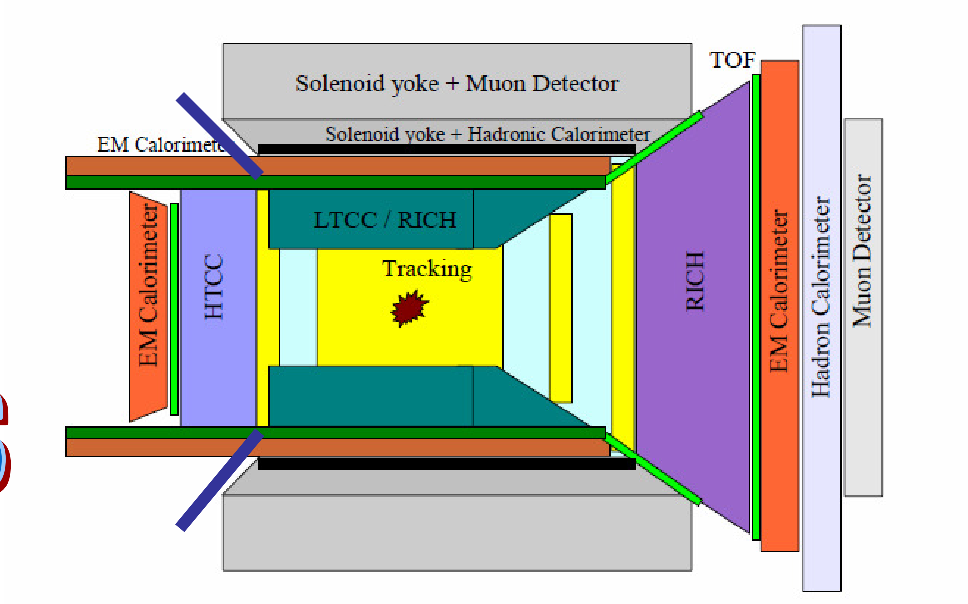
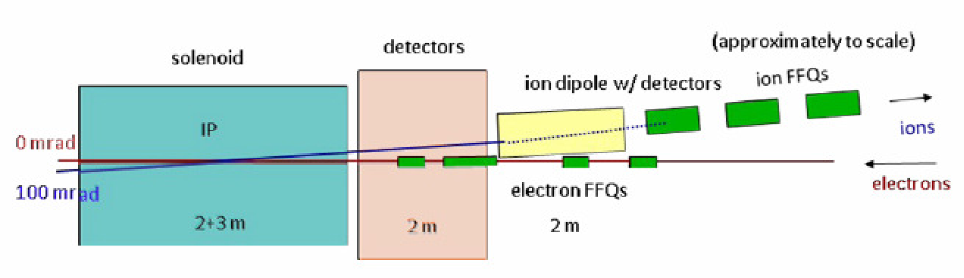
tracking detectors





Franz Klein (CUA)

EIC Detector Workshop - Jefferson Lab 6/4-5/2010

basics: charged particle tracking

- **charged particle tracking in B field:**
  5 d.o.f. → typical: $\mathbf{k=(q/p,\lambda,\varphi,d_{\perp},d_{\parallel})}$

- **track based on associated hits in detectors;**
  quality depends critically on track multiplicity, detector geometry/ alignment/ calibration, B-fields

- **procedure:**

1. exploration - pattern recognition (segments)
2. selection - track finding (seeds)
3. fit - global fit (spline, global track model) or recursive fitting (Kalman filter)
4. final selection - multi-track fit, global vertex fit

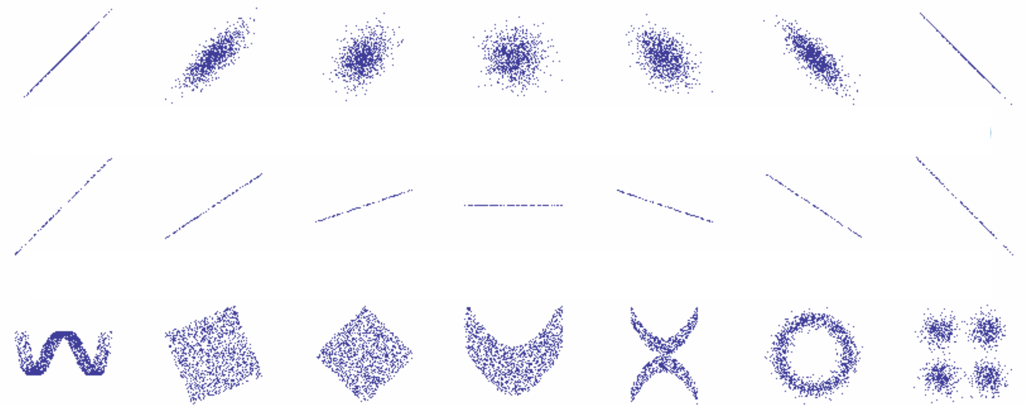
- **requirements: precision, efficiency (, speed, memory)**

- **considerations: multiple scattering and energy loss,**
  reconstruction and rejection efficiency

principles of pattern recognition

- collection of detector hits (position, time and maybe energy deposit)
  → detector cell position, time (TDC), charge (fADC)

- features and correlations in patterns

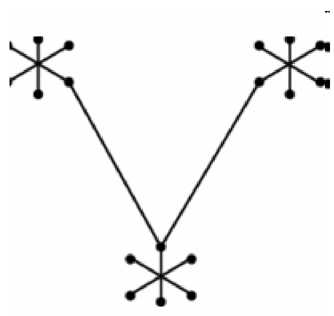


→ linear feature extraction
(coordinate transformation)

→ template matching
(expected pattern → training sample)

→ neural network
(e.g. Hopfield net, simulated annealing)

→ minimum weighted spanning tree
(consider tracks as clusters of points)



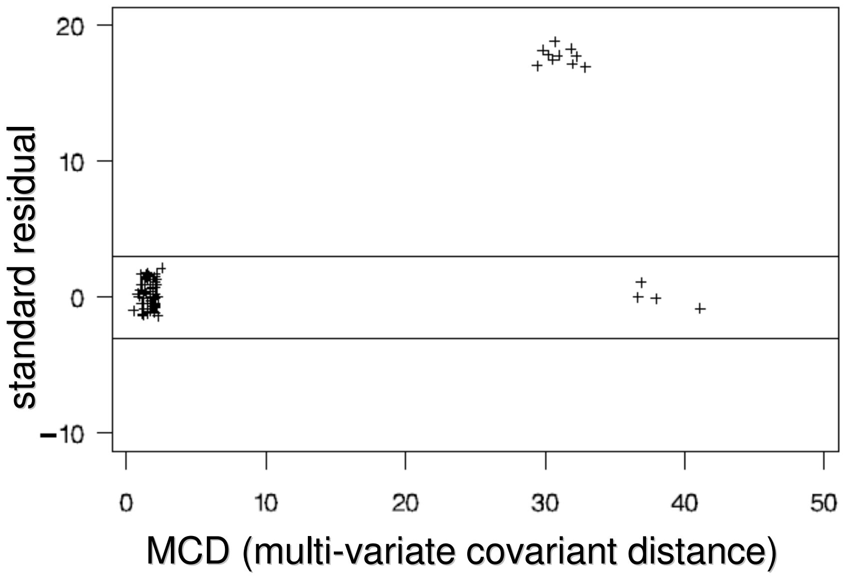
aspects of track finding / fitting

- working in projection or space

→ treating track overlaps

→ compatibility of tracks

→ efficiency (and speed) of track finding



- hit collection and point removal (noise, outliers)

(significance test, biweight test, least trimmed square)

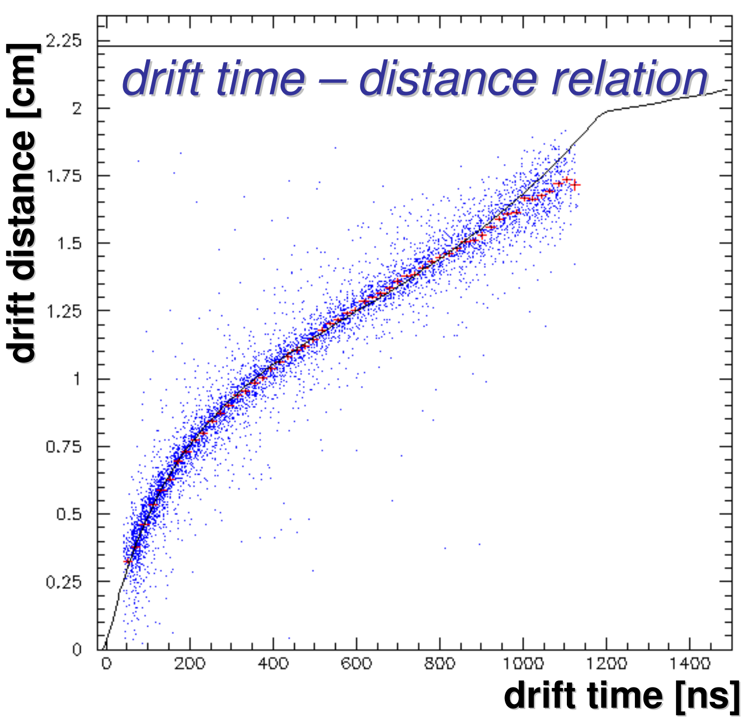
- robust filtering and fitting (track model, quintic spline, Kalman filter)

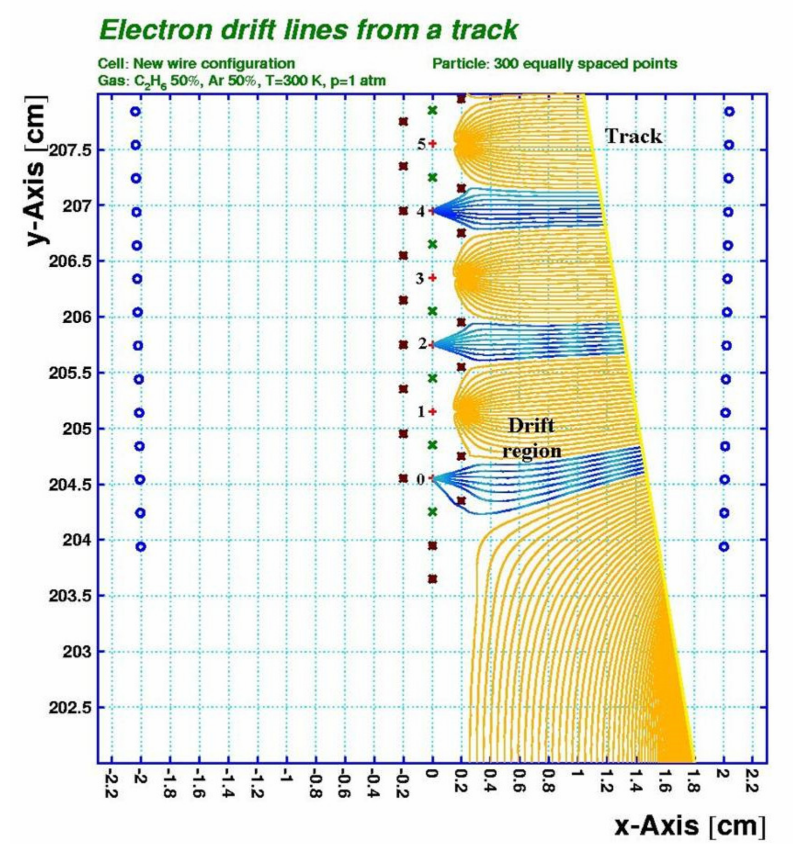
→ weight matrix, detector resolution, alignment, material (mult. scatt., energy loss)

- ghost (mirror) track detection
- vertex reconstruction (in part. decay vertices)

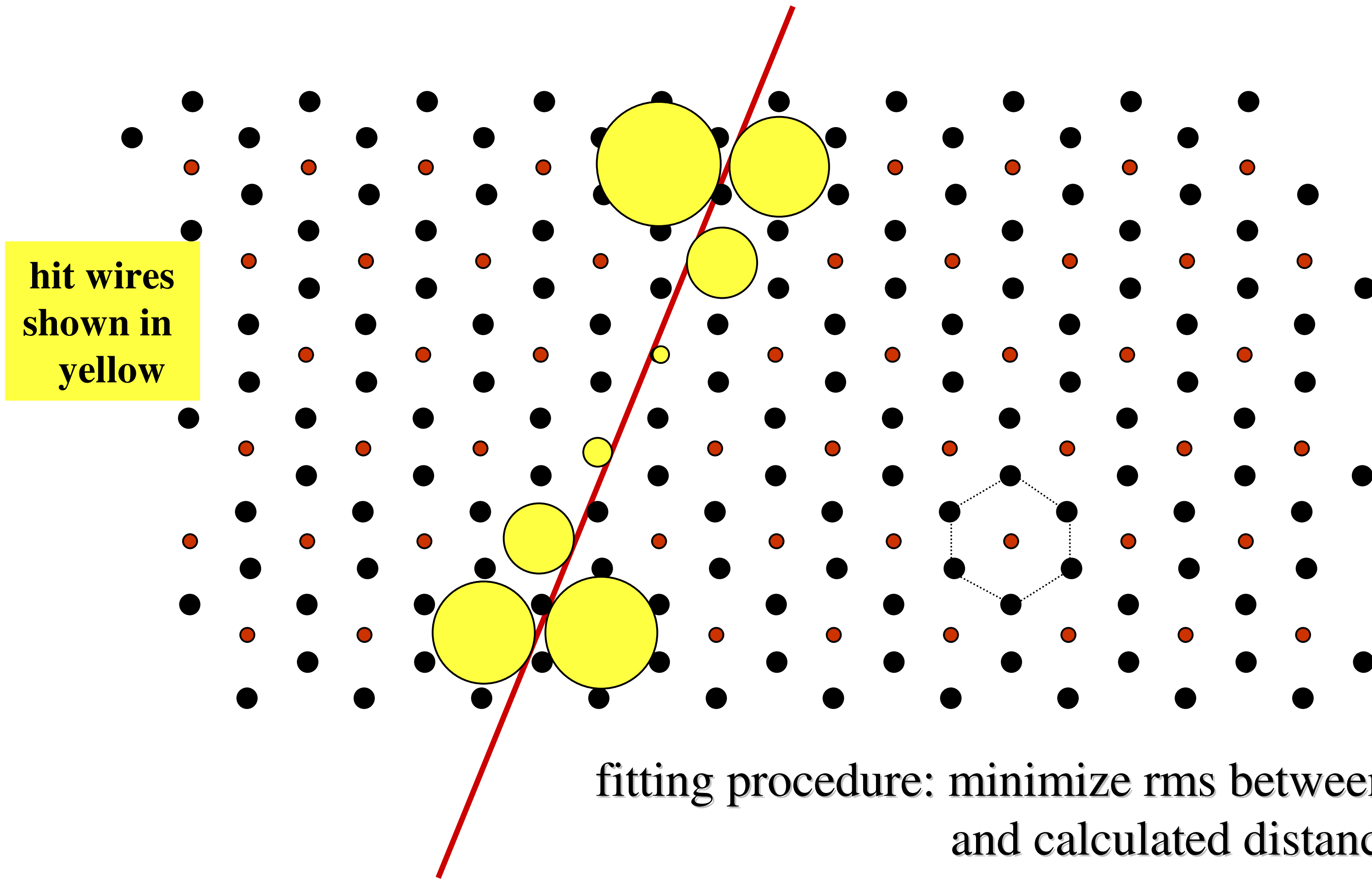
drift chambers

- little material in large volume, strong E-field via sets of field wires (or cathode strips)
- operational in strong B-field (distorted drift path)
- not very sensitive to small changes of gas mixture & wire position
- good spatial resolution & two-track separation (for sufficiently large stereo angles)
- Left-Right ambiguity → staggering of drift cells

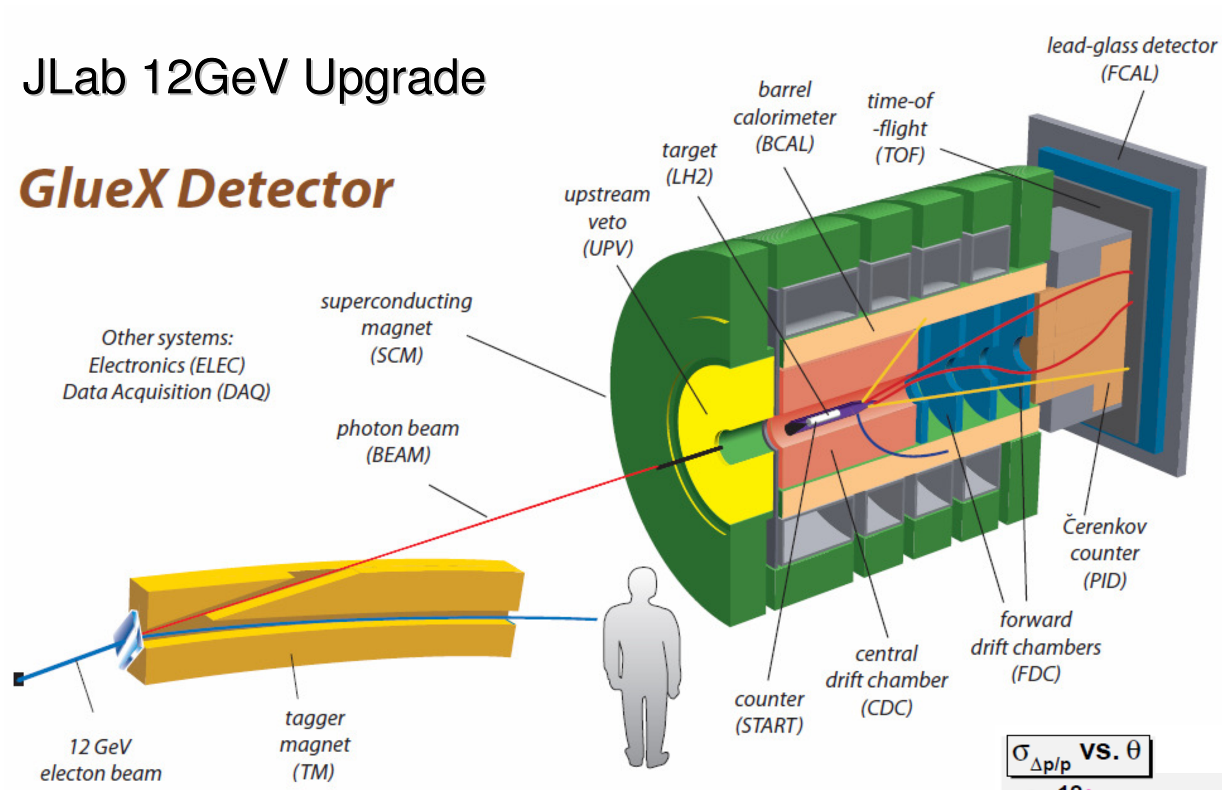




tracking in a drift chamber



fitting procedure: minimize rms between track
and calculated distance



tracking detectors:

CDC: straw chamber

$\sigma_\perp$~150 μm at 30°-165°

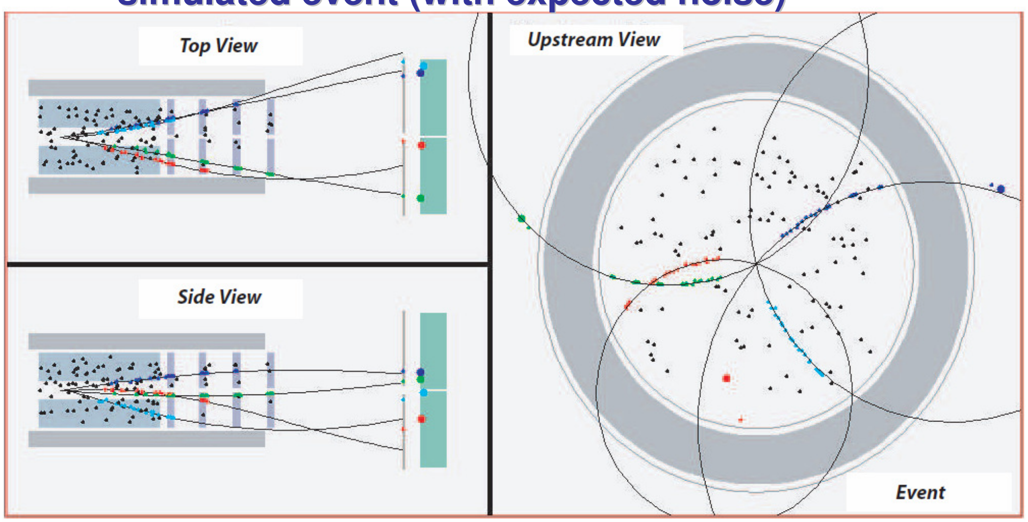
(ø1.6 cm, 28 layers at 0°, 6°)

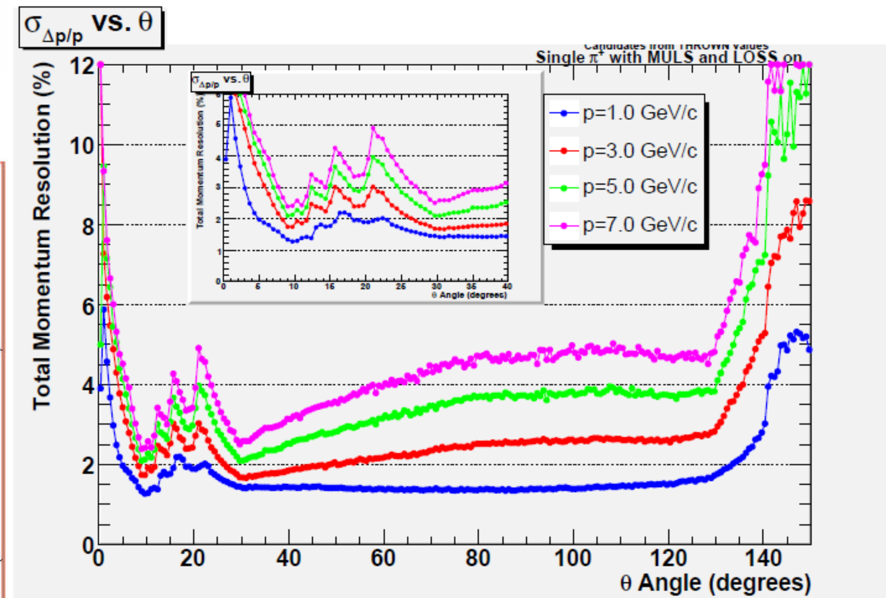
FDC: planar drift chambers

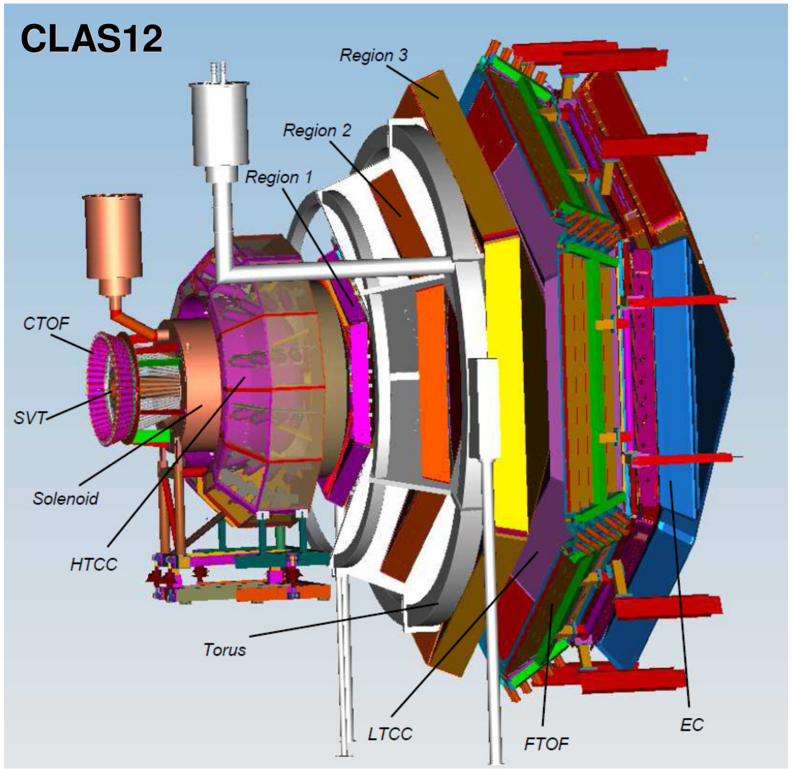
$\sigma_\perp$~200 μm at 1.5°-30°

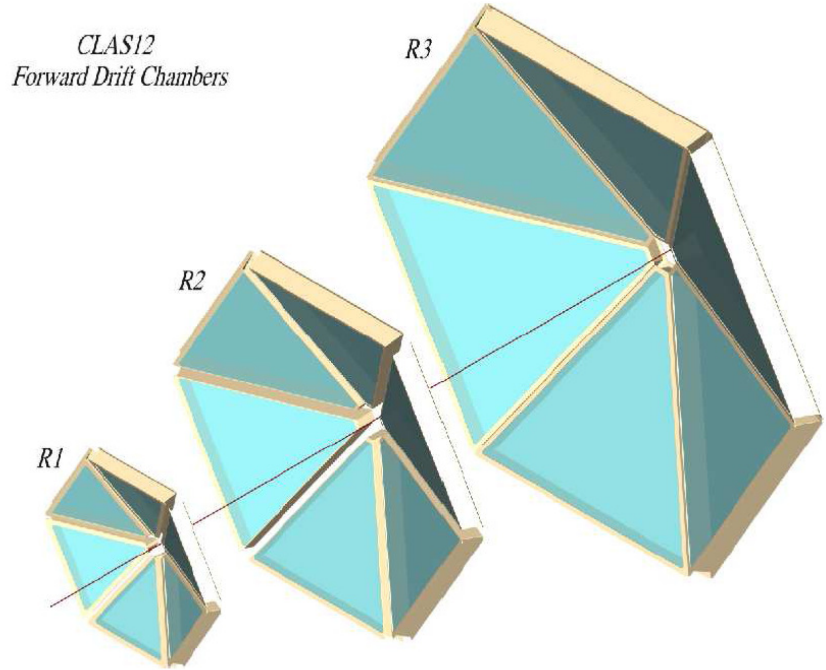
(ø1.6 cm, 4 x 6 layers)

simulated event (with expected noise)

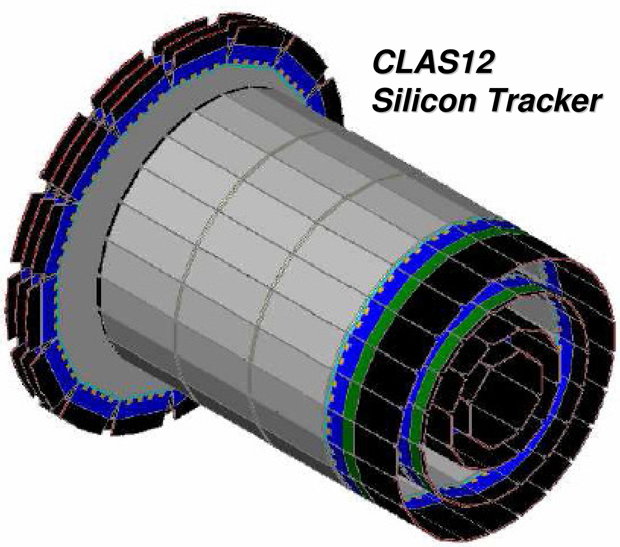


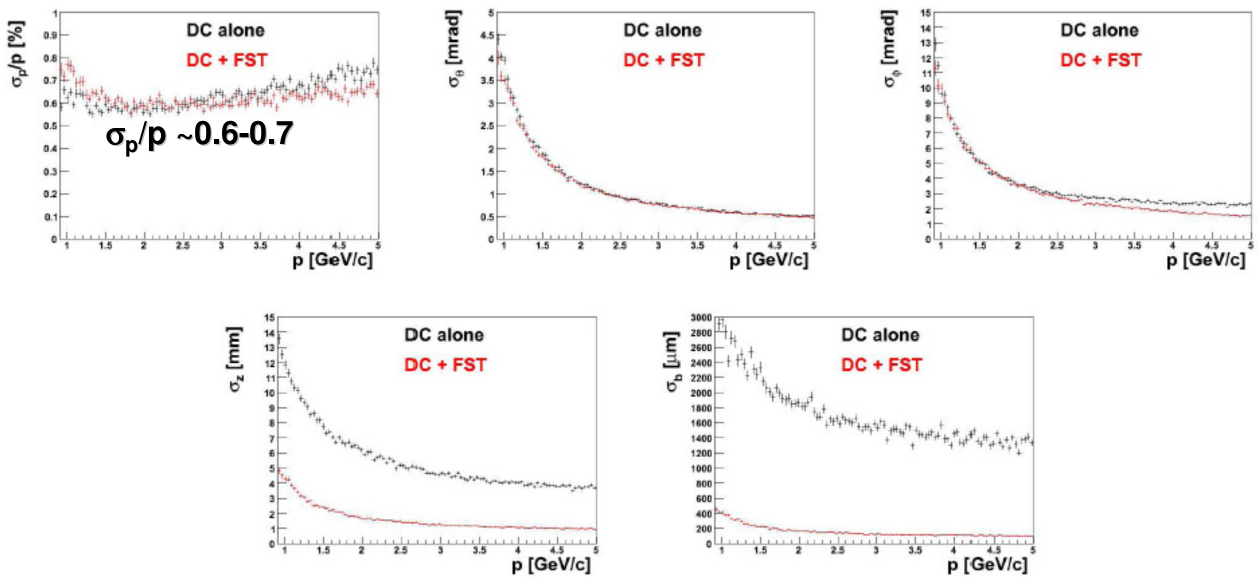






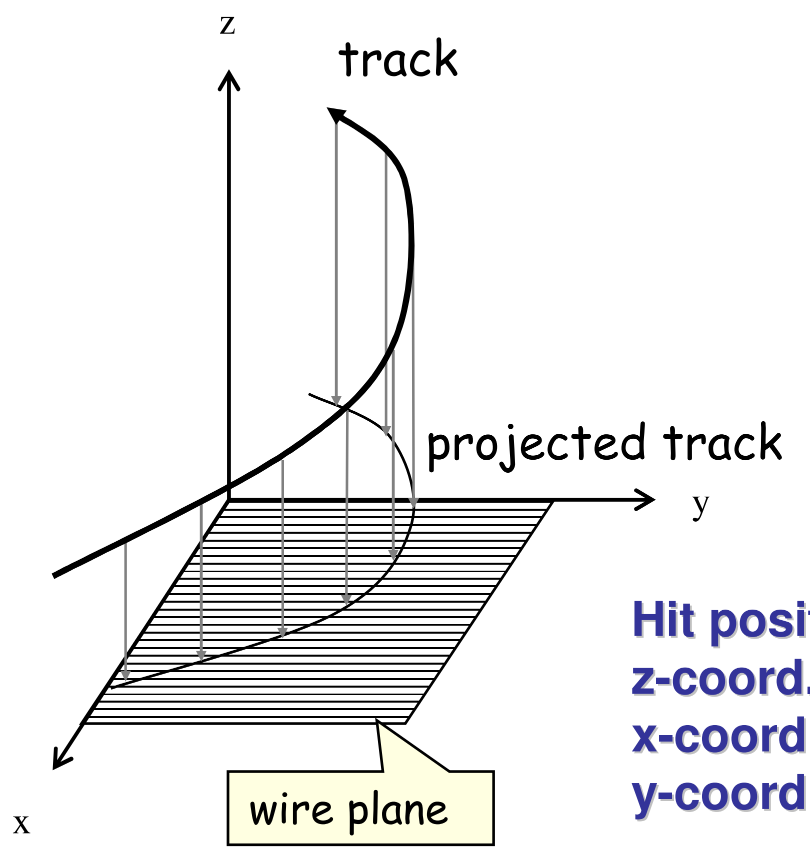
FST: Forward Silicon Tracker (3 layers)

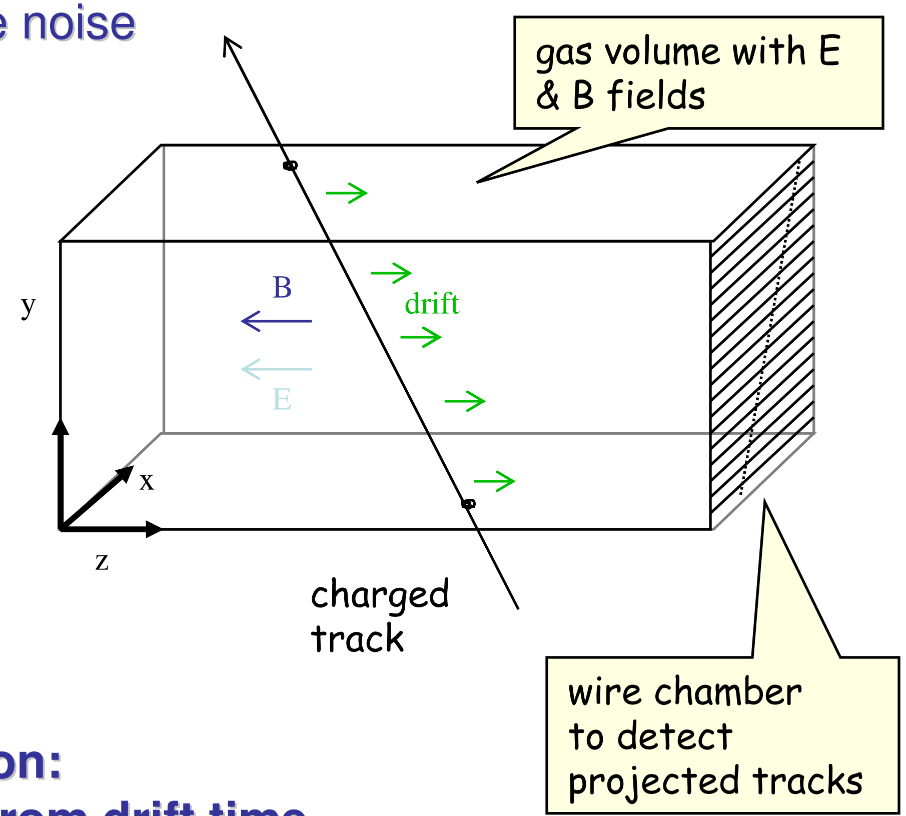




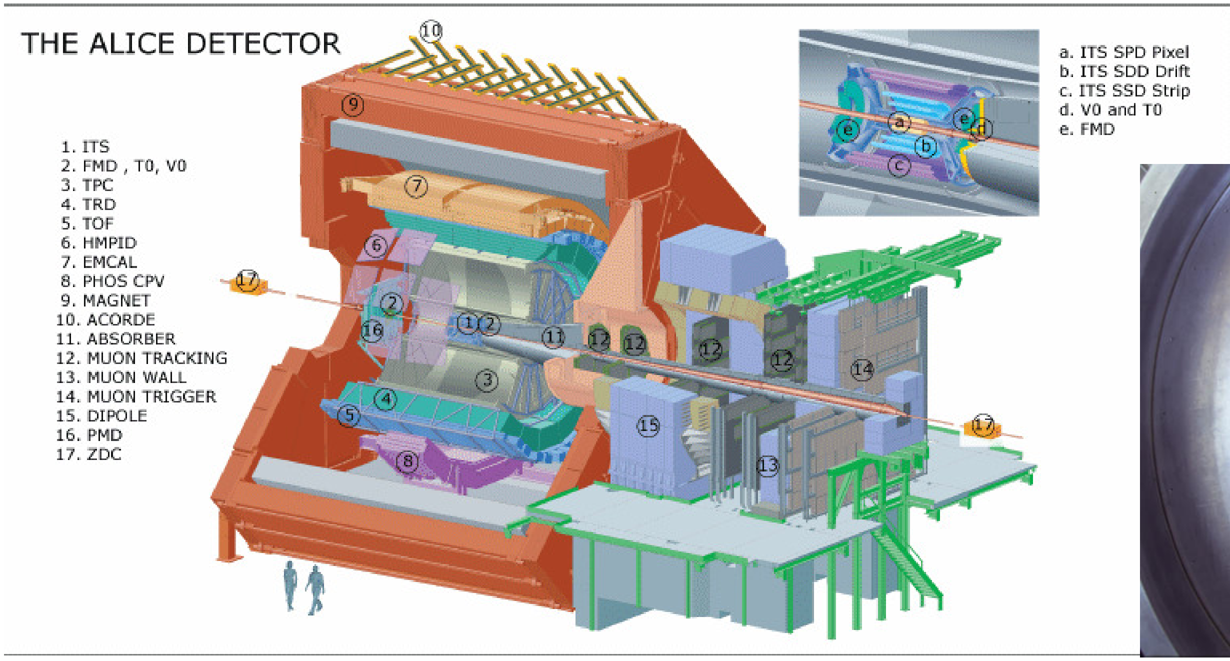
time projection chamber

- drift space extends mainly on one side of the sense wire (no LR ambiguity)
- row of small pads receive induced pulse from avalanche at the sense wire
- (strong) B-field parallel to E-field: confines the drifting electron cloud
- wire chamber gated to reduce out-of-time noise
- position resolution up to 50µm

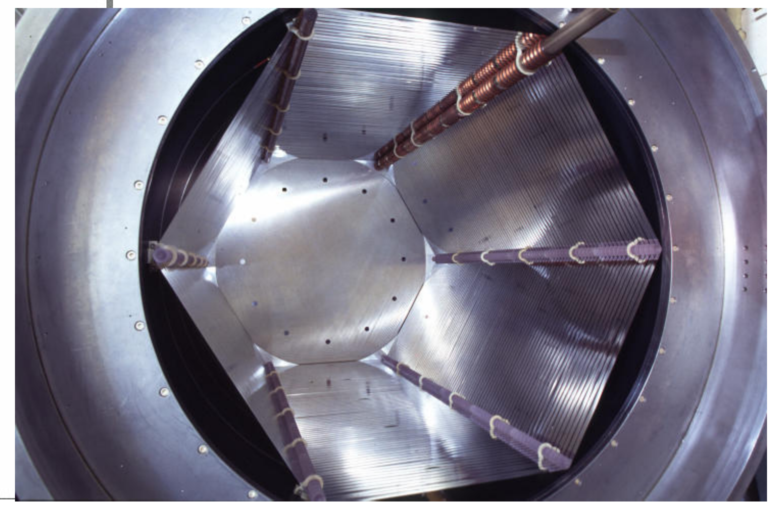




Hit position:
z-coord. from drift time
x-coord. from wire number
y-coord. from cathode pads

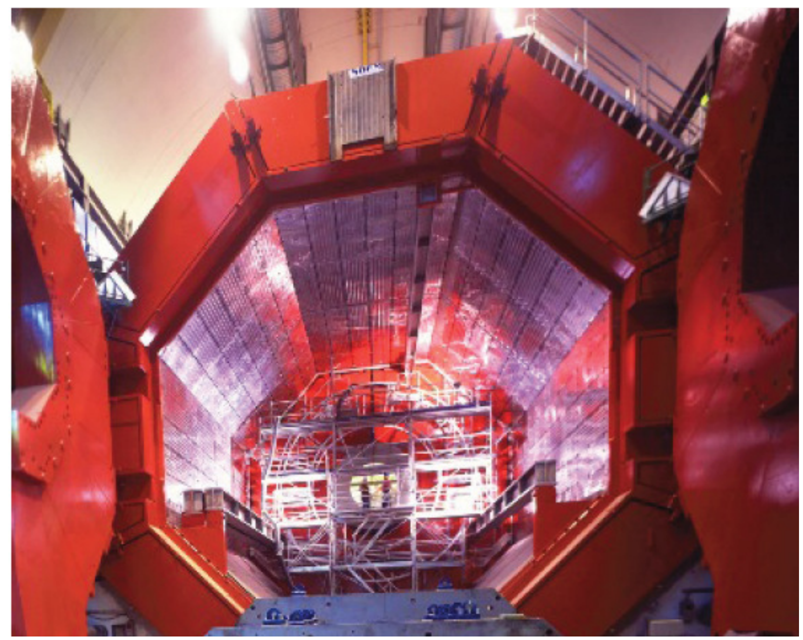


field cage

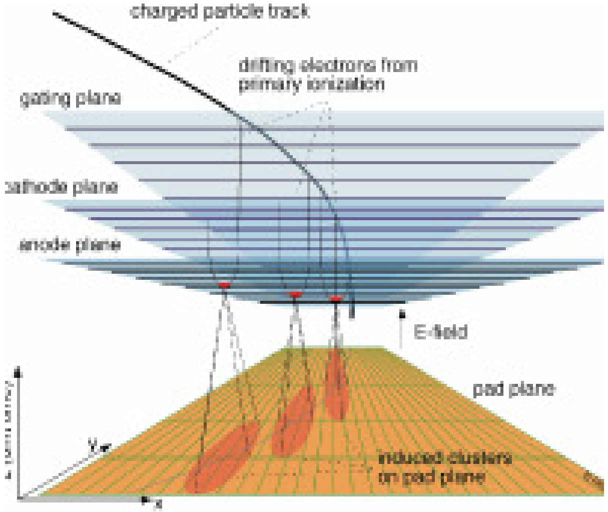


high magnetic field parallel to E-field reduces transverse diffusion by $1/\omega\tau$

ω = cyclotron freq.; τ=mean time between collisions

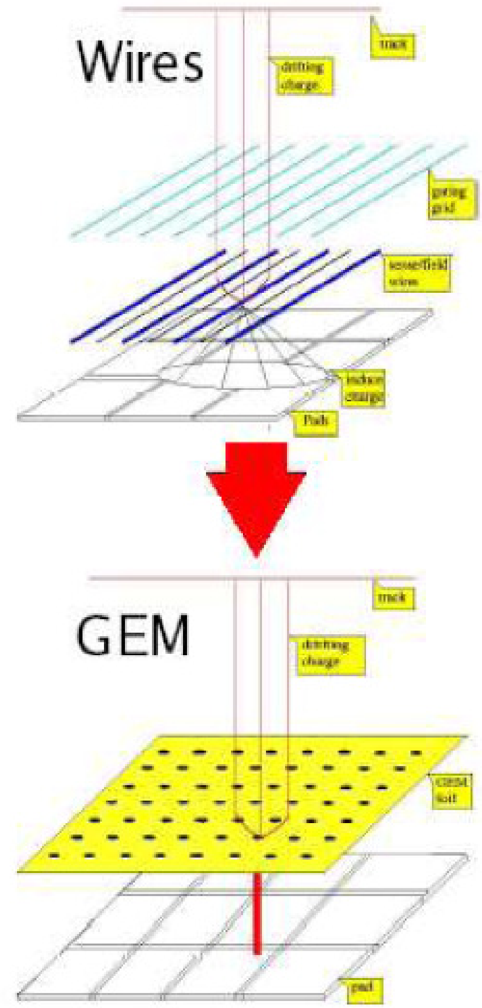


TPC gas amplification

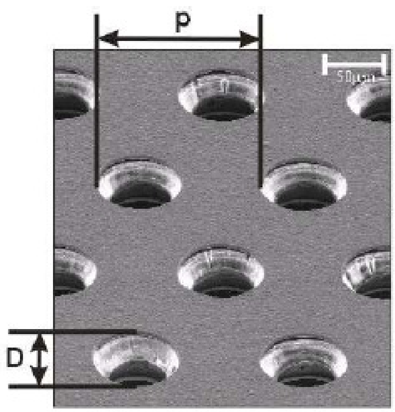


conventionally:
MWPC system

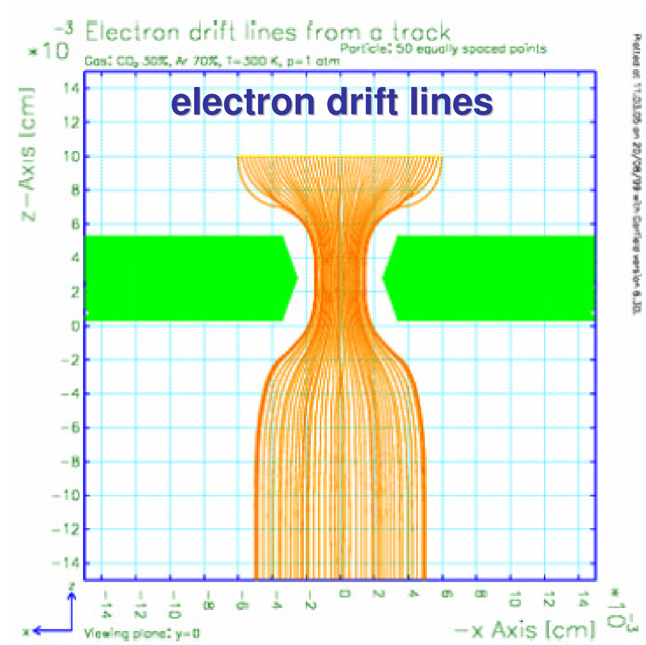
replace by
Micro Pattern Gas Detectors



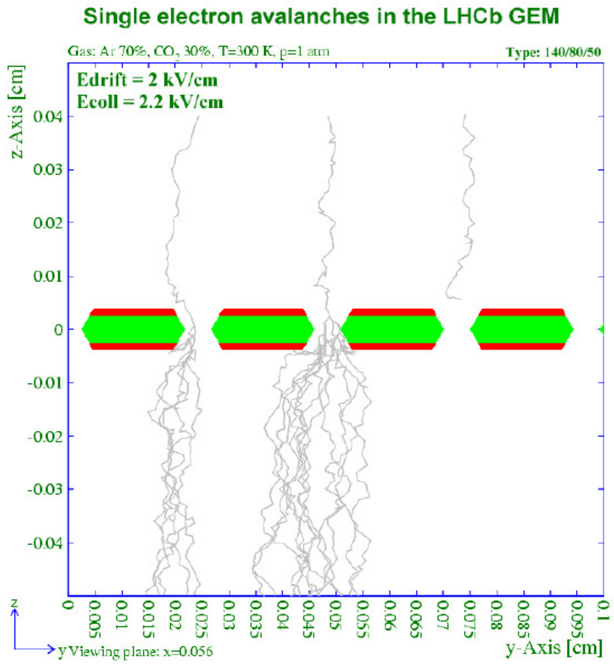
Gas Electron Multiplier (GEM)



P ~ 140 µm; D ~ 60 µm

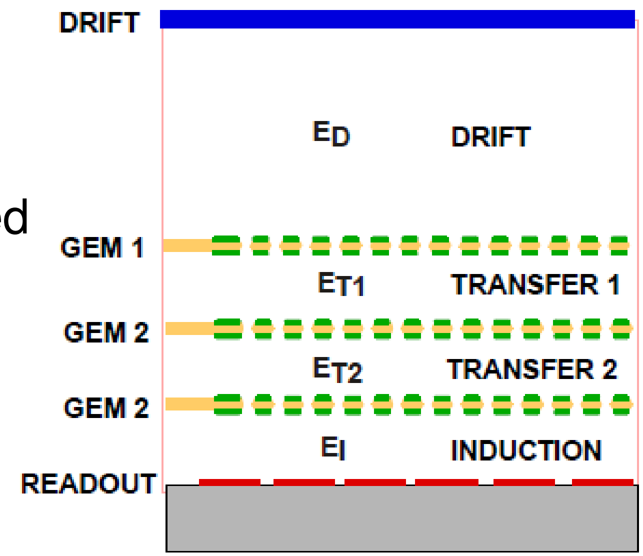


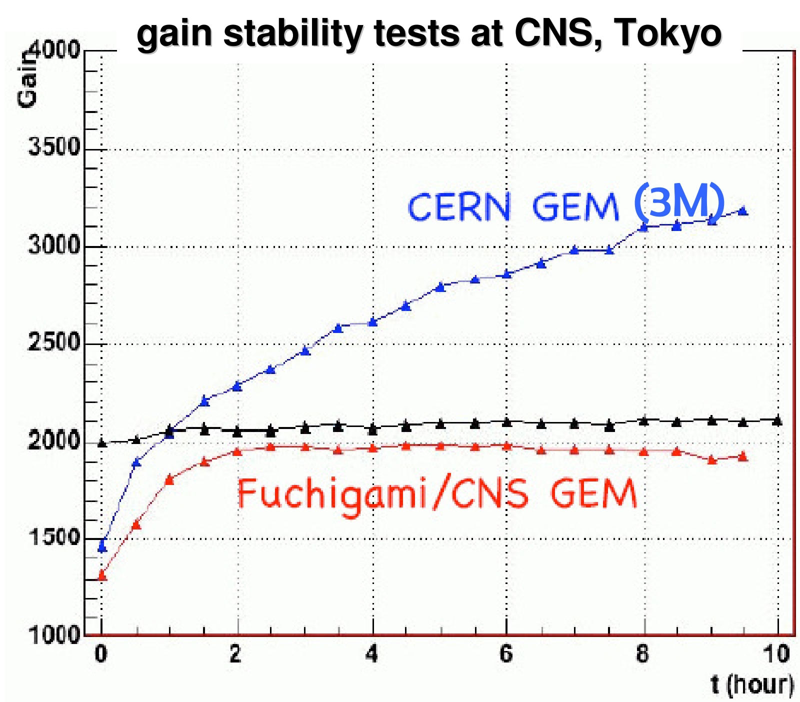
TPC gas amplification



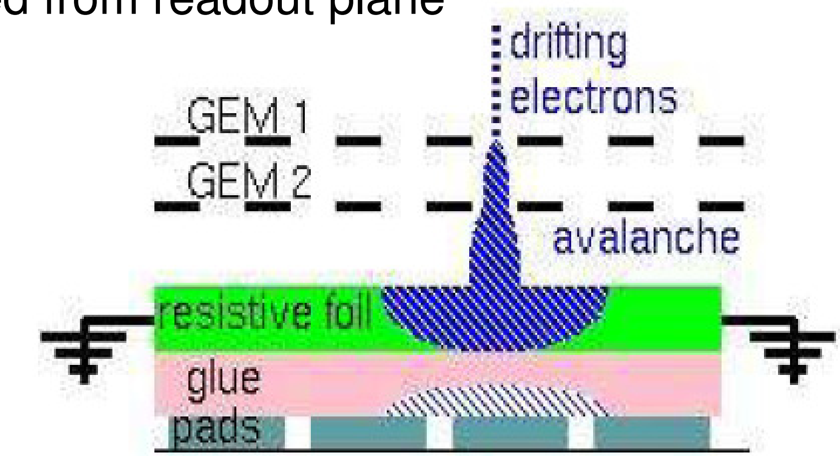
improvements:

- cascade GEM
  (triple GEM)
- first plane gated



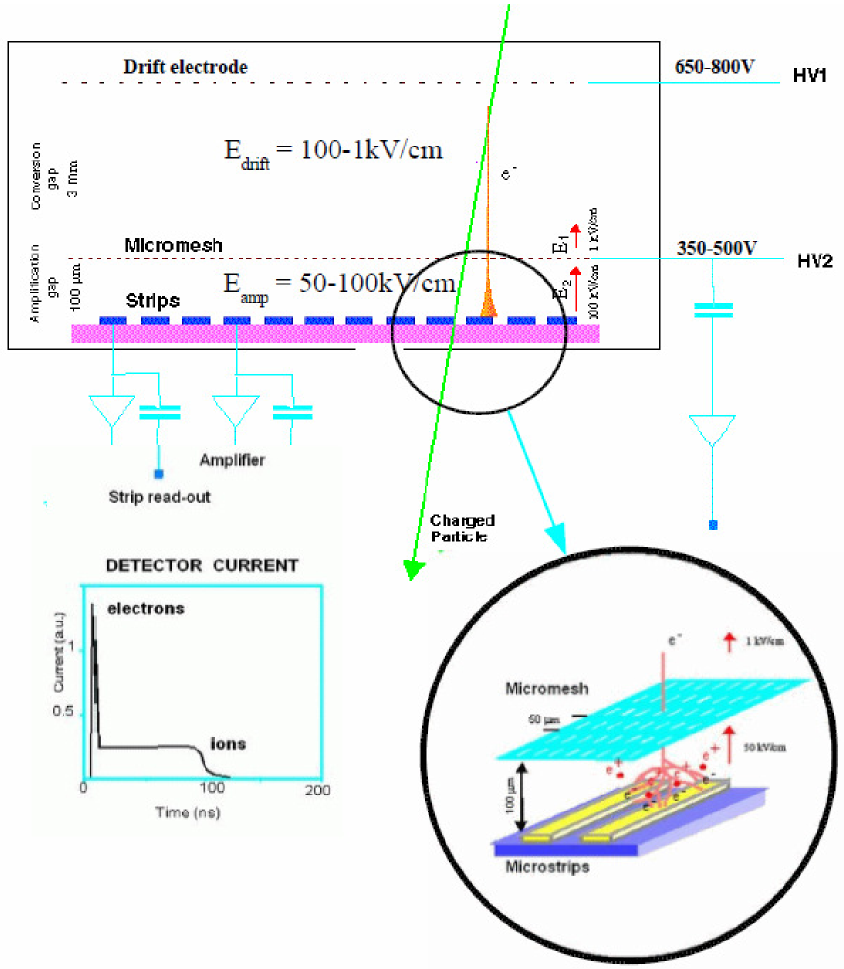


- charge dispersion readout:
  modified anode with high-resistivity film
  insulated from readout plane

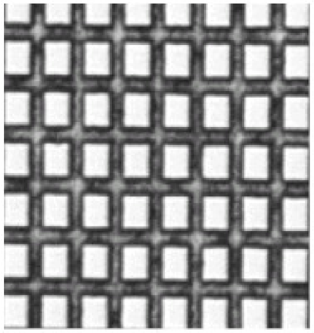


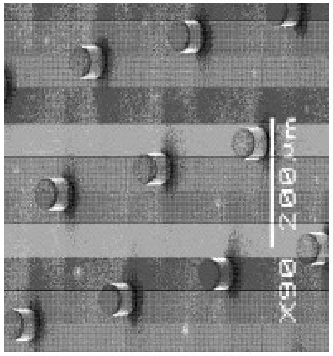
TPC gas amplification

micro mesh gas structure (μmegas)



Metallic woven or electro-produced micromesh sustained by 50-100 μm pillars over anode plane.
Very high gain electron multiplication between anode and mesh.

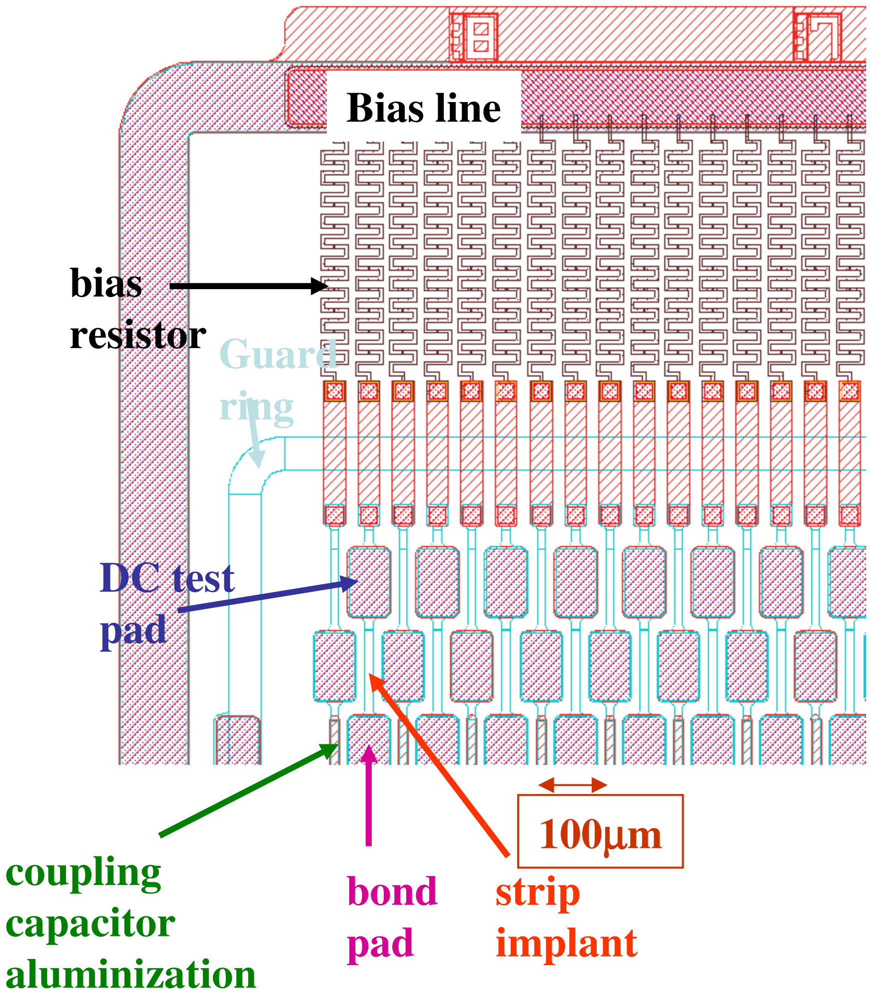




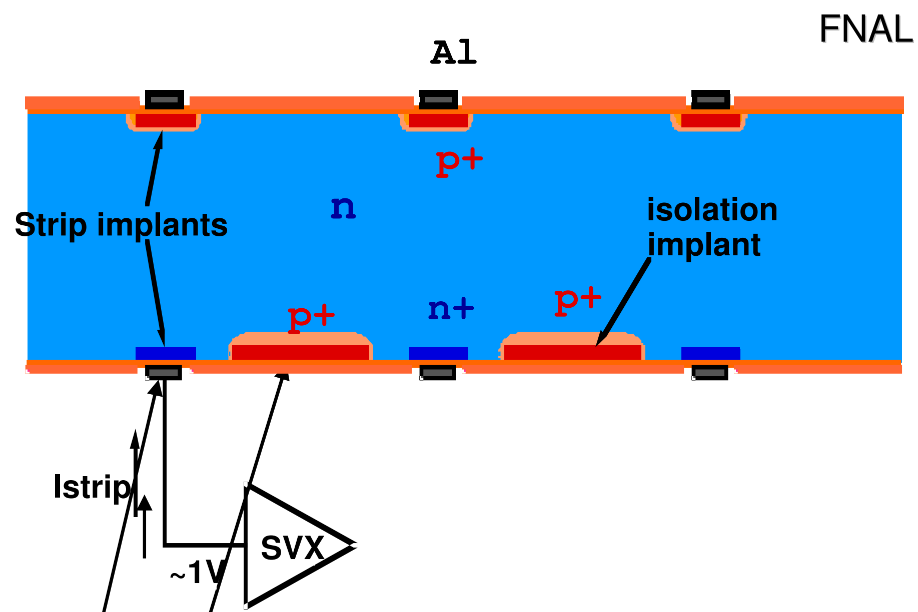
He-isobutane (80:20):
gain ~ 20,000

Solid-state detectors

Single sided devices



Double sided devices



AC-coupling: add thin (2500Å) SiO_2 layer between readout implant and Al (integrated capacitor).

⇨ Immunity to DC reverse currents caused by radiation.

Capacitors must withstand bias voltage.

p-stop: add blocking p+ strips on n-side to ensure strip isolation at full depletion

D0 silicon tracker

(800k channels, double-layer, 50 μm pitch)

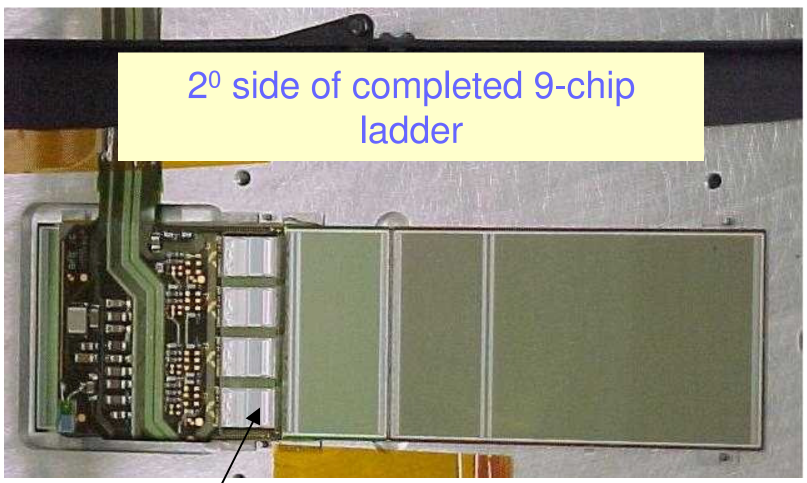
Hybrid system:

barrel detectors measuring primarily r-ϕ of vertices for low η tracks,

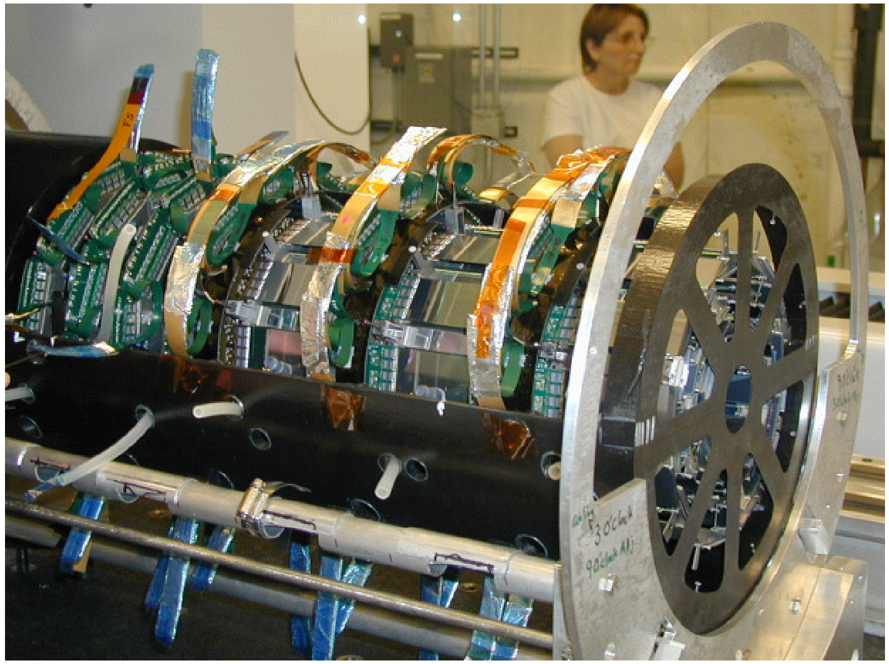
disk detectors measuring r-z as well as r-ϕ of vertices for high η tracks (3D)

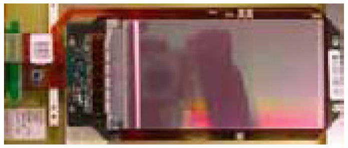
- disk separation must be kept small to minimize extrapolation errors
- each plane of disks represents a dead region (~8 mm gap) between the barrels which lowers overall efficiency of the detector

- 3D track reconstruction capabilities,
- axial hit resolution: ~ 10 μm,
- detectors and onboard electronics radiation hard up to 1 MRad
- *z* hit resolution: ~35 μm for 90^0 stereo, ~450 μm for 2^0 stereo



SVXIIe chips



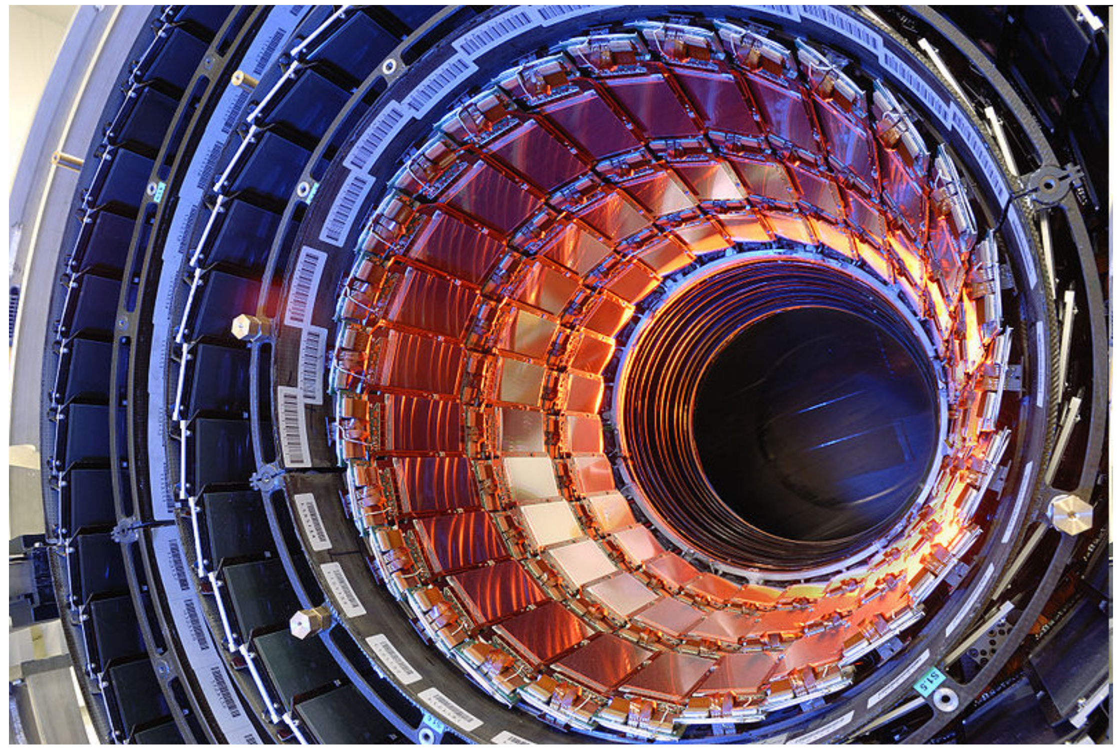


microstrip and pixel detectors

- resolution:
  ~8-30 μm for 25-200 μm strips
- pixel detector without
  double-track ambiguities
- radiation tolerant to ~10 kGy

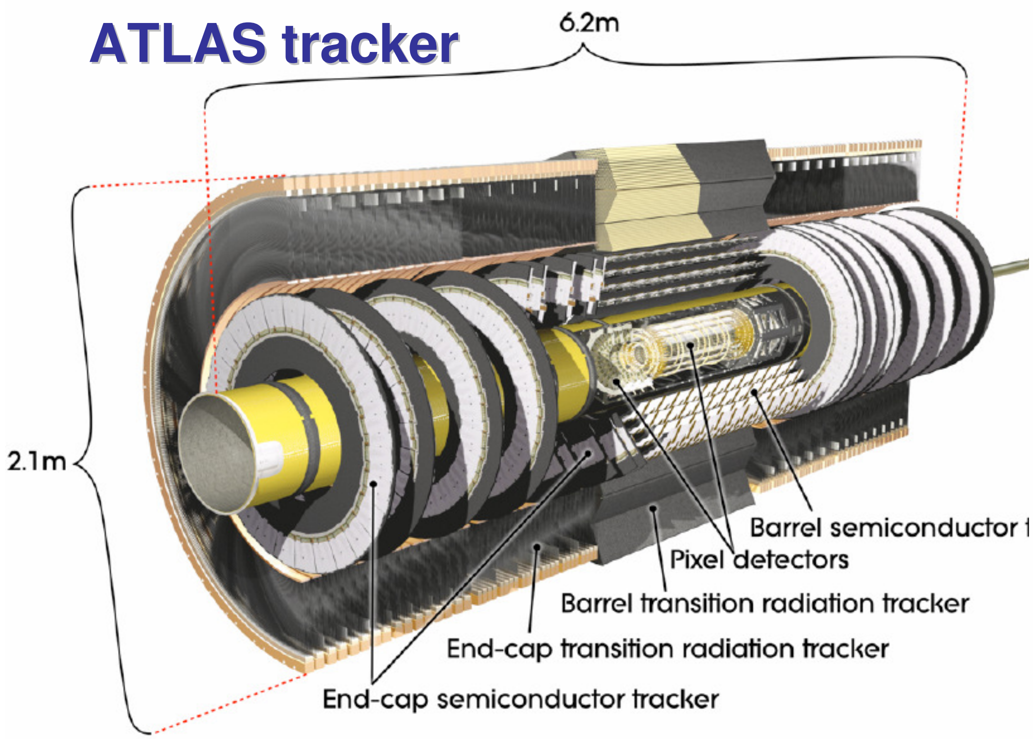
- CMS: 16,500 μstrip detectors
  (76 M channels)
  cooled to -10 °C,
  320 or 500 μm thick,
  80-180 μm pitch,
  25 ns ASIC readout time,
  σ ~23-53 μm for strips and
  σ ~15-20 μm for pixels.

- CMS alignment goal <10 μm

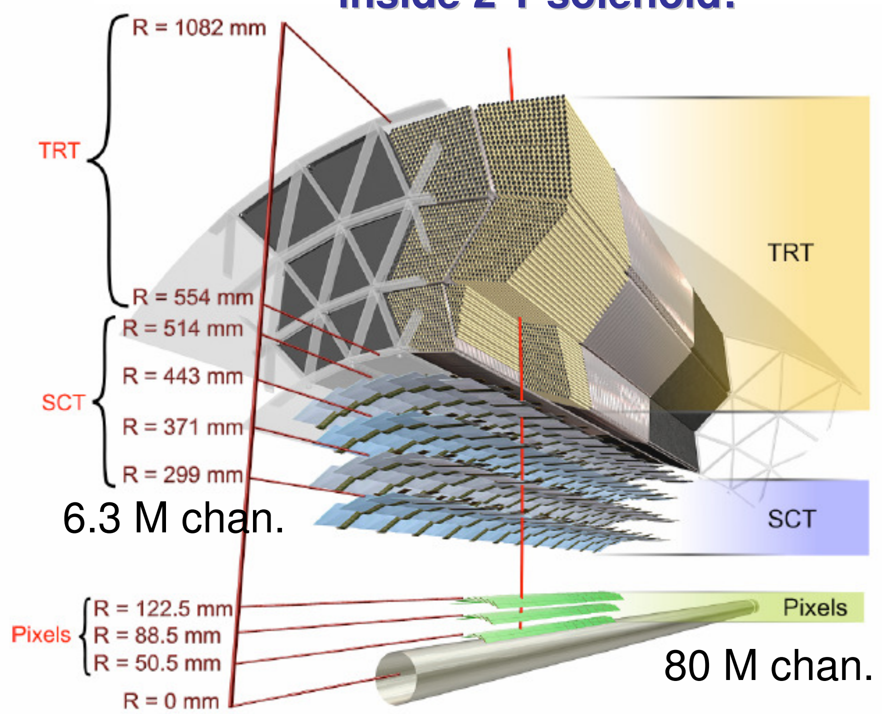


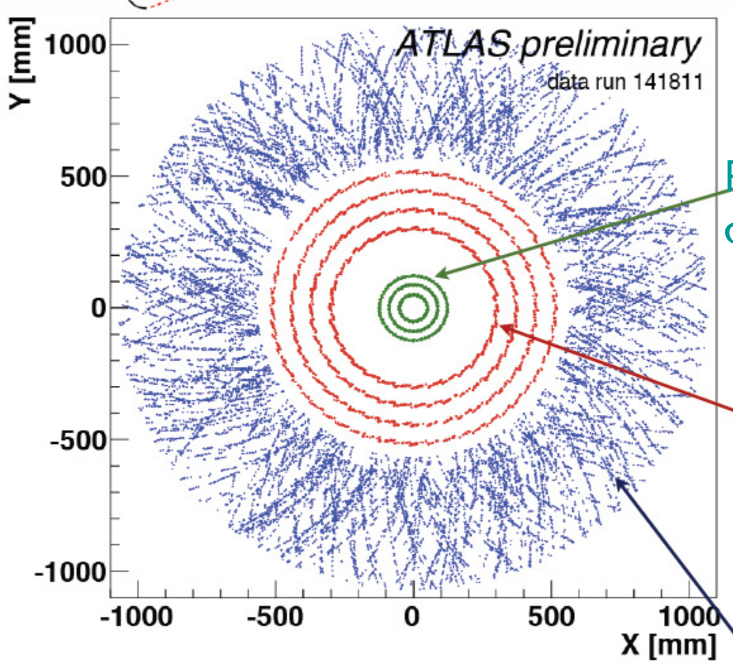
CMS – 3.8 T

ATLAS tracker



inside 2 T solenoid:





Pixel:
$\sigma_{r\varphi}$~10 μm; σ_z ~115 μm

SCT:
$\sigma_{r\varphi}$~17 μm; σ_z ~580 μm

TRT (73 straw layers):
σ_r~130 μm

Nominal performances in barrel region:
$\sigma(p_t)/p_t \sim 3.4\times10^{-4}\ x(p_t/\mathrm{GeV}) \oplus 0.015$
$\sigma(d_0) \sim 10 \oplus 140/(p_t/\mathrm{GeV})$ μm

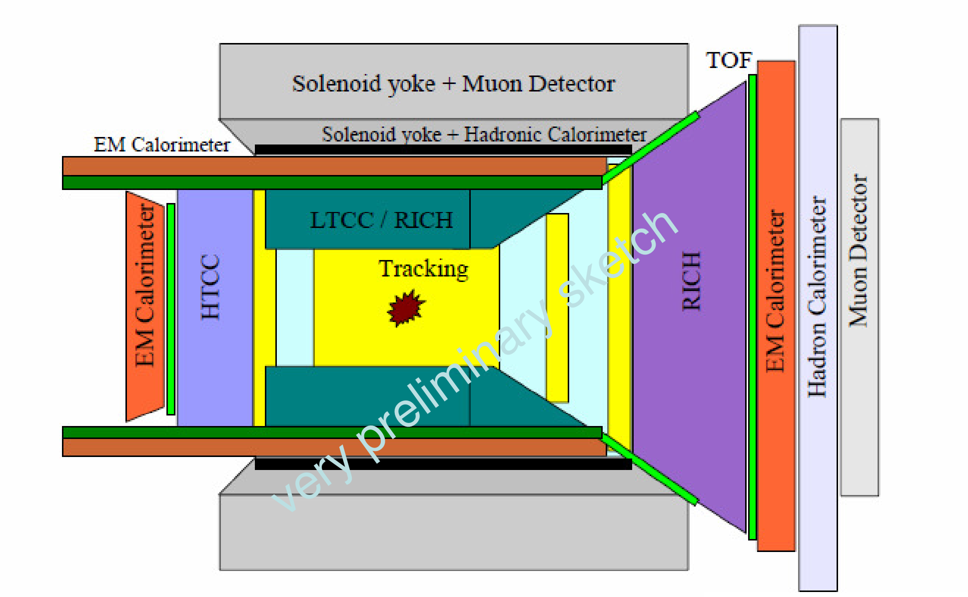
Nov/Dec. collision data:
alignment to ~80 μm (goal 30 μm)

summary

to be considered when choosing the tracking detector:

- efficiency of available tracking algorithms
- material budget (multiple scattering, energy loss)
- TPC (maybe divided into smaller volumes) optimal for solenoid spectrometer, readout via GEMs or micromegas
- supported by additional GEM layers in radial direction
- solid-state (strip and/or pixel detector) or micromegas (?) as vertex detector
- drift chambers with large stereo angles or GEM/μstrip wedges as endcap detectors

EIC detector



vertex tracker: µstrip, pixel
barrel tracker: TPC, GEM
forward e/i tracker: DC, GEM