Detector Concept for CLIC

Dieter Schlatter / CERN

Context

Expect to learn from LHC which new physics at what energy scale!

If it is 1 - 3 TeV, than CLIC would be the option.

CLIC project is preparing a feasibility prove by end 2010.
(= Conceptual Design Report)

Mainly for accelerator, but detector concept(s) as well.

Max. e^+e^- energy is 3 TeV, but could start at 0.5 TeV a few years before high energy collider is completed.

Detector should be well suited for physics from 0.5 – 3 TeV

Strategy for CLIC Detector concept

- Assume CLIC running from E = 0.5 TeV up to 3 TeV
- Starting points are ILC detector concepts. Follow as much as possible ILC strategy (2 detectors, push-pull, etc)

Try to understand

- what are minimal changes for ILC detector concepts for physics at 3 TeV?

  (Major systems should not be replaced for high energy phase, while e.g. vertex detector or electronics could be replaced before going to high E)
- what are consequences of different machine parameters of CLIC as compared to ILC? *(bunch spacing CLIC: 0.5 ns, ILC: 337 ns , rep. rate..)*
- what needs to be adopted to higher energy? *(denser HCAL, longer barrel?)*
- how to cope with increased background? *(pair BG, $\gamma\gamma \rightarrow$ hadrons)*
- hardware R&D issues *(time stamping, improved SC conductor, power reduction, ...)*

Linear Collider Detector Project at CERN

(Project leader Lucie Linssen)

- Over last 6 months, CERN group has grown to about 15 people (mostly not full time)
- Started with SiD concept and now also ILD
- Excellent contact with our colleagues from SiD (LAPP, RAL, SLAC) and ILD (DESY, Cambridge) and also with 4th concept.

  Very good support from the CLIC/ILC Collaboration.
- EUDET collaboration ongoing, very successful.
- CERN has joined FCAL and CALICE and has signed the LoIs.
- Many thanks for continued help to get us up to speed.

CLIC at 3 TeV and 500 GeV

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	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)

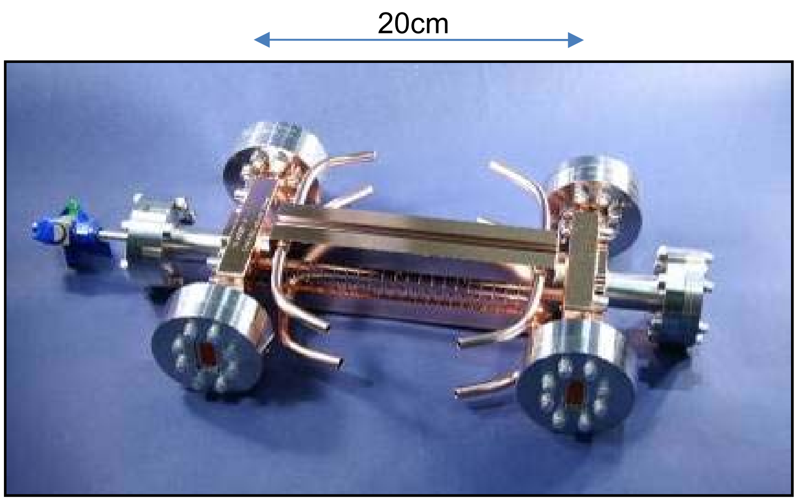
Beam-induced background

Due to the higher beam energy and small bunch sizes
beam background is more severe for CLIC at 3 TeV.

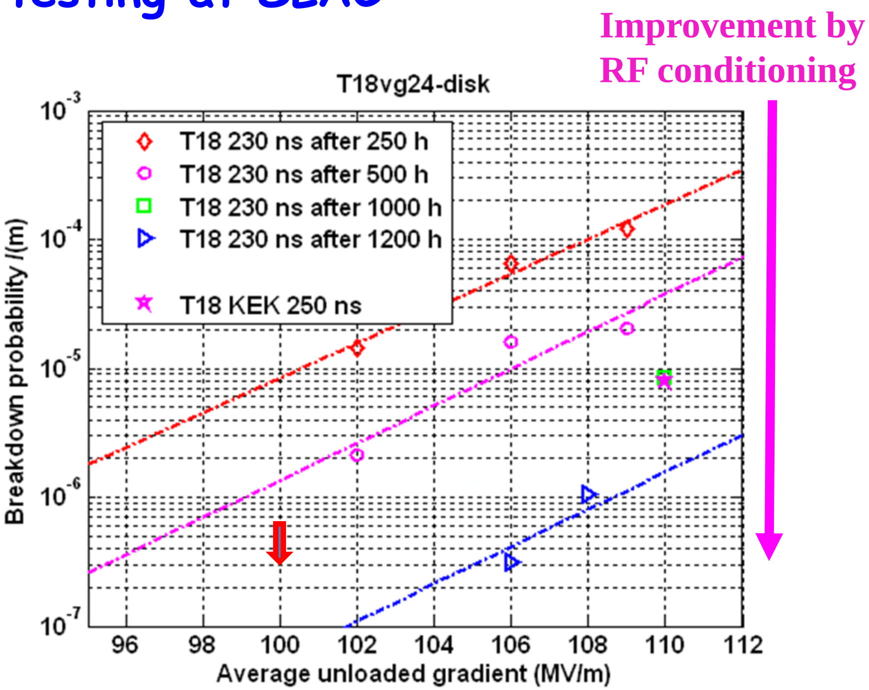
- Peak luminosity is only1/3 of total luminosity (beamstrahlung)
  $\rightarrow$ 2× worse than at 500 GeV
- Incoherent pairs (3.0×10^5 per bunch crossing)
  $\rightarrow$ 3× than at 500 GeV, but suppressed by strong B-field
- Coherent pairs (4×10^8 per bunch crossing)
  $\rightarrow$ a million times more, but disappear in beam pipe!
- γγ interactions => hadrons, 2.7/bx, $\rightarrow$ 20× more than at 500 GeV
- Backscattered particles more energetic (neutrons)
- Muon background from upstream linac
  - More difficult to stop due to higher CLIC energy (active muon shield ?)

CLIC acceleration structure testing

Collaboration between KEK, SLAC and CERN
Design by CERN, fabrication by KEK,
surface prep., bonding and testing at SLAC



(T18_vg2.6_disk)



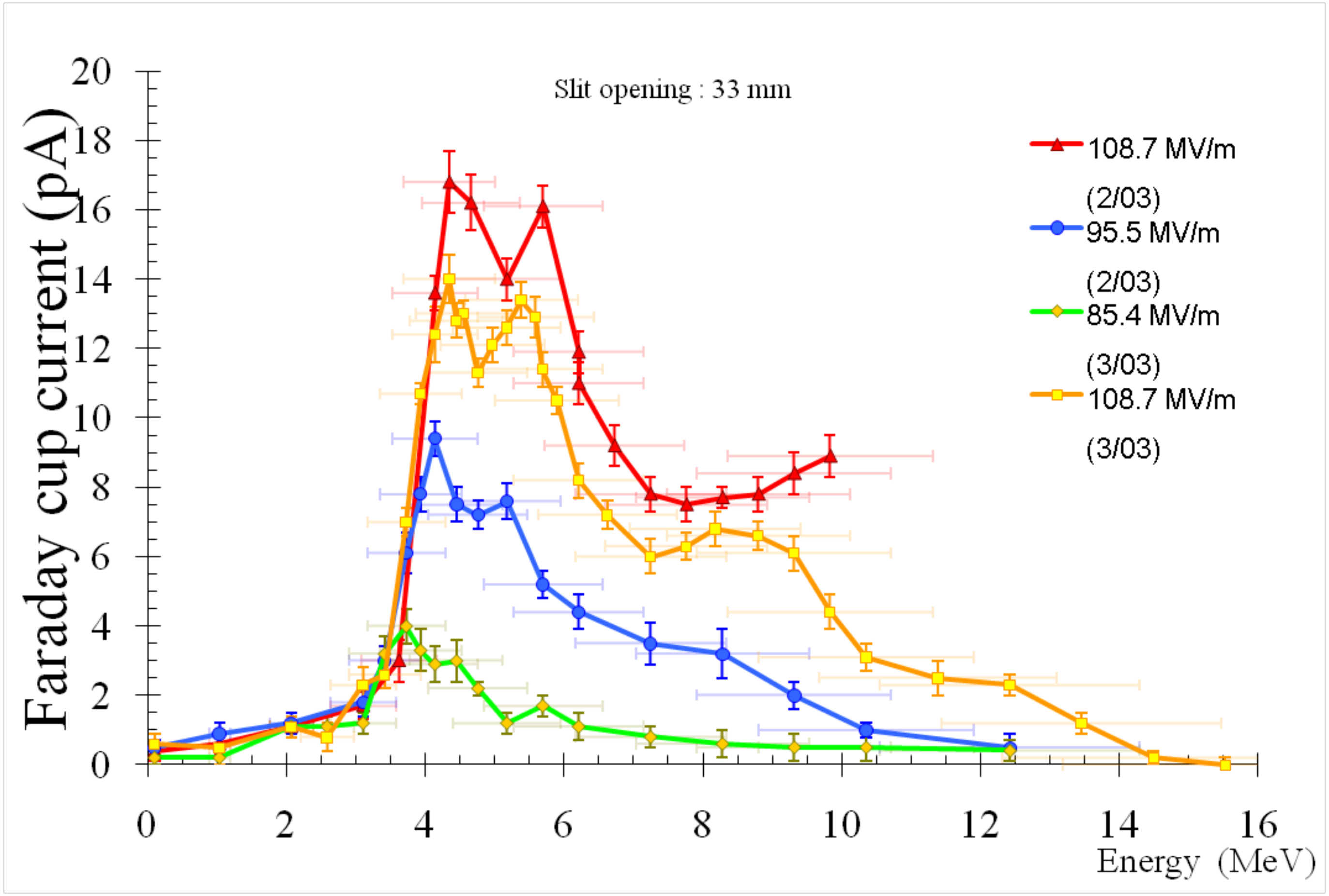
Gradients in excess of 100 MV/m have been obtained for a prototype without HOM damping.

Second structure with identical preparation tested at KEK with similar performance.

⇓ CLIC goal: trip rate < 3 10^{-7}/m at 100 MV/m loaded

Dark current spectrum of a CLIC prototype accelerating structure at 100 MV/m using the NEXTEF facility at KEK

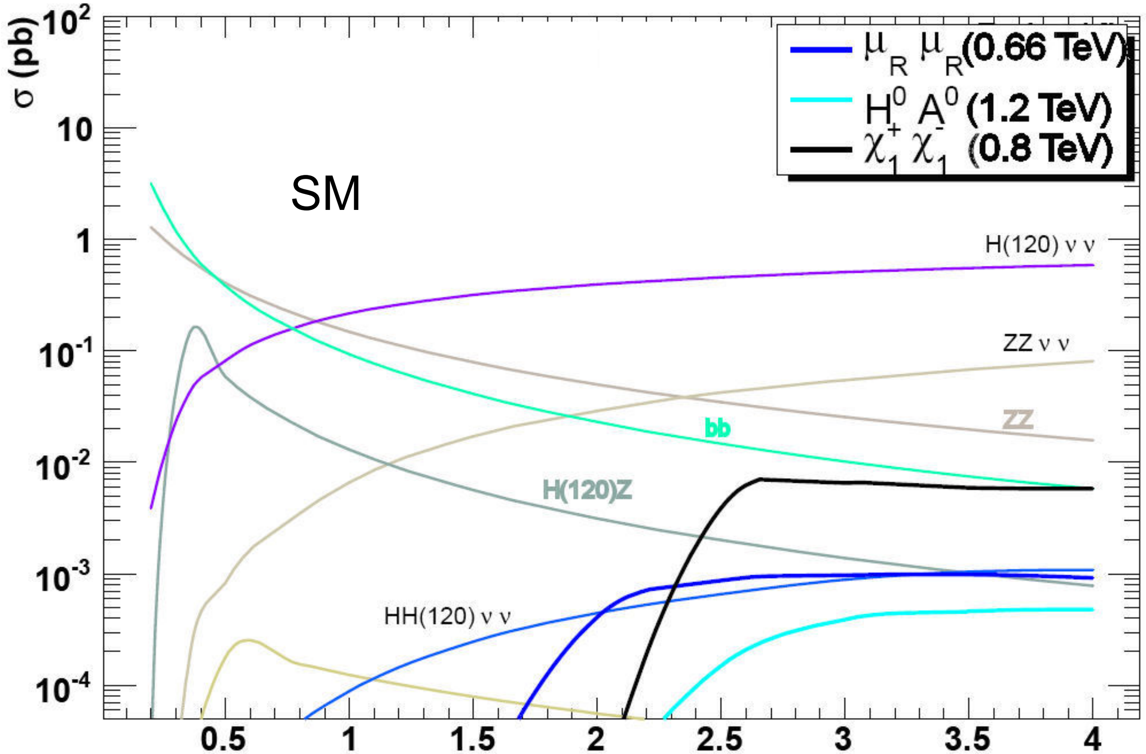
Courtesy Steffen Döbert



Important input for simulations to estimate the consequences for CLIC

Physics
Cross sections

Event Rates/Year (2 10^{34} $cm^{-2}s^{-1}$ and 120 days = 200 fb^{-1})	3 TeV
$e^+e^- \to Z\nu\nu$	440 000
$e^+e^- \to WW$	100 000
$e^+e^- \to ZZ\nu\nu$	14 000
$e^+e^- \to tt$	5 000
$e^+e^- \to bb$	2 000
$e^+e^- \to h(120)Z$ / $h\nu\nu$	300 / 100 000
$e^+e^- \to H^+H^-(1TeV)$	300
$e^+e^- \to \chi^+\chi^-(800)$	1200



M_H (GeV)

Observables at 3 TeV
(SM Events)

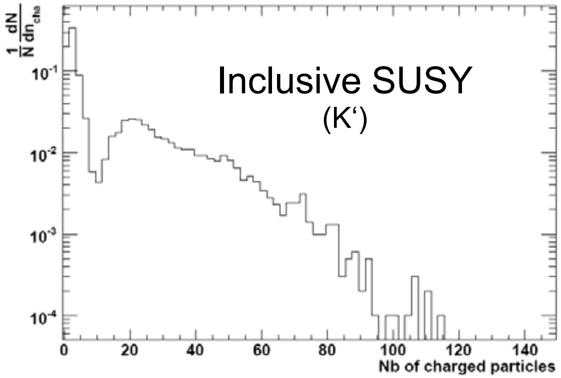
(Marco Battaglia)

Jet Multiplicity

$\sqrt{s}$ (TeV)	0.09	0.20	0.5	0.8	3.0
$< N_{Jets} >$	2.8	4.2	4.8	5.3	6.4

<Charged particle Multiplicity>

	ZZ / WW	tt
500 GeV	19	48
3 TeV	30	55

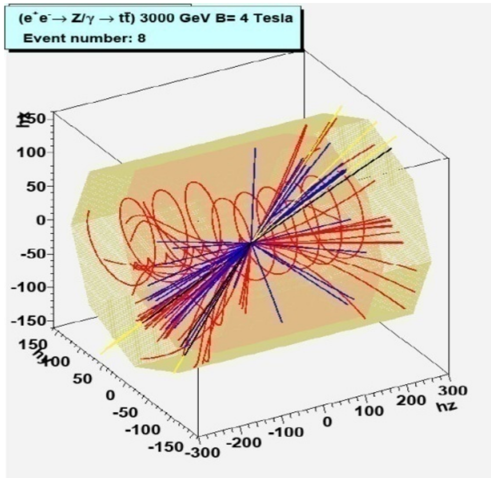


B Hadron Decay Distance

$\sqrt{s}$ (TeV)	0.09	0.2	0.35	0.5	3.0	
Process	Z^0	HZ	HZ	HZ	H^+H^-	$b\bar{b}$
d_{space} (cm)	0.3	0.3	0.7	0.85	2.5	9.0

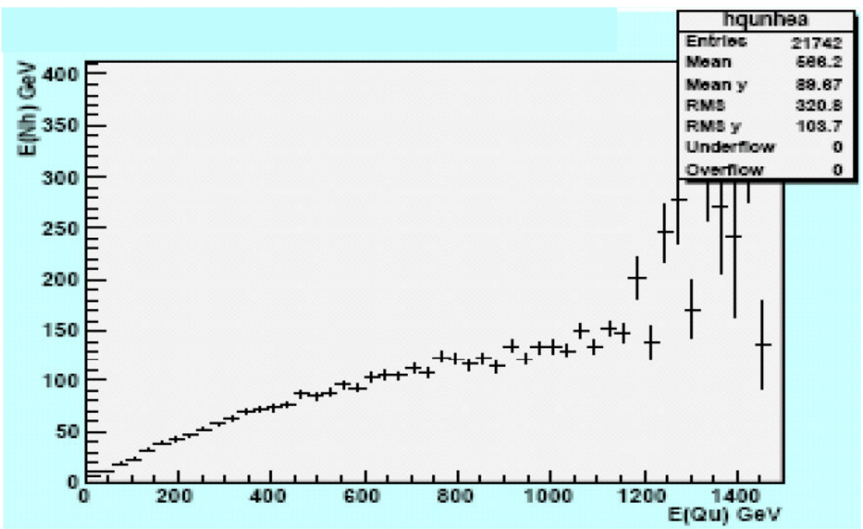
Single hadron energies

(J.J. Blaising)

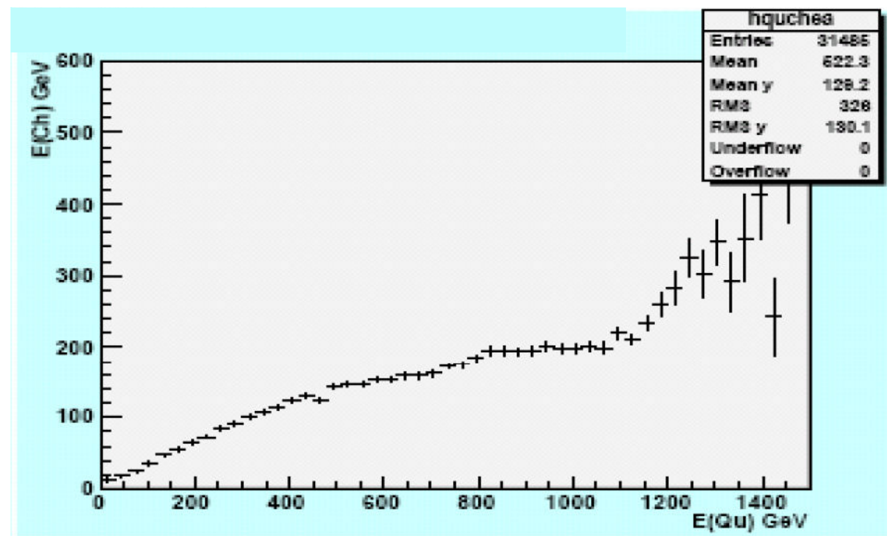


(t tbar @ 3 TeV)

Neutral Hadron



Charged Hadron



In jets, even with high quark energies, leading hadron has E < 300 GeV

Spatial distance neutral – charged hadrons

(J.J. Blaising)

Distance, Δ , at the 1. layer of HCAL

	Njet, Ecm, B	Δ (cm) MPV barrel	Δ (cm) RMS barrel	Δ (cm) MPV endcap	Δ (cm) RMS endcap
$\nu\nu H^0$	2J, 0.5 GeV,4T	8.0	3.6	9.7	4.4
$t\bar{t}$	4/6J, 0.5 GeV,4T	6.4	2.8	8.6	6.7
$\nu\nu H^0$	2J, 3.0 TeV, 4T	3.8	2.6	2.6	2.4
$t\bar{t}$	4/6J, 3.0 TeV, 4T	1.0	1.1	1.7	0.9
$t\bar{t}$	4/6J, 3.0 TeV, 5T	1.4	1.2	1.9	1.0

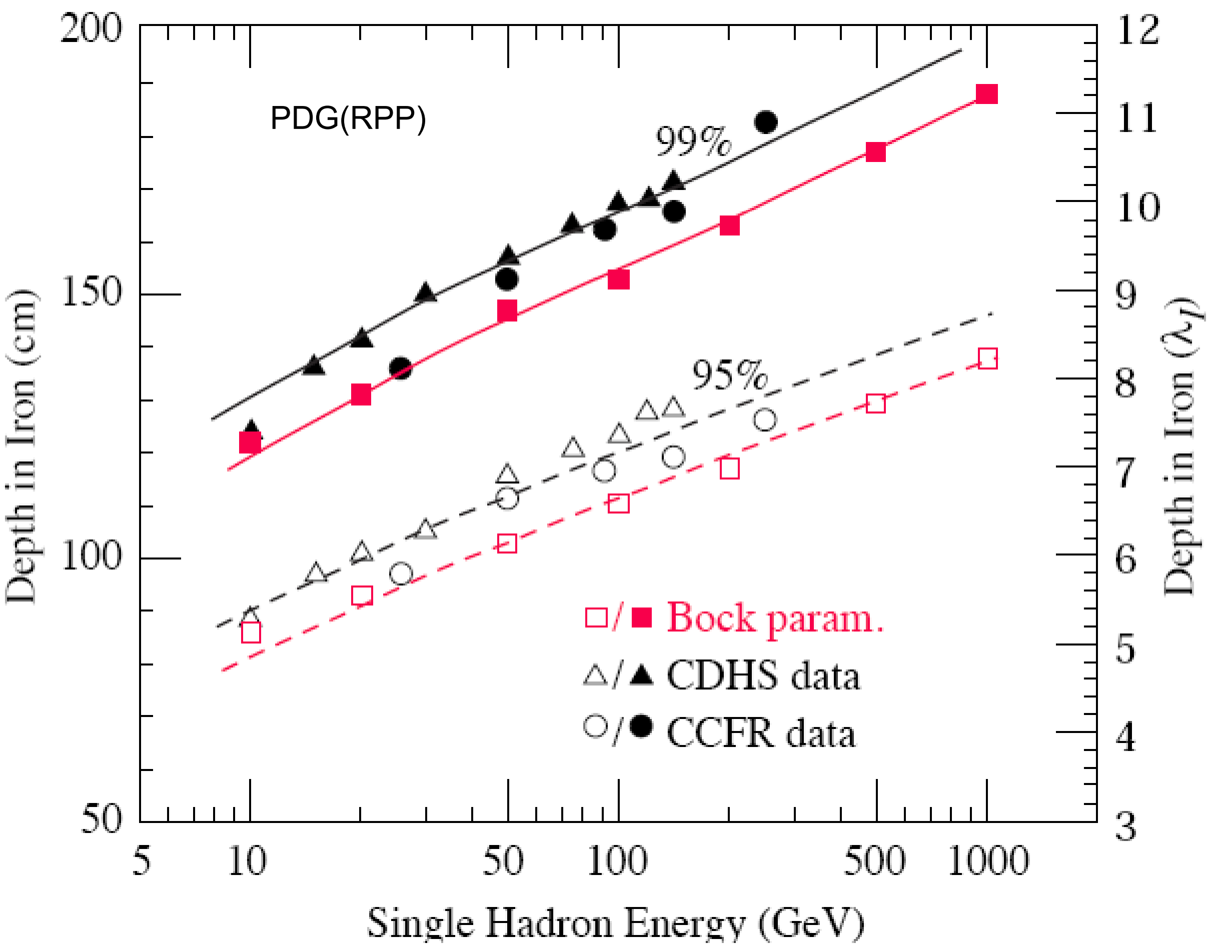
- at 3 TeV neutral - charged particle separation only ~ 1 cm
- cluster of neutral and charged hadrons will overlap in HCAL
- neutral hadron reconstruction (with PFA) only by subtraction

Detector issues: CLIC @ 3 TeV

Issues to be studied for CLIC@3TeV
as compared to detector concepts for 500 GeV:

1. Which Hcal? *Hadrons with p = 500 GeV?*
2. Solenoid parameters: Inner radius? B?
3. Vertex detector layout: *more beam background!*
4. Time stamping: *0.5 ns between bunch crossings*
5. Very forward area: mask, crossing angle, *20mrad*
6. Particle Flow Analysis at multi TeV, *jets are tighter*
7. Engineering studies, power reduction, ...
8. .....

How many interaction length for HCAL?



ILD	SiD
5.7 λ	4.5 λ
ECAL ~1 λ	

	W	**U**	**Fe**
density [g/cm^3]	19.3	19.0	7.9
λ_{Int} [cm]	10.0	11.0	16.8
X_0[cm]	0.3	0.3	1.8

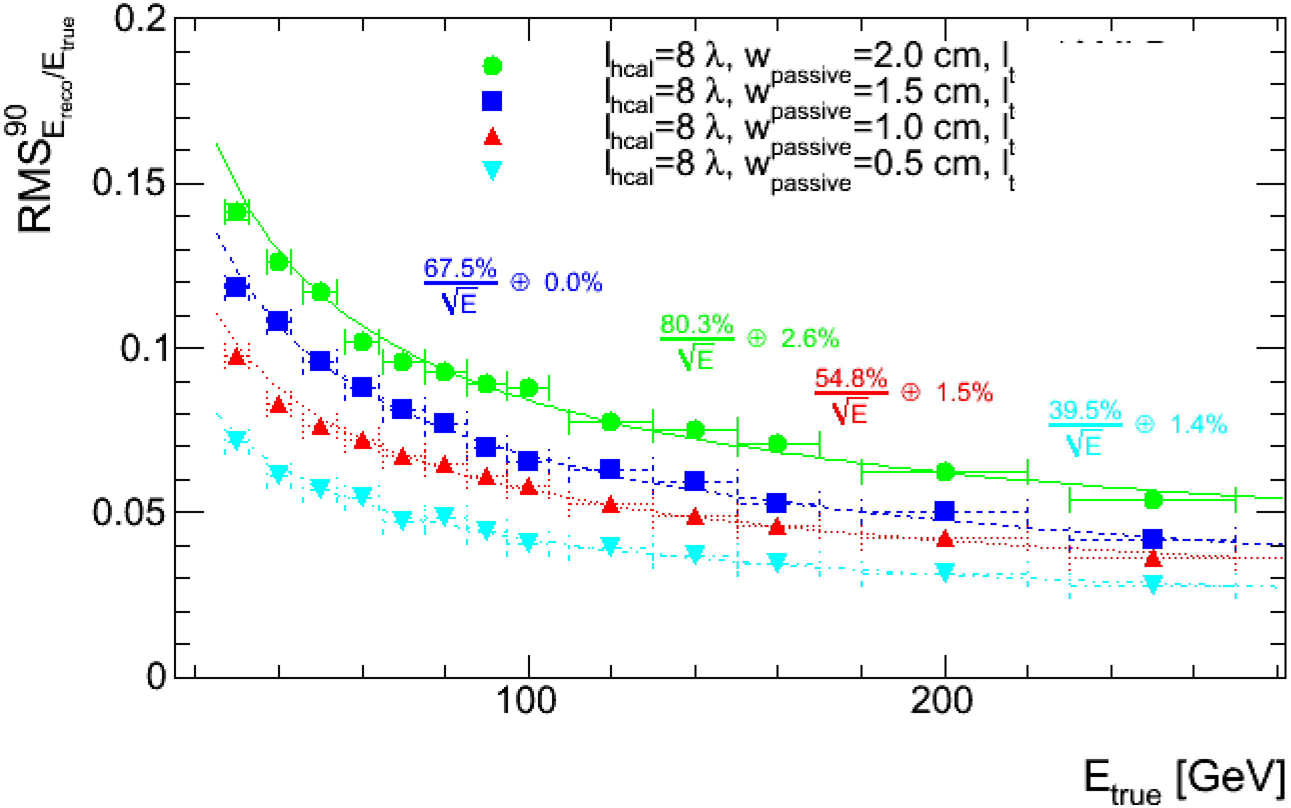
Expl: to absorb 95% of the energy of a 300 GeV pion $\rightarrow$ 8 λ_I

Tungsten HCAL Energy resolution

(single pion)

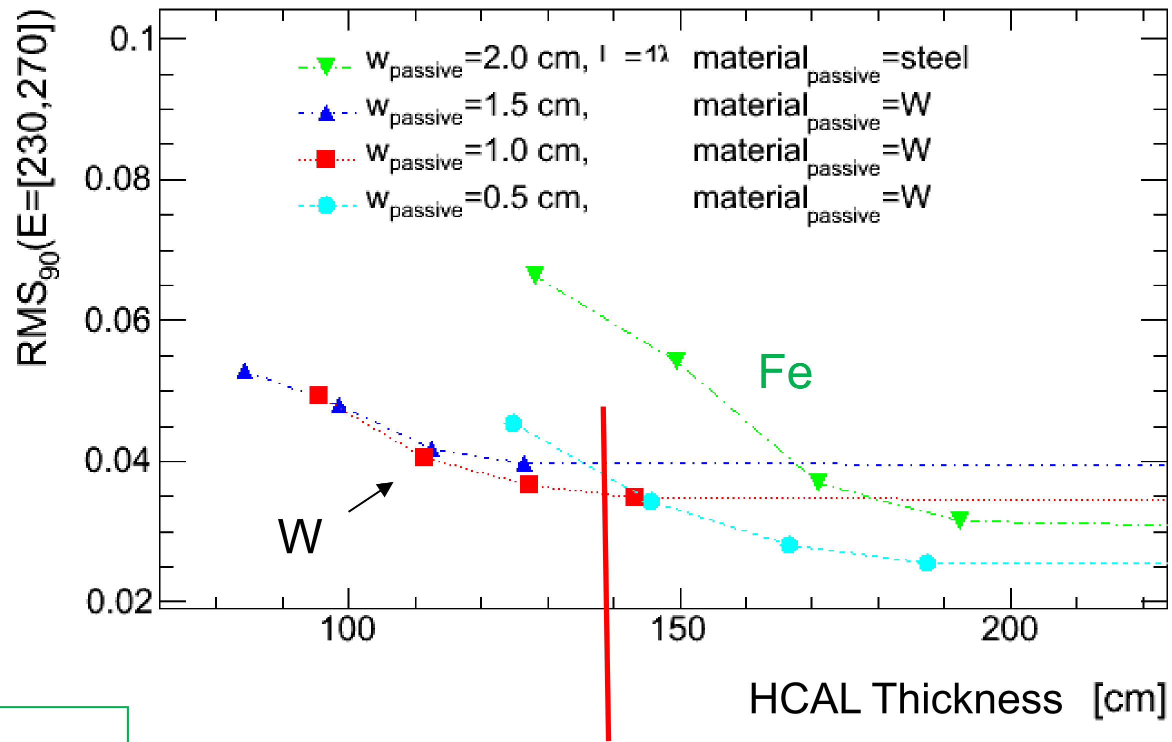
(Peter Speckmayer, Christian Grefe)

W- HCAL, 8 λ_{int} , different sampling thickness



HCAL sampling

(~250 GeV pion)



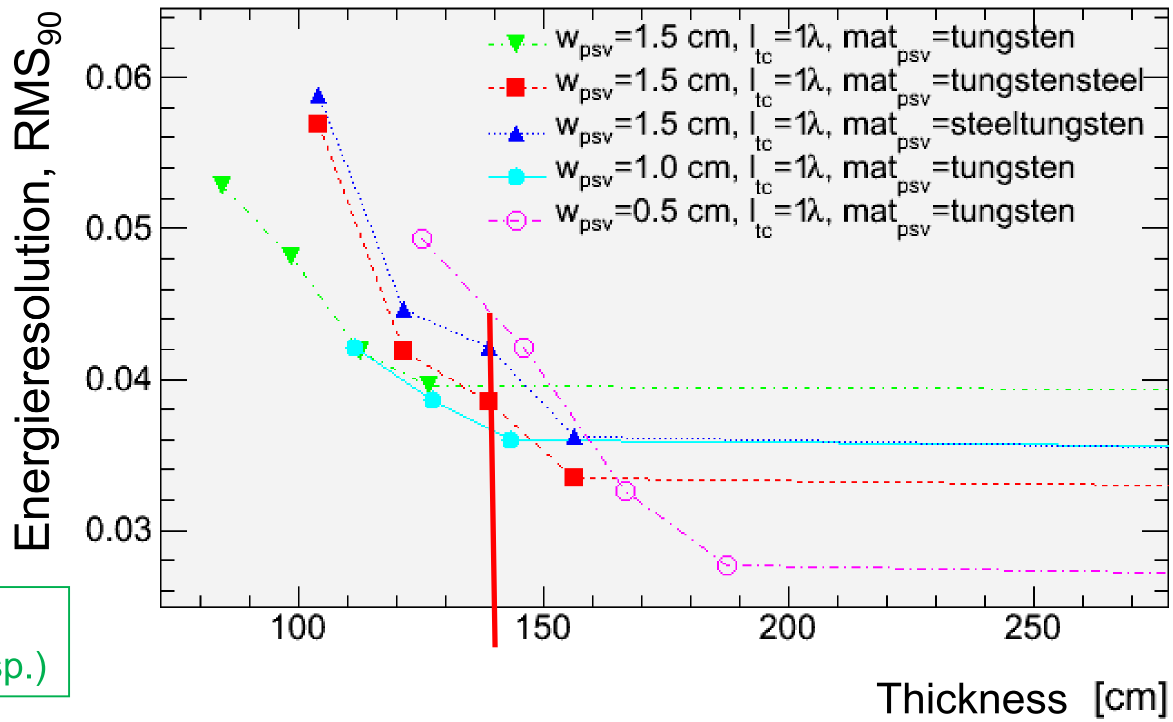
Points are for
6, 7, 8 and 9λ resp.)

140 cm (1 cm W, 0.8 cm scint.) → 8.7 λ

HCAL: Tungsten + Stainless Steel?

(~250 GeV pion)

- 50% W + 50% Fe, better mechanical properties
- more affordable!

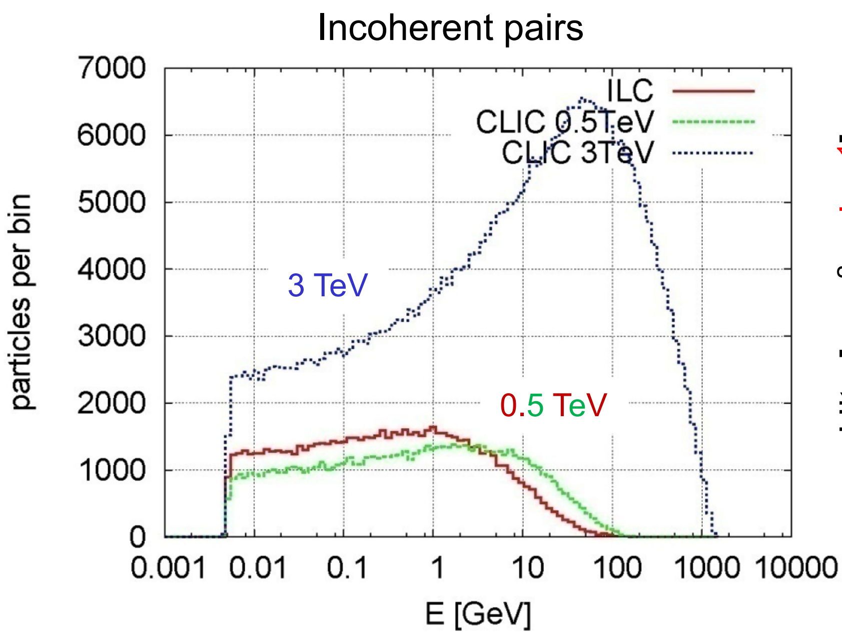


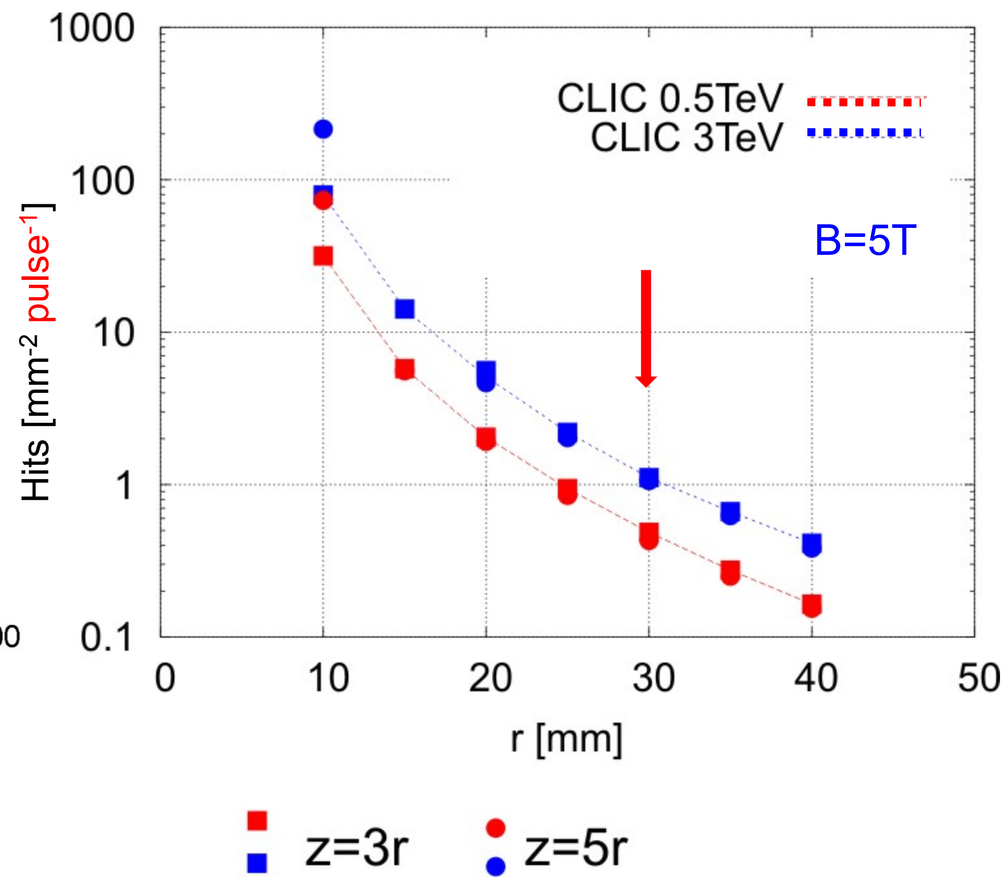
Points are for 6, 7, 8 and 9λ resp.)

140 cm (75mm W, 75mm FE) → 8 λ

Vertex Detector @ 3 TeV

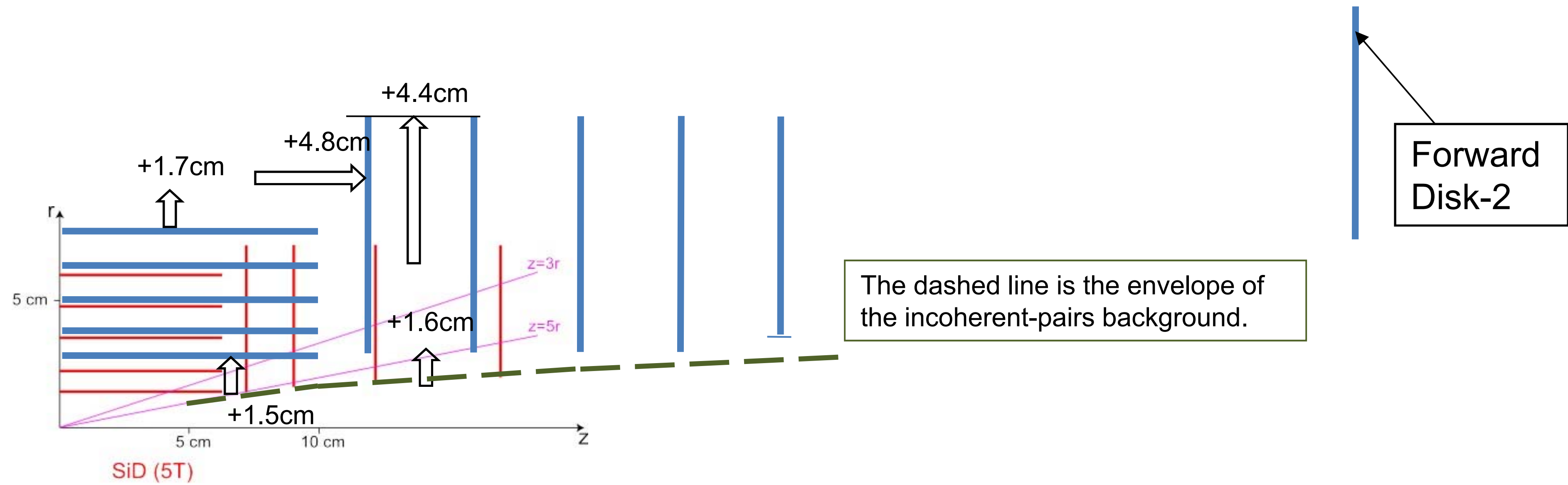
Background hits from incoherent pairs
(courtesy Daniel Schulte)

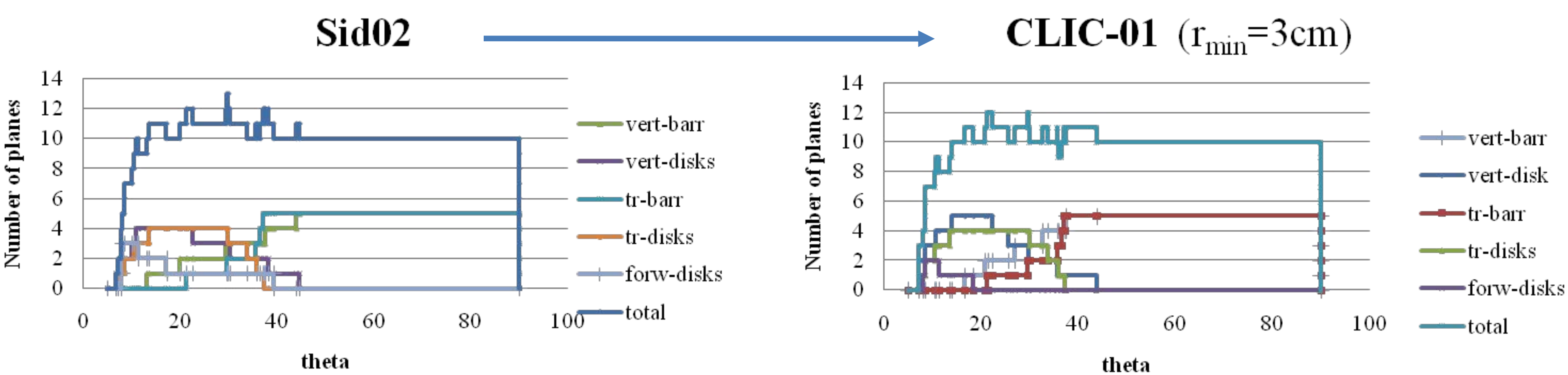




CLIC VTX detector layout

(Sandro Palestini)





PFA: General Considerations (M. Thompson)

- ★ Traditional calorimetry $\boxed{\sigma_E/E \approx 60\%/\sqrt{E/\mathrm{GeV}}}$
- ★ Does not degrade significantly with energy (but leakage will be important at CLIC)
- ★ Particle flow gives much better performance at "low" energies
  - very promising for ILC

rms90 PandoraPFA v03-β

E_{JET}	$\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $\lvert\cos\theta\rvert<0.7$	σ_E/E_j
45 GeV	23.8 %	3.5 %
100 GeV	29.1 %	2.9 %
180 GeV	37.7 %	2.8 %
250 GeV	45.6 %	2.9 %
500 GeV	84.1 %	3.7 %
500 GeV	64.3 %	3.0 %

63 layer HCAL (8 λ_I)
B = 5.0 Tesla

<u>What about at CLiC ?</u>

- ★ PFA perf. degrades with energy
- ★ For 500 GeV jets, current alg. and ILD concept:

$$\boxed{\sigma_E/E \approx 85\%/\sqrt{E/\mathrm{GeV}}}$$

- ★ Crank up field, HCAL depth…

$$\boxed{\sigma_E/E \approx 65\%/\sqrt{E/\mathrm{GeV}}}$$

- ★ Algorithm not tuned for very high energy jets, so can probably do significantly better

<u>Conclude:</u> for 500 GeV jets, PFA reconstruction not ruled out

Particle Flow @ 3 TeV

- PF algorithm needs to be studied in detail! Hoping for collaboration!
- High momentum resolution of tracker dominates PFA up to p_T~500 GeV/c, charged track separation in jets is important.
- π^0 indentification (25% E_{tot}) should be ok with highly segmented SiW calorimeter, even if 2 γ's are merged.
- Neutral hadrons are the challenge, but only 15% E_{tot}. Reconstruction from energy excess on top of clusters from charged particle.
- Technical problems: nested loops and large combinatorics can make code too slow (a few events/day)!
  PANDORA code to run with SiD geometry file is inconvenient

ILD and CLIC

(André Sailer)

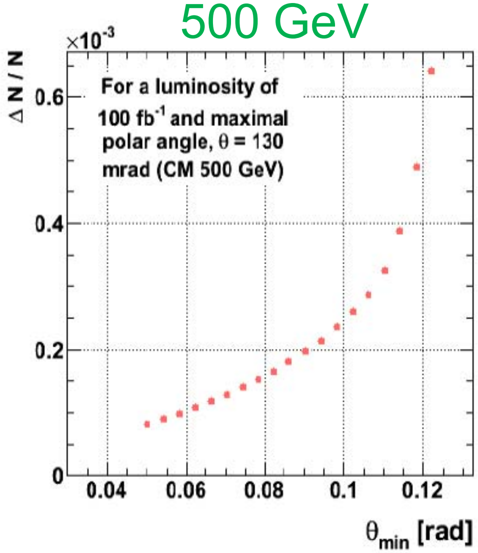
- ILD software installed at CERN (Mokka, Marlin, Pandora)
- ILD'ish CLIC detector (20 mrad, VTX moved to r = 3cm) created.
- Simulating the backscattering of the incoherent pairs from BCAL etc)

LUMCAL for CLIC

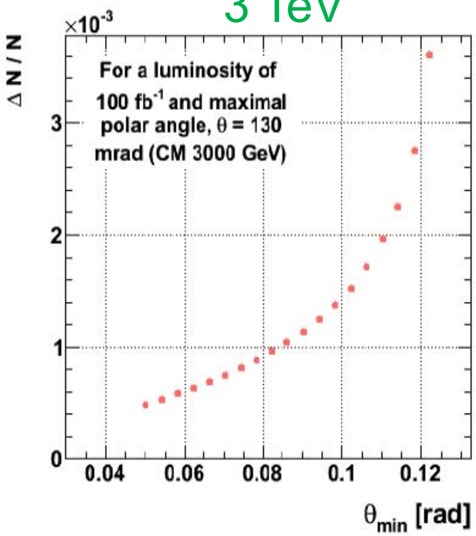
(Iftach Sadeh)

coverage :10 - 35 cm , 44 -153 mrad

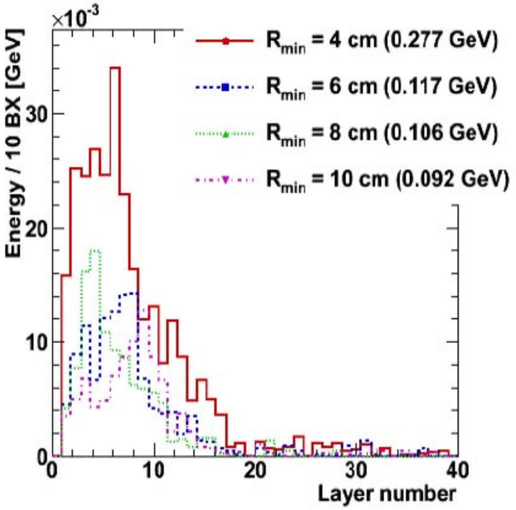
500 GeV



3 TeV



Pair deposits for 3TeV



Software Issues

Study of both ILD and SiD for physics at CLIC@3 TeV, forces us to use both software environments. Therefore:

- in general, encourage common products,
- E.g. converters for geometry descriptions,
- improve links to LHC SW (file format, ROOT, framework?)

→ SW Workshop at CERN 28/29 May.

On Analysis SW:

Particle Flow is key element for LC detectors. Very few people are working on it. Could we have a common project? CERN is interested.

R&D Plans

- Physics/detector simulation studies
- Mechanical engineering support

Beyond CDR time line. Funding pending!

- Time-stamping, combined electronics and sensor integration developments
- CLIC electronics readout, power reduction and power pulsing at 50 Hz
- TPC pad readout (Timepix) with EUDET/LC-TPC community
- Solenoid coil, replacement of the electron beam welding (CEA/Saclay etc)
- mechanical engineering for dense sandwich calorimeter (with W)
- Participation in CALICE , test beam activities, shower models in GEANT4, W-HCAL test?
- Dual readout calorimetry exploring crystal fibres in a fully active geometry
- Forward region hardware studies (with FCAL)
- Core software development (LC SW community)

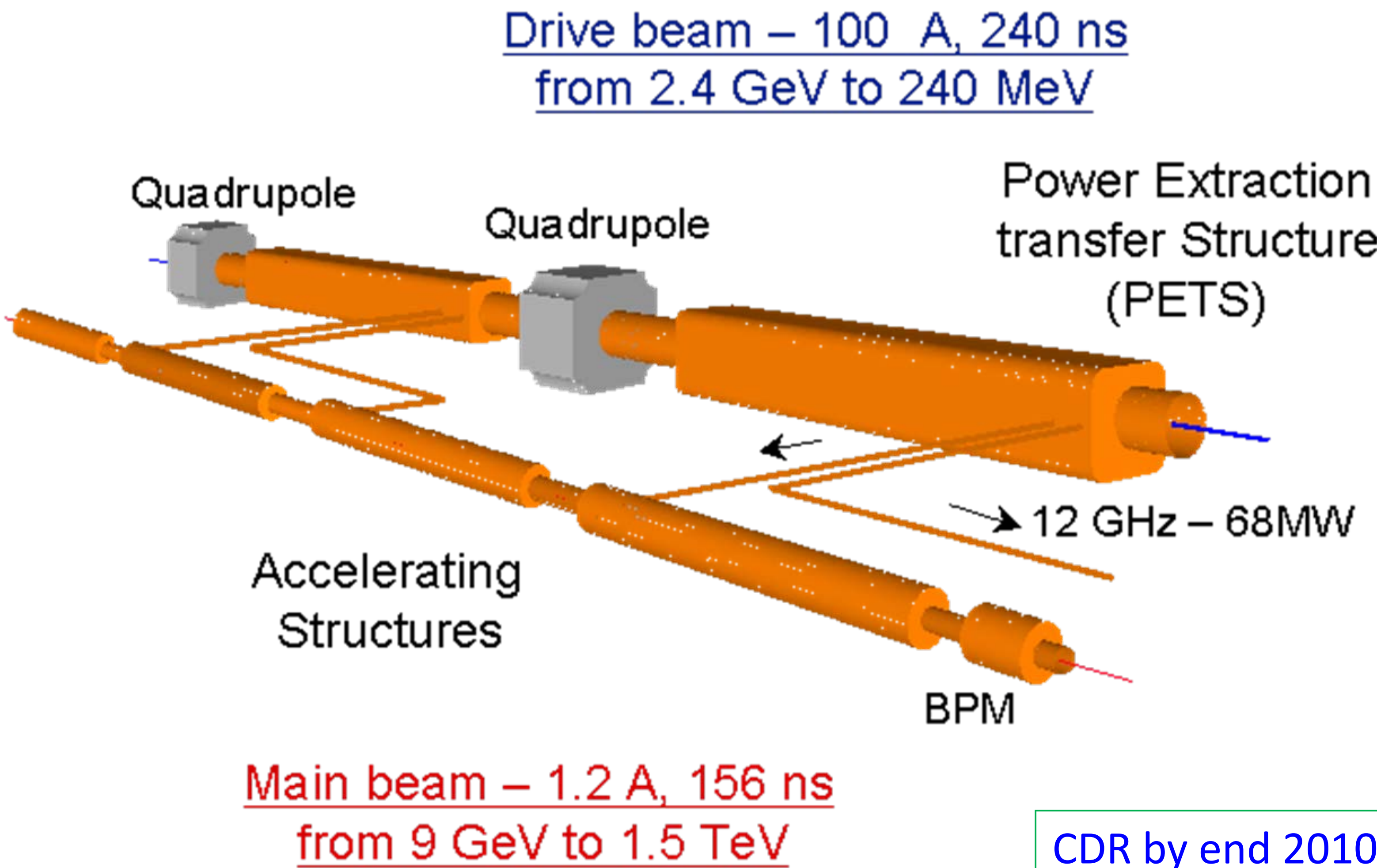
Conclusion

- LC detector group established at CERN (with resources!)
- Excellent collaboration with ILC groups, CERN has joined some R&D groups (CLIC/ILC Collab. is helping).
- next goal is CLIC Conceptual Design report (end 2010)
- Study detector concepts for CLIC, based on SiD and ILD concepts. - Denser HCAL? - Larger 5T coil? - Longer barrel. - Move VTX outwards. Solve read out/time stamping for 0.5ns bunch crossing. – Check backgrounds!
- assuming additional resource → CLIC relevant R&D
- LC software, we like to help towards more interoperability.

Looking forward to even closer collaboration with ILC groups.

End

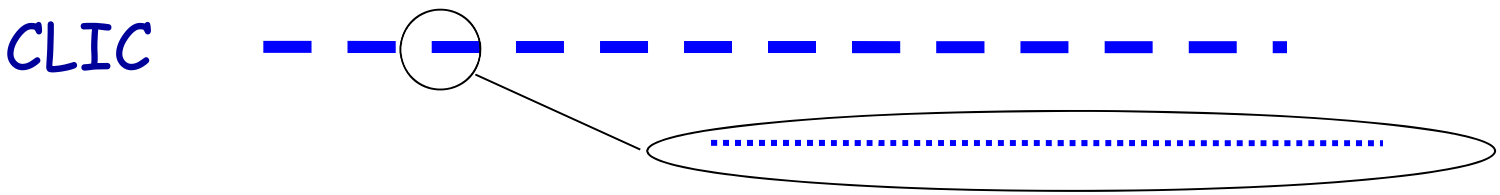
CLIC scheme



CDR by end 2010

CLIC time structure

Train repetition rate 50 Hz



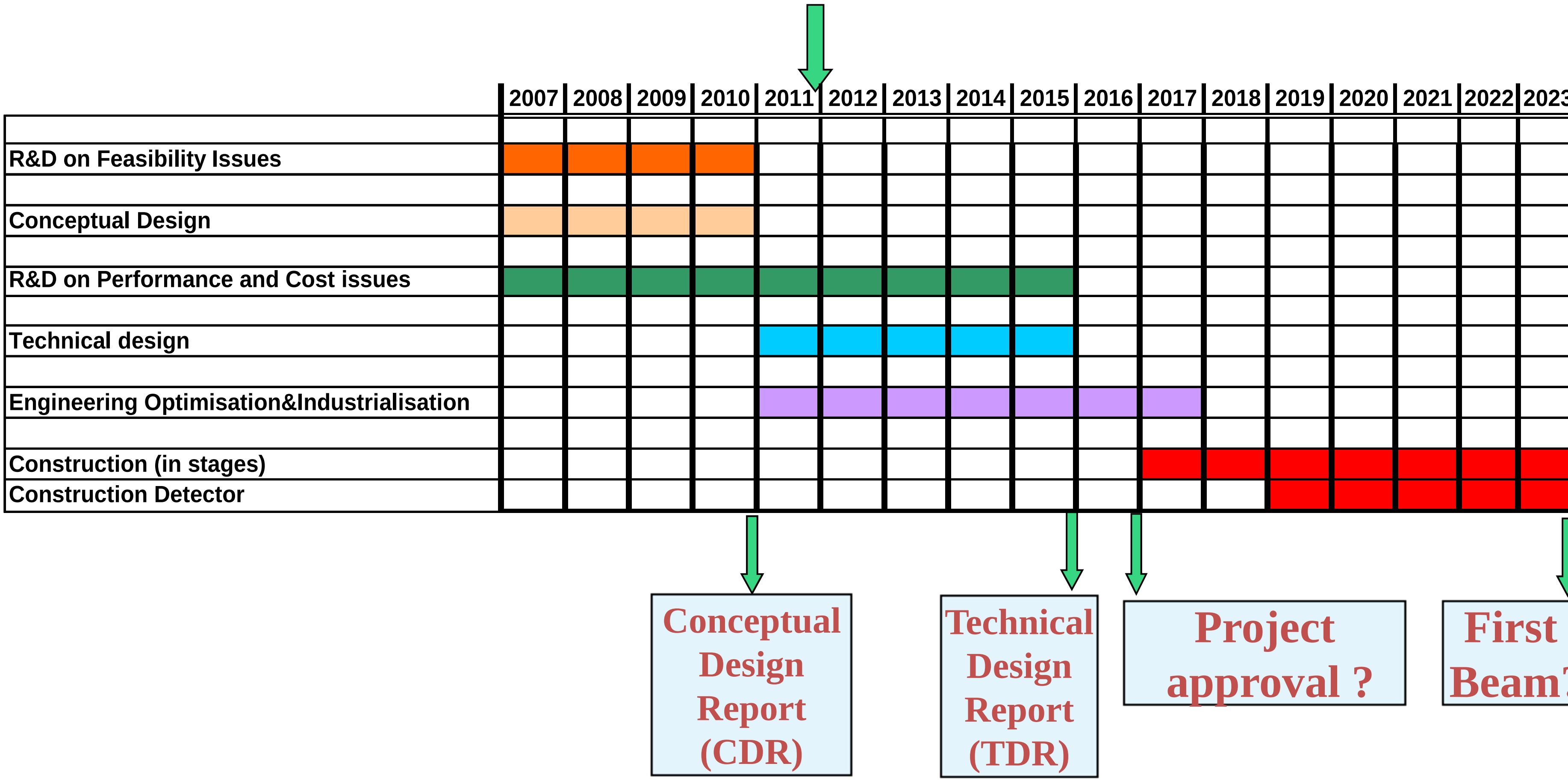
CLIC:	1 train = 156 ns =	312 bunches	0.5 ns apart	50 Hz
ILC:	1 train = 950 μs =	2820 bunches	337 ns apart	5 Hz

Consequences for CLIC detector:

- extra detector elements with time-stamping?
- Readout electronics could be different
- Power reduction. Pulsing at 50 Hz instead of 5 Hz
- ...

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



The CLIC Technology-related key issues as pointed out by ILC-TRC 2003

Covered by CTF3

R1: Feasibility

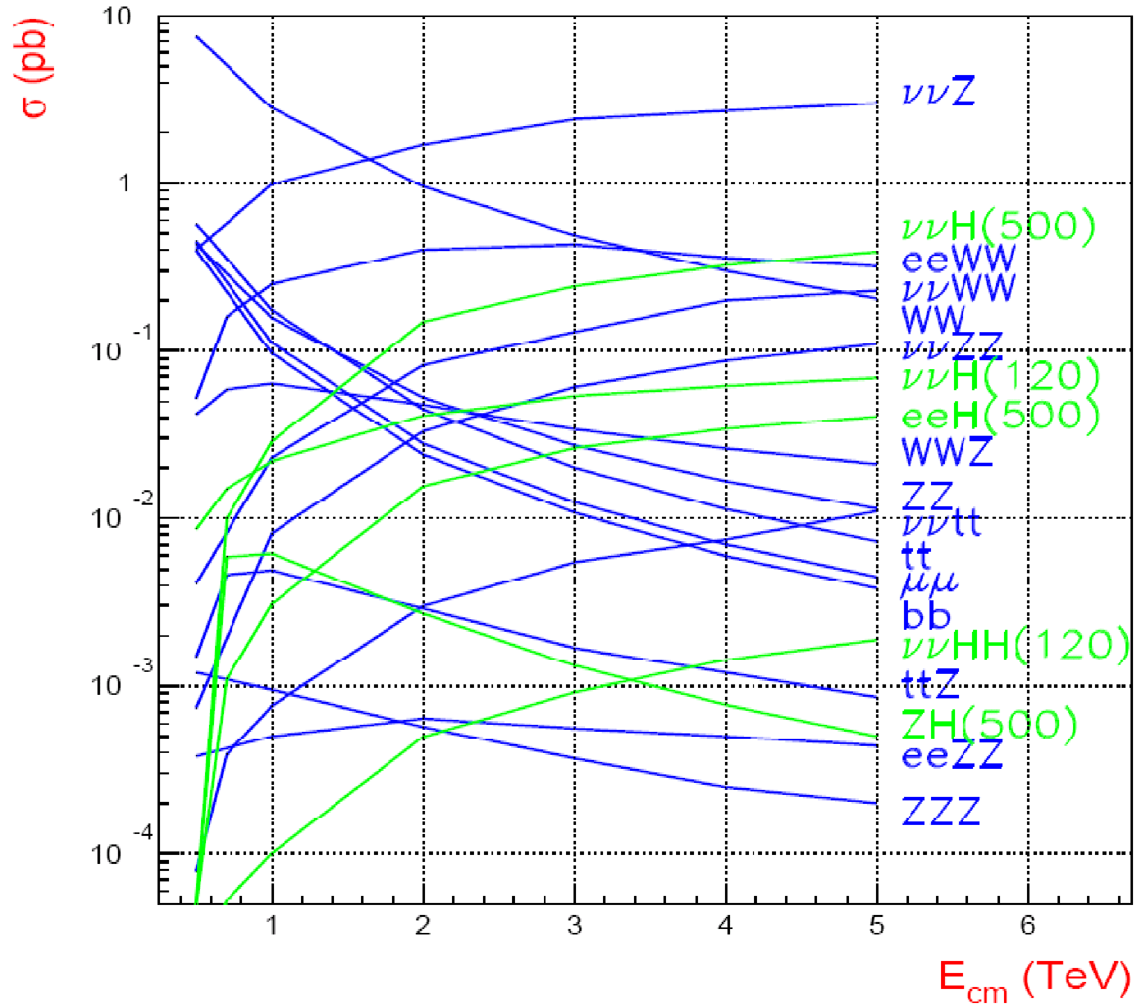
- R1.2: Validation of drive beam generation scheme with fully loaded linac operation
- R1.1: Test of damped accelerating structure at design gradient and pulse length
- R1.3: Design and test of damped ON/OFF power extraction structure

R2: Design finalization

- R2.1: Developments of structures with hard-breaking materials (W, Mo...)
- R2.2: Validation of stability and losses of DB decelerator; Design of machine protection system
- R2.3: Test of relevant linac sub-unit with beam
- R2.4: Validation of drive beam 40 MW, 937 MHz Multi-Beam Klystron with long RF pulse *
- R2.5: Effects of coherent synchrotron radiation in bunch compressors
- R2.6: Design of an extraction line for 3 TeV c.m.

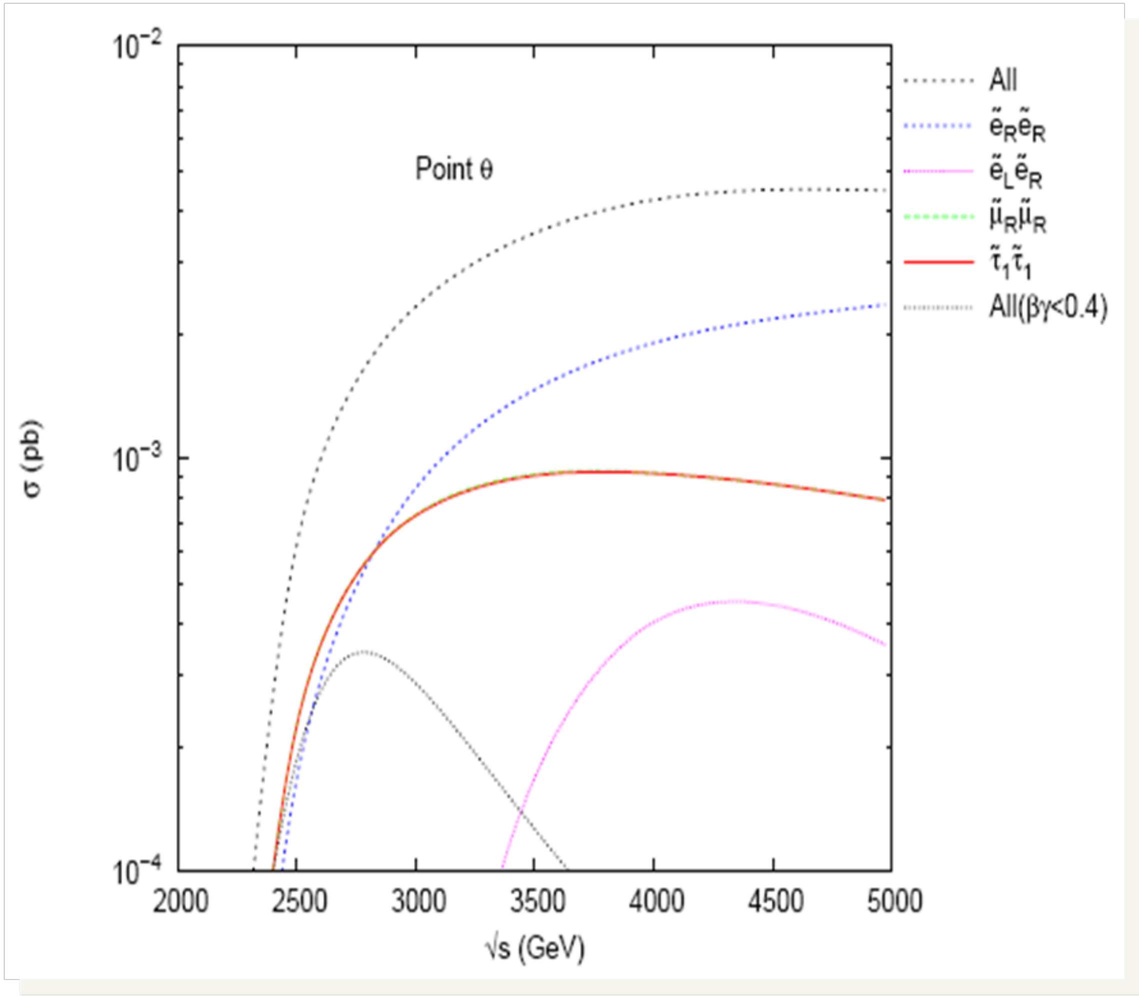
Covered by EUROTeV

** Feasibility study done - need development by industry.*
N.B.: Drive beam acc. structure parameters can be adapted to other klystron power levels


σ (pb)
10
1
10^-1
10^-2
10^-3
10^-4
1
2
3
4
5
6
E_cm (TeV)
ννZ
ννH(500)
eeWW
ννWW
WW
ννZZ
ννH(120)
eeH(500)
WWZ
ZZ
ννtt
tt
μμ
bb
ννHH(120)
ttZ
ZH(500)
eeZZ
ZZZ

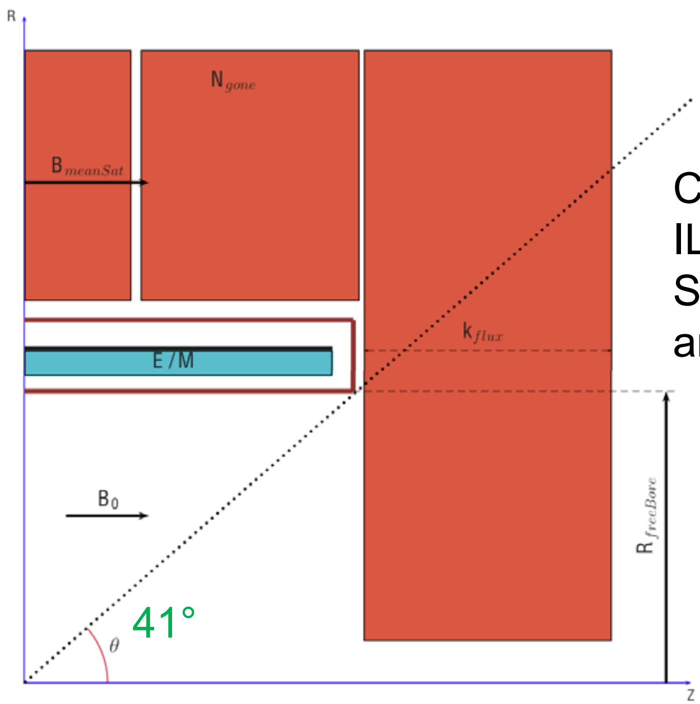
New Physics ???

In SUSY scenarios with a gravitino LSP and long-lived staus one can have very large sparticle masses.



When will we know?

Solenoid



CMS
ILD
SiD
and CLIC!

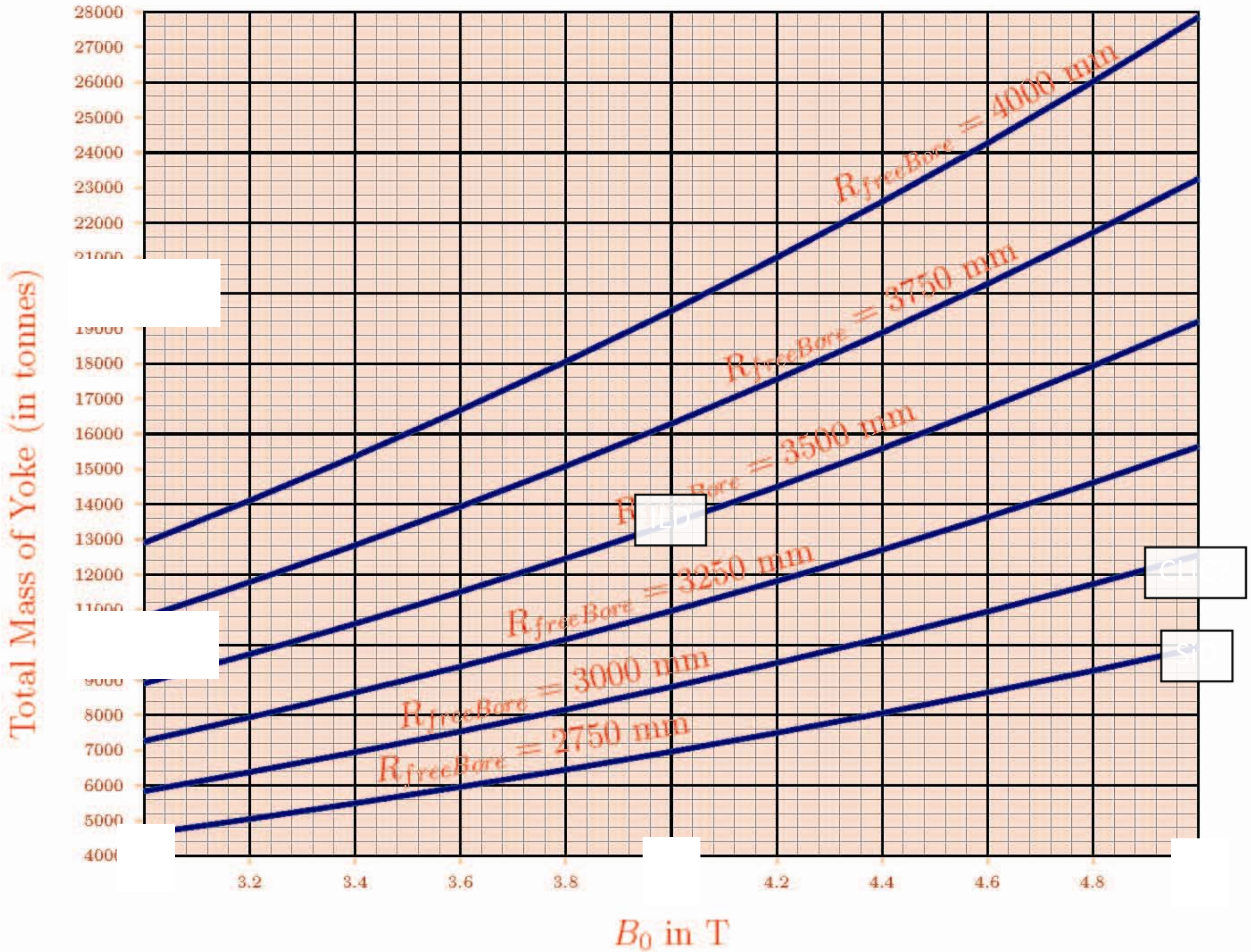
Magnet properties (A. Hervé model)

	CMS	ILD	SiD	CLIC (SiD'ish)
B (T) design	4	4	5	5
R_{inner} (cm)	300	344	260	290
Barrel ½ L (m)	6.5	4	3	3.3
Stored E (GJ)	*2.6*	*3.2*	*1.4*	*1.8*
Yoke weight		*13 kt*	*10 kt*	*12 kt*
Cost (A.H.)	*95%*	*140%*	*100%*	*125%*

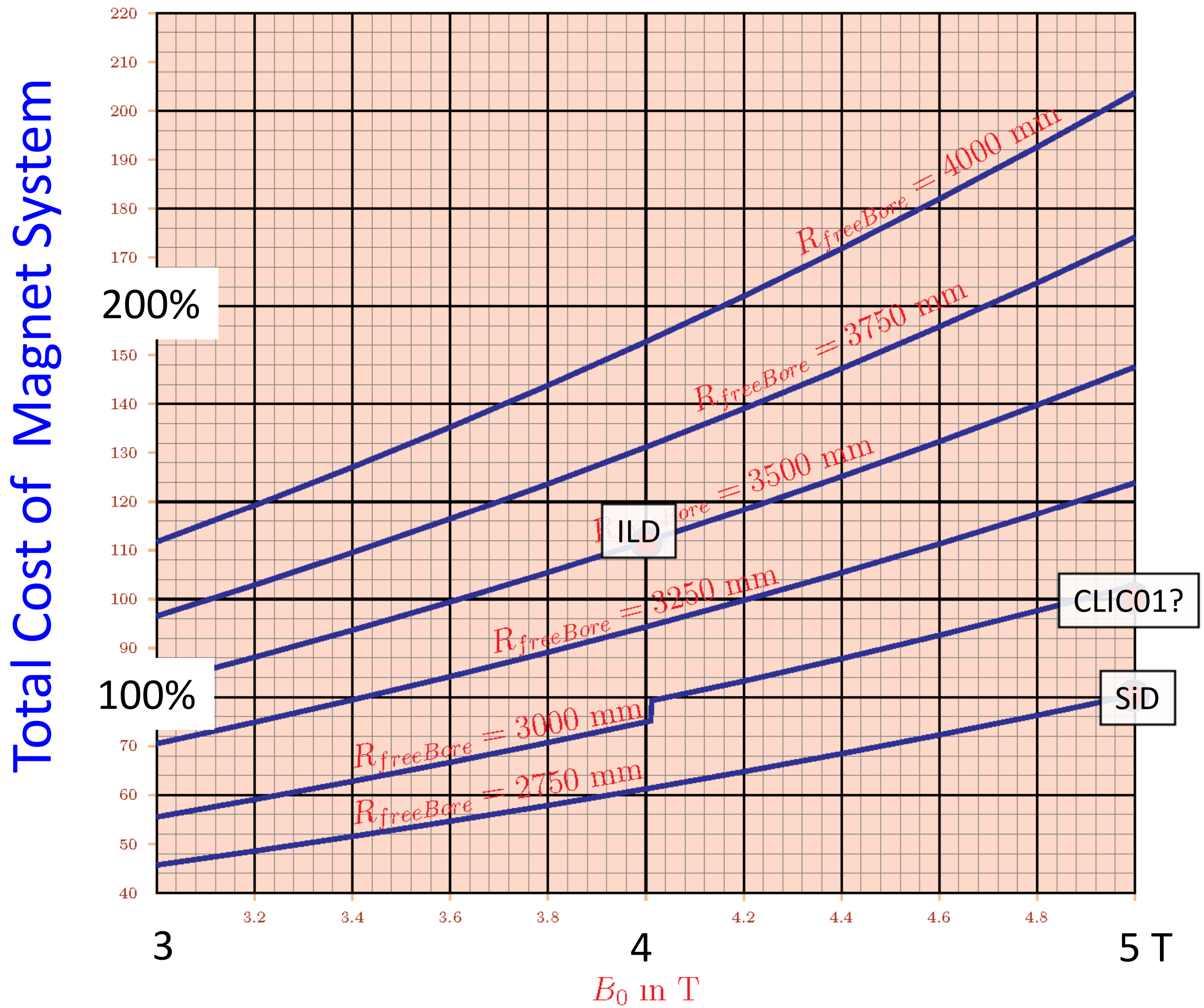
Assume ILD@CLIC would have same magnet as ILD@ILC

Mass of Yoke in tons

courtesy Alain Hervé



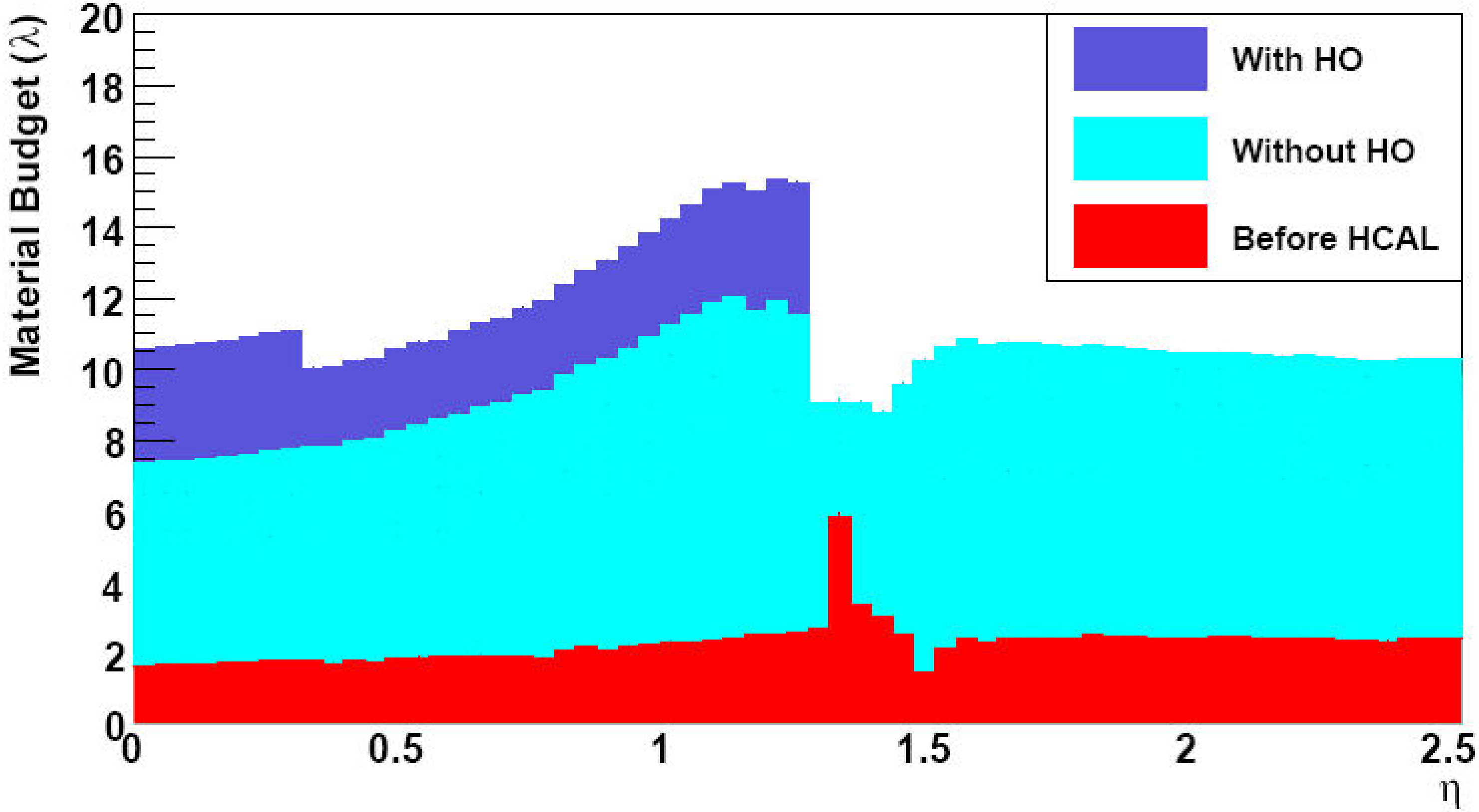
A. Hervé: Parametric Model for Magnet



different $R_{freeBore}$

Increase R by 25 cm → 25% more cost

CMS HCAL material budget



HO = outer HCAL beyond coil

Parton Energy

$\sqrt{s}$ (TeV)	**0.2**	**0.5**	**1.0**	**3.0**
<E_{Parton}> (GeV)	**32**	**64**	**110**	**240**