

Particle Physics Future Vision

Roger as I met him during the early HERA period



Mazal tov on your
very round birthday !
The age of wisdom !!!

- Guidelines from LHC
- Discussed options
- "Consensus" options

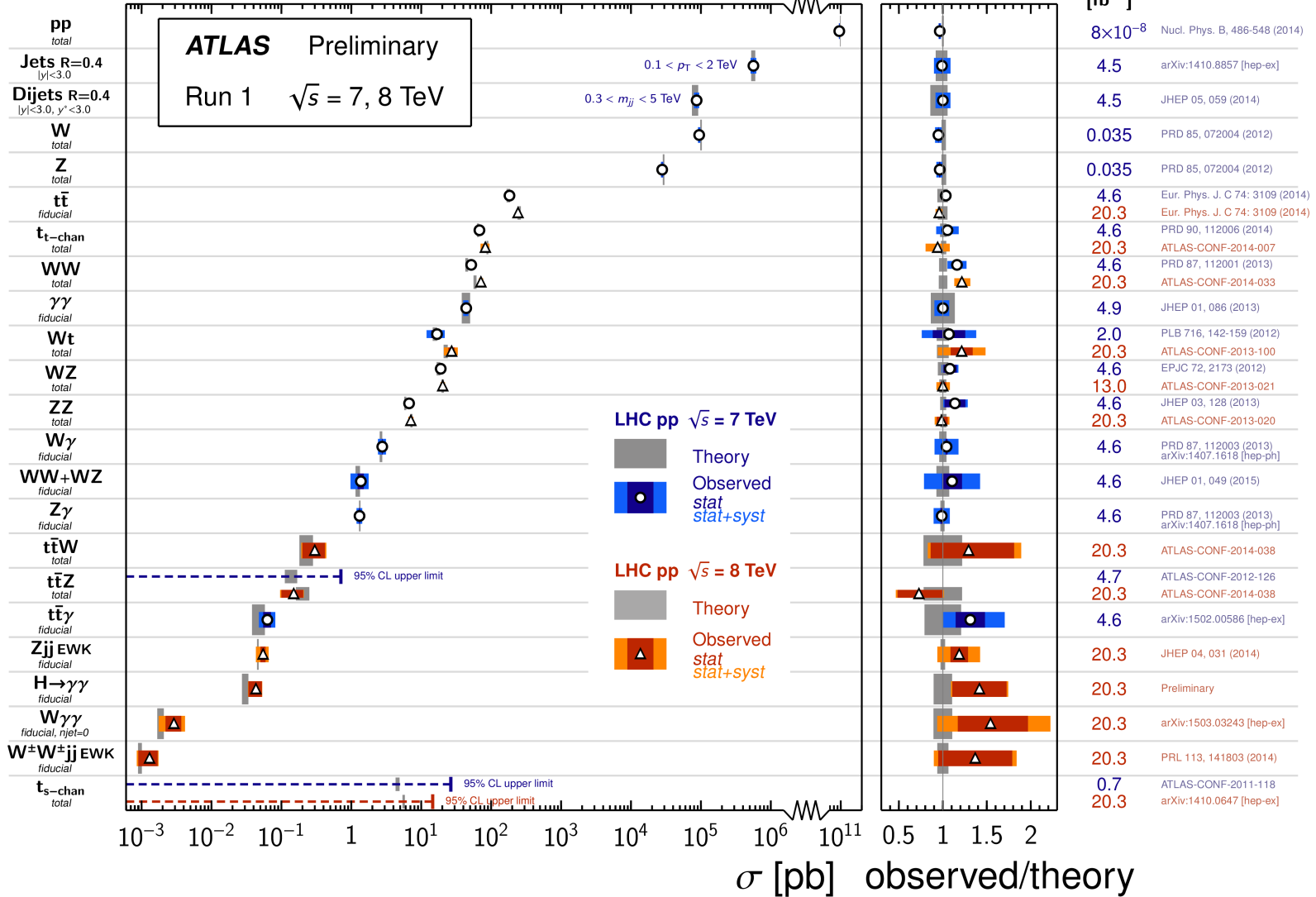


Standard Model at the LHC

Standard Model Production Cross Section Measurements

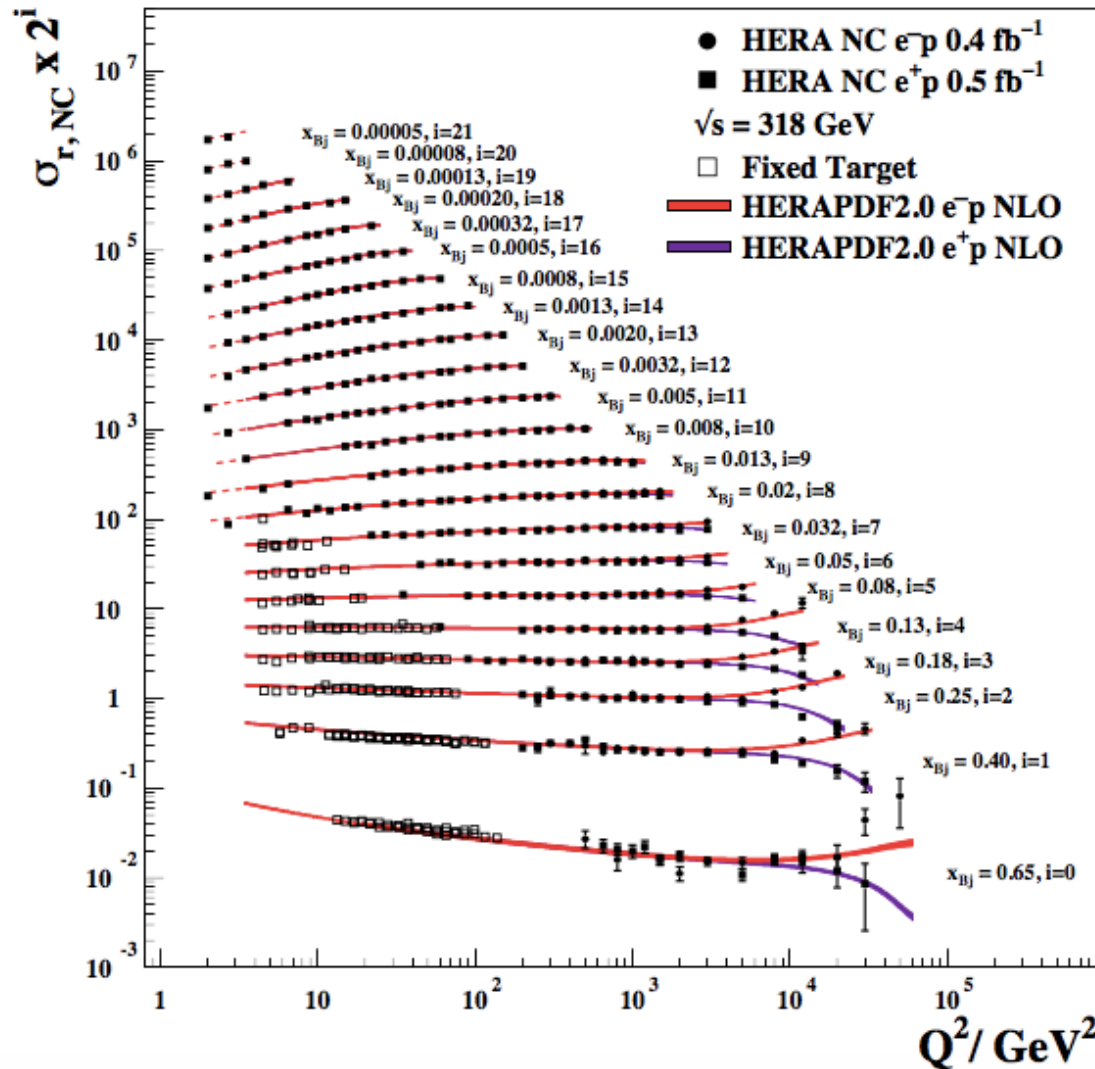
Status: March 2015 $\int \mathcal{L} dt$
[fb⁻¹]

Reference



Latest PDFs from HERA

H1 and ZEUS



Finally recognized through

- EPS prize for DGLAP
- Wolf prize for Bjorken

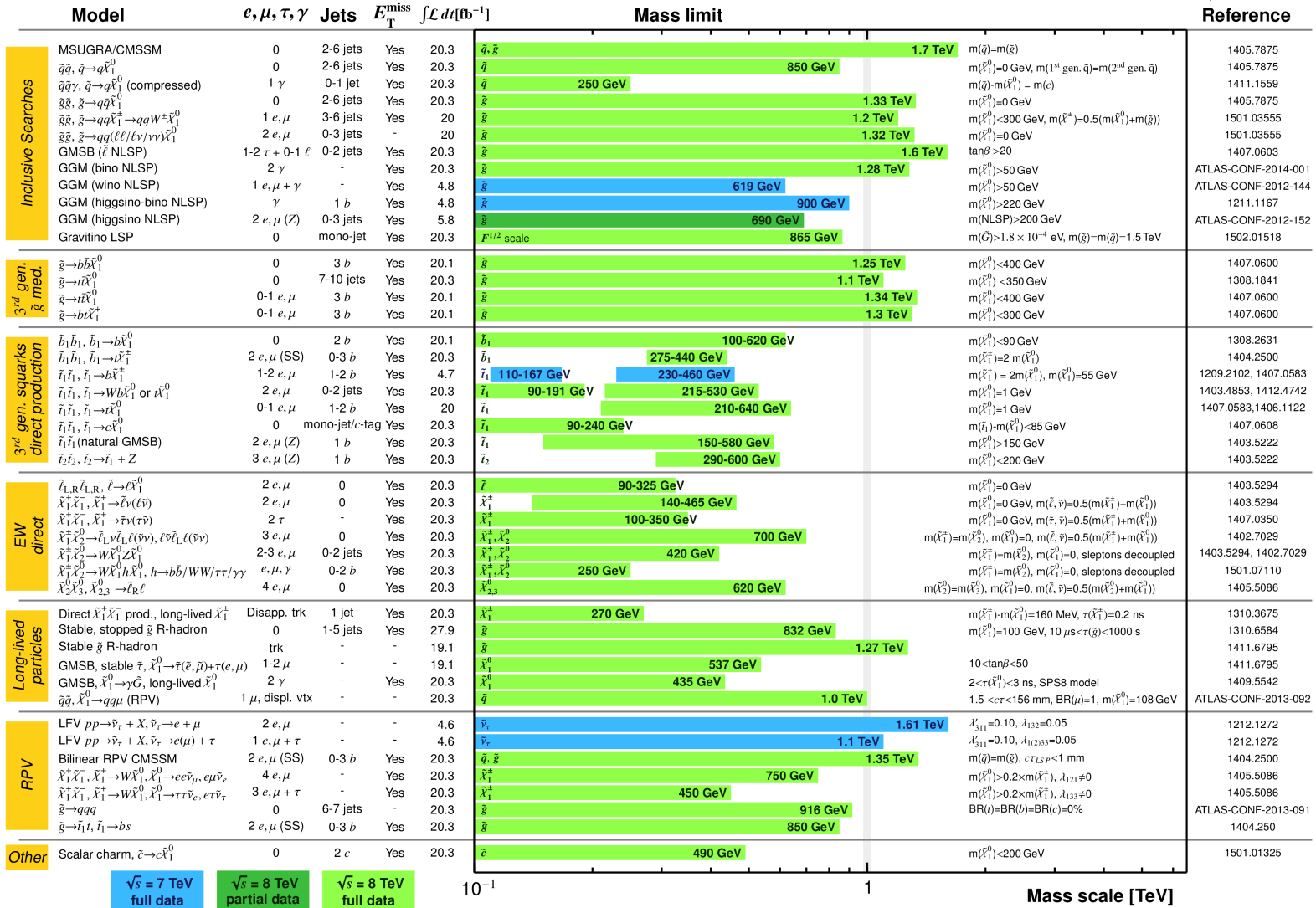
SUSY at the LHC - mass limits

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: Feb 2015

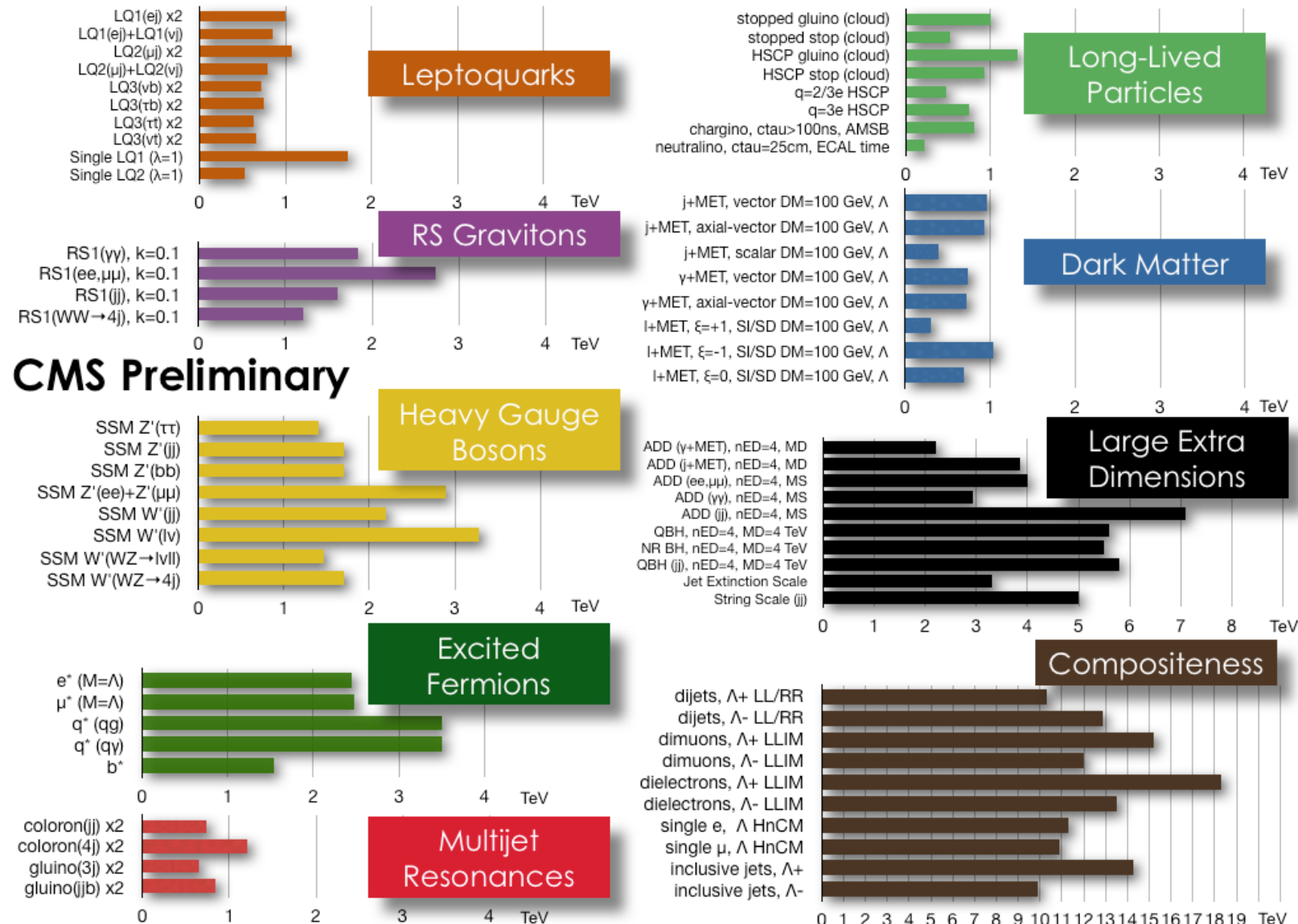
ATLAS Preliminary

$\sqrt{s} = 7, 8 \text{ TeV}$



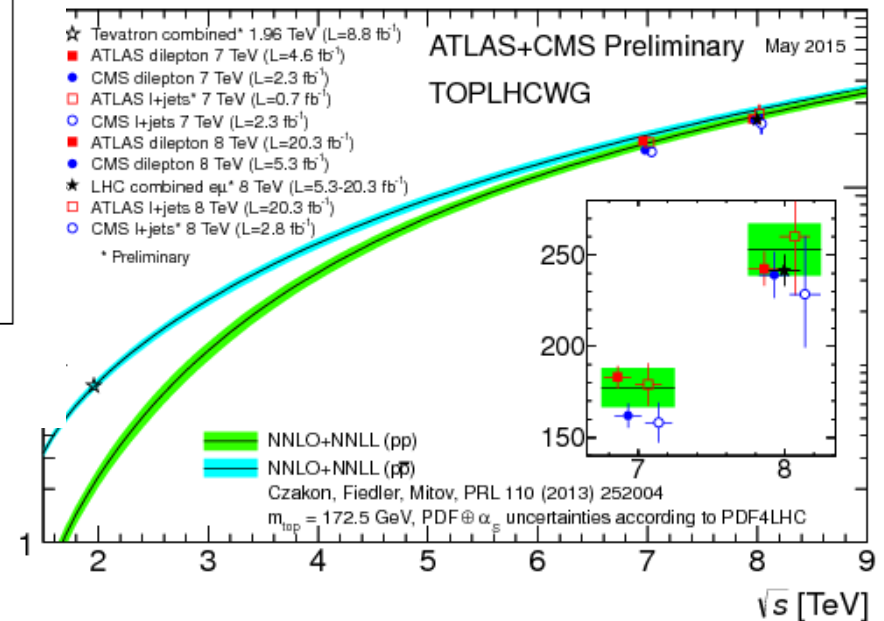
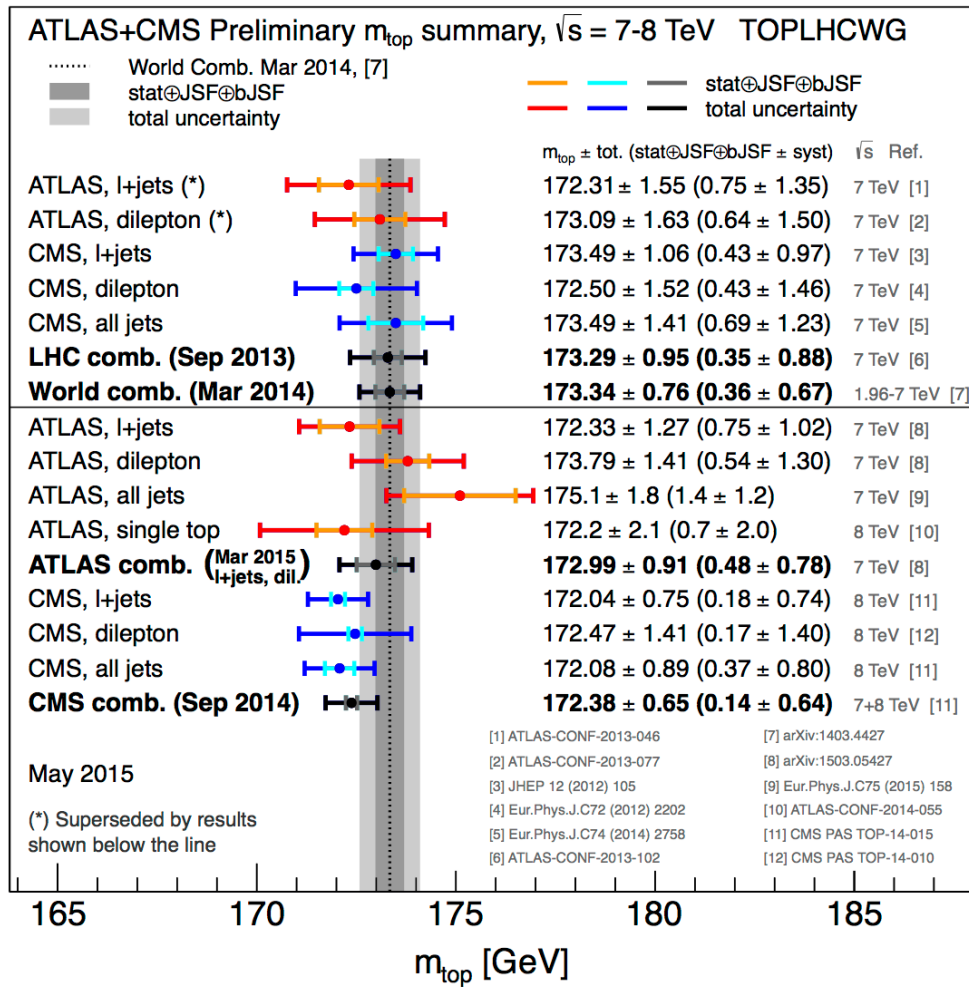
*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

Exotic physics at the LHC - mass limits

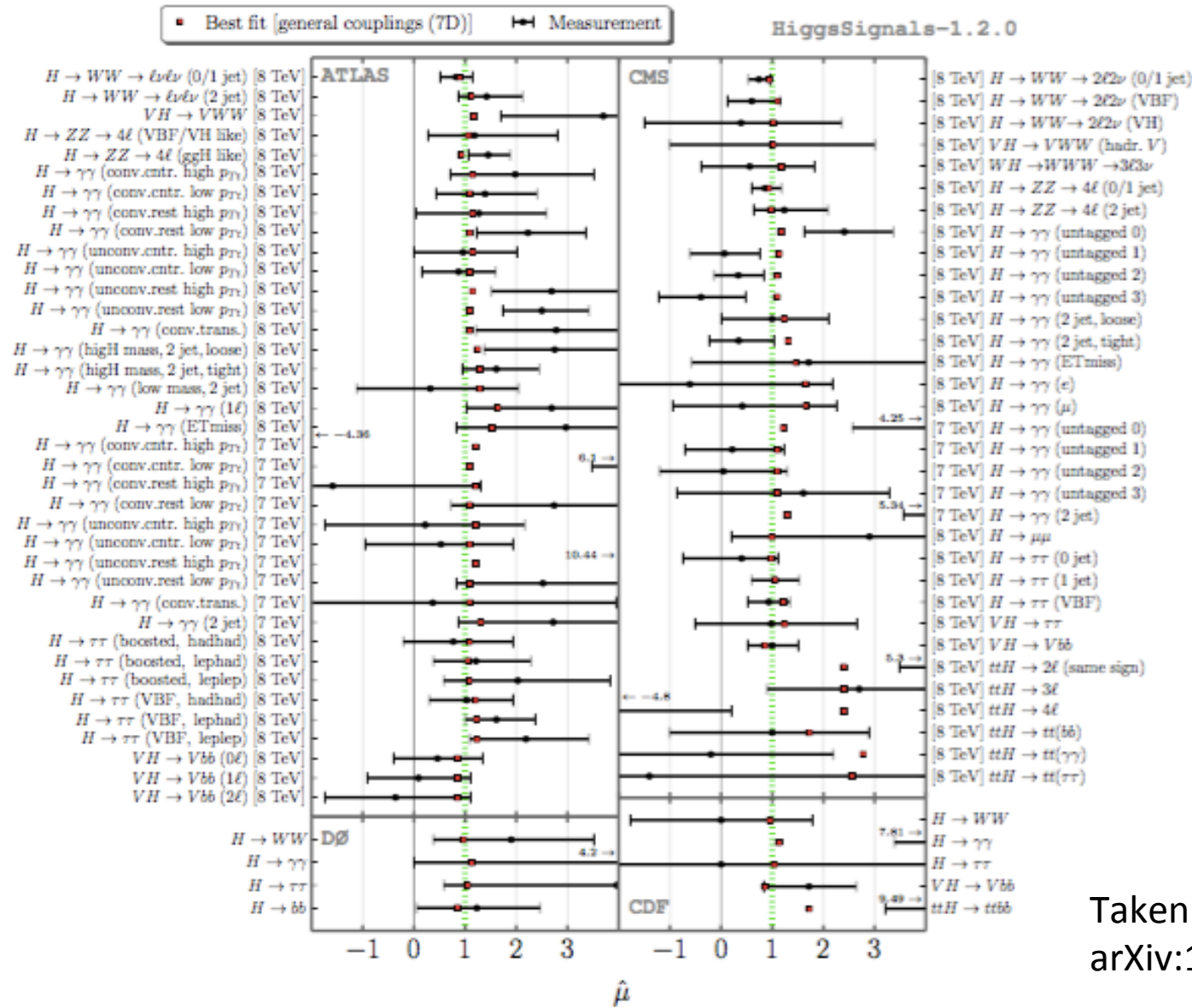


CMS Exotica Physics Group Summary – Moriond, 2015

Top quark at the LHC

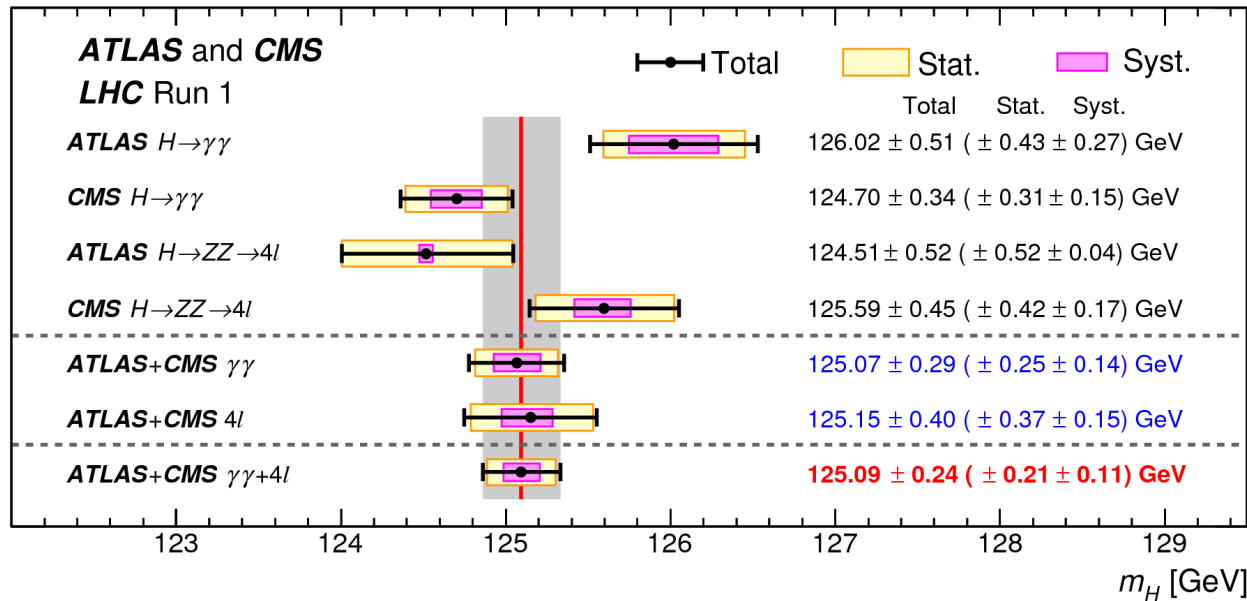


Higgs at the LHC



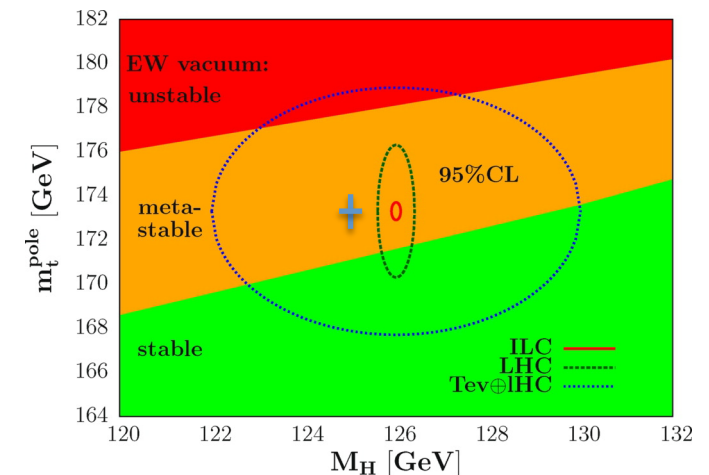
Taken from P. Bechtle et al.
arXiv:1403.1582

Higgs at the LHC



Current preferred option is in the metastable range!!!
BUT WITH SUFFICIENTLY LONG LIFE TIME!
The SM COULD BE A CONSISTENT THEORY
UP TO THE PLANCK SCALE
 (from Stefan Pokorski)

(figure from S. Alekhina, A. Djouadib and S. Moch
 PLB 716 (2012) 214)



Guidelines from LHC

- The Standard Model is doing amazingly well
- The Higgs scalar is very much like expected in the Standard Model
- There is no indication of physics BSM up to scales of the order of 1 to 3 TeV

however

Guidelines from outside LHC

- Neutrinos have masses - not acquired in the SM
- There is dark matter in the Universe with no candidates in the SM (axions???)

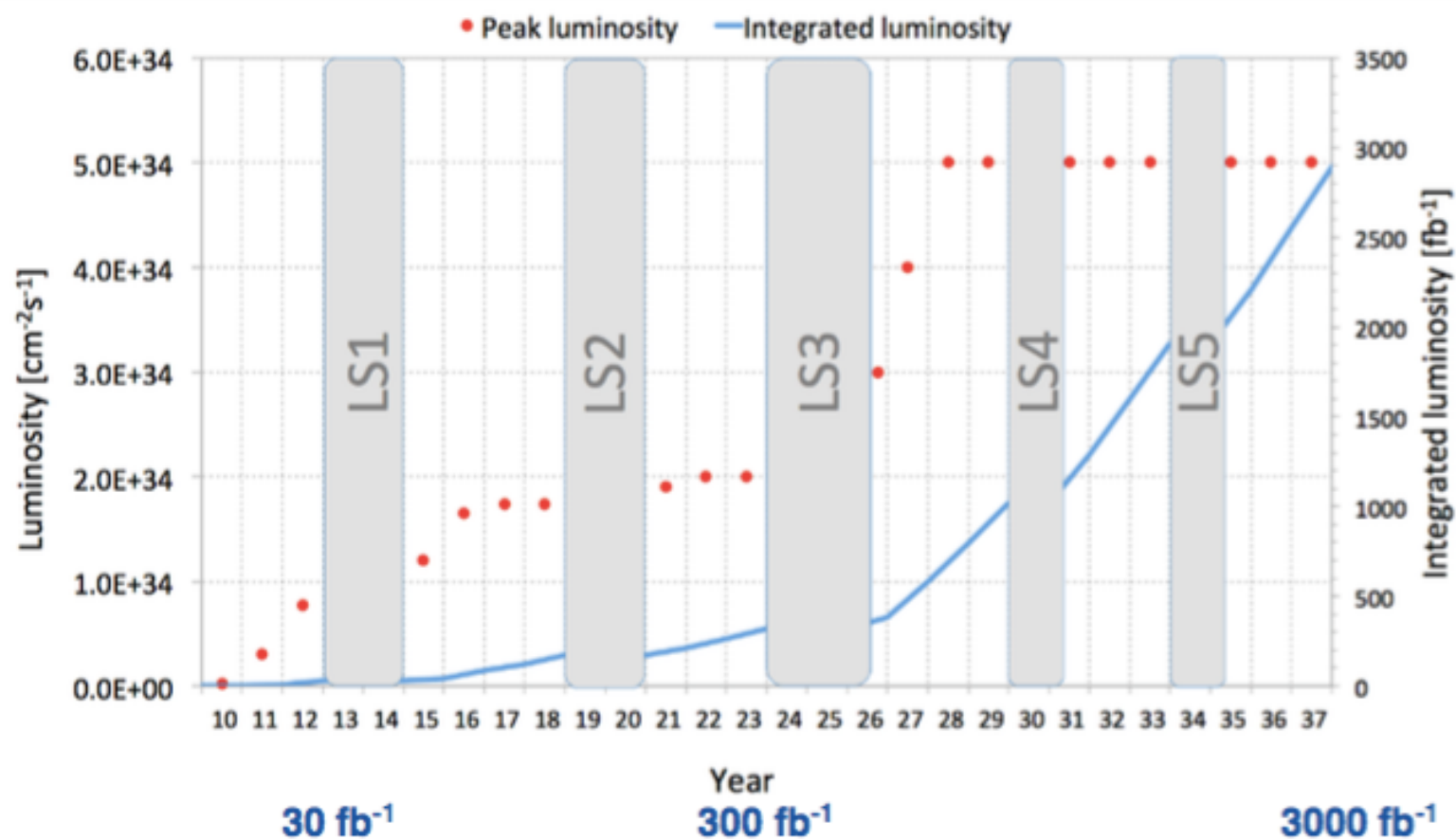
How should we go about understanding all these issues ?

European Strategy

- 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. *(HL-LHC)*
- 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 *(FCC hh,ee,ep ... AWAKE)*
- There is a strong scientific case for *an electron-positron collider*... The Technical Design Report of the International Linear Collider (*ILC*) has been completed, with large European participation... *Europe looks forward to a proposal from Japan to discuss a possible participation. (Waiting for Japanese Gov. decision)*
- CERN should develop a *neutrino programme* to pave the way for a substantial European role in future long-baseline experiments. Europe should explore the possibility of major participation in leading long-baseline neutrino projects *in the US and Japan. (LBNF in FNAL – DUNE in S. Dakota)*

New LHC schedule

Integrated luminosity



Cost & Schedule review of LIU and HL-LHC
Frédéric Bordry
SPC
15th June 2015

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Optimal tools? – from Michelangelo Mangano (CC June 2015)

A “real” story from the past ...

Barcelona, 15 March 1493



Columbus:

Your Majesty, the fleet needs an **upgrade**, we need to go back to the Indies with **10 times** more ships

King Ferdinand and Queen Isabella:

You discovered the Indies, your theory is right, why do you need more?

Columbus:

Theorists* say these may not be the **standard Indies**. They calculated the Earth radius, and the standard Indies cannot be so close: these are likely to be **beyond the standard Indies** (moving eastward ...)

** If the King had listened to theorists to start with, he would have never authorized the mission: everyone one would have died of starvation well before reaching the “standard” Indies ...*

Optimal tools?

The LHC checklist

- **Confirm you've landed in the right place**
 - ▶ *is the new particle at 125 GeV the Higgs of the Standard Model?*
- **Explore surroundings**
 - look for what you expect: the *guaranteed deliverables*
 - ▶ *systematically study and measure with ever-growing precision the interactions of the Higgs boson, and of the other SM particles*
 - search for new “commodities” - the *known unknowns*, follow a path ...
 - ▶ *dark matter, origin of neutrino masses, baryon asymmetry of the universe*
- **Push further the boundary of uncharted territories - search the Eldorado**
 - ▶ *supersymmetry, new forces, extra dimensions, ...*

The Higgs discovery goal provided in the 90's the reference target for the design of the LHC accelerator and experiments.

But the physics goals and ambitions of the LHC always went beyond the Higgs discovery

Possible paper choices for the future

- Hadron machines - Higgs factory and energy frontier

HL - LHC, pp 14 TeV

FCC - pp 100 TeV, 80 to 100 km tunnel, 16 to 20 T magnets

CEPC-SppC - pp 50 to 100 TeV, 50 km tunnel....

SSC - pp 100 to 300 TeV, 270 km tunnel, 5 T to 15 T magnets

- Electron-positron machines - Higgs factory and energy frontier

ILC - linear collider, 500 GeV baseline (expandable to 1 TeV)

CLIC - linear collider, 500 GeV to 3 TeV

FCC ee - circular collider, 240 to 350 GeV

CEPC - circular collider, 240 GeV

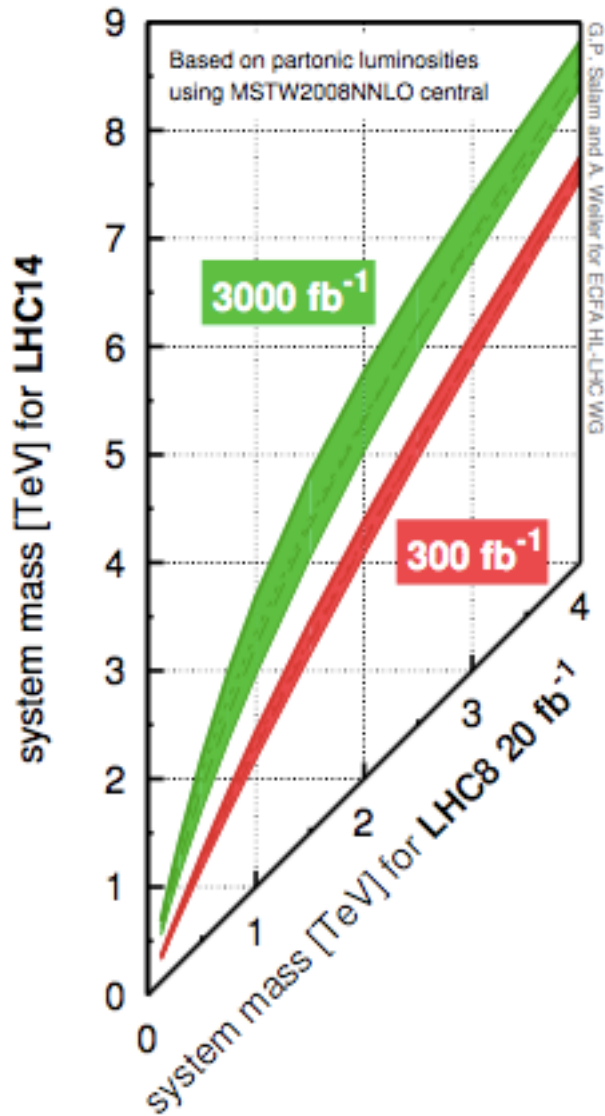
SSC - resurrected 87 km tunnel for circular Higgs factory

- Muon collider - Higgs factory and energy frontier

Circular collider - 120 GeV (expandable to 5 TeV), 300 m long
(neutrino factory as added bonus)

- $\gamma\gamma$ colliders, ep colliders (derivatives of ee and pp colliders)
- Plasma wake field accelerators (laser or beam driven)

Energy Frontiers

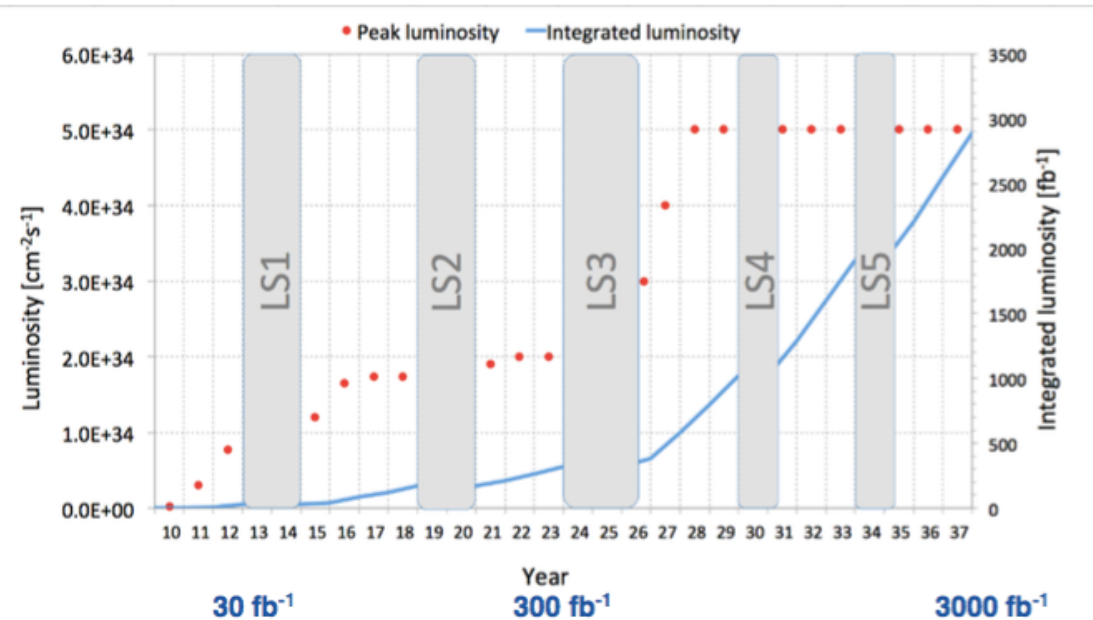


pp interactions are not very efficient energy-wise but no-alternative

At 14 TeV and 3 ab⁻¹ mass reach < 10 TeV

muon collider though competitive –may not be ready

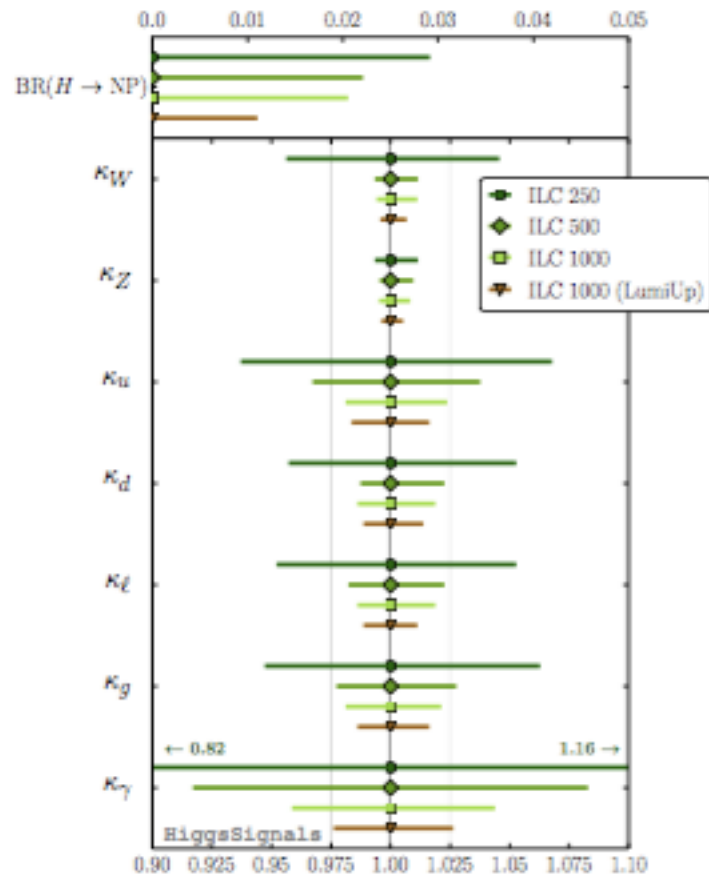
Integrated luminosity



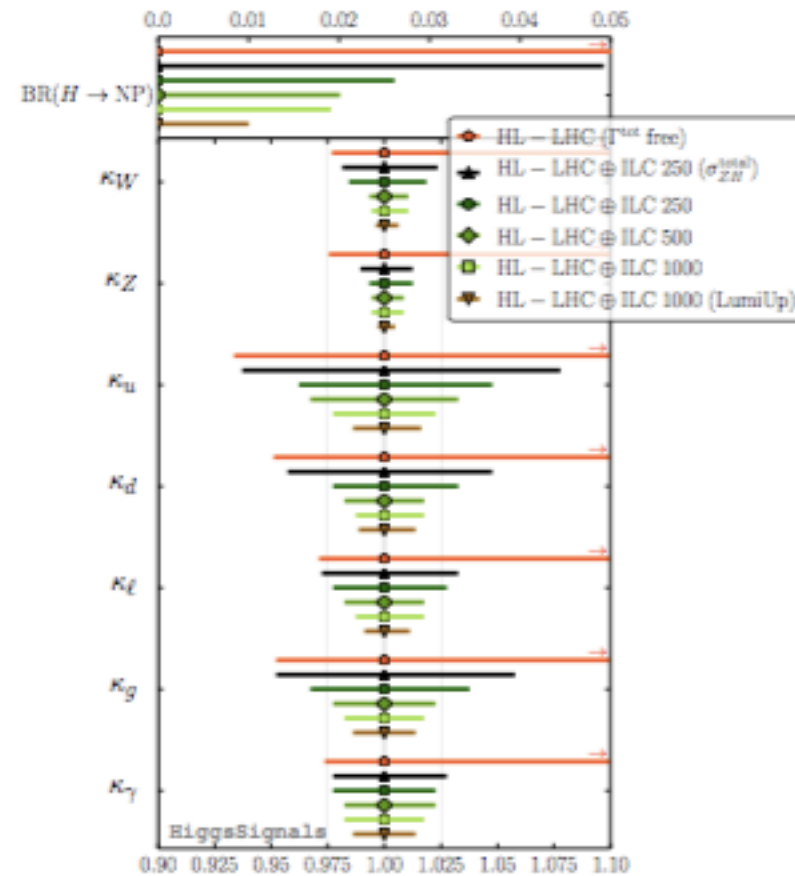
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Higgs factories

Assuming same running time



(a) ILC only.

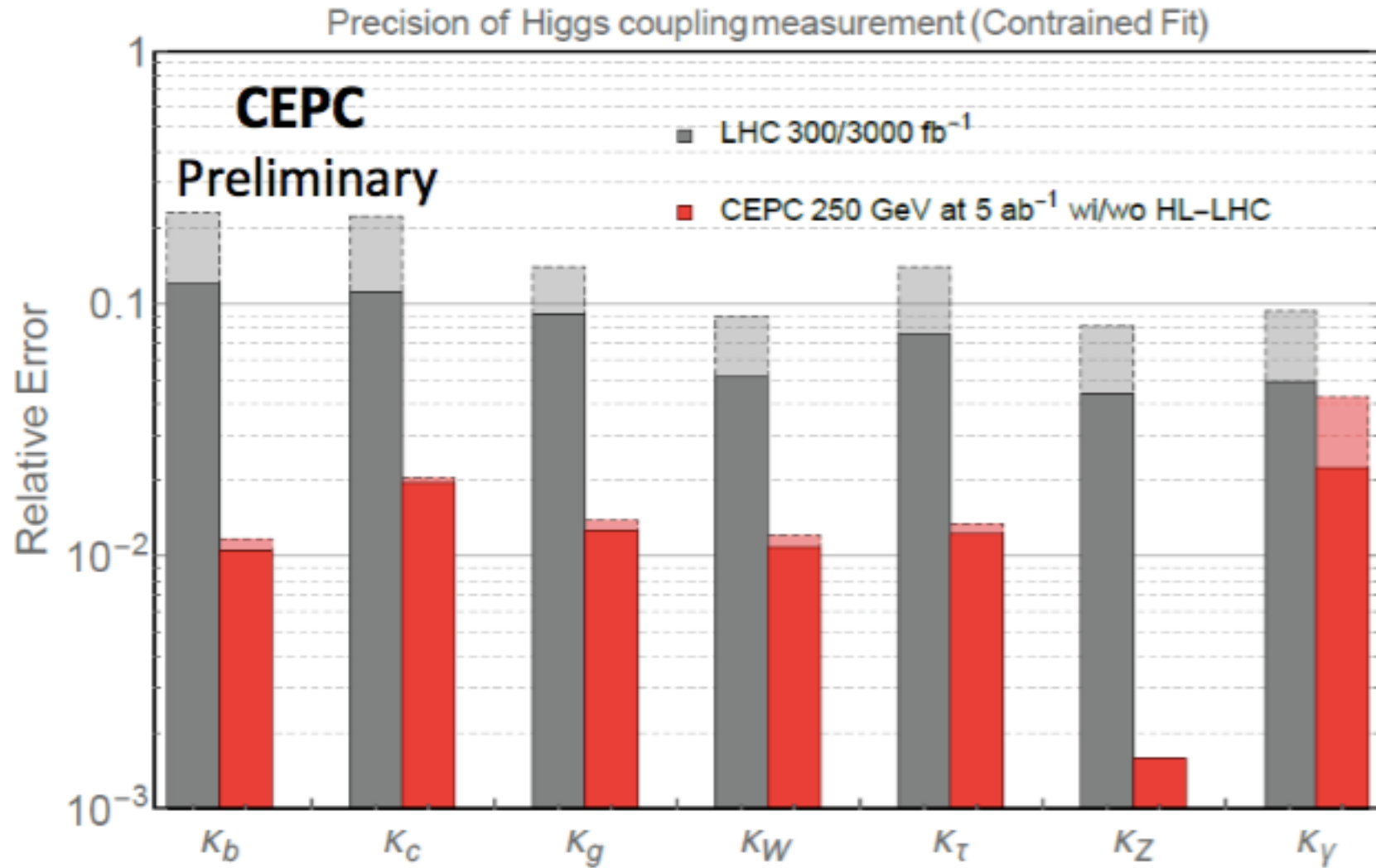


(b) HL-LHC and combination of HL-LHC and ILC.

Muon factory – unbeatable precision on Higgs mass of 0.1 MeV and Higgs width of 0.2 MeV with energy scan

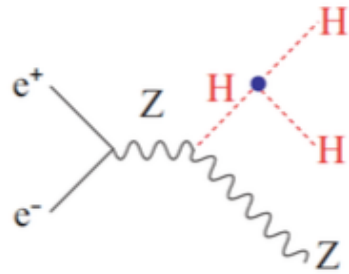
Higgs factories

Assuming comparable luminosity

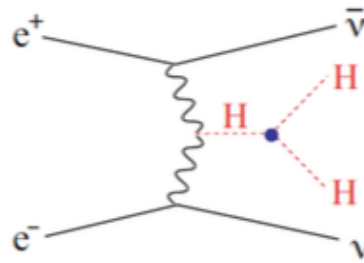


Higgs factories

Higgs Self-coupling



$$\frac{\Delta\lambda}{\lambda} \approx 1.8 \frac{\Delta\sigma}{\sigma}$$

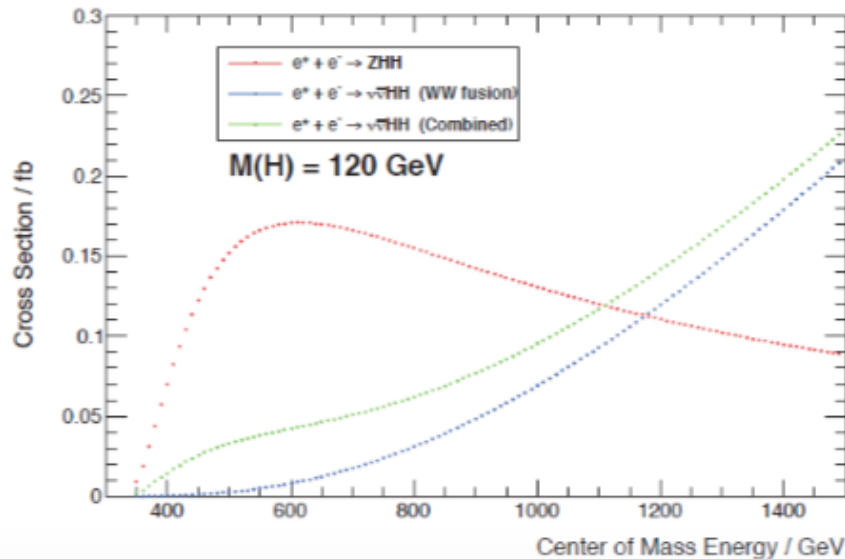


$$\frac{\Delta\lambda}{\lambda} \approx 0.85 \frac{\Delta\sigma}{\sigma}$$

$$\sqrt{s} \geq \sim 500 \text{ GeV}$$

(ILC + CLIC)

$$V(\phi) = \mu^2 (\phi^\dagger \phi) + \lambda (\phi^\dagger \phi)^2$$



Low rates:

~400 events total at ILC

~1000 events at CLIC

and there is a significant
contamination from
continuum HH production

$$\Rightarrow \frac{\Delta\lambda}{\lambda} \sim 26\% \text{ (ILC), } 16\% \text{ (CLIC)}$$

At HL-LHC ~40%

Possible path to discovery or “closure”

- Energy frontier - FCC hh up to 100 TeV (CERN supported)
 - SCC staged up to 300 TeV even better !!!

The mass range to be explored up to <50 TeV (?)

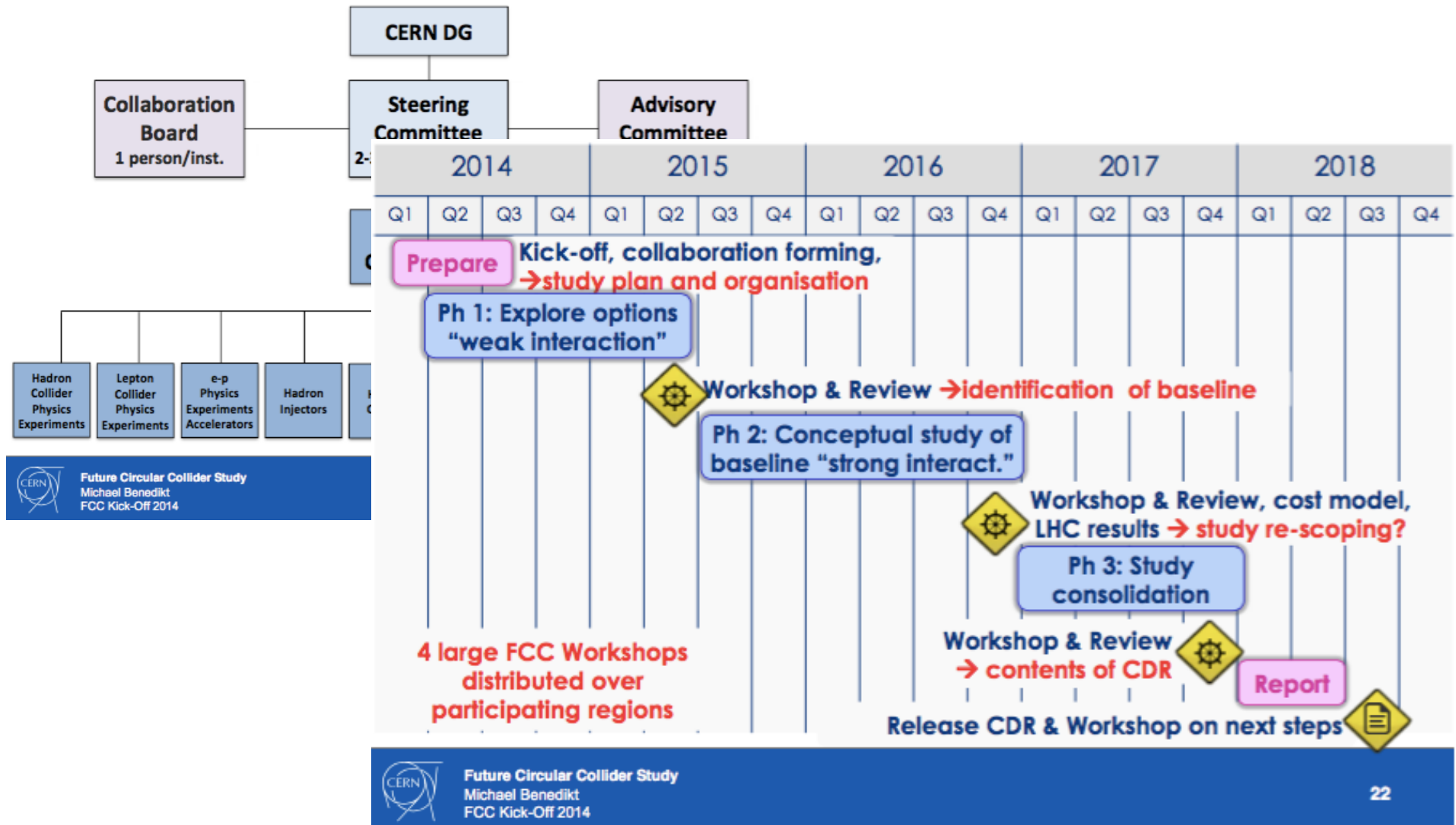
But ... this is like Columbus adventure with the Indies!!!

- Precision physics - preferred Higgs factory with 500 GeV cms to include top quark exploration, preferably expandable to higher energies for Higgs self-coupling measurements

Which option would be optimal?

FCC well on its way - it has a "rich" home

Proposed international organization structure



Talk with Jean-Pierre Delahaye (JPD) during official MICE inauguration last week

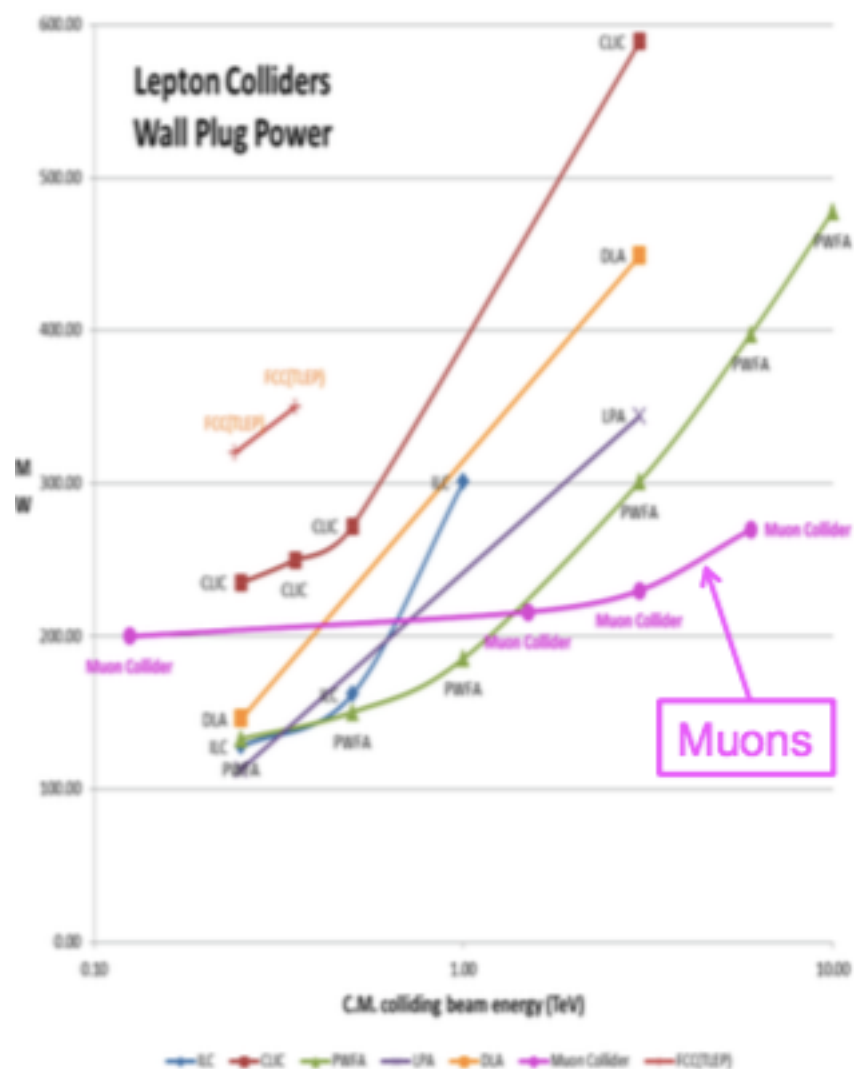
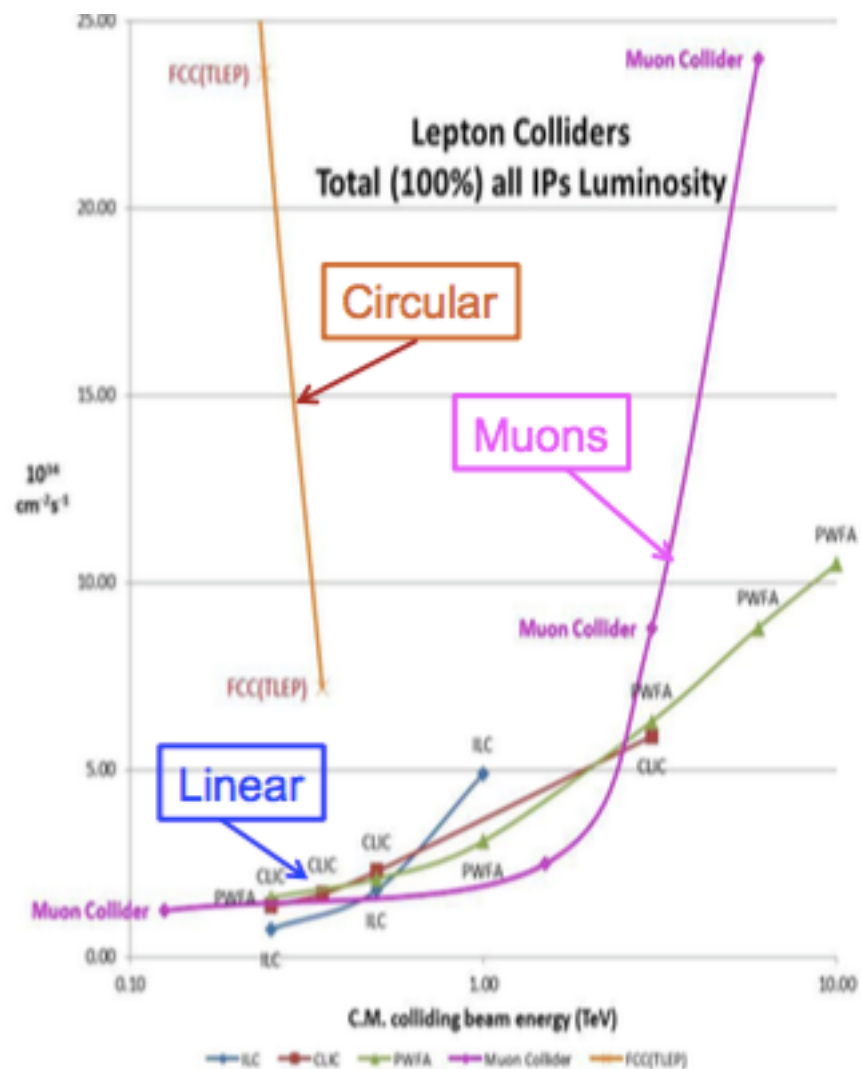


Principles of an ideal project scenario

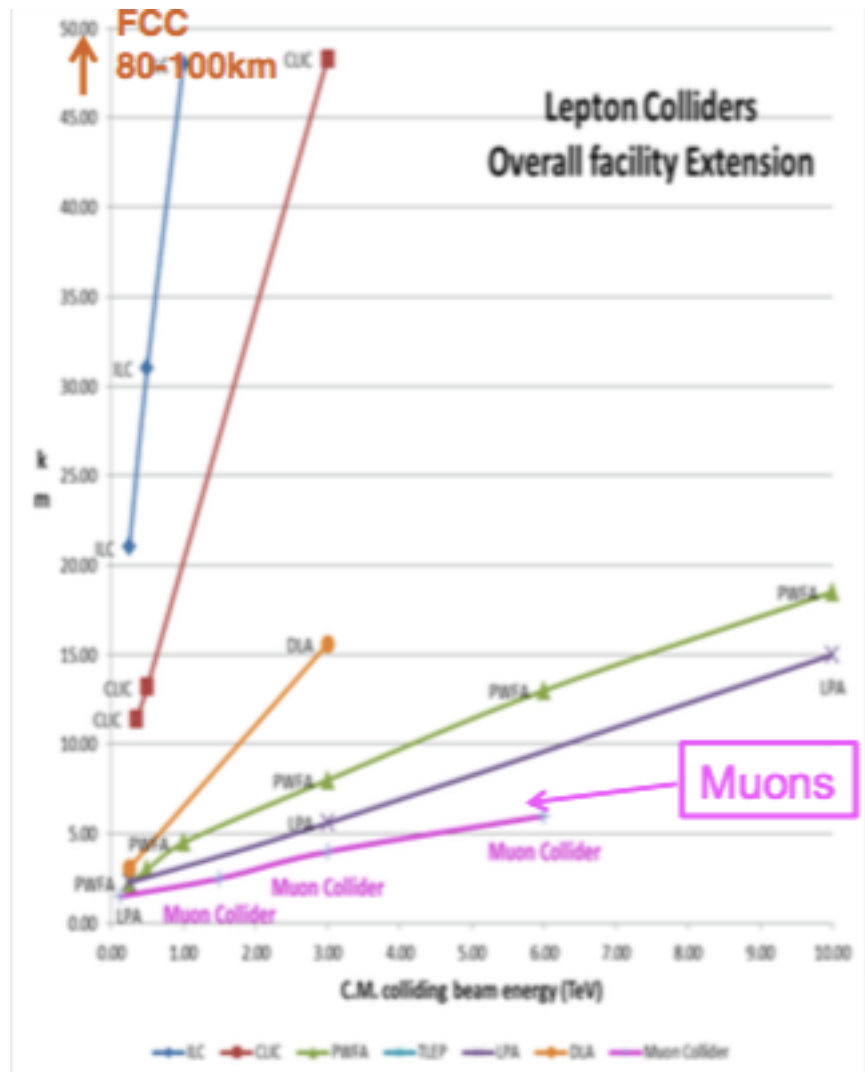
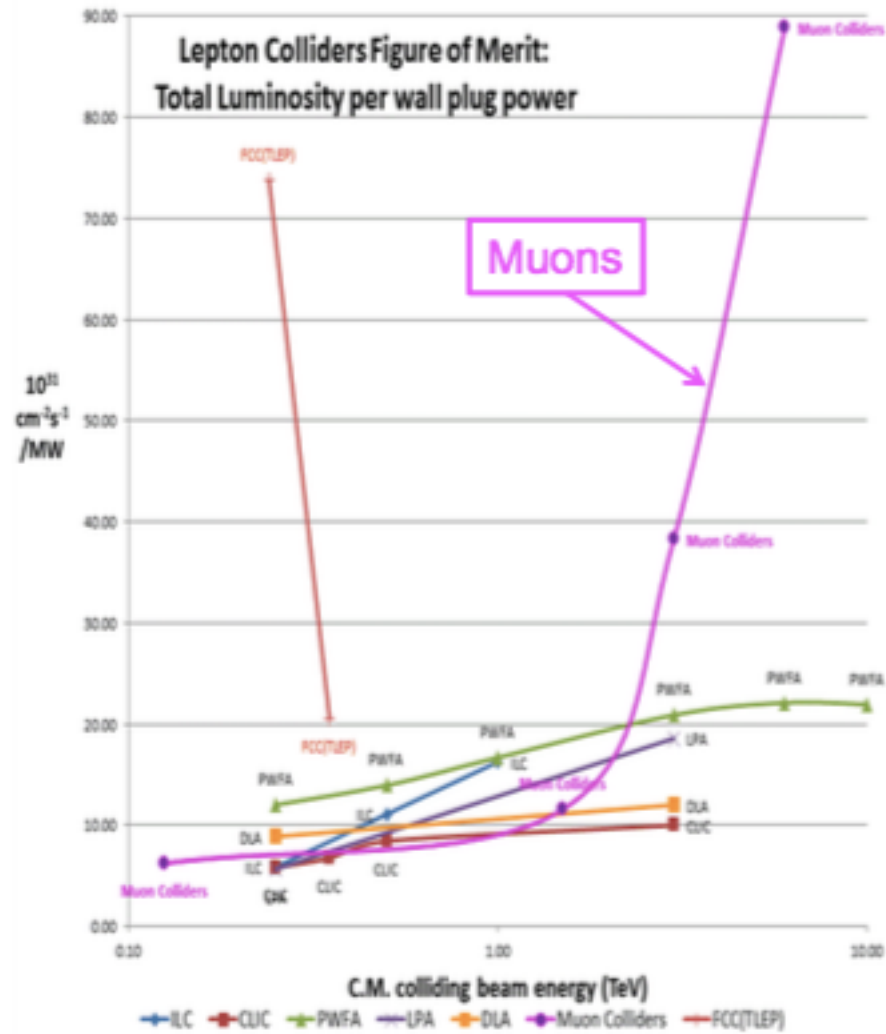
- Series of STAGED facilities**
 - physics interest at each stage
 - Technology with increasing complexity progressively developed and validated
- Preferably MULTIPURPOSE**
 - maximizing supported physics community and funding!
- Affordable budget (< 1B\$) from one facility to next**
 - Stage built-on previous stage with additional facilities
- Taking advantage of existing facilities**
 - synergy between present and future program

J.P.Delahaye IPAC14 (June 18, 2014) 13

JPD figures of merit



JPD figures of merit



Summary

- The good news is that there are many ideas how to go forward
- It is essential that the physics community unites behind the physics priorities to establish the optimal “working” conditions
- The experts should decide which facilities have optimal chances of success
- The finances, geography, infrastructure have to be part of the optimization at a later stage
- Smaller scale projects should be supported to keep the community dynamic
- We need all the wisdom we can get !!!