Test beams for LHC, SLHC and future linear collider detectors

Ingrid-Maria Gregor, DESY

Thanks to:
Laza Dragoslav (#54), Lucie Linssen (#56), Felix Sefkow (#34),

Henric Wilkens, Beniamino Di Girolamo, Kunihiro Nagano,
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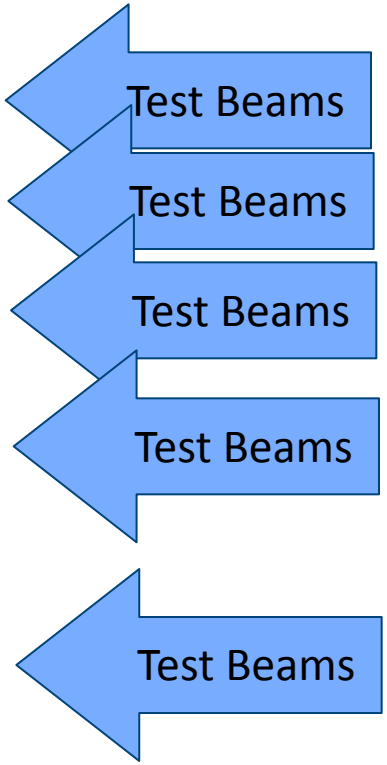
Horst Breuker, Edda Gschwendtner, Christoph Rembser

New Opportunities in the Physics Landscape at CERN
May 11-13 2009

Life is a Test Beam ...

Role of Test Beams in a HEP Experiment

- Conception
- Conceptual design, choice of detectors/technologies
- Technical design, prototypes construction and testing
- Detector construction
- Calibrations
- Commissioning
- Data taking
- Analysis, systematics studies



... the same for all kind of particle detectors

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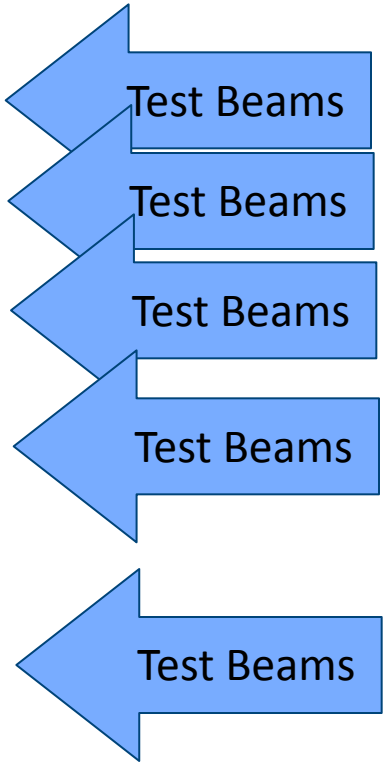
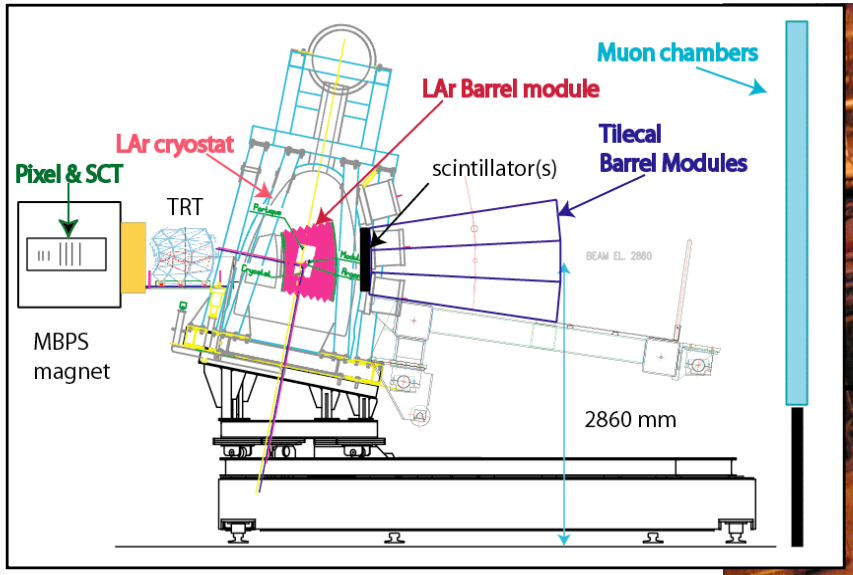
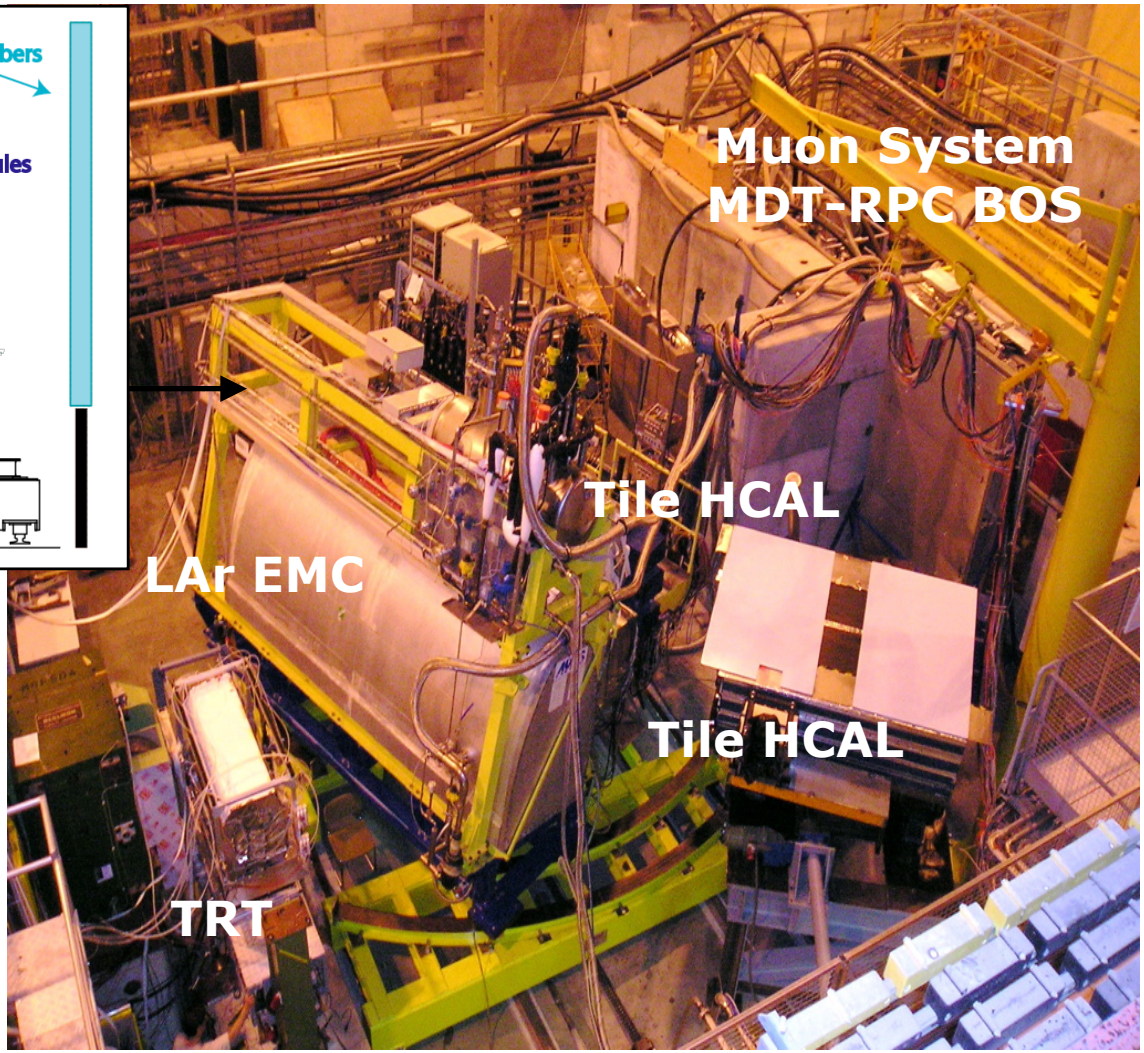


... the same for all kind of particle detectors

2008 RECFA coordinated EU FP7 proposal (DEVDET) showed strong needs for test beams and test beam infrastructures

ATLAS Combined Test Beam 2004





- Drift chambers: beam position
- Scintillators: trigger
- Calorimeters on moving table
- H8 beam: Energy: 1 to 350 GeV

CMS Combined Test Beam (2006)

CMS phi slice test

- HB: 2 wedges
  - 8 ϕ segments
  - Δϕ = 40 deg.
- HE:
  - 4 ϕ segments
  - Δϕ = 20 deg.
  - HO: Ring 0, 1, 2
- ECAL: SM9

+ Real Electronics

- excellent particle ID in H2 beam line

Test beams Current LHC Experiments

- After an impressive test beam program over the last 15 years -> not ready
- Experience of previous HEP experiments: test beam after start of data taking helping to understand data
  - e.g. calorimeters
- And then the future ...

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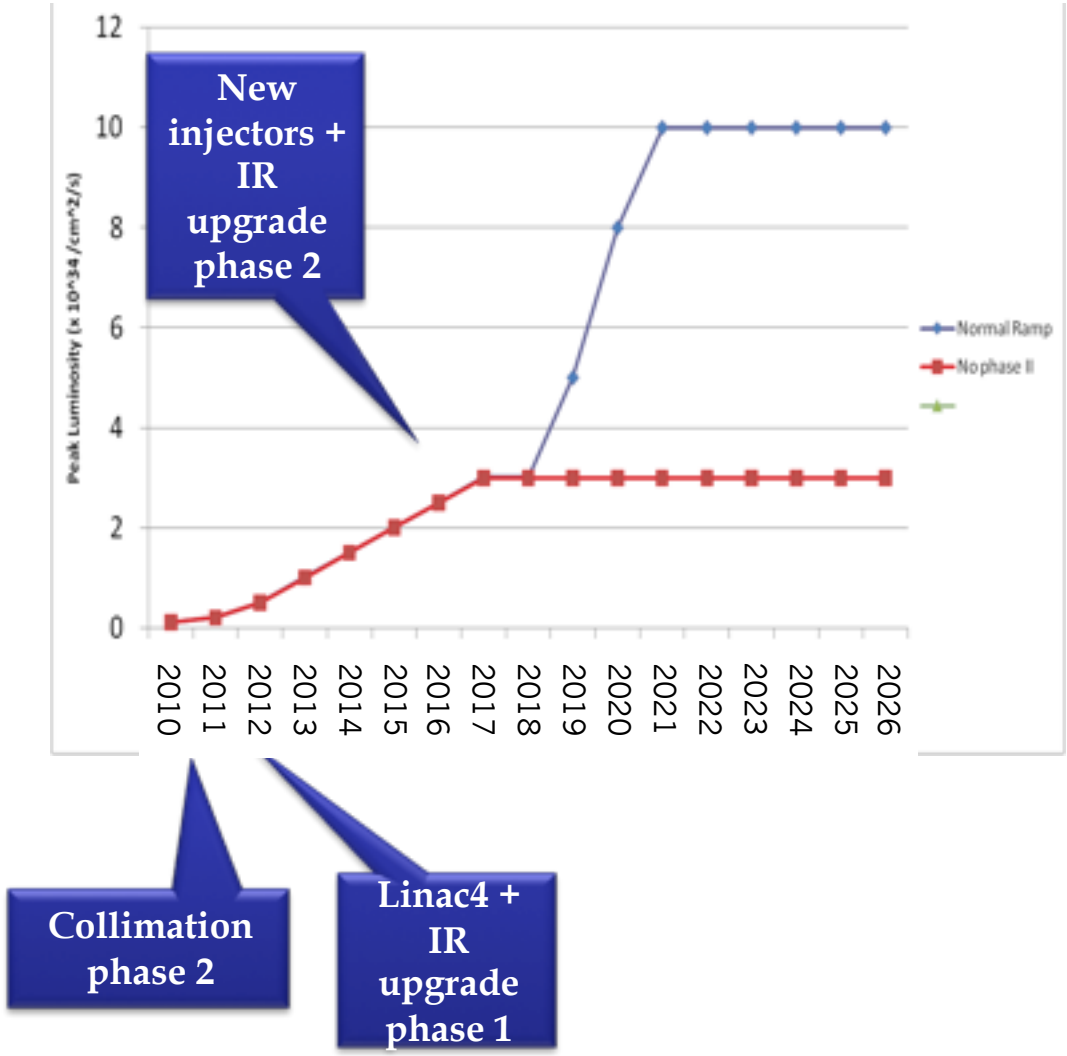
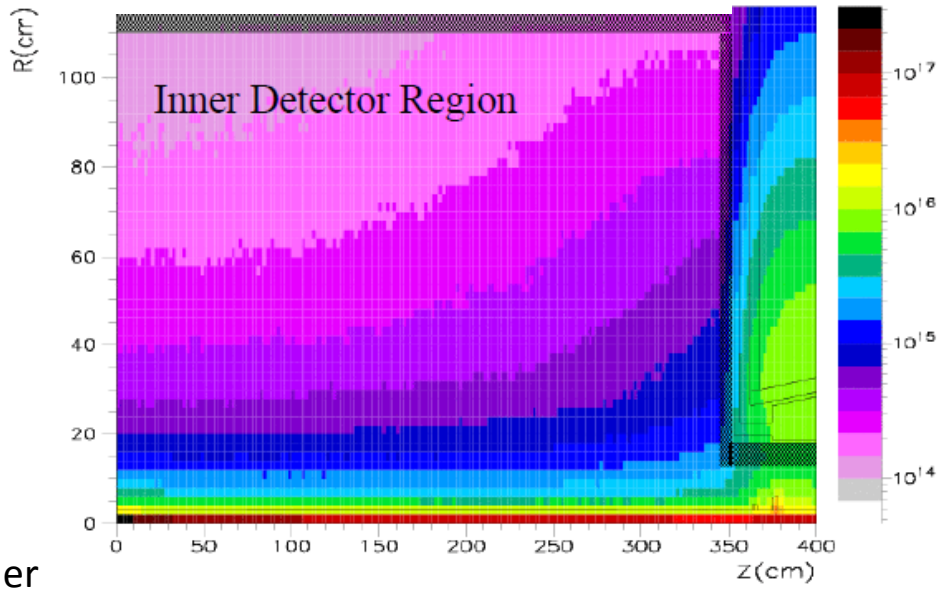


Experimental Challenges (s)LHC

- Detector is designed for $L_{max}= 10^{34}$ /cm^2/s
  - Phase 1 (3 times than design) is already a challenge, in particular given such a short time scale (~5 years)
  - Phase 2 is 10 times than design L_{max} !
- Huge particle rates
  - High occupancy in tracking detectors
  - degradation of performance
  - Saturation effects in forward calorimeter
  - Trigger and DAQ should handle > 10 times higher rates

Example: ATLAS

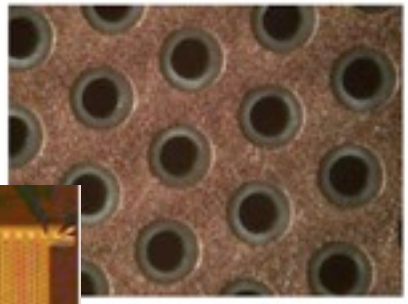


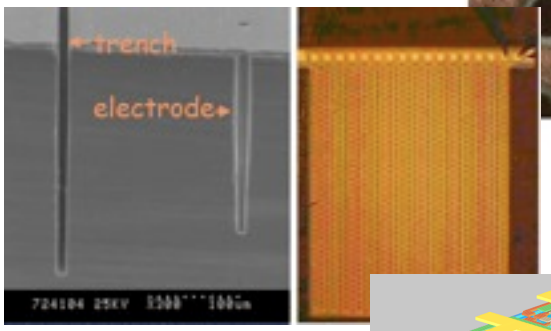
Simulated by I. Dawson with FLUKA

- Radiation damage
  - Inner Detectors will be partially (phase 1) or completely replaced (phase 2)
  - On-detector r/o electronics should be radiation tolerant up to 10^{16} n $_{1\ MeV}$ /cm^2 (one order of magnitude more than current LHC experiments)

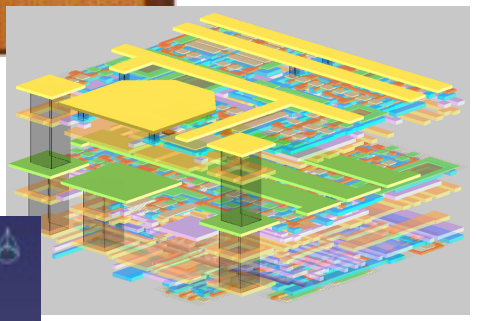
sLHC Detector R&D

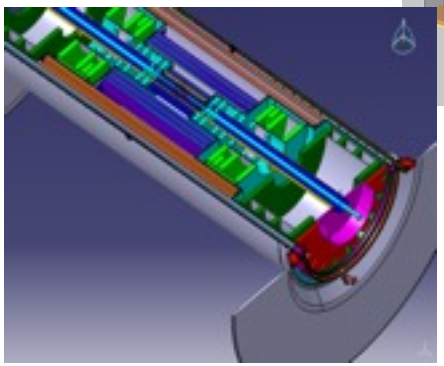
- R&D on new detection techniques is already under way:
  - new pixel technologies (planar, 3D sensors, diamond ...)
  - new silicon strip technologies
  - silicon photomultipliers (SiPM)
  - thick GEMs
  - heavy fibers, new scintillating crystals
  - new diamond devices for luminosity monitoring,
  - use of quartz plates in calorimetry
  - ...
- Continue to require use of test beams first for R&D and eventually for calibration of the detectors that will be built into the experiments


THGEM



3D sensors





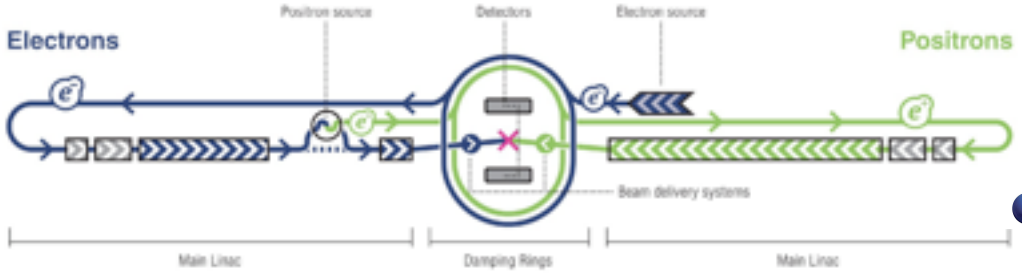
(s)LHC Test Beam Needs

- **Alice:**
  - mostly test beam time needed at PS, only few tests at SPS
  - semi-permanent setup (PS T4)
- **ATLAS:**
  - test beam time at SPS H8 high intensity beam line (e.g. ~250 days in 2009)
  - Magnet, Beam Telescope, gas system
  - permanent setups at SPS H8/H6
- **CMS:**
  - H2 with 3T magnet and very low energy beam
  - permanent setups at SPS H2/H4
- **LHCb:**
  - also test beam time at SPS
  - semi-permanent setup in SPS H6

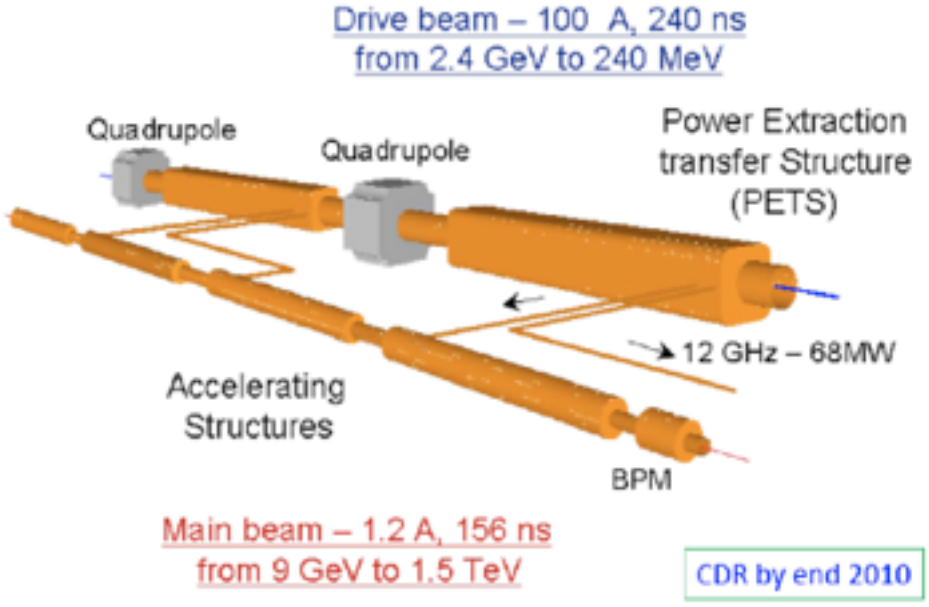
- actual number of weeks per year hard to estimate at this time
- but no indication of a decrease in the test beam needs by the LHC community
- **Test beam facilities needed until well into sLHC running (>2020)**

ILC and CLIC

- ILC: E_{CM} = 500 GeV, upgradeable to 1 TeV, 300ns bunch spacing



- CLIC: E_{CM} = 500 GeV – 3 TeV, 0.2ns bunch spacing, more BG

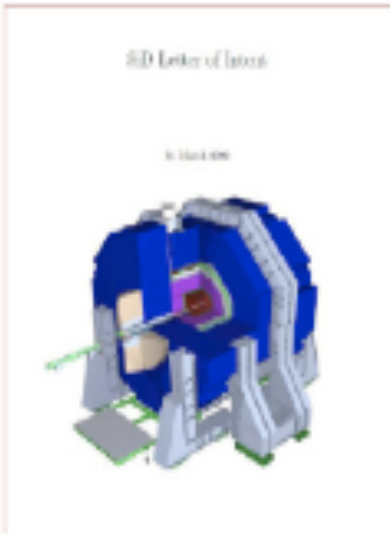


- In general, compared to LHC much more benign radiation environment
- Detector focus on precision
- CLIC detector: must work from 0.5 – 3 TeV
- CLIC and ILC detectors R&D have 90% overlap
- 10% difference in backgrounds, fast timing, deeper HCAL,…

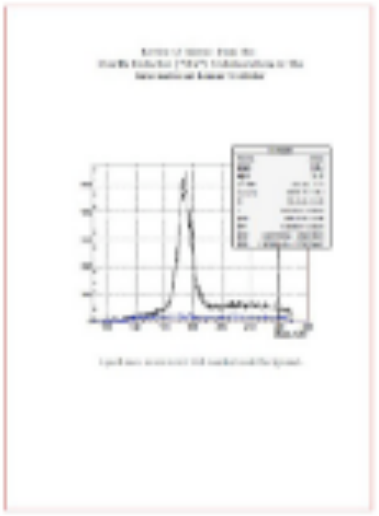
R&D COLLABORATIONS

ILD

SiD



4th



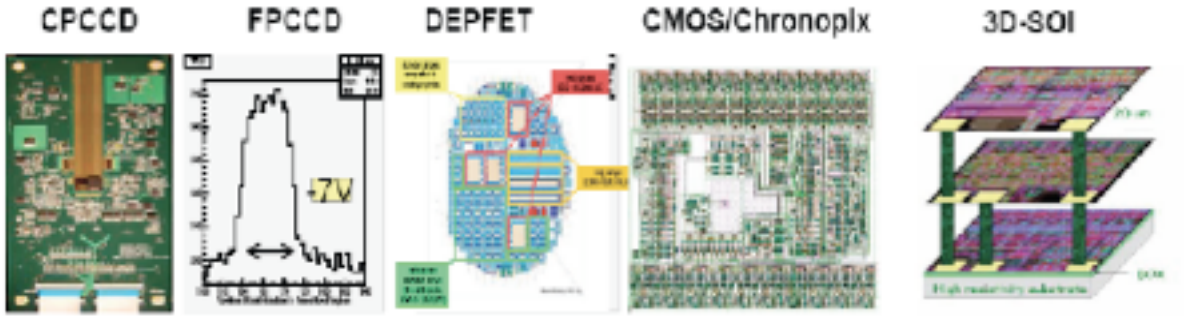
- Detector concept groups submitted LOI end of March
- To be evaluated by international advisory group for technical design phase

- Organized by sub-detector
- Global participation
- task sharing, common infrastructure
- open to different technologies
- **Large test beam campaigns**

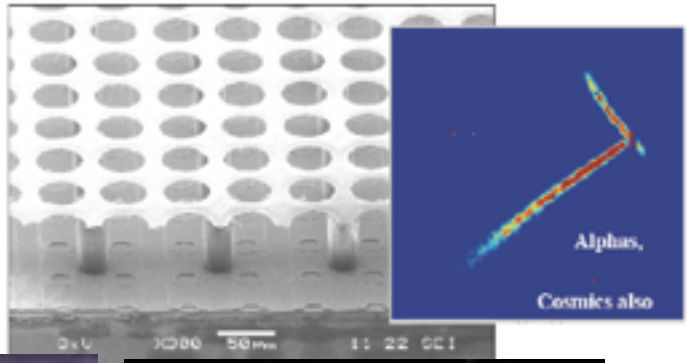
LC Detector technologies

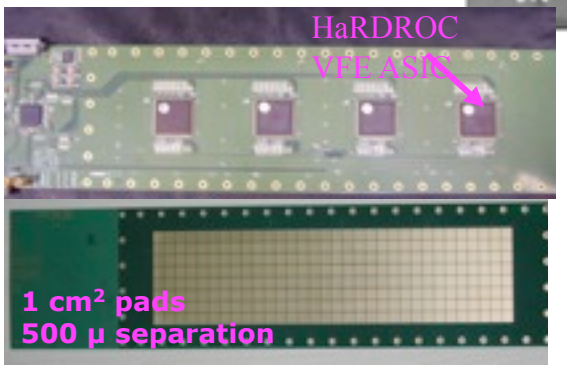
Examples, not complete!

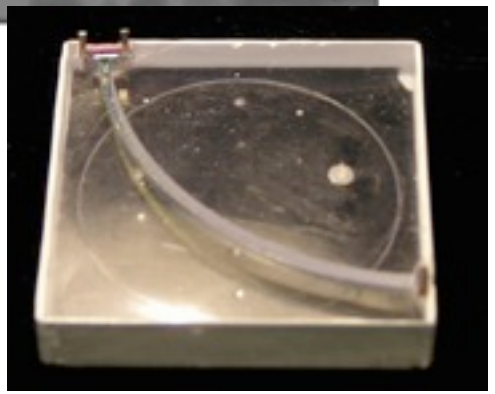
- Vertex detectors
- Main tracking
  - TPC + Si
- EM calorimeters
  - Integrated ultra-low power electronics
- HAD calorimeters
  - Novel photo-sensors
  - Digital approach



Micro-pattern gas detectors
Silicon readout, Medipix

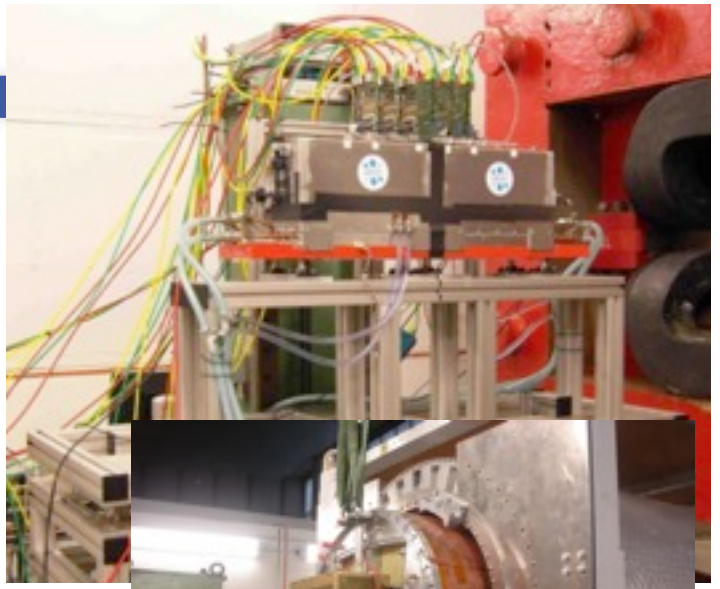


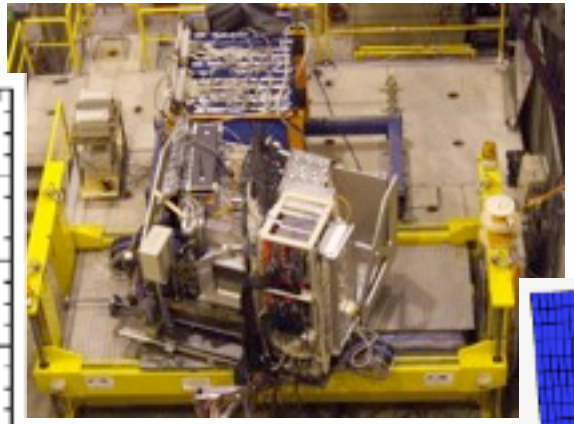


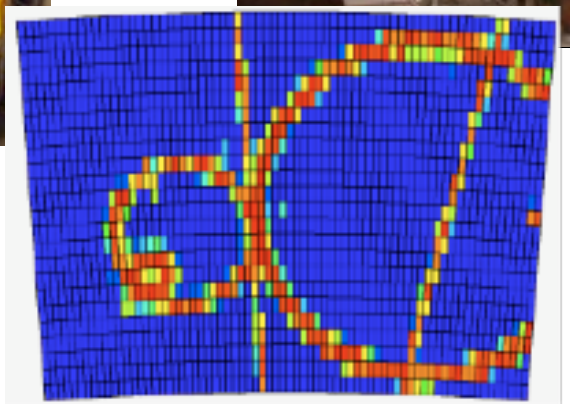


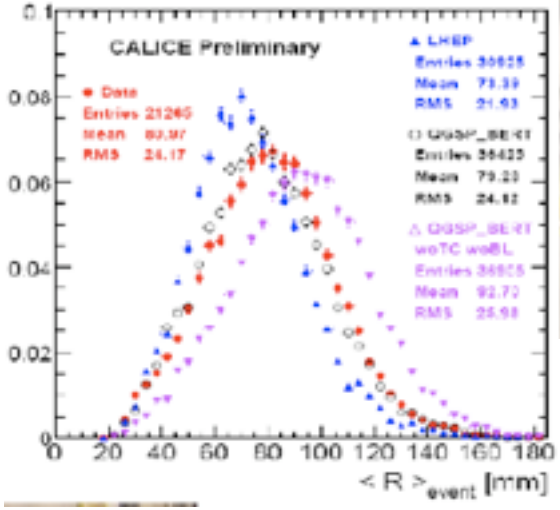
LC test beam, present

- Vertexing/tracking tests using EUDET pixel telescope (DESY and CERN)
- TPC tests in field cage and magnet (sc, 1T) at DESY
- CALICE em+had calo test beam at CERN and Fermilab
- ....





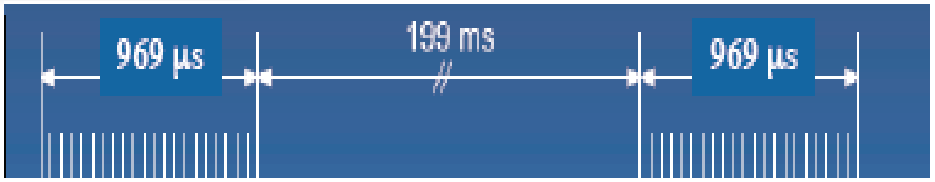




Analysis in close contact with G4 team

Future LC Test Beam Studies

- Standalone tests
  - normal slow extraction
  - with ILC-like time structure
    - Vertex detector readout during or after bunch train (depending on technology)
    - Space charge in TPC, r/o electronics
    - Calorimeter: electronics



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- Should be possible at PS test beam

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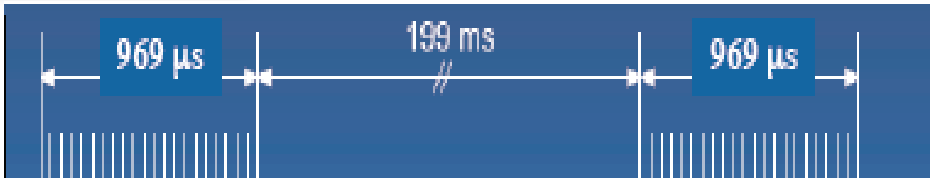

- 1 ms bunch trains, 300ns spacing
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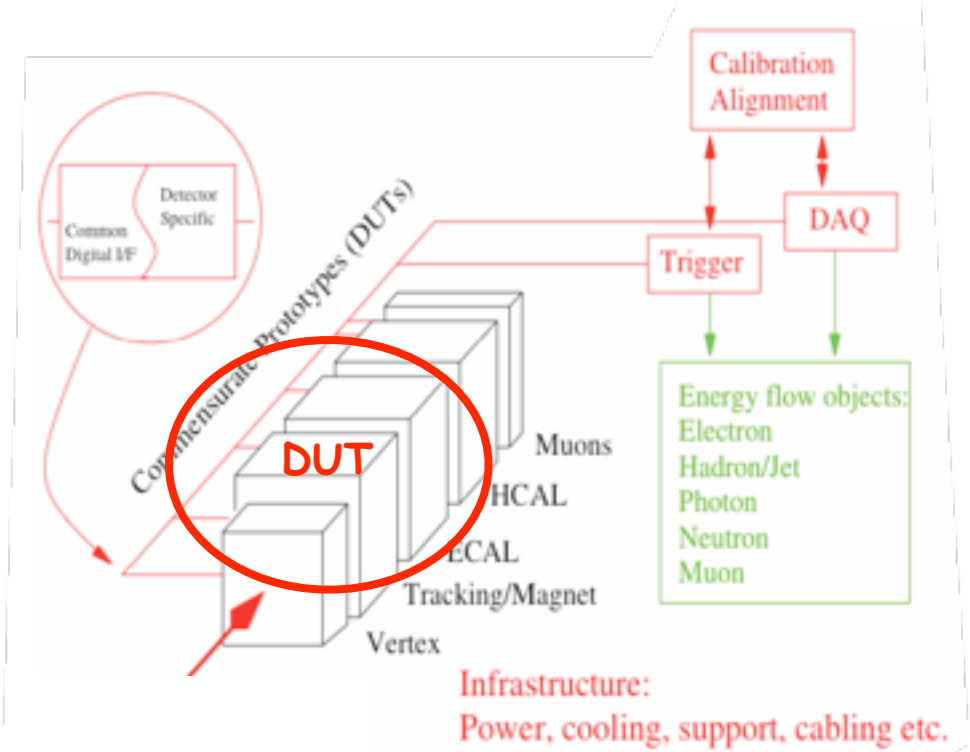
- Combined test beams
  - realistic full-size prototypes become available -> system integration and test
    - Technology and physics

- Needs a versatile facility with interchangeable sub-detectors
  - Open to all concepts - and beyond LC



LC Test Beam Needs

- Electrons, muons and hadrons (pions, tagged protons)
- 1-100 GeV single particles
  - PFLOW goes for single particles, ILC mean pion energy 10 GeV
  - Vertex detector single point precision: multiple scattering up to 100 GeV!
- Future: multi-particle events from targets
- Large statistics: 100 configurations * 1 million events
  - PFLOW: tails, fluctuations, sub-structure, correlations

Magnet

- Vertex detector resolution, mechanical stability
- TPC sine-qua-non; resolution
- Calorimeter: shower broadening
- ~ 3T desirable, 1 T maybe sufficient
- TPC: solenoid
- Calo: could do with dipole

Linear Collider test beams in 2008:

- Vertex/tracking (EUDET, DEPFET,LCFI, ...)
  - 6 groups, 65 days at SPS, 10 days at PS
  - => similar demand in future
- Calorimetry
  - 1 group, 10 days at SPS, 30 days at PS
  - => plans for more calorimeter tests (CALICE)

RD51 test beam facility at SPS/H4

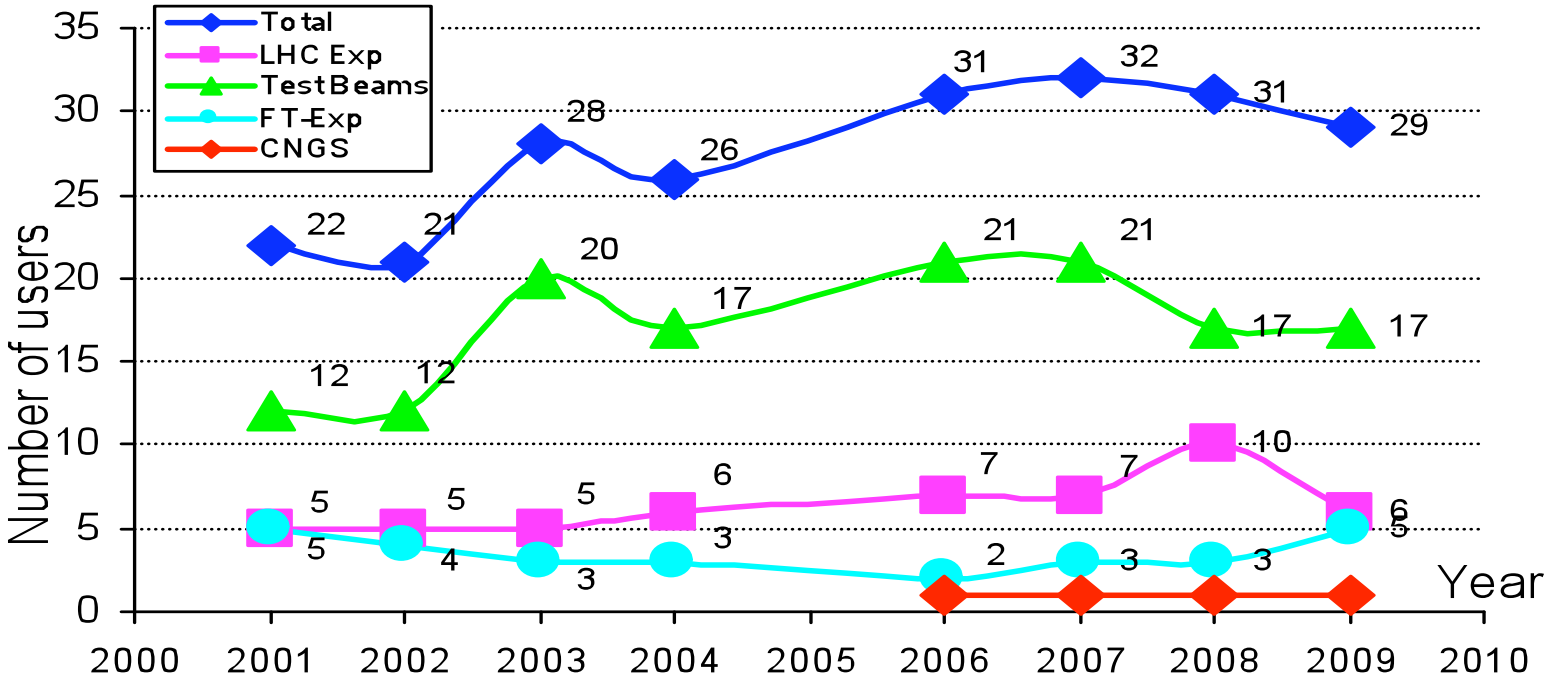
RD51 Motivation and Main Objective:
World-wide coordination of the research in the field to advance technological developments of Micropattern Gas Detectors
- many partners from sLHC and LC

- Installation of the RD51 test beam setup at CERN including **"semi-permanent"** infrastructure is well progressing:
  - services and gas system,
  - common detectors for trigger and tracking,
  - common DAQ and analysis software

→ allow to reduce installation dead times and to avoid duplication of efforts and resources

- SPS/H4 beam line has been chosen for the availability of the large "Goliath" dipole magnet, and for the large amount of space in the experimental zone
- RD51 test-beam periods in 2009: June 21- July 5, October 22-31

SPS Secondary Beams



[Edda Gschwendtner]

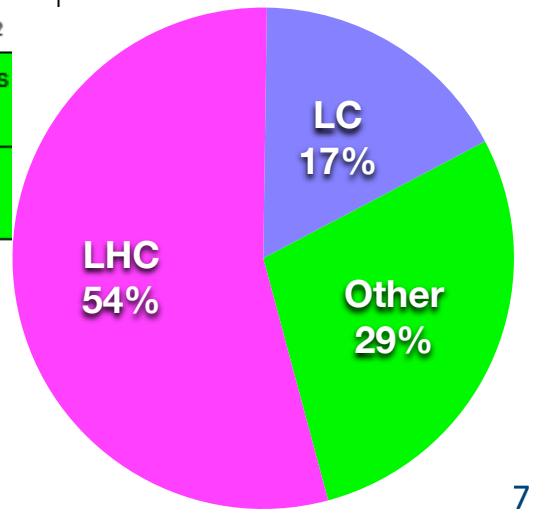
- Number of experiments versus year from 2001 on
- Test beam experiments rose due to LHC tests but did not decrease after LHC experiment installation
- “peak” at 2006/2007 -> more LC test beams
- Increase of number of experiments expected in the future

2009 SPS Fixed Target Program

	P1	P2	P3	P4	P5	P6
	35 30 Apr 4 Jun	35 4 Jun 9 Jul	35 9 Jul 13 Aug	35 13 Aug 17 Sep	35 17 Sep 22 Oct	32 22 Oct 23 Nov
T2 -H2	EA 3 CMS CASTOR 12 CREAM 7 NA61 TR 5 2	CMS HCAL 8 WCALO 11 CMS 10 4	CMS HCAL 10 7 NA61 18	NA61 35	NA61 11 CREAM 7 NA61 17	NA61 24 8
T2 -H4	CERF 6 0 CMS ECAL 10 NA63 7 SITRD 7 SiTRD 11 RD51 15 CMS ECAL 8	CMS ECAL 6 DREAM 16 RPC 7 6	COMPASS CALO 9 CALET 7 INSURAD 14 CMS ECAL 5	CMS ECAL 5 NA63 20 UA9 10	RD51 10 CMS ECAL 9 LHCf 13	
T4 -H6	EA 3 CMS BCM 7 7 3 ATLAS MMEGAS 7 ATLAS BCM 7 RD42 7 7 ATLAS LUCID 14	ATLAS MMEGAS 8 EUDET 14 6 LCFI 7	PiLC 6 SiLC 12 ATLAS FP420 7 8 2	ATLAS BCM 7 RD42 7 ATLAS LUCID 13 ATLAS FP420 8	ATLAS 14 8 ATLAS MMEGAS 7 3	
T4 -H8	EA 3 ATLAS 3DSi 17 3 4 ATLAS 10 ATLAS 7 3 ATLAS MDT-Roma 13 2	ATLAS STRAW 13 3 UA9 12 ATLAS RP 7	ATLAS 13 3 AMS 19	AMS 28 3 RP 4 ATLAS RP 7 3	UA9 22	
T4 -P0	EA 3 8 NA62 16 28 NA62 7 NA62 7 28	35	30 NA62 5	NA62 10 22		
T6 -M2	EA 3 COMPASS 24	COMPASS 35	COMPASS 35	COMPASS 35	COMPASS 35	COMPASS 32
CNGS	EA 3 CNGS 24	CNGS 35	CNGS 35	CNGS 35	CNGS 35	CNGS 32

Experiments and test beams

Test beams H2-H8 only:



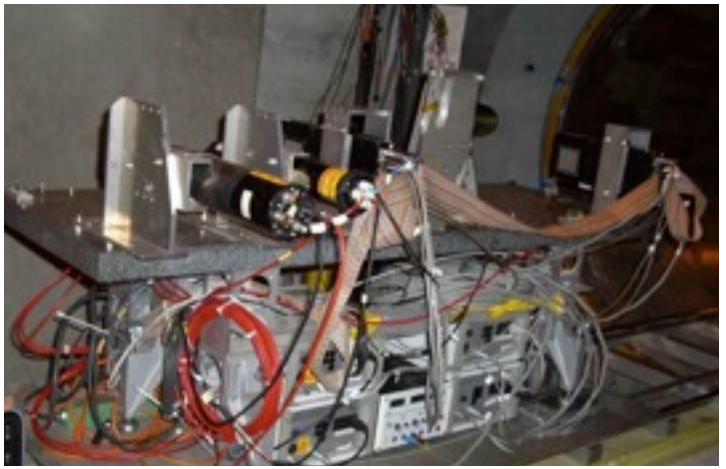
Support and Infrastructure

Support by CERN

- Basic installation support
  - → electronics hut with beam control terminal
  - → computer network connection
  - → crane usage (with operator)
- Assistance for beam tuning and operation
  - → provision of beam position monitors
  - → provision of (threshold) Cerenkov counter(s) (not all beam lines)

What additional infrastructure is needed ?

- Discussions showed: experiments and R&D groups have similar ideas about the needed additional infrastructure at the beam lines
  - magnets
  - trigger devices and logic
  - tracking telescope(s)
  - ....



Example: Bonn ATLAS telescope

Magnets

Goliath

- EHN1, H4 beam line
- large classical dipole
- ~160*240*360 cm
- 0.85 T field

CMS test beam magnet

Morpurgo

- EHN1, H8 beam line
- Superconducting dipole,
- diam. 1.6 m, ~4 m overall length,
- 1.56 T field at 5000A, used by ATLAS, contains a rail system for inserting detectors

Clear interest from community for more magnet facilities.

- EHN1, H2 beam line
- M1 magnet,
- superconducting
- large dipole, 82 cm gap
- 1.4 m diameter, Field 3T

EUDET Beam Telescope

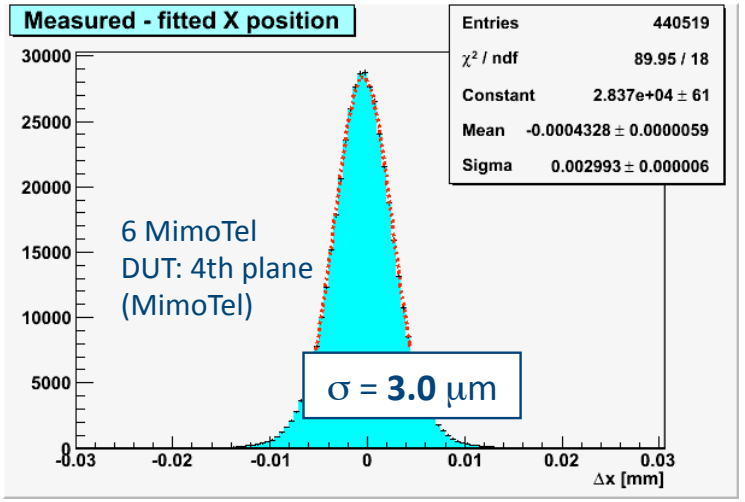
EUDET Telescope in CERN SPS H6B

- Pixel Beam Telescope will be at CERN ~June-November 2009

Clear interest from community for additional telescopes.

Pixel beam telescope:

- 6 layers of Monolithic Active Pixel Sensor (MAPS) detectors
- Pointing resolution: CERN SPS ~3 µm
- DUT positioner
- DAQ system (trigger, hardware + software)
- Analysis Software
- Demonstrator telescope in use since summer 2007



Summary

- LHC experiments
  - after start of data taking fine details start to emerge that require exercising a realistic copy of the system in controlled conditions.
  - better understanding of detectors might be necessary (e.g. calorimeters)
  - need of test beam facilities until ~2012
- sLHC Detector R&D has started
  - many new technologies are already being studied
  - after technology decision similar exhaustive TB program as for LHC needed
  - test beams needed until >2020 (permanent installations)
- LC - CLIC and ILC detectors have 90% synergy -> test beam efforts cover both
  - realistic prototypes under way
  - next step: integrated test beam (tracking + magnet + calorimetry) --> permanent installation
  - test beams needed until >2020
- Additional infrastructure as magnets and beam telescopes needed
- Education - hands on detectors for students often only possible during test beam