

# PROSPECTS FOR HIGGS BOSON PHYSICS AT FUTURE CIRCULAR COLLIDERS

Daniela Bortoletto  
University of Oxford

**Higgs Hunting 2026**  
Results and prospects in the electroweak symmetry breaking sector

**16-18 September**  
**Orsay/Paris**

16<sup>TH</sup> HIGGS HUNTING

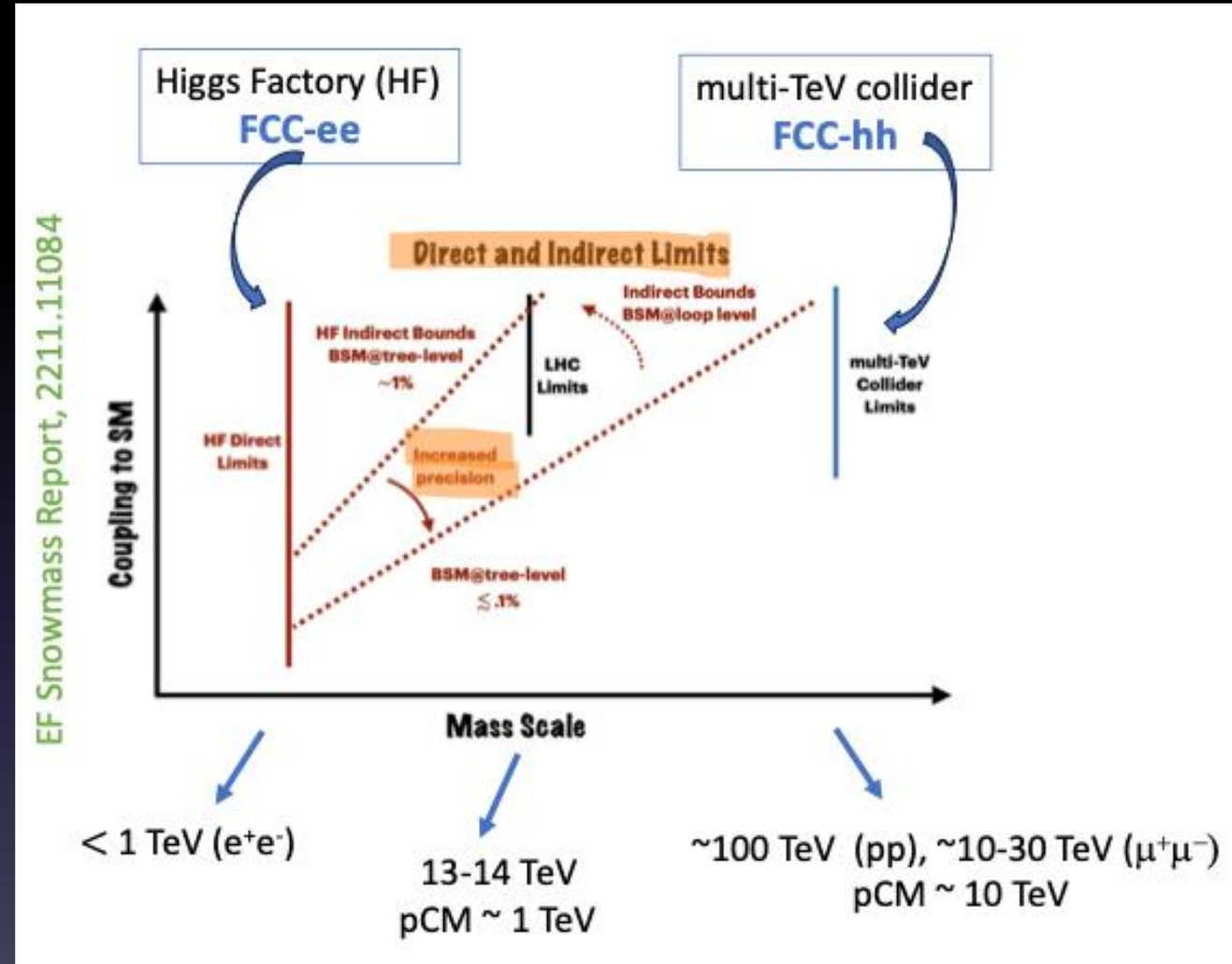
[www.higgshunting.fr](http://www.higgshunting.fr)

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# Future directions: precision and energy

- The Higgs remains our central goal because it is tied to many open questions
  - EWSB, flavor, CP violation, hidden sector, and the stability of the universe
- Given the level of consistency of the SM we expect new physics effects to be small
- The extreme precision at  $e^+e^-$  collider is crucial to identify small deviations from SM predictions and point to the scale of new physics.
- The energies available at a multi-TeV collider are complementary and they allow to probe directly multi-TeV new physics.



# The HL-LHC Higgs programme

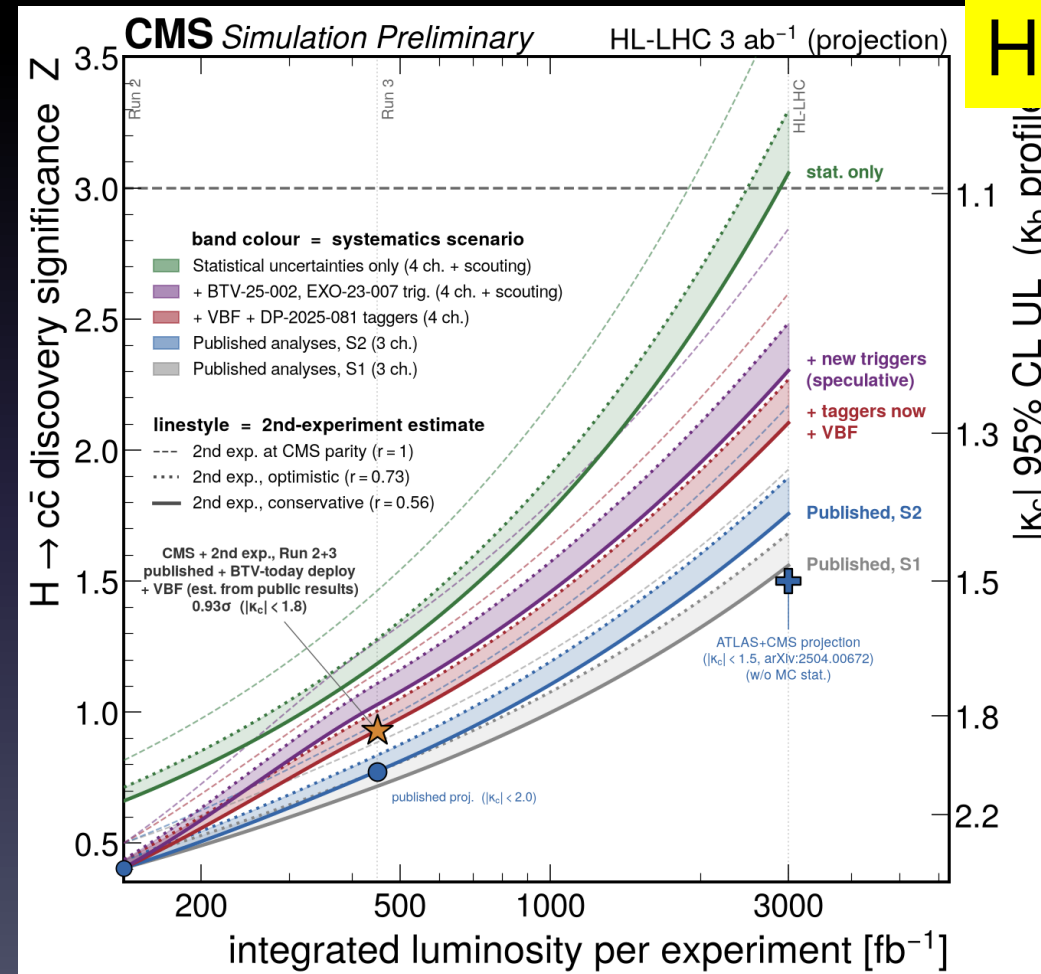
- Run 1 (25/fb) :  
Higgs discovery

- Run 2 (139/fb) :  
Higgs couplings

- Run 3 (332/fb) :  
Higgs precision  
program

- Run4 and beyond  
(3000/fb) will bring  
a 6-fold increase  
in statistics

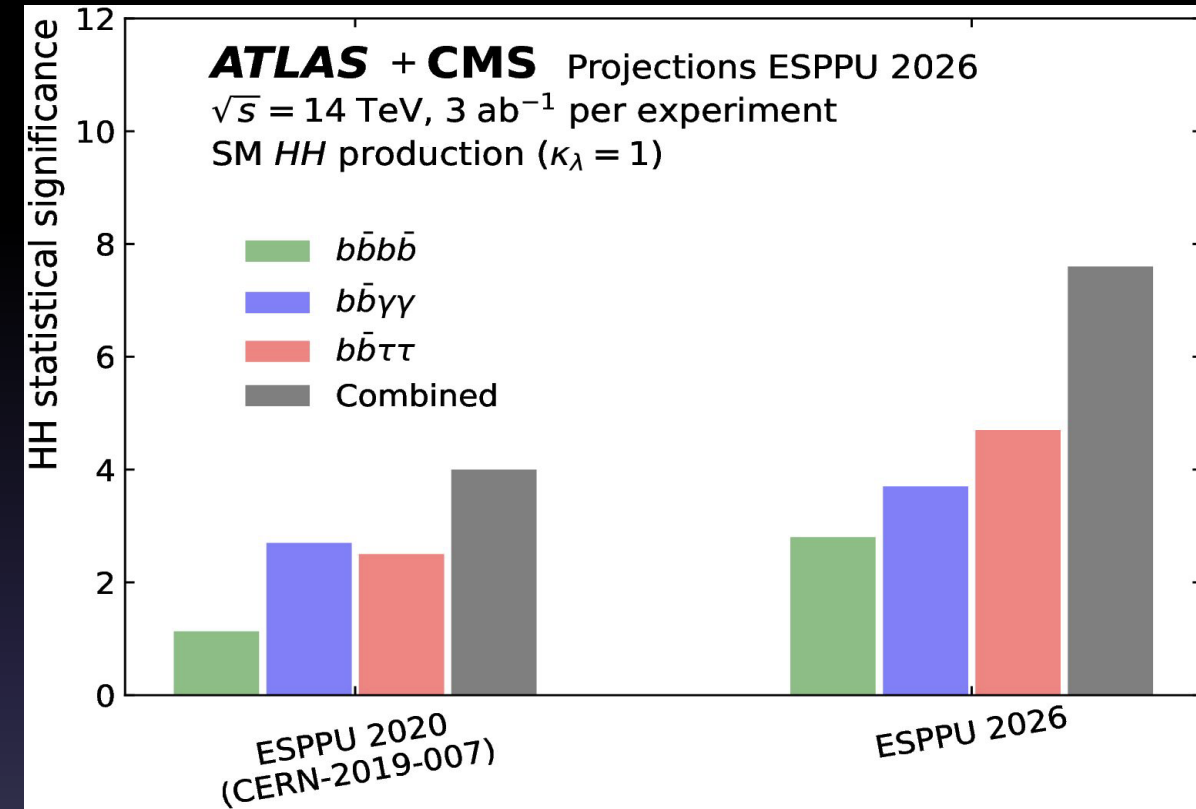
- Improvements in tools will bring results  
beyond expectation



**H → c $\bar{c}$**

# The legacy of the LHC + HL-LHC

- HL-LHC projections for the ESPPU based on Run 2 data:
  - 1.6-3.6 % on main couplings
  - 3-7% on  $H \rightarrow \mu^+ \mu^-$  and  $H \rightarrow Z\gamma$
  - < 30% on Higgs (trilinear) self-coupling
- Analyses and tools improving fast
- Theory could become main limitation



Measurements of  $HH$  production/Higgs self coupling will remain unbeaten until FCC-hh

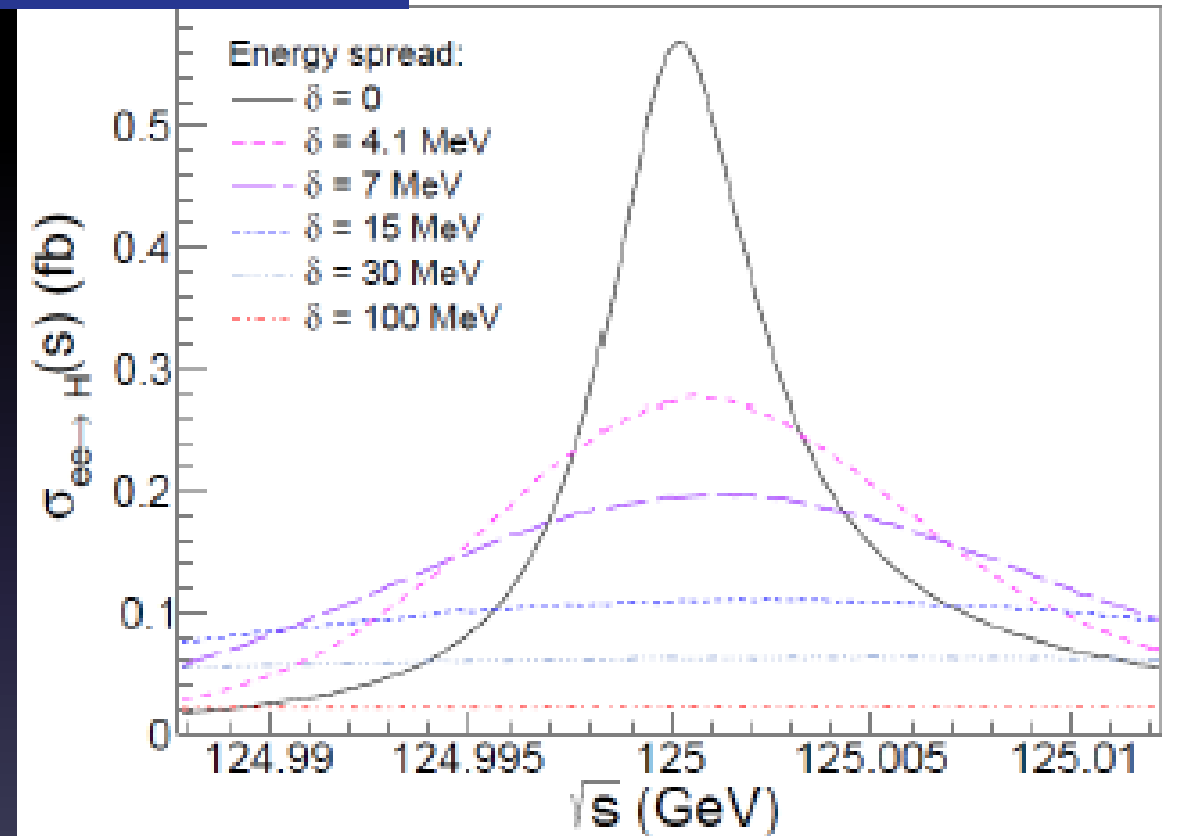
# FCC-ee: a Higgs factory

## Higgs Couplings

| Coupling                                        | HL-LHC                 | FCC-ee               |
|-------------------------------------------------|------------------------|----------------------|
| $\kappa_Z$ (%)                                  | 1.3*                   | 0.10                 |
| $\kappa_W$ (%)                                  | 1.5*                   | 0.29                 |
| $\kappa_b$ (%)                                  | 2.5*                   | 0.49                 |
| $\kappa_g$ (%)                                  | 2*                     | 0.54                 |
| $\kappa_\tau$ (%)                               | 1.6*                   | 0.46                 |
| $\kappa_c$ (%)                                  | —                      | 0.87                 |
| $\kappa_\gamma$ (%)                             | 1.6*                   | 1.1                  |
| $\kappa_{Z\gamma}$ (%)                          | 10*                    | 4.3                  |
| $\kappa_t$ (%)                                  | 3.2*                   | 3.1                  |
| $\kappa_\mu$ (%)                                | 4.4*                   | 3.3                  |
| $ \kappa_s $ (%)                                | —                      | +29<br>-67           |
| $\Gamma_H$ (%)                                  | —                      | 0.78                 |
| $\mathcal{B}_{\text{inv}} (<, 95\% \text{ CL})$ | $1.9 \times 10^{-2} *$ | $5 \times 10^{-4}$   |
| $\mathcal{B}_{\text{unt}} (<, 95\% \text{ CL})$ | $4 \times 10^{-2} *$   | $6.8 \times 10^{-3}$ |

\* next to HL-LHC numbers → not model independent

- Incredible precision
- Model independent results



Unique possibility: direct access to the electron Yukawa through s-channel Higgs production?

# FCCee: More than a Higgs Factory

Z pole:  
 $6 \times 10^{12}$  Z

WW Threshold:  
 $2.4 \times 10^8$  WW

ZH @ 240 :  
 $2.2 \times 10^6$  H

350-360 GeV :  
 $2.6 \times 10^6$  top  
+ 370k ZH  
+92 k WW  $\rightarrow$  H

| Observable                                              | present value | ± uncertainty | FCC-ee Stat.             | FCC-ee Syst. | Comment and leading uncertainty                                                                                  |
|---------------------------------------------------------|---------------|---------------|--------------------------|--------------|------------------------------------------------------------------------------------------------------------------|
| $m_Z$ (keV)                                             | 91 187 600    | ± 2000        | <b>4</b>                 | 100          | From Z line shape scan<br>Beam energy calibration                                                                |
| $\Gamma_Z$ (keV)                                        | 2 495 500     | ± 2300        | <b>4</b>                 | 12           | From Z line shape scan<br>Beam energy calibration                                                                |
| $\sin^2 \theta_W^{\text{eff}} (\times 10^3)$            | 231 480       | ± 160         | <b>1.2</b>               | 1.2          | From $A_{\text{FB}}^{\text{le}} \text{ at Z peak}$<br>Beam energy calibration                                    |
| $1/\alpha_{\text{QED}}(m_Z^2) (\times 10^3)$            | 128 952       | ± 14          | <b>3.9</b><br><b>0.8</b> | small<br>thc | From $A_{\text{FB}}^{\text{le}}$ off peak<br>From $A_{\text{FB}}^{\text{le}}$ on peak<br>QED&EW uncert. dominate |
| $R_e^Z (\times 10^3)$                                   | 20 767        | ± 25          | <b>0.05</b>              | 0.05         | Ratio of hadrons to leptons<br>Acceptance for leptons                                                            |
| $\alpha_S(m_Z^2) (\times 10^4)$                         | 1 196         | ± 30          | <b>0.1</b>               | 1            | Combined $R_e^Z, \Gamma_{\text{had}}^Z, \sigma_{\text{had}}^0$ fit                                               |
| $\sigma_{\text{had}}^0 (\times 10^3)$ (nb)              | 41 480.2      | ± 32.5        | <b>0.03</b>              | 0.8          | Peak hadronic cross section<br>Luminosity measurement                                                            |
| $N_\nu (\times 10^3)$                                   | 2 996.3       | ± 7.4         | <b>0.09</b>              | 0.12         | Z peak cross sections<br>Luminosity measurement                                                                  |
| $R_b (\times 10^6)$                                     | 216 290       | ± 660         | <b>0.25</b>              | 0.3          | Ratio of $b\bar{b}$ to hadrons                                                                                   |
| $A_{\text{FB}}^{b,0} (\times 10^4)$                     | 992           | ± 16          | <b>0.04</b>              | 0.04         | b-quark asymmetry at Z pole<br>From jet charge                                                                   |
| $A_{\text{FB}}^{\tau,\tau} (\times 10^4)$               | 1 498         | ± 49          | <b>0.07</b>              | 0.2          | $\tau$ polarisation asymmetry<br>$\tau$ decay physics                                                            |
| $\tau$ lifetime (fs)                                    | 290.3         | ± 0.5         | <b>0.001</b>             | 0.005        | ISR, $\tau$ mass                                                                                                 |
| $\tau$ mass (MeV)                                       | 1 776.93      | ± 0.09        | <b>0.002</b>             | 0.02         | estimator bias, ISR, FSR                                                                                         |
| $\tau$ leptonic ( $\mu_\nu \nu_\tau$ ) BR (%)           | 17.38         | ± 0.04        | <b>0.00007</b>           | 0.003        | PID, $\pi^0$ efficiency                                                                                          |
| $m_W$ (MeV)                                             | 80 360.2      | ± 9.9         | <b>0.18</b>              | 0.16         | From WW threshold scan<br>Beam energy calibration                                                                |
| $\Gamma_W$ (MeV)                                        | 2 085         | ± 42          | <b>0.27</b>              | 0.2          | From WW threshold scan<br>Beam energy calibration                                                                |
| $\alpha_S(m_W^2) (\times 10^4)$                         | 1 010         | ± 270         | <b>2</b>                 | 2            | Combined $R_e^W, \Gamma_{\text{tot}}^W$ fit                                                                      |
| $N_\nu (\times 10^3)$                                   | 2 920         | ± 50          | <b>0.5</b>               | small        | Ratio of invis. to leptonic<br>in radiative Z returns                                                            |
| $m_{\text{top}}$ (MeV)                                  | 172 570       | ± 290         | <b>4.2</b>               | 4.9          | From $t\bar{t}$ threshold scan<br>QCD uncert. dominate                                                           |
| $\Gamma_{\text{top}}$ (MeV)                             | 1 420         | ± 190         | <b>10</b>                | 6            | From $t\bar{t}$ threshold scan<br>QCD uncert. dominate                                                           |
| $\lambda_{\text{top}}/\lambda_{\text{top}}^{\text{SM}}$ | 1.2           | ± 0.3         | <b>0.015</b>             | 0.015        | From $t\bar{t}$ threshold scan<br>QCD uncert. dominate                                                           |
| $t\bar{t}Z$ couplings                                   | ± 30%         |               | <b>0.5–1.5 %</b>         | small        | From $\sqrt{s} = 365$ GeV run                                                                                    |

- Exploiting these huge samples requires understanding detector systematics, beam properties, backgrounds — and theory — at a completely new level.

## Precision for extraction from data

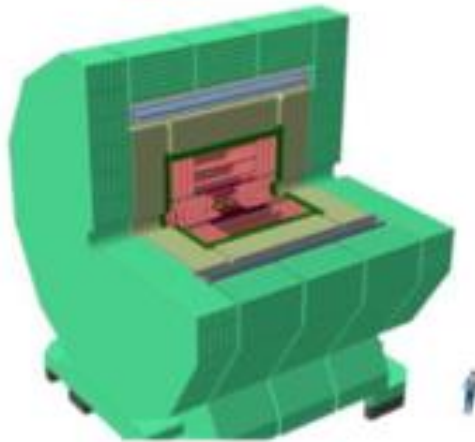
| Quantity                       | Current precision    | FCC-ee stat. (syst.) precision | Required theory input                               | Theory status as of today                                                                            | Needed theory improvement <sup>†</sup>                                       |
|--------------------------------|----------------------|--------------------------------|-----------------------------------------------------|------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------|
| $m_Z$ (MeV)                    | 2.0                  | 0.004 (0.1)                    | non-resonant $e^+e^- \rightarrow f\bar{f}$          | NLO, ISR logarithms up to 6 <sup>th</sup> order                                                      | NNLO for $e^+e^- \rightarrow f\bar{f}$                                       |
| $\Gamma_Z$ (MeV)               | 2.3                  | 0.004 (0.012)                  | initial-state radiation (ISR)                       |                                                                                                      |                                                                              |
| $\sin^2 \theta_{\text{eff}}^l$ | $1.6 \times 10^{-4}$ | $1.2 (1.2) \times 10^{-6}$     |                                                     |                                                                                                      |                                                                              |
| $m_W$ (MeV)                    | 9.9                  | 0.18 (0.16)                    | lineshape of $e^+e^- \rightarrow WW$ near threshold | NLO ( $e^+e^- \rightarrow 4f$ or EFT framework)                                                      | NNLO for $e^+e^- \rightarrow WW, W \rightarrow f\bar{f}'$ in EFT setup       |
| HZZ coupling                   | — *                  | 0.1%                           | cross section for $e^+e^- \rightarrow ZH$           | NLO EW plus partial NNLO QCD/EW                                                                      | full NNLO EW                                                                 |
| $m_{\text{top}}$ (MeV)         | 290                  | 4.2 (4.9)                      | threshold scan $e^+e^- \rightarrow t\bar{t}$        | N <sup>3</sup> LO QCD, NNLO EW, resummations up to NNLL, $\mathcal{O}(30 \text{ MeV})$ scale uncert. | Matching fixed orders with resummations, merging with MC, $\alpha_S$ (input) |

FCC feasibility study report – 2505.00272

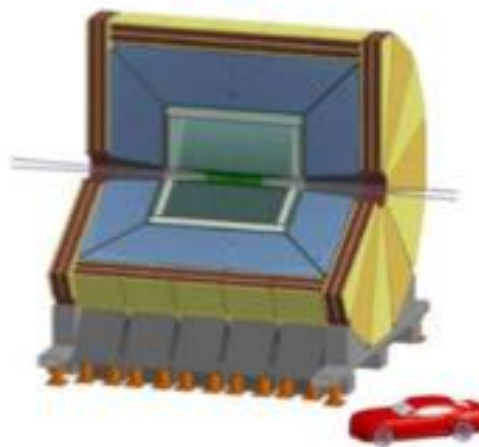
- Operation at the Z pole poses the most demanding experimental challenges

# Detectors Concepts

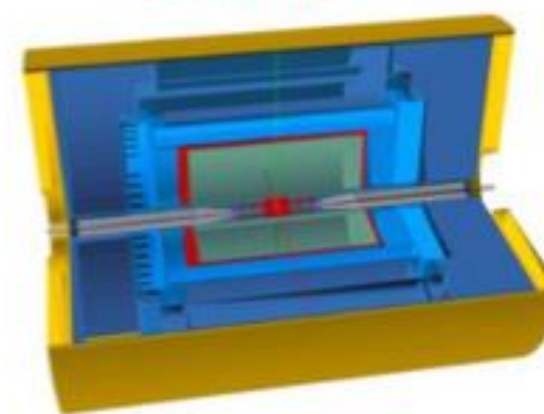
CLD



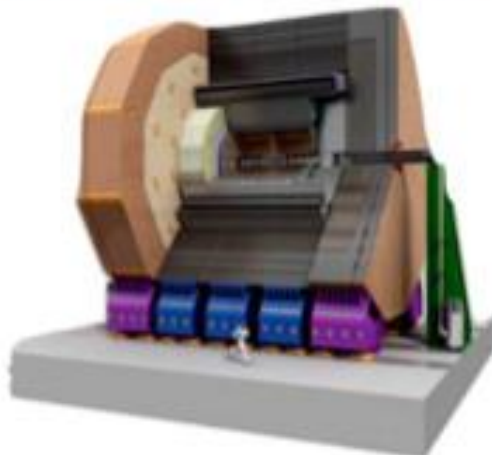
IDEA



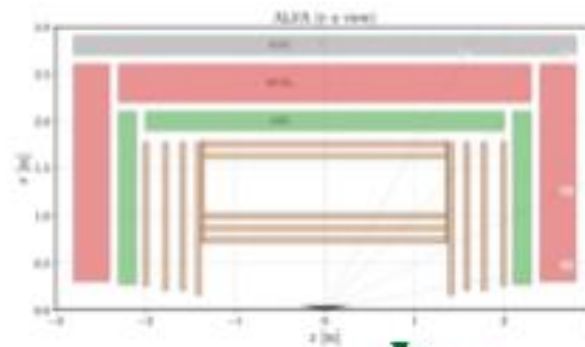
ALLEGRO



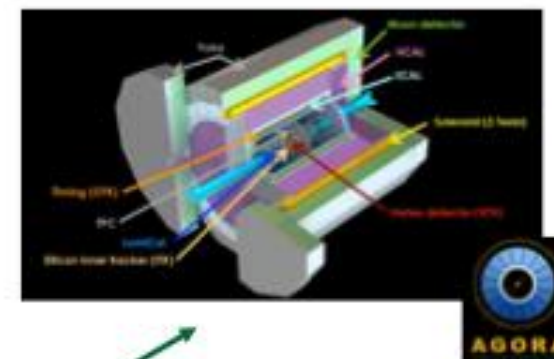
ILD (being ported from ILC)



ALFA



AGORA (being ported from CEPC)

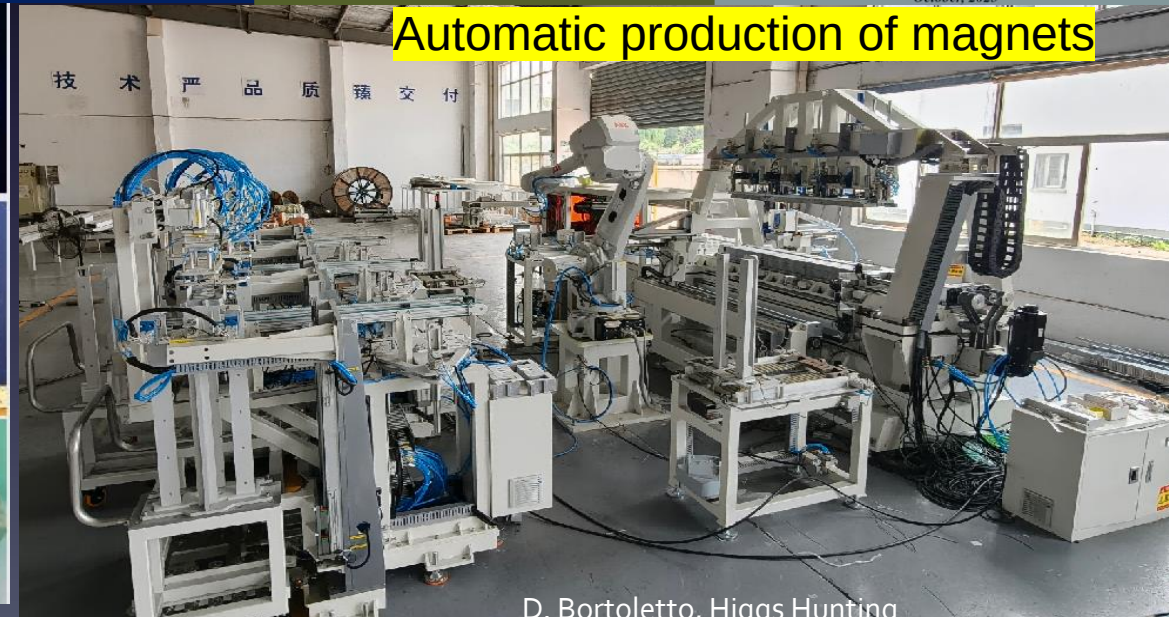
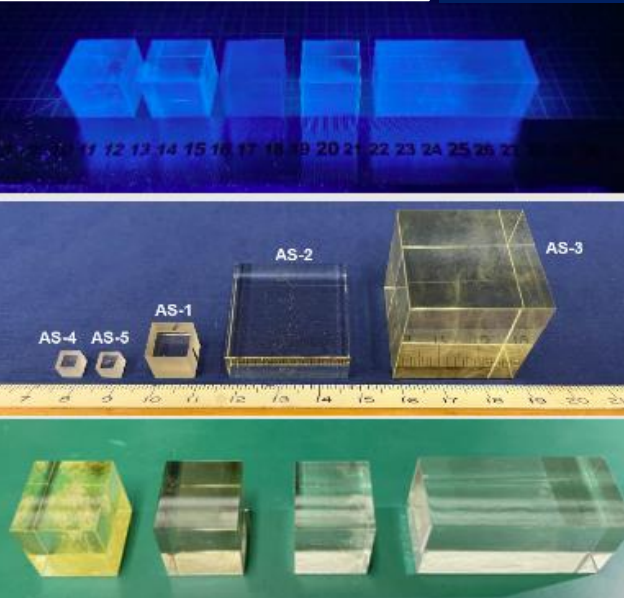
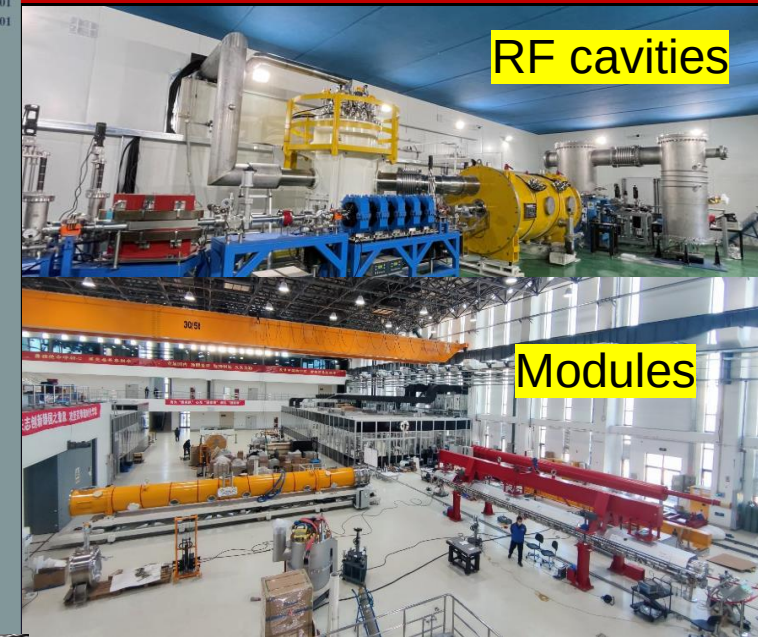


New additions

# Detector Concepts

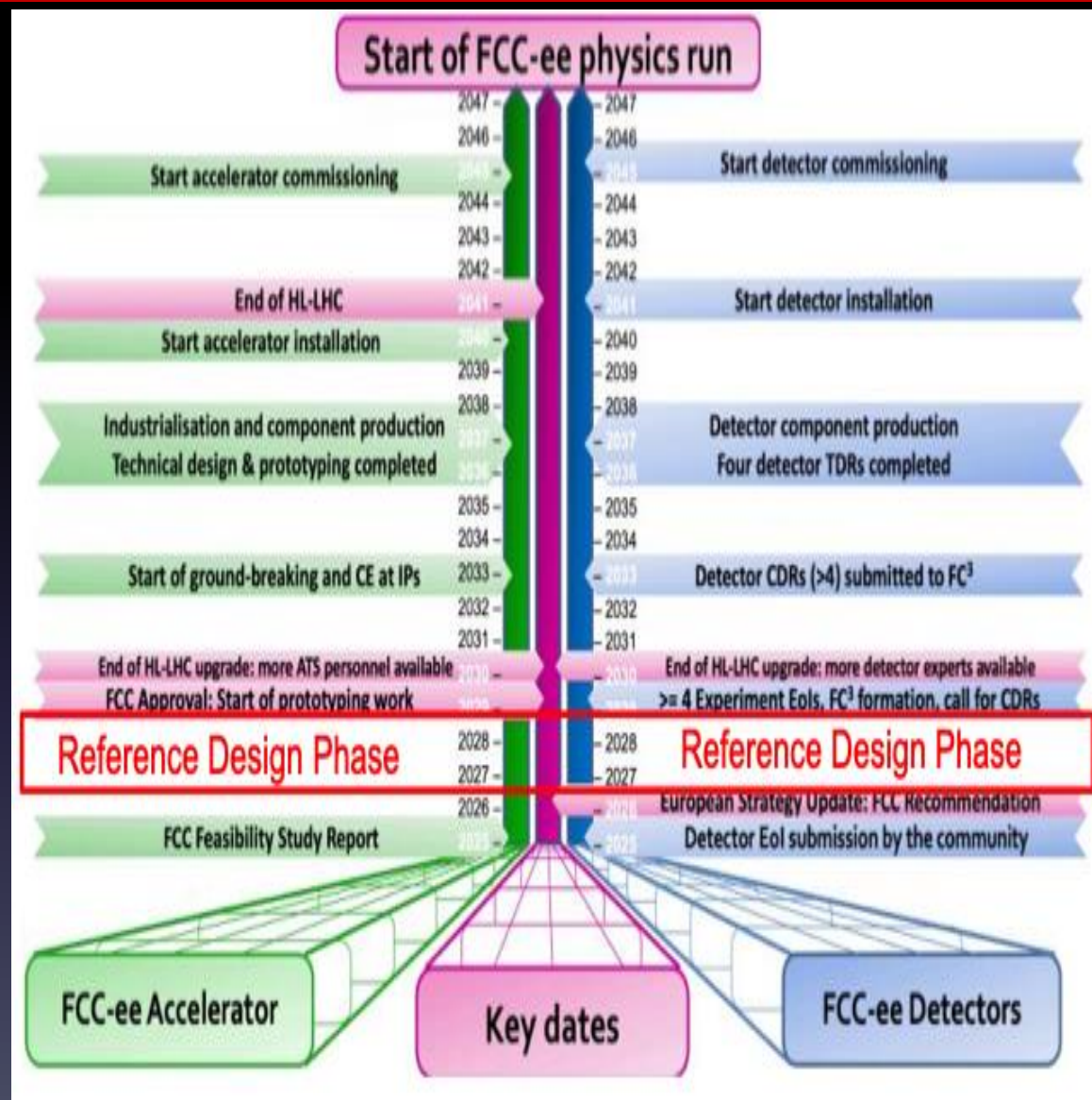
|                                                   | Tracker                                                     | PID                                      | ECAL                                                                 |
|---------------------------------------------------|-------------------------------------------------------------|------------------------------------------|----------------------------------------------------------------------|
| <b>CLD</b><br><a href="#">[FCC week link]</a>     | Si based<br>(precise technology<br>under review)            | Option for RICH ('ARC')                  | Silicon tungsten                                                     |
| <b>IDEA</b><br><a href="#">[FCC week link]</a>    | Drift chamber, plus<br>Si wrapper                           | dE/dx, dN/dx, plus TOF                   | Crystal dual<br>readout                                              |
| <b>ALLEGRO</b><br><a href="#">[FCC week link]</a> | Drift chamber or<br>straw tube or SciFi,<br>plus Si wrapper | dE/dx, dN/dx<br>(if available), plus TOF | Noble-liquid                                                         |
| <b>ILD</b><br><a href="#">[FCC week link]</a>     | TPC                                                         | dE/dx, dN/dx,<br>possibly plus TOF       | Silicon tungsten                                                     |
| <b>ALFA</b><br><a href="#">[FCC week link]</a>    | MAPS                                                        | RICH ('ARC')                             | GRAINITA (novel<br>crystal-based),<br>better than<br>2%/sqrt(E) + 1% |
| <b>AGORA</b><br><a href="#">[FCC week link]</a>   | TPC (for now)                                               | dE/dx, dN/dx<br>Possible forward RICH    | BGO crystal<br>2%/sqrt(E) + 1%                                       |

# Impressive R&D for CEPC



# Reaching the goal

- CEPC was not included in China's 15th Five-Year Plan (2026–2030)
- Accelerator and detector R&D continues, including applications/upgrades for BEPCII
- Looking toward a major partnership with FCC and identifying common interests and technologies
- If FCC construction is not officially approved before 2030, the CEPC proposal would be resubmitted to the Chinese government



- The ESPPU has concluded.
- Key points regarding FCC:
  - Overwhelmingly strong endorsement of the physics and strategic case for FCC-ee as the next flagship collider at CERN
  - A descoped/staged FCC-ee is preferred to other options as the alternative
- Council has approved the strategy and given CERN a mandate to prepare FCC-ee for a 2028 decision

# Are we ready for 2028 ?

## 1. Detector readiness

- Are we on a credible path to TDRs?

## 2. Physics + theory readiness

- Can we exploit the precision that the machine promises?

## 3. Machine / Running strategies / Possible descoping

- Do we know enough to define the machine — while preserving physics flexibility?

## 4. Community / collaboration readiness

- Could we form strong experimental collaborations rapidly after approval?