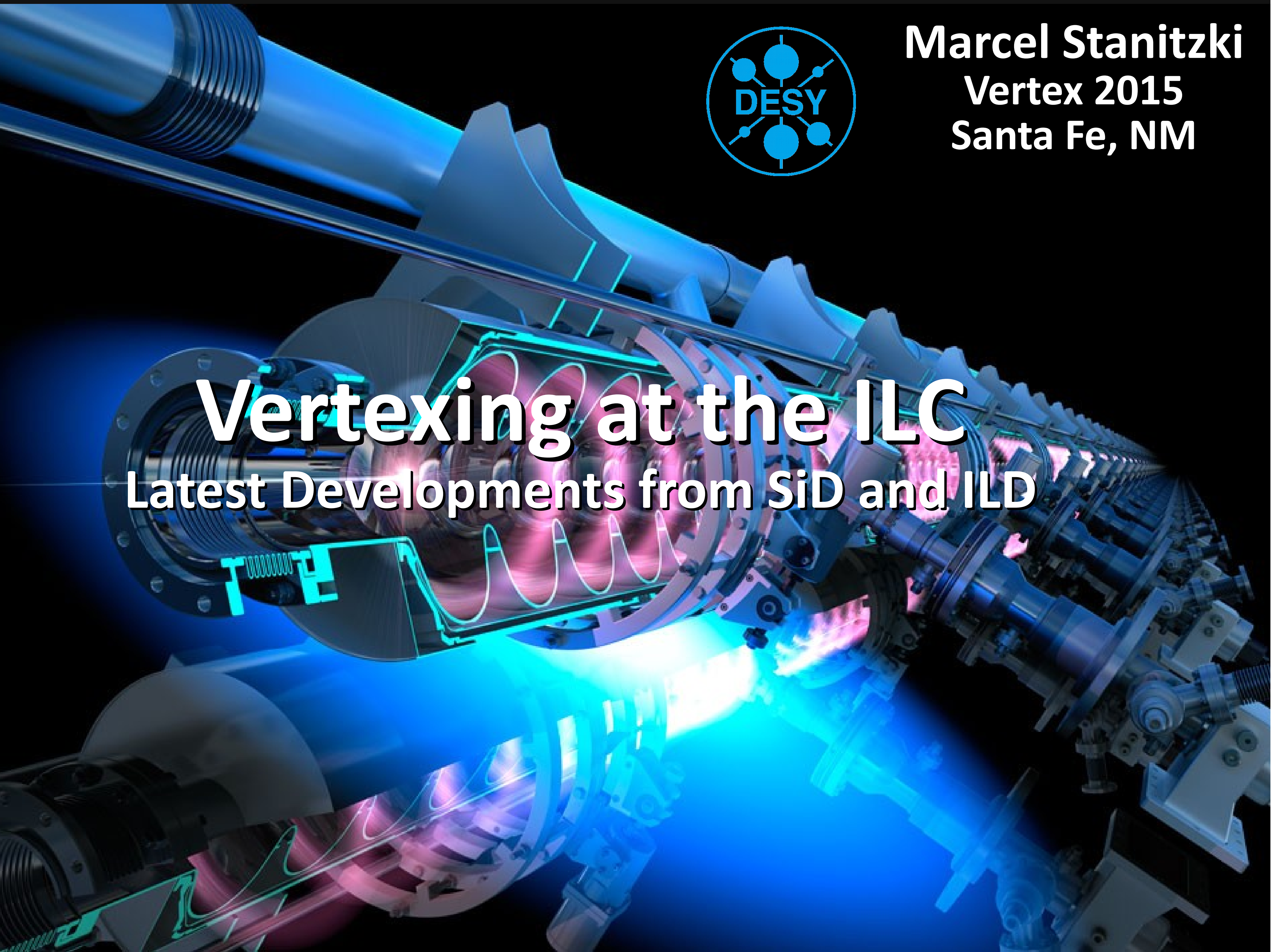
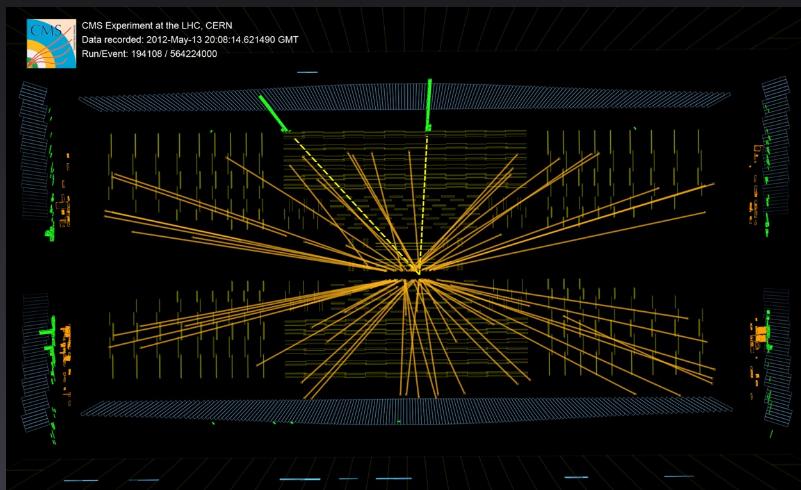
Marcel Stanitzki
Vertex 2015
Santa Fe, NM

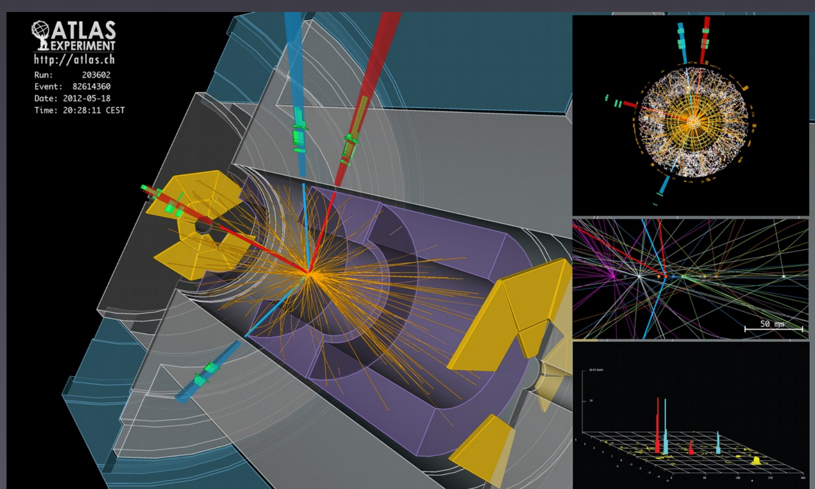


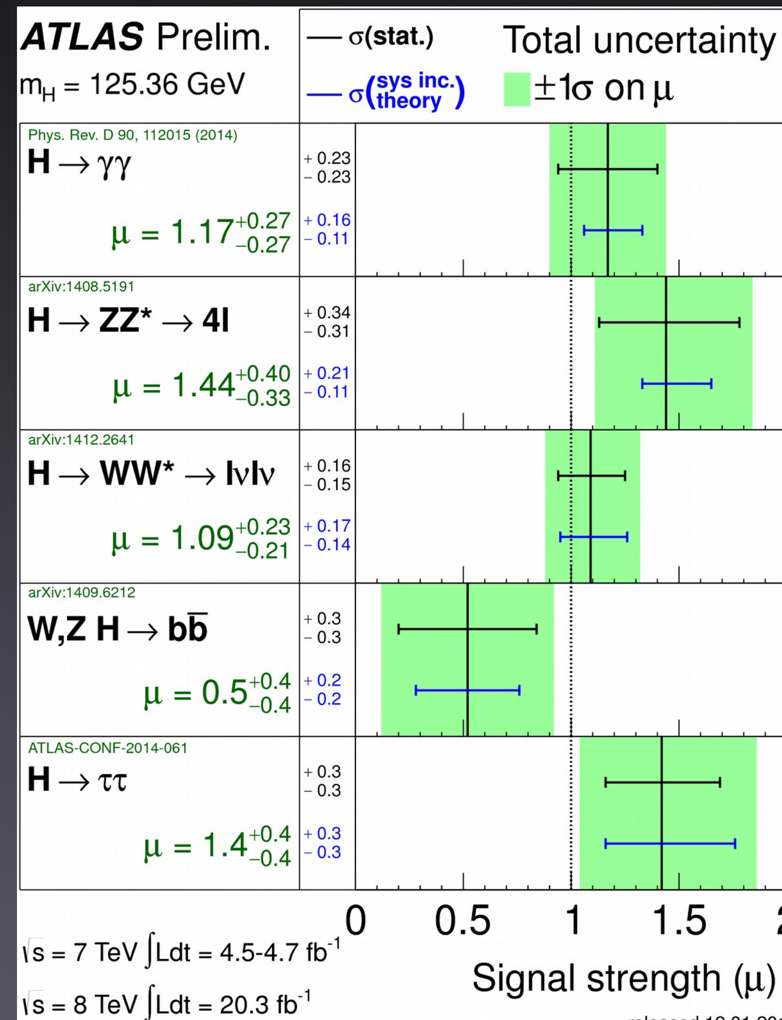
Vertexing at the ILC

Latest Developments from SiD and ILD

Higgs – What do we know ?

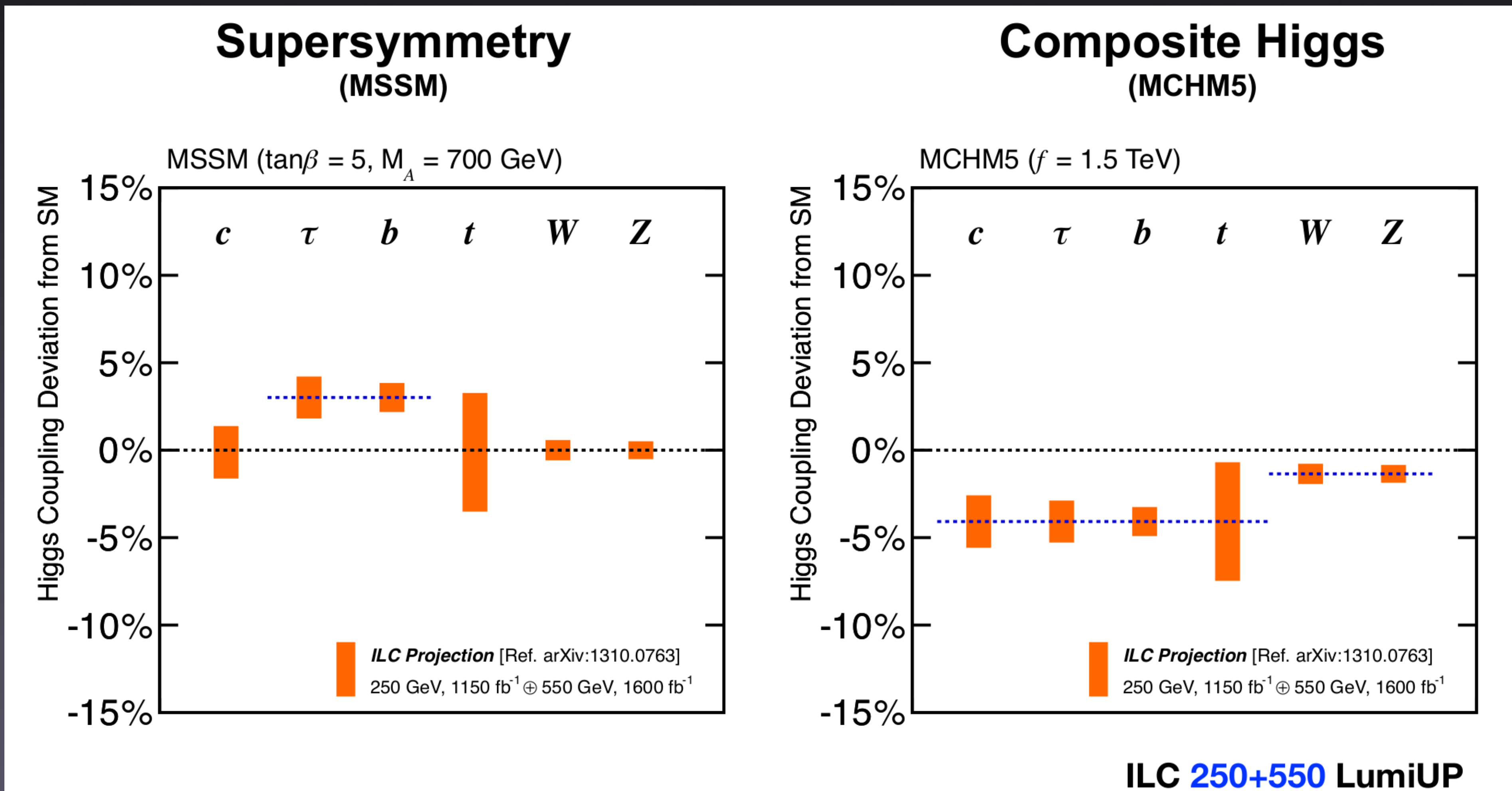






It all looks like the Standard Model Higgs Boson

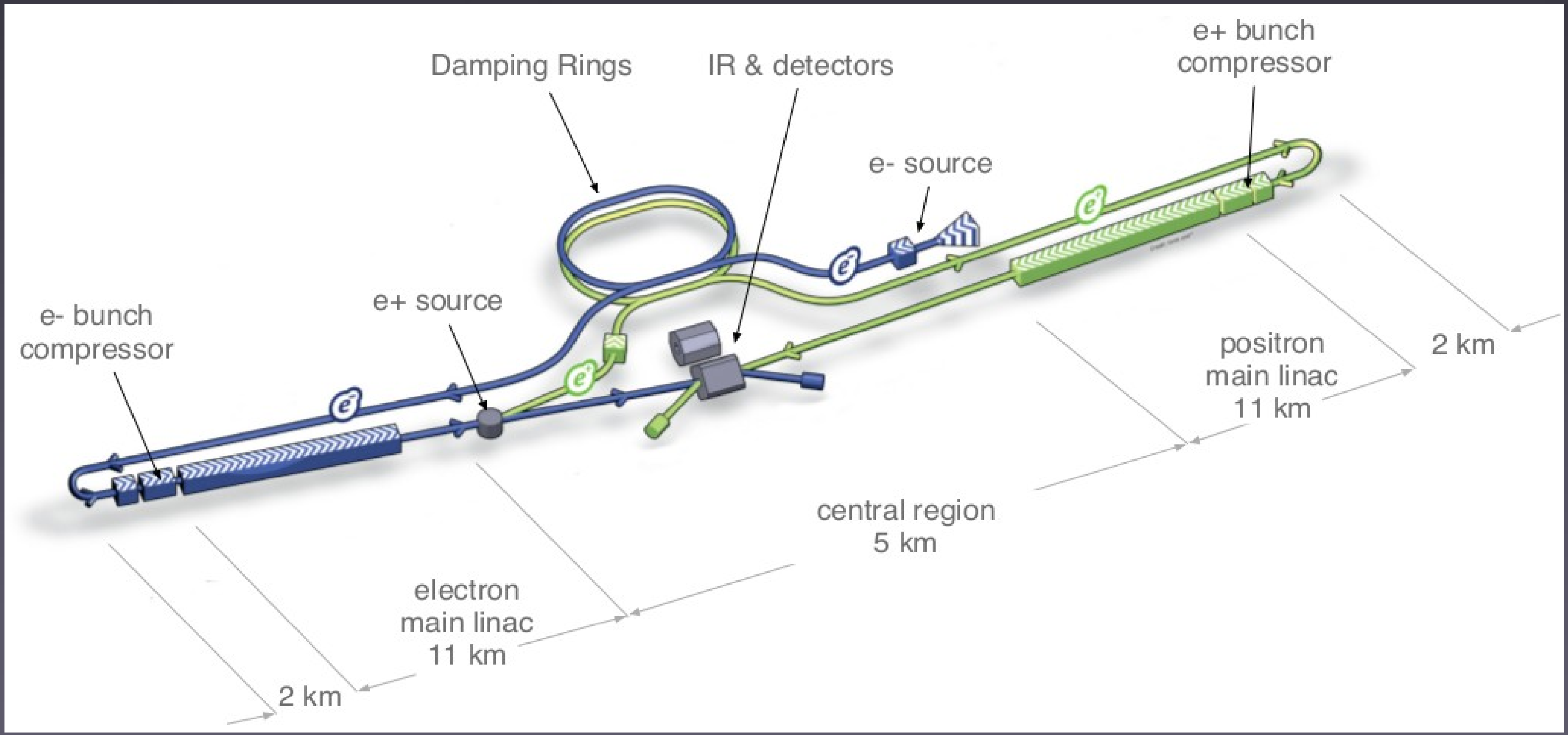
Probing new physics



Percent-level accuracy on Higgs Couplings essential !

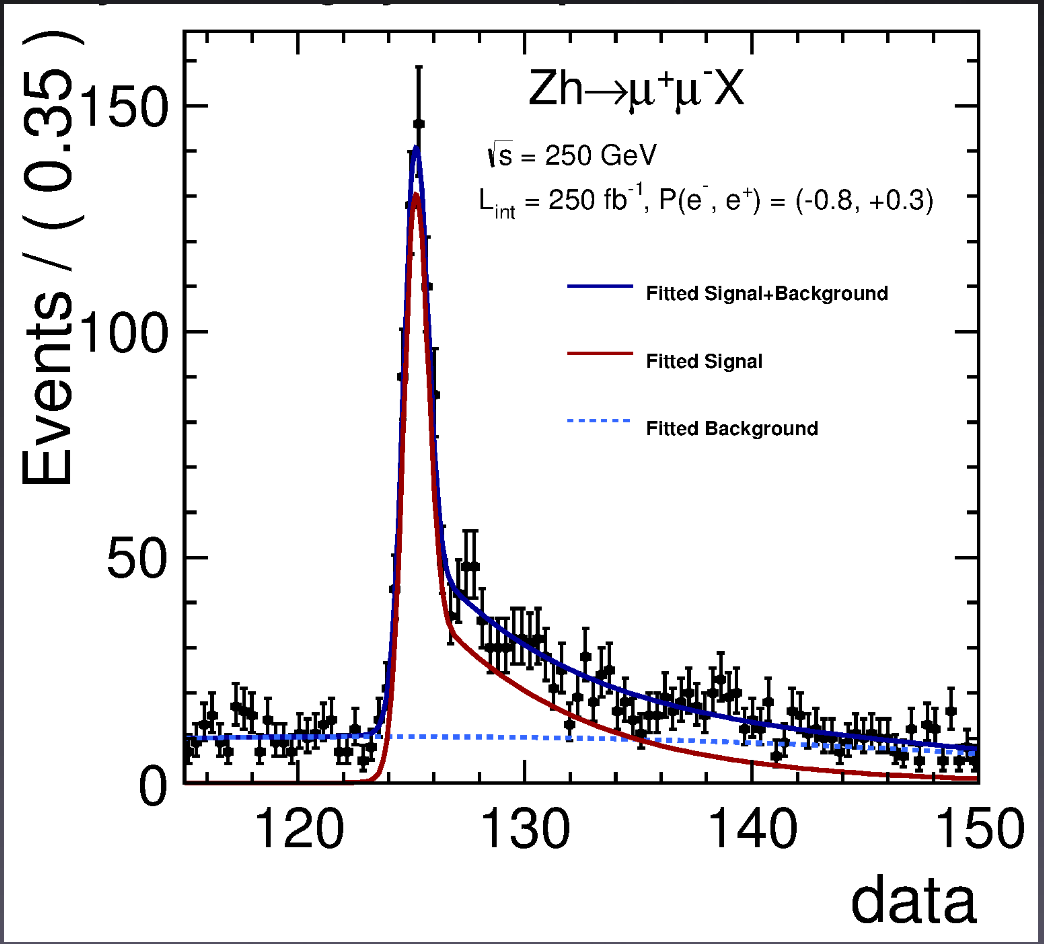
The ILC Project

- The ILC (International Linear Collider)
  - A 500 GeV (baseline) GeV e+e- Linear Collider
  - Upgrade Path to 1 TeV
  - Polarization of both beams possible
- Interaction Region with two detectors



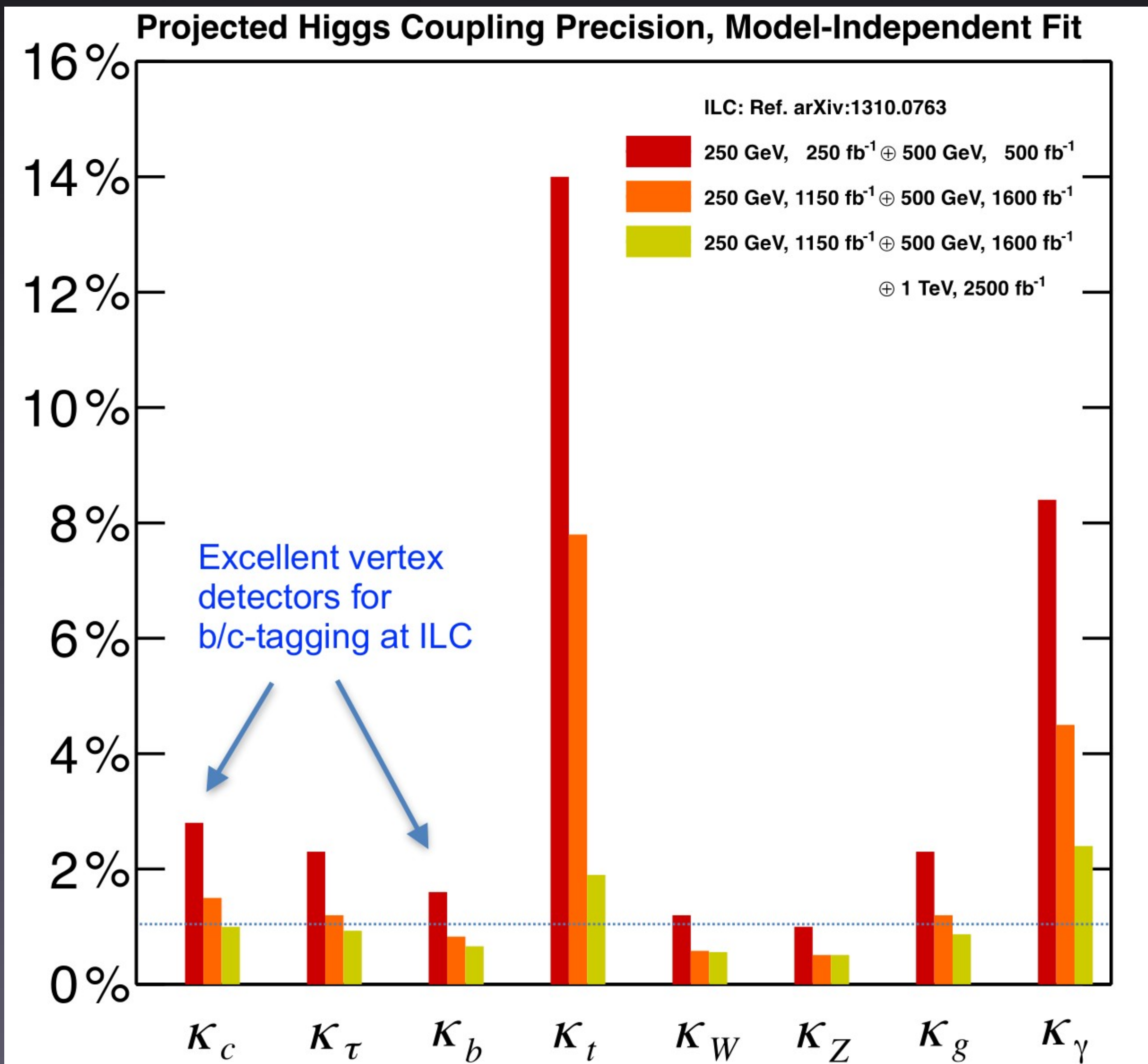
Higgs physics at the ILC

- ILC will do everything the LHC/HL-LHC does
  - Couplings, Mass, Spin
- ILC does Model-independent measurements
- Unique at the ILC
  - Total Higgs Width
  - $H \rightarrow c\bar{c}/gg$
- Higgs-Selfcoupling
  - ILC will establish its existence



Model-independent Measurement of σ_{HZ} at 250 GeV

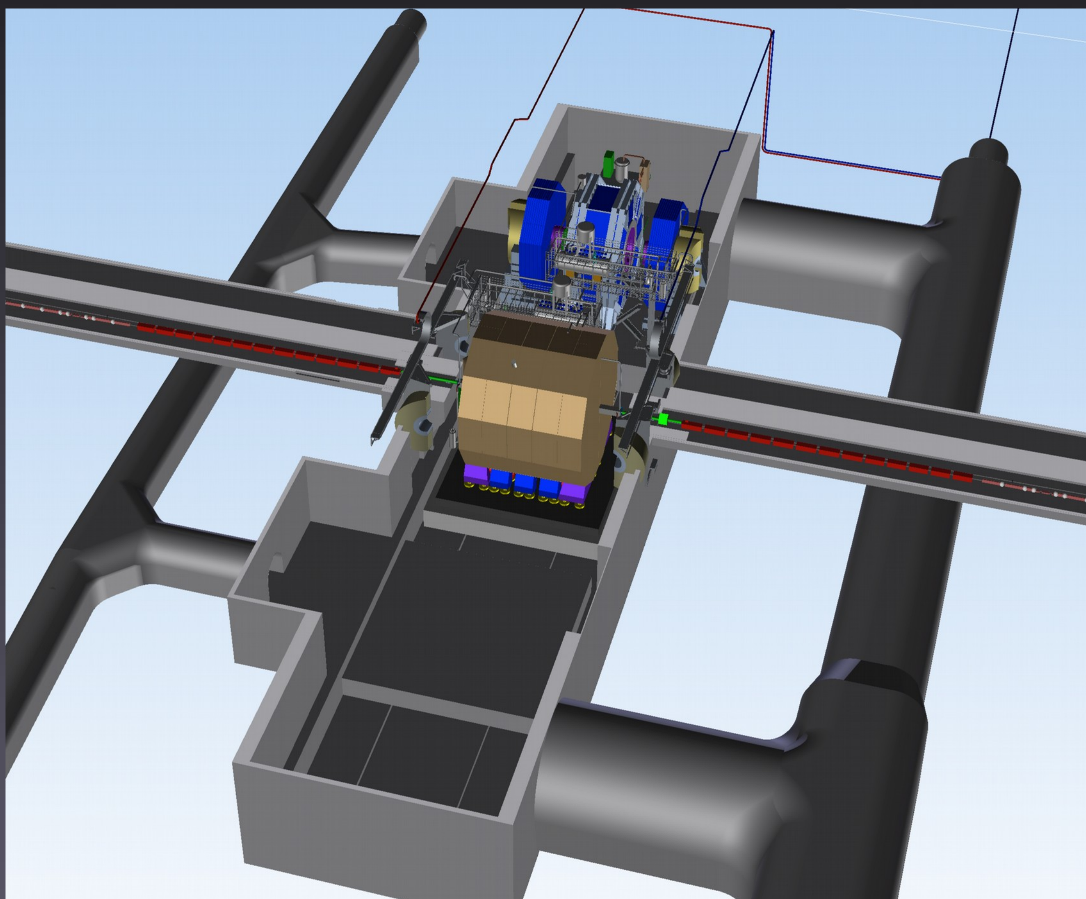
ILC BR Measurements



- Most couplings
  - Approaching 1% accuracy
- Model-independent Fit
  - No assumptions made
- Accuracy on top-coupling
  - Improves with higher E_{CMS}
- $H \rightarrow \gamma\gamma$
  - Benefits from 1 TeV Upgrade

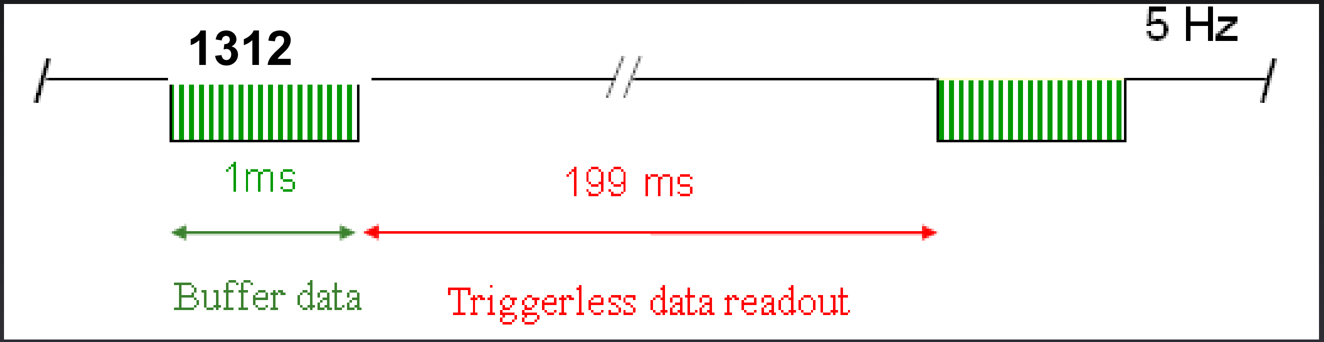
The ILC Detectors

ILC Interaction Region



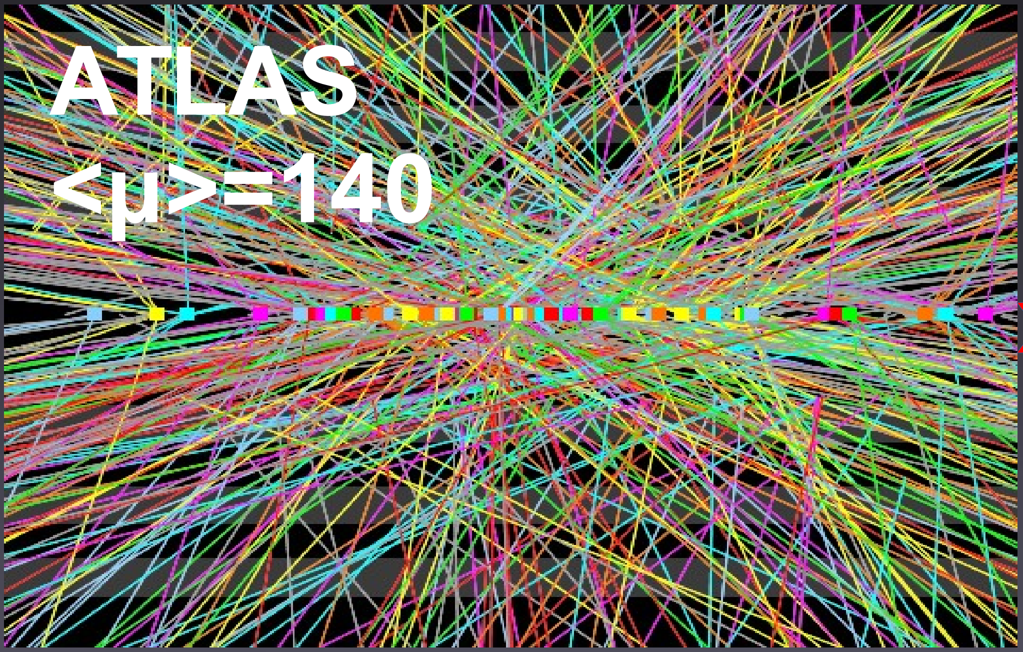
- ILC
  - 1 Interaction Region
  - 2 Detectors
- Push-Pull
  - Detectors mounted on movable platforms
  - Sharing of beam time
  - Switching time ~ 48 hours
- Push-Pull allows
  - Complementarity
  - Cross-Checking of results

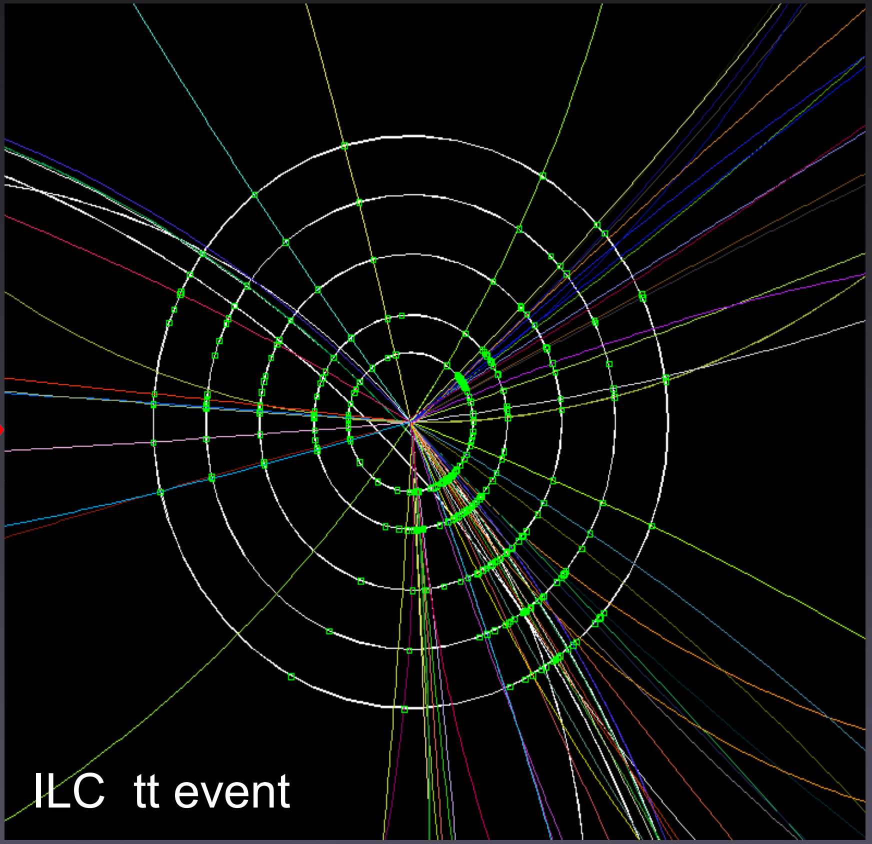
ILC Environment



- ILC environment is very different compared to the LHC
  - Bunch spacing of ~ 554 ns (baseline)
  - 1312 bunches in 1 ms
  - 199 ms quiet time
- Occupancy dominated by beam background & noise
  - ~ 1 hadronic Z ($e^+e^- \rightarrow Z \rightarrow q\bar{q}$) per train ...
- Readout during quiet time is possible
- Big Impact on detector design

From HL-LHC to ILC

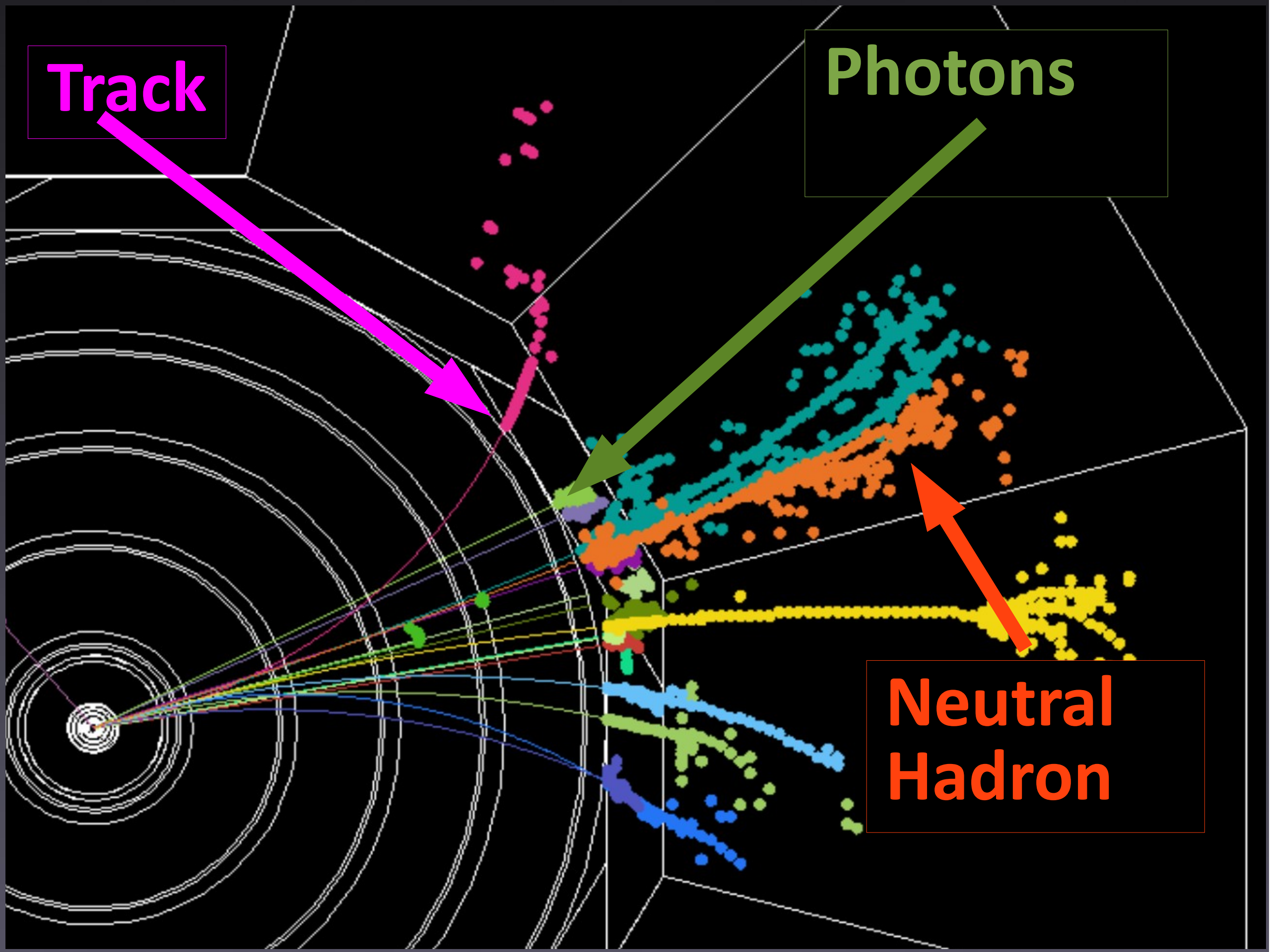




Moving from 140 interactions per crossing to ~1 event/train

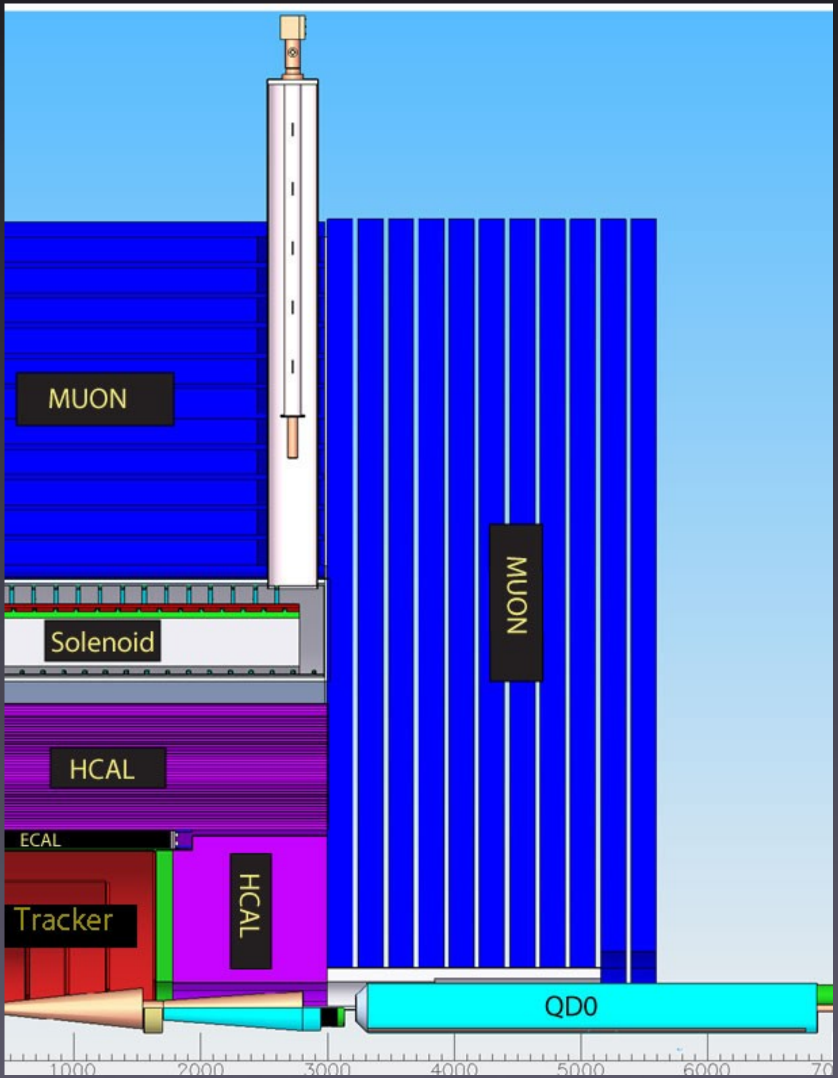
The PFA Approach

- PFA = Particle Flow Algorithms
- Combining all available reconstruction information
  - Momentum (Tracker), Energy (Calorimetry), Particle type (PID)
  - Typical ILC Jet :
    - 60 % charged particles, 30 % photons, 10% neutrals
- PFA is key to desired Jet Energy Resolution at the ILC

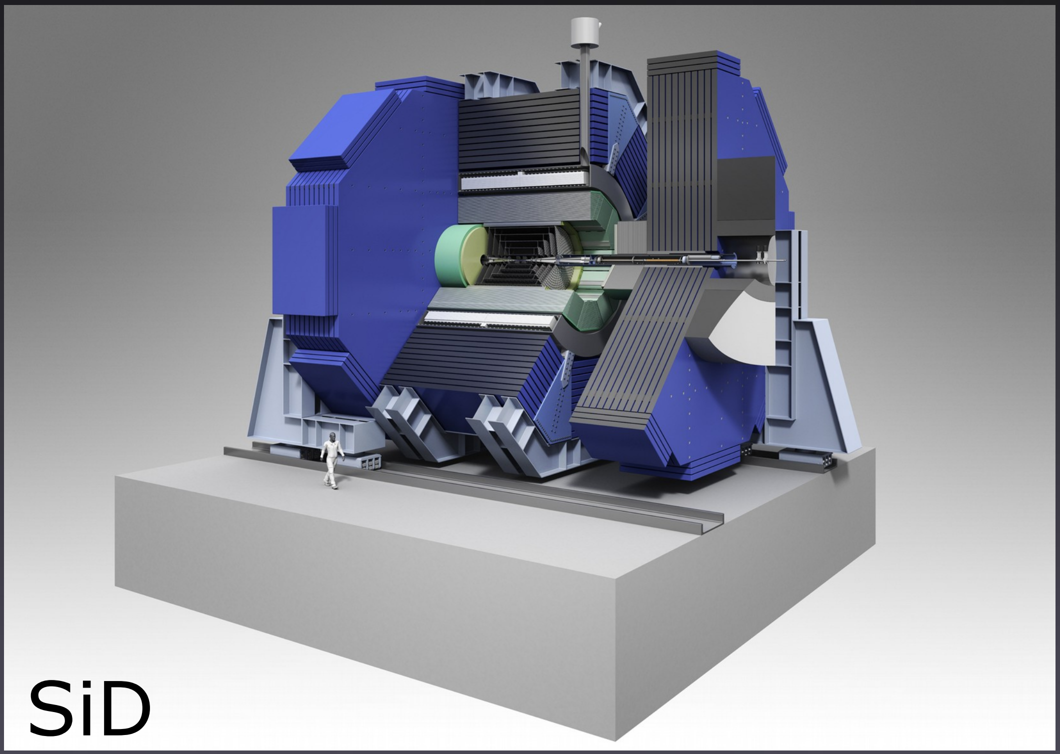


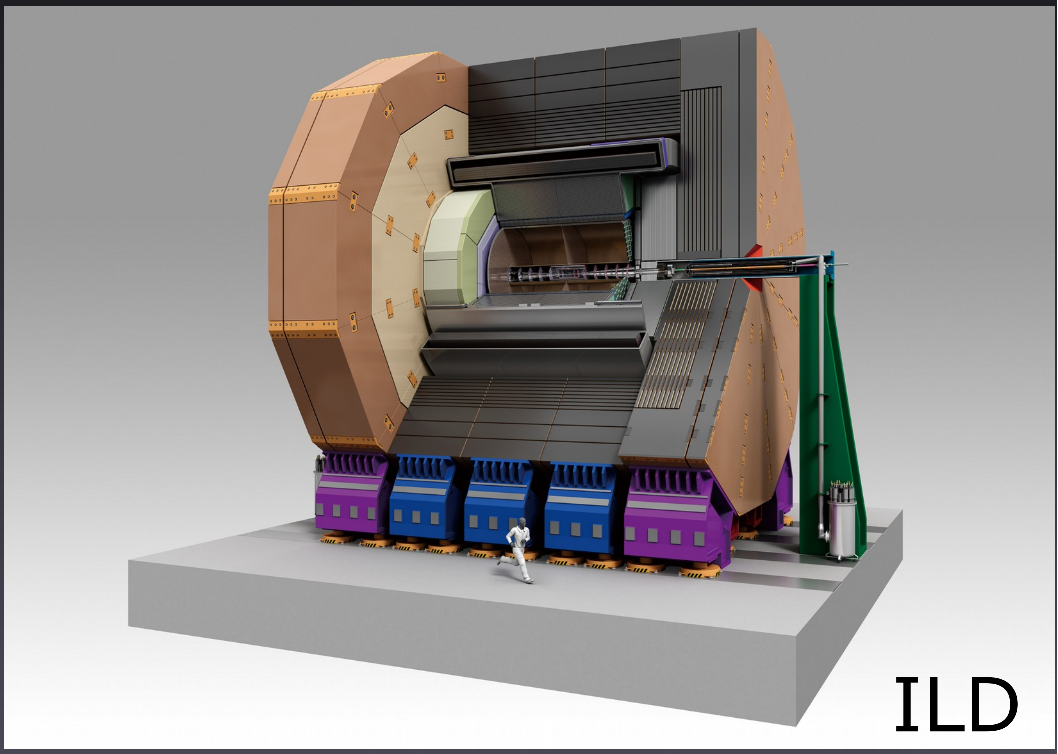
ILC Detectors

- PFA has been used at LEP, HERA and LHC
- Novel Approach at the ILC
  - PFA drives design of the detector
- Consequences
  - Calorimetry inside the Solenoid
  - Highly Granular Calorimetry
  - Low-mass tracking



SiD & ILD





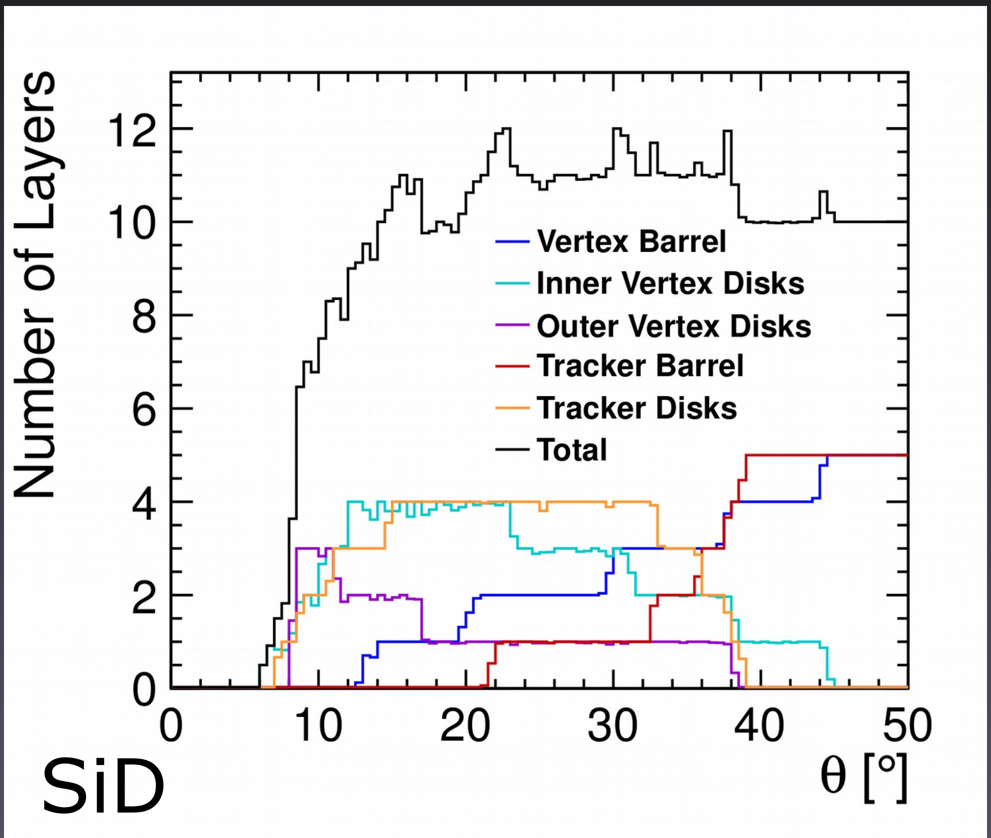
- SiD
  - $r_{Tracker}$=1.25 m
  - B = 5 T
  - All-silicon tracking
- ILD
  - $r_{Tracker}$=1.8 m
  - B = 3.5 T
  - Time Projection Chamber

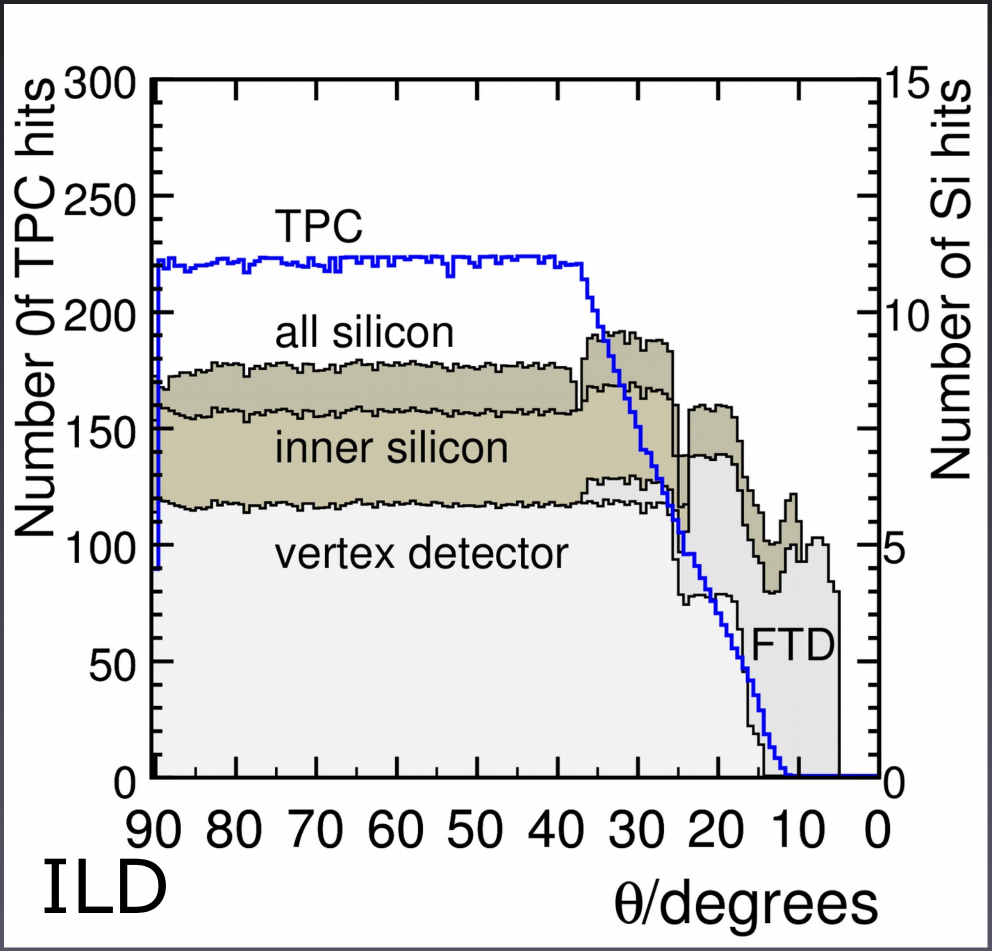
Two Tracking Approaches

- All-silicon Tracking
  - SiD's choice
- Tracking system
  - 5 layer pixel Vertex detector
  - 5 layer Silicon strip tracker
- Few highly precise hits
  - Max 12 hits
- Low material budget
- Concept proven by CMS

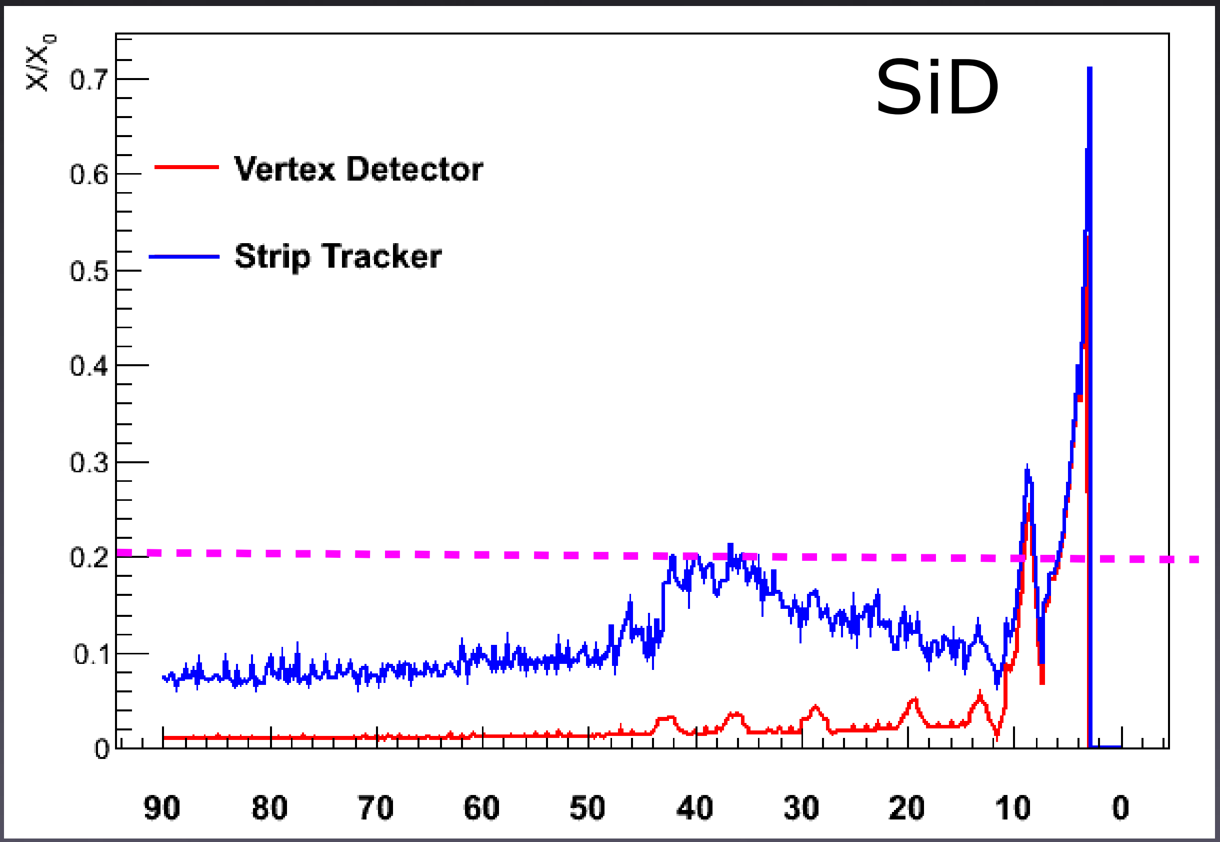
- Gaseous Tracking
  - ILD's choice
- Tracking System
  - 3 double layer Vertex detector
  - Intermediate silicon layers
  - TPC
- Max number of hits
  - 228
- High hit redundancy
- Classical approach

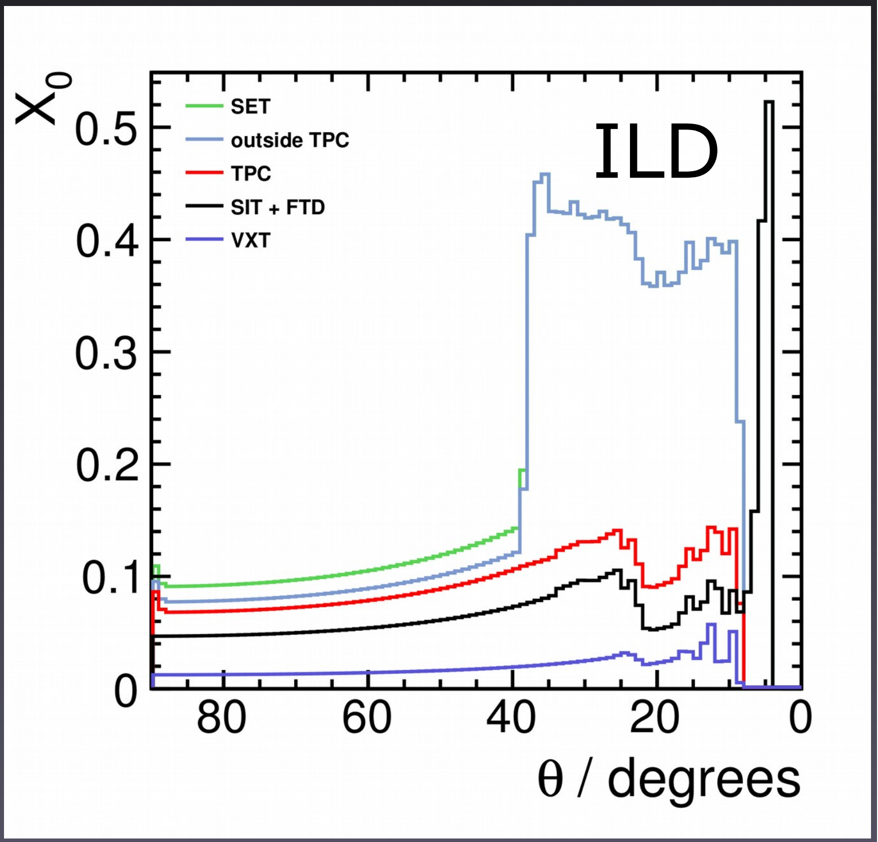
Available Hits





Material Budget

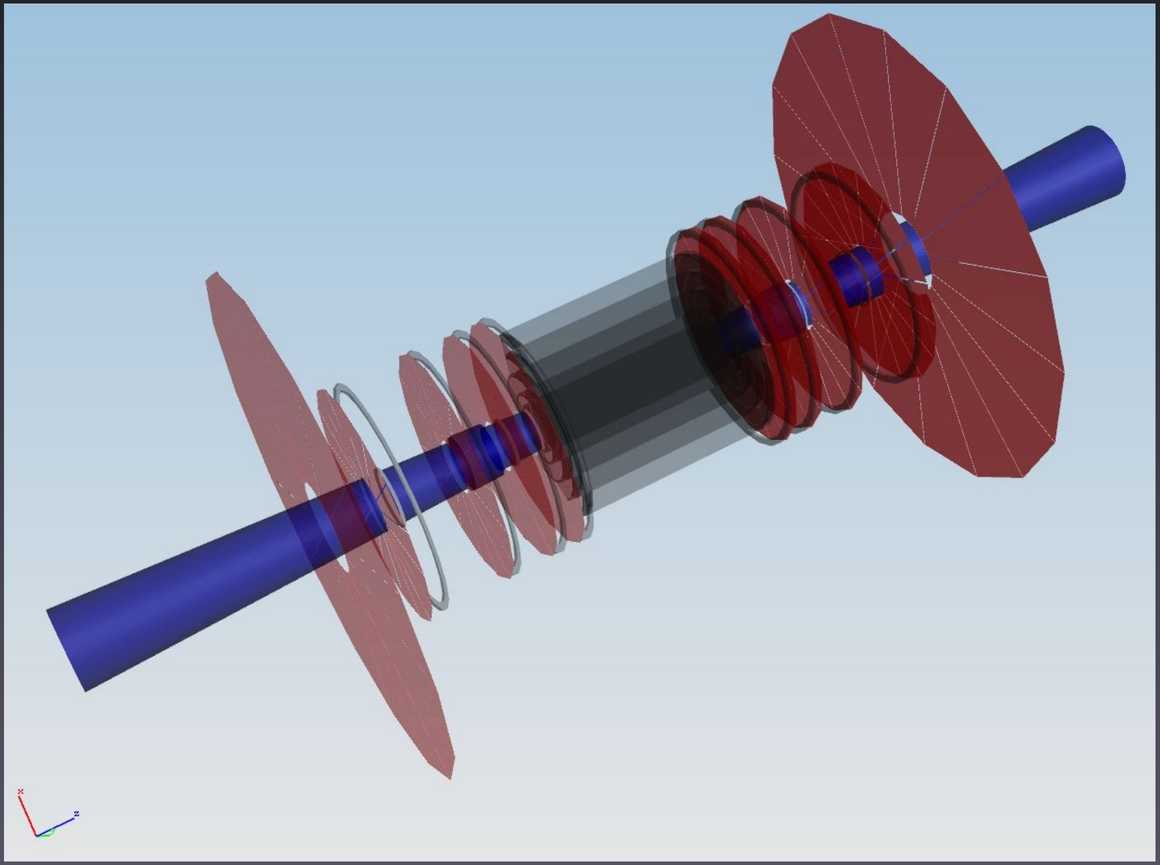




- Ambitious Material budget goals
  - Entire Tracking < 20 % X_0
  - Vertex Detector layer ~ 0.1 % X_0

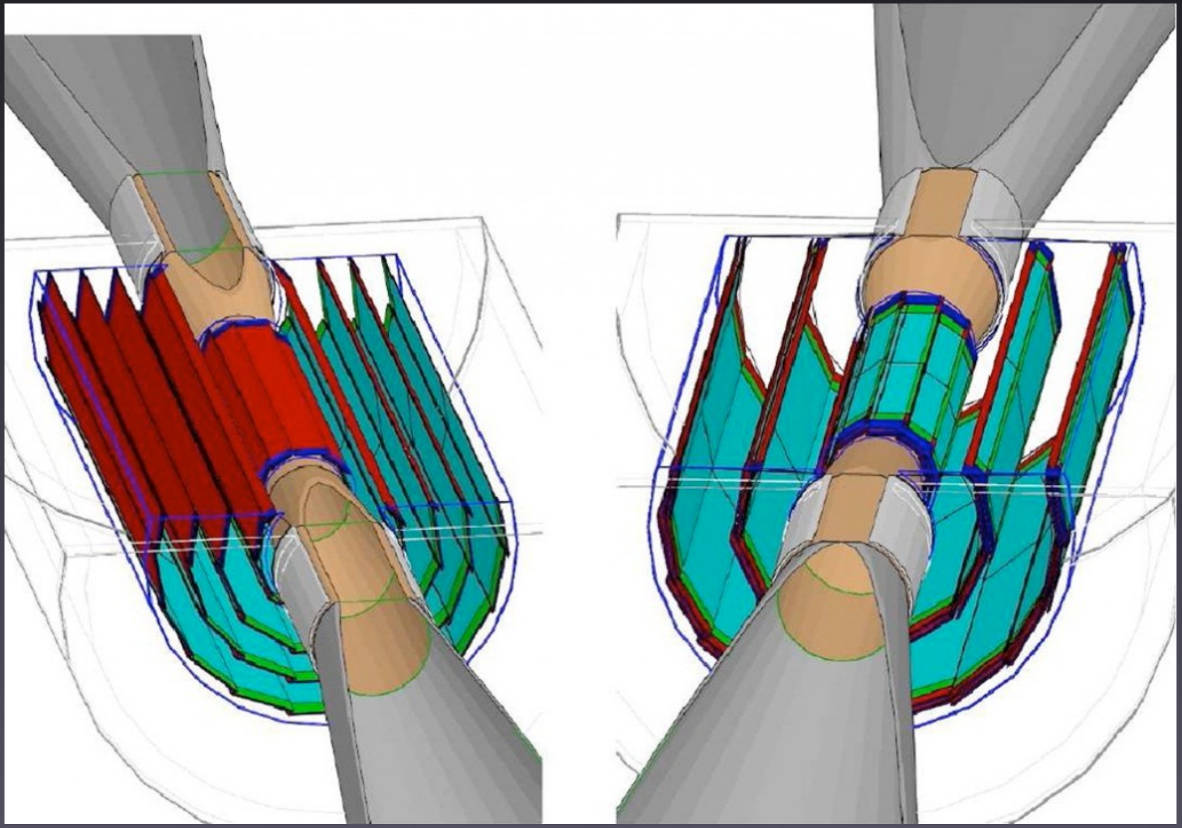
Vertex Detector – SiD Design

- Design
  - 5 barrel layers
  - 4 disk
  - 3 forward disks
- Requirements
  - <3 µm hit resolution
  - Pixel sizes of O(20 µm)
  - ~ 0.1 % X_0 per layer
  - < 130 µW/mm^2
  - Single bunch timing resolution

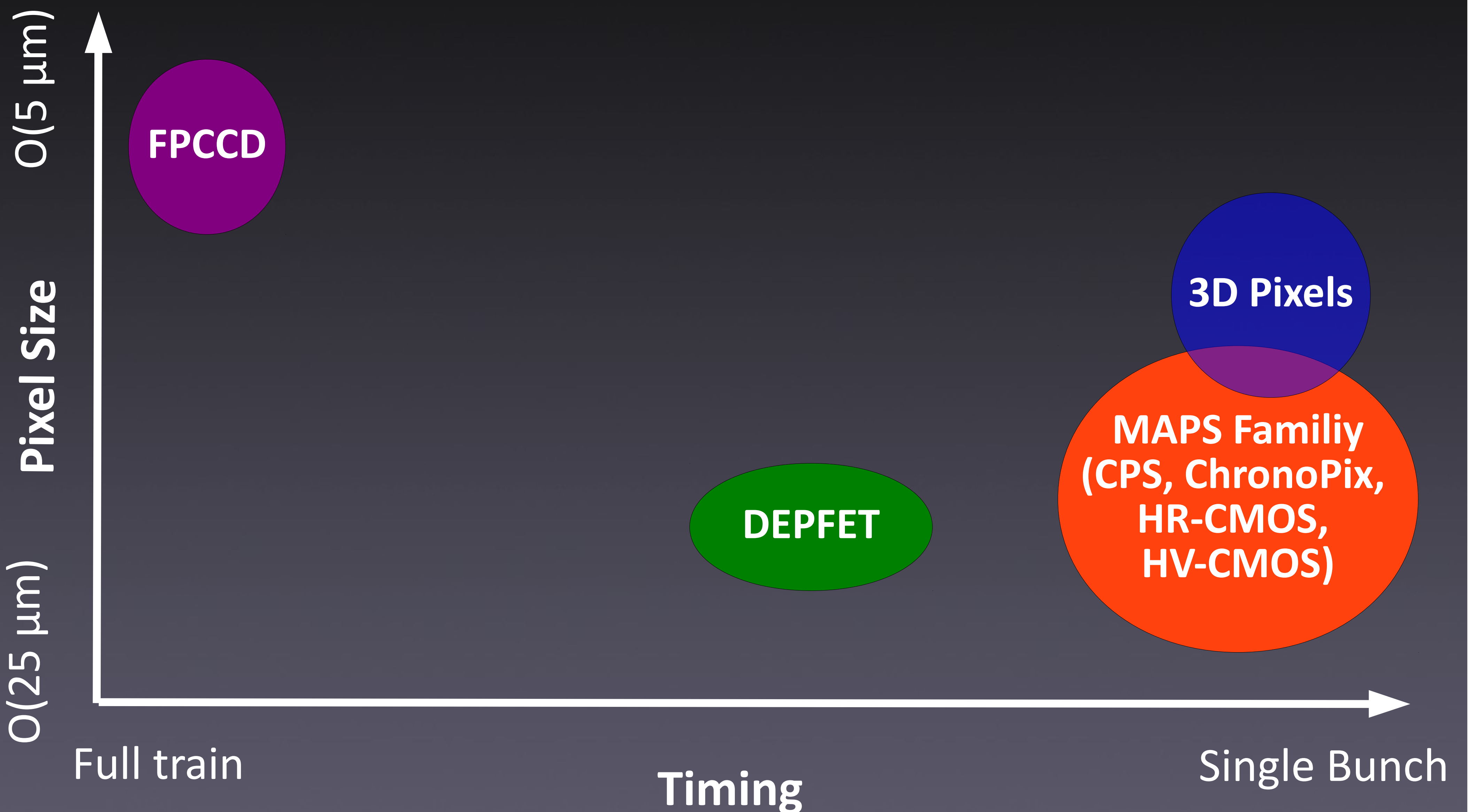


Vertex Detector – ILD Design

- Design
  - 25cm long barrel
  - No end caps
  - Alternates:
    - 5 single layers
    - 3 double layers
- Requirements
  - Similar to SiD
  - Not fixed on single-bunch time stamping

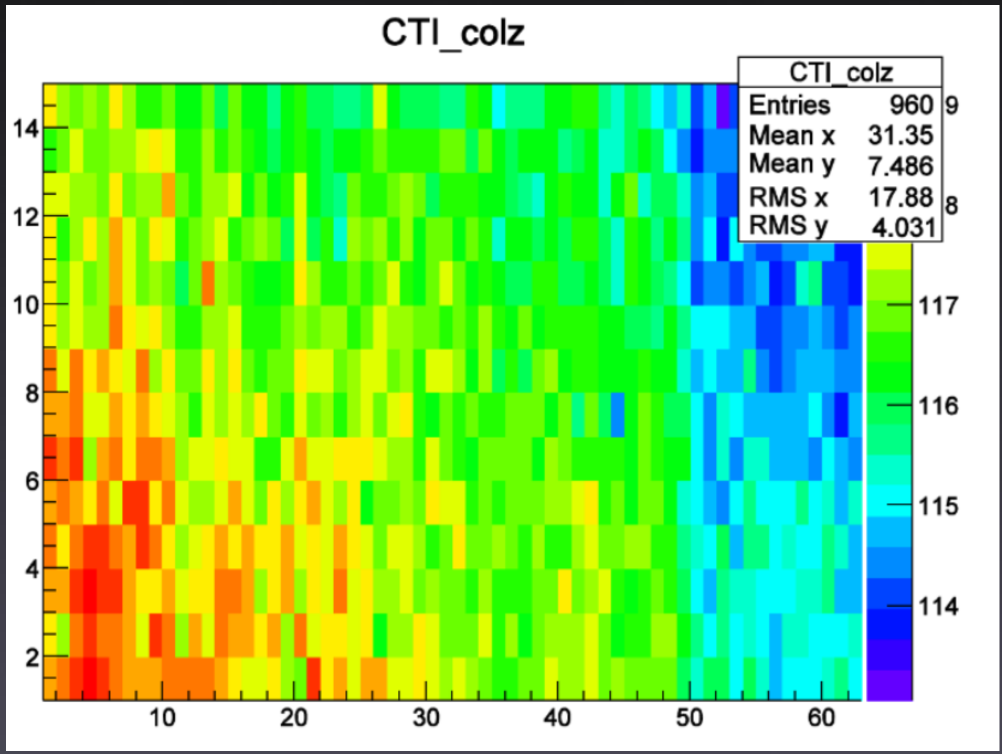


Candidate Technologies



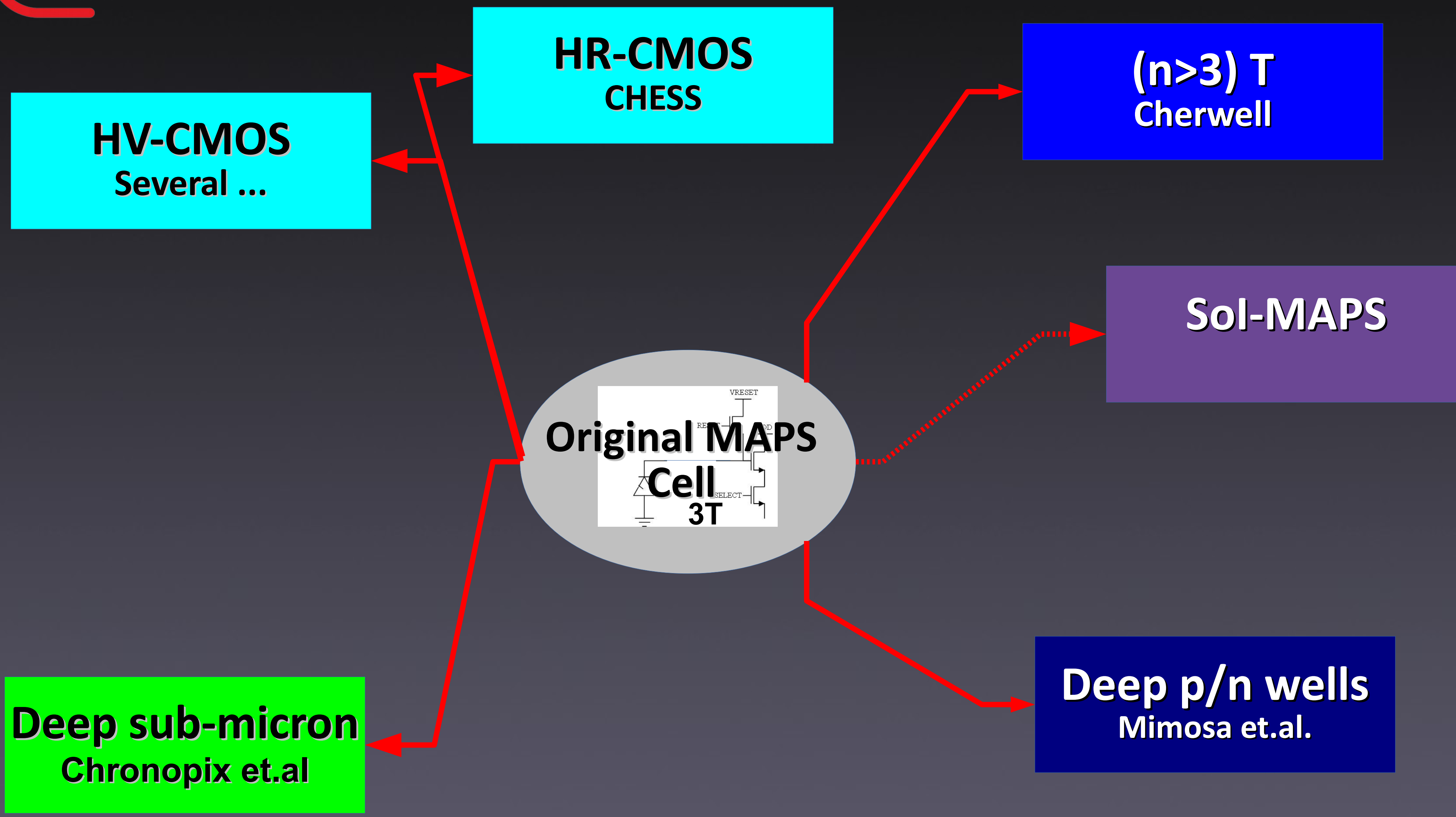
FPCCD

- Target pixel size 5 µm x 5 µm
  - 6 µm x 6 µm achieved
- Readout during quiet time
- 50 µm thin silicon
- Operating at -40 C
- Recently studies of radiation hardness
  - Goal $1x10^{12}$ neq/cm^2



Position of ^{55}Fe peak after irradiation

MAPS

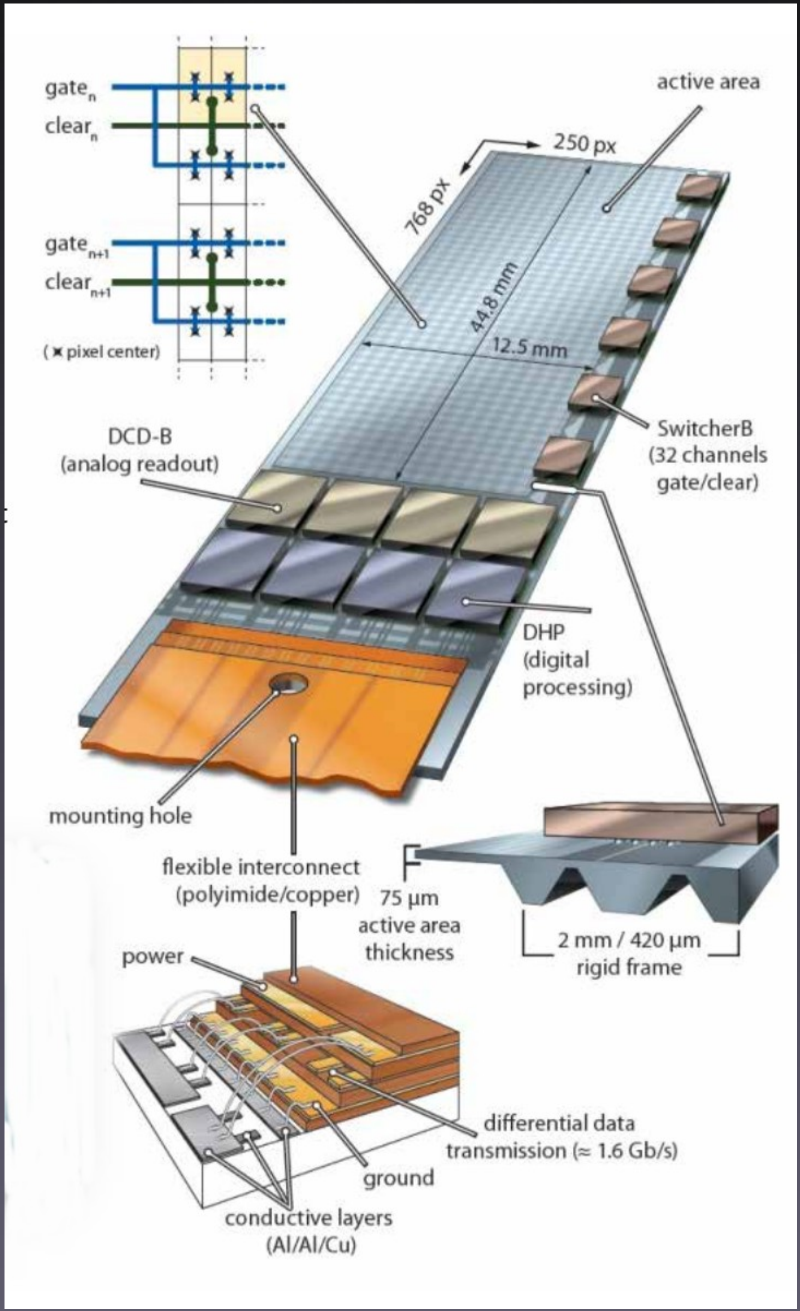

HV-CMOS
Several ...
HR-CMOS
CHESS
(n>3) T
Cherwell
Sol-MAPS
Original MAPS Cell
3T
VRESET
SELECT
Deep sub-micron
Chronopix et.al
Deep p/n wells
Mimosa et.al.

Mimosa Familiy

- Family of monolithic CMOS pixel sensors (Strasbourg)
  - EUDET/AIDA telescopes
  - STAR heavy-ion experiment at Brookhaven
- PLUME collaboration building ~0.3% X_0 modules
  - Double-sided: time-stamp/spatial-resolution sensors paired

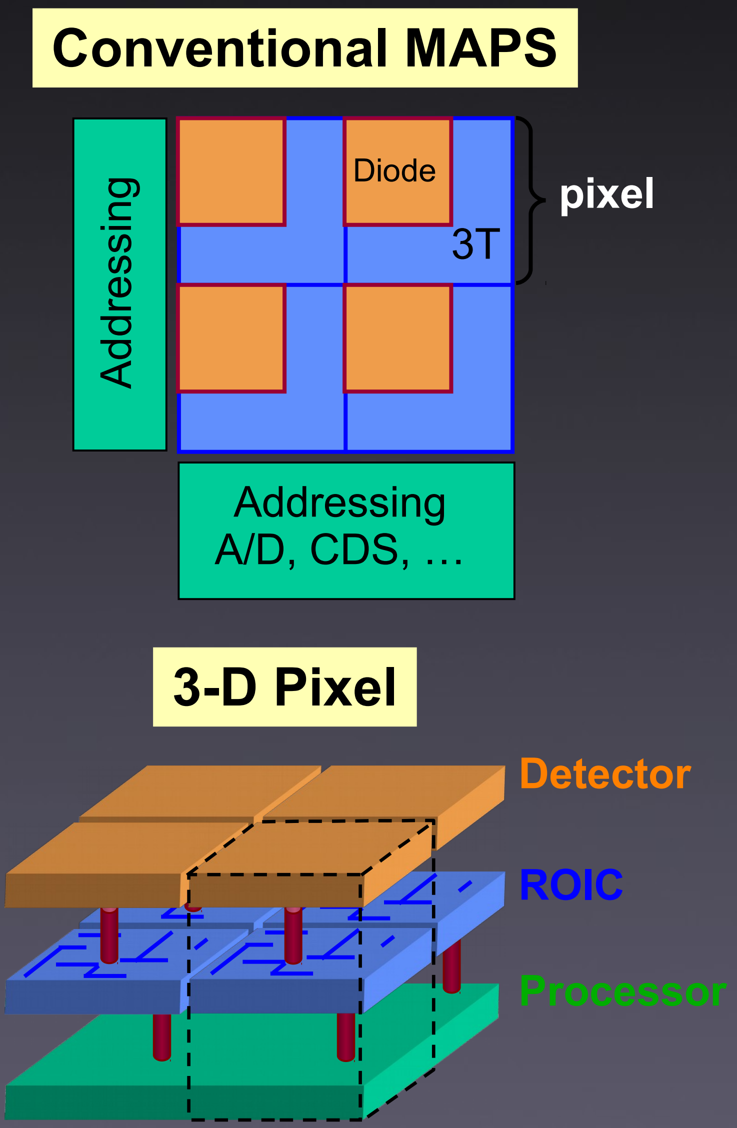
DEPFFET

- Small pixels (~20µm) for excellent single point resolution (~3µm)
- Thin sensors with large S/N; minimize support, services, and cooling material
- Rolling shutter mode readout
  - take as many frames as possible to minimize occupancy!
  - goal is ~1/50µs frame rate, 1/50ns row rate (innermost layer)
- radiation tolerant up to ~1Mrad and ~10^{12} n eq /cm^2 for 10 years operation (e - in the MeV range)
- Will have Lots of Experience from Belle-II Upgrade



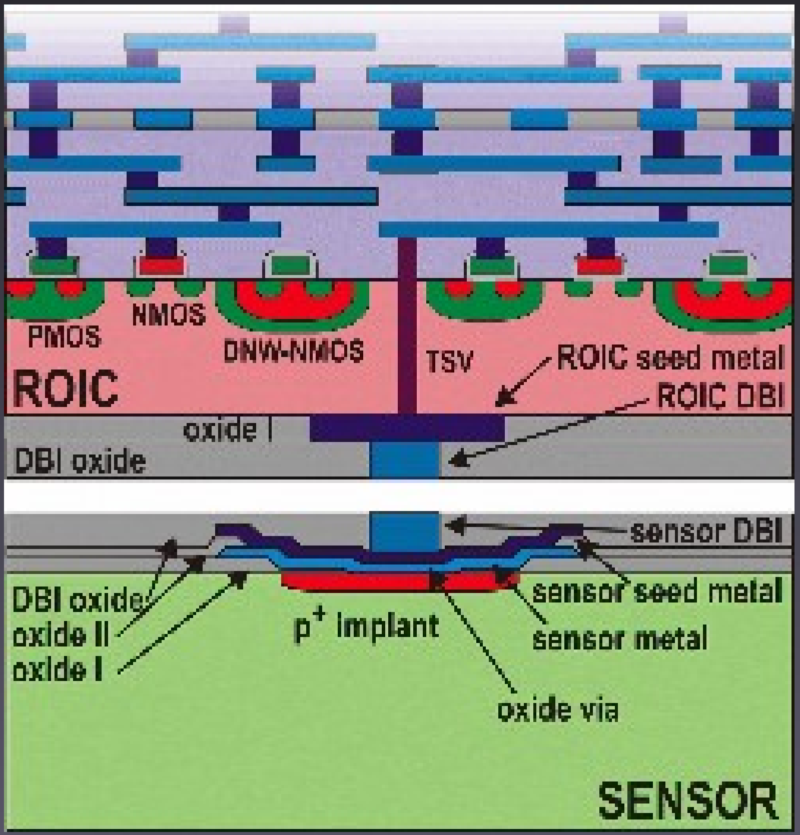
3D Integration

- The ultimate dream of any pixel designer
  - Fully active sensor area
  - Independent control of substrate materials for each of the tiers
  - Fabrication optimized by layer function
  - In-pixel data processing
  - Increased circuit density due to multiple tiers of electronics
- A new way of doing things



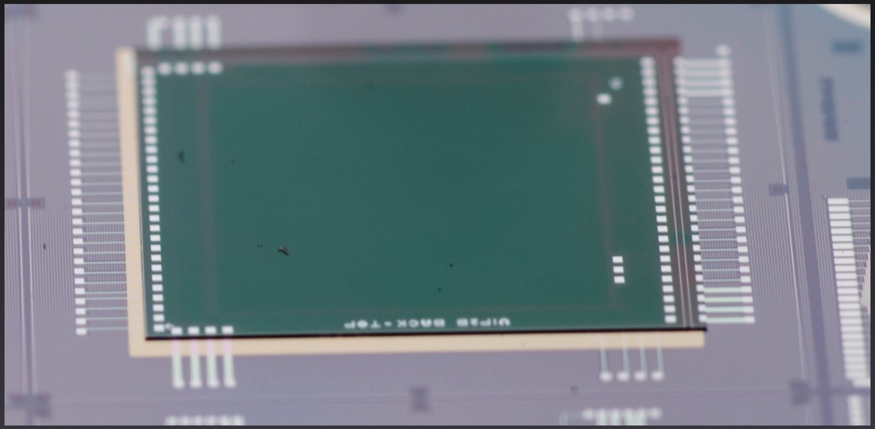
3D Technologies

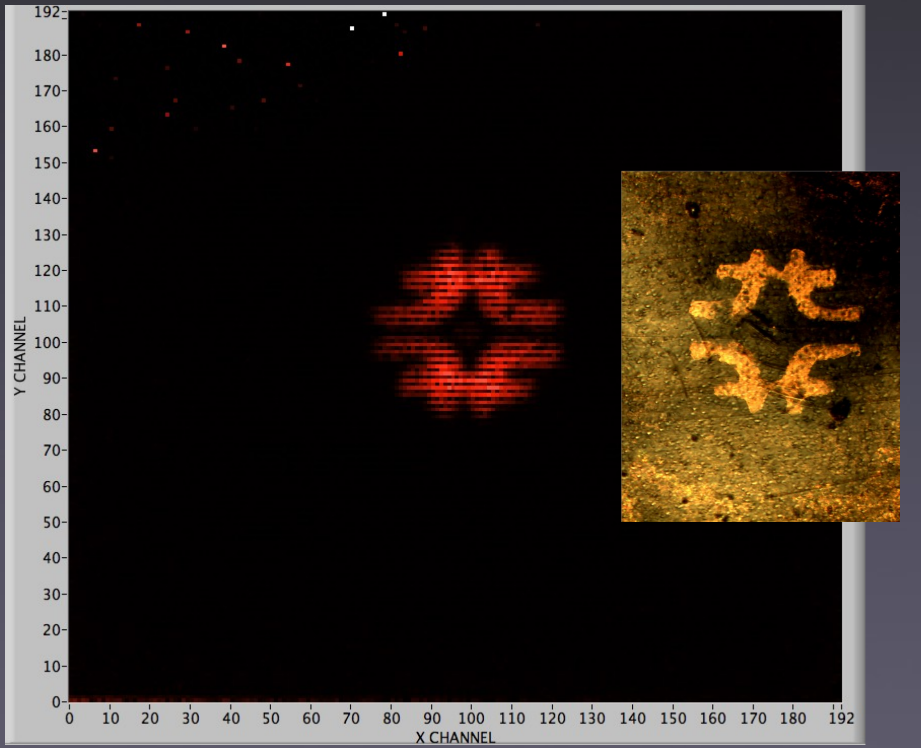
- Component Technologies
  - Through Silicon Vias (TSV)
  - Bonding: Oxide-, polymer-, metal-, or adhesive , Wafer-Wafer, Chip-Wafer or Chip-Chip
  - Wafer thinning
  - Back-side processing: metalization and patterning
- Three Chips made by Fermilab
  - VIP(ILC), VICTR(CMS), and VIPIC(X-Ray)



VIP for ILC

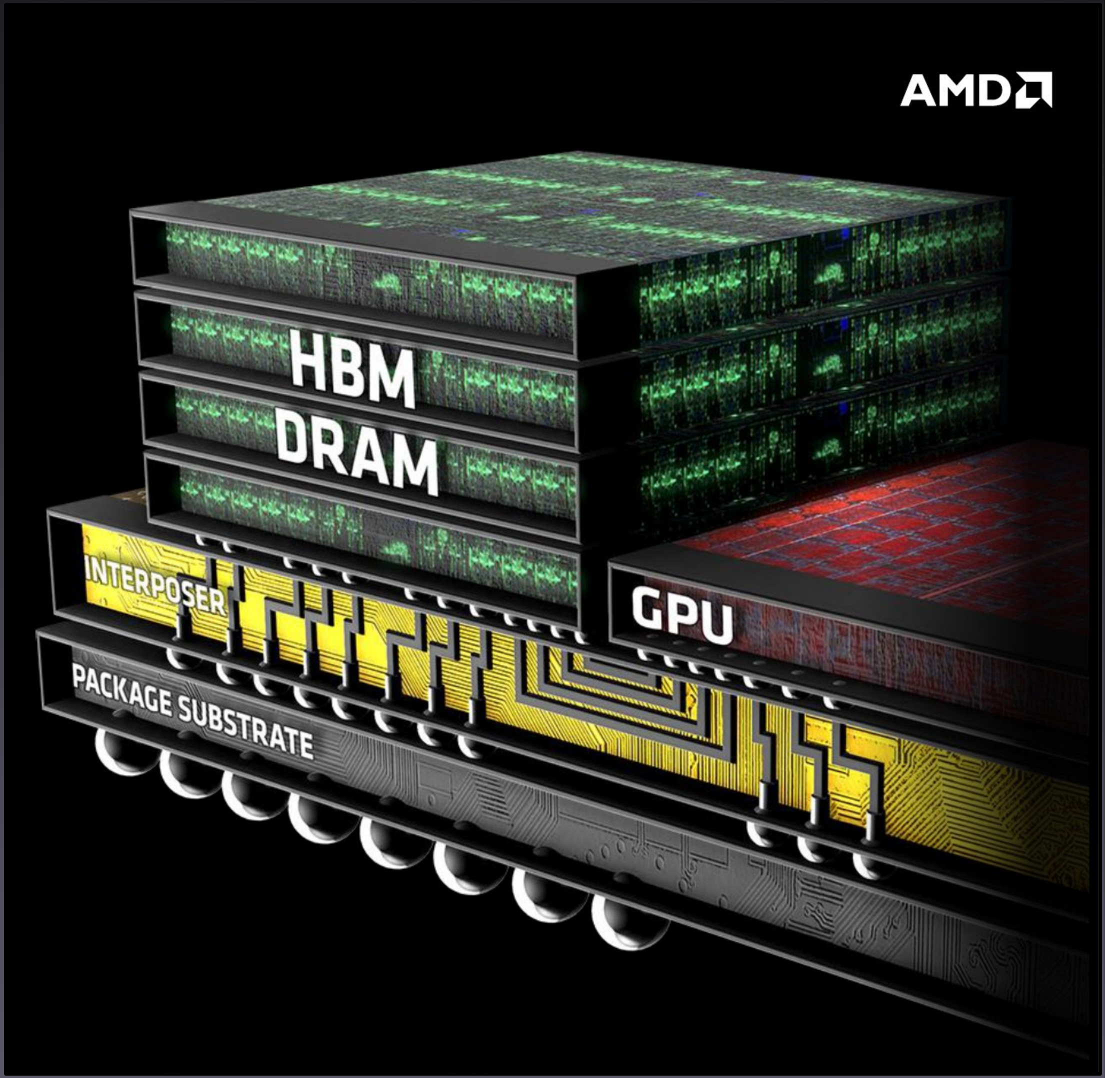
- Features
  - 192 × 192 array of 24x24 μm^2 pixels
  - 8 bit digital time stamp
  - Readout between ILC bunch trains of sparsified data
  - Analog signal output with CDS
  - Analog information available for improved resolution
  - Serial output bus
  - Polarity switch for collection of e- or h+





On the Side...

- New GPU's feature
  - High-Bandwidth DRAM
  - Interposers
- Enter Mainstream GPU market
  - AMD now
  - Nvidia in 2016
- It's all 3D Integration ..
  - No niche application anymore

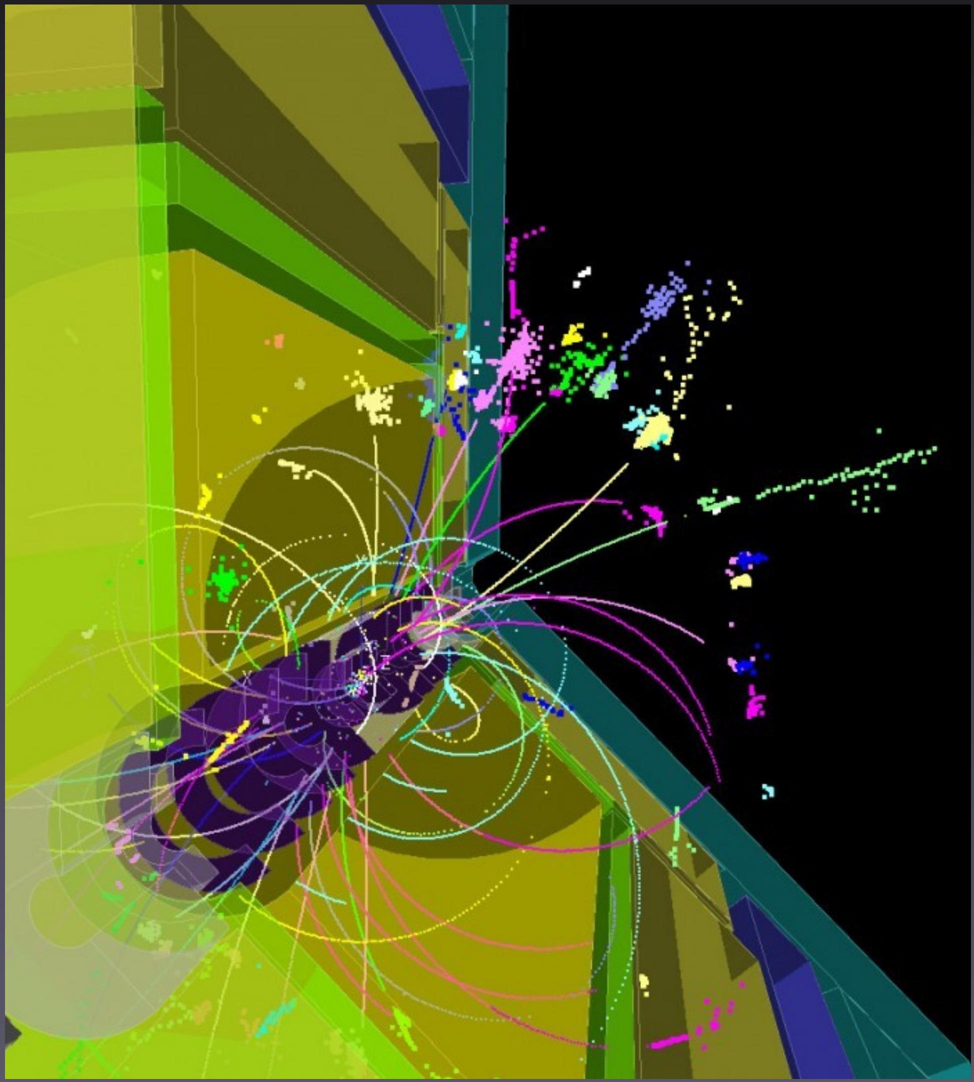


Some Comments

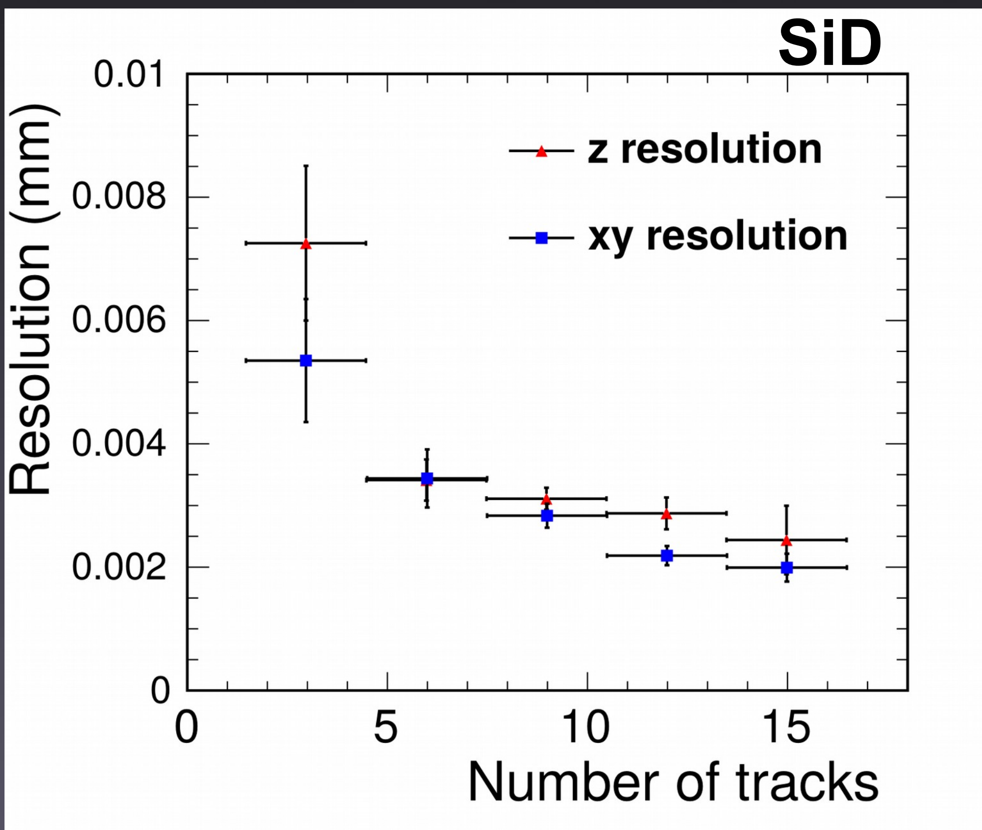
- The Vertex detector is technologically challenging
  - Data rates, resolution, Mechanics, cooling
  - Lots of things we learn from HL-LHC
- Number of channels is impressive
  - ~ 1.7 Gigapixels
- Area not so much (compared to LHC)
  - ~ 0.7 m^2
- Both ILD and SiD plan for late technology decision, which is possible
  - Assembly time
  - "Vertex Detector last" approach
- What is late ?
  - ILC construction time is ~ ten years
  - Can be halfway down the road

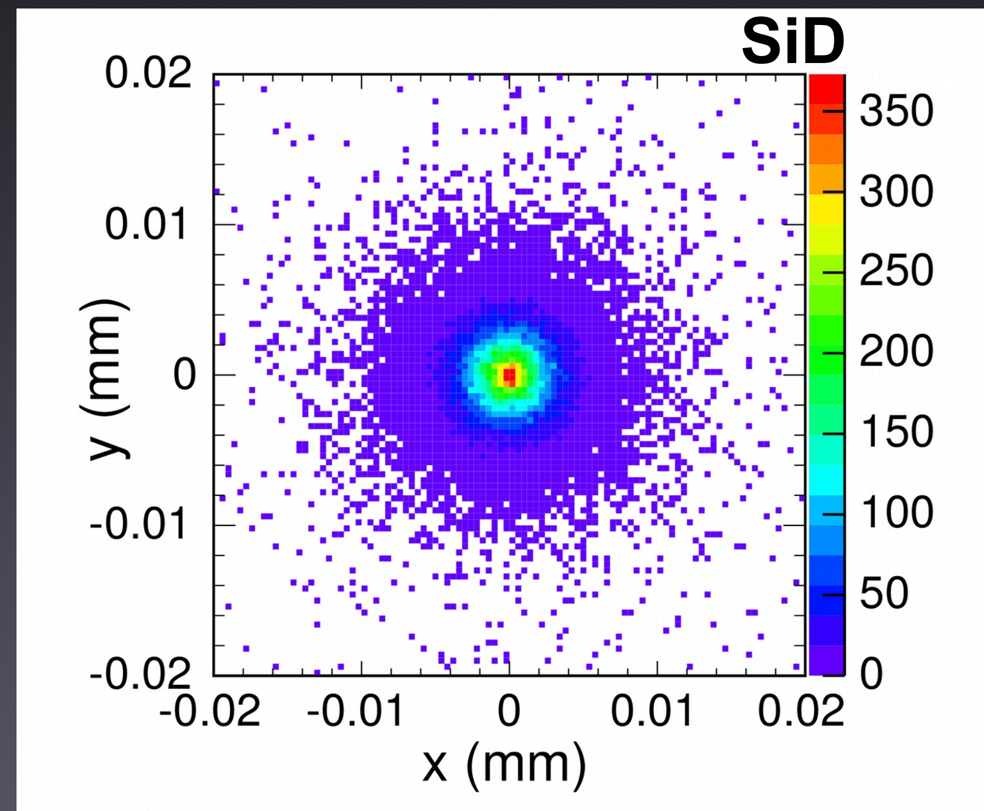
Reconstruction Suite

- Both concepts
  - GEANT4-based simulation
  - Full reconstruction (no cheating)
  - Common EDM (LCIO)
- Full background simulation
  - e^+e^- pairs
  - $\gamma\gamma \rightarrow$ hadrons
- Recent developments
  - New MDI, new beam parameters
  - Studies will be re-done



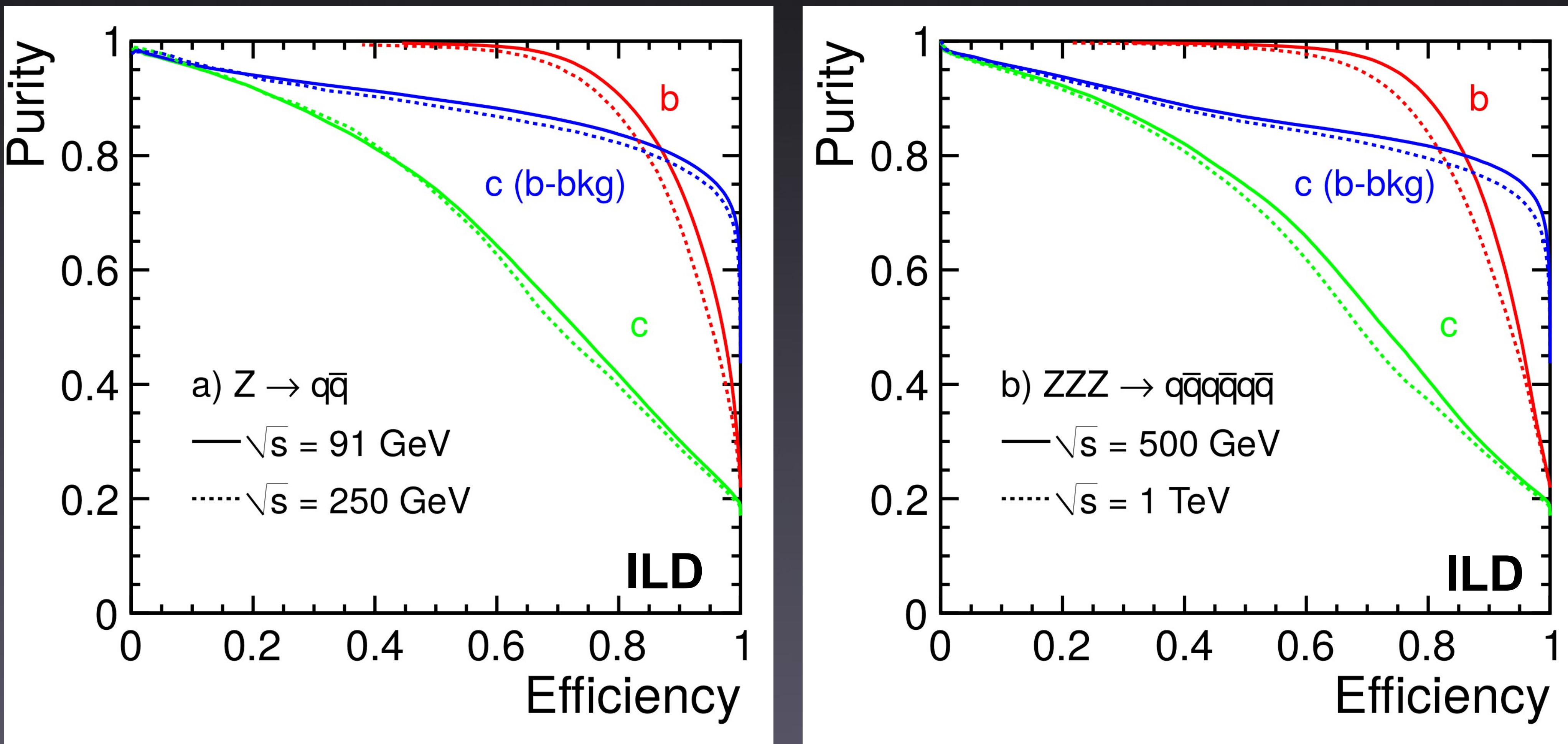
DBD Vertexing Performance



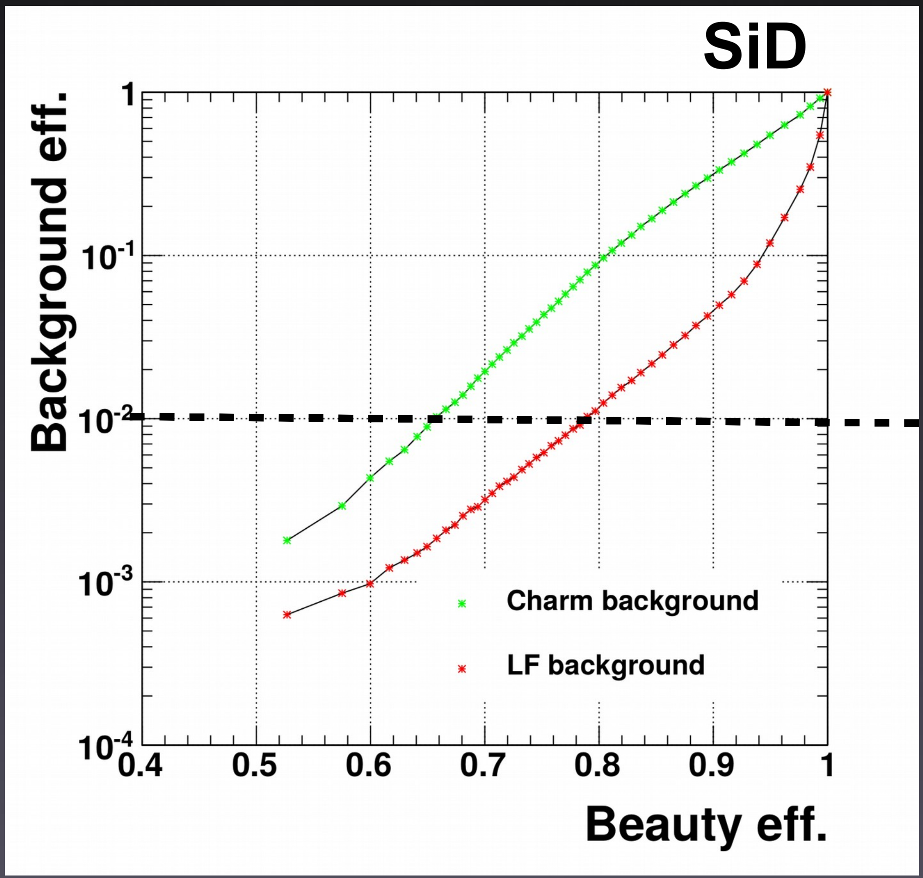


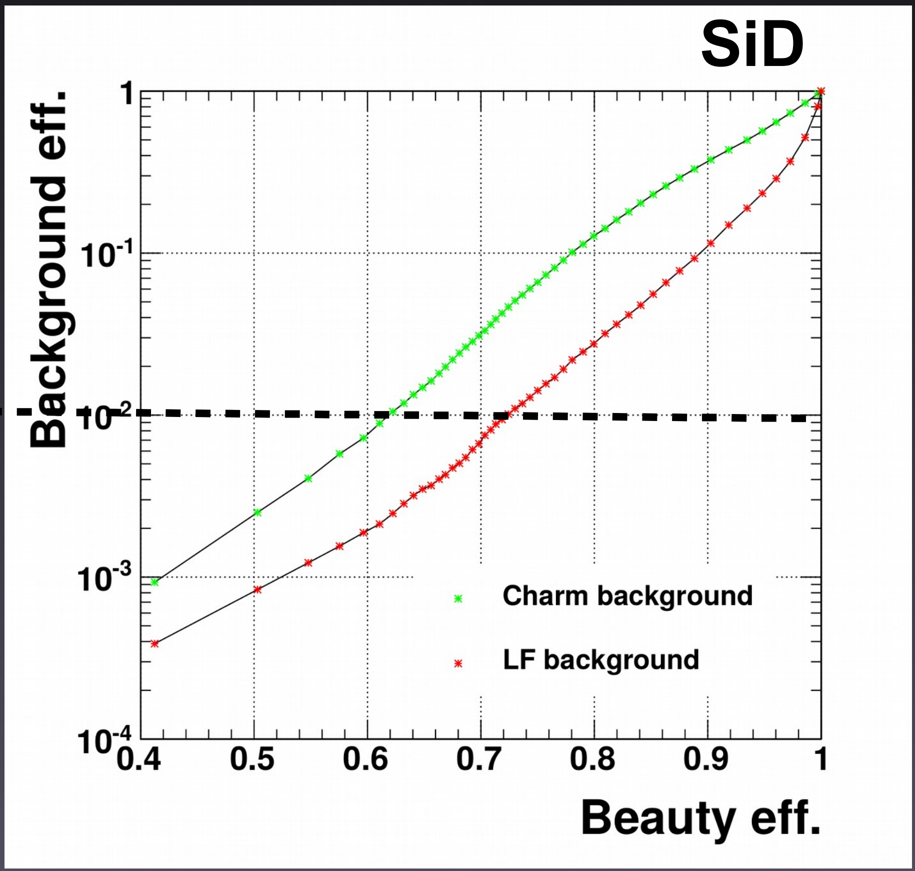
- Vertex resolution is execellent
  - < 4 µm in both xy an z

DBD Flavor Tagging



DBD Robustness vs. backgrounds

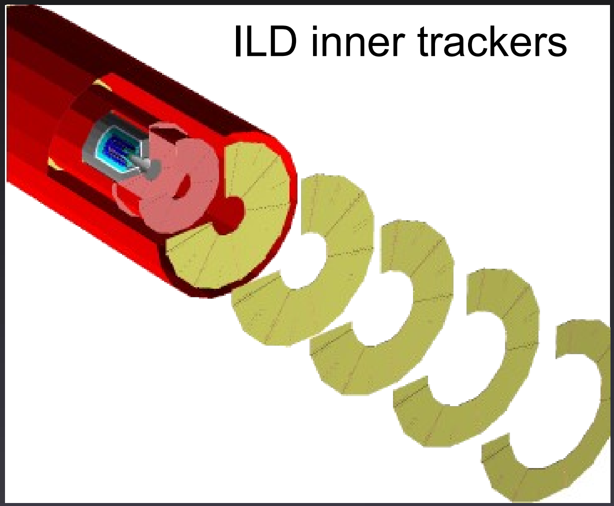


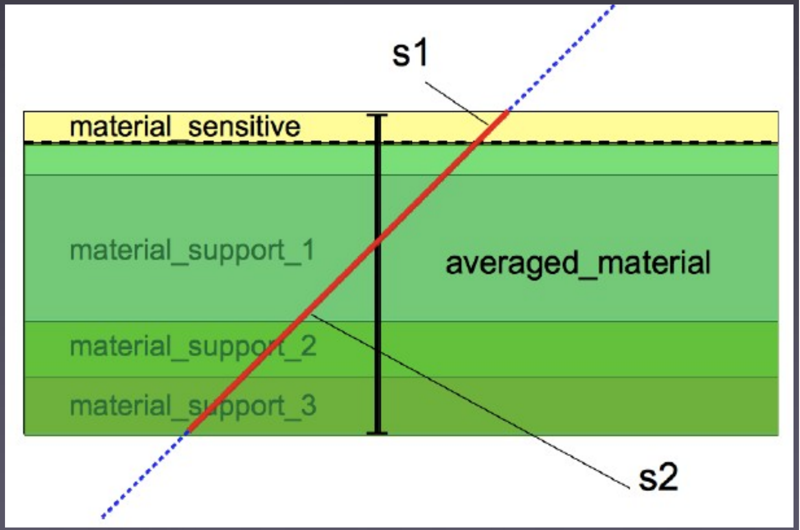


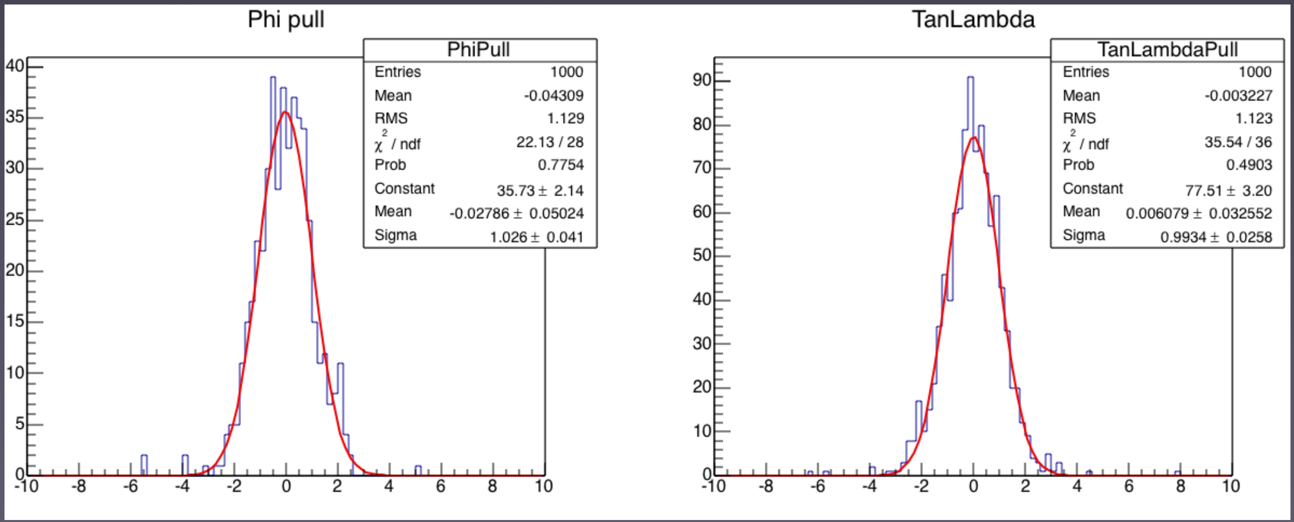
- Performance of the Flavor tagging with full background simulation
  - Minor impact on performance

New LC-Tracking Code

- New geometry system DD4hep
  - provides interface for reconstruction
- Tracking surfaces
  - attached to volumes in the detailed geometry model, provide: u,v,n,o, thicknesses and material properties (automatically averaged from detailed model)
- Generic interface allows for changing the track fitting model w/o changing the pattern recognition
  - tracking code can be fairly easily ported
- Example: pull distributions in CLIC like all Si-tracker:

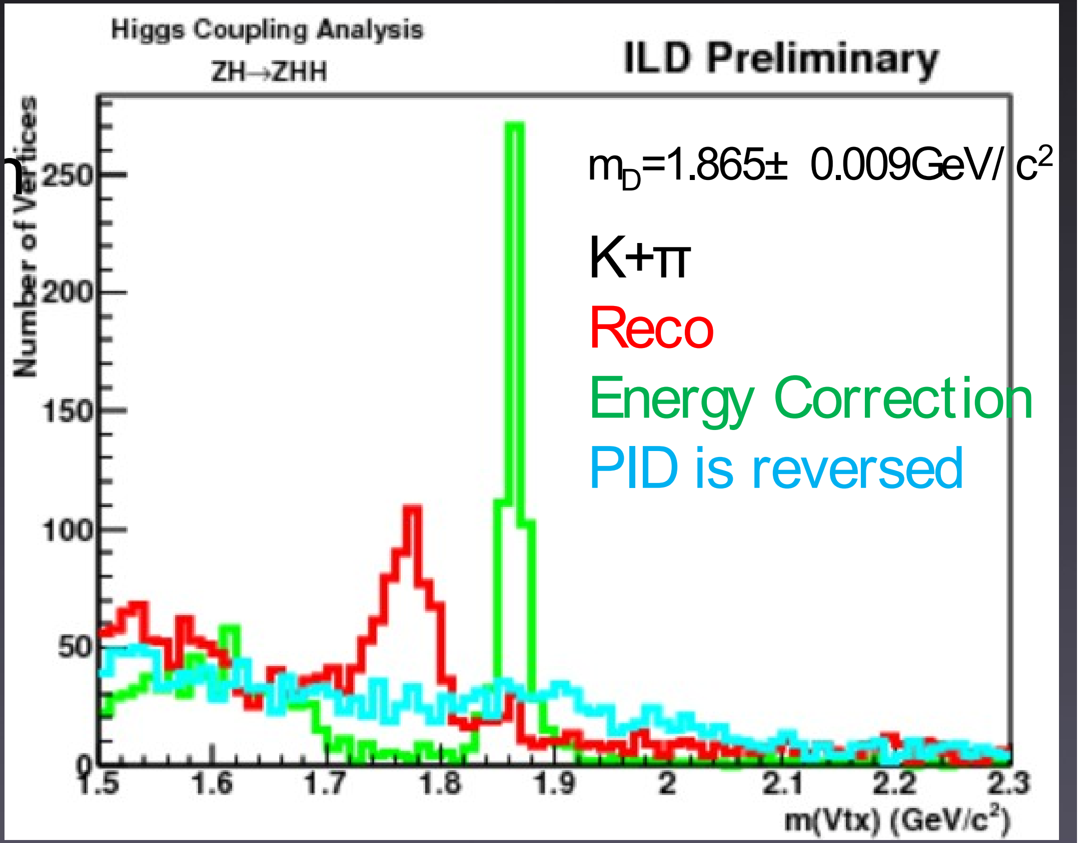






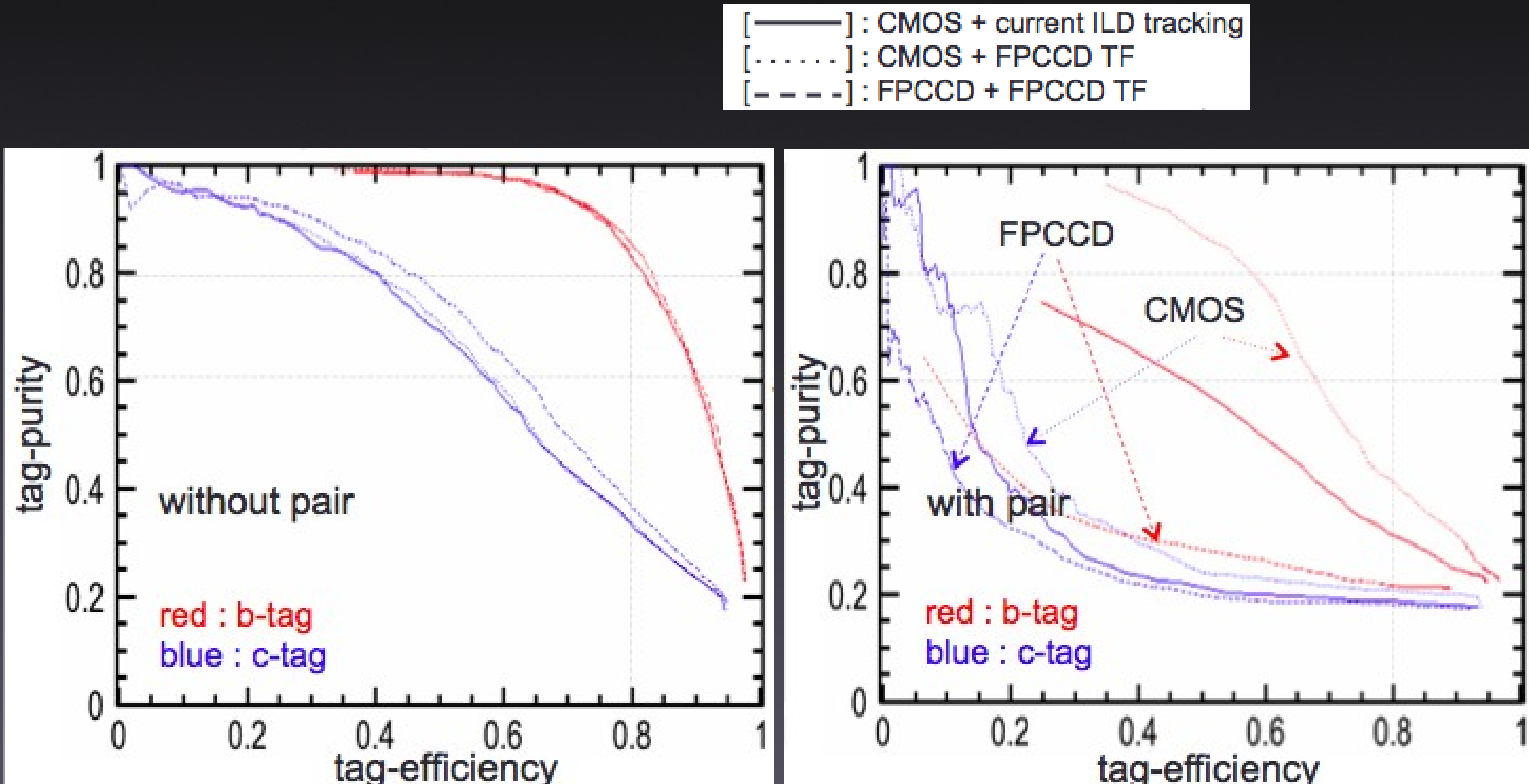
Further Flavor tagging improvements

- Low-p_t tracking benefits vertex mass
  - High B fields , low ω, fewer Si hits
  - Time stamping essential to reduce multiplicity
- Adaptive Vertex fitting
  - Introduce weight of track k on Vertex n
  - Preliminary result: 4% more vertices reconstructed
- π^0 finding
  - Improved separation of photon clusters: GARLIC
  - Association of π^0 with vertex (improves Vertex mass)
  - Difficult, but looks promising



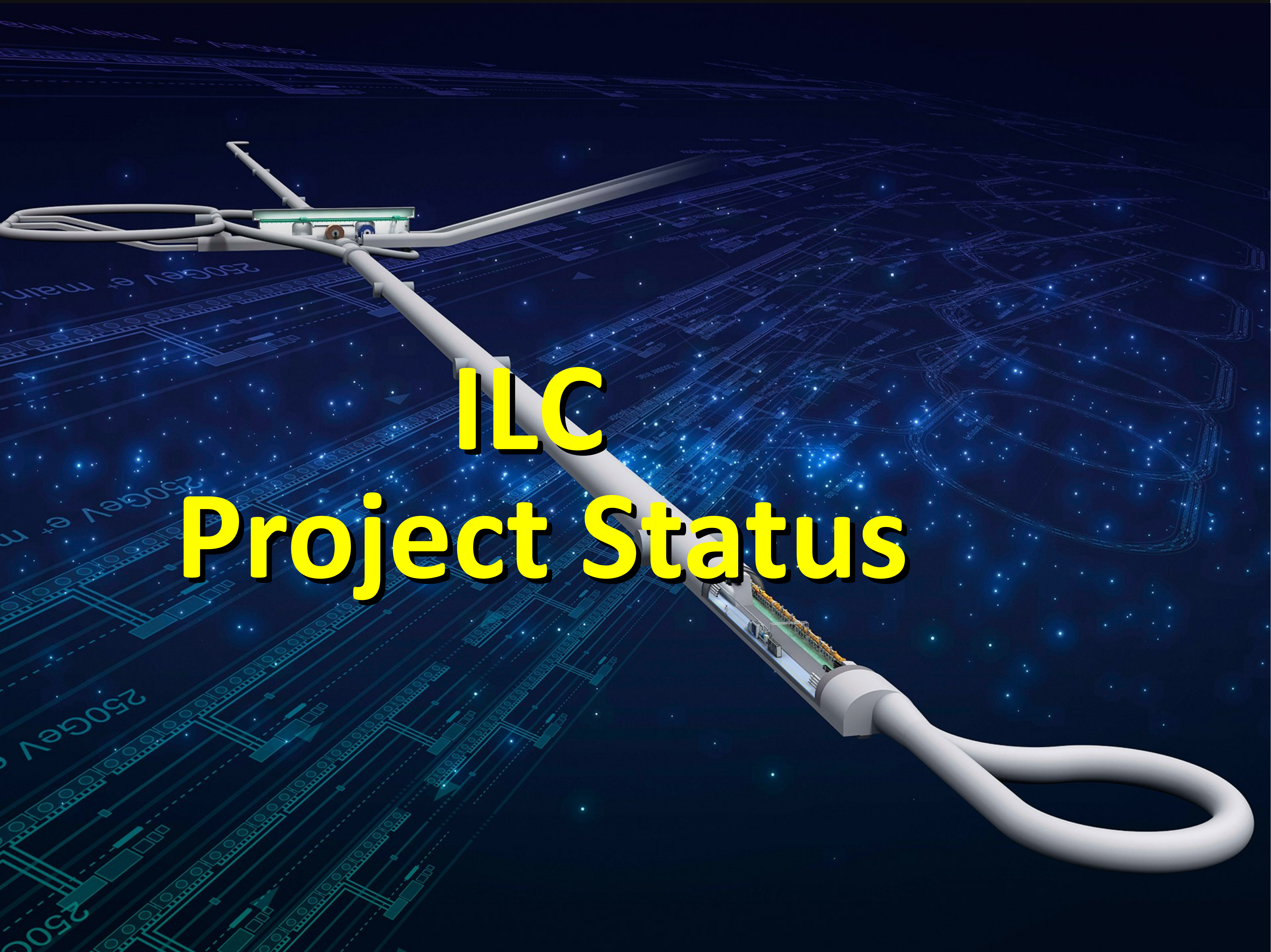
Vertex Mass using PID

Impact of Time Stamping



- Performance of the Flavor tagging with full background simulation
  - Time Stamping becomes important in the presence of background
  - Performance is almost fully recovered if the Timing information from the silicon strips (SIT) is used

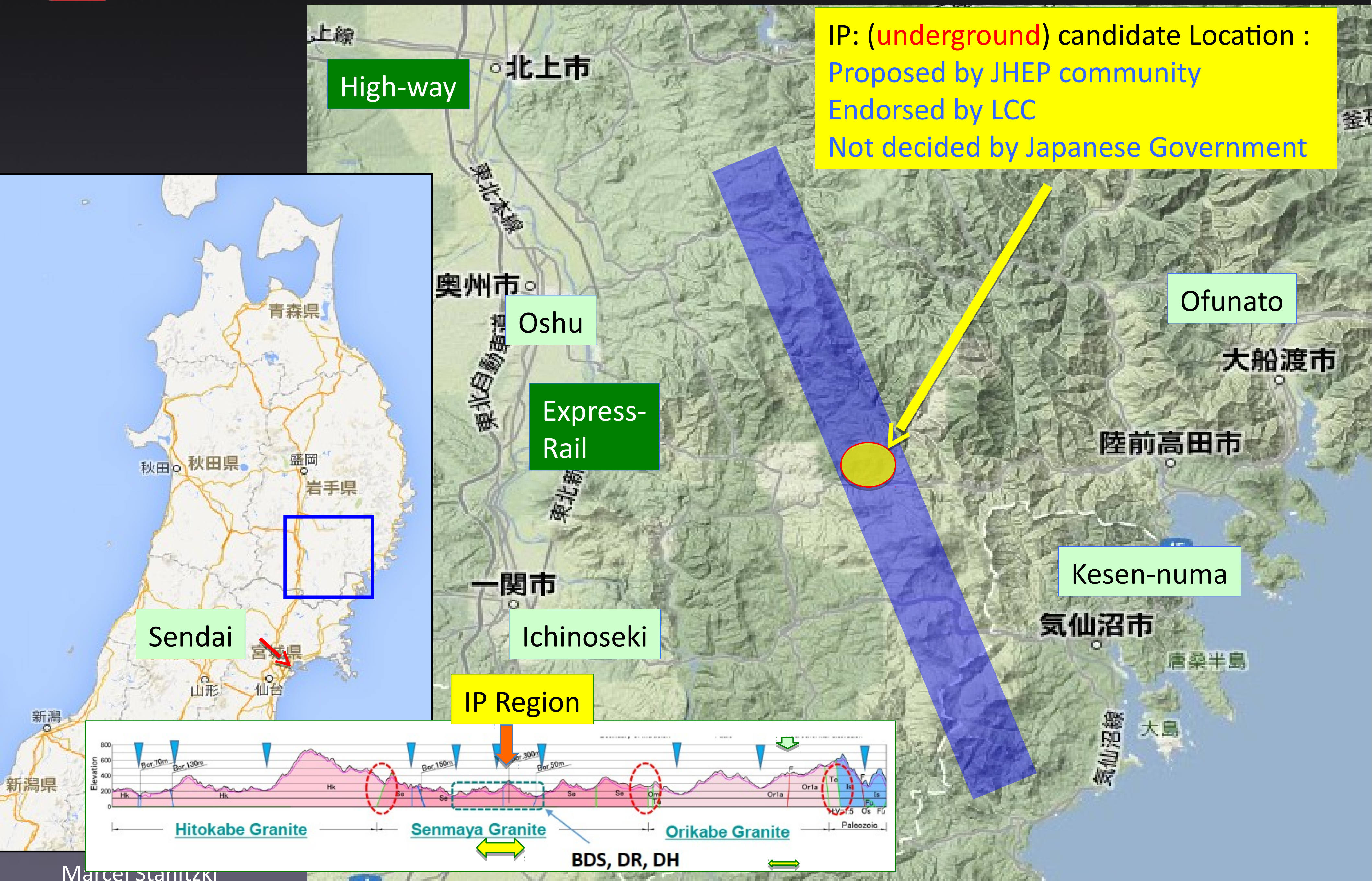
ILC
Project Status



ILC Site Selection

- Japan proposed two sites
  - Kitakami, Honshu "Northern Site"
  - Sefuri, Kyushu "Southern Site"
- Expert Panel Review on Scientific merits of each site
  - Geology, Infrastructure
  - Economic impact

ILC Site – Kitakami Mountains



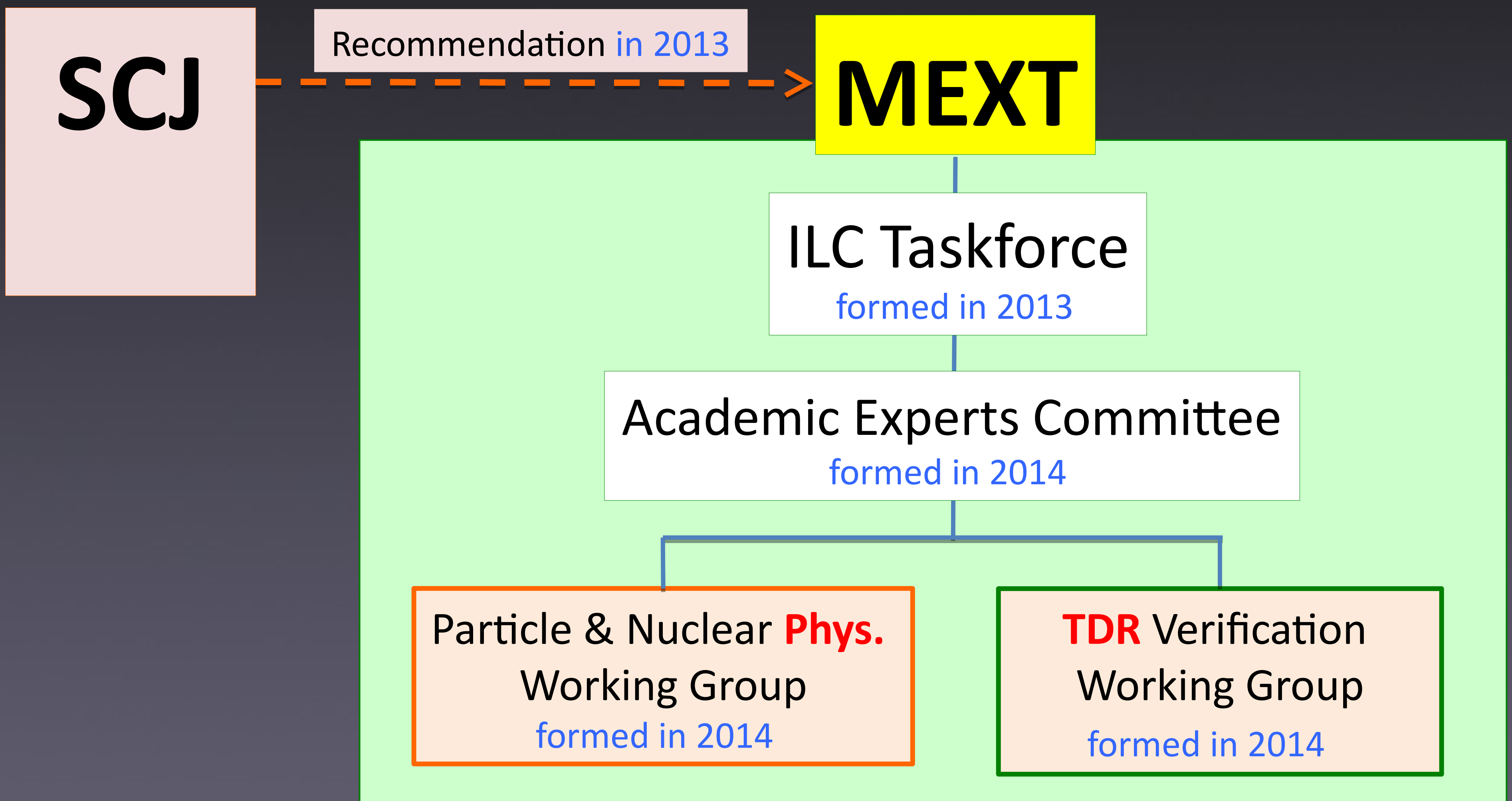
Kitakami Mountains

ILC Detector and Machine experts Visit September 2014

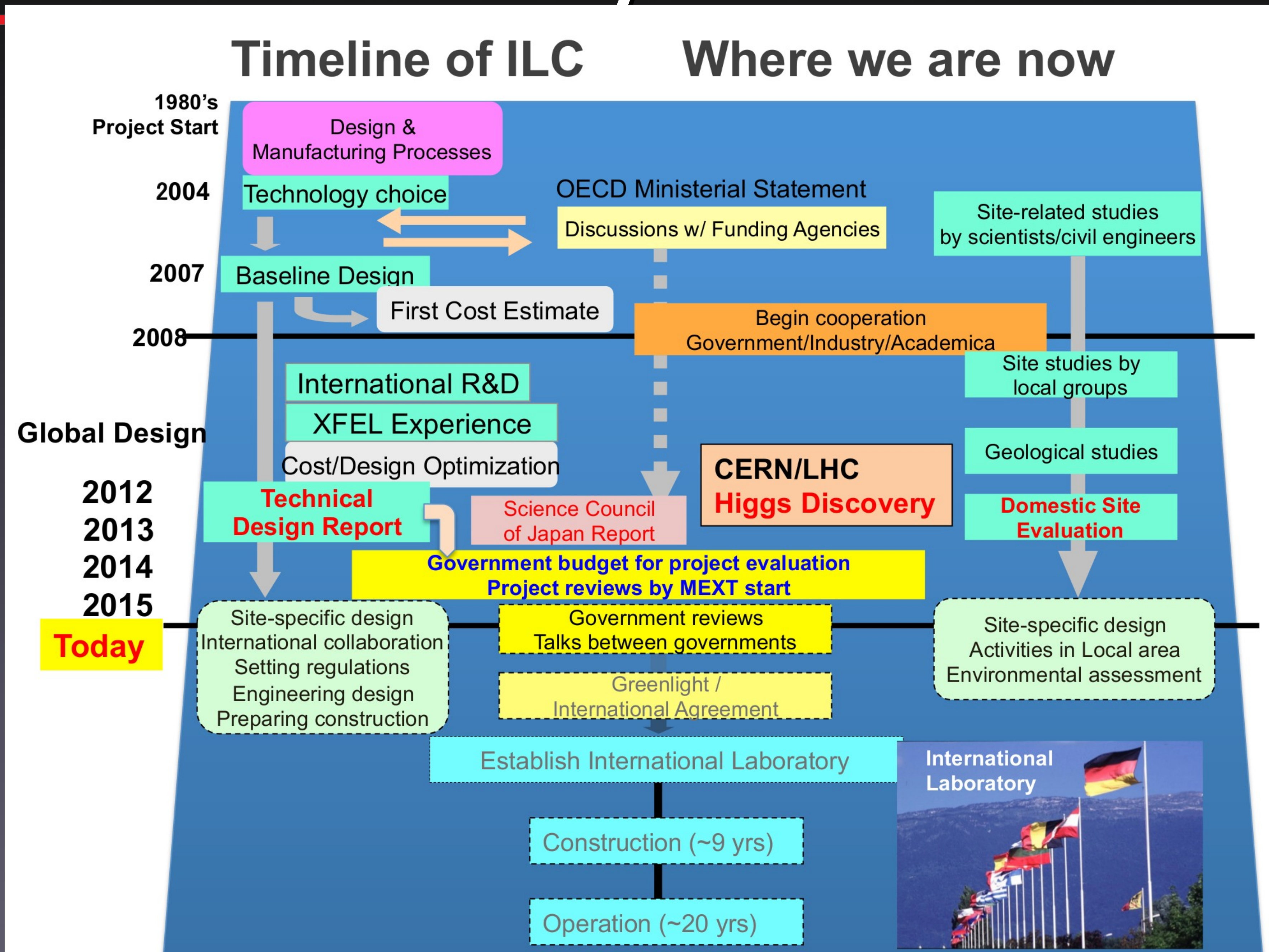
MEXT Review

MEXT's Organization for Studying ILC

based on Science Council of Japan's Recommendation



The way forward



Summary

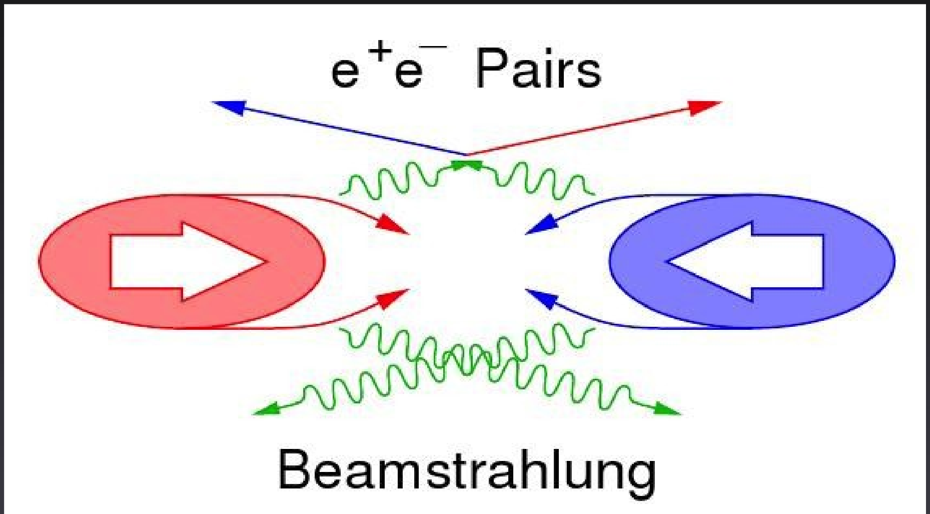
- A Precision machine is necessary to complement the LHC
  - ILC is the right machine to do this
- ILC Vertexing
  - Lots of activity- No technology decisions have been made
  - Site specific design has triggered a lot of new studies
  - Always open to new ideas
- Strong Japanese Interest in hosting the ILC
  - Kitakami Mountain Site proposed
  - Political Process has started
  - Tokyo Statement
- Thanks to
  - M. Demarteau, F. Gaede, J. Goldstein, R. Lipton, J. Strube, Y. Sugimoto, A. White

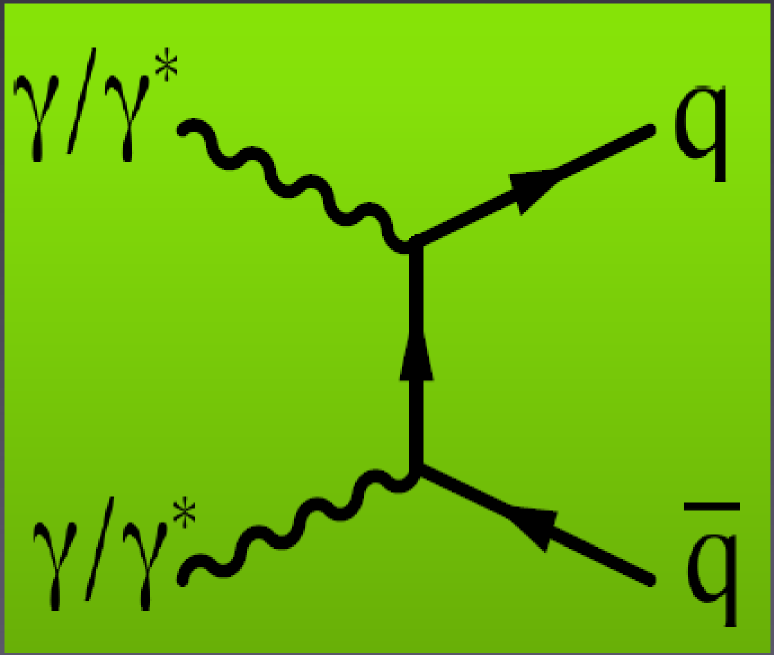
Why a Linear Accelerator

- Basic Limitations e^+e^- synchrotons
  - Synchrotron radiation loss ~ E^4/r
  - Synchrotron cost ~ quadratically with Energy (B. Richter 1980)
    - E_{CMS}=~ 200 GeV as upper limit
- A Linear Accelerator offers 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 for c-tagging

Simulating backgrounds

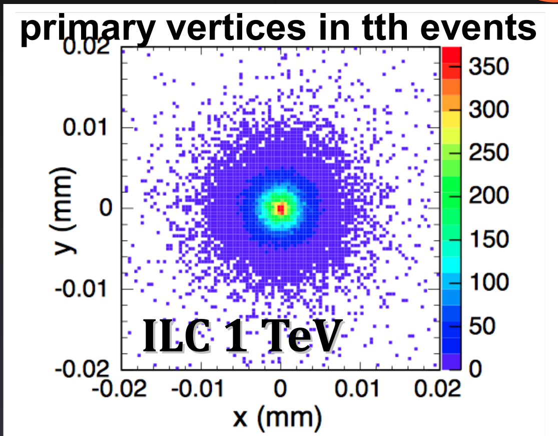
- Pair background
  - ~ 400k/ BX @ 1 TeV
  - Very forward
- $\gamma\gamma \rightarrow$ hadrons
  - 4.1 events per BX @ 1 TeV
  - 1.7 events per BX at 500 GeV
  - More central
- Overlays these over "physics events"

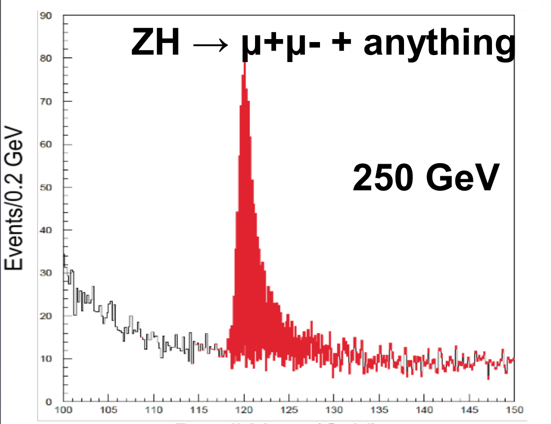


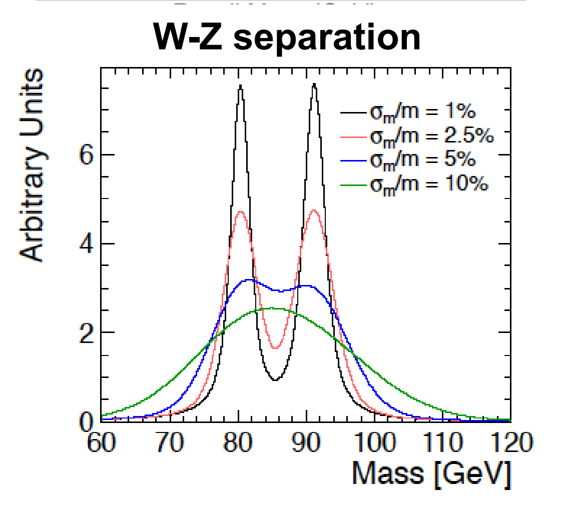


ILC Detector Requirements

- Exceptional precision& time stamping
  - Single Bunch resolution
- Vertex detector
  - < 4 µm precision
  - $\sigma_{r\varphi} \approx 5\ \mu m \oplus 10\ \mu m / p \sin^{\left(\frac{3}{2}\right)}(\theta)$
- Tracker
  - $\sigma(1/p) \sim 2.5 \times 10^{-5}$
- Calorimeter
  - $\frac{\sigma_{E_{Jet}}}{E_{Jet}} = 3-4\%, E_{Jet} > 100\ GeV$

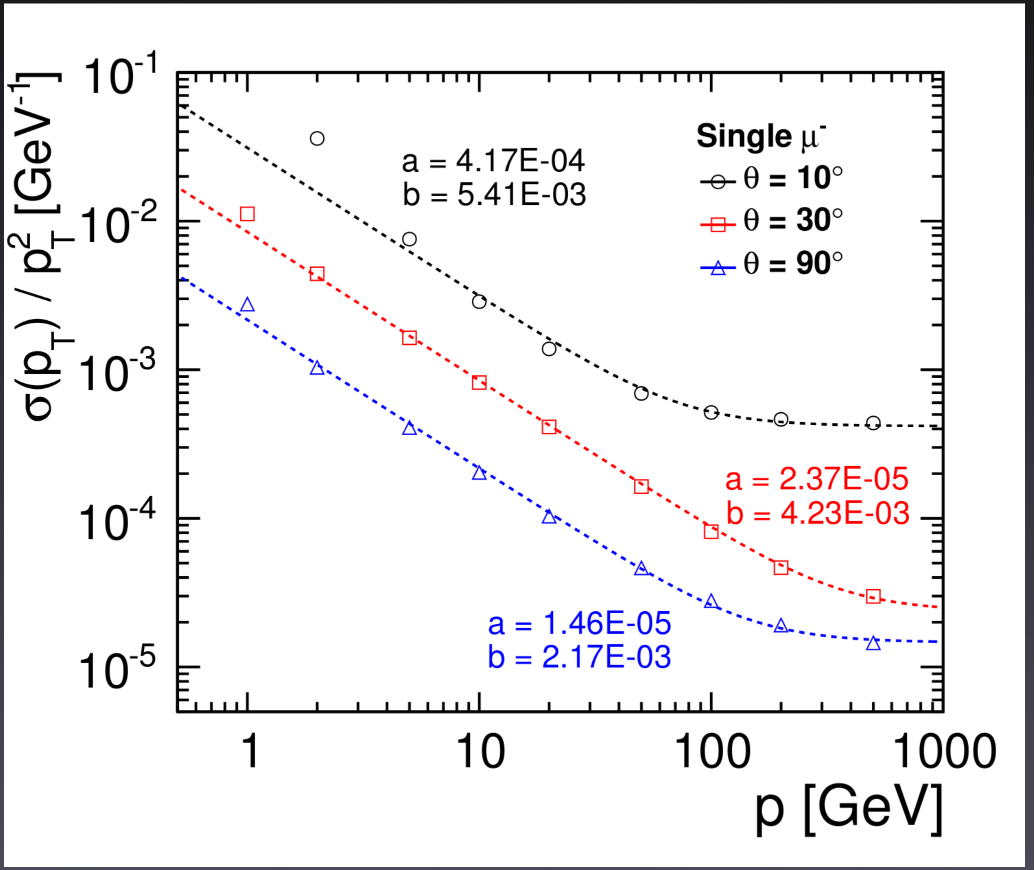






Vertexing & Tracking Performance

- SiD tracking is integrated
  - Vertex and Tracker
  - 10 Hits/track coverage for almost entire polar angle
- Tracking system
  - Achieves desired $\Delta p_T/p_T$ resolution of $1.46 \cdot 10^{-5}$
  - >99 % efficiency over most of the phase space



$$\frac{\sigma(p_T)}{p_T^{\,2}} = a \oplus \frac{b}{p\sin\theta}$$

Pointing resolution

Multiple scattering

It is not just the luminosity

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