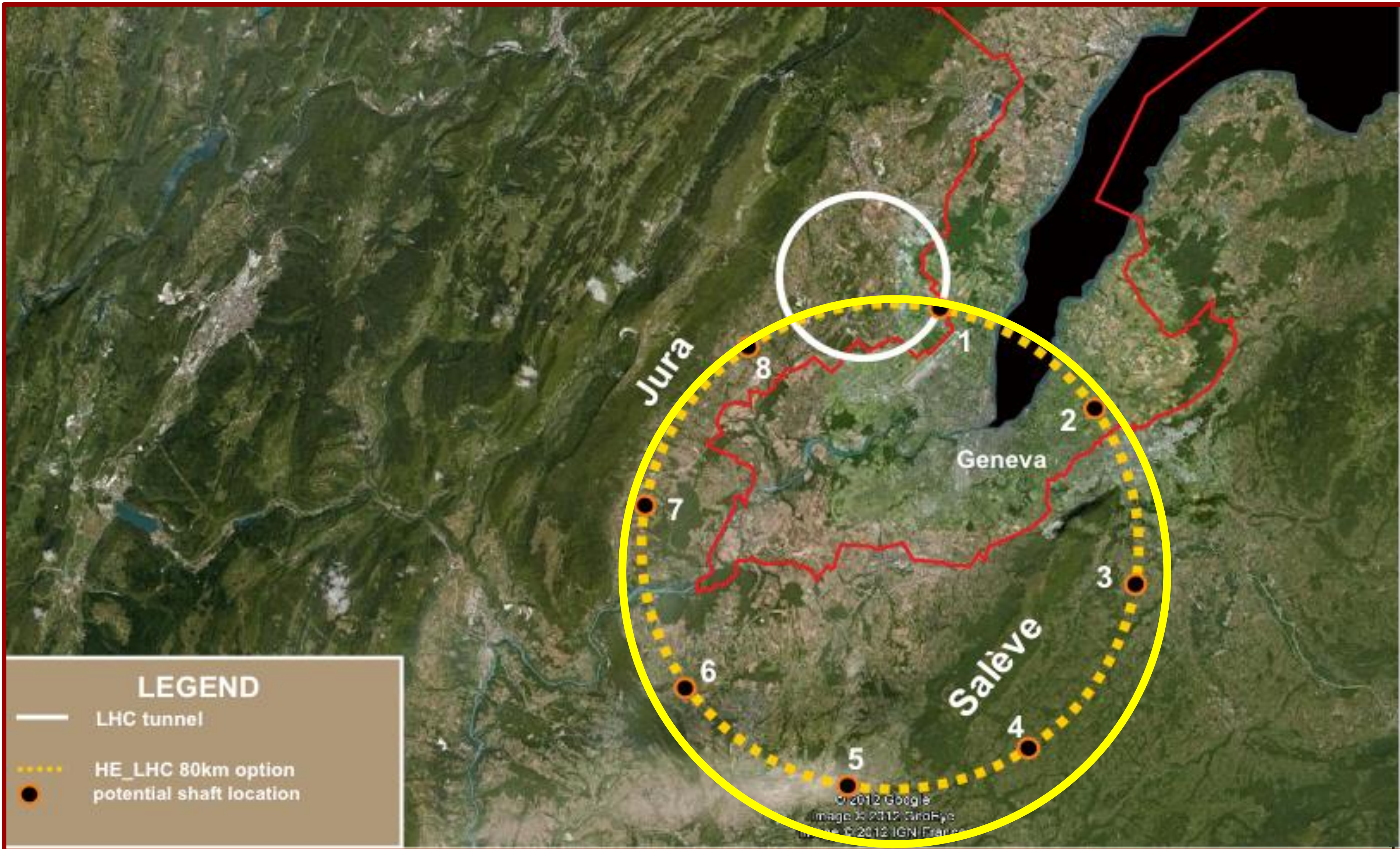
Future Circular Colliders (FCC) study: Introduction

A. Ball, F. Gianotti, M. Mangano



From European Strategy deliberations

d) To stay at the forefront of particle physics, Europe needs to be in a position to propose an ambitious post-LHC accelerator project at CERN by the time of the next Strategy update, when physics results from the LHC running at 14 TeV will be available. ***CERN** should undertake design studies for accelerator projects **in a global context**, with emphasis on proton-proton and electron-positron high-energy frontier machines. These design studies should be coupled to a vigorous accelerator R&D programme, including high-field magnets and high-gradient accelerating structures, **in collaboration with national institutes, laboratories and universities worldwide**.*

- European ambition is energy frontier physics.
- The main motivation of the next ambitious machine is physics beyond Higgs.
- Cohegence with outside of Europe i.e. "global context" important

T. Nakada (European Strategy) CERN PH Meeting, Geneva, 30 September, 2013 12

CERN Management set up a FCC project, with the main goal of preparing a Conceptual Design Report by the time of the next ES (~2018)

CDR main scope is to describe technical feasibility (e.g. tunneling, magnets), design (e.g. machine, experiments), cost, and physics motivations

Project Leader: Michael Benedikt (BE-OP)

Emphasis on (and design driven by) high-energy pp collider requirements. An e^+e^- machine (previously known as "TLEP") and/or an ep machine could be built in the same tunnel if justified by physics in the international context (e.g. no ILC)

- A kick-off meeting is planned on 12-14 February 2014 (in full clash with ATLAS week … date driven by DG availability)
- Location: University of Geneva
- Preparatory group (Steering committee) put in place

FCC Study Scope and Structure

Future Circular Colliders - Conceptual Design Study for next European Strategy Update (2018)

Infrastructure

tunnels, surface buildings, transport (access roads), civil engineering, cooling ventilation, electricity, cryogenics, communication & IT, fabrication and installation processes, maintenance, environmental impact and monitoring, safety

Hadron injectors	Hadron collider	e+ e- collider
Beam optics and dynamics Functional specs Performance specs Critical technical systems Operation concept	Optics and beam dynamics Functional specifications Performance specs Critical technical systems Related R+D programs *HE-LHC comparison* Operation concept Detector concept Physics requirements	Optics and beam dynamics Functional specifications Performance specs Critical technical systems Related R+D programs Injector (Booster) Operation concept Detector concept Physics requirements

e- p option: Physics, Integration, additional requirements

Main areas for design study

Preparatory group for a kick-off meeting => Steering committee

Machines and infrastructure conceptual designs	Technologies R&D activities Planning	Physics experiments detectors
Infrastructure	High-field magnets	Hadron physics experiments interface, integration
Hadron collider conceptual design	Superconducting RF systems	$e^+ e^-$ coll. physics experiments interface, integration
Hadron injectors	Cryogenics	e^- - p physics and integration aspects
Lepton collider conceptual design	Specific technologies	
Safety, operation, energy management environmental aspects	Planning	

PP-131007-MBE_FCC Design Study

Team for kick-off and study preparation

Future Circular Colliders - Conceptual Design Study
Study coordination, host state relations, global cost estimate
Benedikt, Zimmermann

Hadron injectors **B. Goddard**	**VL Hadron collider** **D. Schulte**	**Infrastructure, cost estimates** **P. Lebrun**	**e+ e- collider** **J. Wenninger**	High Field Magnets **L. Bottura**	**Physics and experiments**
				Supercon-ducting RF **E. Jensen**	Hadron physic Experiments, infrastructure **A. Ball, F. Gianotti, M. Mangano**
				Cryogenics **L. Tavian**	
	e- p option Integration aspects **O. Brüning**			Specific Technologies (MP, Coll, Vac, BI, BT, PO) **JM. Jimenez**	e+ e- exper., physics **A. Blondel J.Ellis, P.Janot**
Operation aspects, energy efficiency, OP & mainten., safety, environment. **P. Collier**					
Planning (Implementation roadmap, financial planning, reporting) **F. Sonnemann**					e- p physics + **M. Klein**

PP-131007-MBE_FCC Design Study

Machine parameters: √s vs ring size and magnets

Facility	Ring (km)	Magnets (T)	√s (TeV)
(SSC)	87	6.6	40
LHC	27	8.3	14
HE-LHC	27	16-20	26-33
FHC	80 80 100	8.3 20 15	42 100 100

Note:
- ❑ big jump in technology from 15-16T magnets (Nb_3Sn) to 20T magnets (HTS)
- → the latter may require many more years of R&D than the former
- → optimum balance between tunnel size (cost ?) and magnet technology (<u>time</u> and cost ?)
- ❑ for a cost-affordable and technically-viable (big) machine need "routine" industrial production of magnets …

Nomenclature:
FHC = Future Hadron Collider (pp part of FCC)
FEC = Future Electron Collider (e^+e^- part of FCC, previously known as TLEP)
FEHC = Future Electron Hadron Collider (ep part of FCC)

Physics case and goals

Will need to be studied in detail in the years to come …

Likely, 2 main goals (quite different in terms of machine and detector requirements):

Explore High-E frontier → look for heavy objects, including high-mass VV scattering:

- requires as much integrated luminosity as possible (cross-section goes like 1/s)
  → maximising mass reach may require operating at higher pile-up than HL-LHC
- events are mainly central → ATLAS/CMS-like geometry is ok
- main experimental challenges: muon momentum resolution up to ~50 TeV; size of detector to contain up to ~50 TeV showers; forward jet tagging; pile-up

Precise measurements of Higgs boson (beyond HL-LHC and FEC/ILC-if-any):

- would benefit from moderate pile-up
- light-objects (Higgs !) production is "flat" in rapidity
- main experimental challenges: higher acceptance for precision physics than ATLAS/CMS: tracking/B-field and good EM granularity down to |η|~4-5 ?; forward jet tagging; pile-up

First ideas about detector layout: → see D.Fournier's talk

Other goals:

- "Bread-and-butter" SM physics: W, Z, top, QCD (with general-purpose experiments and perhaps also dedicated experiments ?)
- Physics case for dedicated HI and B-physics experiments ? LHCb (T.Gershon) and ALICE (A. Dainese, S.Masciocchi, W.Riegler) are looking.. Others at FHC ?
- "Intensity-frontier" type (LFV, etc.) smaller-scale (fixed-target) experiments beyond present worldwide program with SPS and/or LHC extracted beams ? → see D.Coté's talk

→ FCC could become a facility …

After discussion with the machine experts on the Steering Committee, we agreed on the following baseline parameters for kick-off meeting (they give similar pile-up as HL-LHC → can extrapolate physics studies)

Parameter	LHC	HL-LHC		HE-LHC	VHE-LHC
c.m. energy [TeV]	14			33	100
circumference C [km]	26.7				80
dipole field [T]	8.33			20	20
dipole coil aperture [mm]	56			40	≤ 40
beam half aperture [cm]	2.2 (x), 1.8 (y)			1.3	< 1.3
injection energy [TeV]	0.45			>1.0	>3.0
no. of bunches	2808	2808	1404	2808	8420
bunch population [10^{11}]	1.125	2.2	3.5	0.81	0.80
init. transv. norm. emit. [μm]	3.73,	2.5	3.0	1.07	1.70
initial longitudinal emit. [eVs]	2.5			3.48	13.6
no. IPs contributing to tune shift	3	2	2	2	2
max. total beam-beam tune shift	0.01	0.021	0.028	0.01	0.01
beam circulating current [A]	0.584	1.12	0.089	0.412	0.401
RF voltage [MV]	16			16	22
rms bunch length [cm]	7.55			7.55	7.55
IP beta function [m]	0.55	$0.73 \rightarrow 0.15$		0.3	0.9
init. rms IP spot size [μm]	16.7	$15.6 \rightarrow 7.1$	$24.8 \rightarrow 7.8$	4.3	5.3
Stored energy [MJ]	362	694		601	4573
Peak luminosity [10^{34} cm^{-2}s^{-1}]	1	(7.4)		5	5

Bunch-spacing: 25 ns

Average pile-up: ~140/xing

In parallel and longer-term: optimize machine parameters for highest possible integrated luminosity with smallest possible pile-up: considering bunch spacing down to 5 ns (can detector benefit from bunch spacing smaller than 25 ns ?)
Note: likely long bunches (14 cm ?) → to be optimised by machine and experiments together

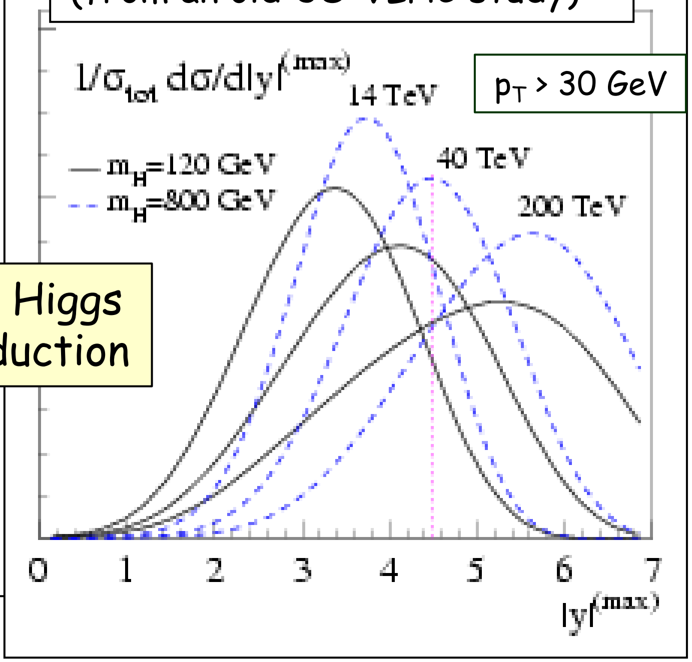
Physics/detector studies for kick-off meeting

- Use LHC and HL-LHC studies as much as possible, scaled by √s and acceptance as obtained from MC generators (PDF should be good enough for this purpose)
- E-frontier studies: mass reach for few benchmarks, e.g. q*, W'/Z', SUSY (squarks-gluino); VV scattering is a must …
  Detector: understand most promising magnet configurations (central and forward) and Muon Spectrometer size vs B-field
- Higgs measurements: few relevant benchmarks: HH, ttH, rare decays
  → optimise detector coverage vs physics acceptance (e.g. high-p_T vs inclusive Higgs)
  Detector: forward tracking and EM calorimeter granularity/technology; trigger !

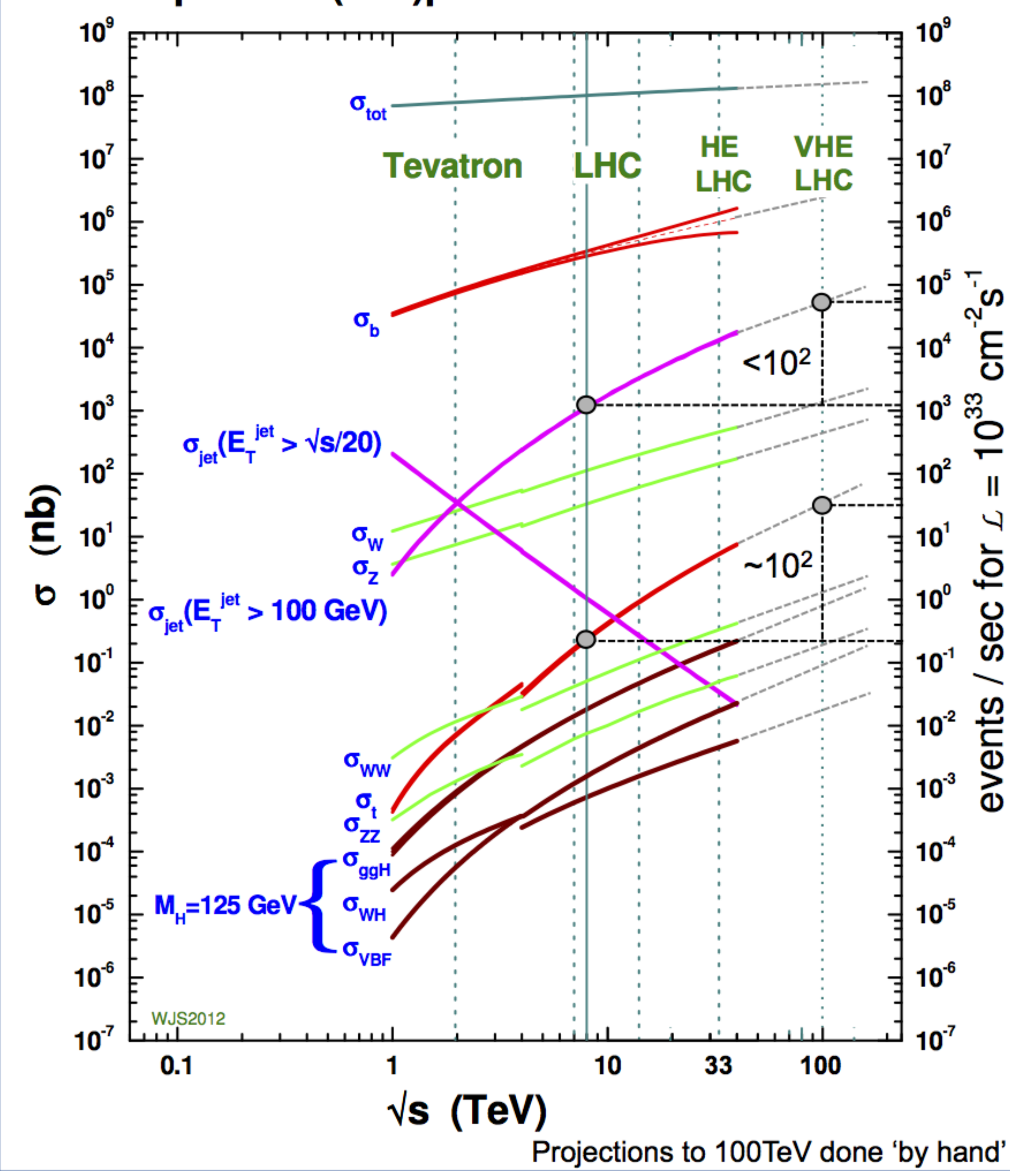
Note: forward jet tag expected to be crucial for both, Higgs and VV scattering studies

Maximum jet rapidity vs √s
(from an old US-VLHC study)

VBF Higgs production



Projections to 100 TeV made by hand by Anna Sfyrla starting from original Stirling's plot



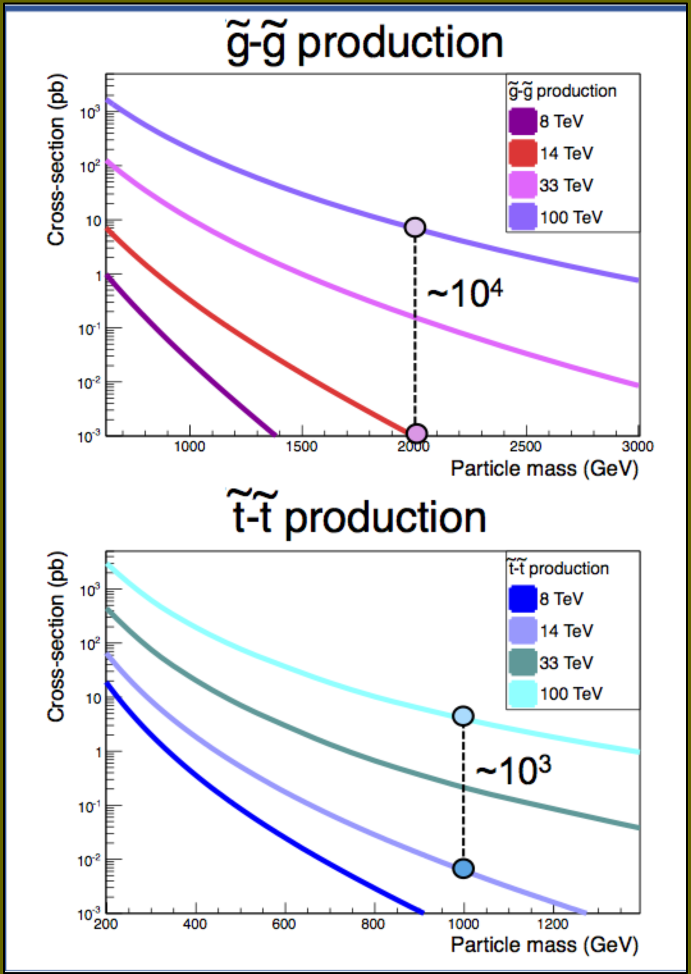
Process	R(100 TeV/14 TeV)
W	6.7
Z	7.2
WW	9.6
ZZ	10.3
tt	32.5
bb	~ 3

M. Mangano

Longer-term: studies vs √s needed:
- ❑ comparison with HE-LHC
- ❑ if cost forces machine staging

Process	√s = 14 TeV	√s = 33 TeV	√s = 40 TeV	√s = 60 TeV	√s = 80 TeV	√s = 100 TeV
ggF [a]	50.35 pb	178.3 pb (3.5)	231.9 pb (4.6)	394.4 pb (7.8)	565.1 pb (11.2)	740.3 pb (14.7)
VBF [b]	4.40 pb	16.5 pb (3.8)	23.1 pb (5.2)	40.8 pb (9.3)	60.0 pb (13.6)	82.0 pb (18.6)
WH [c]	1.63 pb	4.71 pb (2.9)	5.88 pb (3.6)	9.23 pb (5.7)	12.60 pb (7.7)	15.90 pb (9.7)
ZH [c]	0.904 pb	2.97 pb (3.3)	3.78 pb (4.2)	6.19 pb (6.8)	8.71 pb (9.6)	11.26 pb (12.5)
ttH [d]	0.623 pb	4.56 pb (7.3)	6.79 pb (11)	15.0 pb (24)	25.5 pb (41)	37.9 pb (61)
$gg \rightarrow HH^{e}(\lambda=1)$	33.8 fb	207 fb (6.1)	298 fb (8.8)	609 fb (18)	980 fb (29)	1.42 pb (42)

Higgs cross sections (LHC HXS WG)



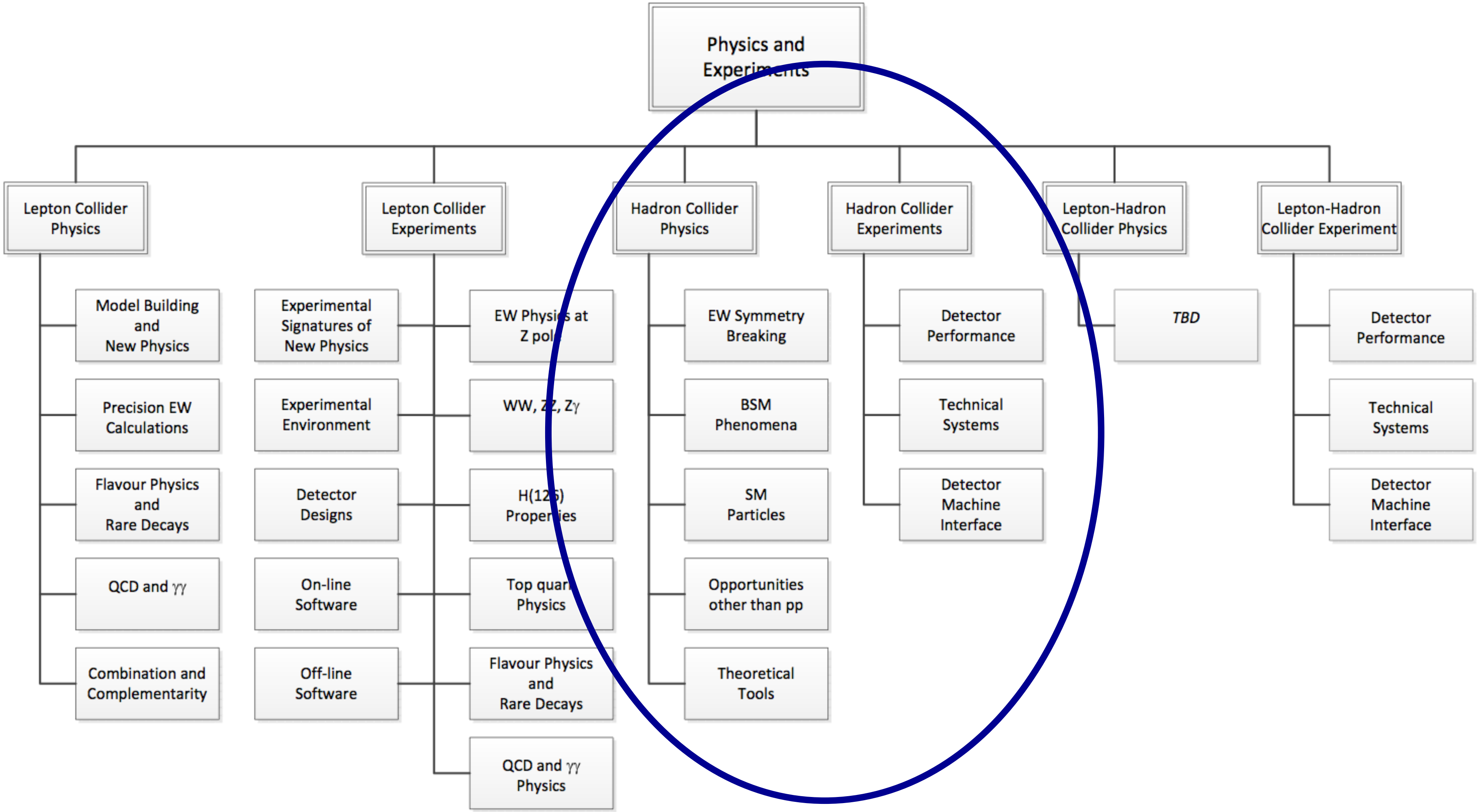
SUSY cross sections (Anna Sfyrla)

- 8 & 14TeV at NLO+NLL.
- 33 & 100TeV at NLO.
- Large increase in SUSY cross-sections for relevant ('natural') particle masses.

Thanks to Robin van der Leeuw for his help with Prospino

Preliminary work breakdown structure
(should also match CDR chapters)

A.Ball, F.Gianotti, M.Mangano, M.Benedikt, J.Gutleber

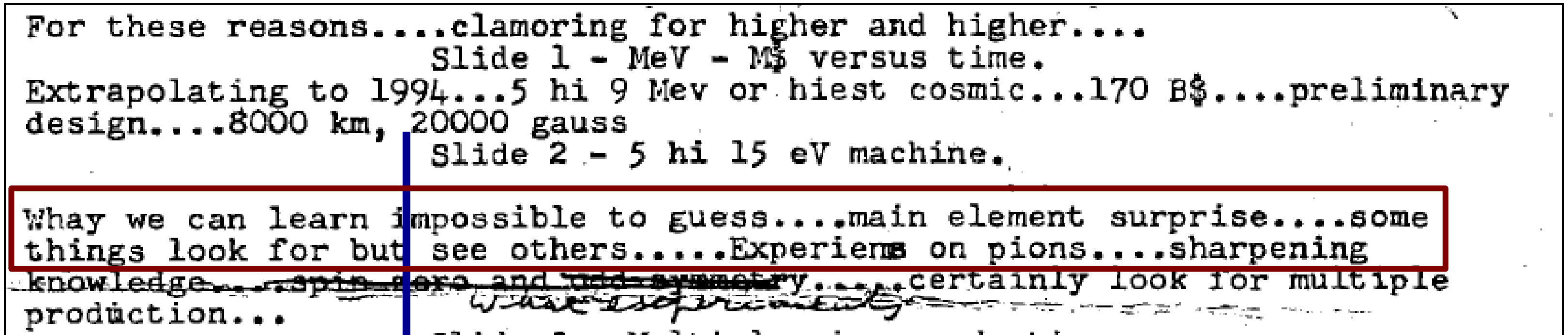


Preliminary work breakdown structure (should also match CDR chapters)

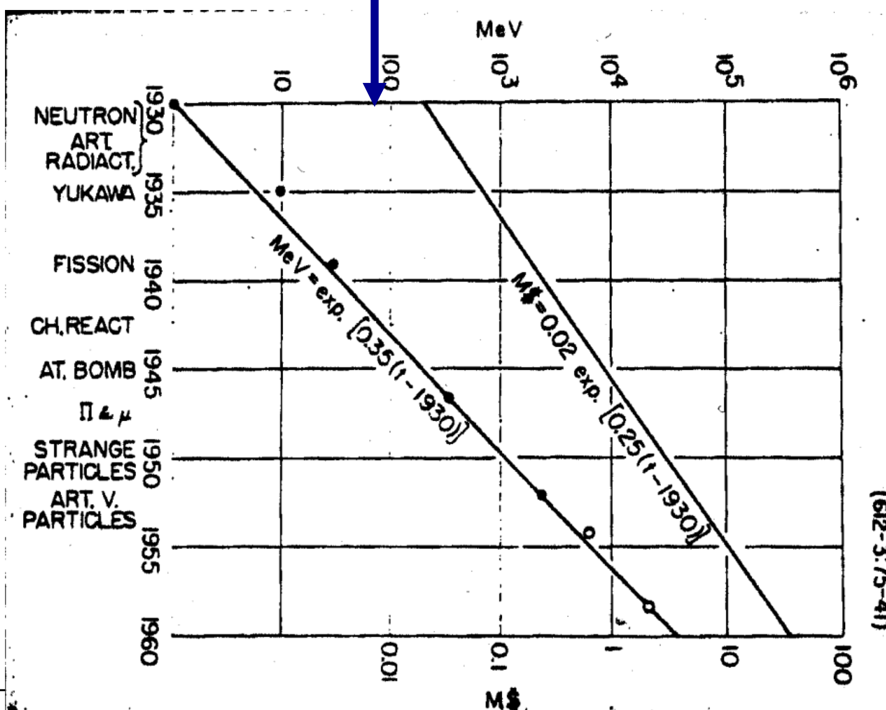
A.Ball, F.Gianotti, M.Mangano

Physics and experiments	
Hadron collider physics	Physics at the hadron collider
Exploration of EW Symmetry Breaking	Study consequences of models on potential experiments and what searches should be conducted in the experiments
High-mass WW scattering, high mass HH production	
Rare Higgs production/decays and precision studies of Higgs properties	
Additional BSM Higgs bosons: discovery reach and precision physics programme	
New handles on the study of non-SM EWSB dynamics	e.g. dynamical EWSB and composite H, etc
Exploration of BSM phenomena	
Discovery reach for various scenarios	(SUSY, new gauge interactions, new quark and leptons, compositeness, etc.)
Theoretical implications of discovery/non-discovery of BSM scenarios	e.g. what if nothing seen after 100 TeV, dark matter opportunities, BSM frameworks beyond HL-LHC reach
Continued exploration of SM particles	
Physics of the top quark	Rare decays, FCNC, anomalous couplings
Physics of the bottom quark	Rare decays, CPV
Physics of the tau lepton	E.g. tau -> 3 mu, tau -> mu gamma and other LFV decays
W/Z physics	
QCD dynamics	
Opportunities other than pp physics	
Heavy Ion Collisions	e.g. Intensity frontier: kaon physics, mu2e conversions
Fixed target experiments	Explore feasibility of fixed-target experiments as test-beam facilities
Smaller-size experiments for dedicated purposes	e.g. HI, B-physics, dedicated W/Z/top measurements
Theoretical tools for the study of 100 TeV collisions	
Parton Distribution Function	
MC generators	
N^nLO calculations	
Hadron collider experiments	Study and conceptual design of experiments at the hadron collider
Detector performance	Study and describe a generic layout for a detector that meets the physics requirements for the assumed experiments
Rapidity coverage for tracking, leptons, jets	
Forward tracking and b-tag vs pile-up density	
Electromagnetic calorimeter: dynamic range, forward granularity	
Forward jet tagging	
Muon resolution in the O(10 TeV) region	
Optimisation of the bunch spacing (trigger and readout vs pile-up)	
Technical systems	Study and describe the technical detector elements that make up the generic experiment
Technologies that require R&D	List those detector technologies that should be considered, but that require particular R&D to achieve maturity
Detector technologies	Describe the detector technologies to be used in the detector concept, indicate their state of maturity and their development paths
Radiation effects	Study and document the assumed effects of radiation onto the detectors
Shielding	Study needs for shielding that goes beyond the shielding covered by the accelerator
ECAL	Study and document a specific calorimetry conceptual design
HCAL	
Magnet system	Study and document a main magnet conceptual design
Muon detection	Study and document a muon detection conceptual design
Inner detector	
Tracking	Study and document a tracking conceptual design
Trigger system	Study and specify requirements for first level event filtering systems
Data acquisition, detector controls and detector safety	Study and specify requirements for on-line data processing such as number of channels, throughput, latency, rates, computing and storage needs
Detector machine Interface	
L*, TAS, TAN locations and specifications	
Bunch structure, luminous region and crossing angle	
Beam pipe and vacuum design	
Fluencies, shielding, dose rates, activation, and radiological dose minimization	includes radiation simulation software
Physics and detector protection instrumentation in the long straight section	

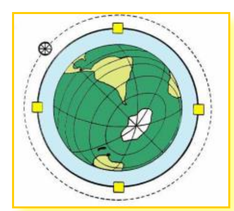
From E. Fermi, preparatory notes for a talk on
"What can we learn with High Energy Accelerators ? "
given to the American Physical Society, NY, Jan. 29th 1954


For these reasons....clamoring for higher and higher....
Slide 1 - MeV - M$ versus time.
Extrapolating to 1994...5 hi 9 Mev or hiest cosmic...170 B$....preliminary design....8000 km, 20000 gauss
Slide 2 - 5 hi 15 eV machine.

Whay we can learn impossible to guess....main element surprise....some things look for but see others.....Experiems on pions....sharpening knowledge... ~~spin zero and odd symmetry~~.....certainly look for multiple production...



Fermi's extrapolation to year 1994:
2T magnets, R=8000 Km (fixed target !),
E_{beam} ~ 5×10^3 TeV, cost 170 B$



Fortunately we have invented colliders and superconducting magnets …

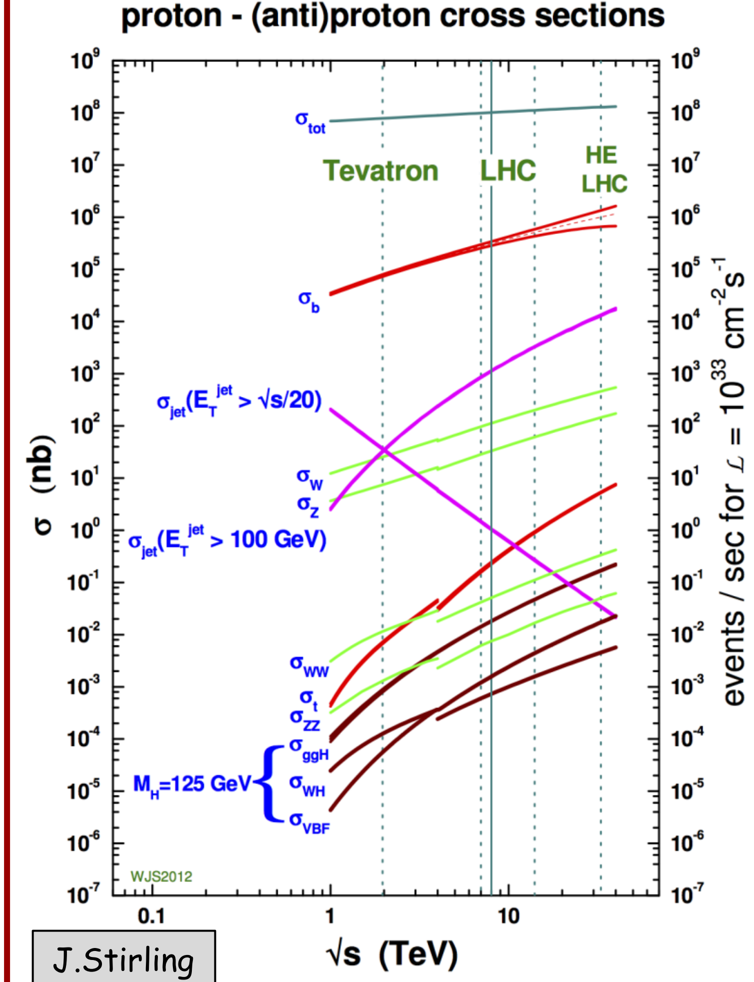
PLEASE JOIN !

No heavy simulation work needed until kick-off meeting, rather intellectual exercise capitalizing on what we learned from ATLAS, CMS and LHC plus simple (mainly generator-level) simulations

Next meeting (26 November): main focus will be first "cross-section x acceptance results" for SM and new processes and organisation of physics studies for kick-off meeting

People involved in physics studies (as far as I know): M.Baak, M.Duehrssen, J.Ferrando, D.Froidevaux, F.Gianotti, H.Gray, C.Helsens, M.Mangano, F.Moortgat, A.Sfyrla, …
PLEASE JOIN !

Subcribe to the following mailing list:fcc-experiments-hadron@cern.ch



Extrapolating this plot to √s = 100 TeV:
σ (W, Z) : x 10
σ (tt) : x 30

Longer-term: studies vs √s needed:
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