Concepts for Experiments at Future Colliders I

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Recapitulation of the previous lecture

Shockley-Ramo theorem

The instantaneous current I induced on a given electrode of a gaseous ionization detector due to the motion of a charge q is given by

$$I = q\vec{E} \cdot \vec{v}_q$$

where

$\vec{v}_q$ is the instanteneous velocity of the charge q,

$\vec{E}$ is the electric field for the following configuration: charge q removed, given electrode raised to unit potential, all other electrodes grounded.

Example: Cylindrical tube

- The signal induced by electrons from the avalanche is short (due to the small distance to the anode wire) and high (due to the large electron drift velocity).
- The signal induced by the ions from the avalanche is long (due to the long distance between the anode wire and the tube wall) and with a smaller amplitude than the electron signal (due to the small ion drift velocity).

Recapitulation of the previous lecture

Operation of a cylindrical drift tube under high γ background

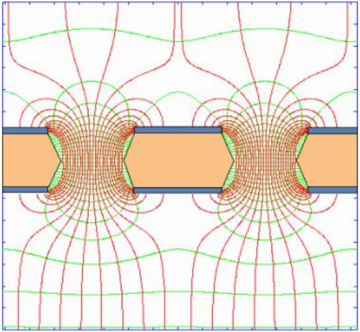
- The muon chambers in the ATLAS detector and in a future hadron 100 TeV hadron collider experiment will be exposed to a large flux of γ rays.
- These γ rays will create background hits in drift-tube chambers mainly by knocking out electrons from the tube walls by Compton scattering.
- The γ background hits can mask subsequent muon hits within the tube's dead time and reduce the muon detection efficiency.
- The space charge of ions from γ background hits reduces the electric field close to the anoder wire, hence the gas gain.
  This reduces the spatial resolution and, at very high background rates, the detectability of a muon signal.

Micropattern gaseous ionization detectors

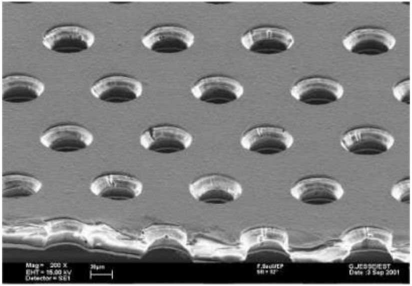
- The charge particle detection efficiency of a detector under high particle background is given/determined by the size of its active "space-time" area, i.e. its spatial granularity and its dead time.
- Micropattern gaseous ionization detectors are fast gaseous ionization detectors with high spatial granularity for the operation in high background environments.
- Most prominent examples: GEMs, MicroMegas.

Gas Electron Multiplier (GEM)

- The heart of a GEM is a thin, metal-clad polymer foil, chemically pierced by a high density of holes (typically 50 to 00 per mm^2.
  On application of a difference of potential between the two electrodes, electrons released by radiation in the gas on one side of the structure drift into the holes, multiply and transfer to a collection region.



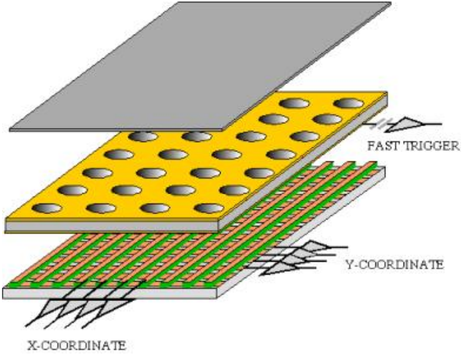
Field lines and equipotentials in the GEM holes on application of a voltage between the two metal sides. A drift (top) and transfer field (bottom) transport ionization electrons into and out of the holes.



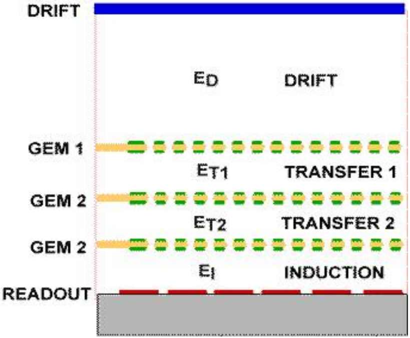
Close view of a GEM electrode, etched on a metal-clad, 50 μm thick polymer foil. The hole's diameter and distance are 70 μm and 140 μm.

Single and multiple GEMs

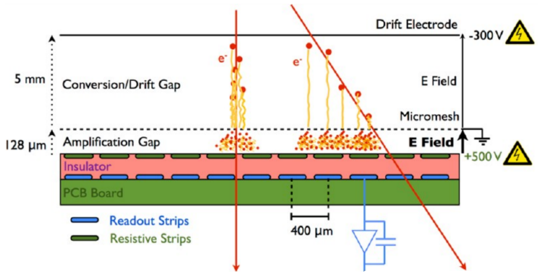
Schematics of a single GEM detector. Electrons released by ionization in the top gas volume drift and multiply in the holes; the charge is collected on the anode, with 1-D or 2-D projective strips, pads or other patterns.



A triple-GEM detector: gain sharing between the foils improves the reliability of operation at high gains.



MicroMegas



- A MicroMegas can be considered as an RPC with an additional ionization and drift region.
- Advantage of the additional ionization region: higher primary charge than in an RPC.
- Disadvantage of the additional ionization region: A MicroMegas is slower than an RPC.

- Time-projection chambers were developed in the 1980s to allow for charge particle detections with a very small amount of material along the track.

Leo 1993

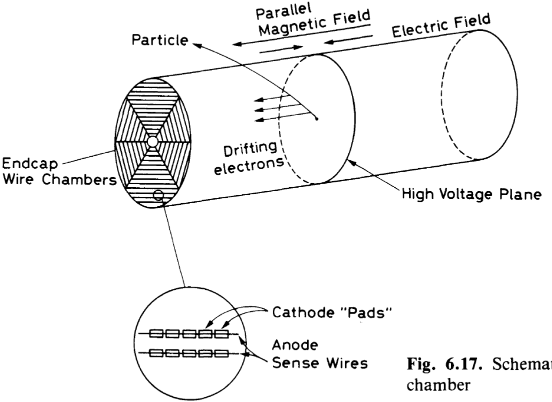
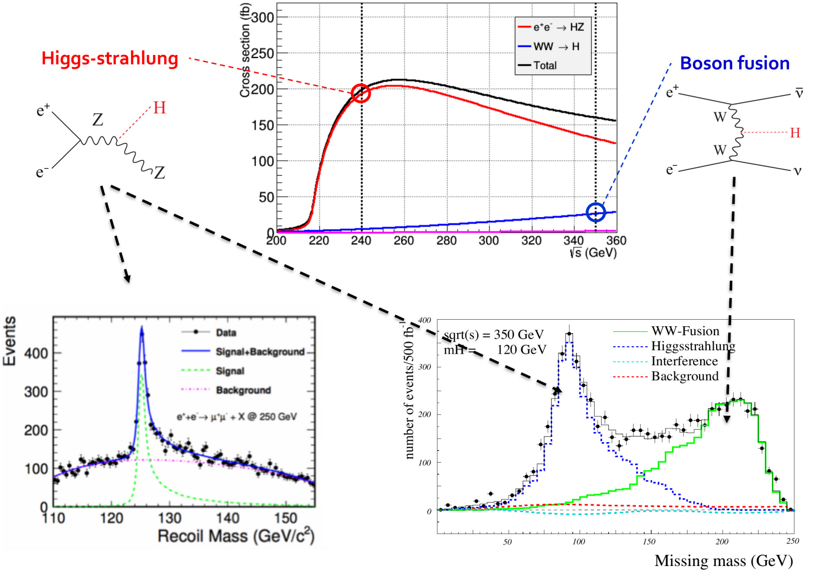


Fig. 6.17. Schematic diagram of a time projection chamber

- Modern TPCs use different detectors on the end caps, e.g. GEMs.
- Problem at the FCC-ee: Magnetic field must not exceed 2 T in order not to spoil the $e^{\pm}$ beams. This leads to a reduced spatial resolution.

FCC-ee detector concepts

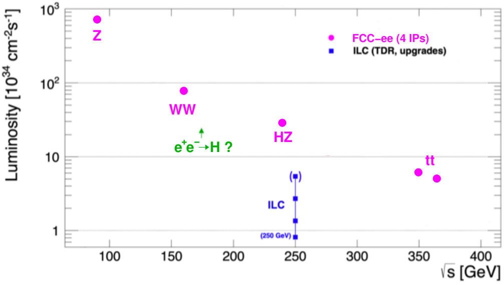
Higgs boson production at an e^+e^- Higgs factory



FCC-ee as Higgs factory plus EW and top factory

Higgs factory programme

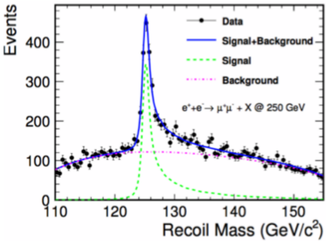
- $2 \cdot 10^6$ HZ events (similar to the HL-LHC, but higher purity and selectrion efficiency) and 125,000 W^+W^- events.
- Precise measurements of Higgs couplings to fermions and bosons.
- Sensitivity to Higgs self-coupling at 2-4 σ level via loop diagrams.
- Unique opportunity to measure the electron coupling in $e^+e^- \to H$ at $\sqrt{s} = 125$ GeV.



By changing the centre-of-mass energy of the collider the FCC-ee can also be operated as an electroweak and top quark factory.

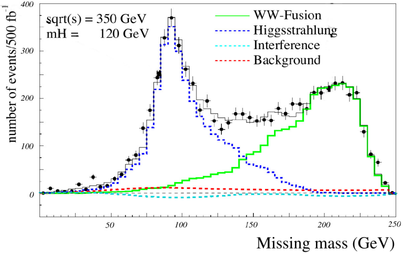
- $\sim 100,000$ Z/s (1 Z/s at LEP).
- $\sim 10,000$ Ws/h (20,000 Ws in 5 years at LEP).
- $\sim 1,500$ top quarks/d.

Higgs-strahlung



momentum resolution

WW fusion



jet energy resolution

M_H = 125 GeV	SM BF
bb	56.1%
WW*	23.1%
gg	8.2%
ττ	6.3%
ZZ*	2.6%
cc	2.9%
γγ	0.2%
Zγ	0.15%
ss	0.1%
μμ	0.02%

flavour tagging

Particle ID

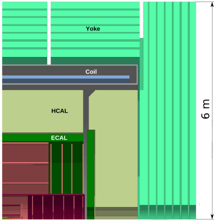
- $\frac{\delta p_T}{p_T} \sim 0.1\%$ for $p_T \sim 50$ GeV (to commensurate with beam energy spread).
- Jet energy resolution of $\frac{30\%}{\sqrt{E}}$ in multi-jet environment for Z/W separation.
- Superior impact parameter resolution for c and b tagging.

FCC-ee detector concepts

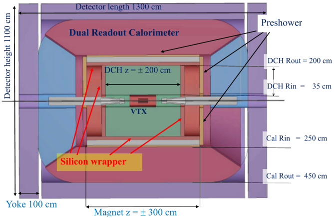
- 4 interaction zones at the FCC-ee allowing for 3 general-purpose detectors.
- 2 FCC-ee detector concepts, CLD and IDEA, presented in the FCC-ee CDR, + one new proposal. Designs are evolving.

FCC-ee detector concepts

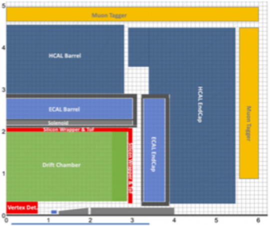
CLD



IDEA



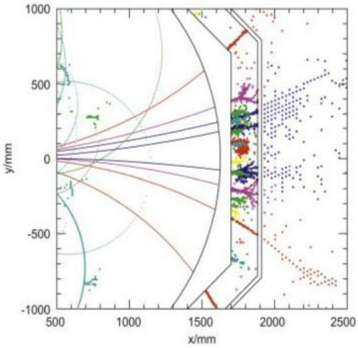
Liquid Ar based ECAL



Subsystem	CLD	IDEA	LAr based ECAL
ID	Full silicon tracker	Silicon vertex detector, low X0 drift chamber with high-resolution PID via dE/dx, drift-chamber silicon wrapper	
ECAL	High-granularity silicon-tungsten	Dual-readout calorimeter Lead-scintillating/Cherenkov fibres	High-granularity lead/noble liquid ECAL
HCAL	High-granularity scintillator-steel		To be specified
Muon	Instrumented steel-yoke with RPCs	µRwell chambers	To be specified
Magnet	Enclosing ID, ECAL, HCAL	MPGD/magnet coil/lead preshower	Enclosing ID

- Difficult to achieve required p_T resolution and PID performance with a full silicon tracker.
- Instrumented return yoke allows for momentum determination in the muon system.
- μRwell new technology with unclear advantages over RPCs.

Motivation for particle-flow hadron calorimeters



- Particle-flow algorithms construct individual particles and estimate their energy/momentum in the best suited subdetector.
- Particle-flow algorithms require highly granular subdetectors including the calorimeters.
- Particle-flow algorithms use the granularity to separate the neutral form the charged contributions and exploit the tracking system to measure charged particle momenta precisely.

E_{jet}	$=$	$E_{charged}$	$+ E_{\gamma}$	$+ E_{neutral\ hadrons}$
$Fraction$		65%	26%	9%

Charged track resolution	$\frac{\delta p}{p} \lesssim 0.1\%$
γ energy resolution	$\frac{\delta E}{E} \sim \frac{12\%}{\sqrt{E}}$
Neutral hadron energy resolution	$\frac{\delta E}{E} \sim \frac{45\%}{\sqrt{E}}$

Dual read-out based calorimeters

Starting idea

- Use scintillators to detect/measure the energy depositions of shower particles.
- Use Čerenkov light to measure the spead of light of relativistic charged shower paricles.

Scintillation signal S and Čerenkov signal C

$$S = E\left[f_{em} + \frac{1}{(e/p)_S}(1 - f_{em})\right],$$
$$C = E\left[f_{em} + \frac{1}{(e/p)_C}(1 - f_{em})\right].$$

If one knows $(e/p)_S$ and $(e/p)_C$, one gets

$$E = \frac{S - \chi \cdot C}{1 - \chi}$$

with

$$\chi := \frac{1 - (p/e)_S}{1 - (p/e)_C}$$

which is independent of E and the particle nature.