Highlights from the CLIC workshop 2016

Felix Sefkow

DESY

ILC project meeting, DESY, Feb 12, 2016

Outline:

- Setting
- Physics
- Detector
- Accelerator

- 220 participants, ~ 70 from physics and detector
- only plenary sessions, ~ 50 talks

Towards the next European Strategy update

- CLIC workshop started just after Fabiola’s inaugural speech

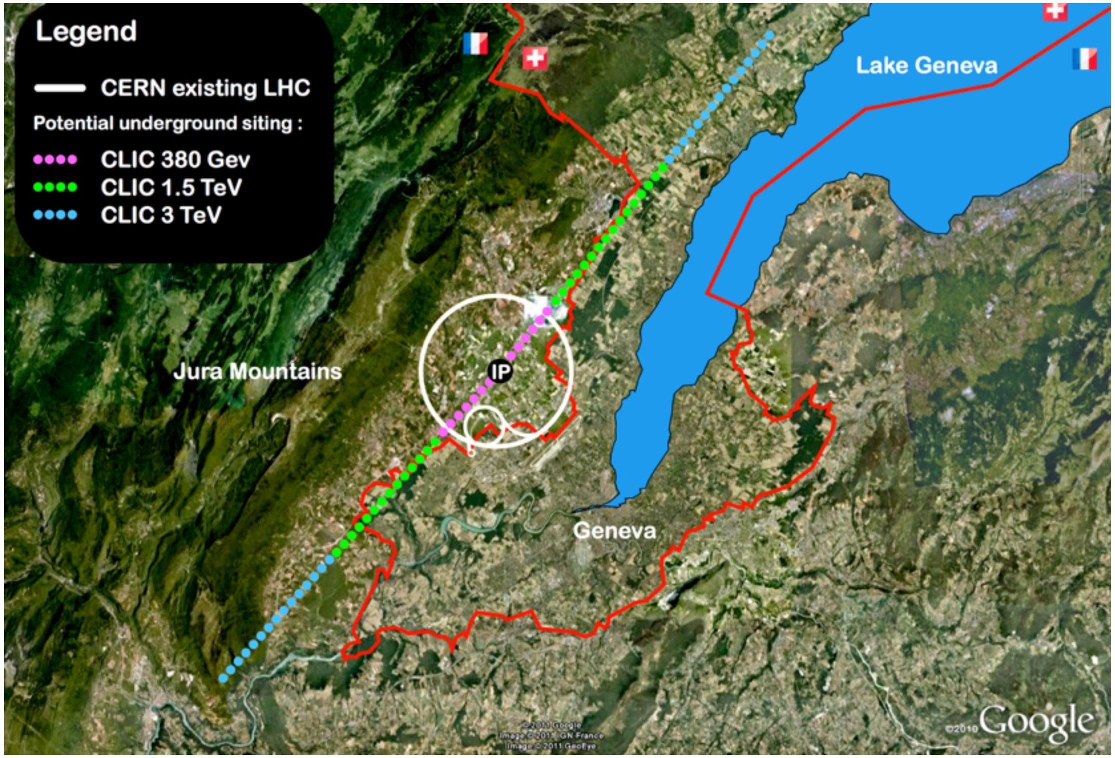
- Strategy update announced for **~2019-2020**
- Clear mandate for CLIC

- Also picked up by Eckhard in his opening remarks, with appeal for cooperation

Compact Linear Collider (CLIC)

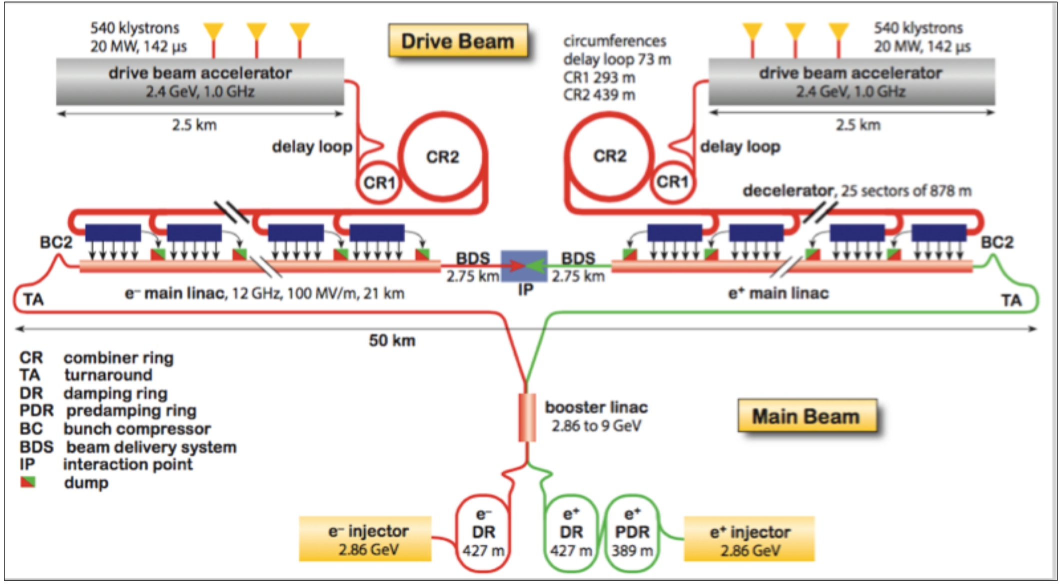
Linear e^+e^- collider with $\sqrt{s}$ up to 3 TeV

100 MV/m accelerating gradient needed for compact (~50 km) machine
→ based on normal-conducting accelerating structures and a two-beam acceleration scheme



Conceptual Design Report completed end 2012
International Collaboration: ~80 Institutions

Challenges:
- ❑ Minimise RF breakdown rate in cavities
- ❑ efficient RF power transfer from drive beam to main beam
- ❑ reduction of power consumption (600 MW at 3 TeV)
- ❑ nm size beams, final focus
- ❑ huge beamstrahlung in detectors



Fabiola

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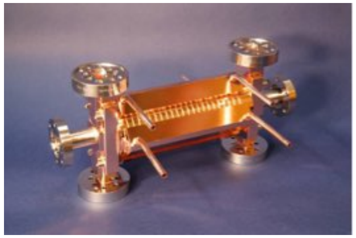

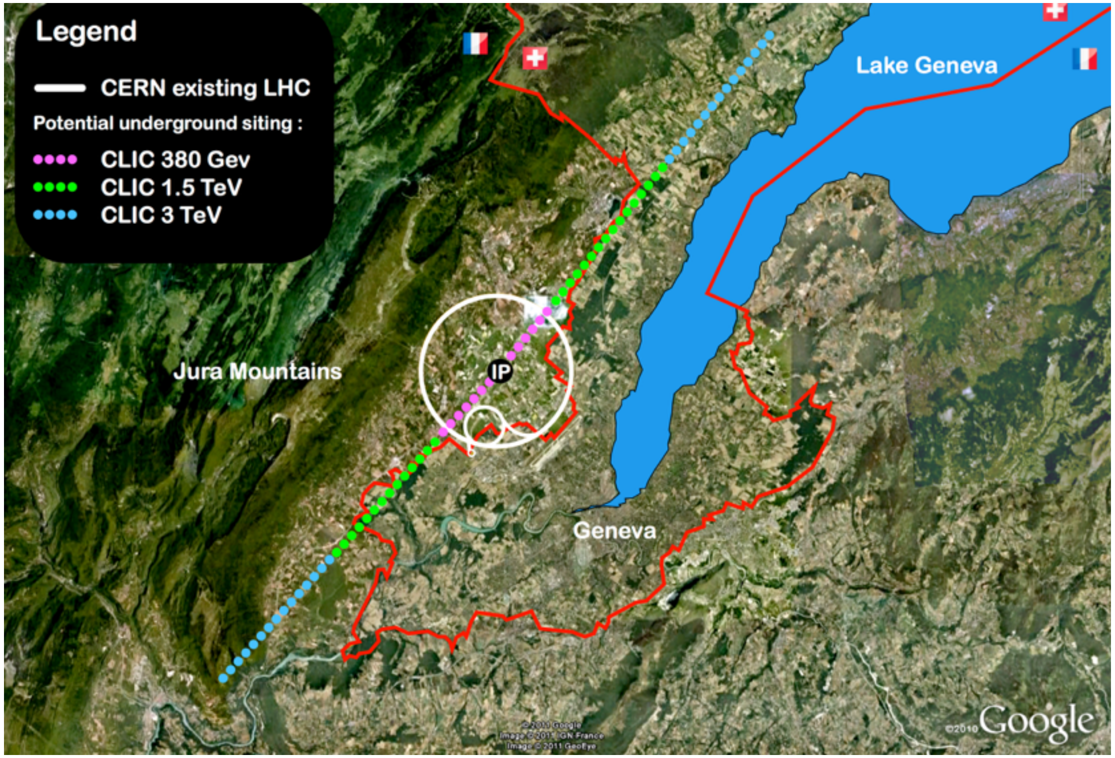

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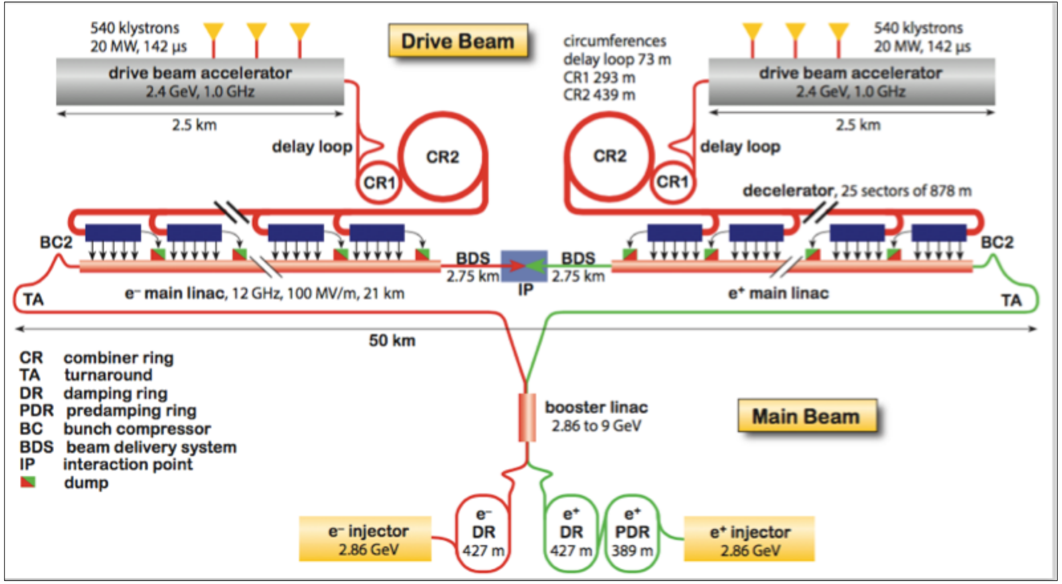

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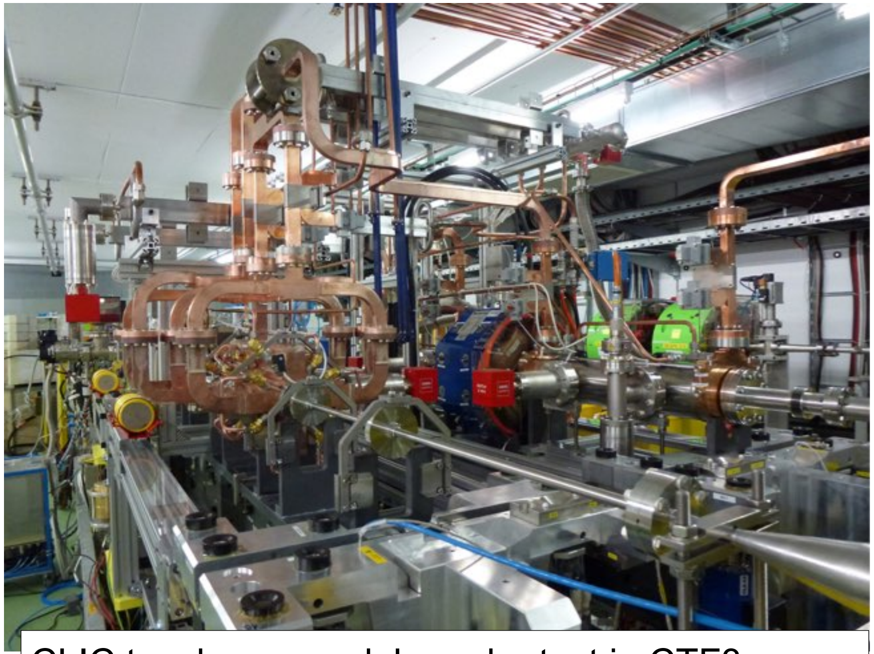
CLIC

- ❑ Direct discovery potential and precise measurements of new particles (couplings to Z/γ*) up to m~ 1.5 TeV
- ❑ Indirect sensitivity to E scales Λ ~ O(100) TeV
- ❑ Measurements of "heavy" Higgs couplings: ttH to ~ 4%, HH ~ 10%

Parameter	**Unit**	**380 GeV**	**3 TeV**
Centre-of-mass energy	TeV	0.38	3
Total luminosity	$10^{34}cm^{-2}s^{-1}$	1.5	5.9
Luminosity above 99% of √s	$10^{34}cm^{-2}s^{-1}$	0.9	2.0
Repetition frequency	Hz	50	50
Number of bunches per train		352	312
Bunch separation	ns	0.5	0.5
Acceleration gradient	MV/m	72	100

Most recent operating scenario: start at √s=380 GeV for H and top physics



CLIC two-beam module under test in CTF3

CTF3 facility:
testing two-beam acceleration concept: efficient power transfer from high-intensity low-E "drive" beam to the accelerating structure of the main ("probe") beam.
→ to be completed in 2016

CLIC construction could technically start ~2025, duration ~6 years for √s ~ 380 GeV (11 km Linac)
→ physics could start by ~2035

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Future Circular Colliders (FCC)

International conceptual design study of a ~100 km ring:

- ❑ pp collider (FCC-hh): ultimate goal → defines infrastructure requirements

  $\sqrt{s}$ ~ 100 TeV, L~2x10^{35}; 4 IP, ~20 ab^{-1}/expt

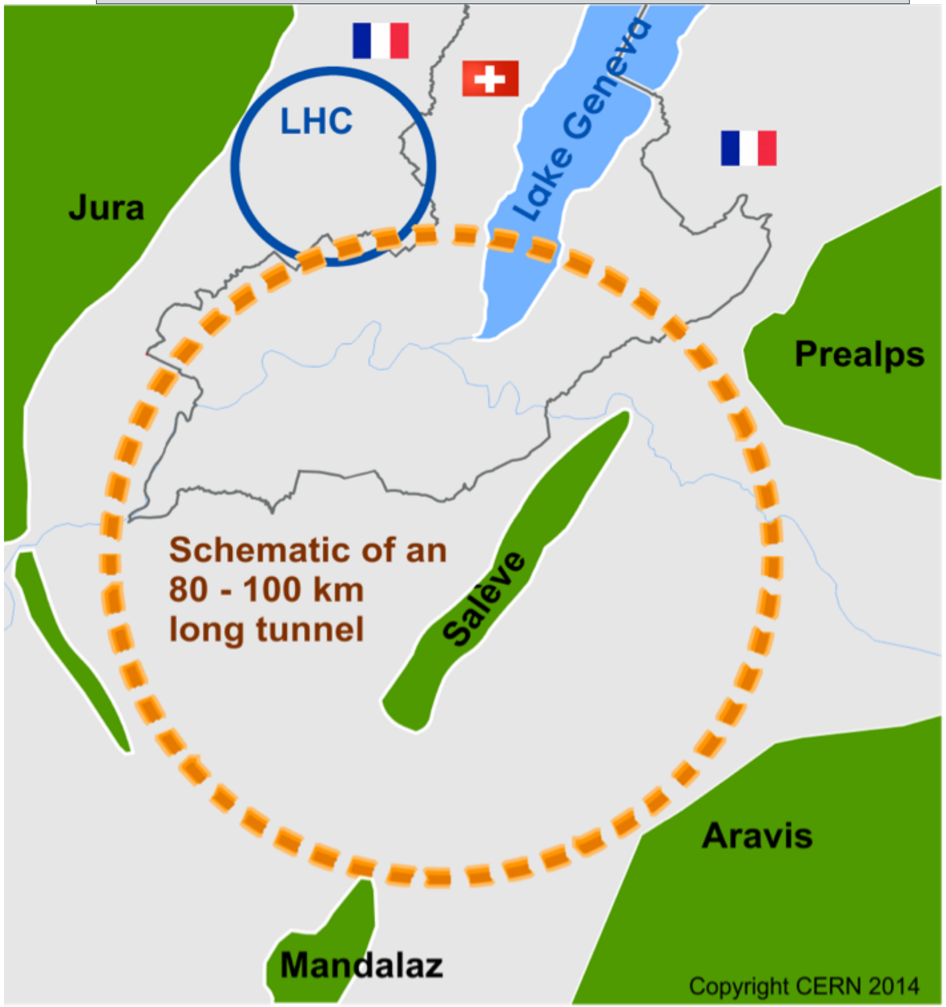
- ❑ e^+e^- collider (FCC-ee): possible first step

  $\sqrt{s}$ = 90-350 GeV, L~200-2 x 10^{34}; 2 IP

- ❑ pe collider (FCC-he): option

  $\sqrt{s}$ ~ 3.5 TeV, L~10^{34}

International Collaboration: ~ 70 Institutes

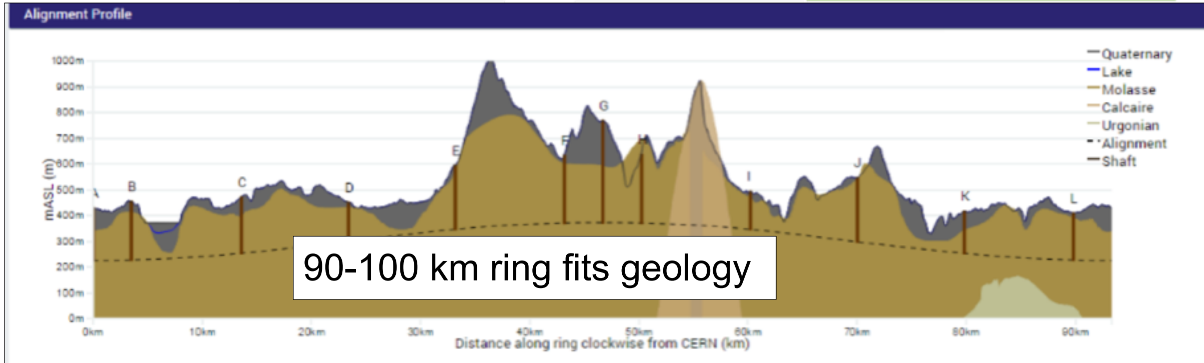


Also part of the study: HE-LHC: FCC-hh dipole technology (~16 T) in LHC tunnel → $\sqrt{s}$ ~ 30 TeV

GOAL: CDR in time for next ES

Machine studies are site-neutral. However, FCC at CERN would greatly benefit from existing laboratory infrastructure and accelerator complex

Fabiola



90-100 km ring fits geology

FCC

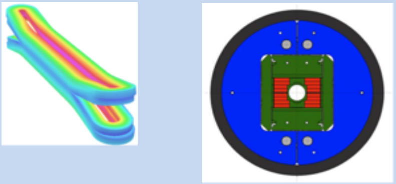
FCC-hh: a ~100 TeV pp collider is expected to:
- ❑ explore directly the 10-50 TeV E-scale
- ❑ conclusive exploration of EWSB dynamics
- ❑ say the final word about heavy WIMP dark matter

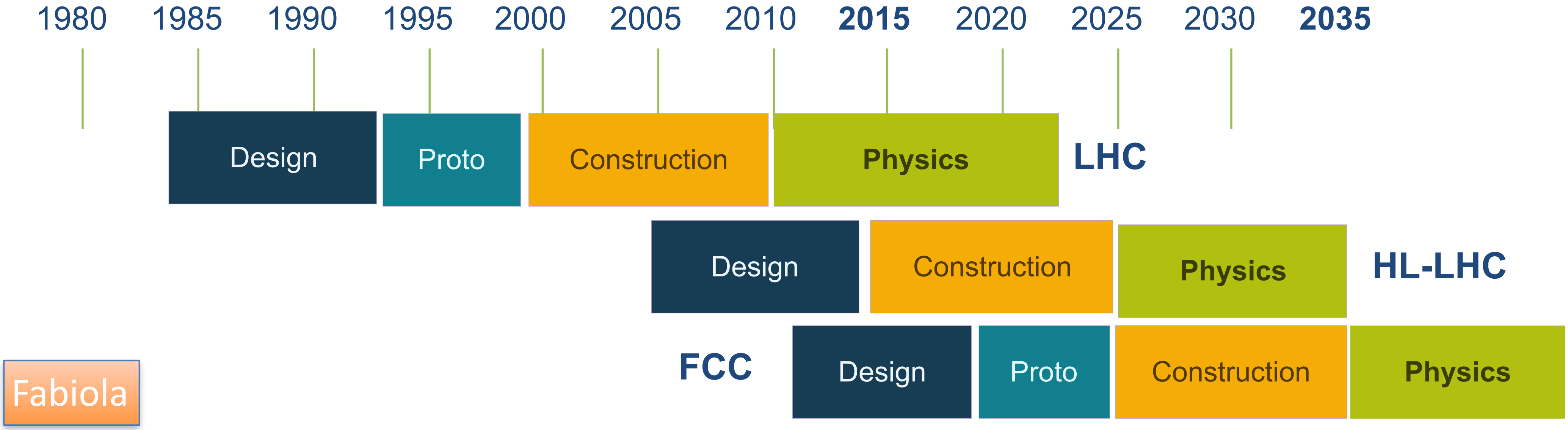
The two machines are complementary and synergetic

FCC-ee: 90-350 GeV
- ❑ measure many Higgs couplings to few permill
- ❑ indirect sensitivity to E-scale up to O(100 TeV) by improving by ~20-200 times the precision of EW parameters measurements, $\Delta M_W < 1$ MeV, $\Delta m_{top} \sim 10$ MeV

Many huge technological, design and operational challenges: e.g. ~16 T Nb_3Sn magnets

Demonstrator
(16 T, 50 mm gap)
~ 1m, end 2018,





1980 1985 1990 1995 2000 2005 2010 **2015** 2020 2025 2030 **2035**

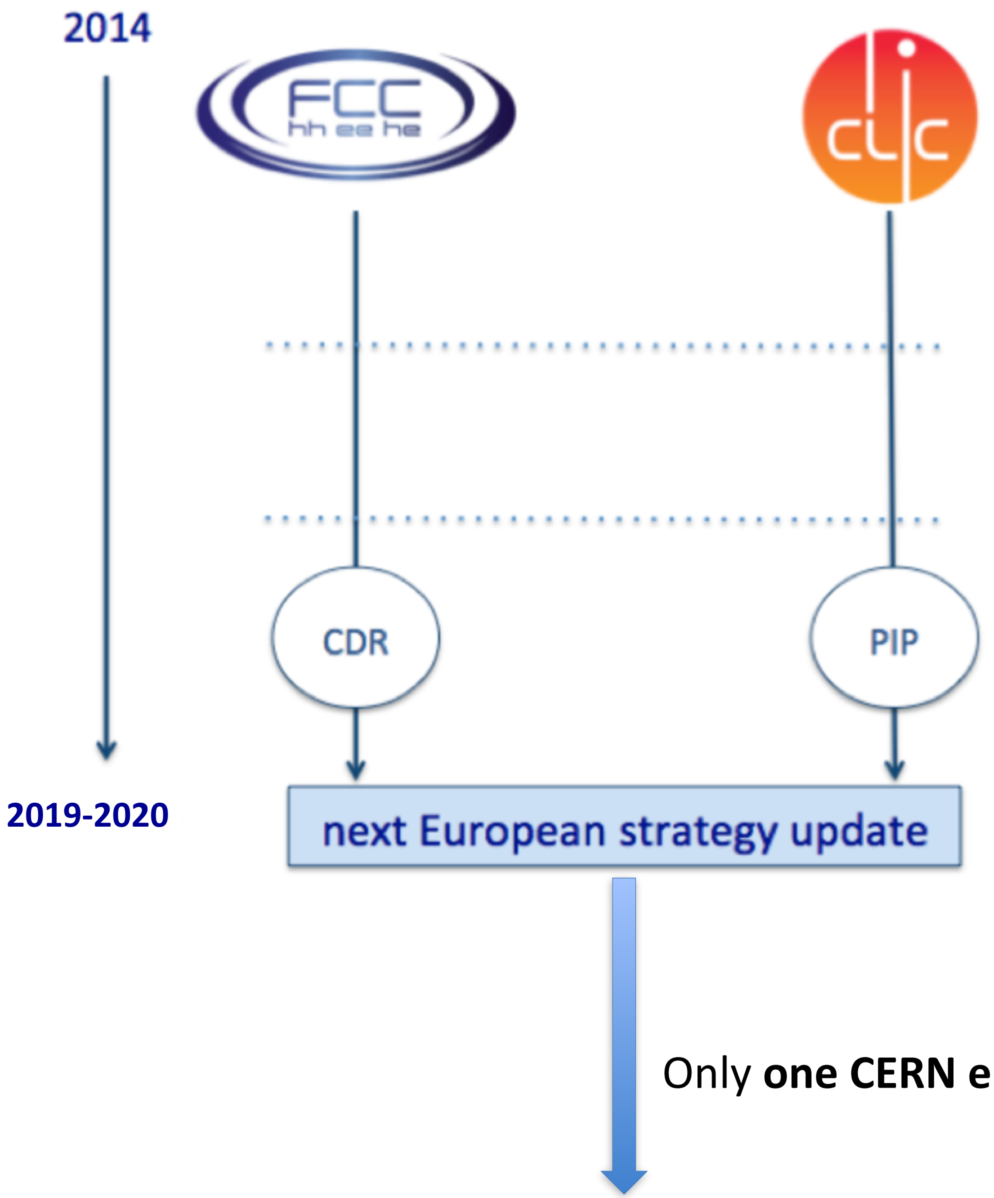
Design | Proto | Construction | **Physics** — **LHC**

Design | Construction | **Physics** — **HL-LHC**

FCC — Design | Proto | Construction | **Physics**

Fabiola

After the strategy update => context



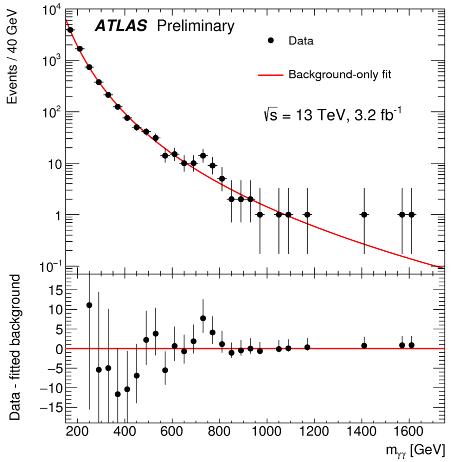
From the European strategy document: "… Europe needs to be in a position to propose an ambitious post-LHC accelerator project at CERN by the time of the next strategy update"

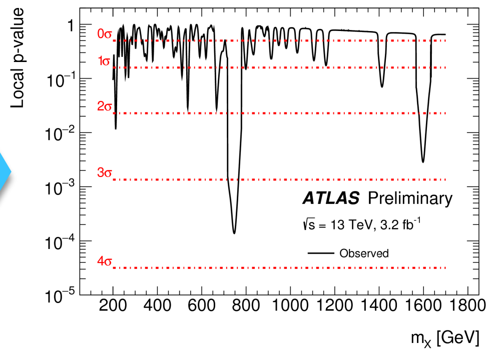
This is reflected in the **CERN financial plan** in which FCC and CLIC fuse into a single budget line from 2020 onwards

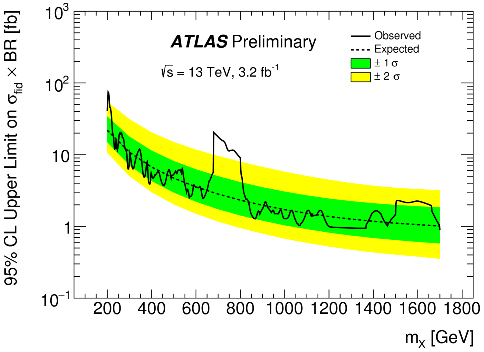
Only **one CERN energy frontier project** as of 2020

The X (750)

Diphoton resonances





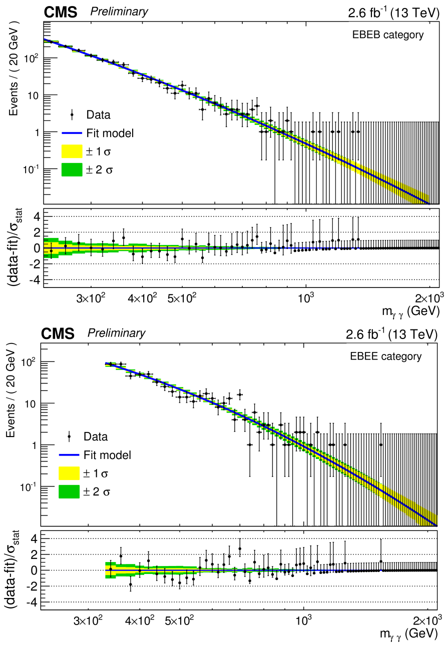


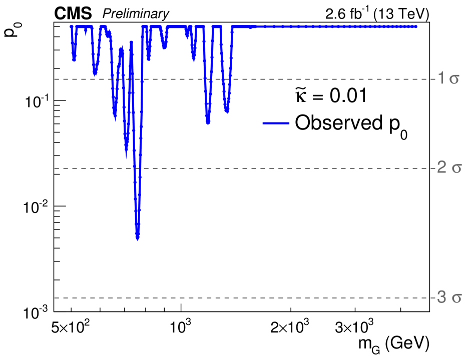
>90% prompt-prompt, σ_m/m ~1%

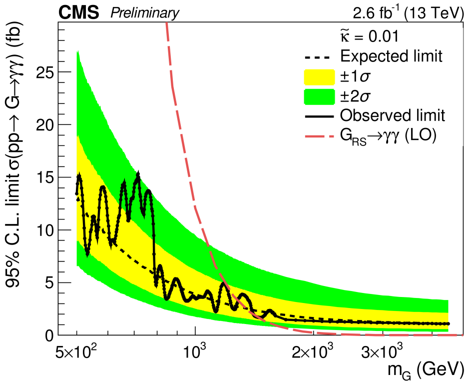
For m_X = 750 GeV

3.6σ → **2.0σ after LEE**

(3.9σ → 2.3σ for Γ = 6%)





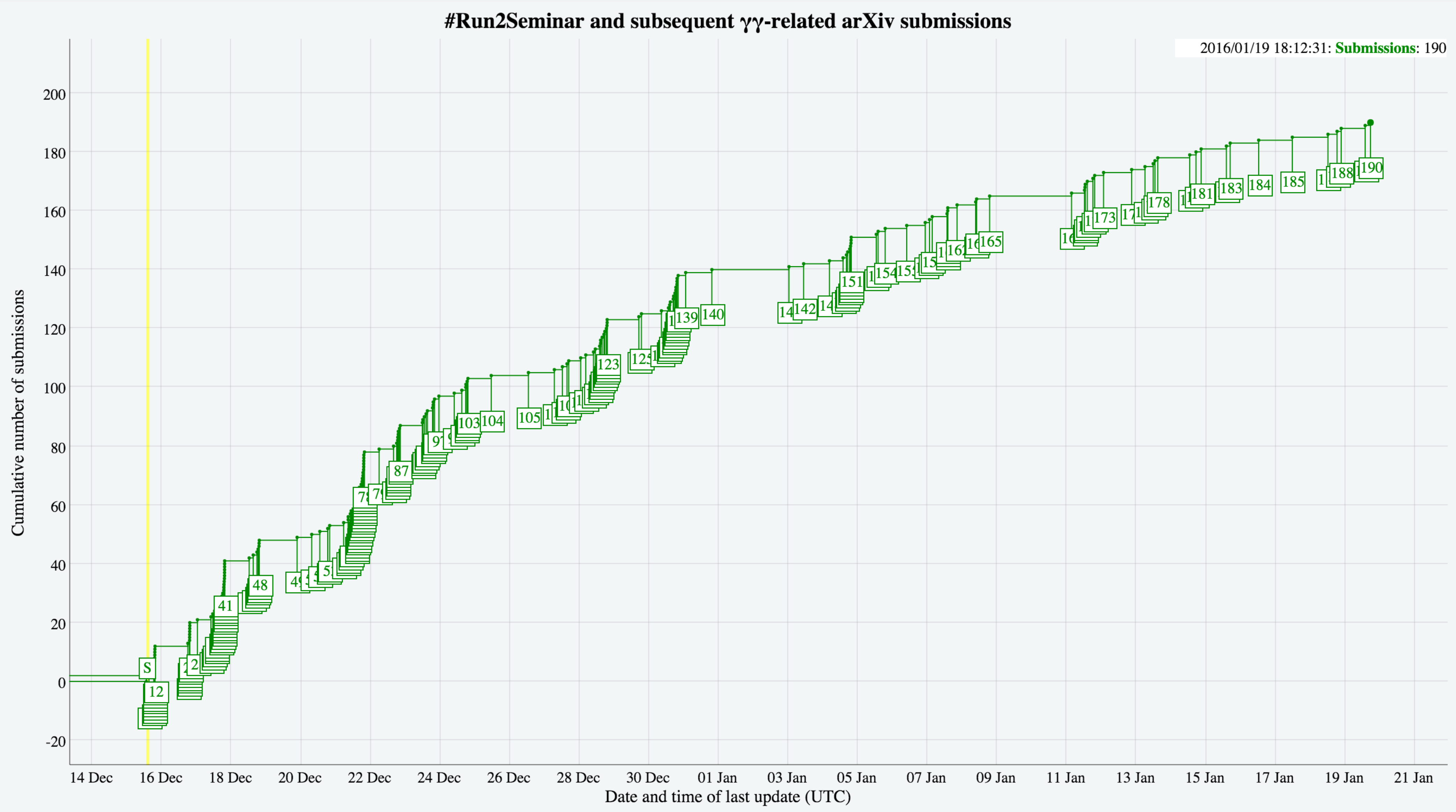


For m_G = 760 GeV

2.6σ → **1.2σ after LEE**

Post-seminar stampede

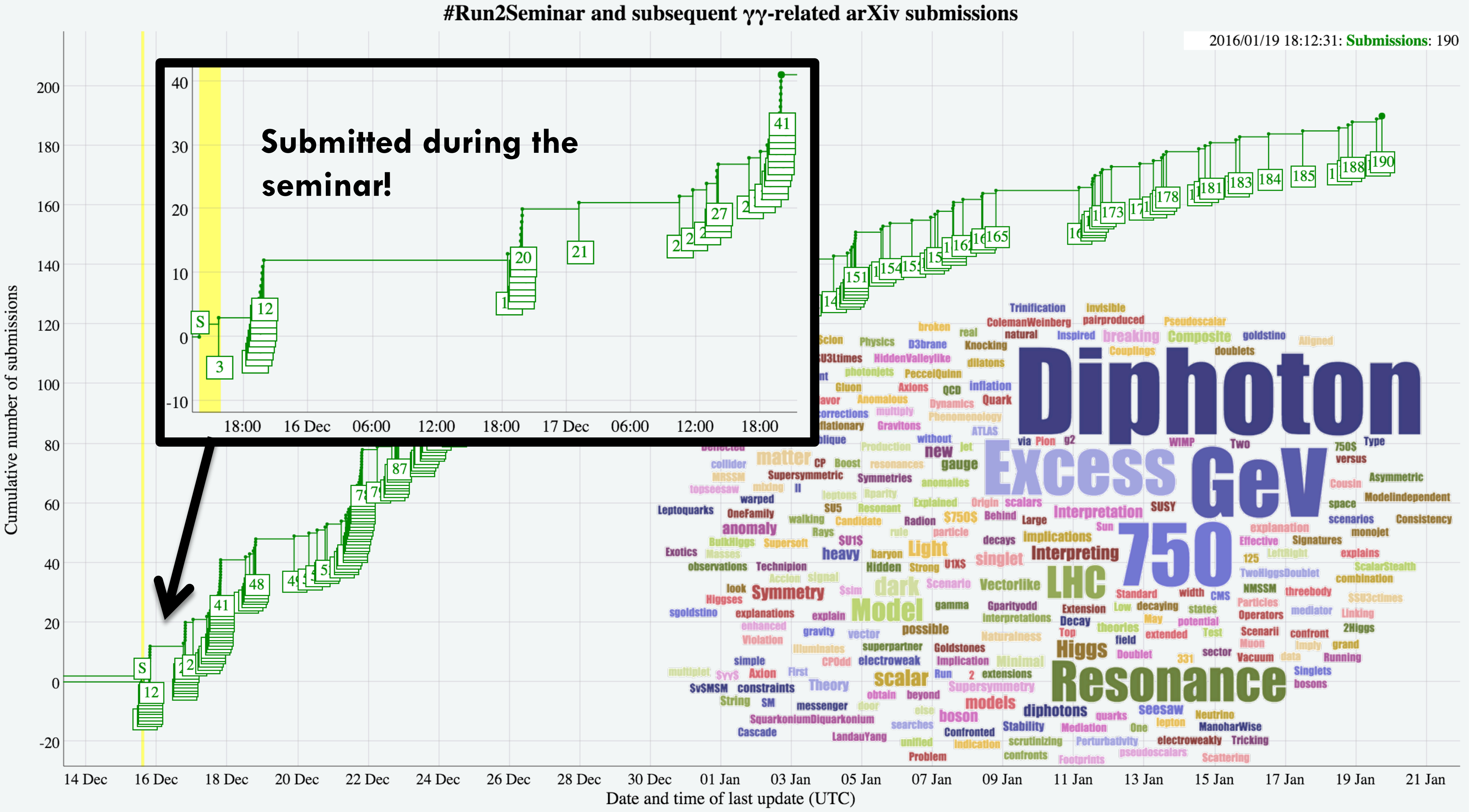
[http://cern.ch/go/DZt8]



#Run2Seminar and subsequent γγ-related arXiv submissions

Post-seminar stampede

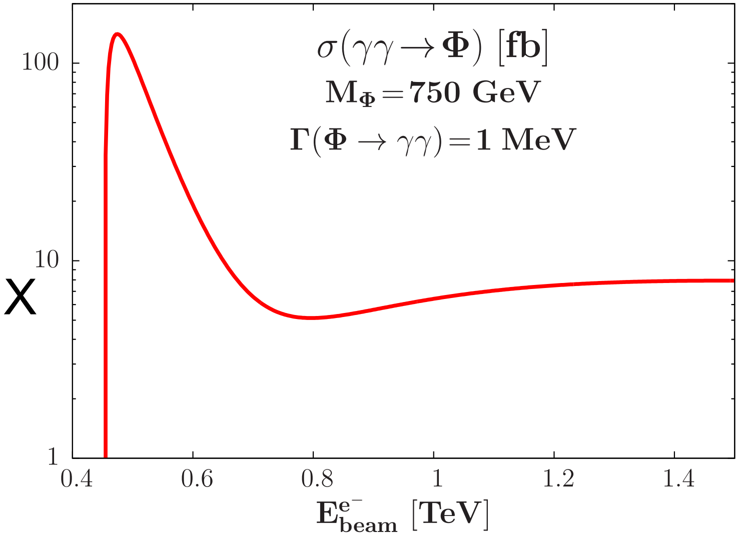
[http://cern.ch/go/DZt8]



Submitted during the seminar!

The X(750)

- will presumably remain in the news until summer at least
- can be produced in γγ collisions
- even minimal models predict additional particles mass ~ 1/2 m_X



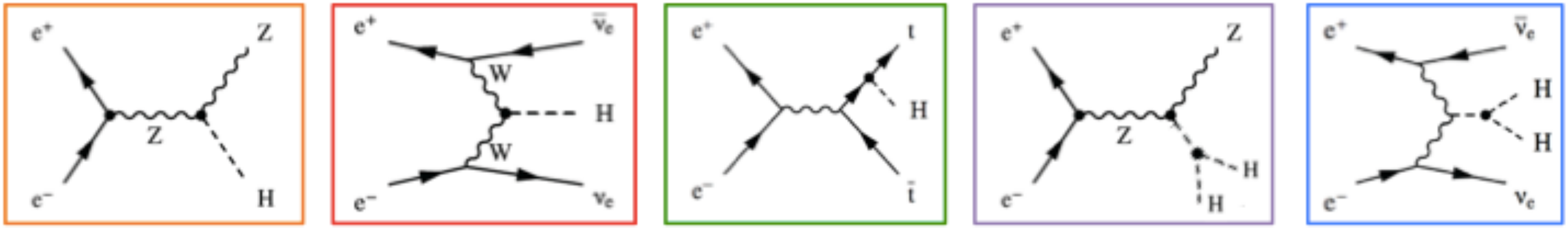
arXiv:1601.03696

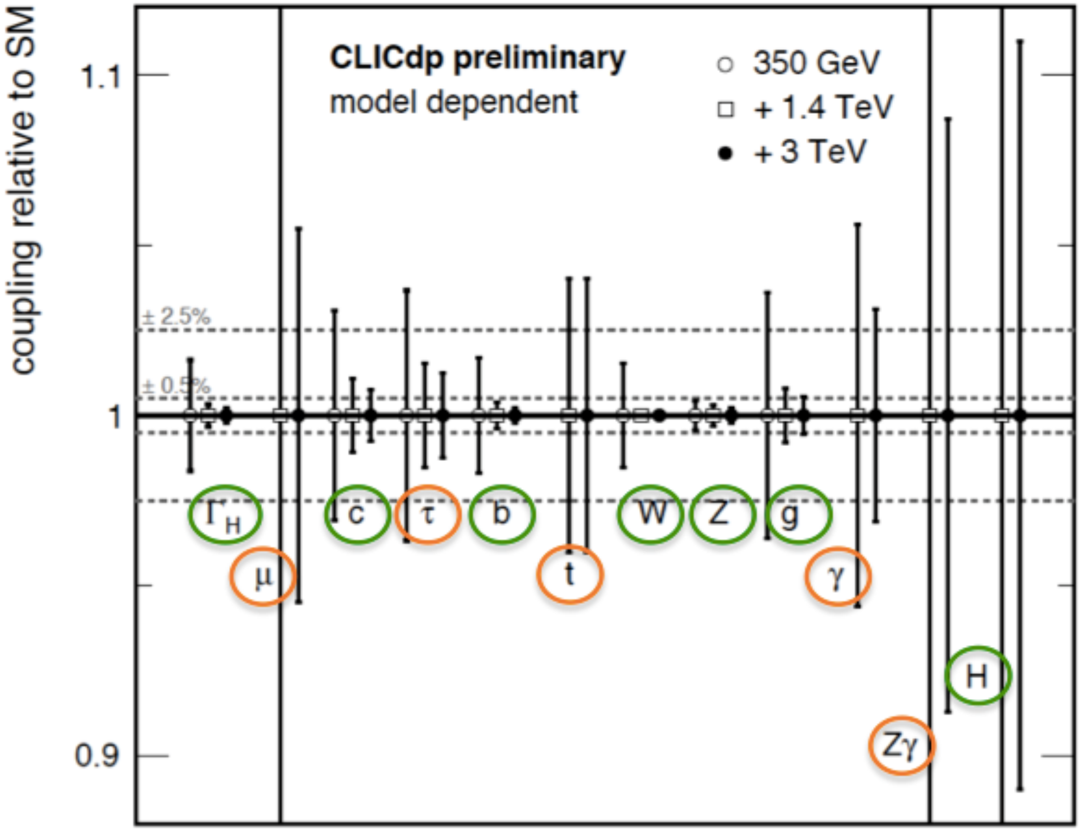
- CLICdp is setting up a task force to prepare answers to FAQs
  - machine (γγ option)
  - physics

Physics

- Higgs paper nearing completion
- focus moving to top and BSM physics

physics studies: Higgs





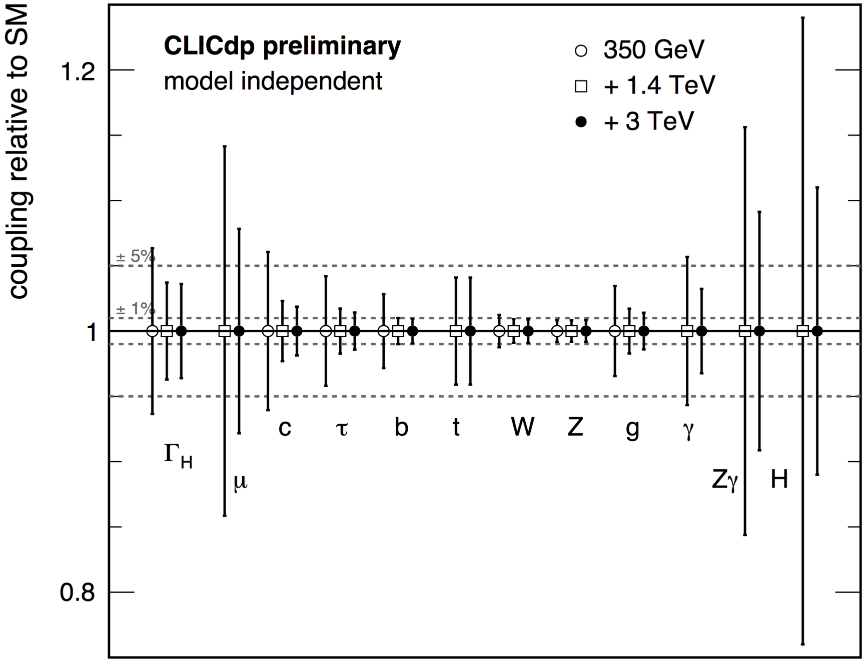
Focus of the CLIC benchmark studies in the past ~3 years
~20 individual physics analyses, covering different CLIC energies

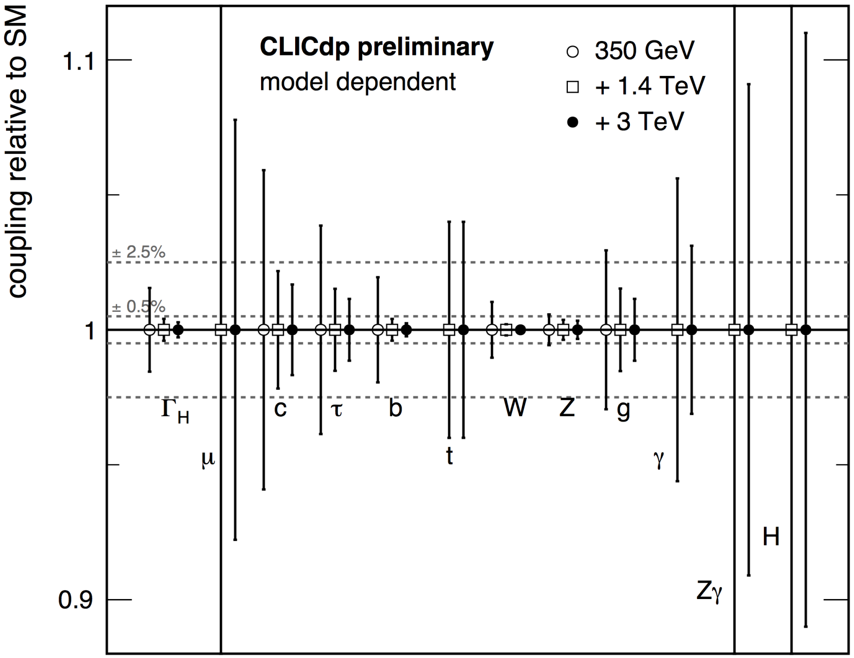
Collaboration-wide effort
involving 9 institutes

🟢 Accuracy significantly better than HL-LHC
🟠 Accuracy comparable to HL-LHC

→ *CLIC Higgs overview publication, draft soon for collab. review: http://proloff.web.cern.ch/proloff/clichiggspaper/*

Higgs paper summary plots





Higgs paper summary plots

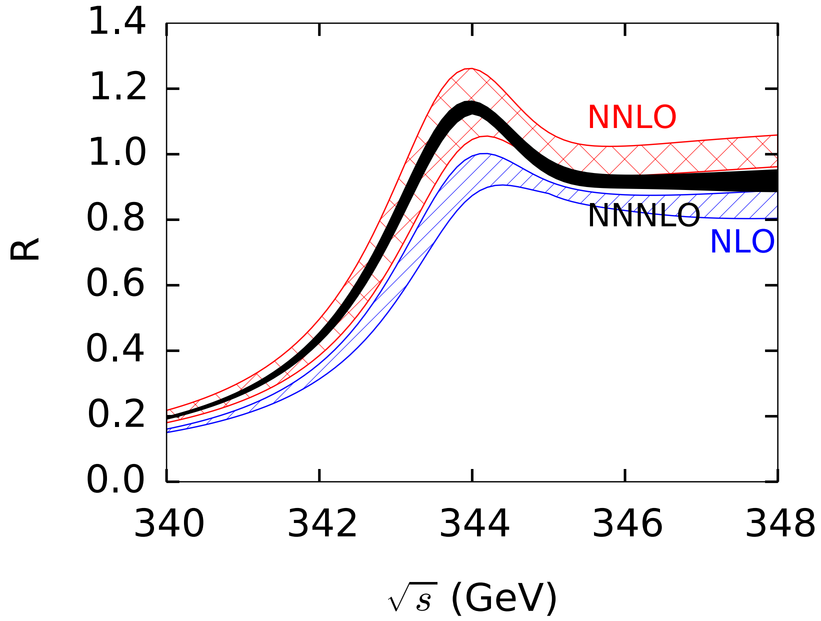
M ~ 1 TeV for new particles

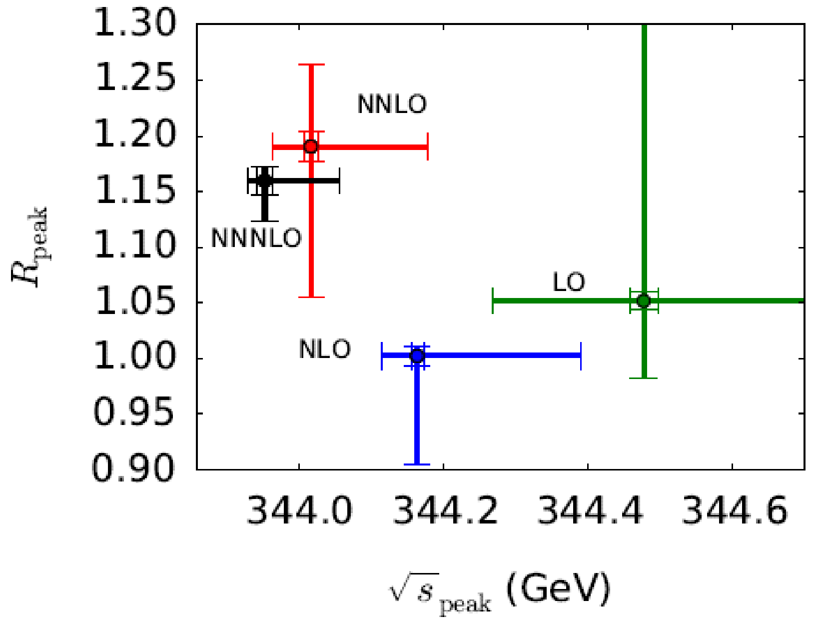
Model	κ_V	κ_b	κ_γ
Singlet Mixing	$\sim 6\%$	$\sim 6\%$	$\sim 6\%$
2HDM	$\sim 1\%$	$\sim 10\%$	$\sim 1\%$
Decoupling MSSM	$\sim -0.0013\%$	$\sim 1.6\%$	$\sim -.4\%$
Composite	$\sim -3\%$	$\sim -(3-9)\%$	$\sim -9\%$
Top Partner	$\sim -2\%$	$\sim -2\%$	$\sim +1\%$
CLIC precision: (model independent)	0.8%	0.9%	3%

Top pair threshold: Theory status

NNNLO QCD description of tt production at threshold: A decade of work to get the 3rd order!

Beneke, Kiyo, Marquard, Penin, Piclum, Steinhauser, 1506.06864 [hep-ph]

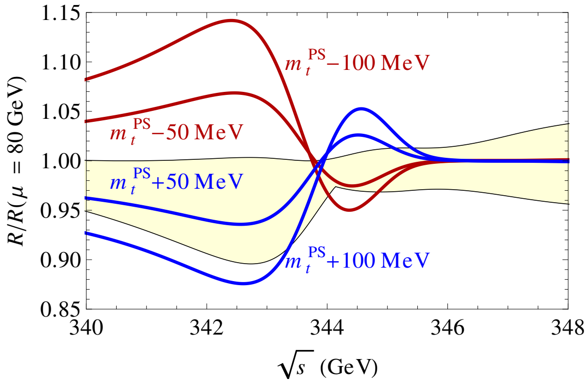




Position shift for PS mass:

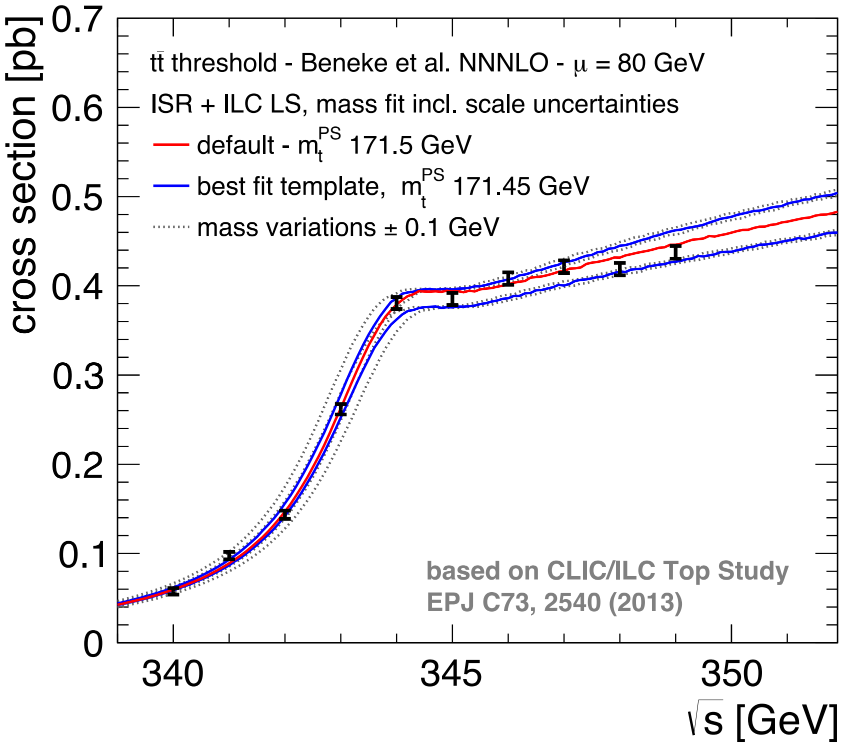
- 310 MeV (LO to NLO)
- 150 MeV (to NNLO)
- **64 MeV (to NNNLO)**

Improvement of factor 3 in uncertainty in peak height



- suggests uncertainties on the 50 MeV level

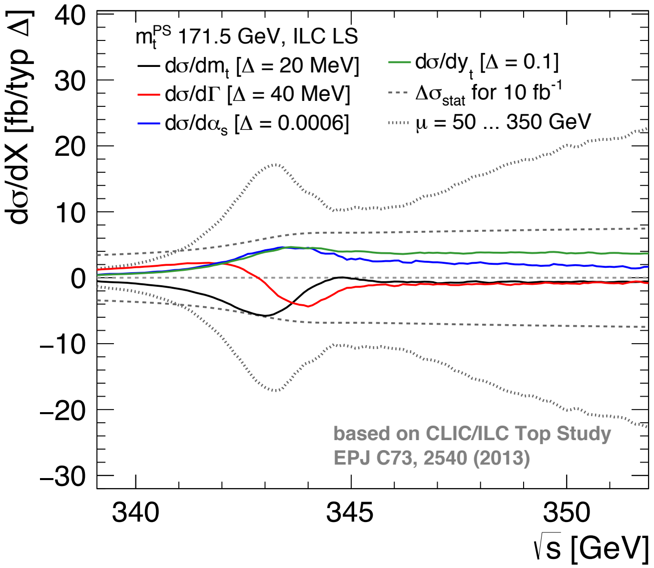
Top pair threshold: Top mass measurement



Threshold scan: **10 x 10 fb^{-1}**, points spaced by 1 GeV **from 340 to 349 GeV**

Based on CLIC/ILC top threshold study EPJ C73, 2540 (2013)

- CLIC_ILD detector model
- Efficiency and backgrounds from full simulations
- ILC TDR luminosity spectrum



For the first time: **Incorporation of NNNLO scale uncertainties** in the experimental evaluation

It translates into:

32 MeV fit uncertainty (including 19 MeV stat)

CLICdp documents in preparation for next European Strategy

CLICdp reports serving as ingredients for a CLIC summary report:

- 2015 CLIC re-baselining report (380 GeV, 1.5 TeV, 3 TeV) ✔
  - Together with CLIC accelerator. Full draft exists, for publication.
- The CLIC Higgs physics overview publication of 2015 ✔
  - Full draft exists, for publication.
- The new optimised CLIC detector model (2015) ✔
  - Nearly complete draft exists, technical note.
- An overview of CLIC top physics
  - CLIC top physics publication in 2016/2017.
- Extended BSM studies (hopefully also motivated by LHC discoveries)
  - CLIC BSM publication by 2017/2018.
- CLIC R&D report => with main CLIC technology demonstrators
  - Summary publication(s) in 2017+2018
- Plan for the period ~2019-2025 in case CLIC would be supported by next strategy
  - 2017/2018, note to be included in CLIC input summary report for the Strategy

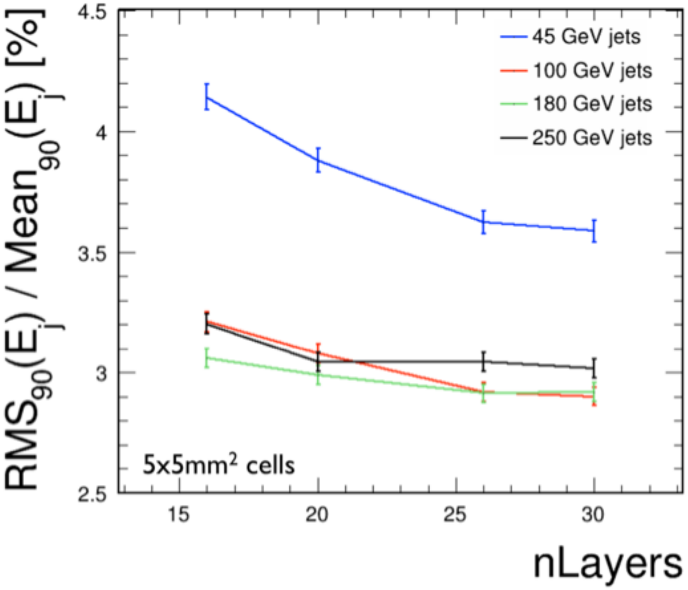
Lucie

Detector

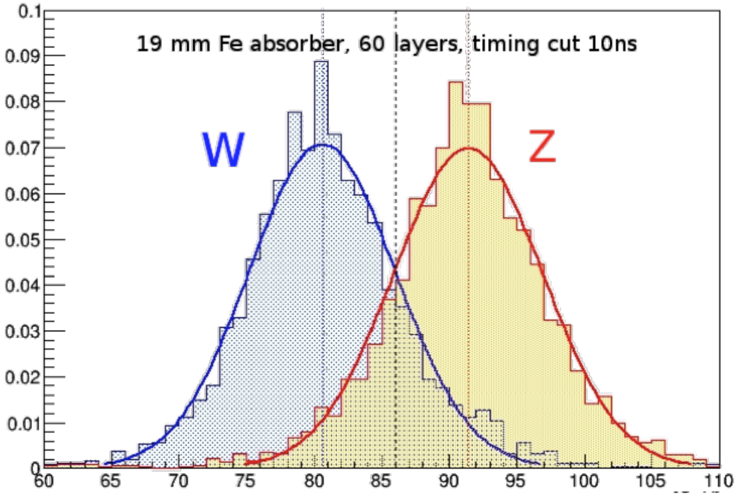
- optimisation
- software
- R&D

detector optimisation

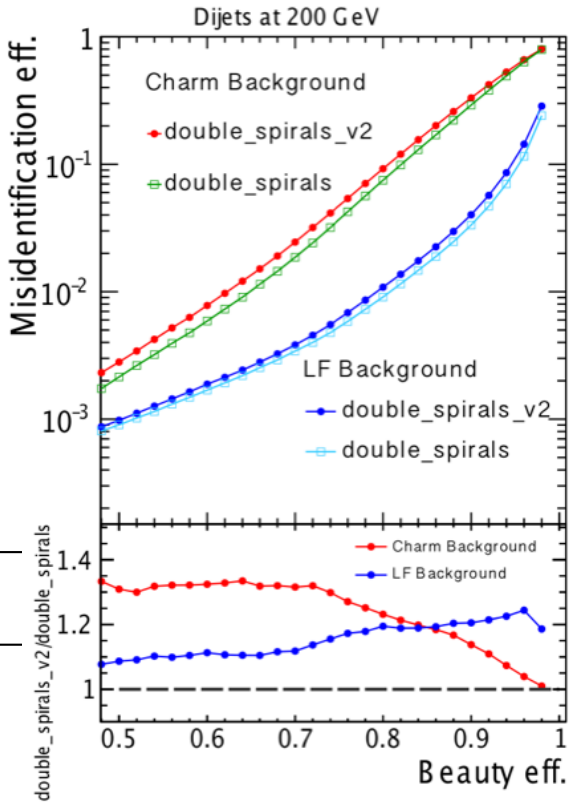
ECAL



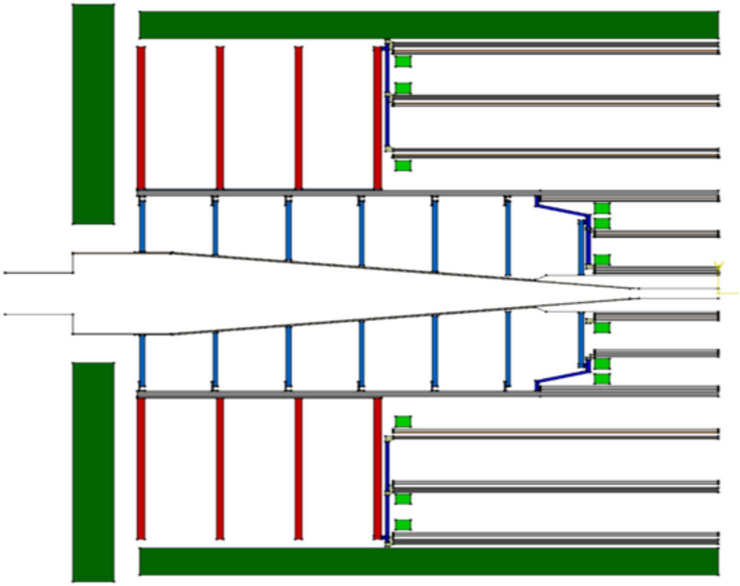
HCAL



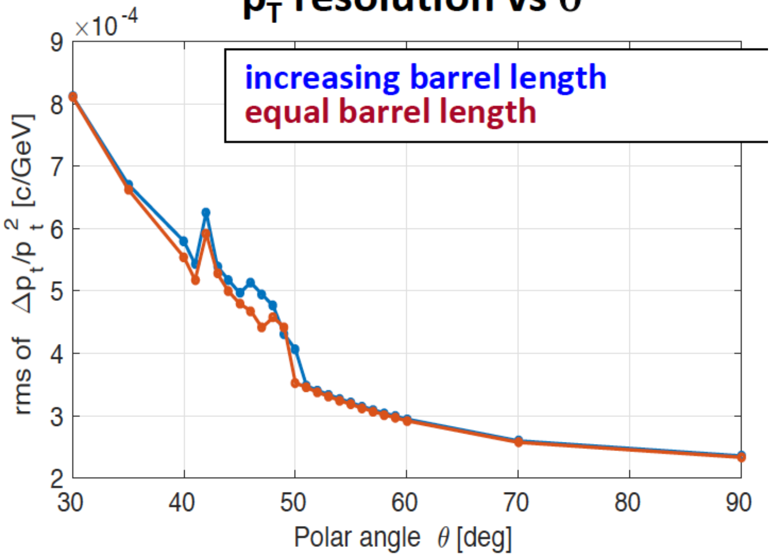
Vertex detector



Tracker layout



p_T resolution vs θ



... etc, with many other optimisation studies

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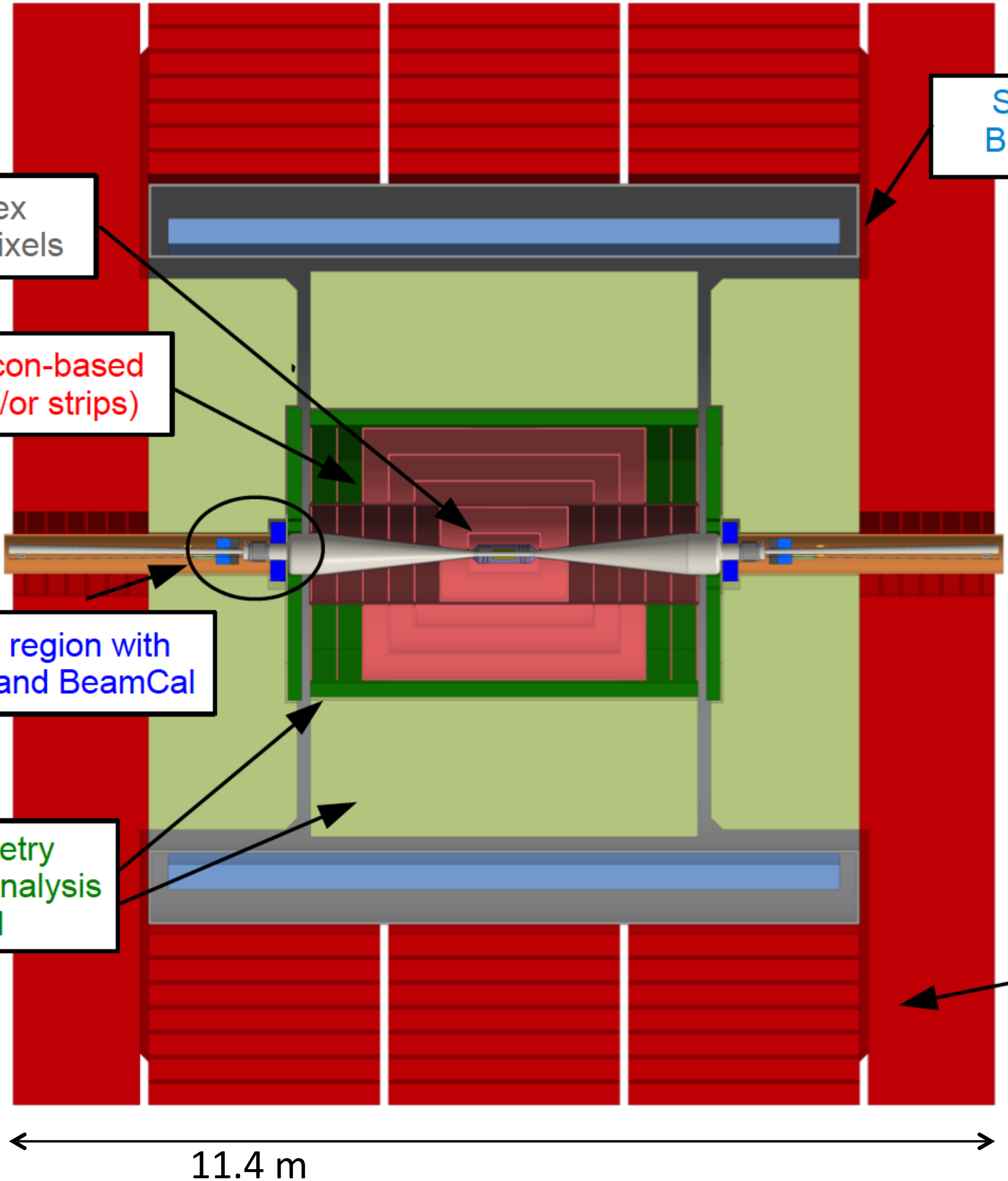
New detector model



Solenoid magnet
B=4 T, R_{in} = 1.7 m

Ultra low-mass vertex
detector with 25 µm pixels

Main tracker, silicon-based
(large pixels and/or strips)

Note: *final beam focusing is outside the detector*

Forward region with
LumiCal and BeamCal

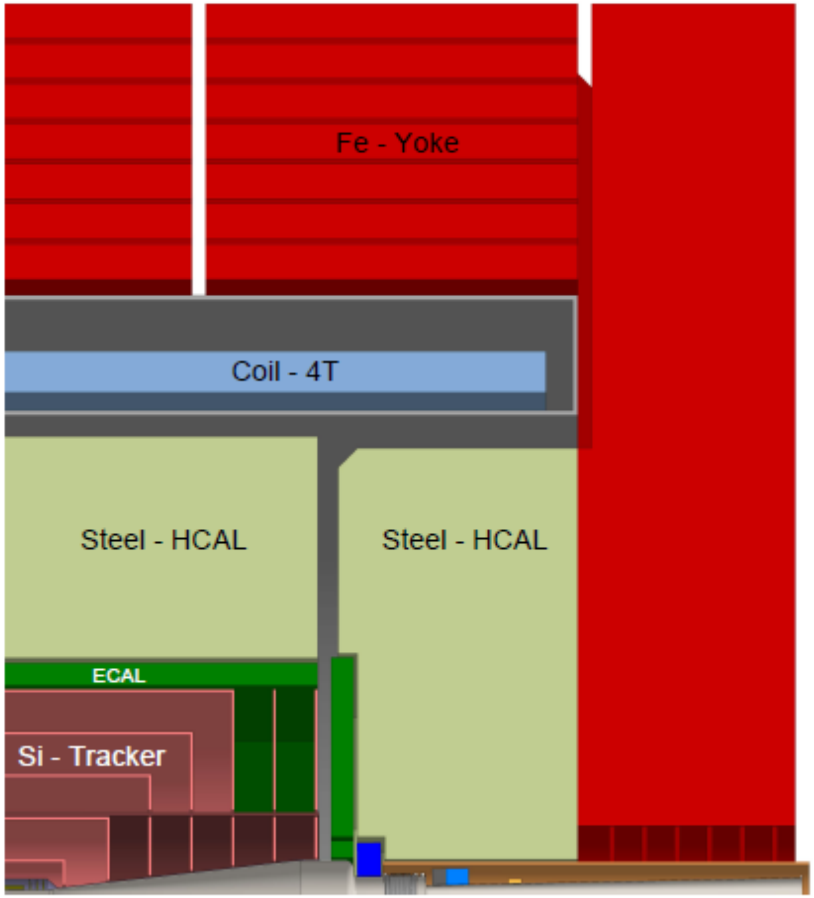
Fine grained calorimetry
used for Particle Flow Analysis
(PFA): **λ = 7.5 + 1**

Return yoke (iron)
with detectors for
muon ID

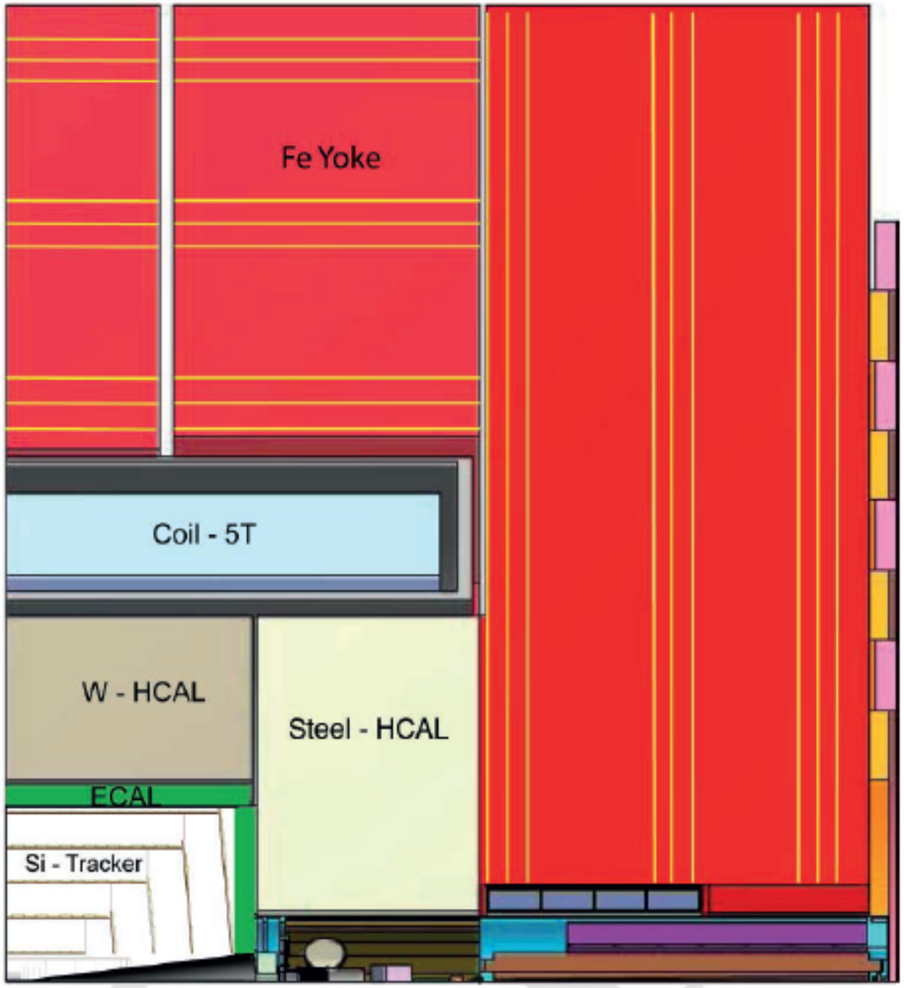
11.4 m

Lucie

Overall Dimensions and Parameters



CLICdet_2015



CLIC_SiD (CDR)

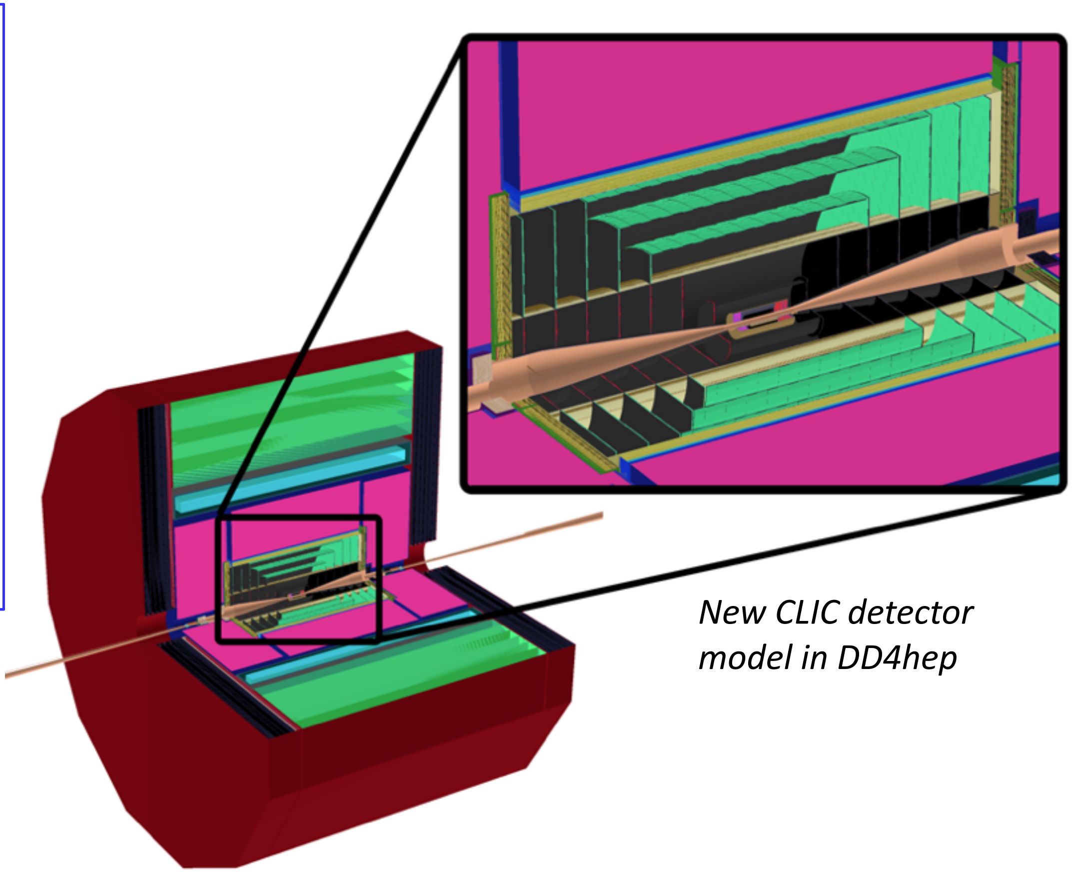
Konrad

software development for new CLIC detector

Renewal of software chain for detector optimisation and physics simulations

- Detector geometry description based on DD4hep
- Most critical item: track reconstruction (intensive work ongoing)
- Improved high-level analysis tools (e.g. vertex reco, flavour tagging)

Grid production with ILCDIRAC



New CLIC detector model in DD4hep

Software developments serve: CLIC, ILC, FCC

Status:

The new detector model is nearly completed.

Draft note on new model exists: → https://edms.cern.ch/document/1572676/

(see Konrad's presentation on the note on 19/1)

The new software is very advanced, mostly "validation" phase.

Hope to start physics simulations with the new model early 2016

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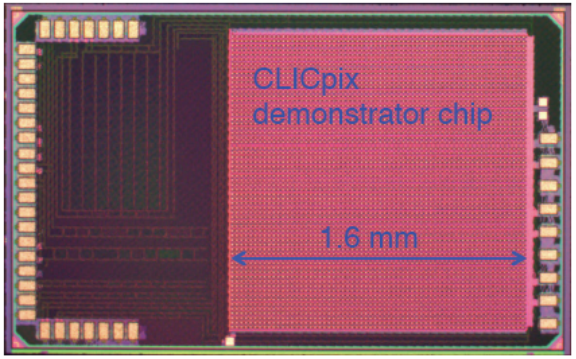
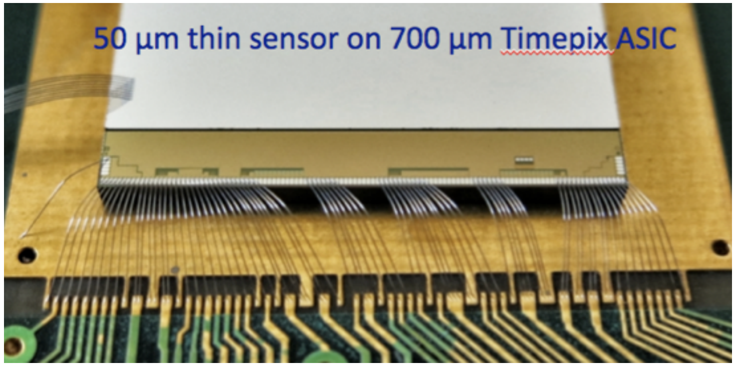
Si vertex and tracker detector R&D (1)

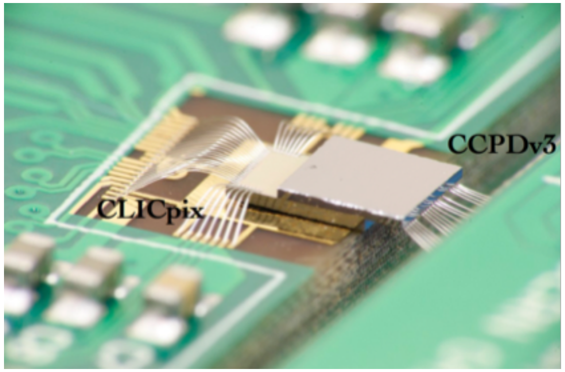
electronics chip (65 nm)

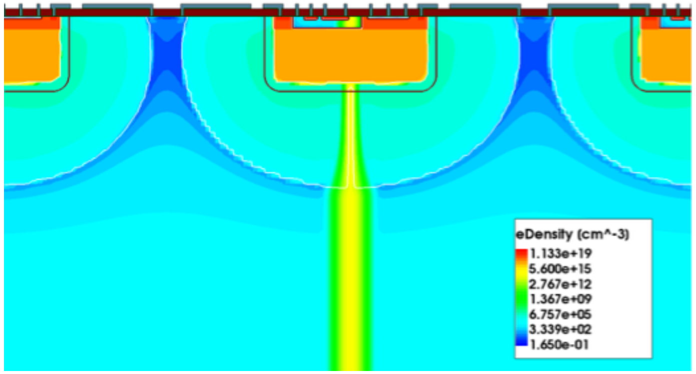


thin sensor+ASIC assemblies



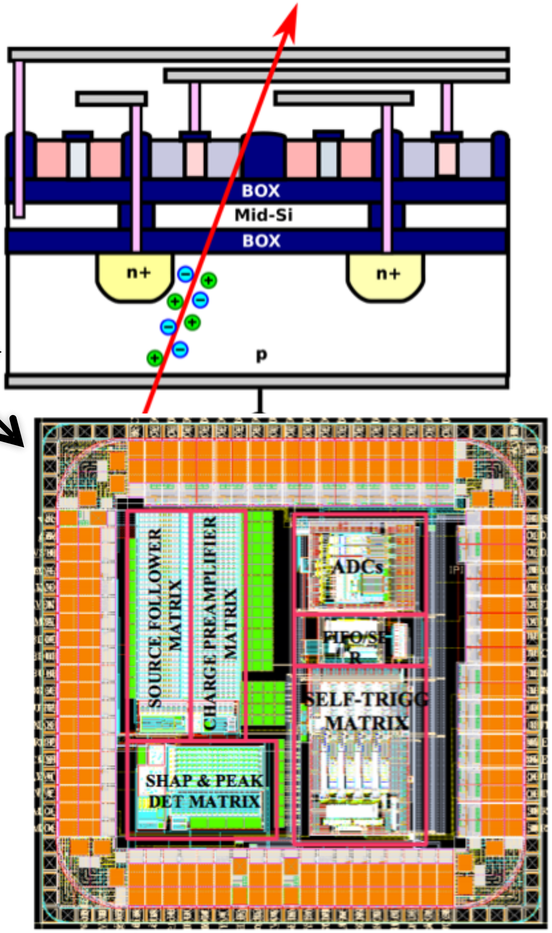
HV-CMOS sensor + CLICpix

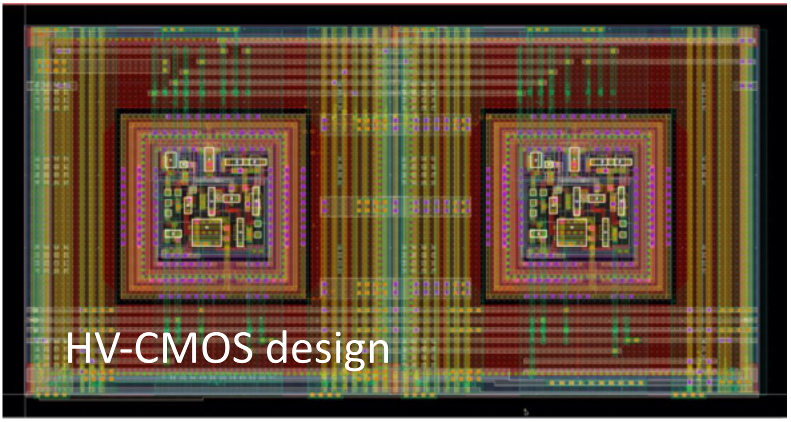


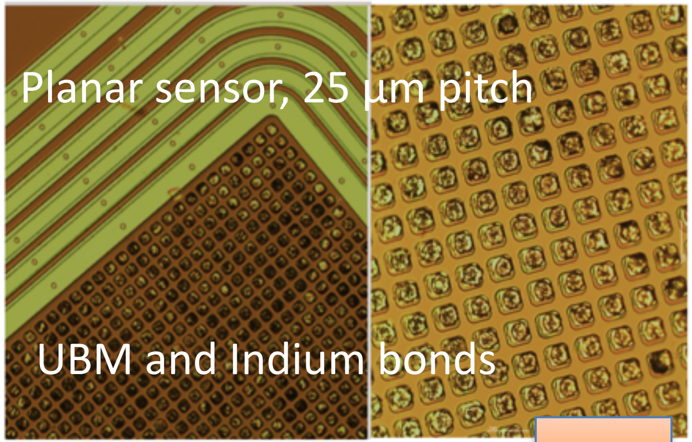


HV-CMOS sensor, signal simulations in TCAD

SoI sensor design

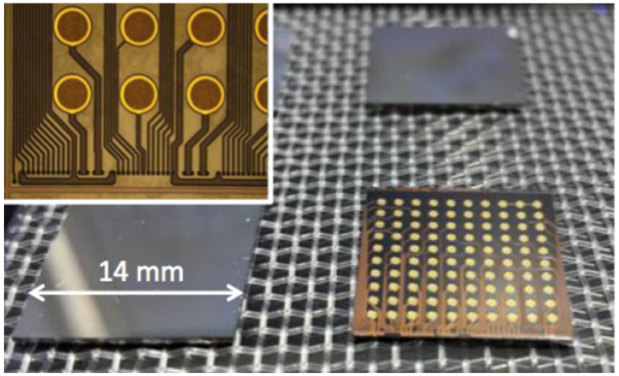




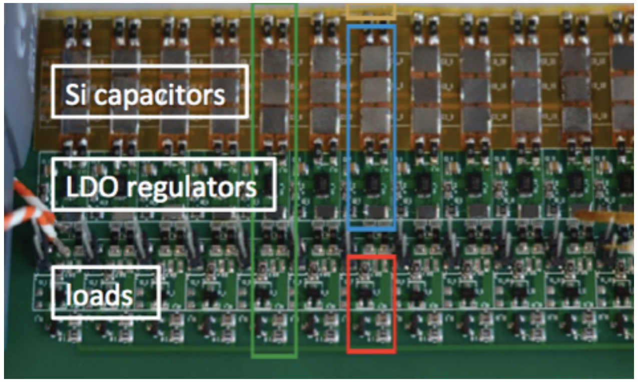


Si vertex and tracker R&D (2)

TSV interconnect technology

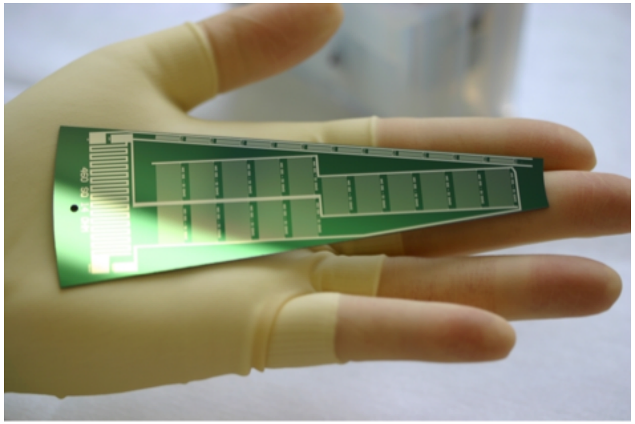


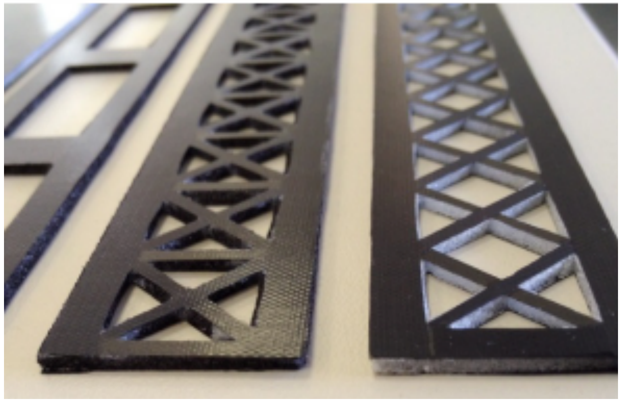
power delivery + pulsing



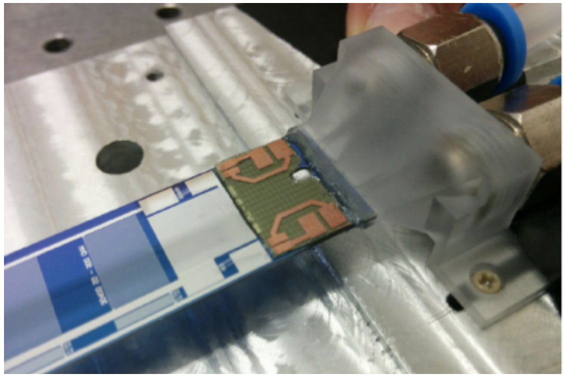
Timepix3 beam telescope

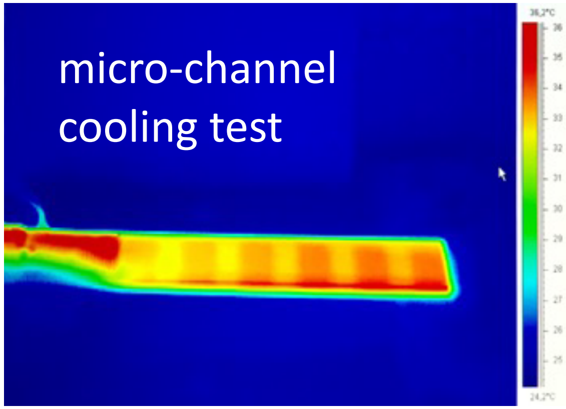
thin supports





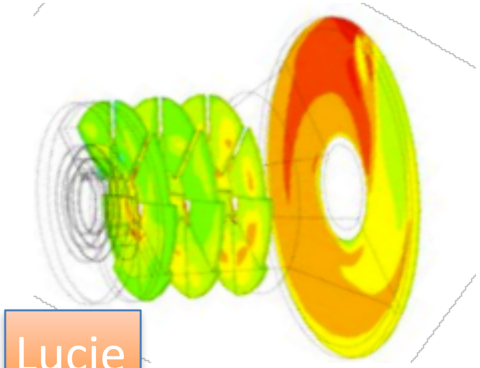
micro-channel cooling

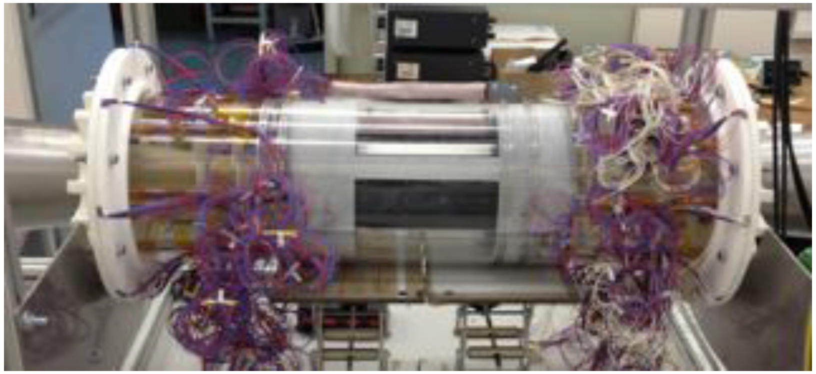




micro-channel cooling test

air cooling simulations/tests



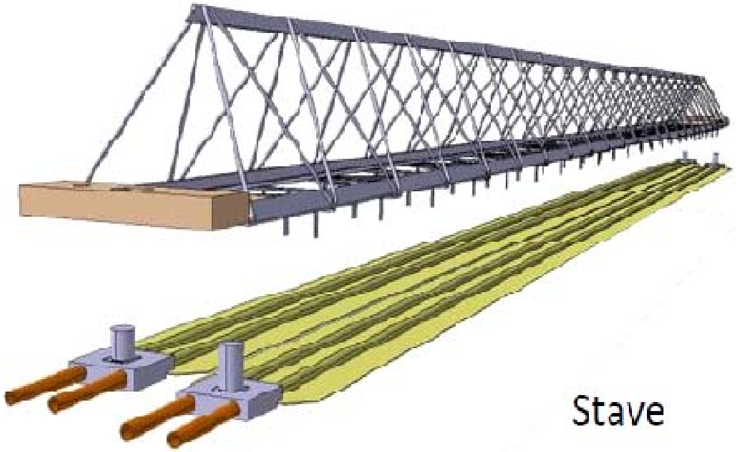


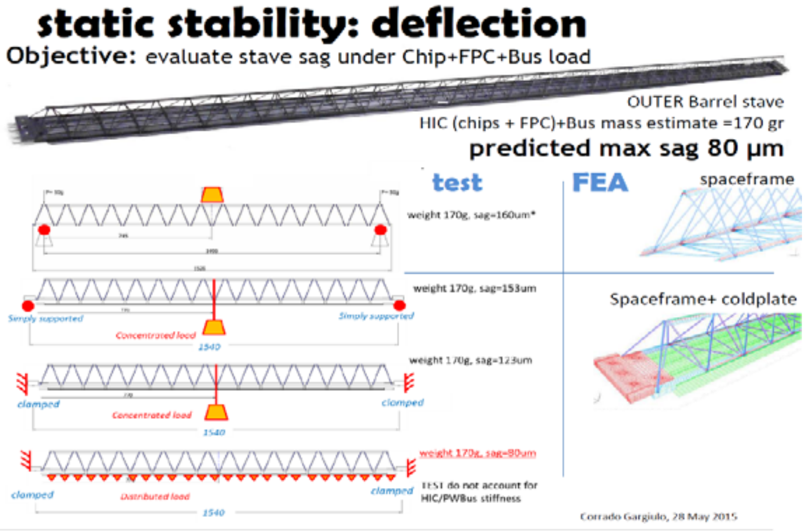
Lucie

Alternative support structure

Looking for inspiration

One way of minimizing the radiation length?





static stability: deflection

Objective: evaluate stave sag under Chip+FPC+Bus load

OUTER Barrel stave

HIC (chips + FPC)+Bus mass estimate =170 gr

predicted max sag 80 µm

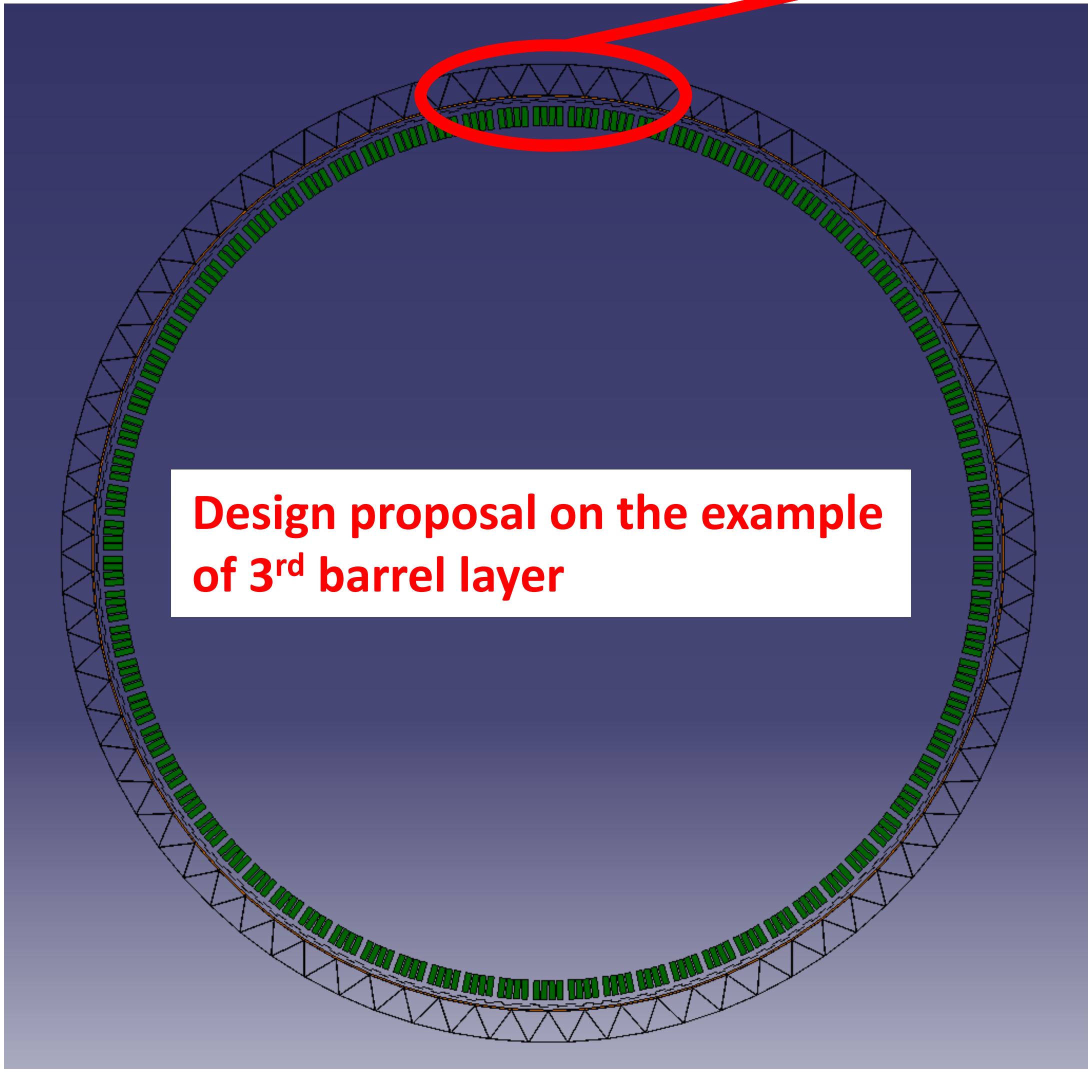
test	FEA
weight 170g, sag=160um*	spaceframe
weight 170g, sag=153um	Spaceframe+ coldplate
weight 170g, sag=123um	
weight 170g, sag=80um	

TEST do not account for HIC/PWBus stiffness

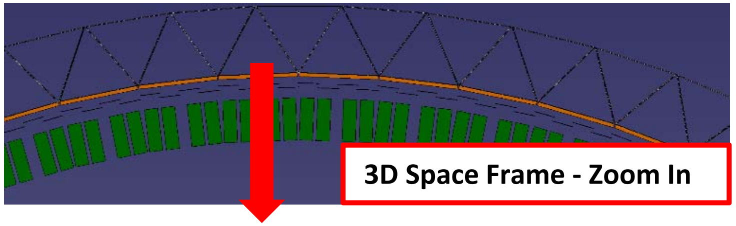
Corrado Gargiulo, 28 May 2015

Alternative support structure

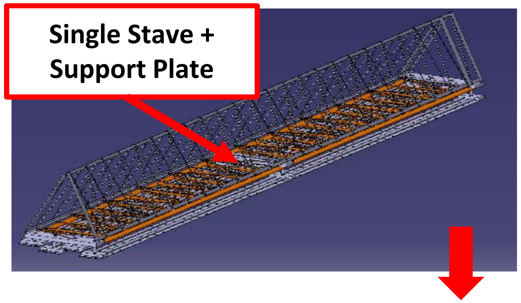
New concept of 3D Space Frame



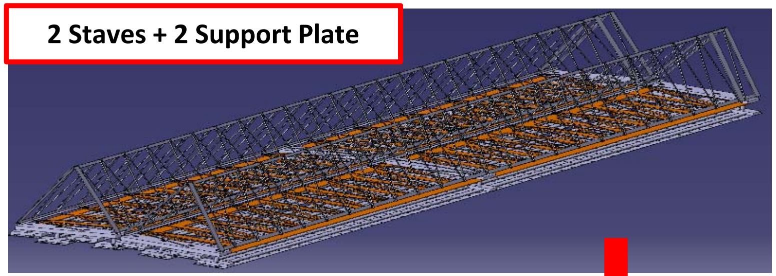
Design proposal on the example of 3rd barrel layer



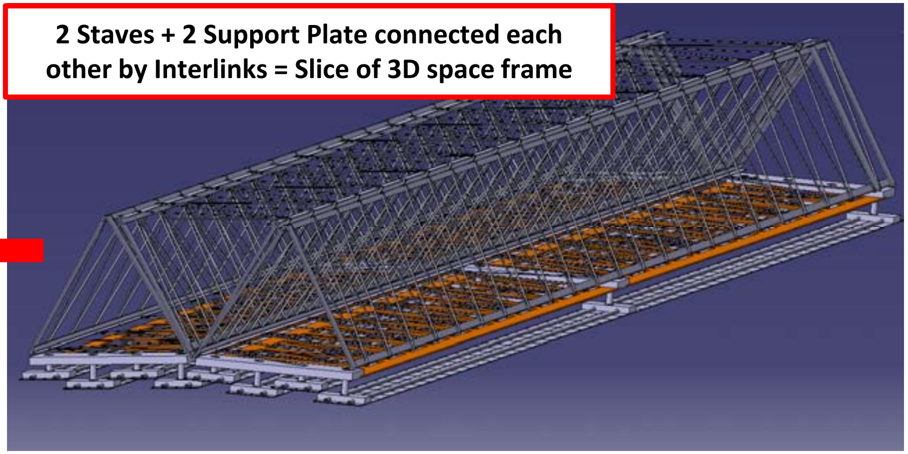
3D Space Frame - Zoom In



Single Stave + Support Plate

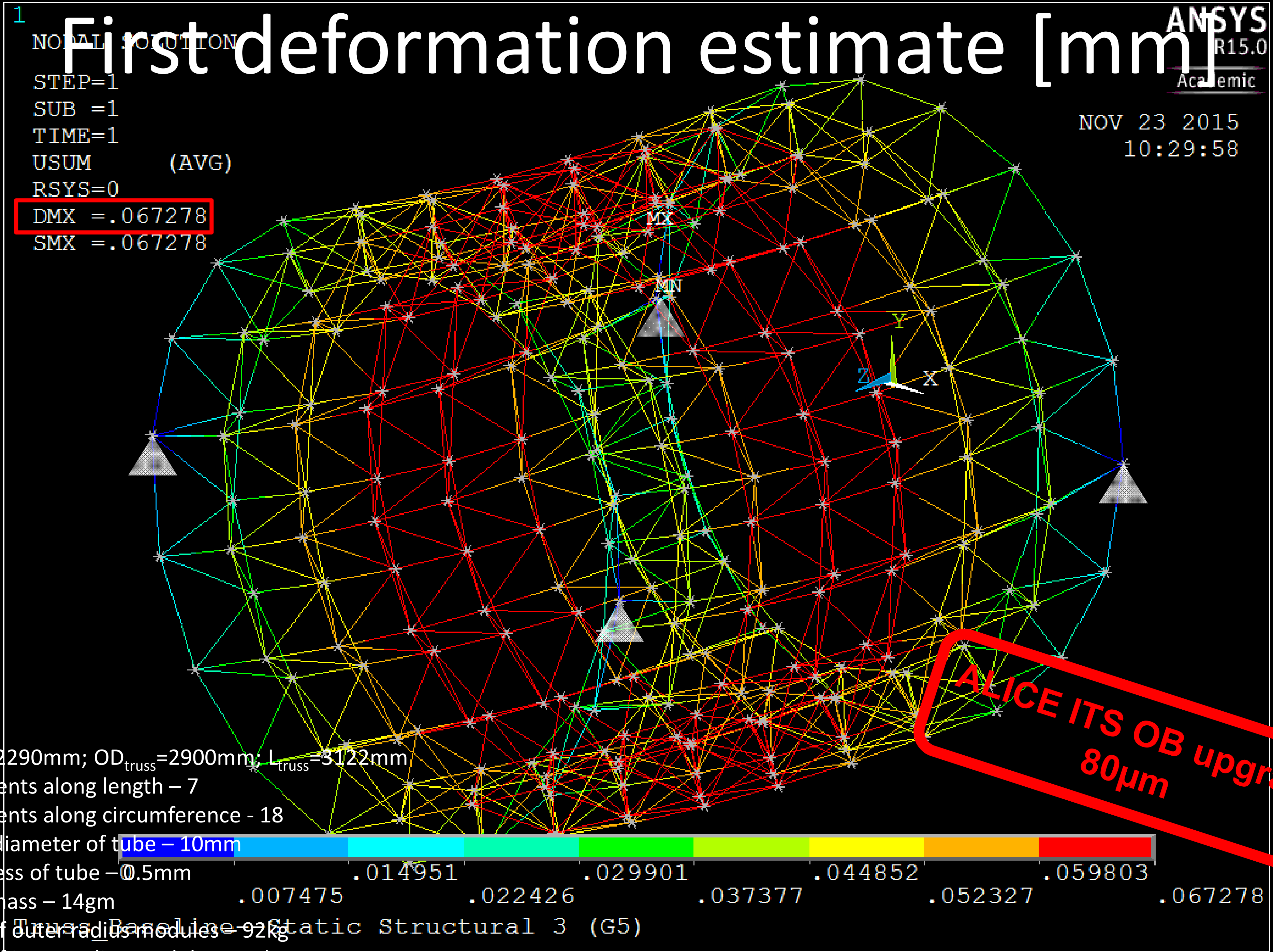


2 Staves + 2 Support Plate



2 Staves + 2 Support Plate connected each other by Interlinks = Slice of 3D space frame

First deformation estimate [mm]



```
1
NODAL SOLUTION

STEP=1
SUB =1
TIME=1
USUM        (AVG)
RSYS=0
DMX =.067278
SMX =.067278
```

ALICE ITS OB upgrade 80μm

ID_{truss}=2290mm; OD_{truss}=2900mm; L_{truss}=3122mm

elements along length – 7

elements along circumference - 18

Outer diameter of tube – 10mm

Thickness of tube – 0.5mm

Node mass – 14gm

Mass of outer radius modules – 92kg

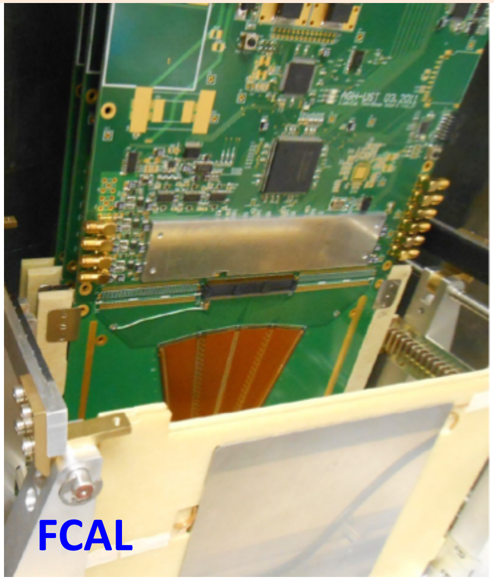
Mass of inner radius modules – 60kg

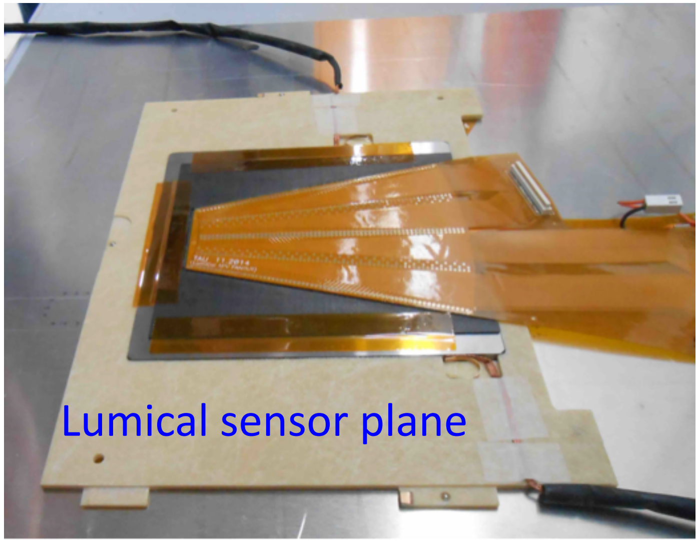
fine-grained calorimetry (CALICE/FCAL)

Strong CLICdp participation in CALICE and FCAL collaborations

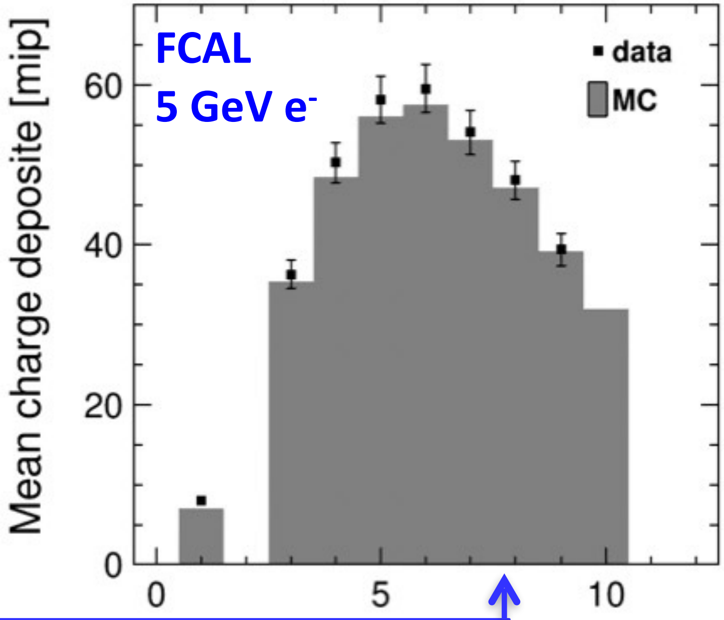
Beam tests in 2015
- CALICE at CERN
- FCAL at DESY

Several publications in 2015





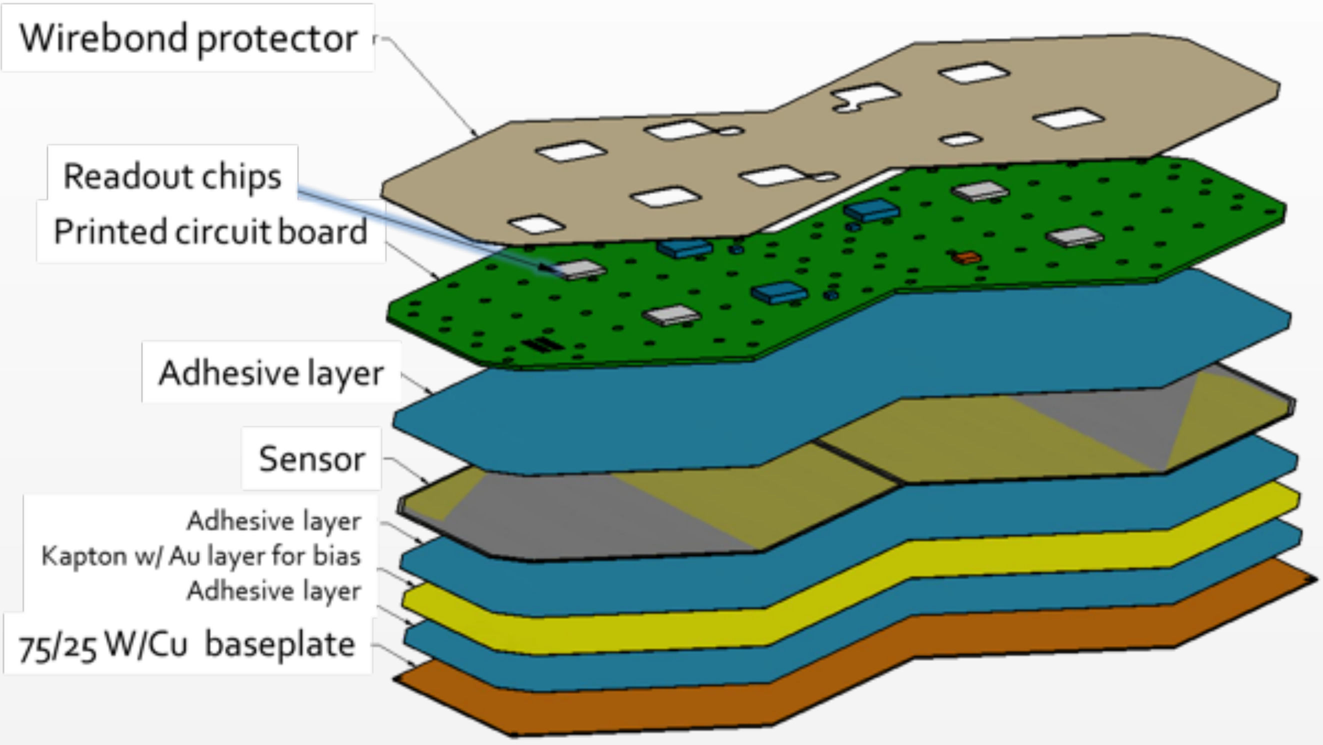
CALICE AHCAL beam tests with steel and tungsten absorbers



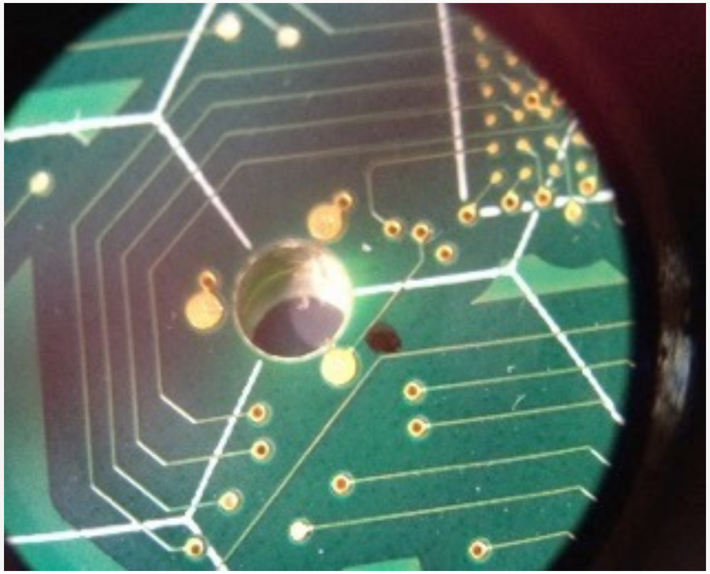
FCAL e- shower depth profile

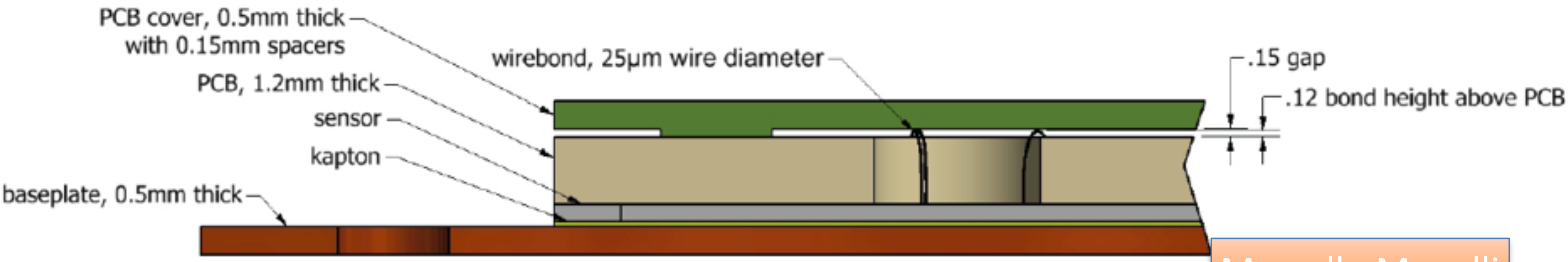
Lucie

Si HGC Detector Module



2 sensors per baseplate



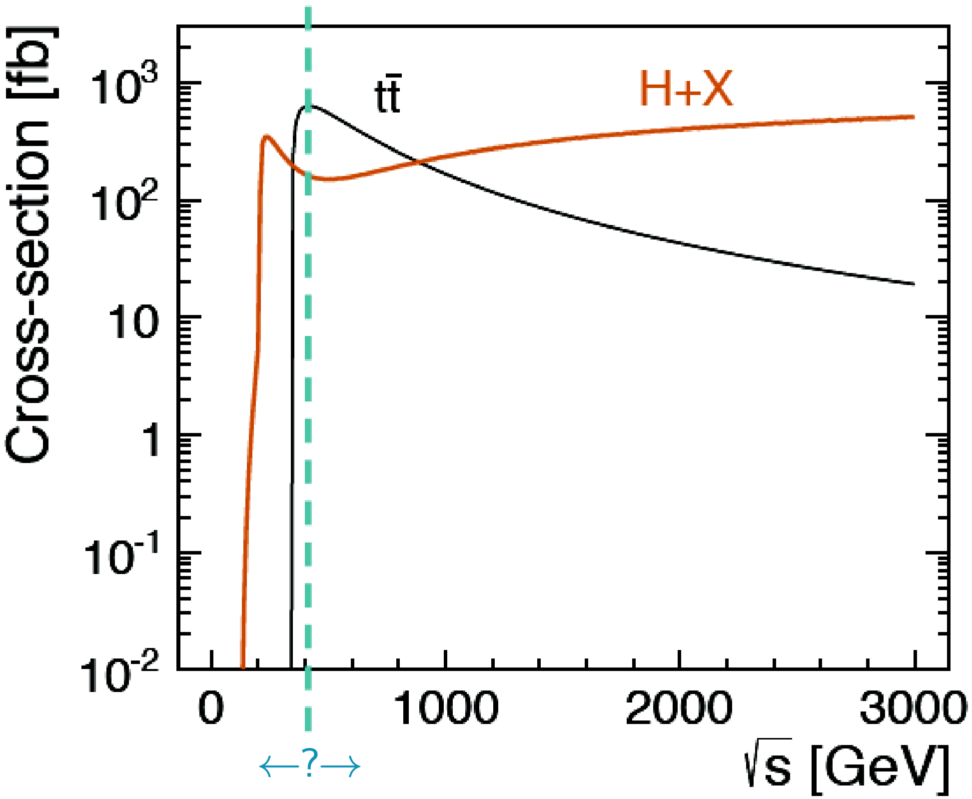


Marcello Manelli

Re-baselining

Physics motivation of re-baselining

- CLIC is foreseen as staged machine with $\sqrt{s}$ from few-hundred GeV to 3 TeV

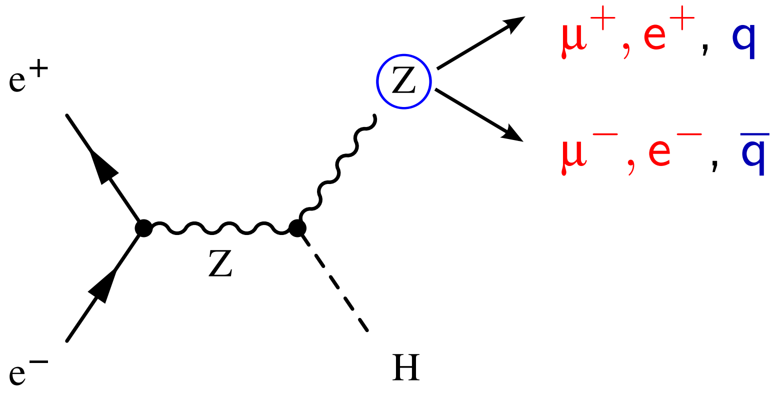


- 1st stage
  - Guaranteed physics: **Higgs couplings + width** and **top**
  - Higgs discovered after CDR
  - $m_{\mathrm{H}} = 125$ GeV
- Subsequent (2nd and 3rd) stages
  - Motivated by Higgs physics and new physics
  - → Potential discoveries at the LHC at 14 TeV
  - → Direct and indirect searches for beyond standard model physics

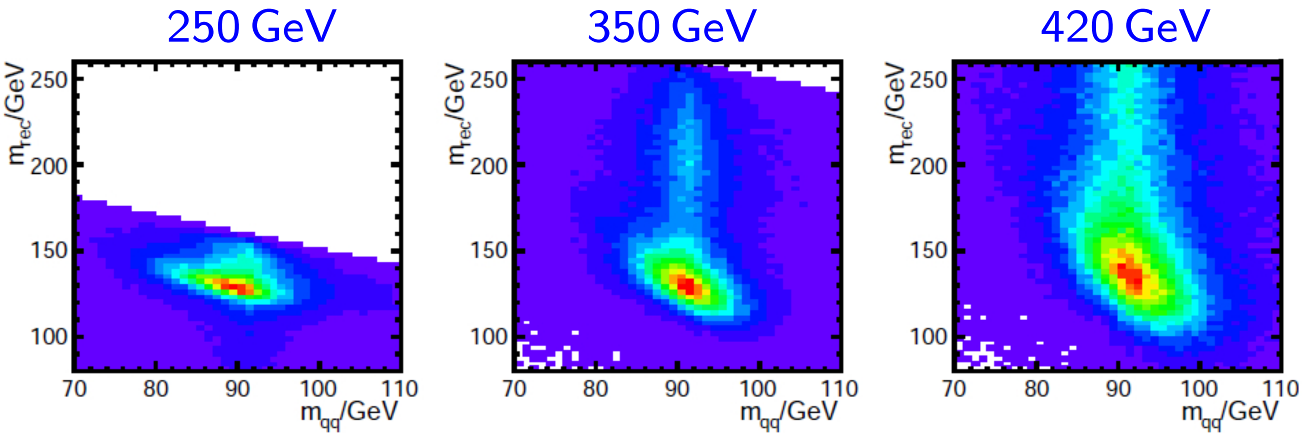
- Optimal $\sqrt{s}$ for 1st stage is not at peak of HX and $t\bar{t}$ cross sections
  → luminosity and backgrounds can scale with centre-of-mass energy
  → theory uncertainties for $t\bar{t}$ can be larger close to on-set of $t\bar{t}$ production

Higgs recoil mass at $\sqrt{s} = 250/350/420\,\text{GeV}$

- Accuracies of Higgs results governed by accuracy of **HZ coupling**
- HZ coupling in Z recoil mass measurement in first energy stage
- Hadronic channel ($\text{BR}_{Z\to q\bar{q}} \approx 70\,\%$) has largest impact
- Test three energies:



$$m^2_{\text{recoil}} = s + m^2_Z - 2E_Z\sqrt{s}$$


250 GeV

350 GeV

420 GeV

$\sqrt{s}$	$\sigma(\text{HZ})$	$\Delta\,\sigma(\text{HZ})$
250 GeV	136 fb	$\pm 3.65\,\%$
350 GeV	93 fb	$\pm 1.80\,\%$
420 GeV	68 fb	$\pm 2.63\,\%$

→ arXiv:1509.02853[hep-ex]

- Find optimal energy for first CLIC stage
  - Cross section decreases with $\sqrt{s}$
  - Absolute detector resolution degrades with $\sqrt{s}$
  - Background rejection improves with increasing $\sqrt{s}$

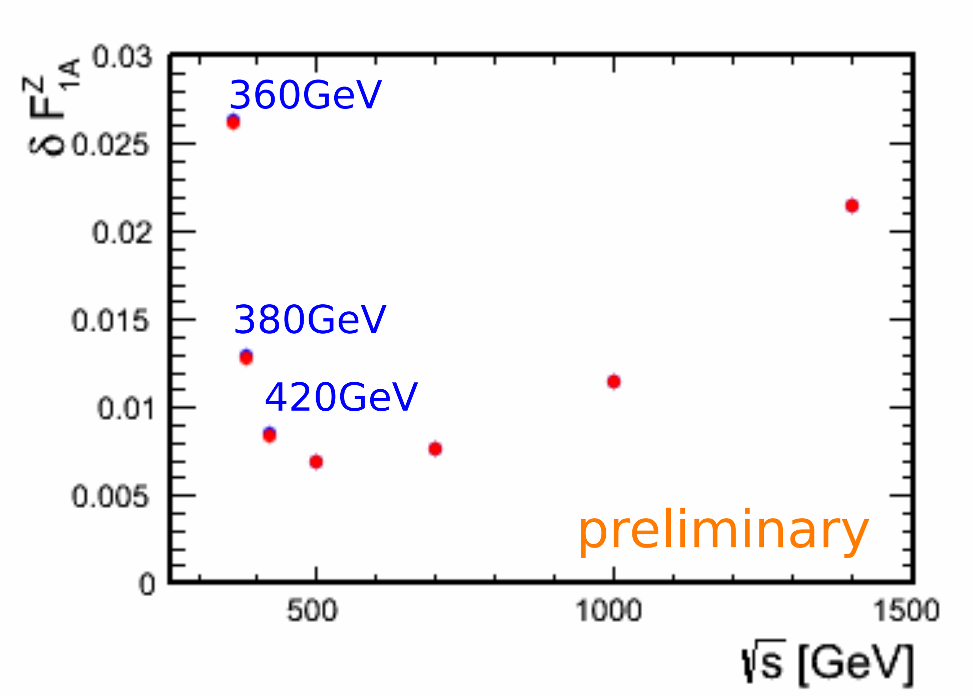
→ Optimum close to 350 GeV

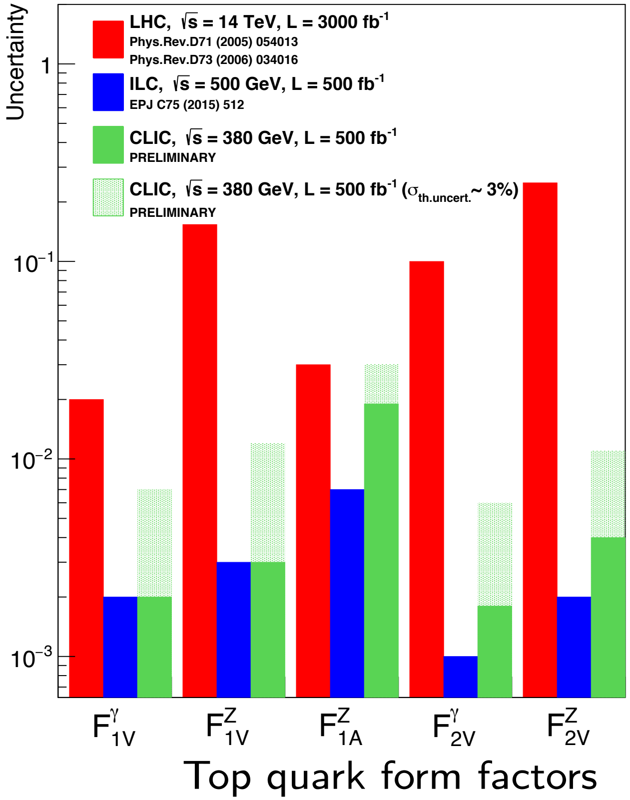
Top form factor measurement

→ Talk by Ignacio Garcia on Thursday

- Probe top vertex through cross section and forward-backward asymmetry (A_{FB})
  - Derive top form factors (F)
  - Expect deviations from SM expectations in form factors for BSM models

- Form factor uncertainty vs. $\sqrt{s}$ (500 fb^{-1} each)





- Reconstruction capability and impact of BSM on form factor increases with $\sqrt{s}$
- Theoretical uncertainty decrease with $\sqrt{s}$

→ Optimum close to 500 GeV (for fixed luminosity per $\sqrt{s}$)

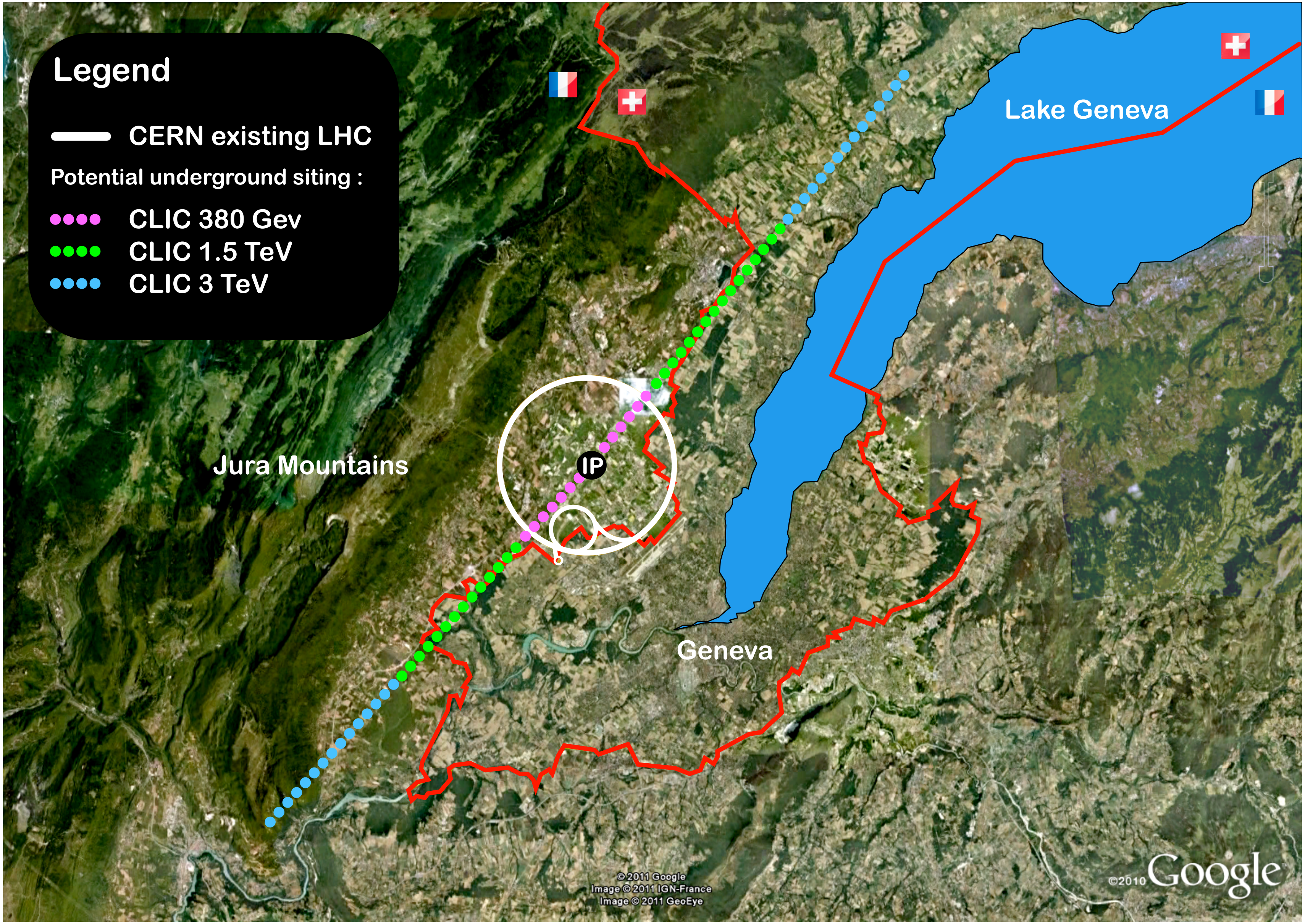
Conclusion on CLIC first energy stage

Find compromise for comprehensive physics programme of initial stage

- Higgs recoil mass measurement
  - → 250 GeV$< \sqrt{s} <$ 420 GeV
- Higgs production via Higgsstrahlung and WW-fusion
  - → 250 GeV$< \sqrt{s} <$ 450 GeV
- Top pair production
  - → $\sqrt{s} >$ 350 GeV, maximum at $\sqrt{s} \approx$ 420 GeV
- Top as probe for BSM
  - → $\sqrt{s} >$ 360 GeV
- Top not too close to threshold (theory uncertainties, boost)
  - → $\sqrt{s} >>$ 350 GeV

$$\rightarrow \sqrt{s} = 380\ \text{GeV}$$

Updated CLIC footprint

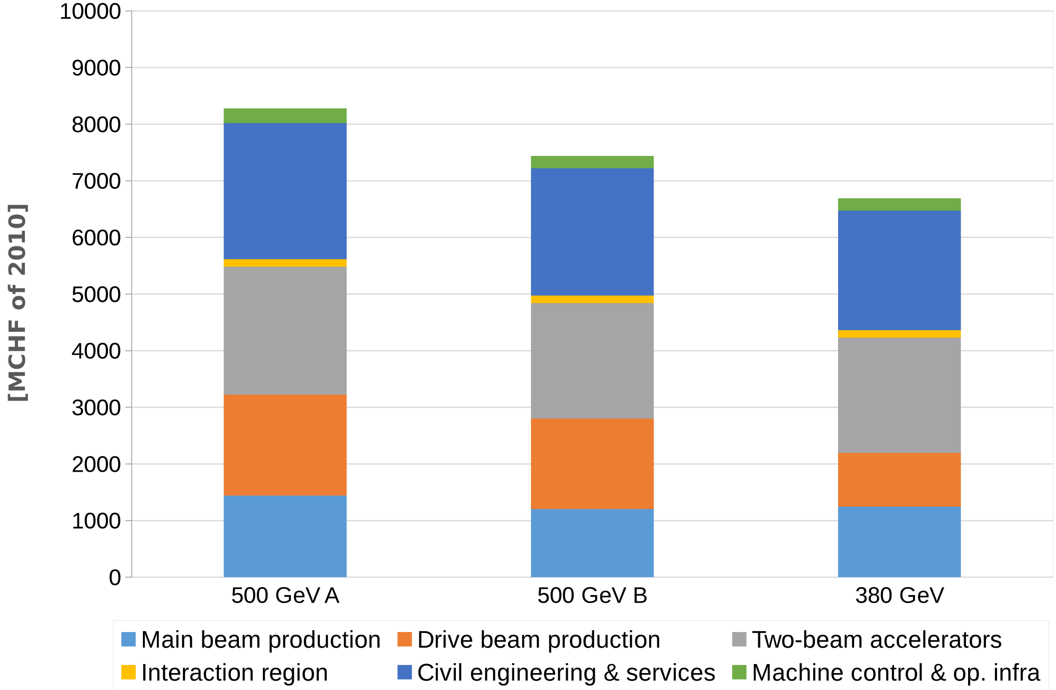


Cost estimate for 380 GeV

- Full CLIC cost estimation including all contributions
- Use 2010 CHF for direct comparison to CDR estimates

	Value [MCHF (2010)]
Main beam production	1245
Drive beam production	974
Two-beam accelerators	2038
Interaction region	132
Civil engineering & services	2112
Machine control & operational infrastructure	216
Total	6690

Comparison to CDR values



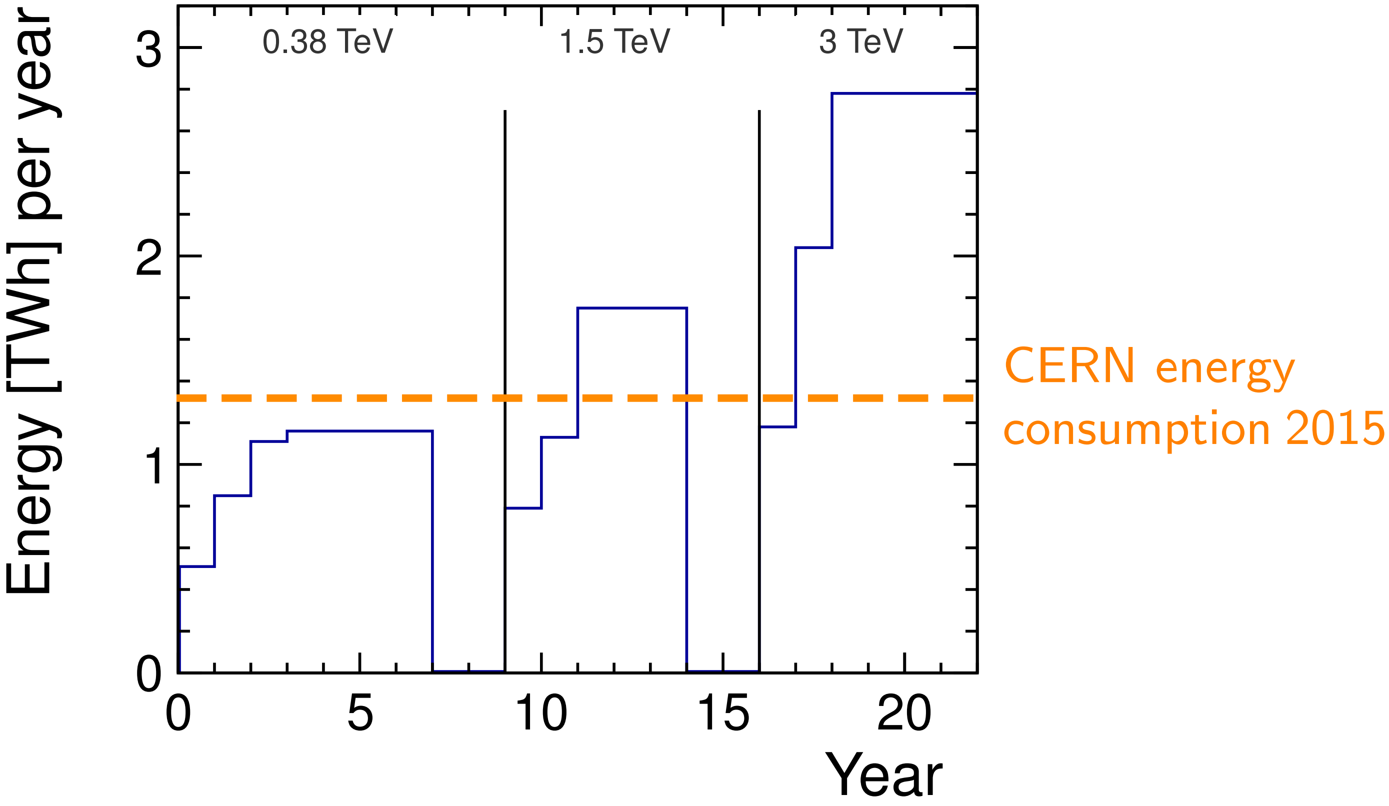
- Full 380 GeV CLIC machine: $\sim$ 6.7 BCHF $(2010)_{\text{preliminary}}$ (+ 4 MCHF/GeV up to 1.5 TeV)

(Note → Numbers scaled from CDR design at 500 GeV
→ To be repeated with detailed tech. description of 380 GeV CLIC)

Cost estimate for 380 GeV

- Full CLIC cost estimation including all contributions
- Use 2010 CHF for direct comparison to CDR estimates

	[
Main beam production	
Drive beam production	
Two-beam accelerators	
Interaction region	
Civil engineering & services	
Machine control & operational infrastructure	
Total	



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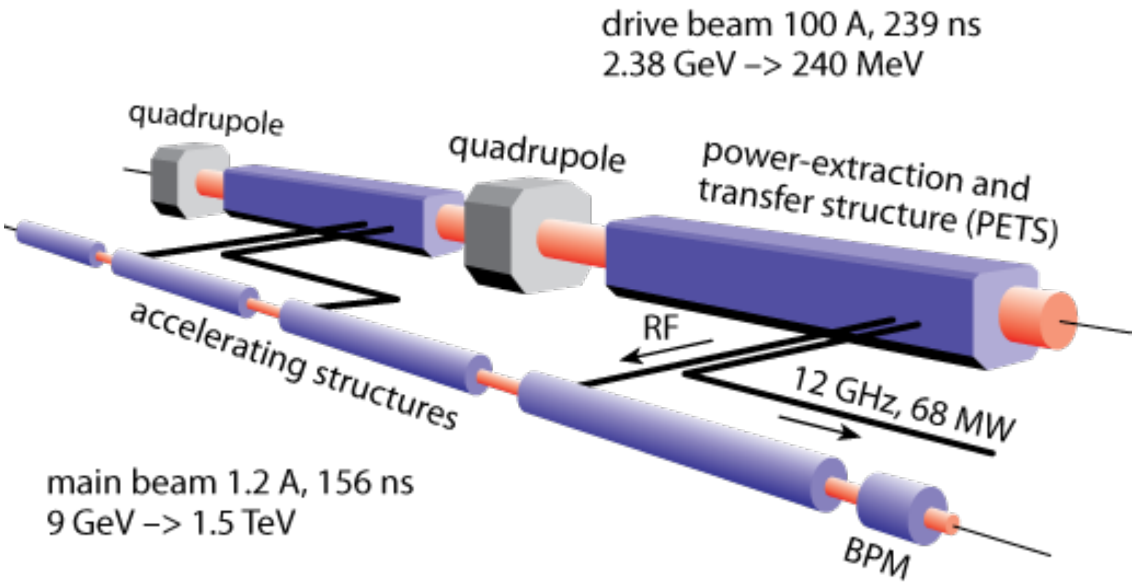
Accelerator

Drive Beam Quadrupoles

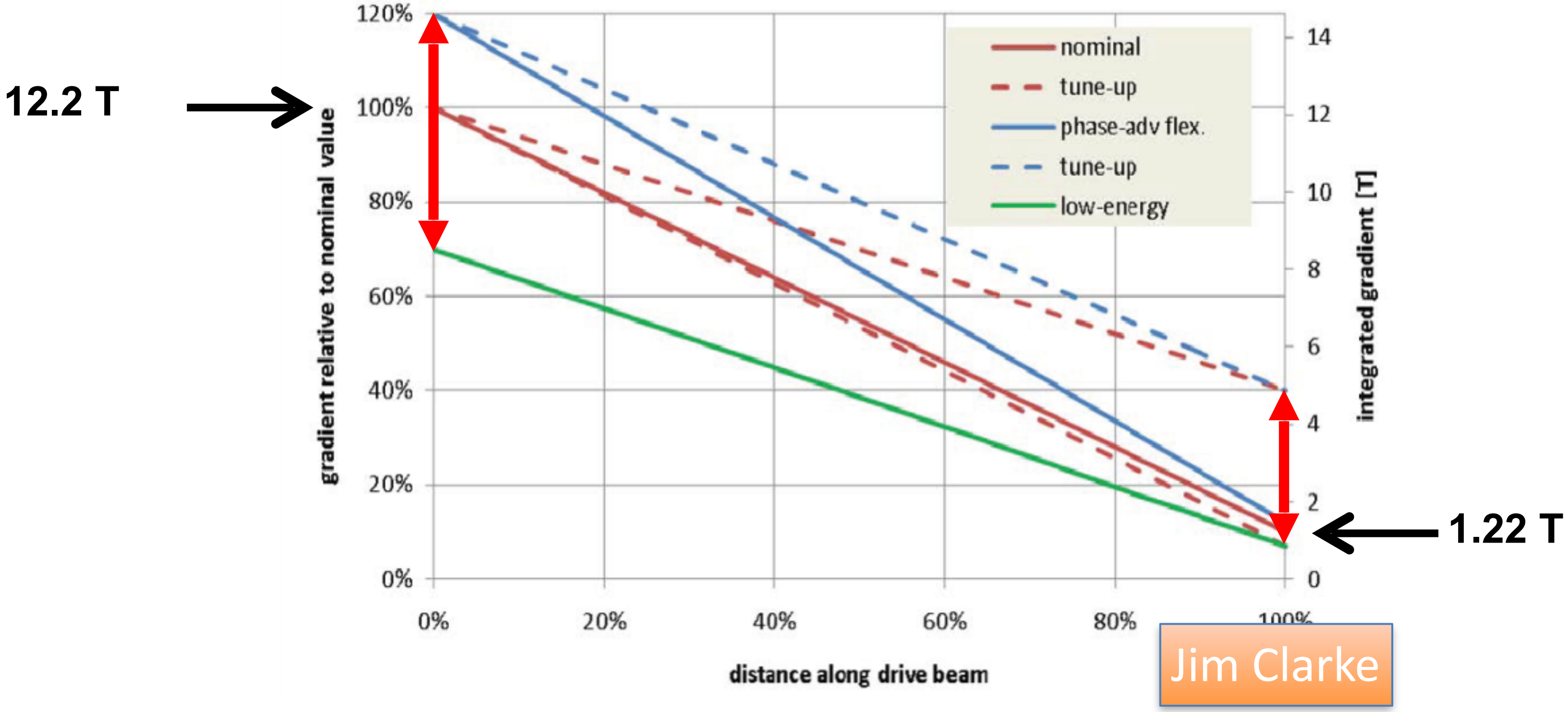


- The drive beam decelerates from 2.4GeV to 0.24GeV transferring energy to the main beam
- As the electrons decelerate, quadrupoles are needed every 1m to keep the beam focused
- The quadrupole strengths scale with the beam energy
- The CLIC accelerator length is **~42km** so there are **~42,000** quadrupoles needed

Jim Clarke

Quadrupole Tunability

- The **nominal** maximum integrated gradient is 12.2T and the minimum is 1.22T
- For operational flexibility each individual quadrupole must operate over a wide tuning range
  - 70% to 120% at high energy (2.4 GeV)
  - 7% to 40% at low energy (0.24 GeV)
- The power consumption for the EM version will be **~13MW** in nominal mode and up to **~34 MW** in tune-up mode



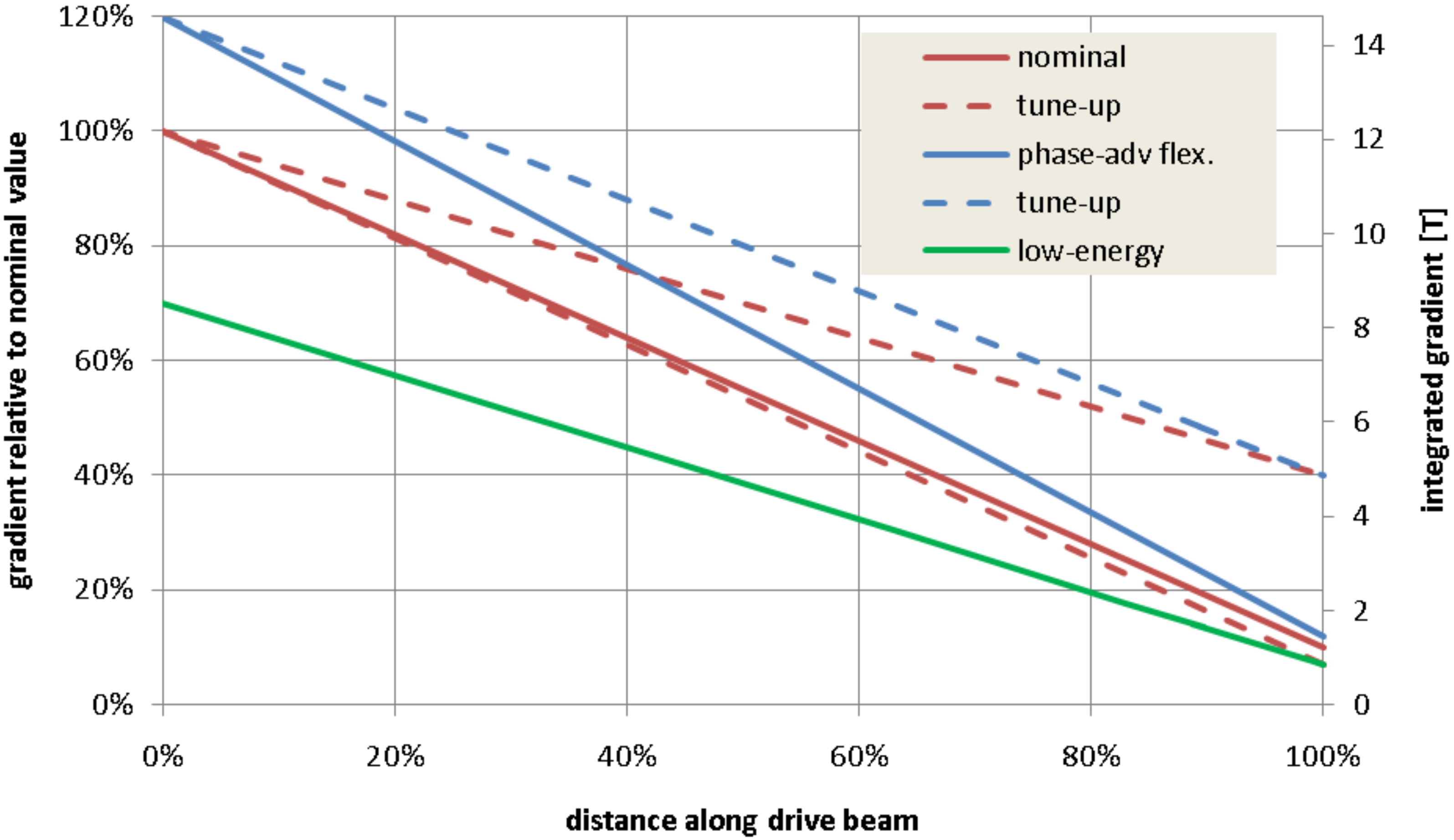
Jim Clarke

Drive Beam Quads

- The complete tuning range (120% to 7%) could not be met by a single design
- We have broken the problem down into two magnet designs – **one high energy and one low energy**

Jim Clarke

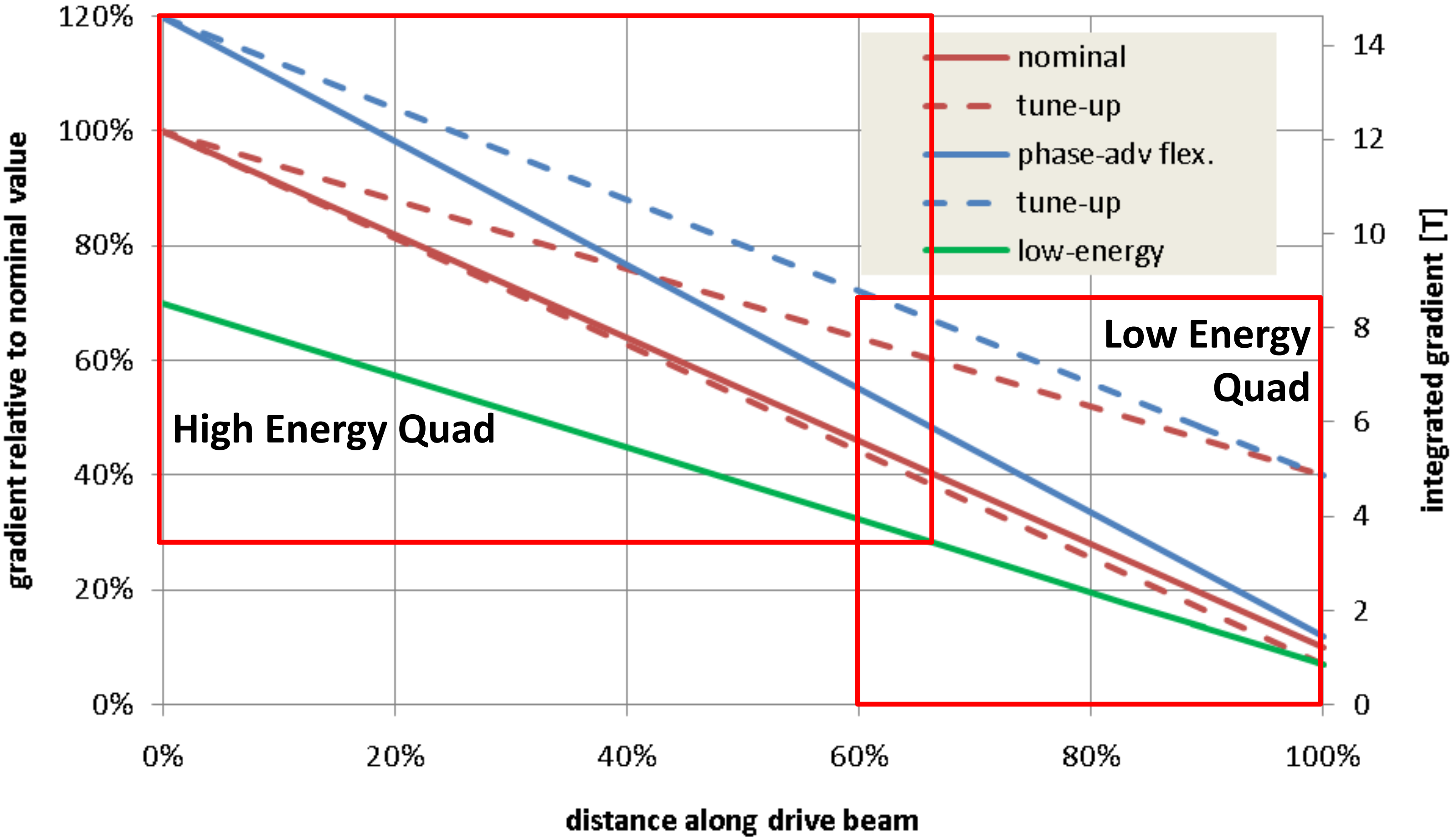
Quadrupole Types



- **High energy quad – Gradient very high**
- **Low energy quad – Very large tuning range**

Jim Clarke

Quadrupole Types



- **High energy quad – Gradient very high**
- **Low energy quad – Very large tuning range**

Jim Clarke

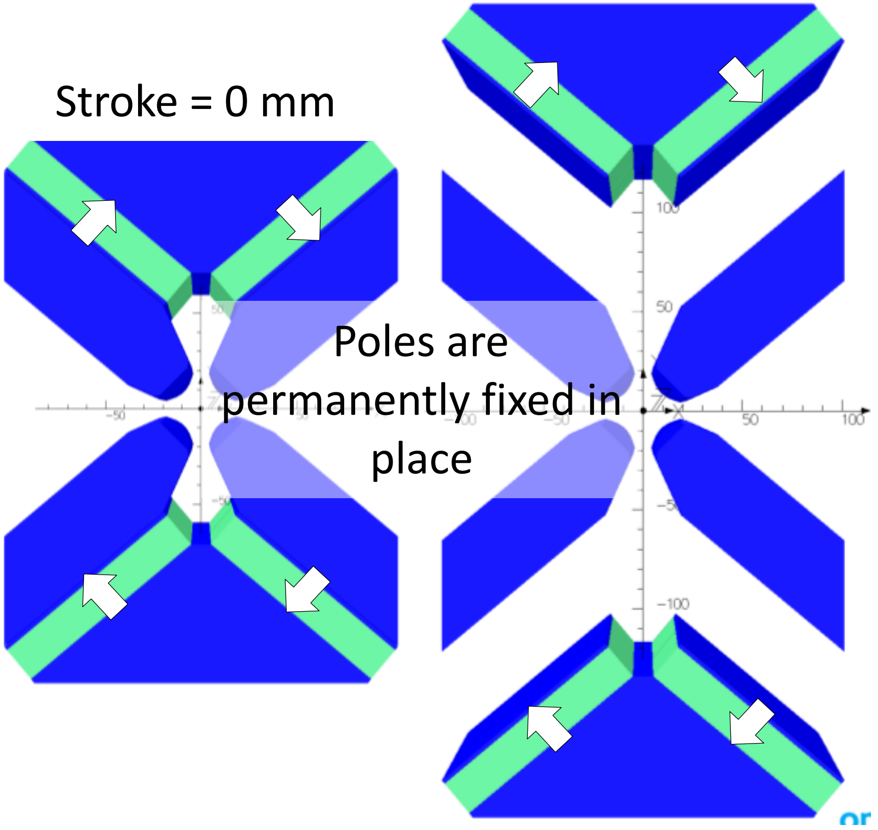
High Energy Quad Design

- **NdFeB** magnets with **B_r = 1.37 T** (VACODYM 764 TP)
- 4 permanent magnet blocks each 18 x 100 x 230 mm

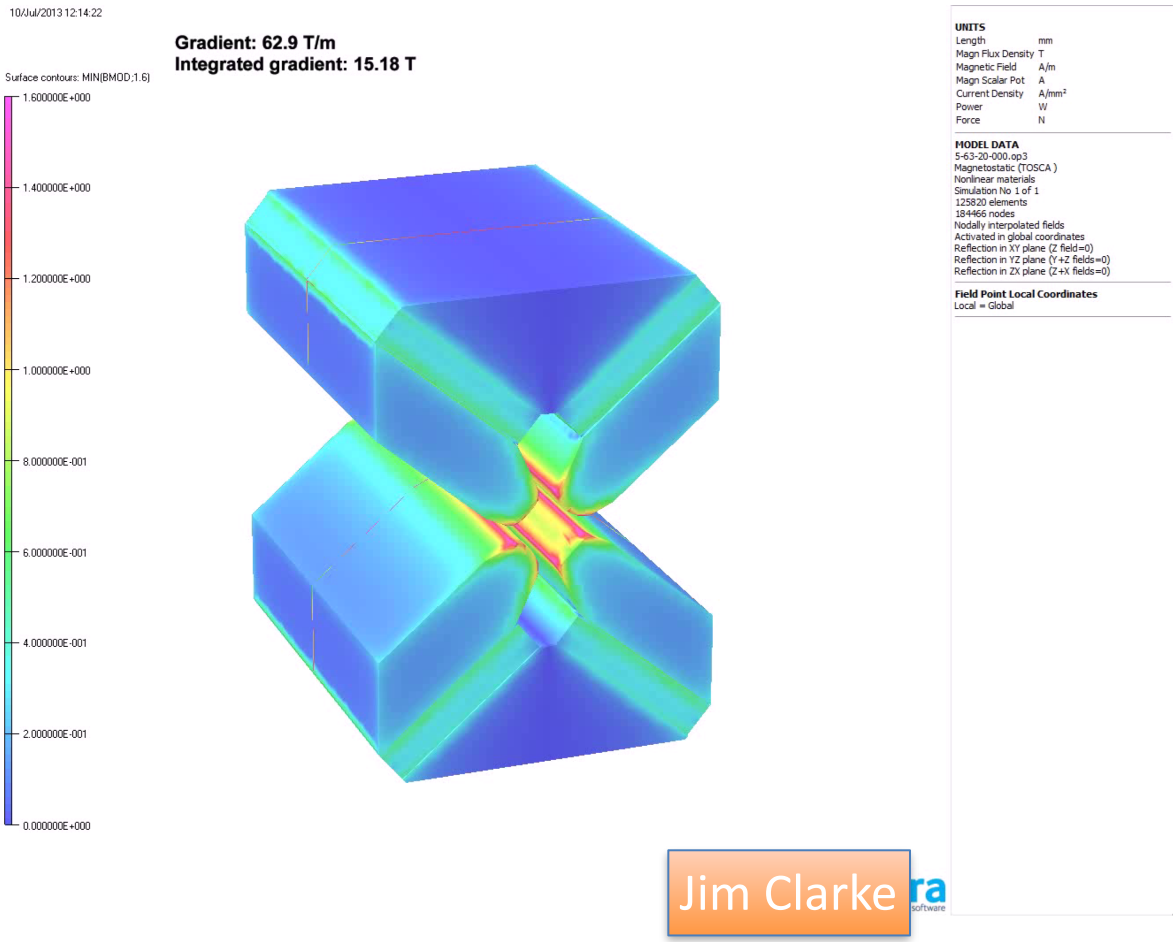
- Max gradient = **60.4 T/m** (stroke = 0 mm)
- Min gradient = **15.0 T/m** (stroke = 64 mm)
- Pole gap = 27.2 mm
- Field quality = ±0.1% over 23 mm

Stroke = 64 mm

Stroke = 0 mm



Poles are permanently fixed in place


10/Jul/2013 12:14:22

Surface contours: MIN(BMOD;1.6)

Gradient: 62.9 T/m
Integrated gradient: 15.18 T

UNITS

Length	mm
Magn Flux Density	T
Magnetic Field	A/m
Magn Scalar Pot	A
Current Density	A/mm²
Power	W
Force	N

MODEL DATA
5-63-20-000.op3
Magnetostatic (TOSCA)
Nonlinear materials
Simulation No 1 of 1
125820 elements
184466 nodes
Nodally interpolated fields
Activated in global coordinates
Reflection in XY plane (Z field=0)
Reflection in YZ plane (Y+Z fields=0)
Reflection in ZX plane (Z+X fields=0)

Field Point Local Coordinates
Local = Global

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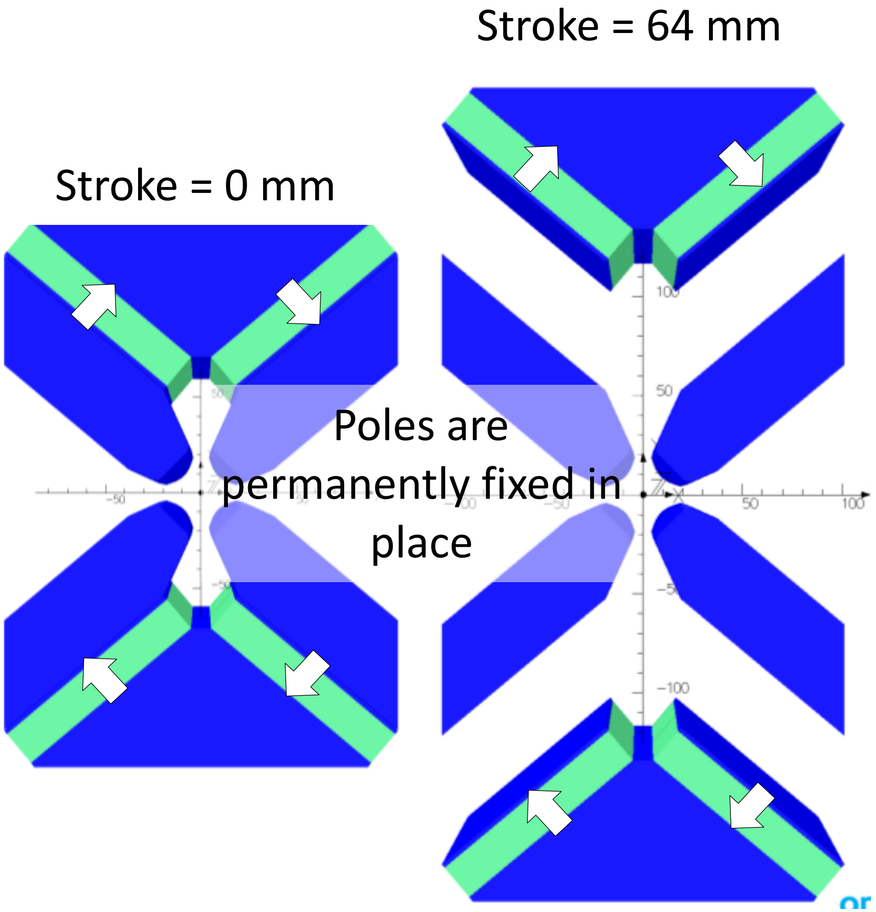
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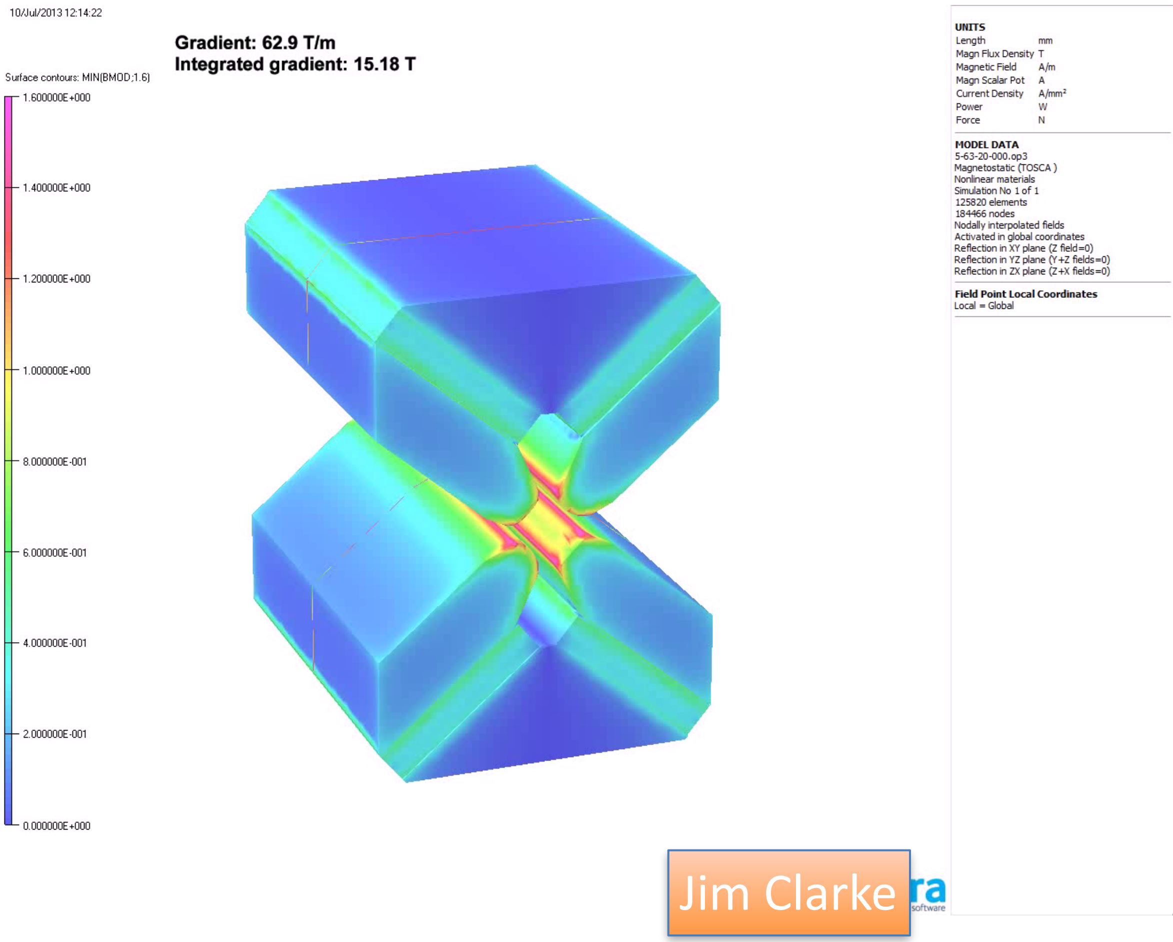
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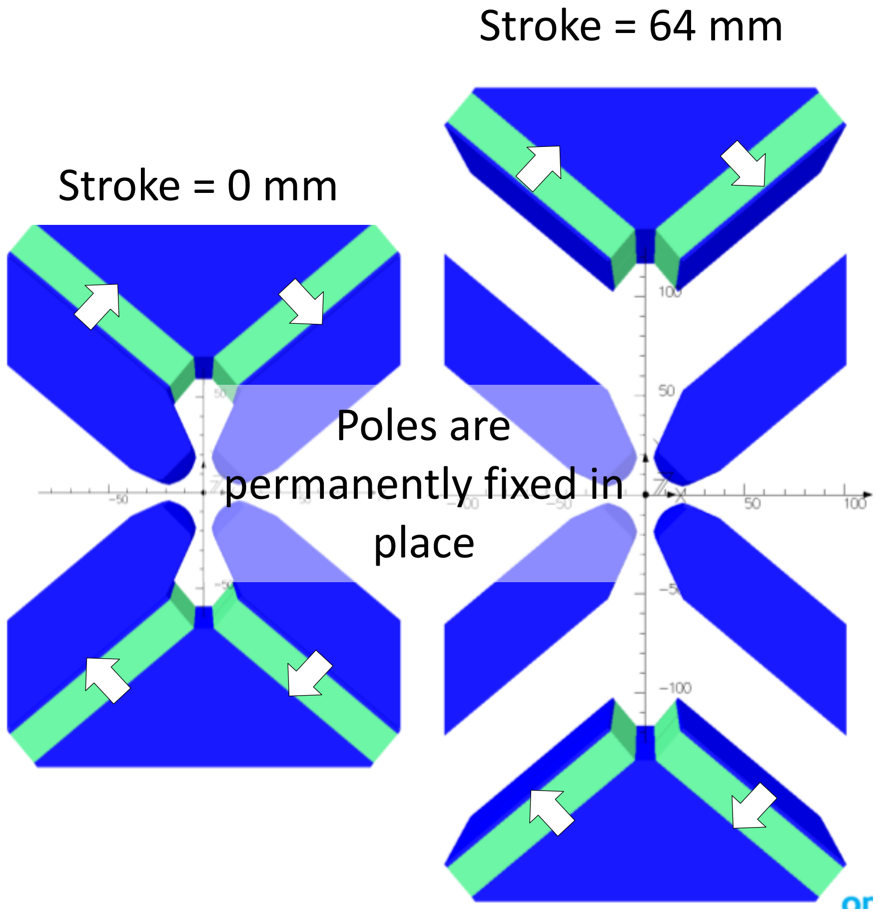
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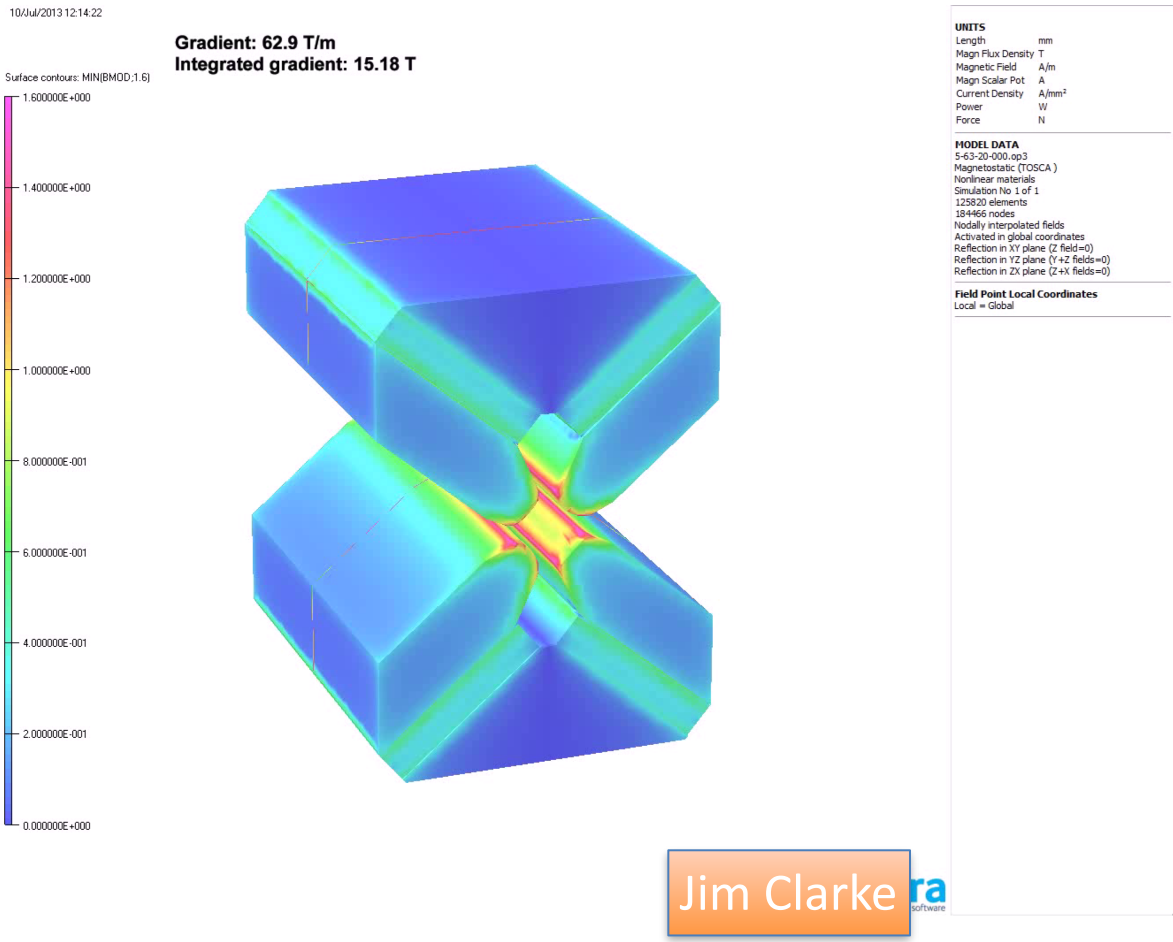
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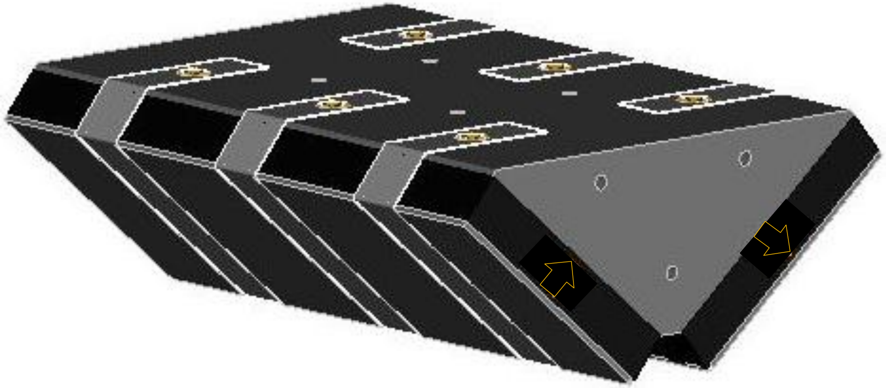
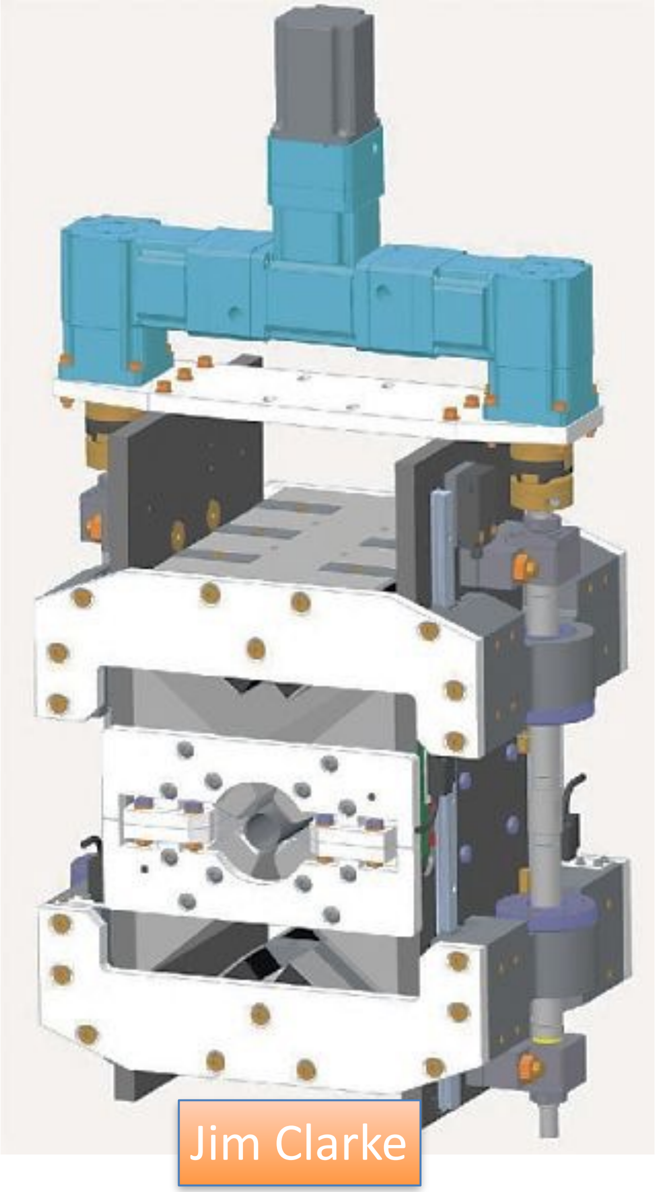
Jim Clarke

Engineering of High Energy Quad

- Single axis motion with one motor and two ballscrews
- Rotary encoder on motor (linear encoders used during setup to check repeatability)
- Maximum force is 16.4 kN per side, reduces by x10 when stroke = 64 mm
- PM blocks bonded to steel bridge piece and protective steel plate also bonded
- Steel straps added as extra security





Jim Clarke

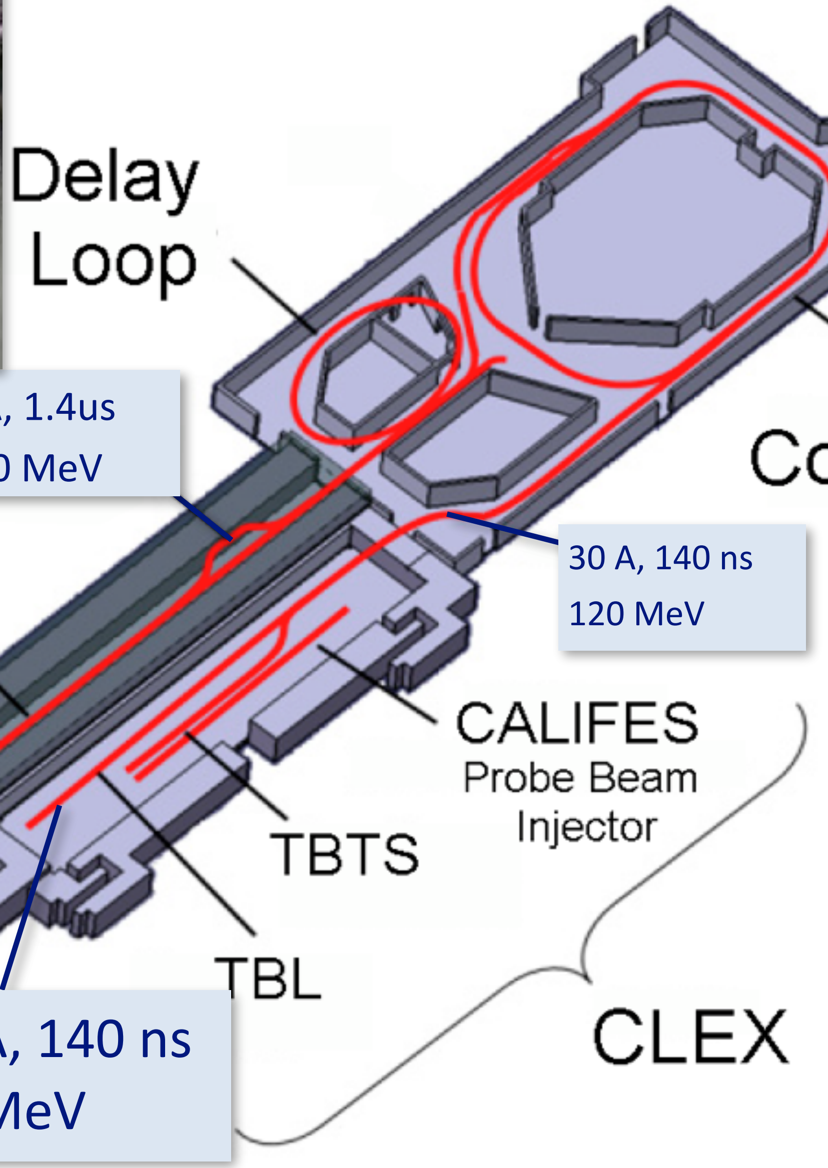
Assembled Prototype

Recently installed 2-beam acceleration module in CTF3
(according to latest CLIC design)

Phil Burrows

CLIC Test Facility

Drive Beam Linac



Delay Loop

4 A, 1.4us
120 MeV

Linac

Combiner Ring

30 A, 140 ns
120 MeV

CALIFES
Probe Beam
Injector

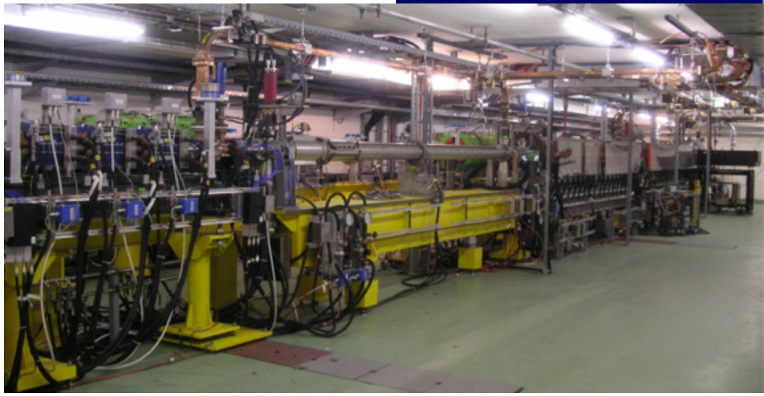
TBTS

TBL

CLEX

30 A, 140 ns
60 MeV

Injector



CALIFES

Probe Beam Linac
CALIFES

Erik Adli

Main achievements of CTF3

Drive beam generation:

•Linac operation (4A) with full beam loading

•Phase-coding of beam with sub-harmonic buncher system

•Factor of ~8 current amplification by beam recombination

•Power extraction from drive beam at 2 x CLIC nominal

Two-beam test stand + TBL:

•2-beam acceleration in CLIC structures up to 1.5 x nominal

•Drive-beam stable deceleration to 35% of initial energy

•12 GHz RF power @ ~ 1 GW in string of 13 decelerators

CALIFES parameters

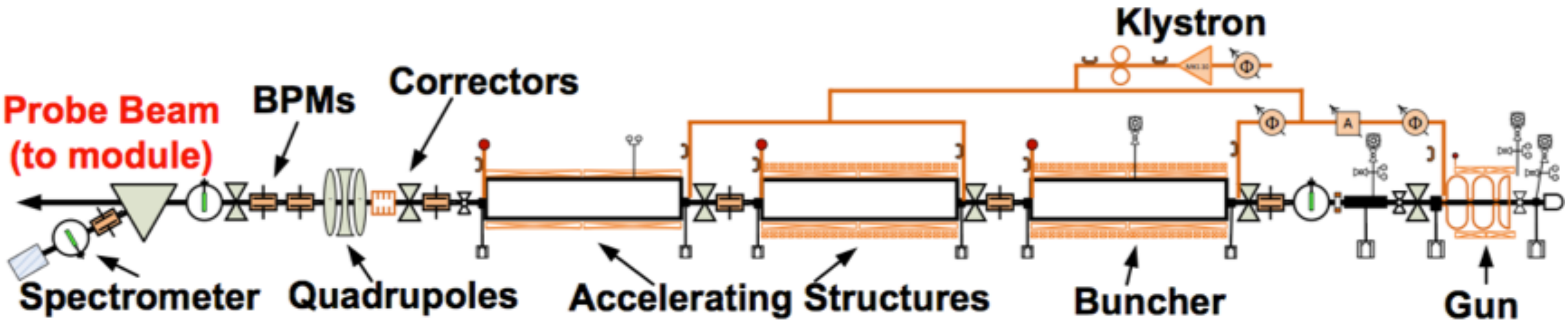
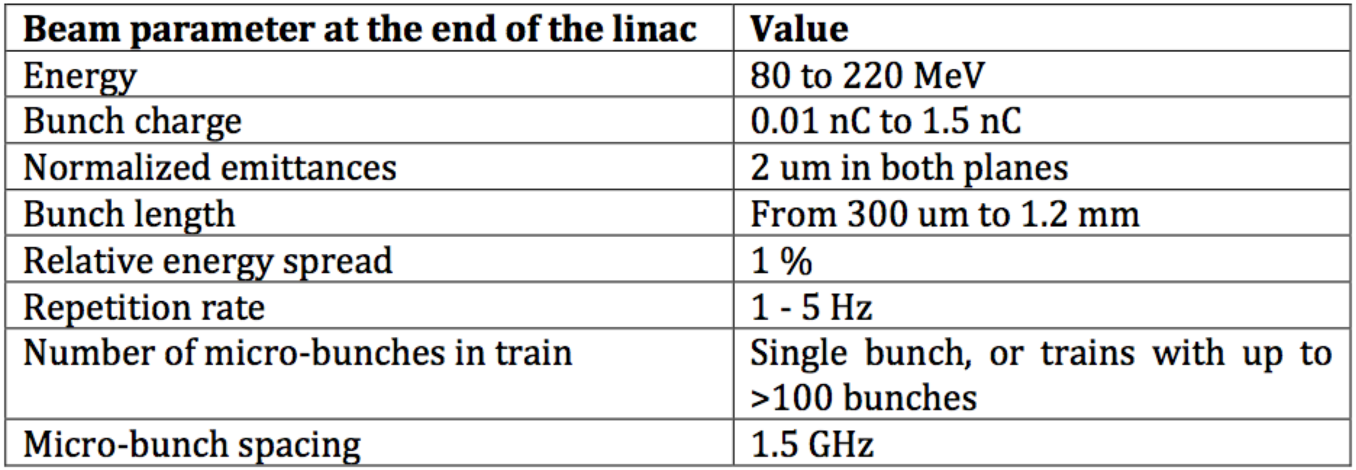


Photo-injector: provides easily adjustable beam parameters, over a large range.



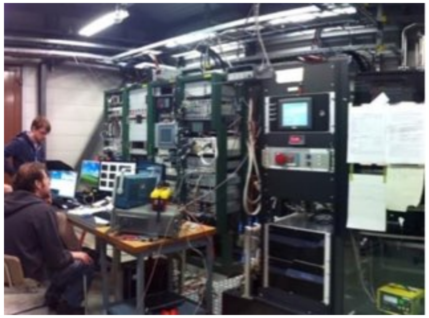
Beam parameter at the end of the linac	Value
Energy	80 to 220 MeV
Bunch charge	0.01 nC to 1.5 nC
Normalized emittances	2 um in both planes
Bunch length	From 300 um to 1.2 mm
Relative energy spread	1 %
Repetition rate	1 - 5 Hz
Number of micro-bunches in train	Single bunch, or trains with up to >100 bunches
Micro-bunch spacing	1.5 GHz

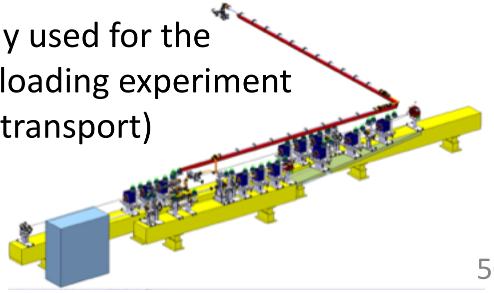
Table 1: CALIFES parameters

Important additional asset: Xbox 1

Provides the possibility of providing 12 GHz RF power to CALIFES X-band components

Erik Adli





Already used for the beam loading experiment (35 m transport)

General motivations to keep CALIFES

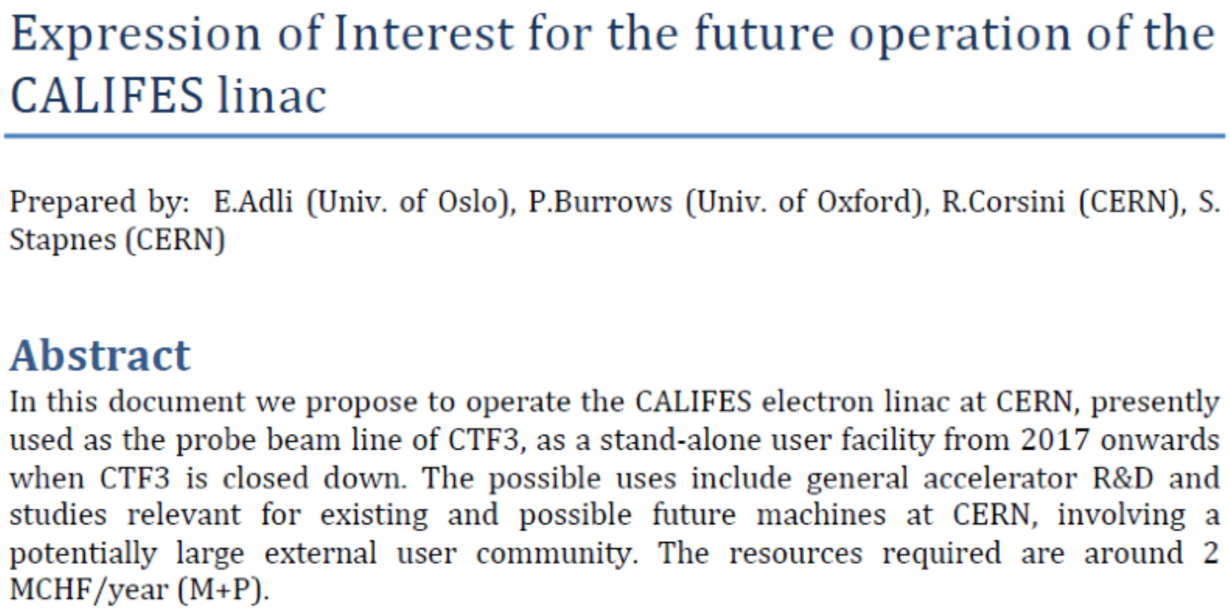
- Post CTF3 there will be **no electron test facility at CERN**, unless operation of CALIFES continues. We believe that **maintaining electron beam expertise at CERN** is important **to push high gradient research**, and to ensure **CERN remains a plausible alternative for the next lepton collider at the energy frontier**

- **Very few electron beam lines worldwide are available for advanced R&D.** The number of available electron beam test facilities world wide is decreasing. **NLCTA at SLAC shut down last year. FACET this April**. The long term future of ATF2 is not clear.

- **Educational aspects** : educating the next generation of accelerator physicist is an important task for CERN. Based on the experience from the CTF3/CLIC collaboration (**~70 accelerator students**), a large number of students and researchers from external institutes may get hands-on expertise with electron beam operation if CALIFES remains operational

Erik Adli

Proposal of a CALIFES-based Accelerator Test Stand

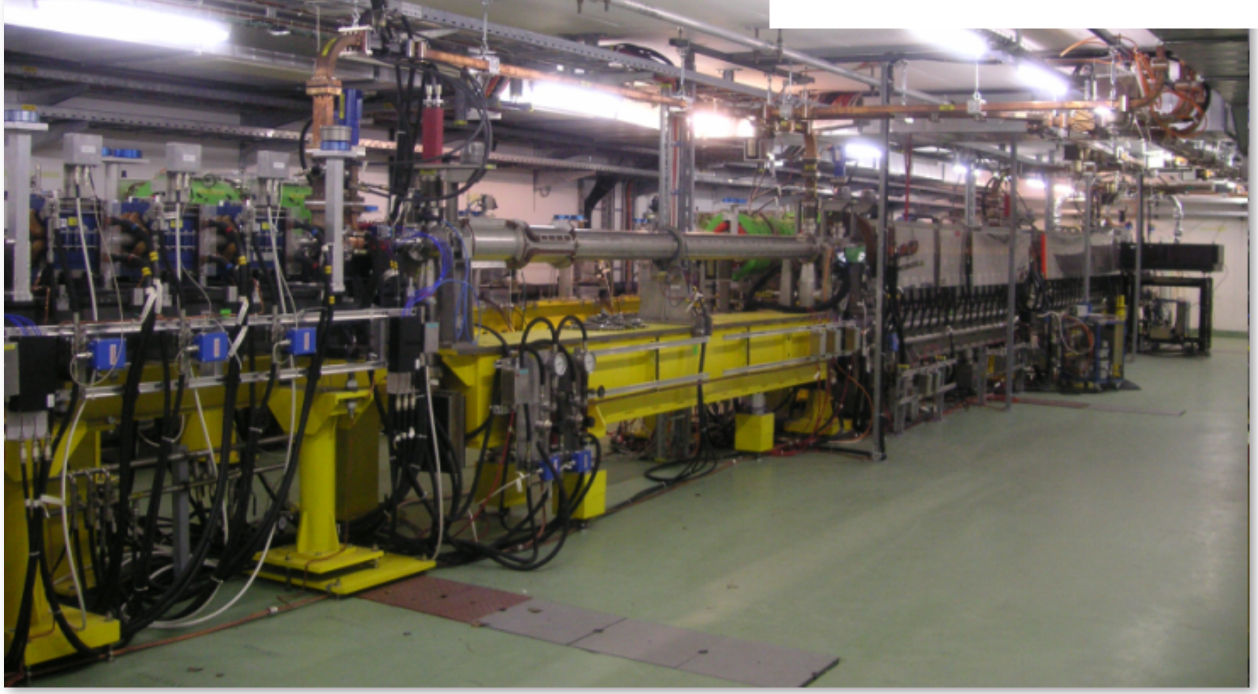


Expression of Interest for the future operation of the CALIFES linac

Prepared by: E.Adli (Univ. of Oslo), P.Burrows (Univ. of Oxford), R.Corsini (CERN), S. Stapnes (CERN)

Abstract

In this document we propose to operate the CALIFES electron linac at CERN, presently used as the probe beam line of CTF3, as a stand-alone user facility from 2017 onwards when CTF3 is closed down. The possible uses include general accelerator R&D and studies relevant for existing and possible future machines at CERN, involving a potentially large external user community. The resources required are around 2 MCHF/year (M+P).



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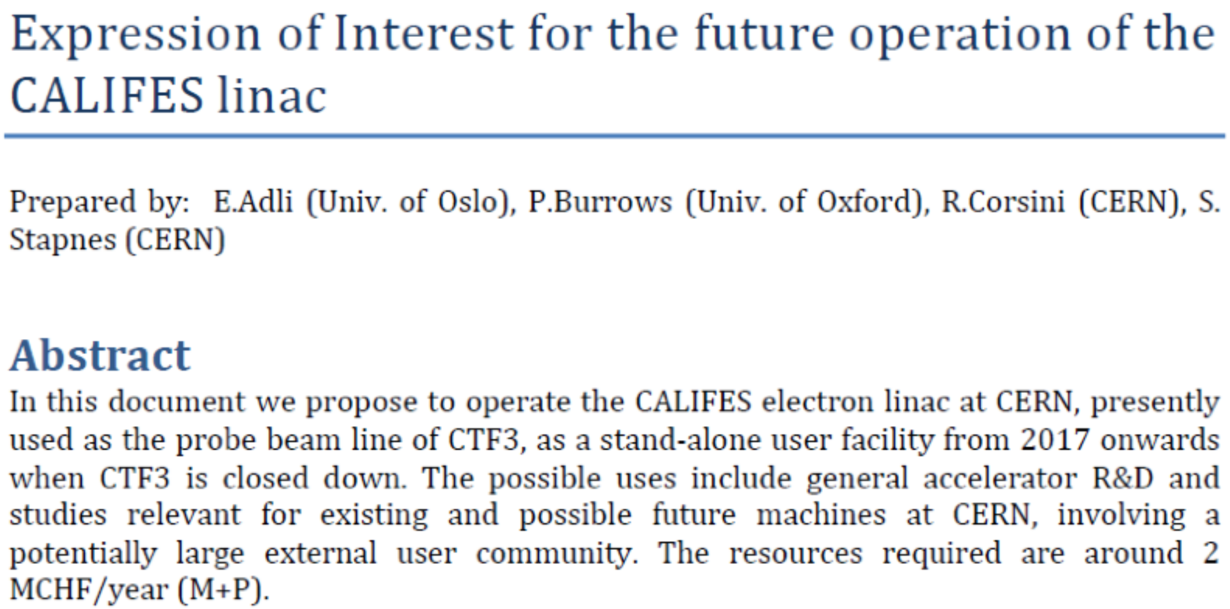

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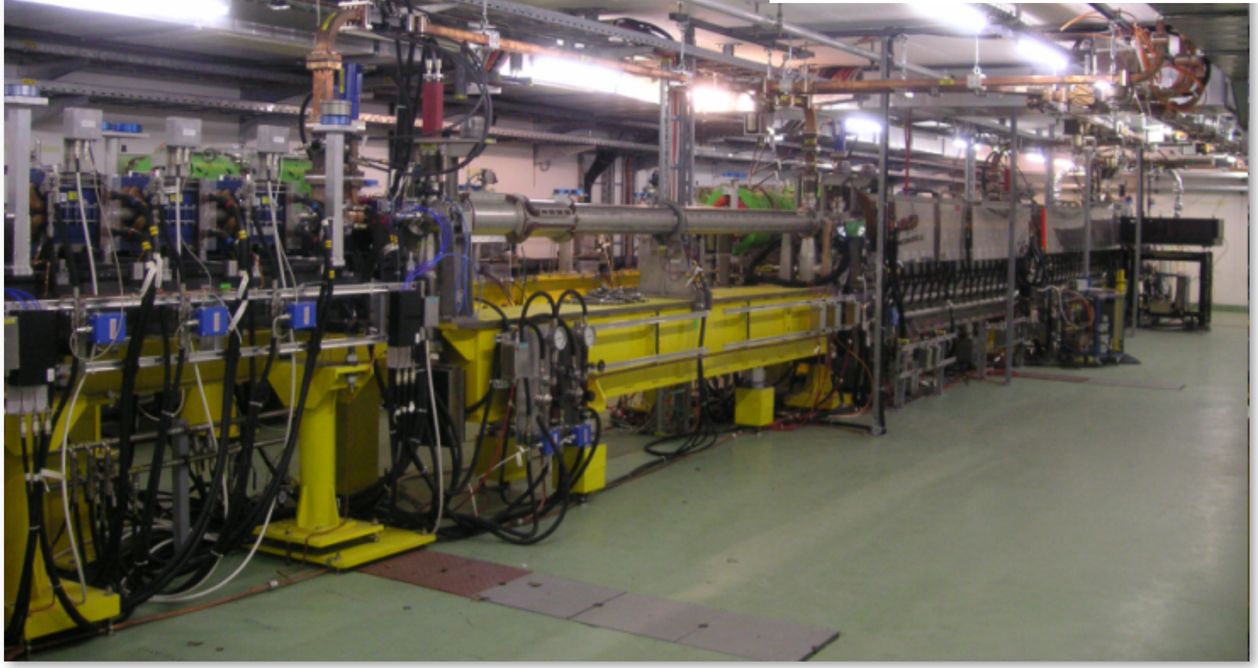

CATS

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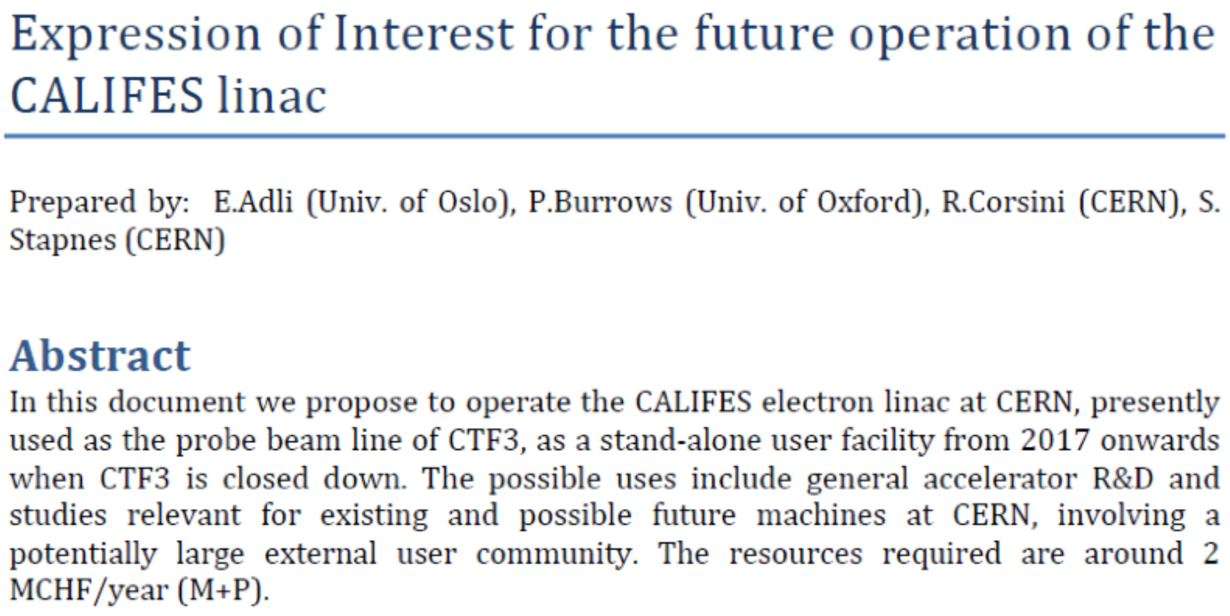

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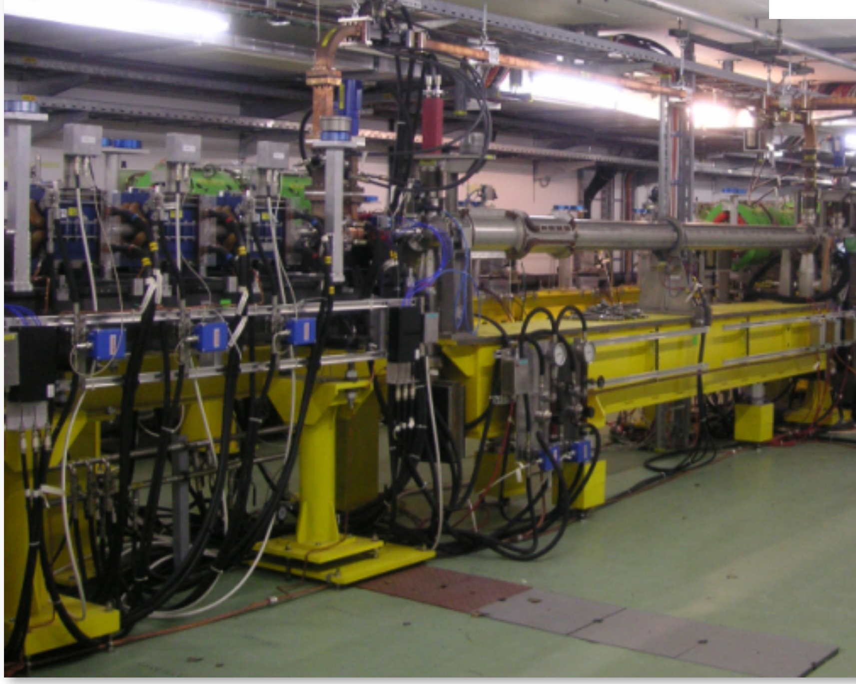
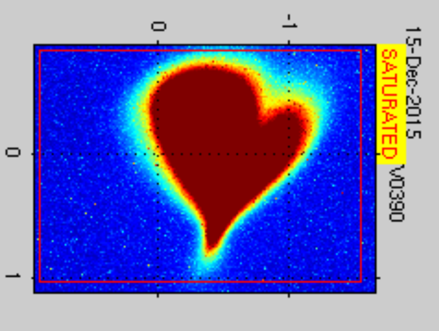
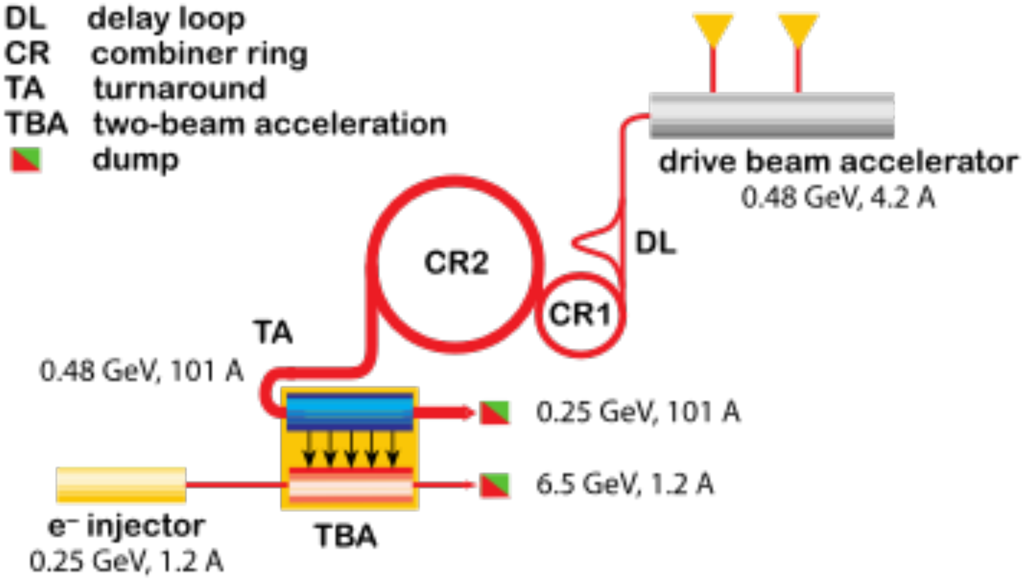




CATS

The CLIC Zero issue

- CLIC Zero was proposed in the past as part of the post-CDR phase. Motivations:
  - Focus to develop main components to large scale
  - Needed for modules qualification tests
  - Gain experience/time in operation of full scale drive beam complex
  - Full-scale system test for Two-Beam



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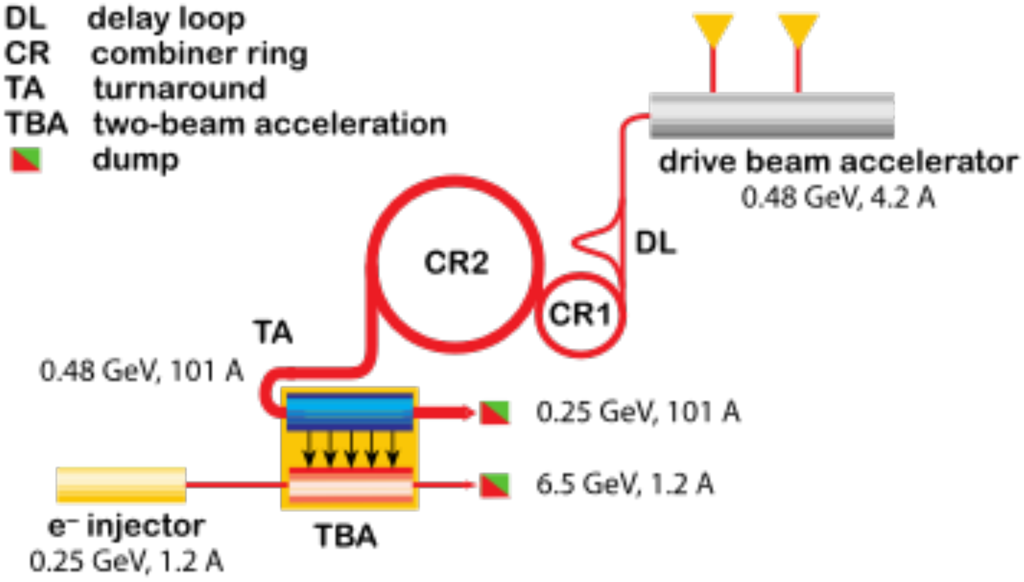

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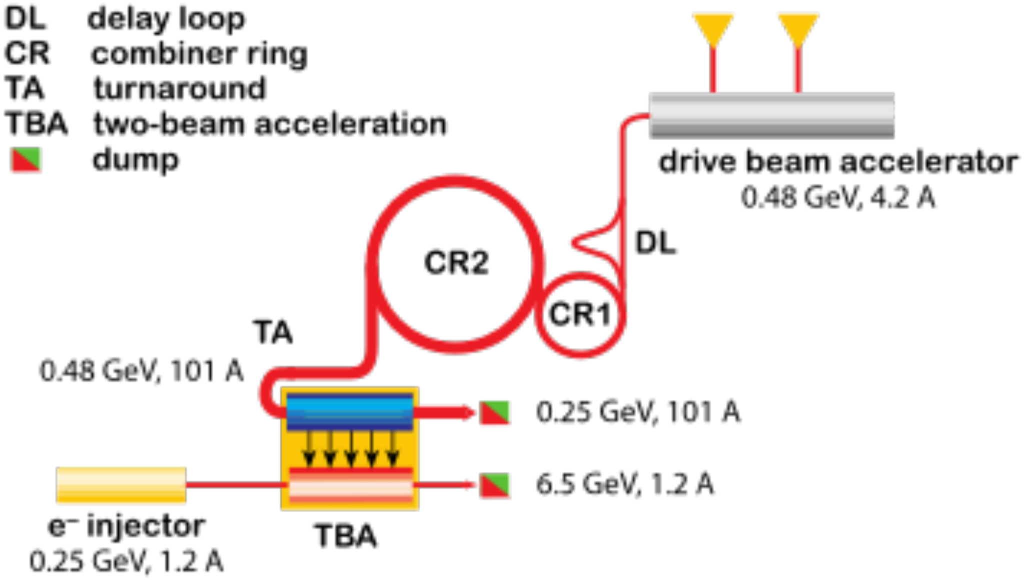
- Will need a serious commitment towards CLIC

- May CLIC Zero be integrated in early construction stage?
- Were will we test modules?
- What kind of facility will we need if we choose the klystron option?



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- However, we should soon define a decision point, in order to not duplicate efforts in a period were investment will have to go up

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- However, we should soon define a decision point, in order to not duplicate efforts in a period were investment will have to go up

- Will we have a decision already before 2020?
- Should we present two alternative plans for the next phase?

Summary

In case CLIC would be selected as the preferred option for CERN:

- Detailed sub-system R&D will continue in many areas
- To be complemented with:
    - Significant increase in engineering activities
    - System-level prototypes and tests

Such a next phase will require:

- Significantly more resources
- Significantly increased collaboration involvement
    - => Adaptation in the collaboration structure (less light-weight)

In case CLIC would not be chosen:

- Generic R&D needs to be preserved and resources secured
- Resources may be in danger if we do not prepare for the situation

Lucie

Social

Thank you for your attention!

Back-up

CLIC detector and physics (CLICdp)

Australia	Australian Collaboration for Accelerator Science (ACAS), University of Melbourne
Belarus	National Scientific and Educational Centre of Particle and High Energy Physics (NC-PHEP), Belarusian State University, Minsk
Chile	Pontificia Universidad Católica de Chile, Santiago
Czech Republic	Institute of Physics of the Academy of Sciences of the Czech Republic, Prague
Denmark	Department of Physics and Astronomy, Aarhus University
France	Laboratoire d'Annecy-le-Vieux de Physique des Particules (LAPP), Annecy
Germany	Karlsruher Institut für Technologie (KIT), Institut für Prozessdatenverarbeitung und Elektronik (IPE), Karlsruhe
Germany	Max-Planck-Institut für Physik, Munich
Israel	Department of Physics, Faculty of Exact Sciences, Tel Aviv University
Norway	Department of Physics and Technology, University of Bergen
Poland	The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Cracow
Poland	Faculty of Physics and Applied Computer Science, AGH University of Science and Technology, Cracow
Poland	University of Warsaw
Romania	Institute of Space Science, Bucharest-Magurele
Russia	JINR, Dubna ●
Serbia	Vinca Institute for Nuclear Sciences, Belgrade
Spain	Spanish Network for Future Linear Colliders
Switzerland	CERN
Switzerland	Département de Physics Nucléaire et Corpusculaire (DPNC), Geneva
United Kingdom	The School of Physics and Astronomy, University of Birmingham
United Kingdom	University of Bristol
United Kingdom	University of Cambridge
United Kingdom	University of Glasgow
United Kingdom	The Department of Physics of the University of Liverpool
United Kingdom	Oxford University
USA	Argonne National Laboratory, High Energy Physics Division
USA	University of Michigan, Physics Department

27 institutes from **17 countries**

http://clicdp.web.cern.ch/

● JINR Dubna joined in December 2015