



Notes from FCC (Future Circular Collider) Meeting M. Martínez

FCC Week 2015
♦ IEEE International Future Circular Collider Conference
March 23 - 27, 2015 | Washington DC, USA

Organising & Scientific Program Committee:

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IFAE Pizza Seminar, 8th April 2015

Disclaimer

Impossible to summarize
a full week of dense and
rather detailed talks in
just 25 minutes

..and I also need to give you
some background information

So, I focused on few topics
(and decided to ignore e-p collider)

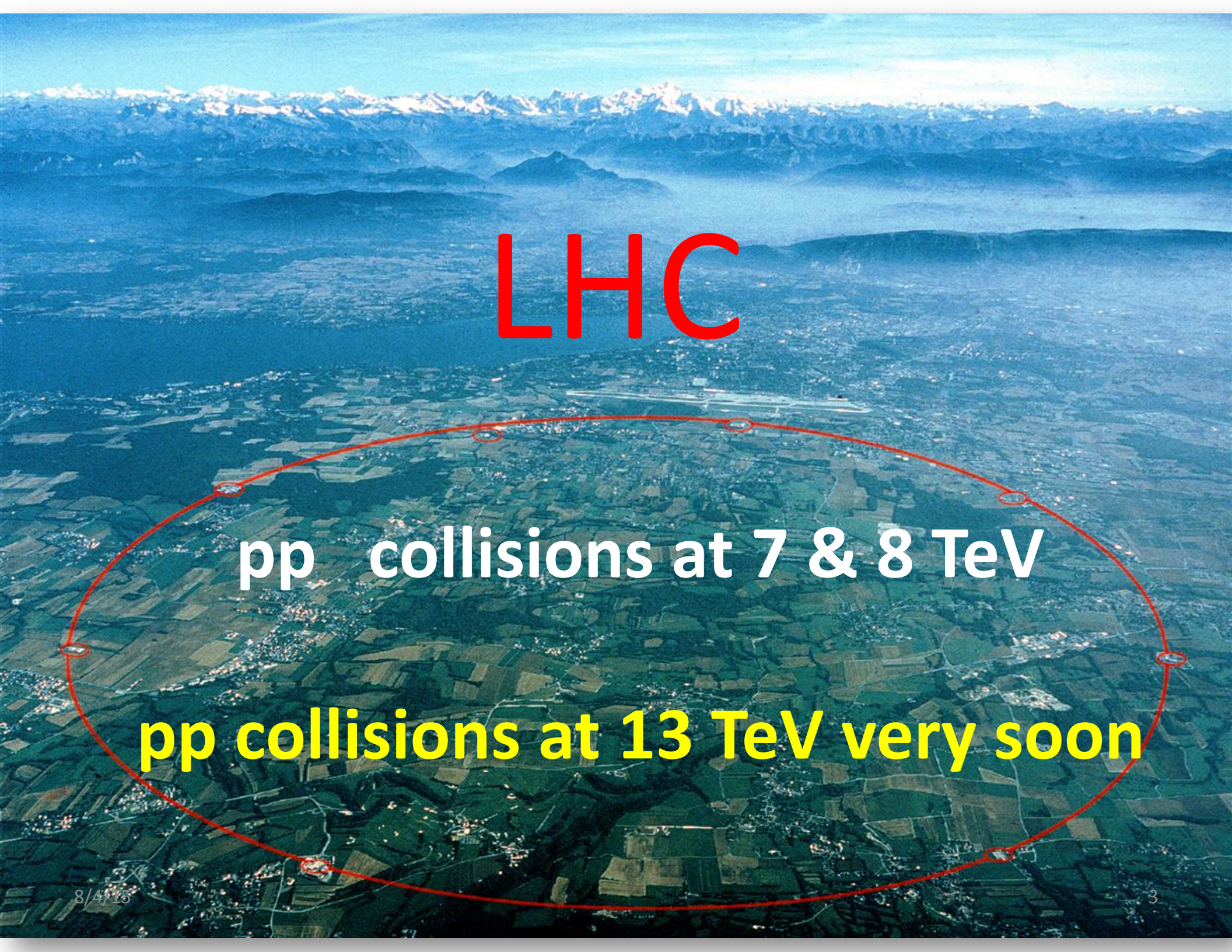


..and I have too many slides...

For those of you really interested in super details

FCC kick-off : <https://indico.cern.ch/event/282344>

FCC first meeting: <https://indico.cern.ch/event/340703>

An aerial photograph of the LHC region in Switzerland, showing the snow-capped Alps in the background and the green landscape of the valley below. A red circle is drawn over the landscape, representing the LHC tunnel. Small red circles are placed at intervals along this path, indicating the locations of the four main collision points. The text 'LHC' is written in large red letters at the top, and two lines of text are centered within the red circle.

LHC

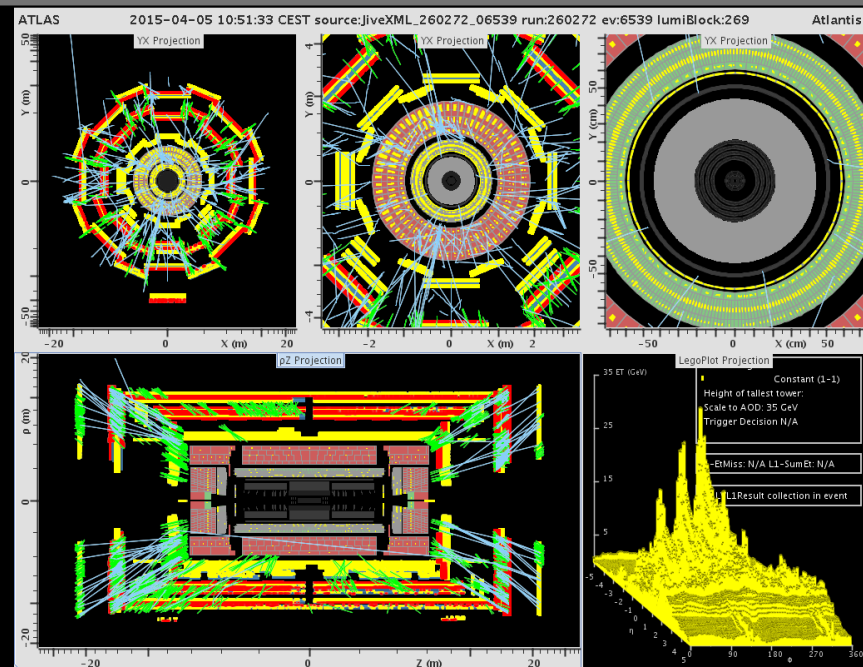
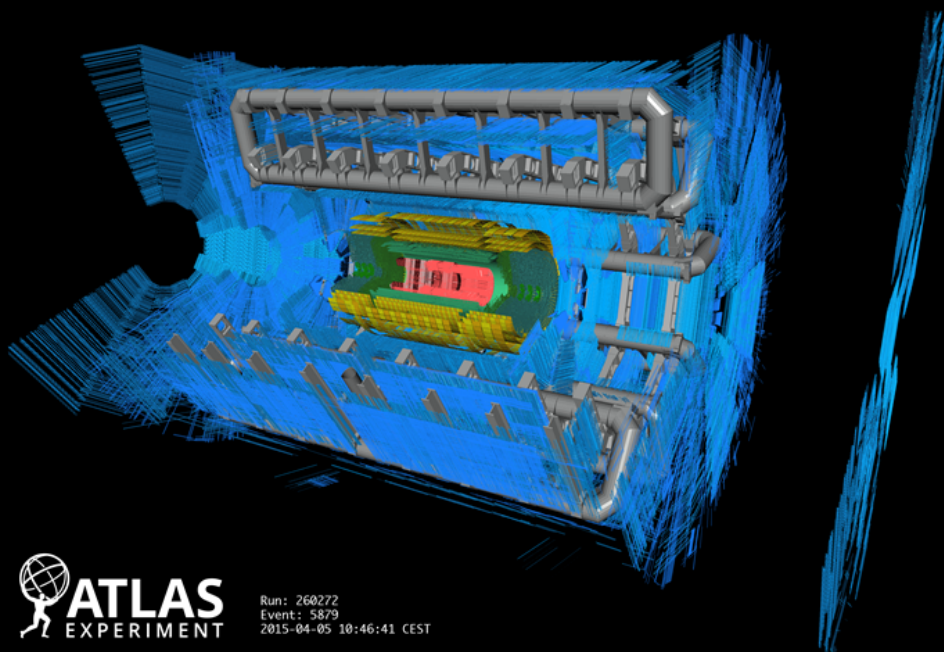
pp collisions at 7 & 8 TeV

pp collisions at 13 TeV very soon

Easter Sunday Morning -- Beam



LHC is back !



Run: 260272
Event: 5879
2015-04-05 10:46:41 CEST

7 April 2015

A. Cerri, A. Polini, ATLAS weekly

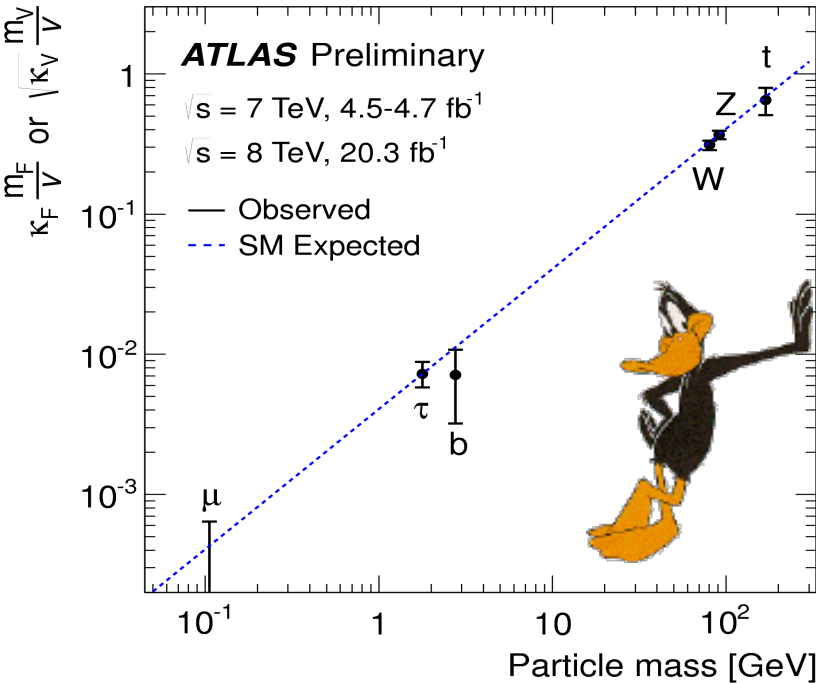
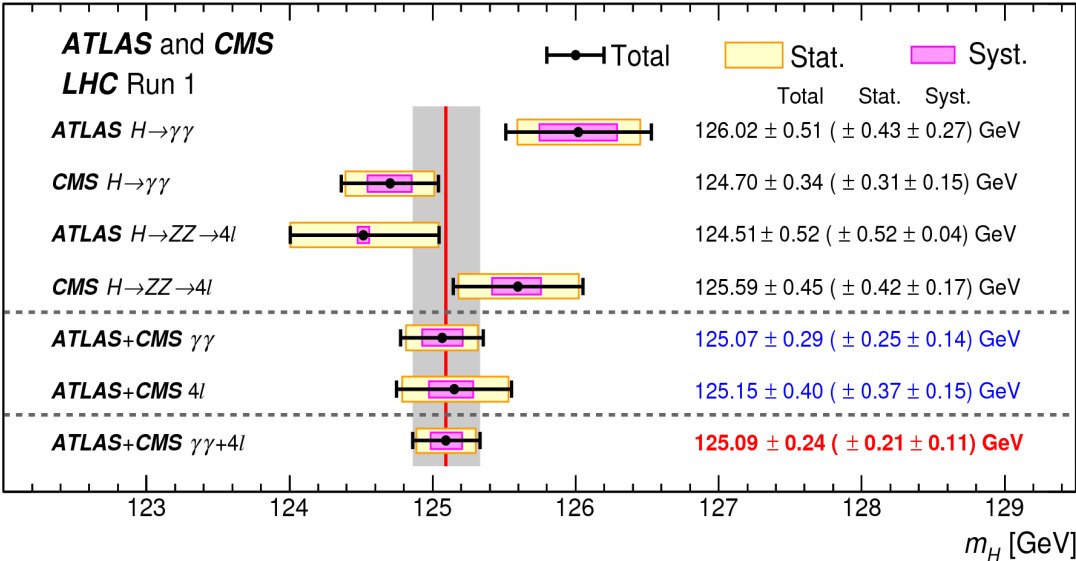
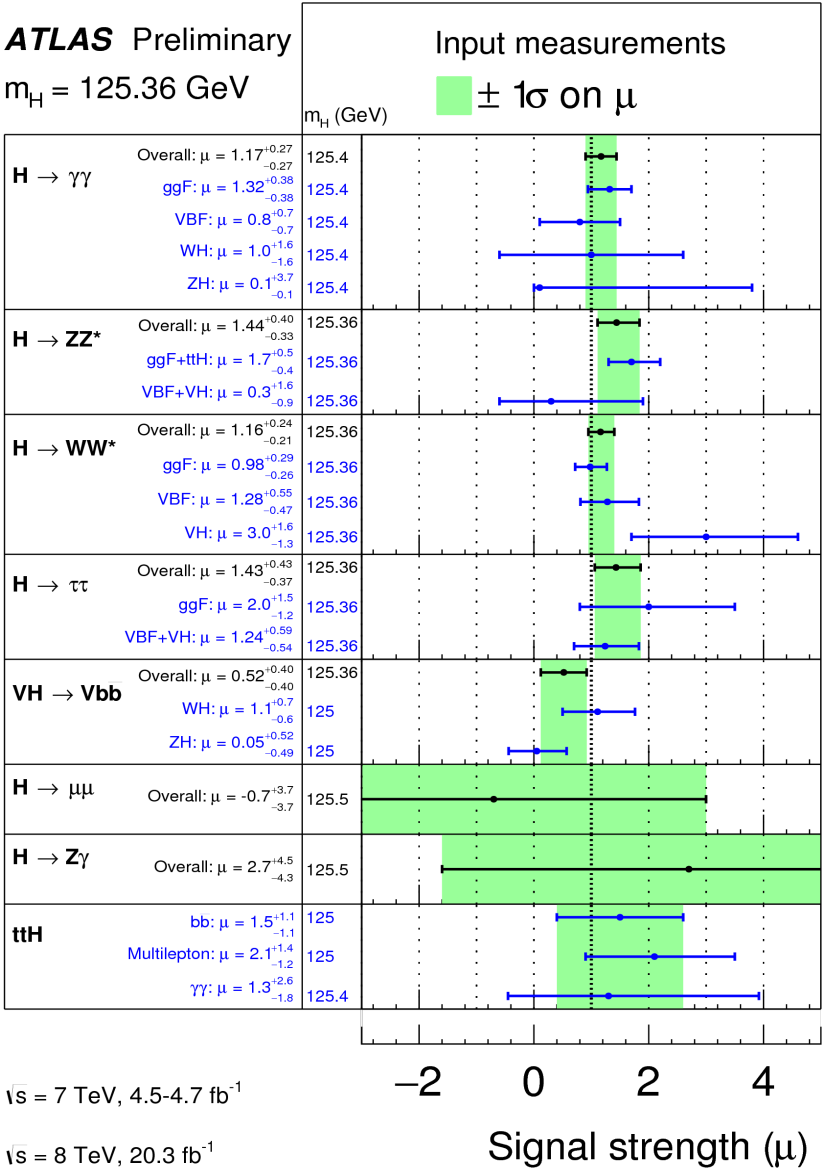
Where do we stand ?

SM Higgs

SUSY & BSM

Latest Higgs Results

If it looks like a duck, swims like a duck, and quacks like a duck...

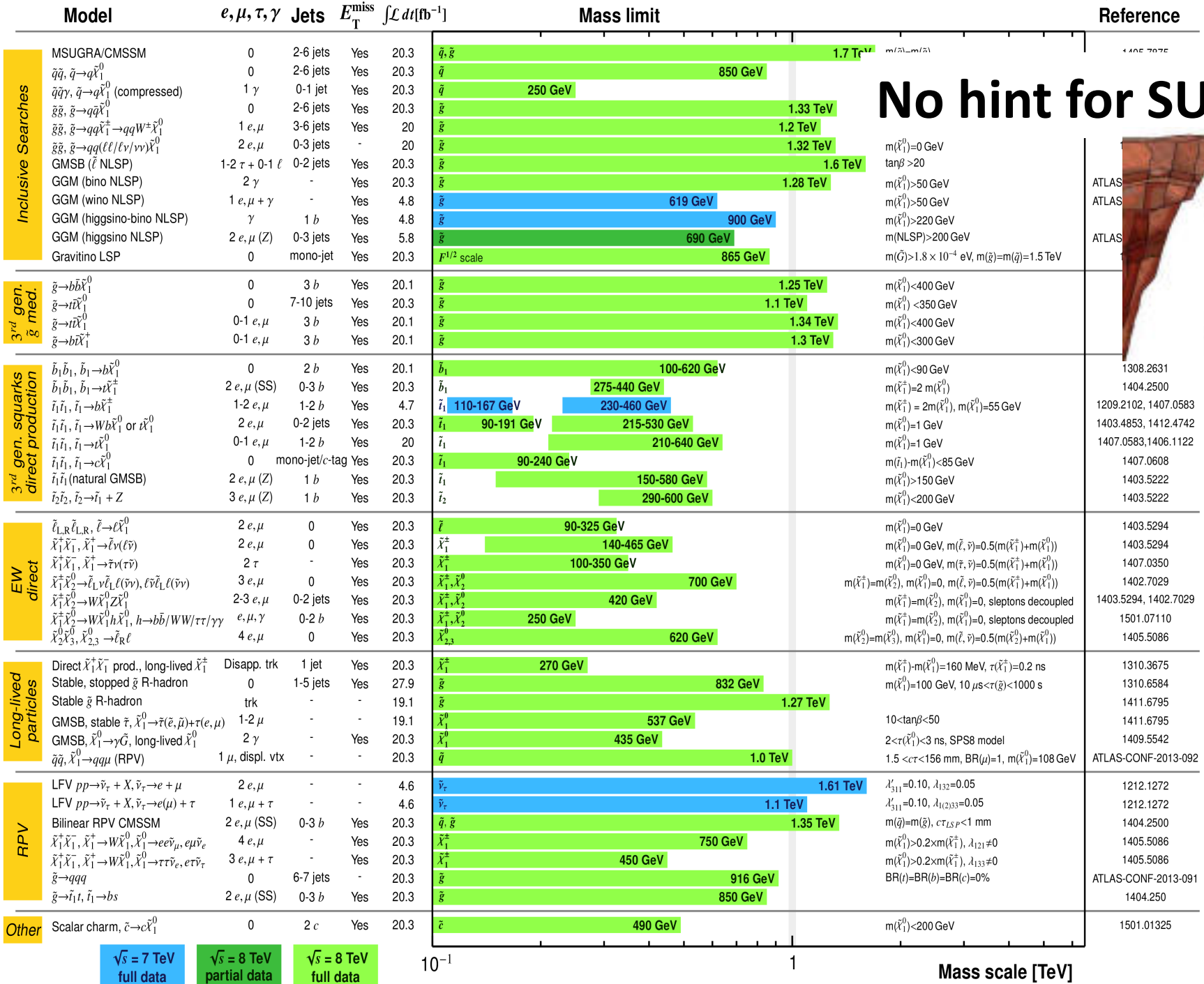


ATLAS SUSY Searches* - 95% CL Lower Limits

Status: Feb 2015

ATLAS Preliminary

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



No hint for SUSY



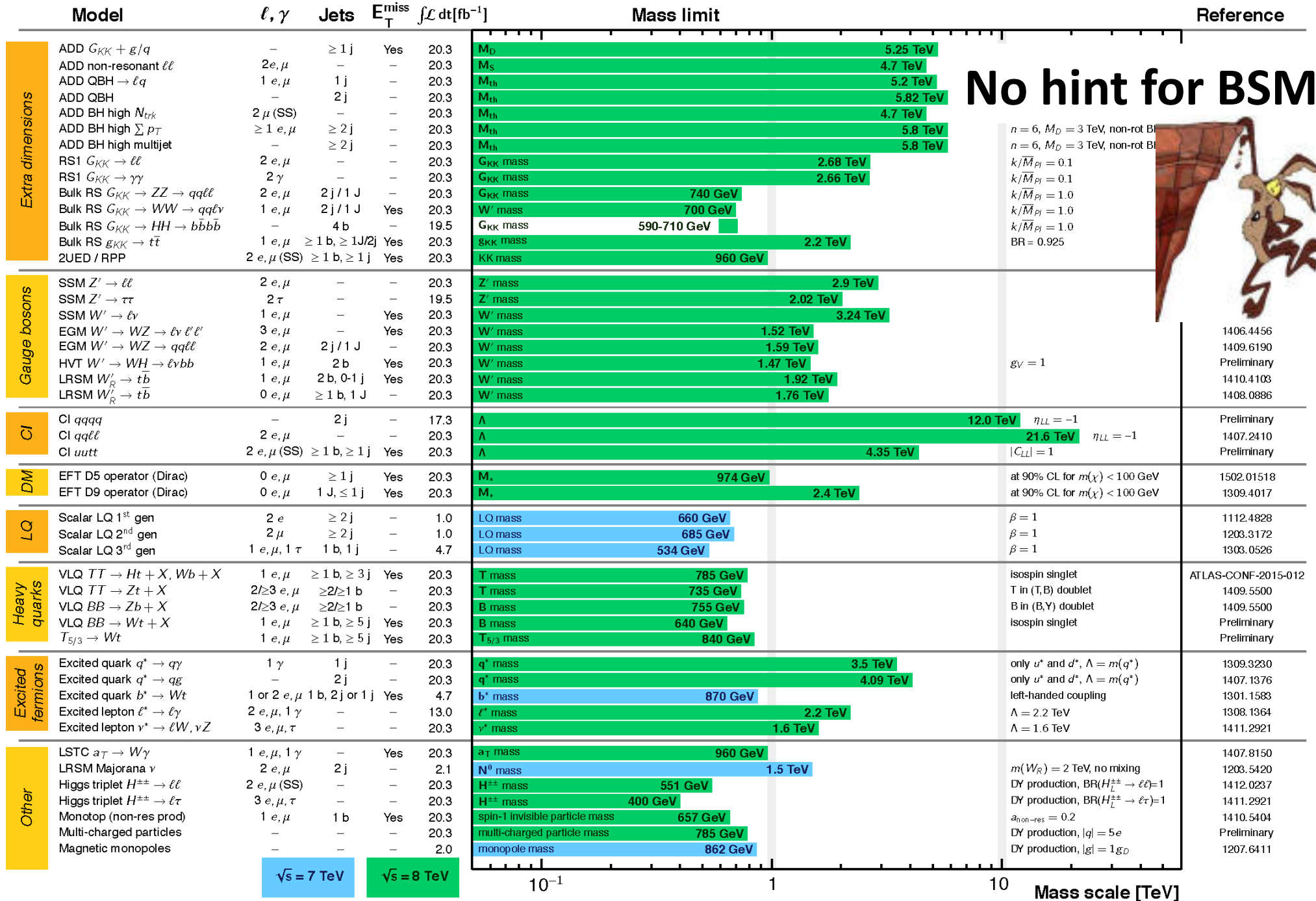
*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

ATLAS Exotics Searches* - 95% CL Exclusion

Status: March 2015

ATLAS Preliminary

$$\int \mathcal{L} dt = (1.0 - 20.3) \text{ fb}^{-1} \quad \sqrt{s} = 7, 8 \text{ TeV}$$



*Only a selection of the available mass limits on new states or phenomena is shown.

But lots of remaining questions..

naturalness

dark matter

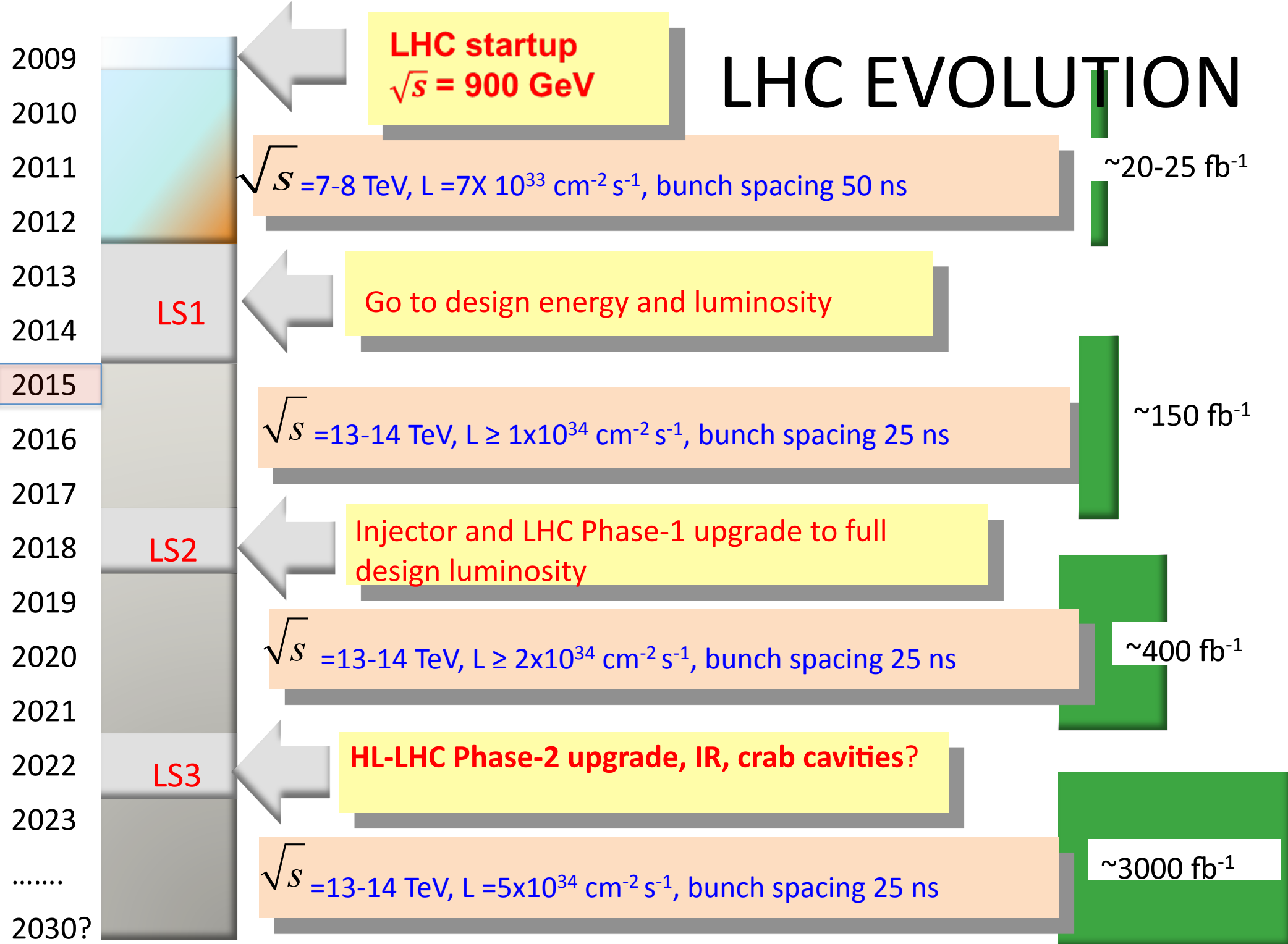
matter/antimatter asymmetry

the flavor/family problems

unification of coupling constants

.....

LHC EVOLUTION

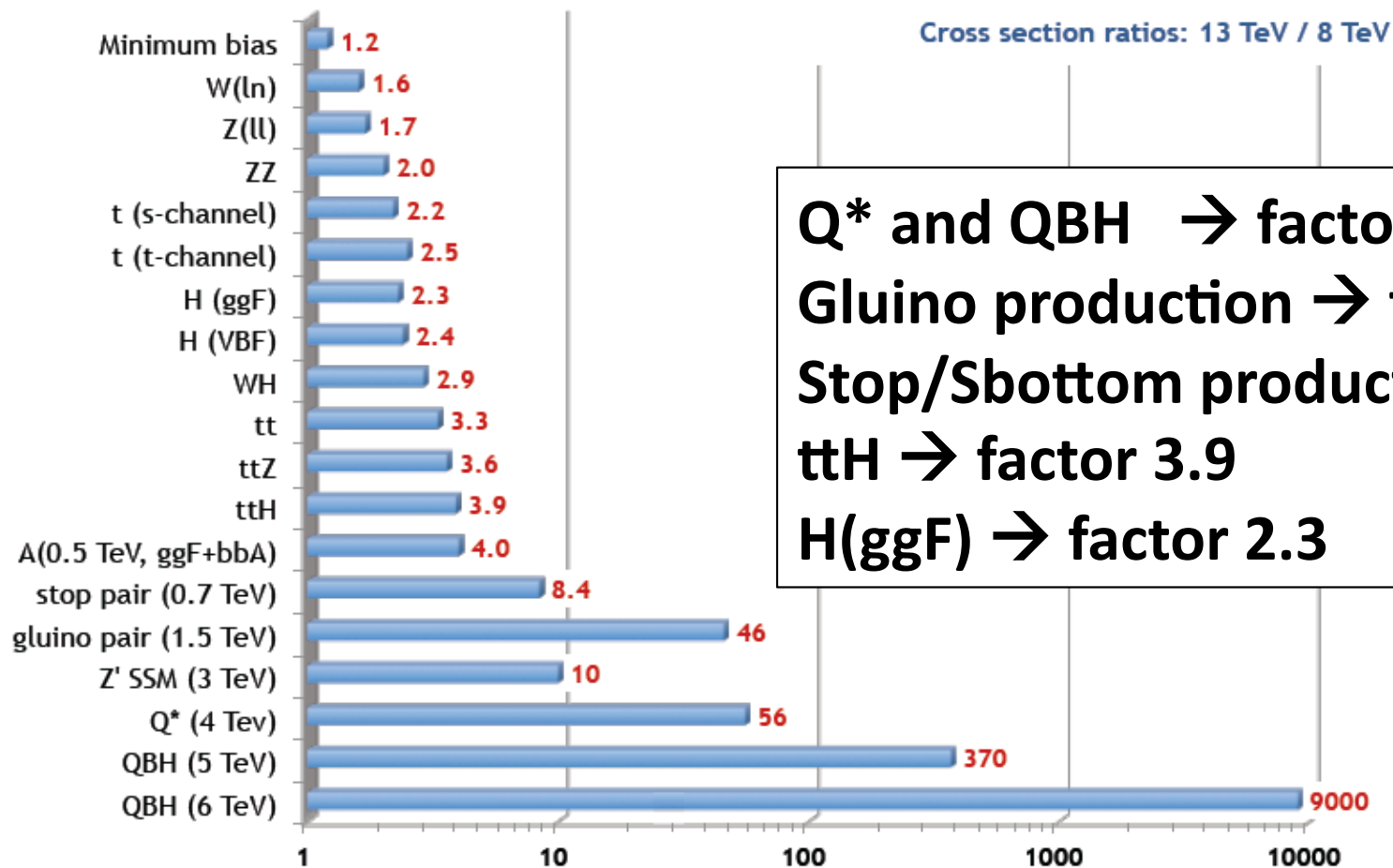


What can we expect ?

SUSY & BSM

SM Higgs “radiography”

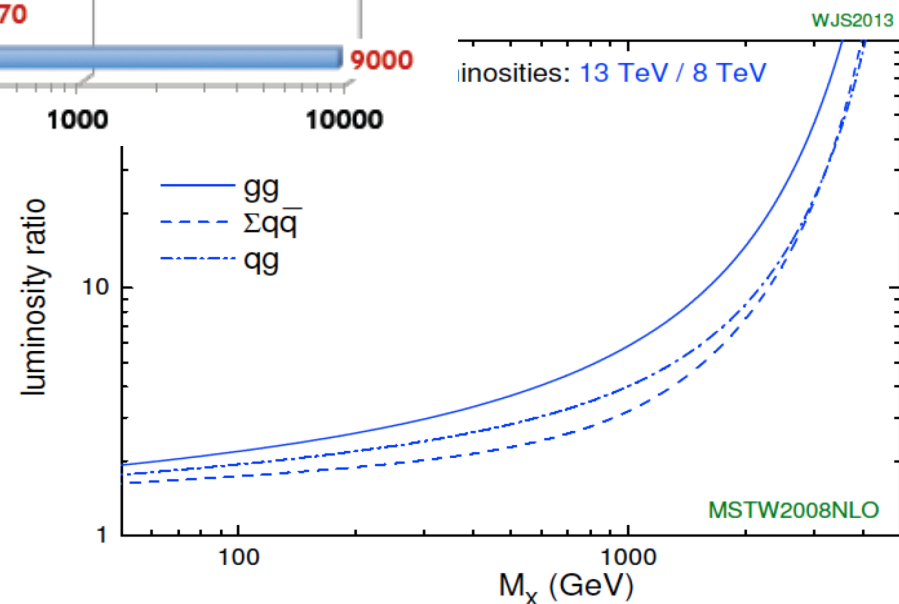
The physics gain 8 TeV $\rightarrow$ 13 TeV

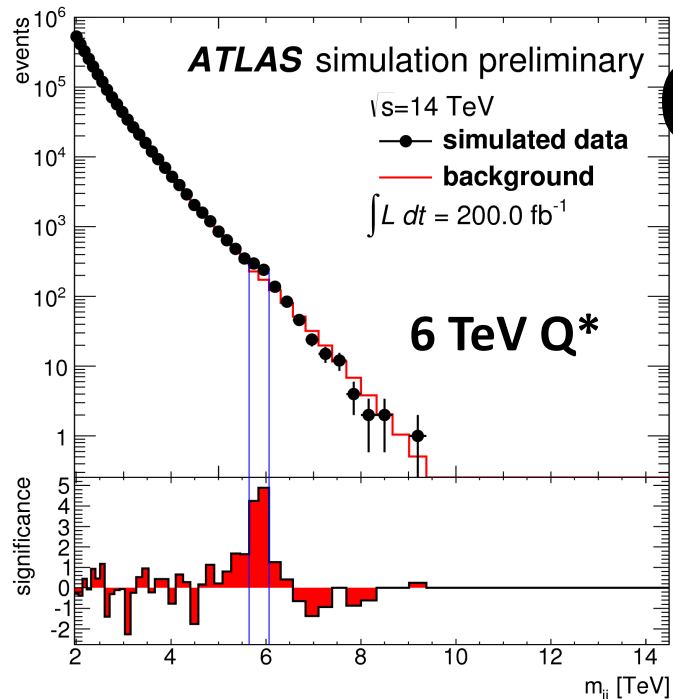


Q* and QBH $\rightarrow$ factors 56 – 370
Gluino production $\rightarrow$ factor 46
Stop/Sbottom production $\rightarrow$ factor 8
ttH $\rightarrow$ factor 3.9
H(ggF) $\rightarrow$ factor 2.3

- Huge improvement at the edge of phase space
- Searches should be priority one in first two years

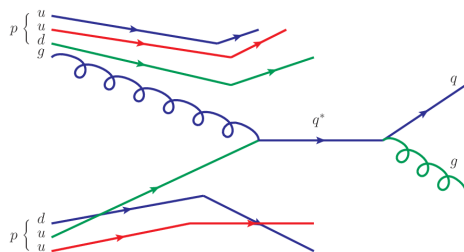
*First pp Collisions by the 22nd May
(VdM scans scheduled by then....)*



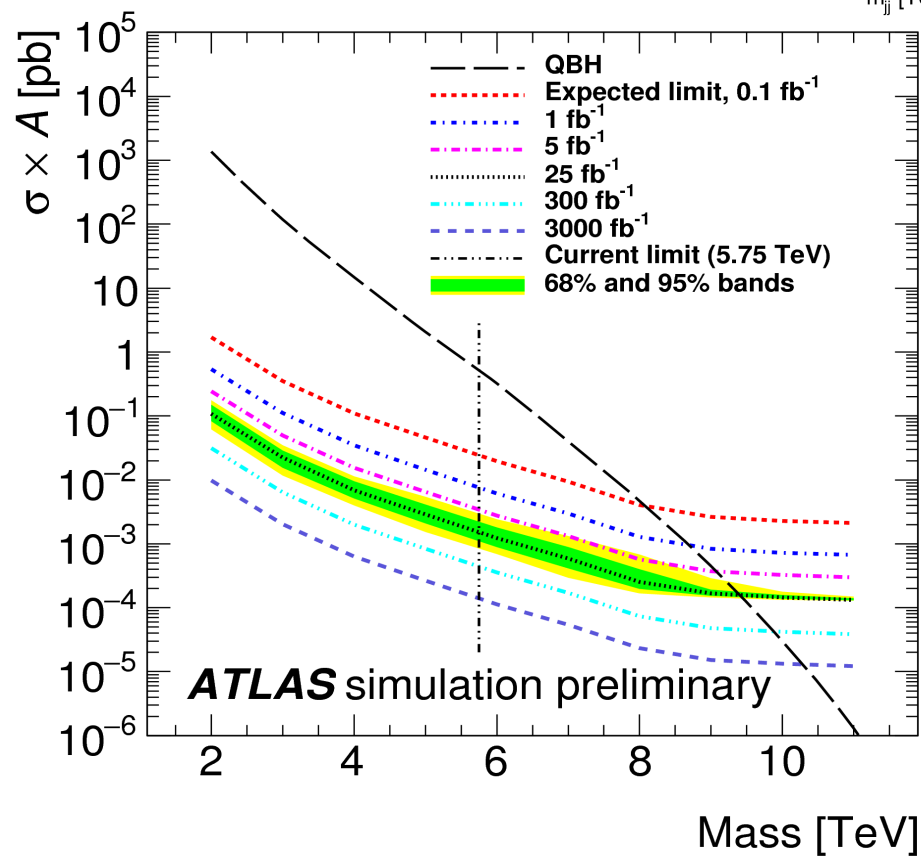
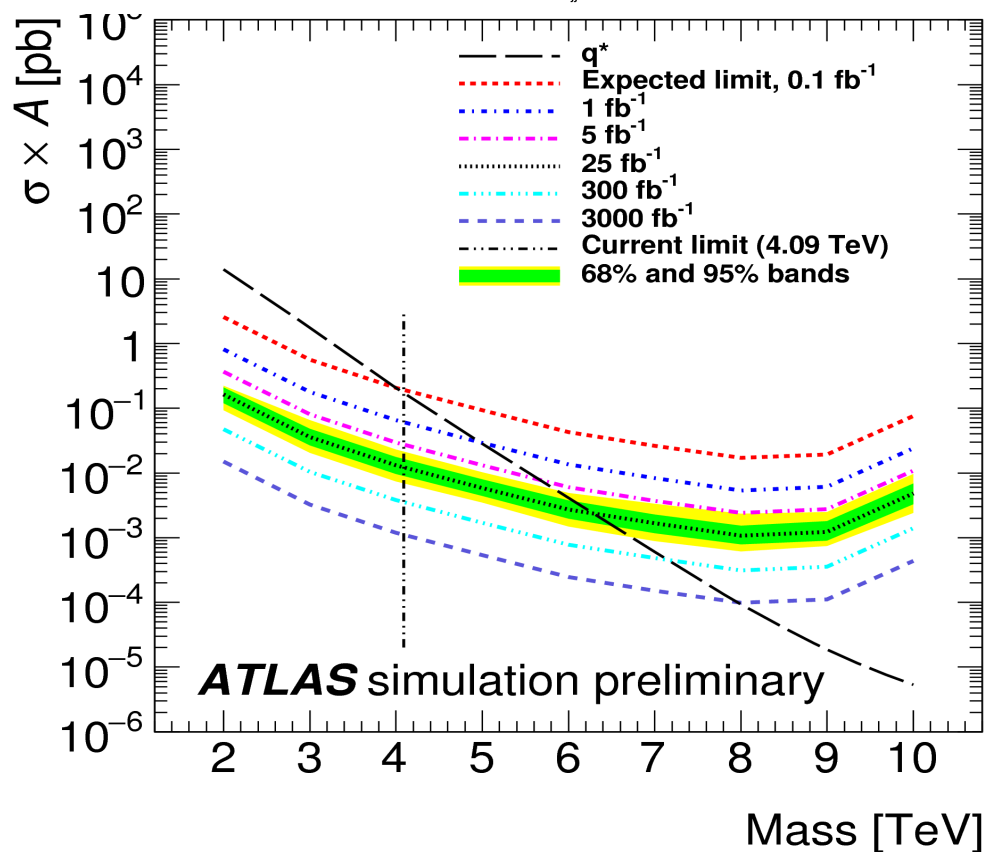
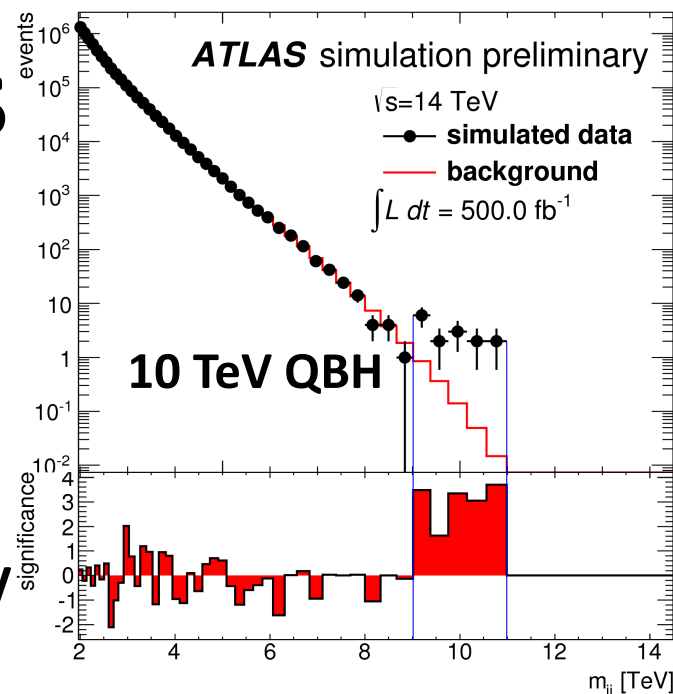


Q^* and QBHs

ATL-PHYS-PUB-2015-004



**Large increase in sensitivity
(it happens early on)**

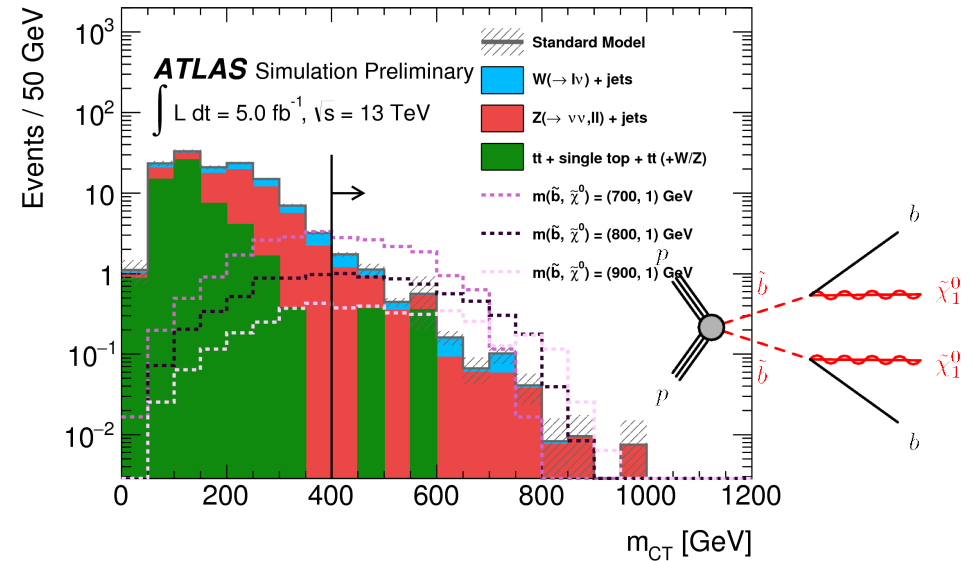
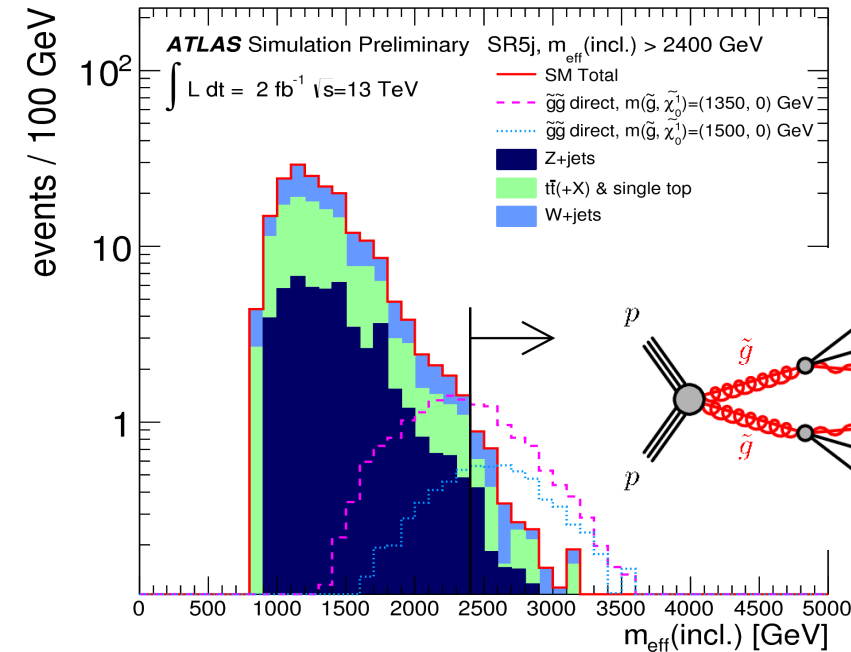


SUSY prospects (2015)

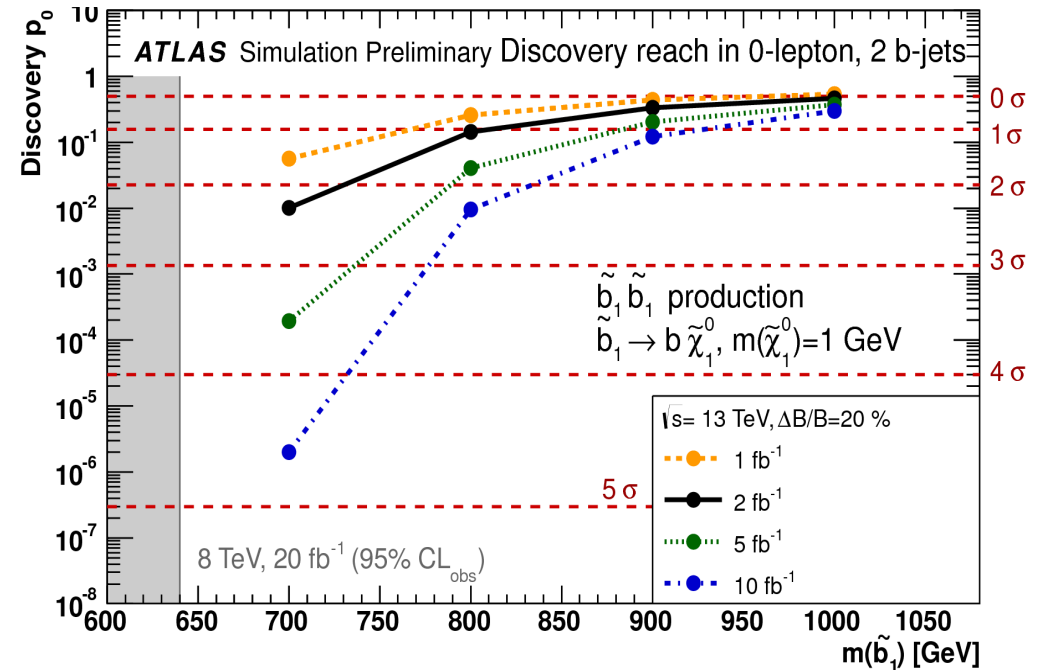
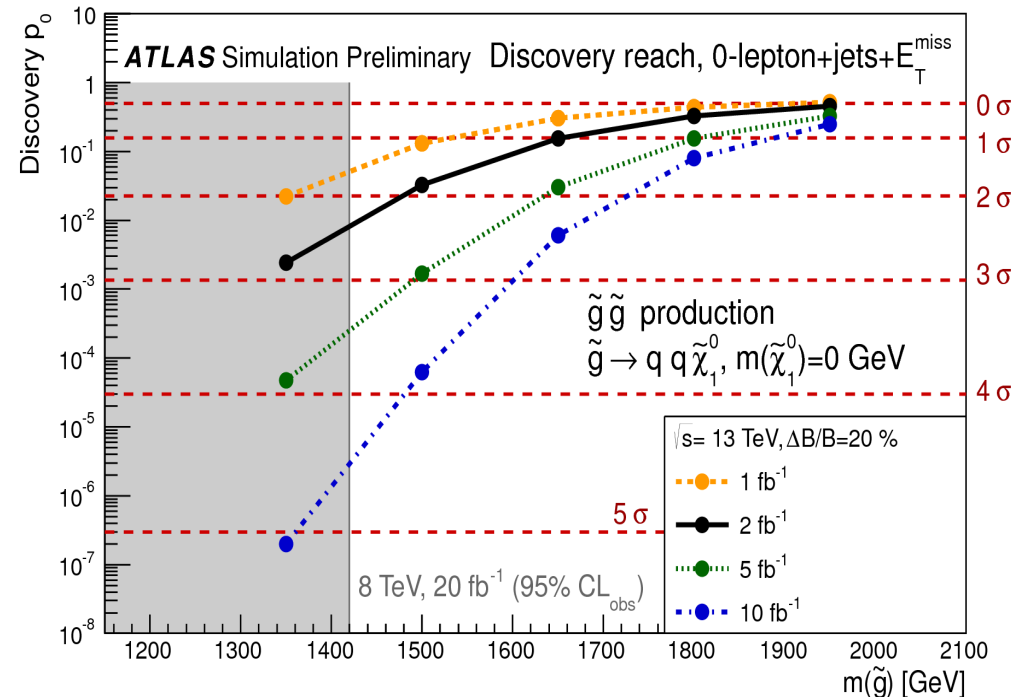
ATL-PHYS-PUB-2015-005

As inspired by 8 TeV analyses

Assuming 20% uncertainty on backg.



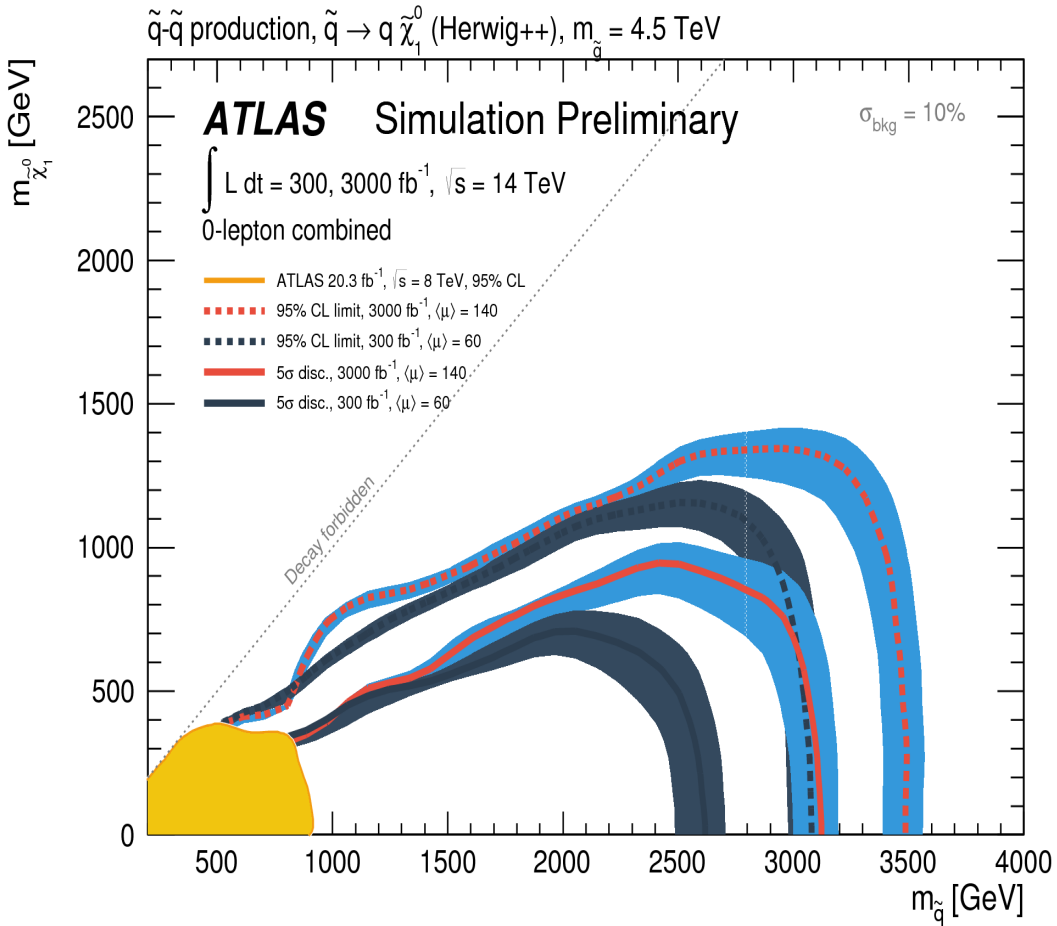
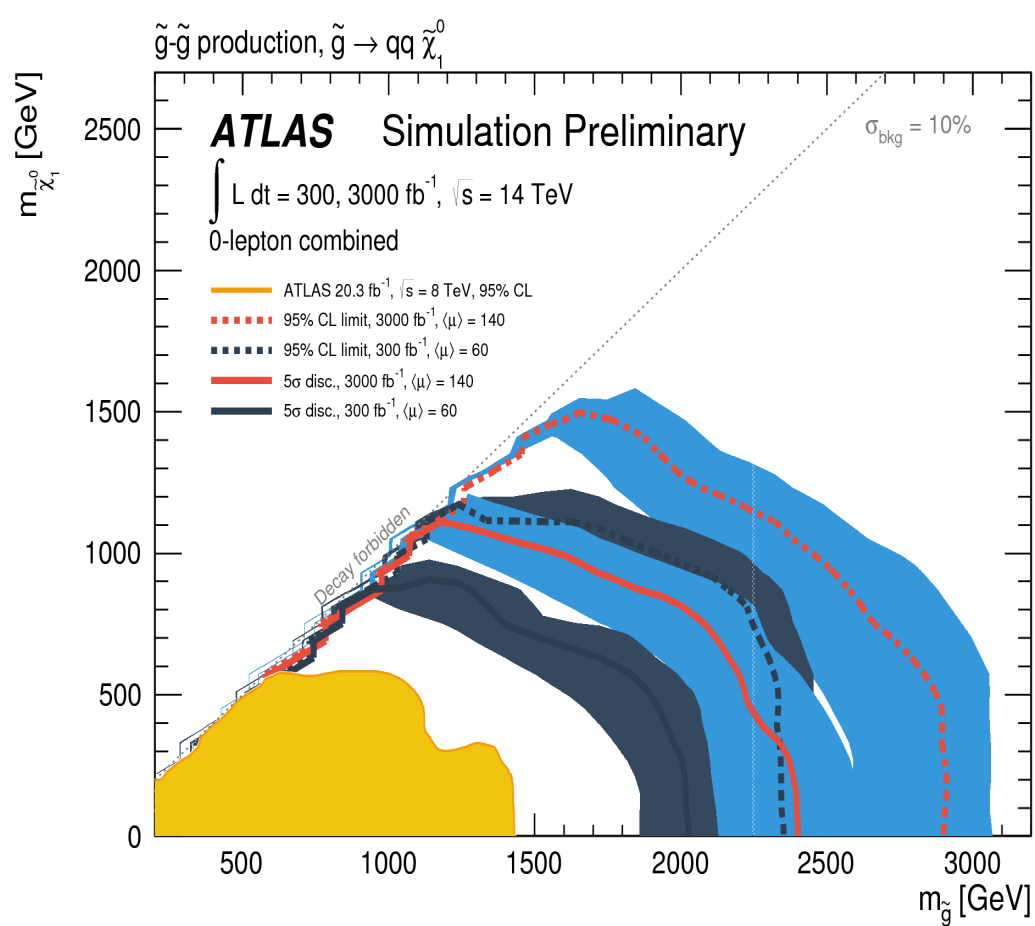
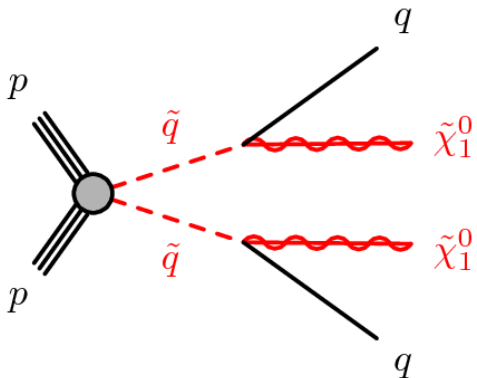
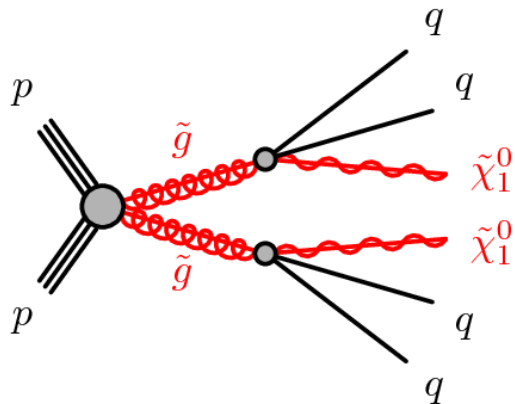
A hint for SUSY signal still possible if the SUSY particles are around the corner



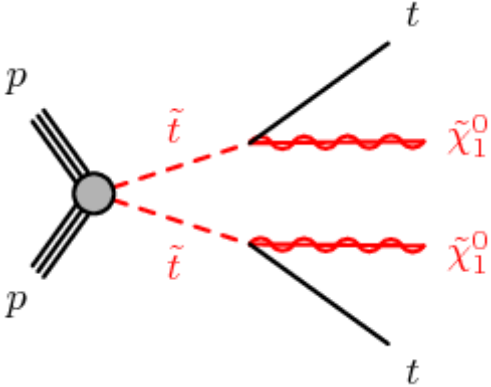
LHC-HL prospects

Will be in the position
to “kill natural SUSY”

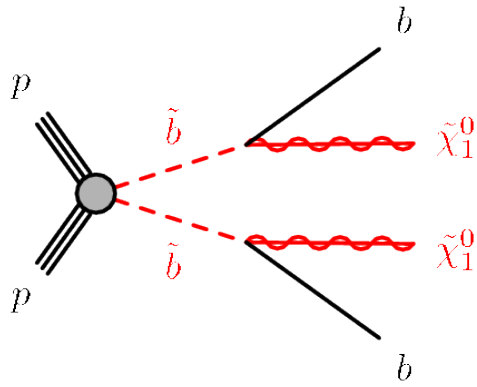
Sensitivity up to 3 – 3.5 TeV



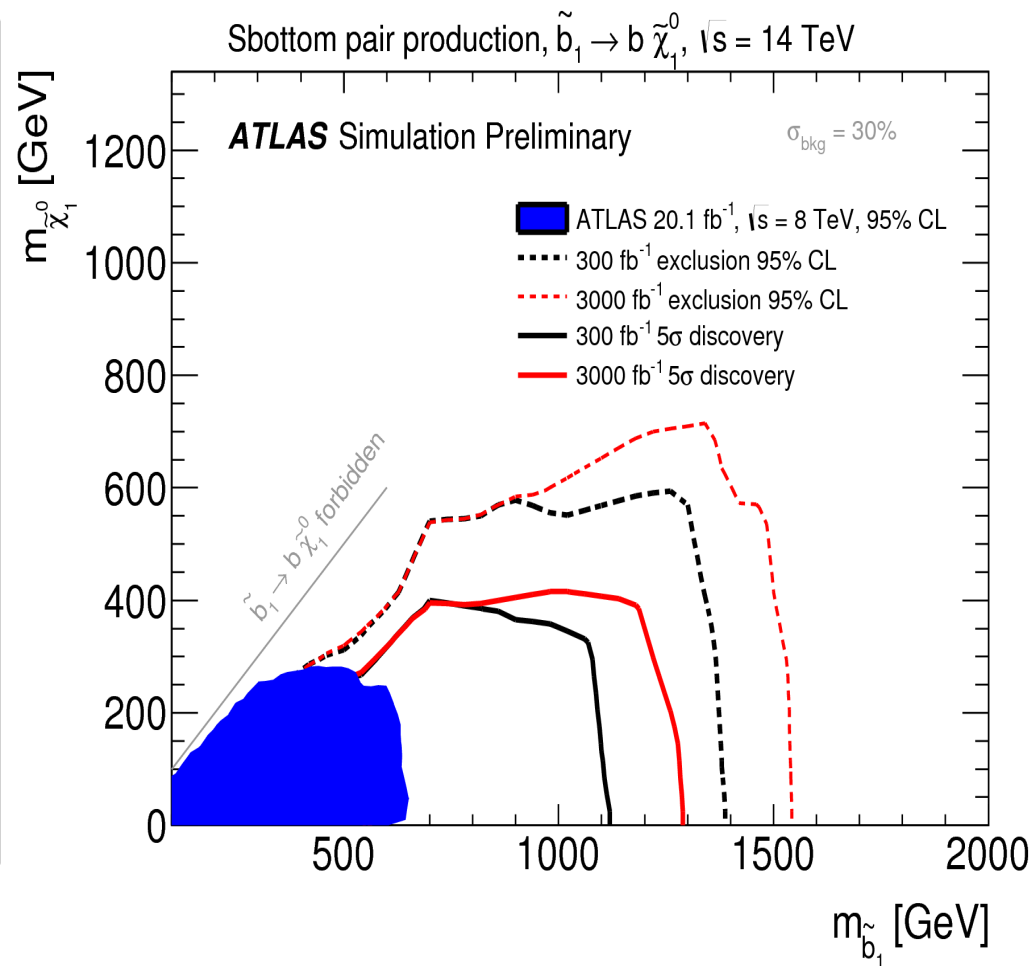
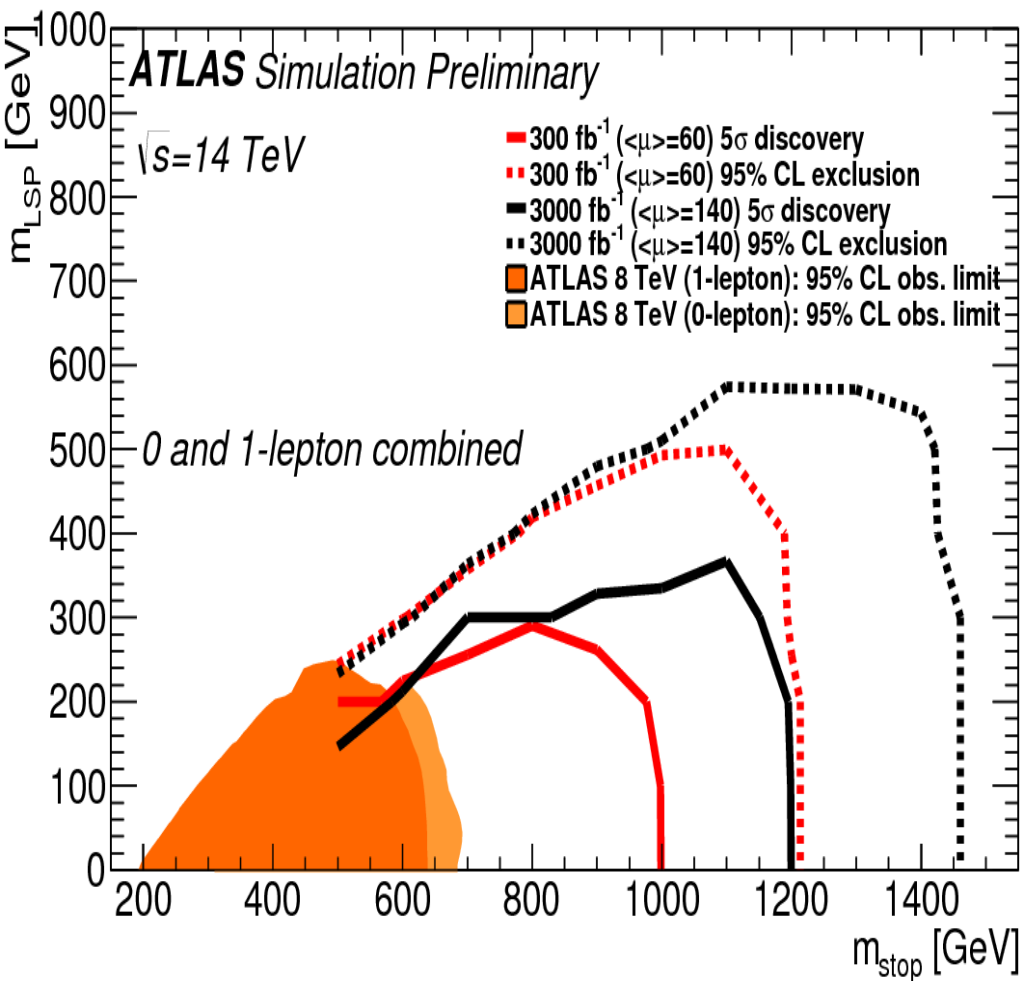
LHC-HL prospects



Will be in the position
to “kill natural SUSY”



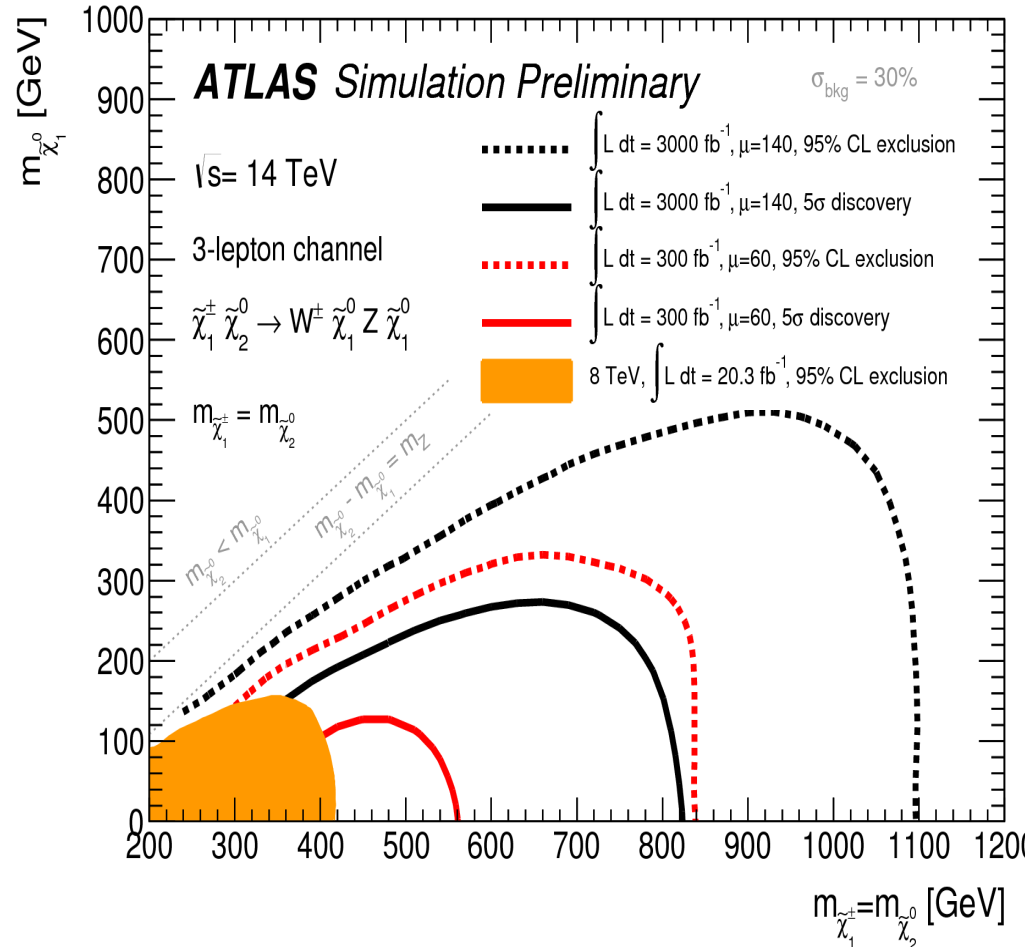
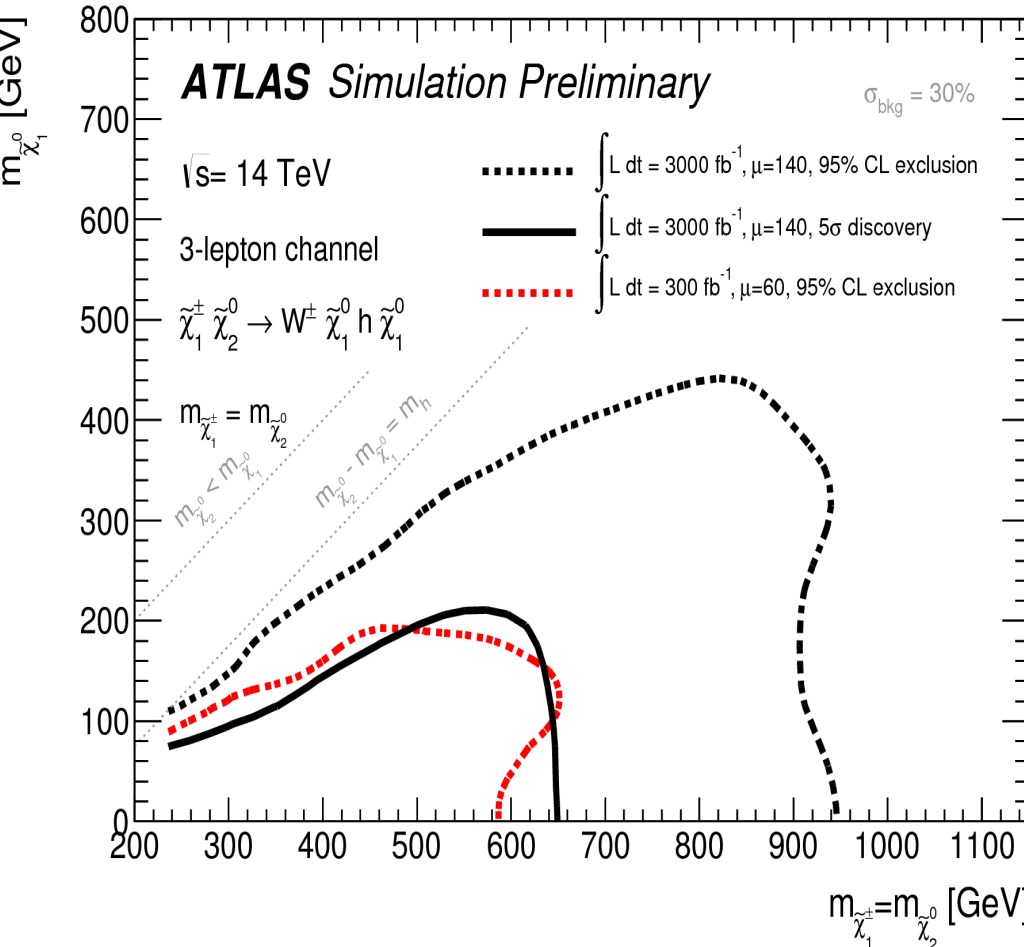
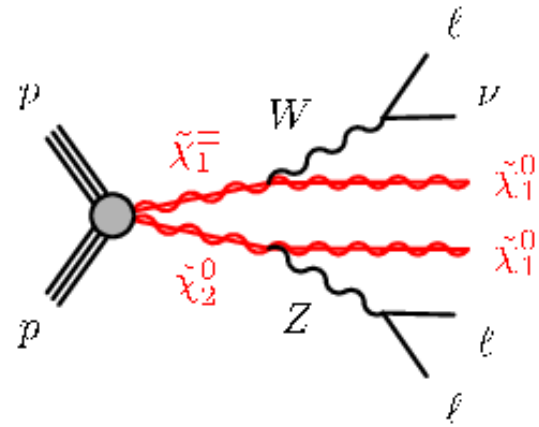
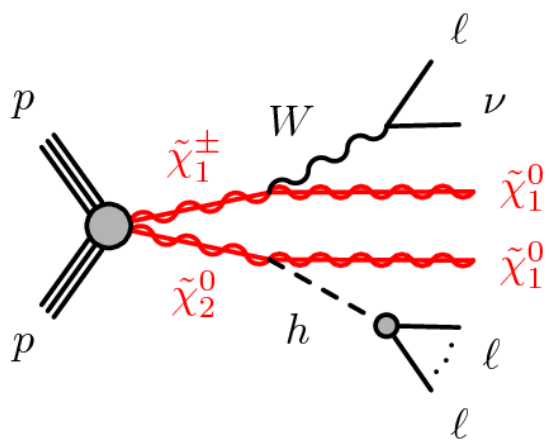
Sensitivity up to 1 – 1.5 TeV



LHC-HL prospects

SUSY Weakly interacting

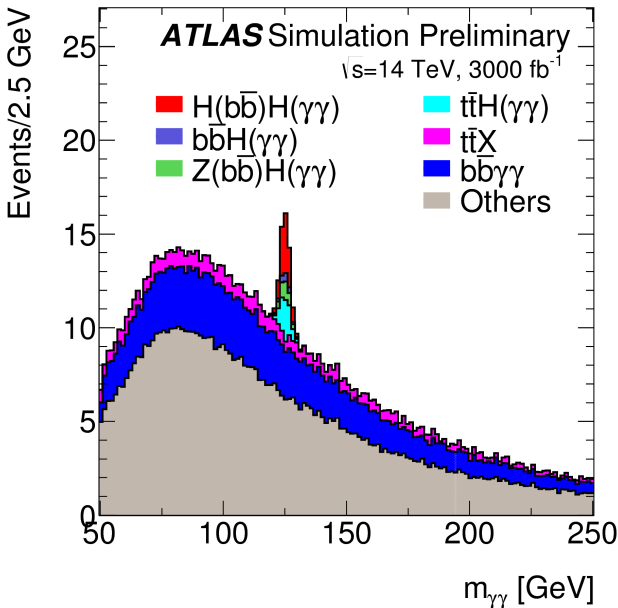
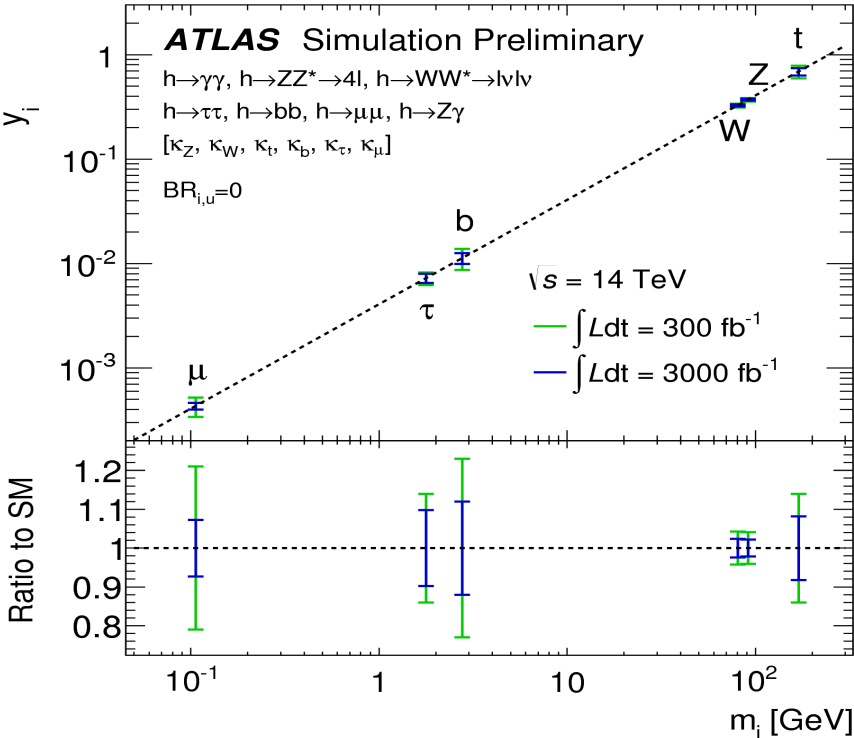
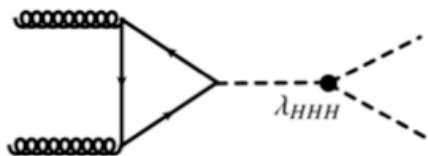
Sensitivity up to 1 – 1.1 TeV



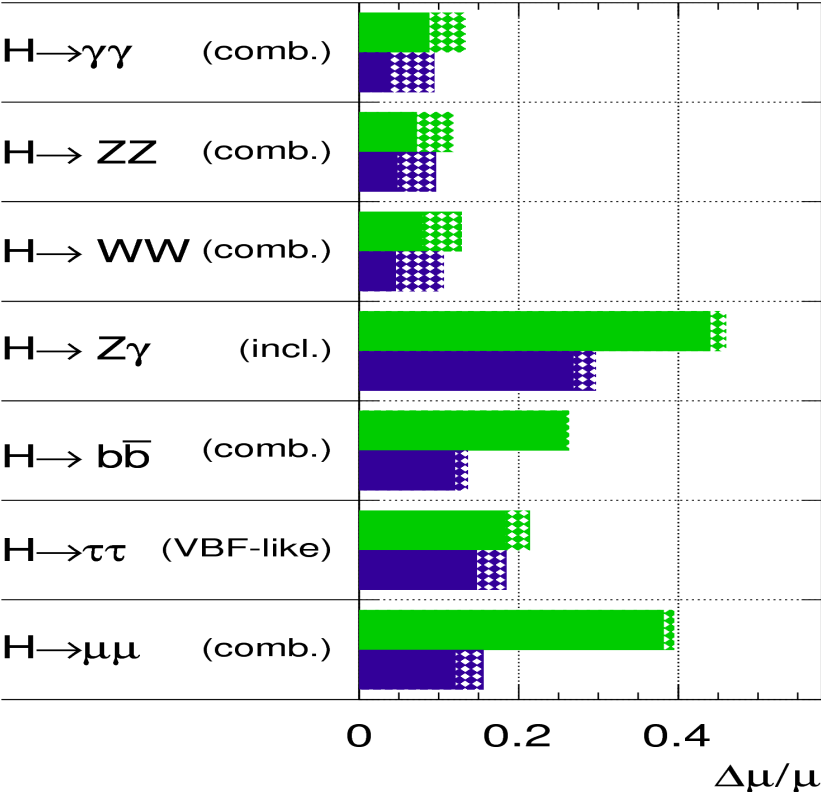
LHC-HL prospects

Higgs couplings (assuming SM Γ_H)

- 2-5% in most cases
- 10% for rare processes ($H \rightarrow \mu\mu$, $t\bar{t}H \rightarrow t\bar{t}\gamma\gamma$)
- may measure Higgs self couplings to 30% ?



ATLAS Simulation Preliminary
 $\sqrt{s} = 14$ TeV: $\int L dt = 300 \text{ fb}^{-1}$; $\int L dt = 3000 \text{ fb}^{-1}$



What next ??



CERN Roadmap

USA Roadmap

Japanese & Chinese Connections

EU and DOE-P5 Statements

- **European Strategy for Particle Physics 2013:**

“...to propose an ambitious post-LHC accelerator project....., CERN should undertake design studies for accelerator projects in a global context,...with emphasis on proton-proton and electron-positron high-energy frontier machines.....”

- **US P5 recommendation 2014:**

”....A very high-energy proton-proton collider is the most powerful tool for direct discovery of new particles and interactions under any scenario of physics results that can be acquired in the P5 time window....”

**Both CERN and DOE willing to collaborate in the Japanese ILC (if it realizes...)
DOE / P5 (USA community) with an unclear position about a circular e⁺e⁻ collider**

But then comes the Chinese Effect.....



Chinese CEPC

Table 1.2: Top Level Parameters for CEPC.

Parameter	Design Goal
Particles	e^+, e^-
Center of mass energy	240 GeV
Integrated luminosity (per IP per year)	250 fb^{-1}
No. of IPs	2

Table 1.3: Top Level Parameters for SPPC.

Parameter	Design Goal
Particles	p, p
Center of mass energy	70 TeV
Integrated luminosity (per IP per year)	(TBD)
No. of IPs	2

Proposal for a e^+e^- circular machine at 240 GeV to study the Higgs (10 years operation)

50 – 100 KM depending on funding

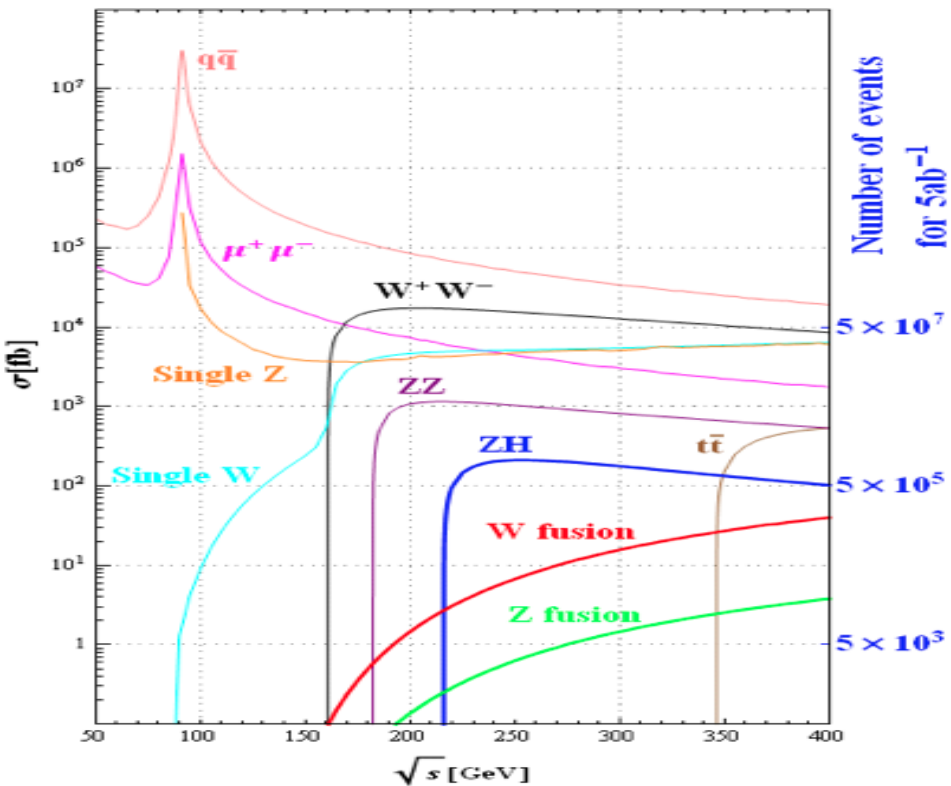
Upgradable to a pp collider at 70 – 100 TeV in a second phase

→ e^+e^- project profiting enormously from LEP/SuperKEKB experience and ILC studies....



Figure 3.3: Illustration of the CEPC-SPPC ring sited in Qinghuangdao. The small circle is 50 km, and the big one 100 km. Which one will be chosen depends on the funding scenario.

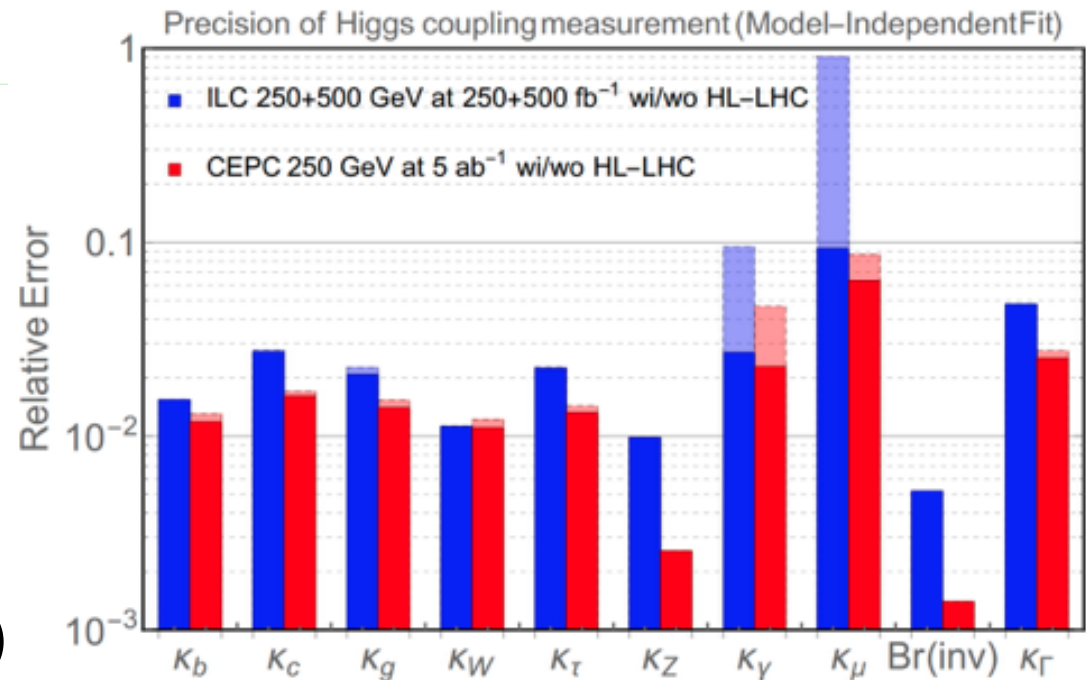
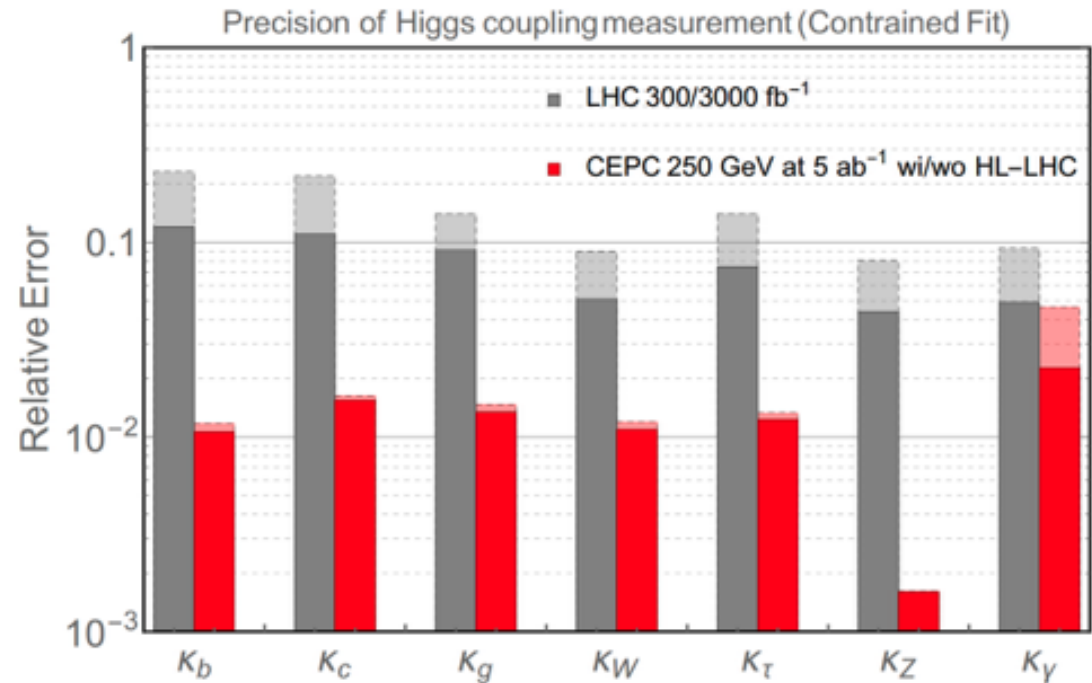
Physics Potential of CEPC



Running at the ZH maximum cross section
(possibility to run at Z-pole and WW)

It terms of Higgs couplings:

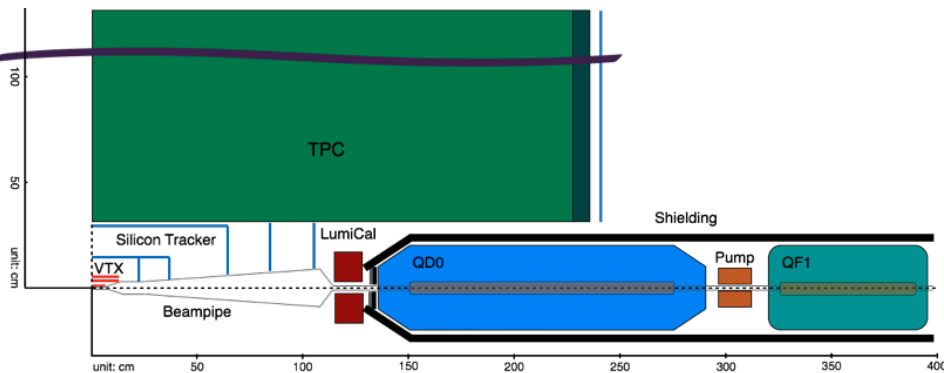
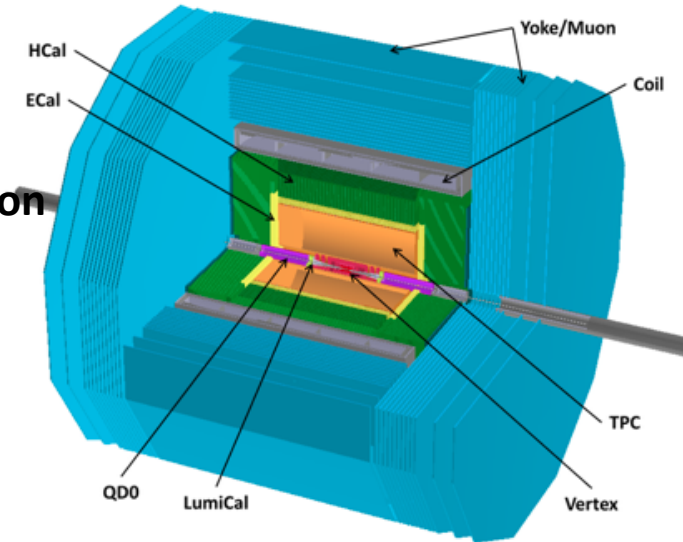
- It goes beyond LHC-HL precision
- Better precision than ILC
(Thanks to the total integrated luminosity)



CEPC proposal for Detector

Detector Concept inspired on ILD

- Calorimeter designed using intense R&D by CALICE collaboration
- Vertex detector: R&D on pixel detectors similar to LHC-HL

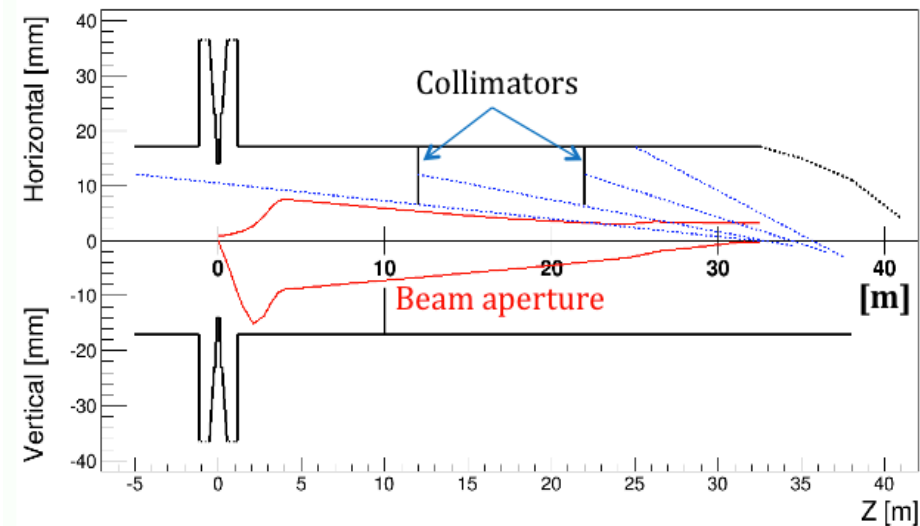


Detailed simulation of Detector-Machine interface and configuration of the collimator configuration
→ Final focusing magnets inside the detector

Ongoing studies on Physics Backgrounds at machine

- Synchrotron radiation
- electron-positron pair production
- Radiative Bhabha scattering
-

Altogether this proposal (looks) solid



CEPC Schedule

CEPC



1st Milestone: pre-CDR (by the end of 2014) → R&D funding request to Chinese government in 2015 (China's 13th Five-Year Plan 2016-2020)

SppC

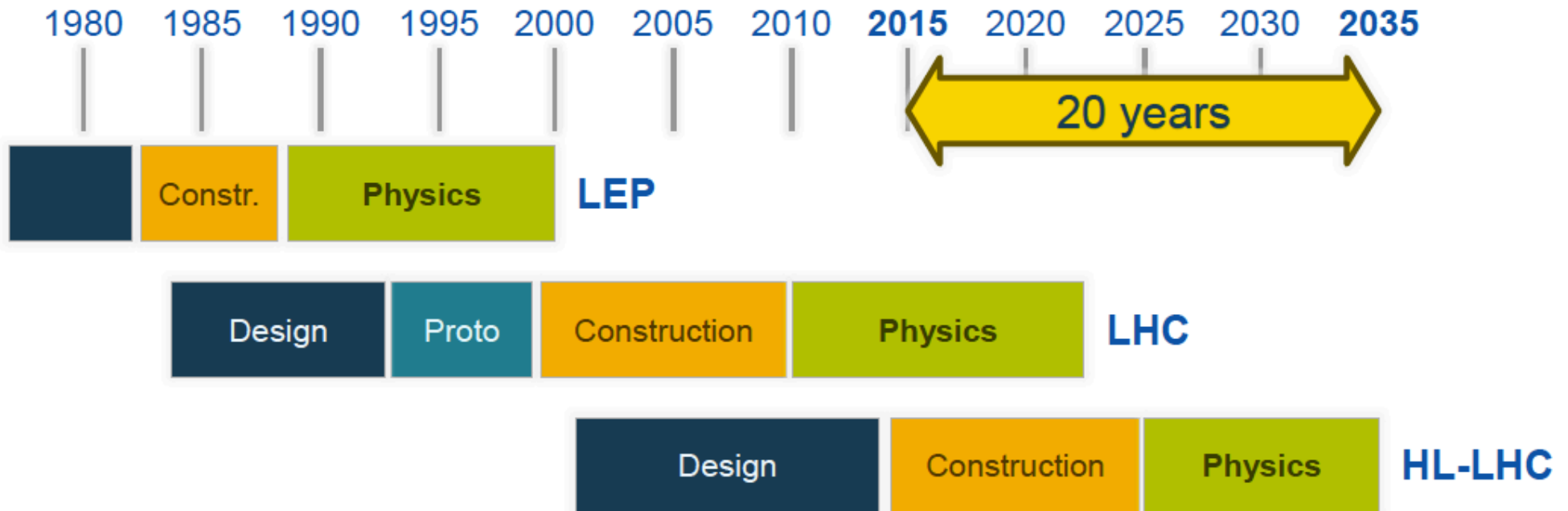


Funding request to take place this year for 2016 – 2020

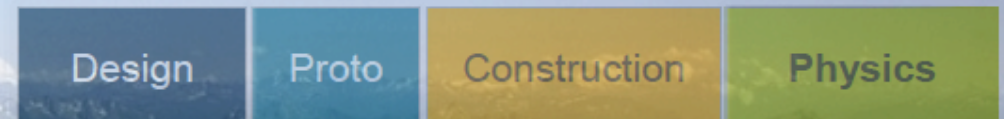
→ In principle, aiming for an international collaboration

→ Interesting times... how is this going to “collide” with ILC-Japan ?

CERN roadmap



Future Collider



In parallel CERN launched in 2014 a 3-years effort towards a comprehensive study on Future Circular Colliders (FCC) with the aim to have a CDR by 2018 and in time for the next European Strategy discussion.

→ It includes now all possible options (pp, ee and ep colliders) in a single study

Future HEP Global Facilities

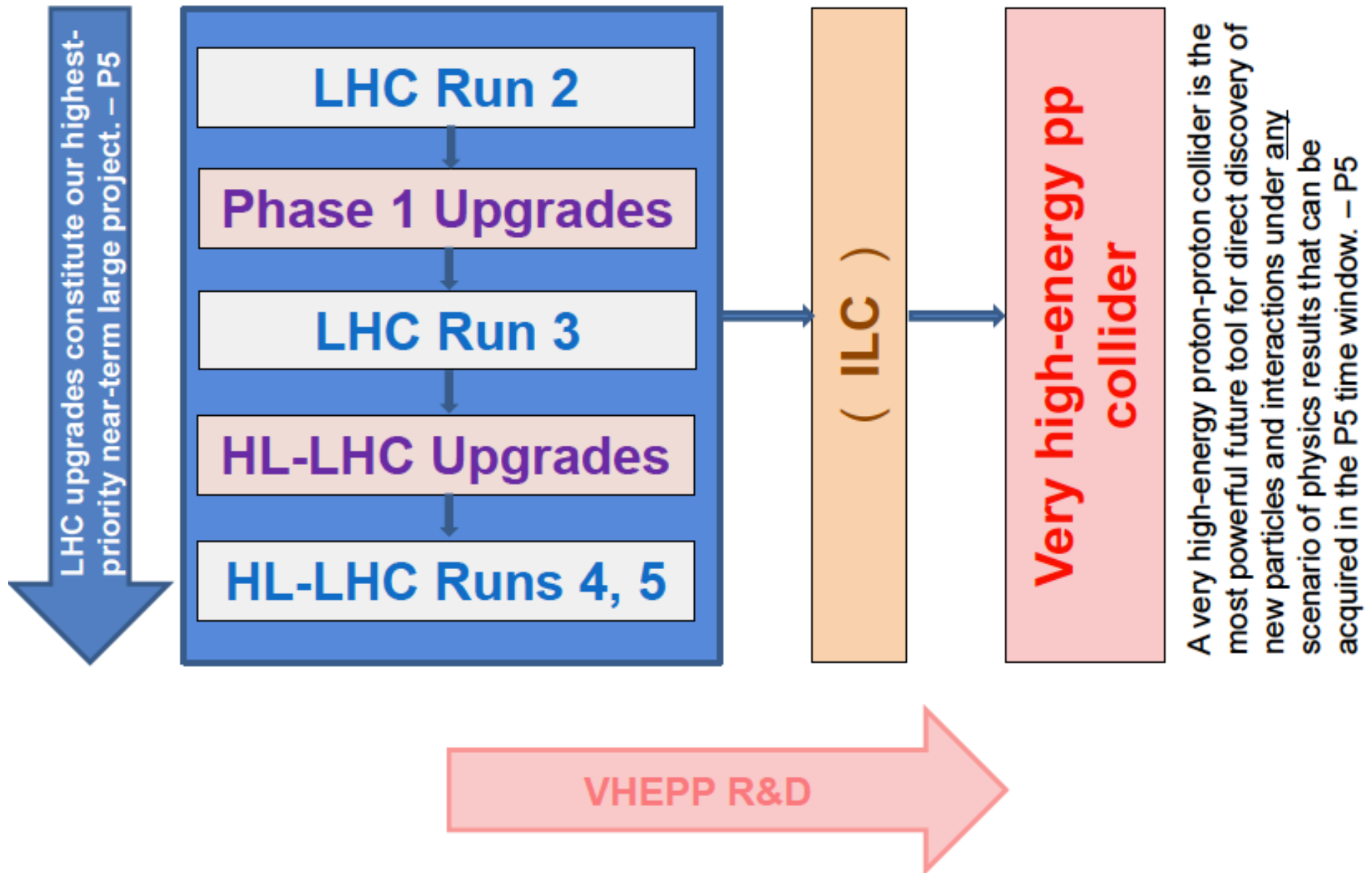
	Intense Frontier Accelerators	Hadron Colliders	Lepton Colliders
Current Efforts	PIP	LHC	
	PIP-II	HL-LHC	ILC
Next Steps	Multi-MW proton beam	100 TeV class pp collider	1 TeV class energy upgrade of ILC
Further Future Goals	Neutrino factory		Multi-TeV collider

As already mentioned, the circular e^+e^- is not part of the current plan

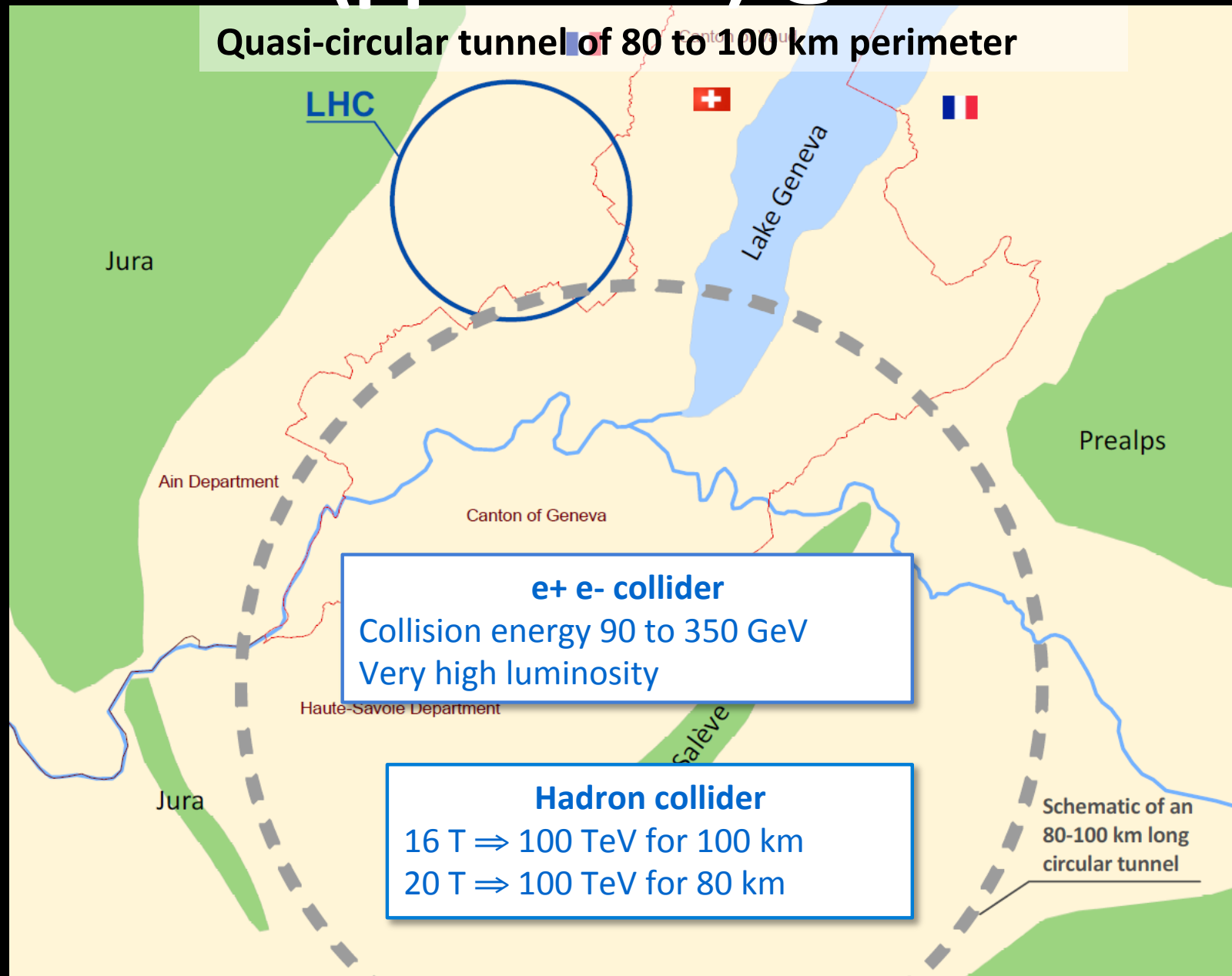
**dependent on how physics unfolds*



P5 vision for evolution of Energy Frontier facilities



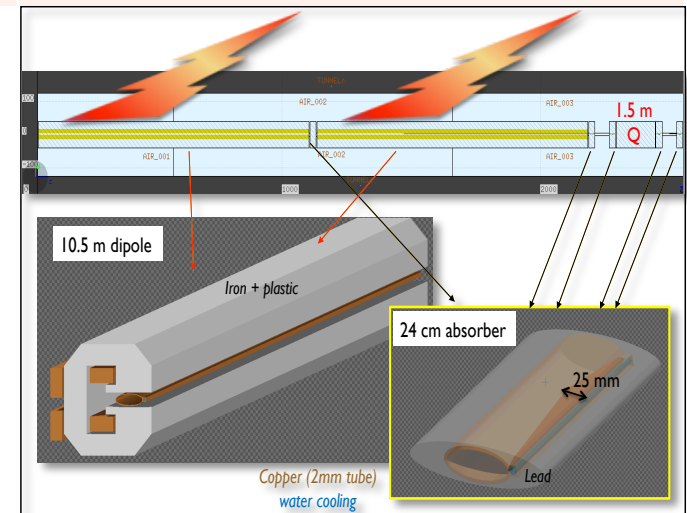
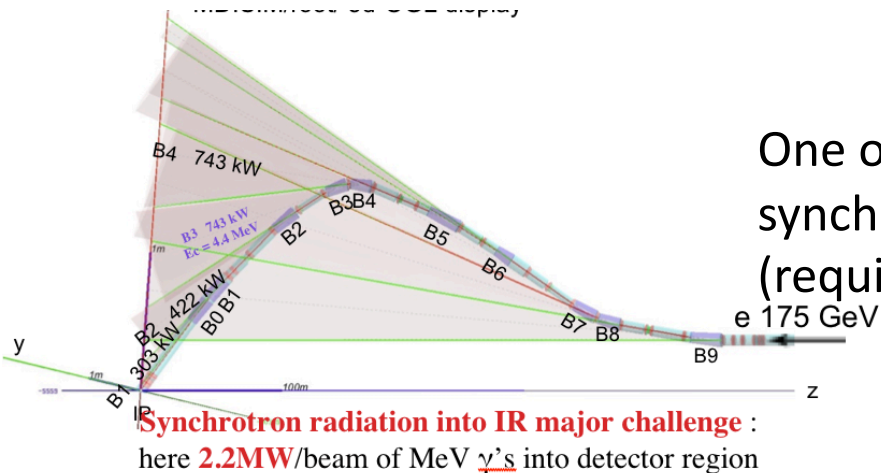
FCC (pp and ee) @ CERN



Key technologies are high-field magnets for the hadron collider and an efficient high-power superconducting RF (SRF) system for the lepton collider.

FCC-ee parameters

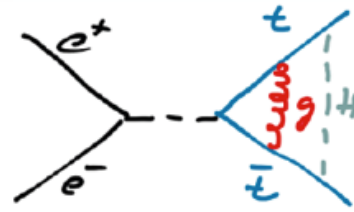
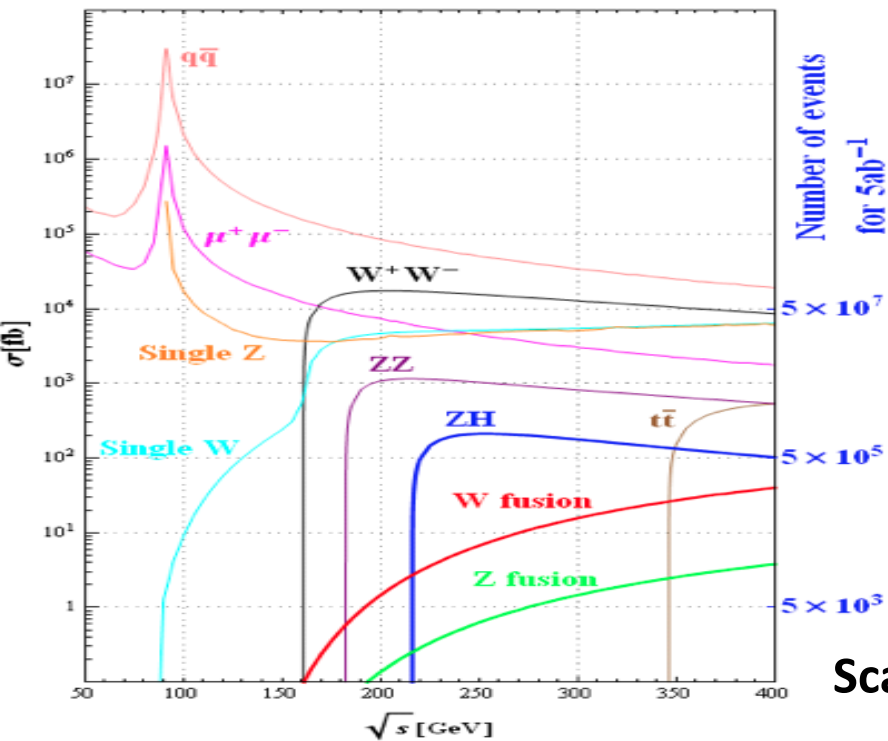
parameter	FCC-ee	LEP2
energy/beam	45 – 175 GeV	105 GeV
bunches/beam	50 – 60000	4
beam current	6.6 – 1450 mA	3 mA
hor. emittance	~2 nm	~22 nm
emittance ratio $\varepsilon_y/\varepsilon_x$	0.1%	1%
vert. IP beta function β_y^*	1 mm	50 mm
luminosity/IP	1.5-280 $\times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$	$0.0012 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$
energy loss/turn	0.03-7.55 GeV	3.34 GeV
synchrotron radiation power	100 MW	23 MW
RF voltage	0.3 – 11 GV	3.5 GV



Few notes on FCC-ee (previously known as TLEP)

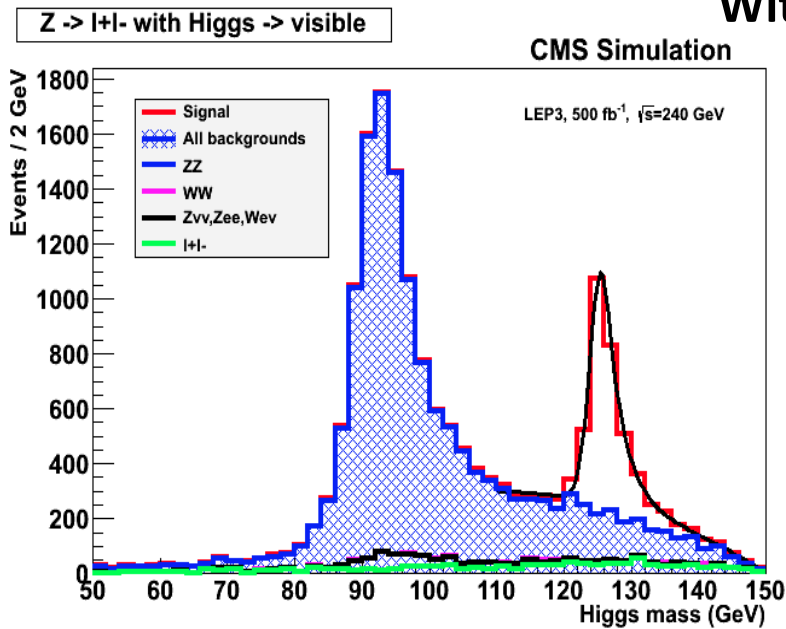
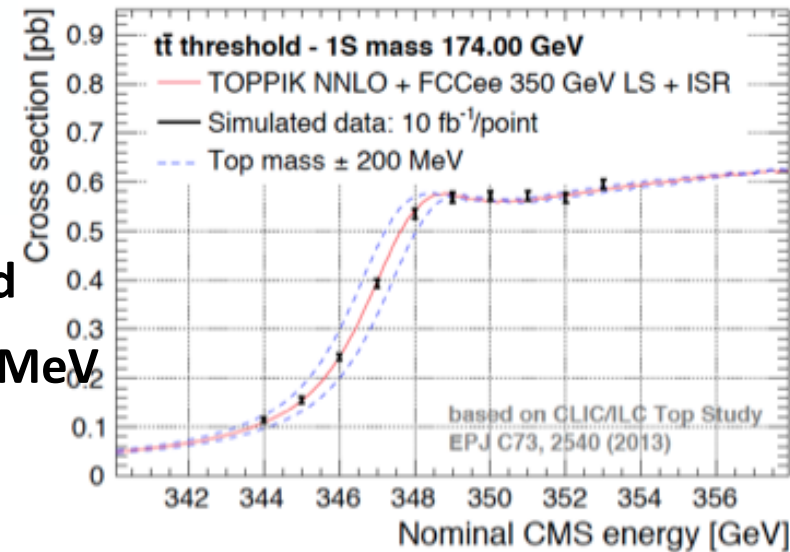
Energy in the range 45 – 175 GeV beam

Luminosities in the range $1.5\text{--}280 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$

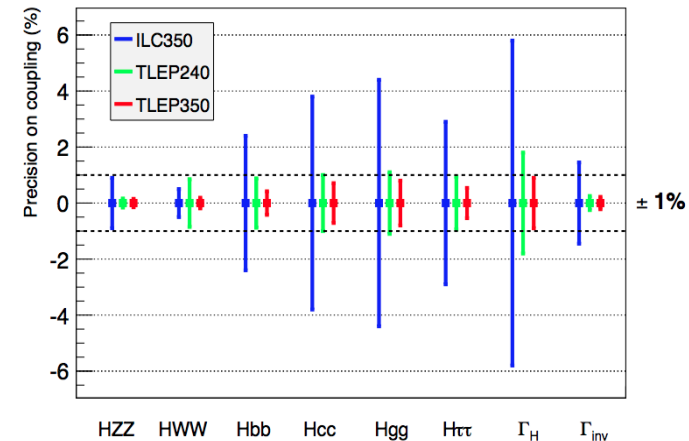


Scan over $t\bar{t}$ threshold

With $100 \text{ fb}^{-1} \rightarrow \pm 16 \text{ MeV}$



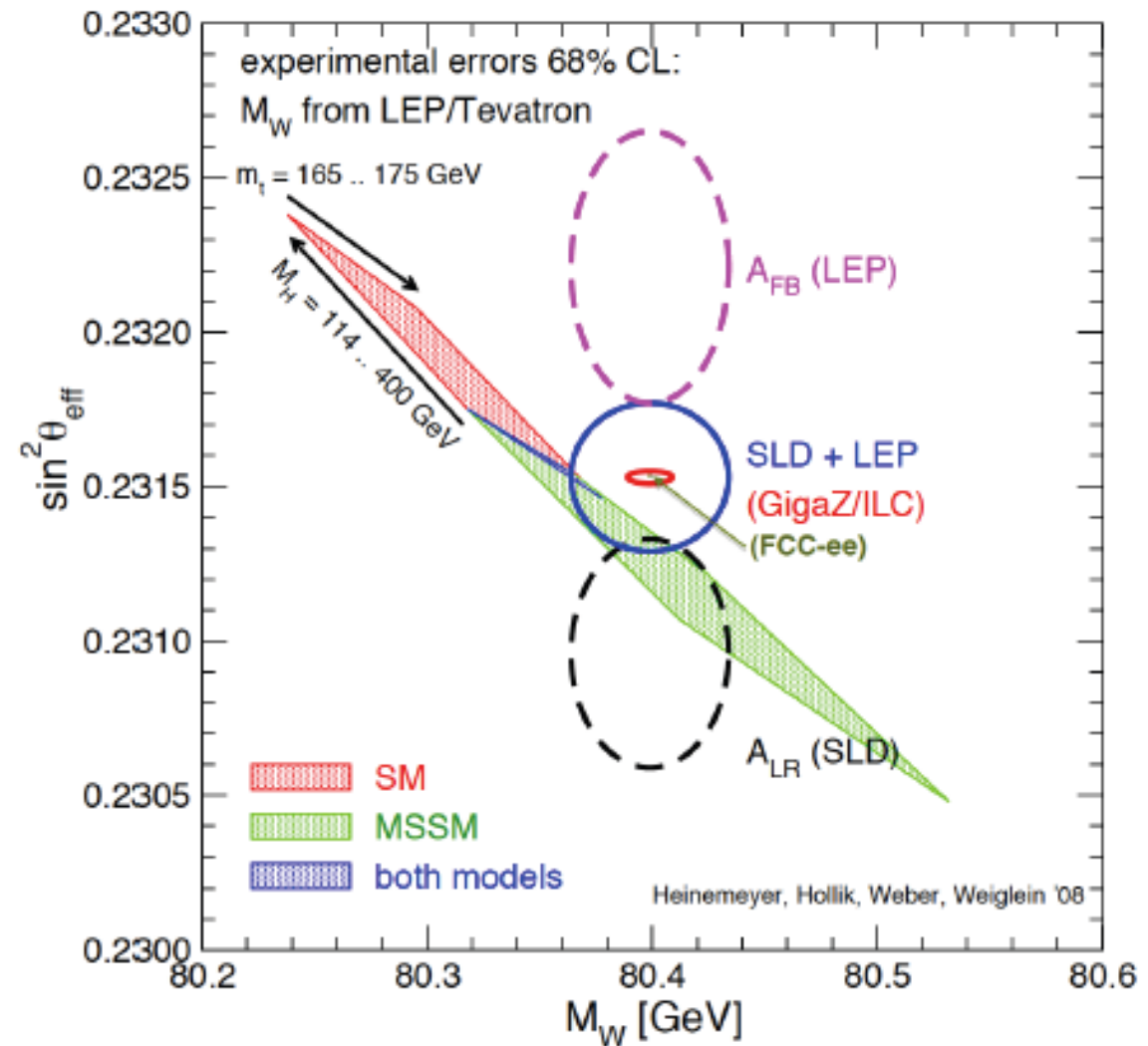
ZH ($H \rightarrow \text{inv}$)
Reaches 1% on Γ_{inv}



In general this should come together with a significant effort on reducing TH uncertainties

EWK precision measurements

M_H [GeV] ^(o)	125.14 ± 0.24	LHC
M_W [GeV]	80.385 ± 0.015	Tev.
Γ_W [GeV]	2.085 ± 0.042	
M_Z [GeV]	91.1875 ± 0.0021	
Γ_Z [GeV]	2.4952 ± 0.0023	LEP
σ_{had}^0 [nb]	41.540 ± 0.037	
R_ℓ^0	20.767 ± 0.025	
$A_{\text{FB}}^{0,\ell}$	0.0171 ± 0.0010	
$A_\ell^{(*)}$	0.1499 ± 0.0018	SLD
$\sin^2 \theta_{\text{eff}}^\ell(Q_{\text{FB}})$	0.2324 ± 0.0012	
A_c	0.670 ± 0.027	SLD
A_b	0.923 ± 0.020	
$A_{\text{FB}}^{0,c}$	0.0707 ± 0.0035	
$A_{\text{FB}}^{0,b}$	0.0992 ± 0.0016	LEP
R_c^0	0.1721 ± 0.0030	
R_b^0	0.21629 ± 0.00066	
$\bar{m}_c$ [GeV]	$1.27^{+0.07}_{-0.11}$	
$\bar{m}_b$ [GeV]	$4.20^{+0.17}_{-0.07}$	
m_t [GeV]	173.34 ± 0.76	Tev.+LHC
$\Delta\alpha_{\text{had}}^{(5)}(M_Z^2)$	2757 ± 10	



A full program of precision measurements that will require also lots of theoretical work

FCC-pp

A 100 TeV pp Collider..

The FCC-pp playground



Development of short 16-T dipole models in all regions (America, Asia and Europe) by 2018 and, in parallel, demonstration of 20-T magnet technology based on the combination of high- and low-temperature superconductors

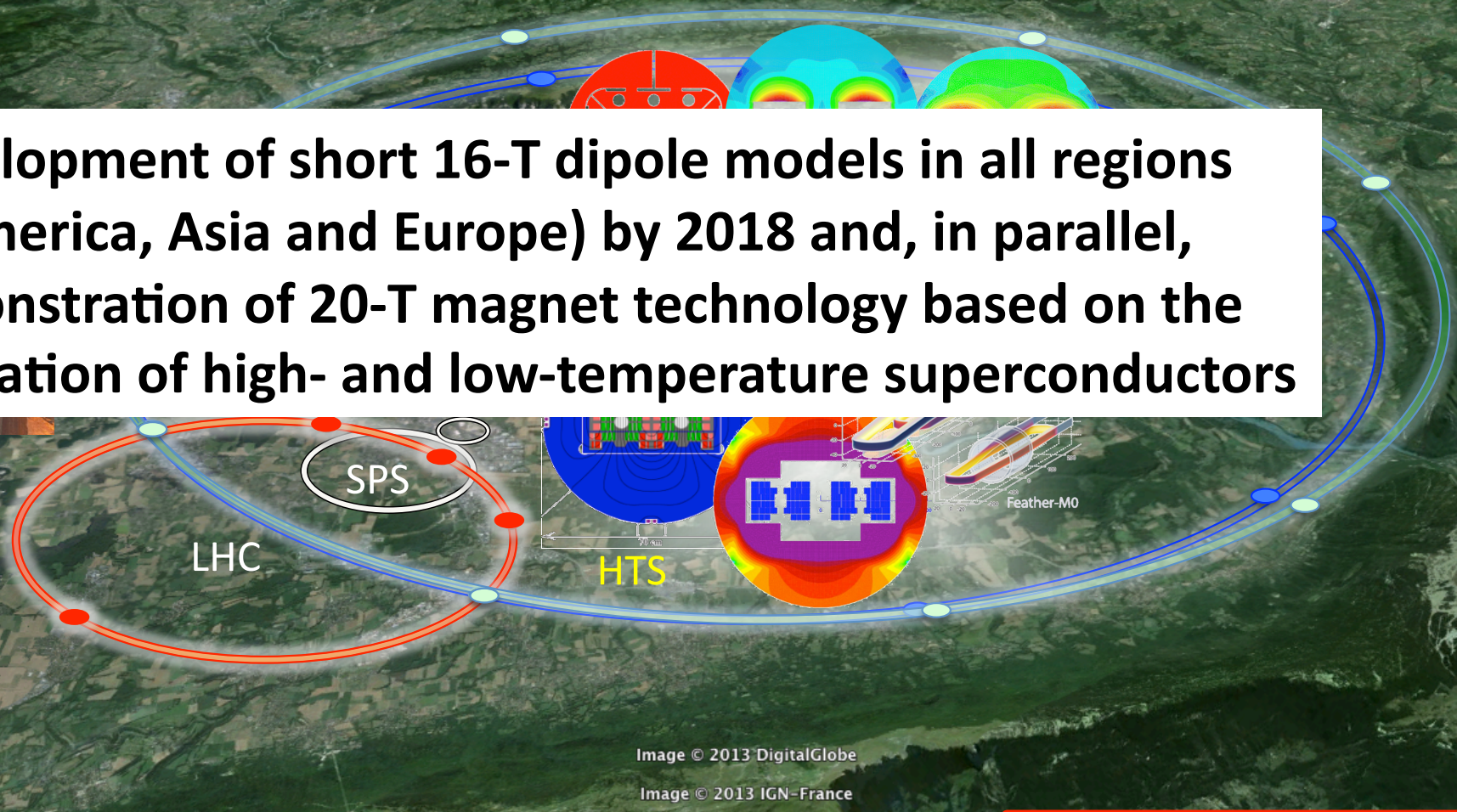


Image © 2013 DigitalGlobe

Image © 2013 IGN-France

LHC

27 km, 8.33 T
14 TeV (c.o.m.)
1300 tons NbTi

HE-LHC

27 km, 20 T
33 TeV (c.o.m.)
3000 tons LTS
700 tons HTS

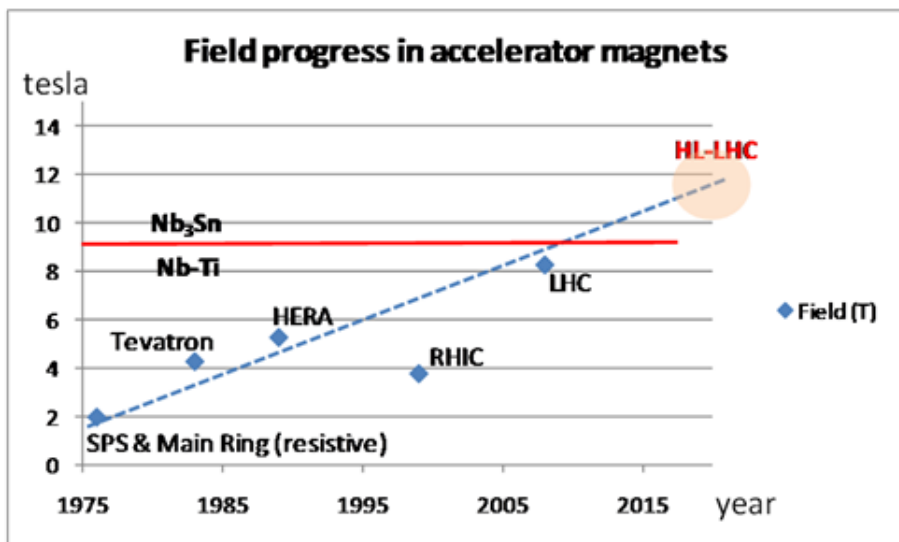
FCC-hh

80 km, 20 T
100 TeV (c.o.m.)
9000 tons LTS
2000 tons HTS

FCC-hh

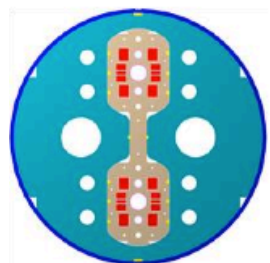
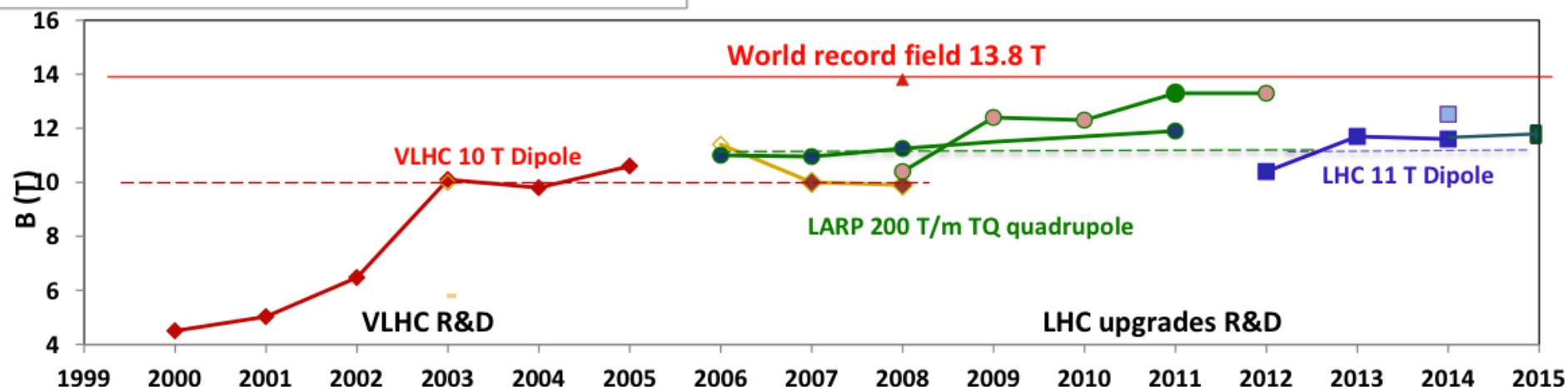
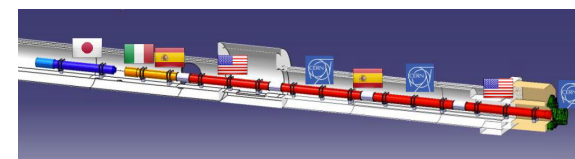
100 km, 16 T
100 TeV (c.o.m.)
6000 tons Nb₃Sn
3000 tons Nb-Ti

R&D on Machine for LHC-HL

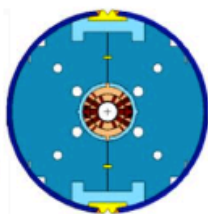


- New IR-quads Nb₃Sn (inner triplets)
- New 11 T Nb₃Sn (short) dipoles
- Collimation upgrade
- Cryogenics upgrade
- Crab Cavities
- Cold powering
- Machine protection
- ...

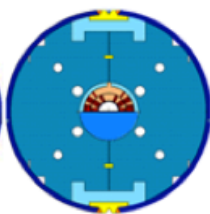
1.2KM of LHC modified



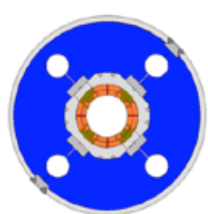
HFDC (R&W)
40 mm 10 T dipole



HFDA
43.5 mm
10 T dipole



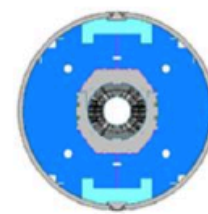
HFDM-LM
Dipole mirror



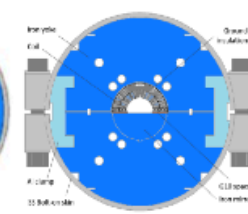
TQC
90 mm 200 T/m
quadrupole



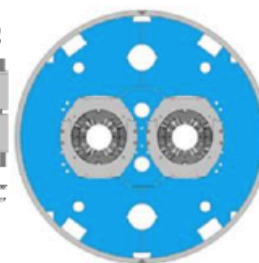
TQM-LQM
Quadrupole
mirror



MBHSP
60 mm 11 T dipole



MBHSM
Dipole mirror



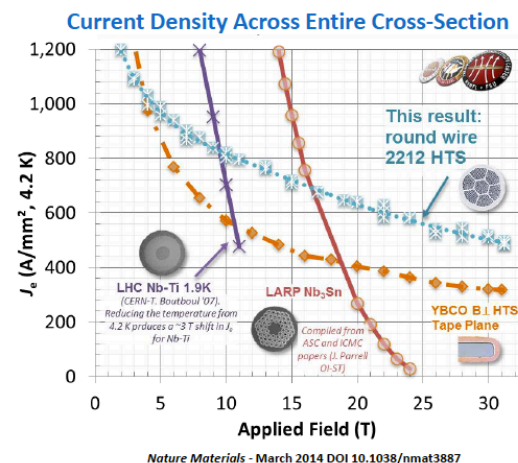
MBHDP
60 mm 11 T dipole

R&D on HTS and SRF

Also significant advances on HTS and SFR technologies towards FCC-hh/ee

Long way to go to make it affordable (now about \$2000/Kg magnet)

Record Current in High-Temperature Superconductor (HTS)



- Achieved 500 A/mm² at 30 T, 4.2 K in Bi₂Sr₂CaCu₂O_{8-x} (Bi-2122)
 - Existing state-of-the-art conductors (Nb₃Sn for LARP) sustain this performance only to 18 T
 - LHC NbTi conductors sustain this performance only to 11 T
 - This practical HTS magnet material is an isotropic round wire which can be cabled on existing machines
 - Competing HTS materials are anisotropic tapes and not easily made into magnet cables

Impact

- This level of current density could technically enable magnetic field levels that double existing particle collision energies

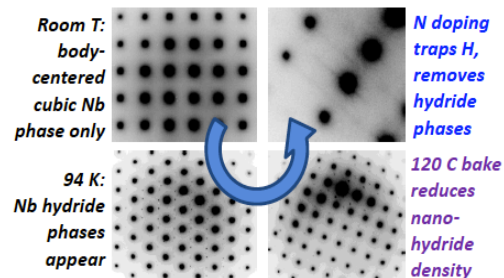


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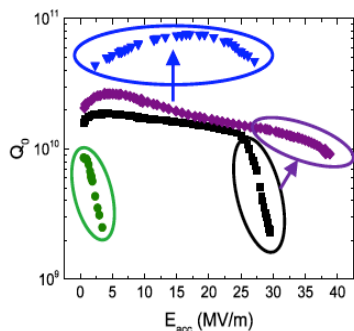
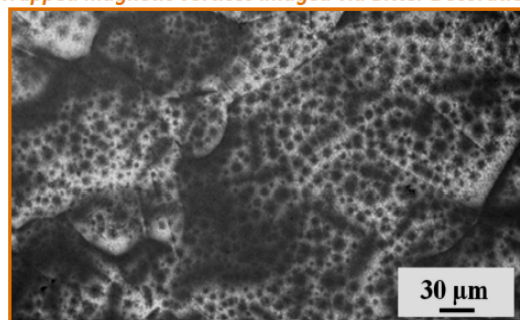
U.S. Research Activities Related to Future Colliders - 3/23/2015 12

Advances in SRF Performance

- Recent SRF advancements have been driven by fundamental understanding of the underlying physics of the cavity surface
 - Microscopic mechanism of “Q-disease”
 - Origin of the “high field Q slope”
 - Mechanism of the “120 C baking”
 - Nitrogen doping to increase Q
 - Effect of cooling dynamics on Q

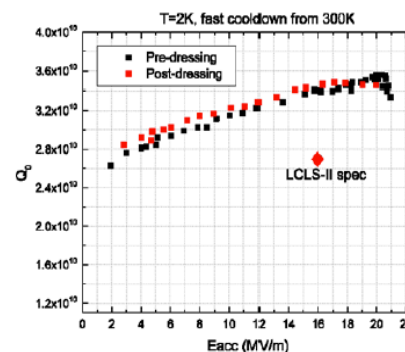
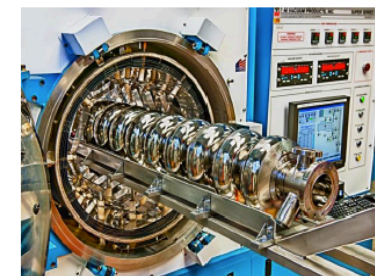


Trapped magnetic vortices imaged via Bitter Decoration

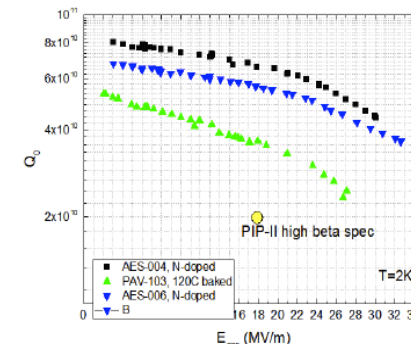


SRF Advances Widely Benefit DOE SC Program

- Lower loss (higher Q_0) SRF cavities will reduce the cryogenic plant capital cost and long-term operating cost of future accelerators
 - The BES LCLS-II project will be the first beneficiary
 - Process applied to PIP-II 650 MHz ($\beta=0.9$) cavities leads to double Q_0 compared to 120 C bake (standard surface treatment ILC/XFEL)
 - World record Q_0 of $\sim 7 \times 10^{10}$ at 2 K, 17 MV/m attained at this frequency!



SRF cavity performance exceeds LCLS-II specifications



PIP-II cavity performance after N doping



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FCC-pp

	LHC	HL-LHC	Baseline	Ultimate
Luminosity [$10^{34}\text{cm}^{-2}\text{s}^{-1}$]	1	5	5	20
Bunch distance [ns]	25	25	25 (5)	25 (5)
Background events/bx	27	135	170 (34)	680 (136)
Bunch charge [10^{11}]	1.15	2.2	1 (0.2)	1 (0.2)
Norm. emitt. [μm]	3.75	2.5	2.2(0.44)	2.2(0.44)
IP beta-function [m]	0.55	0.15	1.1	0.3
IP beam size [μm]	16.7	7.1	6.8 (3)	3.5 (1.6)
RMS bunch length [cm]	7.55	7.55	8	8
Turn-around time [h]			5	4
Crossing angle [σ']			12	Crab. Cav.

One of the multiple challenges: Machine protection

8GJ kinetic energy per beam (2000kg TNT per beam)

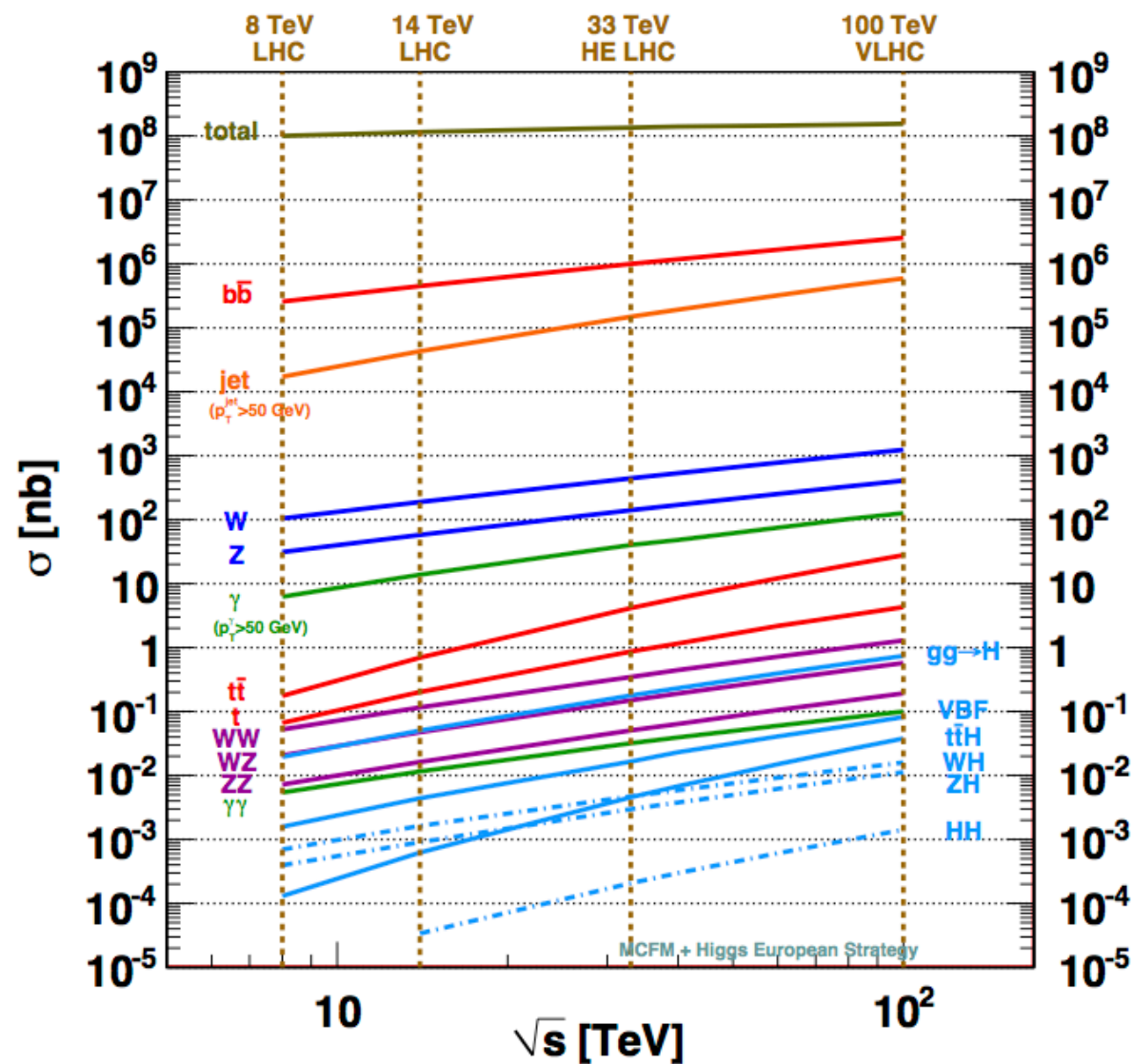
O(160GJ) in magnets

O(20) times LHC

→ **High risk at injection and extraction**

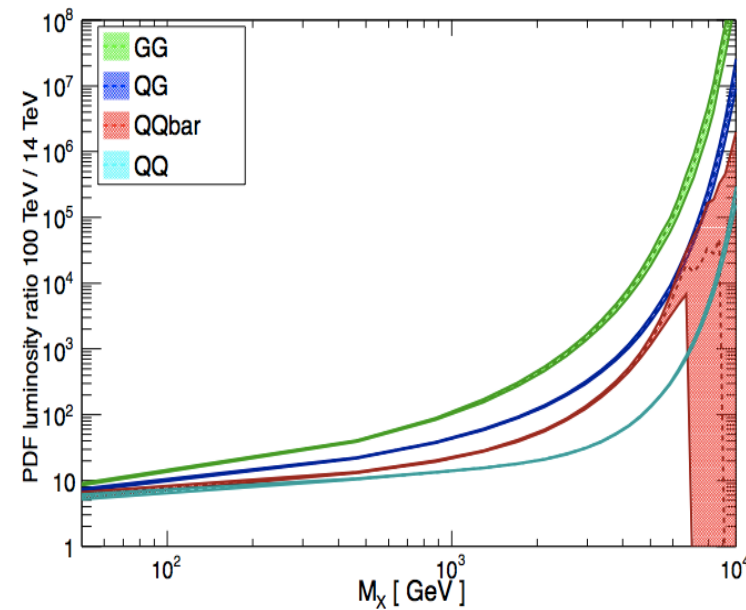


100 TeV pp collisions



Process	σ (100 TeV)/ σ (14 TeV)
WW	~10
ZZ	~10
tt	~30
H	~15 (ttH ~60)
HH	~40
stop (m=1 TeV)	~10 ³

100 TeV vs 14 TeV PDF Luminosities, NNPDF2.3 NNLO

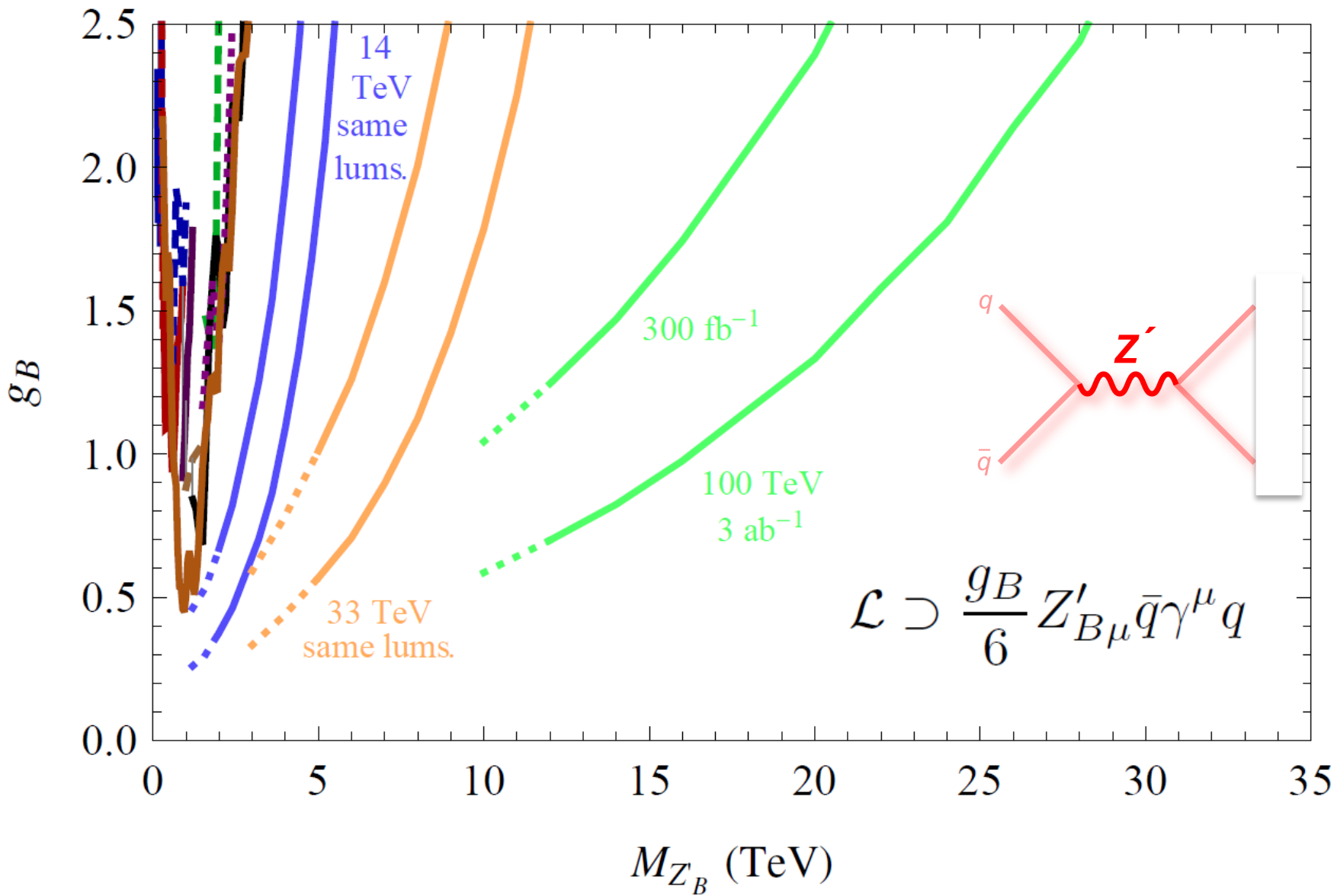


It really opens a new energy frontier---

FCC-pp at 100 TeV and considering a
total integrated luminosity of 3 ab-1

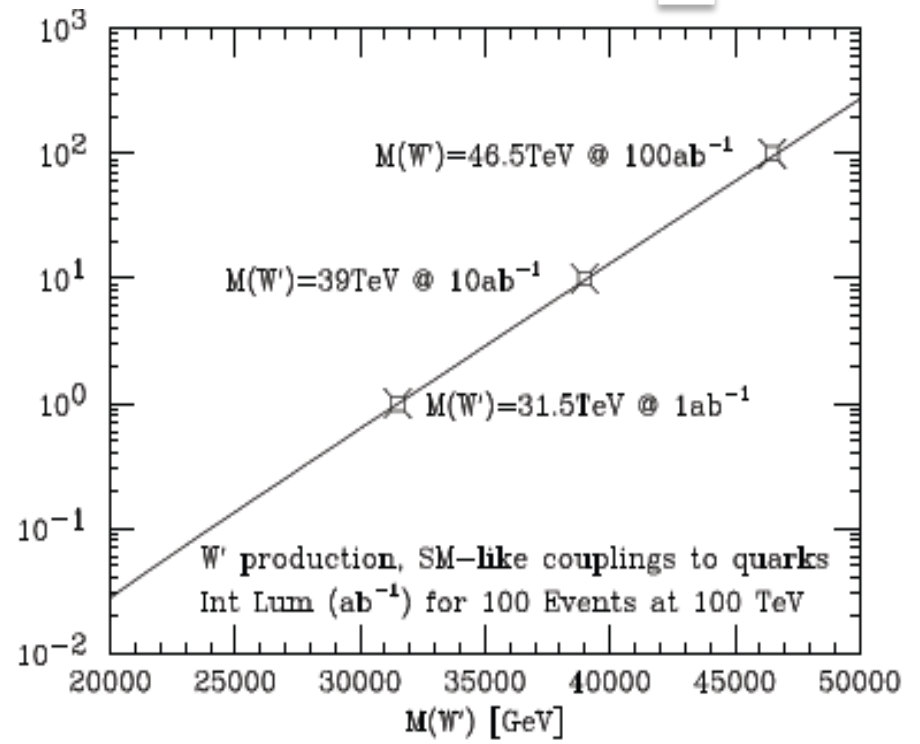
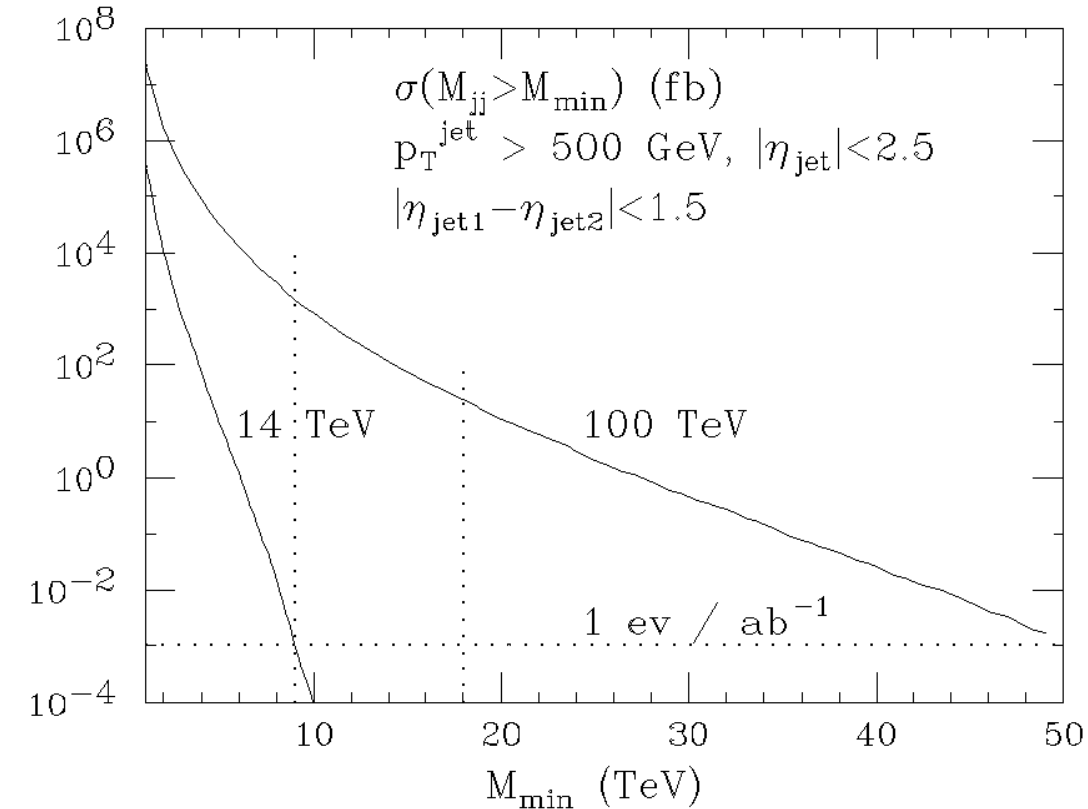
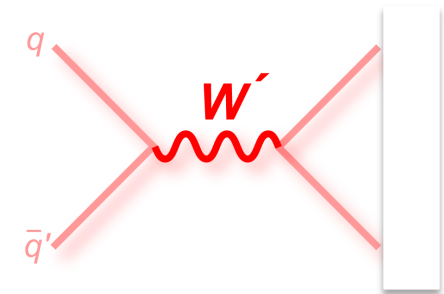
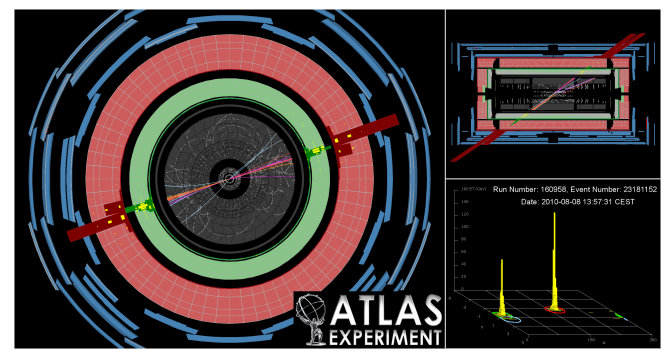
Drell-Yan

Discovery reach
4.5 TeV @ 14 TeV LHC, 300 fb-1
5.5 TeV @ 14 TeV LHC, 3 ab-1
28 TeV @ 100 TeV, 3 ab-1



FCC-pp at 100 TeV and considering a total integrated luminosity of 3 ab-1

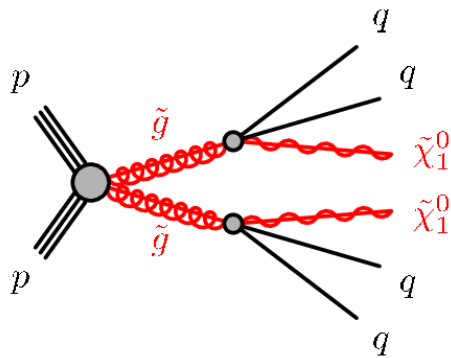
Dijets and W'



To recover LHC-HL sensitivity would take 1 pb-1 (1 day operations)

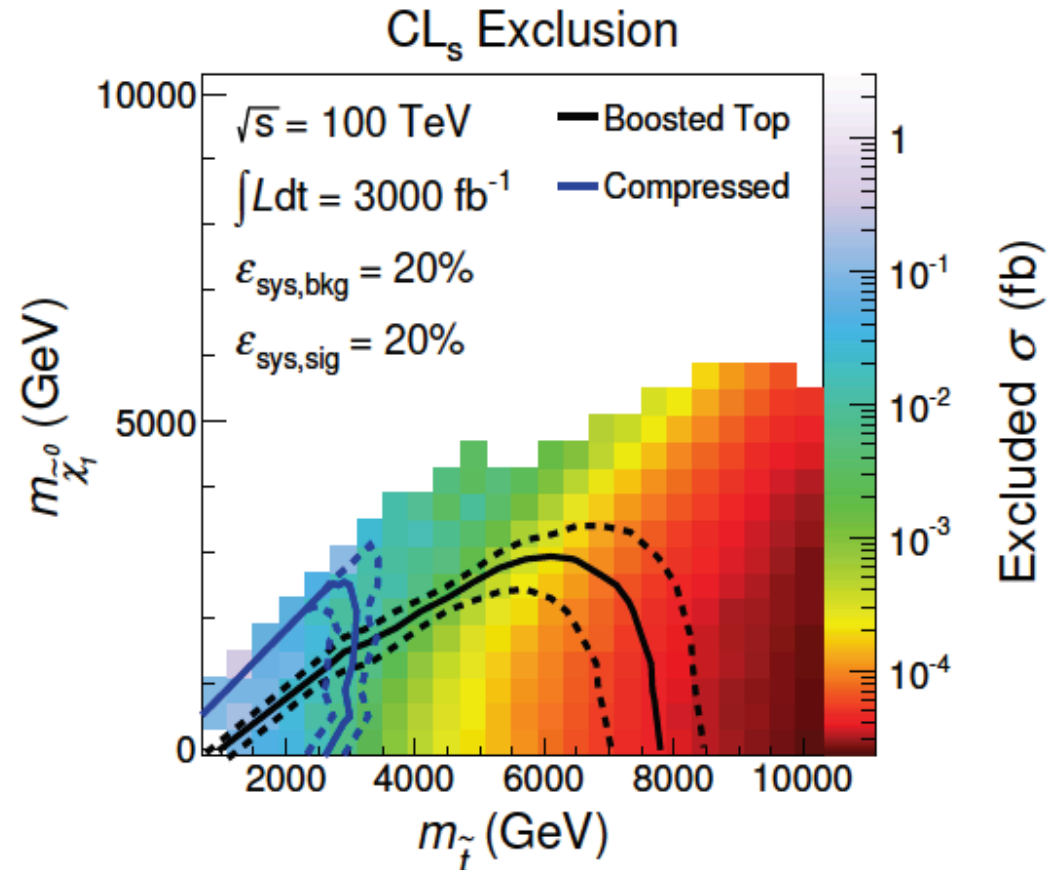
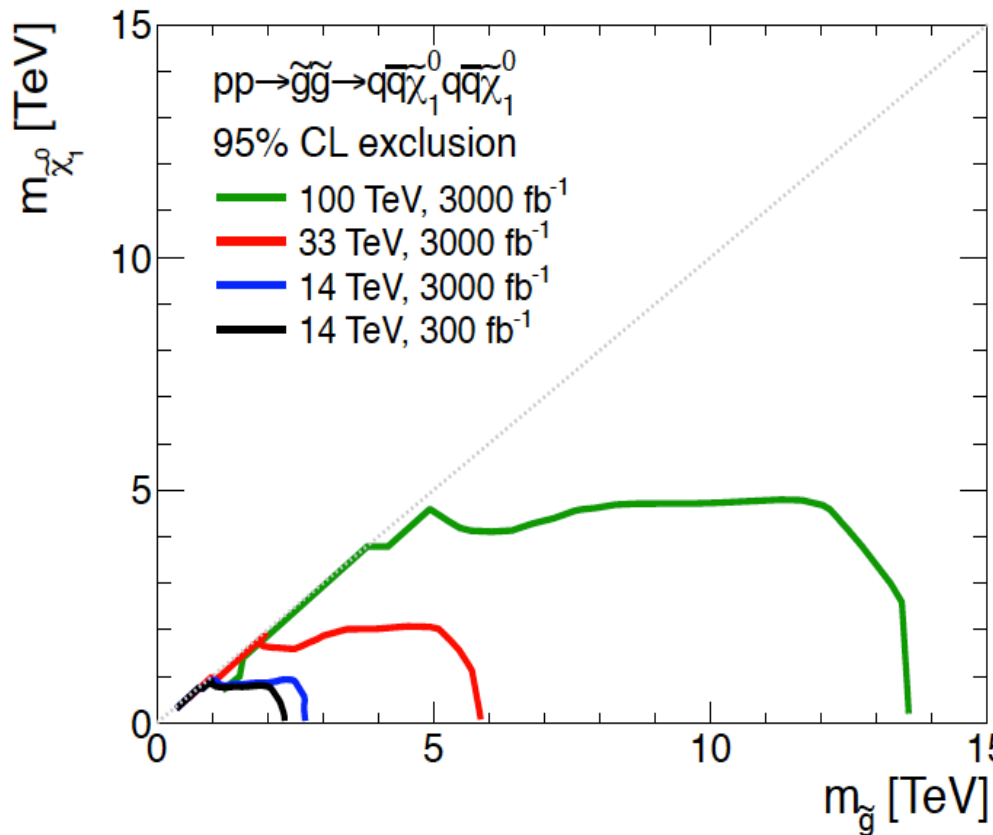
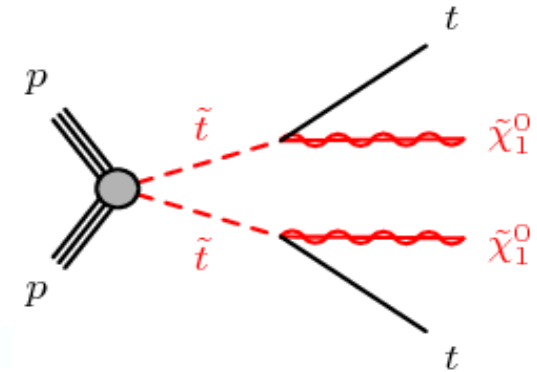
Assuming SM couplings... FCC-pp could exclude a W' of 32 TeV

SUSY Reach for pp @ 100 TeV

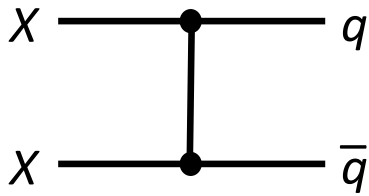


In terms of Higgs/EWK hierarchy problem

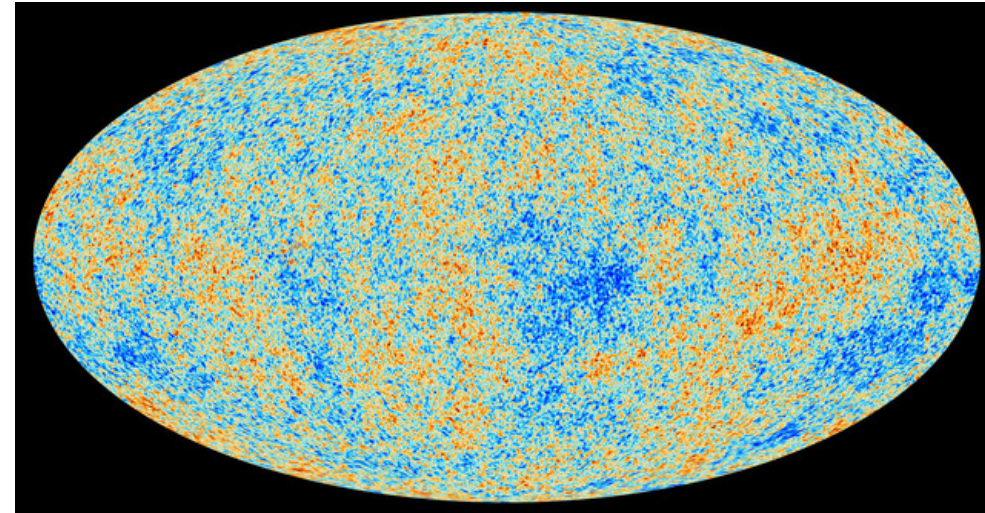
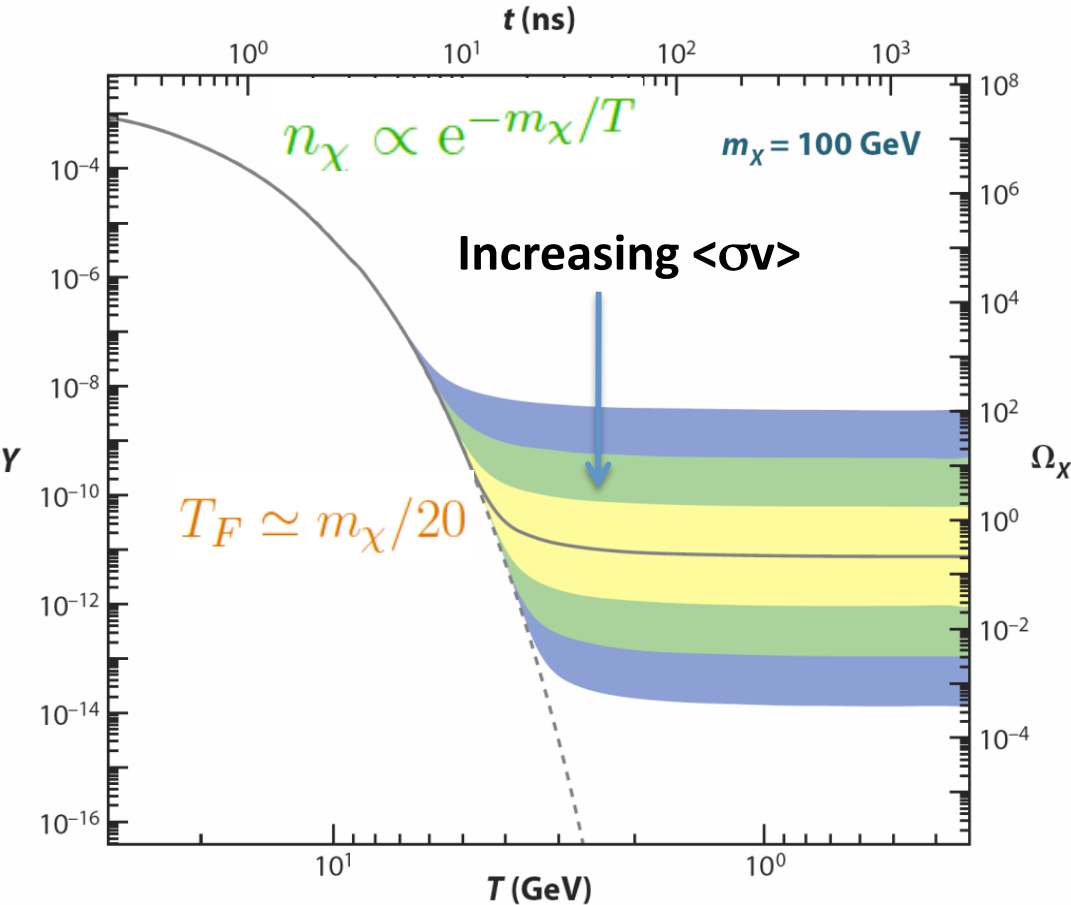
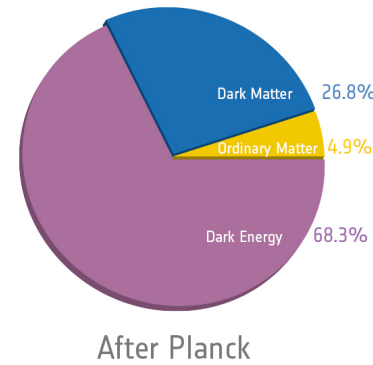
This scenario implies a tuning of the level of 0.05%



Dark Matter



$$\Omega_X \propto \frac{1}{\langle \sigma v \rangle} \sim \frac{m_X^2}{g_X^4}$$



$$\Omega_X h^2 \simeq \frac{0.1 \text{ pb} \cdot c}{\langle \sigma(\chi\chi \rightarrow \text{SM})v \rangle}$$

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

$$\langle \sigma(\chi\chi \rightarrow \text{any})v \rangle \simeq 3 \cdot 10^{-26} \text{ cm}^3 \text{ s}^{-1}$$

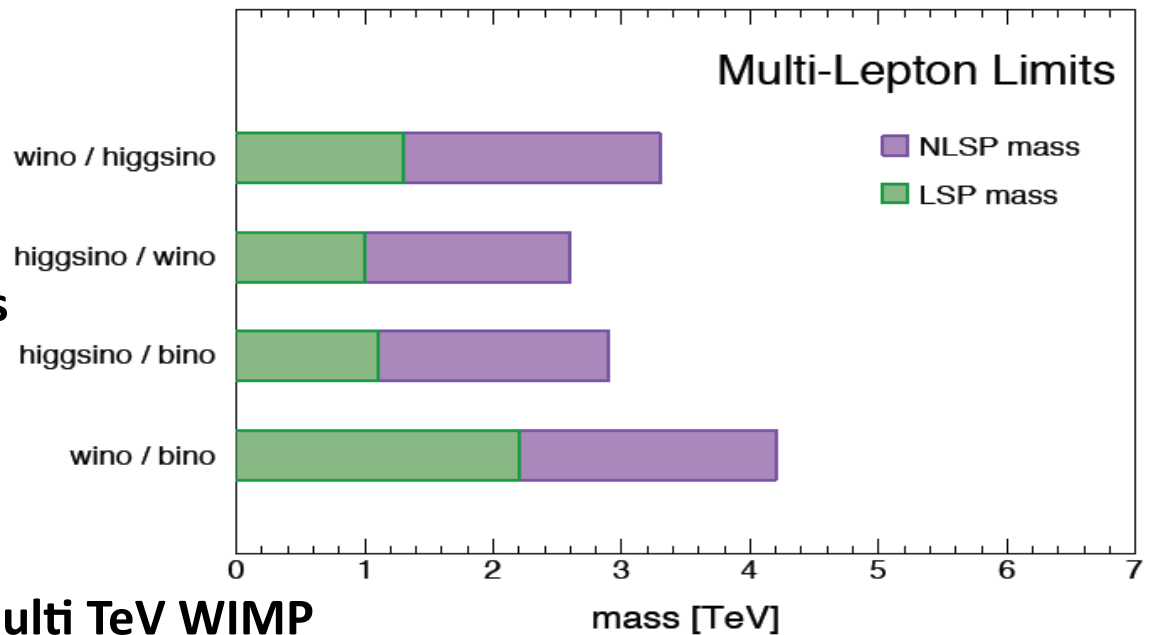
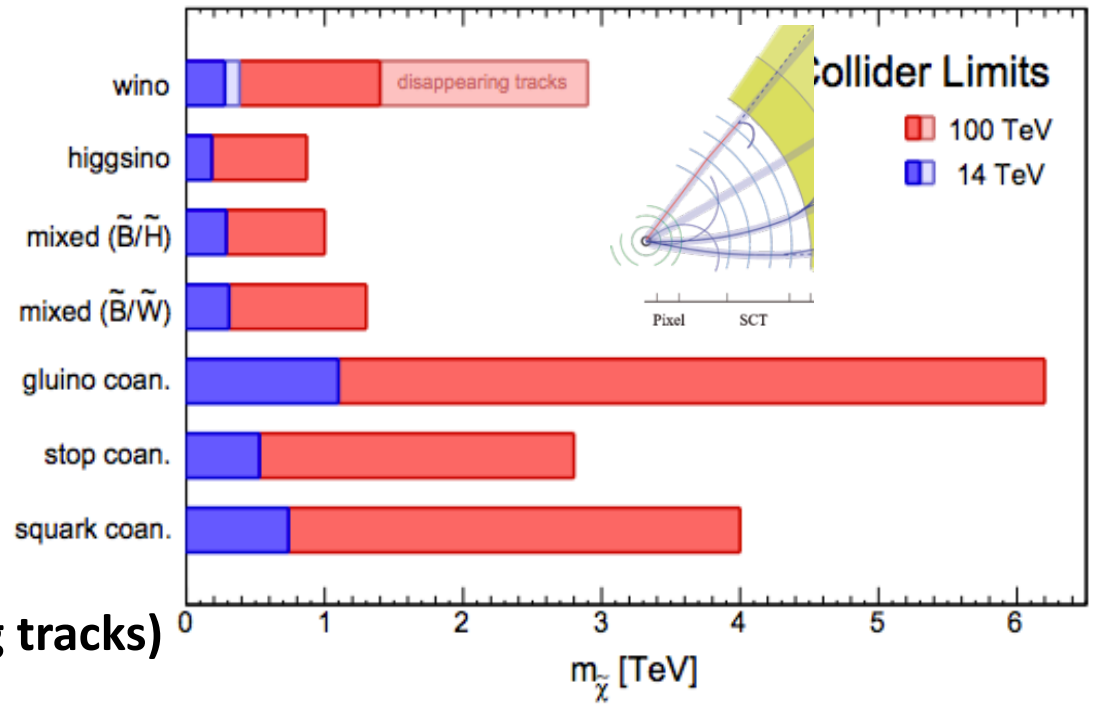
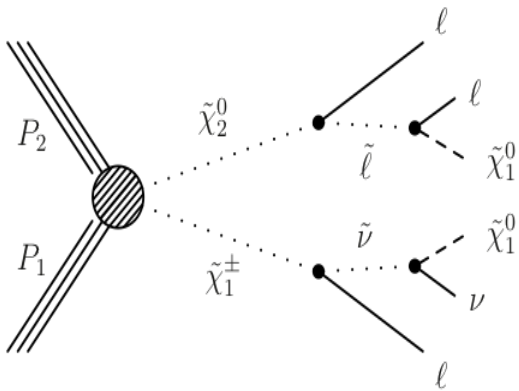
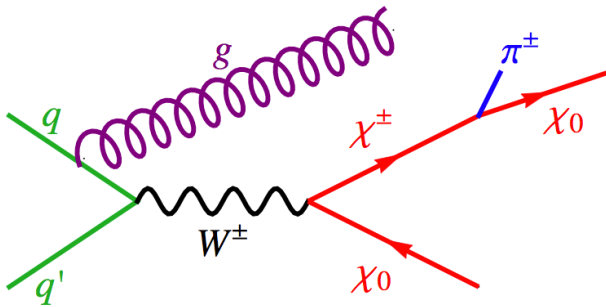
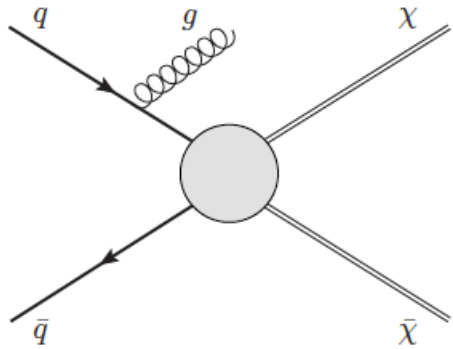
Weak scale for $\chi\chi$ annihilation cross section

Dark Matter @ 100 TeV

Monojets

Long-lived (disappearing tracks)

Multileptons

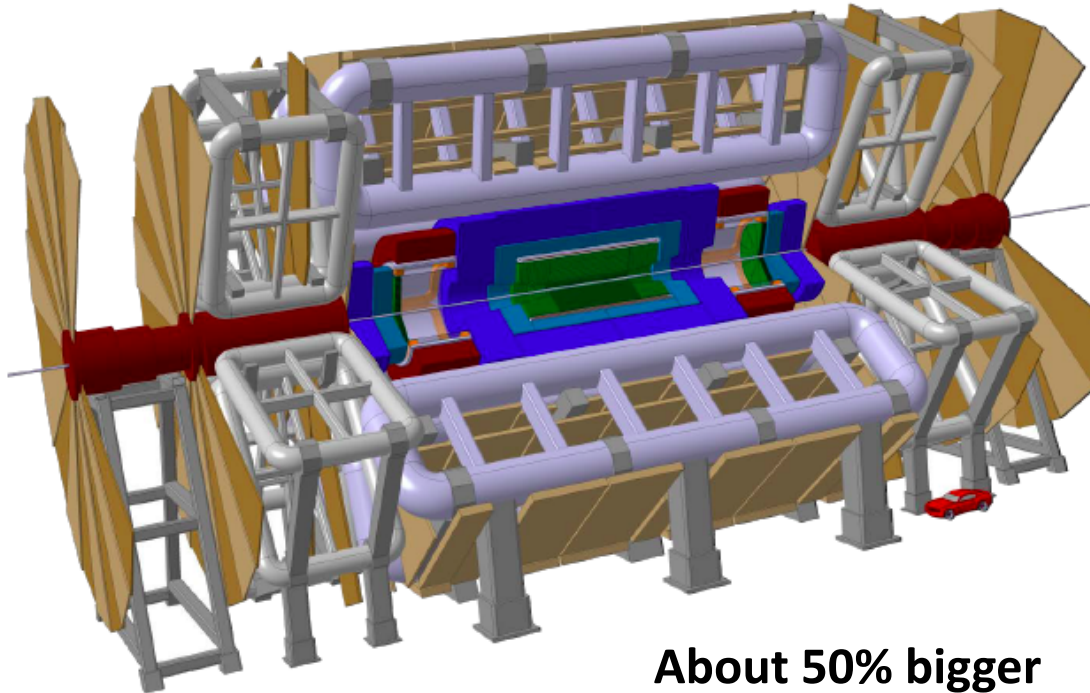


A 100 TeV pp collider would probe the multi TeV WIMP

R&D on Detectors

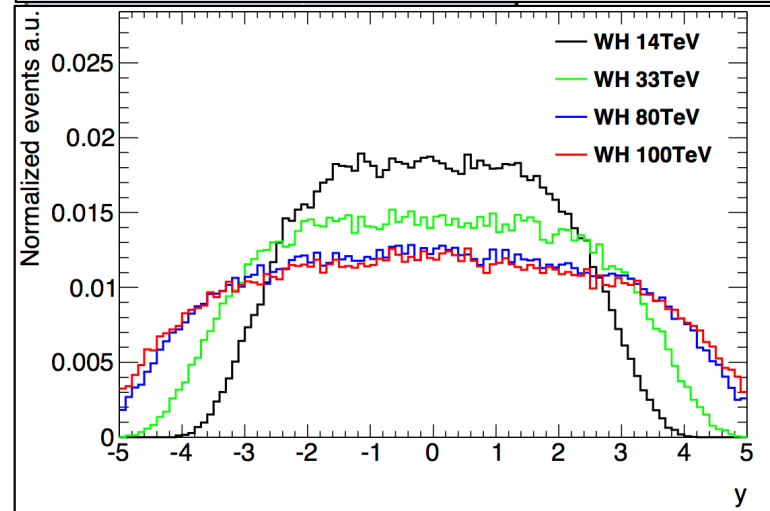


2. Option 3: Toroids + Solenoid + Dipoles (ATLAS+)



About 50% bigger

Physics gets boosted and detectors coverage needs to be increased in the forward regions



Toroid + Dipole, BL^2 scaled

Tracker $r=2.5\text{m}$ p_t reso 15% at 10TeV

Thin Coil $R= 2.5\text{m}$, $B= 4\text{T}$

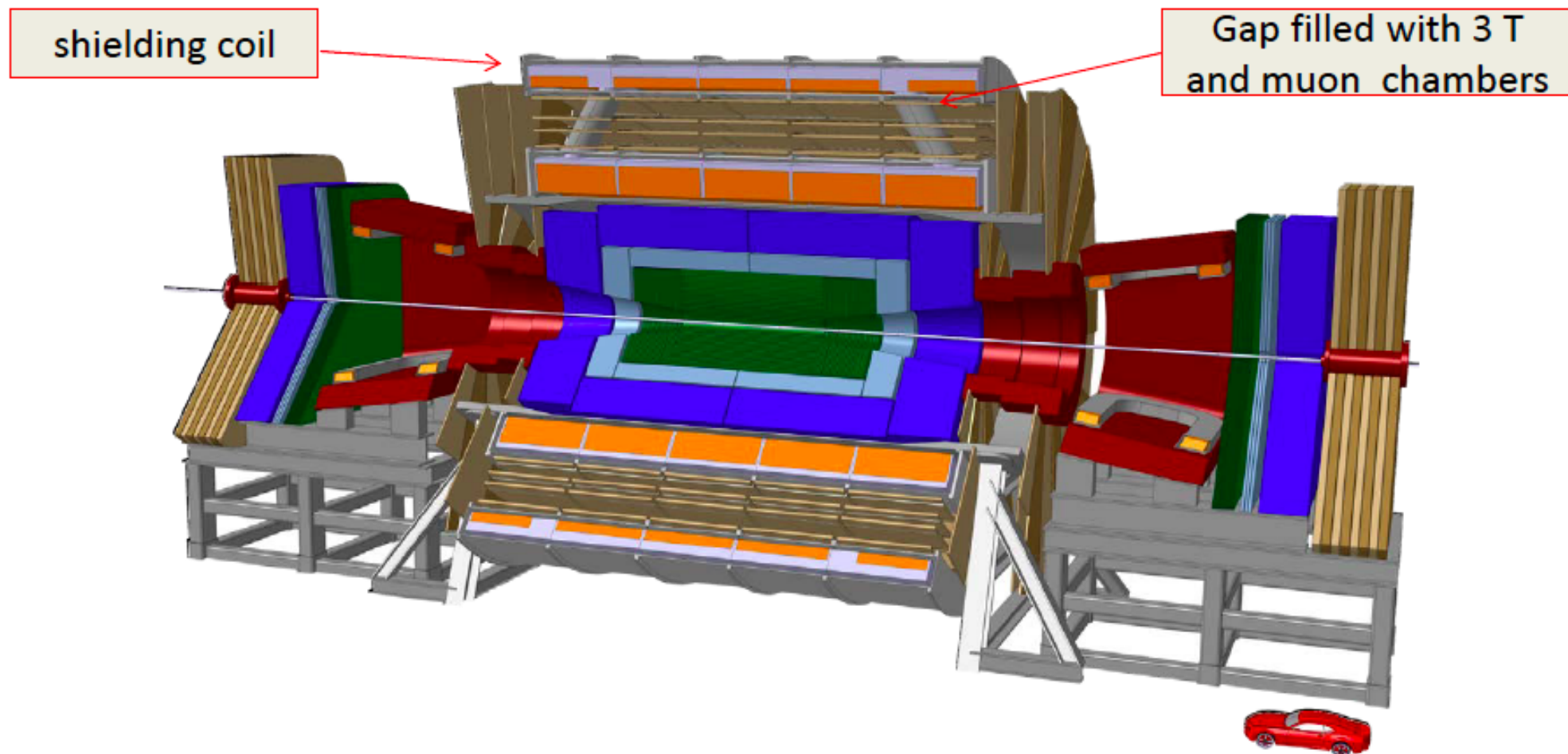
12 lambda ECAL+HCAL =1m+2.5m

Muon Toroid

Forward Dipole 10Tm

In addition the detector needs bigger calorimeters to contain the particle showers and finer segmentation to resolve particle flows

2. Option 2: Twin Solenoid + Dipoles



Twin Solenoid: 6 T, 12 m dia, 23 m long main solenoid + shielding coil

Important advantages:

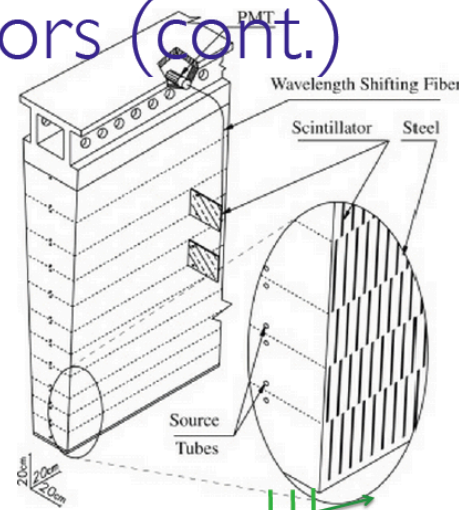
- **Nice muon tracking space:** gap with $\approx 2-3$ T for muon tracking in 4-5 layers.
- **Light:** shielding coil + structure ≈ 8 kt, much lighter than the iron yoke!

examples close to us (Hadronic Calorimetry & Pixels)

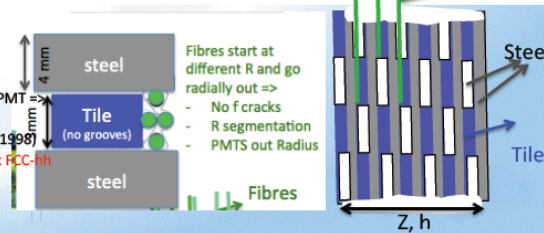
Organic Scintillators (cont.)

- High segmentation achievable by optimised organization of tiles and by the number of fibres coupled to a single photo-detector:

- Minimal changes needed in optics/mechanics to exploit full granularity @ FCC-hh



Dh: 3mm tiles every 9-18mm in Z $\rightarrow 0.0007 < Dh < 0.008$
 DR: 11 tiles and 8 fibres in R $\rightarrow 8-11$ layers with $1l < DR < 0.5l$
 DF: 20 cm tiles $\rightarrow Df=0.1$ (with dual fibre readout)
 In total ~ 620k fibres and 40k tiles; but ~80-300 Tile-fibres couplings in 1PMT $\Rightarrow$
 10 k channels; $Dh \times Df = 0.1 \times 0.1$; 3 longitudinal layers in LHC
 Cost/performance compromise in electronics costs (~730CHF/channel in 1998)
 Minimal changes needed in optics/mechanics to exploit full granularity at FCC-hh

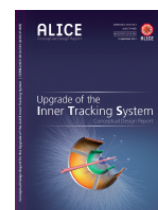


For Hadron Calorimetry ATLAS TileCal with finer segmentation and increased λ is already considered a good solution

For the tracker a full-pixel solution (similar to ALICE 2018 upgrade) considered

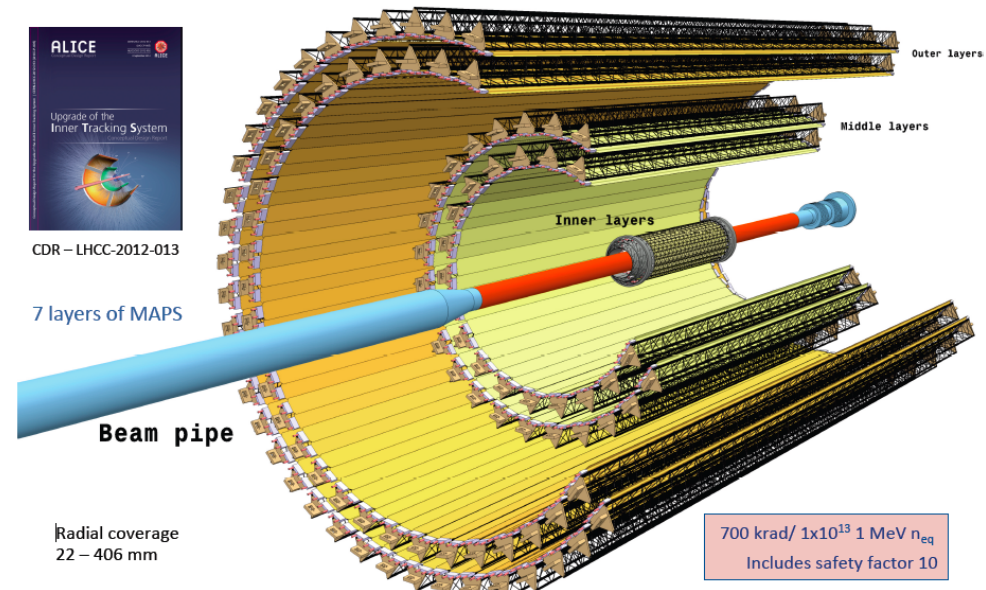
New ITS Layout

25 G-pixel camera
(10.3 m²)



CDR – LHCC-2012-013

7 layers of MAPS



700 krad/ 1×10^{13} 1 MeV n_{eq}
Includes safety factor 10

- 12 λ in depth
- Energy resolution with $C \sim 3\%$ and below
- Longitudinal segmentation for 3D clusters
- $\Delta\eta \times \Delta\phi = 0.05 \times 0.05$ (and smaller)
 - Based on resolution studies of substructure variables
- $\Delta\eta \times \Delta\phi = 0.025 \times 0.025$ (and smaller) for $pT(jet) \sim 10$ TeV
 - ~ 4 better than for ATLAS/CMS
 - $\times 2 \rightarrow$ increase of the distance from IP
 - $\times 2 \rightarrow$ improvement in instrumentation

Lets look into the future...

Final notes..



Final notes: Scenario I

- **Scenario Ia (we find new physics at LHC-HL)**
 - Name it.. SUSY....etc
 - The next natural step is to explore the complete mass spectrum
 - strong motivation for a 100 TeV pp collider
- **Scenario Ib (we find hints for new physics at 10-50 TeV)**
 - For example via contact interactions indicating new physics coming with $\Lambda \sim 10$ TeV
 - Again, strong motivation to go for a 100 TeV pp collider
- **Are Ia/Ib above still consistent with an e⁺e⁻ collider for precise Higgs and EWK measurements ?**
 - If contemporaneous with LHC-HL it might add to the physics case for a 100 TeV pp collider and/or will indicate better which energy to target (ILC in Kapan ?, Circular Collider in China ?, FCC-ee ?)
 - If considered as a natural continuation of the LHC-HL ... it will take long...time



Final notes: Scenario II



- Scenario II (we do not find new physics)
 - There will be no indication on where BSM would be
 - However, one can argue we are moved by curiosity and an order-of-magnitude increase of energy (at the edge of the near future technology) just makes sense.....
 - One can also argue the R&D effort to make it possible will have a positive impact on the Society and will keep the field alive.
(provided it is not ridiculously expensive)
- It still makes sense to study in detail the Higgs in a e^+e^- machine
 - Might still give us hints on where BSM would be and a scale for it
 - Hard to believe the community will build more than one e^+e^- machine
 - It might include $t\bar{t}$ thresholds scan or not
 - ILC, CLIC, FCC-ee, CeeC in competition (all good friends.. of course..)
 - Some questions related to Higgs (HH couplings $V_L V_L$ scattering) might need a higher energy machine above 1 TeV e^+e^-) ... a pp collider...?



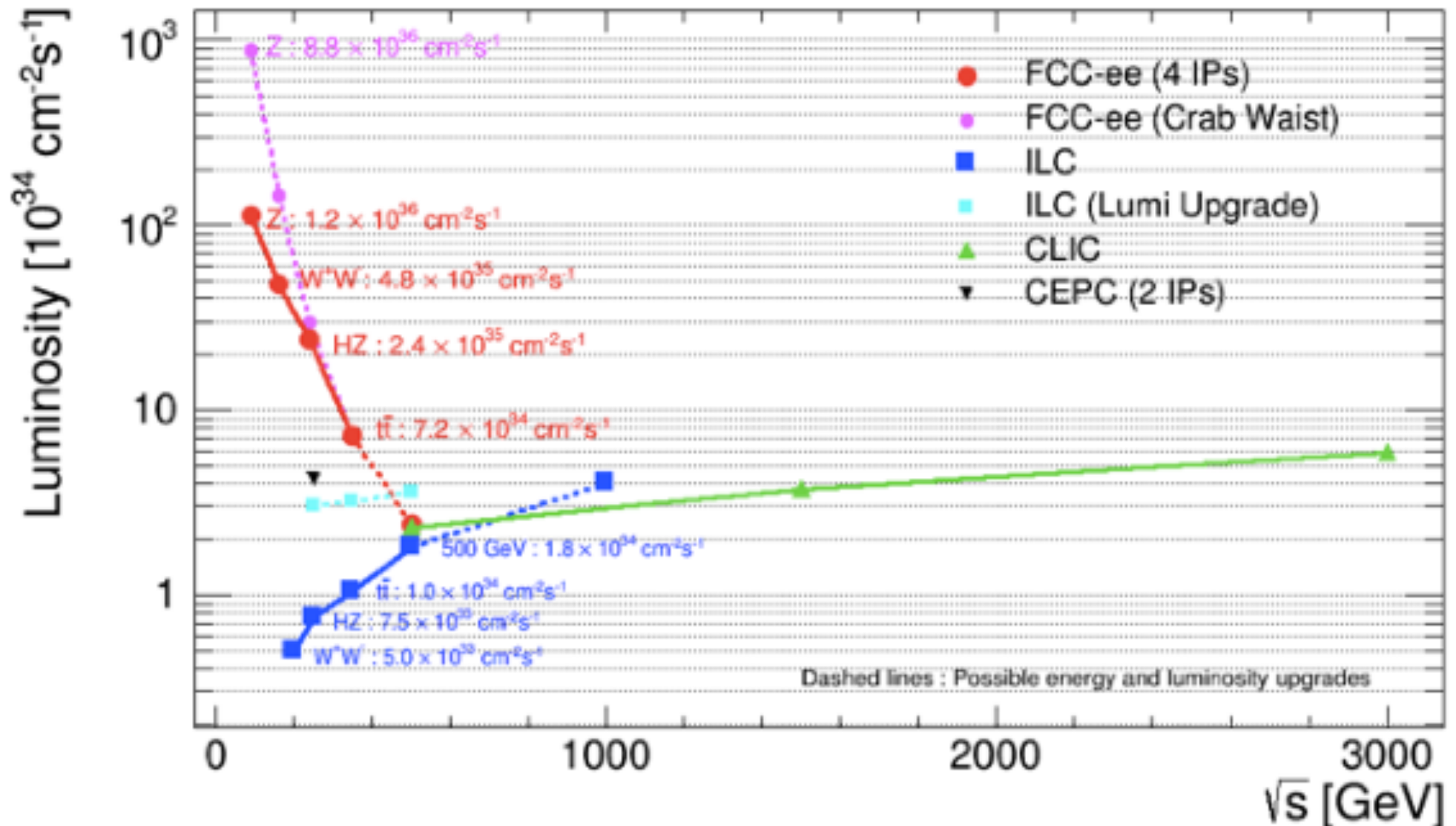
My cristal ball did not work...

**In any case... the next three years of LHC @ 13-14 TeV
will dictate to large extent where to go (or where not to go...)**

Fist Physics Data in June... we will have a hot (and busy) summer

For today.. Lets collide at the Pizza Desk

ILC, CLIC, CEPC, FCC-ee



Shows clearly how a circular collider wins in terms of luminosity and precision

Notes on FCC-eh

Asymmetric ep collider
(e energy of 50 GeV)

Motivation--- PDFs, Higgs $\rightarrow$ bb, LQ

Probably it will never see the light...

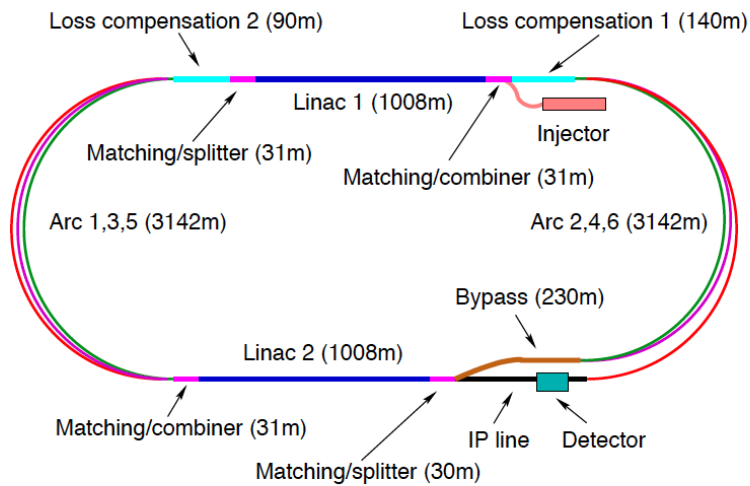
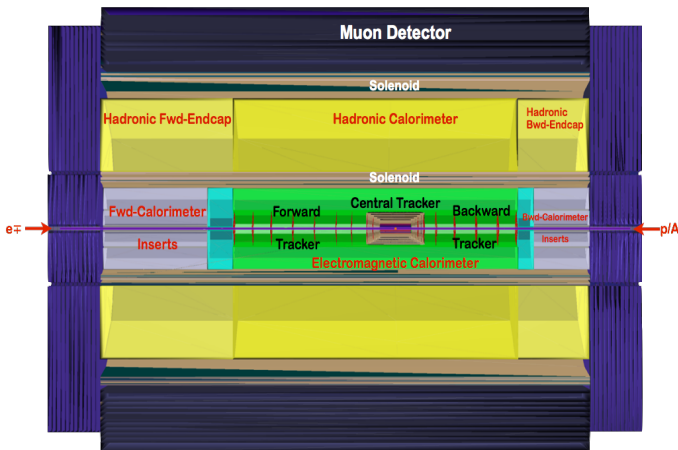
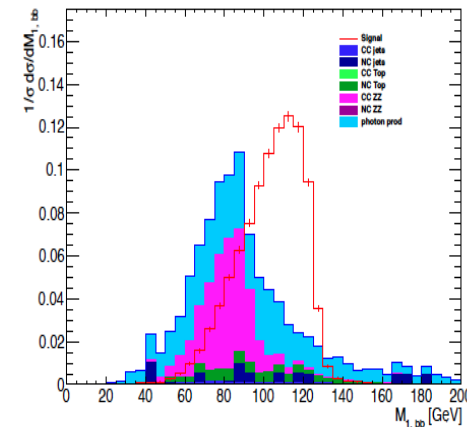
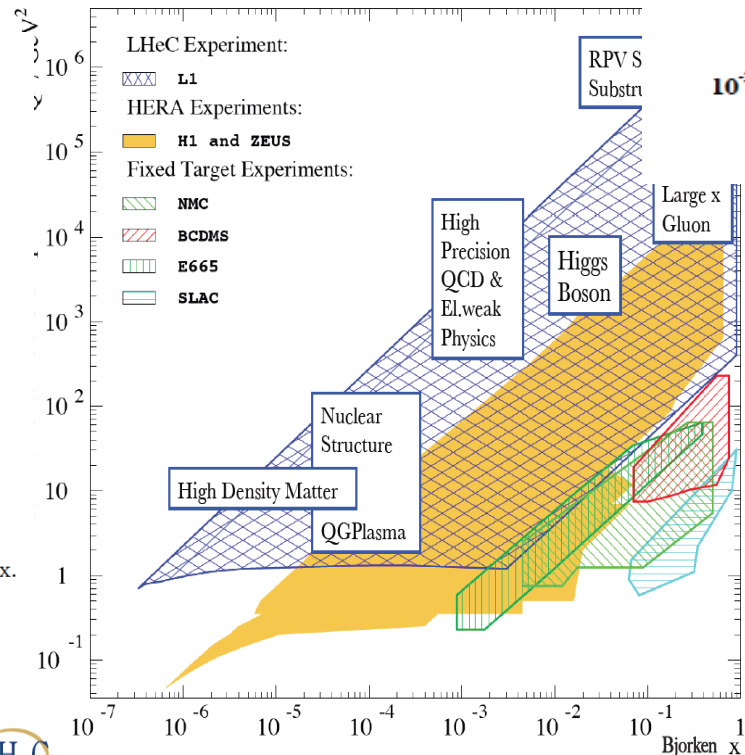
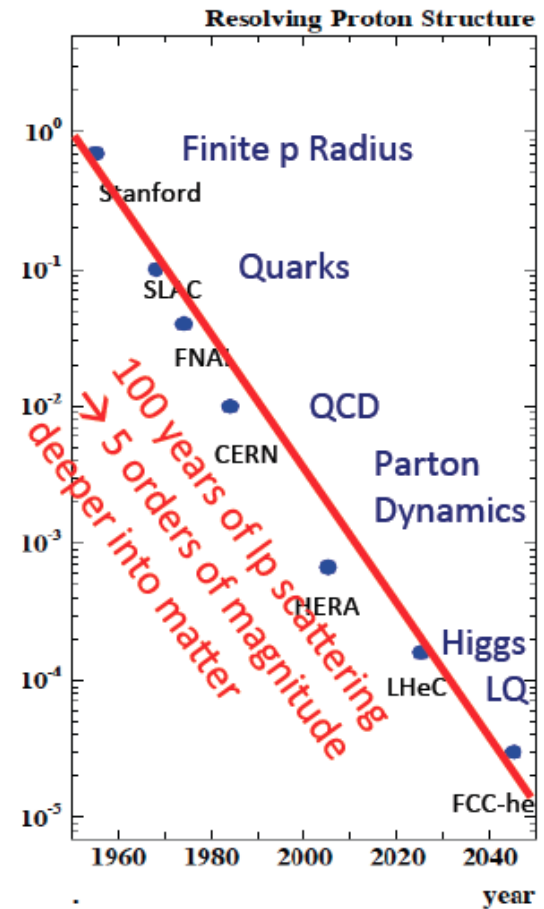


Figure 7.29: The schematic layout of the recirculating linear accelerator complex.

To be included in the beam lines
and to run together with FCC-pp



distance [fm]



“Natural SUSY 2015”

Cumulative Natural SUSY

1500



$\tilde{g}$

400



$\tilde{t}_{L,R}, \tilde{b}_L$

120



h

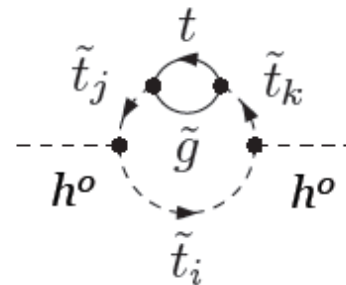
Unavoidable tunings: $\left(\frac{400}{m_{\tilde{t}}}\right)^2, \left(\frac{4m_{\tilde{t}}}{M_{\tilde{g}}}\right)^2$

N. Arkani-Hamed talk at CERN Oct. 2012

→ Light higgsinos

→ Light stop ($t_1 < 1 \text{ TeV}$)

→ Light gluinos ($< 1\text{-}2 \text{ TeV}$)



$$\frac{m_H^2}{2} = -|\mu|^2 + \dots + \delta m_H^2$$

$$\delta m_H^2|_{\text{stop}} \cong -\frac{3y_t^2}{8\pi^2} (m_{Q_3}^2 + m_{U_3}^2 + |A_t|^2) \ln\left(\frac{\Lambda}{\text{TeV}}\right)$$

$$\delta m_H^2|_{\text{gluino}} \cong -\frac{2y_t^2}{\pi^2} \left(\frac{\alpha_s}{\pi}\right) |M_3|^2 \ln^2\left(\frac{\Lambda}{\text{TeV}}\right)$$

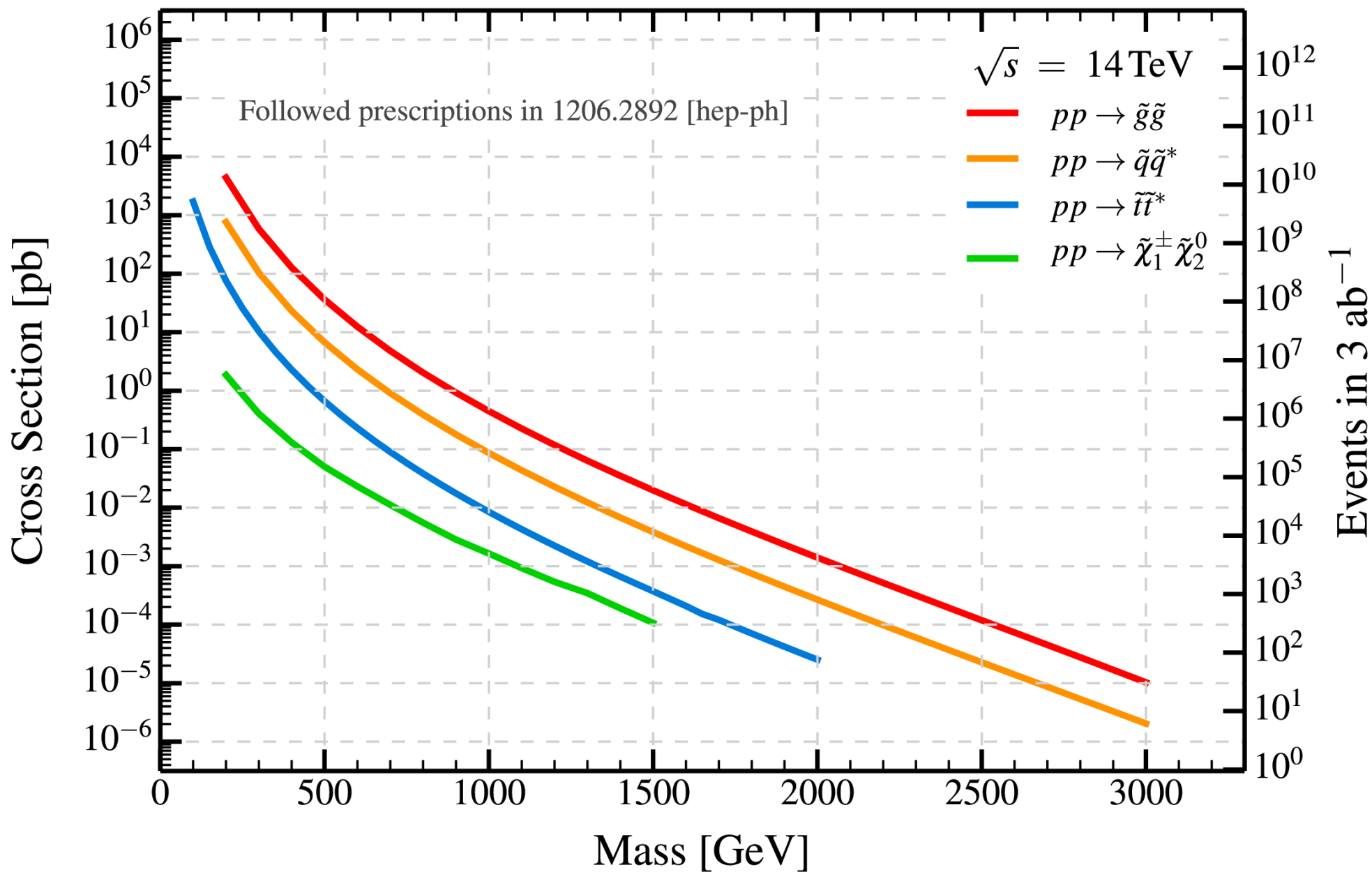
$$\begin{pmatrix} \tilde{t}_1 \\ \tilde{t}_2 \end{pmatrix} = \begin{pmatrix} \cos \theta_t & \sin \theta_t \\ -\sin \theta_t & \cos \theta_t \end{pmatrix} \begin{pmatrix} \tilde{t}_L \\ \tilde{t}_R \end{pmatrix}$$

One light stop and sbottom
...rest of sparticles can be
decoupled....

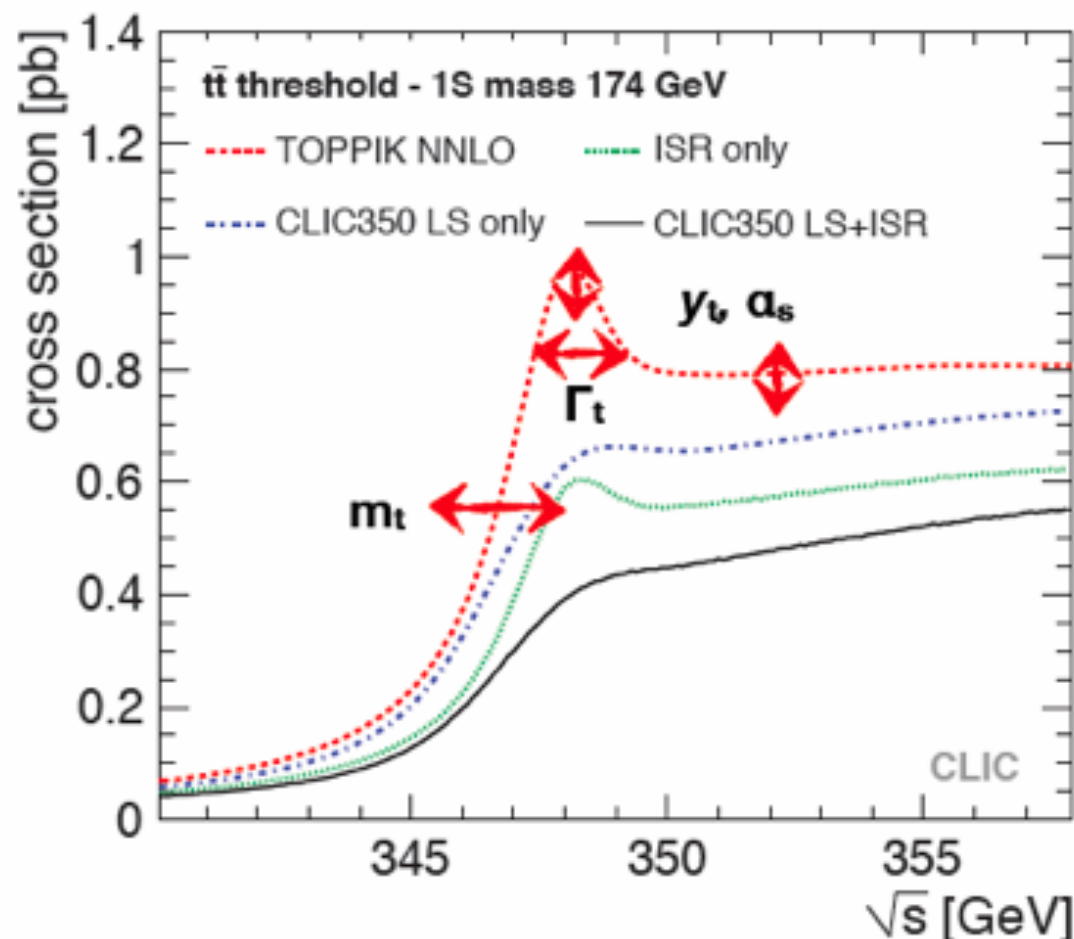
$$\begin{pmatrix} \tilde{t}_L \\ \tilde{b}_L \end{pmatrix} \quad \tilde{t}_R \quad \tilde{b}_R$$

(same weak isospin multiplet)

SUSY @ 14 TeV LHC



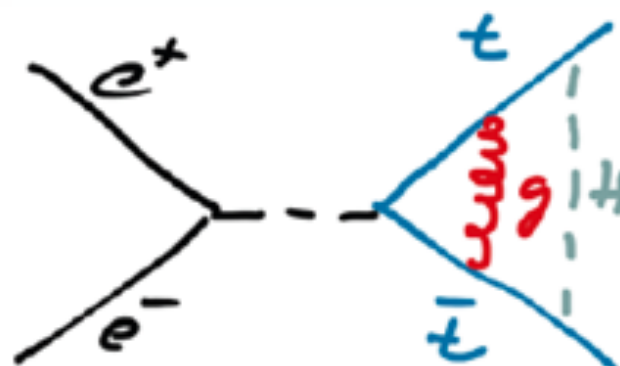
The Top Threshold - Ultimate Sensitivity



- Effects of some parameters are correlated; dependence on Yukawa coupling rather weak - precise external α_s helps

The cross-section around the threshold is affected by several properties of the top quark and by QCD

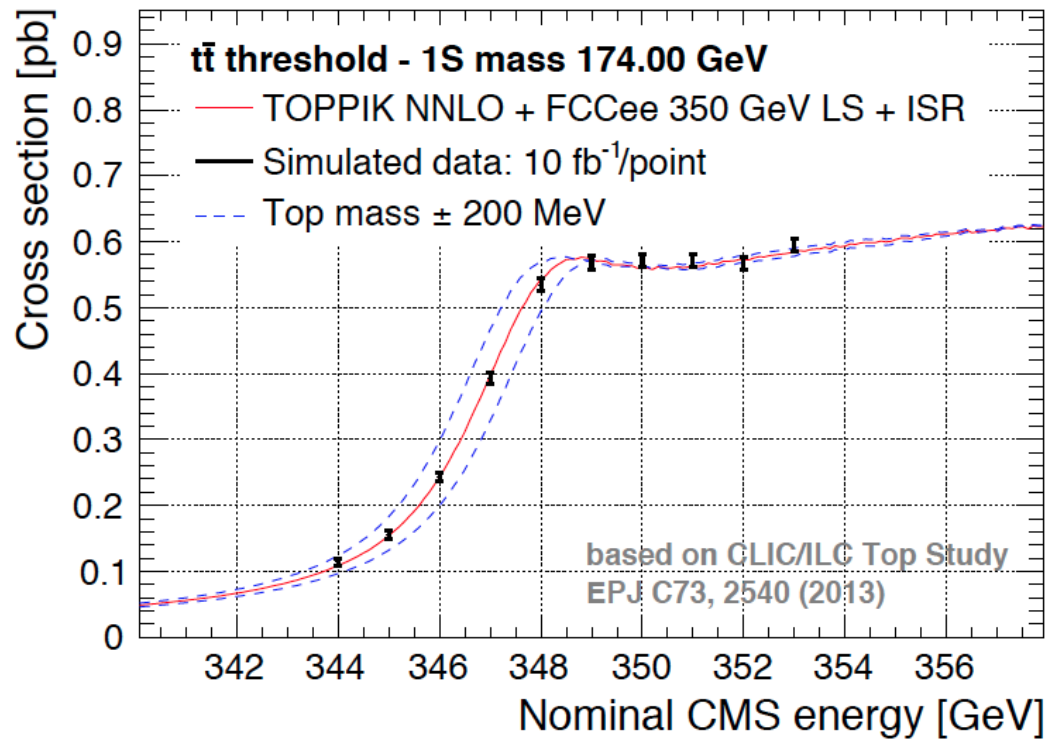
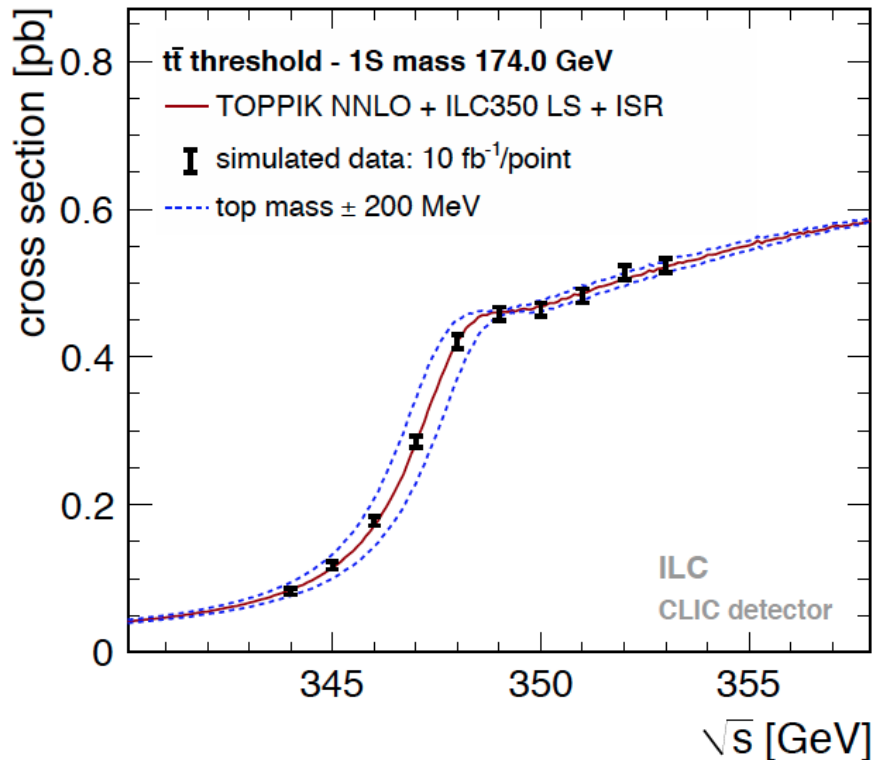
- Top mass, width, Yukawa coupling
- Strong coupling constant



Here: Extract mass and α_s

ILC vs FCC-ee

- Comparing ILC and FCCee - assuming identical detector performance

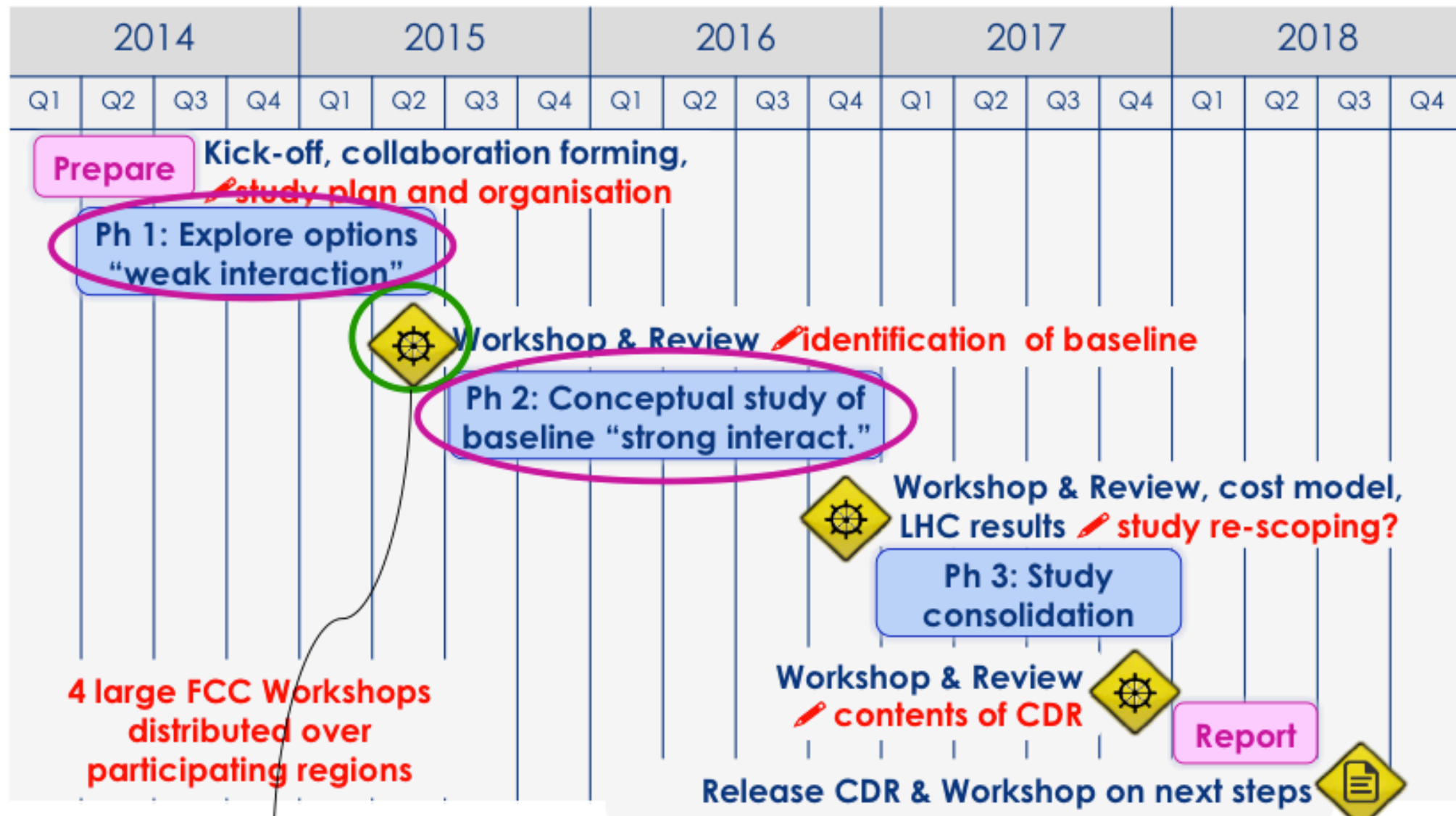


Simulated data points -
same integrated luminosity

NB: Assuming unpolarized beams - LC
beams can be polarized, increasing cross-
sections / reducing backgrounds

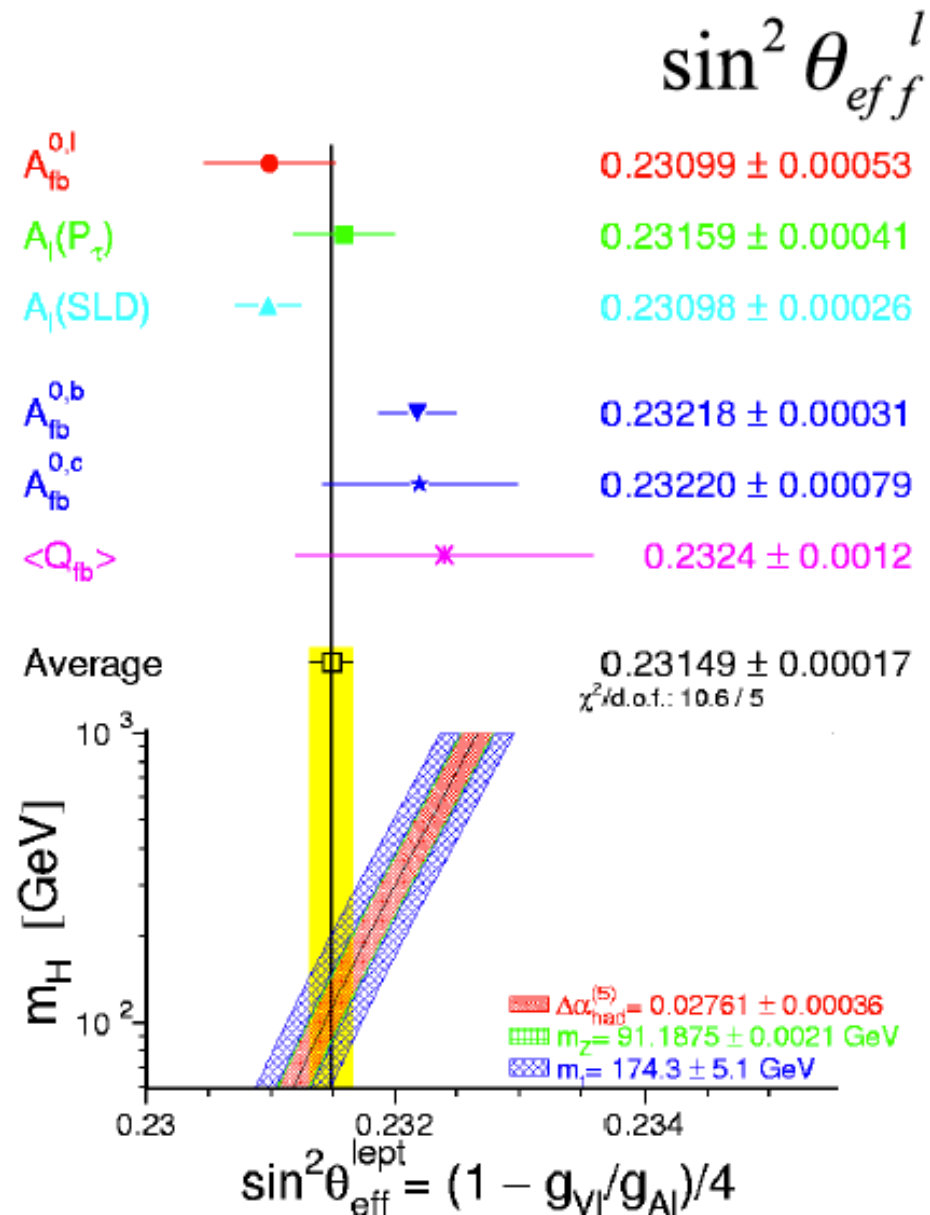
With 100 fb⁻¹ at same conditions ILC reaches a precision of 18 MeV vs 16 MeV at FCCee

FCC Design Study: Timeline



TeraZ: final word on Asymmetries

- Long standing difference between A_{lr} and $A_{FB}(b)$, **it must be sorted out**
- measurement of A_{lr} with **long. polarized beams**
- **direct measurement of the b couplings** (again need long. polarization)
- **Could potentially reach $\sim 10^{-6}$ on $\sin^2\theta$**
- What can be done without long polarization ? (next slides)



P5's collider vision: **ILC**

Precision tool: ***“Use the Higgs boson as a new tool for discovery”***
contributes also to: *“Identify the new physics of dark matter”*
“Explore the unknown: new particles, interactions, and physical properties”

Energy upgrade path to ~1 TeV,

Upgrade path differs from circular colliders, whose upgrade path is to pp .
Scientifically **motivated** by:

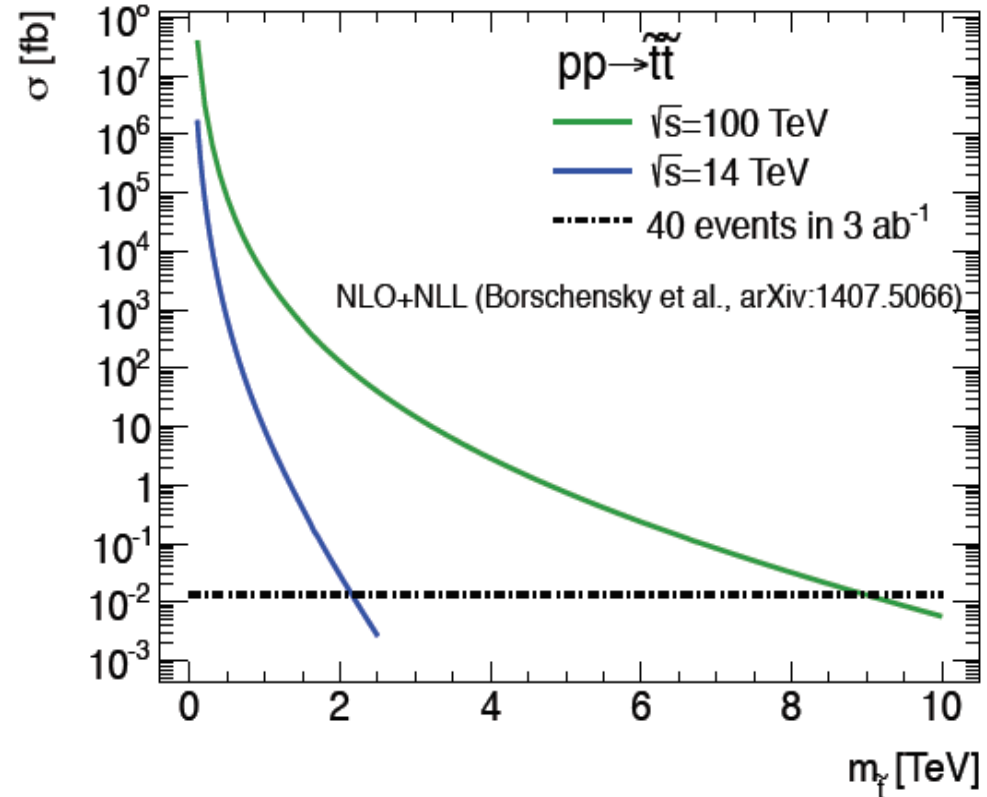
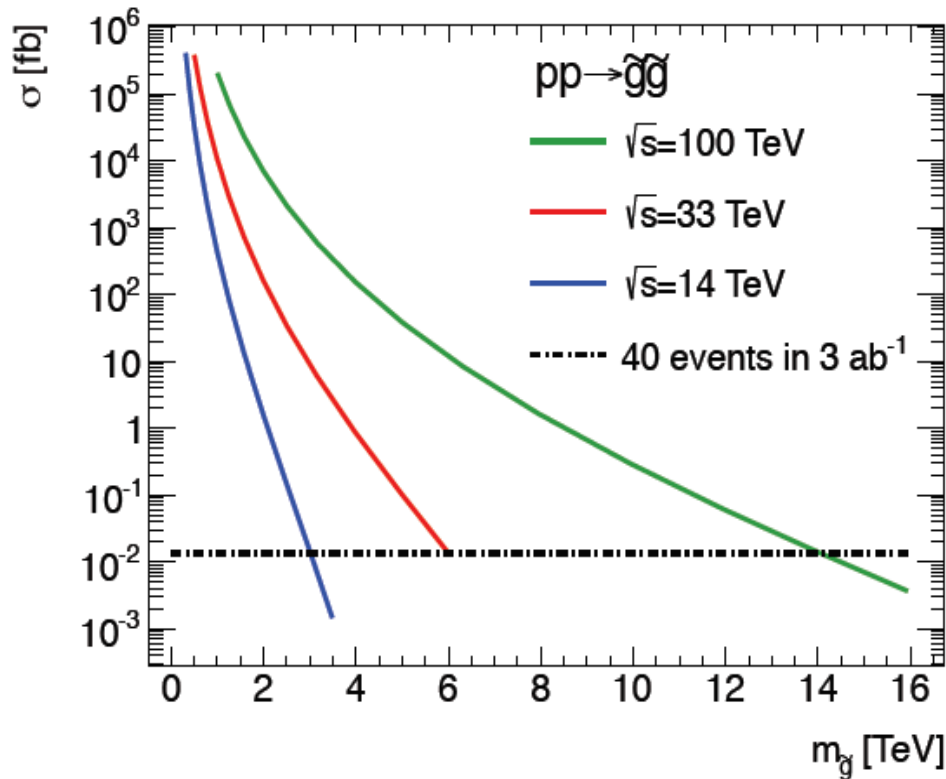
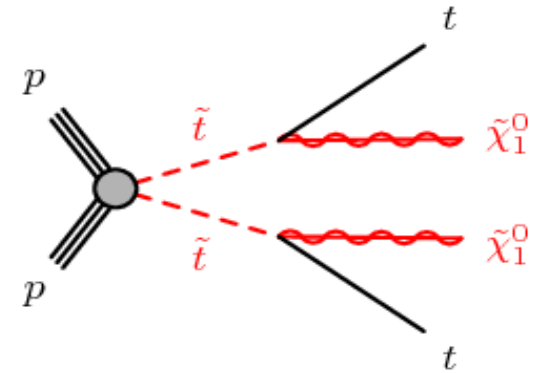
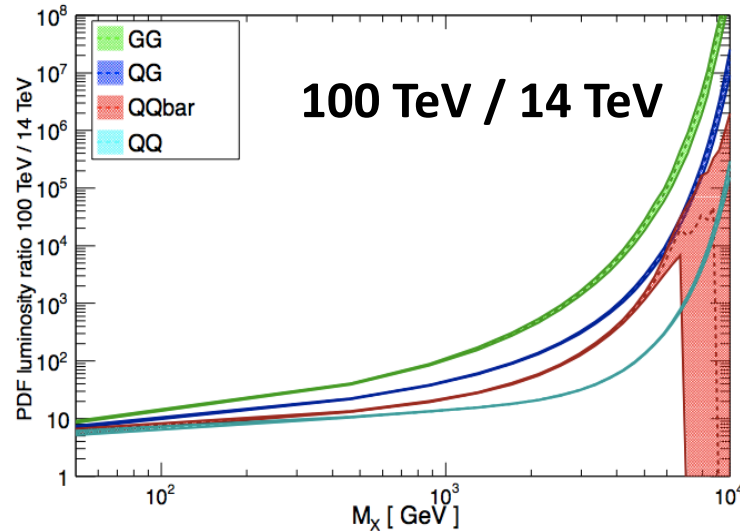
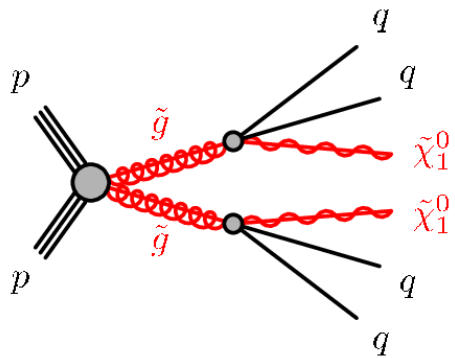
- **Higgs self-coupling** (~13%); precision Higgs-top coupling (~2%)
- Extended **search for new particles** coupling to γ & Z
- Motivation increased if **LHC/HL-LHC discovers new particles**

Status:

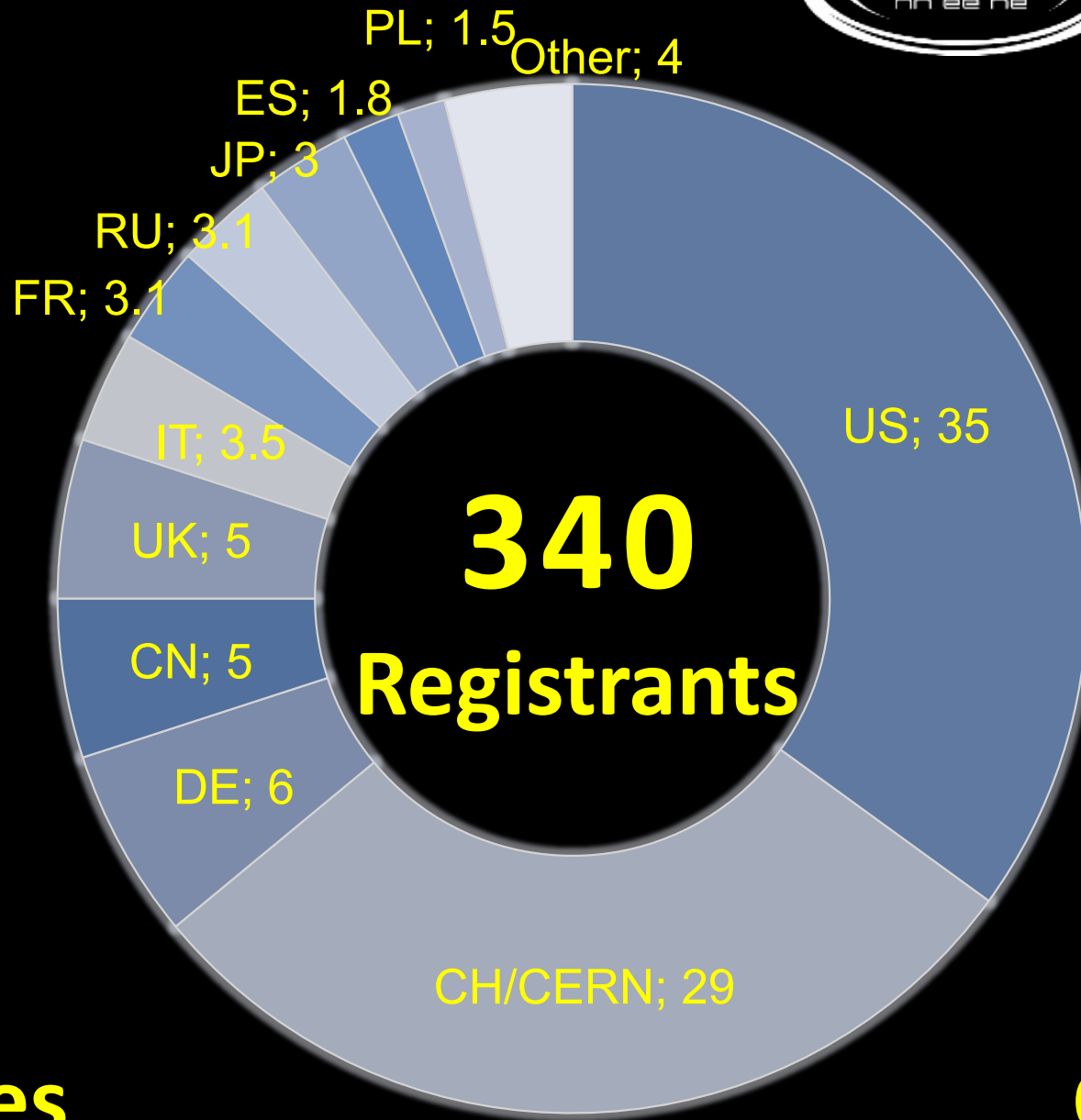
- TDR – June 2013 -> ***technically ready***
- **Japan** is considering whether or not to host ILC.
- Subject of active discussion between DOE and MEXT (Japanese Ministry of Education, Culture, Sports, Science and Technology)
- LCC is targeting 2018 construction start.

SUSY Reach for pp @ 100 TeV

100 TeV vs 14 TeV PDF Luminosities, NNPDF2.3 NNLO



FCC Participants



128

Institutes

21

Countries



Estrategia Europea

The European Strategy for Particle Physics

Update 2013



“The discovery of the Higgs boson is the start of a major programme of work to measure this particle’s properties with the highest possible precision for testing the validity of the Standard Model and to search for further new physics at the energy frontier. The LHC is in a unique position to pursue this programme.

Europe’s top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030. This upgrade programme will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma.”

Brussels/Geneva, 30 May 2013

Very much supported by the recent USA P5 Panel recommendations

Building for Discovery

Strategic Plan for U.S. Particle Physics in the Global Context

Report of the Particle Physics Project Prioritization Panel (P5)



Near-term & Mid-term High-energy Colliders

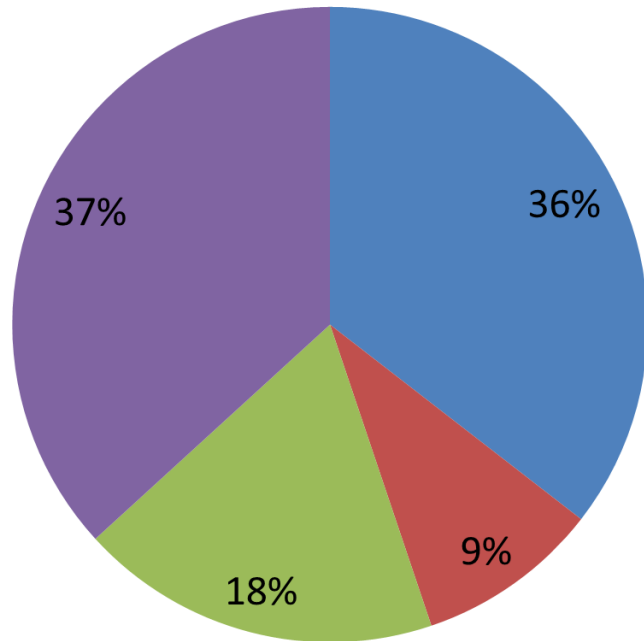
LARGE HADRON COLLIDER

- The HL-LHC is strongly supported and is the first high-priority large-category project in our recommended program. It should move forward without significant delay to ensure that accelerator and experiments can continue to function effectively beyond the end of this decade and meet the project schedule.
- *Recommendation 10: Complete the LHC phase-1 upgrades, and continue the strong collaboration in the LHC with the phase-2 (HL-LHC) upgrades of the accelerator and both general-purpose experiments (ATLAS and CMS). The LHC upgrades constitute our highest-priority near-term large project.*

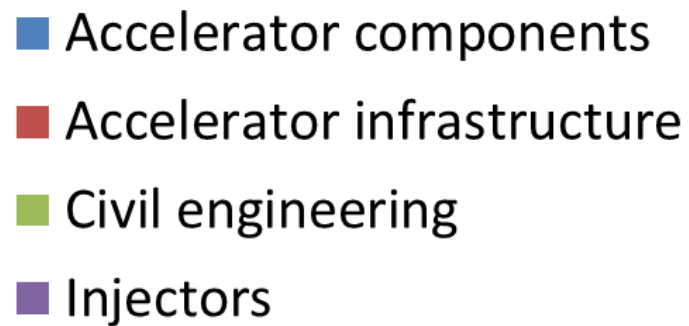
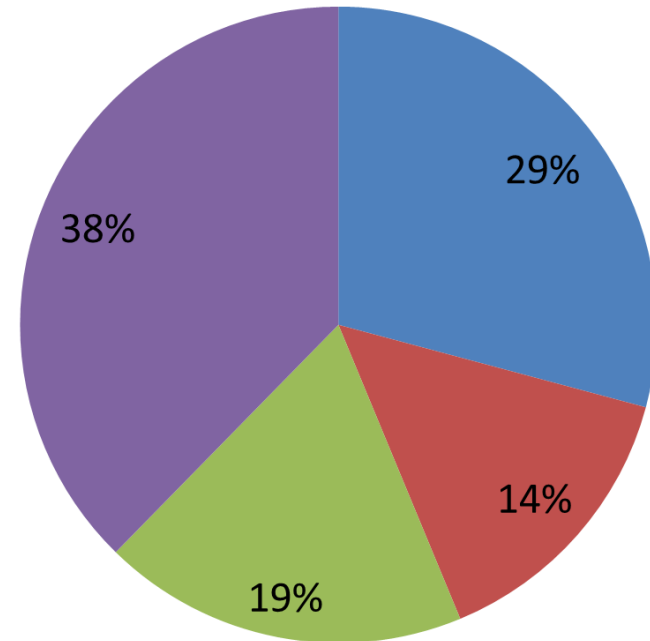
Infrastructure is a cost driver

Cost structure of high-energy accelerators

LHC “green field” (reconstructed)



CLIC 500 $\equiv$ “green field”



FCC 100 km perimeter

