LHC: Overview and Outlook

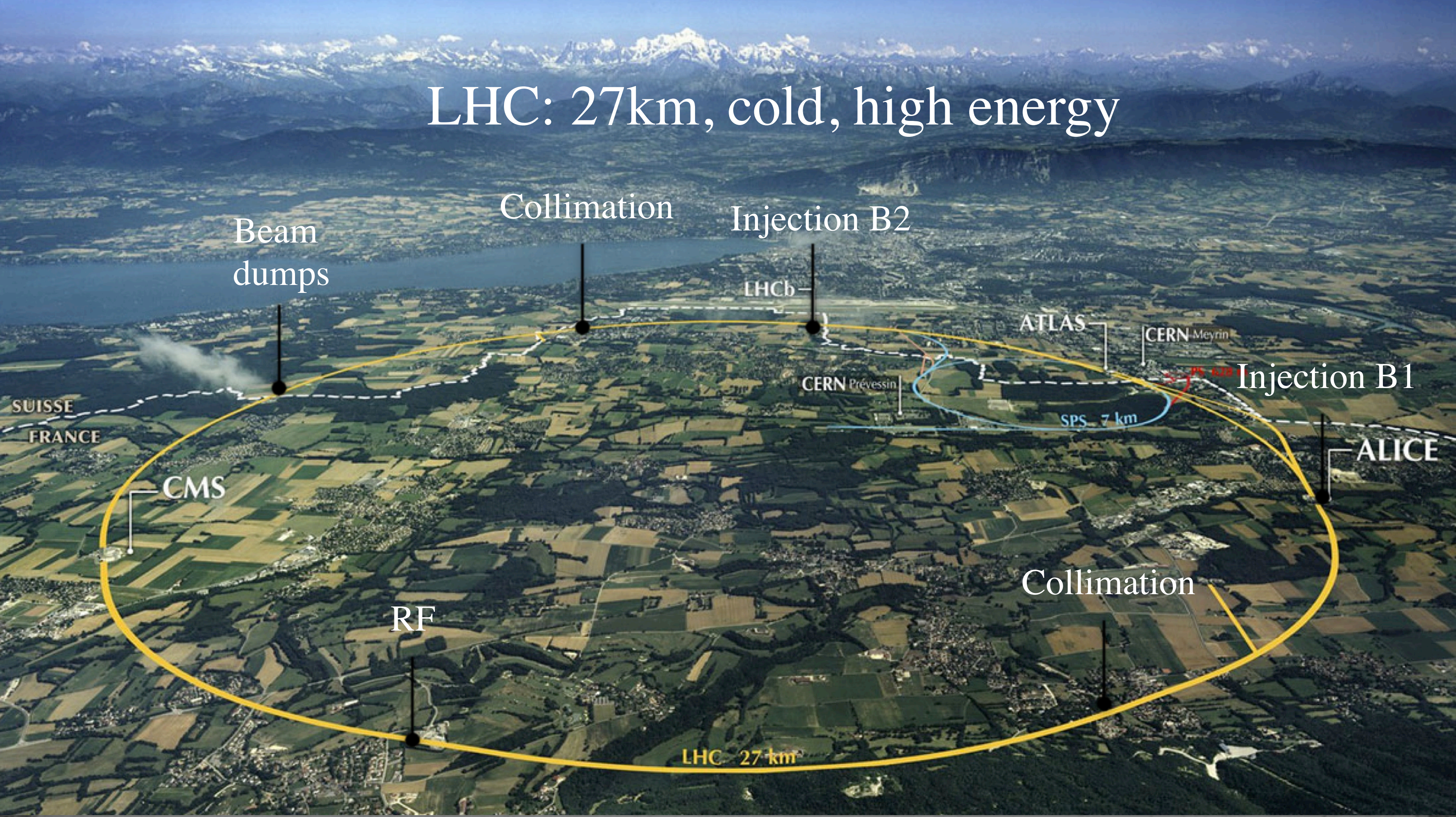
LHC Status
Results on QCD at the LHC
HL LHC, Partons, Precision
Future Higgs
LHeC Development
Remarks

Max Klein, University of Liverpool

Introduction of/to QCD@LHC, DESY, 2.9.2013

Elbe Fireworks in May 2009

LHC: 27km, cold, high energy



1720 Power converters
> 9000 magnetic elements
7568 Quench detection systems
1088 Beam position monitors
~4000 Beam loss monitors

150 tonnes Helium, ~90 tonnes at 1.9 K
140 MJ stored beam energy in 2012
450 MJ magnetic energy per sector at 4 TeV

M.Lamont, EPS13

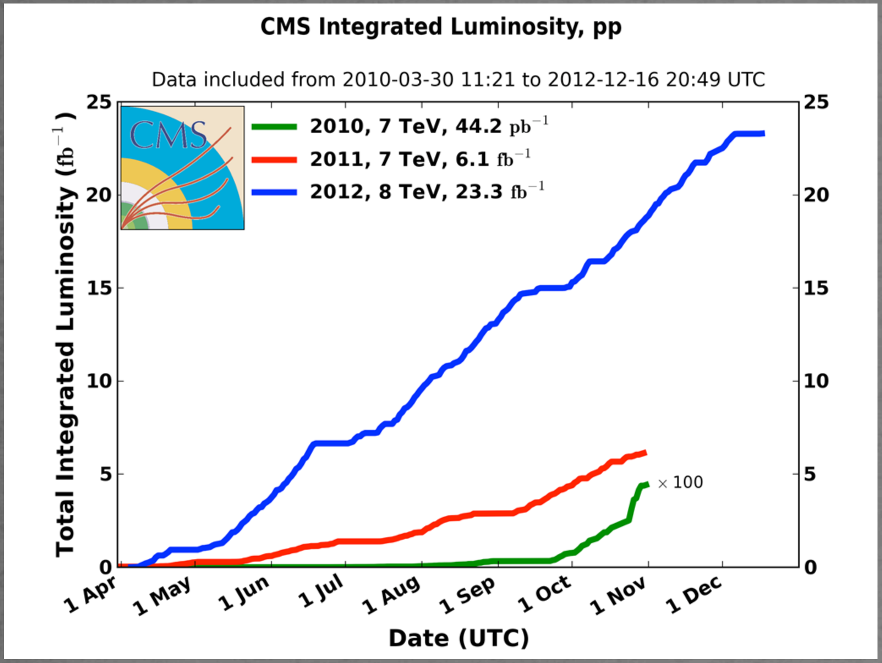
Development of LHC 2010-2012

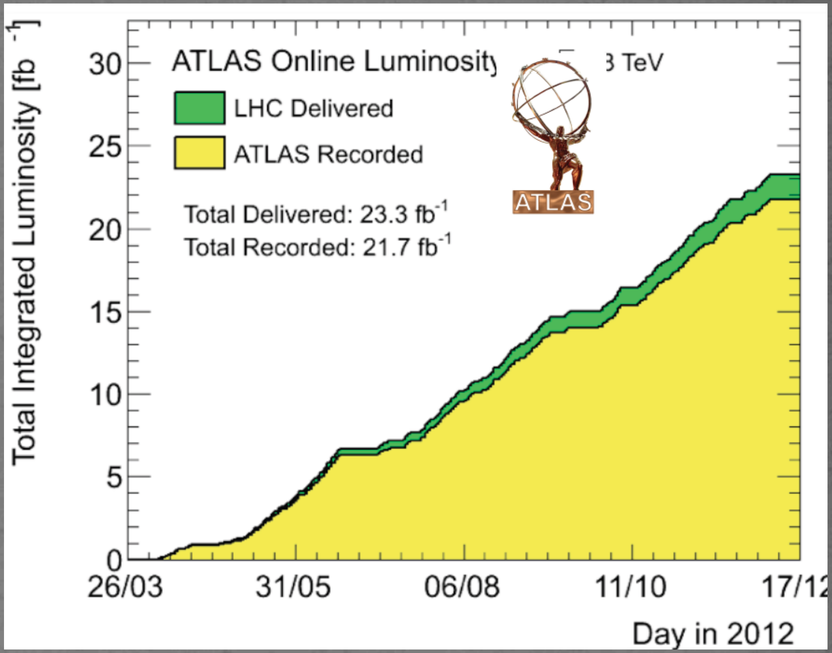
	2010	2011	2012	**Nominal**
Bunch spacing [ns]	150	50	50	25
No. of bunches	368	1380	1380	2808
beta* [m] ATLAS and CMS	3.5	1.0	0.6	0.55
Max **bunch intensity** [protons/bunch]	1.2×10^{11}	1.45×10^{11}	1.7×10^{11}	1.15×10^{11}
Normalized **emittance** [mm.mrad]	~2.0	~2.4	~2.5	3.75
Peak luminosity [$cm^{-2}s^{-1}$]	2.1×10^{32}	3.7×10^{33}	7.7×10^{33}	1.0×10^{34}

O.Bruening at ATLAS US 7/13

Major success of CERN and the basis for the existence of modern particle physics

Accumulation of Luminosity

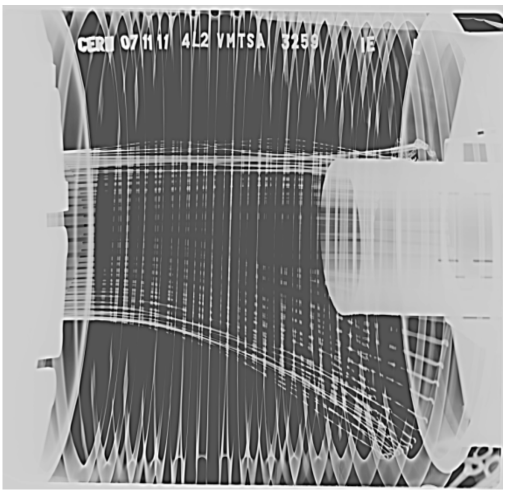




Outstanding efficiency for luminosity recording by the experiments.
Measured with beam scans and forward detectors to 2-4% precision!
4 TeV beam energy: 3988 +-5 +- 26 GeV → J.Wenninger CERN-ATS-2013-040

Smooth appearance of LHC ...

Beam induced heating

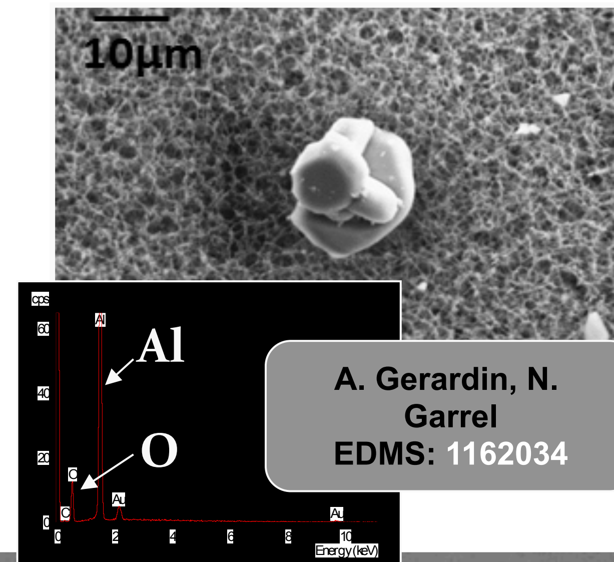


Vacuum, RF fingers 7R7, August 2012.

not Au coated..

UFOs

- 20 dumps in 2012
- Timescale 50-200 μs
- Conditioning observed
- Worry about 6.5 TeV



A. Gerardin, N. Garrel
EDMS: 1162034

Spark discharges at injection kicker and arcs
Increase with E and reduced bunch spacing
New calibration of beam loss signals..

Blow up of emittance in LHC wrt injectors,
Impedance and beam stability
UFOs
Time for scrubbing – e cloud – 25ns?
Electronics away from radiation..

....owing to superb accelerator team

The main 2013-14 LHC consolidations

1695 Openings and final reclosures of the interconnections

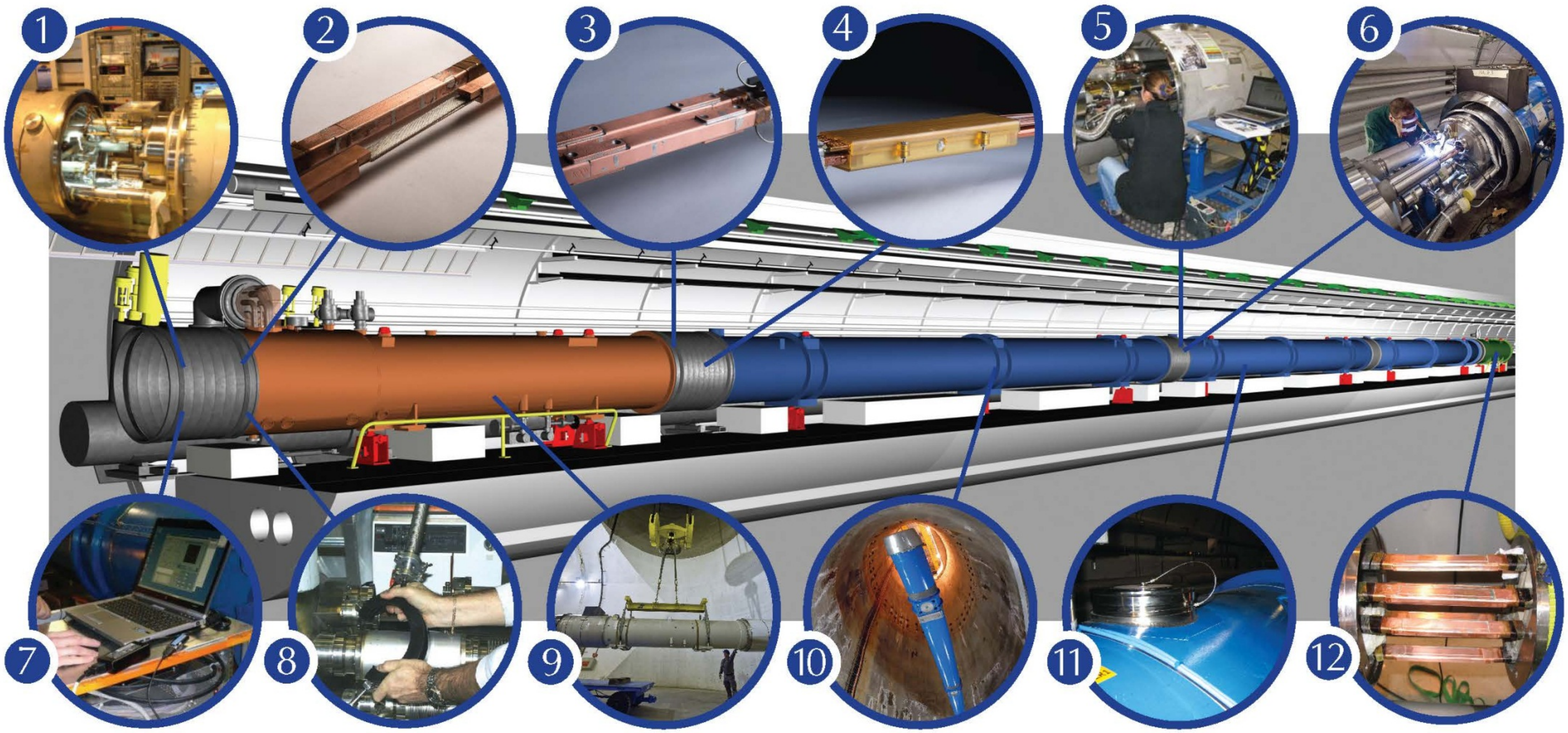
Complete reconstruction of 1500 of these splices

Consolidation of the 10170 13kA splices, installing 27 000 shunts

Installation of 5000 consolidated electrical insulation systems

300 000 electrical resistance measurements

10170 orbital welding of stainless steel lines



18 000 electrical Quality Assurance tests

10170 leak tightness tests

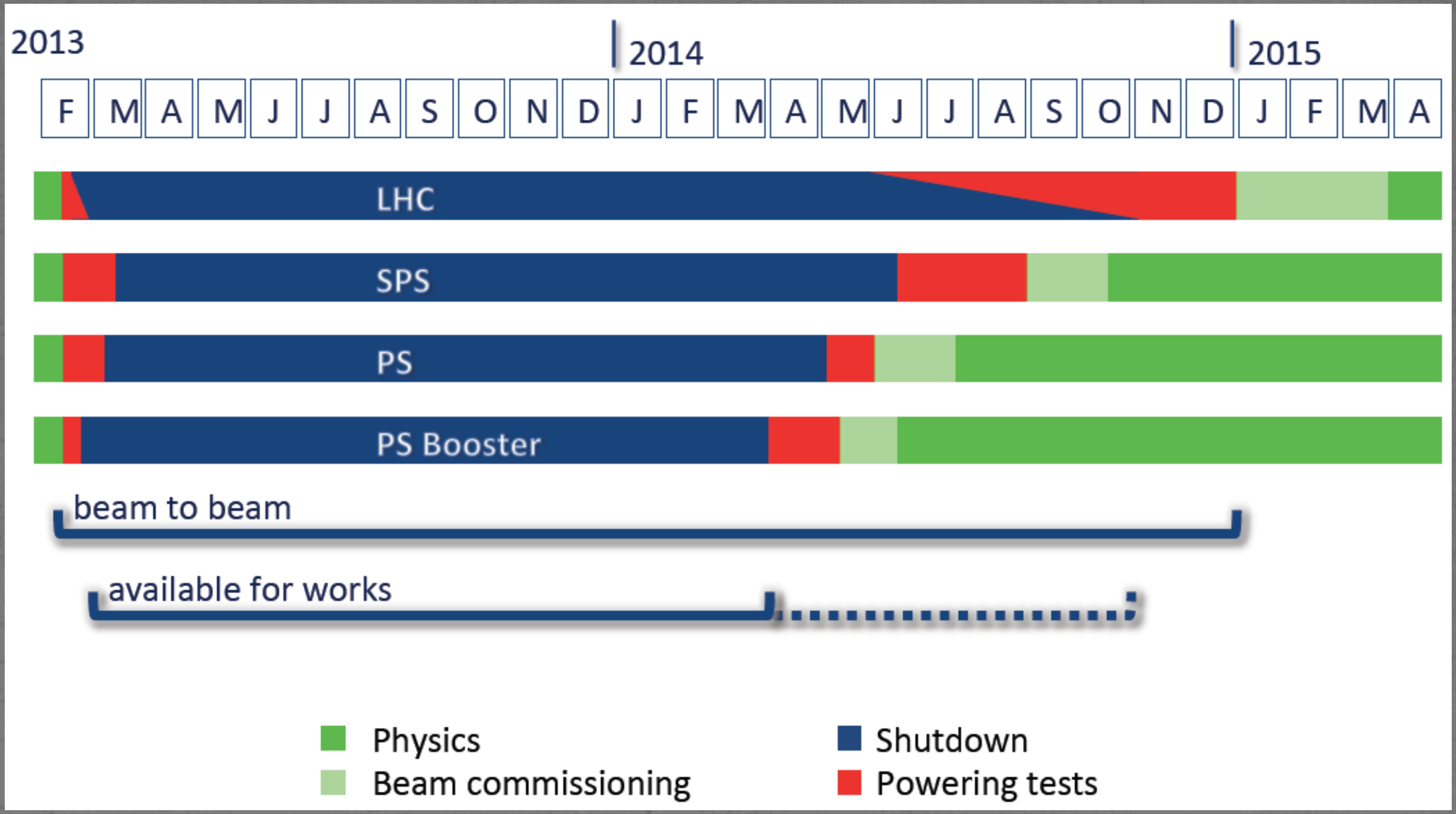
4 quadrupole magnets to be replaced

15 dipole magnets to be replaced

Installation of 612 pressure relief devices to bring the total to 1344

Consolidation of the 13 kA circuits in the 16 main electrical feedboxes

LHC Shutdown LS1



K.Foraz, LHCC June 2014

LHC back for physics in April 2015 with most probably 13 TeV, i.e. 1.6 times enlarged energy

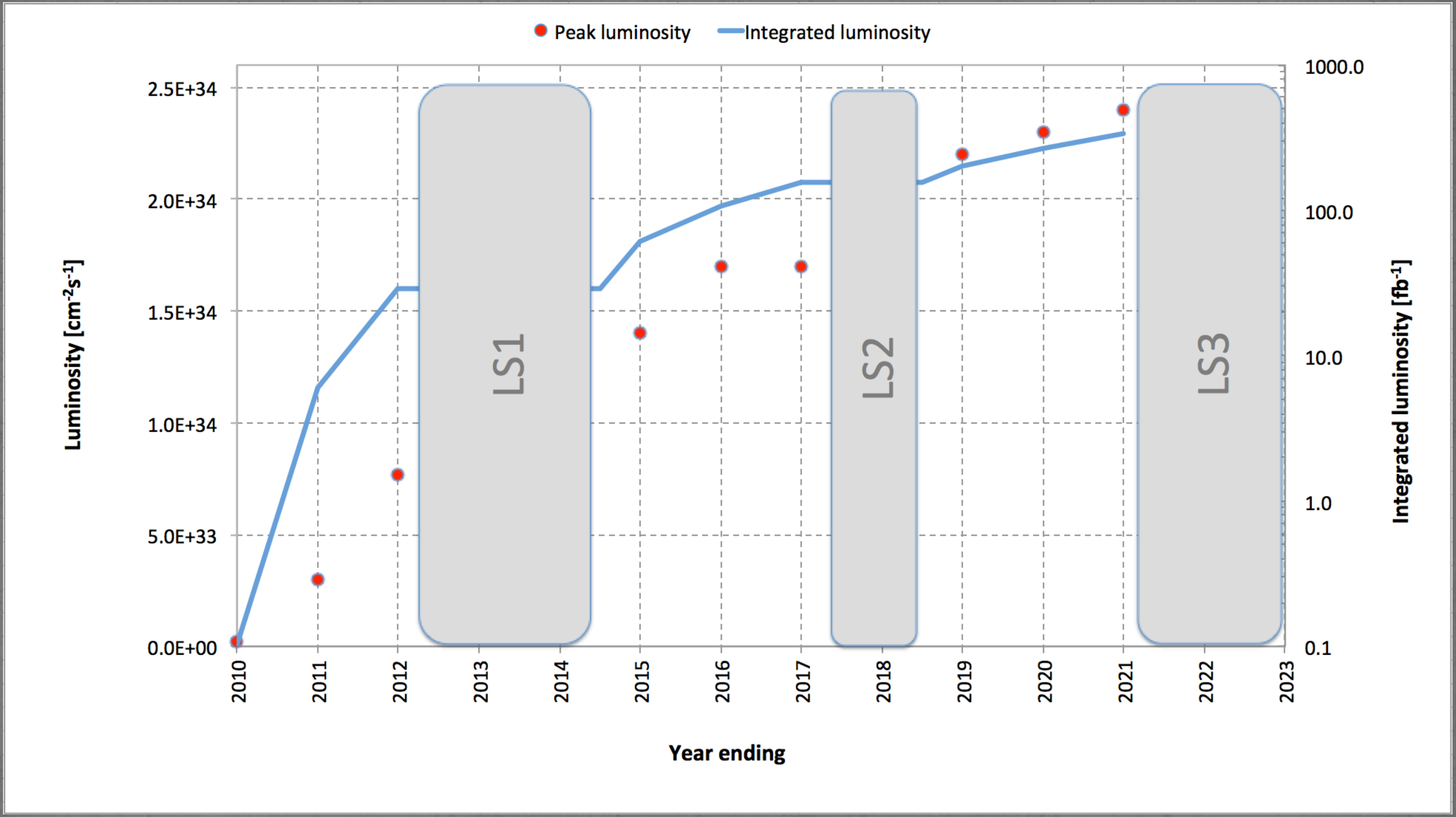
Conditions for Restart in 2015

	Numbe r of bunche s	Bunch intensity LHC [1e11]	β*X/ β*sep/ Xangle	Emit LHC [μm]	Peak Lumi [$cm^{-2}s^{-1}$]	~Pile-up	Int. Lumi per year [fb^{-1}]
25 ns	2760	1.15	55/43/189	3.75	0.93 x 10^{34}	25	~24
25 ns low emit	2520	1.15	45/43/149	1.9	1.7 x 10^{34}	52	~45
50 ns	1380	1.6	42/43/136	2.5	1.6 x 10^{34} level to 0.8 x 10^{34}	87 level to 44	~40
50 ns low emit	1260	1.6	38/43/115	1.6	2.3 x 10^{34} level to 0.8 x 10^{34}	138 level to 44	~40

O.Brüning at ATLAS US 7/13

→ Increase in L_{peak} by 2-3 and energy by 1.6

Luminosity Expectation until early Twenties*)



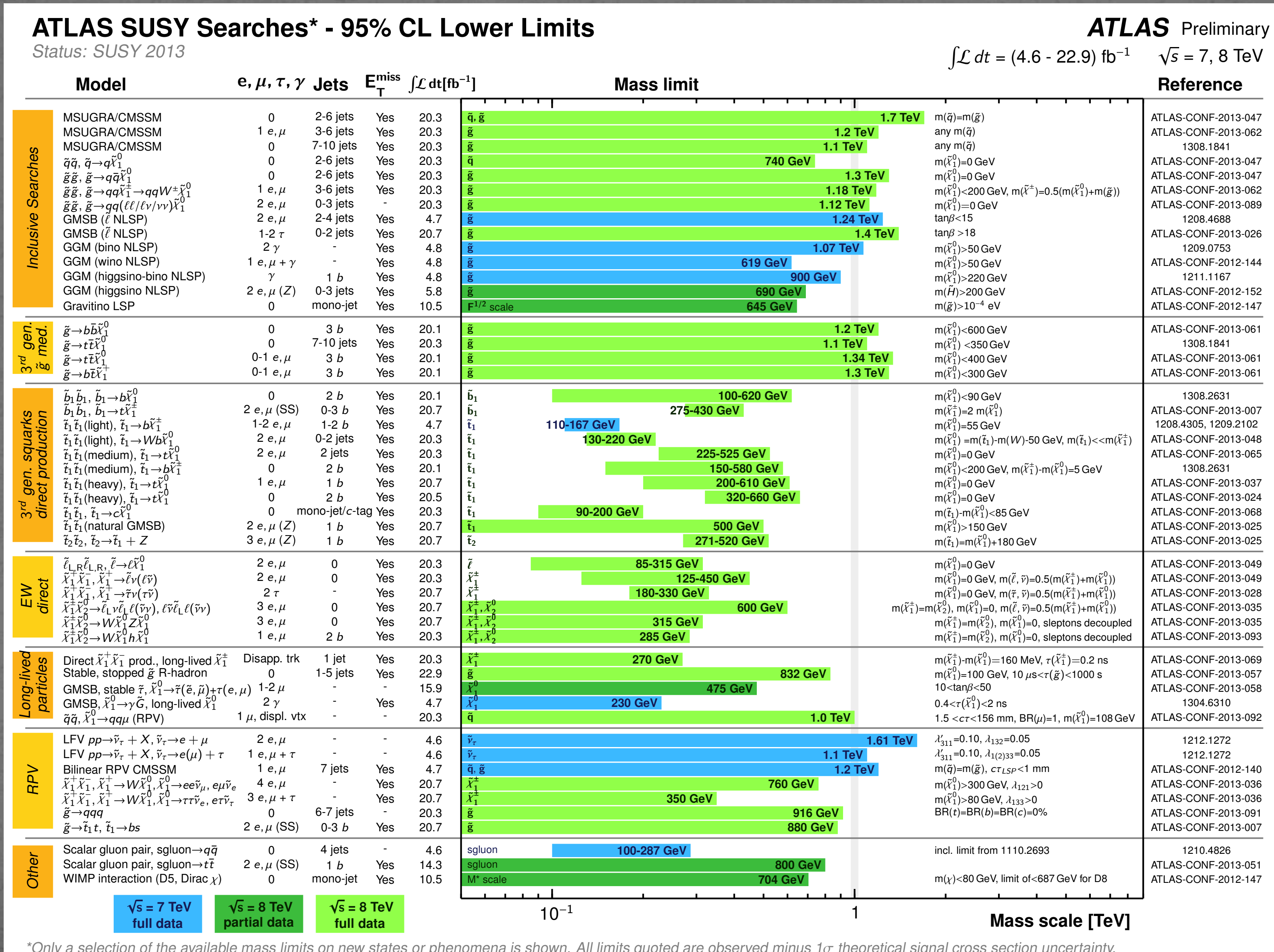
*) This fall machine workshop to discuss near and further schedule and plans

Huge success of the HEP Community

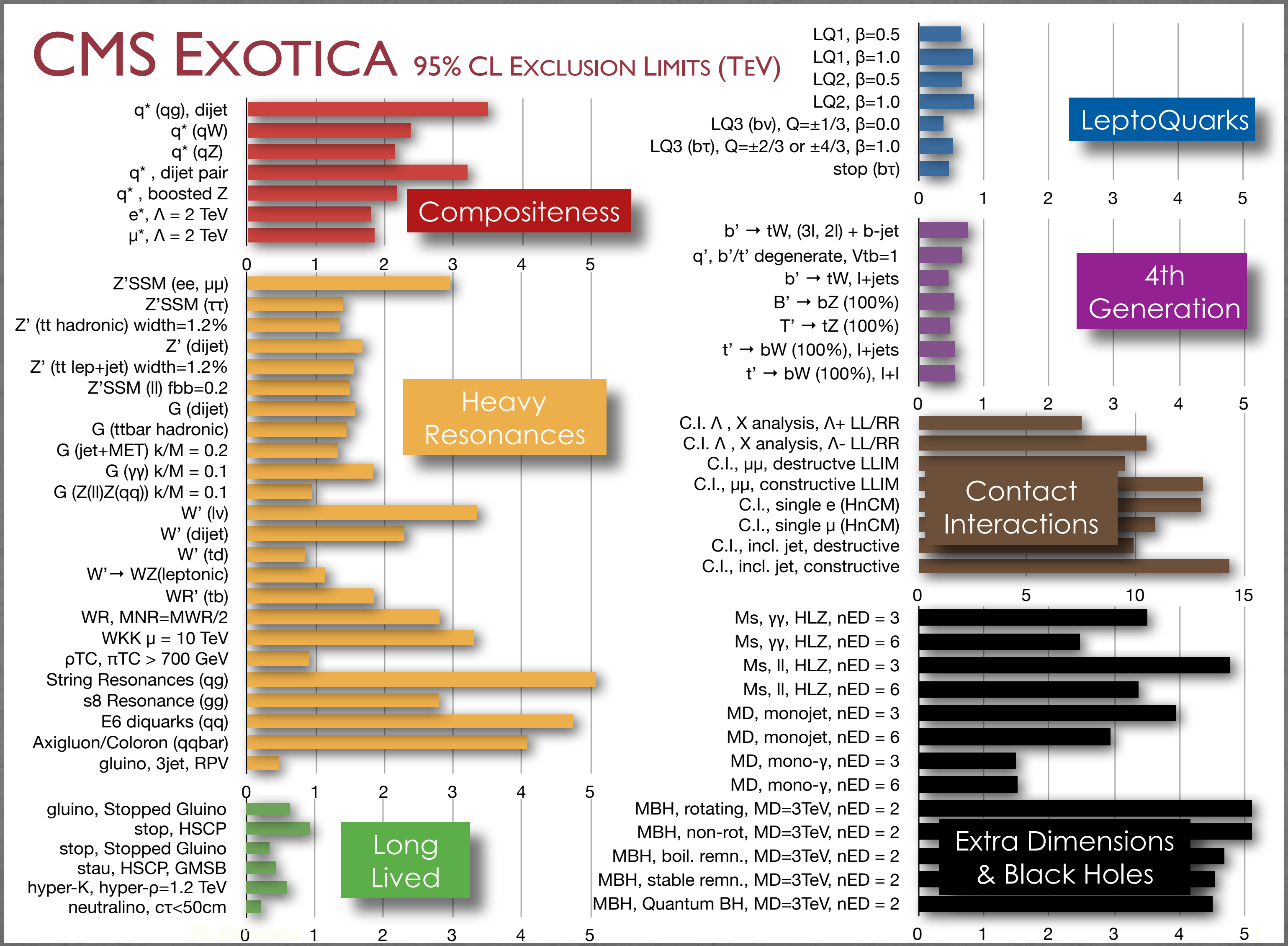
4.7.2012 greeting Melbourne from CERN

"The Higgs: So simple and yet so unnatural" G.Altarelli,arXiv:1308.0545

Searches for New Physics BSM



Searches for New Physics BSM



Results on QCD at the LHC

Preface

“We like to see particle physics as driven by experiment …”

Burt Richter
2009

FUNDAMENTAL THEORETICAL QUESTIONS

M. Froissart, Rapporteur

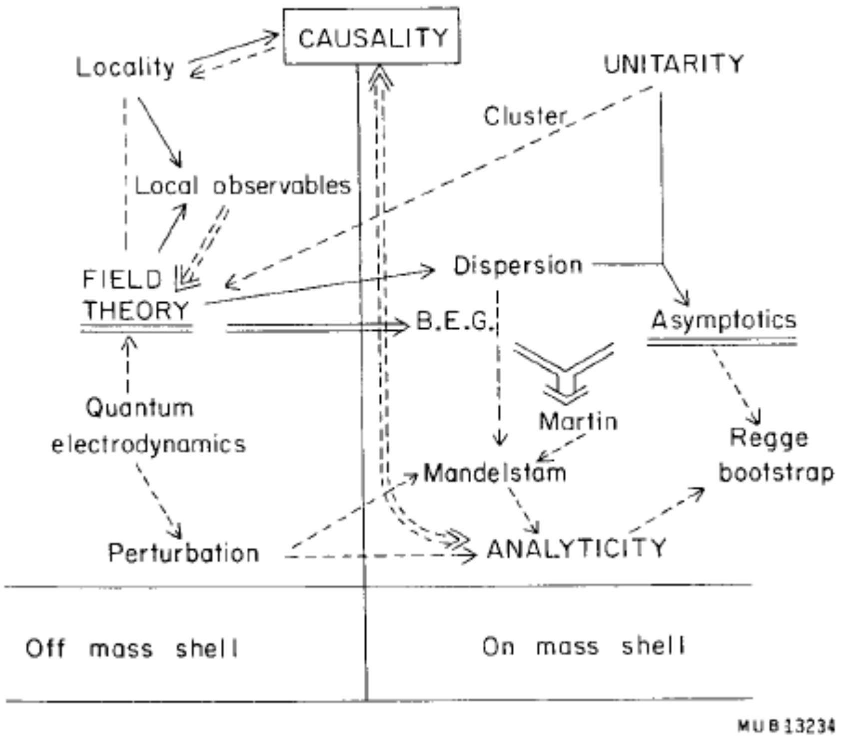


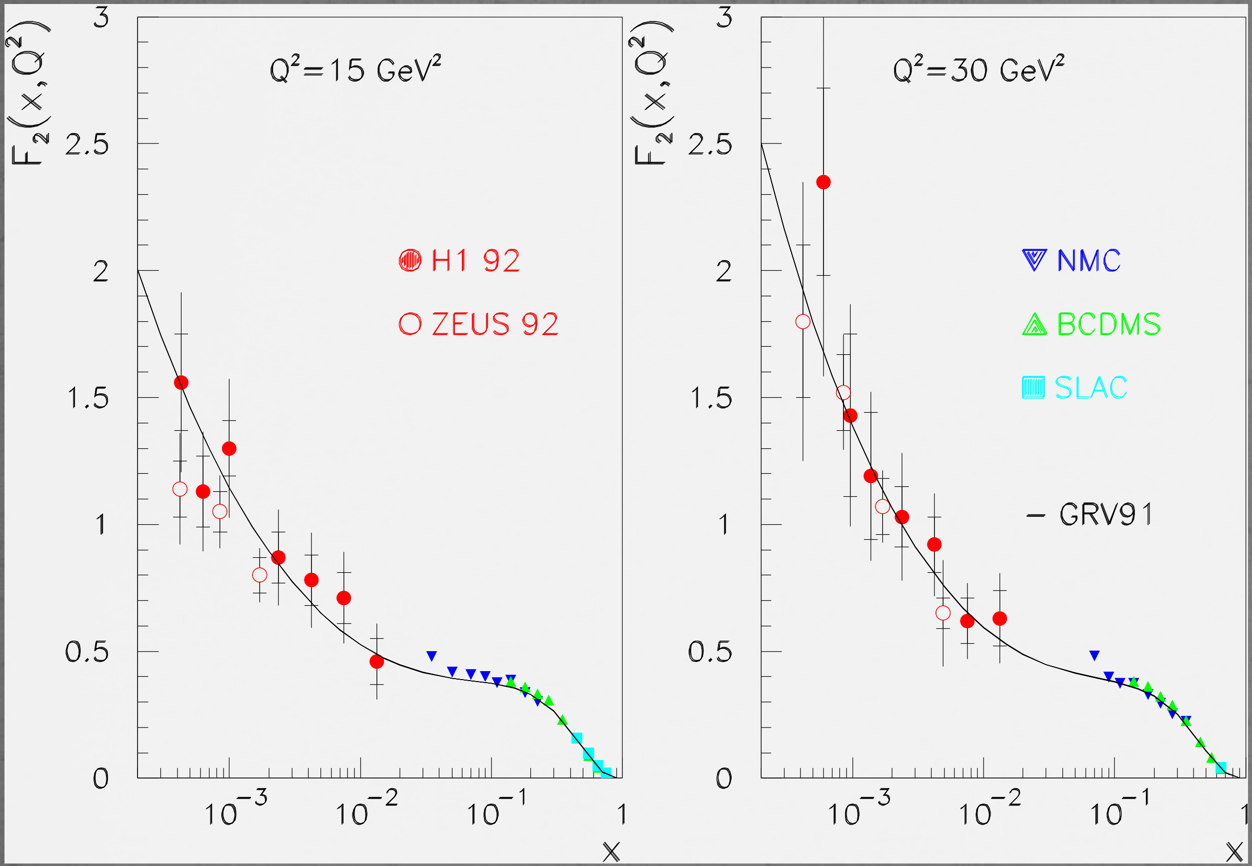
Fig. 1-1. Logical map of "Fundamental" concepts.

QCD yet a prime example of the joint efforts of experiment AND theoretical physics

Rapporteur talk by M.Froissart, Rochester Conference 1966

The rise of F_2 to Low x

August 1993



First measurements of low x scaling violations with ~20nb^{-1} (!), by H1 and ZEUS at HERA

"Not for the New York Times but for the textbooks of physics.." Bjoern Wiik

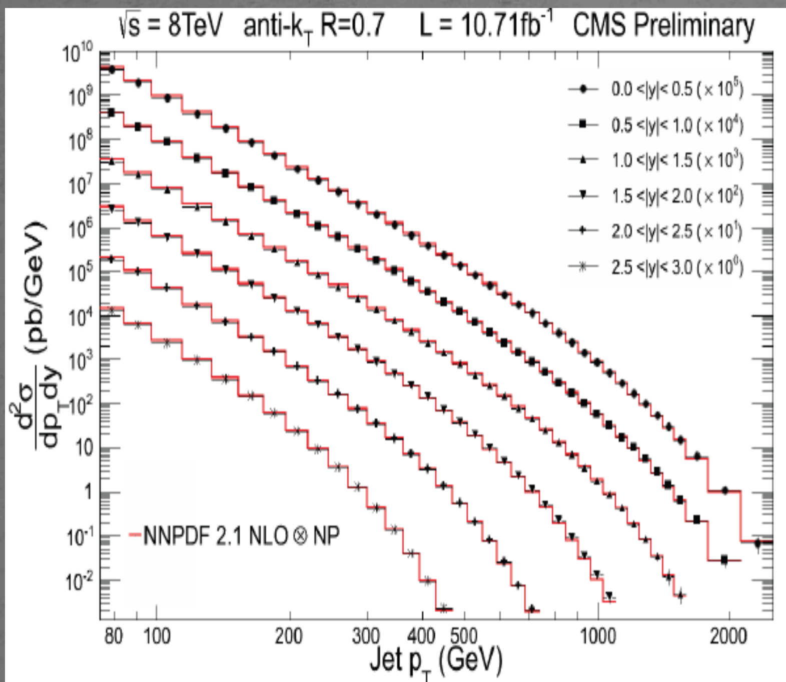
Practically free of background, apart from a bit of γp at high y.. Redundant e-h kinematics → precision

Not rigorously predicted though in accord with QCD:

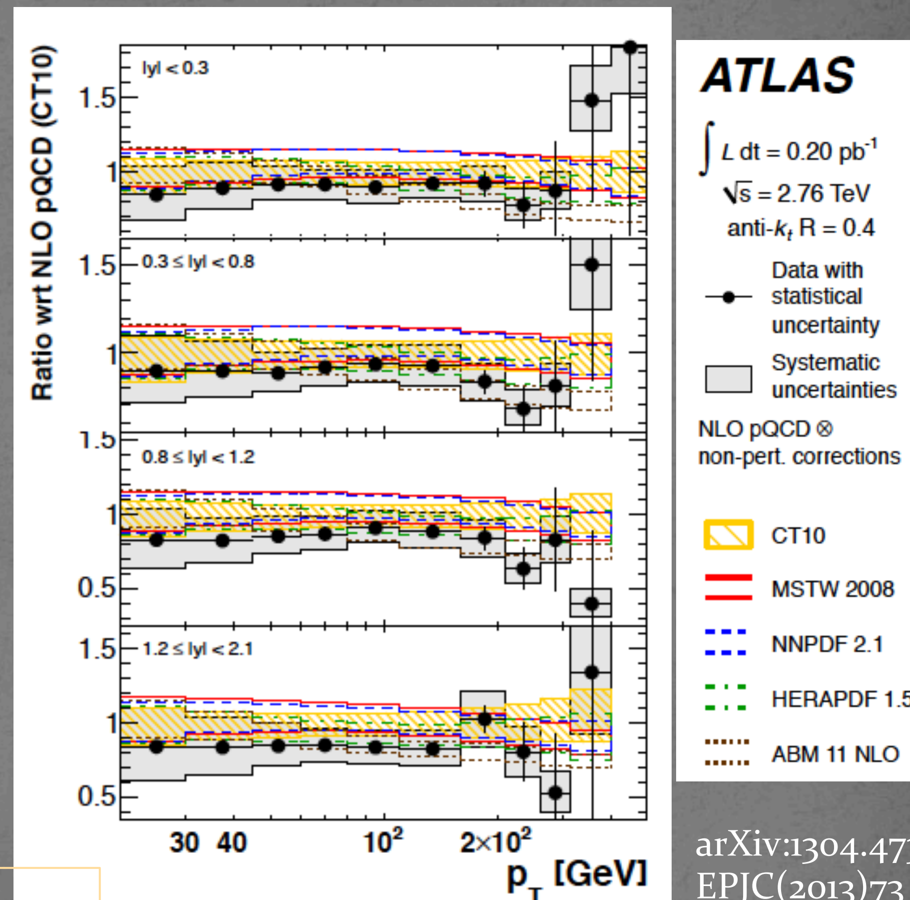
"Possible non-Regge behaviour of Electroproduction Structure Functions"
A DeRujula, SL Glashow, HD Politzer, SB Treiman, F Wilczek, A Zee: PhysRev D10(1974)1649

QCD at the LHC

Jets, Photons, Vector Bosons, Vector Bosons+Jets, Soft QCD [lowx, MPI, diffraction]



CMS-PAS-SMP-12-02



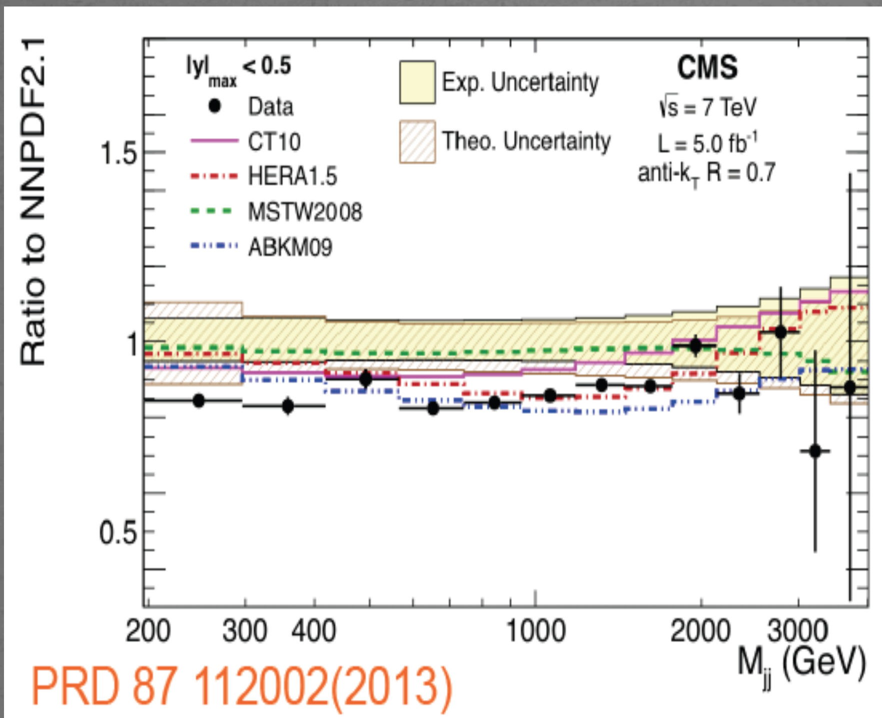
arXiv:1304.4739
EPJC(2013)73 2509
.. extends to 4.4

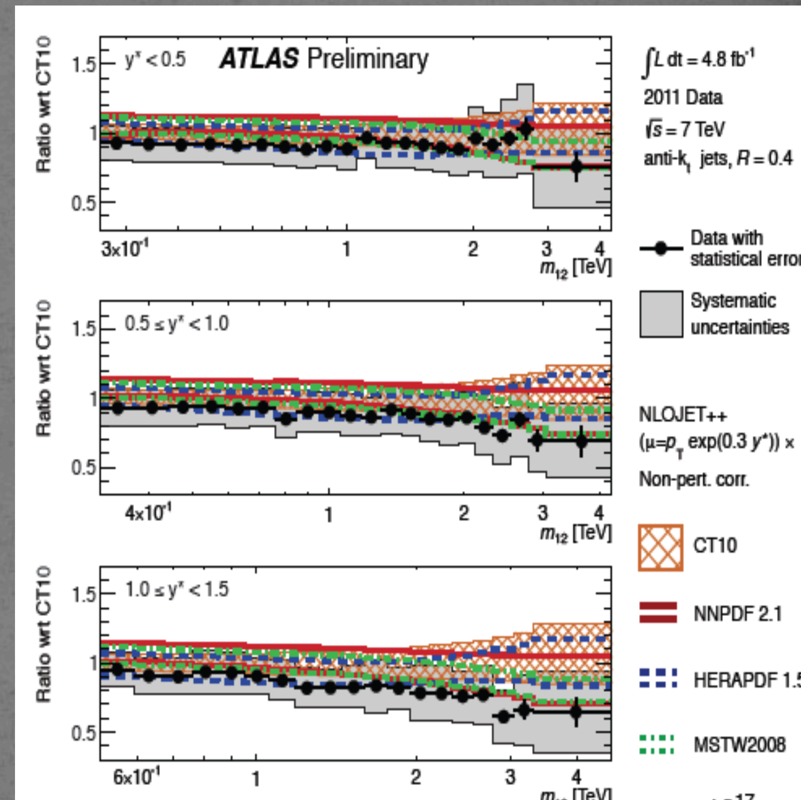
ATLAS-CONF-2013-041:R3/2
α_s = .111 +- .006 +0.016-0.003 (thy)

Inclusive jet cross sections and their energy dependent ratios well described by NLO QCD

QCD at the LHC

Jets, Photons, Vector Bosons, Vector Bosons+Jets, Soft QCD [lowx, MPI, diffraction]



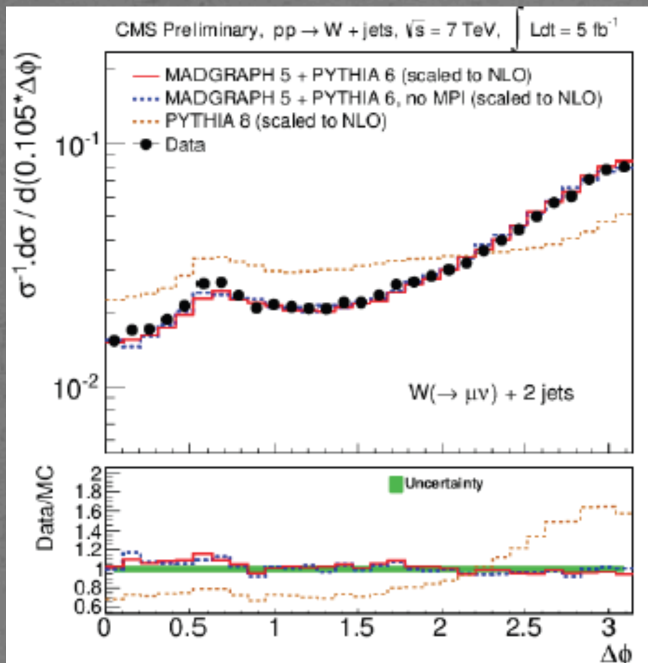


ATLAS-CONF-2012-021

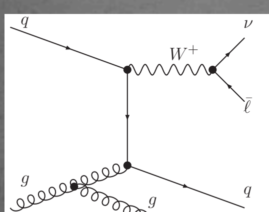
Di-jet cross sections to about 10% in agreement with QCD + different PDFs

QCD at the LHC

Jets, Photons, Vector Bosons, Vector Bosons+Jets, Soft QCD [lowx, **MPI**, **diffraction**]



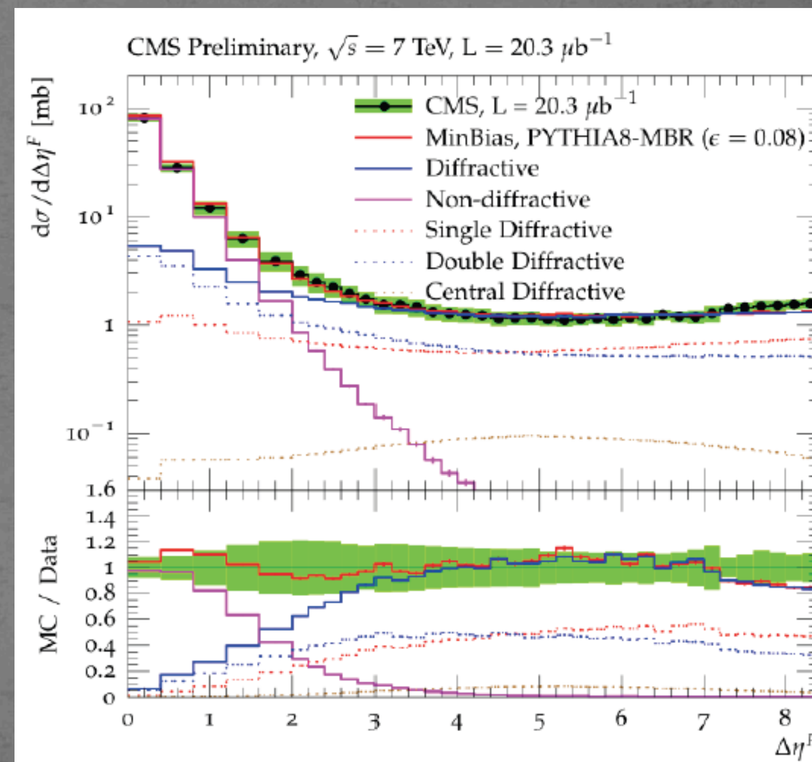
CMS-PAS-FSQ-12-028



MPI's in W+jj data

ATLAS: New J. Phys. 15 (2013) 033038

Diffraction (SD+DD) up to Δη =8



CMS-PAS-FSQ-12-005

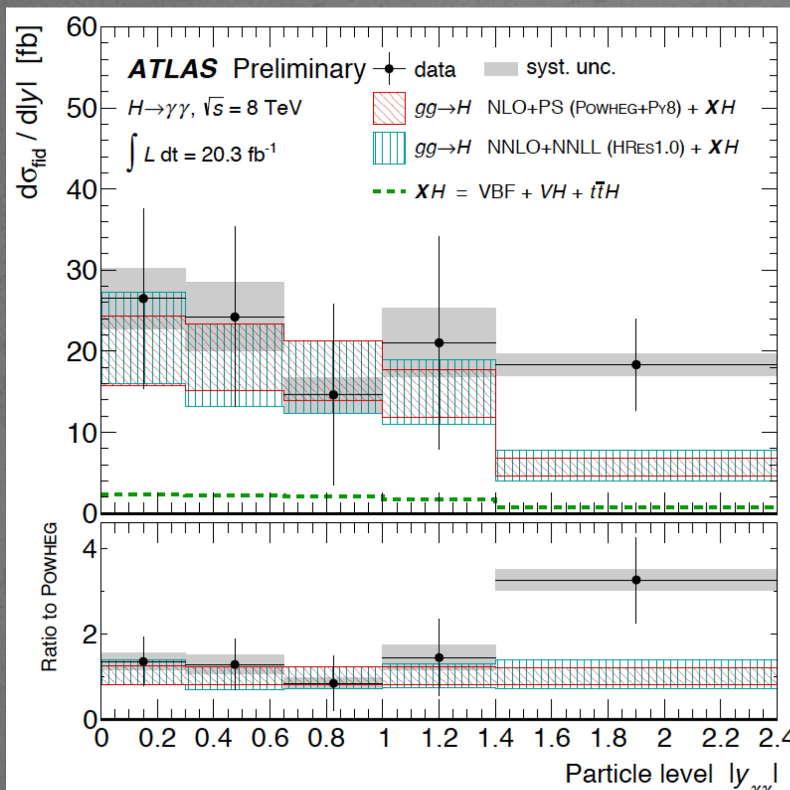
Consistent with ATLAS EPJC72(2012)1926

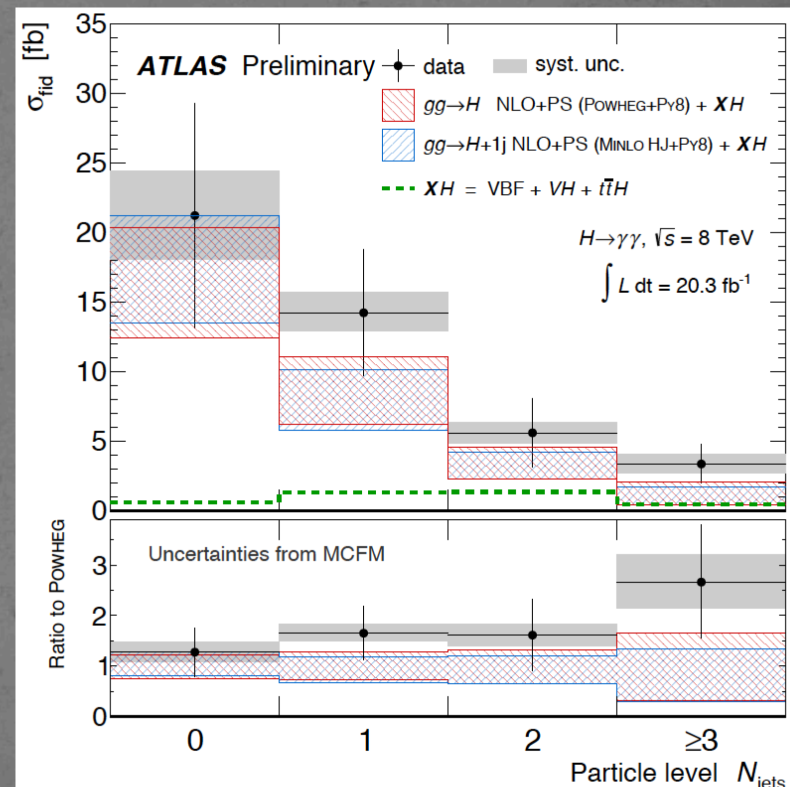
Comparisons with PYTHIA and PHOJET

QCD at the LHC

Jets, Photons, Vector Bosons, Vector Bosons+Jets, Soft QCD [lowx, MPI, diffraction]

and since summer 13: **Higgs as a QCD object**



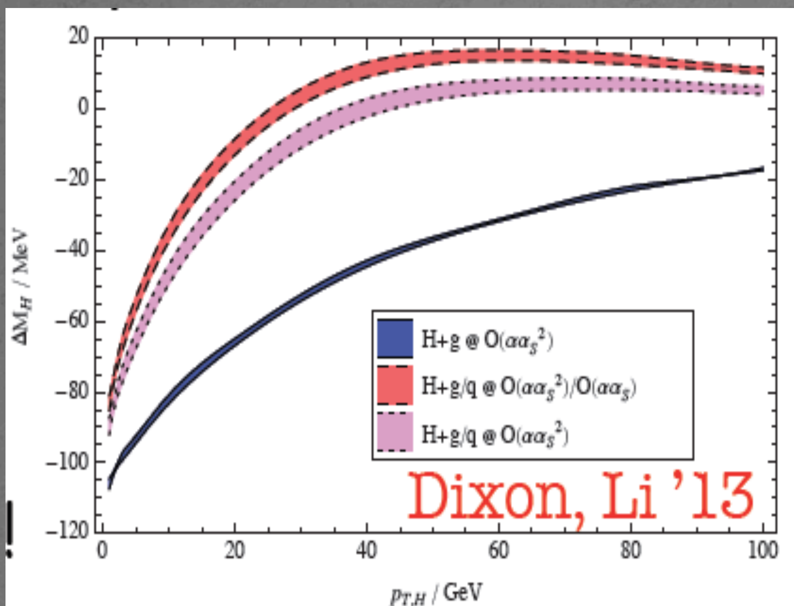


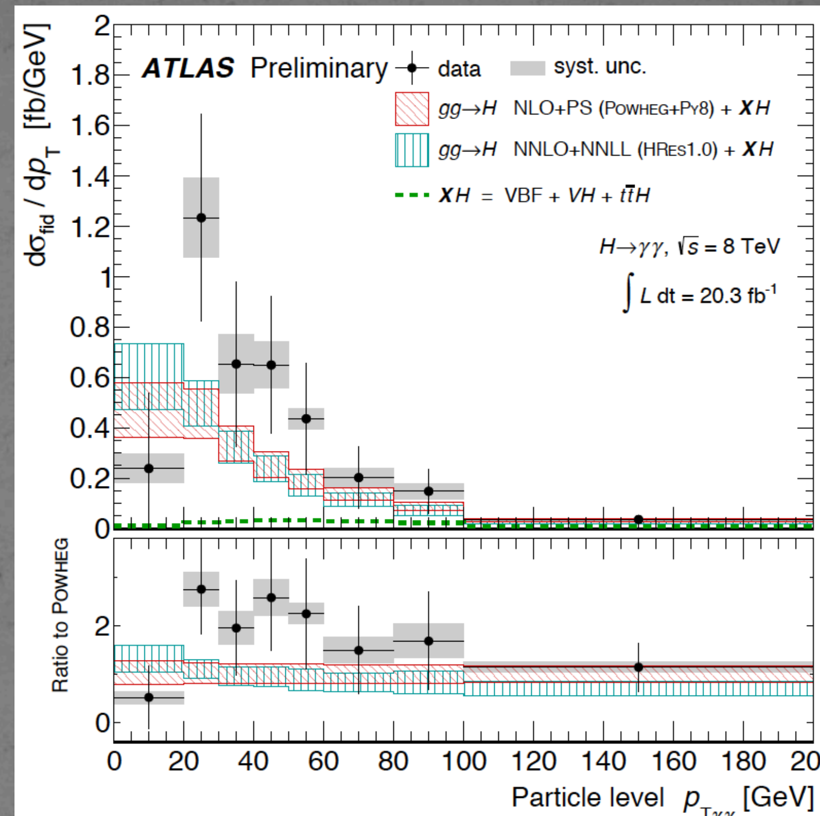
First differential cross sections of pp→X+H→γγ.
Large background but clear signal observed.

ATLAS-CONF-2013-072

Higgs and QCD at the LHC

The first pt measurement of H:





ATLAS-CONF-2013-072

cf C. Grojean at EPS Stockholm

Small width (4 MeV) results in pt(H) dependent reduction of Mγγ. Very high precision required to verify this and thus access Higgs width at the LHC..

Experimenters NLO wishlist les Houches 05-09

Process ($V \in \{Z, W, \gamma\}$)	Comments
1. $pp \to VV$ jet	WW jet completed by Dittmaier/Kallweit/Uwer; Campbell/Ellis/Zanderighi ZZ jet completed by Binoth/Gleisberg/Karg/Kauer/Sanguinetti WZ jet, $W\gamma$ jet completed by Campanario et al.
2. $pp \to$ Higgs+2 jets	NLO QCD to the gg channel completed by Campbell/Ellis/Zanderighi NLO QCD+EW to the VBF channel completed by Ciccolini/Denner/Dittmaier Interference QCD-EW in VBF channel
3. $pp \to V\,V\,V$	ZZZ completed by Lazopoulos/Melnikov/Petriello and WWZ by Hankele/Zeppenfeld see also Binoth/Ossola/Papadopoulos/Pittau VBFNLOmeanwhile also contains $WWW, ZZW, ZZZ, WW\gamma, ZZ\gamma, WZ\gamma, W\gamma\gamma, Z\gamma\gamma, \gamma\gamma\gamma, W\gamma\gamma j$
4. $pp \to t\bar{t}\,b\bar{b}$	relevant for $t\bar{t}H$, computed by Bredenstein/Denner/Dittmaier/Pozzorini and Bevilacqua/Czakon/Papadopoulos/Pittau/Worek
5. $pp \to V$+3 jets	W+3 jets calculated by the Blackhat/Sherpa and Rocket collaborations Z+3jets by Blackhat/Sherpa
6. $pp \to t\bar{t}$+2jets	relevant for $t\bar{t}H$, computed by Bevilacqua/Czakon/Papadopoulos/Worek
7. $pp \to VV\,b\bar{b}$,	Pozzorini et al.Bevilacqua et al.
8. $pp \to VV$+2jets	W^+W^++2jets, W^+W^-+2jets, relevant for VBF $H \to VV$ VBF contributions by (Bozzi/)Jäger/Oleari/Zeppenfeld
9. $pp \to b\bar{b}b\bar{b}$	Binoth et al.
10. $pp \to V + 4$ jets	top pair production, various new physics signatures Blackhat/Sherpa: W+4jets, Z+4jets see also HEJfor $W + n$jets
11. $pp \to Wb\bar{b}j$	top, new physics signatures, Reina/Schutzmeier
12. $pp \to t\bar{t}t\bar{t}$	various new physics signatures, Bevilacqua/Worek
$pp \to W\gamma\gamma$ jet	Campanario/Englert/Rauch/Zeppenfeld
$pp \to$ 4 jets	Blackhat/Sherpa

Theory

"The NLO Industrial Revolution"

Subtracting loops as master integrals

Feynmanian reduction

Unitarian approach

Semiautomated programs (BlackHat..)

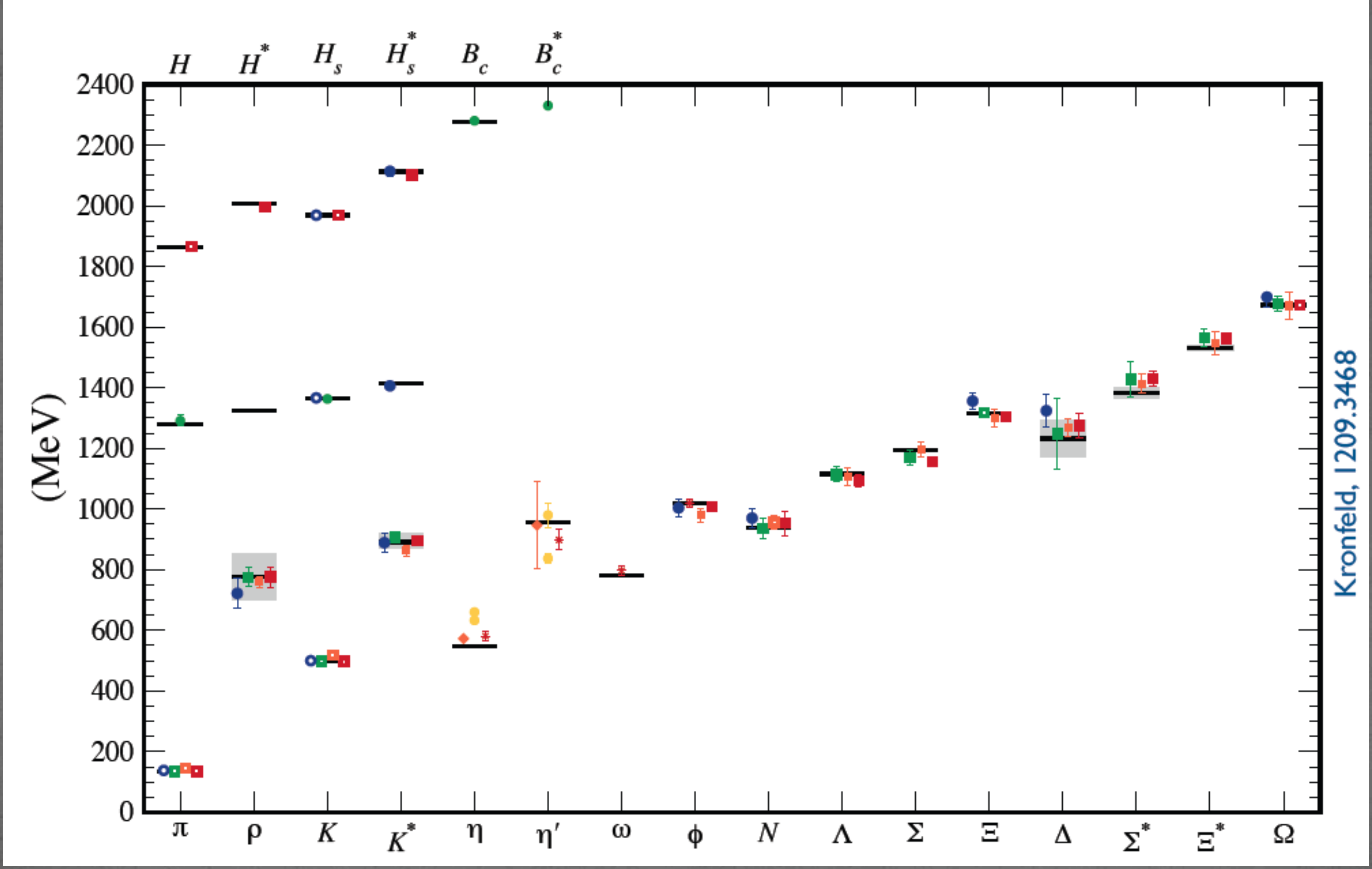
Automated subtraction

Standalone codes…

cf S. Hoeche ly SLAC 7/13

Now various processes, as gg→H, are being calculated at NNLO

Lattice QCD



H
H*
H_s
H_s*
B_c
B_c*
(MeV)
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
π
ρ
K
K*
η
η′
ω
φ
N
Λ
Σ
Ξ
Δ
Σ*
Ξ*
Ω
Kronfeld, 1209.3468

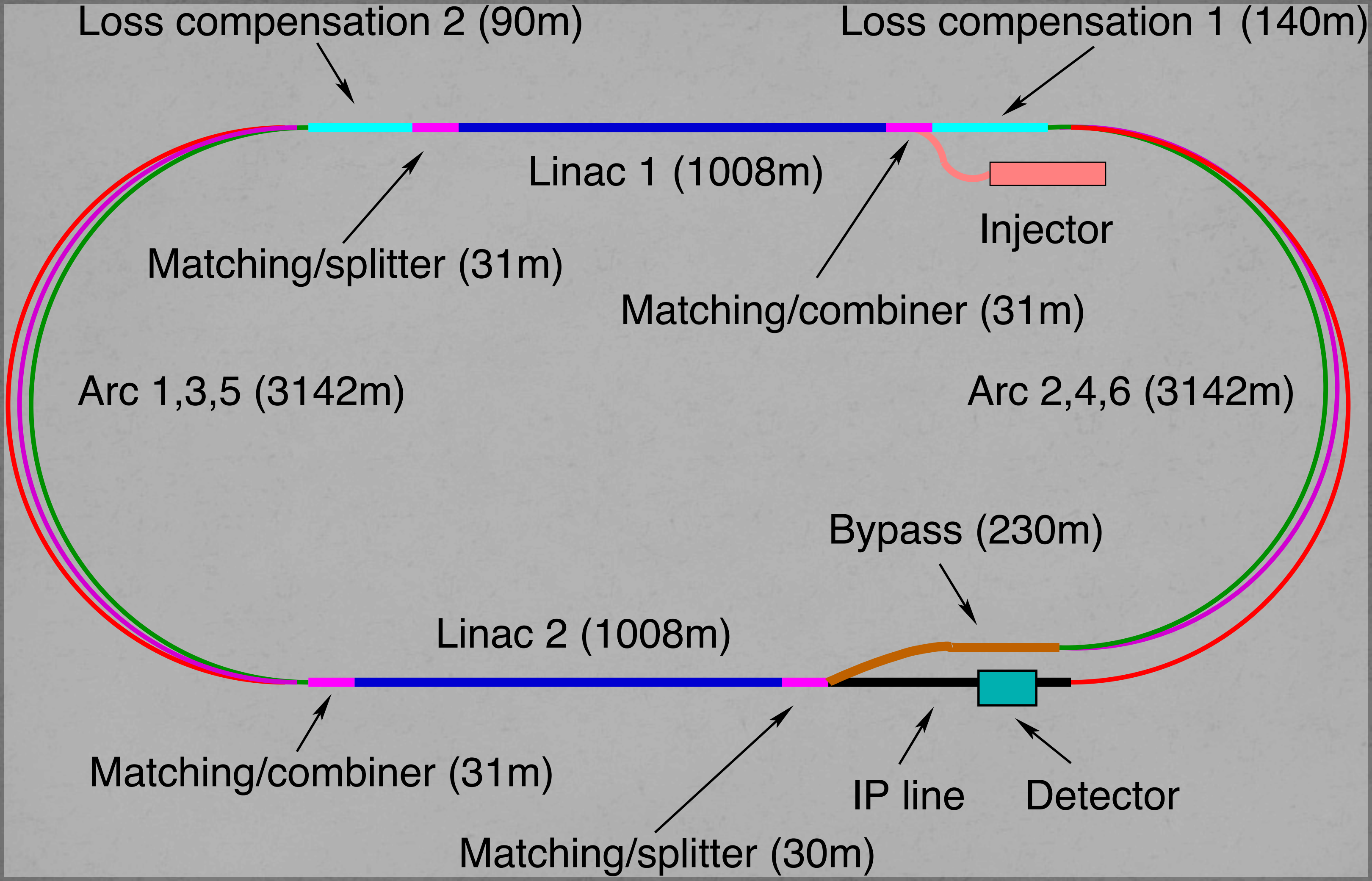
HL LHC, Partons and the need for precision

HL-LHC is the program to achieve $3ab^{-1}$ in pp at 14 TeV by 2030+

HL-LHC Upgrade Ingredients

- Geometric reduction factor ➔ $\beta^* \geq 10$ cm & Crab Cavities
- Triplet aperture ➔ New large aperture triplet magnets
- Bunch intensity ➔ $N_b = 2.2\ 10^{11}$ (limited in LHC by e-cloud)
  ➔ injector complex upgrade prerequisite for HL-LHC!!!
- Event pile-up in detectors ➔ luminosity leveling
- Beam Losses and Radiation ➔ shielding, Cryo upgrade &
  relocation of electronics and PC
- Collective effects and impedance ➔ Collimator Upgrade
- Electron cloud effect ➔ beam scrubbing & feedback

LHeC - electron beam upgrade



JPhysG:39(2012)075001, arXiv:1206.2913 http://cern.ch/lhec

CDR: default design. 60 GeV. $L=10^{33-34}cm^{-2}s^{-1}$, ERL, synchronous ep/pp

Why Precision?

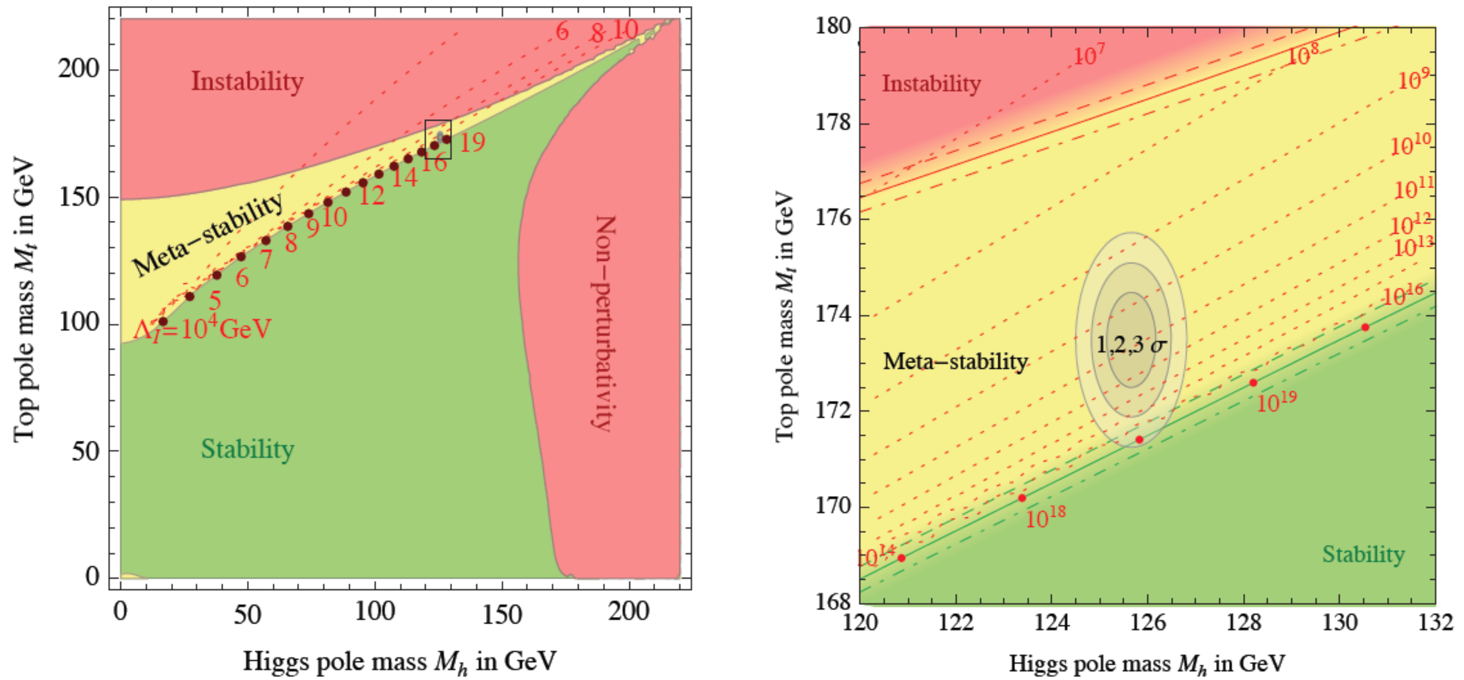


Figure 1: Regions of absolute stability, meta-stability and instability of the SM vacuum in terms of the top and Higgs masses. The frame on the right zooms into the preferred experimental region (the grey ellipses denote the allowed region at 1, 2, and 3σ). The three boundary lines correspond to $\alpha_s(M_Z) = 0.1184 \pm 0.0007$, and the grading of the colours indicates the size of the theoretical error. The dotted contour-lines show the instability scale in GeV, assuming the central value of $\alpha_s(M_Z)$. (For details see refs. [10, 11].)

G Giudice Why Naturalness, arXiv:1307.7879

The strong coupling "constant"

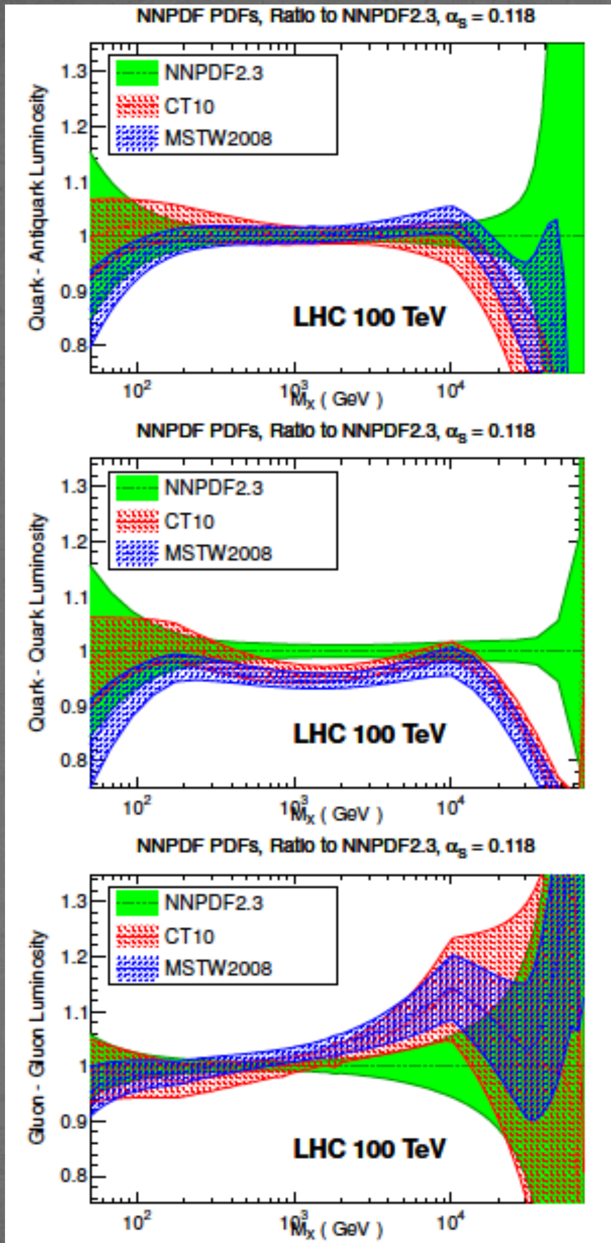
Method	Current relative precision		Future relative precision
e^+e^- evt shapes	expt $\sim 1\%$ (LEP) thry $\sim 3\%$ (NNLO+NLL, n.p. signif.)	[24]	$< 1\%$ possible (ILC/TLEP) $\sim 1.5\%$ (control n.p. via Q^2-dep.)
e^+e^- jet rates	expt $\sim 2\%$ (LEP) thry $\sim 1\%$ (NNLO, n.p. moderate)	[25]	$< 1\%$ possible (ILC/TLEP) $\sim 0.5\%$ (NLL missing)
precision EW	expt $\sim 3\%$ (R_Z, LEP) thry $\sim 0.5\%$ (N^3LO, n.p. small)	[26, 7]	0.1% (TLEP [8]), 0.5% (ILC [9]) $\sim 0.3\%$ (N^4LO feasible, ~ 10 yrs)
τ decays	expt $\sim 0.5\%$ (LEP, B-factories) thry $\sim 2\%$ (N^3LO, n.p. small)	[6]	$< 0.2\%$ possible (ILC/TLEP) $\sim 1\%$ (N^4LO feasible, ~ 10 yrs)
ep colliders	$\sim$ 1–2% (pdf fit dependent) (mostly theory, NNLO)	[27, 28, 29, 30]	0.1% (LHeC + HERA [21]) $\sim 0.5\%$ (at least N^3LO required)
hadron colliders	$\sim 4\%$ (Tev. jets), $\sim 3\%$ (LHC $t\bar{t}$) (NLO jets, NNLO $t\bar{t}$, gluon uncert.)	[15, 19, 31]	$< 1\%$ challenging (NNLO jets imminent [20])
lattice	$\sim 0.5\%$ (Wilson loops, correlators, ...) (limited by accuracy of pert. th.)	[32, 33, 34]	$\sim 0.3\%$ (~ 5 yrs [35])

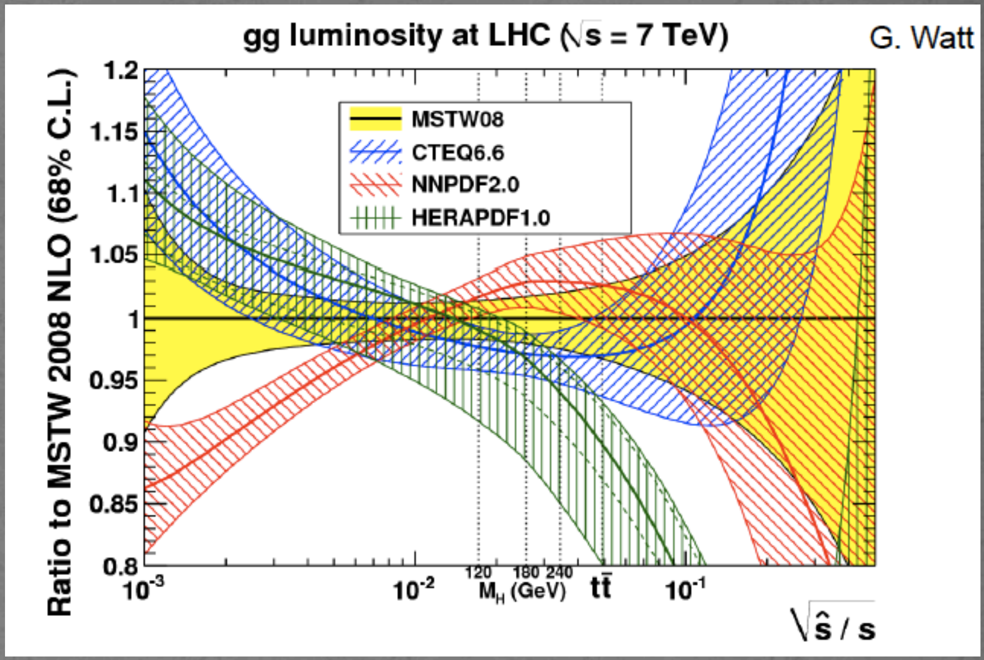
Table 1-1. *Summary of current uncertainties in extractions of $\alpha_s(M_Z)$ and targets for future (5 − 25 years) determinations. For the cases where theory uncertainties are considered separately, the theory uncertainties for future targets reflect a reduction by a factor of about two.*

Snowmass QCD WG report 9/2013

Prospects to measure $\alpha_s(M_Z^2)$ to per mille precision with future ep and ee colliders
Important for gauge unification, precision Higgs at LHC, and to overcome the past..

Parton Distributions

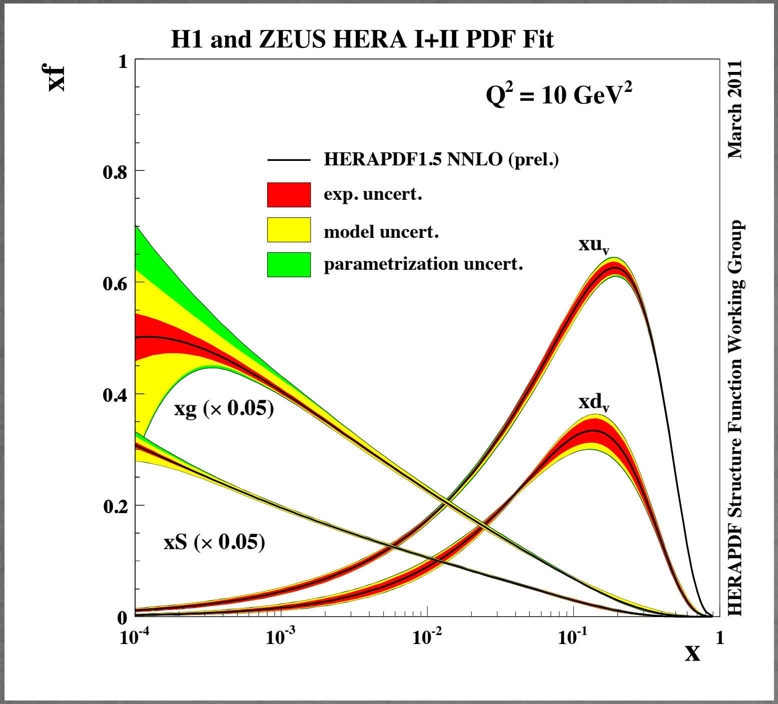


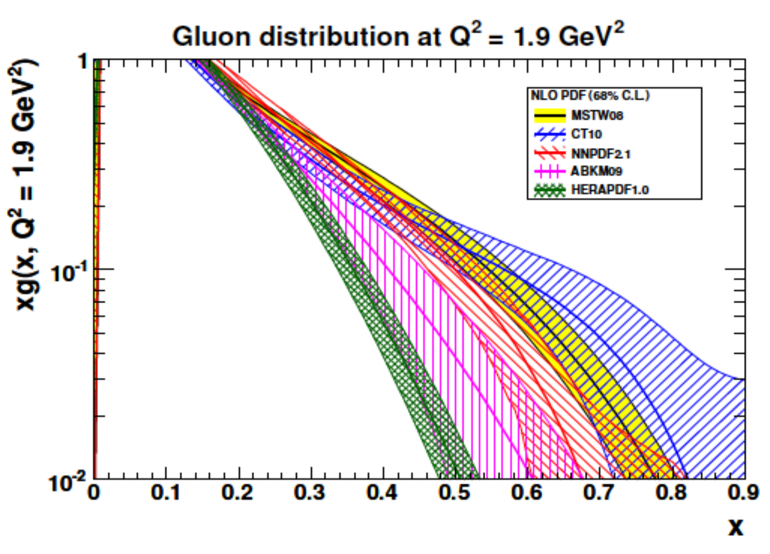


Need to know the PDFs much better than so far, for nucleon structure, q-g dynamics, Higgs, Searches, future colliders, and the development of QCD

Snowmass13 QCD WG report

(Un)certainty on PDFs





Light Quarks:
valence x < 0.01, u_v x > 0.8, d_v x>0.6
light sea (related to strange) -8% ATLAS/F_2,
light sea quark asymmetry, d/u=?
Isospin relations (en!) ??

Strange: unknown, =dbar? strange valence?

Charm: need high precision to % for α_s
(recent HERA 5%)
Beauty: HERA 10-20%, bb → A?
Top: tPDF at high Q^2 >M_t^2 - unknown

Gluon: low x, saturation?, high x - unknown
medium x: preciser for Higgs!

Recent review: cf E.Perez, E.Rizvi 1208.1178, in RPP

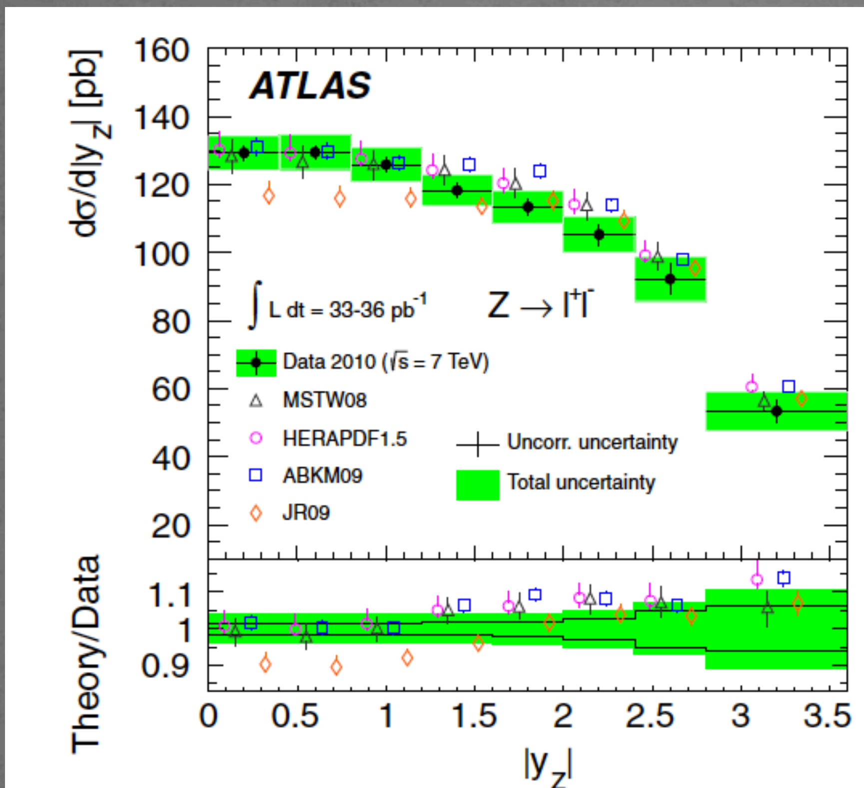
..unintegrated, diffractive, generalised, polarised, photonic, nuclear PDFs ???

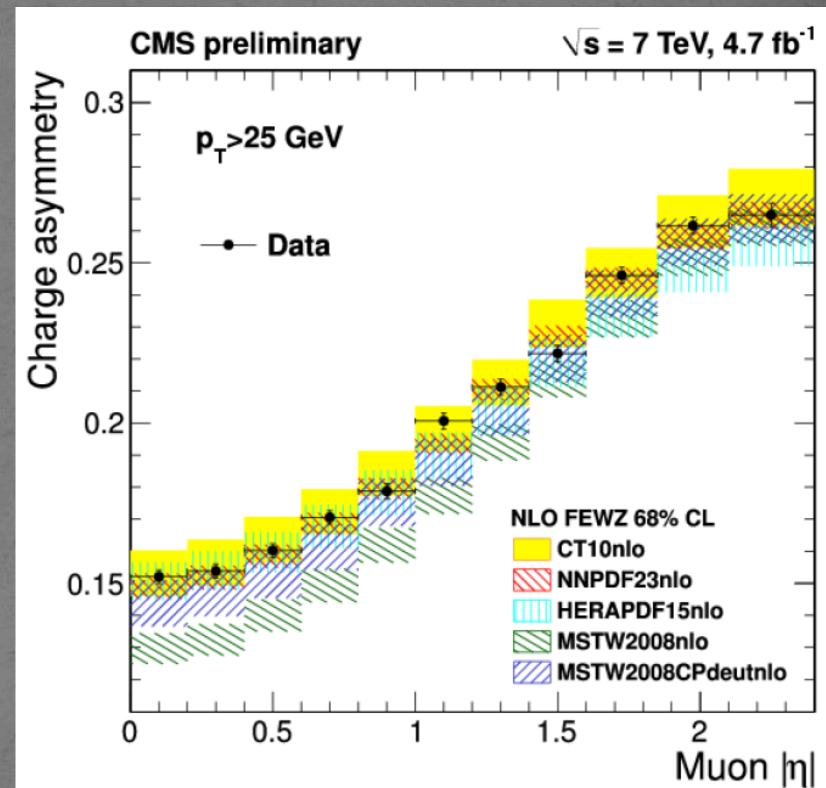
Z, W

Low and high mass Drell-Yan,W,Z, + jets, di-bosons, TGC's … W,Z in heavy ions…

Inclusive Z and W production and leptonic decay

PRD85(2012)072004, cf also PRL109(2012)012001

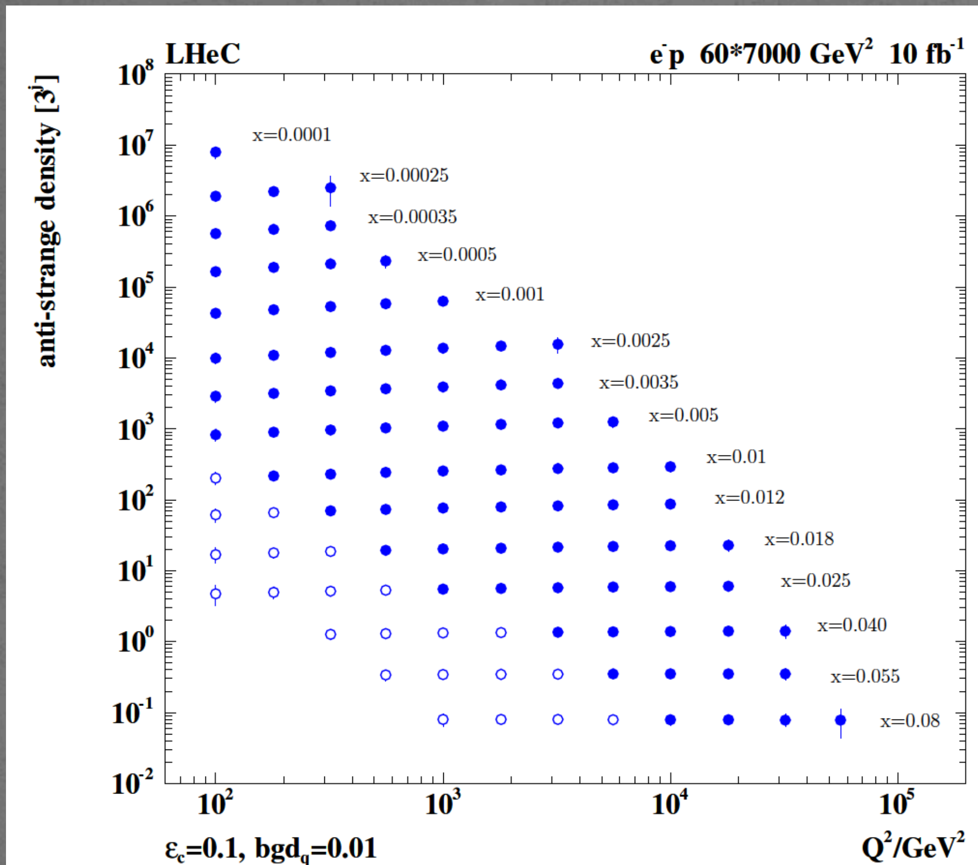




CMS PAS SMP-12-021

Constraining PDFs at high $Q^2 \sim M_{W,Z}^2$ - in large rapidity range (very fwd LHCb)
Measurements reach 1% precision level in differential distributions + δ(Lumi).
QCD analysis to NNLO + electroweak corrections to per mille level → s/d=1

Strange Quark Distribution



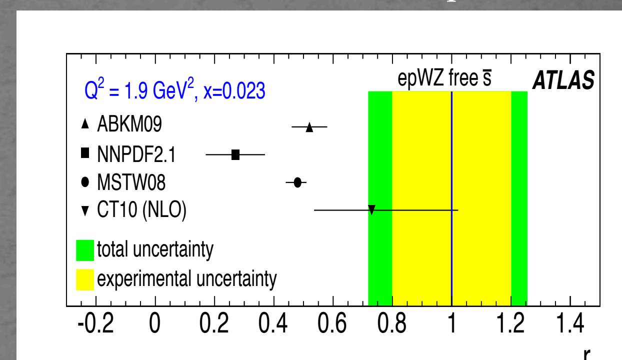
JPhysG 39(2012)7

Leads to first (x,Q^2) measurement of the (anti-)strange density, HQ valence?

$x = 10^{-4}$ .. 0.05

$Q^2 = 100 - 10^5$ GeV^2

ATLAS+HERA: Recent surprise: s/d =1



PRL109(2012)012001

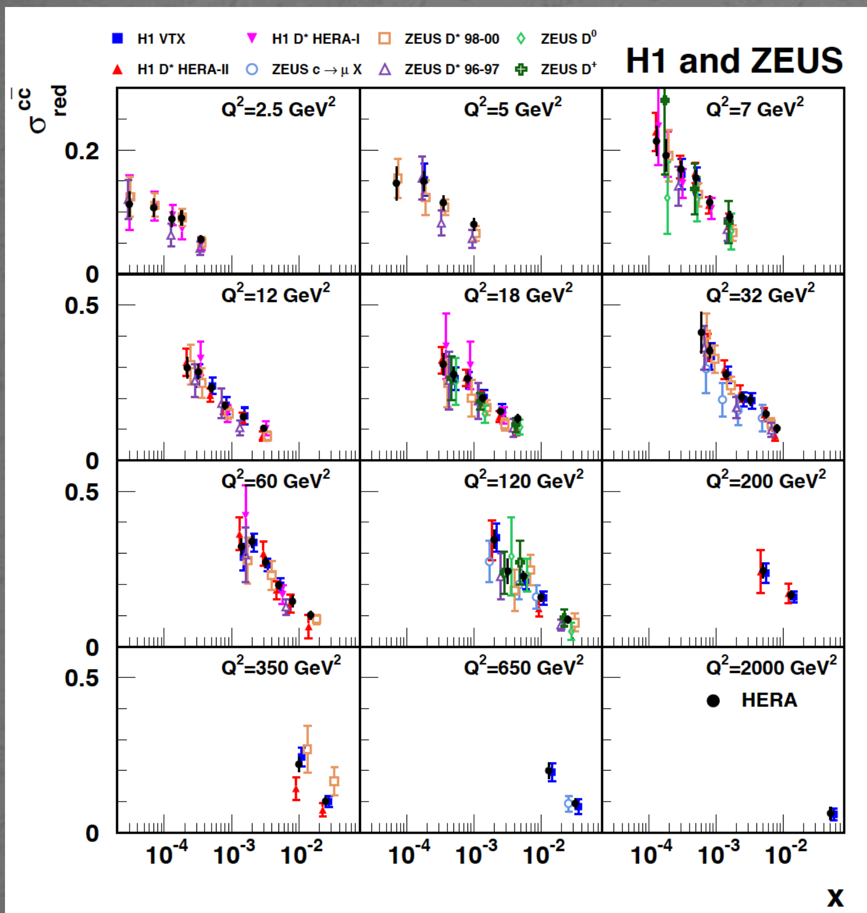
cf also HERMES: N_K PLB666(2008)446
W+c measurements from ATLAS+CMS

Important PDF constraints from LHC though no direct determinations (Q^2,x)

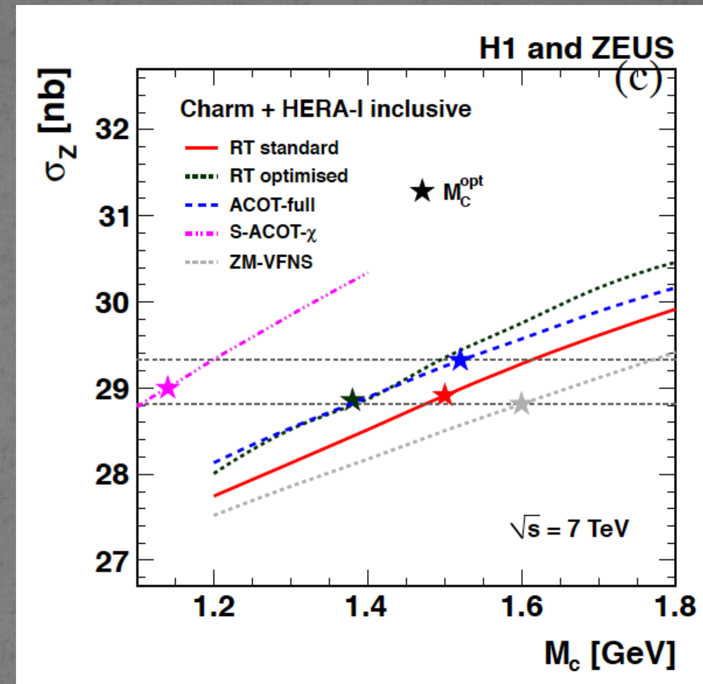
PDF4LHC → PDFs from LHC

Charm Structure Function - F_2^c

Culmination of 20 years of analysis…



EPJC73(2013)2311



$$m_c(m_c) = 1.26 \pm 0.05_{\rm exp} \pm 0.03_{\rm mod} \pm 0.02_{\rm param} \pm 0.02_{\alpha_s}\ {\rm GeV}$$

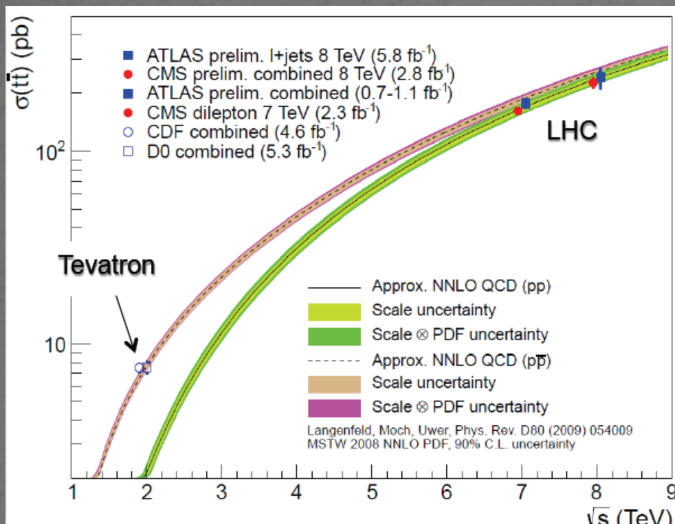
Uses FFNS ABM prescription.
$\delta(m_c)$ = 3 MeV at LHeC (cf CDR)

Understanding of heavy flavour dynamics in the proton is crucial for QCD [VFNS?, light-heavy?, intrinsic c?..], VHE ν, interpretation of LHC data

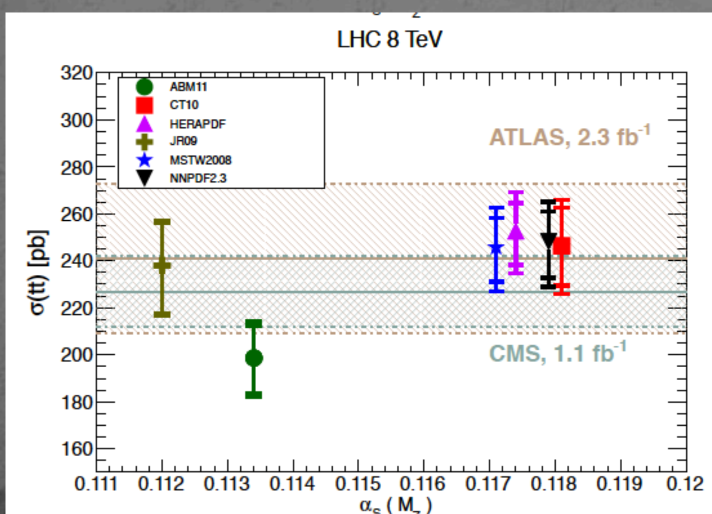
Top at the LHC

Pair production, Decay, Single Top, Top Loop → H, Mass and the SM Universe..

J.Varela, "Top Quark Properties" ly13

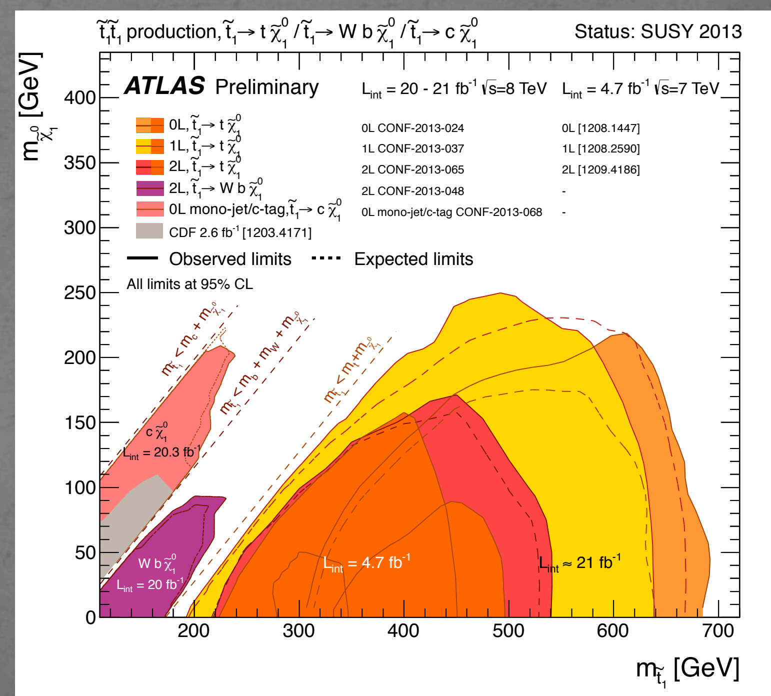


Cf. M.Czakon et al: arXiv:1303.6254 & .7215



M_{top} to 0.5% precision from Tevatron and now also the LHC experiments

Top lead the way to Higgs and it may to further new physics..



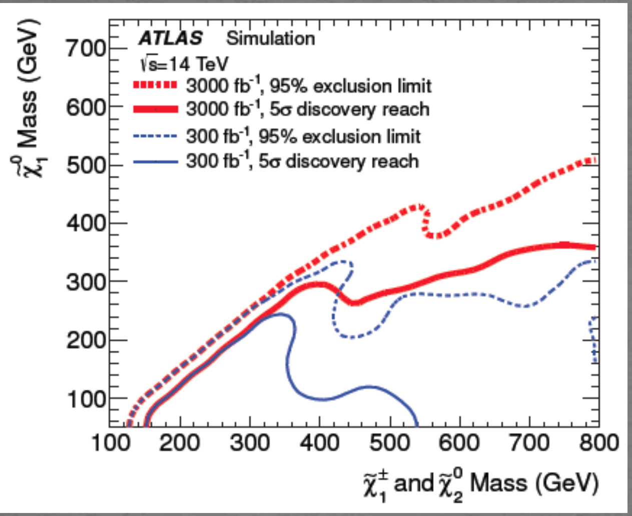
Is there a "light" stop partner of the top?

LHC physics @ 3ab^{-1}

Higgs precision and rarer channels

New particles: pairs to ~4 TeV
singly to ~8 TeV
leptoquarks to ~2 TeV

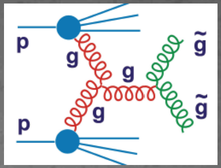
Rare processes as FCNC top decays…

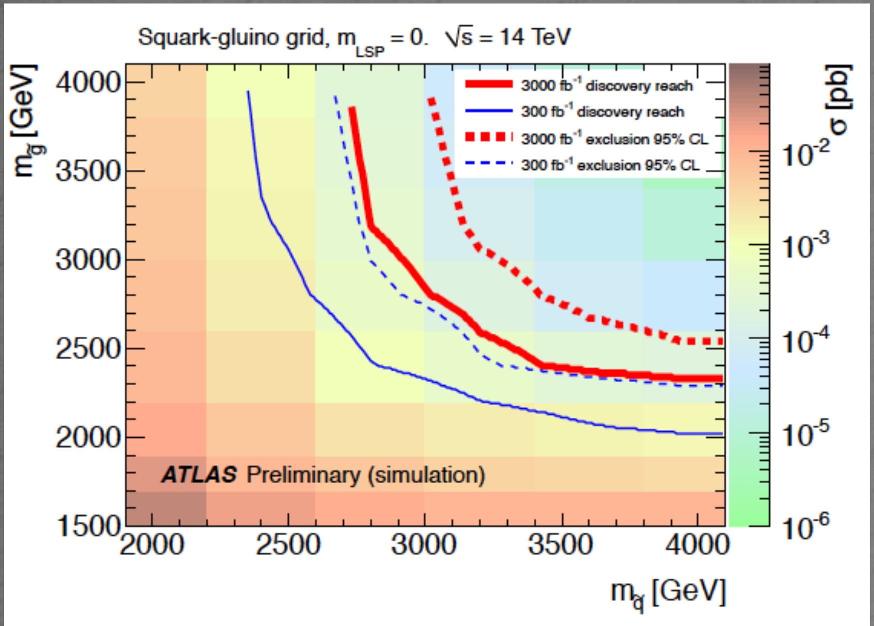


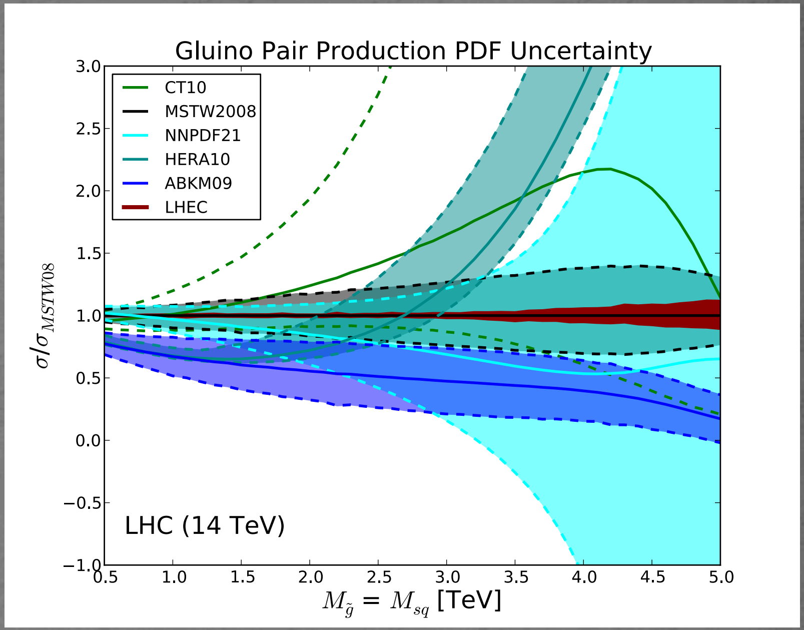
cf P.Wells, ly13, SLAC July13

Increase of L especially important for the investigation of new signals ..

HL-LHC - Searches





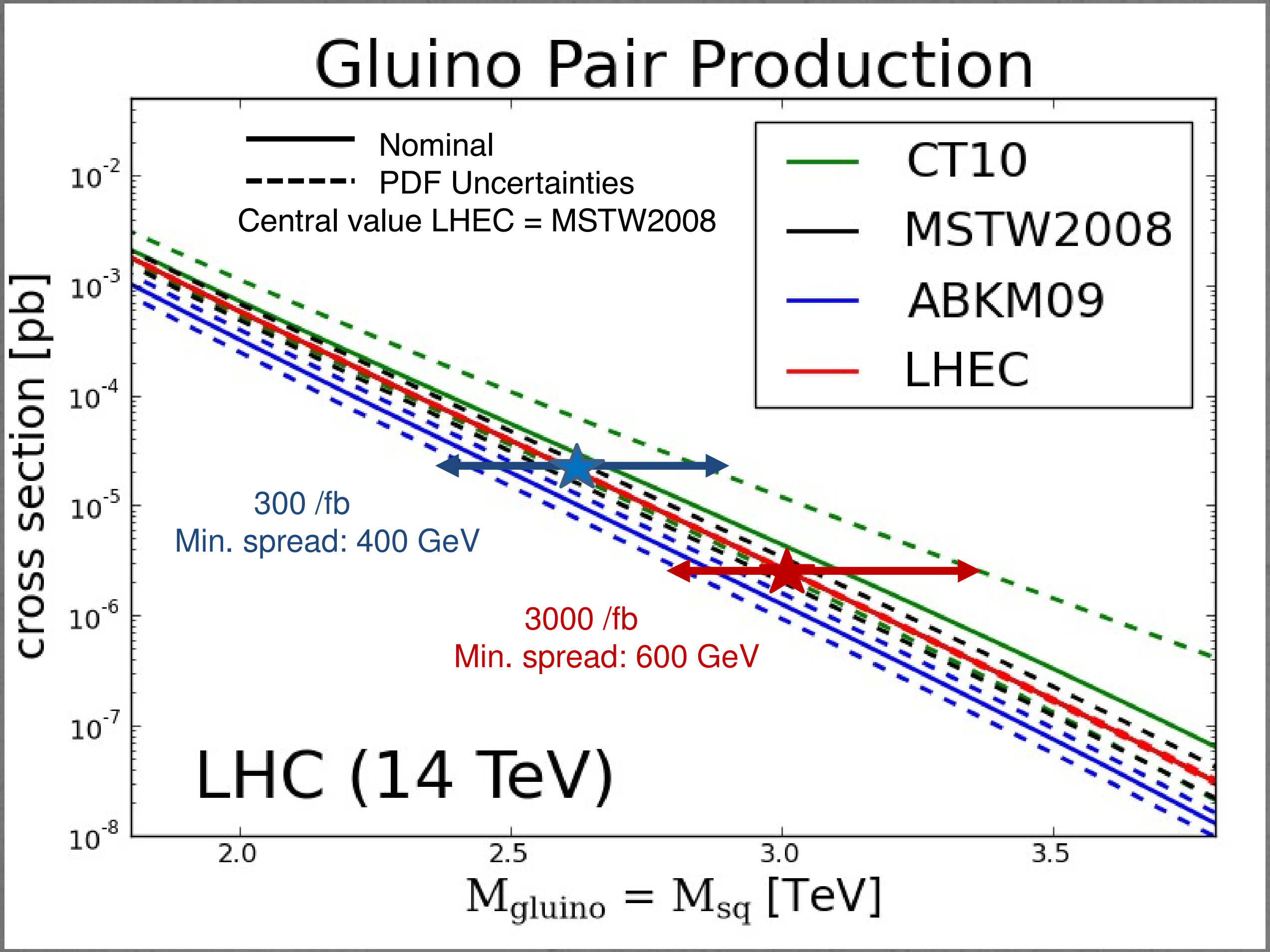


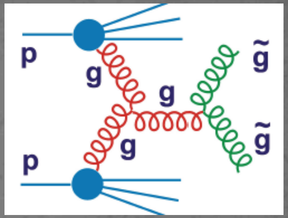
ATLAS October 2012 to EU strategy forum

LHeC October 2012 to EU forum arXiv:1211.5102

With high energy and luminosity, the search range will be extended to high masses, up to 4-5 TeV in pair production, and PDF uncertainties come in ~ 1/(1-x), CI effects?

HL-LHC - Searches



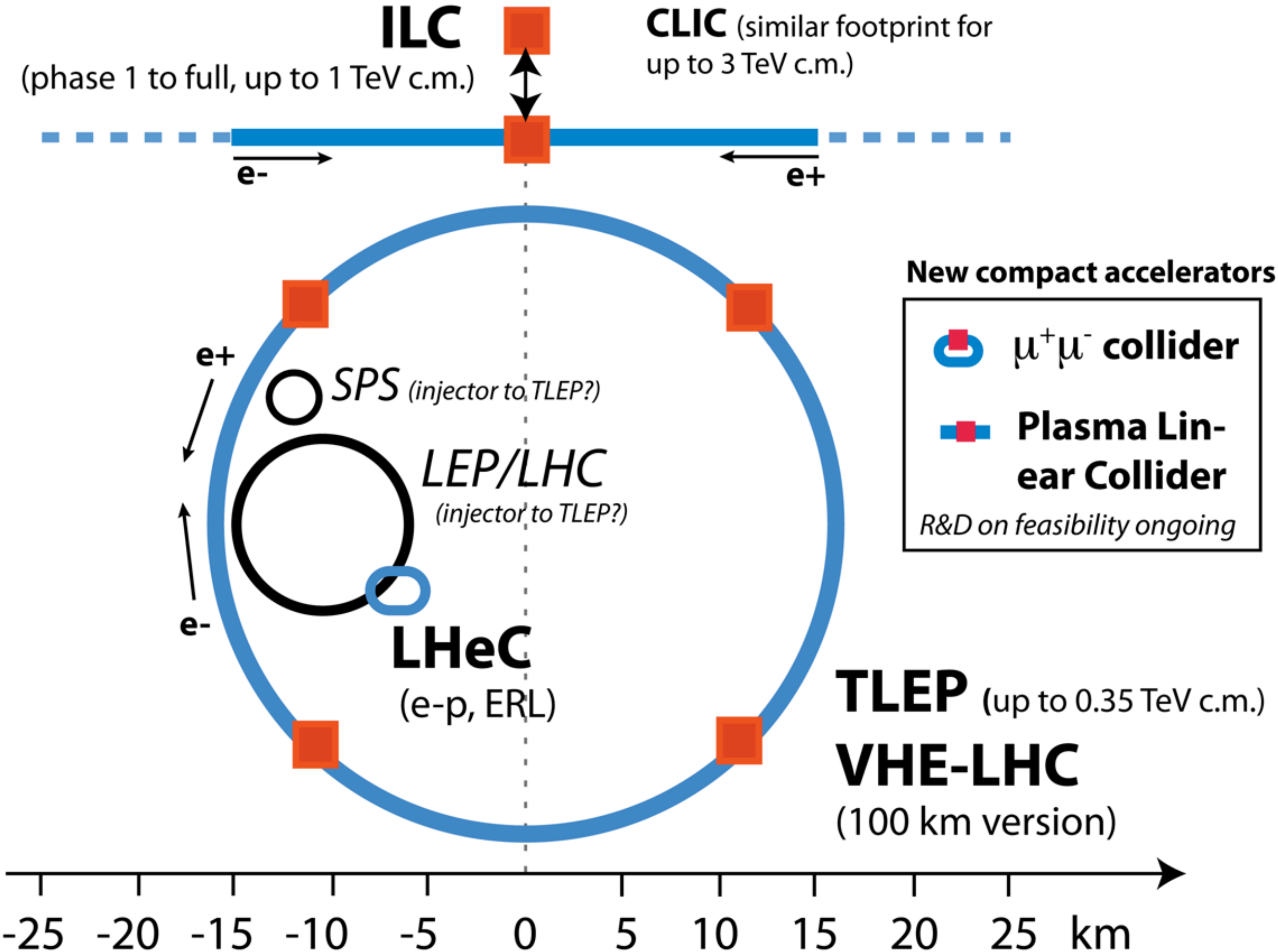


High precision PDFs are needed for the HL-LHC Searches in order to probe into the range opened by the luminosity increase and to interpret possibly intriguing effects based on external information.

LHeC BSM poster at EPS13 M.D'Onofrio et al. see also arXiv:1211:5102 Relation LHeC-LHC
Simulated PDFs from LHeC are on LHAPDF (Partons from LHeC, MK, V.Radescu LHeC-Note-2013-002 PHY)

Future Higgs

Lepton collider options beyond LHC



R.Aβmann, EPS13

Higgs with HL-LHC

LHC 300 fb^{-1} at 14 TeV:

- Mass: <100 MeV (statistical)
- Coupling κ rel. precision*
  - Z, W, b, τ   10-15%
  - t, μ   3-2 σ observation
  - γγ and gg   5-11%

HL-LHC 3000 fb^{-1} at 14 TeV:

- Mass: << 50 MeV (statistical)
- Couplings κ rel. precision*
  - Z, W, b, τ, t, μ   2-10%
  - γγ and gg   2-5%

**Assuming sizeable (1/2) reduction of theory errors*

- "QCD scale" go to Higher order QCD computation ?
- gg "PDF" from LHC data ?

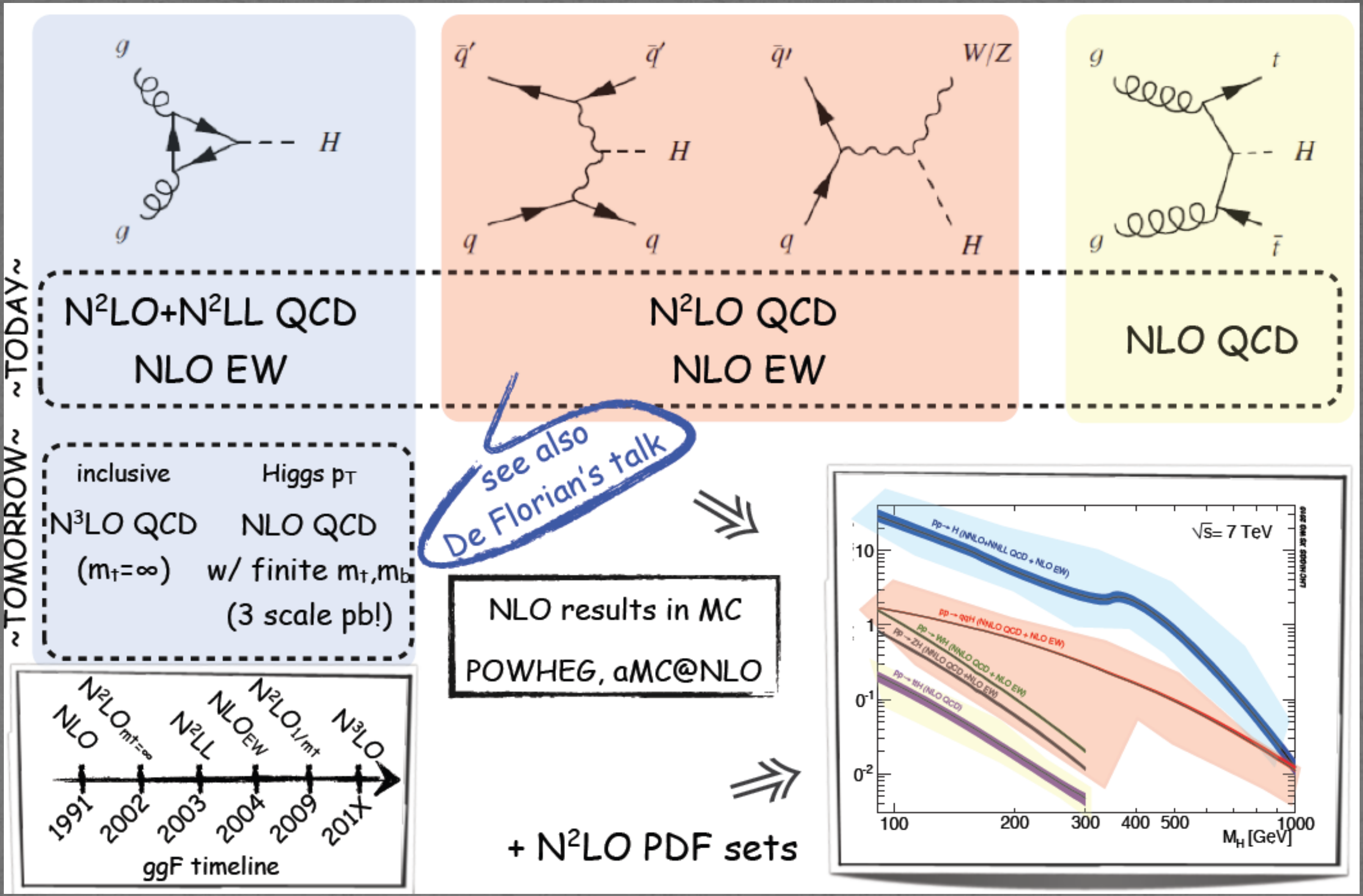
Mass Measurement:

Several exp./theory challenges to reach 50 MeV (e/γ/μ calibration E-scale, Interference, FSR, ..)

F.Cerutti, "Properties of the New Boson" EPS13 Stockholm

Higgs physics at the LHC is a long term challenge [di-H, CP, M, VV damping..]

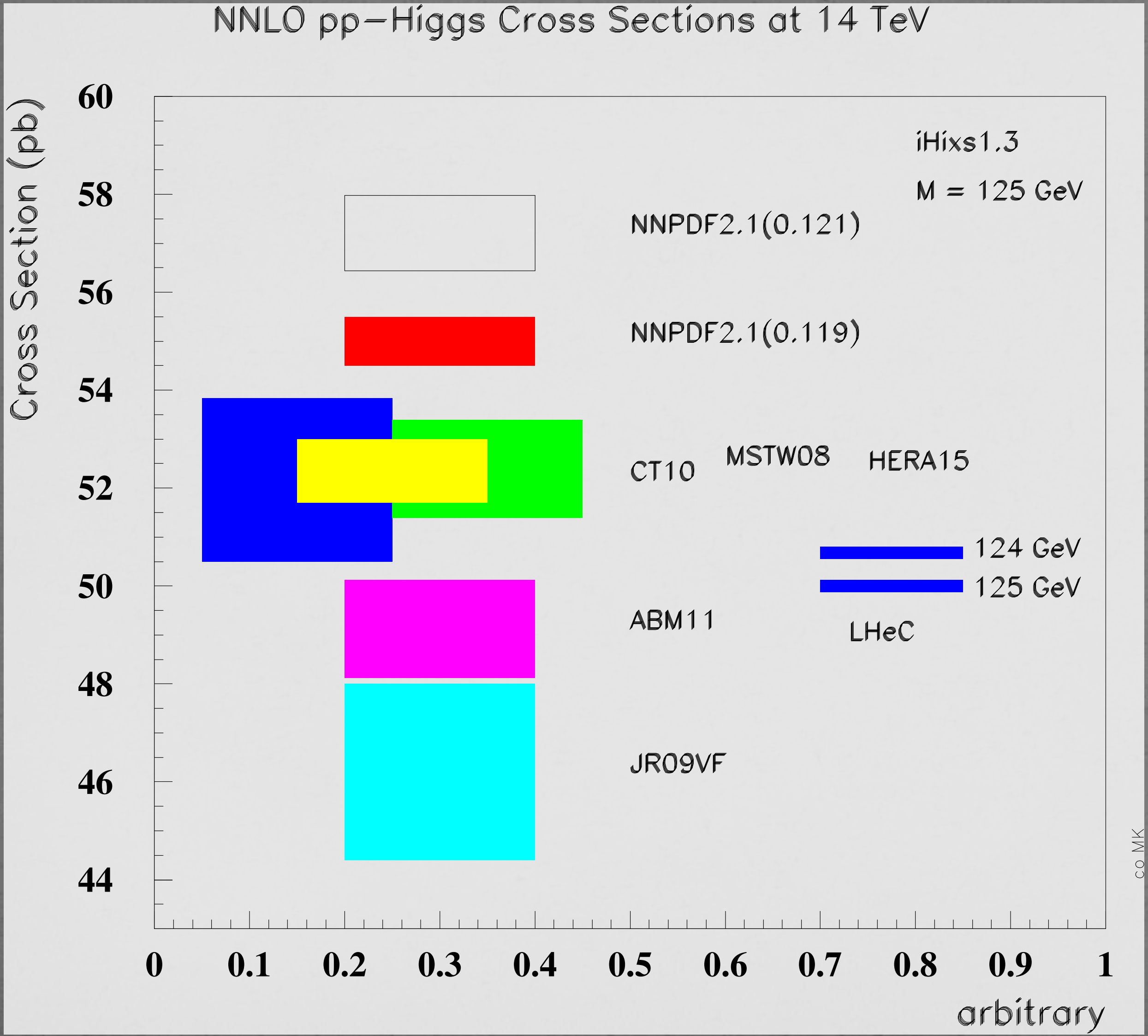
Theory



cf C. Grojean at EPS Stockholm

Will need ultraprecise PDFs to match thy and **make the LHC a precision Higgs factory**

pp → H Cross Section



LHeC:

Exp uncertainty of predicted H cross section is 0.25% (sys+sta), using LHeC only.

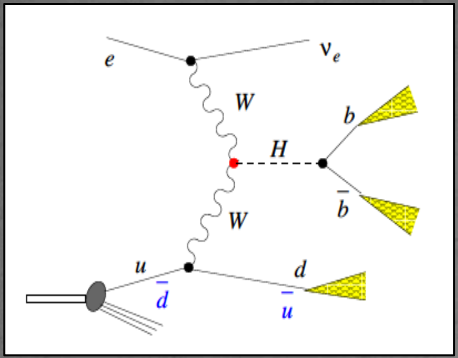
Leads to H mass sensitivity.

Strong coupling underlying parameter (0.005 – 10%). LHeC: 0.0002

Needs N^3LO

HQ treatment important ...

Higgs with the LHeC



LHeC Higgs		CC (e^-p)	NC (e^-p)	CC (e^+p)
Polarisation		-0.8	-0.8	0
Luminosity [ab^{-1}]		1	1	0.1
Cross Section [fb]		196	25	58
Decay	BrFraction	N^H_{CC} e^-p	N^H_{NC} e^-p	N^H_{CC} e^+p
$H \to b\bar{b}$	0.577	113 100	13 900	3 350
$H \to c\bar{c}$	0.029	5 700	700	170
$H \to \tau^+\tau^-$	0.063	12 350	1 600	370
$H \to \mu\mu$	0.00022	50	5	–
$H \to 4l$	0.00013	30	3	–
$H \to 2l2\nu$	0.0106	2 080	250	60
$H \to gg$	0.086	16 850	2 050	500
$H \to WW$	0.215	42 100	5 150	1 250
$H \to ZZ$	0.0264	5 200	600	150
$H \to \gamma\gamma$	0.00228	450	60	15
$H \to Z\gamma$	0.00154	300	40	10

Polarised electrons
Maximum lumi
Forward tracking
High resolution
No pile-up
Direction asymmetry
…

H-bbar coupling to 0.7% precision with 1ab^{-1}, at an S/B of 1 – studies of τ, c, .. to come

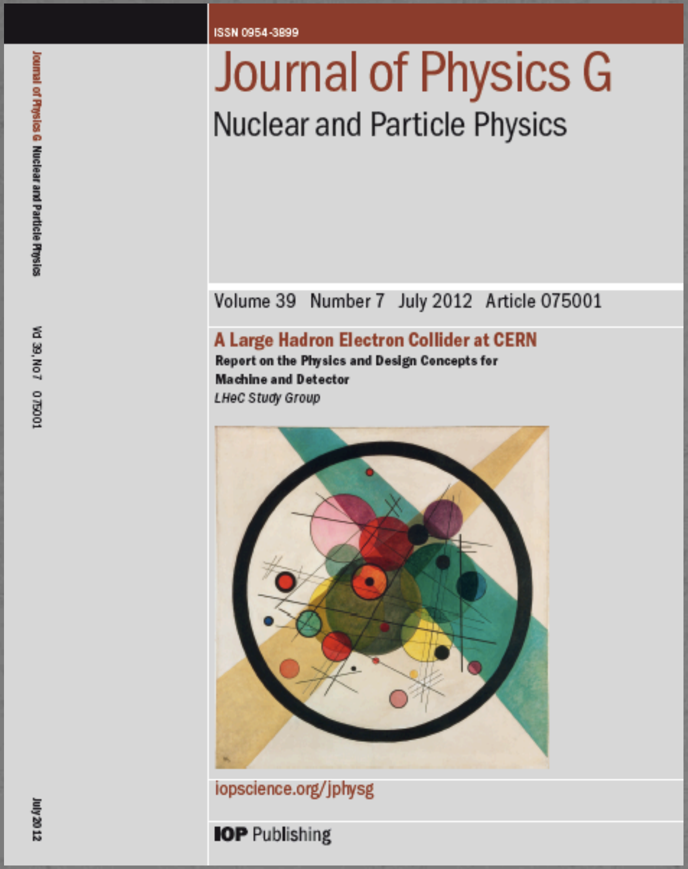
The LHeC WW → H cross section is as large as the ILC Z*→ZH cross section (300fb)…

→ 50pb@LHC, hiLumi + ep [H + PDFs] +QCD@h.o. : LHC - a high precision H factory

LHeC Development

A next workshop: 20/21. January 2014 near CERN - http://cern.ch/lhec

Design Report 2012

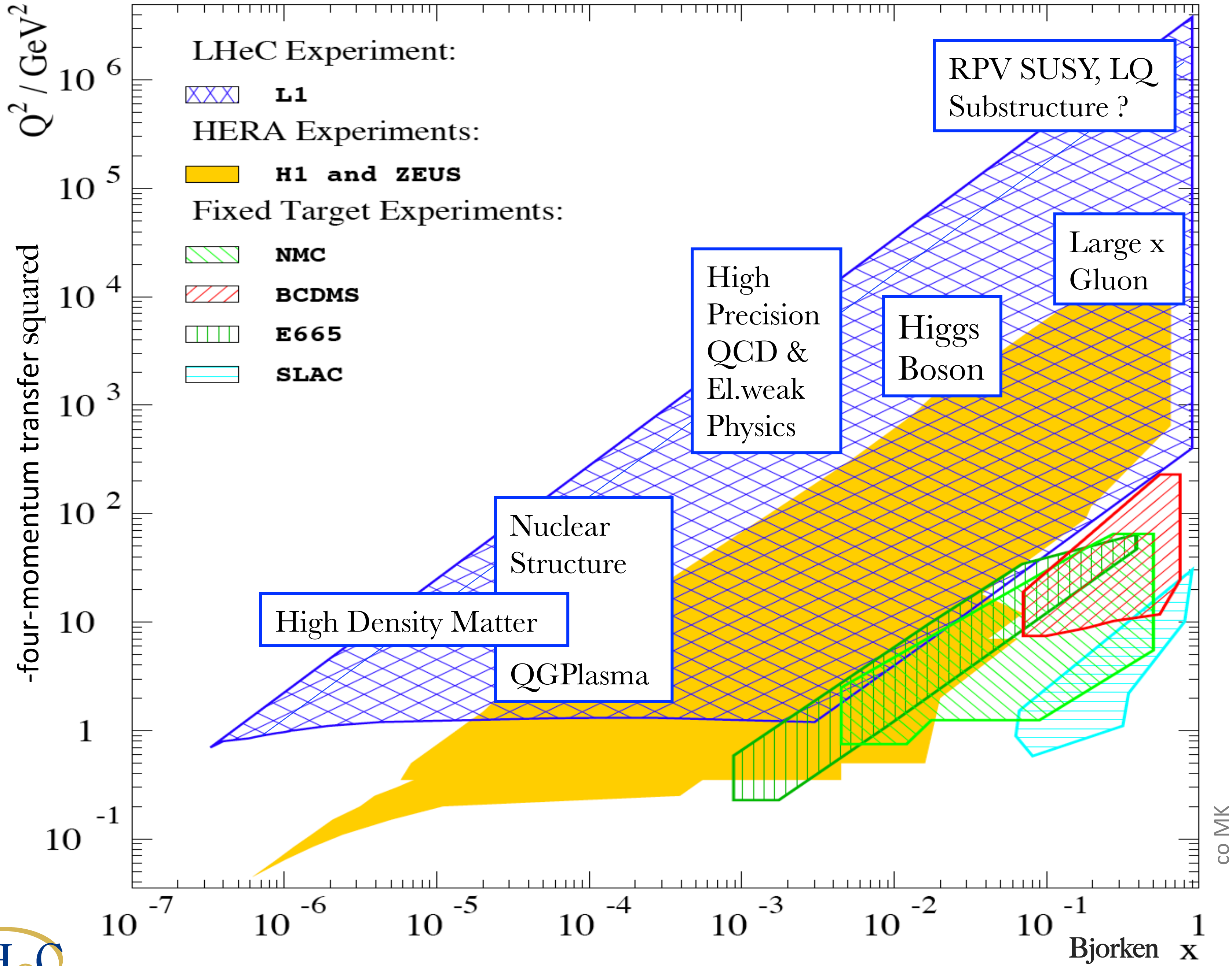


arXiv:1206.2913 http://cern.ch/lhec

CERN Referees

Ring Ring Design
Kurt Huebner (CERN)
Alexander N. Skrinsky (INP Novosibirsk)
Ferdinand Willeke (BNL)
Linac Ring Design
Reinhard Brinkmann (DESY)
Andy Wolski (Cockcroft)
Kaoru Yokoya (KEK)
Energy Recovery
Georg Hoffstaetter (Cornell)
Ilan Ben Zvi (BNL)
Magnets
Neil Marks (Cockcroft)
Martin Wilson (CERN)
Interaction Region
Daniel Pitzl (DESY)
Mike Sullivan (SLAC)
Detector Design
Philippe Bloch (CERN)
Roland Horisberger (PSI)
Installation and Infrastructure
Sylvain Weisz (CERN)
New Physics at Large Scales
Cristinel Diaconu (IN2P3 Marseille)
Gian Giudice (CERN)
Michelangelo Mangano (CERN)
Precision QCD and Electroweak
Guido Altarelli (Roma)
Vladimir Chekelian (MPI Munich)
Alan Martin (Durham)
Physics at High Parton Densities
Alfred Mueller (Columbia)
Raju Venugopalan (BNL)
Michele Arneodo (INFN Torino)

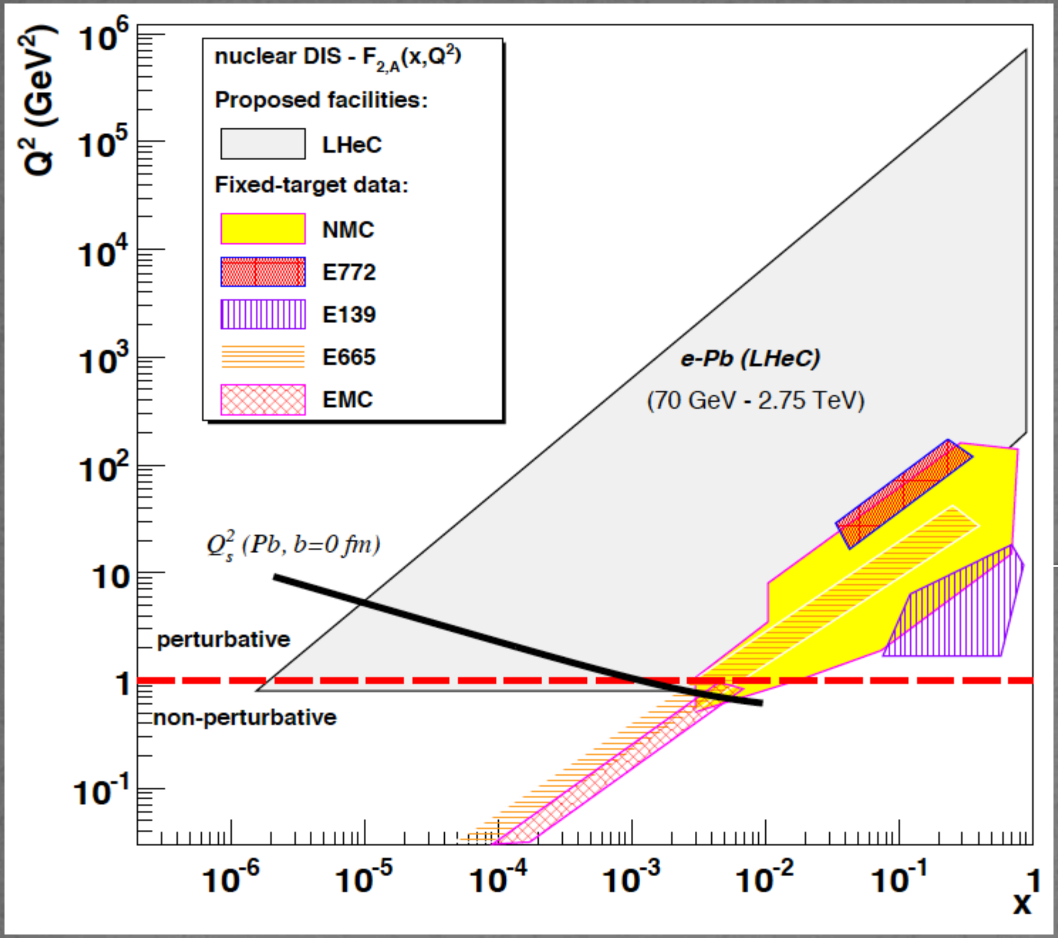
The theory of DIS has developed much further: J.Blümlein Prog.Part.Nucl.Phys. 69(2013)28
DIS is an important part of particle physics: G.Altarelli, 1303.2842, S.Forte, G.Watt 1301:6754

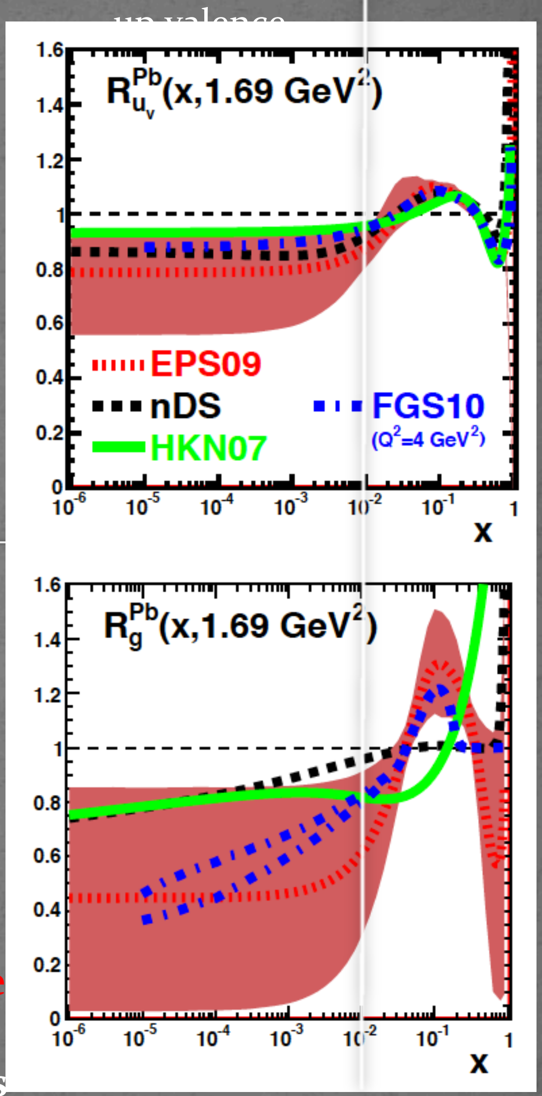


Q^2 / GeV^2
-four-momentum transfer squared
LHeC Experiment:
L1
HERA Experiments:
H1 and ZEUS
Fixed Target Experiments:
NMC
BCDMS
E665
SLAC
RPV SUSY, LQ
Substructure ?
Large x
Gluon
High
Precision
QCD &
El.weak
Physics
Higgs
Boson
Nuclear
Structure
High Density Matter
QGPlasma
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10
1
10^{-1}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
Bjorken x
co MK

LHeC

Nuclear Parton Distributions from eA





3-4 orders of magnitude extension of lA kinematic range

→ **LHeC has huge discovery potential for new HI physics**
(bb limit, saturation.. will put nPDFs on completely new ground

unmeasured | known?

LHeC at $10^{34}cm^{-2}s^{-1}$ Luminosity

parameter [unit]	LHeC	
species	e^-	p, $^{208}Pb^{82+}$
beam energy (/nucleon) [GeV]	60	7000, 2760
bunch spacing [ns]	25, 100	25, 100
bunch intensity (nucleon) [10^{10}]	0.1 (0.2), 0.4	17 (22), 2.5
beam current [mA]	6.4 (12.8)	860 (1110), 6
rms bunch length [mm]	0.6	75.5
polarization [%]	90	none, none
normalized rms emittance [μm]	50	3.75 (2.0), 1.5
geometric rms emittance [nm]	0.43	0.50 (0.31)
IP beta function $\beta^*_{x,y}$ [m]	0.12 (0.032)	0.1 (0.05)
IP spot size [μm]	7.2 (3.7)	7.2 (3.7)
synchrotron tune Q_s	—	1.9×10^{-3}
hadron beam-beam parameter	0.0001 (0.0002)	
lepton disruption parameter D	6 (30)	
crossing angle	0 (detector-integrated dipole)	
hourglass reduction factor H_{hg}	0.91 (0.67)	
pinch enhancement factor H_D	1.35	
CM energy [TeV]	1300, 810	
luminosity / nucleon [10^{33} cm^{-2}s^{-1}]	1 (10), 0.2	

Table 1: LHeC *ep* and *eA* collider parameters. The numbers give the default CDR values, with optimum values for maximum *ep* luminosity in parentheses and values for the *ePb* configuration separated by a comma.

$$L = \frac{N_e N_p f \gamma_p}{4\pi \epsilon_p \beta^*}$$

σ(H)=200fb
Access of rare channels and differential measurements:

How to reach 10^{34} ?

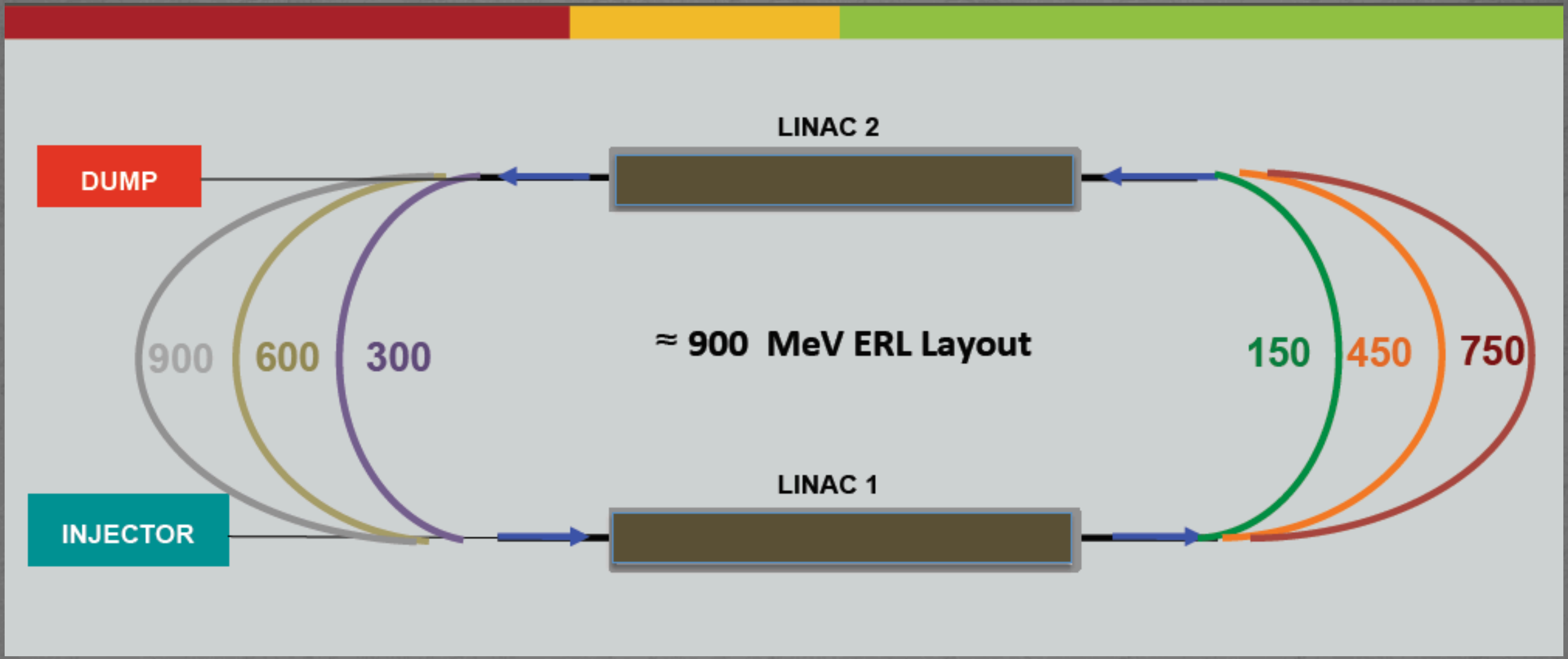
N/ε =brightness*2.5
β* = 5 cm
I_e = 12 mA

HERA: 1-4 10^{31} cm^{-2}s^{-1}

LHeC Collaboration arXiv:1211:5102, see also O.Brüning and M.Klein arXiv:1305.2090, MPLA A28(2013)16

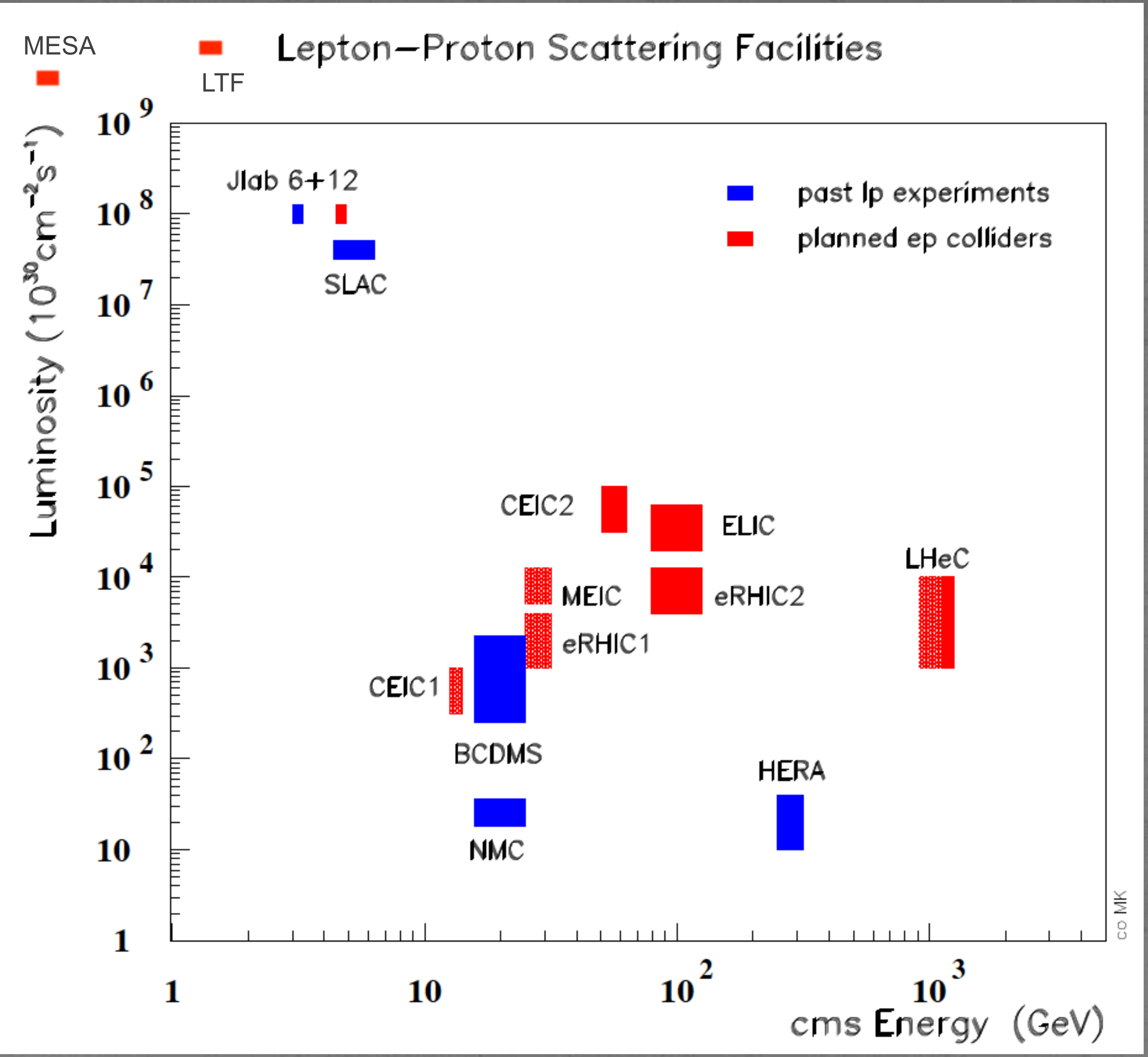
ERL Testfacility

Under design at CERN in international collaboration. f=801.58 MHz SC RF



A.Valloni, LHeCmeeting, 16.7.2013, see also LHeC-Note 2012-001 ACC, and Contribution to IPAC2013

Test of ERL, Operation experience, Sources, Magnet Tests, Injector for the LHeC
Physics: ep with $10^{40}cm^{-2}s^{-1}$: $\sin^2\Theta$ [high E MESA], proton radius; Testbeam facility



Energy frontier deep inelastic scattering - following HERA with the LHC
LHeC: A new laboratory for particle physics, a 5th large LHC experiment

Remarks and Outlook

AdS/CFT

Instantons

Odderons

Non pQCD

QGP

N^kLO

Resummation

Non-conventional PDFs ...

Breaking of Factorisation

Free Quarks

Unconfined Color

New kind of coloured matter

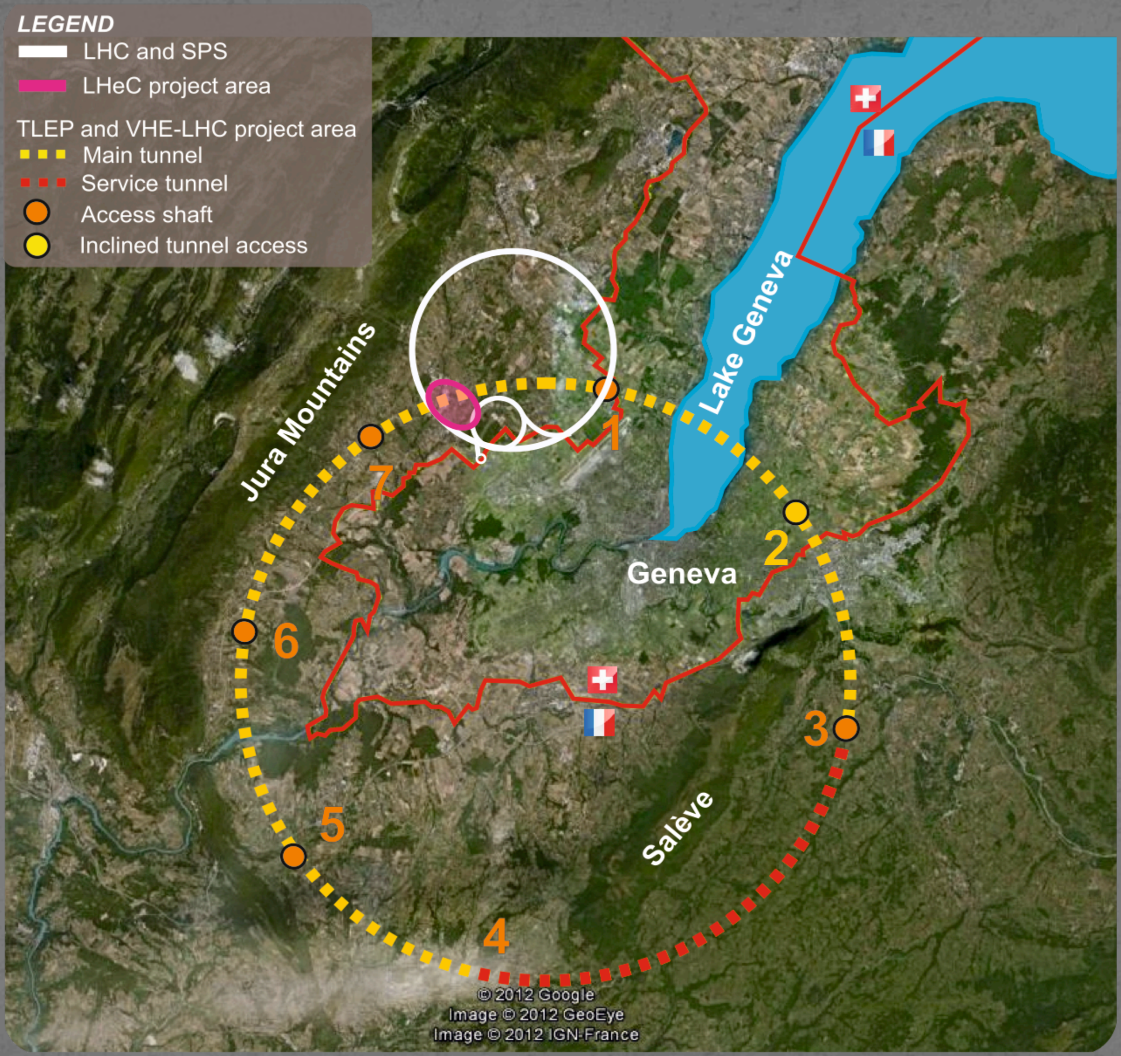
Quark substructure

New symmetry embedding QCD

QCD may break .. (Quigg DIS13)

QCD is the richest part of the Standard Model Gauge Field Theory and will (have to) be developed much further, on its own and as background

Future Rings at CERN*)



100km with 20T provides 50 TeV per beam.

80km may not be clever due to Saleve, if placed below Lac Leman → 100km.

New tunnel may host a Triple LEP Higgs facility.

LHeC to run with LHC and later with VHE-LHC

*) "Civil Engineering Feasibility Studies for Future Ring Colliders at CERN", Contributed by O.Brüning, M.Klein, S.Myers, J.Osborne, L.Rossi, C.Waaijer, F.Zimmerman to IPAC13 Shanghai

Cost

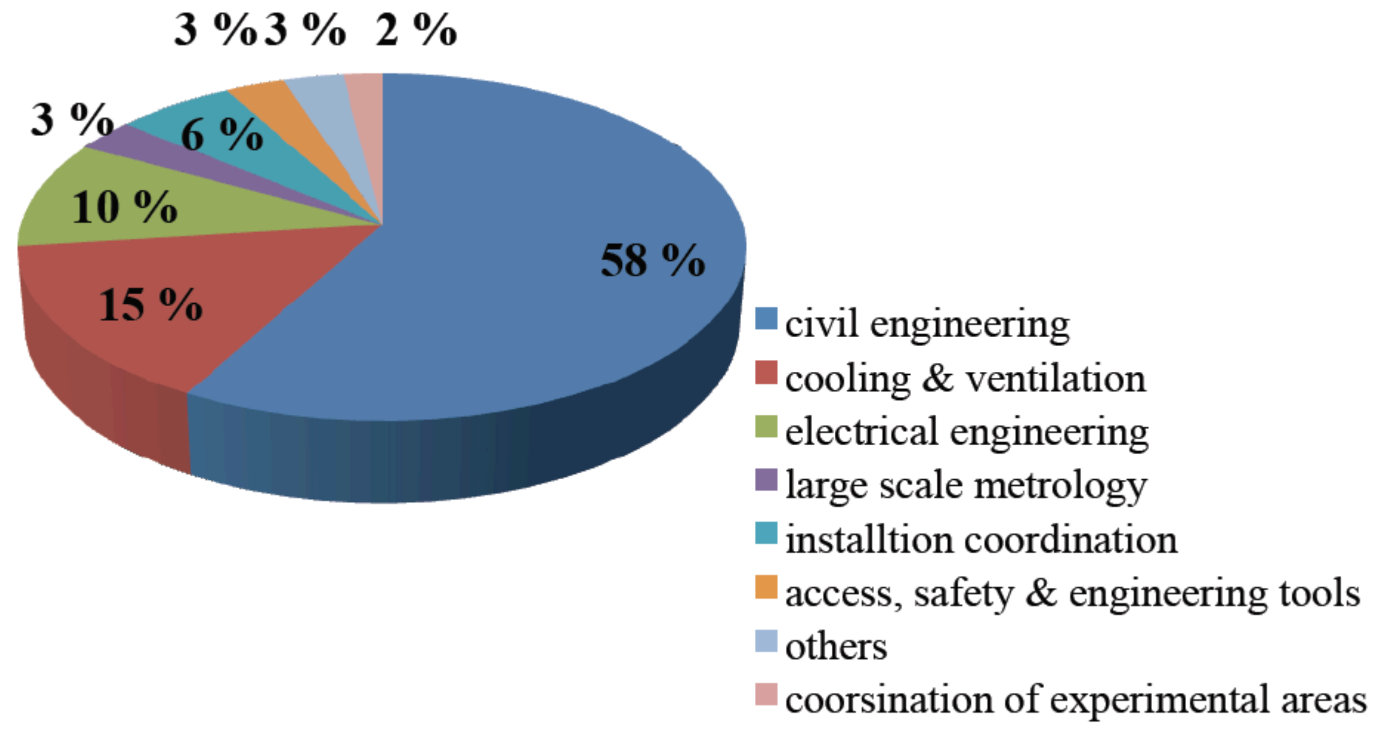


Figure 5: LHC infrastructure cost distribution.

J.Osborne et al. IPAC13, Shanghai
62% CE, 26% surface, 12% consulting

A 100km machine is very challenging, it will not be cheap and demands firm, excellent science reason to become real

Time

ps

LEP Note 440

11.4.1983

PRELIMINARY PERFORMANCE ESTIMATES FOR A LEP PROTON COLLIDER

S. Myers and W. Schnell

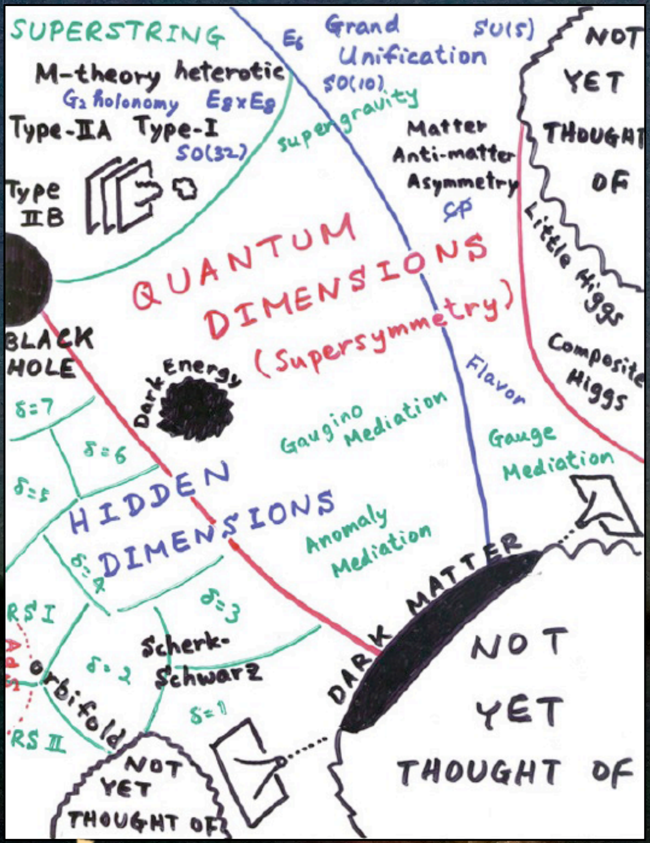
1. Introduction

This analysis was stimulated by news from the United States where very large $p\bar{p}$ and pp colliders are actively being studied at the moment. Indeed, a first look at the basic performance limitations of possible $p\bar{p}$ or pp rings in the LEP tunnel seems overdue, however far off in the future a possible start of such a p-LEP project may yet be in time. What we shall discuss is, in fact, rather obvious, but such a discussion has, to the best of our knowledge, not been presented so far.

We shall not address any detailed design questions but shall give basic equations and make a few plausible assumptions for the purpose of illustration. Thus, we shall assume throughout that the maximum energy per beam is 8 TeV (corresponding to a little over 9 T bending field in very advanced superconducting magnets) and that injection is at 0.4 TeV. The ring circumference is, of course that of LEP, namely 26,659 m. It should be clear from this requirement of "Ten Tesla Magnets" alone that such a

30 years from the first p-LEP = LHC paper to LS1

The challenge, again, is to find the way forward, through the dark matter of the universe and towards a genuine unification of the known and hidden forces:



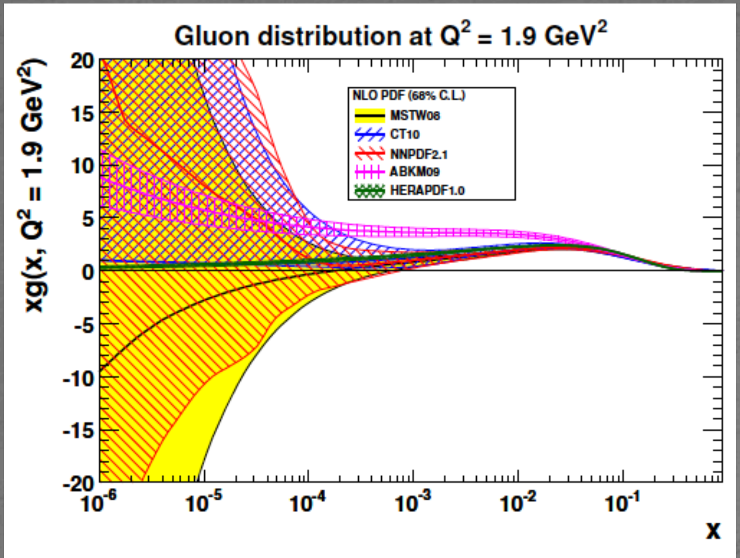
H.Murayama – ICFA11

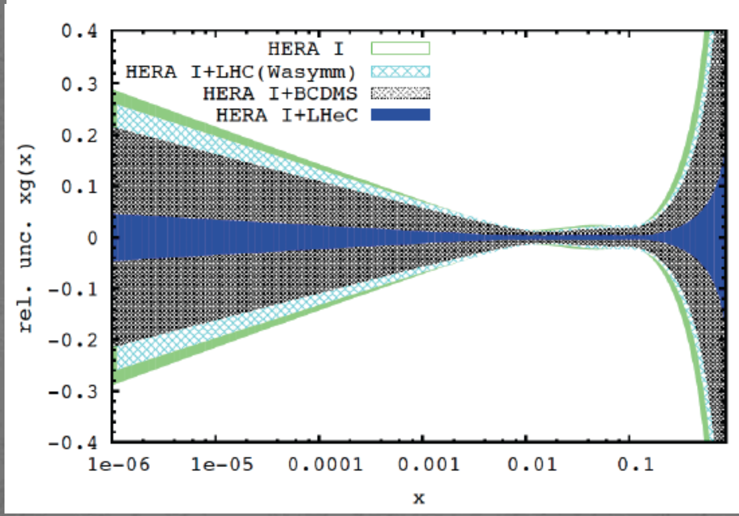
Theory needs help and much hope is directed to the near and far future of the LHC
Particle physics is one coherent subject and it better is pursued as an entity further.

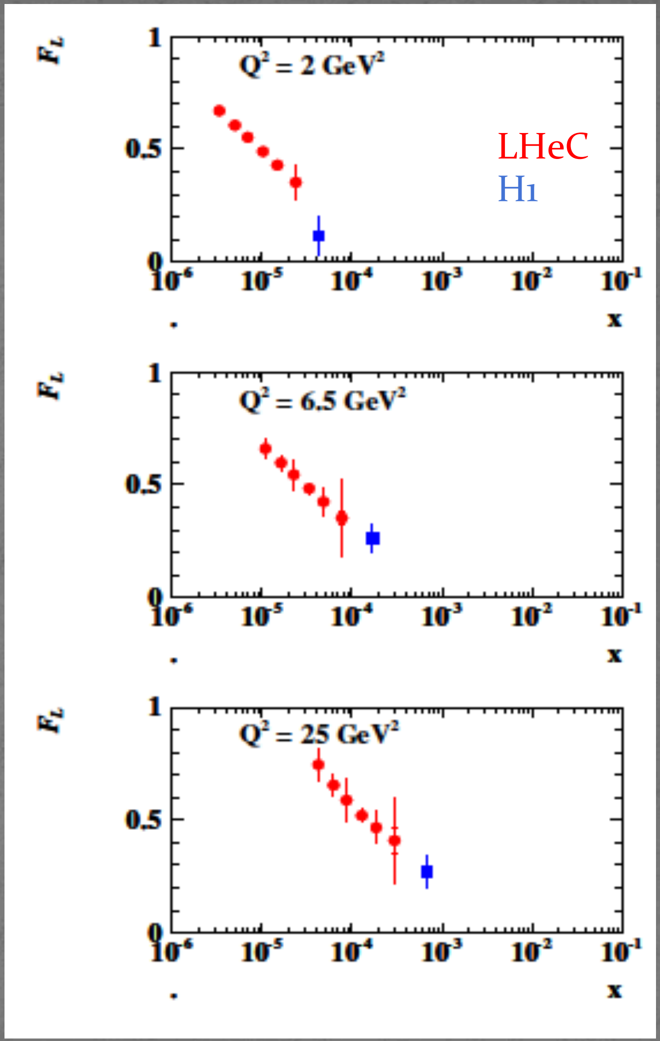
Sincere thanks to many colleagues on H1, ATLAS, LHeC, LHC, Theory, ..

Elbe Fireworks in May 2009

Gluon Saturation at Low x?







Gluon measurement down to $x=10^{-5}$, **Saturation or no saturation** (F_2 and precise F_L)
Non-linear evolution equations? Relations to string theory, and **SUSY at ~10 TeV**?

cf H.Kowalski, L.Lipatov, D.Ross, arXiv:1205.6713

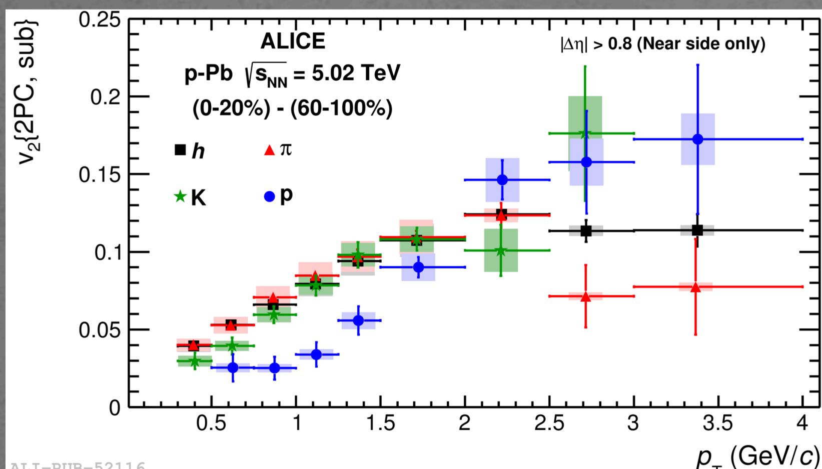
Proton-Lead at the LHC

$$\frac{dN}{d\Phi_Z} \propto \sum_n [1 + v_n \cos(n(\Phi_Z - \Phi_{EP}))]$$

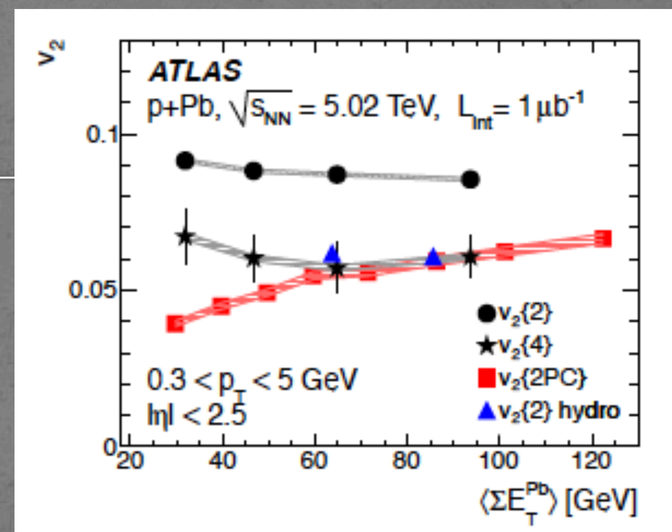
Φ_Z boson azimuthal emission angle
Φ_{EP} event plane azimuth

v_2 for Z is zero, it decays before the plasma is formed ..

1307.3237 – ALICE



1303.2084 – ATLAS



Perhaps surprising, recent results indicate that the flow in pPb resembles PbPb
Possibly the determination of nPDFs in AA and pA is reduced to W,Z production
[collective effects in final state – rescattering of produced partons – hydrodynamics]