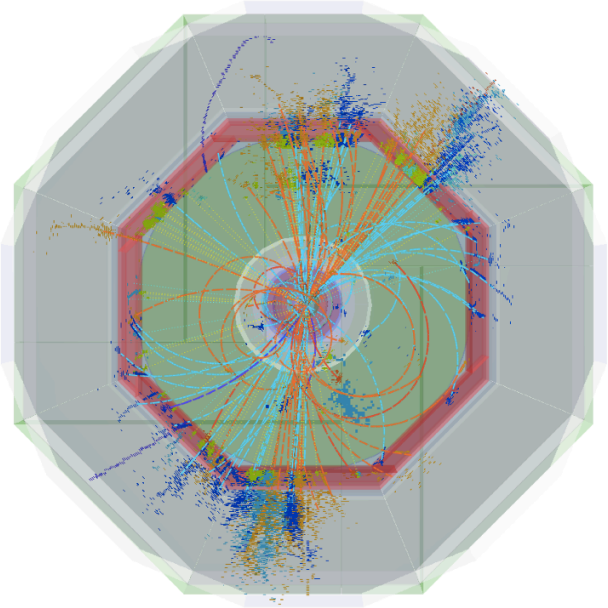
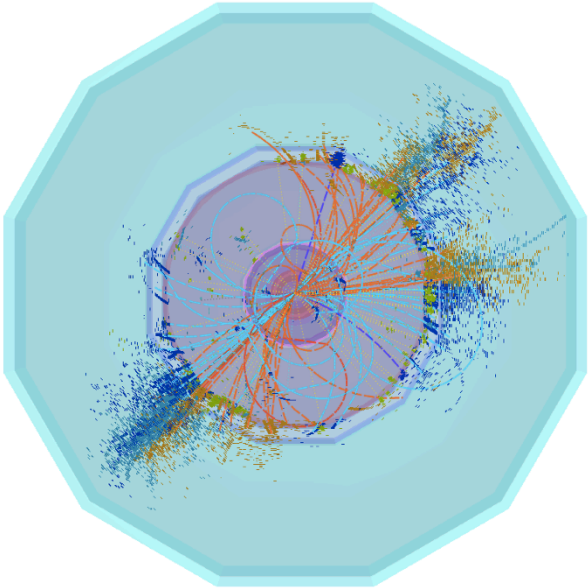
report on the CLIC physics and detector study





Lucie Linssen, CERN
on behalf of the CLIC physics and detector study

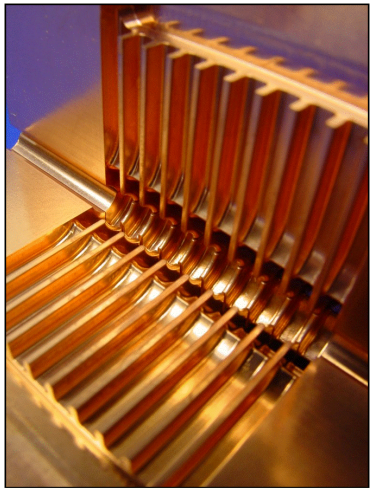
Outline

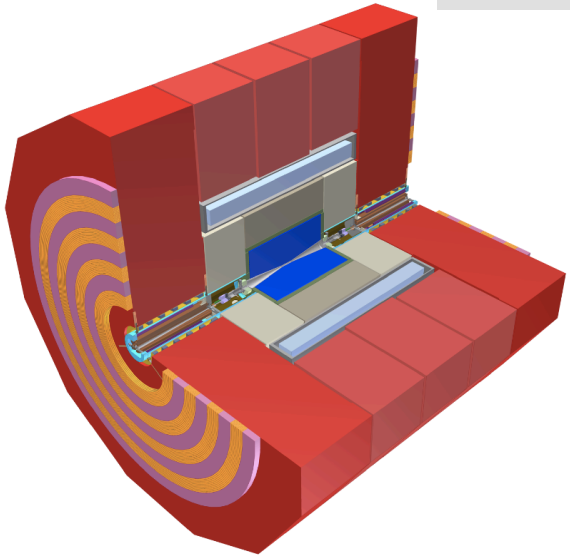
- CLIC conceptual design report
- CLIC accelerator introduction
- Physics at CLIC
- Experimental conditions
- Detector requirements
- Detector concepts CLIC_SiD and CLIC_ILD
- Background suppression at CLIC
- Detector benchmark studies
- Physics and Detectors in next phase 2012-2016
- CLIC energy staging
- Summary and outlook

CLIC, in just a few words

Linear collider, e^+e^- collisions, high luminosity

- Based on 2-beam acceleration scheme
  - Generation of RF power through low-energy, high-intensity drive beam
- Gradient 100 MV/m, room temperature
- Energy: from few-hundred GeV upgradable in steps up to 3 TeV; R&D has focused on 3 TeV





- Two detector concepts CLIC_ILD and CLIC_SiD
- Detector study has focuses on 3 TeV, lower √s energies now under study

Current project stage:

Conceptual Design Report (CDR) stage is just finished for accelerator and detector

CLIC conceptual design report(s)

CLIC conceptual design report (CDR):

1. Accelerator

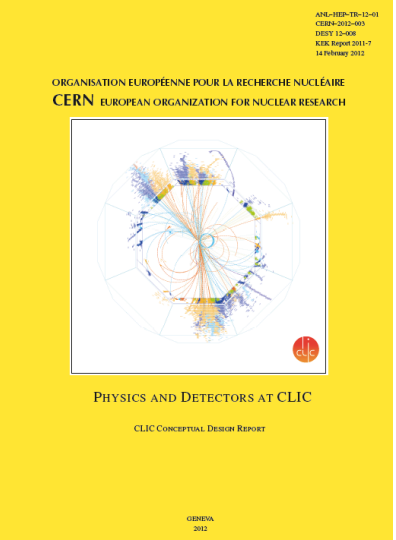
   Officially presented to CERN SPC, final text editing still ongoing
   http://clic-study.org/accelerator/CLIC-ConceptDesignRep.php

2. Physics and Detectors => published

   http://arxiv.org/abs/1202.5940

3. Strategic CDR volume (energy staging, cost, power...)

   In progress, foreseen summer 2012



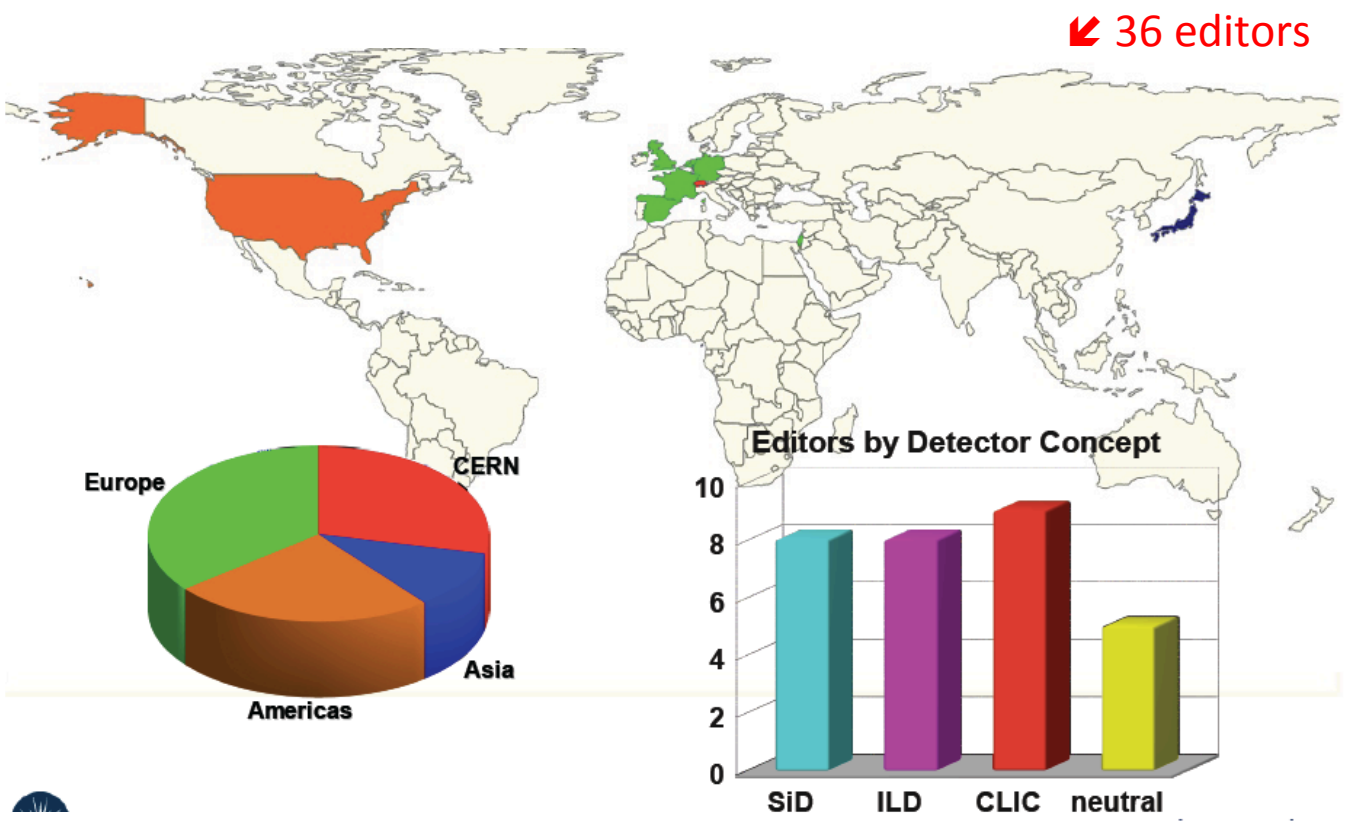
The physics & detector CDR was reviewed in October 2011:
https://edms.cern.ch/document/1172721

Signatories list of the CLIC CDR
https://indico.cern.ch/conferenceDisplay.py?confId=136364

Currently 1375 signatories

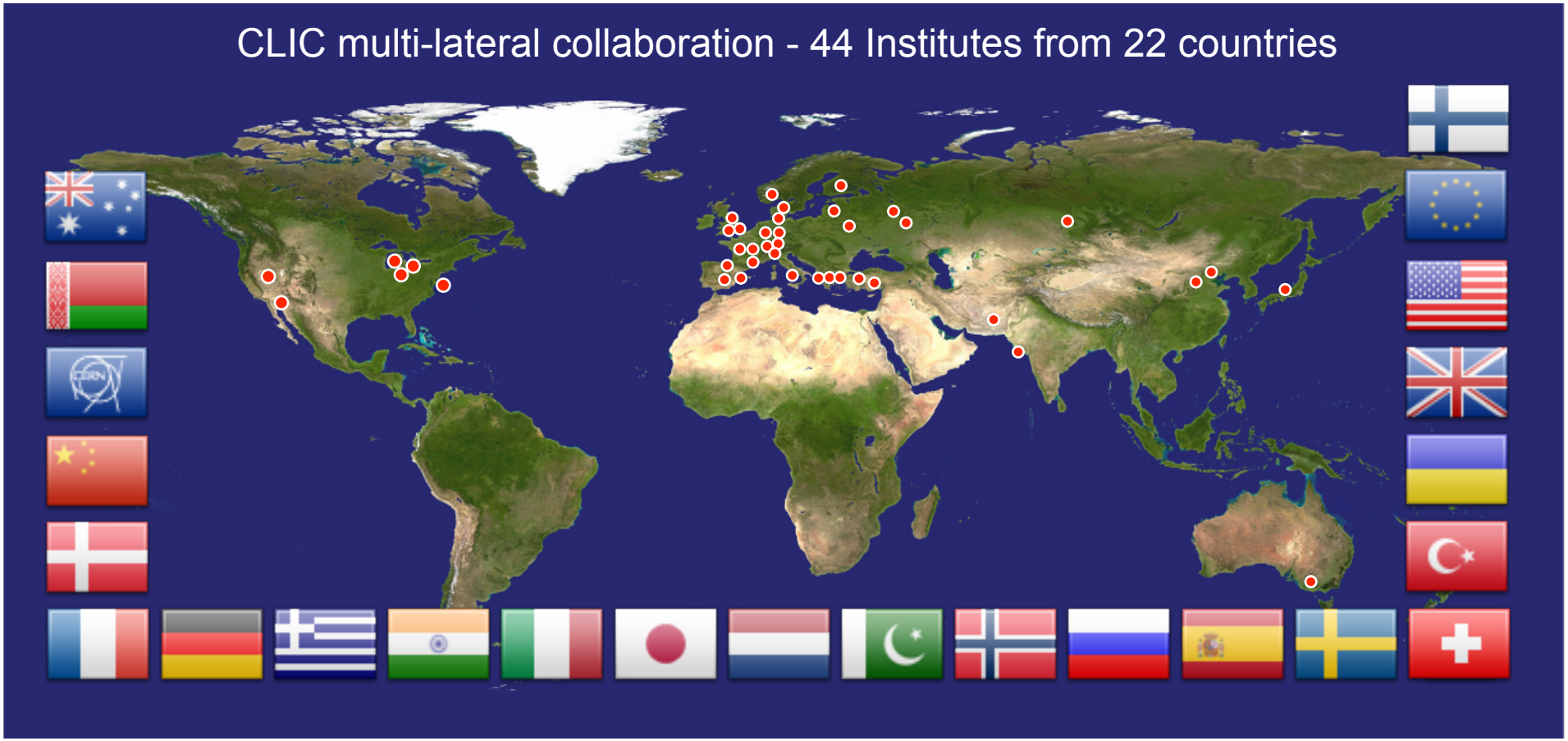
Participants CLIC CDR detector studies

CLIC physics & detector CDR studies were carried out within a broad international **Linear Collider physics and detector effort**, drawing on existing ILC (etc.) studies



http://lcd.web.cern.ch/LCD/CDR/CDR.html

CLIC&CTF3 accelerator collaboration



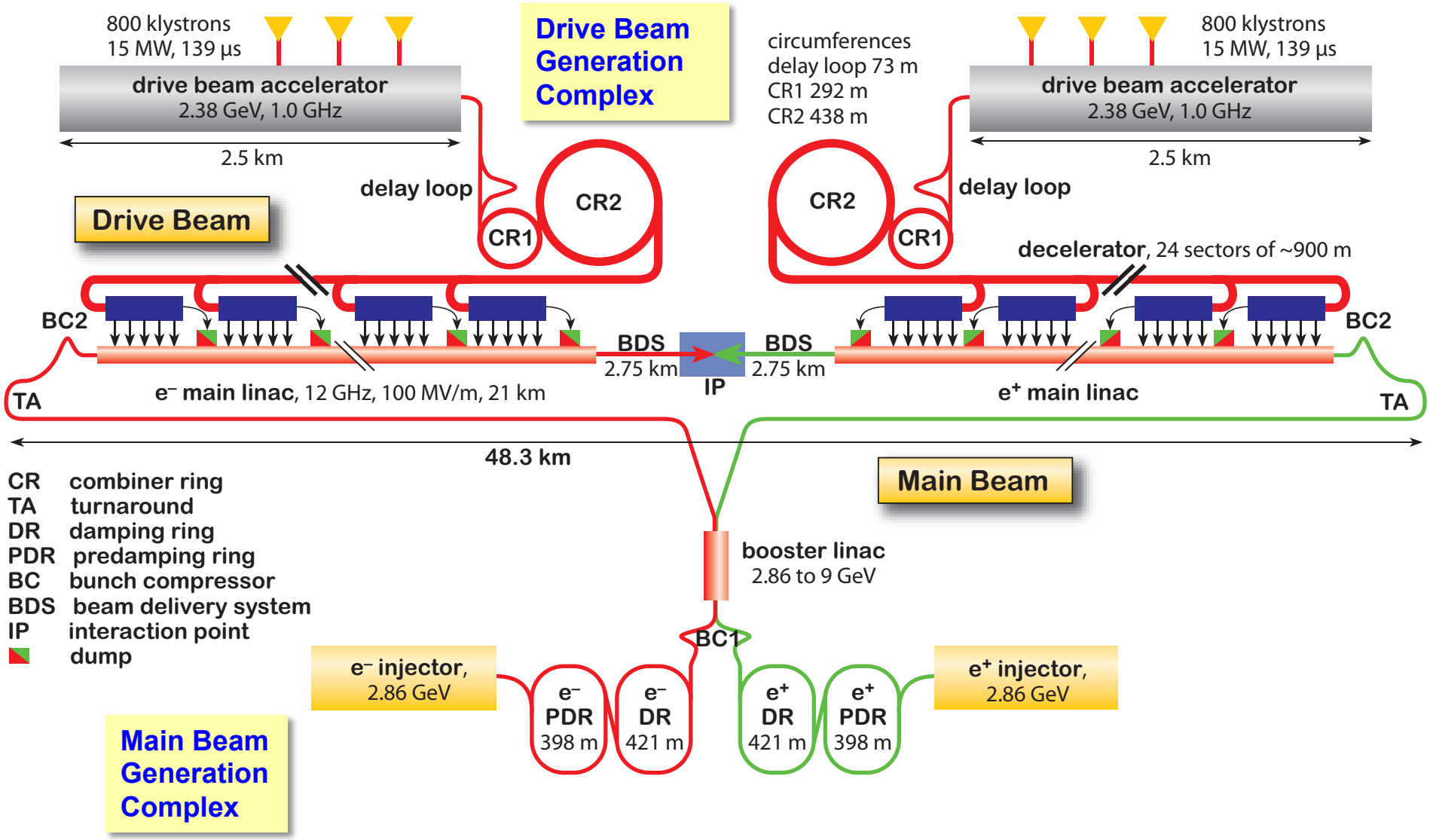
ACAS (Australia)
Aarhus University (Denmark)
Ankara University (Turkey)
Argonne National Laboratory (USA)
Athens University (Greece)
BINP (Russia)
CERN
CIEMAT (Spain)
Cockcroft Institute (UK)
ETH Zurich (Switzerland)
FNAL (USA)

Gazi Universities (Turkey)
Helsinki Institute of Physics (Finland)
IAP (Russia)
IAP NASU (Ukraine)
IHEP (China)
INFN / LNF (Italy)
Instituto de Fisica Corpuscular (Spain)
IRFU / Saclay (France)
Jefferson Lab (USA)
John Adams Institute/Oxford (UK)
Joint Institute for Power and Nuclear Research SOSNY / Minsk (Belarus)

John Adams Institute/RHUL (UK)
JINR (Russia)
Karlsruhe University (Germany)
KEK (Japan)
LAL / Orsay (France)
LAPP / ESIA (France)
NIKHEF/Amsterdam (Netherland)
NCP (Pakistan)
North-West. Univ. Illinois (USA)
Patras University (Greece)
Polytech. Univ. of Catalonia (Spain)

PSI (Switzerland)
RAL (UK)
RRCAT / Indore (India)
SLAC (USA)
Sincrotrone Trieste/ELETTRA (Italy)
Thrace University (Greece)
Tsinghua University (China)
University of Oslo (Norway)
University of Vigo (Spain)
Uppsala University (Sweden)
UCSC SCIPP (USA)

CLIC Layout at 3 TeV

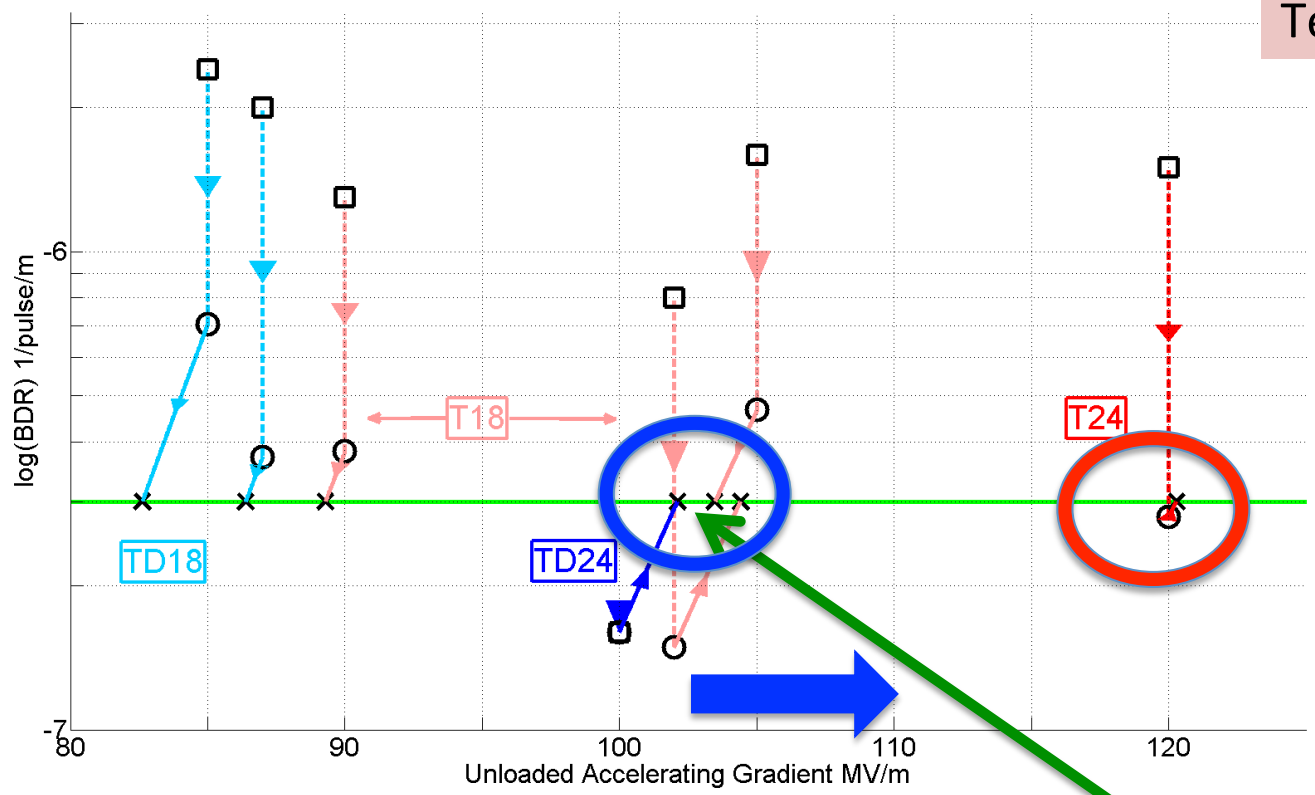


design issues addressed in acc. CDR

Main linac gradient	– Accelerating structure
Drive beam scheme	– Drive beam generation – PETS (power extraction and transfer structures) – Two beam acceleration – Drive beam deceleration
Luminosity	– Main beam emittance generation, preservation and focusing – Alignment and stabilisation
Operation and Machine Protection System (robustness)	

achieved gradient

Tests at KEK and SLAC



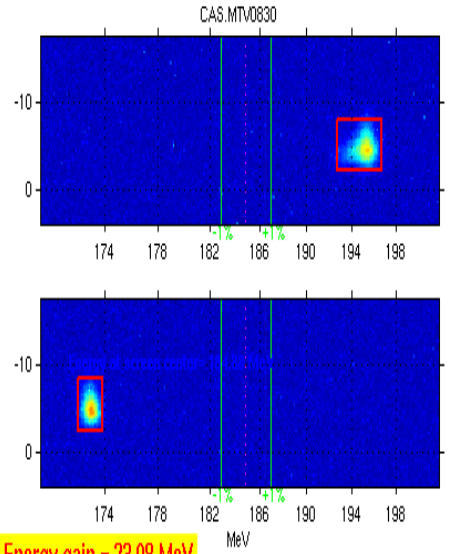
Measurements scaled according to

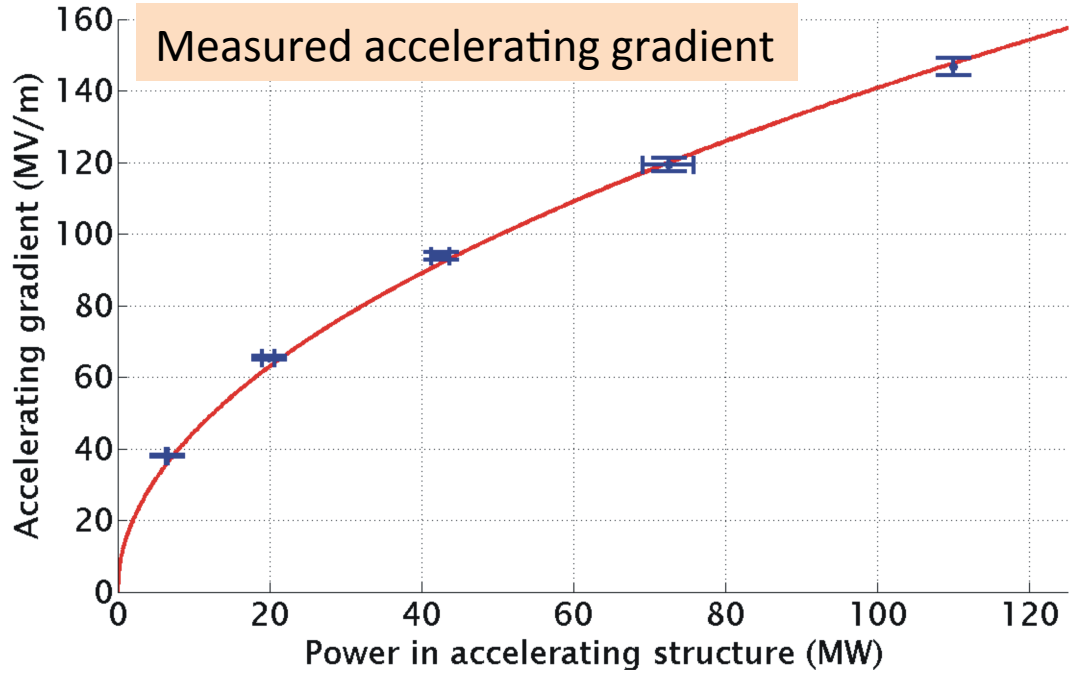
$$p \propto G^{30}\tau^{5}$$

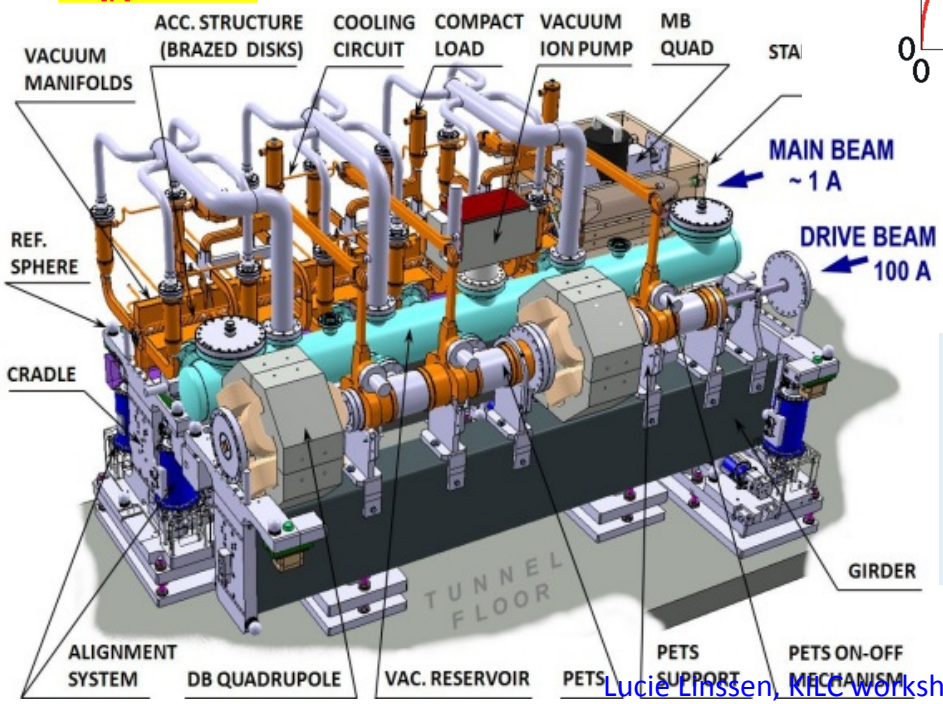
Unloaded 103MV/m
Expected with beam loading 86-103 MV/m

	Simple early design to get started	More efficient fully optimised structure
No damping waveguides	T18	T24
Damping waveguides	TD18	TD24 = CLIC goal

two-beam acceleration







Maximum gradient 145 MV/m

Consistency between
- produced power
- drive beam current
- test beam acceleration

accelerator achievements in CDR

Main linac gradient	– Ongoing test close to or on target – Uncertainty from beam l[illegible]ing
Drive beam scheme	– Generation tested, [illegible]elerate test beam, decelerati[illegible]cted – Improvemen[illegible]ation, reliability, losses, m[illegible]ation (more PETS) to come
Luminosity	– D[illegible]g like an ambitious light [illegible] show stopper [illegible]ent system principle demonstrated [illegible]bilisation system developed, benchmarked, better system in pipeline Simulations seem on or close to the target
Operation Machine P[illegible]n	– Start-up sequence defined – Most critical failure studied – First reliability studies – Low energy operation developed

ready for the next project phase

CLIC physics potential

CLIC physics potential is complementary to LHC

Beyond LHC discovery reach:

- e+e- collisions give access to additional physics pocesses
  - weakly interacting states (e.g. slepton, chargino, neutralino searches)
  - more clean conditions than in LHC
- Defined initial state + more precise measurements

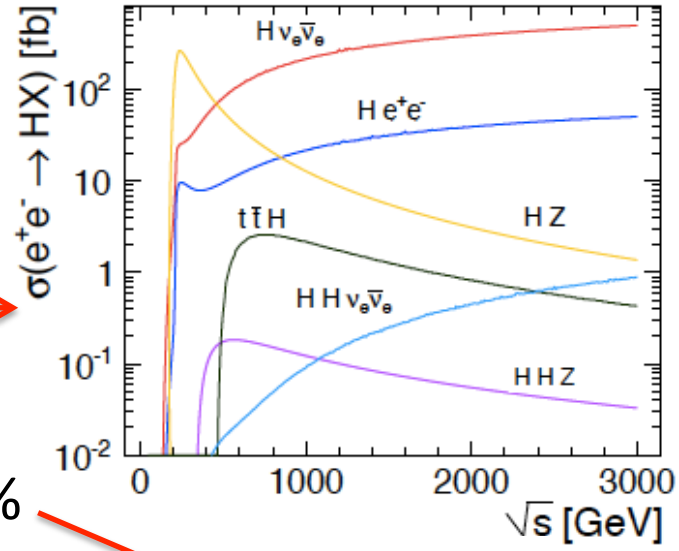
Examples highlighted in the CDR

- Higgs physics (SM and non-SM)
- Top
- SUSY
- Higgs strong interactions
- New Z' sector
- Contact interactions
- Extra dimensions
- Enhancement with polarised beams
- ….

SM Higgs

Standard model Higgs (example 120 GeV)

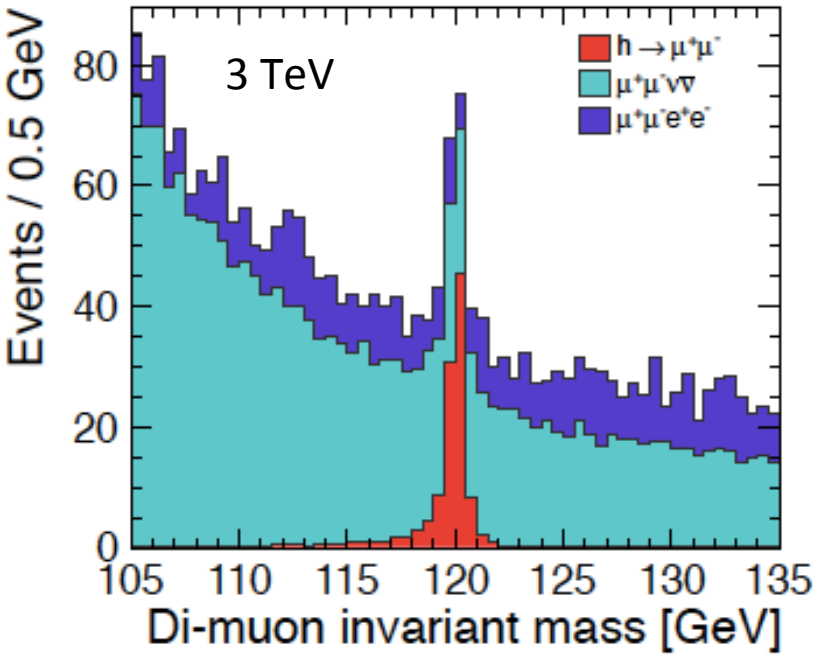
CLIC √s range give access to a wealth of Higgs studies

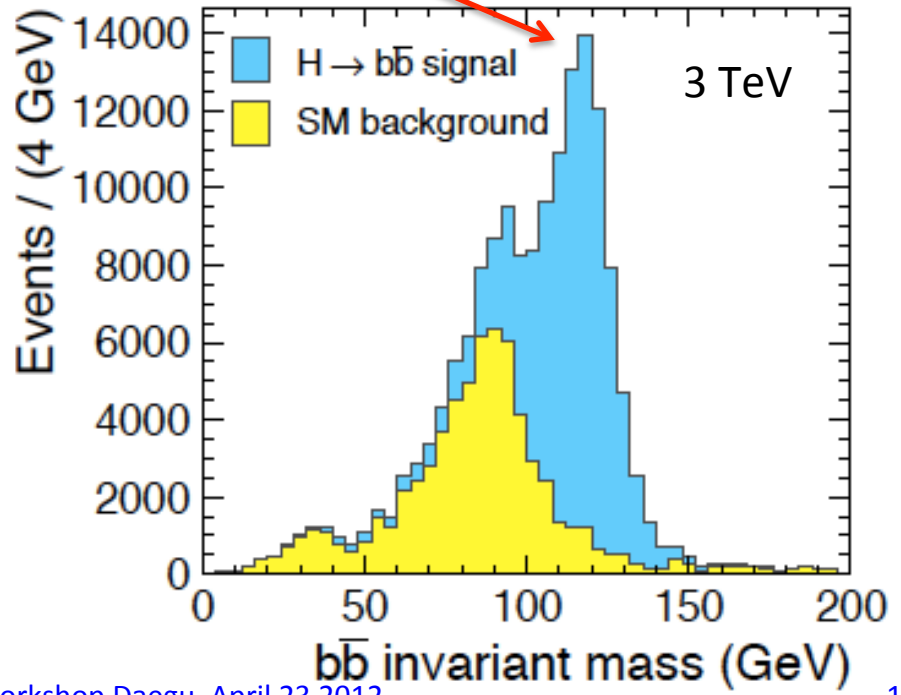


Results: Full simulation + Background overlay

$\sigma(h \rightarrow \mu^+\mu^-) \rightarrow \pm 15\%$

$\sigma(h \rightarrow b\bar{b}) \rightarrow \pm 0.2\%$



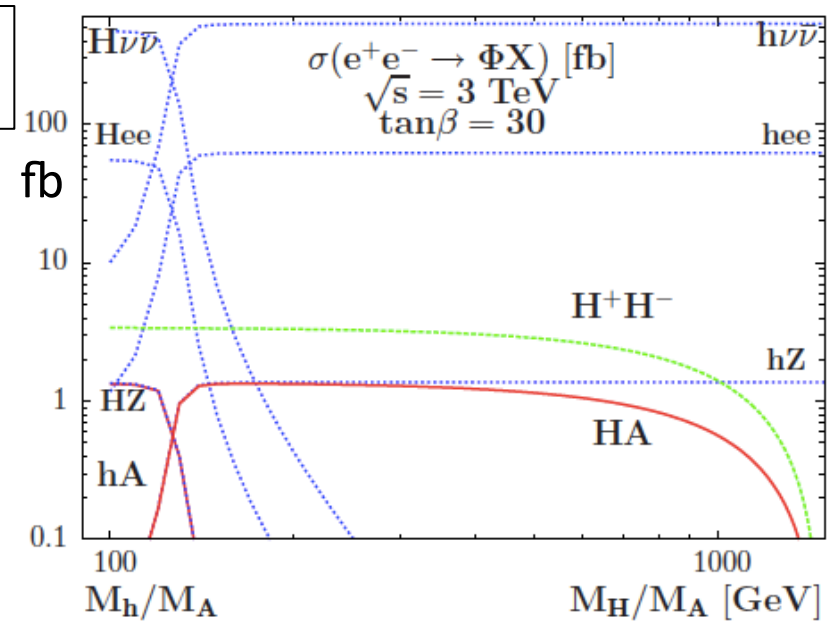


heavy Higgs, non-SM

Non-SM Higgs

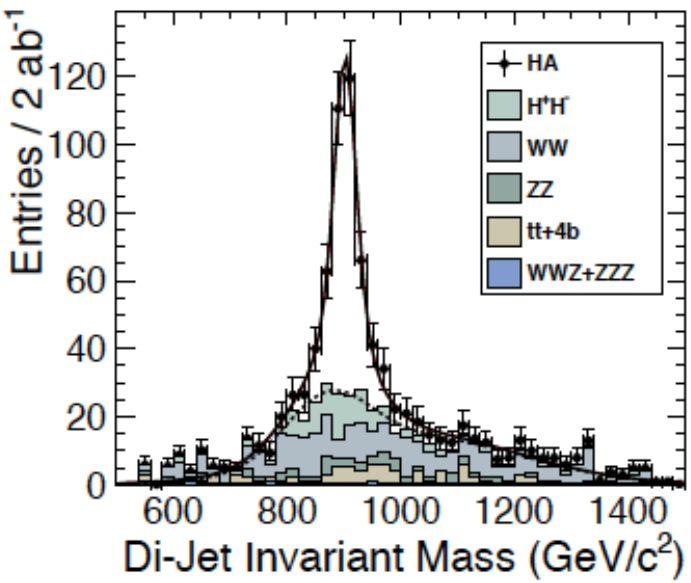
e.g. SUSY heavy Higgs

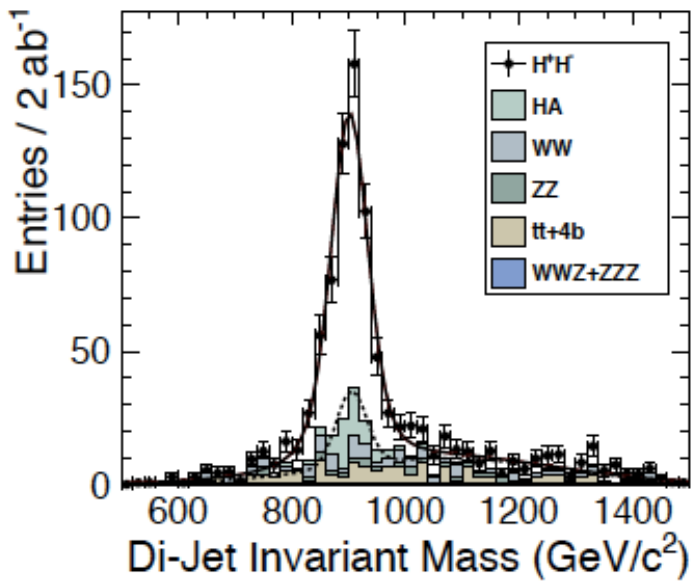
MSSM
3 TeV CM



m_{A^0/H^0} : ± 2.8 GeV

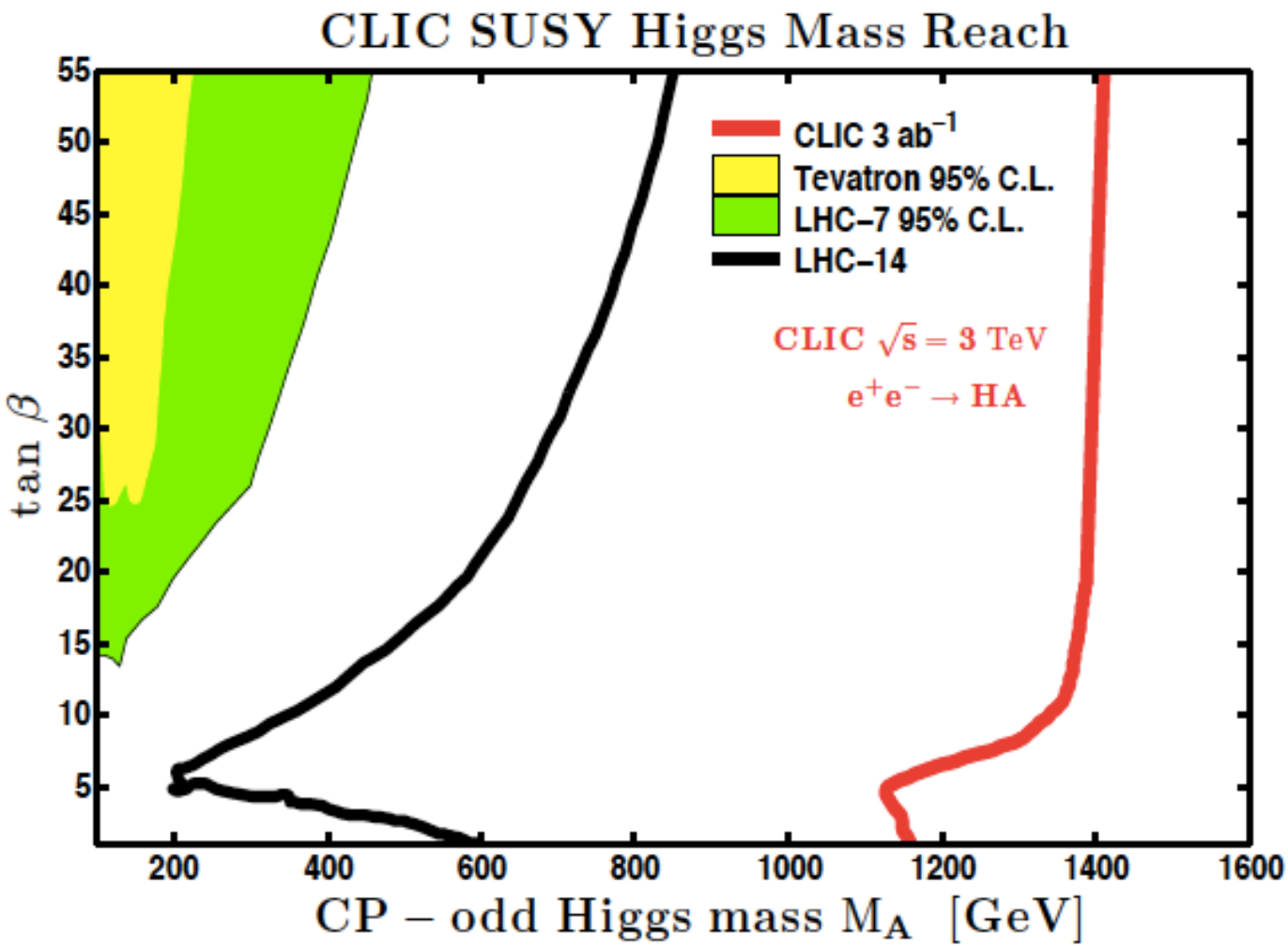
$m_{H^\pm}$: ± 2.4 GeV





heavy Higgs searches

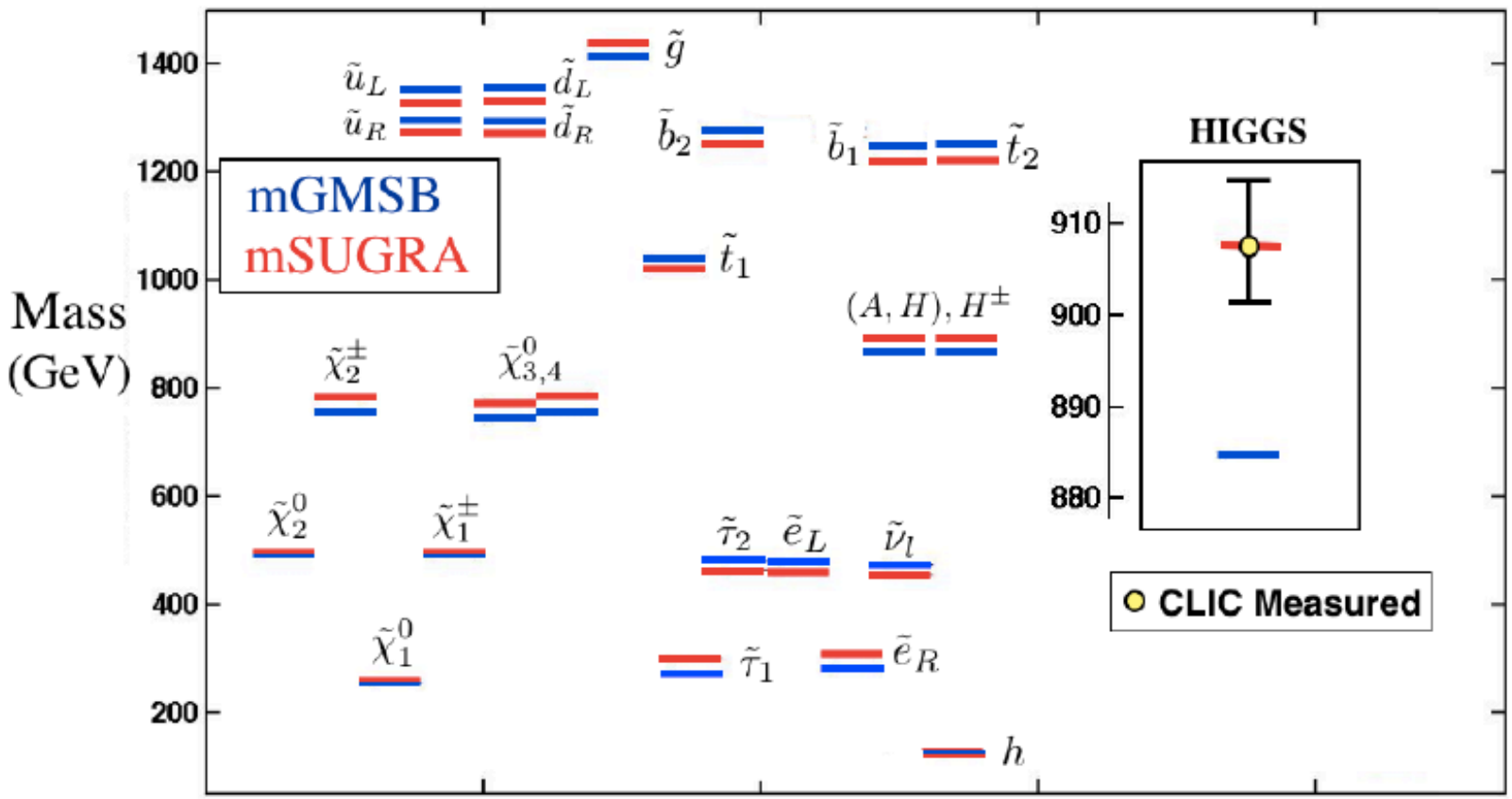
CLIC access to SUSY heavy Higgs searches



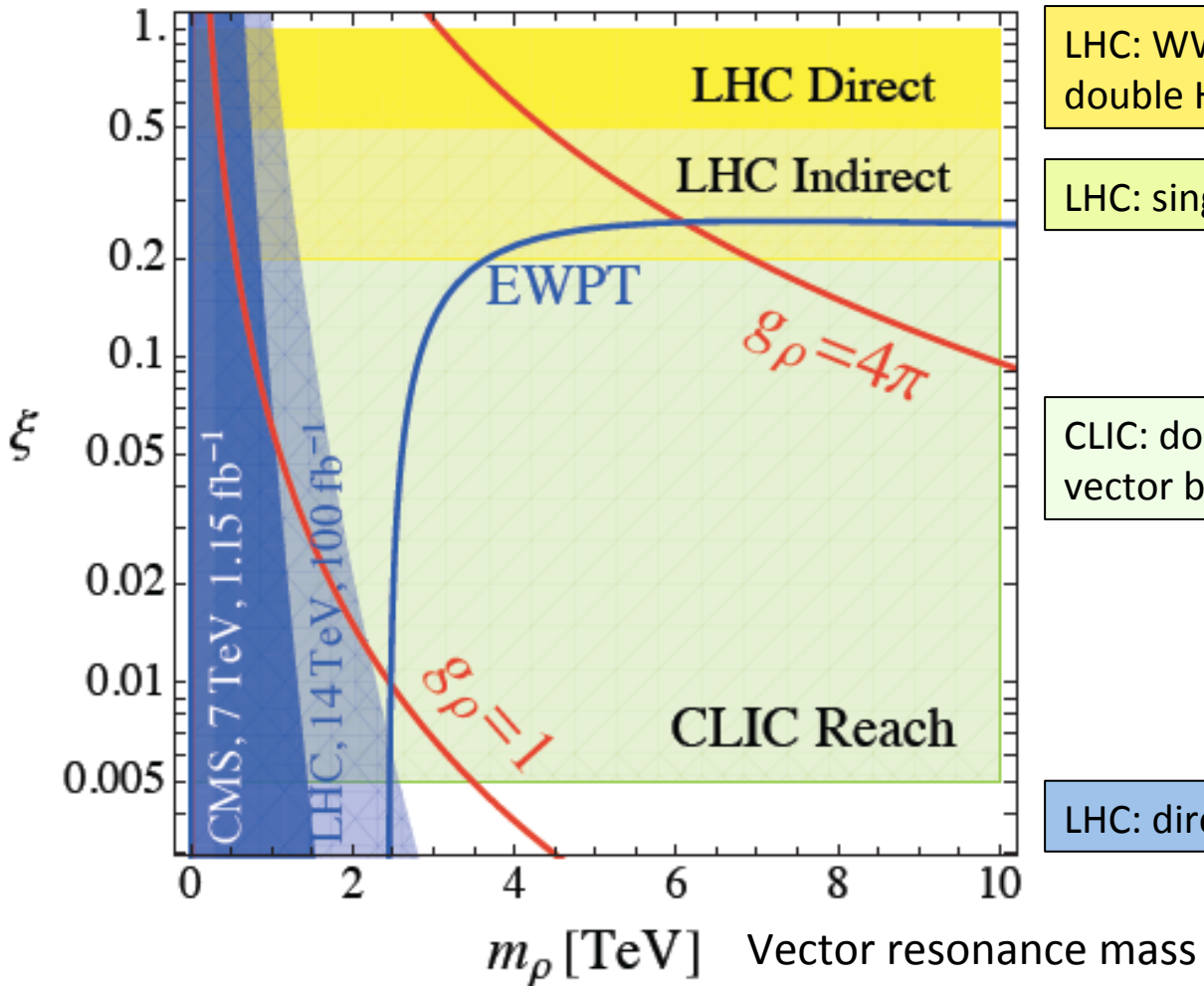
resolving new physics models

Precision measurements at CLIC allow to distinguish between models of new physics, e.g. following first observations at LHC

e.g. CLIC resolving power for SUSY breaking models



Higgs compositeness



Vector resonance mass

LHC: WW scattering and strong double Higgs production

LHC: single Higgs processes

CLIC: double Higgs production via vector boson fusion

LHC: direct search WZ =>3 leptons

Allows to probe Higgs compositeness at the 30 TeV scale for 1 ab^{-1} at 3 TeV

(60 TeV scale if combined with single Higgs production)

physics reach, short overview

Discovery reach (indicative) for new physics:

New particle	collider: $\mathscr{L}$:	LHC14 100 fb^{-1}	SLHC 1 ab^{-1}	LC800 500 fb^{-1}	CLIC3 1 ab^{-1}
squarks [TeV]		2.5	3	0.4	1.5
sleptons [TeV]		0.3	-	0.4	1.5
Z' (SM couplings) [TeV]		5	7	8	20
2 extra dims M_D [TeV]		9	12	5-8.5	20-30
TGC (95%) (λ_γ coupling)		0.001	0.0006	0.0004	0.0001
μ contact scale [TeV]		15	-	20	60
Higgs compos. scale [TeV]		5-7	9-12	45	60

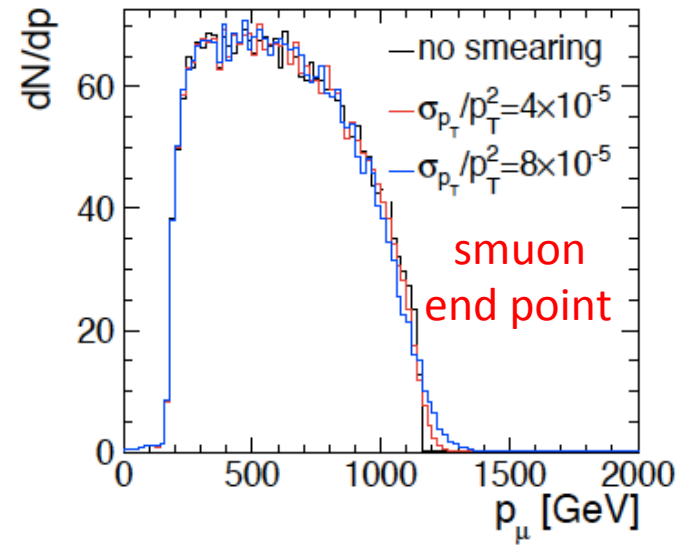
physics aims => detector needs

★ momentum resolution:

e.g. Smuon endpoint

Higgs recoil mass, Higgs coupling to muons

$$\sigma_{p_T}/p_T^2 \sim 2\times 10^{-5}\ \mathrm{GeV}^{-1}$$

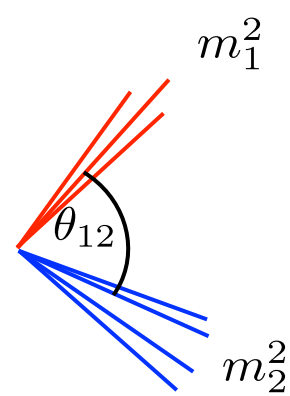


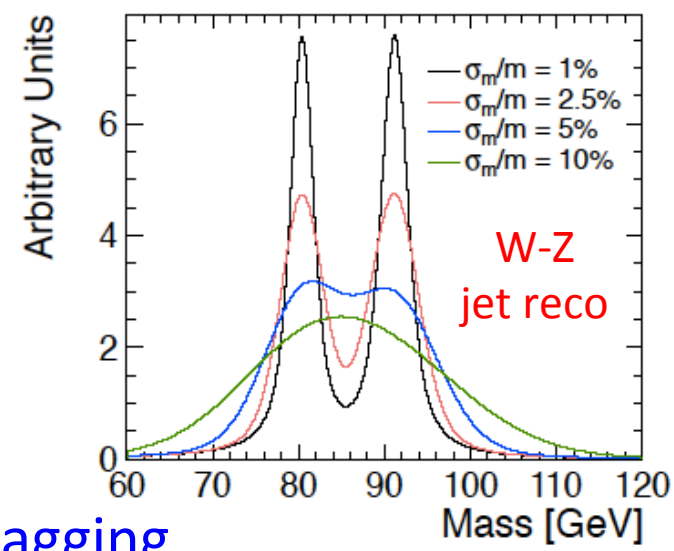
★ jet energy resolution:

e.g. W/Z/h di-jet mass separation

$$\frac{\sigma_E}{E} \sim 3.5-5\,\%$$

(for high-E jets)





★ impact parameter resolution:

e.g. c/b-tagging, Higgs BR

$$\sigma_{r\phi} = 5 \oplus 15/(p[\mathrm{GeV}]\sin^{\frac{3}{2}}\theta)\,\mu\mathrm{m}$$

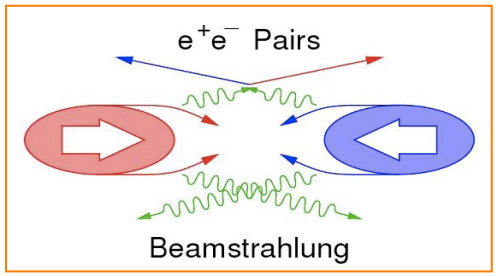
★ angular coverage, very forward electron tagging

CLIC machine environment (1)

	CLIC at 3 TeV
L ($cm^{-2}s^{-1}$)	5.9×10^{34}
BX separation	0.5 ns
#BX / train	312
Train duration (ns)	156
Rep. rate	50 Hz
σ_x / σ_y (nm)	≈ 45 / 1
σ_z (μm)	44

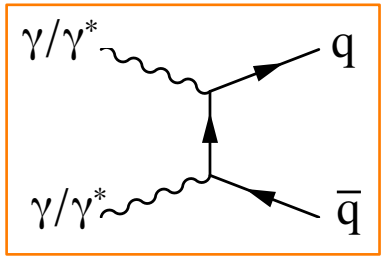
Drives timing requirements for CLIC detector

very small beam size



Beam related background:

- Small beam profile at IP leads very high E-field
  - **Beamstrahlung**
    - Pair-background
    - γγ to hadrons

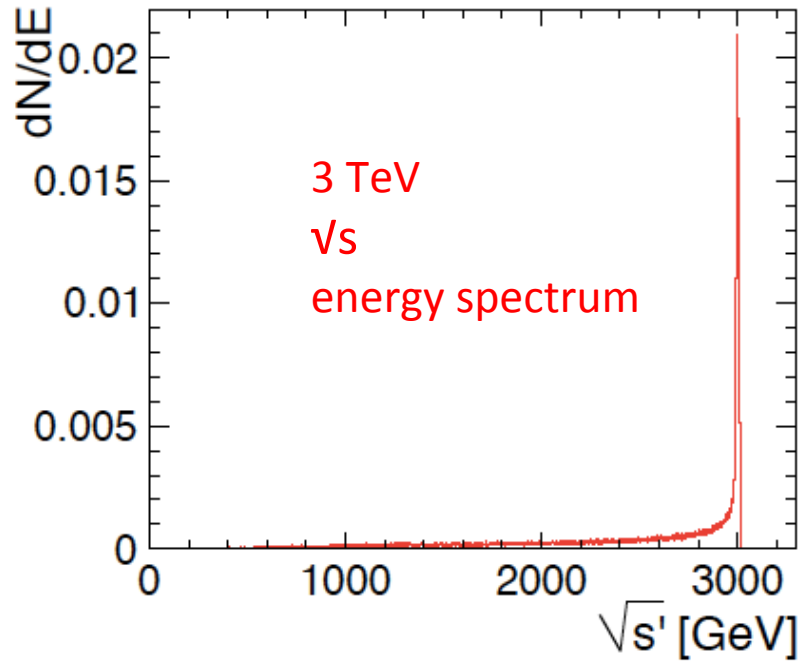


CLIC machine environment (2)

Beamstrahlung ➔ important energy losses right at the interaction point

Full luminosity:
5.9×10^{34} cm^{-2}s^{-1}
Of which in the 1% most energetic part:
2.0×10^{34} cm^{-2}s^{-1}

Most physics processes are studied well above production threshold => profit from full luminosity



Coherent e^+e^- pairs
- 7×10^8 per BX, very forward

Incoherent e^+e^- pairs
- 3×10^5 per BX, rather forward

$\gamma\gamma \rightarrow$ hadrons
- 3.2 evts. per BX
- main background in calorimeters

➔

Simplified view:
Pair background
- Design issue (high occupancies)

$\gamma\gamma \rightarrow$ hadrons
- Impacts on the physics
- Needs suppression in data

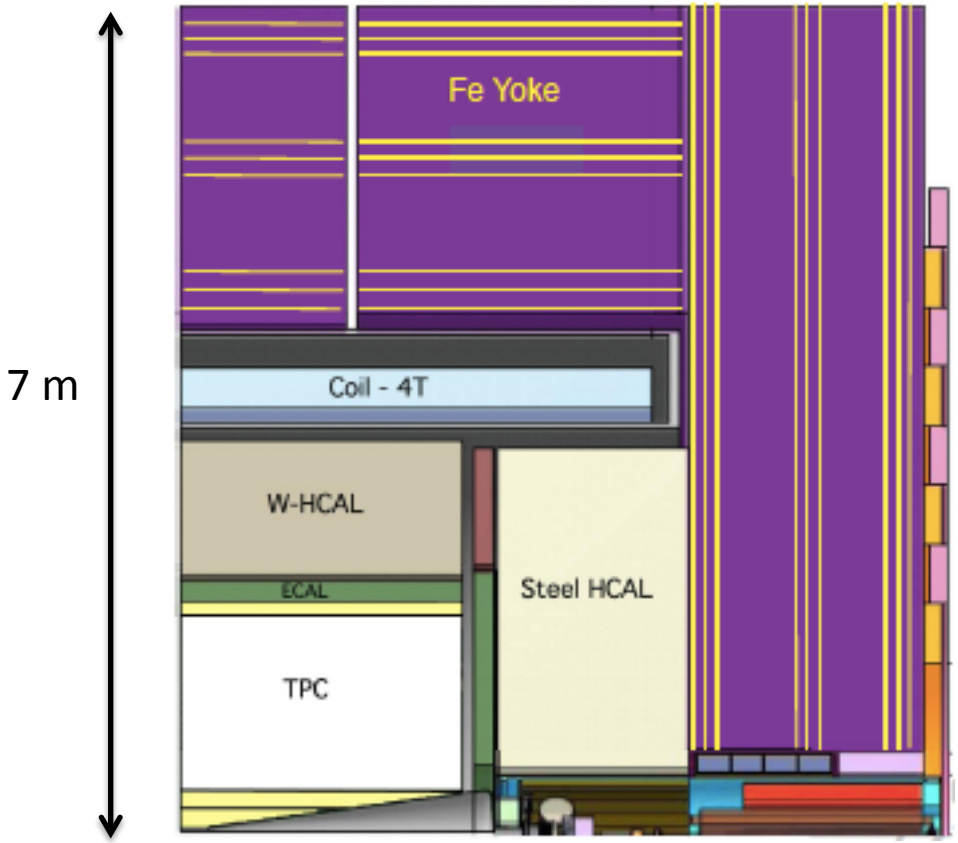
CLIC_ILD and CLIC_SiD

Two general-purpose CLIC detector concepts

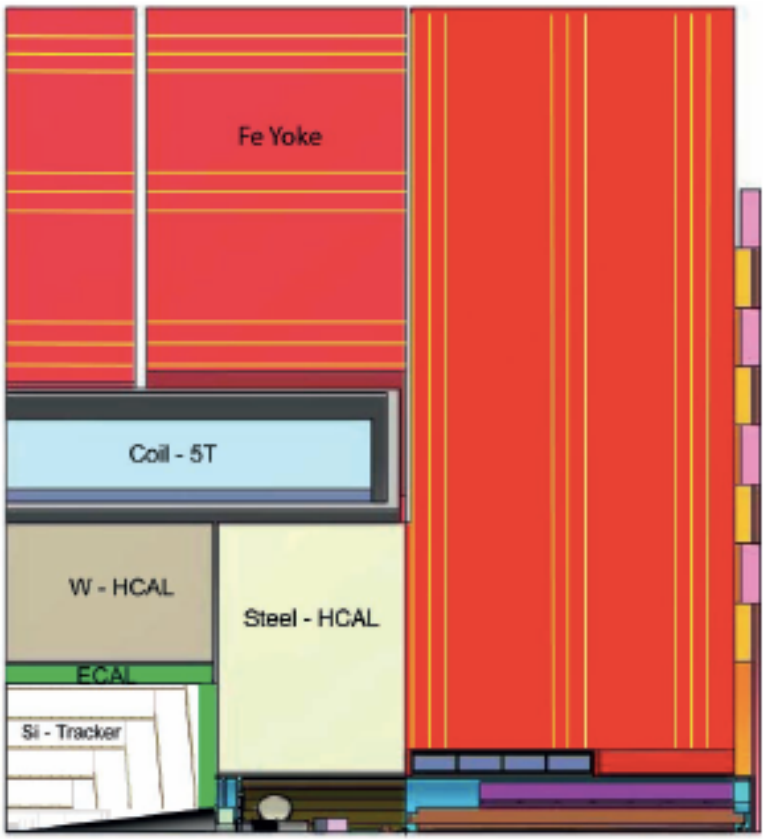
Based in initial ILC concepts (ILD and SiD)

Optimised and adapted to CLIC conditions

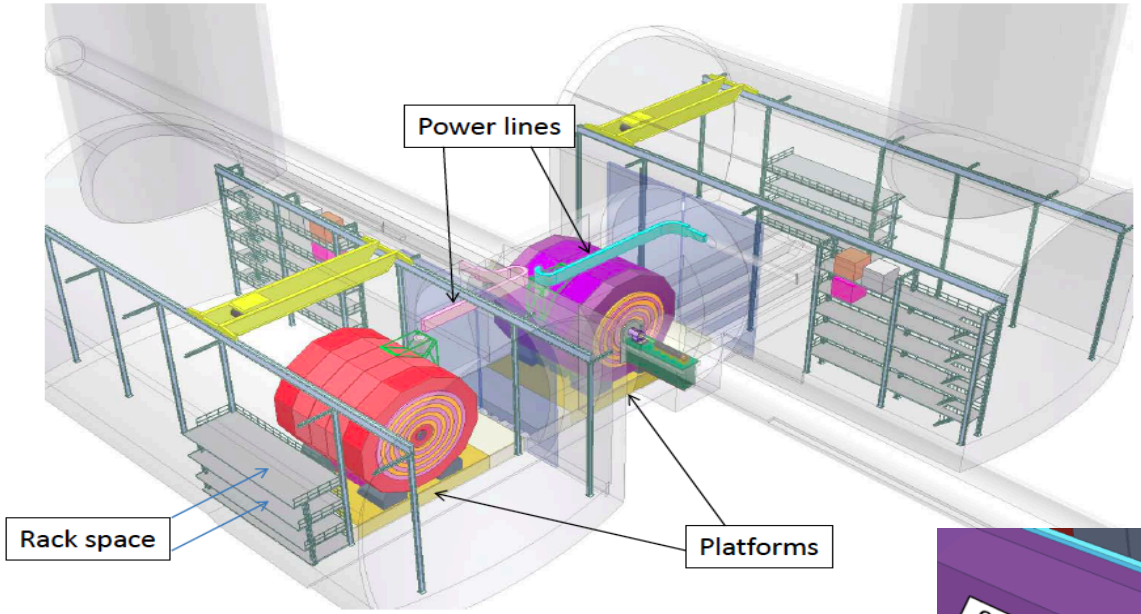
CLIC_ILD



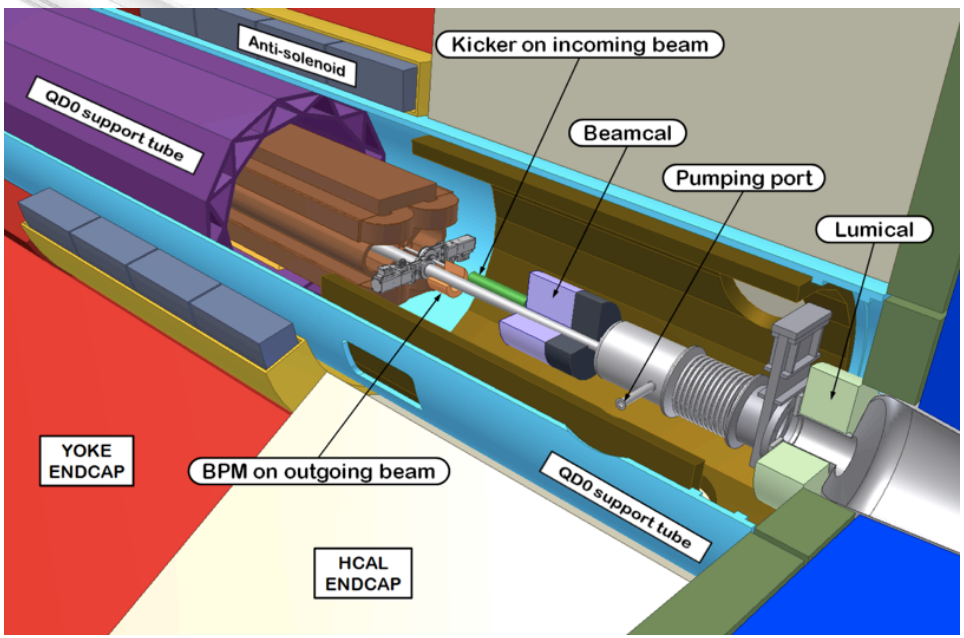
CLIC_SiD



Engineering / push-pull / forward region



see talk A. Gaddi 25/4 MDI

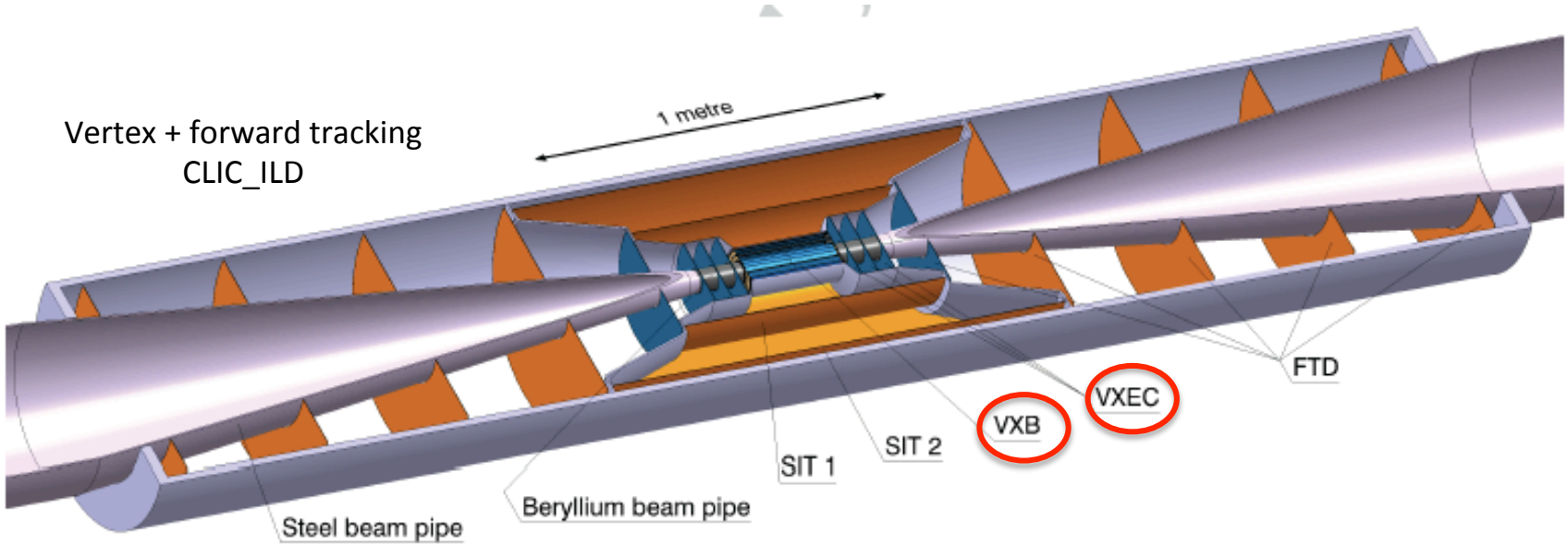


see talk W. Lohmann 24/4 MDI

see talk H. Gerwig 25/4 MDI

vertex detector

Vertex + forward tracking
CLIC_ILD



- ~20×20 µm pixel size
- 0.2% X_0 material par layer <= very thin !
  - Very thin materials/sensors
  - Low-power design, power pulsing, air cooling
- Time stamping 10 ns
- Radiation level $<10^{11}$ $n_{eq}cm^{-2}year^{-1}$ <= 10^4 lower than LHC

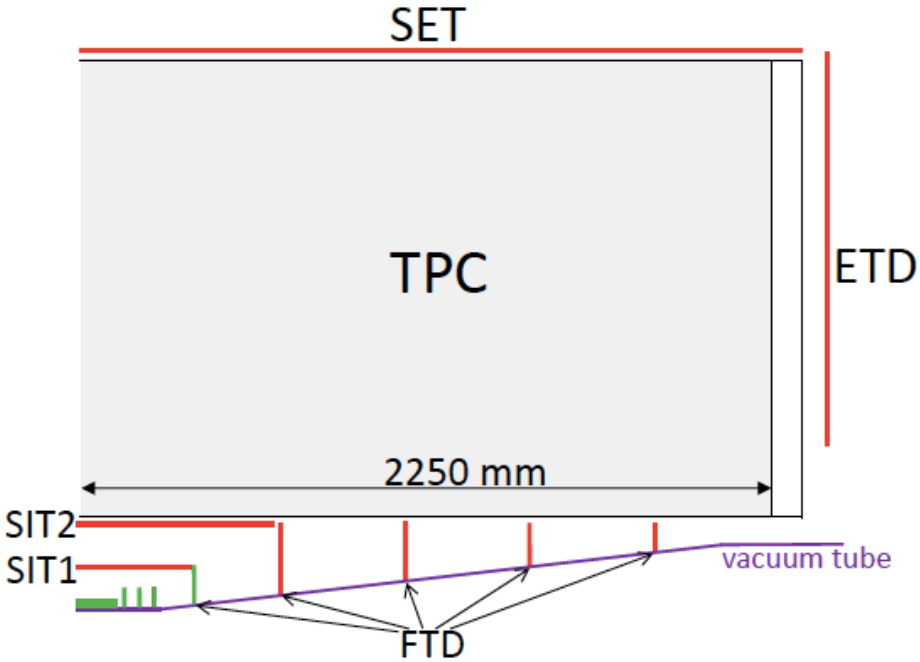
Challenging ongoing R&D project

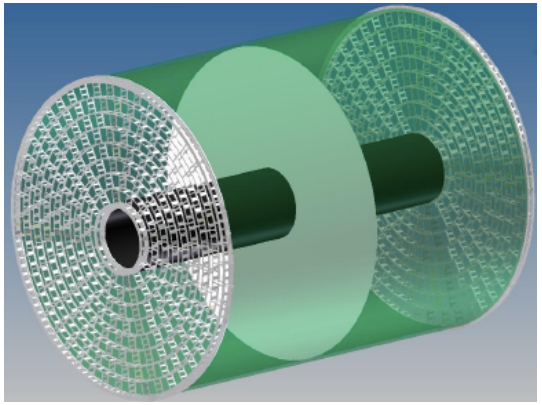
see talk D. Dannheim 24/4 ACFA trackers

see talk H. Gerwig24/4 ACFA trackers

CLIC_ILD ↙ and CLIC_SiD ↘ tracker

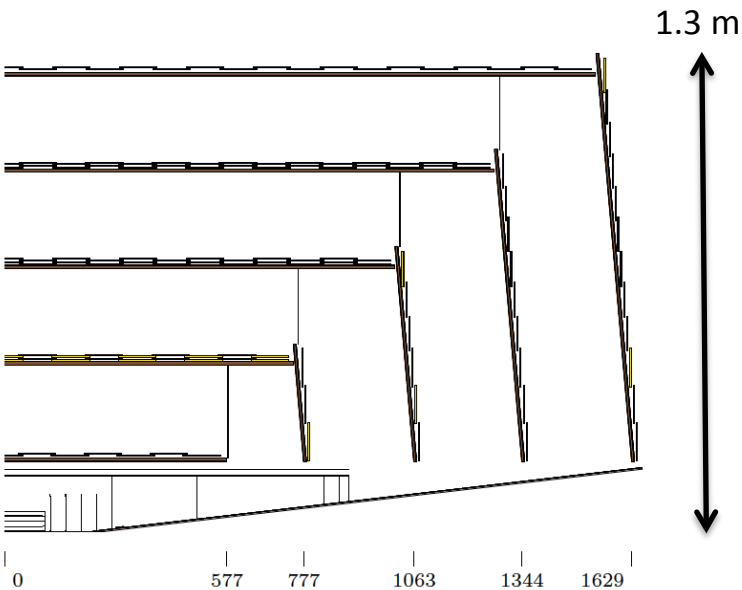
TPC + silicon tracker in 4 Tesla field

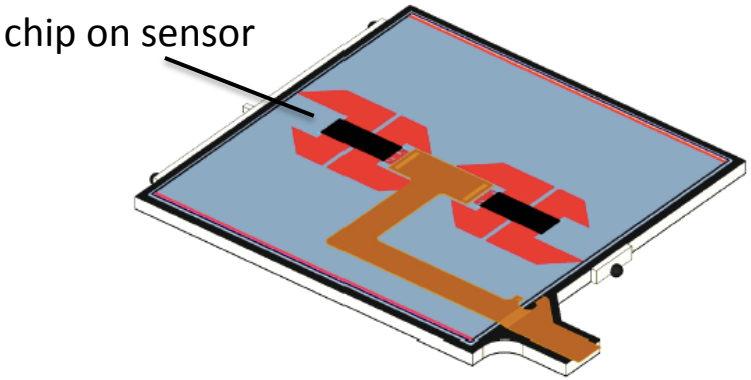




Time Projection Chamber (TPC) with MPGD readout

all-silicon tracker in 5 Tesla field





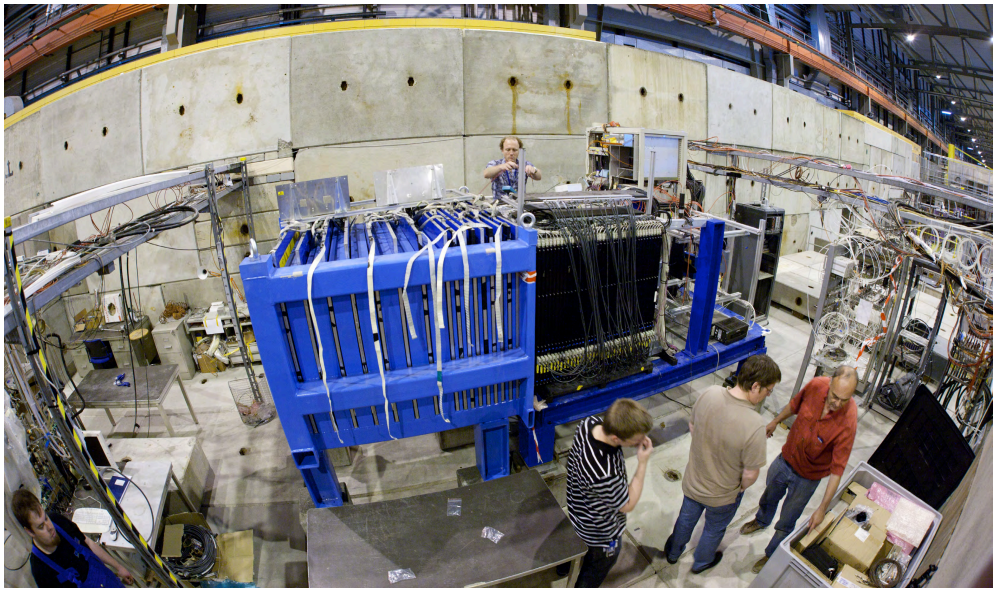
calorimetry and PFA

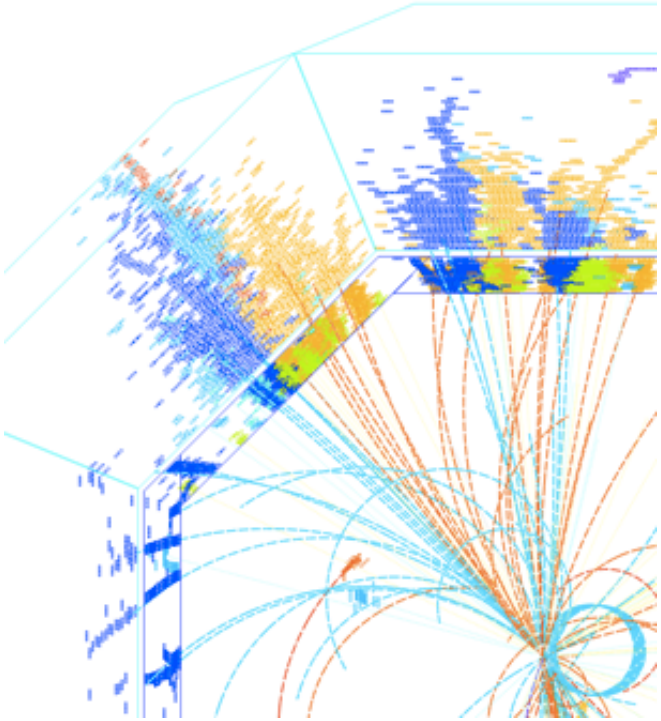
Jet energy resolution and **background rejection** drive the overall detector design

=> => fine-grained calorimetry + Particle Flow Analysis (PFA)

HCAL:
Several technology options
Tungsten (barrel), steel (endcap)
cell sizes 9 cm^2 (analog) or 1 cm^2 (digital)
60-75 layers in depth
Total depth 7.5 Λ_i

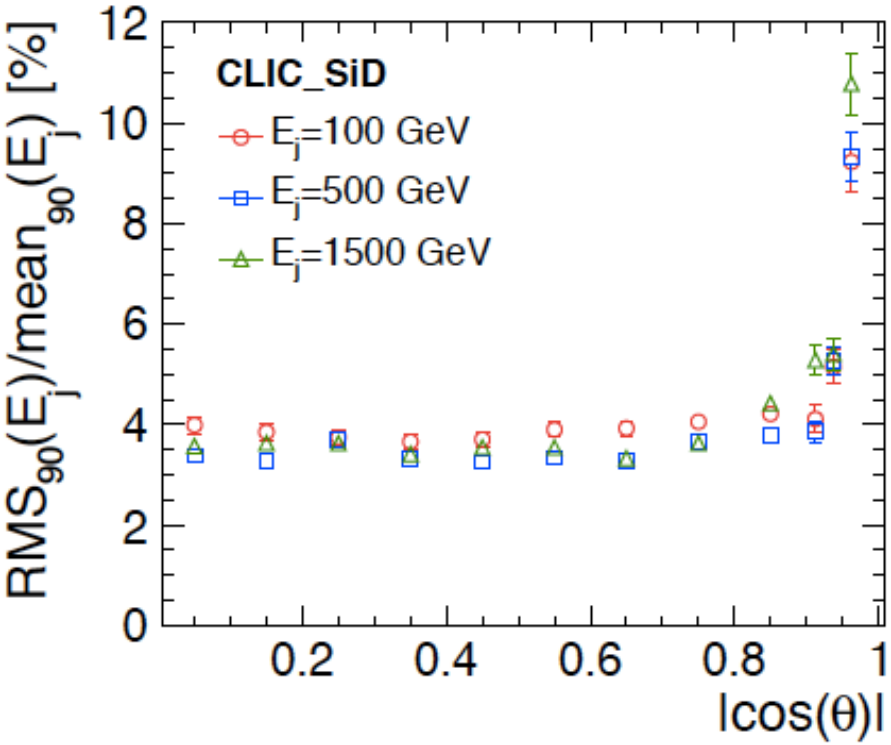
ECAL:
Si or Scint. (active) + Tungsten (absorber)
cell sizes 13 mm^2 or 25 mm^2
30 layers in depth

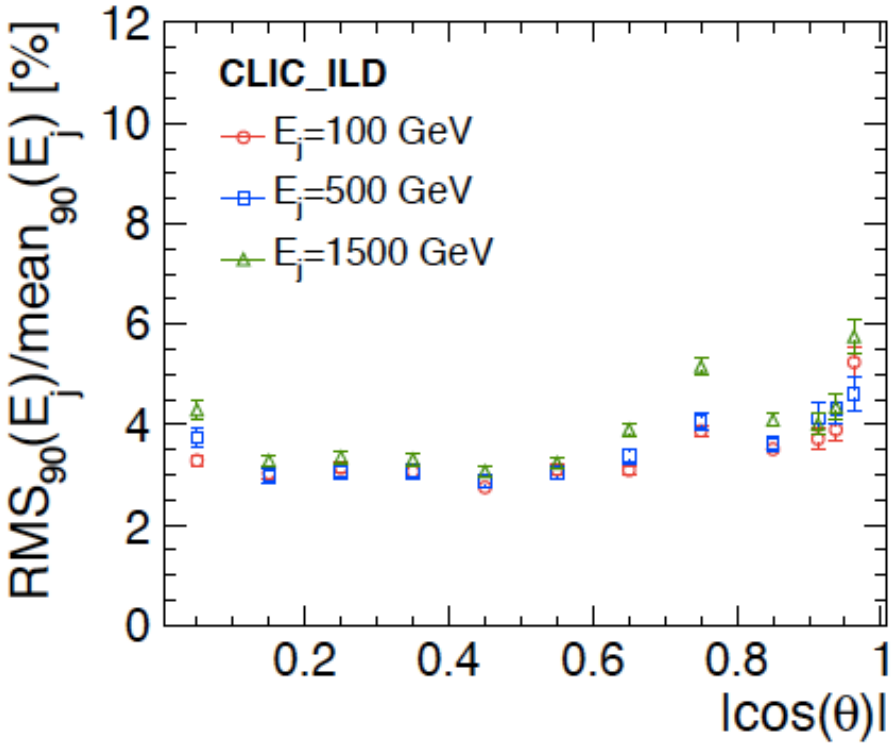




calorimetry and PFA

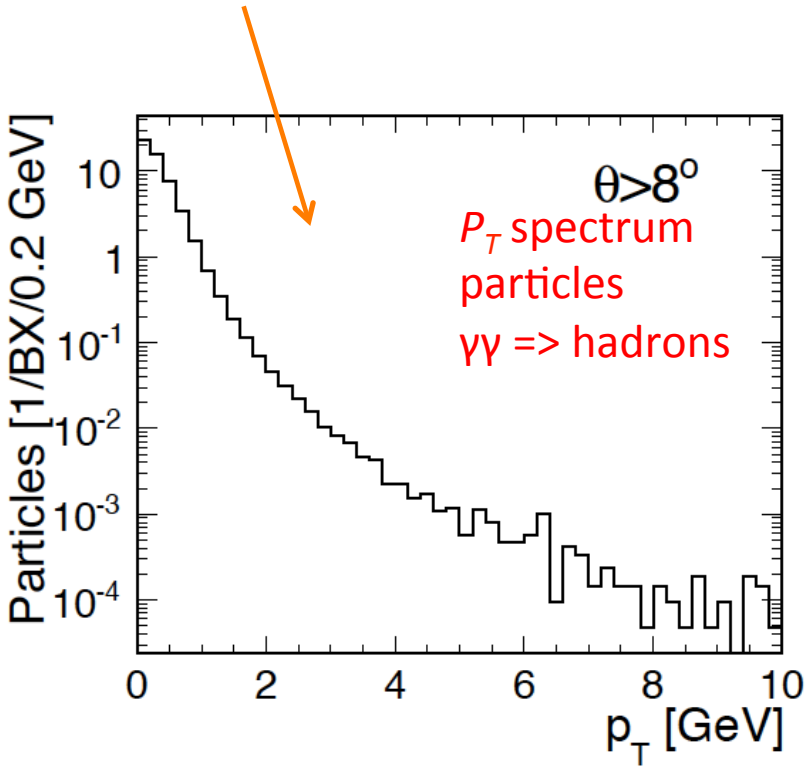
jet energy resolution
(no jet clustering, no background overlay)

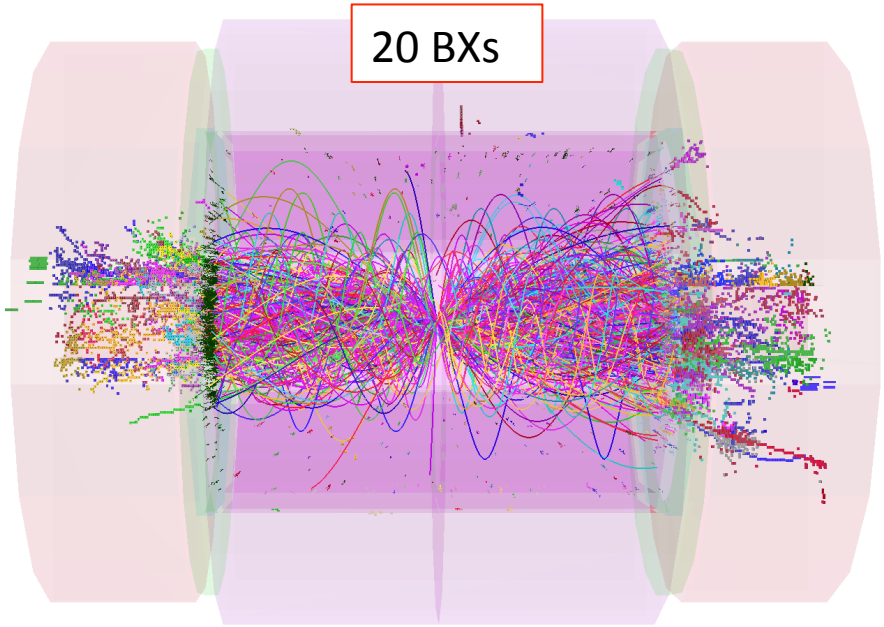




impact of γγ → hadrons

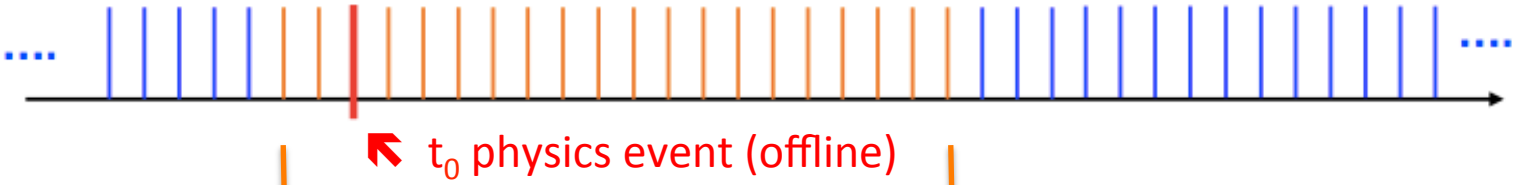
- Dominating background
- For entire bunch-train (312 BXs)
  - 5000 tracks giving total track momentum : 7.3 TeV
  - Total calorimetric energy (ECAL + HCAL) : 19 TeV
- Mostly low p_T particles



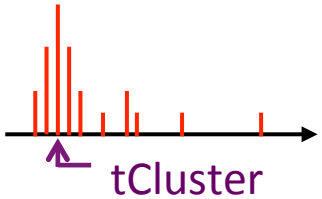


background suppression at CLIC

Triggerless readout of full train



- **Full event reconstruction + PFA analysis with background overlaid**
  - => physics objects with precise p_T and cluster time information
  - Time corrected for shower development and TOF
- **Then apply cluster-based timing cuts**
  - Cuts depend on particle-type, p_T and detector region
  - Allows to protect high-p_T physics objects



+

- **Use well-adapted jet clustering algorithms**
  - Making use of LHC experience (FastJet)

time window / time resolution

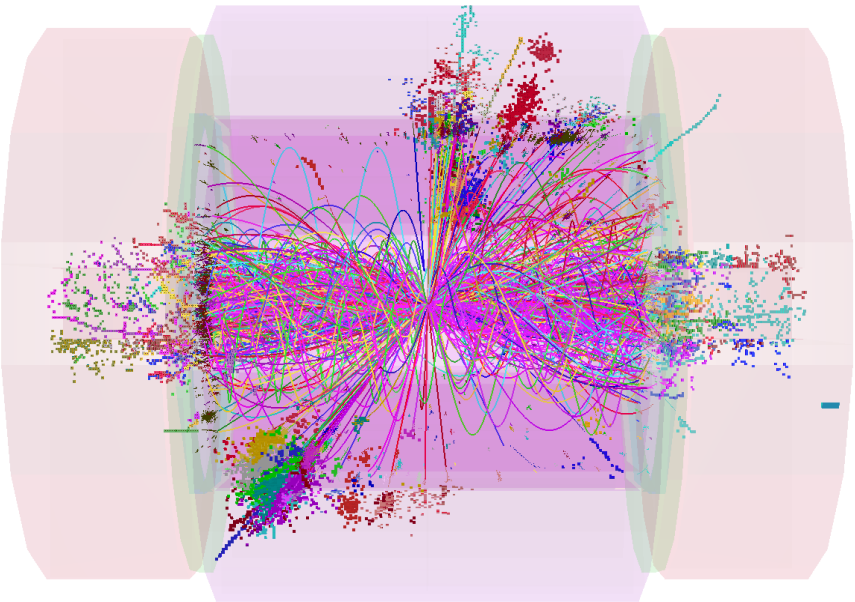
The event reconstruction software uses:

Subdetector	Reconstruction window	hit resolution
ECAL	10 ns	1 ns
HCAL Endcaps	10 ns	1 ns
HCAL Barrel	100 ns	1 ns
Silicon Detectors	10 ns	$10/\sqrt{12}$ ns
TPC	entire bunch train	n/a

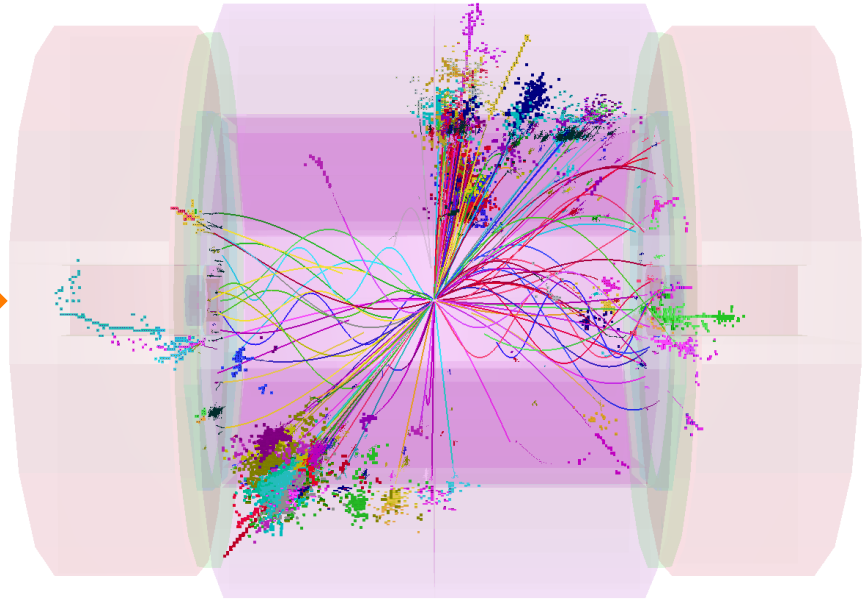
Translates in precise timing requirements of the sub-detectors

combined p_T and timing cuts

1.2 TeV



100 GeV



$$e^+e^- \rightarrow H^+H^- \rightarrow t\bar{b}b\bar{t} \rightarrow 8 \text{ jets}$$

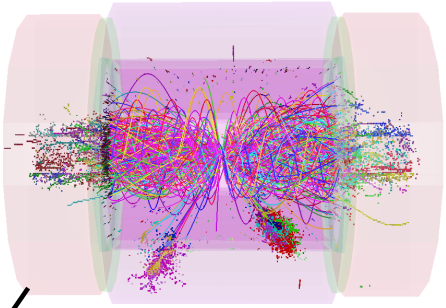
1.2 TeV background in reconstruction time window

100 GeV background after tight cuts

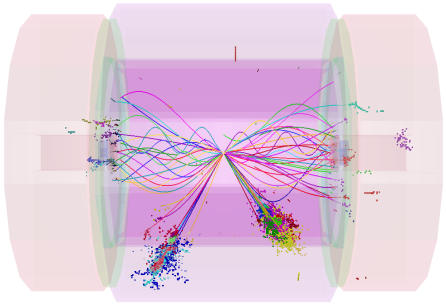
jet clustering (example)

e.g. $e^+e^- \rightarrow \tilde{q}_R\tilde{q}_R \rightarrow q\bar{q}\,\tilde{\chi}_1^0\,\tilde{\chi}_1^0$

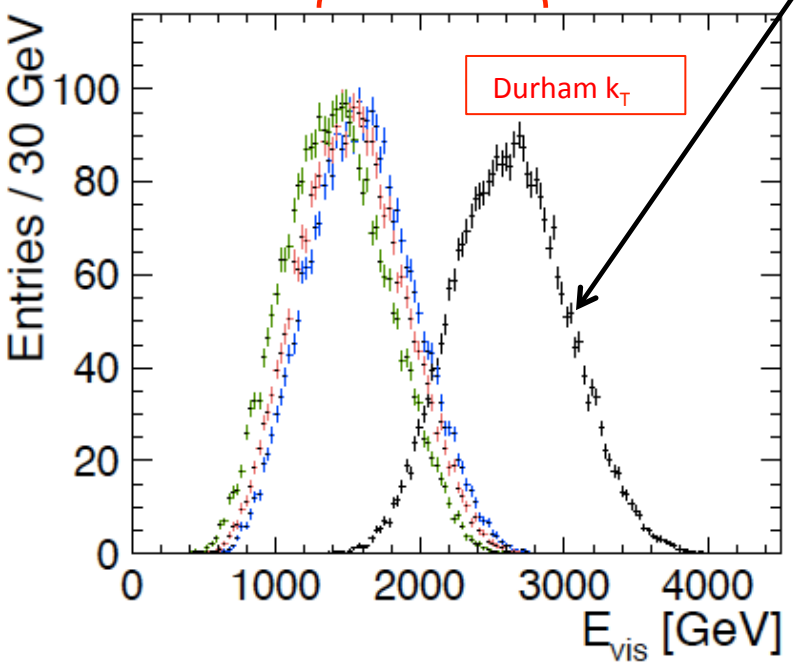
- for squark mass ~1.1 TeV
- two jets + missing energy

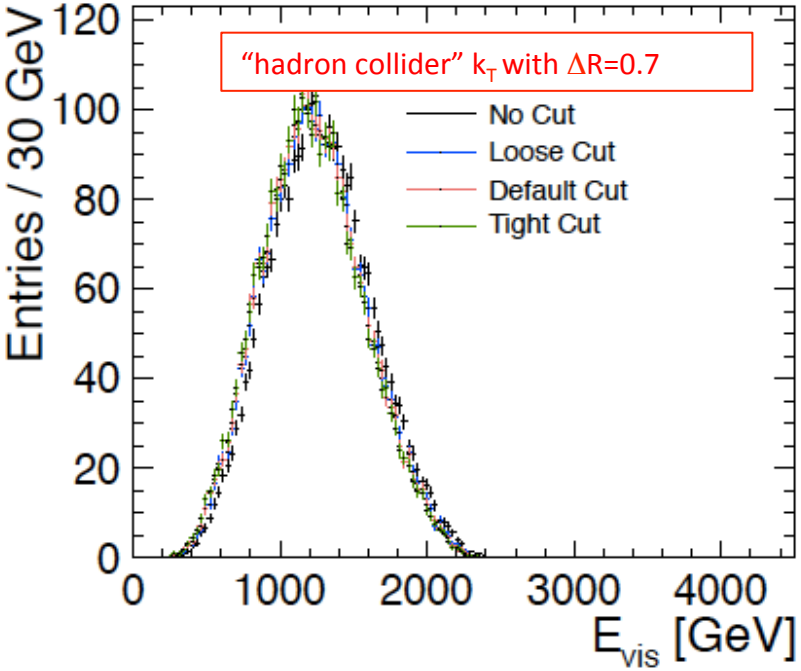


TIGHT timing



All particles clustered





Result of this detector benchmark study: $m_{\tilde{q}_R}$: $\pm 6\,\mathrm{GeV}$

summary of CDR benchmark studies (1)

Table 12.19: Summary table of the CLIC benchmark analyses results. All studies at a centre-of-mass energy of 3 TeV are performed for an integrated luminosity of 2 ab^{-1}. The study at 500 GeV assumes an integrated luminosity of 100 fb^{-1}.

$\sqrt{s}$ (TeV)	Process	Decay mode	SUSY model	Observable	Unit	Generator value	Stat. uncertainty
3.0	Light Higgs production	$h \to b\bar{b}$ $h \to c\bar{c}$ $h \to \mu^+\mu^-$		σ $\times$ Branching ratio	fb	285 13 0.12	0.22% 3.2% 15.7%
3.0	Heavy Higgs production	$HA \to b\bar{b}b\bar{b}$	I	Mass Width	GeV GeV	902.4	0.3% 31%
			II	Mass Width	GeV GeV	742.0	0.2% 17%
		$H^+H^- \to t\bar{b}b\bar{t}$	I	Mass Width	GeV GeV	906.3	0.3% 27%
			II	Mass Width	GeV GeV	747.6	0.3% 23%
3.0	Production of right-handed squarks	$\tilde{q}_R\tilde{q}_R \to q\bar{q}\tilde{\chi}_1^0\tilde{\chi}_1^0$	I	Mass σ	GeV fb	1123.7 1.47	0.52% 4.6%

see talk F. Simon 24/4 ACFA trackers

summary of CDR benchmark studies (2)

3.0	Sleptons production	$\tilde{\mu}_R^+\tilde{\mu}_R^- \to \mu^+\mu^-\tilde{\chi}_1^0\tilde{\chi}_1^0$	II	σ	fb	0.72	2.8%
				$\tilde{\ell}$ mass	GeV	1010.8	0.6%
				$\tilde{\chi}_1^0$ mass	GeV	340.3	1.9%
		$\tilde{e}_R^+\tilde{e}_R^- \to e^+e^-\tilde{\chi}_1^0\tilde{\chi}_1^0$		σ	fb	6.05	0.8%
				$\tilde{\ell}$ mass	GeV	1010.8	0.3%
				$\tilde{\chi}_1^0$ mass	GeV	340.3	1.0%
		$\tilde{e}_L^+\tilde{e}_L^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 e^+e^- hh$ $\tilde{e}_L^+\tilde{e}_L^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 e^+e^- Z^0Z^0$		σ	fb	3.07	7.2%
		$\tilde{\nu}_e\tilde{\nu}_e \to \tilde{\chi}_1^0\tilde{\chi}_1^0 e^+e^- W^+W^-$		σ	fb	13.74	2.4%
				$\tilde{\ell}$ mass	GeV	1097.2	0.4%
				$\tilde{\chi}_1^\pm$ mass	GeV	643.2	0.6%
3.0	Chargino and neutralino production	$\tilde{\chi}_1^+\tilde{\chi}_1^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 W^+W^-$	II	$\tilde{\chi}_1^\pm$ mass	GeV	643.2	1.1%
				σ	fb	10.6	2.4%
		$\tilde{\chi}_2^0\tilde{\chi}_2^0 \to h^0/Z^0h^0/Z^0\tilde{\chi}_1^0\tilde{\chi}_1^0$		$\tilde{\chi}_2^0$ mass	GeV	643.1	1.5%
				σ	fb	3.3	3.2%
0.5	$t\bar{t}$ production	$t\bar{t} \to (q\bar{q}b)(q\bar{q}b)$		Mass	GeV	174	0.046%
				Width	GeV	1.37	16%
		$t\bar{t} \to (q\bar{q}b)(\ell\nu b)$, $\ell = e, \mu$		Mass	GeV	174	0.052%
				Width	GeV	1.37	18%

Physics/detector objectives: 2012-2016

Implementation study and technical demonstration phase

Lots of work in common with ILC !

Physics studies, following up on 7-8 TeV and 14 TeV LHC results

- Exploration of SM physics (incl. Higgs, top) and reach for new physics
- Adaptation of strategy for CLIC energy staging and luminosity levels

Detector optimisation

- General detector optimisation + simulation studies in close relation with detector R&D

R&D: Implementation examples *demonstrating* the required functionality

- Vertex detector
  - Demonstration module that meets the requirements
- Main tracker
  - Demonstration modules, including manageable occupancies in the event reconstruction
- Calorimeters
  - Demonstration modules, technological prototypes + addressing control of cost
- Electronics
  - Demonstrators, in particular in view of power pulsing
- Magnet systems
  - Demonstrators of conductor technology, safety systems and moveable service lines
- Engineering and detector integration
  - Engineering design and detector integration harmonized with hardware R&D demonstrators

Challenging detector technologies, considered feasible in a 5-year R&D program

CLIC energy staging

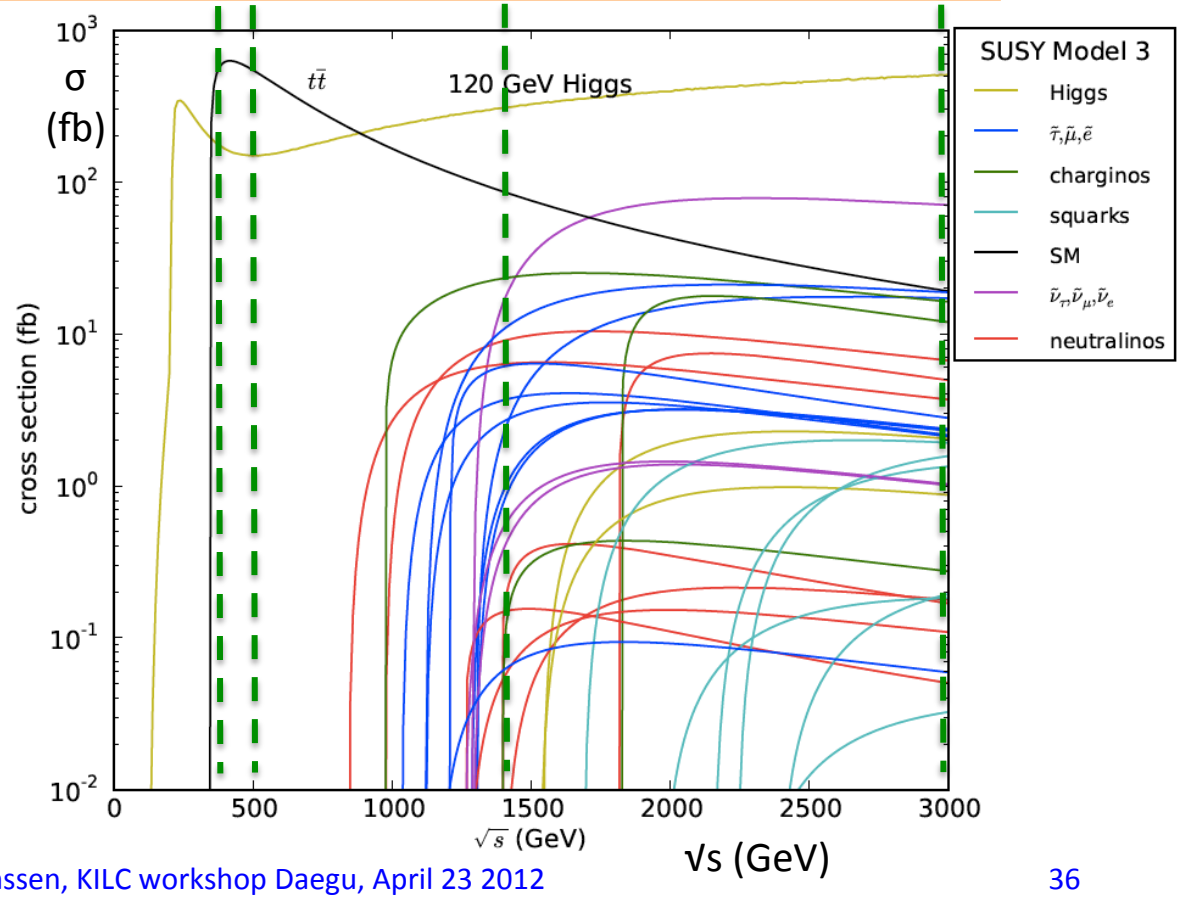
- Majority of CDR studies done at √s = 3.0 TeV
  - most challenging for beam-induced backgrounds in the detector
  - ultimate physics reach
- Staged construction and operation of CLIC
  - Address SM physics (Higgs, top, etc.) at lower-E stage
  - Explore new physics and ultimate physics goal at higher-E stage

Example of CLIC energy staging currently studied for Volume 3 of the CDR

Accelerator + detector

Including cost + schedule + power consumption

Study of Physics reach based on Higgs, top and a specific SUSY model



New benchmark studies, staged energy

Currently ongoing benchmark studies with staged energies
(In addition to studies already reported in the CDR)

Stage 1: E_{cm} = 500 GeV machine (+350 GeV running)
$\mathcal{L}_{int}$ = 500 fb^{-1}
Higgs mass measurement (500 GeV, 350 GeV)
t-tbar threshold scan (350 GeV)

Stage 2: E_{cm} = 1.4 TeV
$\mathcal{L}_{int}$ = 1.5 ab^{-1}
triple Higgs coupling
SUSY studies with "Model 3"
sleptons (inc. stau), gauginos

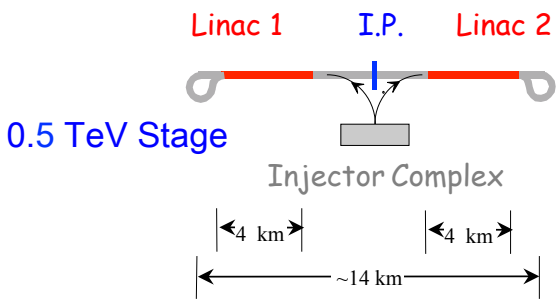
Stage 3: E_{cm} = 3 TeV
$\mathcal{L}_{int}$ = 2 ab^{-1}
triple Higgs coupling

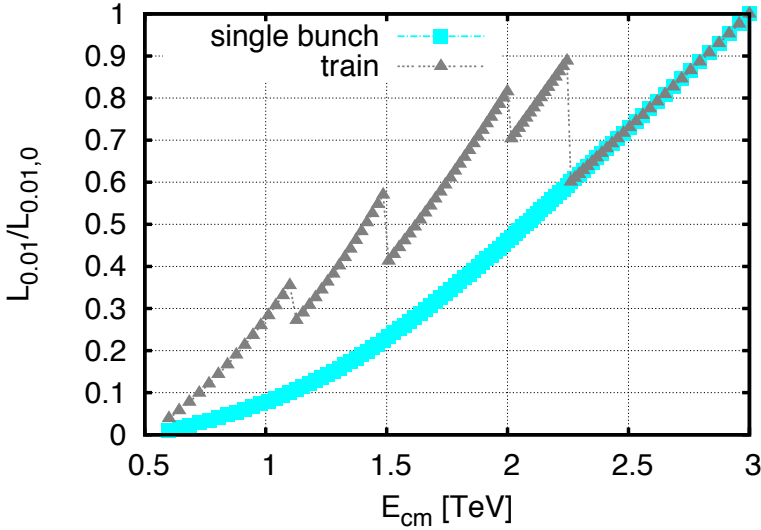
see talk F. Simon 24/4 ACFA trackers

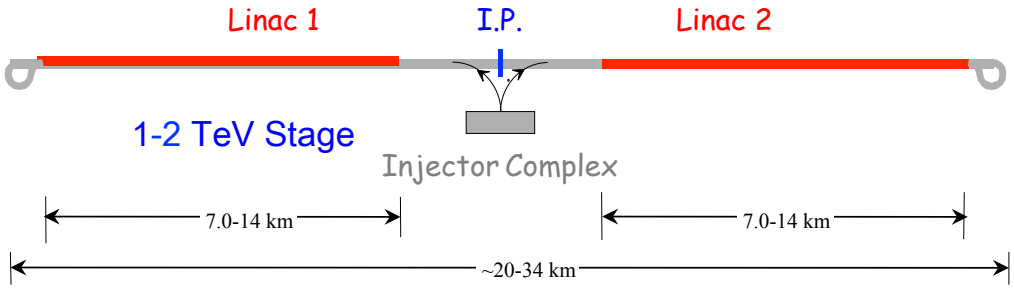
CLIC Implementation – in stages?

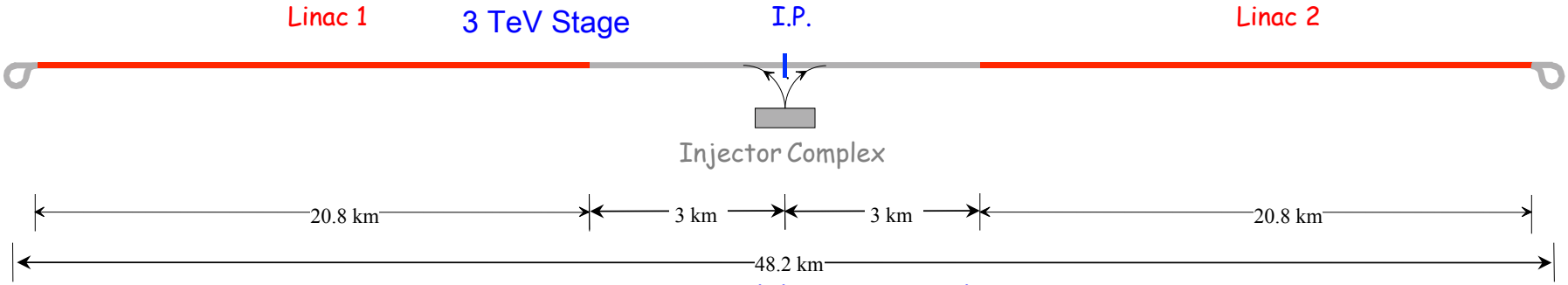
CLIC two-beam scheme compatible with energy staging to provide the optimal machine for a large energy range

Lower energy machine can run most of the time during the construction of the next stage. Physics results will determine the energies of the stages







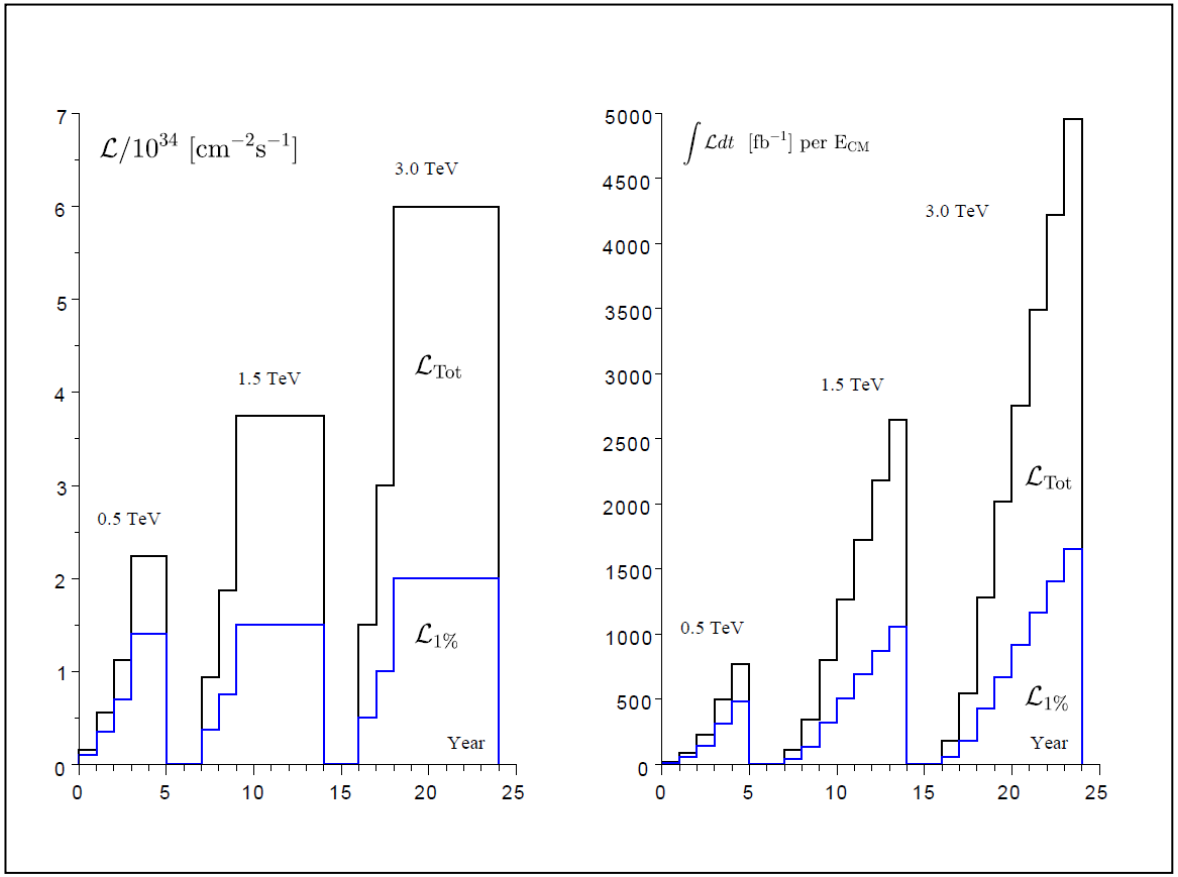


Potential Staged Parameters

Preliminary, implementation options still under discussion

parameter	symbol			
centre of mass energy	E_{cm} [GeV]	500	1400	3000
luminosity	$\mathcal{L}$ [10^{34} cm^{-2}s^{-1}]	2.3	3.2	5.9
luminosity in peak	$\mathcal{L}_{0.01}$ [10^{34} cm^{-2}s^{-1}]	1.4	1.3	2
gradient	G [MV/m]	80	80/100	100
site length	[km]	13	28	48.3
charge per bunch	N [10^9]	6.8	3.7	3.7
bunch length	σ_z [μm]	72	44	44
IP beam size	σ_x/σ_y [nm]	200/2.26	$\approx$ 60/1.5	$\approx$ 40/1
norm. emittance	ϵ_x/ϵ_y [nm]	2400/25	660/20	660/20
bunches per pulse	n_b	354	312	312
distance between bunches	Δ_b [ns]	0.5	0.5	0.5
repetition rate	f_r [Hz]	50	50	50
est. power cons.	P_{wall} [MW]	271	361	582

possible E_{cm} / luminosity scenario



This is just an example

Reducing the instantaneous luminosity reduces both power and yearly energy

Finer energy scans might well be needed within one stage

summary and outlook

Good results on feasibility of CLIC accelerator technologies, and progress continues

CLIC has a large physics potential, complementary to LHC

Physics can be measured with high precision, despite challenging background conditions

Physics can be explored in a staged approach:
few-hunred GeV – 3 TeV

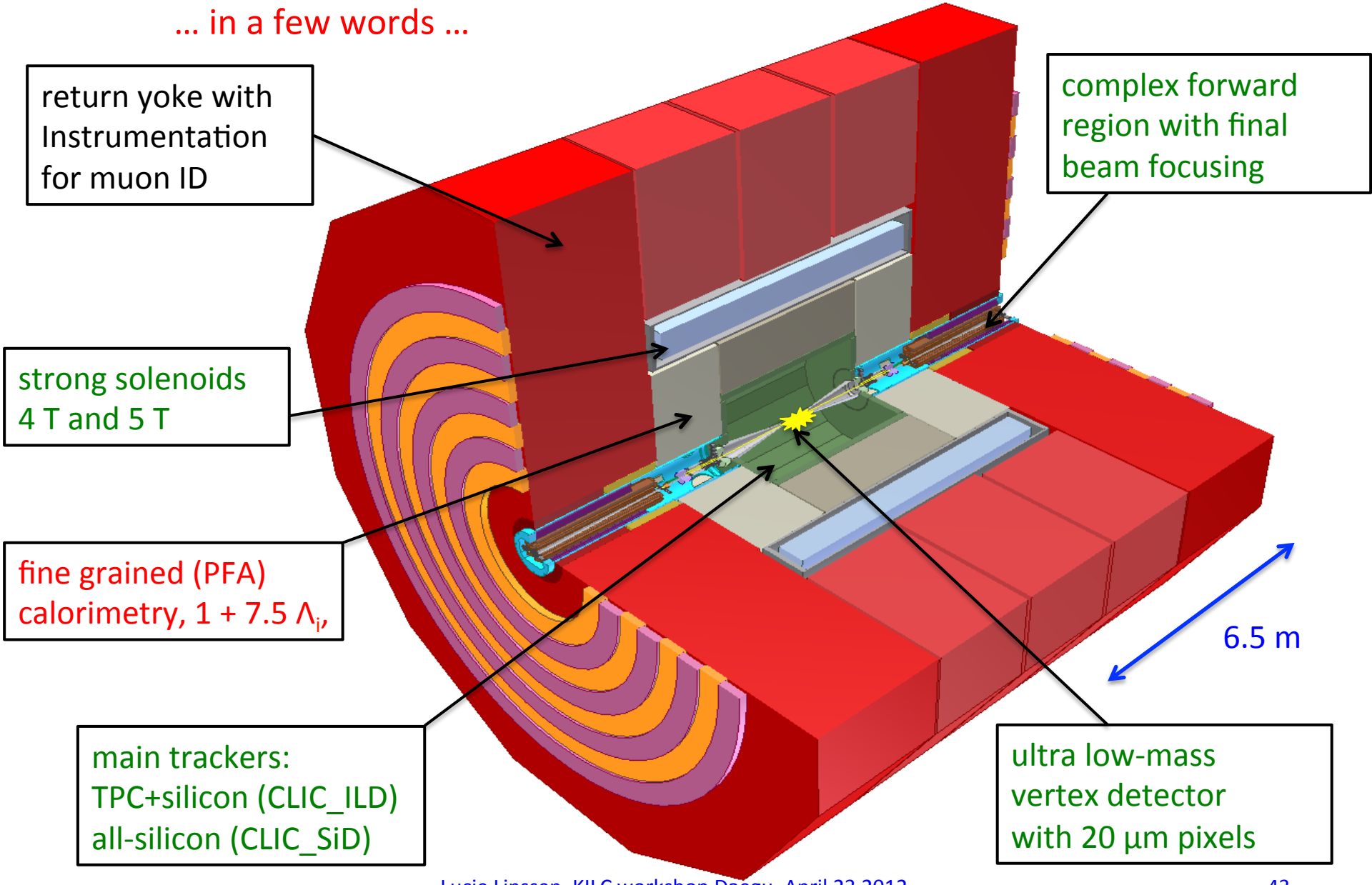
Plans for the next phase 2012 – 2016 are well underway

With many thanks to all those who participated, in particular giving credit to prior ILC work on physics and detectors who made CLIC CDR work possible

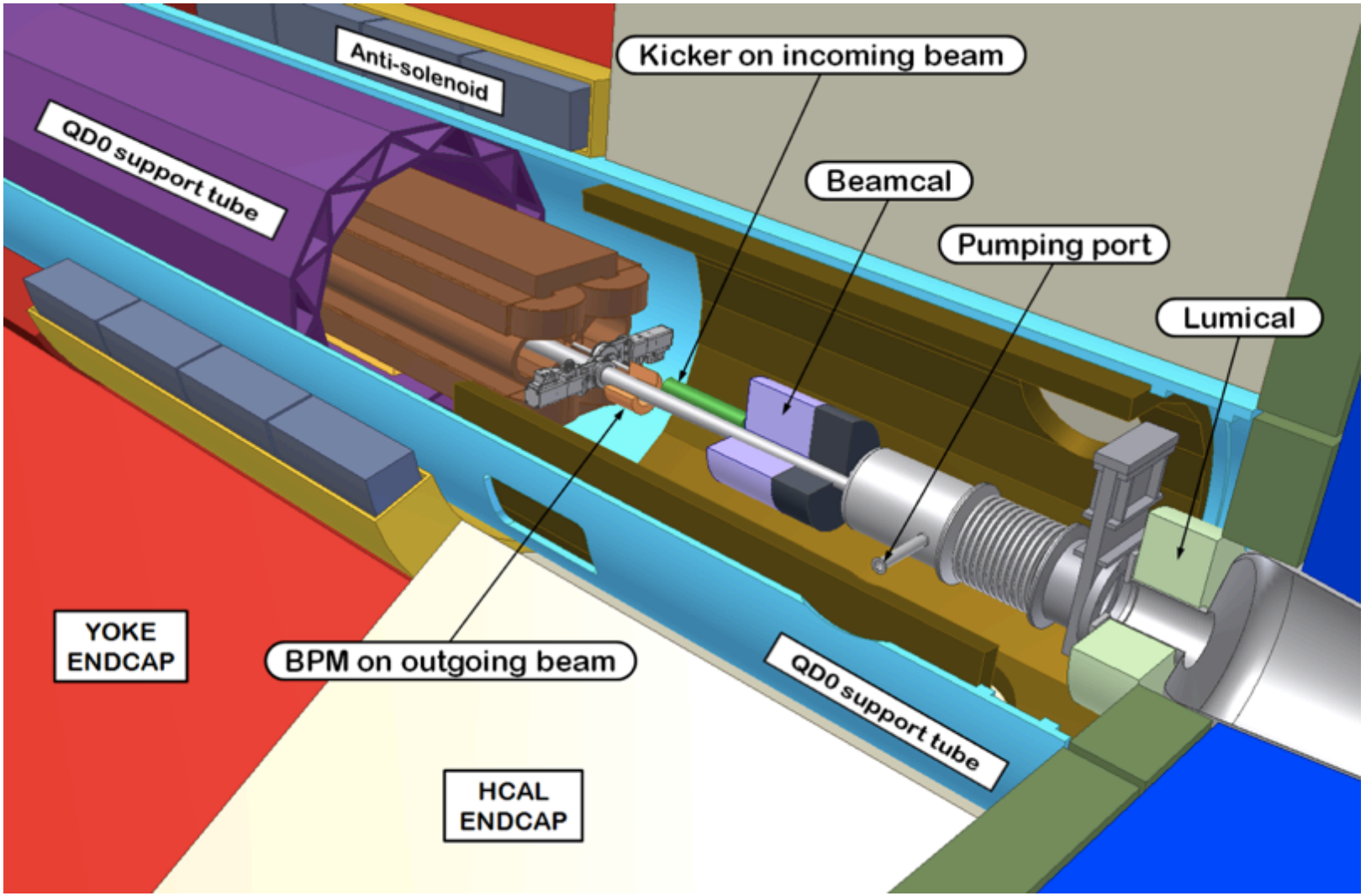
SPARE SLIDES

detector concepts

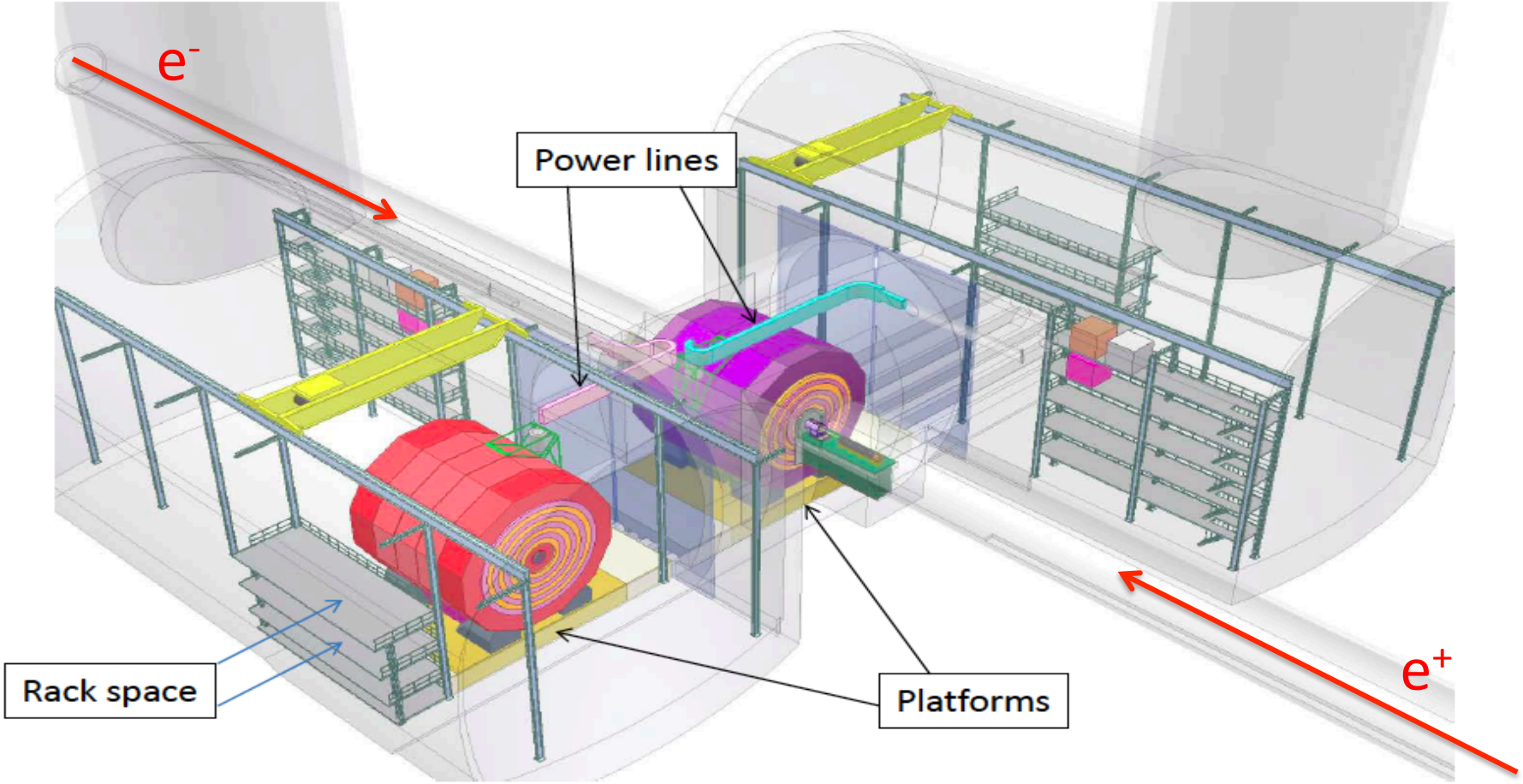
… in a few words …



details of forward detector region



two experiments in push-pull



PFA jet performance study

W → 2 jets

with jet finding and timing cuts

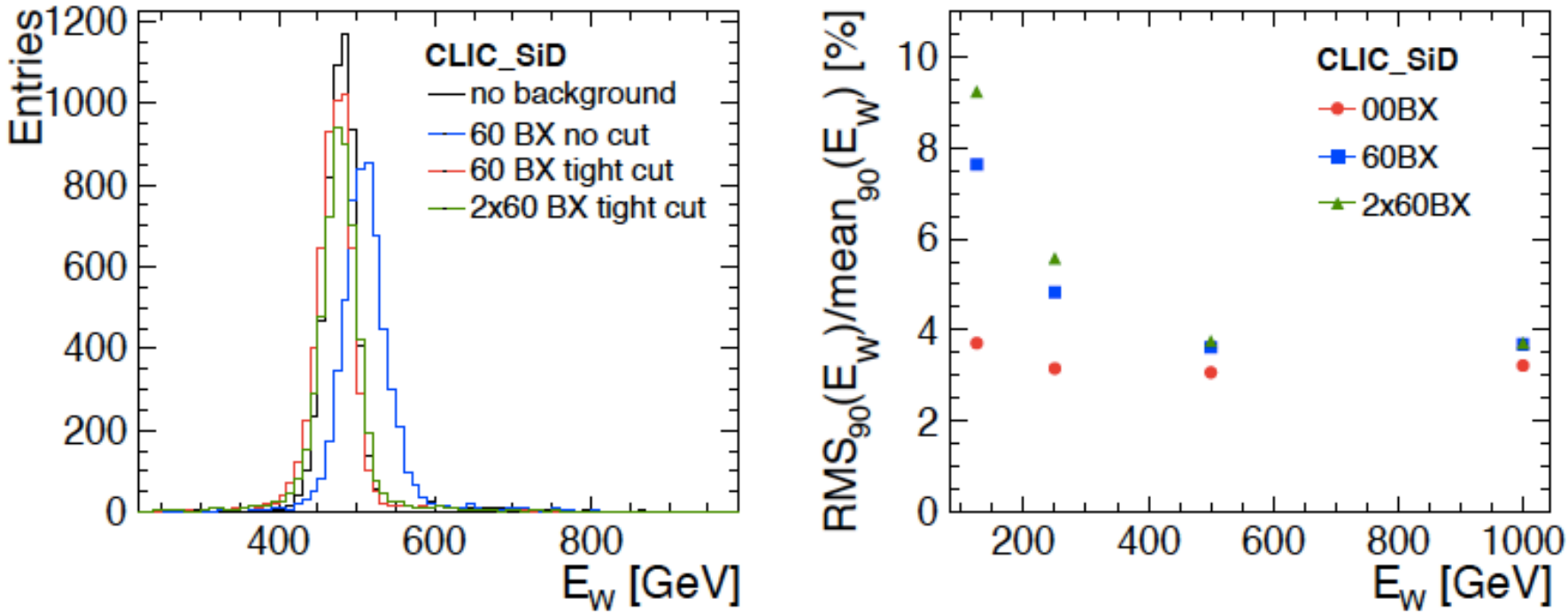


Fig. 12.9: Left: Energy distribution of the reconstructed W with an energy of 500 GeV for various amounts of $\gamma\gamma \rightarrow$ hadrons background overlaid (no background, 60 BX and 2×60 BX) and for different timing cuts (no cut and tight timing cuts). Right: Energy resolution of the reconstructed W as a function of the W energy for various amounts of $\gamma\gamma \rightarrow$ hadrons background overlaid. In case of background the tight timing cuts are used. The results in both figures are obtained for the CLIC_SiD detector model.

PFO-based timing cuts

Region	p_t *range*	Time cut
Photons		
central ($\cos\theta \leq 0.975$)	$0.75\ \mathrm{GeV} \leq p_t < 4.0\ \mathrm{GeV}$ $0\ \mathrm{GeV} \leq p_t < 0.75\ \mathrm{GeV}$	$t < 2.0$ nsec $t < 1.0$ nsec
forward ($\cos\theta > 0.975$)	$0.75\ \mathrm{GeV} \leq p_t < 4.0\ \mathrm{GeV}$ $0\ \mathrm{GeV} \leq p_t < 0.75\ \mathrm{GeV}$	$t < 2.0$ nsec $t < 1.0$ nsec
Neutral hadrons		
central ($\cos\theta \leq 0.975$)	$0.75\ \mathrm{GeV} \leq p_t < 8.0\ \mathrm{GeV}$ $0\ \mathrm{GeV} \leq p_t < 0.75\ \mathrm{GeV}$	$t < 2.5$ nsec $t < 1.5$ nsec
forward ($\cos\theta > 0.975$)	$0.75\ \mathrm{GeV} \leq p_t < 8.0\ \mathrm{GeV}$ $0\ \mathrm{GeV} \leq p_t < 0.75\ \mathrm{GeV}$	$t < 2.0$ nsec $t < 1.0$ nsec
Charged PFOs		
all	$0.75\ \mathrm{GeV} \leq p_t < 4.0\ \mathrm{GeV}$ $0\ \mathrm{GeV} \leq p_t < 0.75\ \mathrm{GeV}$	$t < 3.0$ nsec $t < 1.5$ nsec

- Track-only minimum p_t: 0.5 GeV
- Track-only maximum time at ECAL: 10 nsec

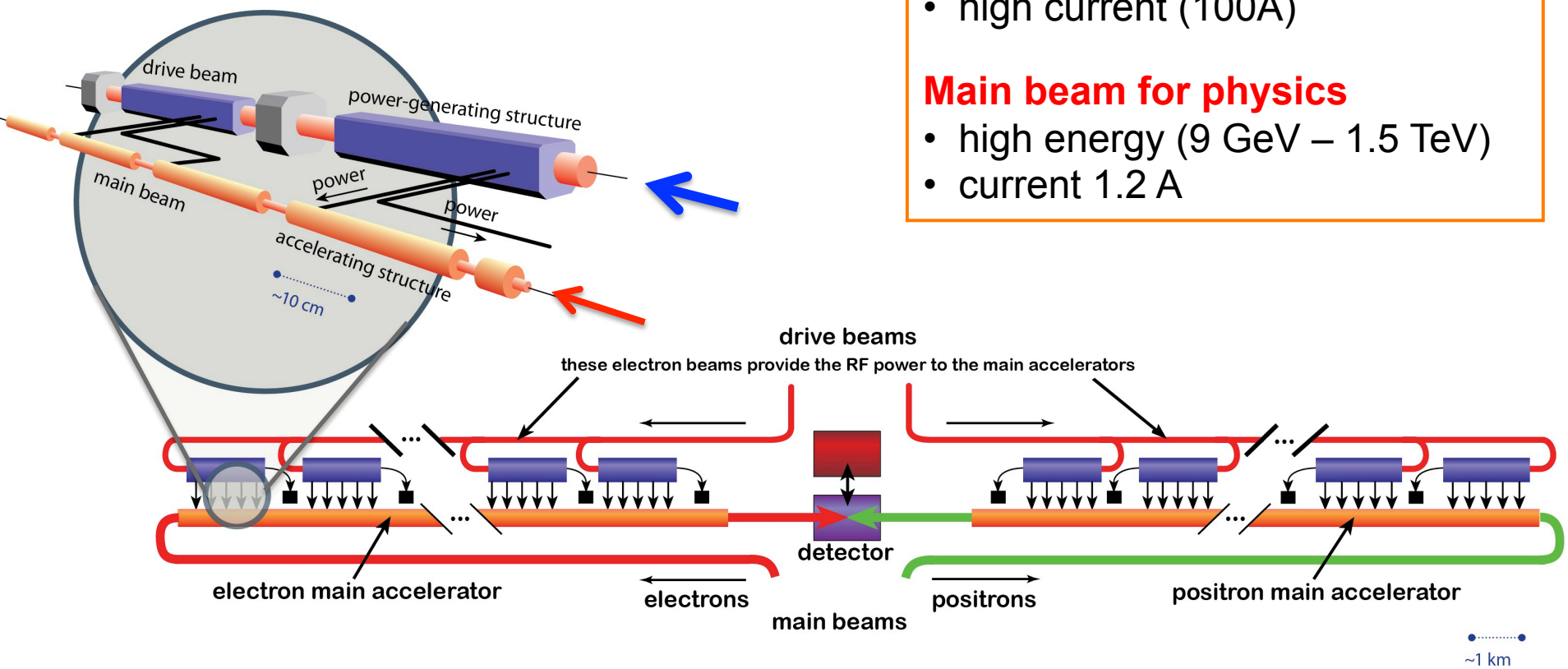
CLIC two-beam acceleration scheme

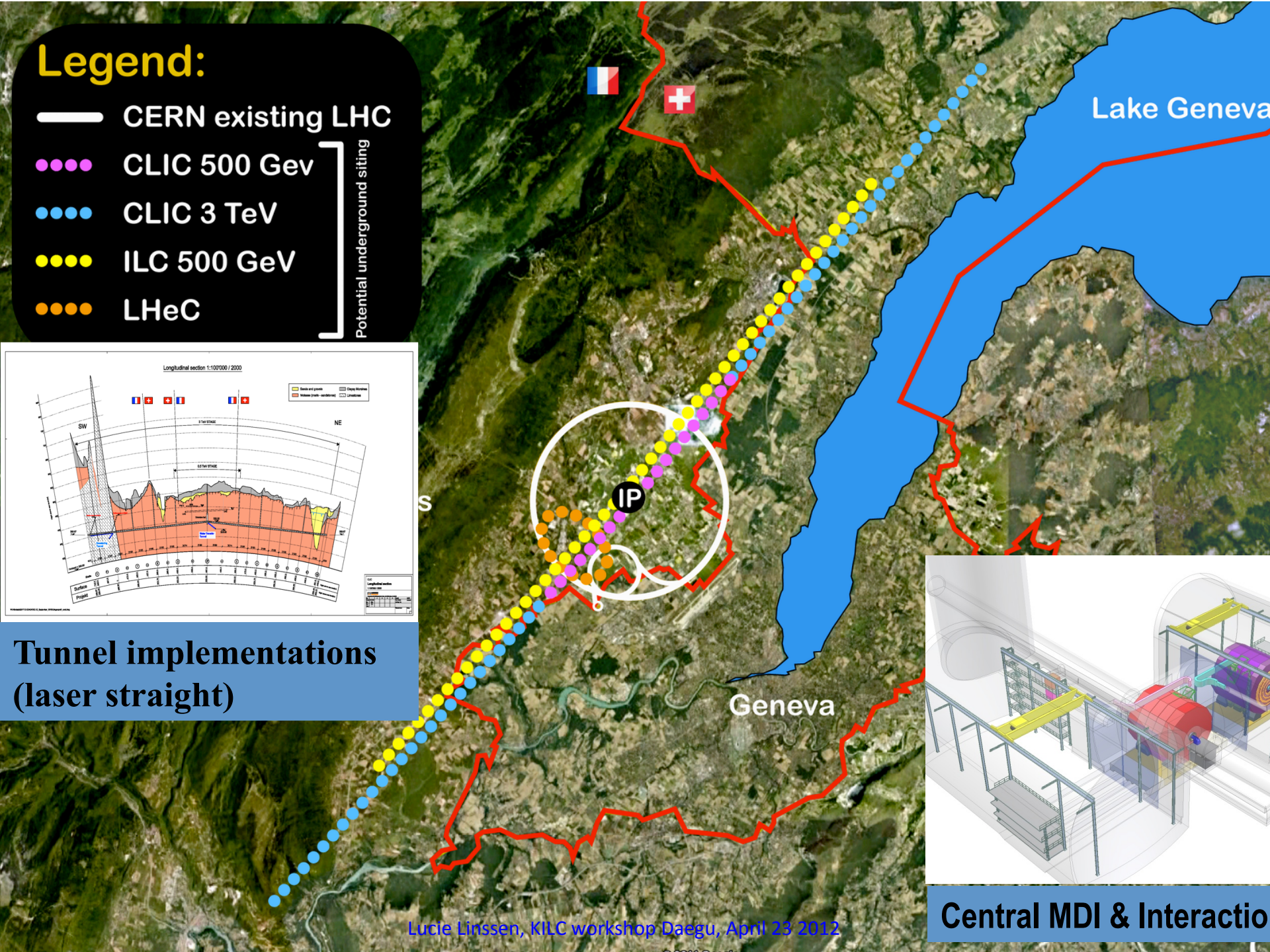
Accelerating gradient: 100 MV/m

Two Beam Scheme:

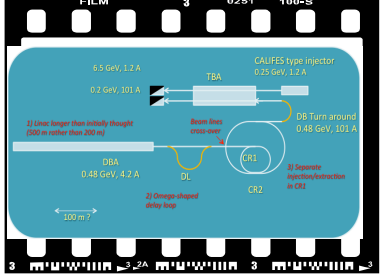
Drive Beam supplies RF power
- 12 GHz bunch structure
- low energy (2.4 GeV - 240 MeV)
- high current (100A)

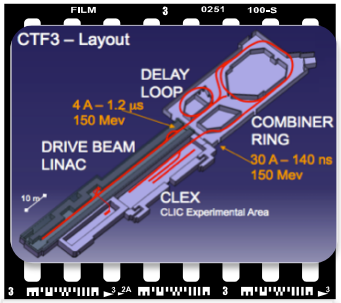
Main beam for physics
- high energy (9 GeV – 1.5 TeV)
- current 1.2 A




Legend:
CERN existing LHC
CLIC 500 Gev
CLIC 3 TeV
ILC 500 GeV
LHeC
Potential underground siting
Lake Geneva
IP
Geneva
Longitudinal section 1:100'000 / 2000
SW
NE
Tunnel implementations (laser straight)
Central MDI & Interactio

CLIC project time-line





Final CLIC CDR and feasibility established, also input for the Eur. Strategy Update

From 2016 – Project Implementation phase, including an initial project to lay the grounds for full construction:

- CLIC 0 – a significant part of the drive beam facility: prototypes of hardware components at real frequency, final validation of drive beam quality/main beam emittance preservation, facility for reception tests – and part of the final project)
- Finalization of the CLIC technical design, taking into account the results of technical studies done in the previous phase, and final energy staging scenario based on the LHC Physics results, which should be fully available by the time
- Further industrialization and pre-series production of large series components for validation facilities
- Other system studies addressing luminosity issues (emittance conservation) …
- Environmental Impact Study

2004 - 2012

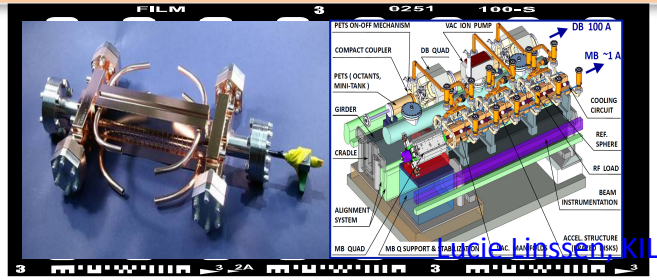
2012 - 2016

2016 – 2022

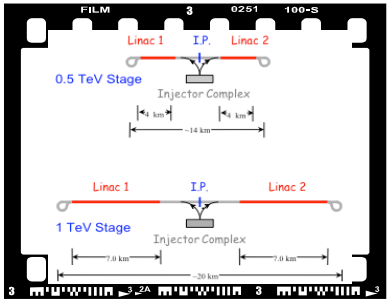
~ 2020 onwards

2011-2016 – Goal: Develop a project implementation plan for a Linear Collider:

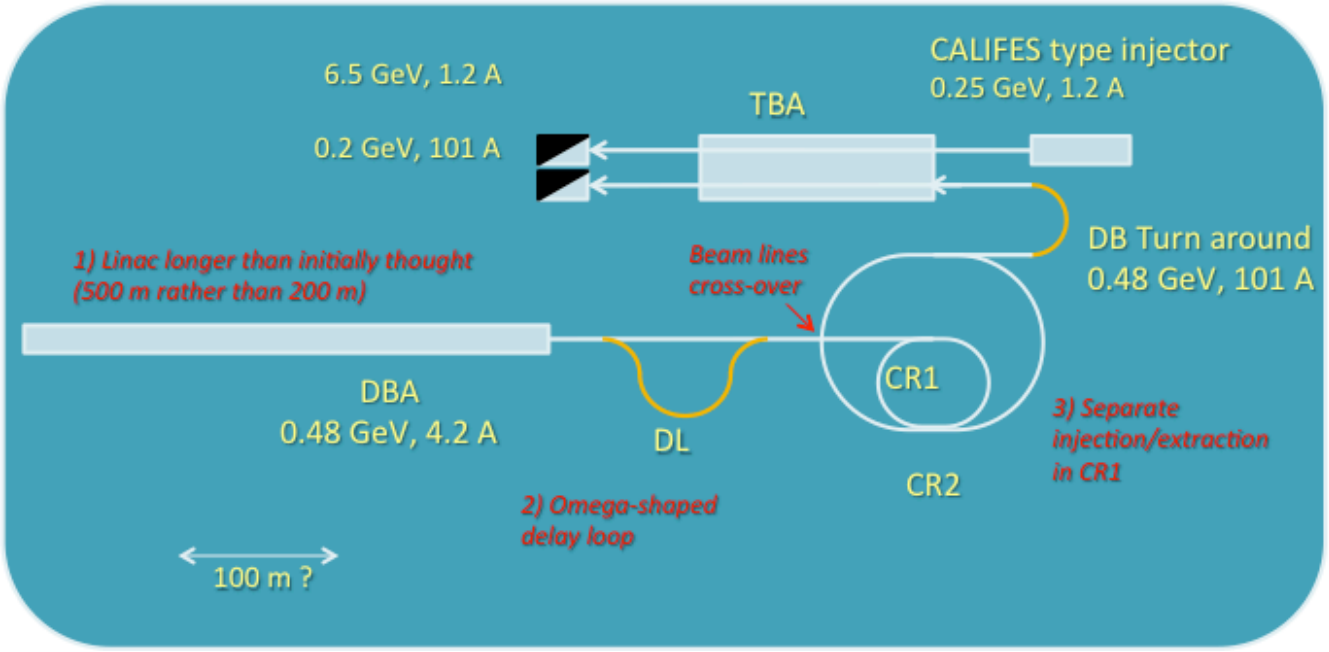
- Addressing the key physics goals as emerging from the LHC data
- With a well-defined scope (i.e. technical implementation and operation model, energy and luminosity), cost and schedule
- With a solid technical basis for the key elements of the machine and detector
- Including the necessary preparation for siting the machine
- Within a project governance structure as defined with international partners



CLIC project construction – in stages, making use of CLIC 0



System test and initial step for CLIC



parameter	unit	CLIC	CTF3
accelerated current	A	4.2	3.5
combined current	A	101	28
final energy	MeV	2400	≈ 120
accelerated pulse length	μs	140	1.2
final pulse length	ns	240	140
acceleration frequency	GHz	1	3
final bunch frequency	GHz	12	12

Objectives beyond 2016:

- Final components at some scale
- Full currents
- Needed for initial phase of project (receptions and conditioning of final modules before installation)

Tentative beam parameters

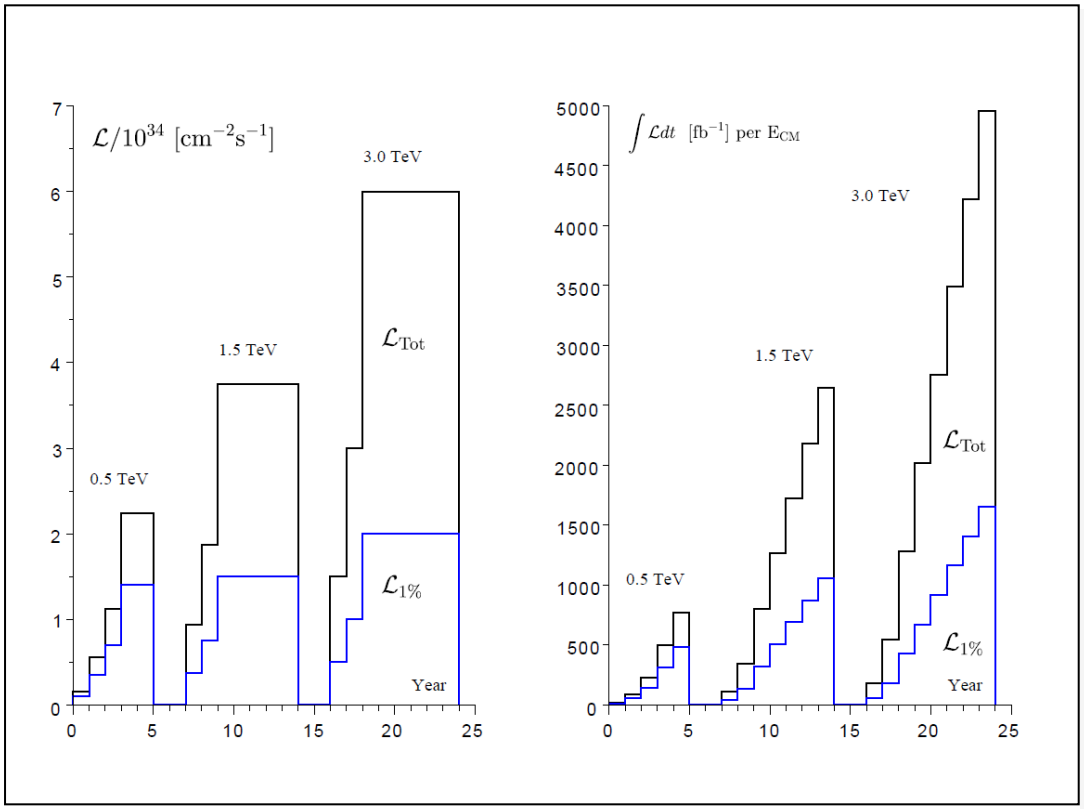
Drive beam (TBA entrance)

Energy	480	MeV	
Emittance, norm. rms	≤ 150	um	
Energy spread, rms	~ 1 %		
Bunch length, rms	1	mm	(3.6 ps)
Bunch charge	8.4	nC	
Pulse Current	101	A	(4.2 A in DBA)
Pulse length	244	ns	(~ 6 us in DBA, option for full pulse length – 140 us)
Rep. Rate	50	Hz	

Probe beam (end of TBA)

Energy	6.5 – 6.75	GeV	(250 to 500 MeV injector exit, 6.25 GeV acceleration)
Emittance, norm. rms	1 – 20	um	(both horizontal and vertical)
Energy spread, rms	0.1 – 1 %		
Bunch length, rms	~ 0.5	mm	(1.8 ps – may changed by adding a bunch compressor)
Bunch charge	0.2 - 1	nC	
Pulse Current	0.4 – 2	A	
Pulse length	up to 156 ns		(possibility of single bunch)
Rep. Rate	up to 50	Hz	

A possible energy/luminosity scenario



With a model (see figure for one example) for energies and luminosities, and assumptions about running scenarios (see below), one can extract power and energy estimates as function of time (next slide).

For each value of CM energy:

- 177 days/year of beam time
- 188 days/year of scheduled and fault stops
- First year
  - 59 days of injector and one-by-one sector commissioning
  - 59 days of main linac commissioning, one linac at a time
  - 59 days of luminosity operation
  - Quoted power : average over the three periods
  - All along : 50% of downtime
- Second year
  - 88 days with one linac at a time and 30 % of downtime
  - 88 days without downtime
  - Quoted power : average over the two periods
- Third year
  - Still only one e+ target at 0.5 TeV, like for years 1 & 2
  - Nominal at 1.5 and 3 TeV
- Power during stops (scheduled, fault, downtime) :
  - (40 MW, 45 MW, 60 MW) at (0.5, 1.5, 3) TeV, respectively

detector benchmark studies for CDR

Full physics simulation and reconstruction studies with beam background overlay (γγ => hadrons)

Choose six channels, with emphasis on mapping various crucial aspects of detector performance (jet measurement, missing energy, isolated leptons, flavour tagging etc.)

3 TeV

- $e^+e^- \to h\nu_e\bar{\nu}_e$ ★
- $e^+e^- \to H^+H^-/H^0A$ ★
- $e^+e^- \to \tilde{q}_R\bar{\tilde{q}}_R$ ★
- $e^+e^- \to \tilde{\ell}^+\tilde{\ell}^-$ ★
- $e^+e^- \to \tilde{\chi}_i^+\tilde{\chi}_i^-/\tilde{\chi}_i^0\tilde{\chi}_i^0$ ★

500 GeV

- $e^+e^- \to t\bar{t}$

slepton production

Slepton production at CLIC very clean

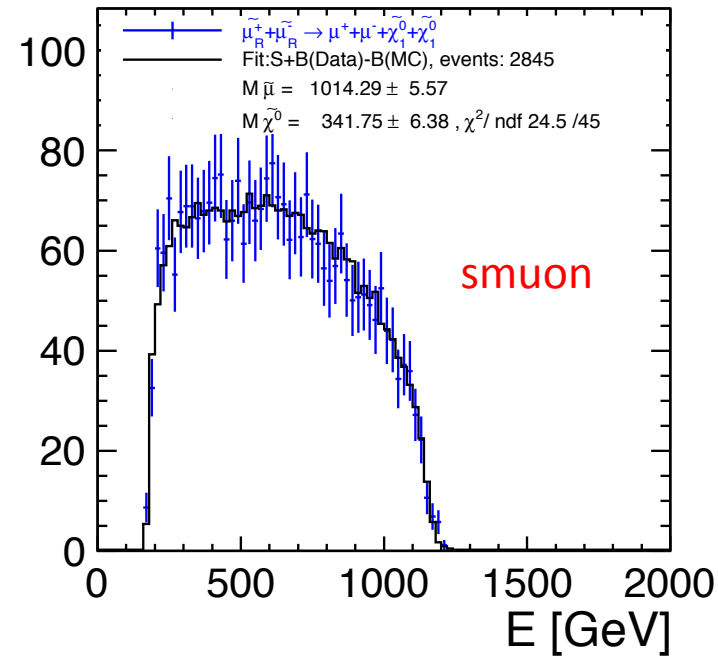
SUSY "*model II*": slepton masses ~ 1 TeV

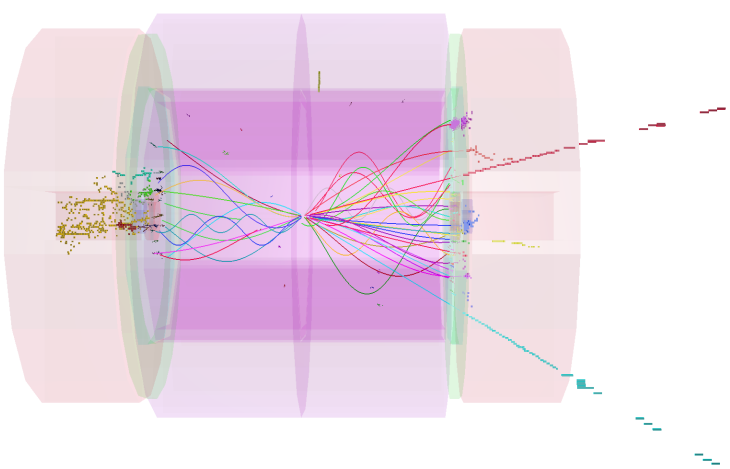
Channels studied include

- $e^+e^- \to \tilde{\mu}_R^+\tilde{\mu}_R^- \to \mu^+\mu^- \tilde{\chi}_1^0 \tilde{\chi}_1^0$
- $e^+e^- \to \tilde{e}_R^+\tilde{e}_R^- \to e^+e^- \tilde{\chi}_1^0 \tilde{\chi}_1^0$
- $e^+e^- \to \tilde{\nu}_e\tilde{\nu}_e \to e^+e^-W^+W^- \tilde{\chi}_1^0 \tilde{\chi}_1^0$

Leptons and missing energy

Masses from analysis of endpoints of energy spectra





All channels combined

$$m(\tilde{\mu}_R) : \pm 5.6\,\text{GeV}$$
$$m(\tilde{e}_R) : \pm 2.8\,\text{GeV}$$
$$m(\tilde{\nu}_e) : \pm 3.9\,\text{GeV}$$
$$m(\tilde{\chi}_1^0) : \pm 3.0\,\text{GeV}$$
$$m(\tilde{\chi}_1^\pm) : \pm 3.7\,\text{GeV}$$

gaugino pair production

SUSY "*model II*": $m(\tilde{\chi}_1^0) = 340\,\mathrm{GeV}$ $m(\tilde{\chi}_2^0), m(\tilde{\chi}_1^+) \approx 643\,\mathrm{GeV}$

Pair production and decay:

$$e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 W^+W^-$$

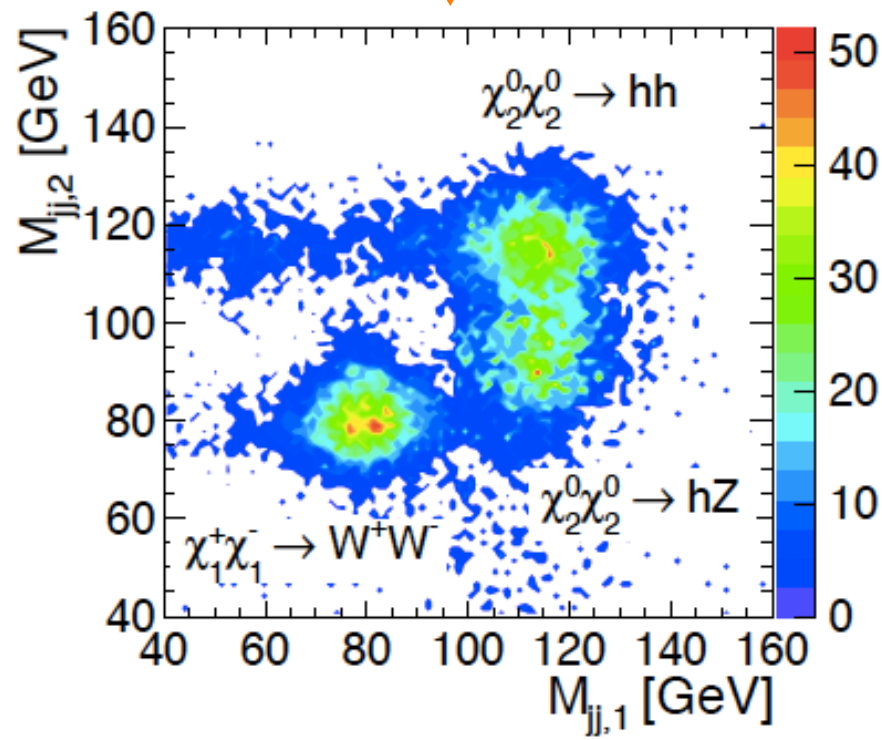
$$e^+e^- \to \tilde{\chi}_2^0\tilde{\chi}_2^0 \to hh\,\tilde{\chi}_1^0\tilde{\chi}_1^0 \quad 82\,\%$$

$$e^+e^- \to \tilde{\chi}_2^0\tilde{\chi}_2^0 \to Zh\,\tilde{\chi}_1^0\tilde{\chi}_1^0 \quad 17\,\%$$

$m(\tilde{\chi}_1^\pm)$: $\pm 7\,\mathrm{GeV}$
$m(\tilde{\chi}_2^0)$: $\pm 10\,\mathrm{GeV}$

use slepton study result
$m(\tilde{\chi}_1^0)$: $\pm 3\,\mathrm{GeV}$

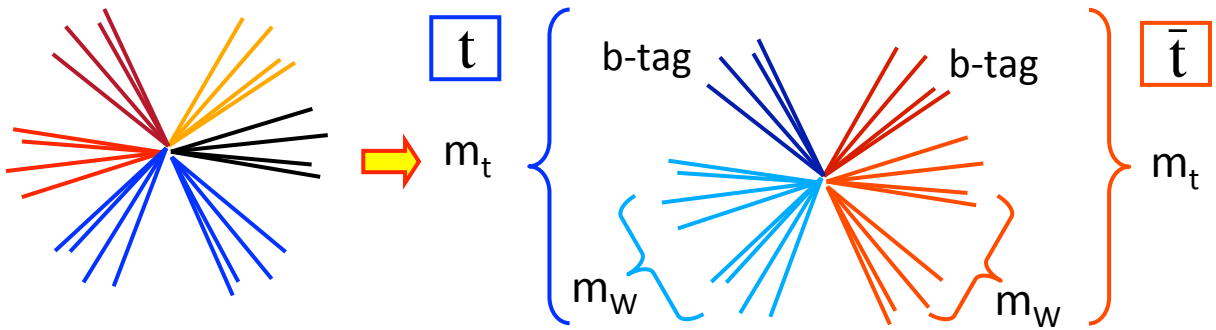
Separation using di-jet invariant masses (test of PFA)



top mass at √s 500 GeV

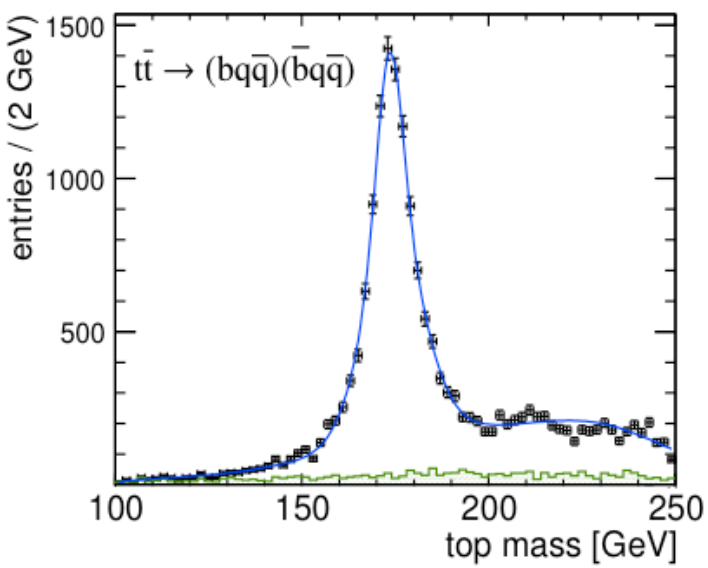
Study top production at √s = 500 GeV under CLIC background conditions

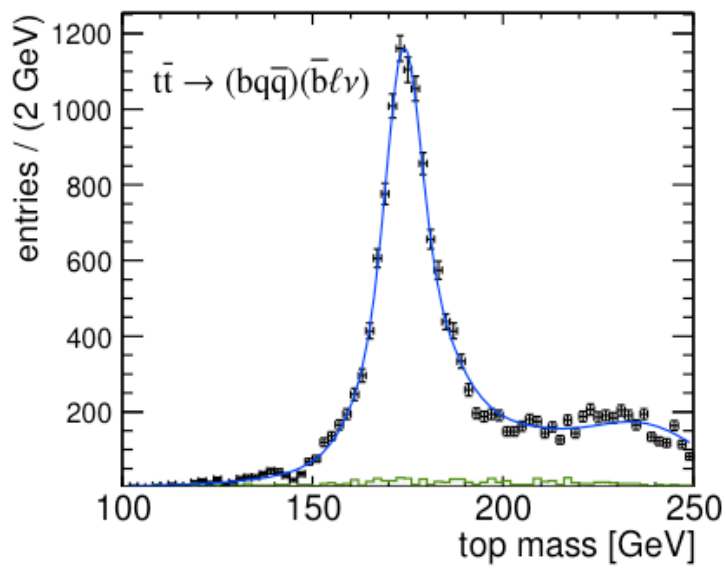
- fully hadronic $t\bar{t} \to (bq\bar{q})(\bar{b}q\bar{q})$ and semi-leptonic $t\bar{t} \to (bq\bar{q})(\bar{b}\ell\nu)$



Use:

- b-tagging
- Invariant masses
- Kinematic fits





100 fb^{-1}

m_t : ± 60 MeV

comparison CLIC ⇔ LHC detector

In a nutshell:

CLIC detector:

- **High precision:**
  - Jet energy resolution
    - => fine-grained calorimetry
  - Momentum resolution
  - Impact parameter resolution
- **Overlapping beam-induced background:**
  - High background rates, medium energies
  - High occupancies
  - Cannot use vertex separation
  - Need very precise timing (1ns, 10ns)
- **"No" issue of radiation damage (10^{-4} LHC)**
- **Beam crossings "sporadic"**
- **No trigger, read-out of full 156 ns train**

LHC detector:

- **Medium-high precision:**
  - Very precise ECAL (CMS)
  - Very precise muon tracking (ATLAS)
- **Overlapping minimum-bias events:**
  - High background rates, high energies
  - High occupancies
  - Can use vertex separation in z
  - Need precise time-stamping (25 ns)
- **Severe challenge of radiation damage**
- **Continuous beam crossings**
- **Trigger has to achieve huge data reduction**