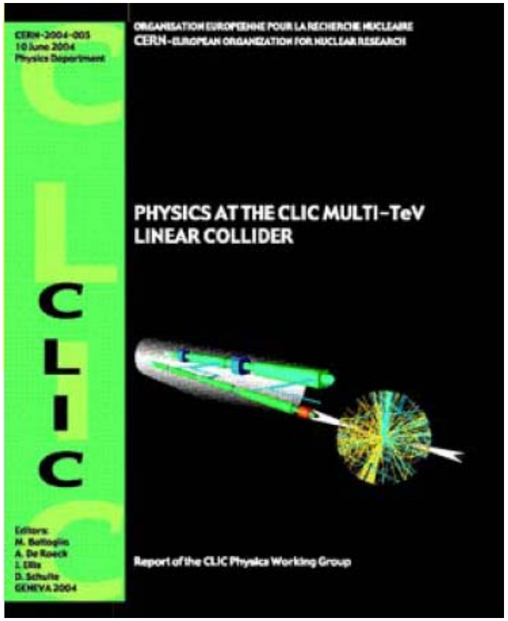
News from the PH Linear Collider Physics Group
D. Schlatter/PH

Topics:
1. goals of LC Physics group in PH
2. Faculty meeting on
   - ILC Detector R&D
   - CLIC physics benchmarks
   - CLIC parameters
3. LC Detector R&D proposals in PH.
4. EUDET

Linear Collider Physics group in PH

Goals:

- continue very successful work of CLIC Physics group (Albert de Roeck, John Ellis, Marco Battaglia, …)
- (re) connect CERN to ILC physics studies groups
- work on CLIC specific open questions (prepare for "2010")
- start selective R&D for LC detector (in line with existing expertise an in collaboration with outside groups, mainly working on ILC)
- continue discussions with CLIC accelerator group
- provide platform at CERN for younger physicists to work on LC physics and detector issues



Difficulties: LHC exciting and demanding, also no money!

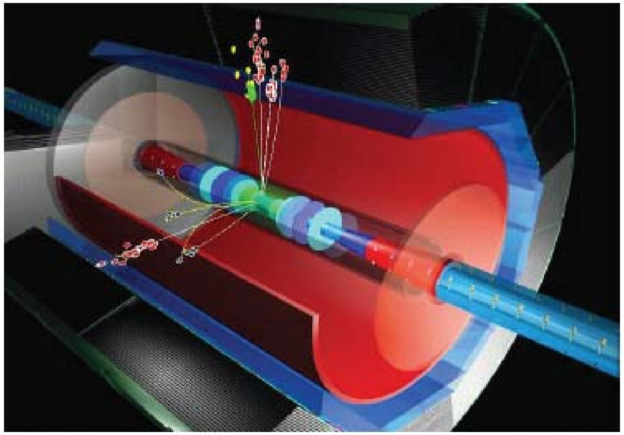
→ MUST work with our colleagues in the institutes

Detector R&D for the ILC

Projects, Concepts and Collaborations

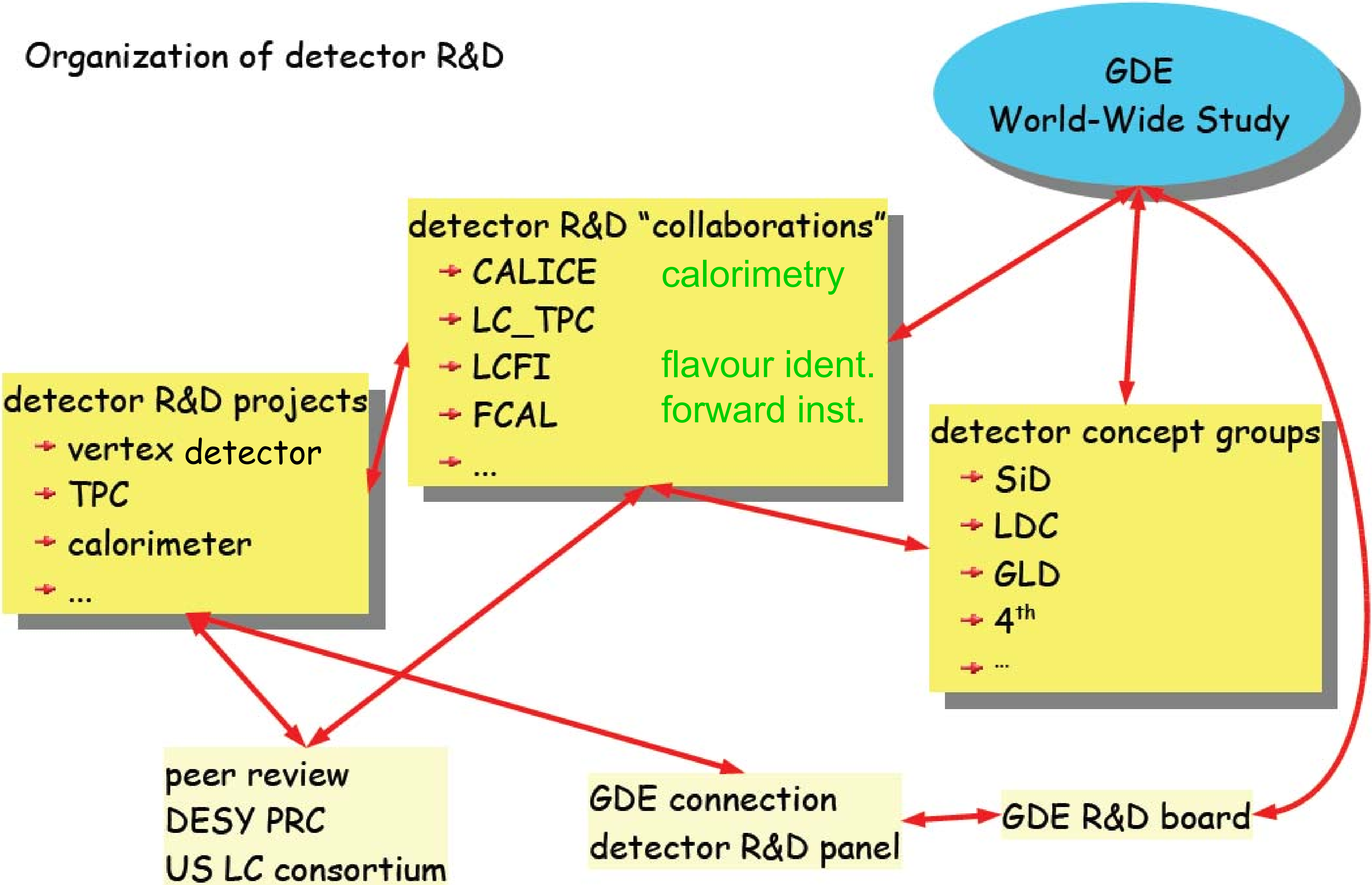
Ties Behnke, DESY

CERN staff meeting, June 14, 2006



Detector R&D for the ILC

Organization of detector R&D



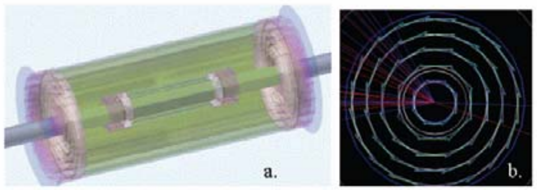
Performance requirements

		present
Jet mass resolution:	30 % / √E	60%
Momentum resolution:	$\sigma(p)/p = 7\times10^{-5}\,GeV^{-1}$	1×10^{-4}
Vertex Resolution :	few μm	10 μm

In particular the Jet energy resolution cannot be reached with traditional approaches: new concepts needed.

R&D for Tracking/ Vertexing

Vertex Detector:
- multi layer, high precision pixel detector is required



close to IP
(1.5 cm radius)

Thin

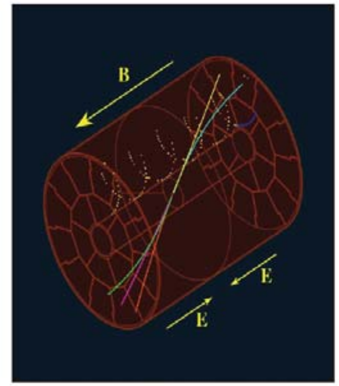
Different technologies are being investigated:
CCD, MAPS, DEPFET, plus derivates

precision: µm level
material budget/ cooling / mechanics are main concerns
readout speed (minimise number of overlapping bunches)

Ties Behnke:Particle Flow at the ILC

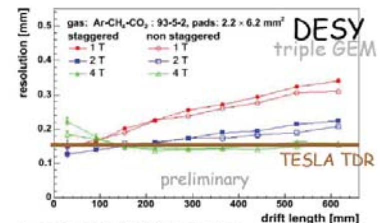
TPC R&D for the ILC

LDC and GLD: TPC is part of central tracking system



Main R&D items:

- gas amplification and readout (GEM, micromegas)
- control of parameters
- resolution
- double track separation

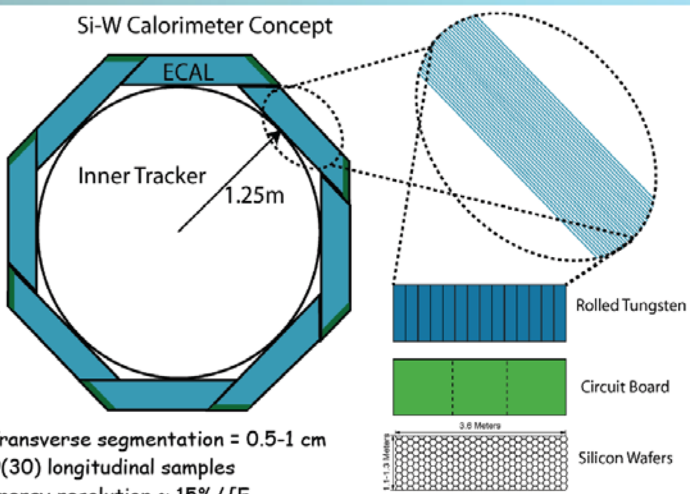


standard "GEM" solution

Ties Behnke:Particle Flow at the ILC

R&D: Calorimeter ECAL

Si-W Calorimeter Concept



Transverse segmentation = 0.5-1 cm
O(30) longitudinal samples
Energy resolution ~ 15%/√E

Development of an extremely fine-grained electromagnetic calorimeter

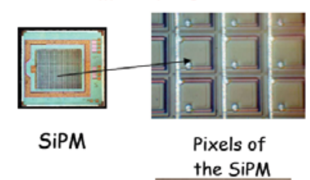
Ties Behnke:Particle Flow at the ILC

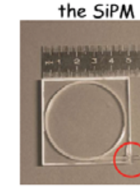
CLI

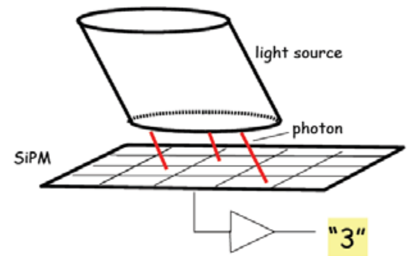
Silicon Photo-Multipliers

Silicon photo-multiplier (SiPM):
- new detector concept, first test with beam
- sizes: 1x1mm², 1024 pixels/mm²
- gain ~ 1*10⁶ → No pre-amplifier needed
- quantum efficiency ~ 15-20%
- single tile read out / mounted directly on tile

Silicon PhotoMultiplier (SiPM)
MEPhI&PULSAR





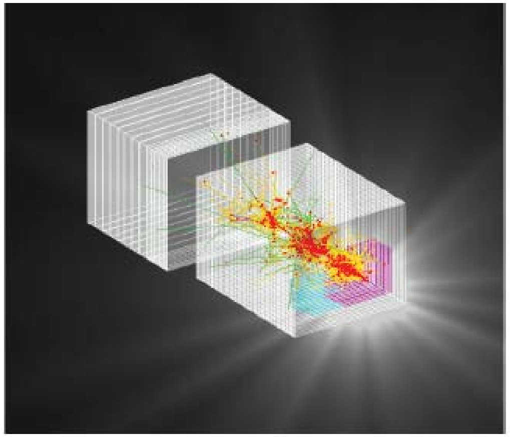


Novel concept with applications beyond particle physics

Ties Behnke:Particle Flow at the ILC

Test Beam effort

ECAL and HCAL: plan combined test beams at CERN 2006, at Tevatron 2007



- test individual components and technologies
- test combined function
  includes common DAQ, analysis etc
- accumulate data to test simulation
- tune the simulation to gain trust in full event reconstruction

major effort by the CALICE collaboration
Europe – USA - Asia

the biggest player in the ILC calorimeter field

also DREAM calorimeter, test beams at CERN 2006

R&D Challenges

Calorimetry: Develop granular technologies for ECAL and HCAL

Vertexing: Develop fast, highly precise, very thin sensors

Tracking: Develop precise and "thin" TPC realization, minimize systematic error sources

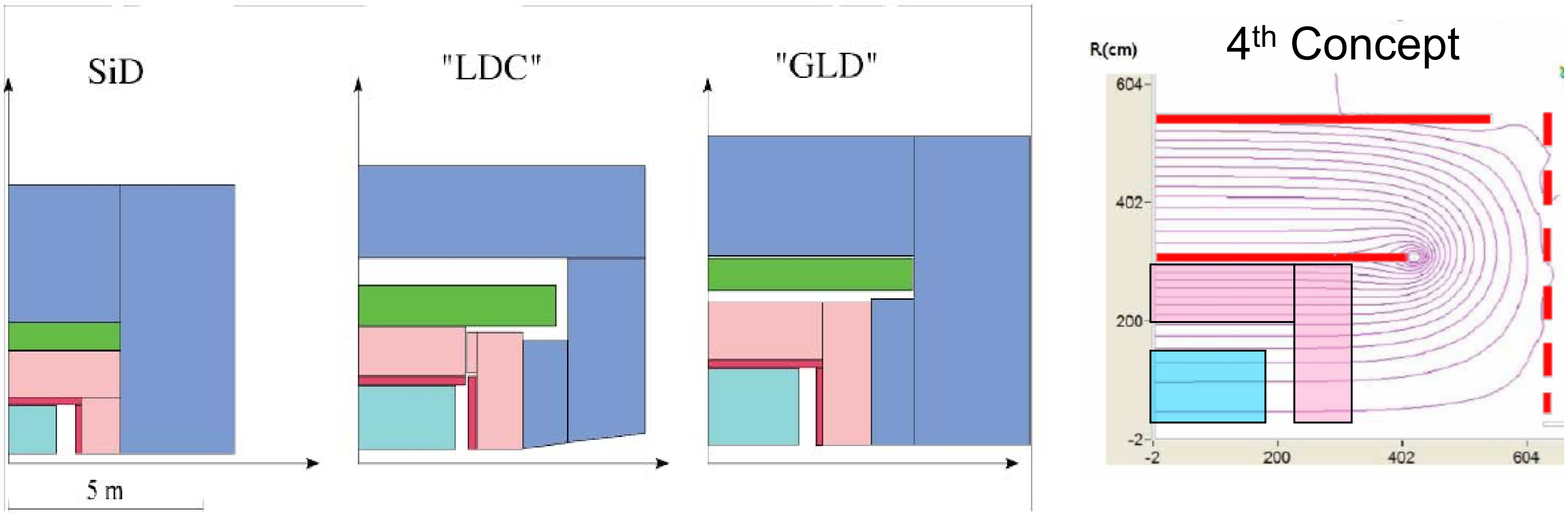
SI tracking: Develop thin, long ladder structures which can give good precision

Very forward: Develop radiation hard and very hard calorimeter techniques for beam and luminosity monitoring

The focus of all these developments is very different from the focus for the LHC or the SLHC, where radiation hardness and speed are most important!

Detector concepts

- Sizes: "small", "large", "giant"; but: GLD < CMS



US, EU, JP	EU, US, ..	JP, EU, US	US, IT, +
SI tracking SI-W ECAL high field (5T)	TPC+SI tracking Si-W ECAL 4T field	TPC + SI tracking W-scintillator ECAL 3-4T field	TPC+SI tracking DREAM calo 4T field

particle flow as driving principle

non PFLOW

"4th Concept"

different ideas: - new compensating calorimeter (Dual Readout)
- iron-less muon system (dual solenoid)

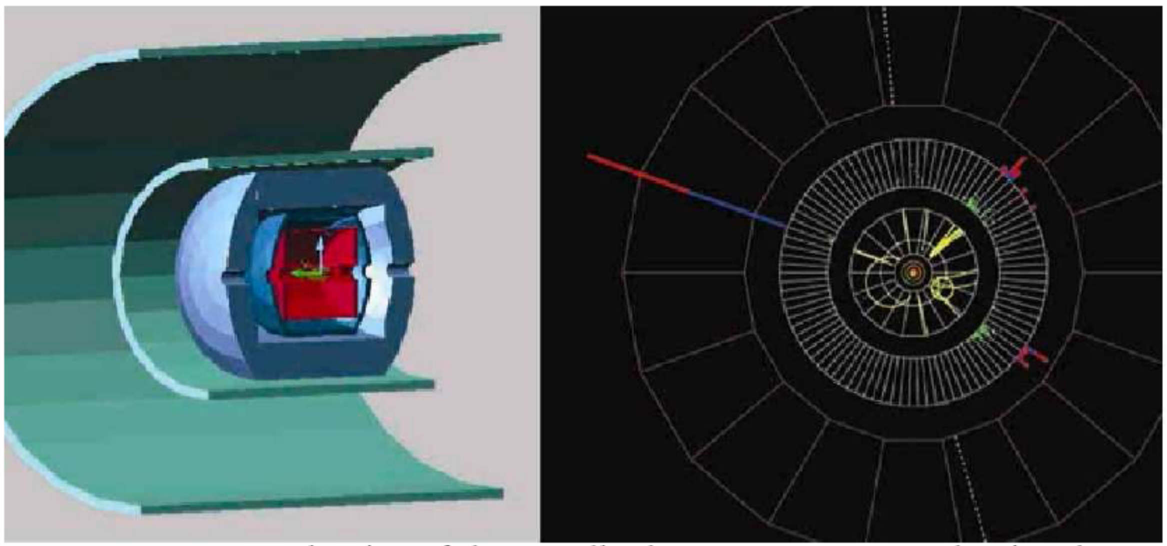
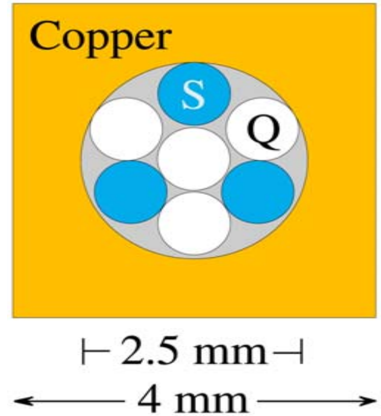


Figure 1. A drawing of the overall 4th Concept geometry showing the projective dual-readout calorimeter surrounding the tracking volume with the TPC, the inner solenoid at $r = 3\text{m}$ outside the calorimeter, and the muon tracking volume in the annulus between the inner solenoid and the outer solenoid at $r = 5.6\text{m}$.

US, Italy, + …

…and DREAM [Dual REAdout Module]

4th Concept



(S, Q fibers 0.8 mm ϕ)

Cell

[basic element of detector]

2m long extruded copper rod, [4 mm x 4 mm]; 2.5mm hole contains 7 fibers: 3 scintillator & 4 quartz (or acrylic plastic).

scintillator light → total energy

Cherenkov light → em energy

In total, 5580 copper rods (1130Kg) and 90km optical fibers.

Composition (volume) Cu: S : Q : air = 69.3 : 9.4 :12.6 : 8.7 (%)

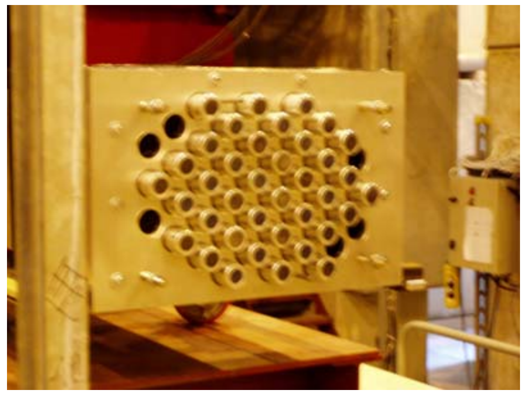
Effective Rad. length (X0) = 20.1mm; Moliere radius(rM)=20.35mm

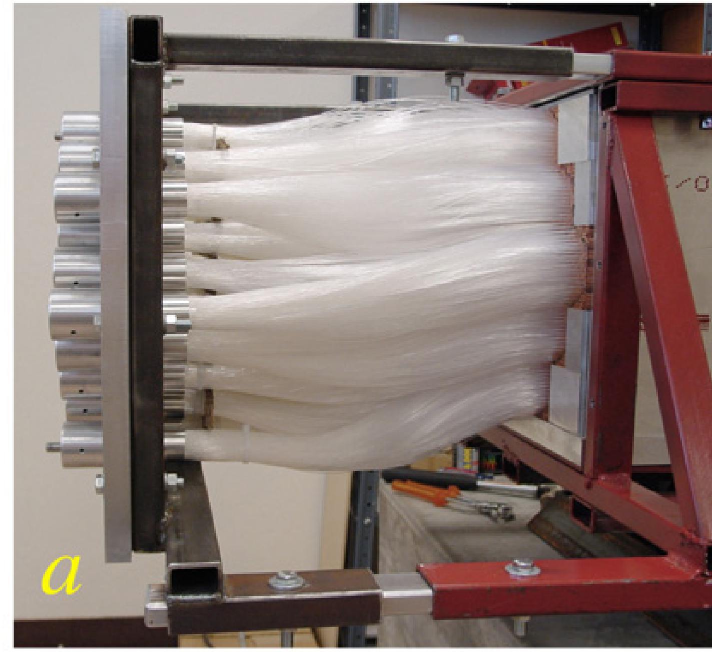
Nuclear Inter. length (lint) = 200mm;10 lint depth Cu.

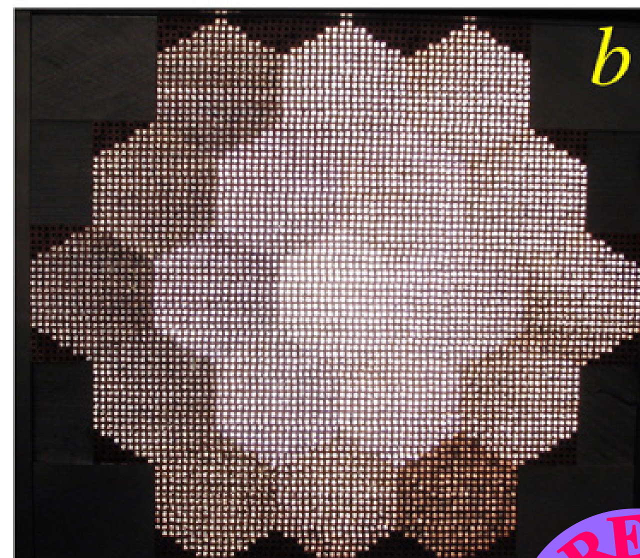
Filling fraction = 31.7%; Sampling fraction = 2.1%

- **Tower : readout unit**

Hexagonal shape with 270 cells (Fig. *b*);
Readout 2 types of fibers to PMTs
(PMT: Hamamatsu R580) (Fig. *a*)







- **Detector : 3 groups of towers (Fig. *b*)**

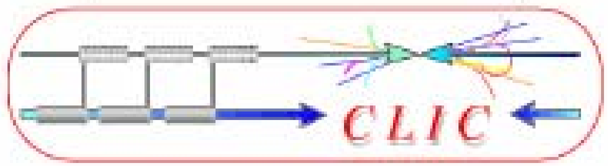
center(1), inner(6) & outer(12) rings;
Signals of 19 towers routed to 38 PMT

Fig. ***a*** : fiber bundles for read-out PMT;
38 bundles of fibers

Fig ***b*** : front face of detector with rear end illuminated: shows 3 rings of honey-comb hexagonal structure..

Benchmarks for a 0.5/1 TeV CLIC

Albert De Roeck

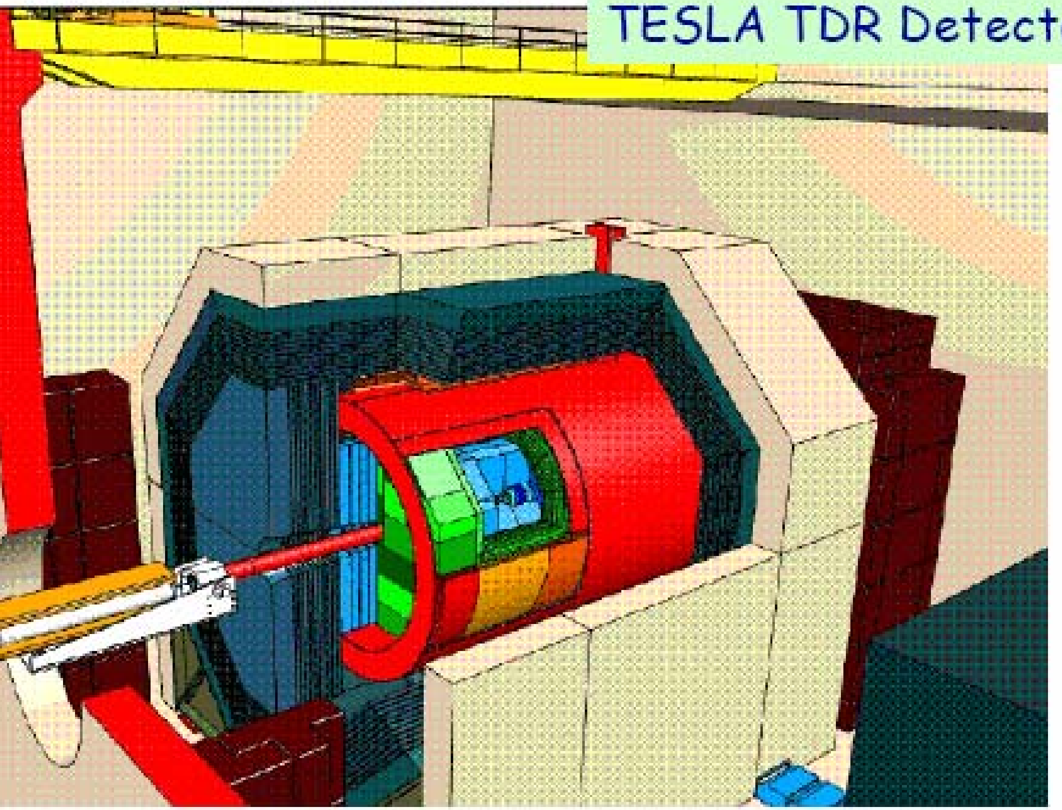


- Introduction
- Example processes as studied for the warm/cold technologies(*)
- Summary with proposed list of benchmarks

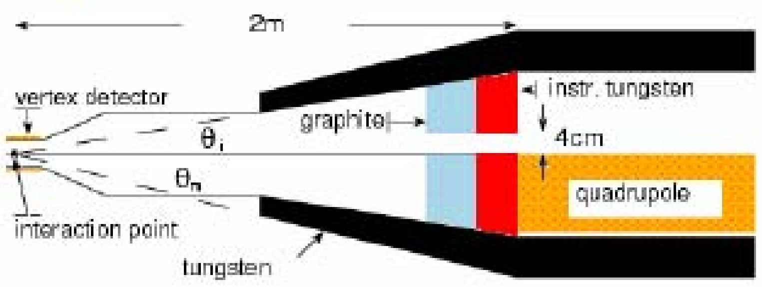
(*) K. Desch/LCWS04

Origine of the 'CLIC' detector (2001)

TESLA TDR Detector



Background at the IP enforces use of a mask



CLIC: Mask covers region up to 120 mrad
Energy flow measurement possible down to 40 mrad

~TESLA/NLC detector qualities: good tracking resolution, jet flavour tagging, energy flow, hermeticity,...

Detector Parameters

Detector	CLIC
Vertexing	$15\mu m \oplus \frac{35\mu m GeV/c}{p\sin^{3/2}\theta}$ $15\mu m \oplus \frac{35\mu m GeV/c}{p\sin^{5/2}\theta}$
Solenoidal Field	$B = 4\ T$
Tracking	$\frac{\delta p_t}{p_t^2} = 5. \times 10^{-5}$
E.m. Calorimeter	$\frac{\delta E}{E(GeV)} = 0.10\frac{1}{\sqrt{E}} \oplus 0.01$
Had. Calorimeter	$\frac{\delta E}{E\ (GeV)} = 0.40\frac{1}{\sqrt{E}} \oplus 0.04$
μ Detector	Instrumented Fe yoke
Energy Flow	$\frac{\delta E}{E\ (GeV)} \simeq 0.3\frac{1}{\sqrt{E}}$
Acceptance mask beampipe small angle tagger	$\lvert\cos\theta\rvert < 0.98$ 120 mrad 3 cm $\theta_{min} = 40$ mrad

Starting point: the TESLA TDR detector
Adapted to CLIC environment

First ideas:

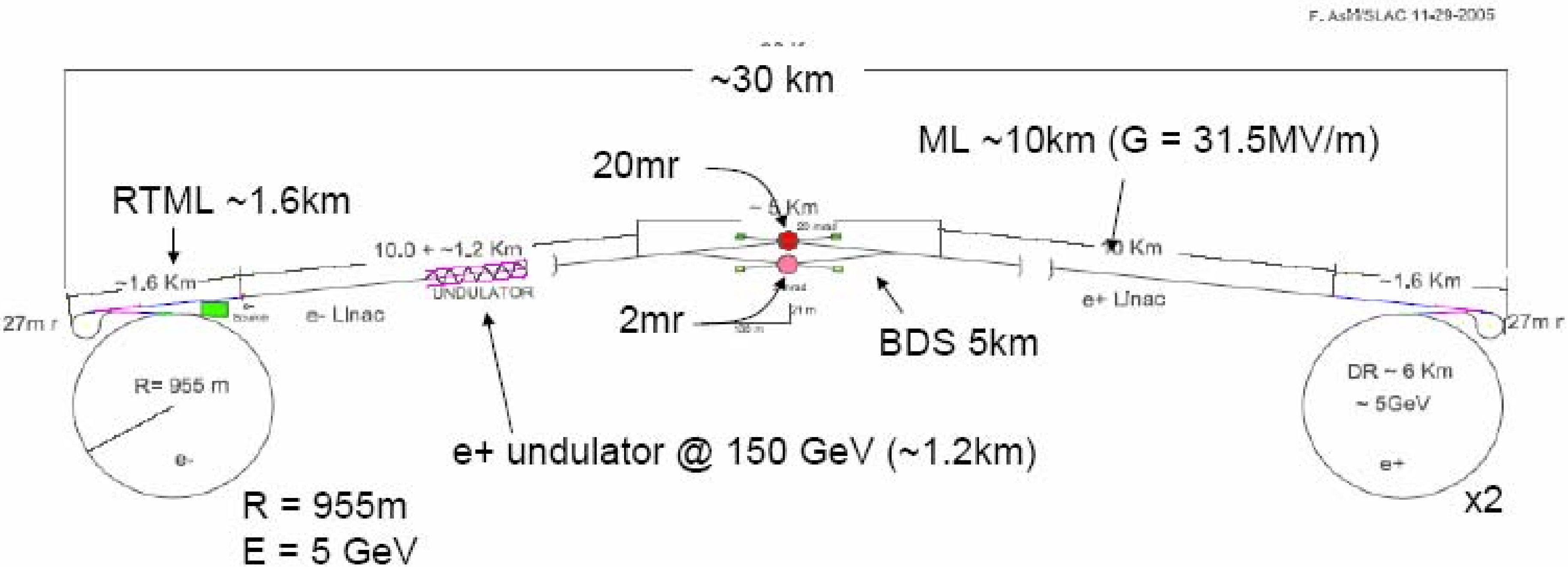
3–15 cm	VDET
15–80 cm	Silicon/forward disks
80–240 cm	TPC
240–280 cm	ECAL (30 X_0)
280–400 cm	HCAL (6λ)
400–450 cm	Coil (4T)
450–800 cm	Fe/muon

..or all silicon (15-120 cm)
more compact...

Needs a more detailed study/different detector or low $\sqrt{s}$?

The Baseline Machine (500GeV)

ILC

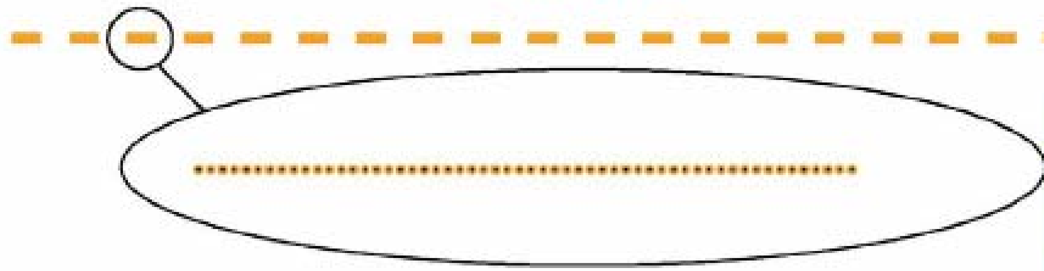


not to scale

Time Structure of the Beams

Train repetition rate: 150 Hz

CLIC



1 train =
154 bunches
0.27 nsec apart
~ 10 cm

Sub-TeV colliders

Warm technology
⇒ 120 Hz 1 train = 192 bunches 1.4 nsec apart

Cold technology
⇒ 5 Hz 1 train = 2820 bunches 336 ns apart

⇒ Experimenting at CLIC similar to the NLC

Hadronic Background

from ILC-TRC report:

	TESLA 500	TESLA 800	JLC-C	JLC-C	NLC/GLC 500	NLC/GLC 1000
n_γ [number of γs per e]	1.56	1.51	1.36	1.30	1.26	1.30
$N_{\rm pairs}(p_T^{\rm min} = 20$ MeV/c, $\Theta_{\rm min} = 0.2)$	39.4	37.3	10.7	15.0	11.9	15.0
$N_{\rm hadron\ events}$/crossing (W>5 GeV)	0.248	0.399	0.075	0.270	0.103	0.270

Number of $\gamma\gamma\to$hadrons events per bunch-crossing (BX) for W>5GeV:

NLC: 0.10/0.27 events at 500/1000 GeV
TESLA: 0.25/0.40 events at 500/800 GeV

CLIC: 0.07/0.17 for 500/1000 GeV

Probably not a very big problem if single bunches can be resolved

Battaglia, Schulte (2000)

Readout of whole detector between two consecutive BX is very tough within 1.4 ns at NLC

→ detector will integrate the signals over more than one BX at NLC

If detector granularity is fine enough, a single cell will not be hit in two consecutive BX (low occupancy).

→ no need to readout the cell immediately; storing time-info enough (time-stamping).

Very forward region will have high occupancy – effects not considered in this study

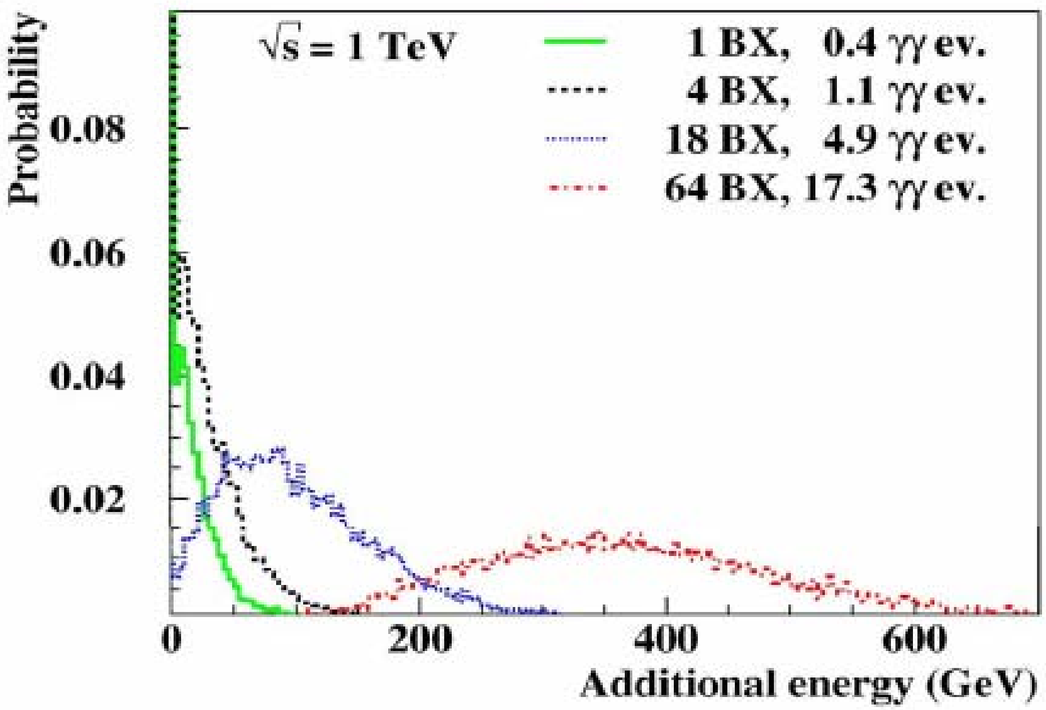
Time-Stamping: how much pile-up can we afford?

Physics has to give the answer.

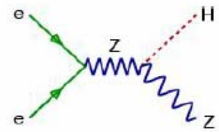
At LCWS04:
physics studies for overlaid background from America, Asia and Europe for the

Cold/warm scenarios

Additional energy in the detector from $\gamma\gamma \rightarrow$ hadrons:



Physics impact 1: Higgs mass measurement

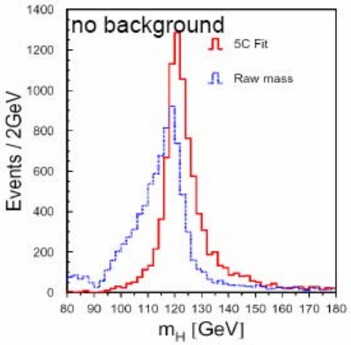


Mass measurement for a light Higgs boson

Higgs-strahlung process

Best final state: H→bb, Z→qq (4 jets)

Improve mass resolution with a kinematic fit (assume 4-momentum conservation)



Study at 500 GeV for 500 fb^{-1}

m_h = 120 GeV

Overlaid background will (seemingly) violate 4-momentum conservation
→ expect kinematic fit to fail:

NLC/TESLA comparison: Summary

Benchmark: mass determination of 120 GeV Higgs in HZ→bbqq

# of BX	US/optimized for <10BX	US/optimized for>=10BX	EU/optimized for 1BX
0	71	74	68
1	74	78	
TESLA	77	79	75
4	79	82	78
5	79	82	
10	91	82	
20	92	81	92
64			110

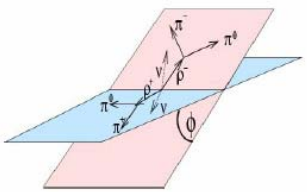
At NLC, a bunch tagging of few ns is required, but a lot can be gained also from optimized analyse. R&D on detector timing is remains very important

But a similar precision can be reached

Physics Impact 2: CP study in H→ττ

Select HZ→ττνν→$\rho^+ \rho^-$ υυυυ→$\pi^+ \pi^0 \pi^- \pi^0$ νννν events

Measure ρρ acoplanarity



Overlaid events may disturb tau ID and reconstruction of ρ decay products

Simplified selection:

- require 2 cones(15^0) with exactly 1 charged track (not e,μ) with E>2 GeV
- at least 1 GeV neutral energy within 10^0 around charged track
- ρ mass between 0.4 and 4 GeV
- ρρ mass between 25 and 125 GeV

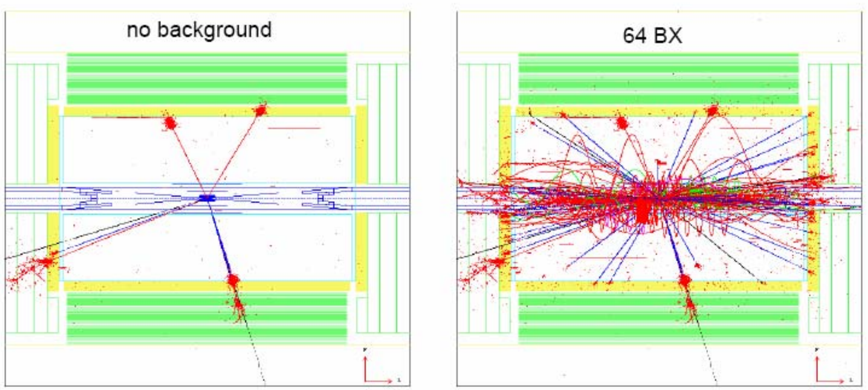
p_t-cut not easily applicable since photons from τ decay often low-energetic

cone size will be varied to reduce impact of background

;LI

2. Hadronic Background

HZ → ττee event



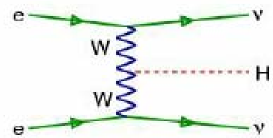
Physics Impact 3: Higgs in WW-fusion @ 1 TeV

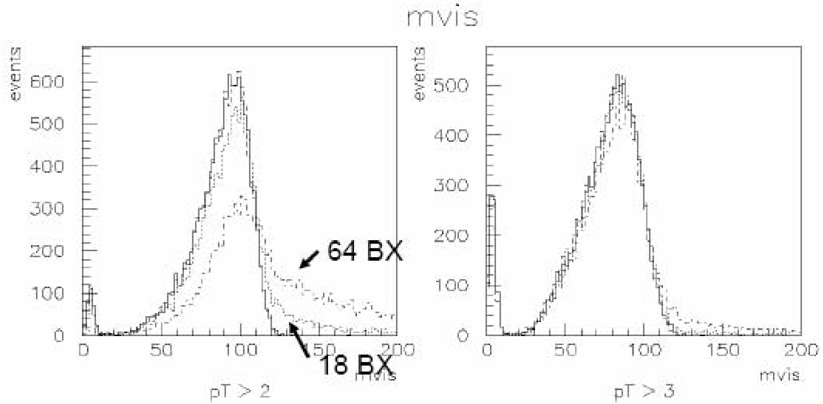
$e^+e^- \rightarrow b\bar{b}\nu\bar{\nu}$

look at visible mass ($=m_H$)

larger background at 1 TeV

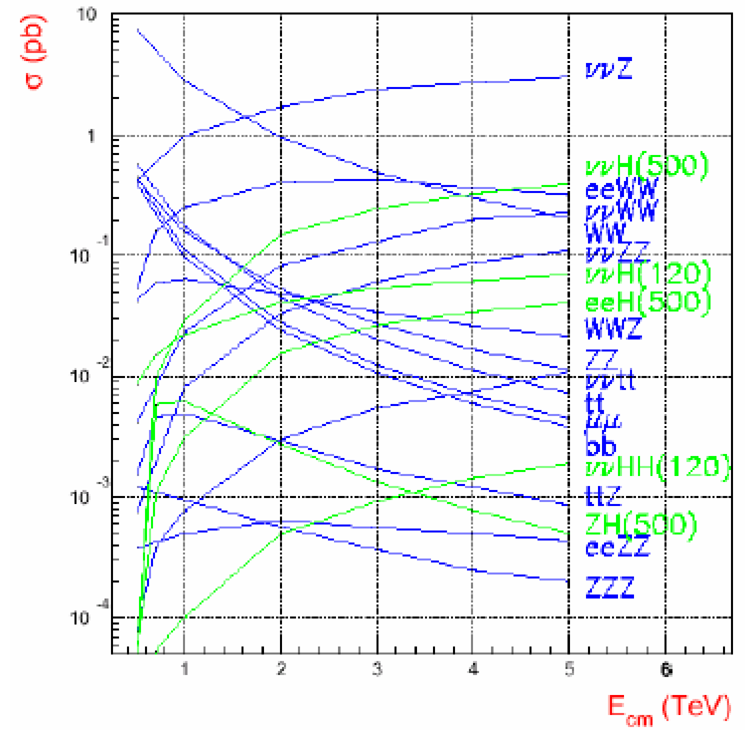
no kinematic constraints in this channel





need a significant p_t cut to get m_{vis} distribution back into right ballpark

e^+e^- cross sections



R&D at CERN for Linear Collider Detector 2007-2009

5 R&D proposals made to PH Dept. with very modest request for resources.
No decision yet.

1) TPC at ILC (gating with GEMs, novel read-out chambers)
2) Pixel detectors for LC (thinner detectors, hybrid detectors without bump bonding, ASIC with 100 ps readout!)
3) Ultrafast sensor based on nano-channel-plate for time stamping (100 ps?)
4) Calorimetry with Crystal Fibers ("Dual Readout")
5) Engineering design of the forward regions of a CLIC detector

People: A. Cattai, M. Hauschild, P. Jarron, P. Lecoq, G. Stefanini, …

possible collaboration with:

EUDET 1) and 2)
NIKHEF TimePix 1)
P326 Gigatracker 2)
ALICE TPC and pixel groups 1), 2)
SIAM collab. 3)
PPARC 3)
Crystal Clear (part) 4)
AB CLIC group 5)

What is EUDET?

- FP6, 6th framework program, EU
- "Integrated Infrastructure Initiative I3" ← Networking !
- Detector R&D towards the International Linear Collider
- Starting date ≈ January 2006
- Duration 4 years
- Budget:
  - total 21.5 MEuro
  - of which 7 MEuro funded by EU
- 30 institutes (mainly European)
- 20 associated institutes

specific EUDET elements

Blue = with CERN participation

- **Networking:**
  - Computing and analysis infrastructure, web-based info
  - Validation of simulation => hadronic process in GEANT4 **√ 1 FTE**
  - Access to deep submicron microelectronics **√ frame contract with IBM**
- **Installation of large-bore magnet for TPC tests:**
  - Magnetic field map **√ 1 FTE, use LHC expt equipment**
- **Construction of pixel beam telescope:** **No**
  - MAPS detectors
  - CCD and DEPFET pixel detectors for validation
  - DAQ

specific EUDET elements

Blue = with CERN participation

- **Large TPC prototype:**
  - Low mass field cage — **No**
  - End plate for GEM and Micromegas readout — **No**
  - Development of prototype electronics for TPC readout — **√ with ALICE**
  - Silicon pixel readout for TPC (using Medipix→TimePix) — **√ 1 FTE**
- **Infrastructure for Silicon tracking devices**
- **Calorimetry:** — **No**
  - Scalable ECAL prototype with tungsten absorbers
  - Scalable HCAL including calibration systems
  - Very forward calorimeter (silicon and diamond sensors)
  - FE and DAQ systems for calorimeters

Lucie Linssen, PH senior staff meeting 23 Nov '05 slide 17