FCC-eh Machine Configuration and Performance

- Configuration:

  Modular design elements:

  -60 GeV ERL configuration for the ‘e’ beam documented in the LHeC CDR ➔ varied sizes; applicable to LHC, HE-LHC and FCC

  -IR configuration with head-on collisions

  ➔ without Crab Cavities (vs EI in US)!

  ➔ SR acceptance in detector and beam separation

  ➔ Dipole integrated into detector

  ➔ ‘Sweetspot’ IR magnet design

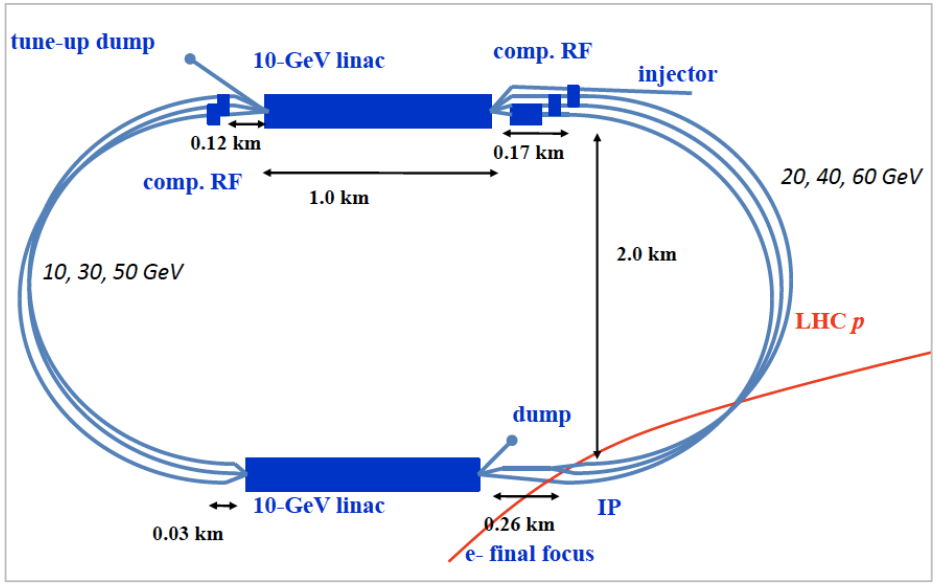
  -800MHz SRF: synergy with FCC-ee and FCC-hh

60GeV ERL Baseline Configuration:

Peter Kostka

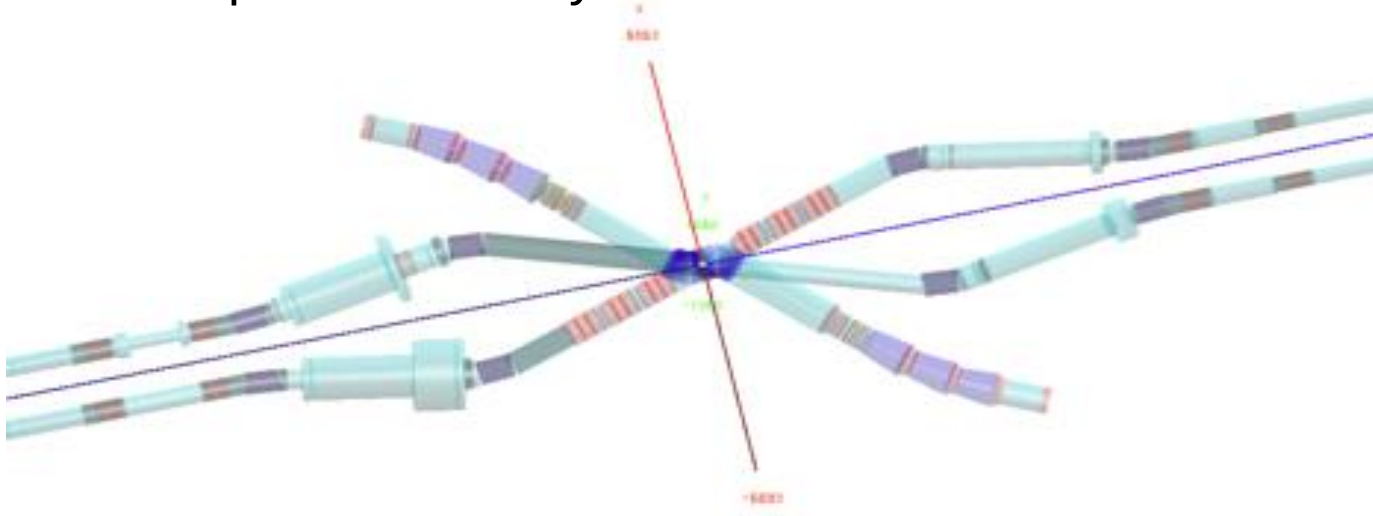
* LHeC CDR, arXiv:1206.2913

Super Conducting Recirculating Linac with Energy Recovery



Operation in parallel with LHC/HE-LHC/FCC-hh

- TeV scale collision energy
  - ➔ 50-150 GeV beam energy
- power consumption < 100 MW
  - ➔ 60 GeV beam energy
- int. luminosity > 100 * HERA
- peak luminosity L > 10^{34} $cm^{-2}s^{-1}$



➔ 944 cavities; 59 cryo modules per linac
➔ ca. 9 km underground tunnel installation
➔ more than 4500 magnets

courtesy H.Burkhardt, BE-ABP CERN (layout scaled !)

LHeC/FCC-eh interaction region

Peter Kostka

non focused beam bypasses the interaction

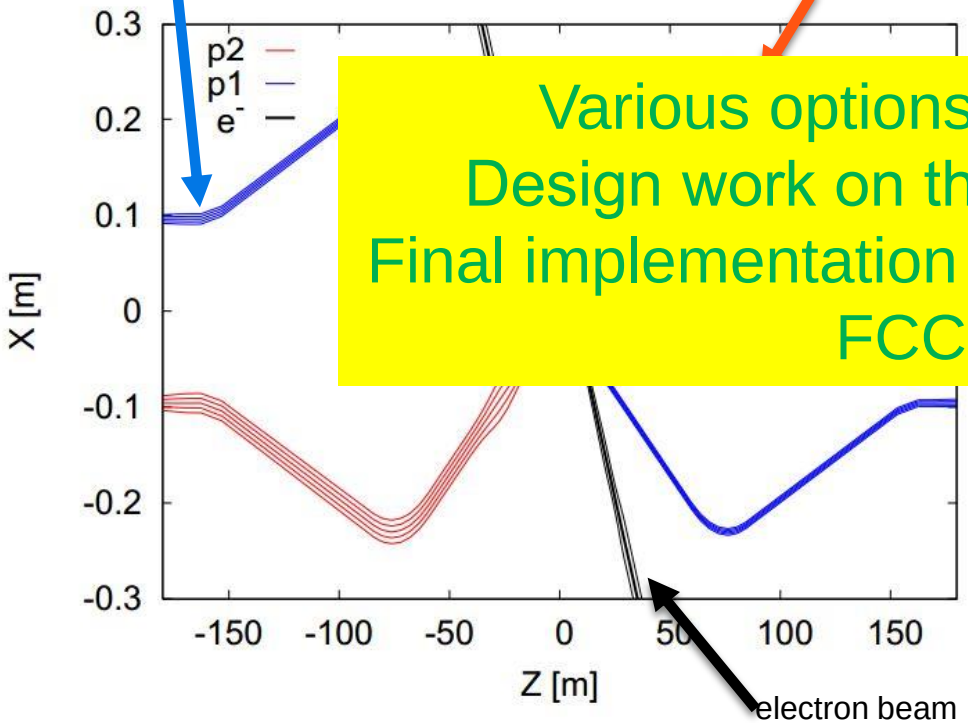
focused interacting proton beam

Synchrotron Radiation and various beams

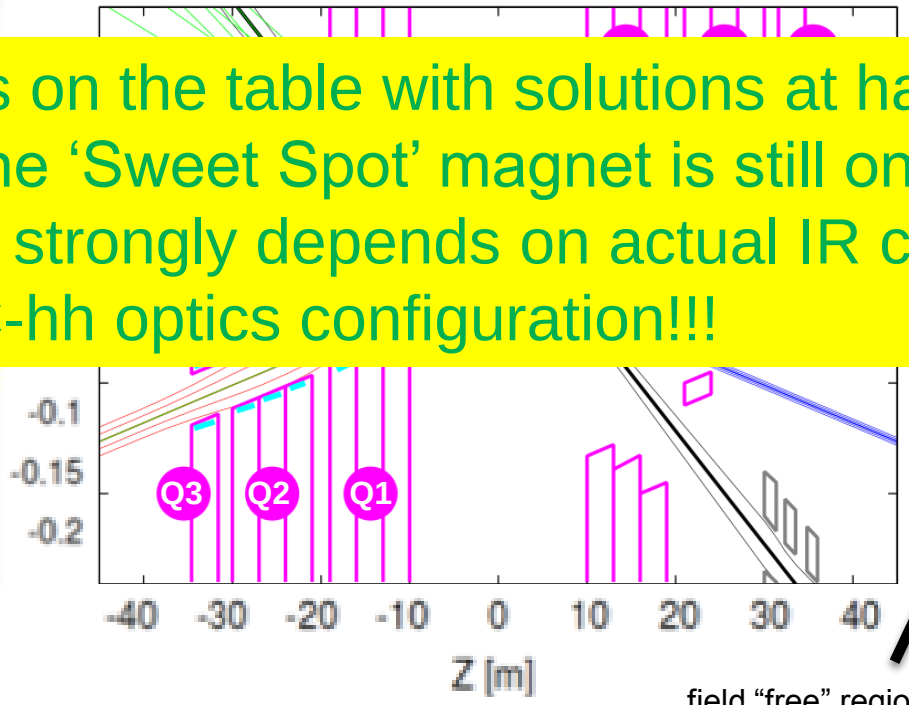
SR fan

exit hole - electrons and non-colliding protons

Final quadrupole magnet Q1 example design "sweet spot"



Various options on the table with solutions at hand!
Design work on the 'Sweet Spot' magnet is still ongoing!
Final implementation strongly depends on actual IR choice and FCC-hh optics configuration!!!



electron beam from ERL

field "free" region

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

electron proton beams well matched!

E. Cruz, R. Tomas, F. Zimmermann et al.

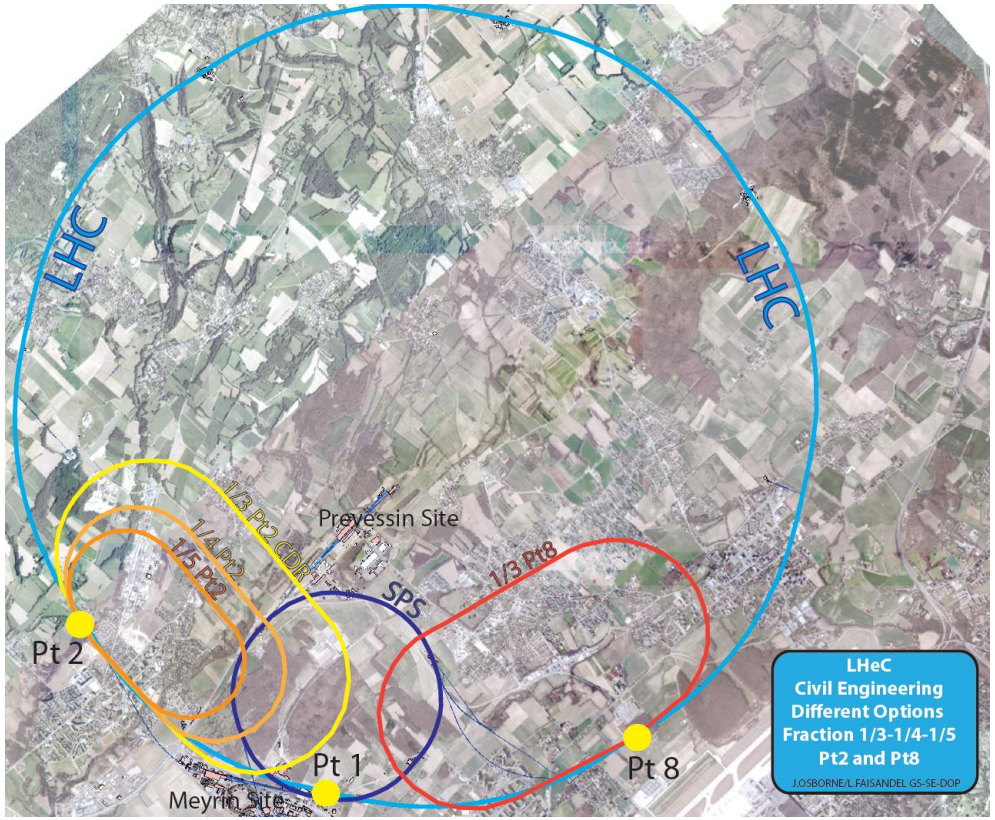
B. Parker, S. Russenschuck et al.

FCC-eh Configuration: Layout & Civil Engineering

C. Cook @ FCC week in Rome

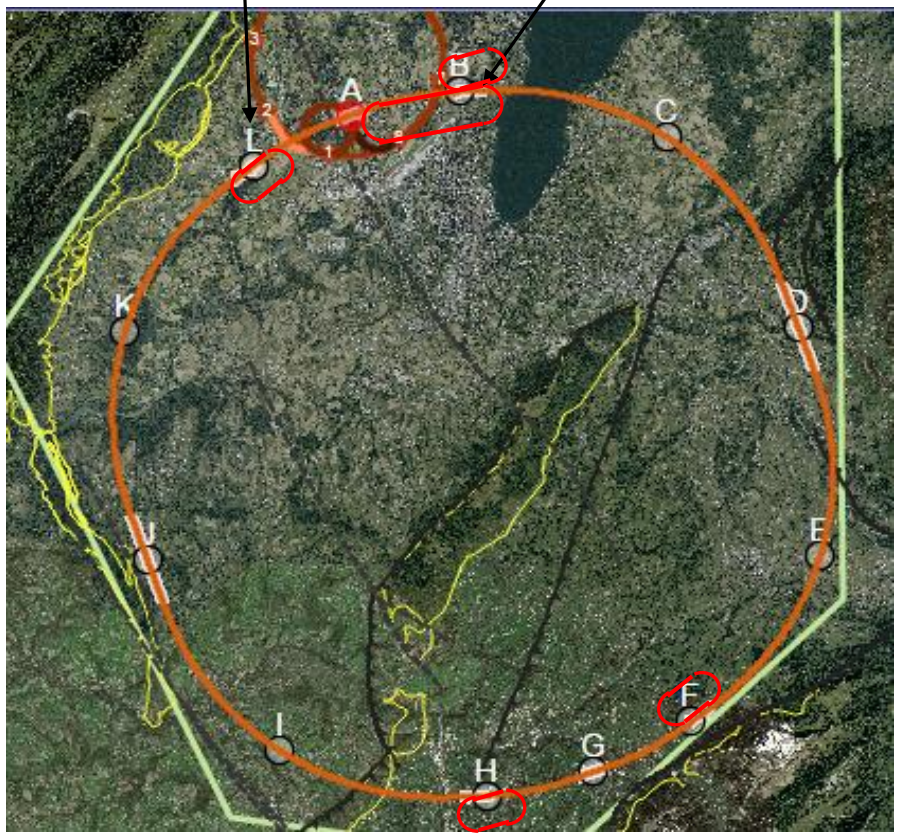
Configuration:

Different Size Variations:
e.g LHeC



Independent FCC-he
Point L, F, H or B

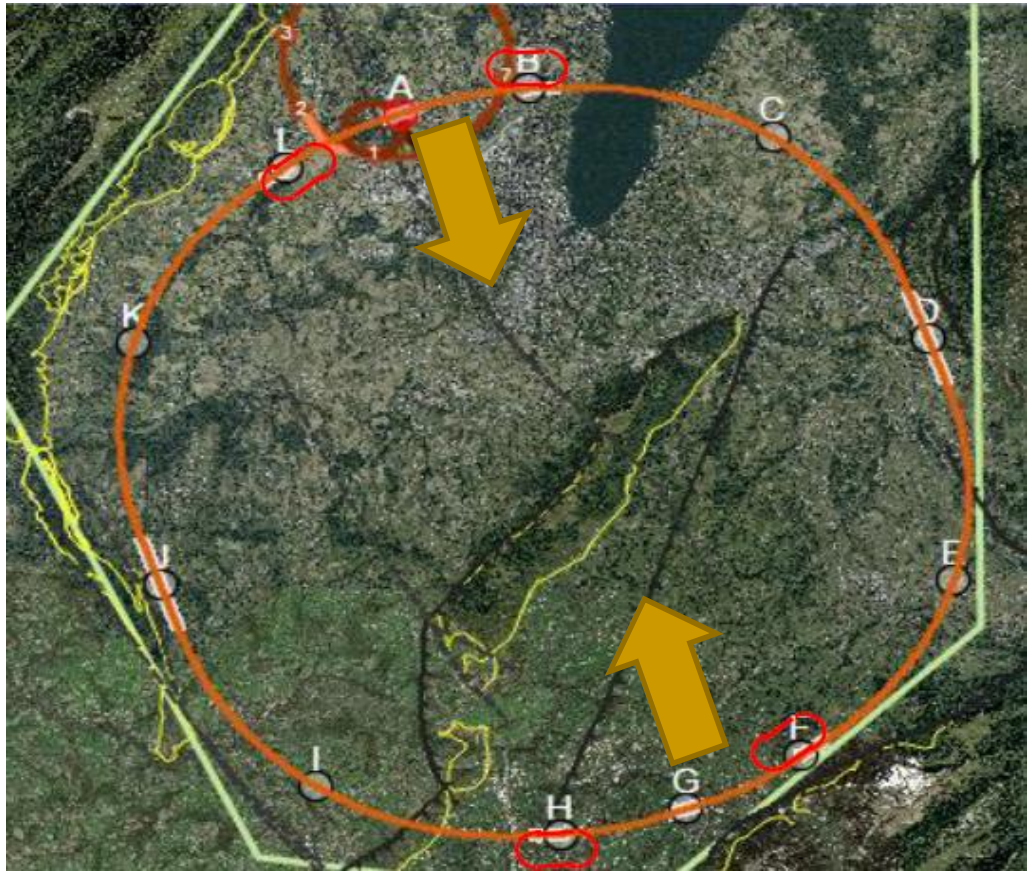
LHeC / FCC-he
LHC P8 & FCC PB



FCC Layout Changes

Jo Stanyard

Rome 2016 Layout



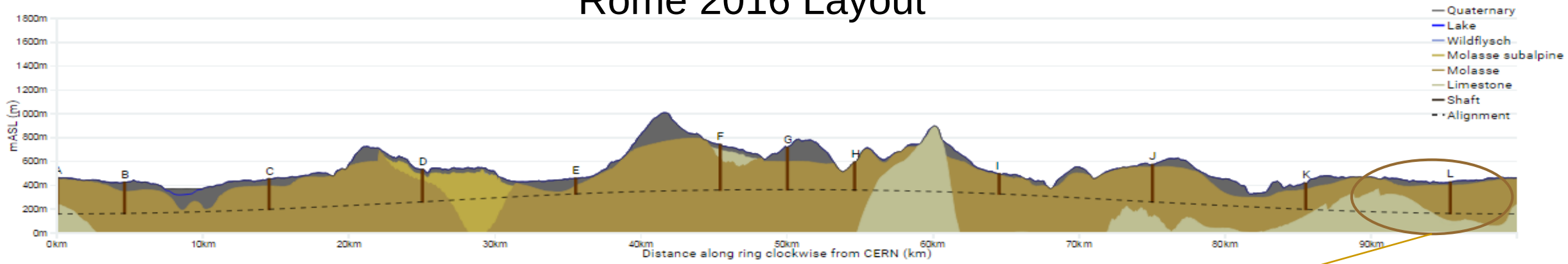
Updates since Rome 2016 layout:

- Reduced depth below surface level.
- Reduced length of straight sections at J and D.
- Increased tunnel length from A-L, A-B and G-F, G-H.
- Avoids Jura Limestone and Pre-Alps region.
- Reduced Total Tunnel Length.

FCC Layout Changes (profile)

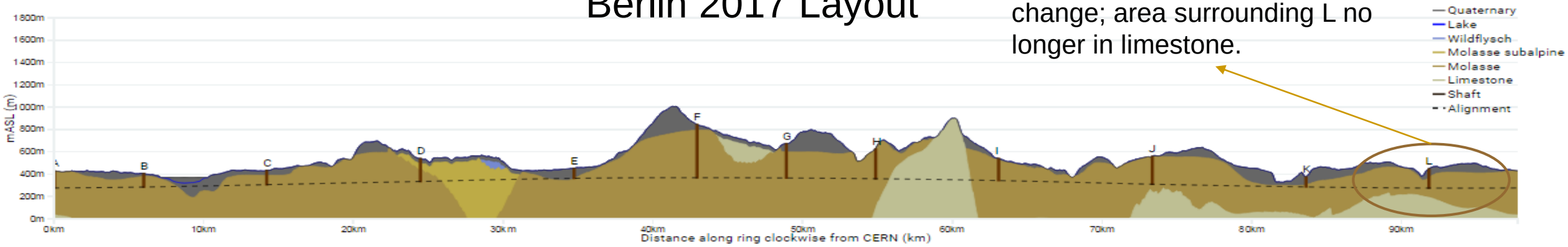
Jo Stanyard

Rome 2016 Layout



Reduced Depth & alignment change; area surrounding L no longer in limestone.

Berlin 2017 Layout

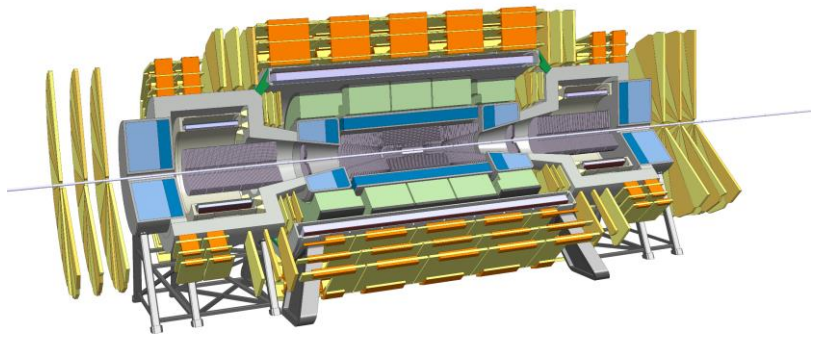


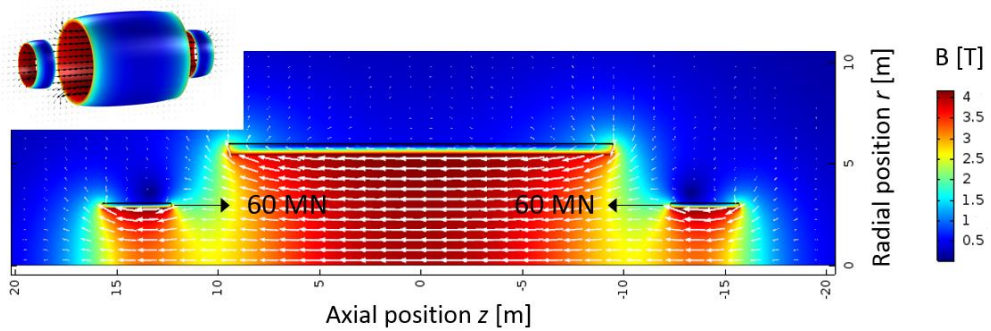
Detector Considerations from the LHeC to the FCC

Pictures W.Riegler on Monday
talk of Herman ten Kate, Matthias Mentink
https://indico.cern.ch/event/556692/contributions/2465157/

- **Interaction region:**
  - Assume similar interaction region as for LHeC
    - FCC-hh bunch spacing? 25 ns no showstopper,
    - 5 ns, 12.5ns to be looked at → stronger dipole field?
  - dipole field across the whole detector
  - $e^{\pm}$ syn radiation → elliptical beam-pipe
- **Detector:**
  - Higher momenta/energies → Larger BL^2
  - Larger transverse calorimetry (up to 12 λ_I in the fwd region)
  - Large acceptance over η
  - Bunch spacing (25ns → 12.5ns → 5ns)
  - Pile-up no problem in ep than for LHC/FCC-hh
- **Beam Pipe Design**
  - low X_0, λ_I material (Be), stable, capable for 1° tracks
  - allowing low p_T particle measurement
- **Magnets**
  - Use the solenoid option as proposed for FCC-hh + balanced conical solenoid.
  - Strong field in the fwd/bwd region to allow for tracking over a wide range of η - down 1^0 θ-angle.
  - The concept is attractive and could be adjusted.

New Reference Design FCC-hh





Peter Kostka

FCC-he Detector Layout - Inner Dipoles and Solenoid

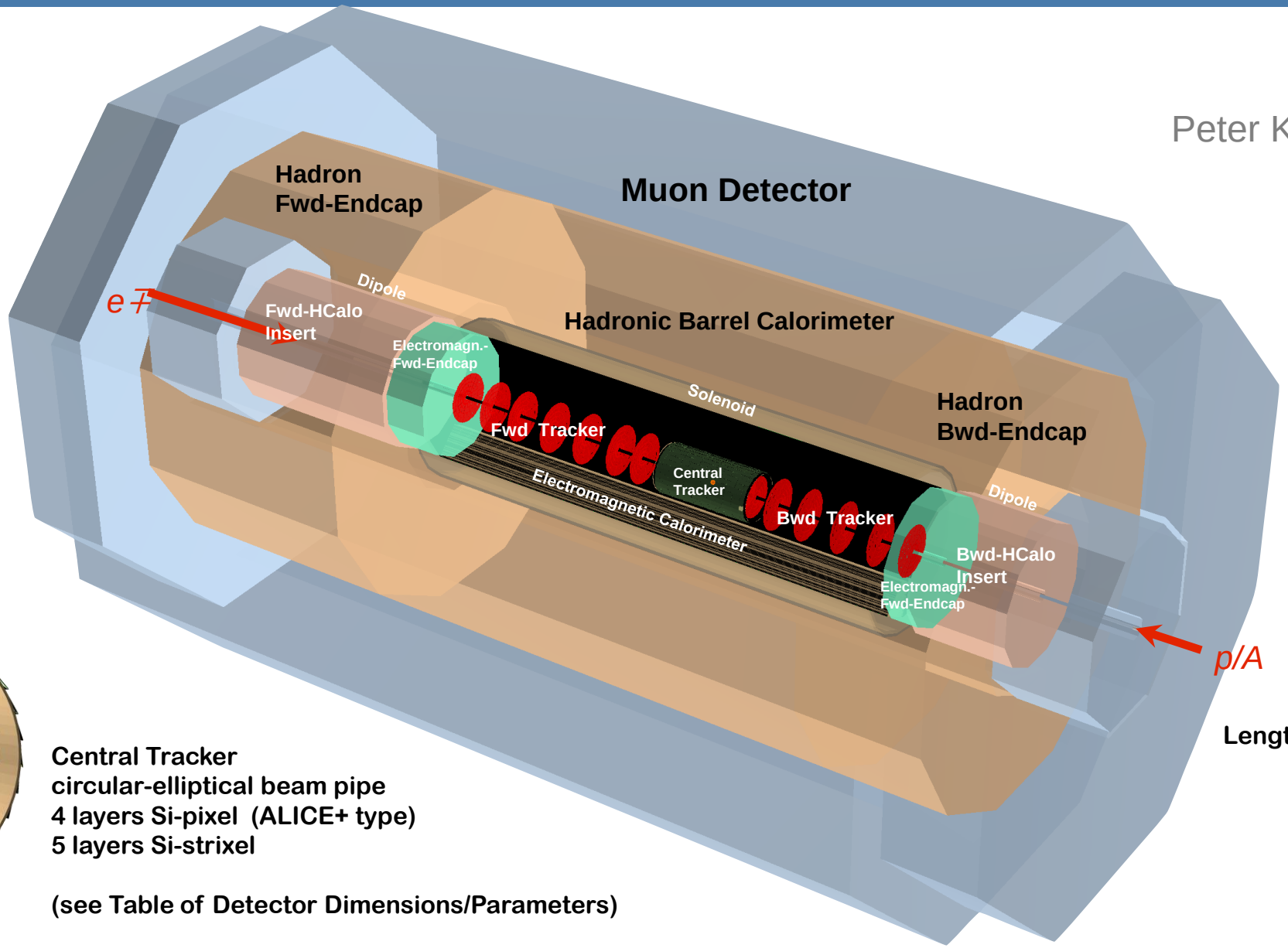
Peter Kostka

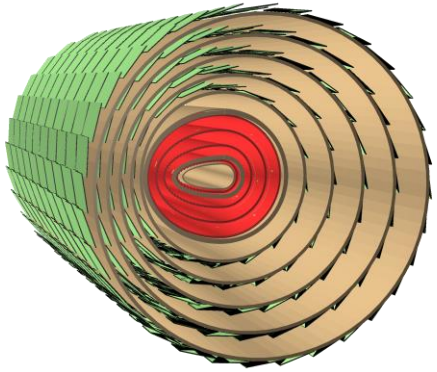
3 beams:

e∓ + proton1 + proton2
(or heavy ions A)

Dipole magnets to guide the e-beam in and out, for making electrons to collide head-on with p-beam1;

0.3 T dipoles (transverse) field along 2 x 9 m (internal shown only)





Central Tracker
circular-elliptical beam pipe
4 layers Si-pixel (ALICE+ type)
5 layers Si-strixel

(see Table of Detector Dimensions/Parameters)

Length of Solenoid ~10m

PERLE: Powerfull ERL for Experiments @ Orsay

PERLE at Orsay (LAL/INP) Collaboration: BINP, CERN, Daresbury/Liverpool, Jlab, Orsay +

3 turns, 2 Linacs, 400 MeV, 15mA, 802 MHz, Energy Recovery Linac facility

-Demonstrator of ERL for ep at LHC/FCC

Machine Study Goals:

- -High current, multi-turn (3) ERL concept with 802MHz SRF
- -Beam Breakup intensity limit and filling patterns,
- -ERL efficiency,
- -beam size evolution etc.
- -SRF LLRF feedback and control
- -Failure scenarios
- -Beam Halo formation and dump line acceptance
- -Beam Instrumentation
- -Build up operational experience
- -Source and injector

FCC-eh Physics Motivation

Max Klein

- Five Major Themes for eh Physics:

  -Cleanest high-resolution microscope

  -Joint eh and hh physics ➔ high precision PDFs open door for high precision pp physics

  -High precision Higgs exploration

  -Discovery Beyond the Standard Model

  -Unique Nuclear Physics Facility

Gluon PDF with FCC-eh data

Gluon PDF

- Most important parton for most SM and BSM scenarios
- Precise knowledge at all scales and x-values is imminent

Low-x

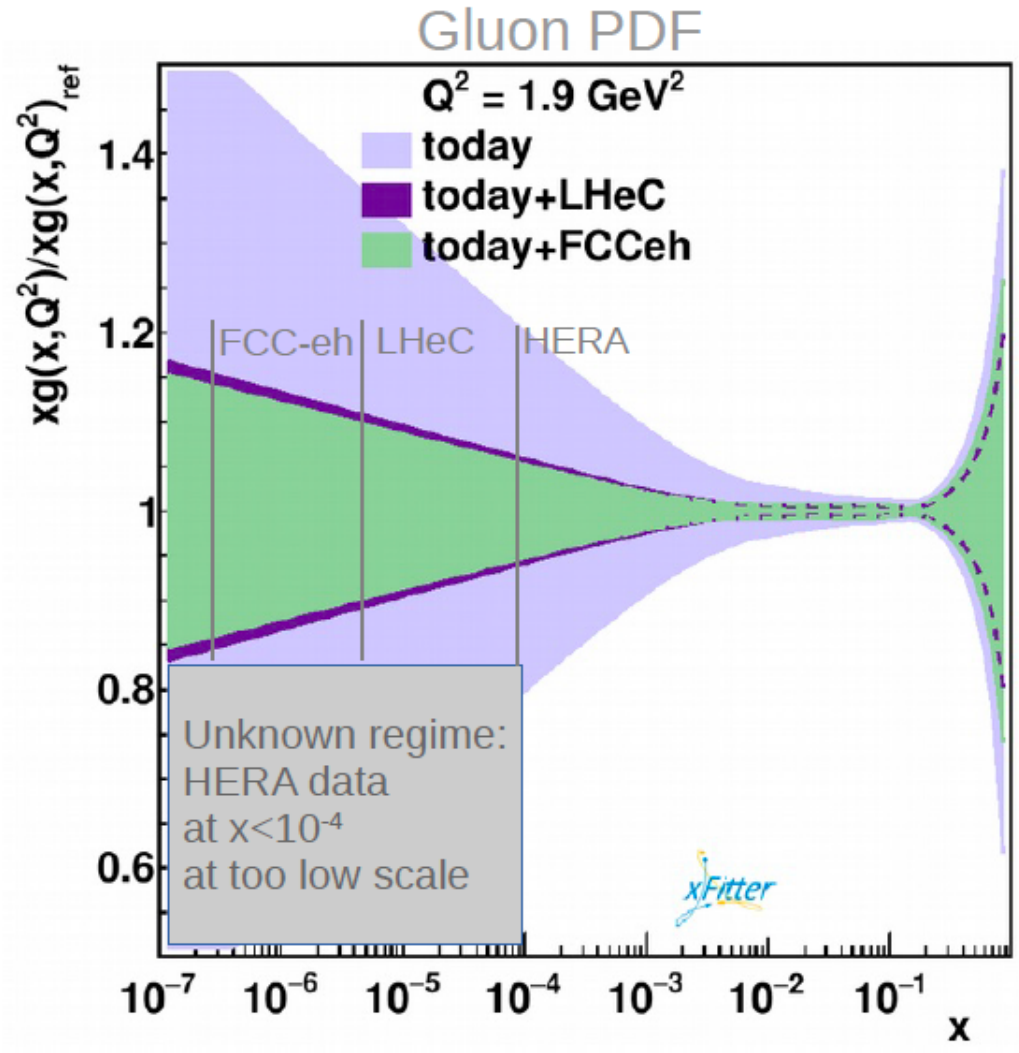
- Important for boosted topologies at FCC-eh
- Currently no data at $x<10^{-4}$
- Uncertainty only from 'extrapolation' but

High-x

- poorly constraint because of limited statistics

FCC-eh

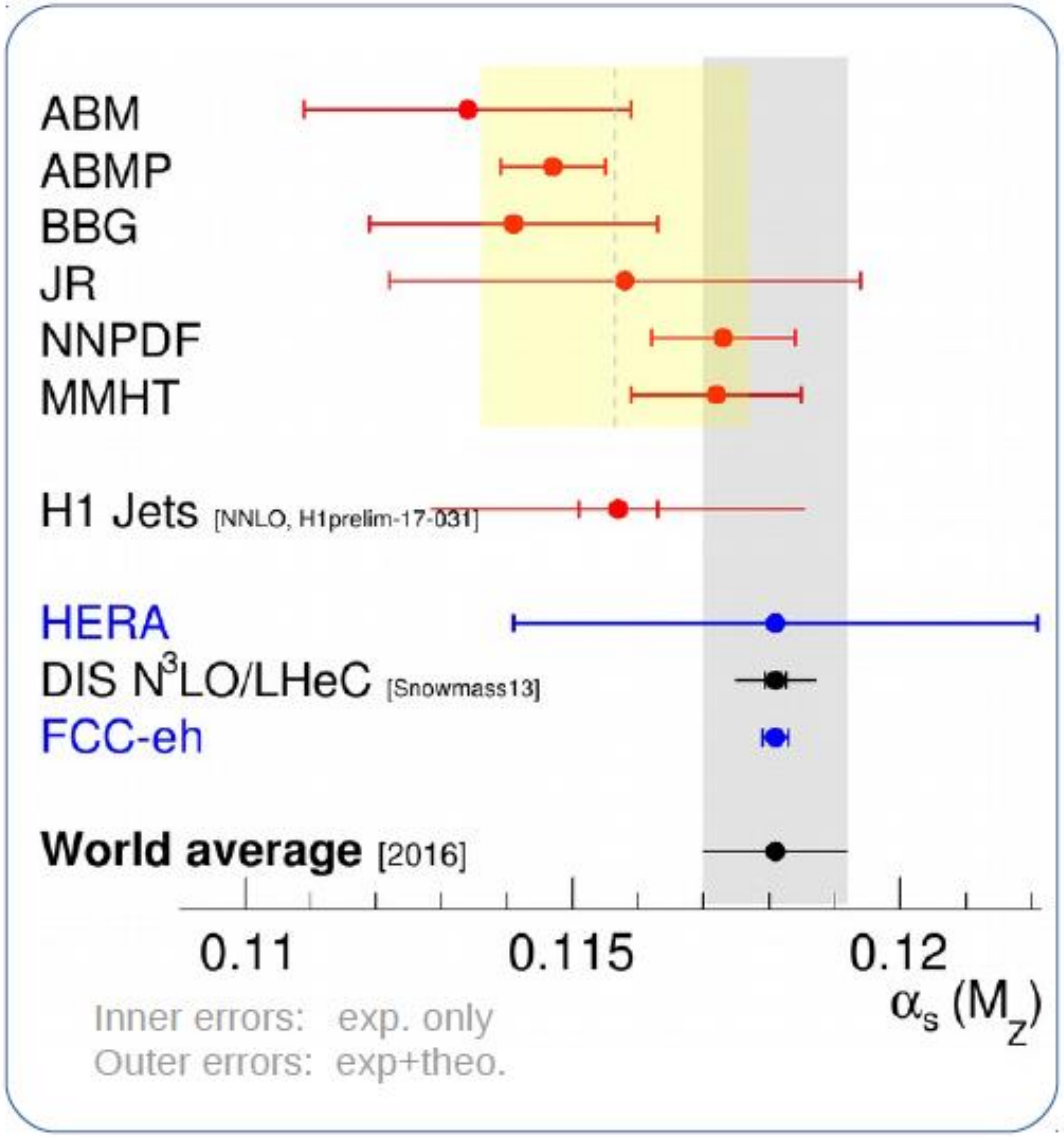
- Explore region of x down to $x\sim10^{-7}$
- Small-x phenomenology:
  BFKL or saturation effects may show up
  -> Physics topics on their own



High precision determination of strong coupling constant α_s to 0.1%

FCC-eh prospects

- *Highest precision expected incl. PDF uncert.*

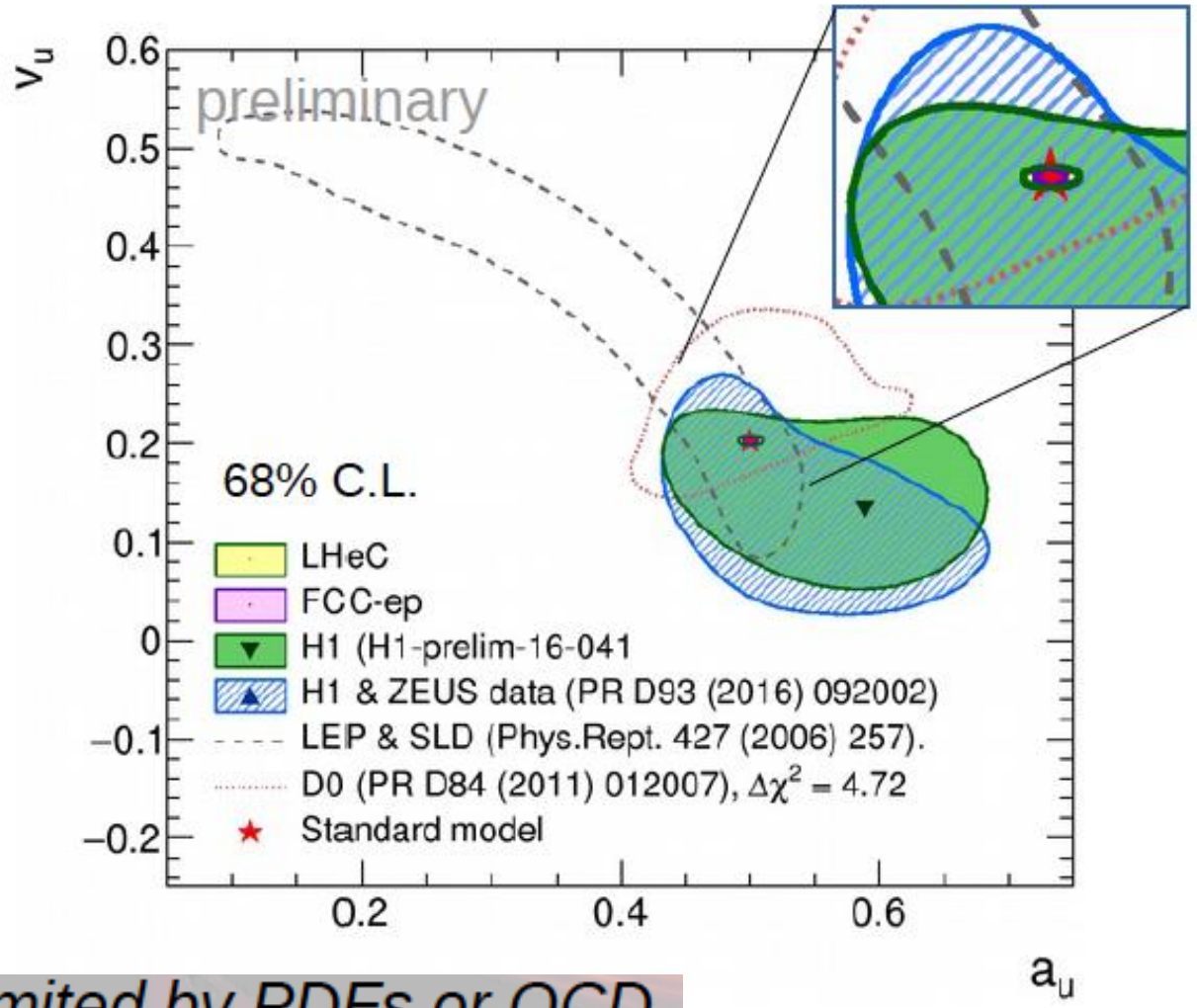


Daniel Britzger

High precision couplings: up quark-Z boson

High precision test of electroweak sector of the Standard Model

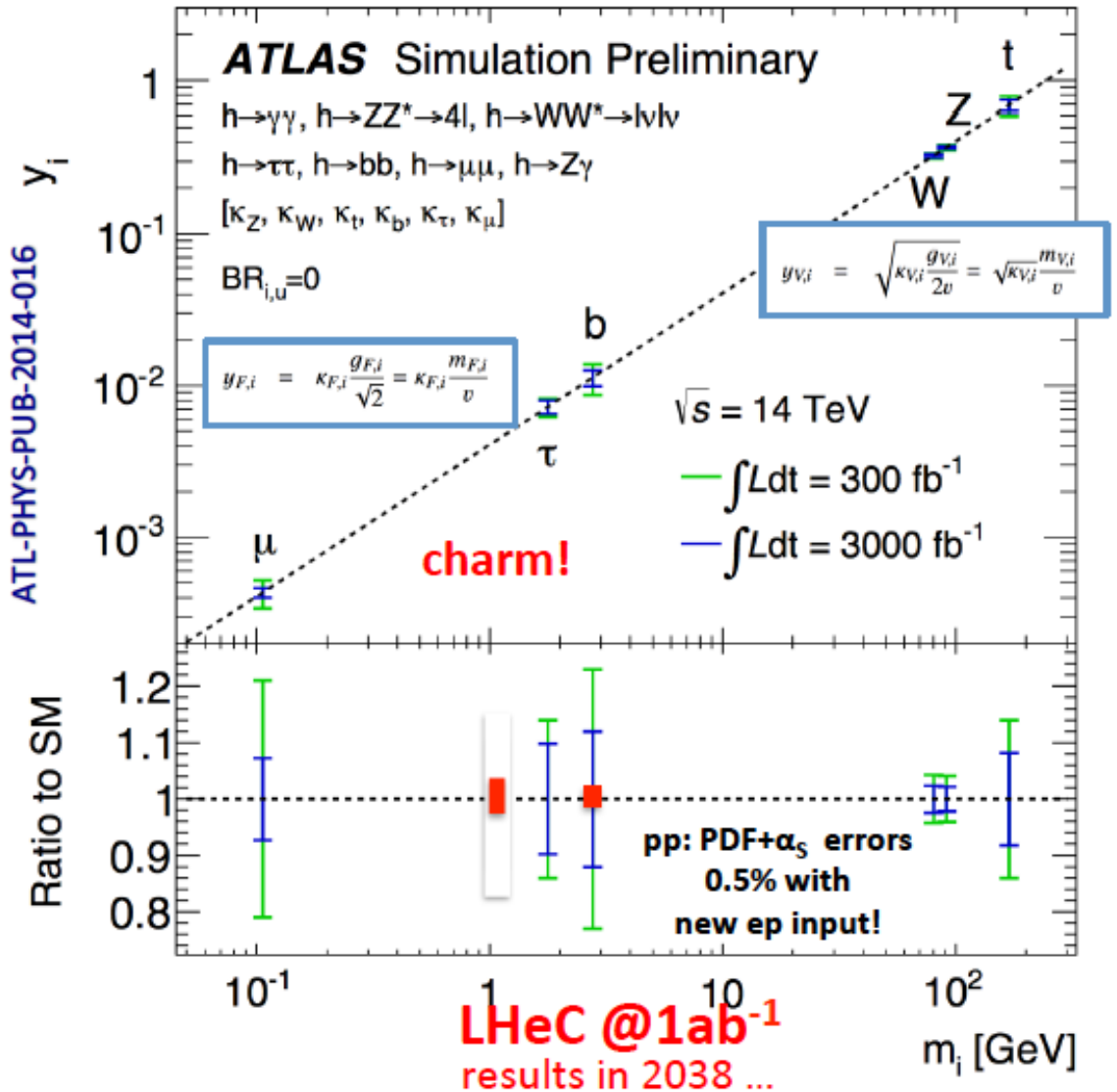
Daniel Britzger

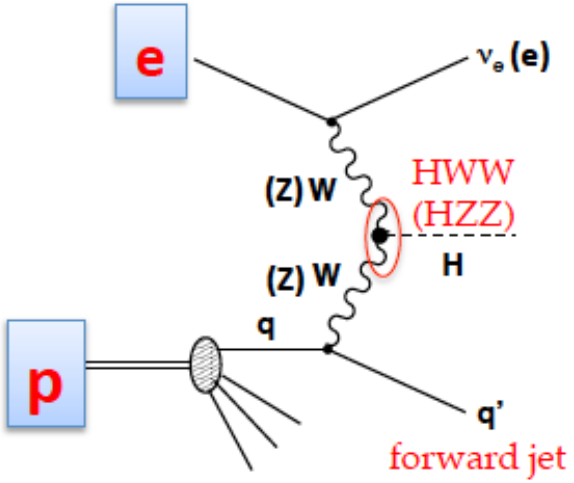


- *precision EW physics in ep is not limited by PDFs or QCD*
- *precision QCD physics in ep is not limited by EW corrections*

Higgs Couplings at pp + ep

running concurrently





→ use ep as the 'near' detector for pp to beat α_s and PDF uncertainties to <~0.5%, δm_b to 10 MeV, δm_{charm} to 3 MeV

LHeC @1ab^{-1}

results in 2038 …

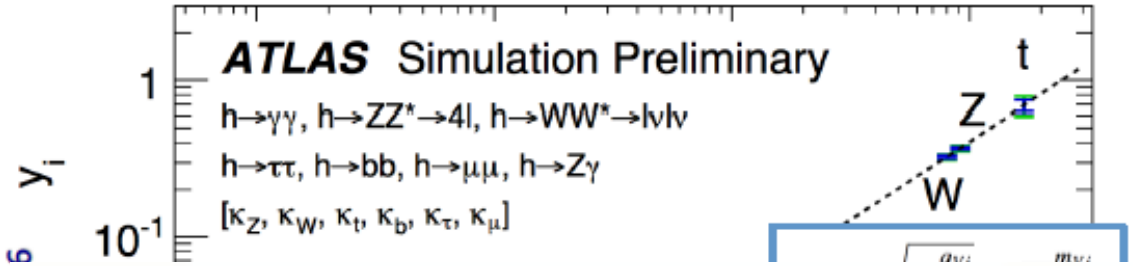
concurrent with HL-LHC end

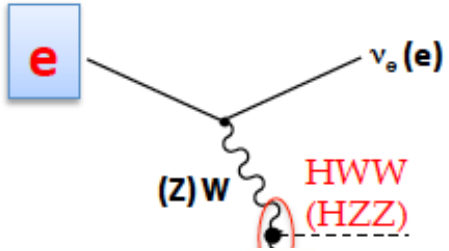
Uta Klein, Higgs@FCC-eh

8

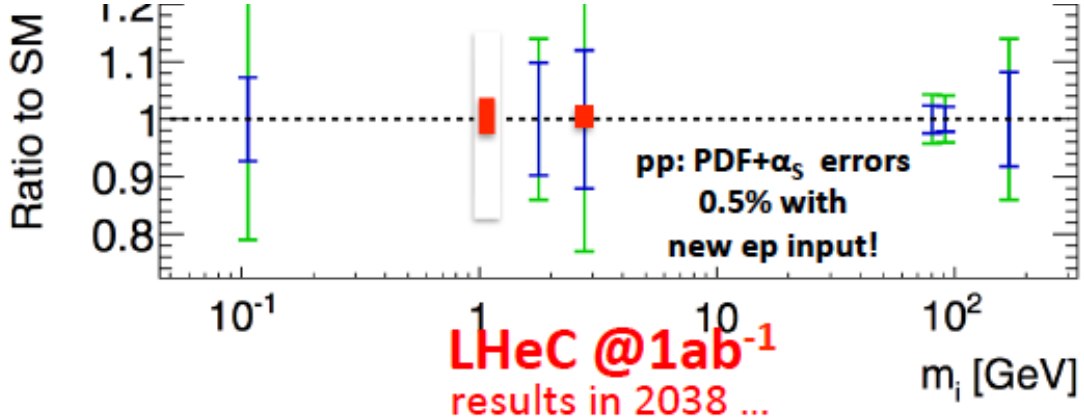
Higgs Couplings at pp + ep

running concurrently





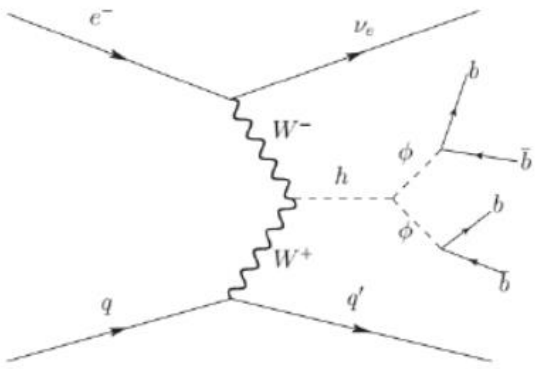
	LHeC (E_p = 7 TeV $\sqrt{s}$ ~1.3 TeV)	DLHC (E_p = 14 TeV $\sqrt{s}$ ~1.8 TeV)	FCC ep (E_p = 50 TeV $\sqrt{s}$ ~ 3.5 TeV)
κ (Hbb)	0.5%	0.3%	0.2%
κ (Hcc)	4%	2.8%	1.8%



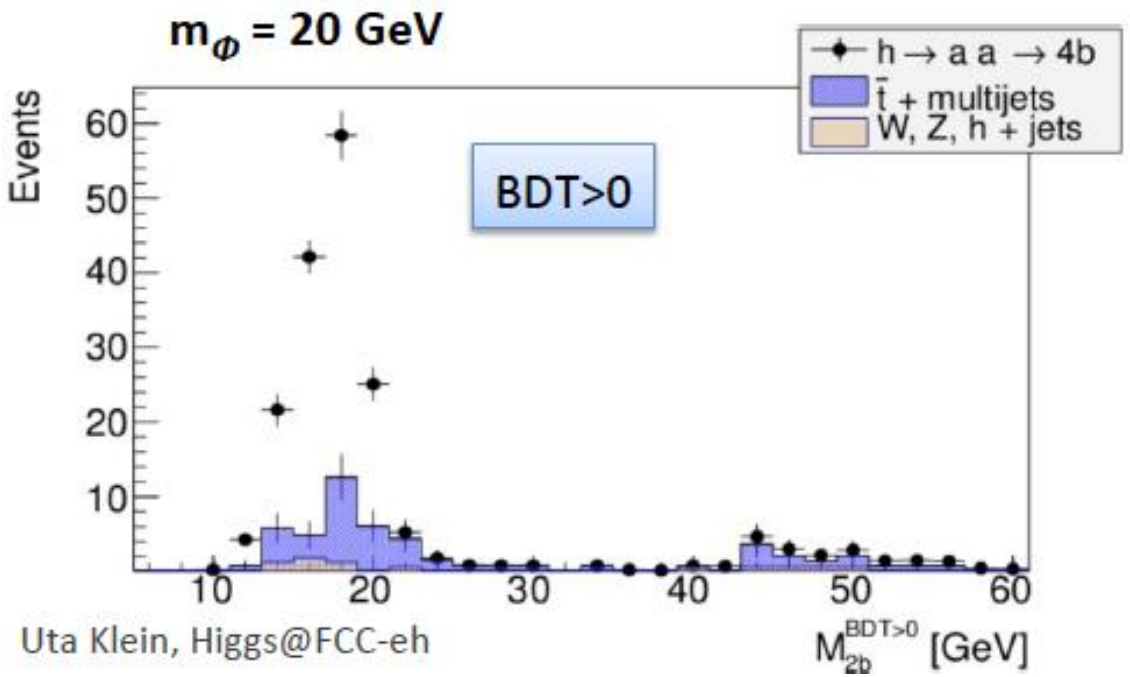
detector for pp to beat α_s and PDF uncertainties to <~0.5%, δm_b to 10 MeV, δm_{charm} to 3 MeV

LHeC @1ab^{-1}
results in 2038 ...
concurrent with HL-LHC end

Higgs Portal to New Physics: exotic Higgs decay



Very promising first results to discover an exotic Higgs decay into two new light scalars at FCC-eh down to a BR of 1% for 1 ab^{-1}. A BR of 10% could be discovered within 1 year (100 fb^{-1}).



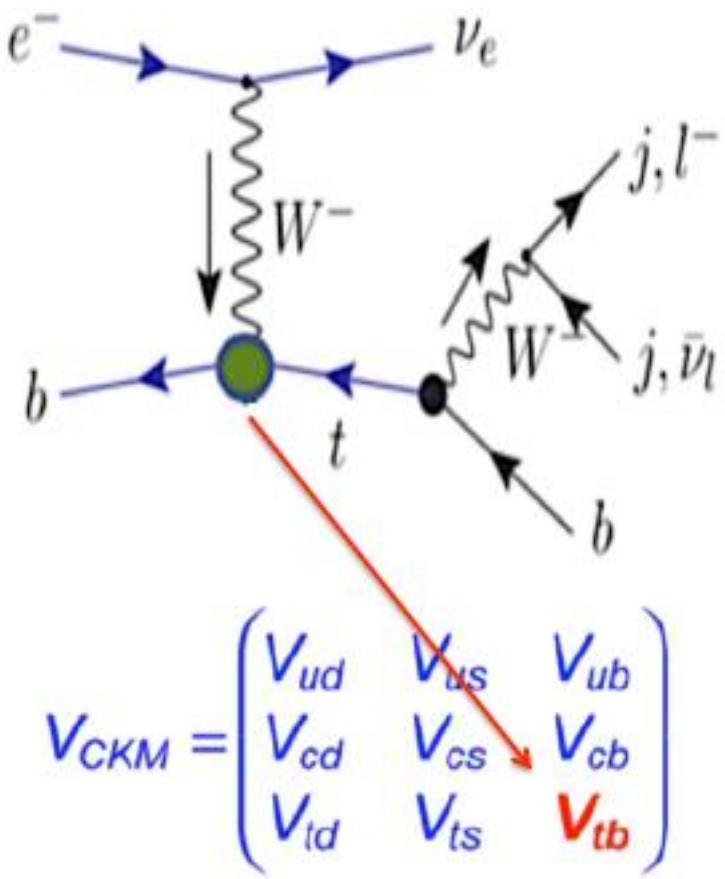
Many more, often published studies on BSM Higgs physics,

e.g. Higgs into Dark Matter
charged Higgs bosons

and Higgs self coupling H→HH

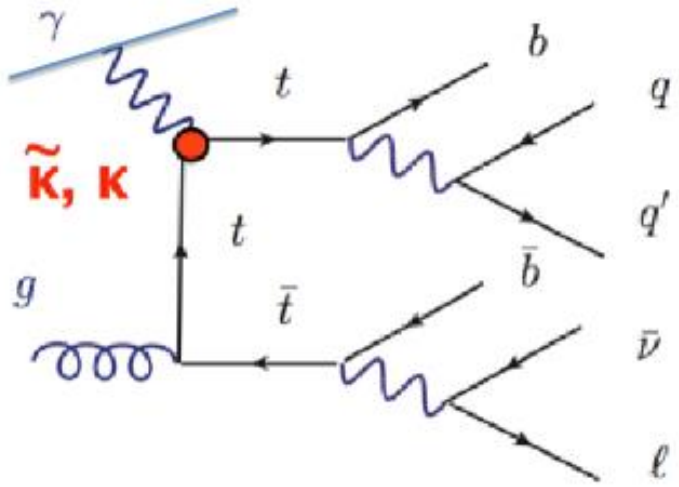
Precision Top Physics in ep

Orhan Cakir



V_{tb} to 0.5% with 0.1 ab^{-1}

Electric and magnetic dipole moments to O(5%) precision LHeC, better at FCC-eh

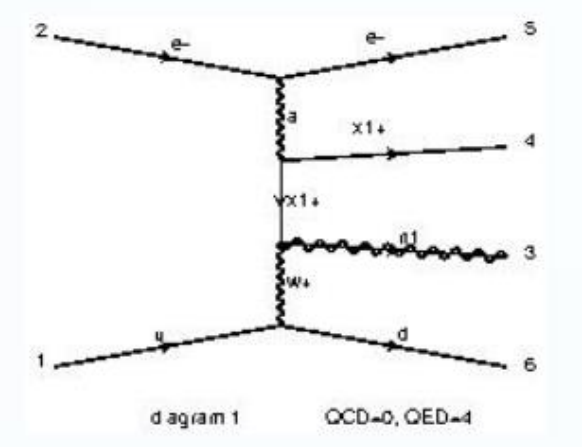


Top physics a strong area of study
More results coming for the CDR

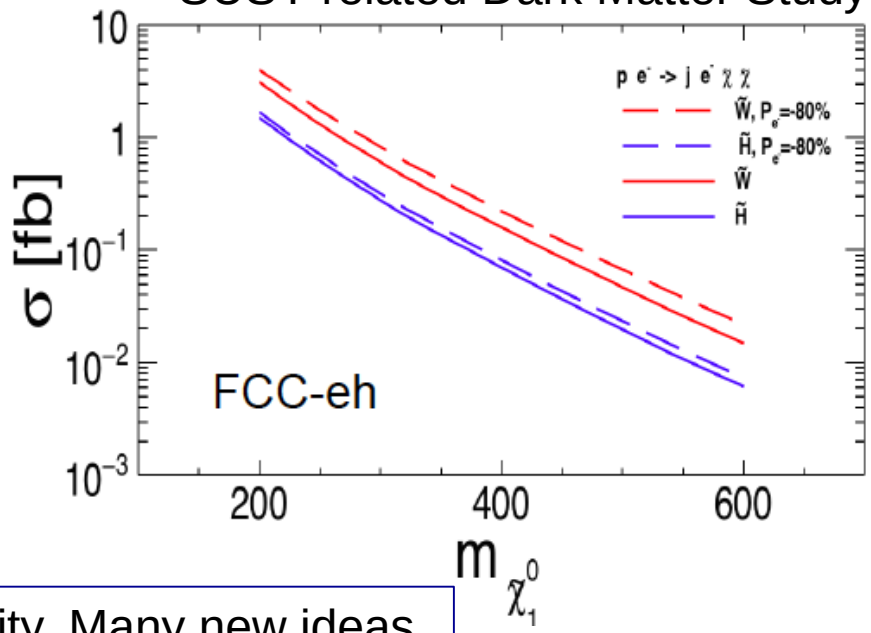
BSM Physics in ep

Kechen Wang

- ★ Indirect impact from improved PDF
- ★ **Direct Searches**
  - Leptoquarks: limits, quantum # & couplings
  - Contact interactions: eeqq
  - Anomalous gauge couplings: VVV
  - Vector boson scattering
  - BSM in the top sector
  - RPC SUSY: DM, sleptons
  - RPV SUSY: neutralinos, squarks
  - BSM Higgs: exotic (invisible) decay; H^+, H^{++}
  - Sterile neutrinos



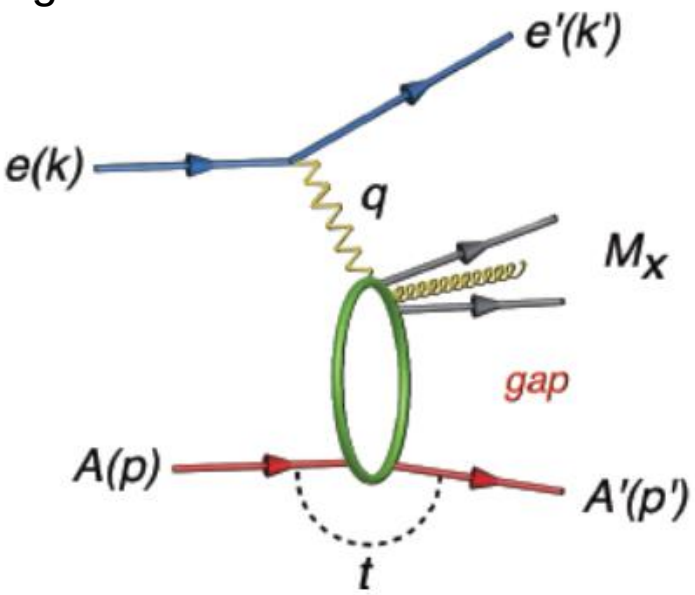
SUSY related Dark Matter Study



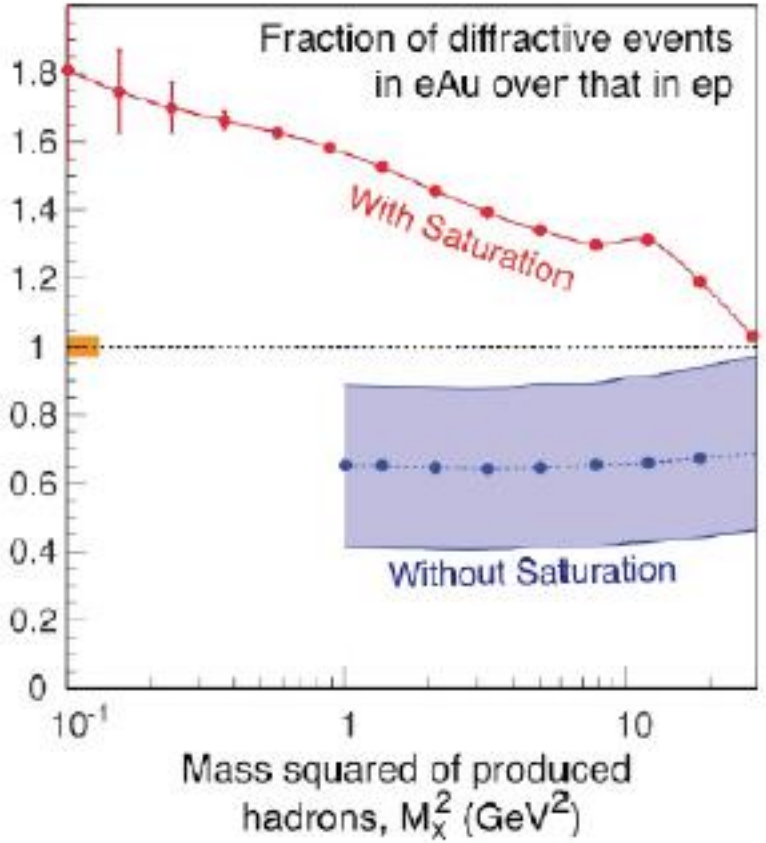
Dedicated studies still underway, use clean final state and high luminosity. Many new ideas

New Physics in eA

Example: diffractive scattering



Guilherme Milhano



Search for new physics at high densities through huge extension of range and unique property of eA collision: LHC showed p is collective projectile much as A
High precision exploration of parton dynamics in nuclei and extension of QCD.

Main eh Tasks for Completion of CDR

4 areas of activity

Accelerator: Update of the eh IR design for LHC/HE-LHC/FCC at 10^{34}

PERLE: Technical design and fabrication+test of an 802 MHz cavity

Detector: Update detector technology choice (collaboration with hh)

Physics: Update wrt LHC results and integration with hh+ee

Contributions to 4 FCC CDR Books (see M Benedikt today)

B1: Physics with the FCC (hh-he-ee)

B2: Summary of FCC-hh with integrated FCC-eh

B3: Details to B2

B6: HE LHC with eh (based on LHeC CDR Update B0)

a total of ~300 FCC pages

End

FCC Layout Changes

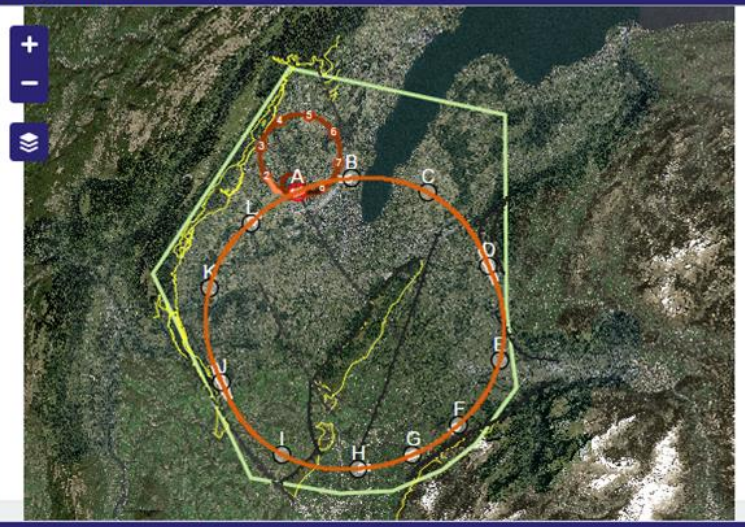
Jo Stanyard

Alignment | Shafts | Query

Highlights:

- Avoids Jura and Pre-Alps limestone.
- Only one sector containing limestone.
- Significantly reduced total shaft length.
- Experimental Site at Point A on existing CERN land.
- Avoids extremely large overburden.

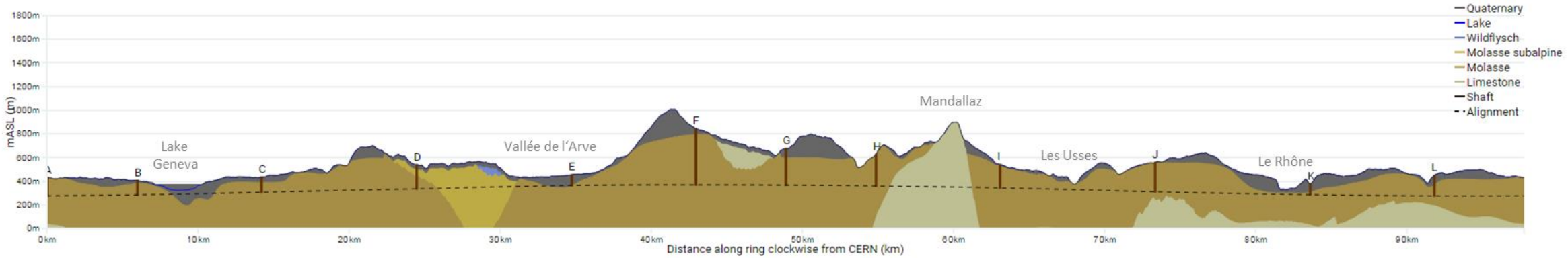
Alignment Location



Geology Intersected by Shafts | Shaft Depths

Point	Shaft Depth (m) Actual	Molasse SA	Wildflysch	Quaternary	Molasse	Geology (m) Urgonian	Limestone
A	152	0	0	0	152	0	0
B	121	0	0	26	95	0	0
C	127	0	0	44	83	0	0
D	205	66	0	40	100	0	0
E	89	0	0	89	0	0	0
F	476	0	0	49	427	0	0
G	307	0	0	73	234	0	0
H	266	0	0	0	266	0	0
I	198	0	0	11	187	0	0
J	248	0	0	1	247	0	0
K	88	0	0	70	18	0	0
L	172	0	0	89	83	0	0
Total	2449	66	0	492	1892	0	0

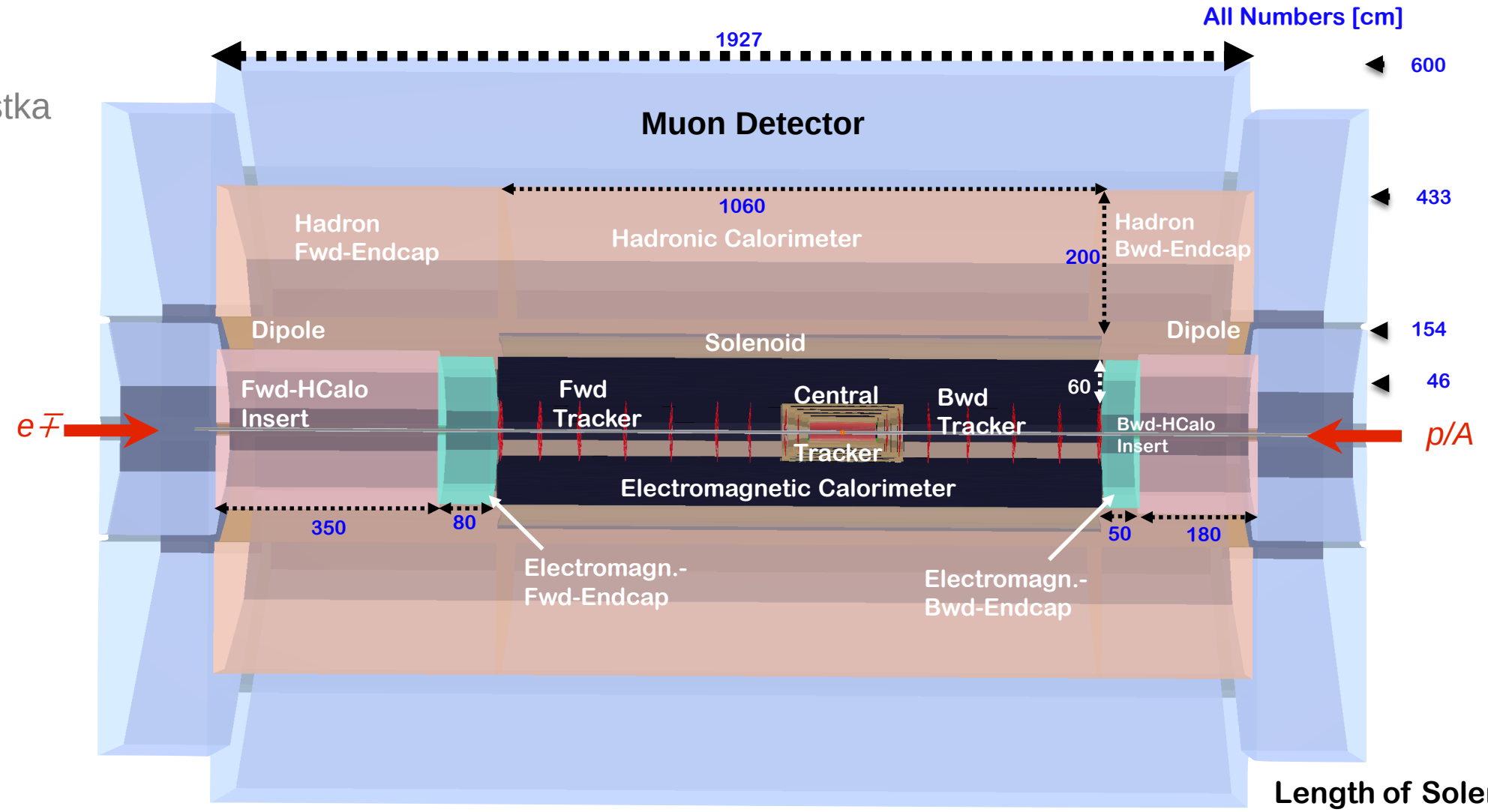
Alignment Profile



Geology Intersected by Tunnel | Geology Intersected by Section

FCC-he Detector Basic Layout

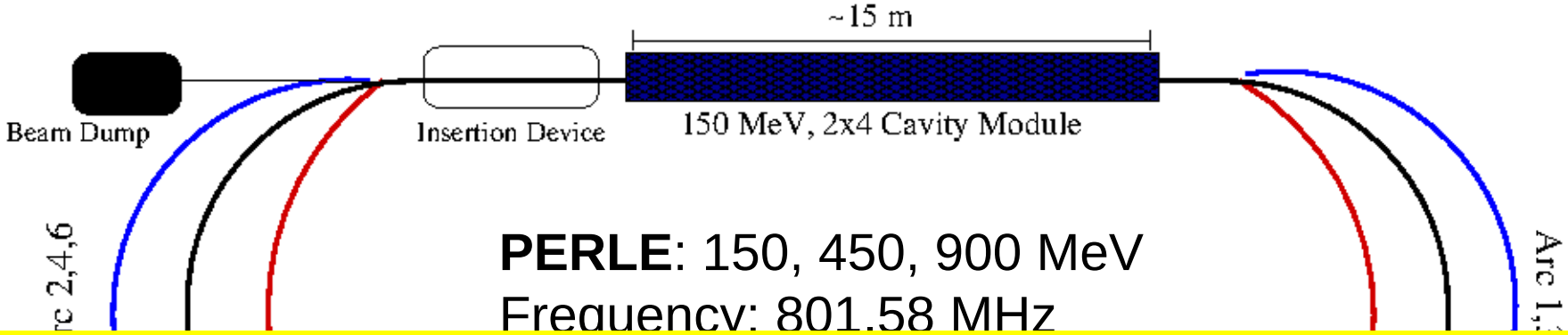
Peter Kostka



Length of Solenoid 10m

Based on the LHeC design; figure shows the version using a single solenoid system; Solenoid&Dipoles between Electromagnetic Calorimeter and Hadronic Calorimeter.

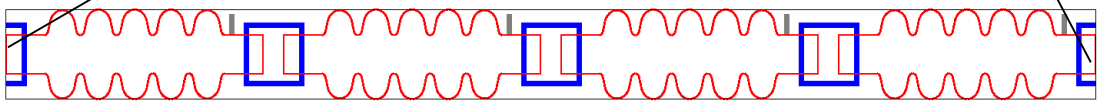
ERL SRF: PERLE @ Orsay



PERLE: 150, 450, 900 MeV
Frequency: 801.58 MHz

High current, multi-turn (3) ERL concept with 802MHz SRF to be tested at PERLE facility in LAL in Orsay!!!

Key questions to be addressed: BB limit, ERL efficiency, beam size evolution etc.



Basic unit: 5-cell cavity into 4-cavity module

FCC-eh: 60 GeV, ERL
1km SRF linac; 944 cavities; 59 cryo modules / linac
Number of passes: 6
Beam current: 6.6-25.6 mA