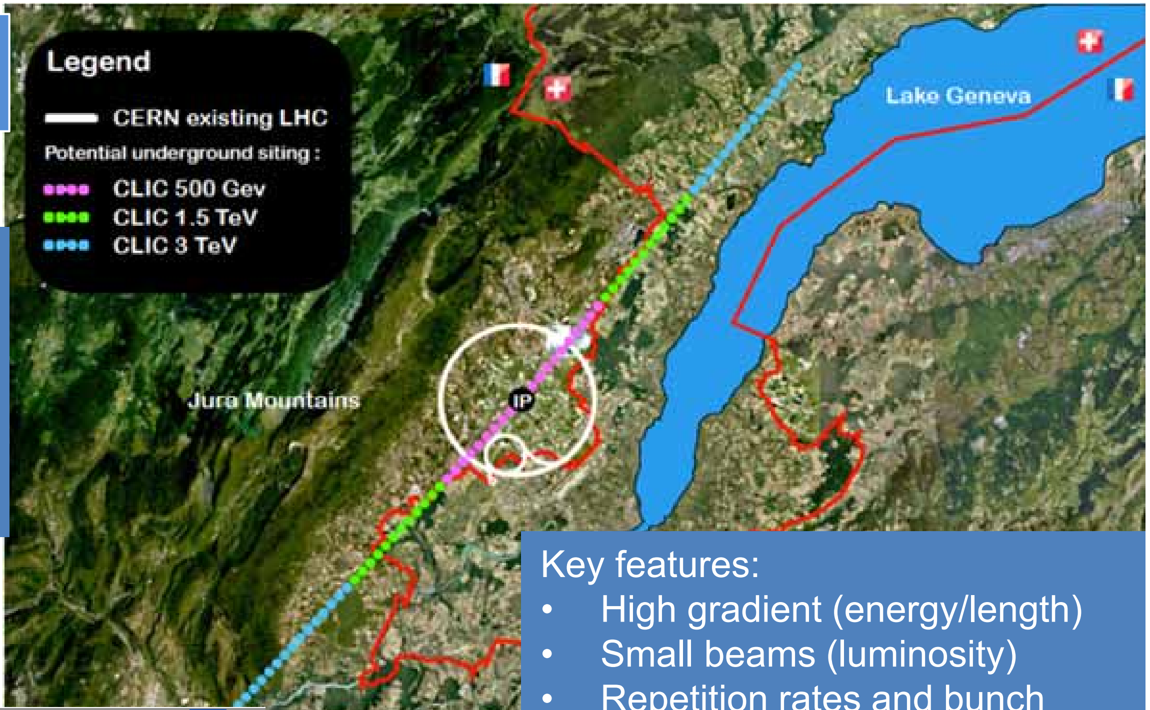
The CLIC project

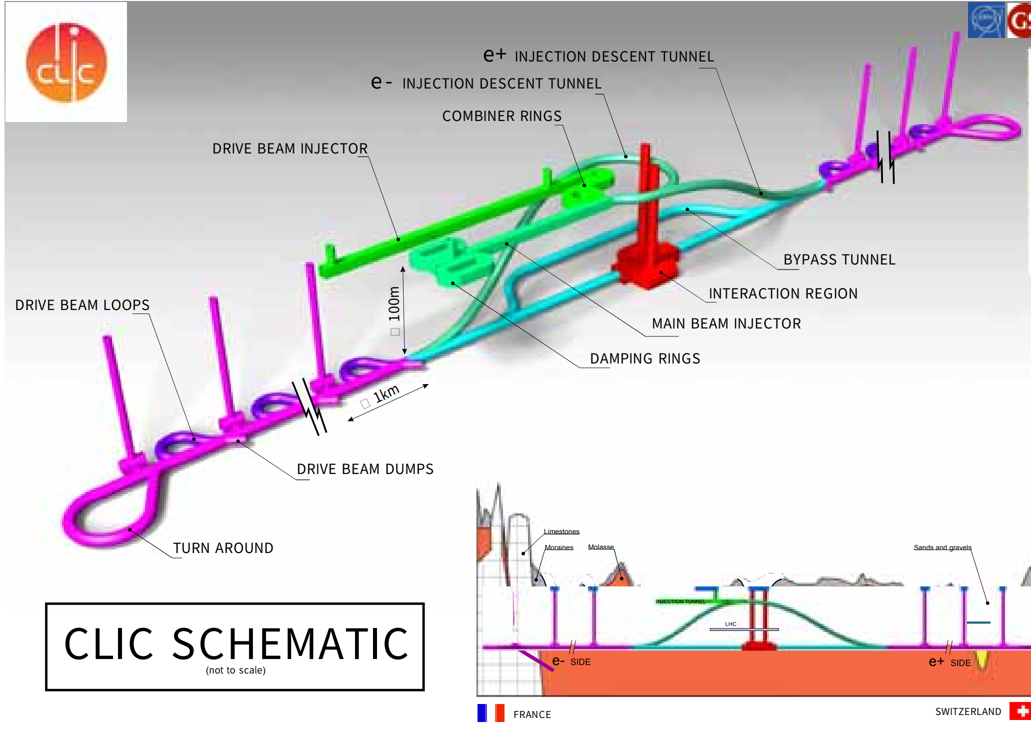
Outline:

- Brief introduction and overview
- Across the main activities
- Brief summary



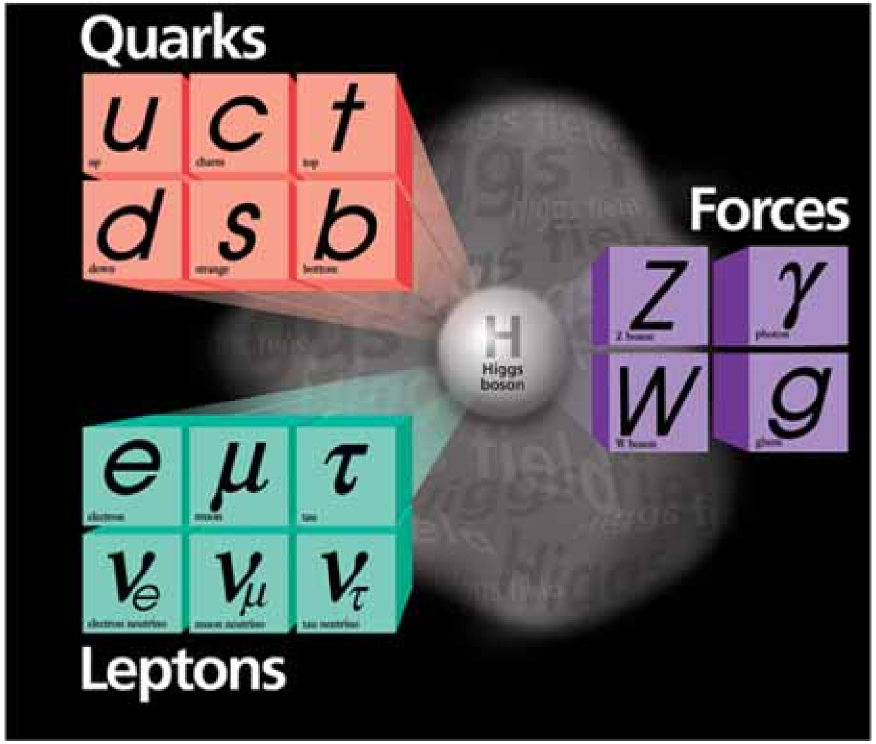
Key features:

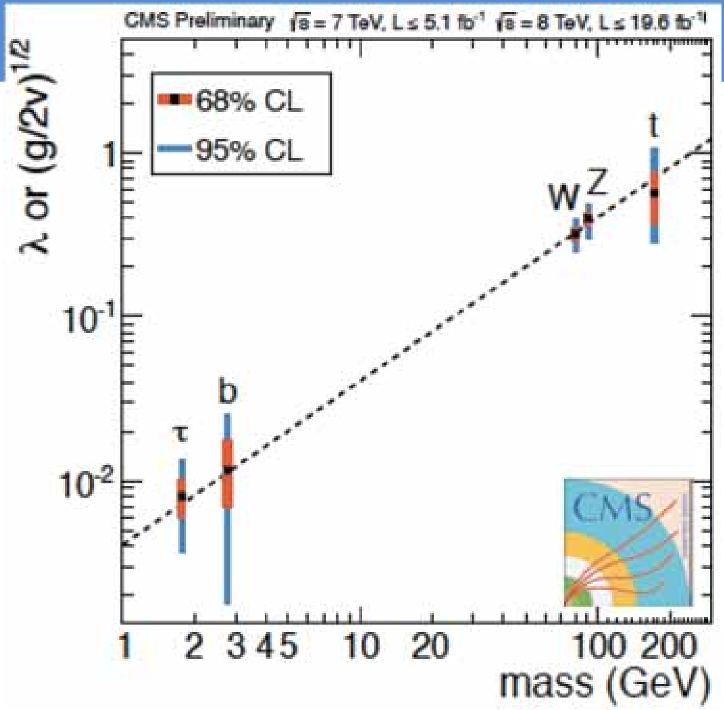
- High gradient (energy/length)
- Small beams (luminosity)
- Repetition rates and bunch spacing (experimental conditions)

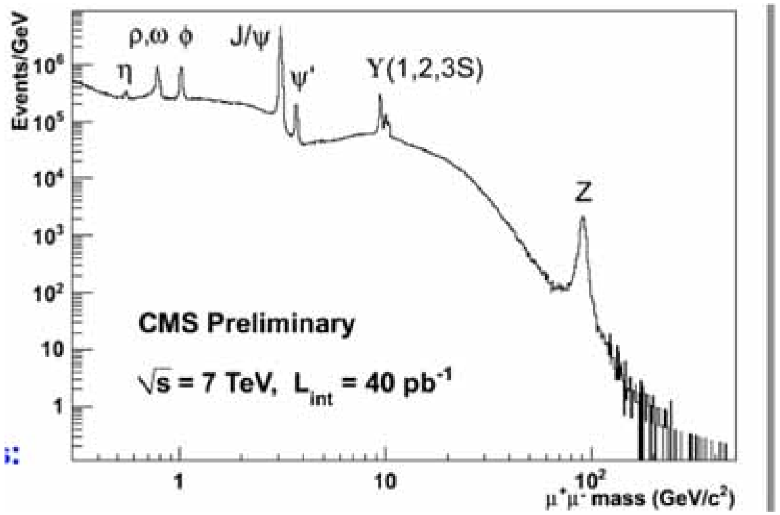


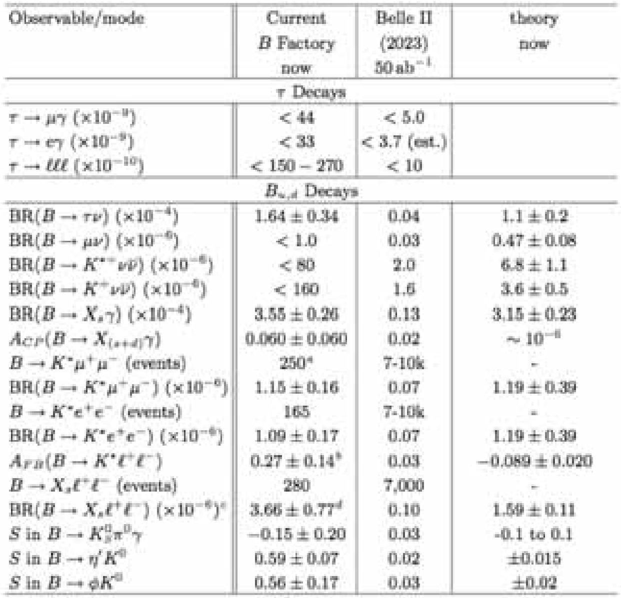
CLIC SCHEMATIC
(not to scale)

The Standard Model







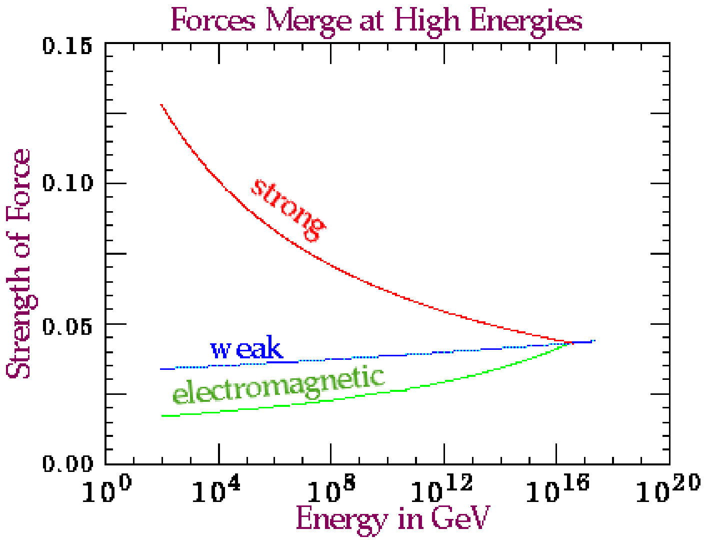


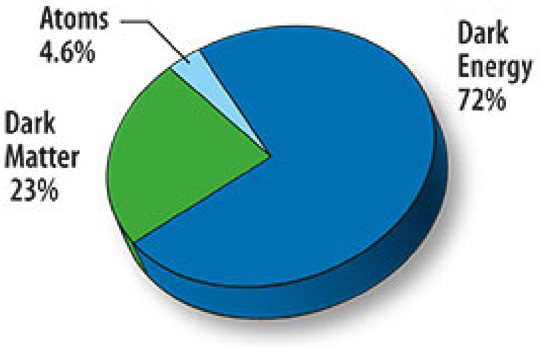
Observable/mode	Current B Factory now	Belle II (2023) $50\,\mathrm{ab}^{-1}$	theory now
	τ Decays		
$\tau \to \mu\gamma$ $(\times 10^{-9})$	< 44	< 5.0	
$\tau \to e\gamma$ $(\times 10^{-9})$	< 33	< 3.7 (est.)	
$\tau \to \ell\ell\ell$ $(\times 10^{-10})$	$< 150 - 270$	< 10	
	$B_{u,d}$ Decays		
$\mathrm{BR}(B \to \tau\nu)$ $(\times 10^{-4})$	1.64 ± 0.34	0.04	1.1 ± 0.2
$\mathrm{BR}(B \to \mu\nu)$ $(\times 10^{-6})$	< 1.0	0.03	0.47 ± 0.08
$\mathrm{BR}(B \to K^{*+}\nu\bar{\nu})$ $(\times 10^{-6})$	< 80	2.0	6.8 ± 1.1
$\mathrm{BR}(B \to K^{+}\nu\bar{\nu})$ $(\times 10^{-6})$	< 160	1.6	3.6 ± 0.5
$\mathrm{BR}(B \to X_s\gamma)$ $(\times 10^{-4})$	3.55 ± 0.26	0.13	3.15 ± 0.23
$A_{CP}(B \to X_{(s+d)}\gamma)$	0.060 ± 0.060	0.02	$\sim 10^{-6}$
$B \to K^*\mu^+\mu^-$ (events)	250^a	7-10k	-
$\mathrm{BR}(B \to K^*\mu^+\mu^-)$ $(\times 10^{-6})$	1.15 ± 0.16	0.07	1.19 ± 0.39
$B \to K^*e^+e^-$ (events)	165	7-10k	-
$\mathrm{BR}(B \to K^*e^+e^-)$ $(\times 10^{-6})$	1.09 ± 0.17	0.07	1.19 ± 0.39
$A_{FB}(B \to K^*\ell^+\ell^-)$	0.27 ± 0.14^b	0.03	-0.089 ± 0.020
$B \to X_s\ell^+\ell^-$ (events)	280	7,000	-
$\mathrm{BR}(B \to X_s\ell^+\ell^-)$ $(\times 10^{-6})^c$	3.66 ± 0.77^d	0.10	1.59 ± 0.11
S in $B \to K_S^0\pi^0\gamma$	-0.15 ± 0.20	0.03	-0.1 to 0.1
S in $B \to \eta' K^0$	0.59 ± 0.07	0.02	± 0.015
S in $B \to \phi K^0$	0.56 ± 0.17	0.03	± 0.02

Beyond the Standard Model

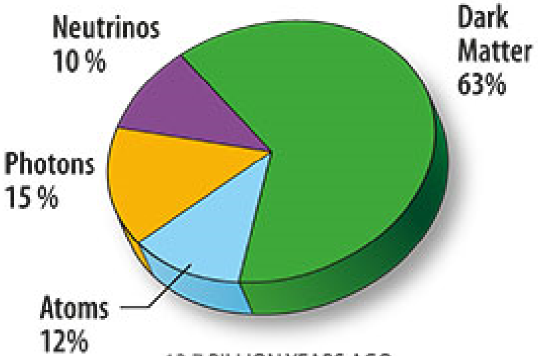
Unknowns :

- Flavour structure
- Matter-antimatter
- Why is the Higgs so light
- Forces merging ?
- Gravity
- …

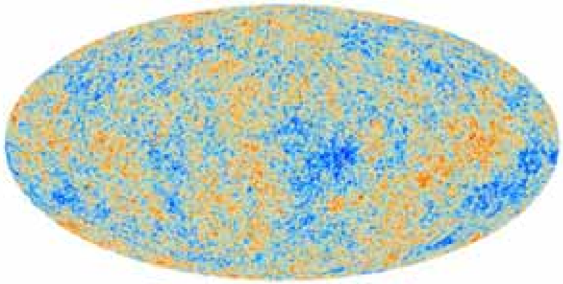




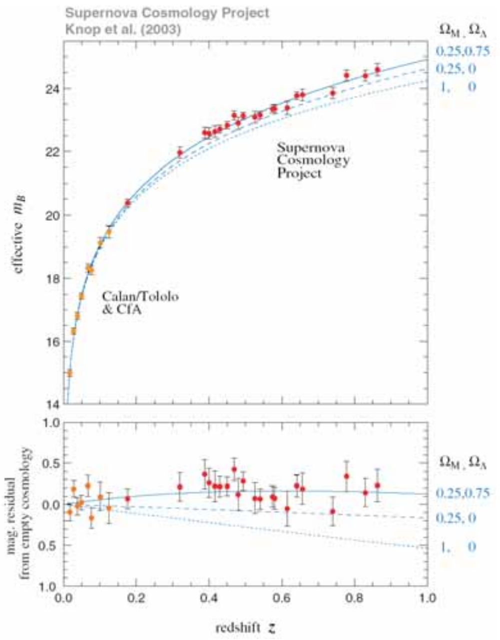
TODAY



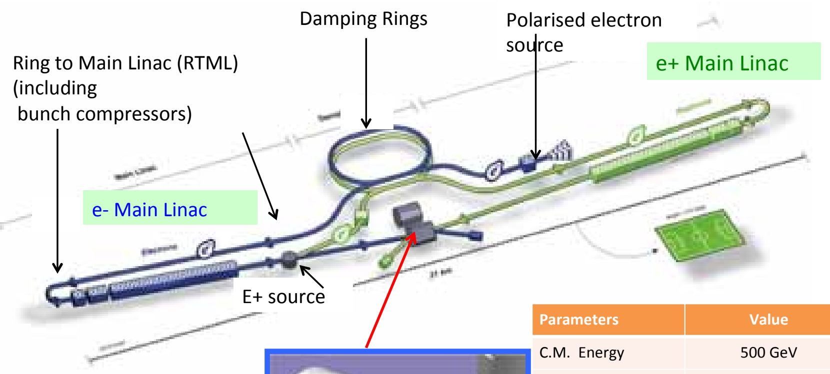
13.7 BILLION YEARS AGO
(Universe 380,000 years old)

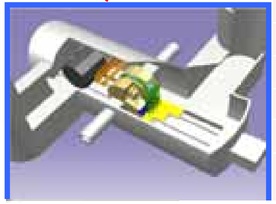


The universe as seen by Planck

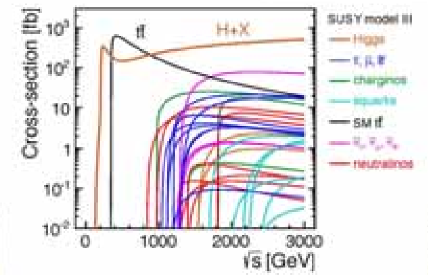


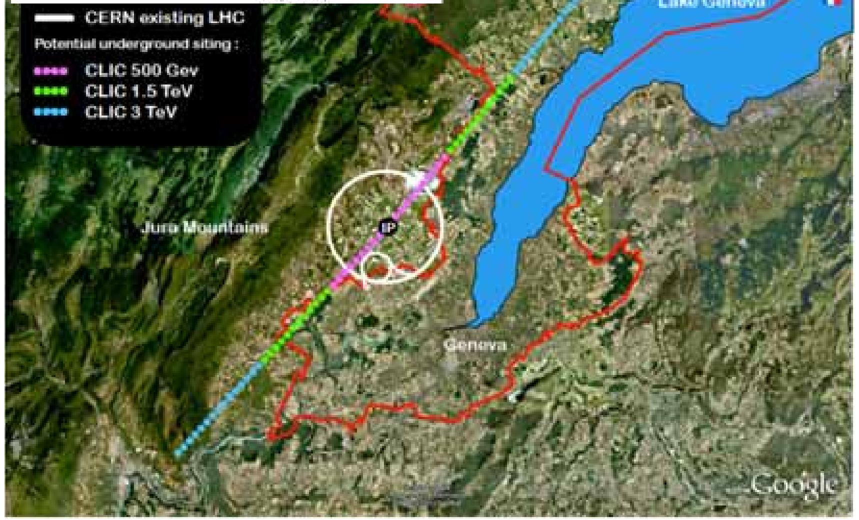
ILC Layout





Parameters	Value
C.M. Energy	500 GeV
Peak luminosity	1.8 x10^{34} cm^{-2}s^{-1}
Beam Rep. rate	5 Hz
Pulse duration	0.73 ms
Average current	5.8 mA (in pulse)
E gradient in SCRF acc. cavity	31.5 MV/m +/-20% Q$_0$ = 1E10





Some possibilities

Circular machine (~50km) in China, e+e- and pp

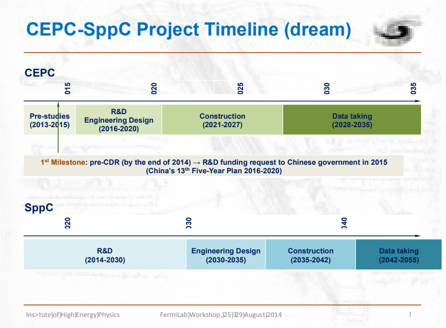
CEPC – Site Investigation

!!!!!!!A!good!example!is!秦 岛:!!

300!km!from!Beijing!
3!hours!by!car;!1!hours!by!high!speed!train!!

Y.!F.!Wang

14#



CEPC-SppC Project Timeline (dream)

CEPC

Pre-studies (2013-2015)	R&D Engineering Design (2016-2020)	Construction (2021-2027)	Data taking (2028-2035)

1st Milestone: pre-CDR (by the end of 2014) → R&D funding request to Chinese government in 2015 (China's 13th Five-Year Plan 2016-2020)

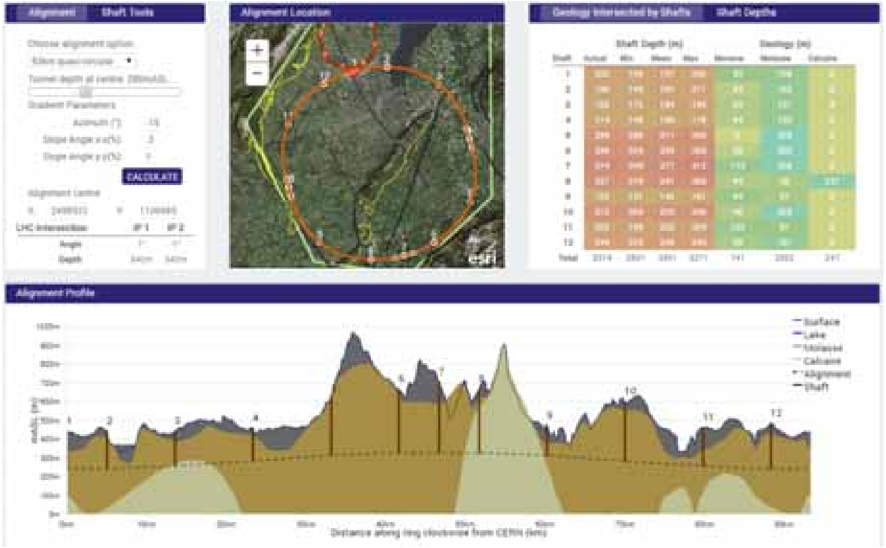
SppC

R&D (2014-2030)	Engineering Design (2030-2035)	Construction (2035-2042)	Data taking (2042-2055)

Ins>tute)of)High)Energy)Physics FermiLab)Workshop,)25)3 29)August)2014 1

European Organization for Nuclear Research
Organisation européenne pour la recherche nucléaire

From talk by W.Chou



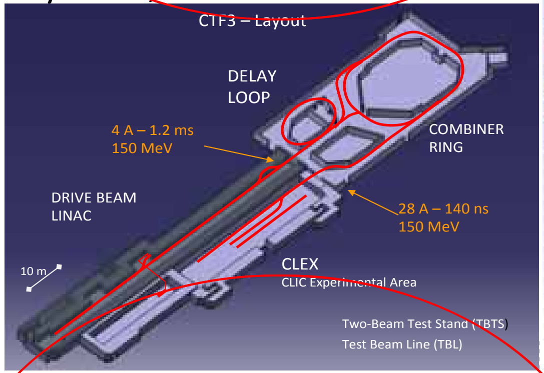
LINEAR COLLIDER COLLABORATION

Accelerator collaboration with ~50 institutes
New institutes are joining:
In 2014 SINAP Shanghai and IPM Tehran

Detector collaboration operative with ~25 institutes

2013-18 Development Phase

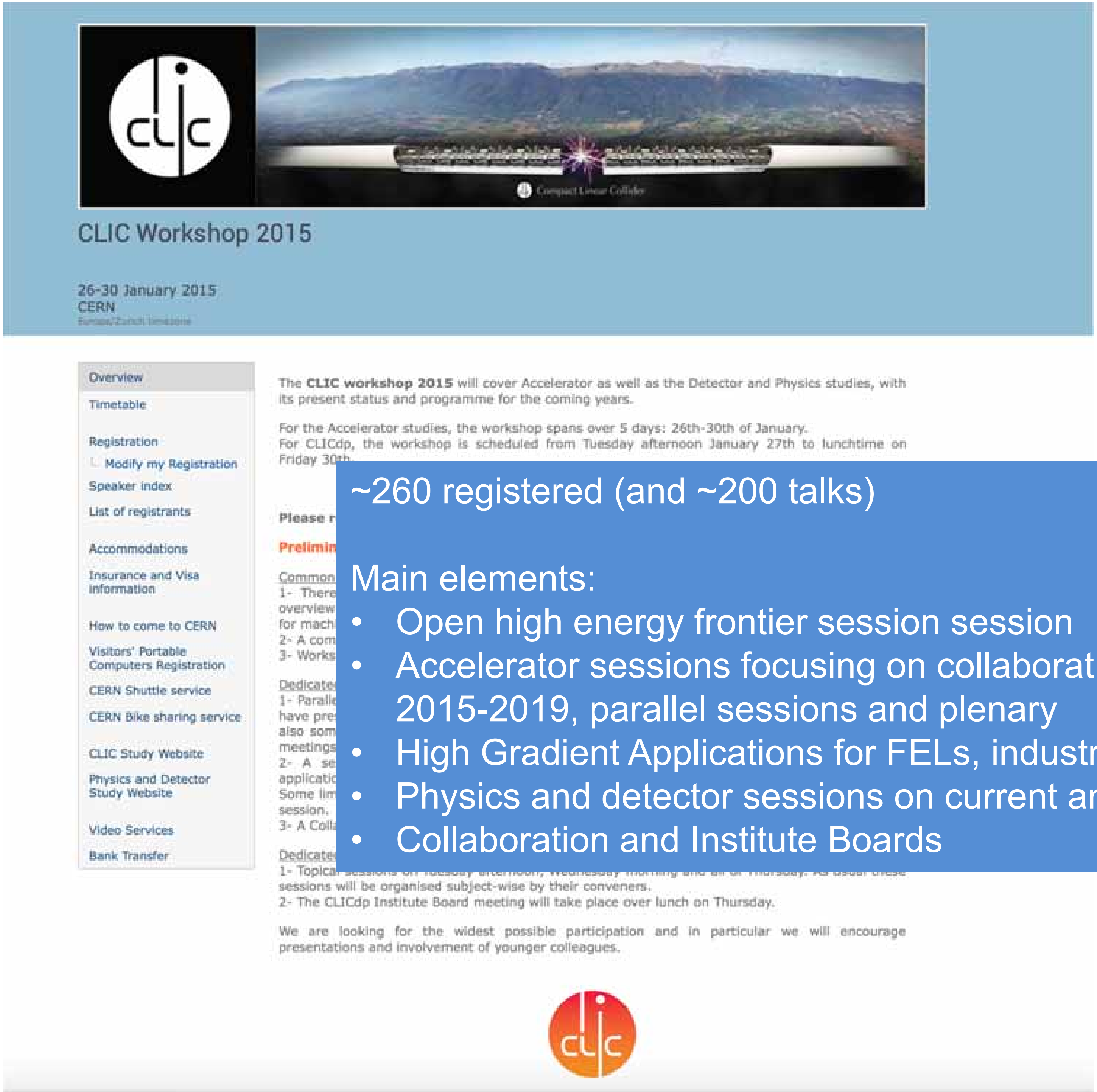
Develop a Project Plan for a staged implementation in agreement with LHC findings; further technical developments with industry, performance studies for accelerator parts and systems, as well as for detectors.



2018-19 Decisions

On the basis of LHC data and Project Plans (for CLIC and other potential projects as FCC), take decisions about next project(s) at the Energy Frontier.

- Common work with ILC related to several acc. systems as part of the LC coll., also related to initial stage physics and detector developments
- Common physics benchmarking with FCC pp and common detect. challenges (ex: timing, granularity), as well as project implementation studies (costs, power, infrastructures …)



CLIC Workshop 2015

26-30 January 2015
CERN
Europe/Zurich timezone

The **CLIC workshop 2015** will cover Accelerator as well as the Detector and Physics studies, with its present status and programme for the coming years.

For the Accelerator studies, the workshop spans over 5 days: 26th-30th of January.
For CLICdp, the workshop is scheduled from Tuesday afternoon January 27th to lunchtime on Friday 30th.

Please r

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1- Topical
sessions will be organised subject-wise by their conveners.
2- The CLICdp Institute Board meeting will take place over lunch on Thursday.

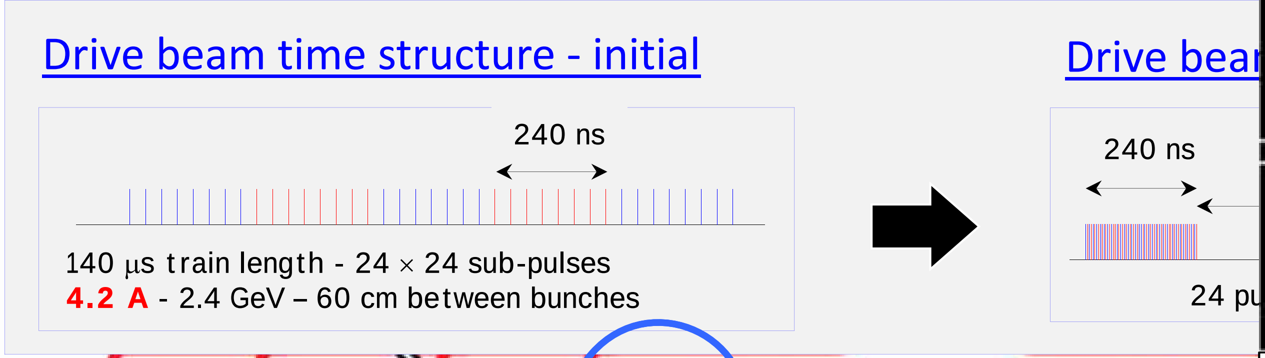
We are looking for the widest possible participation and in particular we will encourage presentations and involvement of younger colleagues.

~260 registered (and ~200 talks)

Main elements:
- Open high energy frontier session session
- Accelerator sessions focusing on collaboration efforts and plans 2015-2019, parallel sessions and plenary
- High Gradient Applications for FELs, industry, medical
- Physics and detector sessions on current and future activities
- Collaboration and Institute Boards

CLIC Layout at 3 TeV

Drive Beam Generation



Drive beam time structure - initial

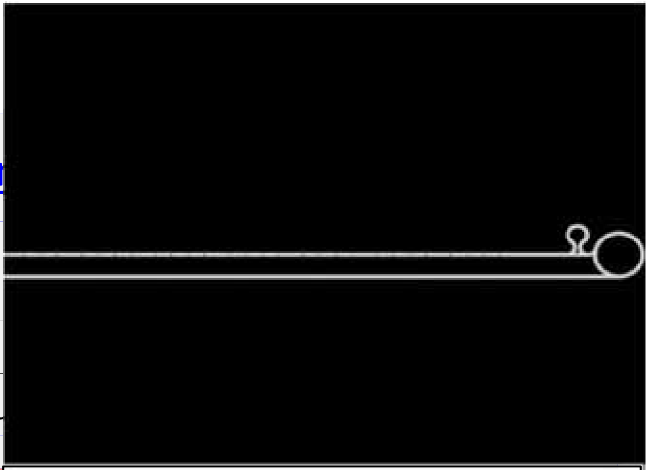
240 ns

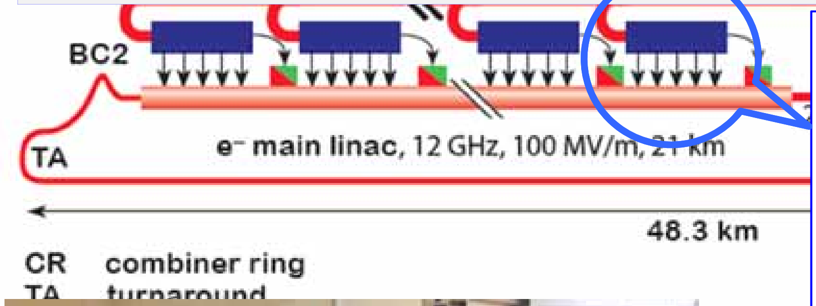
140 μs train length - 24 × 24 sub-pulses
4.2 A - 2.4 GeV – 60 cm between bunches

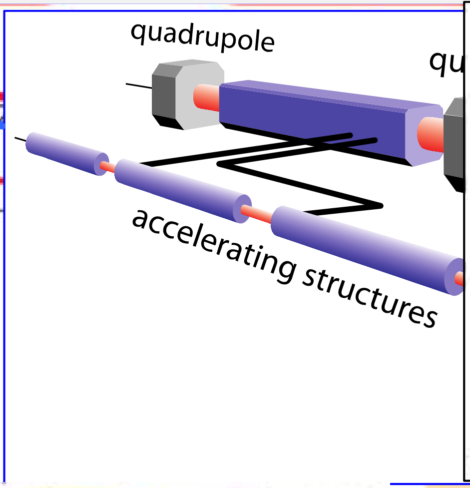
Drive bear

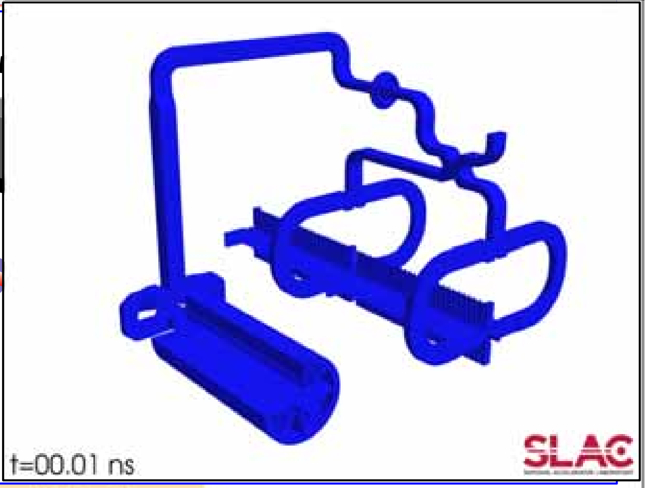
240 ns

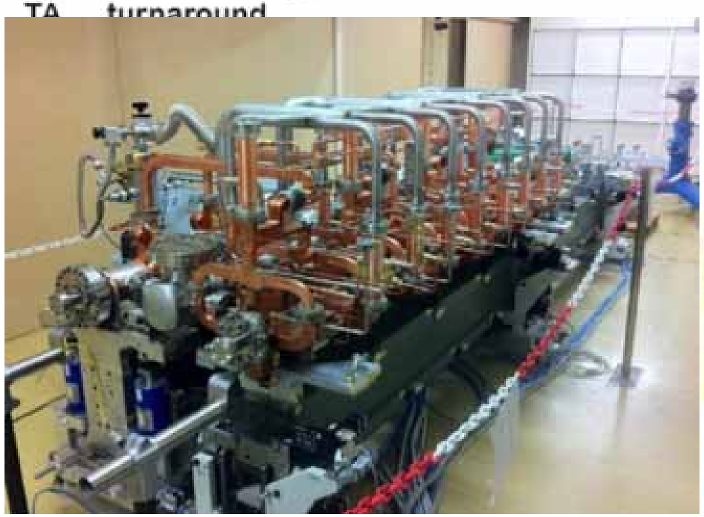
24 pu

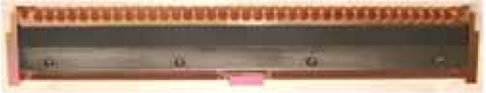






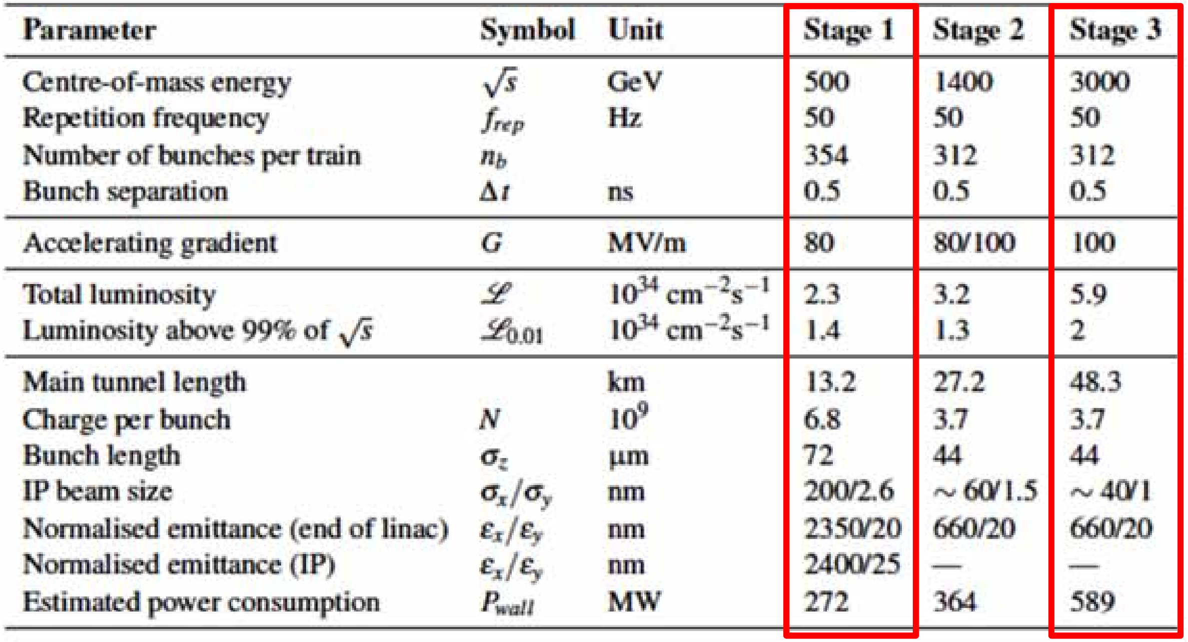






Possible CLIC stages studied in the CDR

Table 1: Parameters for the CLIC energy stages of scenario A.



Parameter	Symbol	Unit	Stage 1	Stage 2	Stage 3
Centre-of-mass energy	$\sqrt{s}$	GeV	500	1400	3000
Repetition frequency	f_{rep}	Hz	50	50	50
Number of bunches per train	n_b		354	312	312
Bunch separation	Δt	ns	0.5	0.5	0.5
Accelerating gradient	G	MV/m	80	80/100	100
Total luminosity	$\mathscr{L}$	10^{34} cm^{-2}s^{-1}	2.3	3.2	5.9
Luminosity above 99% of $\sqrt{s}$	$\mathscr{L}_{0.01}$	10^{34} cm^{-2}s^{-1}	1.4	1.3	2
Main tunnel length		km	13.2	27.2	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	200/2.6	~ 60/1.5	~ 40/1
Normalised emittance (end of linac)	ϵ_x/ϵ_y	nm	2350/20	660/20	660/20
Normalised emittance (IP)	ϵ_x/ϵ_y	nm	2400/25	—	—
Estimated power consumption	P_{wall}	MW	272	364	589

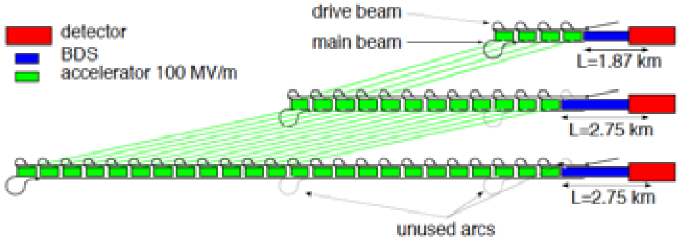
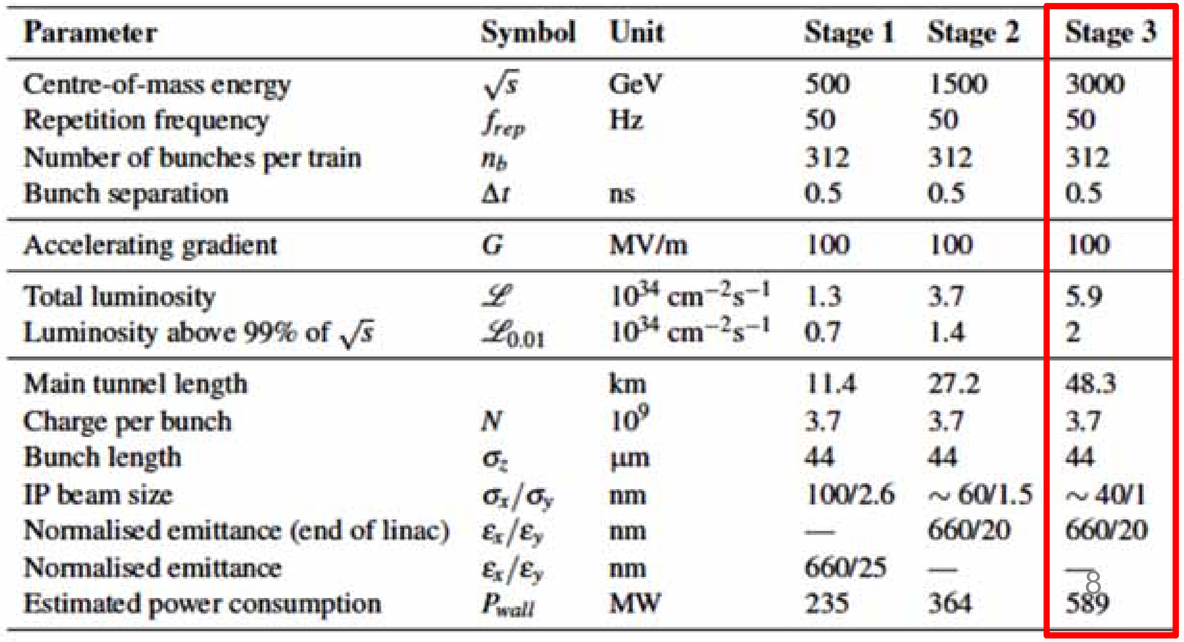


Fig. 3.6: Simplified upgrade scheme for CLIC staging scenario B.

Table 2: Parameters for the CLIC energy stages of scenario B.



Parameter	Symbol	Unit	Stage 1	Stage 2	Stage 3
Centre-of-mass energy	$\sqrt{s}$	GeV	500	1500	3000
Repetition frequency	f_{rep}	Hz	50	50	50
Number of bunches per train	n_b		312	312	312
Bunch separation	Δt	ns	0.5	0.5	0.5
Accelerating gradient	G	MV/m	100	100	100
Total luminosity	$\mathscr{L}$	10^{34} cm^{-2}s^{-1}	1.3	3.7	5.9
Luminosity above 99% of $\sqrt{s}$	$\mathscr{L}_{0.01}$	10^{34} cm^{-2}s^{-1}	0.7	1.4	2
Main tunnel length		km	11.4	27.2	48.3
Charge per bunch	N	10^9	3.7	3.7	3.7
Bunch length	σ_z	μm	44	44	44
IP beam size	σ_x/σ_y	nm	100/2.6	~ 60/1.5	~ 40/1
Normalised emittance (end of linac)	ϵ_x/ϵ_y	nm	—	660/20	660/20
Normalised emittance	ϵ_x/ϵ_y	nm	660/25	—	—
Estimated power consumption	P_{wall}	MW	235	364	589

Key features:

- High gradient (energy/length)
- Small beams (luminosity)
- Repetition rates and bunch spacing (experimental conditions)

LINEAR COLLIDER COLLABORATION

Main activities

http://clic-study.web.cern.ch/content/clic-accelerator-activities

Parameters, Design and Implementation

- Integrated Baseline Design and Parameters
- Integrated Modeling and Performance Studies
- Feedback Design, Background, Polarization
- Machine Protection & Operational Scenarios
- Electron and positron sources
- Damping Rings
- Ring-To-Main-Linac
- Main Linac - Two-Beam Accelerati
- Beam Delivery System
- Machine-Detector Interface (MDI
- Drive Beam Complex
- Cost, power, schedule, stages

X-band Technologies

- X-band Rf structure Design
- X-band Rf structure Production
- X-band Rf structure High Power Testing
- Novel RF unit developments (high efficiency)
- Installation and Operation of High power Testing Facilities
- Basic High Gradient R&D

Experimental verificati

- CTF3 Consollidation & Upgrades
- Drive Beam phase feed-forward and feedbacks
- Two-Beam module string, test with beam
- Drive-beam front end including modulator development and injector
- Modulator development, magnet converters
- Drive Beam Photo Injector
- Low emittance ring tests
- Accelerator Beam System Tests (ATF and FACET, others)

Technical Developments

- Damping Rings Superconducting Wiggler
- Survey & Alignment
- Quadrupole Stability
- Warm Magnet Prototypes
- Beam Instrumentation and Control
- Two-Beam module development
- Beam Intercepting Devices
- Controls
- Vacuum Systems

Detector and Physics

- Physics studies and benchmarking
- Detector optimisation
- Technical developments

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Detector and Physics

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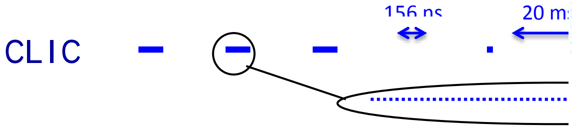
- Technical developments

CLIC experimental conditions

	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
Duty cycle	0.00078%
σ_x / σ_y (nm)	≈ 45 / 1
σ_z (μm)	44

Drives timing requirements for CLIC detector

very small beam size



1 train = 312 bunches, 0.5 ns apart

- not to scale -

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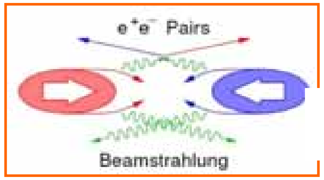
time window / time resolution

The event reconstruction software uses:

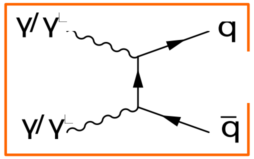
Subdetector	Reconstruction window
ECAL	10 ns
HCAL Endcaps	10 ns
HCAL Barrel	100 ns
Silicon Detectors	10 ns
TPC	entire bunch train

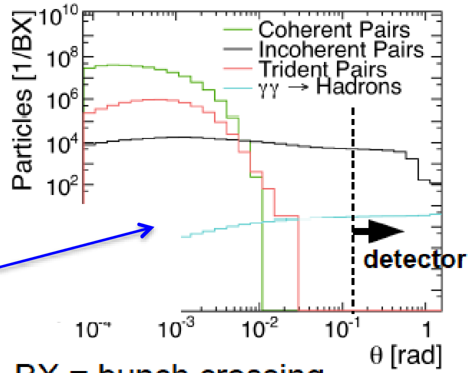
CLIC machine environment



Beam-beam background at IP:

- Small beams => very high E-fields
- Beamstrahlung
- Pair-background
  - High occu
- γγ to hadron
  - Energy deposits (19TeV/train @ √s 3TeV)



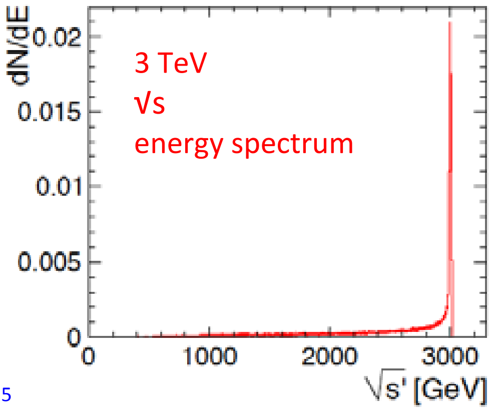


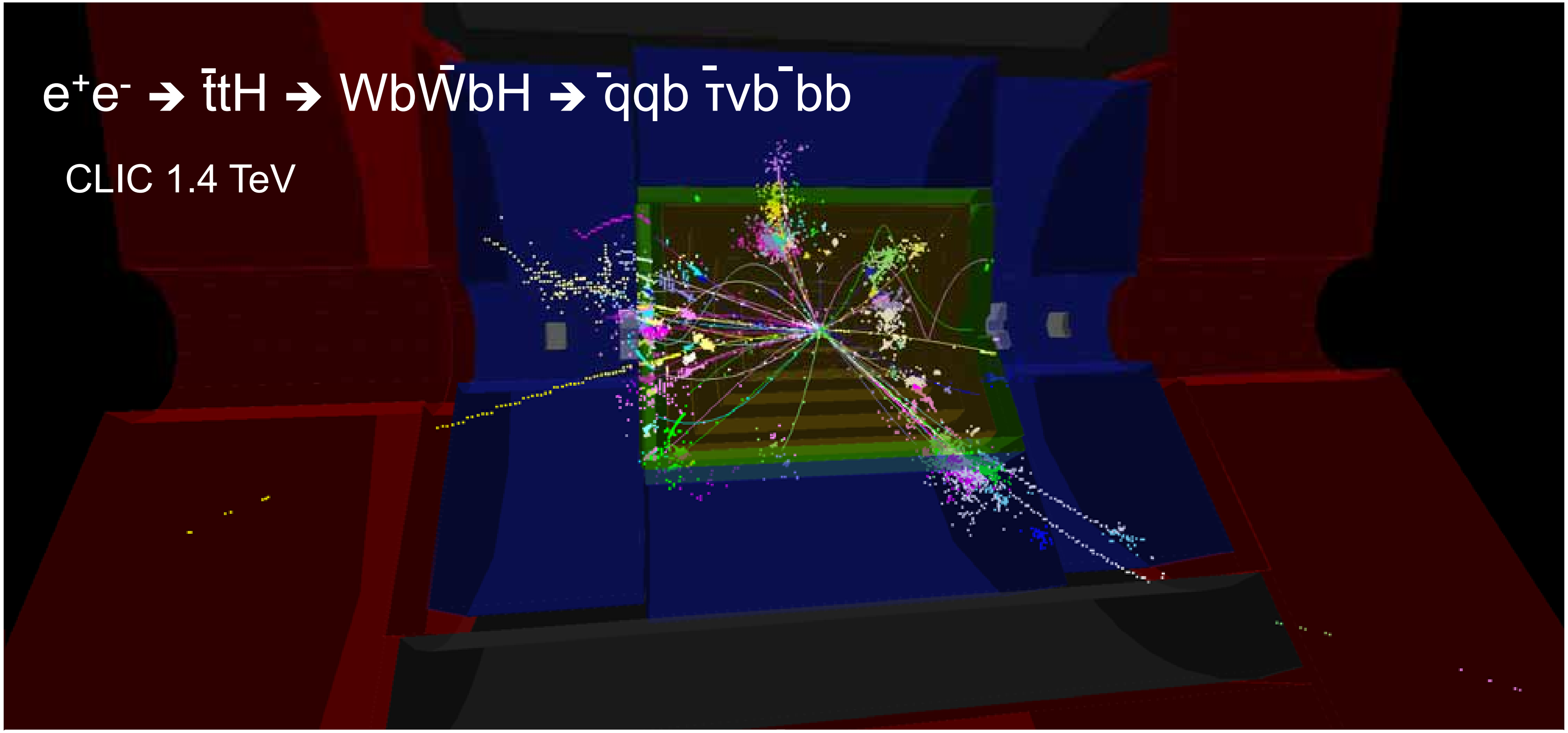
BX = bunch crossing

Beamstrahlung ➔ important energy losses right at the interaction point

E.g. full luminosity at 3 TeV:
5.9×10^{34} $cm^{-2}s^{-1}$
Of which in the 1% most energetic part:
2.0×10^{34} $cm^{-2}s^{-1}$

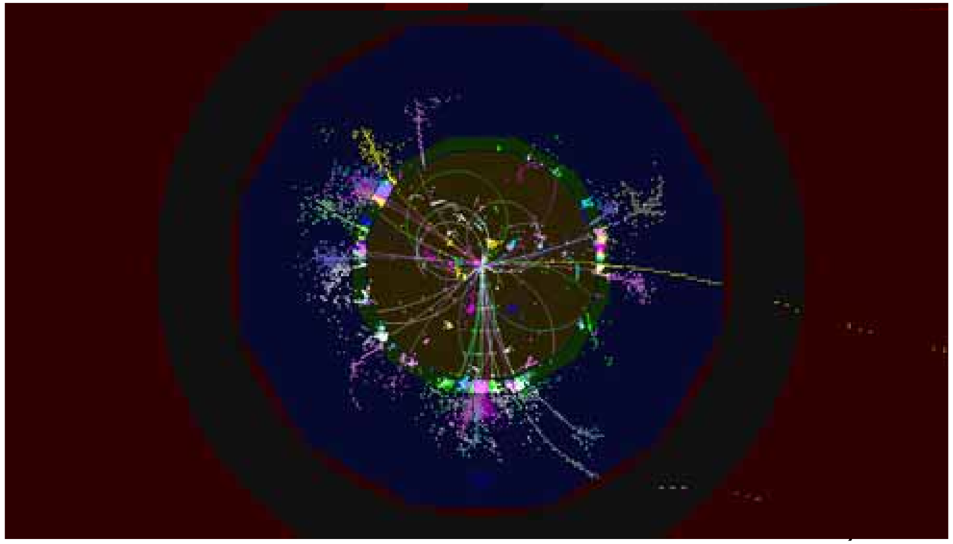
Most physics processes are studied well above production threshold => profit from full luminosity

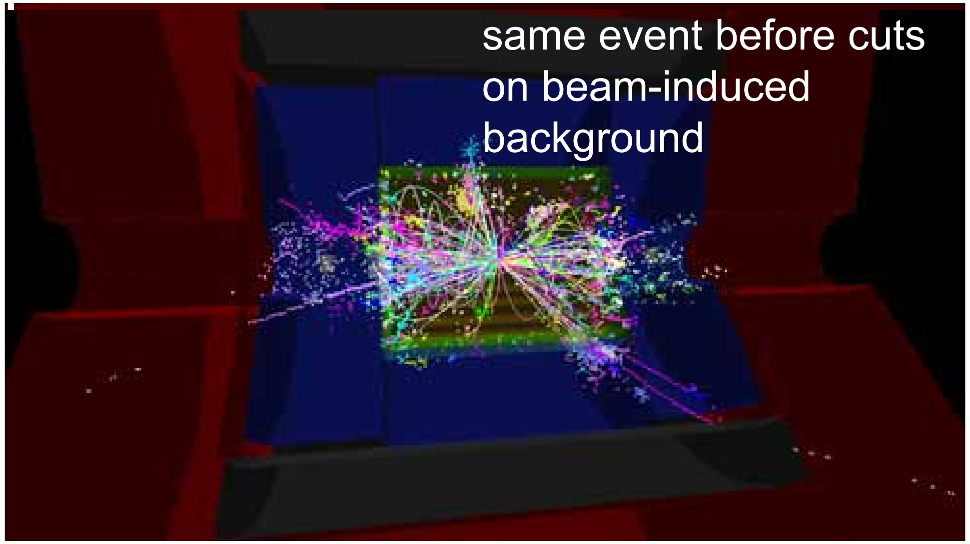




$e^+e^- \rightarrow \bar{t}tH \rightarrow Wb\bar{W}bH \rightarrow \bar{q}qb\ \bar{\tau}\nu b\ \bar{b}b$

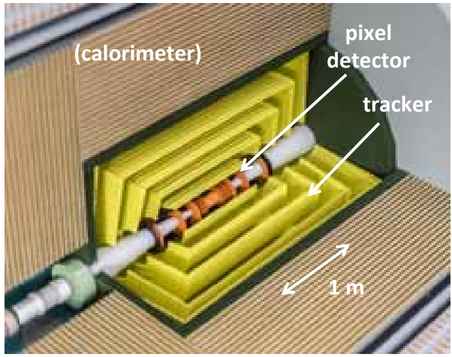
CLIC 1.4 TeV





same event before cuts on beam-induced background

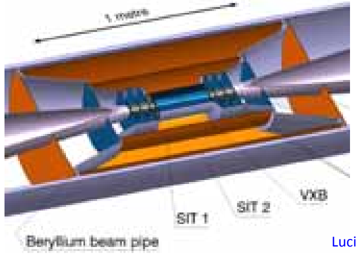
Pixel detector



Flavour tagging capabilities drive the design of the pixel detector

has to be extremely accurate and light !

- 2 billion pixels
- 3 µm single point accuracy
- 25*25 µm² pixels (25 times smaller pixel area at LHC)
  - Pulse height measurement
  - Time measurement to 10 ns
- Ultra-light => 0.2%X_0 per layer
  - Very thin materials/sensors
  - Low-power design, power pulsing, air cooling
  - Aim: 50 mW/cm²
- Radiation level 1



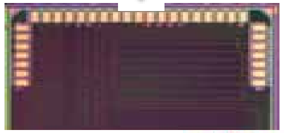
high
covering s

CLIC vertex detector R&D roadmap

Hybrid approach pursued: (<= other options possible)
- Thin (~50 µm) silicon sensors
- Thinned high-density readout ASIC (50 µm)
  - R&D within Medipix/Timepix effort
- Low-mass interconnect
- Power pulsing
- Air cooling

CLICpix demonstrator ASIC
64×64 pixels, fully functional
- 65 nm technology
- 25×25 µm² pixels
- 4-bit ToA and ToT info
- Data compression
- Pulsed power: 50 mW/cm²

⇩



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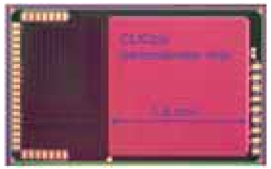
pixel detector R&

thin silicon sensor

electronics chip (65 nm)



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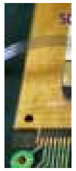
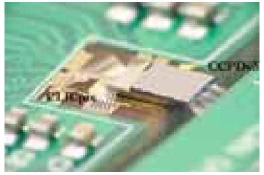
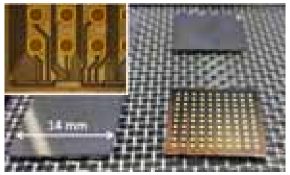


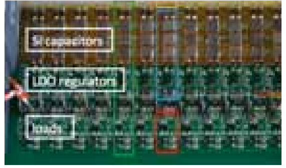
HV-CMOS sensor + CLICpix



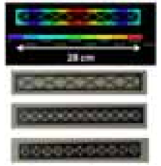
interconnect technology



power delivery + pulsing



thin supports



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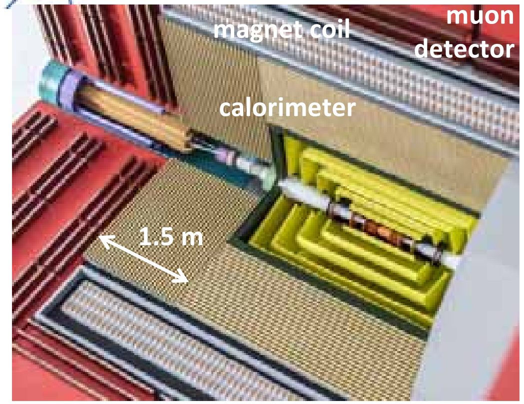
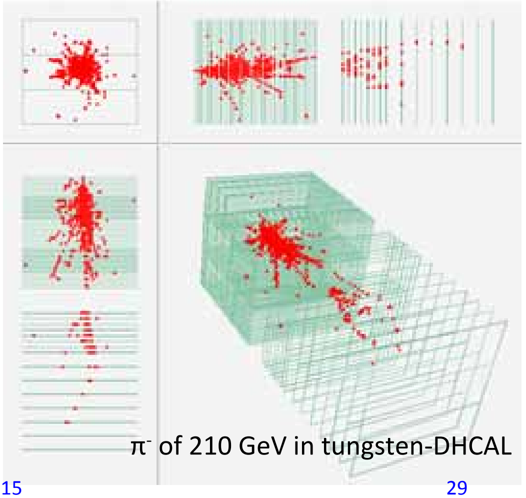
calorimeter R&D



fine-grained calorimeters
"electromagnetic (ECAL) + hadronic (HCAL)"

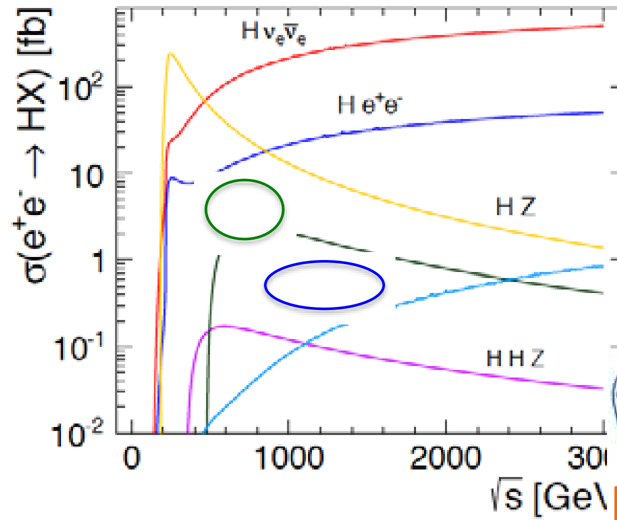
	# layers	cell sizes	technology option
ECAL	~25	5×5 mm²	silicon
HCAL	~60	3×3 cm²	scintillator+SiPM

~80 million readout channels (400* larger than LHC)
R&D in the framework of **CALICE** collaboration



π⁻ of 210 GeV in tungsten-DHCAL

Higgs physics at CLIC



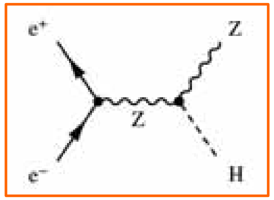
Higgs-Strahlung: $e^+e^- \to ZH$

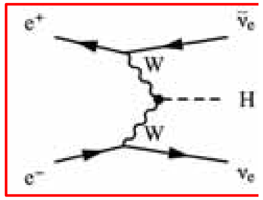
- Measure H from Z-recoil mass
- Model-independent meas.: m_H, σ
- Yields absolute value of g_{HZZ}

WW fusion: $e^+e^- \to H\nu_e\nu_e$

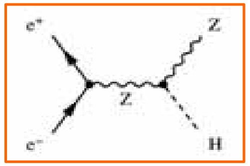
- Precise cross-section measurements in ττ, μμ, qq, … decay modes
- Profits from higher √s (≥350 GeV)

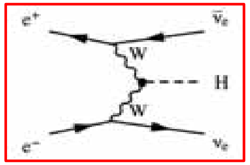
Radiation off top-quarks: $e^+e^- \to t\bar{t}H$

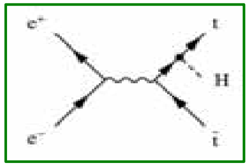




Higgs coupling to mass

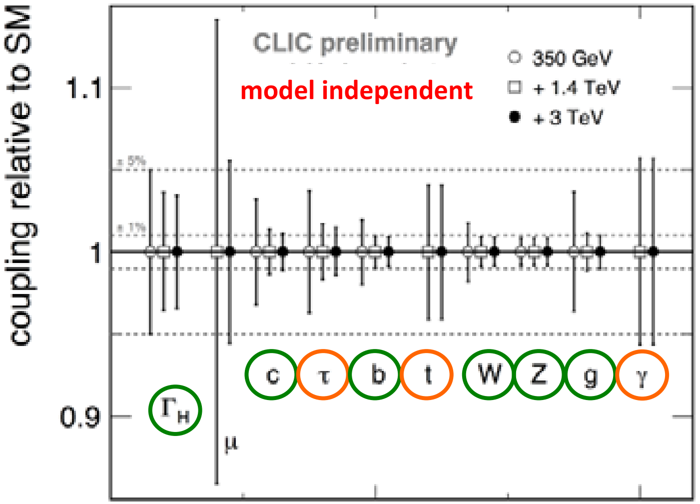






combining all Higgs information

production + decay

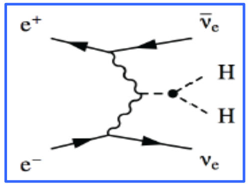


○ much more accurate than HL-LHC

○ similar accuracy as HL-LHC

Note: contrary to (HL-)LHC, CLIC results are model-independent

Work in progress !



Higgs self-coupling H=> HH

Gives access to understanding the Higgs field

Requires high energies => coupling g_{HHH} to 24% at 1.4 TeV, 10% at +3 TeV

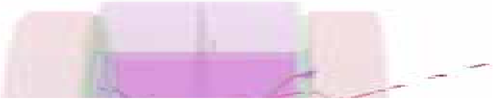
the simplest case: slepton at 3 TeV

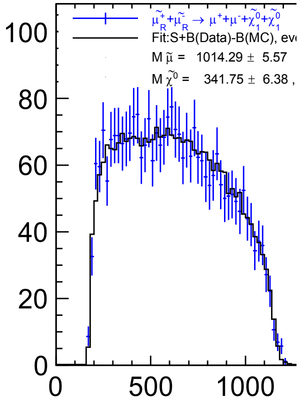
Slepton production at CLIC very clean

slepton masses ~ 1 TeV

Investigated channels

- e^+e^- ! $\tilde{\mu}_R^+$
- e^+e^- ! $\tilde{e}_R^+$
- e^+e^- ! $\tilde{\ }_e$





di-jet masses: gauginos at 3 TeV

$m(\tilde{\chi}_1^0)$ = 340 GeV

$m(\tilde{\chi}_2^0), m(\tilde{\chi}_1^+)$ □ 643 GeV

Chargino and neutralino pair production

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

e^+e^- ! $\tilde{\chi}_2^0$

e^+e^- ! $\tilde{\chi}_2^0$

$m(\tilde{\chi}_1^\pm)$

$m(\tilde{\chi}_2^0$

use sle

$m(\tilde{\chi}_1^0$

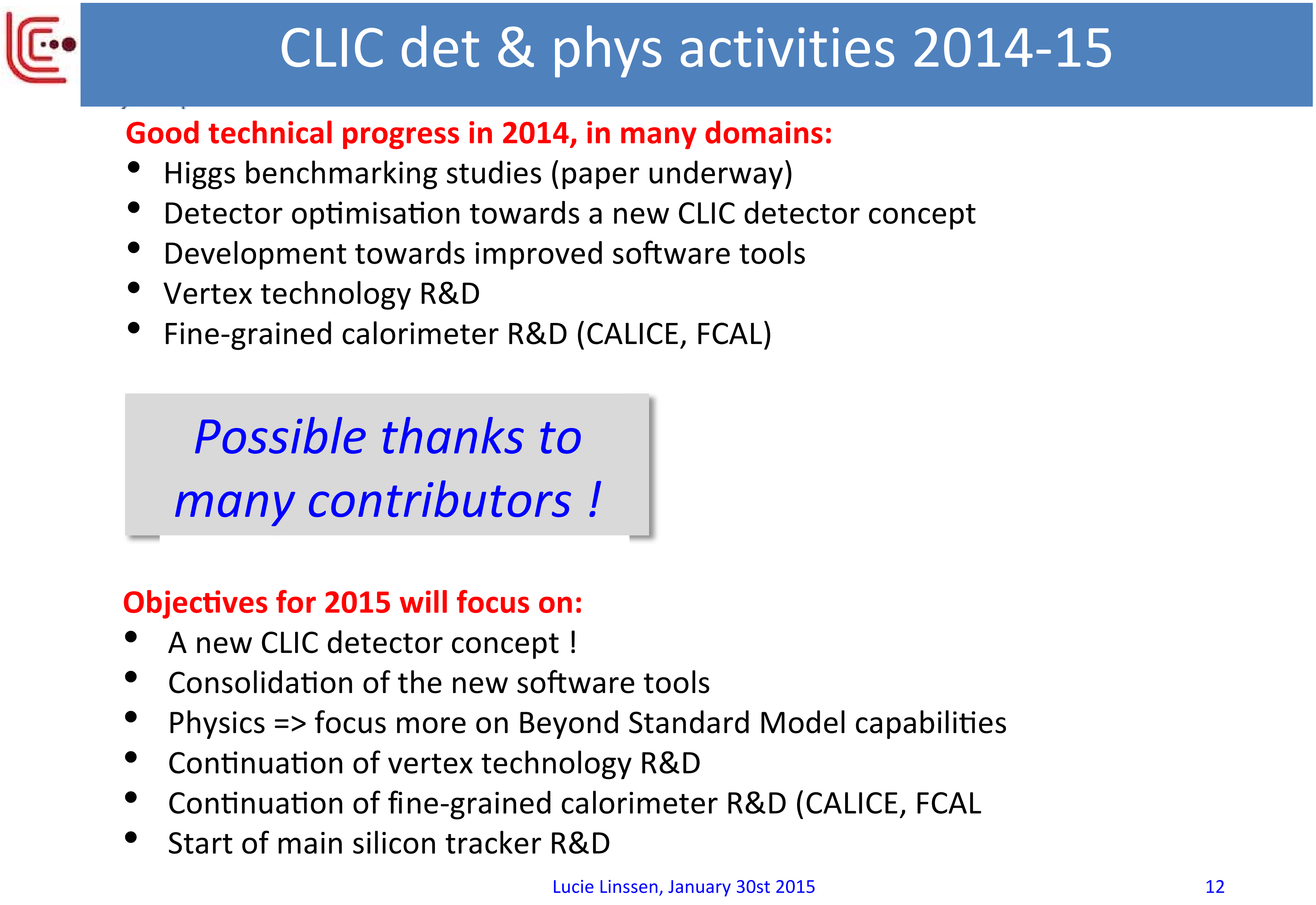
result:

results of SUSY benchmarks

Table 8: Summary table of the CLIC SUSY benchmark analyses results obtained with full-detector simulations with background overlaid. All studies are performed at a center-of-mass energy of 3 TeV (1.4 TeV) and for an integrated luminosity of 2 ab^{-1} (1.5 ab^{-1}) [21, 22, 23, 24, 25, 26, 27].

$\sqrt{s}$ (TeV)	Process	Decay mode	SUSY model	Measured quantity	Generator value (GeV)	Stat. uncertainty
3.0	Sleptons	$\tilde{\mu}_R^+\tilde{\mu}_R^- \rightarrow \mu^+\mu^-\tilde{\chi}_1^0\tilde{\chi}_1^0$	II	$\tilde{\ell}$ mass	1010.8	0.6%
				$\tilde{\chi}_1^0$ mass	340.3	1.9%
		$\tilde{e}_R^+\tilde{e}_R^- \rightarrow e^+e^-\tilde{\chi}_1^0\tilde{\chi}_1^0$		$\tilde{\ell}$ mass	1010.8	0.3%
				$\tilde{\chi}_1^0$ mass	340.3	1.0%
		$\tilde{\nu}_e\tilde{\nu}_e \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 e^+e^-W^+W^-$		$\tilde{\ell}$ mass	1097.2	0.4%
				$\tilde{\chi}_1^\pm$ mass	643.2	0.6%
3.0	Chargino Neutralino	$\tilde{\chi}_1^+\tilde{\chi}_1^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 W^+W^-$ $\tilde{\chi}_2^0\tilde{\chi}_2^0 \rightarrow h/Z^0 h/Z^0 \tilde{\chi}_1^0\tilde{\chi}_1^0$	II	$\tilde{\chi}_1^\pm$ mass $\tilde{\chi}_2^0$ mass	643.2 643.1	1.1% 1.5%
3.0	Squarks	$\tilde{q}_R\tilde{q}_R \rightarrow q\bar{q}\tilde{\chi}_1^0\tilde{\chi}_1^0$	I	$\tilde{q}_R$ mass	1123.7	0.52%
3.0	Heavy Higgs	$H^0A^0 \rightarrow b\bar{b}b\bar{b}$ $H^+H^- \rightarrow t\bar{b}b\bar{t}$	I	H^0/A^0 mass $H^\pm$ mass	902.4/902.6 906.3	0.3% 0.3%
1.4	Sleptons	$\tilde{\mu}_R^+\tilde{\mu}_R^- \rightarrow \mu^+\mu^-\tilde{\chi}_1^0\tilde{\chi}_1^0$	III	$\tilde{\ell}$ mass	560.8	0.1%
				$\tilde{\chi}_1^0$ mass	357.8	0.1%
		$\tilde{e}_R^+\tilde{e}_R^- \rightarrow e^+e^-\tilde{\chi}_1^0\tilde{\chi}_1^0$		$\tilde{\ell}$ mass	558.1	0.1%
				$\tilde{\chi}_1^0$ mass	357.1	0.1%
		$\tilde{\nu}_e\tilde{\nu}_e \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 e^+e^-W^+W^-$		$\tilde{\ell}$ mass	644.3	2.5%
				$\tilde{\chi}_1^\pm$ mass	487.6	2.7%
1.4	Stau	$\tilde{\tau}_1^+\tilde{\tau}_1^- \rightarrow \tau^+\tau^-\tilde{\chi}_1^0\tilde{\chi}_1^0$	III	$\tilde{\tau}_1$ mass	517	2.0%
1.4	Chargino Neutralino	$\tilde{\chi}_1^+\tilde{\chi}_1^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 W^+W^-$ $\tilde{\chi}_2^0\tilde{\chi}_2^0 \rightarrow h/Z^0 h/Z^0 \tilde{\chi}_1^0\tilde{\chi}_1^0$	III	$\tilde{\chi}_1^\pm$ mass $\tilde{\chi}_2^0$ mass	487 487	0.2% 0.1%

Large part of the SUSY spectrum measured at <1% level



CLIC det & phys activities 2014-15

Good technical progress in 2014, in many domains:

- Higgs benchmarking studies (paper underway)
- Detector optimisation towards a new CLIC detector concept
- Development towards improved software tools
- Vertex technology R&D
- Fine-grained calorimeter R&D (CALICE, FCAL)

Possible thanks to many contributors !

Objectives for 2015 will focus on:

- A new CLIC detector concept !
- Consolidation of the new software tools
- Physics => focus more on Beyond Standard Model capabilities
- Continuation of vertex technology R&D
- Continuation of fine-grained calorimeter R&D (CALICE, FCAL
- Start of main silicon tracker R&D

Lucie Linssen, January 30st 2015

More information and details for each point

LINEAR COLLIDER COLLABORATION

Main activities

http://clic-study.web.cern.ch/content/clic-accelerator-activities

Parameters, Design and Implementation

- Integrated Baseline Design and Parameters
- Integrated Modeling and Performance Studies
- Feedback Design, Background, Polarization
- Machine Protection & Operational Scenarios
- Electron and positron sources
- Damping Rings
- Ring-To-Main-Linac
- Main Linac - Two-Beam Accelerati
- Beam Delivery System
- Machine-Detector Interface (MDI
- Drive Beam Complex
- Cost, power, schedule, stages

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- X-band Rf structure Design
- X-band Rf structure Production
- X-band Rf structure High Power Testing
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- Basic High Gradient R&D

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- Accelerator Beam System

Technical Developments

- Damping Rings Superconducting Wiggler
- Survey & Alignment
- Quadrupole Stability
- Warm Magnet Prototypes
- Beam Instrumentation and Control
- Two-Beam module development
- Beam Intercepting Devices
- Controls
- Vacuum Systems

Detector and Physics

- Physics studies and benchmarking
- Detector optimisation
- Technical developments

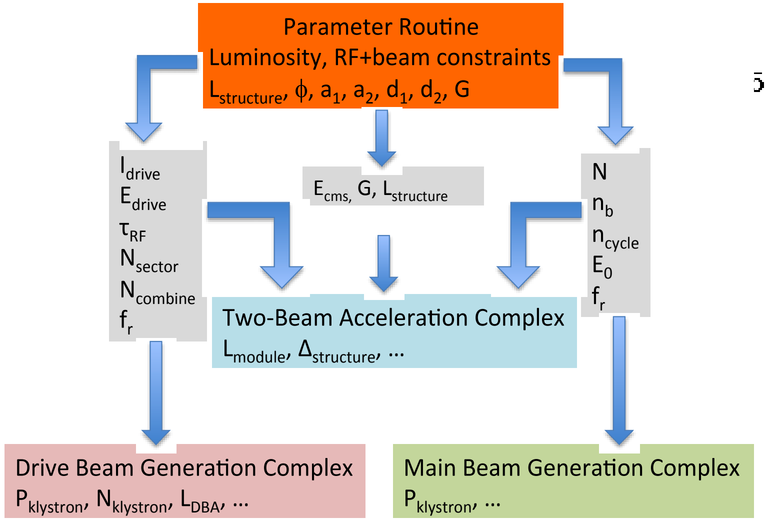
Cost/power: Design/parameters & Technical developments

Automatic procedure scanning over many structures (parameter sets)

Structure design fixed by few parameters
$a_1, a_2, d_1, d_2, N_c, f, G$

Beam parameters derived automatically

Cost calculated – and power



Parameter Routine
Luminosity, RF+beam constraints
$L_{structure}$, ϕ, a_1, a_2, d_1, d_2, G

I_{drive}
E_{drive}
τ_{RF}
N_{sector}
$N_{combine}$
f_r

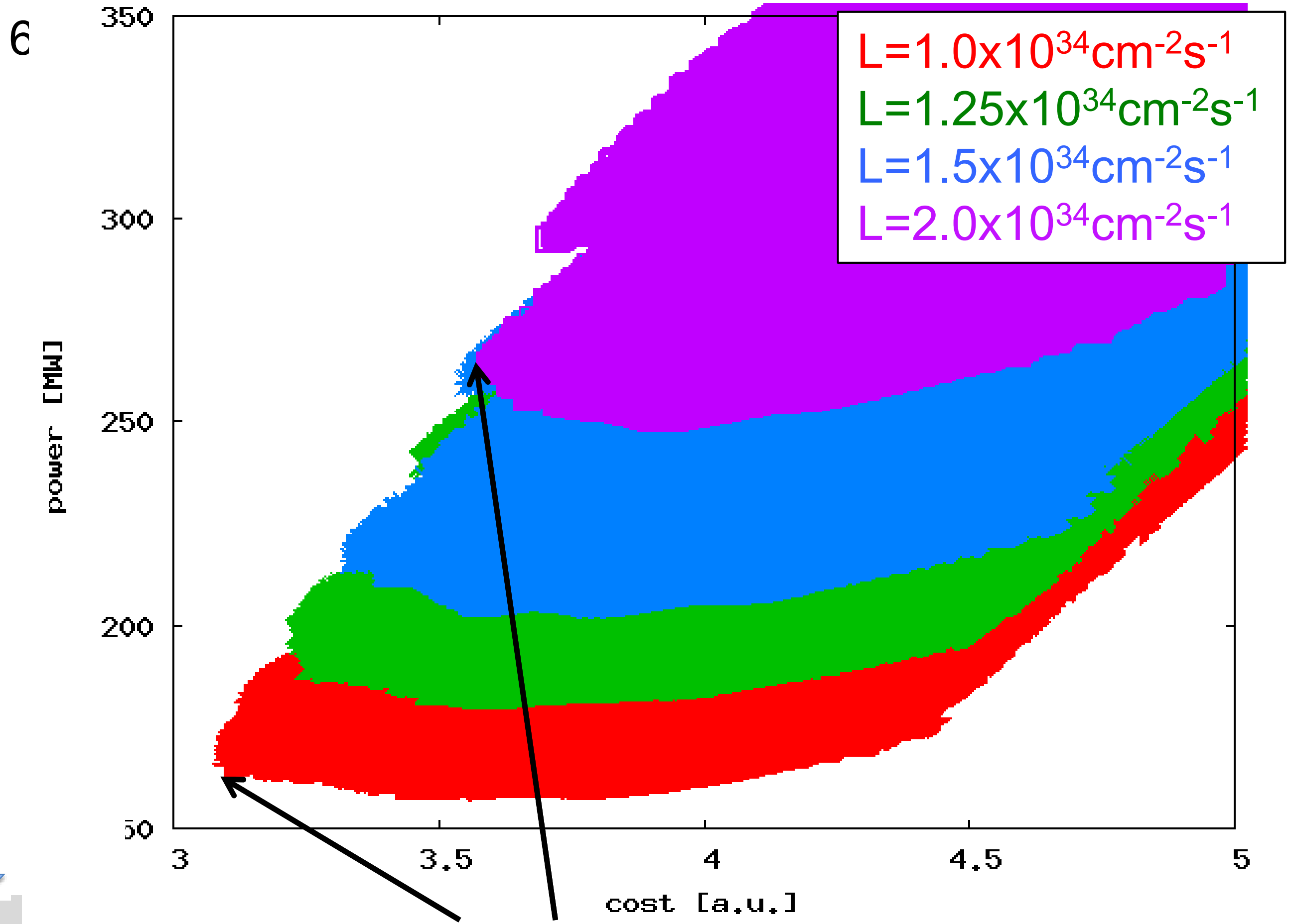
E_{cms}, G, $L_{structure}$

N
n_b
n_{cycle}
E_0
f_r

Two-Beam Acceleration Complex
L_{module}, $\Delta_{structure}$, …

Drive Beam Generation Complex
$P_{klystron}$, $N_{klystron}$, L_{DBA}, …

Main Beam Generation Complex
$P_{klystron}$, …

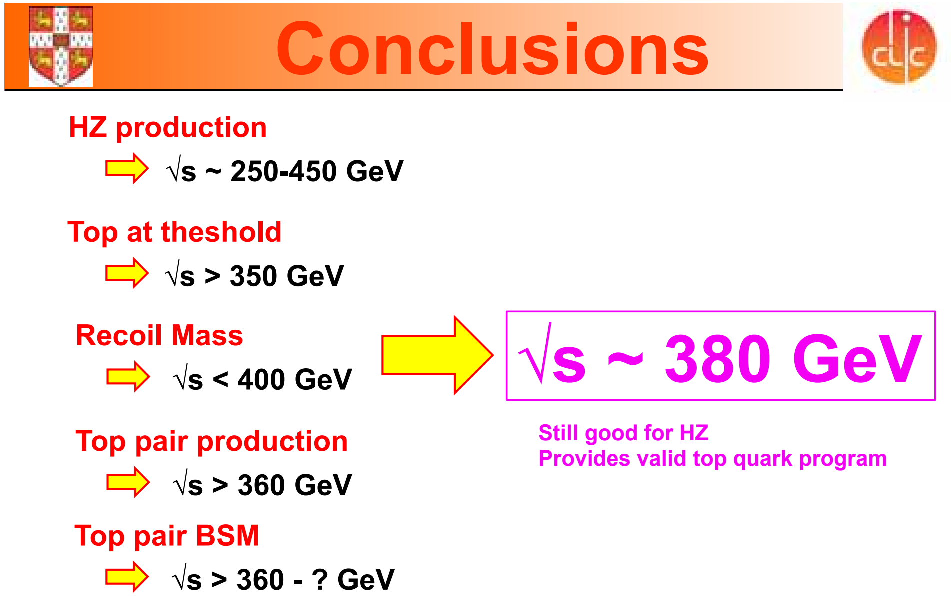


Luminosity goal significantly impact minimum cost
For $L=1\times10^{34}\,cm^{-2}s^{-1}$ to $L=2\times10^{34}\,cm^{-2}s^{-1}$:
Costs 0.5 a.u. and O(100MW)

Cheapest machine is close to lowest power consumption

Stages to be studied

- First stage: E_{cms}=380Gev, L=1.5×10^{34}cm^{-2}s^{-1}, $L_{0.01}$/L>0.6
  - Luminosity based on physics and machine studies in 2014
  - 420 GeV and 360GeV have also been studied
- Second stage: E_{cms}=O(1.5TeV)
- Final stage: E_{cms}=3TeV, L=5.9×10^{34}cm^{-2}s^{-1}, $L_{0.01}$/L>0.3



Conclusions

HZ production
⇨ √s ~ 250-450 GeV

Top at theshold
⇨ √s > 350 GeV

Recoil Mass
⇨ √s < 400 GeV

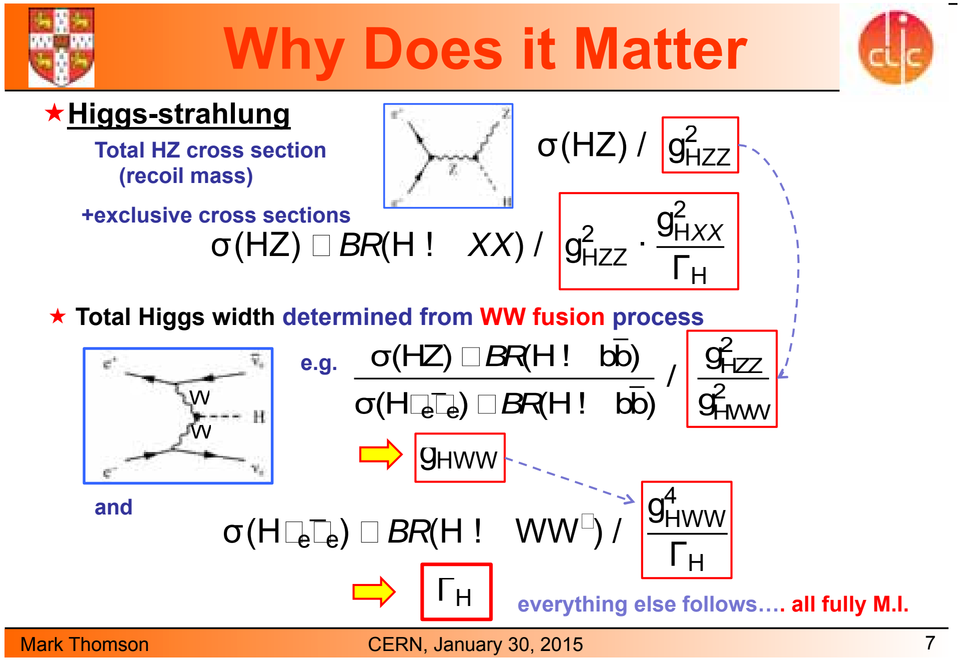
Top pair production
⇨ √s > 360 GeV

Top pair BSM
⇨ √s > 360 - ? GeV

⇨ **√s ~ 380 GeV**

Still good for HZ
Provides valid top quark program

- Next natural steps: Optimised cost and power for given luminosity
- Hopefully needed to redo with new LHC results at some point



Why Does it Matter

★ **Higgs-strahlung**

Total HZ cross section (recoil mass)

$\sigma(HZ) \propto g^2_{HZZ}$

+exclusive cross sections

$\sigma(HZ) \times BR(H \to XX) \propto g^2_{HZZ} \cdot \frac{g^2_{HXX}}{\Gamma_H}$

★ Total Higgs width determined from WW fusion process

e.g. $\frac{\sigma(HZ) \times BR(H \to b\bar{b})}{\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to b\bar{b})} \propto \frac{g^2_{HZZ}}{g^2_{HWW}}$

⇨ g_{HWW}

and

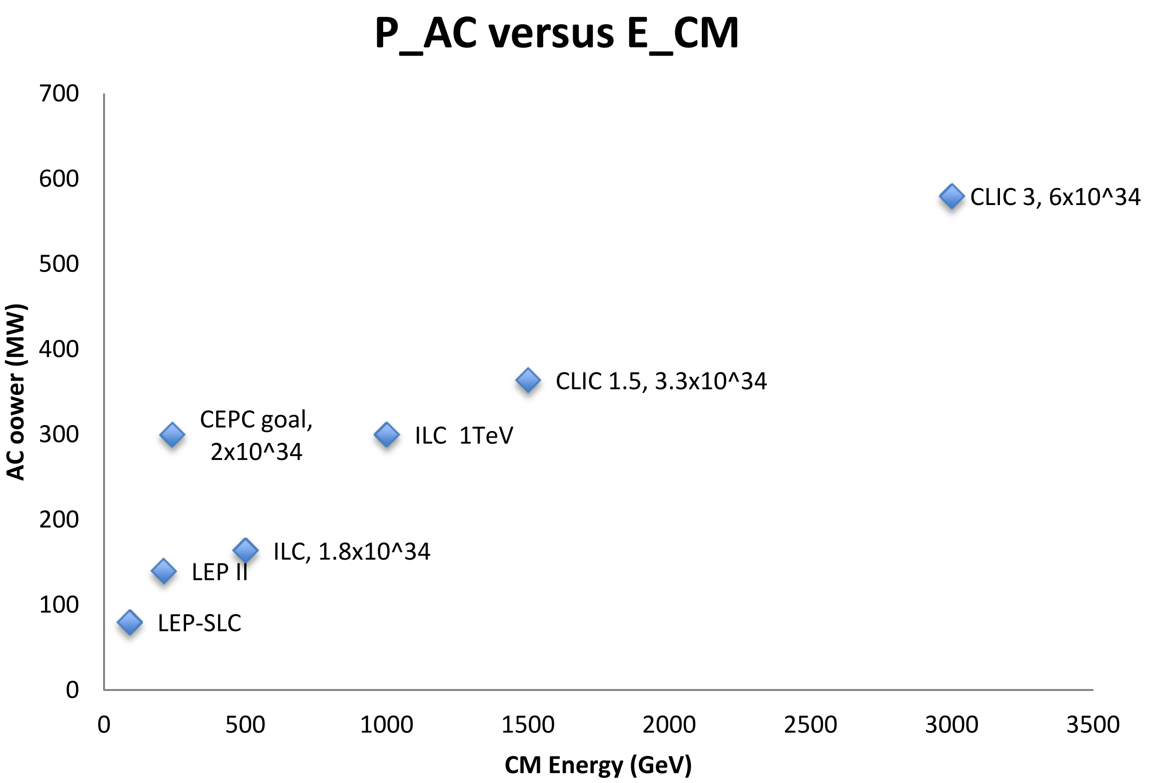
$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to WW^*) \propto \frac{g^4_{HWW}}{\Gamma_H}$

⇨ Γ_H

everything else follows…. all fully M.I.

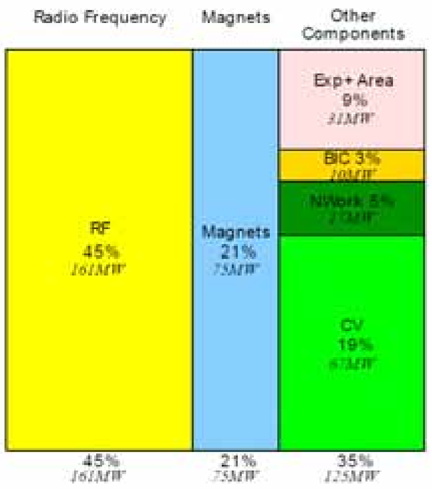
Mark Thomson CERN, January 30, 2015 7

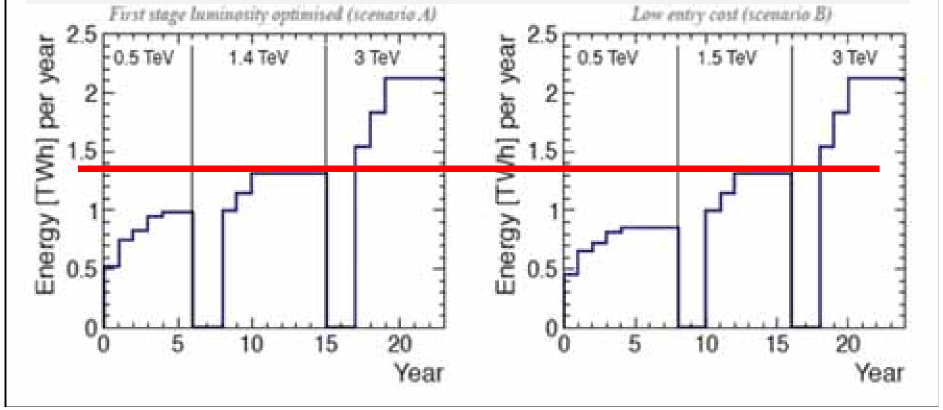
e+/e- Colliders: P_{AC} vs E_{CM}



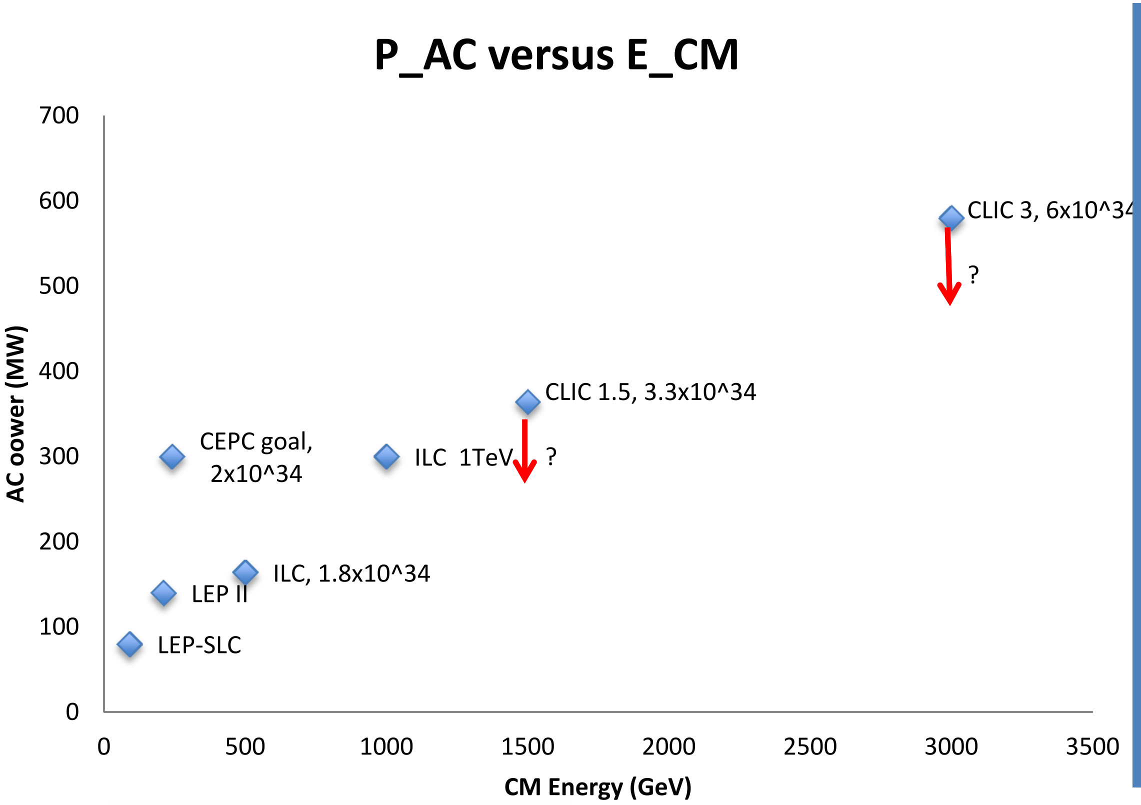
Power reductions are being looked at:

- Machine parameters and technical developments
- Consider where the power is dissipated (distributed or central)
- Look at daily and yearly fluctuation – can one run in “low general demand” periods
- Understand and minimize the energy (consider also standby, MD, down periods, running scenarios



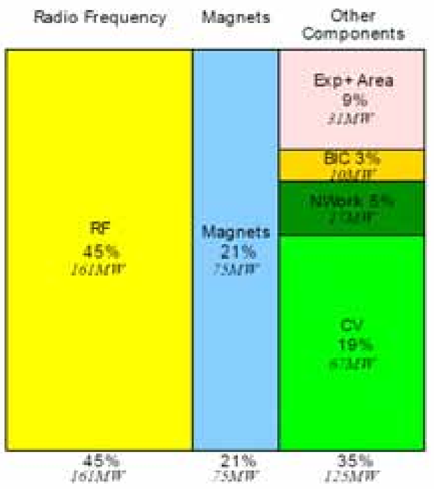

CERN energy consumption 2012: 1.35 TWh

e+/e- Colliders: P_{AC} vs E_{CM}



Beyond the parameter optimization there are other on-going developments (design/technical developments):

- Use of permanent or hybrid magnets for the drive beam (order of 50’000 magnets)
- Optimize drive beam accelerator klystron system
- Electron pre-damping ring can be removed with good electron injector
- Dimension drive beam accelerator building and infrastructure are for 3 TeV, dimension to 1.5 TeV results in large saving
- Systematic optimization of injector complex linacs in preparation
- Optimize and reduce overhead estimates



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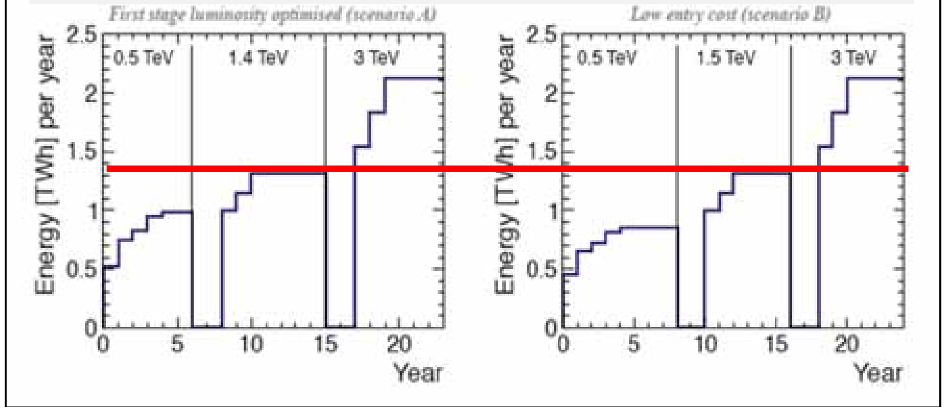
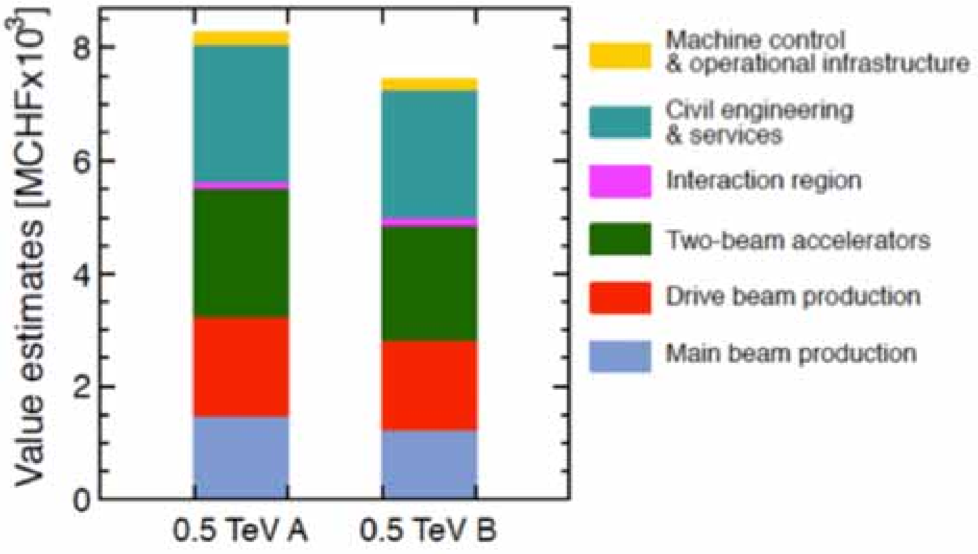


Developments for costs



First to second stage: 4 MCHF/GeV (i.e. initial costs are very significant)

Caveats:

Uncertainties 20-25%
Possible savings around 10%
However – first stage not optimised (work for next phase), parameters largely defined for 3 TeV final stage

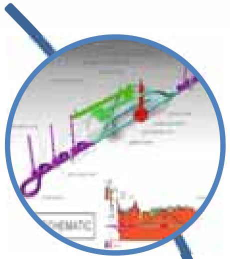
CDR costs can now be updated

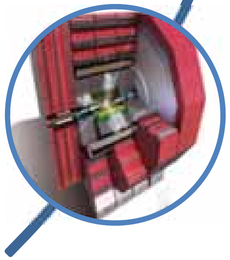
- New parameters optimizing costs, affect mostly initial stages
- Technical developments, affects all stages
- Too early for updated industrial quotes in some areas (other areas can be updated)

2012 CHF versus 2015 CHF ?

Main activities

http://clic-study.web.cern.ch/content/clic-accelerator-activities





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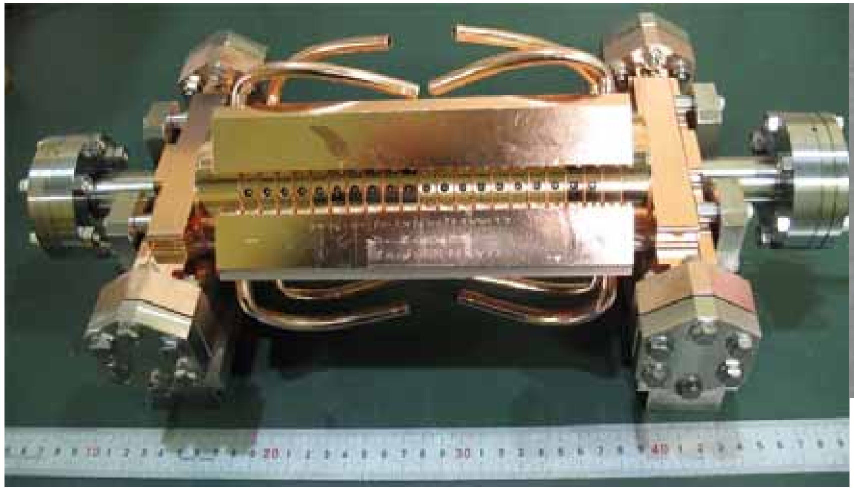
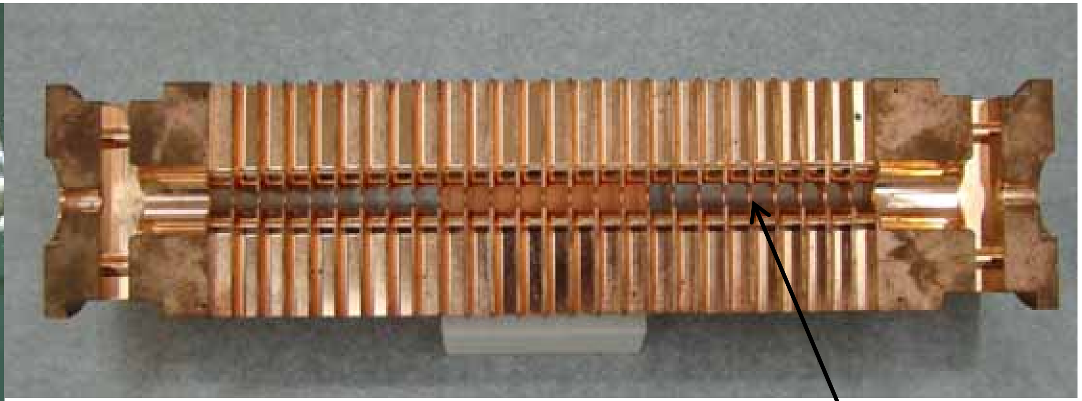
CLIC accelerating structure

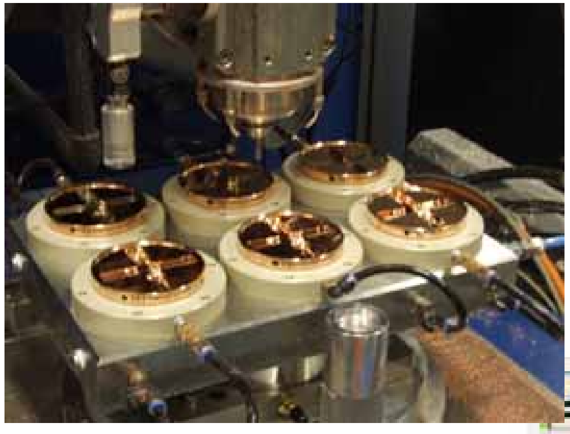


Outside

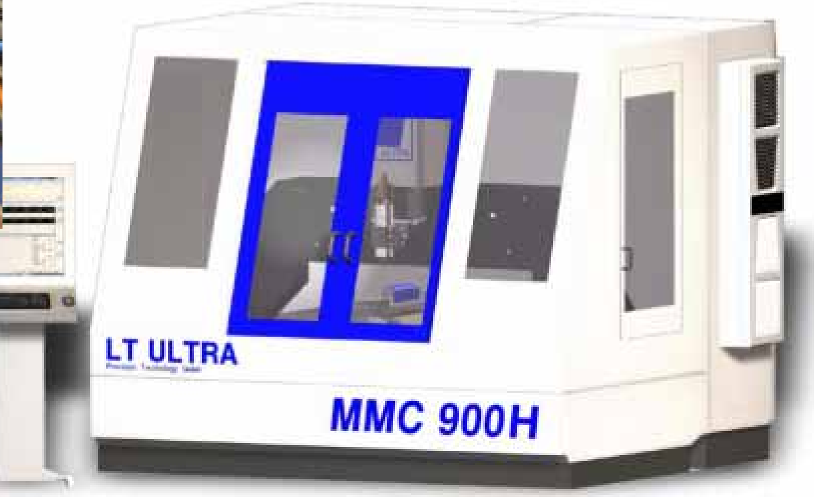


Inside (cut)

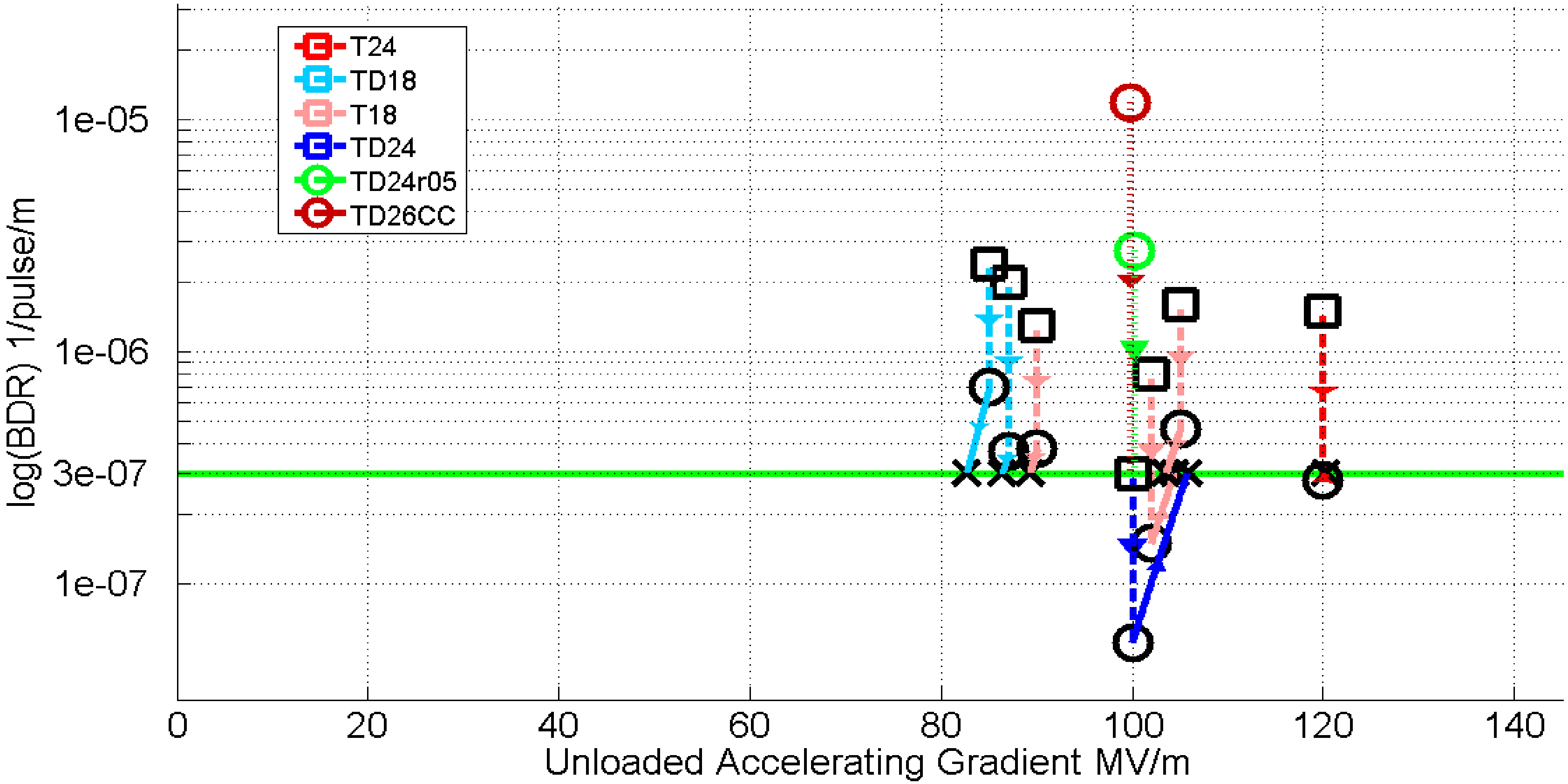
6 mm diameter
beam aperture,
25 cm long



Micron-precision turning
and milling.



High-gradient accel. structure test status



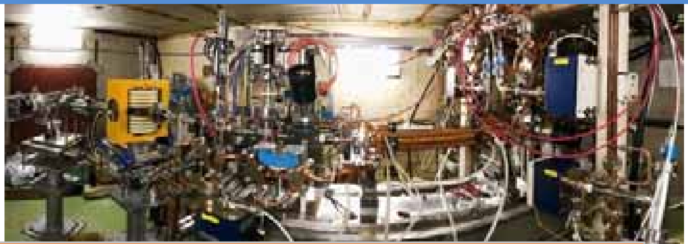
Results very good, design/performance more and more understood – but:

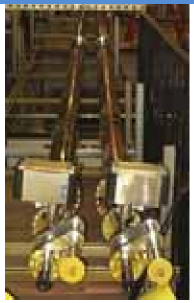
- numbers limited, industrial productions also limited
- basic understanding of BD mechanics improving
- condition time/acceptance tests need more work
- use for other applications (e.g. FELs) needs verification in coming years

In all cases test-capacity is crucial

X-band test-stands

Previous:
Scaled 11.4 GHz
tests at SLAC and KEK.

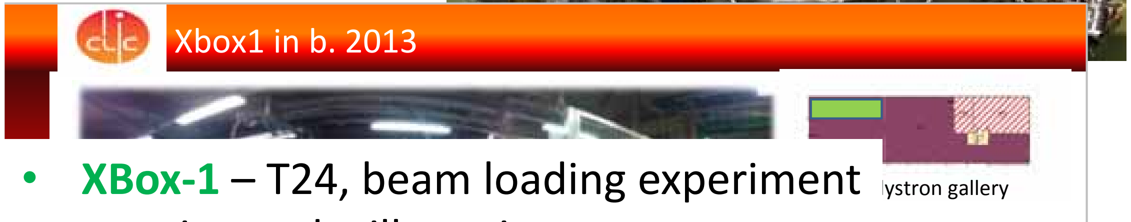




NEXTEF at KEK

ASTA at SLAC

… remain important, also linked to testing of X-band structures from Tsinghua and SINAP

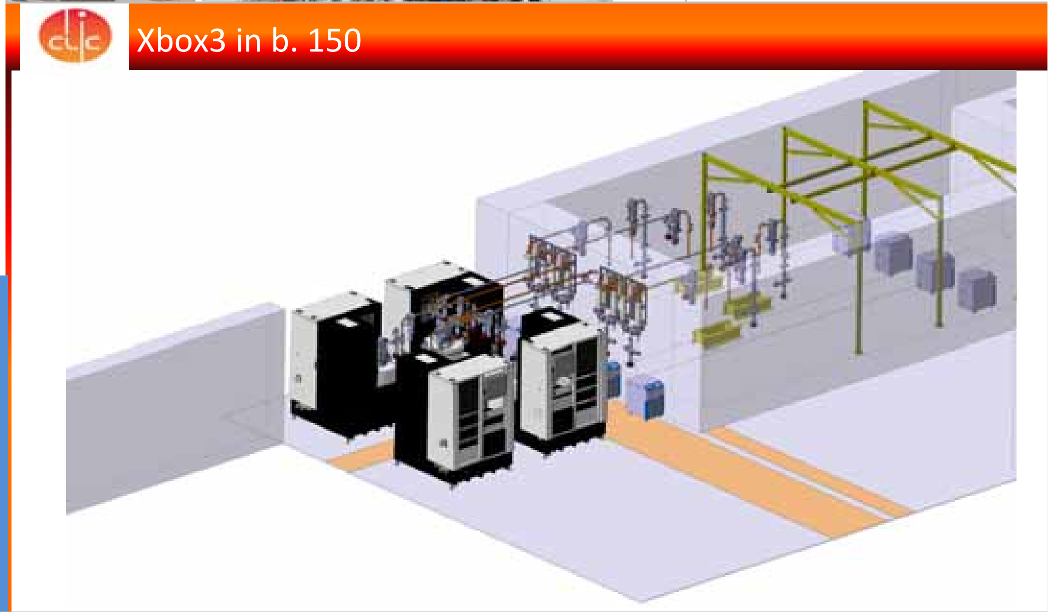


Xbox1 in b. 2013

- **XBox-1** – T24, beam loading experiment ongoing and will continue.
- **XBox-2** – Finish crab cavity, TD26CC next.
- **XBox-3** – Under preparation.
- **NEXTEF** – Finish Tsinghua-built T24. KEK-built TD24R05 next.
- **ASTA** – Commissioning clone of our NI-based control system. KEK/SLAC-built TD24R05 installed and ready to go.

Very significant increase of test-capacity:

- First commercial 12 GHz klystron systems available
- Confidence that one can design for good (and possibly better) gradient performance
- As a result: now possible to use Xband technology in accelerator systems – at smaller scale



Xbox3 in b. 150

Accelerating structures in the pipeline

CLIC structures:

- Two TD26CC built and tested by KEK. *Still superb production*
- One TD26CC built by CIEMAT. *Next step after PETS.*
- Two T24s built by PSI in their production run. *Vacuum brazing alternative, benchmark for their production line.*
- One T24 built by SINAP. *Potentially leads to large X-band installation.*
- Whole structure in industry – Technical specifications are under preparation. *Industrialization, cost estimate.*

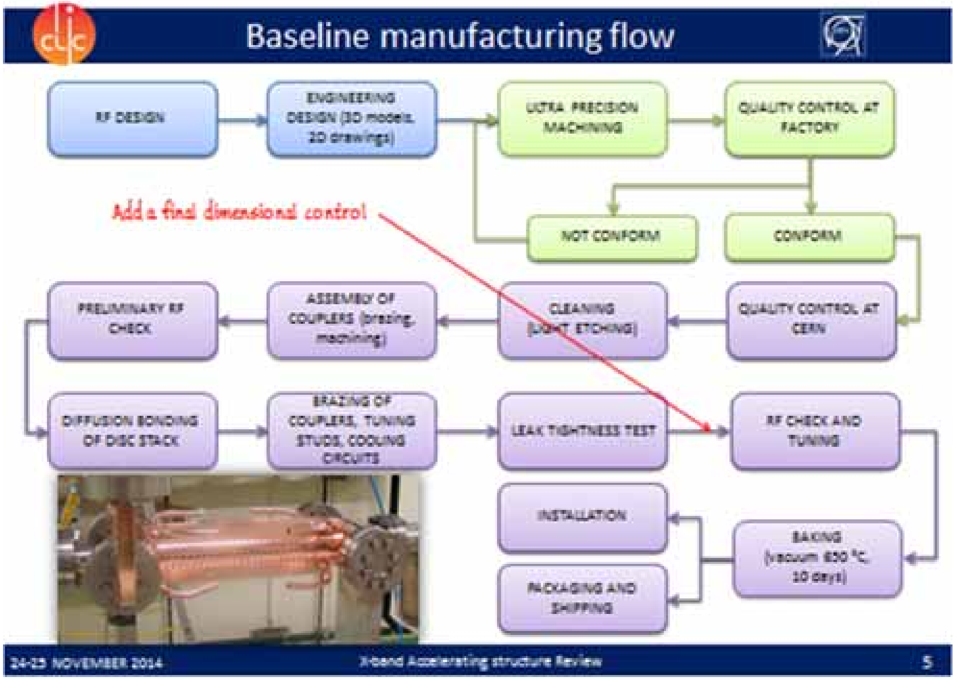
Other related structures:

- Structure in halves by SLAC. *Potentially cheaper, hard materials, preconditioned surfaces possible.*
- Choke-mode damping by Tsinghua. *Potentially cheaper*
- Four XFEL structures by SINAP. *New application with large potential.*

- High-gradient proton funded by KT (CERN technology transfer). *New application.*

Xband accelerating structures review
24-25.11.2014

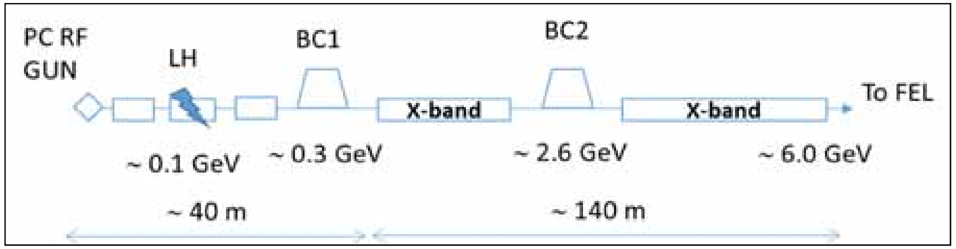
N. Catalan Lasheras

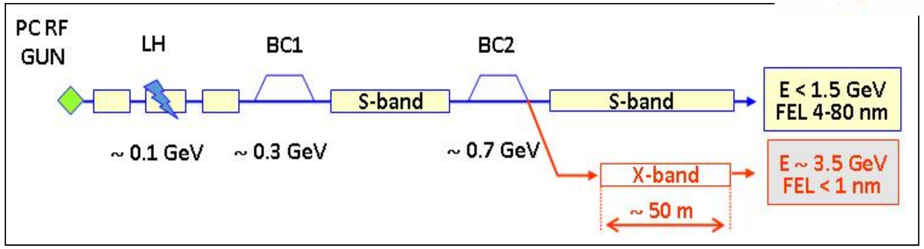


Baseline manufacturing flow

24-25 NOVEMBER 2014 X-band Accelerating structure Review 5

Xband facilities - FELs





- X-band technology appears interesting for compact, relatively low cost FELs – new or extensions
  - Logical step after S-band and C-band
  - Example similar to SwissFEL: E=6 GeV, Ne=0.25 nC, σ_z=8μm
- Use of X-band in other projects will support industrialisation
  - They will be klystron-based, additional synergy with klystron-based first energy stage
- Started to collaborate on use of X-band in FELs
  - Australian Light Source, Turkish Accelerator Centre, Elettra, SINAP, Cockcroft Institute, TU Athens, U. Oslo, Uppsala University, CERN
- Share common work between partners
  - Cost model and optimisation
  - Beam dynamics, e.g. beam-based alignment
  - Accelerator systems, e.g. alignment, instrumentation…
- Define common standard solutions
  - Common RF component design, -> industry standard
  - High repetition rate klystrons (200->400 Hz now into test-stands)

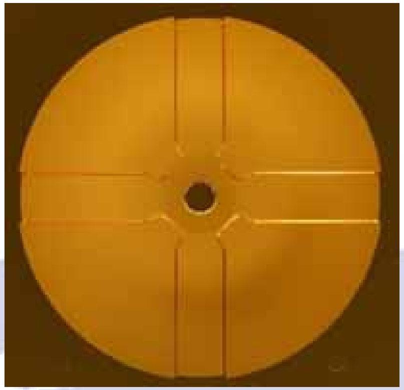

SINAP 中国科学院上海应用物理研究所 Shanghai Institute of Applied Physics, Chinese Academy of Sciences

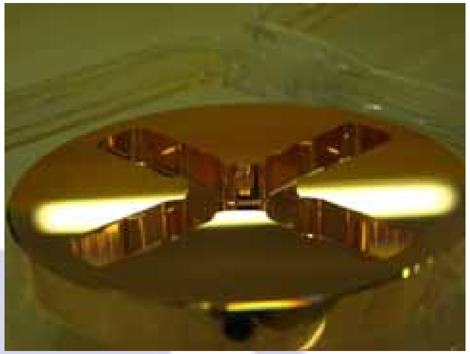
Background (Shanghai Photon Science Center)

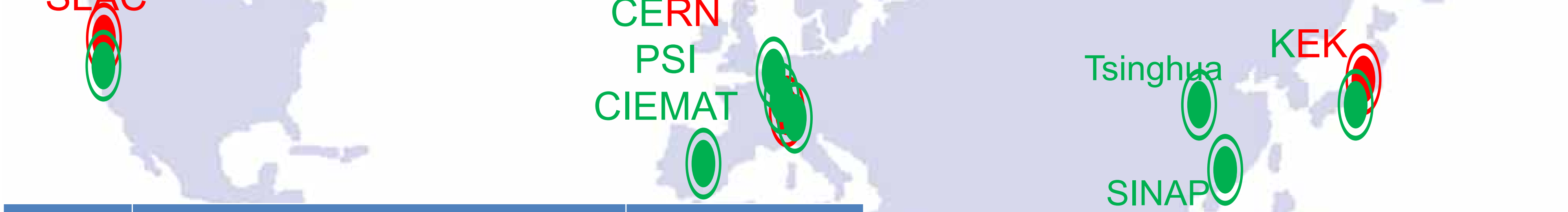
Important collaboration for X-band technology

X-band structures and testing

X-band Technologies:
- High gradient structures and high efficiency RF (structure prod. in green)
- X-band High power Testing Facilities (x3 increase) (in red)
- Use of X-band technologies for FELs







Institute	Structure	Status
KEK	Long history – latest TD26CC	Mechanical design
Tsinghua	T24 - VDL machined, Tsinghua assembled, H bonding, KEK high-power test	At KEK
	CLIC choke	manufacturing tests
SINAP	XFEL structure, KEK high-power test	rf design phase
	T24, CERN high-power test	Agreement signed
	Four XFEL structures	H2020 proposal
CIEMAT	TD24CC	Agreement signed
PSI	Two T24 structures made at PSI using SwissFEL production line including vacuum brazing	Mechanical design work underway
VDL	XFEL structure	H2020 proposal
SLAC	T24 in milled halves	machining
CERN	Structures and Test-stands	
	KT (Knowledge Transfer) funded medical linac	machining

LINEAR COLLIDER COLLABORATION

Main activities

Parameters, Design and Implementation

- Integrated Baseline Design and Parameters
- Feedback Design, Background, Polarization
- Machine Protection & Operational Scenarios
- Electron and positron sources
- Damping Rings
- Ring-To-Main-Linac
- Main Linac - Two-Beam Acceleration
- Beam Delivery System
- Machine-Detector Interface (MDI
- Drive Beam Complex
- Cost, power, schedule, stages

X-band Technologies

- X-band Rf structure Design
- X-band Rf structure Production
- X-band Rf structure High Power Testing
- Novel RF unit developments (high efficiency)
- Creation and Operation of x-band High power Testing Facilities
- Basic High Gradient R&D

Experimental verification

- Drive Beam phase feed-forward and feedbacks
- Two-Beam module string, test with beam
- Drive-beam front end including modulator development and injector
- Modulator development, magnet converters
- Drive Beam Photo Injector
- Low emittance ring tests
- Accelerator Beam System Tests (ATF and FACET, others)

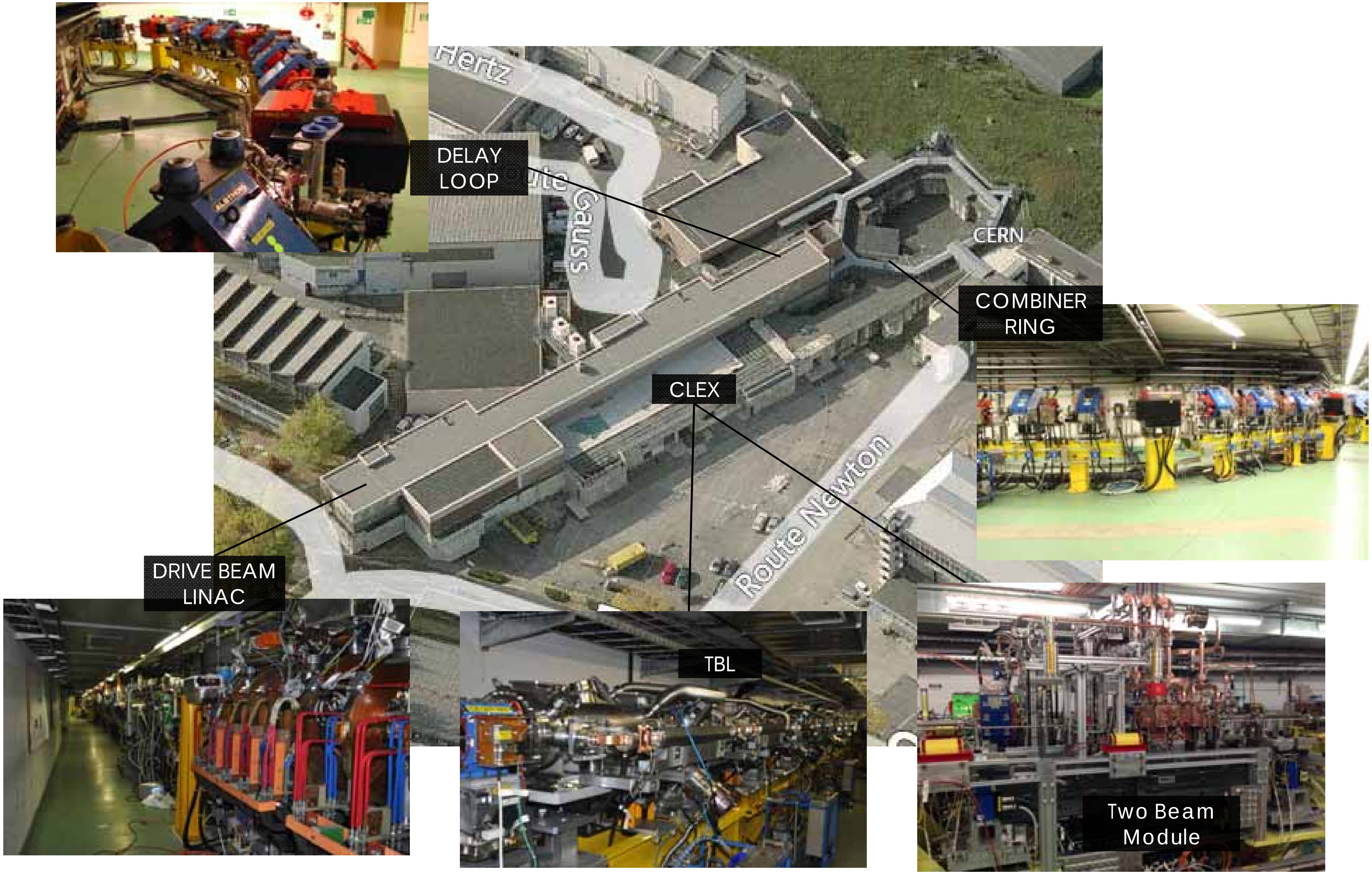
Technical Developments

- Damping Rings Superconducting Wiggler
- Survey & Alignment
- Quadrupole Stability
- Warm Magnet Prototypes
- Beam Instrumentation and Control
- Two-Beam module development
- Beam Intercepting Devices
- Controls
- Vacuum Systems

Detector and Physics

- Physics studies and benchmarking
- Detector optimisation
- Technical developments

CLIC Test Facility (CTF3)



DELAY LOOP

COMBINER RING

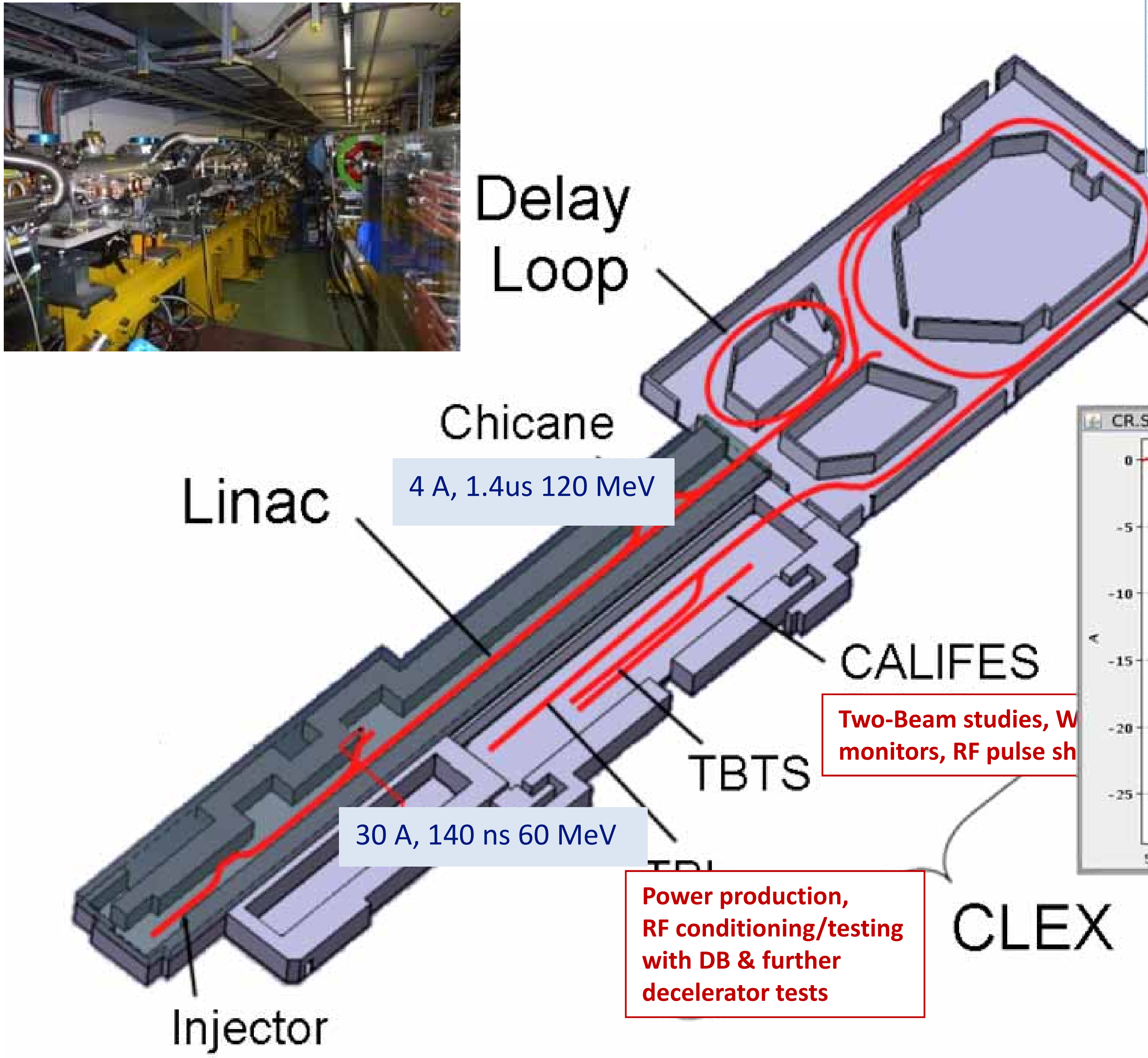
CLEX

DRIVE BEAM LINAC

TBL

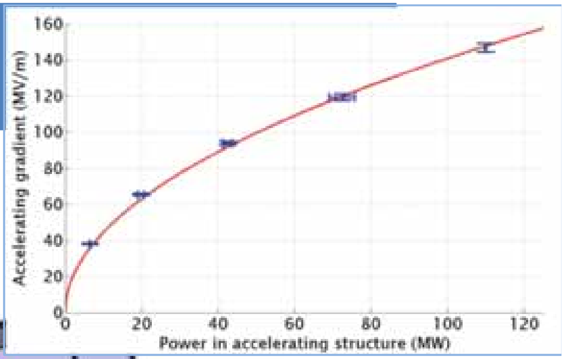
Two Beam Module

CLIC test facility - CTF3

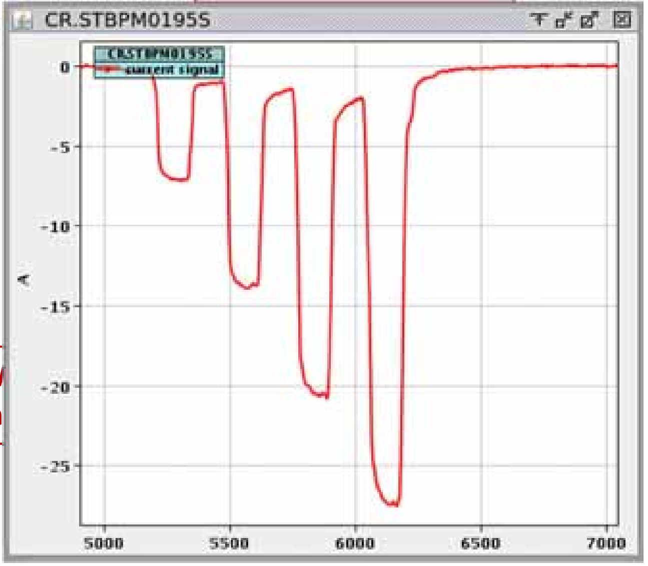


4 A, 1.4us 120 MeV

30 A, 140 ns 60 MeV



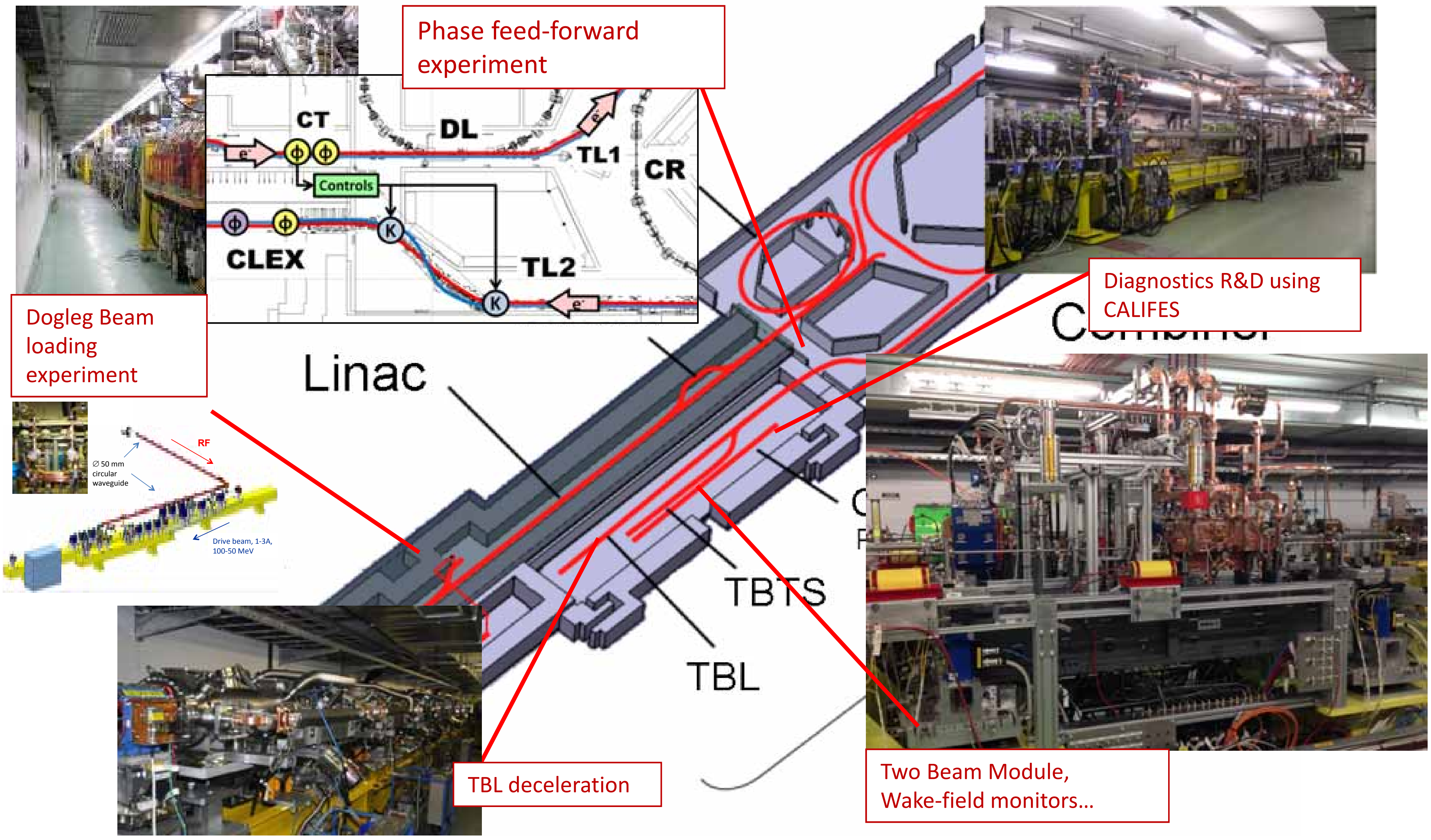
Phase feed-forward, DB stability studies



Two-Beam studies, W monitors, RF pulse sh

Power production, RF conditioning/testing with DB & further decelerator tests

The next two years (2015-16)



Phase feed-forward experiment

Diagnostics R&D using CALIFES

Dogleg Beam loading experiment

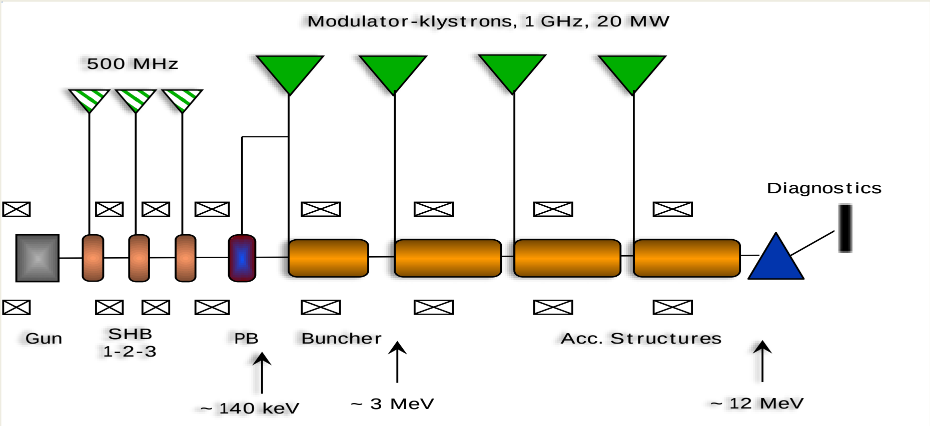
TBL deceleration

Two Beam Module, Wake-field monitors…

Recently installed 2-beam acceleration module in CTF3
(according to latest CLIC design)
First 2-beam tests stand reached 145 MV/m (2012)

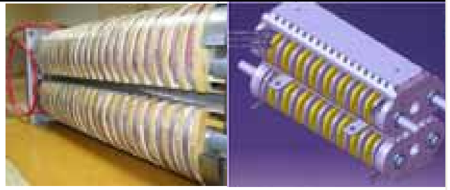
CLIC system tests beyond CTF3

- Drive beam development beyond CTF3
  - RF unit prototype with industry using CLIC frequency and parameters
  - Drive beam front-end (injector), to allow development into larger drivebeam facility beyond 2018
- Damping rings
  - Tests at existing damping rings, critical component development (e.g. wigglers) ... large common interests with light source laboratories
- Main beam (see slide later)
  - Steering tests at FACET, FERMI, …
- Beam Delivery System (see slide later)
  - ATF/ATF2



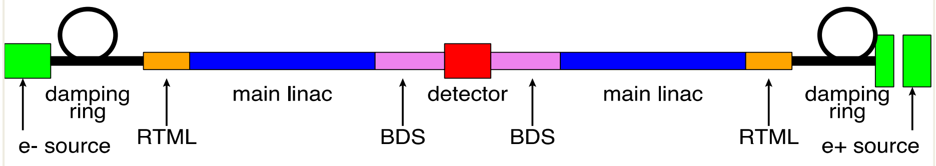
- Super-conducting wigglers
  - Demanding magnet technology combined with cryogenics and high heat load from synchrotron radiation (absorption)
- High frequency RF system
  - 1 GHz RF system respecting power and transient beam
- Coatings, chamber design and ultra-low vacuum
  - Electron cloud mitigation, low-impedance, fast-ion instability
- Kicker technology
  - Extracted beam stability
- Diagnostics for low emittance

Parameters	BINP	CERN/Karlsruhe
B_{peak} [T]	2.5	2.8
λ_W [mm]	50	40
Beam aperture full gap [mm]	13	13
Conductor type	NbTi	$NbSn_3$
Operating temperature [K]	4.2	4.2



Experimental program set-up for measurements in storage rings and test facilities:

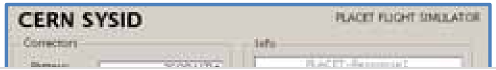
ALBA (Spain), ANKA (Germany),
ATF (Japan), CESRTA (USA),
ALS (Australia) …



Performance verifications – CLIC

Our goal: an (almost) automatic correction

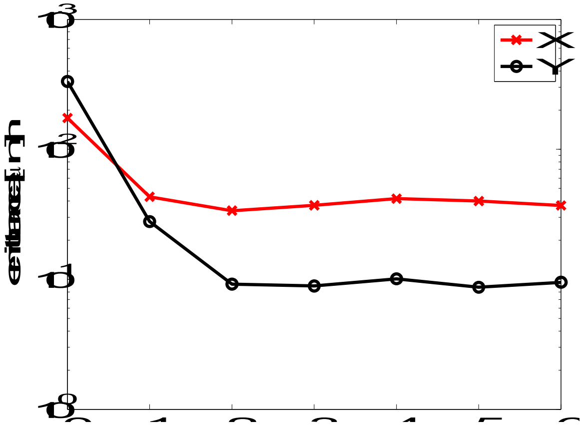
We want to make our BBA algorithms as automatic as possible. Two tools have been developed. SYSID and BBA tools



SYSID:

- Measures the machine optics

DFS at the SLAC Linac

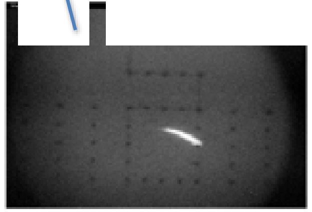


LI04-LI10:
Incoming oscillation/dispersion is taken out and flattened; emittance in LI11 and **emittance growth significantly reduced.**

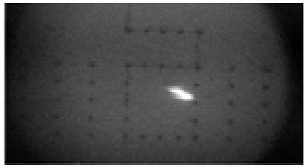
Emittance at LI11 (iteraton 1)
X: 43.2 x 10^{-5} m
Y: 27.82 x 10^{-5} m

Emittance at LI11 (iteration 4)
X: 3.71 x 10^{-5} m
Y: 0.87 x 10^{-5} m

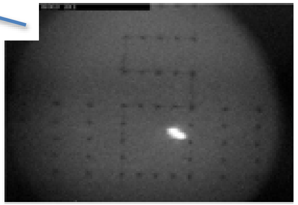
9 phos, PR185 :



Before correction

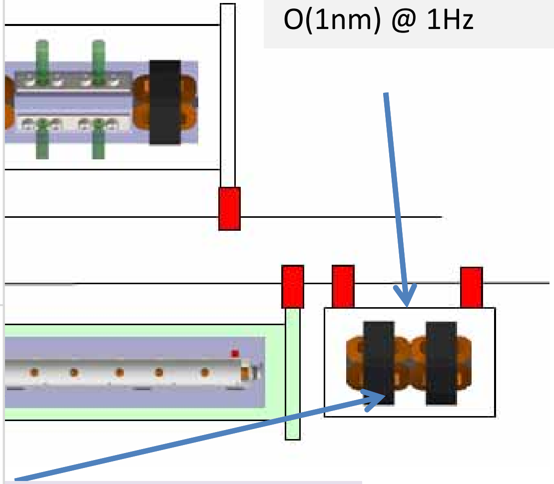


After 1 iteration

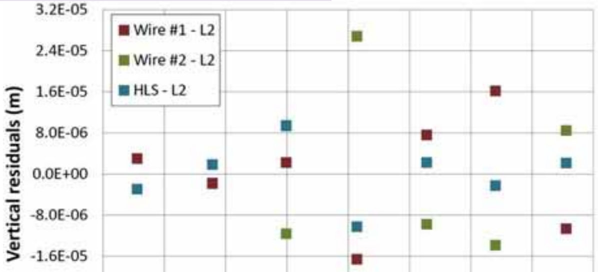


After 3 iterations

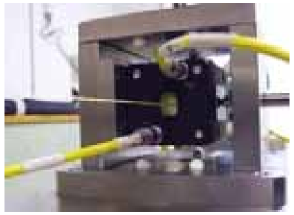
Stabilise quadrupole
O(1nm) @ 1Hz



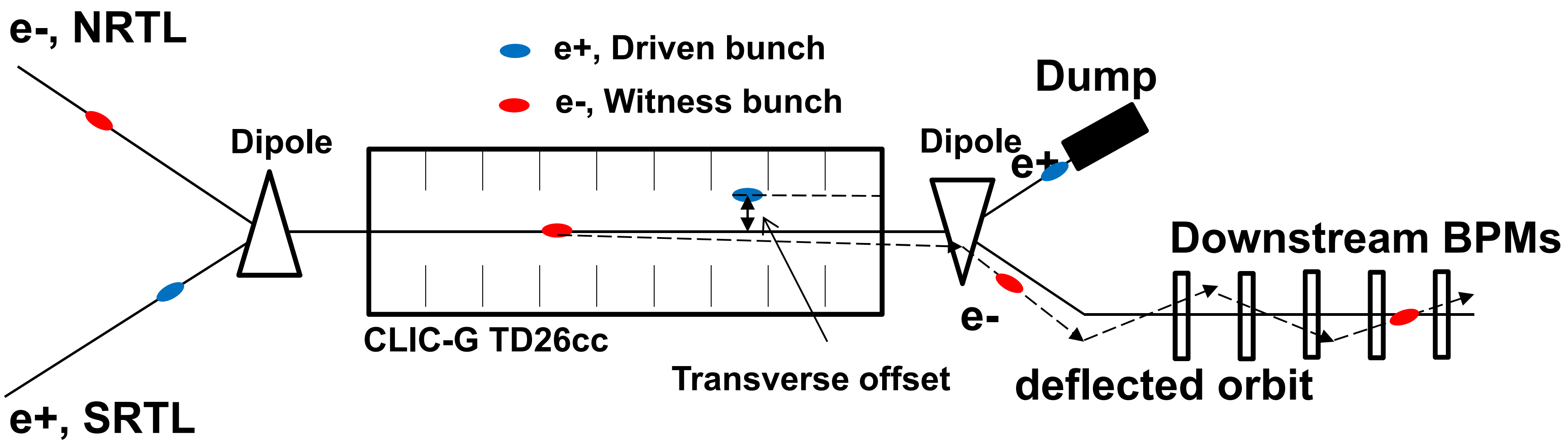
s+quads
) over about 200m

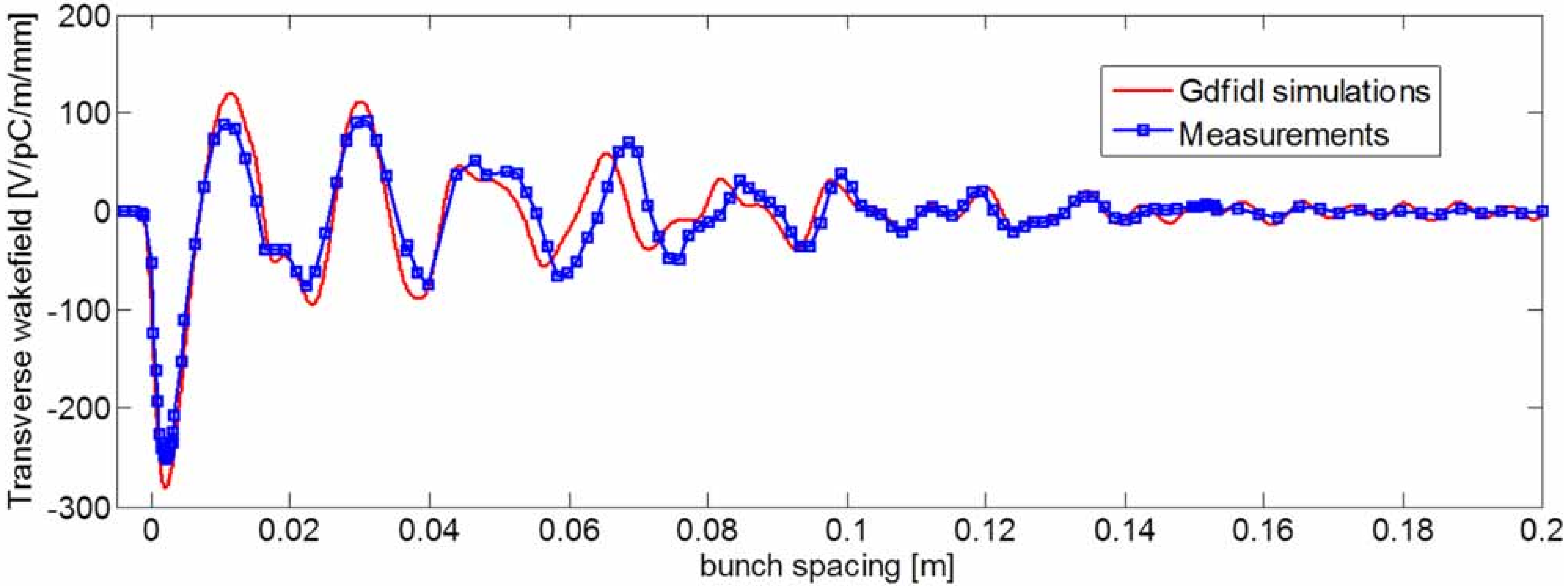


- Test of prototype shows
  - vertical RMS error of 11µm
  - i.e. accuracy is approx. 13.5µm



FACET measurements of wakefields

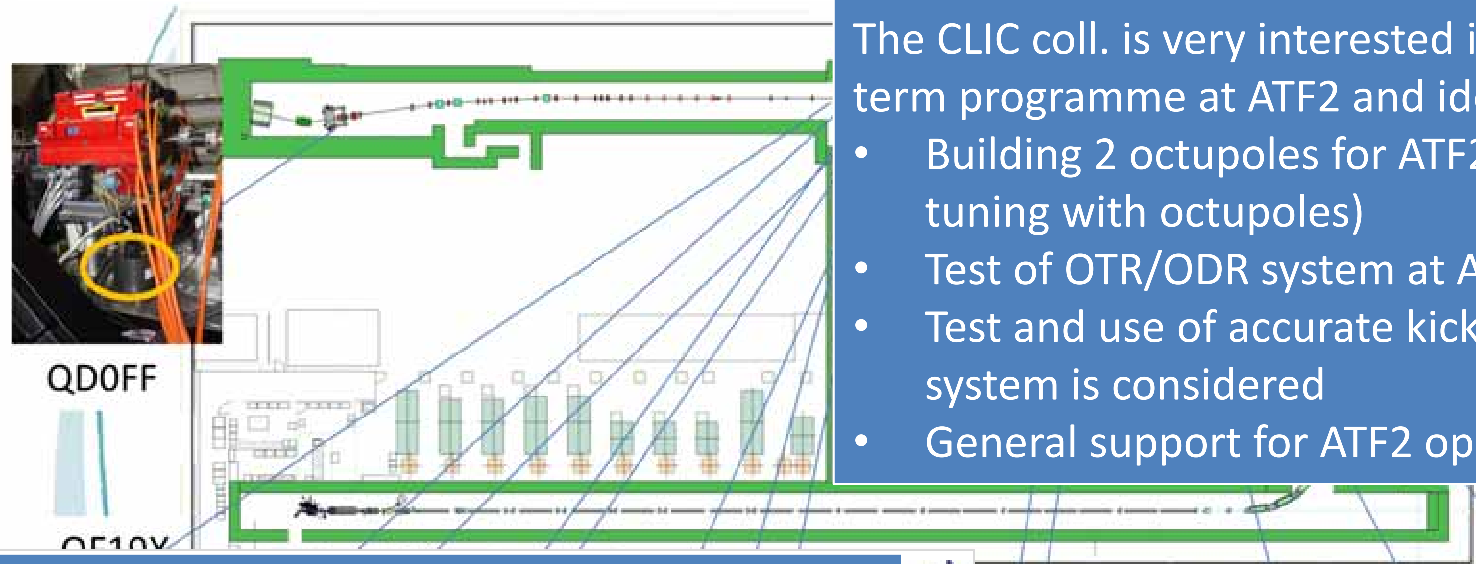


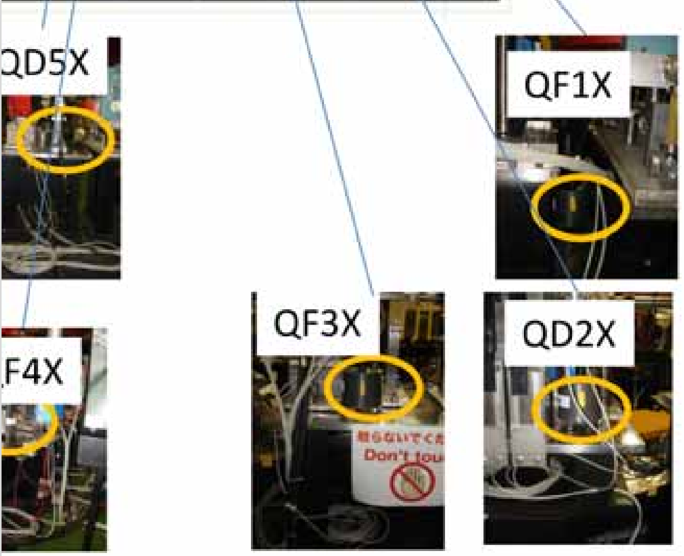


ATF2: Stabilisation Experiment

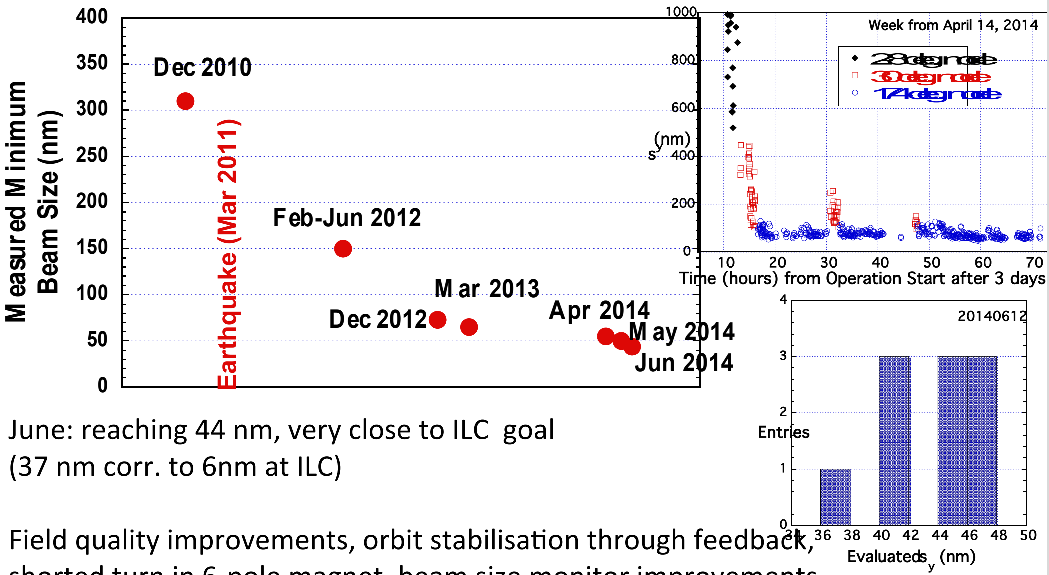
The CLIC coll. is very interested in a longer term programme at ATF2 and ideas exist for:

- Building 2 octupoles for ATF2 (to study FFS tuning with octupoles)
- Test of OTR/ODR system at ATF2
- Test and use of accurate kicker/amplifier system is considered
- General support for ATF2 operation





ATF-2 beam size development



June: reaching 44 nm, very close to ILC goal
(37 nm corr. to 6nm at ILC)

Field quality improvements, orbit stabilisation through feedback, shorted turn in 6-pole magnet, beam size monitor improvements

LINEAR COLLIDER COLLABORATION

Main activities

http://clic-study.web.cern.ch/content/clic-accelerator-activities

Parameters, Design and Implementation

- Integrated Baseline Design and Parameters
- Integrated Modeling and Performance Studies
- Feedback Design, Background, Polarization
- Machine Protection & Operational Scenarios
- Electron and positron sources
- Damping Rings
- Ring-To-Main-Linac
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- X-band Rf structure High Power Testing
- Novel RF unit developments (high efficiency)
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- Survey & Alignment
- Quadrupole Stability
- Warm Magnet Prototypes
- Beam Instrumentation and Control
- Two-Beam module development
- Beam Intercepting Devices
- Controls
- Vacuum Systems

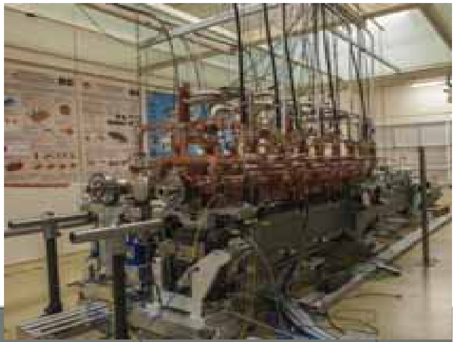
Detector and Physics

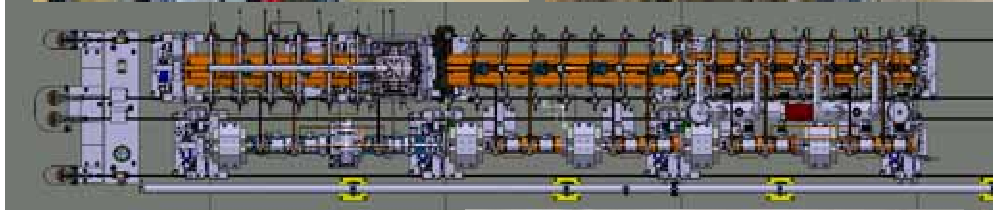
- Physics studies and benchmarking
- Detector optimisation
- Technical developments

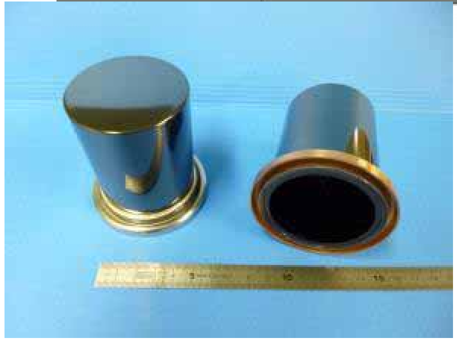
Technical activities – examples

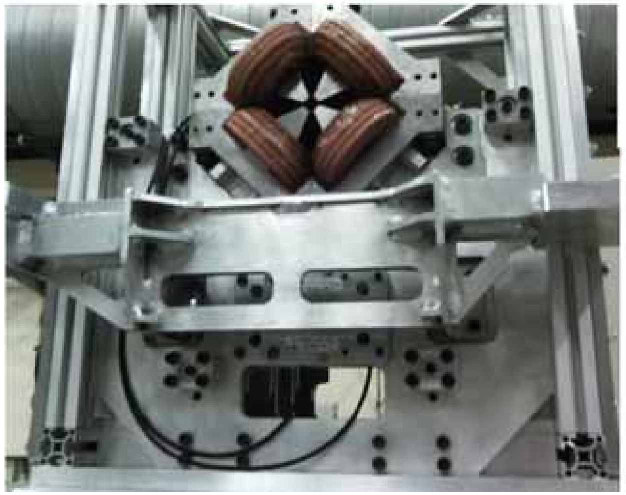
Technical Developments are motivated by several possible reasons:

- Key components for systemtests
- Critical for machine performance
- Aimed at cost or power reduction



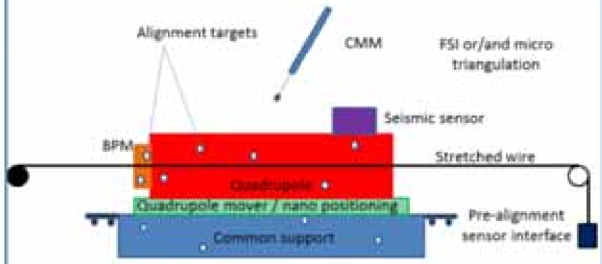






Short term: some key issues

- Integration, ultra-high precision engineering and manufacturing
- Magnetic measurements with a vibrating stretched wire (and alternative based on printed circuit boards rotating search coils)
- Determination of the electromagnetic centre of BPM and RF structure using a stretched wire
- Absolute methods of measurements: new measuring head for CMM, combination of FSI and micro-triangulation measurements as an alternative
- Improve seismic sensors and study ground motion
- Nano-positioning system to position the quadrupole and BPM



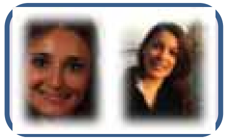
Long term

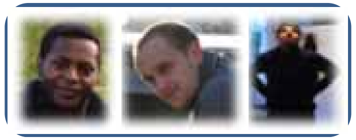
- Preparation of industrialization
- Optimization of performances and precision in all domains
- Extrapolation to other components

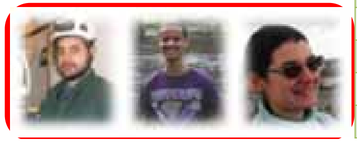
DMP	ES
ELTOS	IT
ETALON	DE
METROLAB	CH
SIGMAPHI	FR

Hexagon Metrology	DE
National Instruments	HU
TNO	NL

Cranfield University	GB
ETH Zürich	CH
LAPP	FR
SYMME	FR
University of Sannio	IT
IFIC	ES
University of Pisa	IT
Delft University of Technology	NL



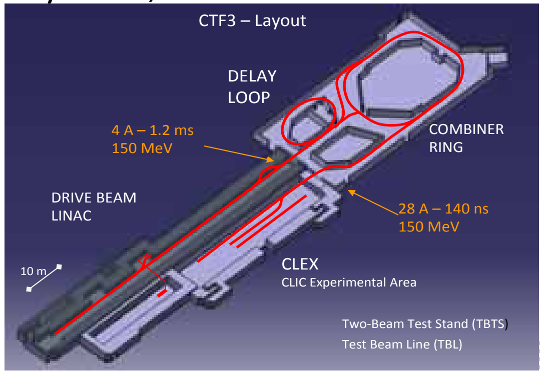




Issues for a next CERN machine … timescales

2013-18 Development Phase

Develop a Project Plan for a staged implementation in agreement with LHC findings; further technical developments with industry, performance studies for accelerator parts and systems, as well as for detectors.



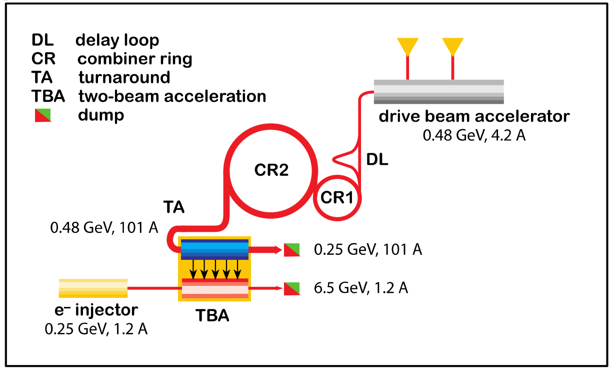
2018-19 Decisions

On the basis of LHC data and Project Plans (for CLIC and other potential projects as FCC), take decisions about next project(s) at the Energy Frontier.

4-5 year Preparation Phase

Finalise implementation parameters, Drive Beam Facility and other system verifications, site authorisation and preparation for industrial procurement.

Prepare detailed Technical Proposals for the detector-systems.



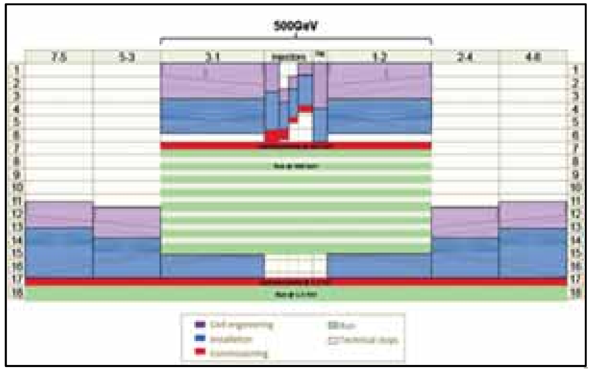
2024-25 Construction Start

Ready for full construction and main tunnel excavation.

Construction Phase

Stage 1 construction of CLIC, in parallel with detector construction.

Preparation for implementation of further stages.

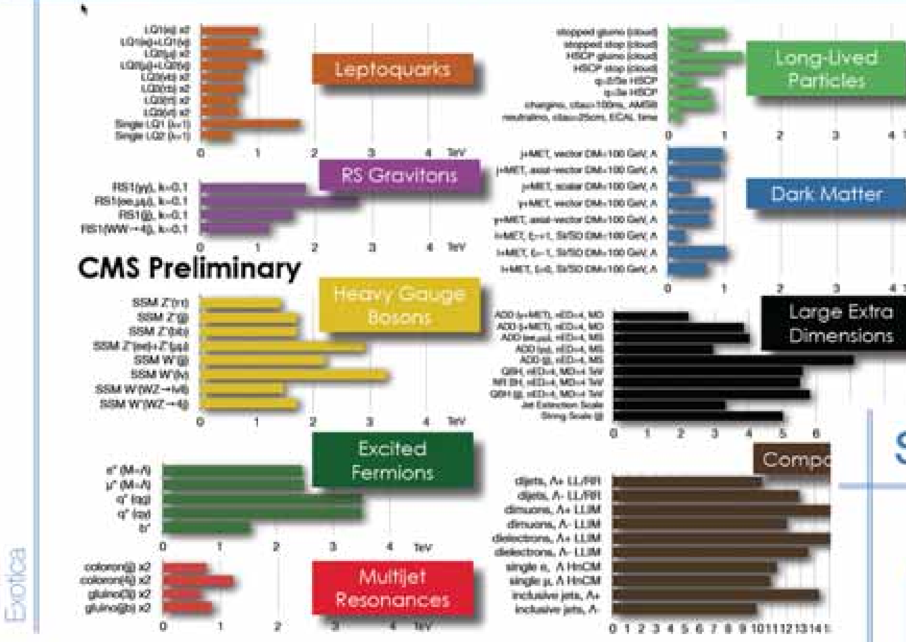


Commissioning

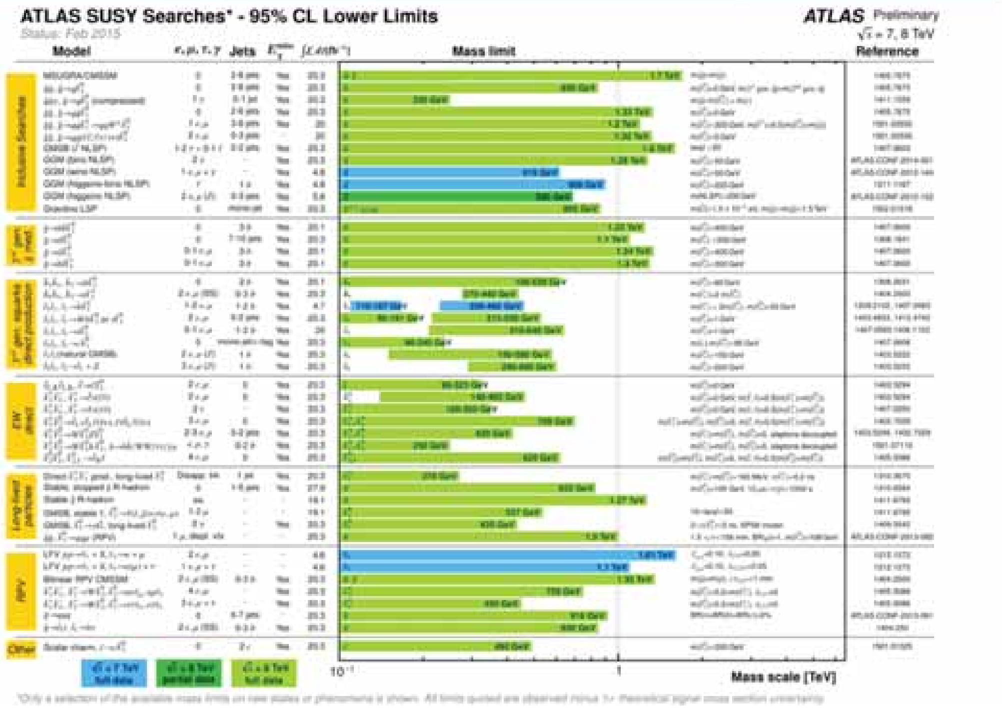
Becoming ready for data-taking as the LHC programme reaches completion.

LHC at 13 TeV – the key to it all ?

CMS Exotica summary



SUSY Grand Summary at ATLAS



Summary

The goals and plans for 2015-18 are well defined for CLIC, focusing on the high energy frontier capabilities – well aligned with current strategies – also preparing to align with LHC physics as it progresses in the coming years:

- Aim provide optimized stages approach up to 3 TeV with costs and power not too excessive compared to LHC
- Very positive progress on X-band technology, due to availability of power sources and increased understanding of structure design parameters
  - Applications in smaller systems; FEL linacs key example – with considerable interesting in the CLIC collaboration
- Also recent good progress on performance verifications, drivebeam, main beam emittance conservation and final focus studies
  - BBA discussions, BDS/ATF important
  - CTF3 running and plan until end 2016, strategy for systemtests beyond
- Technical developments of key parts well underway – with increasing involvement of industry – largely limited by funding
- Collaborations for CLIC accelerator and detector&physics studies are growing

Thanks

- Slides/figures/advice from CLIC collaboration members. Knowingly from L. Linssen, M.Thomson, A. Latina, K.Kubo and ATF colleagues, D.Schulte, R.Corsini, W.Fang, W.Wuensch and X-band team, , F.Tecker, T.Lefevre, M.Modena, N.Catalan, C.Garion, I.Syratchev, H.Mainaud Durant and PACMAN team, R.Tomas, Y.Papaphilippou, G.D'Auria, … and several more unknowingly or indirectly