Multi-TeV detector optimisation studies for CLIC

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CERN

Outline

Outline:

- Introduction
- CLIC detector issues <= difference wit ILC case
  - Time structure
  - Beam-induced background and forward region studies
  - HCAL concept studies
  - Solenoid parameters
- Future CLIC detector R&D
- Outlook

See also: talk Marco Battaglia 16/11/2008 LCWS08

The CLIC Two Beam Scheme

Two Beam Scheme:

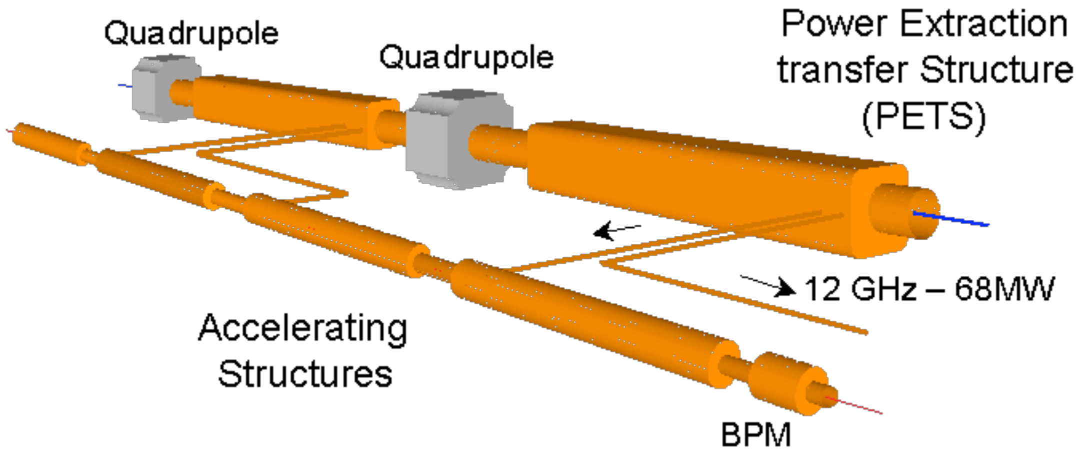
Drive Beam supplies RF power

- 12 GHz bunch structure
- low energy (2.4 GeV - 240 MeV)
- high current (100A)

Main beam for physics

- high energy (9 GeV – 1.5 TeV)
- current 1.2 A

Drive beam – 100 A, 240 ns
from 2.4 GeV to 240 MeV



Main beam – 1.2 A, 156 ns
from 9 GeV to 1.5 TeV

No individual RF power sources

CLIC parameters

Center-of-mass energy	3 TeV
Peak Luminosity	$6 \cdot 10^{34}$ cm^{-2} s^{-1}
Peak luminosity (in 1% of energy)	$2 \cdot 10^{34}$ cm^{-2} s^{-1}
Repetition rate	50 Hz
Loaded accelerating gradient	100 MV/m
Main linac RF frequency	12 GHz
Overall two-linac length	42 km
Bunch charge	$3.72 \cdot 10^{9}$
Bunch separation	0.5 ns
Beam pulse duration	156 ns
Beam power/beam	14 MWatts
Hor./vert. normalized emittance	660 / 20 nm rad
Hor./vert. IP beam size bef. pinch	40 / ~1 nm
Total site length	48 km
Total power consumption	415 MW

General Physics Context

- New physics expected in TeV energy range
  - Higgs, Supersymmetry, extra dimensions, …?
- LHC will indicate what physics, and at which energy scale (is 500 GeV enough or need for multi TeV?)

- However, even if multi-TeV is final goal, most likely CLIC would run over wide range of energies (e.g. 0.5 – 3.0 TeV)
- ILC detector concepts are excellent starting point for high energy detector
- Like for ILC, assume 2 CLIC detectors in pull push mode

CLIC links and timeline

Useful links:

- **CLIC website**
- http://clic-study.web.cern.ch/CLIC-Study/

- **CLIC physics/detector web**
- http://clic-meeting.web.cern.ch/clic-meeting/CLIC_Phy_Study_Website/default.html

- **CLIC08 workshop, October 14-17 2008**
- http://project-clic08-workshop.web.cern.ch/project-clic08-workshop/

CLIC timeline:

- **CDR in 2010**
- **TDR in 2015**

Collaboration between ILC and CLIC

See also talk of Jean-Pierre Delahaye 16/11 LCWS08

Since February 2008: official collaboration between ILC and CLIC

http://clic-study.web.cern.ch/CLIC-Study/CLIC_ILC_Collab_Mtg/Index.htm

Topic	Conveners
Civil Engineering and Conventional Facilities (CFS)	Claude Hauviller (CERN), John Osborne (CERN), Vic Kuchler (FNAL)
Beam Delivery Systems and Machine Detector Interface	Brett Parker (BNL), Daniel Schulte (CERN) , Andrei Seryi (SLAC), Emmanuel Tsesmelis (CERN), Rogelio Tomas Garcia (CERN)
Detectors and Physics	Lucie Linssen (CERN), Francois Richard (LAL), Dieter Schlatter (CERN), Sakue Yamada (KEK)
Cost & Schedule	Hans Braun (CERN), John Carwardine (ANL), Katy Foraz (CERN), Peter Garbincius (FNAL), Tetsuo Shidara (KEK), Sylvain Weisz (CERN)
Beam Dynamics	Andrea Latina (FNAL), Kiyoshi Kubo (KEK), Daniel Schulte (CERN), Nick Walker (DESY)
Damping rings	*** new ***
Positron generation	*** new ***

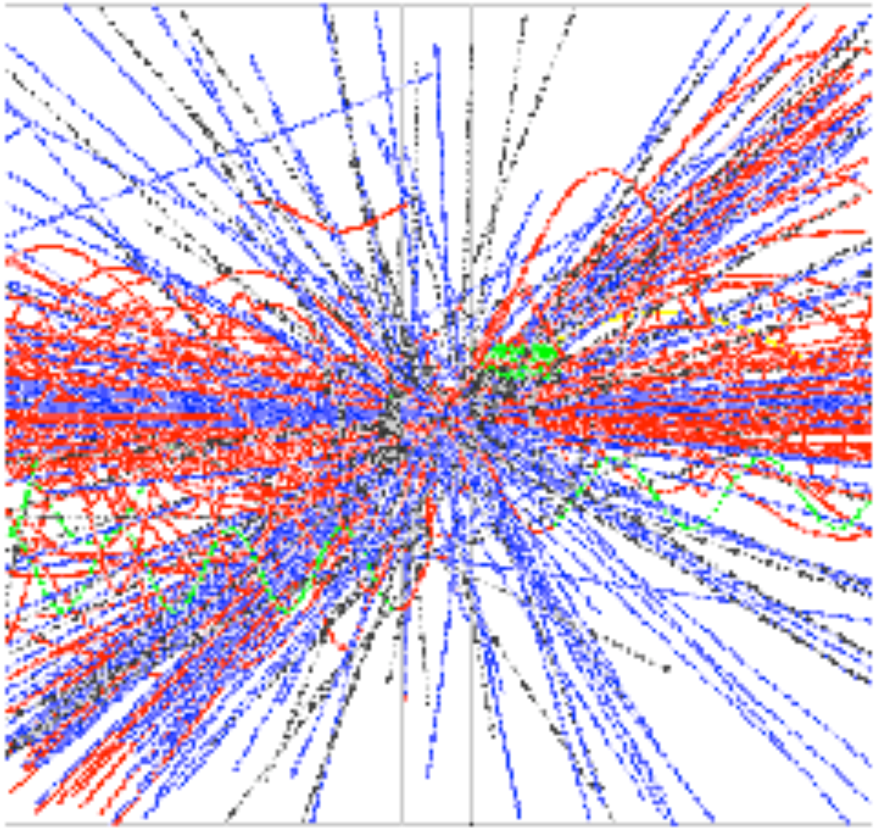
ILD contact: Mark Thomson

SiD contact: Norman Graf

4th contact: Corrado Gatto

CLIC detector issues, and comparison with ILC

CLIC detector issues



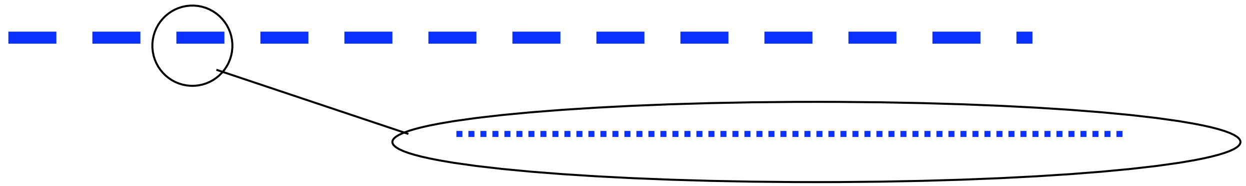
3 main differences with ILC:

- Energy 500 GeV => 3 TeV
- More severe background conditions
  - Due to higher energy
  - Due to smaller beam sizes
- Time structure of the accelerator

CLIC time structure

Train repetition rate 50 Hz

CLIC



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

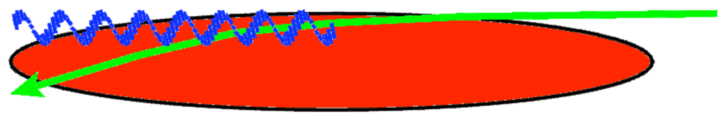
Consequences for CLIC detector:

- Assess need for detection layers with time-stamping
  - Innermost tracker layer with sub-ns resolution
  - Additional time-stamping layers for photons and for neutrons
- Readout electronics will be different from ILC
- Power pulsing at 50 Hz, instead of 5 Hz

Beam-induced background

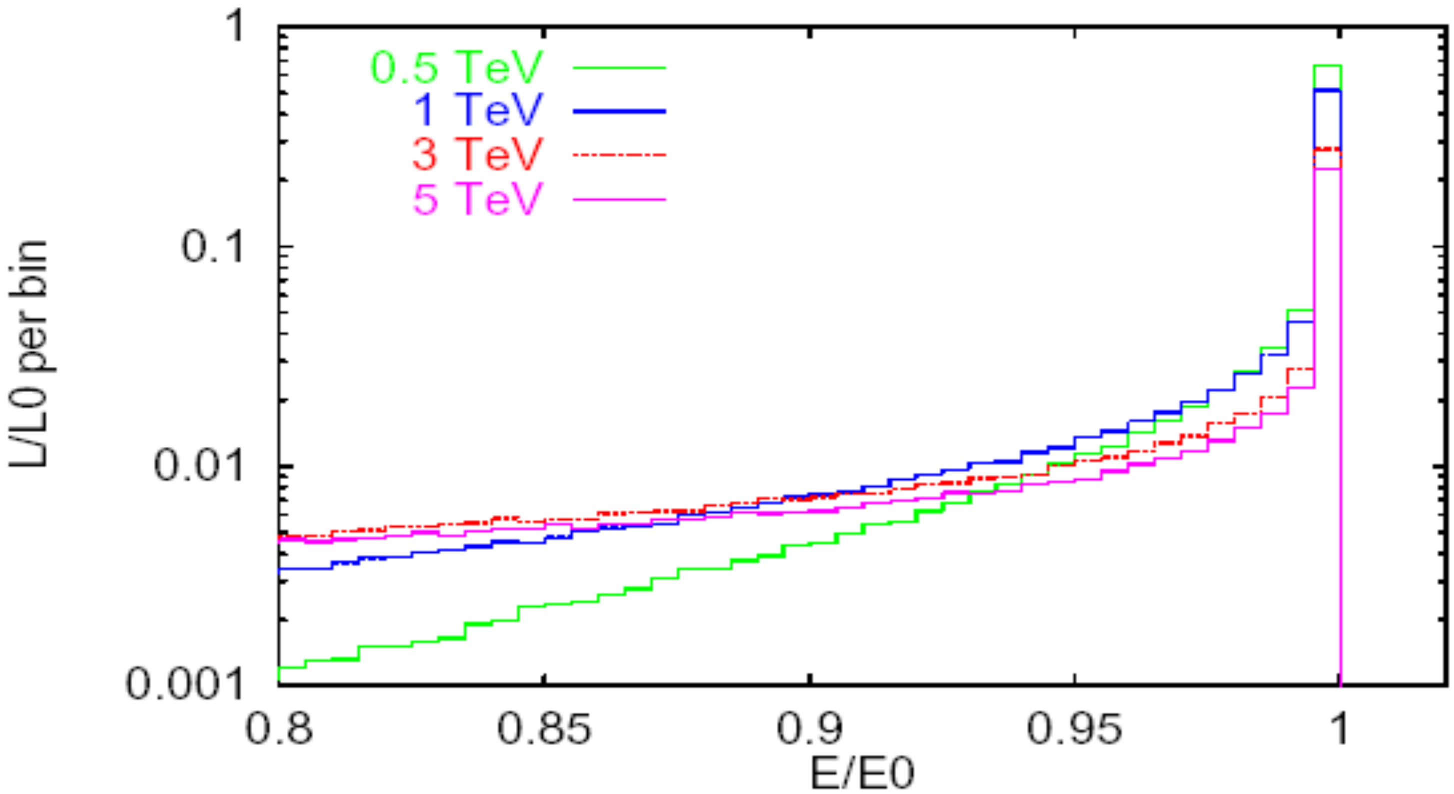
Background sources: CLIC and ILC similar

Due to the higher beam energy and small bunch sizes they are significantly more severe at CLIC.



- CLIC 3TeV beamstrahlung ΔE/E = 29% (10×ILC_{value})
  - **Coherent pairs (3.8×10^{8} per bunch crossing)** <= disappear in beam pipe
  - Incoherent pairs (3.0×10^{5} per bunch crossing) <= suppressed by strong B-field
  - γγ interactions => hadrons
- Muon background from upstream linac
  - More difficult to stop due to higher CLIC energy (active muon shield)
- Synchrotron radiation
- Beam tails from the linac
- Backscattered particles from the spent beam (neutrons)

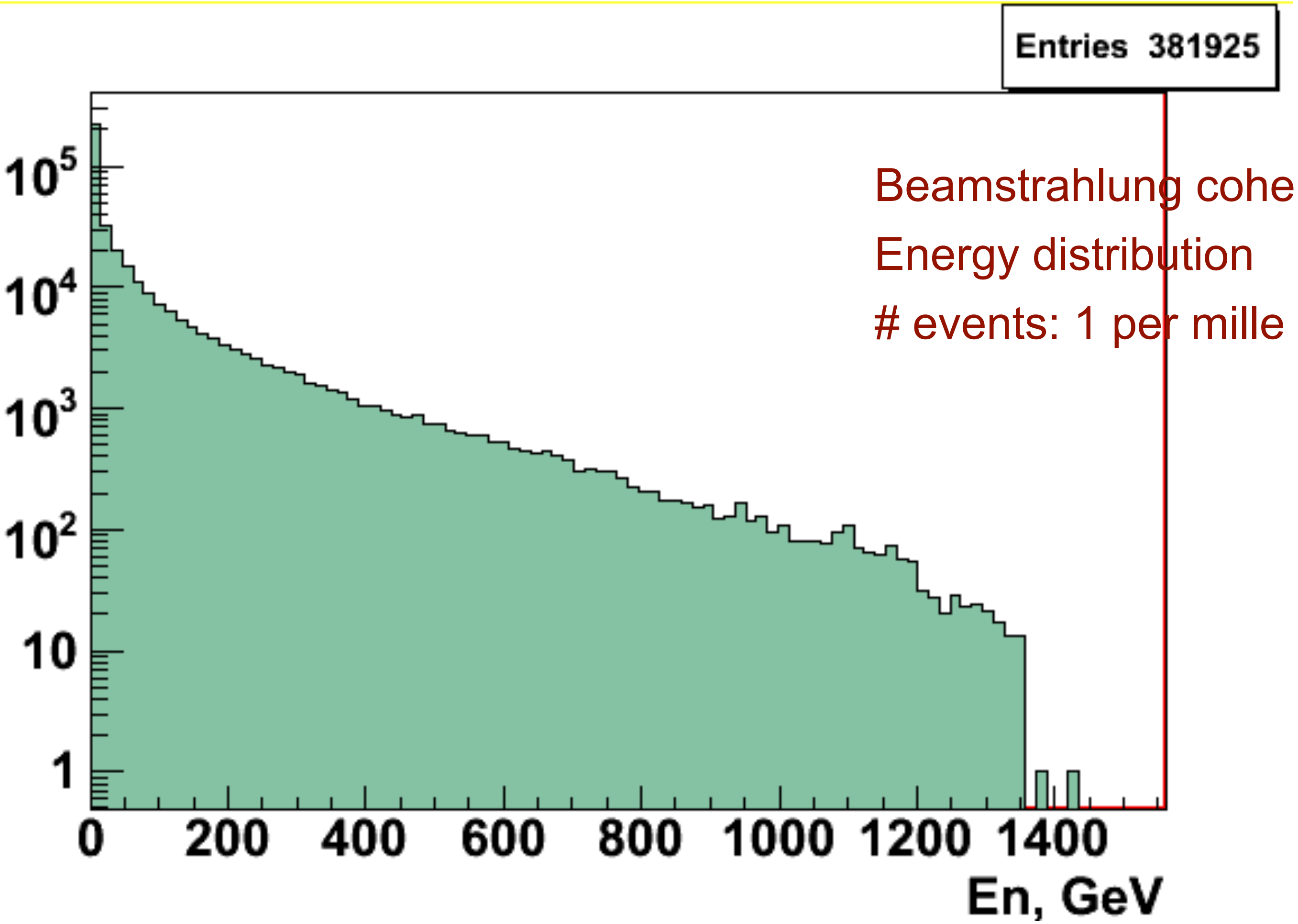
CLIC CM energy spectrum



Due to beamstrahlung:

- At 3 TeV only 1/3 of the luminosity is in the top 1% Centre-of-mass energy bin
- Many events with large forward or backward boost

Beamstrahlung



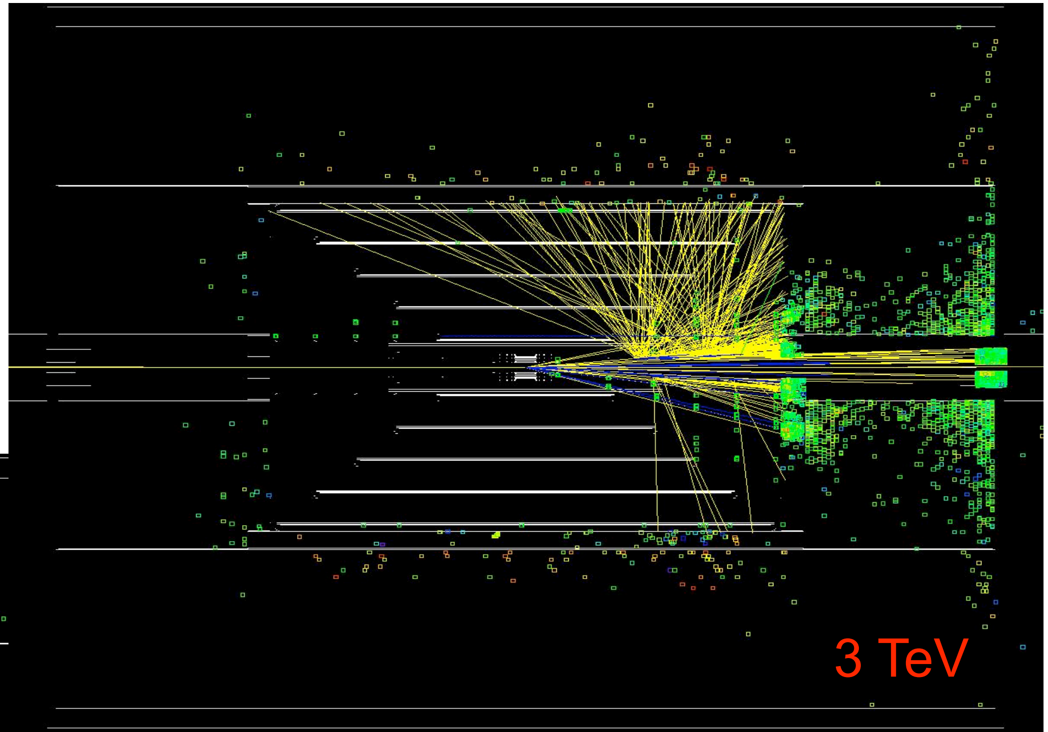
Beamstrahlung coherent pairs

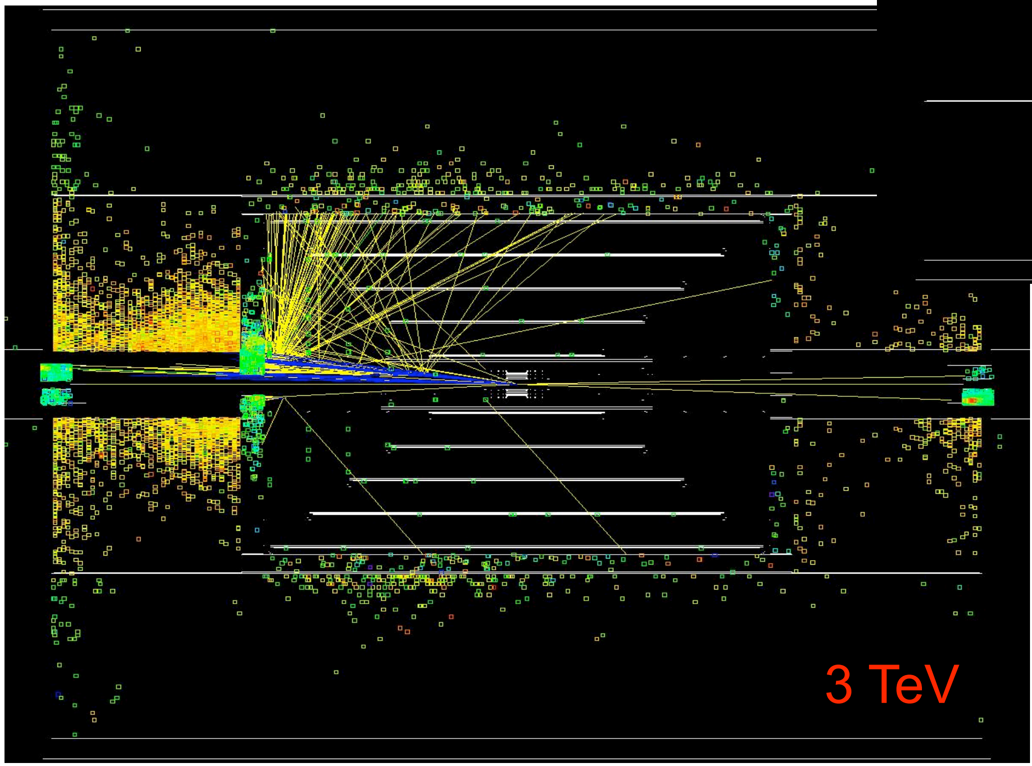
Energy distribution

events: 1 per mille of 1 bunch crossing

Beamstrahlung, continued…..

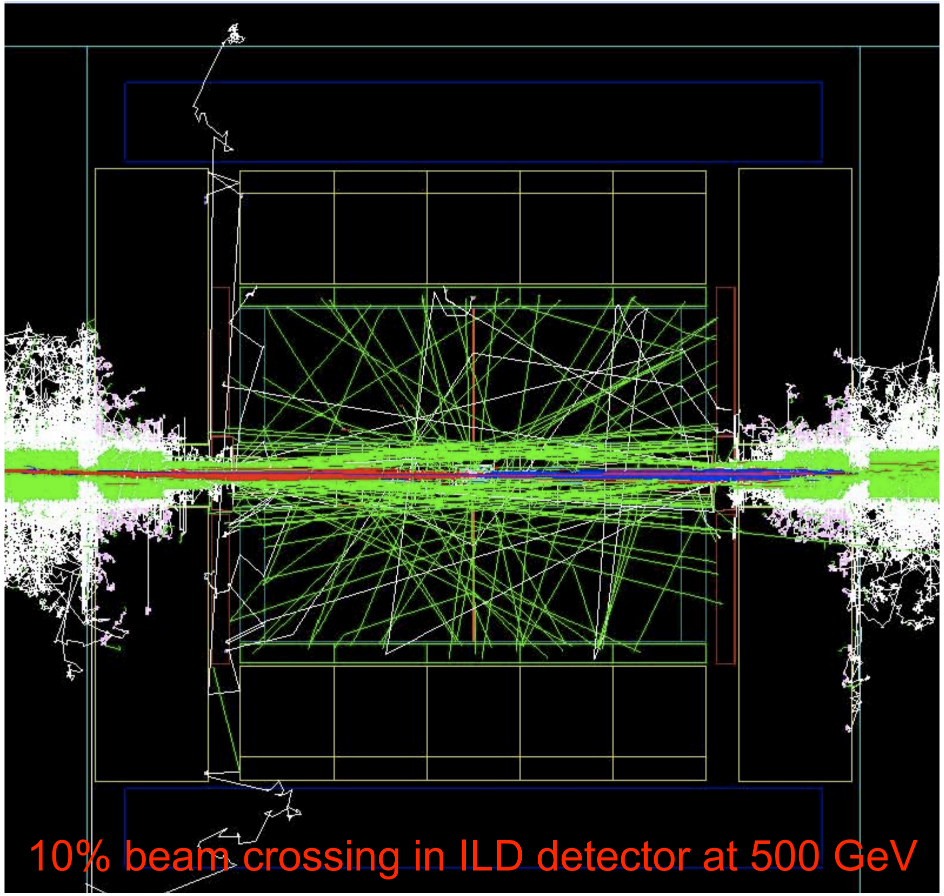
At 3 TeV many events have a large forward or backward boost, plus many back-scattered photons/neutrons





Many thanks to Marcel Stanitzki, Jan Strube and Norman Graf for setting up SiD software tools for CLIC simulation

Beamstrahlung => lessons learnt from ILC case



Courtesy: Adrian Vogel, DESY

- Pair production is the dominant background
- Most backgrounds can be controlled by a careful design
- Use full detector simulation to avoid overlooking effects

- Innermost Vertex layer (r=1.5 cm) has 0.04 hits/mm^2/BX
- Critical level of neutrons (radiation damage) at small radii of HCAL end-cap

Extrapolation ILC = > CLIC

Full LDC detector simulation at 3 TeV

Simulation of e^+e^- pairs from beamstrahlung origin

Courtesy: Adrian Vogel, DESY

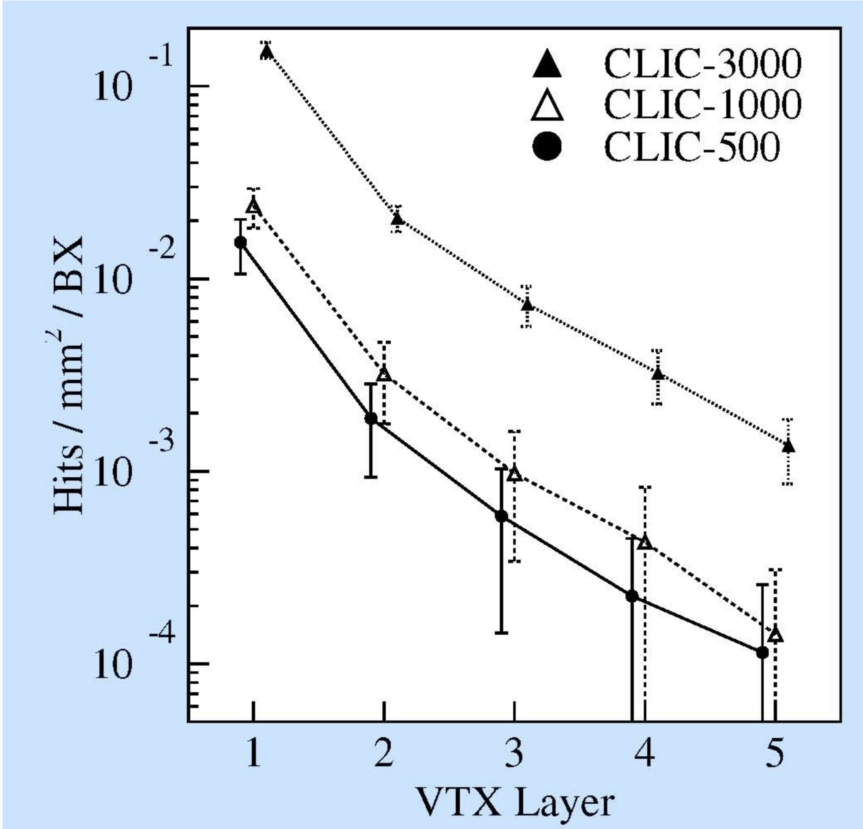
•**Conclusion of the comparison:**

•ILC, use 100 BX (1/20 bunch train)

•CLIC, use full bunch train (312 BX)

•**CLIC VTX: O(10) times more background**

•**CLIC TPC: O(30) times more background**

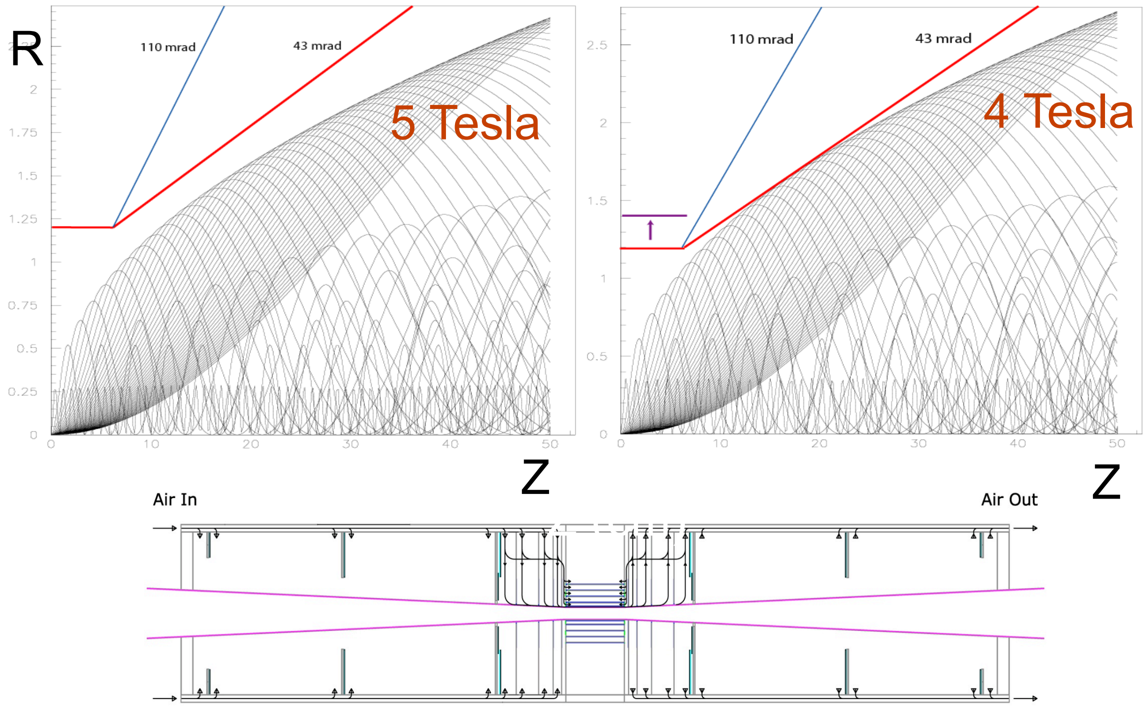


LDC 3 TeV, with forward mask

Beamstrahlung (continued)

Consequences of machine-induced background for CLIC detector:

Need: **higher magnetic field** and/or **larger tracking/vertex opening angle** and **larger crossing angle** (20 mrad) and **Mask in forward region**



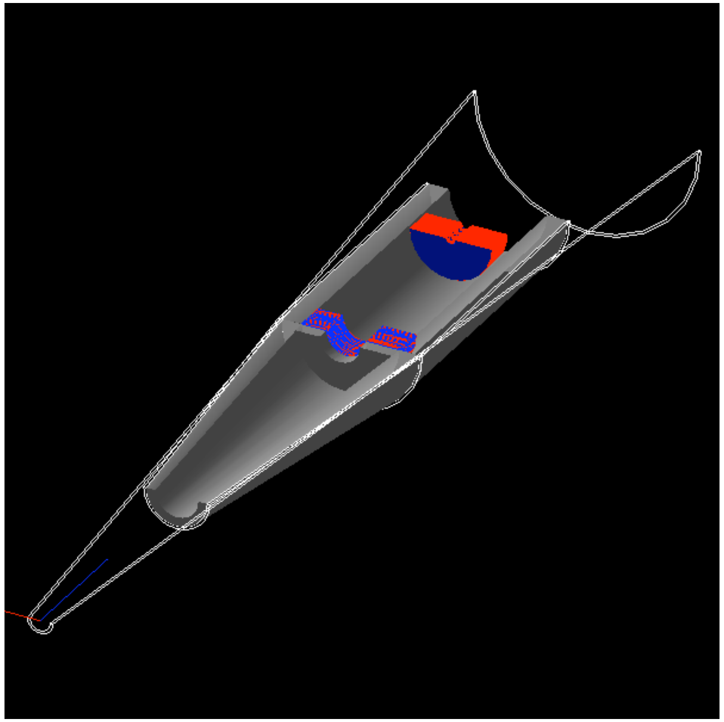
SiD plots
500 GeV

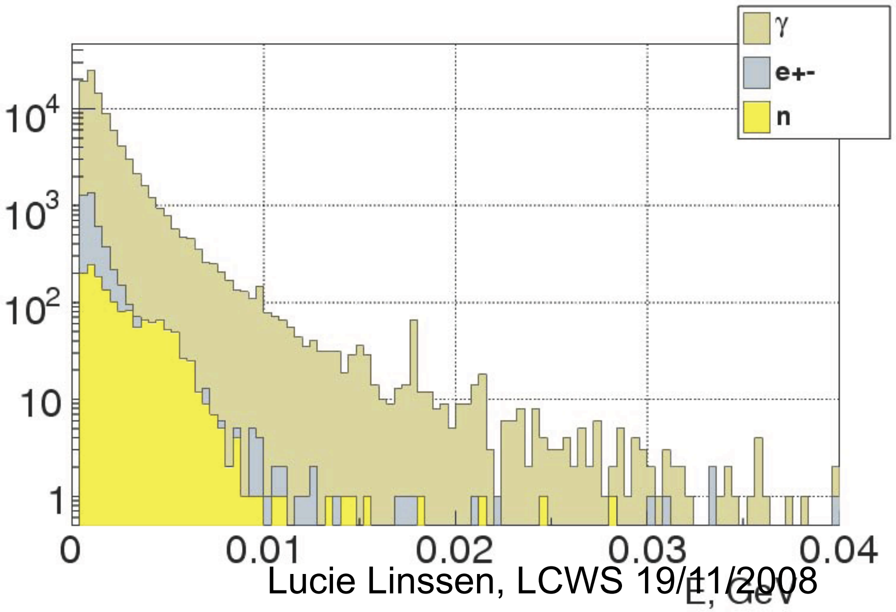
Forward mask studies

Andrey Sapronov, JINR
FCAL collaboration

Stand-alone simulation with flexible geometry:
Geant4.9.0p01 (QGSP_BERT_HP)

- **Conclusions from preliminary background estimates**:
- Conical part of mask can be made thin (or suppress tbc)
- Cylindrical part of mask needs effective neutron shielding.





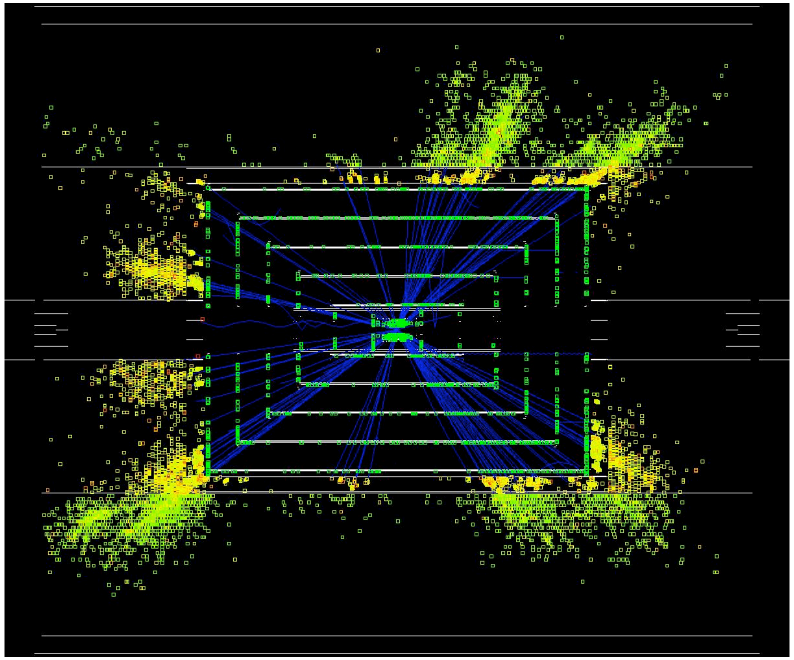
Background energy spectrum (without mask)

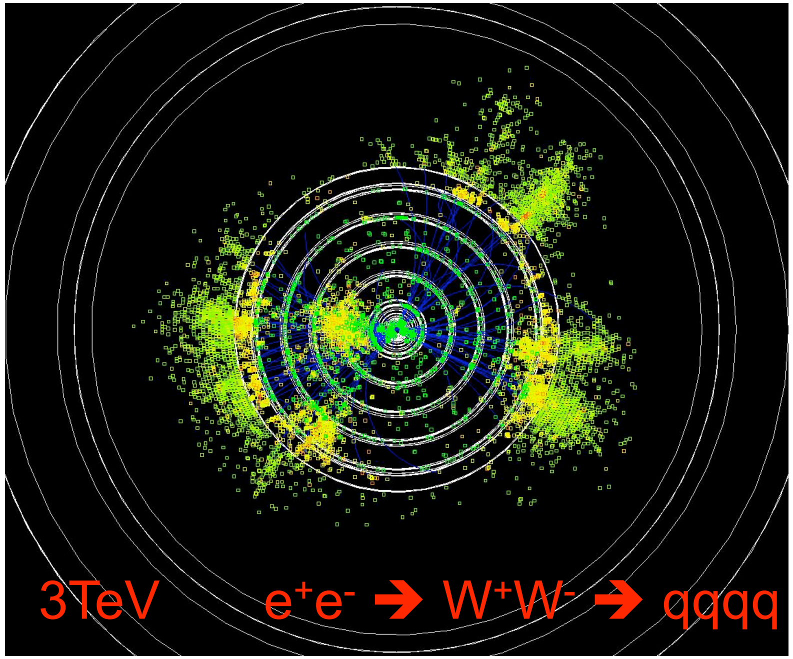
Origin: beamstrahlung => coherent pairs => backscattering γ,e,n

Tracking

Tracking issues:

- Due to beam-induced background and short time between bunches:
  - Inner radius of Vertex Detector has to move out (30-40 mm)
  - High occupancy in the inner regions
- Narrow jets at high energy
  - 2-track separation is an issue for the tracker/vertex detector
  - Track length may have to increase (fan-out of jet constituents)?



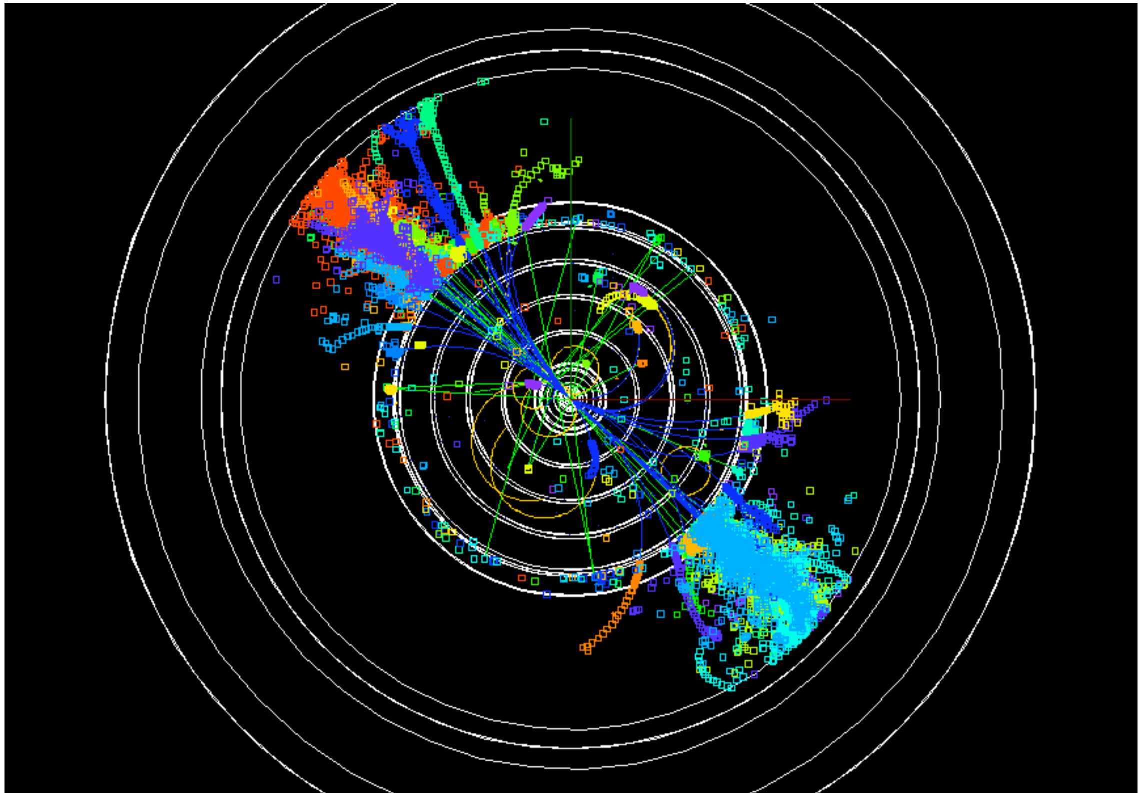


CLIC Calorimetry

High CLIC energies call for deep HCAL ($7\Lambda_i$ to $9\Lambda_i$, tbc)

Tradeoff between: HCAL depths ⇔ coil radius ⇔ heavy HCAL material

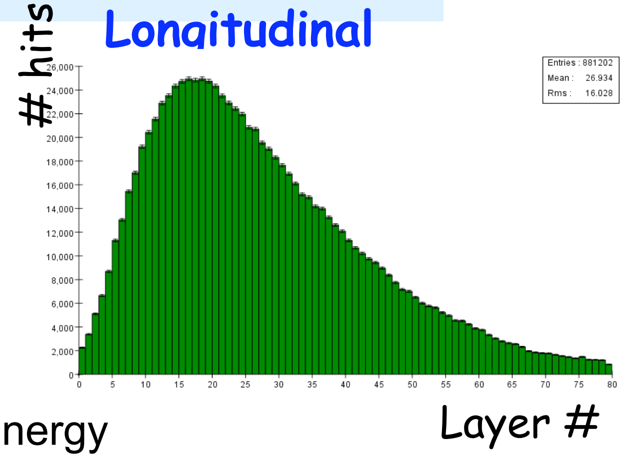
- Tradeoff between X_0 and Λ_i for hadron calorimetry



3 TeV e^+e^- event on SiD detector layout, illustrating the need for deeper calorimetry

20

Study of HCAL depth/leakage



Currently 2 studies ongoing:

1. LAPP Annecy, DHCAL micromegas

- Detailed DHCAL simulation, deep calorimeter at high energy
- See talk Jan Blaha, Wednesday 14:50 hrs calorimetry session

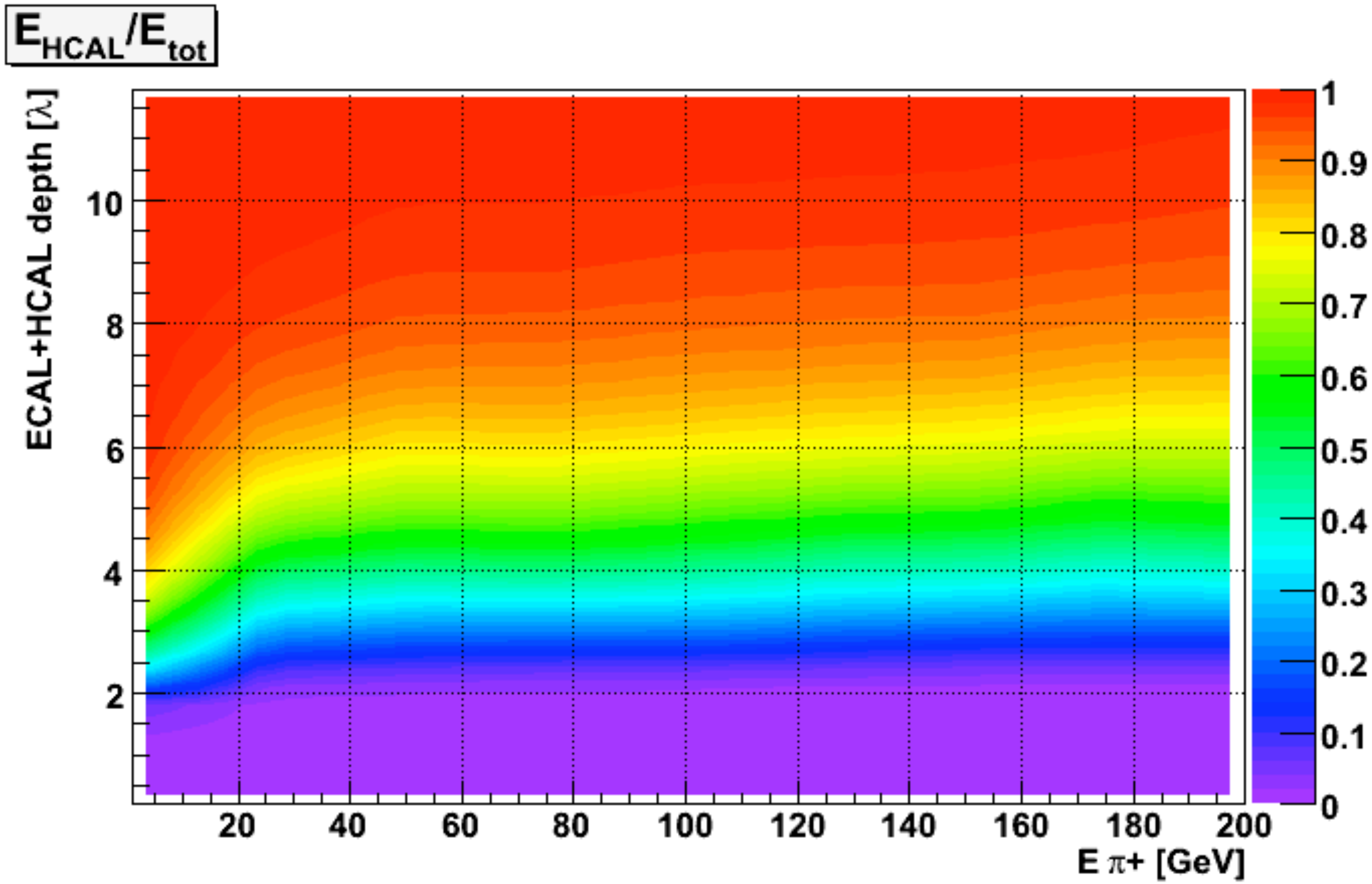
2. Use stand-alone calorimeter stack

- Simulated using SiD software tools
- 200 layers in depth (total 40 λ_I!), no specific ECAL structure
  - 2 cm tungsten + 0.5 cm scintillator (0.2 λ_I per layer)
- **Study the effect of placement/thickness of solenoid coil on calorimetry signal, combine with use of a tail catcher**
  - Single pions at 1 GeV => 200 GeV used
  - Next step will be: jets

HCAL leakage studies

Christian Grefe

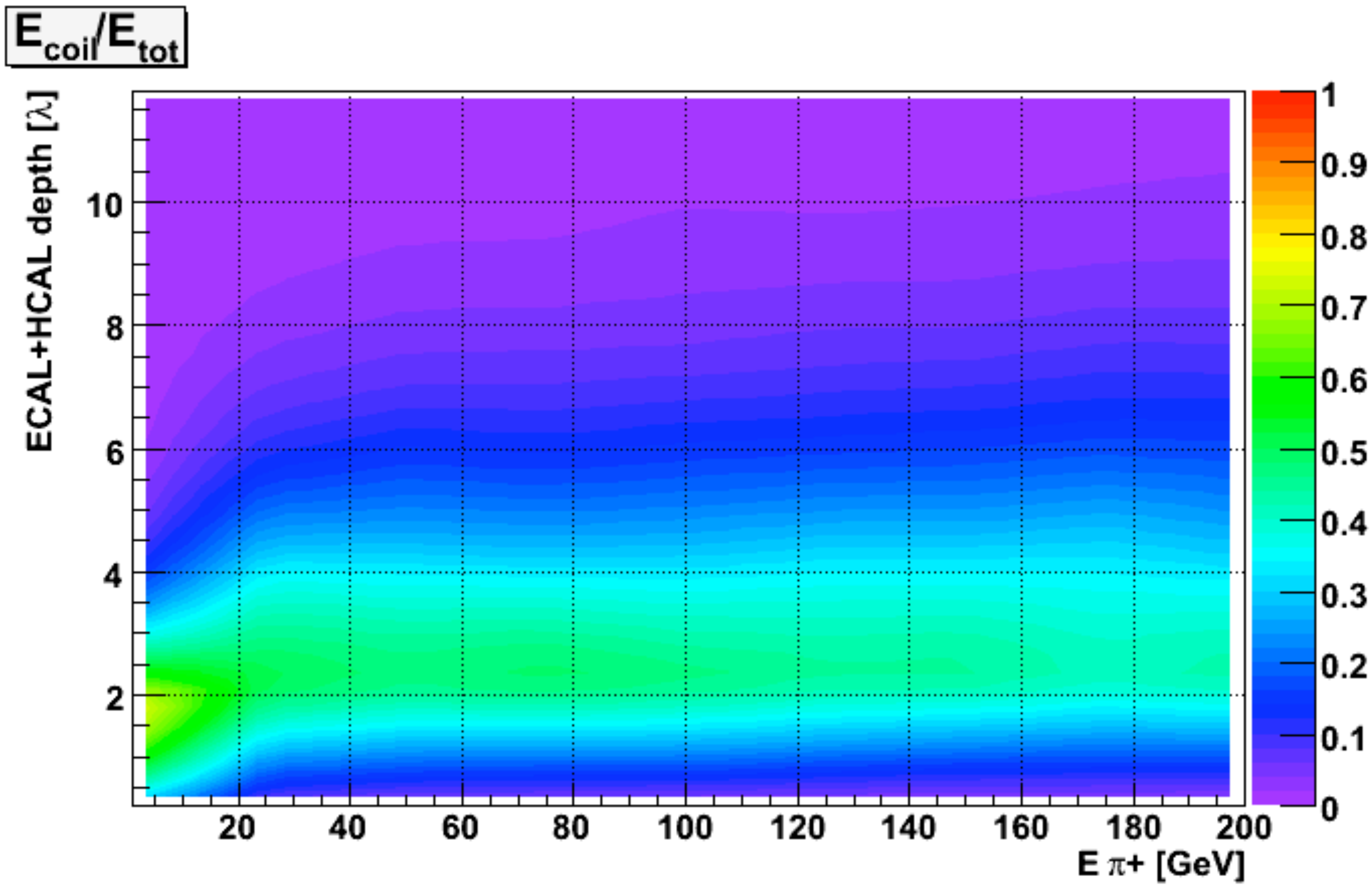
- Fraction of energy deposited in the HCAL



HCAL leakage studies

Christian Grefe

- Fraction of energy deposited in the coil ($2\lambda_i$)

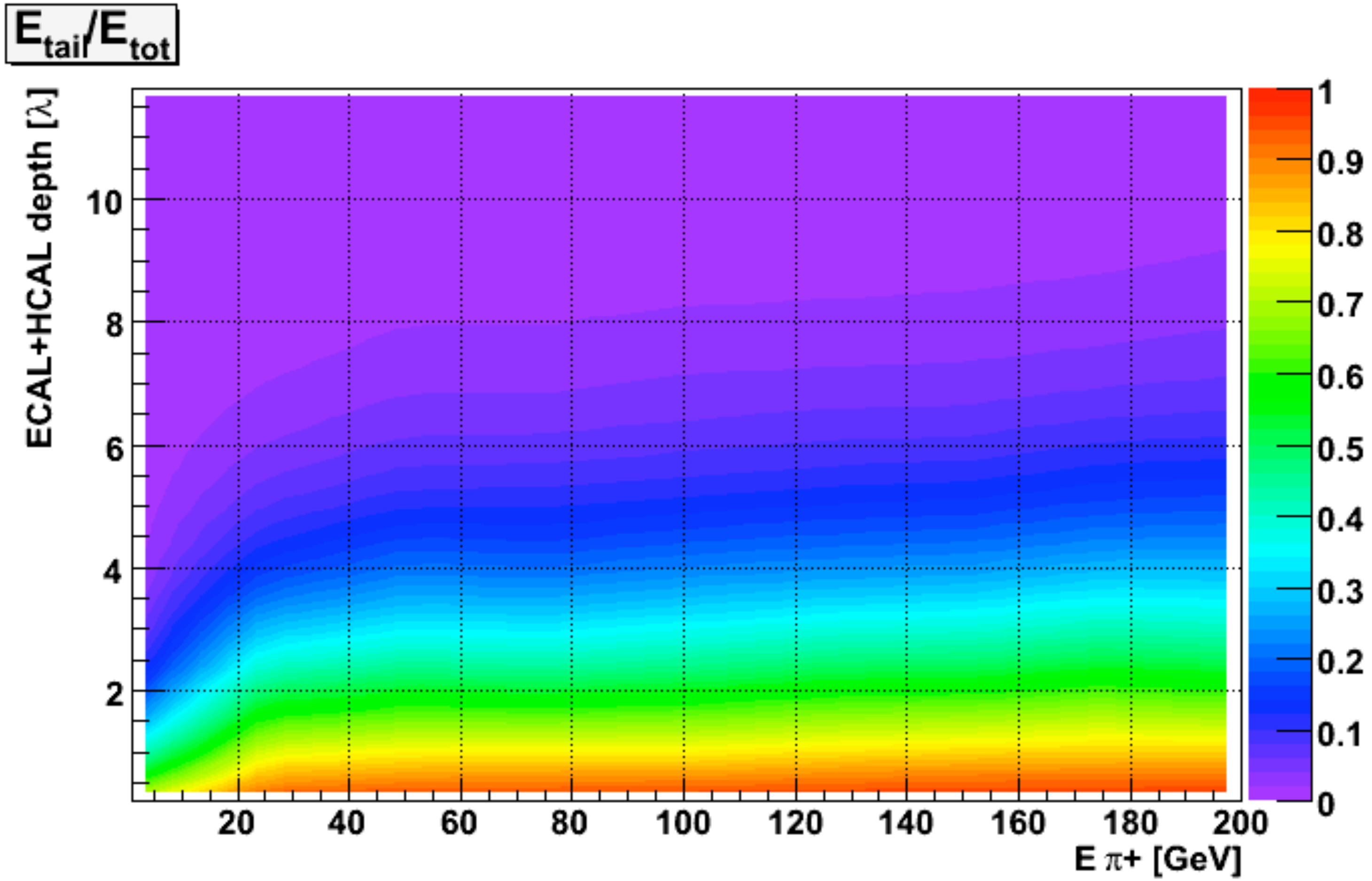


HCAL leakage studies

Christian Grefe

- Fraction of energy deposited in the tail catcher

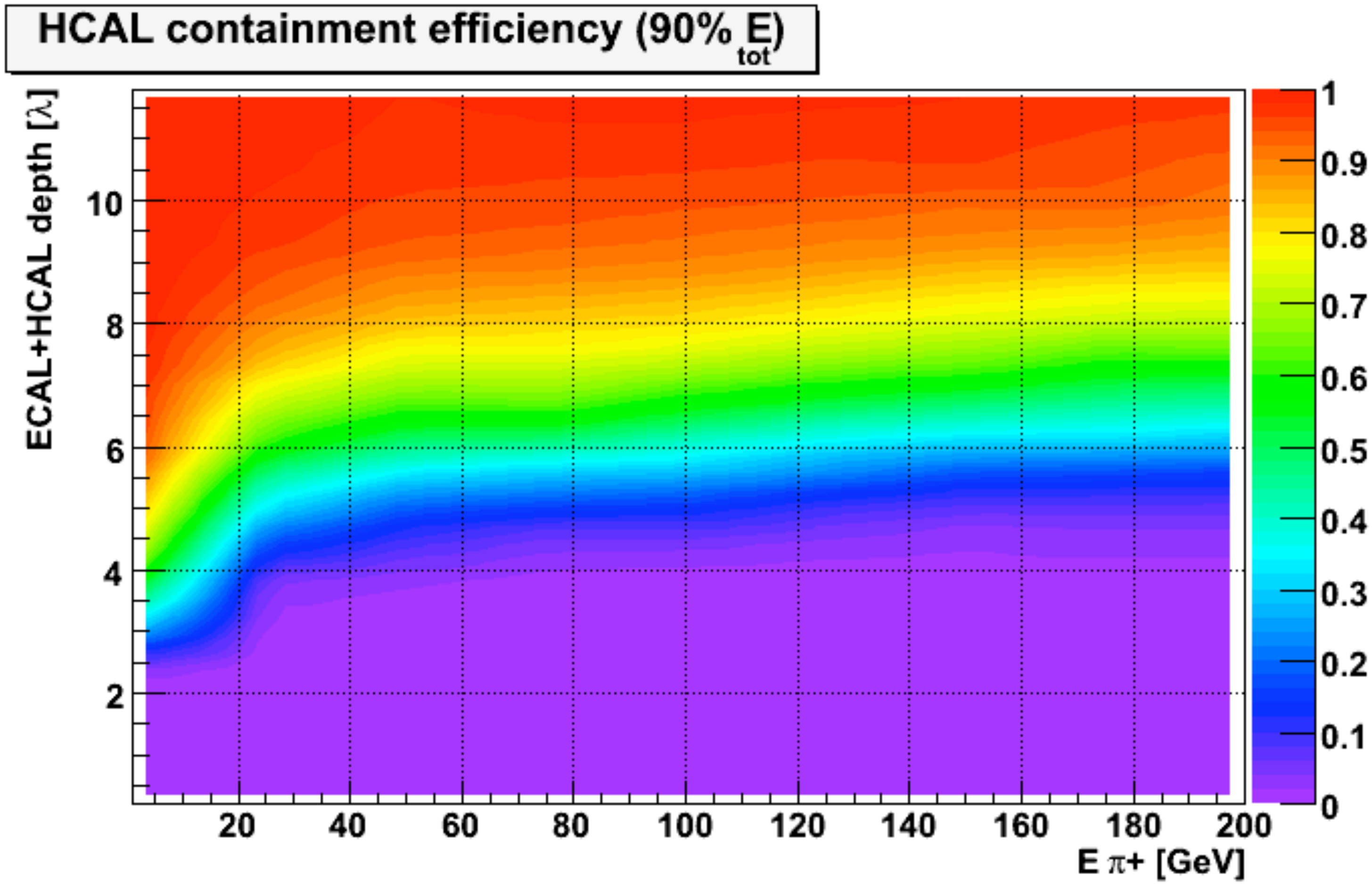
(after HCAL and $2\lambda_i$ coil)



HCAL leakage studies

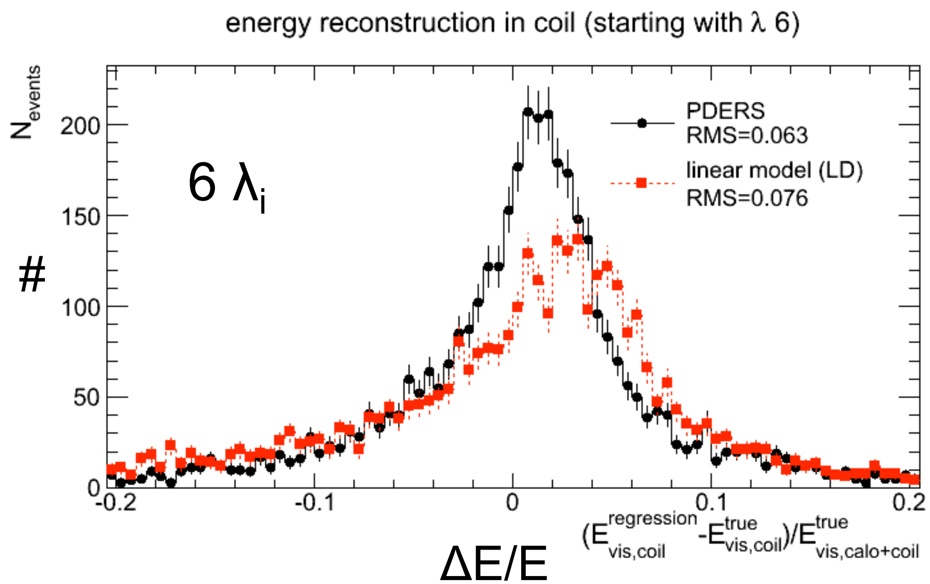
Christian Grefe

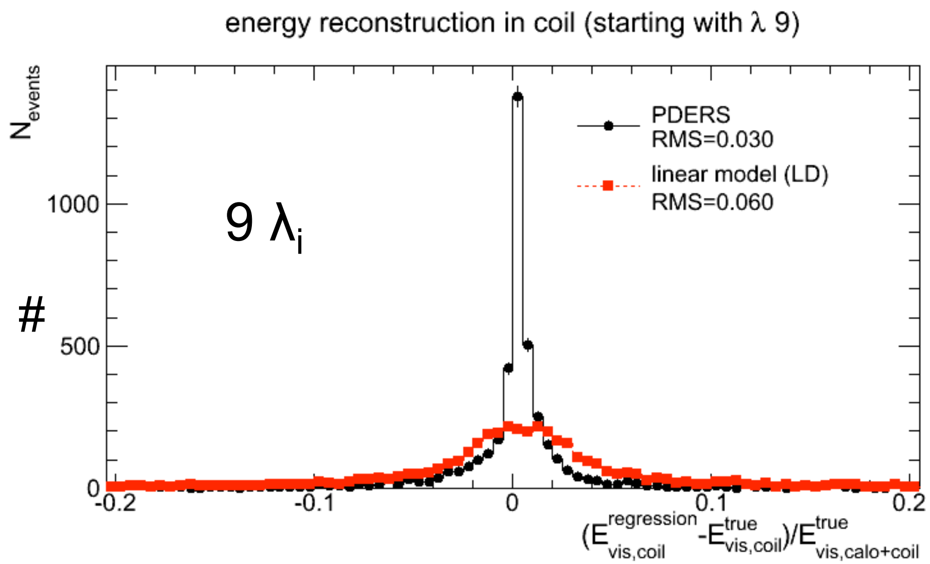
- Fraction of events with at least 90% containment in the calorimeter



Use of tail catcher

Christian Grefe,
Peter Speckmayer





Combine knowledge of HCAL deposits and Tail Catcher deposits to optimise energy resolution in the presence of 2 λ_i coil.

ΔE/E for:

- Linear model (red)
- Probability density estimator (black)

	linear	PDESR
6 λ_i	8%	6%
9 λ_i	6%	3%

Does PFA work for high-energy jets?

Mark Thomson CLIC08 using ILD detector description

★ Traditional calorimetry $\sigma_E/E \approx 60\%/\sqrt{E/\text{GeV}}$

★ 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

What about at CLiC ?

★ PFA perf. degrades with energy

★ For 500 GeV jets, current alg. and ILD concept:

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

★ Crank up field, HCAL depth…

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

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

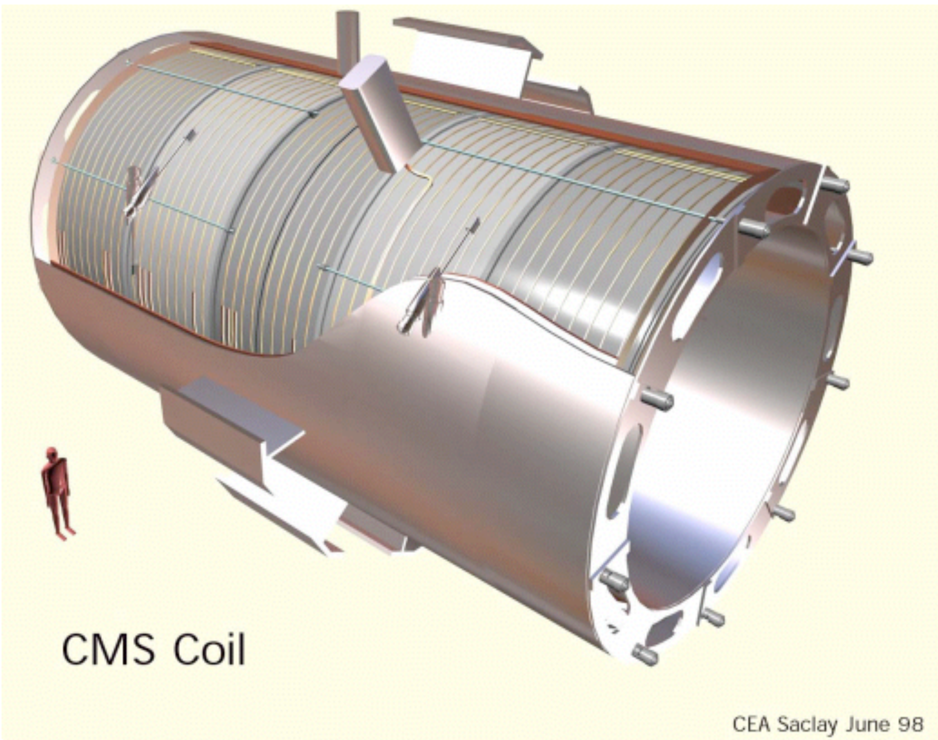
Conclude: for 500 GeV jets, PFA reconstruction not ruled out

CLIC solenoid coil

Initial assessments of calorimetry/tracking/background seem to point to higher demands on the coil (large radius and field)

⇒ Need to study constraints coming from the feasibility of the solenoid coil.

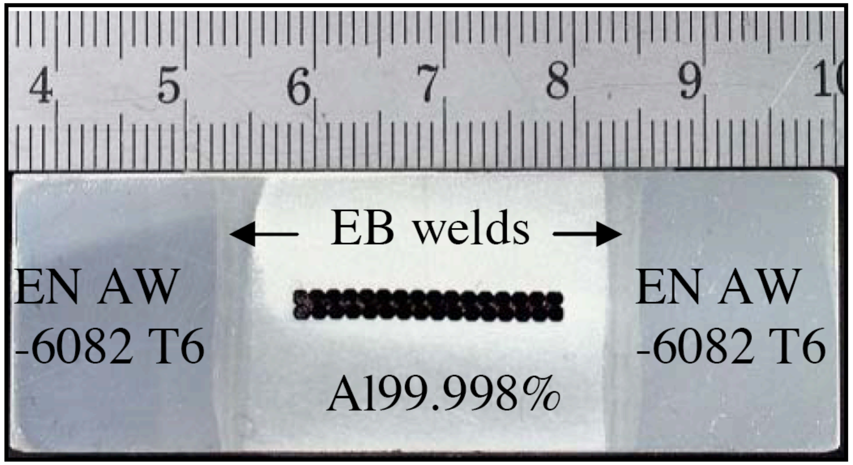
Start from CMS experience



Magnetic length	**12.5 m**
Free bore diameter	**6.0 m**
Central magnetic induction	**4.0 T**
Max induction on conductor	4.6 T
Nominal current	19.2 kA
Mean inductance	14.2 H
Stored energy	**2.6 GJ**
Stored energy / unit of cold mass	**11.6 kJ/kg**
Operating temp.	4.5 K

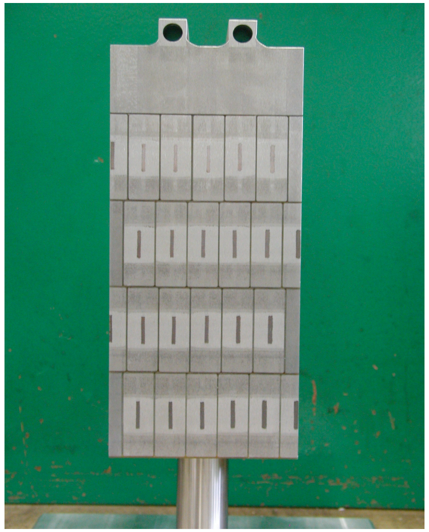
CLIC solenoid coil

Alain Herve @ CLIC08



Preliminary conclusions:

- CMS conductor (NbTi cable extruded in stabiliser) can technically form the basis for a larger/stronger coil
- R&D needed on conductor reinforcement (strength of Al alloy) and welding technique (replacing electron-beam welding).
- Note: stronger field => more windings => more material
- Return yoke will become a concern (have to keep stray field low, also in view of push-pull)
- Parametric model, including all major parameters, under construction



Possible future CLIC R&D

Preliminary list

1. Time stamping. Develop specific layers in tracker and calorimeter to reject background events from other bunches crossings (0.5 ns separation).
2. High-field solenoid conductor. Replacement of the pure aluminum coil stabilizer and replacement of the electron beam welding.
3. Mechanical engineering support. Integration, heavy HCAL, coil, stability issues, etc.
4. Alternative to PFA calorimetry (e.g. dual readout calorimetry with crystal fibres).
5. Synergy of R&D (approved CERN) between LC and SLHC for on-detector powering and for integrated silicon pixel detectors

To be carried out in collaboration with CERN and outside institutes

Conclusions

- Work on the CLIC detector/physics has re-started
- **CLIC detector concept studies are based on the ILC work**
  - Basic concepts will be similar
  - ILC hardware developments are most relevant for CLIC
  - Software tools
- A number of areas have been identified, where the CLIC detector at 3 TeV differs from the ILC concepts at 500 GeV
  - The initial CLIC concept simulation studies will concentrate on these areas
  - CLIC-specific R&D will be required in a number of technology domains
- Many thanks to ILC physics community, who helped to get the CLIC detector studies restarted in the framework of the recently established CLIC-ILC collaboration !

Spare slides

Calorimeter depth

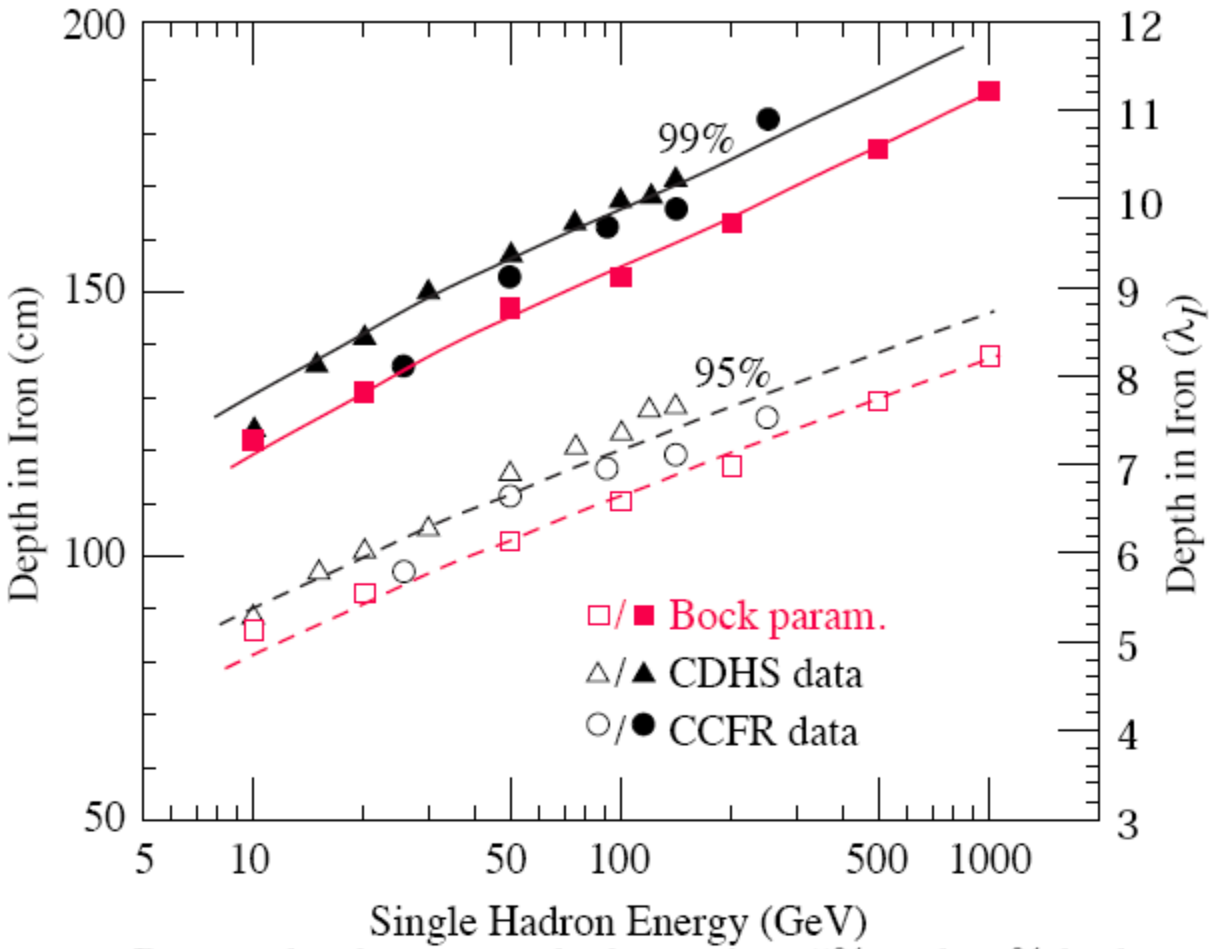
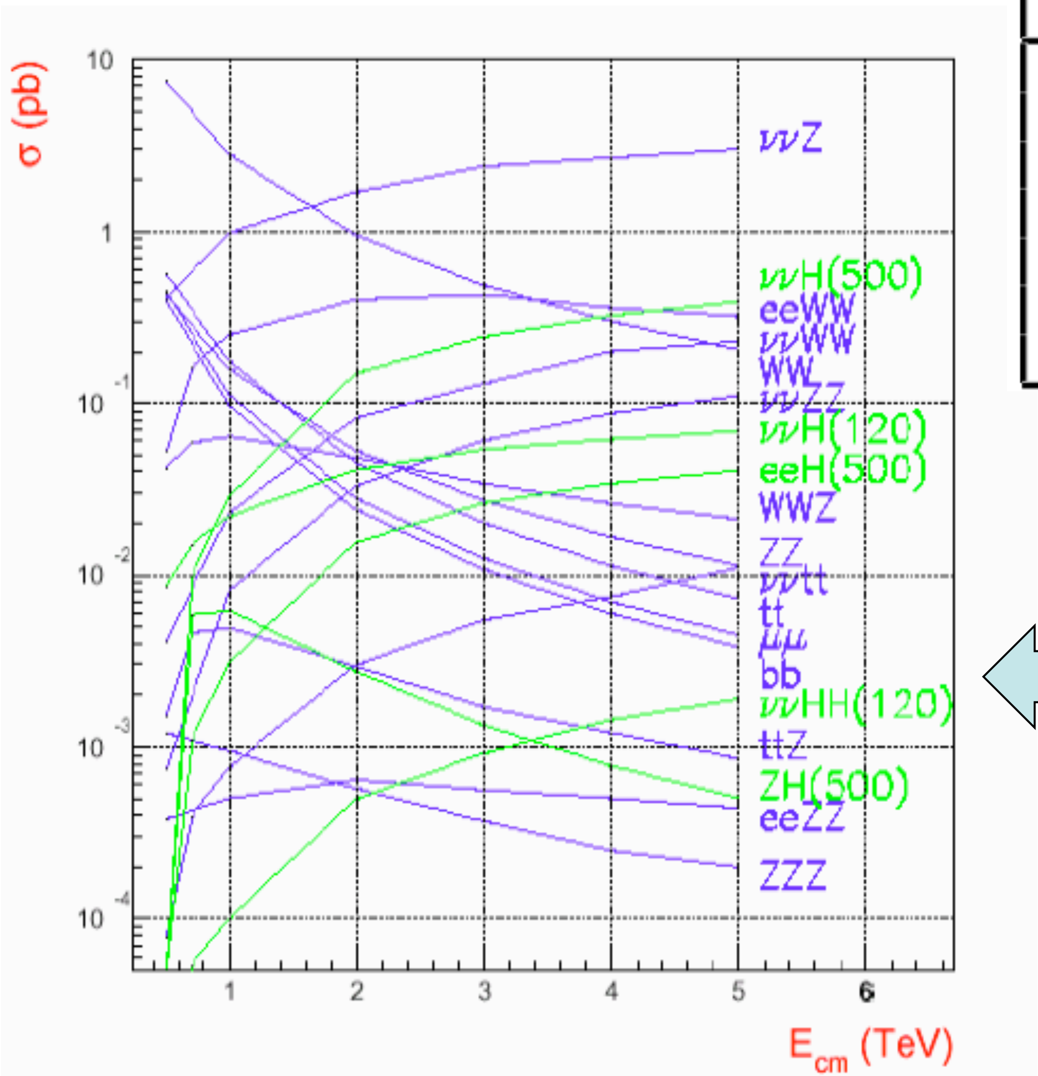


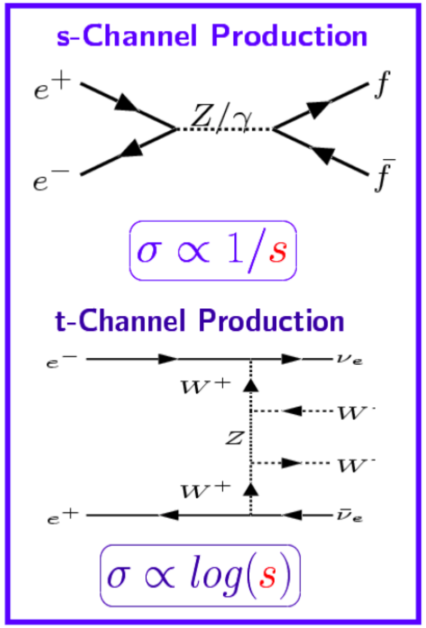
Figure 28.22: Required calorimeter thickness for 95% and 99% hadronic cascade containment in iron, on the basis of data from two large neutrino detectors and Bock's parameterization [143].

CLIC physics

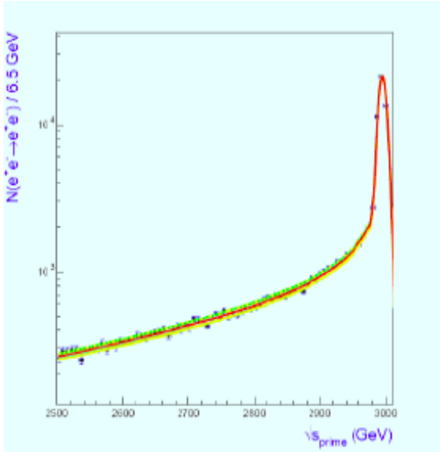
Cross-sections at a few TeV



Event Rates (1000 fb^{-1})	3 TeV 10^3 events
$e^+e^- \to t\bar{t}$	20
$e^+e^- \to b\bar{b}$	11
$e^+e^- \to ZZ$	27
$e^+e^- \to WW$	490
$e^+e^- \to hZ/h\nu\nu$ (120 GeV)	1.4/530
$e^+e^- \to H^+H^-$(1 TeV)	1.5
$e^+e^- \to \tilde{\mu}^+\tilde{\mu}^-$ (1 TeV)	1.3



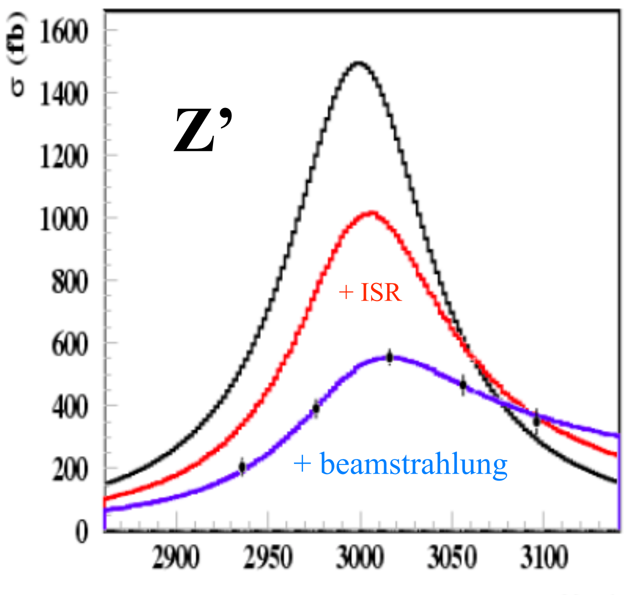
Luminosity spectrum and effect on Resonance Production



@CLIC significant beamstrahlung

→ Luminosity spectrum not as sharply peaked as at lower energy

→ need for luminosity



Resonance scans, e.g. a Z'

FIT ACCURACY

Observable	Breit Wigner	CLIC.01	CLIC.02
$M_{Z'}$ (GeV)	$3000 \pm .12$	$\pm .15$	$\pm .21$
$\Gamma(Z')/\Gamma_{SM}$	$1. \pm .001$	$\pm .003$	$\pm .004$
σ^{eff}_{peak} (fb)	1493 ± 2.0	564 ± 1.7	669 ± 2.9

1 ab^{-1} ⇒ $\delta M/M \sim 10^{-4}$ & $\delta\Gamma/\Gamma$ = 3.10^{-3}

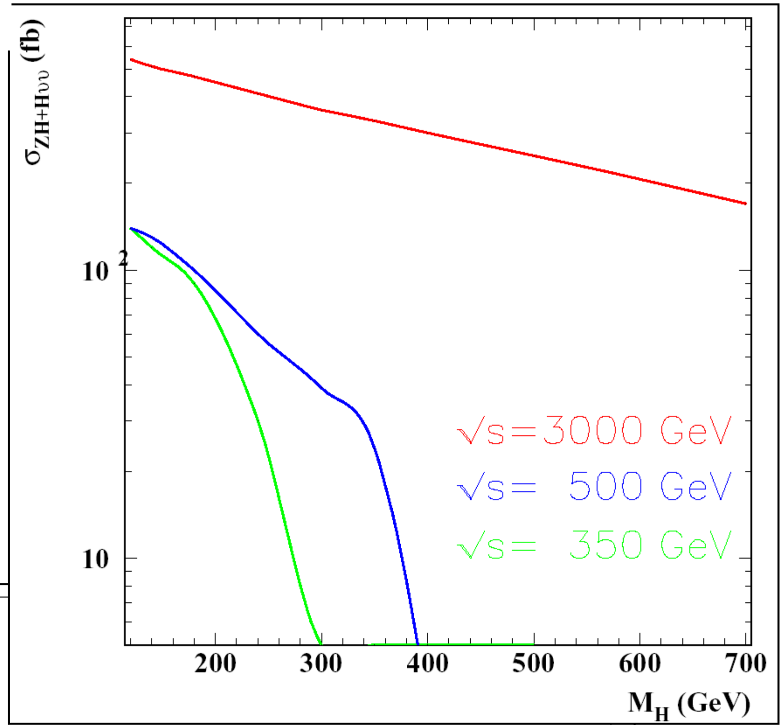
John Ellis, CLIC07

If there is a light Higgs boson …

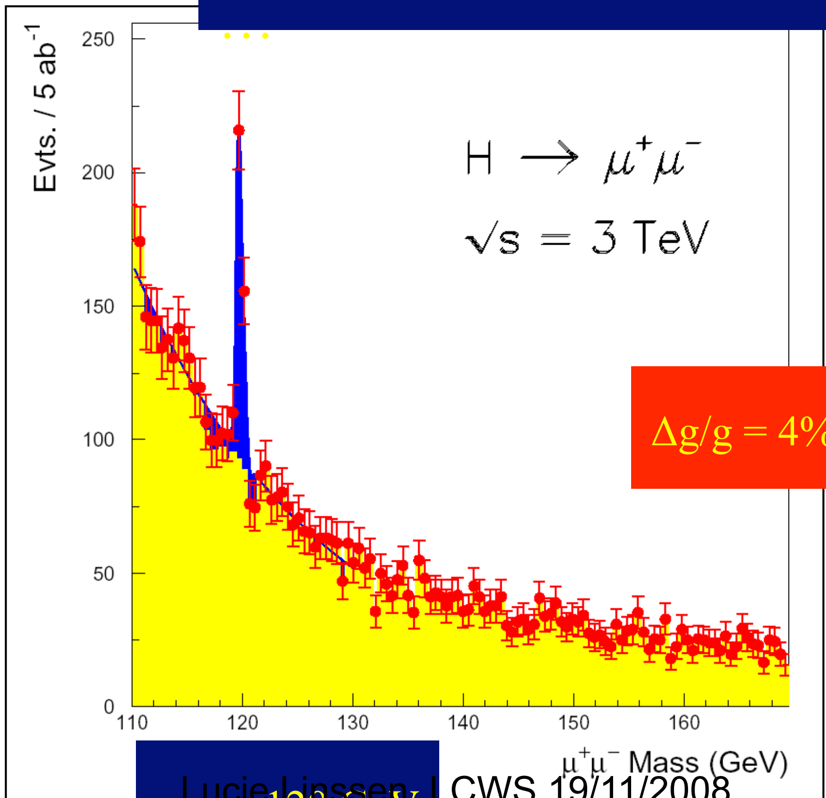
- Large cross section @ CLIC
- Measure rare Higgs decays unobservable at LHC or a lower-energy $e^+ e^-$ collider
- CLIC could measure the effective potential with 10% precision
- CLIC could search indirectly for accompanying new physics up to 100 TeV
- CLIC could identify any heavier partners

John Ellis, CLIC07

Large Cross Section @ CLIC

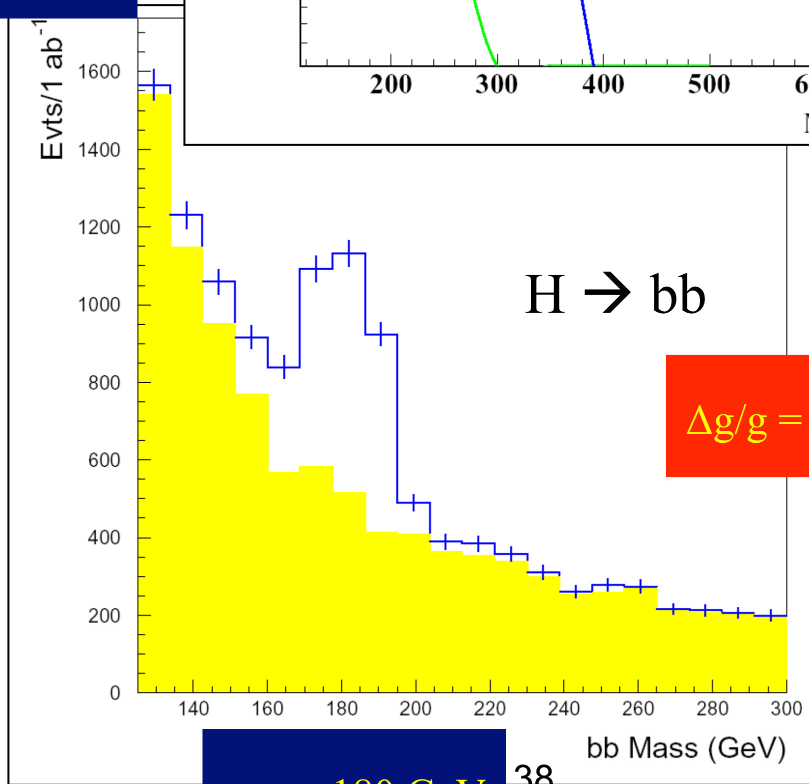


Can measure rare decay modes



$\Delta g/g = 4\%$

$m_H = 120$ GeV

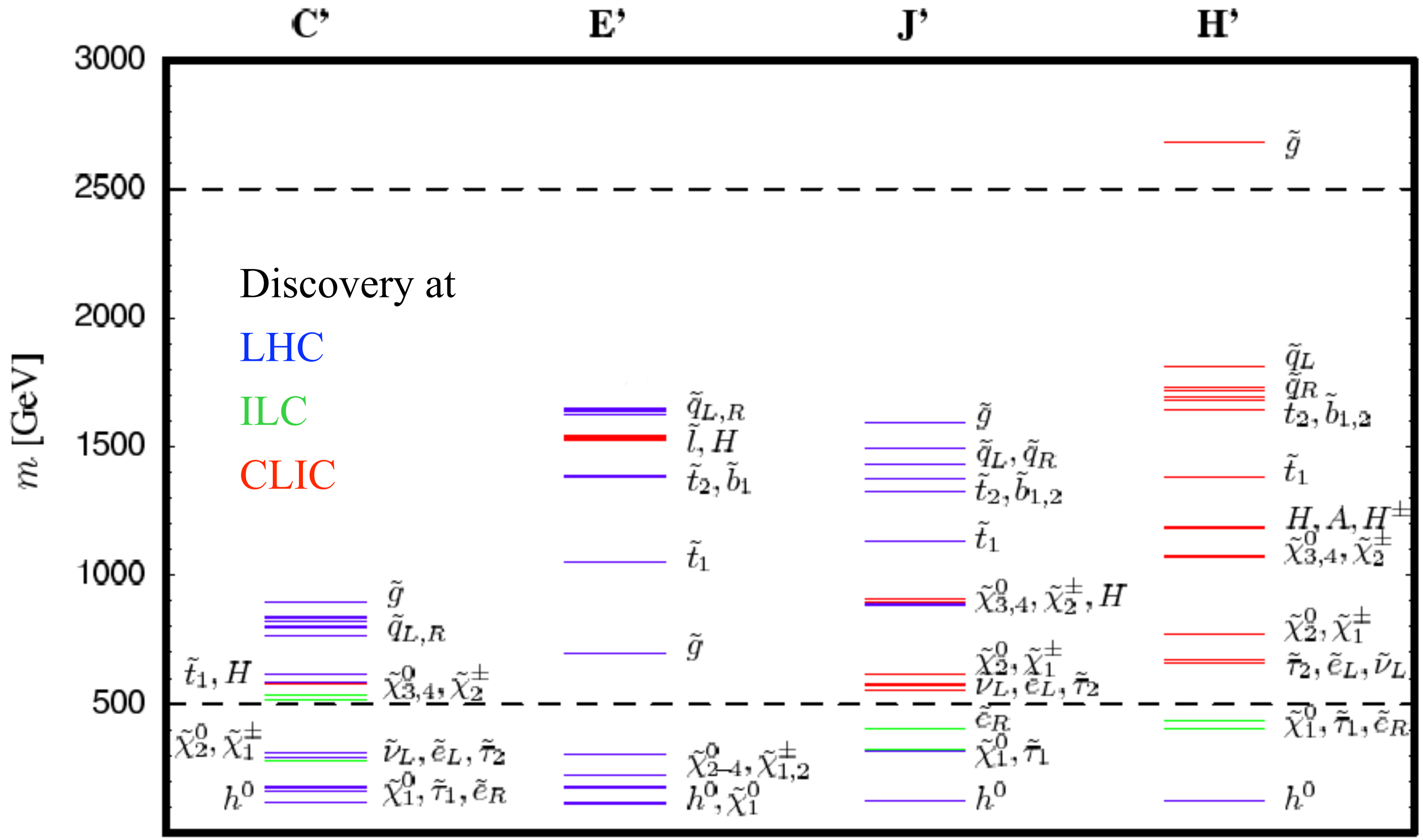


$\Delta g/g = 2\%$

$m_H = 180$ GeV

Physics case: Supersymmetry

Examples of mass spectra for 4 SUSY scenarios (there are many more!)

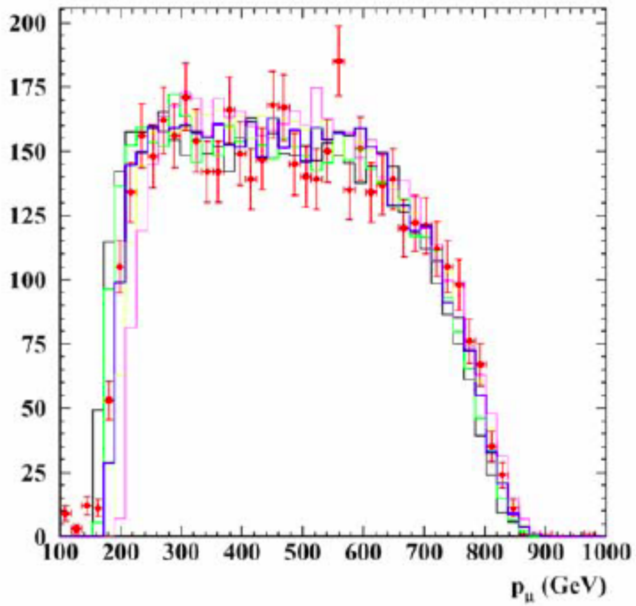


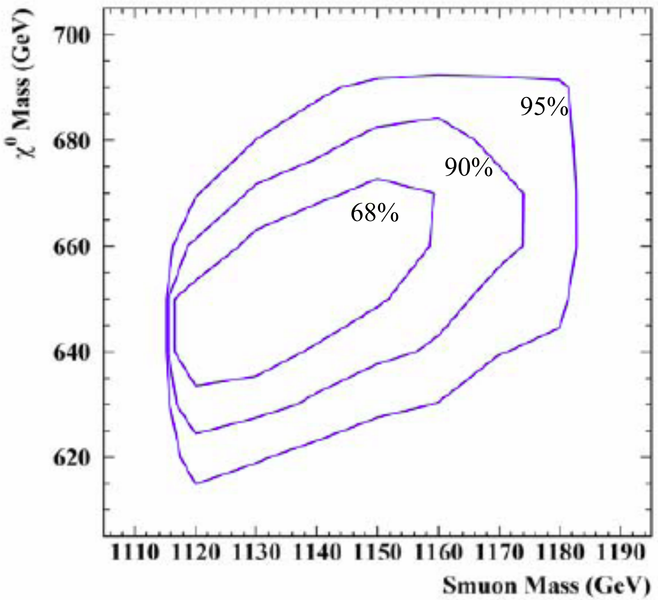
Physics case: Supersymmetry

Mass determinations: $e^+e^- \to \tilde{\mu}_L^+\tilde{\mu}_L^- \to \mu^+\chi_1^0\mu^-\chi_1^0$

- If $\sqrt{s} >> 2\tilde{m}_\mu$, μ spectrum end points

$$E_{\min,\max} = \frac{\sqrt{s}}{4}\left(1-\tilde{m}_\chi^2/\tilde{m}_\mu^2\right)\left(1\pm\sqrt{1-4\tilde{m}_\mu^2/s}\right)$$





$\tilde{m}_\mu = (1145 \pm 25)\,\text{GeV}$ 2%

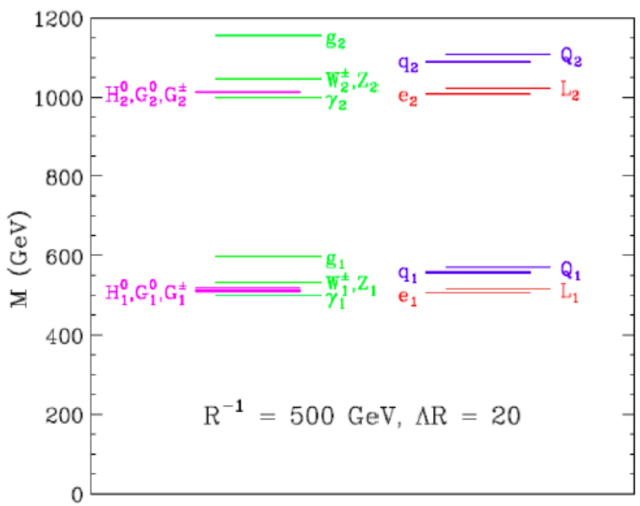
$\tilde{m}_\chi = (652 \pm 22)\,\text{GeV}$ 3%

Physics case: Extra dimensions

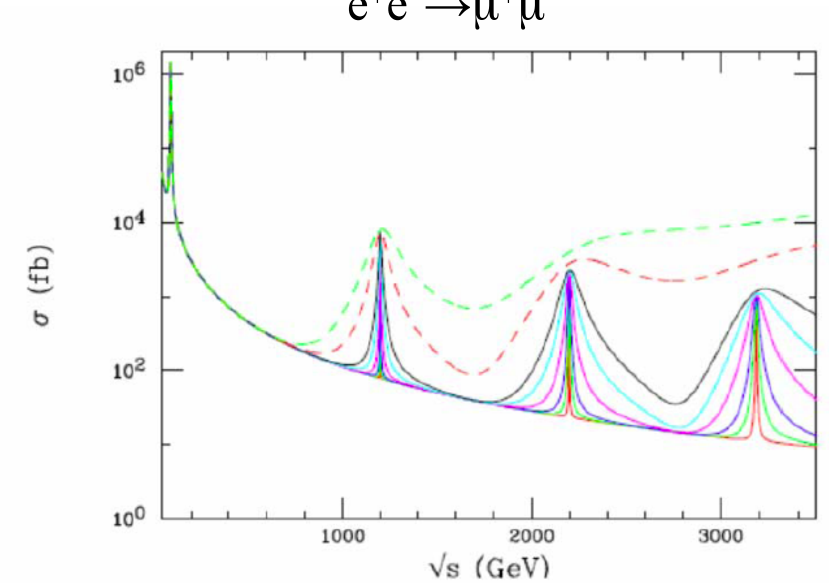
Extra-dimension scenario (Randall, Sundrum) predicts production of

- TeV-scale graviton resonances, decaying into two fermions.
- Cross sections are large, but wide range of parameters.

Examples:



$e^+e^- \to \mu^+\mu^-$



Could be discovered at LHC

Forward region

- Tungsten **Mask** with polyethylene coating to absorb low-energy backscattered relics (e,γ,n) from beamstrahlung. Containing **Lumical** and **BeamCal**