Europejska Strategia Fizyki Cząstek
sprawozdanie z Otwartego Sympozjum w Krakowie
(część I)

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Seminarium Fizyki Wielkich Energii

Warszawa, 12 października 2012

Outline

- Introduction
  - Strategy 2006
  - Strategy update
- Open Symposium in Cracow
  - Results and current status
  - Plans and projects
  - Discussion
  - Conclusions

Part I: High Energy Frontier, Flavour Physics, Strong Interactions...

European Strategy 2006

- Timeline decided in June 2005 (CERN Council).
- The Strategy Group composition and mandate approved in September 2005.
- Input from community: Nov 2005 – March 2006
- Open Symposium Jan 30 - Feb 1 2006 in Orsay
- Workshop in Zeuthen 2-6 of May 2006.
  The Zeuthen workshop resulted in a Draft Strategy Document submitted to Council
- Approved at a special CERN Council meeting July 2006 in Lisbon.

European Strategy for Particle Physics

- Current strategy was adapted by the Council in July 2006
- It consists of 17 strategy statements:
  - two General issues; necessity of strategy
  - eight Scientific activities (LHC, Accelerator R&D, ILC, Neutrino, Astroparticle, Flavour, Nuclear physics, Theory)
  - four Organizational issues
    - CERN Council's role in coordinating European particle physics
    - Globalization
    - Non-member state relation
    - Relation with EU
  - three Complementary issues
    - Outreach
    - Technology Transfer Network
    - Relation with industry

General issues

1. European particle physics is founded on strong national institutes, universities and laboratories and the CERN Organization; *Europe should maintain and strengthen its central position in particle physics.*

2. Increased globalization, concentration and scale of particle physics make a well coordinated strategy in Europe paramount; *this strategy will be defined and updated by CERN Council as outlined below.*

Scientific activities

3. The LHC will be the energy frontier machine for the foreseeable future, maintaining European leadership in the field; *the highest priority is to fully exploit the physics potential of the LHC, resources for completion of the initial programme have to be secured such that machine and experiments can operate optimally at their design performance.* A subsequent major luminosity upgrade (SLHC), motivated by physics results and operation experience, will be enabled by focussed R&D; *to this end, R&D for machine and detectors has to be vigorously pursued now and centrally organized towards a luminosity upgrade by around 2015.*

4. In order to be in the position to push the energy and luminosity frontier even further it is vital to strengthen the advanced accelerator R&D programme; *a coordinated programme should be intensified, to develop the CLIC technology and high performance magnets for future accelerators, and to play a significant role in the study and development of a high-intensity neutrino facility.*

5. It is fundamental to complement the results of the LHC with measurements at a linear collider. In the energy range of 0.5 to 1 TeV, the ILC, based on superconducting technology, will provide a unique scientific opportunity at the precision frontier; *there should be a strong well-coordinated European activity, including CERN, through the Global Design Effort, for its design and technical preparation towards the construction decision, to be ready for a new assessment by Council around 2010.*

6. Studies of the scientific case for future neutrino facilities and the R&D into associated technologies are required to be in a position to define the optimal neutrino programme based on the information available in around 2012; *Council will play an active role in promoting a coordinated European participation in a global neutrino programme.*

7. A range of very important non-accelerator experiments take place at the overlap between particle and astroparticle physics exploring otherwise inaccessible phenomena; *Council will seek to work with ApPEC to develop a coordinated strategy in these areas of mutual interest.*

Strategy Update

- At appropriate intervals, at most every 5 years, the European Strategy Session of Council will re-enact the process aimed at updating the medium and long-term European Strategy for Particle Physics, by setting up a Working Group, the European Strategy Group (ESG) (...) The remit of the ESG will be to establish a proposal for the European Strategy Session of Council to update the medium and long-term European Strategy for Particle Physics.

Council, September 2007

Strategy Update

Proposed timeline (June 2011)

- Kick-off meeting in July 2011
  - Dedicated session at EPS-HEP 2011, Grenoble
- Invitation to submit input: end 2011
- Open Symposium: **April 2012**
  - Too early for concluding LHC results (?!)
  - Expecting new nutrino results by mid 2012
- Strategy Workshop: September 2012
- Final approval: December 2012 (in Brussels)

Strategy Update

Proposed timeline (updated Oct 2011)

- Kick-off meeting in July 2011
  - Dedicated session at EPS-HEP 2011, Grenoble
- Invitation to submit input: Feb 2012
  - Deadline for symposium: end of July 2012
  - Deadline for strategy document: October 15th
- Open Symposium: **September 2012**
- Strategy Workshop: January 2013
- Final approval: May/June 2013 (in Brussels)

Purpose of this Open Symposium

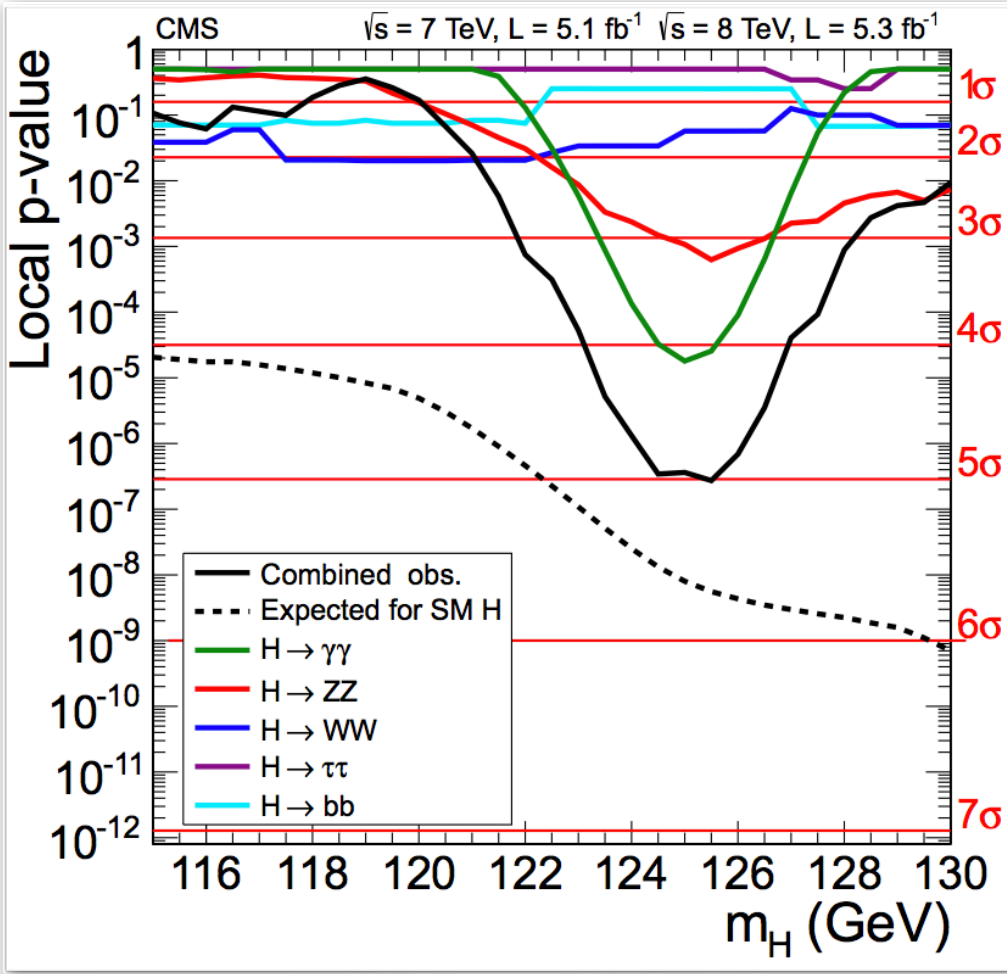
- Review the current scientific situation in particle physics:
  high energy frontier, flavour and symmetries,
  strong interactions, astroparticle (scientific enlargement),
  neutrino, theory
  and related area:
  accelerator, detector, computing, general infrastructure
  by plenary speakers. Talks reflect the community inputs but contain speaker's private view as well.
- Understand the situation in other regions: plenary speakers from Americas and Asia. (global perspective needed)
- Discussion session to collect opinions on the scientific priority in Europe by various communities.
- Starting point to build up a common understanding among the different communities in particle physics.

Sessions

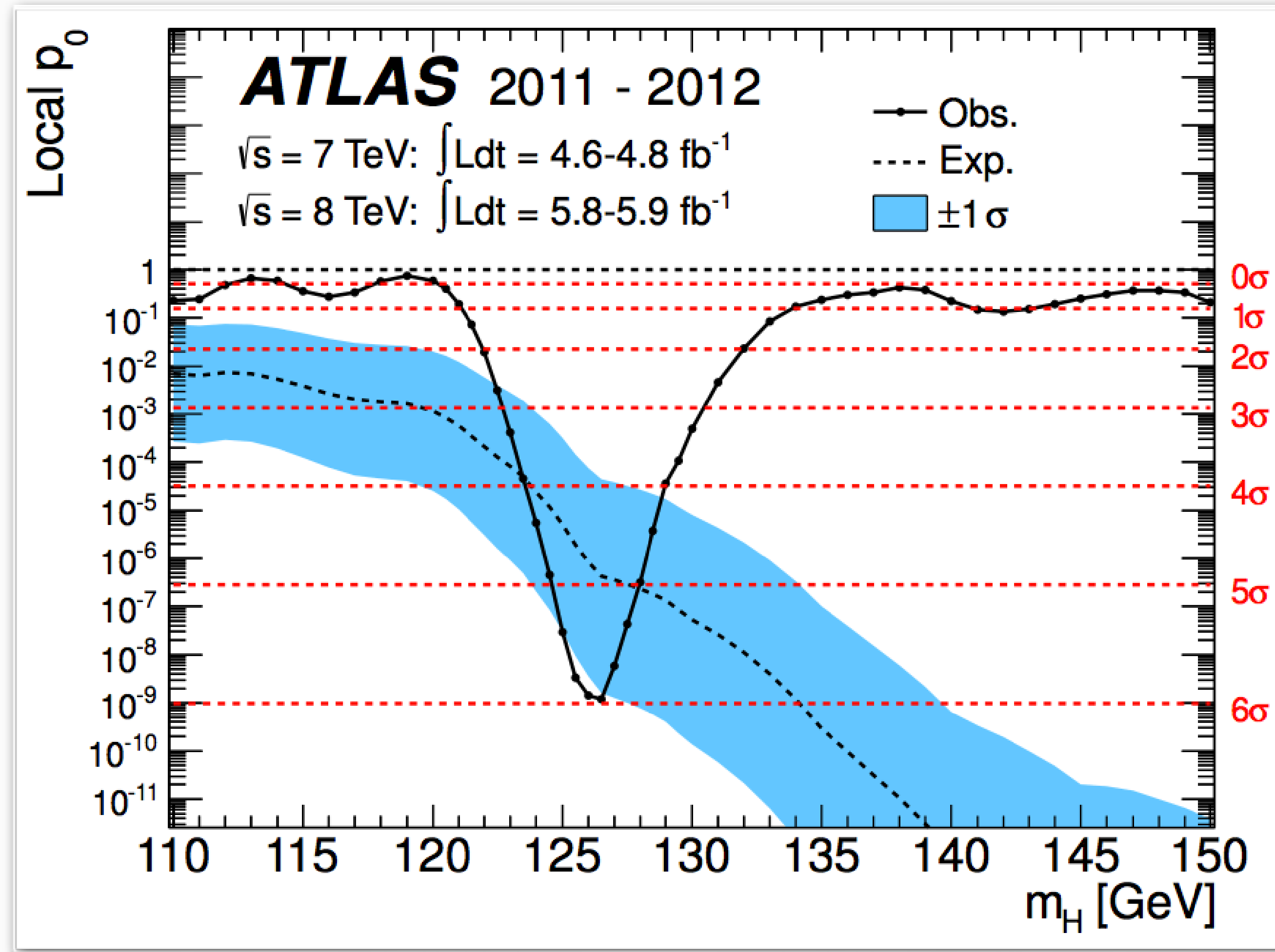
- Introduction
- Physics at High Energy Frontier **and** Flavour Physics
- Strong Interaction Physics
- Astroparticle Physics, Gravitation and Cosmology
- Physics of Neutrinos
- Accelerator Science and Technology
- Instrumentation, Computing and General Infrastructure
- Particle Physics Theory
- Status of Other Regions and Closing Discussion

High Energy Frontier and Flavour Physics

The LHC discovery



arXiv:1207.7235v1 [hep-ex]



arXiv:1207.7214v1 [hep-ex]

expected and observed p-values....

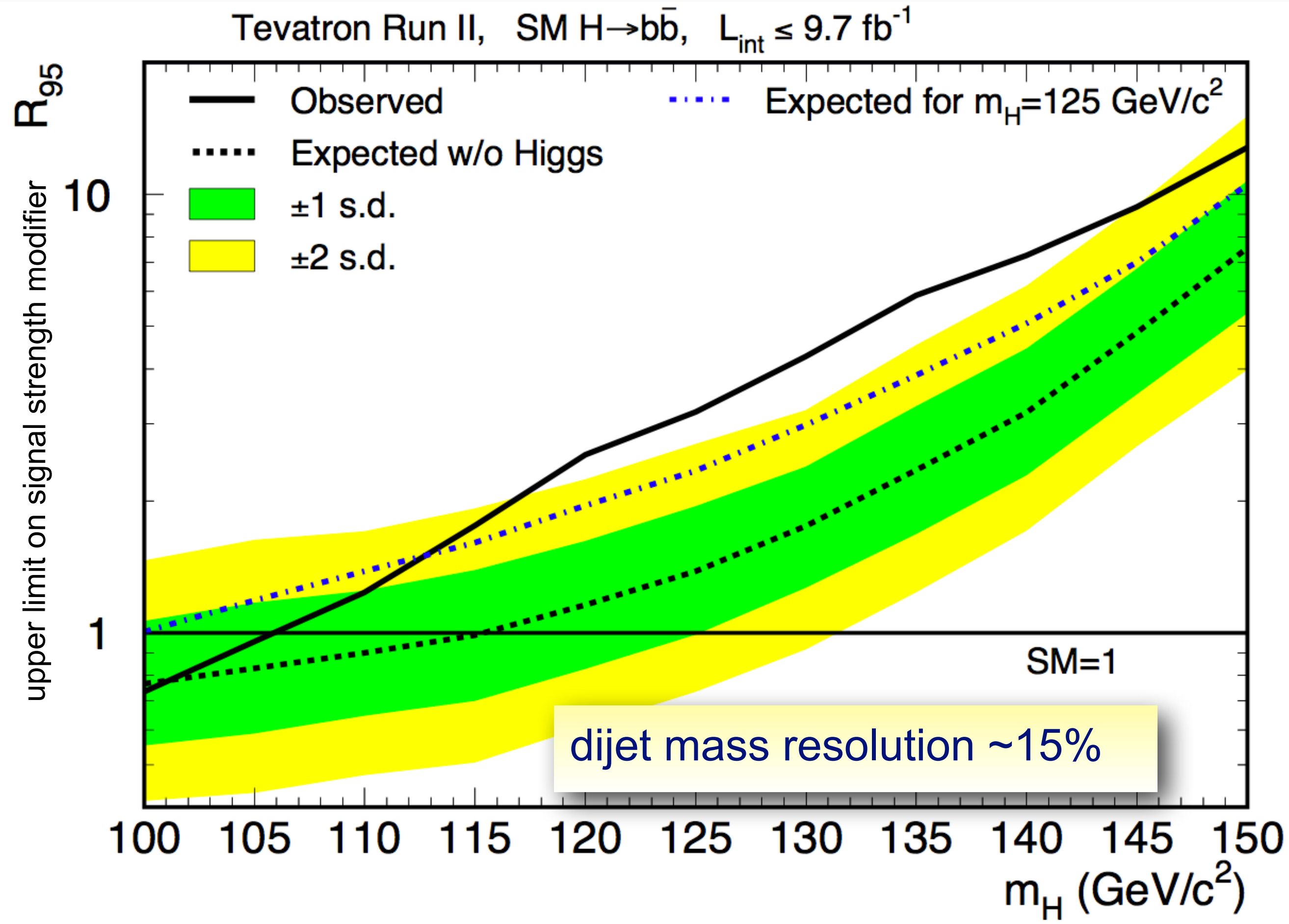
Decay mode/combination	Expected (σ)	Observed (σ)
$\gamma\gamma$	2.8	4.1
ZZ	3.6	3.1
$\tau\tau + bb$	2.4	0.4
$\gamma\gamma + ZZ$	4.7	5.0
$\gamma\gamma + ZZ + WW$	5.2	5.1
$\gamma\gamma + ZZ + WW + \tau\tau + bb$	5.8	5.0

Search channel	Dataset	m_{max} [GeV]	Z_l [σ]	$E(Z_l)$ [σ]
$H \to ZZ^{(*)} \to 4\ell$	7 TeV	125.0	2.5	1.6
	8 TeV	125.5	2.6	2.1
	7 & 8 TeV	125.0	3.6	2.7
$H \to \gamma\gamma$	7 TeV	126.0	3.4	1.6
	8 TeV	127.0	3.2	1.9
	7 & 8 TeV	126.5	4.5	2.5
$H \to WW^{(*)} \to \ell\nu\ell\nu$	7 TeV	135.0	1.1	3.4
	8 TeV	120.0	3.3	1.0
	7 & 8 TeV	125.0	2.8	2.3
Combined	7 TeV	126.5	3.6	3.2
	8 TeV	126.5	4.9	3.8
	7 & 8 TeV	126.5	6.0	4.9

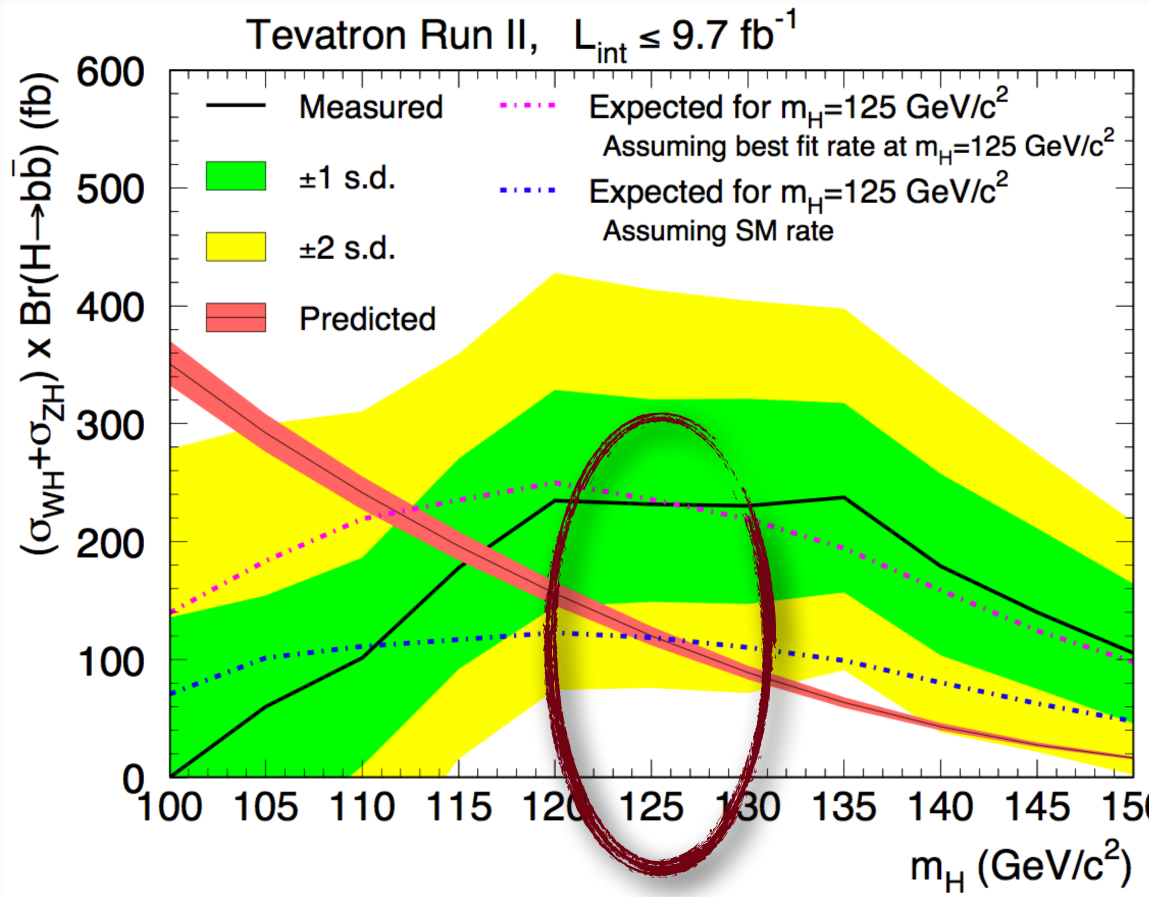
- ATLAS and CMS: significance driven by the γγ, ZZ and WW channels
- besides the excess at 125-126 GeV: 95% CL exclusion of a SM-like Higgs up to ~600 GeV

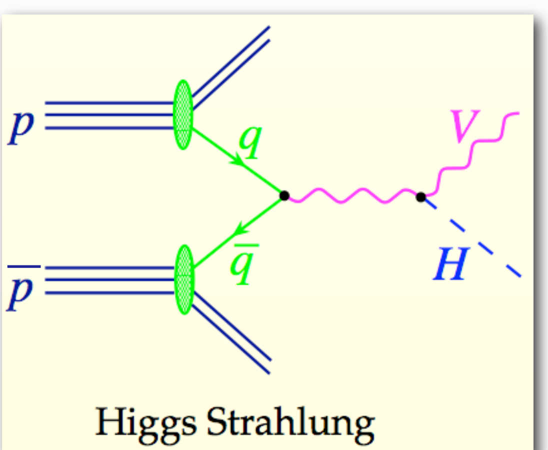
The TEVATRON evidence

arXiv:1207.6436v2 [hep-ex]



dijet mass resolution ~15%





Z,W: lept. and inv. decays

H→bb

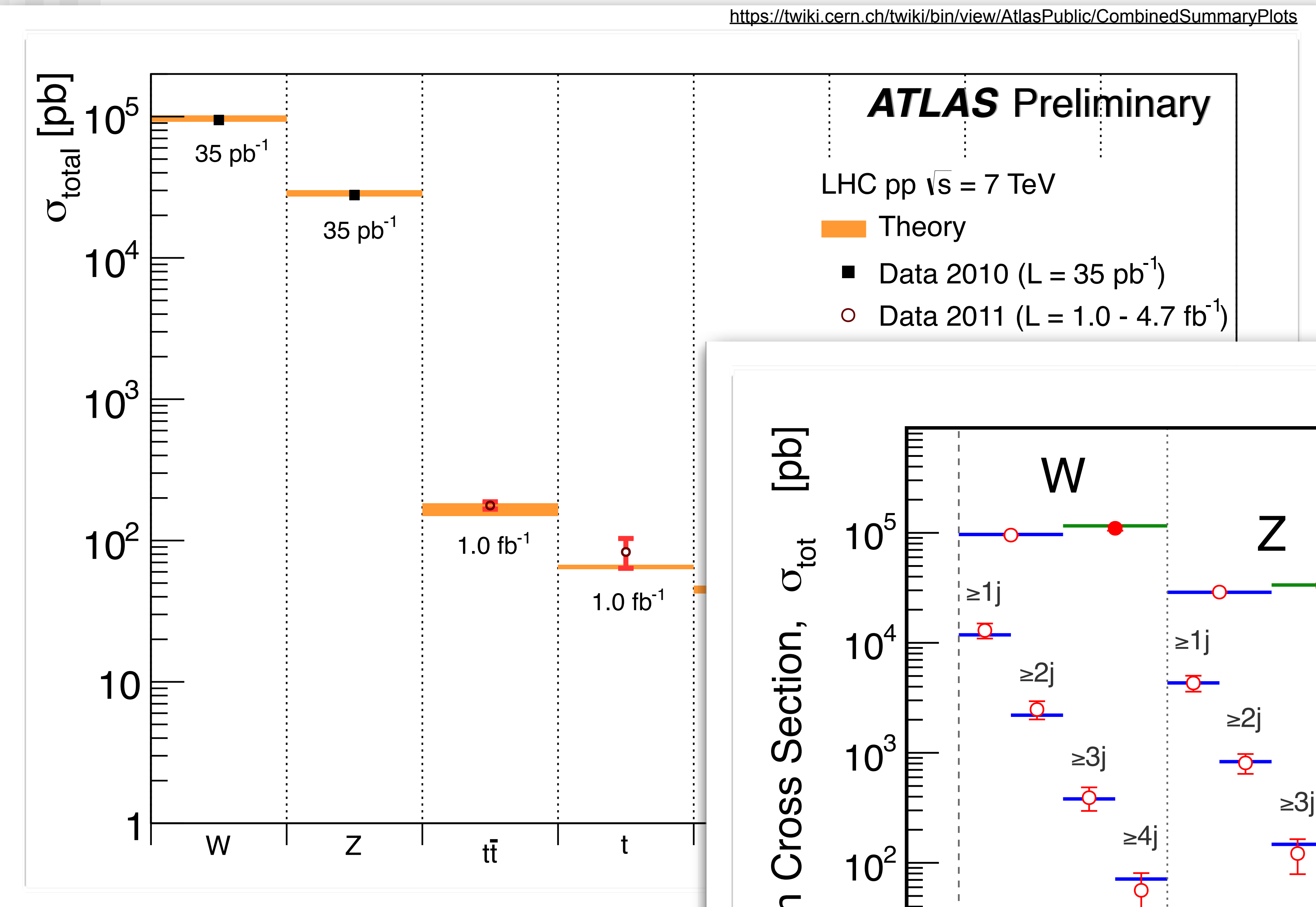
- max. local significance: 3.3 σ at m_H=135 GeV
- **global significance (115-150 GeV) : 3.1 σ**
- local significance at m_H=125 GeV : 2.8 σ
- measured **σ x BR about 2x higher than expected** for a SM H at 125 GeV
- so far, most direct probe of Higgs coupling to bottom quarks
- Here shown: latest, most significant result, not include other channels

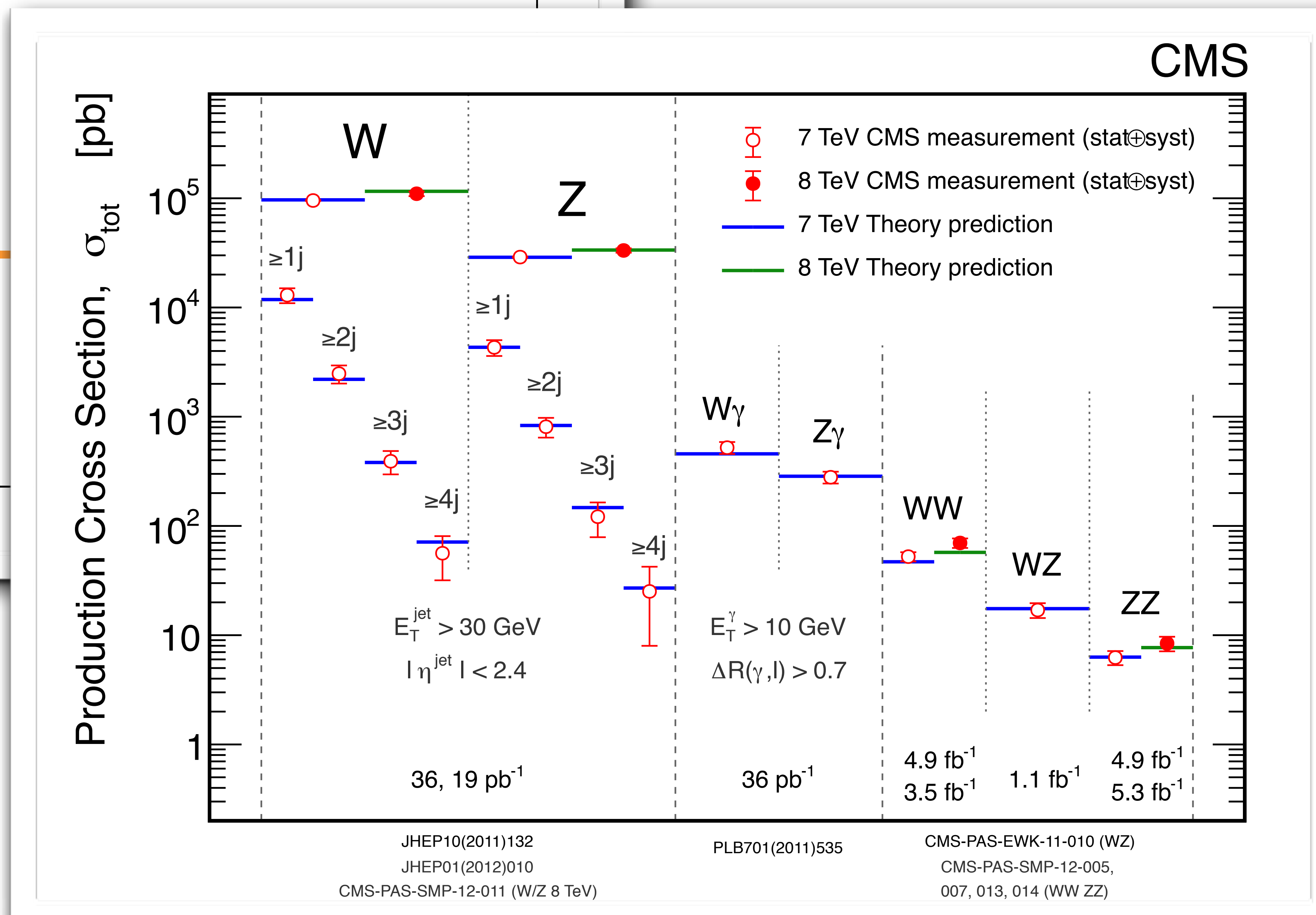
The big picture

European Strategy for Particle Physics

ETH Institute for Particle Physics

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/CombinedSummaryPlots

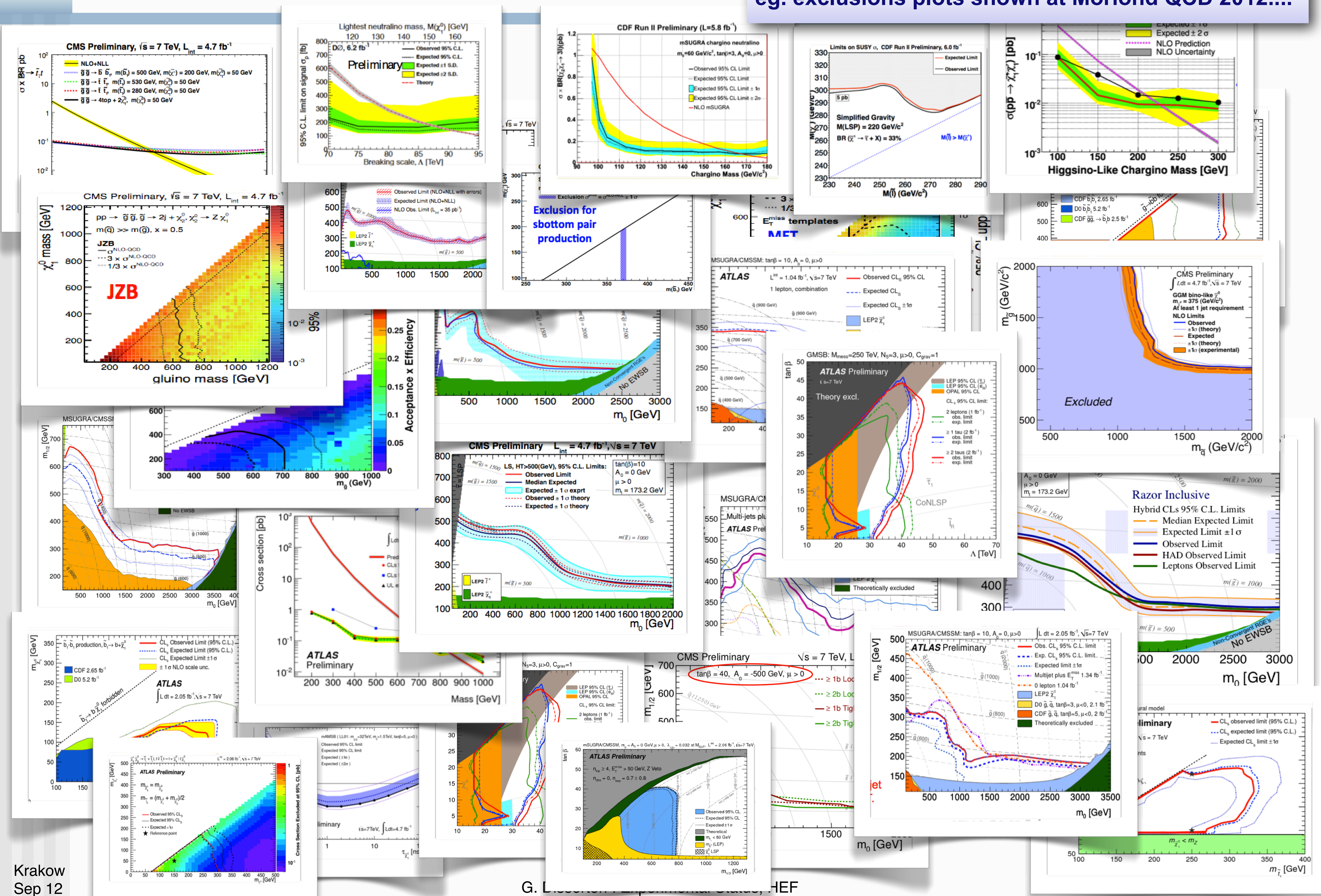




overall, the SM works at 7 and 8 TeV centre-of-mass energy...

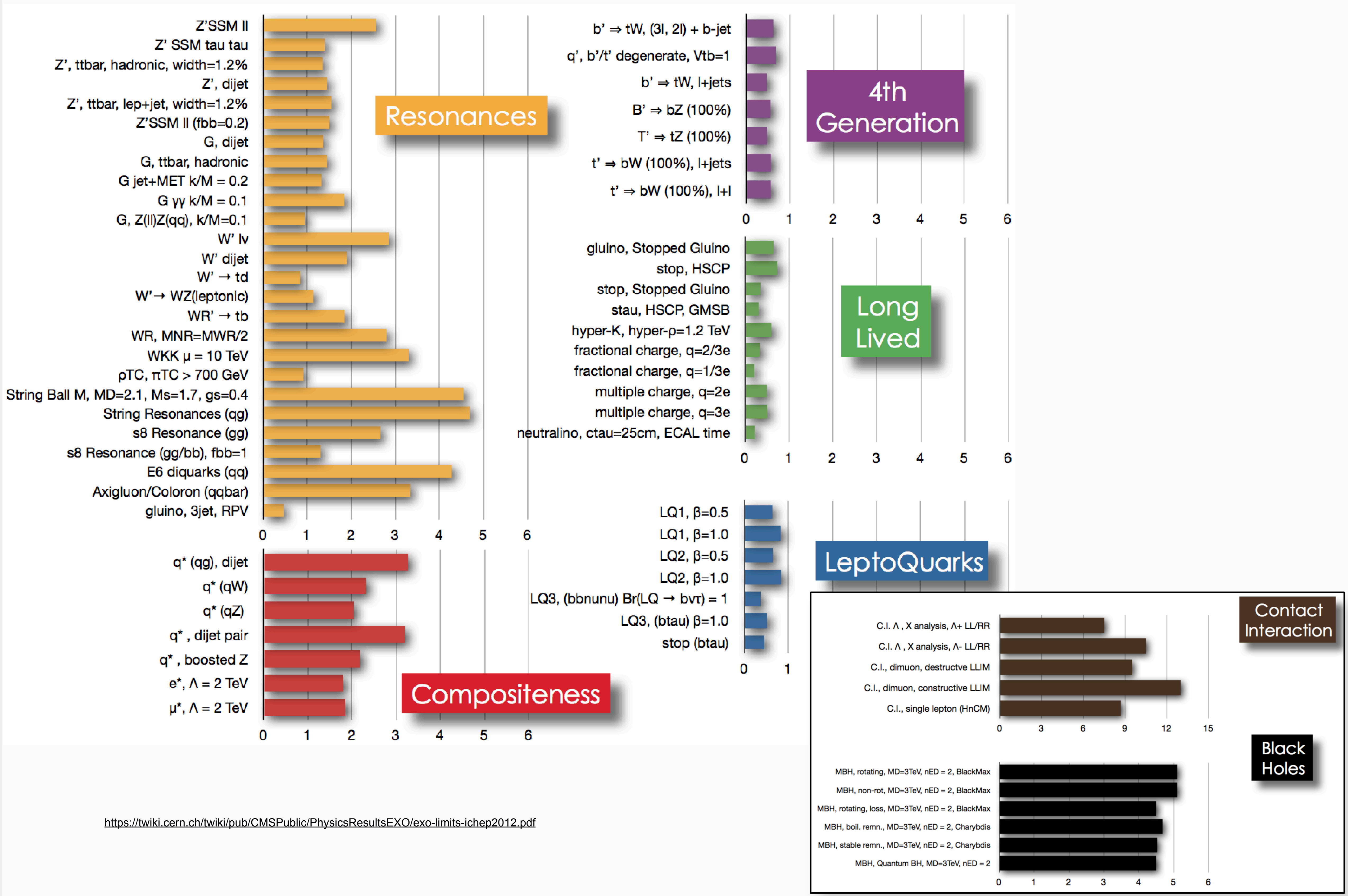
We have searched....

eg. exclusions plots shown at Moriond QCD 2012....



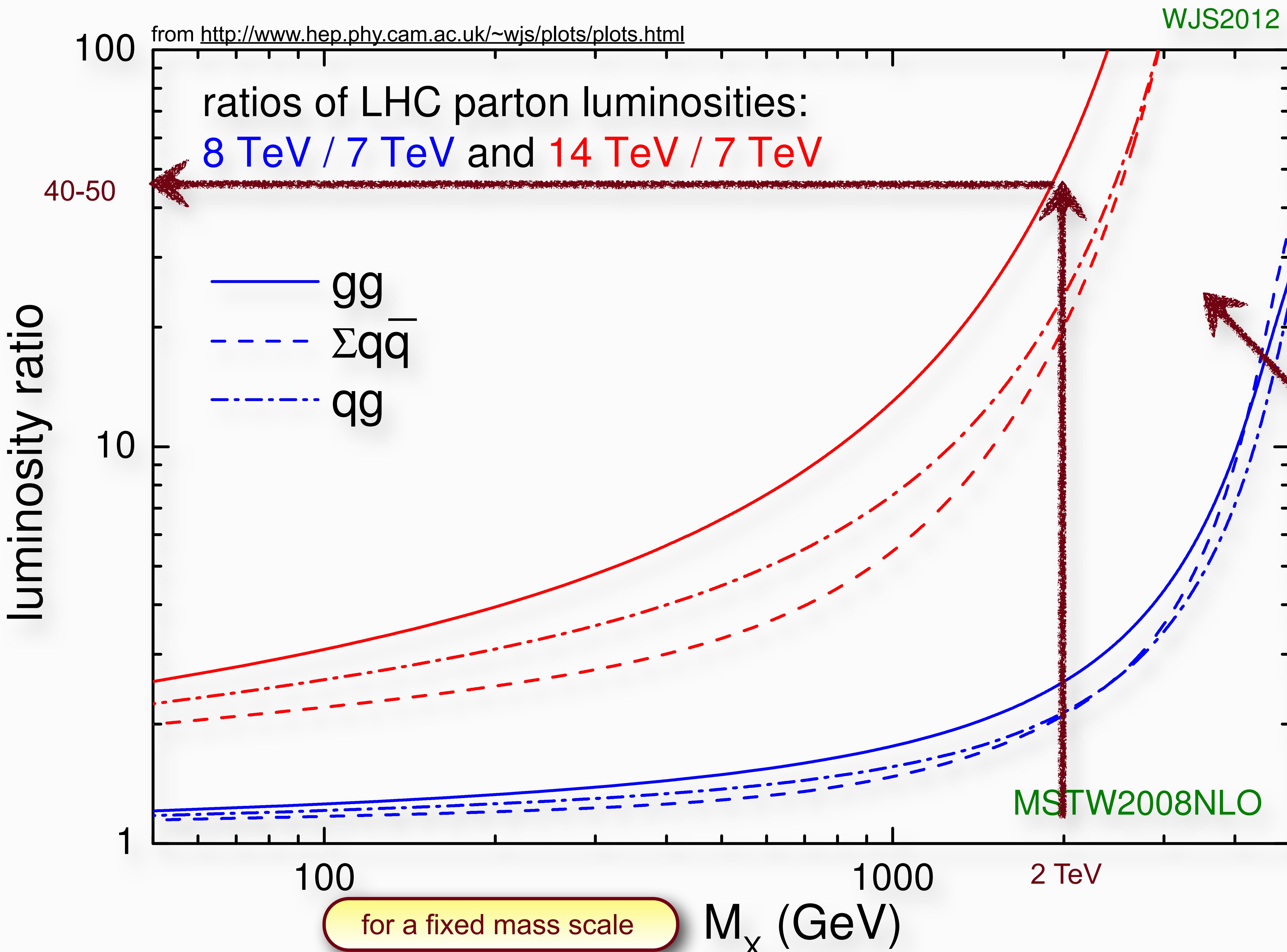
Exotica: Executive summary

- CMS searches at ICHEP2012 (lower limits in TeV), similar picture for ATLAS



https://twiki.cern.ch/twiki/pub/CMSPublic/PhysicsResultsEXO/exo-limits-ichep2012.pdf

Parton luminosities



rise because of steep fall-off of the lower-energy PDF, at large x

for a fixed mass scale

Executive Summary

- the **SM** (in terms of its QCD and EWK parts) **works perfectly well**, up to the % level, at the highest energies probed so far (7 and 8 TeV).
- We have **very advanced theory tools** at hand
- there is **a new boson** of mass ~125 GeV, with properties consistent with the SM Higgs, within the current uncertainties.
  More data needed to ascertain the nature of this object.
- **so far, no indications of BSM** physics from direct searches at the HEF:
  - colored SUSY particles (first generations) ruled out up to O(1 TeV), for a light LSP;
  - "natural" SUSY probed at level of a few hundred GeV of 3rd generation spartners;
  - exotica: heavy objects probed up to masses of 2-3 TeV;
  - a lot of room still to be explored, **14 TeV will be essential**!
- **very few anomalies** in the world-wide HEF data, no strongly smoking gun
- most important: at the LHC, we are **JUST AT THE BEGINNING** of the HEF exploration!

Back to Reality

For many years, physicists kept repeating:

the utmost important question in particle physics
is to discover the Higgs

After July 4th, things have changed and physicists now want to:

firmly elucidate its nature and its role in the
mechanism of electroweak symmetry breaking

In the absence of any direct evidence of new physics, the Higgs will be (one of?) the best source of information about possible new physics and we need to make sure that the future experimental program is well designed to answer questions like

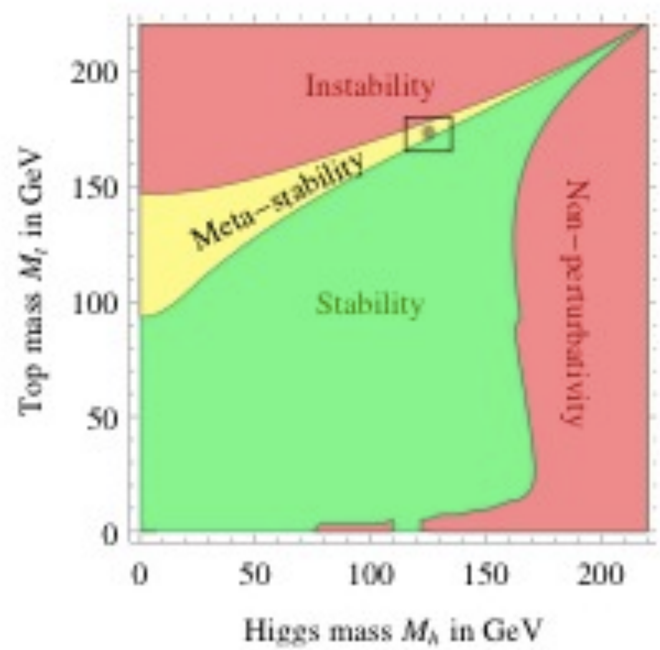
- ☑ what are its quantum numbers: J^{PC}? SU(2)xU(1) charges?
- ☑ what screens the quantum corrections to its mass?
- ☑ is it an elementary scalar or a composite bound state?
- ☑ is it alone or part of an extended sector?
- ☑ is it a portal to SM-neutral new physics?

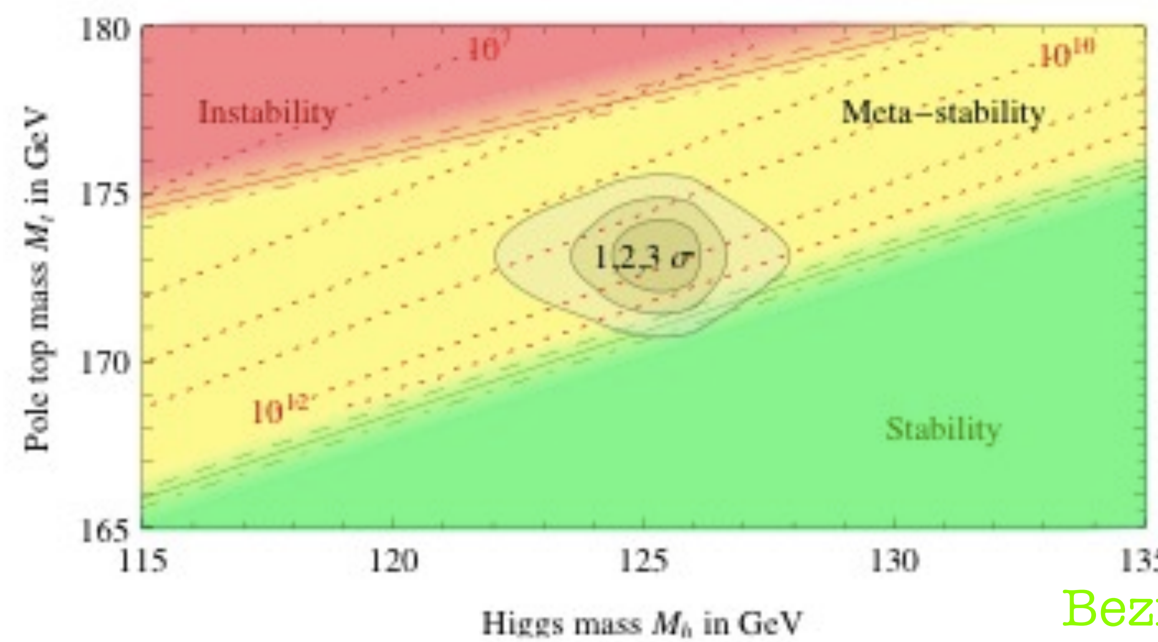
Theory speculations/implications

Many of my theory colleagues also started wild speculations/extrapolations

the SM vacuum is stable/metastable

and the validity of the SM can be extended up to the Planck scale!





Bezrukov et al '12
Degrassi et al '12

It is almost certain (>4σ) that $m_H > M_{mestability}$ and totally certain that $m_H < M_{Landau}$
Not totally clear yet if m_H is above $M_{stability}$, but rather important question since

- ☑ if $m_H > M_{stability}$, the Higgs could serve as an inflaton
- ☑ if $m_H = M_{stability}$ the SM is asymptotically safe, ie consistent up to arbitrary high energy

see contribution by Bezrukov et al

need precise Higgs&top mass/couplings (and α_s) measurements (ILC, μ coll.)

Chiral Lagrangian for a light Higgs

$$\mathcal{L} = \frac{1}{2}(\partial_\mu h)^2 - \frac{1}{2}m_h^2 h^2 - \frac{d_3}{6}\left(\frac{3m_h^2}{v}\right)h^3 - \frac{d_4}{24}\left(\frac{3m_h^2}{v^2}\right)h^4 \dots$$

$$- \left(m_W^2\, W_\mu W_\mu + \frac{1}{2}m_Z^2\, Z_\mu Z_\mu\right)\left(1 + 2a\frac{h}{v} + b\frac{h^2}{v^2} + \dots\right)$$

$$- \sum_{\psi=u,d,l} m_{\psi^{(i)}}\, \bar{\psi}^{(i)}\psi^{(i)}\left(1 + c_\psi \frac{h}{v} + c_{2\psi}\frac{h^2}{v^2} + \dots\right)$$

$$+ \frac{g^2}{16\pi^2}\left(c_{WW}\, W^+_{\mu\nu}W^-_{\mu\nu} + c_{ZZ}\, Z^2_{\mu\nu} + c_{Z\gamma}\, Z_{\mu\nu}\gamma_{\mu\nu}\right)\frac{h}{v} + \dots$$

$$+ \frac{g^2}{16\pi^2}\left[\gamma^2_{\mu\nu}\left(c_{\gamma\gamma}\frac{h}{v} + \dots\right) + G^2_{\mu\nu}\left(c_{gg}\frac{h}{v} + c_{2gg}\frac{h^2}{v^2}\dots\right)\right]$$

$$+ \frac{g^2}{16\pi^2}\left[\frac{c_{hhgg}}{\Lambda^2}G^2_{\mu\nu}\frac{(\partial_\rho h)^2}{v^2} + \frac{c'_{hhgg}}{\Lambda^2}G_{\mu\rho}G_{\rho\nu}\frac{\partial_\mu h \partial_\nu h}{v^2} + \dots\right]$$

$$+ \dots$$

Contino, Grojean, Moretti, Piccinini, Rattazzi '10

SM

$a = b = c = d_3 = d_4 = 1$

$c_{2\psi} = c_{WW} = c_{ZZ} = c_{Z\gamma} = c_{\gamma\gamma} = \dots = 0$

A few (reasonable) assumptions:

- ☑ spin-0 & CP-even
  - ↖ $\gamma\gamma$ ↖ WW & ZZ
- ☑ custodial symmetry
  - ↖ EWPD
- ☑ no Higgs FCNC (generalization of Glashow-Weinberg th.)
  - ↖ Flavor

Higgs couplings measurements

Peskin'12

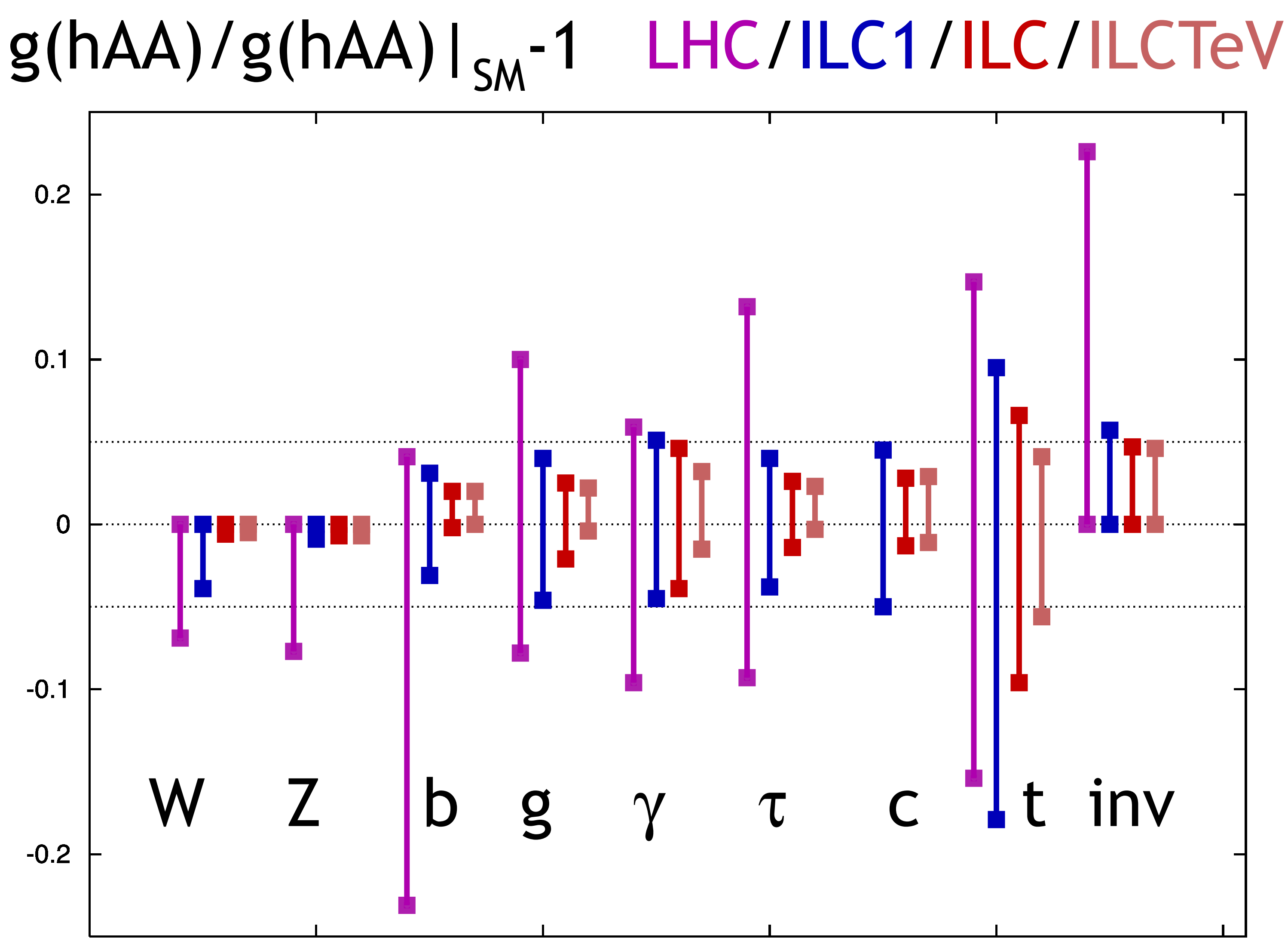


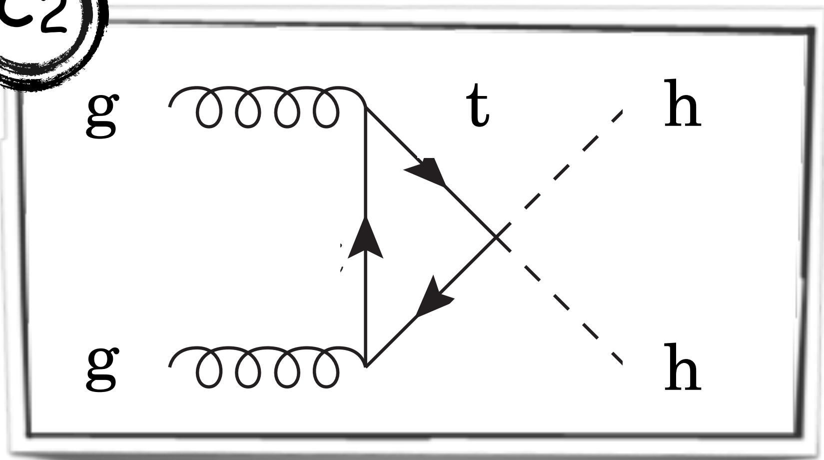
Figure 2: Comparison of the capabilities of LHC and ILC for model-independent measurements of Higgs boson couplings. The plot shows (from left to right in each set of error bars) 1 σ confidence intervals for LHC at 14 TeV with 300 fb^{-1}, for ILC at 250 GeV and 250 fb^{-1} ('ILC1'), for the full ILC program up to 500 GeV with 500 fb^{-1} ('ILC'), and for a program with 1000 fb^{-1} for an upgraded ILC at 1 TeV ('ILCTeV'). The marked horizontal band represents a 5% deviation from the Standard Model prediction for the coupling.

5-10% @ $LHC^{14TeV}_{300/fb}$ 1-5% @ ILC/CLIC

Which Higgs couplings?

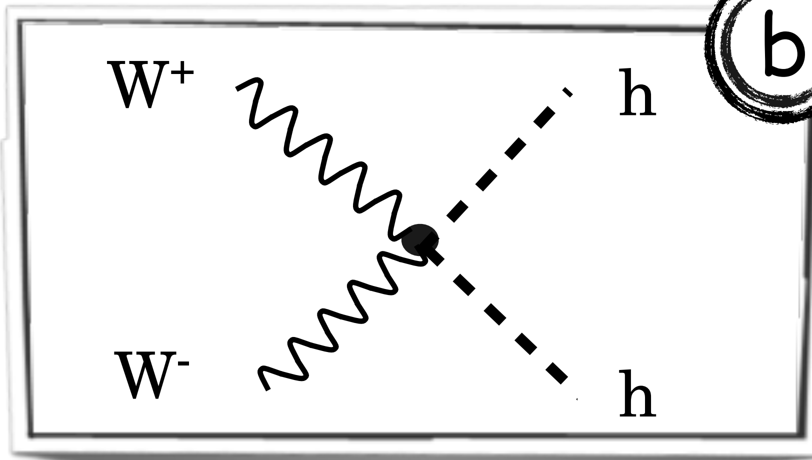
lot of study on SM-like Higgs couplings
but should also access the prospects for non-SM couplings

c_2



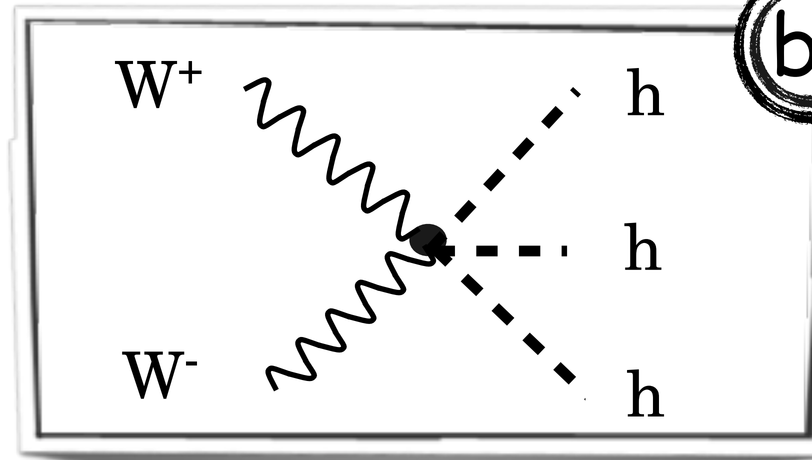
Grôber, Mühlleitner '10
Contino et al '12
Gillioz et al '12

b



Contino, Grojean, Moretti, Piccinini, Rattazzi '10

b_3



Contino, Grojean, Pappadopoulo, Rattazzi, Thamm 'to appear

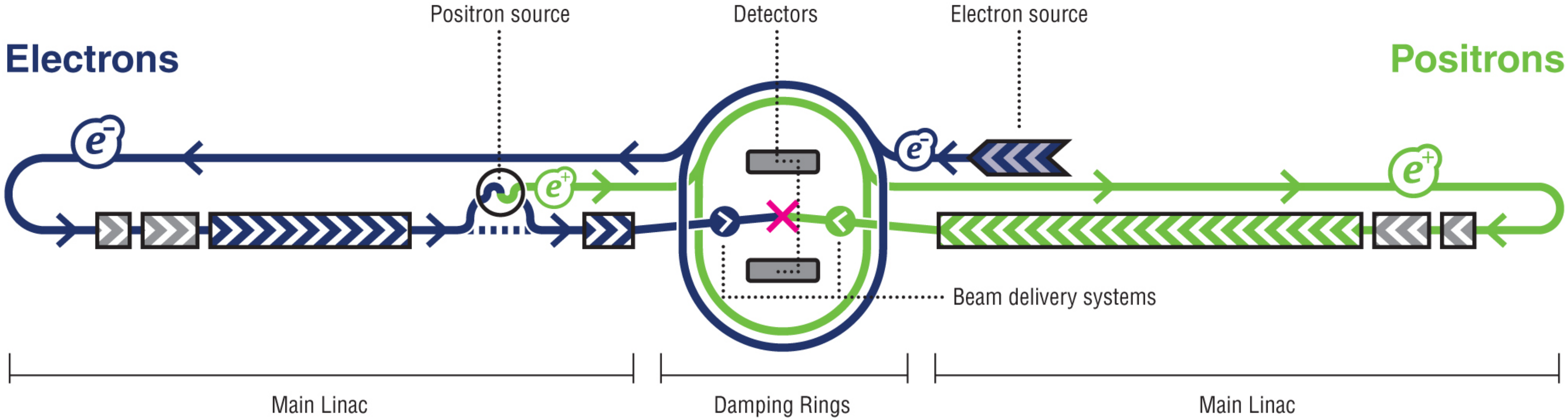
tests of Higgs non-linearities, can answer crucial questions:

- ☑ is the Higgs composite or elementary?
- ☑ is the EW sym. breaking sector strongly coupled?
- ☑ is the Higgs a doublet or a singlet (eg a dilaton): $b-1 = 2(a^2-1)$?
- ☑ is the Higgs a doublet or a singlet (eg a dilaton): $3b_3 = 4a(b-a^2)$?

require a new facility beyond current LHC

ILC

Two single-beam linacs with superconducting RF accelerating cavities ~40 MV/m

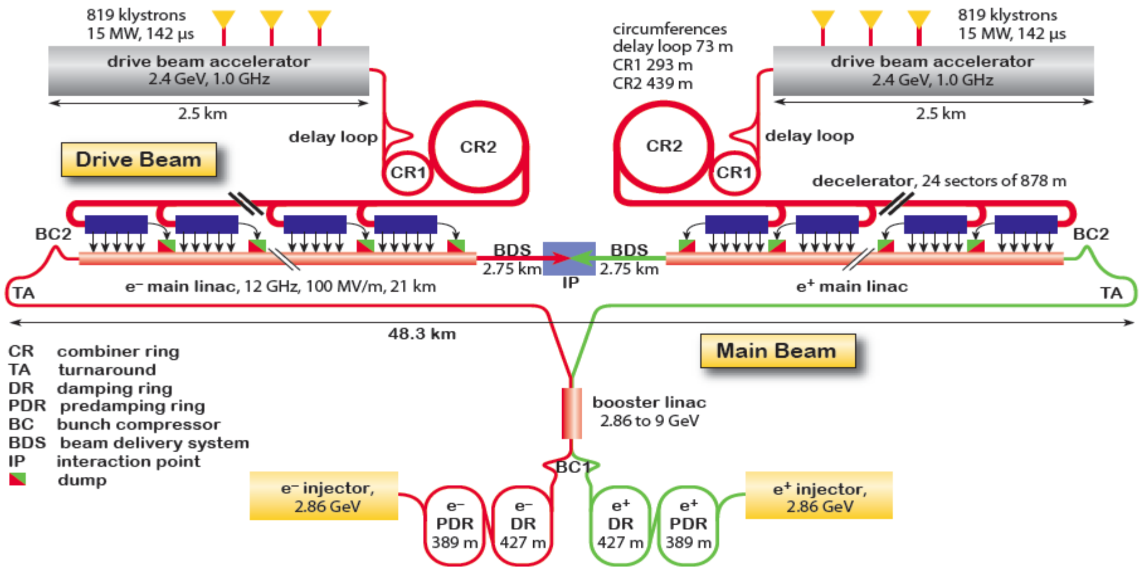


Schematic layout of the ILC complex

- For √s = 500 GeV total length of facility ~30 km
- Established technology
  - Industrial production of high field superconducting cavities now well established

CLIC

Overview of the CLIC layout at √s = 3 TeV

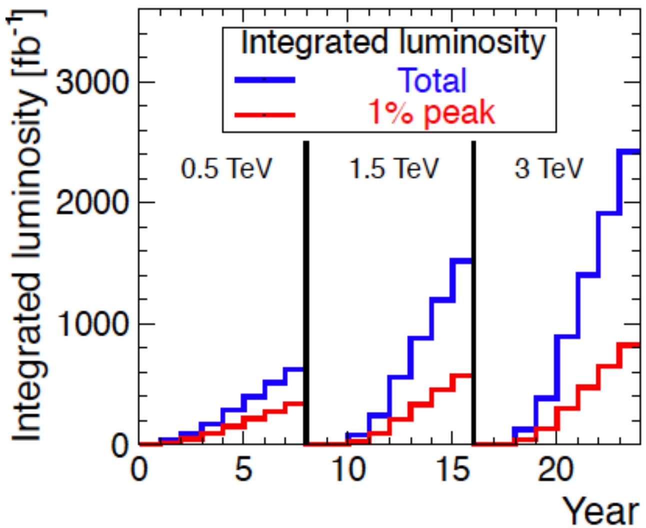


Two double-beam linacs

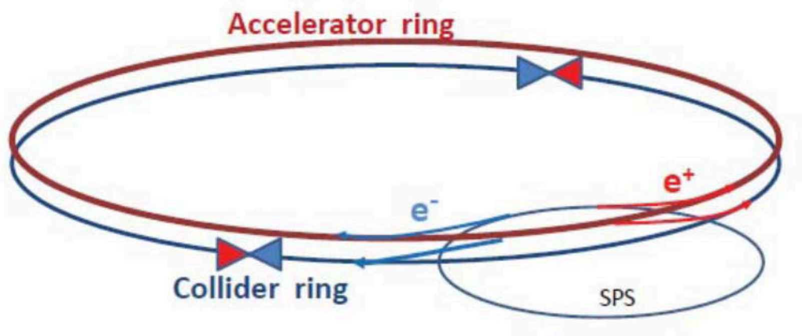
- Low energy, high current drive beam powers ~100 MV/m RF cavities in main linac

- Two scenarios considered for staged construction of machine
- Scenario A employs higher aperture cavities for 500 GeV running:
  - allows higher beam current and factor 2 increase in luminosity above 99% of √s
  - but these cavities must be replaced for 3 TeV running
- Scenario B employs nominal aperture cavities throughout the programme to minimize overall cost

Projected integrated luminosity for CLIC "scenario B"



Circular e^+e^- colliders



E.g., LEP3:

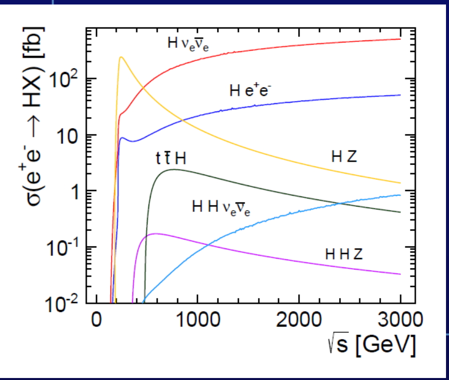
- $\sqrt{s}$ = 240 GeV in the LHC tunnel to produce $e^+e^- \rightarrow ZH$ events
- Short beam lifetime (~16 mins) requires two ring scheme
  - Top up injection from 240 GeV "accelerator ring"
  - "Collider ring" supplying 2-4 interaction points L = 10^{34} $cm^{-2}s^{-1}$ per IP
    - Re-use ATLAS and CMS and/or install two dedicated LC-type detectors
- Current design uses arc optics from LHeC ring
  - Dipole fill factor 0.75 (smaller than for LEP)
  - increased synchrotron energy loss (7 GeV per turn)
  - redesign possible?
- $e^{\pm}$ polarization probably not possible at $\sqrt{s}$ = 240 GeV
- In principle space is available to install compact e^+e^- facility on top of LHC ring
  - Is this really feasible?
  - Alternatively wait until completion of LHC physics programme and removal of LHC ring?
- SuperTRISTAN is a proposal for a similar machine in Japan

E.g., TLEP:

- $\sqrt{s}$ = 350 GeV in 80 km LHC tunnel to reach thresholds for top pair and $e^+e^- \rightarrow \nu\nu WW \rightarrow \nu\nu H$

HIGGS FACTORIES e+e-

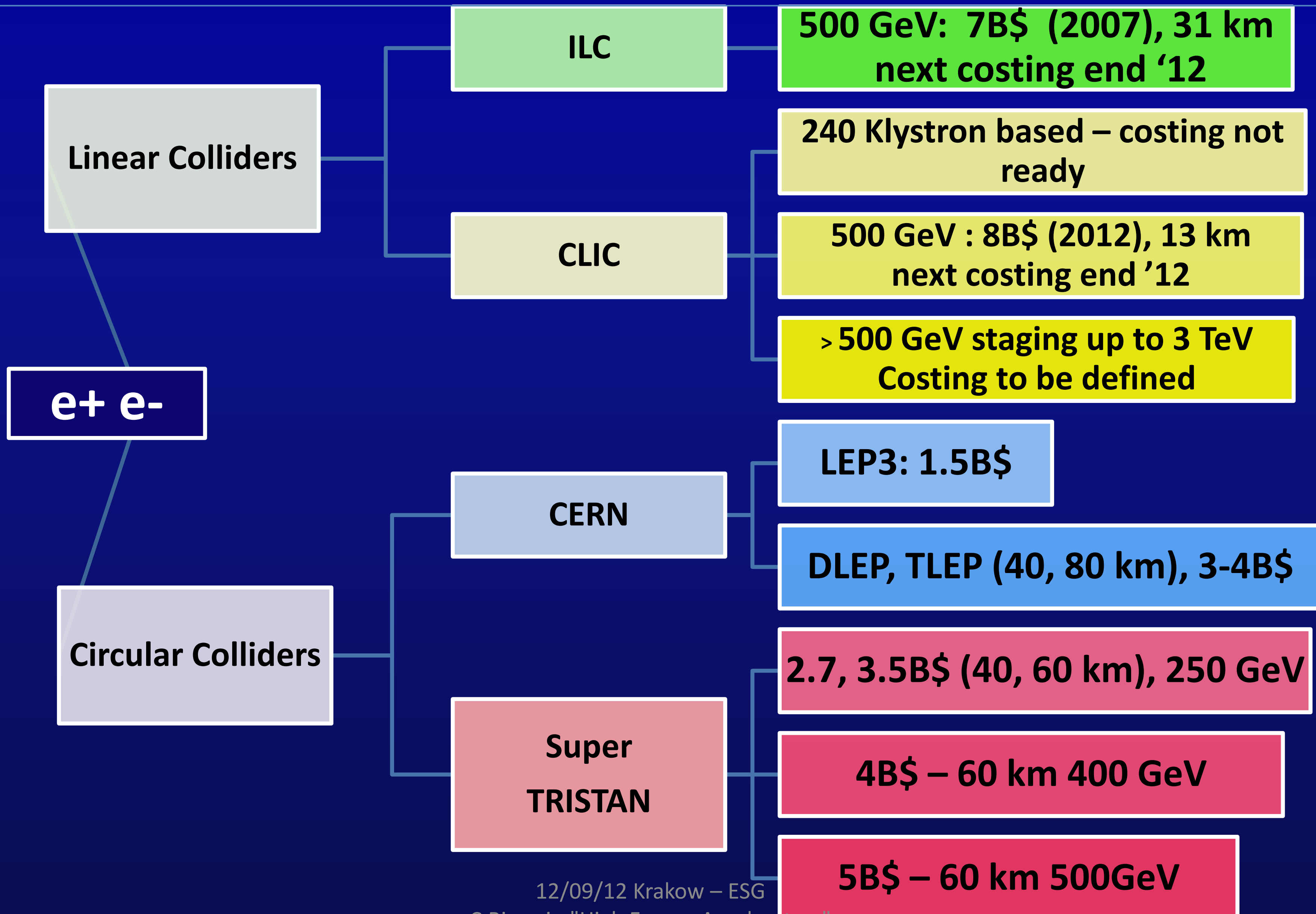
- **e+ e-**
  - **Linear Colliders**
    - **ILC**
      - 250 GeV
      - 500 GeV
    - **CLIC**
      - 250 GeV + Klystron based
      - 500 GeV
      - > 500 GeV
  - **Circular Colliders**
    - **CERN**
      - LEP3 at LHC tunnel
      - DLEP – New tunnel, 53 km
      - TLEP – New tunnel, 80 km
    - **Super TRISTAN**
      - 250 GeV– 40, 60 km tunnel
      - 400
      - 500



HIGGS FACTORIES e+e- R&D & main issues

- **e+ e-**
  - **Linear Colliders**
    - **ILC**
      - Almost ready SC rf technology, need of opt for low energy, TDR by end ‘12, XFEL as test facility
    - **CLIC**
      - Low E : X-band Klystron technology
        Demonstrated High gradient cavities
        Sinergy with XFELs
      - ≥ 500, CDR, need of >10 years R&D
        CTF3 test facility
  - **Circular Colliders**
    - **CERN**
      - Low E - Tunnel ready (not available) , technology ok , SCrf cavities ok
      - Long tunnel, high costs, environment impact
    - **Super TRISTAN**
      - Technology assessed, tunnel & site ???

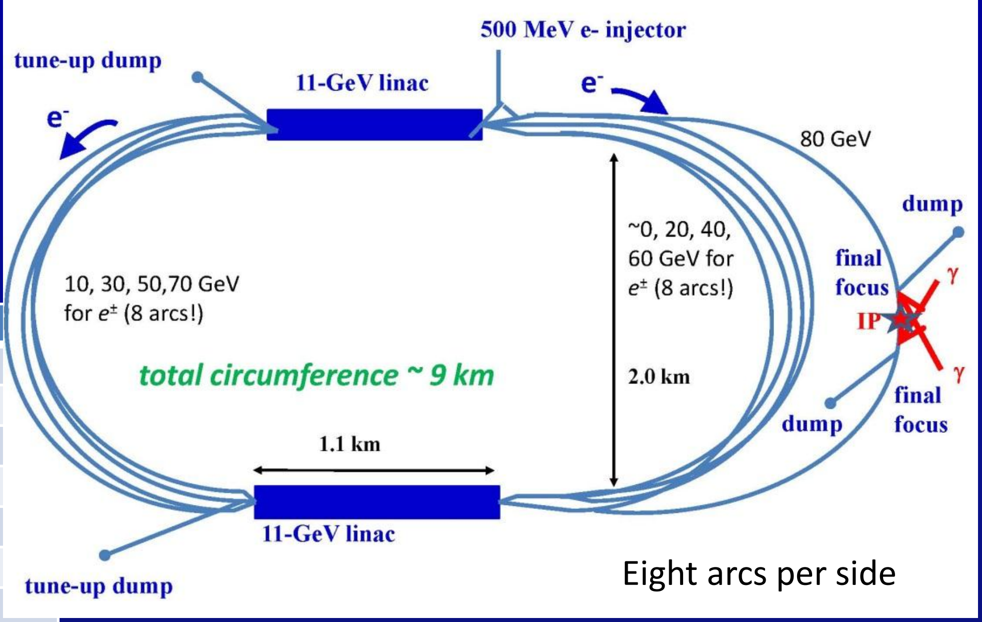
HIGGS FACTORIES e+e- rough costs estimations (B$)



SAPPHiRE

LHeC e beam ERL as γ–γ collider

total electric power	P	100 MW
beam energy	E	80 GeV
beam polarization	P_e	0.80
bunch population	Nb	10^{10}
repetition rate	f_{rep}	200 kHz
bunch length	s_z	30 mm
crossing angle	q_c	≥20 mrad
normalized horizontal emittance	ge_x	5 mm
normalized vertical emittance	ge_y	0.5 mm
e-e- geometric luminosity	L_{ee}	$2x10^{34}$ $cm^{-2}s^{-1}$



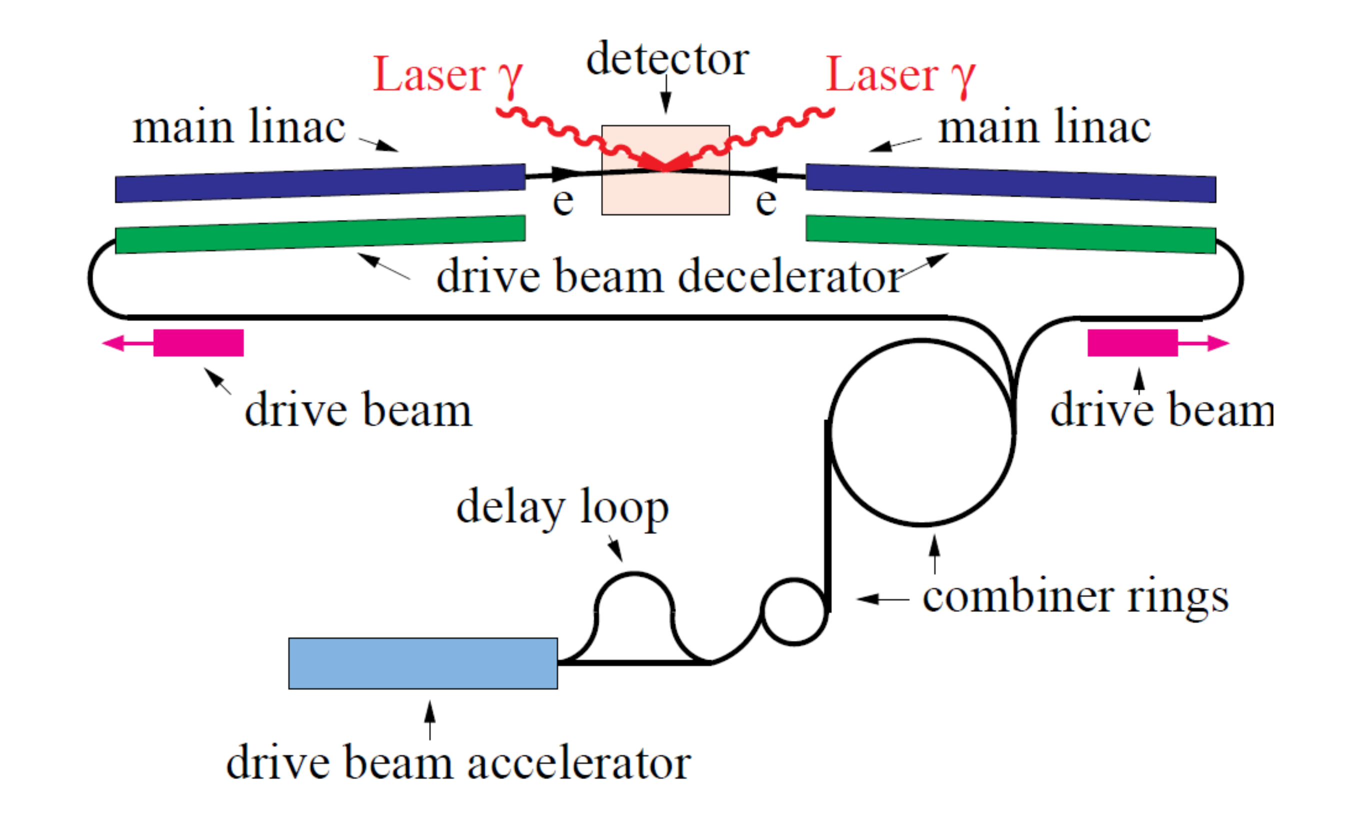
Challenges: ERLs physics (emittance preservation…)

Laser pulses at 200 kHz

Total energy few Joules (1 TW peak power, 5 ps pulse length == 1 MW average power)

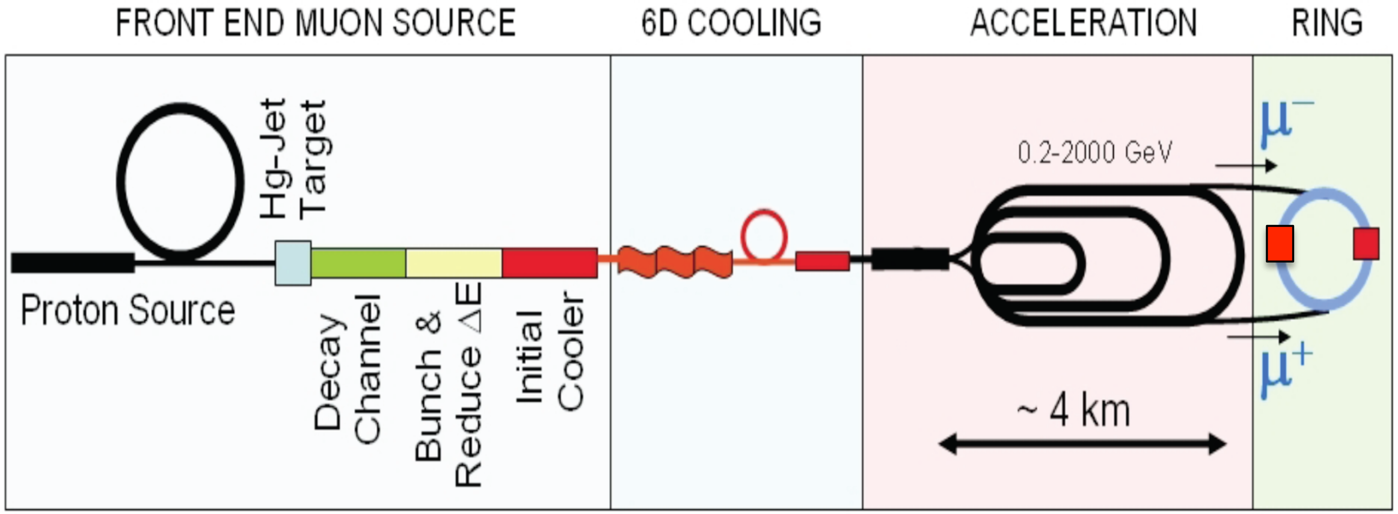
For a photon energy around 3.53 eV, equivalent to a laser wavelength of 351 nm, we have *x*=4.5.

CLICHE (2001) Proposal of using first stage of CLIC for γ–γ collider



Higgs Physics with a γγ Collider Based on CLIC 1: Asner et al, 2001

Muon collider



- Potential advantages wrt. e^+e^-
- Smaller facility size
  - Synchrotron radiation losses ~ E^4/m^4r
- Smaller energy spread
  - Beamsstrahlung ~ E^4/m^4
- s-channel Higgs production ~m^2

- Target L = 10^{34} $cm^{-2}s^{-1}$ per IP
- Many technical challenges to be faced
  - Intense proton source
  - Muon cooling
  - Can detectors survive muon decay rate and still do the physics?
- Could be a follow-on from (or precursor to) a ν-factory

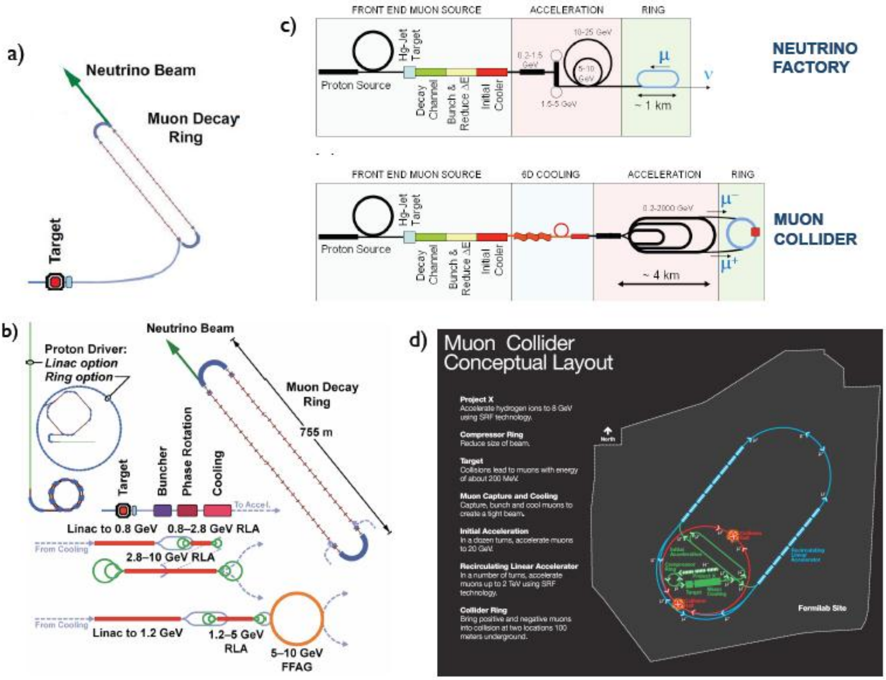


Figure 7: Ingredients for a possible muon-facility staging plan: a) νSTORM; b) IDS-NF Neutrino Factory; c) Muon Collider as Neutrino Factory upgrade; d) possible siting of multi-TeV Muon Collider at Fermilab.

Proton-proton colliders

Facility	Years	Ecm [TeV]	Luminosity [10^{34} $cm^{-2}s^{-2}$]	int Luminosity [fb^{-1}]	Comments
nominal LHC	2014-2021	14	1-2	300	
HL-LHC	2023-2030	14	5	3000	luminosity levelling
HE-LHC	>2035	26-33	>2	100-300 / yr	dipole fields 16-20 T
V-LHC		42-100			new 80 km tunnel

c.f. previous steps in √s at hadron colliders

Sp$\bar{p}$S ➔ Tevatron ➔ LHC
0.63 ➔ 2 ➔ 14 TeV

N.B. Very significant challenges to operate trigger/detector and do physics at very high luminosity/high pile-up at HL-LHC and beyond

HE-LHC (High Energy LHC)

Increasing proton energy beyond 7 TeV:

(2010: study group and workshop)

- reuse of the CERN infrastructure
- “ease” in producing luminosity with proton circular collider
- practical and technical experience gained with LHC

Beam energy set by SC magnets **dipole field:**
16-20 T == 26 to 33 TeV in the centre of mass.

R&D on high field SC magnets

R&D started in view of VLHC and ITER - Multi Labs and Industrial Collaborations
examples: LARP - bnl - fnal- lbnl – slac (prototype for 2012)
FRESCA - EuCARD WP7 – 12 Institutes - main involvement from CERN, FERMILAB, LBNL, BNL, KEK

NbTi

- Robust, ductile, well extablished techology
- B < 10 T

Nb_3Sn

- Heat treatment, brittleness
- B < 15 T
- US-LARp, Bruker - Prototyping

Nb_3AL

- KEK, Hitachi
- Subscale Magnet for demonstration (B = 13 T)

HTS

- B up to 45 T
- R&D on wires , still long road for High fields magnets
- Mechanical weakness

HE-LHC needs substantial advance in many other domains:

- accelerator physics
- collimation (with increased beam energy and energy density)
- beam injection – strong Injector upgrade (…SPS 1 TeV)
- beam dumping
- handling a synchrotron radiation = 20 LHC > challenge for vacuum and cryogenics.

Synchrotron radiation will also constitute a real advantage for HE-LHC design: for the first time a hadron collider will benefit of a short damping time 1-2 hours instead of 13-25 h (longitudinal and transverse respectively) of the present LHC.

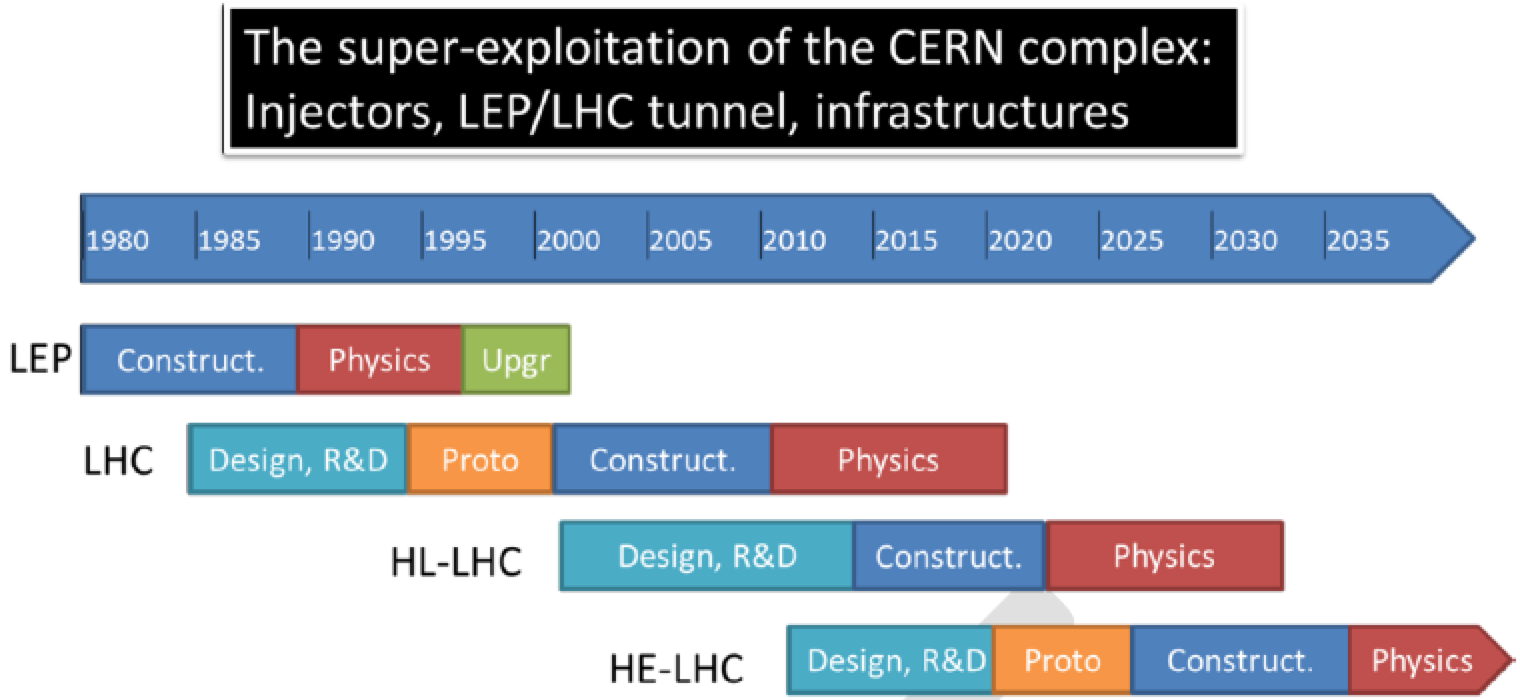


Figure 10. The possible timeline of LHC and its upgrades.

Beyond HE-LHC : new tunnels in Geneve area 47 km – 80 km

1) 42 TeV c.o.m. with 8.3 T (present LHC dipoles)
2) 80 TeV c.o.m. with 16 T (high field based on Nb3Sn)
3) 100 TeV c.o.m with 20 T (very high field based on HTS)

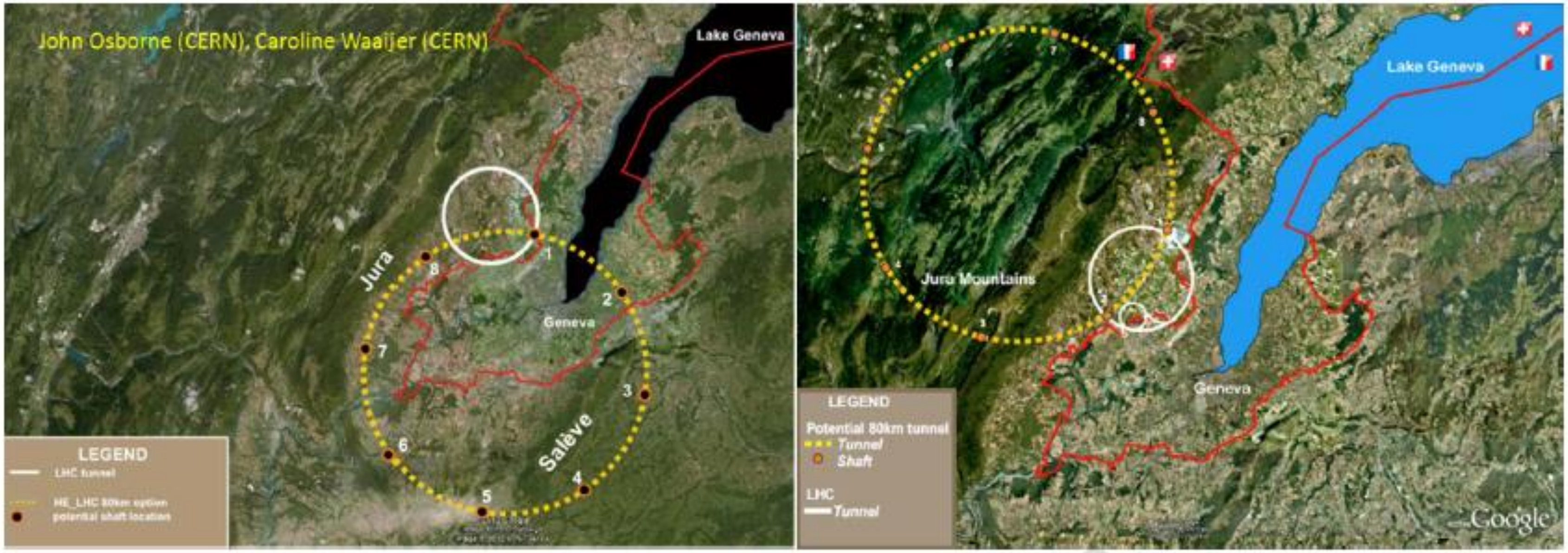


Figure 9. Two possible location, upon geological study, of the 80 km ring for a Super HE-LHC (option at left is strongly preferred)

$$V(\phi) = - \mu^2 \phi^+\phi + \lambda (\phi^+\phi)^2 + Y^{ij} \psi_L^{\ i} \psi_R^{\ j} \phi + \frac{g^{ij}}{\Lambda} \psi_L^{\ i}\psi_L^{\ Tj} \phi \phi^T + \ldots$$

- ***General consideration:***

  Quark & Lepton flavor physics are a complementary (and necessary) ingredient to better understand the Higgs or, more generally, the symmetry-breaking sector of the theory.

- ***Two key open questions:***

  - *What determines the observed pattern of masses and mixing angles of quarks and leptons?* [is there a rational behind the observed hierarchies?]

  - *Which are the sources of flavor symmetry breaking accessible at low energies?* [Is there anything else beside Yukawa couplings & the neutrino mass matrix that distinguishes the three families?]

Indirect Searches for NP

If the **energy** of the particle collisions is high enough, we can discover NP detecting the production of "real" new particles.

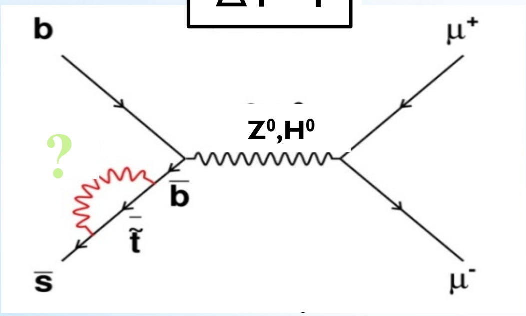
If the **precision** of the measurements is high enough, we can discover NP due to the effect of "virtual" new particles in loops.

Contrary to what happens in "non-broken" gauge theories like QED or QCD, the effect of **heavy ($M>q^2$) new particles does not decouple** in weak and Yukawa interactions.

Therefore, precision measurements of FCNC can reveal NP that may be **well above the TeV scale**, or can provide key information on the **couplings and phases** of these new particles if they are visible at the TeV scale.

Direct and indirect searches *are both needed and equally important, complementing each other.*

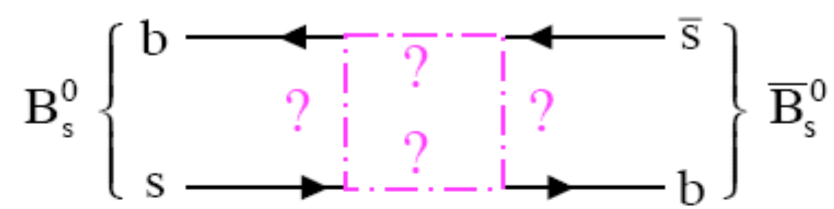
$\Delta F=1$



$B_s \to \mu^+\mu^-$ Higgs "Penguin"

$\Delta F=2$

$\phi_s \neq \phi_s^{SM} = -\arg(V_{ts}^2)$



B_s–$\bar{B}_s$ oscillations: "Box" diagram

Future facilities in heavy flavour physics

- LHCb upgrade
  - In 2012 luminosity levelled at 4 x 10^{32} $cm^{-2}s^{-1}$
    - Mean number of collisions per crossing μ ~ 1.6 (design 0.4)
  - By 2017 can expect to collect total of ~7 fb^{-1}
  - 2018 upgrade
    - Readout entire detector at 40 MHz + software trigger
    - Replace precision tracking detectors
  - 2019 onwards
    - Luminosity levelled at 1-2 x 10^{33} $cm^{-2}s^{-1}$ (μ ~ 2-4)
    - Collect ~5 fb^{-1}/year to achieve total of ~50 fb^{-1}
- Next generation B factory
  - SuperKEKB and Super-B (Frascati)
  - Luminosity ~10^{36} $cm^{-2}s^{-1}$
    - approaching two orders of magnitude increase wrt. first generation B factories
  - Collect ~50 ab^{-1} or more on Υ(4s) and several ab^{-1} on Υ(5s)
  - Substantially improved detectors wrt. first generation
- Many HF observables sensitive to contributions from potential BSM physics
  - e.g., $B_s^0 \rightarrow \mu\mu$, $b \rightarrow s\gamma$, $B^+ \rightarrow \tau^+\nu$ complement SUSY constraints from direct searches at ATLAS/CMS

Future prospects

"Minimalistic" list of the key (low-energy) quark flavor-violating observables:

- γ from tree ($B \to DK$, ...)
- $|V_{ub}|$ from exclusive semi-leptonic B decays

→ Clean (tree-level) determination of the main SM inputs [key ingredient to improve the precision of $\Delta F=2$ tests]

- $B_{s,d} \to l^+l^-$ — Higgs-mediated FCNCs [$\sigma(f_B) < 5\%$ (from lattice)]
- CPV in B_s mix. [ϕ_s] — New CPV (SUSY, ...) [$\sigma(S_{\psi\varphi}) \sim 0.01$]
- $B \to K^{(*)} l^+l^-$, $\nu\nu$ — Non-standard FCNCs [$\sigma(A_{FB}) \lesssim 5\%$]
- $B \to \tau\nu$, $\mu\nu$ (+D) — Scalar charged currents [$\sigma(f_B) \to 5\%$ (from lattice)]
- $K \to \pi\nu\nu$ — Best probe of non-MFV [$\sigma(BR) \lesssim 5\%$]
- CPV in charm — Key window on up-type dynamics [more work on the th. side]

Future prospects

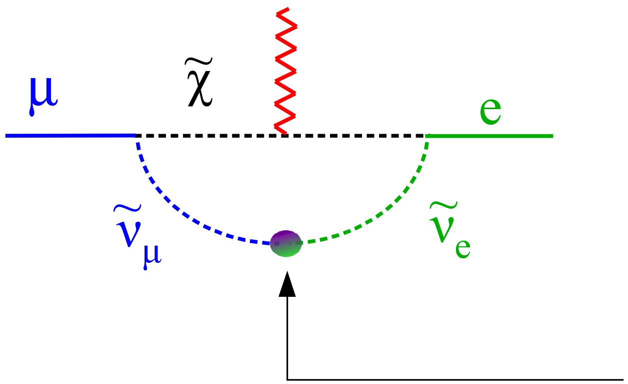
"Minimalistic" list of the key (low-energy) quark flavor-violating observables:

- γ from tree ($B \to DK$, ...) — S-LHCb
- $|V_{ub}|$ from exclusive semi-leptonic B decays — S-Bfactory [SuperKEKB & SuperB]
- $B_{s,d} \to l^+l^-$ — S-LHCb + ATLAS & CMS
- CPV in B_s mix. [ϕ_s] — S-LHCb + ATLAS & CMS
- $B \to K^{(*)}\, l^+l^-$, $\nu\nu$ — S-LHCb / S-Bfactory
- $B \to \tau\nu$, $\mu\nu$ (+D) — S-Bfactory
- $K \to \pi\nu\nu$ — Kaon beams [NA62, KOTO, ORKA]
- CPV in charm — S-LHCb / S-Bfactory

The key role of LFV and EDMs

LFV in charged leptons at "visible rates" if there are new particles carrying lepton flavor not too far from the TeV scale:

E.g.: SUSY



$$(\delta_{LL})_{12} \sim \begin{cases} y_t^2 \; V_{13}V_{23}^* \; [\textit{GUT}] \\ y_{\nu_3}^2 \; U_{13}U_{23}^* \; [\textit{see-saw}] \end{cases}$$

$$B(\mu \to e\gamma) \sim 10^{-13} \left[\frac{\tan\beta}{10}\right]^2 \left[\frac{0.5\ \text{TeV}}{\tilde{m}}\right]^4 \left[\frac{(\delta_{LL})_{12}}{10^{-4}}\right]^2$$

…and similar expressions holds in many other models:

=> MEG has realistic chances to see $\mu \to e\gamma$ (*but remember that* $\Gamma \sim \Lambda^{-4}$)

The key role of LFV and EDMs

The recent MEG bound, $BR(\mu\to e\gamma) < 2.4\times10^{-12}$, and its final sensitivity ($\sim10^{-13}$), can be taken as reference values to estimate potentially interesting levels for future LFV searches in different channels:

$\mu\to e\gamma$: $< 2\times10^{-12}$

same flavor →

$\mu\to 3e$, $\mu N\to eN$: $\lesssim 10^{-14}$

O(α/π) suppression if dipole dominated

same dynamics ↓

$\tau\to\mu\gamma$: $\lesssim 4\times10^{-9}$

enhancement of
O(10^3) [CKM hierarchy]
O(10) [PMNS hierarchy]

Key observables & planned exp. Limits:

- $\mu\to e\gamma$ — 5×10^{-14} [PSI/MEG-II]
- $\mu\to 3e$ — 10^{-16} [PSI/μ3e]
- $\mu N\to eN$ — $10^{-15} \to 10^{-18}$ [JPARC/COMET]; $10^{-15} \to 10^{-18}$ [FNAL/Mu2e]
- $\tau\to\mu\gamma$ — 2×10^{-9} [S-Bfactory ($50ab^{-1}$)]
- $\tau\to 3\mu$ — 10^{-9}-10^{-10} [S-Bfact., S-LHCb]

Summary by Belle II collaboration demonstrating complementarity of next generation B factory and LHCb

Assumed integrated luminosities:

Belle II: 50 ab^{-1}

LHCb: 10 fb^{-1}

Theoretical uncertainties and "gold-plated" tests of SM:

What is the quality of the gold-plating?

Observable	Expected th. accuracy	Expected exp. uncertainty	Facility
CKM matrix			
$\|V_{us}\|$ $[K \to \pi \ell \nu]$	**	0.1%	K-factory
$\|V_{cb}\|$ $[B \to X_c \ell \nu]$	**	1%	Belle II
$\|V_{ub}\|$ $[B_d \to \pi \ell \nu]$	*	4%	Belle II
$\sin(2\phi_1)$ $[c\bar{c}K^0_S$	***	$8 \cdot 10^{-3}$	Belle II/LHCb
ϕ_2		1.5°	Belle II
ϕ_3	***	3°	LHCb
CPV			
$S(B_s \to \psi\phi)$	**	0.01	LHCb
$S(B_s \to \phi\phi)$	**	0.05	LHCb
$S(B_d \to \phi K)$	***	0.05	Belle II/LHCb
$S(B_d \to \eta' K)$	***	0.02	Belle II
$S(B_d \to K^*(\to K^0_S\pi^0)\gamma))$	***	0.03	Belle II
$S(B_s \to \phi\gamma))$	***	0.05	LHCb
$S(B_d \to \rho\gamma))$		0.15	Belle II
A^d_{SL}	***	0.001	LHCb
A^s_{SL}	***	0.001	LHCb
$A_{CP}(B_d \to s\gamma)$	*	0.005	Belle II
rare decays			
$\mathcal{B}(B \to \tau\nu)$	**	3%	Belle II
$\mathcal{B}(B \to D\tau\nu)$		3%	Belle II
$\mathcal{B}(B_d \to \mu\nu)$	**	6%	Belle II
$\mathcal{B}(B_s \to \mu\mu)$	***	10%	LHCb
zero of $A_{FB}(B \to K^*\mu\mu)$	**	0.05	LHCb
$\mathcal{B}(B \to K^{(*)}\nu\nu)$	***	30%	Belle II
$\mathcal{B}(B \to s\gamma)$		4%	Belle II
$\mathcal{B}(B_s \to \gamma\gamma)$		$0.25 \cdot 10^{-6}$	Belle II (with 5 ab^{-1})
$\mathcal{B}(K \to \pi\nu\nu)$	**	10%	K-factory
$\mathcal{B}(K \to e\pi\nu)/\mathcal{B}(K \to \mu\pi\nu)$	***	0.1%	K-factory
charm and τ			
$\mathcal{B}(\tau \to \mu\gamma)$	***	$3 \cdot 10^{-9}$	Belle II
$\|q/p\|_D$	***	0.03	Belle II
$arg(q/p)_D$	***	1.5°	Belle II

Concluding remarks on heavy flavour

- LHCb upgrade and next generation B factory physics programmes are largely complementary
  - LHCb dominates most measurements with B_s, b-baryons, decays to final states consisting entirely of charged particles
  - Next generation B factory dominates measurements in final states containing invisible or neutral particles
- Both are likely to make important contributions

- Physics programme of next generation B factories consists largely of refining measurements and searches for rare decays
  - No guarantee of BSM effects – maybe results will be "only" improved limits?
  - Motivation for two facilities (SuperKEKB and Super-B)?
    - C.f. when the first generation B factories were proposed
    - A major new observation was expected (CPV in B^0)
      - Natural to have two experiments to confirm discovery and cross check subsequent measurements

Discussion

- Physics scenarios
- HL LHC
- Higgs factories/Linear colliders
- Flavour physics
- multi TeV

Discussion

- Physics scenarios
  - SM-Higgs-like particle also consistent with SUSY

    (predicted to be below 135 GeV)
  - Higgs properties need to be studied in detail, but „priorities" not clear
    - h^3 coupling crucial for confirming Higgs mechanism
    - hVV coupling much more sensitive to NP
  - What are implications of the discovery on cosmology?
  - Precision of m_t measurement limits theory predictions
  - Many „natural" SUSY models predict light weakly interacting particles, hard to find at LHC

Discussion

- HL LHC
  - There are measurements which require „highest possible" luminosity
  - Expectations for HL LHC „conservative" - experiments performing much better than expected.
  - Qualitative difference between 1000fb^{-1} and 3000fb^{-1} not demonstrated
  - R&D almost complete
  - Substantial investments required to continue running beyond LS3 even without HL upgrade.
  - Need to keep „luminosity doubling" time short to attract young people.
  - What if we will not find any trace of NP till 2017-18?

Discussion

- Higgs factories/Linear colliders

Japan strategy document (Feb. 2012):

> Should a new particle such as a Higgs boson with a mass below approximately 1 TeV be confirmed at LHC, Japan should take the leadership role in an early realization of an e^+e^- linear collider. In particular, if the particle is light, experiments at low collision energy should be started at the earliest possible time. In parallel, continuous studies on new physics should be pursued for both LHC and the upgraded LHC version.

Japan Policy Council proposal (July 2012):

> Creation of Global Cities by hosting the International Linear Collider (ILC)

Discussion

- Higgs factories/Linear colliders
  - ILC can be constructed in stages:
    - 250 GeV – Higgs Factory
    - 350 GeV – Top Factory
    - 500 GeV
    - extension to 1TeV possible, if there is a case for it
  - First stages could run in parallel with LHC, we need these results soon!
  - It is very important to „take momentum” from the Higgs discovery. We have our „window of opportunity”
  - We should not discuss „if” but „how” we should best support building ILC
  - Technology is ready for construction

Discussion

- Higgs factories/Linear colliders
  - We have only 1% of LHC luminosity. We should still wait for possible discoveries.
  - It is important to keep the possibility to go higher in energy, if there are suprises from LHC in few years.
  - There are other options for Higgs Factory - LEP3
    - Not mature projects, significant differences to LEP
    - High running costs (saturate CERN power limit)
    - It is much more difficult to „sell" old technology
    - At CERN: only after LHC
  - CERN can loose its position
  - There are not enough resources

Discussion

- Higgs factories/Linear colliders
  - Separate decision on ILC from strategy towards possible future HEF machine at CERN
    - HE-LHC, CLIC, TLEP, VLHC, $\mu\mu$ ...
  - European contribution to ILC
    - Estimated to ~70-100 M$ per year (informal !)
      It will not „kill us”, it is not competition for CERN...
    - There are industries interested
    - Japan has invested a lot in Europe...
  - Possibility to get „fresh money” still to be verified. We have to make a strong case...
  - We have no other choice but to join and keep community strong and active...

Discussion

- Flavour physics
  - No discussion...

- Multi-TeV
  - We should not discuss 80km collider, as it is beyond 2040...
  - If LHC finds SUSY, we will hold another meeting...

  - Building ILC soon opens path to next generation, high gradient e^+e^- machine (in the same tunnel?)
  - Globalisation is a must, but survival of few large HEP laboratories worldwide is crucial

Strong Interaction Physics

Strong Interactions and QCD

Open Fundmental Questions ⟷ **Practical Concerns**

- Confinement
- Hadronic mass generation
- High energy unitarity
- Spin `Crisis'
- 3 dimensional structure
- Coupling unification
- Strong CP / axions
- QCD instantons
- Bound states (glueballs, hybrids, pentaquarks?)
- AdS/CFT connection to Super-gravity?
- …

- Proton parton densities
- Photon, pomeron, nuclear parton densities
- Multi-parton / heavy flavour final states
- (Non)-factorisation schemes
- Hadronisat^n & fragmentat^n
- Underlying event / MPI
- Minimum bias (pile-up)
- Boosted jets / substructure,
- Jet vetoes
- …

A rich and subtle theory with lots still to be discovered and many deeper tests of our understanding still needed

COMPASS: past, present and future

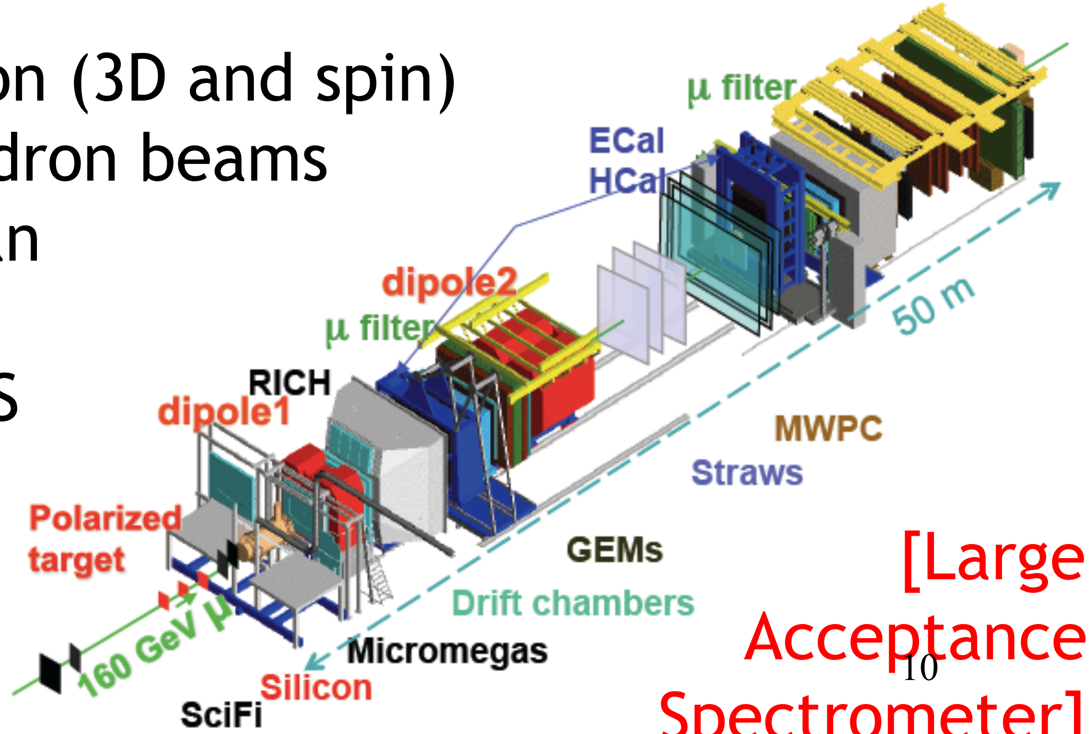
100-200 GeV secondary / tertiary SPS muon and hadron beams on various fixed targets (LH2, Polarized NH_3, ^{6}LiD, Nuclei…)

- 2002-7, 2010-11: Muon beam, polarised targets (nucleon spin)

- 2008-9: Diffractive and central reactions with hadron beam (hadron spectroscopy)

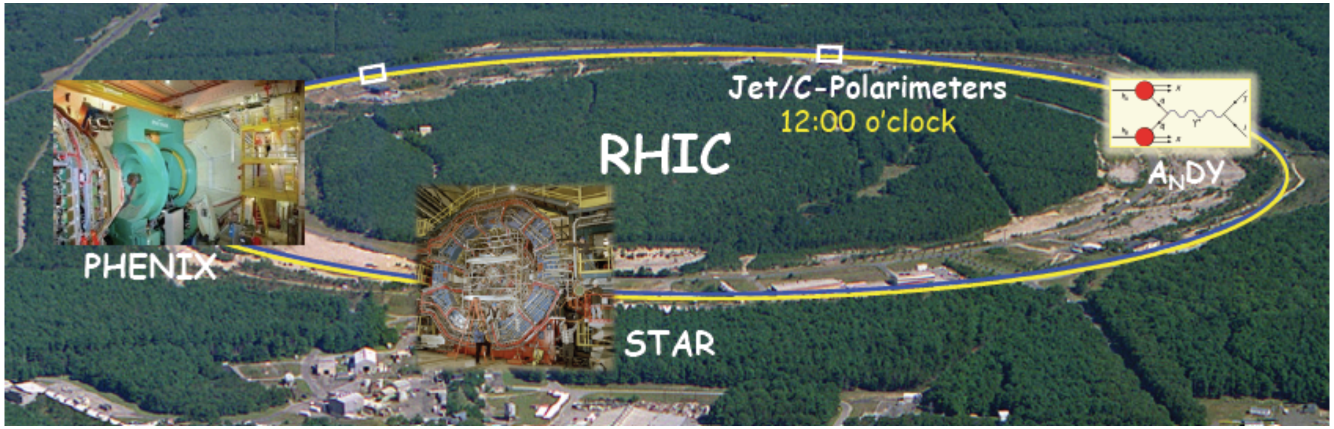
- 2014-17 [Approved]: Nucleon (3D and spin) structure using muon and hadron beams
  - TMDs via polarised Drell-Yan
  - GPDs via DVCS etc
  - (un)polarised semi-incl. DIS

- Planning further programme on all topics beyond 2017



[Large Acceptance Spectrometer]

Polarised Proton Programme @ RHIC



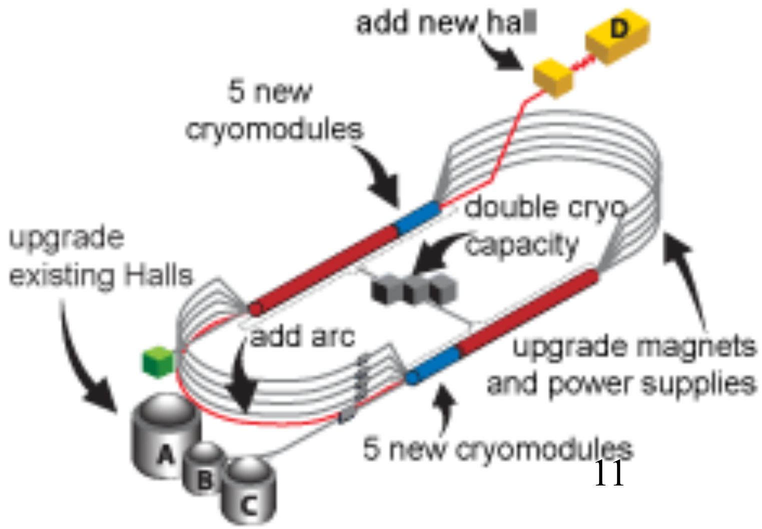
Polarised pp with $\sqrt{s}$ = 500 GeV : current highest energy spin and nucleon tomography programme

Detector Upgrade programme ~ 2016-18

(Approved) J-Lab CEBAF 12 GeV Upgrade

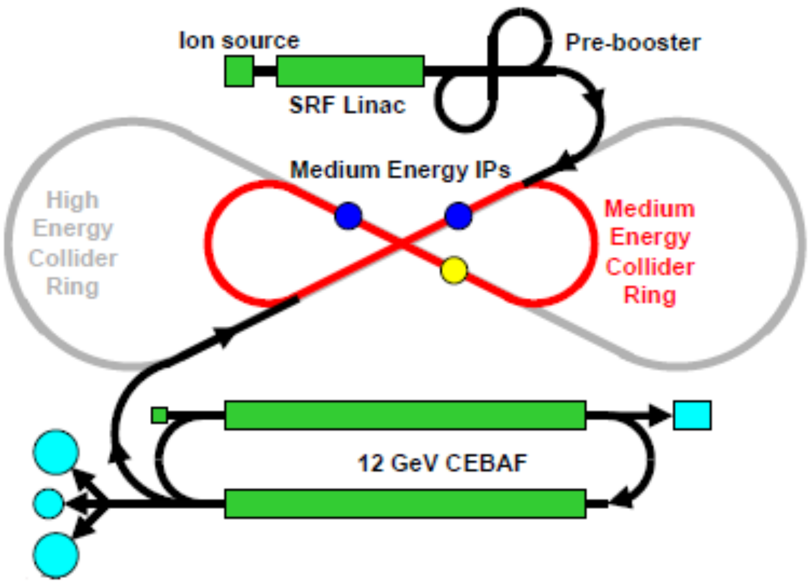
Intense 12 GeV electron beam on fixed targets

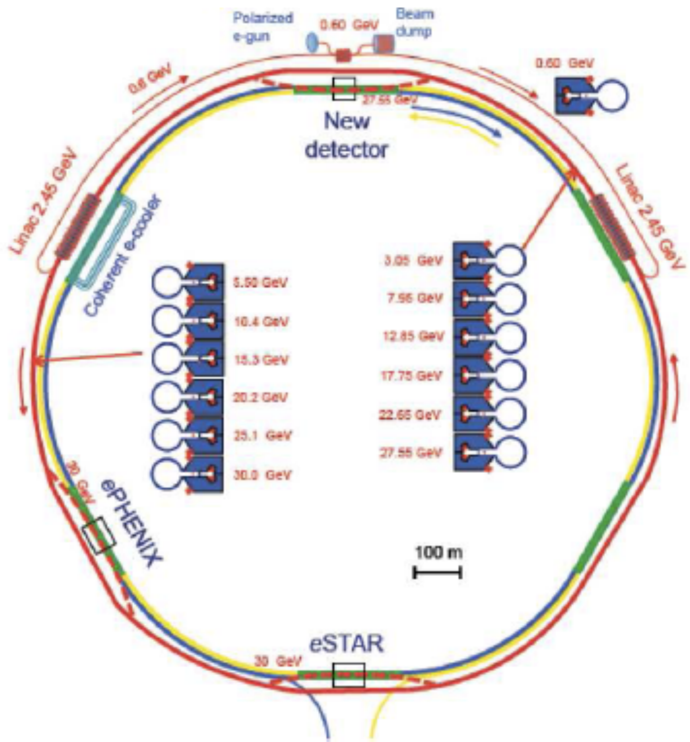
High x nucleon and nuclear structure, nucleon tomography, meson spectroscopy, confinement …



(Proposed) US Electron Ion Collider (EIC)

- MEIC/ELIC @ Jlab: Add figure of 8 hadron rings to CEBAF
- eRHIC @ BNL: Add energy recovery LINAC in RHIC tunnel





E_e <~ 20 GeV, E_p <~ 250 GeV,
$\sqrt{s_{NN}}$ <~ 140 GeV, Lumi > 10^{33} cm^{-2} s^{-}

- Limited in energy, but >100 times HERA luminosity
- Polarised hadrons → DIS spin, 3D structure in new regime
- Heavy ions → large step forward for eA kinematic range

AFTER @ LHC

Multi-purpose proposed experiment with LHC p, Pb beams on various polarised and unpolarised fixed targets.

AFTER @ LHC

- pp $\sqrt{s}$ = 115 GeV (comparable to RHIC) ; $\sqrt{s_{NN}}$ = 72 GeV in Pb A.

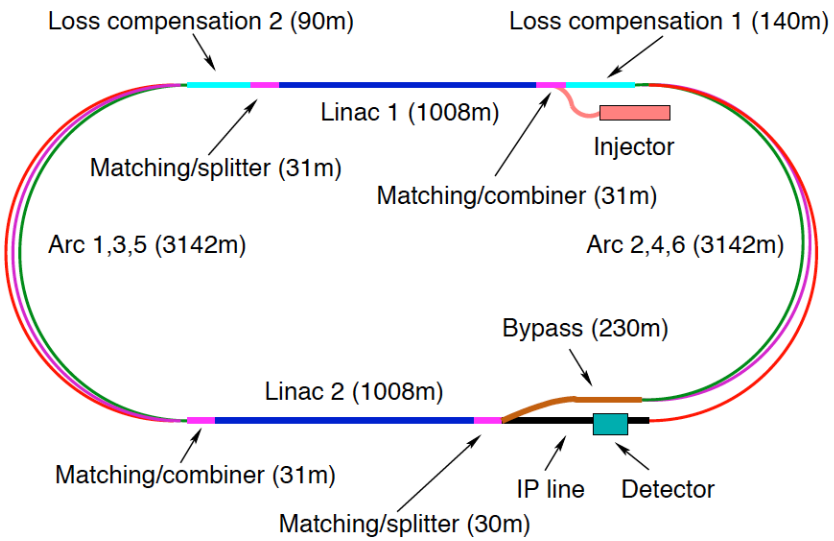
- Full backward access (to x_F = -1)

- Potentially high luminosity ("slow extraction" 5.10^8 protons/sec)

    - Proton, neutron, nuclear structure (gluon, dbar-ubar, HQ)
    - 3D structure through e.g. TMDs (Sivers function from SSAs)
    - Complementary deconfinement observables in heavy ions
    - Ultra-peripheral quasi-elastic gamma-p, diffraction …

Relatively small cost extension to LHC programme.
No timeline yet, but LHCC recommended further studies.

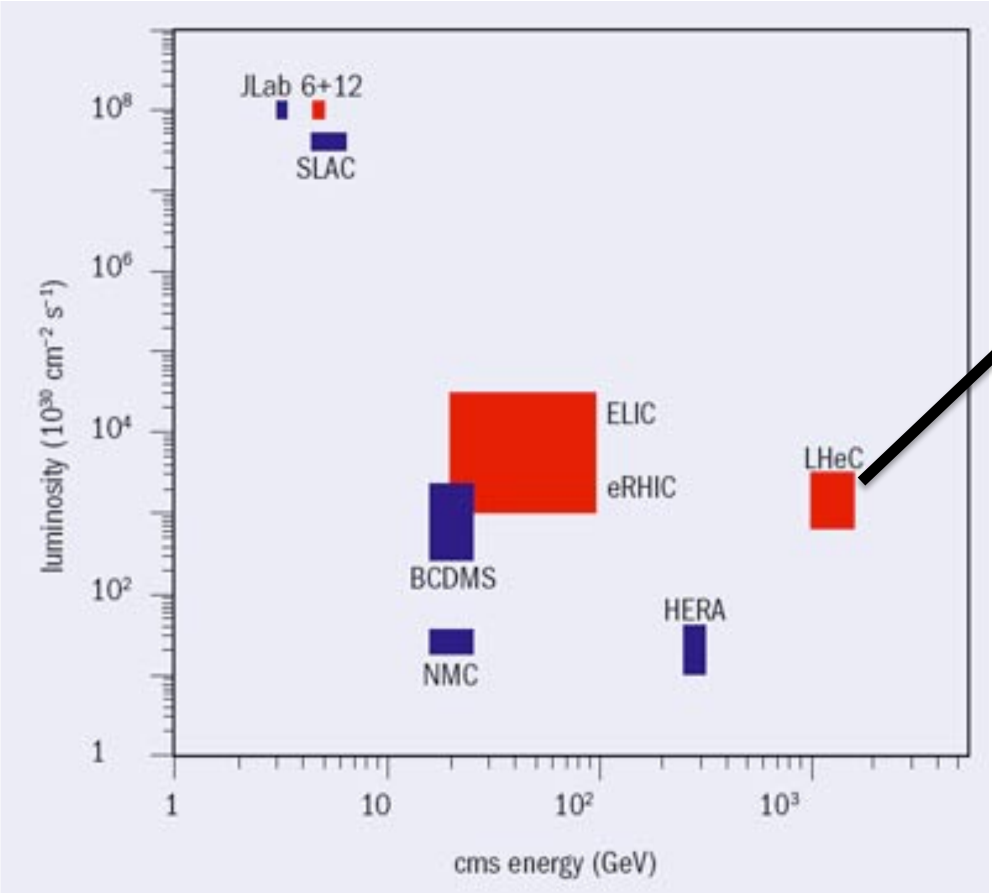
electron-proton collider (LHeC)

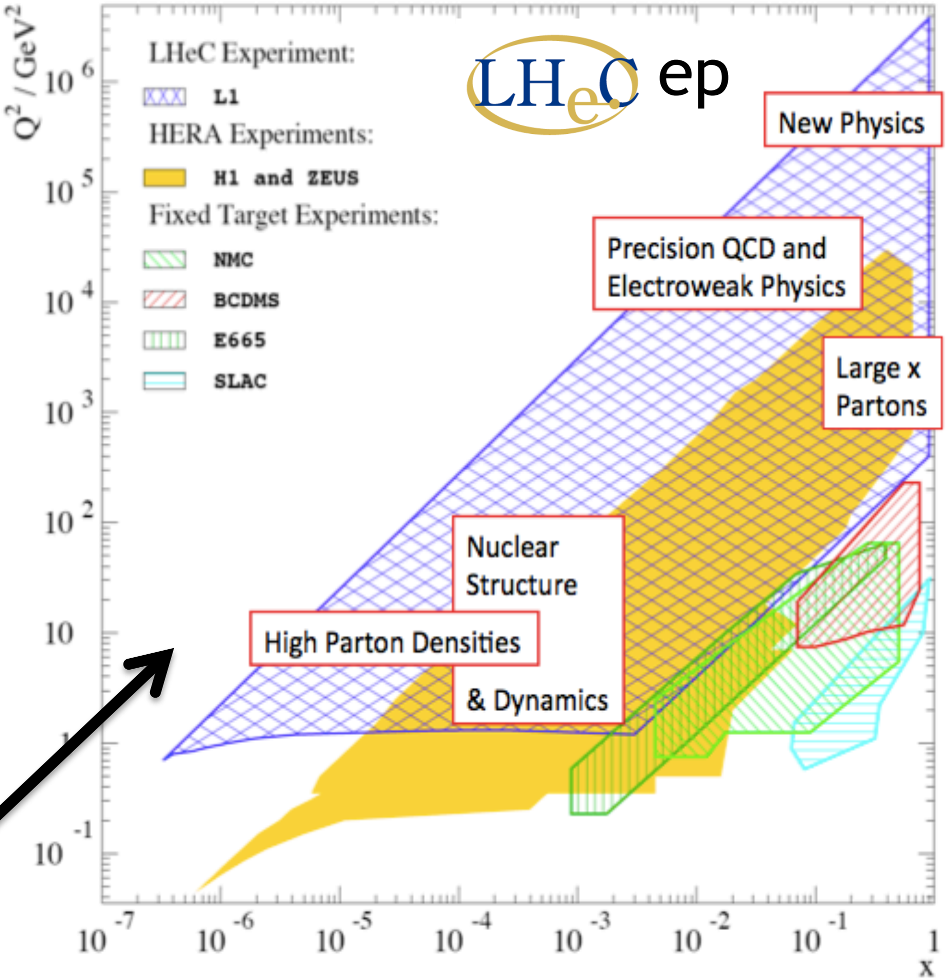


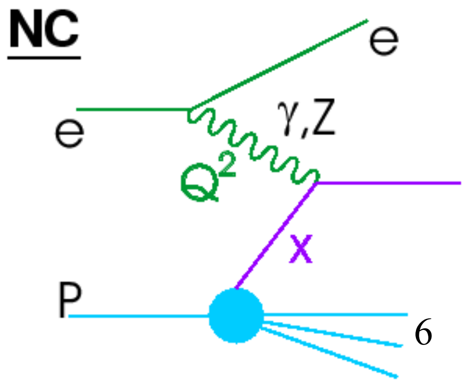
- Double ("race-track") linear accelerator option now preferred
- 10 x 2 x 3=60 GeV $e^{\pm}$ beam
- Unused beam returned from IP to recover energy

- Q^2_{max} ~ 1 TeV
- Luminosity 10^{33} $cm^{-2}s^{-1}$ (e^-p), 10^{32} $cm^{-2}s^{-1}$ (e^+p)
- Integrated luminosity aim ~100 fb^{-1}
- e^- polarization ~ 90%
  - Q^2_{max} and luminosity are factors of around 30 and 100, respectively, higher than at HERA
- N.B. precise QCD (PDFs, α_s, MC, etc) is very important for HEF programme at LHC!
  - In addition, some particular HEF reach
  - e^-N collisions also possible

Past, Present and Future ep Colliders

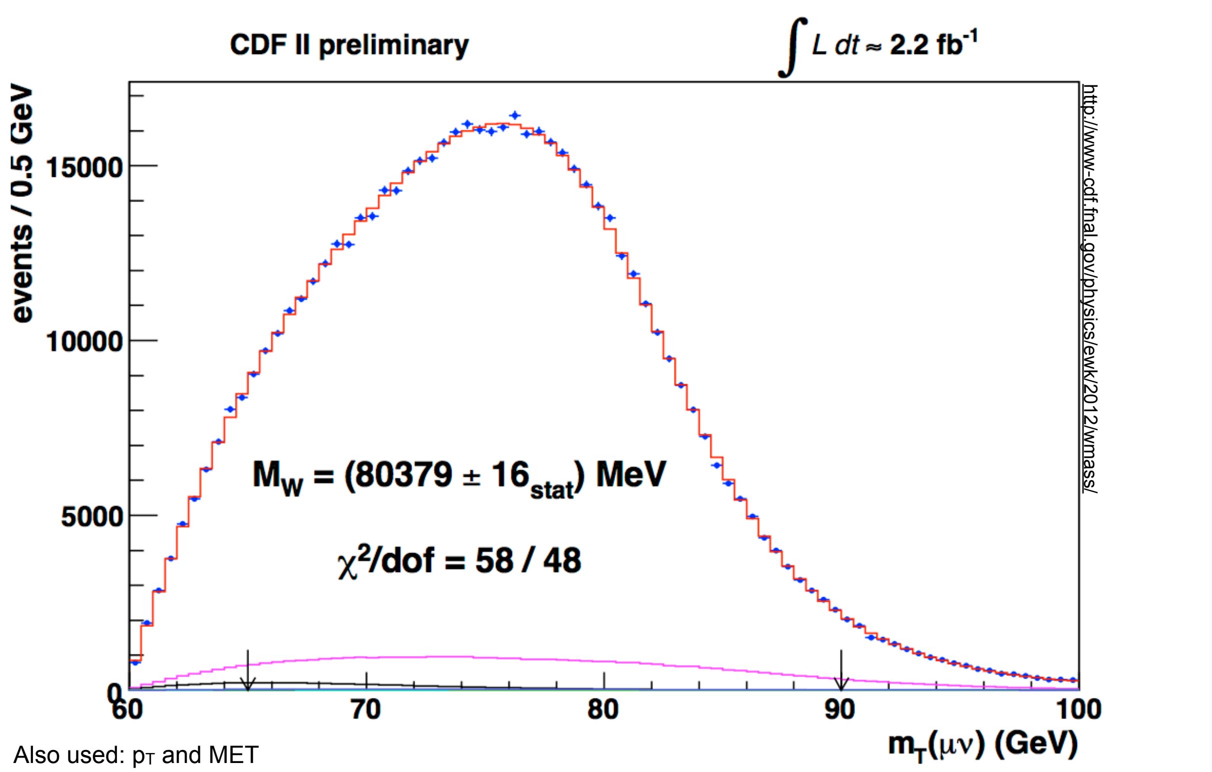




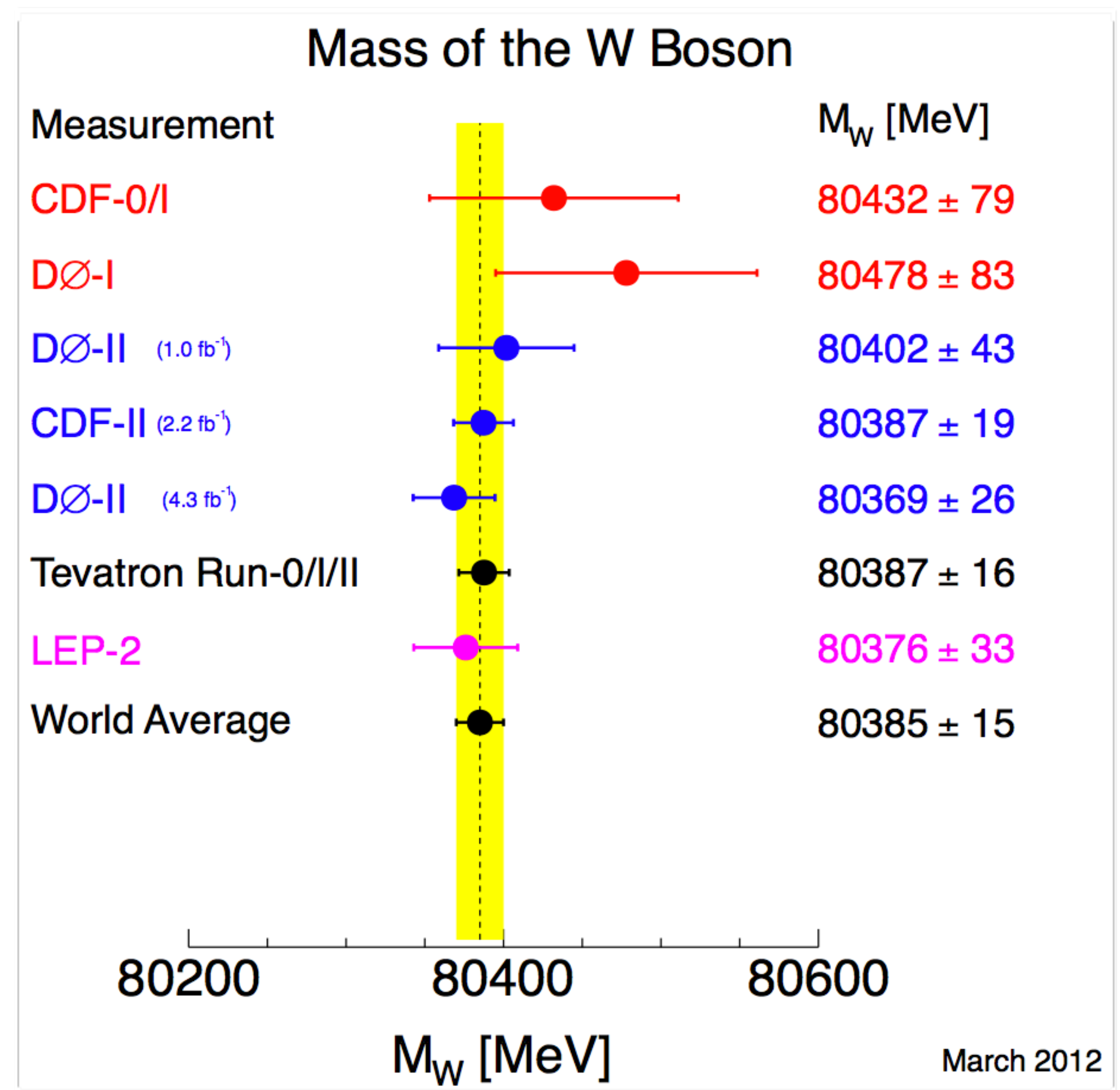


The W mass

currently, best measurements from the TEVATRON



Also used: p_T and MET



arXiv:1204.0042v2 [hep-ex]

arXiv:1203.0275 [hep-ex]

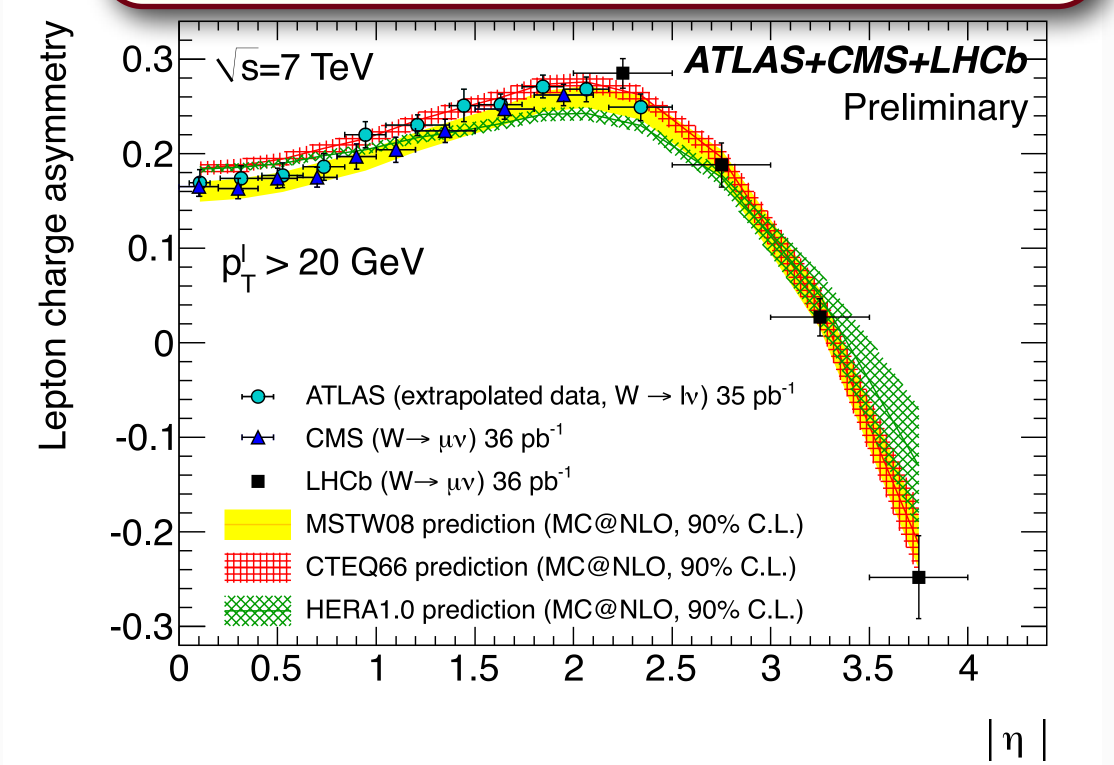
Source	Uncertainty (MeV)
Lepton energy scale and resolution	7
Hadronic recoil energy scale and resolution	6
Lepton removal	2
Backgrounds	3
Experimental subtotal	10
Parton distributions	10
QED radiation	4
$p_T(W)$ model	5
Production subtotal	12
Total systematic uncertainty	15
W-boson statistics	12
Total uncertainty	19

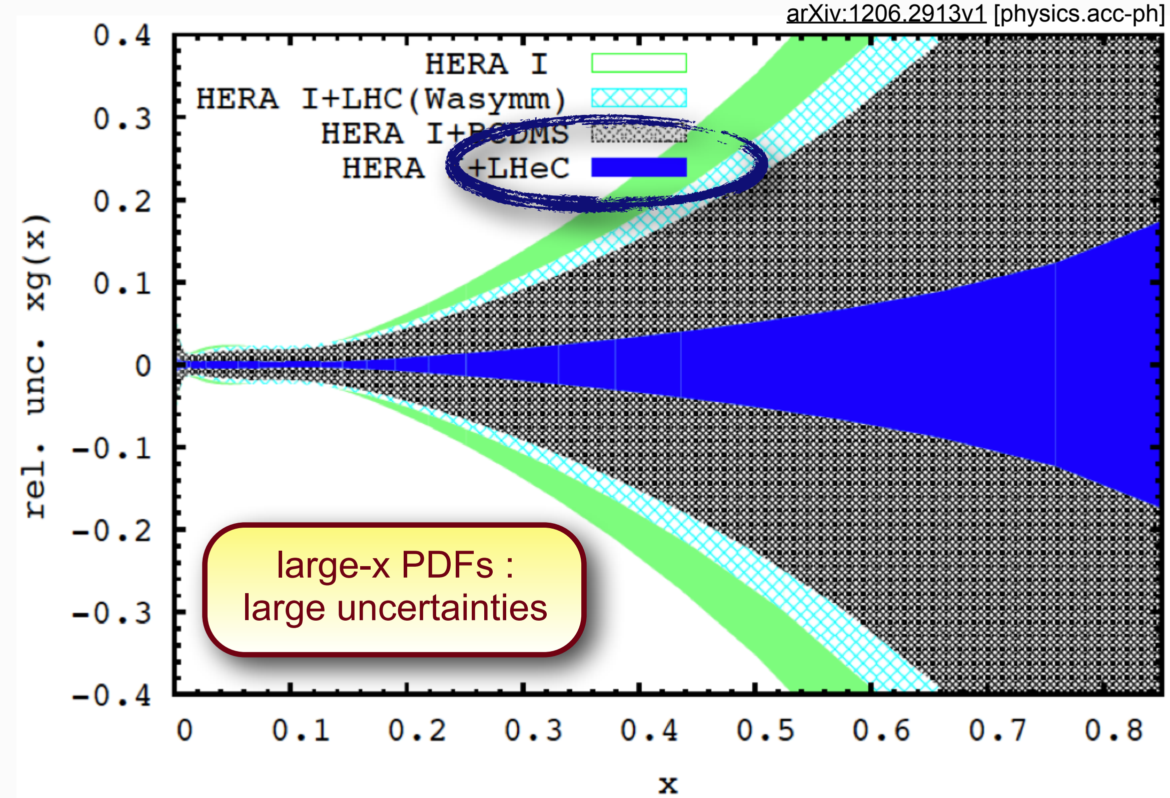
- where is the limit at hadron colliders?
- no LHC results so far, but claims are that pushing somewhat below 10 MeV might be possible
- proposed e^+e^- colliders claim to attain MeV-level precision

CDF: single most important uncertainty: PDF(similar for Dzero). Further improvements envisaged: PDF constraints from W charge asymmetry, extension of rapidity coverage.

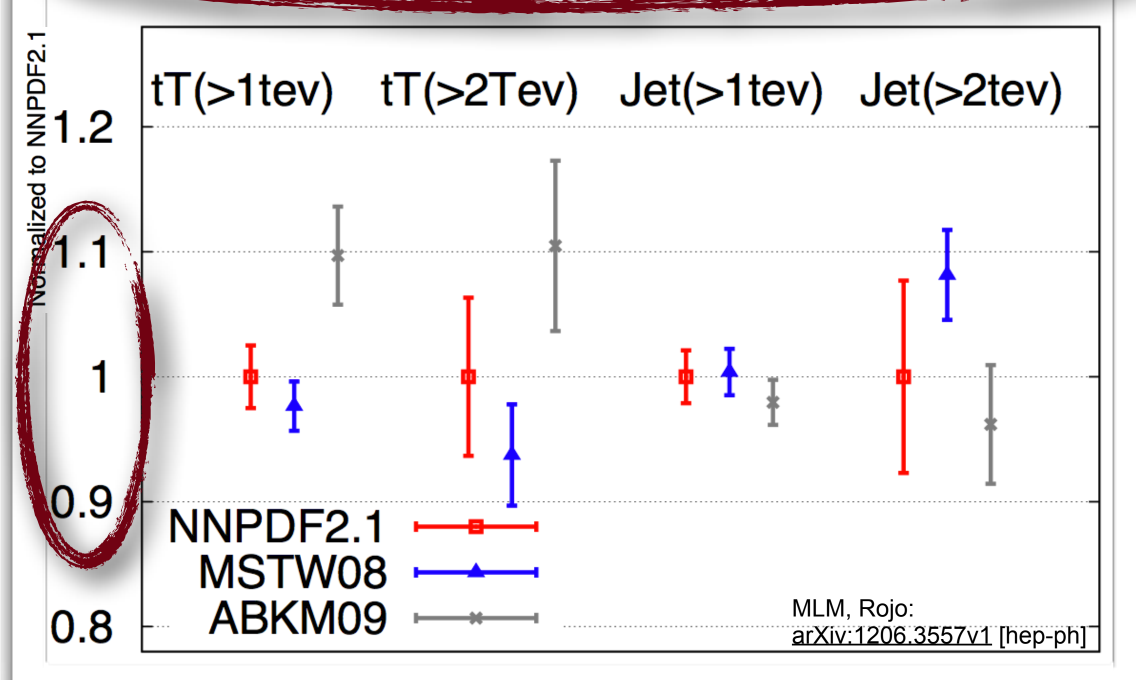
Improving the PDF knowledge

large phase space to be covered at the LHC (Q^2 and x)





Cross section Ratios between 14 and 8 TeV



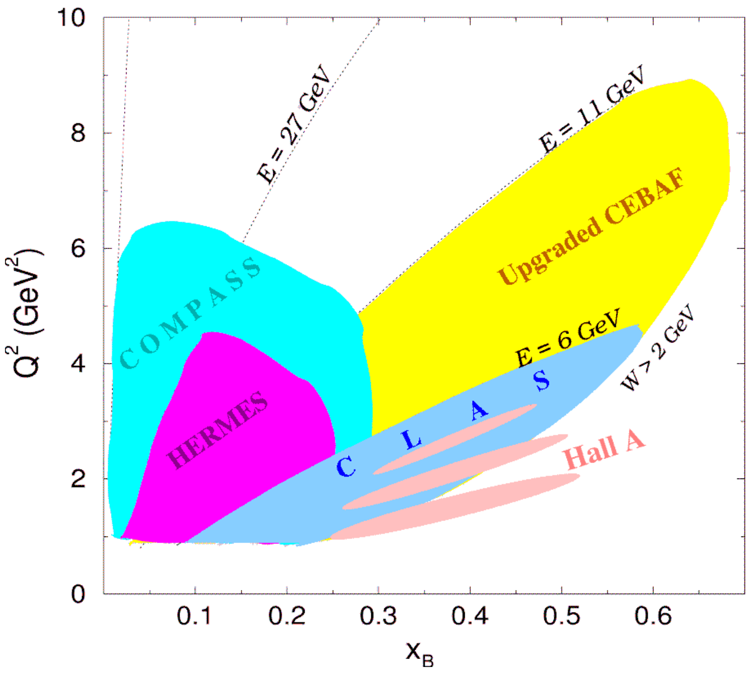
- in my mind, still a huge potential in LHC data for improving our PDF knowledge
- PDF fitter groups start to incorporate LHC data, much more hopefully to arrive in coming years
- large-x PDFs especially important for heavy-object searches
- **great potential in ratio observables**: either to obtain %-level (or better) theory predictions, or to constrain PDFs to the % level, over large x-range

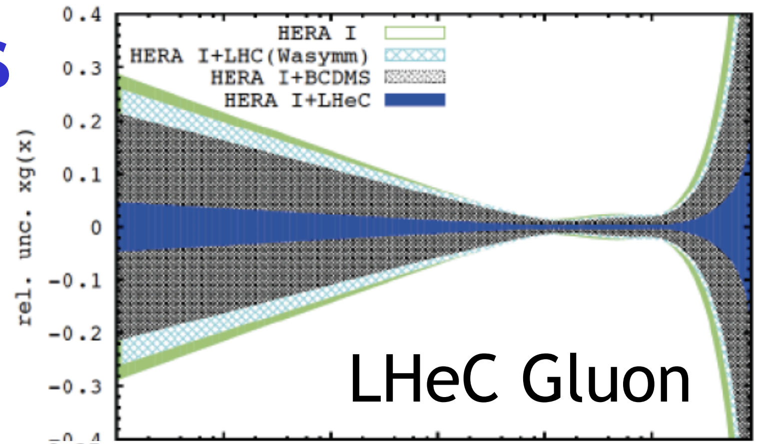
New Proton PDF Constraints

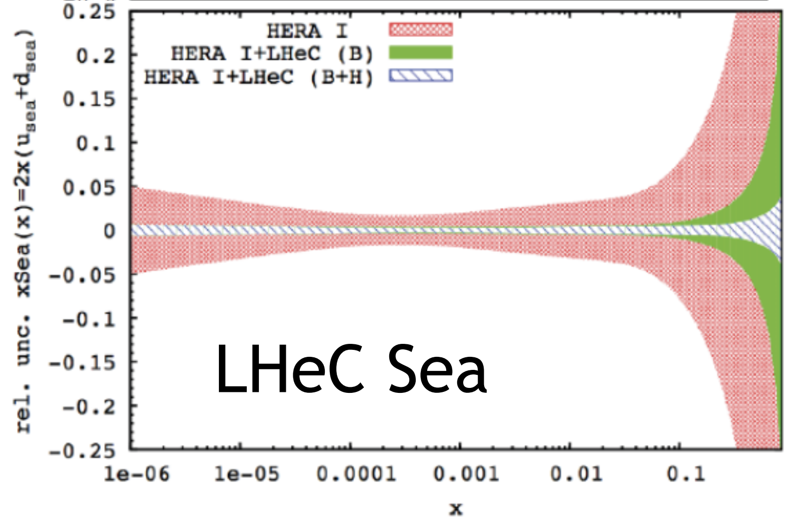
LHeC: huge impact at low x (kinematic range) and high x (lumi). Full flavour decomposition without assumptions

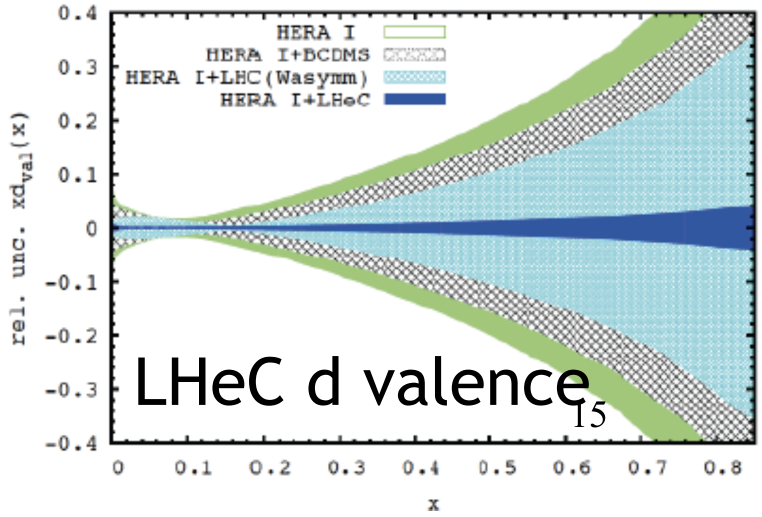
LHC: complementary information in limited range (W, Z, direct γ, DY …)

Fixed Target (Jlab, COMPASS): flavour sensitivity (semi-incl' DIS) and high x, low Q^2 for quark density

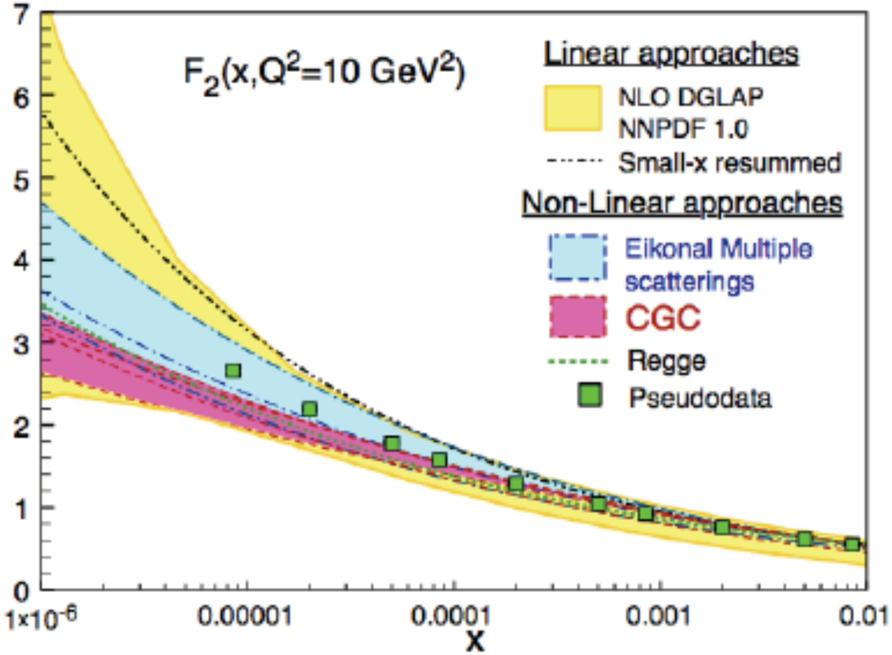








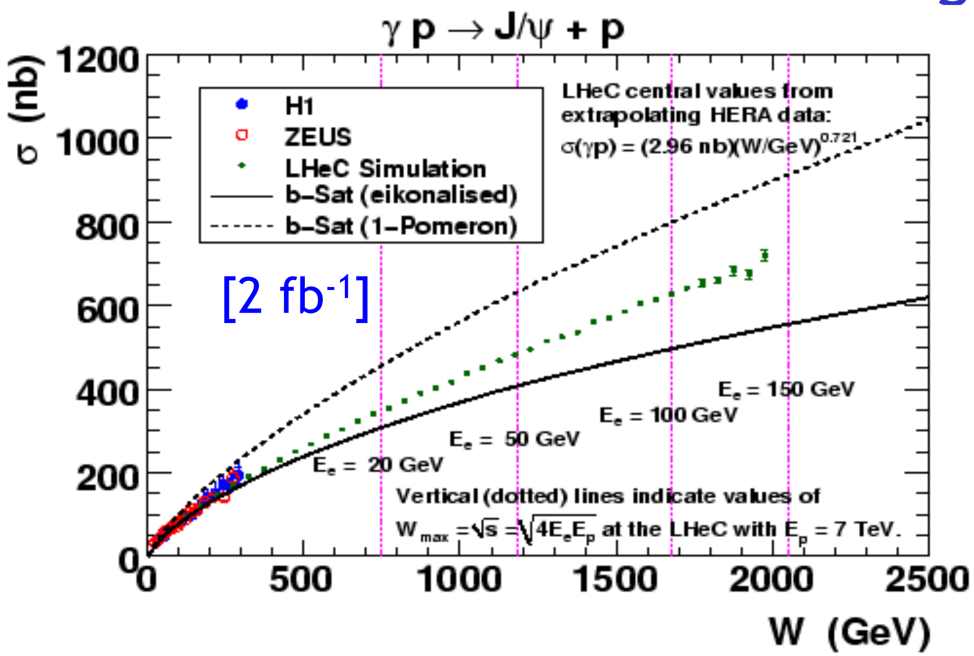
Precision Low x Physics at LHeC



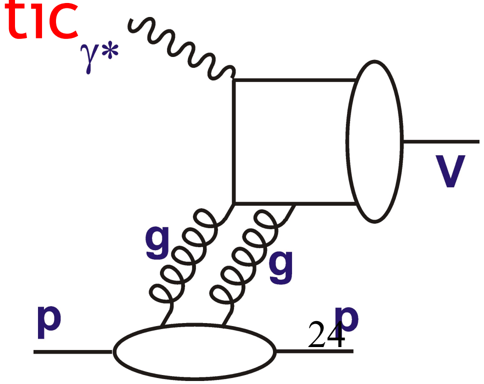
- LHeC can distinguish between different QCD-based models for the onset of non-linear dynamics

- Unambiguous observation of saturation will be based on tension between different observables

e.g. F_2 v F_L in ep or F_2 in ep v eA

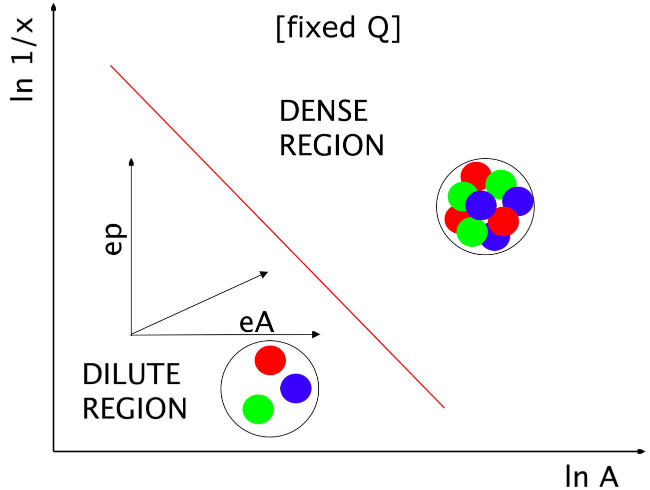


- Significant non-linear effects expected in diffraction in LHeC kinematic range, even for ep → eJ/Ψp – even more so in eA …



LHeC Sensitivity to Saturation Region

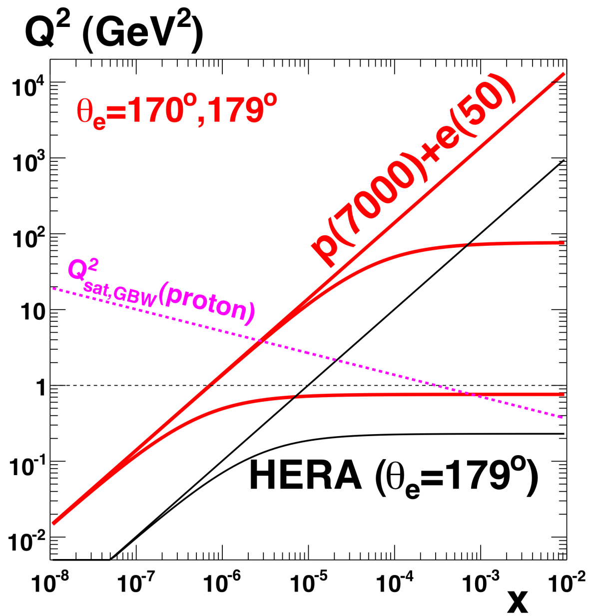
LHeC delivers a 2-pronged approach:

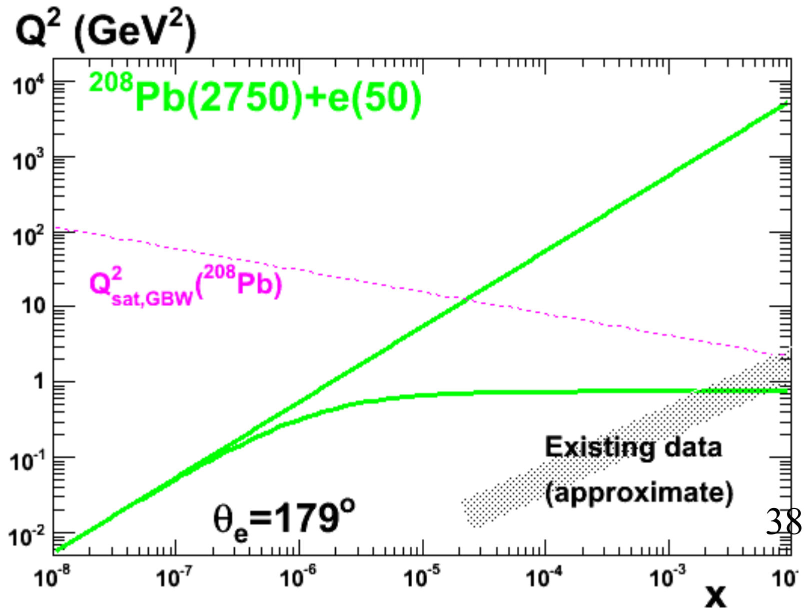


Enhance target `blackness' by:

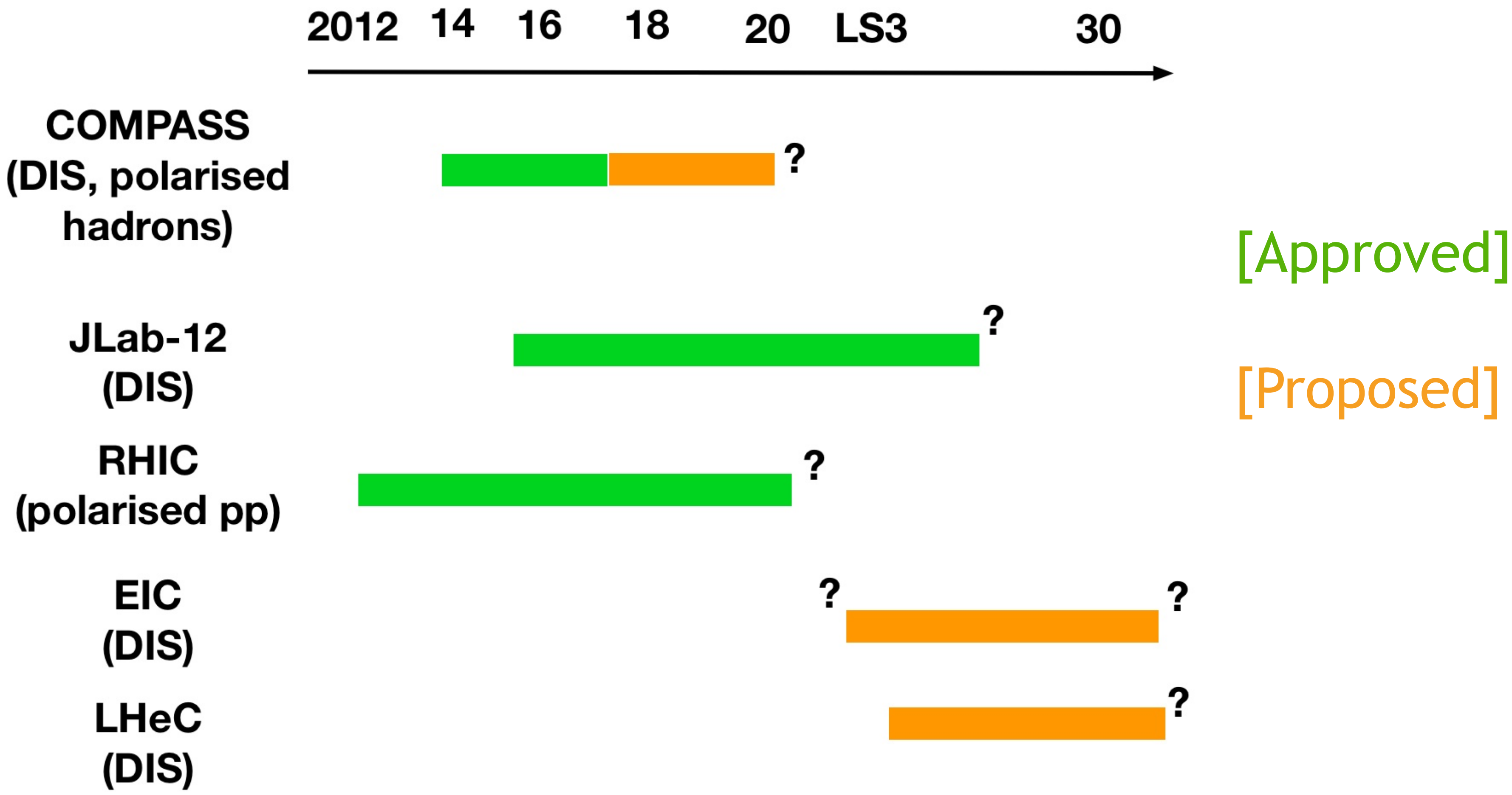
1) Probing lower x at fixed Q^2 in ep
   [evolution of a single source]

2) Increasing target matter in eA
   [overlapping many sources at fixed kinematics … density ~ $A^{1/3}$ ~ 6 for Pb … worth 2 orders of magnitude in x]





Rough Timeline of Main Projects Discussed Here



We cannot afford so much uncertainty about the future when we meet again in 2018!

LHC heavy-ion running

Phase 0: 2010-2013

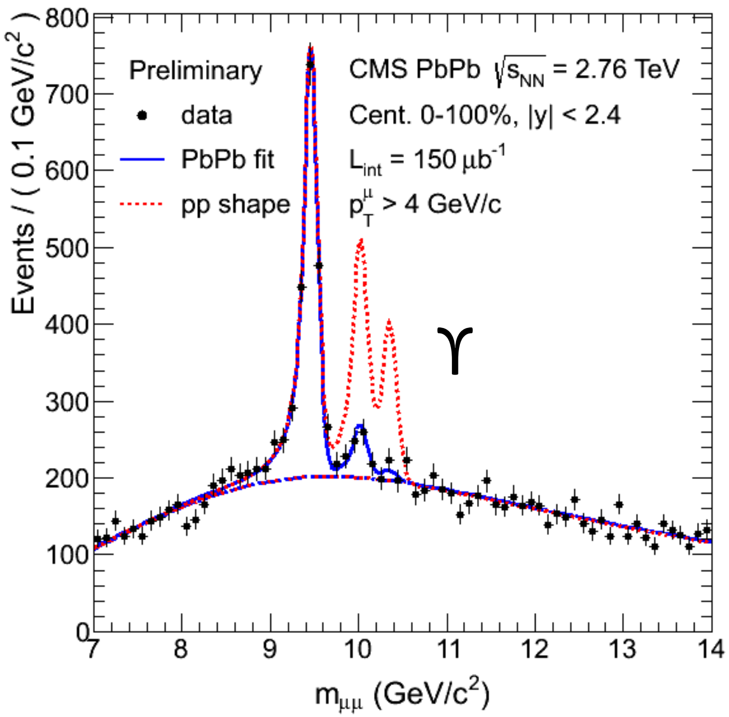
- 0.15 nb^{-1} Pb-Pb at $\sqrt{s_{NN}}$=2.76 TeV
  i.e. twice the design luminosity (at 50% design energy)!
- reference pp data at $\sqrt{s}$=2.76 TeV

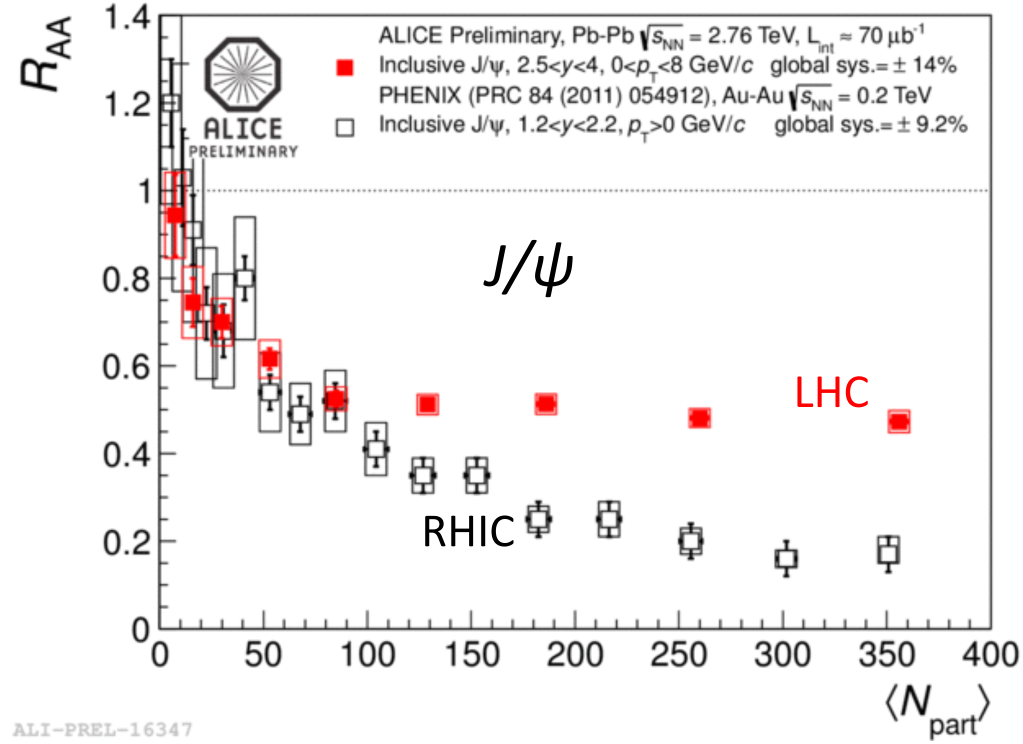
Major results by ALICE, ATLAS, CMS:

- Jets and jet quenching
- Electroweak probes
- Upsilon spectroscopy
- Charmonium suppression
- Heavy flavor R_{AA}, v_2
- Bulk properties

August 2012, Washington DC
http://qm2012.bnl.gov

LHC HI-highlights – quarkonia suppression





Melting of weakly bound bottonium states indicating strong color screening in the QGP

J/ψ suppression pattern at LHC qualitatively different from RHIC: enhancement via regeneration predicted as consequence of deconfinement and large charm cross section

future opportunities at LHC

Jets	- precision measurements: γ-Jet, b-Jet, Z-Jet, multi-Jet, PID fragmentation functions, TeV-scale jet quenching
ϒ spectroscopy	- 1s, 2s, 3s states, onset-behaviour
Charmonia	- low p_T J/ψ over wide rapidity range, ψ', X_c
Heavy Flavors	- comprehensive measurement of D, D^*, D_s, Λ_c, B, Λ_b: Baryon/Meson ratios down to low p_T, R_{AA}, v_2 accurate normalization for quarkonia
EM radiation	- low mass dileptons
Exotica	- anti- and hypernuclei

→ enter 10 nb^{-1} regime

LHC near future - phase 1

Phase 0: 2010-2013

- 0.15 nb^{-1} Pb-Pb at $\sqrt{s_{NN}}$=2.76 TeV
  i.e. twice the design luminosity (at 50% design energy)!
- reference pp data at $\sqrt{s}$=2.76 TeV
- 30 nb^{-1} p-Pb at $\sqrt{s_{NN}}$=5 TeV

2013-2014: LS1

- detector completion and upgrades (ALICE-TRD, - CAL, ATLAS-IBL,...)

Phase 1: 2015-2017

- 1 nb^{-1} Pb-Pb at $\sqrt{s_{NN}}$=5.5 TeV
- reference data pp, p-Pb

LHC upgrade – Phase 2

2017-2018: LS2

- significant detector upgrades
- LHC collimator upgrades

Phase 2: 2019-LS3 and beyond:

- aiming for luminosity increase to 6×10^{27} $cm^{-1}s^{-1}$
  → peak collision rate 50 kHz, average 20 kHz
  → O (10) nb^{-1} Pb-Pb at $\sqrt{s_{NN}}$=5.5 TeV
- pp and p-Pb reference data
- more nuclei

Heavy-Ion collisions at the LHC - conclusions

Conclusions of the Heavy-Ion Town Meeting June 29 2012 at CERN:

http://indico.cern.ch/event/HItownmeeting

Contribution ID 55:

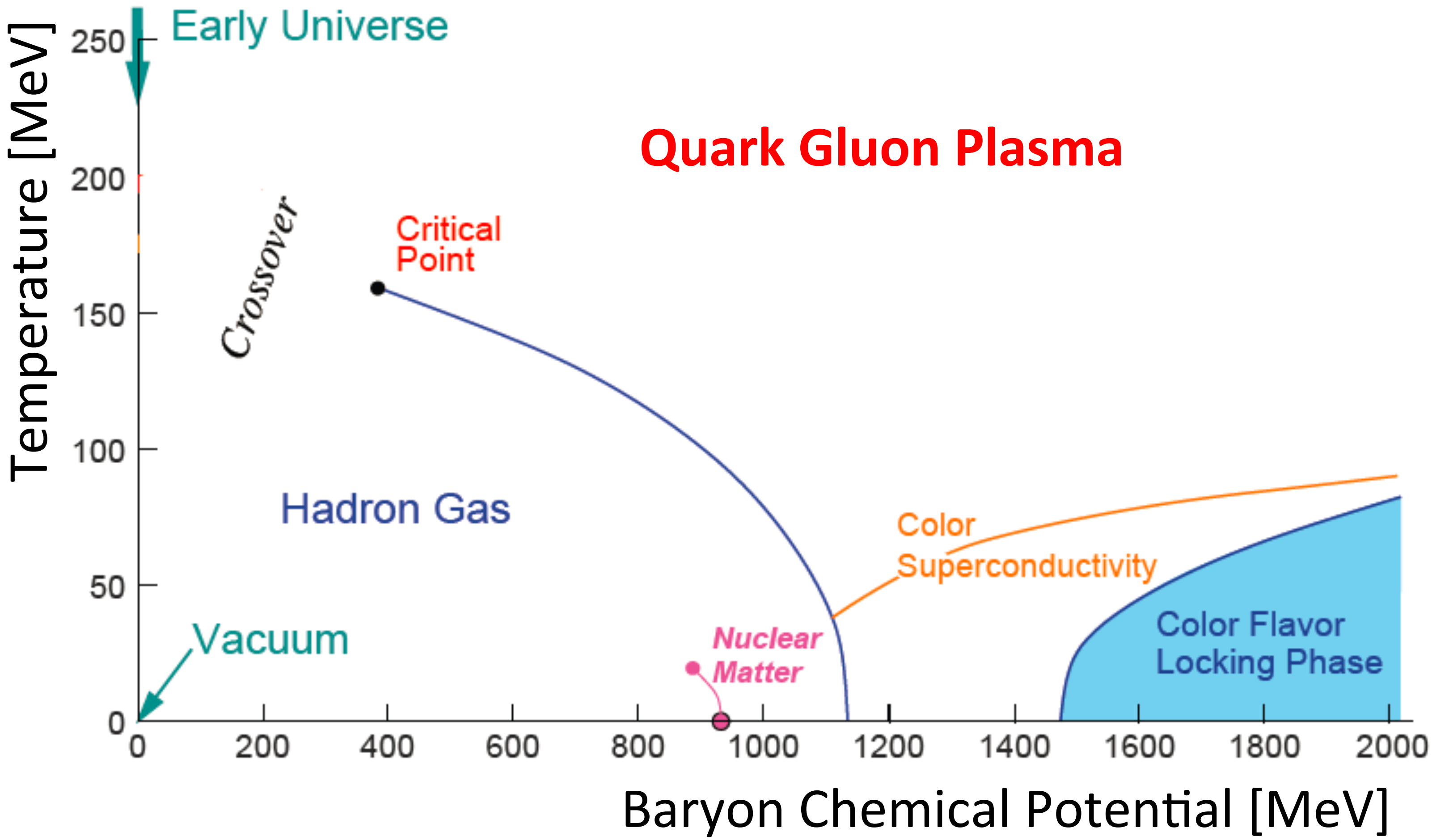
„1. The top priority for future quark matter research in Europe is the full exploitation of the physics potential of colliding heavy ions in the LHC“

Priority endorsed by NUPECC:

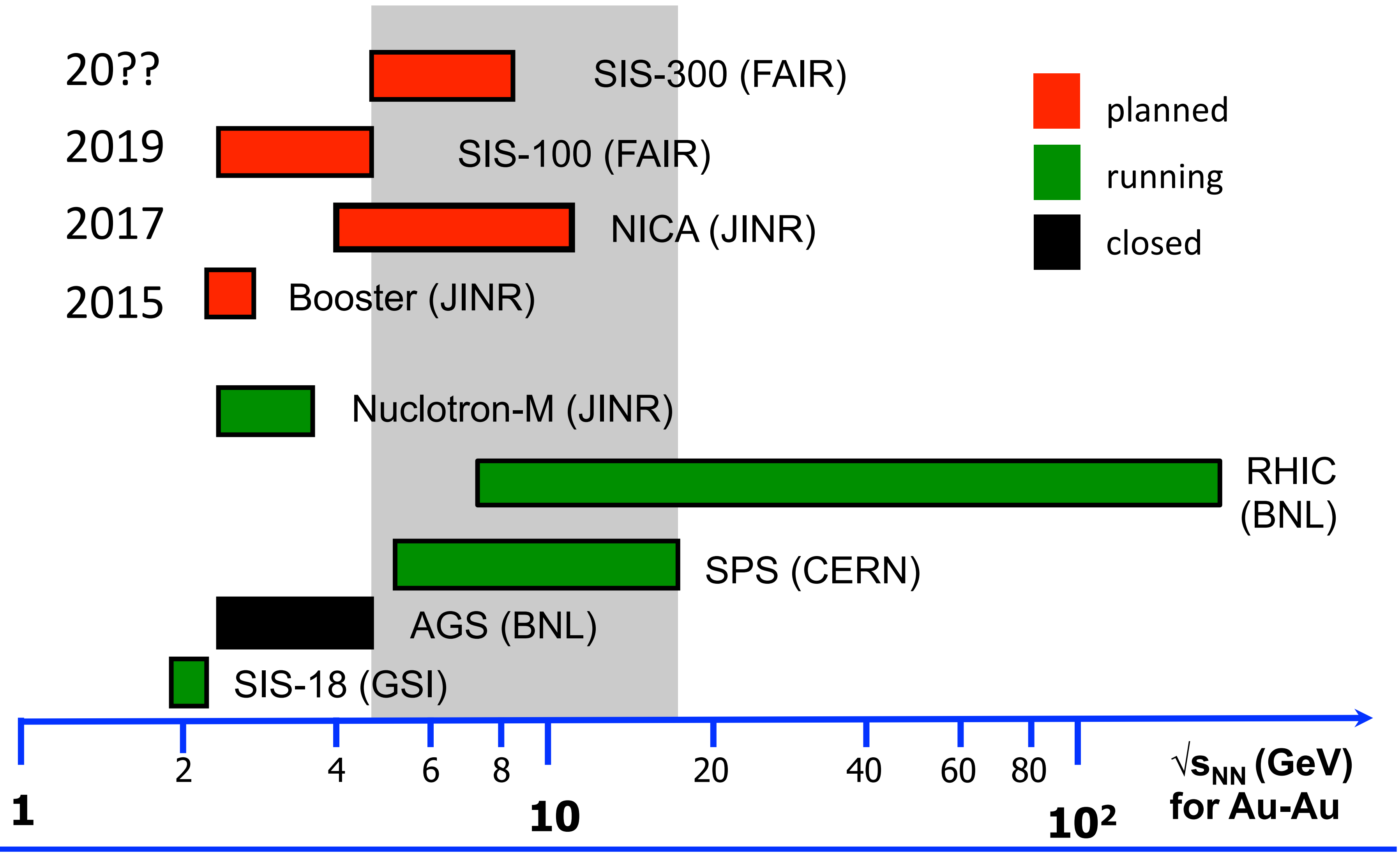
Contribution ID 32:

„Support for R & D to complete a technical design report for the LHeC was also included among the recommendations in the Long Range plan, but with lower priority. From the point of view of the Heavy Ion community, the LHec could thus be seen as an interesting option in the future, if the necessary critical mass of people could be assembled. The recent proposal to use Point 2 (where the ALICE experiment is located) as the interaction region for the LHeC is not supported, if installation were to start before 2025, because it is incompatible with the top priority of the Long Range plan.“

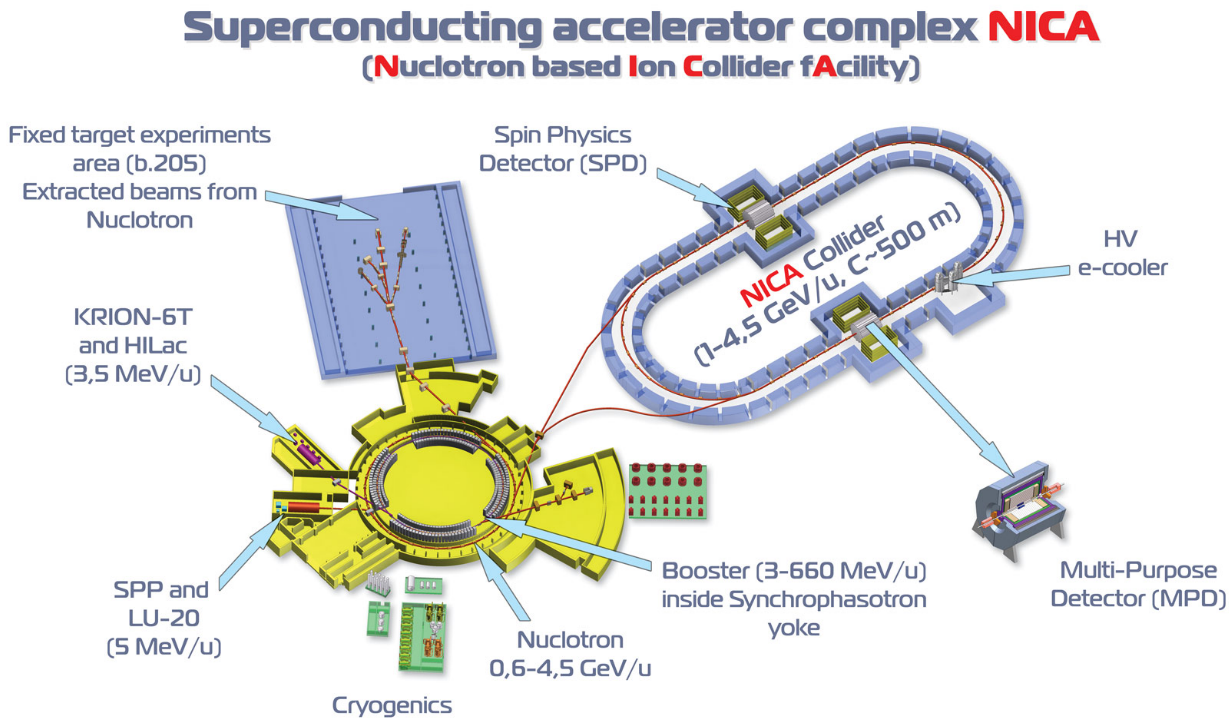
High baryon densities



Heavy-Ion facilities for high-μ_B studies



Future facilities - NICA



NICA:

- Based on existing Nuclotron at JINR/Dubna
- Heavy-Ion collisions in fixed-target (2015) and collider (2017) mode ($\sqrt{s_{NN}}$= 4-11 AGeV)

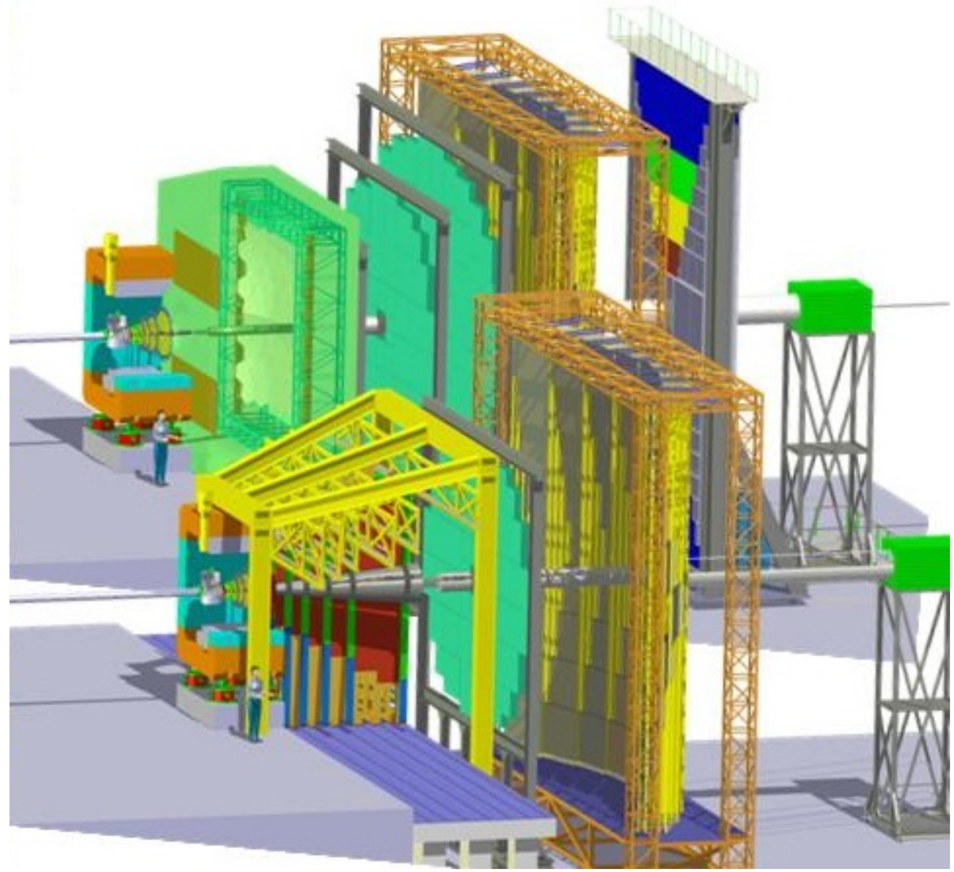
→ Competitive high luminosity collider at the low energy end

Future facilities - FAIR

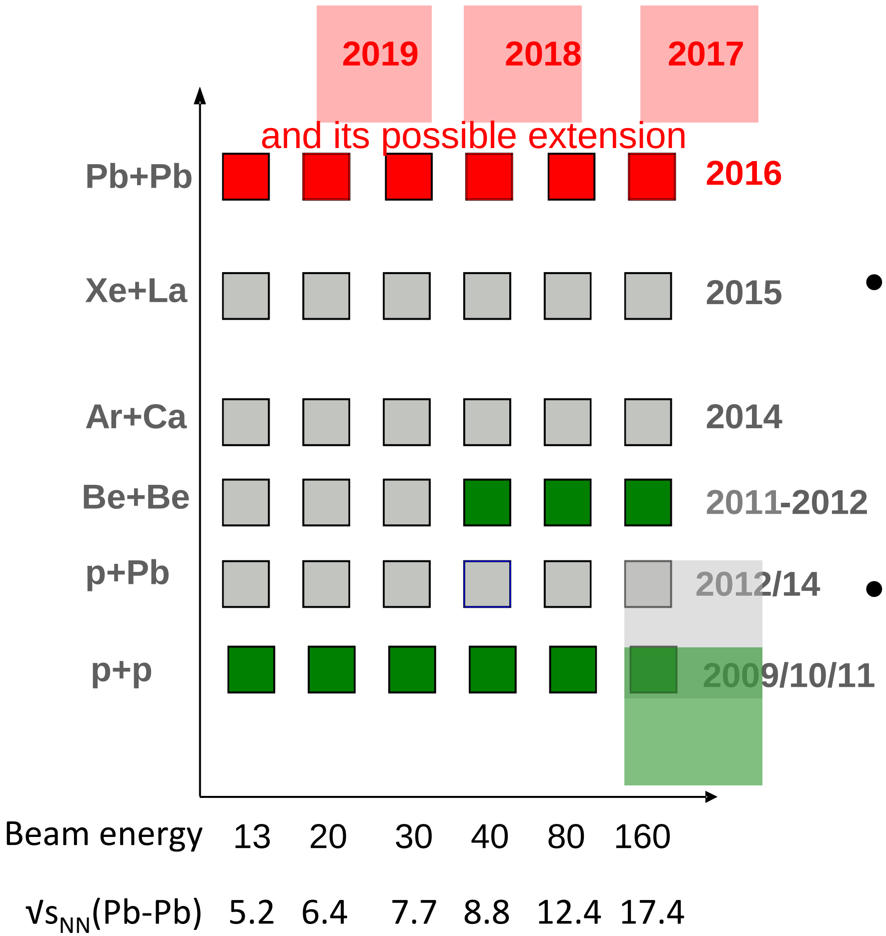
Compressed-Baryonic-Matter Experiment (CBM) at FAIR/GSI Darmstadt

2019: SIS100 ($\sqrt{s_{NN}}$ = 2-4.5 AGeV)
20??: SIS300 ($\sqrt{s_{NN}}$ = 4.2-9 AGeV)

- Fixed-target heavy-ion collisions at unprecedented rates (up to 10^9 ions/s)
- Study of rare probes (EM and charm) at highest baryon densities



SPS fixed-target: NA61/SHINE

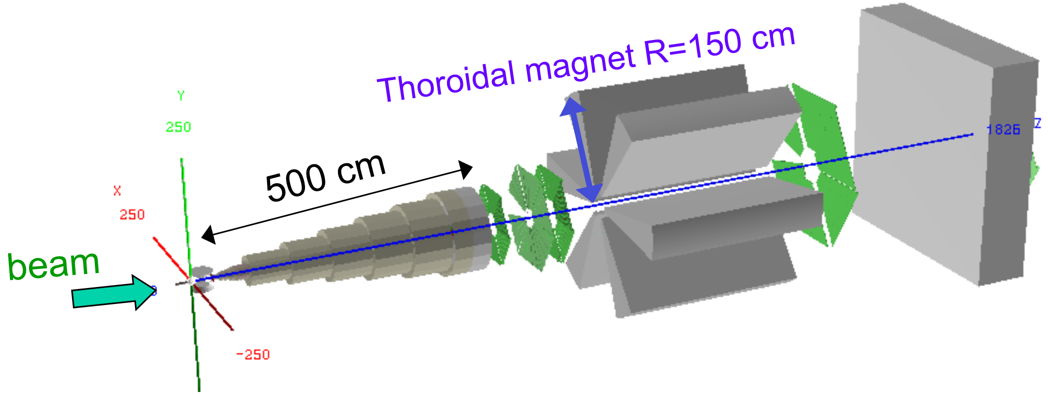


- systematic scan of system sizes and collision energies to locate the critical point
- possible extension beyond 2016 for high-statistics Pb-Pb running and charm measurement (upgrade required)

Future activities at the SPS

Proposal for NA60-like dimuon spectrometers to measure low-mass dileptons and charm at E_{beam}=20 – 160 AGeV ($\sqrt{s_{NN}}$= 6-17 AGeV):

- complementary to NA61: leptons vs hadrons
- high physics potential: onset of deconfinement and critical point
- competitive with RHIC: high luminosity



New facilities and fixed-target - conclusions

Conclusions of the Heavy-Ion Town Meeting:

„2. At lower center of mass energies where the highest baryon densities are reached, advances in accelerator and detector technologies provide opportunities for a new generation of precision measurements that address central questions about the QCD phase diagram“

„The town meeting also observed that the CERN SPS would be well-positioned to contribute decisevely and at a competetive time scale to central open physics issues at large baryon density. In particular, the CERN SPS will remain also in the future the only machine capable of delivering heavy-ion beams with energies exceeding 30 AGeV, and the potential of investigating rare probes at this machine is very attractive.“

Discussion

- QCD
  - Need to continue fixed target program at CERN
    - COMPASS, NA61 and possible new experiments at SPS
    - AFTER @ LHC
  - Saturation effects are probe dependent
    - One should study them in all configurations: ep, pp and HI
  - Lattice calculations continue to improve in precision
    - Need to be verified experimentally

Discussion

- LHeC
  - Clear physics case, but one should also consider what can be done at LHC (with HL and possible detector upgrades).
  - No statement from LHC on the need for concurrent running.
  - Possible conflict with LHC running / ALICE
    - Installation within ~1 year shutdown too optimistic
    - HL running with HI planned – LHeC only after 2025
  - Work on TDR not yet completed
    - Any decision not before LHC 14TeV results, next strategy update?

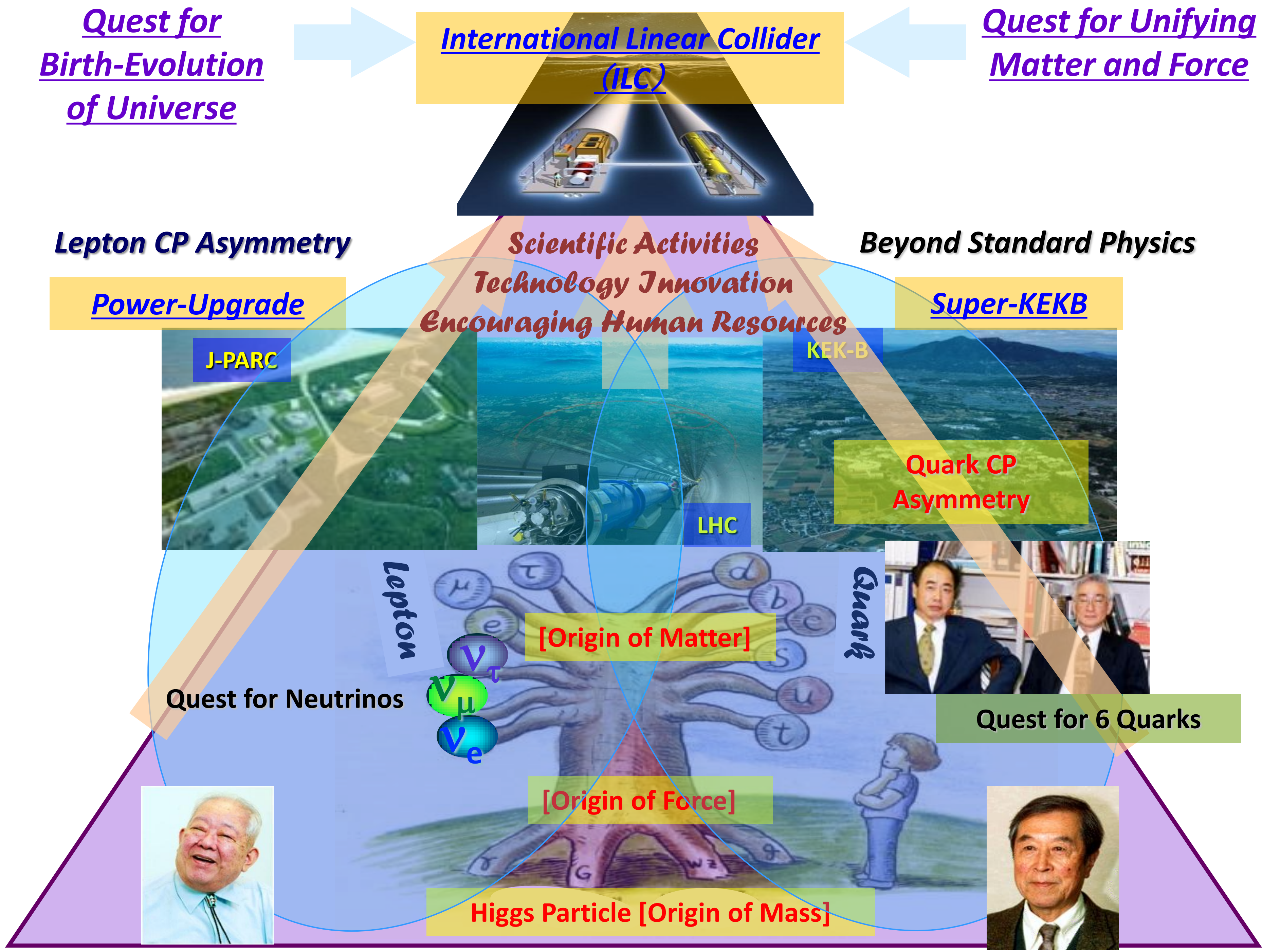
Discussion

- LHeC
  - Is it complementary with US projects (EIC)?
    - No option for spin-spin scattering
  - New detector needed, but not many people involved so far.
    - Difficult to attract people from LHC experiments.
  - Liniac considered for LHeC could first run as $\gamma\gamma$ collider (resonant Higgs production)
    - Energy recovery not possible

Discussion

- Heavy Ions
  - Why not consider going beyond 10nb^{-1} at LHC?
    - Accelerator and detector limitations
  - B physics in HI collisions - challenging
    - detector upgrades and high luminosity required
  - Higher priority should be given to HI physics at SPS
    - Interesting physics case in this domain
    - otherwise community will move to RHIC
  - Do we need experiments at 4 HI facilities?
    - RHIC, SPS, NICA, FAIR

Time line of particle physics program in Japan



Quest for Birth-Evolution of Universe
International Linear Collider (ILC)
Quest for Unifying Matter and Force
Lepton CP Asymmetry
Scientific Activities
Technology Innovation
Encouraging Human Resources
Beyond Standard Physics
Power-Upgrade
Super-KEKB
J-PARC
KEK-B
LHC
Quark CP Asymmetry
Lepton
Quark
[Origin of Matter]
Quest for Neutrinos
Quest for 6 Quarks
[Origin of Force]
Higgs Particle [Origin of Mass]

What follows LHC on Energy Frontier?

What new facility will follow the LHC: **Higgs factory, ILC (500 GeV), CLIC (>1 TeV), Muon collider (>1 TeV), HE-LHC energy?**

Science must be the guide! What will 14 TeV running at the LHC reveal?

- **Too early to select a Higgs factory.**
- **Agency does not see the science justification at this moment to put U.S. hosting or participation into future budgets.**
  - **Intensity Frontier and LHC plans nearly saturate budget planning.**
  - **Situation can change if science arguments emerge that are powerful enough.**

U.S. is doing R&D on several of possible future accelerators.

- **ILC technology is aligned with Project X. U.S. continues relevant SRF R&D program even after the ILC funding cut off in 2012.**
- **If several TeV is needed ultimately, either CLIC or a Muon Collider will be needed. Most U.S. effort is on studying the feasibility of the muon collider (MAP program). Both are formidable enterprises.**
- **If the basis for lepton colliders is not established by the LHC, a natural extension will be the "energy doubler" for LHC, HE-LHC. The U.S. program is carrying out the R&D program on Nb_3Sb in collaboration with CERN.**

To conclude I

- If we can do everything in everyplace at anytime, we do not need strategy.
- We can do (almost) everything only if we exploit fully the four dimensional space-time → strategy
- Scientific case is a crucial input for setting up the strategy, however…
  - Obviously there is not enough resources.
  - Many non-scientific (political, social, economical, etc.) factors.
  - But also importance for different scientific cases are neither uniquely nor objectively defined: different scientific tastes.
- As nature shows, difference is also strength: but we need compromises, concessions, patience, and determination to reach a strategy!

To conclude II

- New facilities are getting long term and expensive projects: consequence of failing is BIG!

becoming too conservative?

(Some) Questions for Discussion from Klaus Desch's talk

(Remember: "Physics First")

1. What is the physics case for upgrades or new machines if LHC provides a null result?

2. Clear statements (ECFA, ACFA, HEPAP, ICFA, GSF,…) in 2001-2004 that a Linear Collider of up to at least 500 GeV, upgradeable to 1 TeV, should be the next major project and requires timely realization. Has the physics case changed since then?

3. Is there a clear physics case for multi-TeV lepton colliders now? At which energy?

4. What is the physics case for SLHC/DLHC? Which priority?

5. Muon Collider: any physics reason to discuss it (already) now?

Conclusions

- New results should have helped defining strategy, but
  - Physics scenario still not clear
  - Physics case still not convincing (!?)
  - Other constraints enter due to limited resources
    - Financial
    - Manpower
    - Expertise
    - Space-time (eg. at CERN)
- Symposium did not end with any firm conclusions
  - Input from community reviewed
  - Key questions identified
  - Preparatory Group and invited experts will work on preparing a consistent picture for Strategy Group (Briefing Book).