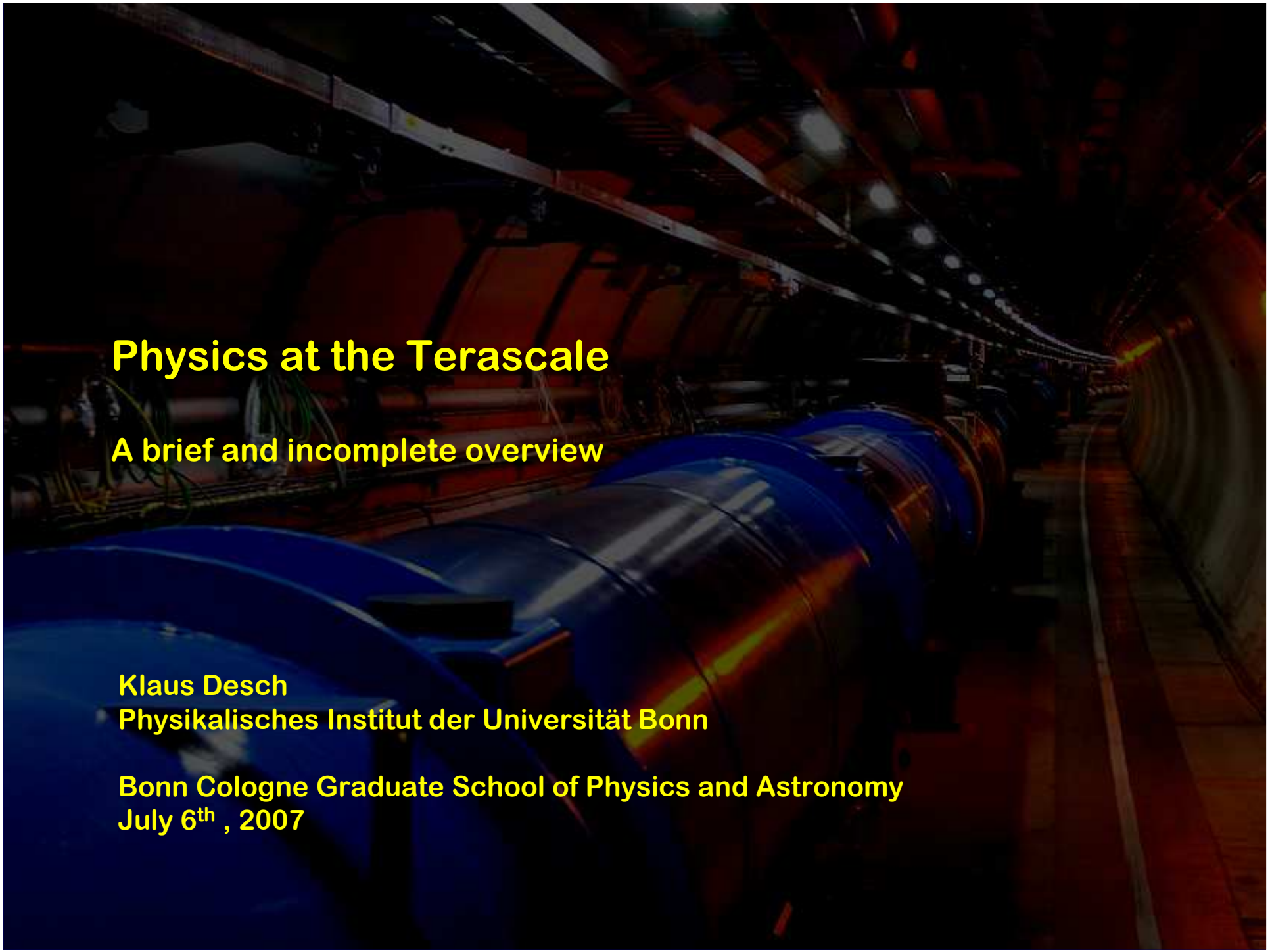


Physics at the Terascale

A brief and incomplete overview

Klaus Desch
Physikalisches Institut der Universität Bonn

Bonn Cologne Graduate School of Physics and Astronomy
July 6th , 2007

Outline

„The Standard model is (almost) complete and so is particle physics – there´s (almost) nothing left to do…“ *

Part 1: The Standard Model and why it is far from complete

„Detectors at colliders look alike each other so much – why should I work on novel detectors at all?“ *

Part 2: Better Detectors

„The LHC will be the last machine – any new collider will be too monstrous“ *

Part 3: Future Colliders

* commonly heard prejudices and convictions…

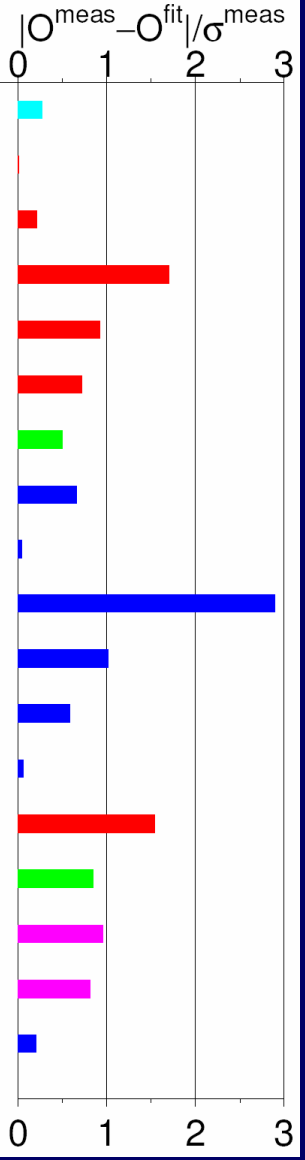
Part 1: The Standard-Model and why it is incomplete

- 3 families of matter particles (fermions)
  - quarks
  - leptons
- 3 Forces (gauge bosons)
  - U(1): electromagnetism
  - SU(2): weak force
  - SU(3): strong force
- Relativistic Quantum Field Theory – Action from Gauge Principle
- 1 Higgs boson (scalar)

symmetry breaking ↓ masses

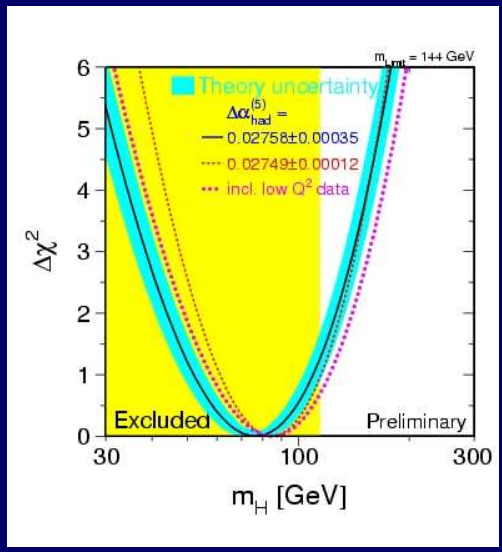
Experimental consistency…

	Measurement	Fit
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02768
m_Z [GeV]	91.1875 ± 0.0021	91.1875
Γ_Z [GeV]	2.4952 ± 0.0023	2.4957
σ^0_{had} [nb]	41.540 ± 0.037	41.477
R_l	20.767 ± 0.025	20.744
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01645
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1481
R_b	0.21629 ± 0.00066	0.21586
R_c	0.1721 ± 0.0030	0.1722
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1038
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0742
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1481
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.398 ± 0.025	80.374
Γ_W [GeV]	2.140 ± 0.060	2.091
m_t [GeV]	170.9 ± 1.8	171.3



This is only the essence of several hundreds of independent and precise (often % or better) measurement (LEP,Tevatron,SLC,HERA, …)

They test the model at the level of quantum corrections



But fundamental puzzles…

- Electro-weak symmetry breaking: Higgs or no Higgs?

- If Higgs, why is it so light??

- Three different forces without a common origin???

- What is the dark matter made of, if it exists ????

- Three flavours without a common origin ?????

- A stable proton ????? and Q(p) = Q(e^+) ??????

- Why is there only matter in our world
  – where has the antimatter gone ???????

guaranteed good chance maybe, maybe not

to find answers at the Terascale: Energy 1 TeV = 1 Teraelectronvolt

The standard beyond the standard: Supersymmetry

- Electro… …metry breaking: Higgs or no Higgs?

- If Higgs, w… …SY …so light??

- Three diff… …ces without a common origin???

- What is th… …matte… ma…e of, if it exists ????

- Th… …hidden in SUSY brea…g sector …mon origin ?????

- A st… …on ??? ?? and Q(p) = Q(e^+) ??????

- Why is there … …ur world
  – wh… …antimatter gone ?????

SUSY-Higgs

SUSY

SUSY-GUT

SUSY-LSP

SUSY-GUT

SUSY with CP violation

could be excluded by LHC in 2010…

guaranteed good chance maybe, maybe not

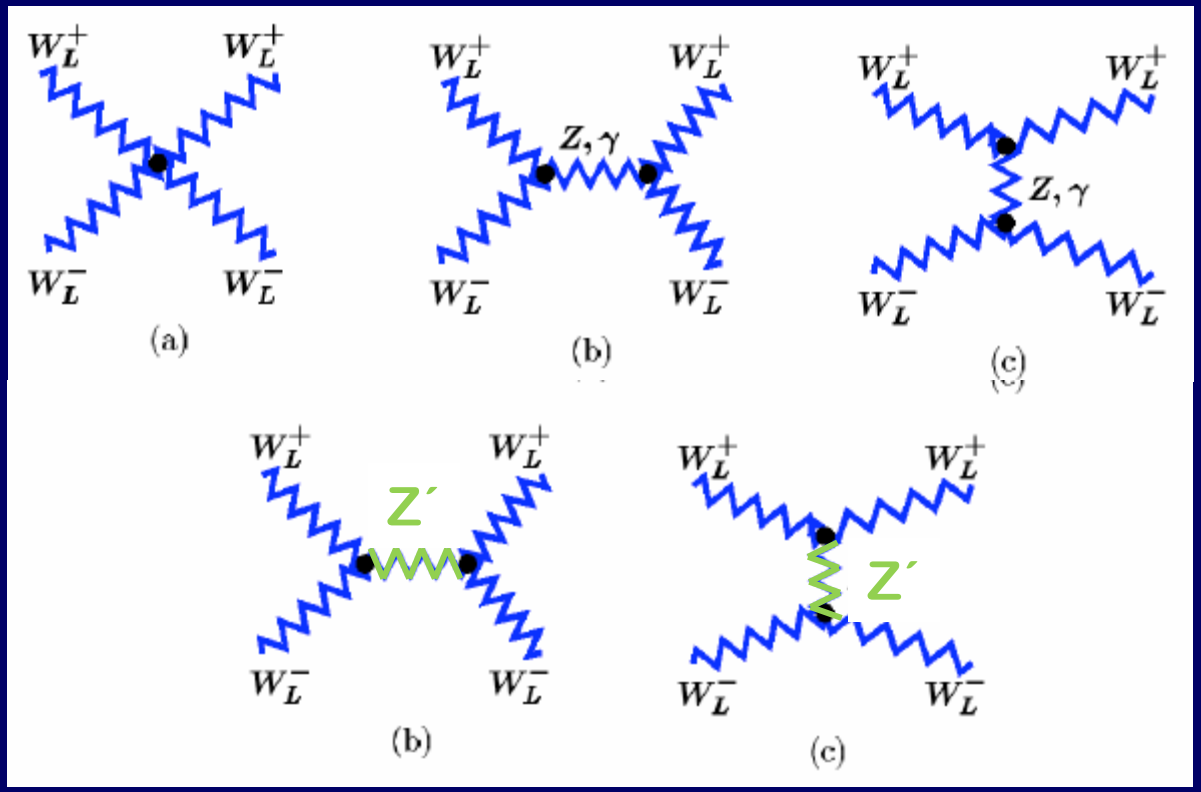
to find answers at the Terascale: Energy 1 TeV = 1 Teraelectronvolt

A non-standard beyond standard (one out of many…)

- EWSB: no Higgs

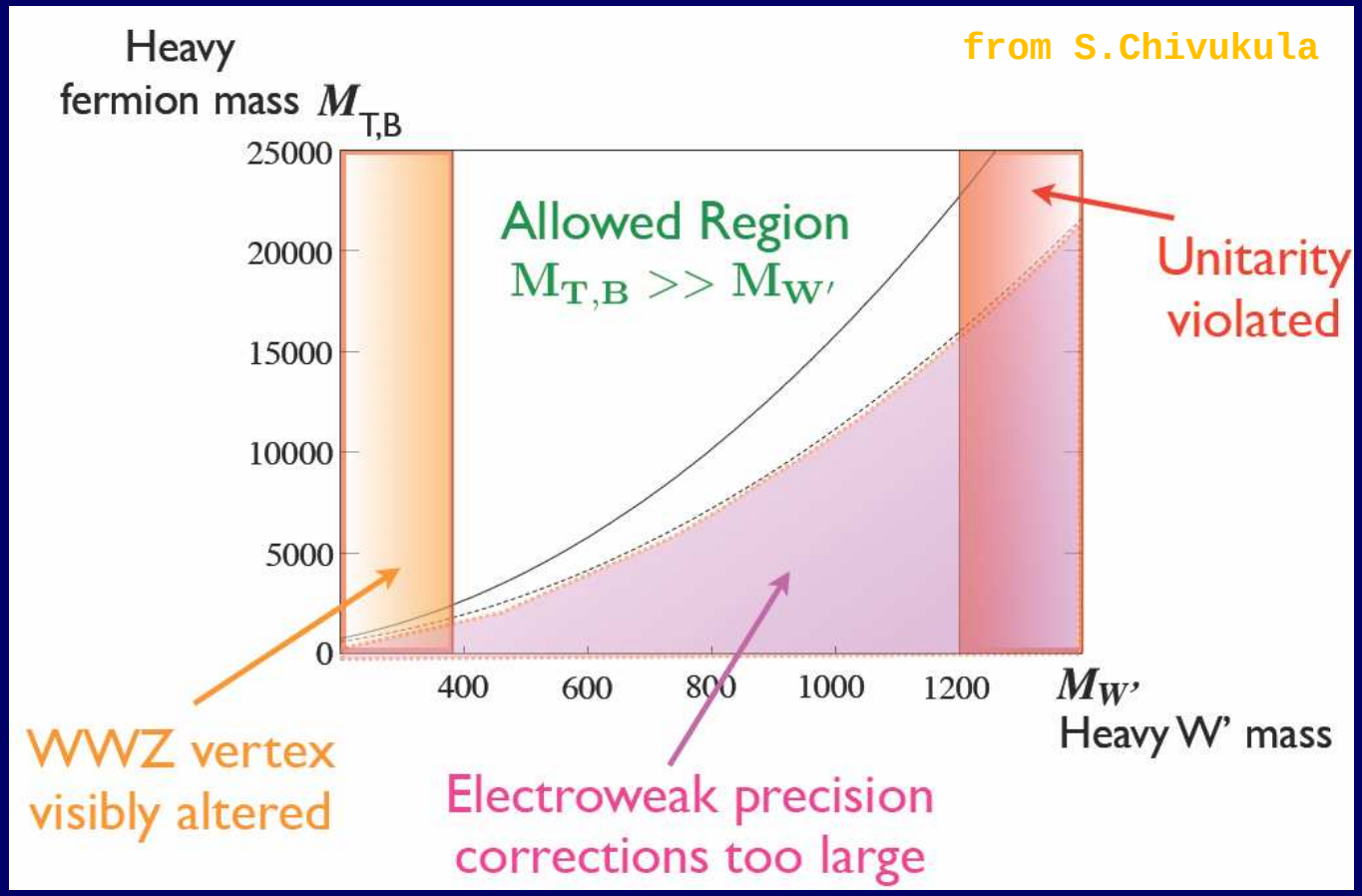
eg. Chivukula et al, hep-ph/0607124
A three site Higgsless model

(Very) Schematically:



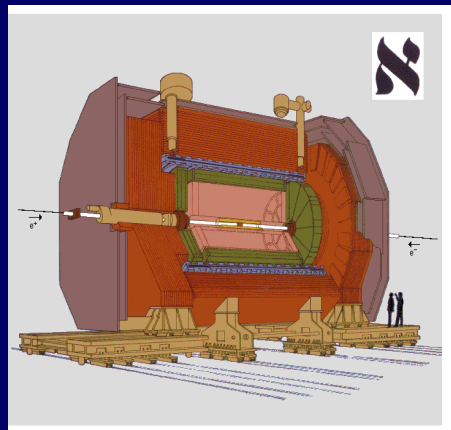
→ ∞
→finite up to
→finite
~ O(10 TeV)
if H´ <~ 1 TeV
if Z´ <~ 1 TeV

A non-standard beyond standard (one out of many…)

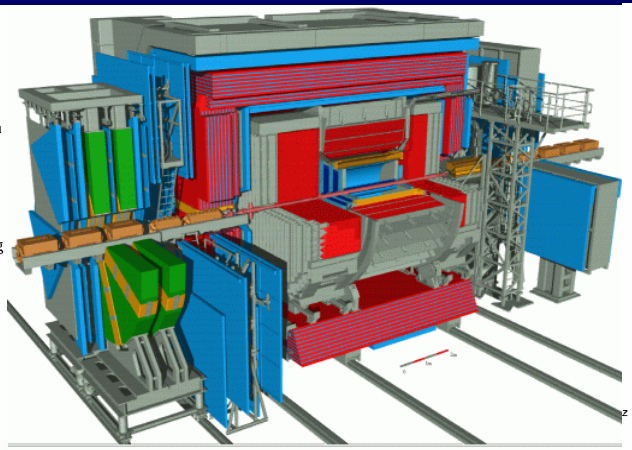


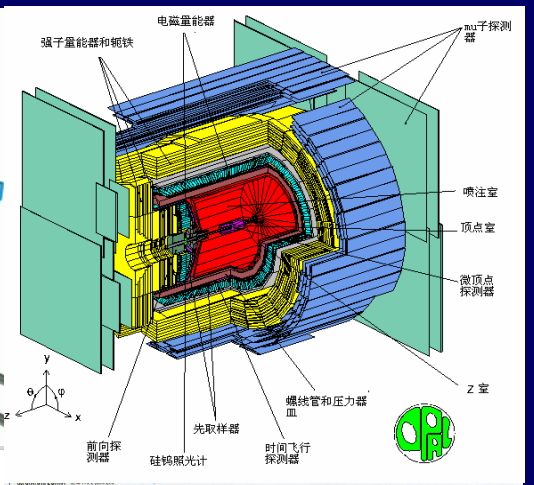
- fermiophobic Z´, W´ can be seen at LHC, but may need longer
- ILC can do precise tests of couplings (triple gauge couplings)
- ultra-heavy fermions are beyond LHC/ILC reach

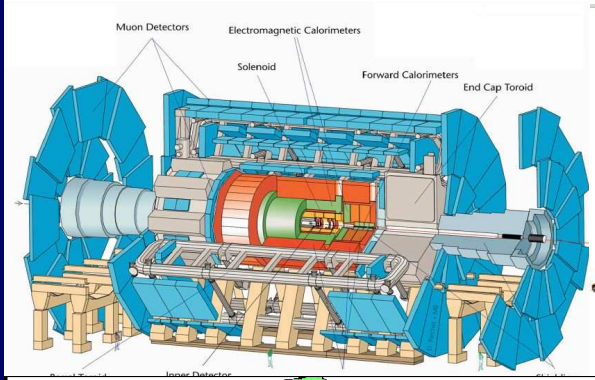
Part 2: Advancing detectors

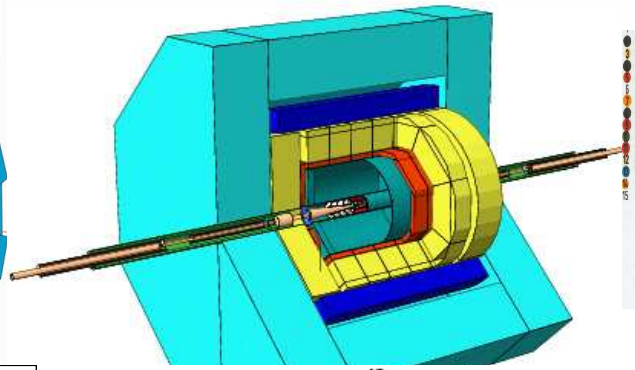


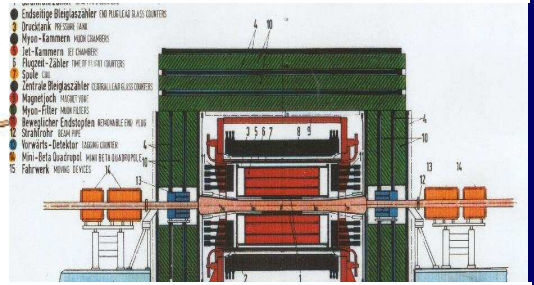
Vertex Detector
Inner Tracking Chamber
Time Projection Chamber
Electromagnetic Calorimeter
Superconducting Magnet Coil
Hadron Calorimeter
Muon Chambers
Luminosity Monitors

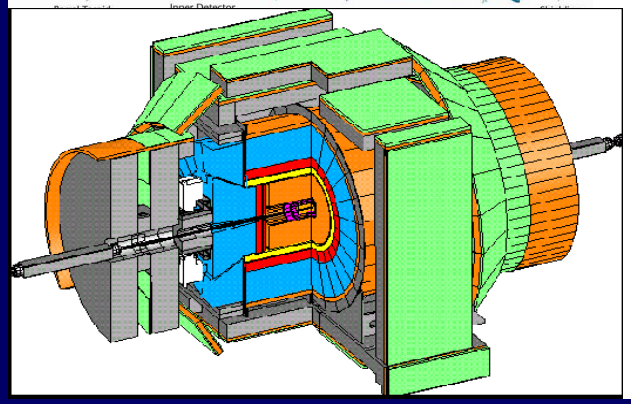


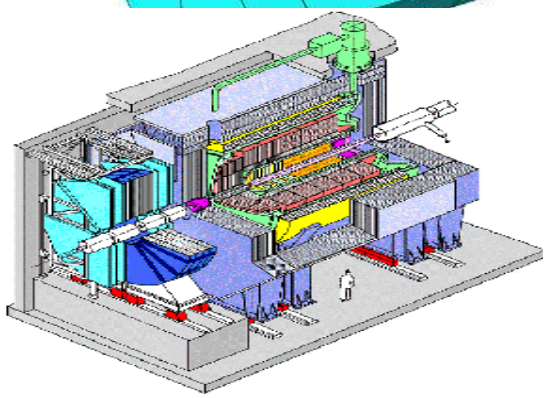


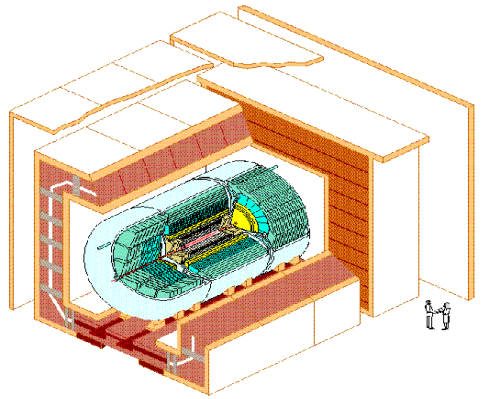












DØ Detector

Part 2: Advancing detectors

Progress in high-energy physics is not only driven by higher energies and higher collision rates but also by progress in detector physics

- collider environment (backgrounds, radiation, collission rates)
- measurement precision (resolution, efficiencies)

Next steps:

+ lots of impact on other fields (medical imaging, photon science, …)

Improving the LHC detectors:

Radiation hardness
Better and faster triggers
Specialized detectors – depending on physics…

New detectors for Lepton Colliders and precision experiments (sth rather different…)

Different Detector Challenges

Charged particle tracking goals (momentum resolution):

LHC (ATLAS): $\Delta p/p = 0.4\ p$ [TeV]
ILC (LDC): $\Delta p/p = 0.05\ p$ [TeV] factor 10

Calorimetry (jet energy resolution):

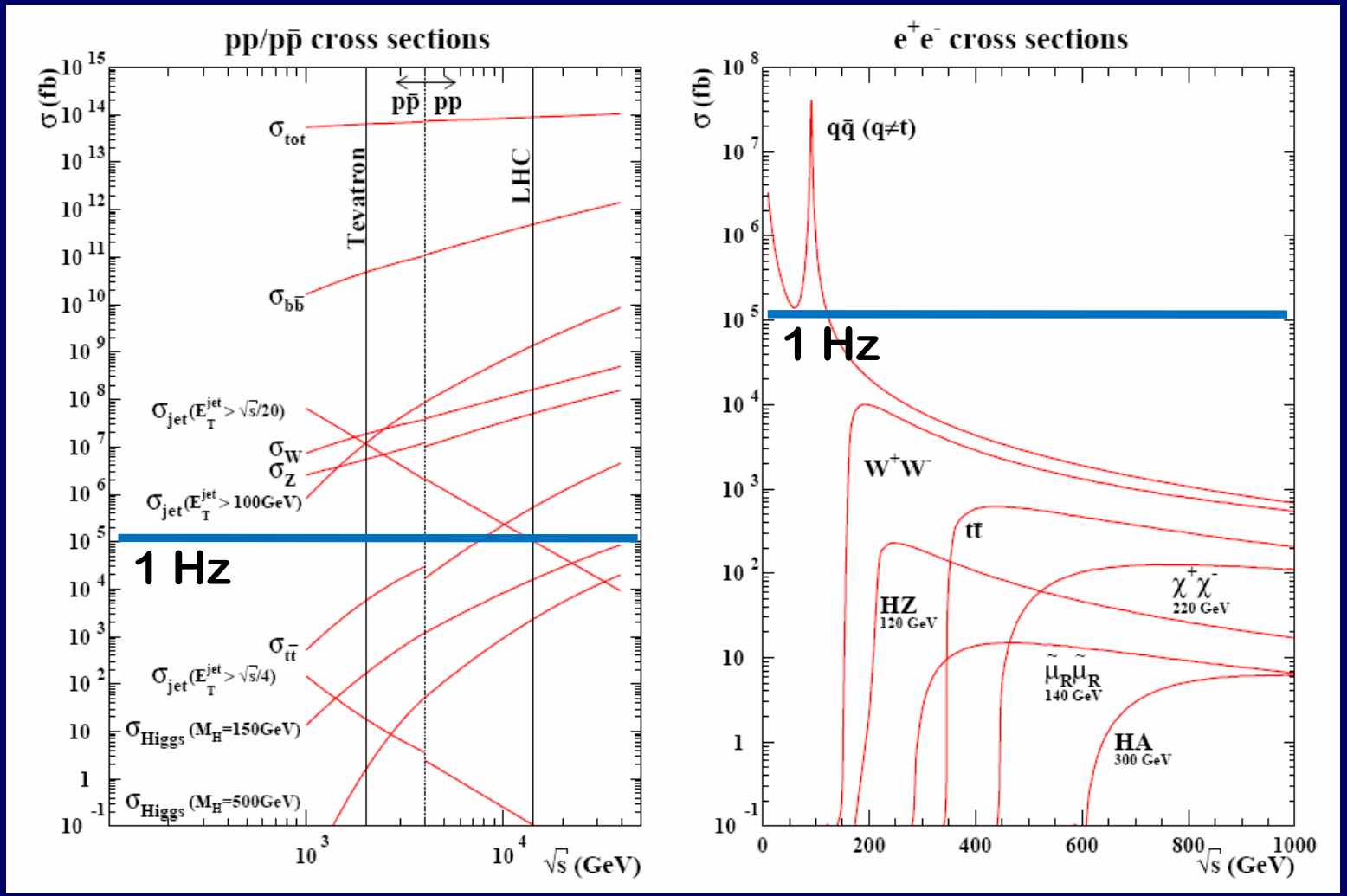
LHC (ATLAS) $\Delta E/E = 50\%/\sqrt{E[\text{GeV}]} + 3\%$
ILC (LDC) $\Delta E/E = 30\%/\sqrt{E[\text{GeV}]} + 1\%$ factor 2-3

Radiation levels:

LHC (1st pixel layer) o(10^{14} /cm^2 a)
ILC (1st pixel layer) o(10^{10} /cm^2 a)

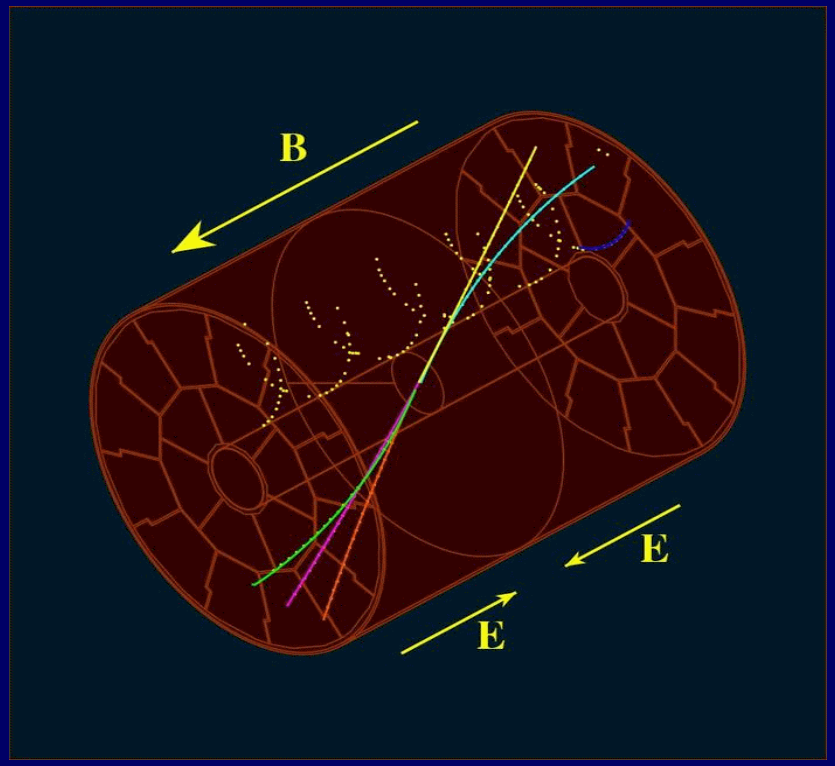
Different Detector Challenges

Event rates



New detectors for ILC: an example

TPC – elegant principle for charged particle tracking with ~ no material



invented by D.Nygren (Berkeley)

Challenges:

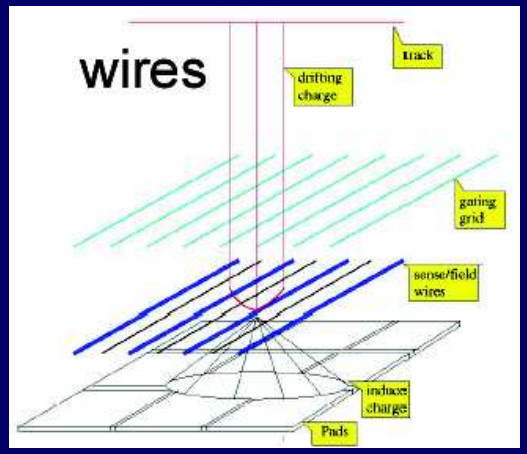
Minimize material in endplate

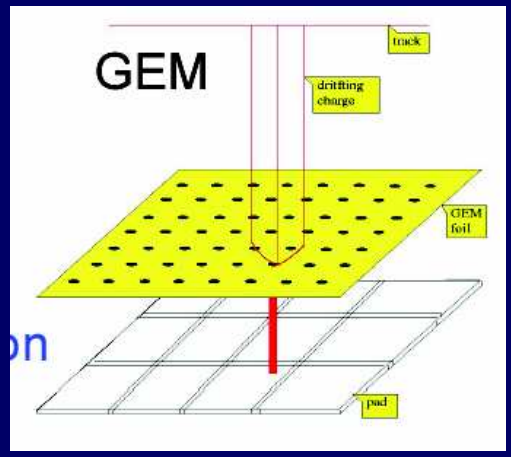
Maximize spatial resolution

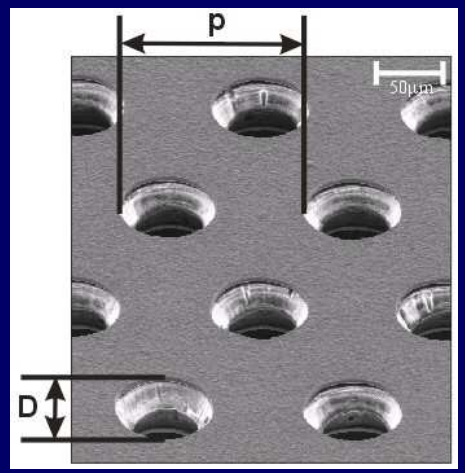
Maximize robustness
+ redundancy

New detectors for ILC: an example

Use Micro Pattern Gas Detectors (GEMs, MicroMegas) for gas amplification and micro-pads (pixelized electronics)

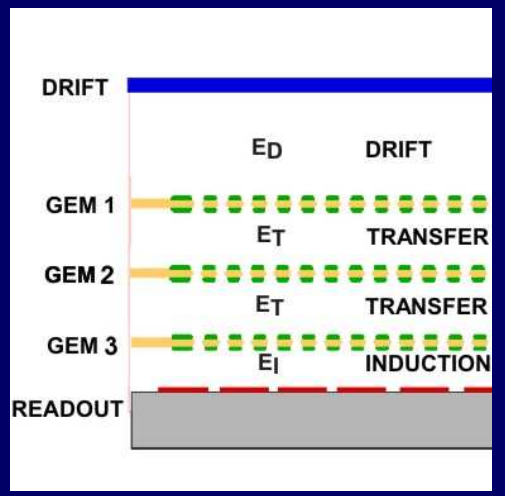






GEM foil

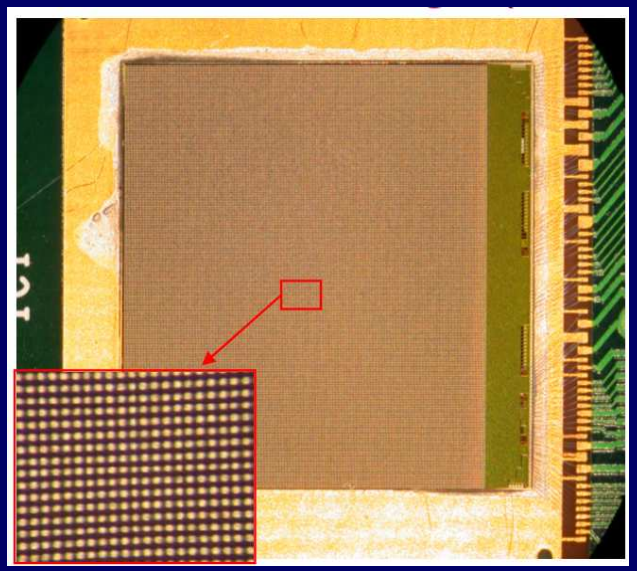
invented by F. Sauli (CERN)



setup

New detectors for ILC: an example

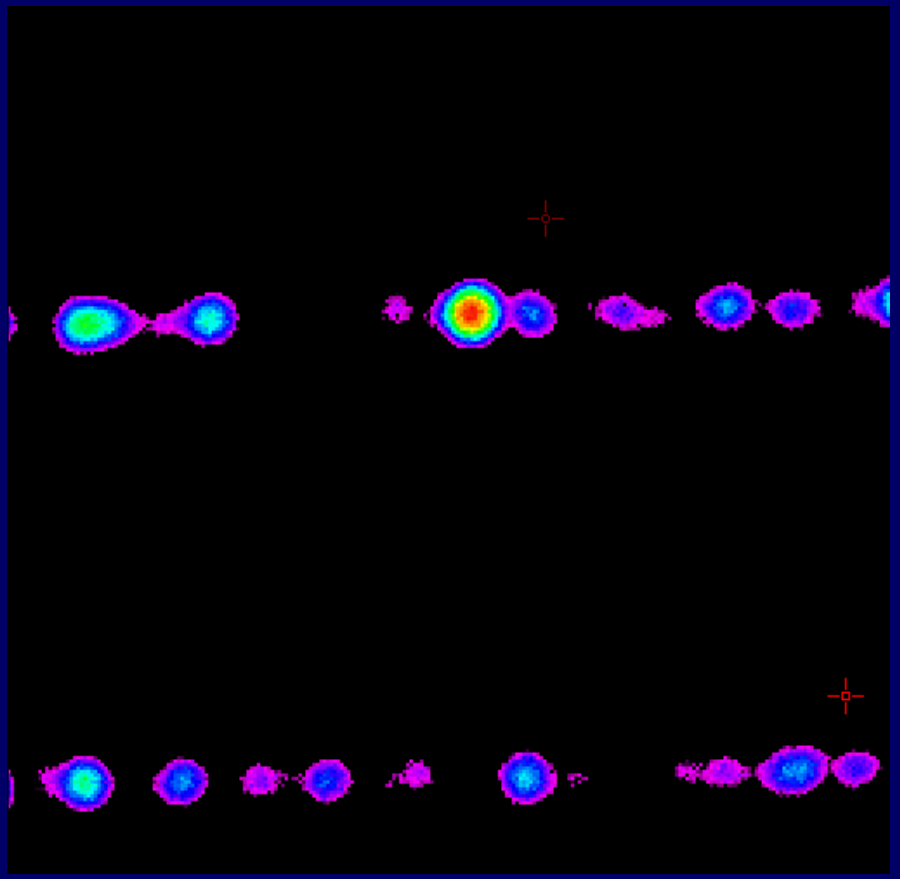
Timepix-Chip



55 μm pixel pitch

Achieved point resolution
of <20 μm (for 0 drift length)

first tracks at DESY test beam
looks like “digital bubble chamber”



Part 3: Future Colliders

Prof. K.H. Althoff (Bonn) (in my 2nd semester exp. physics lecture)
„Whenever a significant increase in energy was needed,
a new idea had to come along to make it possible“

Wait for the LHC??
Sure – but accelerator projects have very long lead times
(e.g. LHC planning started in 1984)

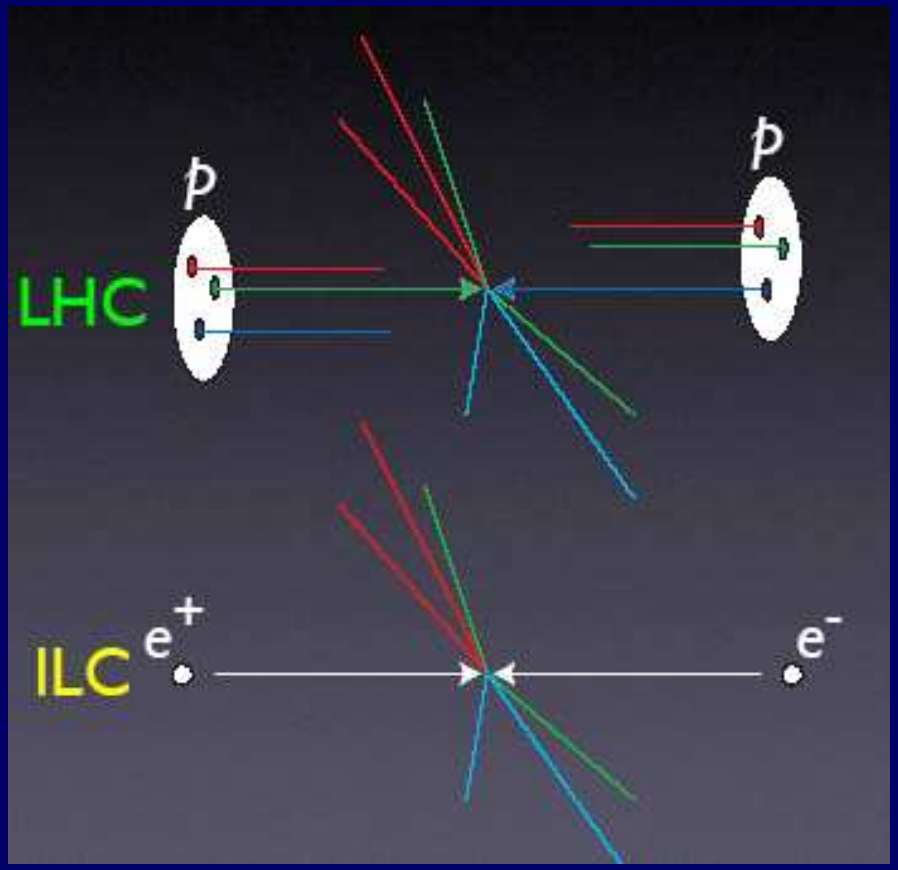
The future:

- The immediate future: ILC

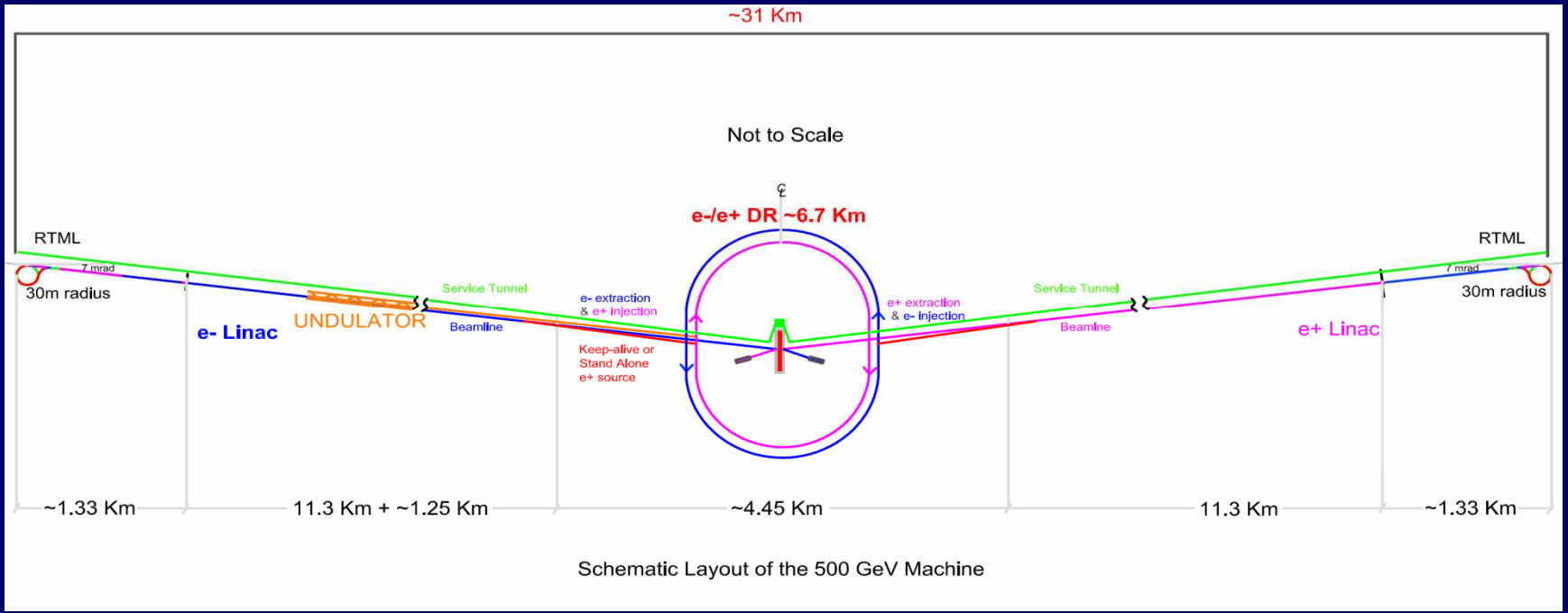
- Ideas for bright young kids – new accelerating principles

The International Linear Collider ILC

- elementary particles
- well-defined
  - energy,
  - spin
- uses full CM energy
- produces particles democratically (ew. interaction)
- can mostly fully reconstruct events



The International Linear Collider



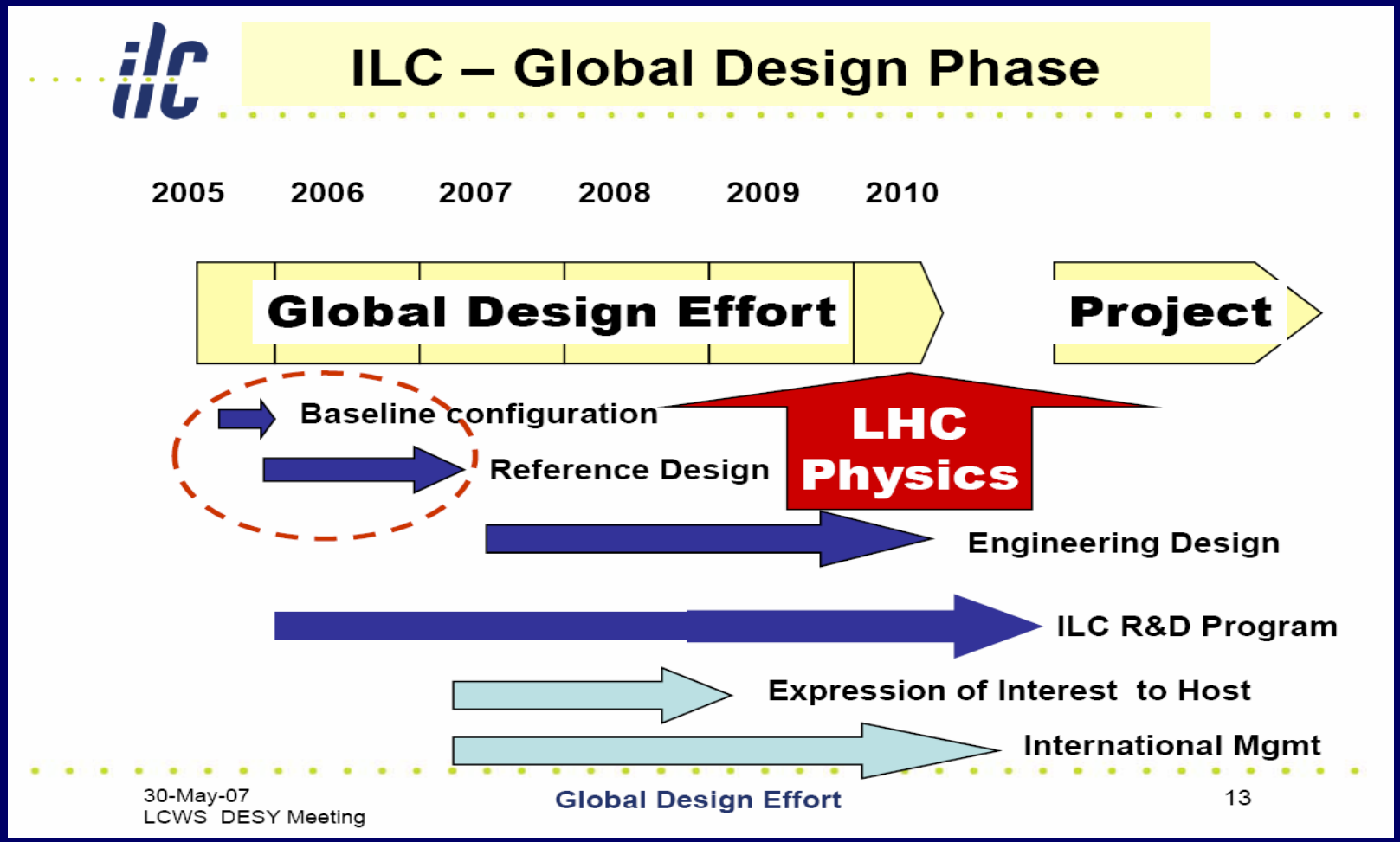
Schematic Layout of the 500 GeV Machine

The „one shot“ problem: in a linear machine, particles only have one chance to collide

→ each accelerating structure (resonator) can be used only once (need a high gradient)

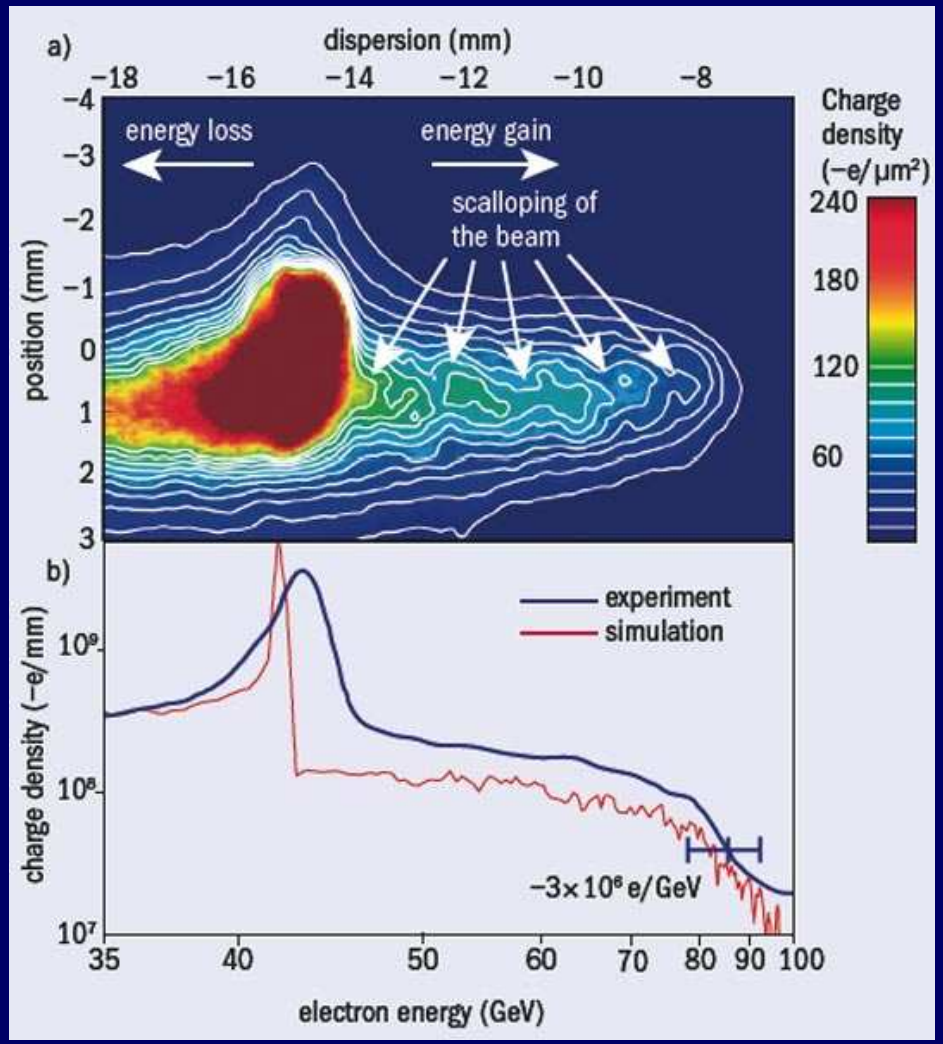
→ make the beams as small (nm!) as posible to make sure that a collision happens!

The International Linear Collider: a real plan



needs to be „ready to be built“ when LHC data give us enough motivation to do so

Beyond the ILC: Plasma wakefield acceleration?

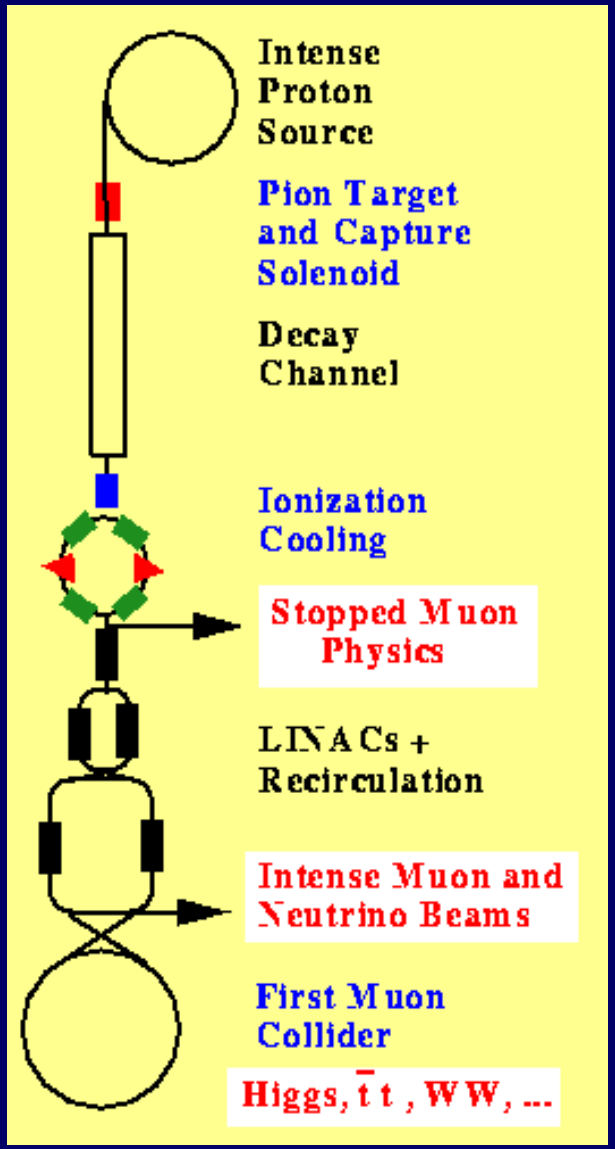


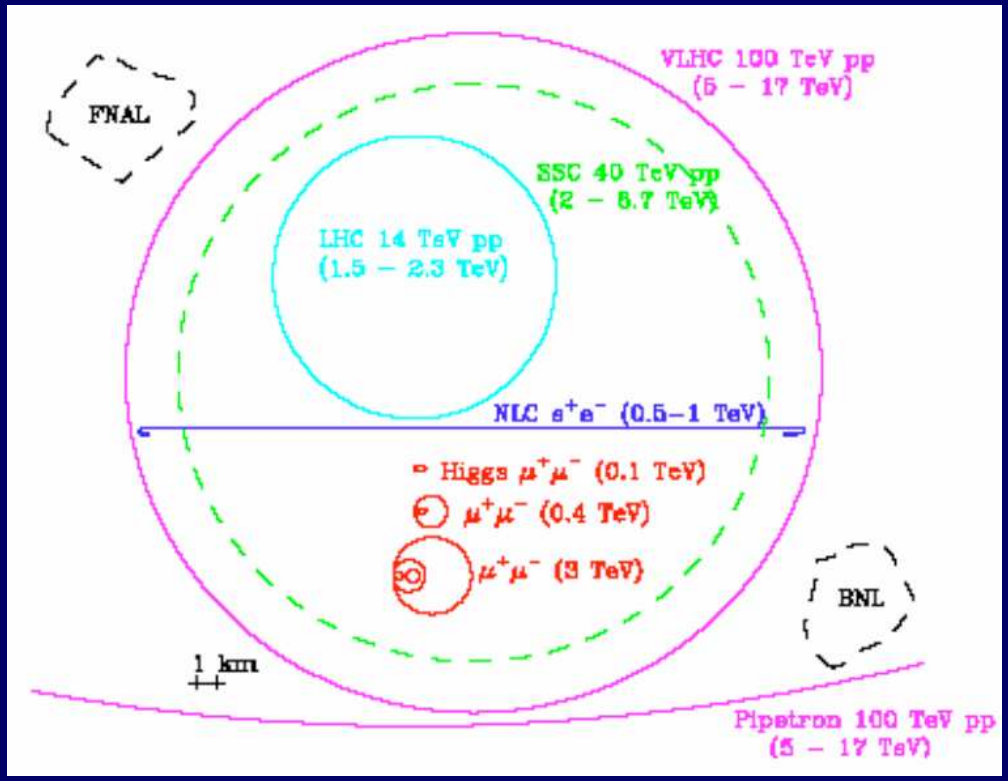
http://cerncourier.com/cws/article/cern/30148

use a pre-accelerated beam through gaseous Lithium to produce a plasma which though electromagnetic interaction with the head of the beam can produce an accelerating electric field

SLAC: achieved energy increase of (tiny part) of the particle bunch of 40 GeV on 85 cm

Colliding heavy but pointlike particles: Muon collider





challenge (far from being met):
provide enough muons in sufficiently small phase space suffiently fast (i.e. before they decay)
„muon cooling“

Upshot

Particle physics at highest energies is as fascinating as it could be
There fundamental, well-posed questions awaiting answers
at the Terascale

The future is not set
I´d like to see Supersymmetry – but „no Higgs, no SUSY“ will be
at least as interesting…

Sharpening the experimental tools is a must

- Detector R&D for LHC upgrade, ILC and beyond

I would not bet that LHC and ILC will be the last (colliding)
machines… - room for fantasy