Detectors and Physics Working Group

A. De Roeck M. Hauschild R. Settles

CLIC Workshop 07

First Session: Wednesday

Detectors

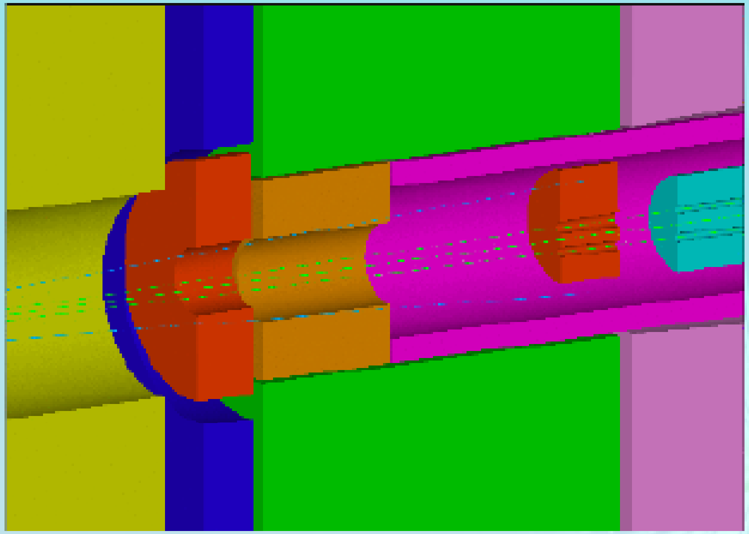
13:40->*18:40* **Physics & Detectors Wkg (Location: Main Auditorium)** (Convener: Michael Hauschild (*CERN*) , Ron Settles (*Max-Planck-Institut fuer Physik*))

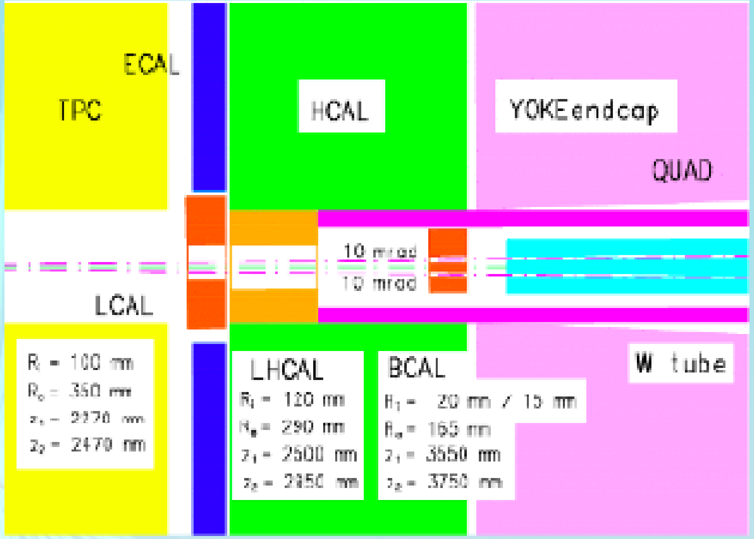
13:40	MDI Experience from the ILC (20') (Slides ; video; video download)	Karsten Buesser (*DESY*)
14:05	ILC Pixel/microvertexing (20') (Slides)	Marc Winter (*Institut de Recherches Subatomiques (IReS)*)
14:30	ILC Tracking (20') (Slides)	Klaus Dehmelt (*DESY*)
14:55	ILC Calorimetry (20') (Slides)	Erika Garutti (*DESY*)
15:20	EUDET (15') (Slides)	Joachim Mnich (*DESY*)
15:40	Coffee Break	
16:00	Calorimetry (crystals) (15') (Slides)	Paul Lecoq (*CERN*)
16:20	Time stamping (15') (Slides)	Pierre Jarron (*CERN*)
16:40	Pixel microvertex technologies (15') (Slides)	Michael Campbell (*CERN*)
17:00	3D silicon (15') (Slides)	Cinzia Da Via (*Brunel University*)
17:20	TOF (15') (presentation)	Crispin Williams (*Universita & INFN, Bologna*)
17:40	Interaction Region Engineering at ILC: Push-Pull option (15') (Slides)	Alain Herve (*CERN*)
18:00	Detector Services Design for push-pull option (15') (Slides)	Andrea Gaddi (*CERN*)
18:20	SiD detector at 3 TeV (15') (Slides)	Marco Battaglia (*UC. Berkeley & LBL. Berkeley*)

~ 35 participants

MDI experience from the ILC

LDC Forward Region





- L*=4.05 m
- 14 mrad crossing angle
  - 2 and 20 mrad exist as alternative
- Tungsten absorber around BeamCal
- LumiCal: precision lu
- BeamCal: pair signal
- Calorimeters centred
- LowZ absorber

K. Buesser

Also a report on backgrounds →Messages:
Check backgrounds after all even smallest change
Neutron background estimate still an issue…

For CLIC: need to revisite the IP/Mask area (Design?)

Vertex Detectors at ILC

ILC-VD - **Constraints from the Physics Goals**

M. Winter

- Overall objective: identify $\sim$ all flavours involved in most final states

  Ex: $e^+e^- \rightarrowtail ZH \quad \Rightarrow$ measure Br $(H \rightarrowtail c\bar{c}, \tau^+\tau^-, b\bar{b}, gg, ...)$

- In practice:
  - ▷ *tag c and τ jets with unprecedented efficiency & purity (b tagging much less challenging)*
  - ▷ *reconstruct very efficiently Vx1 $\rightarrowtail$ Vx2 $\rightarrowtail$ Vx3 $\rightarrowtail$ ....*
  - ▷ *reconstruct vertex flavour and electrical charge ...*
  - ▷ *cope with high jet multiplicity final states containing numerous b, c, τ jets*
  - ▷ *minimise secondary interactions (missleading particle flow reconstruction)*
  - ▷ *etc.*

- $\sigma_{IP} = a \oplus b/p \cdot \sin^{3/2}\theta$ with $a < 5\ \mu m$ and $b < 10\ \mu m$
  - ▷ limits on a and b are still "very educated guesses" ▷ SLD: a = 8 μm and b = 33 μm
  - $\sigma_{sp} \lesssim 3\mu m$ • $R_{in} \sim$ 1–2 cm ? • $R_{out} \sim 4 \cdot R_{in}$ • VD layer $\sim$ 0.1–0.2 % X_0 • beam pipe $\sim$ 0.1 % X_0

- *Constraint on σ_{IP} satisfies simultaneoulsy requirement on 2-hit separation in inner most layer ($\sim 30 - 40\ \mu m$)*

Vertex Detectors

ILC-VD -

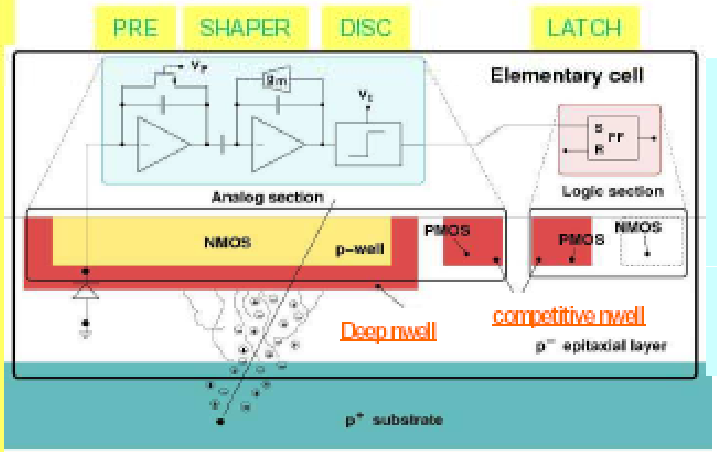
Next Generation of CMOS Sensors (1/2)

Deep NWell 130nm CMOS MAPS

- *Rad-hard* MAPS *with data sparsification and high rate capability (self-triggering pixel design, in-pixel comparator, in-pixel time stamping and sparsification logic)*
  - *Deep N-Well (DNW) as collecting electrode*
  - *Classical pixel analog processing with charge-sensitive preamplifier*

    Gain independent of the sensor capacitance collecting electrode can be extended and include NMOS of the analog section
  - *Area of the "competitive" n wells housing PMOSFETs inside the pixel kept to a minimum. Fill factor = DNW/total n-well area ~90% in the prototype test structures*
- **Pros:** *With 100-nm scale CMOS, integration of advanced analog and digital functions at the pixel level (as in hybrid pixels), rad-hard electronics*
- **Cons:** *possible limitations in pixel pitch (go to more scaled CMOS, but higher cost, only binary readout) and detection efficiency (pixel layout critical, deep P-well option?)*

SLIM5, ILC – INFN & Italian Universities



DEPFETS…

Vertical Integration 3D

- *2004-2006: Proof of principle achieved with the first prototypes in a 130 nm triple well CMOS process*
- *2007-2009: Full size MAPS sensors and detector modules, beam tests*

Still lot of developments

Vertex Detectors

ILC-VD - **SUMMARY**

- No technology yet that is ideally suited for all purposes at ILC
-
- Connection with industry?

- **General trend : exploit 3D (vertical) Integration Technologies**

  $\hookrightarrow$ *SoI or existing technologies (CMOS sensors, DEPFETs) obviously going to take big advantage of 3DIT*

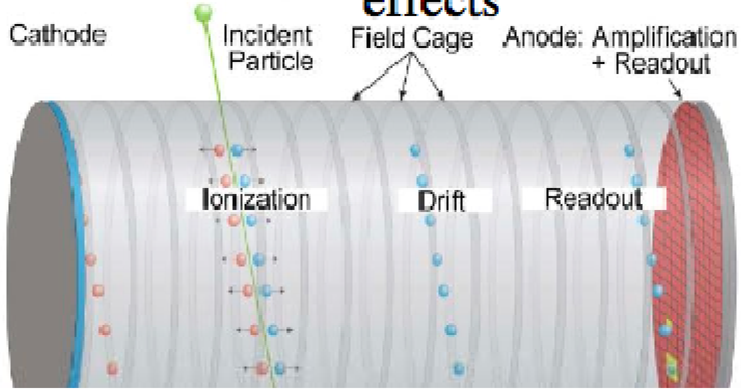
- **Common ILC - CLIC R&D ?**
  - *explore overlaping objectives $\rightarrowtail$ ex: fully integ. sensor architectures & (3D) fab. technologies*
  - *assess CLIC physics and running requirements : CLIC-500 ($\sim$ ILC-500 ?) vs CLIC-3000 ($\gg$ ILC-1000) ?*
  - *integration issues $\equiv$ natural ILC-CLIC field of synergy :*
    - *new (composite) materials*
    - *T_{room} operation*
    - *data flow*
    - *3DIT (mech. support, ...)*

Tracking at the ILC

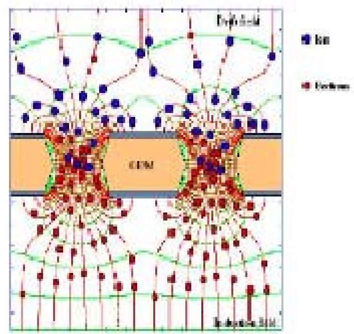
TPC with MPGD

K. Dehmelt

TPC with
MultiWireProportionalChamber MWPC
has been ruled out: limited by **E x B** effects



MicroPatternGasDetector
MPGD
not limited by **E x B**



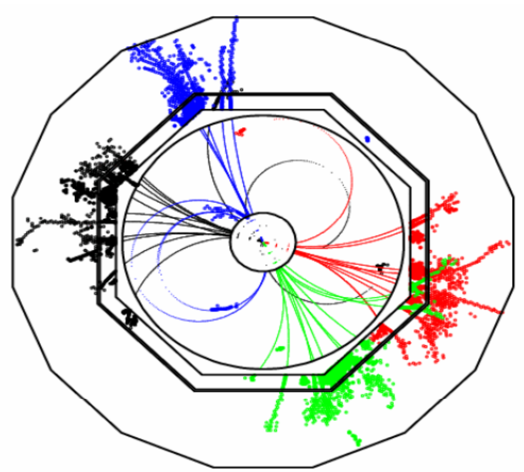
- Is a gaseous tracker viable for E_{cms} = 3 TeV ?
  - **background will be higher as E_{cms} increases**
  - **CLIC: large coherent-pair background**
    - → at small polar angle θ, at large angles essentially unchanged from ILC
  - **time stamping: 0.667 ns vs 337 ns ?**
  - **dense jet environment ?**

Discussion indicates that it seems possible

Calorimetry: P-flow performance today

E. Garutti

from Mark Thompson, CALICE-UK, Cambridge



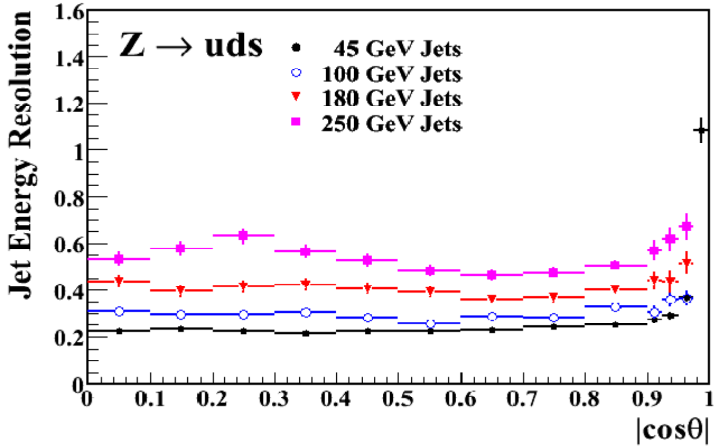
several algorithms are being developed
today best performing:
PandoraPFA (M. Thompson)

PandoraPFA v02-α

E_{JET}	$\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $\lvert\cos\theta\rvert<0.7$	σ_E/E_j
45 GeV	0.227	3.4 %
100 GeV	0.287	2.9 %
180 GeV	0.395	2.9 %
250 GeV	0.532	3.4 %

★ For 45 GeV jets, performance now equivalent to

23 % / √E



09/2007

energy range > 100 GeV still problematic
but … work in progress !

For CLIC: separation of particles within a jet difficult due to high density?

The ECAL: alternative R&D

MAPS based ECAL design

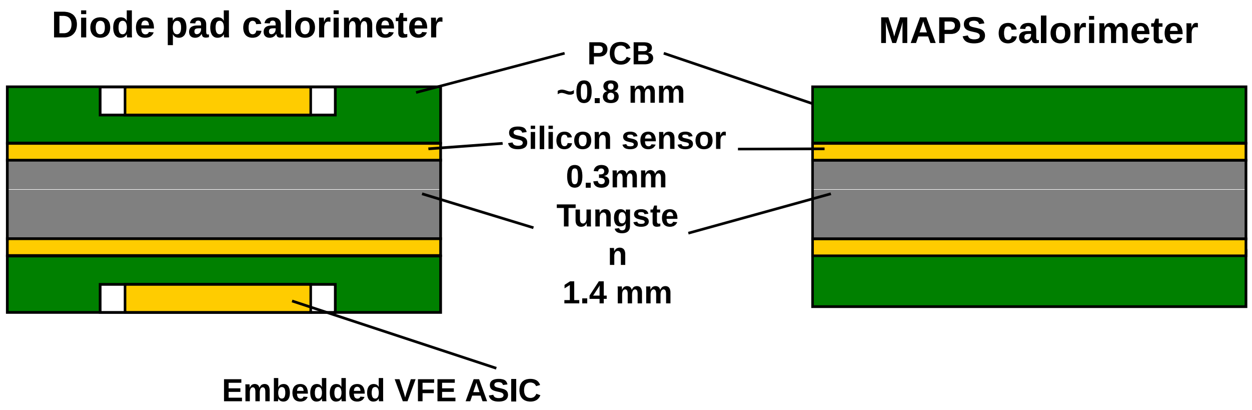
Monolithic Active Pixel Sensor

can the ECAL be digital!?

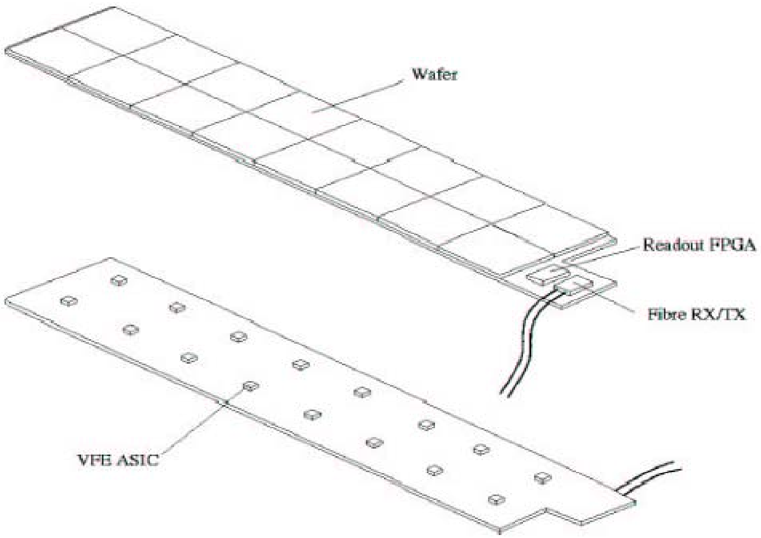
$E f N_{hits}$?

need extremely small cells

~ $50x50\ um^2$ ➔ MAPS



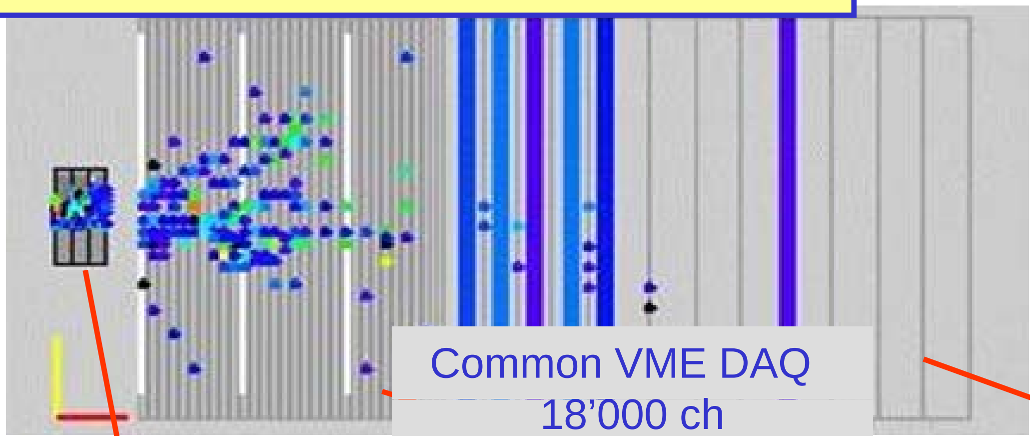
same slab mechanics as for Si-W



- use CMOS technology (no high resistive Si)
- electronic readout constructed on PCB (no extra ASIC)
- $50x50um^2$ MAPS + binary readout
- Simplified assembly (single sided PCB, no grounding substrate)
- total ECAL ~10^{12} pixels
- multiplicity in a pixel ~ 1, noise level < 10^{-6}

The test beam prototypes

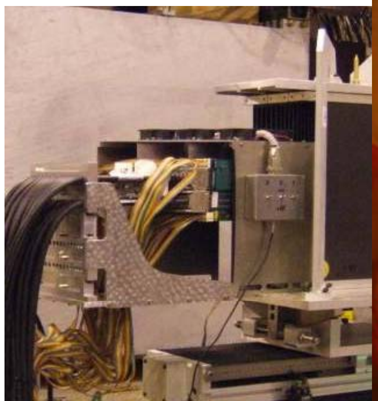
10 GeV pion shower @ CERN test beam

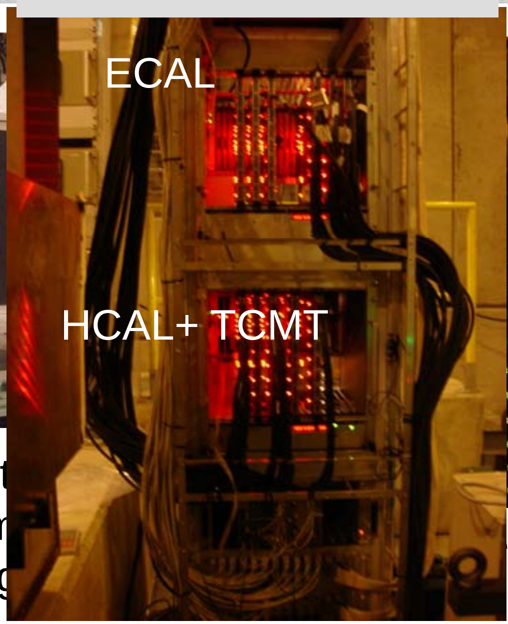


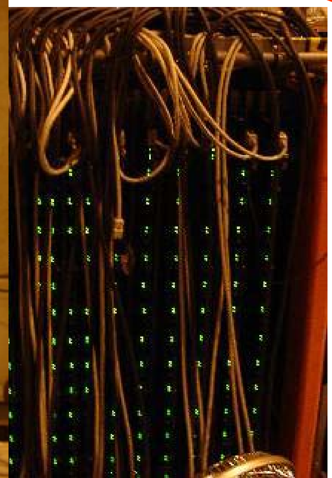
goal of prototype calorimeters:

- establish the technology
- collect hadronic showers data with unprecedented granularity to:
    - tune reco. algorithms
    - validate MC models

Common VME DAQ
18’000 ch



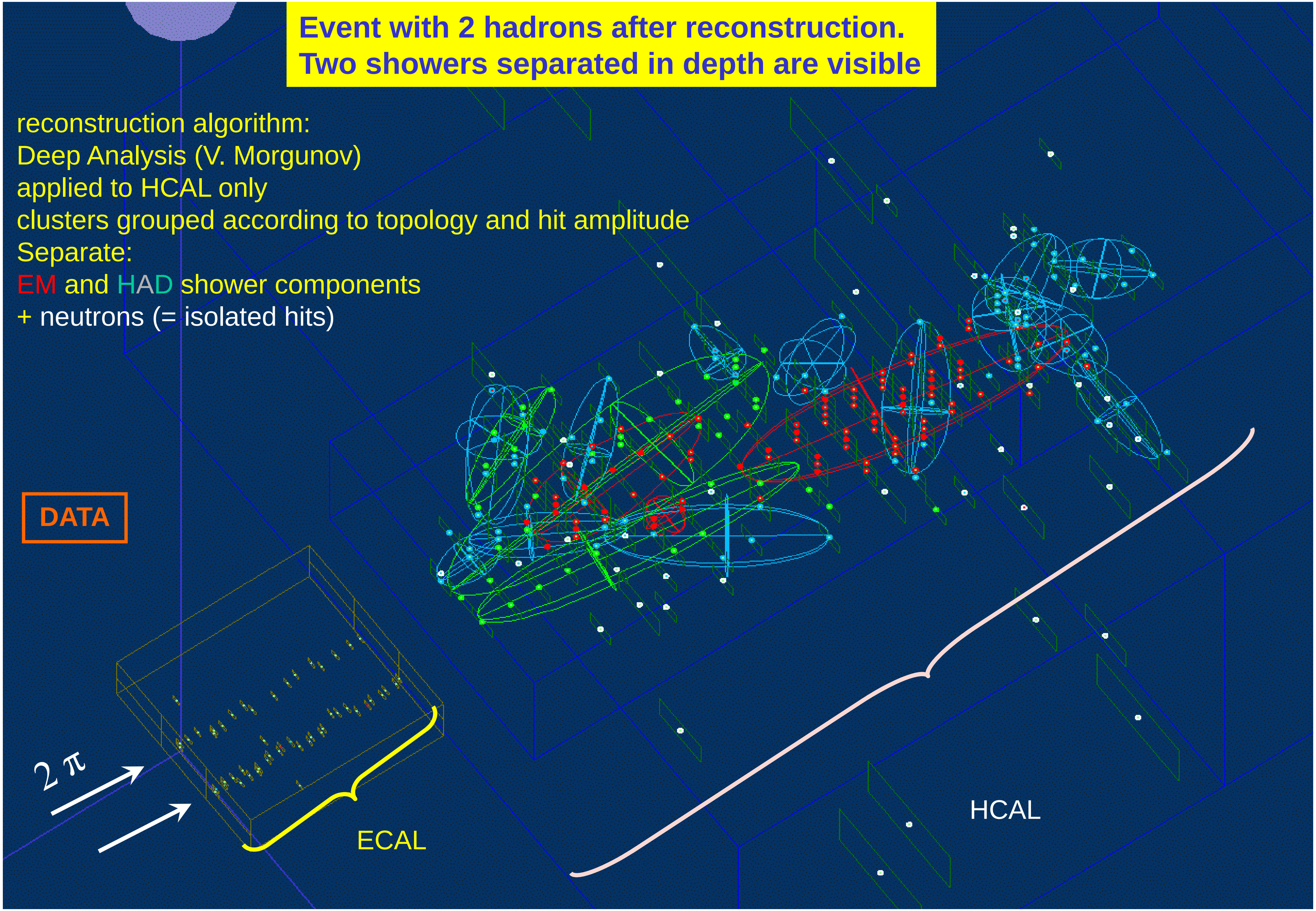




Si-W Electromagnet
$1x1cm^2$ lateral segm
1 X_0 longitudinal seg
~1λ total material

hadronic calor.
segmentation
~4.5 λ in 38 layers

Scint. Strips-Fe Tail Catcher
& Muon Tracker
$5x100cm^2$ strips
~5 λ in 16 layer


Event with 2 hadrons after reconstruction.
Two showers separated in depth are visible
reconstruction algorithm:
Deep Analysis (V. Morgunov)
applied to HCAL only
clusters grouped according to topology and hit amplitude
Separate:
EM and HAD shower components
+ neutrons (= isolated hits)
DATA
2 π
ECAL
HCAL

EUDET

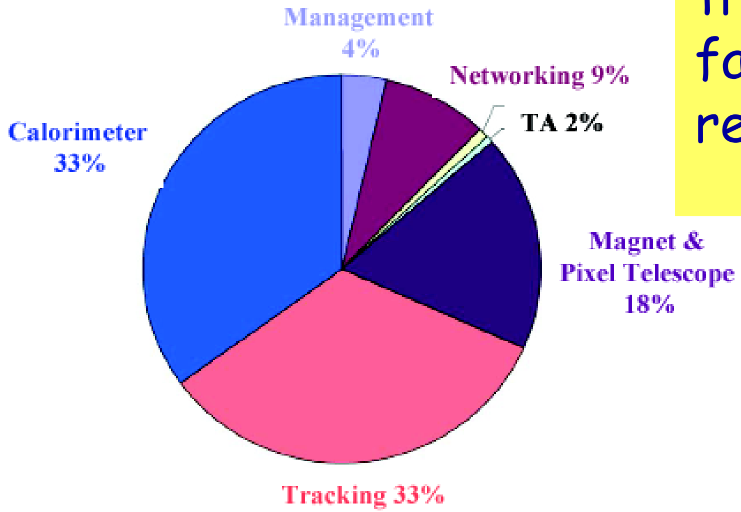
J. Mnich

Introduction to EUDET

- EU funded program supporting ILC detector R&D in Europe

SIXTH FRAMEWORK PROGRAMME
Structuring the European Research Area Specific Programme
RESEARCH INFRASTRUCTURES ACTION

- Project duration:
  - Jan 2006 to Dec 2009
- Budget:
  - 21.5 million Euro total
  - 7.0 million Euro EU contribution
- Manpower:
  - ≈ 57 FTE total (= 230 man years)
  - ≈ 17 FTE funded by EU



- 23 (31) partner institutes in Europe
  provide own commitments & receive EU funds
- 27 associated institutes worldwide
  contribute to design & construction of infrastructures
  interested in later exploitation

Transnational access EUDET can supply for travel funds to facilities (not restricted to ILC/LC)

CERN involvement :

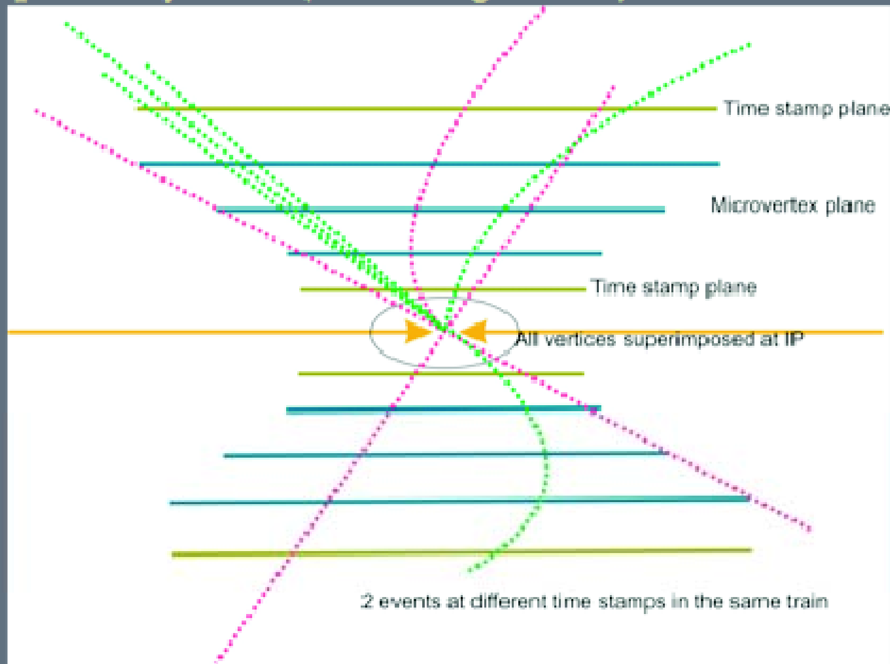
- Timepix,
- Geant4
- Mapping TPC magnet
- Micro-electronics

Vertex Detector/Tracker at CLIC

P. Jarron

Timing Issue at CLIC

- Time tagging of vertices
  - 331 BX's piled up in detector/electronics
- Issue of track reconstruction ambiguities
  - No longitudinal spread of BX interactions
  - Bunch identification by time stamp
    - Ideal time stamp precision 1/6 of bunch separation, 100 ps rms
    - Interaction point very stable (10 μm longitudinal)



CLIC workshop 16-18 Oct. 07 time stamp pixel P. Jarron CERN-PH

Vertex Detector/Tracker at CLIC

Conclusions

- Preliminary results of 130 nm FE circuits encouraging
  - 0.3 mm x0.3 mm pixel
    - Time resolution <100 ps for a power of 300 μW
    - Charge sensing feature makes possible pixel multiplicity estimate
- Fast sensors looks also encouraging
    - Silicon detector in carrier saturation regime 4 ns collection time
    - 3-D silicon , 1 or 2 ns collection time
- Feasibility of a time stamp pixel tracker
  - Proposal R&D for building a demonstrator pixel module of reduced size for NA62, CLIC and TOF applications
- Material budget is probably the most challenging issue
  - Optimization with time-space measurement precision, cooling and power budget

Options for CLIC

M. Campbell

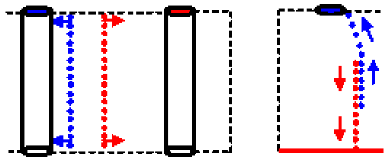
3 Possible R&D proposals
⇒I ntegrated pixel detector readout
⇒ Charged summing pixel detector readout
⇒ Timepix like readout

- Combine charge summing front-end with Timepix time stamping?
- Can 0.7ns time resolution be obtained? Maybe. Tradeoff with power. GOSSIPO-2 approach (Nikhef) may provide a solution.
- How many hits/pixel/train? Assuming 1cm radius and 1m overall length (θ = 20mrad) there are 24Mpixels of 50μm x 50 μm in inner plane. Maybe one timestamp per pixel is enough?

3D Detectors

C. Da Via

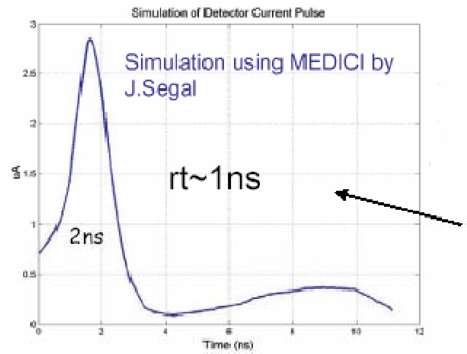
Full-3D sensor speed



❖Short collection distance

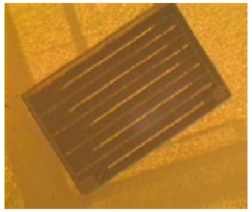
❖High average e-field at low V_{bias}

❖Parallel charge collection



Preliminary analysis of the time resolution at room temperature

S. Parker



.20 pulses from the the hex sensor

•a preliminary version of a 0.13 μm integrated circuit readout

•using data from un-collimated 90-Sr βs

•(A wall-electrode with parallel plates would give shorter times, but the hex sensor already has the same output rise time as a 0.8 ns input rise time pulse generator, so the output shape is primarily determined by the amplifier, not the sensor).

•To simulate a constant fraction discriminator set at 50% (where slope is steepest):

•Fit leading baseline, and measure noise,

•Fit top and find halfway point,

•ΔT = σ-noise / slope

•With wall-electrode sensor and a parallel beam, might do better fitting entire pulse.

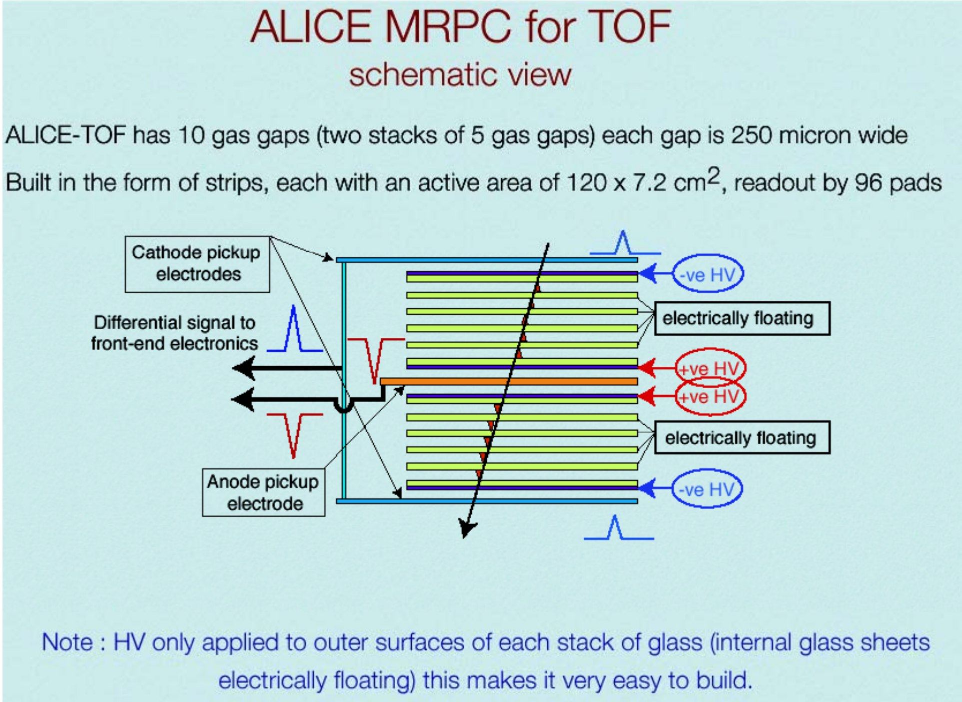
The measured **ΔT** values for first 20 pulses (other than two channel cases): **average 131 ps, maximum 286 ps, minimum 40 ps**. (partial, very preliminary)

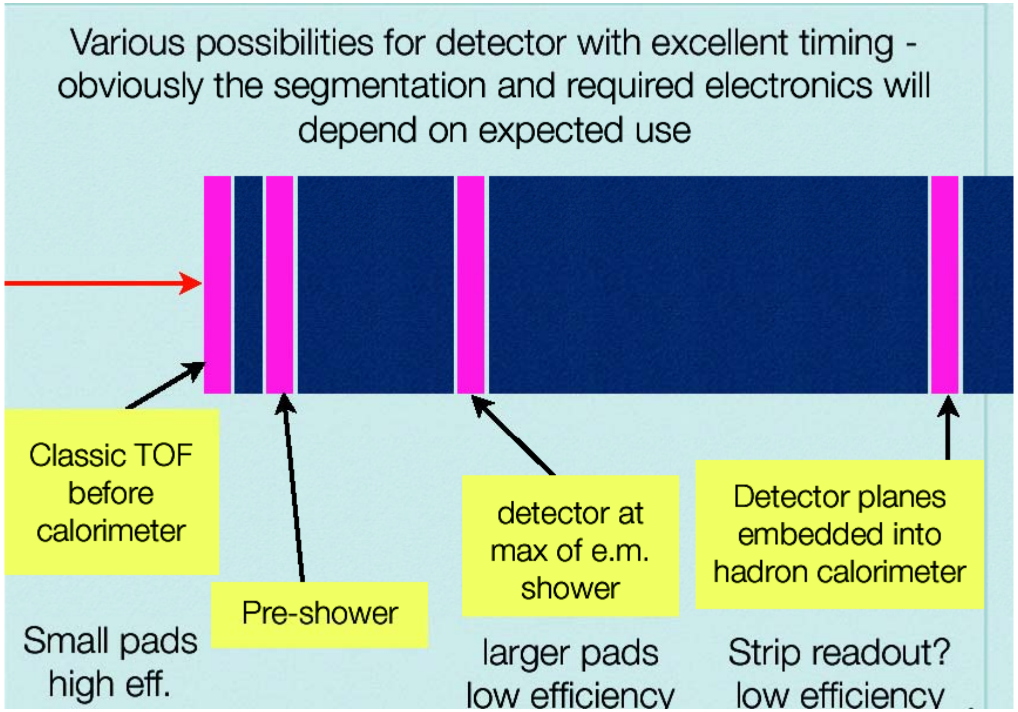
If random, 9 layers would give **44, 95, and 13.3 ps**. But watch out for beam pipe fields!

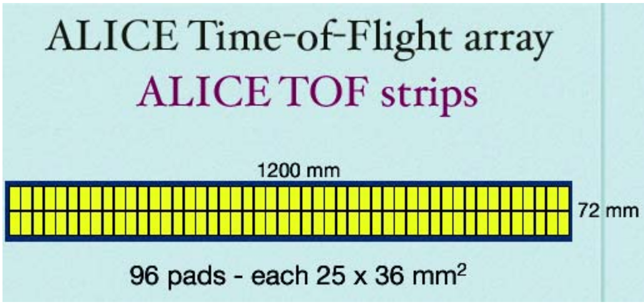
3D speed limit in future ~ few 100 ps?

ALICE TOF

C. Williams







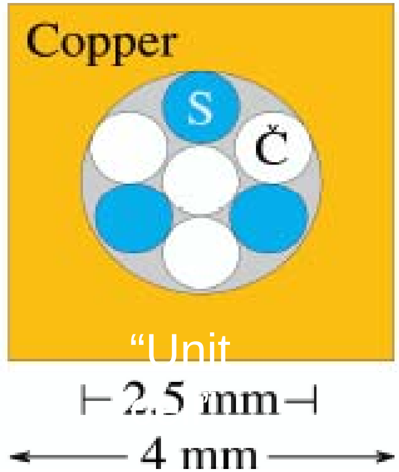
Multigap-RPC→ 150 m^2 with 160000 channels
Timing better than 100 ps

Calorimetery: Multi-readout proposal

P. Lecoq et al.

- This approach is based on the DREAM concept
- Added value: quasi-homogeneous calorimeter
  - scintillating and Cerenkov fibres of the same heavy material allowing to suppress sampling fluctuations
- Additional neutron sensitive fibers can be incorporated
- Very flexible fiber arrangement for any lateral or longitudinal segmentation: for instance twisted fibers in "mono-crystalline cables"
- em part only coupled to a "standard" DREAM HCAL or full calorimeter with this technology? Simulations needed

DREAM

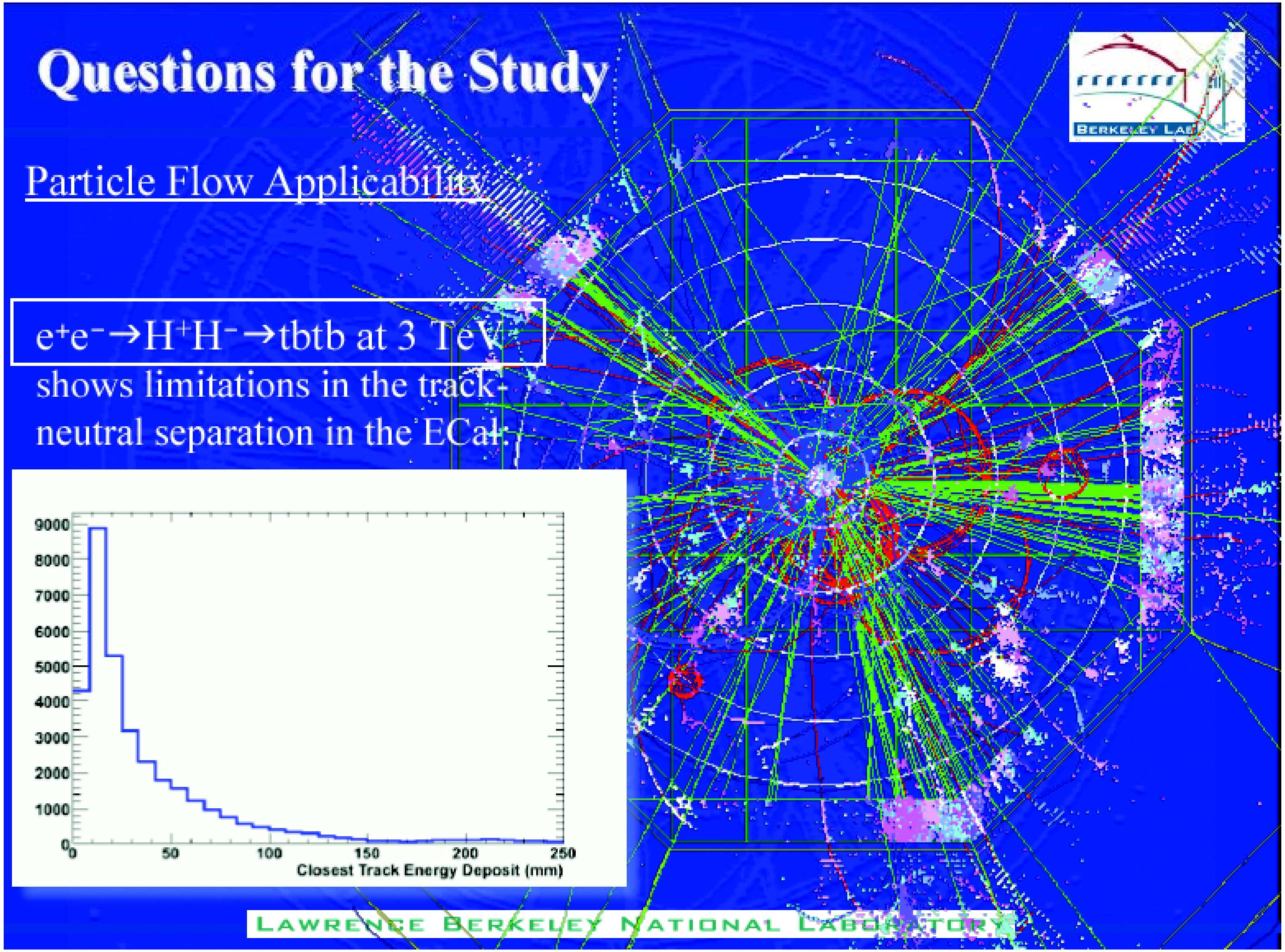


Here: use Meta-materials

Interested groups from Crystal Clear, DREAM and a number of growing institutes

SiD detector at 3 TeV

M. Battaglia



Push-Pull Discussion

A. Herve

- Most of this reasoning is certainly applicable to CLIC IR, however there will be differences, for example the amount of services and the radiation environment outside the detectors.
- It would be useful to form early enough a study group, working closely with a proto-collaboration and a typical CLIC detector, to orient correctly the civil engineering studies for the CLIC IR and experimental hall(s), (and also other studies for CLIC detectors…)

Consequences for services for the detector discussed by A. Gaddi

Second Session: Thursday

Physics landscape and new studies

09:00->*11:55* **Physics & Detectors Wkg** (Convener: Michael Hauschild (*CERN*) , Ron Settles (*Max-Planck-Institut fuer Physik*))
(Location: 40-S2-B01)

09:00	Detailed discussion on backgrounds etc. (20')	Daniel Schulte (*CERN*)
09:25	New ideas on EWSB (20')	Christophe Grojean (*CERN*)
09:50	The road from LHC->SLHC->LC (20')	Michelangelo Mangano (*CERN*)
10:15	Heavy Higgs study (15')	Arnaud Ferarri (*Univ. of Uppsala*)
10:35	Coffee Break	
10:55	Stau searches at CLIC (15')	Ilkay Turk Cakir (*University of Ankara*)
11:15	Excited leptons at CLIC (15')	Orhan Cakir (*University of Ankara*)
11:35	4th generation at CLIC (15')	Saleh Sultansoy (Sultanov) (*TOBB Univ of Eco & Tech*)
12:35	Lunch break	

~25 people

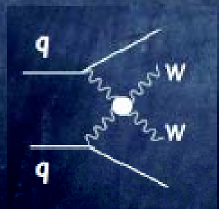
Eg Composite Higgs models

Testing the composite nature of the Higgs?

if LHC sees a Higgs and nothing else*:

- evidence for string landscape???
- it will be more important then ever to figure out whether the Higgs is composite!

- **Model-dependent:** production of resonances at m_ρ
- **Model-independent:** study of Higgs properties & W scattering
  - Higgs anomalous coupling
  - strong WW scattering
  - strong HH production
  - gauge bosons self-couplings



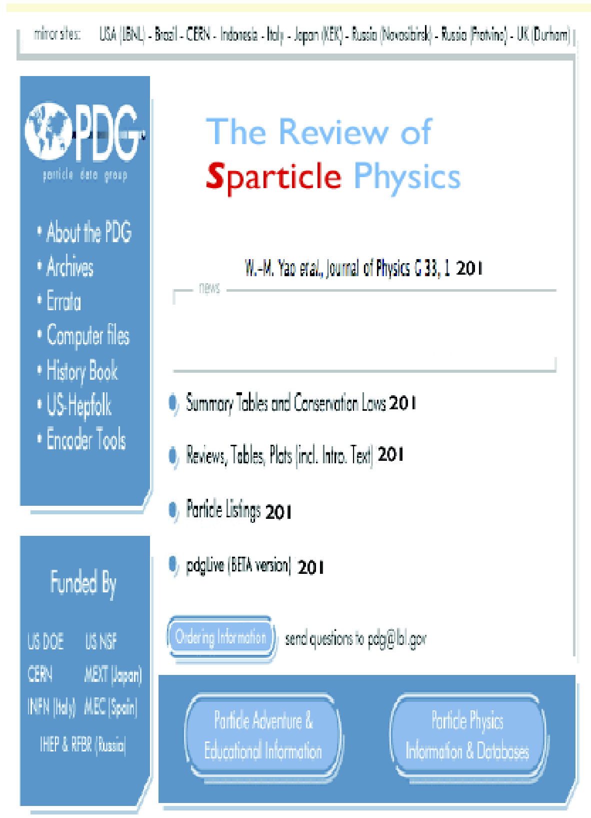
* a likely possibility

C. Grojean

Difficult to establish at the LHC.
Work for a LC

What is the mechanism of EW symmetry breaking?

	LHC	ILC	CLIC
1/ is there a Higgs?	✓	✓	✓
2/ what are the Higgs mass/couplings	-	✓	✓
3/ is the Higgs a SM like weak doublet?	☁	✓	✓
4/ is the Higgs elementary or composite?	☁	✓	✓✓
5/ is EWSB natural or fine-tuned?	?	✓	✓✓
6/ are there new dimensions? new strong forces?	-	✓	✓

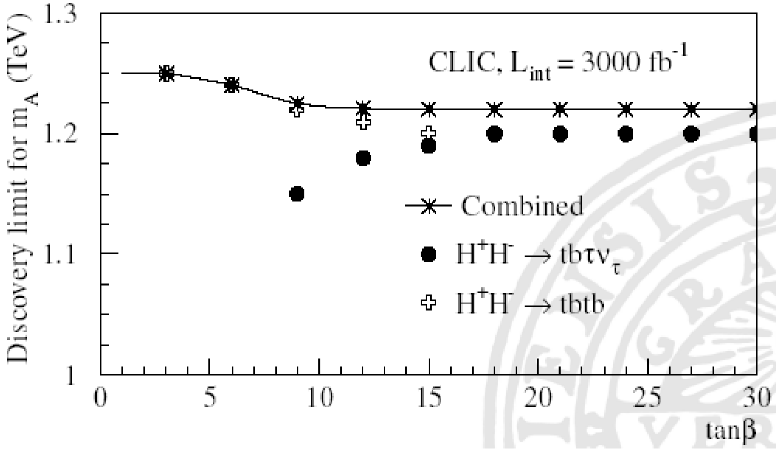


LHC upgrades roadmap
The power of LCs

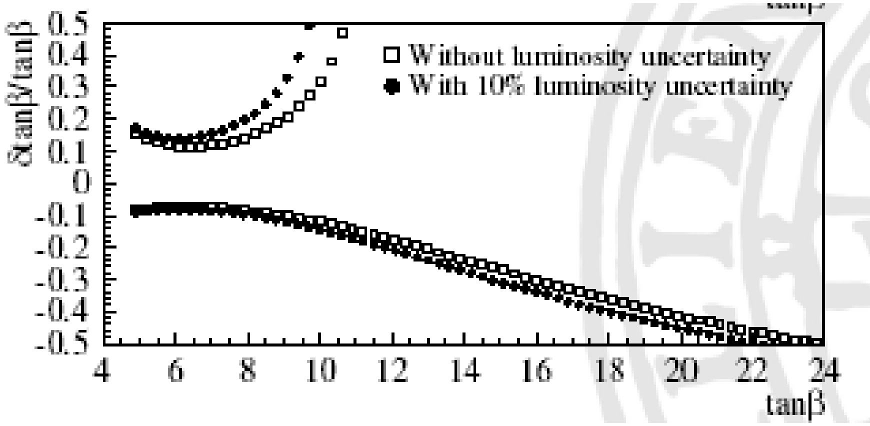
Heavy Higgs Production at CLIC

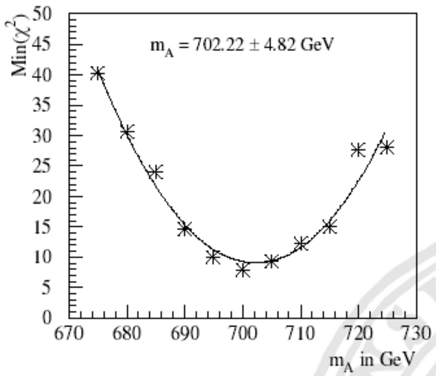
For a discovery, one requires $S \geq 10$ and $S/\sqrt{B} \geq 5$.

A. Ferrari



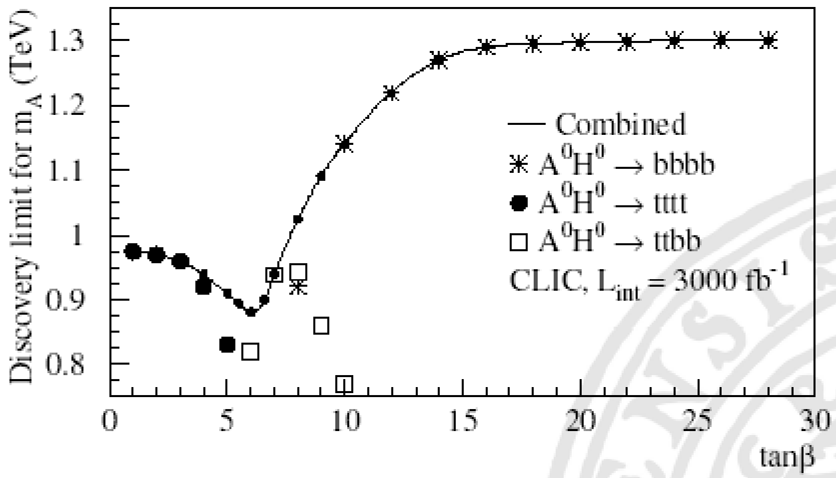
Accurate mass measurement (2)





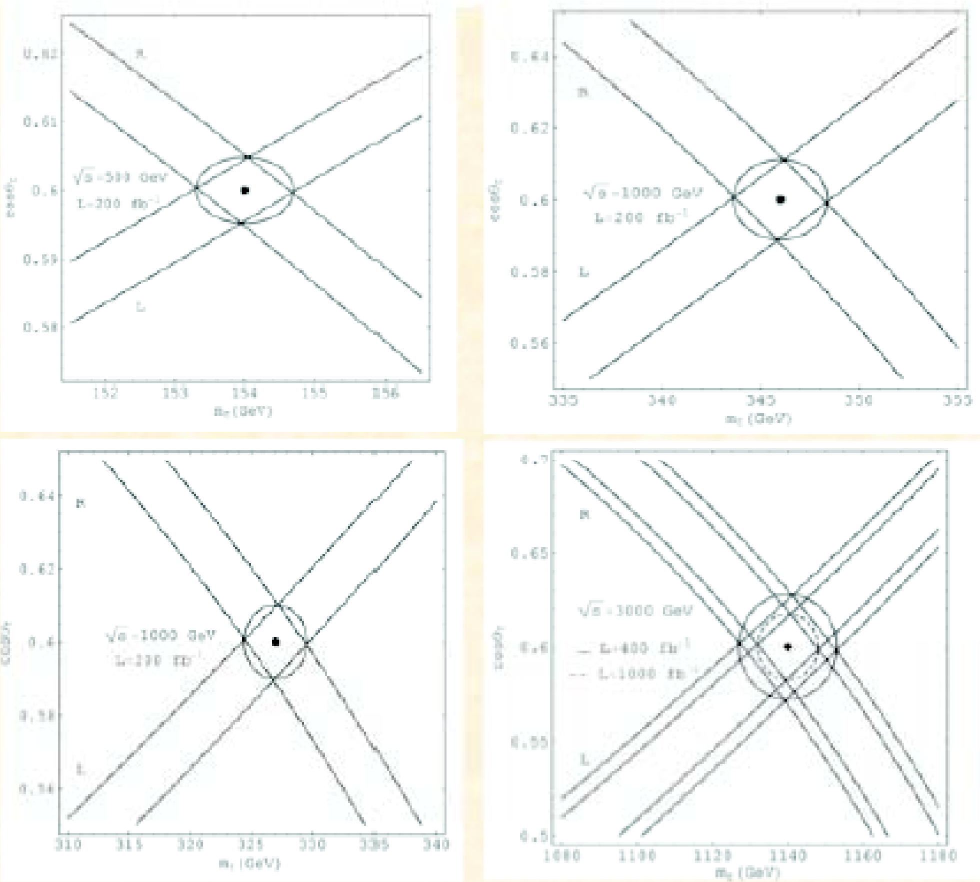
Configuration	m_A (GeV)	δm_A (GeV)
Small tan β with A^0H^0	697.4	3.7
Small tan β without A^0H^0	701.2	3.7
Large tan β with A^0H^0	702.2	4.8
Large tan β without A^0H^0	701.8	4.9

The real mass m_A is 700 GeV and $\mathcal{L} = 3000\ \text{fb}^{-1}$.



Showcase for CLIC…

Stau Studies @ CLIC



Errors on the mixing (cosθ~0.6) and stau mass ($m_{\tilde{\tau}}$)

Polarization

e- 90%

e+ 60%

accuracies on the measurements:

$(\Delta m_{\tilde{\tau}_1}, \Delta \cos\theta_{\tilde{\tau}})$

(0.7, 0.005) for e

(2.4, 0.01) for

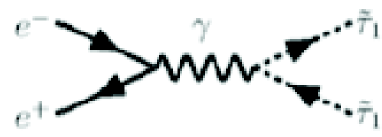
at Ecm=1000 GeV;

(8, 0.02) for

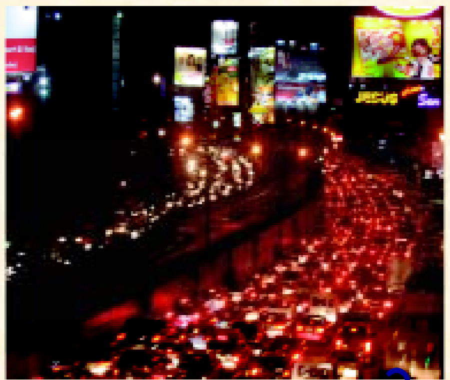
at Ecm=3000 GeV

13

I Cakir



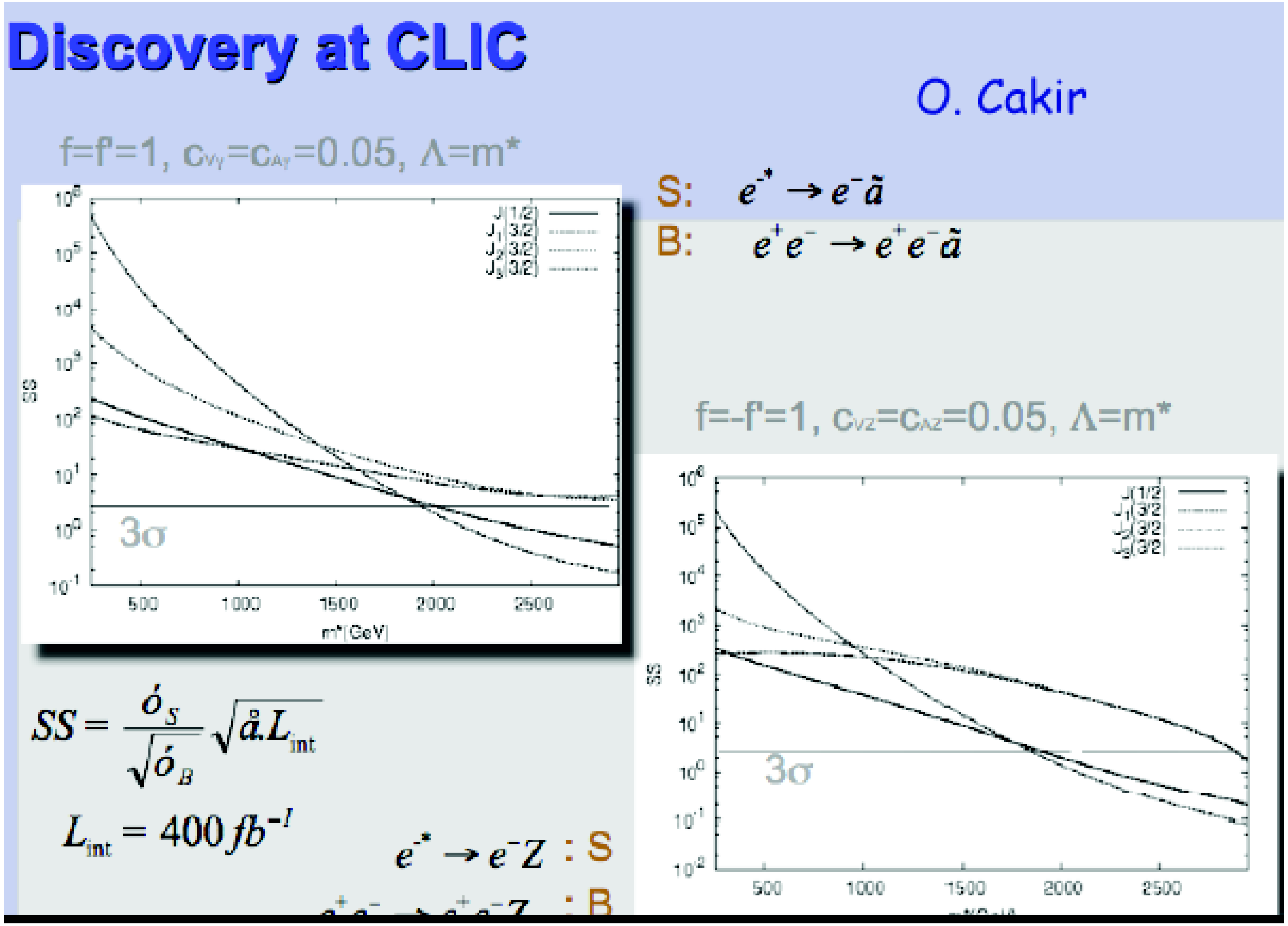
(a)



Many "staus" at CLIC ?

Reminds us that the physics wants polarized beams…

Excited Leptons at CLIC



Discovery op to 1.8 TeV (400 fb-1) or ~√s depending on the state. (3σ)
Can separate spin 1/2 from 3/2 case

4th lepton/quark family studies

Yellow Report CERN-2004-005, hep-ph/0412251

S. Sultansoy

Table 6.11: Cross sections and event numbers per year for pair production of the fourth-SM-family fermions with mass 320 GeV at CLIC ($\sqrt{s_{ee}}$ = 1 TeV, $L_{ee} = 2.7 \times 10^{34}$ cm^{-2}s^{-1} and $L_{\gamma\gamma} = 10^{34}$ cm^{-2}s^{-1})

		$u_4\bar{u}_4$	$d_4\bar{d}_4$	$l_4\bar{l}_4$	$\nu_4\bar{\nu}_4$
e^+e^- option	σ (fb)	130	60	86	15
	N$_{ev}$/year	35 000	16 000	23 000	4100
$\gamma\gamma$ option	σ (fb)	34	2	58	–
	N$_{ev}$/year	3400	200	5700	–

Table 6.12: Cross sections and event numbers per year for pair production of the fourth-SM-family fermions with mass 640 GeV at CLIC ($\sqrt{s_{ee}}$ = 3 TeV, $L_{ee} = 1 \times 10^{35}$ cm^{-2}s^{-1} and $L_{\gamma\gamma} = 3 \times 10^{34}$ cm^{-2}s^{-1})

		$u_4\bar{u}_4$	$d_4\bar{d}_4$	$l_4\bar{l}_4$	$\nu_4\bar{\nu}_4$
e^+e^- option	σ (fb)	16	8	10	2
	N$_{ev}$/year	16 000	8000	10 000	2000
$\gamma\gamma$ option	σ (fb)	27	2	46	–
	N$_{ev}$/year	8100	600	14 000	–

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Table 6.14: The production event numbers per year for the fourth-SM-family ψ_4 quarkonia at a CLIC 1 TeV option with $m_{\psi_4} \simeq 1$ TeV

	$(u_4\bar{u}_4)$	$(d_4\bar{d}_4)$
$e^+e^- \to \psi_4$	26 600	10 400
$e^+e^- \to \psi_4 \to \gamma H$	510	50
$e^+e^- \to \psi_4 \to ZH$	60	80

Table 6.13: Decay widths for main decay modes of ψ_4 for m_H = 150 GeV with $m_{\psi_4} \simeq 1$ TeV

	$(u_4\bar{u}_4)$	$(d_4\bar{d}_4)$
$\Gamma(\psi_4 \to \ell^+\ell^-)$, 10^{-3} MeV	18.9	7.3
$\Gamma(\psi_4 \to u\bar{u})$, 10^{-2} MeV	3.2	1.9
$\Gamma(\psi_4 \to d\bar{d})$, 10^{-2} MeV	1.4	1.7
$\Gamma(\psi_4 \to Z\gamma)$, 10^{-1} MeV	15	3.7
$\Gamma(\psi_4 \to ZZ)$, 10^{-1} MeV	1.7	5.4
$\Gamma(\psi_4 \to ZH)$, 10^{-1} MeV	1.7	5.5
$\Gamma(\psi_4 \to \gamma H)$, 10^{-1} MeV	14.4	3.6
$\Gamma(\psi_4 \to W^+W^-)$, MeV	70.8	71.2

High rates at CLIC (if exist…)

Conclusion

- Dense program, perhaps too limited time for discussion on some topics
- Good exchange with ILC experts/possible basis for future collaborations?
  - There are certainly communalities with the ILC detectors
  - ILC detector studies: R&D and discussions/optimization still ongoing
- Remind that physics wants to keep options, such as polarization
- Work is needed for the CLIC on detector studies
  - Some benchmark channels started (taking SiD)
  - Need to discuss MDI with machine group (e.g.Mask upgrade/forward region instrumentation)
  - How well does particle flow (Energy flow) work at CLIC?
- R&D detector proposals being prepared
  - Good prospects for adequate time stamping at CLIC
  - Novel calorimeter concepts
- Include specific detector R &D in FP7? (February 2008)

In all, it has been a quite useful meeting

Thanks to all speakers!!