

# Experiments at FCC: Overview



## The FCC Physics coordination group

### FCC-ee

Alain Blondel

John Ellis

Christophe Grojean

Patrick Janot

### FCC-hh

Austin Ball

Fabiola Gianotti

Michelangelo Mangano

### FCC-eh

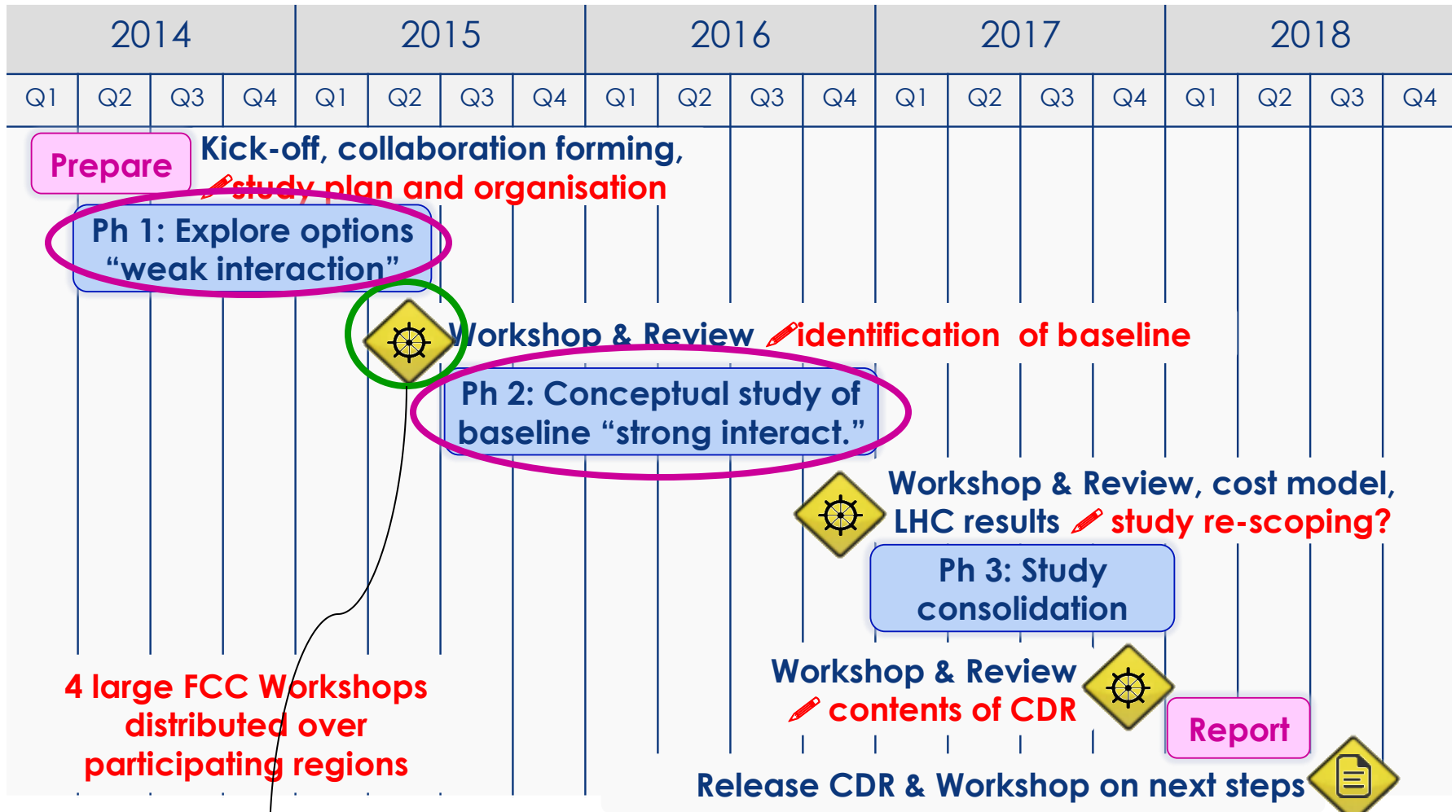
Max Klein

Monica d'Onofrio

# Aims of the “Physics & Experiments” Study

- **Establish the physics capabilities of the FCCs (ee, hh, eh)**
  - ◆ With emphasis on the complementarity and coverage of the whole package
  - ◆ Identify areas where new theoretical calculations / experimental inputs are needed
  
- **Scope and document the potential for (new) physics discovery**
  - ◆ Direct observation of new particles
  - ◆ Precision measurements of Standard Model observables (EW, Higgs, Top, Flavours. ...)
  - ◆ Search for rare or forbidden phenomena
  
- **Understand the detector performance requirements**
  - ◆ Develop possible detector designs
  - ◆ Explore existing and future technologies
  - ◆ Identify areas of necessary R&D
  
- **Study machine-detector interface & experimental environment issues**
  - ◆ Identify consequences on machine infrastructure, detector layout, staging scenarios, ...

# FCC Design Study: Timeline



◆ We are here .

# Physics & Experiments in Phases 1 and 2

## □ **First phase until March 2015**

- ◆ Scoped the physics panorama
- ◆ Identified the main technical issues and the areas that need work
- ◆ Established collaboration and reach out interested groups
- ◆ Defined and started implementation of a common software environment
- ◆ Got things started

## □ **Second phase until November 2016**

- ◆ Study the – often unique – physics opportunities in (some) detail
- ◆ Understand and study the detector options
- ◆ Establish the machine-detector interface layout
- ◆ Perform (detailed) event simulations for experimental studies
- ◆ Document the progress made well before the next annual meeting

# Working group meetings (1)

## Agendas of various working group meetings / workshops

◆ <http://indico.cern.ch/>

The screenshot shows the Indico website interface. On the left, there is a navigation menu with 'Projects' circled in green. In the center, a 'Projects' list includes 'FCC' circled in pink, with a blue arrow pointing to the right. On the right, the 'FCC' section is titled 'FCC (Future Circular Colliders)' and contains a table of event categories. The 'Physics and Experiments' row in this table is circled in red.

FCC (Future Circular Colliders)	
Accelerators	96 events →
Governance	55 events 🛡️ →
Implementation and Planning	empty →
Infrastructure and Operation	22 events →
<b>Physics and Experiments</b>	<b>106 events →</b>
Study Office Meetings	1 event 🛡️ →
Conferences and Workshops	2 events →

# Working group meetings (2)

- Agendas of various working group meetings / workshops (cont'd)

## Physics and Experiments

Meetings related to physics and experiments

Hadron Collider Physics and Experiments	47 events	⇒
Lepton Collider Physics and Experiments	27 events	⇒
Lepton Hadron Collider Physics and Experiment	empty	⇒
Common activities	32 events	⇒
Physics coordination meetings	7 events	🛡️ ⇒
Offline software development	32 events	⇒

- ◆ FCC-eh meetings still under the “LHeC” indico project – to be moved soon
  - <http://indico.cern.ch/category/1874/>

# Activities common to FCC-ee, -hh, -eh (1)

- **Physics coordination: FCC-ee, -hh, -eh coordinators + project managers**
  - ◆ Ensure that all physics studies progress as one single endeavour
    - Propose physics topics to be used in the study of complementarity and synergies

Subject		ee	hh	eh
<b>Higgs Physics</b>	Precision studies Higher dimension operators Composite Higgs Rare and exotic decays Multiple Higgs production Extra Higgs bosons			
<b>Interface with Cosmology</b>	Dark matter Baryogenesis Right-handed/(almost) sterile neutrinos			
<b>EW Symmetry Breaking</b>	WW scattering Supersymmetry Extra dimensions Composite models			
<b>Flavour Changing</b>	Rare H,Z,W,top decays Lepton flavor violation			
<b>Extensions of the SM</b>	Extra vector-like fermions $SU(2)_R$ models Leptoquarks			
<b>QCD</b>	Perturbation theory, structure functions Modelling final states			
<b>EW/SM precision issues</b>	Precision measts ( $m_Z, m_W, m_t, \alpha, \alpha_s(m_Z), \sin^2\theta_W, R_b, \dots$ ) Higher-order EW corrections W,Z triple and quadruple couplings Top (anomalous) couplings Charm/bottom flavor studies			

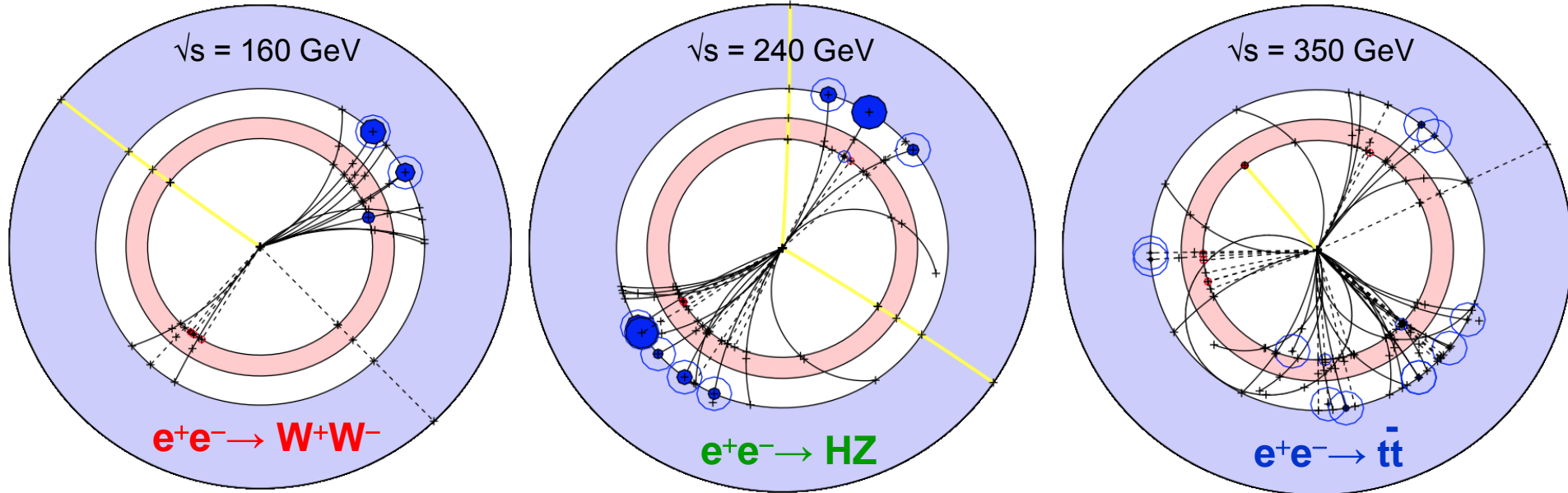
# Activities common to FCC-ee, -hh, -eh (2)

## Offline software developments

Subscribe to [fcc-experiments-sw-dev@cern.ch](mailto:fcc-experiments-sw-dev@cern.ch)

- ◆ Conveners: Colin Bernet & Benedikt Hegner
- ◆ Weekly meetings and monthly tutorials towards enabling physics analyses

See Benedikt's talk today at 16:15



Overall twiki page : <https://twiki.cern.ch/twiki/bin/viewauth/FCC/FccSoftware>



# The ultimate goal – FCC-hh

## □ Topics covered by mandate

- ◆ Study and document the physics opportunities of
  - pp collisions at 100 TeV
  - pA and AA collisions at ~63 TeV and ~40 TeV, resp.
  - Experiments exploiting the injector complex
  
- ◆ For the each item in the above physics programme
  - Define detector performance requirements
  - Develop detector designs
  - Study the machine-detector interface issues

# FCC-hh : Working groups

## □ **Physics studies**

- ◆ Higgs and EW symmetry breaking
- ◆ Beyond the Standard Model
- ◆ Standard Model
- ◆ Physics of heavy ion collisions
- ◆ Experiments with the injectors

## □ **Experiment studies at 100 TeV**

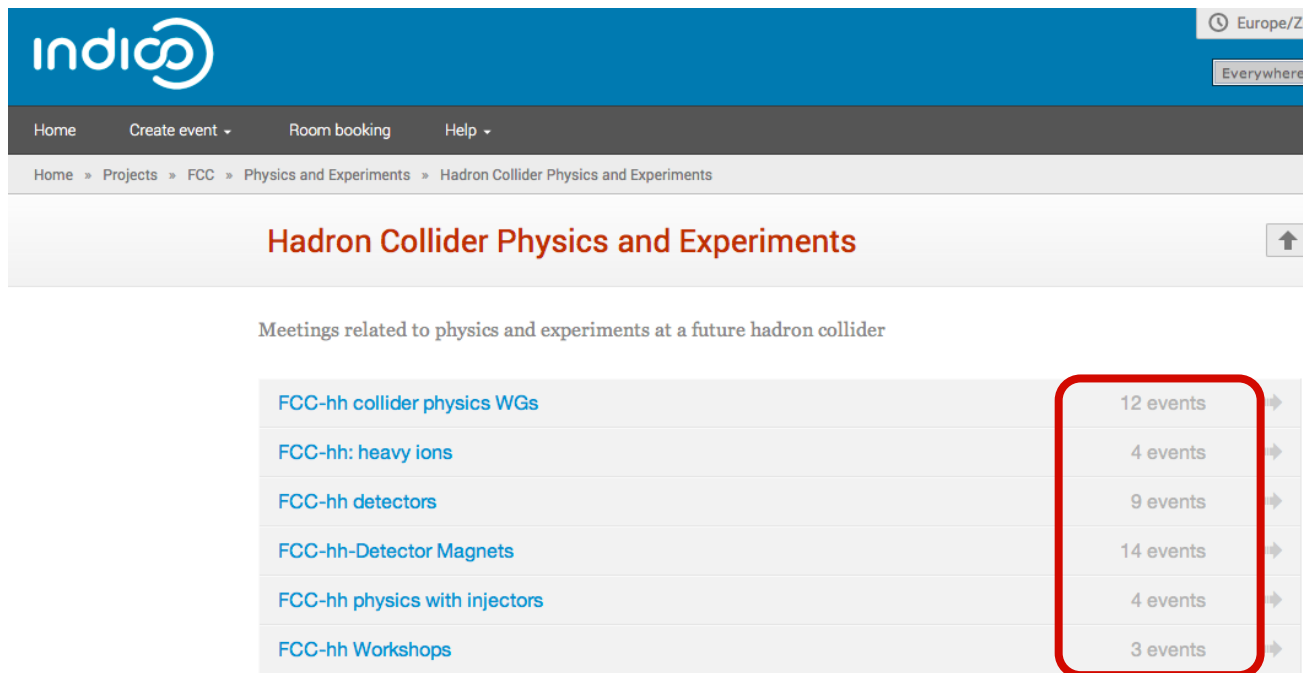
- ◆ Detectors
- ◆ Detector magnets
- ◆ Machine-detector interface

## □ **Overall twiki page**

- ◆ <https://twiki.cern.ch/twiki/bin/view/LHCPhysics/FutureHadroncollider>

# FCC-hh : General documentation

- **Mailing list** for general announcements: *fcc-experiments-hadron@cern.ch*
  - ◆ **To subscribe:** <http://cern.ch/simba3/SelfSubscription.aspx?groupName=fcc-experiments-hadron>
- **Agenda** for WG meetings and workshops  
<http://indico.cern.ch/category/5258/>



The screenshot shows the Indico website interface. The top navigation bar includes the Indico logo, a search bar with 'Europe/Z' and 'Everywhere' filters, and menu items for 'Home', 'Create event', 'Room booking', and 'Help'. The breadcrumb trail indicates the current page is 'Home > Projects > FCC > Physics and Experiments > Hadron Collider Physics and Experiments'. The main heading is 'Hadron Collider Physics and Experiments'. Below this, a sub-heading reads 'Meetings related to physics and experiments at a future hadron collider'. A table lists the following meetings and their event counts:

FCC-hh collider physics WGs	12 events
FCC-hh: heavy ions	4 events
FCC-hh detectors	9 events
FCC-hh-Detector Magnets	14 events
FCC-hh physics with injectors	4 events
FCC-hh Workshops	3 events

# FCC-hh : Physics at 100 TeV (1)

- Higgs and EWSB conveners: Gray (exp) Contino (th)
    - twiki: <https://twiki.cern.ch/twiki/bin/view/LHCPhysics/HiggsEWSymmetry>
  - BSM conveners: Moortgat, Golling (exp), Mangano, Schwaller (th)
    - twiki: <https://twiki.cern.ch/twiki/bin/view/LHCPhysics/BSM>
  - SM convener: Zanderighi (th)
- So far 12 WG meetings, 3 workshops
- *Twiki pages*: document current studies, collect links to literature, cross sections, etc. Everyone welcome to directly contribute, add topics, find topics to contribute to (e.g. with experimental studies of theory proposals)
- *2015 target*: document status of the studies in a report on “Physics opportunities at 100 TeV”, to be completed by end of the year
- *Physics topics* reviewed in the Phenomenology session on Thursday.

See also recent workshop on “Higgs and BSM at 100 TeV”, CERN, March 11-13, <http://indico.cern.ch/event/352868/>

# FCC-hh : Physics at 100 TeV (2)

## □ Example of twiki page : BSM group

The screenshot shows a web browser window with the URL `https://twiki.cern.ch/twiki/bin/view/LHCPhysics/BSM`. The page title is "BSM < LHCPhysics < TWiki". The main heading is "Beyond the Standard Model Physics studies". Below the heading, there is a paragraph: "This working group of the FCC-hh physics program focusses on studies of the Beyond the Standard Model Physics." The "Subgroups" section contains three items: "Dark Matter", "SUSY", and "Resonances, other BSM models and new analysis techniques". The "SUSY" item is circled in red, and a red arrow points from it to the text "see e.g. next slide".

BSM < LHCPhysics < TWiki

<https://twiki.cern.ch/twiki/bin/view/LHCPhysics/BSM>

events Sport Doodle TMP LHCC CERN CONF CDF NEWS TRAVEL Inspire APPS MLM ALPGEN FL@LHC HEP B

Vidyo | Welcome BSM < LHCPhysic... Self subscription... Ions at the Future... Inspire refersto:recid:129...

### Beyond the Standard Model Physics studies

This working group of the FCC-hh physics program focusses on studies of the Beyond the Standard Model Physics.

#### Subgroups

- [Dark Matter](#)  
Exploratory studies for Dark Matter (all types) at 100 TeV.
- [SUSY](#) → see e.g. next slide  
Exploratory studies for supersymmetry at 100 TeV.
- [Resonances, other BSM models and new analysis techniques](#)  
Exploratory studies for resonances (do-jet, di-lepton, ttbar) and other BSM models. New analysis techniques (esp. boosted) relevant at 100 TeV.

# FCC-hh : Physics at 100 TeV (3)

## Supersymmetry studies for the FCC-hh

### Ongoing work

- Exploring pMSSM at 100 TeV (N. Mahmoudi et al) [Show Details](#)
- Rare production mechanisms in SUSY [Show Details](#)

### SUSY production cross sections at 33 and 100 TeV:

The compilation of cross sections and tools is maintained in the [twiki](#) page of the LHC SUSY Cross Section WG. The results are documented in [arXiv:1407.5066](#)

### Values for some reference processes are given here (compiled by Anna Sfyria):

- Stop/sbottom pair-production NLO cross sections with light squarks and gluinos decoupled

[Hide Cross Sections](#)

squark mass [GeV]	33 TeV xsec [pb]	100 TeV xsec [pb]
200.0	441.	3000
300.0	75.5	620.
400.0	20.4	195.
500.0	7.08	77.5
600.0	2.97	36.6
700.0	1.33	18.4
800.0	0.666	10.2
900.0	0.367	6.25
1000.0	0.212	3.95
1200.0	0.857E-01	1.82
1400.0	0.368E-01	0.939

- Gluino pair-production NLO cross sections with all squarks decoupled

[Show Cross Sections](#)

cross sections



literature



### Literature

- *The Relic Neutralino Surface at a 100 TeV Collider*, J.Bramante et al, [arXiv:1412.4789](#)
- *Prospects for Electroweakino Discovery at a 100 TeV Hadron Collider*, S.Gori et al, [arXiv:1410.6298](#)
- *Prospects for observing charginos and neutralinos at a 100 TeV proton-proton collider*, B.Acharya et al, [arXiv:1410.1532](#)
- *Superpartners at LHC and Future Colliders: Predictions from Constrained Compactified M-Theory*, S.A.R.Ellis et al, [arXiv:1408.1961](#)
- *Boosting Stop Searches with a 100 TeV Proton Collider*, T.Cohen et al, [arXiv:1406.4512](#)
- *Squark and gluino production cross sections in pp collisions at  $\sqrt{s}=13, 14, 33$  and 100 TeV*, C.Borschensky et al, [arXiv:1407.5066](#)
- *Prospects for constrained supersymmetry at  $\sqrt{s}=33$  TeV and  $\sqrt{s}=100$  TeV proton-proton super-colliders*, A.Fowlie and M.Raik [arXiv:1407.5066](#)
- *SUSY Simplified Models at 14, 33, and 100 TeV Proton Colliders*, T.Cohen et al, [arXiv:1311.6480](#)
- *A Comparison of Future Proton Colliders Using SUSY Simplified Models: A Snowmass Whitepaper*, T.Cohen et al, <http://arxiv.org/abs/arXiv:1309.1514>
- *Reach in All Hadronic Stop Decays: A Snowmass White Paper*, D.Stolarski, [arXiv:1309.1514](#)

# FCC-hh : Physics at 100 TeV (4)

Vidyo | Welcome | HiggsEWSymmetr... | Self subscription... | Ions at the Future... | Inspi

TWiki > LHCPhysics Web > FutureHadroncollider > HiggsEWSymmetry (2015-02-26, RobertoContino)

## Exploration of Electroweak Symmetry Breaking (incl. Higgs)

This sub-group of the FCC physics program focusses on studies of the Higgs and electroweak symmetry breaking topics that we want to focus on and explore. Please feel free to add any relevant material to the twiki

Conveners: Roberto Contino and Heather Gray

### Topics and Focus Areas

- [Precision Studies of Higgs Properties](#)
- [Rare Higgs production and decays](#)
- [Double Higgs Production](#)
- [WW scattering at high energy](#)
- [Additional BSM Higgs bosons: discovery reach and precision physics program](#)
- [New handles on the study of EWSB dynamics](#)

e.g.

### Double Higgs production

### Meetings

**Kick-off Meeting:** 24 November, 2014 ([agenda](#))

**Next meeting:** 25 February, 2015 ([agenda](#))

**Upcoming Workshop:** 11-13 March 2015 ([homepage](#))

### Ongoing studies

- Double Higgs production via Gluon Fusion (Hance, Son, Spannowsky, Yao) [Hide Details](#)
  - Goal of the project:
  - Status:
  - [Slides1](#), [Slides2](#)
- Double Higgs production via Vector Boson Fusion (Contino, Rojo) [Hide Details](#)
  - Goal of the project:
  - Status:
  - [Slides](#)
- Resonant double Higgs production via Vector Boson Fusion (Kotwal) [Show Details](#)
- ttHH (Spannowsky) [Show Details](#)

# FCC-hh : Experiments at 100 TeV (1)

**Mailing list:** [fcc-experiments-hadron-detector@cern.ch](mailto:fcc-experiments-hadron-detector@cern.ch)

Hadron Collider Experiments study group (WBS 222.1, 222.2)

now beginning to branch into working groups:

1) Detectors: convener: [Pontecorvo](#)

2) Detector magnets: [convenor](#): ten Kate

3) Machine Detector Interface: [convenors](#): Ball/[Riegler](#)

expect further branching of the detectors group eg [tracking](#), [calorimetry](#), [muon system](#),  
trigger & DAQ

For detector design, initial performance needs and required upgrade potential,  
assume the following FCC-hh performance:

	Initial	Ultimate
C.M Energy	100TeV	100TeV
Luminosity	$5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$	$3 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$ *
Integrated <a href="#">Lumi</a>	$3 \text{ ab}^{-1}$	$30 \text{ ab}^{-1}$ *
Bunch spacing	25ns → 5ns	5ns

\* NB upper values used for detector R & D + radiation studies



# FCC-hh : Experiments at 100 TeV (2)

## Detectors

twiki: <https://twiki.cern.ch/twiki/bin/view/LHCPhysics/DetectorGeneral>

mtg agendas: <http://indico.cern.ch/category/6069/> : 8 meetings, 1 recent workshop

“[Workshop on requirements for future detector technologies in view of FCC-hh](http://indico.cern.ch/event/358198/)”,  
CERN, Febr 3-4, <http://indico.cern.ch/event/358198/>

Physics requirements (momentum resolution, calorimetry depth, eta coverage)

--> generic options defined for progressing design of central (high  $p_t$  detector)  
(each incorporating a forward dipole spectrometer for coverage to  $\eta=6$ )

Rates and data volumes

--> trigger/DAQ will present unprecedented challenges  
work just starting – potential for trigger-less schemes?

As for LHC, the engineering structure is driven by choice of magnet design

## Detector Magnets

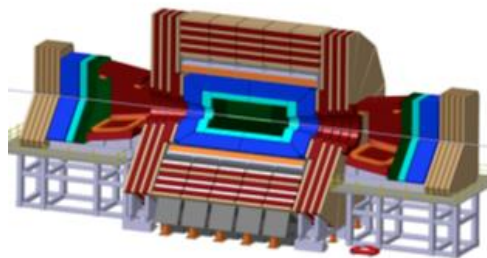
mtg agendas <http://indico.cern.ch/category/6244/> : 2 meetings so far

# FCC-hh : Experiments at 100 TeV (3)

## Design options

Concept Drawings : Herman Ten Kate

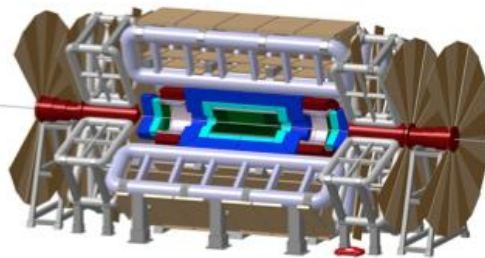
long solenoid



CMS-like

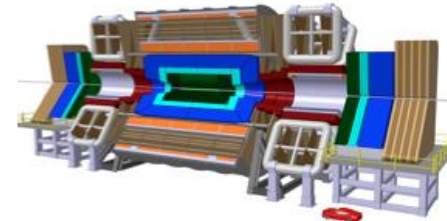
-possible reduced yoke  
(accepting fringe field)

thin solenoid + toroid



ATLAS-like

twin solenoid



no return yoke

To optimise, will need : - simulations of benchmark processes & backgrounds  
- estimates of detector performance evolution  
eg- achieve performance via: increased  $BL^2$ , better resolution, both?  
characteristics of forward spectrometers?

- *Detectors overview & detail* in FCC-hh Expts sessions: Weds 08:30, 10:30, Thurs 15:30
- *TDAQ overview* in FCC-hh Expts session on Thursday 15:30

# FCC-hh : Experiments at 100 TeV (4)

## Machine Detector Interface

mtg agendas: <http://indico.cern.ch/category/5901> : 5 meetings so far

### **Key machine parameters for detector design (apart $E_{\text{beam}}$ and lumi):**

- l\* (ip --> 1<sup>st</sup> quad) : baseline 40m  
option for shorter[  $\geq 25\text{m}$ ]/longer [  $\leq 60\text{m}$ ] kept open
- bunch structure : spacing: 25ns with option for reducing to 5ns  
(likely essential for in-time pile-up mitigation at  $10^{35}$ )
- bunch length : 8cm, possibly increased to 14 cm  
(pileup mitigation & tracker design issues, as for HL-LHC)
- luminous region :  $\sim 7\mu\text{m} \times 57\text{mm}$
- crossing angle :  $74\mu\text{rad}$  at 25 ns

### **Work so far has focussed on :**

- Civil Engineering interface: -cavern size, shape and access  
-services & service caverns  
-construction & maintenance constraints
- Requirements for radiation simulations : design of TAS, in-cavern shielding

➤ *Status report* in the FCC-hh MDI session Tuesday 15:30.

# FCC-hh : Physics with heavy ions

- **Conveners:** Dainese, Masciocchi (exp), Armesto, Salgado, Wiedemann (TH)
- **Mailing list:** [fcc-ions@cern.ch](mailto:fcc-ions@cern.ch)
- **Twiki page:**
  - <https://twiki.cern.ch/twiki/bin/view/LHCPhysics/HeavyIons>

Topics discussed so far (4 workshops, see Indico agendas for details)

- Charm at chemical equilibrium?
- Probes of gluon saturation at small  $x$
- Nuclear PDFs
- Flows
- Hard probes, from jets to top quark production
- Ultrapерipheral collisions
- ...

# FCC-hh : Physics with injectors

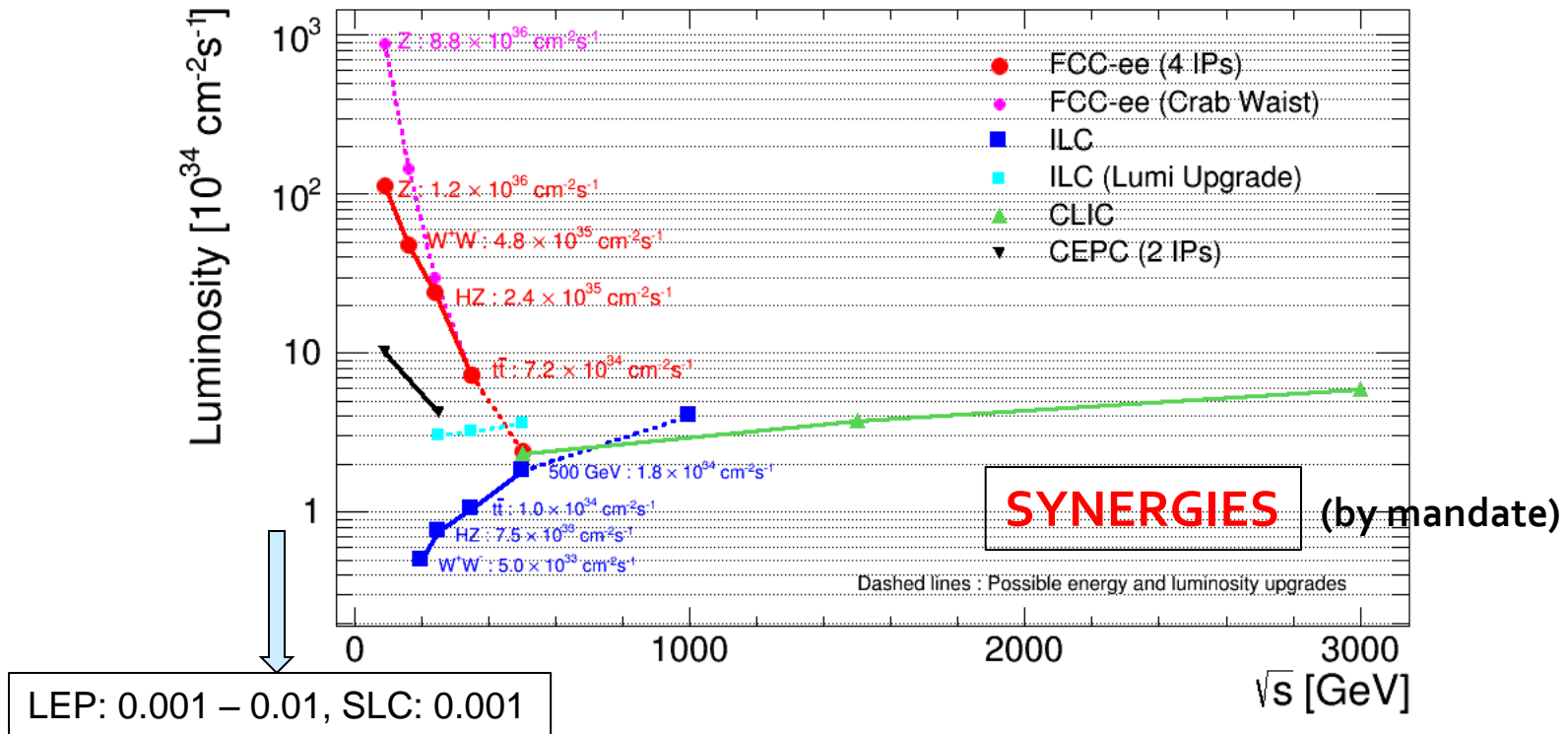
- **Conveners:** Goddard (accelerator), Isidori (theory), Teubert (experiments)
- **Mailing list:** [fcc-experiments-physin@cern.ch](mailto:fcc-experiments-physin@cern.ch)

Topics discussed so far (4 mtgs, see Indico agendas for details)

- Physics prospects with polarized protons, and implications for the injector complex
- Low-energy proton ring for proton electric dipole moment measurement
- Collisions in the high-energy booster for high-rate studies of LFV  $\tau$  decays
- Rare K decays
- Crystal beam extraction
- Test beam requirements for future detectors

# The potential first step: FCC-ee

## Physics topics offered by the unique luminosity profile



### Within a few years at each centre-of-mass energy, FCC-ee would produce

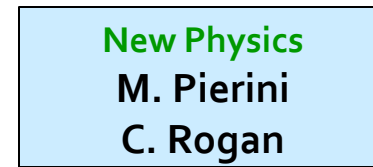
- Several trillions, up to  $10^{13}$ , Z decays
- Several Okus ( $10^8$ ) W decays
- Several millions Higgs and top decays

Working groups organized around the pertaining challenges

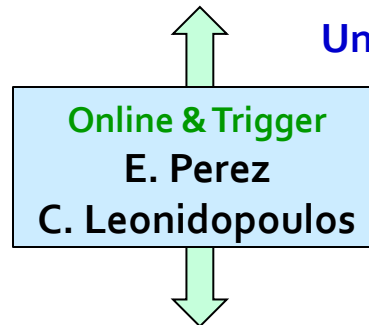
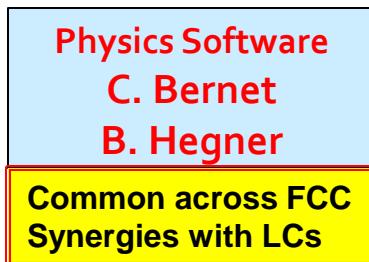
# FCC-ee : Working groups (1)

## Experimental studies – Coordinators A. Blondel, P. Janot

- ◆ Precision measurements of the Z, W, H, t properties - Rare decays – BSM physics



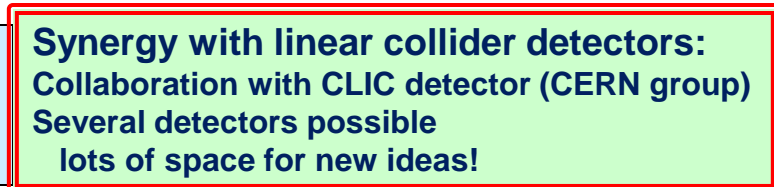
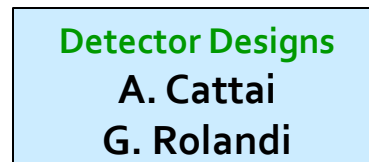
- ◆ Develop the necessary tools



- ◆ Understand the experimental conditions



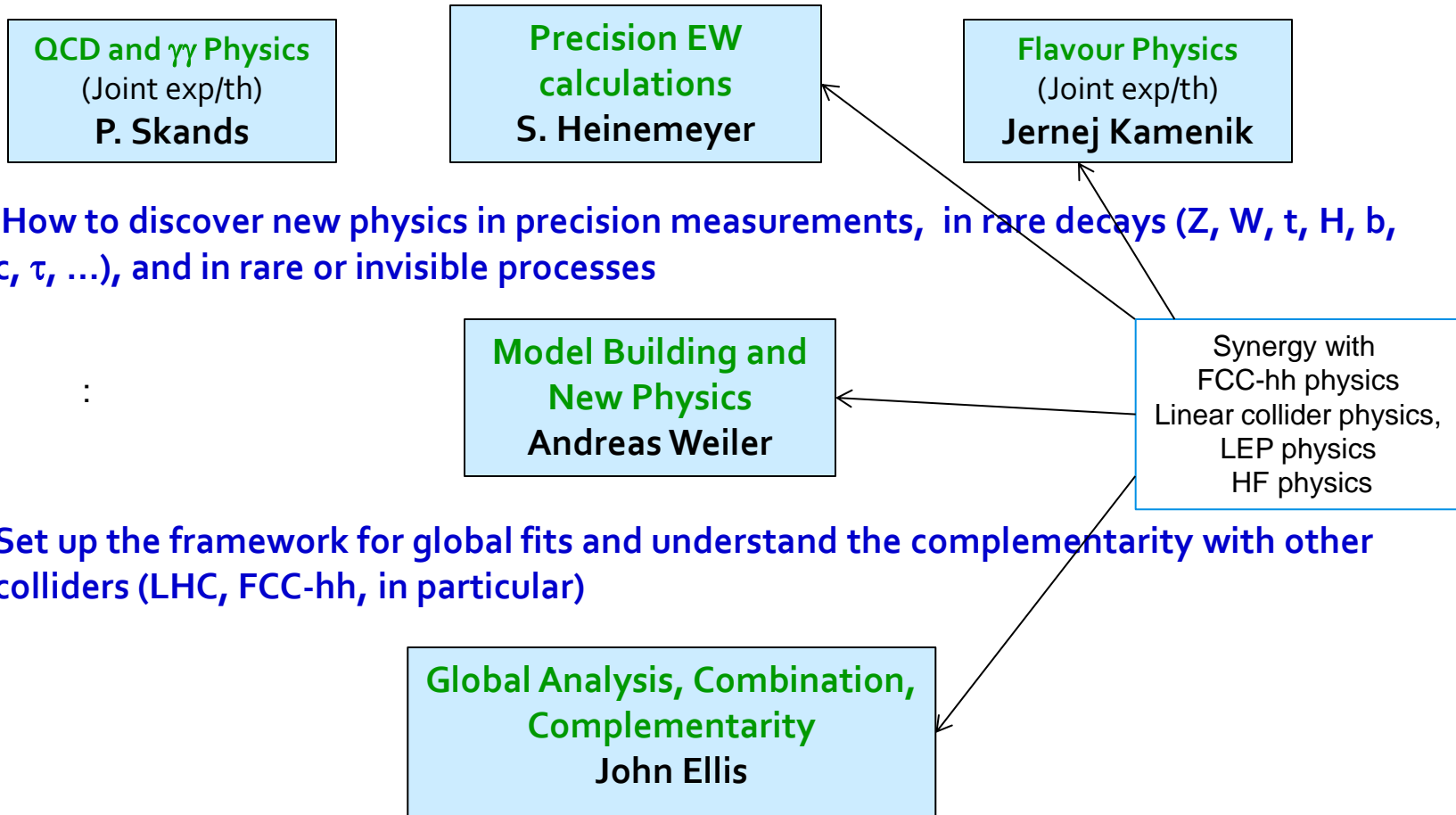
- ◆ Set constraints on the possible detector designs to match statistical precision



# FCC-ee : Working groups (2)

## □ Phenomenology studies – Coordinators J. Ellis, C. Grojean

- ◆ Match theory predictions to FCC-ee experimental precisions





# FCC-ee : General documentation

- All relevant information gathered in <http://cern.ch/fcc-ee> (C. Martin Perez)

**The FCC-ee design study** Since 12/02/2014, the TLEP design study is part of the FCC design study as FCC-ee

<http://indico.cern.ch/category/5259/>

Home About FCC-ee and TLEP **Organization** Archive **Events** The FCCs **Contact/Join us** Site map

**Luminosity [10<sup>34</sup> cm<sup>2</sup>s<sup>-1</sup>]**

**√s [GeV]**

Legend:

- FCC-ee (4 IPs)
- FCC-ee (Crab Waist)
- ILC
- ILC (Lumi Upgrade)
- CLIC
- CEPC (2 IPs)

Dashed lines : Possible energy and luminosity upgrades

**A strong physics case**

The expected luminosity performance of FCC-ee/TLEP lead to the production of a Tera Z, several Ocu W, several Mega Higgs and a Mega top, i.e., orders of magnitude above other projects on the market. Such large statistics samples allow the measurement of the properties of these particles with unprecedented accuracy, and are the tool of choice to discover and study rare Z, W, Higgs boson and top decays. Besides offering the ultimate investigations of electroweak symmetry breaking, these precision measurements would be highly sensitive to the possible existence of yet unknown particles, with masses up to 100 TeV. Sensitive searches for particles with couplings much smaller than weak, such as 'sterile neutrinos', can be envisioned. Click on the figure to access to the original article 'A first look at the physics case of TLEP'.

1 2 3

**Follow us**

**Latest publications**

- Top-quark electroweak couplings at the FCC-ee
- Status of the FCC-ee Interaction Region Design
- Precision Electroweak Measurements at FCC-ee

Check all publications [here](#).

**FCC-ee**

**The FCC-ee in a few words**

The FCC-ee, formerly known as TLEP, is a high-luminosity, high-precision e<sup>+</sup>e<sup>-</sup> circular collider envisioned in a new 80-100 km tunnel in the Geneva area. With a centre-of-mass energy from 90 to 400 GeV, the physics program could pave the way towards the discovery of physics beyond the Standard Model, casting light on unanswered questions, such as dark matter, the baryon asymmetry of the Universe, the hierarchy problem, the stability of the Universe or the nonzero neutrino masses.

The FCC-ee project is part and parcel of the Future Circular Collider design study (FCC) at CERN, and would be the first step towards the long-term goal of a 100 TeV proton-proton collider. It is expected to deliver its conclusion in 2018, just prior the next update of the European Strategy. There are many challenges facing the study, starting with a realistic design that allows these promises to be fulfilled, so feel free to join the design study group if you wish to collaborate

**Next events**

*Conferences and Workshops*

**FCC Week 2015**  
22 Mar 2015 - 15:00 - Marriott Georgetown Hotel

*FCC-ee Accelerator meetings*

**FCC-ee meeting no. 16**  
9 Apr 2015 - 10:00 - CERN - Salle conference BE

# FCC-ee : Physics (1)

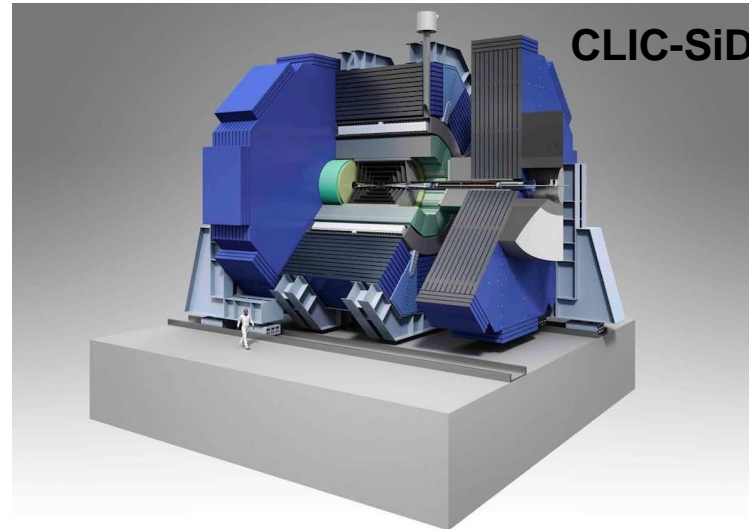
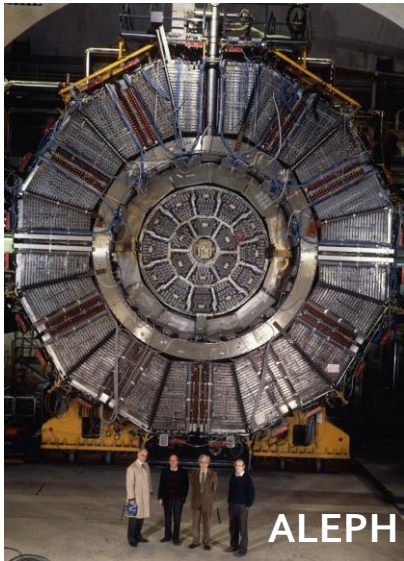
- **First look at the physics case of TLEP, JHEP01 (2014) 164**
  - ◆ Scoped the precision measurements
    - Model-independent Higgs properties: couplings, width, invisible width, mass
    - Z mass (0.1 MeV), W mass (0.5 MeV), top mass (10 MeV),  $N_{\nu}$ ,  $\sin^2\theta_W$ , ...
  - ◆ Inferred a sensitivity to new physics with EW or Higgs couplings up to 100 TeV
  - ◆ Reminded the importance of ultra-precise  $E_{\text{beam}}$  measurements up to WW threshold
    - See talk by M. Koratzinos in the FCC-ee collider session on Wednesday, 13:30
  - ◆ Stressed the need of a step in the precision of theory predictions
- **Novelties appeared in recent workshops, e.g.,**
  - ◆ Higher luminosity prospects at the Z, W, H with crabbed-waist beam crossing
    - Higgs coupling to first generation of quarks and leptons (e.g,  $e^+e^- \rightarrow H$ )
    - Rare Z, W, H, and top decays
    - Sensitivity to sterile neutrinos
  - ◆ Measurements of top EW couplings just above the  $t\bar{t}$  threshold
  - ◆ Discovery potential for very small couplings
- **Mostly paper studies so far: detailed studies are in order.**
  - ◆ Review in the phenomenology session on Thursday

# FCC-ee : Physics (2)

- **Physics opportunities studied in a series of nine general workshops**
  - ◆ <http://indico.cern.ch/category/5684/>
  - ◆ Most recent workshop in Pisa (3-5 Feb 2015):
    - ◆ <https://agenda.infn.it/conferenceDisplay.py?confId=8830>
- **Progress reported in monthly physics meetings**
  - ◆ <https://indico.cern.ch/category/5307/>
  - ◆ + individual group meetings
- **Status report in the FCC-ee experiments session on Tuesday (10:30, 13:30)**
- **Phase 2: mini-workshops dedicated to specific topics will be organized**
  - ◆ Next workshop in Summer 2015 on “Radiative Corrections”
    - State of the art of EW and QCD calculations (Z, W, H, top)
    - Identify where improvement needed to match the experimental precision
    - Set up a worldwide organized effort
    - Being organized by Sven Heinemeyer, Christophe Grojean, John Ellis
- **Phase 2 target**
  - ◆ Document the outcome of these mini-workshops in a report by the end of 2016

# FCC-ee : Detectors and MDI (1)

- **We know today how to build a detector for  $e^+e^-$  precision physics**
  - ◆ Experience with LEP detectors and 20-years R&D with ILC/CLIC detectors
    - The challenge is to build four detectors for an affordable price
      - Something between ALEPH (price) and SiD (performance) would be suitable



Detectors must also have the ability to collect 100 kHz of Z decays, with 100% efficiency

... and be able to repeat the whole LEP<sub>1</sub> programme in about two minutes.

Inspiration should come from LHC detector upgrades and DAQ systems (ALICE, LHCb, CMS)

- ◆ A lot of synergies with the work done already for linear colliders
  - Collaboration with the CLIC group @ CERN is being set up
- ◆ FCC-ee specificities : dedicated session on Tuesday, 8:30am

# FCC-ee : Detectors and MDI (2)

## □ A mini-workshop on detectors is being organized with all relevant experts

◆ Date : ~ Spring 2015

### ◆ Topics

- Possible hardware for sub-detectors (e.g., ALICE inner tracker technology)
- Existing detector geometries (e.g., CLIC detector)
- Implementation in DD4HEP
- Full simulation + reconstruction software
- Fast simulation(s) of different detector performance
- Interface with interaction region
- Radiation in the detector

Session on interaction region  
on Wednesday, 13:30

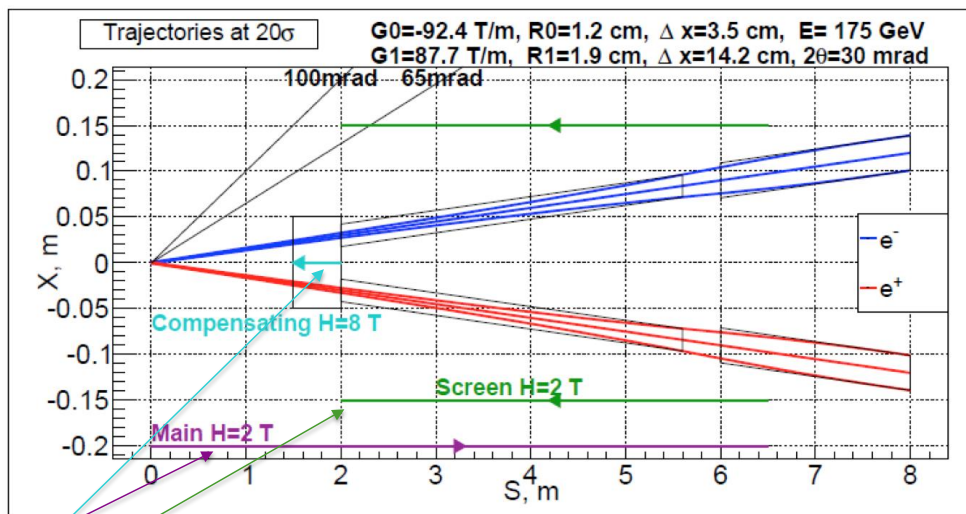
### ◆ Goals

- Get at least one detector fully simulated in a year from now  
→ With particular care about the forward region
- Have fast simulation running for detailed physics analyses
- Get a first estimate of the beam backgrounds in the detector

# FCC-ee : Detectors and MDI (3)

## Machine-detector interface understanding is essential

- High luminosity requires small  $\beta^*$ , small  $L^*$  ( $\sim 2\text{m}$ ), and crossing angle (15 mrad)



Beams are crossing detector B-field at an angle of 15 mrad. Need compensation.

- Here assumed +2 Tesla detector main field
- Screening of quadrupoles: - 2 Tesla
- Compensation for beam path through detector: - 8 Tesla over one quarter of path

## Details of the forward region need to be studied

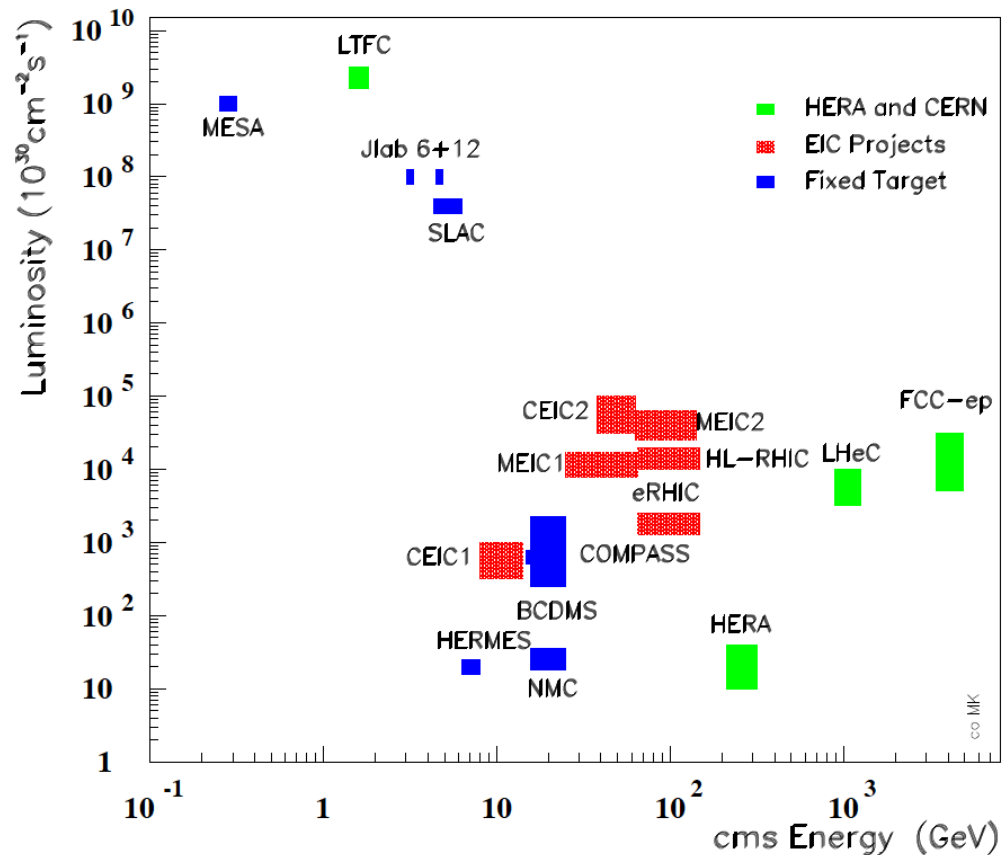
- Luminosity detector integration
- Magnetic field
- Beam backgrounds

Session on interaction region  
on Wednesday, 13:30

# The additional option : FCC-eh

- **An extension of the LHeC study: e-proton and e-ions collisions**
  - ◆ Synergy / complementarity with the FCC project
    - 175 GeV  $e^-$  beam from FCC-ee and 50 TeV p beam from FCC-hh
  - ◆ Highest centre-of-mass energy ep collider; luminosity  $\sim 10^{34} \text{ cm}^{-2}\text{s}^{-1}$

Lepton-Proton Scattering Facilities



# FCC-eh : Organization and documentation

- **Overall coordination : Max Klein, Oliver Brüning**

  - ◆ + coordination group

    - Physics Study Groups (Convenors)

      - PDFs, QCD Fred Olness, Voica Radescu

      - Higgs Uta Klein, Masahiro Kuze

      - BSM Georges Azuelos, Monica D'Onofrio

      - Top Olaf Behnke, Christian Schwanenberger

      - Nuclei Nestor Armesto

      - Small x Paul Newman, Anna Stasto

      - Software Peter Kostka, Paul Laycock

      - Detector Peter Kostka, Alessandro Polini

- **Web page: <http://www.lhec.cern.ch>**

  - ◆ LHeC conceptual design report: arXiv:1206.2913

- **Next dedicated workshop**

  - ◆ CERN and Chavannes, 24-27 June 2015 (theory, experiments, accelerator)

- **Two specific sessions this week**

  - ◆ Tuesday 15:30 (experiments) and Wednesday 15:30 (accelerator)



# FCC-eh : Physics

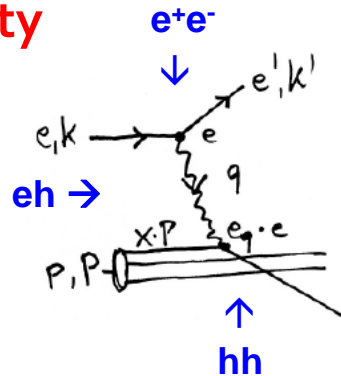
## Complementarity

$$x = \frac{Q^2}{sy}$$

$$Q^2 = -(k - k')^2$$

$$y_{lab} = 1 - \frac{E_{e'}}{E_e}$$

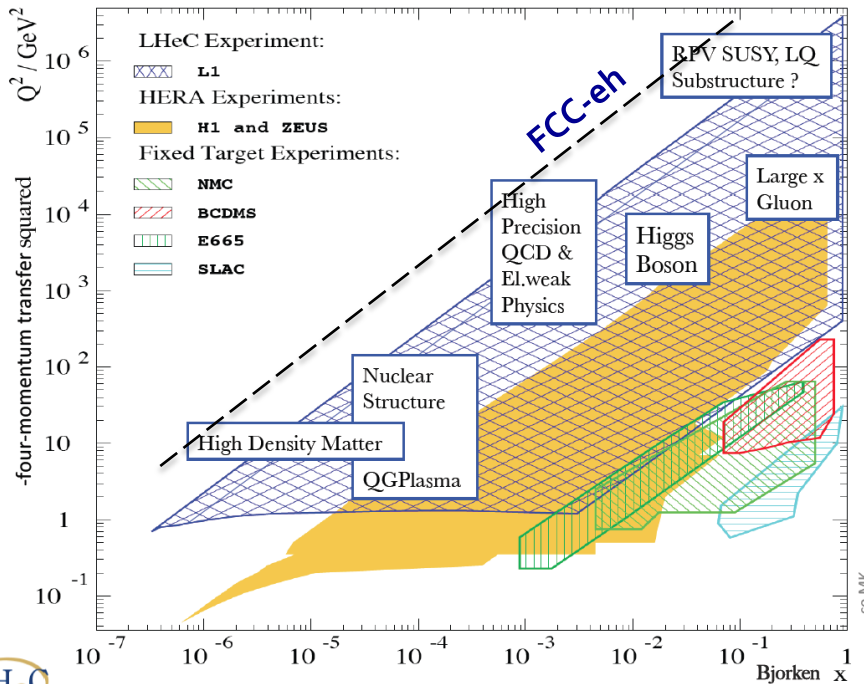
$$s = 4E_e E_p$$



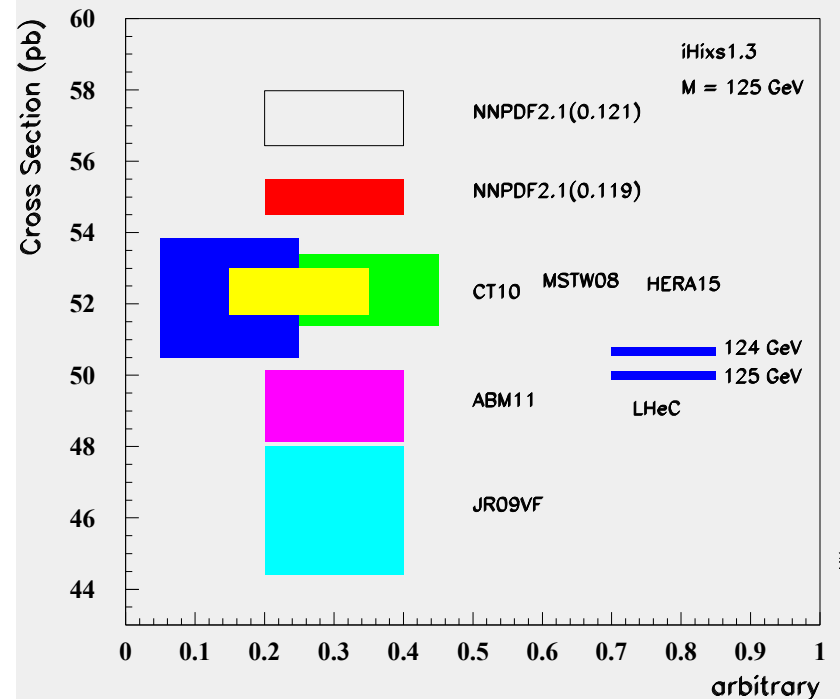
By going deeper into the proton

Resolve the complete set of p.d.f.'s

Essential for precise measurements at FCC-hh

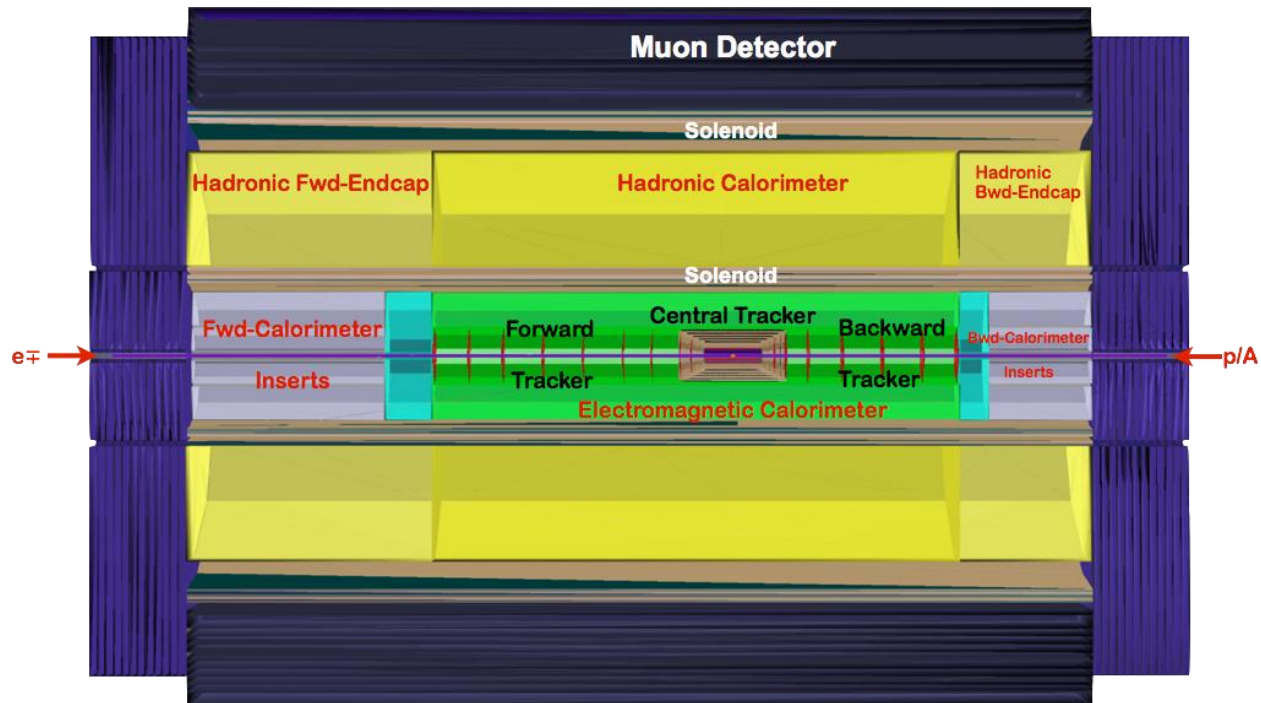


NNLO pp-Higgs Cross Sections at 14 TeV



# FCC-eh : Detector

- Tentative design (18m x 9m)



High resolution of hadron energy and large forward acceptance for Higgs physics (b jets)  
High precision and full polar angle coverage for QCD, electroweak and BSM  
Task: optimization of design, full simulation, design of the interaction region  
Goal: synchronous ep and pp operation from day 1 of p beam

# Towards Phase 2 ...

- **Needless to say: there is a lot to cover in 18 months**
  - ◆ **With not that many people so far ...**
    - Everyone is welcome to contribute to proposed topics
    - Everyone should feel encouraged to think out of the box and add topics
  - ◆ **We need to train the next generation of physicists**
    - Towards the realization of the next generation of circular colliders

**PLEASE SUBSCRIBE AND JOIN THE STUDY !**