Future Energy Frontier Colliders

a contribution to a forthcoming particle physics and CERN strategy debate

Max Klein
U Liverpool

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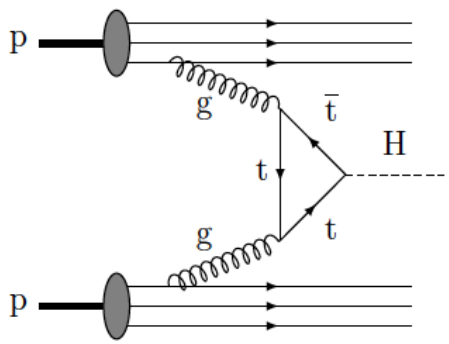
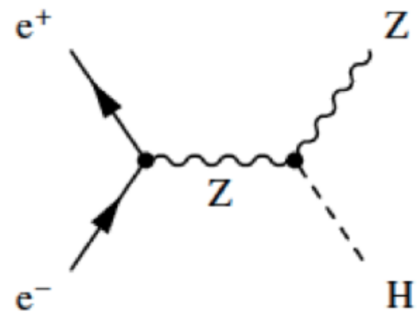
pp collisions / e^+e^- collisions

to tackle the open questions in particle physics



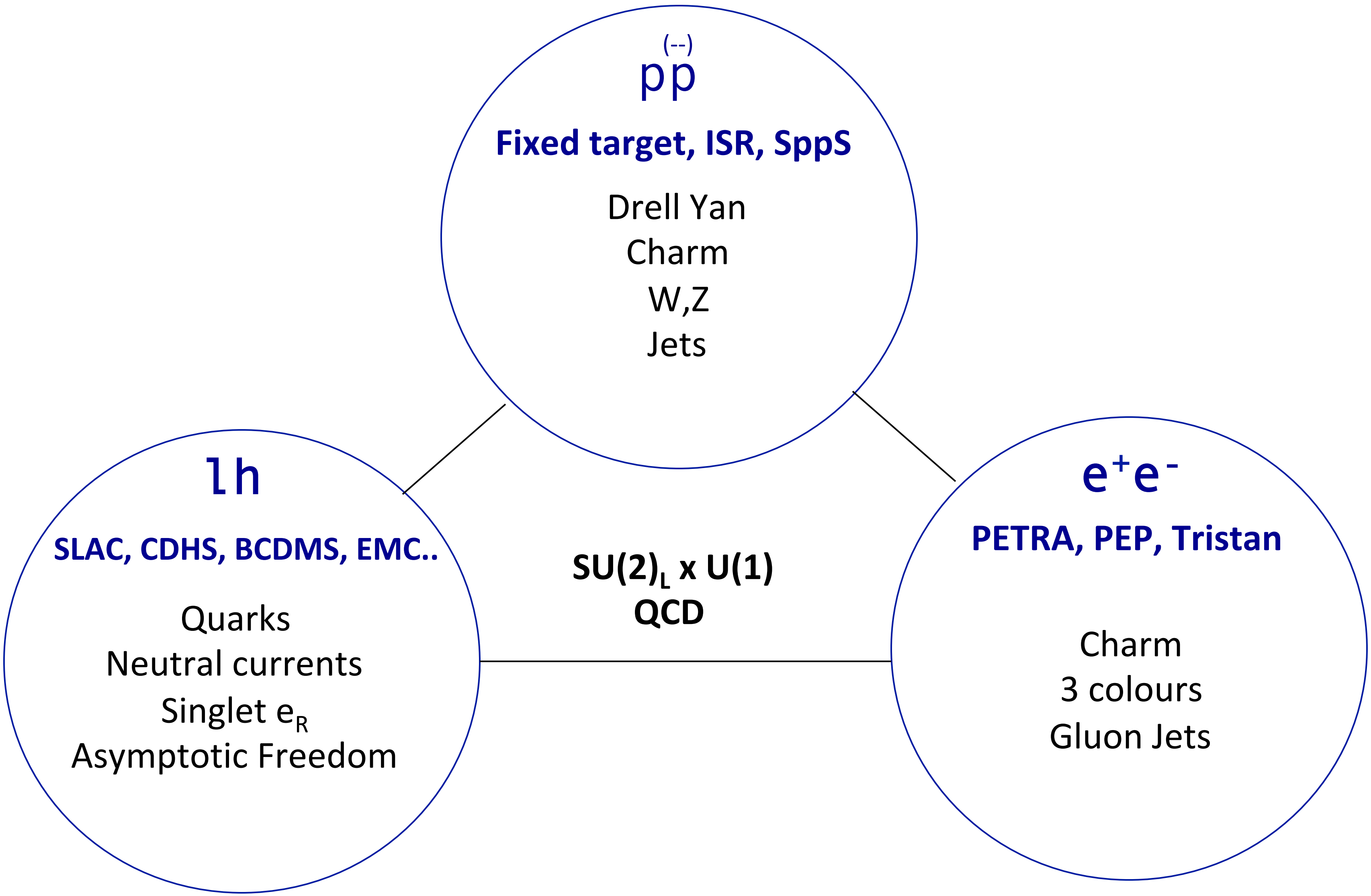
The current paradigm, which erases ep from HEP..!



p-p collisions	e^+e^- collisions
Proton is compound object → Initial state unknown → Limits achievable precision	**e^+/e^- are point-like** → Initial state well defined (√s / opt: polarisation) → High-precision measurements
High rates of QCD backgrounds → Complex triggering schemes → High levels of radiation	**Cleaner experimental environment** → Less / no need for triggers → Lower radiation levels
High cross-sections for **colored-states**	Superior sensitivity for **electro-weak states**
Very high-energy **circular** pp colliders feasible	High energies (>≈350 GeV) require **linear** collider

Particle Physics at O(10) GeV

~1968-1988
Two Decades



Particle Physics at O(100) GeV ~1985-2015

Three Decades

$\bar{p}p$

Tevatron

b quark
top quark
M_W
No SUSY, BSM

ep

HERA

Gluon dominance, low x
Electroweak Unification
h.o. strong → PDFs, c, b
No SUSY, BSM

The Standard Model Triumph

e^+e^-

LEP/SLC

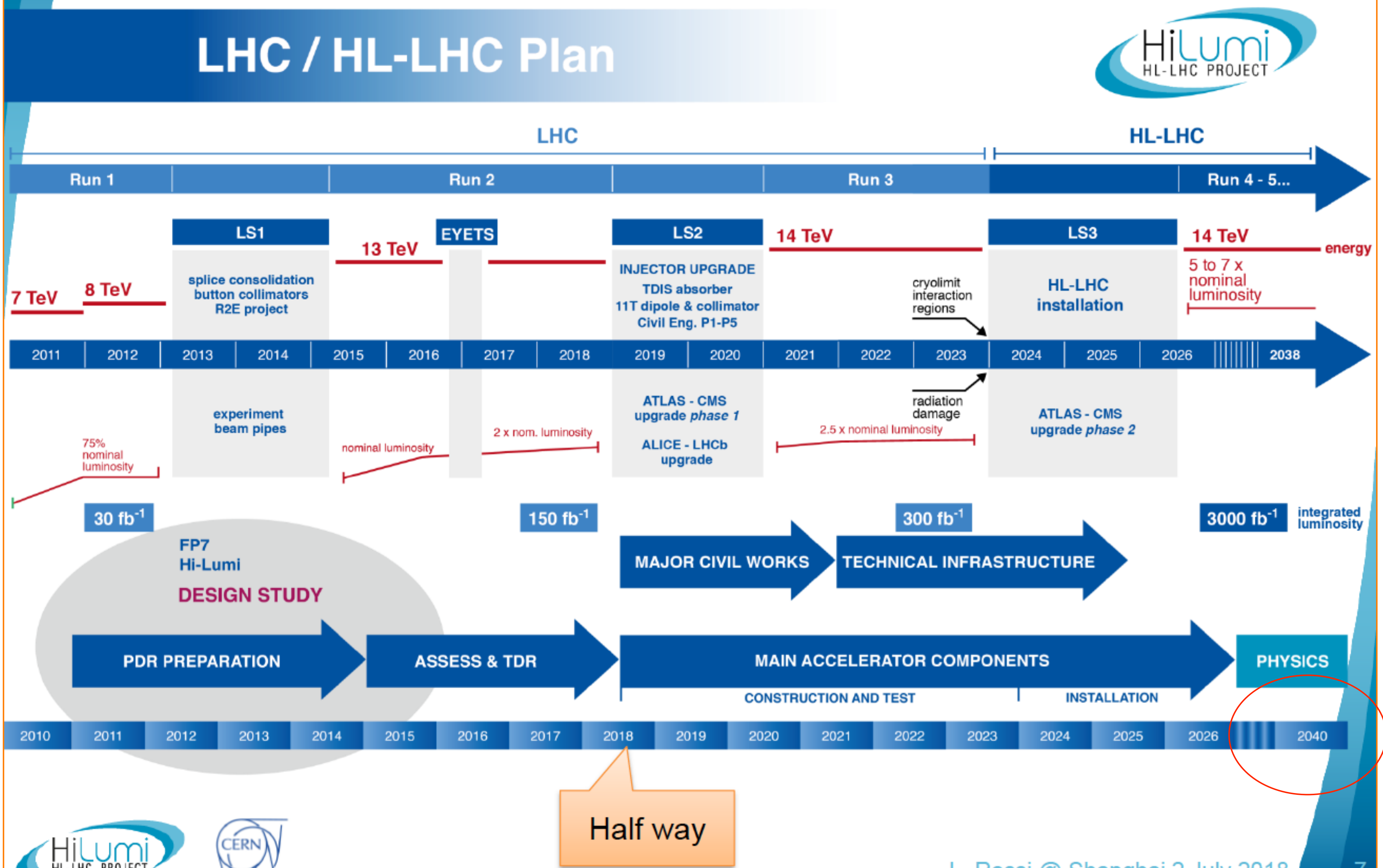
M_Z , $\sin^2\Theta$
Three neutrino families
h.o. el.weak → mt,mH
No SUSY, BSM

CKM - **B factories**

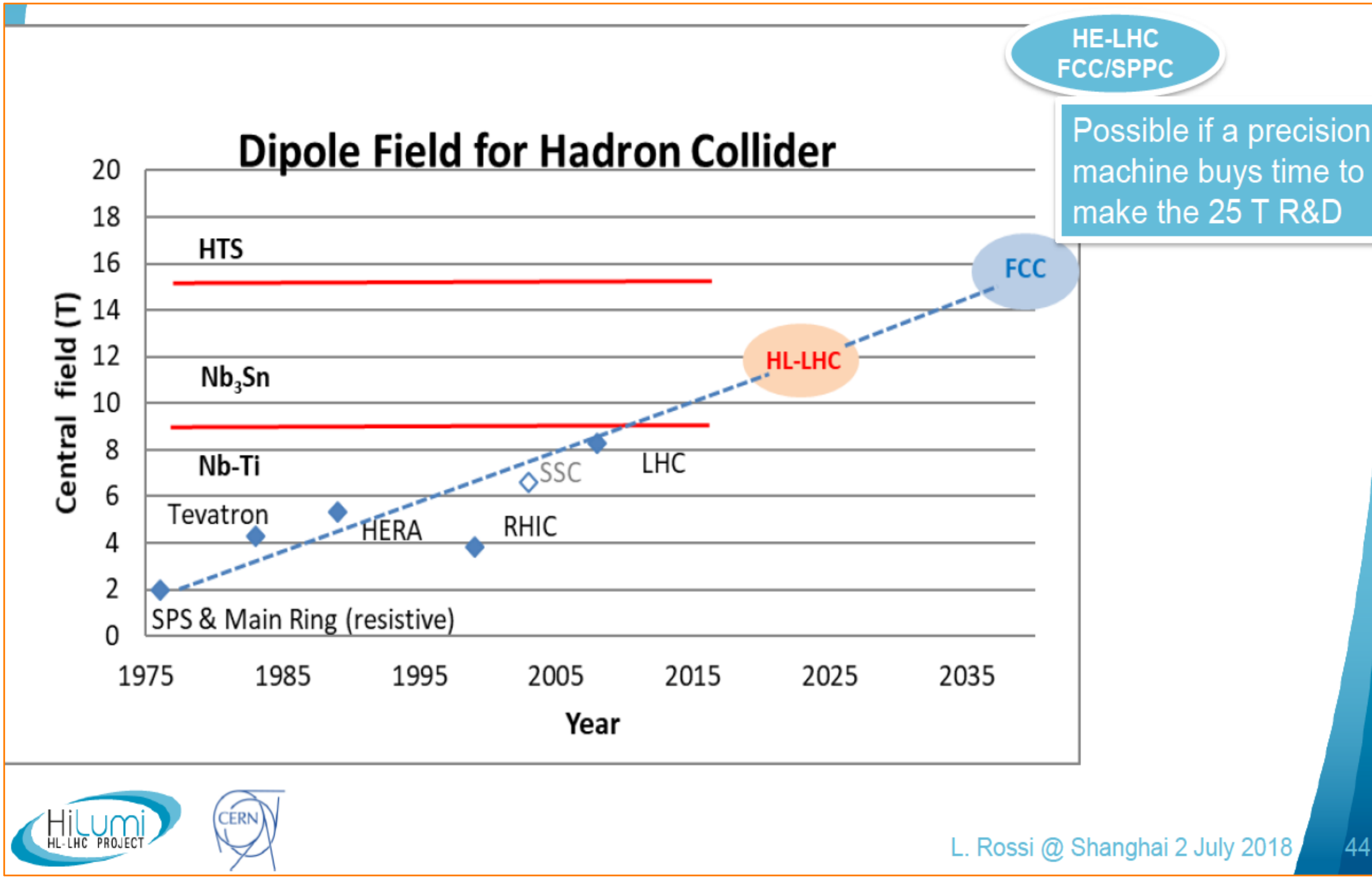
Neutrino Physics

Oscillations, PMNS

High Luminosity: a luminous future for LHC!

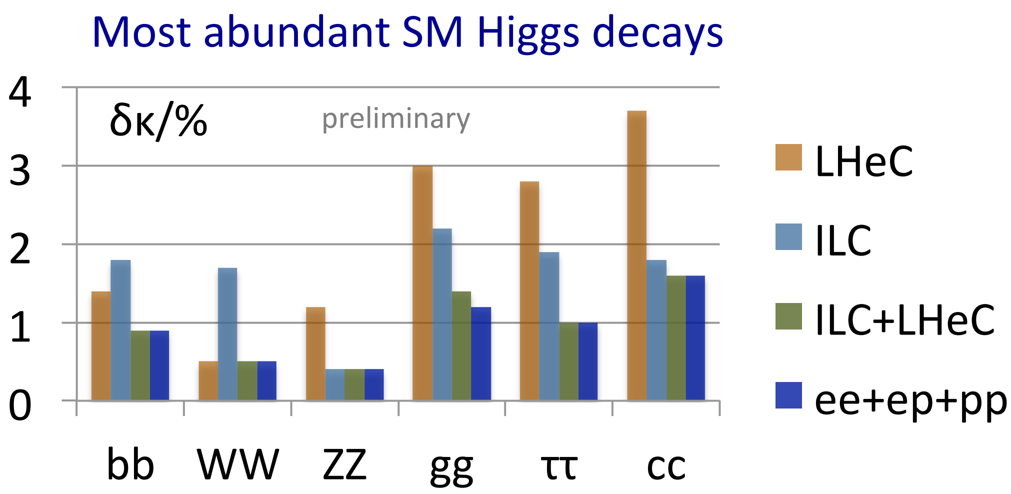


High Field Dipole Magnets



New prospects: possibly triple the LHC energy for the HE LHC phase, beyond 2040.

SM Higgs Physics Prospects: pp+ep+ee



Huge potential for exploring Higgs at percent accuracy with pp+ep+ee in the about 20 years ahead.

Striking example for pp+ep+ee synergy at TeV scale.

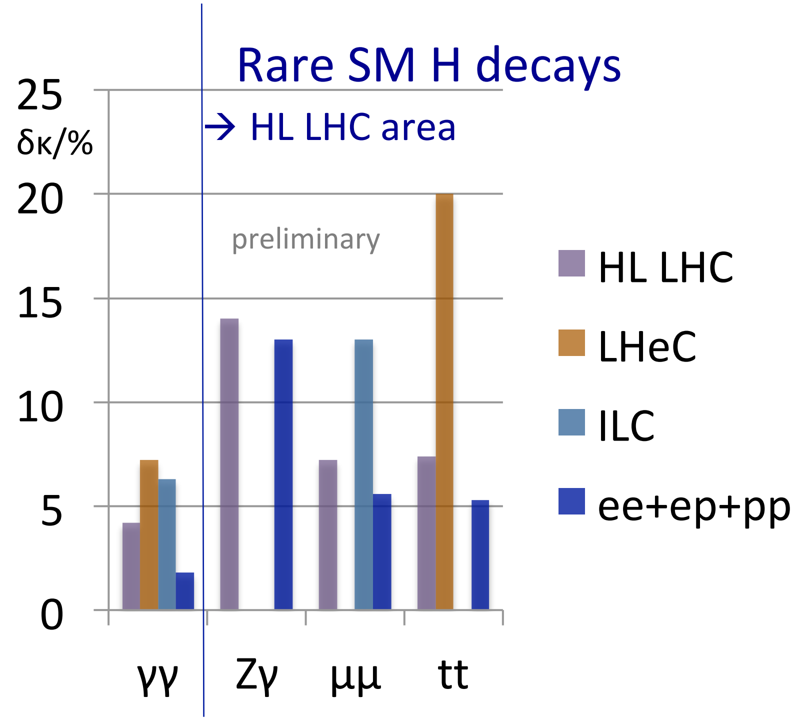
≤ 1% from ee and ep combination.

Note WW & ZZ synergy. Γ_{tot} in ee

Little influence of HL LHC on dominant channels

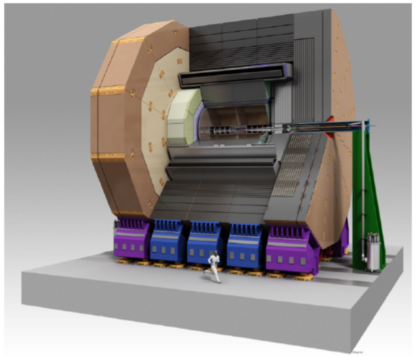
SM rare Higgs decays are for the pp collider →

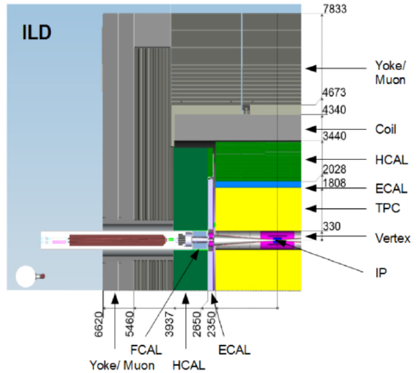
Kappa framework analysis by J. De Blas, prel.: Input:
pp: 3 ab^{-1} ATLAS'14 w/o thy unc.− update: HL LHC WS ..
ep: 1ab^{-1}, LHeC Study Group, U.Klein et al., prel.,
ee: 2 ab^{-1} ILC250 signal strength 1708.08912



Detectors

ILD detector at ILC



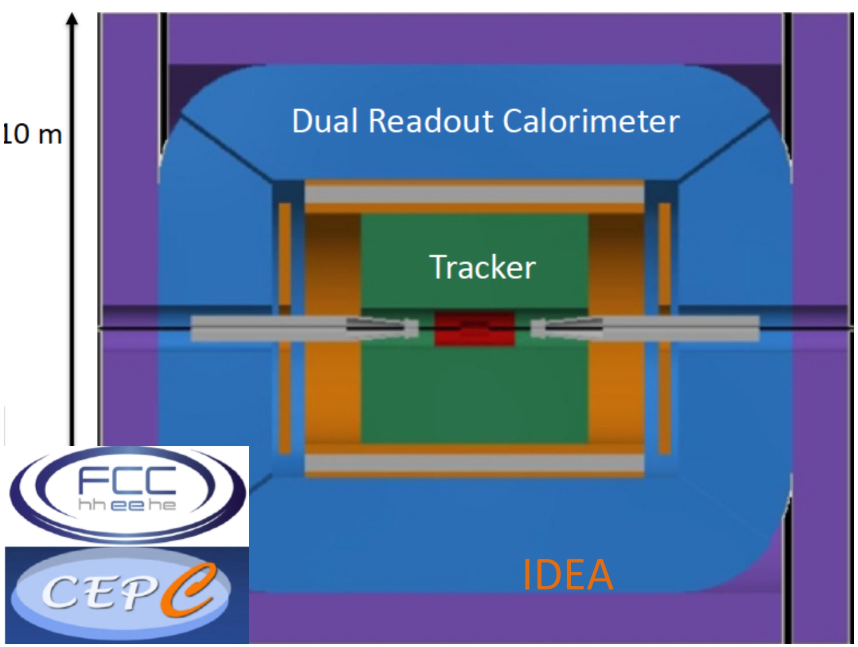


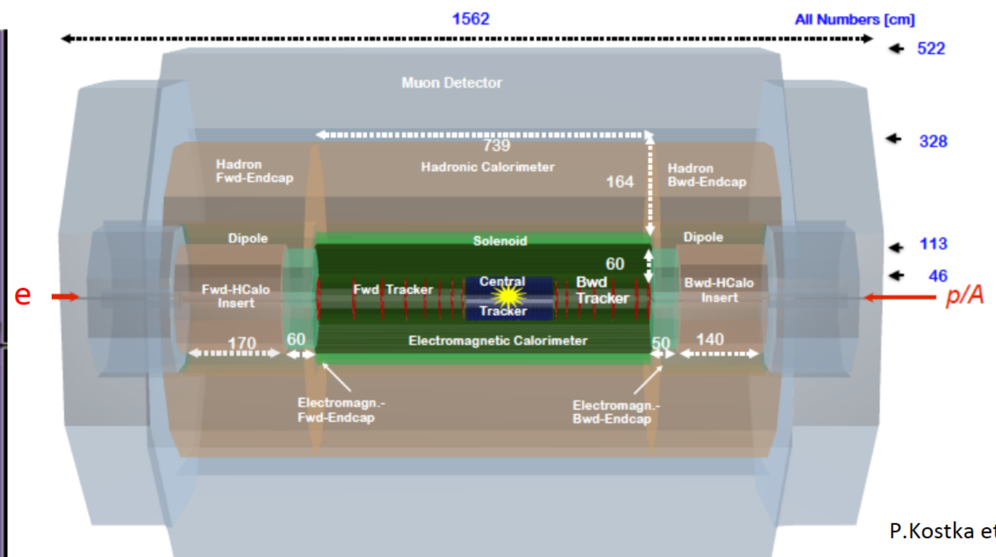
ILD: "International Large Detector"

- Silicon vertex detector
- Time Projection Chamber as tracker
- ... surrounded by Silicon envelope
- Fine-grained calorimetry (PFA)
- Large (L) and small (S) options under study
- Final focus quadrupoles inside the detector

	ILD-L (DBD)	ILD-S
B-field	3.5 T	4 T
TPC outer radius	180 cm	146 cm
Coil inner radius	344 cm	310 cm

New detectors, based on novel tracking ⊕ calorimeter technology, to be built in the twenties, post HL LHC design.



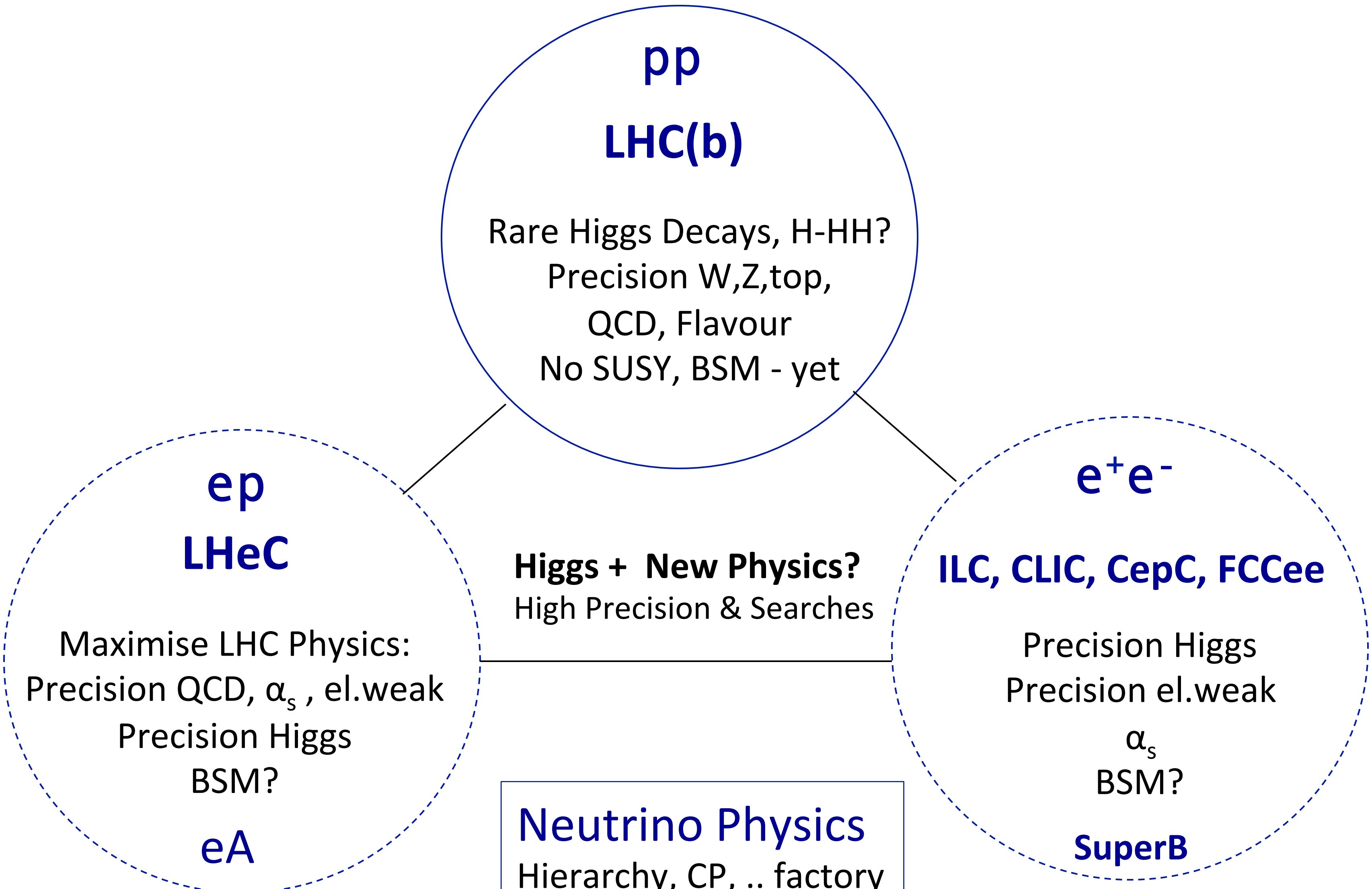


P.Kostka et al

Length x Diameter: LHeC (13.3 x 9 m^2) HE-LHC (15.6 x 10.4) FCCeh (19 x 12)
ATLAS (45 x 25) CMS (21 x 15): [LHeC < CMS, FCC-eh ~ CMS size]

Particle Physics at O(1) TeV ~2010-2050

Four Decades



Considerations

1. Priority for this and the next strategy update will be the exploitation of the HL LHC

2. CERN has the unique opportunity to maximise the LHC physics return (BSM!) and to stay for decades in the focus of Higgs physics with the addition of an electron ERL for concurrent pp+ep (eA) operation: novel twin collider

3. Global particle physics would profit from more than one global center, and pp requires high energy ep and e^+e^- colliders, possibly at CERN and in Asia.

4. This scenario would be fundable, especially CepC vs ILC, it would maximally explore the TeV energy scale, and permit building new detectors (ee+ep) keeping our unique technical expertise and infrastructure alive, in the twenties.

5. This scenario gave time which is required to maximize E_p, by developing high field dipoles (> 20T?) and to prepare new GPD and dedicated experiments for HE LHC, or indeed go to FCC, when the time comes, operation ~2050+

6. If Asia builds neither ILC nor CepC, would one build an e^+e^- collider at CERN?

We have time to think about all this, exploit LHC now and prepare the future well.