CLIC Issues

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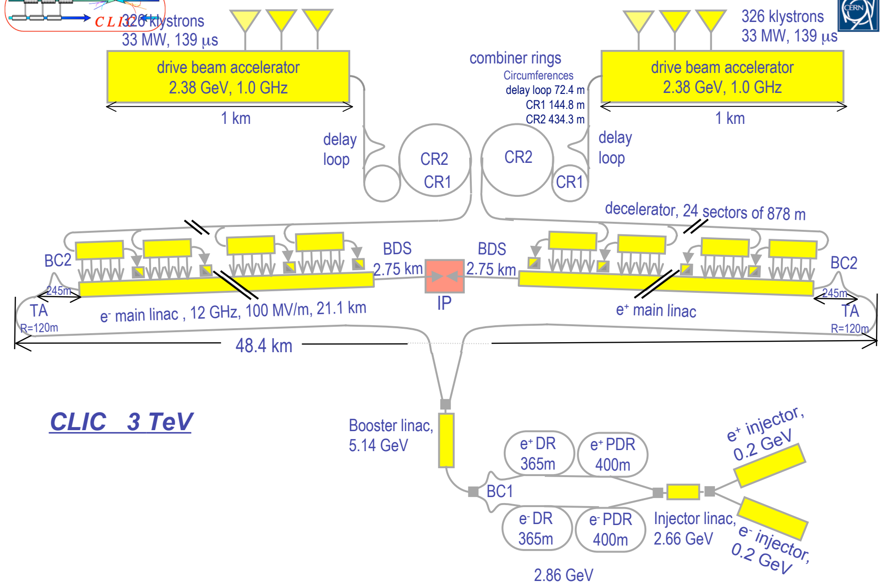


CLIC Study Strategy

- Many critical issues exist for CLIC
- Due to limited resources we have addressed a subset, the most critical issues
- In preparation of the CDR an extension of the work was necessary
  - To cover known very critical items that were not yet addressed
  - To ensure that we do not misse a very critical item
- Have produced a formal list of issues, divided into
  - Feasibility issues, can be a showstopper
  - Performance issues, can have severe impact on machine performance
  - Cost issues, have strong impact on cost
- For CDR focus on feasibility issues
  - Some work on other issues
- A plan for post CDR era is in preparation
  - Will address many more issues
- I will
  - Shortly present list of critical issues
  - Give very short reasoning for choice of feasibility issues
  - Will not justify for all other item why they are not considered feasibility issues

CLIC List of Issues

List of issues contains more than 40 items in the areas

- Structures (accelerating and PETS)
- RF distribution
- Drive beam generation and use
- Two beam
- Beam Physics
- Magnet systems
- Vacuum systems
- Klystrons and modulators
- Dumps and collimators
- Injectors
- Pre-alignment
- Stabilisation
- Feedback and integration with stabilisation and alignment
- Instrumentation
- Operation, machine protection and reliability
- Detector infrastructure

CLIC Feasibility Issues

SYSTEMS		Critical parameters	Relevant Facilities
Structures	Main Beam Acceleration Structures: Demonstrate nominal CLIC structures with damping features at the design gradient, with design pulse length and breakdown rate .	100 MV/m 240 ns < 3·10-7 BR/(pulse*m) RF to Beam efficiency > 30%?	CTF2&3 (2005-2010) Test Stand (2009-10) SLAC/NLCTA SLAC/ASTA KEK/NEXTEF
	RF Power production structures: Demonstrate nominal PETS with damping features at the design power, with design pulse length, breakdown rate and on/off capability	136 MW, 240 ns < 10-7 BR/(pulse*m)? Beam to RF efficiency >? On/Off < 20 ms	CTF3 (2005-2010) CTF3/TBTS (2008-10) CTF3/TBL (2009-10) SLAC/ASTA
Two Beam	Two Beam Acceleration (TBA): Demonstrate RF power production and Beam acceleration with both beams in at least one Two Beam Module equipped with all equipments	Two Beam Acceleration with simultaneous & nominal parameters as quoted above for individual components	CTF2&3/TBTS (2004-10)
Drive Beam	Drive Beam Production - Beam generation and combination - phase and energy matching - Potential feedbacks	100 Amp peak current 12GHz bunch repetition frequency 0.2 degrees phase stability at 12 GHz 7.5 10^{-4} intensity stability	CTF3 (2005-2010) CTF3/TBL (2009-10) X-FEL LCLS
	RF power generation by Drive Beam - Rf power extration - Beam stability	90% extraction efficiency Large momentum spread	CTF3/TBL
Beam Physics	Generation and Preservation of Low Emittances Damping Rings, RTML and Main Linacs	Emittances(nm): H= 600, V=5 Absolute blow-up(nm): H=160, V=15	ATF, SLS, NSLSII Simulations LCLS, SCSS
Stabili zation	Main Linac and BDS Stabilization	Main Linac : 1 nm vert. above 1 Hz; BDS: 0.15 to 1 nm above 4 Hz depending on final doublet girder implementation	CESRTA ATF2
Operation and reliability	Operation and Machine Protection Staging of commissioning and construction MTBF, MTTR Machine protection with high beam power	drive beam power of 72 MW @ 2.4 GeV main beam power of 13 MW @ 1.5 TeV	CTF3
Detector	Beam-Beam Background Detector design and shielding compatible with breakdown generated by beam beam effects during collisions at high energy	3.8 10^{8} coherent pairs	

Luminosity

Luminosity is given by

$$\mathcal{L} \propto H_d \frac{N^2}{\sigma_x \sigma_y} n_b f_r \propto H_D \frac{N}{\sqrt{\epsilon_x \beta_x}} \frac{1}{\sqrt{\epsilon_y \beta_y}} \eta P_{AC}$$

In classical regime $\Upsilon \ll 1$

$$n_\gamma \propto \frac{N}{\sqrt{\beta_x \epsilon_x}} \qquad E_\gamma \propto \frac{N}{\sqrt{\beta_x \epsilon_x \sigma_z}}$$

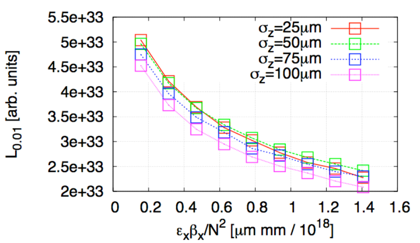
Resulting luminosity is (500GeV)

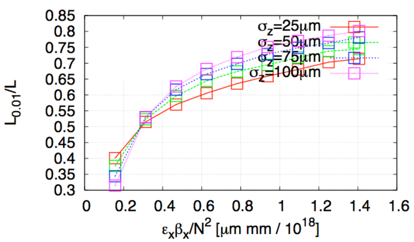
$$\mathcal{L} \propto n_\gamma \frac{1}{\sqrt{\beta_y \epsilon_y}} \eta P_{AC}$$

In quantum case (3TeV)

$$\mathcal{L} \propto \frac{n_\gamma^{3/2}}{\sqrt{\sigma_z}} \frac{1}{\sqrt{\beta_y \epsilon_y}} \eta P_{AC}$$

Luminosity

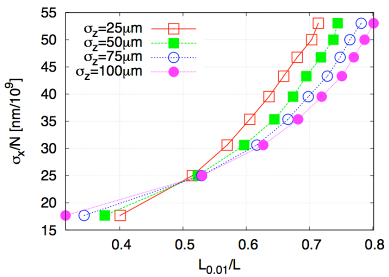




At 500GeV we aim for 65% luminiosity in the peak (see figs.)

$$\left(\frac{N_{opt}}{4\times 10^9}\right)^2 \approx \frac{\epsilon_x}{\mu\mathrm{m}} \frac{\beta_x}{10\,\mathrm{mm}}$$

Similar considerations at 3TeV (we aim for 30%)



Parameter Choice

Horizontal beam size is dominated by

- damping rings, beam delivery system and RTML

Vertical beam size is dominated by

- damping rings, RTML, main linac, beam delivery system, collision point

Structures prefer small iris radius a to reach high field

- but gives an upper limit to the charge

Complex optimisation procedure

Asked ourselfs two questions

- How much do we loose if we use more conservative parameters for emittance and beam sizes at 3TeV?
- How does a 500GeV machine perform that is optimised for more conservative parameters?

Parameters

		CLIC(cons)	CLIC(nom)	CLIC(cons)	CLIC	CLIC(vo)	ILC	NLC
E_{cms}	[TeV]	0.5	0.5	3.0	3.0	3.0	0.5	0.5
f_{rep}	[Hz]	50	50	50	50	100	5	120
n_b		354	354	312	312	154	2820	190
σ_x	[nm]	248	202	83	40	40	655	243
σ_y	[nm]	5.7	2.26	1	1	1	5.7	3
σ_z	[μm]	72	72	45	45	35	300	110
Δt	[ns]	0.5	0.5	0.5	0.5	0.67	340	1.4
N	[10^9]	6.8	6.8	3.7	3.7	4.0	20	7.5
ϵ_x^*	[μm]	3.0	2.4	2.4	0.66	0.68	10	4
ϵ_y^*	[nm]	40	25	20	20	10	40	40
L_{total}	[10^{34}cm^{-2}s^{-1}]	0.88	2.3	2.7	5.9	10.0	2.0	2.0
$L_{0.01}$	[10^{34}cm^{-2}s^{-1}]	0.58	1.4	1.3	2.0	3.0	1.45	1.28
n_γ		1.1	1.3	1.2	2.2	2.3	1.30	1.26
$\Delta E/E$		0.045	0.07	0.13	0.29	0.31	0.024	0.046
N_{coh}	[10^5]	10^{-4}	10^{-3}	5×10^2	3.8×10^3	?	—	—
E_{coh}	[10^3TeV]	0.001	0.015	4×10^4	2.6×10^5	?	—	—
n_{incoh}	[10^6]	0.03	0.08	0.11	0.3	?	0.1	n.a.
E_{incoh}	[10^6GeV]	0.14	0.36	7.2	22.4	?	0.2	n.a.
$n_\perp$		8	20.5	19	45	60	28	12
n_{had}		0.07	0.19	0.75	2.7	4.0	0.12	0.1

Main Linac Accelerating Structures

- The structure is an important driver of the parameter choice with large impact on energy and luminosity
  - Technological challenge
  - Large impact on cost
- Do not understand the gradient and pulse length limitations from first principle
  - Have an empirical model, which has improved very much
  - But experimental confirmation is vital
- Focus on gradient, pulse length, breakdown rate and efficiency
- Other issues are also important
  - Longrange wakefield damping is crucial
    - Failure to damp longrange modes will reduce efficiency due to larger bunch spacing
  - Wake monitors are very important
    - Single bunch emittance growth could become large
  - Structure tolerances, e.g. bookshelfing
    - Can lead to significant single bunch emittance growth

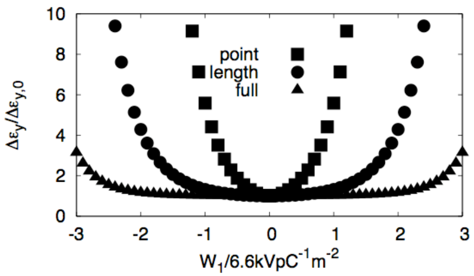
Longrange Wakefields

- Important limit is given by the longrange wakefield
- For point-like bunches can calculate

$$y_{2,f} = (y_{2,0} + a_{1,2} y_1)$$

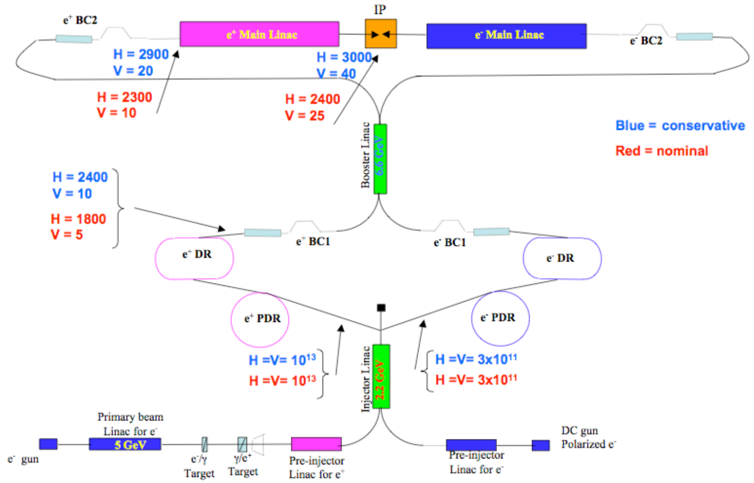
$$a_{j,k} = \int_0^s i \frac{W(z_k - z_j, s') N e^2 \beta(s')}{2E(s')} ds'$$

- Require $\sum_{j>1} a_{1,j} \le 1.5$
- Full effect is $A = \exp(a)$
- Coherent offset of train leads to a phase shift
- Growth of emittance caused by bunch-to-bunch offsets is up to $\Delta\epsilon_{y,f} \approx 5\Delta\epsilon_{y,0}$

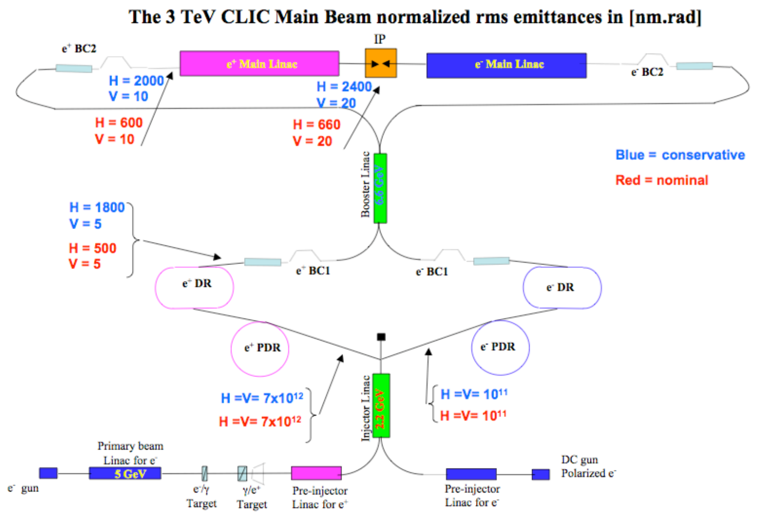


Emittance Preservation at 500GeV

The 500 GeV CLIC Main Beam normalized rms emittances in [nm.rad]



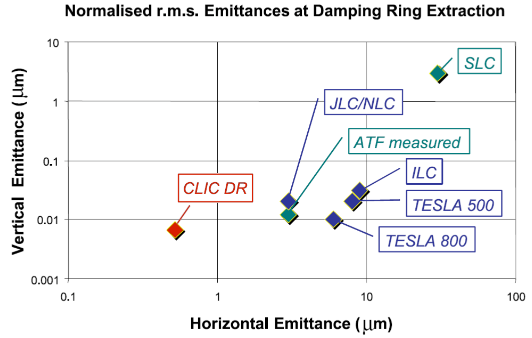
Emittance Preservation at 3TeV



Low Emittance Generation

Emittance targets are very ambitious

- vertical emittance is not too far from what has been reached in light sources
- horizontal emittance is very small for the bunch bunch charge
- lattice design is tough
- wigglers are needed
- IBS is the most important source of emittance
  - currently rely on semi analytical estimates
  - program is being develop



- Many other issues in the damping ring
  - wigglers (design, integration and performance)
  - electron cloud
  - fast beam ion instability
  - ...

Low Emittance Transport

Challenges for lattice design (mainly in BDS and RTML)

- (coherent) synchrotron radiation in bunch compressors and turn-arounds
- for BDS synchrotron radiation and chromaticity at IP
- BDS is basically ready
  - has been a major effort
- Still some work for the RTML

Vacuum challenges (fast beam-ion instability)

- excellent vacuum required and possible everywhere (O(0.1ntorr))
- except in main linac few ntorr possible and probably sufficient

Challenges from static imperfections

- imperfect pre-alignment, component errors, ...
- Mainly studied for main linac, not fully sufficent solution for the BDS, some work done for RTML
- no system should require better pre-alignment than main linac

Dynamic imperfections

- ground motion, technical noise, RF jitter, ...
- Feedback design for main linac exists but integrated study is needed

Low Emittance Preservation

Challenges from lattice design in BDS and RTML

- (coherent) synchrotron radiation, chromaticity at IP
- BDS is basically ready (major effort), still some work for the RTML

Fast beam-ion instability in main linac

Challenges from static imperfections

- Main linac short range pre-alignment tolerances for 1nm emittance growth using one-to-one steering show that more advanced beam-based correction techniques are needed

Element	error	with respect to	tolerance	
			CLIC	NLC
Structure	offset	beam	5.8 μm	5.0 μm
Structure	tilt	beam	220 $\mu radian$	135 $\mu radian$
Quadrupole	offset	straight line	—	—
Quadrupole	roll	axis	240 μm	280 $\mu radian$
BPM	offset	straight line	0.44 μm	1.3 μm
BPM	resolution	BPM center	0.44 μm	1.3 μm

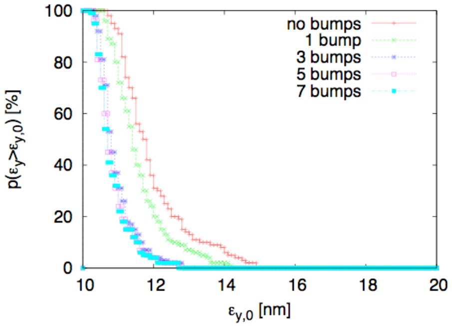
Dynamic imperfections

- element jitter, ground motion, RF jitter ...
- needs stabiolisation and beam-based feedback/feedforward

Static Imperfections in Main Linac

imperfection	with respect to	symbol	value	emitt. growth
BPM offset	wire reference	σ_{BPM}	14 μm	0.367 nm
BPM resolution		σ_{res}	0.1 μm	0.04 nm
accelerating structure offset	girder axis	σ_4	10 μm	0.03 nm
accelerating structure tilt	girder axis	σ_t	200 μradian	0.38 nm
articulation point offset	wire reference	σ_5	12 μm	0.1 nm
girder end point	articulation point	σ_6	5 μm	0.02 nm
wake monitor	structure centre	σ_7	5 μm	0.54 nm
quadrupole roll	longitudinal axis	σ_r	100 μradian	≈ 0.12 nm

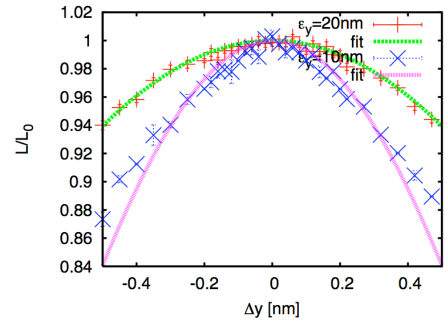
- Multi-bunch wakefield misalignments of $10\,\mu m$ lead to $\Delta\epsilon_y \approx 0.13\,nm$
- Performance of local pre-alignment is acceptable
- More tuning in reserve
  - $\Rightarrow$ pre-alignment stays severe performance issue

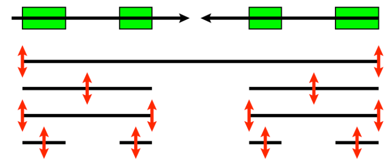


Dynamic Imperfections

- In main linac 1.8nm quadrupole jitter leads to 1% luminosity loss
- For structure have micro-metres

- At IP quadrupole jitter tolerance depends on configuration
- Beam-beam jitter tolerance is 0.27nm for 2% luminosity loss
- Jitter tolerance is (0.5)0.7-3.6 times beam-beam tolerance 0.17-85nm
- Intra-pulse interaction point feedback can help (for 40ns latency up to factor 2)
- Parasitic crossing tighten tolerance (O(10%))





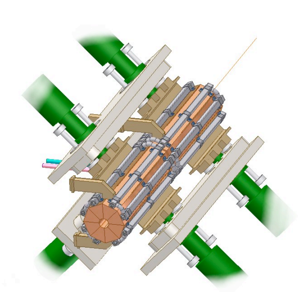
PETS

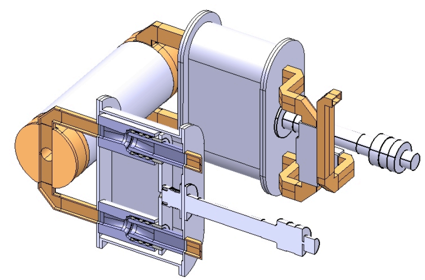
- PETS are a unique type of structure
  - Can profit much less from existing expertise
- Very high output power
  - Need to understand breakdown issues
  - Efficiency of power extraction
- Beam current is very high
  - Longrange wakefields can be very important
    - Damping is needed
  - Small amplitude trapped modes can become dangerous
    - We had designs where this was the case
- Operational considerations are vital
  - How can we switch off a main linac structure?
  - Do we need to switch off PETS itself?
- Technical issues, e.g. tight tolerances
- Cost, they are complex and we have lots of them

PETS On/Off Mechanism

The on/off mechanism is vital for CLIC, need a large number (70,000)

- Beam pulses with break are lost for luminosity (working assumption), so need to switch off structures
- If mechanism fails may have to open for intervention or to reduce gradient in a whole drive beam sector
- Need to avoid too many unwanted switches to off





Drive Beam Generation

- The drive beam generation complex is a novel concept so principle needs demonstration. It also has a number of specific issues
  - e.g. needs to provide required beam quality for decelerator, i.e. coherent phase stability of 0.2° at 12GHz and current stability of 0.075%
- Many issues can be addressed in CTF3
  - general principle (no bad surprises)
  - functioning according to our understanding
    - RF to beam power efficiency
    - single particle dynamics, e.g. isochronicity of combiner rings
    - instabilities, e.g. drive beam accelerator, RF deflectors
    - power generation with drive beam (TBTS, TBL)
    - test of tuning algorithms
  - technology development (e.g. instrumentation)
- Other issues need to be addressed sperately, e.g.
  - concept and hardware to ensure phase stability
  - beam dynamics in drive beam complex

Drive Beam Decelerator

Very different from other beam lines

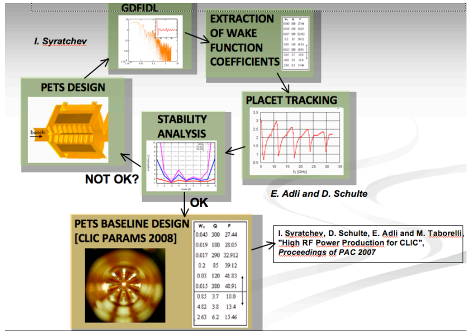
Have 48 decelerators that must work simultaneously

Beam stability and losses are critical

- Large power
- Large beam energy spread
- Large emittance/beam size (10sigma acceptance at the end)

Verification by

- Experimental programme
- Simulations



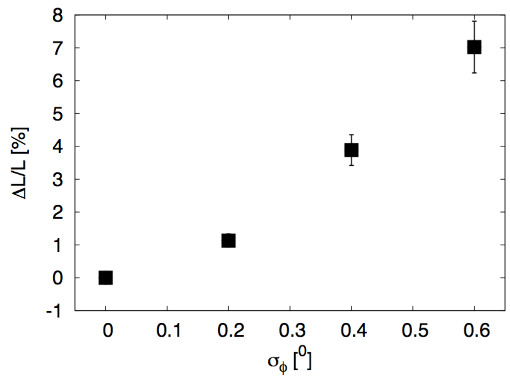
Trapped modes can be important

- Had structures that would have destroyed the beam

Beam-based alignment is a challenge

Phase Stability

- In each decelerator, the same drive beam bunches produce the RF power for a main beam bunch
- The BDS bandwidth is limited
- Tight tolerances exist on the main beam energy error
- Hence tight tolerances on the drive beam phase and amplitude
- Errors can be coherent from decelerator to decelerator or not
- Emittance growth due to RF jitter can become relevant but remains at the same level



$$\frac{\Delta\mathcal{L}}{\mathcal{L}} \approx 0.01\left[\left(\frac{\sigma_{\phi,coh}}{0.2^\circ}\right)^2+\left(\frac{\sigma_{\phi,inc}}{0.8^\circ}\right)^2 + \left(\frac{\sigma_{G,coh}}{0.75\cdot 10^{-3}G}\right)^2+\left(\frac{\sigma_{G,inc}}{2.2\cdot 10^{-3}G}\right)^2\right]$$

Two Beam Acceleration/Main Linac Module

Demonstration of two-beam acceleration with test beam verifies that

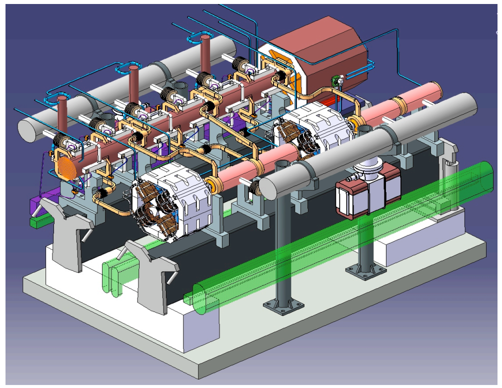
- we have a full understanding of relevant issues
- we can master the technological challenges
- components can be put together

Module is specific for CLIC

Has a significant impact on cost

- directly due to components
- impact on tunnel

Defines boundary conditions for technical solutions for important systems, e.g. accelerating structures, PETS and on/off mechanism, stabilisation, alignment, vacuum, ...



Will provide an integrated design of the module

Conditions for Experiments

Have to prove that we can do good physics

- luminosity spectrum quality
- machine and physics background

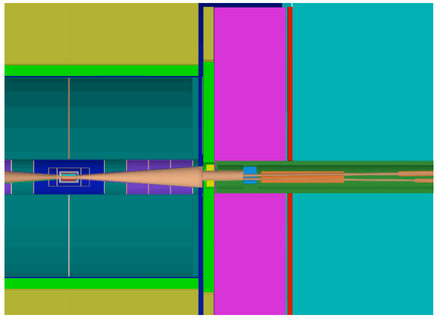
Has impact on design choices

- Crossing angle
- Spent beam extraction

Topics

- crossing angle - baseline exists
- vertex detector design - baseline exists
- forward detector design - in work
- machine background - in work
- final quadrupole and stabilisation - in work
- intra-pulse IP feedback - in work

Physics and detector isuses are addressed by a working group, we contribute to the MDI and background data



Machine Protection and Reliability

- Main and drive beam have a high damage potential
  - Significant charge
  - Small emittances
- Acceptance at drive beam decelerator end is about 10 sigma
- Passive and active protection is required
  - Passive system poses design challenges, e.g. collimation system
  - Active system can compromise luminosity
- Some points have been considered
  - Collimation system in BDS
  - On/off in PETS in decelerator
- But systematic identification of issues is remaining
- An the cures

Conclusion

- Have developed a list of critical issues
  - Identified the feasibility issues from the list
    - These are addressed with very high priority
  - CTC to verify that other issues are not feasibility issues
    - Work started
  - Some other topics are being addressed
    - Necessary for conceptual design
    - High impact on cost
    - Boundary conditions for feasibility studies