Detector Requirements and R&D Challenges at CLIC

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On behalf of the
CLIC Physics and Detector Study
www.cern.ch/LCD

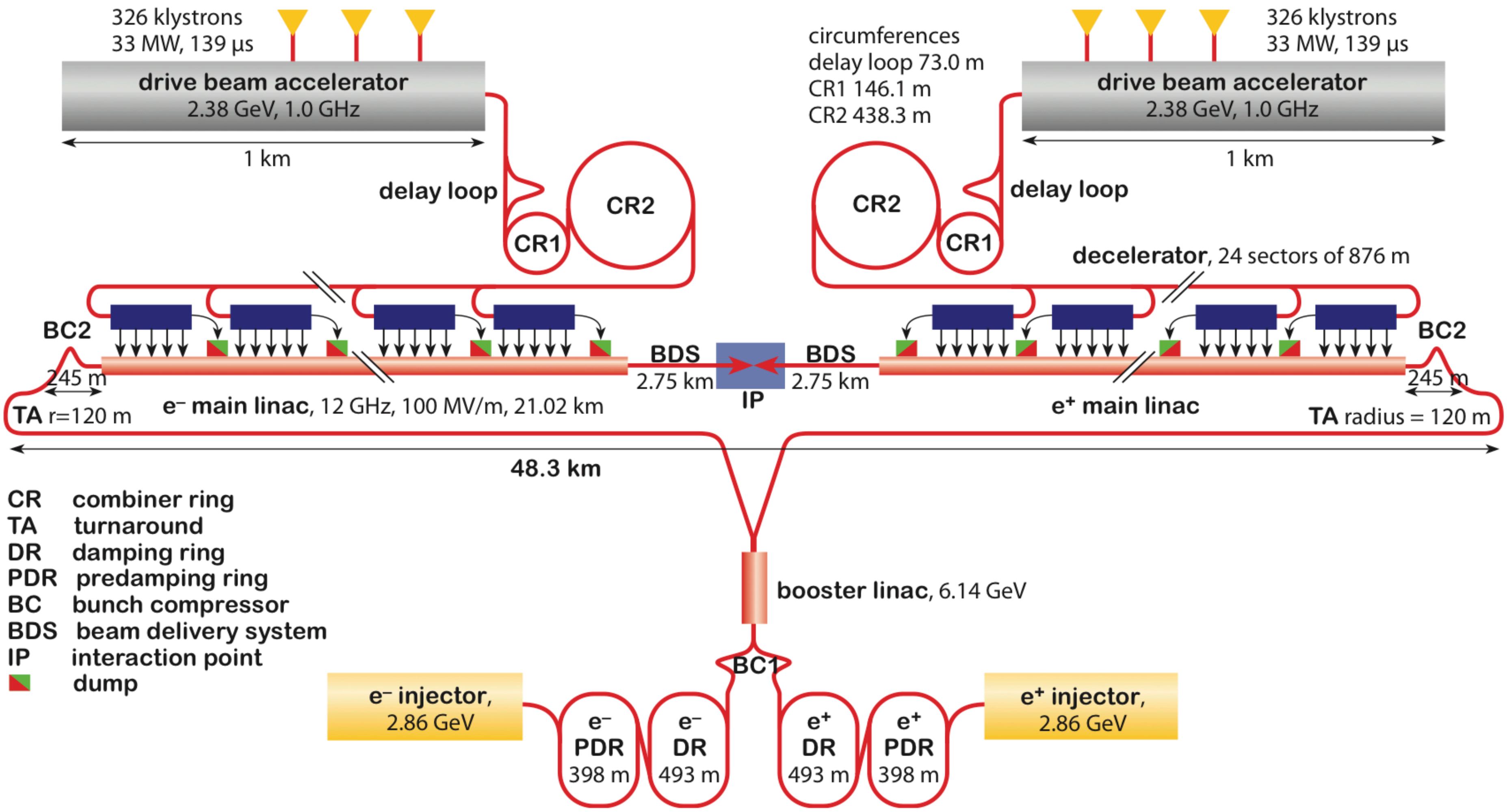
- Physics driven detector requirements:

- Jet energy resolution: $\sigma(E)/E_{jet} \approx 3\%$
  - Distinguish W, Z and H in hadronic decays
  - ➢ Use particle flow (highly granular calorimeters)

- Momentum resolution: $\sigma(1/p_t) \approx 5 \cdot 10^{-5}\,\mathrm{GeV}^{-1}$
  - Higgs mass and SUSY endpoint measurements (sleptons)

- Impact parameter resolution: $\sigma_{IP} \approx \left(5 \oplus \frac{15}{p_t}\right)\mu\mathrm{m}$
  - Excellent flavor tagging: b & c identification and separation
  - ➢ Small pixel sizes
  - ➢ Low material budget to avoid multiple scattering

- Future $e^+ e^-$ linear collider with E_{cms} of 3 TeV (baseline design)
- Can be built in a staged approach to cover lower energies
- Total luminosity of ~ $6 \cdot 10^{34}$ $cm^{-2}s^{-1}$



The Compact LInear Collider

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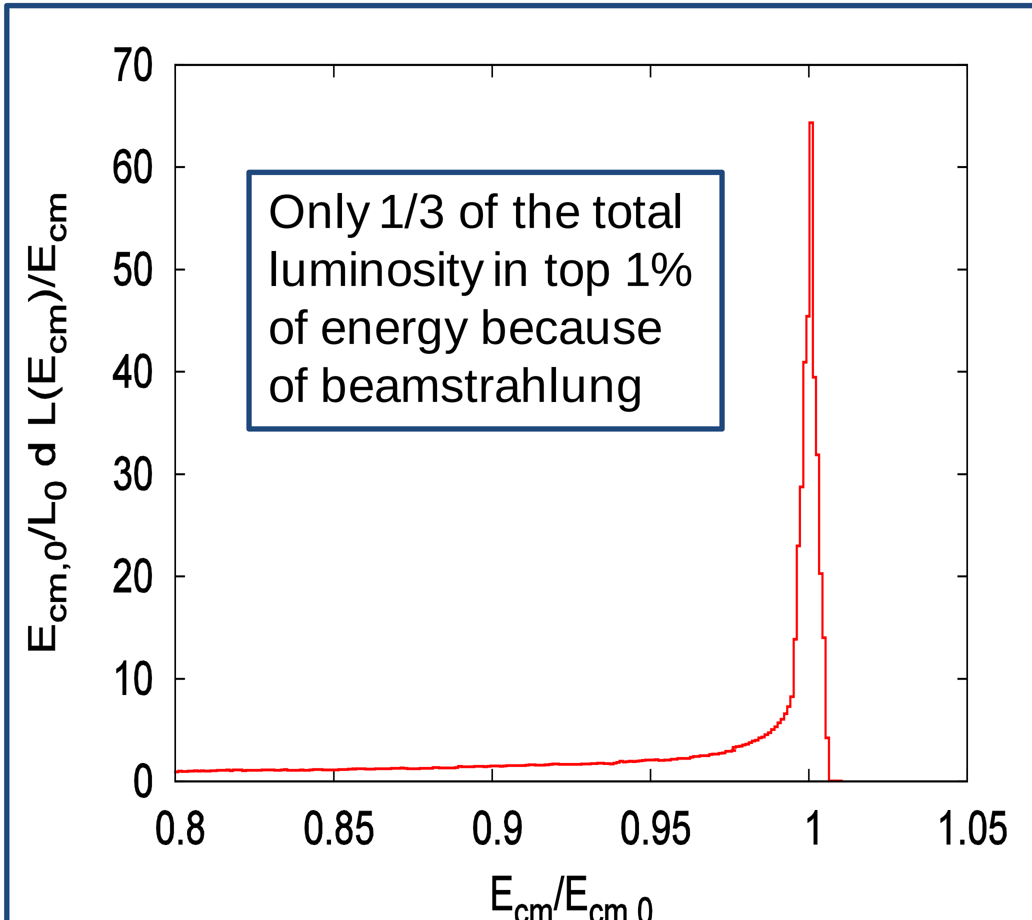
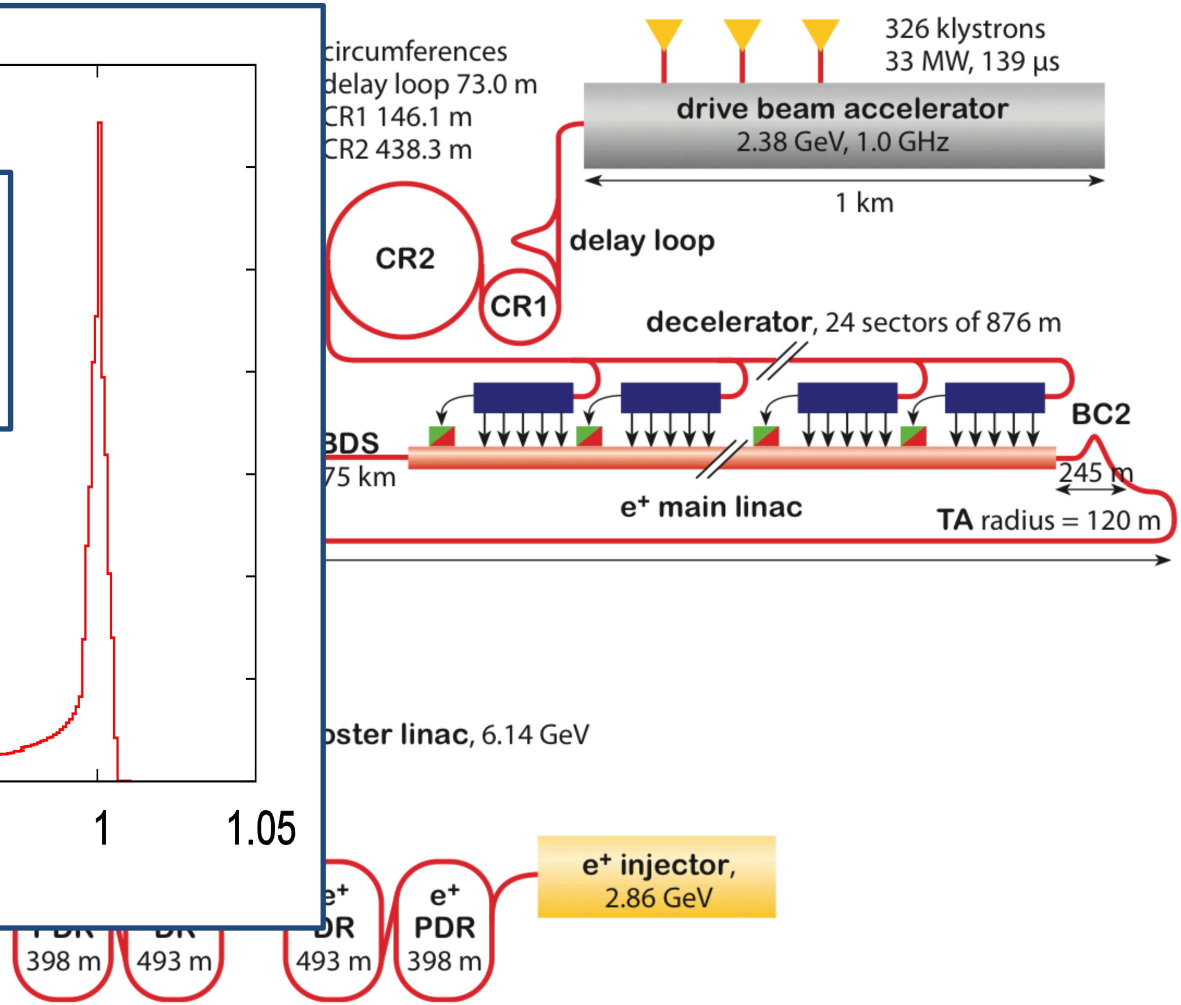
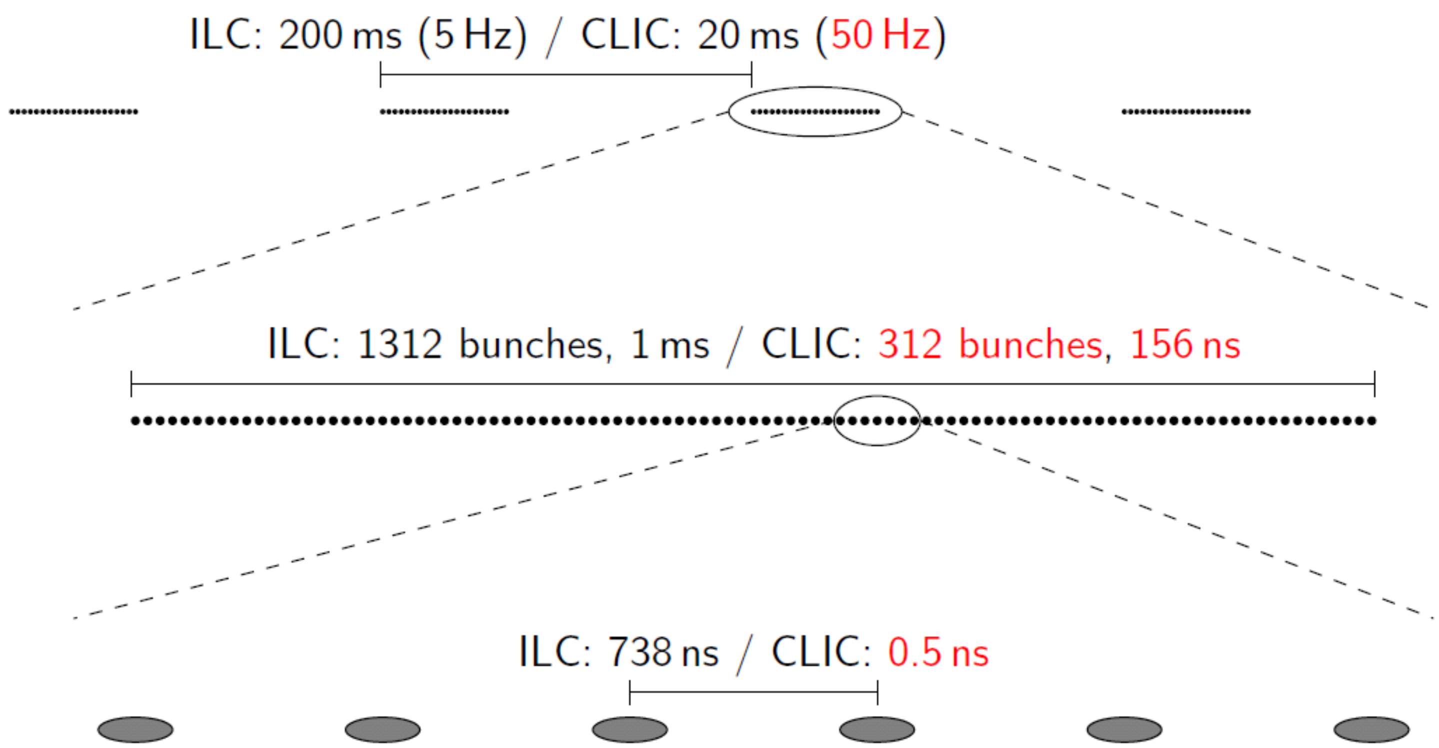
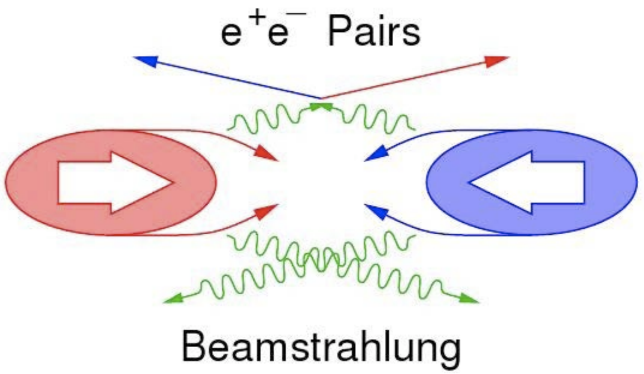


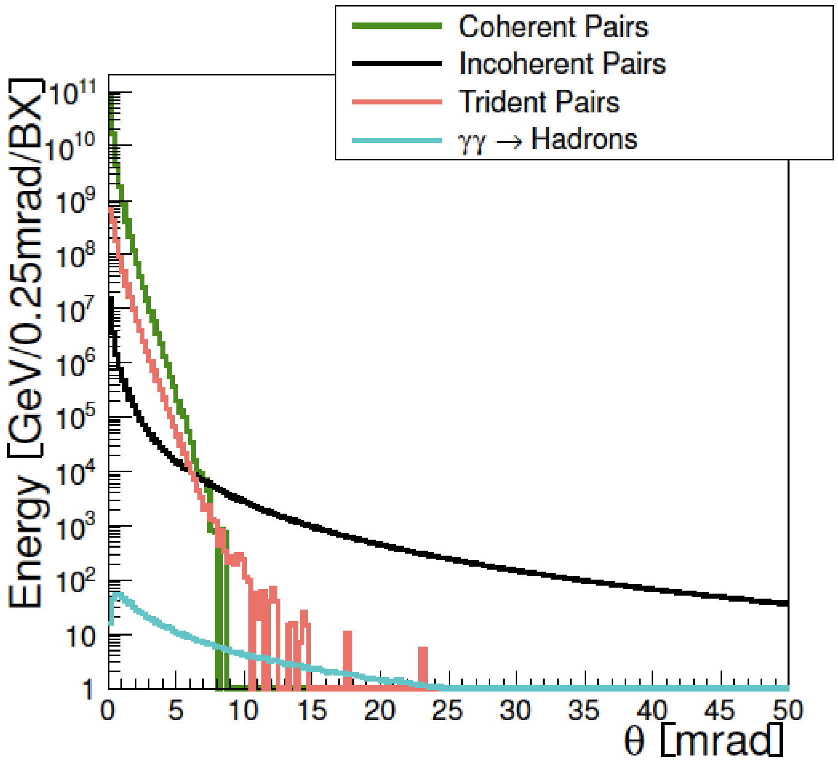




- Beam split into trains (50 Hz)
  - allows power pulsing → less cooling required → lower material budget
- Only 0.5 ns between bunches

- Very small beam sizes cause beamstrahlung
  - 1 nm vertical, 40 nm horizontal, 44 nm longitudinal
- ΔE/E = 29% @ 3 TeV
  - Coherent pairs (3.8×10^8 / BX)
  - Incoherent pairs (3.0×10^5 / BX)
  - $\gamma\gamma \rightarrow$ hadrons (3.2 / BX)





Coherent $e^+ e^-$ pairs at low angles

- Crossing angle of 20 mrad
- Opening angle of outgoing beam pipe 10 mrad

Incoherent pairs extend to larger angles

- radially confined by solenoid field
- drives radius for innermost vertex layer

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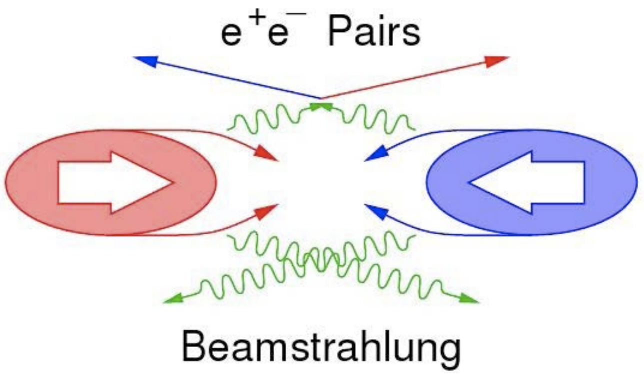

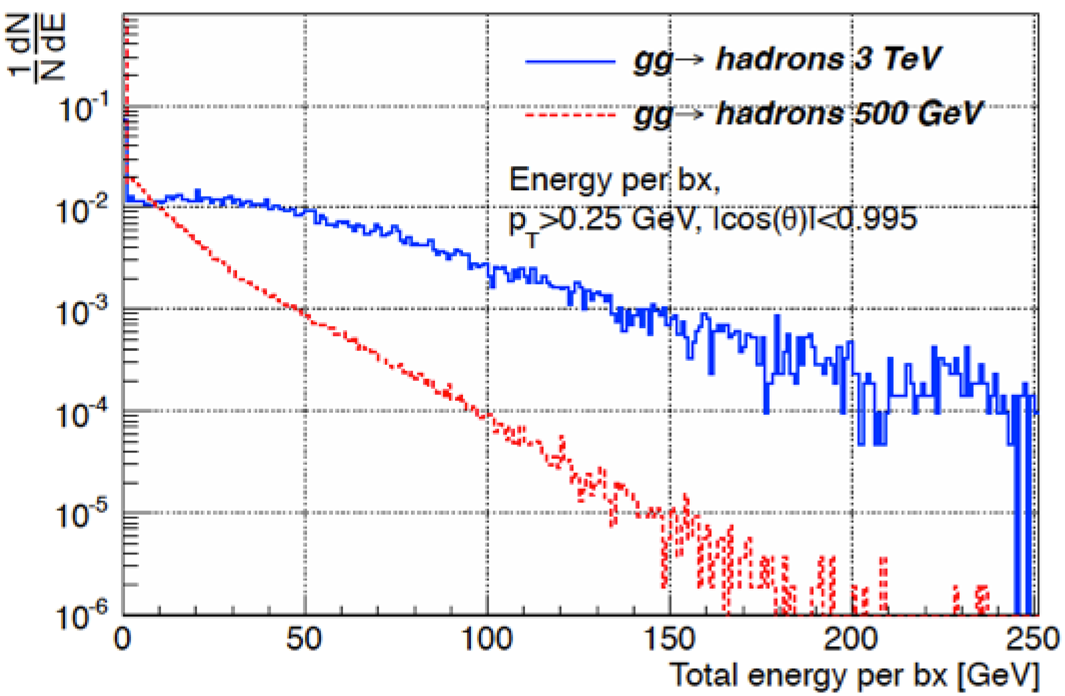

$\gamma\gamma \rightarrow$ hadrons

- ~ 28 charged particles per BX
- ~ 50 GeV per BX (mostly forward)
- ~ 15 TeV deposited during one train
- less than one hard interaction per train
  - timing information can help to reject background
  - sophisticated reconstruction required

- CLIC Conceptual Design Report will be published end of 2011
  - Volume 2: Physics and Detectors
    - Physics case
    - Detector design
    - Detector benchmark analysis

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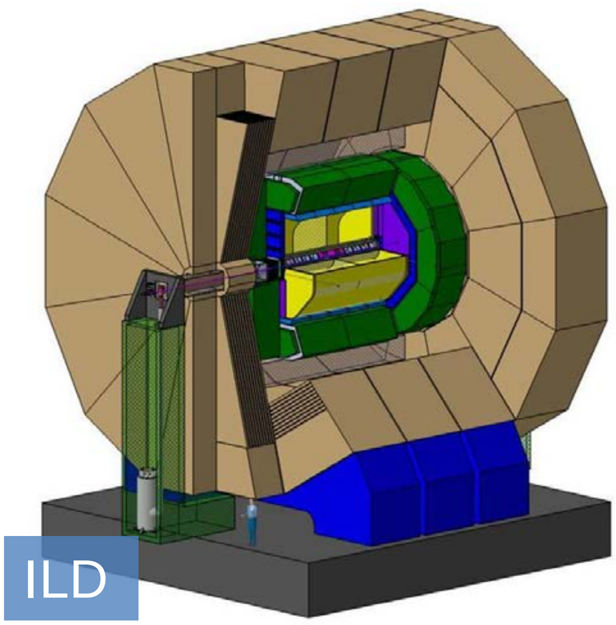
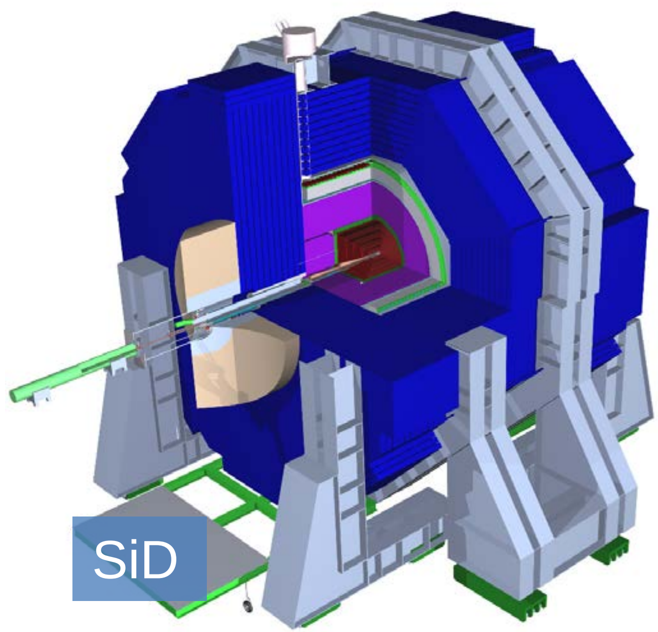
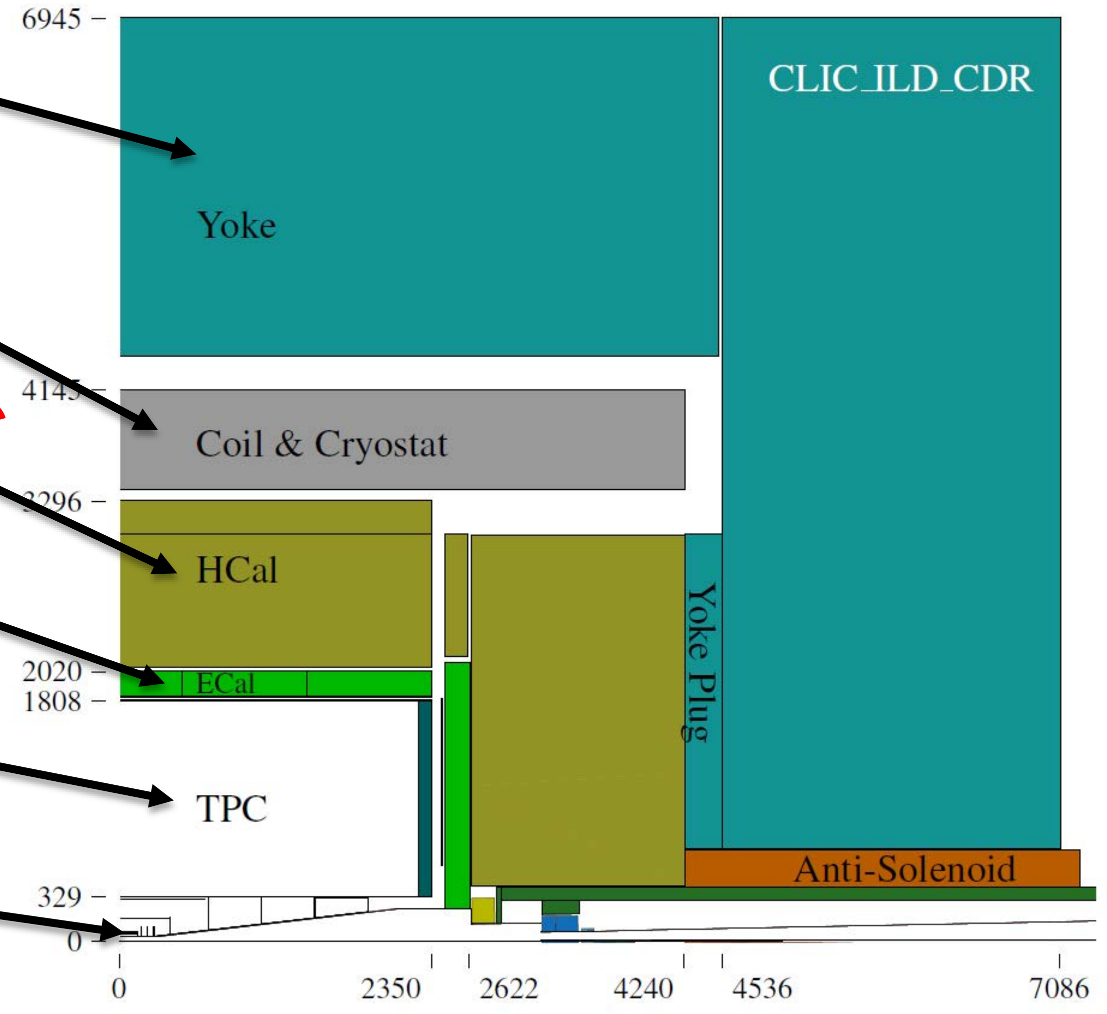
- Use validated ILC detector concepts as starting point
  - Fulfill detector requirements
  - Need to be adapted for CLIC experimental conditions

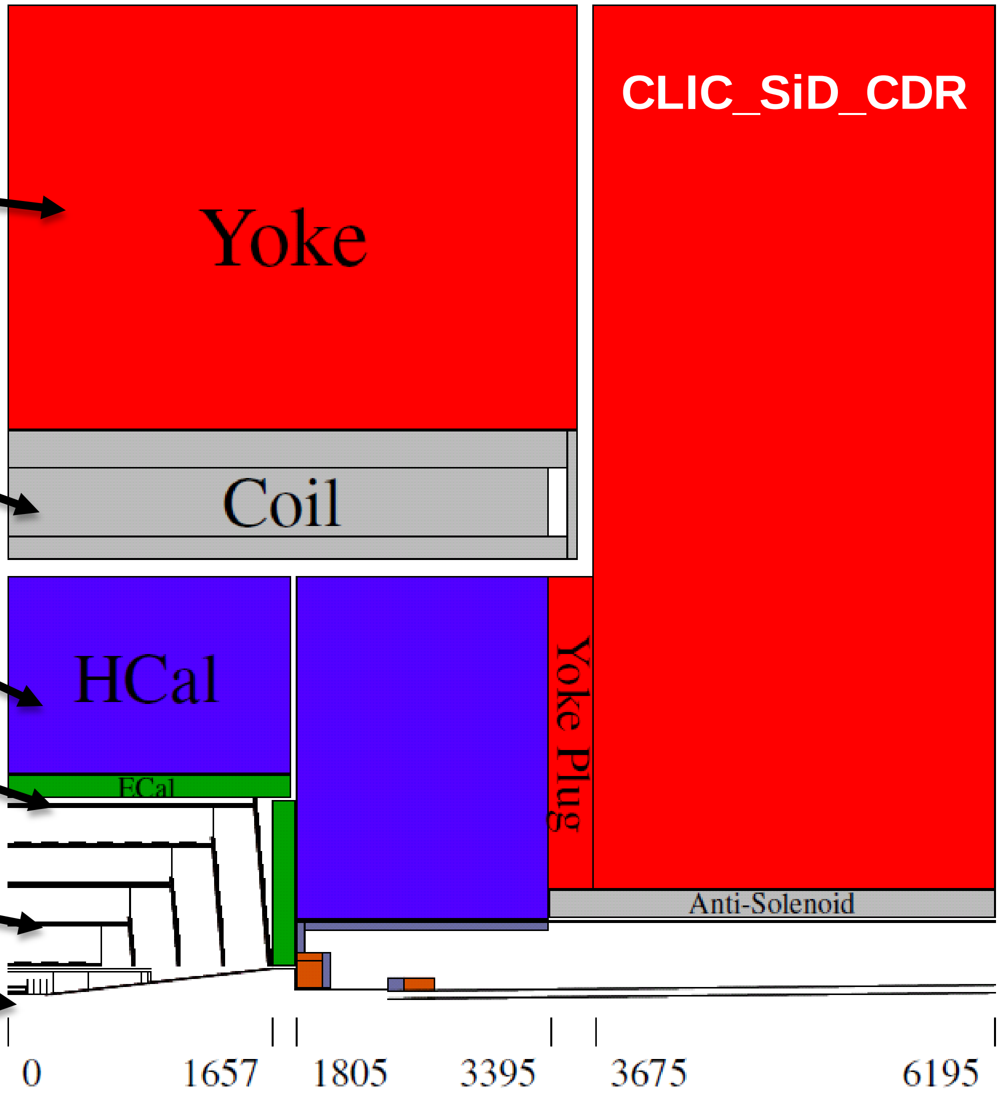




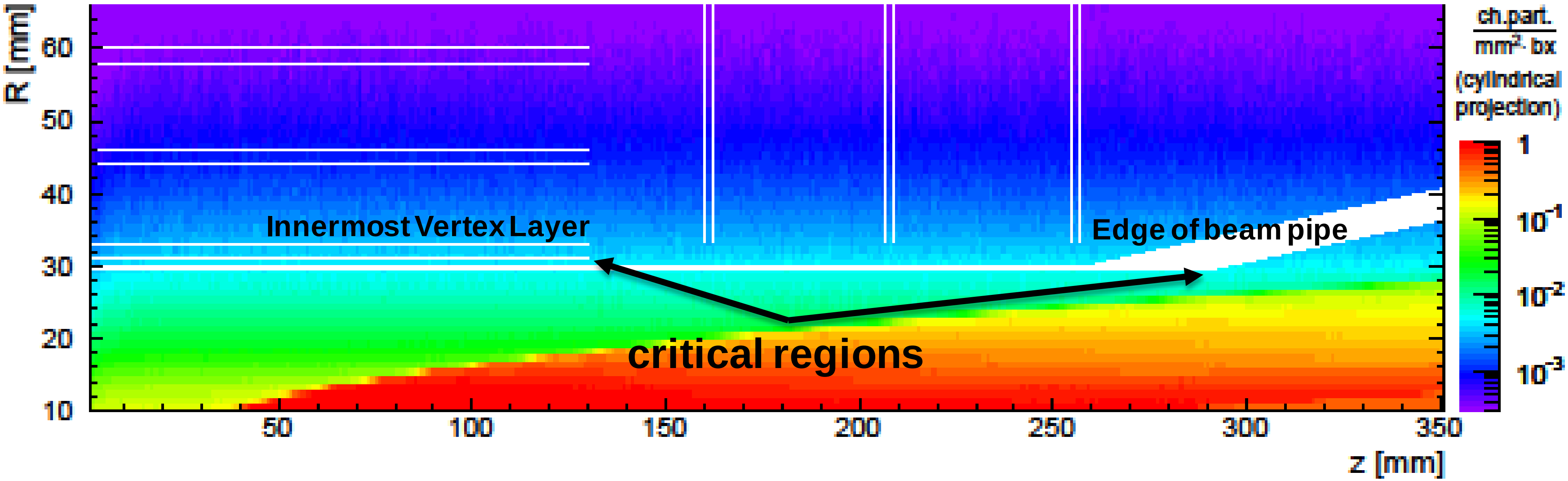
- Instrumented return yoke
- 4T solenoid
- Highly granular HCal
  - ➢ Tungsten instead of steel to keep coil size
- Highly granular Si-W ECal
- Large main tracker (r = 1.8 m) Time projection chamber
- Silicon Pixel Vertex Detector
  - ➢ Increased inner Radius



- Instrumented return yoke
- 5T solenoid
- Highly granular HCal
  - ➢ Tungsten instead of steel to keep coil size feasible
- Highly granular Si-W ECal
- Silicon strip tracker (r = 1.2 m)
- Silicon Pixel Vertex Detector
  - ➢ Increased inner Radius



- Vertex detector should be as close as possible to the IP (~1.5 cm @ ILC)
- Need to keep occupancy low in critical regions
  - Innermost vertex layer – direct hits
  - Beam pipe – creation of secondary particles



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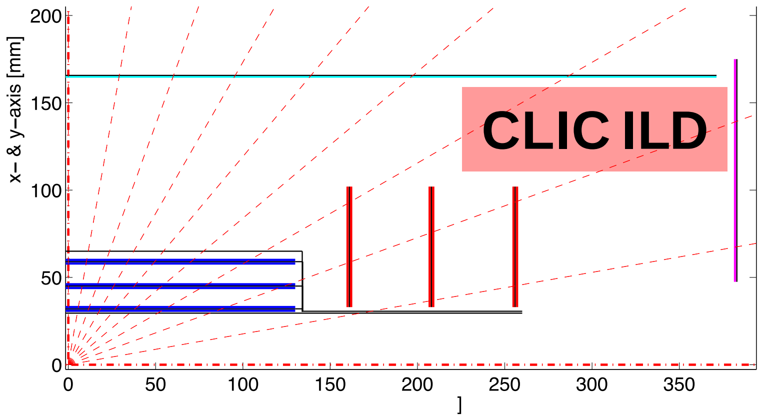
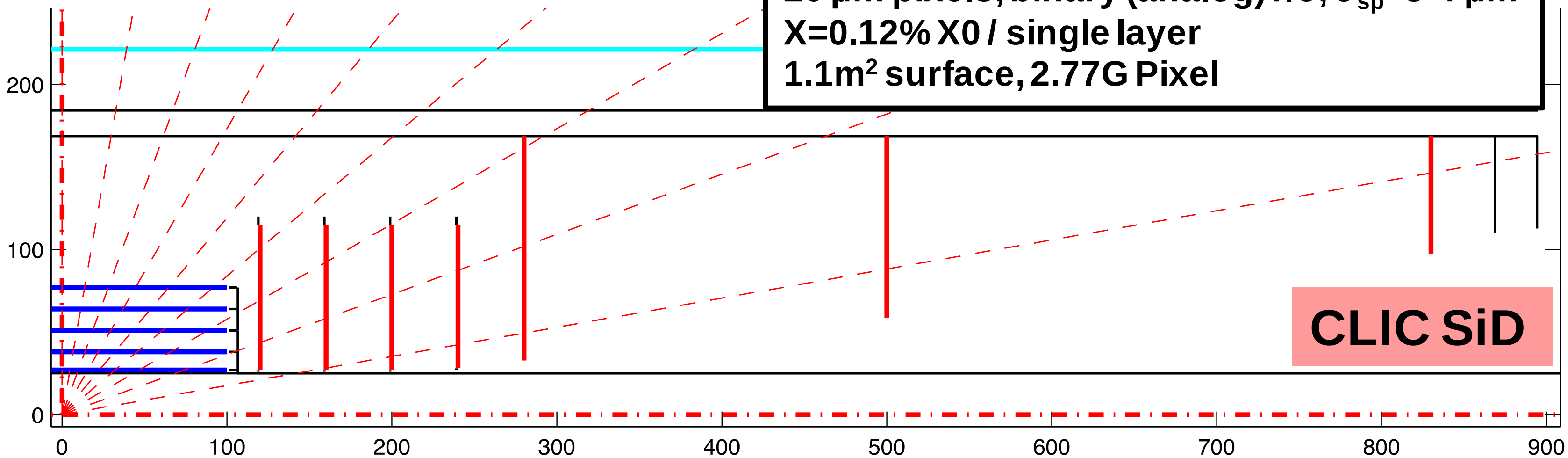
Vertex Detector Challenges

- As close as possible to the IP – still need to avoid incoherent pairs
- Single point resolution: ~ 3 μm, i.e. 20x20 μm² analog pixels
- Very low material budget: 0.1 - 0.2% X_0 per detection layer
- Time stamping of 10 - 15 ns

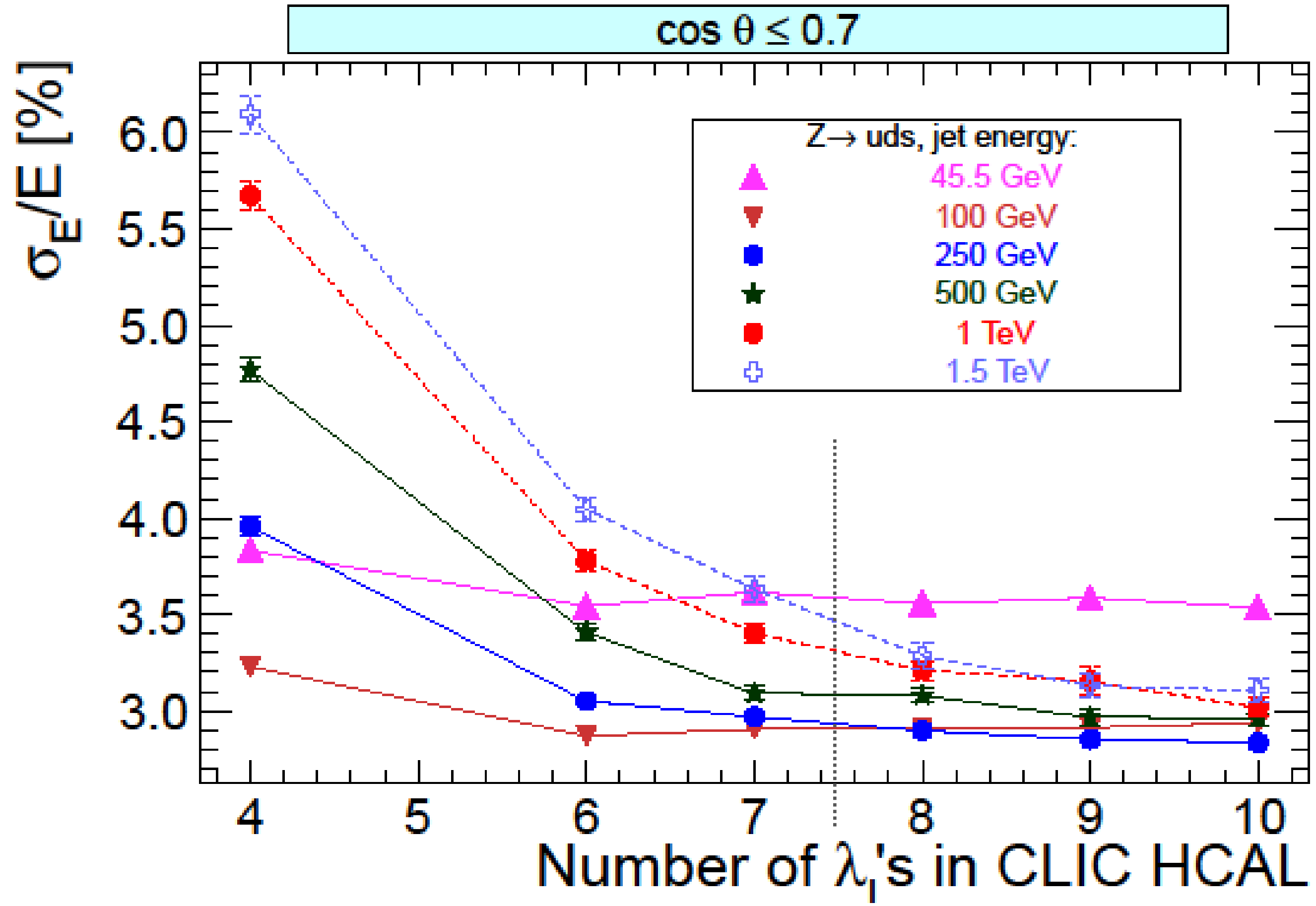


CLIC_ILD
3 double layers of pixel cylinders
3 double layers of pixel disks
20 μm pixels, analog readout, σ_{sp}=2.8 μm
X=0.18% X0 / double layer
0.74m² surface, 1.84G Pixel

CLIC_SiD
5 single layers of barrel pixel cylinders
7 single layers of forward pixel disks
20 μm pixels, binary (analog) r/o, σ_{sp}=3-4 μm
X=0.12% X0 / single layer
1.1m² surface, 2.77G Pixel



- Systematic simulation study of particle flow performance at CLIC energies
- Need to increase HCal depth significantly to avoid leakage
  - Conclusion: ~7.5 λ_I needed in HCal (plus ~1 λ_I in ECal)
  - ILC detector concepts: 5.5 λ_I (ILD), 4.8 λ_I (SiD)



Hadronic Calorimeter

- Good energy resolution requires HCal to be inside coil
- Need dense material to keep coil size feasible
- Tungsten HCal seems suitable in simulation studies

Material	Fe	W
λ_I [cm]	16.77	9.95
X_0 [cm]	1.76	0.35
dE/dx [MeV/cm]	11.4	22.1
R_M [cm]	1.72	0.93

Hadronic Calorimeter

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- No large tungsten calorimeter existed so far
- Check GEANT4 simulations in test beam
  - shower shapes
  - time structure
- W HCal prototype in CALICE: use existing prototypes with tungsten absorber plates
- 2010 @ PS
  - up to 10 GeV with 30 layers instrumented
- 2011 @ SPS (finished last Sunday)
  - up to 300 GeV with 38 layers instrumented (~ 4.8 λ_I) + tail catcher

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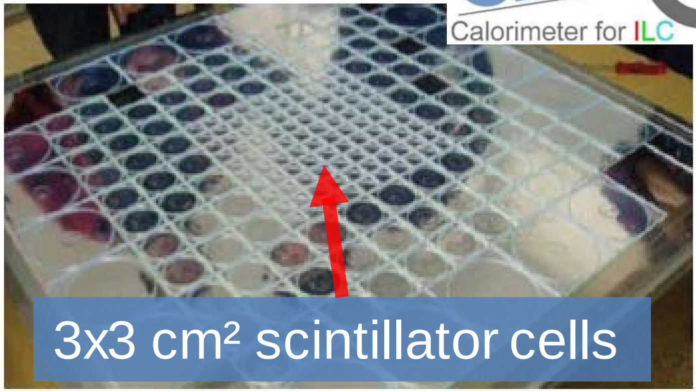

CALICE Calorimeter for ILC

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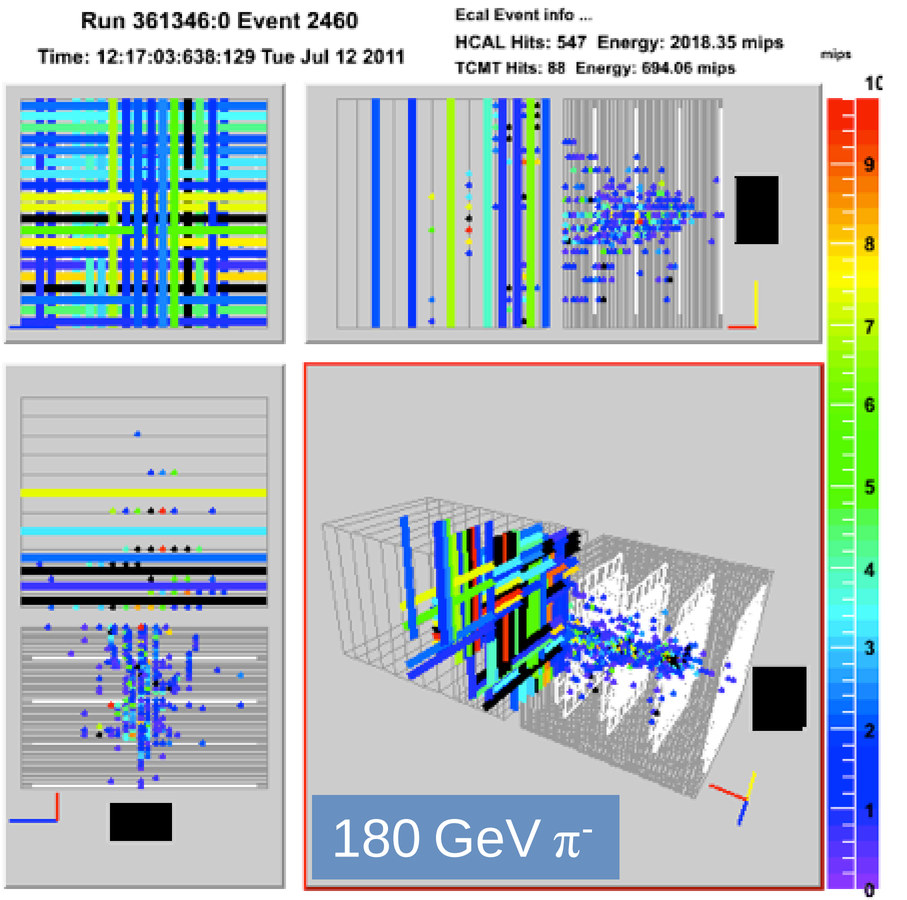
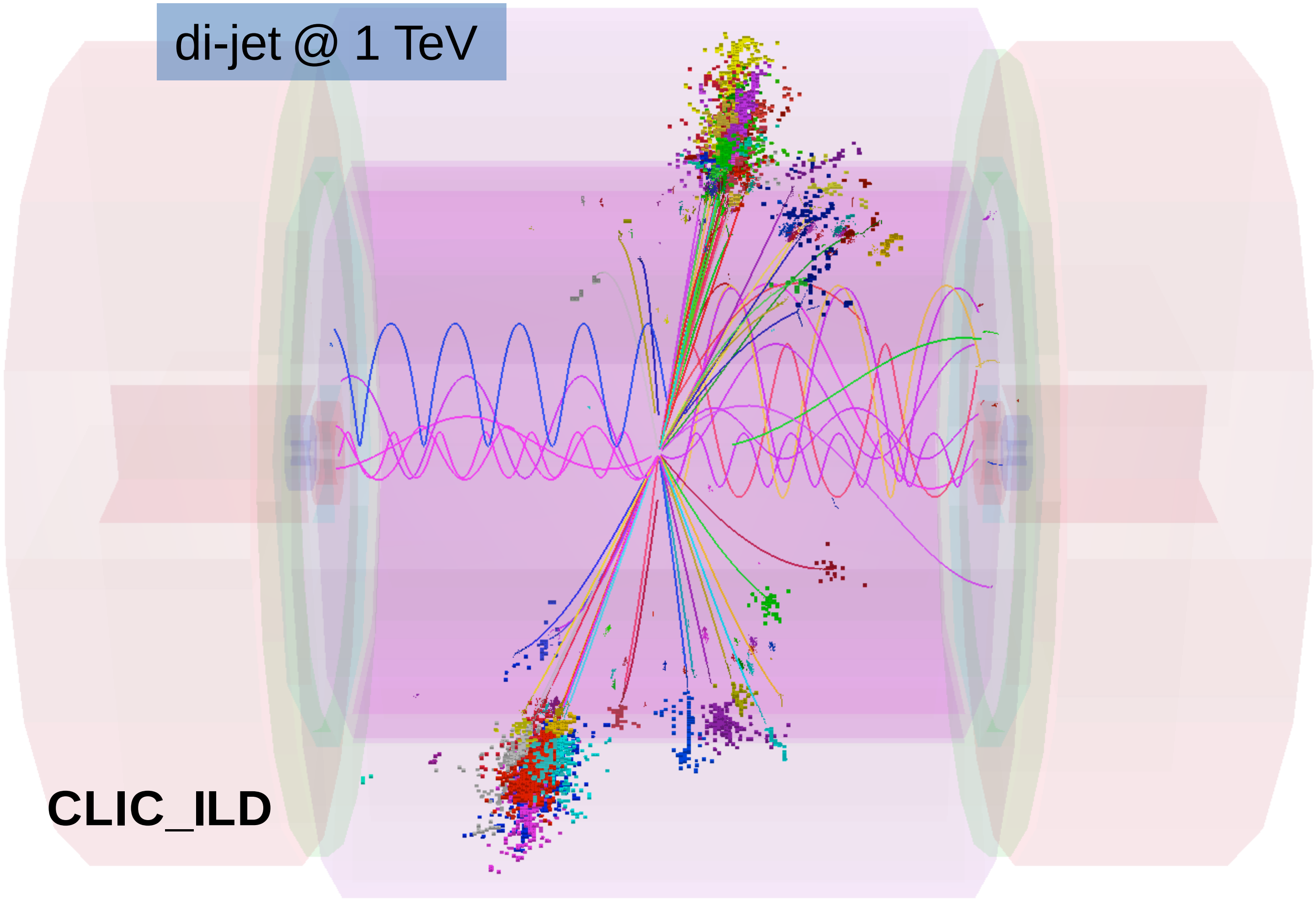


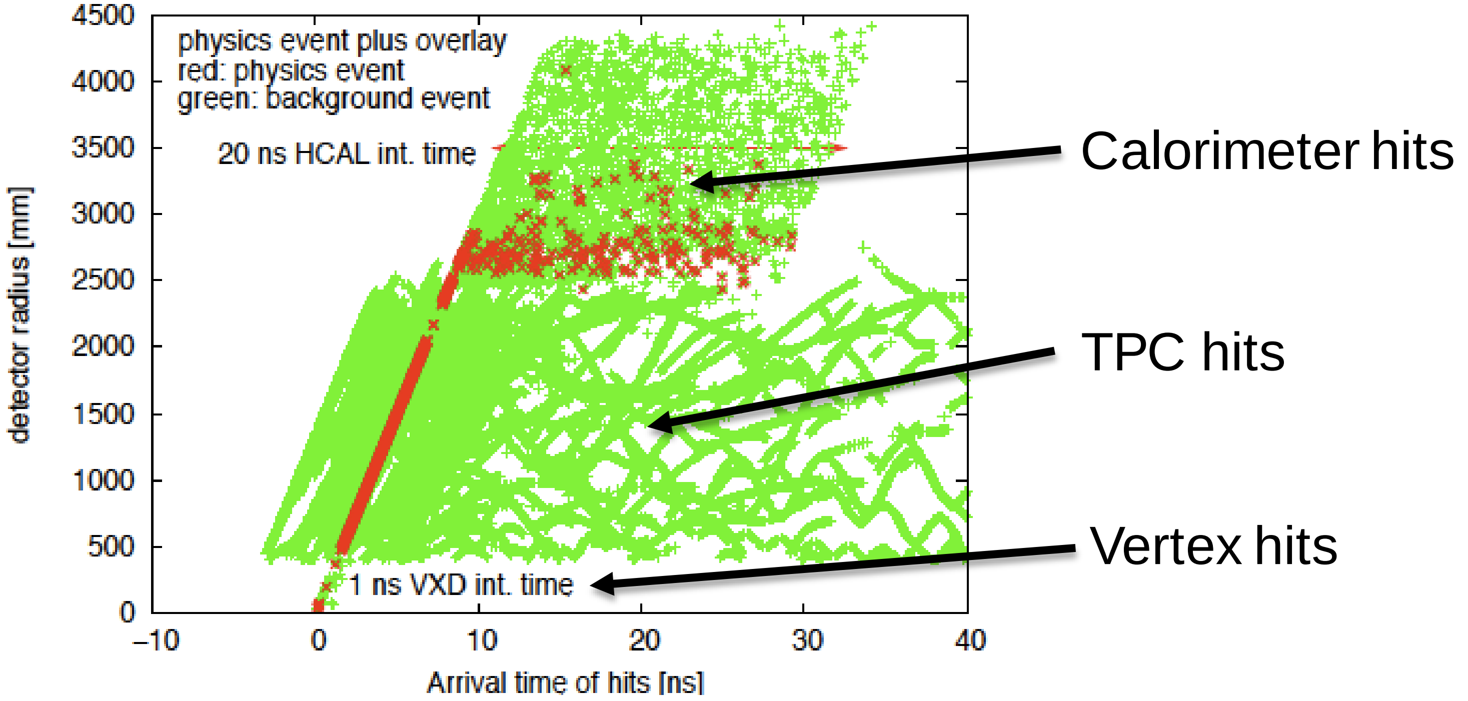
- Several detector benchmark channels have been selected to map out the detector performance in real physics analysis
- All (jet) analysis have realistic background overlaid in full simulation & reco
- 3 TeV benchmark channels:
  - Light Higgs (m_H = 120 GeV), ee → Hνν, H → μμ and H → bb
    - Momentum resolution, forward tracking performance, b-tagging
  - Heavy Higgs (m ≈ 900GeV), H^+H^-, H^0A^0 → tbtb, bbbb
    - b-tagging, multi-jet final state, m_{jj}
  - squark pair production (m ≈ 1.1 TeV)
    - high energy jets, missing energy
  - slepton pair production (m ≈ 1 TeV)
    - high momentum tracks, e and μ ID, missing energy
  - chargino and neutralino pair production (various masses)
    - multi-jet final state, missing energy, m_{jj}
- 500 GeV benchmark channel, similar to ILC LoI benchmark
  - top pair production
    - multi-jet final state, b-tagging

- Full simulation studies, i.e. CLIC CDR benchmark studies have to take into account realistic pile-up of $\gamma\gamma \rightarrow$ hadrons background



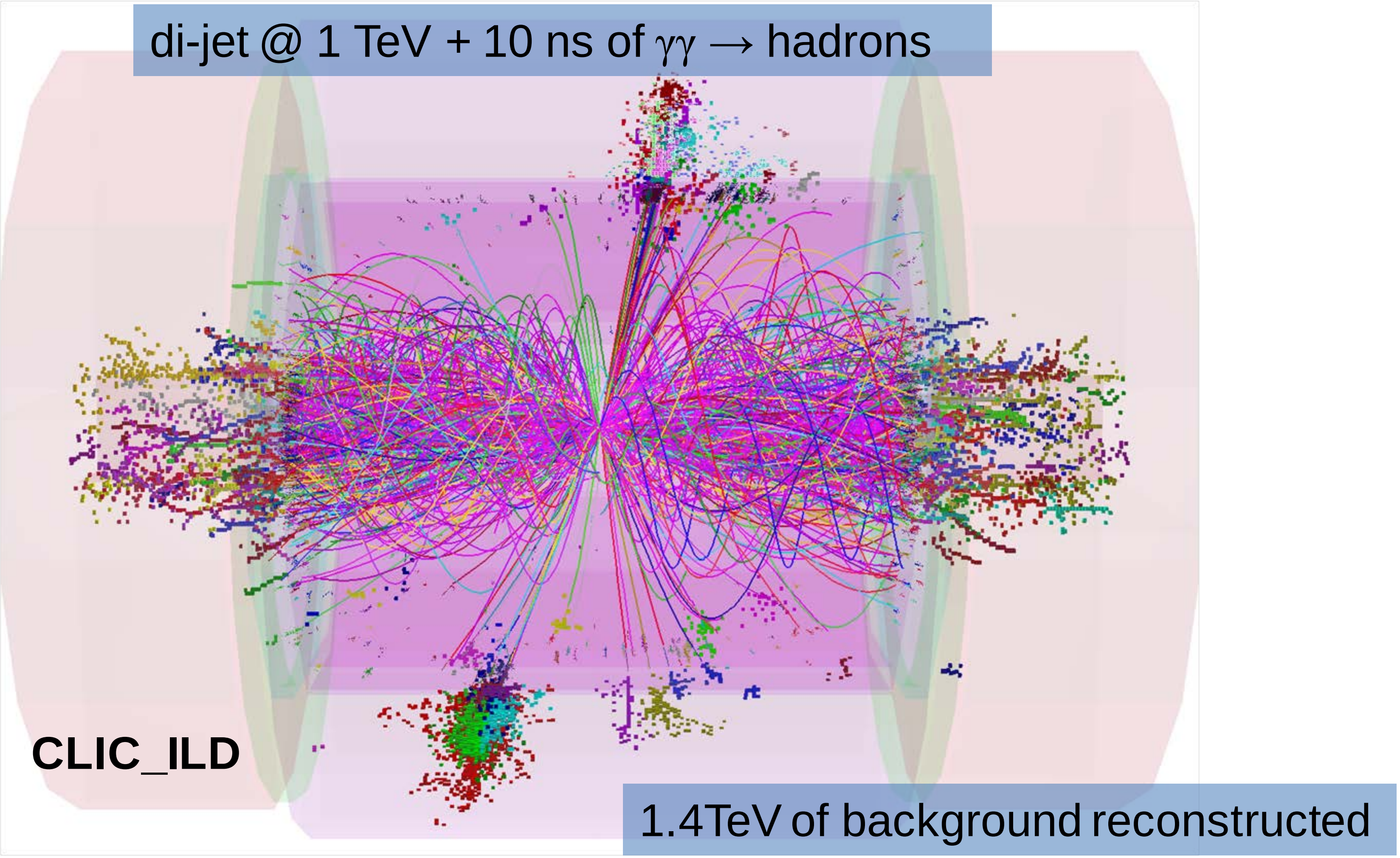
Event Reconstruction with Background

- Simulate signal and background samples individually
- Overlay background before digitization step and reconstruct together
- Define reasonable readout time windows for all sub detectors, i.e. 10 ns
- Overlay sufficient background events to fill time windows with realistic background levels

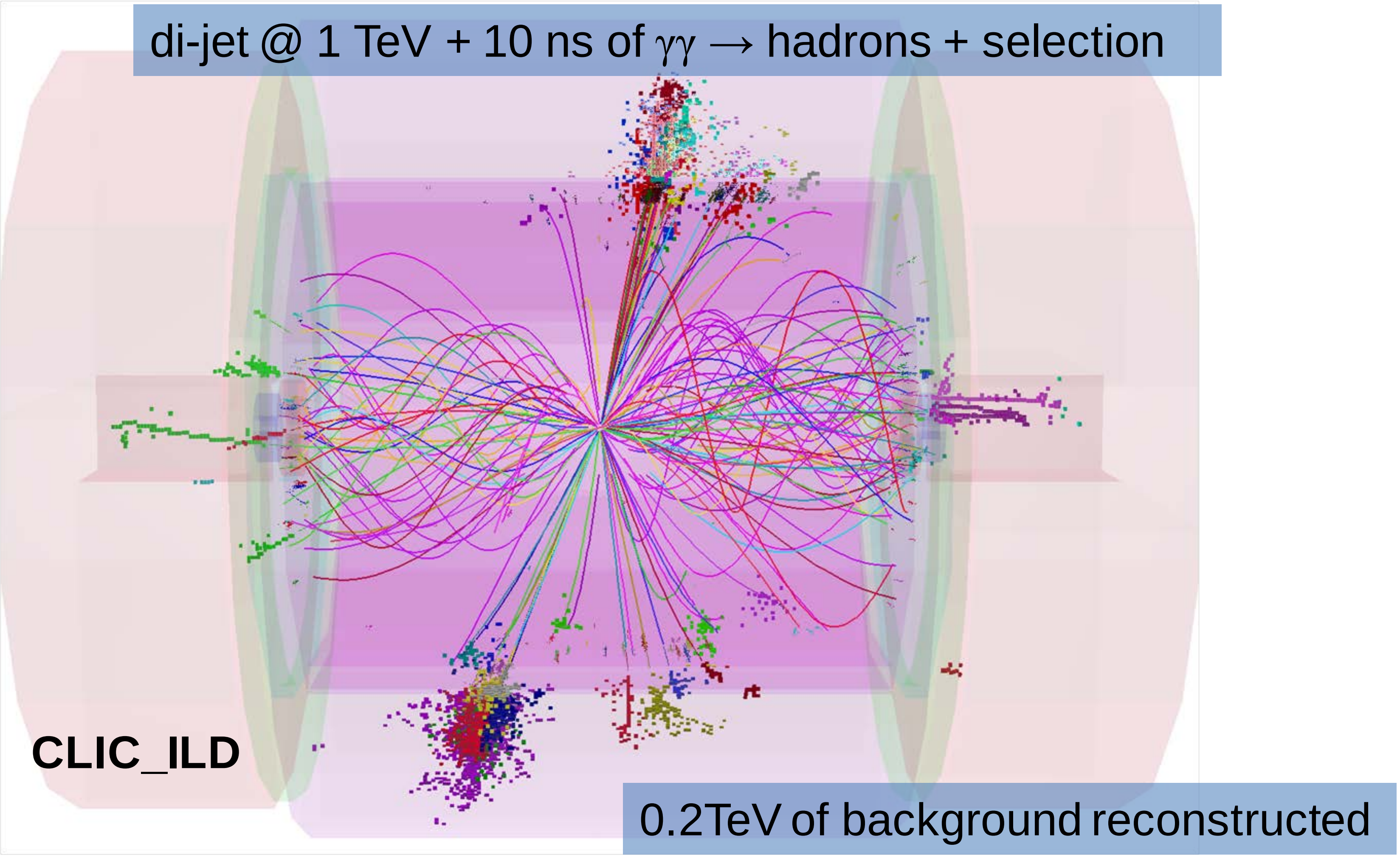


Event Reconstruction with Background

- Assuming 10ns readout time windows for tracker and calorimeter and overlay full bunch train structure within that time window
- Allow longer time window for HCal barrel because of large slow neutron contribution in hadronic showers in tungsten



- Assuming 1ns time resolution for calorimeter hits → sub-ns resolution for clusters
- Calculate cluster time (and track propagation time) for reconstructed particles
- Remove out of time particles (cuts depending on θ on p_t)

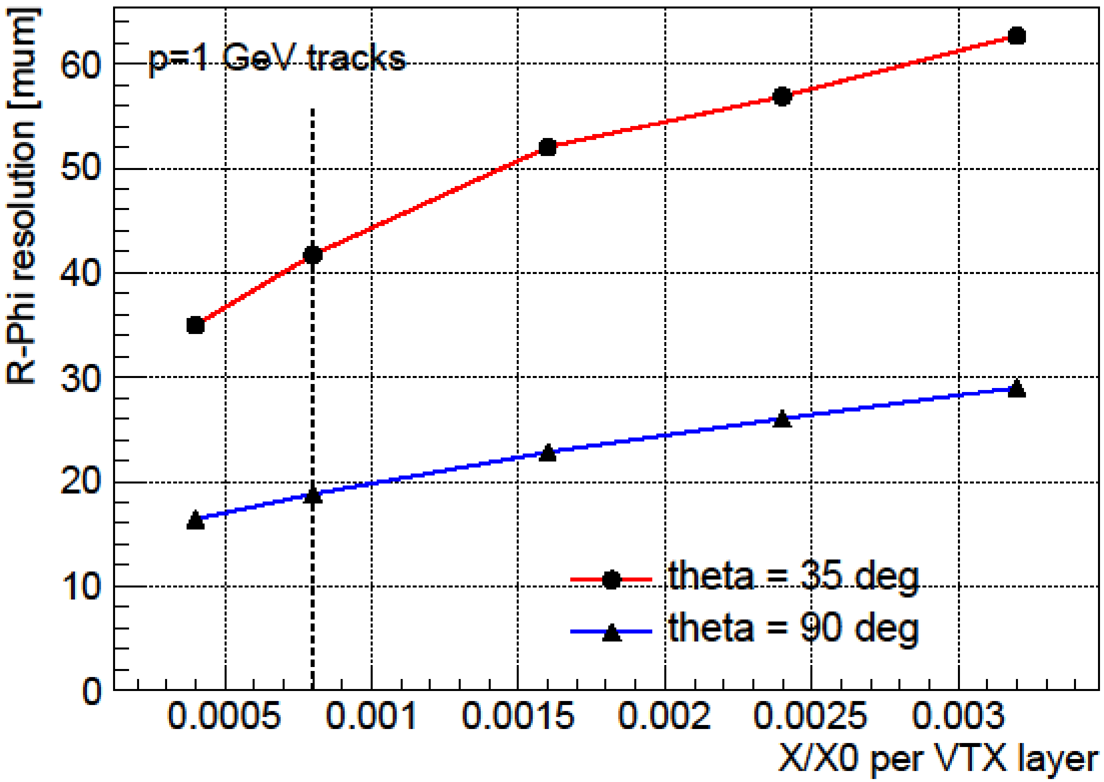


Summary & Outlook

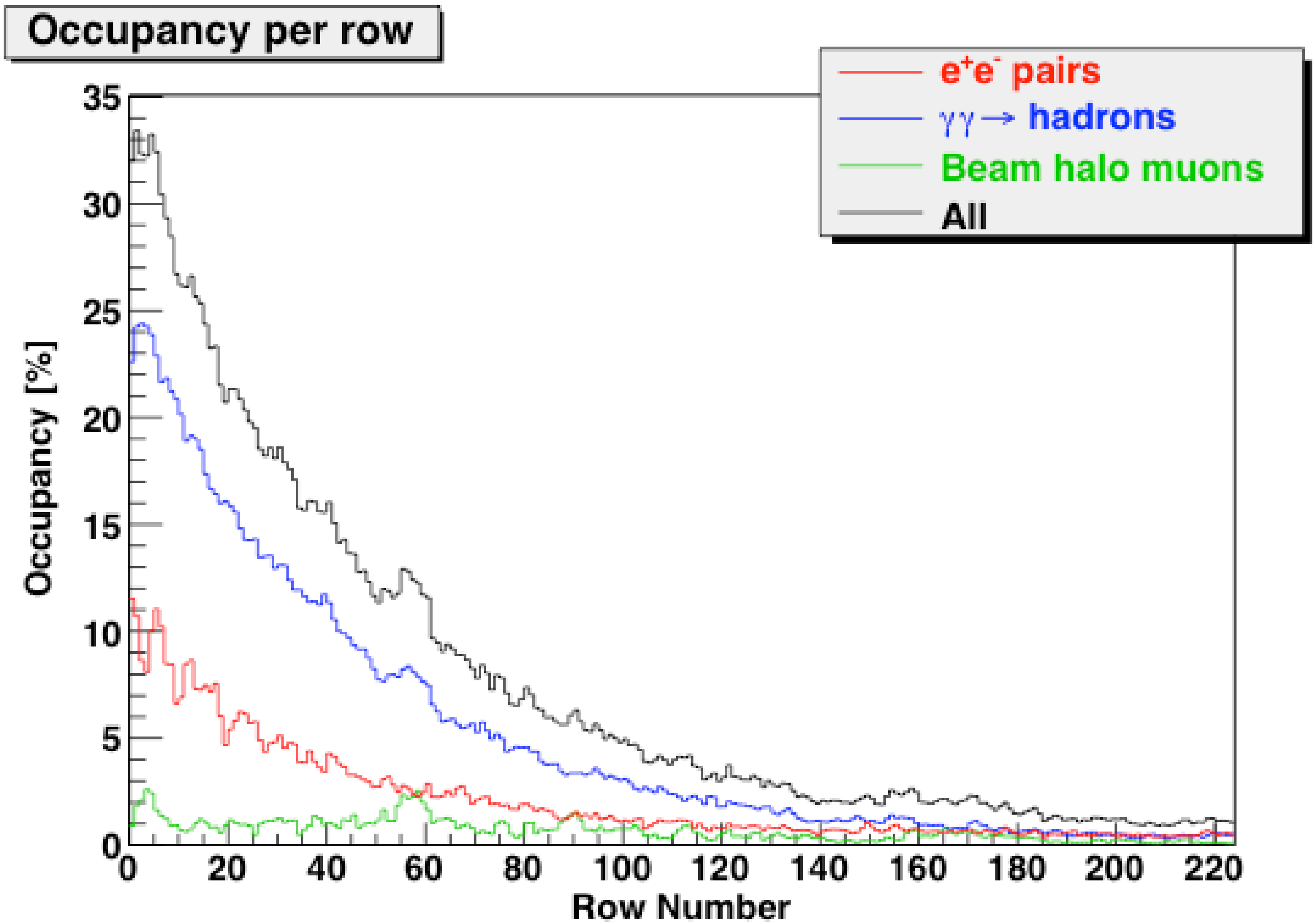
- CLIC CDR will be published at the end of 2011
  - Volume 2: Physics and Detectors covers physics case, detector design and benchmark studies
- Focus will shift towards detector R&D after the CDR
- Large number of detector R&D opportunities at CLIC, even beyond the ongoing efforts for the ILC
  - Vertex detector:
    - high single point resolution and time stamping capability (~10ns)
    - low material budget → use power pulsing to reduce cooling needs
  - Hadron Calorimeter:
    - dense absorber material, i.e. tungsten required to keep coil feasible and contain TeV energy jets
  - Coil:
    - large, high field solenoid required, needs improved sc cable design (not covered here)
  - Detector integration:
    - support of final quadrupole, needs to be isolated from vibrations (not covered here)
- Continue successful collaboration with the ILC R&D collaborations and ILC detector concepts

Backup Slides

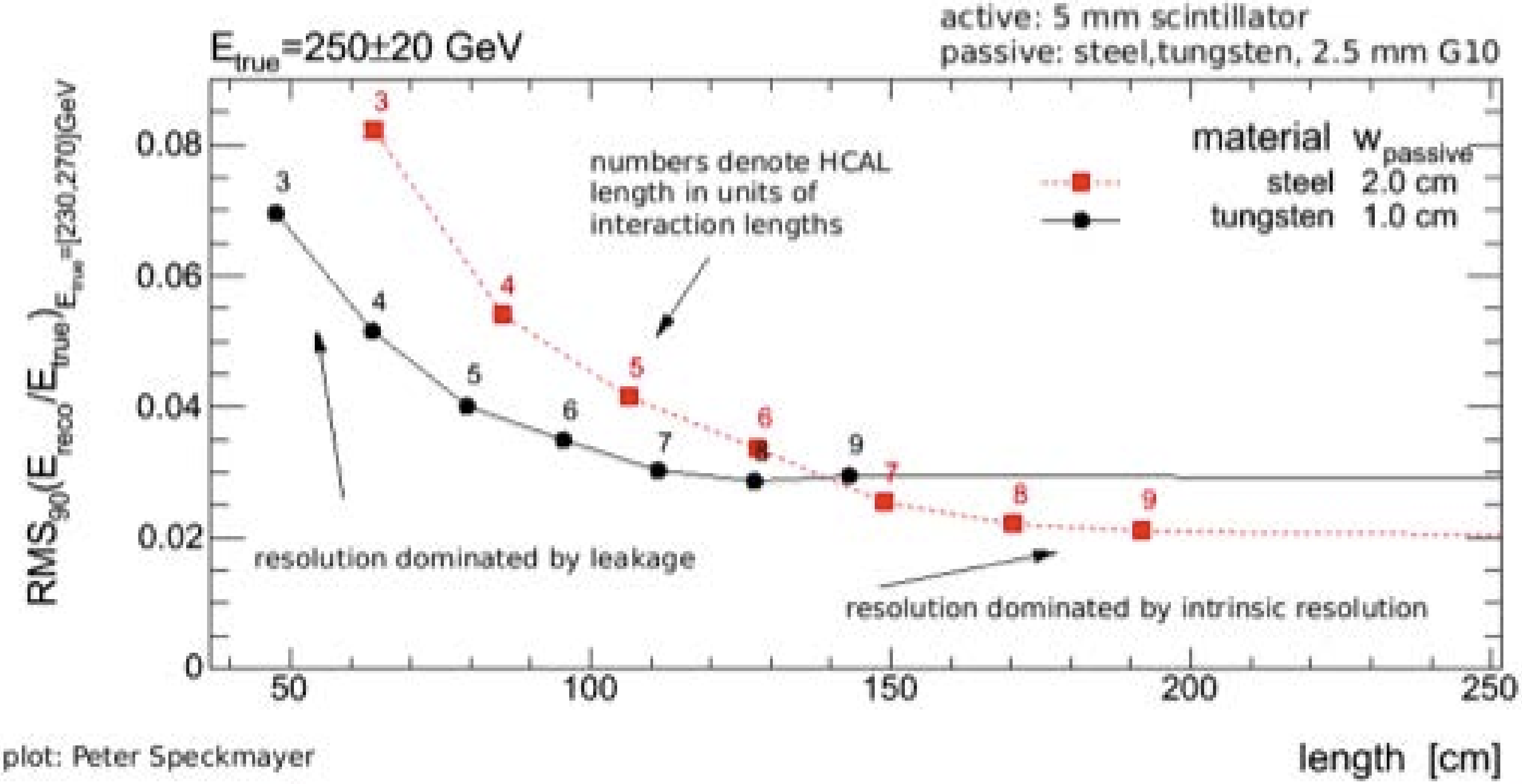
- 0.1% X0 maximum per detection layer is desired, but more is not a show stopper



- Pad occupancy (percent of time voxels occupied) for full bunch train and 6*1 mm^2 pads at 40 MHz readout

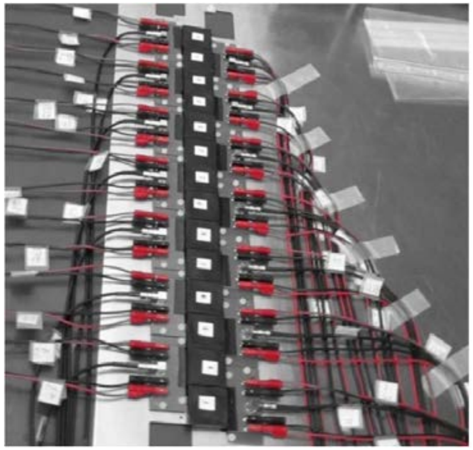


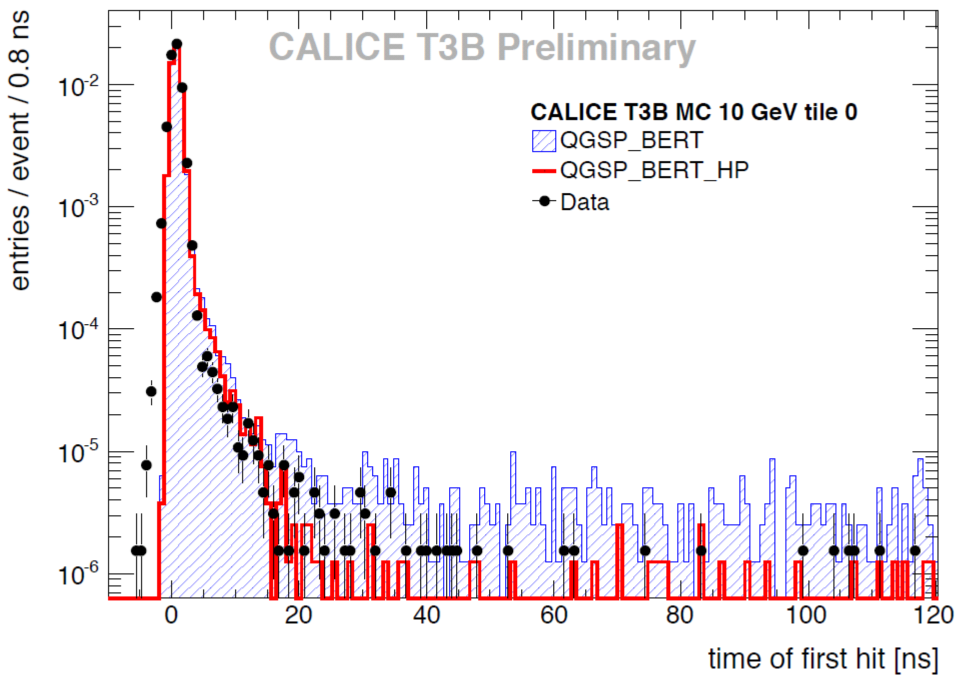
- Systematic study of various absorber materials and sampling ratios vs. total HCal depth

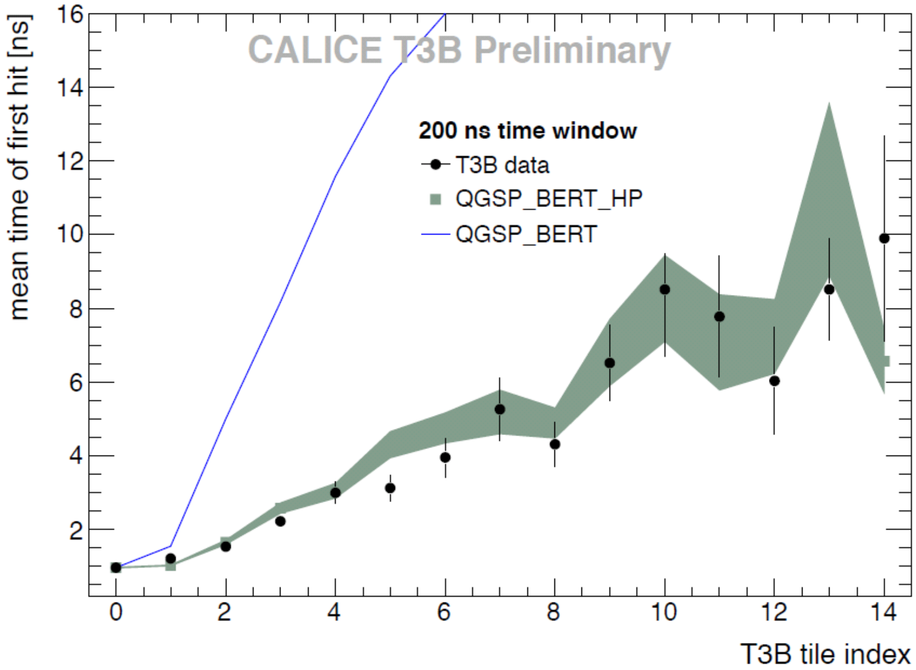


Tungsten HCal Prototype

- Tungsten Timing Test Beam (T3B) set up behind the WHCal prototype
- Small number of scintillator tiles with very fast response
- Precise measurement of time structure of showers
- Data is well described by QGSP_BERT_HP

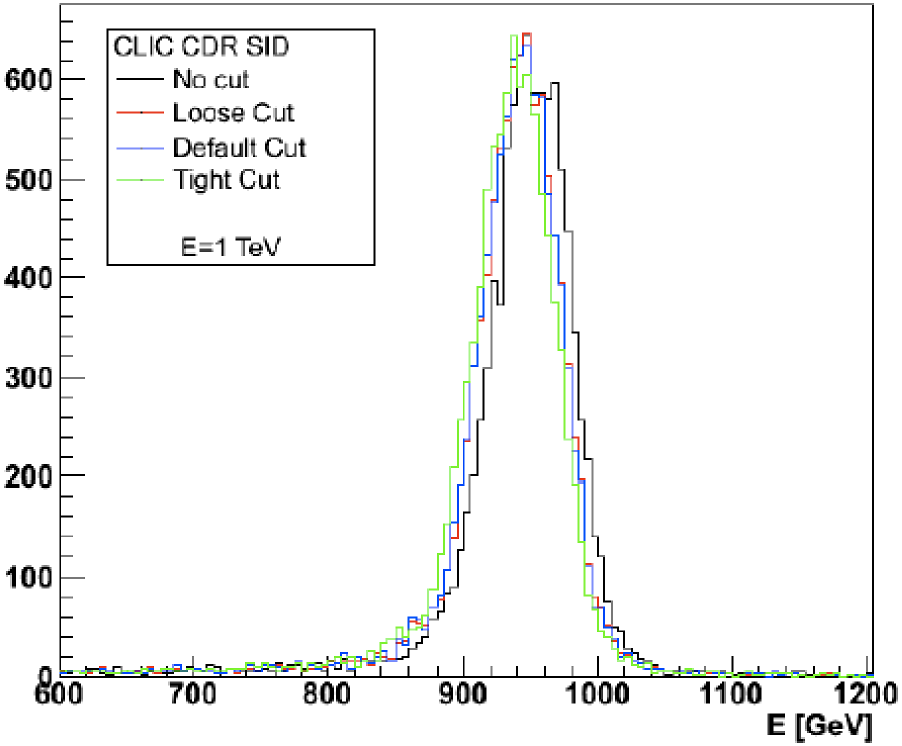


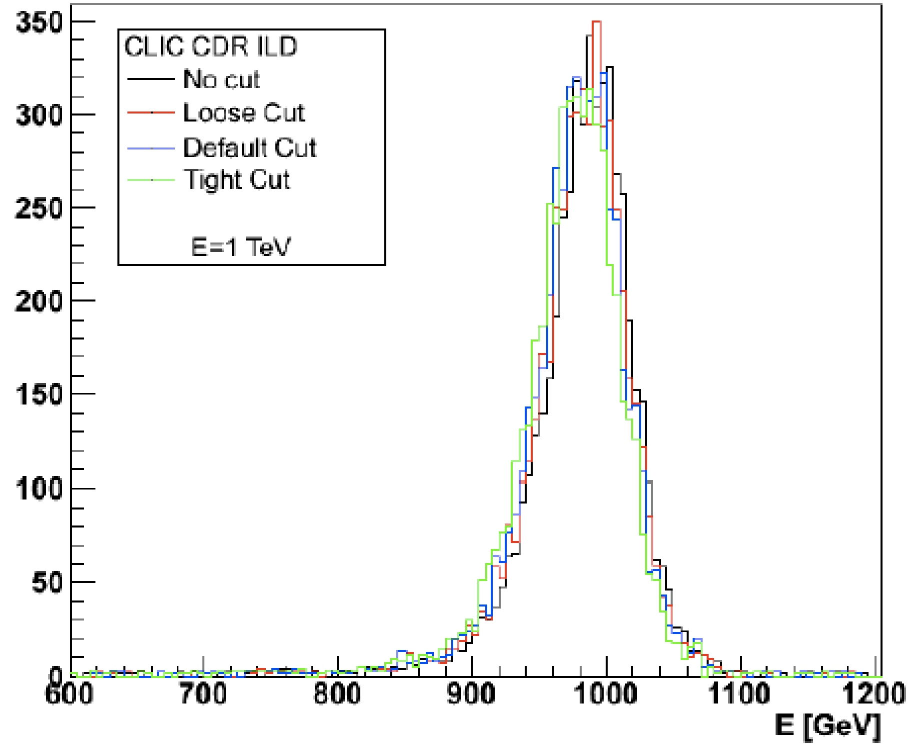




Event Recoonstruction

- Impact of PFO selection on jet energy resolution

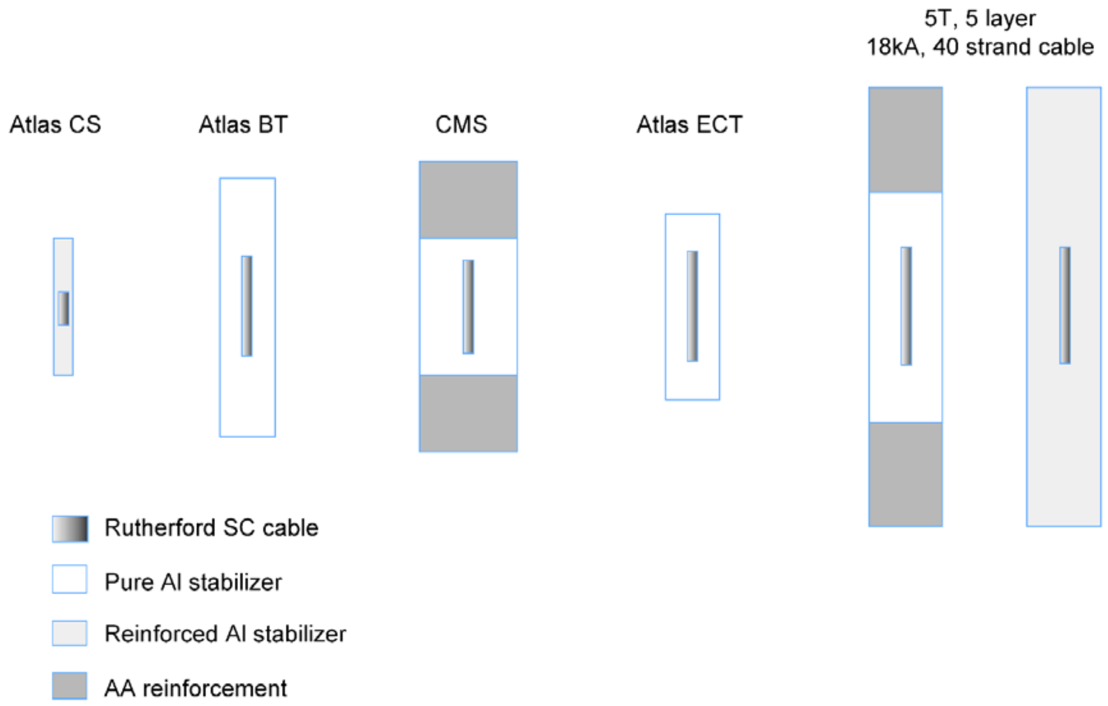




E_{jet} [GeV]	45	100	250	500
no cut	3.98 ± 0.05	3.15 ± 0.04	3.00 ± 0.04	3.26 ± 0.06
loose cut	4.40 ± 0.06	3.34 ± 0.04	3.08 ± 0.04	3.29 ± 0.06
default cut	5.15 ± 0.07	3.64 ± 0.05	3.17 ± 0.04	3.33 ± 0.06
tight cut	5.95 ± 0.08	3.99 ± 0.05	3.30 ± 0.04	3.37 ± 0.06

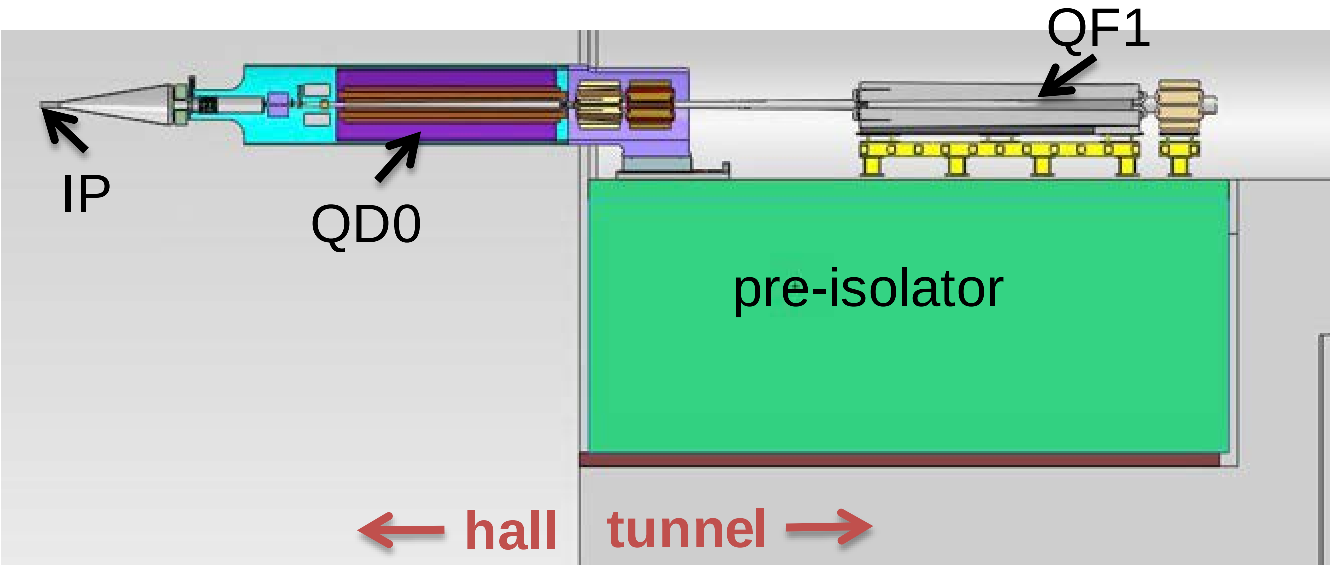
Super Conducting Cables

- Coil design is pushing technological limits
- Forces on sc cable is main challenge for the coil design (100bar pressure)
- Extrapolate ATLAS CS reinforced aluminum design
  - micro-alloy increases mechanical strength without degrading conductivity



Extrusion tests: Collaboration between KEK and CERN together with Swiss industry

- Final quadrupole as close as possible to the IP (luminosity)
- Very high stabilization requirements for QD0 at CLIC
  - Beam size: 1nm vertical, 40nm horizontal, 45nm longitudinal
  - Vertical position better than 0.15nm RMS for $f > 4$Hz
- Minimize vibrations
  - Use permanent magnets and warm magnets
  - Decouple from detector, support from tunnel instead
  - Passive high-mass low stiffness spring system to suppress high frequencies from ground



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Test stand at CERN to cross check simulations