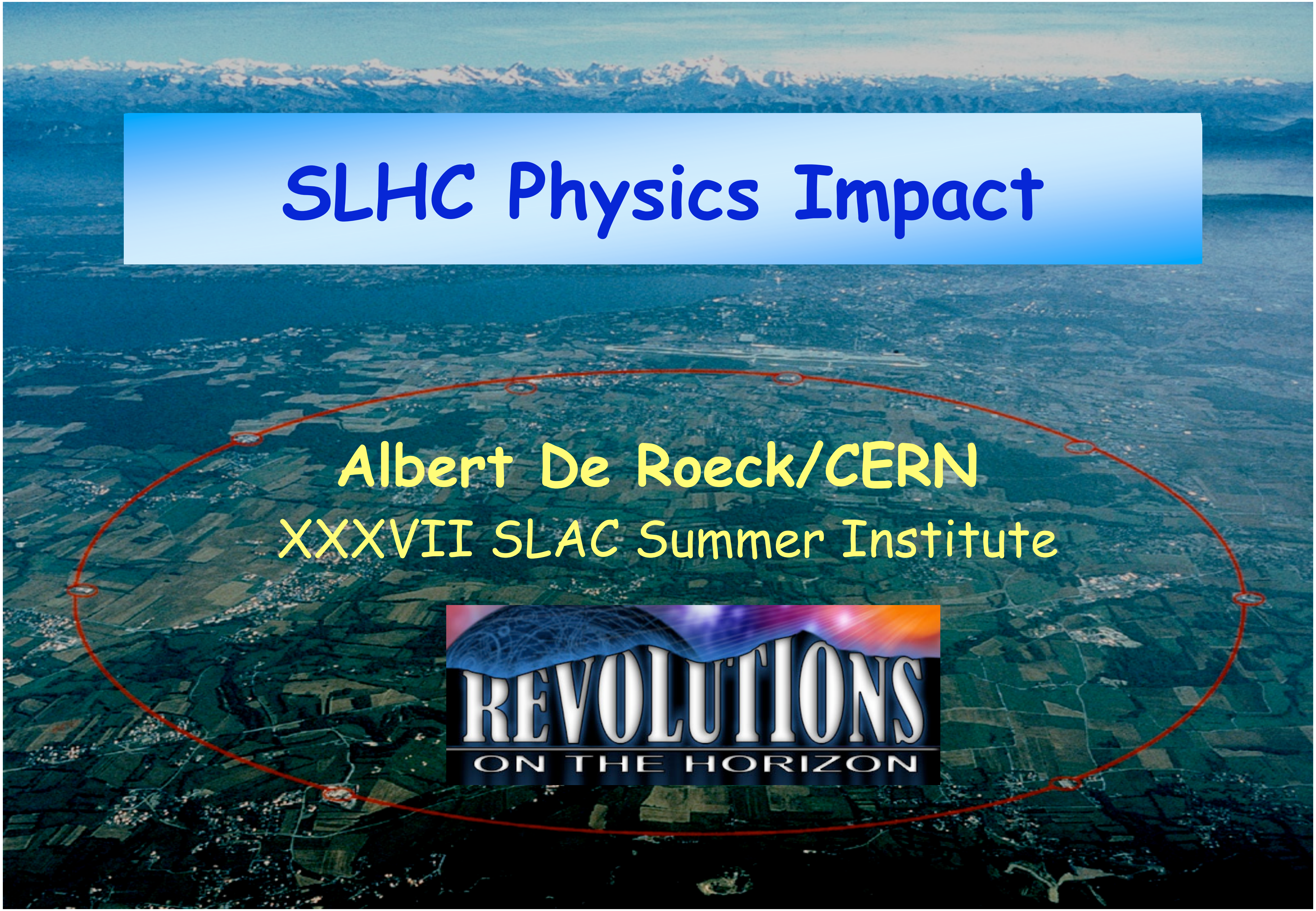


SLHC Physics Impact

Albert De Roeck/CERN

XXXVII SLAC Summer Institute

REVOLUTIONS
ON THE HORIZON

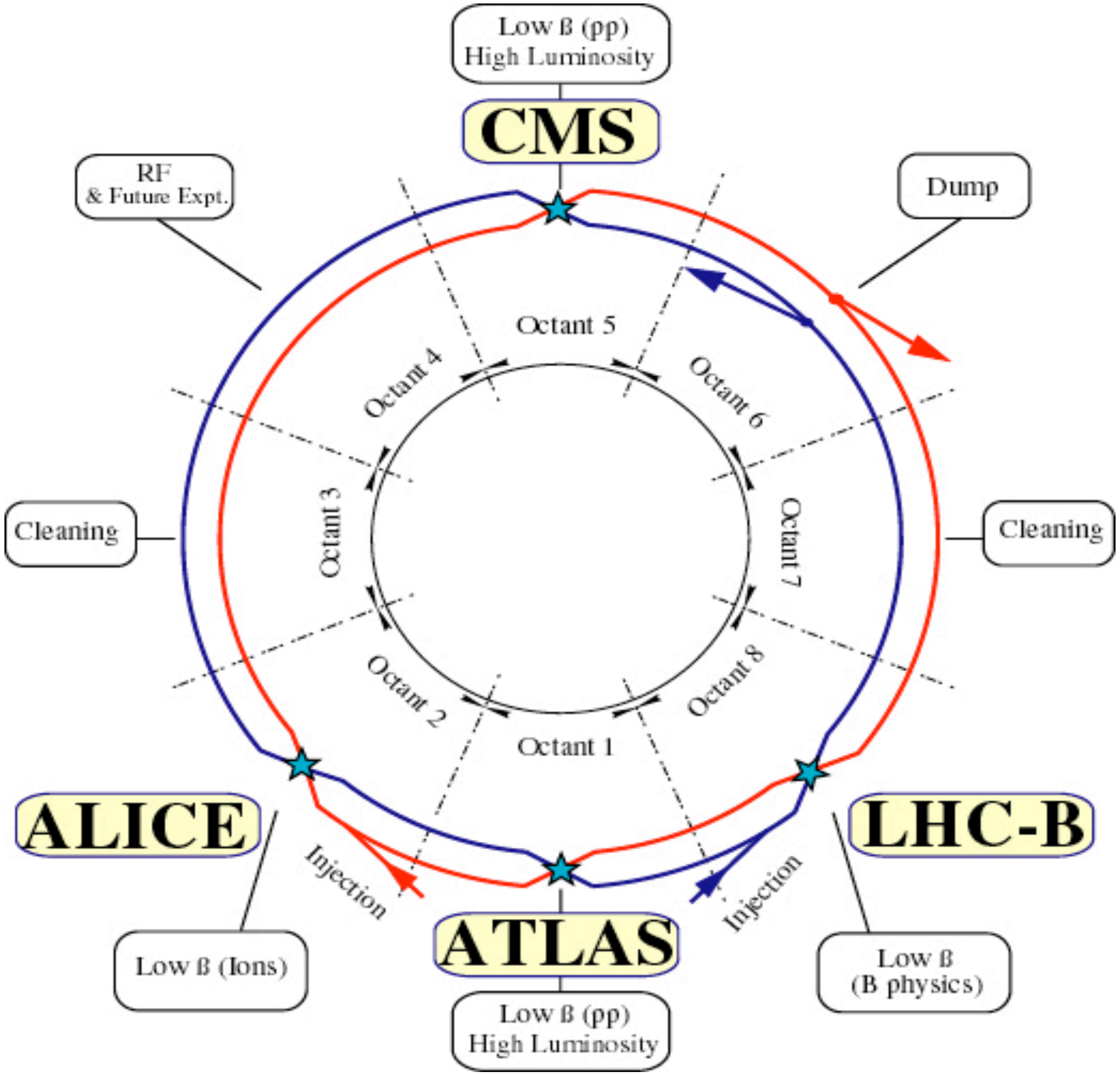
Today's Lecture Contents

- Introduction
- Luminosity upgrade scenario for the LHC machine
- Physics with the SLHC
- Other possible upgrades
- Summary

Your speaker of today

As recorded
by a SSI organizer,
earlier this year

Large Hadron Collider (LHC)



**proton-proton
and ion-ion
collider**

**next energy-frontier
discovery machine**

**c.m. energy 14 TeV
(7x Tevatron)**

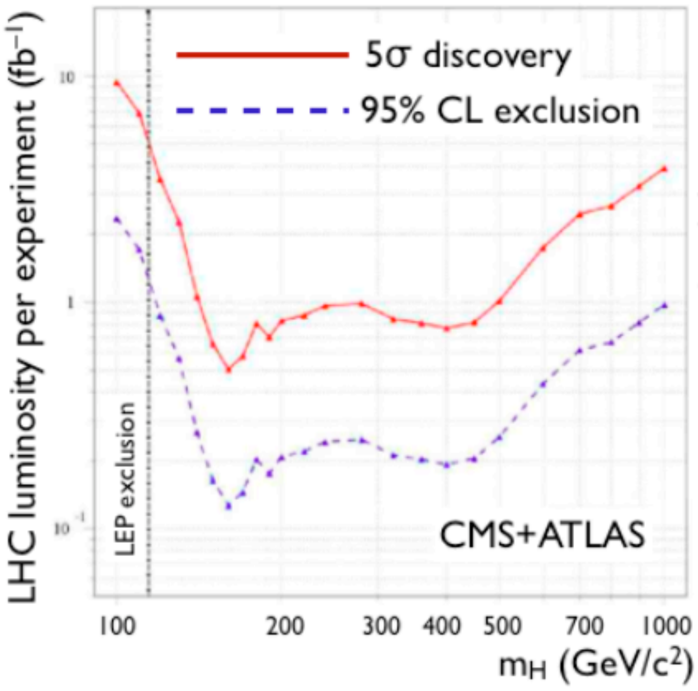
**design pp luminosity
10^{34} cm^{-2}s^{-1}
(~30x Tevatron)**

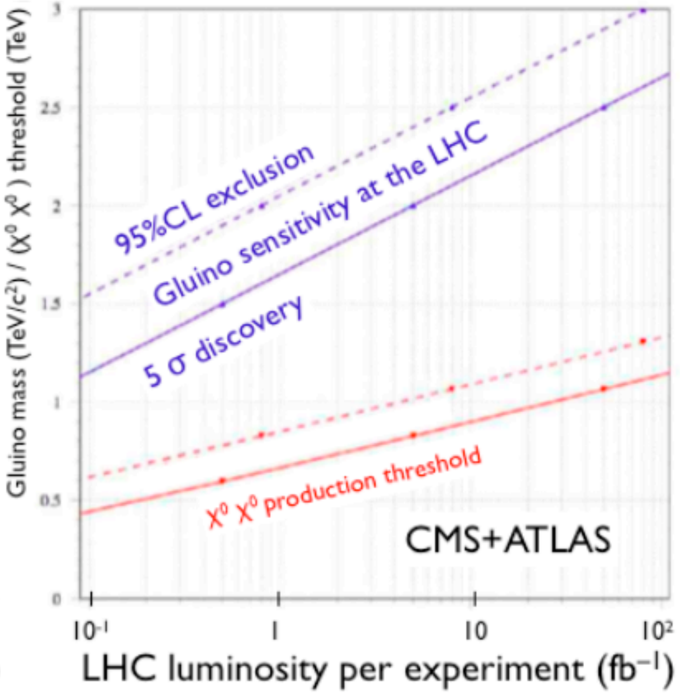
LHC baseline was pushed in competition with SSC (†1993)

What do we expect from LHC?

Say for 10 fb^{-1} :a few good years of LHC running in the early phase

- A SM-like Higgs exists… or not??
- SUSY at the TeV scale?
- Extra Dimensions?
- Other new phenomena in the ~ TeV range? (Z', Leptoquarks,…)

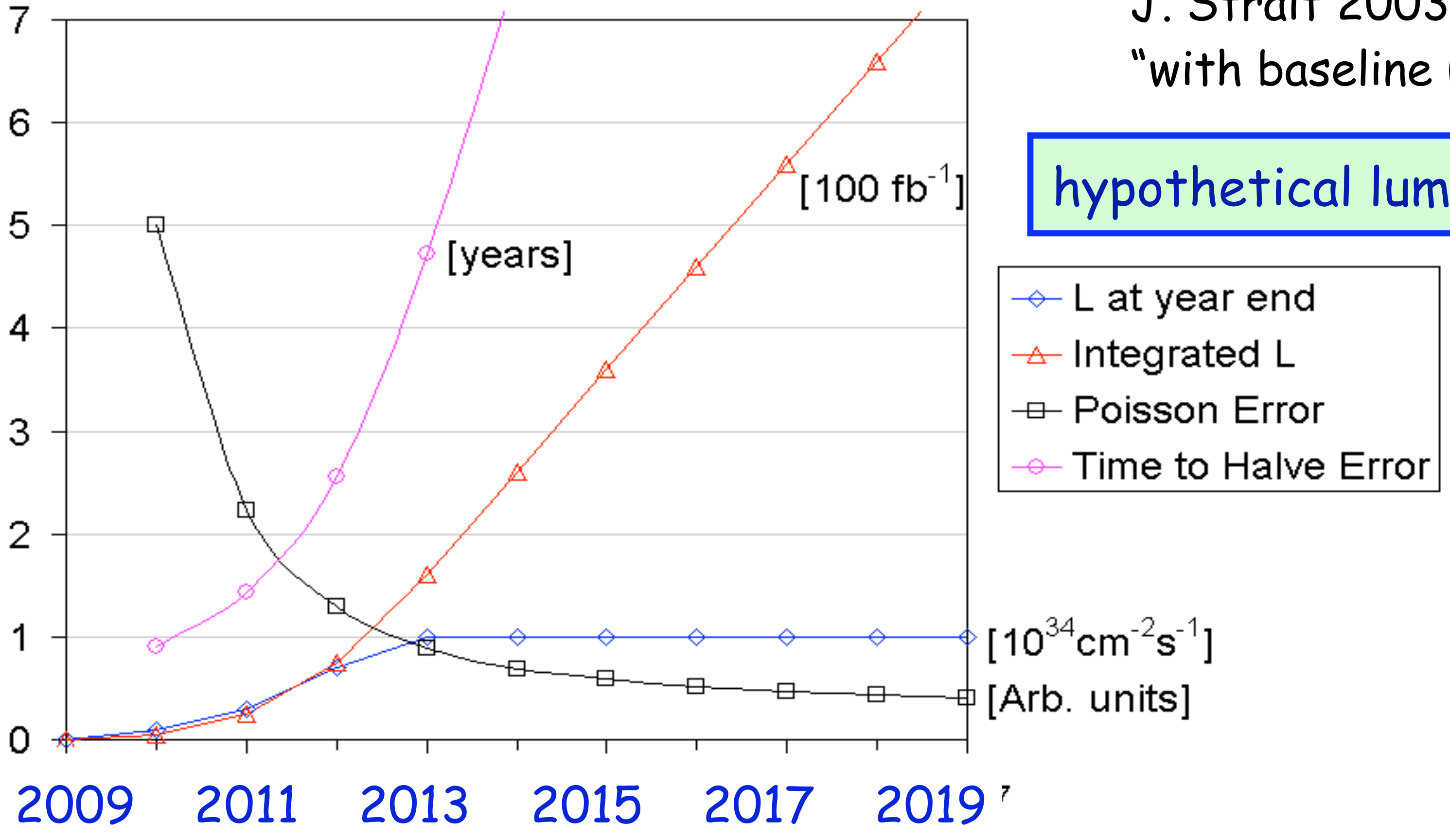




Why Upgrades of the LHC?

J. Strait 2003:
“with baseline updated”

hypothetical lumi scenario



If startup is as optimistic as assumed here (10^{34} cm^{-2}s^{-1} in 2013 already)
⇒After ~3 years the simple continuation becomes less exciting
⇒Time for an upgrade?

The LHC Upgrade

Already time to think of upgrading the machine if wanted in 5-10 years

Two options presently discussed/studied

- Higher luminosity ~10^{35}cm^{-2} s^{-1} (SLHC)
  - Needs changes of the machine and particularly of the detectors
  - ⇒ Start change to SLHC mode some time 2014-2018 (phases)
  - ⇒ Collect ~3000 fb^{-1}/experiment in 3-4 years data taking.

- Higher energy? (DLHC)
  - LHC can reach √s = 15 TeV with present magnets (9T field)
  - √s of 28 (25) TeV needs ~17 (15) T magnets ⇒ R&D needed!
  - Even some ideas on increasing the energy by factor 3 (P. McIntyre)

	Run I √s	Run II √s	Int Lumi (run I)	Int. Lumi (expected/runII)
Tevatron	1.8 TeV	1.96 TeV	100 pb	~6-8fb
HERA	300 GeV	320 GeV	100 pb	~500 pb

SLHC

LHC with 10x higher luminosity
= 10^{35} $cm^{-2}s^{-1}$

Slides from F. Zimmermann/EPS09

LHC Upgrade

SLHC phase I – IR upgrade

- **new Nb-Ti quadrupole triplets** with larger aperture, new separation dipoles, etc
- may allow reaching **b* ~ 0.30 m in IP1 and 5**
- should be completed by **2014**

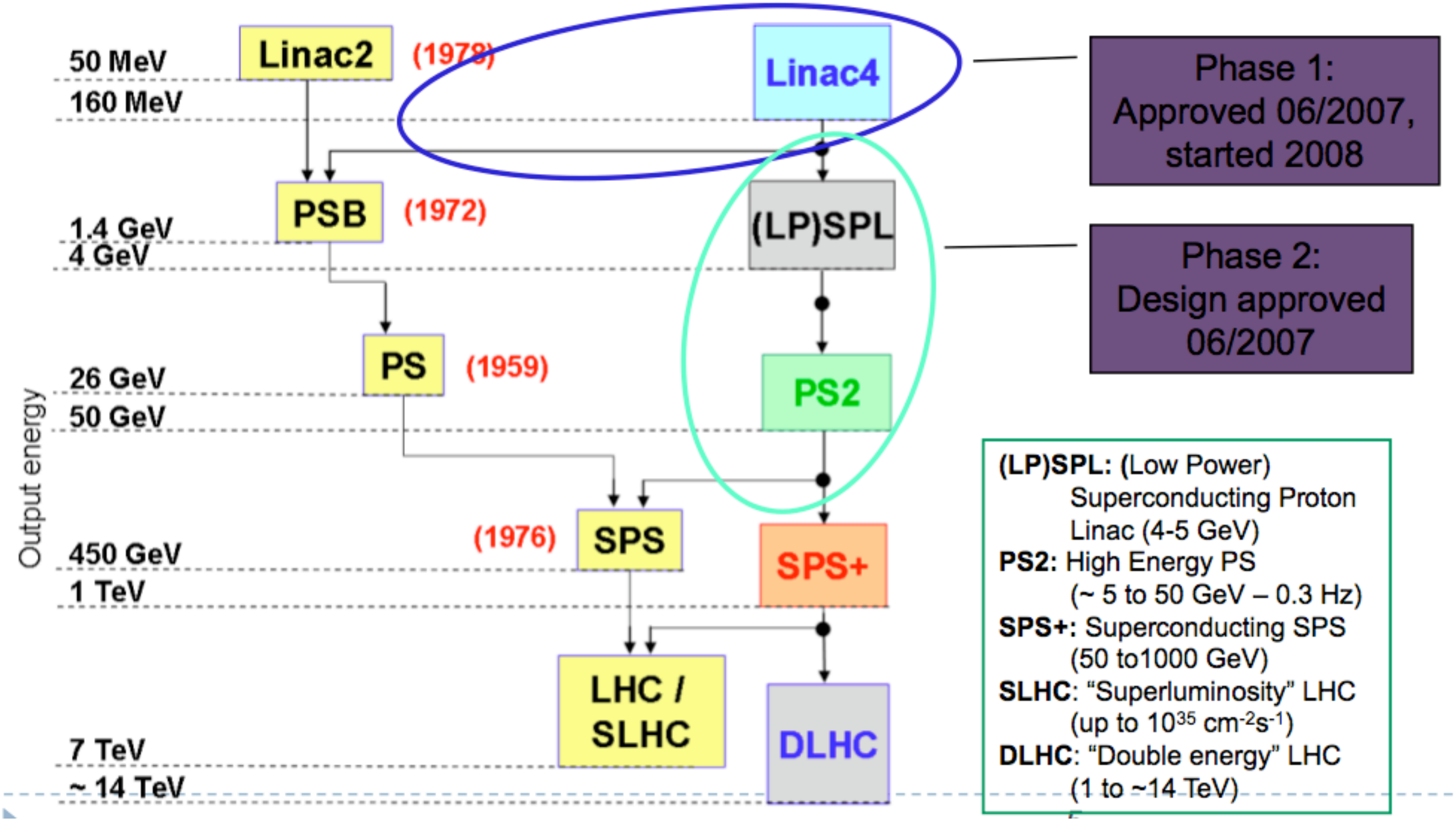
SLHC phase II – IR upgrade

- **Nb_3Sn triplet** with larger aperture providing **b*~0.10-0.15 m**
- **complementary measures**: long-range beam-beam compensation, crab cavities, etc
- realized around **2018-2020**

both phases accompanied by extensive injector upgrades

LHC Injector Upgrade Plans

Motivations: progressively increase the LHC luminosity, increase reliability, simplify operation, reduce radiation, open to new physics applications.



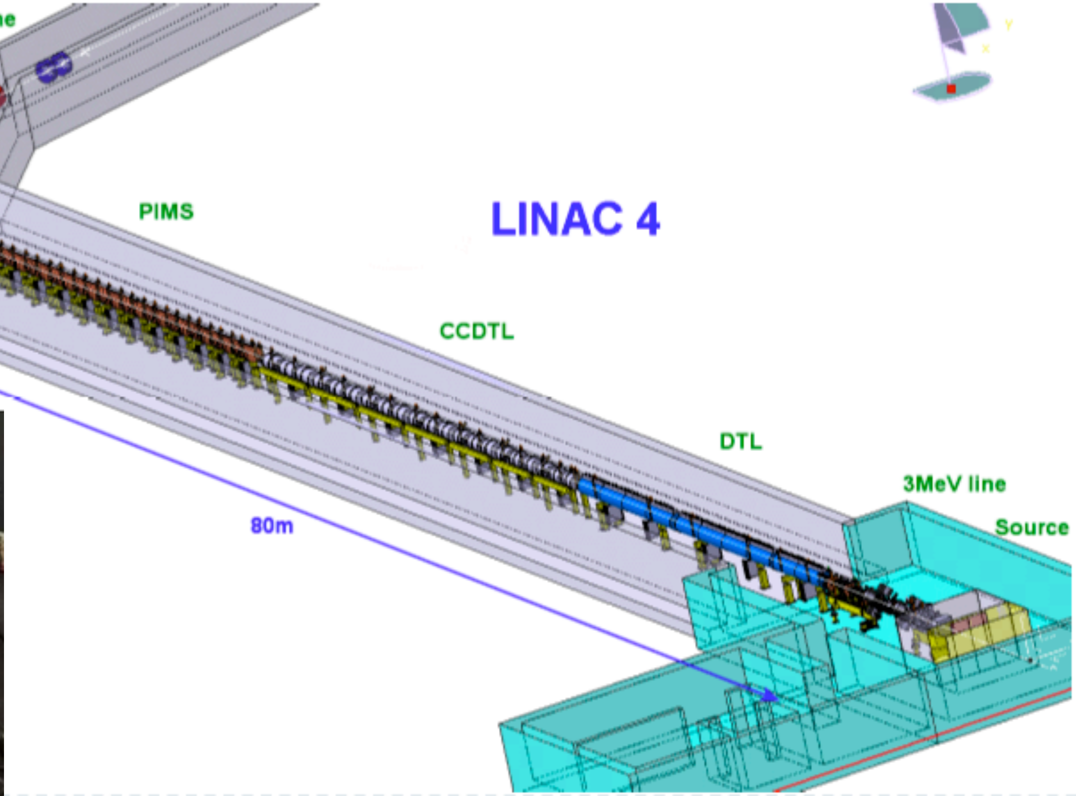
Phase 1: Approved 06/2007, started 2008

Phase 2: Design approved 06/2007

(LP)SPL: (Low Power) Superconducting Proton Linac (4-5 GeV)
PS2: High Energy PS (~ 5 to 50 GeV – 0.3 Hz)
SPS+: Superconducting SPS (50 to1000 GeV)
SLHC: “Superluminosity” LHC (up to 10^{35} cm^{-2}s^{-1})
DLHC: “Double energy” LHC (1 to ~14 TeV)

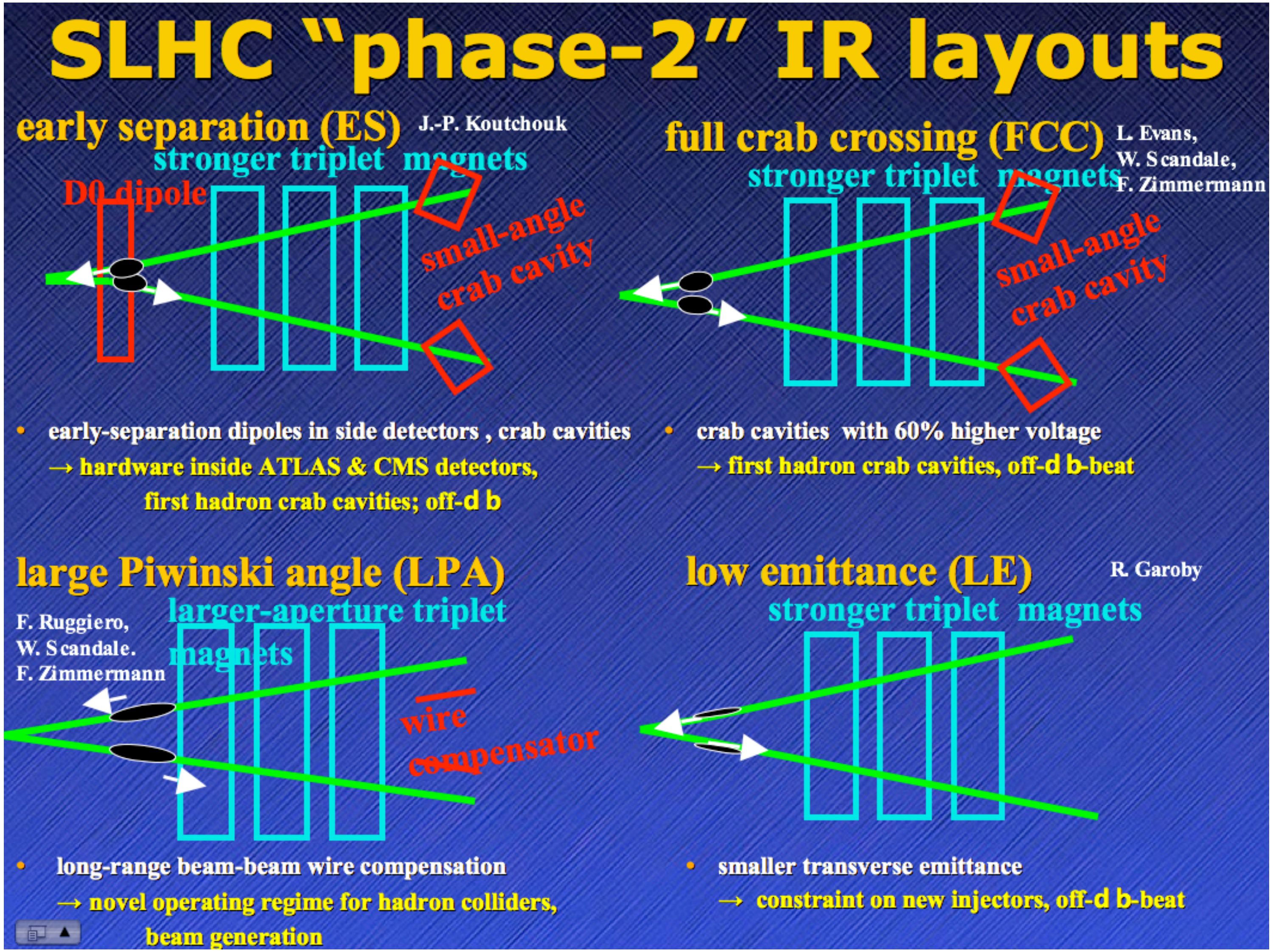
Linac4 Construction Started

- Linac4 is a normal-conducting H⁻ linac at 160 MeV energy that will replace Linac2 as injector to the PSB and can be lately extended to the SPL. Linac4 because the 4th linac to be built at CERN (Linac3 is the heavy-ion linac).
- 160 MeV energy gives a factor 2 in $\beta\gamma^2$ with respect to the present 50 MeV Linac2 → factor 2 increase in bunch density in the PSB → easier production of LHC beam, margin to reach ultimate luminosity



Linac4 Groundbreaking – 16.10.2008

Scenarios to Increase Luminosity



SLHC "phase-2" IR layouts

early separation (ES) J.-P. Koutchouk

- early-separation dipoles in side detectors , crab cavities
  → hardware inside ATLAS & CMS detectors,
  first hadron crab cavities; off-d b

full crab crossing (FCC) L. Evans, W. Scandale, F. Zimmermann

- crab cavities with 60% higher voltage
  → first hadron crab cavities, off-d b-beat

large Piwinski angle (LPA) F. Ruggiero, W. Scandale. F. Zimmermann

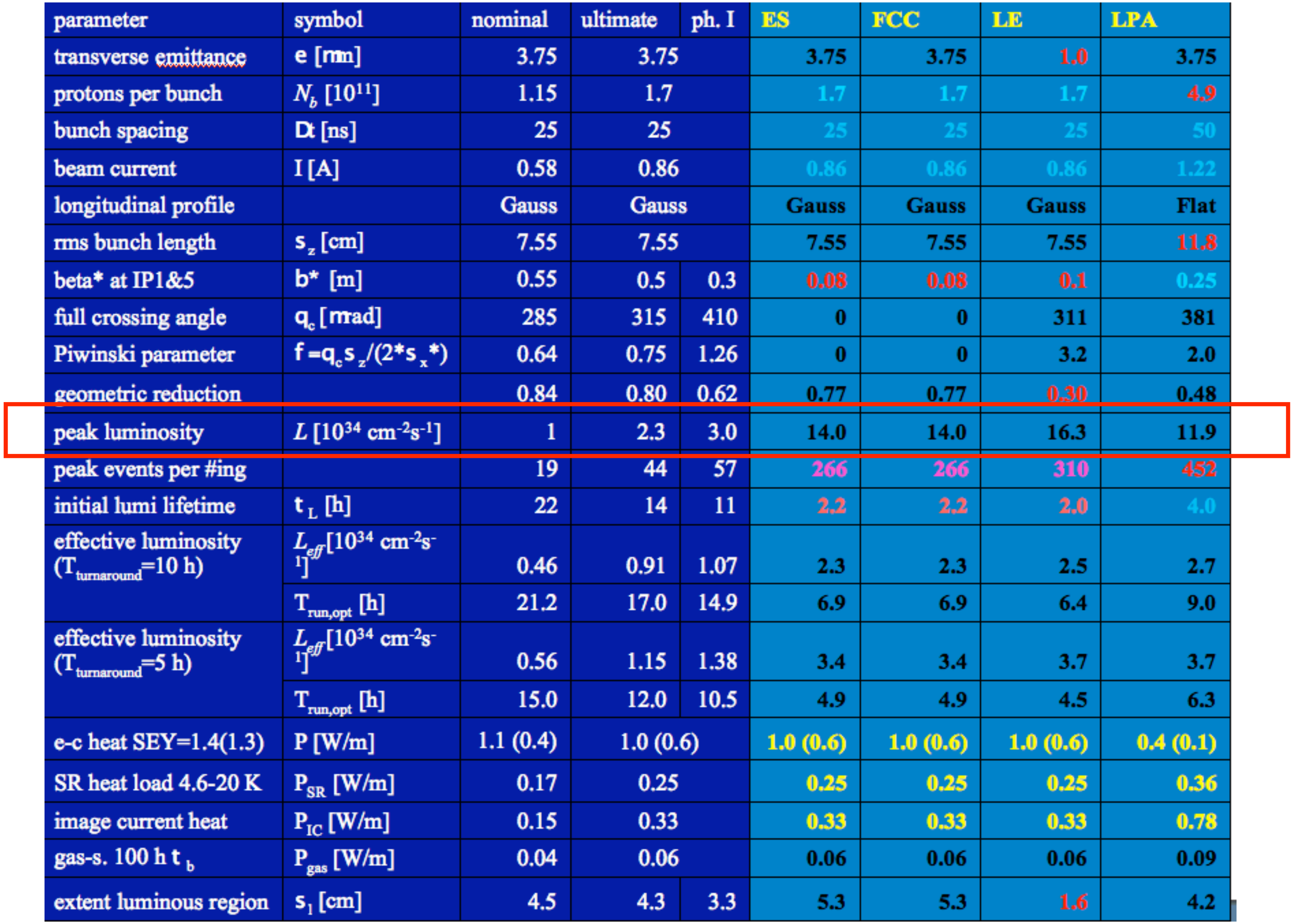
- long-range beam-beam wire compensation
  → novel operating regime for hadron colliders,
  beam generation

low emittance (LE) R. Garoby

- smaller transverse emittance
  → constraint on new injectors, off-d b-beat

LPA and FCC scenarios preferred from pile-up and lumi leveling considerations

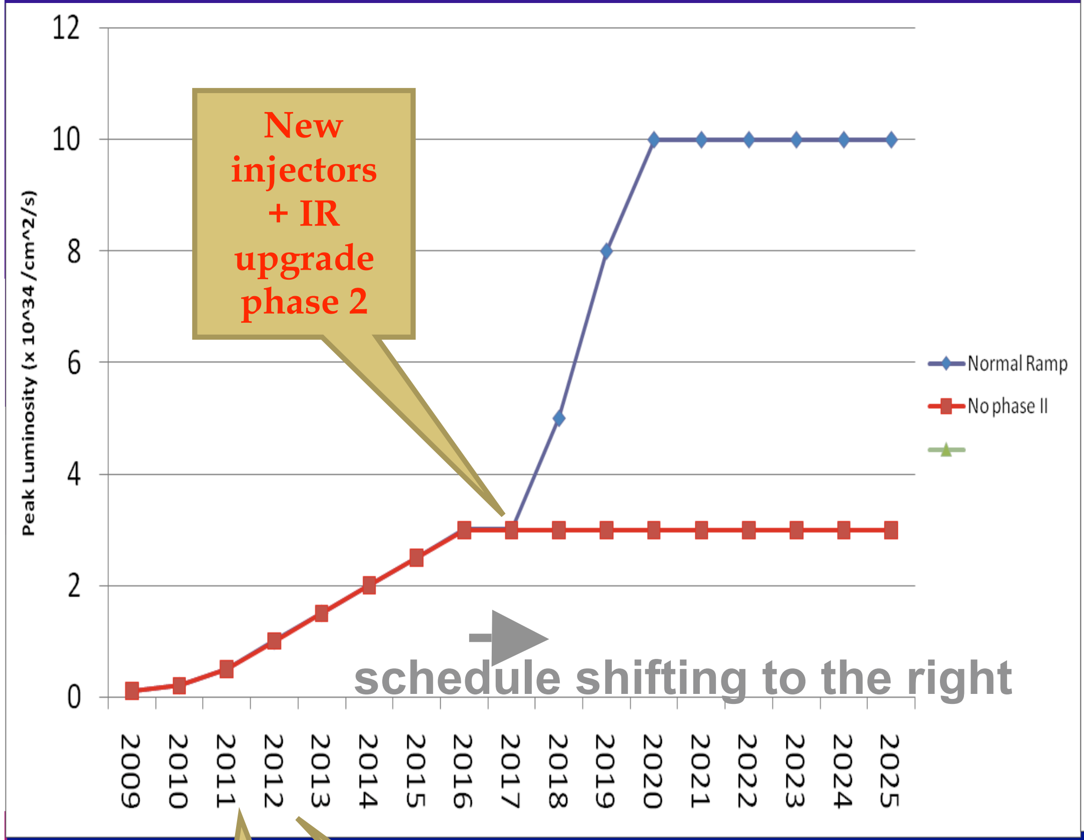
Machine Parameters



parameter	symbol	nominal	ultimate	ph. I	ES	FCC	LE	LPA
transverse emittance	e [mm]	3.75	3.75		3.75	3.75	1.0	3.75
protons per bunch	N_b [10^{11}]	1.15	1.7		1.7	1.7	1.7	4.9
bunch spacing	Dt [ns]	25	25		25	25	25	50
beam current	I [A]	0.58	0.86		0.86	0.86	0.86	1.22
longitudinal profile		Gauss	Gauss		Gauss	Gauss	Gauss	Flat
rms bunch length	s_z [cm]	7.55	7.55		7.55	7.55	7.55	11.8
beta* at IP1&5	b* [m]	0.55	0.5	0.3	0.08	0.08	0.1	0.25
full crossing angle	q_c [mrad]	285	315	410	0	0	311	381
Piwinski parameter	$f=q_c s_z/(2*s_x*)$	0.64	0.75	1.26	0	0	3.2	2.0
geometric reduction		0.84	0.80	0.62	0.77	0.77	0.30	0.48
peak luminosity	L [10^{34} cm^{-2}s^{-1}]	1	2.3	3.0	14.0	14.0	16.3	11.9
peak events per #ing		19	44	57	266	266	310	452
initial lumi lifetime	t_L [h]	22	14	11	2.2	2.2	2.0	4.0
effective luminosity ($T_{turnaround}$=10 h)	L_{eff}[10^{34} cm^{-2}s^{-1}]	0.46	0.91	1.07	2.3	2.3	2.5	2.7
	$T_{run,opt}$ [h]	21.2	17.0	14.9	6.9	6.9	6.4	9.0
effective luminosity ($T_{turnaround}$=5 h)	L_{eff}[10^{34} cm^{-2}s^{-1}]	0.56	1.15	1.38	3.4	3.4	3.7	3.7
	$T_{run,opt}$ [h]	15.0	12.0	10.5	4.9	4.9	4.5	6.3
e-c heat SEY=1.4(1.3)	P [W/m]	1.1 (0.4)	1.0 (0.6)		1.0 (0.6)	1.0 (0.6)	1.0 (0.6)	0.4 (0.1)
SR heat load 4.6-20 K	P_{SR} [W/m]	0.17	0.25		0.25	0.25	0.25	0.36
image current heat	P_{IC} [W/m]	0.15	0.33		0.33	0.33	0.33	0.78
gas-s. 100 h t_b	P_{gas} [W/m]	0.04	0.06		0.06	0.06	0.06	0.09
extent luminous region	s_l [cm]	4.5	4.3	3.3	5.3	5.3	1.6	4.2

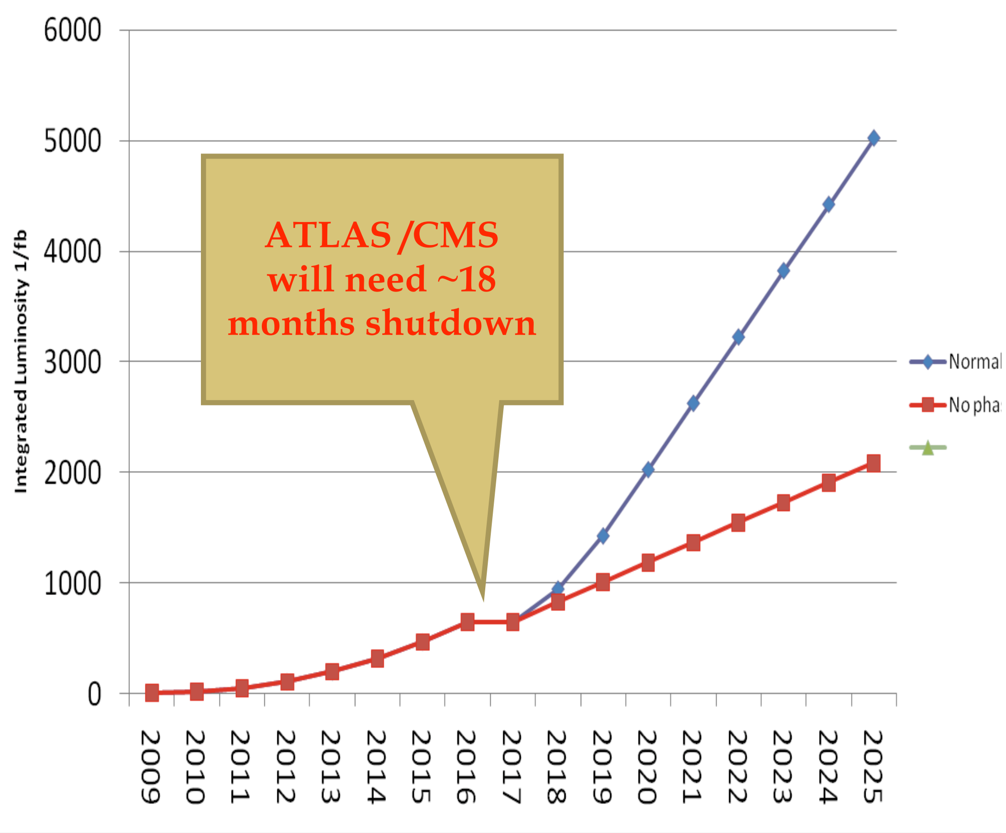
Peak luminosities for all schemes larger than 10^{35}cm^{-2}s^{-1}

Luminosity with Time



New injectors + IR upgrade phase 2

schedule shifting to the right



ATLAS /CMS will need ~18 months shutdown

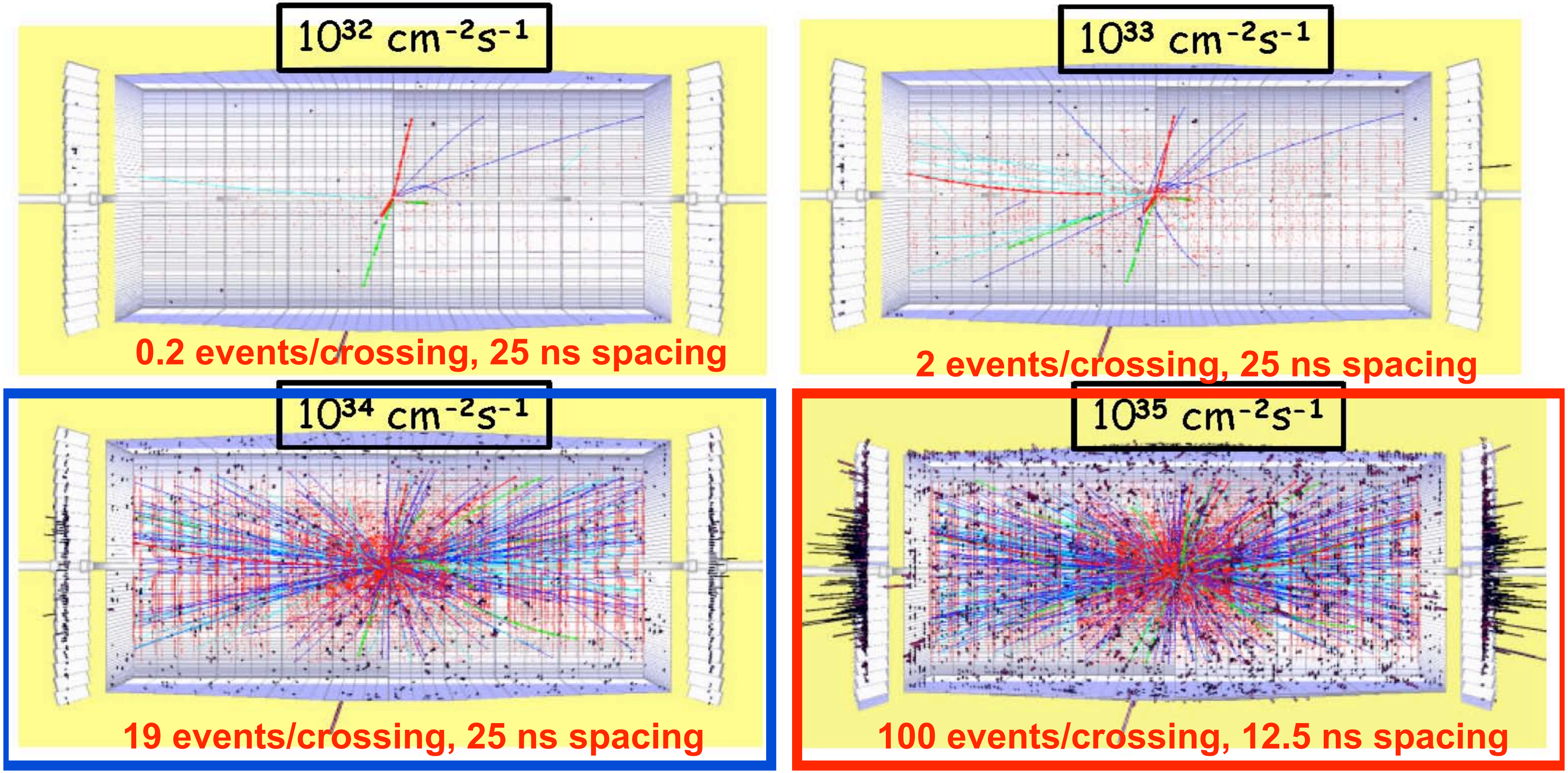
Collimation phase 2

Linac4 + IR upgrade phase 1

For Phase 2 the detectors will need upgrading (tracker, trigger, electronics…)

M. Nessi, R. Garoby, 2008

Event Pile-up!!



$10^{32}\ cm^{-2}s^{-1}$

0.2 events/crossing, 25 ns spacing

$10^{33}\ cm^{-2}s^{-1}$

2 events/crossing, 25 ns spacing

$10^{34}\ cm^{-2}s^{-1}$

19 events/crossing, 25 ns spacing

$10^{35}\ cm^{-2}s^{-1}$

100 events/crossing, 12.5 ns spacing

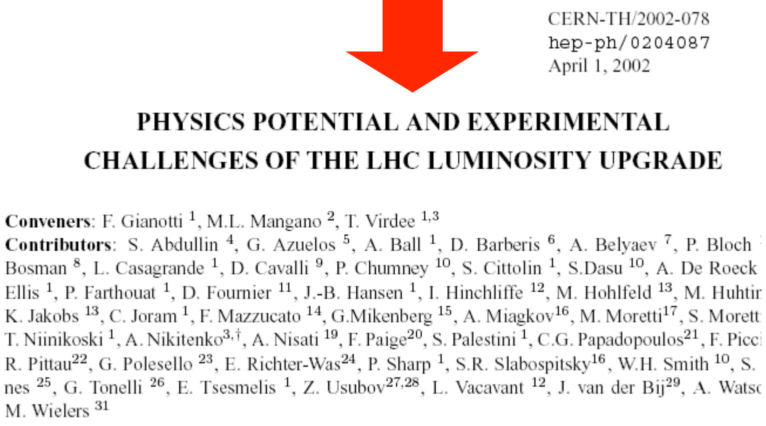
$H \rightarrow ZZ \rightarrow \mu\mu ee$ event with M_H= 300 GeV for different luminosities

$p_t > 1$ GeV/c cut, i.e. all soft tracks removed

Extending the Physics Potential of LHC

- Electroweak Physics
  - Production of multiple gauge bosons ($n_V \geq 3$)
    - triple and quartic gauge boson couplings
  - Top quarks/rare decays
- Higgs physics
  - Rare decay modes
  - Higgs couplings to fermions and bosons
  - Higgs self-couplings
  - Heavy Higgs bosons of the MSSM
- Supersymmetry
- Extra Dimensions
  - Direct graviton production in ADD models
  - Resonance production in Randall-Sundrum models TeV^{-1} scale models
  - Black Hole production
- Quark substructure
- Strongly-coupled vector boson system
  - $W_L Z_L$ g $W_L Z_L$, $Z_L Z_L$ scalar resonance, $W^{+}_{L} W^{+}_{L}$
- New Gauge Bosons

Examples studied in some detail



CERN-TH/2002-078
hep-ph/0204087
April 1, 2002

PHYSICS POTENTIAL AND EXPERIMENTAL
CHALLENGES OF THE LHC LUMINOSITY UPGRADE

Conveners: F. Gianotti [1], M.L. Mangano [2], T. Virdee [1,3]
Contributors: S. Abdullin [4], G. Azuelos [5], A. Ball [1], D. Barberis [6], A. Belyaev [7], P. Bloch
Bosman [8], L. Casagrande [1], D. Cavalli [9], P. Chumney [10], S. Cittolin [1], S.Dasu [10], A. De Roeck
Ellis [1], P. Farthouat [1], D. Fournier [11], J.-B. Hansen [1], I. Hinchliffe [12], M. Hohlfeld [13], M. Huhtir
K. Jakobs [13], C. Joram [1], F. Mazzucato [14], G.Mikenberg [15], A. Miagkov[16], M. Moretti[17], S. Morett
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R. Pittau[22], G. Polesello [23], E. Richter-Was[24], P. Sharp [1], S.R. Slabospitsky[16], W.H. Smith [10], S.
nes [25], G. Tonelli [26], E. Tsesmelis [1], Z. Usubov[27,28], L. Vacavant [12], J. van der Bij[29], A. Watsc
M. Wielers [31]

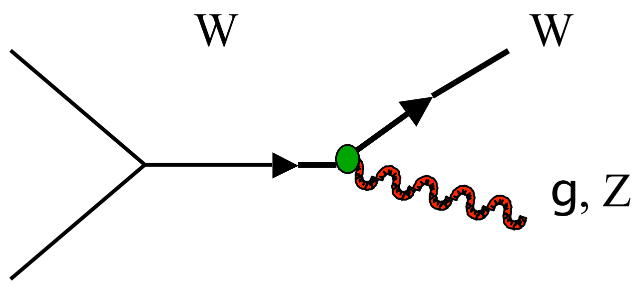
Include pile up, detector…

hep-ph/0204087

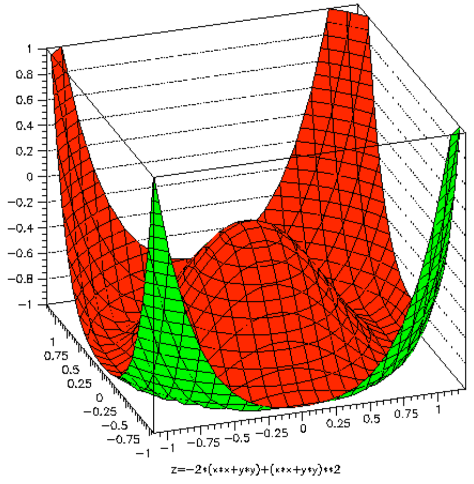
Standard Model Physics

Precision measurements of Standard Model processes and parameters

⇒ Deviations of expectations can point to new physics or help to understand new observed phenomena



TGCs
Rare top decays
Higgs
…

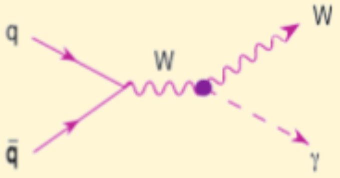


S. Dawson Lectures

Triple/Quartic Gauge Couplings

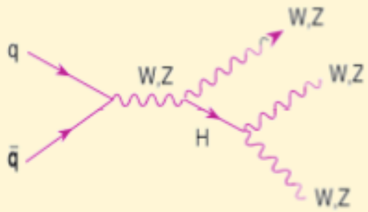
Precise determinations of the self-couplings of EW gauge bosons

5 parameters describing weak and EM dipole and quadrupole moments of gauge bosons. The SM predicts their value with accuracies at the level of **10^{-3}**, which is therefore the goal of the required experimental precision



LHC options

Coupling	14 TeV 100 fb^{-1}	14 TeV 1000 fb^{-1}	28 TeV 100 fb^{-1}	28 TeV 1000 fb^{-1}	LC 500 fb^{-1}, 500 GeV
λ_γ	0.0014	0.0006	0.0008	0.0002	0.0014
λ_Z	0.0028	0.0018	0.0023	0.009	0.0013
$\Delta\kappa_\gamma$	0.034	0.020	0.027	0.013	0.0010
$\Delta\kappa_Z$	0.040	0.034	0.036	0.013	0.0016
g^Z_1	0.0038	0.0024	0.0023	0.0007	0.0050



W, Z fusion/scattering :

(LO rates, CTEQ5M, k ~ 1.5 expected for these final states)

Process	WWW	WWZ	ZZW	ZZZ	WWWW	WWWZ
N(m_H = 120 GeV)	2600	1100	36	7	5	0.8
N(m_H = 200GeV)	7100	2000	130	33	20	1.6

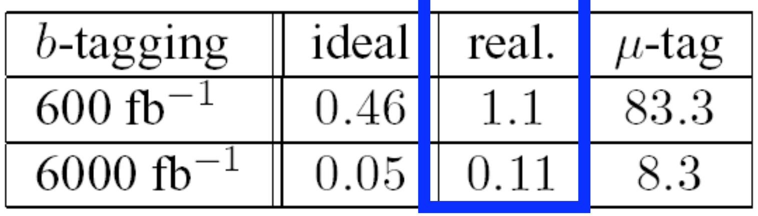
Top Quark Rare Decays

SLHC statistics can still help for rare decays searches

$t \to q\gamma$

b-tagging	ideal	real.	μ-tag
600 fb^{-1}	0.48	0.88	3.76
6000 fb^{-1}	0.14	0.26	0.97

$t \to qZ$



b-tagging	ideal	real.	μ-tag
600 fb^{-1}	0.46	1.1	83.3
6000 fb^{-1}	0.05	0.11	8.3

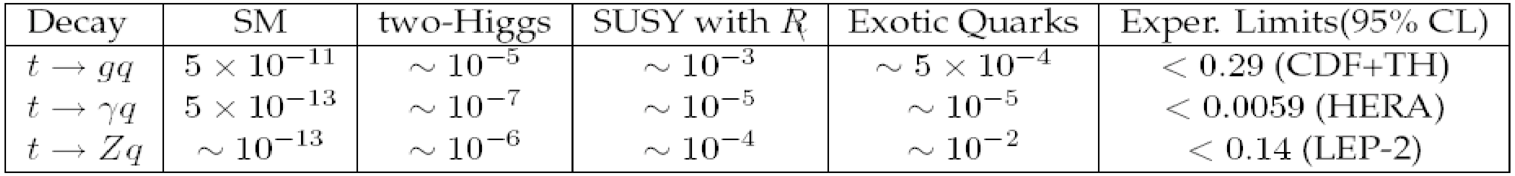
Results in units of 10^{-5}

Ideal = MC 4-vector

Real = b-tagging/cuts as for $10^{34}\text{cm}^{-2}\text{s}^{-1}$

μ-tag = assume only B-tag with muons works at $10^{35}\text{cm}^{-2}\text{s}^{-1}$

Can reach sensitivity down to ~10^{-6} BUT vertex b-tag a must at $10^{35}\text{cm}^{-2}\text{s}^{-1}$

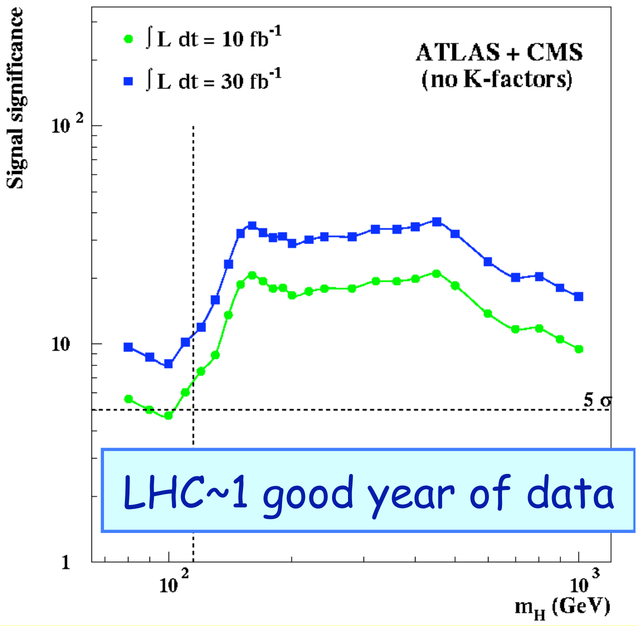


Decay	SM	two-Higgs	SUSY with $\not{R}$	Exotic Quarks	Exper. Limits(95% CL)
$t \to gq$	5×10^{-11}	$\sim 10^{-5}$	$\sim 10^{-3}$	$\sim 5 \times 10^{-4}$	< 0.29 (CDF+TH)
$t \to \gamma q$	5×10^{-13}	$\sim 10^{-7}$	$\sim 10^{-5}$	$\sim 10^{-5}$	< 0.0059 (HERA)
$t \to Zq$	$\sim 10^{-13}$	$\sim 10^{-6}$	$\sim 10^{-4}$	$\sim 10^{-2}$	< 0.14 (LEP-2)

The Higgs at the LHC (SM)

- First step
  - Discover a new Higgs-like particle at the LHC, or exclude its existence
- Second step
  - Measure properties of the new particle to prove it is the Higgs
    - Measure the Higgs mass
    - Measure the Higgs width
    - Measure cross sections x branching ratios
    - Ratios of couplings to particles (~$m_{particle}$)
    - Composite or elementary Higgs?
    - Measure decays with low Branching ratios (e.g $H \rightarrow \mu\mu$)
    - Measure CP and spin quantum numbers (scalar particle?)
    - Measure the Higgs self-coupling ($H \rightarrow HH$), reconstruct the Higgs potential

SLHC added value



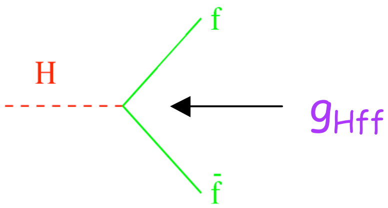
LHC~1 good year of data

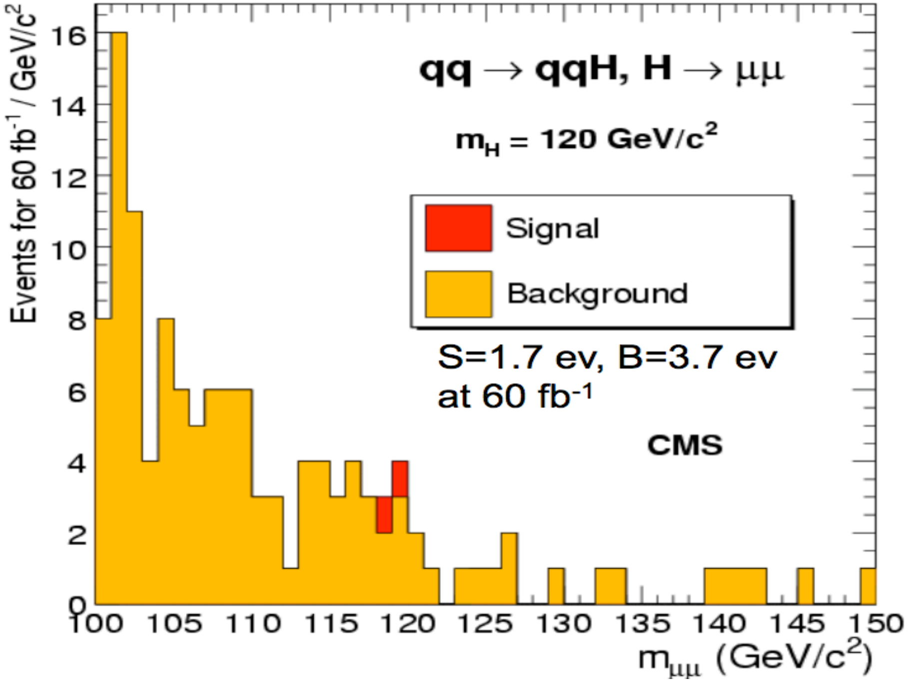
Higgs Decays Modes

Rare Higgs Decays

Channels studied:

- $H \rightarrow Z\gamma \rightarrow \ell\ell\gamma$
- $H \rightarrow \mu\mu$





Branching ratio ~ 10^{-4} for these channels!
Cross section ~ few fb

Channel	m_H	$S/\sqrt{B}$ LHC ($600\ fb^{-1}$)	$S/\sqrt{B}$ SLHC ($6000\ fb^{-1}$)
$H \rightarrow Z\gamma \rightarrow \ell\ell\gamma$	~ 140 GeV	~ 3.5	~ 11
$H \rightarrow \mu\mu$	130 GeV	~ 3.5 (gg+VBF)	~ 9.5 (gg)

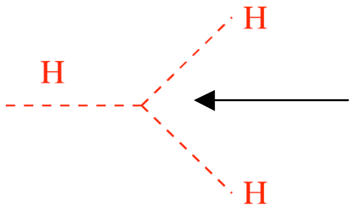
Higgs Couplings (ratios)

Can be improved with a factor of 2: 20%→10% at SLHC

Higgs Self Coupling Measurements

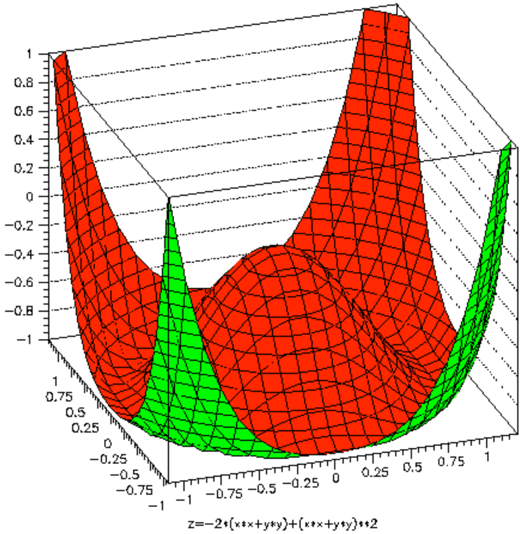
Once the Higgs particle is found, try to reconstruct the Higgs potential

$$\boxed{V(\Phi) = -\lambda v^2(\Phi^\dagger\Phi) + \lambda(\Phi^\dagger\Phi)^2}$$

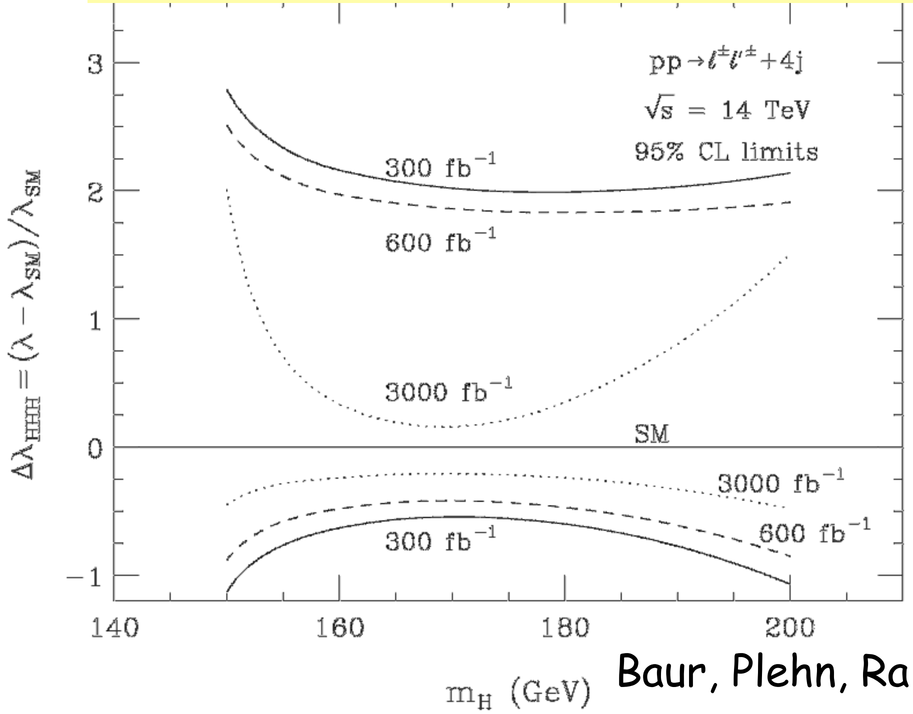


~ λv

$m_H^2 = 2\lambda v^2$



$HH \to W^+ W^- W^+ W^- \to \ell^\pm \nu jj\ \ \ell^\pm \nu jj$

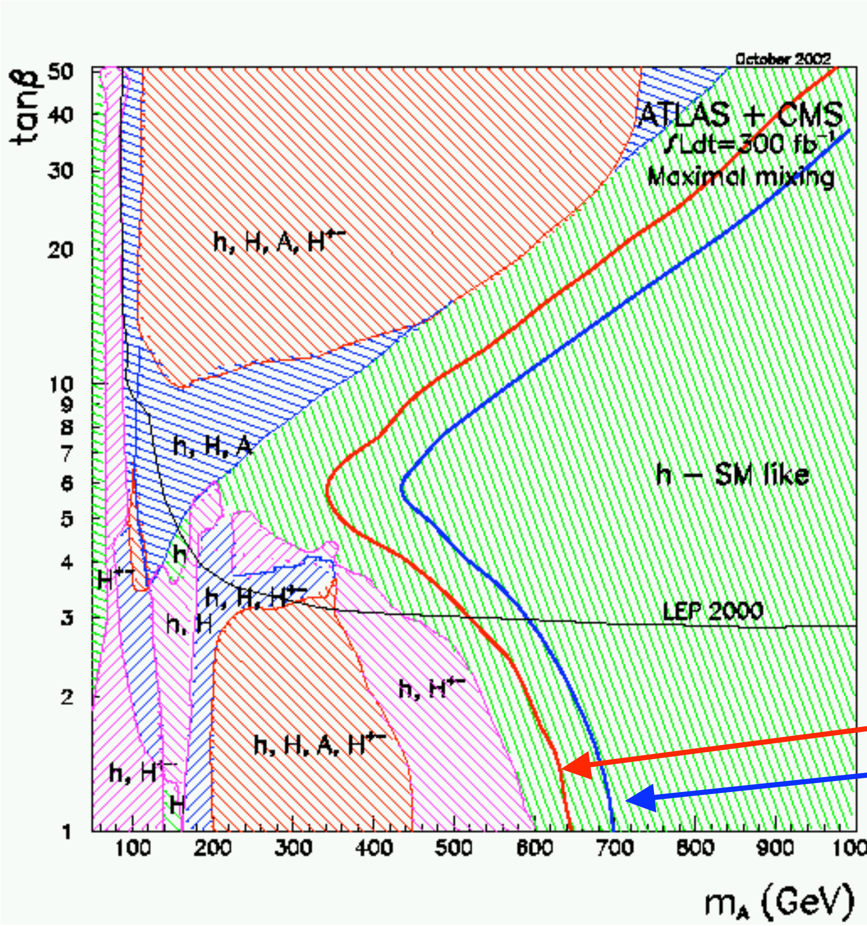


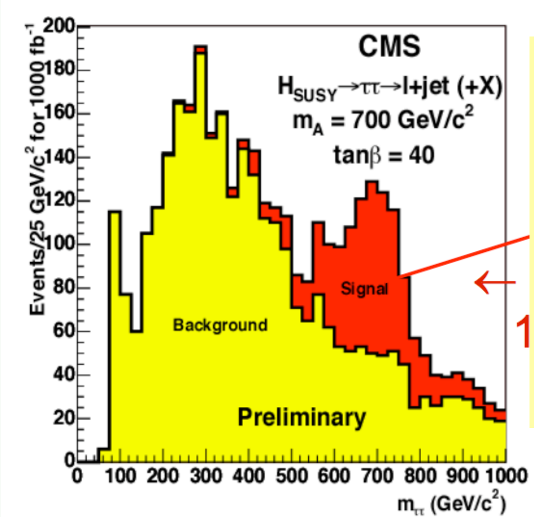
Baur, Plehn, Rainwater

- LHC: $\lambda = 0$ can be excluded at 95% CL.
- SLHC: λ can be determined to 20-30% (95% CL)

Note: Different conclusion from ATLAS study ⇒Jury is still out

SUSY Higgs Particles: h,H,A,H±





Dominated in the green wedge by signal/background.
⇒ Increase in statistics helps!!

In the green region only SM-like h observable with 300 fb^{-1}/exp

Red line: extension with 3000 fb^{-1}/exp

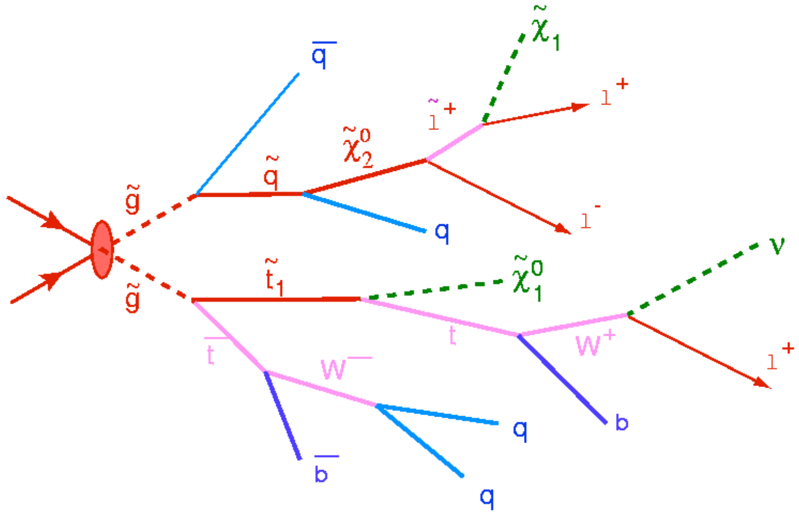
Blue line: 95% excl. with 3000 fb^{-1}/exp

Heavy Higgs reach increased by ~100 GeV at the SLHC.

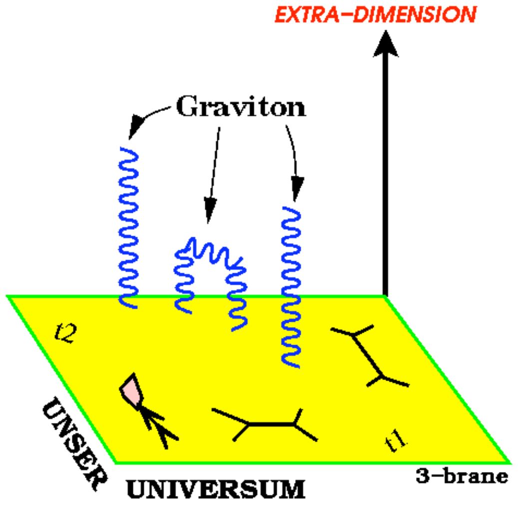
Beyond the Standard Model

New physics expected around the TeV scale ⇒
Stabelize Higgs mass, Hierarchy problem, Unification of gauge couplings, CDM,…

Supersymmetry



Extra dimensions



+…

Wacker, Incandela
Lectures

+ a lot of other ideas…
Little Higgs models, new gauge bosons, hidden valleys, technicolor, compositness, unparticles…

Supersymmetry Reach: LHC and SLHC

Impact of the SLHC

Extending the discovery region for squarks and gluinos by roughly 0.5 TeV i.e. from

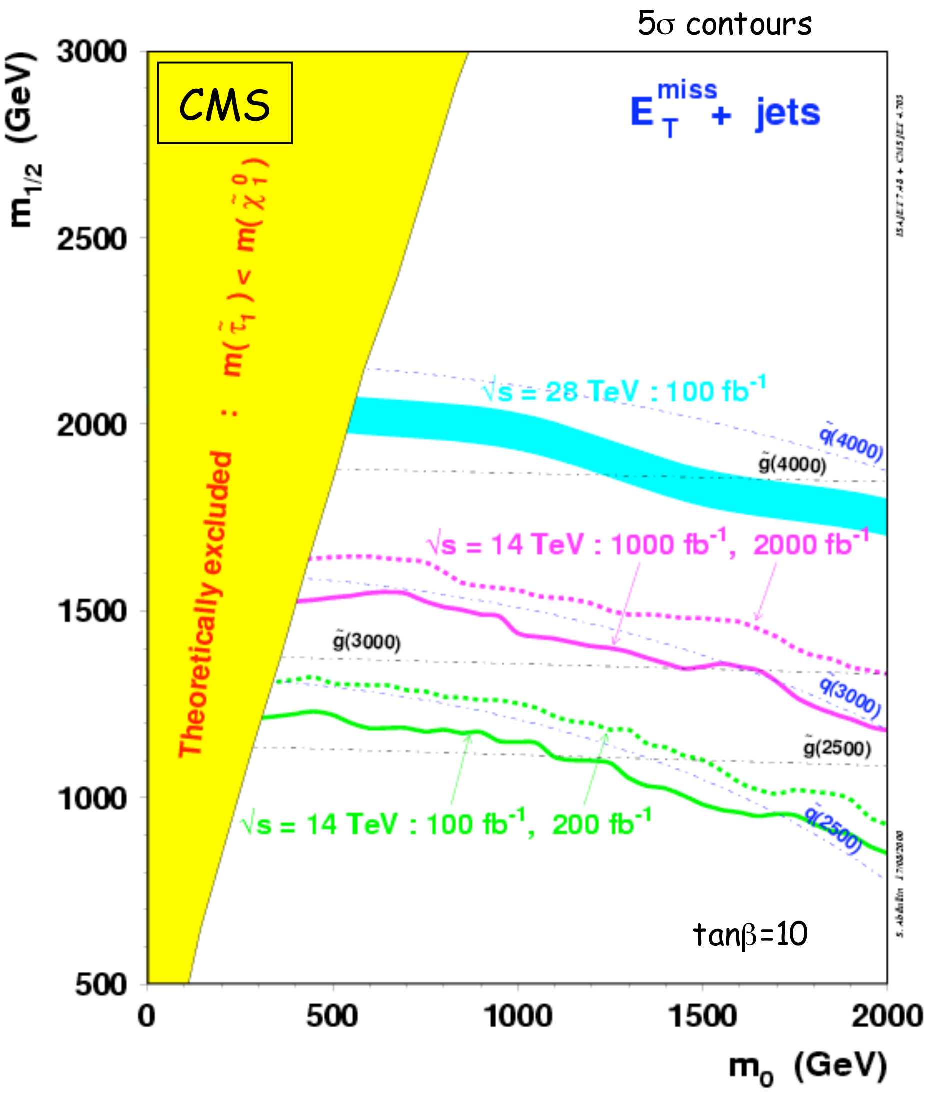
~2.5 TeV → 3 TeV

This extension involved high E_T jets/leptons and large missing E_T

⇒ Not much compromised by increased pile-up at SLHC

$m_{1/2}$: universal gaugino mass at GUT scale

m_0: universal scalar mass at GUT scale



SLHC: tackle difficult SUSY scenarios

Squarks: 2.0-2.4 TeV Gluino: 2.5 TeV

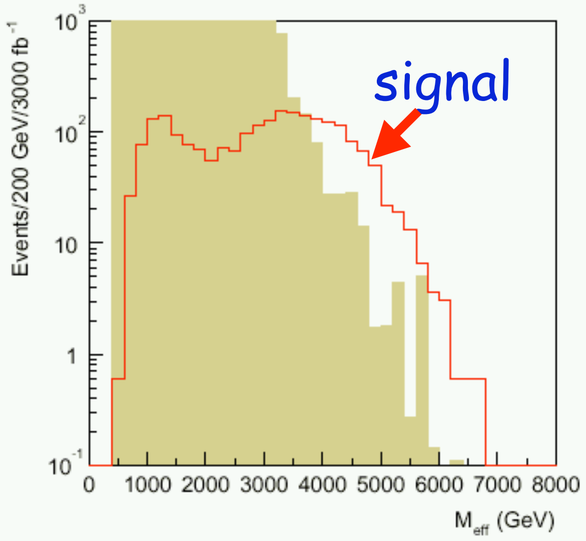
Can discover the squarks at the LHC but cannot really study them

$$M_{eff} = E_T^{miss} + \sum_{jets} E_{T,jet} + \sum_{leptons} E_{T,lepton}$$

P_t >700 GeV & E_t^{miss}>600 GeV

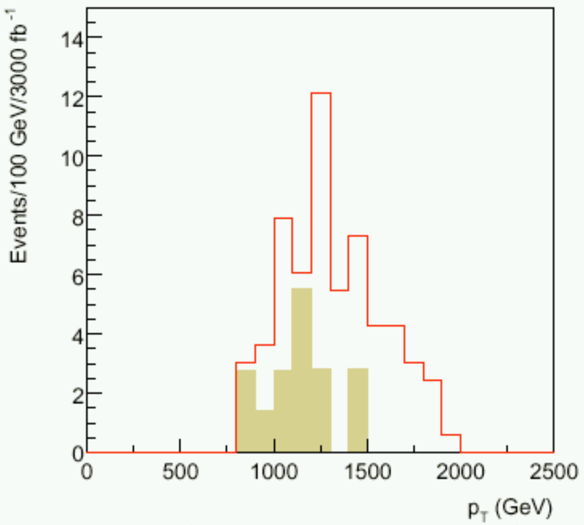
P_t of the hardest jet

eg. Benchmark Point K in hep-ph/0306219



Inclusive: M_{eff} > 4000 GeV

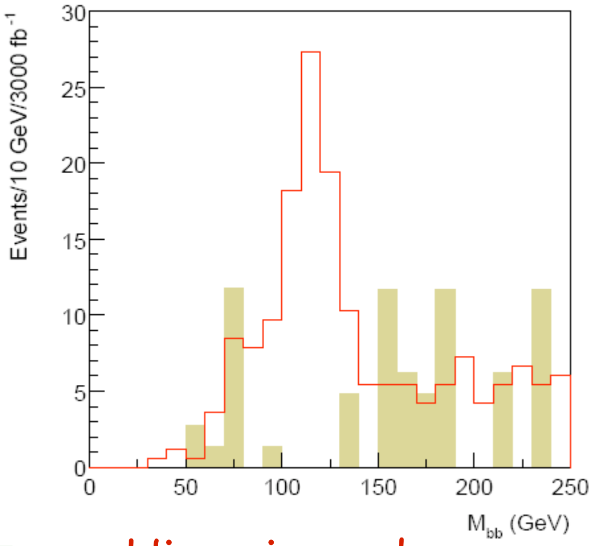
S/B = 500/100 (3000 fb^{-1})



Exclusive channel

$\tilde{q}\tilde{q} \rightarrow \chi_1^0 \chi_1^0 qq$

S/B =120/30 (3000fb^{-1})



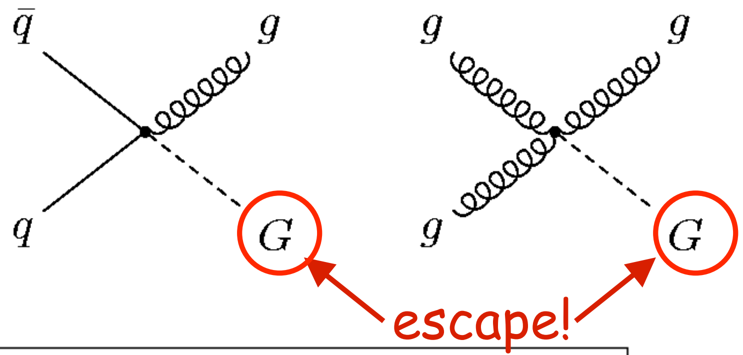
Higgs in χ_2 decay

$\chi_2 \rightarrow \chi_1 h$ becomes

Visible at 3000 fb^{-1}

Measurements of some difficult scenarios become possible at the SLHC

Extra Dimension Signals at the LHC

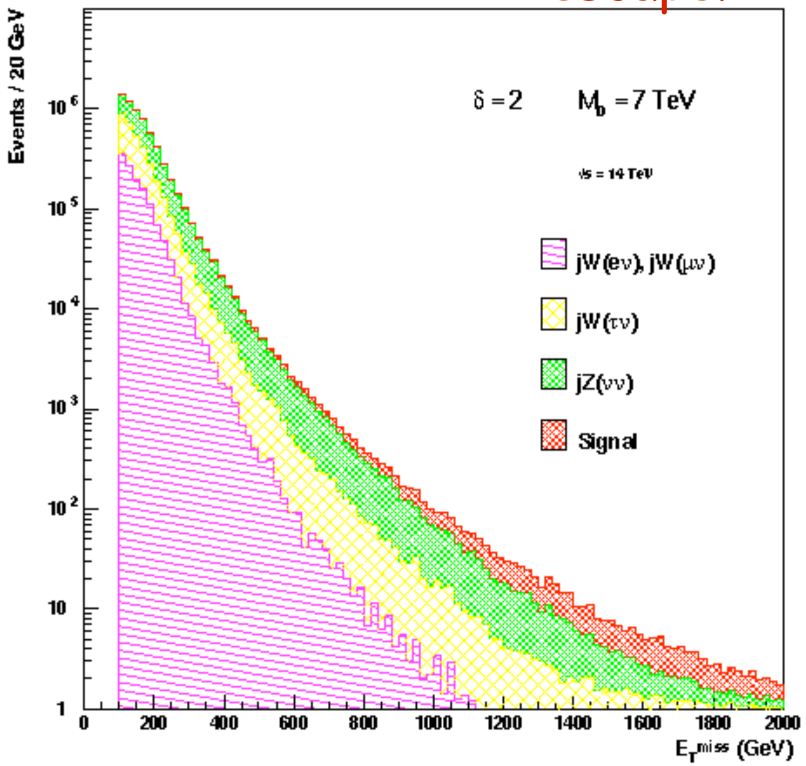


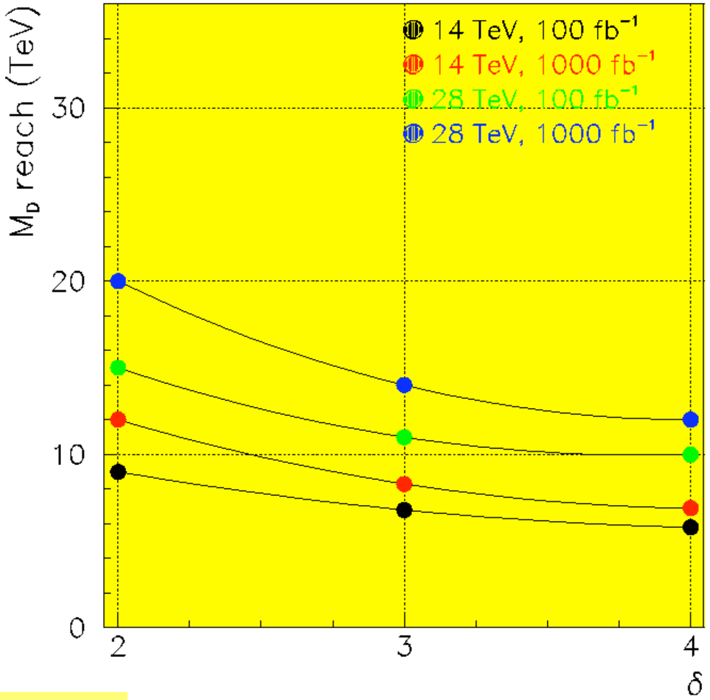
Example

Graviton production!
Graviton escapes detection

Large (ADD) type of Extra Dimensions

Signal: single jet + large missing ET





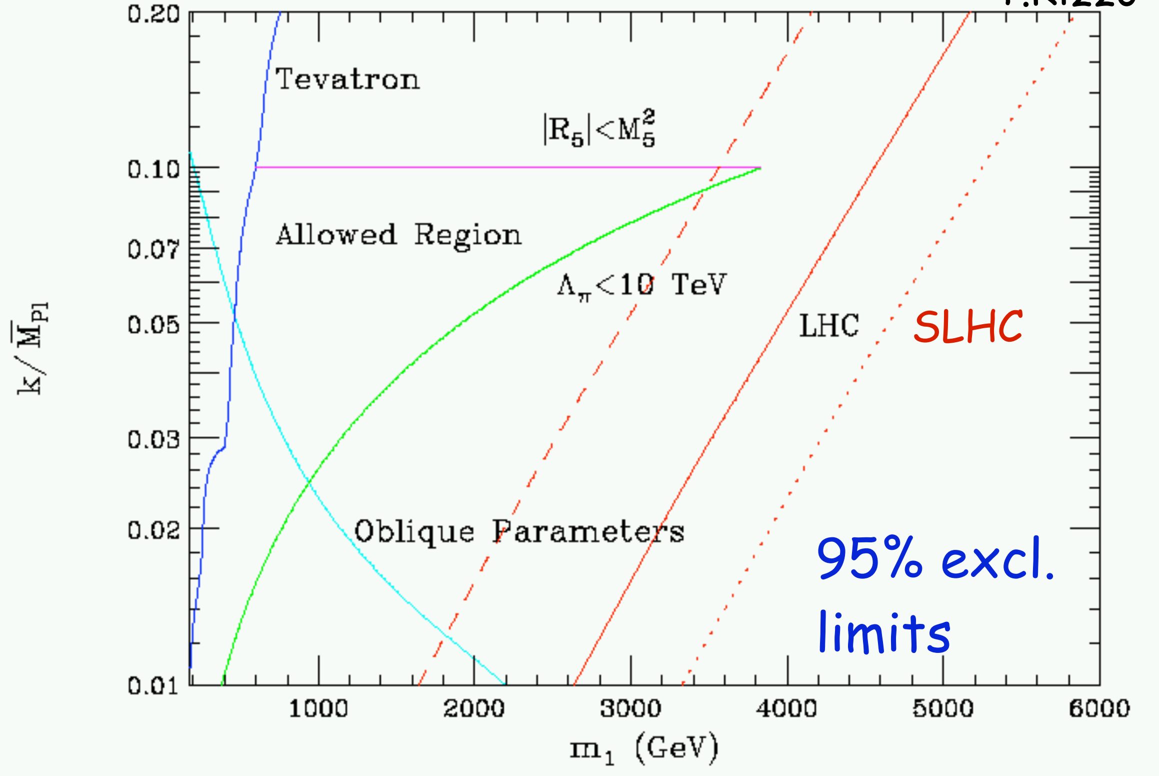
About 25% increase in reach

SLHC: KK Gravitons

Randall Sundrum model

- Predicts KK graviton resonances
- k= curvature of the 5-dim. Space
- m_1 = mass of the first KK state

T.Rizzo

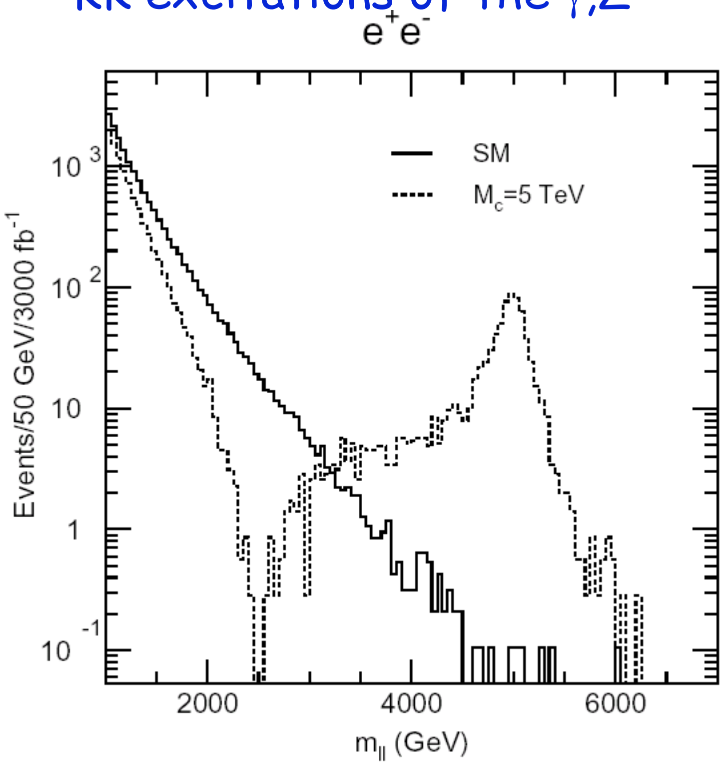


95% excl. limits

100→1000 fb^{-1}: Increase in reach by 25%

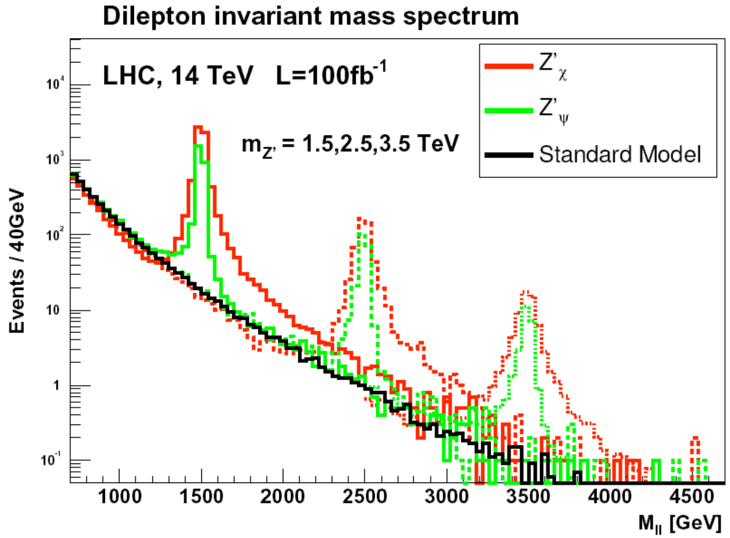
TeV scale ED's

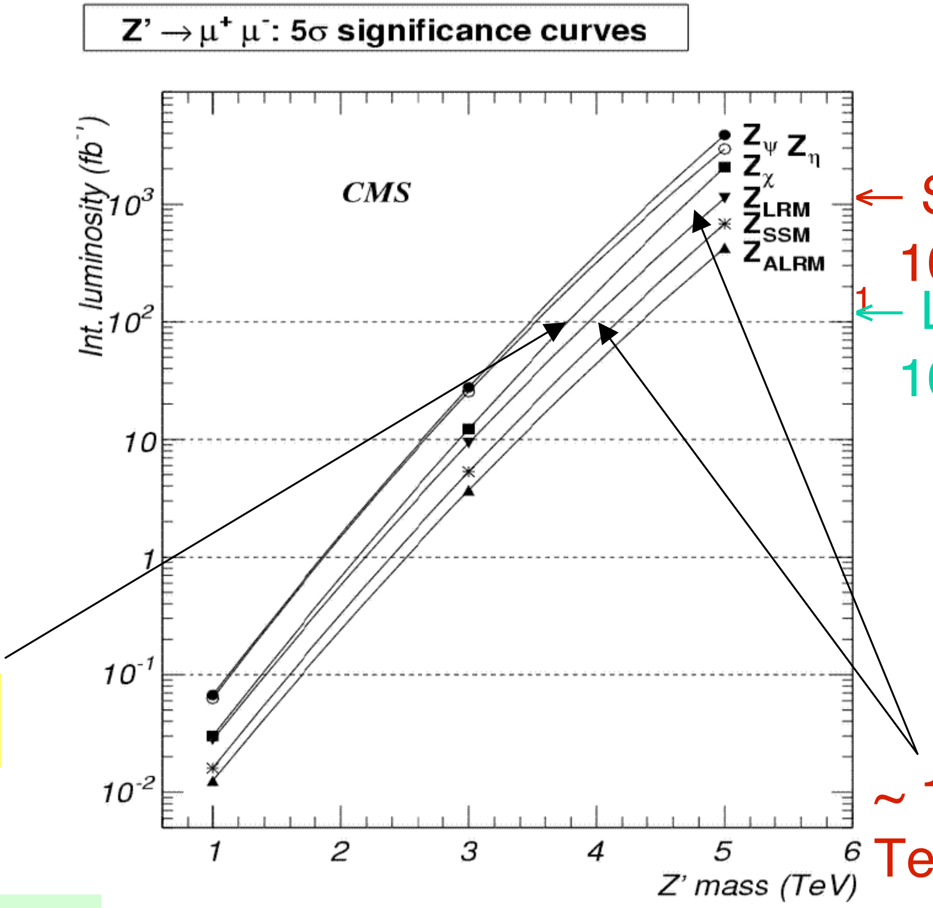
- KK excitations of the γ,Z



Direct: LHC/600 fb^{-1} 6 TeV
SLHC/6000 fb^{-1} 7.7 TeV
Interf:SLHC/6000 fb^{-1} 20 TeV

New Gauge Bosons





← SLHC

1000 fb^{-1}

← LHC

100 fb^{-1}

~ 1.0 TeV

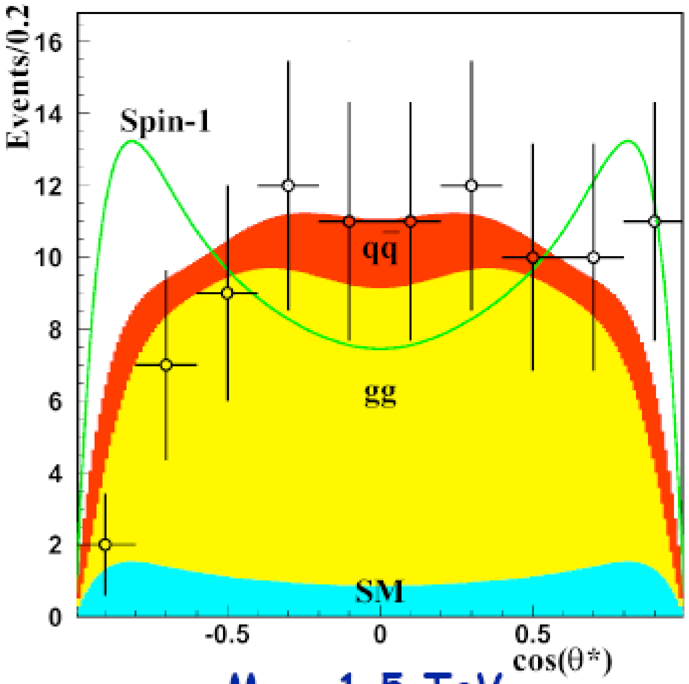
LHC reach ~ 4.0 TeV with 100 fb^{-1}

Gain in reach ~ 1.0 TeV i.e. 25-30% in going from LHC to SLHC

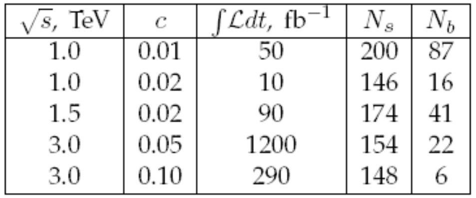
Spin Analysis (Z'⇔Randall Sundrum gravitons)

Luminosity required to discriminate a spin-1 from spin-2 hypothesis at the 2σ level

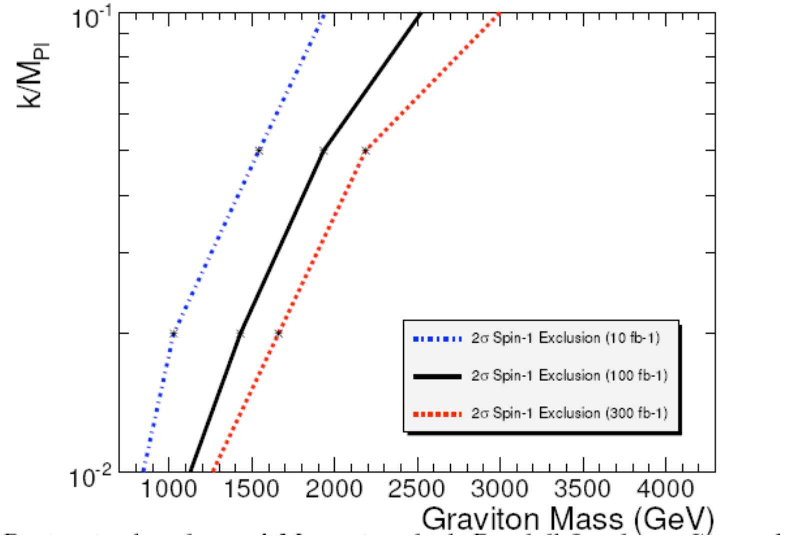
Needs statistics!



M_G = 1.5 TeV
$\int L$ = 100 fb^{-1}



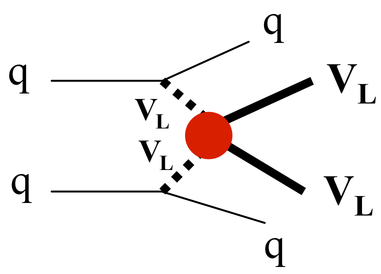
$\sqrt{s}$, TeV	c	$\int\mathcal{L}dt$, fb^{-1}	N_s	N_b
1.0	0.01	50	200	87
1.0	0.02	10	146	16
1.5	0.02	90	174	41
3.0	0.05	1200	154	22
3.0	0.10	290	148	6



- May well be a case for the SLHC
- Also: SUSY particle spin analysis (Barr, Webber, Smiley) need > 100 fb^{-1}

Strongly Coupled Vector Boson System

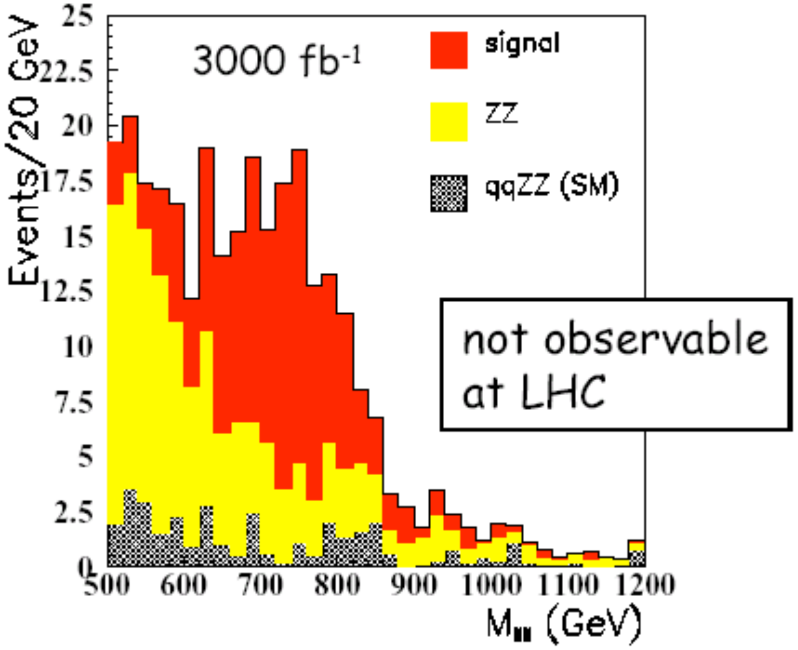
If no Higgs, expect strong $V_L V_L$ scattering (resonant or non-resonant) at ~ 1TeV



Could well be difficult at LHC. What about SLHC?

- degradation of fwd jet tag and central jet veto due to huge pile-up
- BUT : factor ~ 10 in statistics → 5-8σ excess in $W^+_L\ W^+_L$ scattering
  → other low-rate channels accessible

Scalar resonance $Z_L Z_L \rightarrow 4\ell$



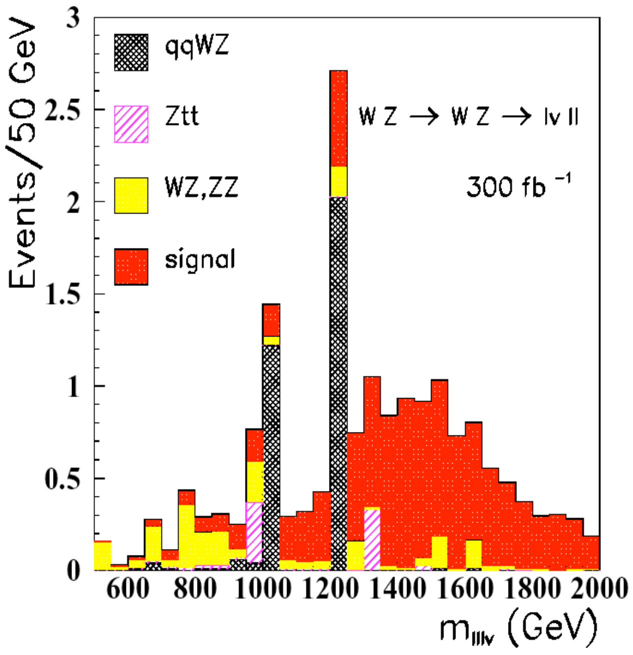
not observable at LHC

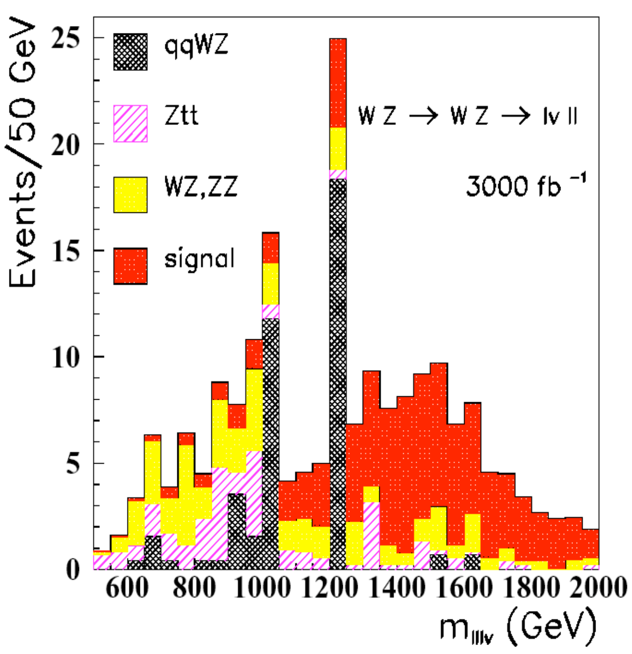
WZ resonances in Vector Boson Scattering

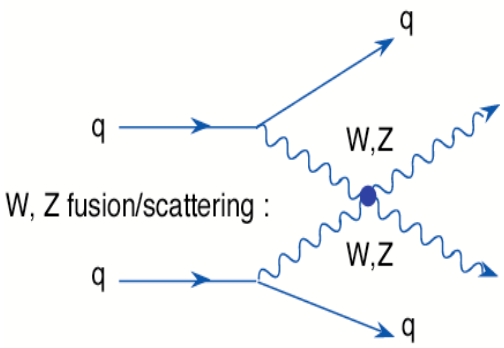
Vector resonance (ρ-like) in W_LZ_L scattering from Chiral Lagrangian model

M = 1.5 TeV ⇒ 300 fb^{-1} (LHC) vs 3000 fb^{-1} (SLHC)

lepton cuts: $p_{t1} > 150$ GeV, $p_{t2} > 100$ GeV, $p_{t3} > 50$ GeV; $E_t^{miss} > 75$ GeV







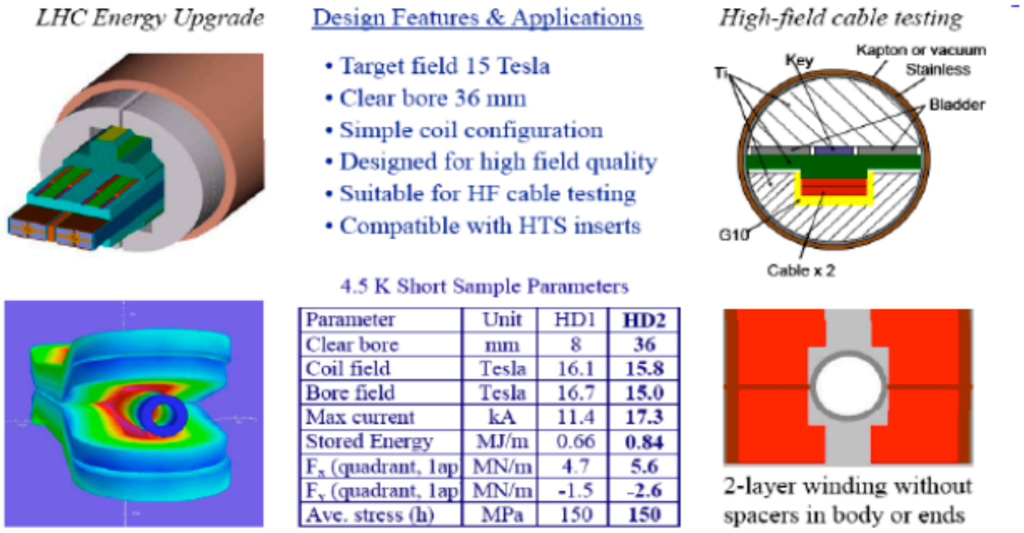
At LHC: S = 6.6 events,
B = 2.2 events

At SLHC: $S/\sqrt{B} \sim 10$

These studies require both forward jet tagging and central jet vetoing! Expected (degraded) SLHC performance is included

LHC energy doubler 14*14 TeV

- dipole field B_{nom} = 16.8 T, B_{design} = 18.5-19.3 T (10-15% margi
  - superconductor - Nb_3Sn
  - 10-13 T field demonstrated in several 1-m long Nb3Sn dipole models
  - DLHC magnet parameters well above the demonstrated Nb3Sn magnet technology
- R&D and construction time and cost estimates
  - 10+ years for magnet technology development and demonstration
  - Magnet production by industry ~ 8-10 years
  - High cost for R&D and construction (cost of dipoles > 3GCHF ?)



LHC Energy Upgrade

Design Features & Applications

- Target field 15 Tesla
- Clear bore 36 mm
- Simple coil configuration
- Designed for high field quality
- Suitable for HF cable testing
- Compatible with HTS inserts

High-field cable testing

4.5 K Short Sample Parameters

Parameter	Unit	HD1	**HD2**
Clear bore	mm	8	**36**
Coil field	Tesla	16.1	**15.8**
Bore field	Tesla	16.7	**15.0**
Max current	kA	11.4	**17.3**
Stored Energy	MJ/m	0.66	**0.84**
F_x (quadrant, 1ap	MN/m	4.7	**5.6**
F_y (quadrant, 1ap	MN/m	-1.5	**-2.6**
Ave. stress (h)	MPa	150	**150**

2-layer winding without spacers in body or ends

W. Scandale
HCP07

LHC energy tripler 21*21 TeV

- dipole field B_{nom} = 25 T, B_{design} = 28-29 T (10-15% margin)
  - superconductor - HTS-BSCCO (low demand) or Nb_3Sn
  - Magnet technology to be fully demonstrated
  - DLHC magnet parameters well above the demonstrated Nb3Sn magnet technology
- Large aperture dipole to accommodate an efficient beam screen
- R&D and construction time and cost/risk estimates
  - 20++ years for magnet technology development and demonstration
  - Extremely high R&D and construction cost and risk
    - SC cable to be developed,
    - Magnetic coil stress requires innovative dipole cross section
  - Magnet production by industry (?) ?? years

The SSC in the LHC tunnel ? ✪

W. Scandale
HCP07

Indicative Physics Reach

Ellis, Gianotti, ADR
hep-ex/0112004+ few updates

Units are TeV (except W_LW_L reach)

ILdt correspond to 1 year of running at nominal luminosity for 1 experiment

PROCESS	LHC 14 TeV 100 fb^{-1}	SLHC 14 TeV 1000 fb^{-1}	DLHC 28 TeV 100 fb^{-1}	VLHC 40 TeV 100 fb^{-1}	VLHC 200 TeV 100 fb^{-1}	ILC 0.8 TeV 500 fb^{-1}	CLIC 5 TeV 1000 fb^{-1}
Squarks	2.5	3	4	5	20	0.4	2.5
W_LW_L	2σ	4σ	4.5σ	7σ	18σ	6σ	90σ
Z'	5	6	8	11	35	8†	30†
Extra-dim (δ=2)	9	12	15	25	65	5-8.5†	30-55†
q*	6.5	7.5	9.5	13	75	0.8	5
Lcompositeness	30	40	40	50	100	100	400
TGC (λ_γ)	0.0014	0.0006	0.0008		0.0003	0.0004	0.00008

† indirect reach
(from precision measurements)

Approximate mass reach machines:

$\sqrt{s}$ = 14 TeV, L=10^{34} (LHC) : up to ≈ 6.5 TeV
$\sqrt{s}$ = 14 TeV, L=10^{35} (SLHC) : up to ≈ 8 TeV
$\sqrt{s}$ = 28 TeV, L=10^{34} : up to ≈ 10 TeV

Summary: SLHC

The LHC luminosity upgrade to 10^{35} cm^{-2}s^{-1}

- Extend the LHC discovery mass range by 25-30% (SUSY,Z',EDs,….)
- Higgs self-coupling measurable with a precision of (20-30%)
- Rare decays accessible: $H \rightarrow \mu\mu$, γZ, top decays…
- Improved Higgs coupling ratios by a factor of 2, SUSY masses…
- TGC precision measurements…

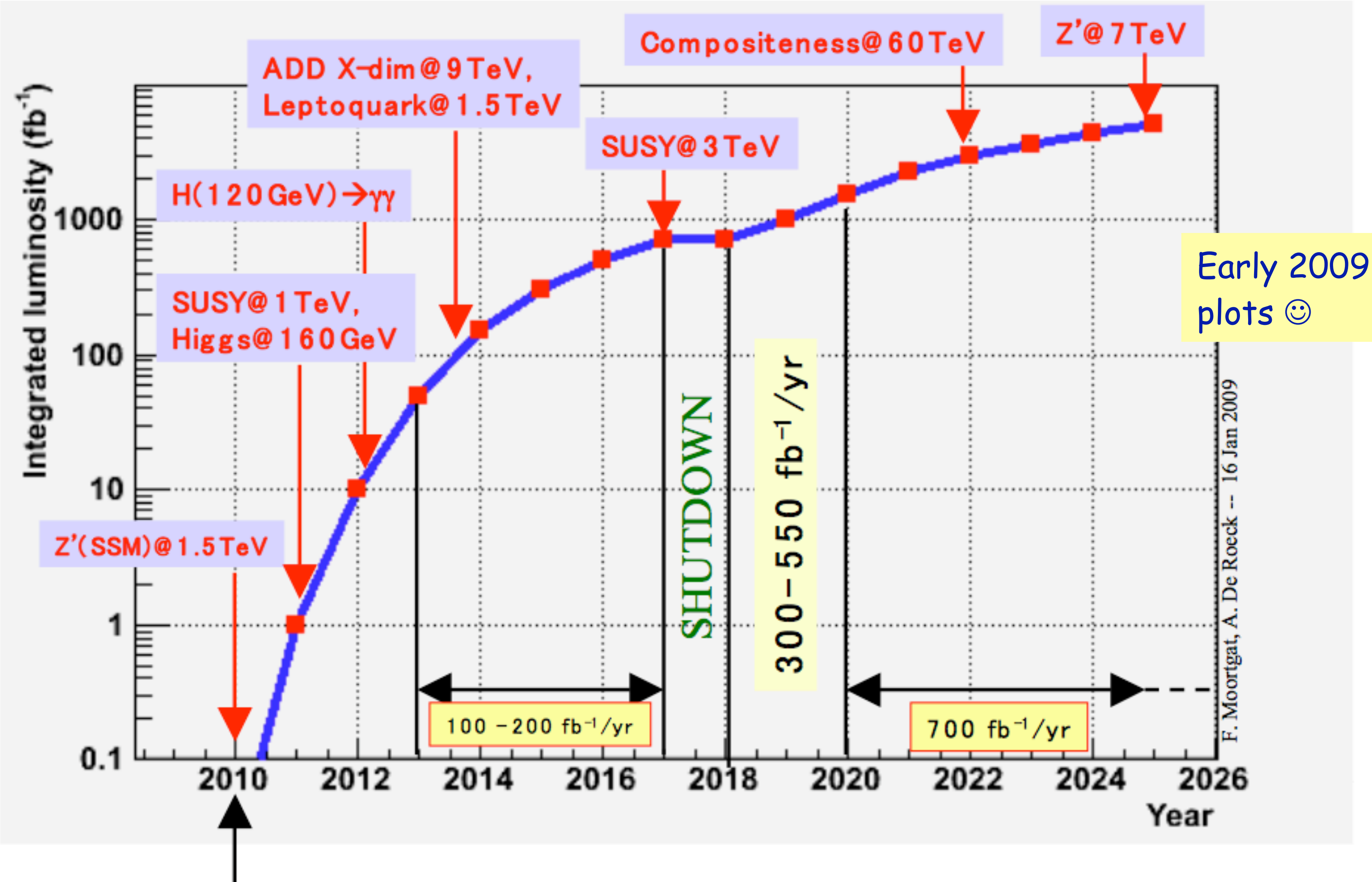
In general: SLHC gives a good physics return for "modest" cost, basically independent of the physics scenario chosen by Nature

⇒ It is a natural upgrade of the LHC (by 2018-2020)

- It will be a challenge for the experiments!
- CMS and ATLAS have working groups/workshops on SLHC

The energy upgrade DLHC is certainly more costly and up for the future

Example of the LHC Outlook



Early 2009 plots ☺

First physics run in 2009: 50 pb^{-1}