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Physics potential of a luminosity upgraded LHC (SLHC at ~10^{35} cm^{-2} s^{-1})

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Physics potential of the LHC at 10^{35} cm^{-2} s^{-1} (SLHC)

What improvements in the physics reach could we expect from operating the LHC at a luminosity of ~ 10^{35} cm^{-2} s^{-1} with an integrated luminosity ~ 1000 fb^{-1} per year at $\sqrt{s} \approx 14$ TeV i.e. retaining present LHC magnets/dipoles -

➡ an upgrade at a relatively modest cost for machine + experiments (< 0.5 GSF) for ~ 2013-15 (much cheaper and before ILC, …..CLIC, VLHC…..)

a more ambitious upgrade - at a much higher cost (~ 2 GSF) - would be to go for a $\sqrt{s} \approx 30$ TeV machine changing LHC dipoles (~16T, Nb_3Sn?) - only sporadically mentioned here

Topics addressed:

- expected modifications/adaptations of LHC and experiments/CMS,
- some experimental requirements/desirability for SLHC, expected performances
- improvements in some basic SM measurements and in SM/MSSM Higgs reach
- improvements in reach at high mass scales, for ex strongly interacting W,Z schemes, sparticle reach and studies, possible new gauge bosons, massive states appearing in extra dimension models - main motivations for an upgrade i.e. exploit maximally the "existing" machine and detectors

Nominal LHC and possible upgrades

Nominal LHC: 7 TeV beams,

- injection energy: 450 GeV, ~ 2800 bunches, spacing 7.5 m (25ns), bunch length 7.5 cm
- 1.1 $*10^{11}$ protons per bunch, β^* at IP : 0.5 m $\Rightarrow 10^{34}$ cm^{-2} s^{-1} (lumi-lifetime 10h)

Possible upgrades/steps considered:

- increase up to 1.7 $*10^{11}$ protons per bunch (beam-beam limit) $\Rightarrow 2*10^{34}$ cm^{-2} s^{-1}
- increase operating field from 8.3T to 9T (ultimate field) $\Rightarrow \sqrt{s} \approx 15$ TeV

minor hardware changes to LHC insertions or injectors:

- modify insertion quadrupoles (larger aperture) for $\beta^* = 0.5 \rightarrow 0.25$ m
- increase crossing angle 300 μrad $\rightarrow$ 424 μrad
- halving bunch spacing (12.5nsec)*, with new RF system

$\Rightarrow L \approx 5 * 10^{34}$ cm^{-2} s^{-1}

major hardware changes in arcs or injectors:

- SPS equipped with superconducting magnets to inject at ≈ 1 TeV $\Rightarrow L \approx 10^{35}$ cm^{-2} s^{-1}
- new superconducting dipoles at B ≈ 16 Tesla for beam energy ≈ 14TeV i.e. $\sqrt{s} \approx 28$ TeV

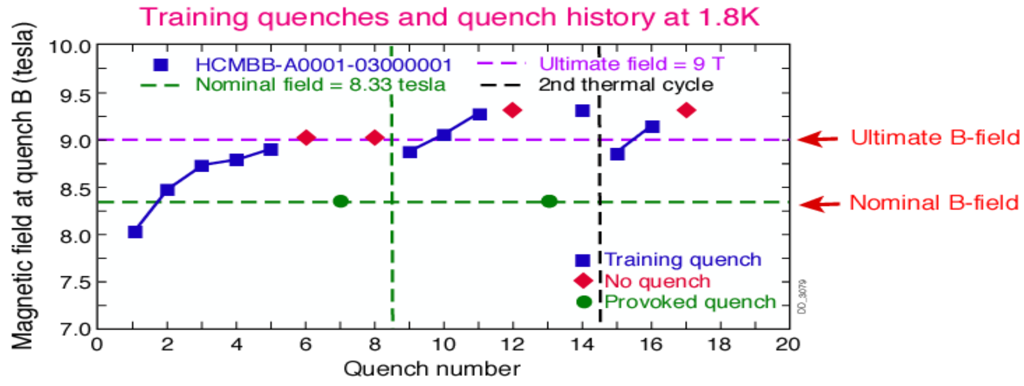
*Comment: 12.5nsec is more favorable for experiments, 10 or 15nsec is more favorable for the PS/SPS RF systems at 200MHz, ultimately a question of cost of electronics to experiments vs. accelerators; a 300m super-bunch option (every 88μsec) is much worse for experiments, not considered any more

Nominal LHC and possible upgrades

-increase operating field from 8.3T to 9T
(ultimate field)

$\Rightarrow \sqrt{s} \approx 15$ TeV

Quench performance of the last tested pre-series dipole



- MBPSN01 dipole reached nominal field after one quench
- Ultimate field of 9T reached after 5 training quenches
- during the following 2 test campaigns magnet never quenched below 8.8T

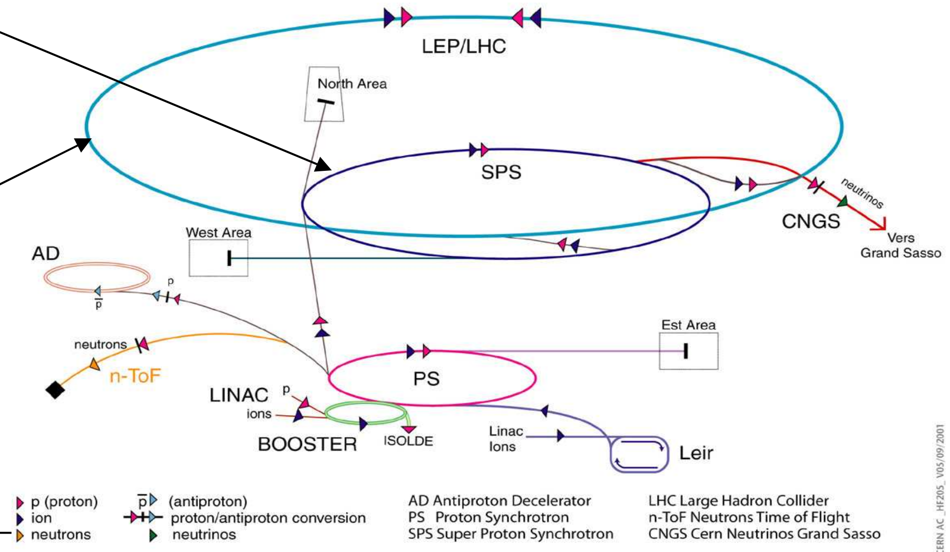
major hardware changes in arcs or injectors:

- SPS equipped with superconducting magnets to inject at ≈ 1 TeV
  $\Rightarrow$ Luminosity increase by factor ≈ 2

- new superconducting dipoles at B ≈ 16 Tesla for beam energy ≈ 14TeV i.e.
  $\sqrt{s} \approx 28$ TeV

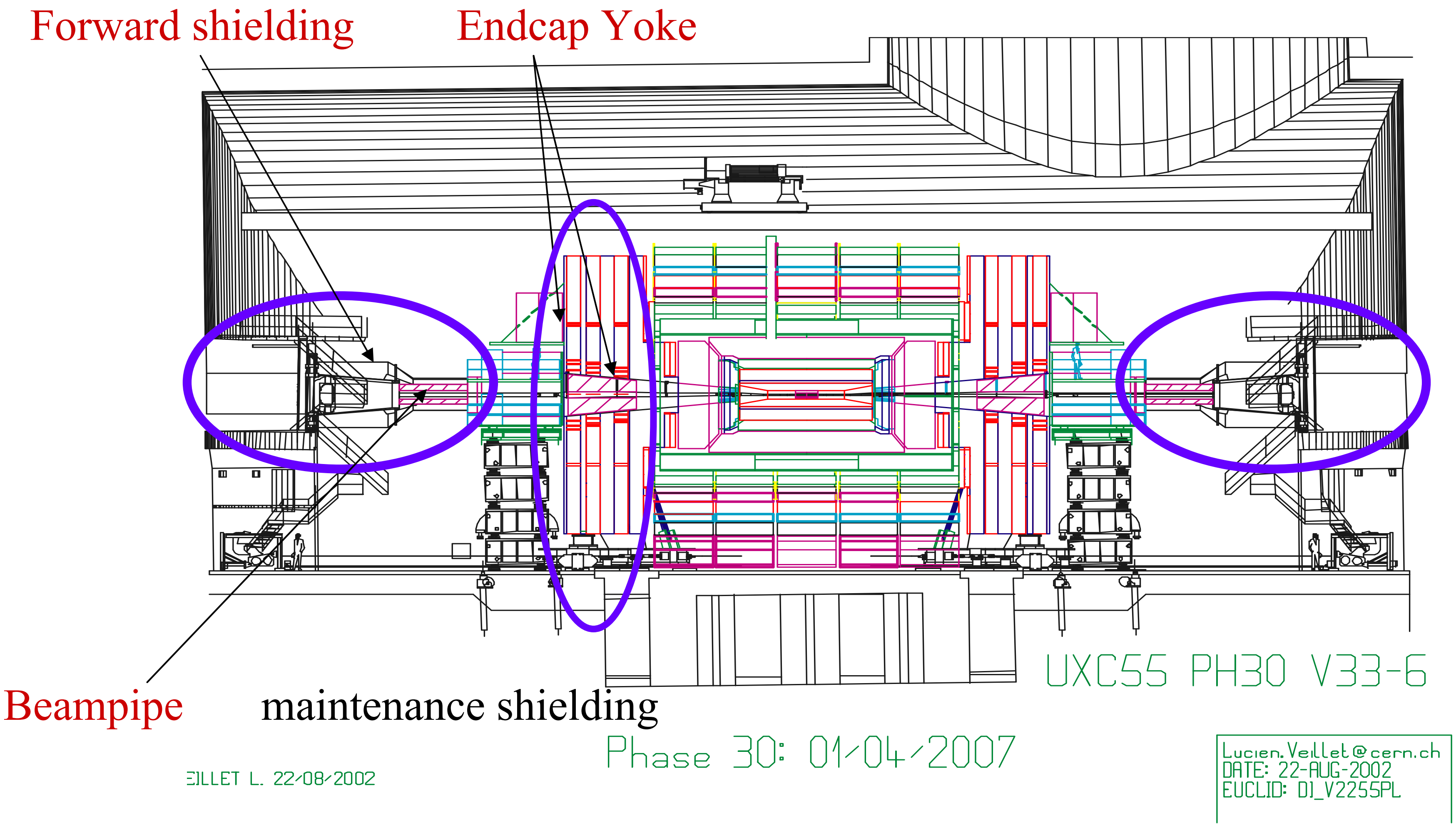
Last step would be very expensive…2 - 3 GSF.

Accelerator chain of CERN (operating or approved projects)



Machine-experiment interface - CMS forward shielding system

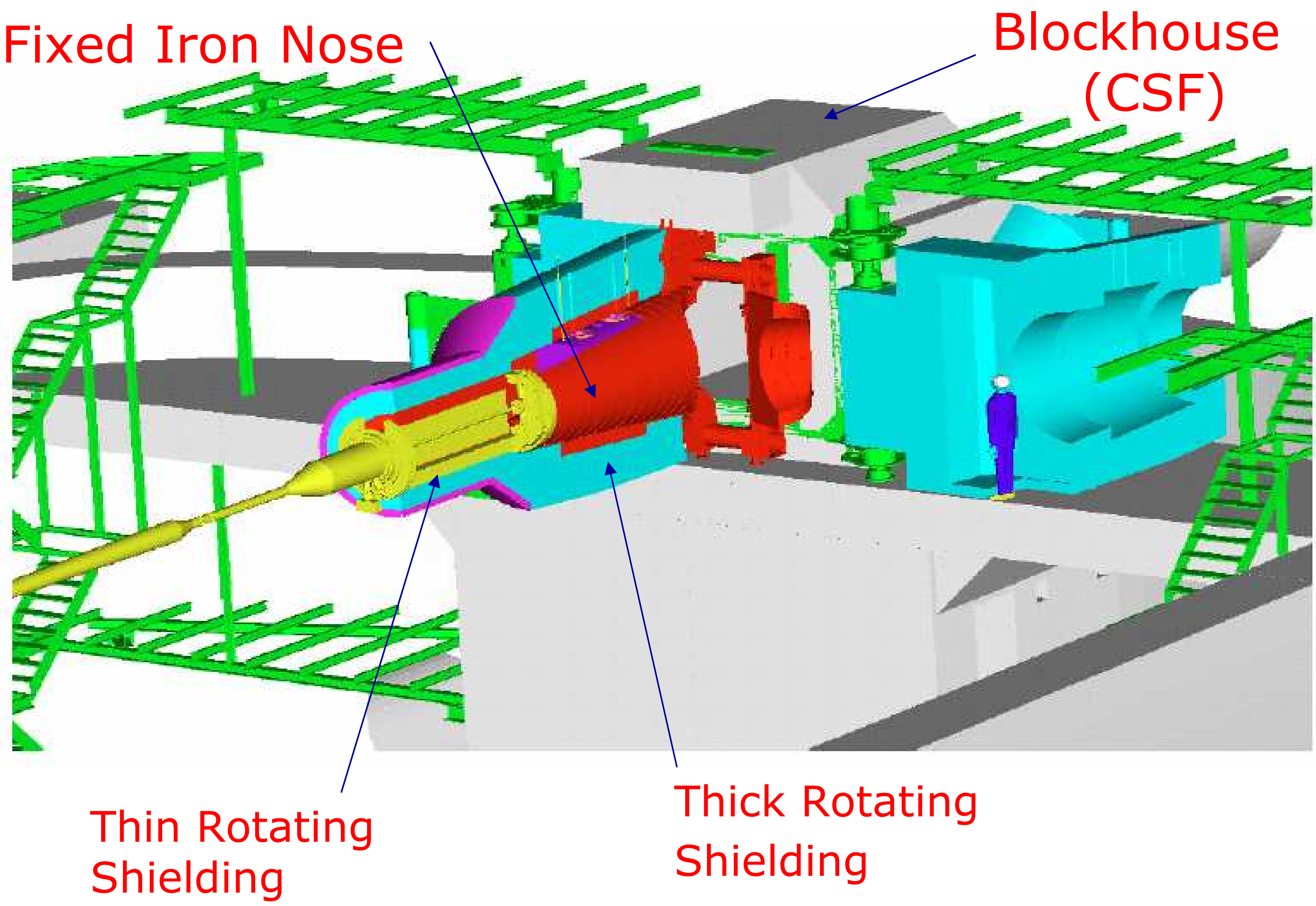
The rotating shielding is part of the CMS forward shielding system, it forms the interface between the CMS experiment and the LHC machine.



CMS experimental cavern delivered March 2005

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Forward shielding system



Shielding between machine and HF

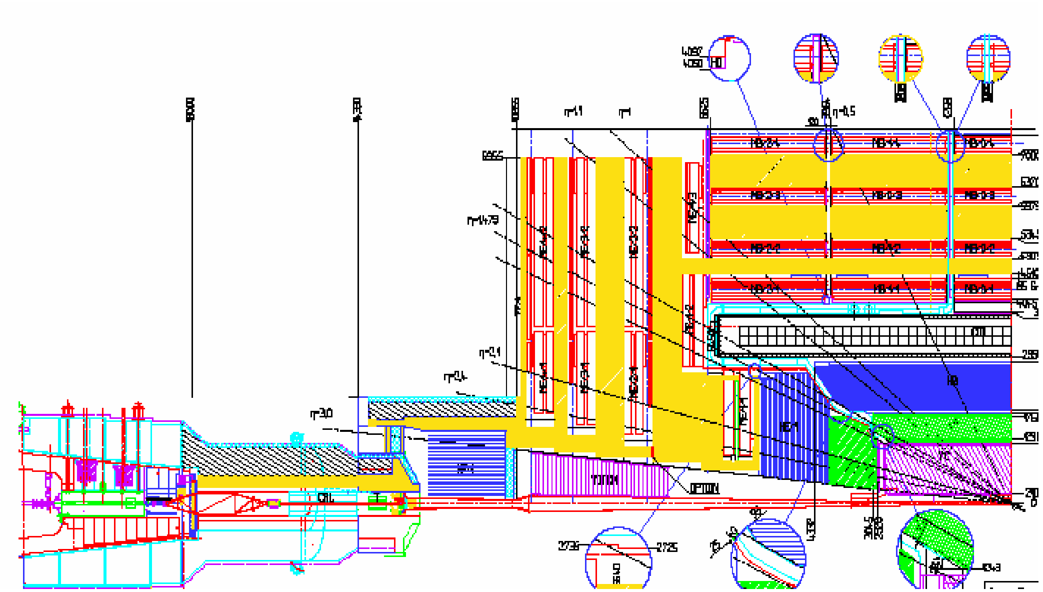
Basic functions of the shielding elements between the machine area and HF are:

-reduce the neutron flux in the cavern by 3 orders of magnitude

-reduce the background rate in the outer muon spectrometer (MB4, ME3,ME4) by 3 orders of magnitude

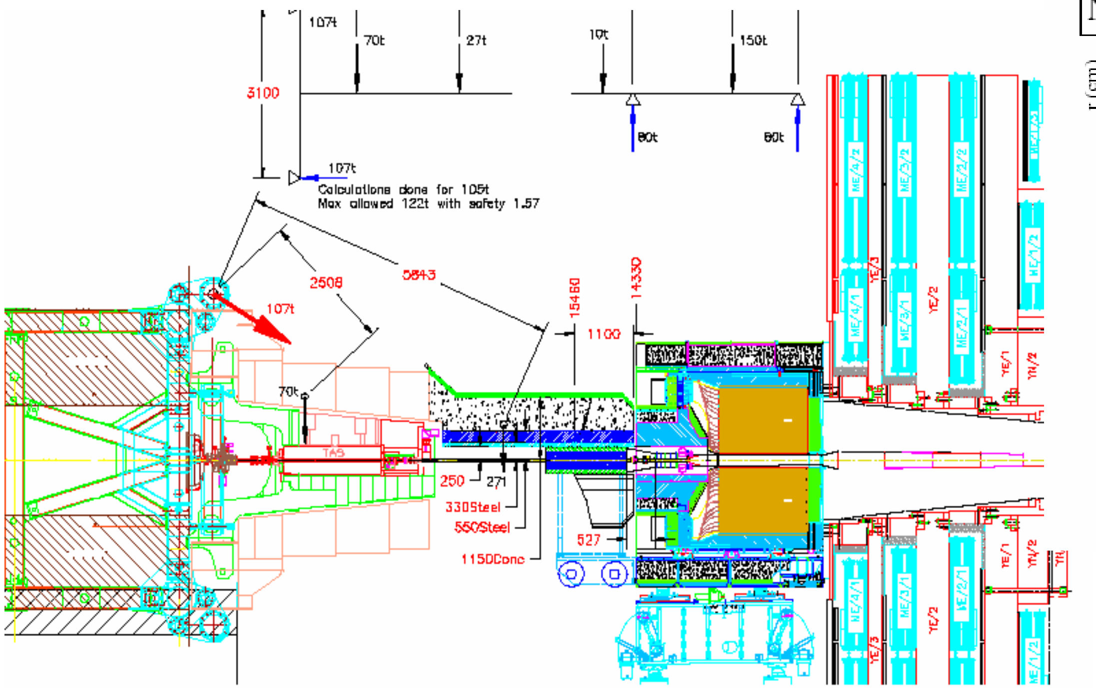
-reduce the radiation level at the HF readout boxes to a tolerable level

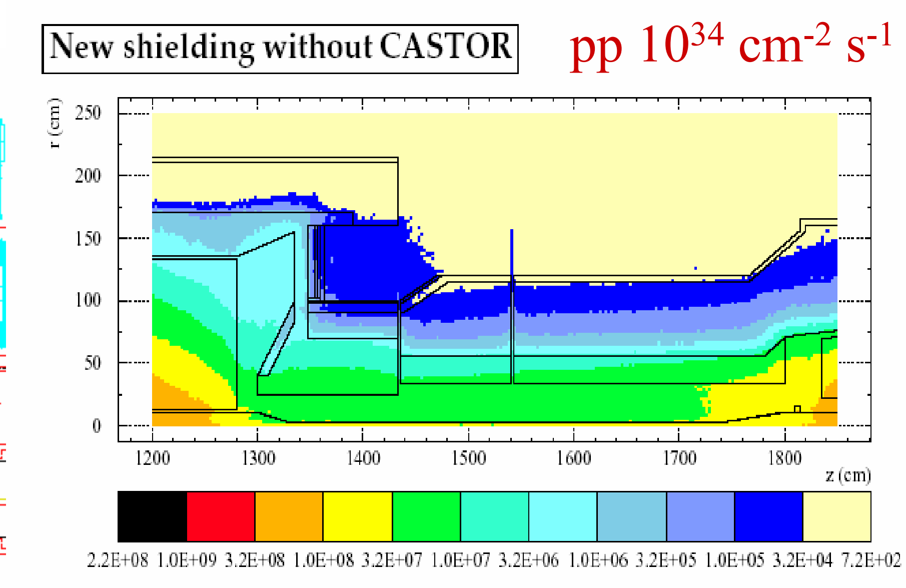
-shield the experiment from low-energy machine-generated background emerging from the LHC tunnel.



Final forward CMS shielding design (April 03)

Neutron (E>100keV) flux maps

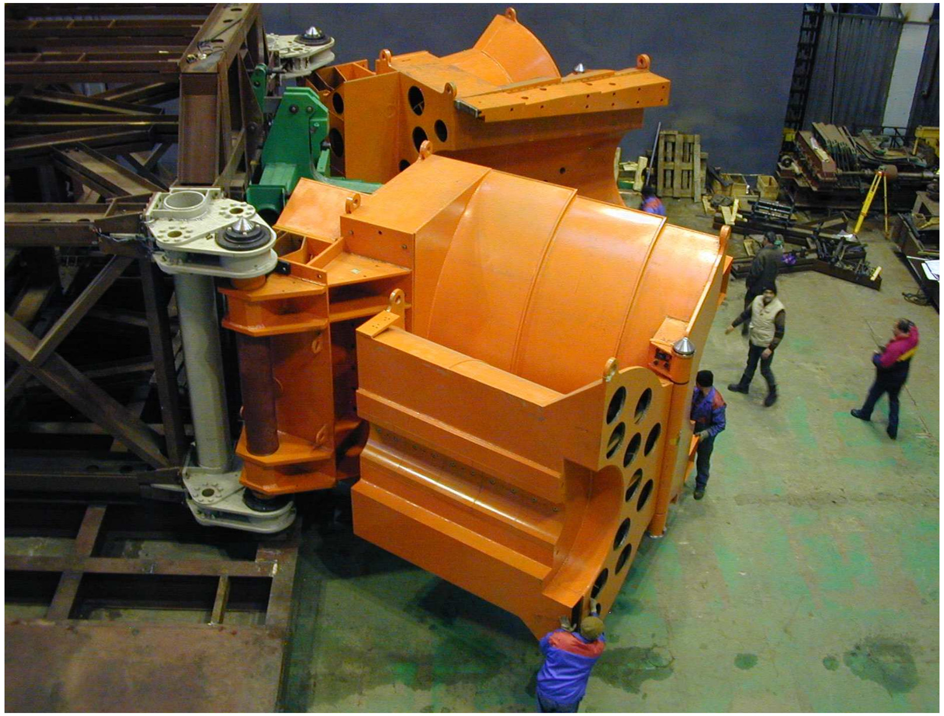




-well balanced along z.(no particular weak-point)

Rotating system is near the limits of mechanical strength,
new concept or supplementary system around existing RS needed for SLHC running,
time needed to open and close CMS would increase significantly (~1 week per shutdown)

Forward shielding system tested at Protvino

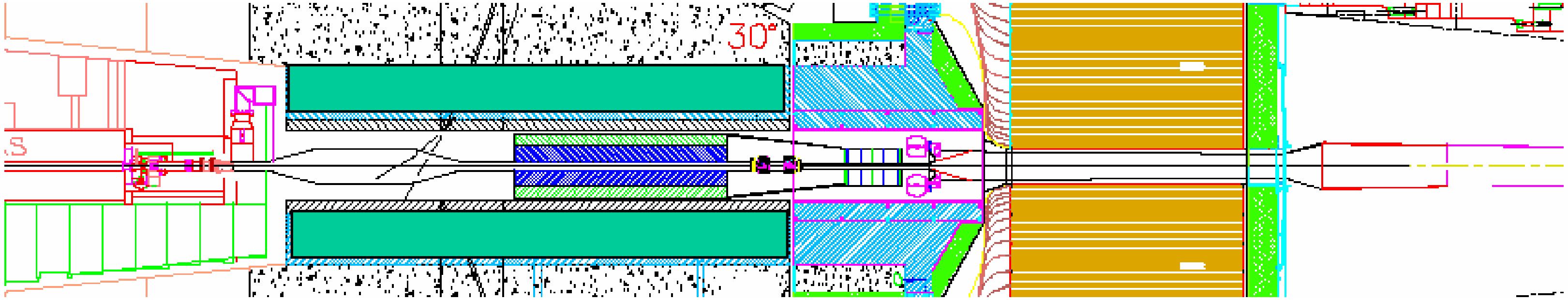


The symmetric piece RS56 will be tested in May**.**

All elements are now in hand for UXC installation.

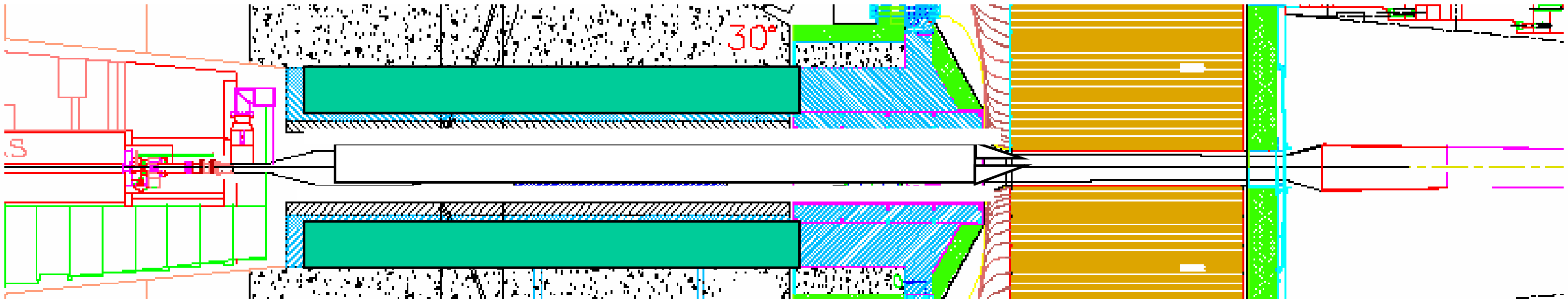
Forward beam pipe

LHC



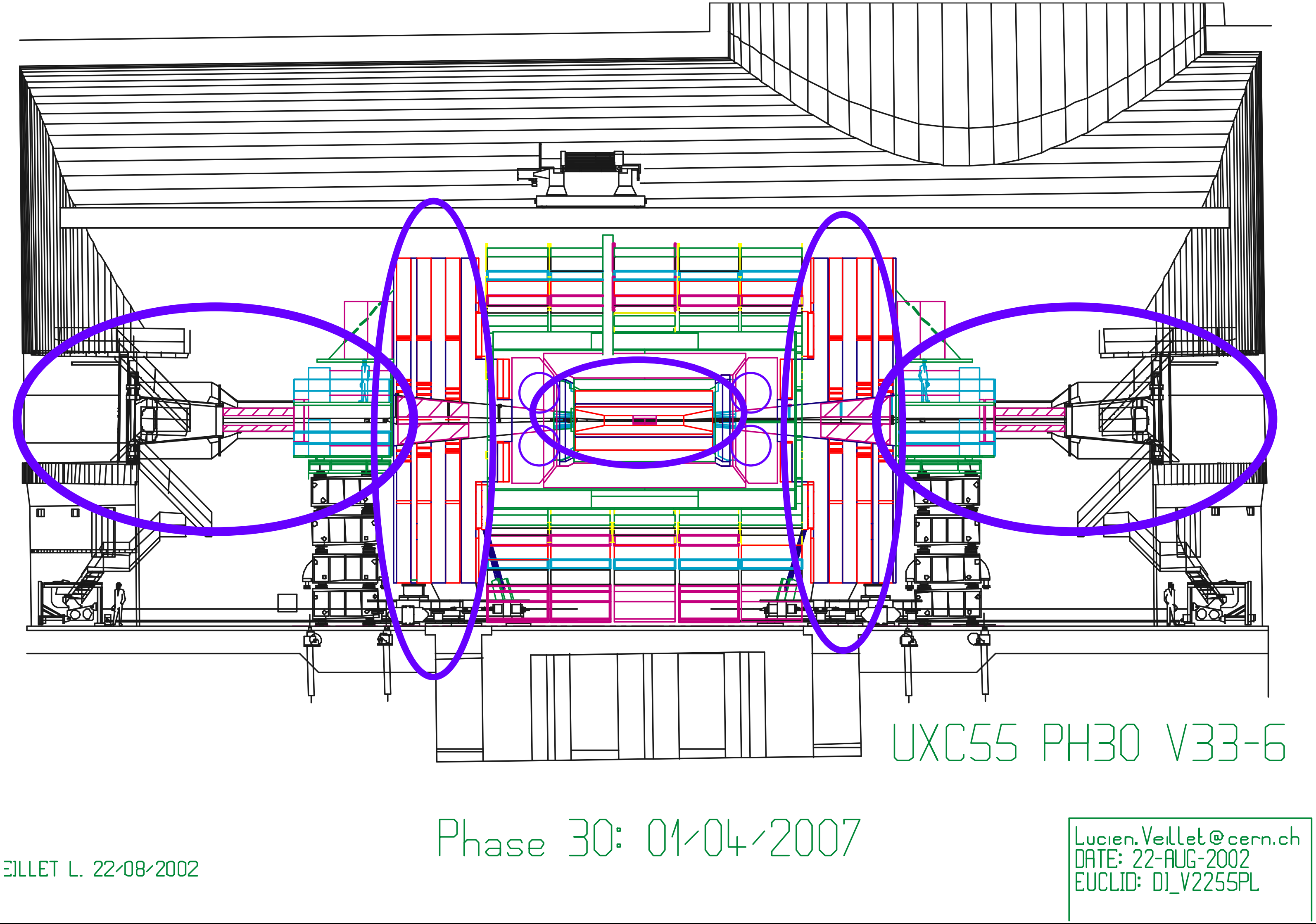
thin pipe 13-16 m believed good for 10^{34} pp
CASTOR & TOTEM easily installed/removed for special runs (eg heavy ion), interspersed with high lumi pp

SLHC



wide pipe (400mm) after HF and in its shadow

CMS areas affected by luminosity upgrade

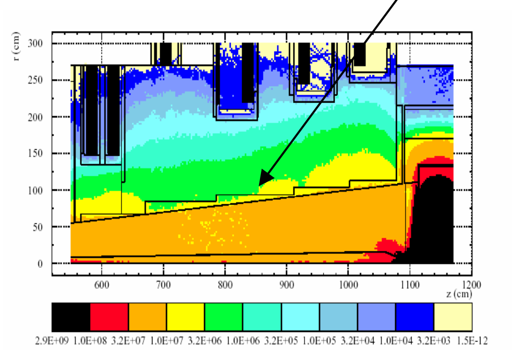


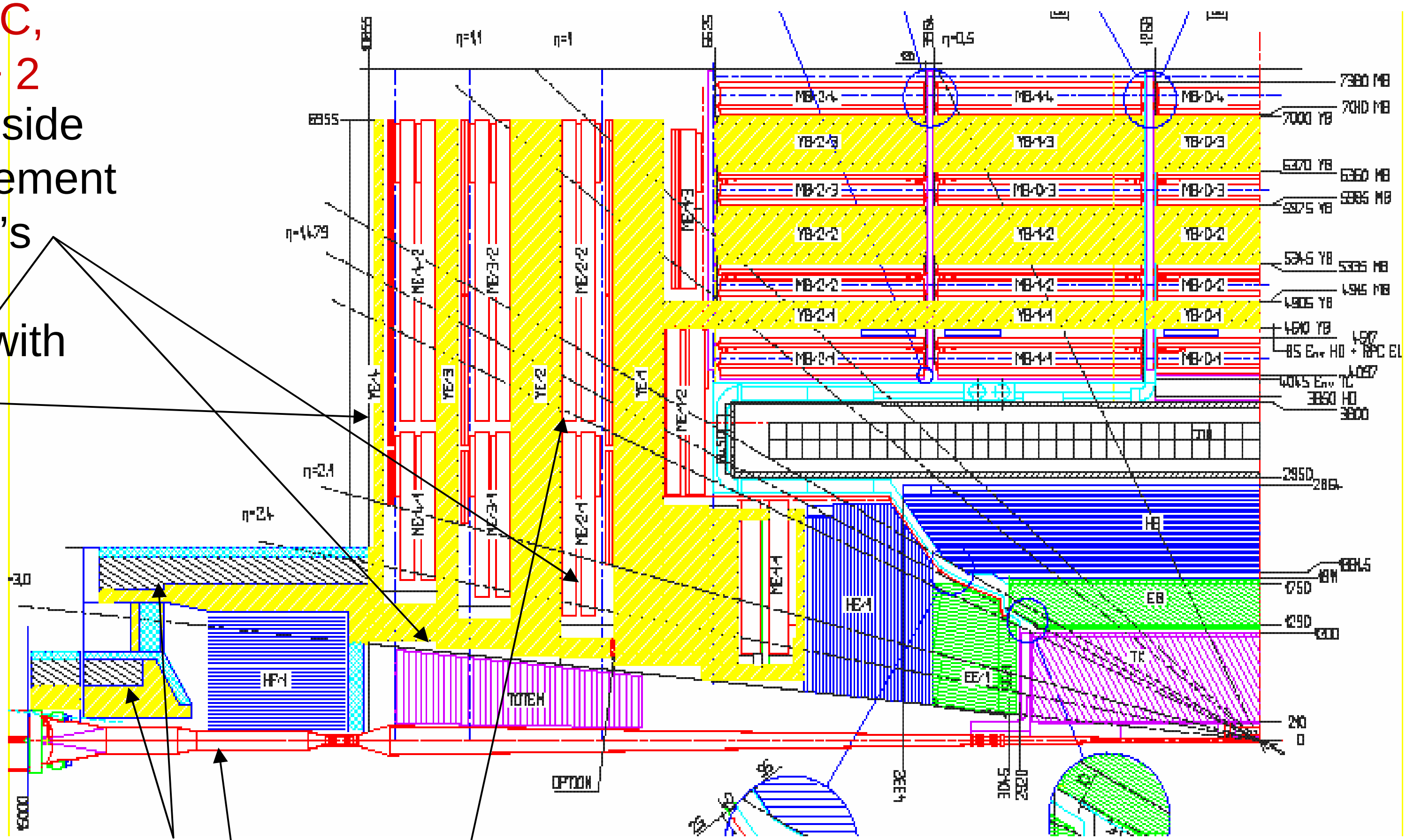
CMS longitudinal view/ modifications considered for SLHC - yoke and forward

End cap yoke for SLHC, acceptance up to |η| ~ 2

Reinforced shielding inside forward muons, replacement of inner CSC and RPC's

Supplement YE4 wall with borated polythene





Improve shielding of HF PMT's

Possibly increase YE1-YE2 separation to insert another detector layer?

Free space in radius in the HF calo is : 14cm beampipe radius + 5cm clearance, the issue - if quads were to be located there or in the "TOTEM part", is the neutron albedo into CMS

Experimental conditions at 10^{35} cm^{-2} s^{-1} (12.5ns) - considerations for tracker and calorimetry

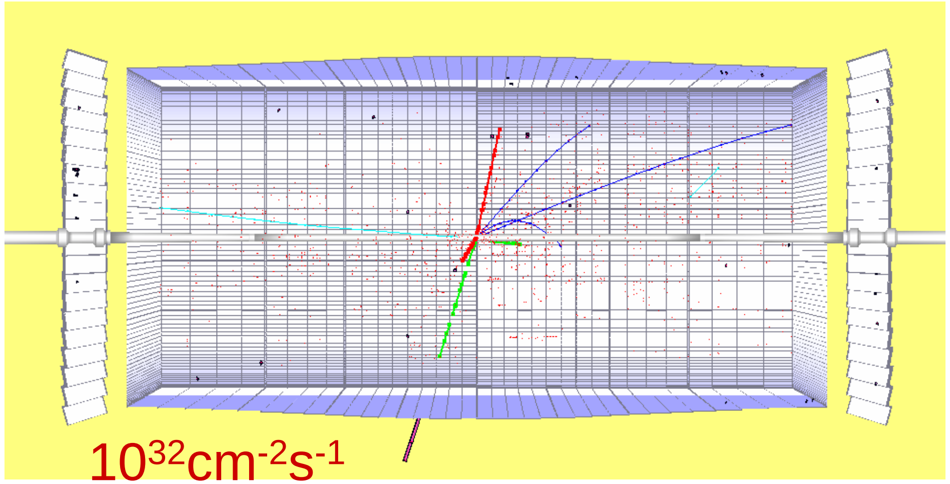
~ 100 pile-up events per bunch crossing - if 12.5 nsec bunch spacing (with adequate/faster electronics, reduced integration time) -
compared to ~ 20 for operation at 10^{34}cm^{-2}s^{-1} and 25 nsec (nominal LHC regime),

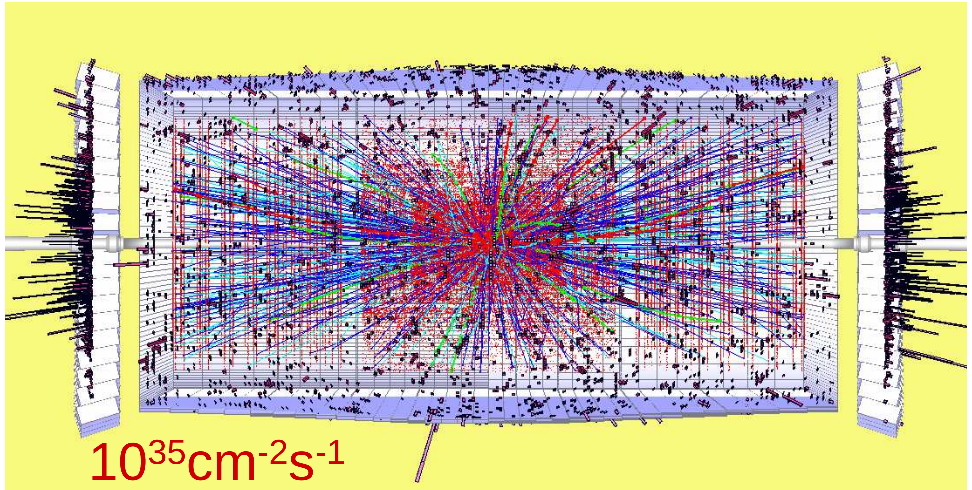
➡ $dn^{ch}/d\eta$/crossing ≈ 600 and ≈ 3000 tracks in tracker acceptance

$H \rightarrow ZZ \rightarrow ee\mu\mu$, m_H = 300 GeV, in CMS

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

I. Osborne





➡ If same granularity and integration time as now: tracker occupancy and radiation dose in central detectors increases by factor ~10, pile-up noise in calorimeters by ~ 3 relative to 10^{34}

Consequences of running at ~10^{35} cm^{-2} s^{-1}

if 12.5 nsec bunch spacing ($dn^{ch}/d\eta$/crossing ≈ 600) - which is the least demanding option in terms of changes to CMS and ATLAS - relative to nominal LHC running, assuming same detector performances as for present ones:

⇒ reduced efficiency for selection of isolated objects (μ, e, γ, τ), trigger and off-line

⇒ degraded energy resolution due to pile-up for e, γ, jets, missing E_t,
effect decreases with increasing E_t, small beyond ~ 50 (e,γ) - 200 (jets) GeV

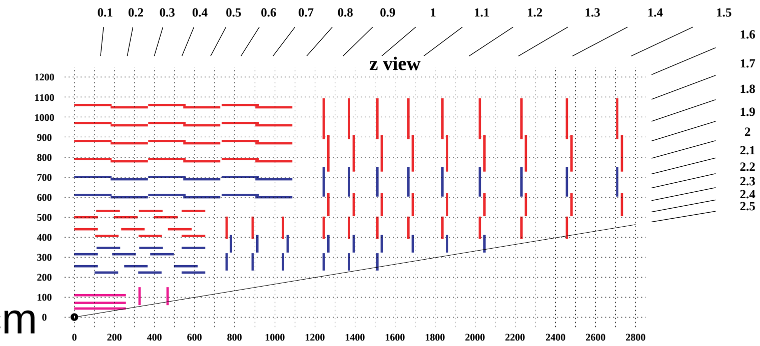
⇒ reduced selectivity of missing E_t cuts (below ~ 100 GeV)

⇒ reduced efficiency and purity of forward jet tagging and central jet vetoing techniques used to improve S/B

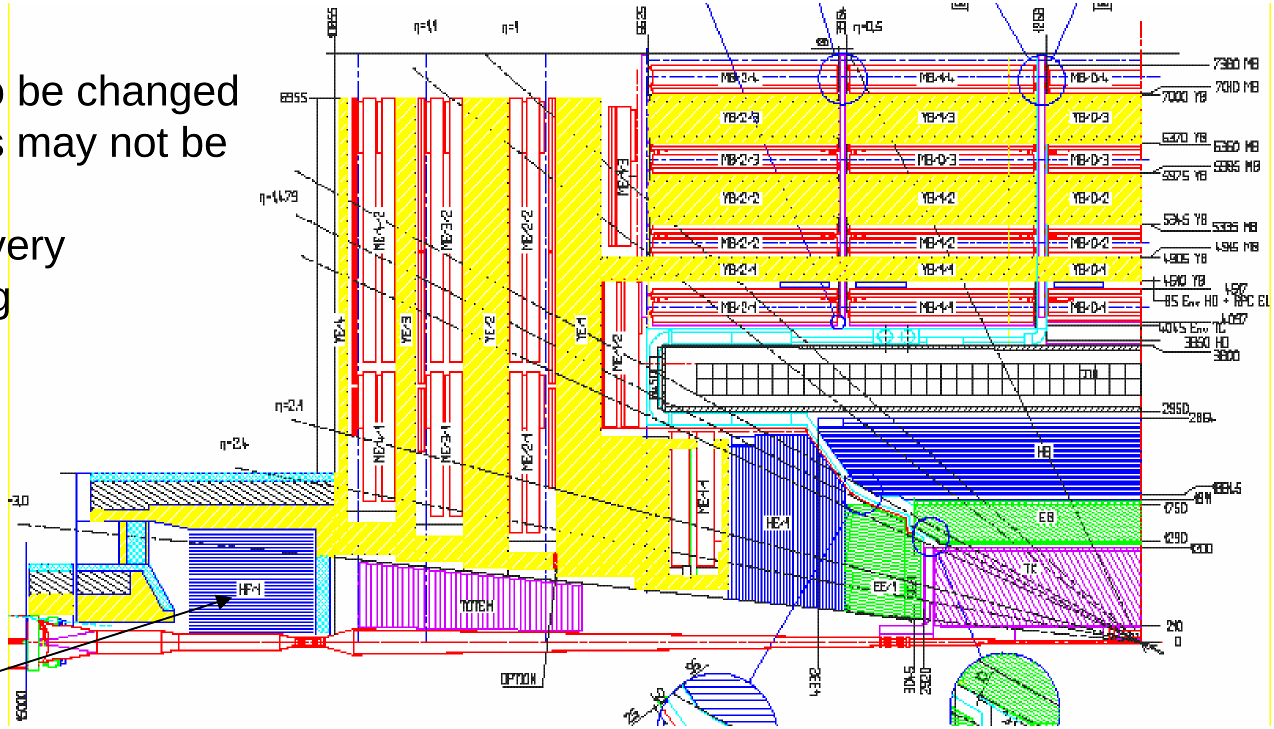
⇒ somewhat reduced muon acceptance, to $|\eta| < \sim 2.0$, due to need for increased forward shielding, not essential as heavy objects are centrally produced, but potentially damaging for ew studies….

Foreseeable changes to detectors for $10^{35}cm^{-2}s^{-1}$

changes to CMS and ATLAS :



- Trackers, to be replaced due to increased occupancy to maintain performance, need improved radiation hardness for sensors and electronics
  - present Si-strip technology is OK at R > 60 cm
  - present pixel technology is OK for the region ~ 20 < R < 60 cm
  - at smaller radii new techniques required
- Calorimeters: ~ OK
  - endcap HCAL scintillators in CMS to be changed
  - endcap ECAL VPT's and electronics may not be enough radiation hard
  - desirable to improve granularity of very forward calorimeters - for jet tagging
- Muon systems: ~ OK
  - acceptance reduced to $|\eta| <\sim 2.0$ to reinforce forward shielding
- Trigger(L1), largely to be replaced, L1(trig.elec. and processor) for 80 MHz data sampling



➡ VF calorimeter for "jet tagging"

Triggers

Higher thresholds for inclusive triggers: e/γ, μ, jets, E_t^{miss} etc and combined

for high mass searches/reach, as dileptons, $\gamma\gamma$/R-S Graviton, lepton-γ for TGC, lepton-jet/LQ, jets + E_t^{miss} /SUSY …..

Prescaled lower p_t triggers - for control samples

Z $\rightarrow l^+l^-$, $t\bar{t} \rightarrow$ 1or 2 leptons, QCD jets and direct photons etc.

Menu of selective triggers for well defined final states:

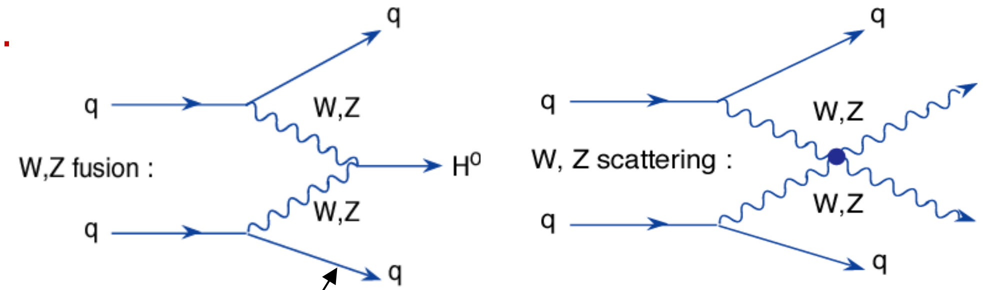
$t\bar{t} \rightarrow$ 3 leptons, $\chi^0\chi^\pm \rightarrow$ 3 leptons, $\chi^0\chi^0 \rightarrow$ 4 leptons,
3 and 4 leptons for TGC and QGC
$\tau^\pm \rightarrow 3\mu^\pm$, $\mu^+\mu^-e^\pm$, $\mu^\pm e^+e^-$ etc, $\Upsilon \rightarrow \mu^+\mu^-$, $B^0_{d,s} \rightarrow \mu^+\mu^-$
slepton pairs $\rightarrow$ 2 leptons, A/H $\rightarrow \mu\mu$, A/H $\rightarrow \tau\tau \rightarrow e\mu$, A/H $\rightarrow \tau\tau \rightarrow$ lepton-jet,
A/H $\rightarrow \tau\tau \rightarrow$ jet-jet (possibly)
ttH(t $\rightarrow$ lept,H $\rightarrow \gamma\gamma$), W/ZH(W/Z $\rightarrow$ lept,H $\rightarrow \gamma\gamma$) channels limited by event rate at LHC, etc.

L1(trig.elec. and processor) for 80 MHz data sampling

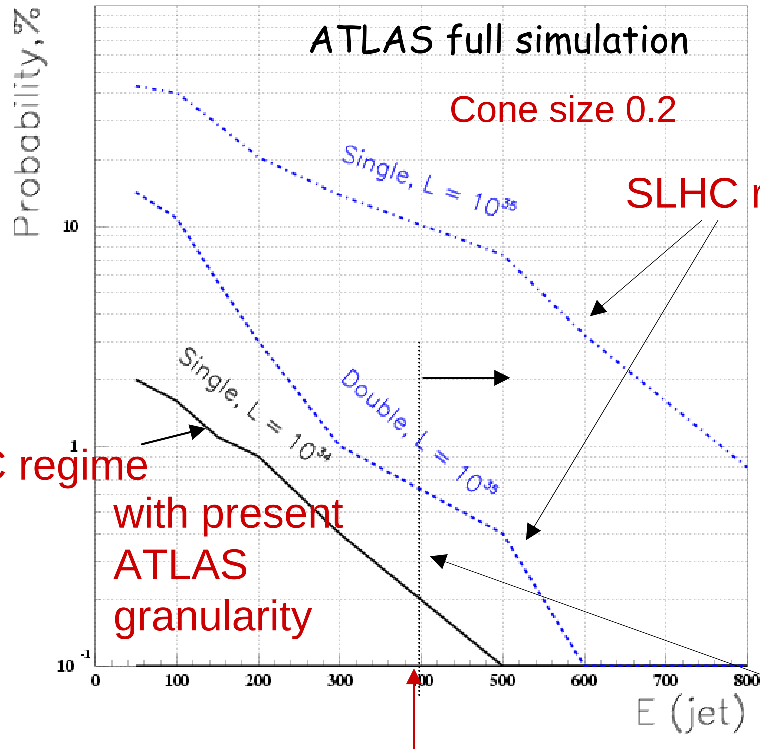
Keep L1 output at 100kHz!

Forward jet tagging at 10^{35} cm^{-2} s^{-1}

Forward jet tagging needed to improve S/B in VB fusion/scattering processes pp → qqH, qqVV ..



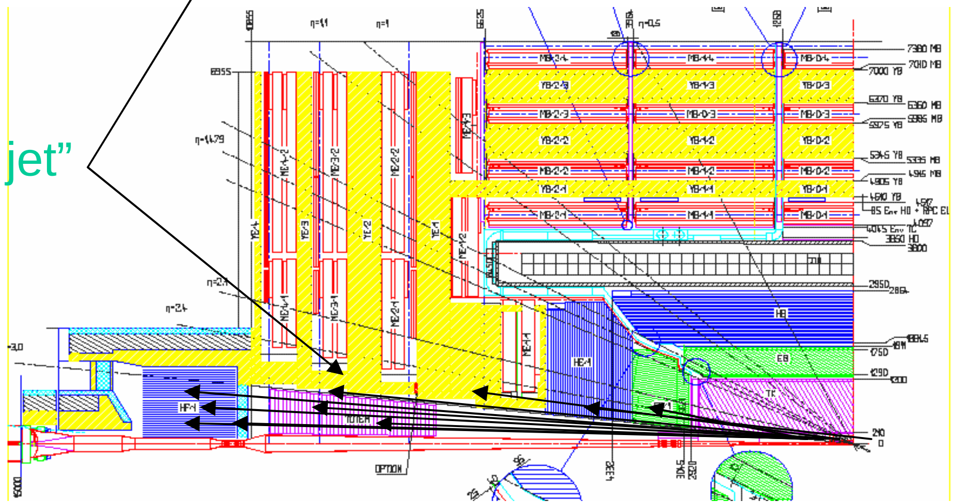
Fake fwd jet tag (|η| > 2) probability from pile-up (preliminary ...)



SLHC regime

LHC regime with present ATLAS granularity

"tagging jet"

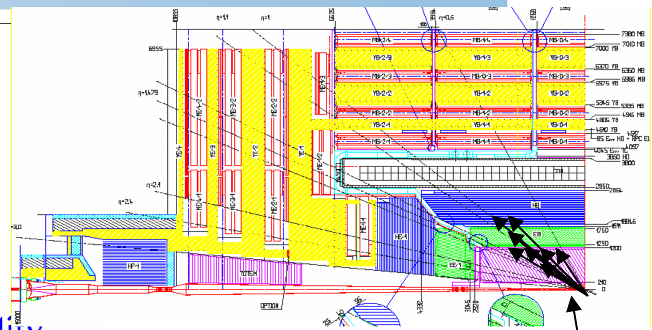


cut at > ~ 400 GeV

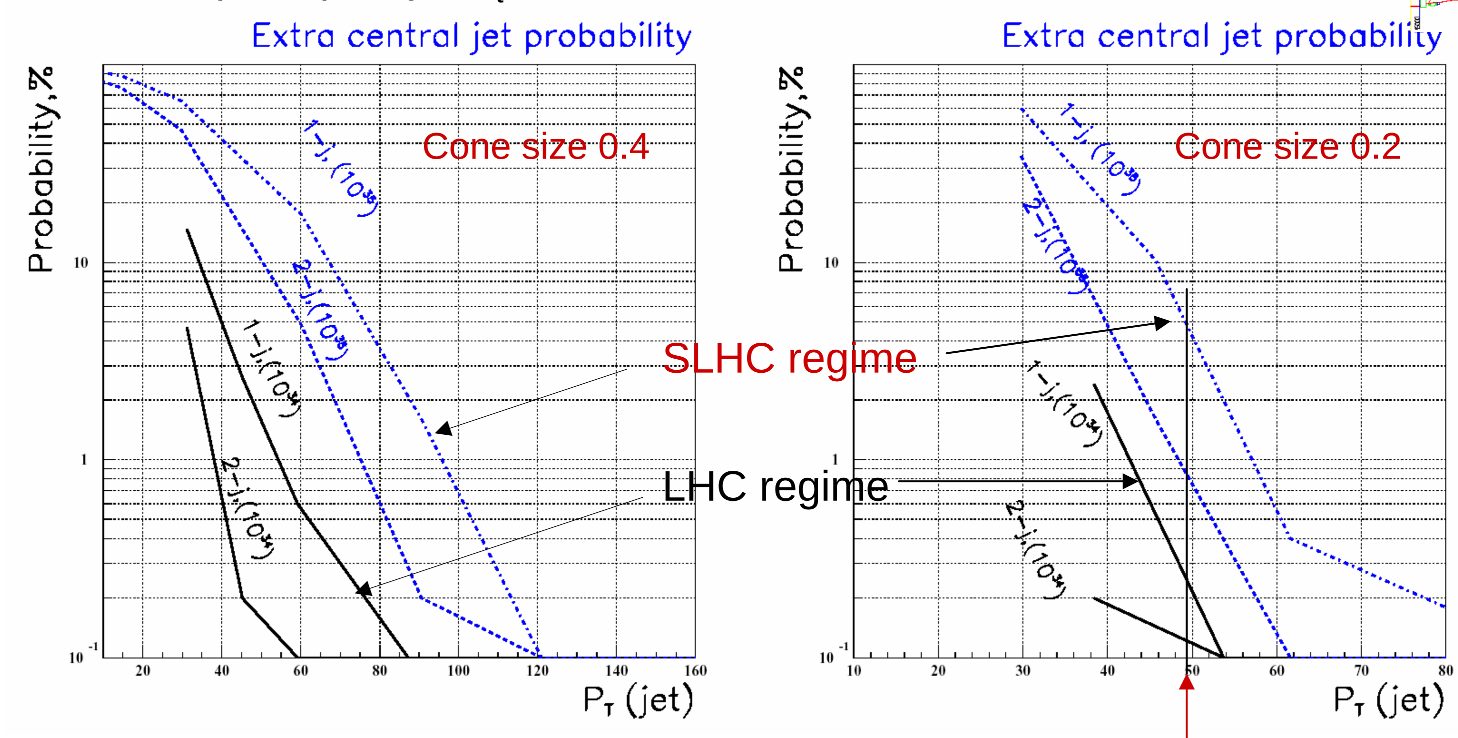
⇒ Method should still work at 10^{35}: increase forward calo granularity, reduce jet reconstruction cone from 0.4 to ~ 0.2, optimise jet algorithms to minimize false jets

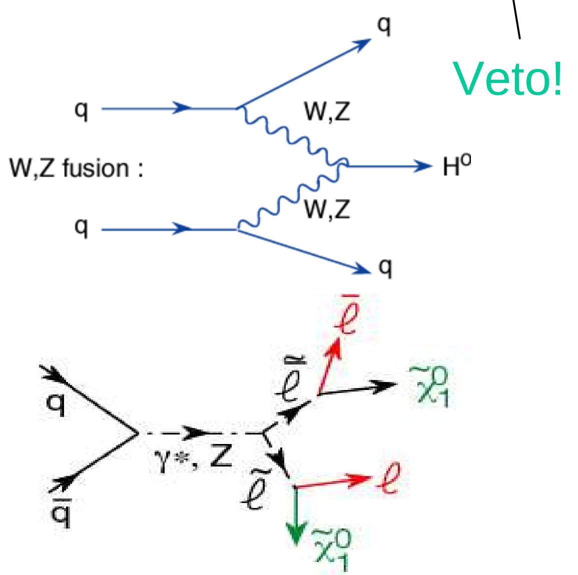
Extra central jets from pile-up at 10^{35} cm^{-2} s^{-1}

"Central jet vetoing" is used to enhance S/B in many types of (ew) searches, jets from event pile-up spoil the method!



Probability of having 1 or 2 extra central jets ($|\eta| < 2$) from pile-up vs jet E_t for two cone sizes





ATLAS full simulation jets at $|\eta| < 2$

⇒ Method should still work at 10^{35} provided jet threshold increased from ~ 30 GeV at LHC to ~ 50 GeV at SLHC - but loss of efficiency on signals

Expectations for detector performances at 10^{35} cm^{-2} s^{-1} - overview

- Electron identification and rejections against jets, E_t = 40 GeV, ATLAS full simulation

L (cm^{-2} s^{-1})	Electron efficiency	Jet rejection
10^{34}	81%	10600±2200
10^{35}	78%	6600±1130

- Electron resolution degradation due to pile-up, at 30 GeV: 2.5% (LHC) → 3.5% (SLHC)

- b-jet tagging performance: rejection against u-jets for a 50% b-tagging efficiency

p_T (GeV)	R_u at 10^{34} cm^{-2}s^{-1}	R_u at 10^{35} cm^{-2}s^{-1}
30-45	33	3.7
45-60	140	23
60-100	190	27
100-200	300	113
200-350	90	42

Preliminary study, ATLAS

⇒performance degradation at 10^{35} factor of ~ 8 - 2 depending on E_t

⇒ increase (pixel) granularity!

- Forward jet tagging and central jet vetoing still possible - albeit at reduced efficiencies reducing the cone size to ≈ 0.2

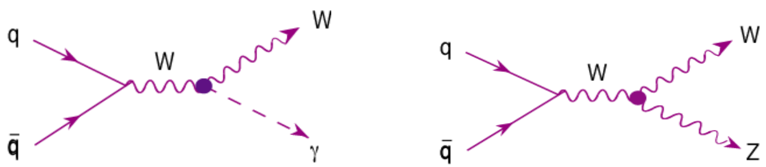
  probability of fake double forward tag is ~ 1% for E_{jet} > 300 GeV (|η| > 2)

  probability of ~ 5% for additional central jet for E_t > 50 GeV (|η| < 2)

ew physics, triple gauge boson couplings

In the SM TGC uniquely fixed, extensions to SM induce deviations

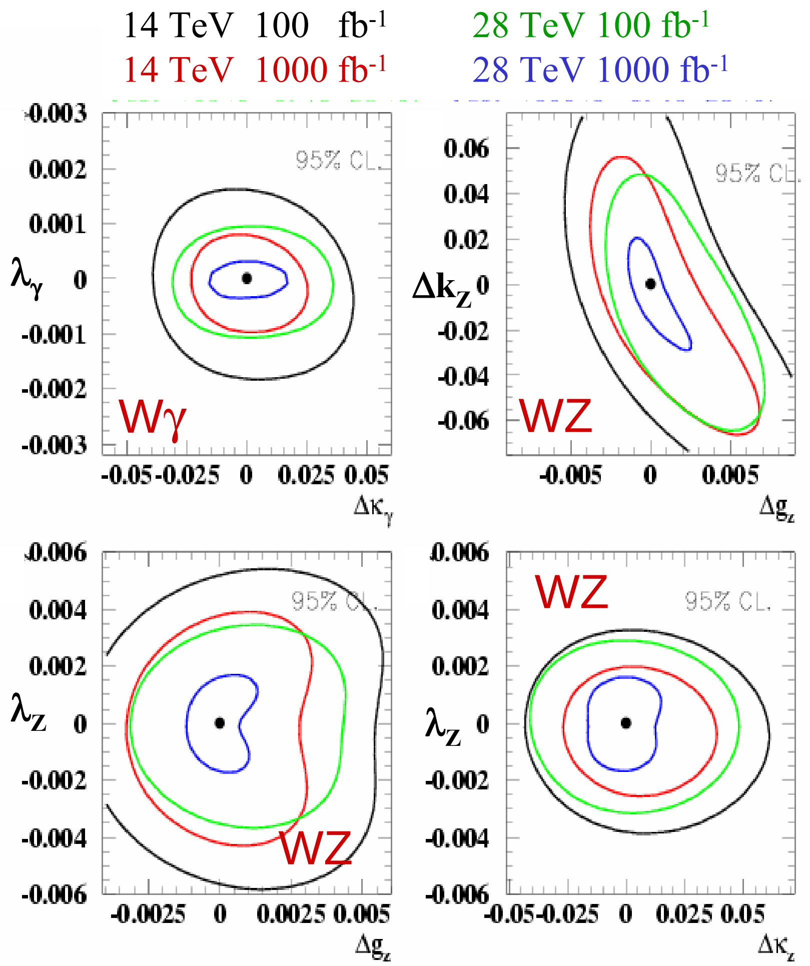
- At LHC the best channels are: $W\gamma \rightarrow l\nu\gamma$ and $WZ \rightarrow l\nu ll$ (need central jet veto!)



5 parameters describe these TGCs:
g_1^Z (1 in SM), $\Delta\kappa_Z$, $\Delta\kappa_\gamma$, λ_γ, λ_Z (all 0 in SM)
$W\gamma$ final state probes $\Delta\kappa_\gamma$, λ_γ and WZ probes g_1^Z, $\Delta\kappa_Z$, λ_Z
sensitivity to λ-couplings in events rates/σ_{tot},
to κ-couplings in angular distributions

- TGCs: a case where a luminosity increase by a factor ~10 is better than a center-of-mass energy increase by a factor ~ 2 (but jet vetoing needed…)

Correlations among parameters



➡ SLHC can bring sensitivity to λ_γ, λ_Z and g_1^Z to the ~ 0.001 level (of SM rad.corrections)

Higgs physics - new modes/larger reach

Increased statistics would allow:

- to look for modes not observable at the LHC for example:

$H_{SM} \rightarrow Z\gamma$ (BR ~ 10^{-3}), $H_{SM} \rightarrow \mu^+\mu^-$ (BR ~ 10^{-4}) - the muon collider mode!

$H^{\pm} \rightarrow \mu\nu$

to check couplings; H_{SM}, $H^{\pm}$ etc masses well known by this time!

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in channels like:

$A/H \rightarrow \mu\mu$, $A/H \rightarrow \tau\tau \rightarrow \mu$□, $A/H \rightarrow \tau\tau \rightarrow$ □/$\mu + \tau$–□□□

$A/H \rightarrow \chi^0_{□}\,\chi^0_{□} \rightarrow 4$ □/μ □□□

Specific examples for new modes:

$H_{SM} \rightarrow Z\gamma \rightarrow l^+l^-\gamma$ □□ $120 < M_H < 150$ GeV, LHC with 600 fb^{-1} signal significance: 3.5σ

SLHC (two exps, 3000 fb^{-1} each) signal of 11σ

$H_{SM} \rightarrow \mu^+\mu^-$ □□ $120 < M_H < 140$ GeV, LHC (600 fb^{-1}) significance: $< 3.5\sigma$,

SLHC (two exps, 3000 fb^{-1} each) $\sim 7\sigma$

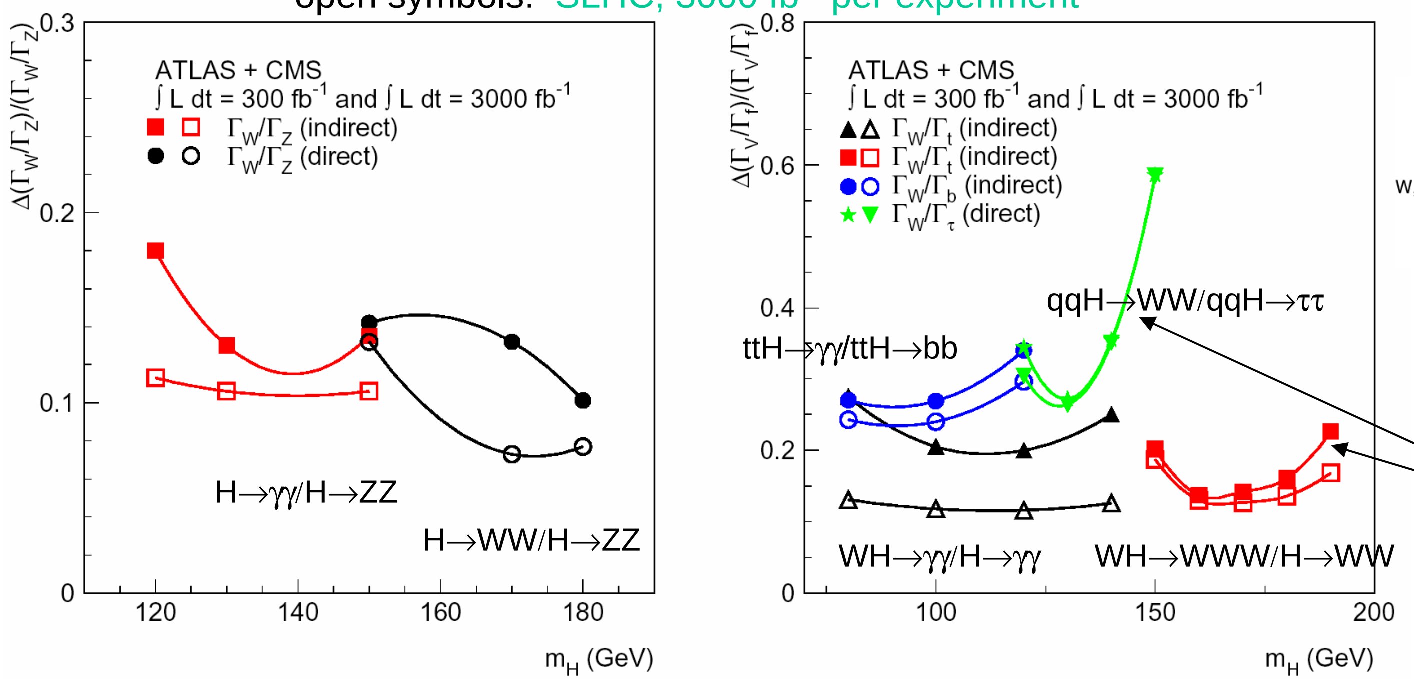
Improvements in SM Higgs couplings

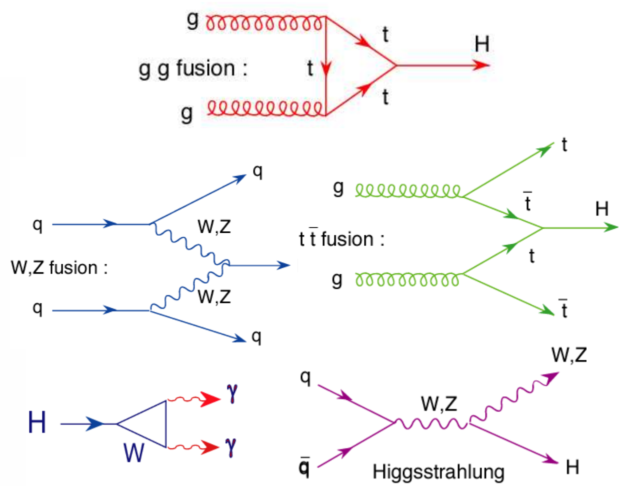
Combining different production mechanisms and decay modes get ratios of Higgs couplings to bosons and fermions - independent of uncertainties on σ_{tot}^{Higgs}, Γ_H and integrated luminosity, it is mostly statistics limited at LHC

$\Rightarrow$ should benefit from LHC $\rightarrow$ SLHC luminosity increase, provided detector performances are not significantly reduced

full symbols: LHC, 300 fb^{-1} per experiment

open symbols: SLHC, 3000 fb^{-1} per experiment



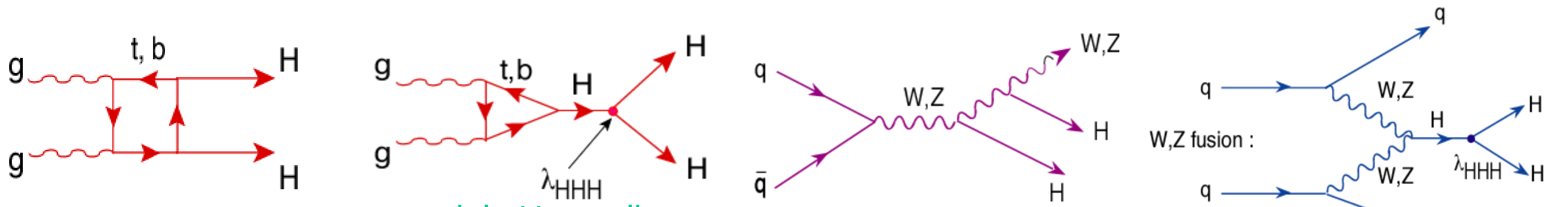


syst.- limited at LHC (σ_{th}),
~ no improvement at SLHC

At the SLHC the ratios of Higgs couplings should be measurable with a ~ 10% precision

Higgs pair production and self coupling

Higgs pair production can proceed through two Higgs bosons radiated independently (from VB, top) and from trilinear self-coupling terms proportional to λ_{HHH}^{SM}



+….

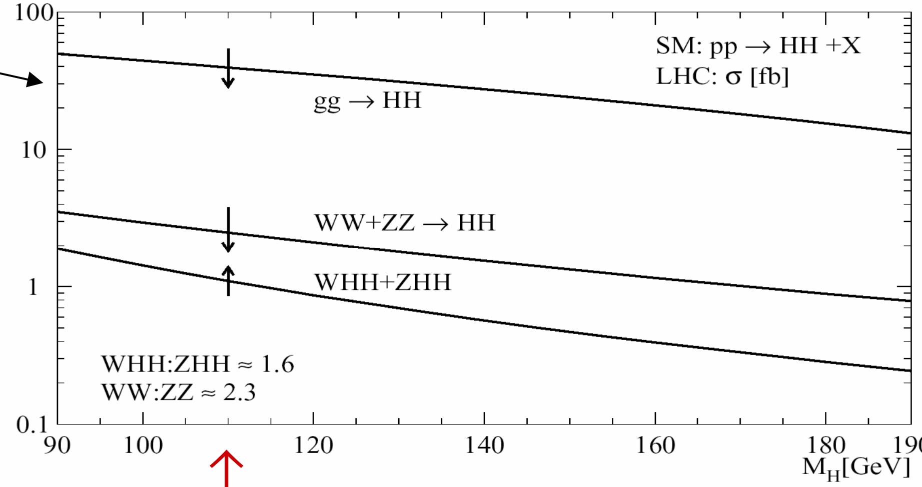
triple H coupling:
$\lambda_{HHH}^{SM} = 3m_H^2/v$

very small cross sections, hopeless at LHC (10^{34}), some hope at SLHC
channel investigated, $170 < m_H < 200$ GeV (ATLAS):

$gg \rightarrow HH \rightarrow W^+ W^- W^+ W^- \rightarrow l^\pm \nu jj \; l^\pm \nu jj$
with same-sign dileptons - very difficult!

➡ total cross section and λ_{HHH} determined with ~ 25% statistical error for 6000 fb^{-1} provided detector performances are comparable to present LHC detectors

cross sections for Higgs boson pair production in various production mechanisms and sensitivity to λ_{HHH} variations



arrows correspond to variations of λ_{HHH} from 1/2 to 3/2 of its SM value

Higgs self couplings (II)

ATLAS made a preliminary study for SLHC (10^{35} cm^{-2} s^{-1}) indicating that a first measurement of λ_{HHH} is possible - provided detector performances are comparable to the expectations for LHC detectors - for a Higgs in the $170 < m_H < 200$ GeV range

Channel considered: $gg \rightarrow HH \rightarrow W^+ W^- W^+ W^- \rightarrow l^\pm \nu jj\ l^\pm \nu jj$ with same-sign dileptons

Backgrounds considered: $t\bar{t}$ + jets, WZ+ jets, $t\bar{t}$ W, WWWjj, $t\bar{t}$ $t\bar{t}$

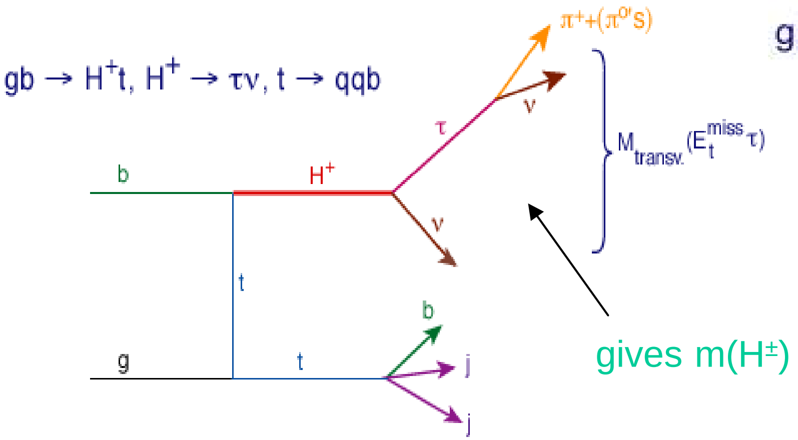
lepton cuts: $p_t > 20$ GeV, $|\eta| < 2.4$
jet cuts: ≥ 4 jets with $E_t > 20$ GeV, of which two with $E_t > 30$ GeV, $|\eta| < 2.4$
veto b-tagged events
veto events with more than 6 jets with $E_t > 30$ GeV

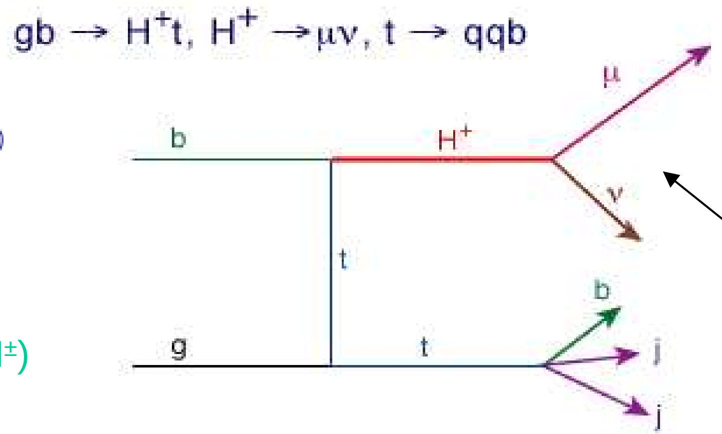
expected number of signal and background events for 6000 fb^{-1}

m_H	signal	$t\bar{t}$	$W^\pm Z$	$W^\pm W^+ W^-$	$t\bar{t}W^\pm$	$t\bar{t}\,t\bar{t}$	$S/\sqrt{B}$
170 GeV	350	90	60	2400	1600	30	5.4
200 GeV	220	90	60	1500	1600	30	3.8

$\Rightarrow$ total cross section and λ_{HHH} determined with ~ 25% statistical error
this is a counting experiment, thus requires very good knowledge of backgrounds

$H^{\pm} \to \mu\tilde{\nu}$ a □□□MSSM □□□□□□□□□□





← under study

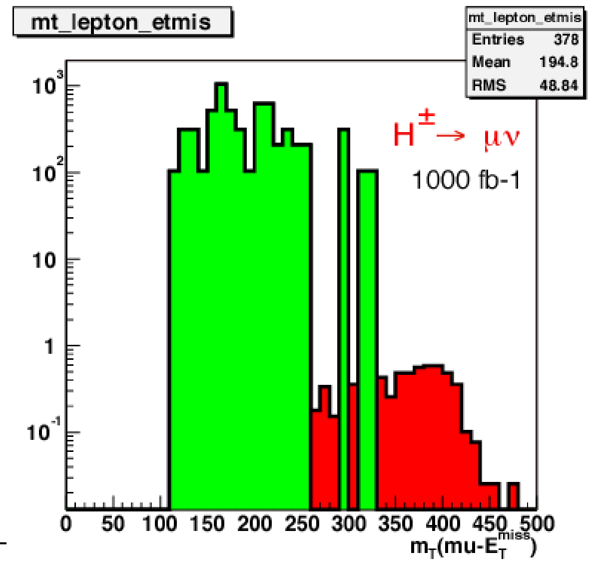
not observable at LHC with 300 fb^{-1}

Comparison of these two rates should give $g_{H\tau\nu}/g_{H\mu\nu} = m_\tau/m_\mu$ ⇒ □□□□□f□□□□□□□□□□□□□□ $\propto m_{fermion}$

Preliminary results (R. Kinnunen):
for $m(H^{\pm})$ = 400 GeV, $tg\beta$ = 40, 1000 fb^{-1}
$\sigma(H^{\pm})$ = 219 fb (T. Plehn), BR = 0.00049, σ*BR = 0.073fb
(including $t \to W \to$ hadrons)

for p_t^{μ} > 100 GeV, E_t^{miss} > 150 GeV, muon isolation, W mass,
one b-jet tag, veto on 4th central jet:
⇒ 5 events left, no bkgd from tt and W+jets - hopeful!
(more studies of bkgd needed)

$H^{\pm} \to \mu\nu$

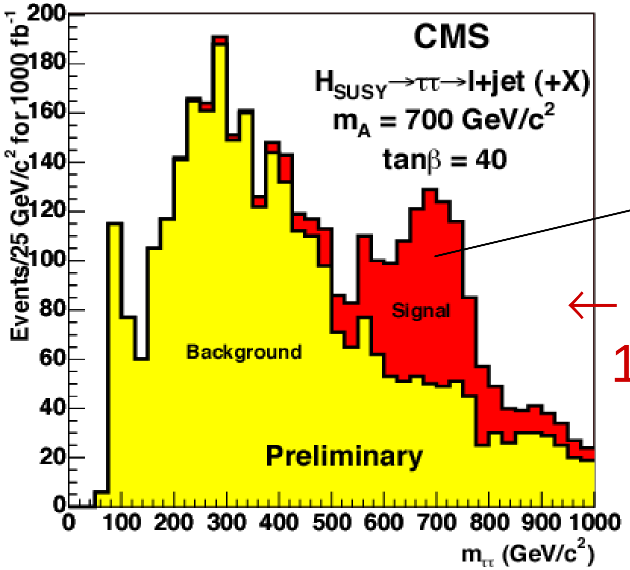


SLHC: improved reach for heavy MSSM Higgs bosons

The order of magnitude increase in statistics with the SLHC should allow to extend the discovery domain for massive MSSM Higgs bosons A,H,$H^{\pm}$

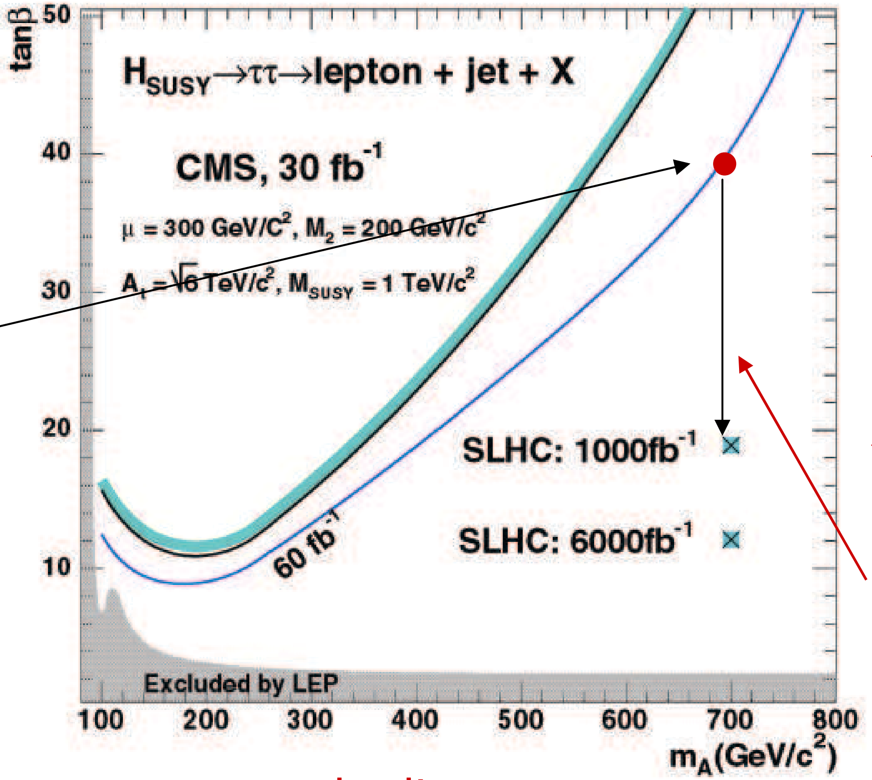
example: A/H $\rightarrow \tau\tau \rightarrow$ lepton + τ-jet, produced in bbA/H

Peak at the 5σ limit of observability at the LHC greatly improved at SLHC, fast simulation, preliminary:



S. Lehti

← SLHC 1000 fb^{-1}



←LHC 60 fb^{-1}

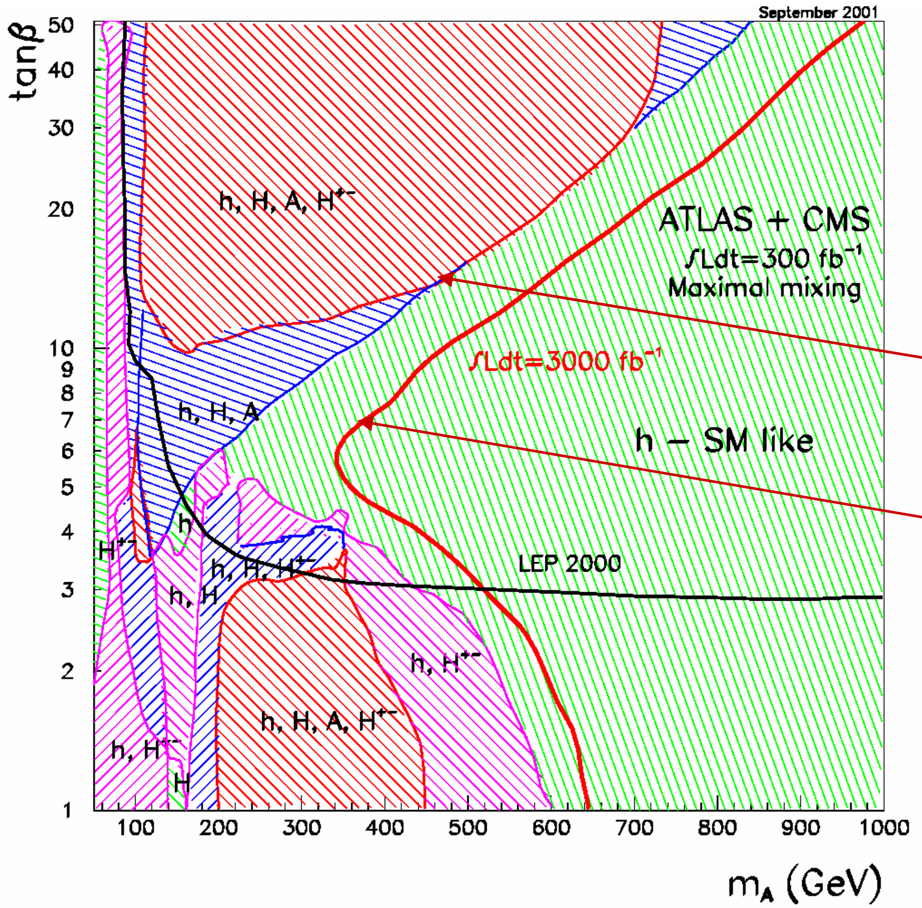
←SLHC 1000 fb^{-1}

gain in reach

b-tagging performance comparable to present one required!

SLHC: improved reach for MSSM Higgs bosons - overview

MSSM parameter space regions for > 5σ discovery for the various Higgs bosons, 300 fb^{-1} (LHC), and expected improvement - at least two discoverable Higgs bosons - with 3000 fb^{-1} (SLHC) per experiment, both experiments combined.



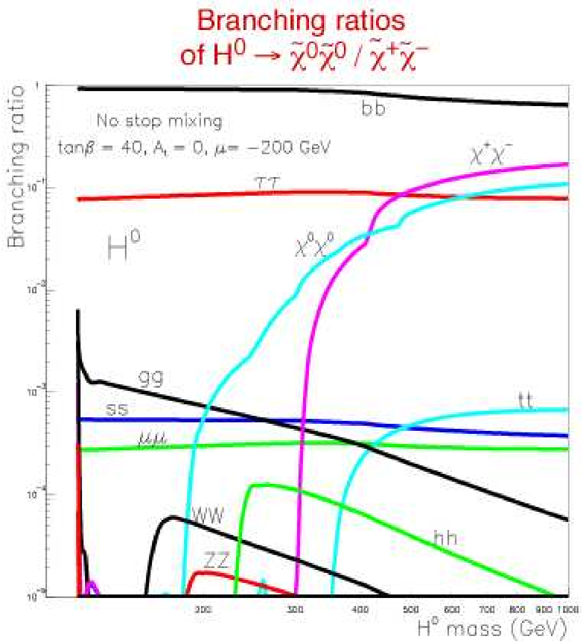
green area: region where only one (the h, ~ SM-like) among the 5 MSSM Higgs bosons can be found (assuming only SM decay modes)

LHC contour, 300 fb^{-1}

SLHC contour, 3000 fb^{-1}

at least one heavy Higgs discoverable up to here

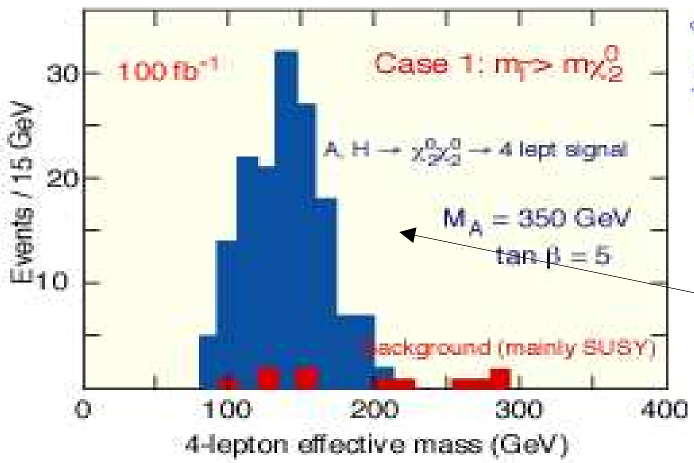
Improved reach for A/H decaying to neutralinos to 4 isolated leptons

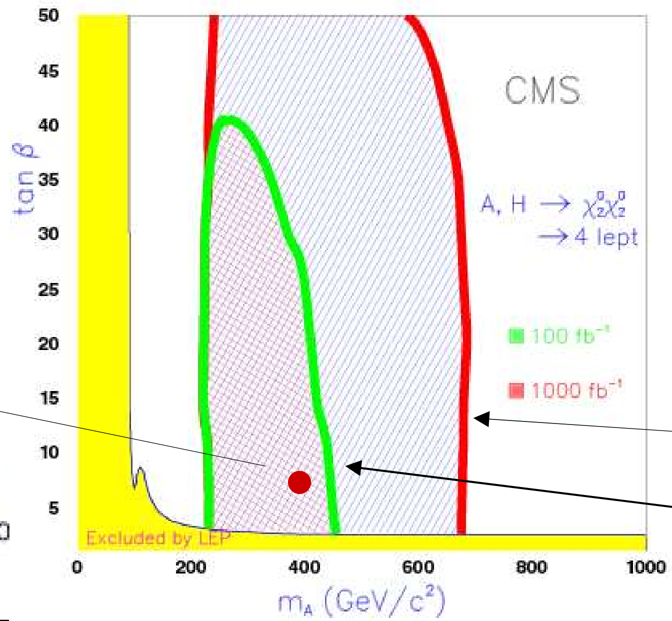


$A/H \to \chi^0{}_2\,\chi^0{}_2 \to 4\ l^{\pm}{}_{isol}$ ⇒ trigger should be easy

Signal: 4 isolated leptons (+ E_t^{miss}),
main bkgd: SUSY, reducible by jet multiplicity, E_t^{miss}, p_t^{lept} etc
cuts to be optimized in different parameter space regions

example:
MSSM parameters: M_2 = 120 GeV, M_1 = 60 GeV, μ = -500 GeV,
m(sleptons) = 250 GeV, m(squarks, gluinos) = 1 TeV





F. Moortgat

CMS, very preliminary
important as complements
parameter space explorable
through SM decay modes!

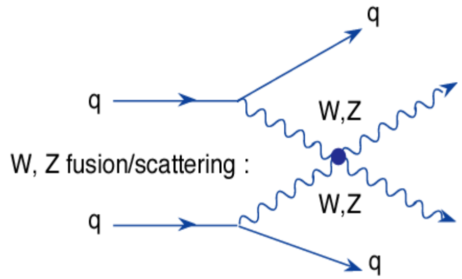
SLHC, 1000 fb^{-1}

LHC, 100 fb^{-1}

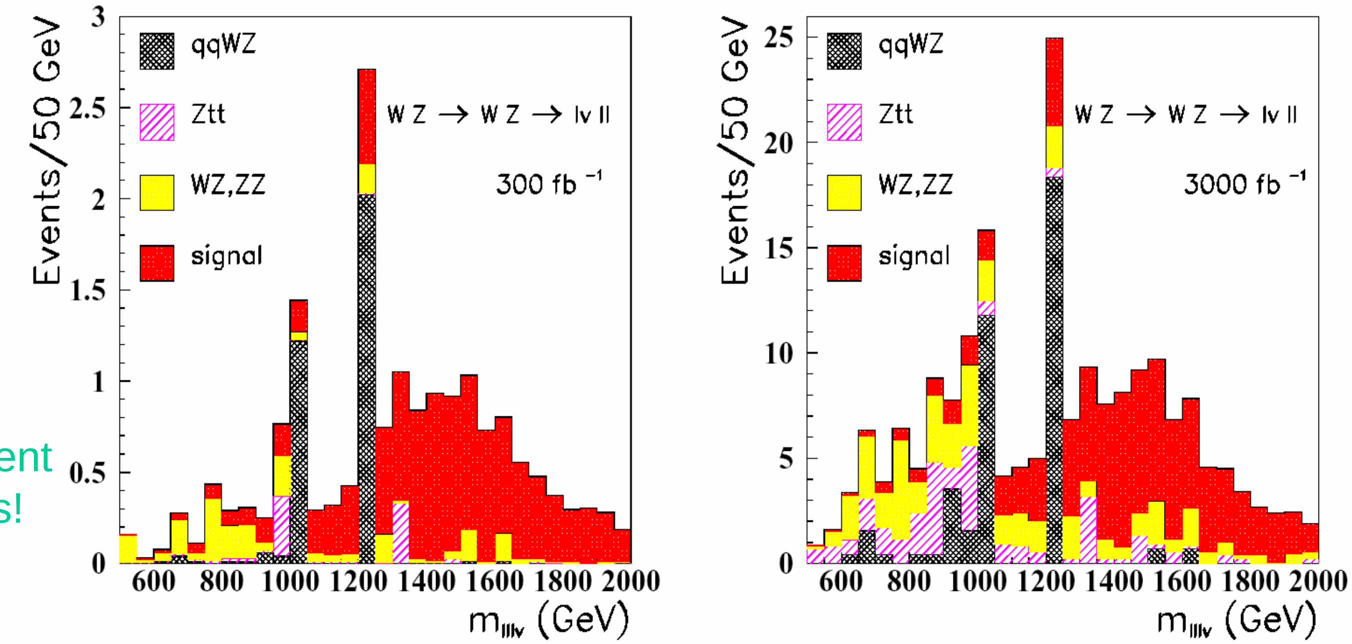
WZ vector resonance in VB scattering

If no (light) Higgs, possibly a new strong interaction regime in $V_L V_L$ scattering, which may be resonant or not;
example with a resonant model:

Vector resonance (ρ-like) in $W_L Z_L$ scattering from Chiral Lagrangian model
M = 1.5 TeV, leptonic final states, 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



Note event numbers!

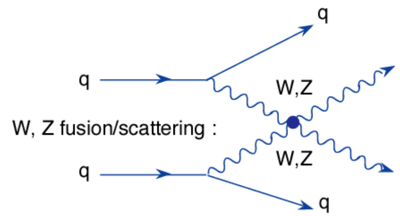
These studies require both forward jet tagging and central jet vetoing! Expected (degraded) SLHC performance is included

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

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

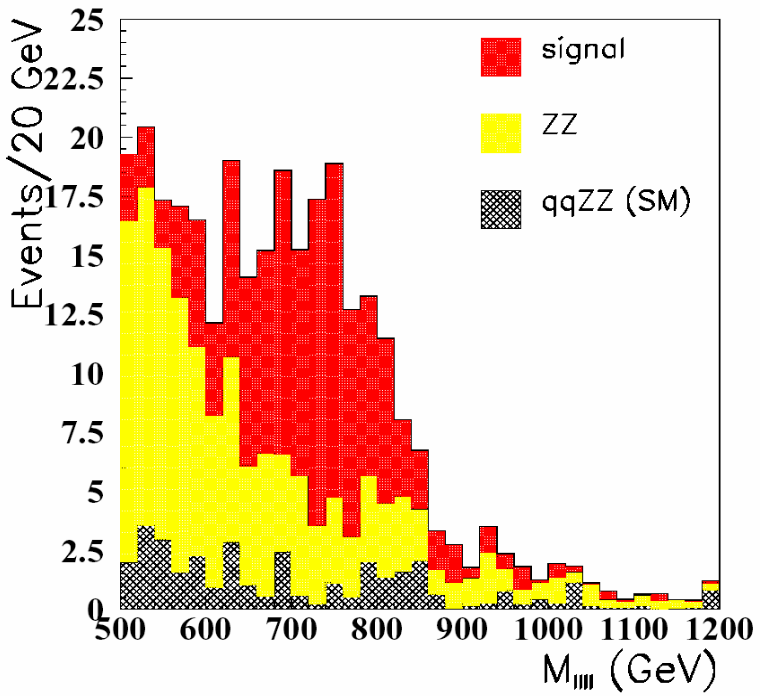
Scalar resonance in VB scattering

Scalar resonance in $W_L W_L$, $Z_L Z_L \rightarrow Z_L Z_L$ scattering from Chiral Lagrangian model
M = 0.75 TeV, 4-lepton final states, 3000 fb^{-1} (SLHC)



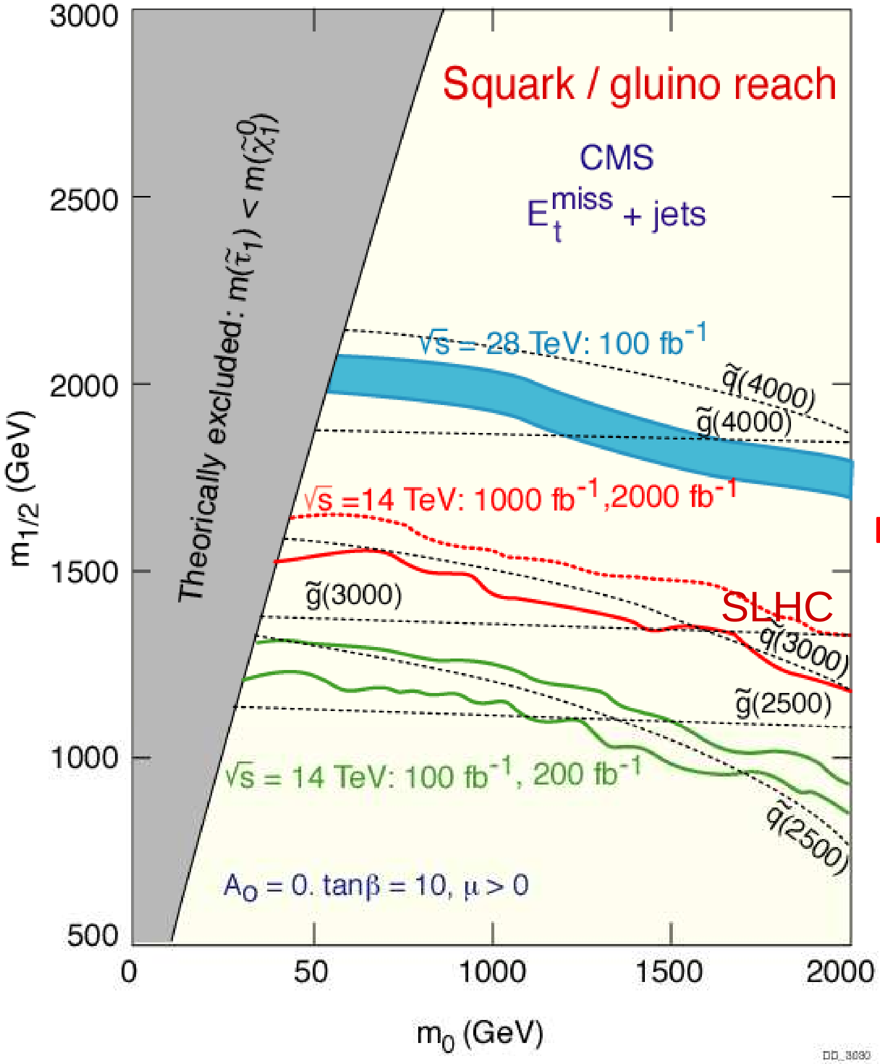
SM backgrounds: $qq \rightarrow qqZZ$, $qq \rightarrow ZZ$, $gg \rightarrow ZZ$

leptons: 4 leptons $p_t > 30$ GeV, two Z-compatible masses; 2 tagging jets with E > 400 GeV



3000 fb^{-1} (SLHC)
(not observable at LHC, cross section too small)

SUSY at SLHC/VLHC - mass reach



Notice advantage of a 28 TeV machine….

- Higher integrated luminosity brings an obvious increase in mass reach in squark, gluino searches, i.e. in SUSY discovery potential; not too demanding on detectors as very high E_t jets, E_t^{miss} are involved, large pile-up not so detrimental

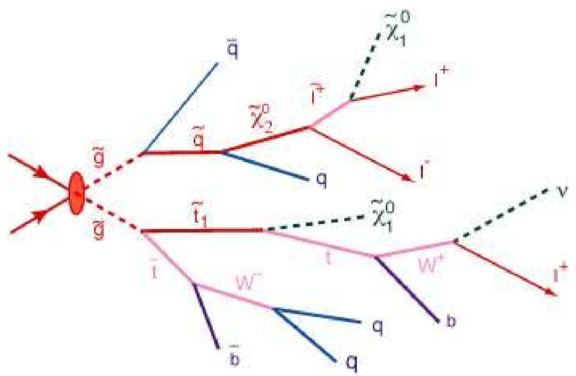
➡ with SLHC the SUSY reach is increased by ~ 500 GeV, up to ~ 3 TeV in squark and gluino masses (and up to ~ 4 TeV for VLHC)

- the main advantage of increased statistics should be in the sparticle spectrum reconstruction possibilities, larger fraction of spectrum, more precision, but this requires detectors of comparable performance to “present ones”

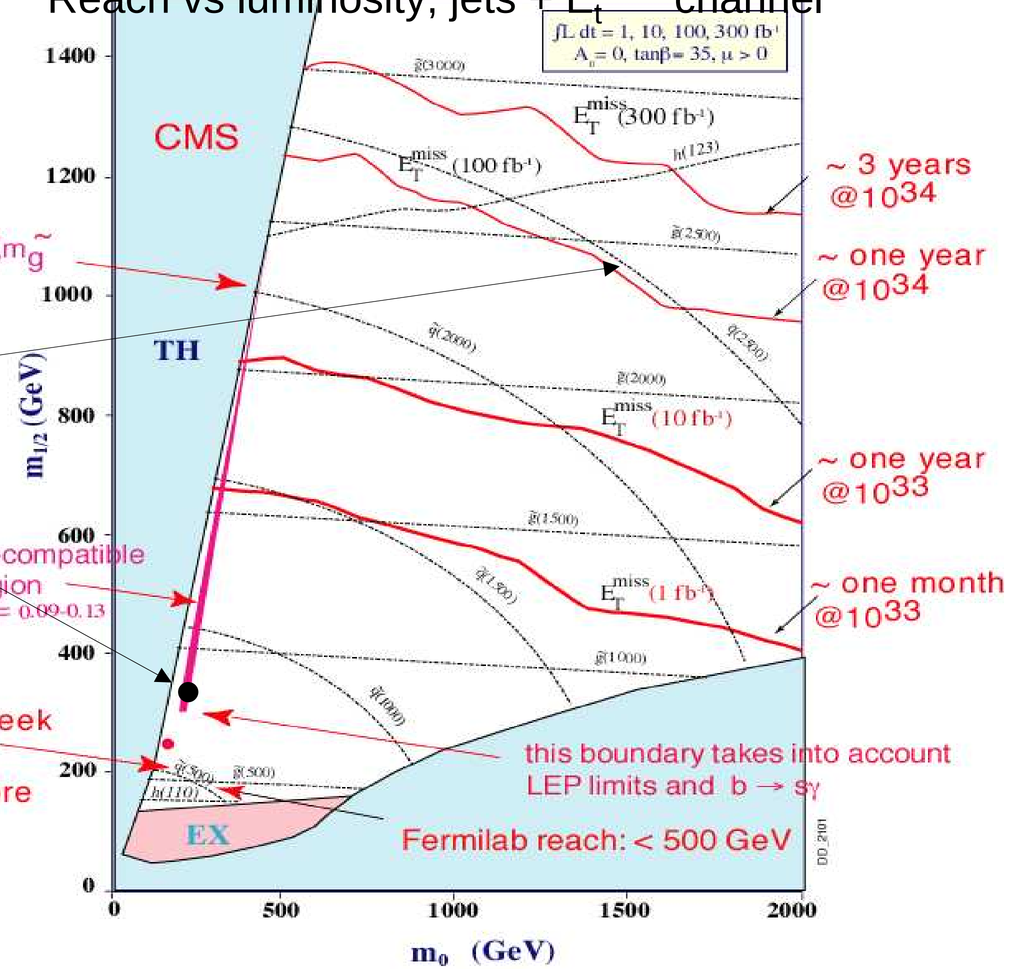
SUSY at SLHC

"Reach" means a > 5σ excess of events over known (SM) and assumed controlled backgrounds; discovering SUSY is one thing, understanding what is seen requires much more statistics!

Compare for ex. 100 fb^{-1} reach and sparticle reconstruction stat limited at 100 fb^{-1} at "point G" ($tg\beta$ = 20), as many topologies required, leptons, b-tagging…



Reach vs luminosity, jets + E_t^{miss} channel



This is domain where SLHC statistics may be decisive!
but LHC-type detector performance needed

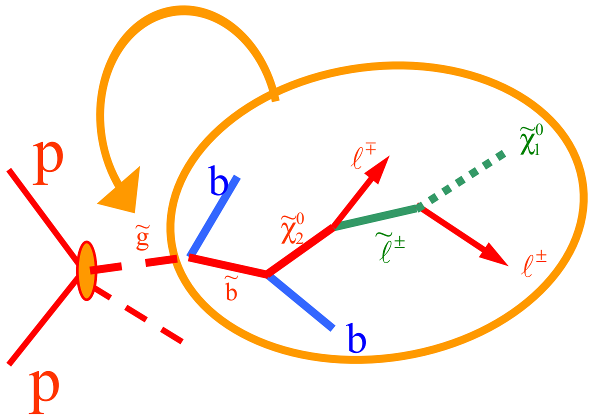
Sparticle reconstruction at LHC - rate limited

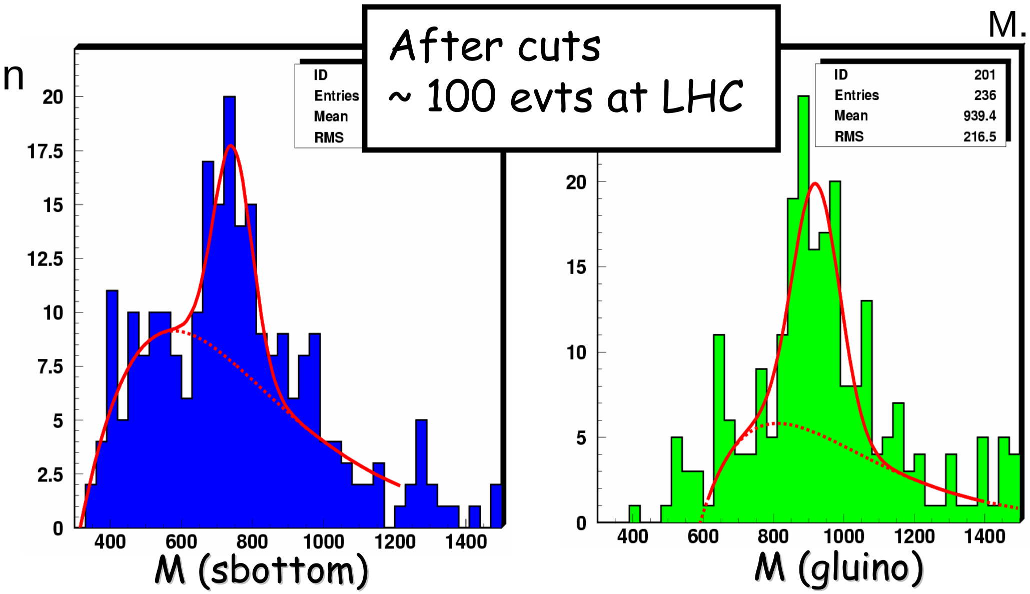
Proposed Post-LEP Benchmarks for Supersymmetry (hep-ph/0106204)

Model	A	B	C	D	E	F	G	H	I	J	K	L	M
$m_{1/2}$	600	250	400	525	300	1000	375	1500	350	750	1150	450	1900
m_0	140	100	90	125	1500	3450	120	419	180	300	1000	350	1500
$\tan\beta$	5	10	10	10	10	10	20	20	35	35	35	50	50
sign(μ)	+	+	+	−	+	+	+	+	+	+	−	+	+
$\alpha_s(m_Z)$	120	123	121	121	123	120	122	117	122	119	117	121	116
m_t	175	175	175	175	171	171	175	175	175	175	175	175	175

M. Chiorboli

Sparticle reconstruction from decay chain

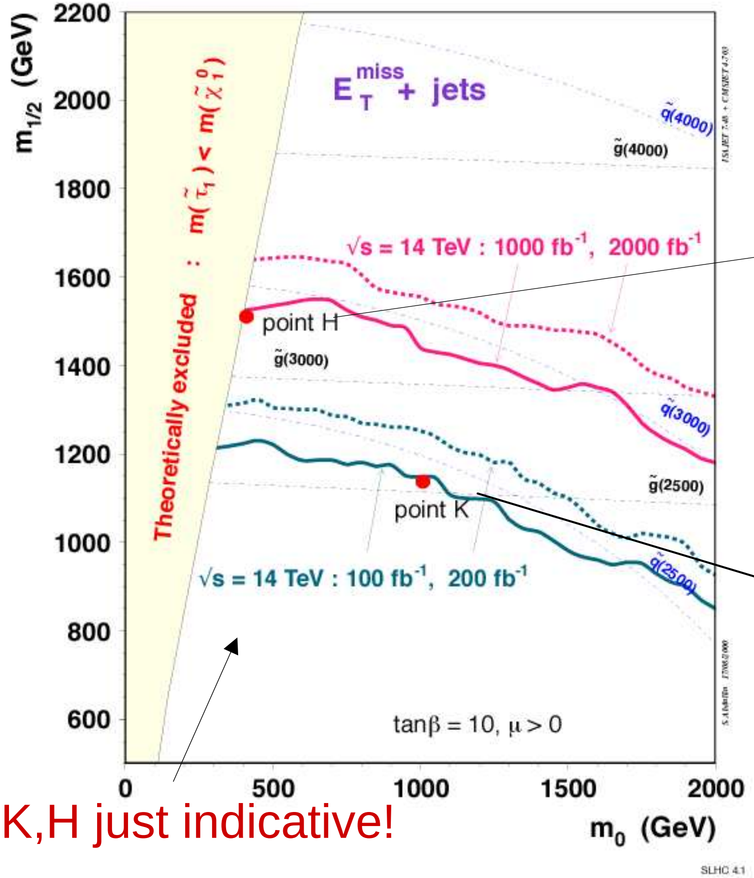




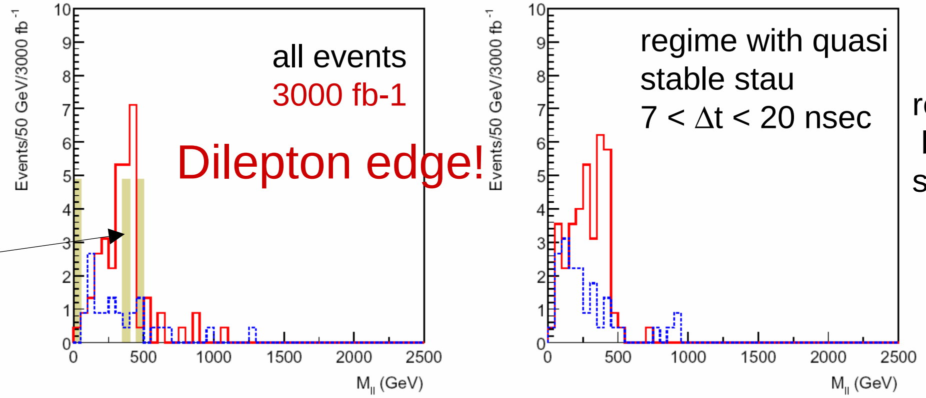
LHC
100 fb-1

Reconstruction of the sbottom (at 770 GeV) and the gluino (at 920 GeV) is obviously statistics limited! But b-tagging performance must be maintained in SLHC regime

What SLHC stat can bring

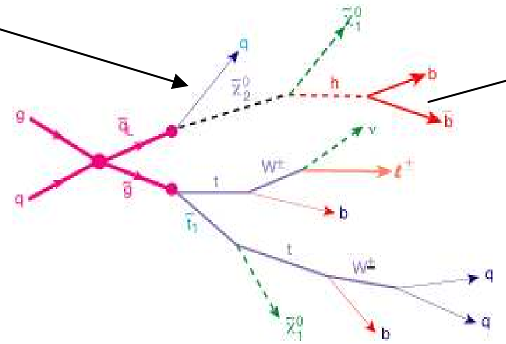


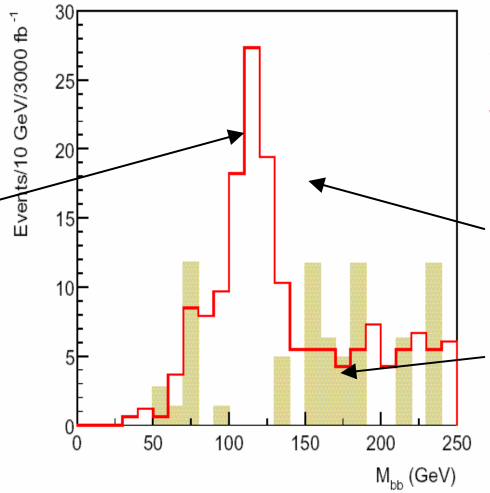
K,H just indicative!



red: same flavor leptons,
blue: different flavors;
shaded: SM bkgd

Point K:
m(squark,gluino) > 2 TeV





SLHC
3000 fb-1

h → bb
signal

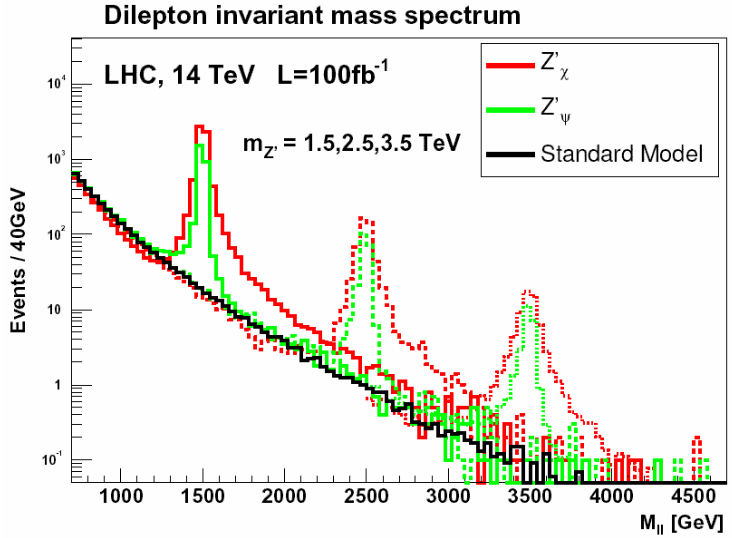
SM bkgd

High momentum leptons, but lot of stat needed to reconstruct sparticle mass peaks from edge regions! SLHC luminosity should be crucial, but also need for jets, b-tagging, missing E_t i.e. adequate detector performances (calorimetry, tracker) to really exploit the potential of increased statistics at SLHC…..

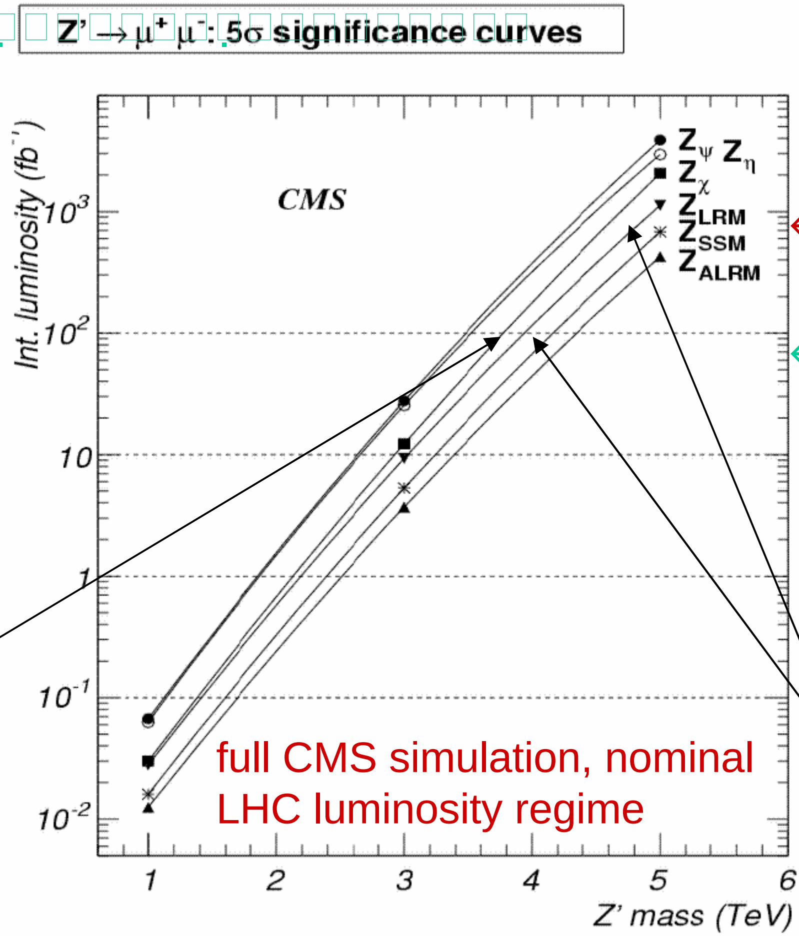
New gauge bosons, Z' → μμ reach at LHC

Additional heavy gauge bosons (W, Z-like) are expected in various extensions of the SM symmetry group (LR, ALR, E_6, SO(10)…..),

Examples of Z' peaks in some models:



LHC discovery potential for Z' → μμ



← SLHC 1000 fb^{-1}

← LHC 100 fb^{-1}

full CMS simulation, nominal LHC luminosity regime

~ 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

New gauge bosons, SLHC vs LHC

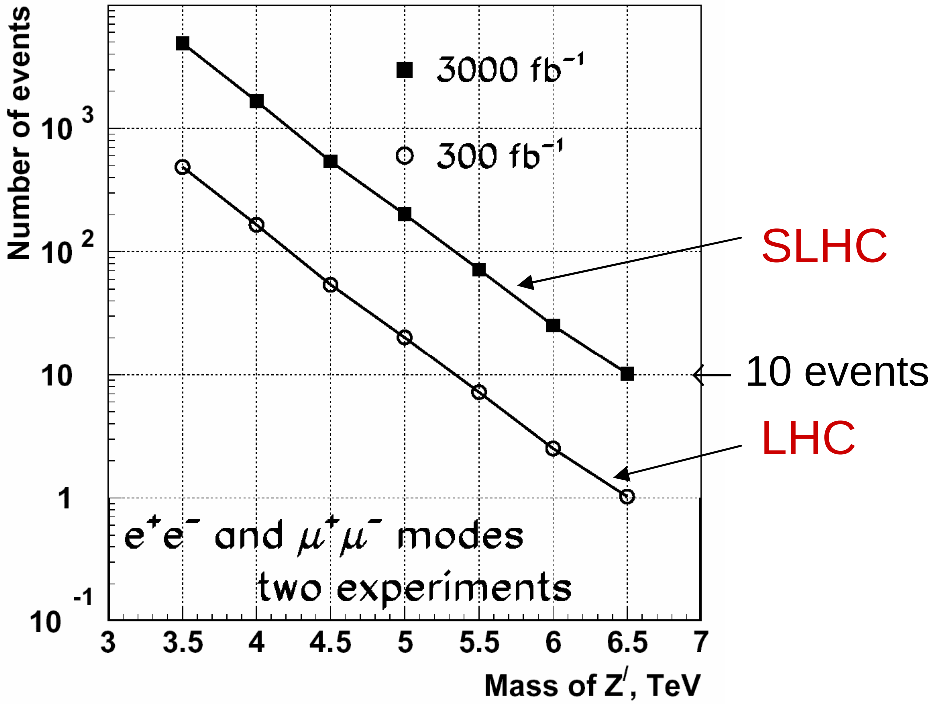
Improvement in mass reach in a specific model: the sequential Z' model

sequential Z' model, Z' production - assuming same BR as for SM Z - and Z' width

Z' mass (TeV)	1	2	3	4	5	6
$\sigma(Z' \to e^+e^-)(fb)$	512	23.9	2.5	0.38	0.08	0.026
$\Gamma_{Z'}$ (GeV)	30.6	62.4	94.2	126.1	158.0	190.0

Acceptance, e/μ reconstruction eff., resolution, effects of pile-up noise at 10^{35}, ECAL saturation included, CMS study

For detecting high mass objects electrons more usefull than muons - thanks to better resolution, for F-B asymmetry both e and μ



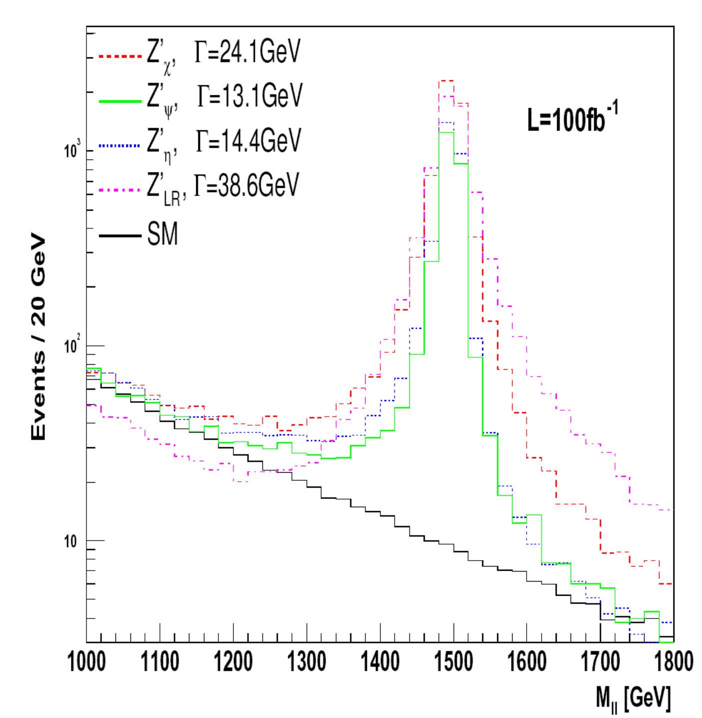
With 10 events to claim discovery, reach improves from ≈ 5.3 TeV (LHC, 600 fb^{-1})

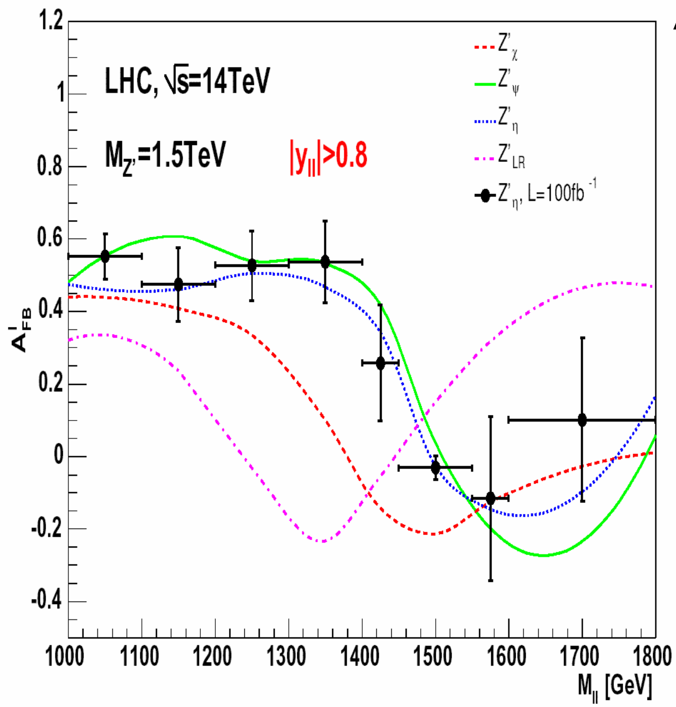
to ≈ 6.5 TeV (SLHC, 6000 fb^{-1}) (≈ 8 TeV for VLHC, 300 fb^{-1})

New Z’ gauge bosons, differentiating among the models

Discovery potential for Z’ □□□□□□□□□□□□□□□□□□, attempt to discriminate among various models, on basis of natural width or F-B asymmetries

fast detector simulation, p_t^{lept} > 20 GeV, $|\eta^{lept}|$ < 2.5





A.S. Nicollerat

← LHC 100 fb^{-1}

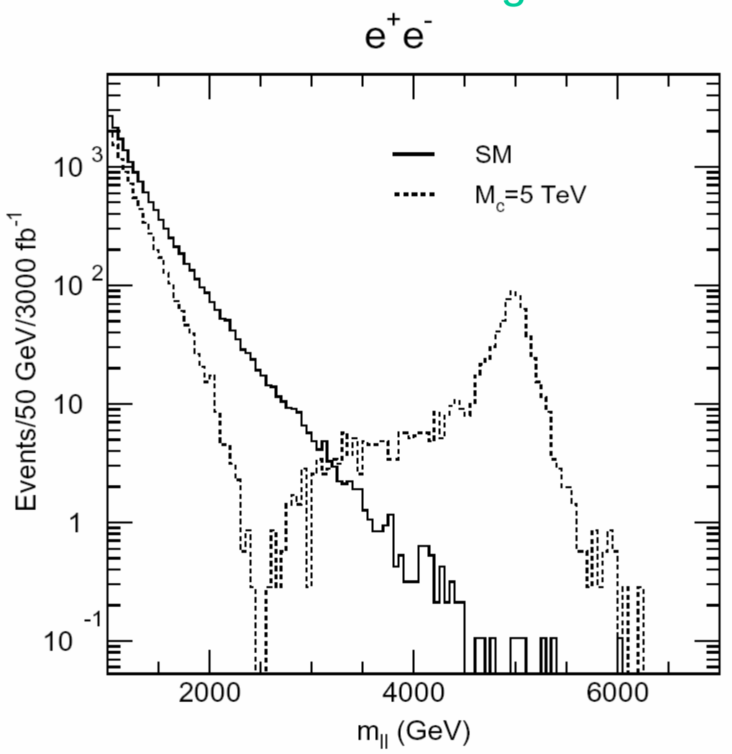
reach up to ~ 5 TeV, discrimination up to ~ 2.5 TeV here SLHC statistics would help!

ee pairs with ~1% mass resolution better than μμ for natural width measurement

μμ pairs better than ee for forward-backward angular asymmetry measurement, less affected by radiative effects

Extra dimensions, TeV^{-1} scale model

Theories with extra dimensions - with gravity scale ~ ew scale - lead to expect characteristic new signatures/signals at LHC/SLHC; various models: ADD, ABQ, RS…



Example: two-lepton invariant mass, TeV^{-1} scale extra dim model (ABQ-type, one "small" extra dim. $R_c = 1/M_c$) with M_c = 5 TeV, 3000 fb^{-1}

(LEP requires Mc > 4 TeV)

peak due to first γ, Z excitation at ~ M_c ;

note interference between γ, Z and KK excitations $\gamma^{(n)}$, $Z^{(n)}$, thus sensitivity well beyond direct peak observation from dσ/dM (background control!) and angular distributions

➡ reach ~ 6 TeV for 300 fb^{-1} (LHC), ~ 7.7 TeV for 3000 fb^{-1} from direct observation

indirect reach (from interference) up to ~ 10 TeV at LHC, 100 fb^{-1}

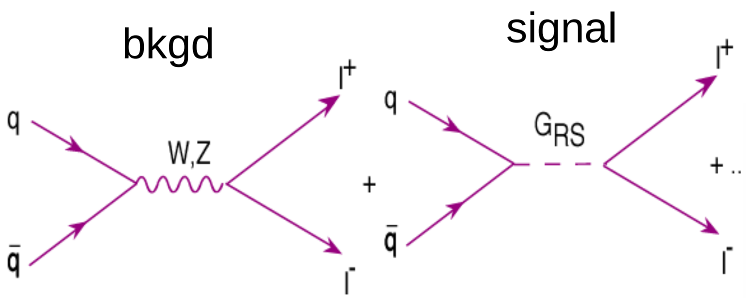
~ 14 TeV for SLHC, 3000 fb^{-1}, e + μ

10σ

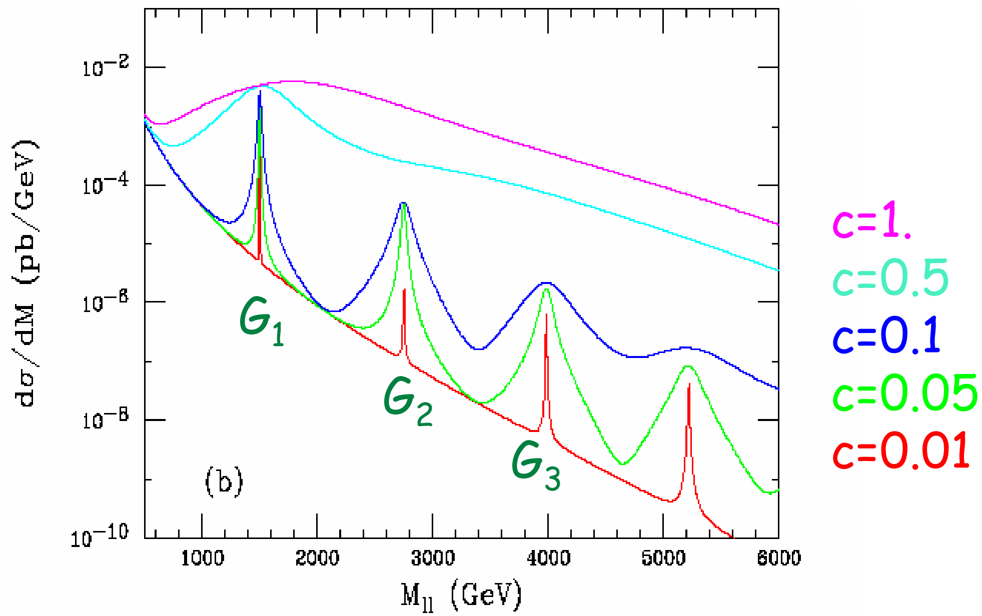
Extra dimensions, Randall-Sundrum model

Direct production of a R-S graviton at weak-scale mass could result in a striking heavy (and narrow - depending on coupling) dilepton or diphoton signal with possibly higher mass recurencies within reach

prod.: pp $\rightarrow G_{RS} \rightarrow ee/\mu\mu/\gamma\gamma$ (□□□□ 2!); ee and $\gamma\gamma$ has much better resolution than $\mu\mu$;

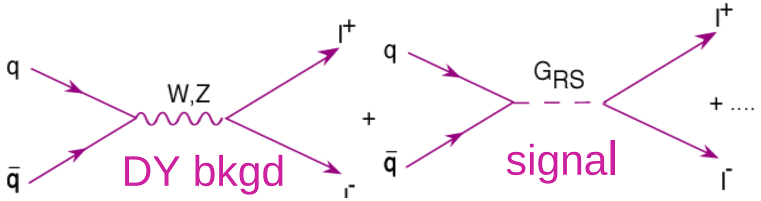


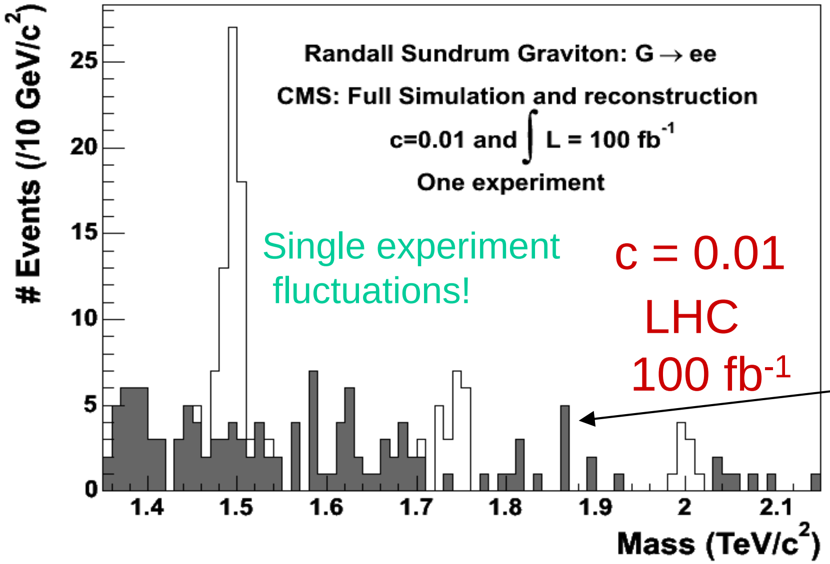
H.Davoudiasl, J.Hewett, T.Rizzo, hep-ph/0006041



Randall-Sundrum model, LHC regime

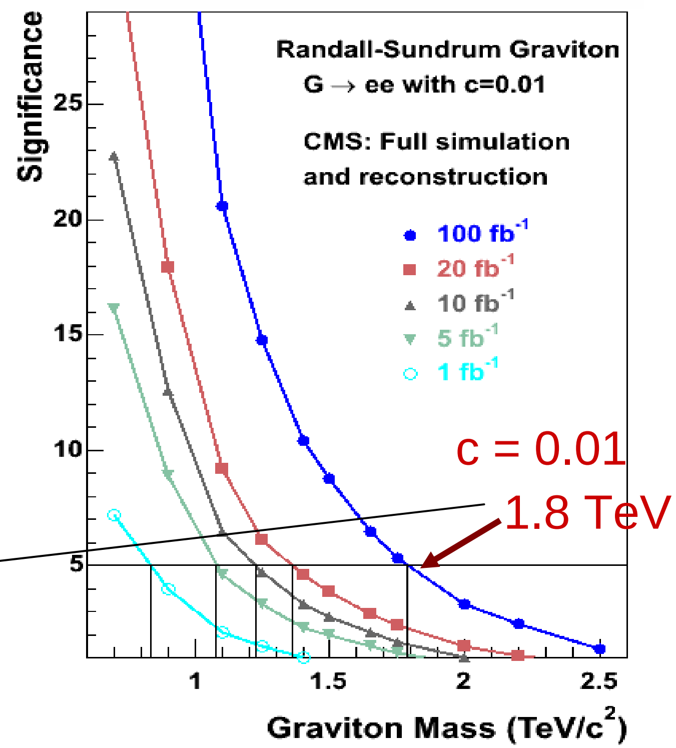
$pp \to G_{RS} \to ee$ full simulation and reconstruction chain in CMS,
2 electron clusters, $p_t > 100$ GeV, $|\eta| < 1.44$ and $1.56 < |\eta| < 2.5$, el. isolation, $H/E < 0.1$, corrected for saturation from ECAL electronics (big effect on high mass resonances!)





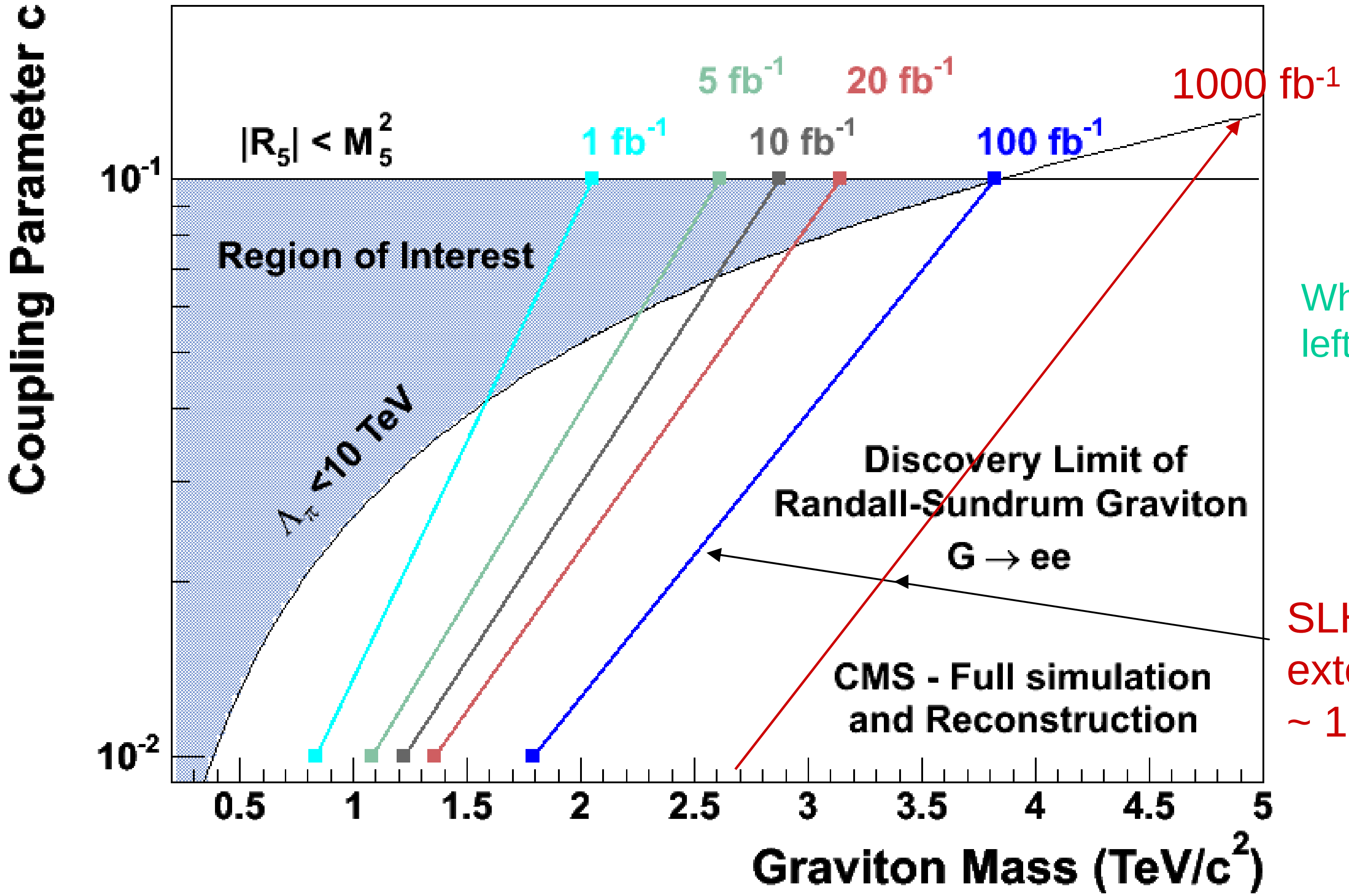
C. Collard

$$S = 2(\sqrt{N_S + N_B} - \sqrt{N_B}).$$



LHC stat limited! A factor ~ 10 increase in luminosity obviously beneficial (SLHC!) for mass reach - increased by 30% - and to differentiate a Z' (spin = 1) from G_{RS} (spin = 2)

R-S model, reach



Whole of plane th-allowed, left part favored

SLHC with 1000 fb^{-1} extends the reach by ~ 1 TeV

General remarks on desirability for detector upgrades (I)

- High mass searches/TeV scale reach studies such as:
SUSY reach (squarks, gluinos), W', Z', Z_{KK}, R-S gravitons, LQ, extra dim monojets etc not much affected by instantaneous luminosity increase/higher pile-up, nor by some reduction in acceptance for leptons, say, $|\eta| < 2.5 \rightarrow |\eta| < 2.0$, as heavy objects are centrally produced; good tracker still needed for muon momentum resolution and electron identification (E/p)

- There are however important topics which would benefit greatly from the ~ 300 fb^{-1} to 3000 fb^{-1} increase, but depend on forward jet tagging and/or central jet veto techniques to suppress backgrounds:

  $pp \rightarrow qqH$, qqVV (heavy Higgs, MSSM Higgs, resonant or non-resonant W_L , Z_L scattering)

  direct slepton pair production ($\rightarrow$ 2 leptons), mass reach potentially increases from ~ 350 GeV $\rightarrow$ 450 GeV

  chargino-neutralino direct pair production ($\rightarrow$ 3 leptons)

  precision measurements of TGC, QGC …….

this requires maintaining present calorimetric angular coverage but with preferably improved granularity and new detector techniques (quartz fibers and clading? or…) to sustain radiation damage

General remarks on desirability for detector upgrades (II)

- b-tagging capability - probably most difficult to maintain at present (expected) level of performance would be most desirable,
  to increase the SUSY spectrum coverage, for stop, sbottom (especially in case of "inverted mass hierarchy" where these could be the only observable sparticles….),
  for precision measurements on SM Higgs BR's,
  to extend MSSM Higgs searches in bbA/H, $tbH^{\pm}$ etc final states
  rare top decays (FCNC) $t \to u/c + \gamma/Z$, rare $B^{o}_{s,d}$ decays……

- τ-tagging capability, even more demanding on tracker/impact parameter/sec vertex measurements,
  for $A/H \to \tau\tau$, $H^{\pm} \to \tau\nu$;
  for SUSY/stau spectroscopy (at large tgβ neutralinos largely decay to tau-stau);
  GMSB with $\tilde{\tau}_1 \to \tau\ G_{3/2}$ (scenario with $\tilde{\tau}_1$NLSP)
  $\tau^{\pm} \to 3\mu^{\pm}, \mu^{+}\mu^{-}e^{\pm}, \mu^{\pm}e^{+}e^{-}$…….

Both these topics require a high performance tracker, measurements close to beam pipe for impact parameter/sec. vertices; τ-related physics requires also understanding hadronic τ triggering need and capability at high luminosity

Conclusions, physics, SLHC vs LHC (I)

- ew physics:
  - multiple VB production, TGC, QGC, SM Higgs….this becomes “precision physics”, the most sure/assured one of being at the rendez-vous, TGC testable at level of SM radiative corrections,
  - ratios of SM Higgs BRs to bosons and fermions measurable at a ~ 10% level,
  - Higgs self-couplings, first observation possible only at SLHC, of fundamental importance as a test of ew theory,

    these measurements however require full performance detectors

- strongly coupled VB regime - central issue if no Higgs found! :
  getting within reach really only at SLHC

    but requires full performance calorimetry, forward one in particular

- SUSY:
  - MSSM □Higgs (A/H,$H^{\pm}$) parameter space coverage significantly improved (A/H $\rightarrow \tau\tau$, $\mu\mu$),
  - new modes become accessible ($H^{\pm} \rightarrow \mu\nu$);
  - SUSY discovery and sparticle mass reach augmented by ~ 20-25%, spectrum coverage and parameter determination improved

    some of these measurements (for ex. sparticle spectrum reconstruction) require full performance detectors

Conclusions SLHC vs LHC (II)

- search for massive objects :
  - new heavy gauge bosons, manifestations of extra dimensions as KK-recurencies of γ, W, Z, gluon, R-S gravitons, LQ's, q*,……

  reach improved by 20-30%,

  but these are much more speculative/unsure topics, probably only limits to be set…..

  these measurements are least demanding in terms of detector performances
- rare/forbidden decays:
  - top in $t \rightarrow u/c + \gamma/Z$, sensitivity down to BR ~ 10^{-6}; tau in $\tau^{\pm} \rightarrow 3\mu^{\pm}, \mu^{+}\mu^{-}e^{\pm}, \mu^{\pm}e^{+}e^{-}$… possibly to BR ~ 10^{-8} (to be studied!), B-hadrons etc

  requires full performance detectors

In conclusion the SLHC ($\sqrt{s} \approx 14$ TeV, L ≈ 10^{35} cm^{-2} s^{-1}) would allow to extend significantly the LHC physics reach - whilst keeping the same tunnel, machine dipoles and a large part of "existing" detectors, but to exploit fully its potential inner/forward parts of detectors must be changed/hardened/upgraded, trackers in particular, to maintain performances similar to "present ones"; forward calorimetry of higher granularity would be highly desirable for jet tagging