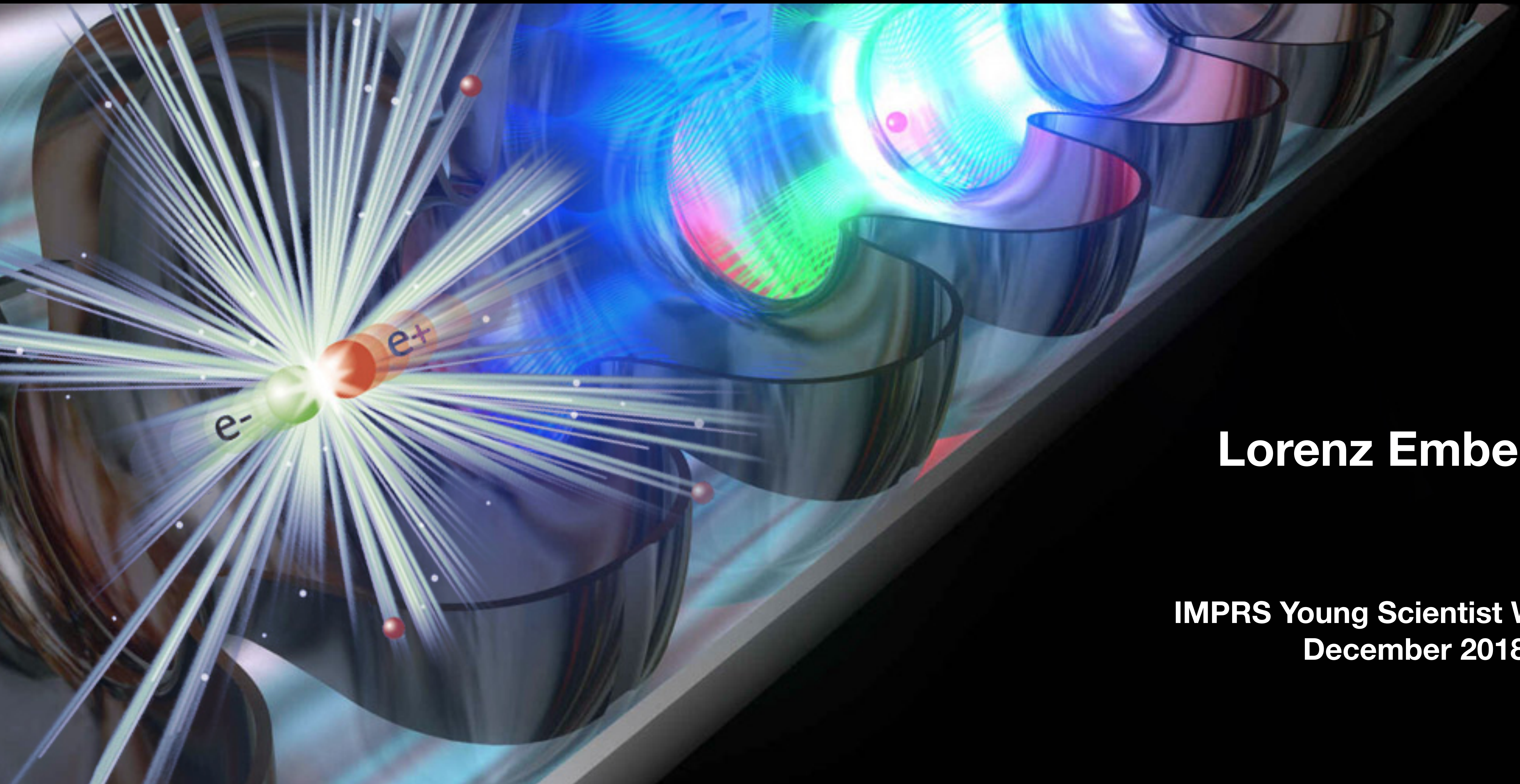
Future Linear Colliders
Physics - Machines - Detectors



Lorenz Emberger

IMPRS Young Scientist Workshop
December 2018

Status of High Energy Collider Physics

Discovery of the Higgs boson in 2012 $\Longrightarrow$ observed all SM predicted particles

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HE-LHC

FCC hh ee he

<u>Go to higher energies:</u>

- Direct production of new particles

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HE-LHC

<u>Go to higher energies:</u>

- Direct production of new particles

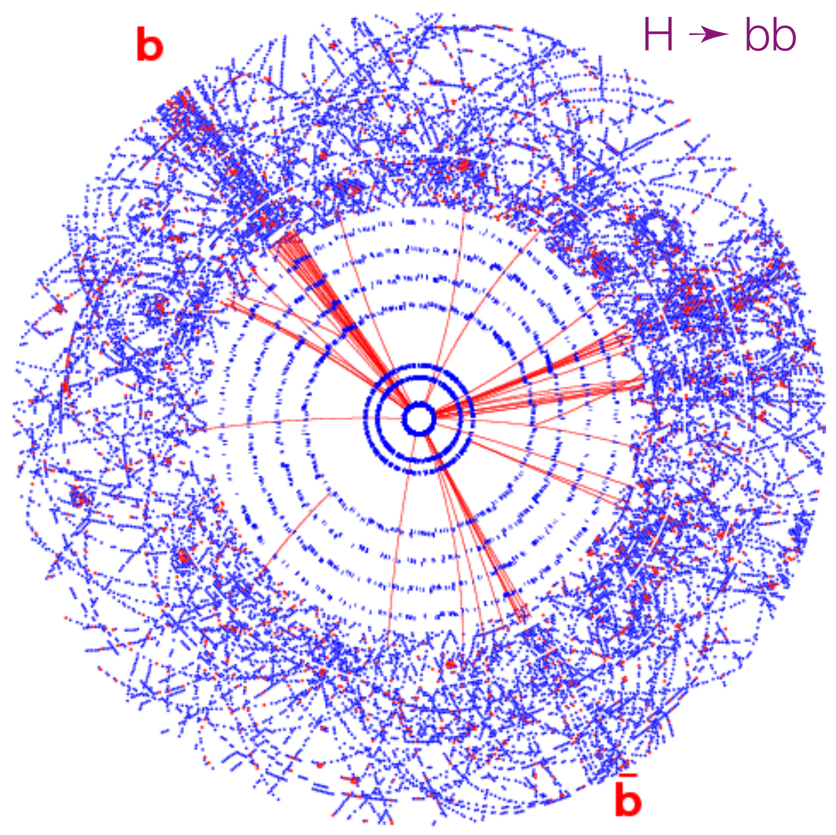
<u>Go to higher precision:</u>

- Detect deviations from the currently established models
- Rare processes

Why Linear e^+e^- Colliders ?

Requirements for highest precision:

- Clean events, low BG $\Longrightarrow$ QCD background in hadron colliders
- Defined initial state $\Longrightarrow$ compound particles in hadron colliders



pp ➝ H + X

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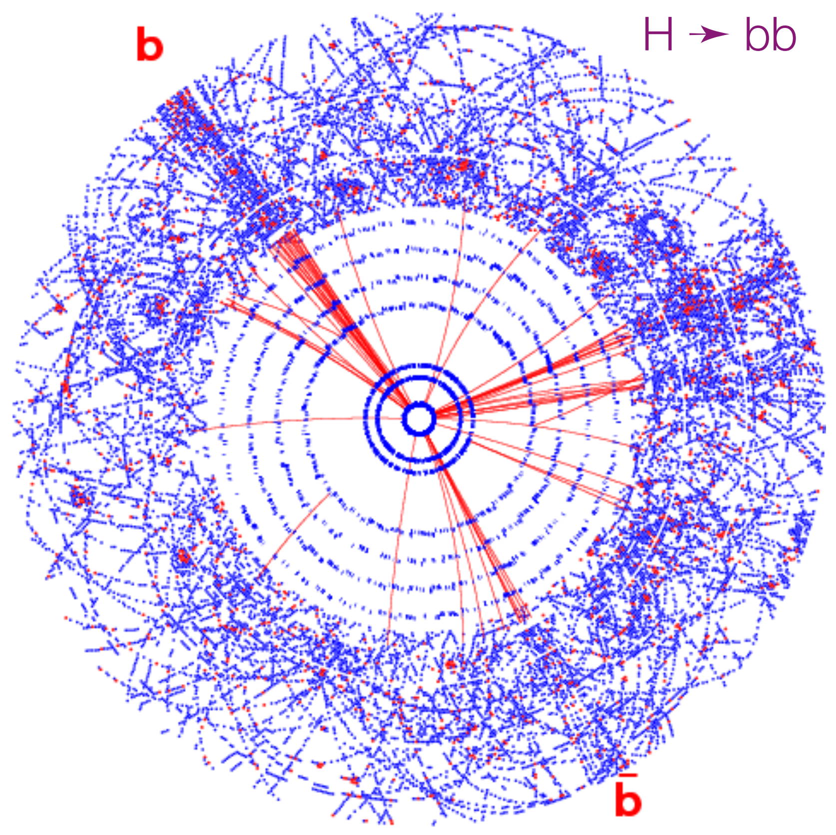

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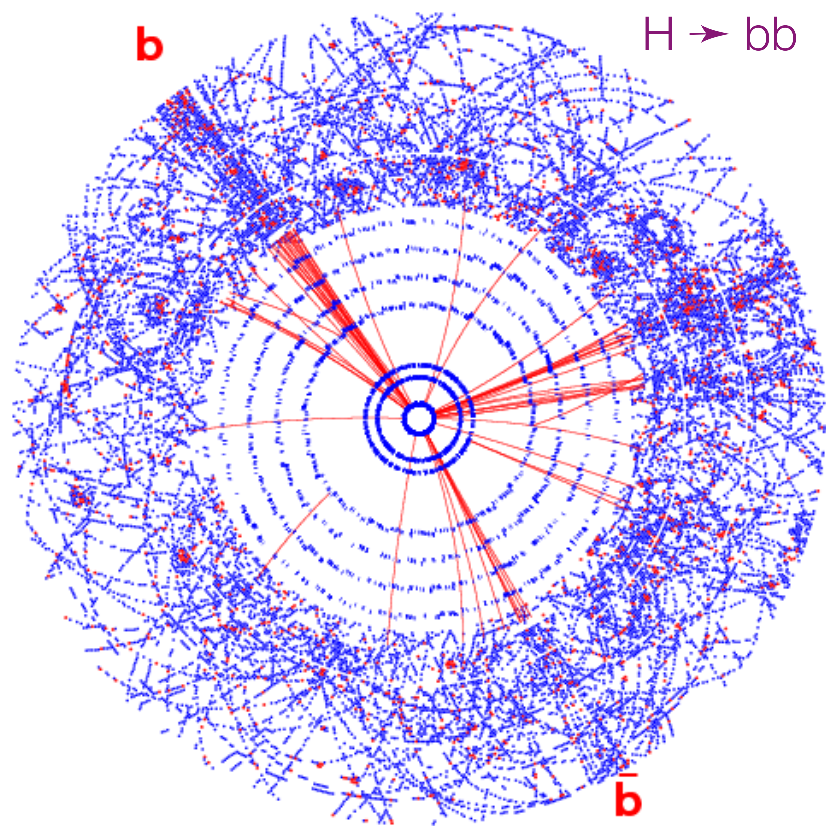

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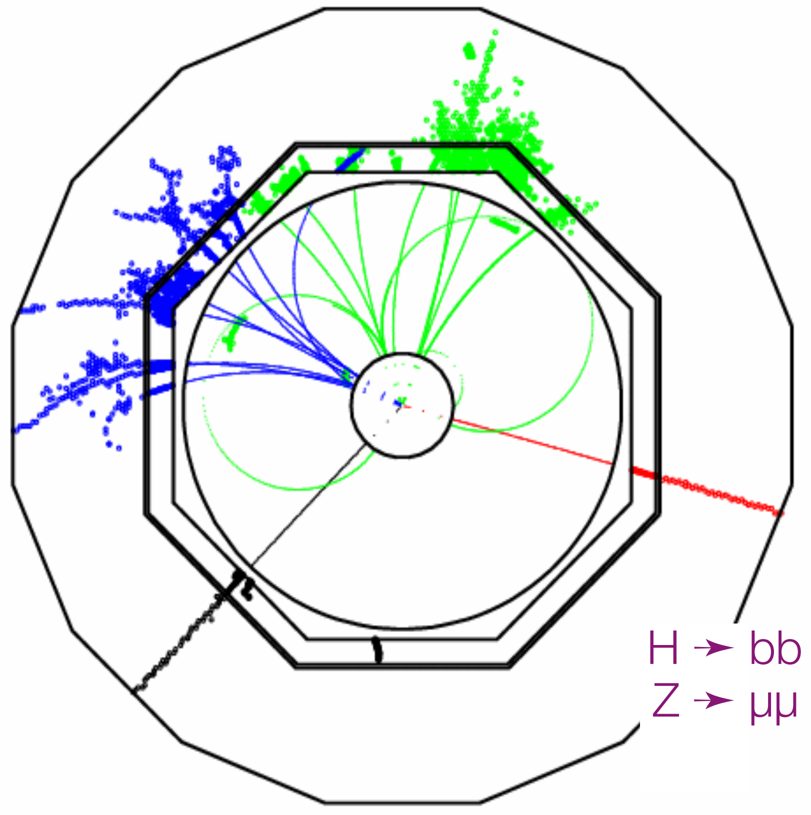
<u>Solution</u>: Use electrons

- Problematic in a circular collider $\Longrightarrow$ Synchrotron rad. increases with E^4/m^4
- Use linear collider:

No synchrotron radiation, power consumption scales linearly with E

Polarization of e^+ and e^- for background suppression

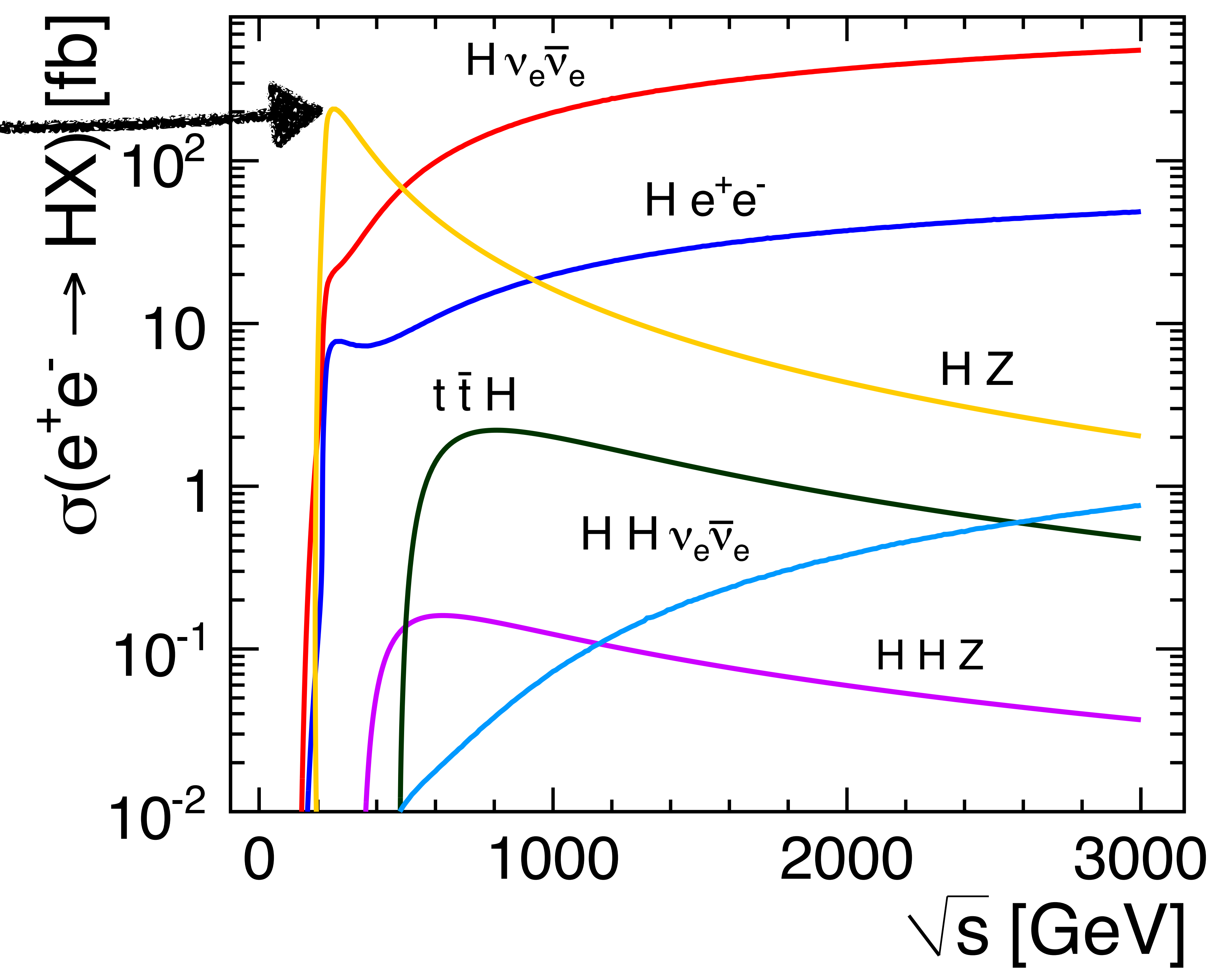
Well suited for staging



ee ➛ H + Z

Physics Cases - Higgs Factory

- Maximum of ZH production (Higgsstrahlung) at ~250GeV



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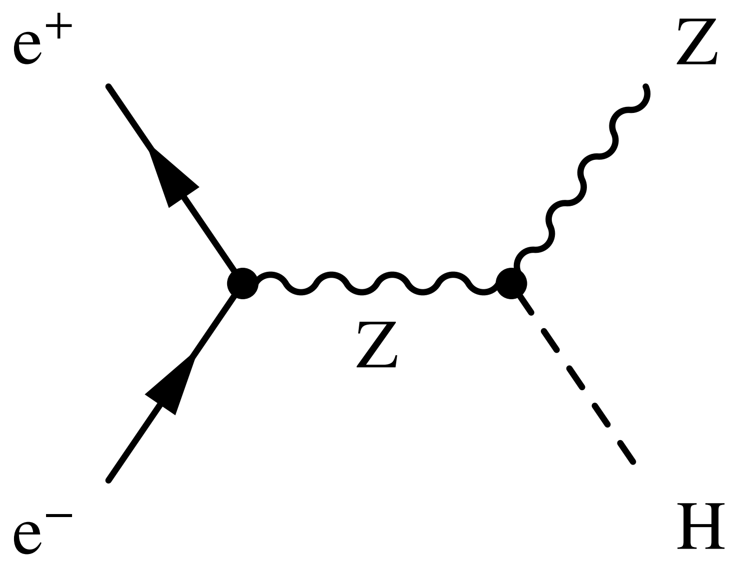
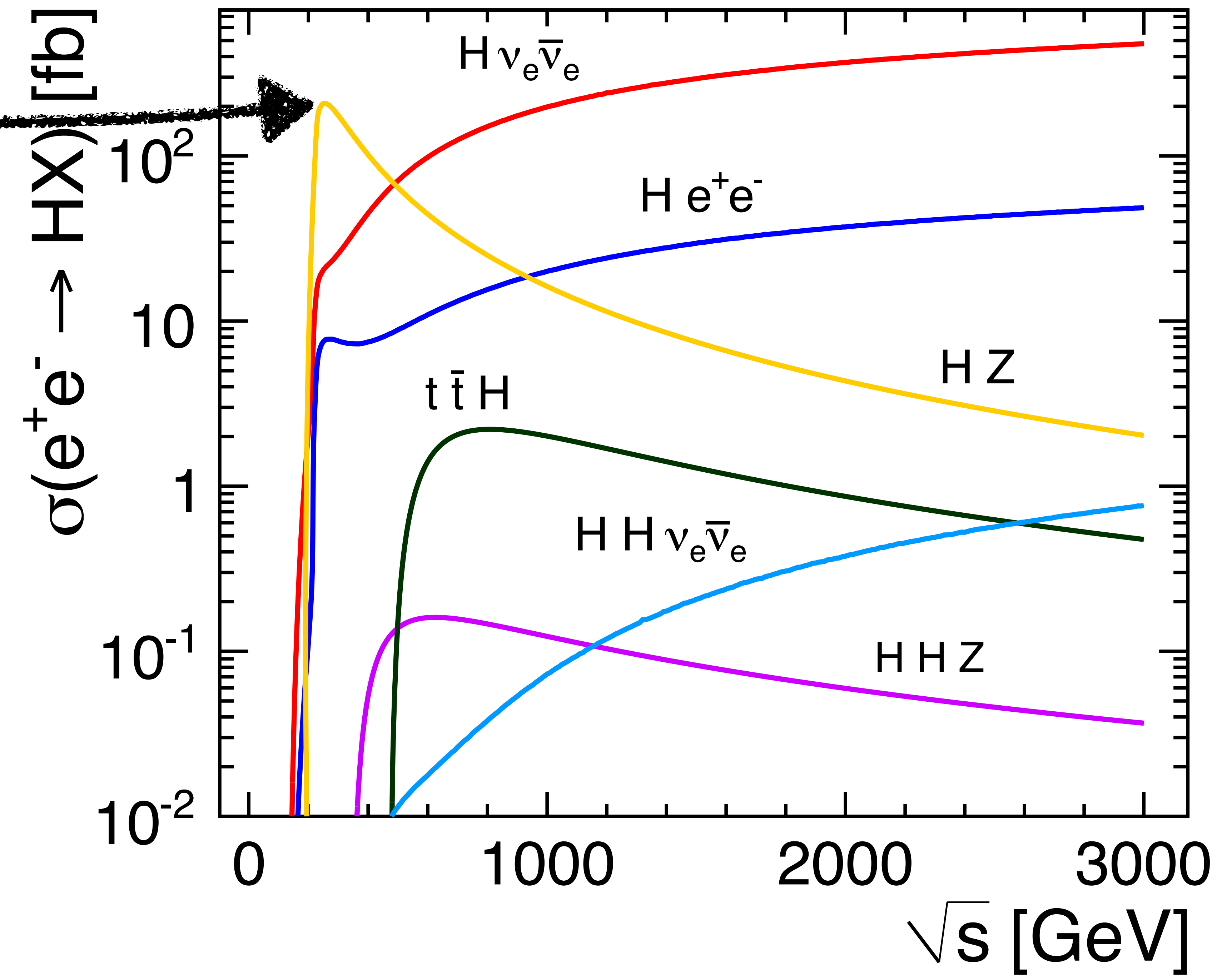


<u>Model independent</u> way of measuring the total $e^+e^- \rightarrow$ ZH cross-section and g_{hZZ}

$\Longrightarrow$ low BG, select events solely on Z four-momentum (recoil mass technique)

$$e^+e^- \rightarrow h\,Z \qquad Z \rightarrow l^+l^-$$

$$M_h^2 = (p_{cm} - (p_{l^+} + p_{l^-}))^2$$



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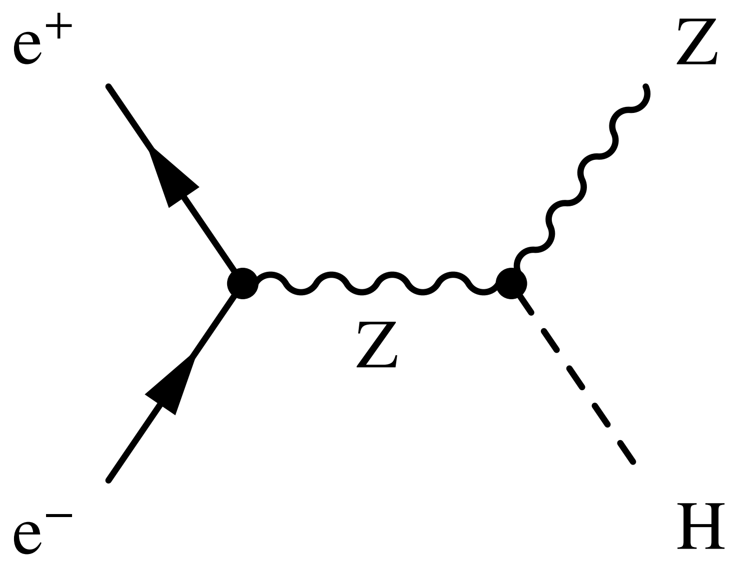

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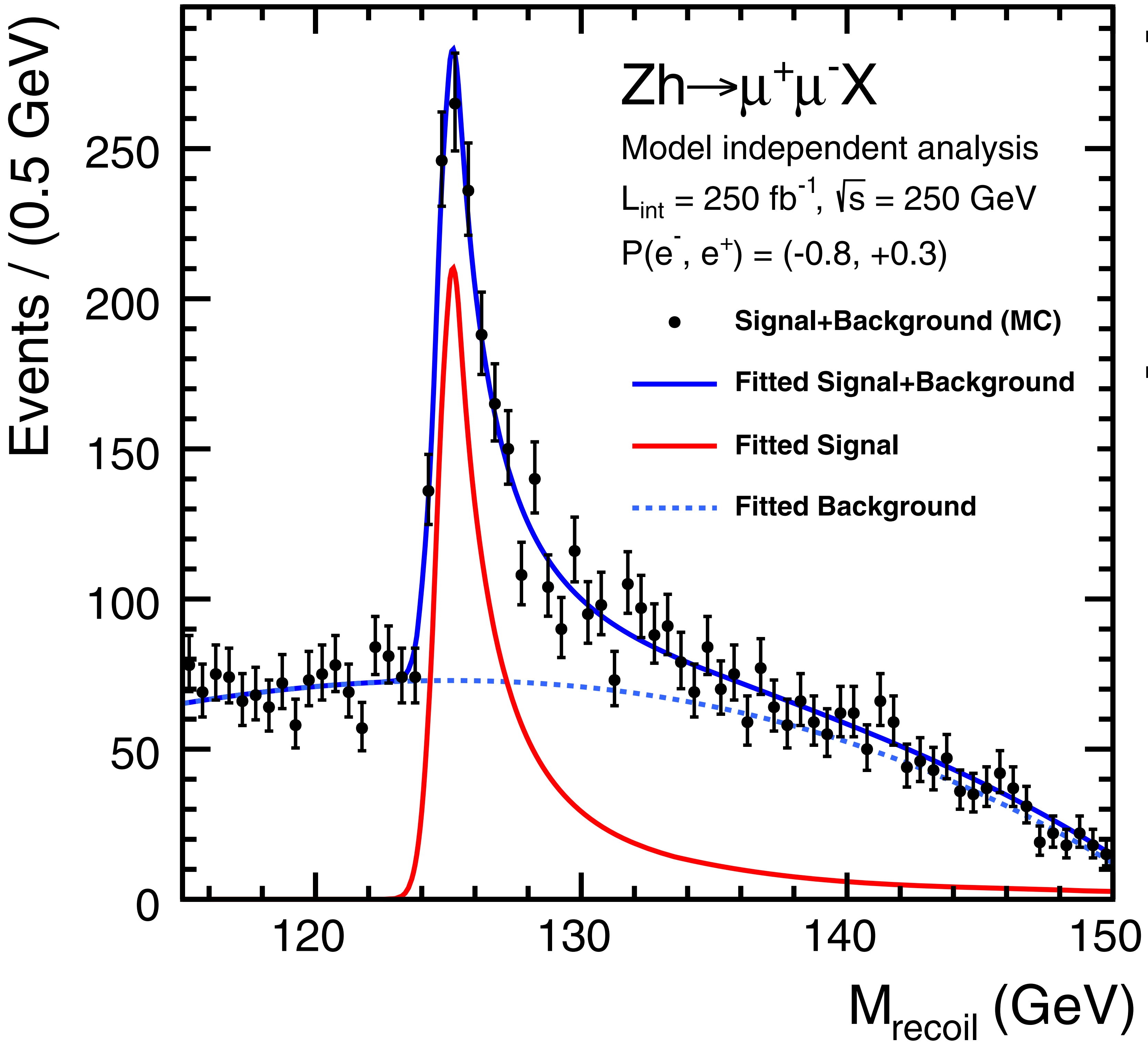
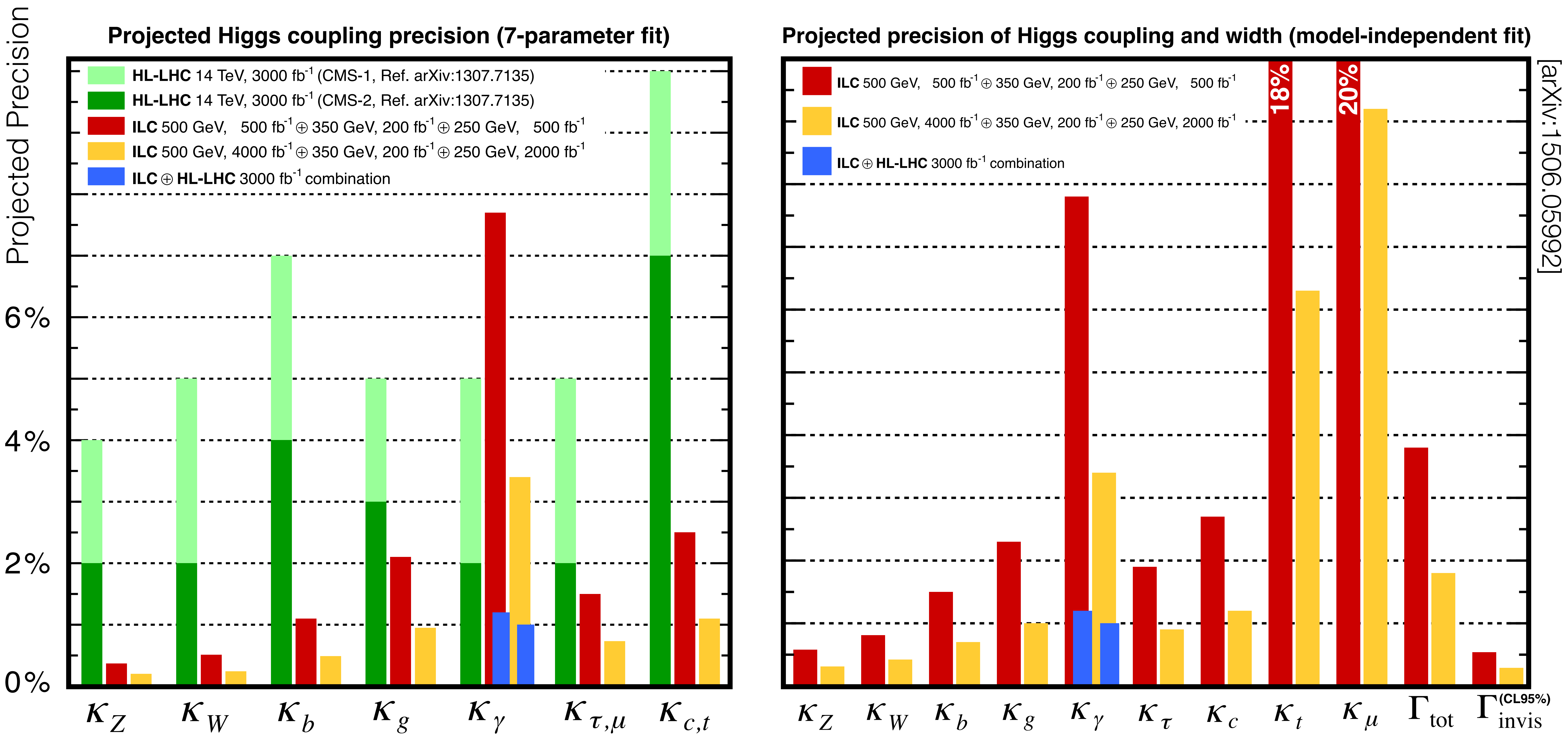


[S. Watanuki]

Physics Cases - Higgs Couplings

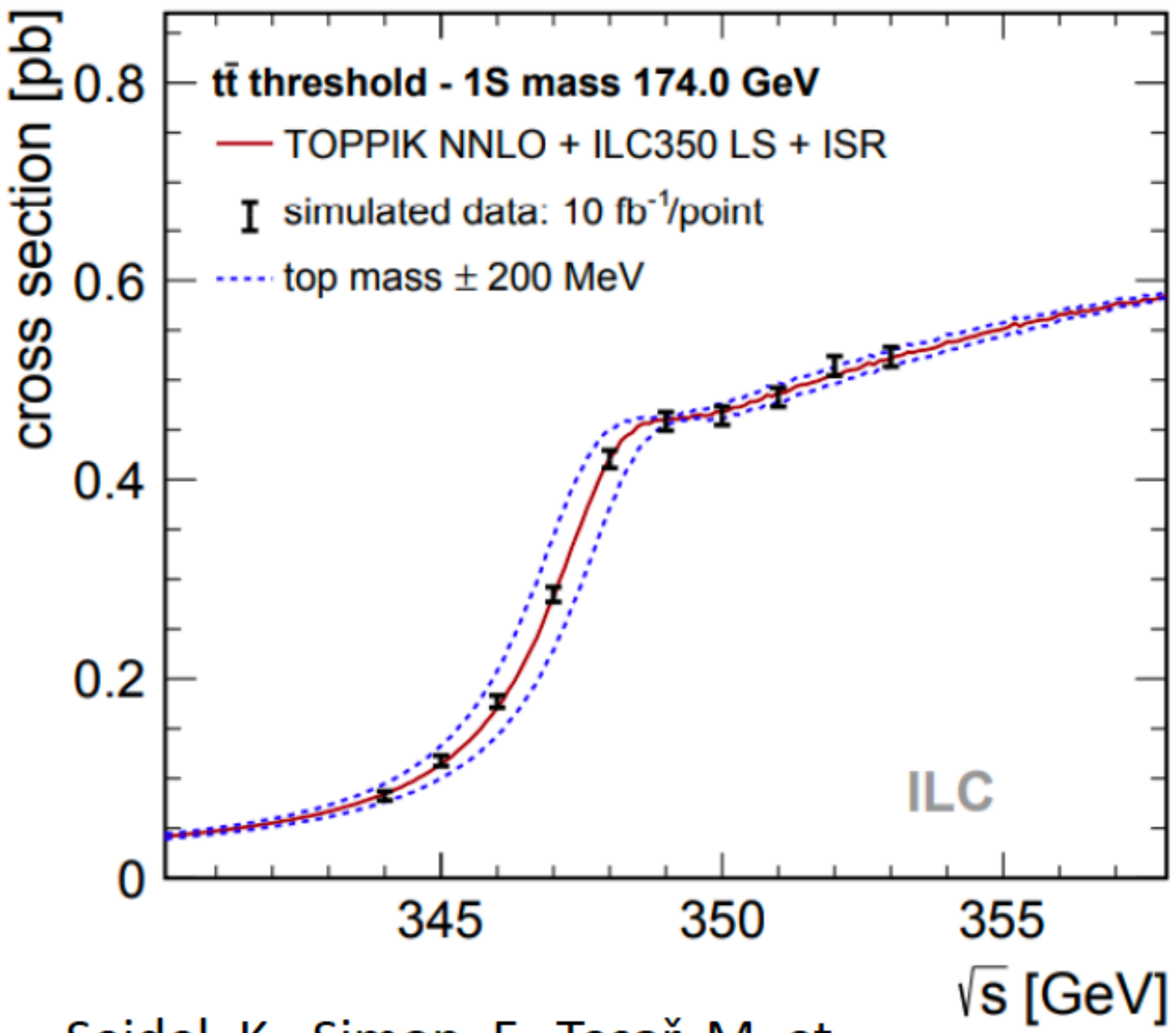


- Model dependent and independent fits
- Many models predict deviations of few percent

Possibility to measure couplings with < 1% precision

Physics Cases - Top Quark

- <u>tt-threshold at ~350 MeV:</u> threshold scan enables precision measurements on top mass and width (500MeV @ LHC $\Longrightarrow$ 50MeV @ ILC)



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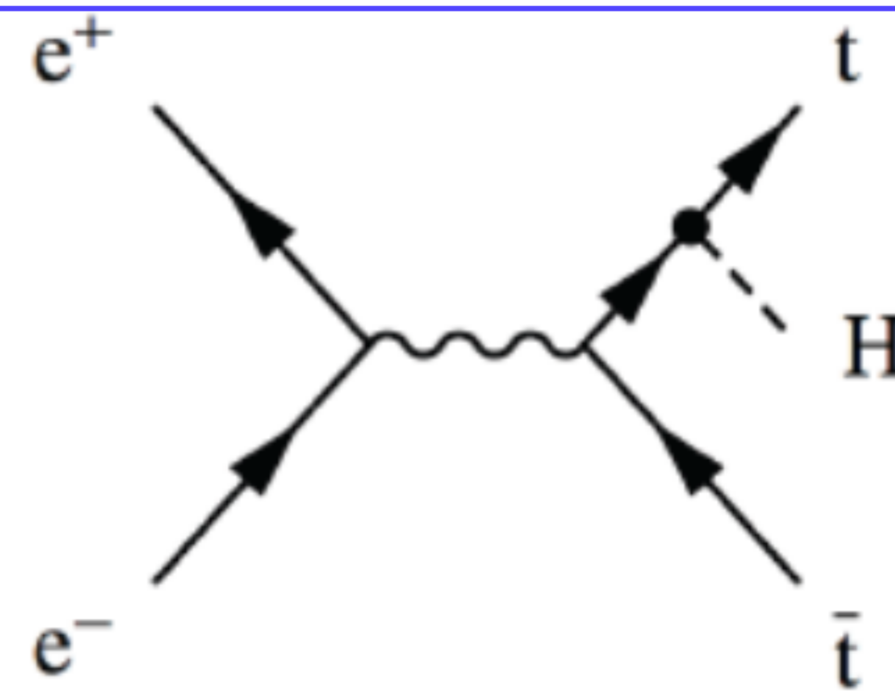
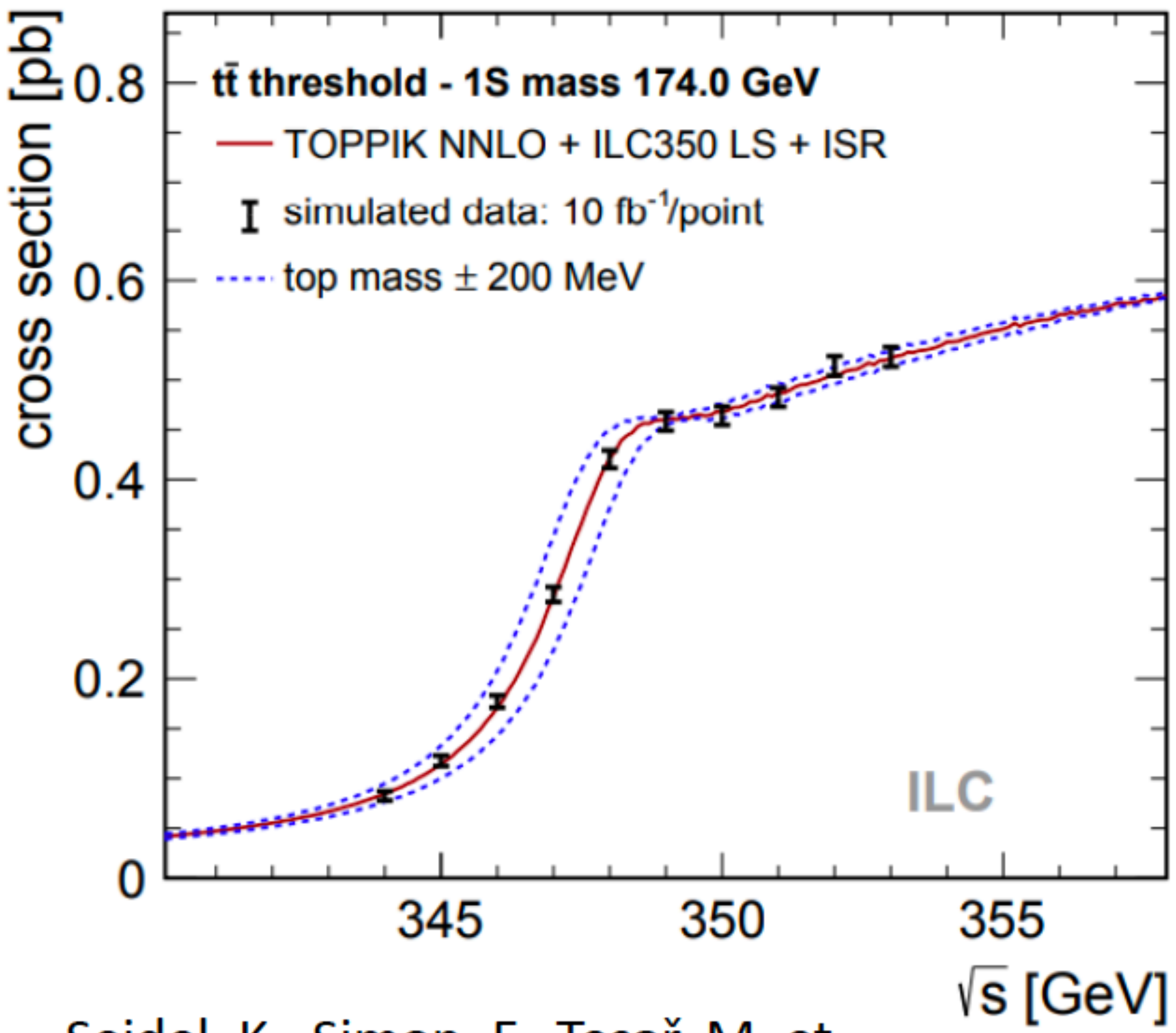
Top Yukawa coupling



(174 GeV)
(125 GeV)
(174 GeV)



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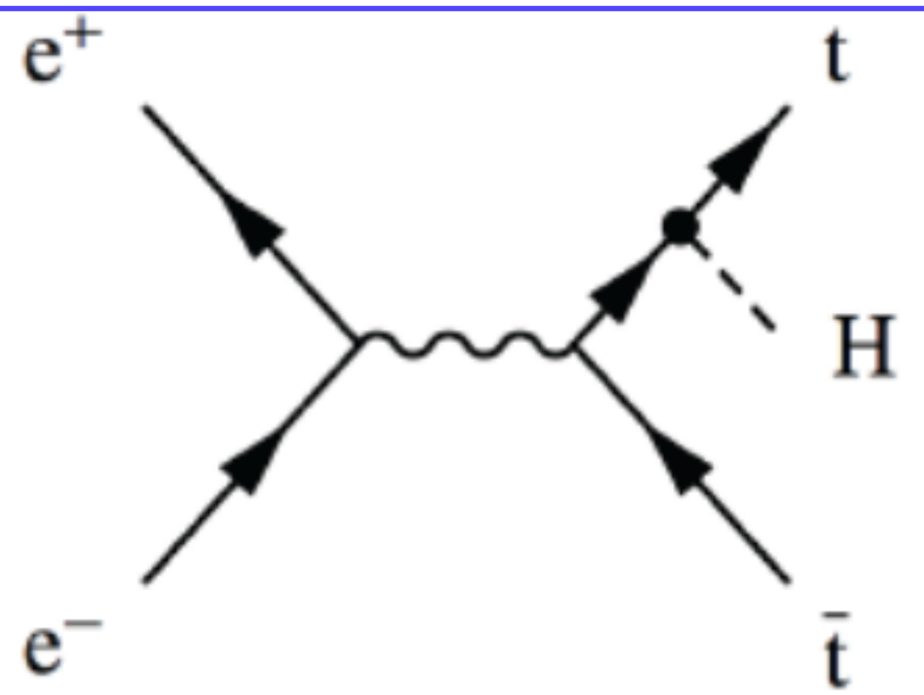
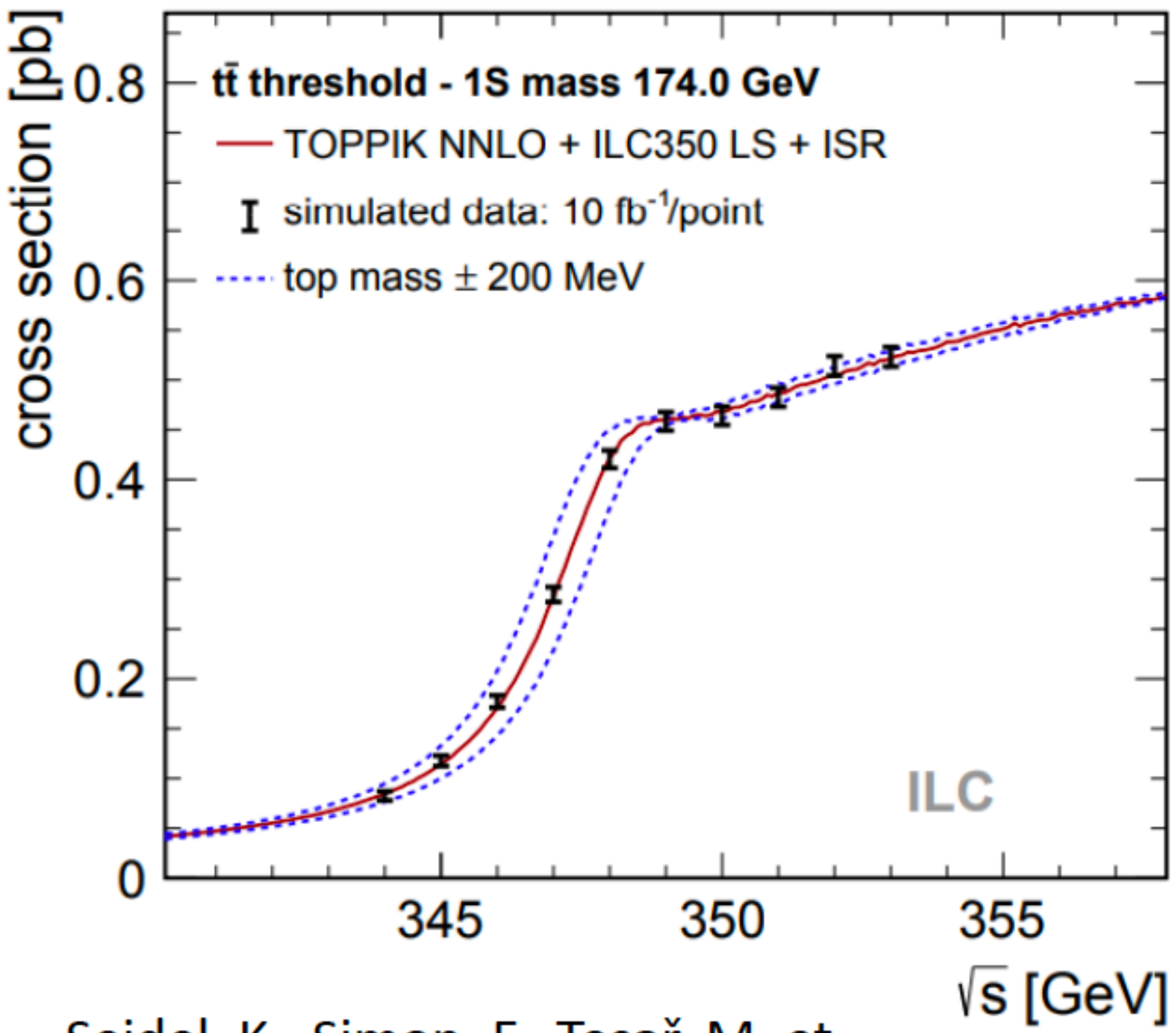
Top Yukawa coupling



(174 GeV)
(125 GeV)
(174 GeV)

- Rare decays: e.g. $t \rightarrow ch$, $t \rightarrow c\gamma$ as flavour changing neutral current decays (new physics)



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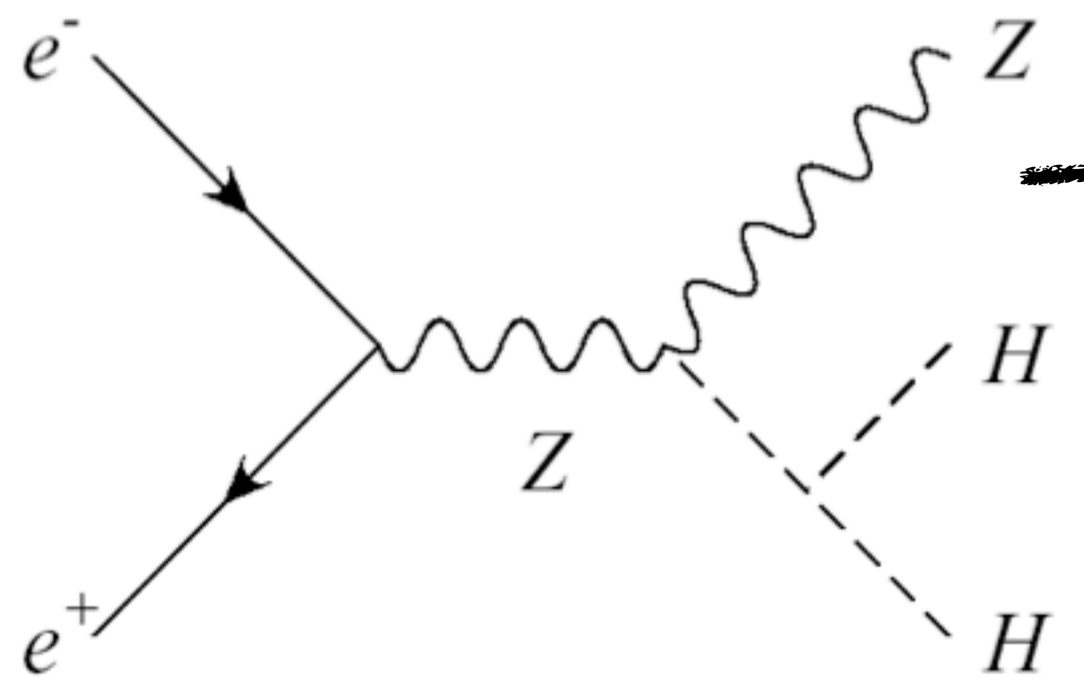
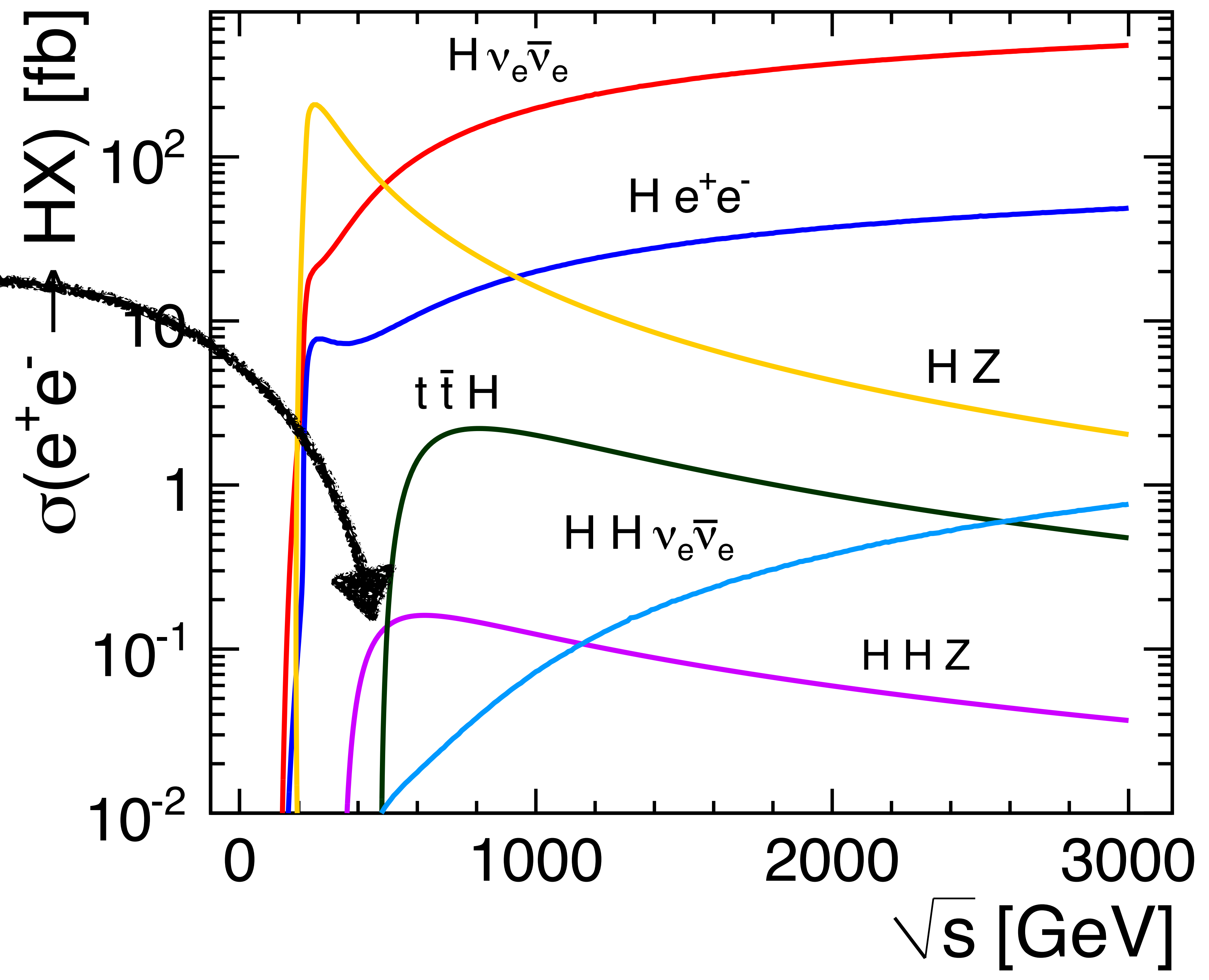
Physics Cases - Higgs Self Coupling

Higgs mechanism predicts self-interaction:

- Probe coupling parameter to validate SM
- Find deviations from SM expectation to open a window for new physics

Higgs Strahlung @ 500GeV





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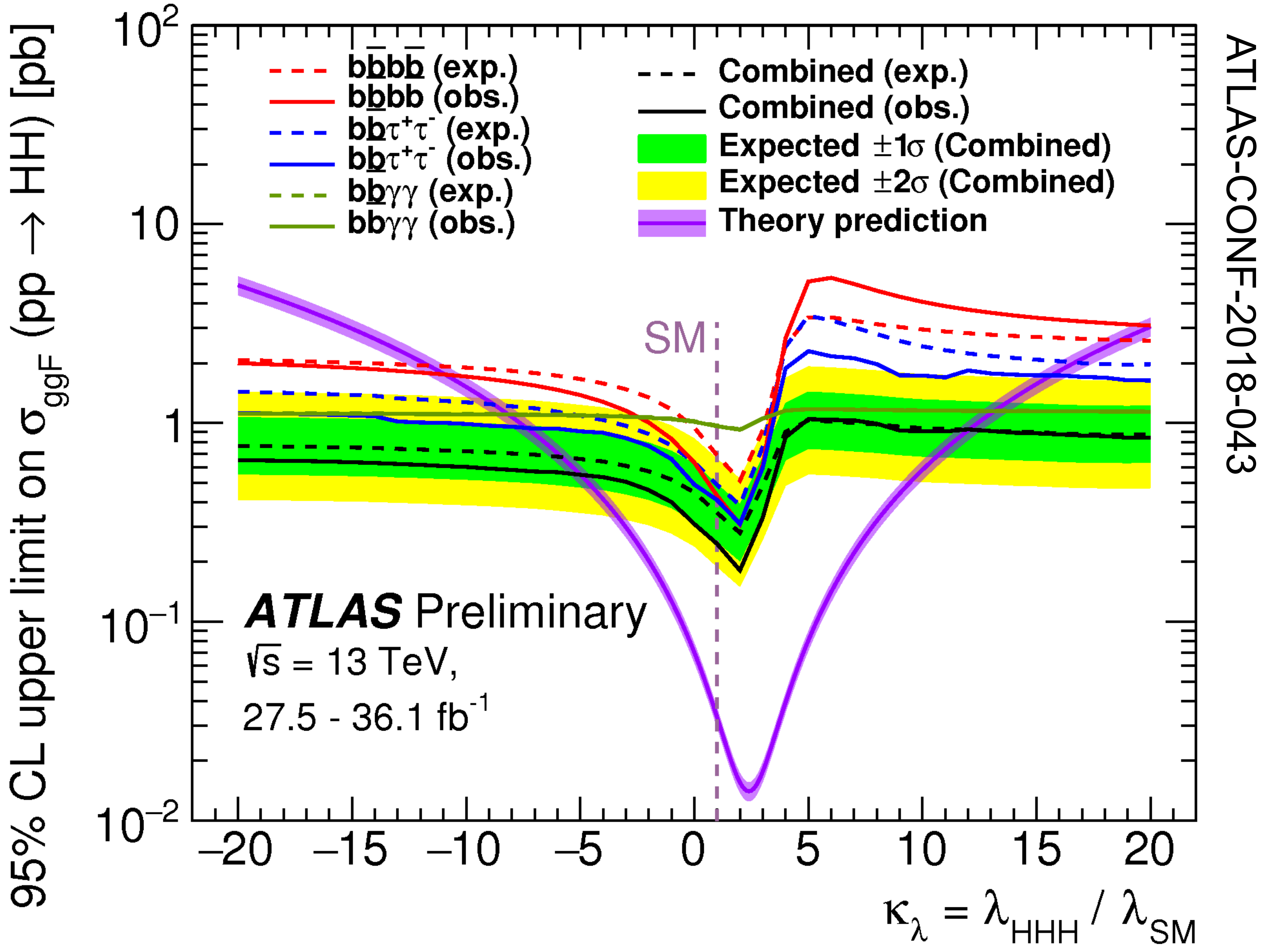
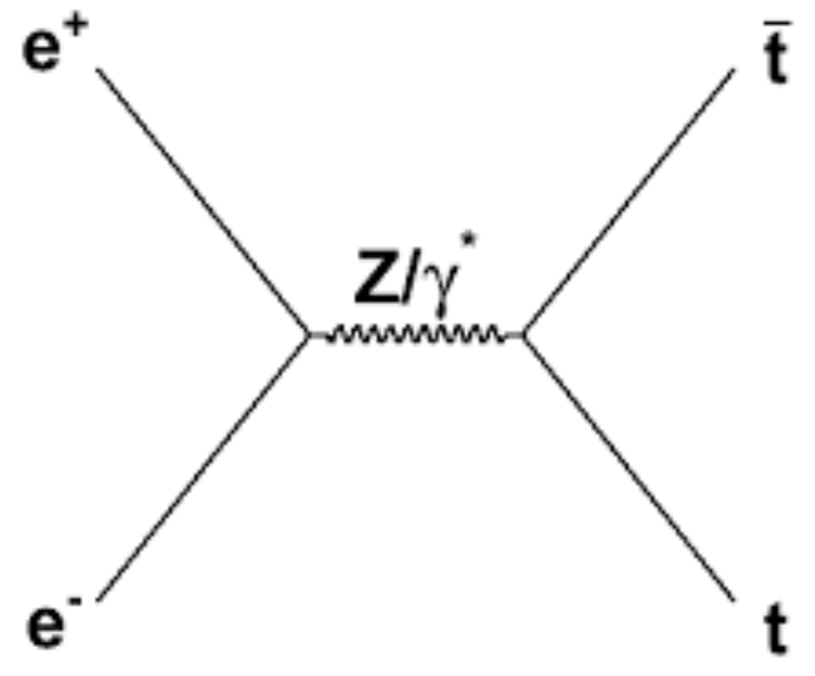


- Latest results constrain a deviation to be within -5 and +12.1

Physics Cases - Beyond Standard Model

1. Direct and indirect detection of new physics

   - Top electroweak coupling, flavour violating NC interactions
   - Chargino pair production or higgsino due to clean environment



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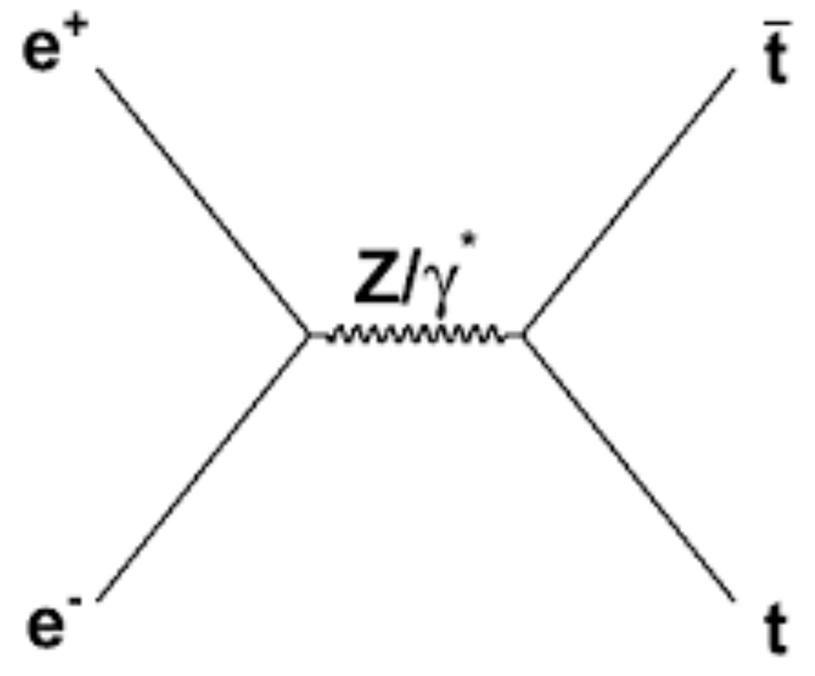
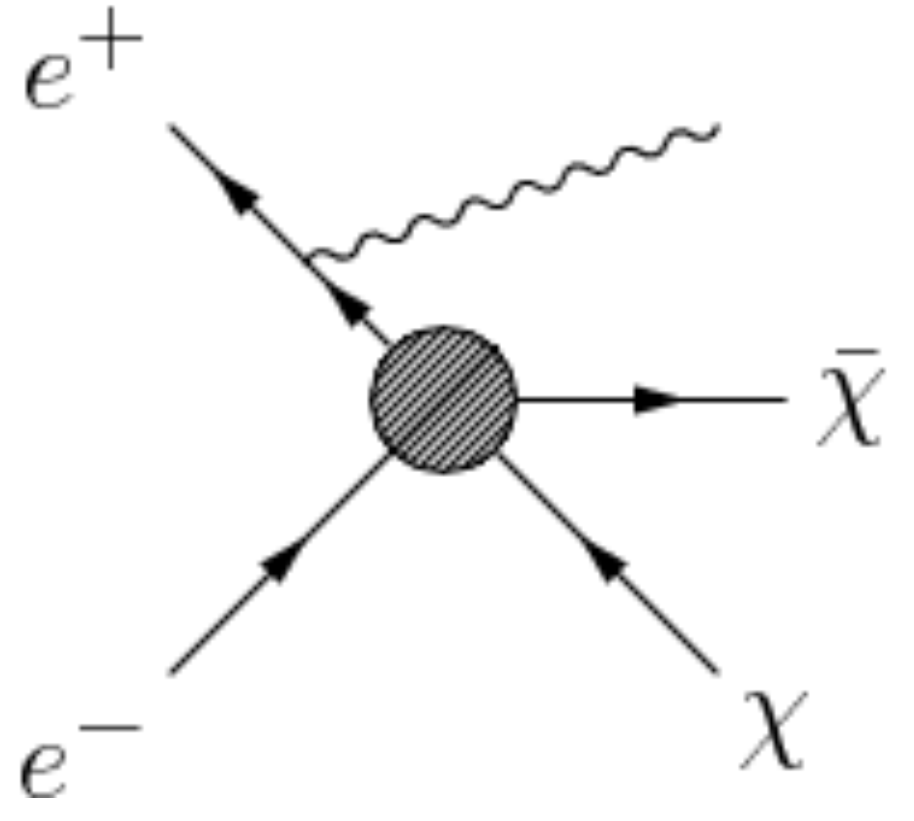
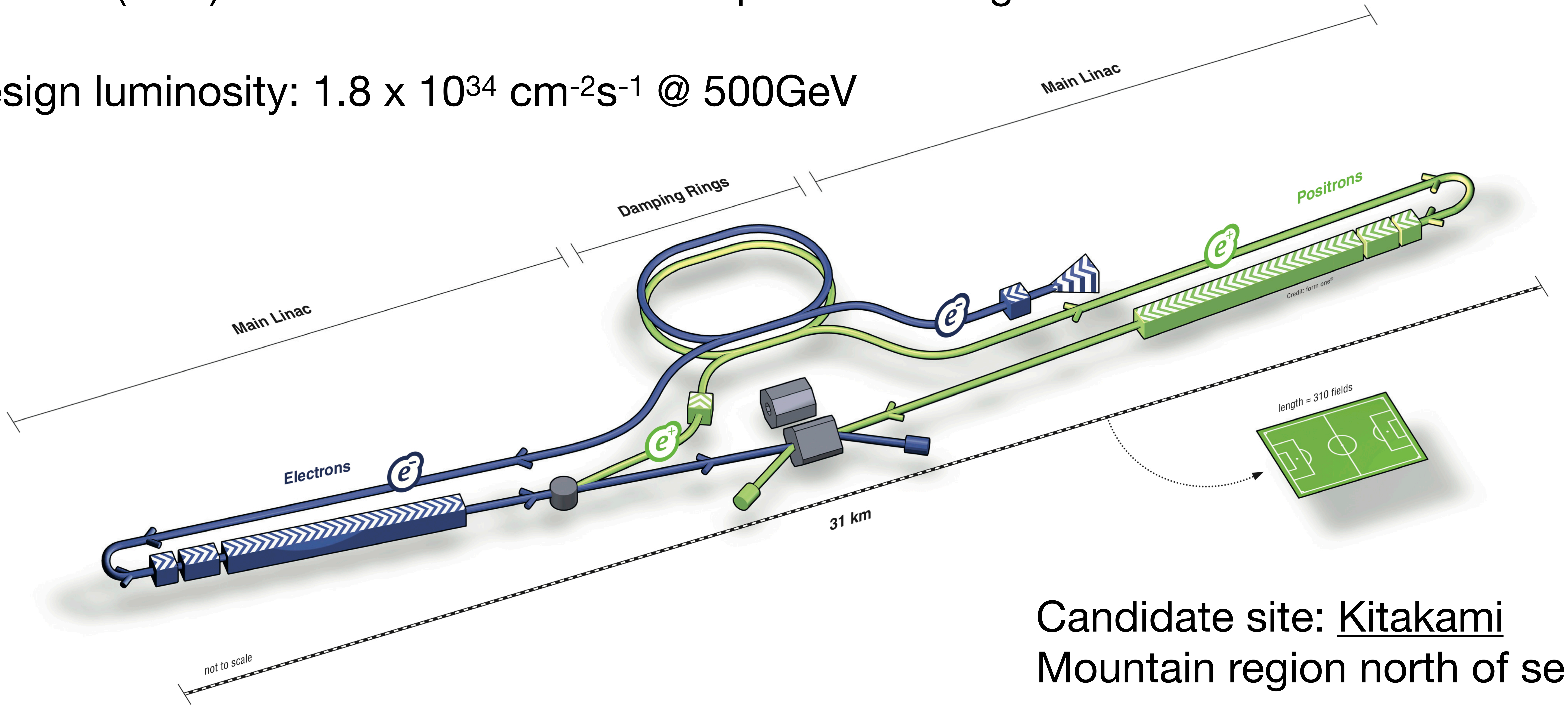


2. Dark matter
   - e.g. mono-photon events with low background



The International Linear Collider - ILC

- 500GeV (TDR) linear collider based on superconducting RF cavities
- Design luminosity: 1.8 x 10^{34} $cm^{-2}s^{-1}$ @ 500GeV



Candidate site: Kitakami
Mountain region north of sendai

ILC Accelerator Technology

<u>Acceleration of particles:</u>

- ~16000 Niobium superconducting RF cavities
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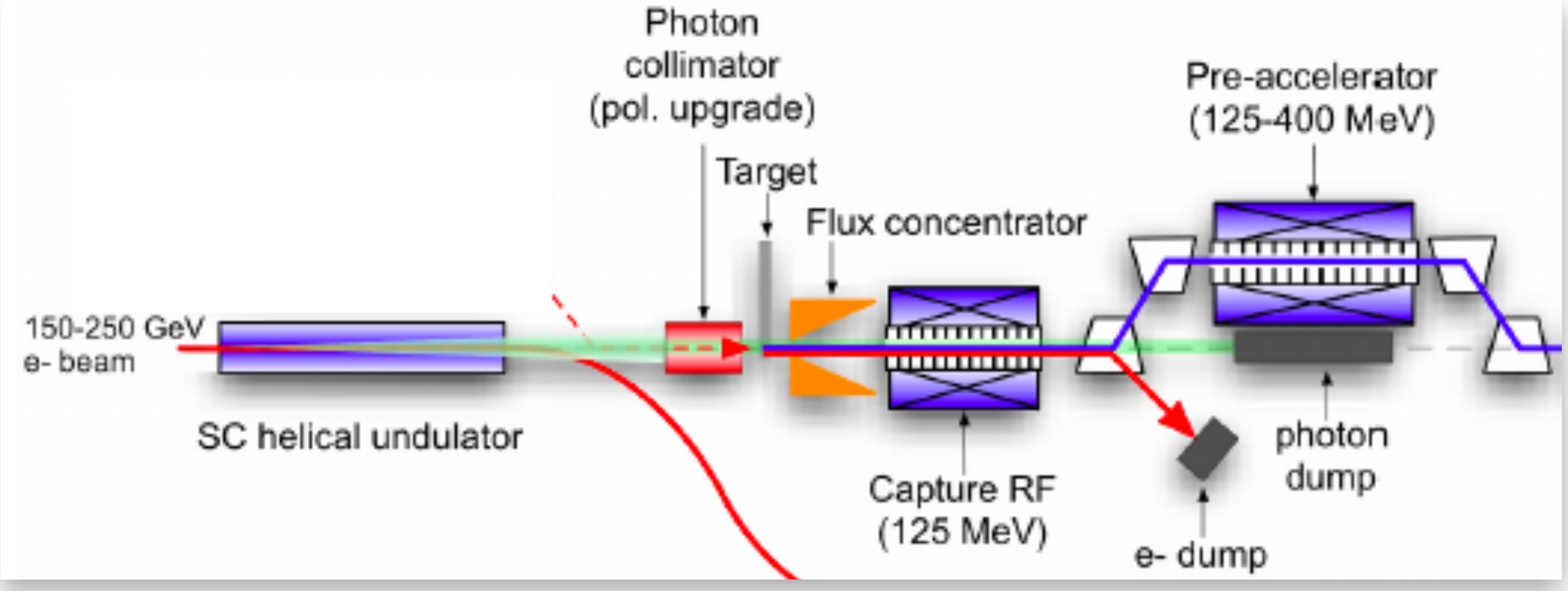
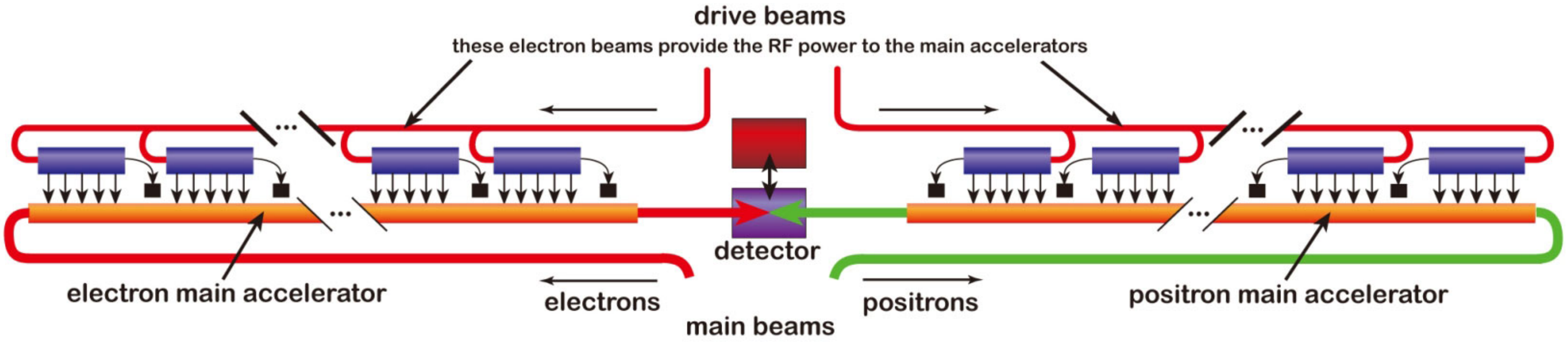


Compact Linear Collider - CLIC

- An up to 3TeV linear collider based on drive beam acceleration technology
- Design Luminosity: 5.9 x 10^{34} $cm^{-2}s^{-1}$ @ 3TeV
- Developed as possible future project at CERN - first decision in 2019/2020



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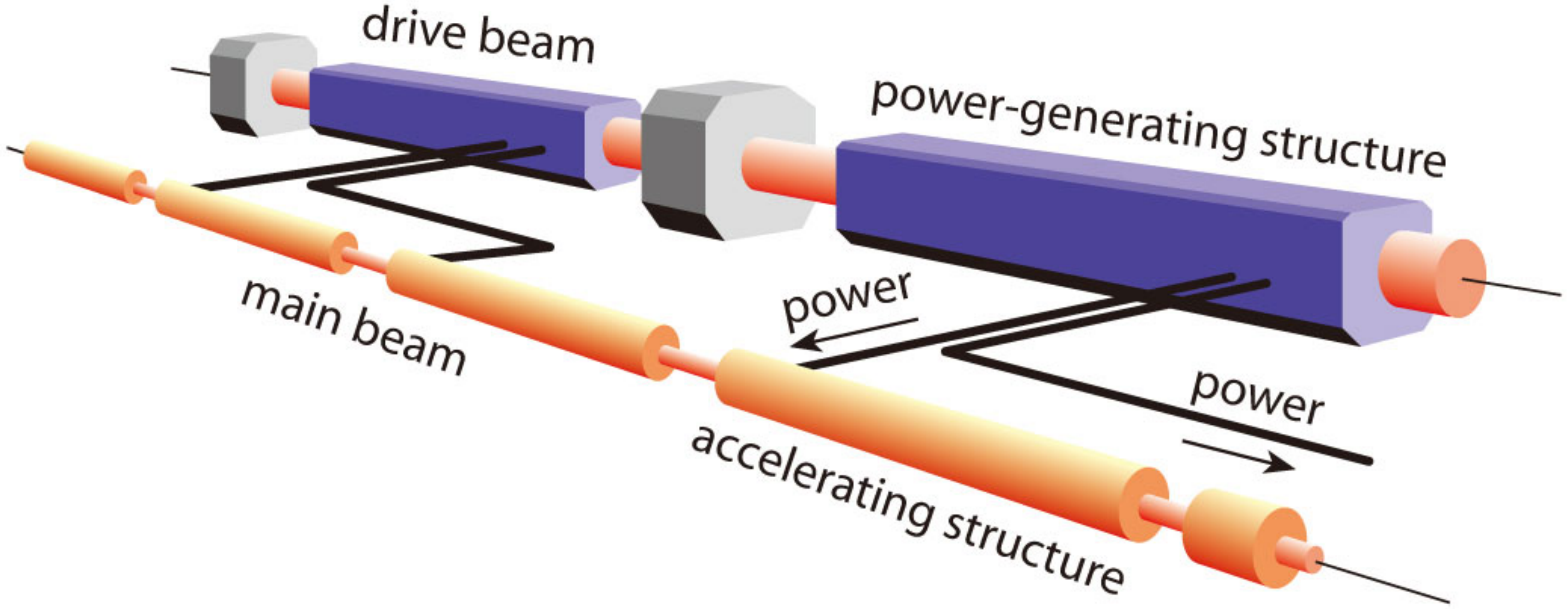

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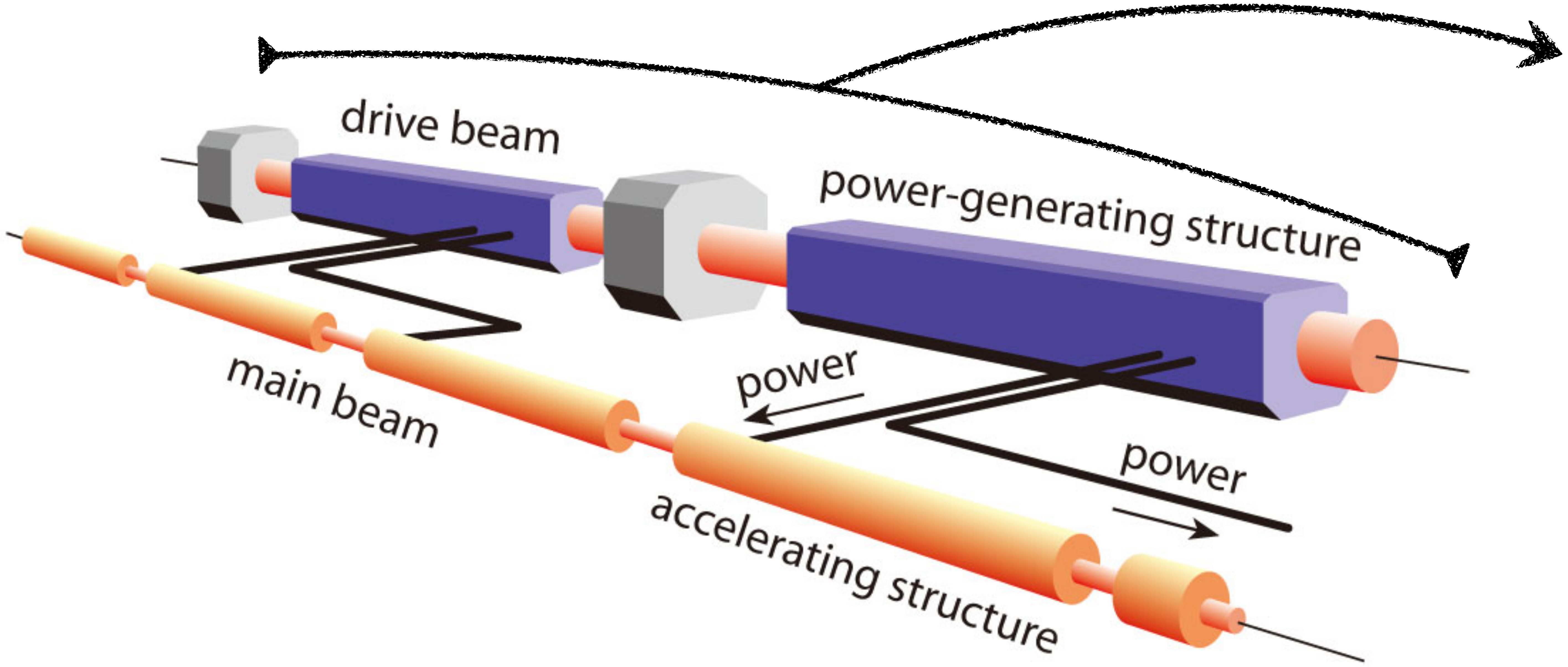

Beamline for “drive beam”:

- Electron beam provided by a dedicated accelerator system
- Only ~2.3GeV, but very high peak current of ~100A
- Electrons guided through cavities, induced RF wave is coupled to accelerating structure

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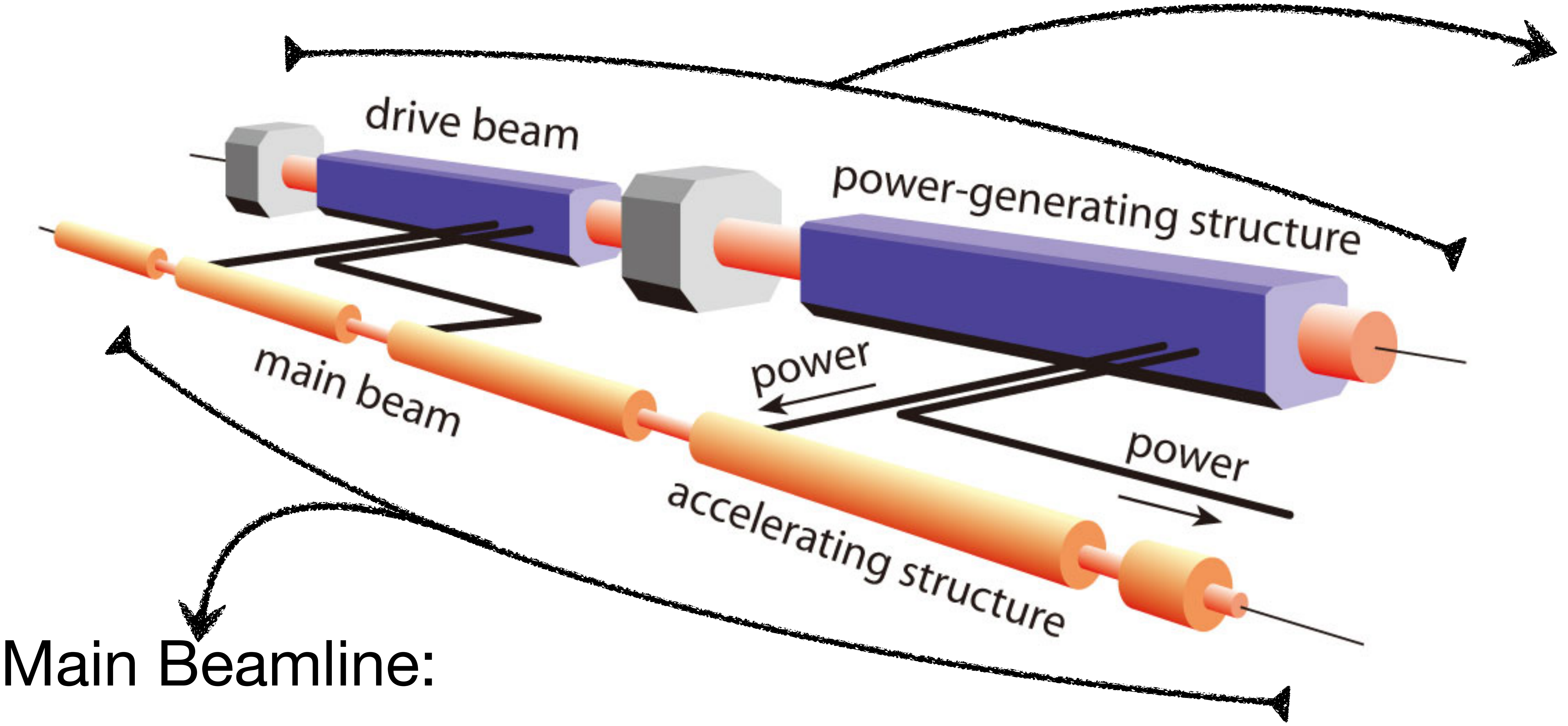

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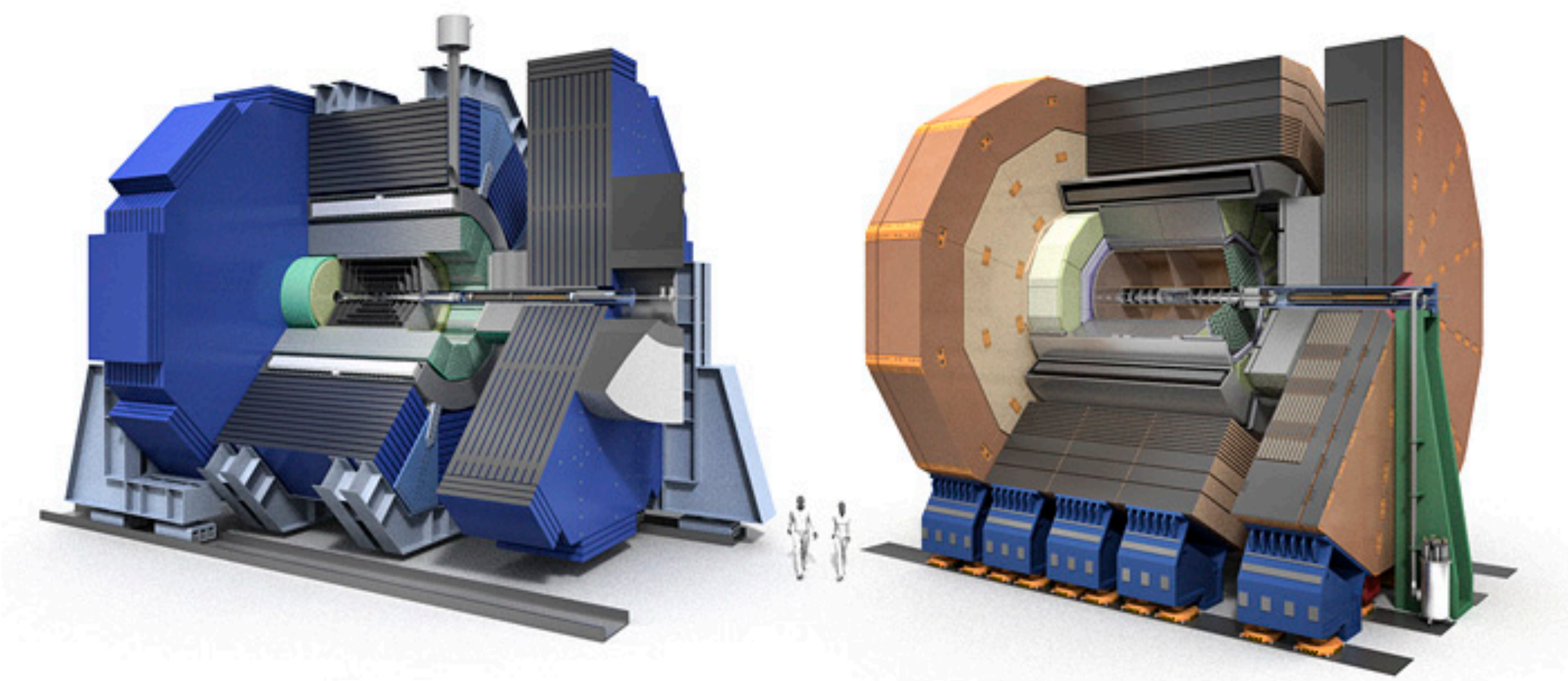
Main Beamline:

- 24 sections of 876m long modules for each linac
- Accelerating gradient of 100MV/m

Detectors for Future Linear Colliders

- General purpose CMS like detector systems



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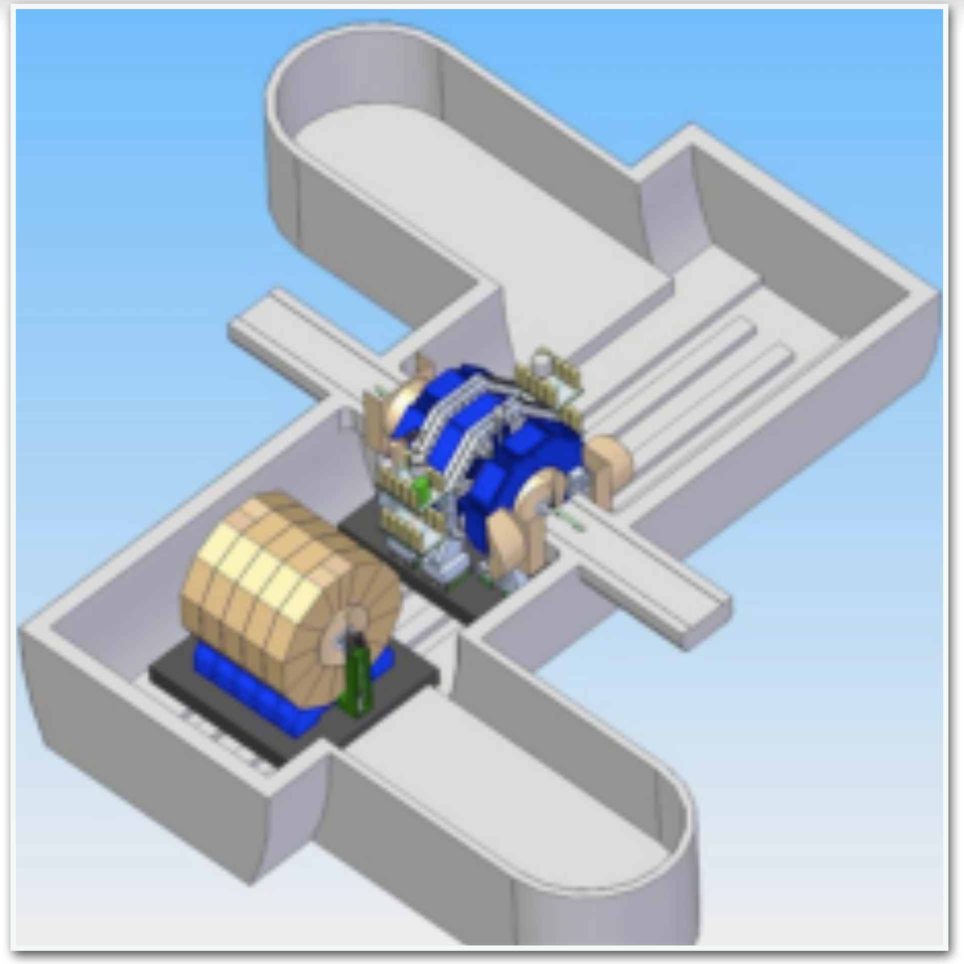
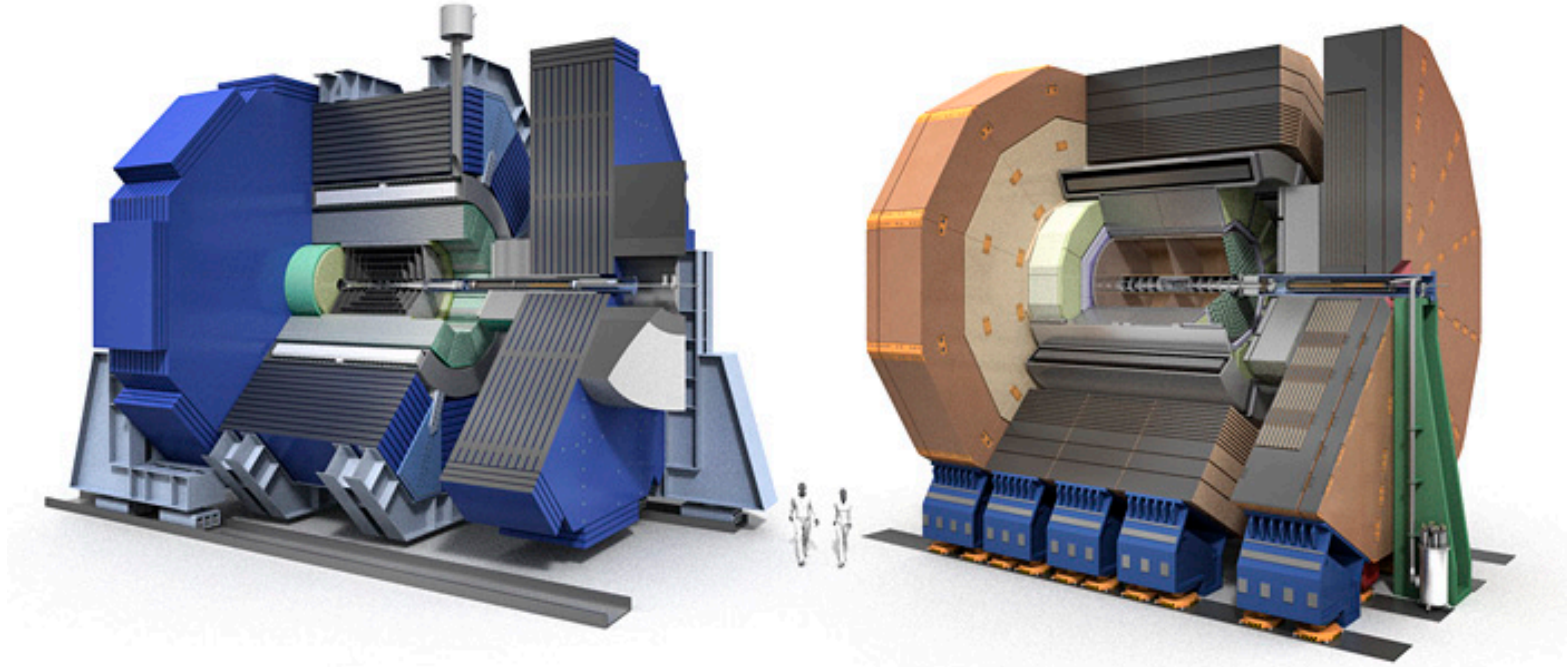
- Only one IP in a linear collider $\Longrightarrow$ proposed push-pull system





Detectors for Future Linear Colliders

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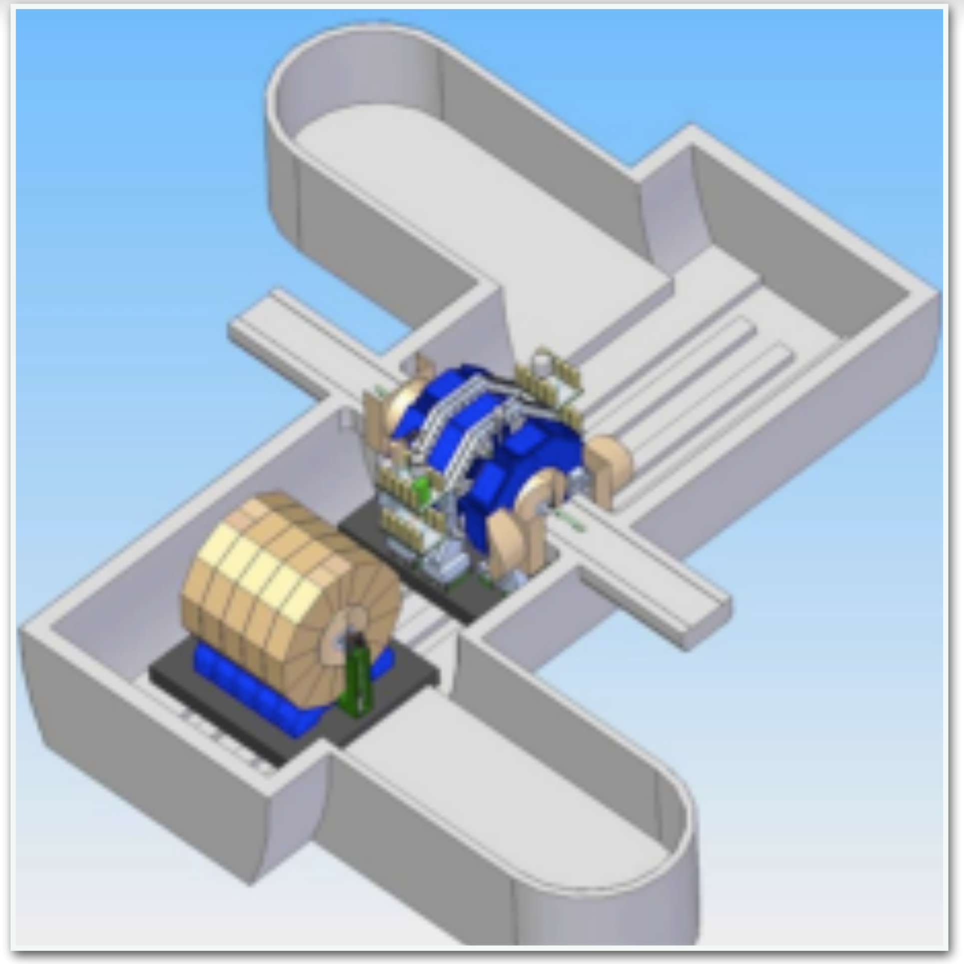
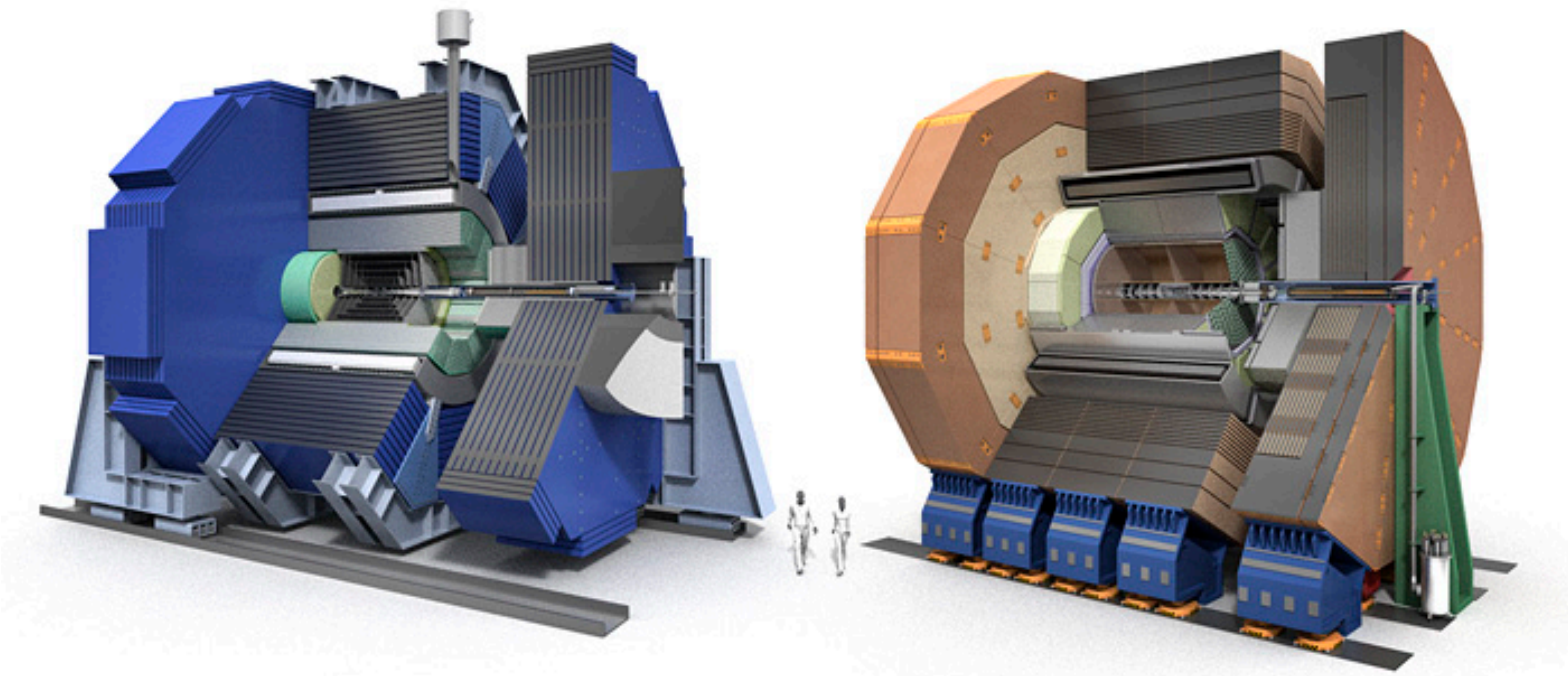
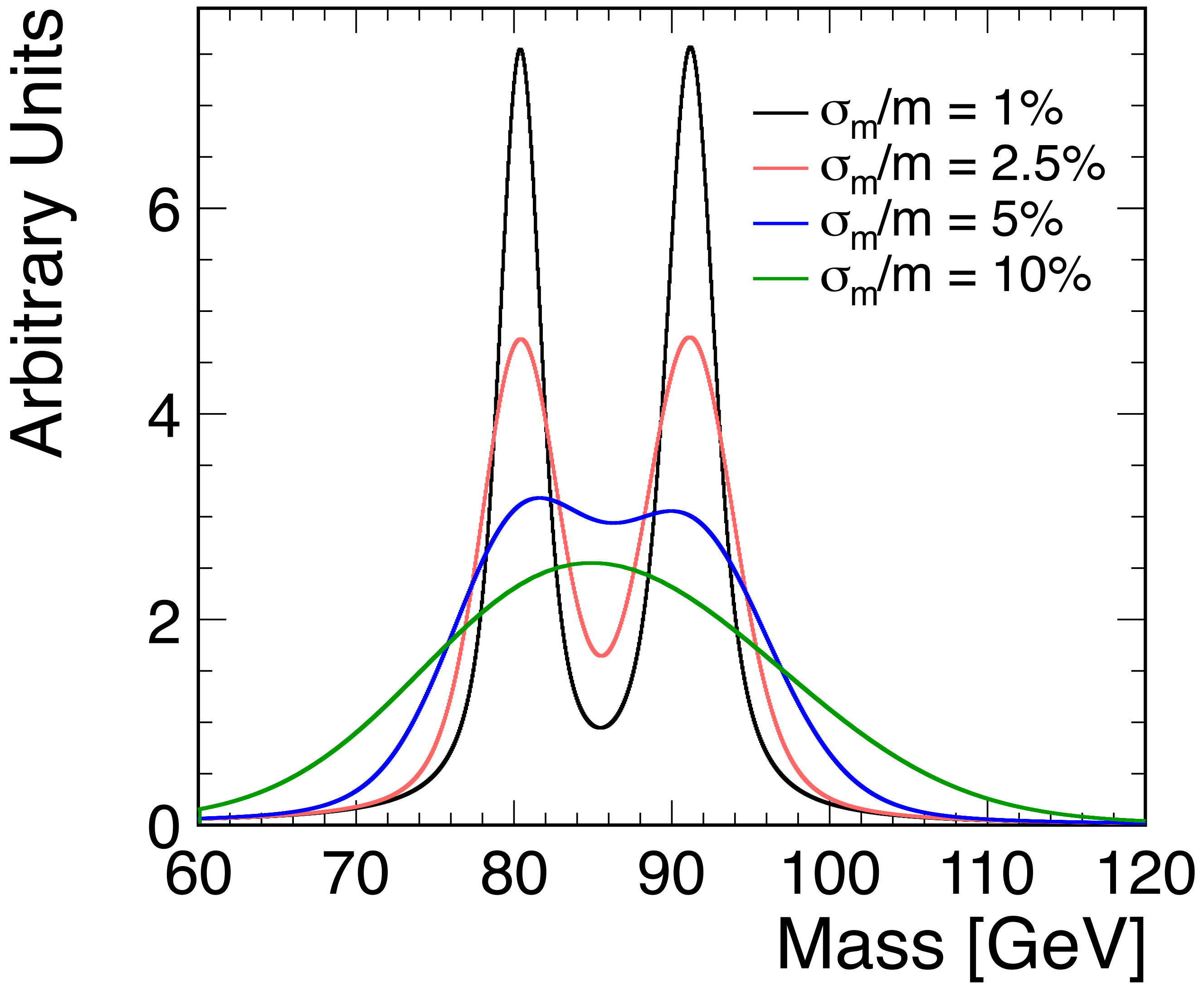
- 3-4% jet energy resolution (W/Z separation) design driver

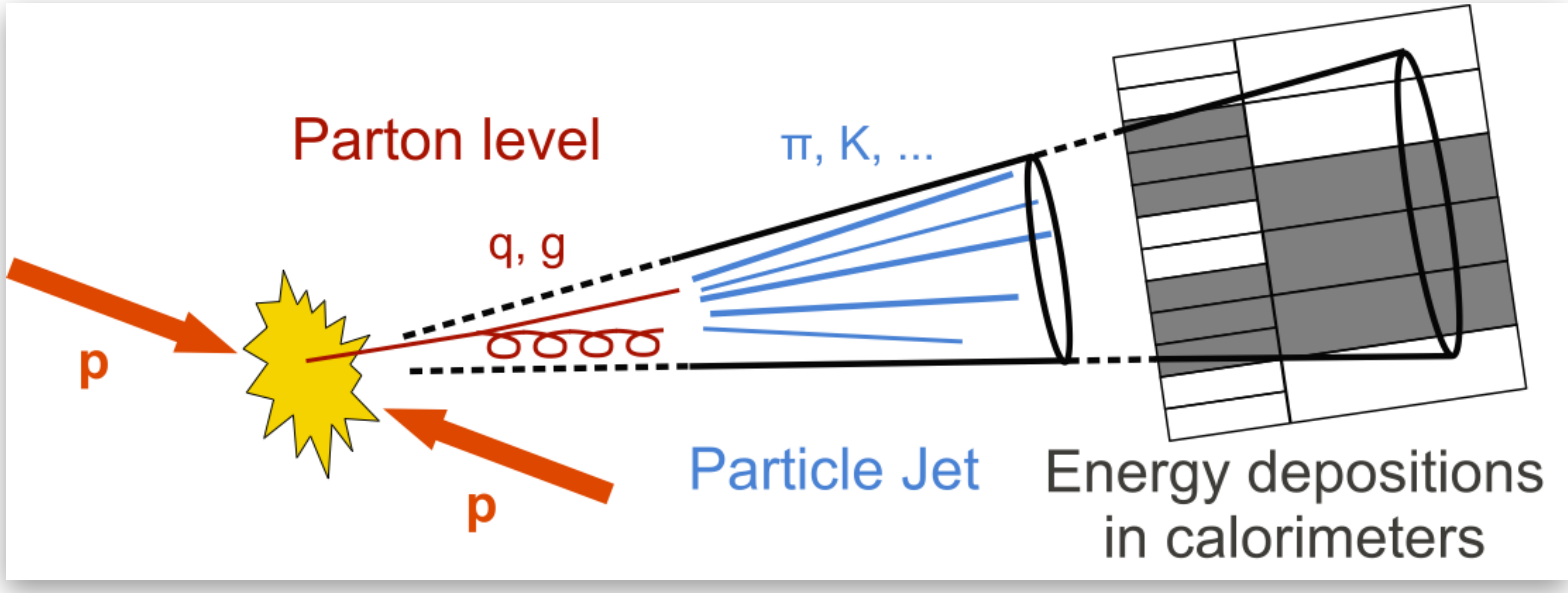






[CLIC - CDR]

Particle Flow Calorimetry



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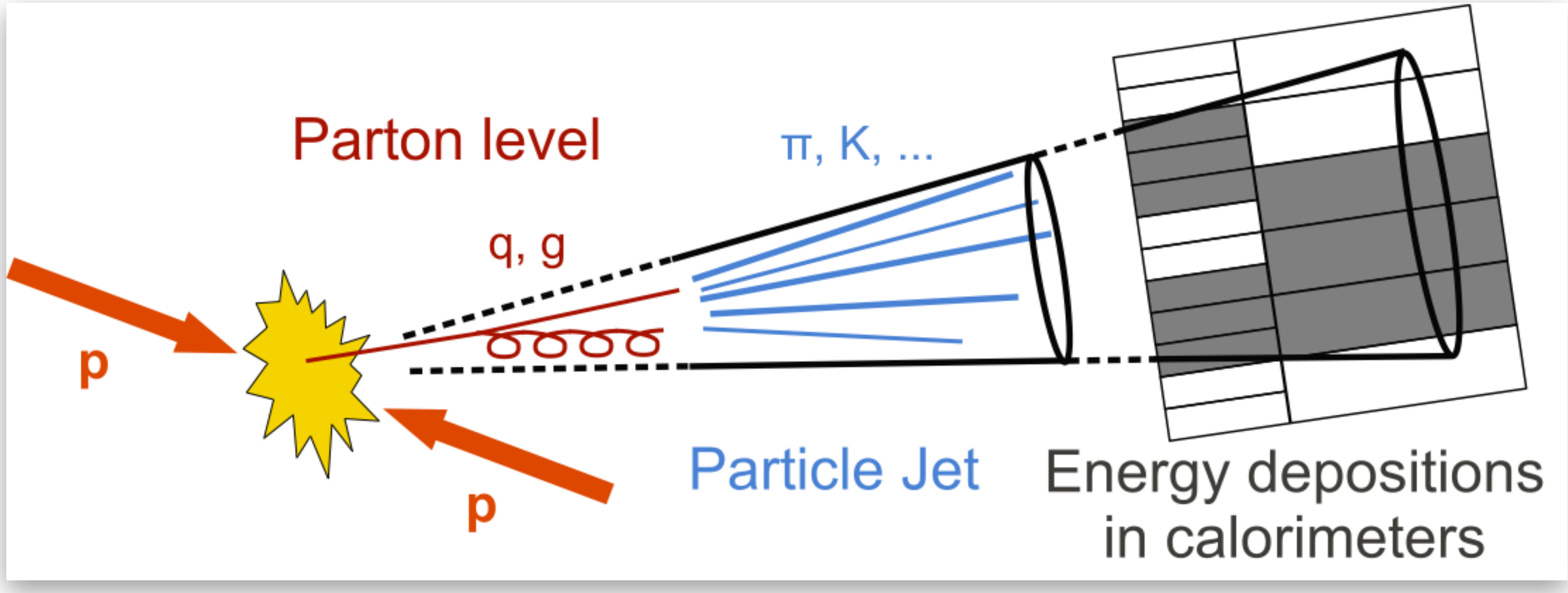

- Classical calorimetry: add up all the energy depositions in the calorimeters

  $\Longrightarrow$ 70% of the energy in a jet is deposited in the worst calorimeter

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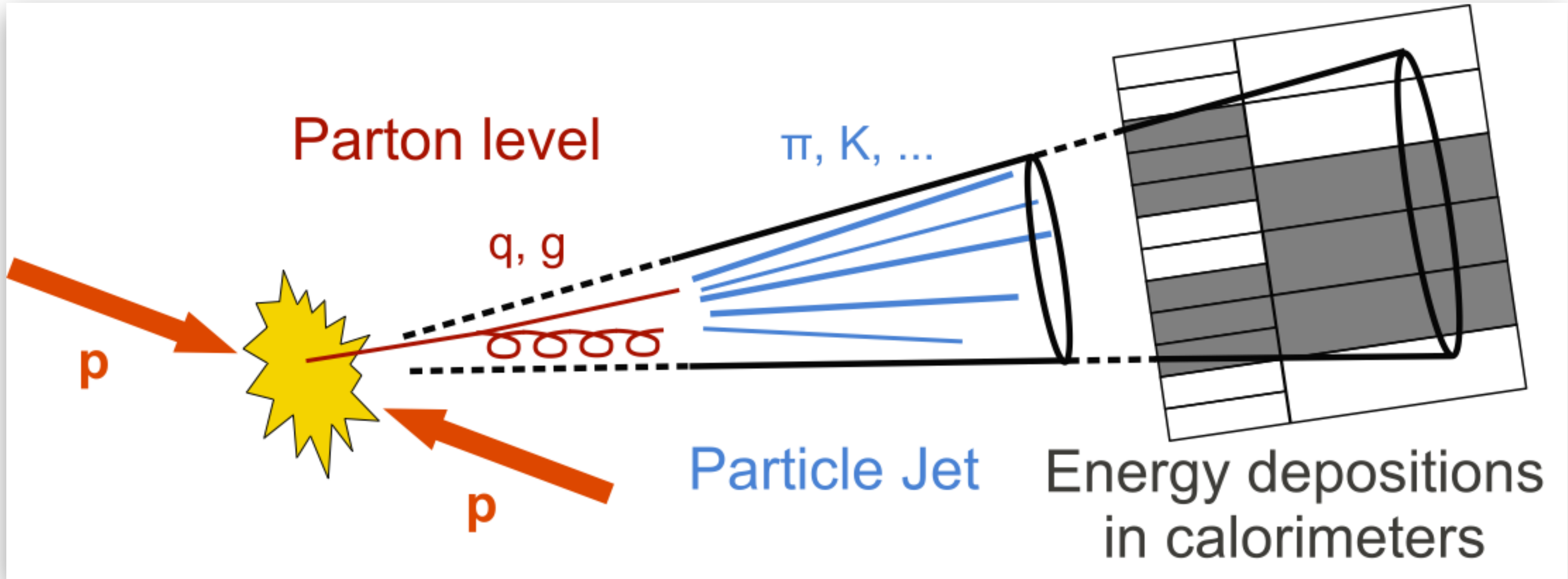


- Classical calorimetry: add up all the energy depositions in the calorimeters

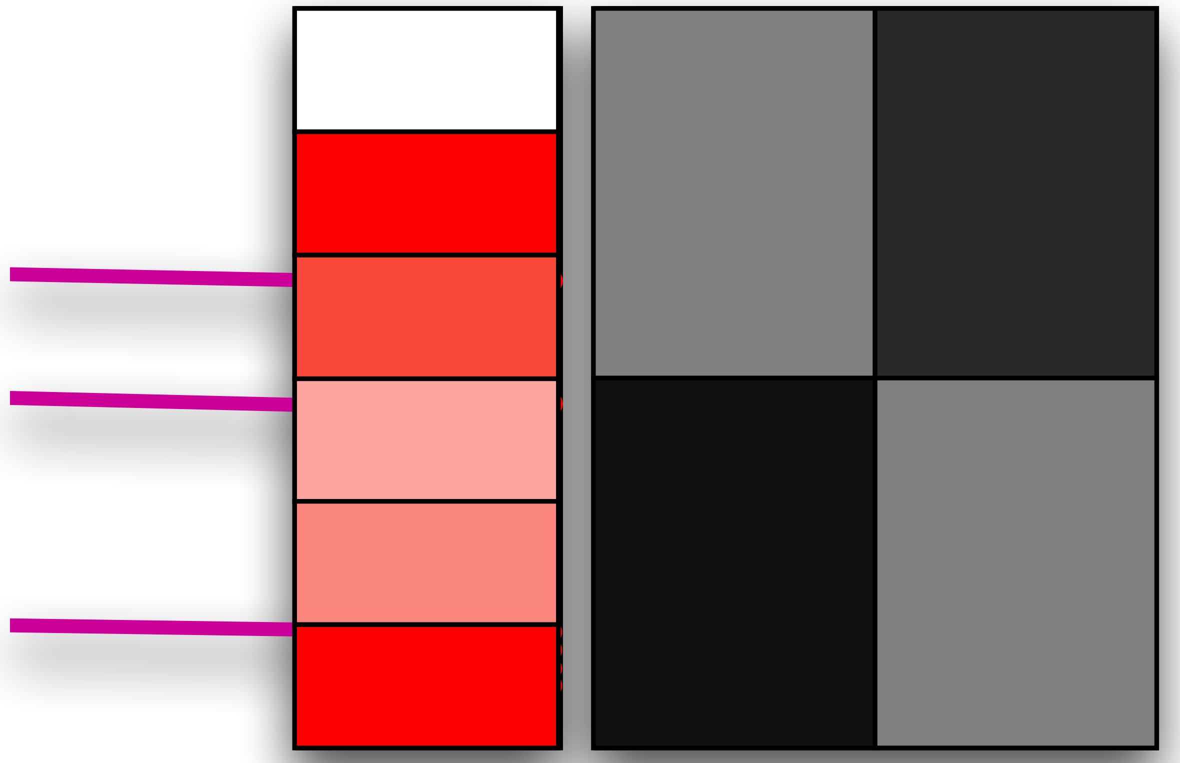
  $\Longrightarrow$ 70% of the energy in a jet is deposited in the worst calorimeter

- On average 60% charged particles, 30% gammas and 10% hadrons in a jet
- Particle flow approach:

  1. Increase granularity in calorimeters
  2. Measure different particles with best suited system

Particle Flow Calorimetry

[M. Thompson]



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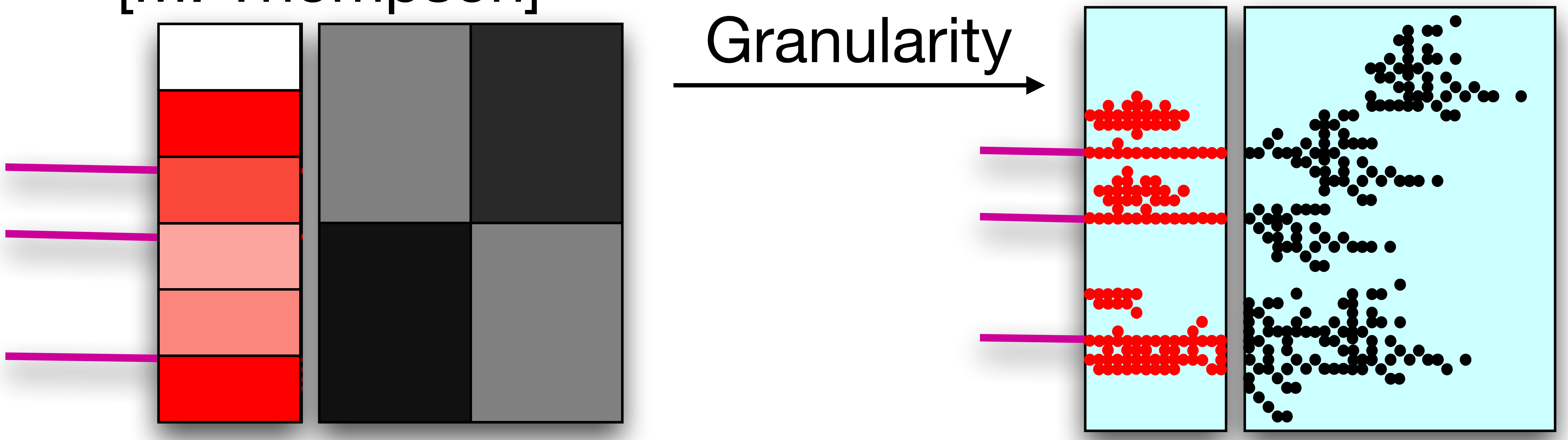

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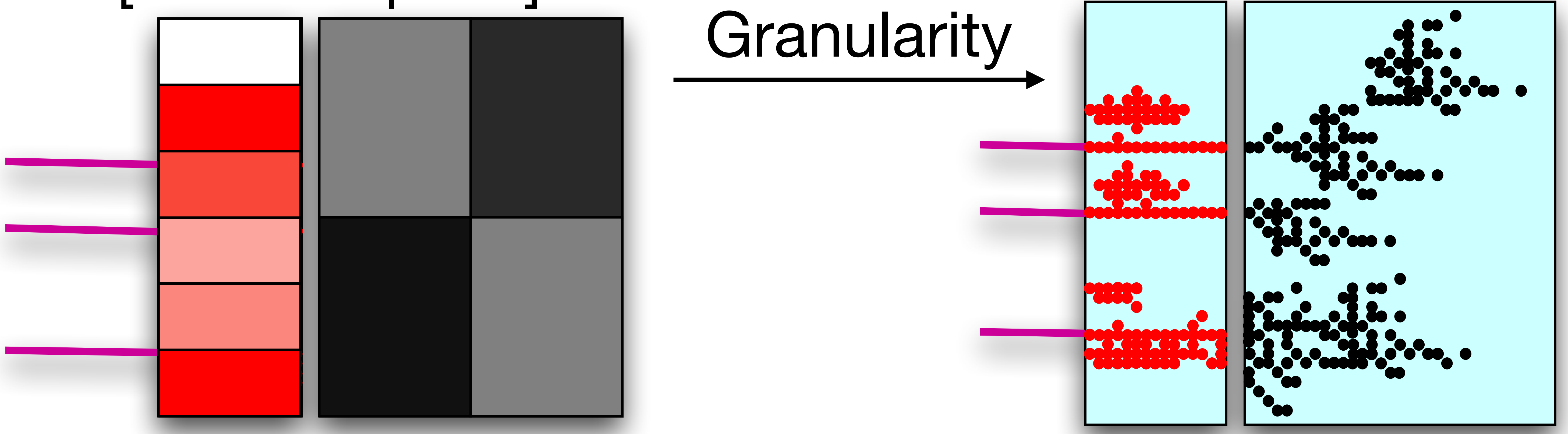

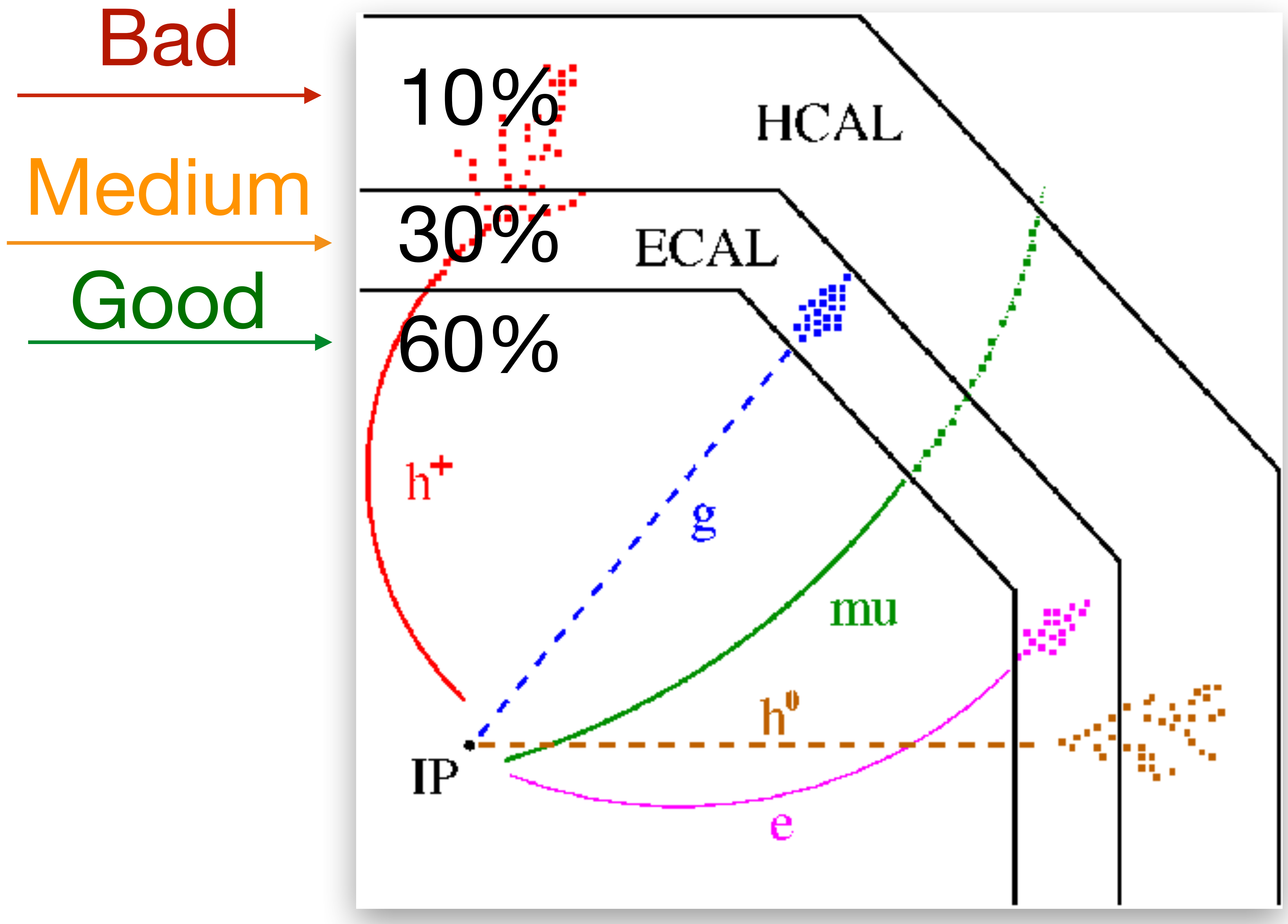

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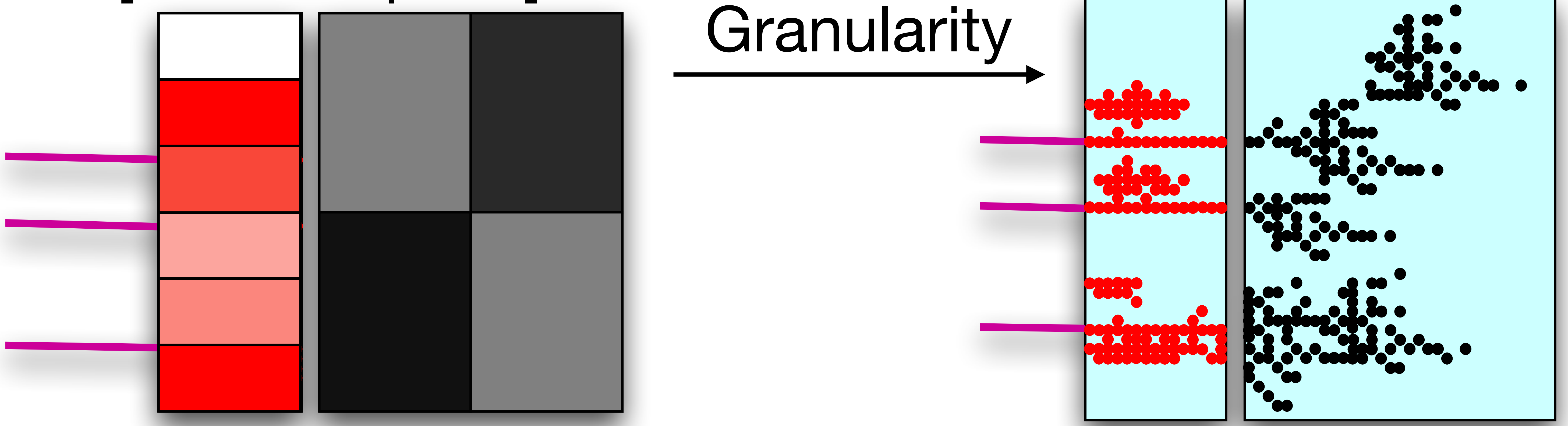
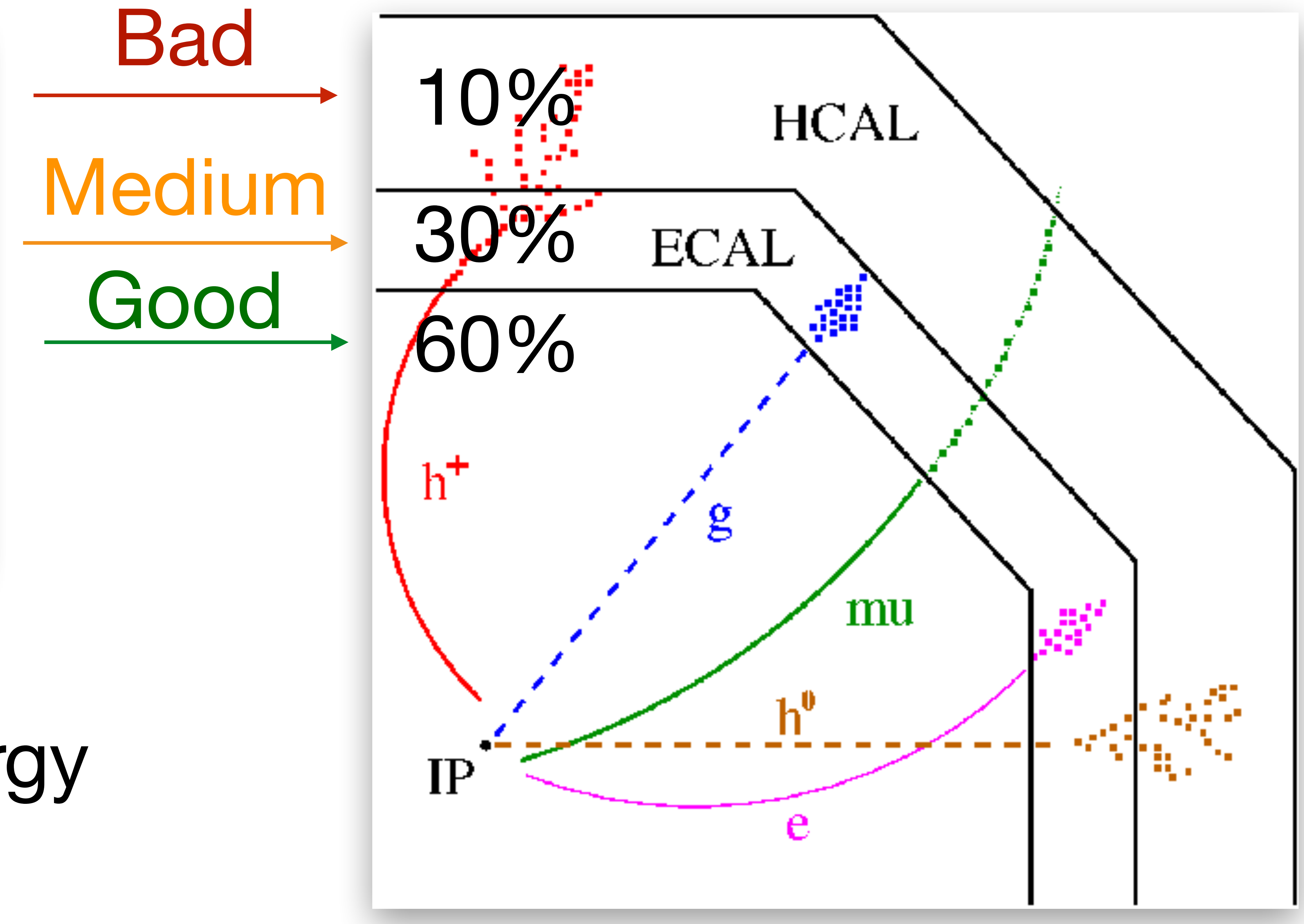




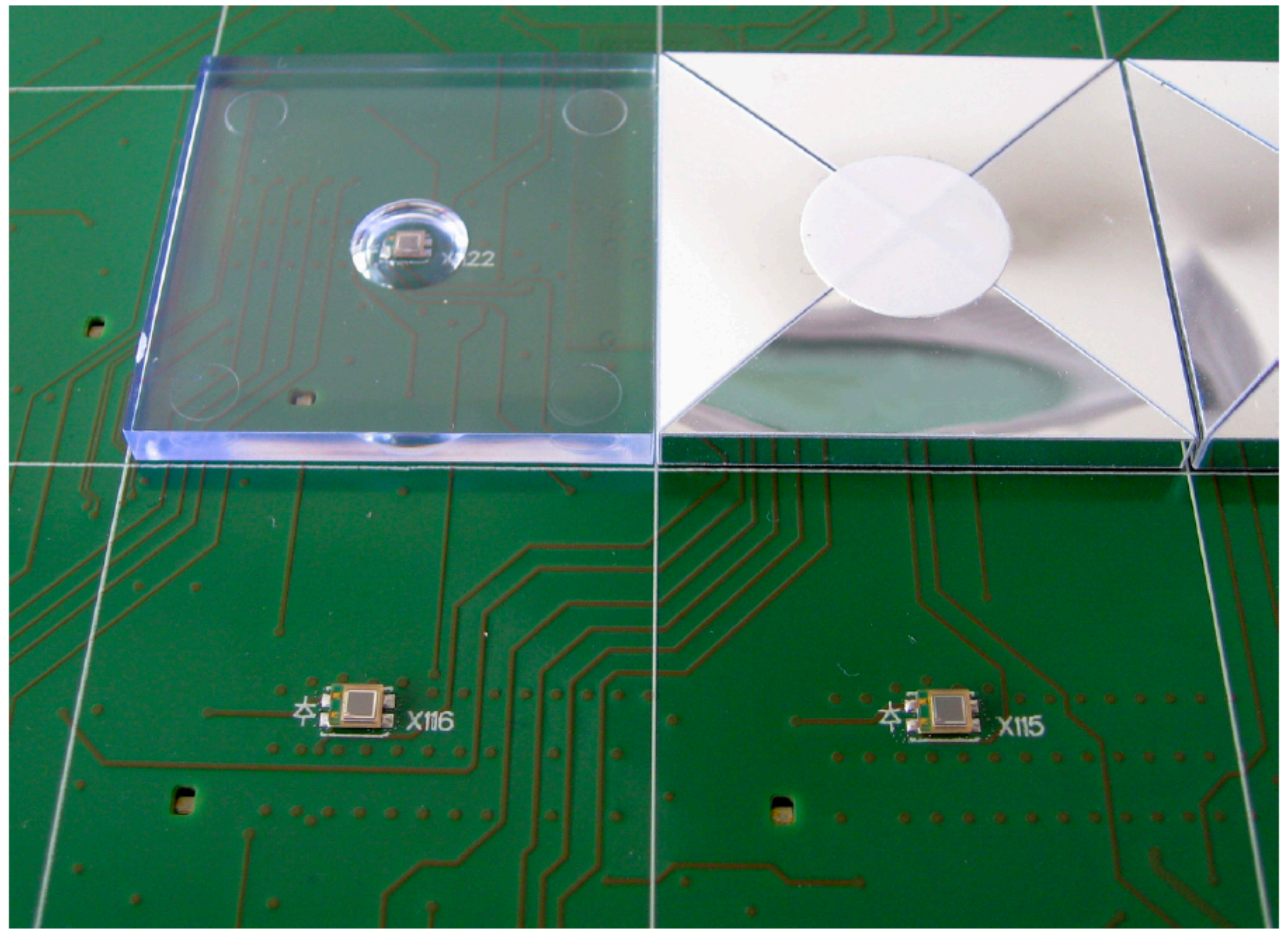
- HCAL contributes now only 10% to the total jet energy
  $\Longrightarrow$ intrinsically enhanced jet energy resolution

- Energy resolution determined by miss-identification of particles (confusion)

- Particle flow first used in ALEPH, but drives the detector design of future colliders

HCAL Prototype

CALICE highly granular analog hadronic calorimeter (AHCAL)



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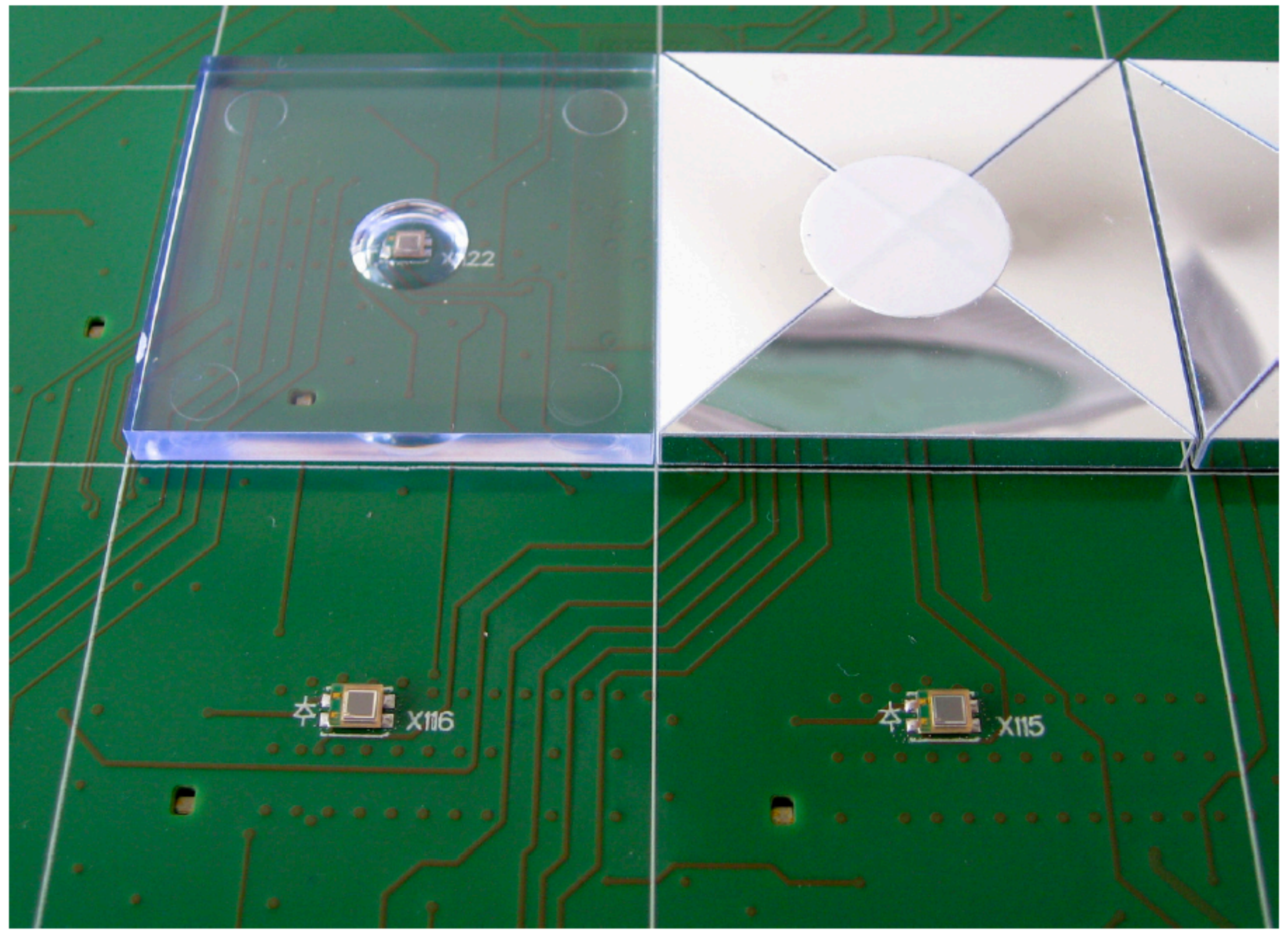

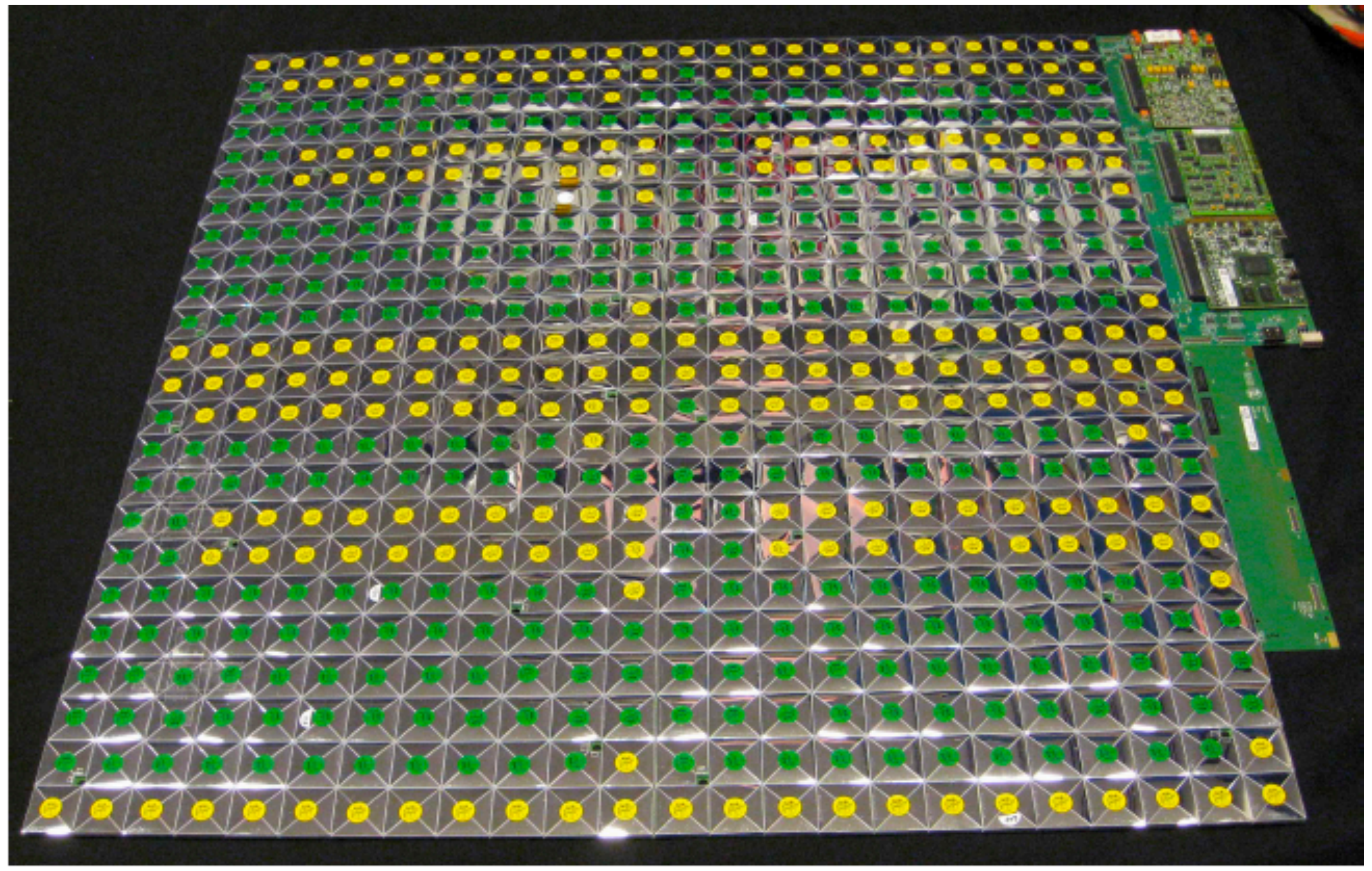

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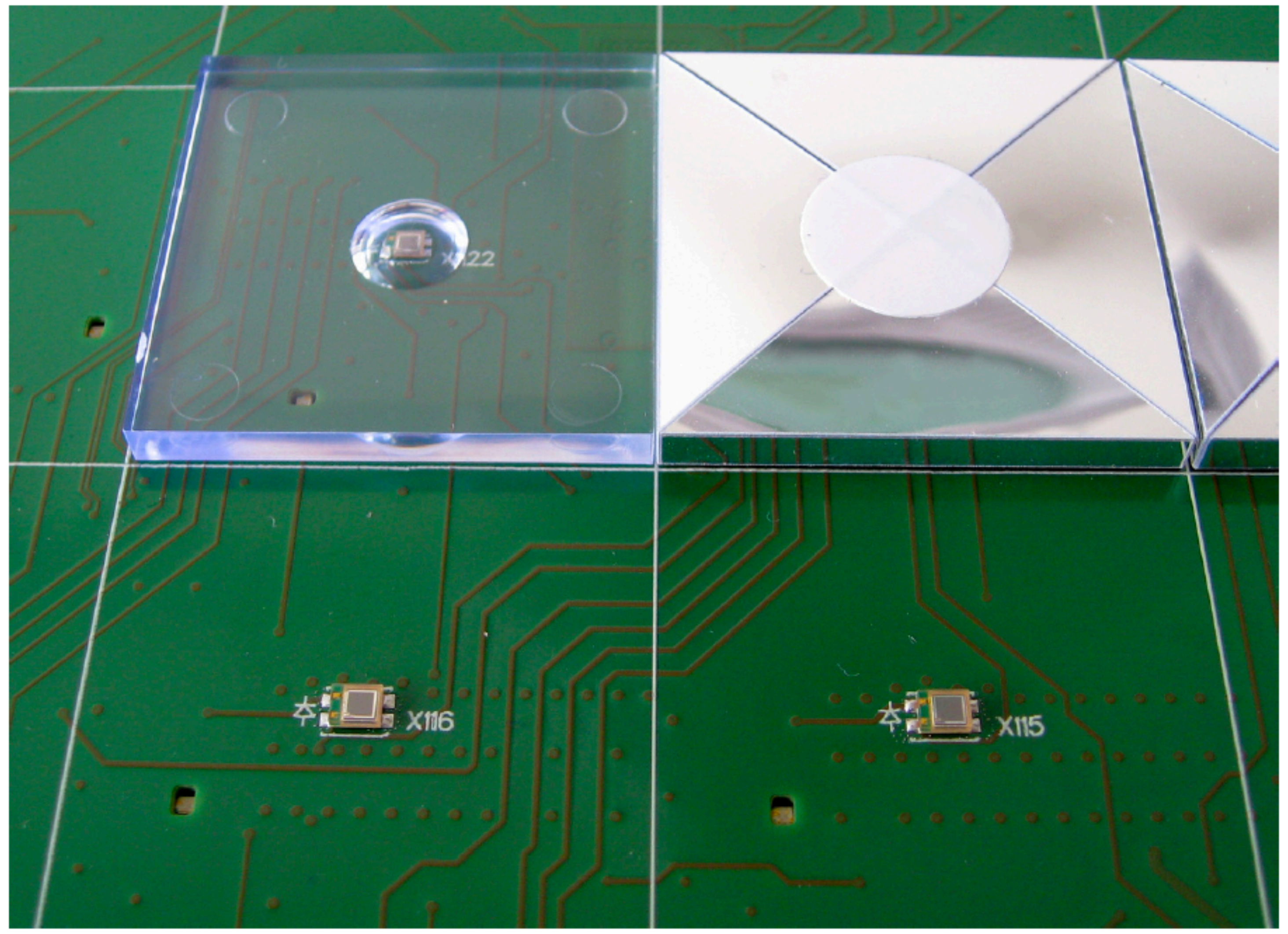

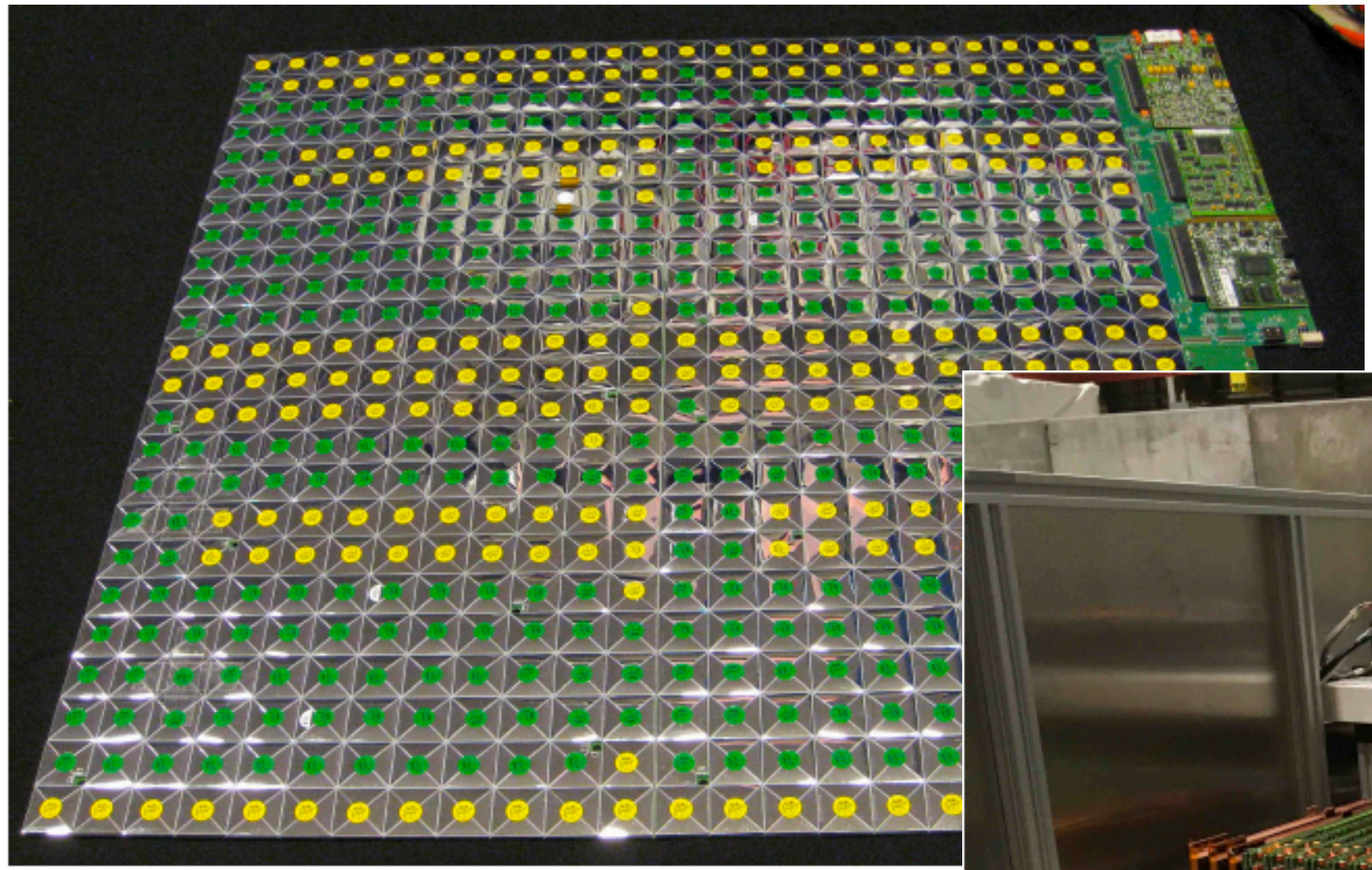

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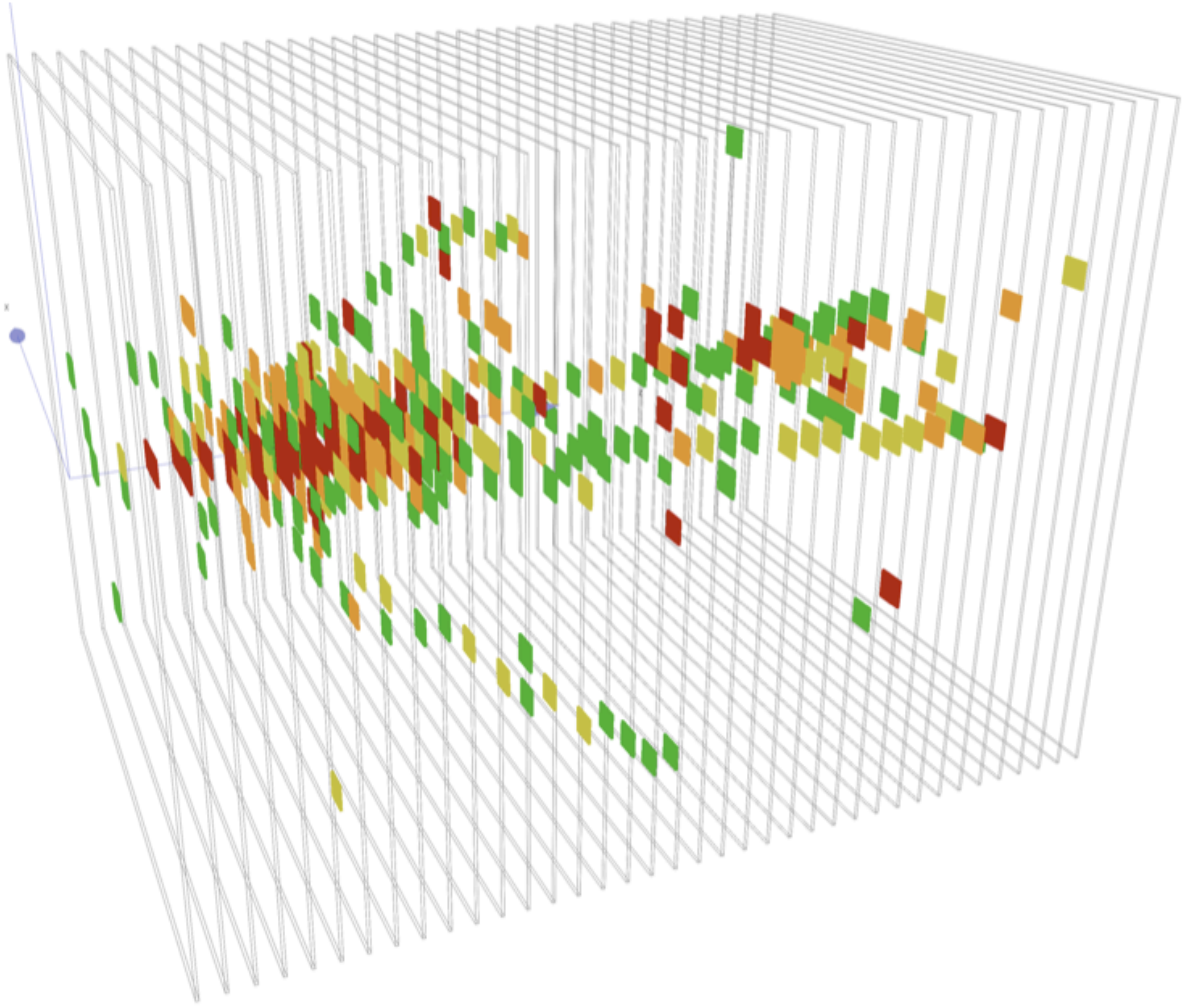

Hadronic shower of a 60 GeV Pion

Low energy deposition

↓

High energy deposition

Prospects for ILC and CLIC

Discussions on 250 GeV ILC in Japan:

- Candidate site: Kitakami
- Await statement in late 2018 (basically now)

Evaluation of staging possibilities to lower project entry costs

After positive response:

- ~4 years of preparation
- ~9 years of construction

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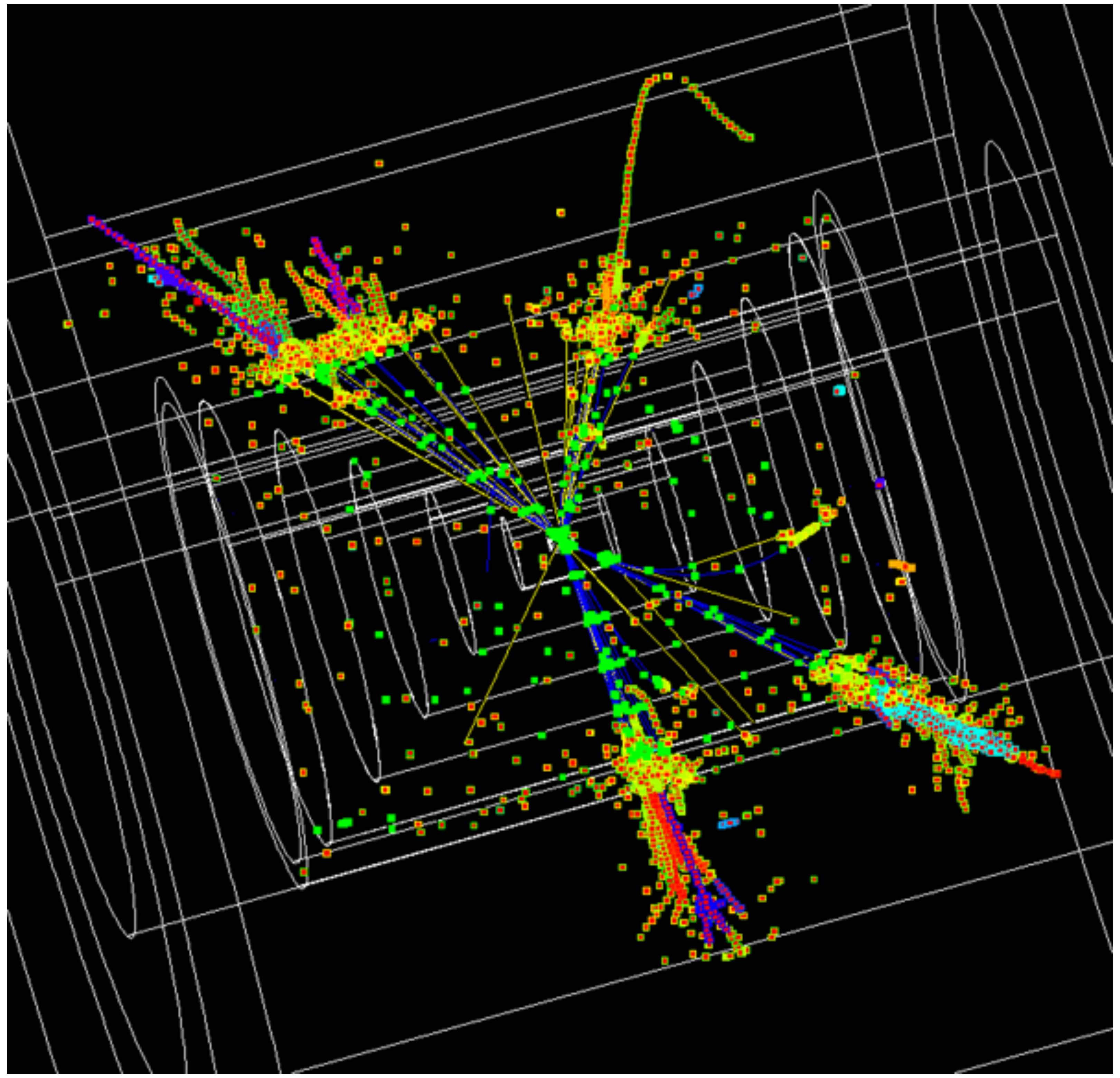
CLIC: Wait for update of European Strategy for Particle Physics

Summary

- Rich physics program to complement LHC
- Precision measurements to possibly detect SM deviations
- Staging capability to increase energy and match funding
- Detector design driven by particle flow approach
- Awaiting decisions on ILC in 2018 and on CLIC in 2019/20



Backup