# FCC
# Future Circular Colliders

Albert De Roeck
CERN
3 September 2016

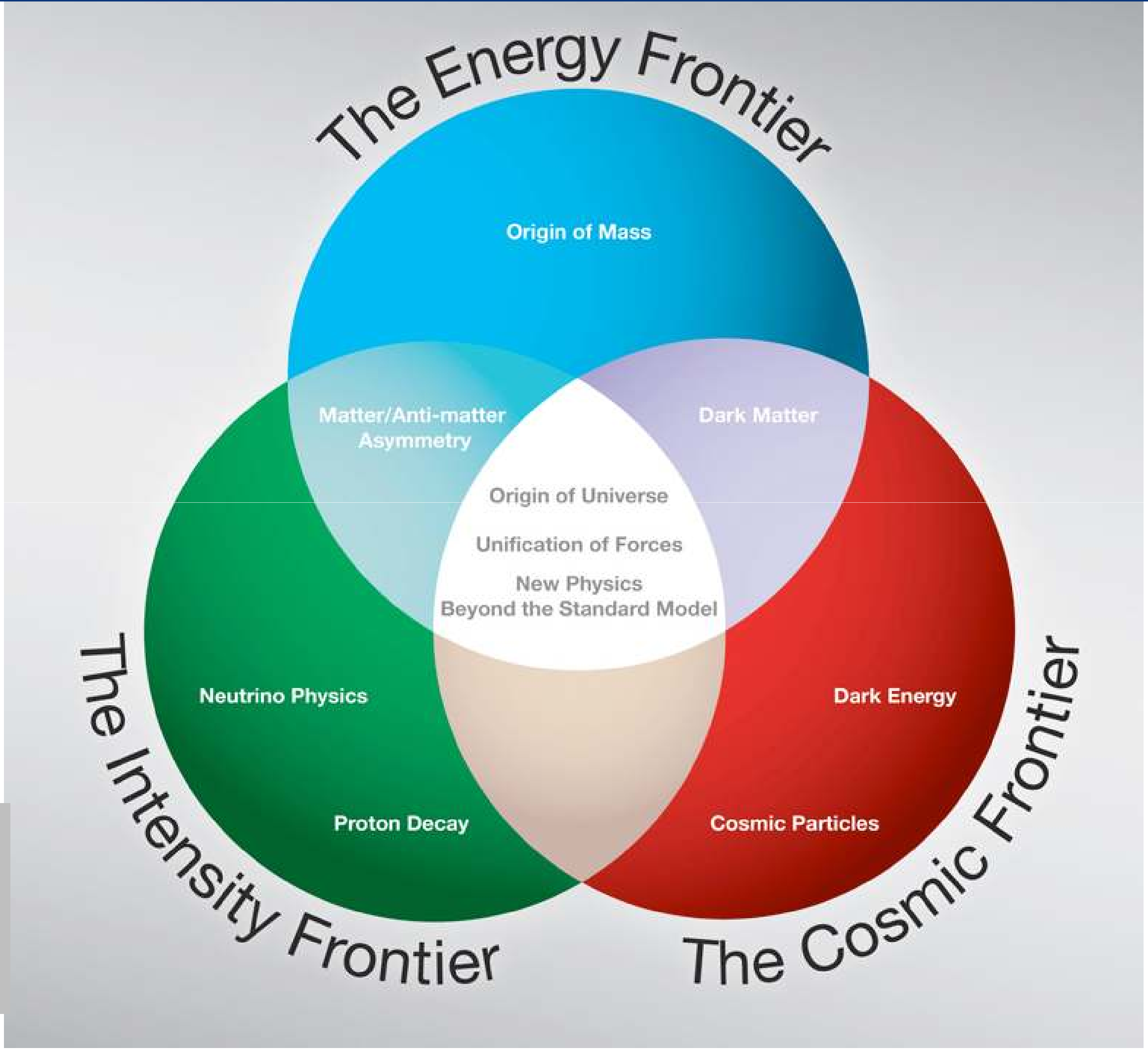
# Future HEP: The Three Frontiers

After the Higgs discovery

2012-2014

Evaluation in all regions: Europe Asia, the Americas

- European strategy group
- Snowmass study and IP5
- Japan strategy group




Will concentrate here on the Energy Frontier

# Europe Strategy Group

## European Strategy for Particle Physics

- Update formally adopted by CERN council at the European Commission in Brussels on 30 May 2013
- The discovery of the Higgs boson is the start of a major programme of work to measure this particle's properties with the highest possible precision for testing the validity of the Standard Model and to search for further new physics at the energy frontier. The LHC is in a unique position to pursue this programme.
- *Europe's top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030. This upgrade programme will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma.*

European Strategy Update

# Europe Strategy Group

….“to propose an ambitious **post-LHC accelerator project at CERN** by the time of the next Strategy update”:

d) ***CERN should undertake design studies for accelerator projects in a global context,***

- *with emphasis on* ***proton-proton and electron-positron high-energy frontier machines****.*
- *These design studies should be coupled to a vigorous accelerator* ***R&D programme, including high-field magnets and high-gradient accelerating structures****,*
- ***in collaboration with national institutes, laboratories and universities worldwide.***

- http://cds.cern.ch/record/1567258/files/esc-e-106.pdf

Similar recommendation from the Snowmass studies in the US

# => The CERN Roadmap

F. Bodry , March 2015

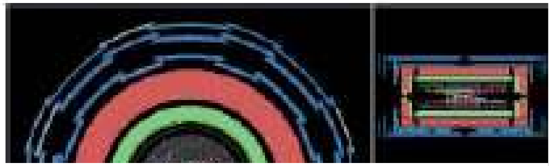
**The CERN Medium Term Plan approved by June'14 Council,** implements the **European Strategy** including a long-term outlook.

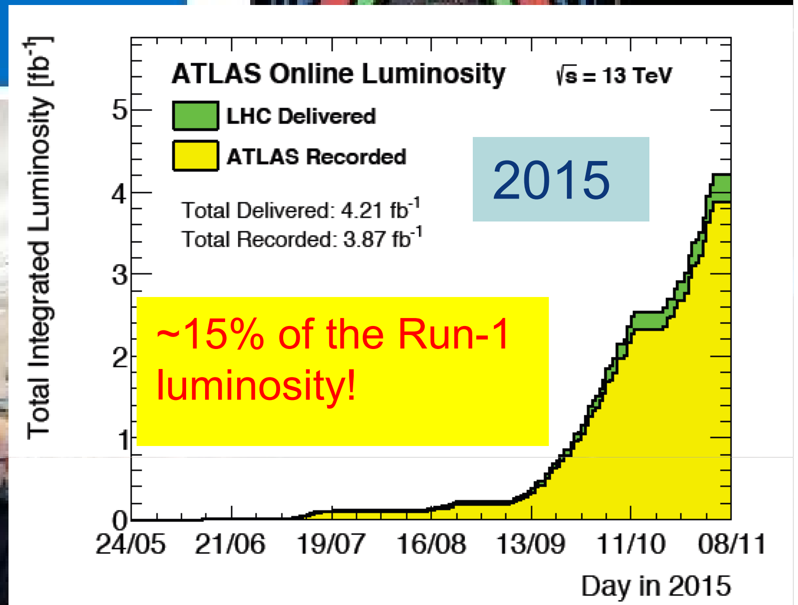
The scientific programme is concentrated around four priorities:

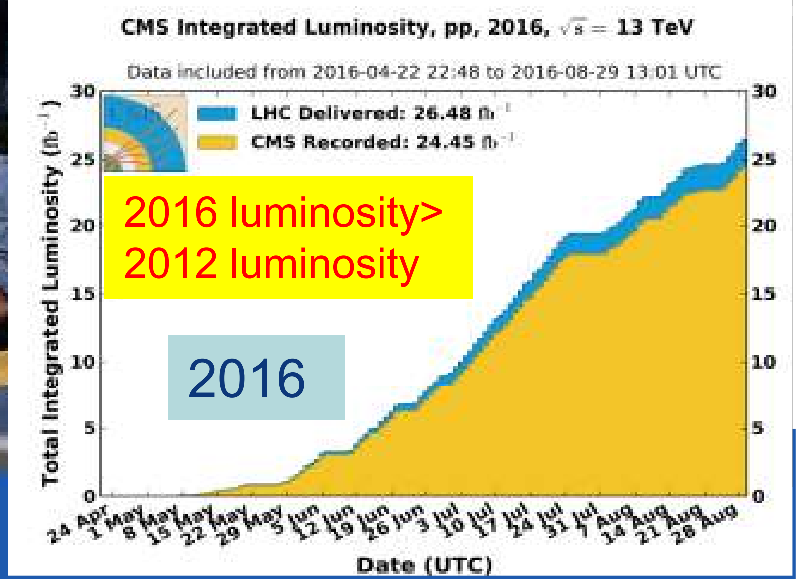
1. **Full LHC exploitation** – the highest priority - including the construction of the High Luminosity Upgrade until 2025
2. **High Energy Frontier** – CERN's role and preparation for the next large scale facility
3. **Neutrino Platform** – allow for to contribute to a future long baseline facility in the US and for detector R&D for neutrino experiments
4. **Fixed-target programme** – maintain the diversity of the field and honour ongoing obligations by exploiting the unique facilities at CERN

# LHC experiments are back in business at a new record energy 13 TeV

3rd June 2015



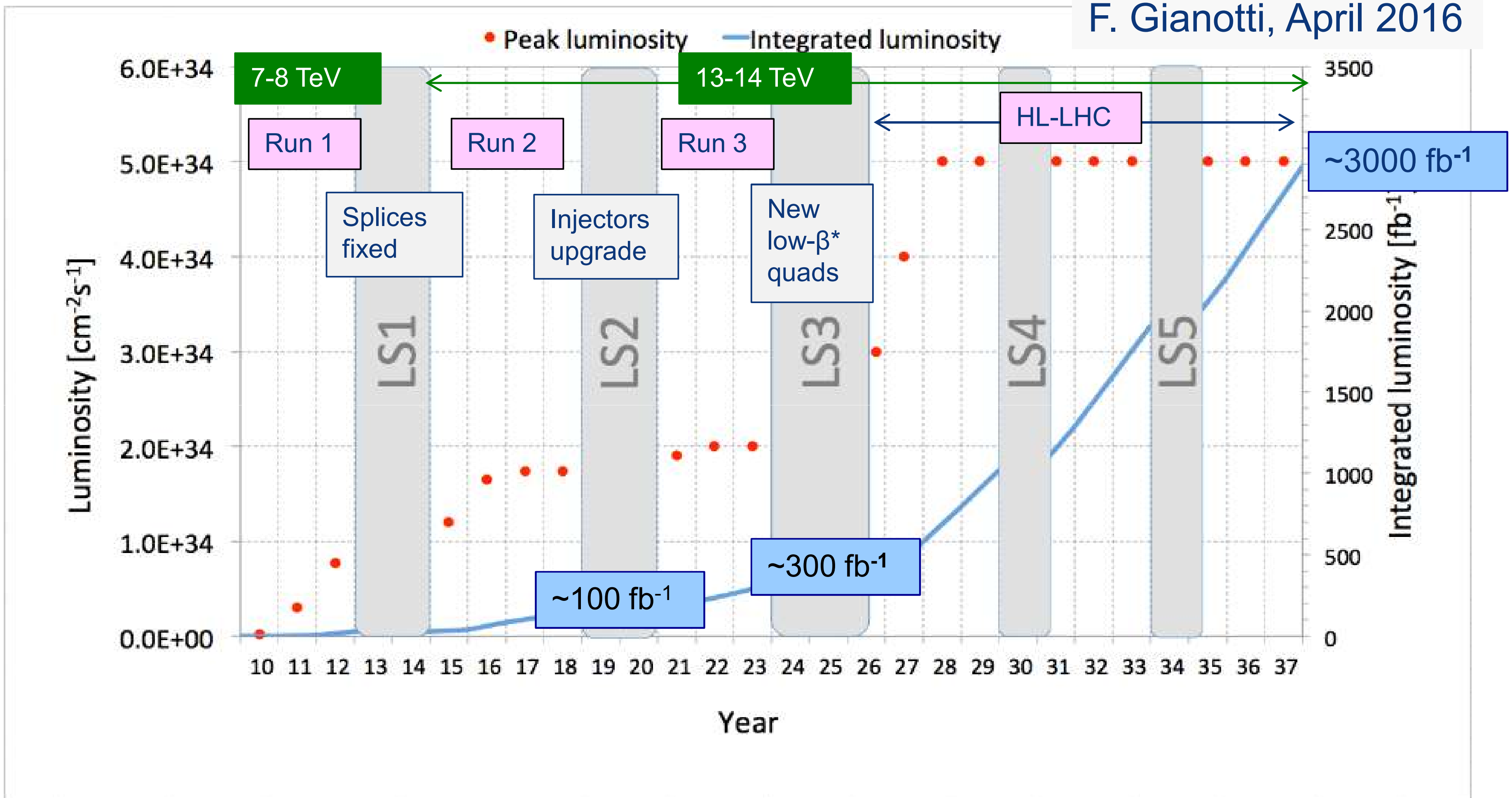


# The LHC Upgrade

# The LHC Approved LHC Roadmap

F. Gianotti, April 2016

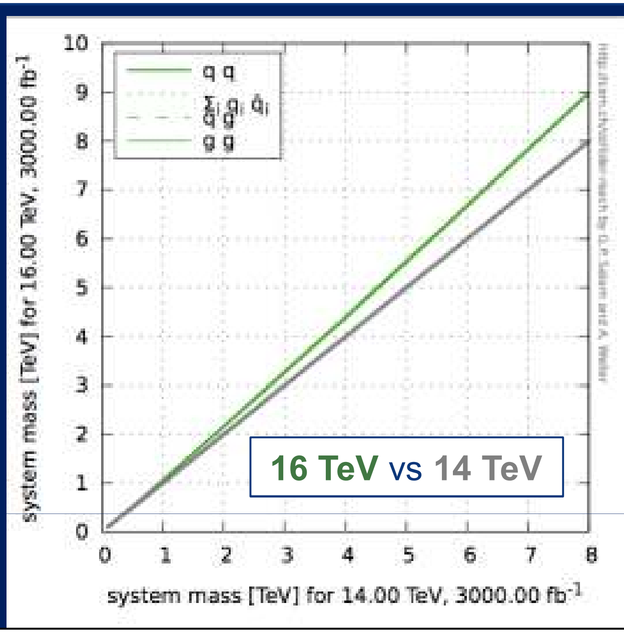


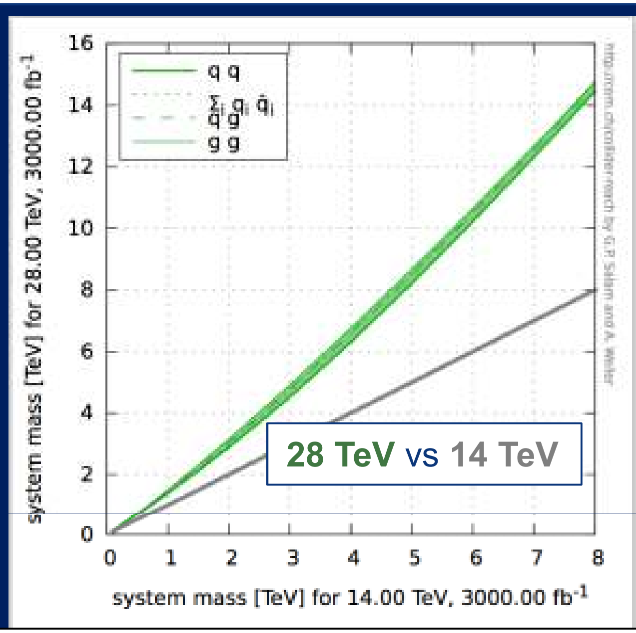

Approved program at CERN to collect 3000 $fb^{-1}$ with the LHC (HL-LHC)

Maximize the reach for searches and for precision measurements (eg Higgs)

# High-Energy LHC

F. Gianotti
FCC meeting
Rome April 2016




Various options, with increasing amount of HW changes, technical challenges, cost, and physics reach

WG set up to explore technical feasibility of pushing LHC energy to:
1) design value: 14 TeV
2) ultimate value: 15 TeV (corresponding to max dipole field of 9 T)
3) beyond (e.g. by replacing 1/3 of dipoles with 11 T $Nb_3Sn$ magnets)
→ Identify open risks, needed tests and technical developments, trade-off between energy and machine efficiency/availability
→ Report on 1) end 2016, 2) end 2017, 3) end 2018 (in time for ES)

**HE-LHC** (part of FCC study): ~16 T magnets in LHC tunnel (→ √s~ 30 TeV)
- ❑ uses existing tunnel and infrastructure; can be built at fixed budget
- ❑ strong physics case if new physics from LHC/HL-LHC
- ❑ powerful demonstration of the FCC-hh magnet technology

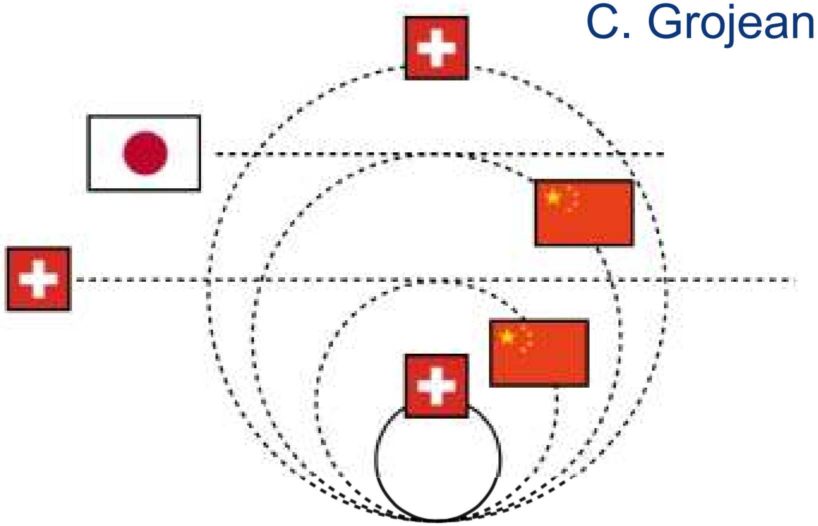
# Beyond the LHC

- Proton-proton machines at higher energy…
- Electron-positron machines for high precision…
- Both? And allowing for electron-proton collisions..?

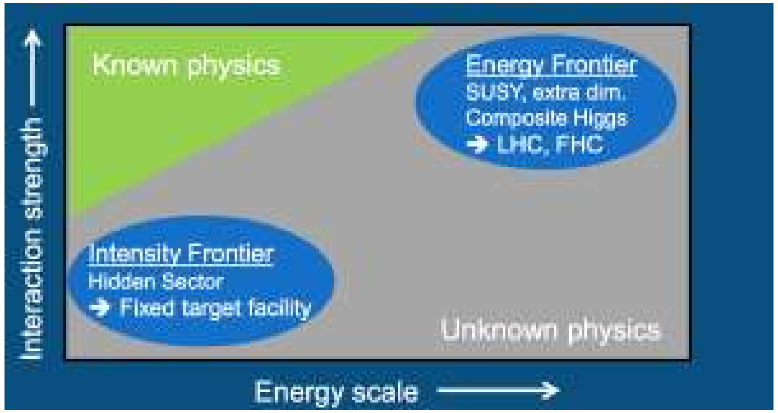
New projects will take 10-20 years before they turn into operation, hence need a vision & studies now!

# Future Colliders?

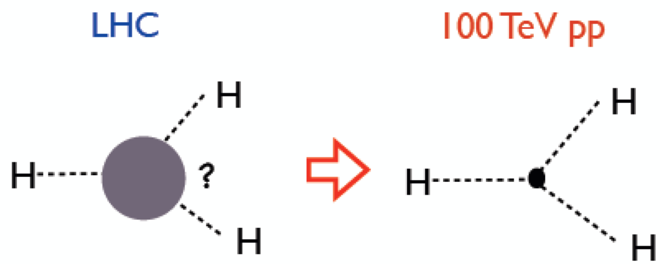
C. Grojean



Theorist view on future colliders




FCC-hh: THE machine for direct search at the higher energy scale.

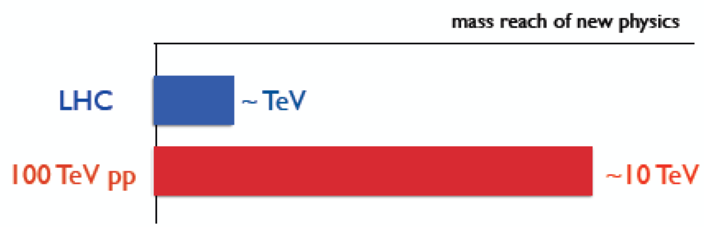



Hadron colliders main themes:

The study of the Higgs Boson(s)

The search for massive new physics

Precision measurements



# High Energy Hadron Hadron Colliders

Thanks to M. Benedikt, M. Mangano, W. Riegler Y. Wang, F.Zimmerman,

# FCC General Yearly Meeting April 2016


Second meeting
First meeting was in DC 2016
Next we take Berlin (spring 2017)

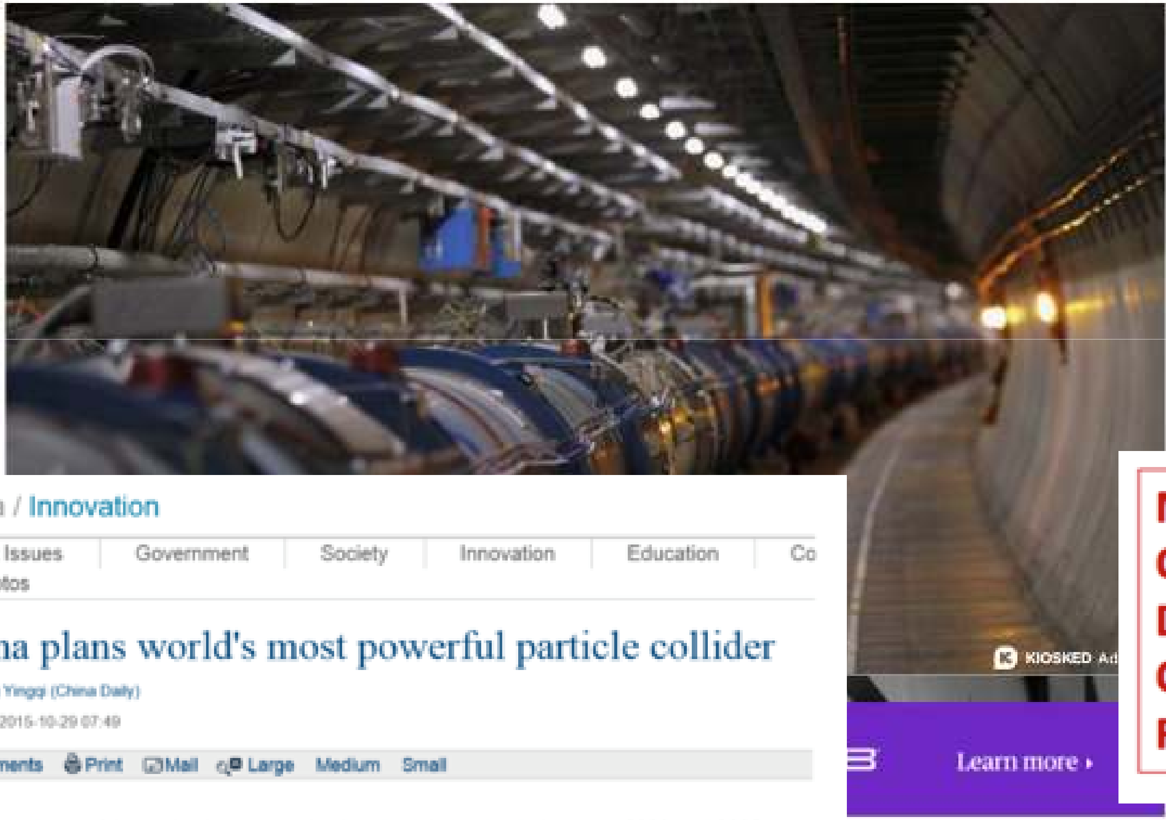
CERN

Science

# China unveils plans for super-giant particle collider – the biggest and most powerful on Earth

By Hannah Osborne
October 29, 2015 10:06 GMT

200




China / Innovation

Hot Issues | Government | Society | Innovation | Education | Co
Photos

## China plans world's most powerful particle collider

By Cheng Yingqi (China Daily)
Updated: 2015-10-29 07:49

Comments Print Mail Large Medium Small

The first phase of the project's construction is scheduled to begin between 2020 and 2025

China is set to build the biggest and most powerful particle collider on Earth, dwarfing the Large Hadron Collider at Cern. The super-giant particle collider will measure between 50 and 100km in circumference – double or quadruple that of the

This hit the news end if 2015!

What is all about??

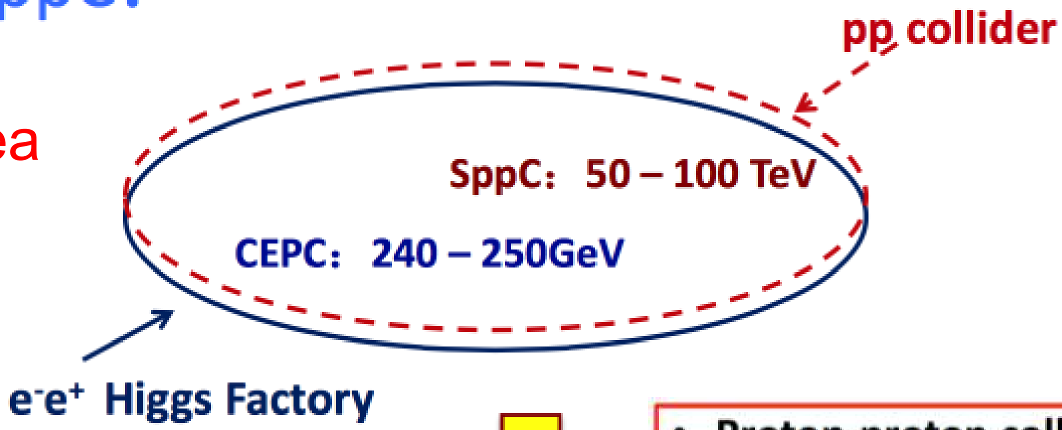
**Media is media**
**Chinese media is also media**
**Don't get too excited, nor panic**
**CEPC will not be easy and quick**
**R&D will come gradually**

Y. Wang

# The CEPC/SppC Design (China)

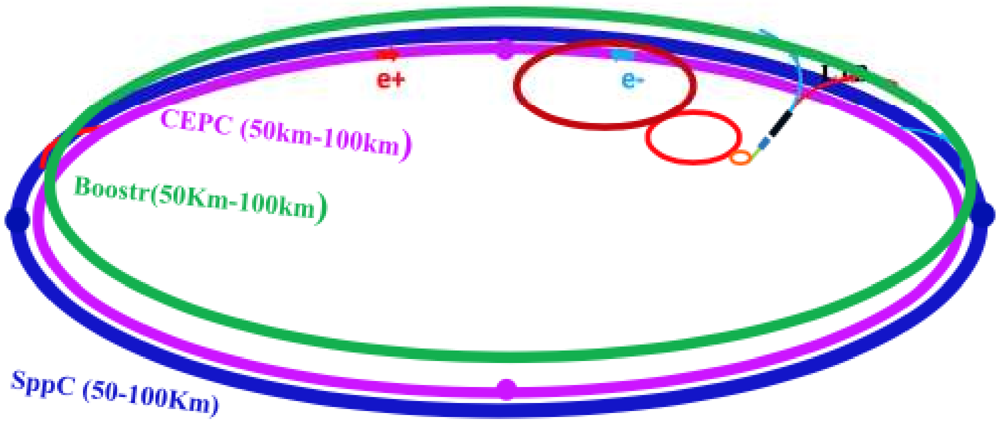
CEPC+SppC:

2012-2014: idea




- Proton-proton collider(~100 TeV)
  - Directly search for new physics beyond SM
  - Precision test of SM
    - e.g., $h^3$ & $h^4$ couplings

2015 pre-CDR



# Parameter choice for SPPC (Potential)

(F. Su et al)

Table 4. Parameter lists for LHC HL-LHC HE-LHC FCC-hh and SPPC.

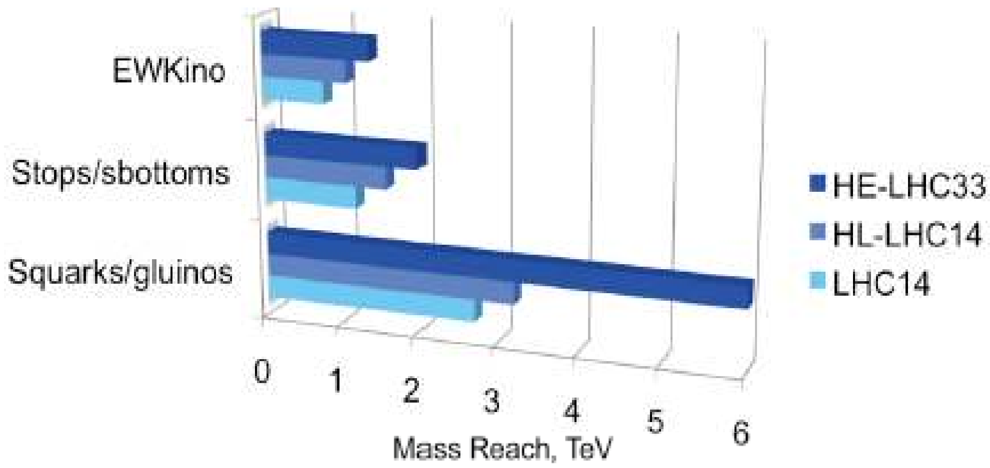
| | LHC | HL-LHC | HE-LHC | FCC-hh | SPPC-Pre-CDR | SPPC-54.7Km | SPPC-100Km | SPPC-100Km | SPPC-78Km | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Value | | | | | | | | | Unit |
| **Main parameters and geometrical aspects** | | | | | | | | | | |
| Beam energy[$E_0$] | 7 | 7 | 16.5 | 50 | 35.6 | 35.0 | 50.0 | 68.0 | 50.0 | TeV |
| Circumference[$C_0$] | 26.7 | 26.7 | 26.7 | 100(83) | 54.7 | 54.7 | 100 | 100 | 78 | km |
| Lorentz gamma[$\gamma$] | 7463 | 7463 | 14392 | 53305 | 37942 | 37313 | 53305 | 72495 | 53305 | |
| Dipole field[B] | 8.33 | 8.33 | 20 | 16(20) | 20 | 19.69 | 14.73 | 20.03 | 19.49 | T |
| Dipole curvature radius[$\rho$] | 2801 | 2801 | 2250 | 10416 (8333.3) | 5928 | 5922.6 | 11315.9 | 11315.9 | 8549.8 | m |
| Bunch filling factor[$f_2$] | 0.78 | 0.78 | 0.63 | 0.79 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | |
| Arc filling factor[$f_1$] | 0.79 | 0.79 | 0.79 | 0.79 | 0.79 | 0.79 | 0.79 | 0.79 | 0.79 | |
| Total dipole magnet length [$L_{Dipole}$] | 17599 | 17599 | 14062 | 65412 (52333) | 37246 | 37213 | 71100 | 71100 | 53720 | m |
| Arc length[$L_{ARC}$] | 22476 | 22476 | 22476 | 83200 (66200) | 47146 | 47105 | 90000 | 90000 | 68000 | m |
| Total straight section length[$L_{ss}$] | 4224 | 4224 | 4224 | 16800 | 7554 | 7595 | 10000 | 10000 | 10000 | m |
| Energy gain factor in collider rings | 15.6 | 15.6 | 13.5 | 15.2 | 17.0 | 16.67 | 17.5 | 17.5 | 17.5 | |
| Injection energy [$E_{inj}$] | 0.45 | 0.45 | >1.0 | 3.3 | 2.1 | 2.1 | 2.9 | 3.9 | 2.9 | TeV |
| Number of IPs[$N_{IP}$] | 4 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | |

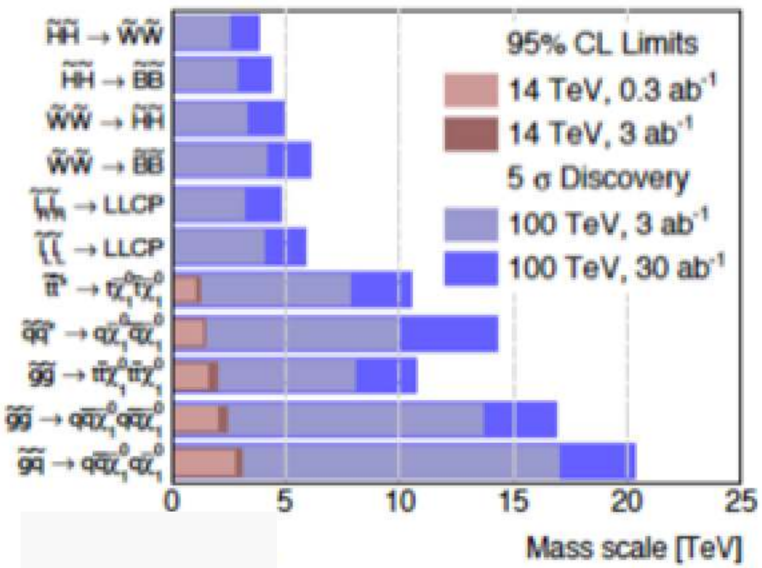
Pre-CDR numbers

# Physics and Detectors for Hadron Hadron Colliders

# Searches for New Physics

Searches for pair produced SUSY particles




## FCC-hh

- -Reach sparticle masses search up to about 20 TeV for gluinos and 10 TeV for stops for 30 $ab^{-1}$
- -Excited quarks probe the structure of quarks down to $4x10^{-21}$ m
- -Discovery of resonances up to masses of about 40-50 TeV
- - Break through the neutrino-wall in dark matter searches

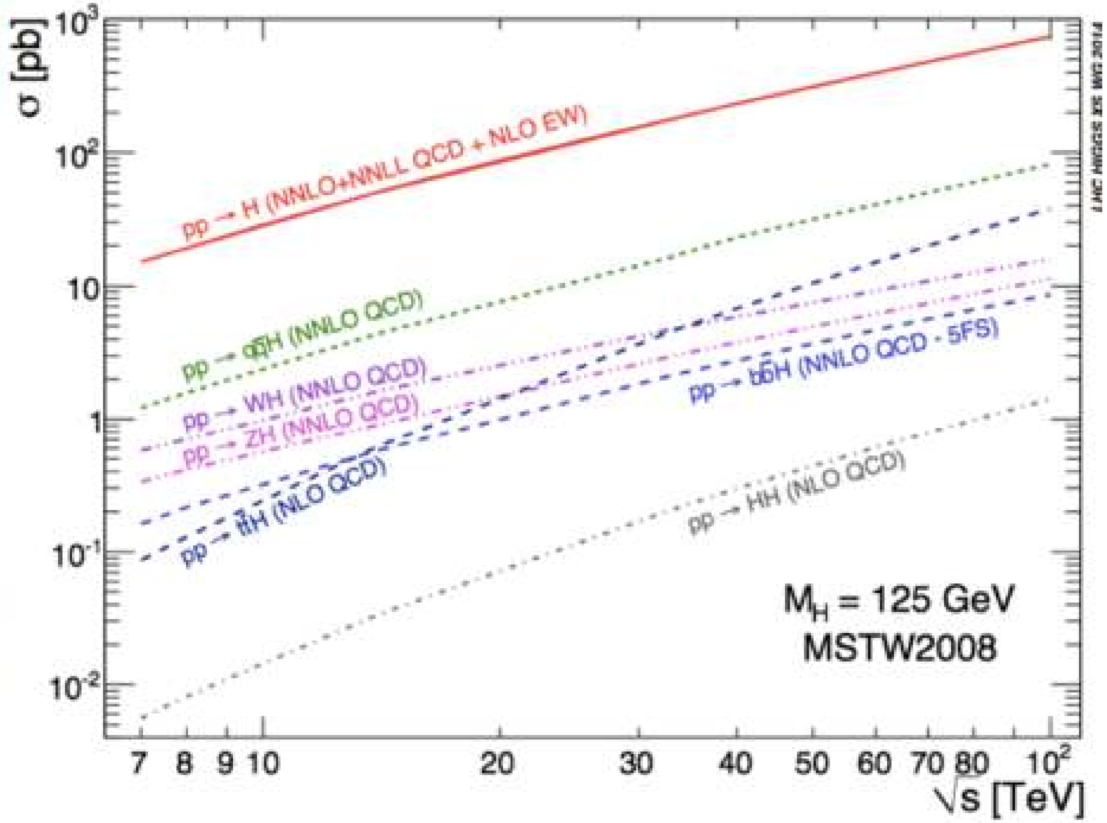
A very huge discovery potential

# Plenty of Higgs Bosons at the FCC-hh

Relative cross section

M. Klute, EPS 2105

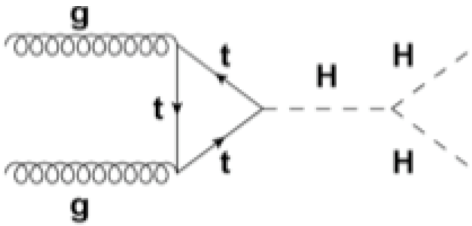
| Process | 8 TeV | 14 TeV | 100 TeV |
|---|---|---|---|
| gF | 0.38 | 1 | 14.7 |
| VBF | 0.38 | 1 | 18.6 |
| WH | 0.43 | 1 | 9.7 |
| ZH | 0.47 | 1 | 12.5 |
| ttH | 0.21 | 1 | 61 |
| bbH | 0.34 | 1 | 15 |
| gF to HH | 0.24 | 1 | 42 |

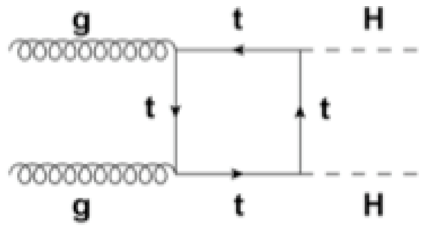


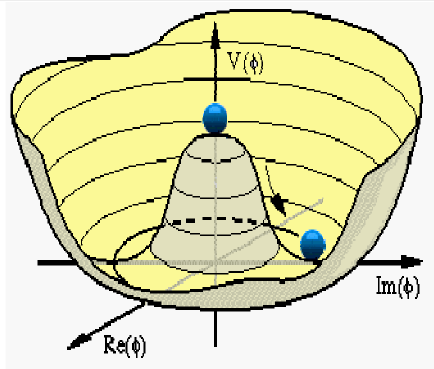

Proton-proton Higgs datasets — LHC Run I → x300-600 → HL LHC → x10-400 → FCC pp

# Di-Higgs Production: Prospects

## *Higgs selfcouplings: pp→HH*




| $HH \to b\bar{b}\gamma\gamma$ | Barr,Dolan,Englert,Lima, Spannowsky<br>JHEP 1502 (2015) 016 | Contino, Azatov, Panico, Son<br>arXiv:1502.00539 | He, Ren Yao<br>arXiv:1506.03302 |
|---|---|---|---|
| $FCC_{@100TeV}$ 3/ab | 30~40% | 30% | 15% |
| $FCC_{@100TeV}$ 30/ab | 10% | 10% | 5% |
| $S/\sqrt{B}$ | 8.4 | 15.2 | 16.5 |
| Details | ✓ $\lambda_{HHH}$ modification only<br>✓ $c \to b$ & $j \to \gamma$ included<br>✓ Background systematics<br>○ $b\bar{b}\gamma\gamma$ not matched<br>✓ $m_{\gamma\gamma} = 125 \pm 1$ GeV | ✓ Full EFT approach<br>○ No $c \to b$ & $j \to \gamma$<br>✓ Marginalized<br>✓ $b\bar{b}\gamma\gamma$ matched<br>✓ $m_{\gamma\gamma} = 125 \pm 5$ GeV<br>✓ Jet /$W_{had}$ veto | ✓ $\lambda_{HHH}$ modification only<br>✓ $c \to b$ & $j \to \gamma$ included<br>○ No marginalization<br>✓ $b\bar{b}\gamma\gamma$ matched<br>✓ $m_{\gamma\gamma} = 125 \pm 3$ GeV |

**Work in progress to compare studies, harmonize performance assumptions, optimize, etc**
**⇒ ideal benchmarking framework**

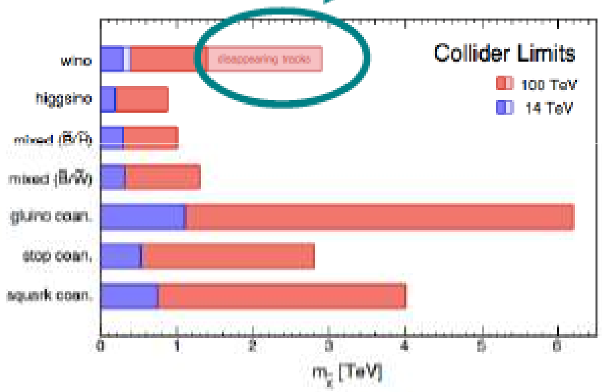
# Dark Matter Studies at the FCC-hh

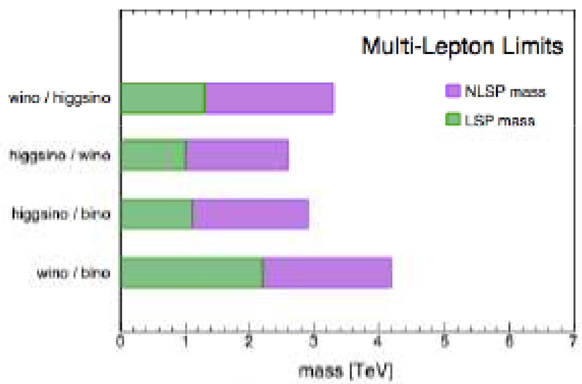
## Dark Matter Searches within SUSY Scenarios

### WIMP searches at colliders

L.Wang @ FCC week

disappearing tracks




Collider reach for neutralino DM

Electroweakino cascades

$$M_{\mathrm{WIMP}} \lesssim 1.8 \text{ TeV} \left(\frac{g^2}{0.3}\right)$$

100 TeV pp collider will probe TeV WIMP very well.

# FCC-hh: More Topics Under Study

- Precision measurements in EWK, top, Higgs, QCD…
- EWK radiation of W's and opportunities
- New high mass scalar resonance sensitivity
- Production of exotic coloured states
- Flavor physics opportunities
- Quadruple Higgs production and quartic couplings
- EW interactions at multi-TeV (eg WW scattering)
- Coloured and neutral naturalness
- Composite Higgs, twin-Higgs… models
- Heavy Leptons and Leptoquarks
- Heavy Ion program
- …

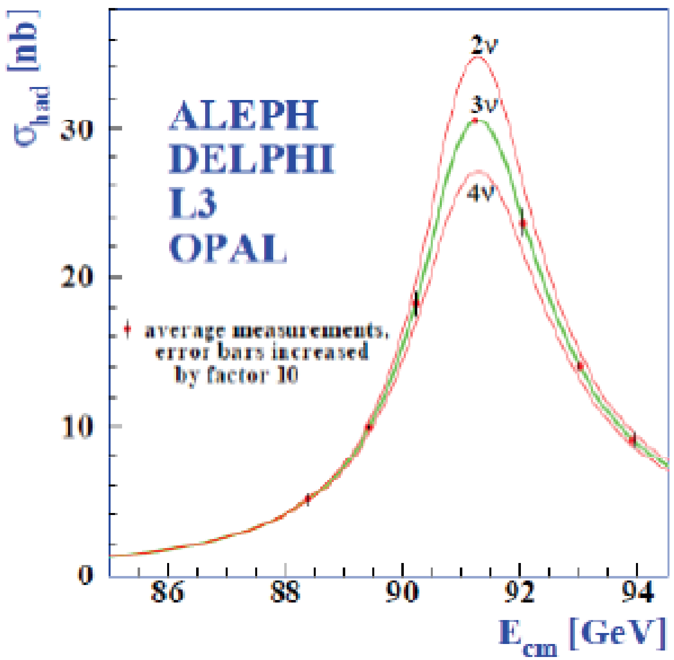
Lots of opportunities for studies

# Future e+e- Colliders

Thanks to E. Perez, F.Zimmerman

# Precision Measurements @ FCC

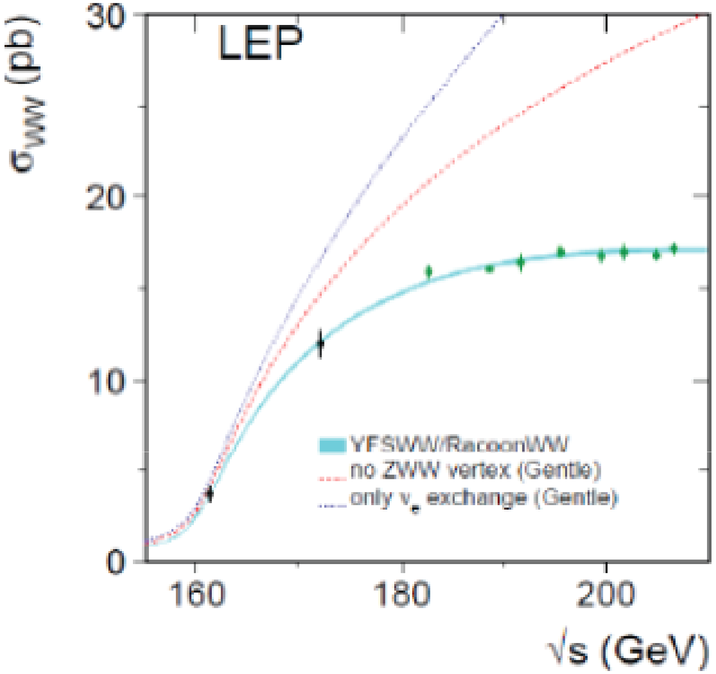
## Z resonance: TeraZ




- Lineshape
  - ➨ Exquisite $E_{beam}$
  - ➨ $m_Z$, $\Gamma_Z$ to 100 keV
- Asymmetries $A_{FB}^{\mu\mu}$
  - ➨ $\sin^2\theta_W$ to $6 \times 10^{-6}$
  - ➨ $\alpha_{QED}(m_Z)$ to $3 \times 10^{-5}$
- Branching ratios, $R_l$, $R_b$
  - ➨ $\alpha_S(m_Z)$ to 0.0002

P. Janot, JHEP1602 (2016) 053

## WW threshold scan: OkuW



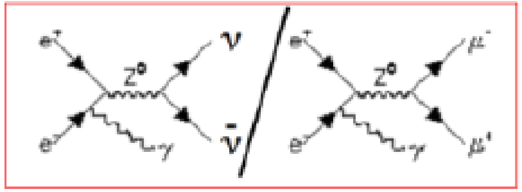

Keys:
- Huge stat
- Ebeam known to < 100 keV via resonant depol. method (unique to circ. ee machines).

Capital as drives the syst. uncert. in many cases.

TLEP paper, JHEP 1401 (2014) 164

- Threshold scan
  - ➨ $m_W$ to 500 keV
- Radiative returns $e^+e^- \to \gamma Z$ $(Z \to \nu\nu, \mu^+\mu^-)$
  - ➨ $N_\nu$ to 0.0004 $N_\nu \sim \sigma(e^+e^- \to \nu\bar{\nu}\gamma)$ / $\sigma(e^+e^- \to \mu^+\mu^-\gamma)$

B(W->had)/B(W->lν) @WW reduces further $\Delta\alpha_S(m_Z)$



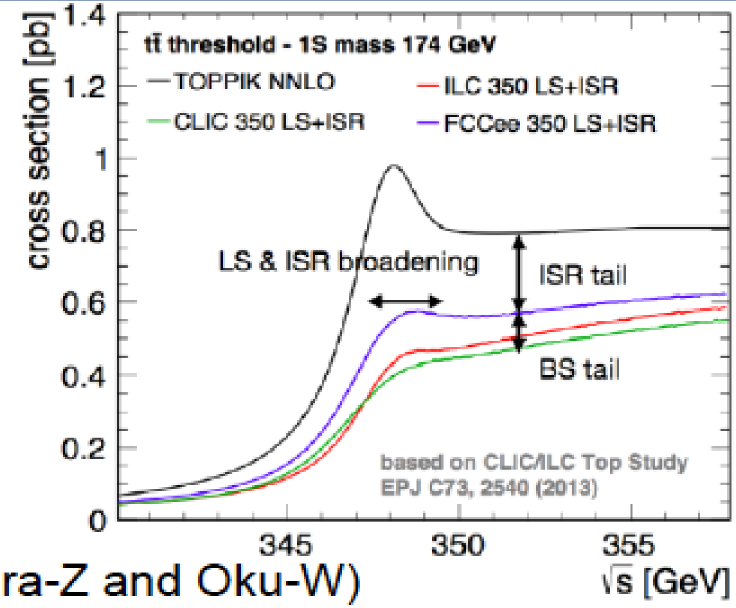
# Precision Measurements Top Sector

Precision measurements in the top sector

Top mass and width via threshold scan

A few points around 2mt, total O(100 fb-1)
Threshold shape affected by ISR and lumi spectrum

$\delta_{stat}$ ~ 10 – 20 MeV on $m_{top}$, $\delta_{tot}$ < 50 MeV




Current $\delta(\alpha_S(m_Z))$ leads to $\delta$ = 30 MeV,
reduced to ~negl. at FCC (improved $\alpha_S(m_Z)$ from Tera-Z and Oku-W)

Electroweak couplings of the top : sensitive to new physics (cf LEP and Rb !)

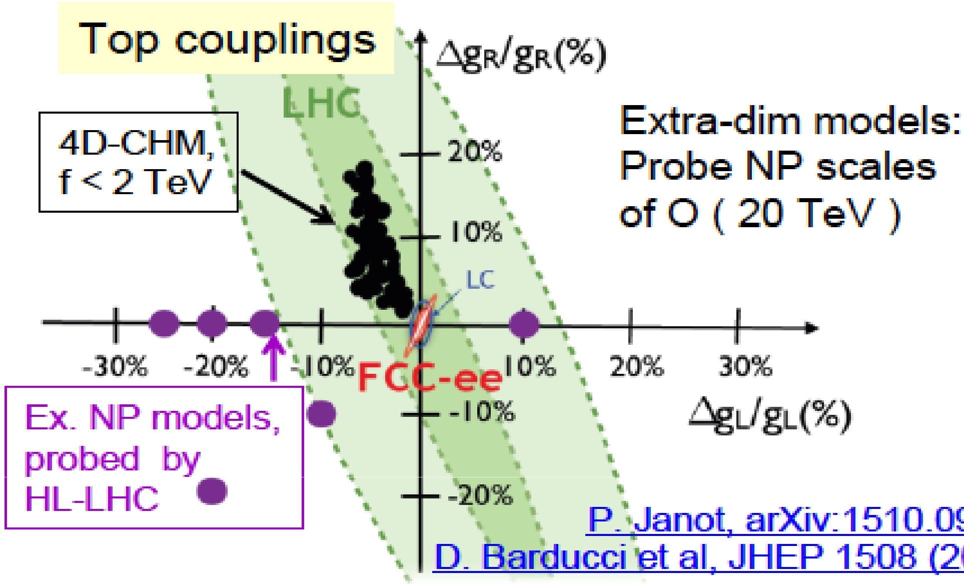
Observables sensitive to the ttV vertex and its chiral structure :
- tt σ's and $A_{FB}$, exploiting the longitudinal polarisation of $e^{\pm}$ , at ILC and CLIC
- event rates and energy & angular distribution of top decay products
  - Exploiting the polarisation of the produced top quarks
    - cf tau polarisation at LEP
  - long. polarisation of the incoming beams not mandatory !
  - realized recently in the context of a FCC study ( √s ~ 365 GeV )

P. Janot, JHEP 1504 (2015) 182

Precision of 1% or better can be achieved – typically 10x better than HL-LHC.

# Indirect Searches for New Physics

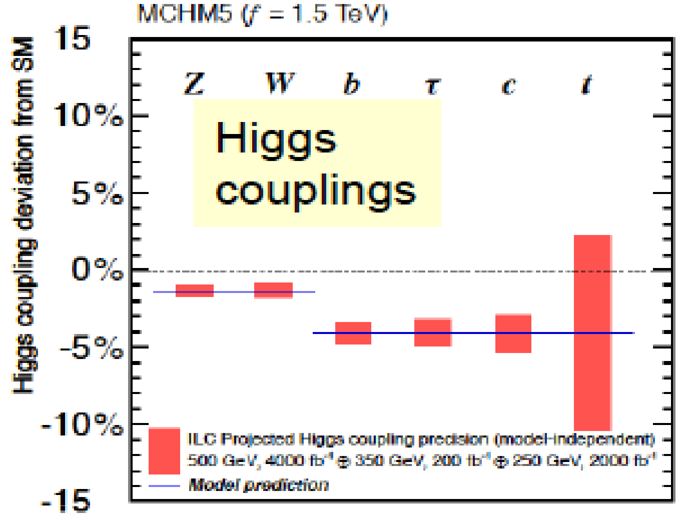
Precision and indirect searches for new physics




P. Janot, arXiv:1510.09056

D. Barducci et al, JHEP 1508 (2015) 127

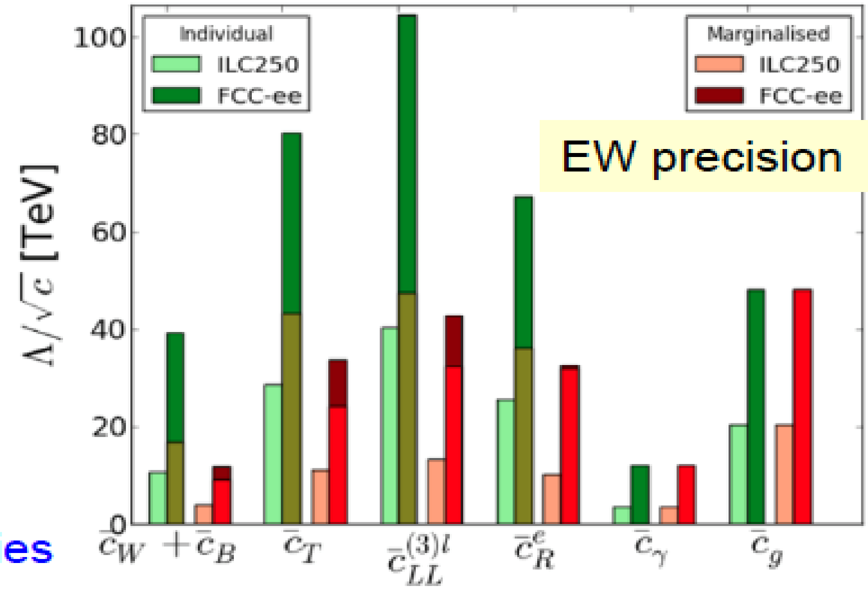
ILC Physics case, arXiv:1506.05992




J. Ellis & T. You, JHEP03 (2016) 089

$$\mathcal{L}_{\rm SMEFT} = \mathcal{L}_{\rm SM} + \sum_i \frac{c_i}{\Lambda^2}\mathcal{O}_i\,,$$

Power of loops :
In terms of weakly-coupled new physics:
$\Lambda_{NP} > 30 – 100$ TeV




Theo. uncertainties need to be improved in the next 20 years, to match the exp. uncertainties

# Direct Searches for New Physics

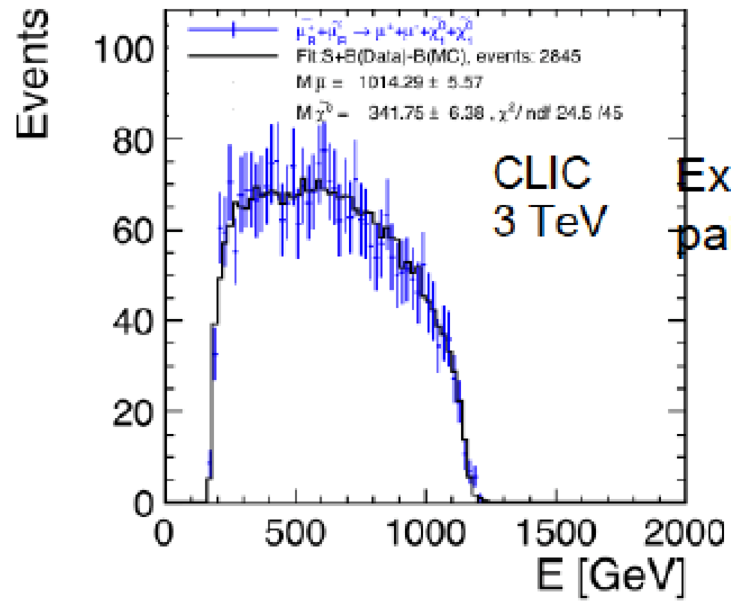
- Clean e+e- environment : explore the holes that LHC will leave (e.g. difficult decay modes leading to soft final states, etc)
  - well motivated models : e.g. in SUSY, compressed spectra often needed to avoid a too large relic density of DM

- Large statistics allows to search for NP in rare decay modes
  - e.g. Z $\rightarrow$ Dark Matter via e+ e- $\rightarrow$ $\gamma$ + Emiss, Higgs $\rightarrow$ inv, LFV decays
  - Tera-Z : light right-handed neutrinos in Z $\rightarrow$ $\nu$N

- If $\sqrt{s}$ large enough for new particles to be produced: very precise measurements of their mass, spin and couplings (threshold scans and/or endpoints) e.g. sleptons of O( 1 TeV )

In general : precision on masses 0.1 – 1%.

Long. polarisation can be very useful to pin down the chiral properties of the new particles.




Ex: smuon pair prod

# Future electron-hadron Colliders

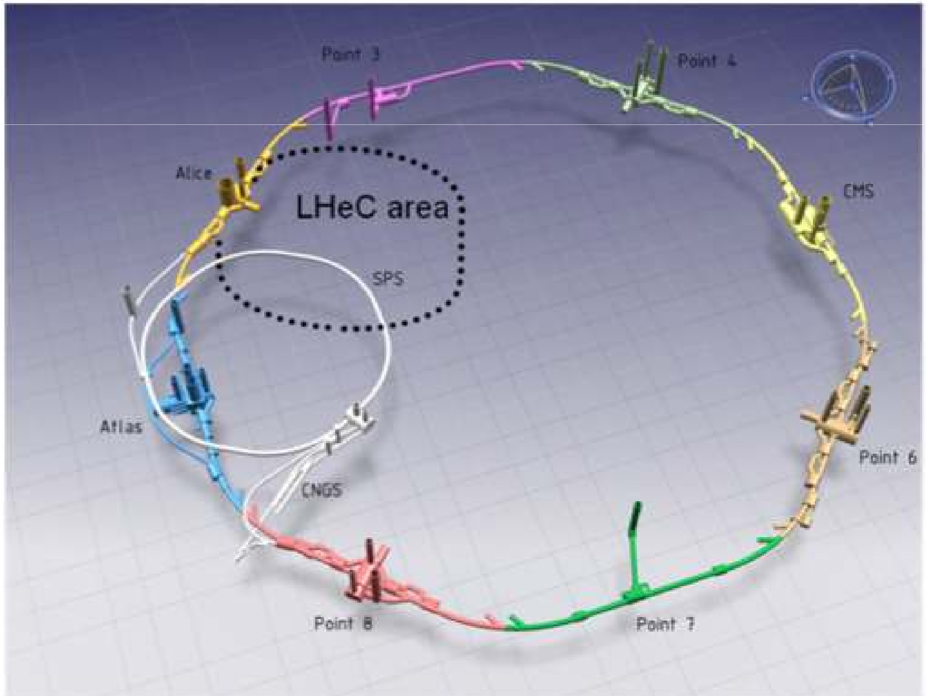
# FCC-eh: The Electron-Hadron Option

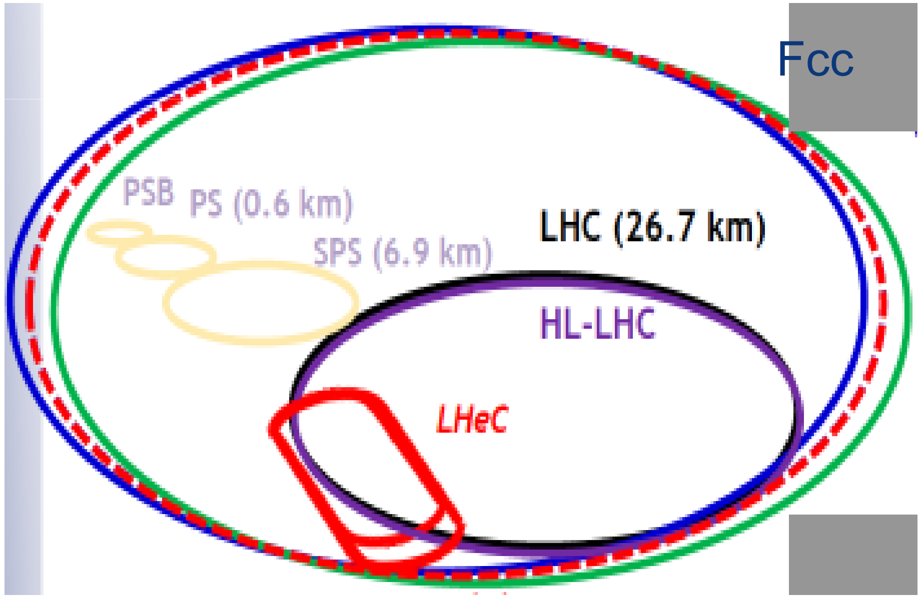
- Future possible hadron-lepton colliders will be excellent QCD explorers
- High luminosity ($10^{34}$-$10^{35}$) and/or energy lepton-hadron colliders

->Dedicated facilities studies include the LHeC (Europe) and EIC (US) projects and now FCC-he

ep: 60 GeV x 7 TeV

ep: 60-175 GeV x 50 TeV



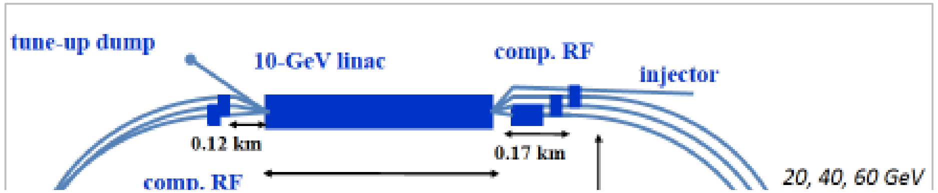




FCC-eh: Use FCC-ee ring or Energy Recovery Linac

# Using an Energy Recovery Linac

Super Conducting Recirculating Linac with Energy Recovery

Choose ⅓ of LHC circumference ➔




| $10^{34}$ $cm^{-2}$ $s^{-1}$ Luminosity reach | PROTONS | ELECTRONS |
|---|---|---|
| Beam Energy [GeV] | 7000 | 60 |
| Luminosity [$10^{33} cm^{-2} s^{-1}$] | 16 | 16 |
| Normalized emittance $\gamma\varepsilon_{x,y}$ [μm] | 2.5 | 20 |
| Beta Funtion $\beta^*_{x,y}$ [m] | 0.05 | 0.10 |
| rms Beam size $\sigma^*_{x,y}$ [μm] | 4 | 4 |
| rms Beam divergence σ□$^*_{x,y}$ [μrad] | 80 | 40 |
| Beam Current @ IP[mA] | 1112 | 25 |
| Bunch Spacing [ns] | 25 | 25 |
| Bunch Population | $2.2*10^{11}$ | $4*10^{9}$ |
| Bunch charge [nC] | 35 | 0.64 |

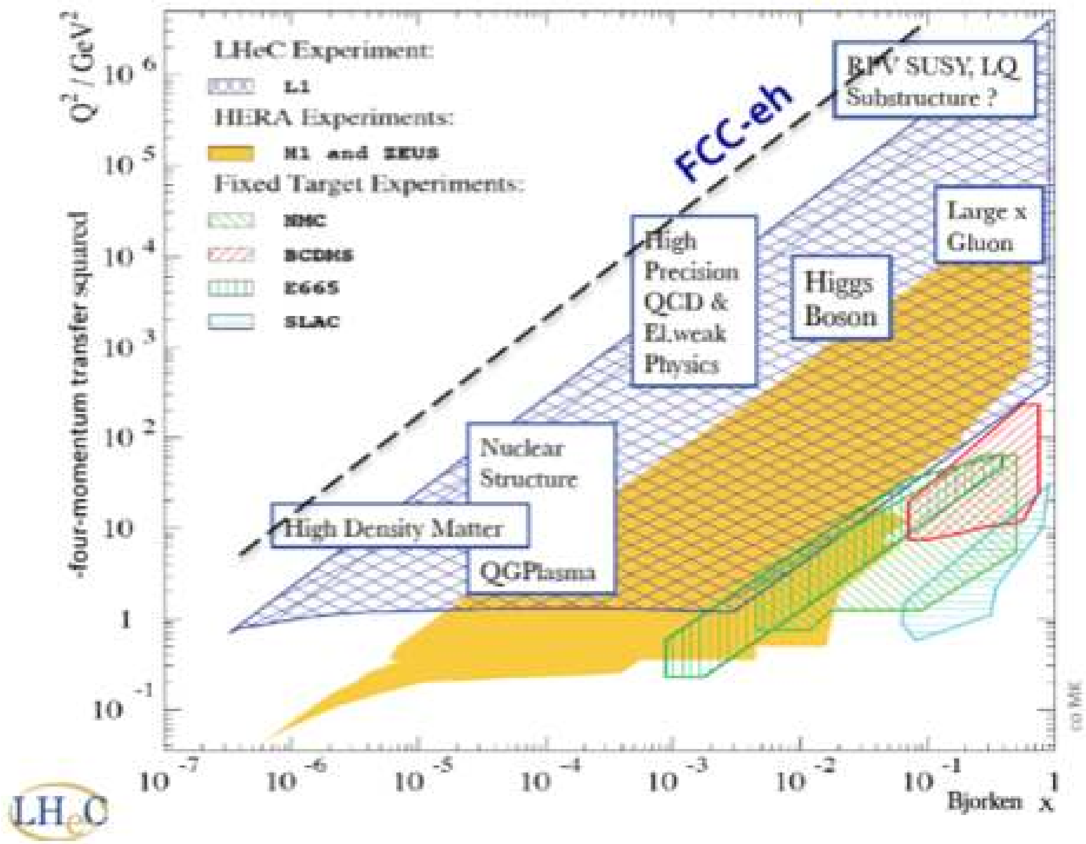
Two 1 km long, 10 GeV SC LINACs with 3 accelerating and decelerating passes in W operation

- SRF sees 6*current at the IP (≈ 4ns spacing)
- $Q_0 = 10^{10}$ requires cryogenic system comparable to LHC system! $Q_0 > 10^{10}$

# FCC-eh

Always a useful complement to a hadron collider eg via measurement parton distribution functions ....

FCC-hh + Energy Recovery Linac for the electrons




- Access to specific Higgs couplings
- Reach for new physics eg Leptoquarks, CIs…

Breaking of Factorisation

Free Quarks

Unconfined Color

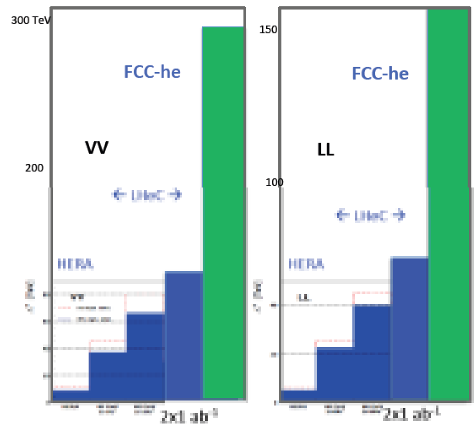
New kind of coloured matter

Quark substructure

New symmetry embedding QCD

QCD may break .. (Quigg DIS13)

Reach for CI (eeqq) at FCC-he

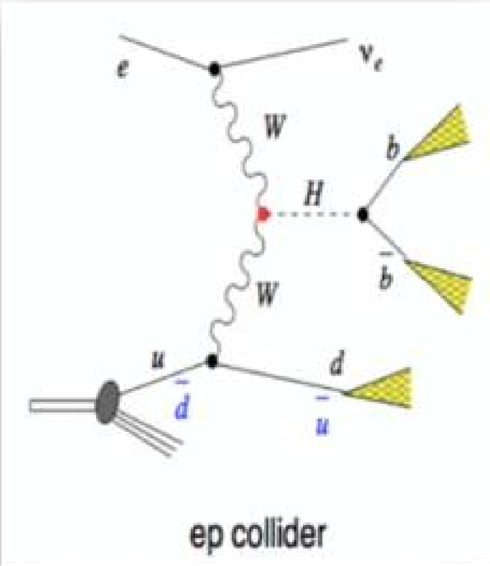


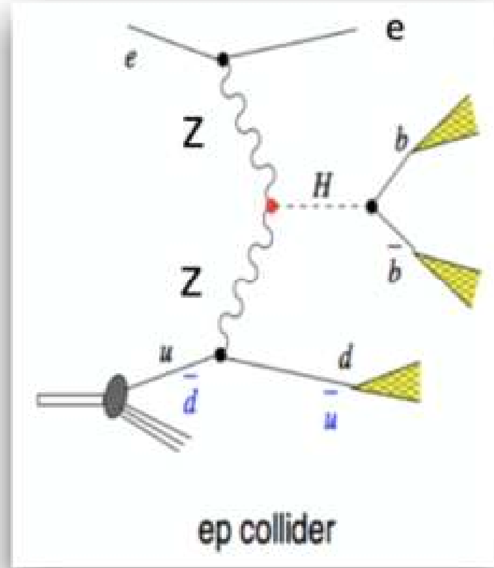

- Very preliminary scaling from LHeC
- Reach about O(100) TeV, expected to be competitive with FHC

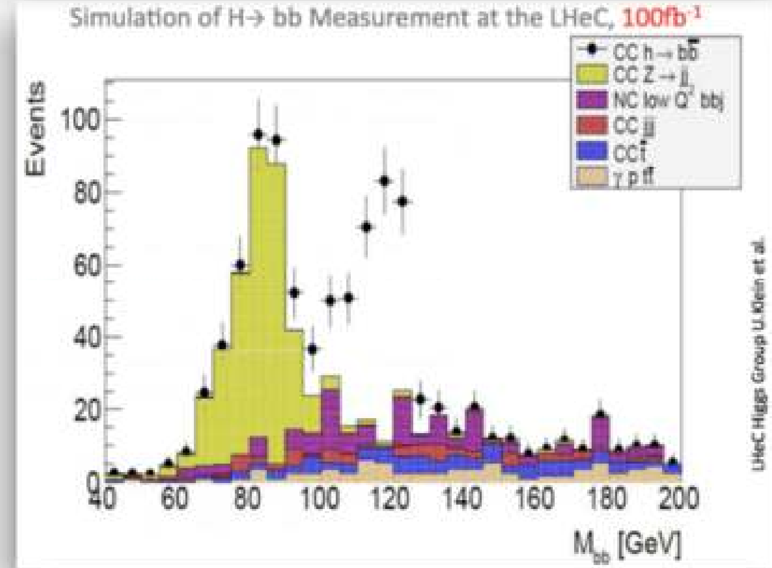
# Higgs at the LHeC and FCC-eh

- ➡ FCC-ep can deliver PDFs for FCC-pp (Higgs) program
- ➡ Higgs studies in relatively clean environment
- ➡ Higgs precision $\kappa_b$ measurement, < 1%
- ➡ Investigation potential of $\kappa_c$ measurement using charm tagging

| Higgs in $e^-p$ | | CC - LHeC | NC - LHeC | CC - FHeC |
|---|---|---|---|---|
| Polarisation | | -0.8 | -0.8 | -0.8 |
| Luminosity [ab$^{-1}$] | | 1 | 1 | 5 |
| Cross Section [fb] | | 196 | 25 | 850 |
| Decay | BrFraction | $N^H_{CC}$ | $N^H_{NC}$ | $N^H_{CC}$ |
| $H \to b\bar{b}$ | 0.577 | 113 100 | 13 900 | 2 450 000 |
| $H \to c\bar{c}$ | 0.029 | 5 700 | 700 | 123 000 |
| $H \to \tau^+\tau^-$ | 0.063 | 12 350 | 1 600 | 270 000 |
| $H \to \mu\mu$ | 0.00022 | 50 | 5 | 1 000 |
| $H \to 4l$ | 0.00013 | 30 | 3 | 550 |
| $H \to 2l2\nu$ | 0.0106 | 2 080 | 250 | 45 000 |
| $H \to gg$ | 0.086 | 16 850 | 2 050 | 365 000 |
| $H \to WW$ | 0.215 | 42 100 | 5 150 | 915 000 |
| $H \to ZZ$ | 0.0264 | 5 200 | 600 | 110 000 |
| $H \to \gamma\gamma$ | 0.00228 | 450 | 60 | 10 000 |
| $H \to Z\gamma$ | 0.00154 | 300 | 40 | 6 500 |



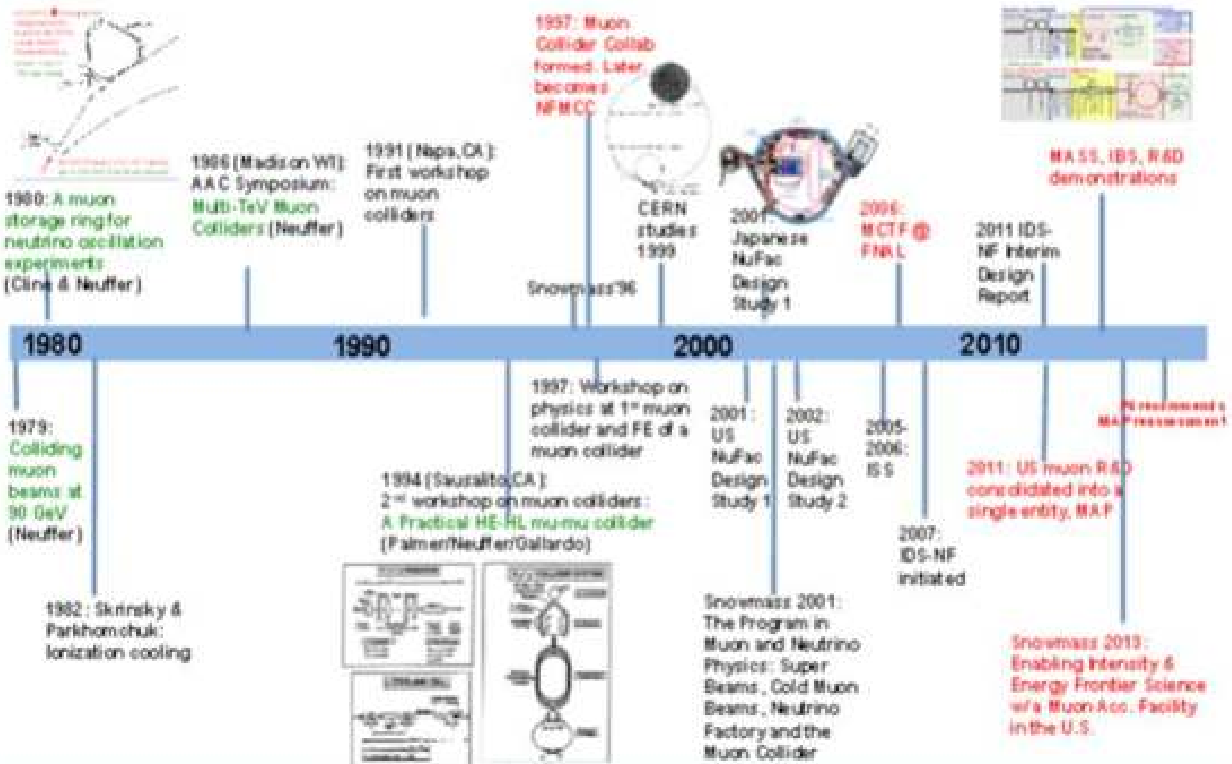



# A Muon Collider?

# A Muon Collider?

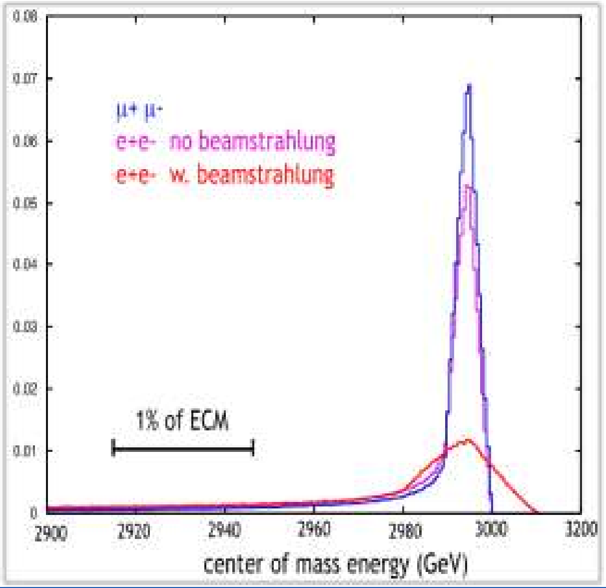
- First ideas and studies back in the ’80, also CERN involved
- Solid and longstanding US effort (FNAL), a lot of simulation and experimental work (MICE, MuCool, etc.)
  - Recently revived by Rubbia’s proposal
- Discussion at CERN last fall:
  - Workshop and summary document edited by Bertolucci

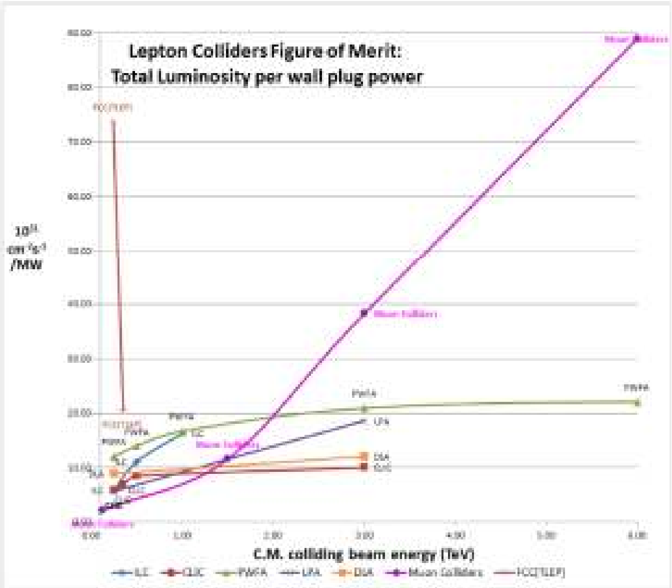


# A Muon Collider?

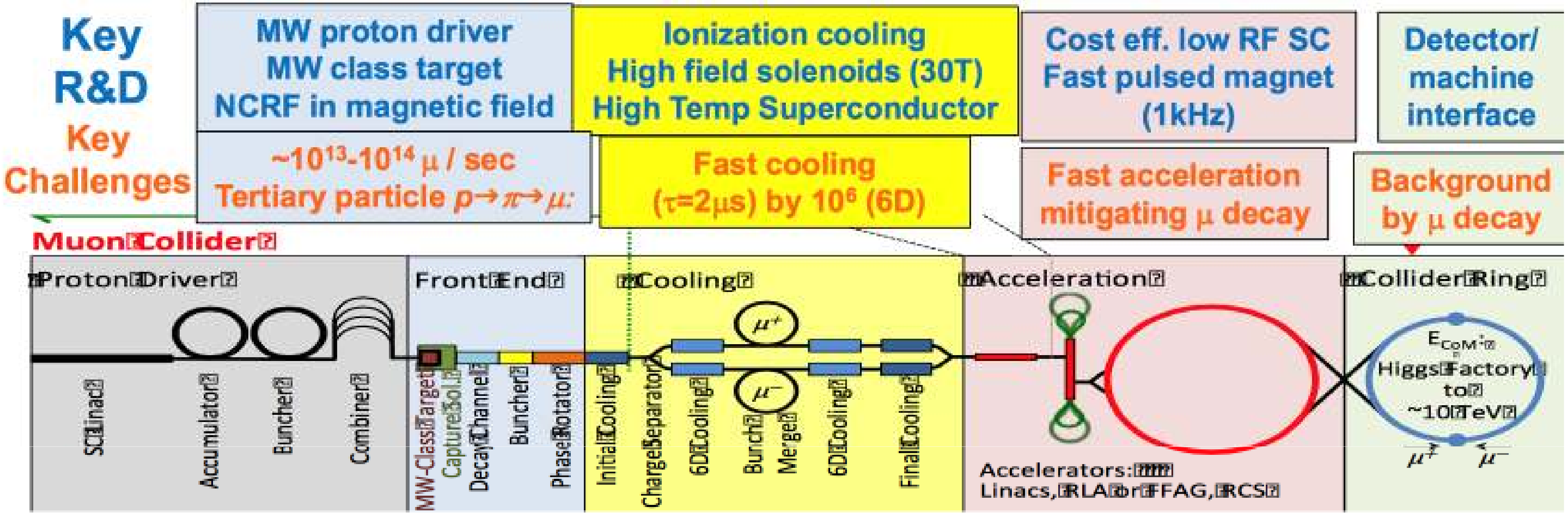
(Once you manage to get two muon beams)

- ↑ Mild sych. rad., allows high energy & compact collider layout
- ↑ Very limited beam-strahlung, allows $1/\gamma$ scaling of luminosity and optimal luminosity spectrum
- ↓ Short lifetime, everything needs to be fast
- ↓ Deal with muon decay products, need shielding for experiments and countermeasures for environmental contamination



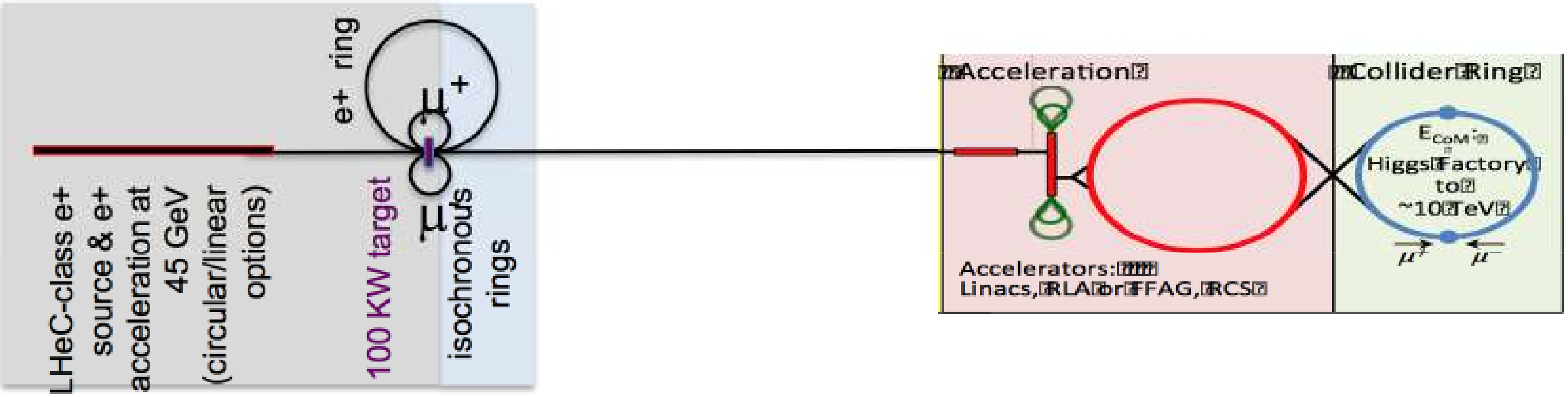
# Muon Collider: Traditional Design




- Muons as tertiary from high intensity proton beam on target
  - Issue with target to sustain required intensity
- Large momentum transverse to the beam direction => huge emittance => need cooling
  - Major issue to be solved

# Muon Collider: the new idea

**Don’t use a proton beam but create muon pair “at rest” in e+e-**




- Asymmetric $e^+e^- \rightarrow \mu^+\mu^-$ with √s at threshold
- Muons at rest in CoM frame, boosted by large ($p_{e+}$- $p_{e-}$) => automatically getting low emittance

# e+e- Driven Muon Collider

**Pros:**

- Low emittance: can be very small close to the μ+μ- threshold ($2xm_{\mu}$ ~0.21 GeV)
- Low background: smaller number of muons → reduced background/radiation from decay products
- More time to accelerate: large boost from asymmetric $e^+e^-$ collisions
- Energy spread: muon energy spread also small at threshold gets (further reduced with shorter bunches)

**Cons:**

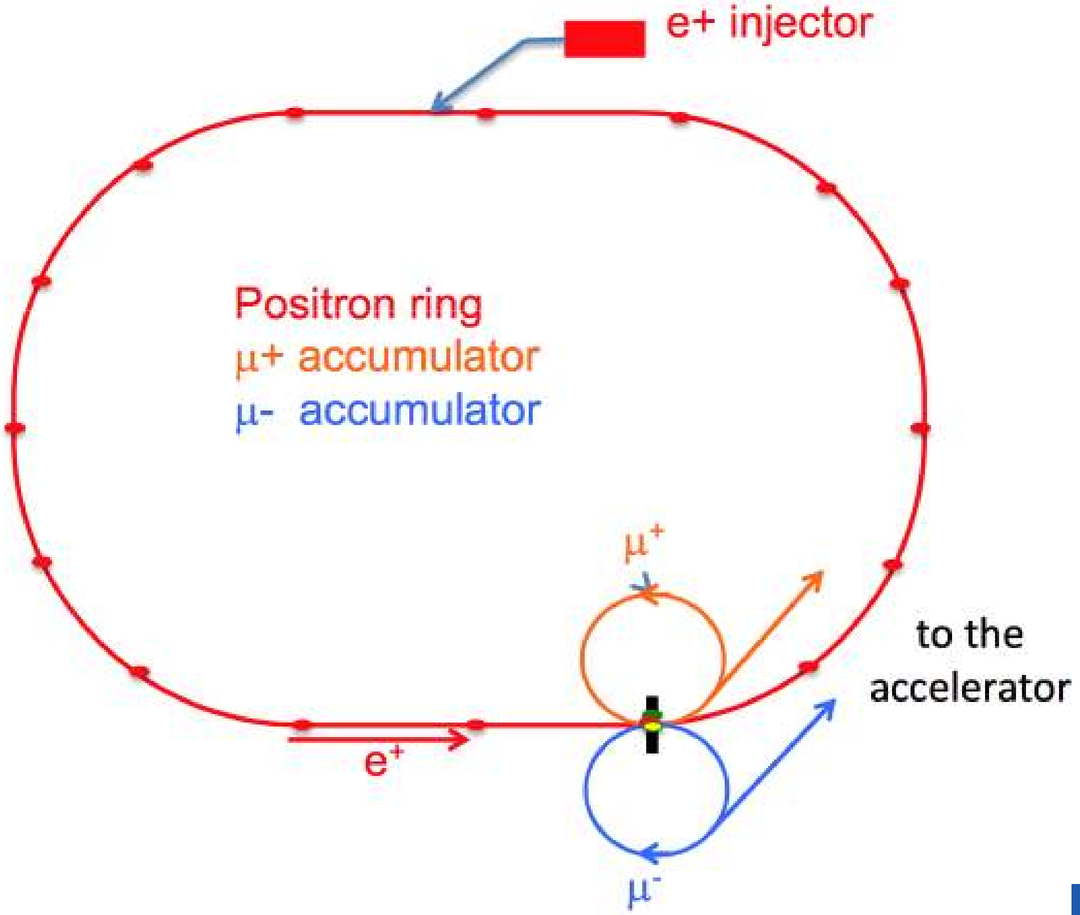
- Rate: much smaller cross section wrt protons: $\sigma(e^+e \to \mu^+\mu^-)$ ~ 1 μb at most:
  - Need $L=10^{40}\,cm^{-2}\,s^{-1}$ for $10^{10}$ Hz μ rate..

Use a fixed target with an 45 GeV e+ beam (from FCC-ee?)

# Layout for the Muon Source

Initial ideas: much work needed to work to a full design

| | LEMMA* |
|---|---|
| e+ bunch spacing | 200 ns |
| e+/bunch | $3 \cdot 10^{11}$ |
| Beam current | 240 mA |
| Rate e+ on target | $1.5 \cdot 10^{18}$ $e^+/s$ |



# Backup

# To follow FCC-hh physics activities

- Register with the FCC-hh mailing list for announcements:
  - http://simba3.web.cern.ch/simba3/SelfSubscription.aspx?groupName=fcc-experiments-hadron
- Check agendas and contents of previous events at the following indico categories:
  - *Informal meetings of all* **physics** *subgroups (SM, Higgs, BSM):*
    - https://indico.cern.ch/category/6067/
  - *Workshops*
    - https://indico.cern.ch/category/6071/
  - *Physics with injectors:*
    - https://indico.cern.ch/category/6070/
  - *Heavy ion physics:*
    - https://indico.cern.ch/category/6068/
  - *Detector subgroup:*
    - https://indico.cern.ch/category/6069/
  - *Detector magnets subgroup:*
    - https://indico.cern.ch/category/6244/
  - *Software group (common with FCC-ee and FCC-eh):*
    - https://indico.cern.ch/category/5666/