Experiments at FCC

FCC-PHYSics-COordination-group

FCC-ee
Alain Blondel
John Ellis
Christophe Grojean
Patrick Janot

FCC-hh
Austin Ball
Fabiola Gianotti
Michelangelo Mangano

FCC-he
Max Klein
Monica d'Onofrio

Aims of the FCC «Physics and Experiments» design study:

-- to establish the physics capabilities of the FCC machines (- ee, hh, he)
and the complementarity and coverage of the complex.

-- scope the discovery sensitivities to a number of (new) physics scenarios by
- -- direct observation of new particles
- -- precision measurements of Higgs, Electroweak, Flavour etc observables
- -- search for rare or forbidden phenomena

-- understand the experimental environment

-- establish the sensitivity of the physics performance of detectors to basic properties and identify which ones:
- -- are within reach of existing technologies and R&D
- -- would most benefit from a new, dedicated, detector R&D program

-- define suitable layouts and requirements for infrastructure , study staging scenarios

-- identify which issues would require new theoretical calculations or additional external or internal experimental input

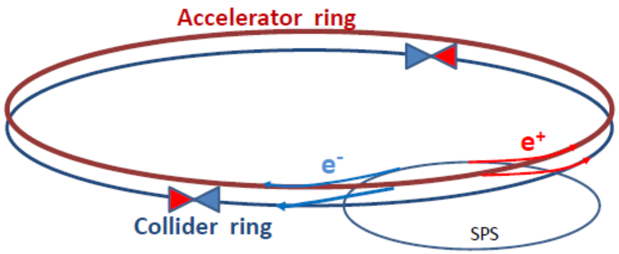
First phase until March 2015:

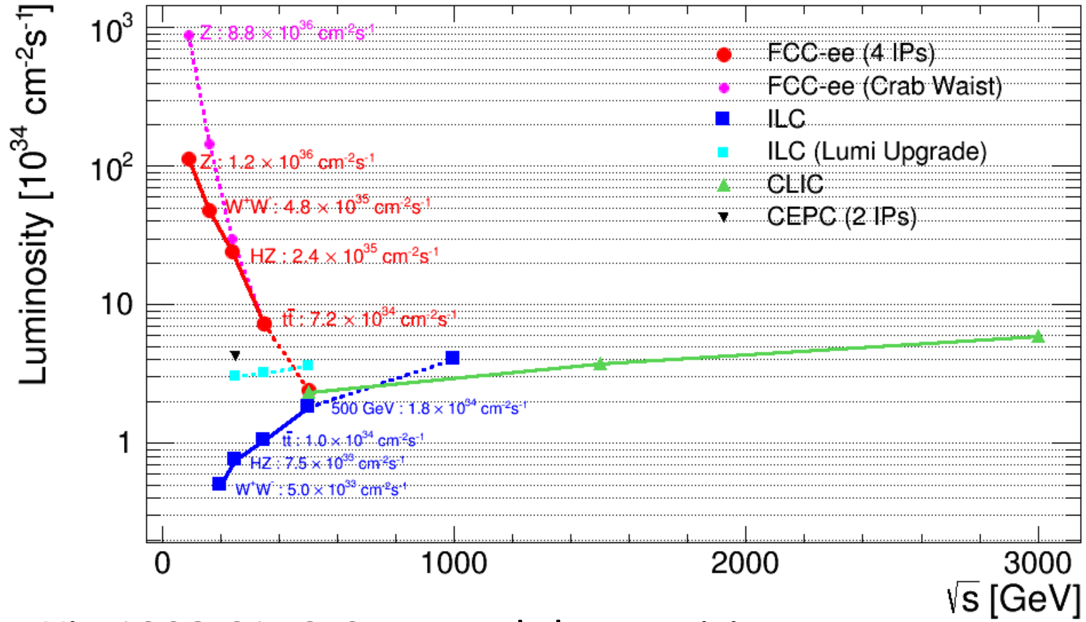
SCOPING the physics panorama and the main technical issues

Establish collaboration and reach out to interested groups

Get things started.

Possible first step : FCC-ee





First look at the physics case of TLEP, arXiv:1308.6176v3 scoped the precision measurements:

-- Model independent Higgs couplings and invisible width

-- Z mass (0.1 MeV), W mass (0.5 MeV) top mass (~10 MeV), $\sin^2{}_W^{eff}$, R_b, N_ν etc...

➔ powerful exploration of new physics with EW couplings up to very high masses

➔ importance of luminosity and E_{beam} calibration by beam depolarization up to W pair

So far: simulations with CMS detector (Higgs) -- or «just» paper studies.

Snapshot of novelties appeared in recent workshops

Higher luminosity prospects at W, Z with **crab-waist**

➔ sensitivity to right handed (sterile) neutrinos

➔ s-channel e+e- → H(125.2) production almost possible (➔ monochromators?)

➔ rare Higgs Z W and top decays, FCNCs etc...

➔ discovery potential for very small couplings

➔ precision event generators (Jadach et al)

http://cern.ch/FCC-ee

FCC hh ee he

Higgs factory

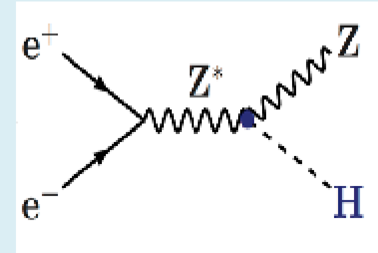
(constrained fit including 'exotic')

	4 IPs TLEP	(2 IPs)
g_{HZZ}	0.05%	(0.06%)
g_{HWW}	0.09%	(0.11%)
g_{Hbb}	0.19%	(0.23%)
g_{Hcc}	0.68%	(0.84%)
g_{Hgg}	0.79%	(0.97%)
$g_{H\tau\tau}$	0.49%	(0.60%)
$g_{H\mu\mu}$	6.2%	(7.6%)
$g_{H\gamma\gamma}$	1.4%	(1.7%)
BR_{exo}	0.16%	(0.20%)

➔ ***total width*** **<1%**

HHH (best at FCC-hh) 28% → from HZ thresh

Htt (best at FCC-hh) 13% → from tt thresh



$2\ 10^6$ ZH events in 5 years

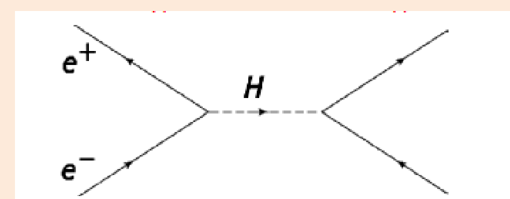
«A tagged Higgs beam».

sensitive to new physics in loops

incl. invisible = (dark matter?)

A big challenge, but unique:

Higgs s-channel production at $\sqrt{s} = m_H$

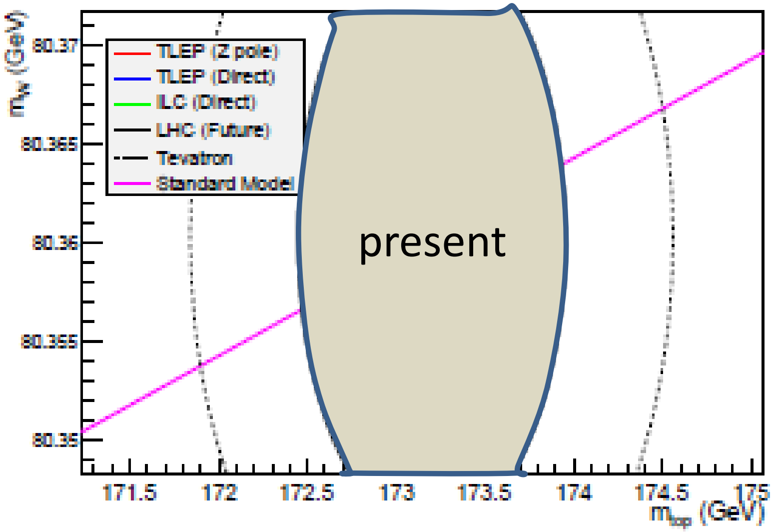


10^4 events per year.

Very difficult because huge background and beam energy spread ~ 10 x Γ_H

limits or signal? monochromators?

Aleksan, D'Enterria, Woijcik



Precision measurements as tests of existence of weakly coupled new physics

🡸 'classical' precision measurements + flavour physics + Higgs precision measts

Thickness of SM line is given by error on m_Z: precise measurements of m_Z and m_W

➔ Energy calibration by resonant depolarization

- **Higher-dimensional operators as relic of new physics ?**
  - Possible corrections to the standard model

$$L_{\text{eff}} = \sum_n \frac{c_n v^2}{\Lambda^2} O_n$$

$$\mathcal{O}_R^e = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{e}_R \gamma^\mu e_R)$$

$$\mathcal{O}_{LL}^{(3)l} = (\bar{L}_L \sigma^a \gamma^\mu L_L)(\bar{L}_L \sigma^a \gamma_\mu L_L)$$

$$\mathcal{O}_W = \frac{ig}{2}\left(H^\dagger \sigma^a \overleftrightarrow{D^\mu} H\right) D^\nu W^a_{\mu\nu}$$

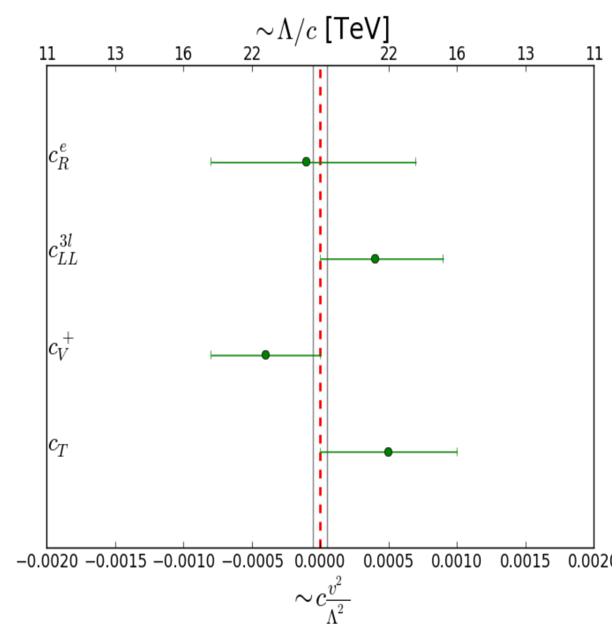
$$\mathcal{O}_B = \frac{ig'}{2}\left(H^\dagger D^\mu H\right) \partial^\nu B_{\mu\nu}$$

$$\mathcal{O}_T = \frac{1}{2}\left(H^\dagger \overleftrightarrow{D}_\mu H\right)^2$$

LEP constraints: Λ_{NP} > 10 TeV

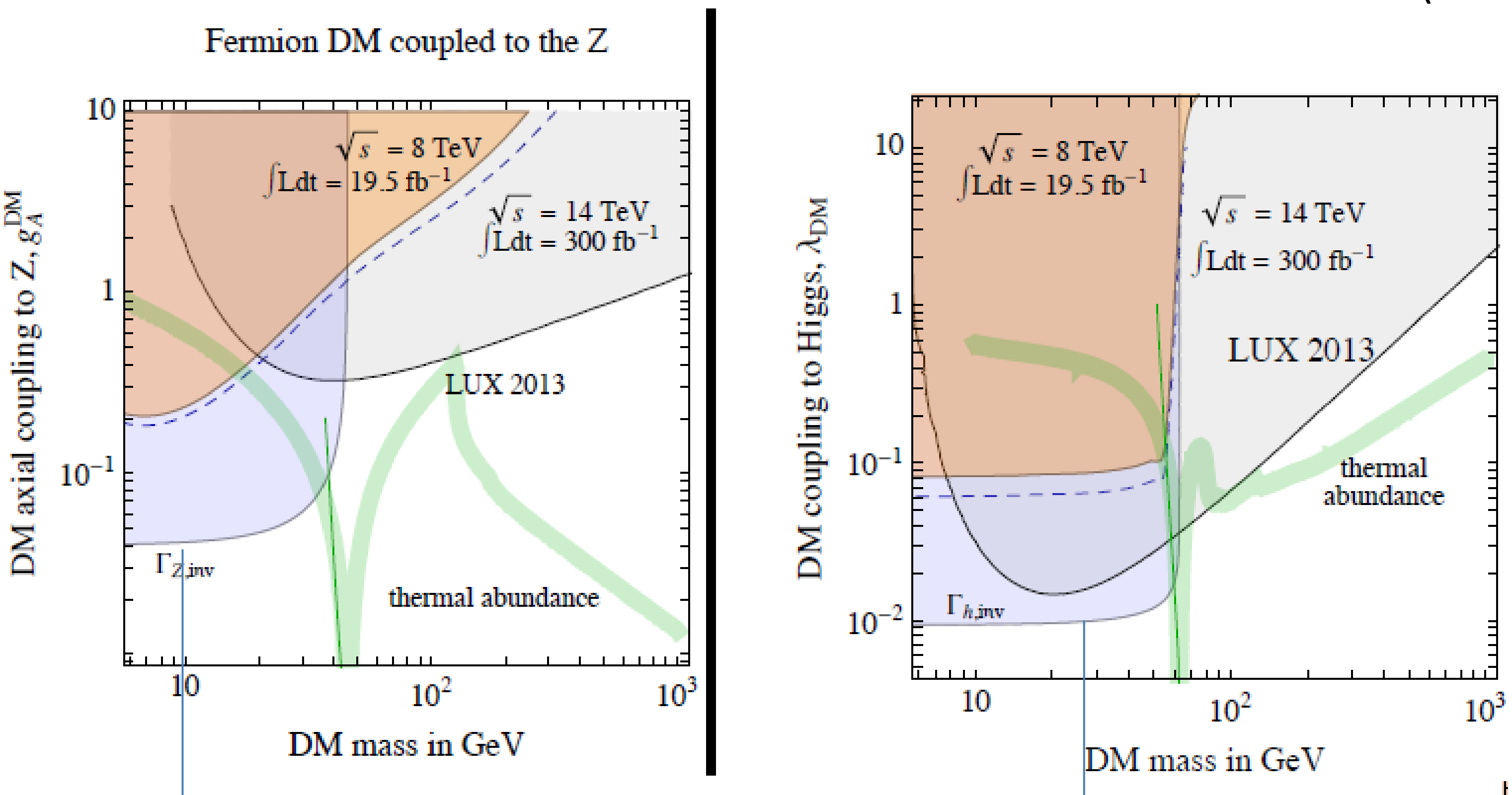
After FCC-ee: Λ_{NP} > 100 TeV ?

Sensitivity to Weakly-coupled NP



Γ_Z and Γ_h invisible are the most efficient way to explore SM-mediated DM at colliders

(Giudice)



Will improve these by large factors!

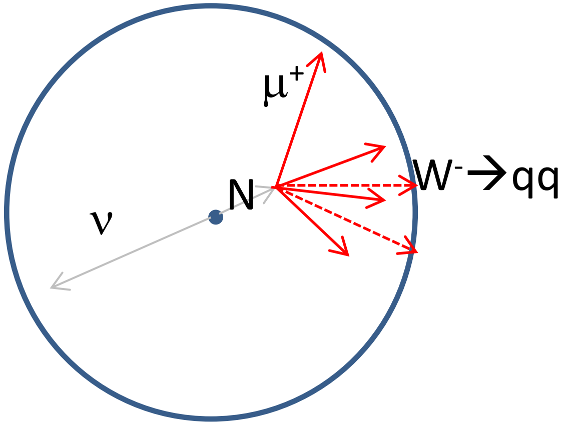
ΔN_ν = 0.0004?
from e+e-→Zγ

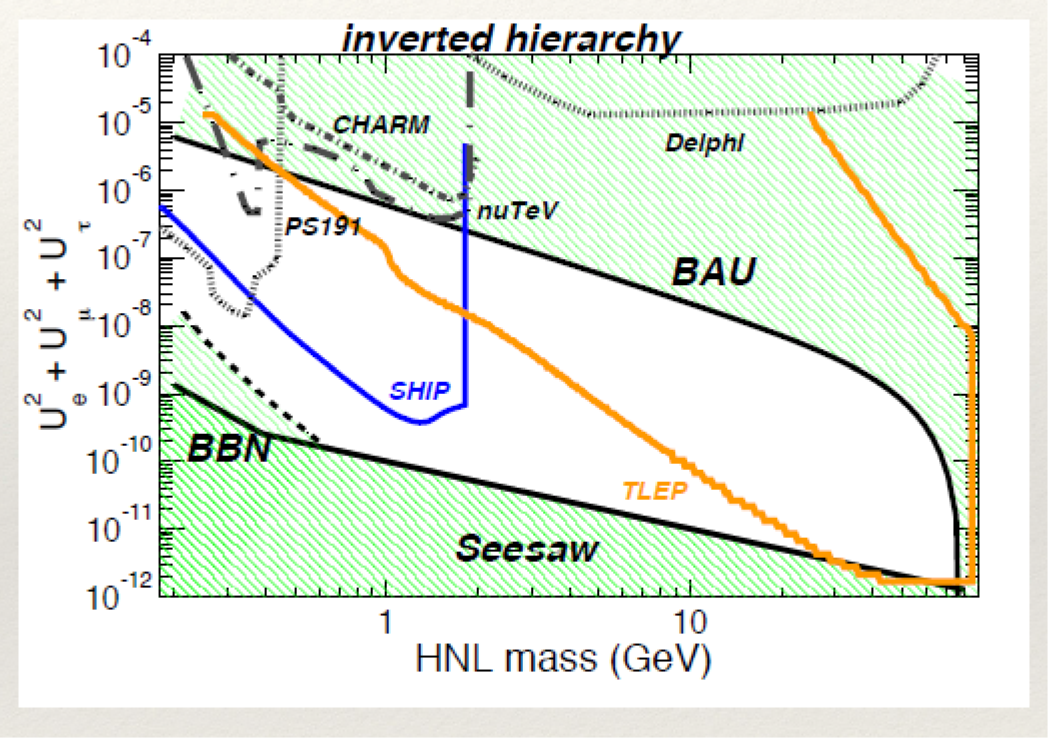
$\Delta\Gamma_{h,inv} / \Gamma_{tot}$ <0.19%

extremely rare process at the Z factory; an example:

see-saw:
$|U|^2 \cong m_\nu/m_N$

Searching for Right-Handed neutrinos in Z decays $Z \rightarrow \nu N$, $N \rightarrow \ell^+ W^-$
we thought it was impossible to reach mixing angle below 10^{-7} (backgrounds)
but realized that for small couplings the RH neutrinos are long lived





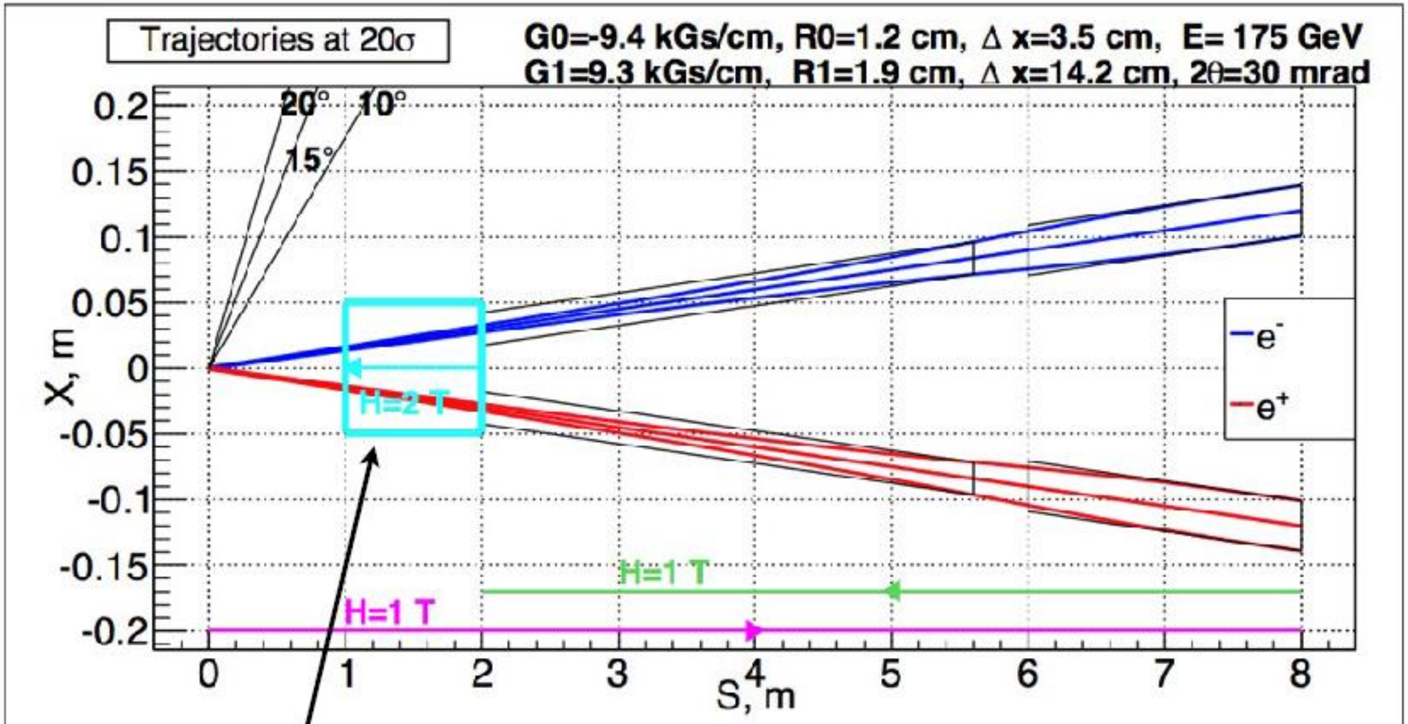
accessible region for N decay between 100 μm and 5 m from IP
-- assuming 10^{13}Z

AB, E. Graverini, N. Serra, M. Shaposhnikov

Machine Detector Interface (MDI) essential!
High Luminosity ➔ small β^* and L^*. ,
detail of small angle region in detector magnetic field.
Similar to ILC /CLIC but beam needs to circulate a few 10^5 times!

FCC-ee MDI - Interaction Region

❖ As presented by Anton Bogomyagkov



❖ $L^* = 2m$

✦ But what is this - Is there any room at all for luminosity monitors...?

+ synchrotron radiation
beamstrahlung

FCC-ee experiments

Experimental Studies: A. Blondel, P. Janot

- **Discovery through precision measurements, rare, or invisible processes.**

Electroweak Physics at the Z pole	Di-boson Physics m_W measurement	H(126) Properties	Top Quark Physics
R. Tenchini F. Piccinini	R. Tenchini	M. Klute K. Peters	P. Azzi

QCD and $\gamma\gamma$ Physics	Flavour Physics	New Physics
D. d'Enterria P. Skands	S. Monteil J. Kamenic	M. Pierini C. Rogan

- **Develop the necessary tools** — **Understand the experimental conditions**

Offline Software	Online Software	Experimental Environment
B. Hegner C. Bernet	C. Leonidopoulos	N. Bacchetta

common across FCC

- **Set constraints (specifications) on possible detector designs to match statistical precision**

Detector Designs
A. Cattai
G. Rolandi

Synergy with linear collider detectors:
ILD proposed as benchmark, SID (CERN group)
both require L* modifications!
Several detectors possible:
lots of space for new ideas!

NB Conveners have mission for one year to assemble group and find co-conveners

FCC-ee Phenomenology Studies

Phenomenology Studies: J. Ellis, C. Grojean

- Match theory predictions to FCC-ee experimental precisions

QCD and $\gamma\gamma$ Physics
(Joint exp/th)
P. Skands

Precision EW calculations
S. Heinemeyer

Flavour Physics
(Joint exp/th)
Jernej Kamenik

- How to discover new physics in precision measurements, in rare decays (Z, W, t, H, b, c, τ, …) in rare or invisible processes (Right Handed neutrinos etc..)

:

Model Building and New Physics
Andreas Weiler

Synergy with
FCC-hh physics
Linear collider physics,
LEP physics
HF physics

- Set up the framework for global fits and understand the complementarity with other colliders (LHC, FCC-hh, in particular)

Global Analysis, Combination, Complementarity
John Ellis

FCC-ee workshops and meetings

FCC-ee physics workshops
https://indico.cern.ch/category/5684/
recent one: 19-21 June at CERN

-- **Next** :27-29 October in Paris
January in Pisa

-- **monthly VIDYO meetings**
see https://indico.cern.ch/category/5307/
+ individual group meetings

-- **link** to
know what is happening (FCC-ee newsletter)
register to mailing list (you will no sign anything without being asked!)
http://cern.ch/fcc-ee

The ULTIMATE GOAL : FCC-hh

FCC-hh physics studies: emphasis on new ideas and understanding implications of 100 TeV collisions for the exploration of BSM physics

- Exploration of EW symmetry breaking (conv. R.Contino and H.Gray)
  - High-mass WW and HH scattering
  - Precision Higgs studies, rare production and decays
  - BSM H dynamics, EW baryogenesis, etc
- Exploration of BSM phenomena (conv. F.Moortgat, P.Schwaller)
  - Discovery reach of various scenarios (SUSY, new interactions, contact interactions, …)
  - DM searches
- Continued exploration of SM particles (temp. conv. M.Mangano)
  - Physics and precise measurements of top, W, Z
  - Flavour phenomena (quarks and charged leptons, rare/forbidden decays, …)
- Opportunities other than pp physics:
  - Heavy Ions (conv. Dainese, Masciocchi, Wiedemann)
  - Physics with the injectors (includes test beam) (conv. B.Goddard, G.Isidori, F.Teubert)
- Theoretical tools for the study of 100 TeV collisions (conv. J.Rojo and G.Zanderighi)
  - PDFs
  - MC generators
  - Higher order QCD adn EW corrections

FCC-hh detector (convener L.Pontecorvo)

Machine-Detector Interface (conveners B.Gorini and W.Riegler)

- Detector performance
  - Rapidity coverage (tracking, jets, b, lepts, MET)
  - Calorimetry: dynamic range, granularity, for central and fwd regions
  - Muon resolution at O(10 TeV)
  - Bunch spacing optimization
- Technical systems
  - New detector technologies and R&D needs
  - Radiation, shielding
  - Calorimeters
  - Muon systems
  - Inner detectors, tracking
  - Trigger, DAQ, controls and safety
- Machine-Detector Interface (MDI)
  - L*, TAS/TAN. Optics and impact on IR design
  - Beam pipe and vacuum
  - Radiation issues
  - Physics and detector-protection instrumentation in the long straight sections

"….an ***ambitious*** ***post-LHC accelerator project at CERN***"

Parameters - choices for initial machine relatively conservative
- a few more aggressive choices where cost savings balance the risks

--> **establishing a credible baseline**

- potential for evolution in performance

- as design process incl R & D proceeds
- as planned machine upgrade

important parameters for detectors	**baseline 2014**	**considered**
Energy	100 TeV	
Lumi	5×10^{34} (p-p)	up to 5×10^{35} (p-p)
	3×10^{27} (Pb-Pb)	
Bunch spacing	25ns	5 ns
Pile-up	170	34 - 340
Bunch-length	8 cm	increased
% circumference filled	80 %	
l *	46m	38m
β^*	0.8m	0.3m
transverse beam size at ip	6.8μm	3μm
optimum run time	12 hrs	

FCC-hh: Physics goals --> experiment design

Explore high energy frontier (E_{LHC} x 7)

requirements: high lumi at 2 points --> 2 x GP expts similar ATLAS/CMS
detectors tolerate rate, pile-up, radiation.
central measurement --> momentum res. ~10% for 20 TeV μ

Precision Higgs measurements, VBF

requirements: tracking, momentum resolution & electromag. resolution to η ~ 5
forward extensions to GP expts with dipole field
and/or dedicated forward experiments

also:

Standard Model studies (top, W, Z, flavour phenomena)

requirements : GP expts + dedicated smaller scale expts at lower lumi points?

Dedicated studies

requirements : eg HI & b-physics expts, similar ALICE/LHCb
at lower lumi points

Intensity frontier

requirements: "smaller" scale experiments using extracted beam from injectors

FCC-hh: General Purpose expts: overview so far

Studies so far: assume today's tracking precision

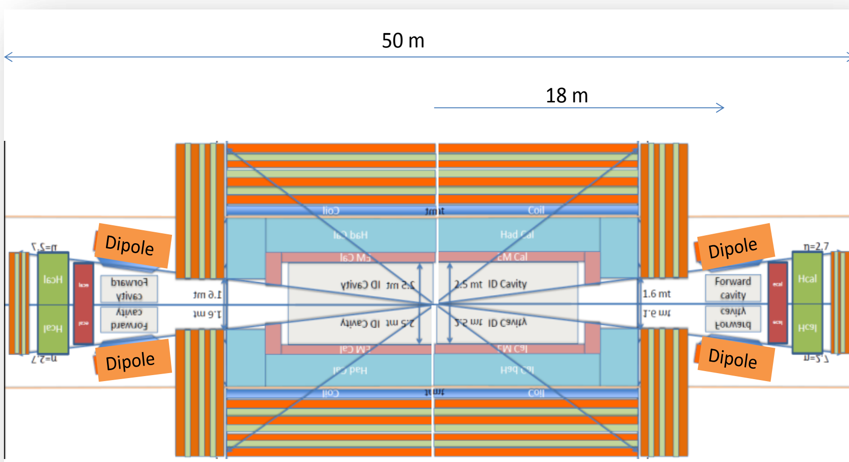
achieve required momentum resolution by x 7 in BL^2 cf LHC expts

HCAL 10 $\lambda \rightarrow$ 12 λ for containment

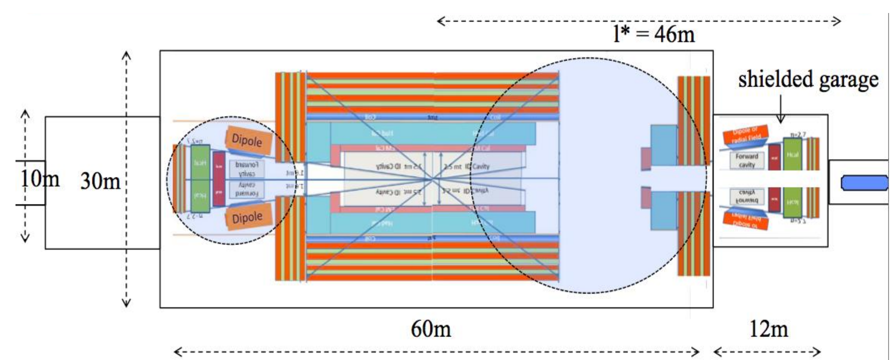
10 Tm dipole in forward direction

Low angle calorimetry by moving detector further from i/p.

Simple extrapolation eg of CMs, can produce a hard-to-maintain monster!



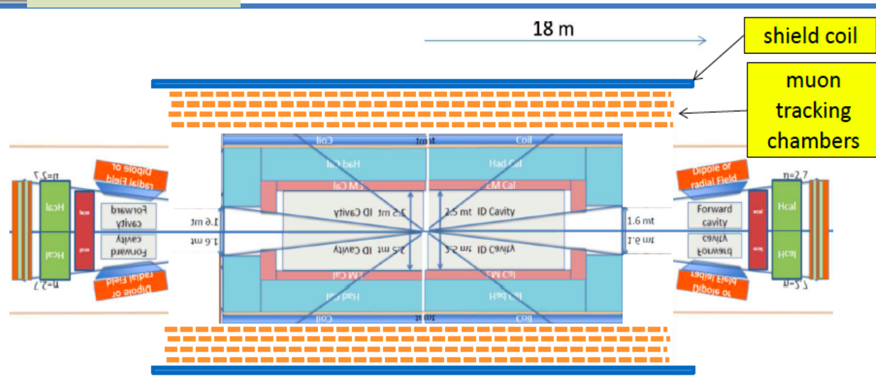
Yoke mass: 120,000 kg !!



opening & maintenance scenario horrible and needs a lot of z : l* (hence β*) issues?

FCC-hh: GP expts: overview so far

Option 1 Twin Solenoid + Dipoles



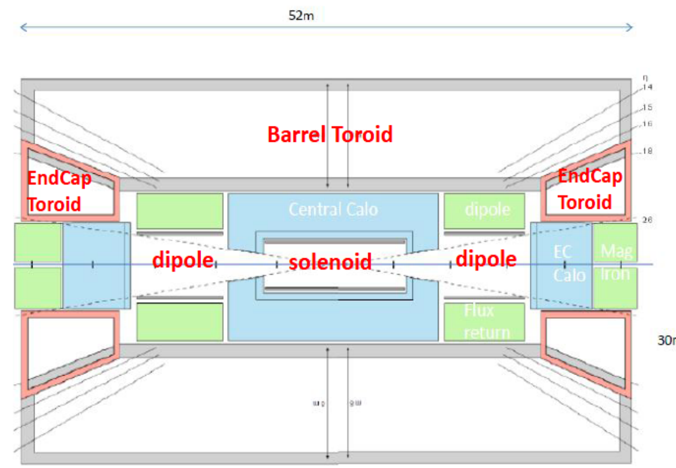
Twin Solenoid: a 6 T, 12 m dia x 23 m long main solenoid + an active shielding coil

Important advantages:

- ✓ **Nice Muon tracking space:** area with 2 to 3 T for muon tracking in 4 layers.
- ✓ **Very light:** 2 coils + structures, ≈ 5 kt, only ≈ 4% of the option with iron yoke!
- ✓ **Much smaller:** system outer diameter is significantly less than with iron .

6

Option 2 Toroids + Solenoid + Dipoles (ATLAS +)



- 1 Air core Barrel Toroid with 7 x muon bending power B_zL^2.
- 2 End Cap Toroids to cover medium angle forward direction.
- 2 Dipoles to cover low-angle forward direction.
- Overall dimensions: 30 m diameter x 51 m length (36,000 m^3).

9

Simulations of 2 magnetic designs (H. ten Kate et al) suggest these magnets could be built

Important now to : - decide on forward coverage of GP expts (or dedicated expts)
- study what could be achieved with future sensor resolution
+ more modest BL^2.

FCC-hh : particular needs

Tracking layout and performance for: i) existing sensor capabilities
ii) ambitious targets for point resolution & material

Focus on calorimetry: - granularity: channel count & consequences
- em & hadron calorimetry interplay

Trigger/DAQ: - develop from the bottom up (workshop needed)

Pileup mitigation: - software (recent workshop)
- detector & machine design: time resolution,
- lumi region shaping

Experiment interface to FCC: - Low β insertion: l* trade-offs, collimation,
shielding, backgrounds, radiation studies
beam pathology
- injector in FCC tunnel?
- construction/assembly/maintenance implications
- clustered or diametrically opposed collision points

FCC-hh most recent / forthcoming workshops and meetings

- BSM at 100 TeV Workshop, Febr 10-11 2014, https://indico.cern.ch/event/284800/
- 1st Future Hadron Collider Workshop, May 26-28 2014, https://indico.cern.ch/event/304759/
- Ions at the FCC, Workshop, https://indico.cern.ch/event/331669/
- Experiments with the FCC injectors, https://indico.cern.ch/event/339178/

- Periodic meetings:
  - **hh Indico** (incl pp, HI and injectors): https://indico.cern.ch/category/5258/
  - **hh mailing lists**:
    - fcc-experiments-hadron@cern.ch (general)
    - fcc-ions@cern.ch (heavy ions)
    - fcc-experiments-physinj@cern.ch (physics with injectors)

FCC
hh ee he

arks Tools Help

New Tab | Careers at CERN | CERN. Take P... | Careers at CERN | CERN. Take P... | Five or

kitty-kats Katya 3 by Aleksan

https://indico.cern.ch/category/5258/

September 2014

- 22 Sep - 23 Sep Ions at the Future Circular Collider

July 2014

- 15 Jul Physics with injectors (first informal discussion)

May 2014

- 26 May - 28 May 1st Future Hadron Collider Workshop
- 21 May FHC EM calorimeters informal meeting

April 2014

- 17 Apr FHC experiments informal meeting
- 15 Apr FHC EM calorimeters informal meeting
- 10 Apr Ions at the Future Circular Collider

March 2014

- 20 Mar FHC experiments informal meeting

February 2014

- 10 Feb - 11 Feb BSM physics opportunities at 100 TeV
- 06 Feb FHC experiments informal meeting

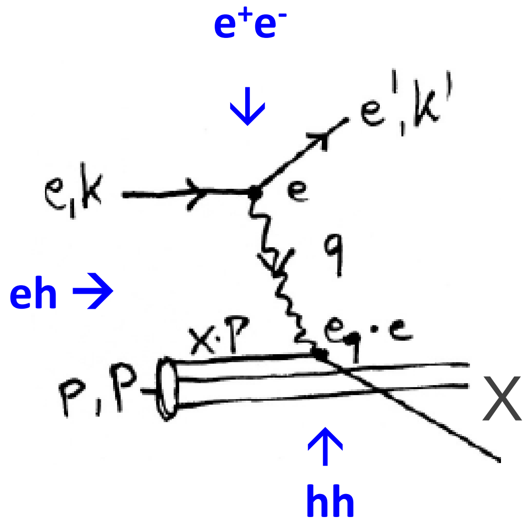
January 2014

- 29 Jan Ions at the Future Hadron Collider
- 27 Jan FHC experiments informal meeting
- 10 Jan FHC experiments informal meeting

December 2013

book Highlight All Match Case

FCC-he: Deep Inelastic Scattering [eh → e'X]



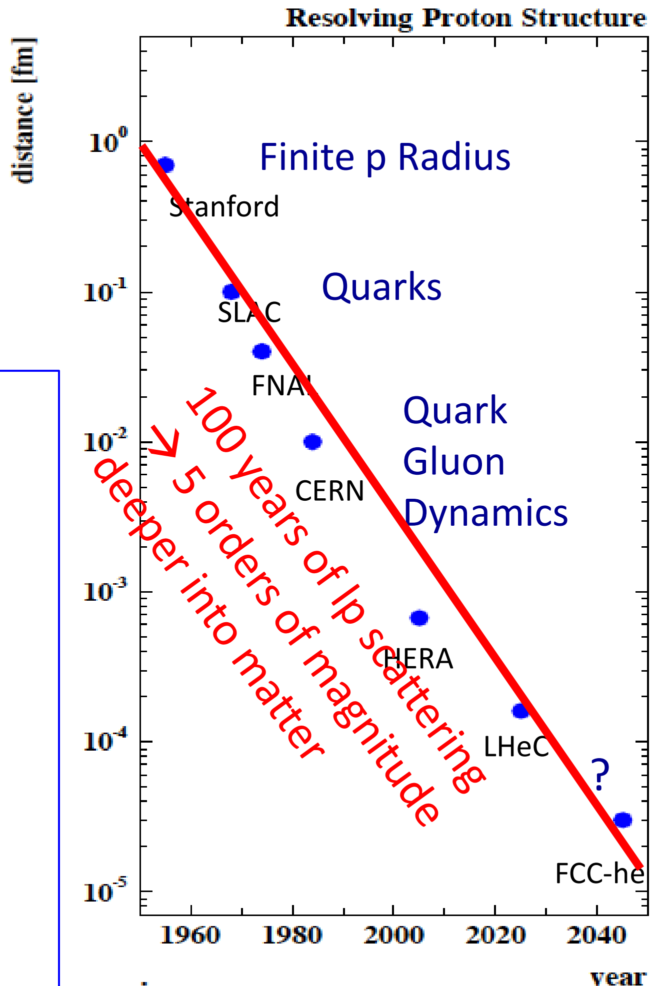
$$x = \frac{Q^2}{sy}$$

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

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

$$s = 4E_eE_p$$

HERA-LHeC-FCC-eh: finest microscopes with resolution varying like $1/\sqrt{Q^2}$



electromagnetic radius

Deep inelastic ep and eA scattering complements pp and ee

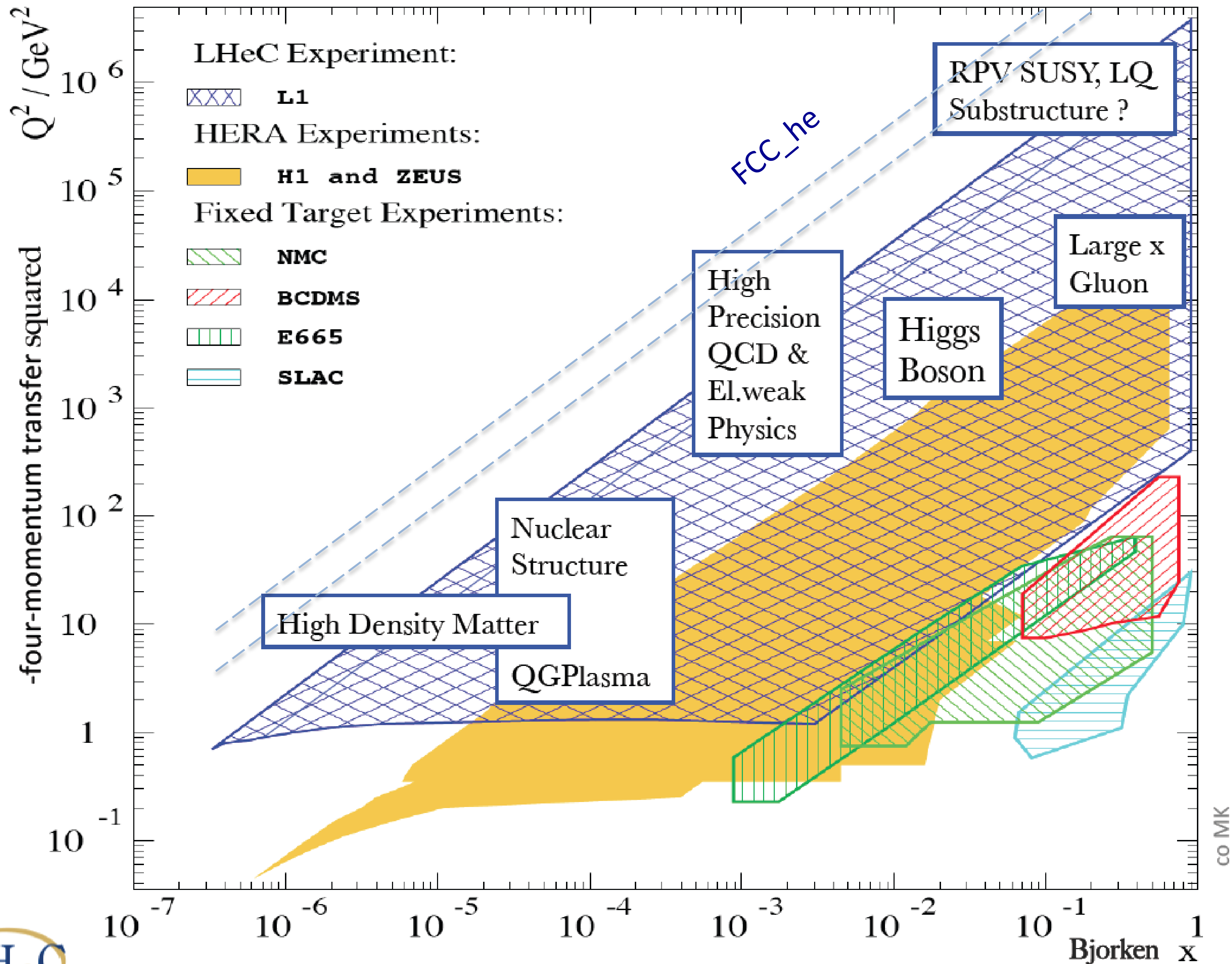
From Hoftstatter to FCC-he: 100 years of eh scattering

CERN is the only place where new DIS experiments at the energy frontier can be planned extending beyond HERA

(LHeC: ongoing study (CDR 2012) for ERL e beam + LHC)

FCC: options for 1 ep collision point :
ERL (of LHeC) on FCC-hh or FCC-hh on FCC-ee → FCC-he

FCC-he option Coordinated by Oliver Brüning and Max Klein



LHeC Experiment:
L1
HERA Experiments:
H1 and ZEUS
Fixed Target Experiments:
NMC
BCDMS
E665
SLAC
FCC_he
RPV SUSY, LQ
Substructure ?
High
Precision
QCD &
El.weak
Physics
Higgs
Boson
Large x
Gluon
Nuclear
Structure
High Density Matter
QGPlasma
Q^2 / GeV^2
-four-momentum transfer squared
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
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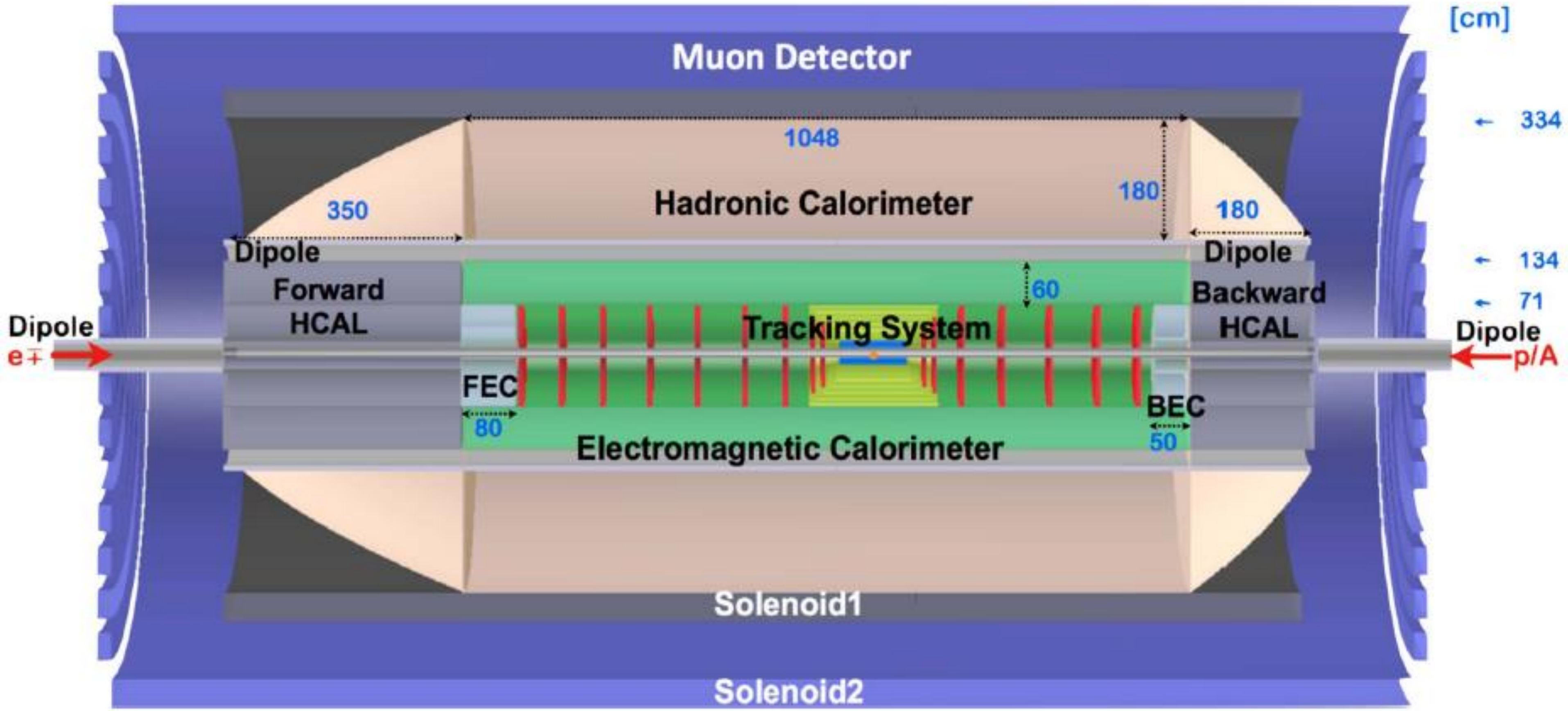
FCC-he Detector (B) – 0.1



Tentative design of detector for ep and eA physics with the FCC-he: 18m (l) x 9m (r)
High resolution of hadron energy and large forward acceptance for Higgs physics
High precision and full polar angle coverage for QCD, electroweak and BSM
Task: optimisation of design, full simulation, design of the interaction region
Goal: synchronous ep and pp operation from day 1 of p beam

P.Kostka, A.Pollini, M.Klein, H TenKate et al

Physics and Organisation of the FCC-he Study

Higgs - Uta Klein, Masahiro Khuze – **selfcoupling, 2nd and 3rd generation, CP**

PDFs – Voica Radescu, Frank Olness – **new evolution, full unfolding, high x**

BSM – Monica D'Onofrio, Georges Azuelos – **SUSY, Leptoquarks, CI, substructure**

Top – Olaf Behnke, Christian Schwanenberger – **6FVS, top PDF, anomalous coupling**

Low x - Paul Newman, Anna Stasto – **Gluon saturation, breakdown of DGLAP**

Heavy Ions – Nestor Armesto with low x – **Nuclear Structure, QGP**

Detector – Peter Kostka, Alessandro Polini - **Design and Simulation, IR**

Software – Paul Laycock and Peter Kostka – **Simulation of ep/eA Detector**

In close collaboration with eh coordination group and machine physicists

Dolce in fine

At this point everybody needs SOFTWARE

→ turn paper studies into real simulations
including acceptance, resolution, PID, backgrounds & pile-up

→ study impact of detector properties on physics sensitivities

→ understand challenges and need for dedicated R&D.

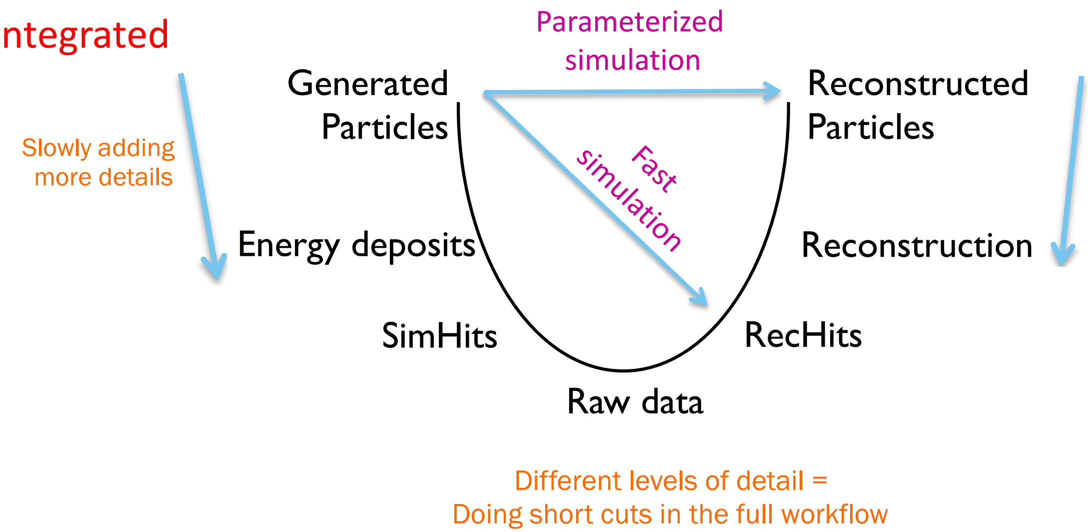
FCC software for experimental studies: Goals

- **Software effort common to FCC-ee, FCC-hh and FCC-eh**
  - Conveners: Fabiola Gianotti, Patrick Janot until 5 September
    - Now taken over by the experts: Benedikt Hegner (CERN) and Colin Bernet (IN2P3)
- **Goal is to find good solutions for**
  - Core framework — **Gaudi**
  - Simulation — **Geant4, DELPHES, others**
  - Detector description — **DD4HEP, DDG4**
  - Reconstruction — **?**
  - Data Model — **Inspired by LCIO**
  - Analysis — **C++ and python**
    - Without starting a software effort from scratch
      - i.e., pick up "existing" solutions / projects and choose pragmatically/wisely

- **A lot of synergies with**
  - **PH-SFT, towards a turn-key universal framework**
  - **ILC/CLIC (e.g., detector description, event data model)**
  - **LHC (Gaudi & GaudiHive adapted from ATLAS, analysis framework adapted from CMS)**
  - **AIDA2 (within which some of these efforts are carried out)**

FCC software for experimental studies: Status

- **After three months of work**
  - Punctuated with 13 informal meetings (https://indico.cern.ch/category/5666/)
    - Core framework infrastructure in active use
    - First test setup for detector description in place (with bugs)
    - Modest example workflow: histogram generated particles. We need much more!
    - Simulation: DELPHES being integrated, but GEANT4 not yet integrated
    - Data model needs to be worked on and integrated
    - Nothing exists on reconstruction
    - Analysis framework needs to be integrated



- **To come soon**
  - Documentation
  - **User training session (mid sept.)**

- **Manpower is critical**
  - Less than one FTE for the time being
    - Three students will start in Sept/Oct 2014

FCC software for experimental studies: Plans

- **More/faster progress require more participation from**
  - **CERN**
    - Applied fellows, associates, invited scientists
  - **External institutes**
    - A number of projects / work-packages will be proposed momentarily
    - ➔ Join the user training session
  - **CLIC / ILC software experts**
    - Towards the use / optimization of common and universal software
      - (Geometry, data model, …)
  - **FCC detector groups (ee, hh, eh)**
    - Towards the parameterization / simulation of well-defined detectors
  - **FCC experimental study groups (ee, hh, eh)**
    - Generators to be interfaced
    - Evaluation of simulation performance
    - Benchmark analyses and analysis tools
- **For more information / organization / participation**
  - Contact Colin.Bernet@cern.ch and Benedikt.Hegner@cern.ch
    - Subscribe to fcc-experiments-sw-dev@cern.ch

Complementarity

Proposed physics topics to be used in the study of **synergy/complementarity** among experiments **at FCC-hh/ee/eh**

Subject		ee	hh	he
Higgs Physics	precision studies higher dimension operators composite Higgs rare and exotic decays multiple Higgs production extra Higgs bosons			
Interface with Cosmology	Dark matter baryogenesis right-handed/(almost) sterile neutrinos			
Electroweak Sym. Breaking	WW scattering supersymmetry extra dimensions composite models			
Flavour Changing	rare H,Z,W,top decays lepton flavor violation			
Extensions of the SM	extra vector-like fermions $SU(2)_R$ models leptoquarks			
QCD	Perturbation theory, structure functions Modelling final states			
EW/SM precision issues	precision measts (m_Z,m_W,m_t,α,$\alpha_s(m_Z)$,$\sin^2\theta_W$.R_b... higher-order EW corrections W,Z triple and quadruple couplings top (anomalous) couplings charm/bottom flavor studies			

What we believe now and hope to demonstrate in a few years:

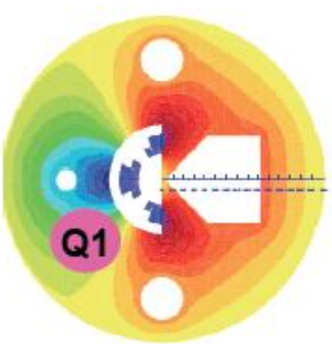
The combination of the FCC machines offers outstanding discovery potential by exploration of new domains of
-- precision
and
-- direct search, both at high energy and at very small couplings

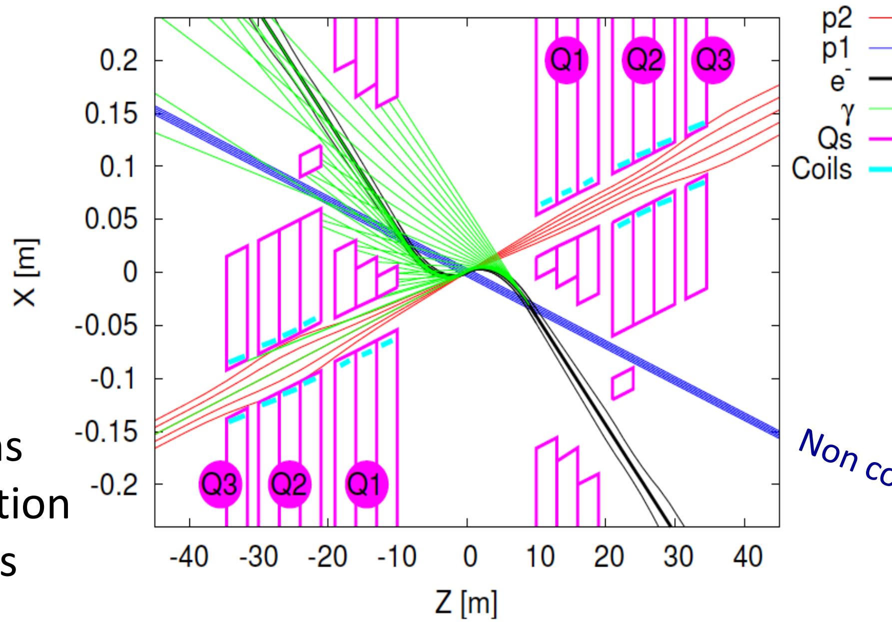
Extra slides

FCC Physics Coordination (Physco)

Meeting / activity	Present goals (as of April 2014)	who is present	Frequency
Physics Coordination Meeting (FCC-Physco) (Chair: A. Blondel until April 2015 Secretary: Mike Koratzinos)	• Ensure that all physics studies progress as one consistent endeavor • Define and align scope and milestones of physics studies • Propose physics topics to be used in the study of synergy/complementarity among experiments at FCC-hh/ee/eh • Track progress of individual physics study activities • Monitor/coordinate/promote talks on FCC physics at conferences and workshops • Identify technical and organizational questions which require further coordination ○ Software platform ○ theoretical calculations ○ conference presentations ○ repository of talks and papers, ○ experimental R&D and infrastructures ○ running scenarios and schedule ○ general study management • Identify issues to be brought to attention to FCC coordination meeting	FCC Study leader and deputy; Hadron physics and experiments study leaders; Lepton physics and experiments study leaders; e-p physics and experiments study leader; others invited as required. ------------------------------ Accelerator: **Benedikt** **Zimmermann** FCC-hh: **Gianotti** **Mangano** **Ball** FCC-ee: **Blondel** **Janot** **Ellis/Grojean** FCC-eh: **Klein/D'Onofrio**	1 / month or as needed (Thursdays 12:00-13:30) 5 February 20 March 10 April **8 May**

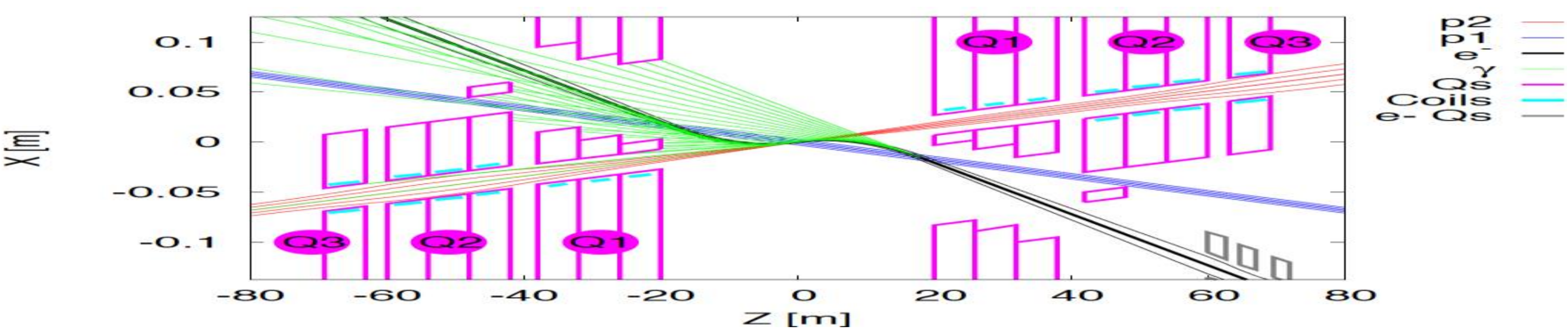
Interaction Regions for ep with Synchronous pp Operation





LHeC (CDR)
60 GeV * 7 TeV

Likely one IR.
Matching e and p beams
Limit synchrotron radiation
Design of inner magnets
Beam-beam effects ….



Rogelio Tomas, Max Klein, ICHEP14

Tentative: ε_p=2μm, β*=20cm → σ_p=3μm ≈σ_e matched! ε_e=5μm ..

FCC-he (ERL)
60 GeV * 50 TeV

collider parameters	FCC ERL	FCC-ee ring		protons
species	e^- (e^+?)	$e^\pm$	$e^\pm$	p
beam energy [GeV]	60	60	120	50000
bunches / beam	-	10600	1360	10600
bunch intensity [10^{11}]	0.05	0.94	0.46	1.0
beam current [mA]	25.6	480	30	500
rms bunch length [cm]	0.02	0.15	0.12	8
rms emittance [nm]	0.17	1.9 (x)	0.94 (x)	0.04 [0.02 y]
$\beta_{x,y}$*[mm]	94	8, 4	17, 8.5	400 [200 y]
$\sigma_{x,y}$* [μm]	4.0	4.0, 2.0		equal
beam-b. parameter ξ	(D=2)	**0.13**	**0.13**	0.022 (0.0002)
hourglass reduction	0.92 (H_D=1.35)	**~0.21**	~0.39	
CM energy [TeV]	3.5	3.5	4.9	
luminosity[10^{34}cm^{-2}s^{-1}]	**1.0**	**6.2**	**0.7**	

F.Zimmermann
ICHEP14, June

PRELIMINARY
L is 1000*HERA