Future Detectors:

Physics & Detectors at Linear Colliders

Frank Simon
Max-Planck-Institut für Physik
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MPP Project Review 2014

The Future Detectors Group

funded by Excellence Cluster

The Core Group

- *Post-Docs*

  Naomi van der Kolk (since 10/2014), Martin Ritter (working on Belle / Belle-II), Michal Tesar (since 03/2014)

- *PhD Students*

  Veronika Chobanova (mostly on Belle analysis), Miroslav Gabriel (since 10/2014), Marco Szalay, Michal Tesar (until 02/2014)

- *Master Student*

  Miroslav Gabriel (until 08/2014)

- *Bachelor Students*

  Tolga Sarp, Hendrik Windel

- *Group Leader*

  Frank Simon

- Close collaboration with:
  - Belle / Belle-II group
  - HLL
  - And **the technical departments**!

The Context: Future Facilities at the Energy Frontier

- With the LHC in regular operation, the planing for future energy-frontier colliders has intensified

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⇨ Maximise our knowledge based on things we already know

- The Higgs: Fully understand electroweak symmetry breaking
- The Top: Measure its properties as precisely as possible - use it as a potential window for New Physics
- Other electroweak precision measurements to look for cracks in the SM

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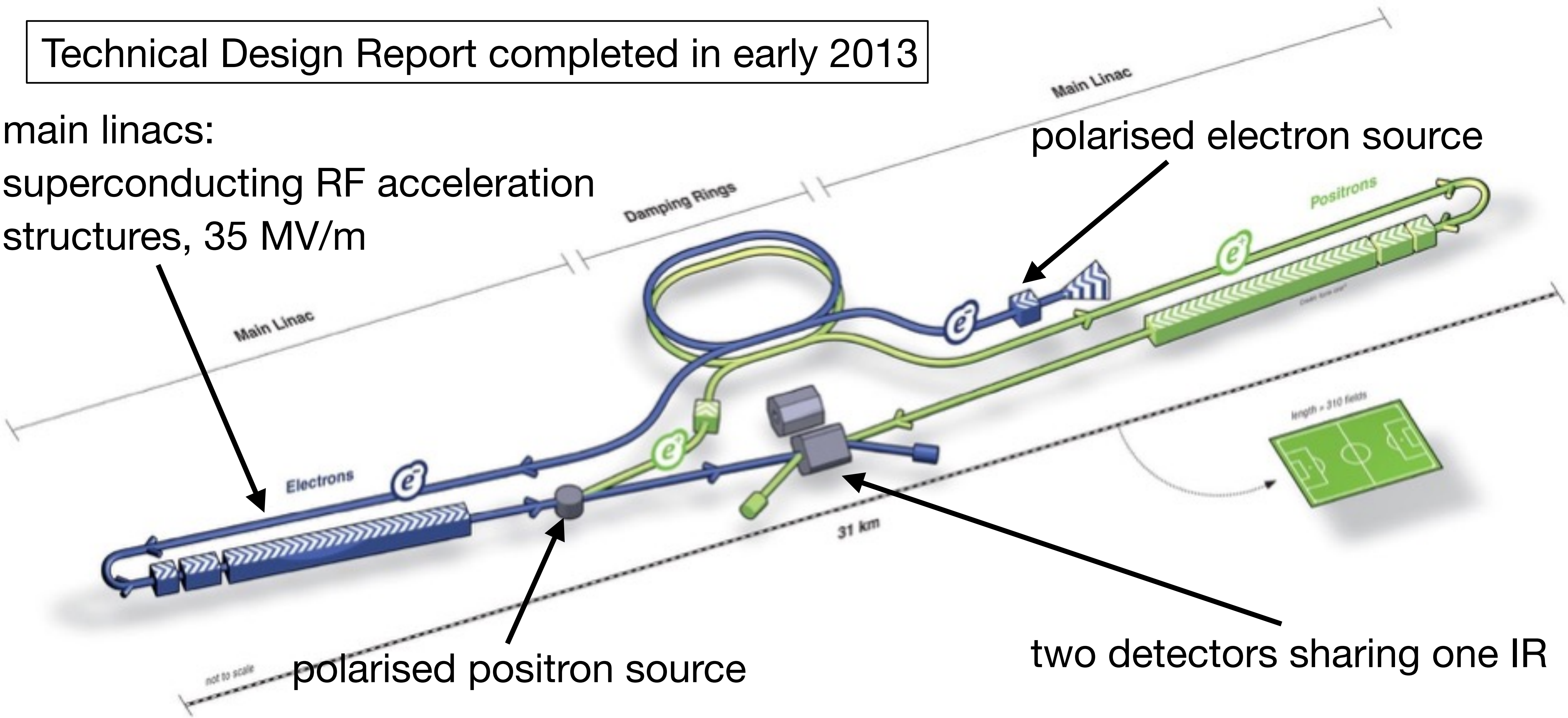
➾ Direct searches for New Physics - Explore higher energy scales, and regions of phase space not yet accessible to find new particles and / or evidence for new fundamental interactions and phenomena

Linear Electron-Positron Colliders - ILC

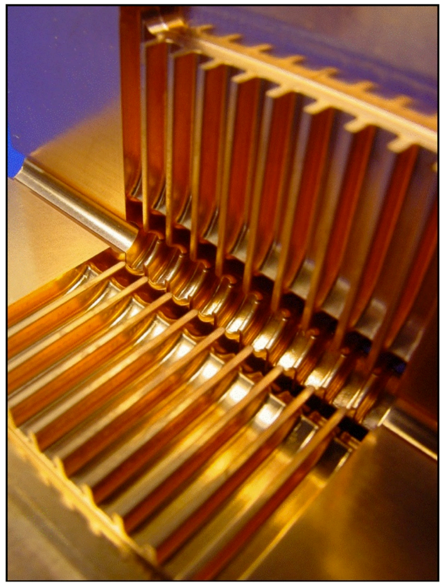
- The highest degree of complementarity to the LHC is provided by e^+e^- colliders
  - Linear colliders provide the possibility to reach energies of 500 GeV and more
- ILC: Currently the most advanced concept for a future energy frontier collider
  - Baseline 500 GeV - upgrade to 1 TeV

Technical Design Report completed in early 2013



Linear Electron-Positron Colliders - CLIC

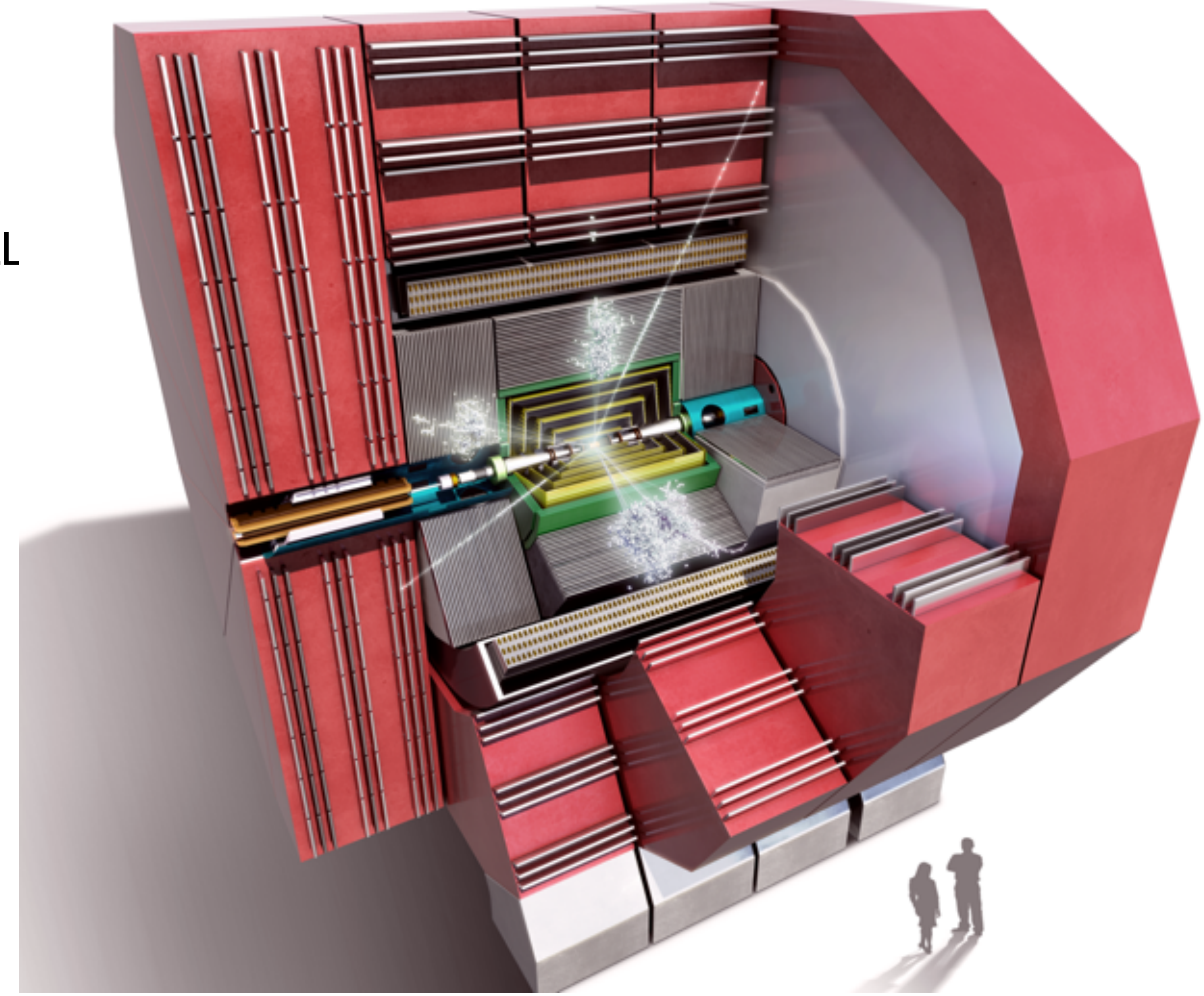
- A possible future energy frontier collider at CERN
  - e^+e^- collisions at up to 3 TeV with high luminosity (~ 6 x 10^{34} $cm^{-2}s^{-1}$ at 3 TeV)
  - Staged construction 350 - 500 GeV, ~ 1.5 TeV, 3 TeV - detailed energies under study, based on physics and technical considerations
  - Based on two-beam acceleration: gradients of 100 MV/m
  - Development phase until ~2018 - CDR completed in 2012



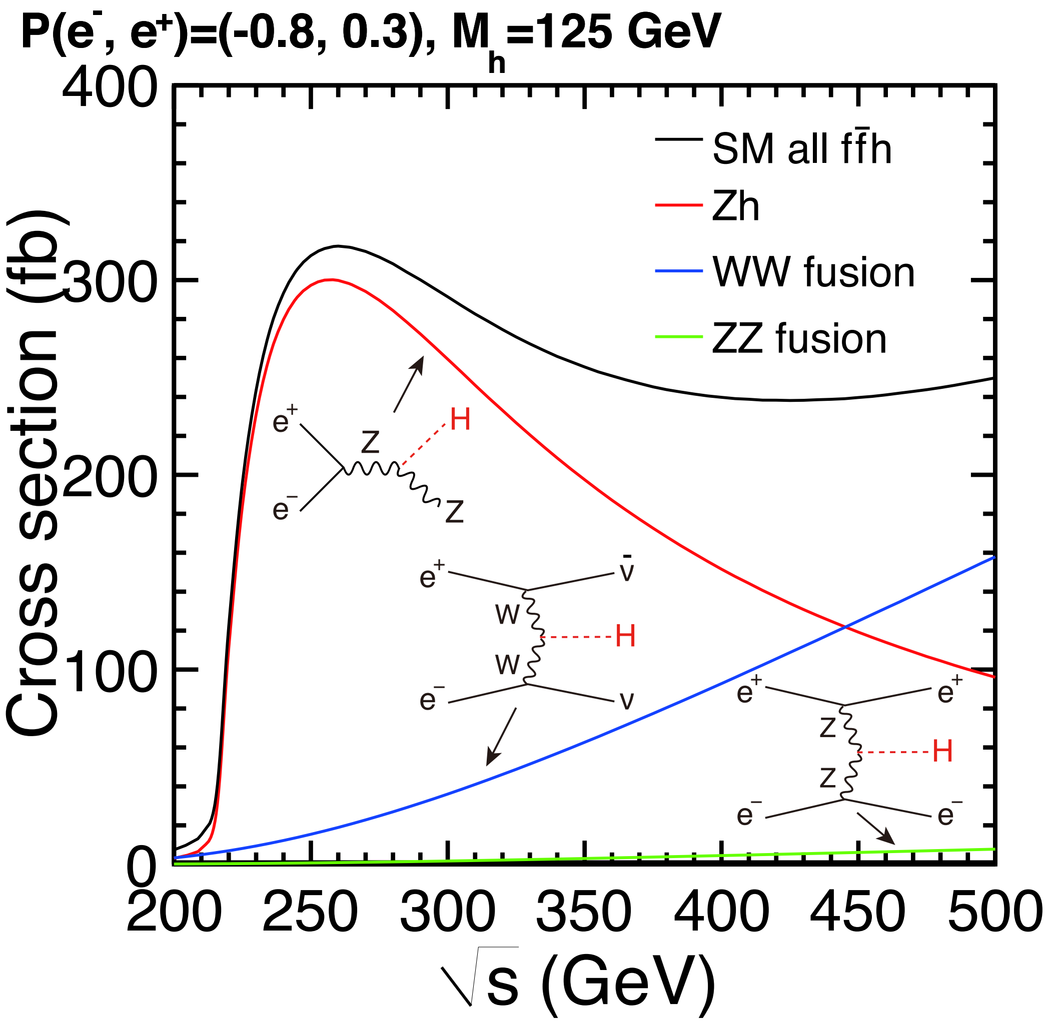
Activities in the Future Detectors Group

- Main topics:
  - Physics at future Linear Colliders
  - Development of highly granular calorimeters
- In addition: Collaboration with vertex detector activities at HLL

common for ILC & CLIC



Higgs Physics: H-> Jets @ 350 GeV



A “sweet spot” for Higgs physics:

- ZH and WW fusion both have appreciable cross-sections
  - Z boost in ZH sufficiently low for precise reconstruction of recoil mass for model-independent measurement of Higgs production
- Performed in the context of CLIC, equally relevant for ILC

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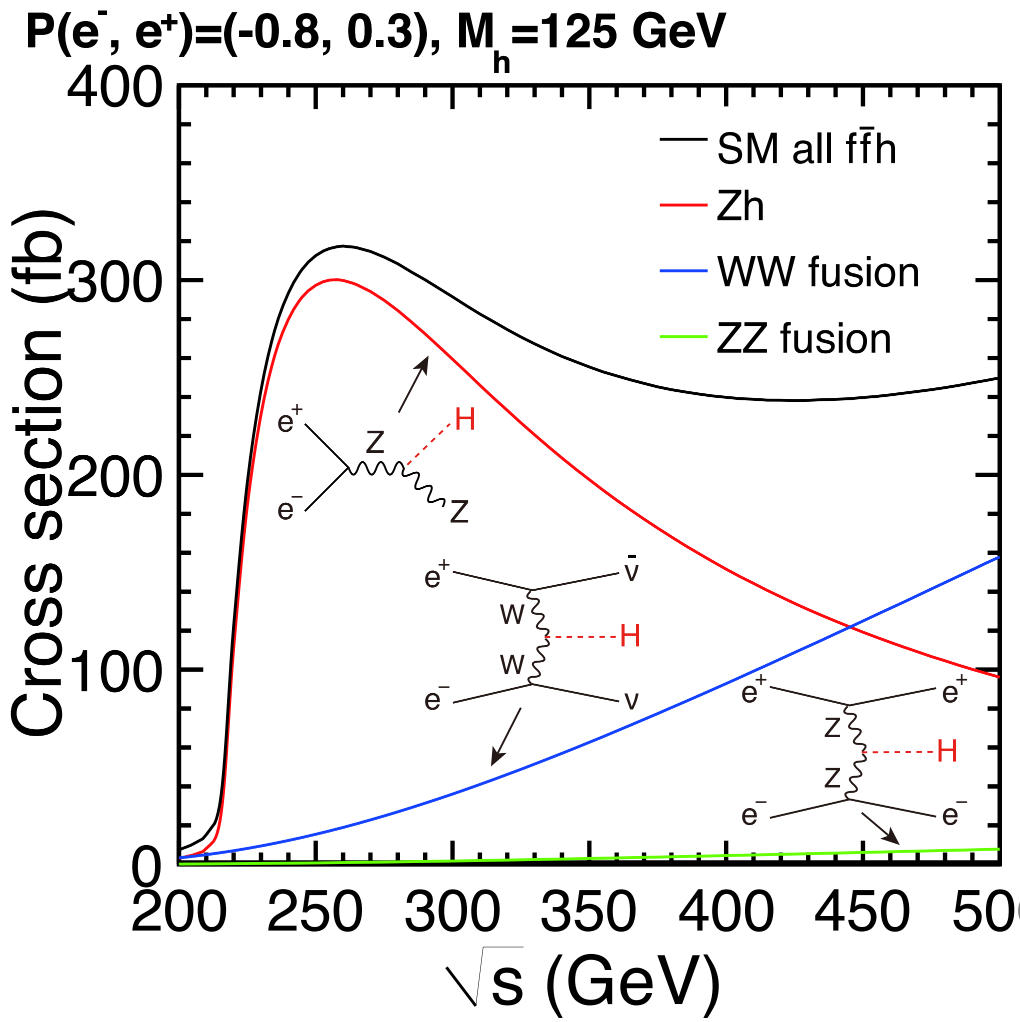

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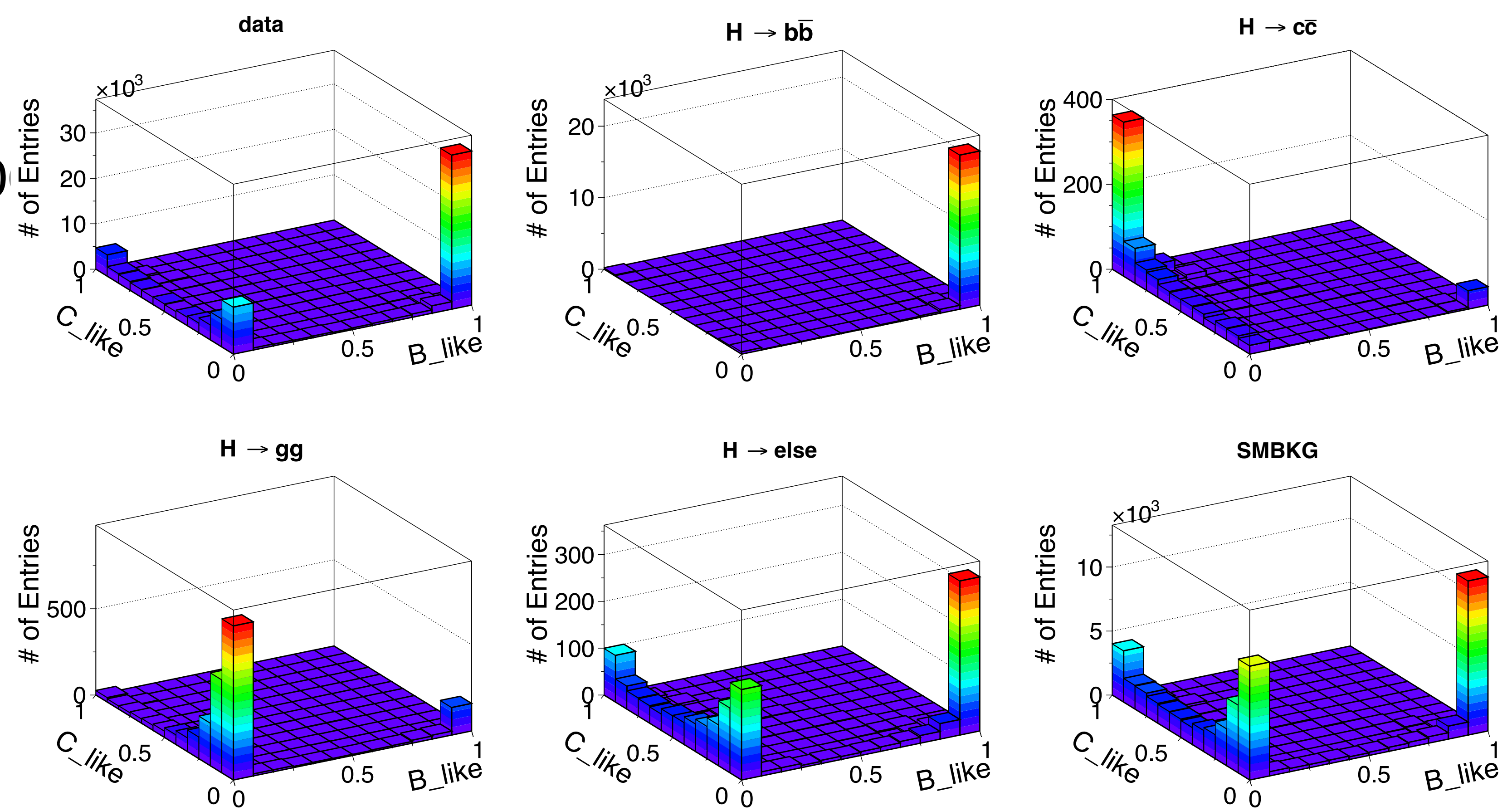
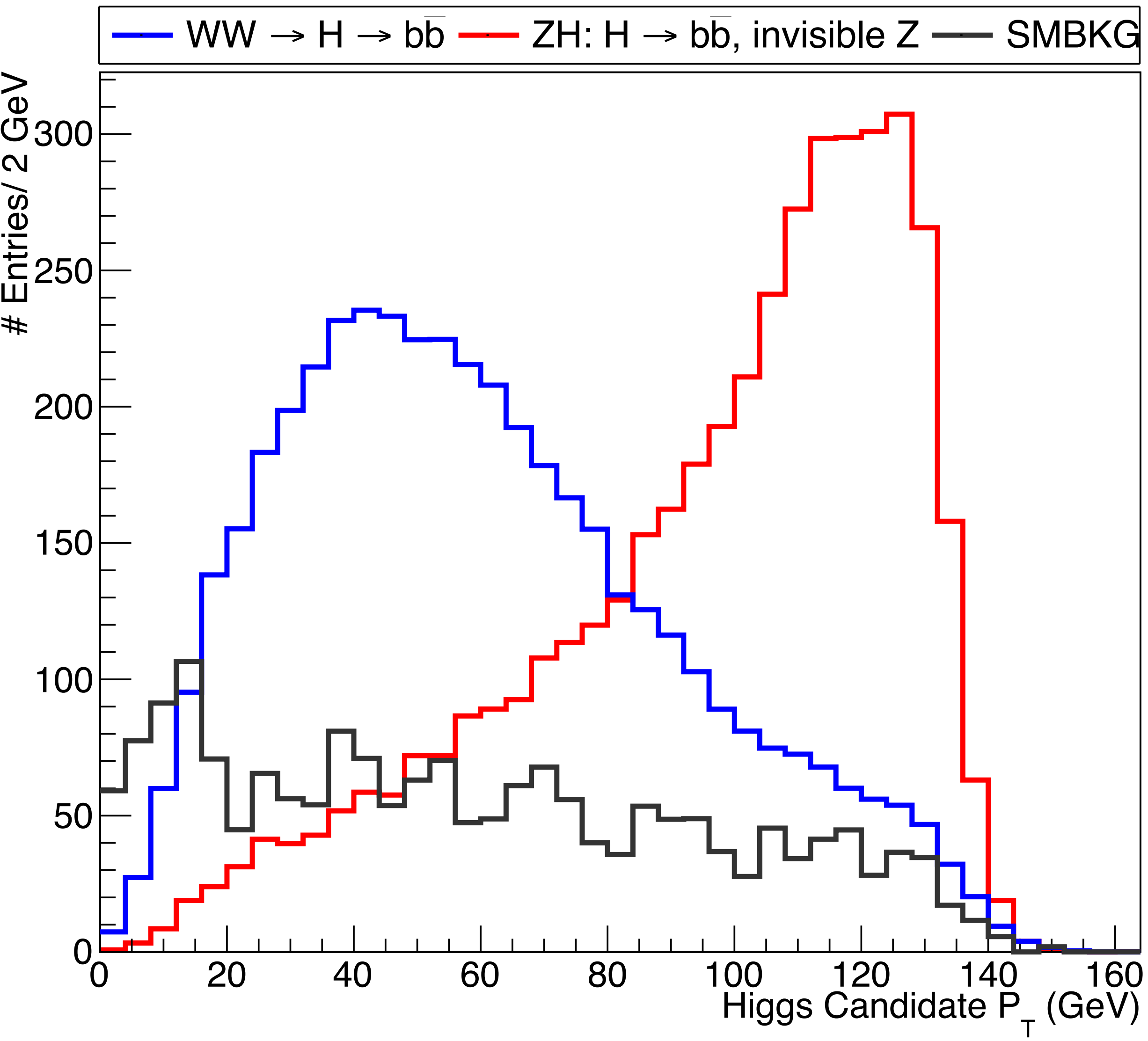
- Identification of Higgs final states based on flavor tagging: Separation of b, c and light (gluon) jets



Branching Fractions of Higgs Decays



- The analysis: Determining σ x BR for H->bb, cc, gg for unpolarised beams
  - Separate determination of ZH and WW fusion process for H->bb
  - Overlap of both production modes in the Hνν final state - separation based on Higgs p_T distribution

Extraction of results via a multi-dimensional template fit including flavor tagging and Higgs p_T distribution

Preliminary results:

H->bb in ZH: ~ 0.8%
H->bb in WW fusion: ~ 1.5 %

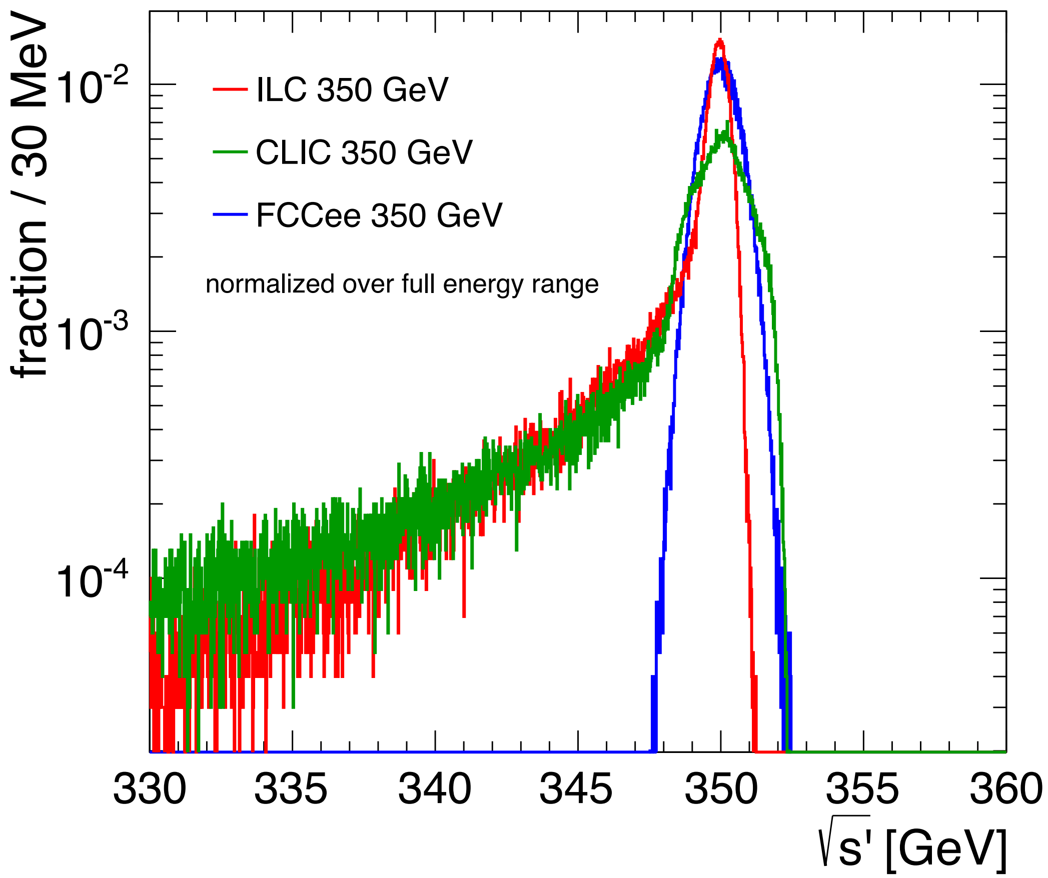
H->cc: ~ 6 %
H->gg: ~ 3.5 %

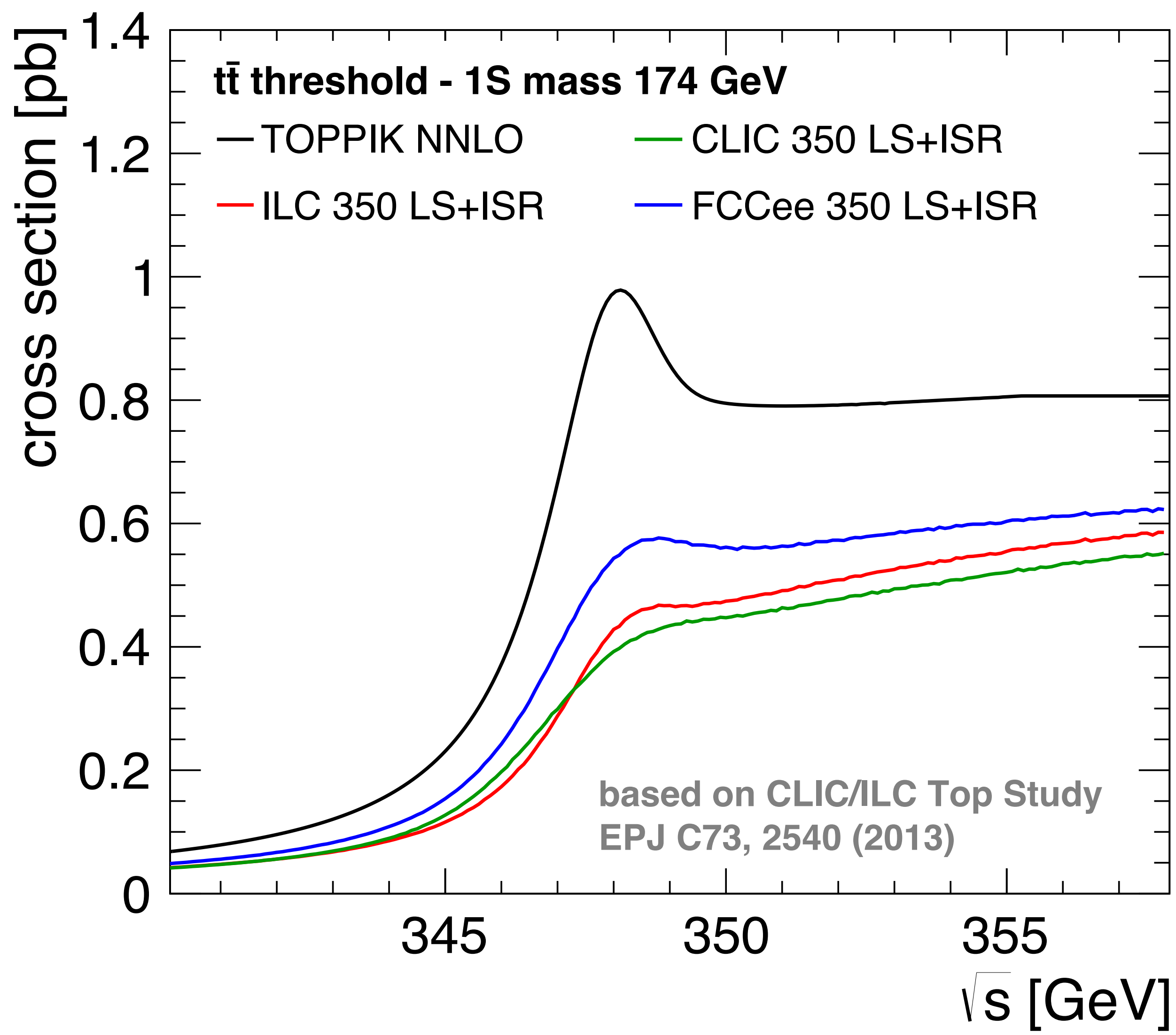
Resulting coupling precision (model-independent):
b ~ 2%; c ~ 3.5%, g (eff) ~ 3%

(NB: The best channel is Hνν, can be increased with polarisation)

Top Mass from a Threshold Scan

- Impact of collider luminosity spectrum on top quark mass measurement at threshold





FCCee (TLEP): circular e^+e^- collider,
100 km circumference, up to ~ 400 GeV

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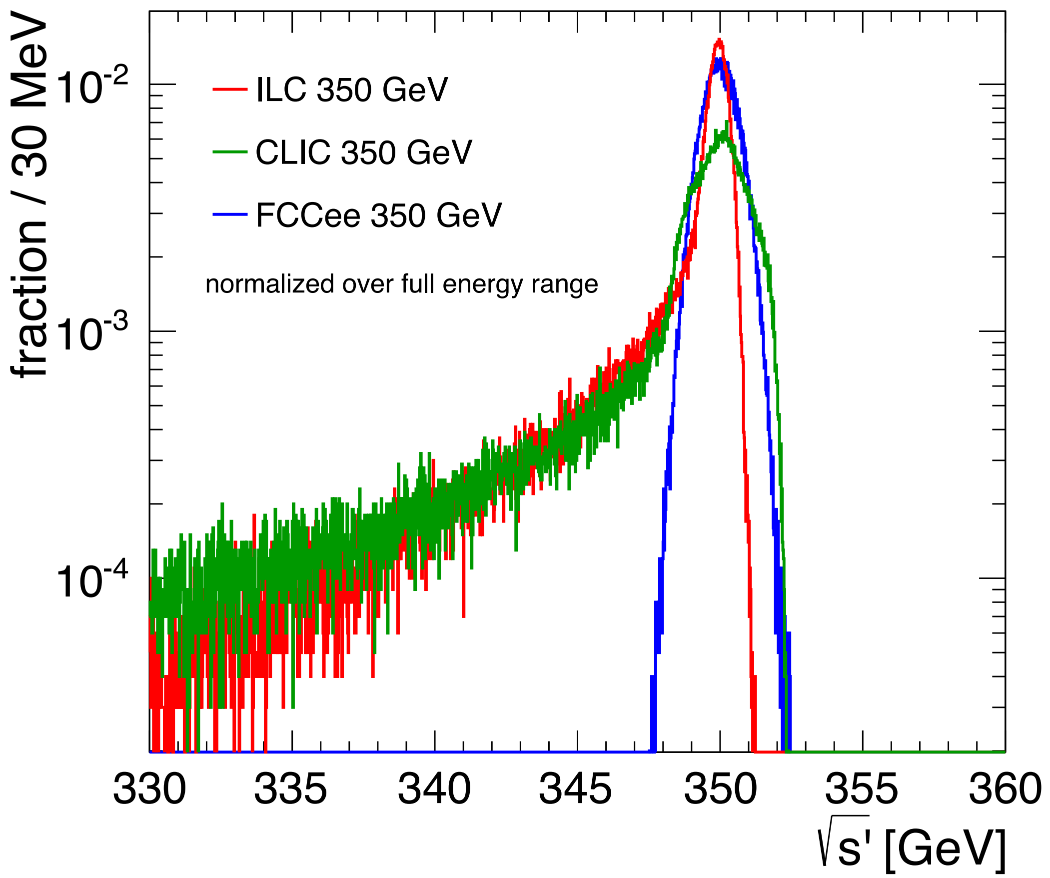

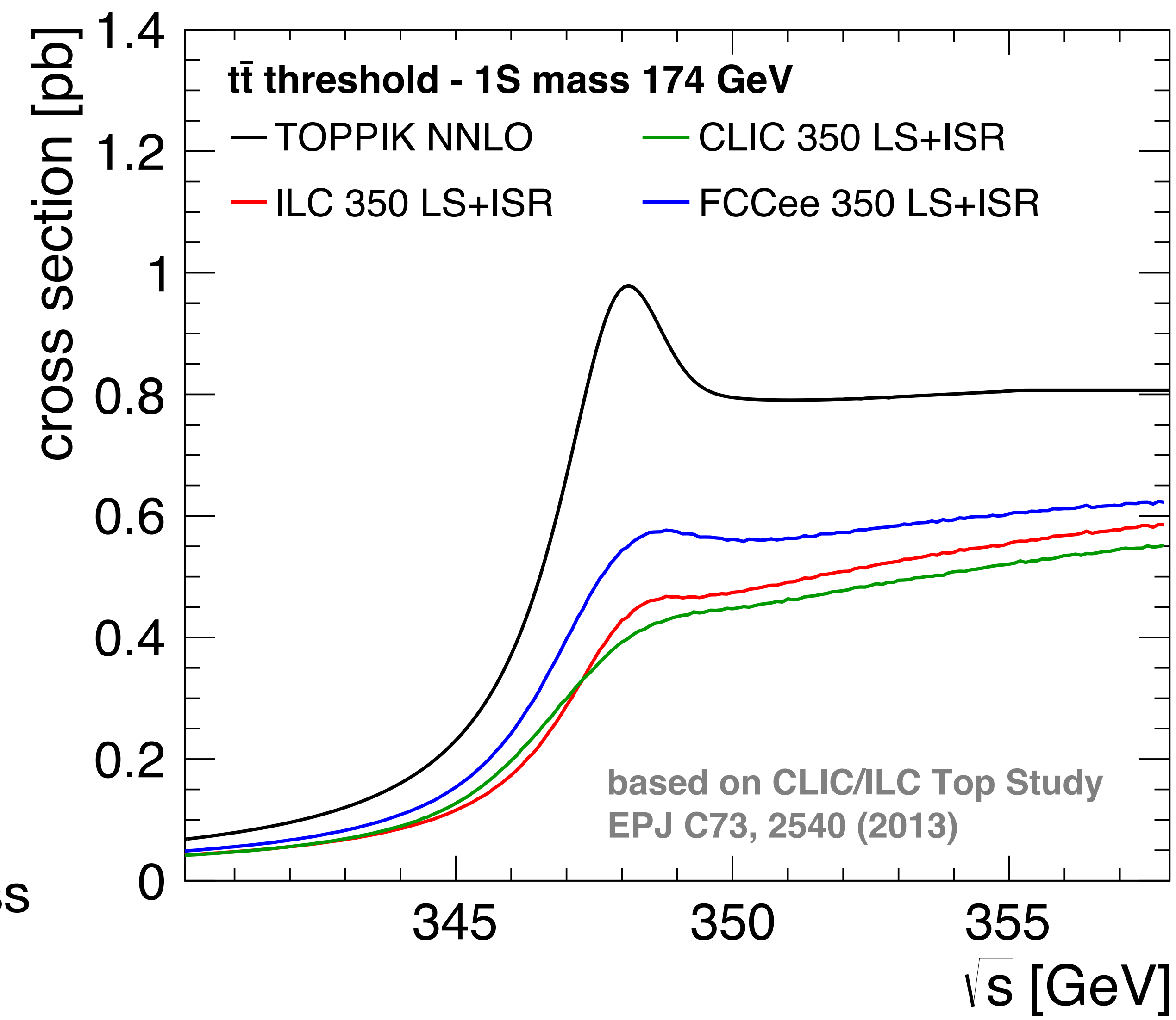

- Slight differences in statistics due to cross section, changes in sensitivity due to steepness of threshold turn-on
- For 100 fb^{-1}, no polarization, 1D mass fit:

16 MeV ➡ 18 MeV ➡ 21 MeV (stat)

FCCee ILC CLIC

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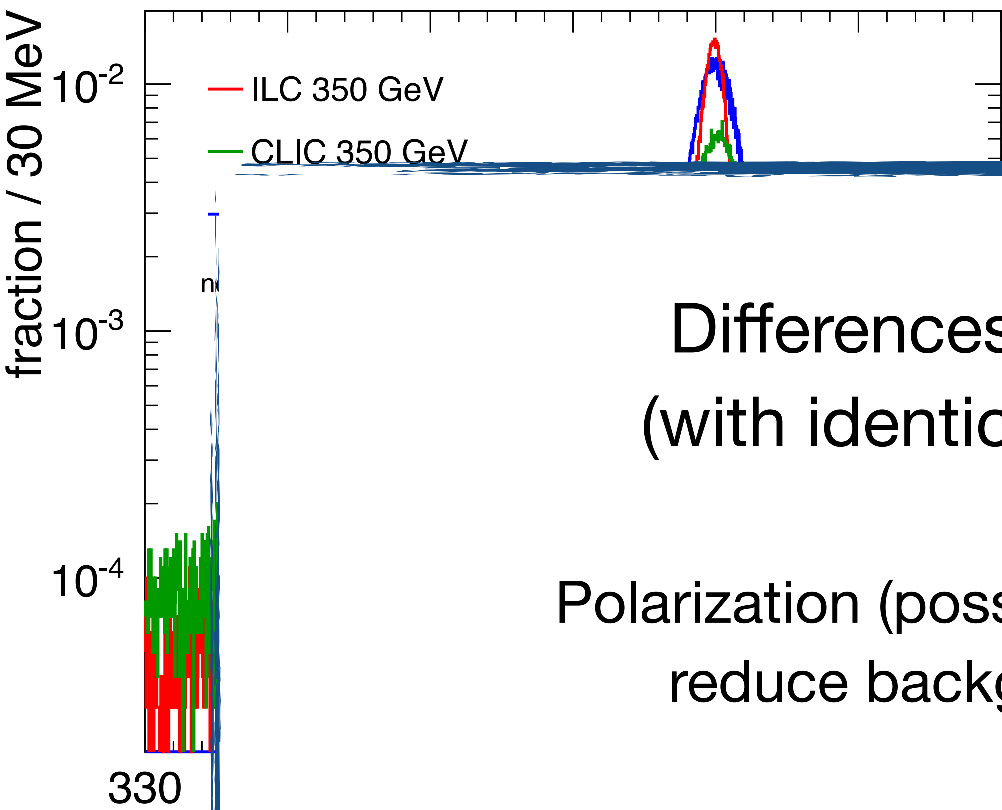

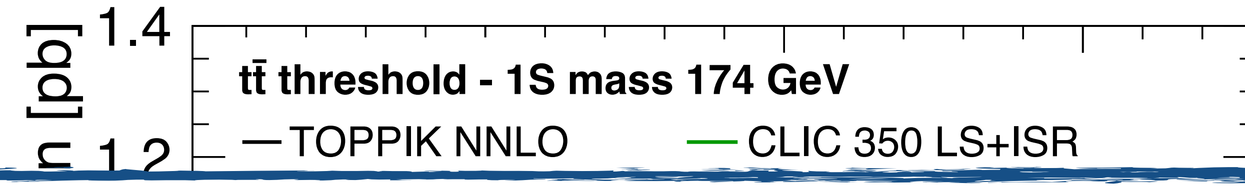

Differences between different collider options (with identical running scenarios) are very small

Polarization (possible only in LCs) can boost cross-sections or reduce backgrounds, resulting in increased sensitivity

In the end systematics will dominate (theory and / or experimental)

- Sligh
section, changes in sensitivity due to steepness of threshold turn-on
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    - Study impact of scale variations in NNNLO calculations on mass extraction

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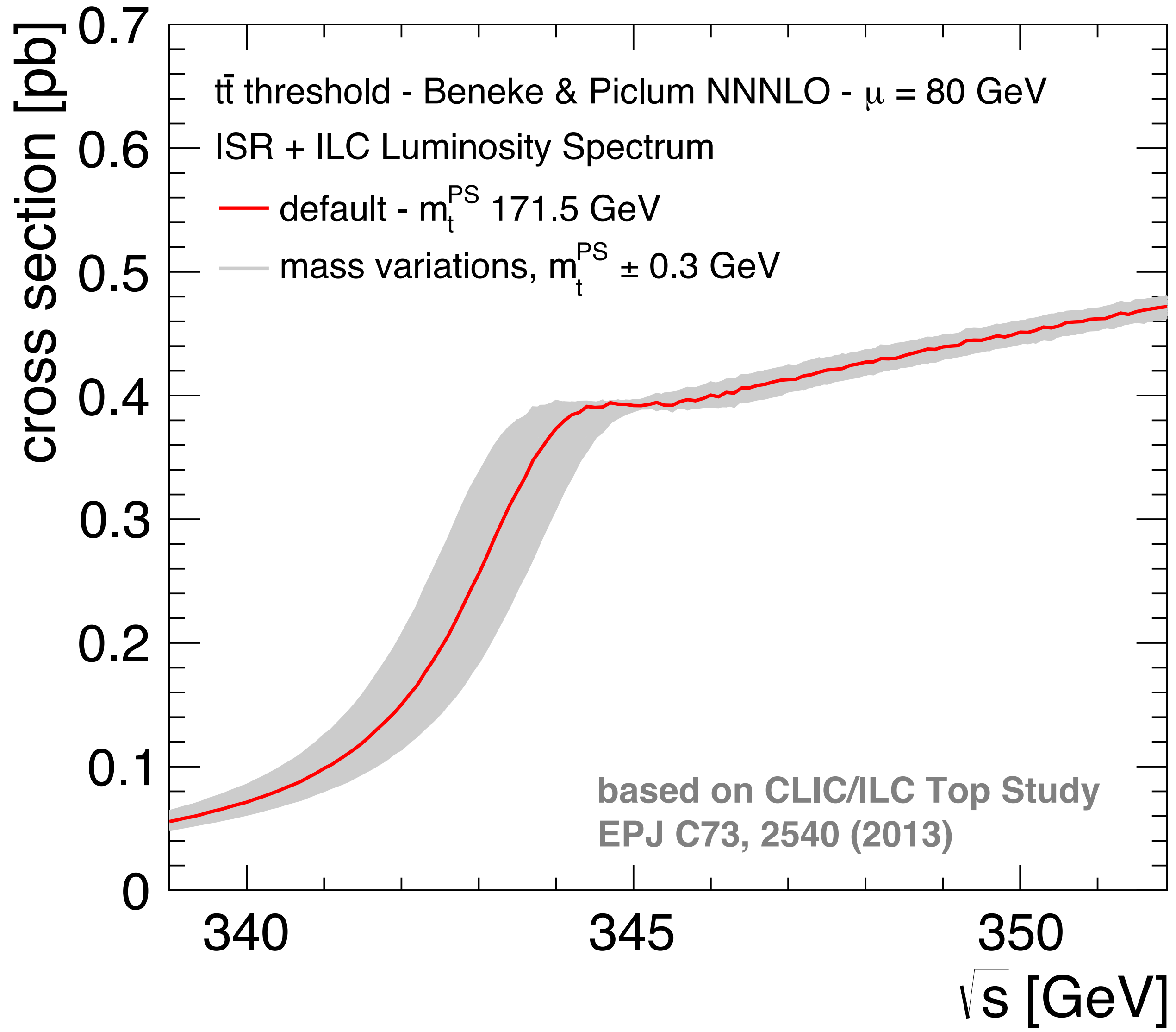

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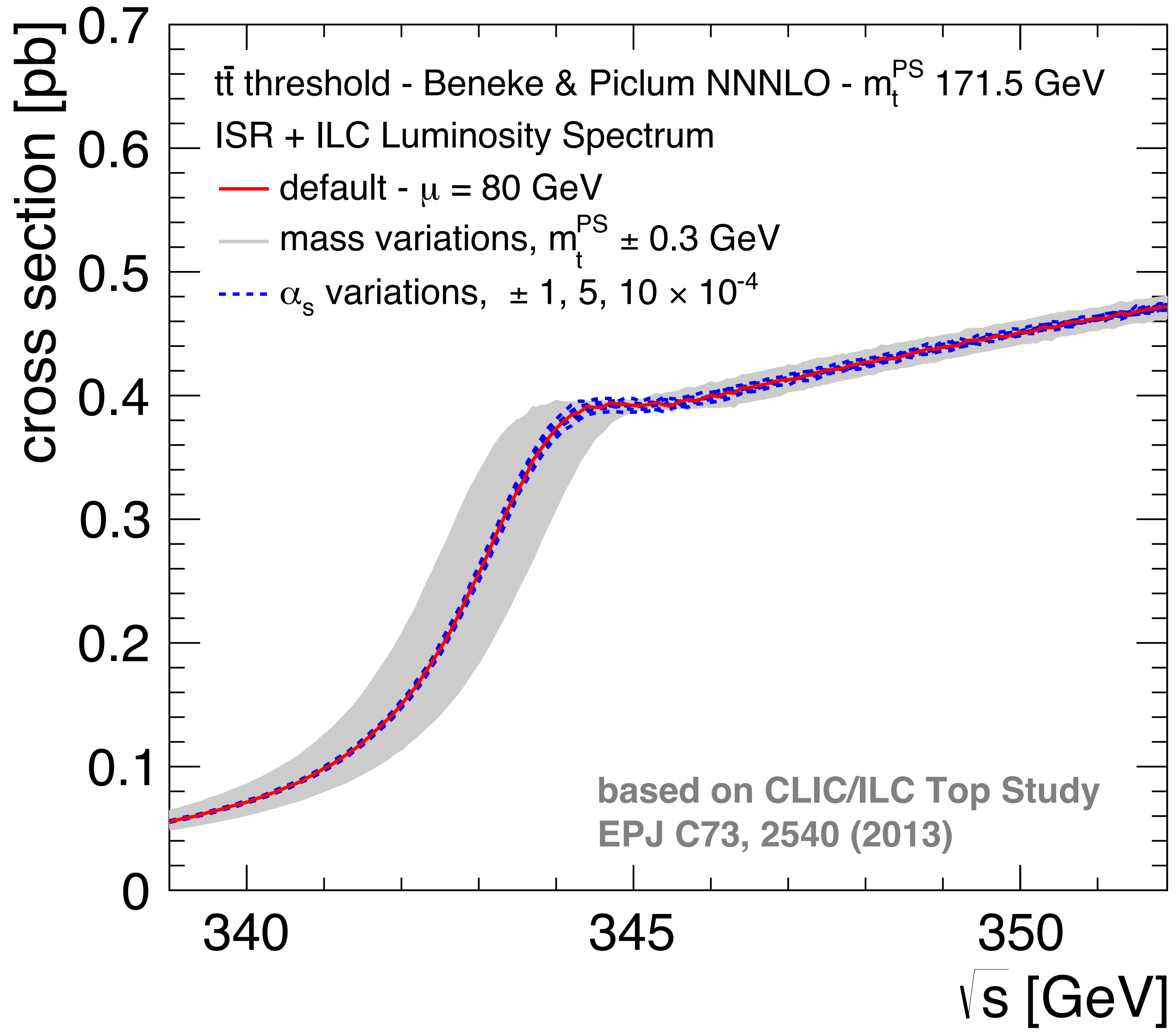

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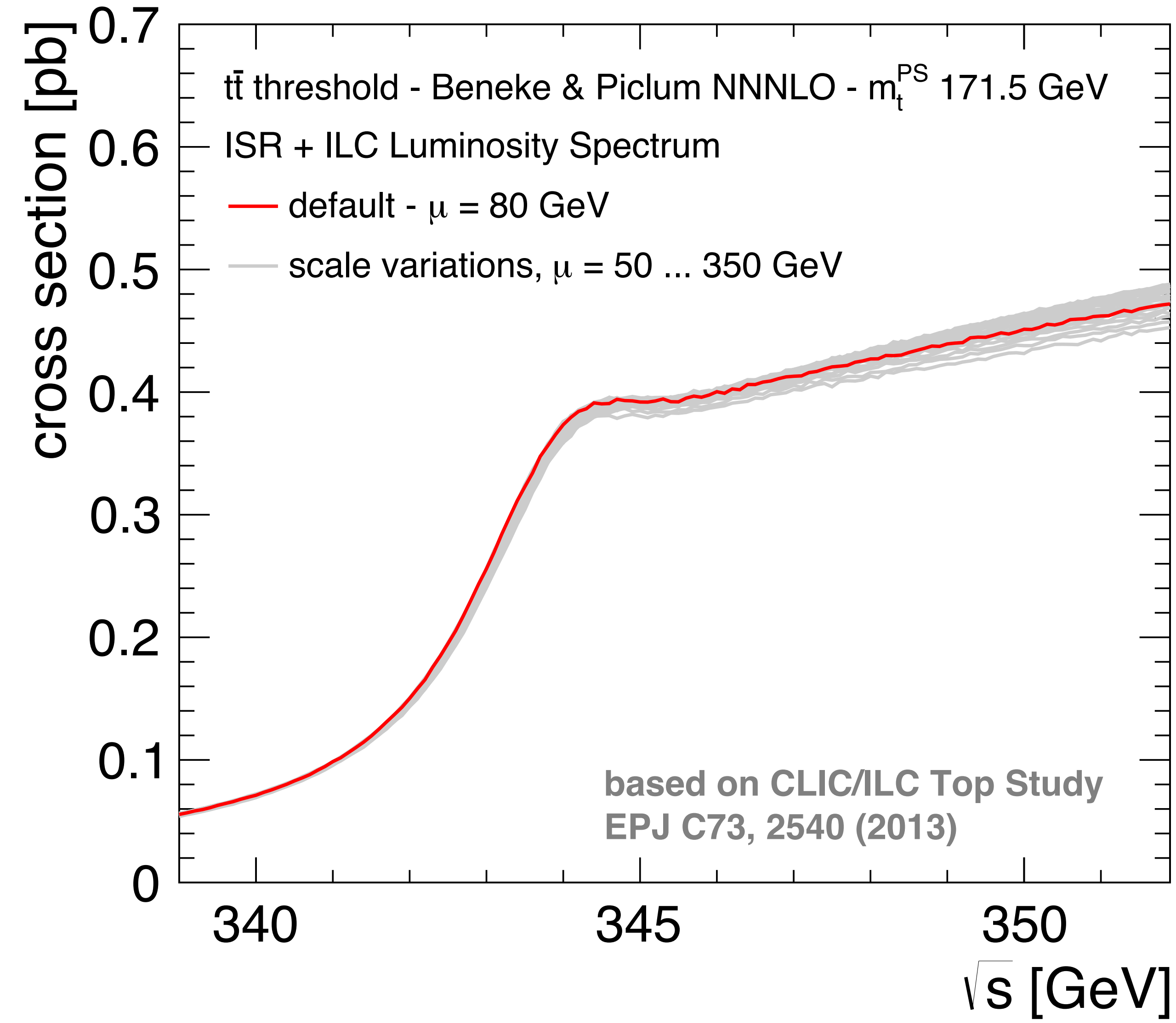

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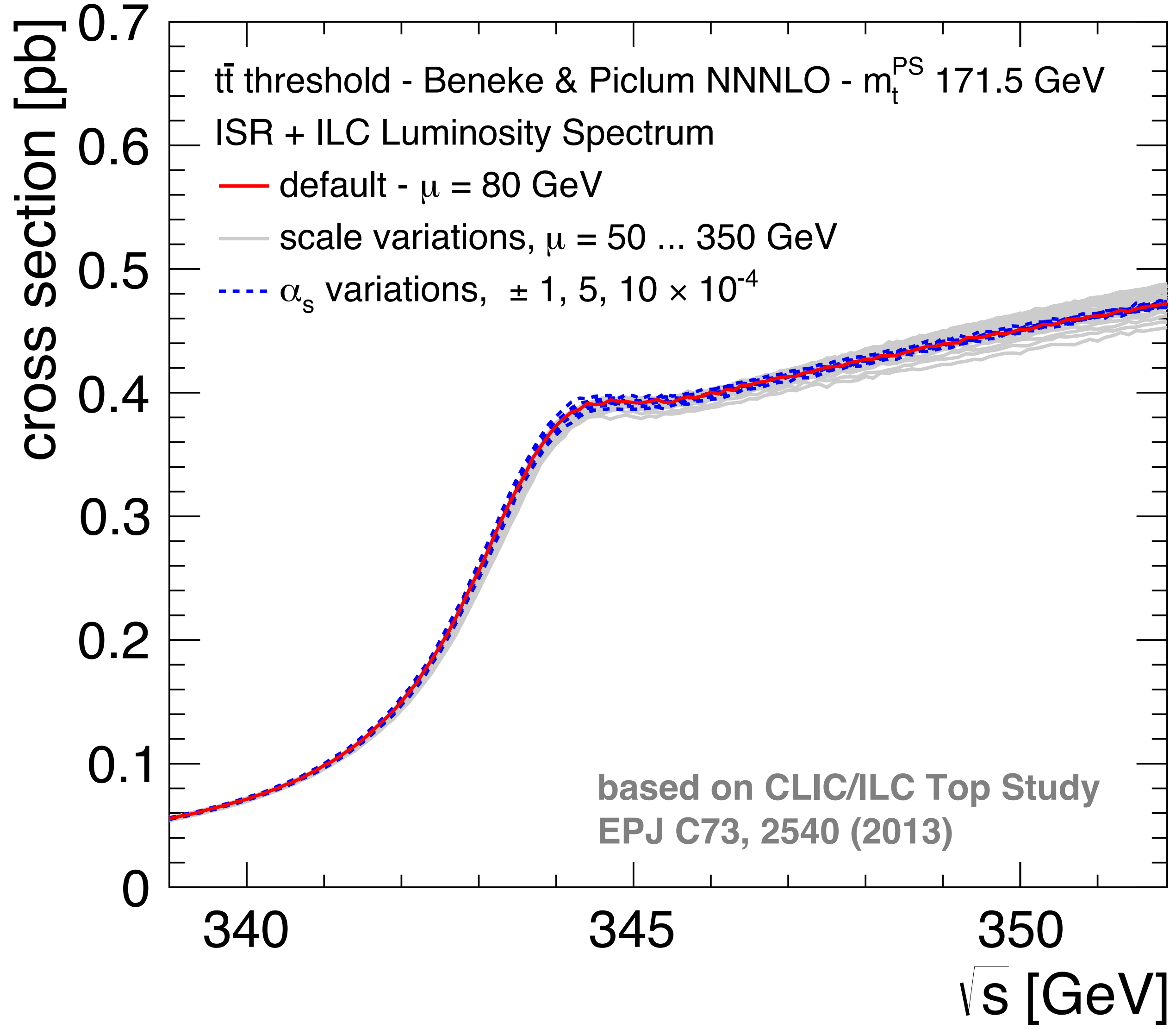

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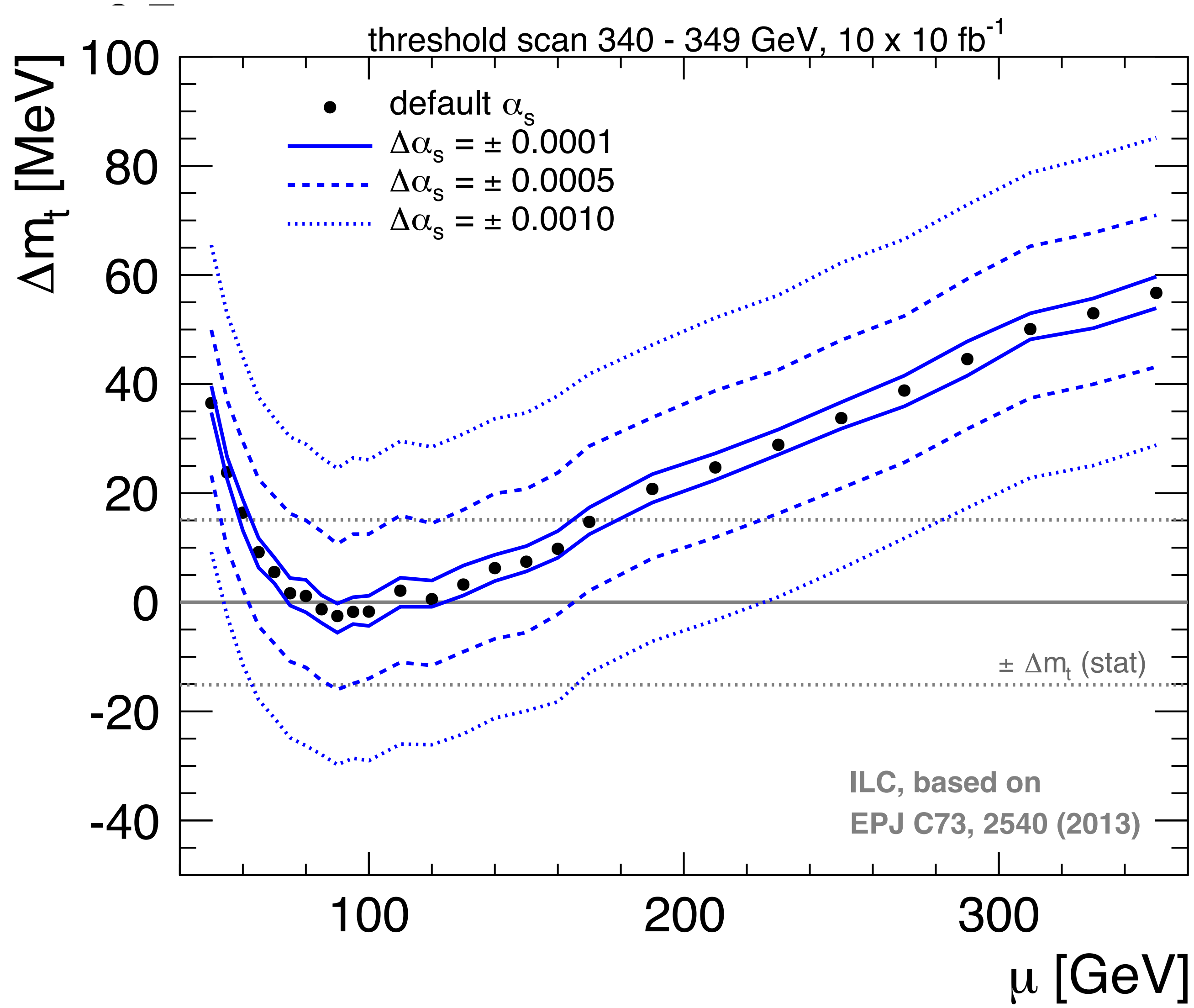

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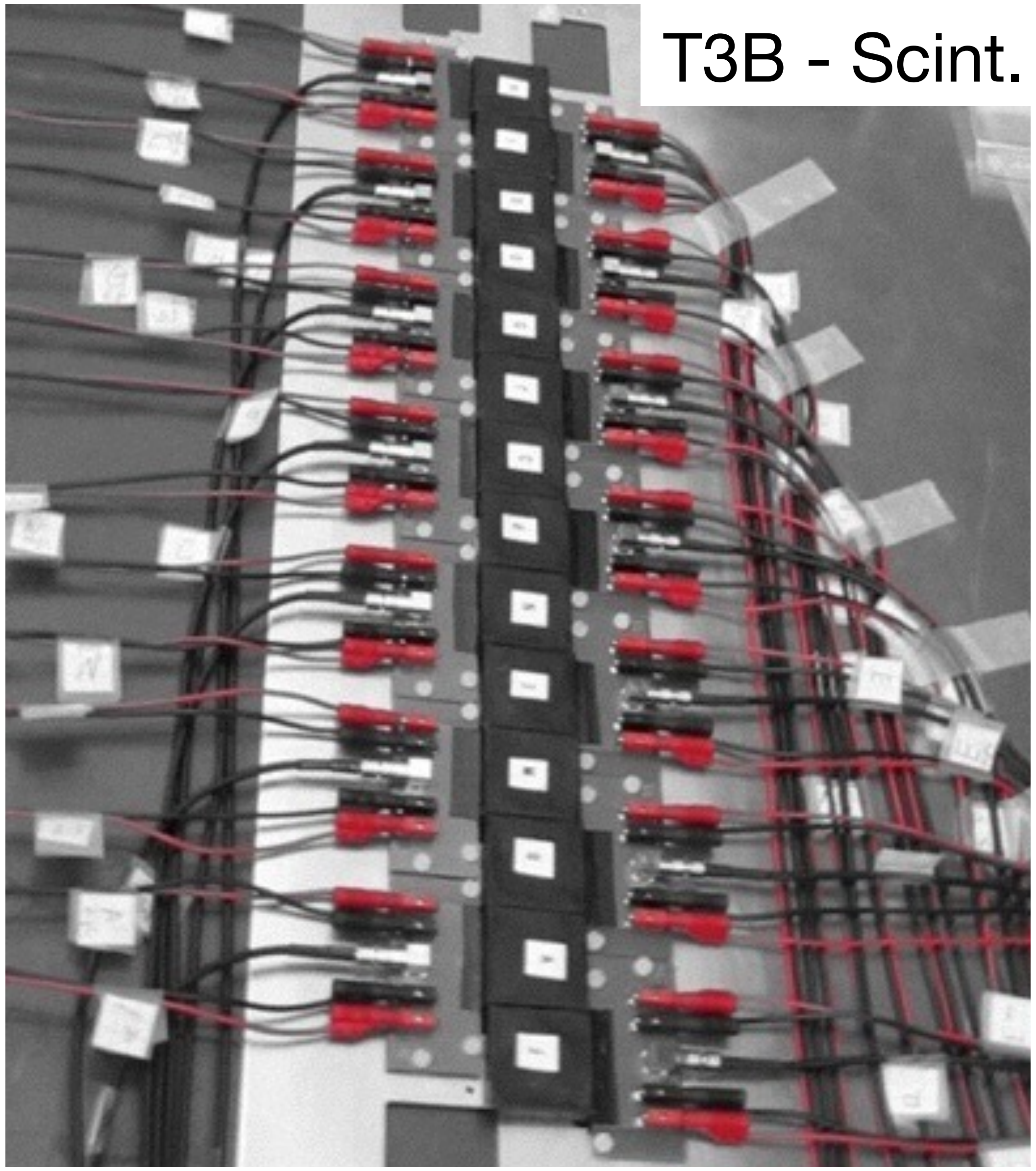
- First indications: Uncertainties up to ~ 50 MeV (+ ~ 20 MeV from α_s assuming current WA) : May well be one of the most important systematics

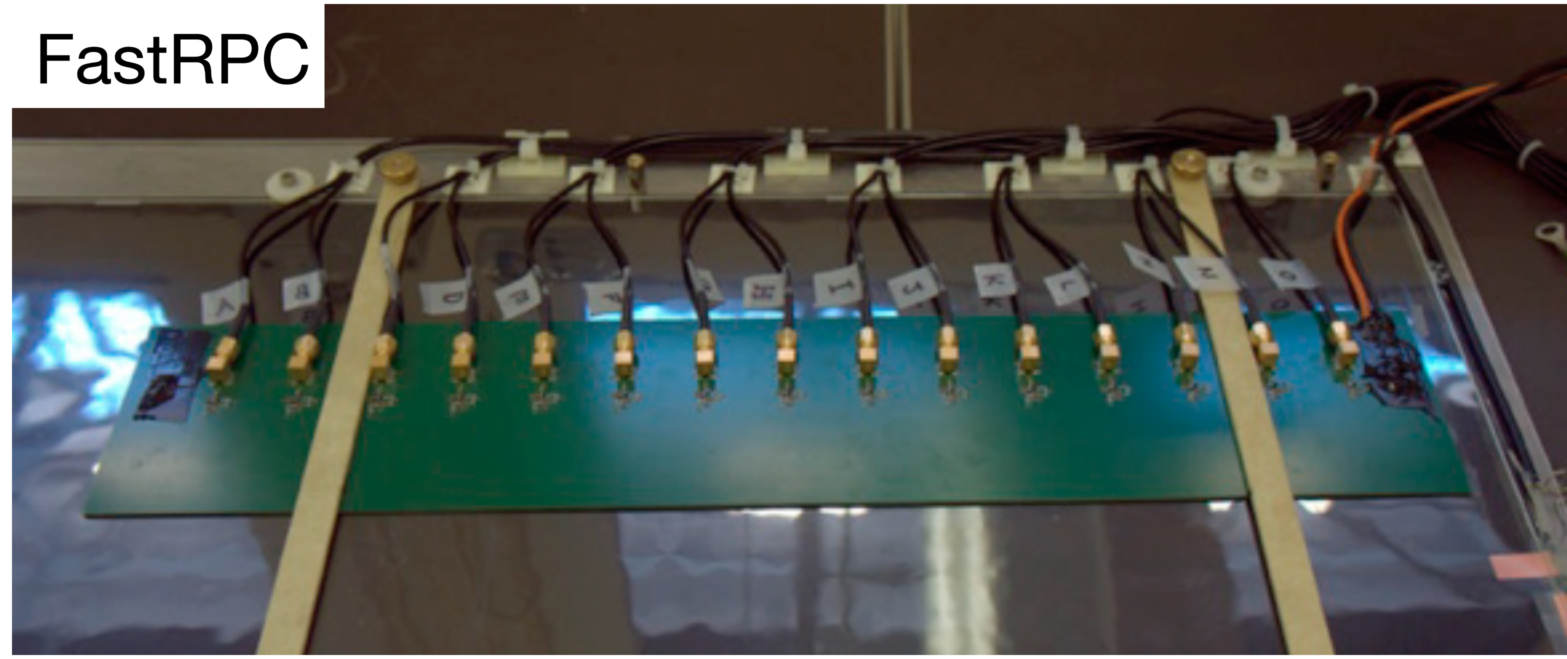
Highly Granular Calorimeters

- Two experiments to measure the time structure with different active medium



T3B - Scint.

FastRPC



JINST 8 P12001 (2013)

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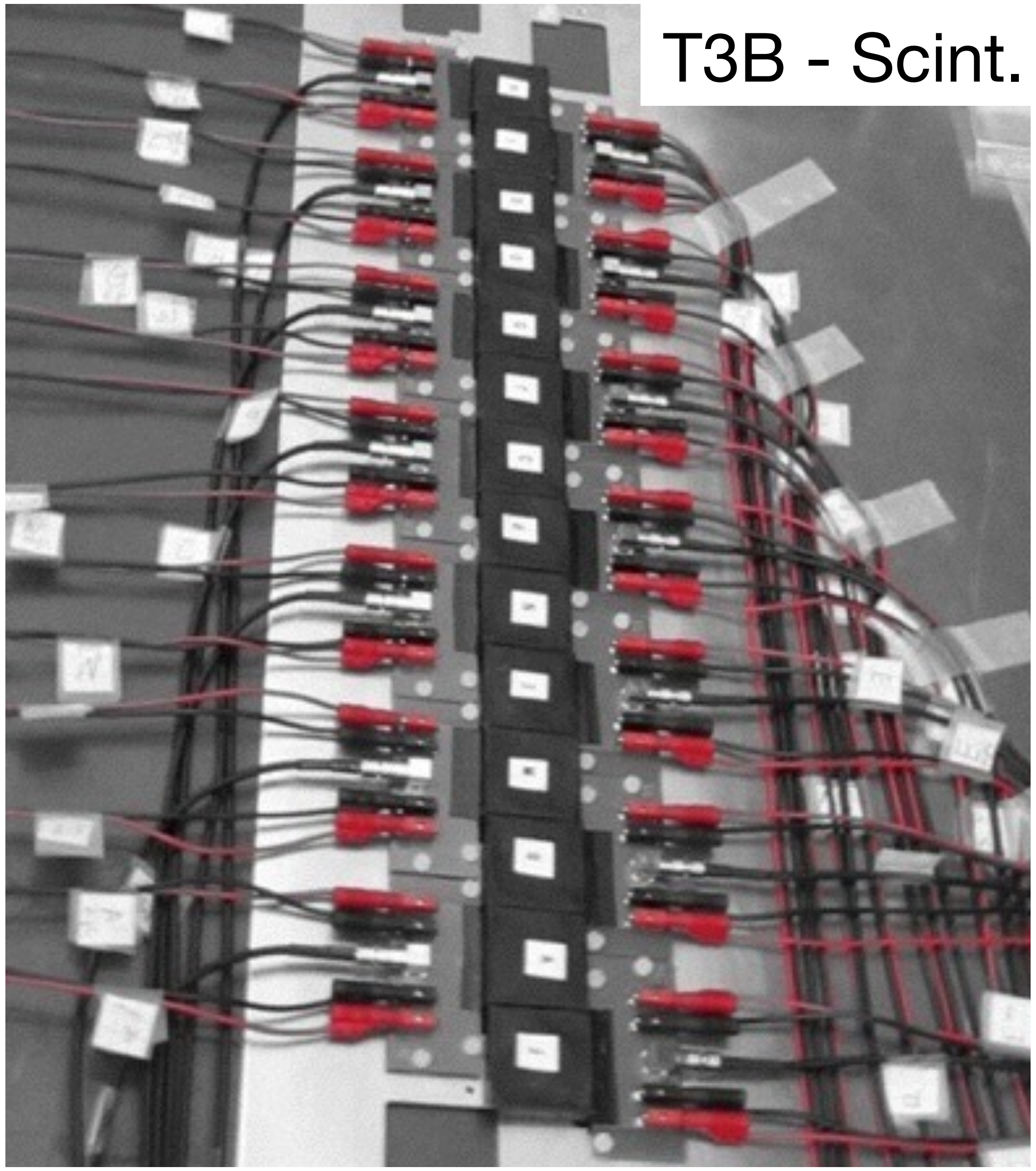

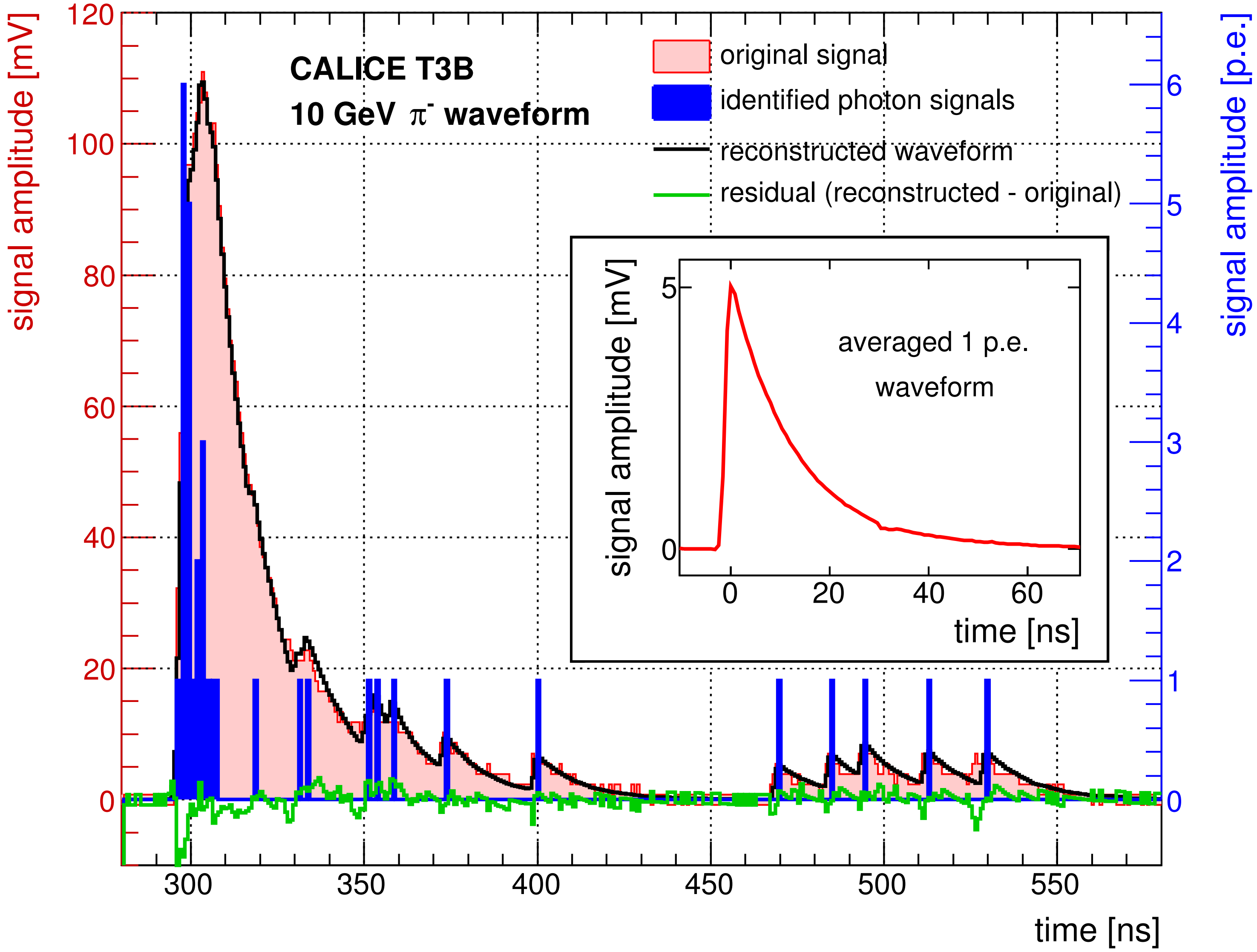

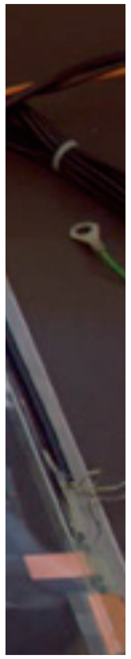

sophisticated event reconstruction:
timing of single photons

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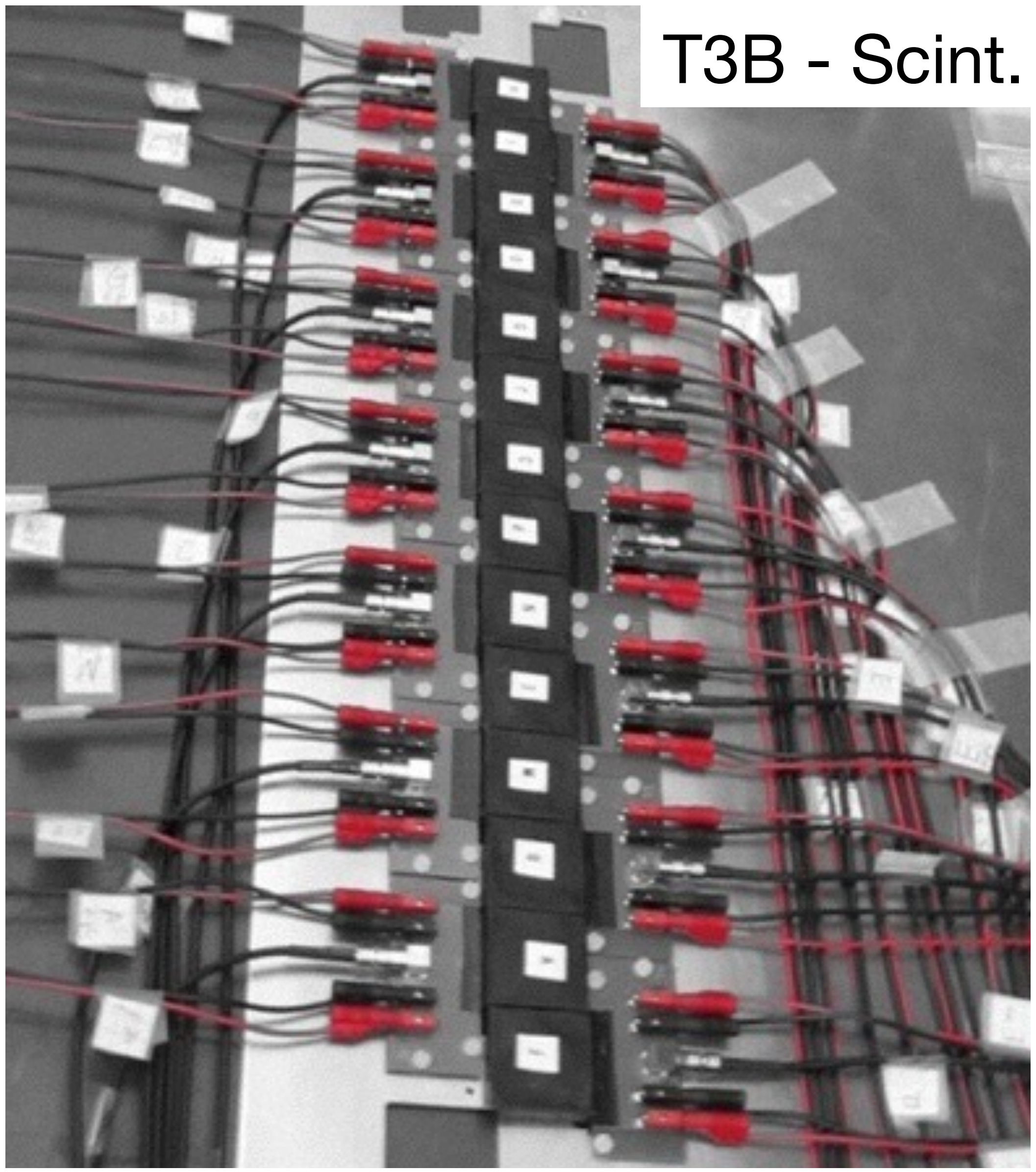

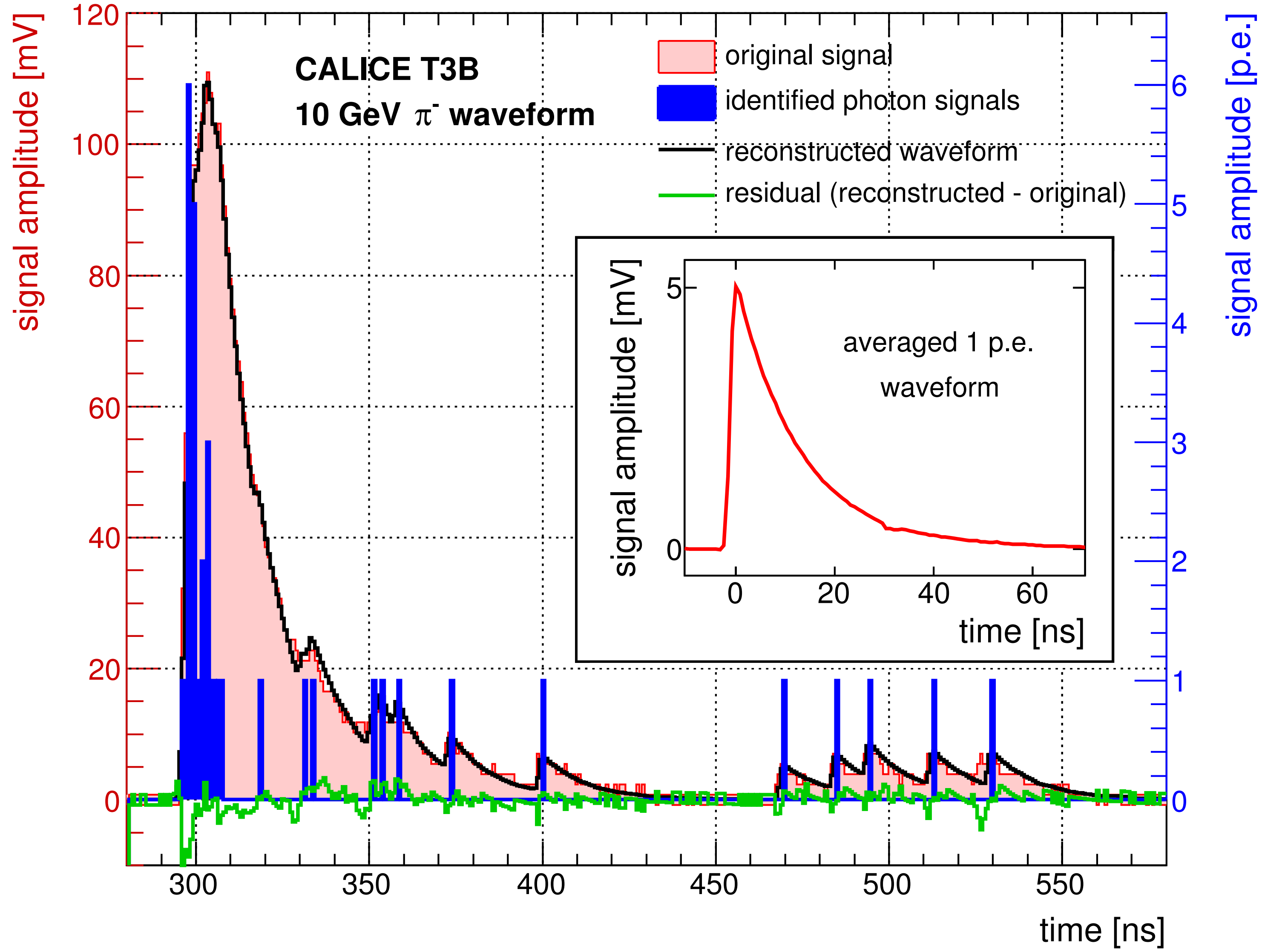

sophisticated event reconstruction:
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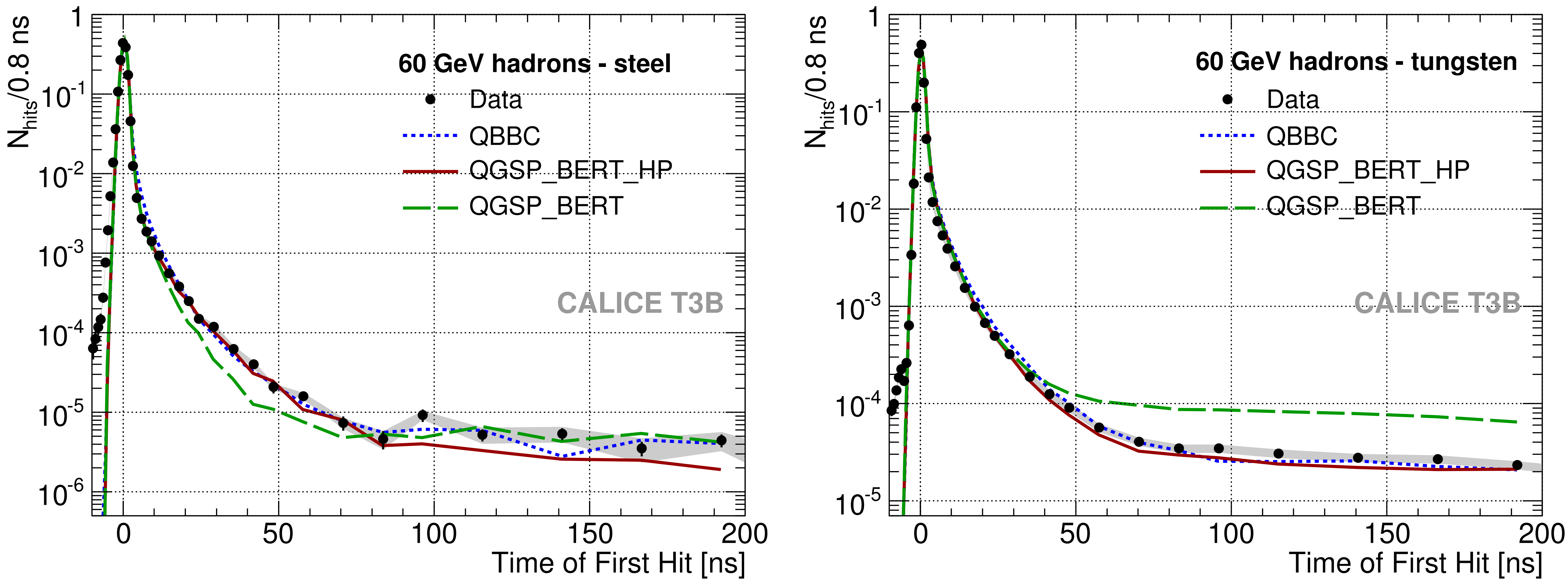
JINST 8 P12001 (2013)

Scintillator technology & readout system currently being evaluated for background measurements during Belle-II commissioning - “BEAST”

The Time Structure of Hadronic Showers

- Comparison of T3B results with simulations - published

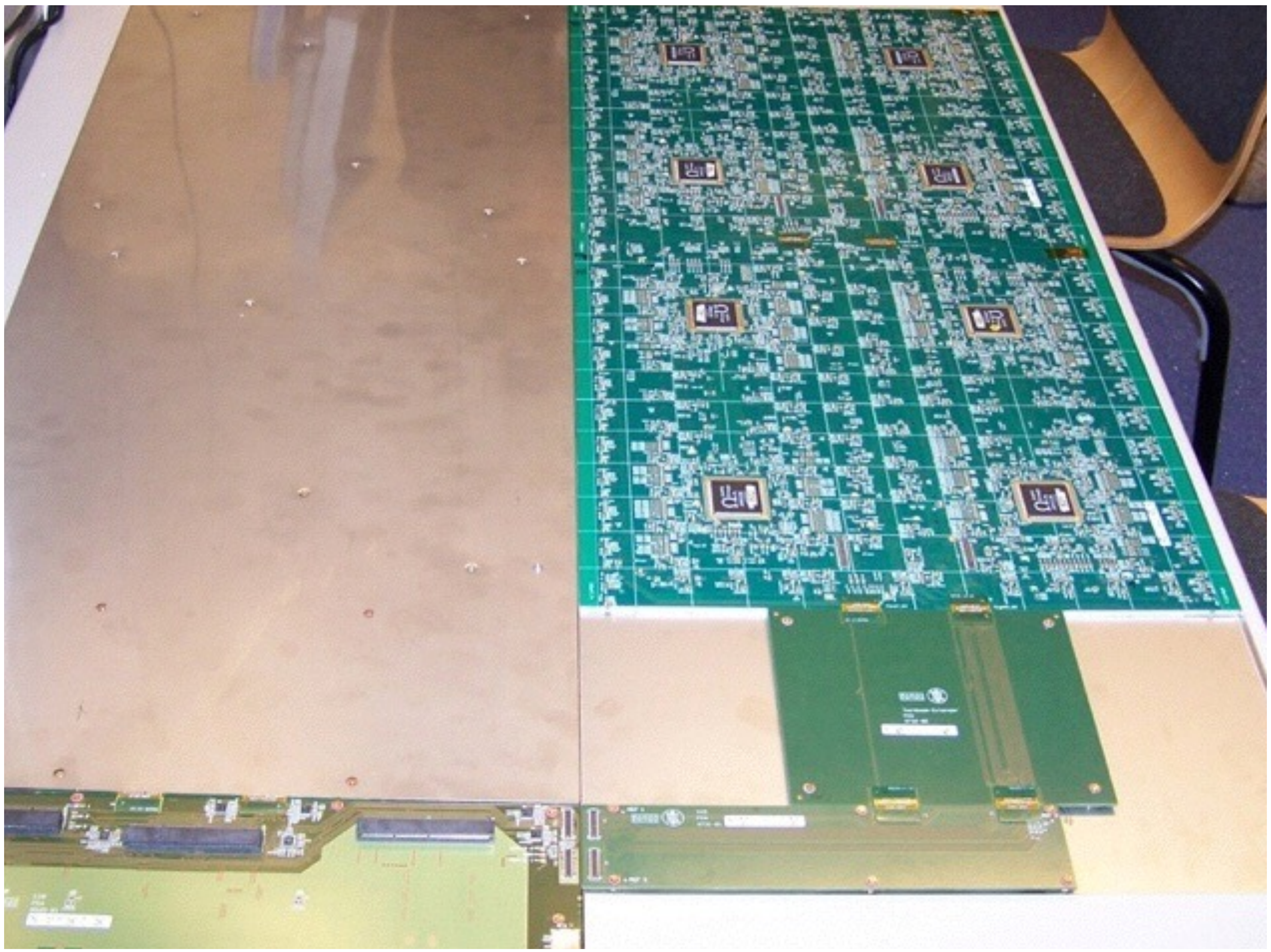


- More late shower activity in Tungsten - Special neutron simulation required for reproduction in GEANT4
  - These results have prompted the GEANT4 developers to change their “standard” physics models - Improved realism from G4.10 on - currently evaluating

JINST 9 P07022 (2014)

2^{nd} AHCAL - Generation in Test Beam

- Precision cassettes for AHCAL active layers produced in the MPP mechanical workshop, electronics installed at DESY



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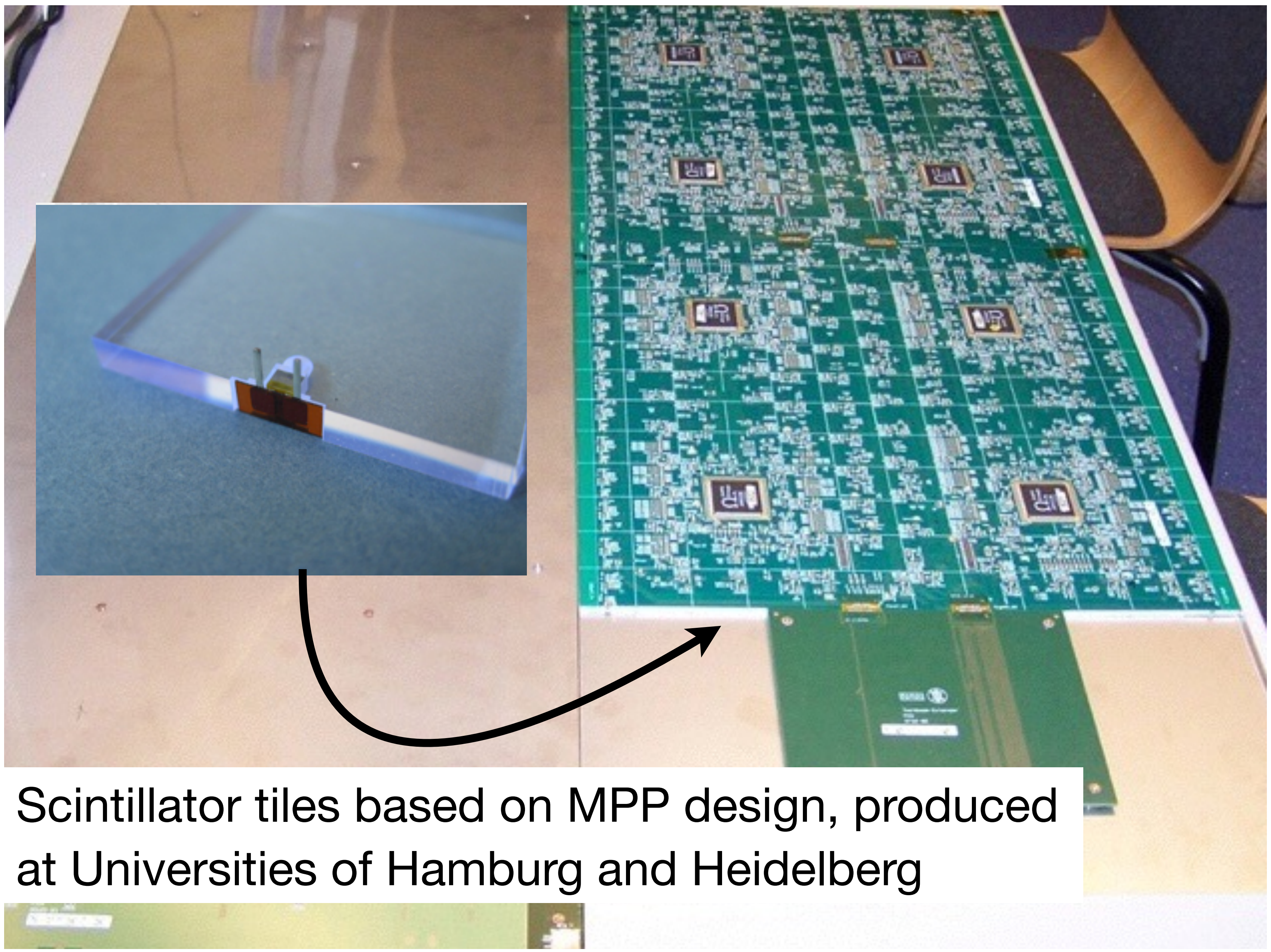

Scintillator tiles based on MPP design, produced at Universities of Hamburg and Heidelberg

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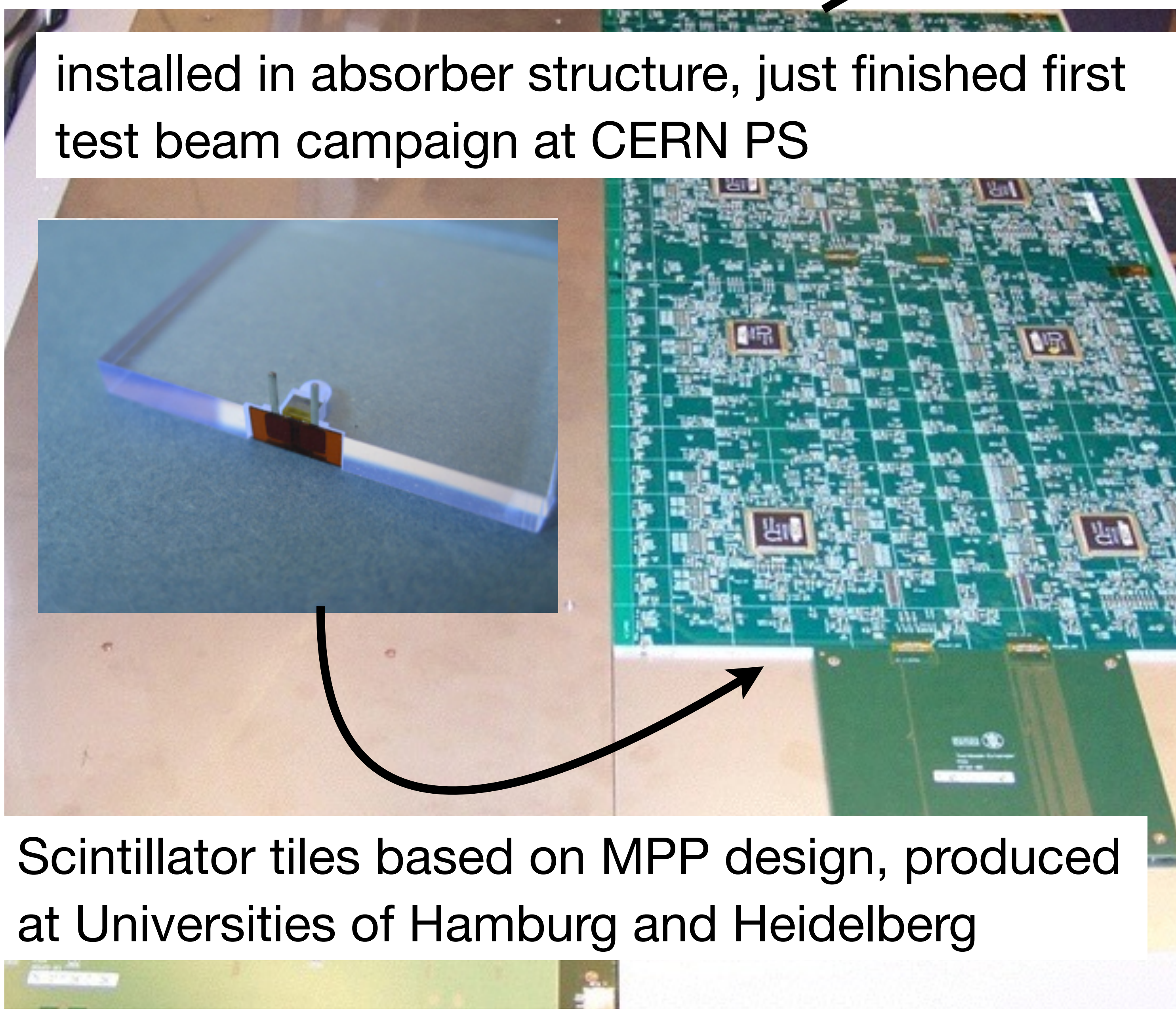

installed in absorber structure, just finished first test beam campaign at CERN PS

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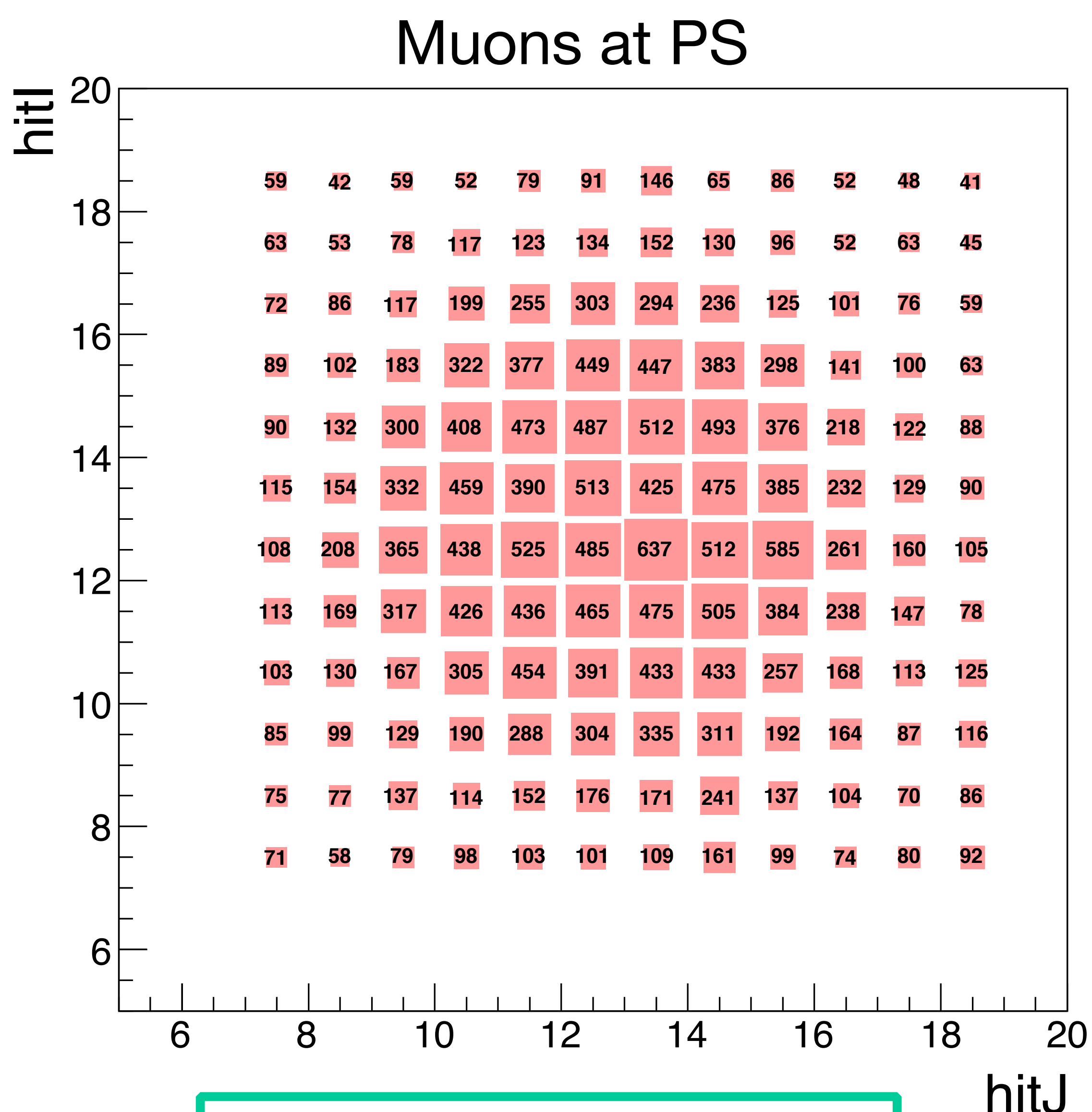
Test Beam - First Impressions

- Successful operation of detector - proof of principle of highly integrated electronics and compact construction - prototype will grow in the coming years



Beam profile visible already for one run

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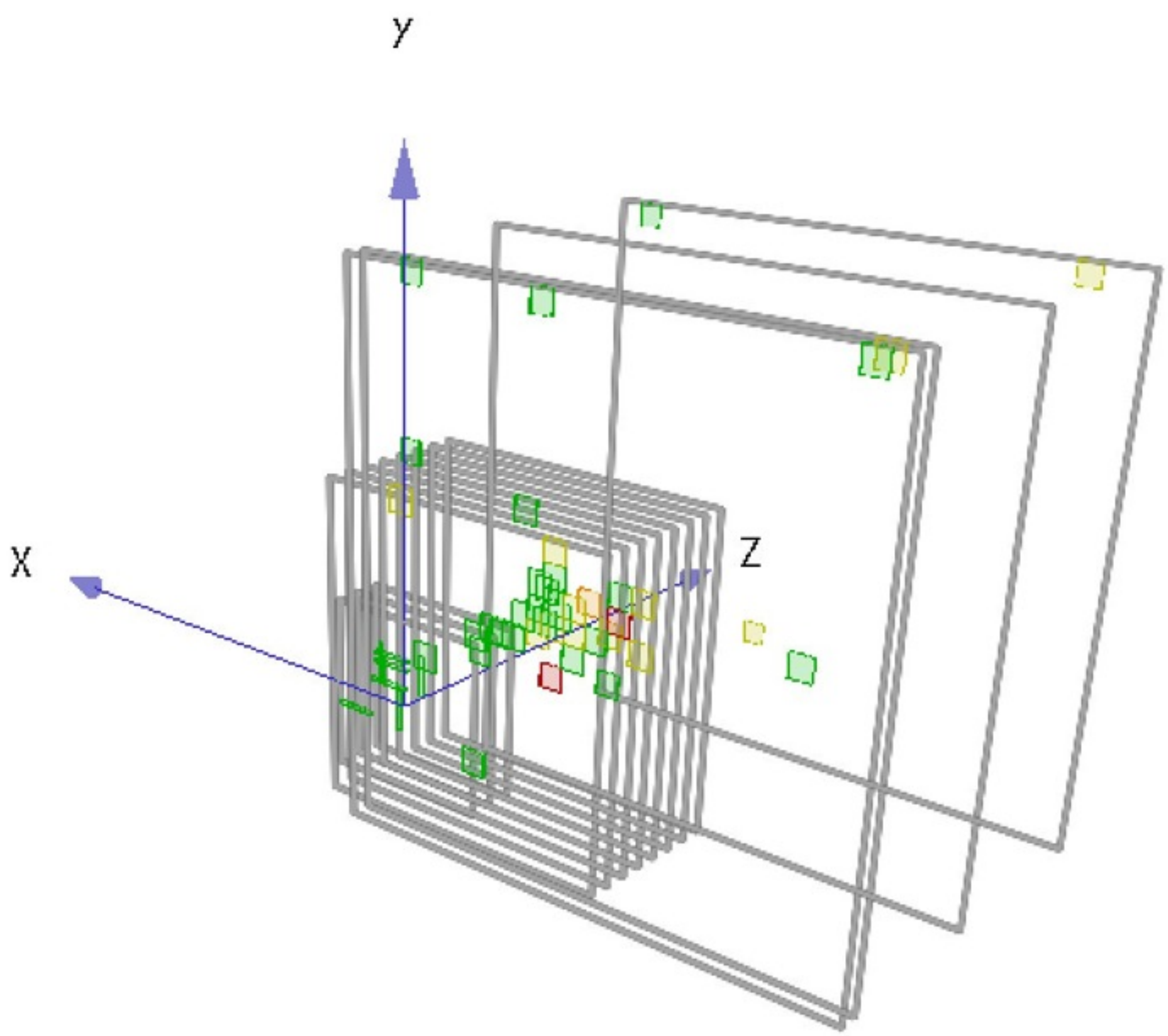
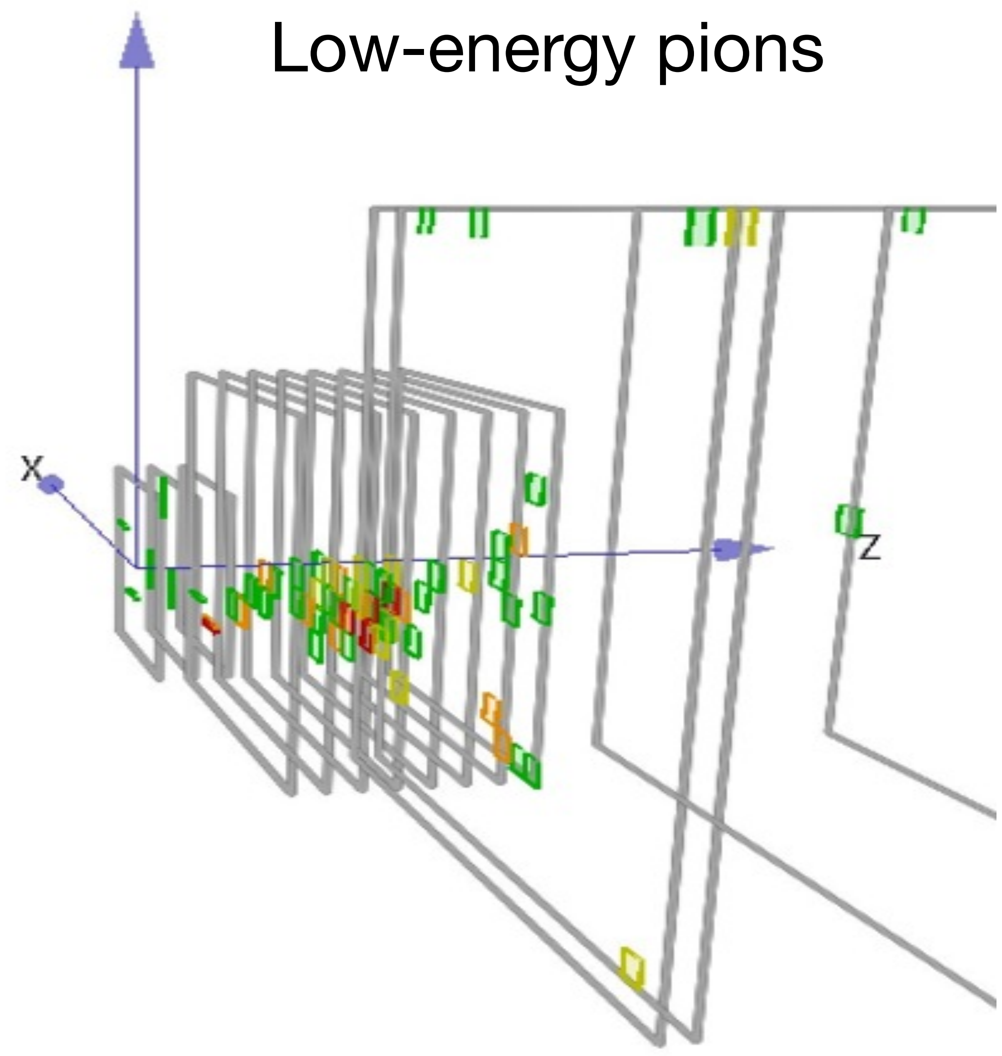


Event 180 - Run 20233

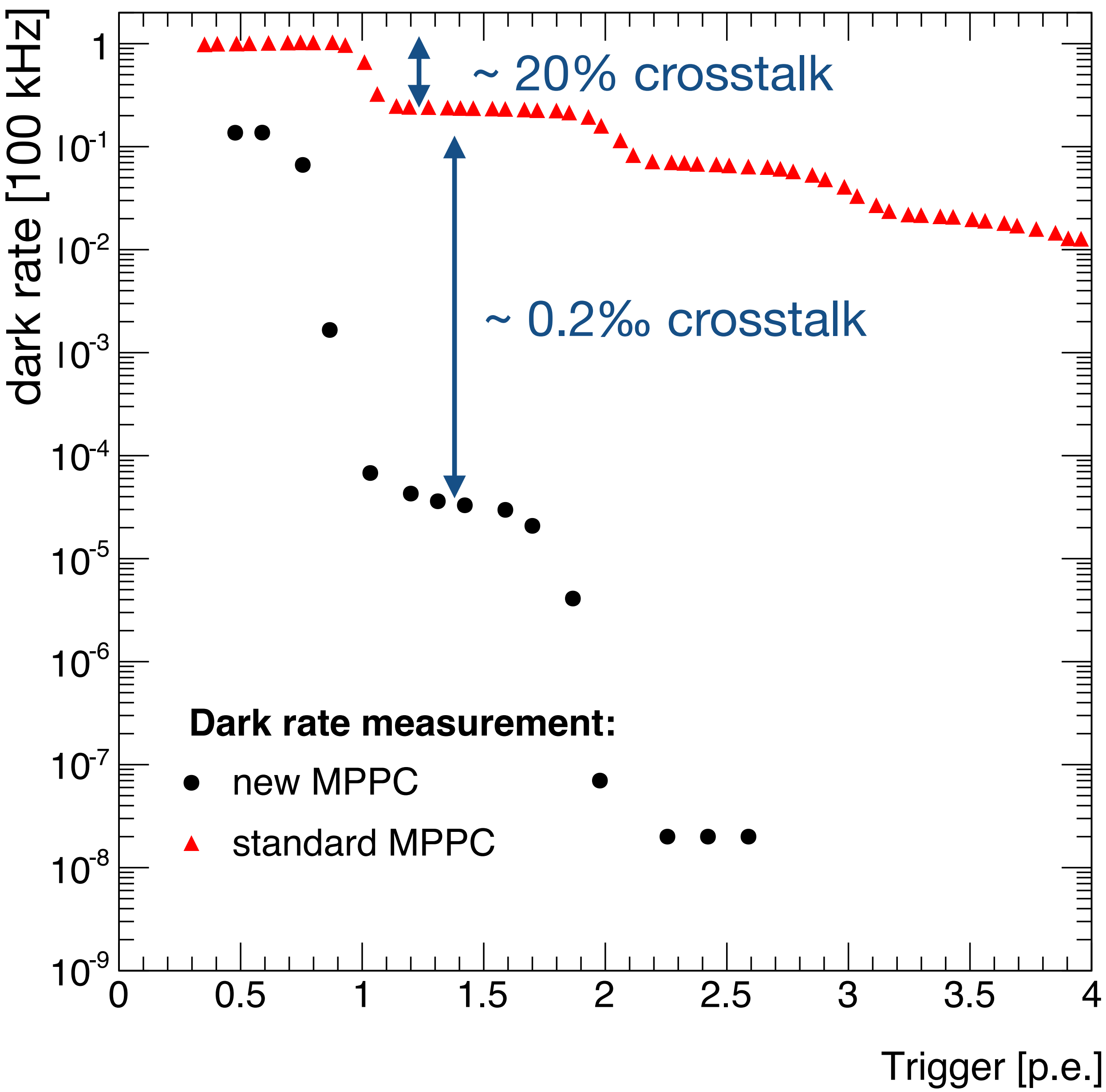
Low-energy pions



Event 1075 - Run 20233

Further Developing AHCAL Technology

- A key feature of the new electronics: cell-by-cell auto trigger
  - Enables trigger-less operation of full ILC detector
  - Puts strong constraints on noise level - in particular for test beams in “DC mode”



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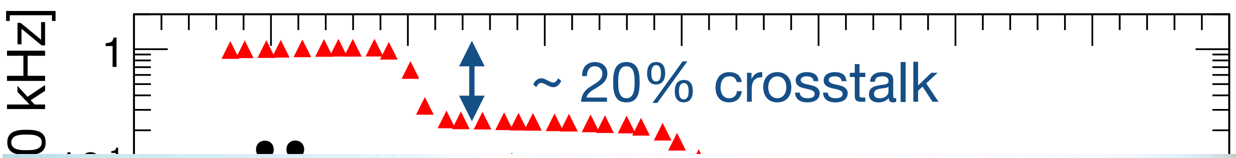

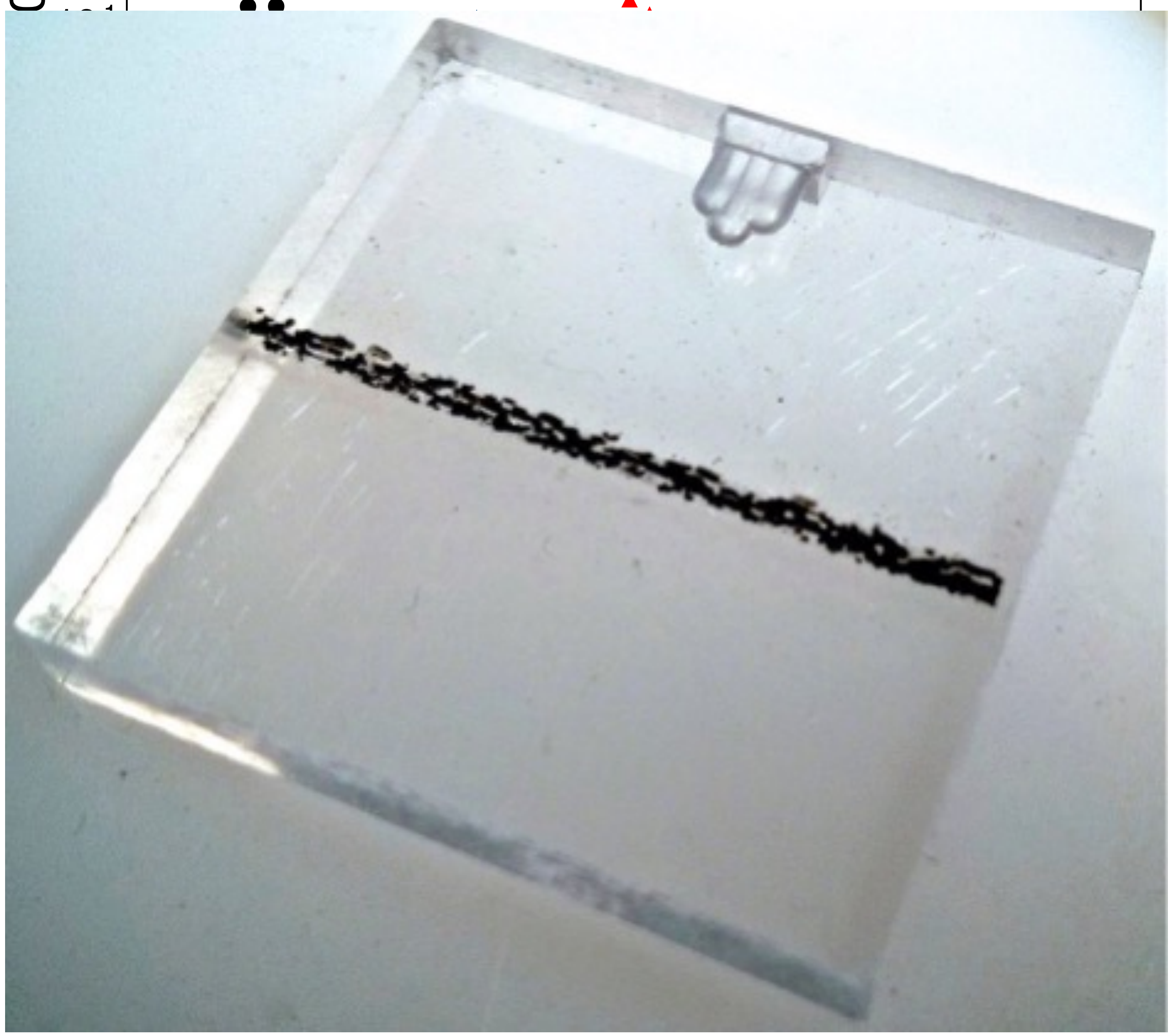

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- Trying out new ideas: optical separation of cells in plastic scintillator plates via laser engraving
  - Would enable fast production of “mega-tiles” to be combined with surface-mounted photon sensors

The "Politics"

- The strategy processes in various regions have been completed: Japan in 2012, European Strategy of Particle Physics 2013, US Snowmass / P5 2014
  - Consensus to fully exploit LHC, recognition of the potential of ILC as a medium-term future energy frontier facility, and recommendation to support long-term R&D for very high energies (for both e^+e^- and pp)

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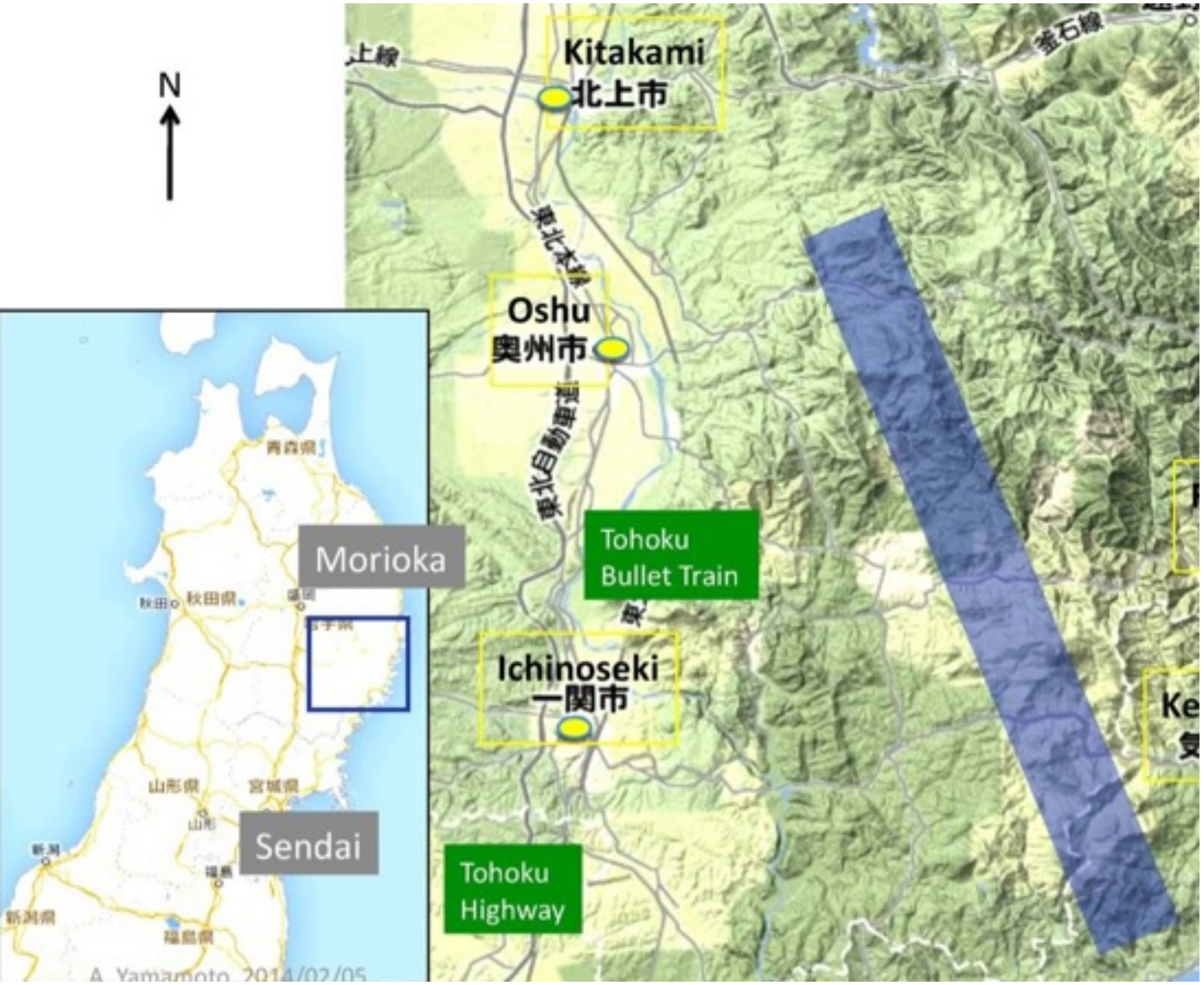
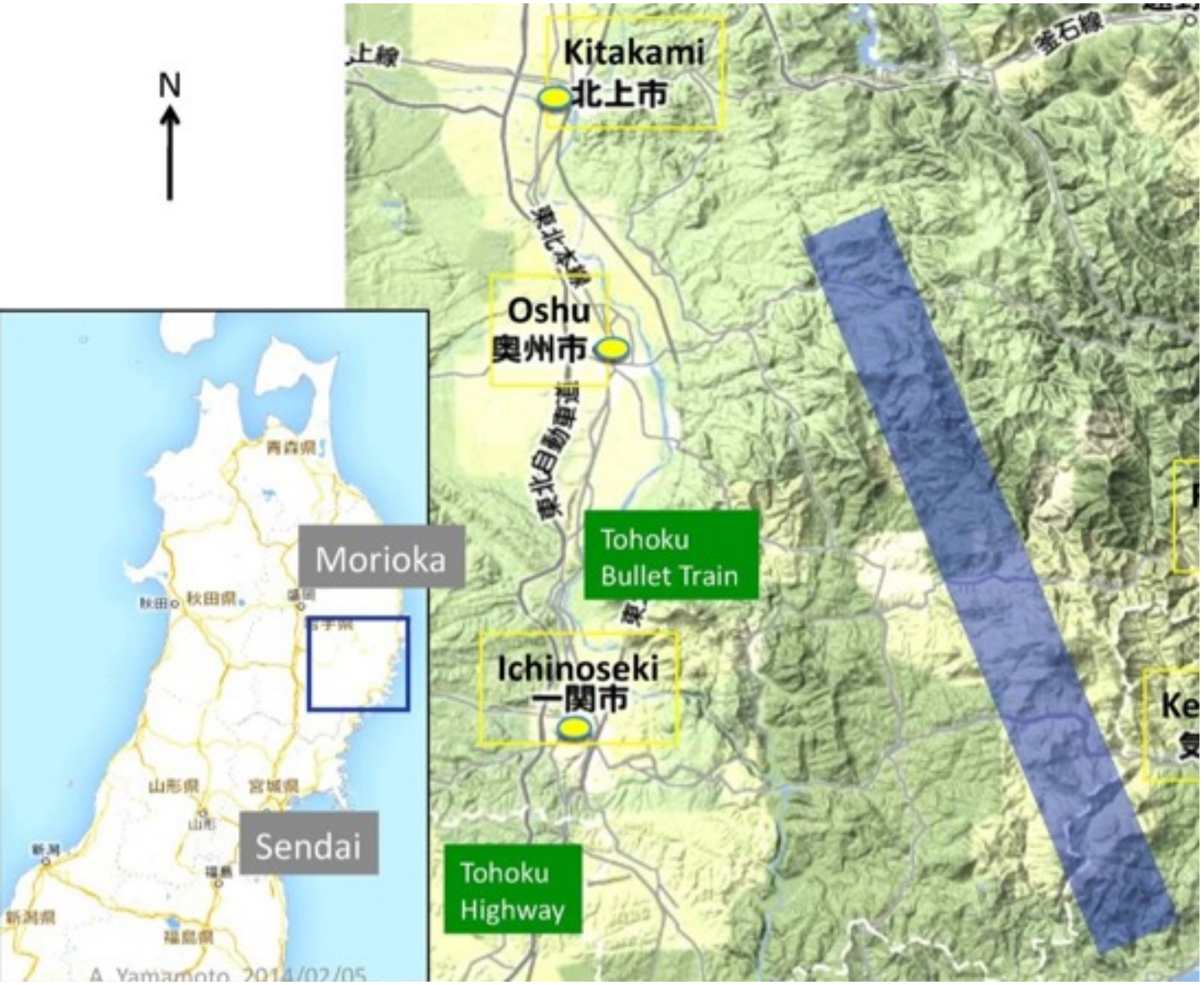
- (I)LC physics & detector activities getting more structured - with MPP participation
  - ILD detector collaboration re-organisation - Institute Assembly now exists
  - LCC Physics WG, Infrastructure WG to work together with MEXT process
  - ILC conference coordination
  - … in addition already ongoing coordination activities in CALICE and CLICdp

The ILC Site - 北上市



The ILC Site - 北上市



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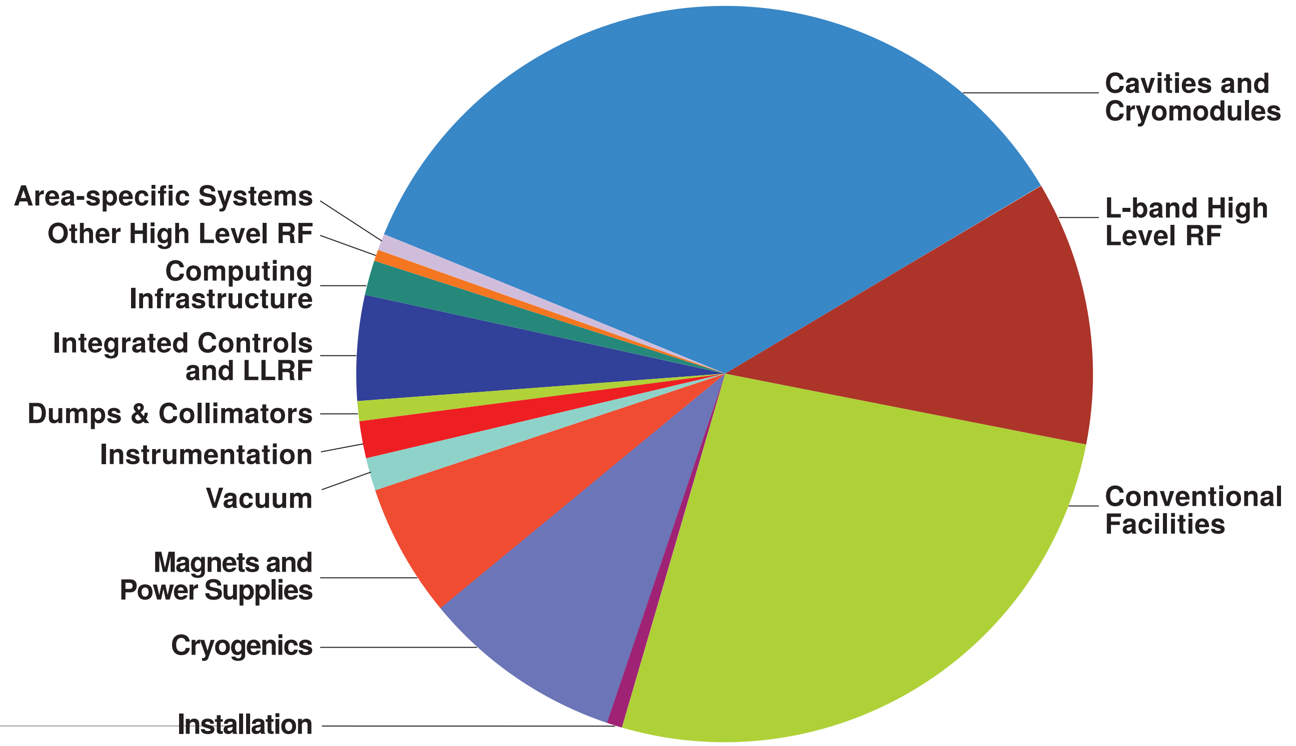
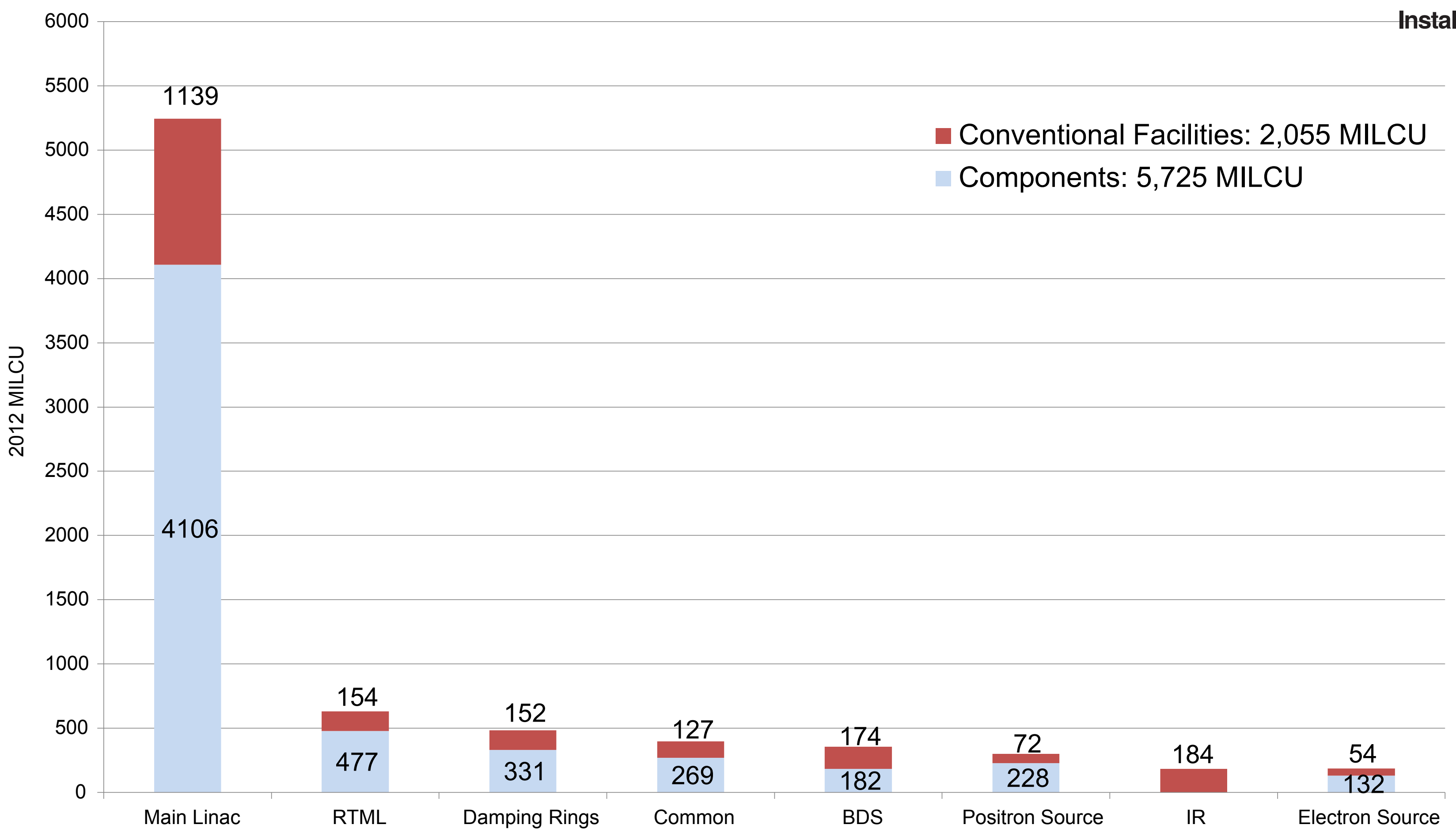
Backup

ILC Cost

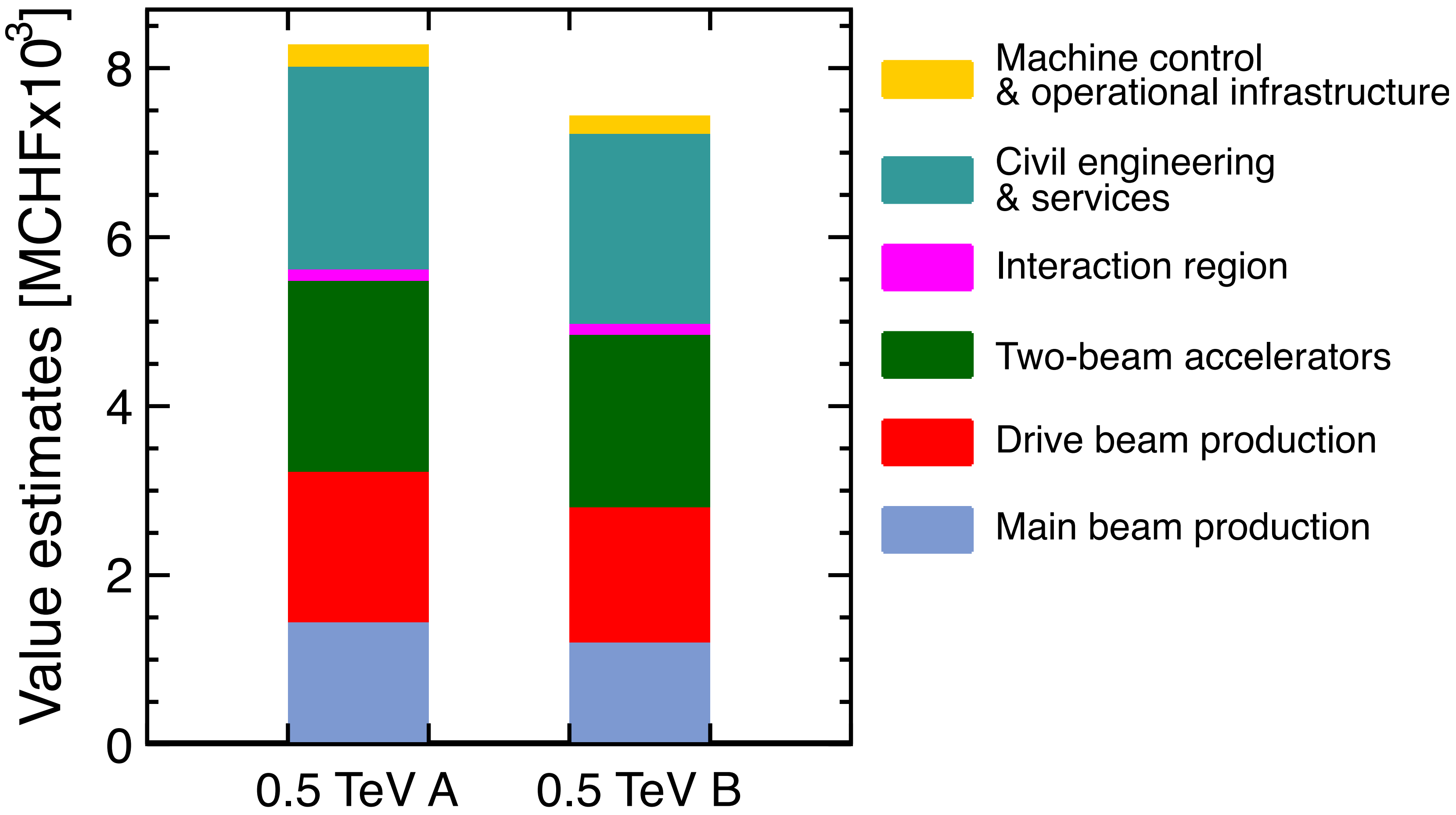
- Not surprising: An energy frontier collider is expensive
  - Rather solid cost estimate for the 500 GeV machine: ~ 8 Billion USD
  - Biggest component: Main linac, acceleration structures



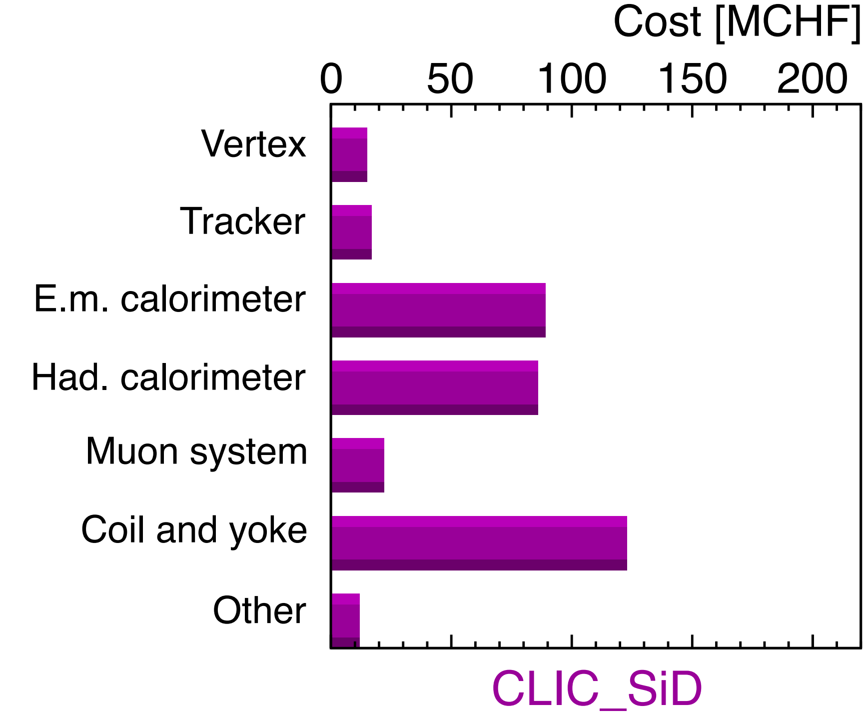


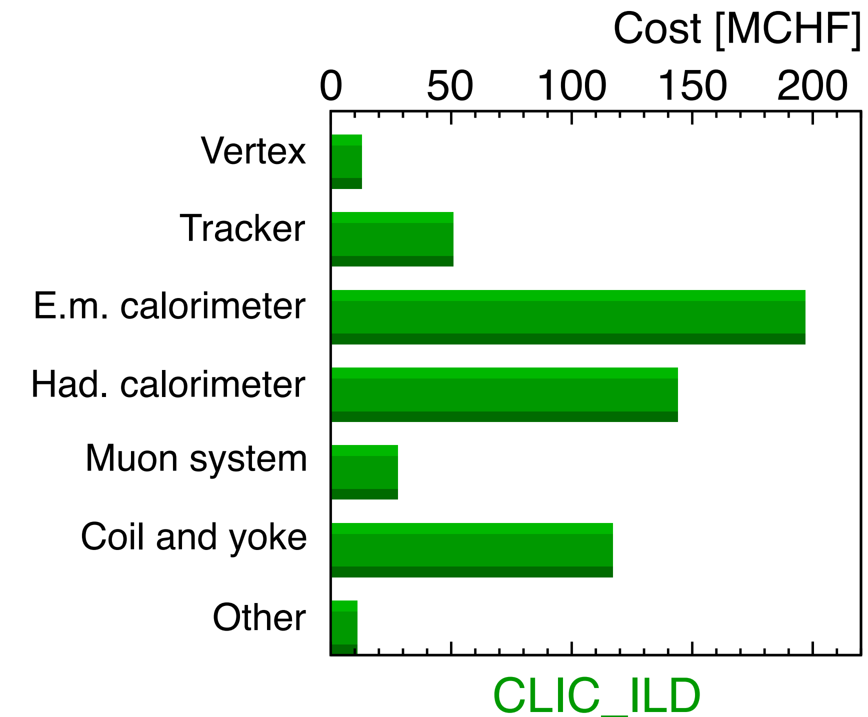
- The construction cost will be spread over ~ 10 years, and shared across the globe - details to be worked out!
- Many contributions expected "in kind": production of components "at home", installation in ILC

CLIC Cost



Detectors





- For second stage: ~ 4 MCHF / GeV (scen. B)
- Going beyond 1.5 TeV requires a second drive beam complex: cost discontinuity

CLIC Schedule

2012-16 Development Phase

Develop a Project Plan for a staged implementation in agreement with LHC findings; further technical developments with industry, performance studies for accelerator parts and systems, as well as for detectors.

2017-22 Preparation Phase

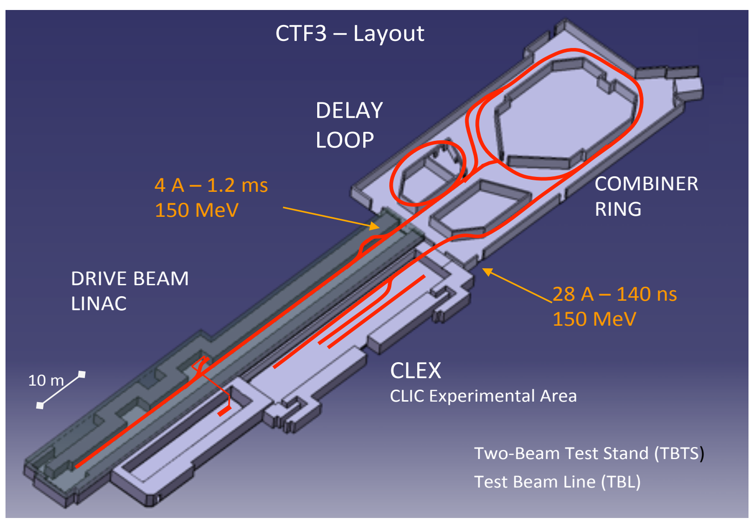
Finalise implementation parameters, Drive Beam Facility and other system verifications, site authorisation and preparation for industrial procurement.

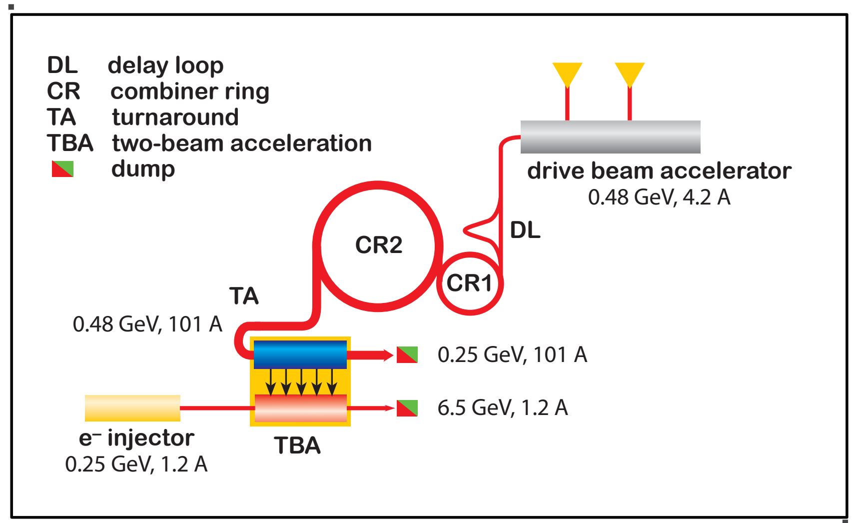
Prepare detailed Technical Proposals for the detector-systems.

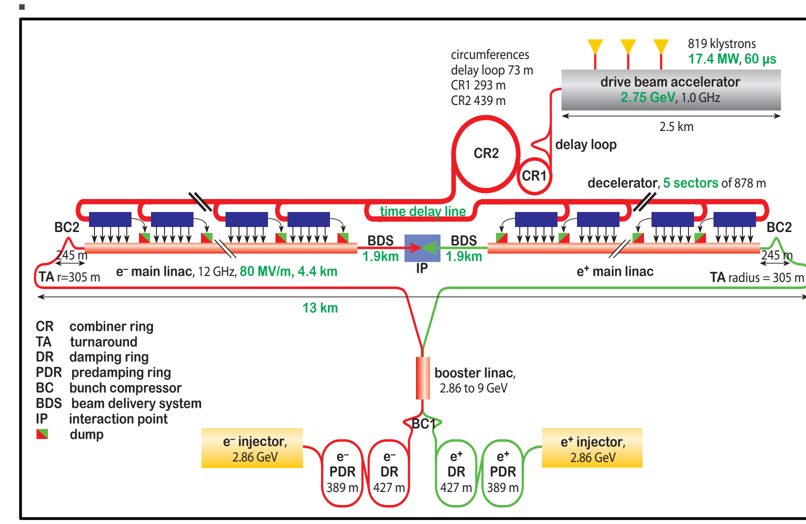
2023-2030 Construction Phase

Stage 1 construction of a 500 GeV CLIC, in parallel with detector construction.

Preparation for implementation of further stages.







2016-17 Decisions

On the basis of LHC data and Project Plans (for CLIC and other potential projects), take decisions about next project(s) at the Energy Frontier.

2022-23 Construction Start

Ready for full construction and main tunnel excavation.

2030 Commissioning

From 2030, becoming ready for data-taking as the LHC programme reaches completion.

ILC - Current Schedule