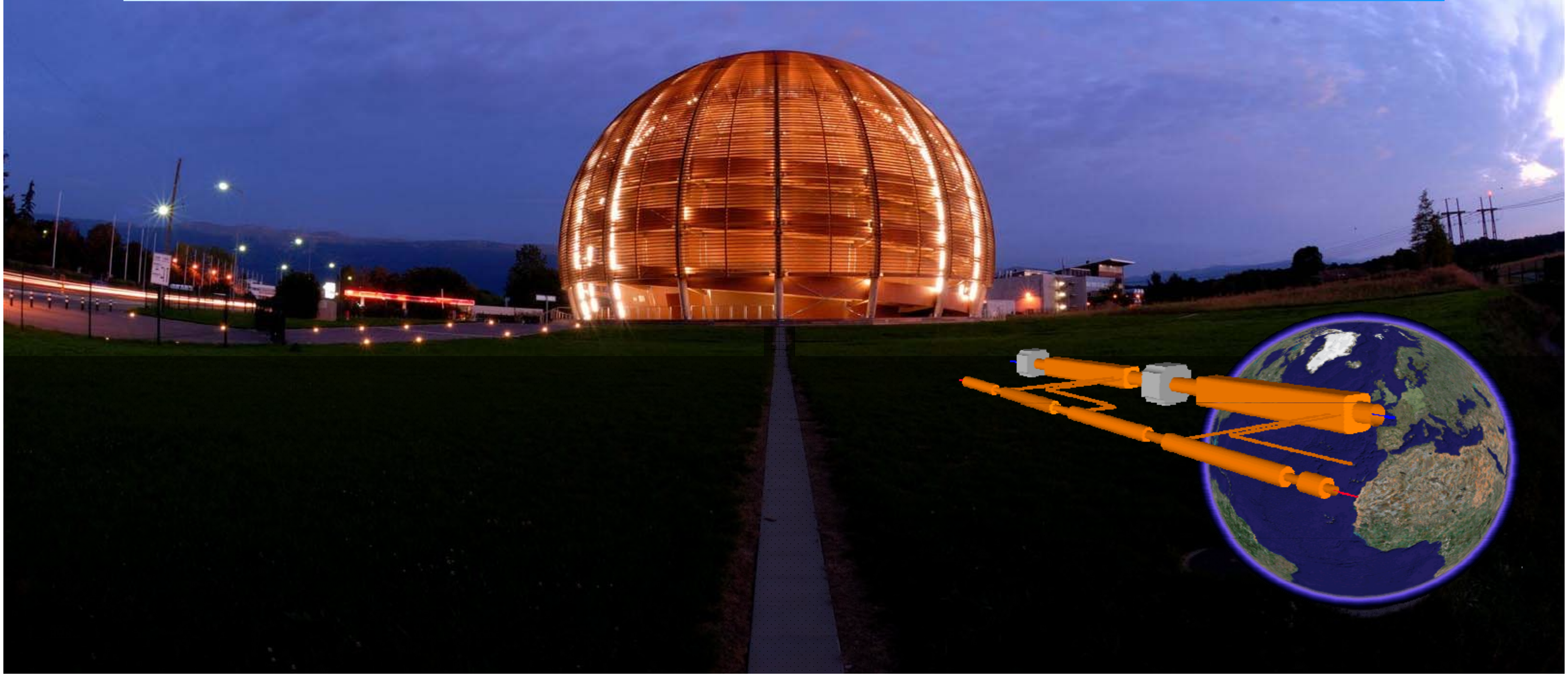
CLIC

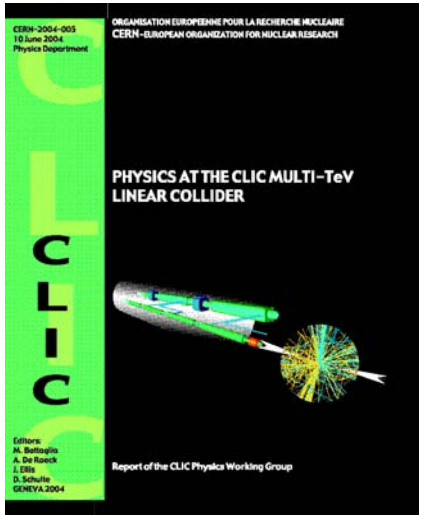
ECFA Study
Physics and Detectors for a Linear Collider

CLIC Detector Studies

A. De Roeck
CERN

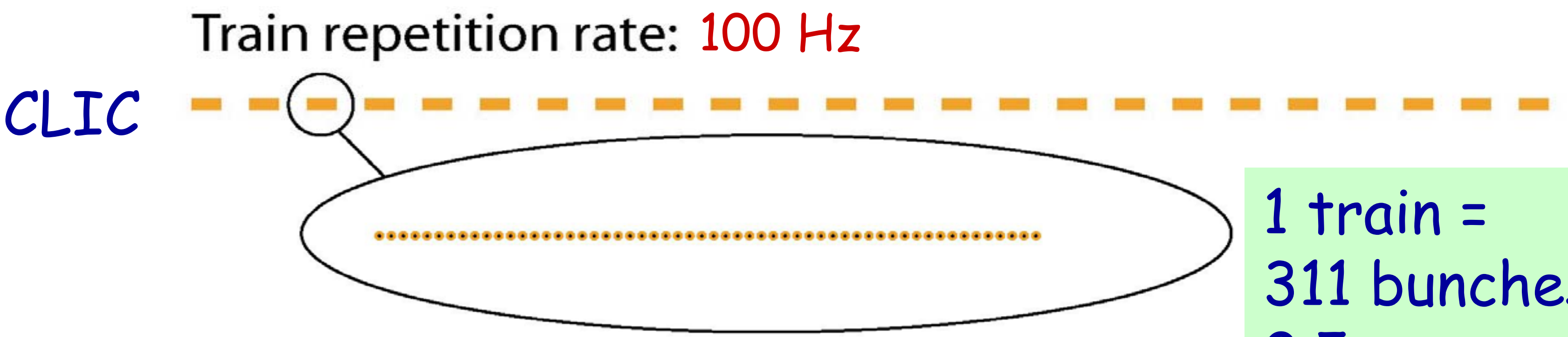


CLIC Detector R&D @ CERN
History, Status + plans



- 2004 CLIC Study group report:
- "Physics at the CLIC Multi-TeV Linear Collider"
- 2006-2009 EUDET R&D
- Oct 2007, CLIC07@CERN, first Workshop on CLIC accelerator and physics aspects → goal: feasibility demo by mid 2010 (CDR)
- Feb 2008 CLIC/ILC Collaboration meeting

Time Structure of the Beams



1 train =
311 bunches
0.5 nsec apart
~ 15 cm

ILC

$\Rightarrow$ 5 Hz 1 train 2625 bunches 369 ns apart

→ Experimenting at CLIC similar to the "NLC"

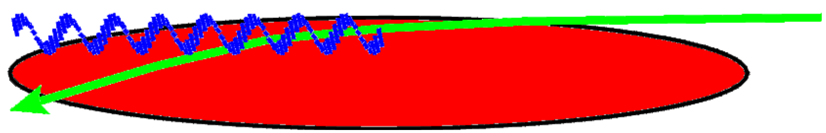
Bunch identification?

Experimental Issues: Backgrounds

CLIC 3 TeV e+e- collider with a luminosity 5.10^{34}-$10^{35}cm^{-2}s^{-1}$ (>0.5 ab^{-1}/year)

E_{cm}	[TeV]	0.5	3	3
$\mathcal{L}$	$[10^{34}cm^{-2}s^{-1}]$	2.1	10.0	5.9
$\mathcal{L}_{0.99}$	$[10^{34}cm^{-2}s^{-1}]$	1.5	3.0	2.0
f_r	[Hz]	200	100	50
N_b		154	154	311
Δ_b	[ns]	0.67	0.67	0.5
N	$[10^{10}]$	0.4	0.4	0.4
σ_z	[μm]	35	30	44
ϵ_x	[μm]	2	0.68	0.66
ϵ_y	[μm]	0.01	0.02	0.02
σ_x^*	[nm]	202	43	53
σ_y^*	[nm]	≈ 1.2	1	1
δ	[%]	4.4	31	31
n_γ		0.7	2.3	2.0
$N_\perp$		7.2	60	45
N_{Hadr}		0.07	4.05	2.7
N_{MJ}		0.003	3.40	

To reach this high luminosity: CLIC has to operate in a regime of high beamstrahlung



Expect large backgrounds
# of photons/beam particle
- e+e- pair production
- γ γ events
- Muon backgrounds
- Neutrons
- Synchrotron radiation

Expect distorted lumi spectrum

Report →Old values
New values close to those used in the report

e+e- Pair Production

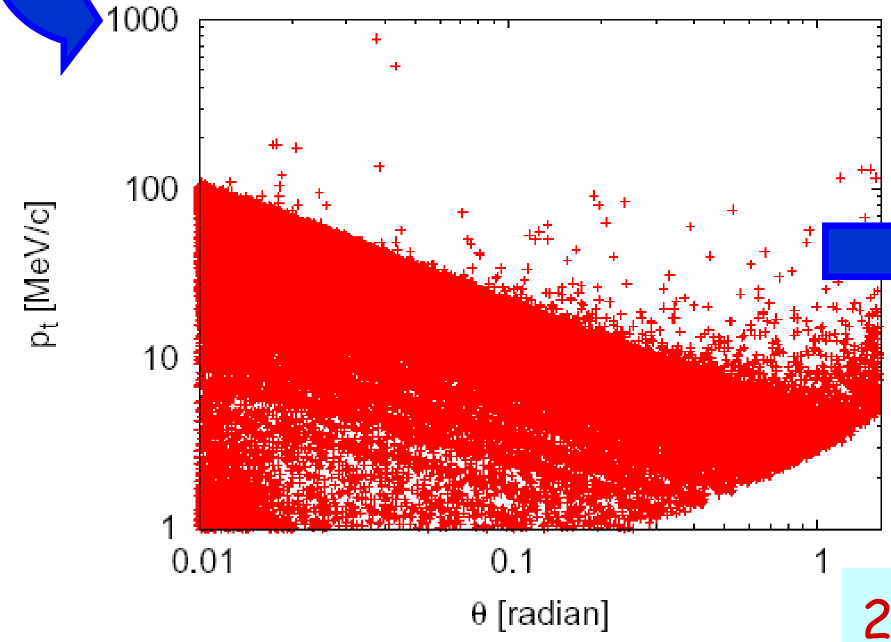
Coherent pair production
- number/BX $3.8\ 10^8$
- energy/BX $2.6\ 10^8$ TeV

Incoherent pair production:
- number/BX $3.0\ 10^5$
- energy/BX $2.2\ 10^4$ TeV

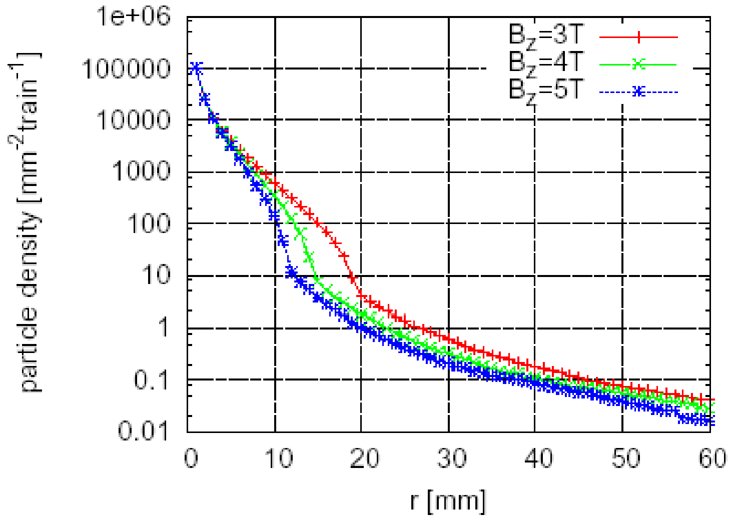
Disappear in the beampipe

Can backscatter on machine elements
Need to protect detector with mask

Can be suppressed by strong magnetic field in of the detector



hits/mm²/bunch train



20mm and 4T ⇒O(1) hit/mm²/bunch train 👍

Detector Specifications

hep-ph/0412251 ; CERN-2004-005

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 $\frac{\delta p}{p} \simeq 30\%$ at $100\ GeV/c$
Energy Flow	$\frac{\delta E}{E\ (GeV)} \simeq 0.3 \frac{1}{\sqrt{E}}$
Acceptance	$\|\cos\theta\| < 0.98$
mask	120 mrad
beampipe	3 cm
small angle tagger	$\theta_{min} = 40$ mrad

CLIC Report 2004:
Starting point: the TESLA TDR detector adapted to CLIC environment

- Detailed studies performed for previous CLIC parameters
- Larger need for time-stamping of events
- No significant difference in performances expected between old and new multi-TeV parameters

CLIC Benchmark Processes studied

Table 3.1: Physics signatures and CLIC physics programme: matrix of the simulated processes

Physics signatures	Higgs sector	SUSY	SSB	New gauge bosons	Extra dimensions
Resonance scan		$\tilde{\mu}$ thresholds	D-BESS	Z'	KK resonances
EW fits				$\sigma_{f\bar{f}}$, $A_{\rm FB}^{f\bar{f}}$,	$\sigma_{f\bar{f}}$, $A_{\rm FB}^{f\bar{f}}$,
Multijets	H^+H^- H^0A^0 $H^0H^0\nu\bar{\nu}$				
$E_{\rm miss}$, Fwd	$H^0e^+e^-$	$\tilde{\ell}$ χ_2^0	WW scattering		

$e^+e^- \rightarrow H^+H^-$ $M_H = 900$ GeV

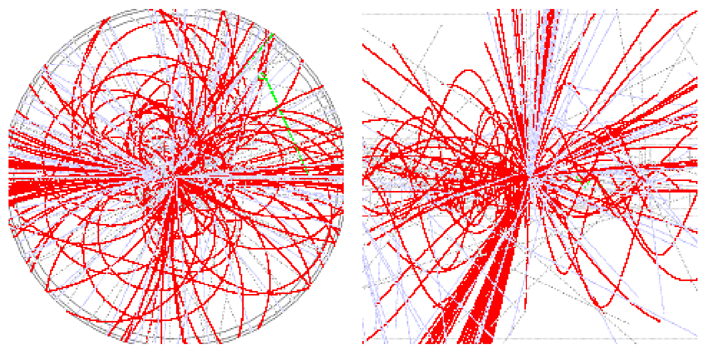


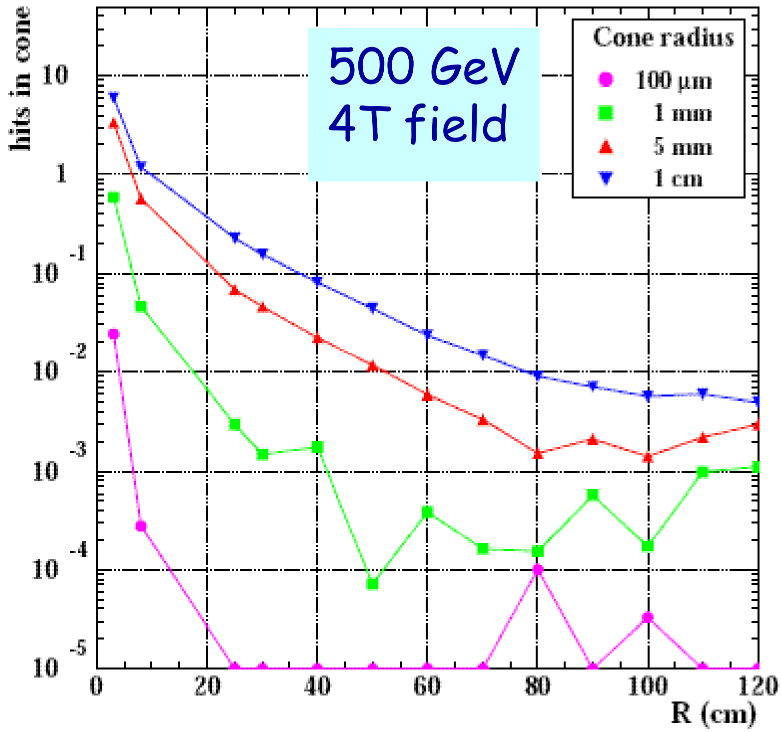
Table 3.7: Average reconstructed jet multiplicity in hadronic events at different $\sqrt{s}$ energies

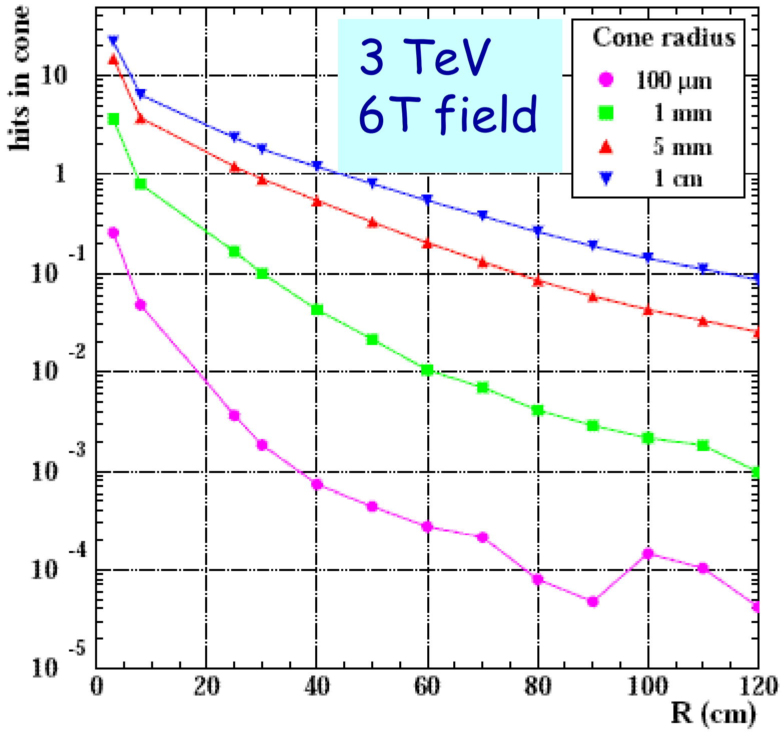
$\sqrt{s}$ (TeV)	0.09	0.20	0.5	0.8	3.0	5.0
$\langle N_{\rm Jets} \rangle$	2.8	4.2	4.8	5.3	6.4	6.7

Processes with up to 14 jets…

Track Density @ CLIC

ee→bb





Average number of additional tracks in a cone of given radius

500 GeV : 10% prob. to have 1 extra track within 1cm cone at 40cm radius

3 TeV : 10% prob. to have 1 extra track within 1cm cone at 1 m radius

What has happened in the last 8 months

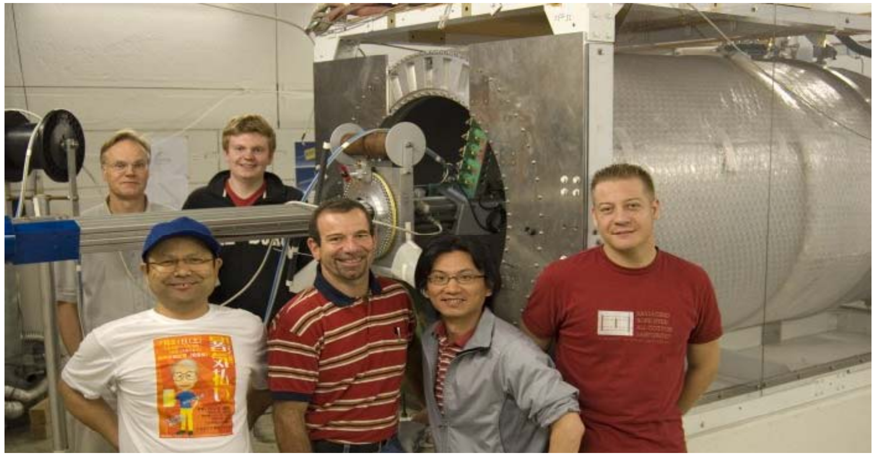
- CLIC 07 workshop (October 07)
  - Important milestone: We had ~200 registered participants, of which ~100 from 54 external institutions
  - Large interest from both CERN and outside
  - Several ideas on detector R&D being presented/ contact with the ILC detector community. Recognized that CLIC needs stronger detector R&D involvement
- Since February: Startup engagement in PH department for LC detector studies (available from September '08 onwards)
  - 2 PhD students
  - 1 Fellow
  - 1 Scientific associate
  - (+ ≥4 part time PH staff)
  - Some resources available for visitors for LC detector studies
  - Collaboration with several other institutes
- Note: CERN involved in EUDET and DEVDET proposal

What has happened in the last 8 months

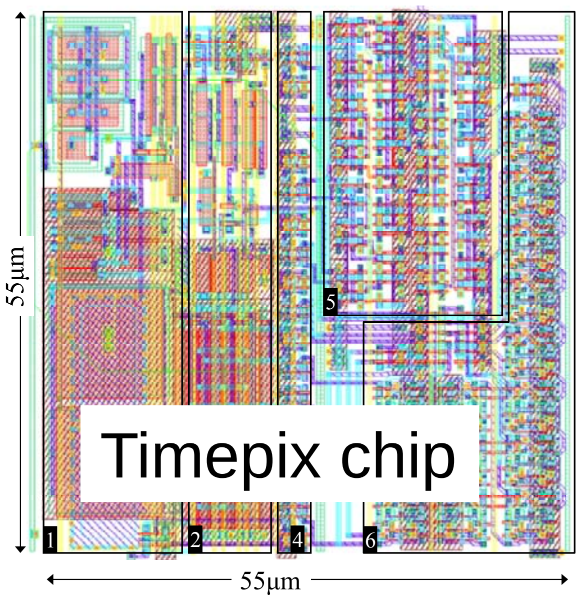
- Interests
  - At start: simulation studies to identify critical areas
    - Fast tracking (time stamping), in connection with pixel group
    - TPC studies: usable @CLIC?
    - MDI/FCAL studies. Redesign the MDI area
    - Calorimetry/particle flow, especially for high densities
- Grand plan
  - CLIC CDR by 2010, including a section on detector options
    - TDR for the machine by 2014
  - Capitalize on working with ILC Detector groups
  - Start with some stdies with SiD (ILD) detectors
- Since February 08: ILC/CLIC collaboration (machine and detectors)

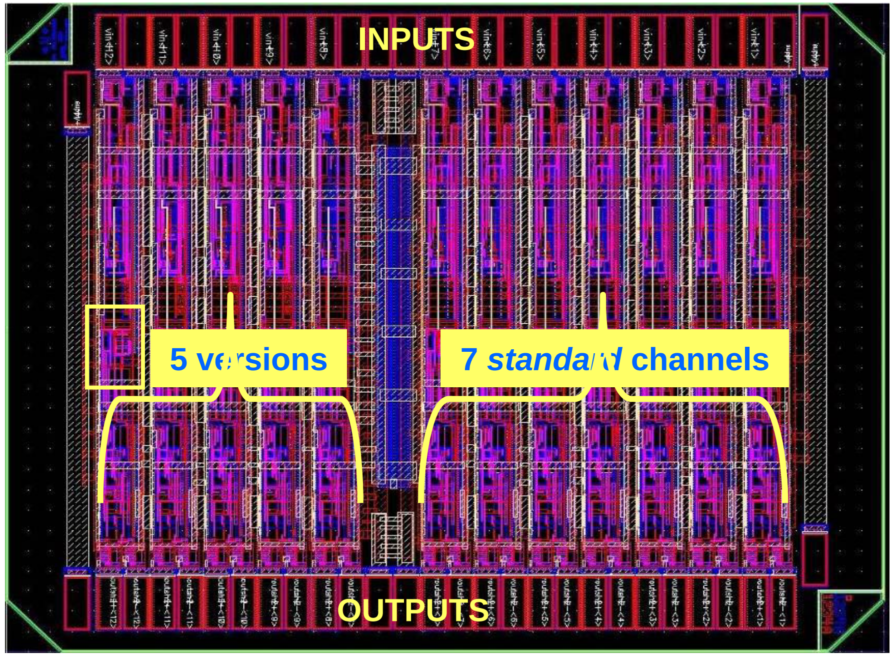
CERN Participation in LC: EUDET 2006-2009

- MICELEC: microelectronics user support
- VALSIM: optimisation of hadronization process in GEANT4
- Magnet: magnetic field map of PCMAG magnet at DESY test beam
- Timepix: development of pixel chip for TPC pixelised readout
- TPC electronics: development of TPC pad readout (aiming for combined analog/digital readout fitting behind 1×4 mm^2 pads)



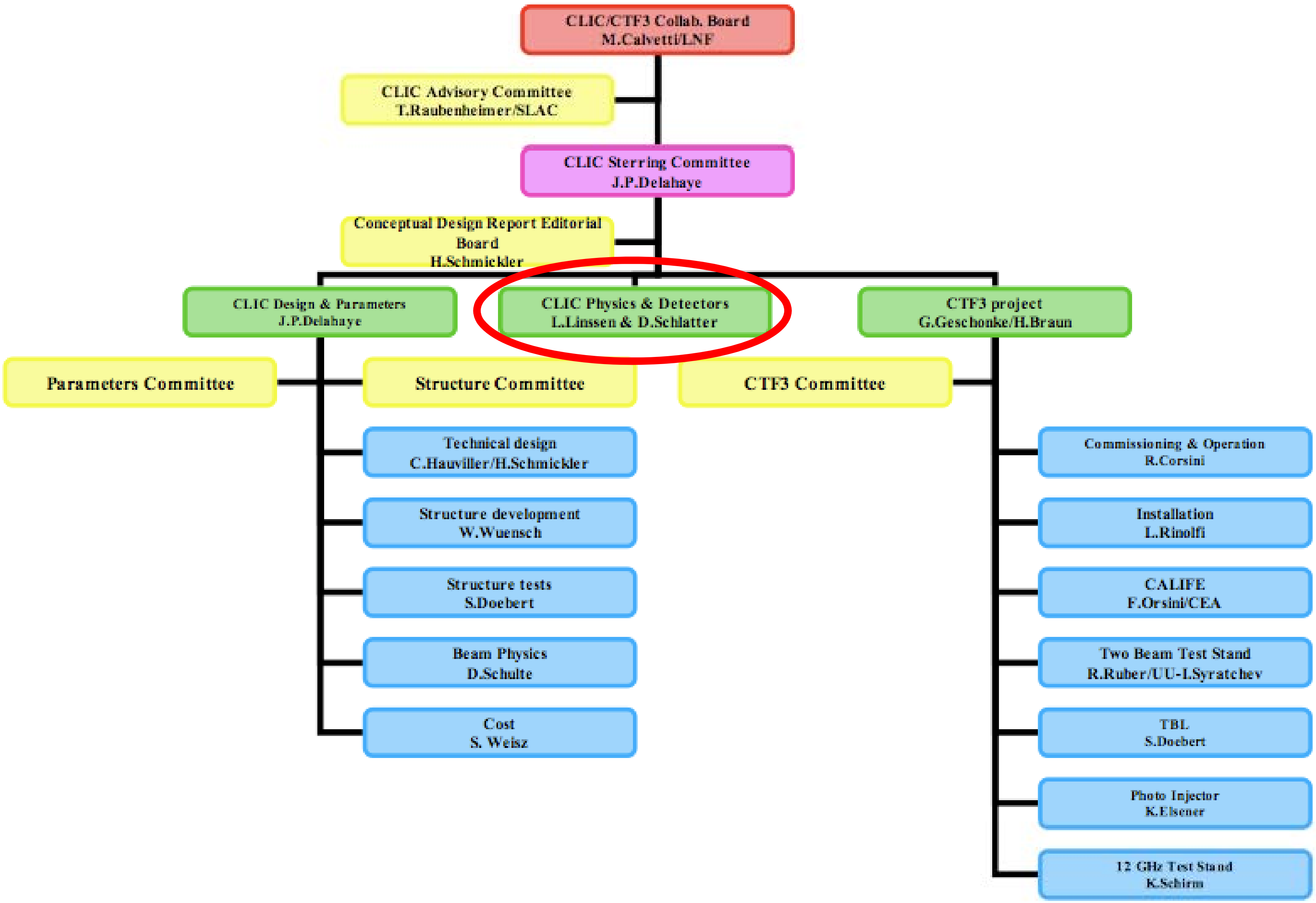
PCMAG field map campaign at DESY 2007





TPC pad readout, programmable amplifier 130 nm technology

CLIC Chart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Two Beam Test Stand
R.Ruber/UU-I.Syratchev
TBL
S.Doebert
Photo Injector
K.Elsener
12 GHz Test Stand
K.Schirm

ILC-CLIC working groups

ILC-CLIC working groups	
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)
Detectors	Lucie Linssen (CERN), Francois Richard (LAL), Dieter Schlatter (CERN), Sakue Yamada (KEK)
Cost & Schedule	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)

First working group meeting, 13/5/2008

Topics for CLIC/ILC Detector R&D

1) Define a CLIC detector concept at 3 TeV.
(update of 2004 CLIC Study) based on ILC detector concepts.

2) Detector simulations
- Simulation tools to be used by ILC and CLIC (WWS software panel)
- Validation ILC detector options for CLIC at high energy, different time structure, higher densities and different backgrounds
- 1 TeV benchmark studies to provide overlap
- compare performance using defined benchmark physics processes (e.g. WW/ZZ separation)

Topics for CLIC/ILC Detector R&D

3) EUDET /DEVDET (infrastructure for LC detector R&D, with associated non-EU groups)

- microelectronic tools
- 3D interconnect technologies (for integrated solid state detectors)
- simulation and reconstruction tools
- combined test with magnet and LC sub-detectors

4) TPC

- TPC performance at high energies (>500 GeV).
- TPC read out electronics

5) Calorimetry

- Dual Readout Calorimetry (feasible at LC?)

6) General

- increased CLIC participation in future ECFA workshops on LC detectors

Machine Detector Interface

- General layout and integration
  - Common meeting/review required
  - Common engineering tools for detector design in preparation (DESY, CERN, IN2P3, FP7)
- Background and luminosity studies
  - Strengthen support
- Masking system
  - Constraints on vertex detector
- Detector field
  - Need a field for CLIC
- Magnet design
- Common simulation tools for detector studies
  - Need to review what is available
- Low angle calorimeters
- Beam pipe design (LHC)
- Vacuum etc. (LHC)

Background and Luminosity Studies

- Common simulation tools
  - BDSIM ()
    - Integration into GEANT?
  - FLUKA (CERN)
  - Halo and tail generation (CERN)
  - Common formats etc
- Study of machine induced background
  - In particular, neutrons, muons and synchrotron radiation
  - Mitigation strategies
    - e.g. tunnel fillers against muons
- Study of beam-beam background and luminosity spectrum

Support, Stabilization and Alignment

- LAPP, Oxford, CERN, FP7, BNL, SLAC, …
  - Room for more to join
- Low-noise design
  - Noise level measurements (DESY, CERN)
    - Among others, measurements at LHC
  - Component design
- Mechanical design of quadrupole support
- Final quadrupole design
- Stabilization feedback design
  - Sensors
  - Actuators
  - Interferometers

Experimental Area Integration

- Common definitions
- Infra-structure
  - Work is quite generic
    - No large differences expected for CLIC detector to some ILC detector
  - Collaboration has started
  - LHC expertise
- Push-pull
  - Is an option for both projects
  - A collaboration has started
  - Brings ILC/CLIC/LHC expertise
- Crossing angle
  - Investigate requirements
  - Then study benefits to find a common crossing angle

CLIC Simulation with SiD

Marco Battaglia, CLIC workshop and follow-up

- Include CLIC $\gamma\gamma$ background (50 bunch crossings)
- Include CLIC luminosity spectrum
- Study $ee \rightarrow \nu\nu H$, $ee \rightarrow H^+H^-$ and $ee \rightarrow$ smuon pair production

	CLIC	SiD DOD
Vertexing	$15+35/p_t$	$5+10/p_t$
$\delta p_t/p_t^2$ (100 GeV)	5.0×10^{-5}	2.5×10^{-5}
B Field (T)	4.0	5.0
ECal	$0.10/\sqrt{E}$	$0.17/\sqrt{E}$

An Example Analysis: $e^+e^- \rightarrow \nu_e \nu_e H \rightarrow \mu^+\mu^-$

$\sigma(e^+e^- \rightarrow H\nu\nu) = 0.51$ pb
for M_H=118.8 GeV, E_{cm} = 3 TeV

$BR(H \rightarrow \mu\mu) = 0.026$ %

SM Background
$\sigma(e^+e^- \rightarrow \mu\mu\nu\nu) = 4.7$ fb

M. Battaglia, submitted to J. Phys G

For 5 ab^{-1}

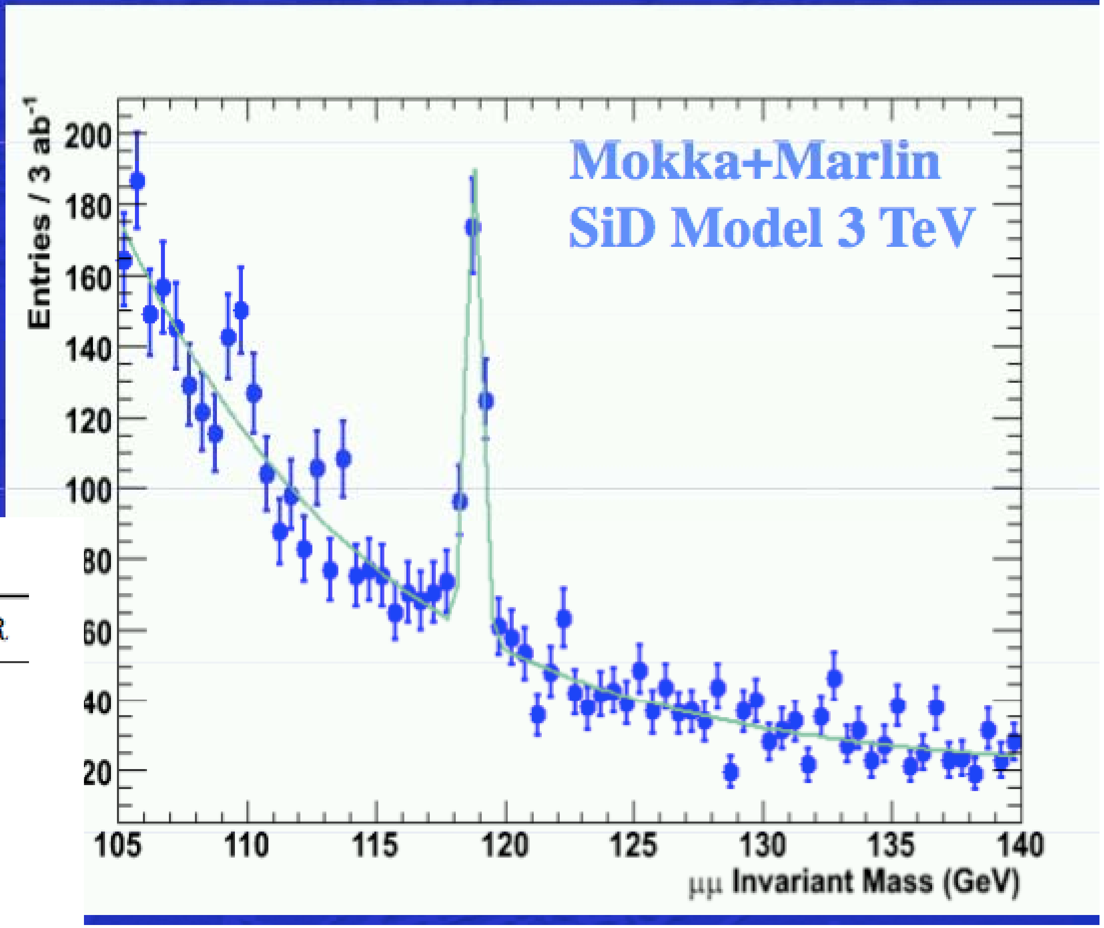
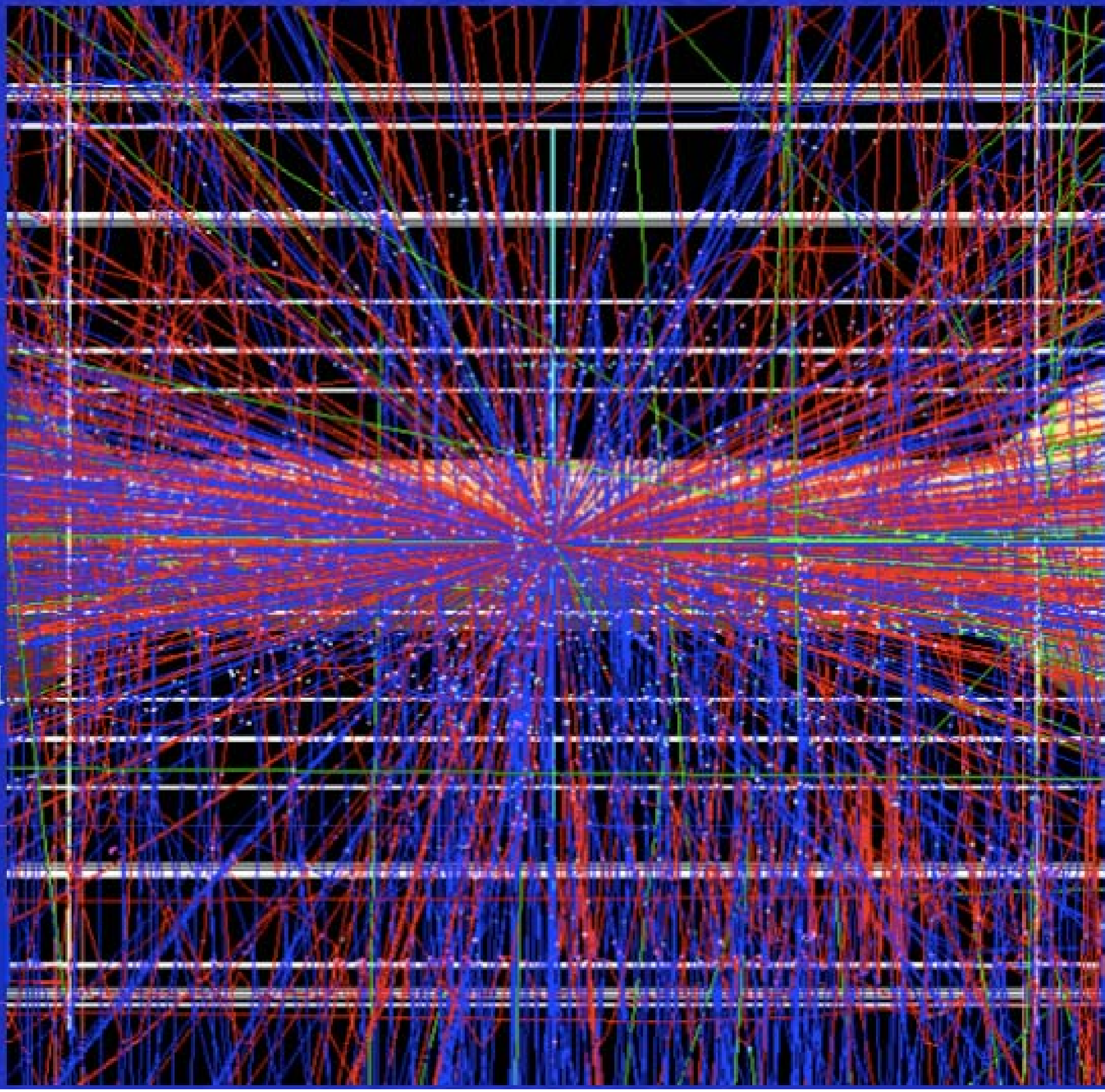


Table 1. Number of selected signal and background events.

M_H (GeV)	Nb. Signal Evts.	Nb. Bkg. Evts.	$S/\sqrt{B}$	$\delta BR/BR$
120	229.6	161.1	18.1	0.086
130	153.1	88.1	16.3	0.101
140	103.2	64.3	12.9	0.125
150	68.1	58.1	9.5	0.160
155	68.1	58.0	5.2	0.253
160	12.1	33.0	2.1	

Questions for the Study



<u>B Field strength</u>

B=5 T adequate for $\delta p/p$, main constrain to come from confinement of soft particles from bkgs;

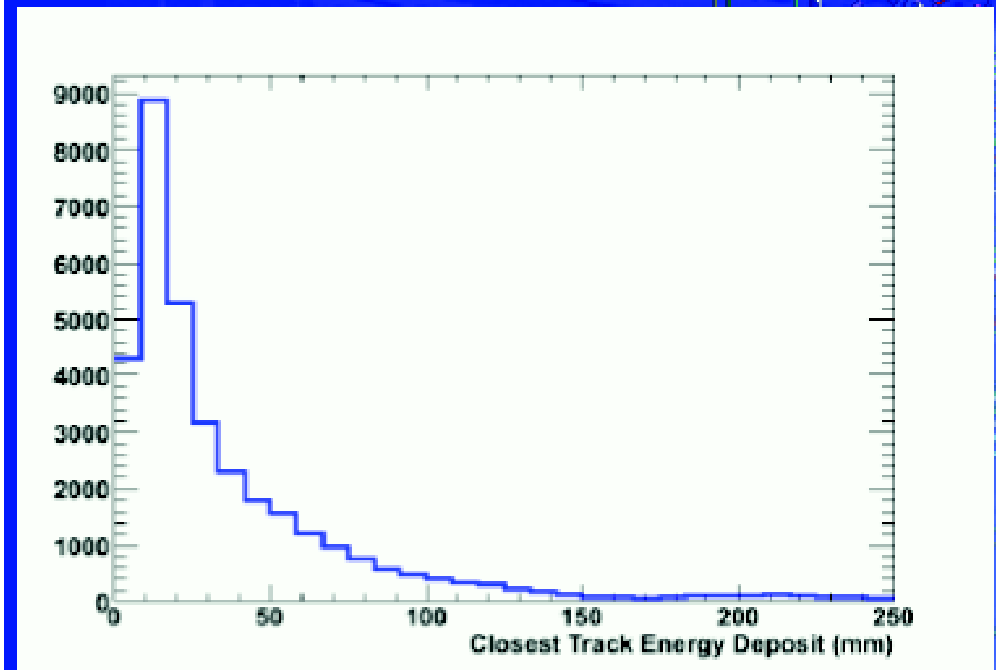
<u>Tracker Optimisation</u>

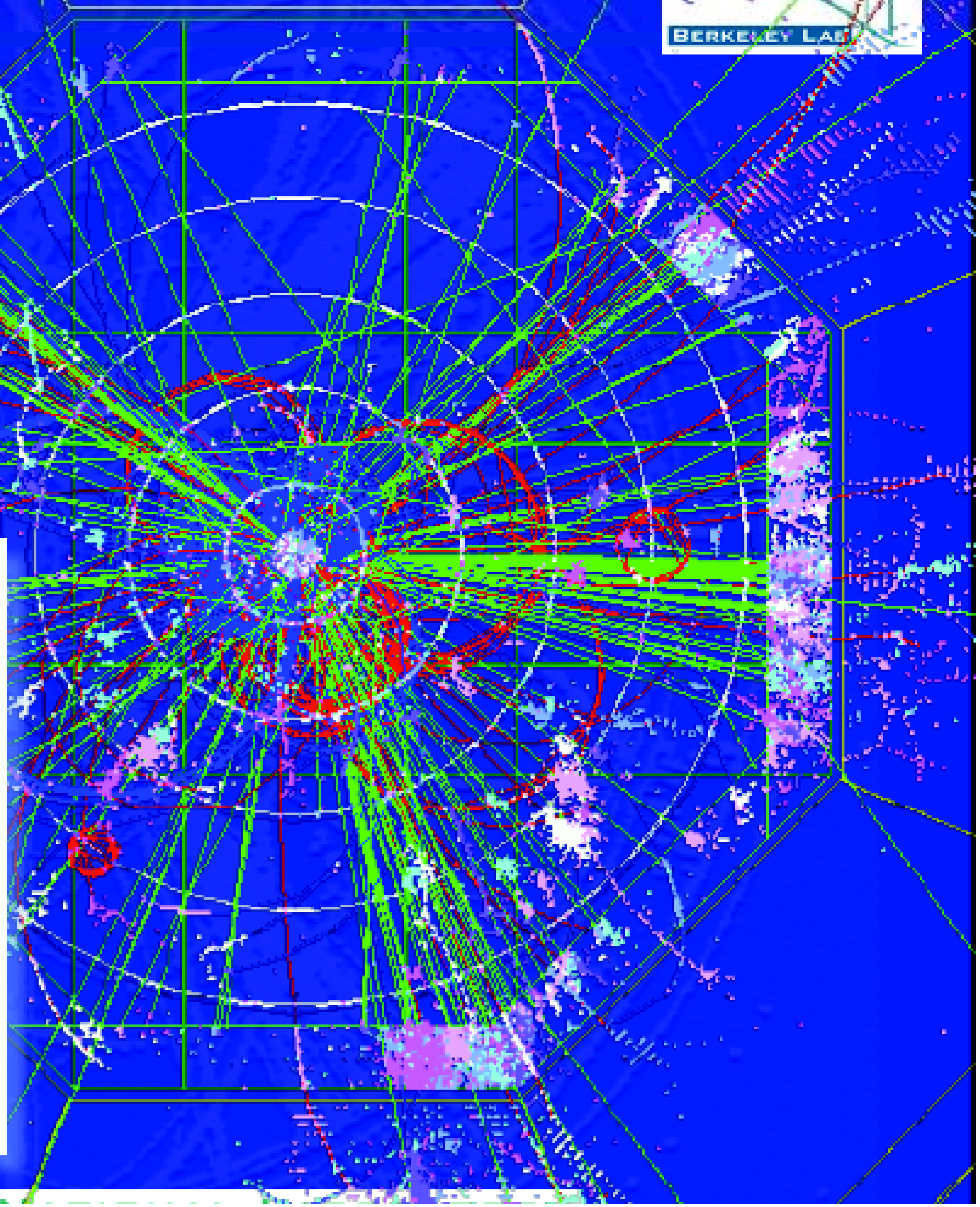
Background and collimated Hadronic jets require to review SiD strategy for track reconstruction and possibly tracker design for CLIC;

Questions for the Study

Particle Flow Applicability

$e^+e^- \rightarrow H^+H^- \rightarrow tbtb$ at 3 TeV shows limitations in the track-neutral separation in the ECal.

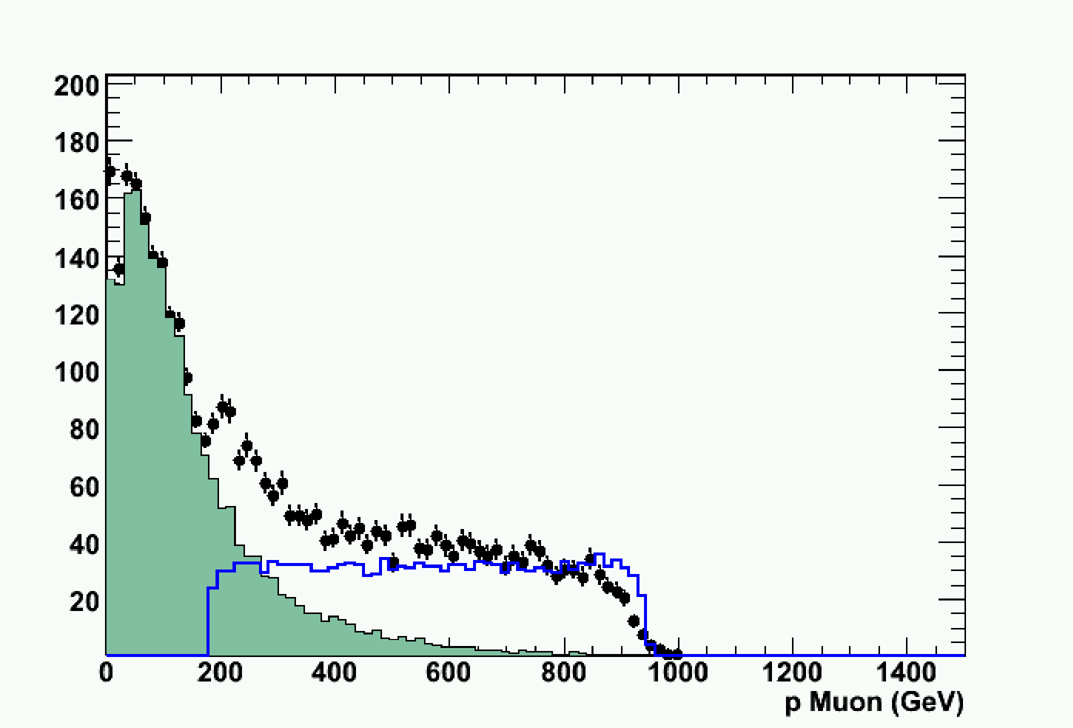


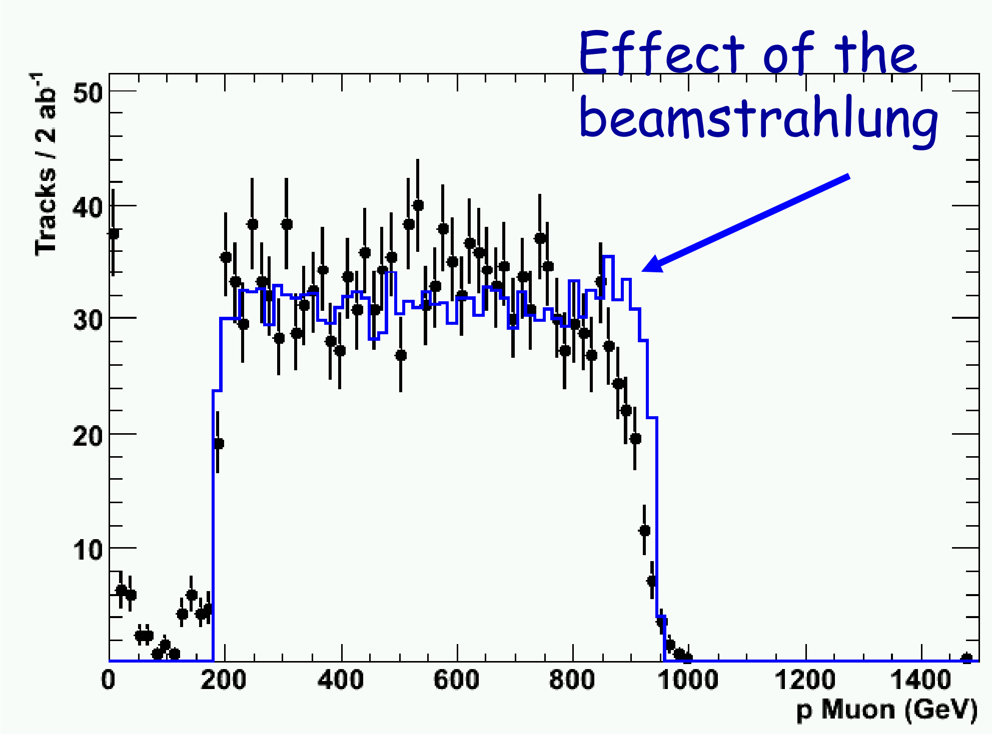


Muons from smuon pair production

Smuon production Benchmark point K, 2 ab^{-1}

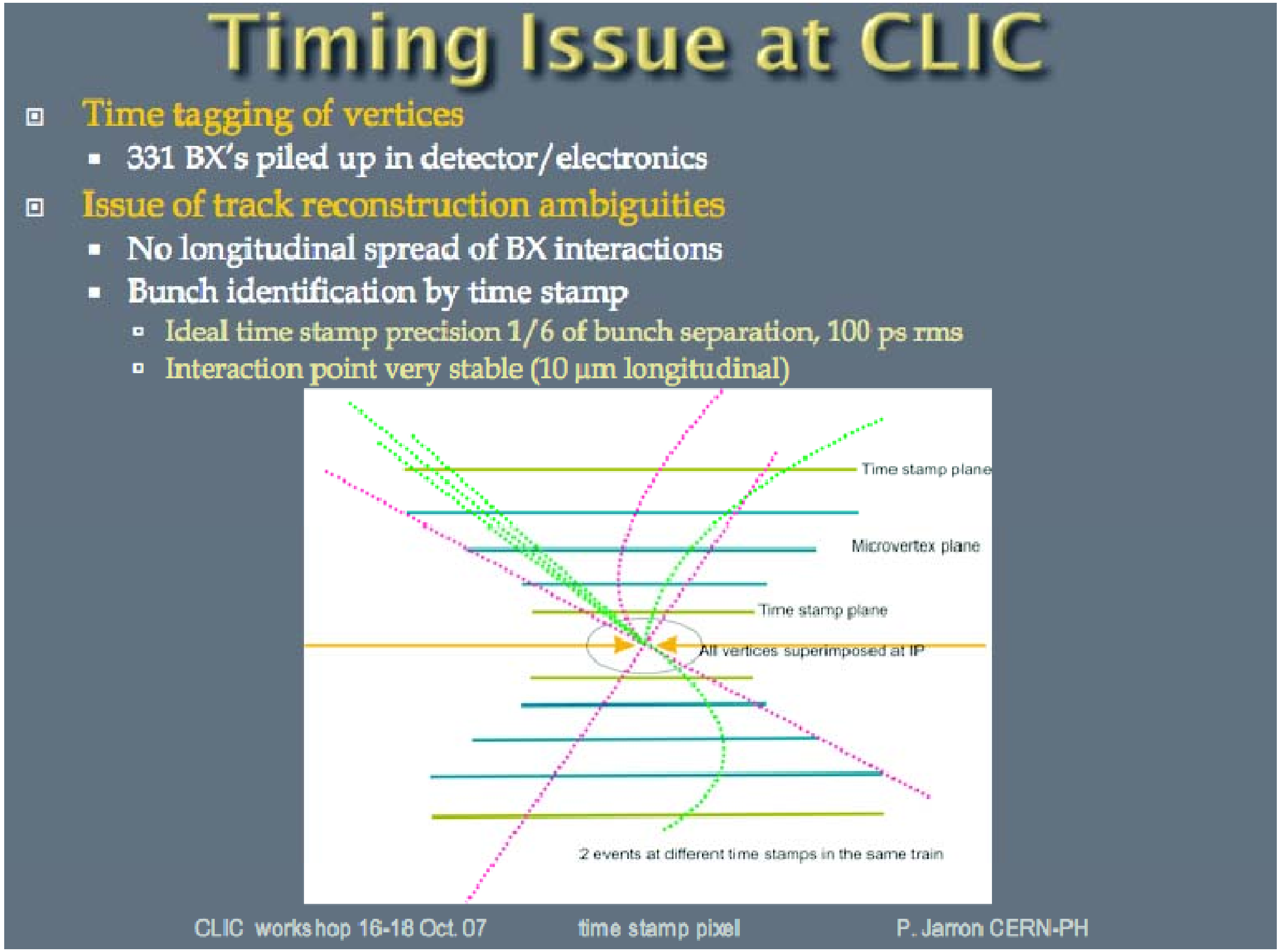
M(smuon) = 1100 GeV, M(neutralino) = 550 GeV





Vertex Detector/Tracker at CLIC

P. Jarron
LCW07



Idea: use a coarse pixel planes (300x300 μm) for timing in addition to precision position pixels. Following developments for the NA62 Gigatracker.
Aim for 100ps or better time resolution. Based on 0.13μm CMOS.

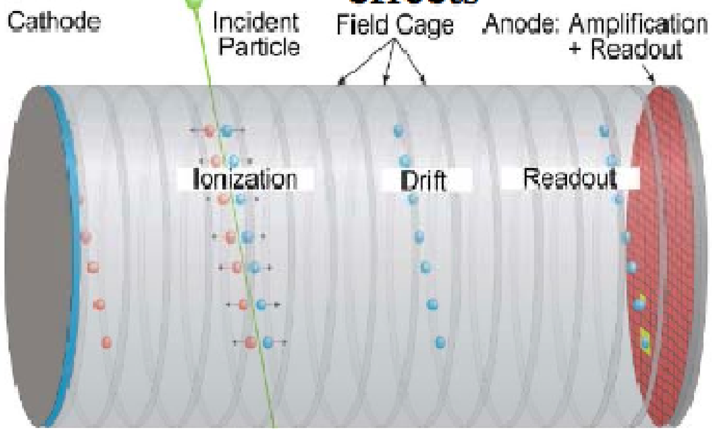
Tracking for CLIC

Silicon tracking… TPC?

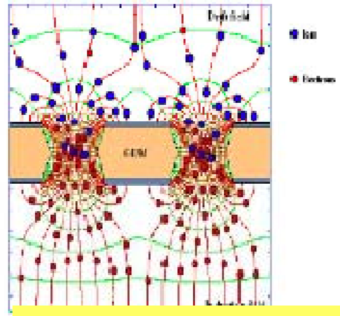
TPC with MPGD

K. Dehmelt
CLIC '07

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



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



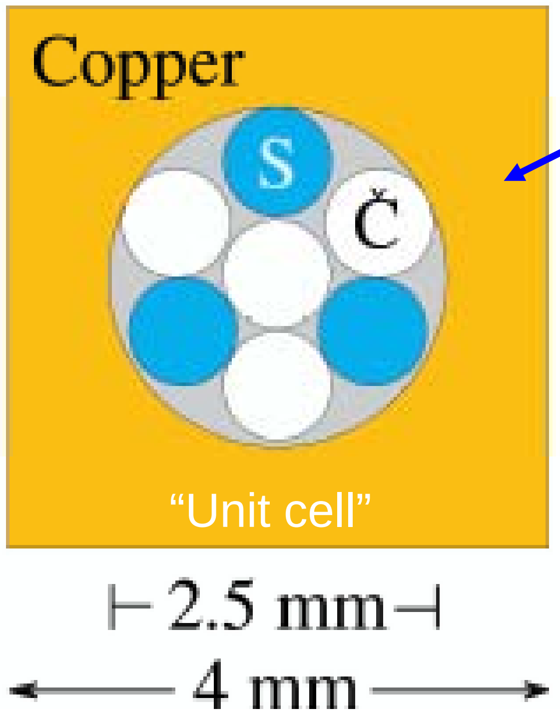
- Is a gaseous tracker viable for E_{cms} = 3 TeV ?
  - **background will be higher as E_{cms} increases**
  - **CLIC: large coherent-pair background**
    → at small polar angle θ, at large angles essentially unchanged from ILC
  - **time stamping: 0.667 ns vs 337 ns ?**
  - **dense jet environment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

Discussion indicates that it seems possible

Ideas for Calorimetery

P. Lecoq et al.

DREAM

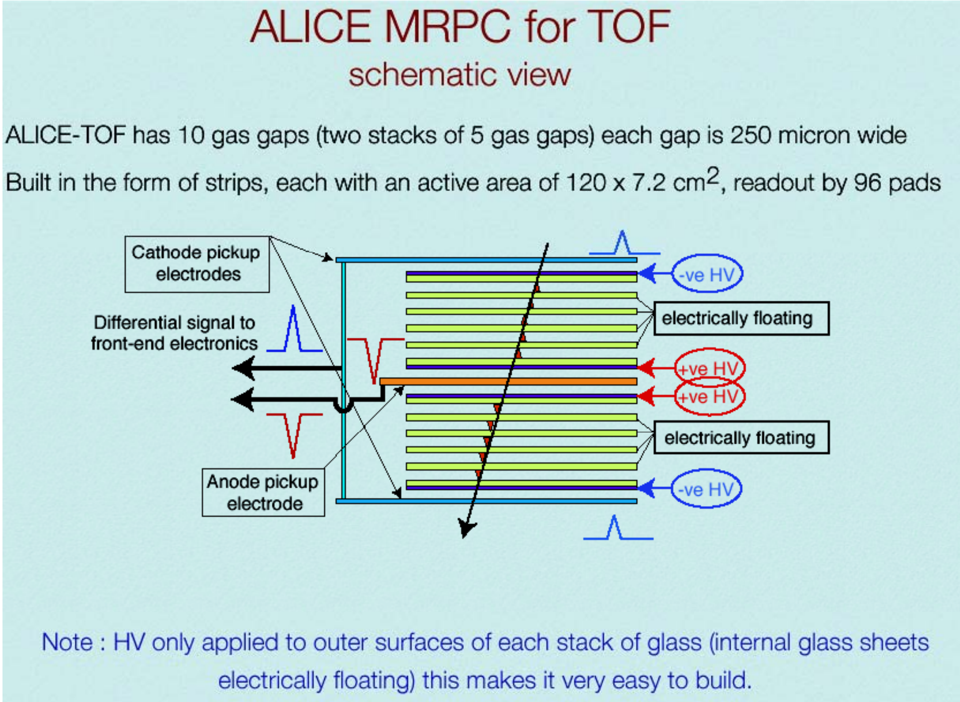


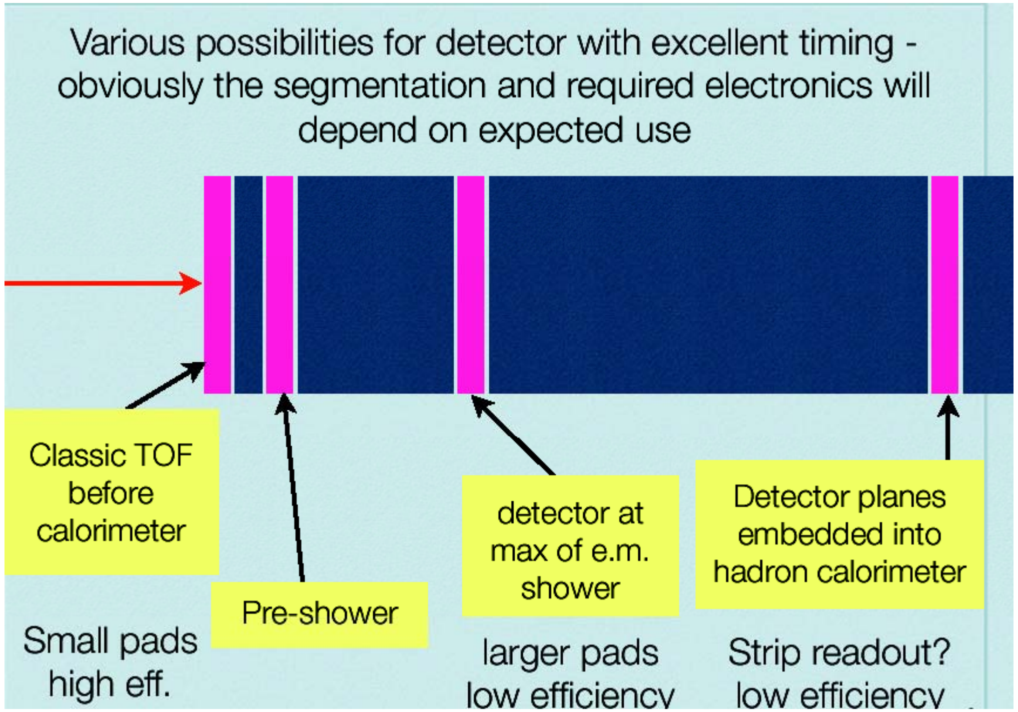
- Detected both total and EM component of shower via detection of scintillating light and cerenkov light, ie the approach of the DREAM concept
- Use instead quasi-homogeneous (scintillating and Cerenkov) fibres of the same heavy material to suppress sampling fluctuations ⇒ fibres are at the same time absorber and detector medium.
- Adequate meta-materials exist
- Additional neutron sensitive fibers can be incorporated
- Simulation studies needed!

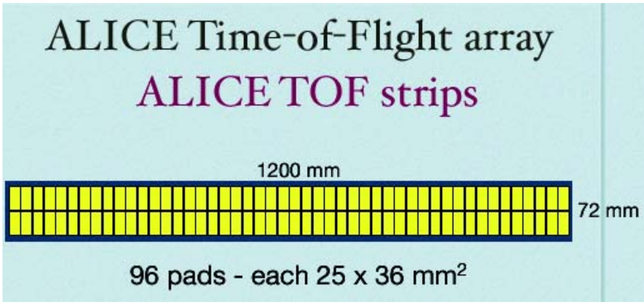
Interested groups from Crystal Clear, DREAM and a growing number institutes

ALICE Time of Flight (MRPCs)

C. Williams CLIC'07

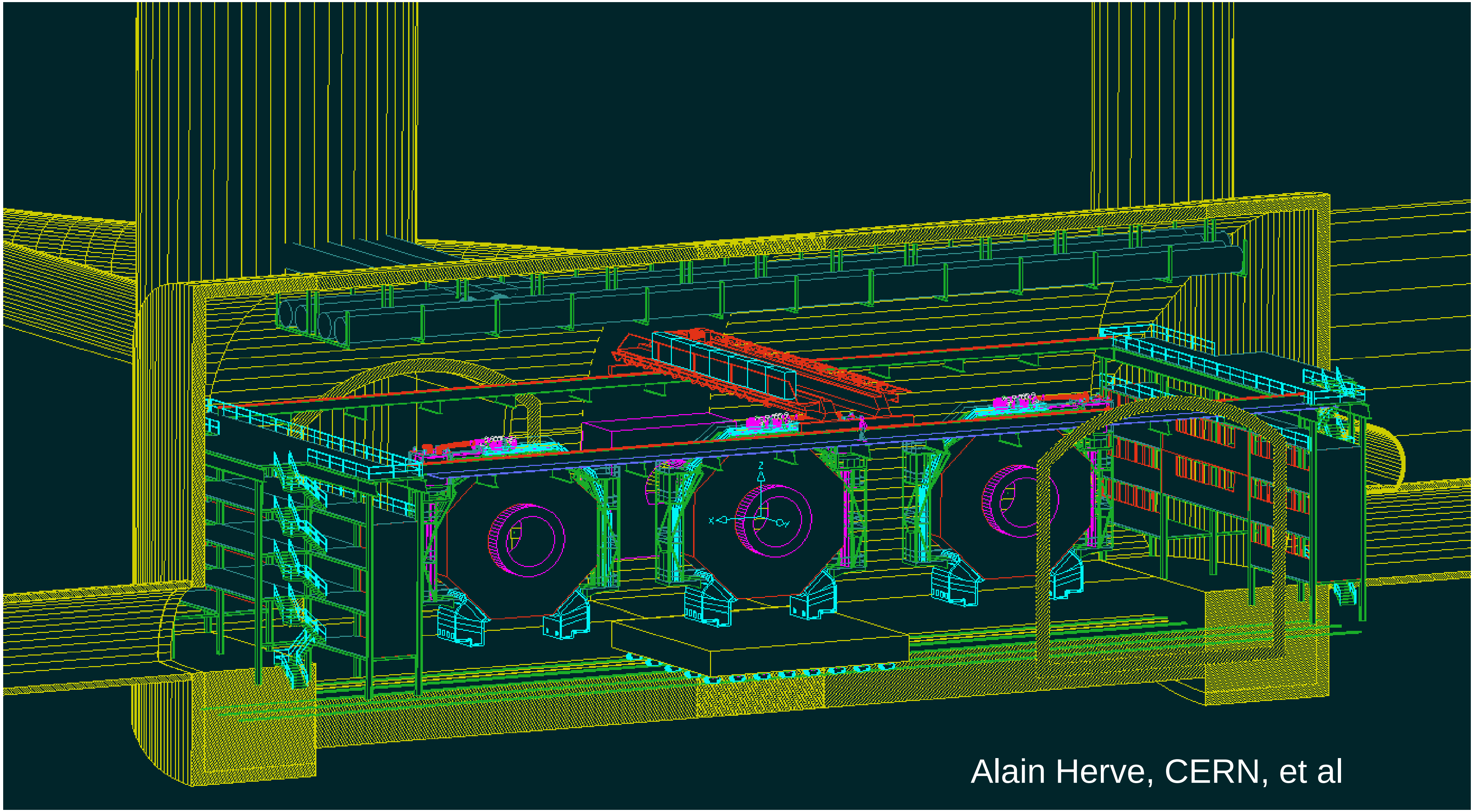






Multigap-RPC→ 150 m^2 with 160000 channels
Timing better than 100 ps

Push-Pull studies for two detectors



Conclusions

- CLIC physics/detector studies resumed as a result of the CLIC07 workshop. Some dedicated manpower for studies being put in place
- Synergy with ILC detector studies $\rightarrow$ ILC-CLIC collaboration starting
  - CERN has very recent expertise with very large detectors
  - MDI expert exchange de facto happening
- Good exchange and collaboration with ILC experts is vital and is underway…..

From: F. Richard, Sendai

Worldwide Study of the Physics and Detectors for Future Linear e^+e^- Colliders

ILC-CLIC

The recent CLIC-ILC meeting at CERN is an example of optimizing resources

- We all agree on a common goal: the need to build a lepton collider after LHC

-> Constructive competitiveness ?

There are mutual benefits to be expected by improving the connections between the two projects:

- CERN expertise on large detectors
- MDI experts sharing common work (already happening)
- CLIC benefiting from our well advanced tools to design a detector concept
- ILC concepts tried at ECM >>500 GeV

-> ILC concepts to designate contacts to help CLIC

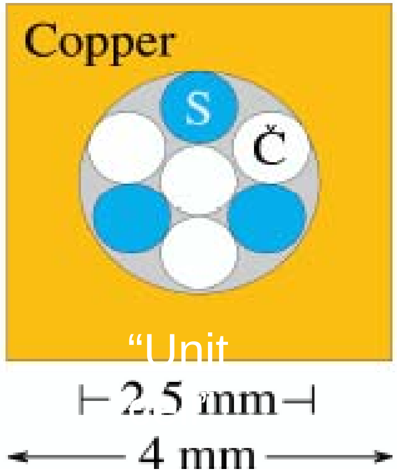
WWS

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

DG to CERN staff
Jan 08

Prospects for Scientific Activities over the Period 2012 - 2016

To be decided in 2010-2011 in light of first physics results from LHC, and designed and R&D results from the previous years. This programme could most probably comprise:

- An LHC luminosity increase requiring a new injector (SPL and PS).

  The total cost of the investment over 6 years (2011-2016: 1000-1200 MCHF + a staff of 200-300 per year. Total budget: ~200-250 MCHF per year.

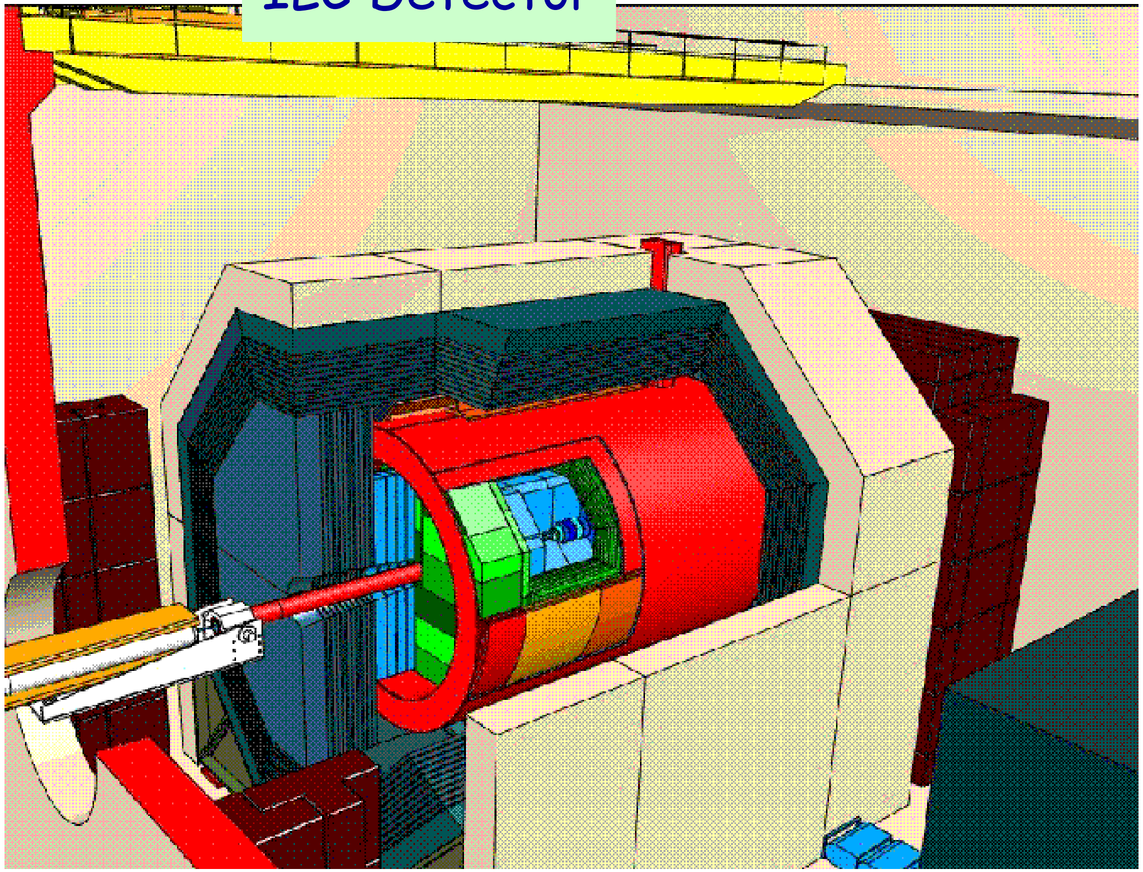
- Preparation of a Technical Design for the CLIC programme, for a possible construction decision in 2016 after the LHC upgrade (depending on the ILC future).
  Total CERN M + P contribution + ~250 MCHF + 1000-1200 FTE over 6 years.

- Enhanced infrastructure consolidation: 30 MCHF + 40 FTEs from 2011.

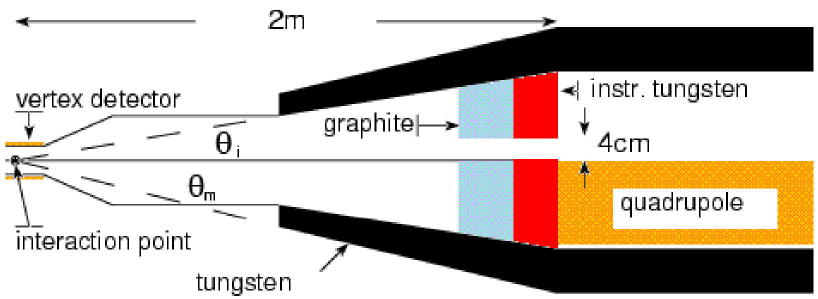
NB: Over the period 2012-2016. Effective participation of CERN in another large programme (ILC or a neutrino factory) will not be possible within the expected resources if positive decisions taken on LHC upgrade and CLIC Technical Design. This situation could totally change *if none of the above programmes is approved* or if a new, more ambitious level of activities and support is envisaged in the European framework.

A Detector for a LC

ILC Detector



Background at the IP enforces use of a mask



CLIC: Mask covers region up to 120 mrad (2003 design)
Energy flow measurement possible down to 40 mrad
⇒ New ideas from ILC
⇒ Needs to new optimization for CLIC

~TESLA/NLC detector qualities: Excellent tracking and jet energy resolution, jet flavour tagging (b,c), lepton identification, hermeticity, small-angle detection...
Particle identification?

Tracking Detectors

- Silicon detectors/TPC (→K. Dehmelt WG6)
- Many developments for Pixel detectors at the ILC (→M. Winter WG6) e.g. new sensor technologies.
  - To be evaluated for CLIC purpose
  - Dedicated R& D for CLIC, → C. Da Via, M. CampBell WG6
- Remember that for CLIC
  - Time between buch crossings: 0.6 nsec
  - Number of bunches/train: 311
- Time stamping/time slicing of the bunch train?

  ⇒ fast sensors and electronics

  Idea (→ P. Jarron WG6): use a coarse pixel planes (300x300 μm) for timing in addition to precision position pixels. Following developments for the NA62 Gigatracker. Aim 100ps or better time resolution. Based on 0.13μm CMOS.
- ALICE TOF proposal (→ C. Williams talk WG6): Large scale TOF with 40ps time resolution

CERN contribution to LC tasks in FP7 proposal DevDet

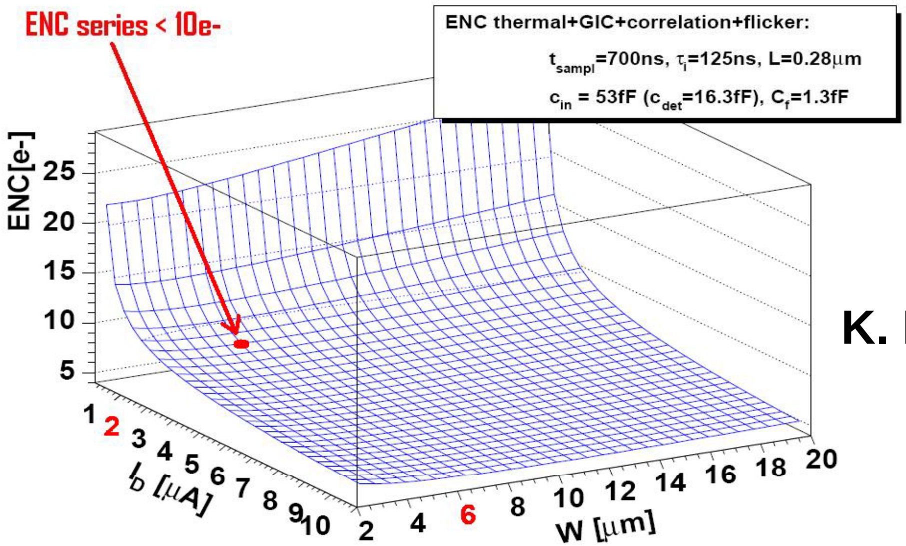
http://project-fp7-detectors.web.cern.ch/project-FP7-detectors/Default.htm

- Test beam for combined linear collider slice tests (providing beam, large magnet, general infrastructures etc.)
- Continued support for TPC electronics
- Participation in Project office for linear collider detectors (engineering tools for project office; design support for test beam set-up)
- Test-case of LC project tools on CLIC forward region example (together with DESY and ILC forward study teams)
- Software tools (geometry and reconstruction tools)
- Microelectronics user support

R&D: Integrating Pixel Detector readout

M. Campbell

- P. Jarron, J. Kaplon, K. Poltorak
- Integrate during pulse train (~200ns) readout during gap (20ms)
- Very low noise (10's e-) possible thanks to soft reset feature
- Pixel dimensions 10's of μm
- Very high spatial resolution – but no timing info

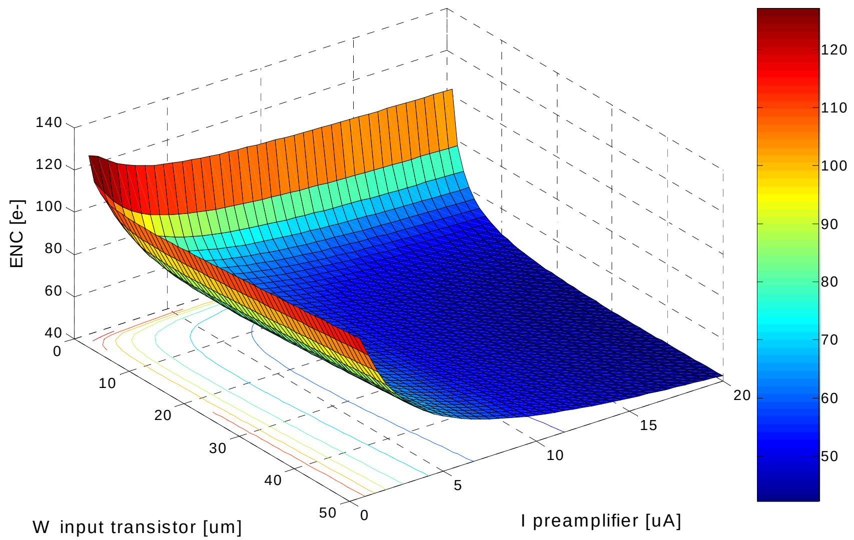


K. Poltorak

R&D: Charge Summing Pixel Detector readout

M. Campbell

- Derived from Medipix3 work
- Pulse processing front-end like LHC
- Clean pattern recognition (noise 100 e^-rms, threshold 1500e^-)
- 10-20ns time tag

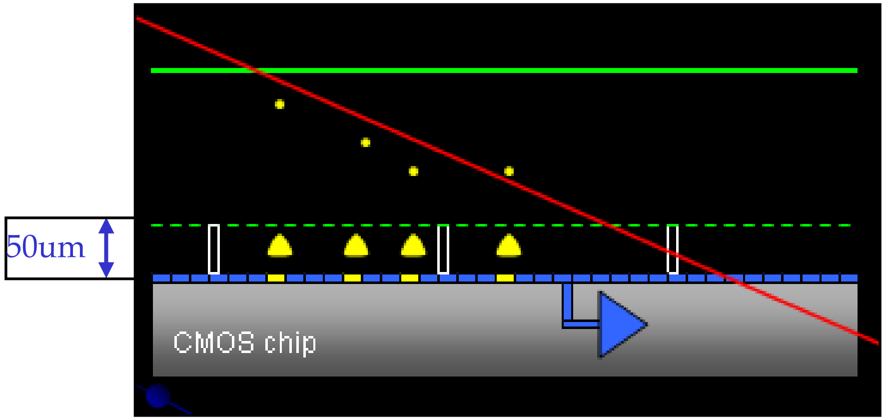


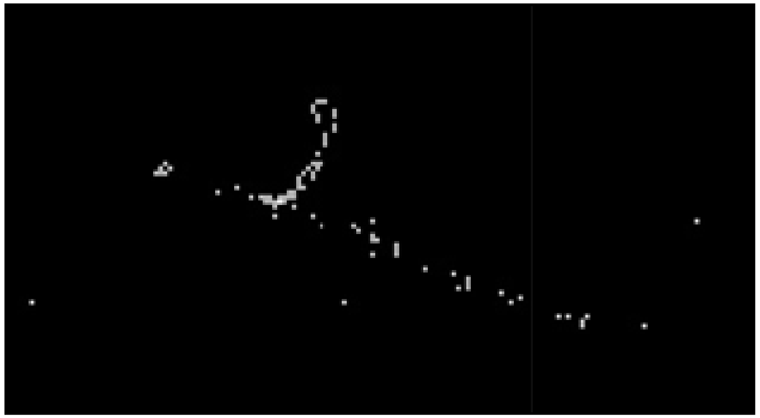
R.Ballabriga

R&D: Timepix-like readout

M. Campbell

A novel approach for the readout of a TPC at the future linear collider is to use a CMOS pixel detector combined with some kind of gas gain grid
Using a *naked* photon counting chip Medipix2 coupled to GEMs or Micromegas demonstrated the feasibility of such approach





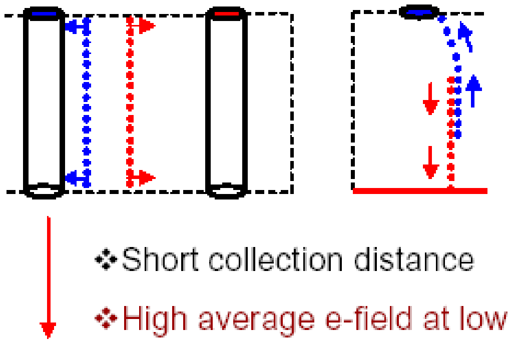
Micromegas

R&D: 3D Detectors

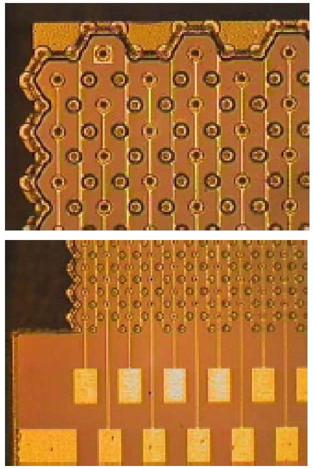
C. Da Via

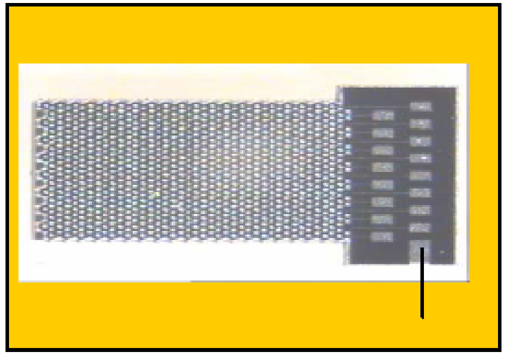
Full-3D sensor speed

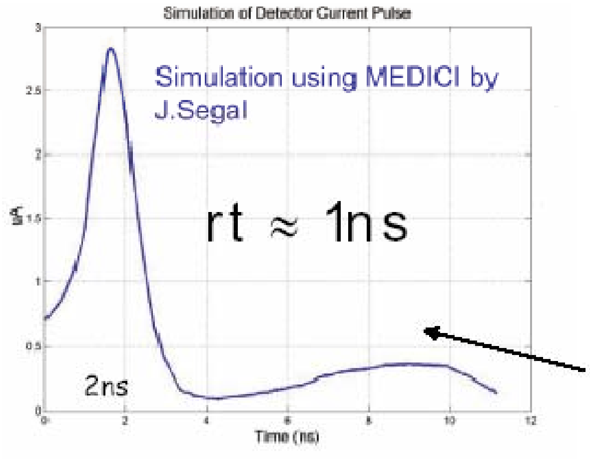
3D Tests with 0.13 μm CMOS Amplifier chip
(A Kok, S. Parker, C. Da Viá, P. Jarron,
M. Depeisse, G. Anelli), fabricated at Stanford
By J. Hasi, C. Kenney



- Short collection distance
- High average e-field at low V_{bias}
- Parallel charge collection

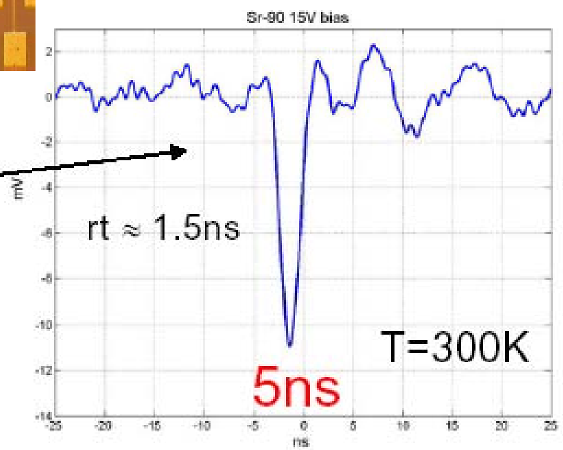






Raw oscilloscope trace

3D signal simulation



3D Inter-electrode distance = 50 μm

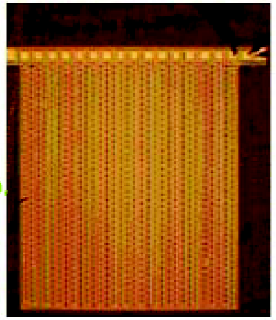
R&D: 3D Detectors

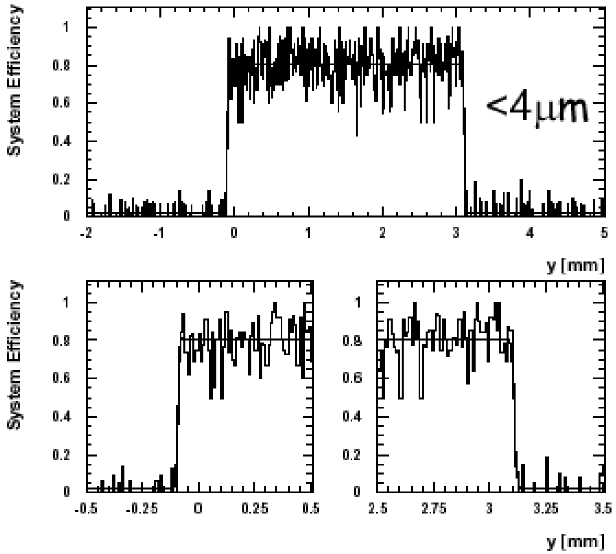
C. Da Via

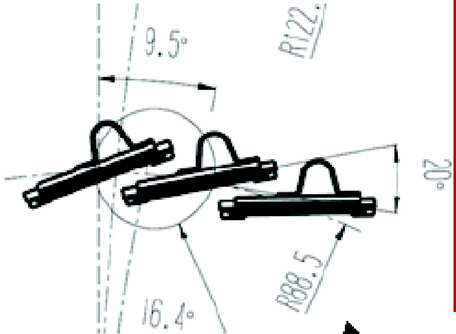
3D silicon- Material budget and active edges

processed at Stanford by J Hasi, Manchester, C. Kenney, MBC

Measurements taken
In 2003 with 120 GeV
Muons
C. Da Vià*, M. Deile*, J. Hasi,
A. Kok, C. Kenney, Sherwood
Parker*, S. Watts, V. Avati ,
VB assetti, V. Boccone,
M. Bozzo, K. Eggert, F. Ferro,
A.Inyakin, P. Jarron, J. Kaplon,
J.J. Lozano-Bahilo, A. Morelli,
H. Niewiadomski, E. Noschis,
F. Oljemark, M. Oriunno,
K. Österberg, G. Ruggiero,
W. Snoeys, S. Tapprogge.

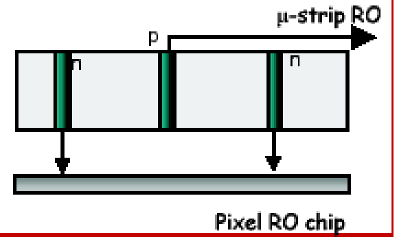






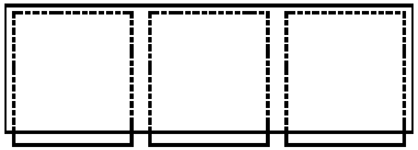
From M. Garcia-Scieveres talk
Presented at the ID ATLAS Upgrade
Workshop. Liverpool 6-8 December 06

Improve the spatial resolution with reduced Material budget: dual RO - C. DaViá et al.
Will be explored in our next R&D run

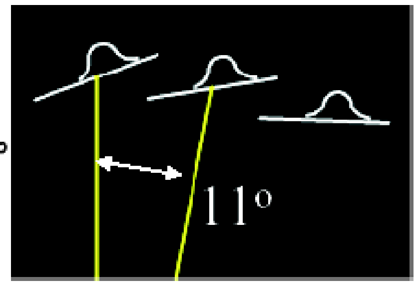


Active edges only would reduce the effective Si thickness by 65%!!!

Effective Si thickness	680 μm	515μm



Module looks the same, but there is no dead margin on the sensor perimeter, allowing less overlap.
Still 2 pixel radial overlap in phi.
This could be a good baseline starting point. M. Garcia-Scievers

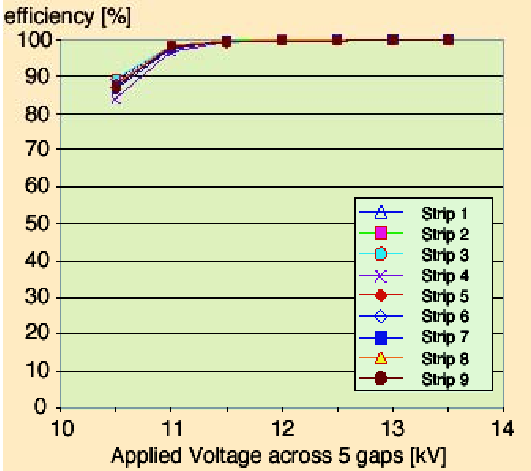


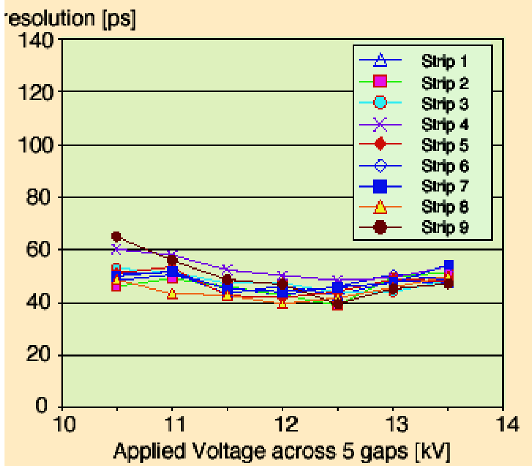
Multi-Gap RPC for TOF

multigap-RPC→ 150 m^2 with 160000 channels

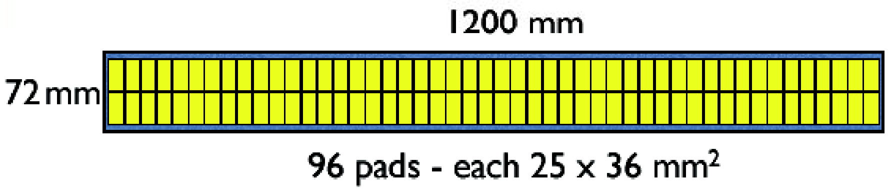
ALICE Time-of-Flight array

→ C. Williams





ALICE TOF strips



(a) long efficiency plateau
(b) time resolution 40-50 ps

n.b. this resolution obtained after correction for slewing. Pulse height measured by time-over-threshold. TDC measures time of both leading and trailing edge. (uncorrected time resolution ~ 100 ps)