Overview of ILC Accelerator/Detectors

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ILC History and TDR

2400 signatories

History

- 1980's: start of LC projects in each region
- 2004: Technology choice: NLC, GLC, Tesla → ILC
  Superconducting technology chosen
- 2007: Reference Design Report
- 2009: Detector LoIs → 2 Detectors (ILD, SiD) validated
- 2012: Technical Design Report & Detailed Baseline Design
- 2013: "LC collaboration" formed
- 2014: Official investigation of Japanese government started

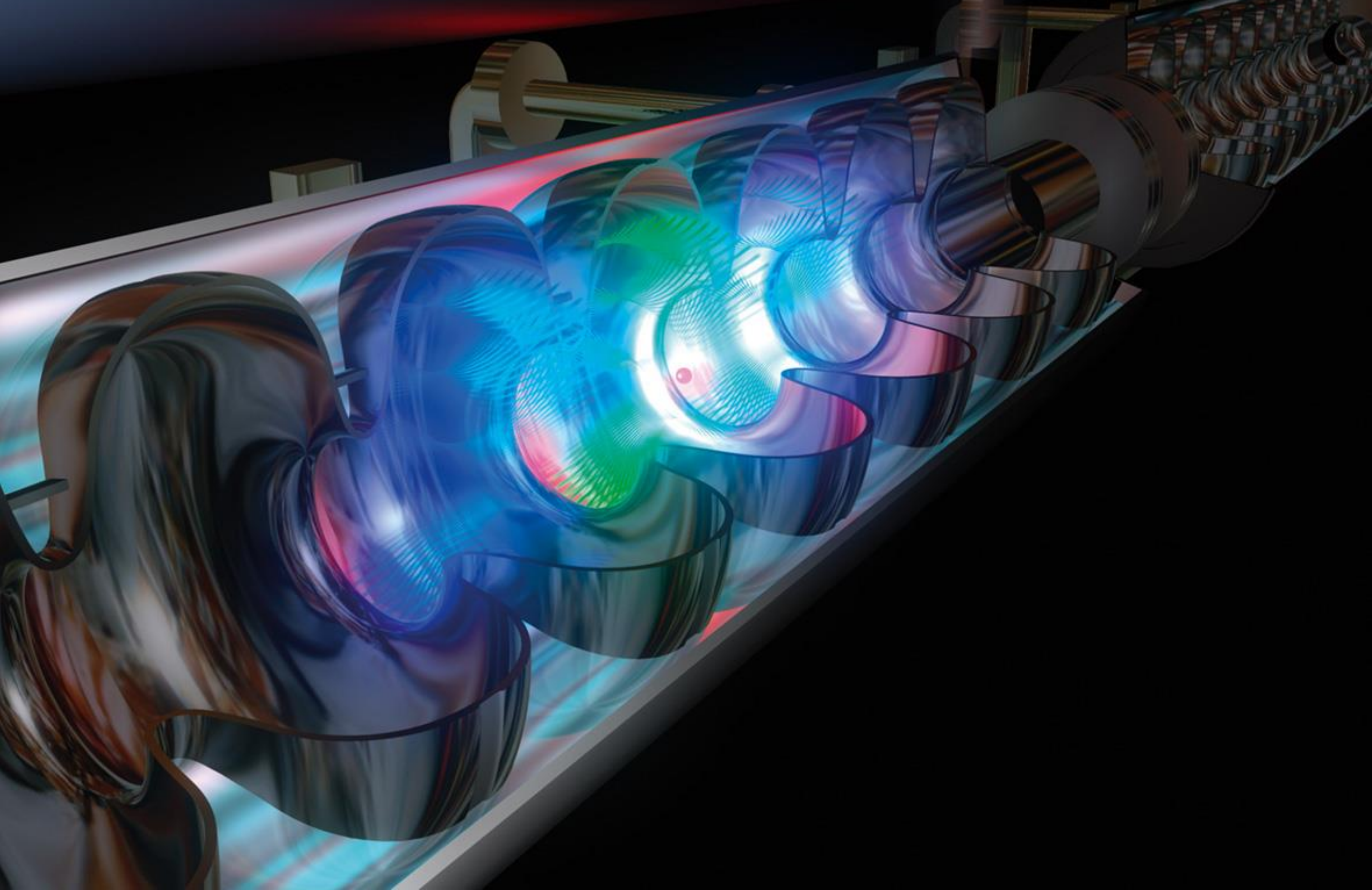
ILC TDR (Accelerator)

- Volume I: R&D report
- Volume II: Baseline Reference
  - ILC parameters @ 500 GeV
  - Technology Choices

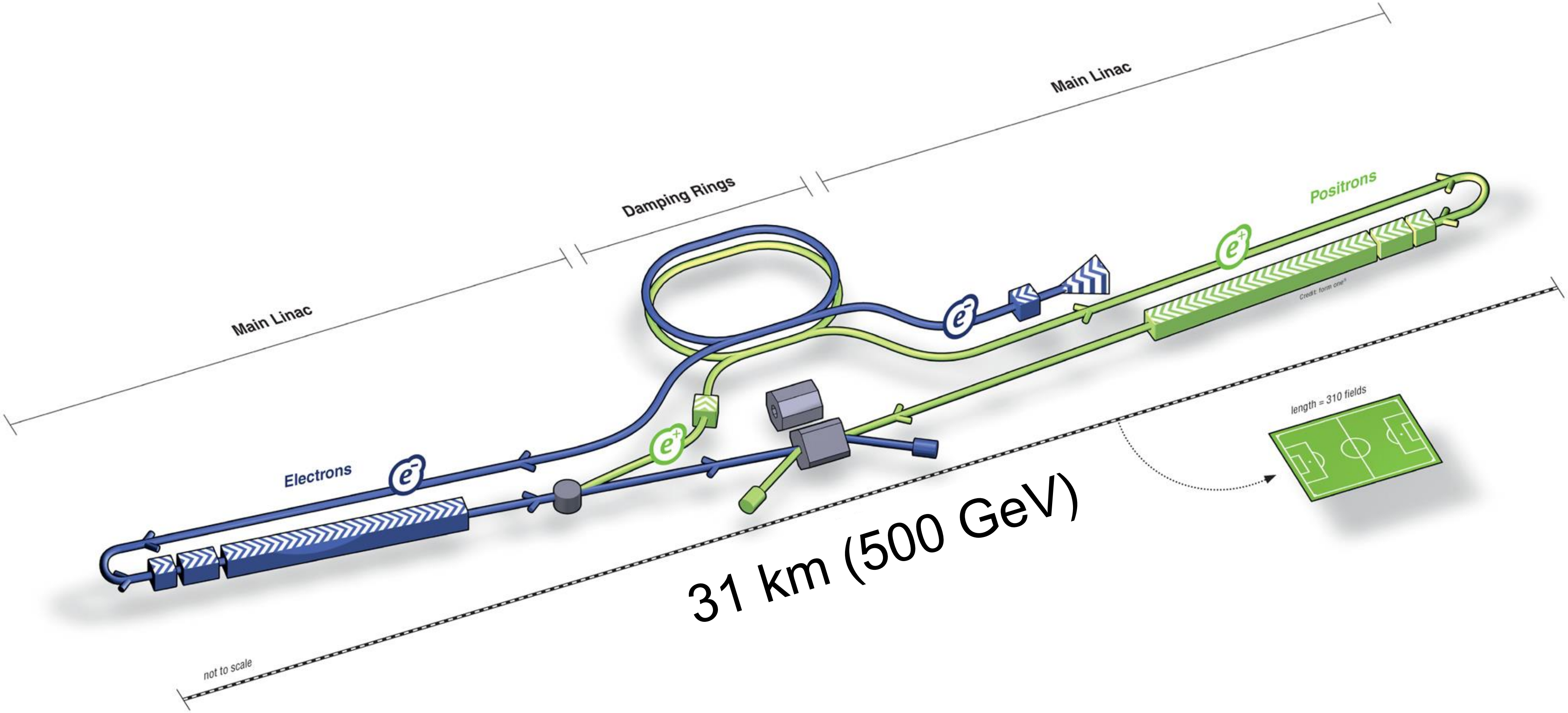
ILC DBD (Detector)

- Executive Summary
- Common Tasks
- Detectors (ILD, SiD)
- Physics Volume

ILC Accelerator

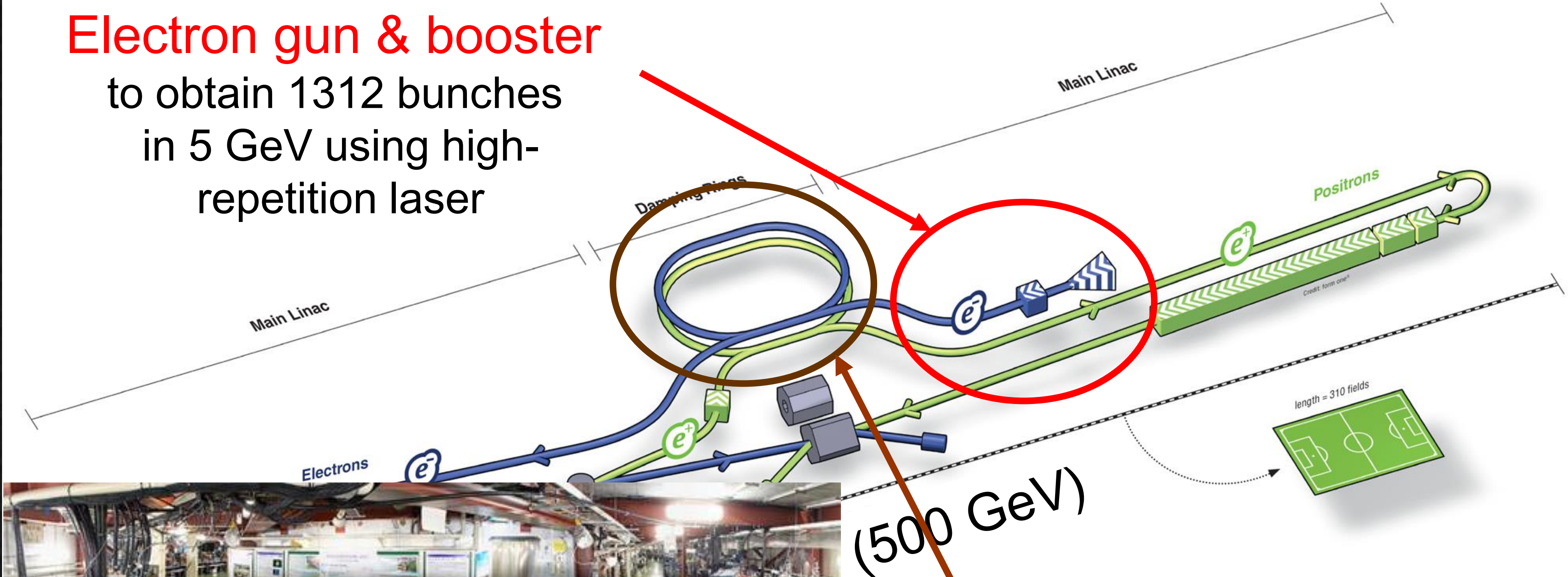


ILC accelerator at a glance



ILC accelerator at a glance

Electron gun & booster
to obtain 1312 bunches in 5 GeV using high-repetition laser

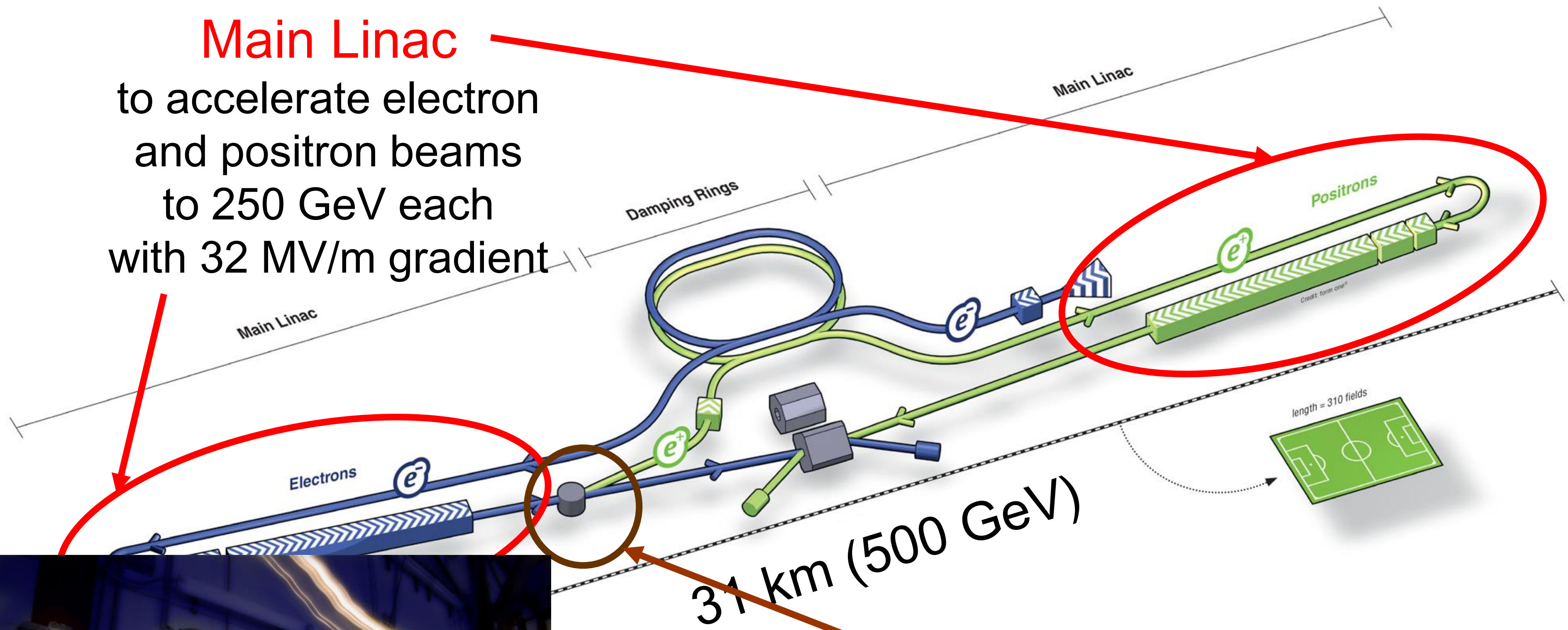


Damping Ring (5km)
to obtain low-emittance beam by rotating > 10,000 turn

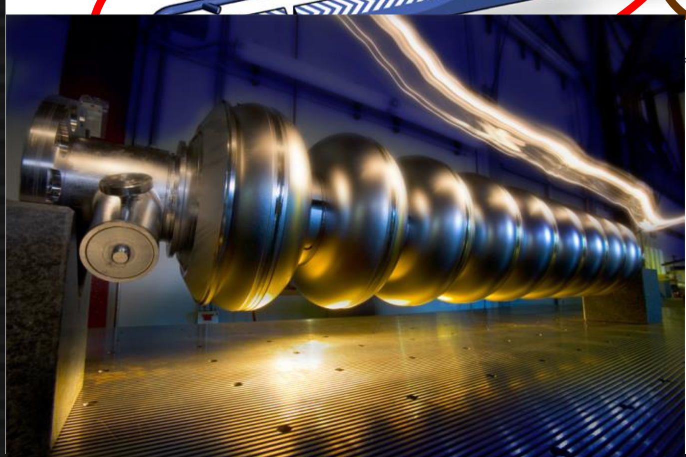
ILC-spec emittance already achieved

ILC accelerator at a glance

Main Linac
to accelerate electron and positron beams to 250 GeV each with 32 MV/m gradient



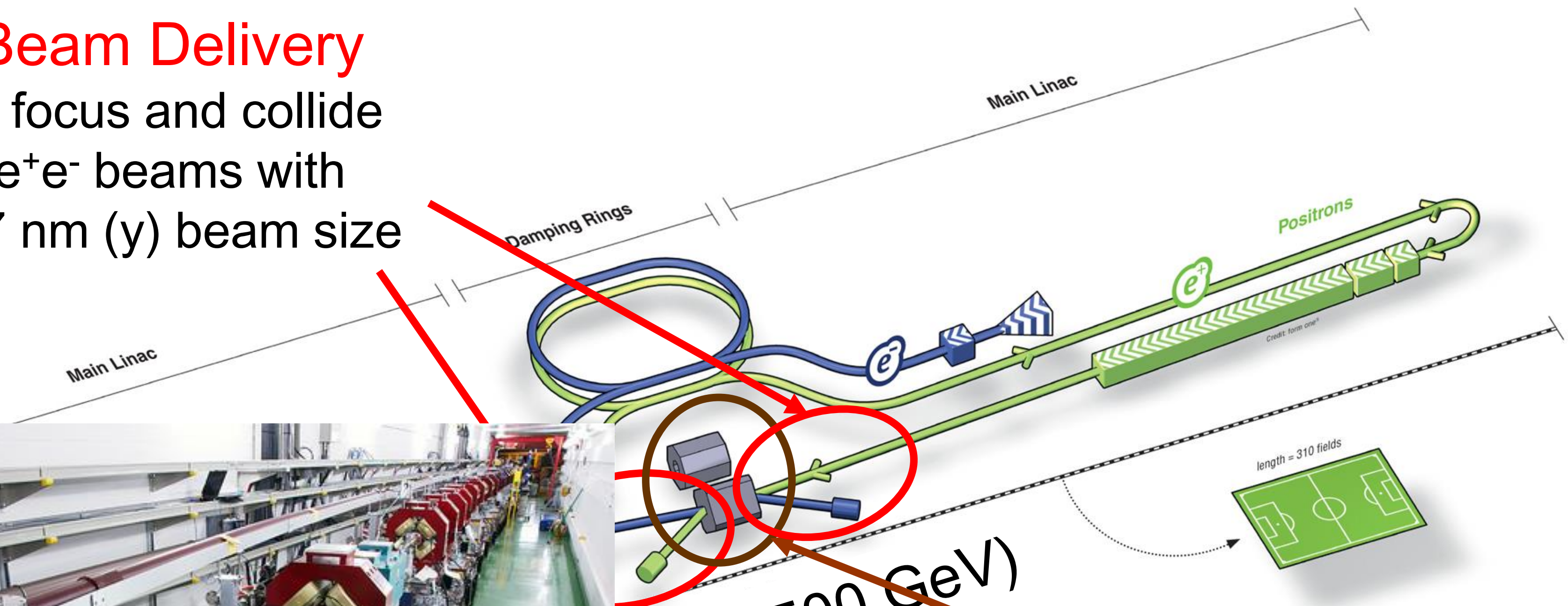
31 km (500 GeV)



Undulator + Target
use synchrotron photons from undulator to create polarized positron

ILC accelerator at a glance

Beam Delivery
to focus and collide
e^+e^- beams with
5.7 nm (y) beam size



1 km (500 GeV)

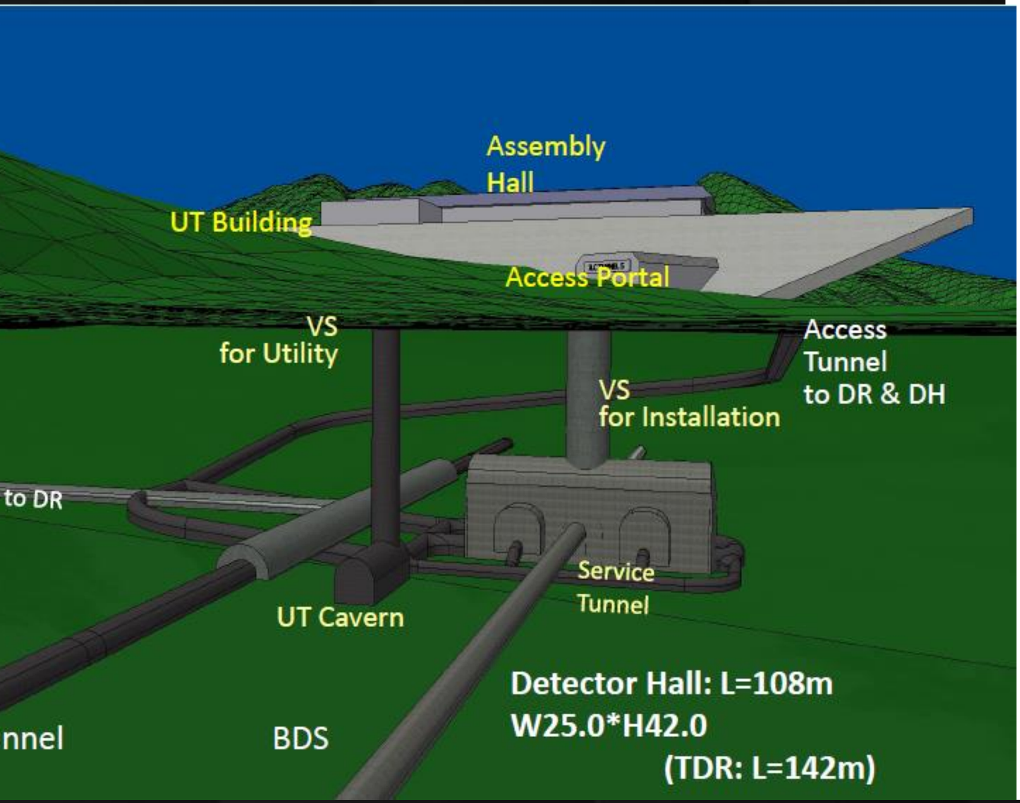
Final Focus test facility

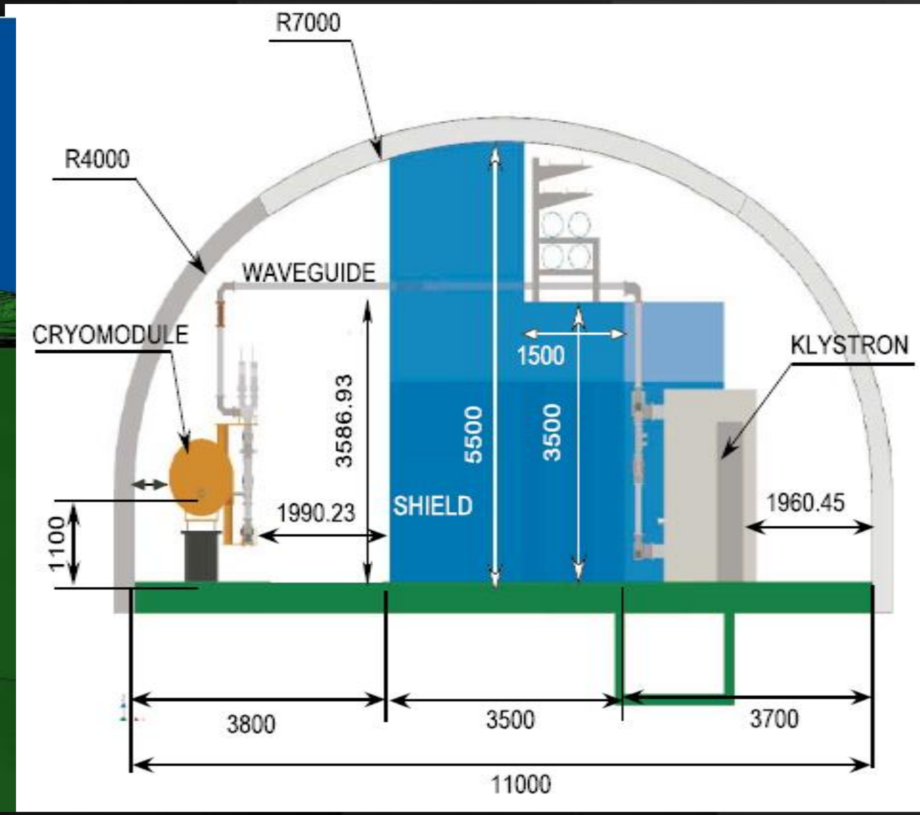
Detectors in push-pull
accommodate two detectors
which can be swapped
in short time

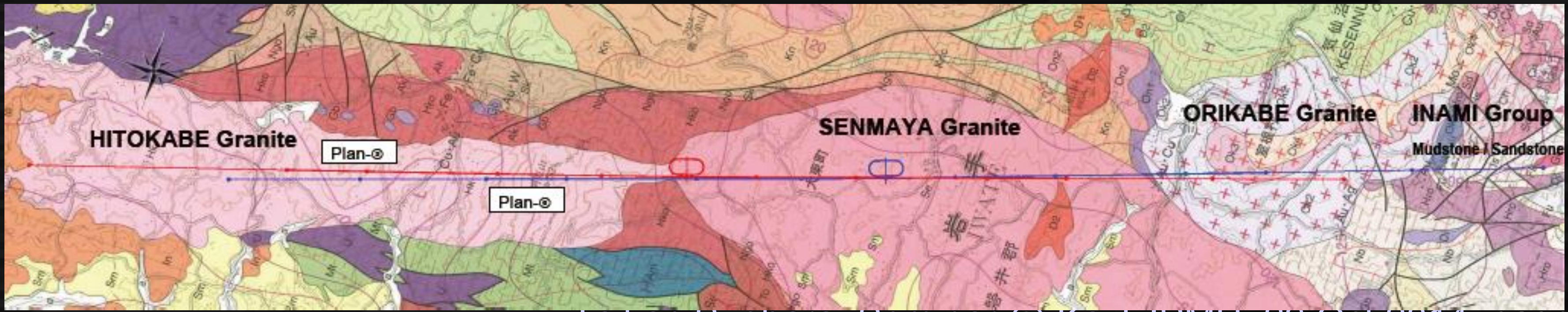
Key technologies

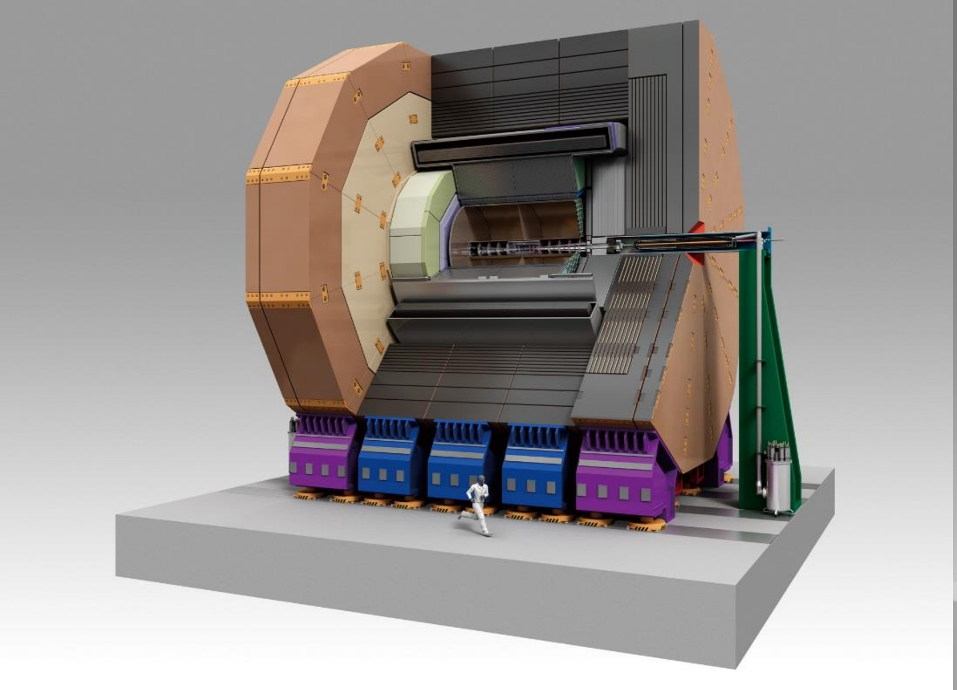
- Positron production
  - Cannot be tested before production
  - Backup option (conventional target) should be more seriously tested
- Main linac
  - Acc. gradient achieved with good statistics
  - Industrialization critically important
- Final focusing
  - 40 nm achieved (recently!) with 1.3 GeV beam
  - < 20 nm only possible in high energy beam

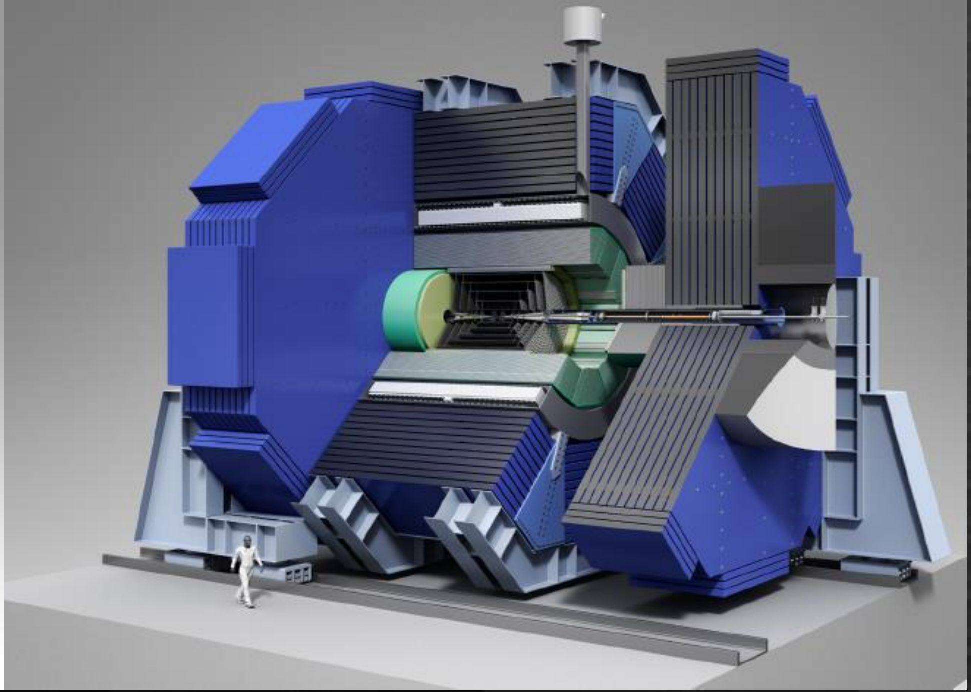
Site studies









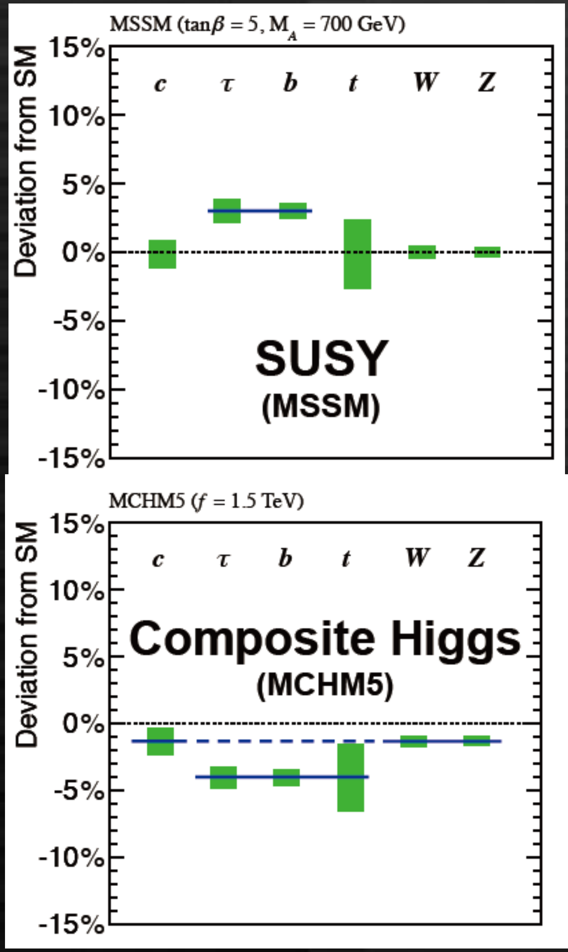


ILC detectors

What will ILC be built for?

1. Higgs as a probe for New Physics

- Higgs discovery phase has been over
  → precise measurements!
- New physics shift Higgs properties
- O(1%) Higgs coupling measurements is critical for new physics search and model identification



2. Various direct/indirect searches

- Electroweakino search (eg. Higgsino)
  ILC is sensitive to LHC blind spots
- DM direct search
- top & electroweak precise measurements
- Exotic search

ILC sales points (cf. LHC)

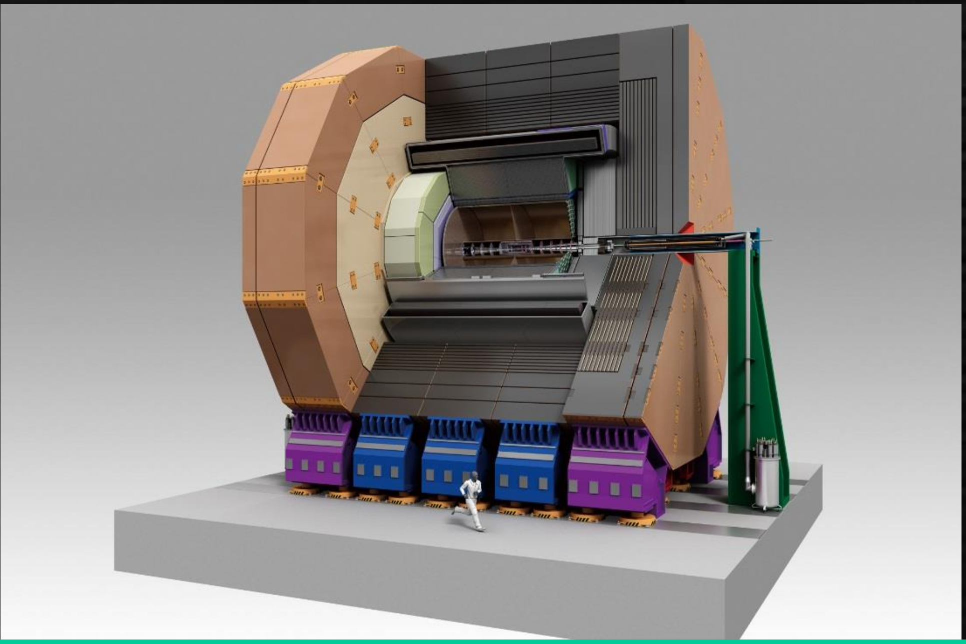
- Electroweak production
  - Predictable process
  - Low background
- 4-Momentum conservation
  - One more constraints
- High resolution detector(s)

ILC & LHC: difference

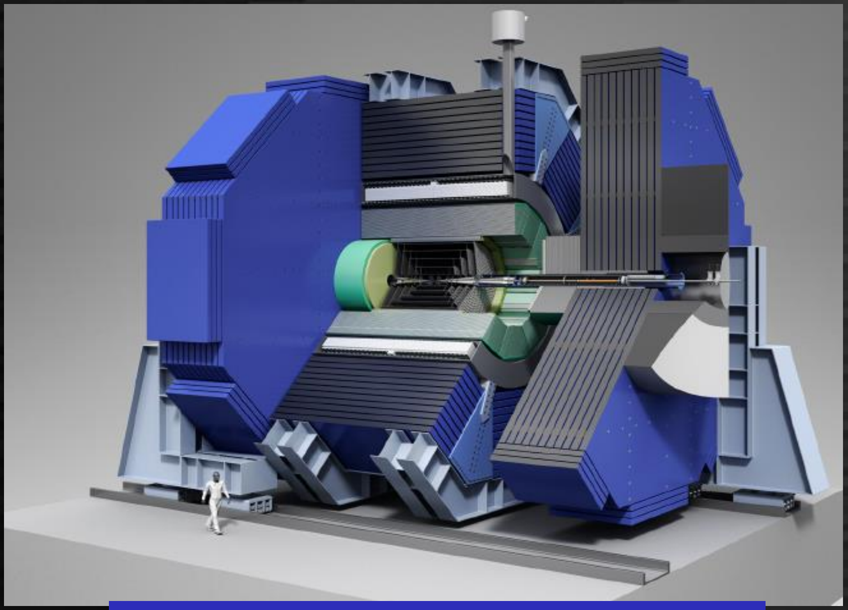
- No QCD production & monochromatic energy
  - LHC: ‘One Higgs per 10^{10} collision’ (collision: qq inelastic)
  - ILC: ‘One Higgs per 100 collision’ (collision: qq production)
- Pileup
  - LHC: O(10-100) per bunch
  - ILC: 1.2 forward low energy jets in 500 GeV
- Radiation
  - LHC: 3.3×10^{15} n_{eq} at 33 mm from IP (ATLAS IBL)
  - ILC: 10^{11} n_{eq} / year at 16 mm from IP
- Trigger
  - ILC: triggerless

Radiation & rate tolerance are less important in ILC → emphasis on resolution

ILC detectors



International Large Detector (ILD)



Silicon Detector (SiD)

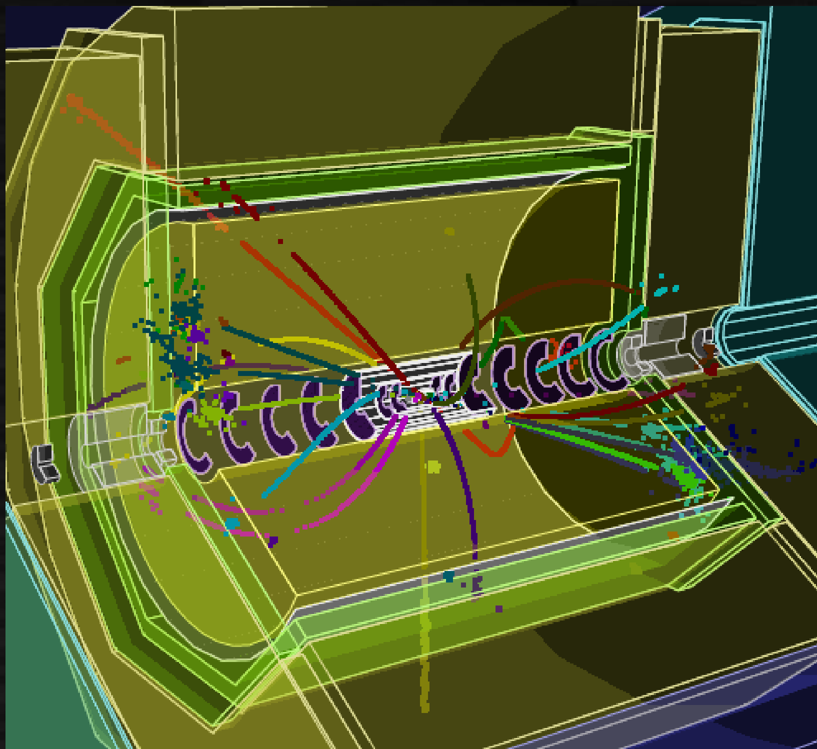
Common features:

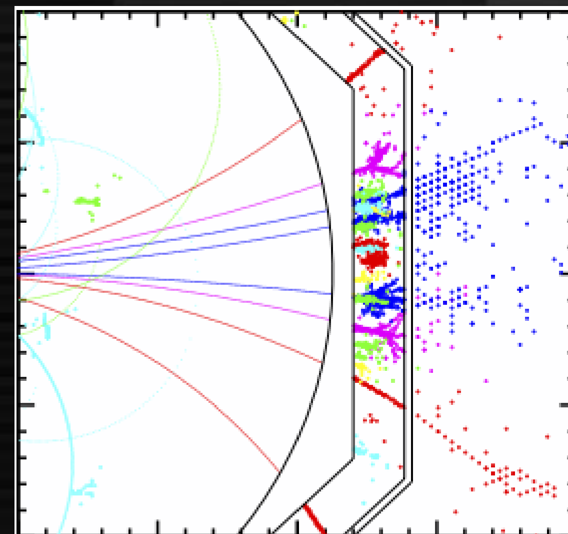
- Low-mass small pixel vertex detector
- Low-mass silicon tracking
- Fine-granular ECAL/HCAL inside coil
- Muon detector
- Forward tracker/calorimeter

Different features:

- Size (SiD: smaller)
- Magnetic field (3.5T/5T)
- Main tracker
  TPC(ILD) Silicon only(SiD)

Detector for Particle Flow





Track-cluster matching 1 by 1
→ Particle flow

Advantages: ~60% of particles in jet are charged hadrons (π/K):
use track momentum for them instead of HCAL
Neutral hadrons (K^0/n) are only ~10%

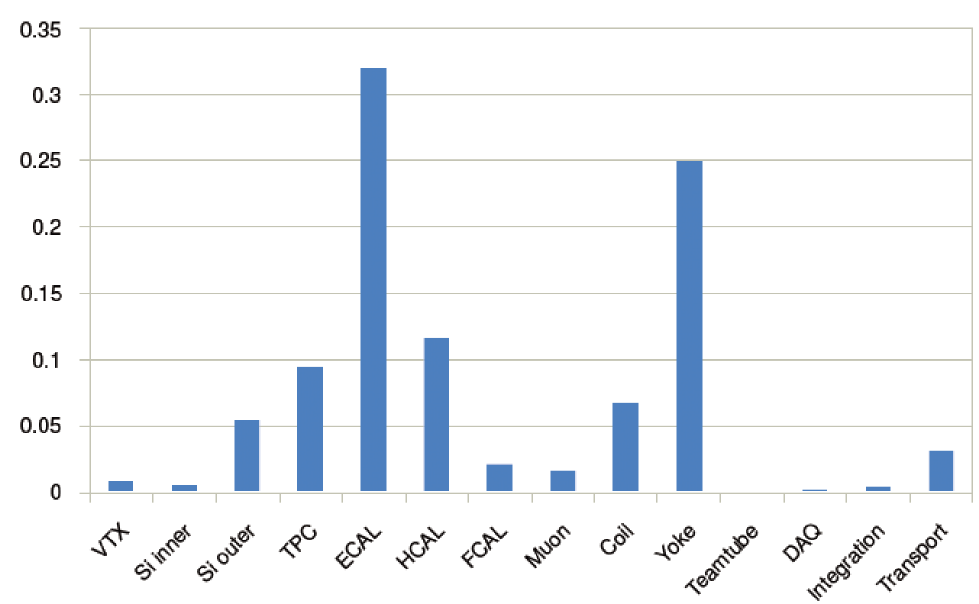
Requirements: Highly granular calorimeter to separate each
→ very precise cells (O(1 cm)) in calorimeters

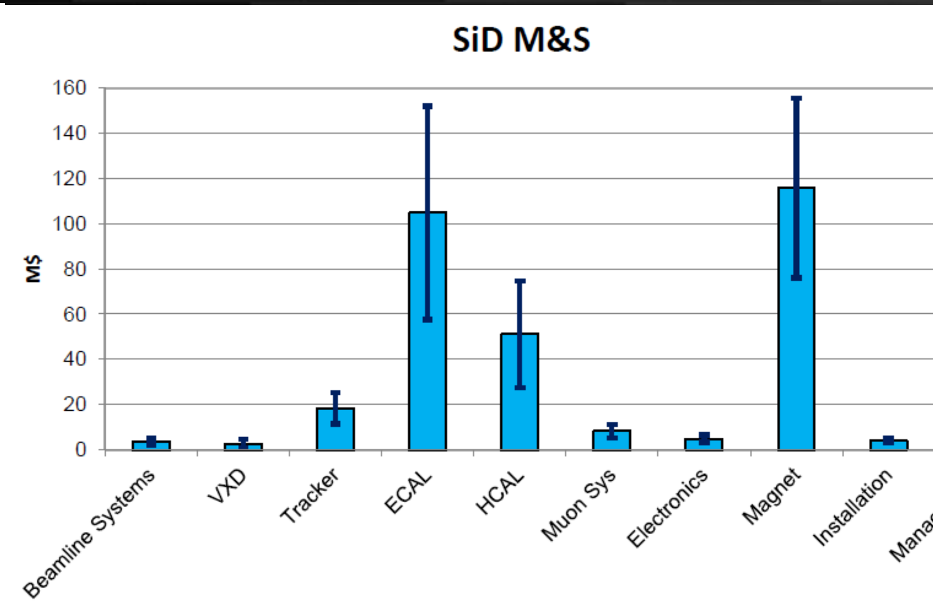
Detector costs

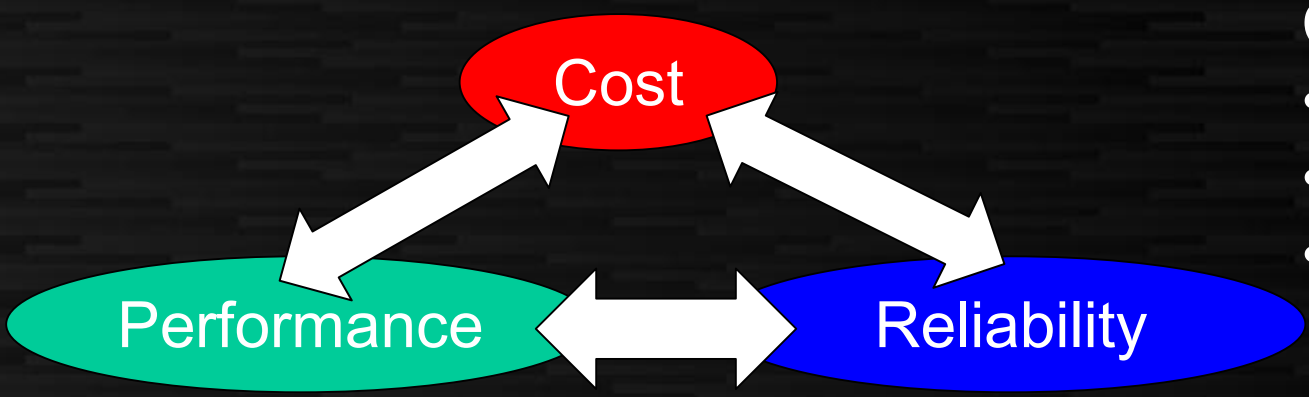
ILC Acc.: 7800 M ILCU

ILD: 391 M ILCU (US$ Jan.2012)

SiD: 314 M US$







Cost concerns:

- Size
- B field
- ECAL

Specialty of ILC detectors

1. Quark flavor tagging capability
   - High S/N ratio in b-tagging
   - Ability of c-tagging

   Vertex

2. Momentum resolution of tracks **Tracking**
3. Jet energy resolution by Particle Flow

   Calorimeter

ILC detector challenges

1. Precise determination of track origin
   – Vertex detector
2. Momentum resolution of tracks
   – Main tracker
3. Jet energy resolution
   – Calorimeter

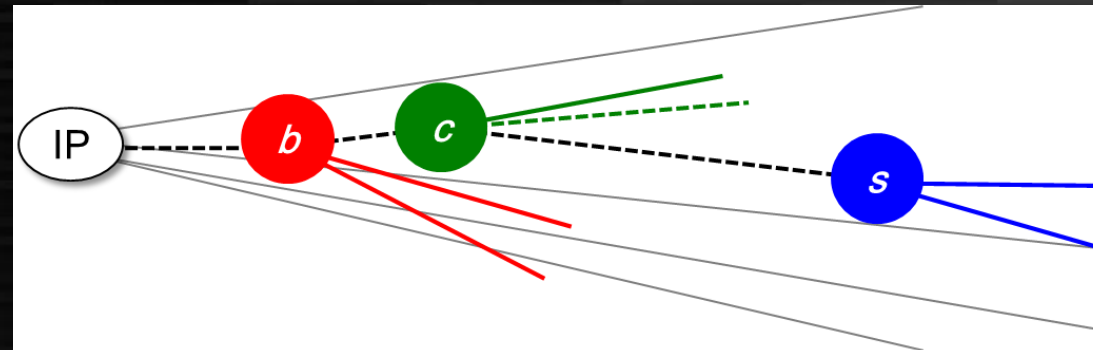
Physics requirements are the key for the optimization

ILC detector challenges

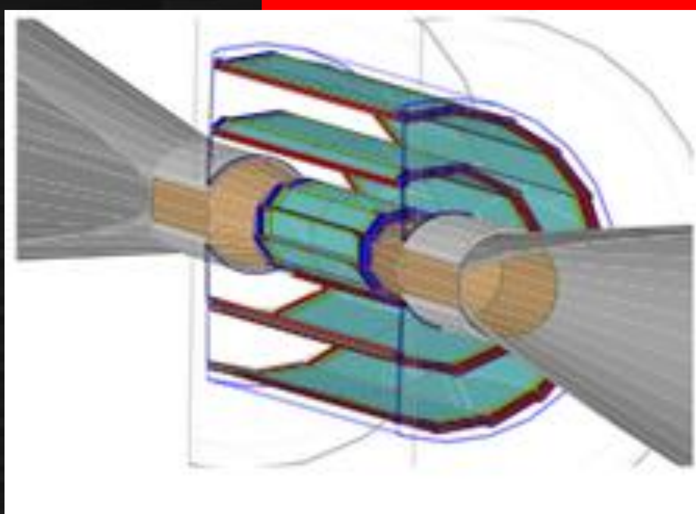
1. Precise determination of track origin
   – Vertex detector
2. Momentum resolution of tracks
   – Main tracker
3. Jet energy resolution
   – Calorimeter

Vertex detector: design

b hadrons: $c\tau \sim 400\ \mu m$
c hadrons: $c\tau$ 30-300 μm
τ: $c\tau = 87\ \mu m$
BSM quasi-stables

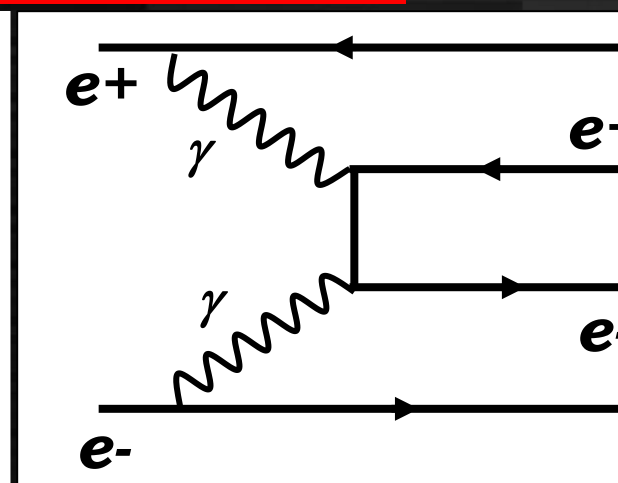


Target: 5 μm position resolution for high-p tracks within high background environment



ILD: 3 double layers

SiD: 5 single layers



beam background

Both at r=14-15 to 60 mm

Vertex detector: technologies

Many hits overlaid – pixel detector!

ILC beam: 1300 bunches with 300 nsec interval

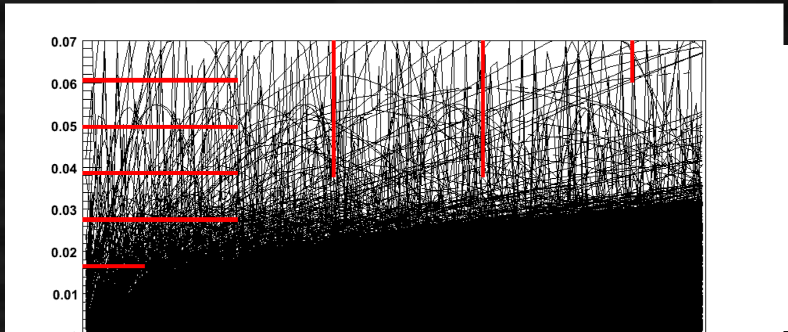
Two options:

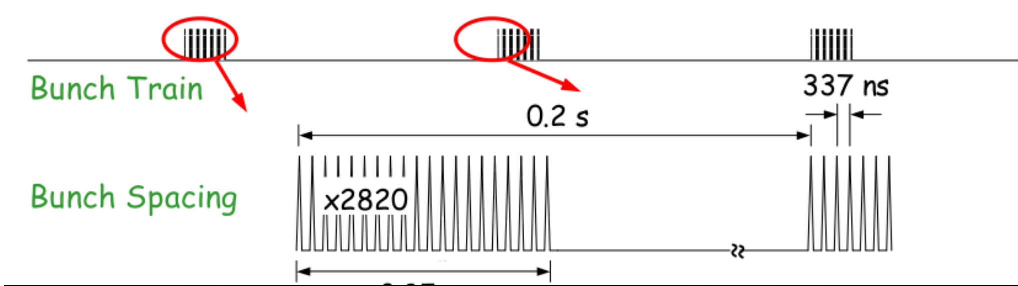
- Faster readout (to reduce bunches to be overlaid)
  - CMOS-type, SOI, 3D, MAPS, etc.
- Smaller pixels (to reduce occupancies by hits)
  - Fine pixel CCD (bonus: better resolution)

Technologies developing

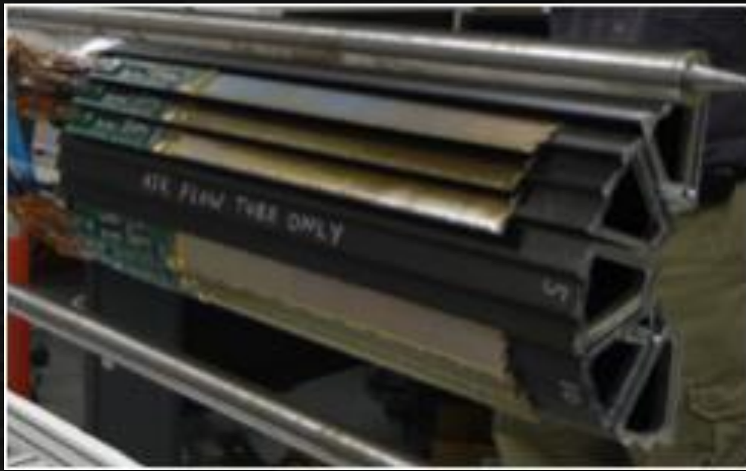
Vertex detector is the last to be installed

- options can be delayed for ~ 5 years

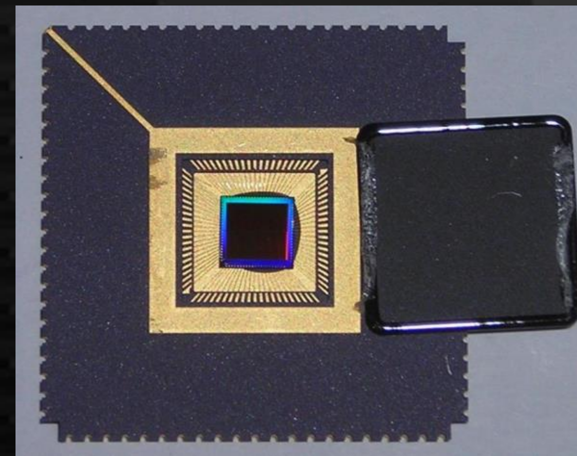




Faster readout: many techs.

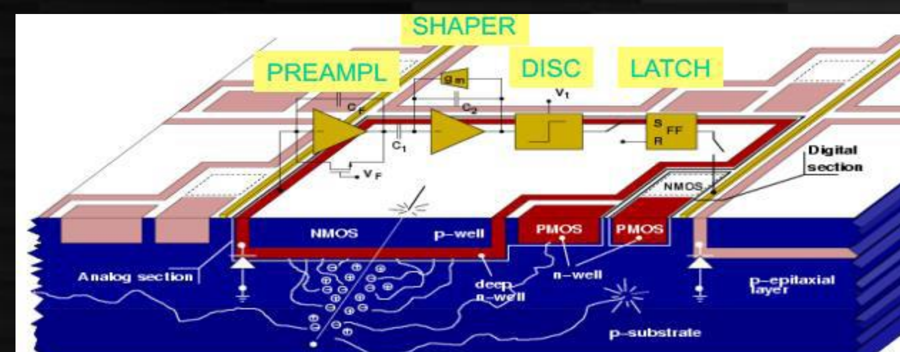


CMOS: readout in 32 μs
(~ every 100 bunches)
with 20 x 20 μm pixels



Chronopixel: aims to
specify bunch on every hits
20 x 20 μm pixels

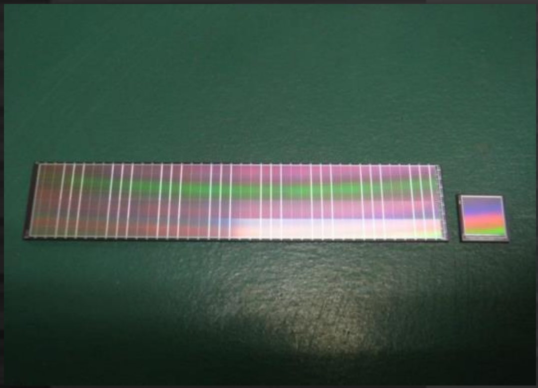
DEPFET: will be used in Belle2



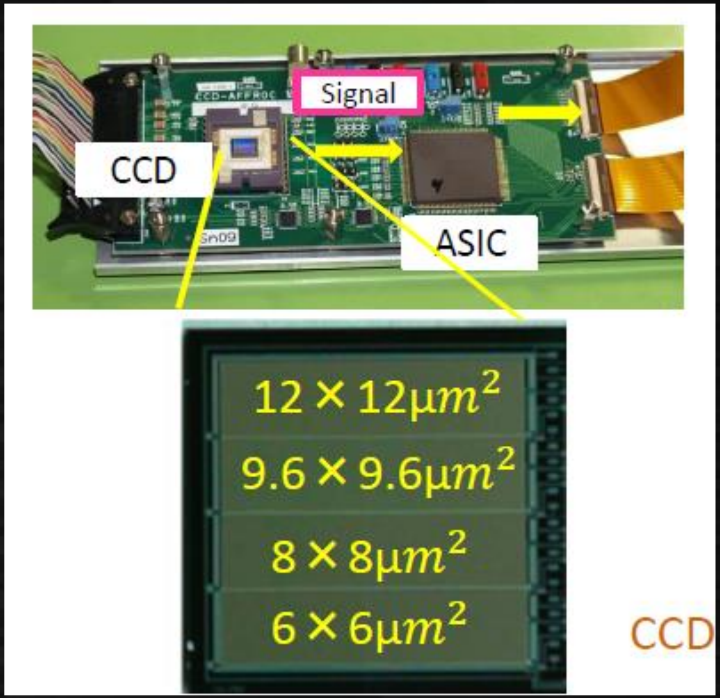
3D sensor in development

Fine Pixel CCD

KEK, Tohoku, Shinshu + Hamamatsu



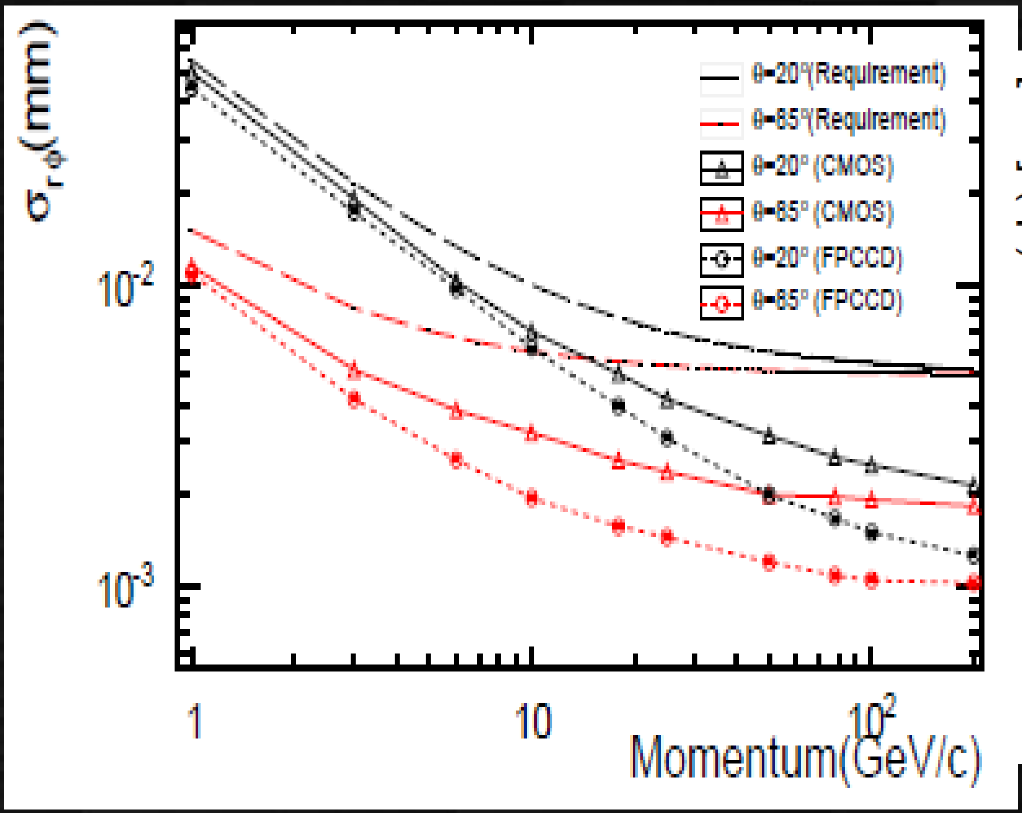
5 x 5 μm pixel (goal), 6 x 6 μm (current)
occupancy will be < 3% at 250 & 500 GeV
after integrating all bunches in a train



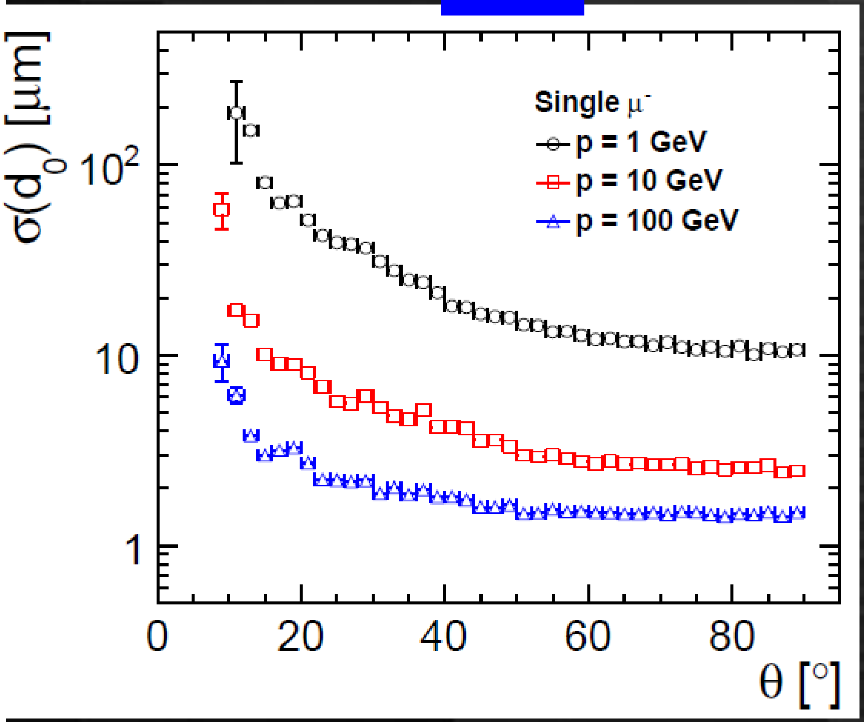
- 50 μm thickness is realized
- Beam test planned (J-PARC)
- Neutron damage test done at CYRIC (Tohoku)
  → slight degradation at charge transfer seen, analyzing
- CO2 two phase cooling: to be tested
- Pair bkg. rejection software is essential

Expected Performance

ILD



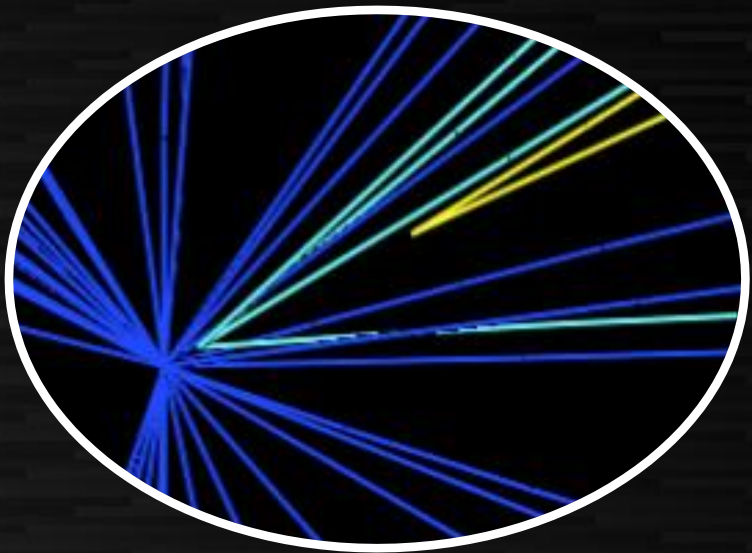
SiD

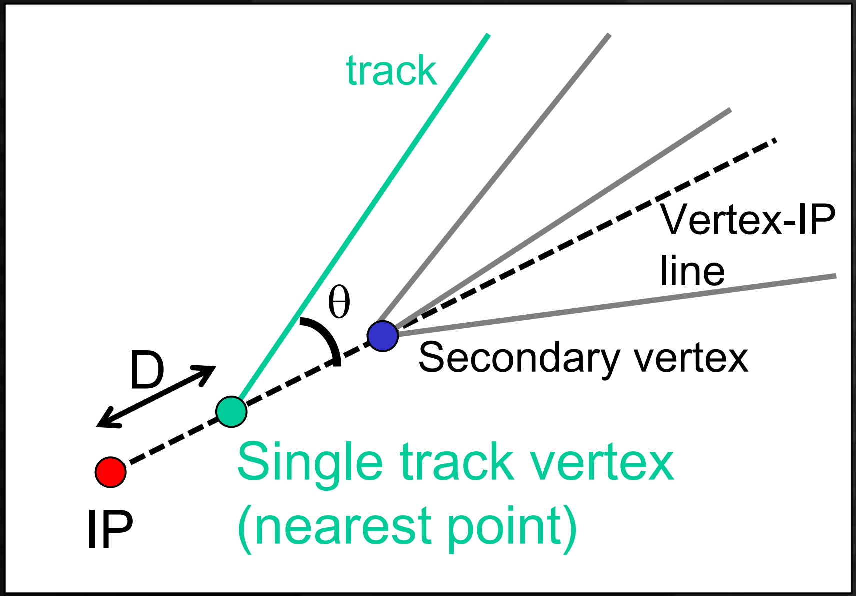


< 5 μm impact parameter resolution with 20 μm pixels

1-2 μm impact parameter resolution with 5 μm pixels

Vertex finder





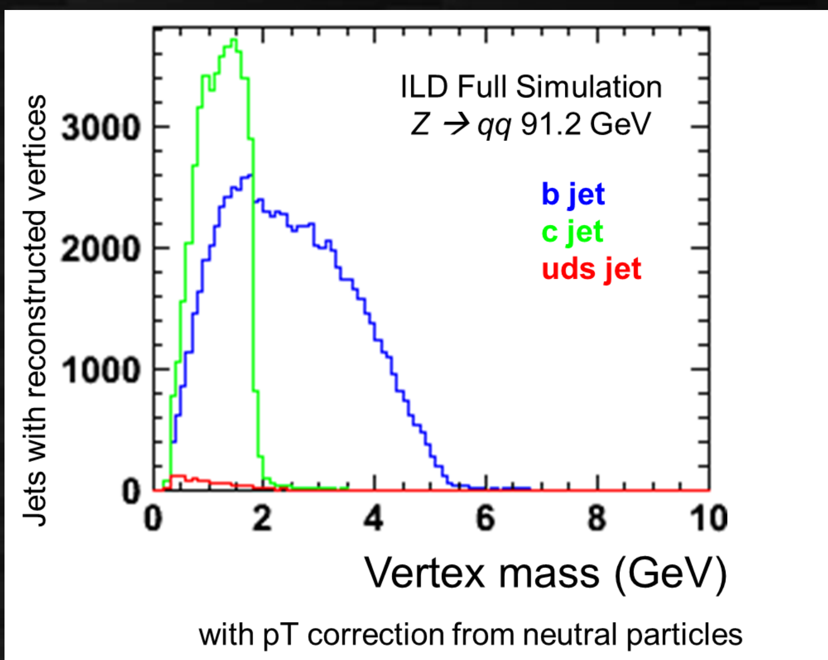
Incorporated in LCFIPlus package

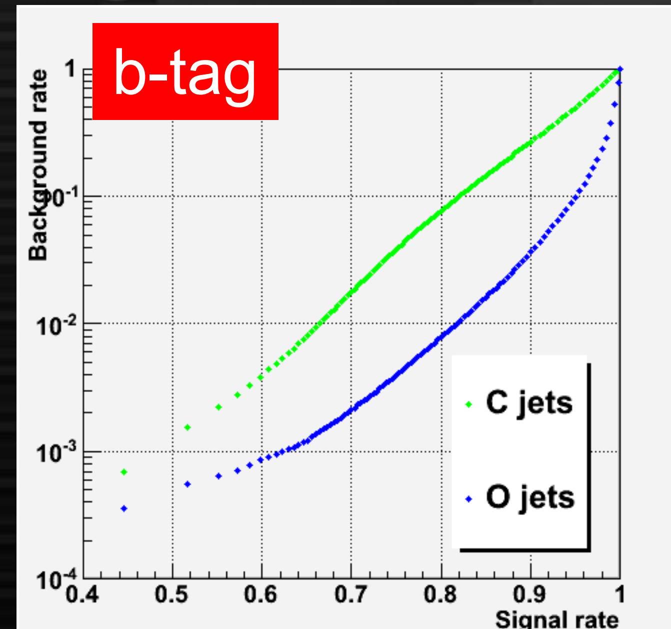
- Build-up method is used for secondary vertex finder
- Does not require jet direction (avoid jet ambiguity)
  → better in multi-jet environments (ZHH etc.)
- Single track can be used to be assigned to second vertex to identify b-c cascade decay

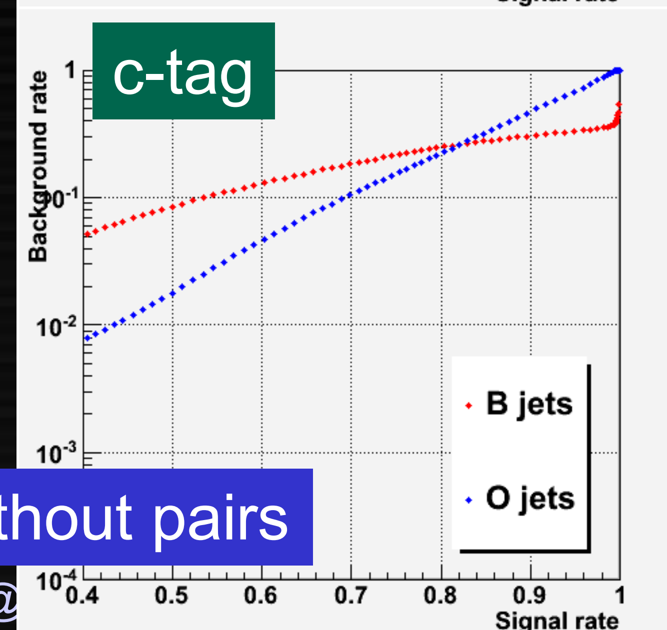
Flavor tagging

In LCFIPlus package

- Multivariate analysis (BDT)
    - Separated by # of vertices
    - Vertex position/mass/tracks
    - Impact parameters of tracks
    - ~ 20 variables
- c-tag depends on vertex resolution







without pairs

ILC detector challenges

1. Precise determination of track origin
   – Vertex detector
2. Momentum resolution of tracks
   – Main tracker
3. Jet energy resolution
   – Calorimeter

Tracker: design & requirement

Requirements

- High momentum resolution
- Low material

Two approaches

- Silicon-only tracking (SiD)
- Silicon + TPC (ILD)

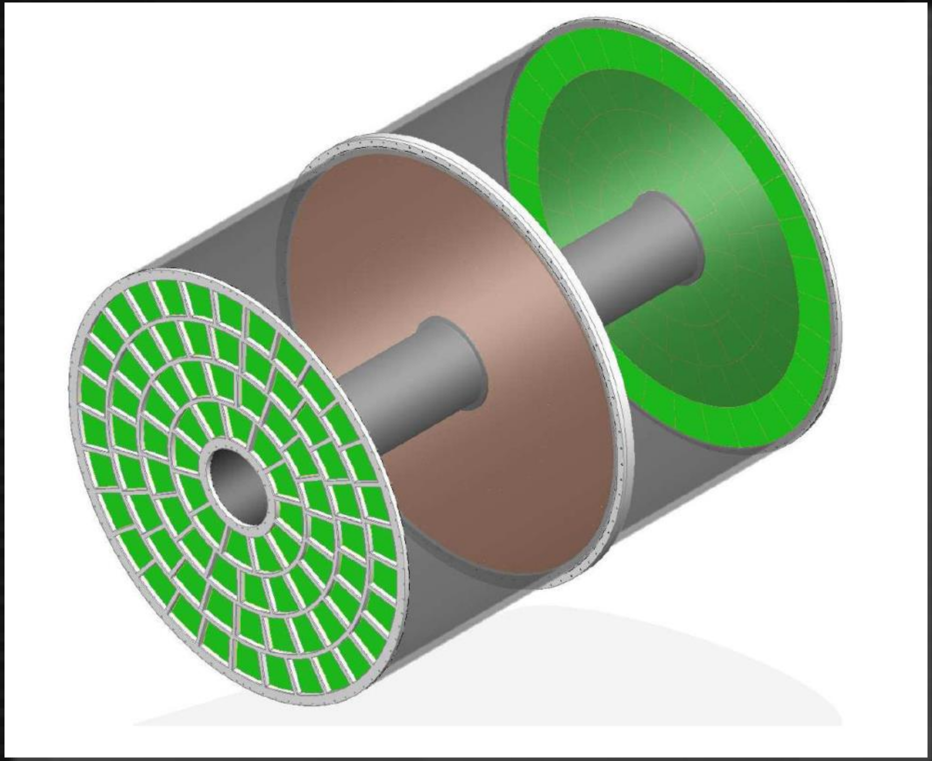
Both gives similar performance & cost

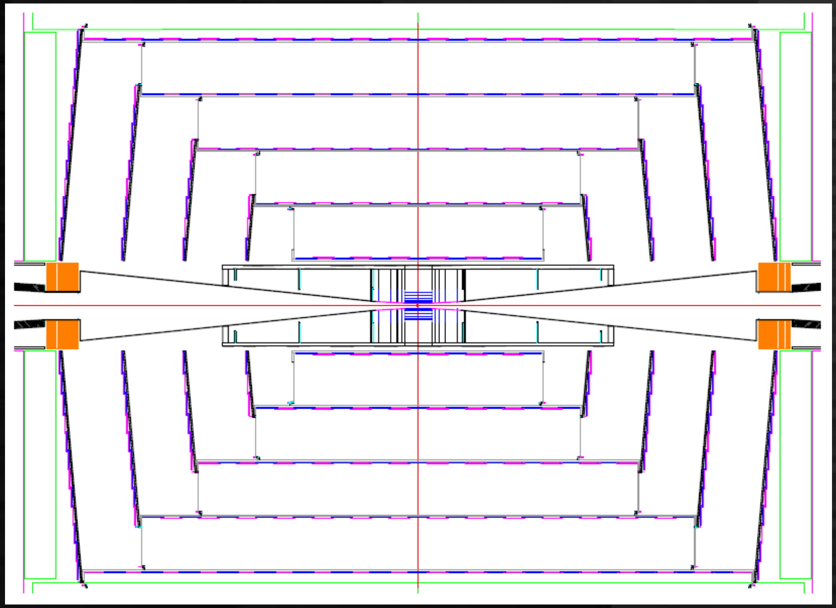
Main tracker – TPC vs silicon only

ILD: Time Projection Chamber
+ inner silicon (2 layers)
+ outer silicon (2 layers)

SiD: Silicon strip only (5 layers)

(+ 5-6 layers of vertex detector
for both ILD & SiD)

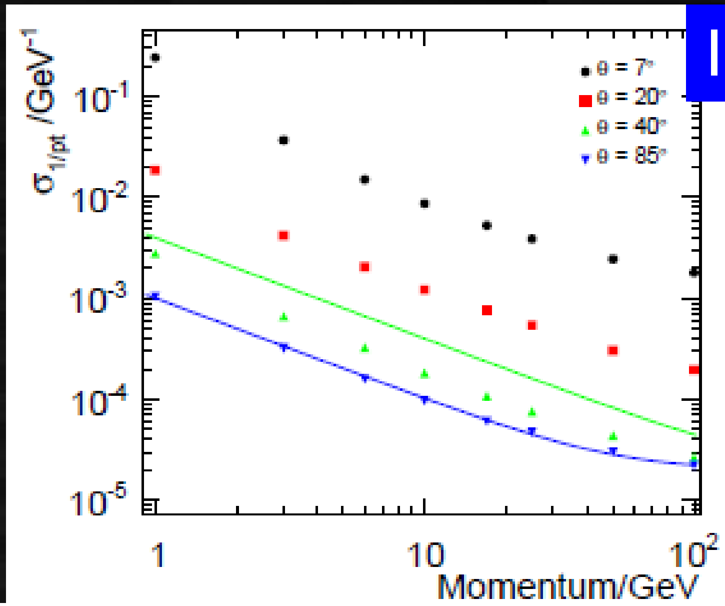


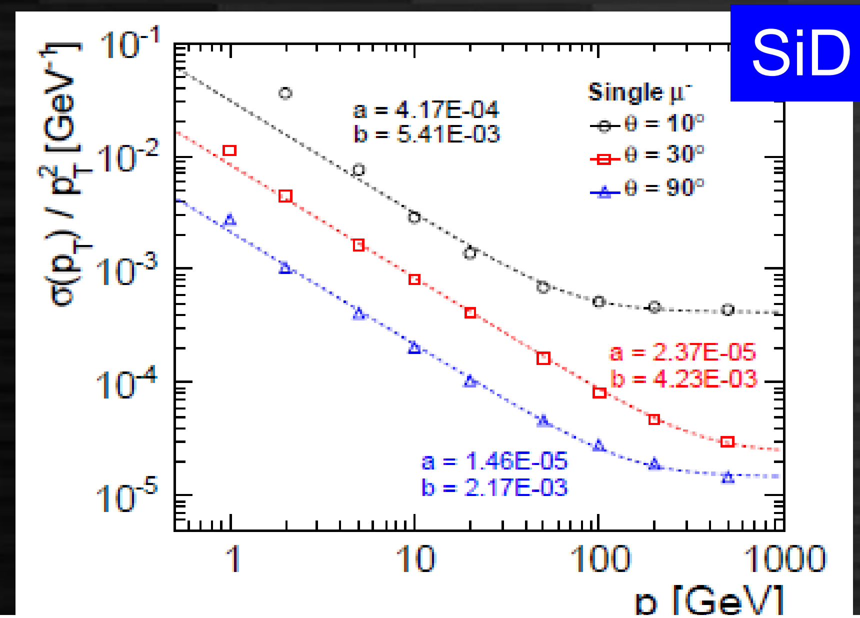


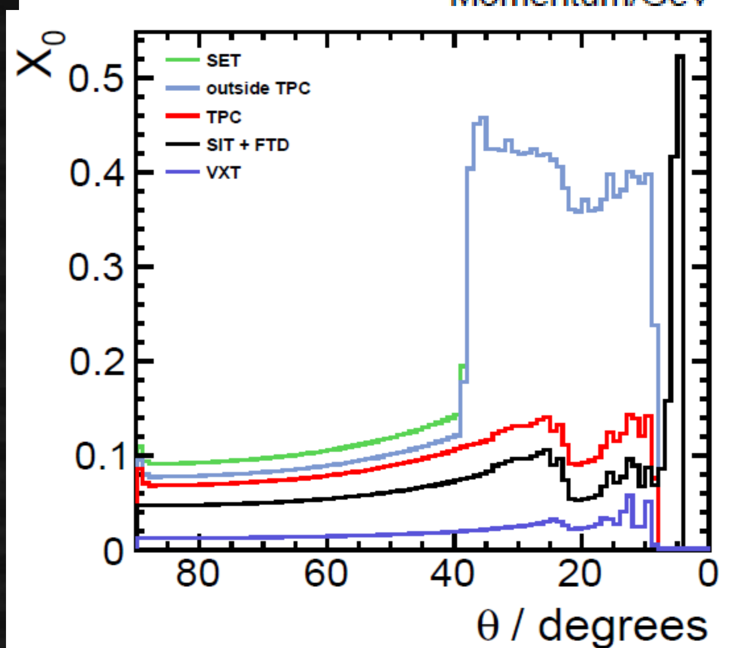
3.5 Tesla, r_{max} ~ 1800 mm

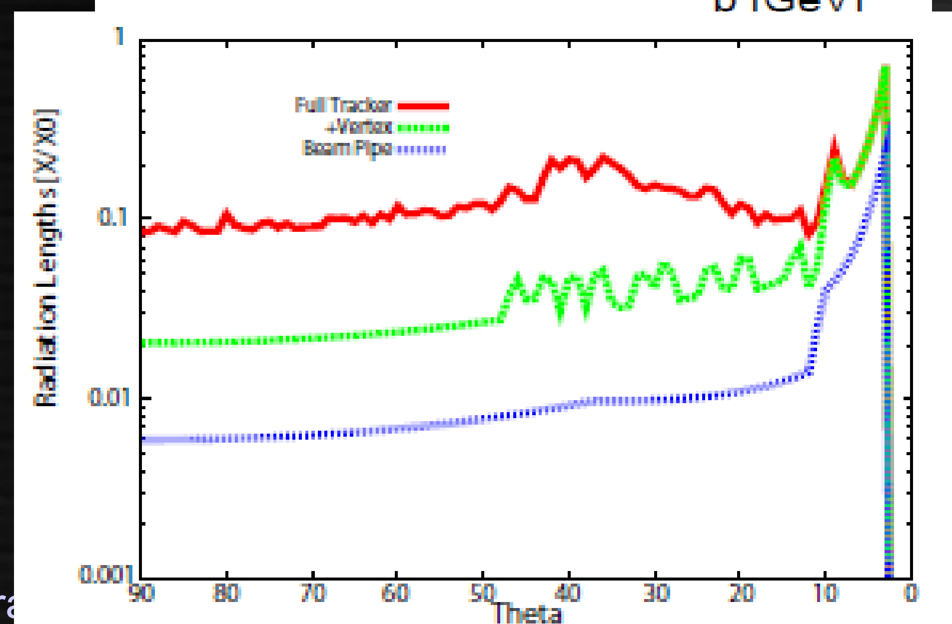
5 Tesla, r_{max} ~ 1220 mm

Resolution / material

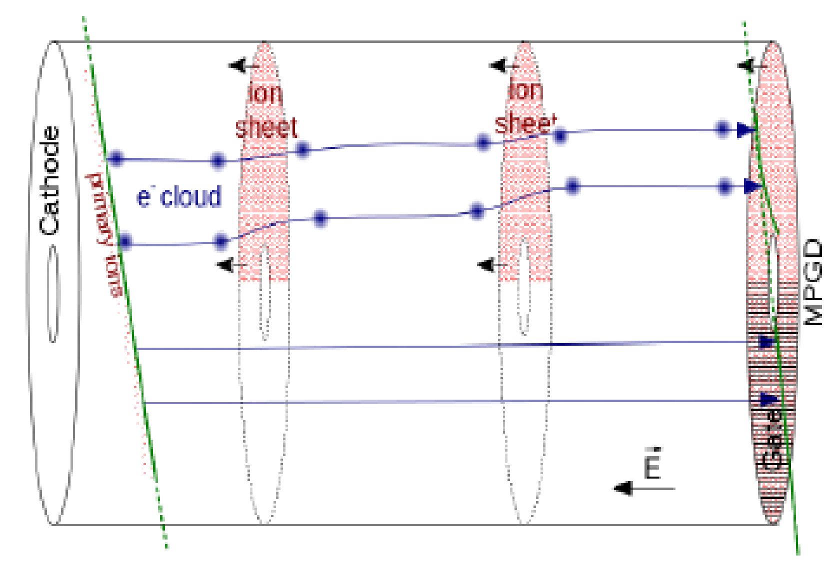








Time Projection Chamber (+ Silicon)



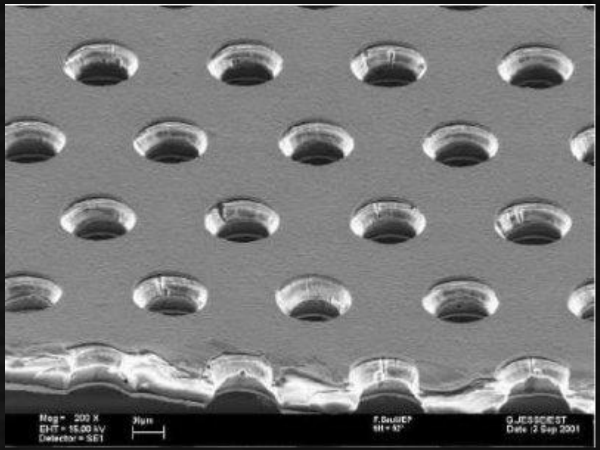
Advantages

- Continuous tracking good for non-pointing tracks and dense tracks
- dE/dx capability for PID
- 2ns topological time stamping with inner silicon strips

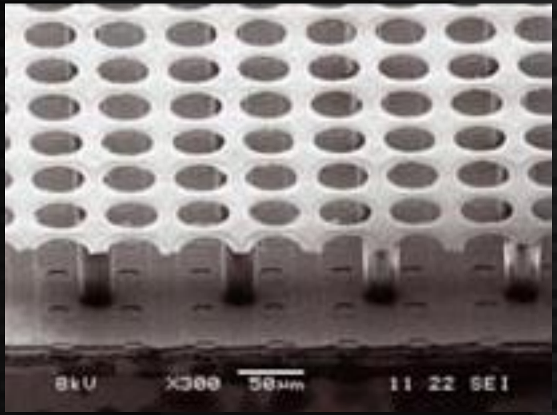
Issues/Disadvantages

- Field distortion by ions from gas amplification → 'gating'
- Cathode plane at z=0
- worse spatial resolution (~ 60 μm)
  - Compensated by number of hits → similar resolution to Si

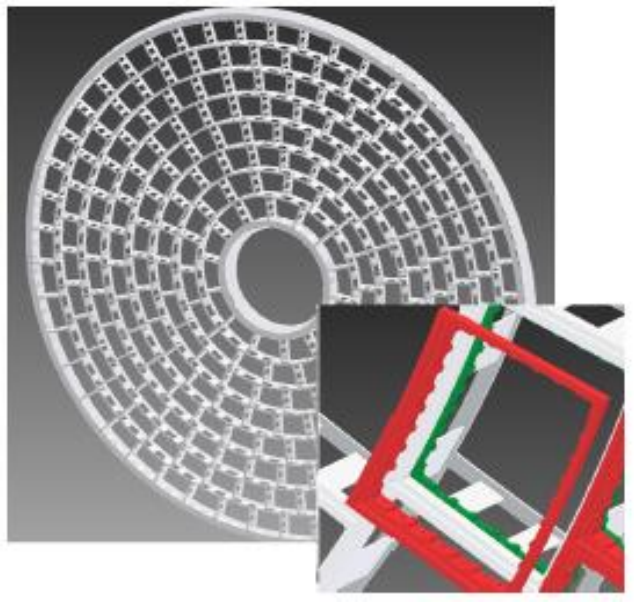
TPC amplification & readout

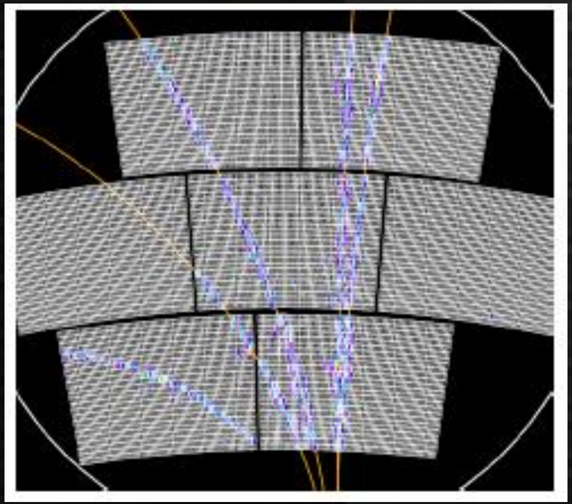


GEM



Micromegas





track at test beam

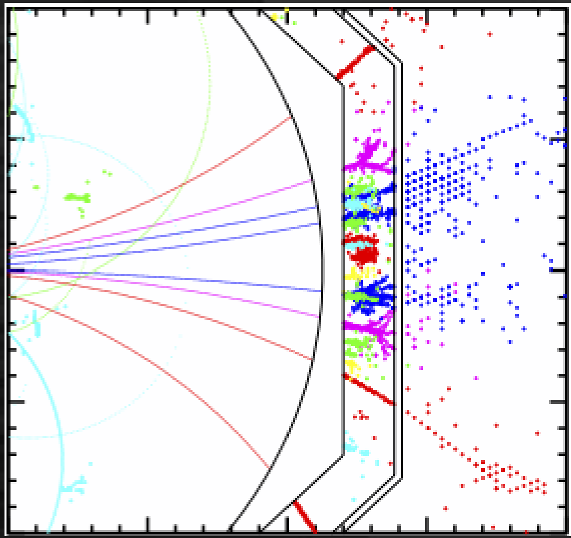
ILC detector challenges

1. Precise determination of track origin
   – Vertex detector
2. Momentum resolution of tracks
   – Main tracker
3. Jet energy resolution
   – Calorimeter

Particle flow calorimetry

Separate each particle in jet

	Detector	Fraction	Resolution
Charged Particle	Tracker	~ 60%	0.1% / $p_T \sin\theta$ (GeV) for each
Photon	ECAL	~ 30%	15% / $\sqrt{E}$ (GeV)
Neutral Hadron	HCAL	~ 10%	60% / $\sqrt{E}$ (GeV)
ILC Calorimetry	All		30% / $\sqrt{E}$ (GeV)



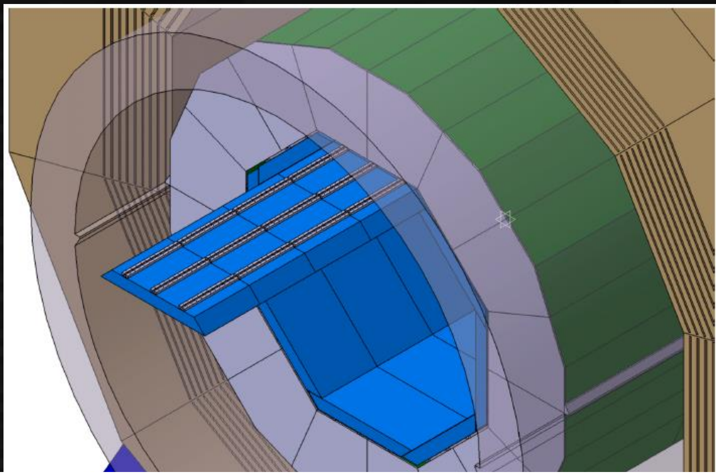
PFA simulation

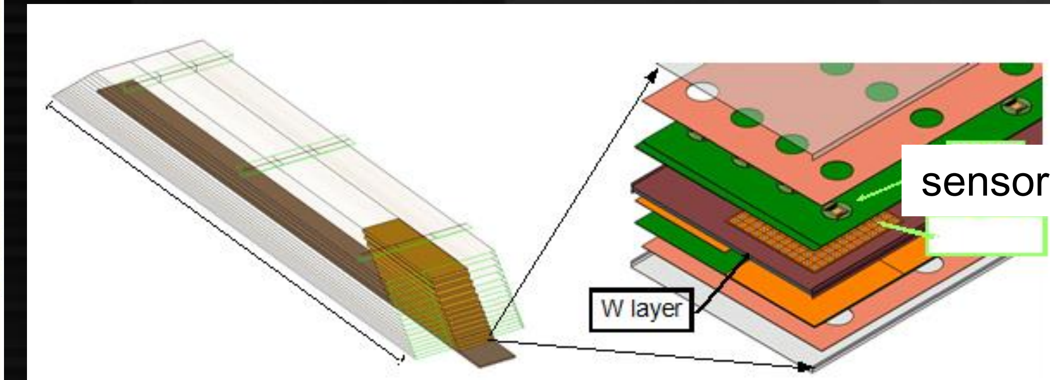
Performance of particle flow calorimetry depends on

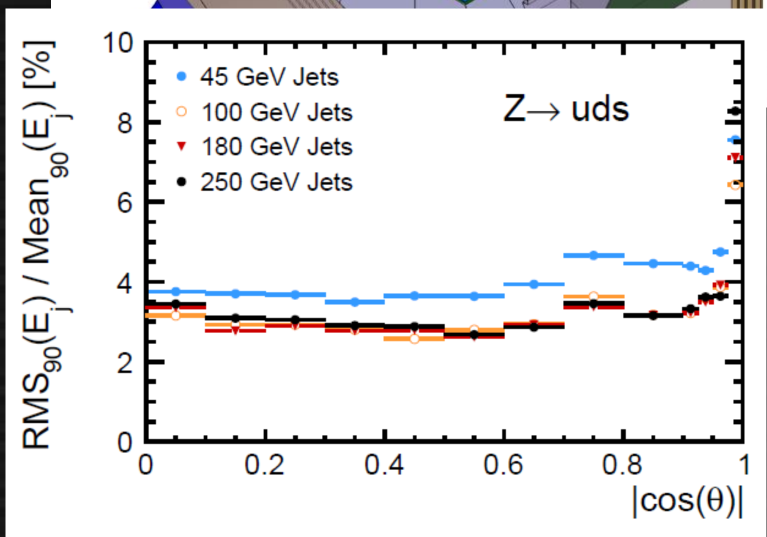
- Mis-clustering → highly granular calorimeter (esp. ECAL)
- Energy resolution of neutral hadrons → HCAL

- Jet clustering dominates in many-jet (6-, 8-jet) final states

ILC Calorimeter







30 %/√E_j obtained for E_j < 100 GeV
(50 %/√E_j expected without PFA)

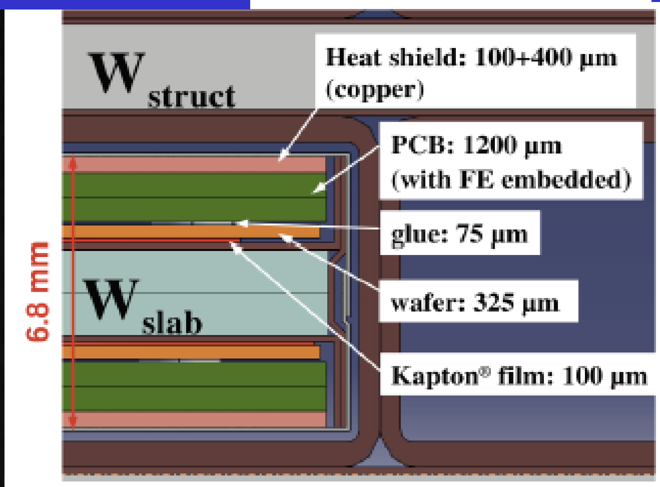
- Sandwich calorimeter
  ECAL: ~ 30 layers, W absorber
  (baseline: Silicon sensor for both ILD/SiD)
  HCAL: 40-50 layers, Fe absorber
  (baseline: Scintillator(ILD) or RPC(SiD))
- Highly granular cells
  ECAL: ~ 5 mm HCAL: 1-3 cm cells
  (in baseline options)
  ASICs/electronics between layers

ECAL

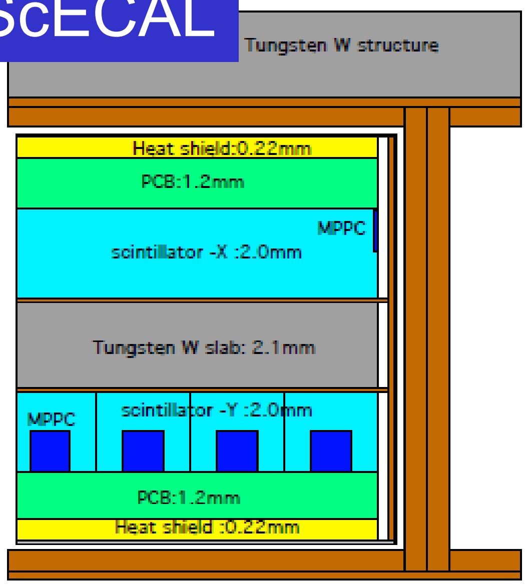
Absorber: W
- 2-2.5 mm thick
- maybe thicker in outer layers

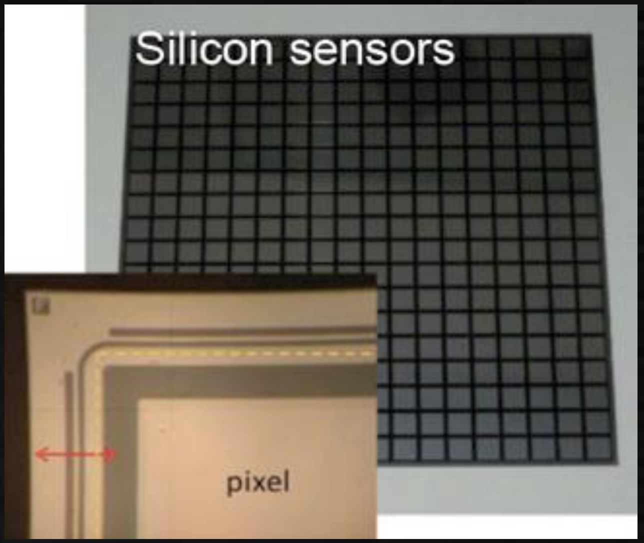
Readout several options:
- Silicon ECAL
- Scintillator ECAL with SiPM
- Hybrid (Si + Sc)
- MAPS (digital readout, 50 x 50 μm pixel)

SiECAL



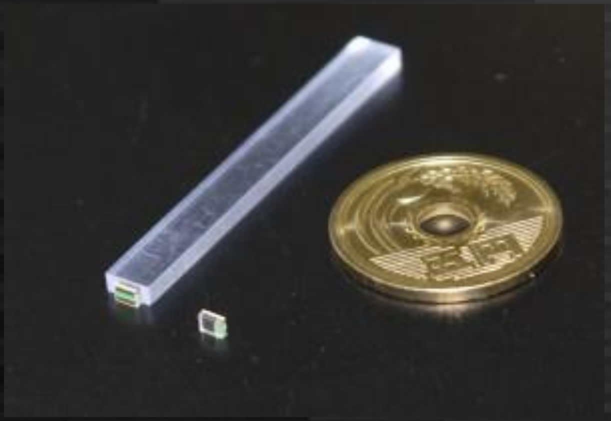
ScECAL

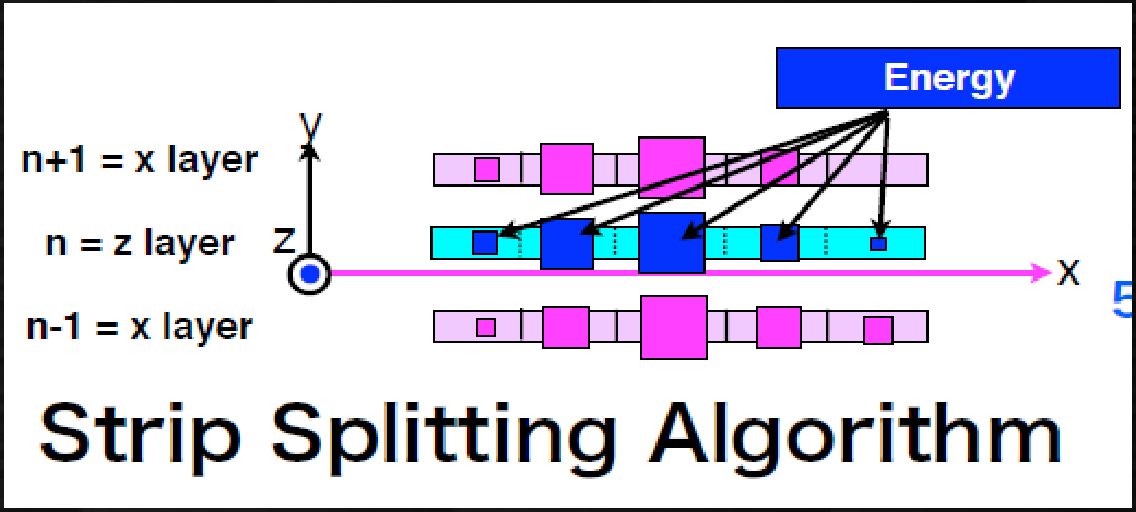


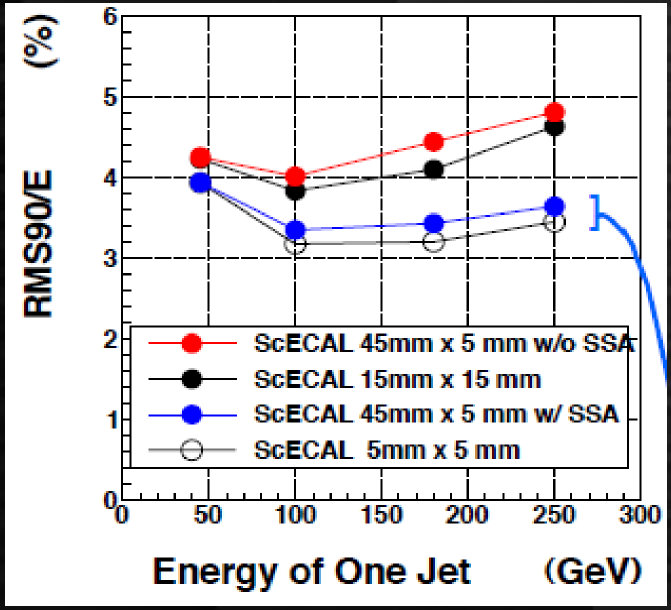


Strip scintillator/clustering

- Scintillator strip (5 x 45 mm) is proposed instead of tiles for ECAL
- Layering horizontal and vertical strips may come to similar resolution as 5 x 5 mm tiles
- Cost is almost half of SiECAL



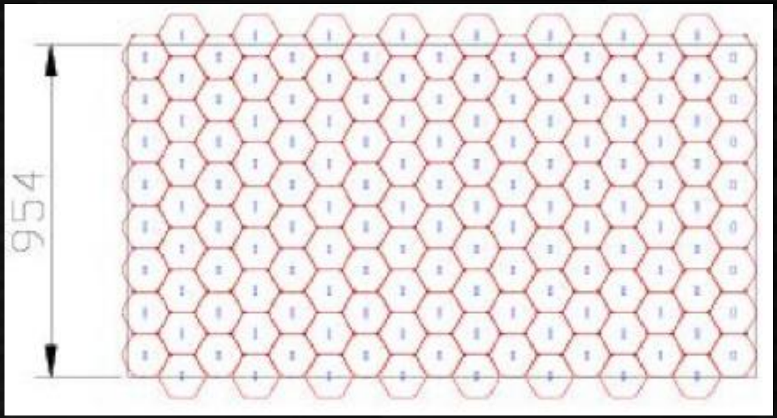




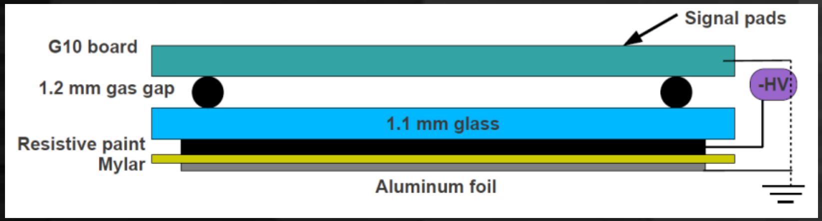
hybrid of SiECAL and ScECAL is also being investigated

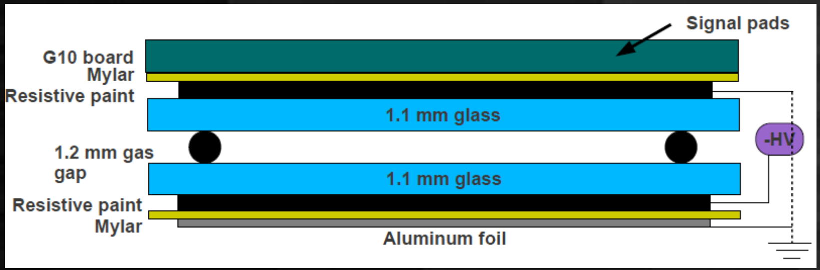
performance close to tile

Sensor & readout technologies

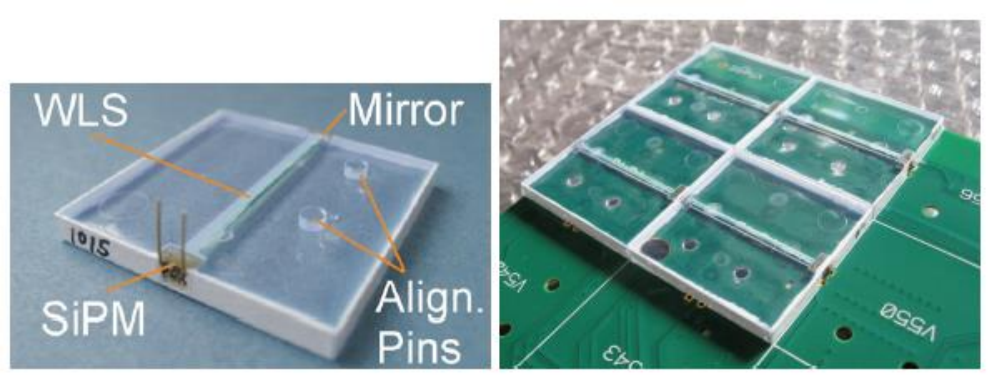


Hexagonal design for Si-ECAL





RPC digital-HCAL (1- and 2-glass)



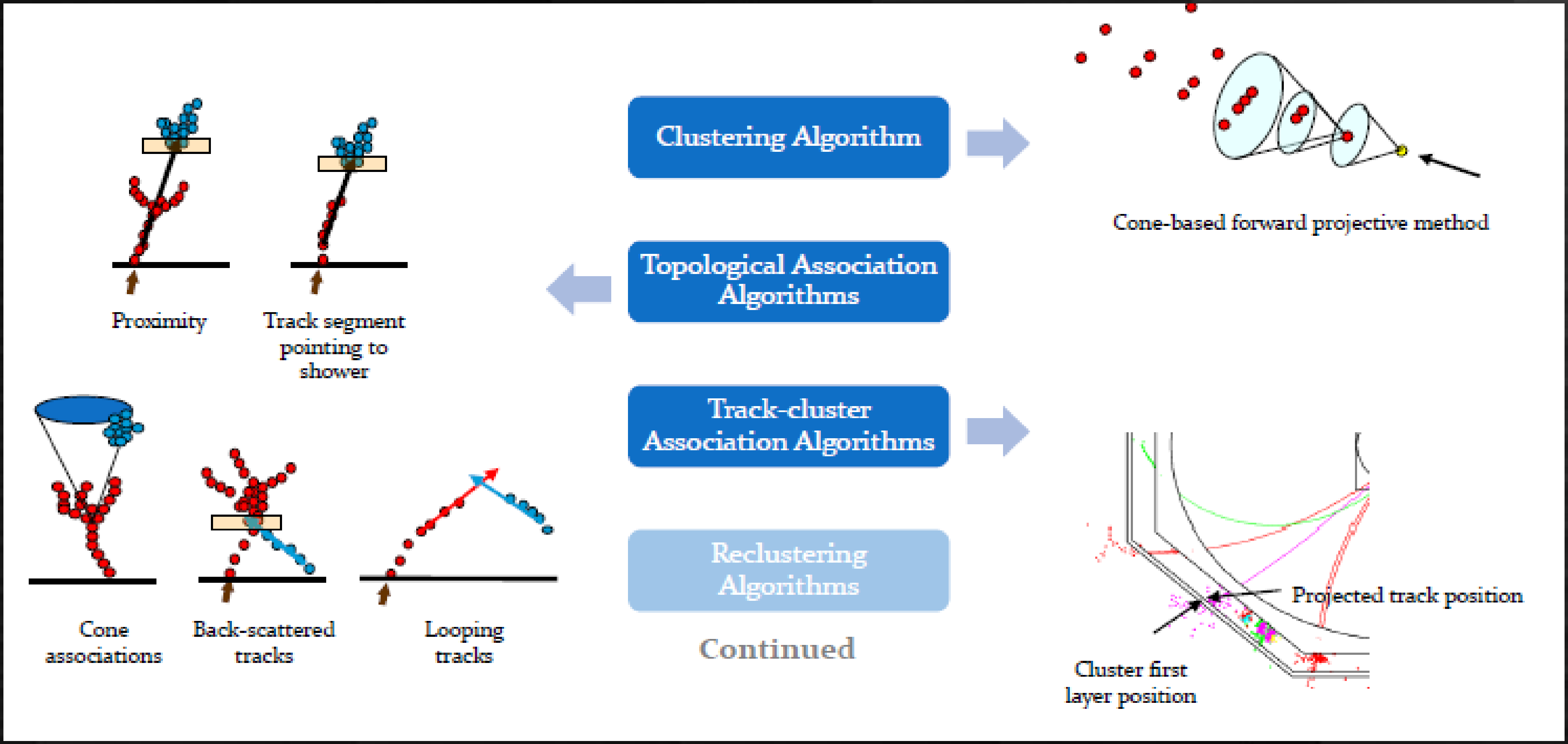
Scintillator-tile analog HCAL

Readout of HCAL

- Analog with 3 x 3 cm^2
- Semi-digital (2-bit) or Digital with 1 x 1 cm^2

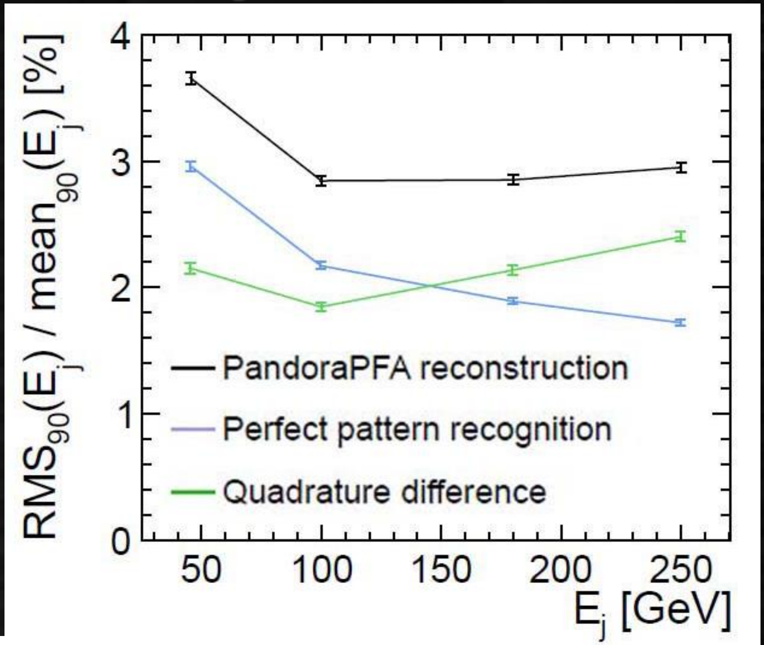
→ similar performance? need detailed study

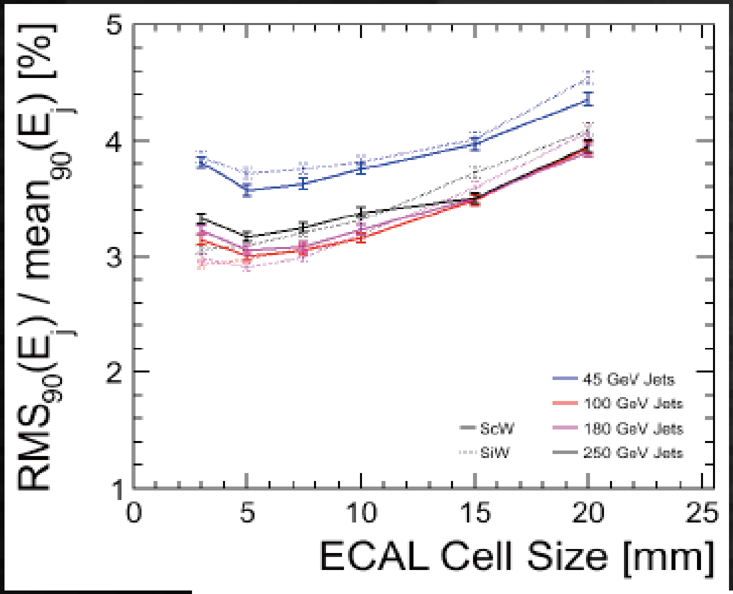
PandoraPFA

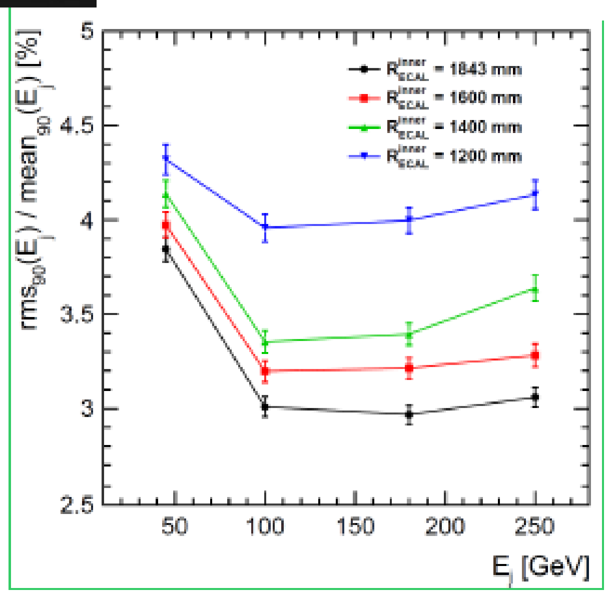


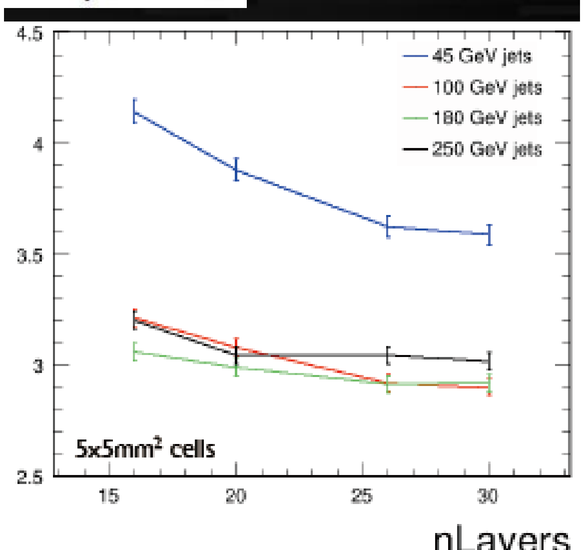
Sophisticated algorithm of track-cluster matching used in ILC community for > 5 years – no substitute

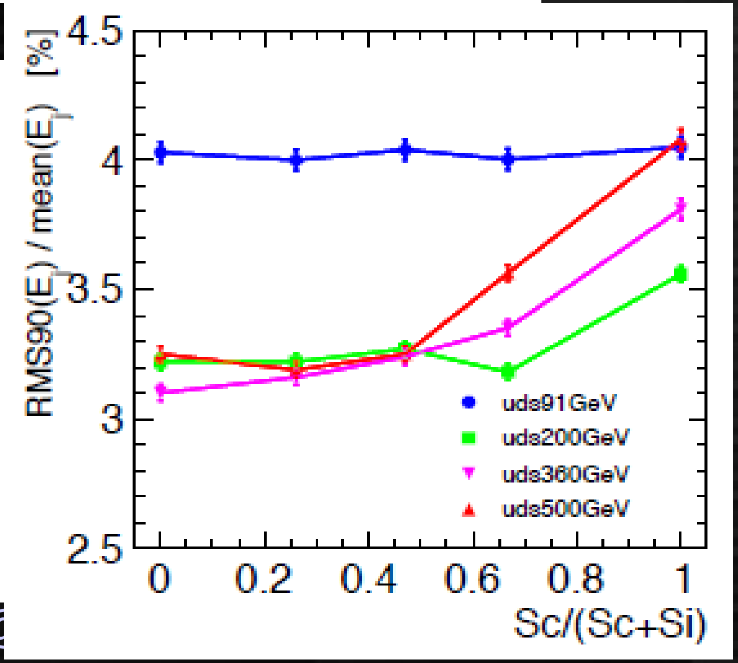
Optimization for particle flow











Jet clustering

- Jet clustering is the performance driver in many-jet (>=6) final states
- Usual Durham clustering, using

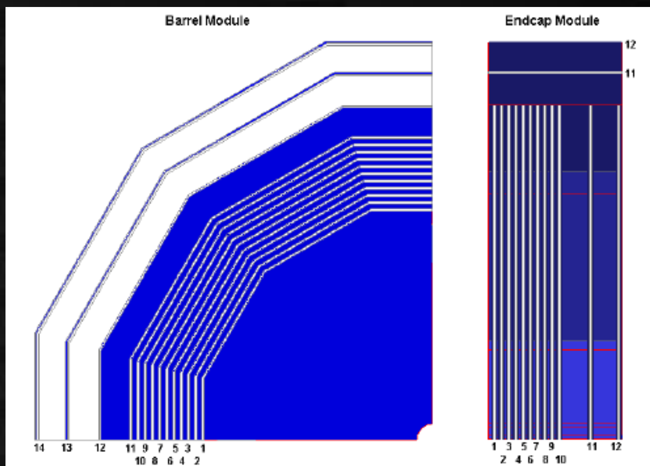
$$y = \frac{2\min(E_1, E_2)^2(1-\cos\theta_{ij})}{Q^2}$$

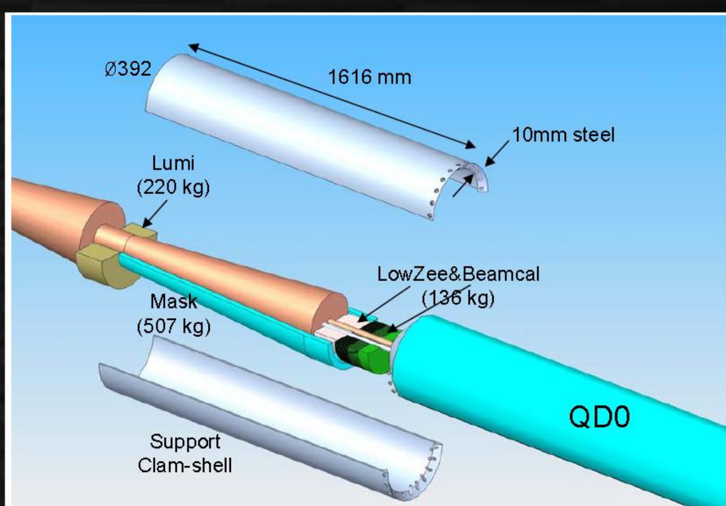
- Many ideas, not so successful...
  - Using reconstructed vertices to be separated
    - good for some cases, used default now
  - Color-singlet clustering
    - connect jets with more particle between them
  - Kinematic constrained jet clustering

Misc

Muon & forward detectors

Muon detector: sandwiched in return yoke (outside of coil)





Forward tracking
ILD: cosθ < 0.996 (outer discs)
SiD: cosθ < 0.990 (forward discs)

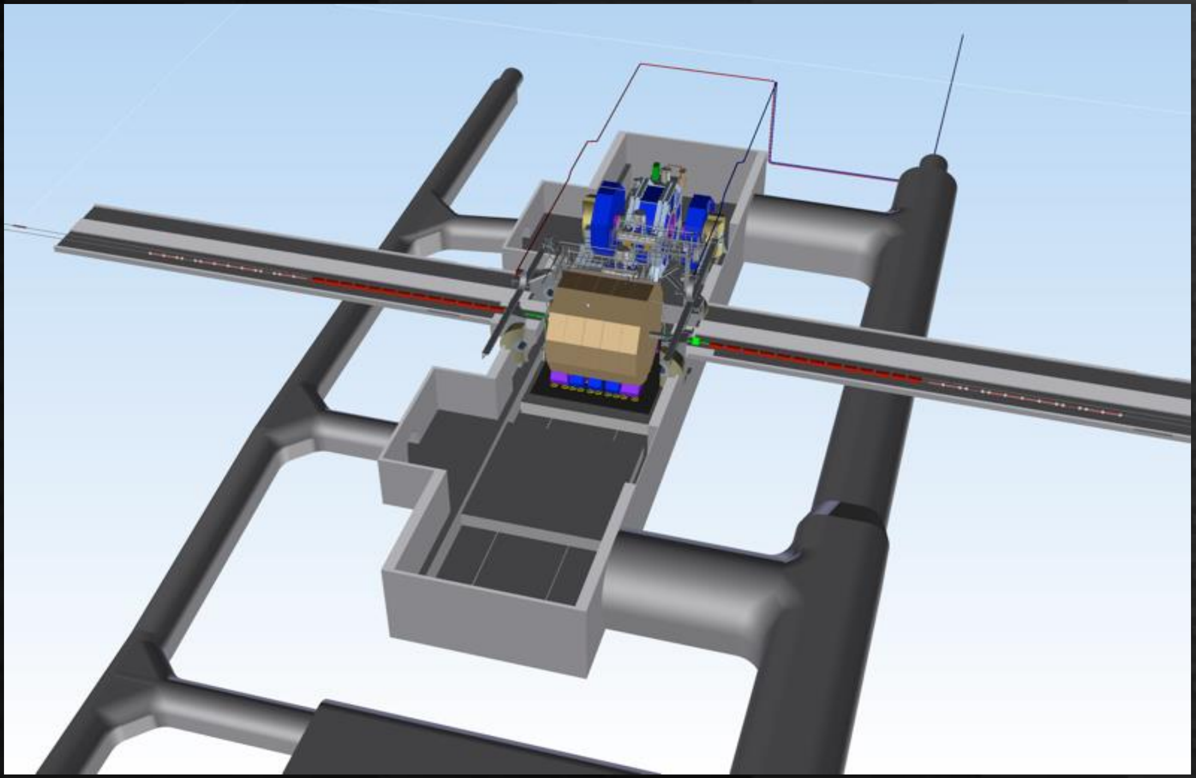
LumiCal (W/Silicon) / LHCal (?)
ILD: 31-77 mrad
SiD: 40-90 mrad

BeamCal (GaAs or CVD)
ILD/SiD: 7-40 mrad

Powerful for rejecting beam backgrounds (two-photon, beamstrahlung)

Push-pull

- Two detectors are on platform
- Change the detector to be used (changing time is assumed to be a week or 2)



- Experts say it's possible

Towards real detector(s)

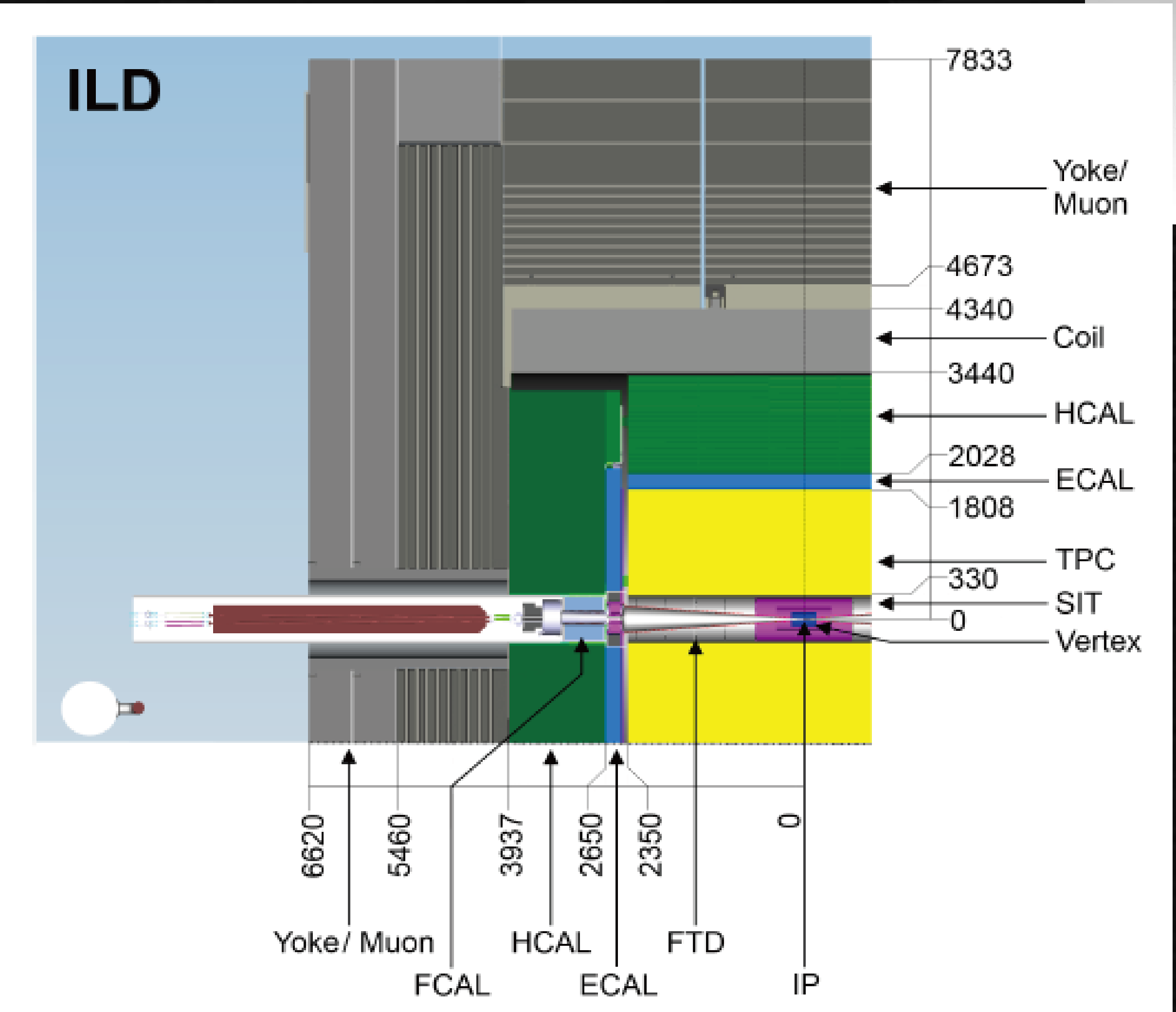
- Optimization and technology choice
- Finalization of design
  - Sensor/structure
  - Electronics
  - Software
- Integration to large prototype
- Combined testbeam
  - ECAL + HCAL (partly done)
  - CAL + tracker (under discussion)
  - with common DAQ (not available yet)

Summary

- Novel technologies are adopted to ILC detectors to employ best possible performance
- Key improvements are
  - Vertex detector for b/c tagging
  - Tracker with excellent momentum resolution
  - PFA calorimeter
- Detector optimization has now being started, in terms of physics performance.

ILD

International Large Detector

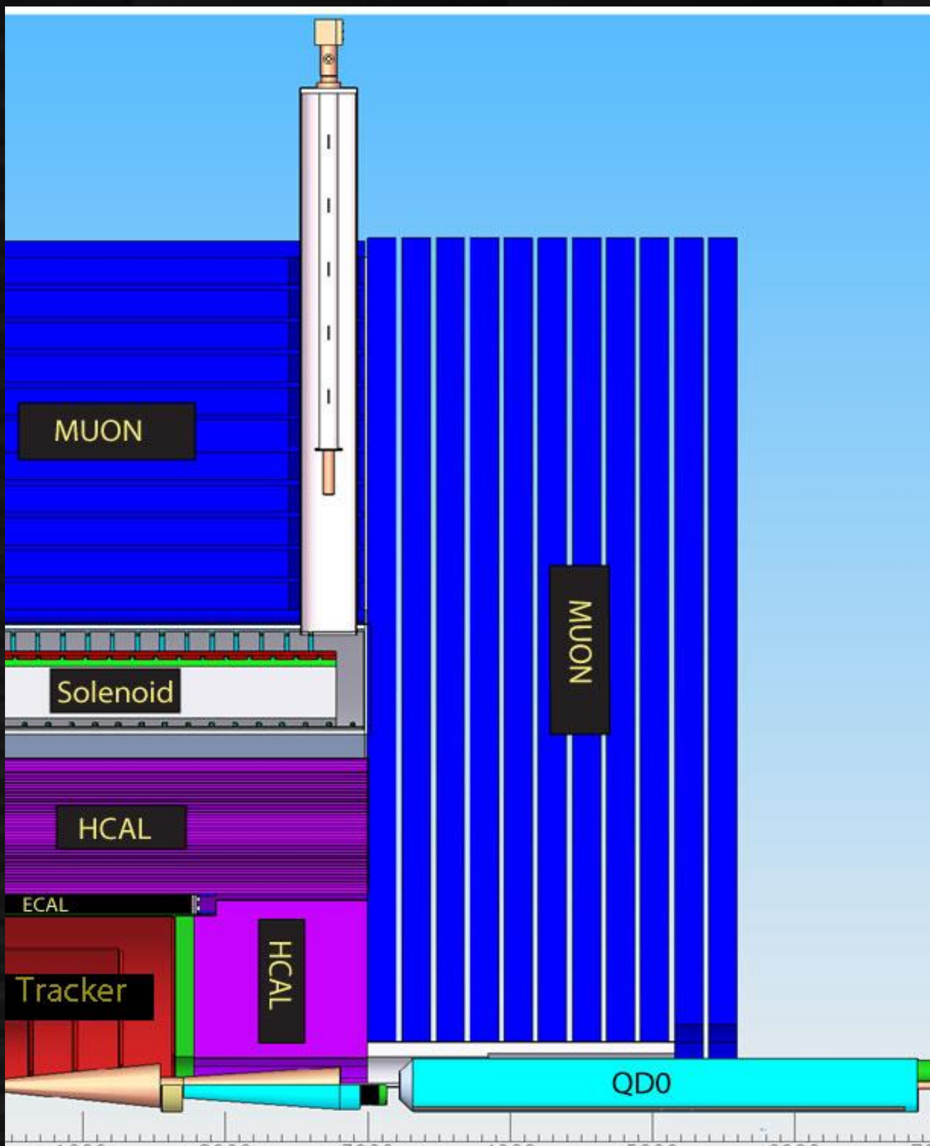


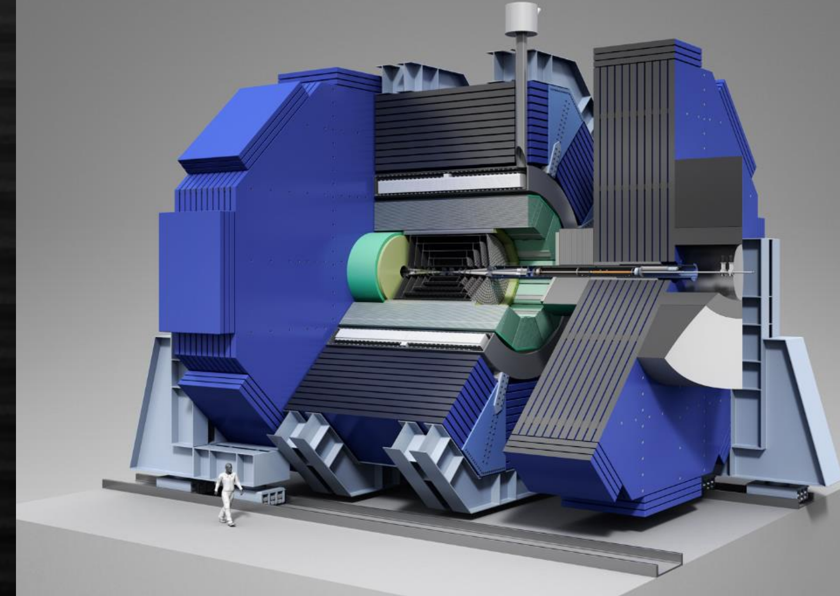
ILD is larger than SiD

Components:

- Vertex
- Silicon tracking (SIT/SET/ETD/FTD)
- Gas TPC
- ECAL/HCAL/FCAL (finely segmented)
- SC Coil (3.5 Tesla)
- Muon in Iron Yoke

SiD
Silicon Detector





Compact → cheaper

Silicon vertex/track/ECAL

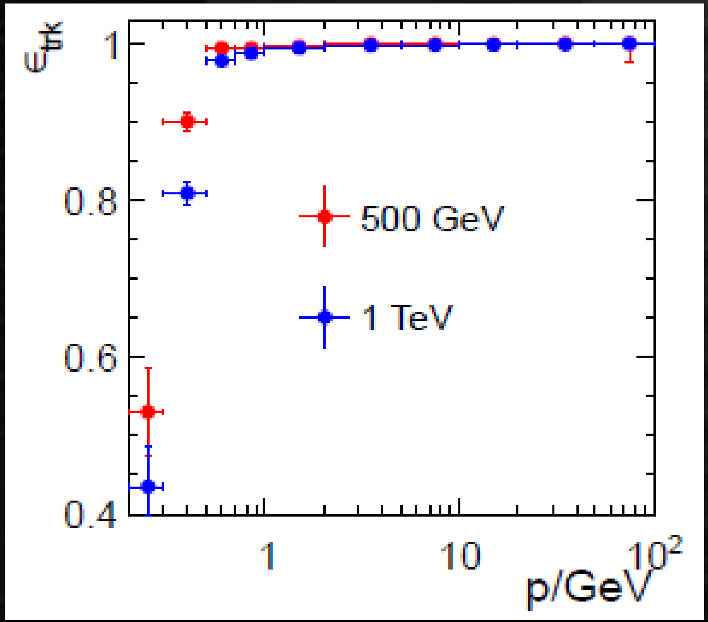
Components:

- Vertex
- Silicon tracker (no gas)
- ECAL/HCAL/FCAL (finely segmented)
- SC Coil (5 Tesla)
- Muon

Similar concept

Tracking software

- ILD tracking (sorry, for SiD I have no info)
- Standalone Silicon tracking (VTX + SIT)
  - Kalman filter (partially) – now improving
  - Cellular automaton also now being developed
- TPC tracking (Clupatra)
  - Kalman filter
- Combining Silicon + TPC tracking



tracking efficiency of tt → 6 jet events