ILC Detector Concepts and their adaptation for CLIC

Dieter Schlatter, CERN

SCENARIO

Two detectors in pull-push mode

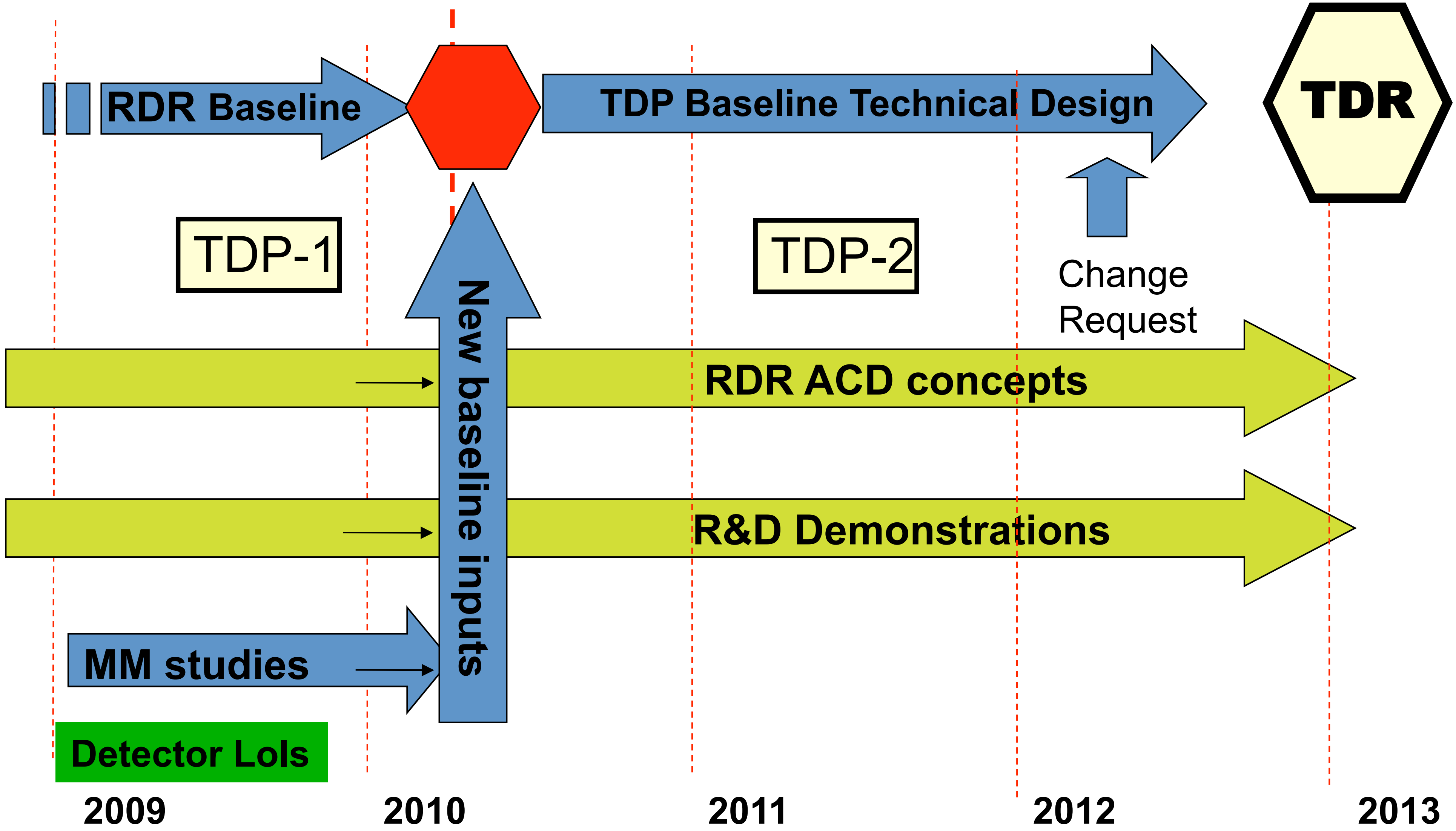
ILC at 500 GeV (baseline)

or

CLIC in staged mode from 500 GeV to 3 TeV

LHC should reveal energy scale of Physics beyond the Standard Model

Technical Design Phase and Beyond

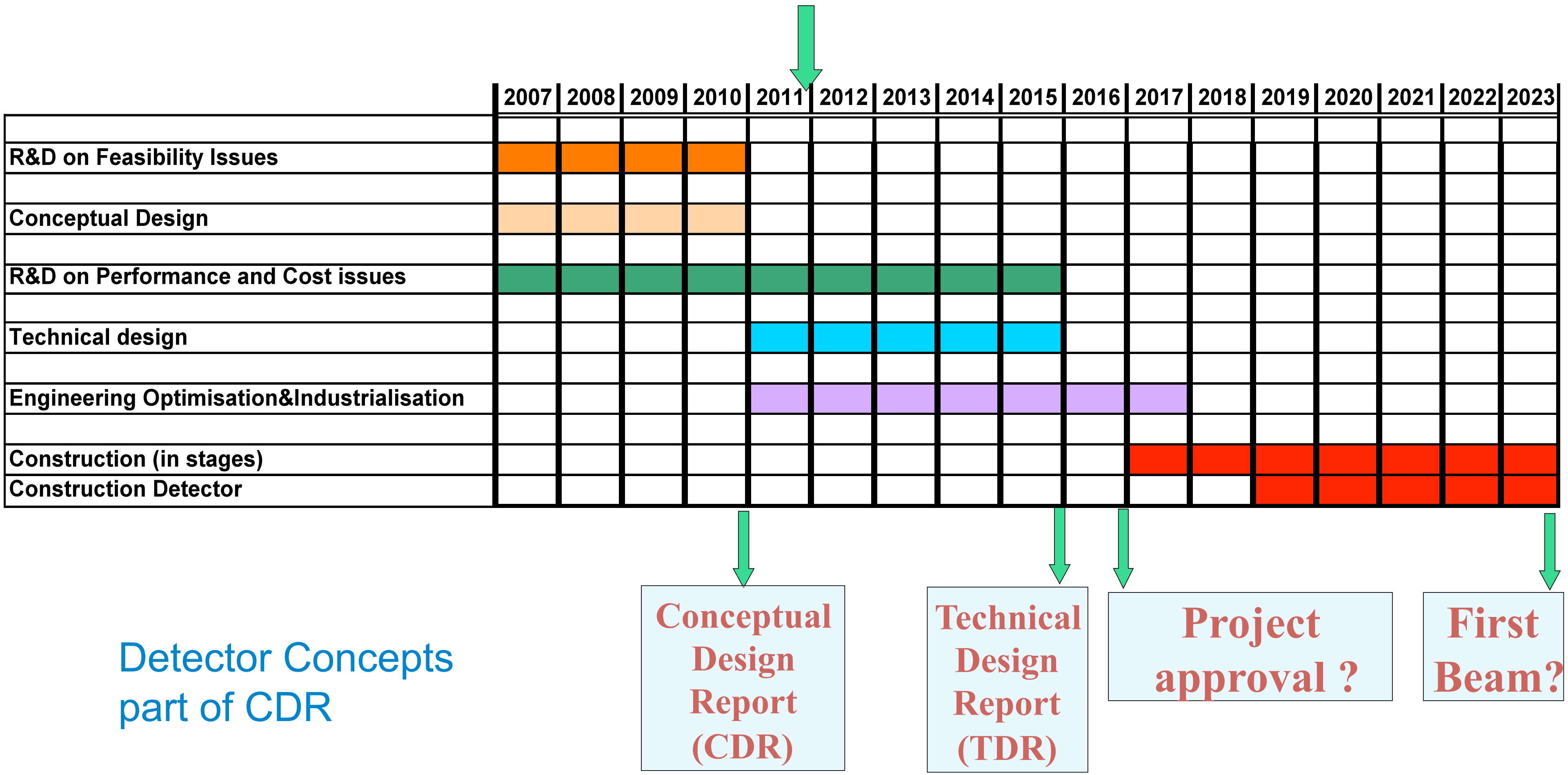


CLIC

Tentative long-term CLIC scenario

Shortest, Success Oriented, Technically Limited Schedule

Technology evaluation and Physics assessment based on LHC results
for a possible decision on Linear Collider with staged construction
starting with the lowest energy required by Physics



ILC and CLIC parameters

Center-of-mass energy	ILC 500 GeV	CLIC 500 GeV	CLIC 3 TeV
Total (Peak 1%) luminosity [$\cdot 10^{34}$]	2(1.5)	2.3 (1.4)	5.9 (2.0)
Repetition rate (Hz)	5	50	
Loaded accel. gradient MV/m	32	80	100
Main linac RF frequency GHz	1.3	12	
Bunch charge [$\cdot 10^9$]	20	6.8	3.7
Bunch separation (ns)	370	0.5	
Beam pulse duration (ns)	950μs	177	156
Beam power/beam (MWatts)		4.9	14
Hor./vert. IP beam size (nm)	600 / 6	200 / 2.3	40 / 1.0
Hadronic events/crossing at IP (γγ interactions)	0.12	0.2	2.7
Incoherent pairs at IP	$1 \cdot 10^5$	$1.7 \cdot 10^5$	$3 \cdot 10^5$
BDS length (km)		1.87	2.75
Total site length km	31	13	48
Total power consumption MW	230	130	415

Crossing Angle 20 mrad (ILC 14 mrad)

For physics, most important difference between ILC and CLIC is bunch separation: 370 ns vs 0.5 ns!
Hadronic background scales with total luminosity and energy.

ILC and CLIC parameters

ILC vs CLIC at 500 GeV:

- Luminosity expected to be the same
- ILC: BX every 370 ns in a train of 2600 bunches, rep rate = 5 Hz
- CLIC: BX every 0.5 ns in a train of 360 bunches, rep rate = 50 Hz

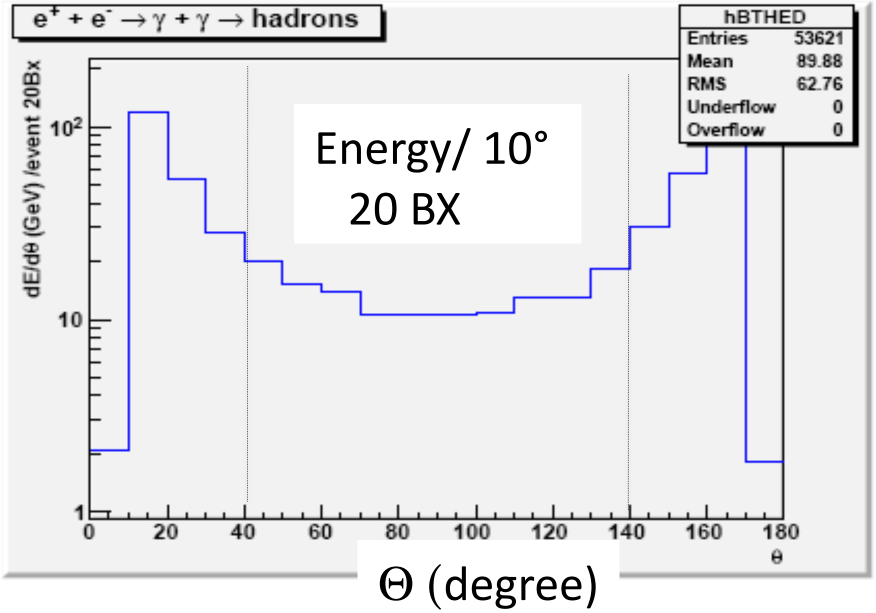
0.5 TeV $\longrightarrow$ 3 TeV CLIC

- Luminosity ratio peak/total decreases from 60% to 33%

Backgrounds

- ee→γγ→hadrons small at 500 GeV, but ≈20 times worse at 3 TeV (≈3 evts/BX)

- Pairs at IP
Always present,
2-3 times worse at 3 TeV



TeV scale Physics

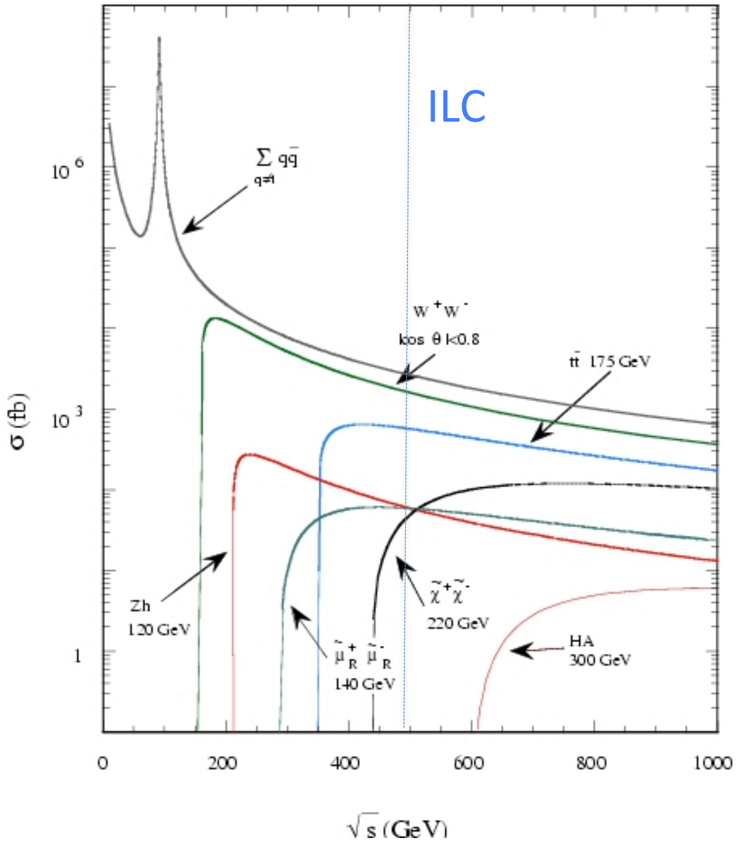
The difficulty is that we don't know what is the physics at the "TeV region" (Gian Giudice)

new phenomena at Terascale energies:

- Higgs sector
- SUSY particle spectrum (masses, Emiss, high p_T)
- extra dimensions
- etc

e.g. Precision measurements of

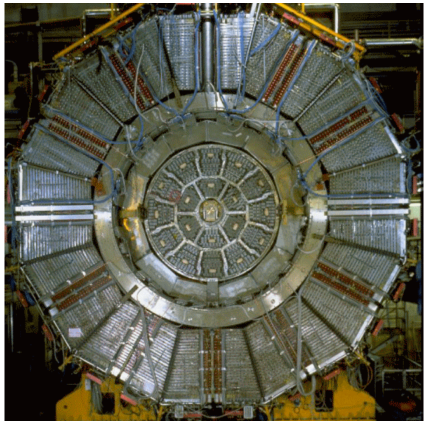
- leptons (including τ)
- Jet energy, missing mass
- W/Z separation



Evolution of Collider Detectors from LEP to LHC to ILC

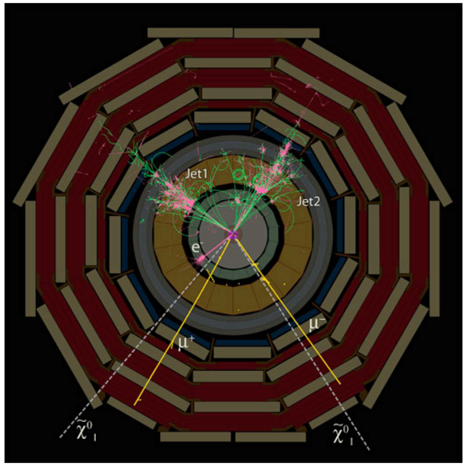
⇒ general purpose, cylindrical, magnetic "4π" detector

ALEPH @ LEP
1989-2000



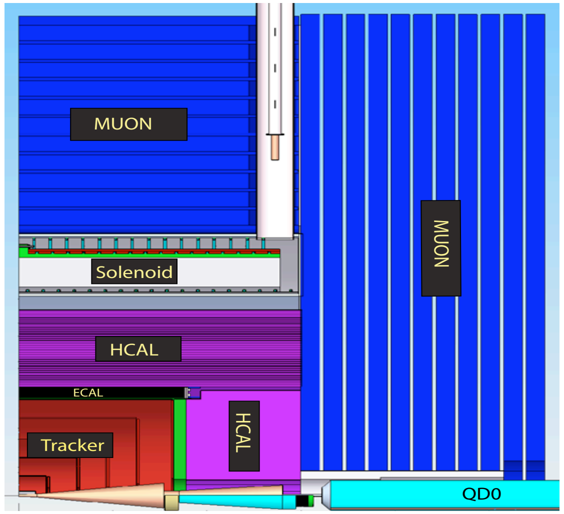
Ø = 12 m Si strip VTX TPC ECAL B=1.5 T HCAL in yoke μ system

CMS @ LHC
2009 -



Ø = 15 m Si Pixel VTX Si Strip TRK ECAL HCAL B= 4 T μ system

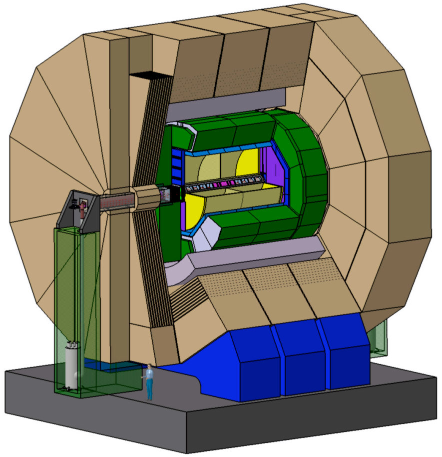
SiD or ILD @ ILC
???



Ø = 13 m Si Pixel VTX Si Strip TRK ECAL SiW HCAL B= 5 T μ system	Ø = 15.5 m Si Pixel VTX TPC ECAL SiW HCAL B= 3.5 T μ system

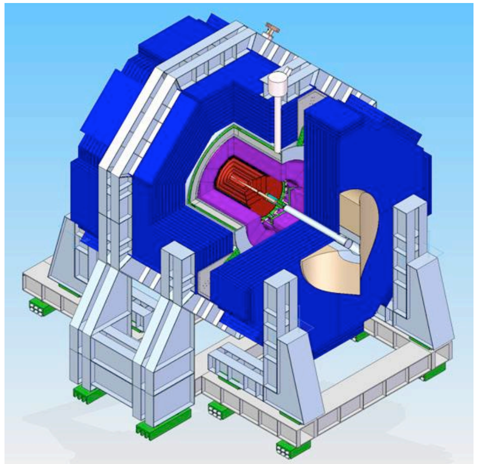
Detector Concepts

- During last decade, world wide design studies of several (=4) detector concepts for ILC @ 500 GeV.
- In 2009 international scientific committee, IDAG, (chair M. Davier) reviewed concepts and "validated" two:



ILD and SiD

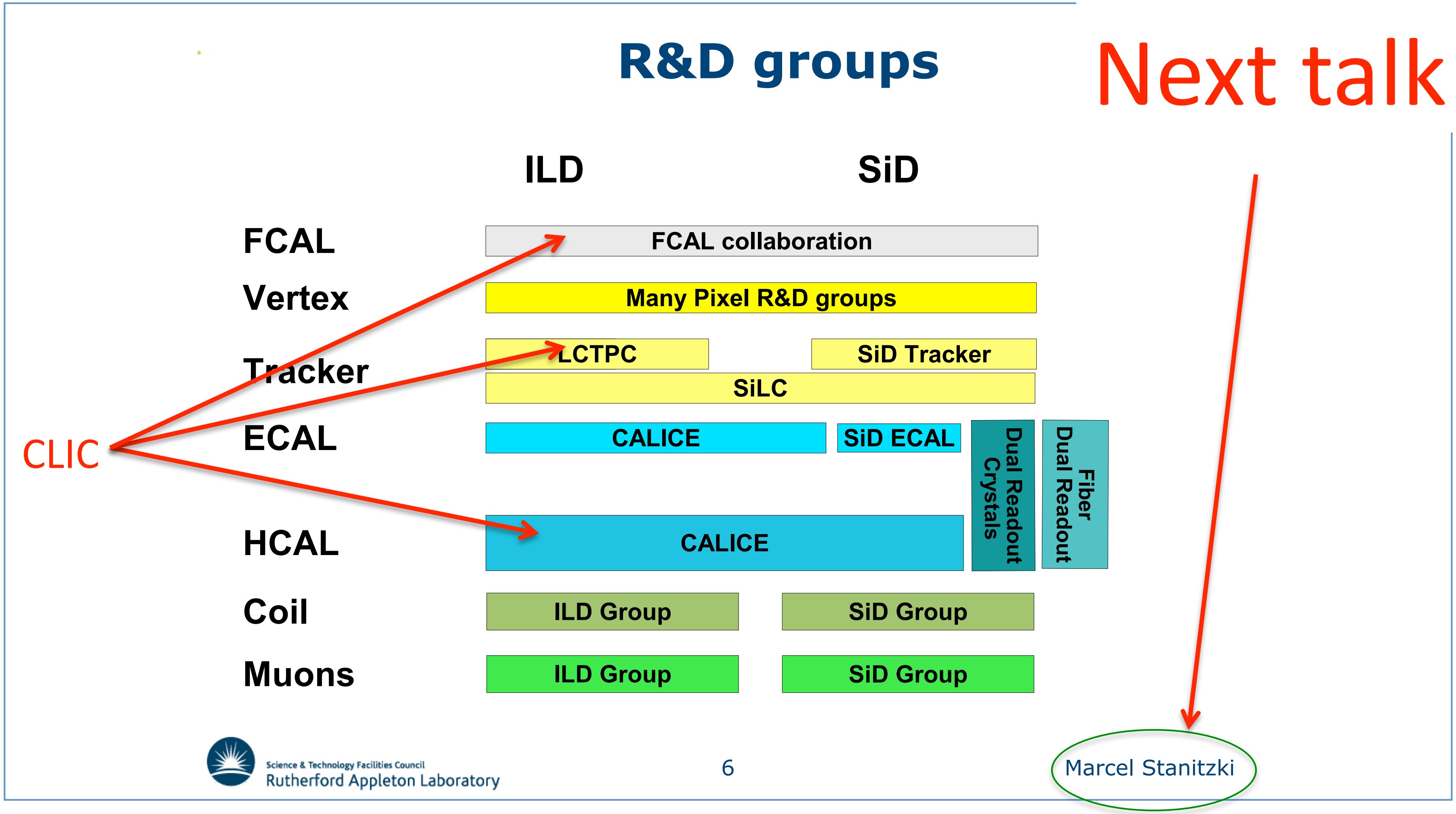
Main differences:
B field (5T / 3.5T),
coil size (r=3.3m / 2.6m)
and tracking (TPC / SiStrips)



- Studies of CLIC detector concepts under way, starting from those two concepts with modification for 3 TeV and CLIC machine conditions

Detector R&D

Much work is on going, even across concepts.
CLIC group has joined too.



General considerations

- Radiation hardness (almost) not a problem.
  Exception inner layer of vertex detector and very forward calorimeters.

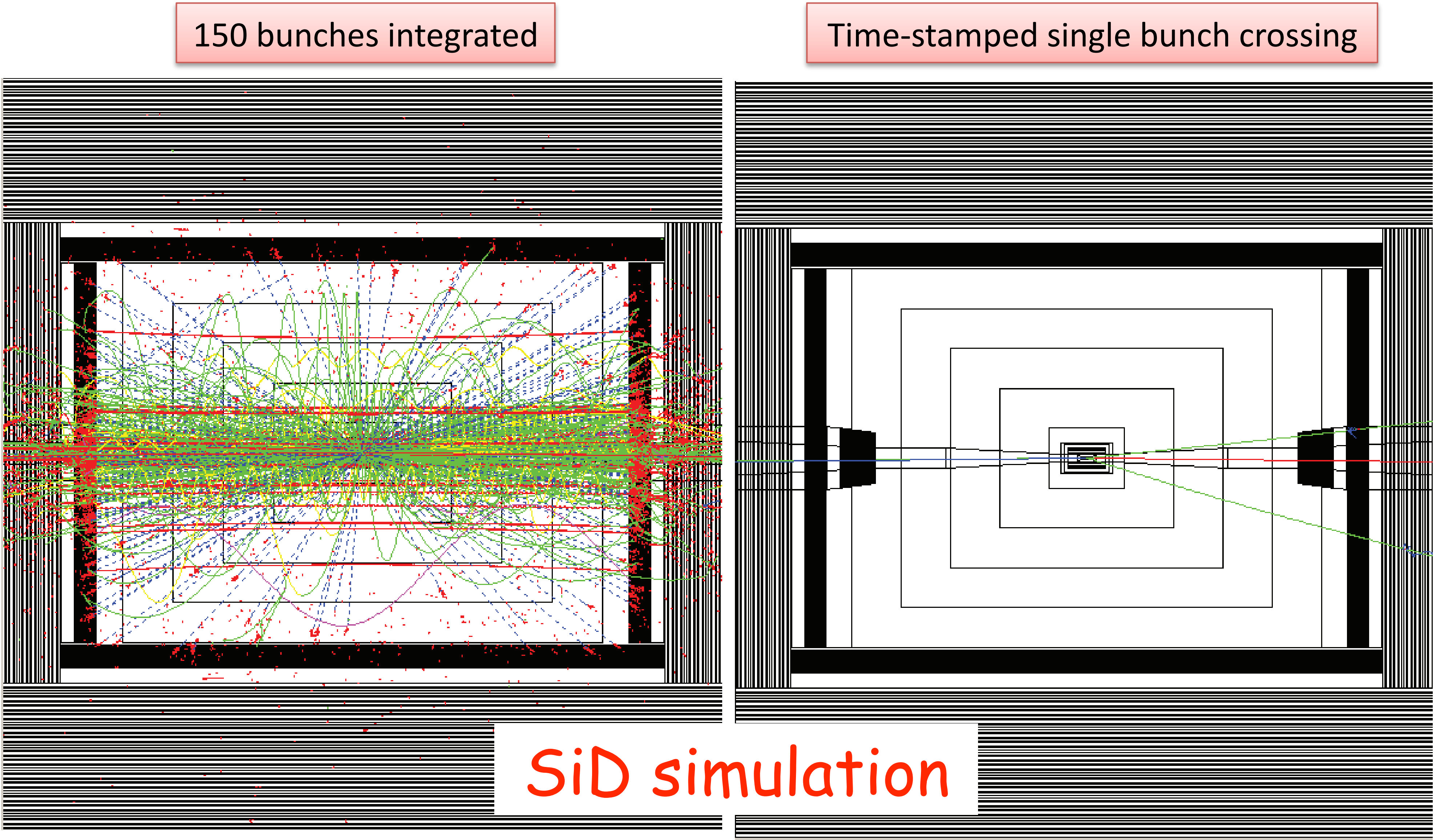
- But material of tracking devices! $2X_0$ @ LHC to 0.1% X_0 @ ILC
  Only gas cooling?

- Background (LC not as clean as LEP):
  - pair background ⟹ strong B field
  - hadronic events from $\gamma\gamma$-interactions ⟹ time stamping

  Gets worse with increasing E_{cm}

- no special trigger, read full train, but with time stamping.
  ILC all bunches are identified (300ns)
  CLIC more difficult, (10ns identification = 20 bunches)

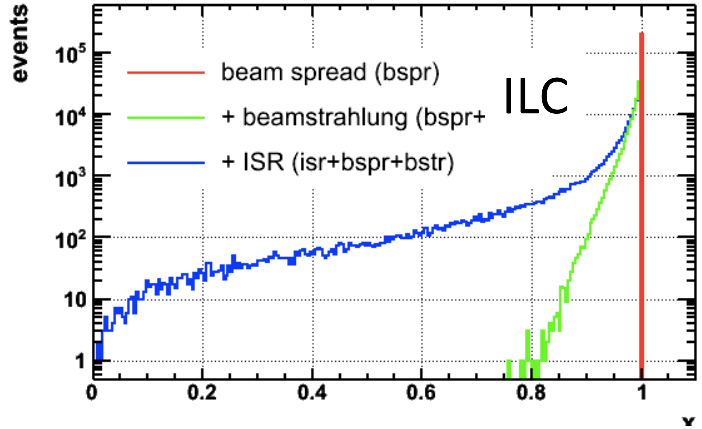
Time Stamping



Luminosity and backgrounds

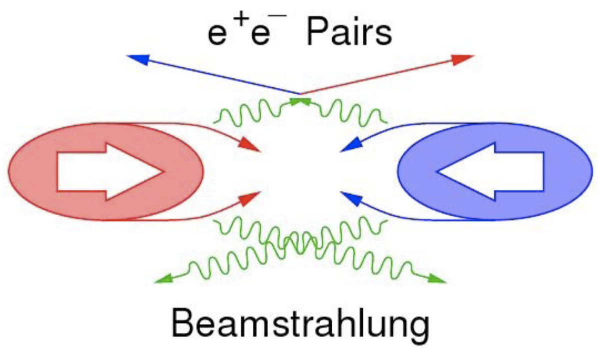
Luminosity spectrum:

- Initial state radiation
- Small beam profile at IP leads to very high E-field
  - Beamstrahlung



Beam related background:

- Beamstrahlung
  - Pair-background
  - Effect 3 times larger at CLIC



$ee \rightarrow \gamma\gamma \rightarrow$ hadrons background:

- at 500 GeV 0.2 evts /BX
- at 3 TeV ≈3 "visible" evts / BX
- Important, since sub-detectors will integrate over several BXs

ILC Detector Requirements

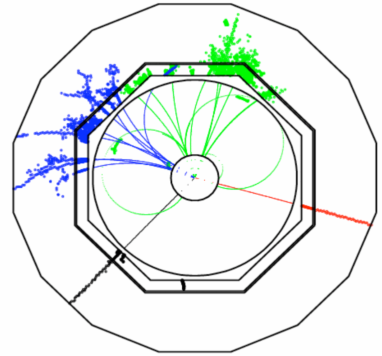
M. Thomson

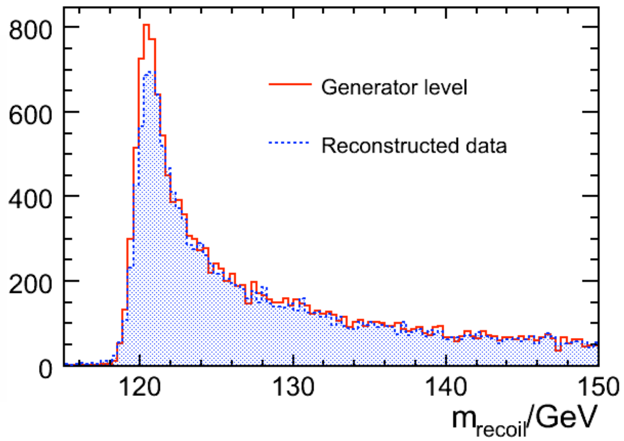
★ momentum: (1/10 x LEP)

e.g. Muon momentum
Higgs recoil mass

$$\sigma_{1/p} < 5 \times 10^{-5}\,\mathrm{GeV}^{-1}$$

$e^+e^- \to HZ$

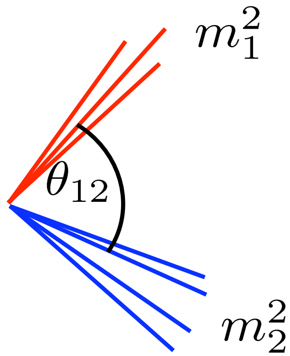


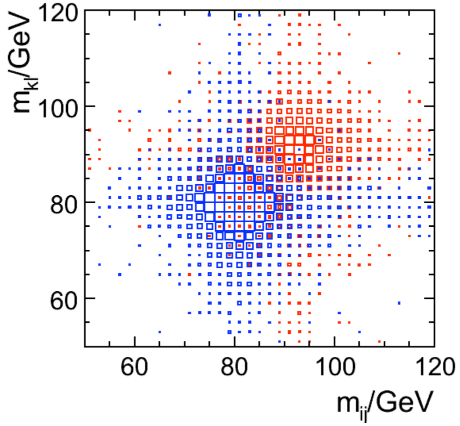


★ jet energy: (1/3 x LEP/ZEUS)

e.g. W/Z di-jet mass separation
EWSB signals

$$\frac{\sigma_E}{E} \approx 3-4\,\%$$

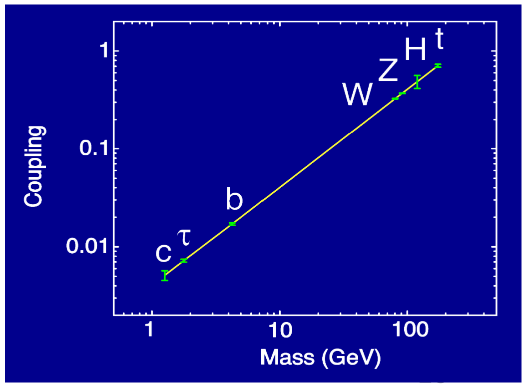




★ impact parameter: (1/3 x SLD)

e.g. c/b-tagging Higgs BR

$$\sigma_{r\phi} = 5 \oplus 10/(p \sin^{\frac{3}{2}}\theta)\,\mu\mathrm{m}$$



★ hermetic: down to θ = 5 mrad

e.g. missing energy signatures in SUSY

From ILC to CLIC Detector Requirements

On assumption that CLIC would be staged: e.g. 500 GeV → 3 TeV

- Must meet all ILC detector goals
- Hence ILD and SiD represent good starting points
- Requirements for 500 GeV are VERY demanding, may still be ok at 3 TeV.

What are the detector requirements at 3 TeV?

- Still want to separate W/Z hadronic decays → good jet energy resolution
- Heavy flavour-tagging still will be important; → good vertex resolution
  heavy new bosons decay to b quarks,
  higher boost of b/c-hadrons will help.
- Measure high p_T muons in cascade decays of heavy new particles
  → good momentum resolution

First studies indicate that ILC requirements are
sufficient and necessary
for physics at 3 TeV

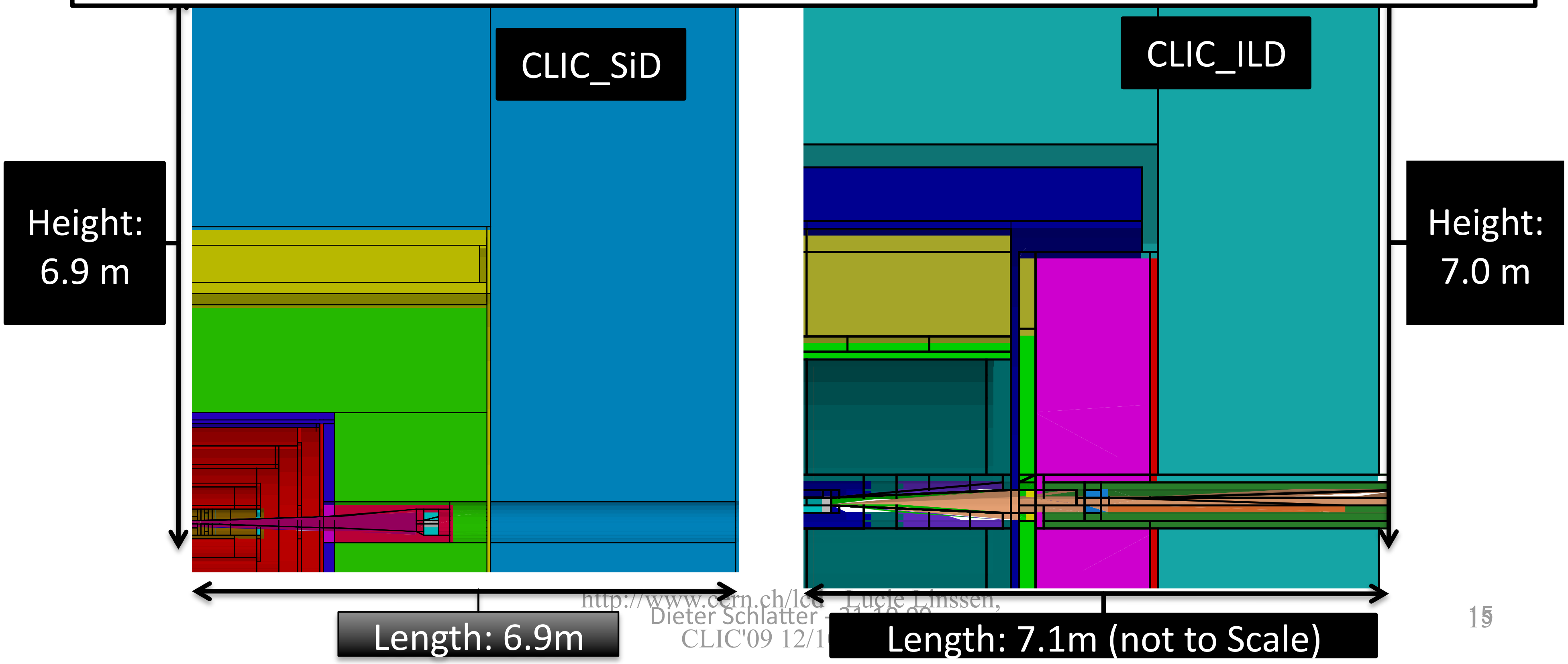
From ILC to CLIC Detectors

Andre Sailer

- CLIC 3 TeV detector models using SiD and ILD geometries

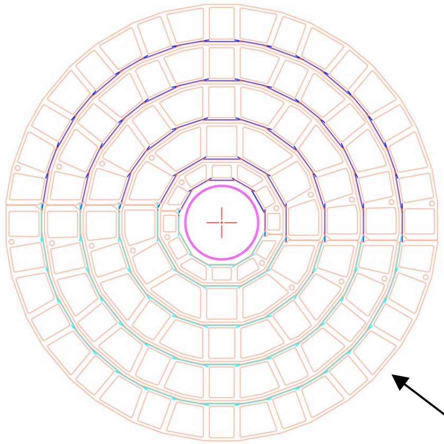
Changes:

- 20 mrad crossing angle (instead of 14 mrad)
- Vertex Detector to ~30 mm inner radius, due to Beam-Beam Background
- Hadron Calorimeter, more dense and deeper (7.5 λ_i) due to higher energetic Jets
- For CLIC_SiD: Moved Coil to 2.9m (CMS Like)

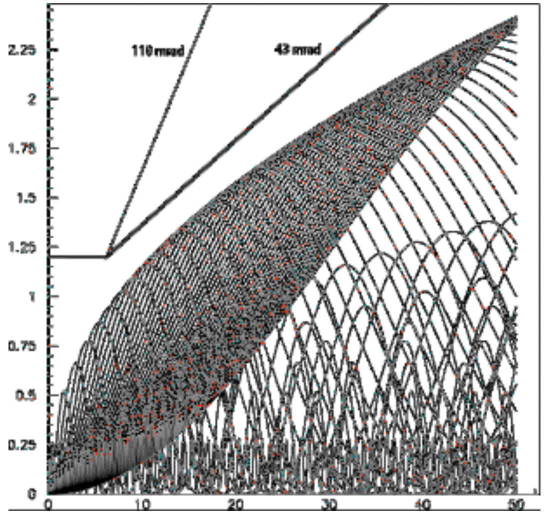


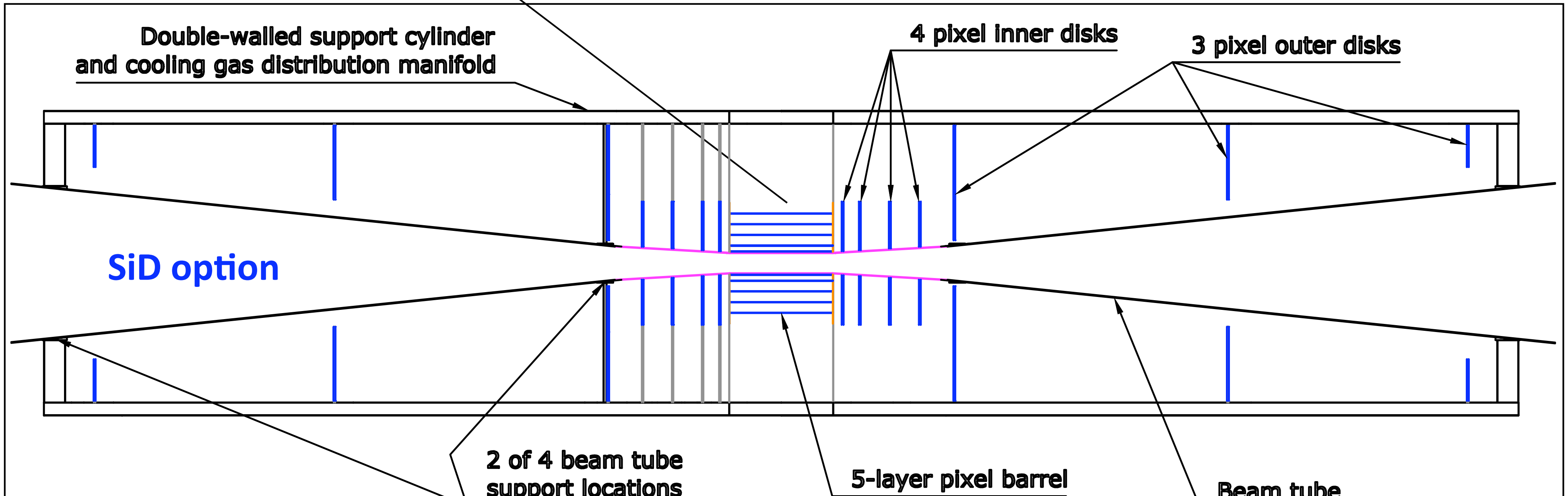
Vertex Detector

Rin = 15mm
Rout = 60mm



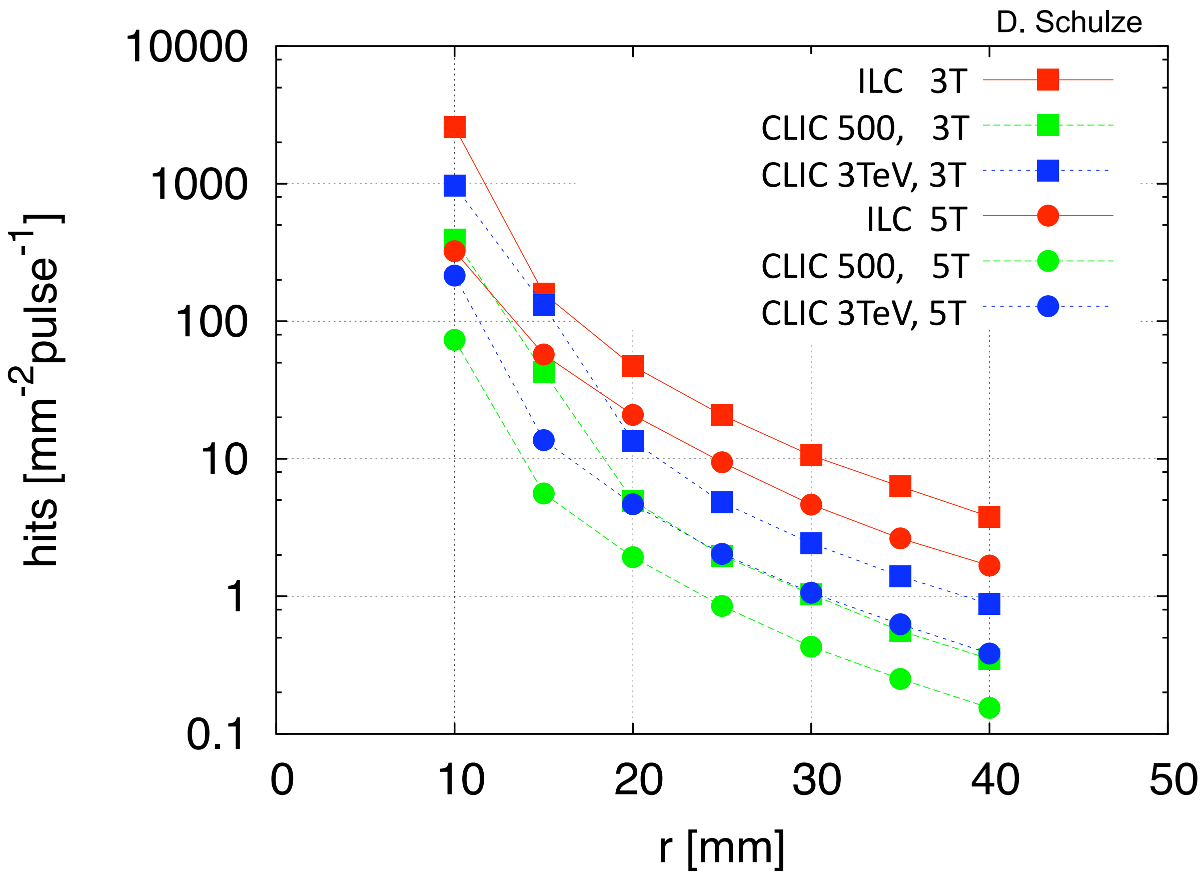
- ILD and SiD assume Silicon pixel (5 single or 3 double layers)
- Gas cooled (Barrel 20 Watts!)
- Power pulsed
- low mass system (0.1% X_0 / layer)
- Several sensor technologies
- Infrared laser for alignment





Vertex Detector

VTX detector occupancy due to pair background
for ILC and CLIC and B=3T and 5T

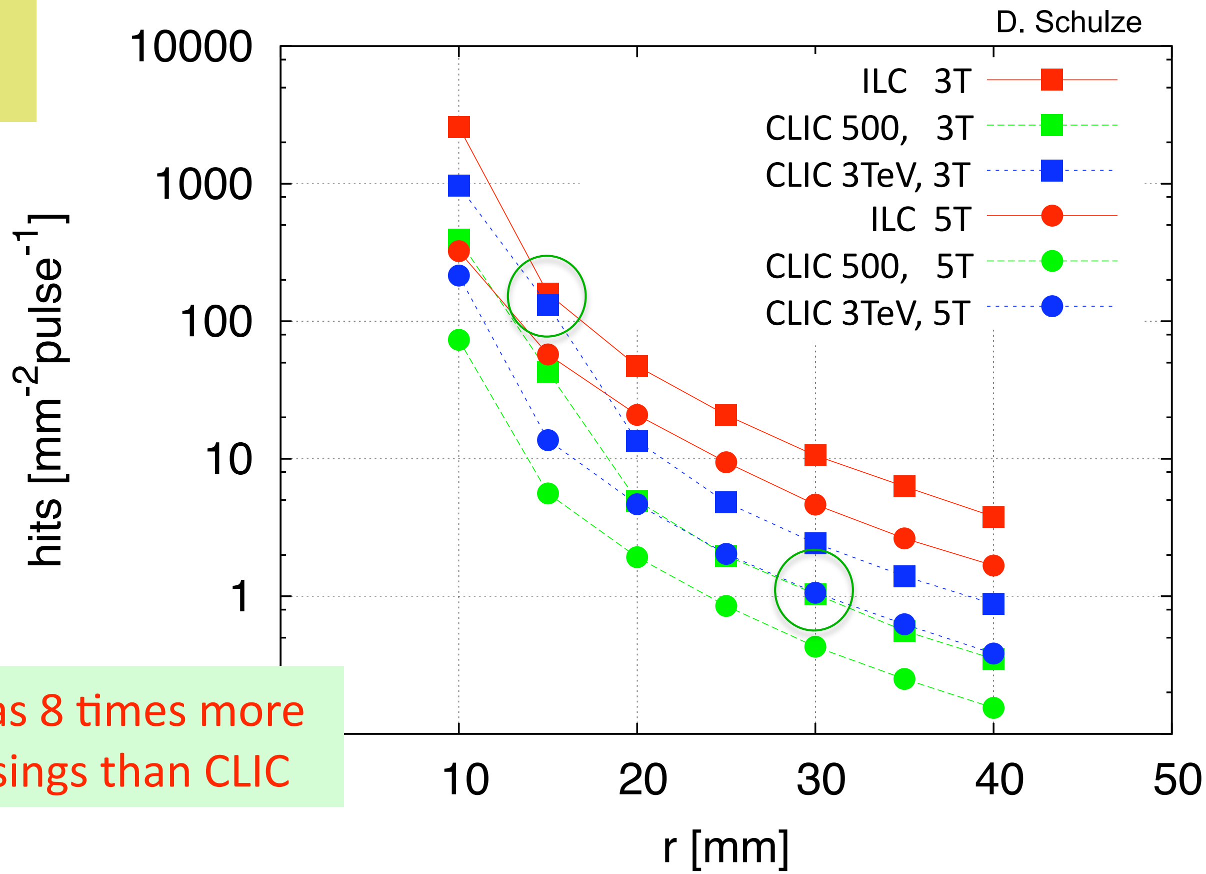


Vertex Detector

ILC pulse
= 2500 bunches

CLIC pulse
= 300 bunches

VTX detector occupancy due to pair background
for ILC and CLIC and B=3T and 5T

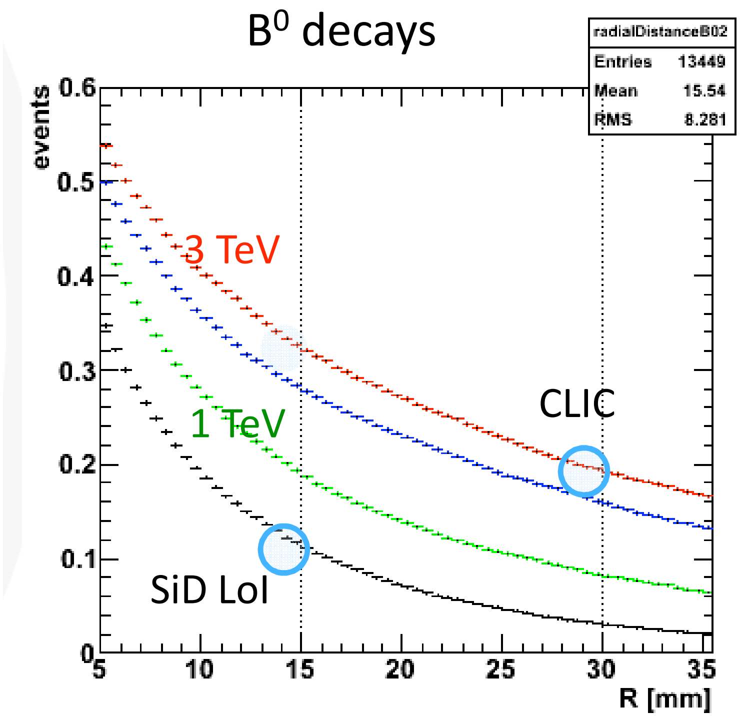


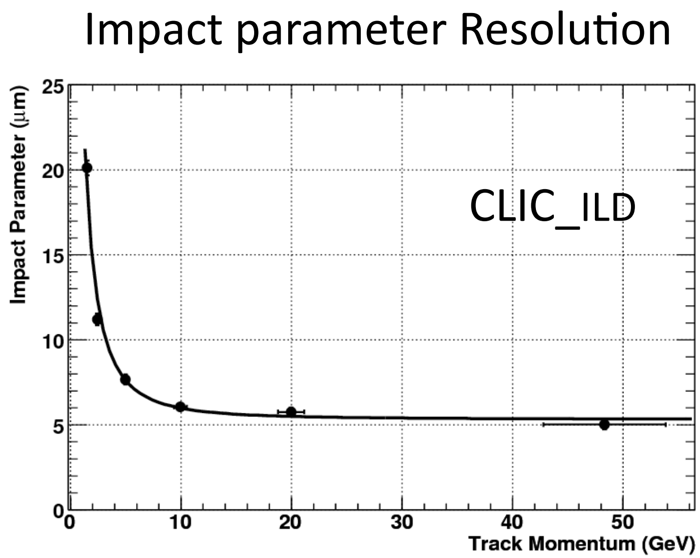
ILC pulse has 8 times more bunch crossings than CLIC

BUT

In addition ≈ 2 hits / mm^2 from particles backscattered upstream.

Vertex Detector





≈ 12% of B^0 decay after 15mm
(ILC, VXT 1st layer)

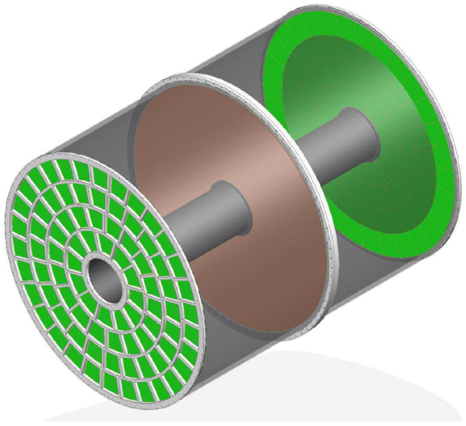
≈ 20% after 30mm @ 3TeV.

P > 10 GeV: $\sigma_{IP} \approx 5\ \mu m$

Tracking

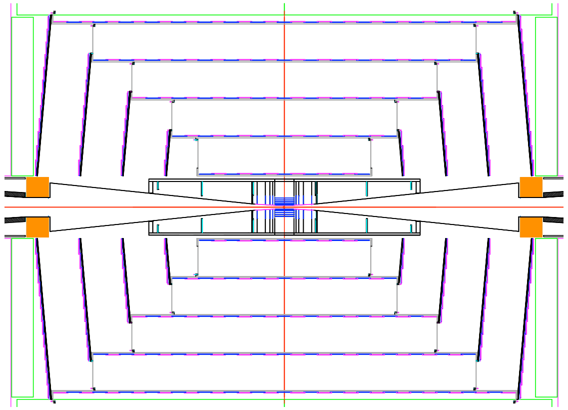
<u>Two options:</u>

- ILD: Time Projection Chamber



- ♦ New technology for read out
- ♦ Large number of space points (>200)

- SiD: Silicon tracker (5 layers)



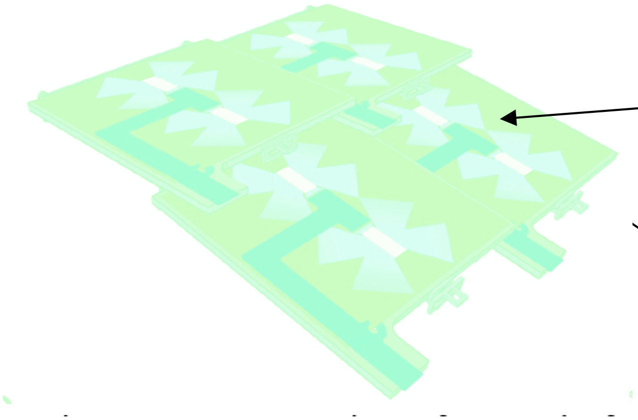
- ♦ Few very well measured points

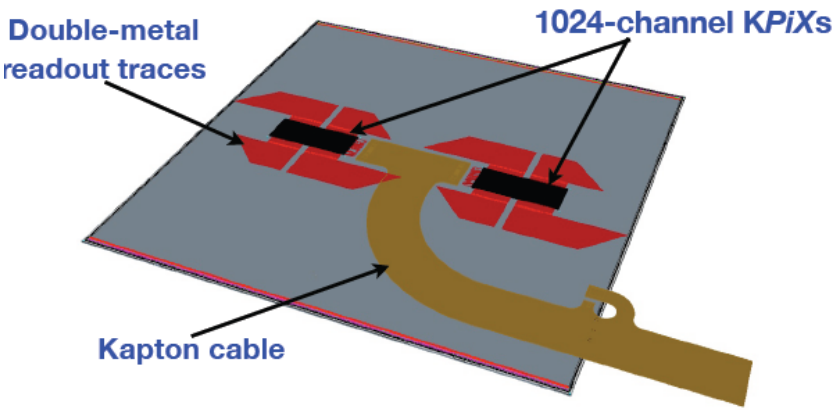
Studies show that both result in :

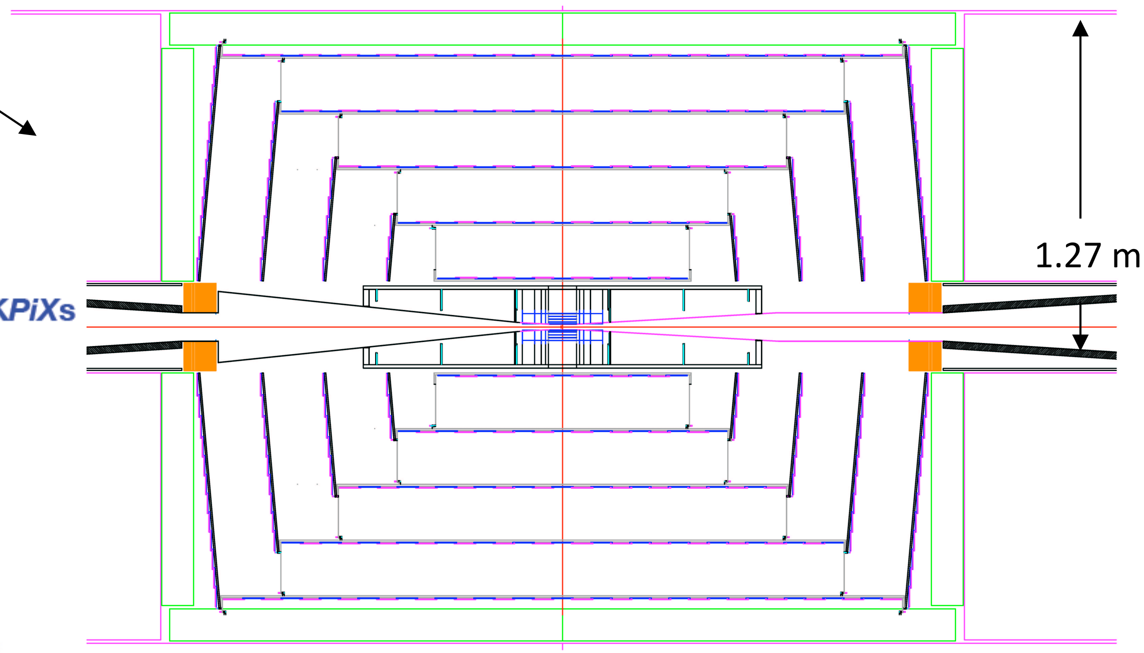
- very high track reconstruction efficiency
- excellent momentum resolution: $\sigma_{1/p} < 5 \times 10^{-5}\,\mathrm{GeV}^{-1}$ (high p_T tracks)

Tracker - SiD option

~100 m^2 Si Strips: Barrel single sided (r- ϕ); endcaps double sided





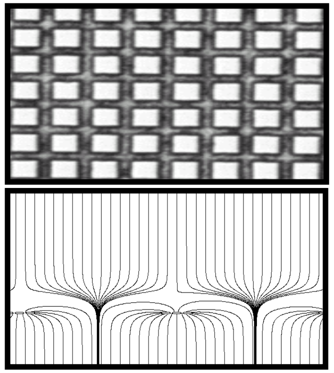


~10 cm x 10 cm; 320 μm thick; 25 μm pitch; 0.07 X_0
S/N > 20; ~5 μm hit resolution
Bump bonded readout chip; no hybrid
Pulsed Power: 20 μW/channel avg; ~600 W for 30 M channels; gas cooling

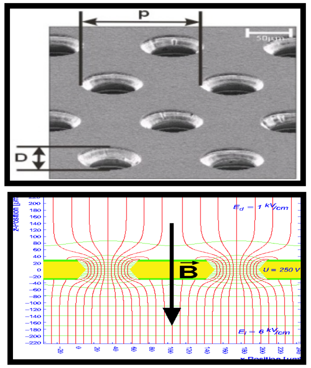
TPC - ILD option

Large TPC with many samples (>200), 3 read out technologies under tests

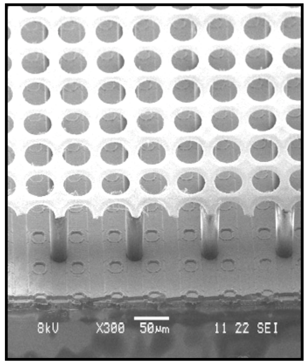
MicroMEGAS

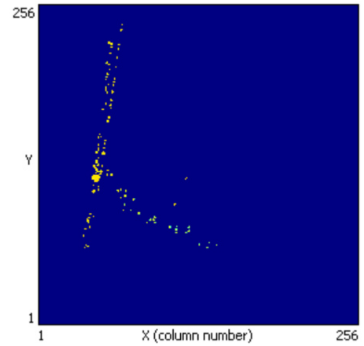


GEM



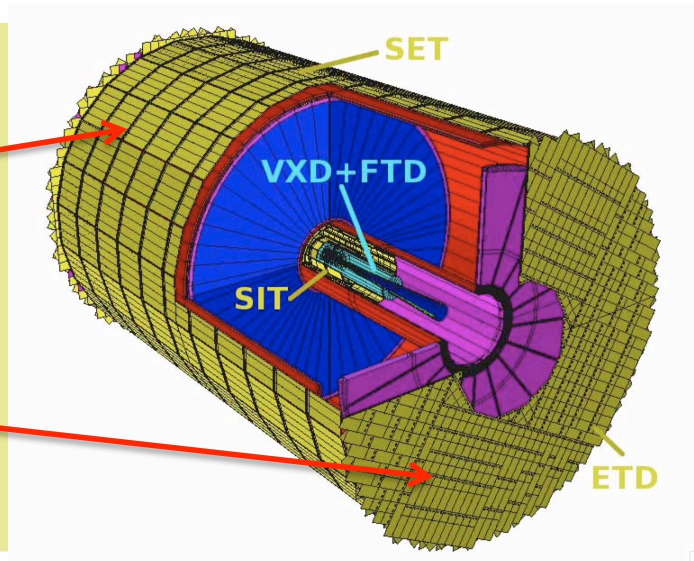
Ingrid TimePix





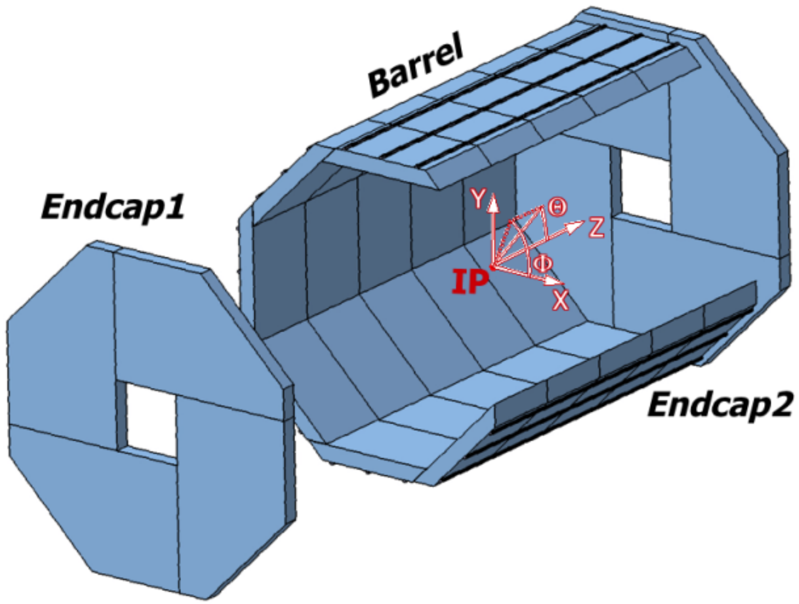
Momentum resolution improved by additional layers of Si detectors

- Si External Tracker (SET)
  - between TPC and barrel ECAL
  - Single layer of false-double-sided Si strip
- Endcap Tracking Detector (ETD)
  - between TPC end plate and endcap ECAL
  - 3 layers of single-sided Si strip (XUV)



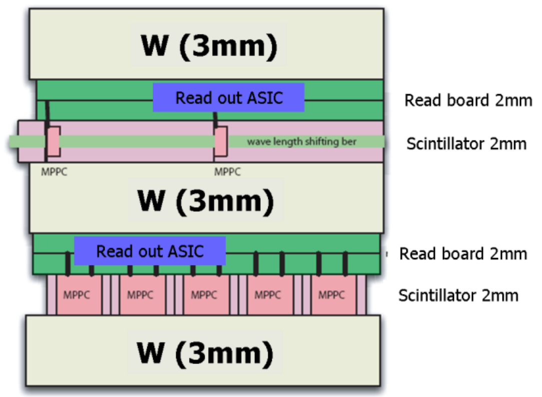
ECAL Si-W sampling/imaging

- 20 layers 2.5 mm W (5/7 X_0)
- 10 layers 5 mm W (10/7 X_0)
- 30 gaps Si pixel or strip sensors
  ILD: 5x5 mm^2; SiD: 1.3 mm^2
- 26 X_0; 1 λ_I
- $\Delta E/E = 17\%/\sqrt{(E)}$;
- Effective Moliere radius = 14 mm



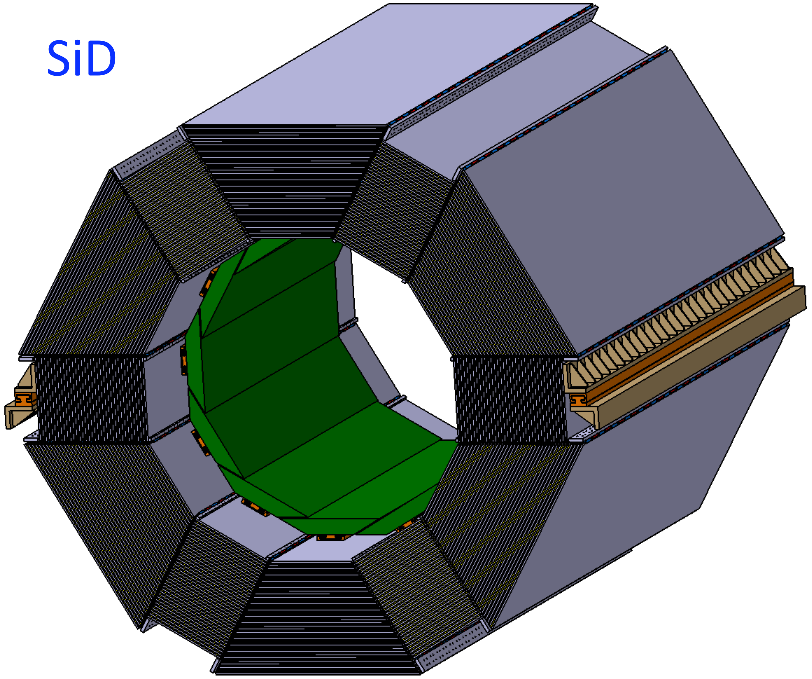
Powerful, very finely segmented, but costly!

Alternative option
ECAL with
W + Scintillator strips
4x1cm^2 x-y strips
→ R&D
Is performance good enough?

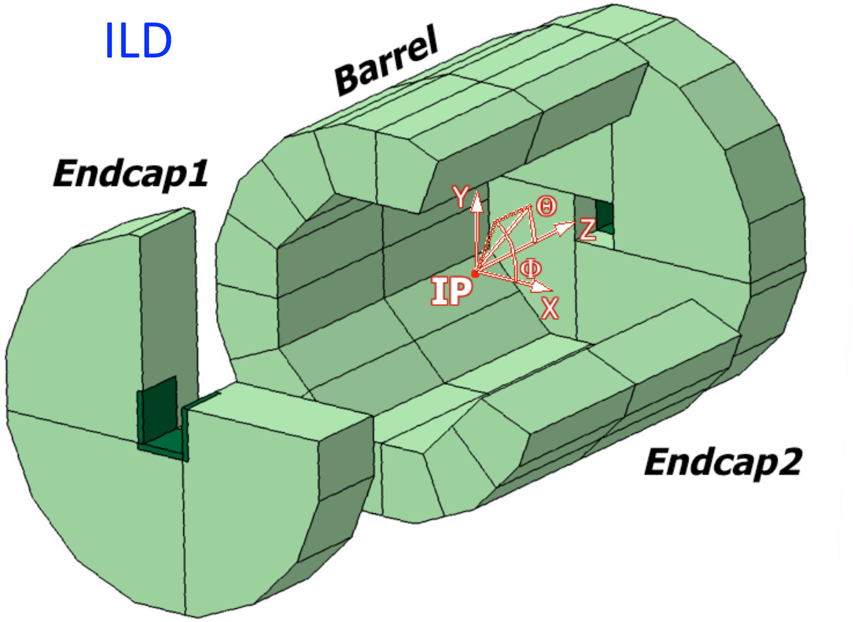


HCAL
Steel-gas/scintillator sampling

SiD



ILD



40 layers, 4.5 , λ_{int}

48 layers, 5.3 , λ_{int}

Stainless Steel Absorber

HCAL, detector options

Scintillator (analog HCAL) or gaseous device (digital HCAL) for active layers, $\Delta E/E \approx 50\%/\sqrt{(E)}$

ILD HCAL option

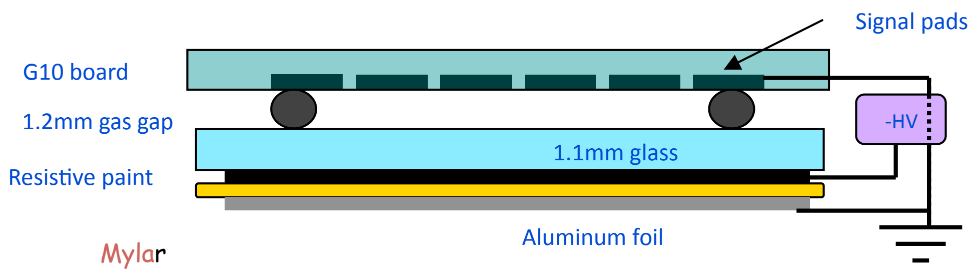
- $3 \times 3\ cm^2$ scintillator tile with 3mm thickness, SiPM readout.

  Or gaseous detectors (RPC)

SiD HCAL option

- $1 \times 1\ cm^2$ glass resistive plate chamber (GRPC) with readout pads.

  Or GEMs, Micromegas

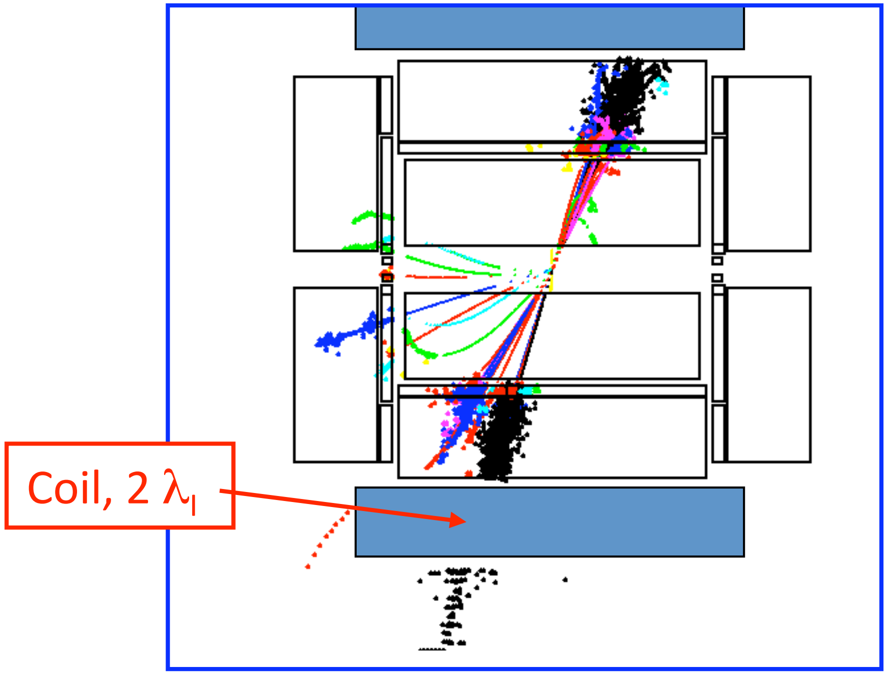


At 3 TeV (CLIC)

To avoid leakage use denser absorber than steel → tungsten ?

HCAL at 3 TeV

- At a Multi-TeV collider, leakage of hadronic showers is an issue
- HCAL in ILD (5.3 λ_I) and SiD (4.5 λ_I) too thin to contain 1 TeV showers



Probably need ~8 λ_I HCAL+ECAL for CLIC energies

- but needs to be inside Solenoid, current ILD concept: 7.4m diameter !
- ⇨ Denser absorber, e.g. replace steel with Tungsten as absorber. Costs ? Barrel only?

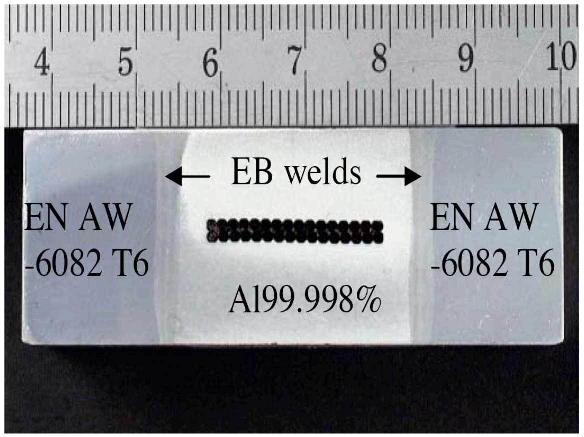
ECAL = 1 λ_I

e.g.
ILD: HCAL of 130 cm depth and sampling of 2cm Fe + 1cm gap $\Longrightarrow$ 5.3 λ_I
but with tungsten: 1cm W + 1cm gap $\Longrightarrow$ 6.5 λ_I

Superconducting Solenoid

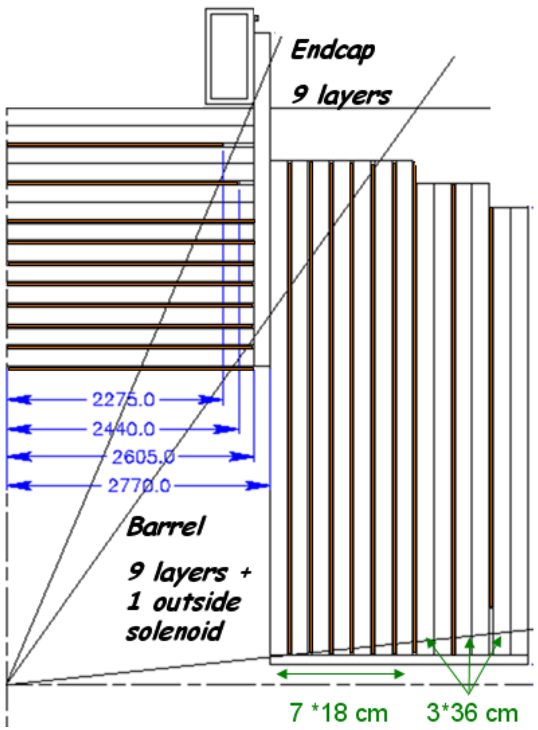
- Following experience of CMS 4T solenoid (r_{in}=3m)
- Due to TPC dimensions, ILD chose large (r_{in}=3.4 m) coil for 3.5 T
- SiD chose 5 T with r_{in}=2.6 m (cost optimum!)
- Coils are thick, 2 λ_I

- R&D on stronger conductor has started



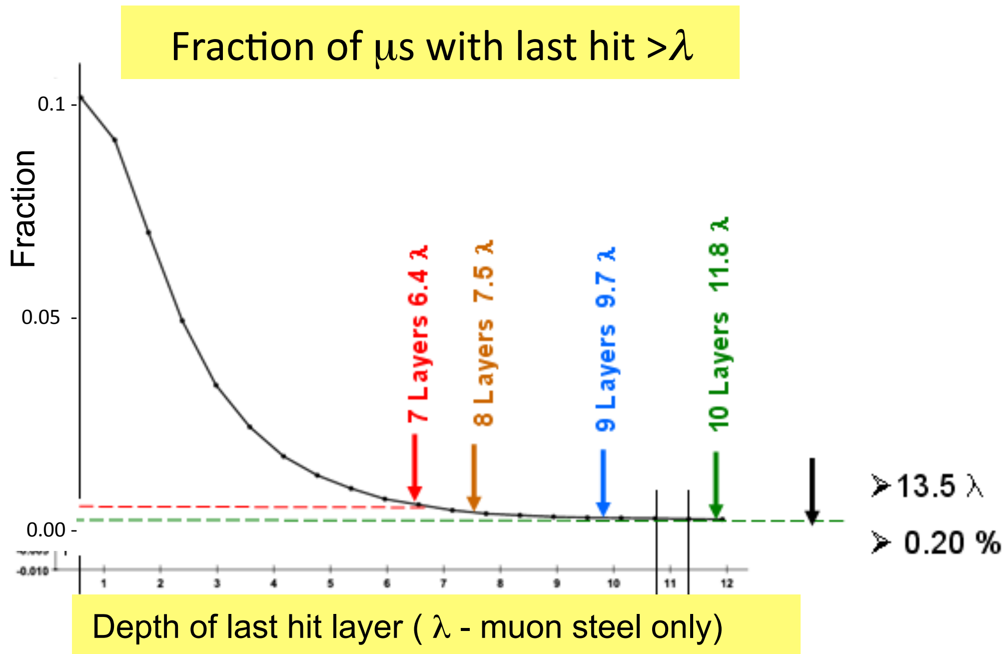
Or advanced conductor designs

Muon /Flux Return



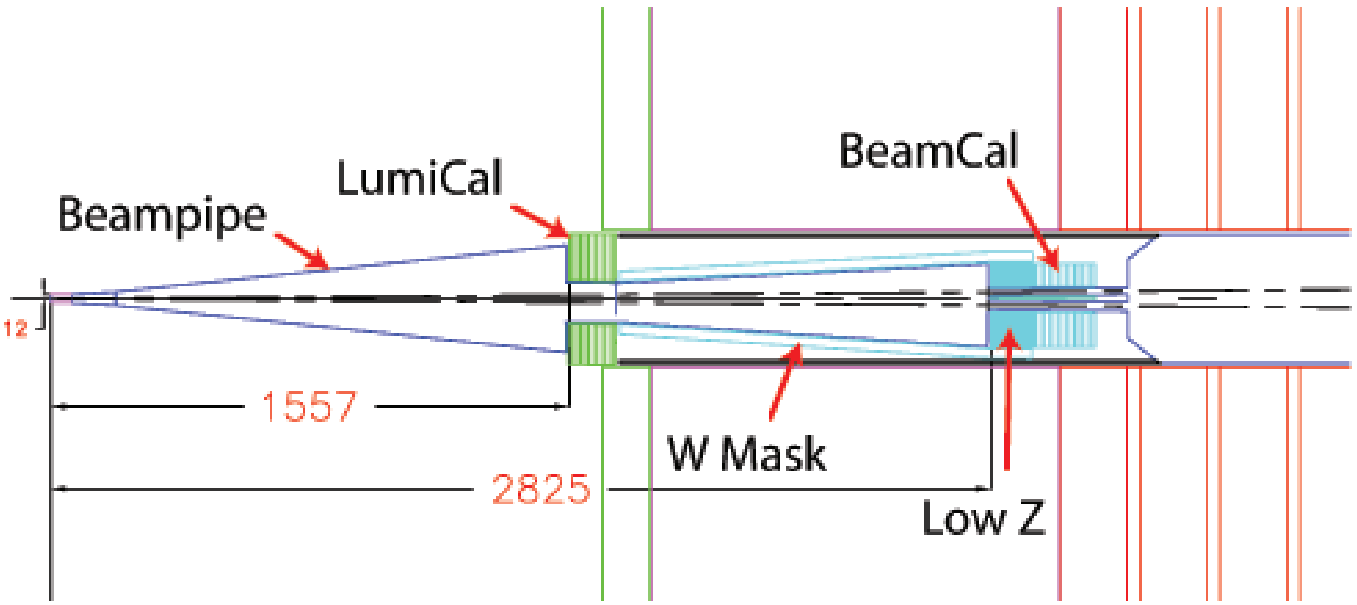
SiD concept

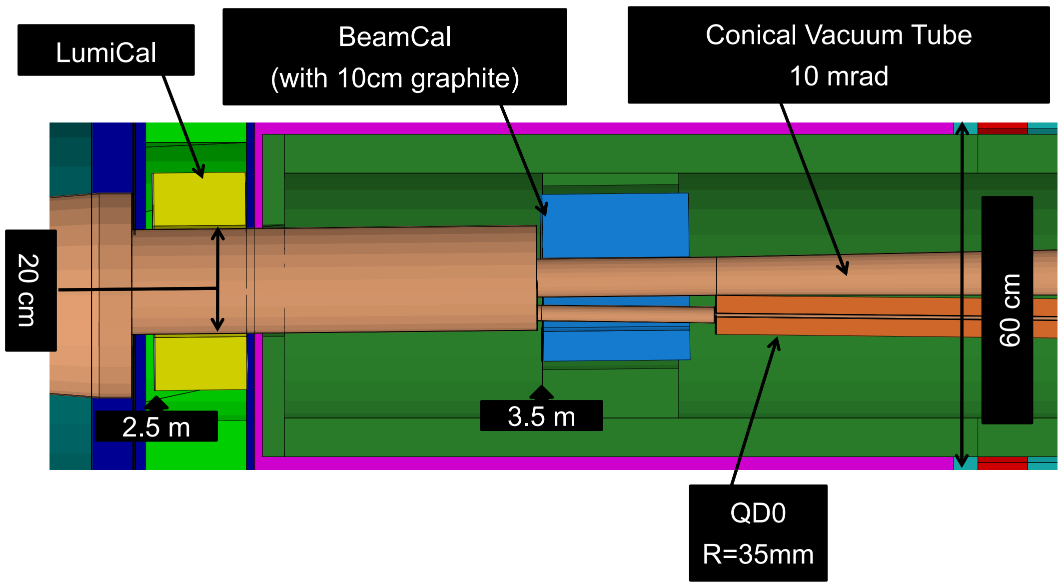
- 11 layers
- ECAL + HCAL + Solenoid = $5.5\lambda_I$
- Muon = 13 λ_I



- Steel thickness determined by flux return requirements
- Modest detector resolution needs can be met by scintillator strips or RPCs

Forward Detectors





LumiCal
measure luminosity

BeamCal
Feedback to accel.
Electron veto
QD protection

Particle Flow Algorithm

- Try best estimate of energy and momentum for each visible particle in the event for best jet reconstruction.
- "Energy Flow" concept of LEP and HERA detectors can be improved with calorimeters with much finer segmentation.

In a typical jet :

- 60 % of jet energy in charged hadrons
- 30 % in photons (mainly from $\pi^0 \rightarrow \gamma\gamma$)
- 10 % in neutral hadrons (mainly n and K_L^0)

Energy / Particle Flow algorithm:

- charged particles, measured in tracker
- Photons in ECAL:
- Neutral hadrons (ONLY) in HCAL
- Only 10 % of jet energy from HCAL !

LEP calorimetry
$\sigma_E/E \approx 0.6 / \sqrt{E(GeV)}$

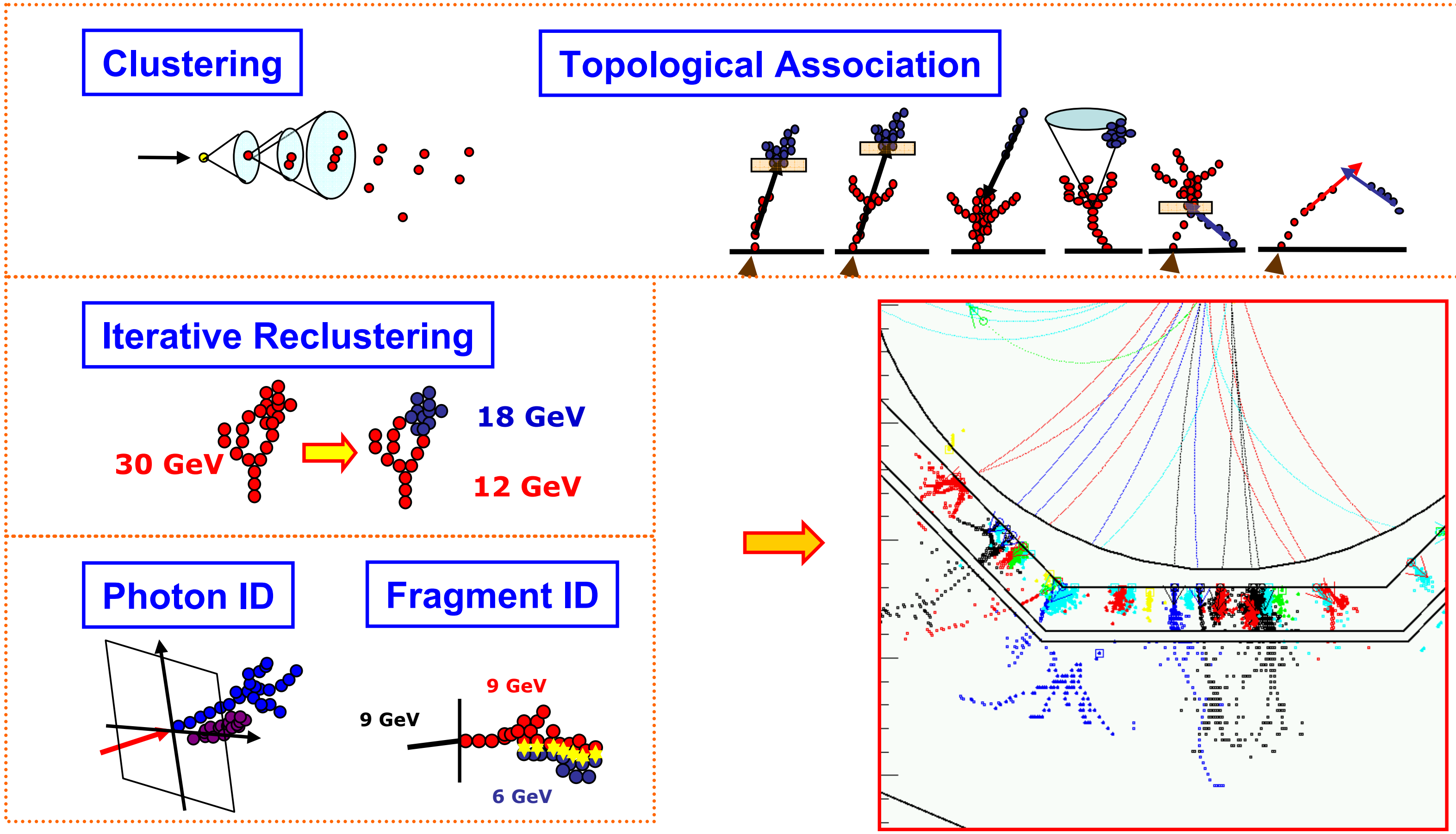
Better momentum resolution → Much better calorimetry

ILC GOAL:
$\sigma_E/E \sim 0.3/\sqrt{E(GeV)}$

Particle Flow Algorithms in practice

★ **Highly non-trivial !**

e.g. **PandoraPFA** consists of a number complex steps (not all shown)



Particle Flow Algorithm

Jet energy resolution: Goal σ_E/E = 3 - 4 %

Simulations for ILD and SiD

E_{JET}	σ_E/E (rms$_{90}$)	
	ILD	SiD
45 GeV	3.7 %	5.5 %
100 GeV	2.9 %	4.1 %
180 GeV	3.0 %	4.1 %
250 GeV	3.1 %	4.8 %

M. Thomson
ALCPG 2009

At 3 TeV ?

ILD B=3.5 T, absorber = 6 λ_I

500GeV	4.1 %

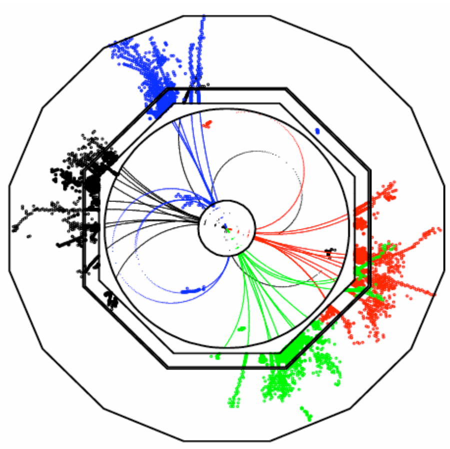
CLIC_ILD B=4 T, absorber = 8 λ_I

500GeV	3.5 %

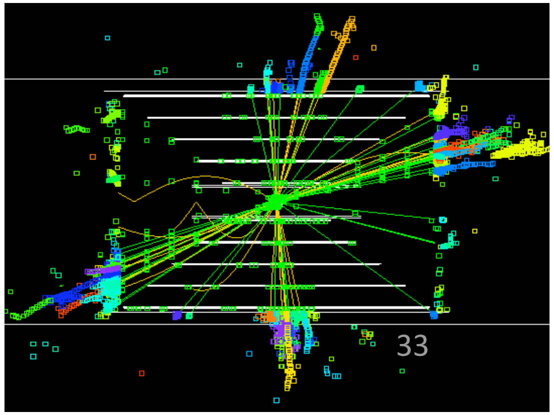
Looks promising ! How can one test this with data?

Conclusion

- Impressive work on conceptual design for ILC detector done.
- Convergence on two concepts: ILD and SiD
- Work to understand adaptation to 3 TeV and CLIC beam conditions has started.
- Physics requirements lead to high resolution tracking and highly segmented calorimetry.
- Particle Flow Algorithm is major tool in event reconstruction and detector optimization.
- R&D activities have addressed many topics but



new ideas will come,
things will still change,
a lot is still to do.



Interesting idea !

Replace ½ of end cap iron yoke by magnet
→ reduce weight and make detector shorter