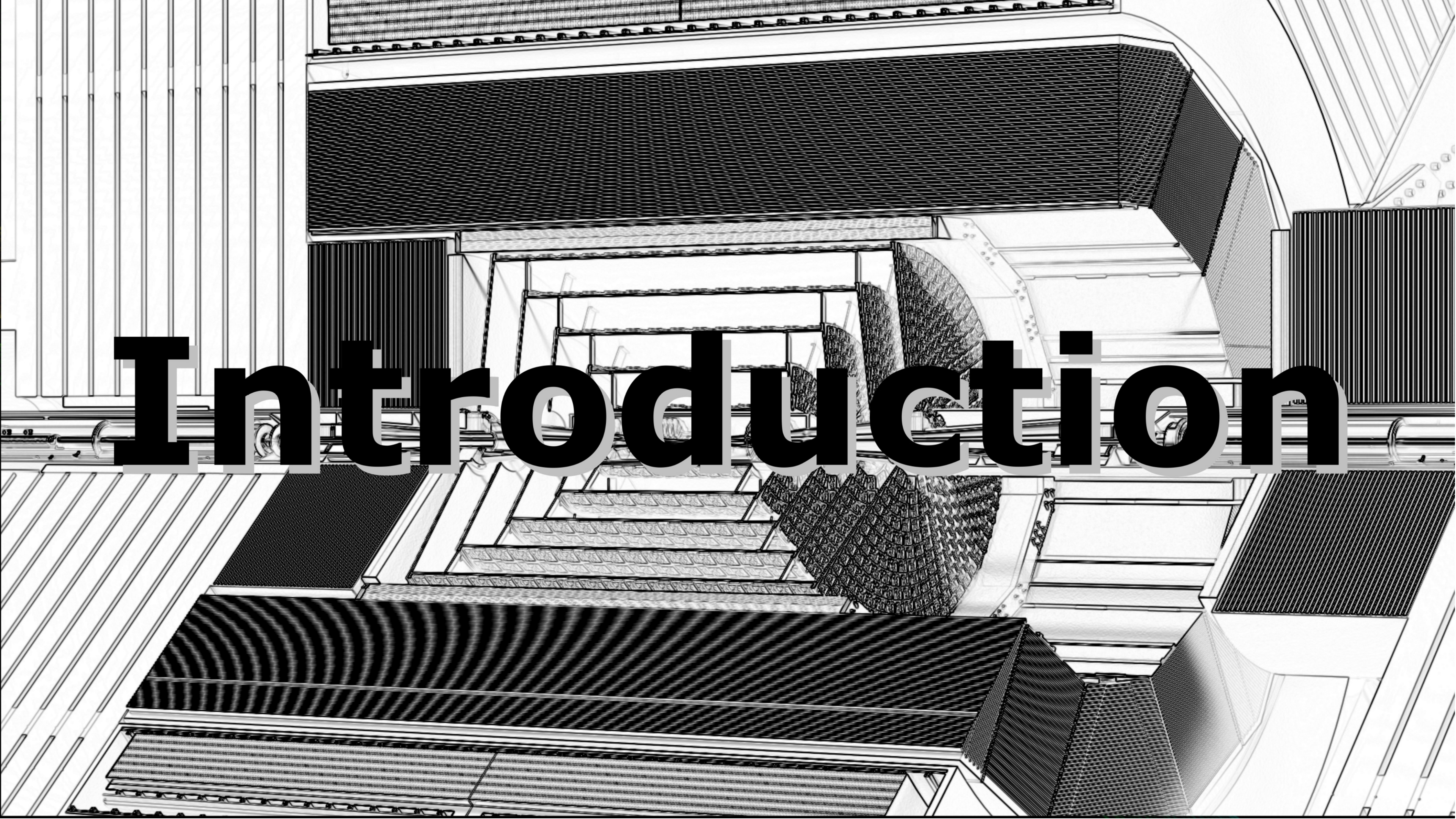
Detectors for the ILC

12th Terascale Detector Workshop

Marcel Stanitzki

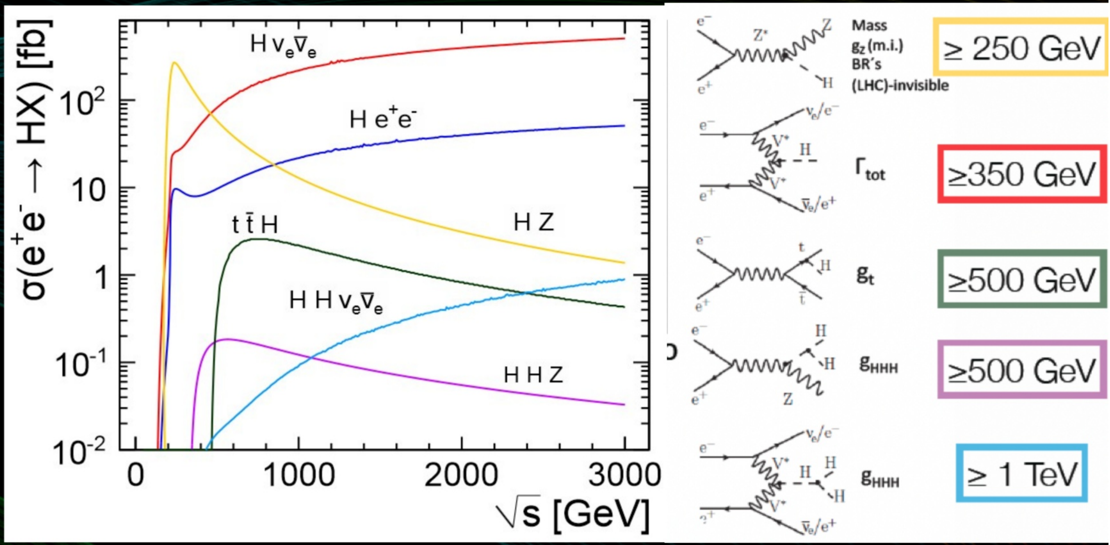
13/03/2019

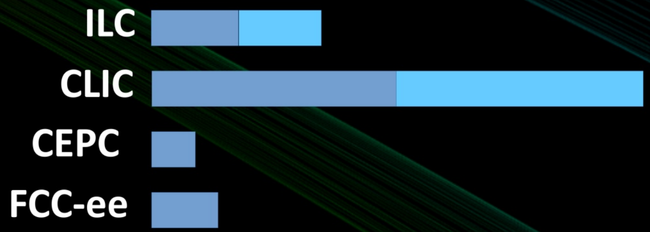
Introduction



Physics at e⁺e⁻ Colliders

- Rich physics program @ 250 GeV – 1 TeV
  - Higgs precision physics, top-quark physics, physics beyond the standard model
- Discovery of a Higgs boson in 2012
  - Higgs as new window into physics beyond the Standard Model
- So far absence of new physics at the LHC
  - precision is key to BSM physics; deviations of e.g. SM Higgs couplings are O(%)

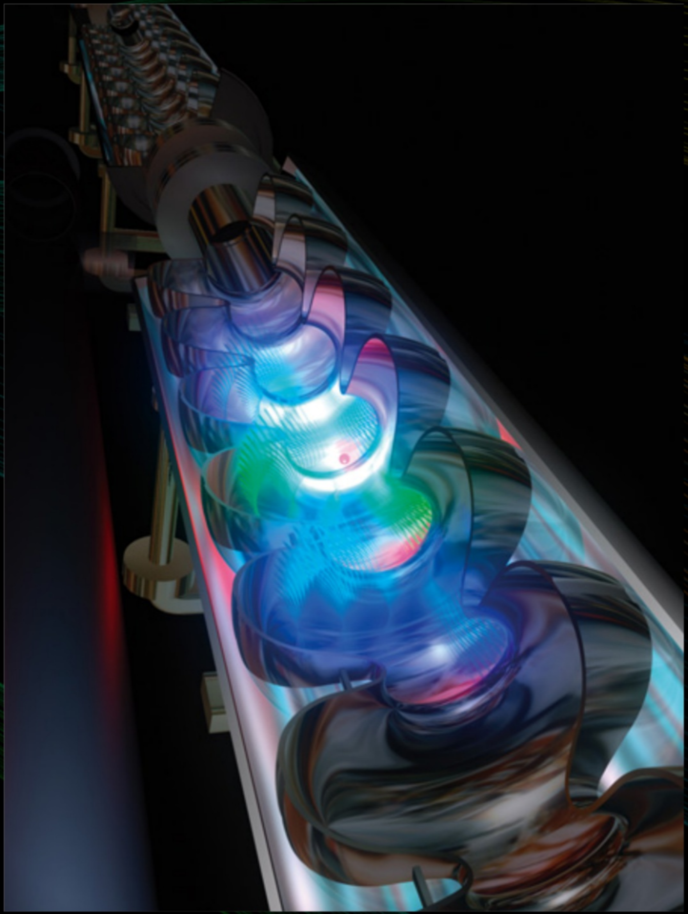




The ILC is a Higgs factory at all energies!
At 250 GeV: Very clean and easy to reconstruct HZ final state.
Precision access to many Higgs properties

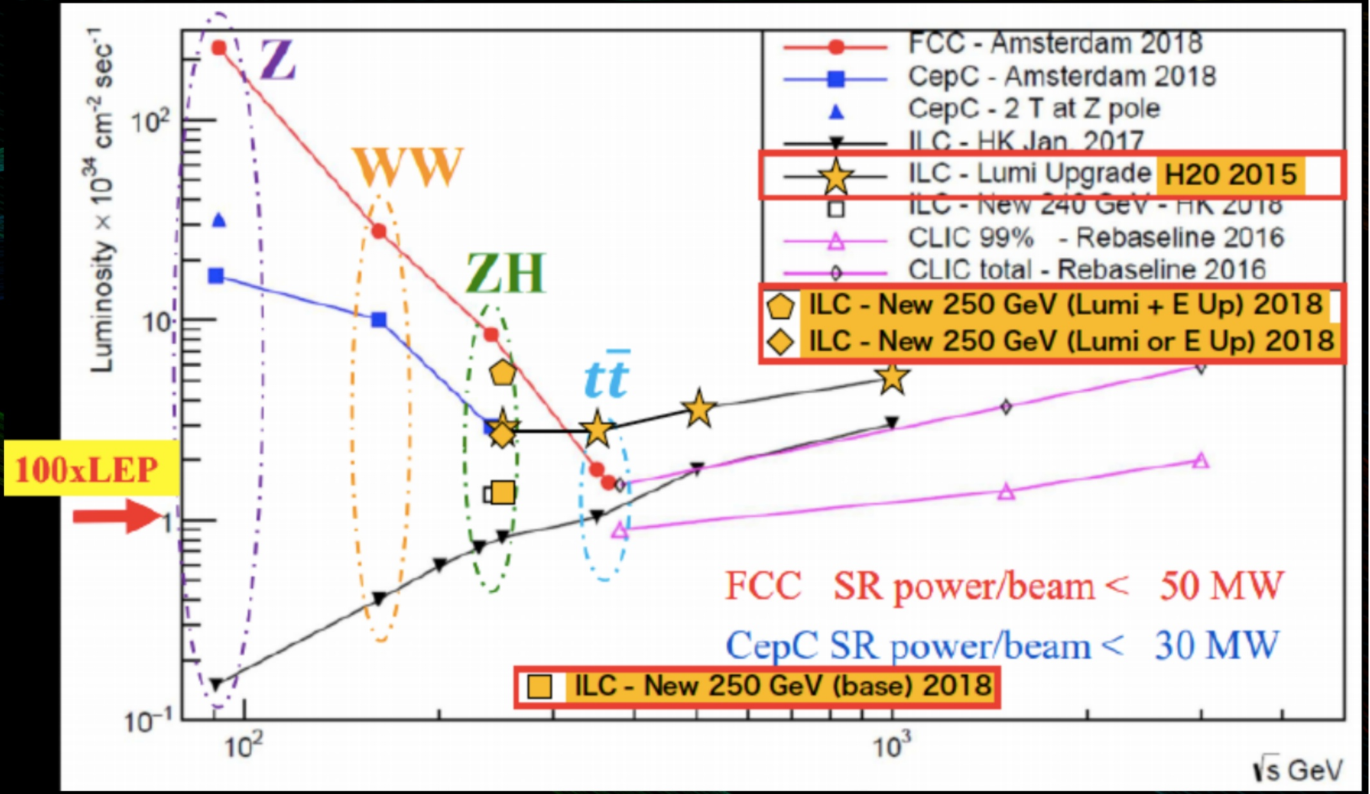
Why a Linear Collider

- Basic Limitations of all e^+e^- synchrotons
  - Synchrotron radiation loss ~ E^4/r
  - Synchrotron cost ~ quadratically with Energy (B. Richter 1980)
  - E_{CMS}=~ 200 GeV as upper limit
- Linear Accelerators offer a clear way to higher energy
  - Not limited by synchrotron radiation
  - Cost ~ linear with Energy
  - Polarization of both beams
- "nano beamspot" allows detectors close to the IP → key ingredient for c-tagging



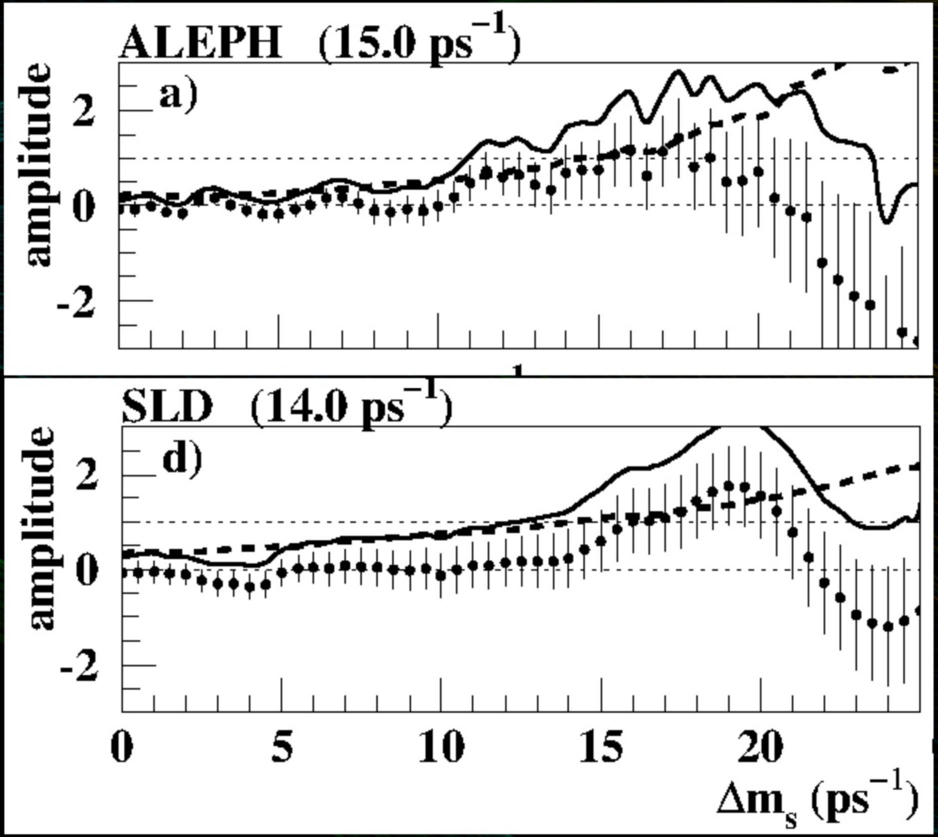
e^+e^- Luminosity

- More Luminosity ?
  - Machine
    - Stronger focus
    - Top-Up
  - Power
    - Just use more power
  - Cost
    - Make it bigger
    - Add more RF
- At the end there is no magic…
  - Balance between performance, cost and reliability

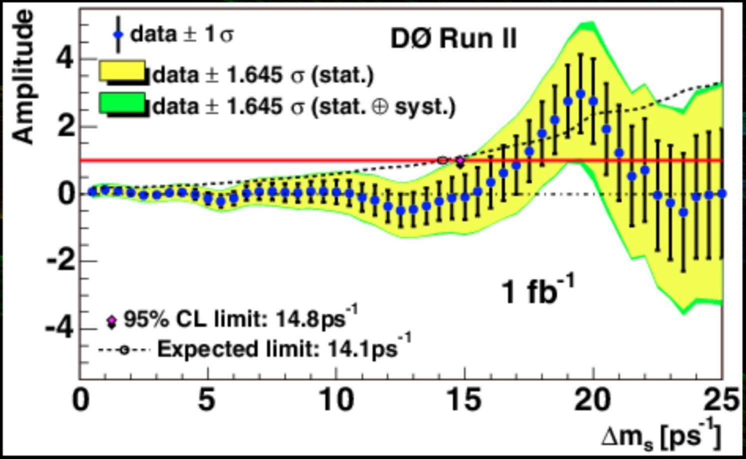


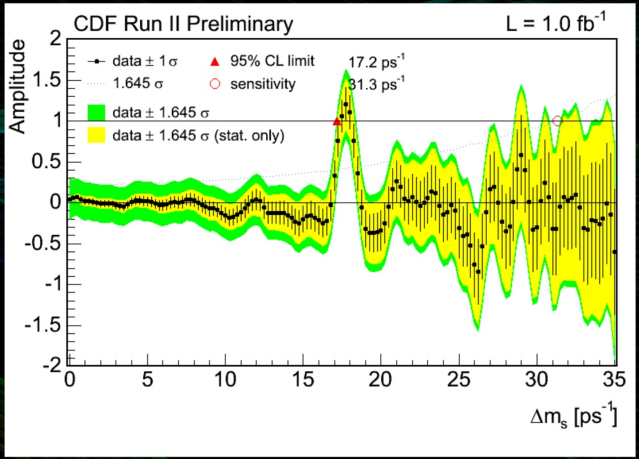
Linear Colliders – It's not just luminosity

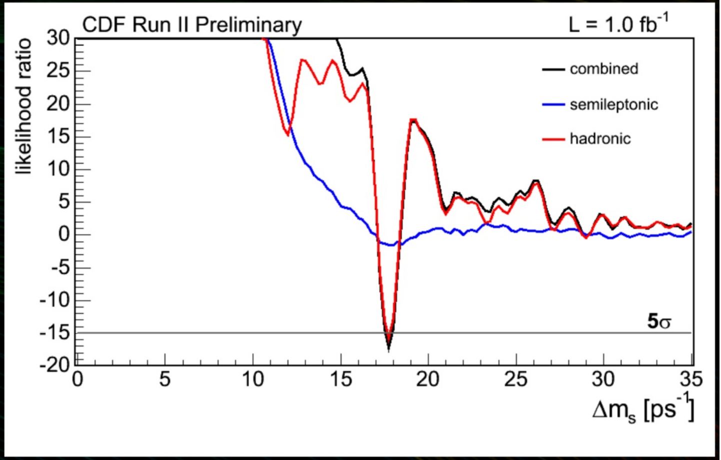
- B_s Oscillation Search
- ALEPH (LEP)
  - ~ 6 million Z's
- SLD
  - ~ 300000 Z's
- Main advantage of SLD:
  - Pixel Vertex detector
  - Much closer to the IP



It’s not just luminosity ….

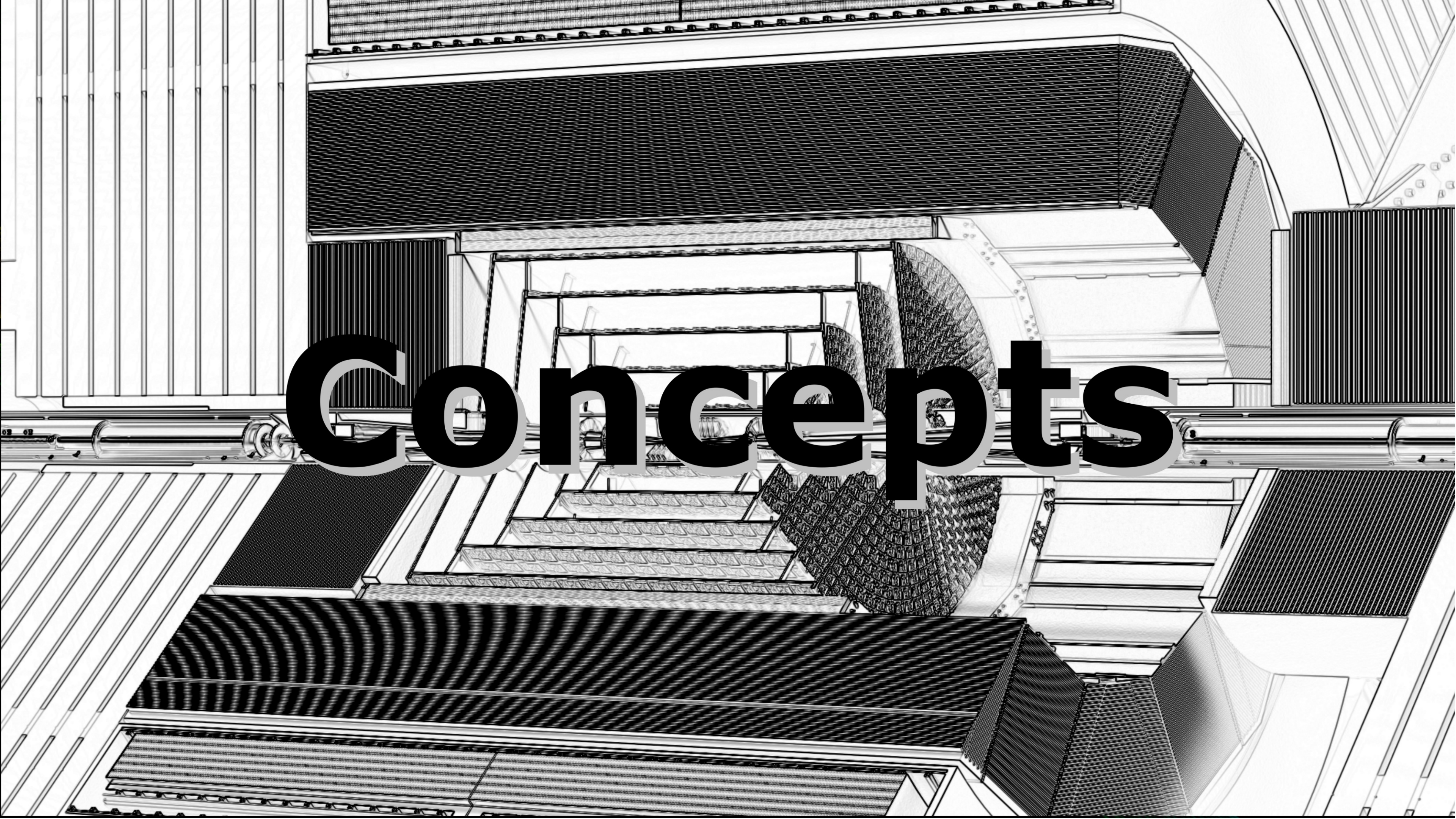






- Having the “better” detector compensates for luminosity
- B_s discovery
  - Deadtime-less Silicon Tracker and Secondary Vertex Trigger gave CDF the clear edge
- Being better in one does not mean to be better everywhere
  - Also some detectors where in better in something, which turned out to be not very interesting …

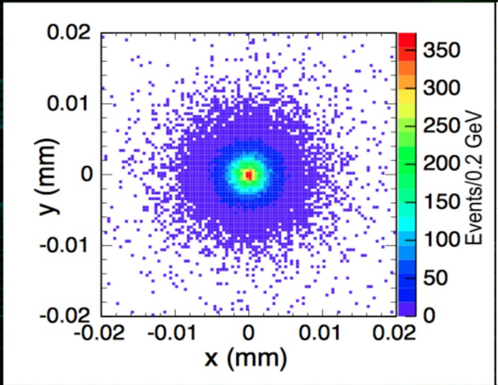
Concepts



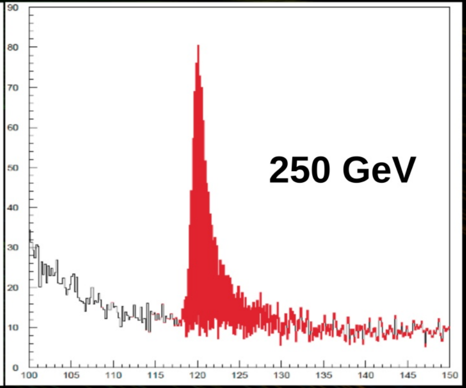
Physics Requirements

Performance Requirements

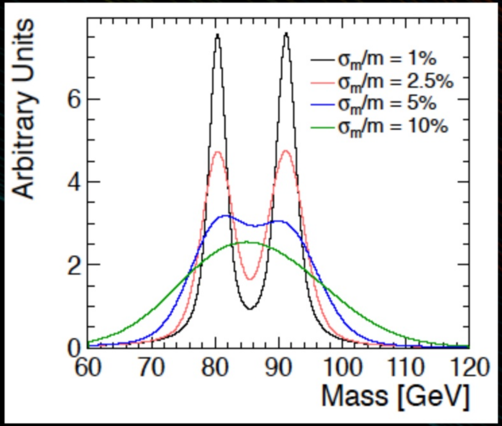
- Time stamping
  - Single Bunch resolution
- Vertex detector
  - < 4 µm precision
- Tracker
  - σ(1/p) ~ 2.5 × 10-5
- Calorimeter
  - $\frac{\sigma_{E_{Jet}}}{E_{Jet}} = 3-4\%, E_{Jet} > 100\ \ GeV$



primary vertices in tth events



ZH → µ+µ- + anything



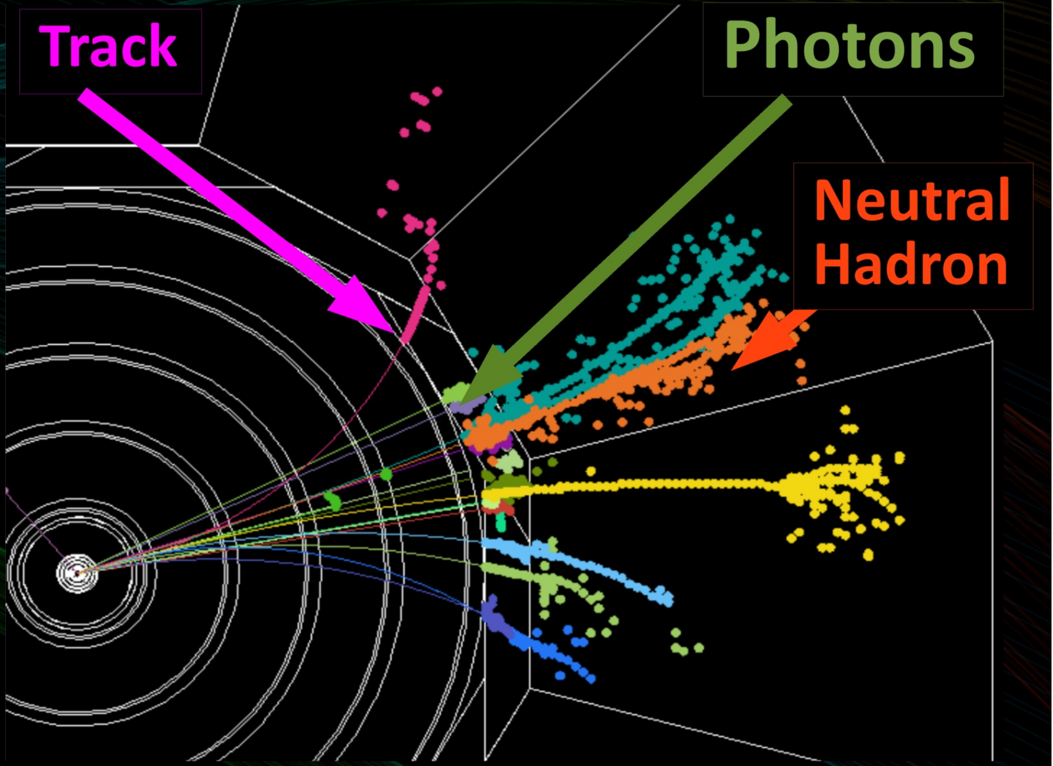
W-Z separation

Design Considerations

- Vertexing
  - Highly-granular and very thin
- Tracking
  - High precision tracking with minimal material budget
- Calorimetry
  - Particle Flow Paradigm
- Cooling and Power
  - Avoid liquid cooling, reduce amount of cabling
- Machine Detector Interface
  - Take advantage of unique Beam structure
  - Push-Pull
- Radiation Damage
  - Not really an issue for most detectors
  - Small Exception for the very forward detectors

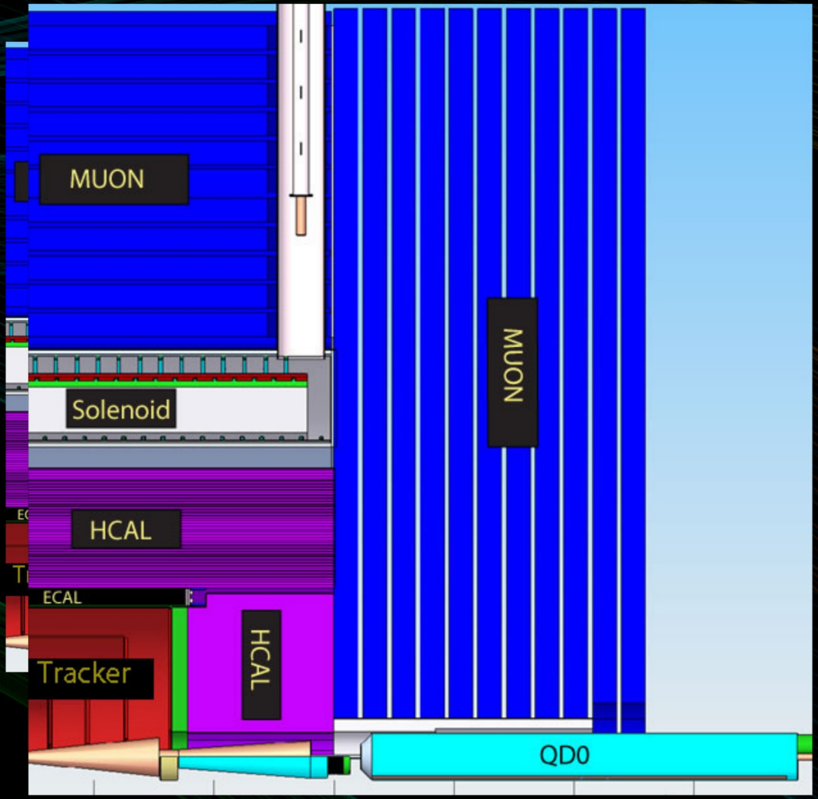
PFA - Particle Flow

- PFA = Particle Flow Algorithm
  - Combining all available reconstruction information
  - Momentum (Tracker), Energy (Calorimetry), Particle type (PID)
  - Reconstruction of each particle's four-vector
- Key ideas
  - Charged particles : Tracking resolution >> Calorimetry resolution
- Typical Jet :
  - 60 % charged particles, 30 % photons, 10% neutrals
  - PFA is the key to desired Jet Energy Resolution



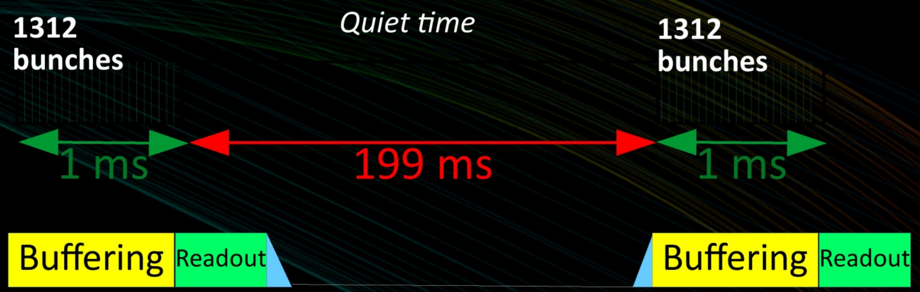
PFA – Design Driver at the ILC

- Particle Flow Algorithms
  - PFA has been used before at LEP, HERA and LHC
- Novel Approach at the ILC→ PFA drives design of the detector
- Impact on the detector design
  - Highly granular calorimetry
  - Low-mass tracking
  - Calorimetry inside the superconducting solenoid

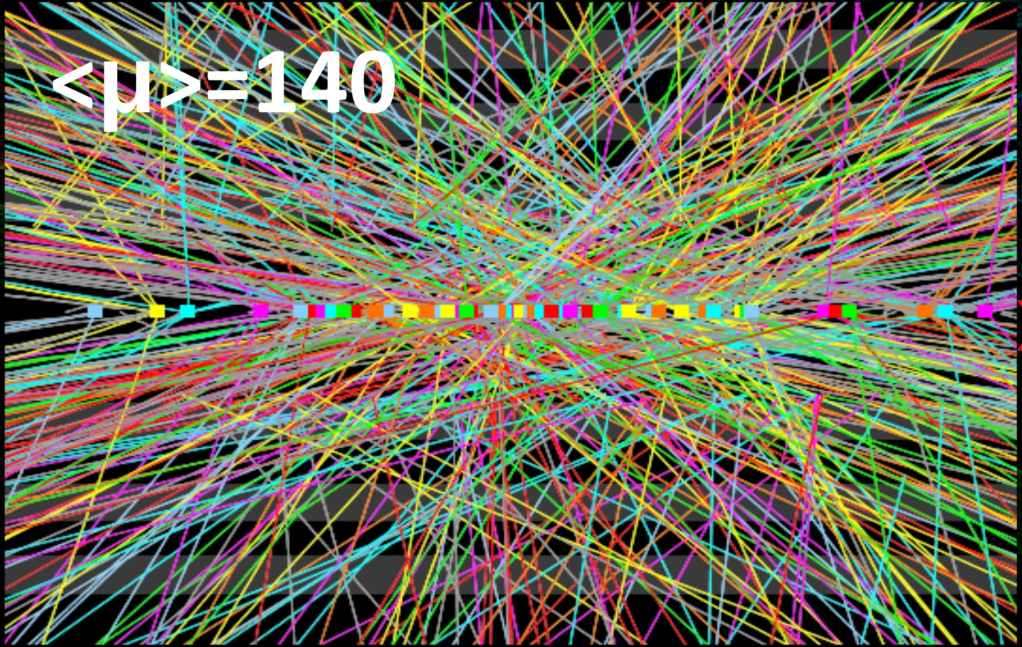


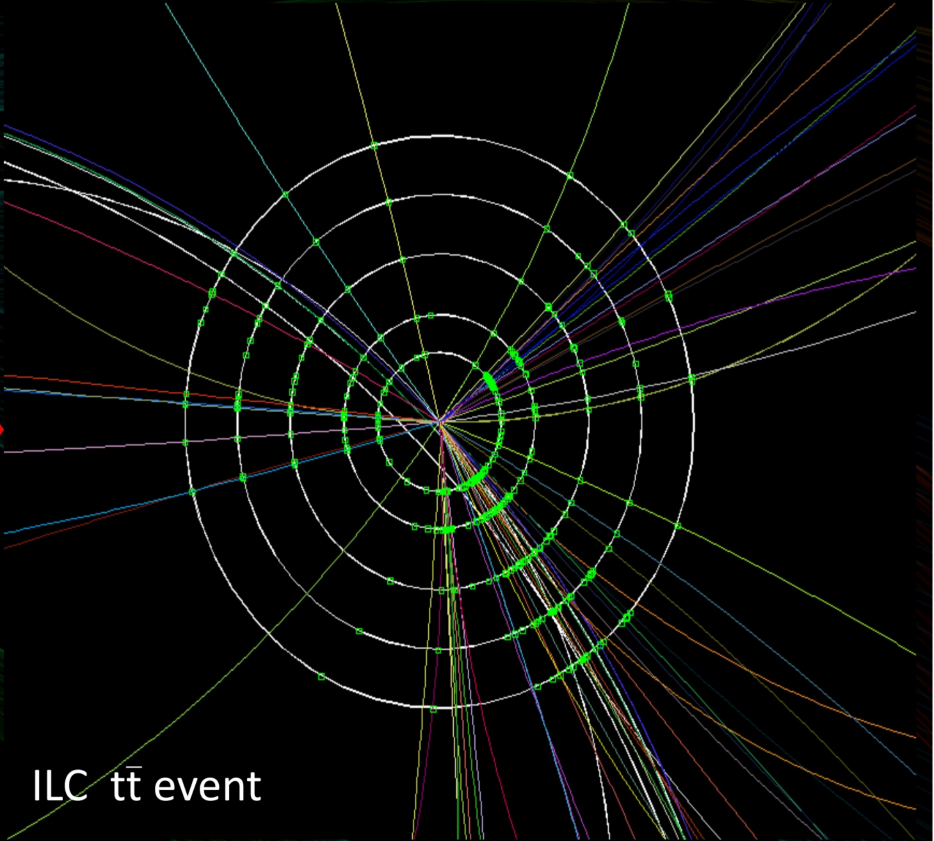
ILC Timing

- Bunch Structure at the ILC is very different compared to a synchrotron
  - Bunch spacing of 554 ns
  - 1 Train has 1312 bunches in ~ 1 ms
  - Then 199 ms quiet time until the next train
- Huge Impact on the Detector design
  - Occupancy dominated by beam background & noise
  - Triggerless Readout
  - Buffering on front-end & Readout after the last bunch
  - Powering off the front-ends during the quiet time
- Power saving of a Factor 100 → No Active cooling



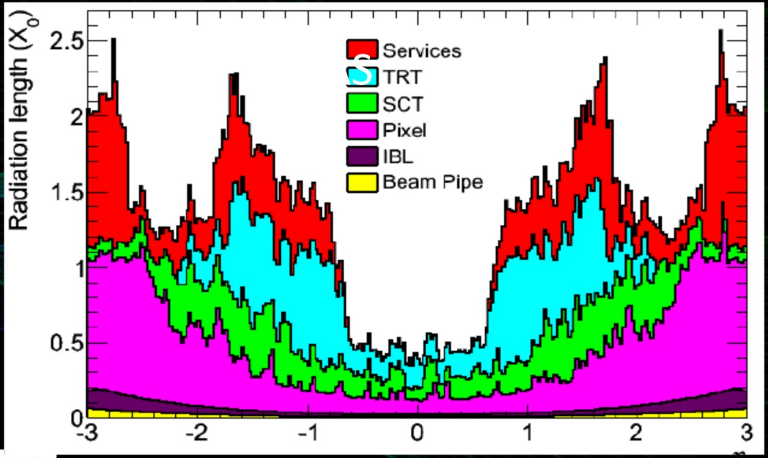
From HL-LHC to ILC



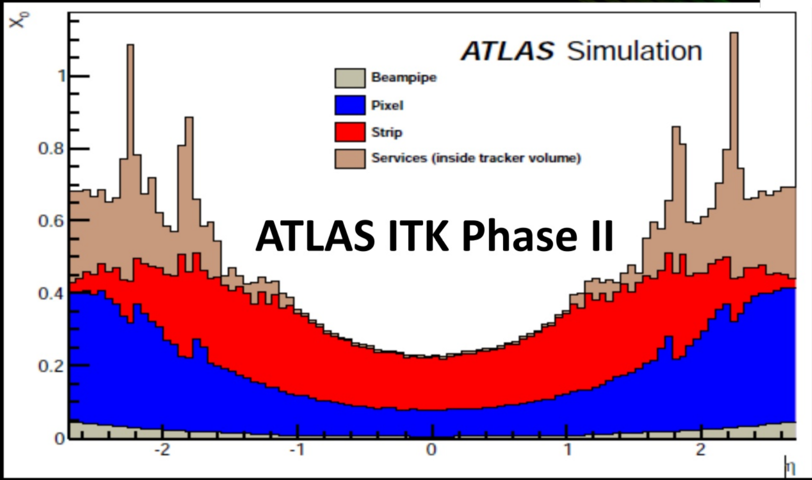


Moving from 140 interactions per crossing to ~1 event/train

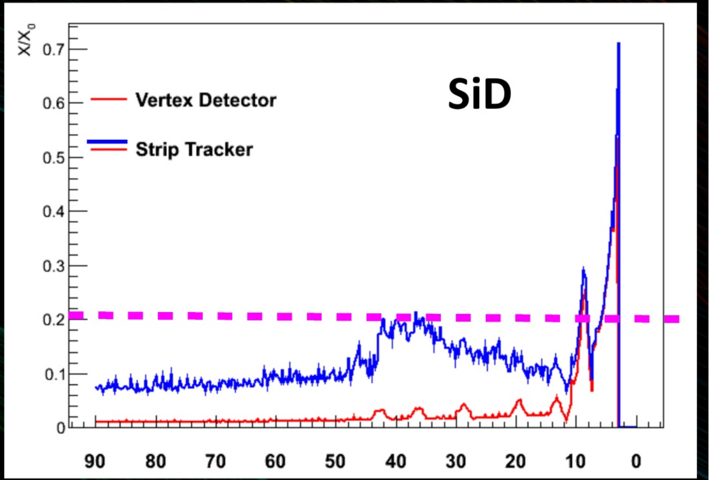
Working on the material budgets



R&D on Services,
Powering,Mechanics
Cooling

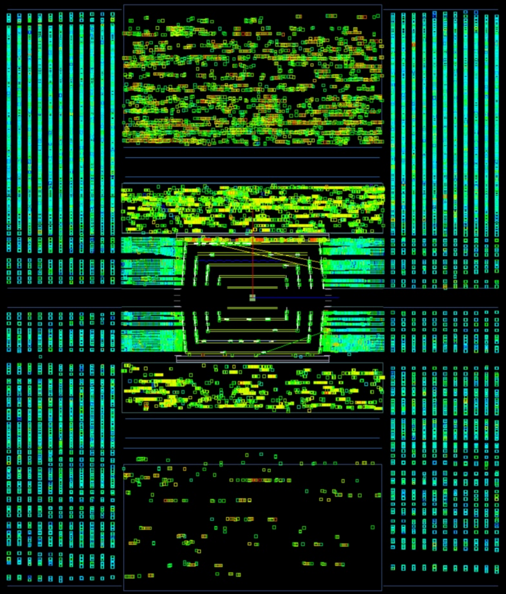


Air Cooling, Power Pulsing

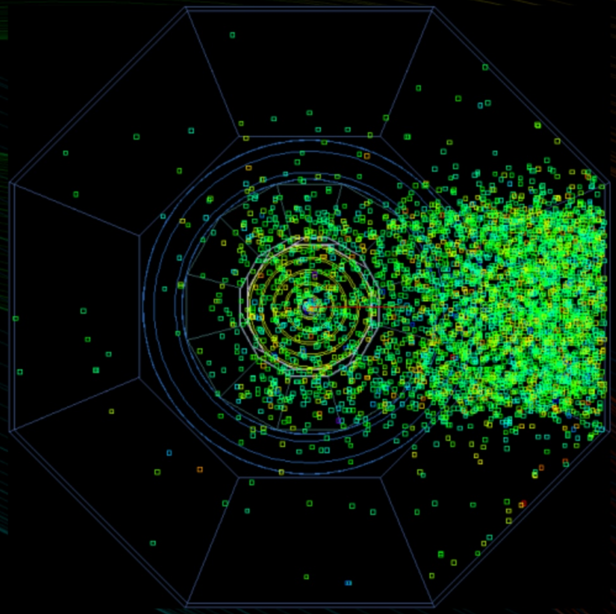


Time-Stamping is good for you …

- Collision at the ILC are not background-free
- Main sources
  - Beam-Beam interactions
  - Muon halo (from collimators)
  - Neutron flux from the beam dump
- Timing matters
  - Within a bunch-train (500 ns)
  - Between bunches (20 ns)

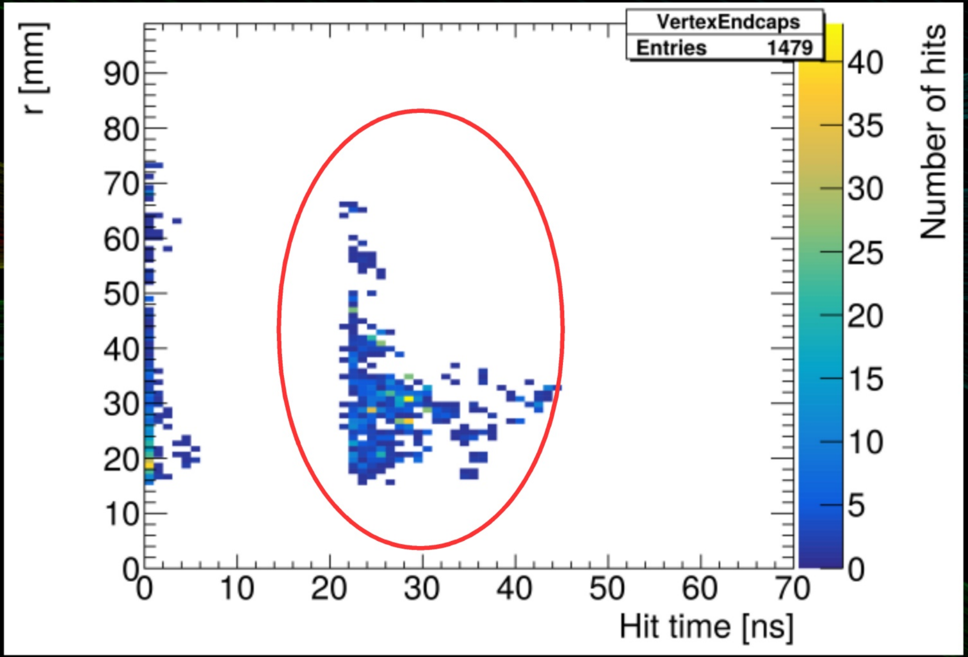


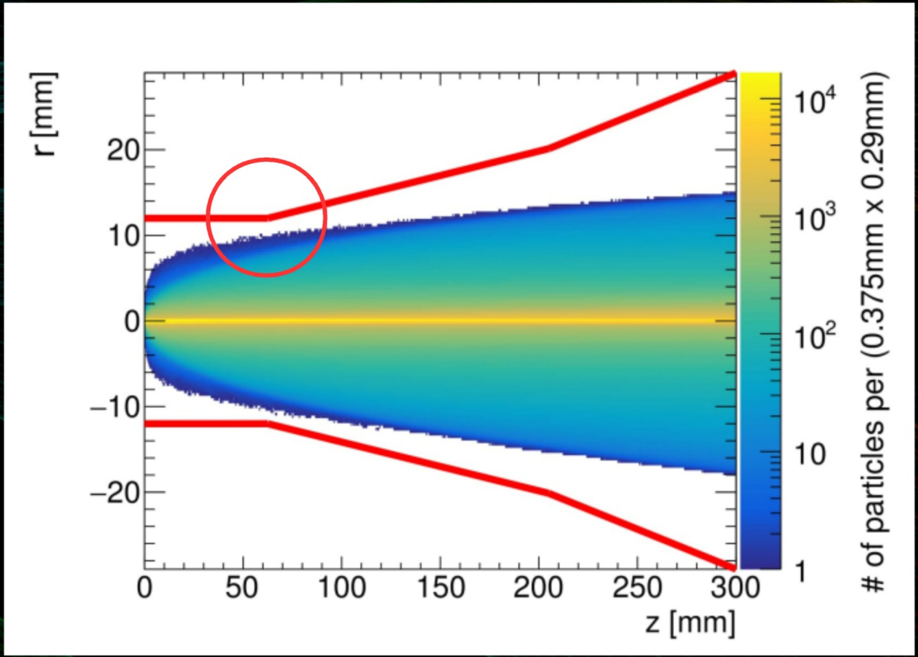
Muon halo (1 ILC train)



Neutron Cloud

Looking in more detail

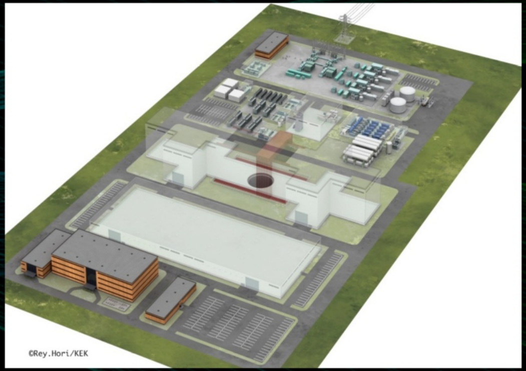


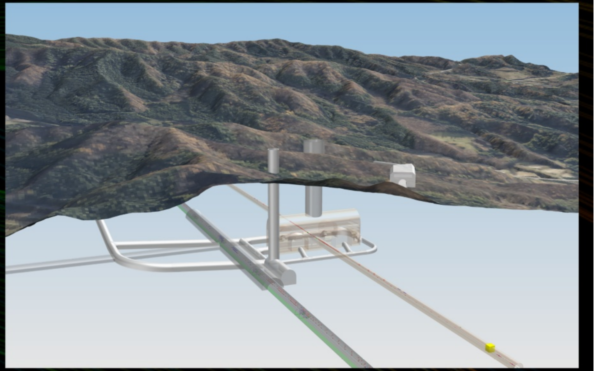


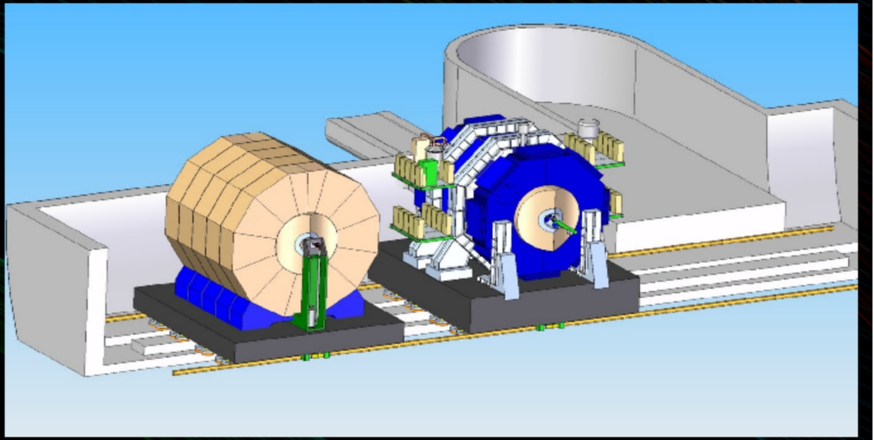
- Understanding the beam background essential
  - Impacts Detector Geometry
  - Electronics design

2 Detectors & 1 IP → Push Pull

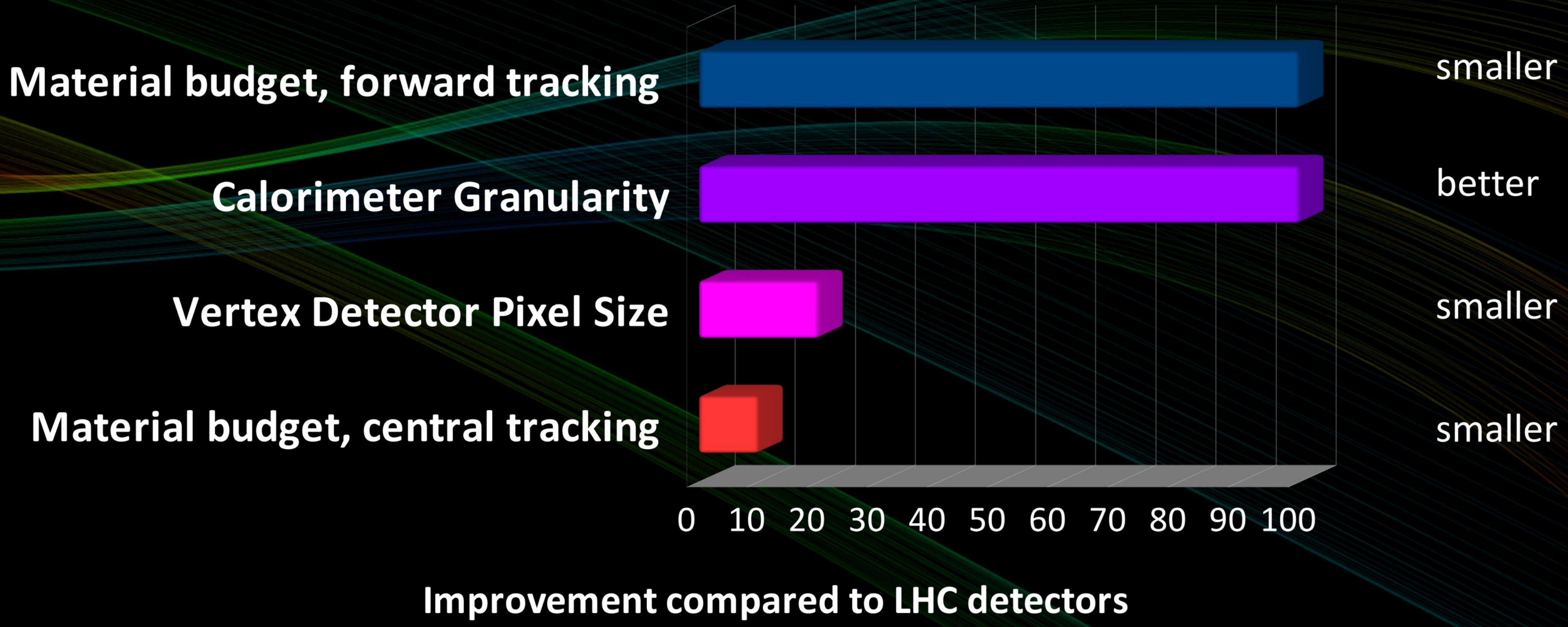
- Interaction Region Campus
  - Campus located in the Kitakami mountains
  - Assembly hall, service buildings
  - Access to IP using vertical shafts
- The ILC has only one interaction region
  - Two detectors share the IP in a push-pull configuration
  - Detectors on platforms
  - Swap-over in 48-72 hours





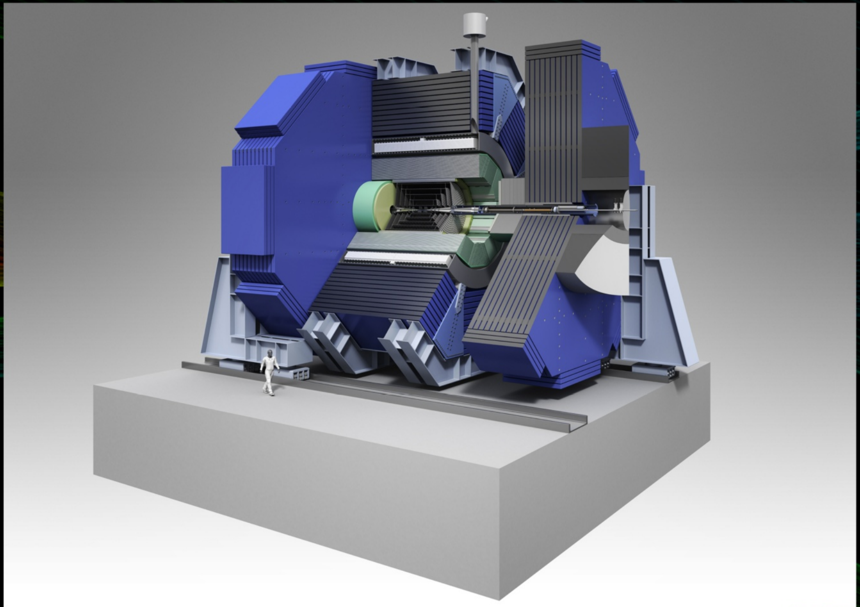


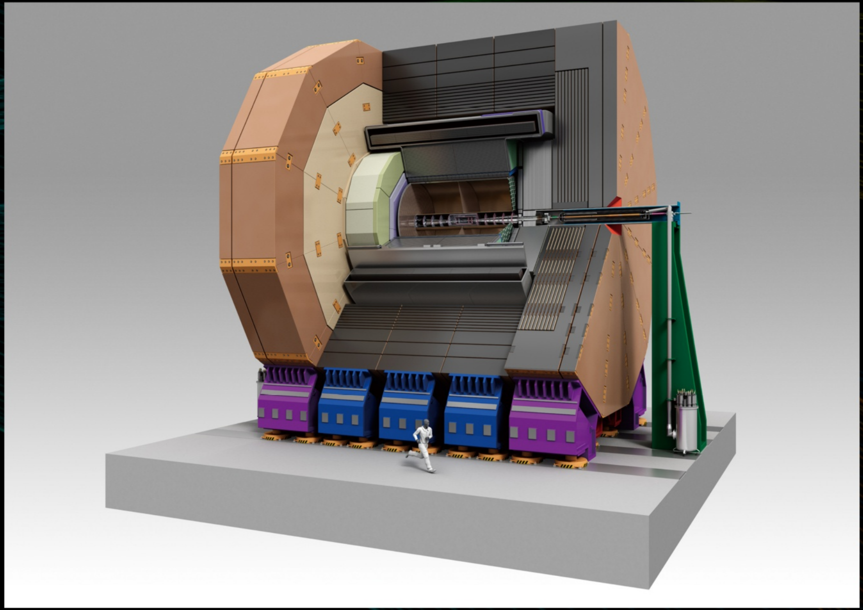
How does this compare to the LHC ?



ILC Requirements for Timing, Data rate and Radiation hardness are very modest compared to LHC

SiD & ILD – Two PFA Implementations

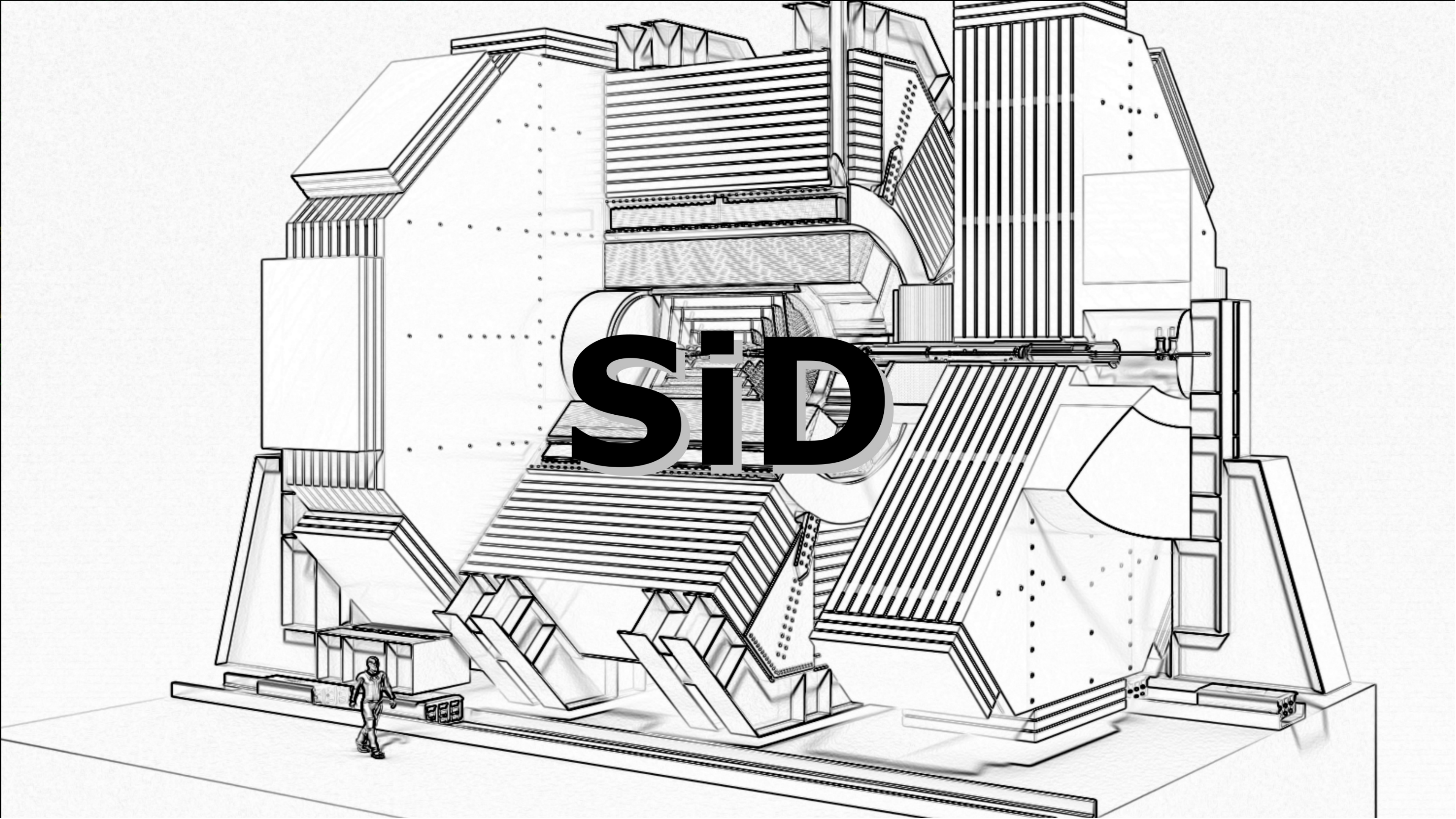




- SiD
  - $r_{tracker}$= 1.25 m
  - B = 5 T
  - All-silicon tracking
- ILD
  - $r_{Tracker}$= 1.8 m
  - B = 3.5 T
  - Time Projection Chamber

And the detector technologies ??

- See e.g. these great talks
  - Silicon track detectors for linear colliders (S. Spannagel)
  - CALICE developments for LC calorimeters (C. Graf)
  - Gaseous Tracking for Linear Colliders (J. Kaminski)


SiD

The Idea behind SiD

- Compact All Silicon PFA detector
- Design choices
  - Compact design with 5 T field
  - Robust silicon vertexing and tracking system with excellent momentum resolution
  - Highly granular Calorimetry optimized for Particle Flow
  - Time-stamping with single bunch crossing resolution
  - Iron flux return/muon identifier is part of the SiD self-shielding
  - Detector is designed for rapid push-pull operation
  - Well defined baseline with further technology options

SiD’s History

2003:SiD first appears at ALCPG.
SiD is aimed at the NLC

2004 :WWS starts the detector concept studies at the Victoria meeting :SiD, GLD, LDC
Beginning of the Silicon Detector Concept Study

2006: Detector Outline Document

2007: Detector Concept Report
First SiD workshop

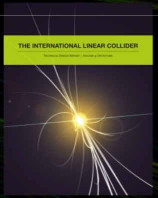
2008/9: CLIC_SiD Starts for Multi-TeV machines

2009: SiD Letter Of Intent

2009: SiD validated

2011: CLIC Physics and Detectors Conceptual Design Report

2013:
ILC TDR/DBD



2014: Site studies

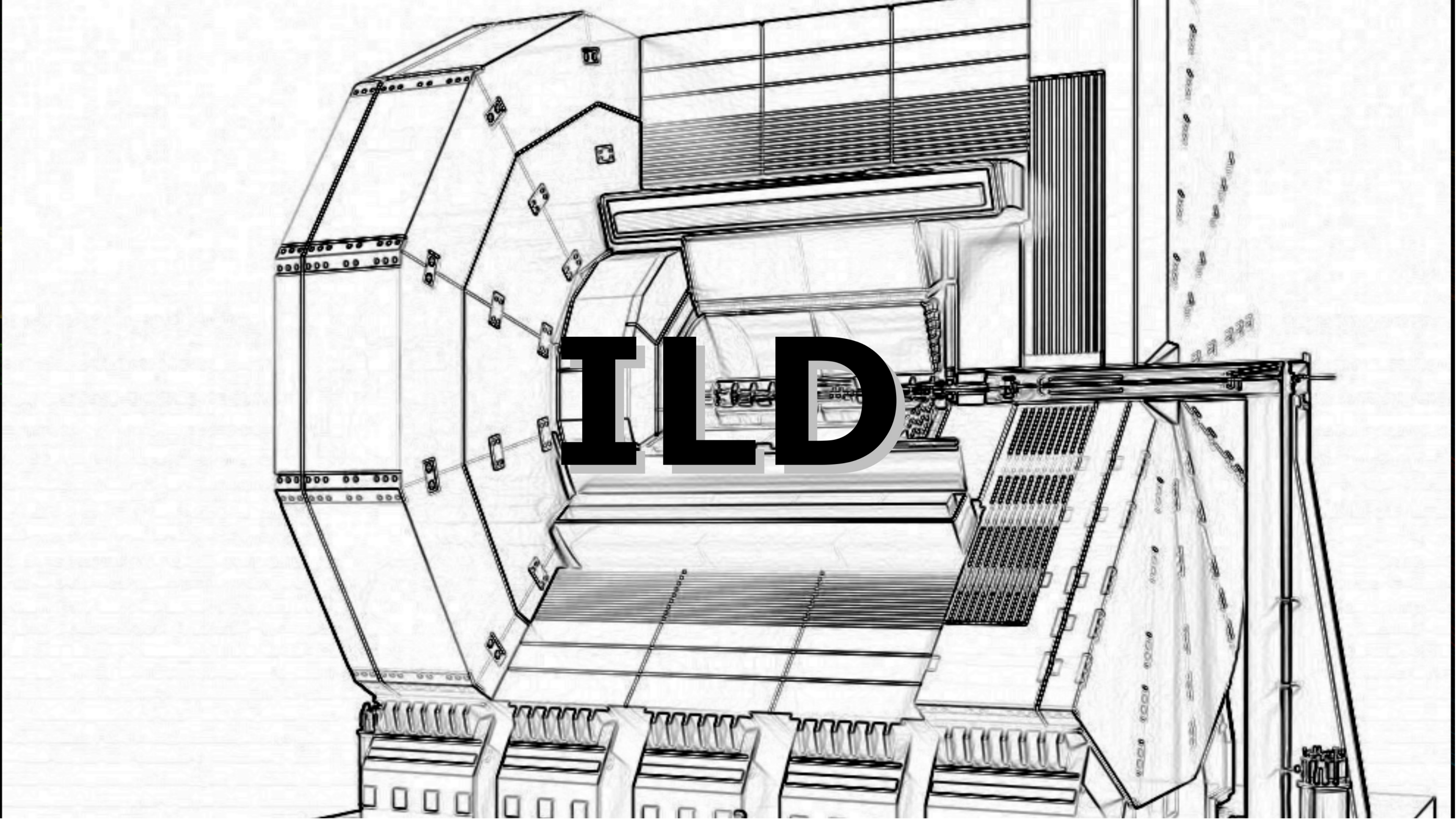
2017: ILC Re-baselining To 250 GeV

2019: Japanese “Decision” ???

Concept Phase

LoI Phase

DBD Phase


ILD

The Ideas behind ILD

- Large PFA detector build around a TPC
- Design choices
  - TPC with silicon envelopes for tracking and PiD
  - Highly granular Calorimetry optimized for Particle Flow
  - 3.5 T field driven by TPC and coil constraints
  - Iron flux return/muon identifier is part of the ILD self-shielding
  - Detector is designed for rapid push-pull operation
  - Trying to accommodate many technology choices

ILD’s history

- Similar to SiD but small differences
- A Merger between LDC and GLD in 2008
  - LDC: TPC + 4 T , originating from TESLA
  - GLD: TPC+ 3 T, originating from JLC
- From the LoI’s it’s very similar

Comparison Table

	SiD	ILD
Vertex Detector	5 pixel layer	3 doublesided pixel layers
Tracker	5 layer Silicon Strips	2 Silicon Layers TPC 2 Silicon Layers
ECAL	SiW 30 layers	SiW 30 layers Scint-W 30 layers
HCAL	Fe+Scint 40 layers	Fe+Scint 48 layers FE+RPC 48 layers
Coil	5 T r_{inner} = 2.6 m	3.5 T r_{inner} = 3.4 m

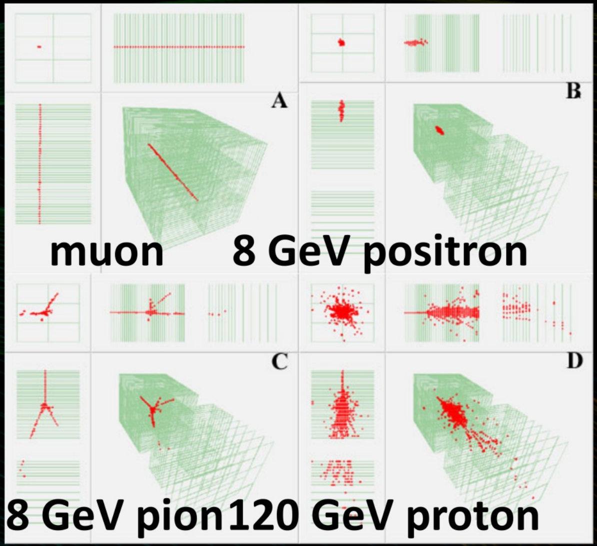
Main Difference - Tracking

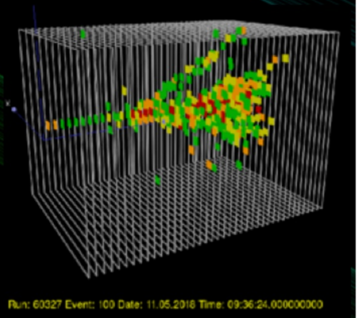
- All-silicon Tracking
- Tracking system
  - 5 layer pixel Vertex detector
  - 5 layer Silicon strip tracker
- Few highly precise hits
  - Max 12 hits
- Low material budget
- All silicon approach used by CMS, ATLAS & CMS Upgrades

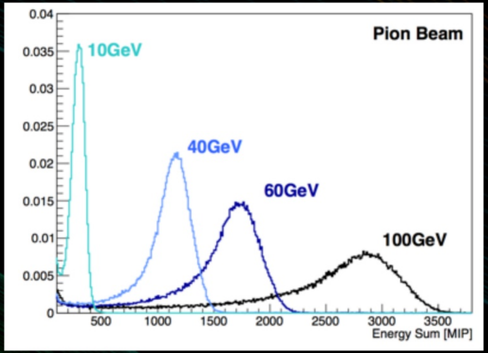
- Gaseous Tracking
- Tracking System
  - 3 double layer Vertex detector
  - Intermediate silicon layers
  - TPC
- Max number of hits
  - 228
- High hit redundancy
- Classical approach (ALEPH, DELPHI)

Evolving designs…

- SiD moved from Digital HCAL with RPCs to Analog HCAL with Scintillator/SiPM
  - SiD Internal Review and Consortium Approval
- Rationale
  - Huge progress with SiPM technology (Industrialized)
  - CALICE AHCAL prototypes very successful
    - Addressed and overcame many previous criticisms
  - CALICE DHCAL prototypes very successful
    - But Operation and Calibration is non-trivial
- System aspects
  - Eliminate elaborated Gas system & HV
  - DHCAL has not yet demonstrated a real performance edge







Summary

- The ILC detectors have come a long way
  - Basic design is sound and understood
  - But still many things need to be addressed → ok for the state of the project
- If the ILC will move forward
  - A detailed review of the designs will follow
  - e.g. Do we still want silicon strips ?
- The ILC Detector R&D has been very successful
  - Many ideas have been picked up and made into real detectors

The Future is Linear