CLIC overview & synergies with circular machines

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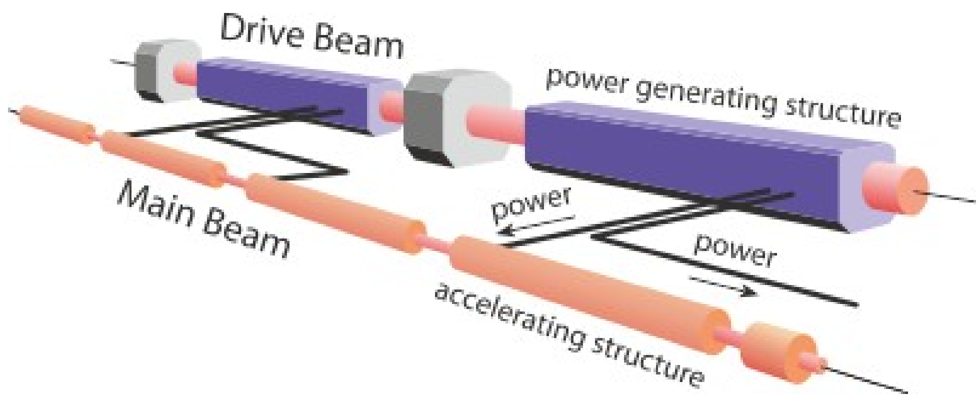
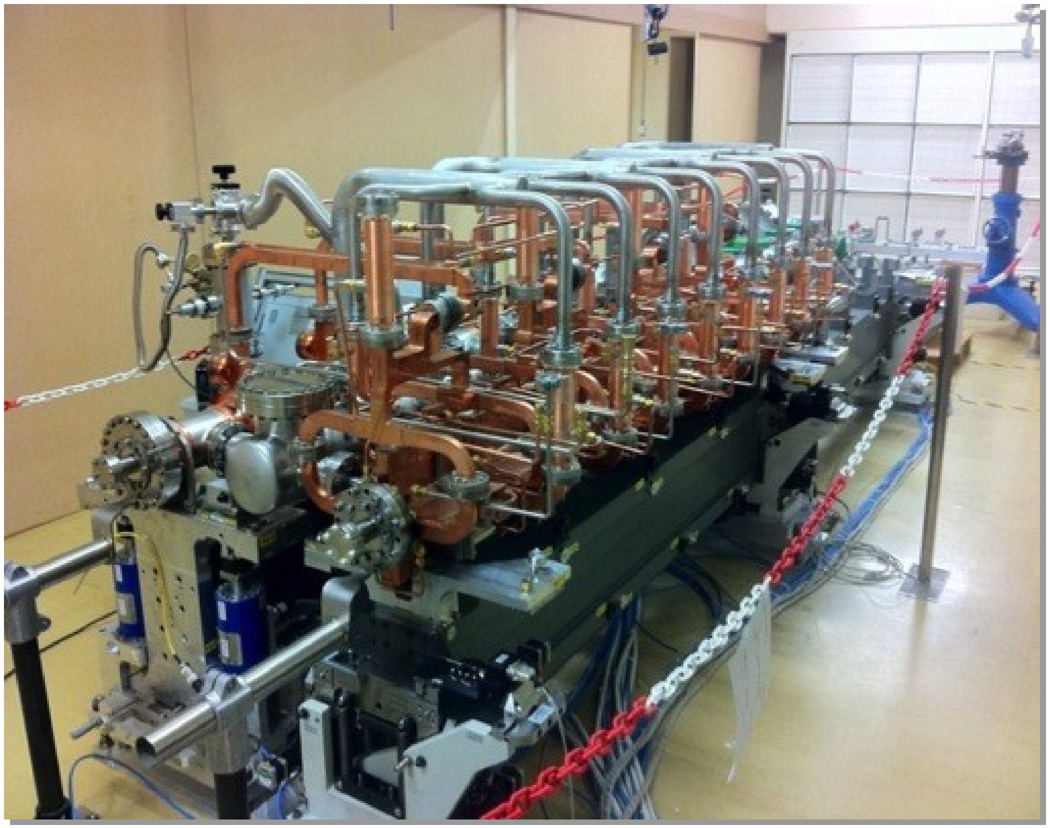
for the CLIC detector & physics group

FCC-ee workshop, Scuola Normale Superiore, Pisa, feb 2015

The Compact Linear Collider

CLIC two-beam acceleration is currently the only mature scheme to build a multi-TeV lepton collider...





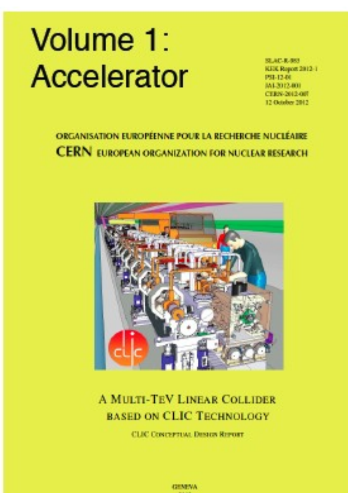
… unique role in the

lepton collider landscape

History

A few dates:

- 1980-ies: => start of (a modest) CLIC accelerator R&D
- 2004: Strengthening of CLIC accelerator R&D and start of CLIC/CTF3 collab.
- 2008: New start of Detector and Physics studies for CLIC
  - In close collaboration with ILC
  - Using ILC detectors (ILC, SiD) as a starting point
- 2012: **CLIC Conceptual Design Report** published
- 2012: CLIC detector and physics collaboration (**CLICdp**) was set up
- 2012/2013: CLIC input to the European strategy and to USA Snowmass



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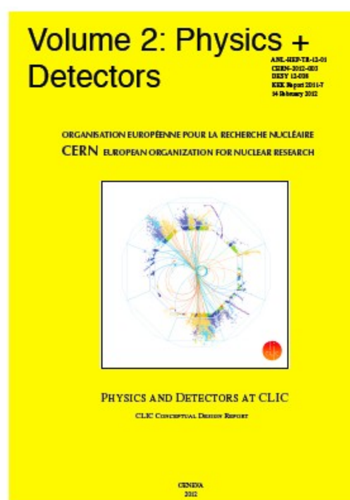

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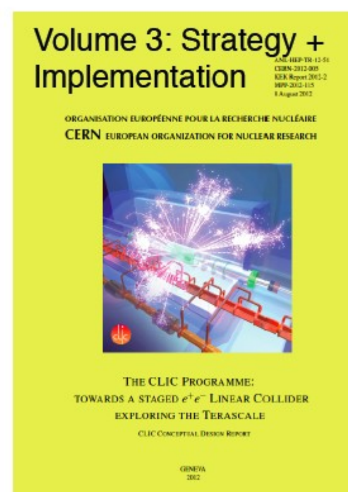

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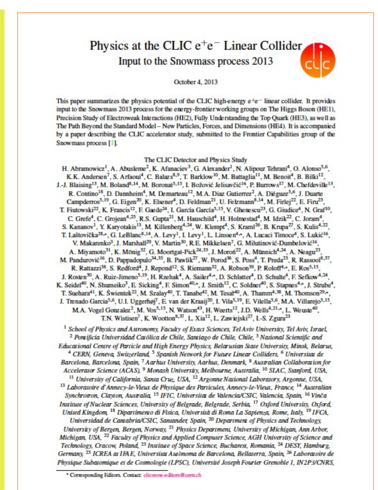

Physics at the CLIC e^+e^- Linear Collider
Input to the Snowmass process 2013

October 4, 2013

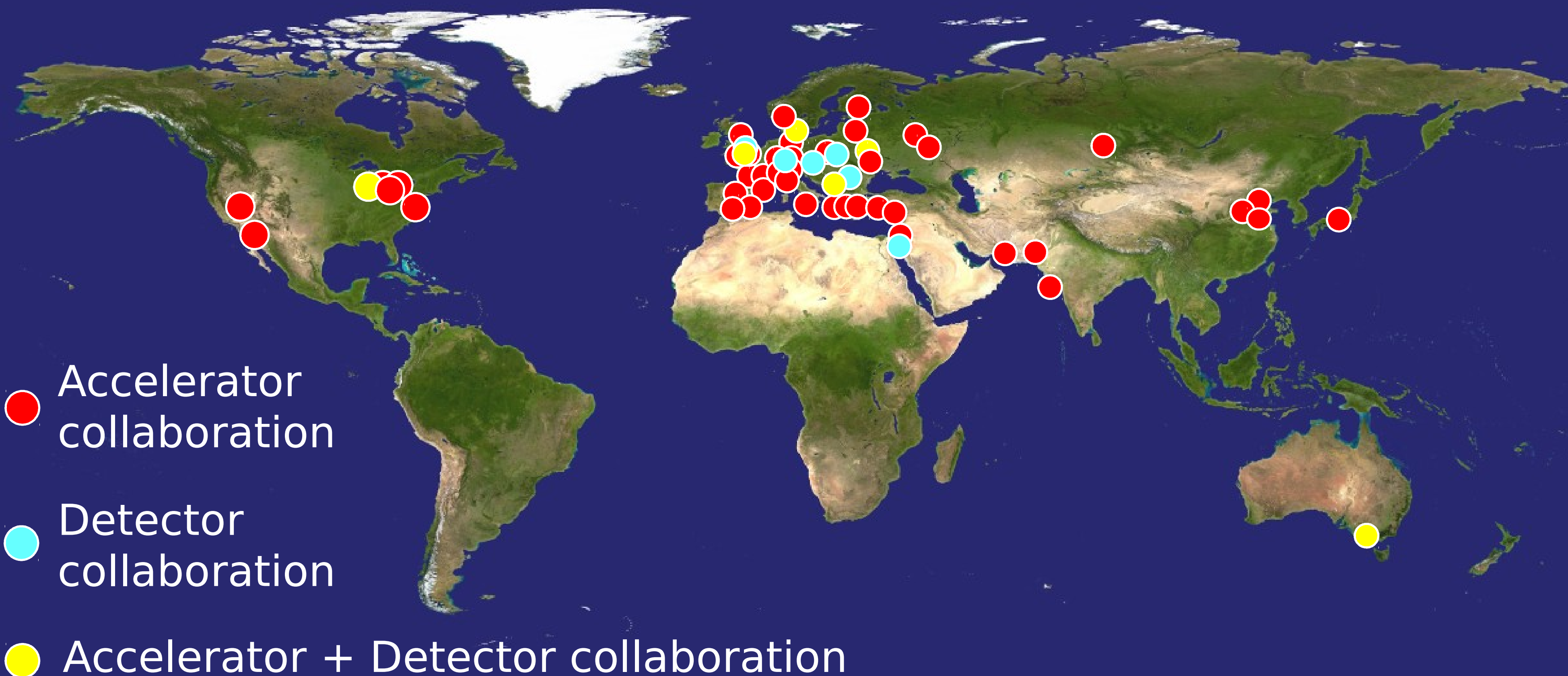
This paper summarizes the physics potential of the CLIC high-energy e^+e^- linear collider. It provides input to the Snowmass 2013 process for the energy-frontier working groups on The Higgs Boson (HE1), Precision Study of Electroweak Interactions (HE2), Fully Understanding the Top Quark (HE3), as well as The Path Beyond the Standard Model – New Particles, Forces, and Dimensions (HE4). It is accompanied by a paper describing the CLIC accelerator study, submitted to the Frontier Capabilities group of the Snowmass process [1].

The CLIC Detector and Physics Study

arXiv:1307.5288

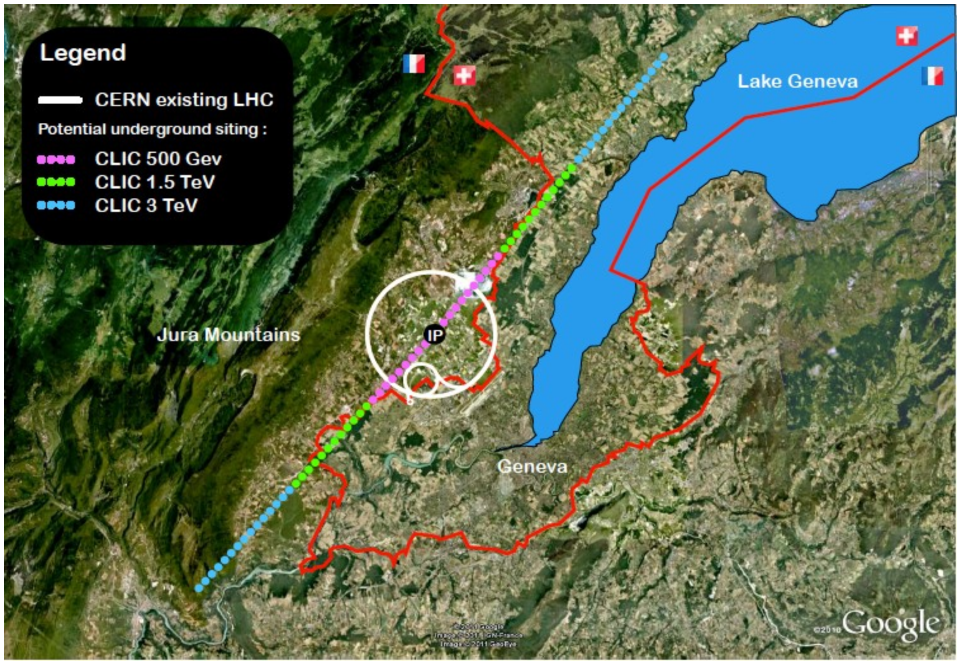
CLIC Collaboration

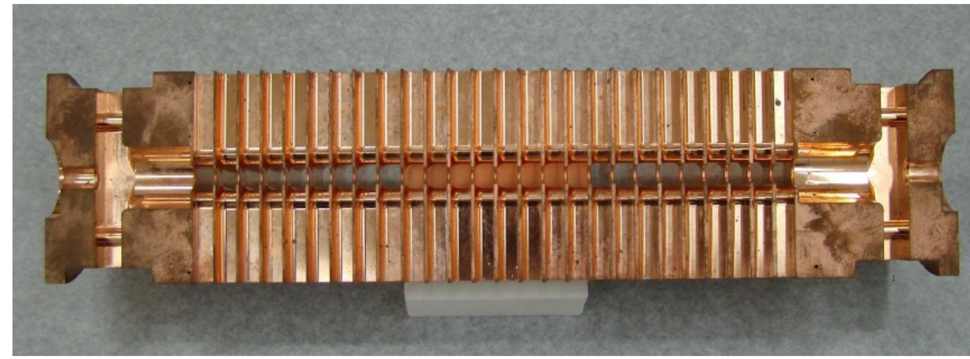
29 Countries – over 70 Institutes

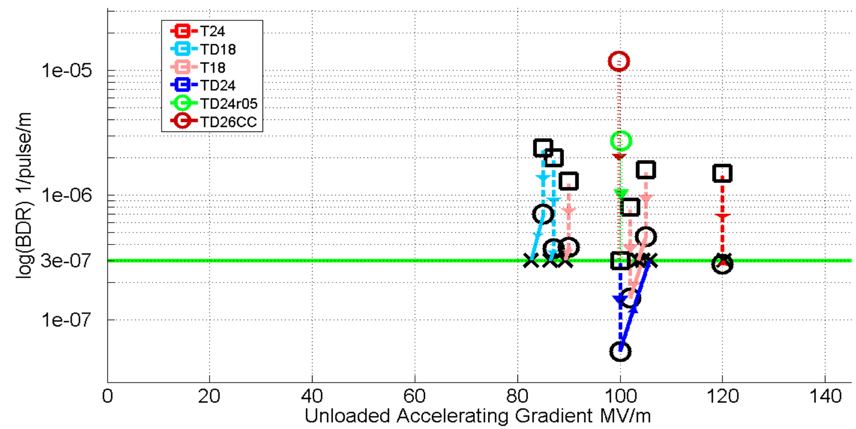


7 (2) new collaboration partners joined in 2013 (2014)

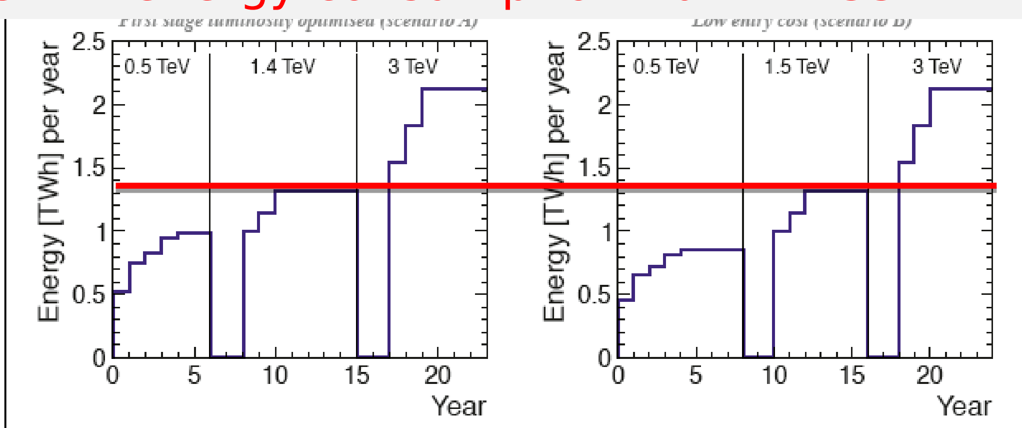
CLIC accelerator studies







CERN energy consumption 2012: 1.35 TWh

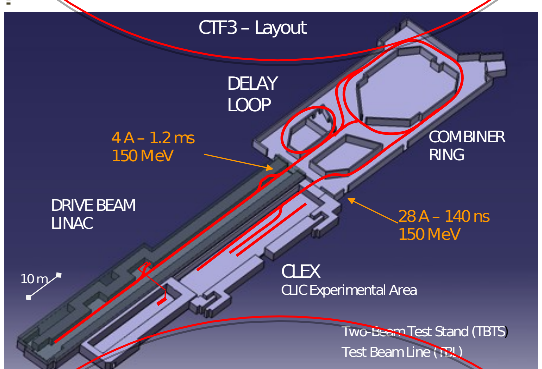


A lot of acccelerator R&D work on accelerating structures (CTF3) and final focus (ATF2)
Siting & geology, cost estimates, power consumption studies...

Schedule (S. Stapnes, Sep 2014)

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.



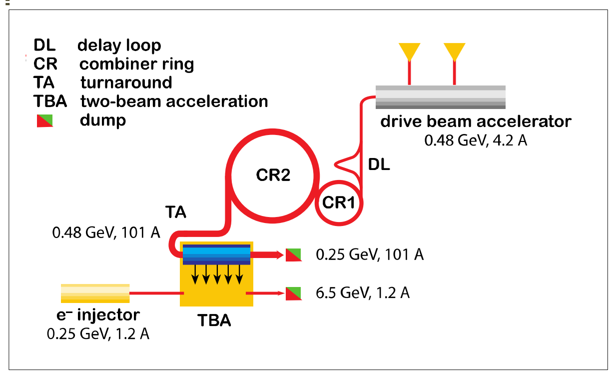
2018-19 Decisions

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.



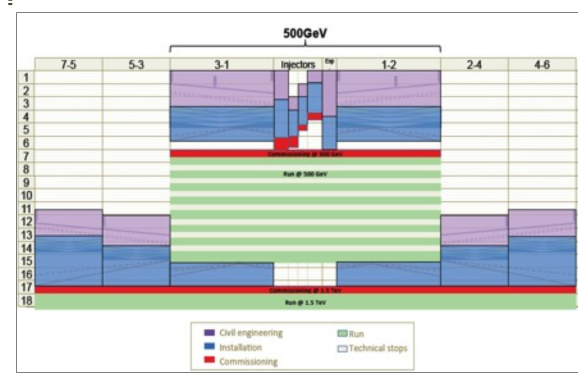
2024-25 Construction Start

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.

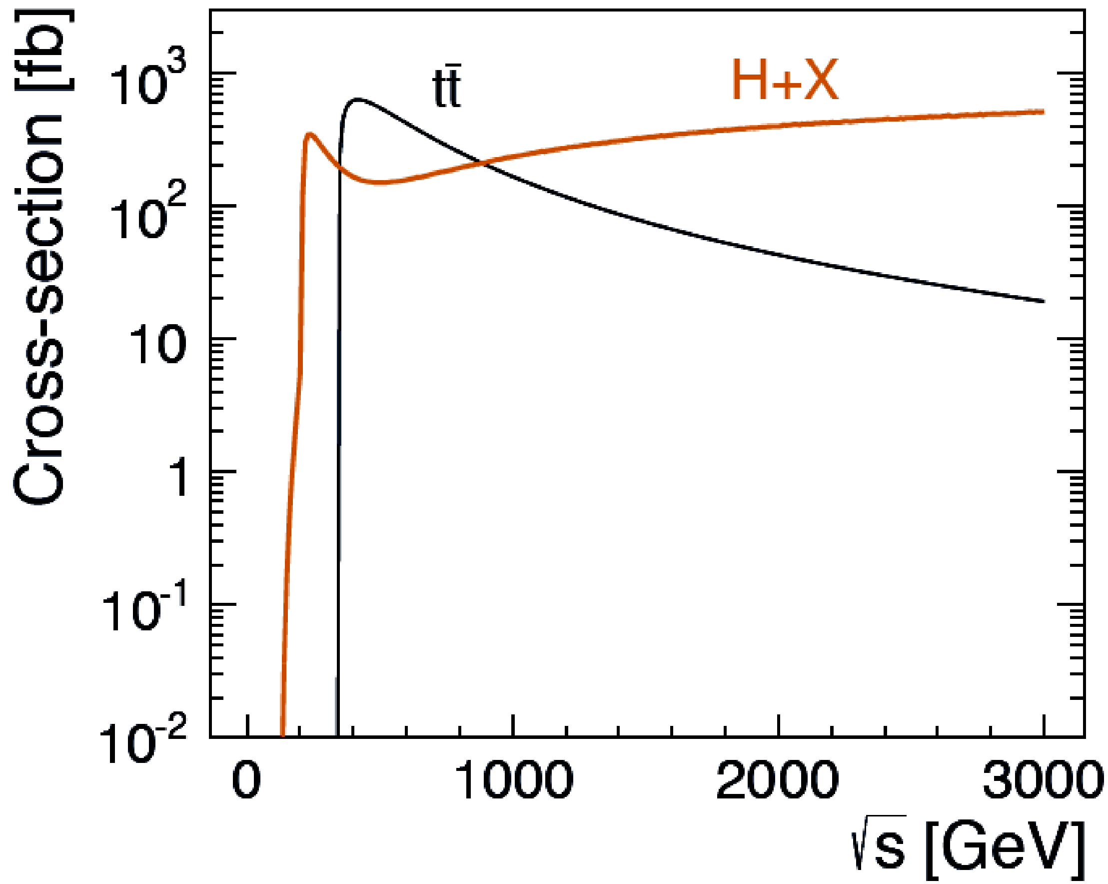
CLIC detector & physics

25 institutes in a light-weight collaboration structure

Physics programme

CLIC has a “guaranteed programme” based on known processes:
→ precise couplings and properties of Z, W, H, t

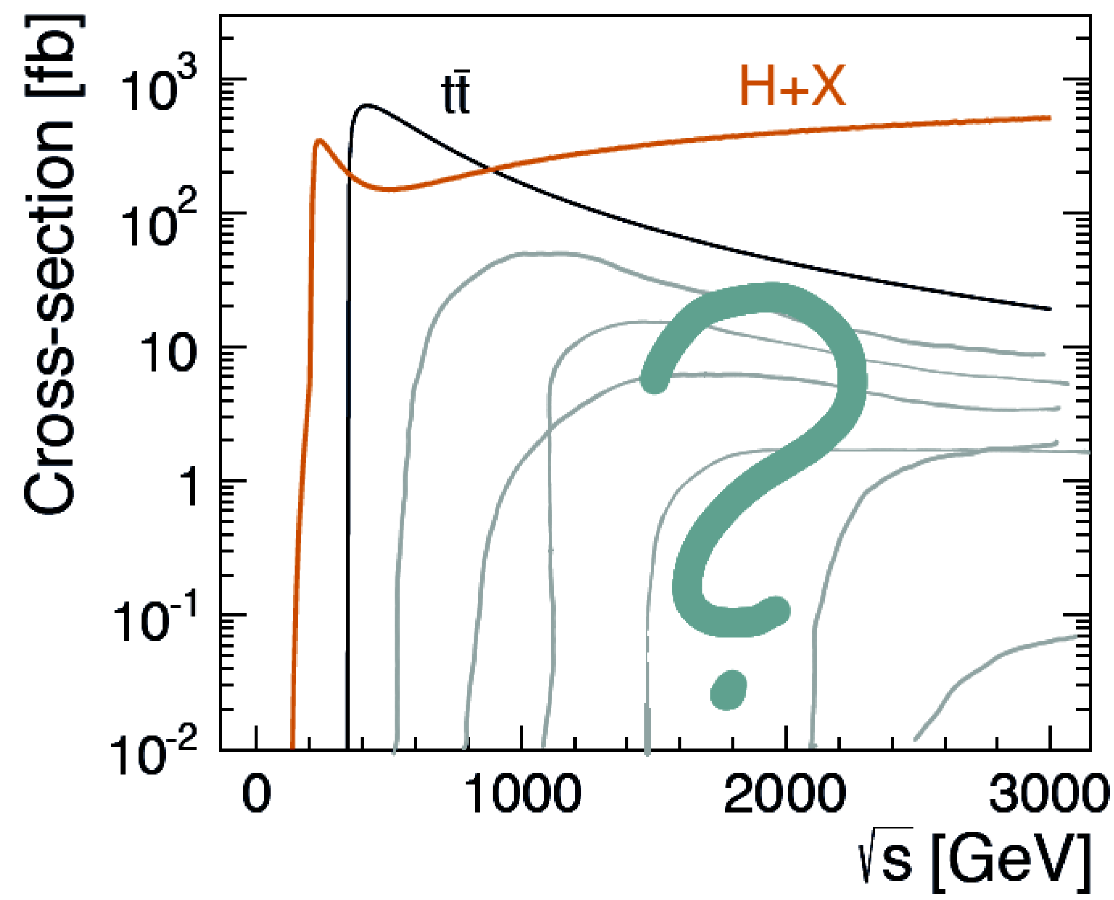
Superior energy reach makes for a unique CLIC potential:
- Higgs self coupling
- top quark dipole moments
- vector boson physics



Physics programme

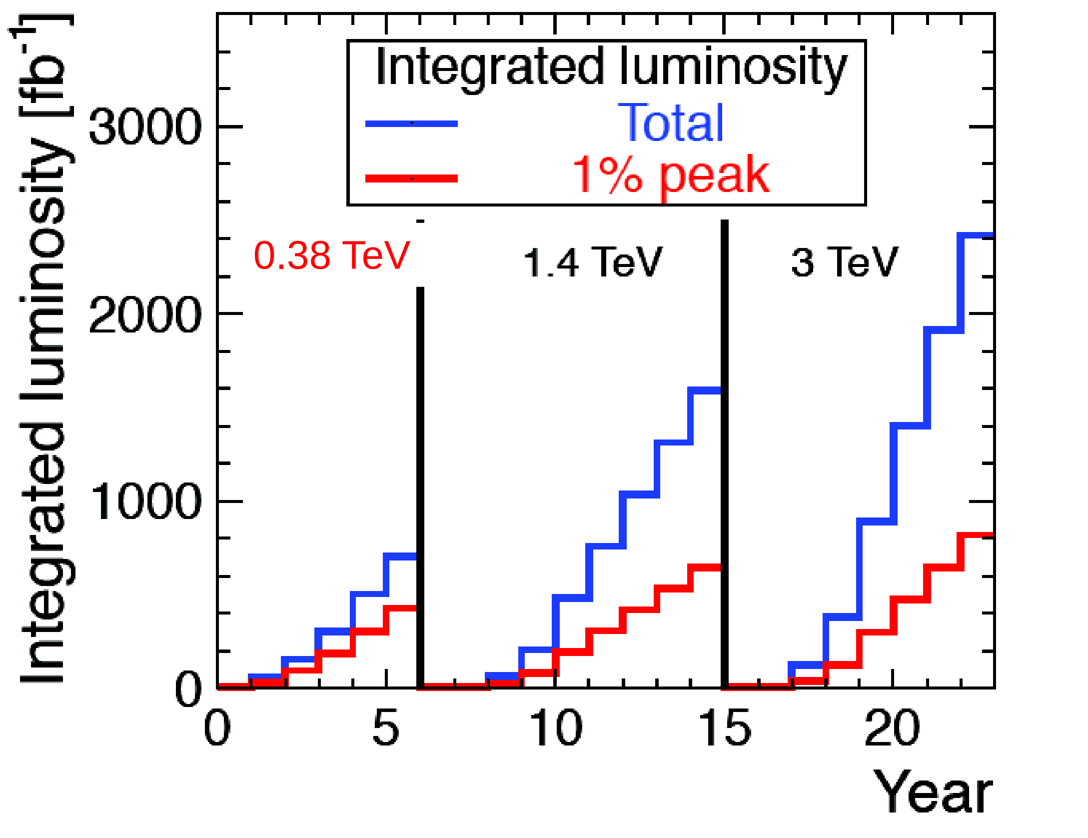
R&D for the unexpected:
Guaranteed programme +
new physics

Direct production of new particles with mass up to √s/2
New physics spectroscopy
Maximize indirect reach of lepton colliders

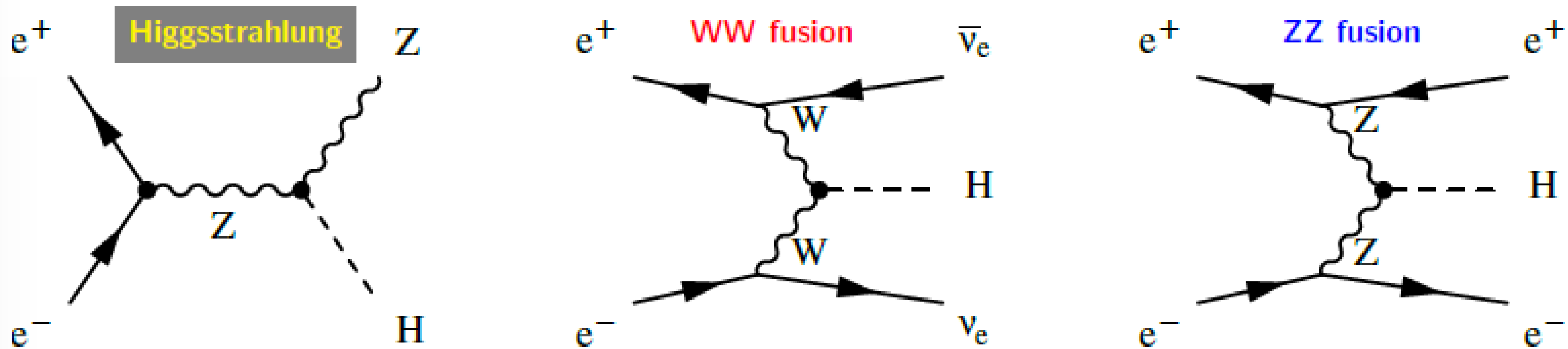


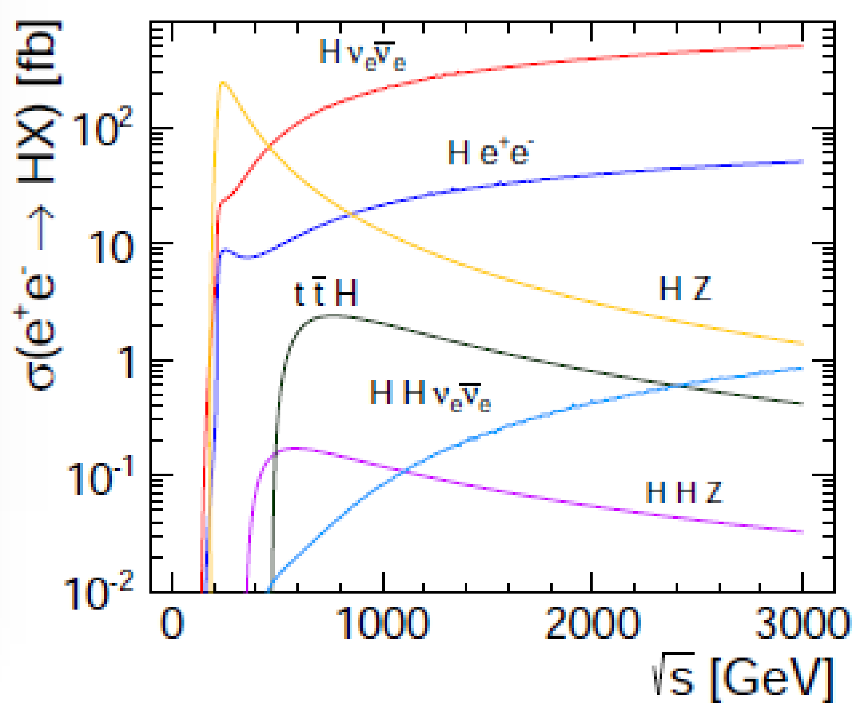
A tentative programme

Based solely on known processes, CLIC envisages a programme that starts at relatively low energy (few 100 GeV), and quickly ramps up to ultimate reach



Higgs physics at CLIC (1)



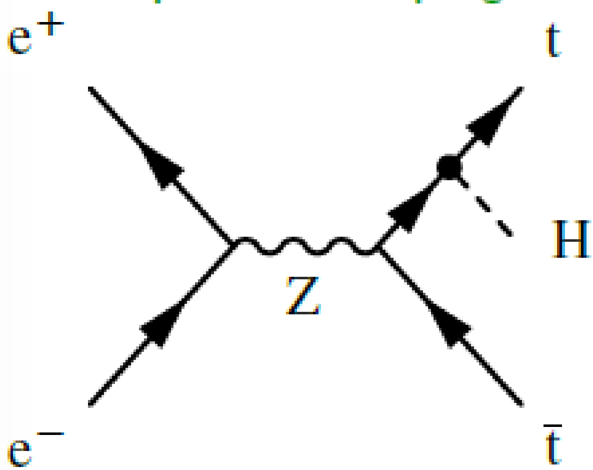


	350 GeV	1.4 TeV	3 TeV
L_{int}	500 fb^{-1}	1.5 ab^{-1}	2 ab^{-1}
# ZH events	68 000	20 000	11 000
# $H\nu_e\bar{\nu}_e$ events	17 000	370 000	830 000
# He^+e^- events	3 700	37 000	84 000

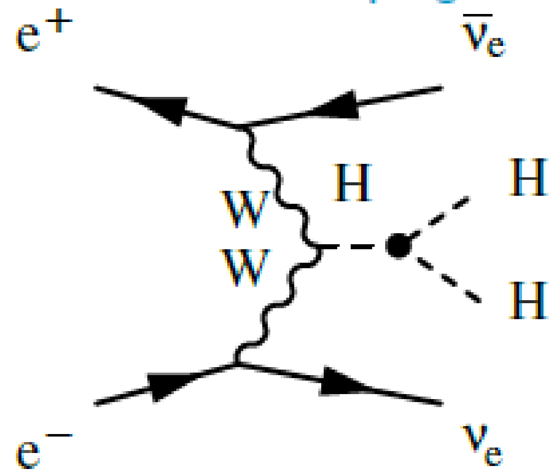
- Large samples of Higgs bosons achievable at CLIC without beam polarisation
- 80 % e^- polarisation foreseen at CLIC
  $\to$ 12 % more HZ and He^+e^- events
  $\to$ 80 % more $H\nu_e\bar{\nu}_e$ events

Higgs physics at CLIC (2)

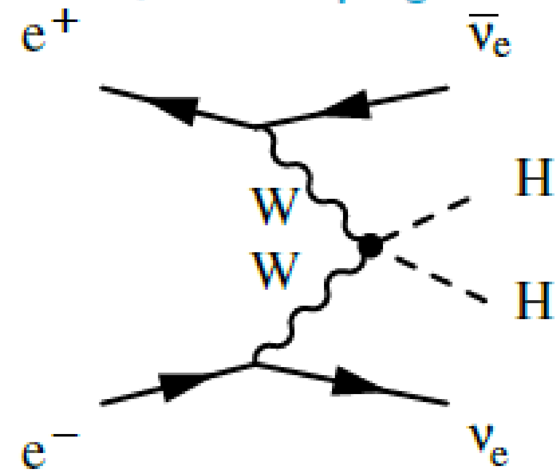
Top Yukawa coupling

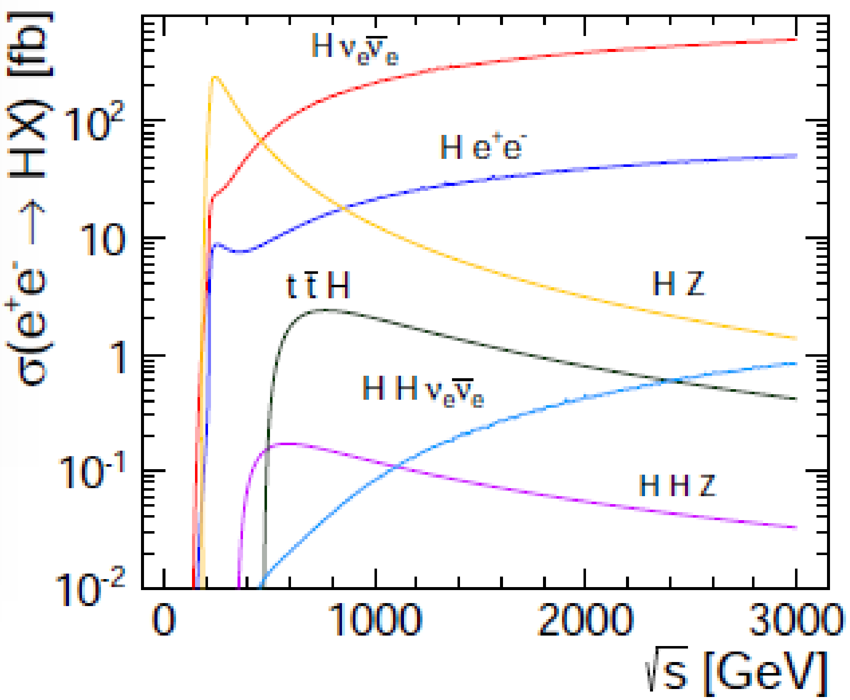


Trilinear self coupling



Quartic coupling

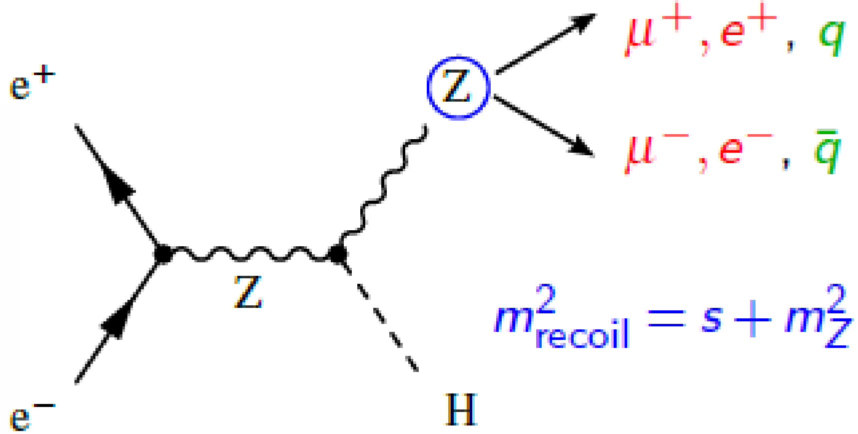




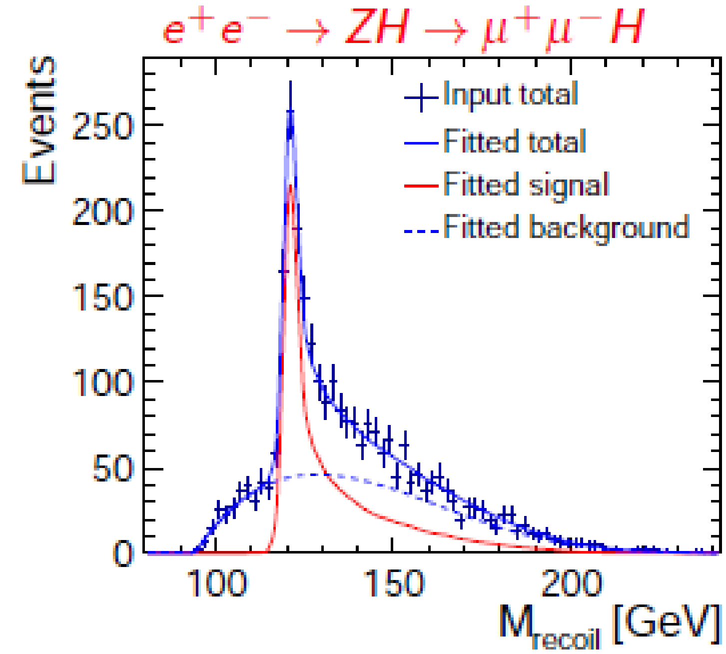
	1.4 TeV	3 TeV
L_{int}	1.5 ab^{-1}	2 ab^{-1}
# $t\bar{t}H$ events	2400	1400
# $HH\nu_e\bar{\nu}_e$ events	225	1200

- High energies and luminosities needed to access rare Higgs production processes

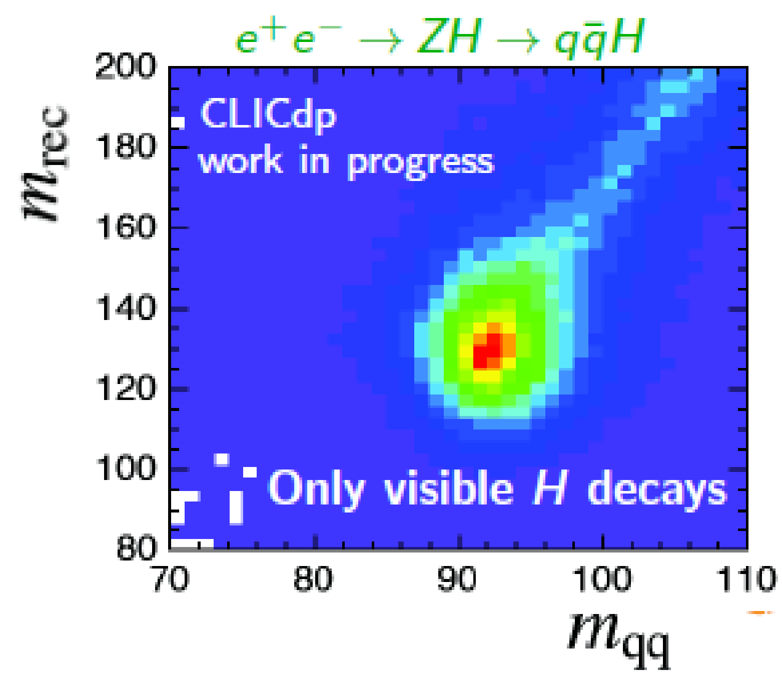
Higgsstrahlung at $\sqrt{s} = 350\,\mathrm{GeV}$



$$m^2_{\mathrm{recoil}} = s + m_Z^2 - 2E_z\sqrt{s}$$

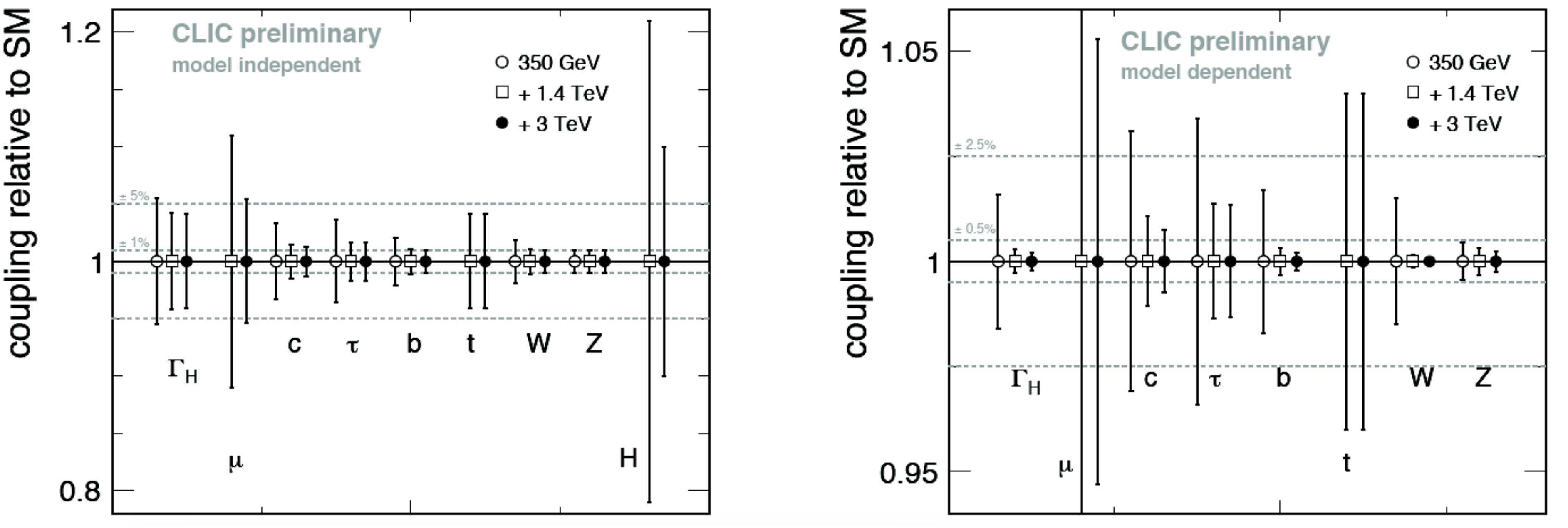


- Measure HZ events from Z recoil mass
- Includes invisible Higgs decays
- Measurement of g_{HZZ} coupling
- $Z \to e^+e^- / \mu^+\mu^-$ decay
  - $\mathrm{BR}(Z \to \mu\mu/ee) \approx 7\%$
  - Fully model independent
  - $\Delta\sigma_{HZ}/\sigma_{HZ} \approx 4.2\% \to \Delta(g_{HZZ})/g_{HZZ} \approx 2.1\%$
- $Z \to q\bar{q}$ decay
  - $\mathrm{BR}(Z \to q\bar{q}) \approx 70\%$
  - Challenge: $Z \to q\bar{q}$ reconstruction may depend on H decay mode
  - $\Delta\sigma_{HZ}/\sigma_{HZ} \approx 1.8\% \to \Delta(g_{HZZ})/g_{HZZ} \approx 0.9\%$



CLIC's internal complementarity

New: includes preliminary hadronic recoil mass analysis



Model-independent: *width is free parameter*
Model-dependent: *assuming SM decays, parameterizing perturbations as* K

CLIC improves on its own 350 GeV results for most couplings.

Results from full Geant4 detector simulations including backgrounds

Channel	Measurement	Observable	Statistical precision		
			350 GeV $500\,\mathrm{fb}^{-1}$	1.4 TeV $1.5\,\mathrm{ab}^{-1}$	3.0 TeV $2.0\,\mathrm{ab}^{-1}$
ZH	Recoil mass distribution	m_H	120 MeV	–	–
ZH	$\sigma(HZ) \times \mathrm{BR}(H \to \text{invisible})$	Γ_{inv}	0.6%	–	–
ZH	$H \to b\bar{b}$ mass distribution	m_H	tbd	–	–
$H\nu_e\bar{\nu}_e$	$H \to b\bar{b}$ mass distribution	m_H	–	40 MeV*	33 MeV*
ZH	$\sigma(HZ) \times \mathrm{BR}(Z \to l^+l^-)$	g^2_{HZZ}	4.2%	–	–
ZH	$\sigma(HZ) \times \mathrm{BR}(Z \to q\bar{q})$	g^2_{HZZ}	1.8%	–	–
ZH	$\sigma(HZ) \times \mathrm{BR}(H \to b\bar{b})$	$g^2_{HZZ}g^2_{Hbb}/\Gamma_H$	1%†	–	–
ZH	$\sigma(HZ) \times \mathrm{BR}(H \to c\bar{c})$	$g^2_{HZZ}g^2_{Hcc}/\Gamma_H$	5%†	–	–
ZH	$\sigma(HZ) \times \mathrm{BR}(H \to gg)$		6%†	–	–
ZH	$\sigma(HZ) \times \mathrm{BR}(H \to \tau^+\tau^-)$	$g^2_{HZZ}g^2_{H\tau\tau}/\Gamma_H$	6.2%	–	–
ZH	$\sigma(HZ) \times \mathrm{BR}(H \to WW^*)$	$g^2_{HZZ}g^2_{HWW}/\Gamma_H$	2%†	–	–
ZH	$\sigma(HZ) \times \mathrm{BR}(H \to ZZ^*)$	$g^2_{HZZ}g^2_{HZZ}/\Gamma_H$	tbd	–	–
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times \mathrm{BR}(H \to b\bar{b})$	$g^2_{HWW}g^2_{Hbb}/\Gamma_H$	3%†	0.3%	0.2%
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times \mathrm{BR}(H \to c\bar{c})$	$g^2_{HWW}g^2_{Hcc}/\Gamma_H$	–	2.9%	2.7%
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times \mathrm{BR}(H \to gg)$		–	1.8%	1.8%
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times \mathrm{BR}(H \to \tau^+\tau^-)$	$g^2_{HWW}g^2_{H\tau\tau}/\Gamma_H$	–	4.2%	tbd
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times \mathrm{BR}(H \to \mu^+\mu^-)$	$g^2_{HWW}g^2_{H\mu\mu}/\Gamma_H$	–	38%	16%
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times \mathrm{BR}(H \to \gamma\gamma)$		–	15%	tbd
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times \mathrm{BR}(H \to Z\gamma)$		–	42%	tbd
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times \mathrm{BR}(H \to WW^*)$	g^4_{HWW}/Γ_H	tbd	1.4%	0.9%
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times \mathrm{BR}(H \to ZZ^*)$	$g^2_{HWW}g^2_{HZZ}/\Gamma_H$	–	3%†	2%†
He^+e^-	$\sigma(He^+e^-) \times \mathrm{BR}(H \to b\bar{b})$	$g^2_{HZZ}g^2_{Hbb}/\Gamma_H$	–	1%†	0.7%†
$t\bar{t}H$	$\sigma(t\bar{t}H) \times \mathrm{BR}(H \to b\bar{b})$	$g^2_{Ht\bar{t}}g^2_{Hbb}/\Gamma_H$	–	8%	tbd
$HH\nu_e\bar{\nu}_e$	$\sigma(HH\nu_e\bar{\nu}_e)$	g_{HHWW}	–	7%*	3%*
$HH\nu_e\bar{\nu}_e$	$\sigma(HH\nu_e\bar{\nu}_e)$	λ	–	32%	16%
$HH\nu_e\bar{\nu}_e$	with −80% e^- polarisation	λ	–	24%	12%

Results without beam polarisation

†: estimated, *: preliminary

Top Physics

- Top quark physics below pair production threshold?
- Top quark mass is best measured at threshold (several 10s of fb^{-1})

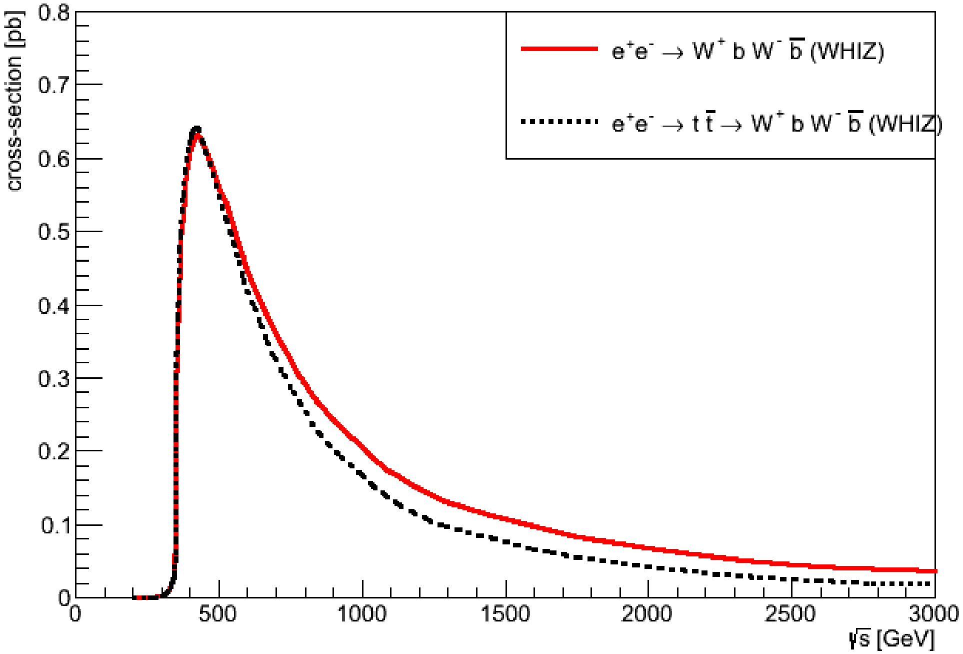
  → threshold scan

- New physics constraints from a measurement of cross-section and Forward-Backward and polarization asymmetry of top quark pair production

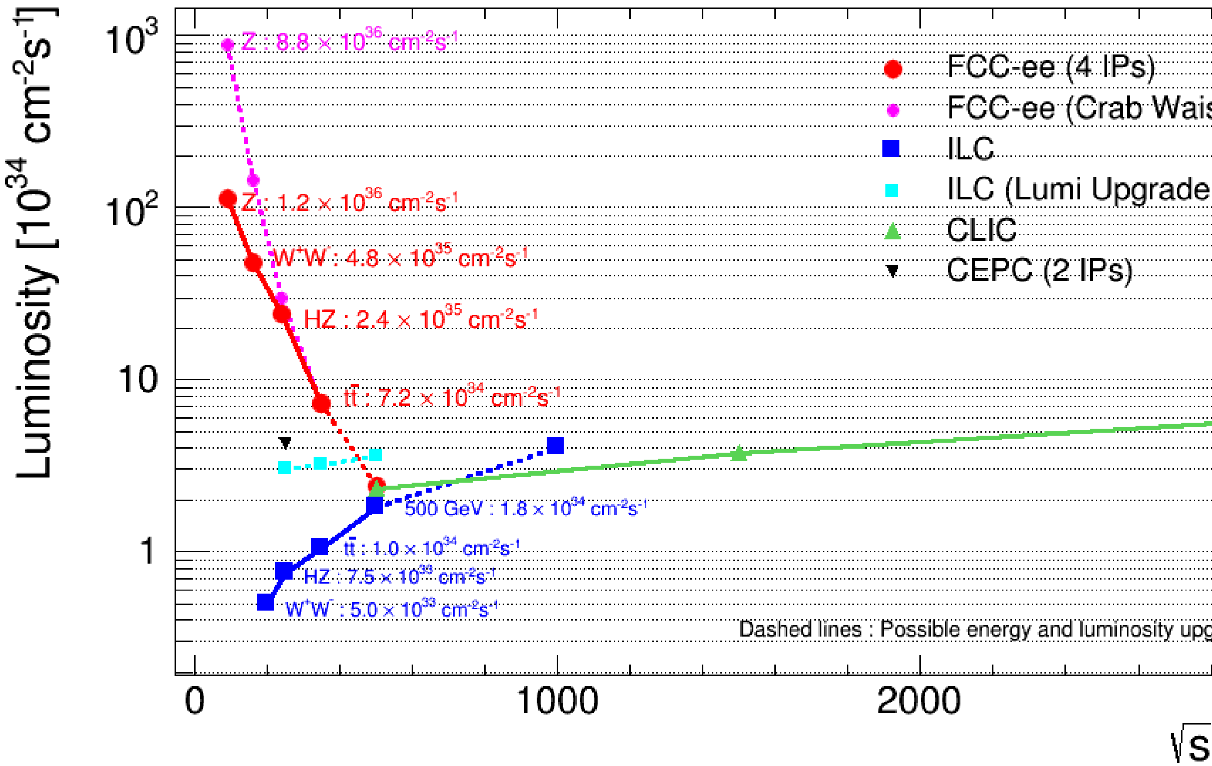
  → 380 GeV – 3 TeV (see my talk tomorrow)

- Top in association with Higgs

  → 550 GeV – 1.4 TeV



Lepton collider complementarity



	LEP1	LEP2	Z	W	H	tt
Circumference [km]	26.7		100			
Bending radius [km]	3.1		11			
Beam energy [GeV]	45.4	104	45.5	80	120	175
Beam current [mA]	2.6	3.04	1450	152	30	6.6
Bunches / beam	12	4	16700	4490	1360	98
Bunch population [10^{11}]	1.8	4.2	1.8	0.7	0.46	1.4
Transverse emittance ε						
- Horizontal [nm]	20	22	29.2	3.3	0.94	2
- Vertical [pm]	400	250	60	7	1.9	2
Momentum comp. [10^{-5}]	18.6	14	18	2	0.5	0.5
Betatron function at IP β^*						
- Horizontal [m]	2	1.2	0.5	0.5	0.5	1
- Vertical [mm]	50	50	1	1	1	1
Beam size at IP σ^* [μm]						
- Horizontal	224	182	121	26	22	45
- Vertical	4.5	3.2	0.25	0.13	0.044	0.045
Energy spread [%]						
- Synchrotron radiation	0.07	0.16	0.04	0.07	0.10	0.14
- Total (including BS)	0.07	0.16	0.06	0.09	0.14	0.19
Bunch length [mm]						
- Synchrotron radiation	8.6	11.5	1.64	1.01	0.81	1.16
- Total	8.6	11.5	2.56	1.49	1.17	1.49
Energy loss / turn [GeV]	0.12[1]	3.34	0.03	0.33	1.67	7.55
SR power / beam [MW]	0.3[1]	11	50			
Total RF voltage [GV]	0.24	3.5	2.5	4	5.5	11
RF frequency [MHz]	352		800			
Longitudinal damping time τ_E [turns]	371	31	1320	243	72	23
Energy acceptance RF [%]	1.7	0.8	2.7	7.2	11.2	7.1
Synchrotron tune Q_s	0.065	0.083	0.65	0.21	0.096	0.10
Polarization time τ_p [min]	252	4	11200	672	89	13
Hourglass factor H	1	1	0.64	0.77	0.83	0.78
Luminosity/IP [10^{34} cm^{-2}s^{-1}]	0.002	0.012	28.0	12.0	6.0	1.8
Beam-beam parameter						
- Horizontal	0.044	0.040	0.031	0.060	0.093	0.092
- Vertical	0.044	0.060	0.030	0.059	0.093	0.092
Luminosity lifetime [min][2]	1250	310	213	52	21	15
Beamstrahlung critical	No		No	No	Yes	Yes

[1] Does not take into account the contribution of damping and emittance wigglers.
[2] The luminosity lifetime corresponds to 4 IPs.

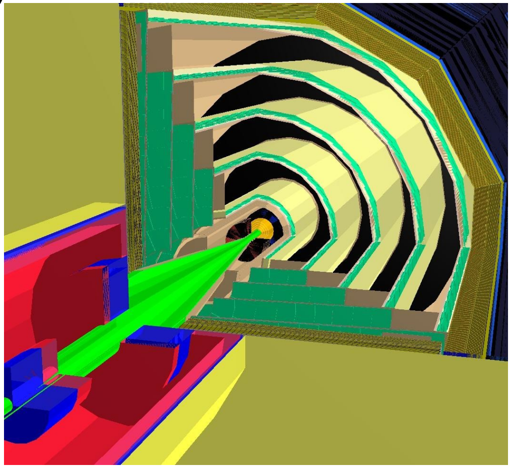
Obviously, luminosity-limited BR measurements can gain from greater Higgs-strahlung production at ~250 GeV

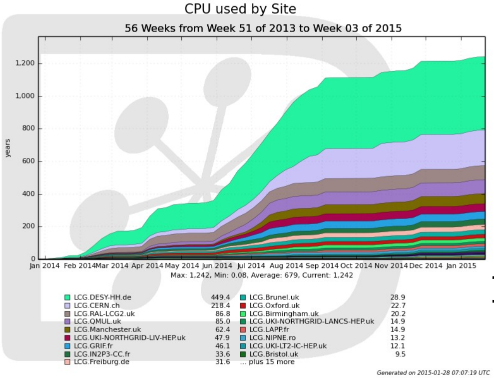
High-energy machines bring in better measurements of vector boson fusion, top-Higgs and Higgs self-coupling at high energy

Software synergy

Software tools

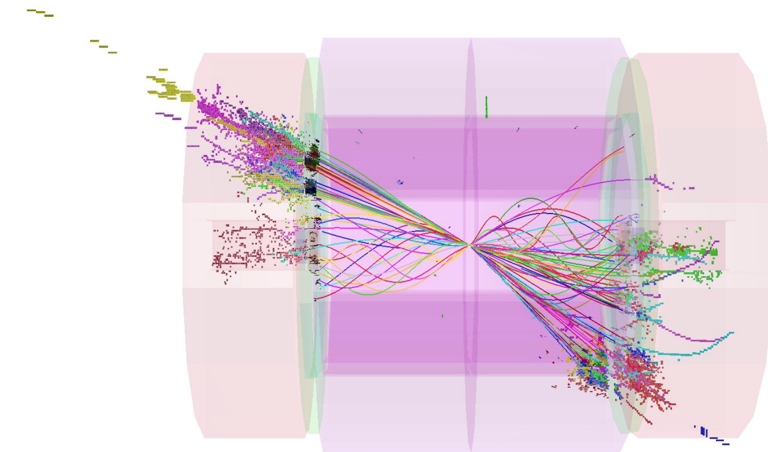
- High-level algorithms
  - Georgi global jets (arXiv:1408.1161)
  - VLC jets (arXiv:1404.4294)
  - LCFIplus flavour tagging
- Low-level reconstruction
  - Particle Flow reconstruction (Pandora, arXiv:1308.4537)
  - Track reconstruction
- Detector geometry
  - DD4HEP
- Pure computing tools:
  - ILCDirac



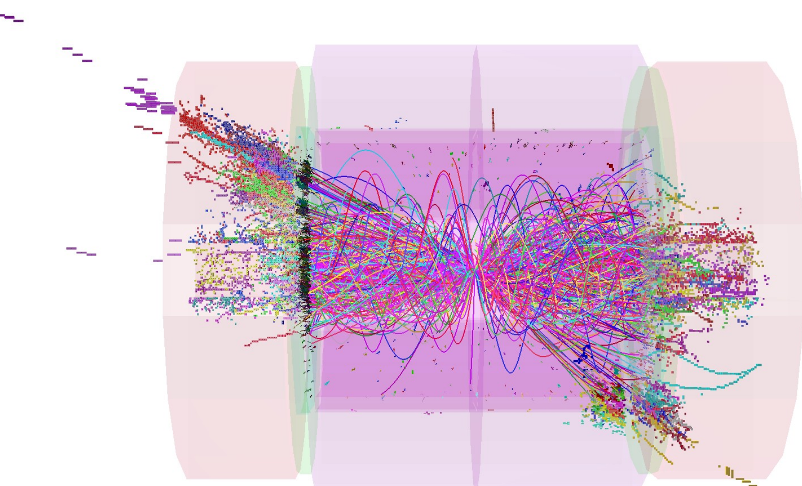


See Ties Behnke's presentation in this session

CLIC background



3 TeV top quark pair



$+ \gamma\gamma \rightarrow$ *hadrons*

Depending on center-of-mass energy, instantaneous luminosity, final focus and bunch structure, e^+e^- colliders may have non-negligible background

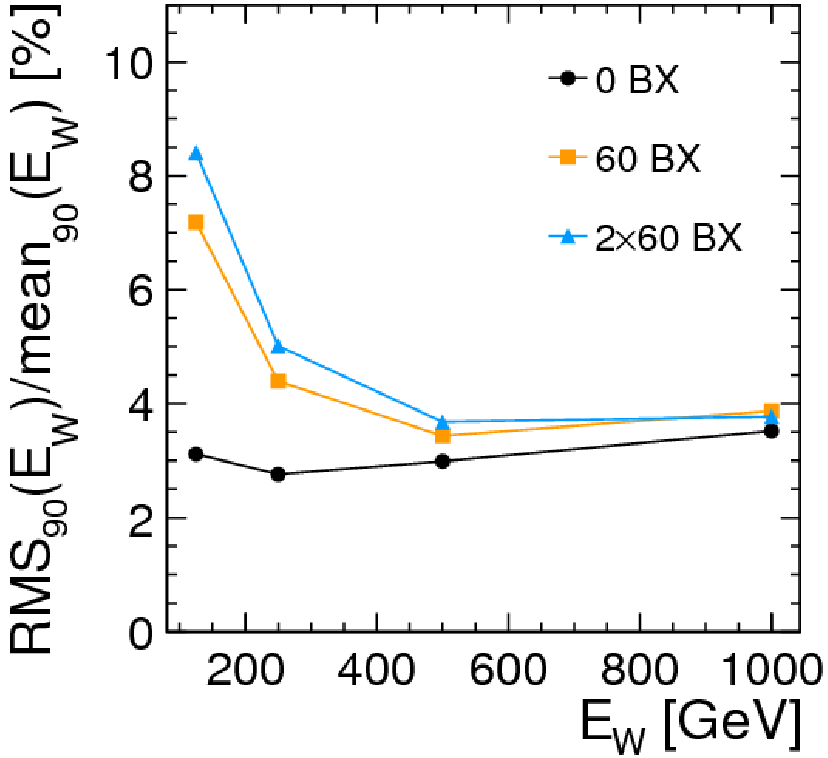
At 3 TeV a CLIC bunch train (156 crossings, separated by 0.5 ns) deposits several TeV in the detector, 90% in the forward system

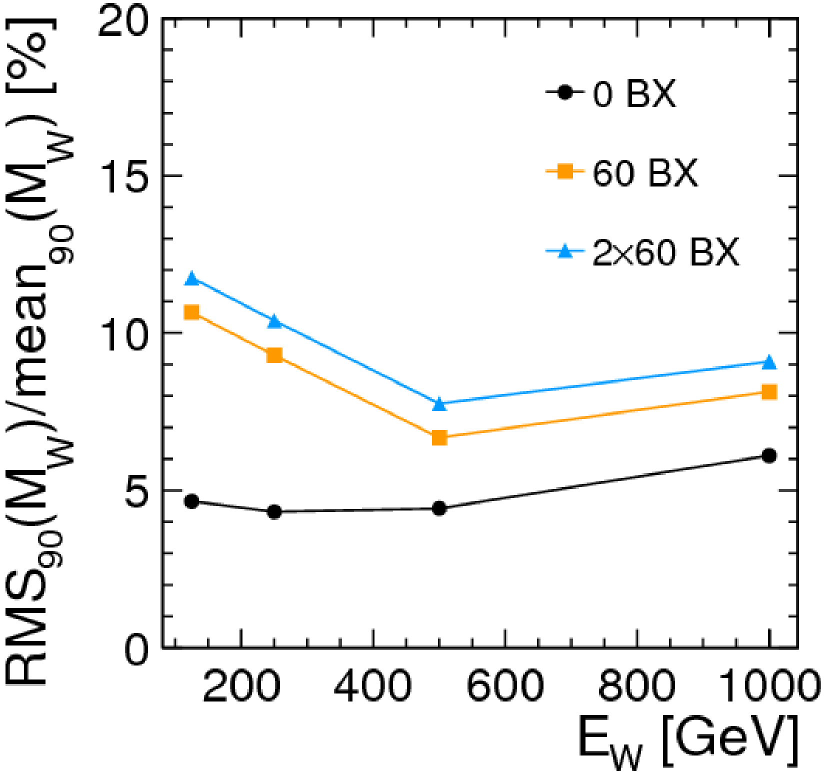
Reduce to O(100 GeV) using timing cuts

What about FCC-ee background levels?

Impact of background

$e^+e^- \to W^+W^- \to l\nu\, q\bar{q}$ events at CLIC at 3 TeV with W energies of 100, 250, 500 and 1000 GeV
Overlay 60 (120) BX worth of $\gamma\gamma \to$ hadrons, select in-time reconstructed particles, remove lepton
Reconstruct long. inv. k_t jets exclusively (N=2, R=0.7)

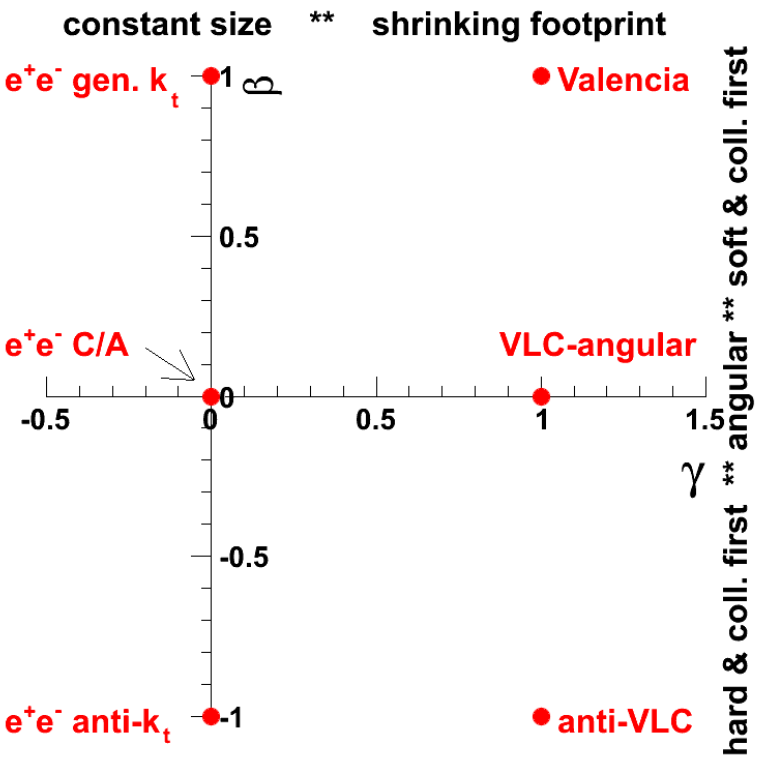




Energy resolution at high energy is not too badly affected, but can deteriorate strongly at low energy. Mass resolution suffers.

[CLIC CDR, Marshall, Münnich & Thomson, arXiv:1209.4039],
non-negligible even for ILC physics [many studies, arXiv:1307.8102]

CLIC jet reconstruction

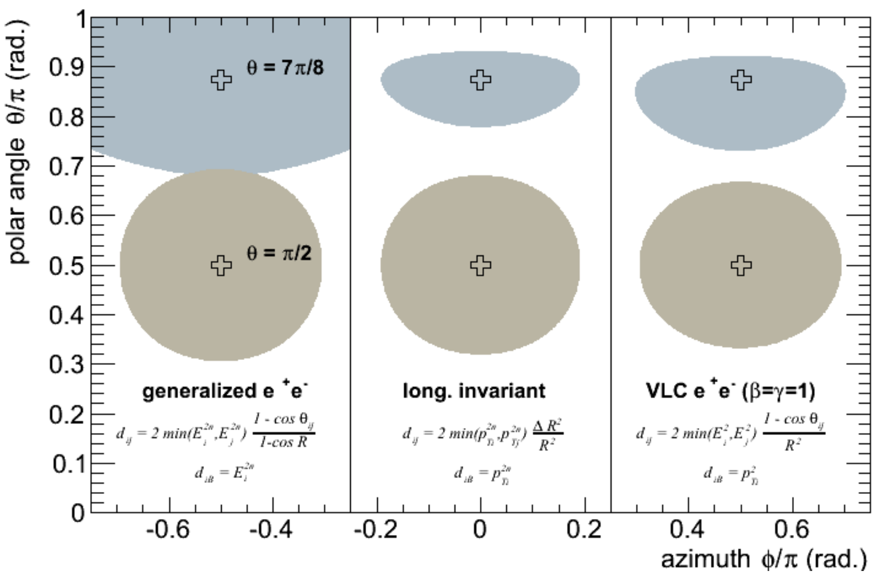


Need to enhance background resilience by reducing jet catchment area in forward region

Longitudinally invariant k_t used extensively

VLC can maintain e+e- distance and achieve robust performance **(arXiv:1404.4294)**

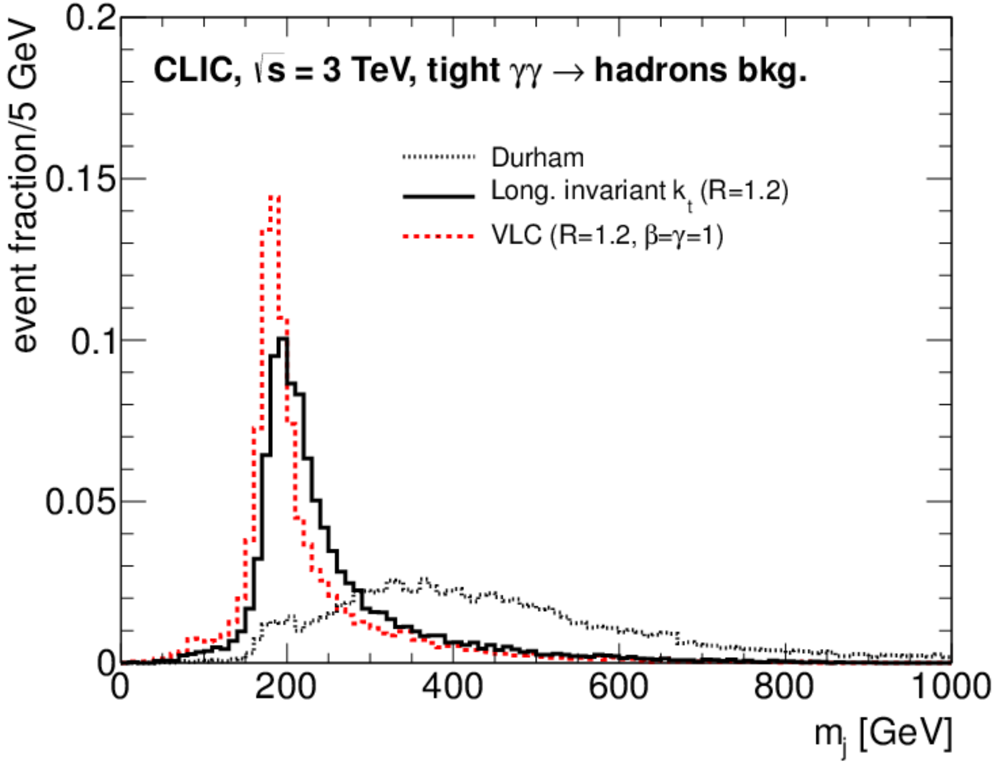
Georgi's global jets under study



Jet reconstruction algorithms

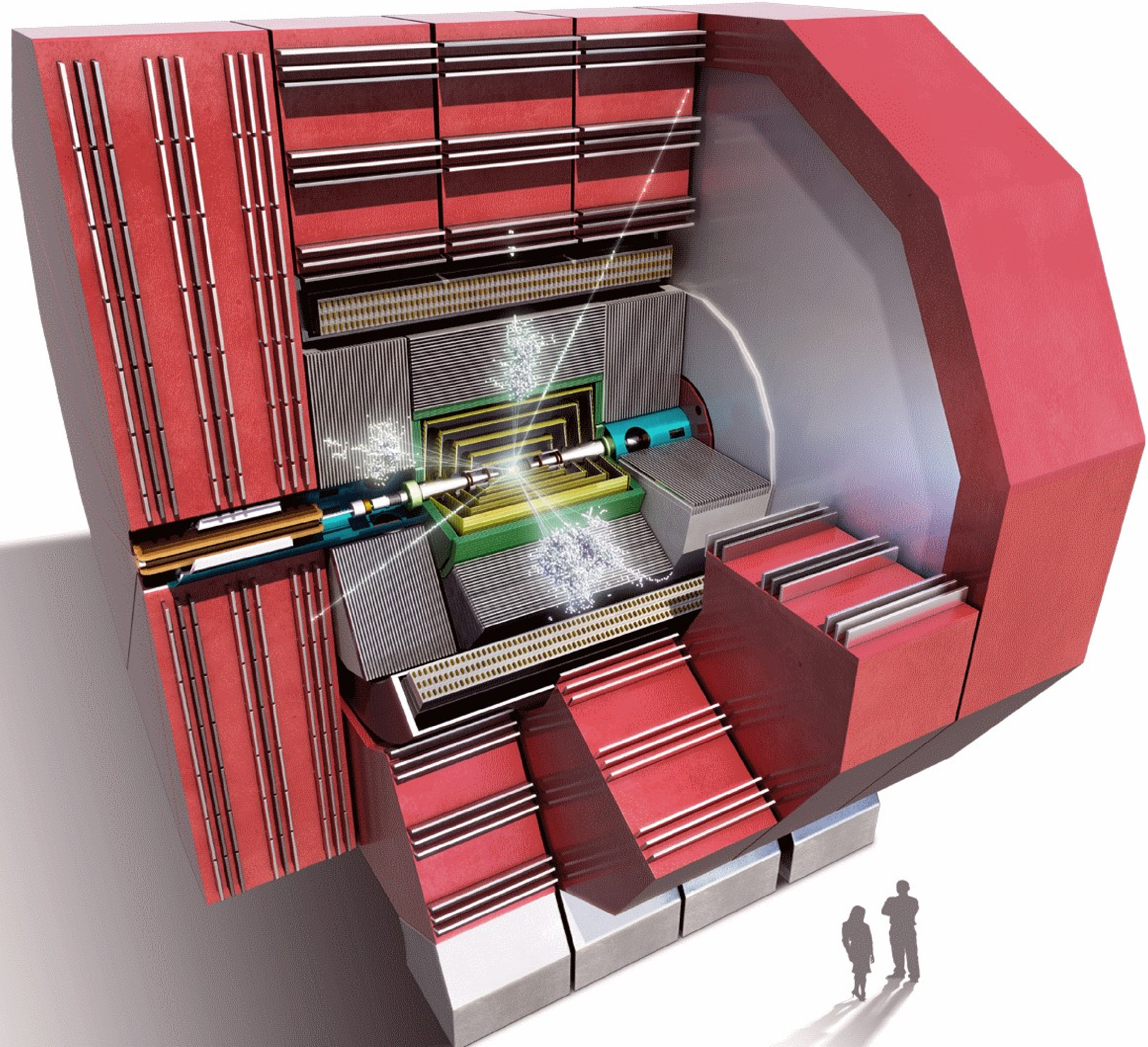
CLIC's high energy stage is definitely the most demanding environment for jet reconstruction that we're going to encounter at lepton colliders any time soon
→ use as test bed for algorithms

CLIC jet mass resolution is excellent even when including realistic background
→particle flow is excellent for jet substructure
→impact of background mitigated by jet algorithm



Time for a fresh look at lepton collider jet algorithms!

Detector design synergy



Requirements

★ **momentum resolution:**

endpoints, Higgs recoil mass, Higgs → μμ

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

★ **jet energy resolution:**

W/Z/h di-jet mass separation

$$\boxed{\frac{\sigma_E}{E} \sim 3.5 - 5\ \%}$$ (for high-E jets)

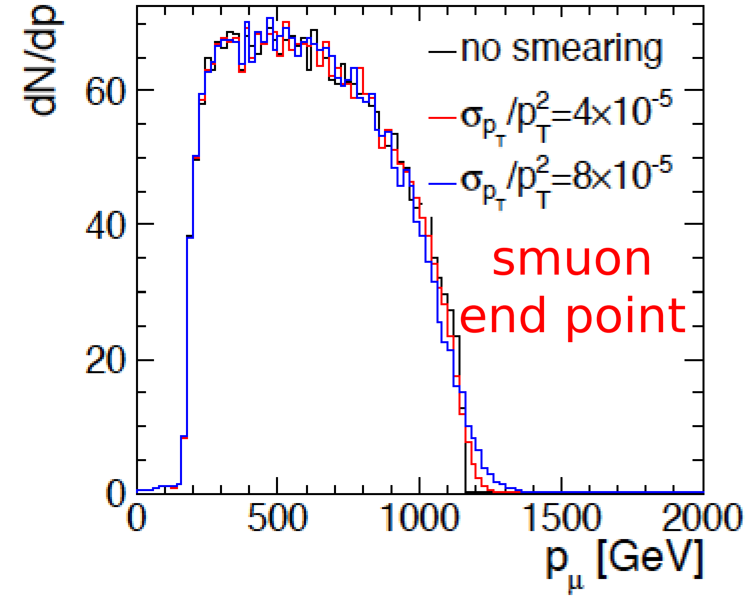
★ **impact parameter resolution:**

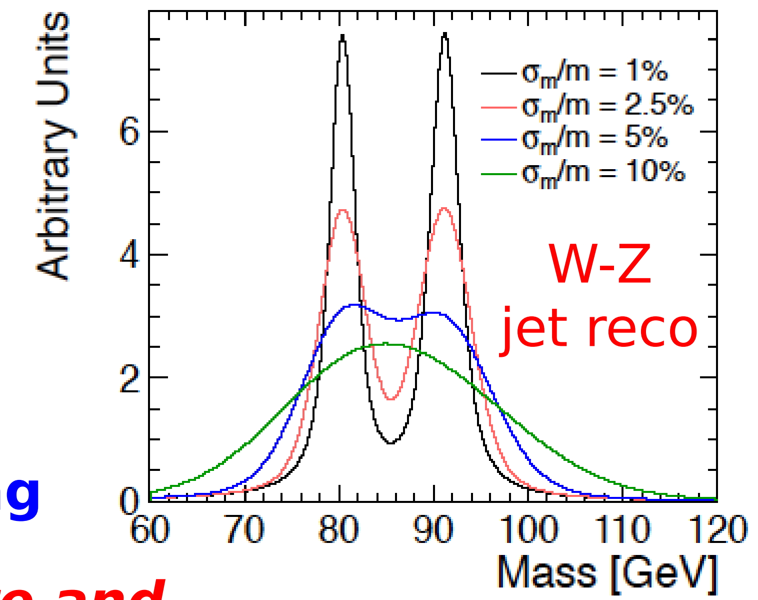
c/b-tagging, Higgs BR

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

★ **angular coverage, very forward e⁻ tagging**

+ requirements from CLIC beam structure and beam-induced background





Jets in e^+e^- colliders

Jet physics AND jet reconstruction performance are important at e^+e^- colliders

After the LHC, e^+e^- collider samples are small:

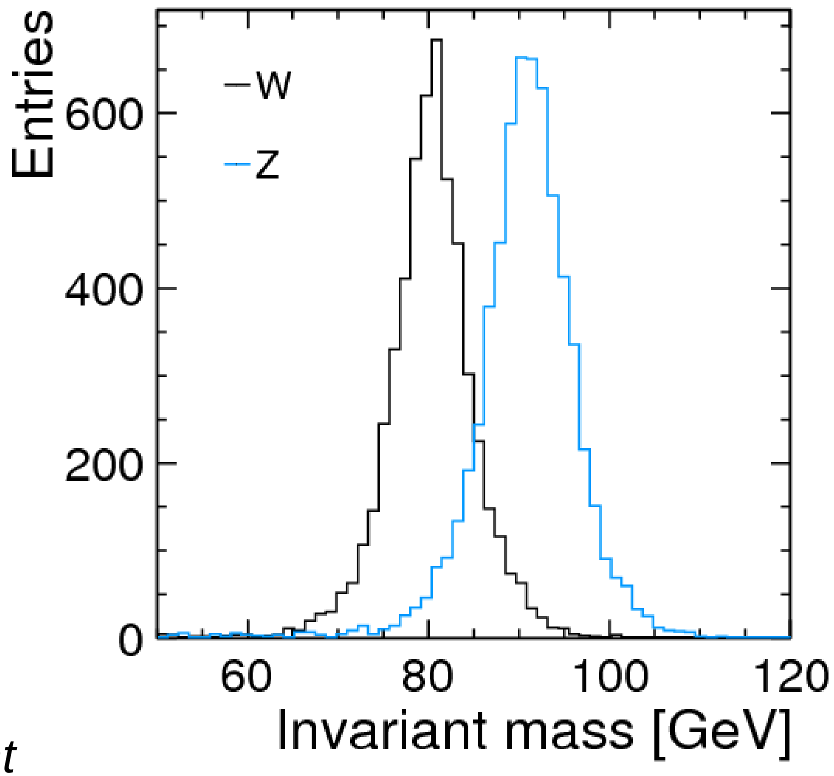
→ *Use hadronic Z decays recoil mass*
→ *Study hadronic W and Z*
→ *Use fully hadronic top decays*

Distinguish hadronic W and Z decays
(the main calorimeter specification on energy resolution at low energy, a requirement on the jet mass resolution at high energy)

Jet multiplicity increases with sqrt(s):

di-boson → 4 jets
Zh → 4 jets
$t\bar{t}$ → 6 jets
$t\bar{t}h$ → 8 jets

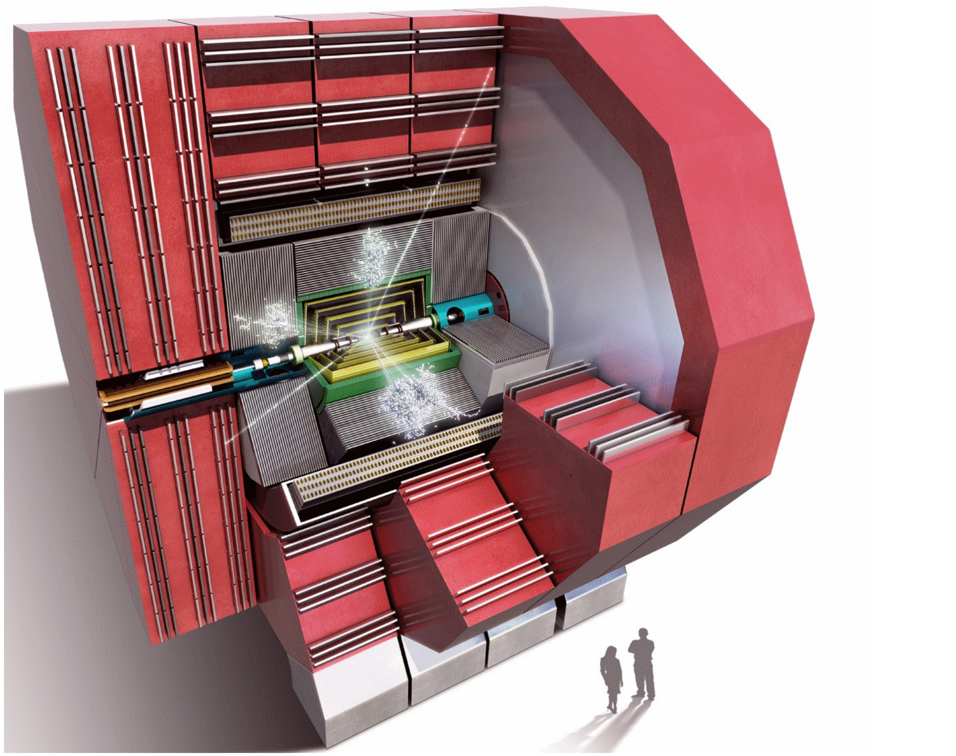
(jet reconstruction can spoil the energy measurement even if all particles are precisely measured)



LC Detector concepts

ILD/SiD: LC detector concepts optimized for particle flow

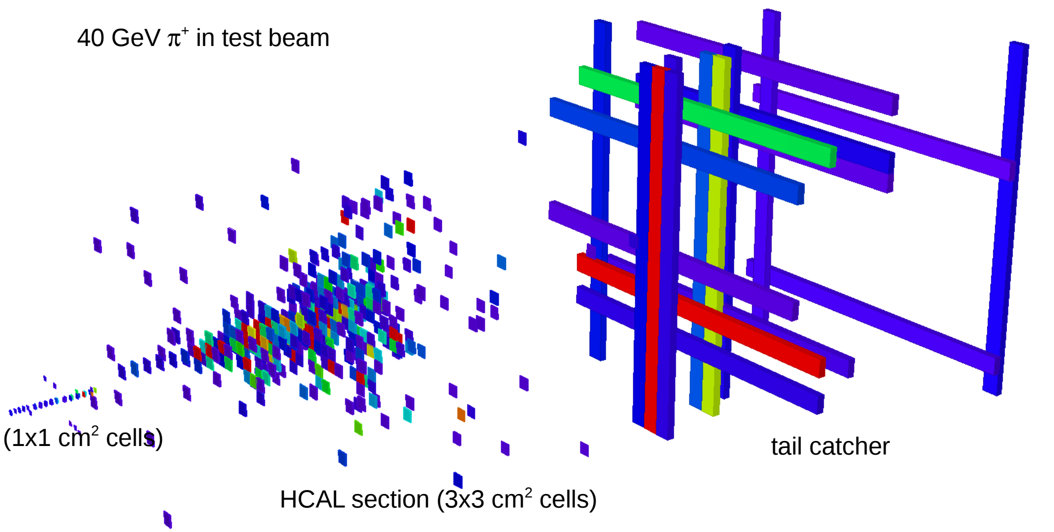
- highly granular calorimeter*
- 4-5 Tesla solenoid
- state-of-the art low-mass tracking system
- precision vertexing



For details:
CLIC CDR, arXiv:1202.5940
ILC TDR, arXiv:1306.6329

Detailed Geant4 model and adequate reconstruction software allow for realistic estimates of performance. This includes ILC/CLIC beam energy spectra and "pile-up" from background processes.

Not (entirely) science fiction:
The **CALICE** R&D collaboration has constructed and tested ultra-granular SiW EM calorimeters and a 1 m^3 prototype ScW hadronic calorimeter



Particle Flow

Particle Flow: Follow individual particles from the cradle to the grave

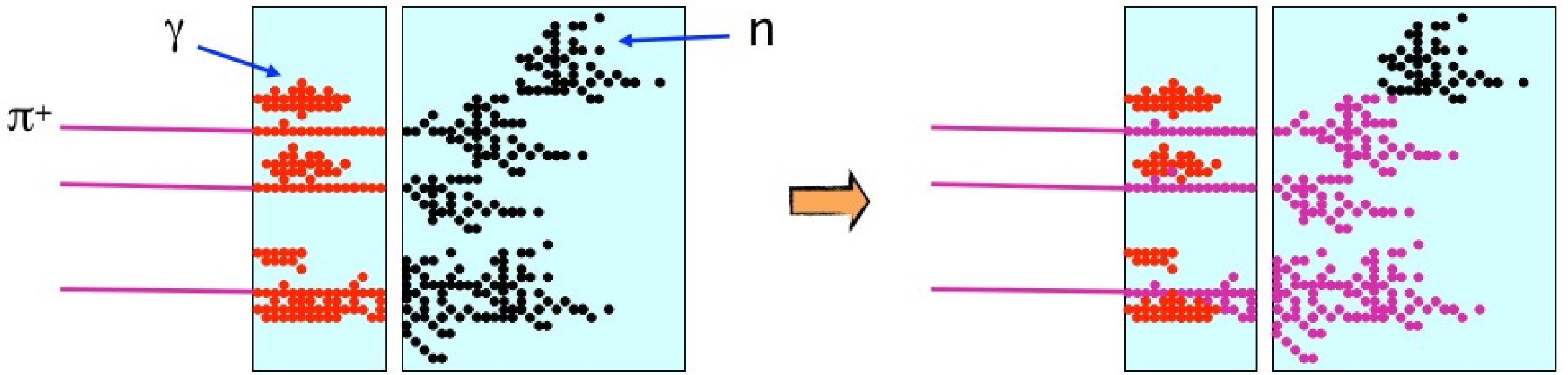
- choose best available energy measurement for each particle
- reject background particles (using time information)

Requires a large, highly granular detector, a strong B-field, and excellent pattern recognition

Take advantage of the tracker's $\Delta(1/p_T) \sim 10^{-5}$ GeV^{-1} whenever possible,

Resort to the $\Delta E/E \sim 50\%/\sqrt{E}$ of the hadronic calorimeter only for neutral hadrons

Pandora Particle Flow: algorithm designed specifically for PF jet energy measurements with highly granular calorimeters (arXiv:1308.4537)



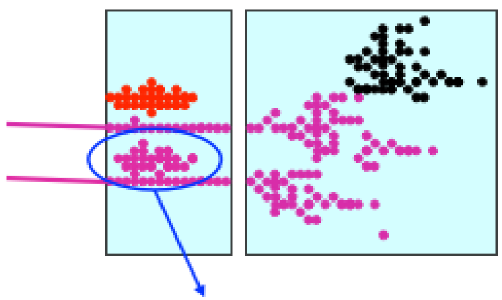
$E_{JET} = E_{ECAL} + E_{HCAL}$ $\quad$ $E_{JET} = E_{TRACK} + E_{\gamma} + E_n$

72% of energy $\quad$ 62% $\quad$ 10%

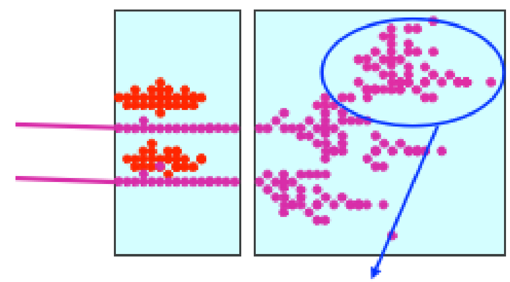
Particle Flow performance

In theory able to achieve *ΔE/E = 19%/√E*

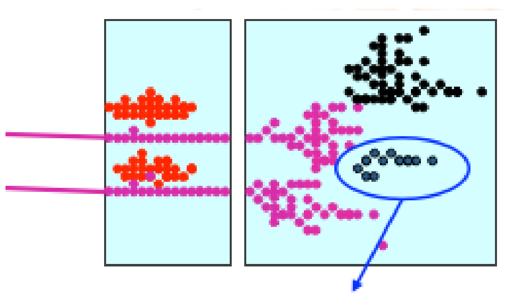
(theoretical limit for perfect track-cluster association)



Failure to resolve photons



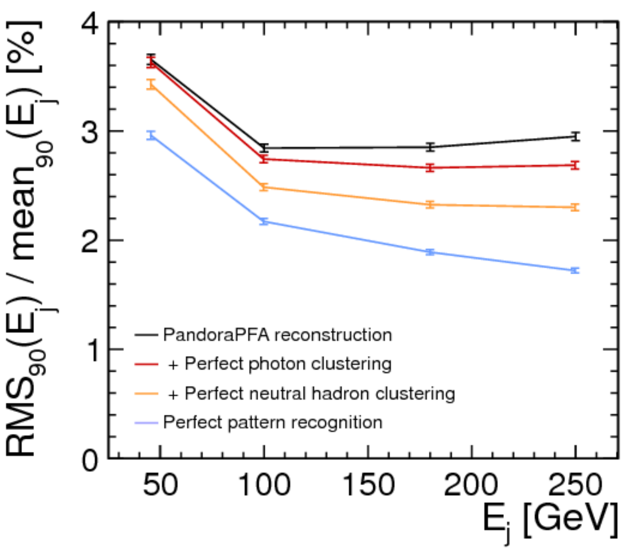
Failure to resolve neutral hadrons

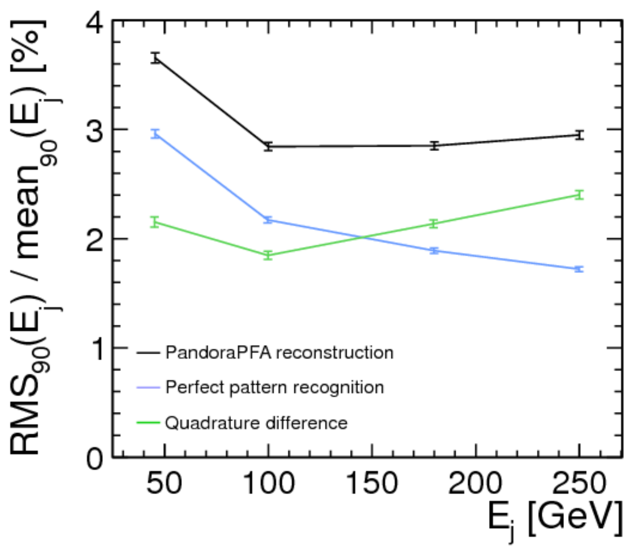


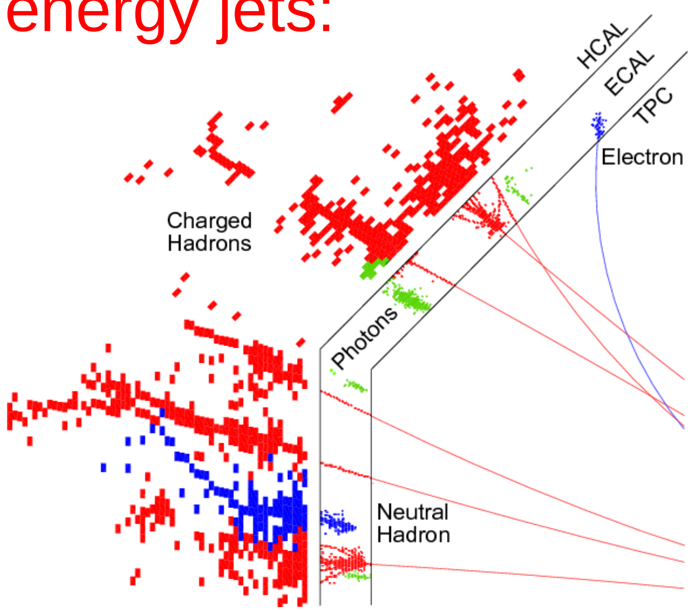
Reconstruct fragments as separate neutral hadrons

In practice limited to by confusion term for high energy jets:

ΔE/E ~ 3%

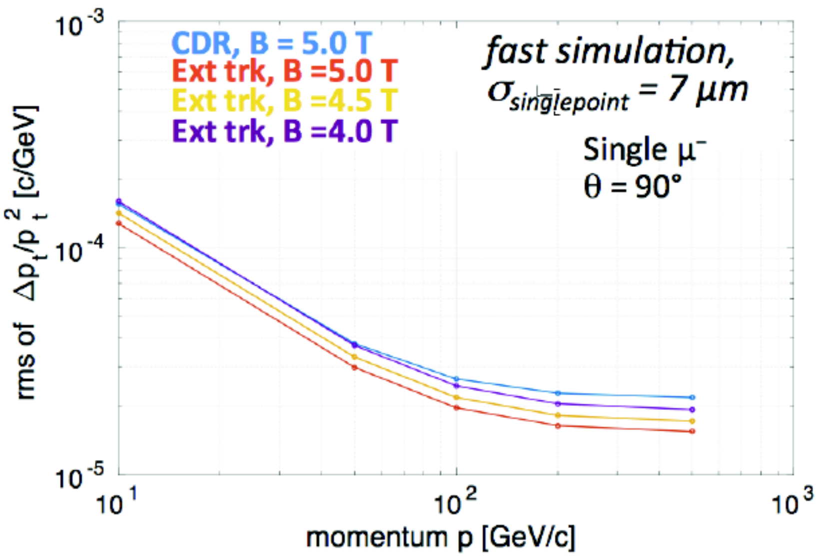






Di-jet events, energy resolution for "jets" inferred from total visible energy

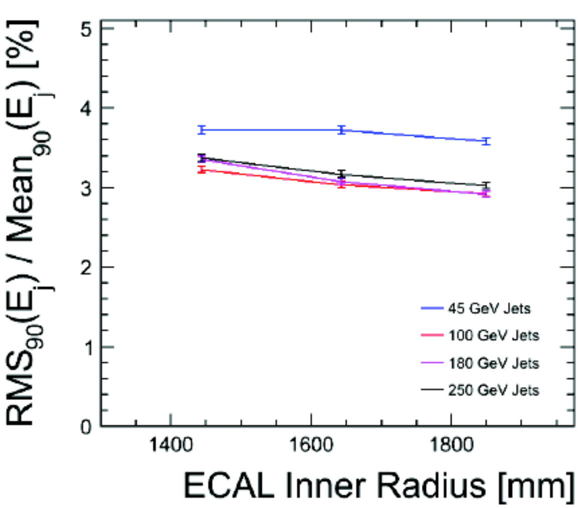
Overall size & magnetic field

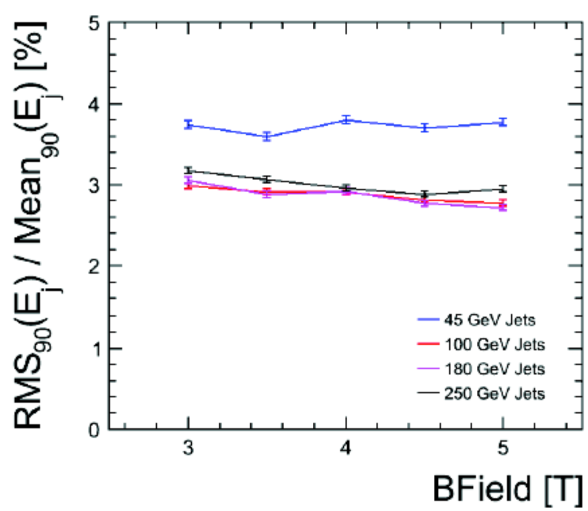


- **Larger tracker has advantages:**

$$\frac{\sigma(p_T)}{p_T^2} \propto \frac{1}{BR^2}$$

- Increase tracker radius (c.f. CLIC_SiD), **R=1.5m**
- Increase length (add disks), half-length **L=2.3m**
- Choose **B=4T** - performance still at least as good as CLIC_SiD, due to extended tracker.





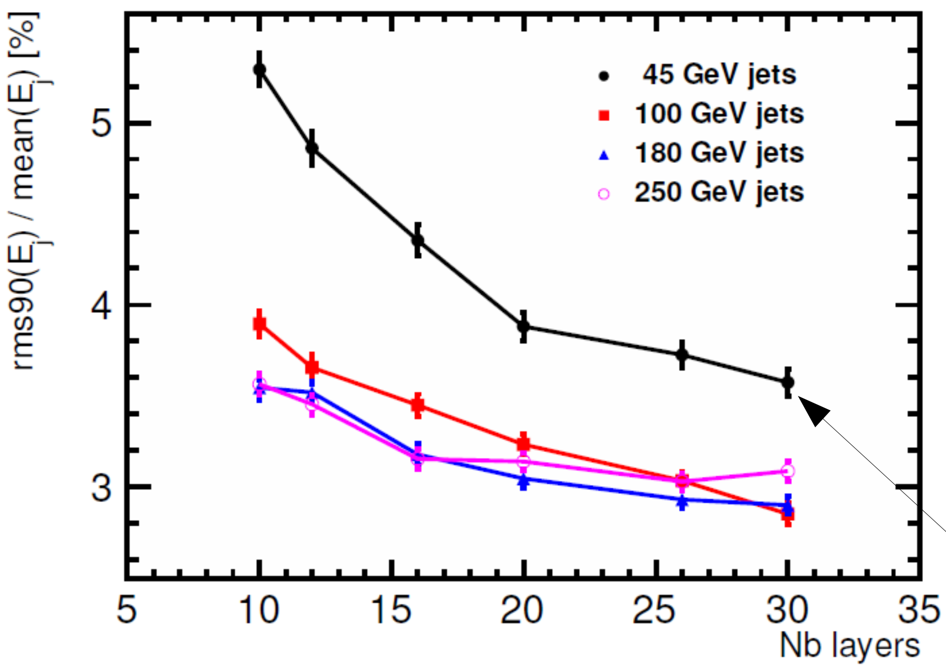
Jet energy resolutions indicate impact on PFA:

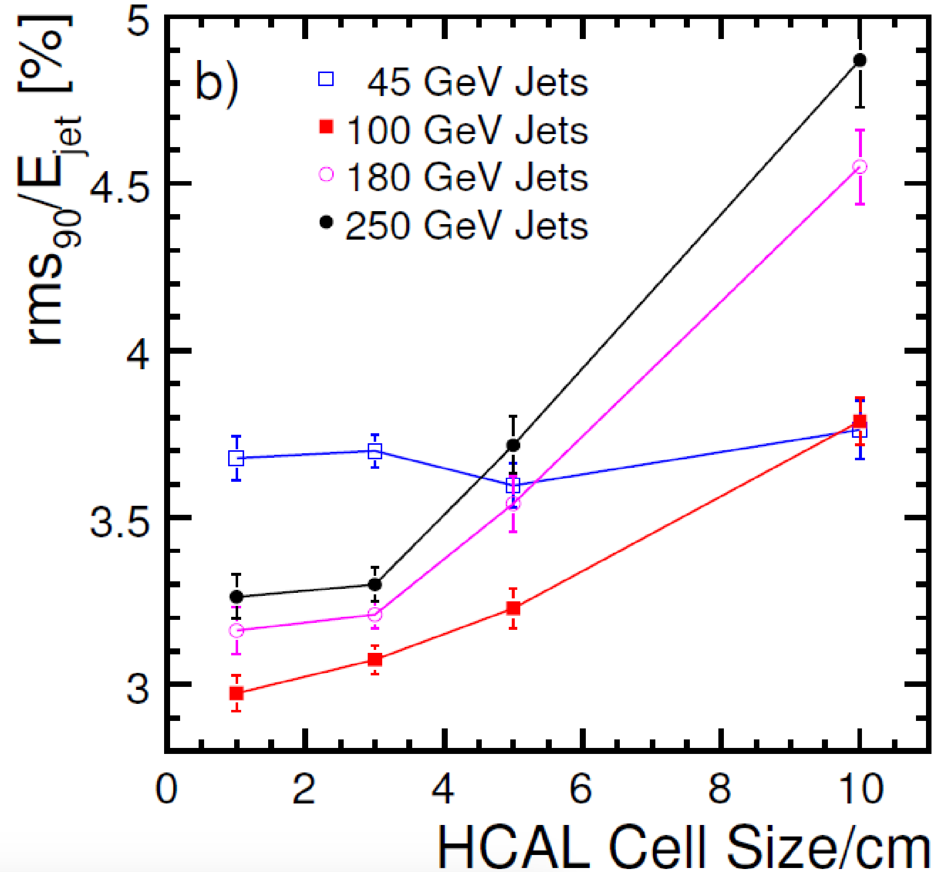
- Larger R increases particle separation in calorimeter.
- Larger B increases charged/ neutral particle separation.
- See **slight** improvement with B and R for high E jets.

More granular is better

Many "detector optimization" studies in CLIC CDR show benefits of longitudinal and lateral segmentation to below Moliere radius and interaction length... and where to stop

ECAL longitudinal segmentation...
More layers, better energy resolution

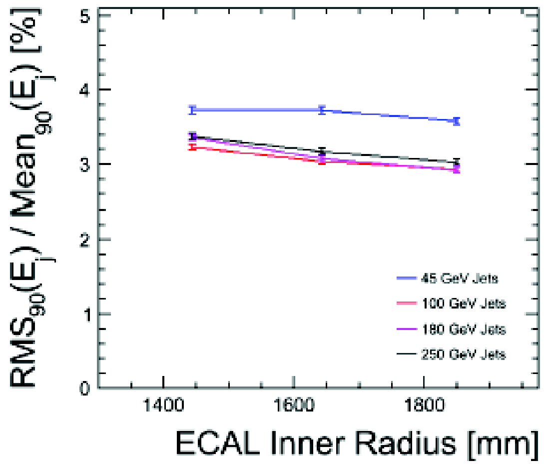


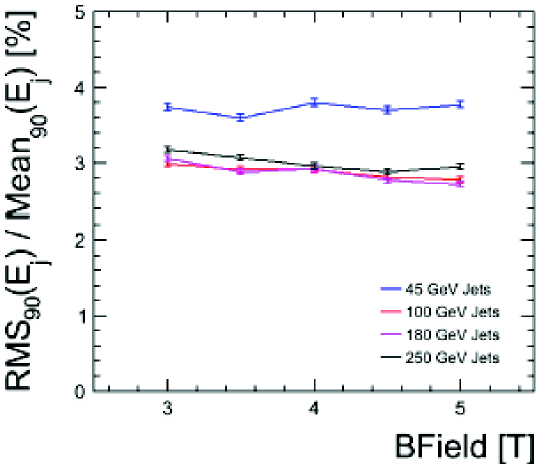


AHCAL lateral segmentation...
baseline design chooses 3x3 cm²
interaction length of iron = 17 cm...

Note: 45 GeV jets suffer...

Detector optimization

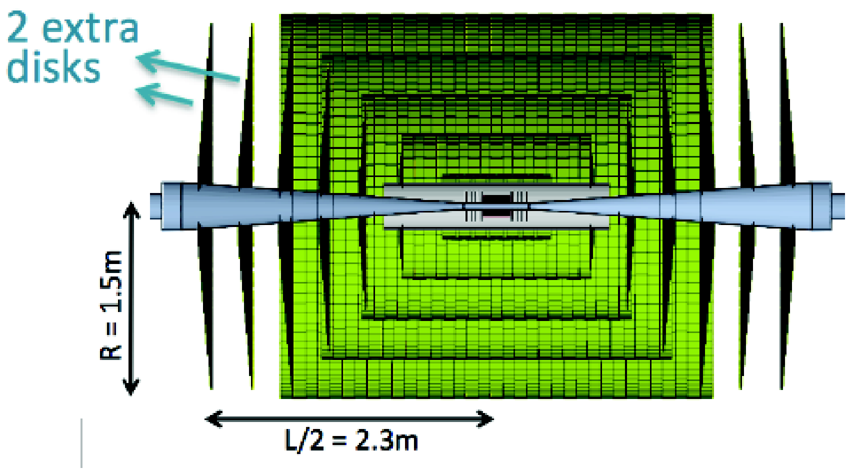




Jet energy resolutions indicate impact on PFA:

- Larger R increases particle separation in calorimeter.
- Larger B increases charged/ neutral particle separation.
- See slight improvement with B and R for high E jets.

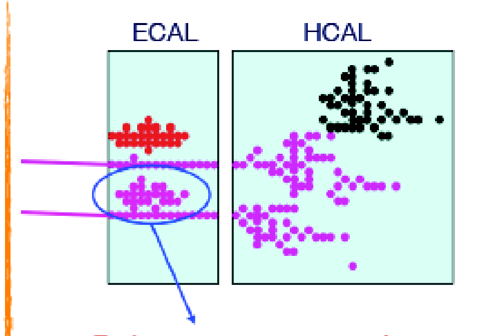
- Determination of the precise tracker layout is work in progress.
- Ongoing development of simulation and reconstruction software.
- Studies underway to consider optimisation in terms of tracker occupancy.
- Input from hardware side required: **CLIC tracker technology working group.**



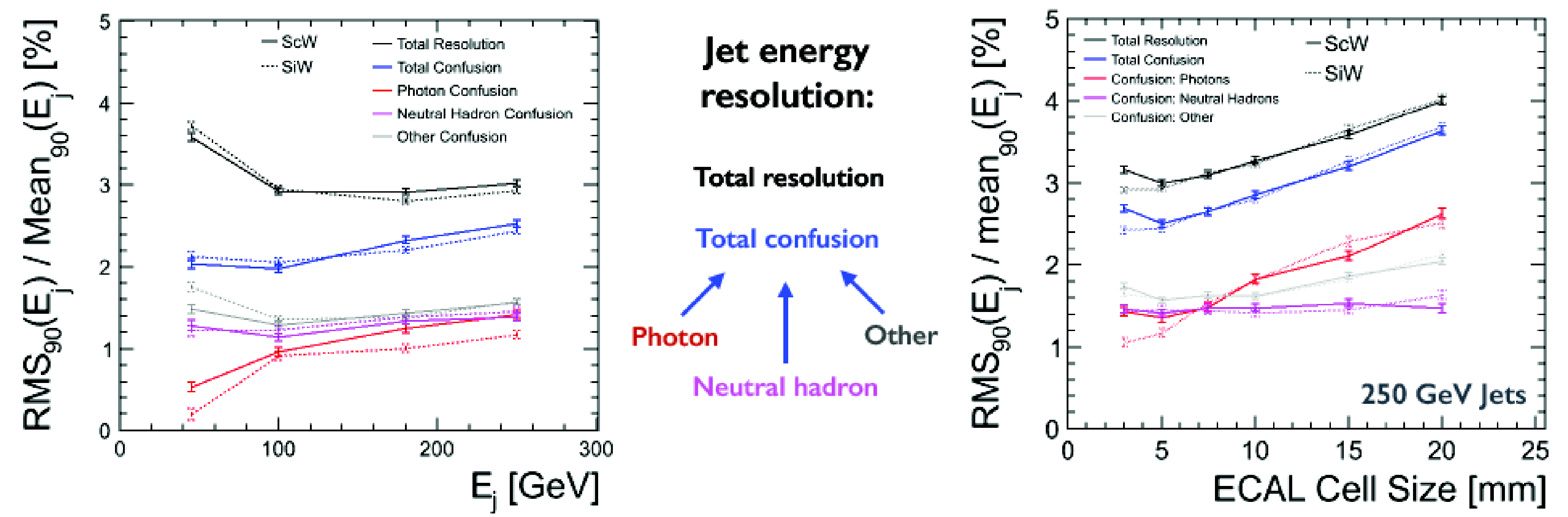
J. Marshall, CLIC workshop, CERN, feb 2015

Detector optimization

- Starting point: 29 layers W absorber ($23X_0, 1\lambda_I$), 30 layers Si active medium (1 pre-sampler), divided into 5x5mm^2 pixels.
- Particle flow means performance depends critically on pattern-recognition, not just intrinsic ECAL energy resolution.
- Granularity requirements and use of Si make ECAL expensive: consider scintillator (Sc) with SiPM readout as active medium.
- Examined wide range of ECAL models, developing detailed understanding of resulting **jet energy resolutions.**



Failure to separate photons from nearby charged hadrons: "photon confusion"



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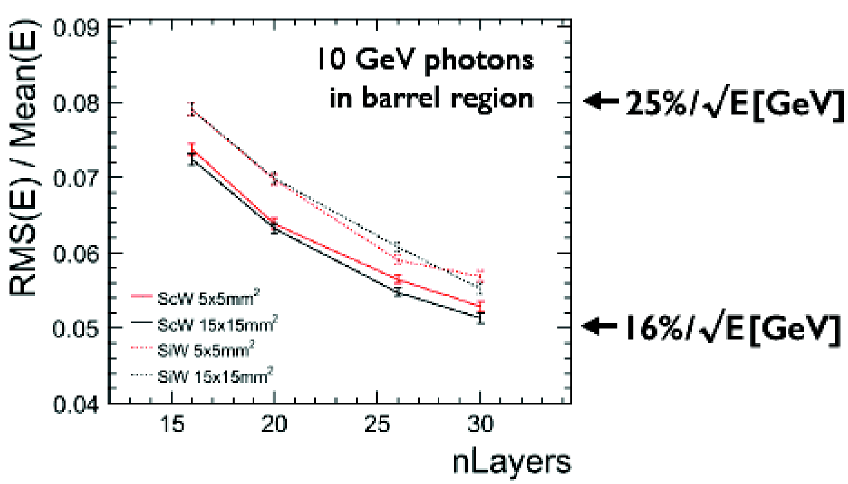
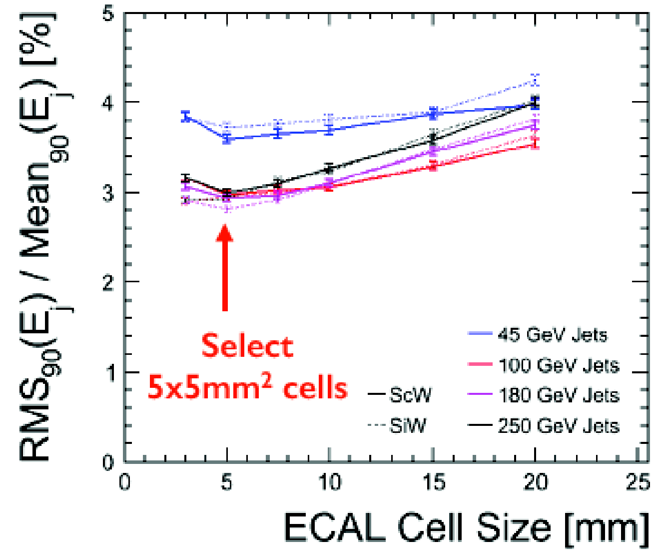
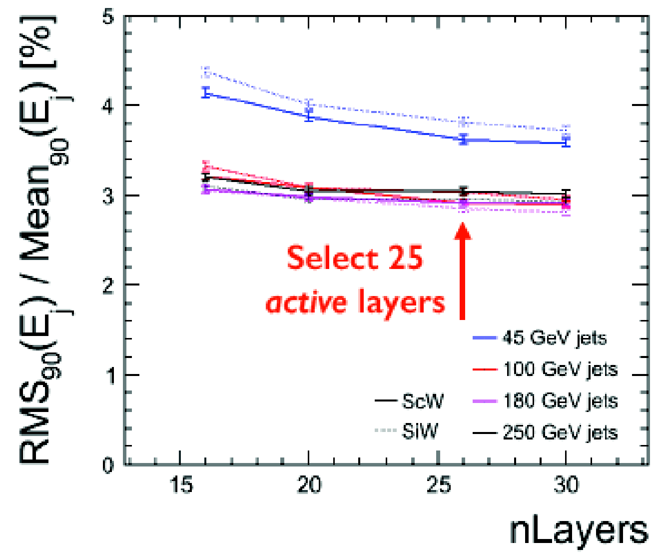
Detector optimization

- Sc (2mm thick; Si 0.5mm) offers better intrinsic E resolution. Side-mounted MPPC affects performance for small Sc cells.
- With same size cells, SiW and ScW yield similar performance. Cost arguments not yet conclusive, so **stick with Si.**
- **Performance vs. nLayers:** very flat, change mostly due to varying intrinsic E-resolution.
- **Performance vs. ECAL cell size:** intuitive and driven by photon confusion.







J. Marshall, CLIC workshop, CERN, feb 2015

CLIC detectors vs. ILC

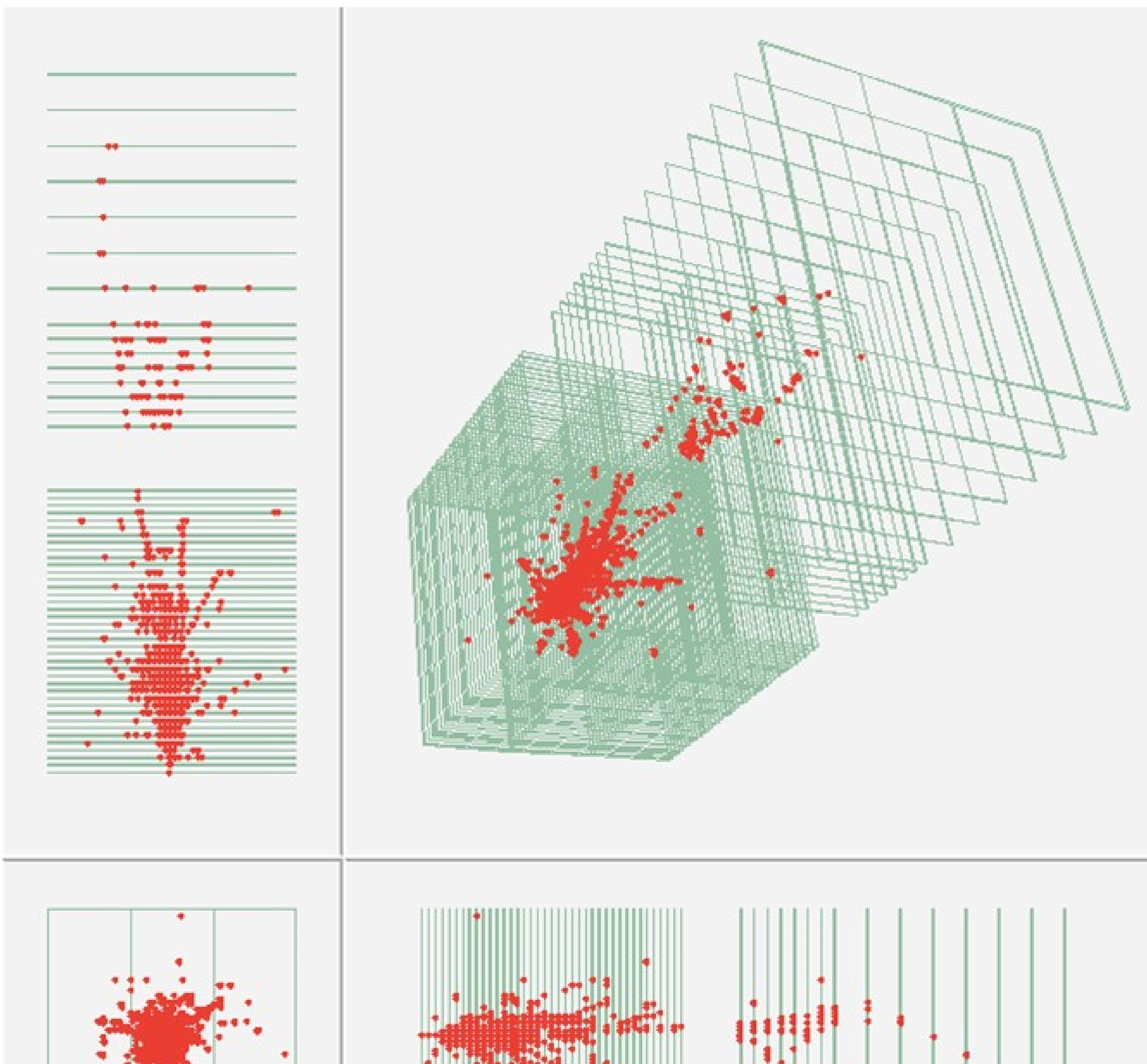
CLIC started from the ILC detector concepts (ILD and SiD), including their software solutions

The CLIC detectors evolved to cope with more stringent requirements from:

- highly energetic jets
  - → hadronic calorimeter must be deep enough to contain energy
  - → tracker pattern recognition (silicon preferred over TPC)
- predominance and relevance of t-channel processes at high sqrt(s)
  - → coverage down to smallest possible polar angle
  - → keep performance as close as possible to barrel
- background level
  - → time stamp every particle
  - → fast read-out (~10 ns) for all sub-systems

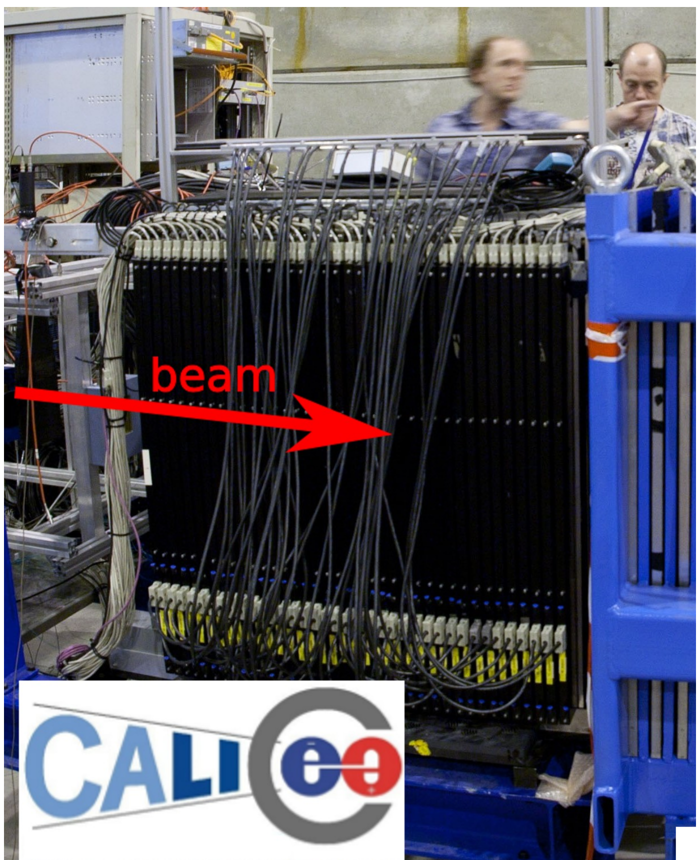
For an efficient use of existing resources CLIC has decided to continue with one detector concept

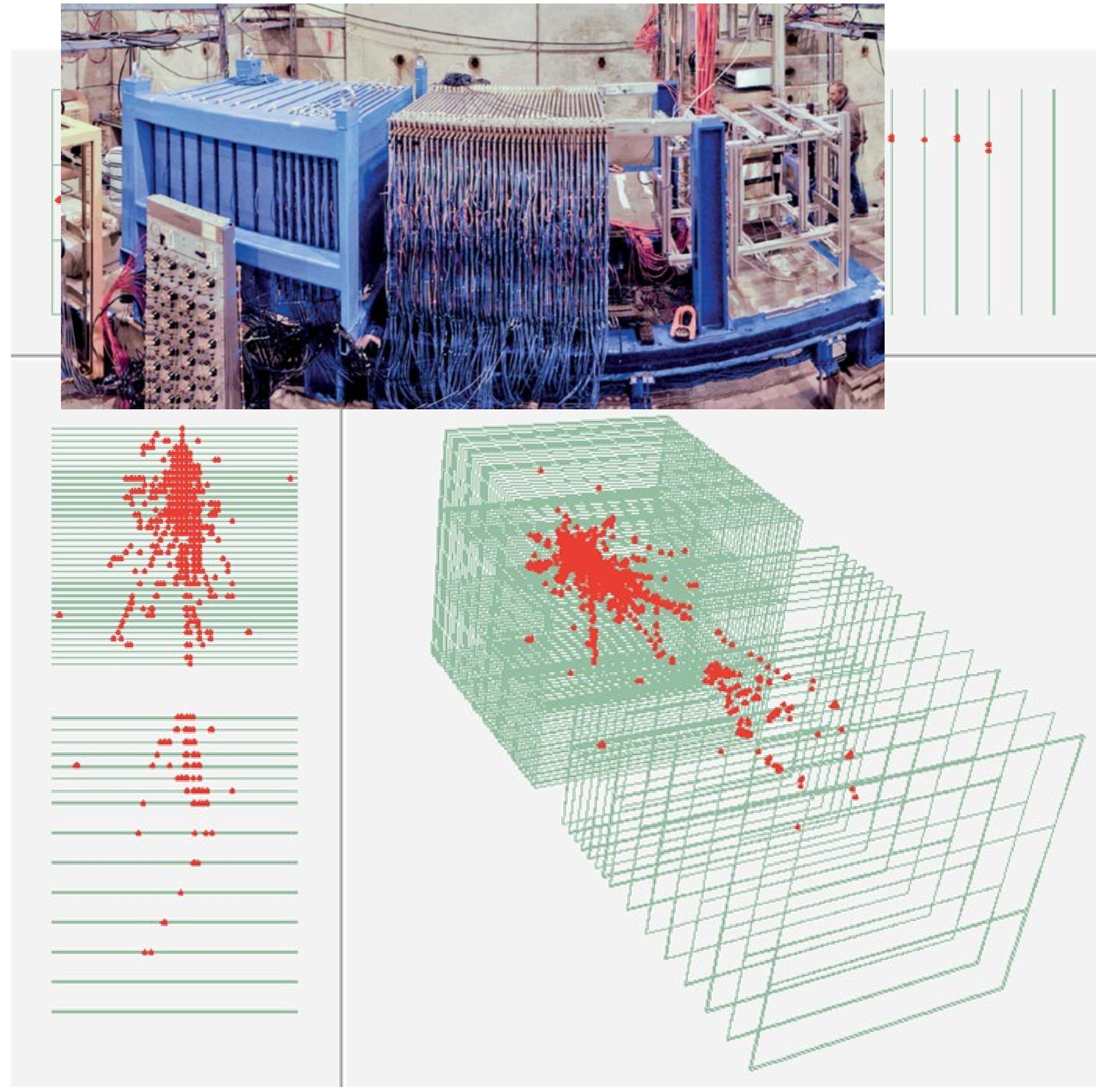
Detector R&D synergy



Detector R&D synergy

CLIC d&p joined CALICE & FCAL to boost the development of ultra-granular and forward calorimetry





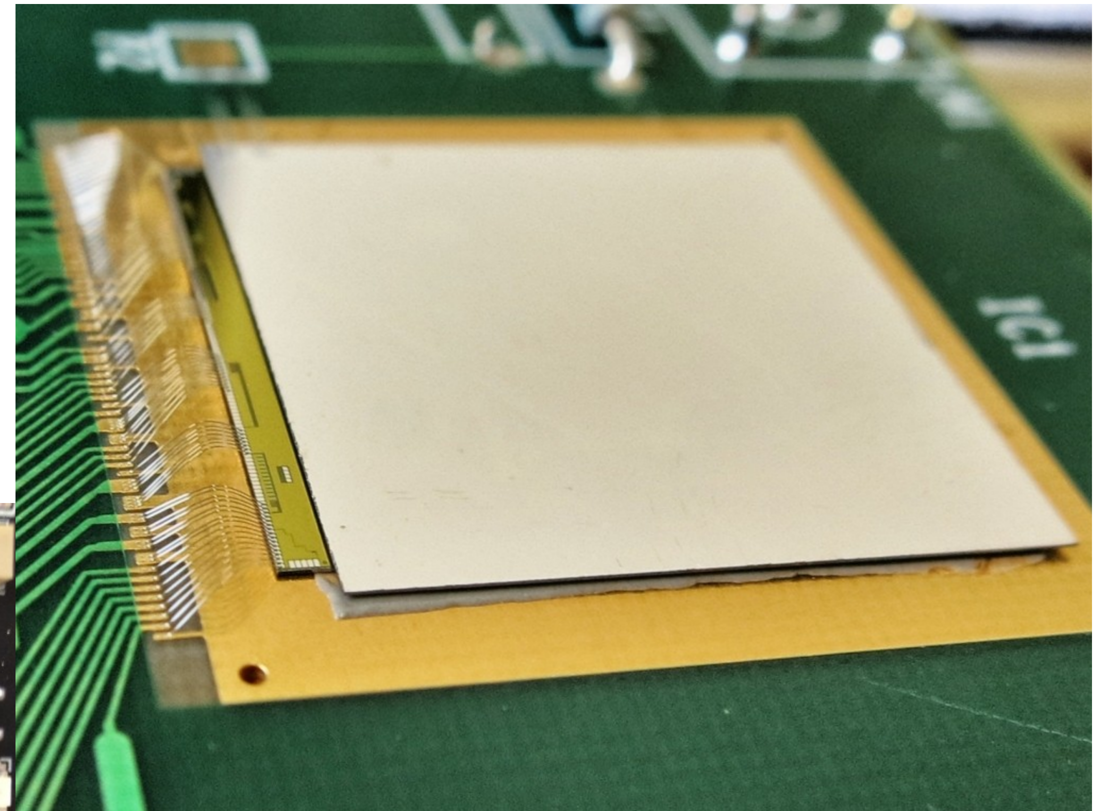
Tungsten stack instrumented as digital hadronic calorimeter tested extensively at CERN

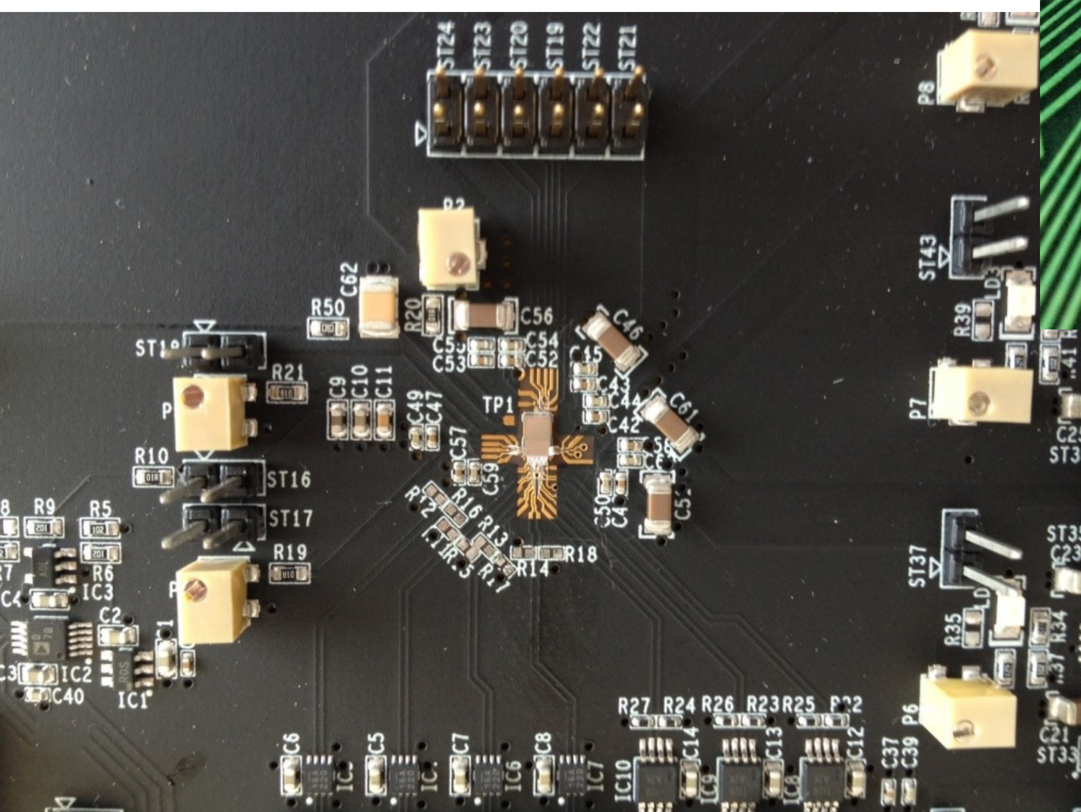
Detector R&D synergy

CLIC is developing high-speed, ultra-light vertex detector concepts

- CLICpix thin&hybrid

- HVCMOS





Pisa, feb. 2015

Summary

The Compact Linear Collider

- A mature lepton collider concept that can reach multi-TeV
- Comprehensive physics programme
  - 350/380 GeV (top mass, Higgs couplings, top couplings)
  - 1.4 TeV (ttH, Higgs self coupling + new physics)
  - 3 TeV (new physics reach)

Lepton colliders have a lot in common

  - Perform studies of potential vs. sqrt(s) rather than repeating the same studies with different assumptions
- High level reconstruction
  - Collaborative effort on particle flow, jet reconstruction
- Detector design:
  - Particle flow detector concept proven
  - Flexible tool kit for detector description
- Detector R&D
  - Ultra-granular particle flow calorimeters
  - Ultra-transparent silicon for vertexing and tracking