T		-100%	120%		1.0E-04	3.9	0.1
D4	Dipole	8	1.5	500	30	0.3T		-100%	120%		1.0E-04	2.3	0.0
Q1	Quadrupole	268	0.3	30	30	63T/m		98%	100%	1E-03	1.0E-04	1.7	0.5
Q2	Quadrupole	223	0.3	30	30	45T/m		60%	100%	1E-03	1.0E-04	1.2	0.3
Q3 Type 1	Quadrupole	318	0.15	30	30	36.6T/m		77%	100%	1E-03	1.0E-04	0.9	0.3
Q3 Type 2	Quadrupole	73	0.2	30	30	39T/m		77%	100%	1E-03	1.0E-04	0.8	0.1
Q3 Type 3	Quadrupole	202	0.3	30	30	37T/m	?		100%	1E-03	1.0E-04	0.6	0.1
Q4 Type 1	Quadrupole	44	0.075	30	30	16T/m		83%	100%	1E-03	1.0E-04	0.2	0.0
Q4 Type 2	Quadrupole	110	0.15	30	30	16.2T/m		74%	100%	1E-03	1.0E-04	0.2	0.0
Q4 Type 3	Quadrupole	230	0.2	30	30	18T/m		79%	100%	1E-03	1.0E-04	0.3	0.1
Q5	Quadrupole	87	0.075	30	30	7.6T/m		53%	100%	1E-03	1.0E-04	0.1	0.0
Q6	Quadrupole	192	0.36	30	30	0.3T/m	?		100%	1E-03	1.0E-04	0.0	0.0
SX2	Sextupole	520	0.2	30	30	1200T/m²	?		100%	1E-03	1.0E-04	0.1	0.1
SX1	Sextupole	16	0.2	30	30	3000T/m²		63%	100%	1E-03	1.0E-04	0.3	0.0

Obvious targets

Likely targets

Possible targets

To be updated and agreed in collaboration with beam dynamics team…

Potential targets

DAMPING AND PRE-DAMPING RINGS

Type	Magnet type	Total	Effective Length [m]	H	V	Strength	Units	Min field	Max field	Rel Field Accuracy	Higher Harmonics [Tm]	per magnet [kW]	total [MW]
D1.7	Dipole	76	1.3	160	80	1.7T		75%	100%	5E-04		37.5	2.9
Q30L04	***Quadrupole***	***408***	***0.4***	***80***	***80***	***30T/m***		***20%***	***100%***	***5E-04***		***11.4***	***4.7***
Q30L02	***Quadrupole***	***408***	***0.2***	***80***	***80***	***30T/m***		***20%***	***100%***	***5E-04***		***8.2***	***3.3***
S300	Sextupole	204	0.3	80	80	$300T/m^2$		0%	100%	5E-04		1.2	0.2
ST0.3	Steerer	312	0.15	80	80	0.3T		-100%	100%	5E-04		1.5	0.5
SkQ5	Skew Quad	76	0.15	80	80	5T/m		-100%	100%	5E-04		0.8	0.1
CFM D1.7Q10.5	Combined Dipole/Quad	204	0.43	100	20	1.4T		75%	125%	5E-04		2.4	0.5
				0	0	10.5T/m							0.0
Q75	Quadrupole	1004	0.2	20	20	75T/m		20%	100%	5E-04		0.8	0.8
S5000	Sextupole	576	0.15	20	20	$5000T/m^2$		0%	100%	5E-04		0.2	0.1
ST0.4	Steerer	712	0.15	20	20	0.4T		-100%	100%	5E-04		0.4	0.3
SkQ20	Skew Quad	96	0.15	20	20	20T/m		-100%	100%	5E-04		0.2	0.0

Obvious targets

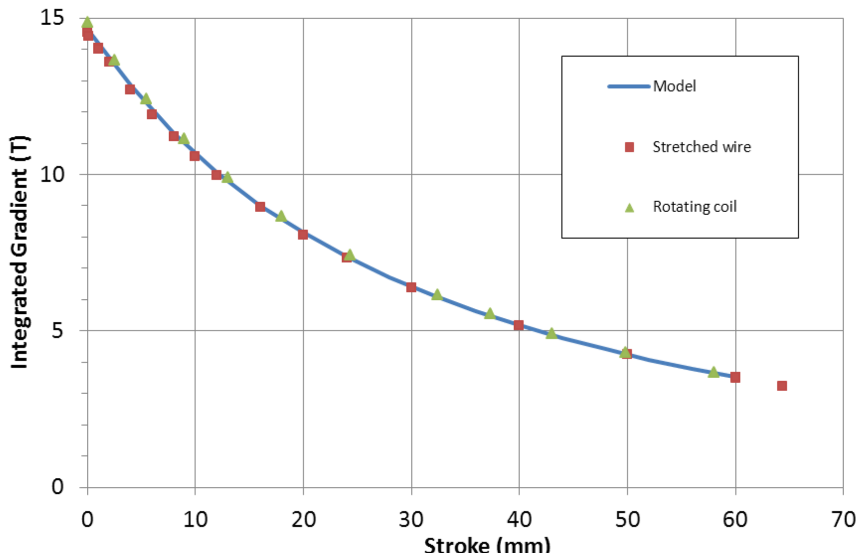
Likely targets

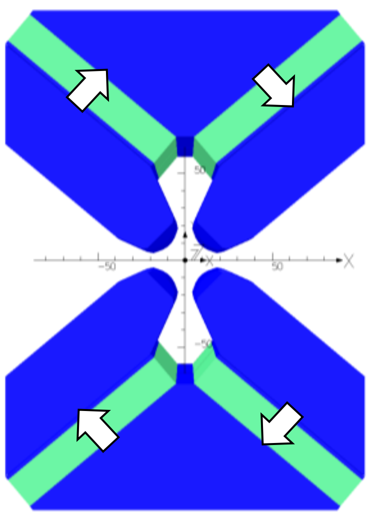
Possible targets

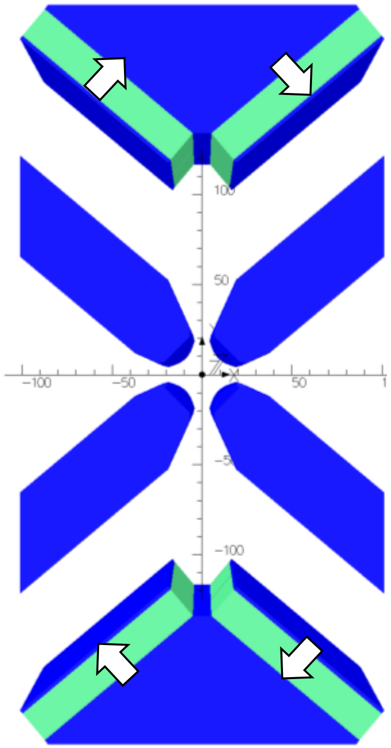
To be updated and agreed in collaboration with beam dynamics team…

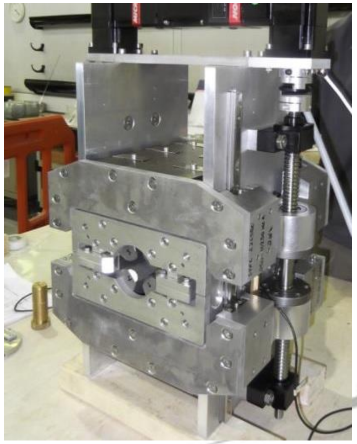
High strength quadrupoles

High strength Drive Beam quadrupole (tunes 60.4 to 15.0 T/M). Uses 4 NdFeB blocks (18x100x230 mm) with Br=1.37, requires 64 mm motion range.







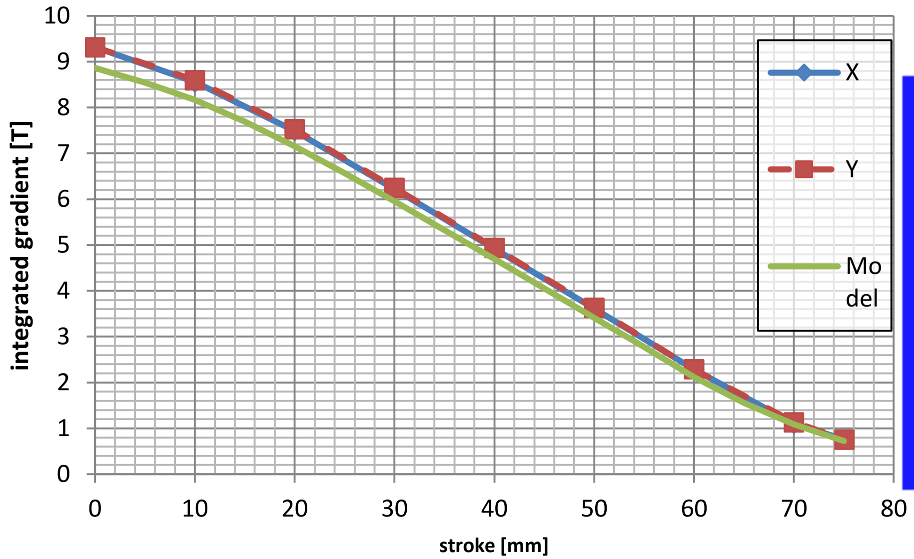


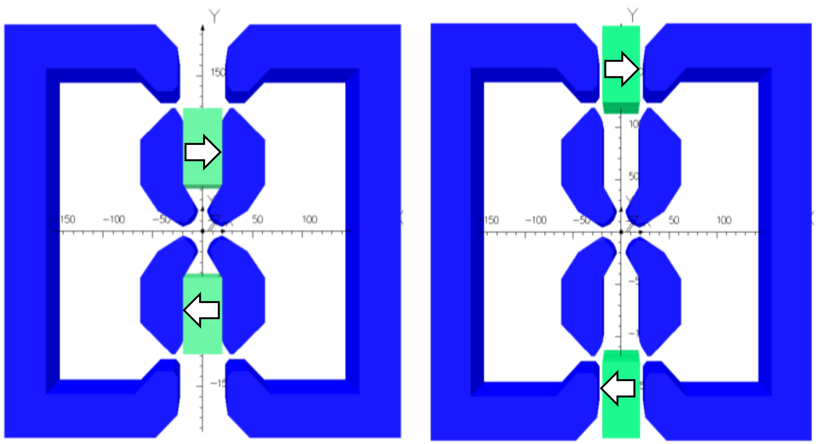
Built and tested at Daresbury and CERN.

Meets to needs of CLIC DB

Low strength quadrupoles

Low strength Drive Beam quadrupole (tunes 43.4 to 3.5 T/M). Uses 2 NdFeB blocks (37.2x70x190 mm) with Br=1.37, requires 75 mm motion range.



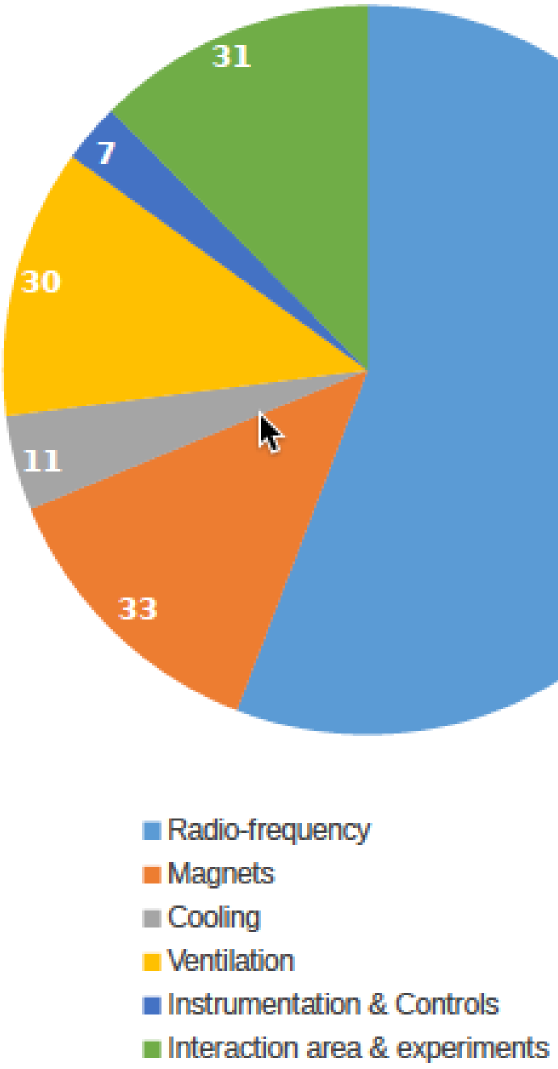


Built and tested at Daresbury and CERN.

Meets to needs of CLIC DB

Science & Technology Facilities Council

Power and energy – the rest



Cost and power updates in progress

Action (v = significant impact expected)	Cost	Power/Energy	Comments
Structure/parameters optimisation, minor other changes	v	**DONE**	Ok for now, 380 GeV at 1.5 10^34 Defines Civ Eng parameters
Further possibility: lower inst. luminosity or initial energy (250 GeV)	v	**WILL NOT DO**	Integrated lum. goal can be maintained, can re-optimise structures
Known corrections needed for injectors and Cooling/Ventilation	v	**Important, on-going**	Partly addressed for injectors CV to be re-designed and clear up average and max estimates
Structure manufacturing	v		Optimise, remove steps, halves
High eff. Klystrons/Modulators and RF distribution	v	**IN PROGRESS**	Technical studies where gains can be large Large commercial uncertainty
Magnets	?	**In PROGRESS**	Technical studies and costing in progress
Running scenario (daily, weekly, yearly)		**In PROGRESS (costs)**	Take advantage of demand/price changes, study foreseen
Commercial studies, currencies and reference costing date	v		Examples: klystrons, CHF, CLIC and FCC will use similar convention, learning curves, cost-escalation

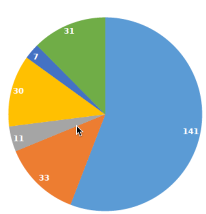
Energy costs and final words

Energy costs reductions are being looked at:

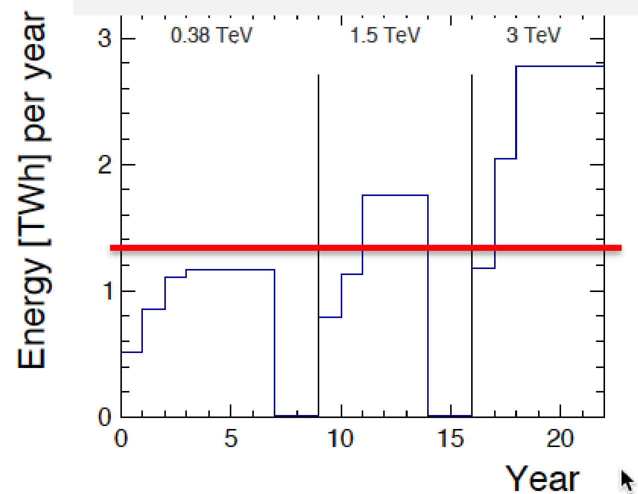
- Look at daily and yearly fluctuation – can one run in “low general demand” periods, adapt quickly to fluctuating demand
- Understand and minimize the energy (consider also standby, MD, down periods)
- Have launched two studies related to this.

We are currently reviewing systematically all power and energy consumptions for CLIC (also those less significant in earlier plot)

Very clear reductions are possible, expect “solid” new numbers by next LCWS (October)



CERN energy consumption 2012: 1.35 TWh



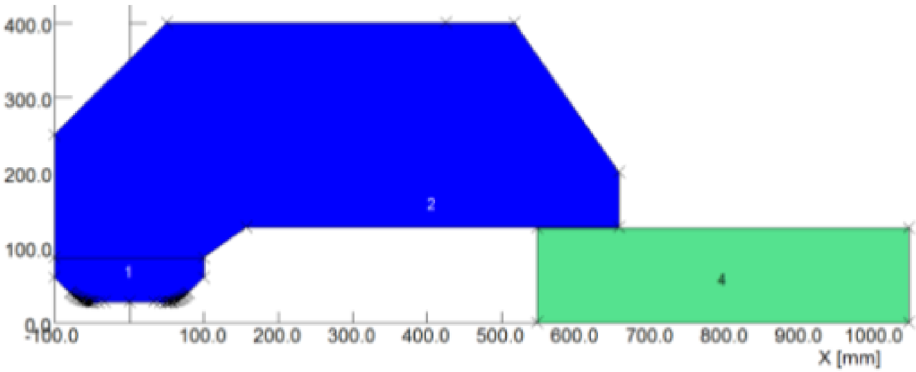
CERN

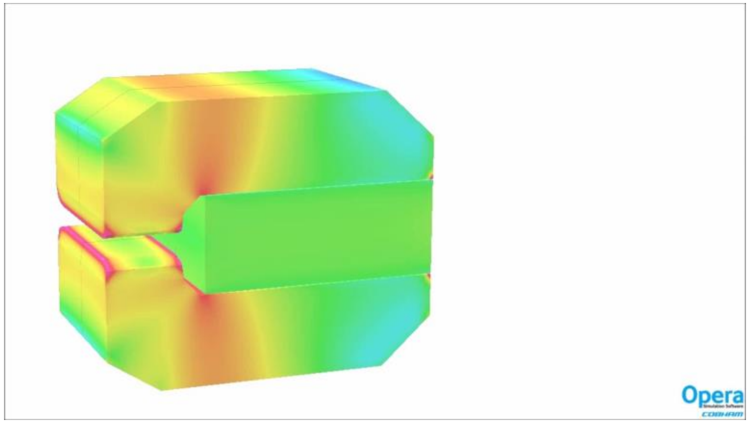
CLIC

Dipole prototype

- Focus on the most challenging case (576 dipoles for drive beam turn-around loop).
  - Length 1.5 m, strength 1.6 T, tuning range 50-100%

- Settled on C-design that uses a single sliding PM block to adjust field

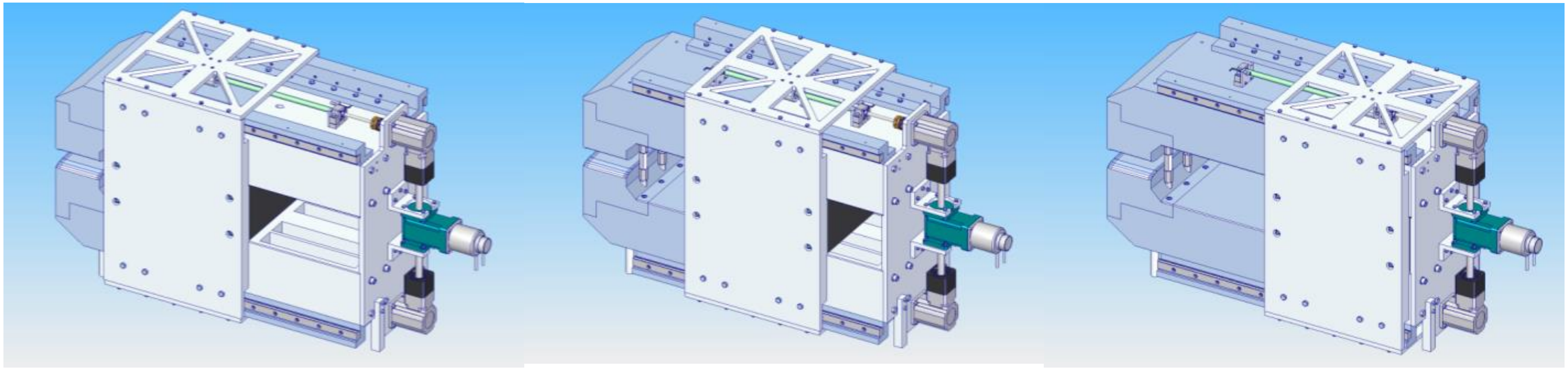


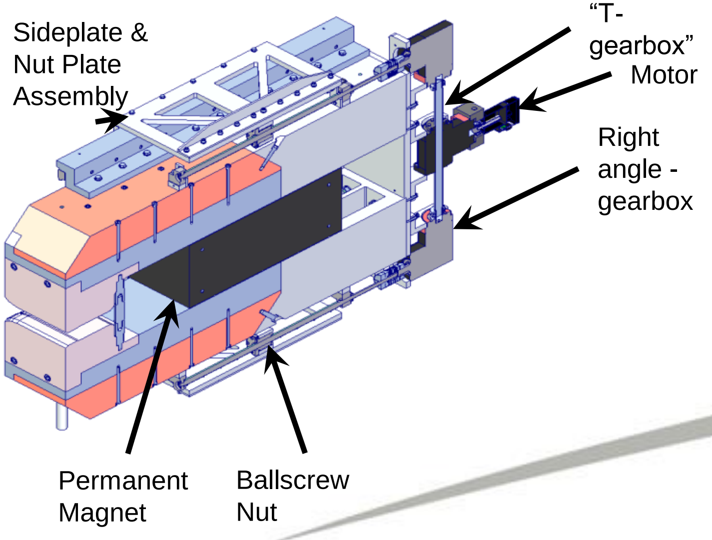


- Advantages:
  Single simple PM
  PM moves perpendicular to largest forces – can be moved easily
  Curved poles possible

Dipole Prototype

- Sliding assembly using rails, stepper motor and gearbox.
- Should cope with horizontal forces (peak >27 kN) and hold the magnet steady at any point on a 400 mm stroke.





3 support rods hold jaws of magnet fixed
Can be independently adjusted

Poles held 2 mm from surface of block

PM Block

- Manufactured, measured & delivered by Vacuumschmelze
- Magnet block dimensions are **500x400x200 mm**, with 4 holes on 400mm axis for mounting rods.
- Magnet material **NdFeB, Vacodym 745TP (Br 1.38T min, 1.41T typical)**
- Constructed from 80 individual blocks (each 100x50x100mm) in resin
- World's largest ever NdFeB PM block?