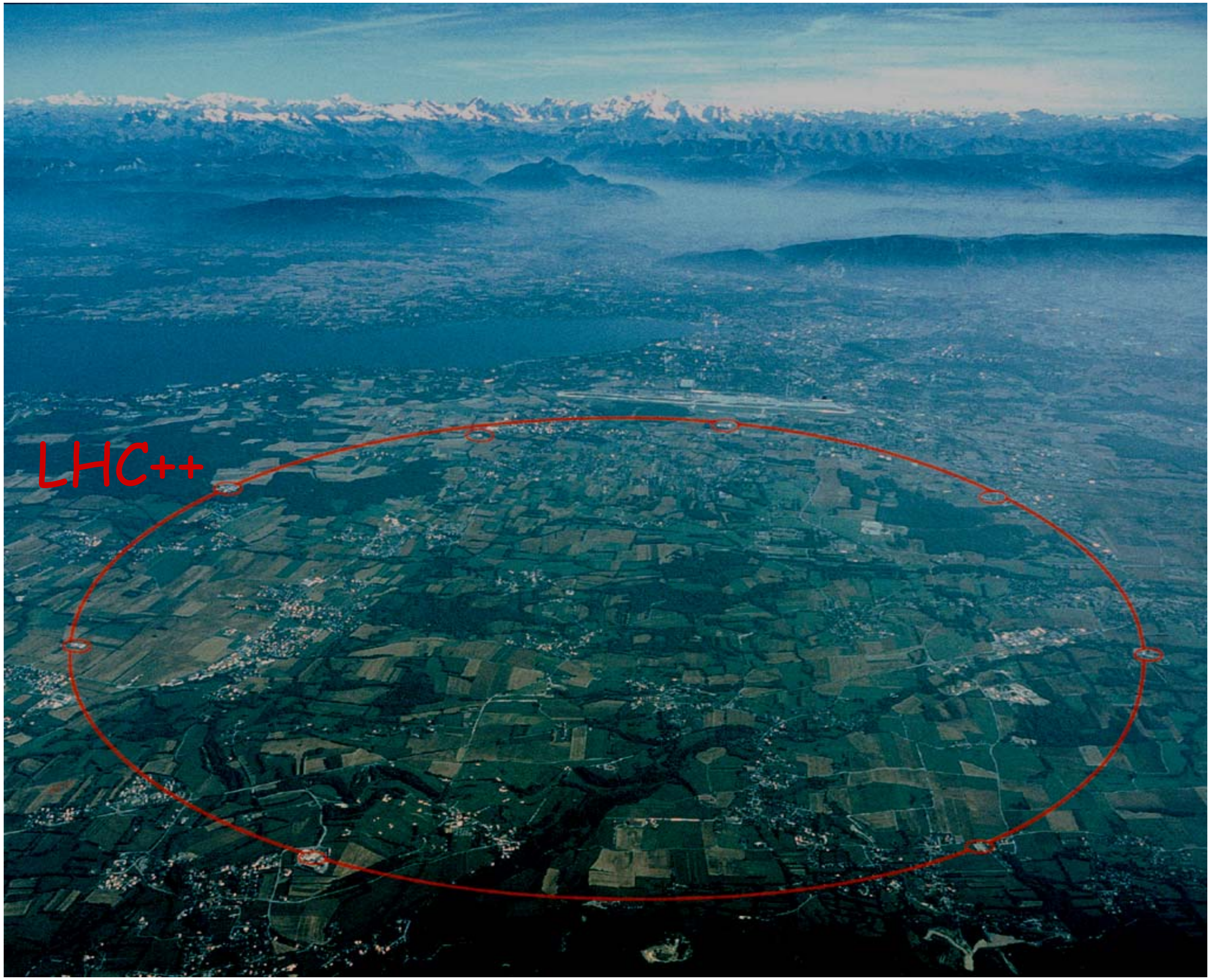
Overview: LHC experiments upgrade



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2008 NSS-MIC
Special Focus Workshops

Oct 19th 2008, Dresden

- Physics motivation
- Machine upgrade
- Detector upgrades

Physics motivation

Physics motivation

- LHC has a huge physics potential
    - new physics expected at the TeV scale
  - → find the missing piece of the SM (Higgs boson)
  - → find new forces/particles beyond the SM
  - → improvements/indications via precision measurements
- prepare further extensions of physics program
  - → extend reach for discoveries
    - access to larger mass scales and/or to rare processes
  - → statistically limited precision measurements
- physics aims of upgrade will be a 'moving target'
  - → to be influenced by first LHC results

Physics motivation (cont'd)

- extension of physics reach via
  - → increase in luminosity (for fixed √s)
  - → increase in √s (for fixed luminosity)
  - → increase in luminosity and √s
- following selected examples use
  - → luminosity: **10^{34}** vs. **10^{35}** cm^{-2} s^{-1}
  - → √s: **14** vs. **28** vs. **42** TeV
- more details to be found in:

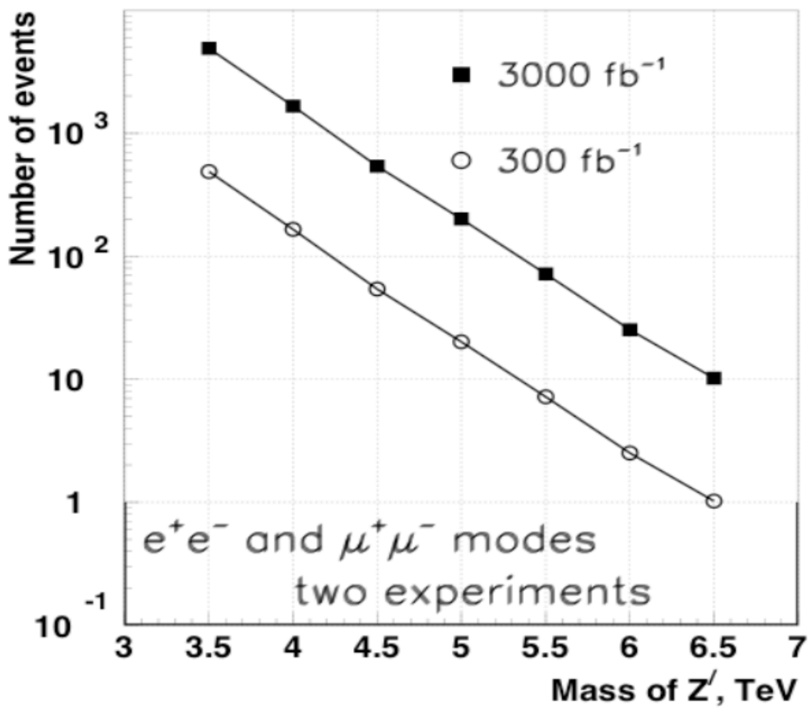
THE EUROPEAN PHYSICAL JOURNAL C

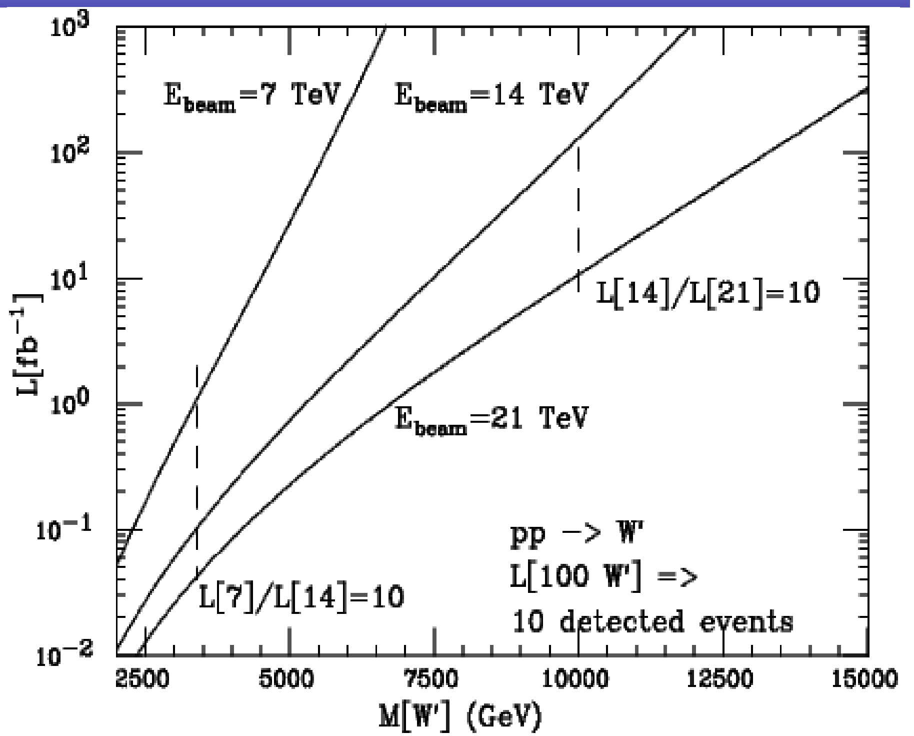
Physics potential and experimental challenges of the LHC luminosity upgrade

Conveners: F. Gianotti[1], M.L. Mangano[2], T. Virdee[1,3]

Eur. Phys. J. C39 (2005), 293

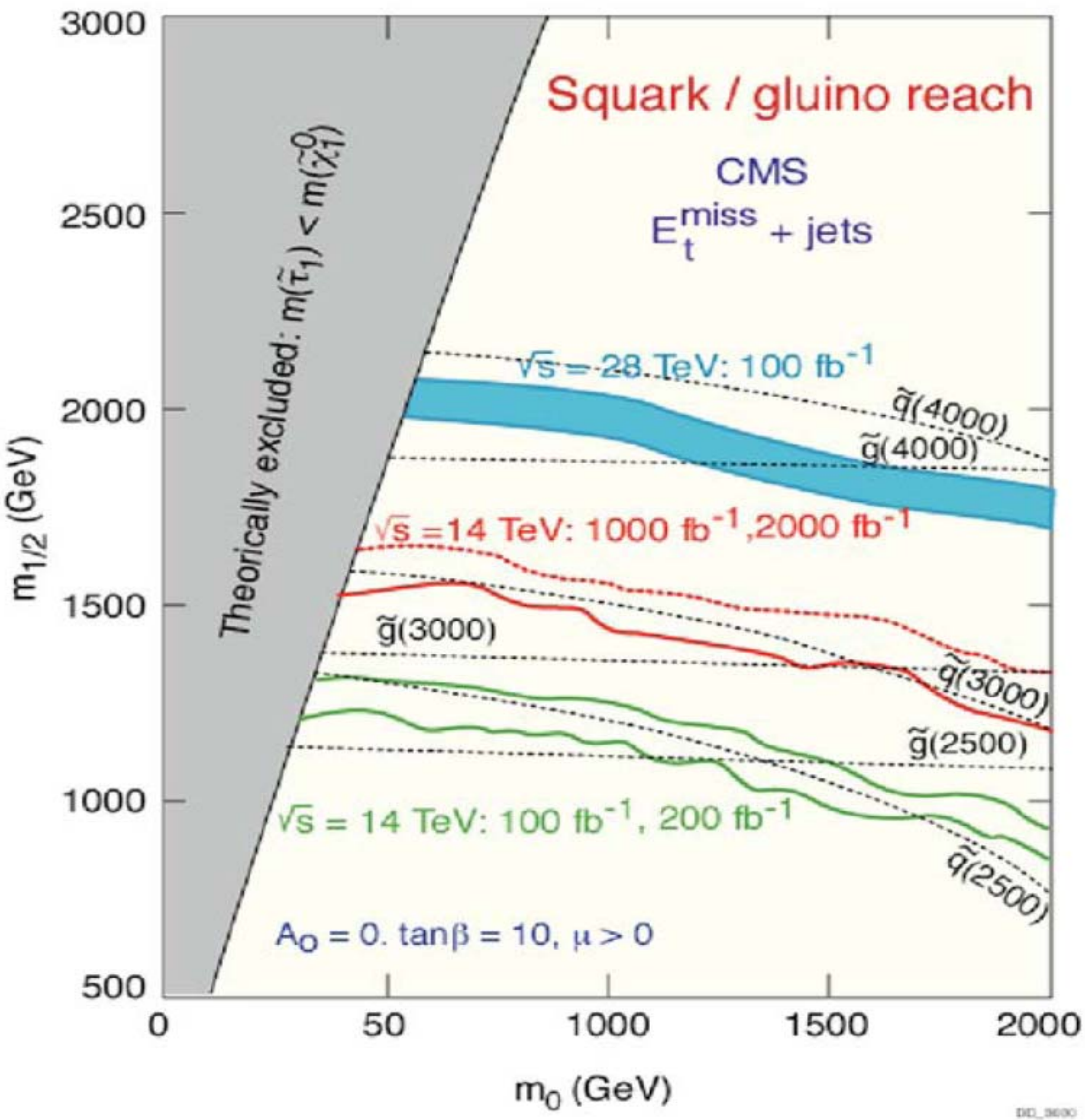
Example: new heavy gauge bosons





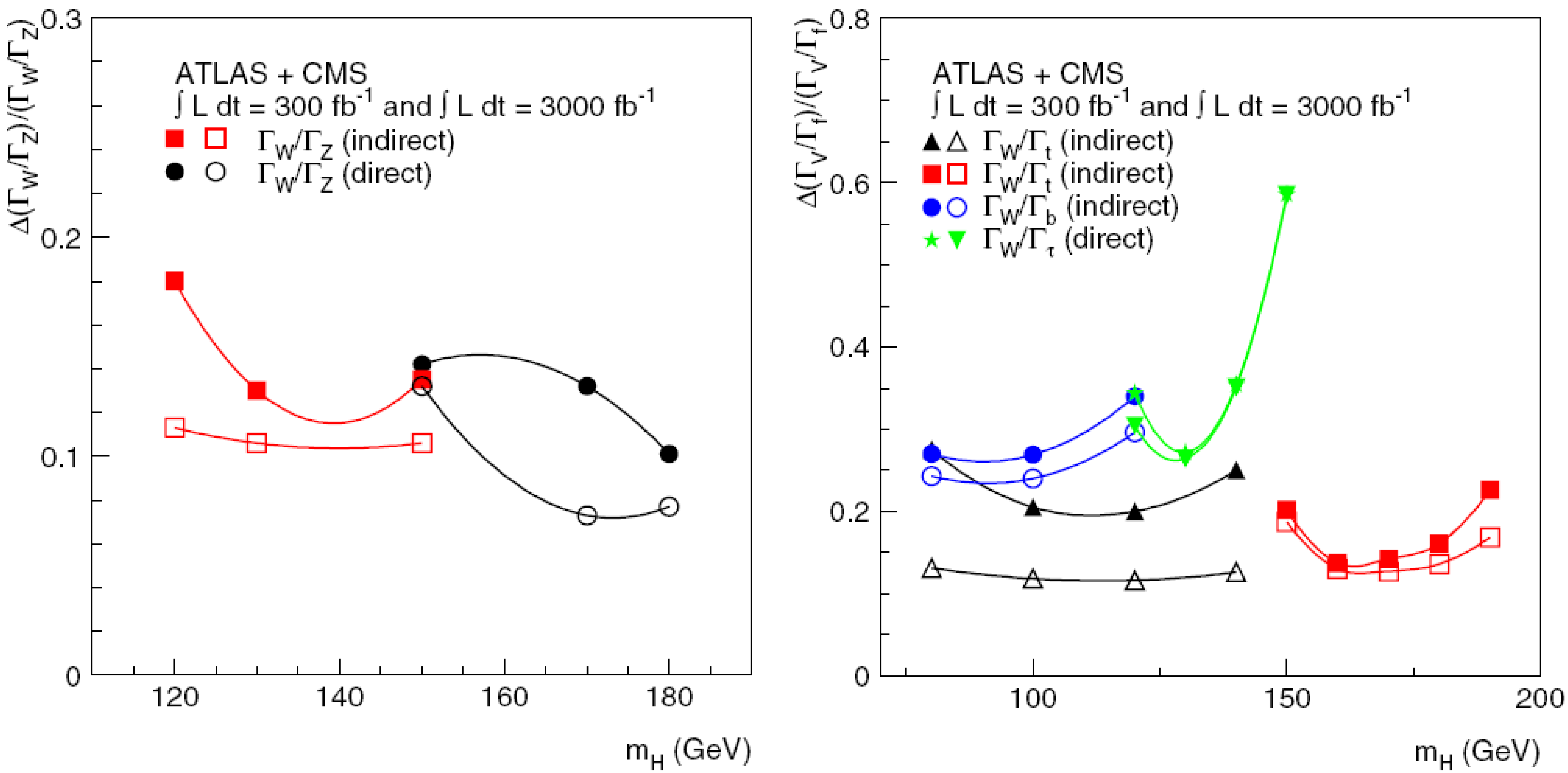
- luminosity increase by factor 10
  - → increase Z′ mass reach by ~ 1 TeV
- √s increase gives larger benefit (wrt lumi increase)
  - → increase W′ mass reach (while less luminosity needed)

Example: supersymmetry



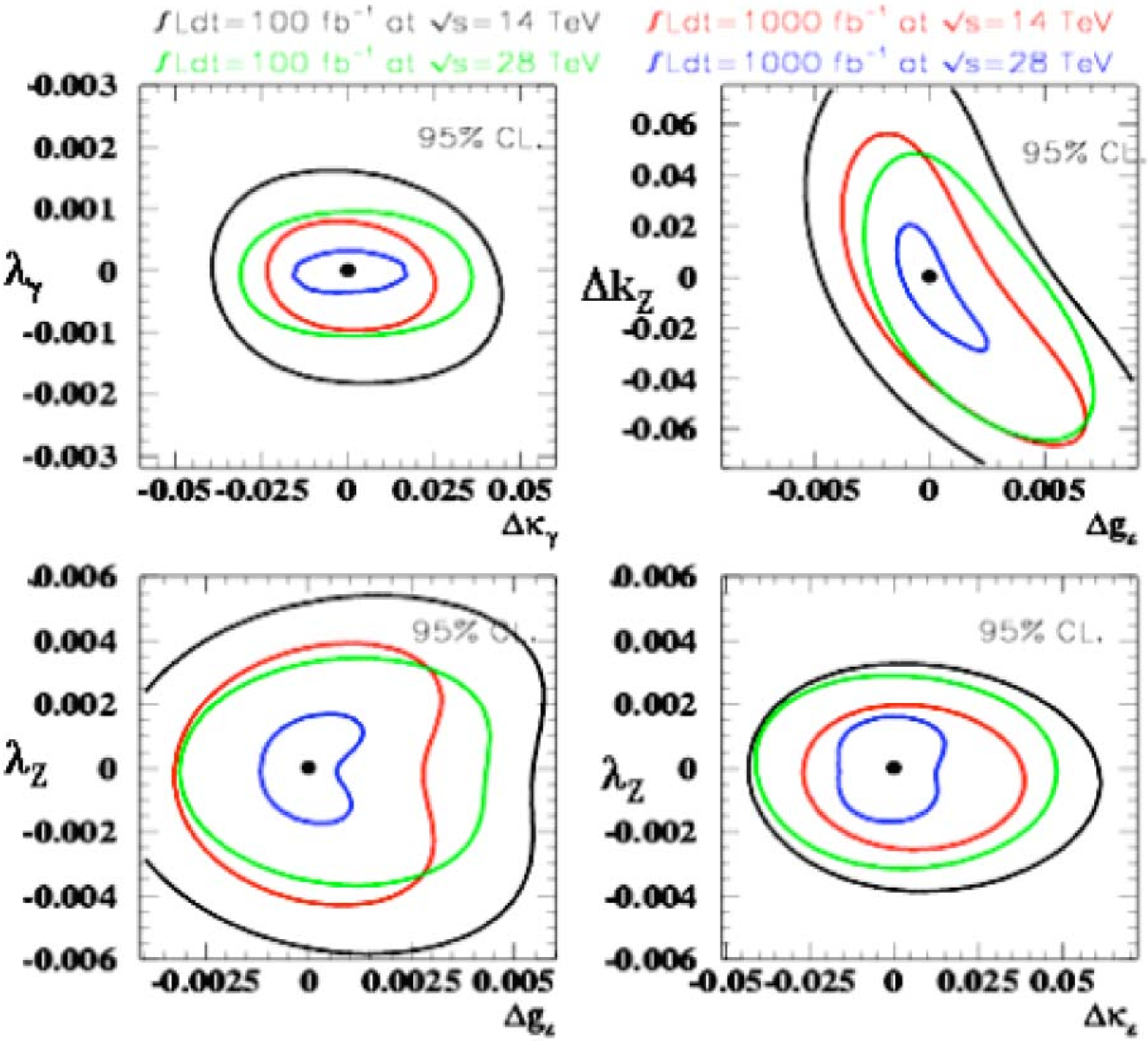
- within the mSUGRA model
- clear extension of physics reach
  - → as expected, higher $\sqrt{s}$ better then higher L
- to profit from extended reach
  - → need good object ID and reconstruction

Example: (SM) Higgs boson properties



- improvement on coupling to fermions and bosons
- access to rare decay modes: $H \rightarrow \mu\mu$, $H \rightarrow Z\gamma$
- access to Higgs self-coupling ?

Example: triple gauge boson couplings



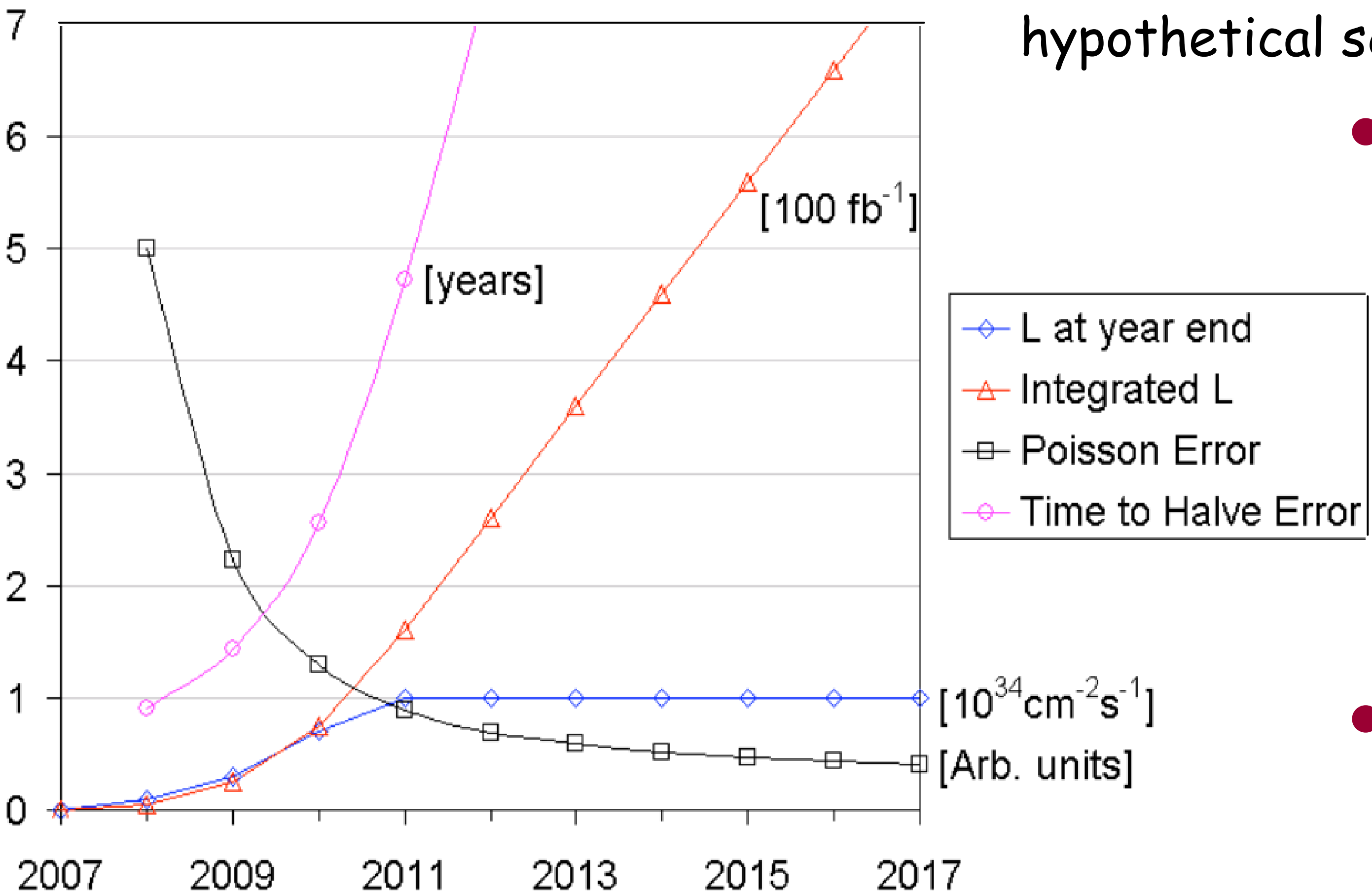
- sensitivity to anomalous couplings improves with
  - → higher √s
  - → higher L
  - → higher √s and L
- SLHC reaches level of ew radiative corrections

Summary on physics motivation

- largest benefits due to increase in $\sqrt{s}$
  - → experimental conditions possibly less challenging
- luminosity increase provides good extension
  - → increased reach in mass scale typically by 20-30 %
  - → strong requirements on detector performance
    - for (some) discoveries reduced performance tolerable
    - for (precision) measurements, similar performance in high p_T signatures as for present detectors needed
  - → further motivation: being prepared for the unforeseen
    - problems, failures, …
- upgrades of LHCb and ALICE to extend their physics potential being studied as well
  - → not so much coupled to accelerator upgrades – not discussed here

Machine upgrade

When to upgrade?



hypothetical scenario (J. Strait)

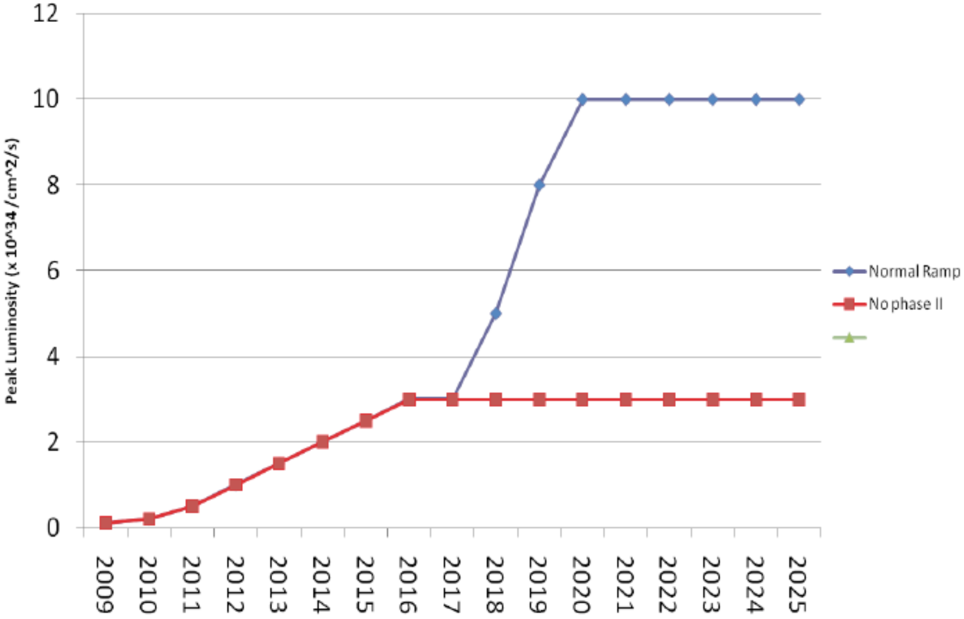
- reduction of stat. errors by simply accumulating luminosity
  → long time – if lumi/year ≈ const.
- radiation limit of about 700 fb^{-1} for quadrupoles

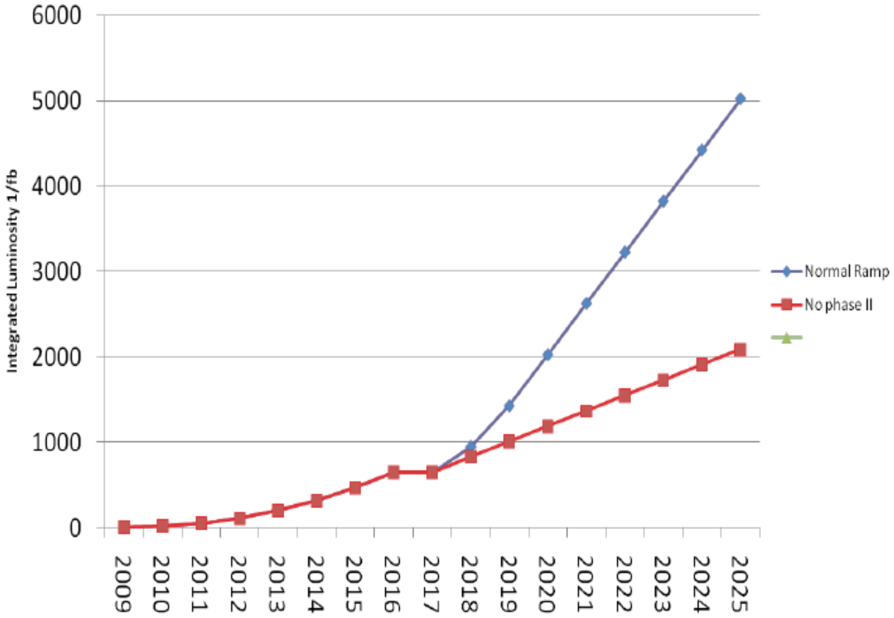
- upgrade around 2016(+n) seems appropriate
  - timescales in this talk as before Sep 19th incident

Upgrade planning

- LHC collimation system not fully installed
  - → to happen in 2010/11 – limited to 40% intensity now
- staged approach
  - → phase 1: reliable operation at up to $3*10^{34}$ cm^{-2} s^{-1}
    - new injector LINAC4: approved
      - ➔ factor of 2.3 in luminosity (larger current)
    - introduce new triplets with $\beta*$=0.25m (larger aperture)
      - ➔ factor of 2 in luminosity
  - → phase 2: target luminosity of 10^{35} cm^{-2} s^{-1}
    - injector upgrades (higher current, reliability; shorter injection time)
    - possibly triplets with $\beta*$=0.15m (Nb_3Sn)
  - → also envisaged: 'complementary measures'
    - long range beam-beam compensation, crab cavities, advanced collimators, …
    - phase 2 might be phase 1 + complementary measures
- longer term: energy upgrade, LHeC, …

Peak and integrated luminosity

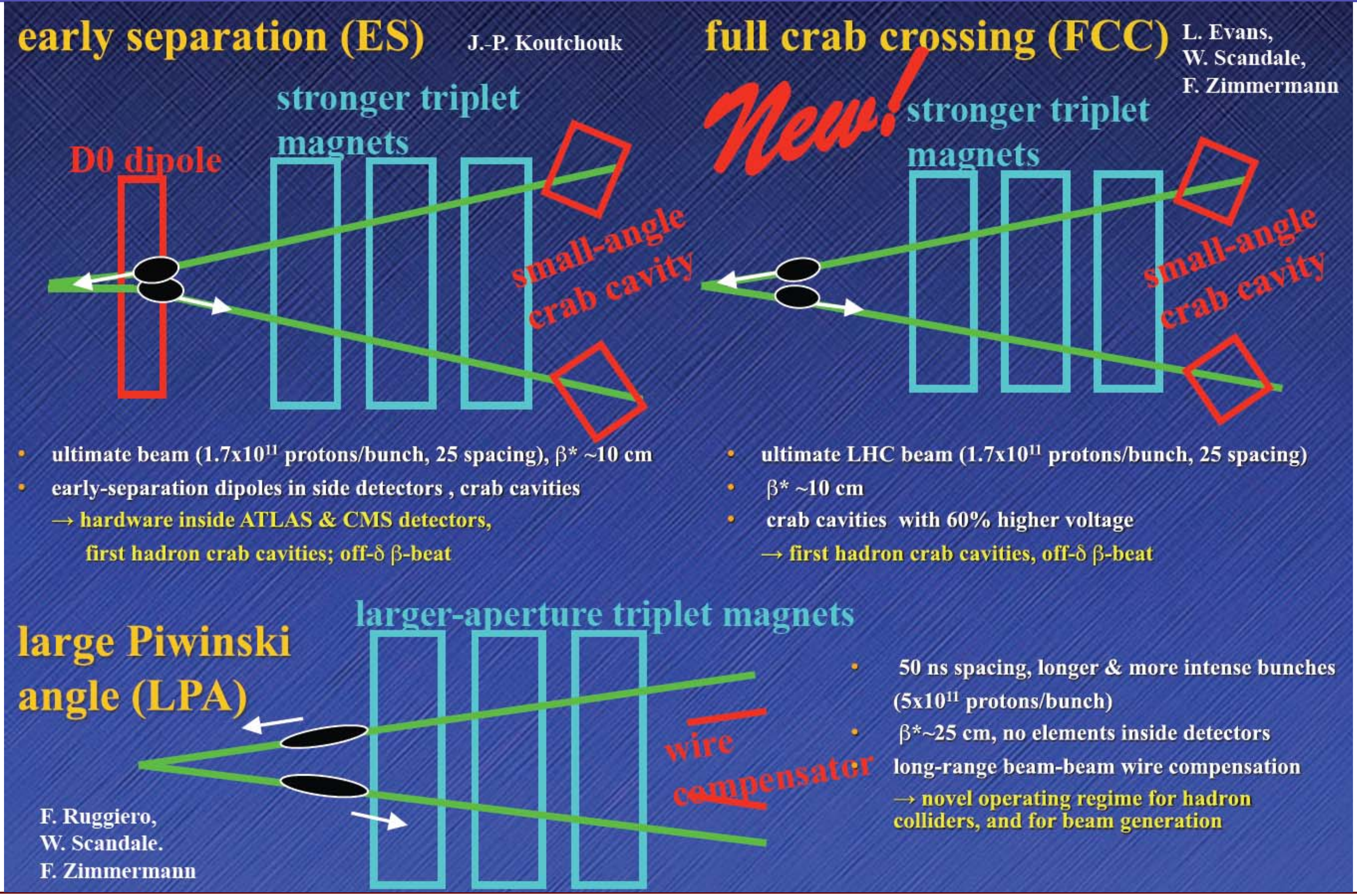




- Basis for planning as approved at LHCC meeting 1st July 2008

- **Phase 1 start: 6 – 8 month shutdown end 2012**
  - → accumulate 700 fb^{-1} of integrated luminosity
- **Phase 2 start: 18 month shutdown at end of 2016**
  - → minimum lifetime of detectors in phase 2 corresponding to 3000 fb^{-1} integrated luminosity

Upgrade schemes



Upgrade parameter overview

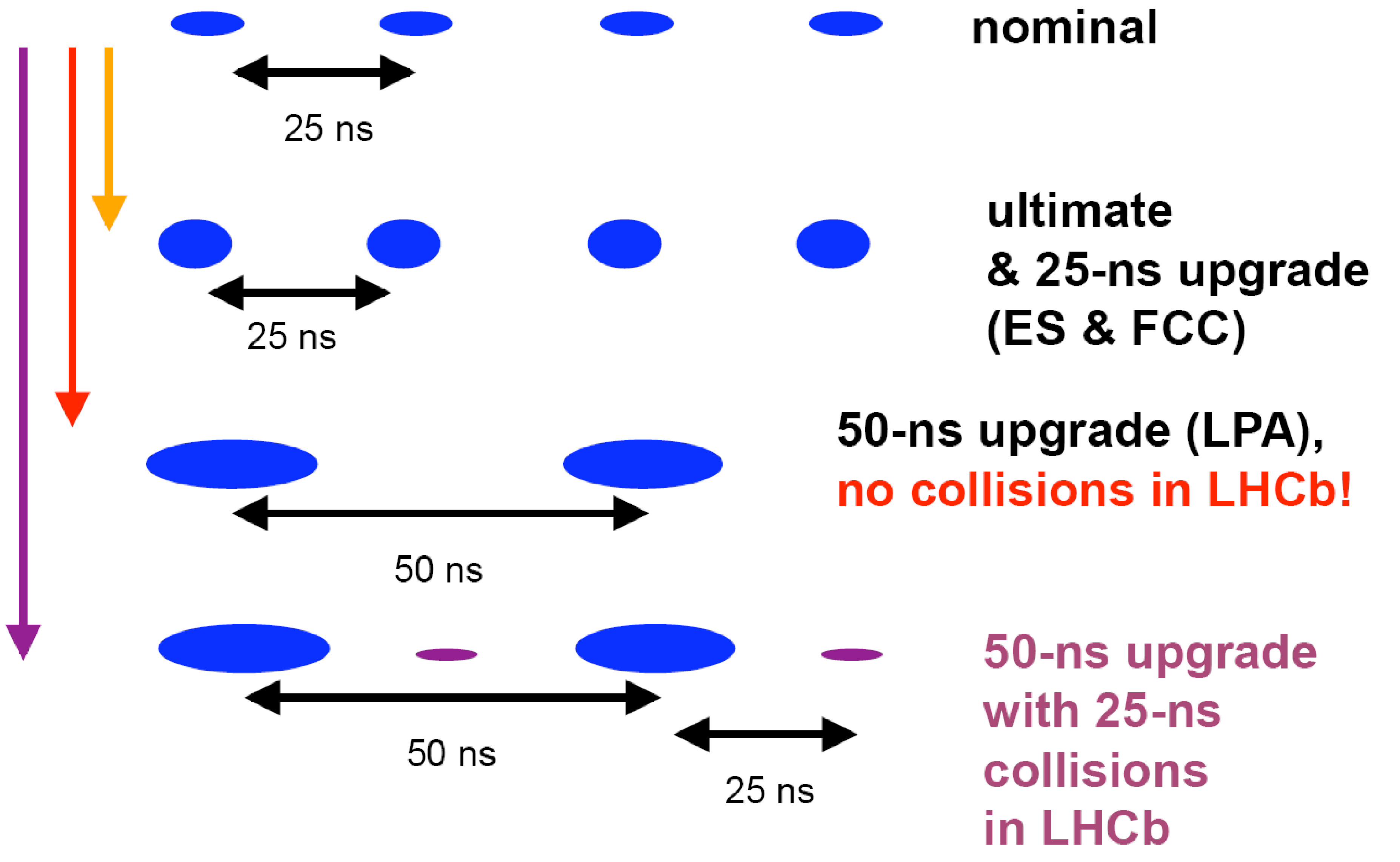
parameter	symbol	nominal	ultimate	Early Sep.	Full Crab Xing	L. Piw Angle
transverse emittance	ε [μm]	3.75	3.75	3.75	3.75	3.75
protons per bunch	N_b [10^{11}]	1.15	1.7	1.7	1.7	4.9
bunch spacing	Δt [ns]	25	25	25	25	50
beam current	I [A]	0.58	0.86	0.86	0.86	1.22
longitudinal profile		Gauss	Gauss	Gauss	Gauss	Flat
rms bunch length	σ_z [cm]	7.55	7.55	7.55	7.55	11.8
beta* at IP1&5	β^* [m]	0.55	0.5	0.08	0.08	0.25
full crossing angle	θ_c [μrad]	285	315	0	0	381
Piwinski parameter	$\phi=\theta_c\sigma_z/(2*\sigma_x^*)$	0.64	0.75	0	0	2.0
hourglass reduction		1.0	1.0	0.86	0.86	0.99
peak luminosity	L [10^{34} cm^{-2}s^{-1}]	1	2.3	15.5	15.5	10.7
peak events per #ing		19	44	294	294	403
initial lumi lifetime	τ_L [h]	22	14	2.2	2.2	4.5
effective luminosity ($T_{turnaround}$=10 h)	L_{eff}[10^{34} cm^{-2}s^{-1}]	0.46	0.91	2.4	2.4	2.5
	$T_{run,opt}$ [h]	21.2	17.0	6.6	6.6	9.5
effective luminosity ($T_{turnaround}$=5 h)	L_{eff}[10^{34} cm^{-2}s^{-1}]	0.56	1.15	3.6	3.6	3.5
	$T_{run,opt}$ [h]	15.0	12.0	4.6	4.6	6.7
e-c heat SEY=1.4(1.3)	P [W/m]	1.07 (0.44)	1.04 (0.59)	1.04 (0.59)	1.04 (0.59)	0.36 (0.1)
SR heat load 4.6-20 K	P_{SR} [W/m]	0.17	0.25	0.25	0.25	0.36
image current heat	P_{IC} [W/m]	0.15	0.33	0.33	0.33	0.78
gas-s. 100 h (10 h) τ_b	P_{gas} [W/m]	0.04 (0.38)	0.06 (0.56)	0.06 (0.56)	0.06 (0.56)	0.09 (0.9)
extent luminous region	σ_l [cm]	4.5	4.3	3.7	3.7	5.3
comment		nominal	ultimate	D0 + crab	crab	wire comp.

early separation (ES)

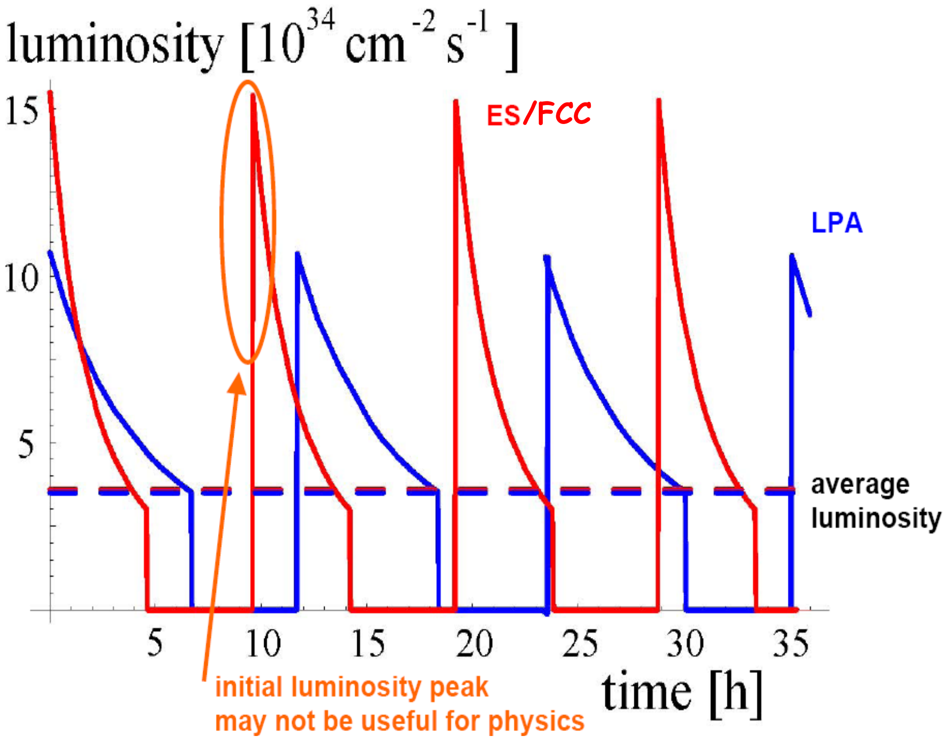
full crab crossing (FCC)

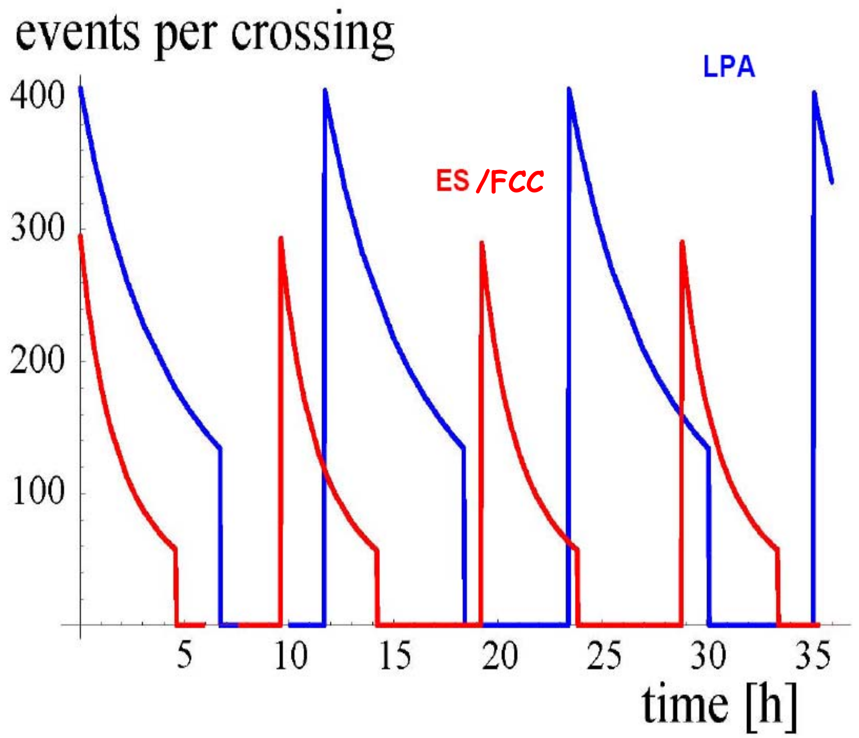
large Piwinski angle (LPA)

Bunch structure: LHC & upgrades



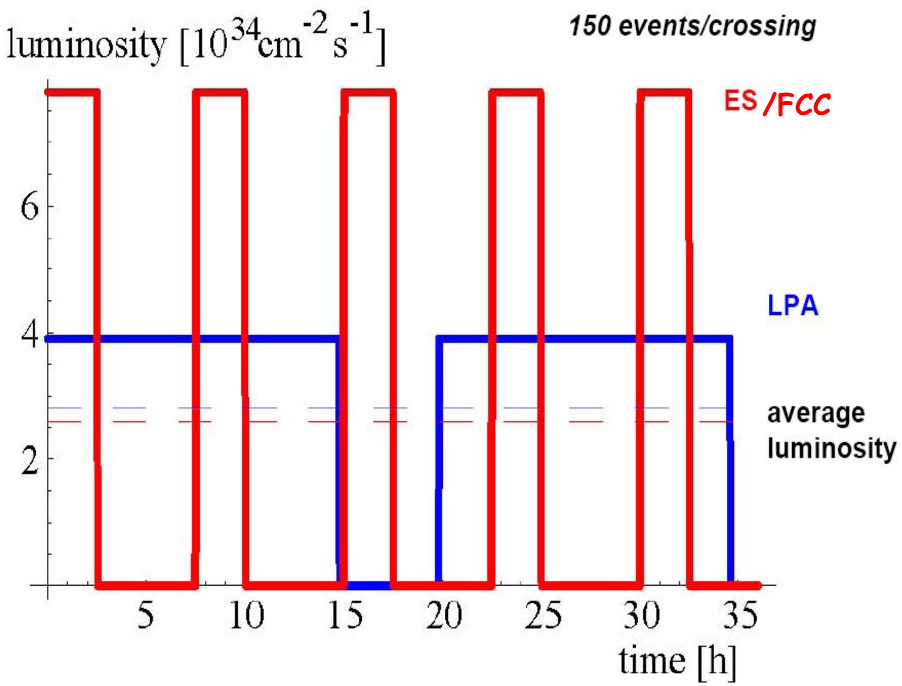
Time evolution: luminosity

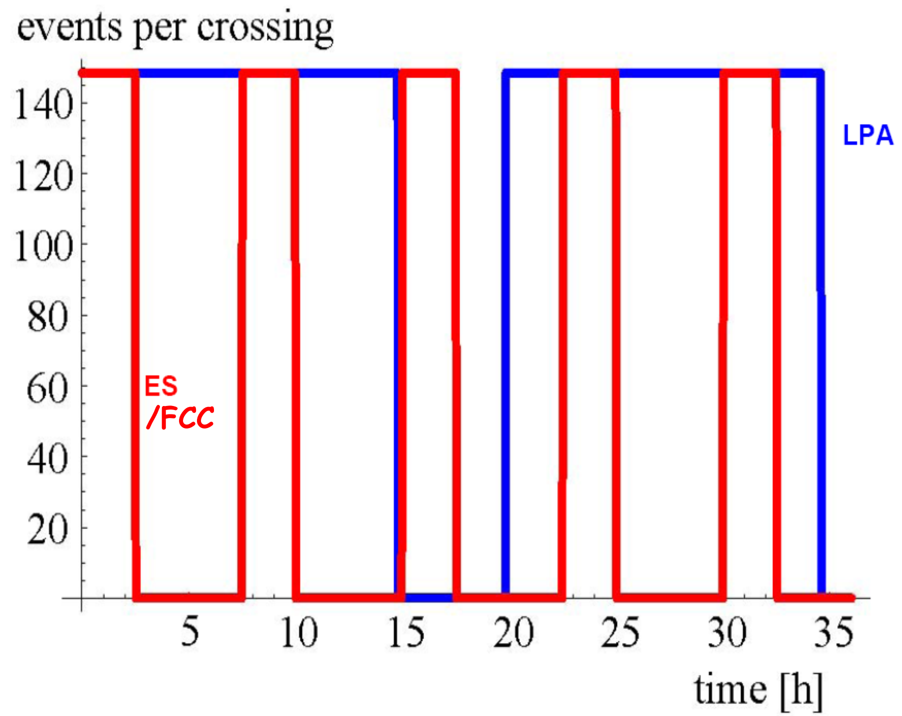




- shorter beam life time of ES/FCC scenario
  - → usefulness of initial peak luminosity?
- larger number of events per crossing (LPA)
  - → up to 400 simultaneous inelastic pp interactions

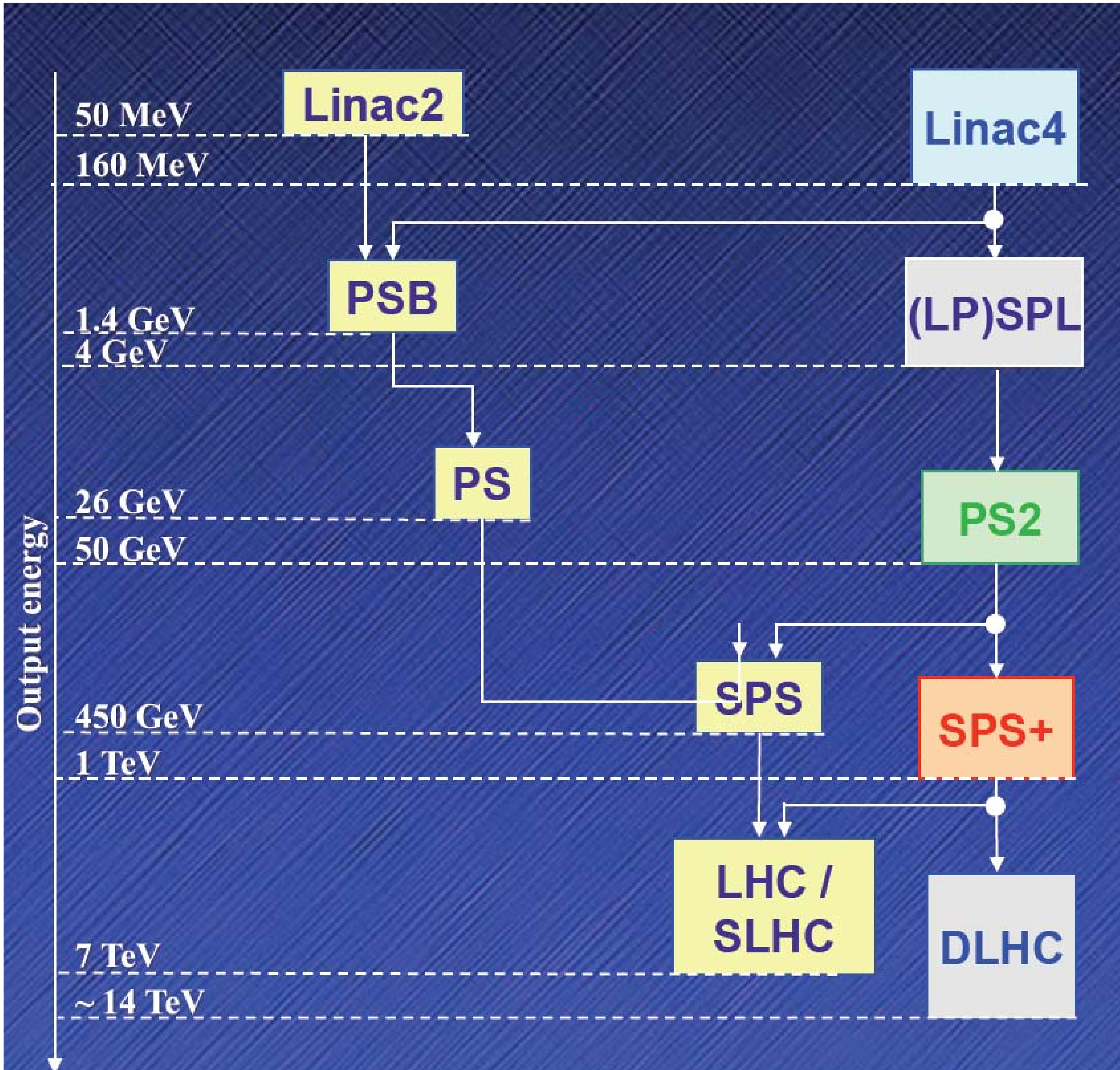
Under study: luminosity leveling





- perform dynamic β* squeeze during a store
  - → alternative for LPA scenario: dynamic bunch length reduction
- favourable for experiments
  - → less 'pile-up' events at beginning of store

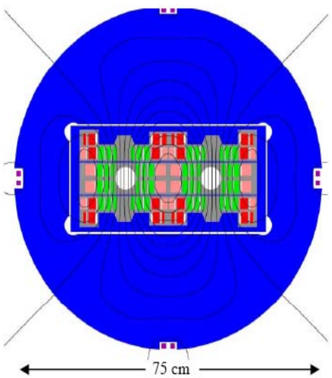
Evolution of CERN accelerator complex



(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)

Increasing the beam energy?

- doubling the energy (DLHC) $\sqrt{s}$ = 28 TeV
  - → nominal B field of 16.8 T (design for 18.5 – 19.3 T)
    - use Nb_3Sn superconductor
    - several 1m models exists (with 10 – 13 T fields)
  - → timescales
    - detailed R&D program: at least 10 years
    - production in industry: ~ 8 – 10 years
    - high cost
- tripling the energy (TLHC): $\sqrt{s}$ = 42 TeV
  - → nominal B field of 25 T (design for 28 – 29 T)
    - HTS-BSCCO supercond., to be fully demonstrated
    - large aperture needed (efficient beam screen)
  - → timescales
    - R&D program: at least 20 years
    - extremely high costs



- P. McIntyre, PAC05

Summary on machine upgrade

- three scenarios are presently available
  - → LPA (50 ns spacing): highest number of pileup events
  - → ES (25 ns spacing): crab cavities and magnet inside exp's
  - → FCC (25 ns spacing): crab cavities, no magnet inside exp's
- clear wishes from experiments (LHCC July 2008)
  - → no machine components inside detectors
  - → pile-up as low as possible
  - → easy luminosity leveling if possible
- significant energy upgrade
  - → much more ambitious and expensive
- keep in mind: what counts in the end is accumulated integrated luminosity!
  - → stable running at somewhat lower peak luminosity preferable to unstable running at higher peak luminosities

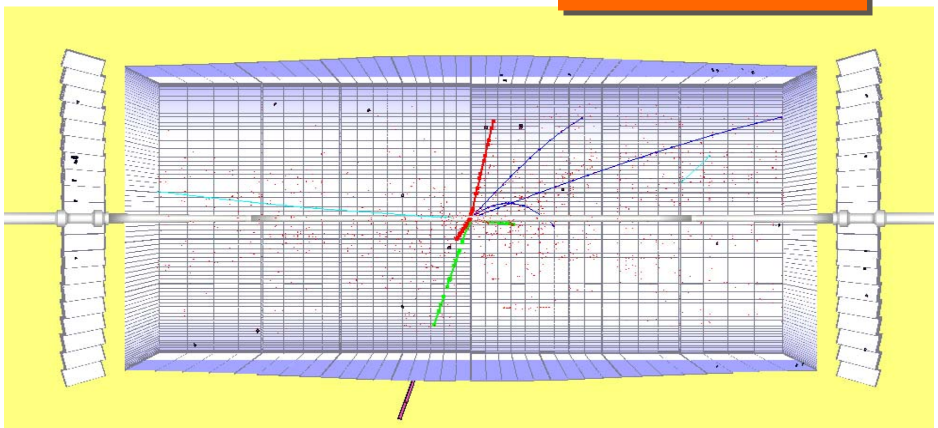
Detector upgrade

The challenges

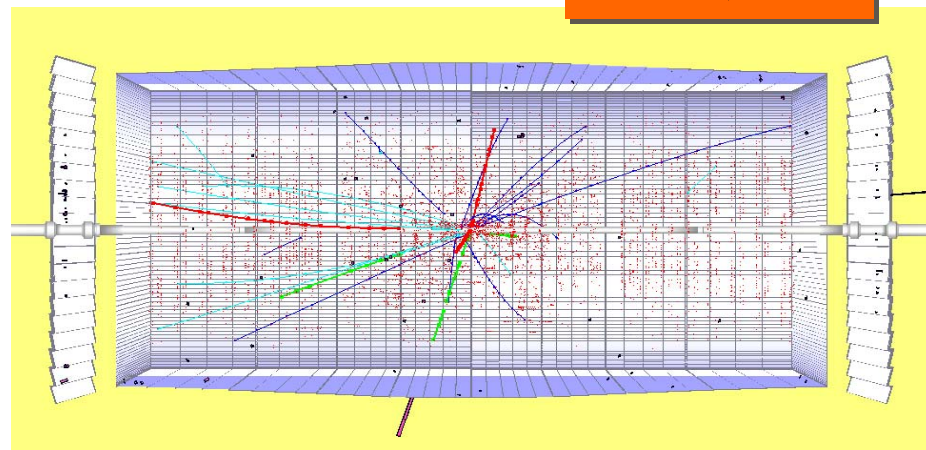
- Requirement to fully exploit physics potential
  - → similar detector performance as 'today'
- However much more demanding environment
  - → increased backgrounds
  - → larger particle fluxes (radiation damage)
  - → higher rates (increase in occupancies, …)
- What to upgrade/adapt?
  - → reasonable approach: can not build a new detector!
  - → replacement of tracking detectors
    - 10 y lifetime expectation @ 10^{34} – sensor/electronics damage
  - → forward region
    - new machine elements closer to interaction point?
  - → check on calorimeter and muon systems
  - → trigger and data acquisition: evolution?

The challenge: visually

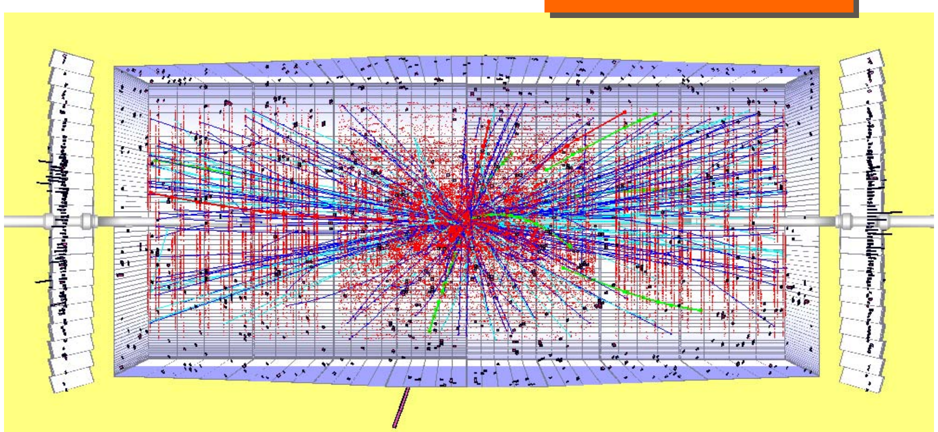
$10^{32}\ cm^{-2}\ s^{-1}$



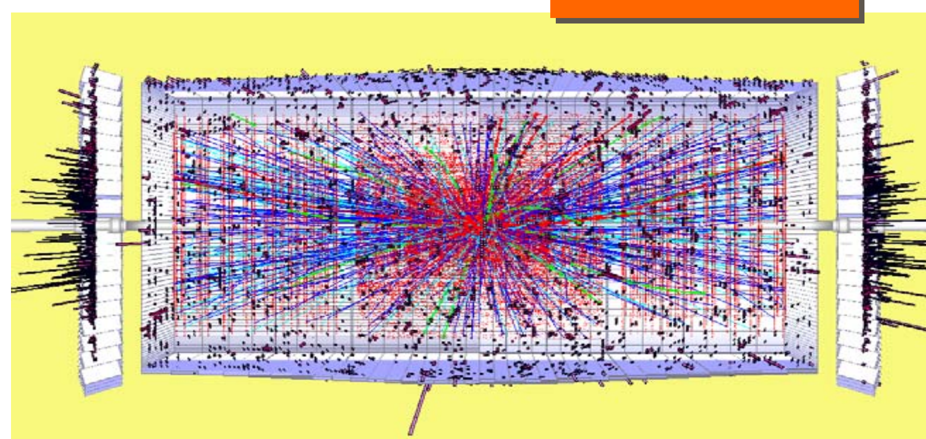
$10^{33}\ cm^{-2}\ s^{-1}$



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

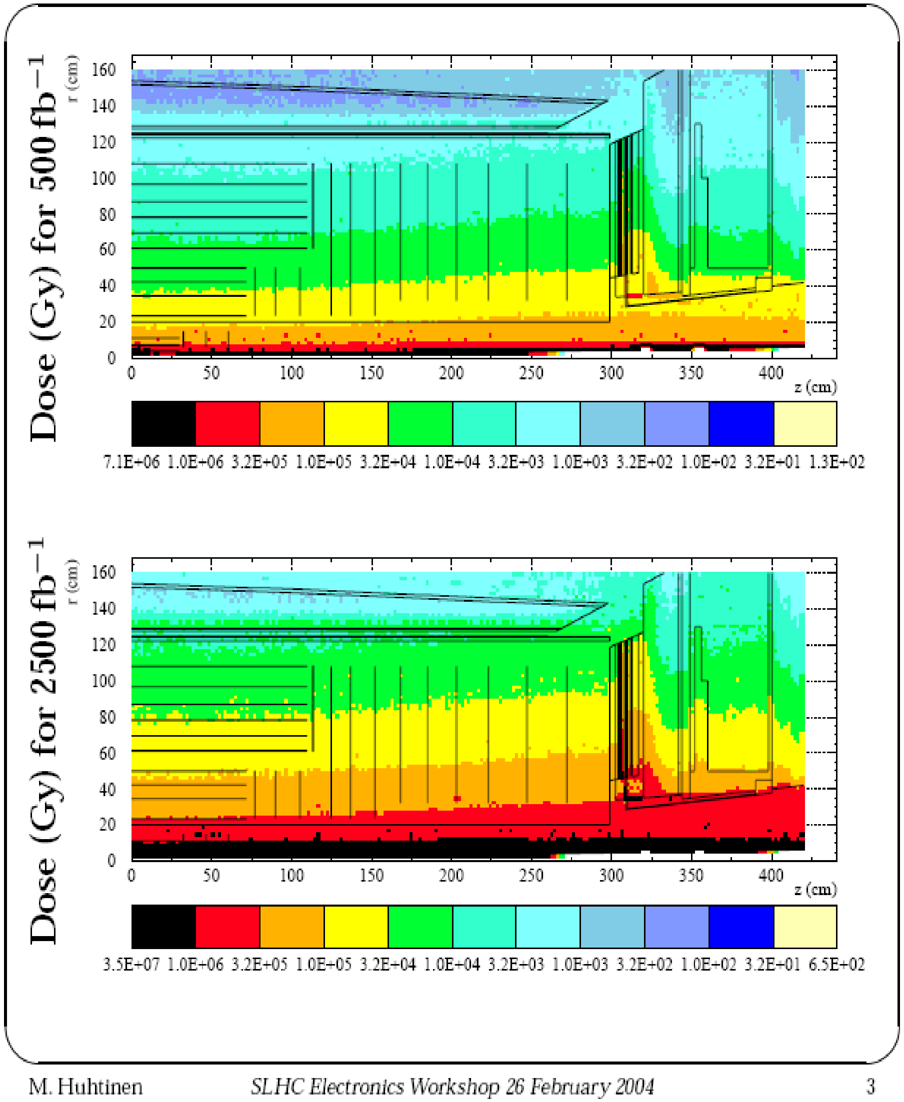


$10^{35}\ cm^{-2}\ s^{-1}$

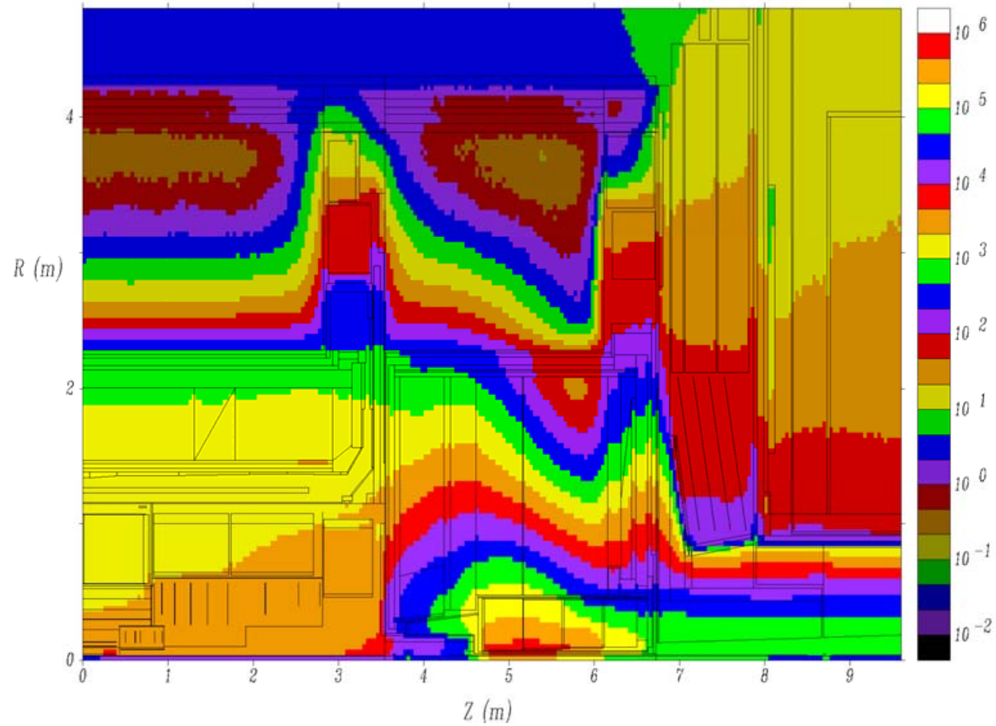


Radiation environment

CMS Radiation Dose in Inner Detectors



ATLAS: neutron flux (kHz/cm²)



→ allow optimisation of shielding, moderators, beampipe layout

- need to verify radiation and activation levels with initial collisions!

Radiation levels

- radiation :

—— 500 fb^{-1} = ~ 10 years at LHC

—— 3000 fb^{-1} = ~ 3 years at SLHC

CMS tracker

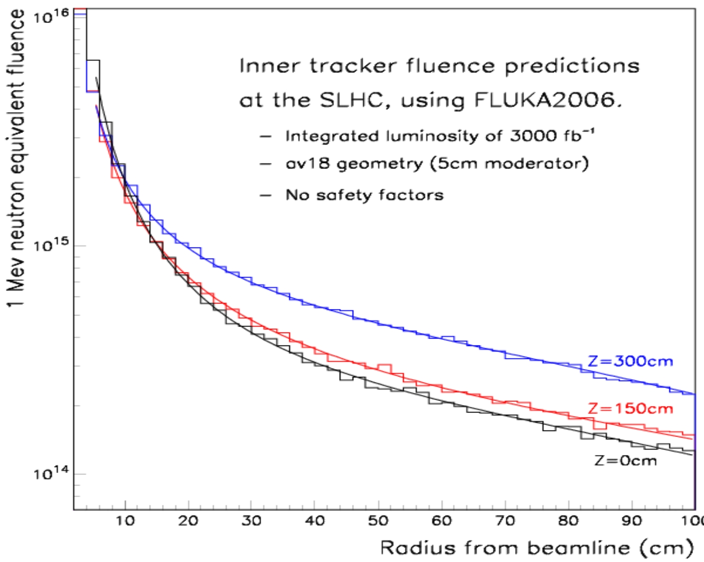
R (cm)	hadron fluence 10^{14} cm^{-2}	Dose (kGy)
4	30/190	840/5000
11	5/28	190/1130
22	1.5/10	70/420
75	0.3/2	7/40
115	0.2/1	2/11

CMS calorimeters

1 Gy = 1 Joule/Kg

η	ECAL dose (kGy)	HCAL dose (kGy)
0-1.5	3/18	0.2/1
2.0	20/120	4/25
2.9	200/1200	40/250
3.5		100/600
5		1000/6000

- important issues
  - → validation with first real LHC data of present background models absolutely mandatory!
  - → need operational experience



Upgrade in phase 1

- no major long shutdown foreseen presently
- tracking detectors
  - → CMS: replace B-layer (possibly whole pixel system)
    - fast replacement of pixel detector possible
  - → ATLAS: install new B-layer inside current pixel system
    - ➔ beam pipe with smaller diameter
- trigger and DAQ
  - → evolve/expand/upgrade to handle higher rates and occupancies
    - profit from larger processing power for more complex trigger algorithms in higher level trigger(s)
  - → CMS:
    - more fine grained information for Level-1 (calo/muon)
    - Level-1 track trigger based on new pixel ?
  - → ATLAS:
    - fast track finder after Level-1 accept?
    - topological selection criteria at Level-1?
- assessment (also including other systems) ongoing

Tracker upgrades

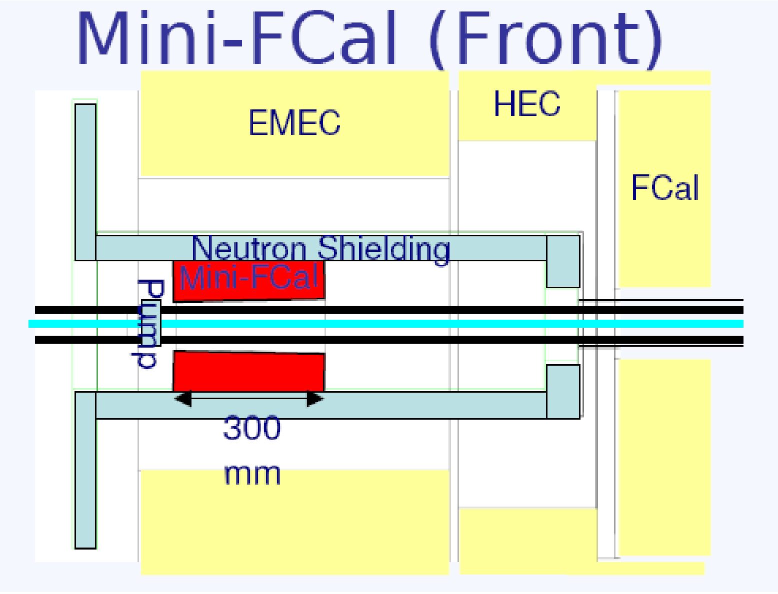
- will be discussed in detail in the next presentation

→'Tracker Upgrades' by P. Allport

→stay tuned !

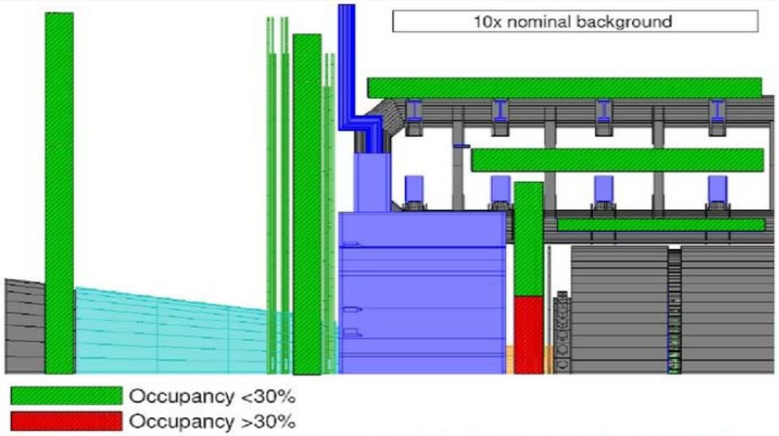
Calorimeters

- will mostly remain adequate for SLHC
  - → new to optimize signal processing
  - → consider (partially) new readout electronics
- ATLAS forward calorimeter (FCAL)
  - → might be suffering from space charge build-up, boiling of liquid Ar
    - assessment in high intensity testbeam on-going
  - → options considered (if necessary)
    - new warm calorimeter in front of present FCAL
    - open (endcap) cryostat and replace FCAL



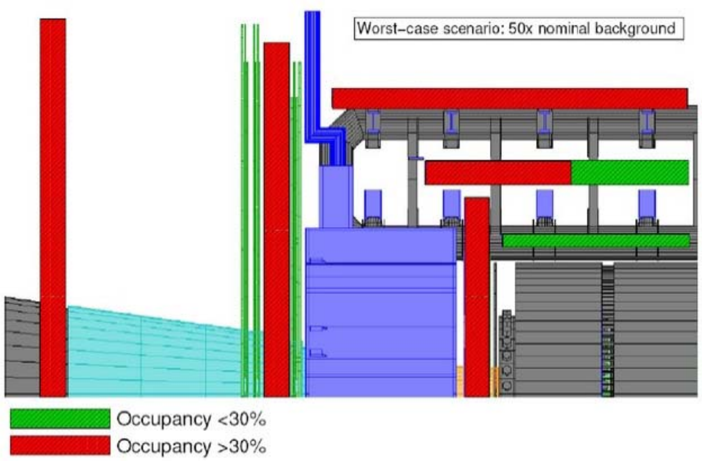
Muon detectors

Limitations – occupancies of the chambers



At least half of the chambers in the inner end-cap disk would have to be replaced by chambers with higher high rate capability.

Limitations – occupancies of the chambers



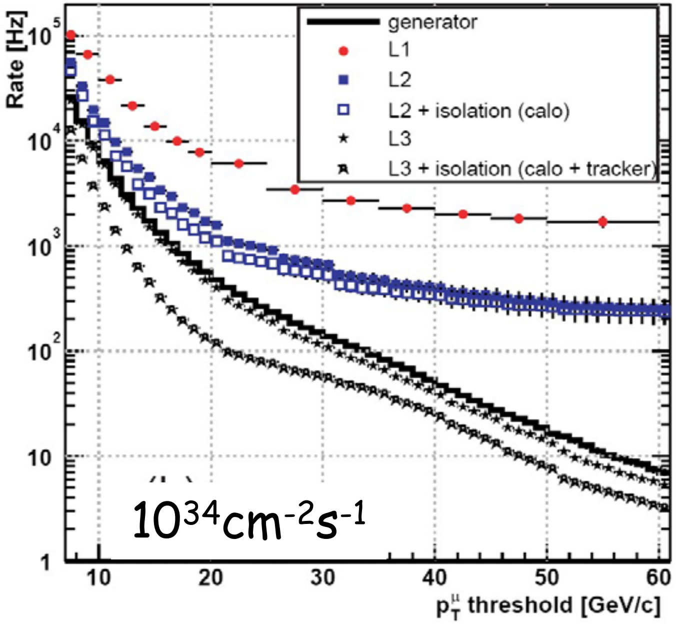
Almost all chamber would have to be replaced.

- large uncertainties in background simulation
  - to be verified with initial data
  - → ATLAS: open air core toroid
    - might need to replace minimal or large fraction of muon chambers
      - → safety factor of 5 in present design
  - → CMS: rates probably ok
    - new readout electronics ?
- options for background reduction
  - → ATLAS: consider to have full Al beam pipe
    - expensive, but up to factor 3
  - → CMS: additional shielding towards $|\eta|=2$
    - borated polyethylene, PMT shielding

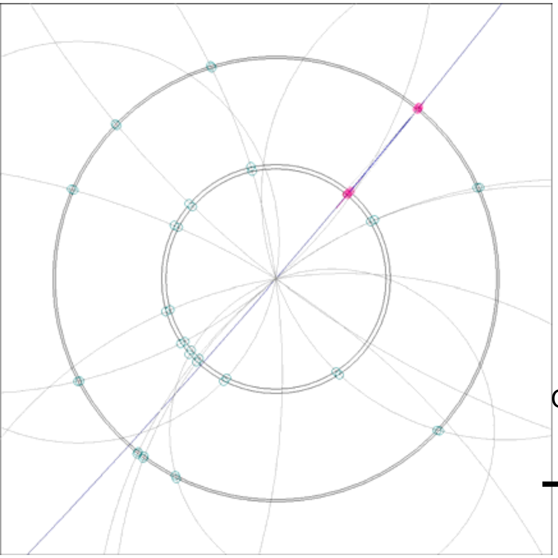
Trigger and DAQ

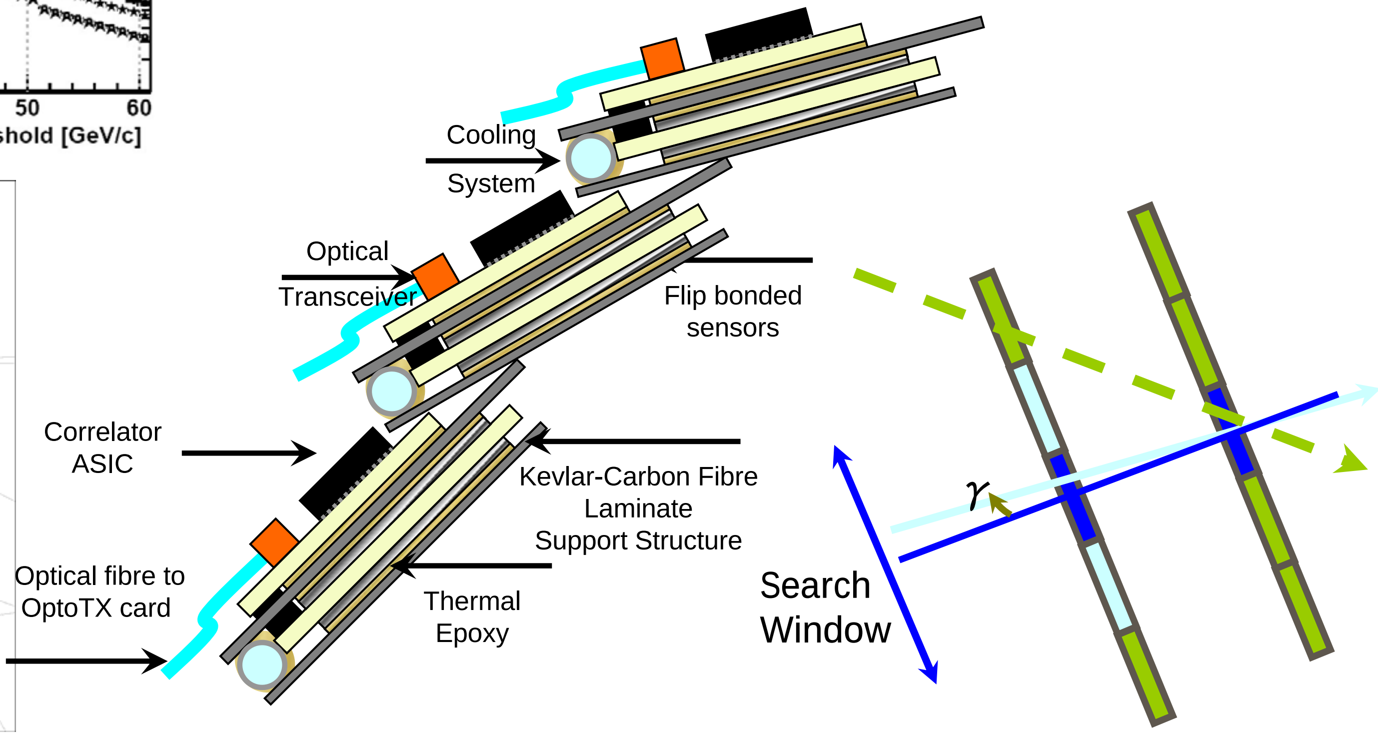
- calorimeters
  - → most parts will be kept (partially new electronics)
  - → ATLAS: forward calorimeter subject to most radiation
  - → CMS: impact of machine elements on HF, radiation damage of scintillator (HCAL) for $|\eta|>2$
- muon systems
  - → need running experience, some electronics might be replaced, background uncertainties (data needed)
  - → ATLAS: reduction of background (factor 2) by Be beampipe
- trigger and data acquisition
  - → has to cope with higher rates, occupancies, …
  - → CMS: need for track trigger at first level

CMS track trigger at Level-1



- motivation: not enough rejection from calorimeter/muon at Level-1 ?
  - → solution: stacked pixel layers 1mm apart
    - local measurement of track segment p_T
      - → one stacked layer → p_T cut
      - → two stacked layers → p_T range





Outlook

Outlook

- **completion and exploitation of design LHC machine and detectors has the highest priority!**

- strong physics case for upgraded LHC
  → 'moving target', will evolve with first LHC results
- luminosity upgrade to happen in (two) phases
  → parameters and details will (continue to) evolve
- detectors will develop with increasing luminosity
  → minimize changes necessary (esp. phase 1)
  → complete replacement of tracking (inner) detectors needed for phase 2
  → costs are not negligible

acknowledgement: results presented based on work from many colleagues from machine groups, ATLAS and CMS!

Resources for more information

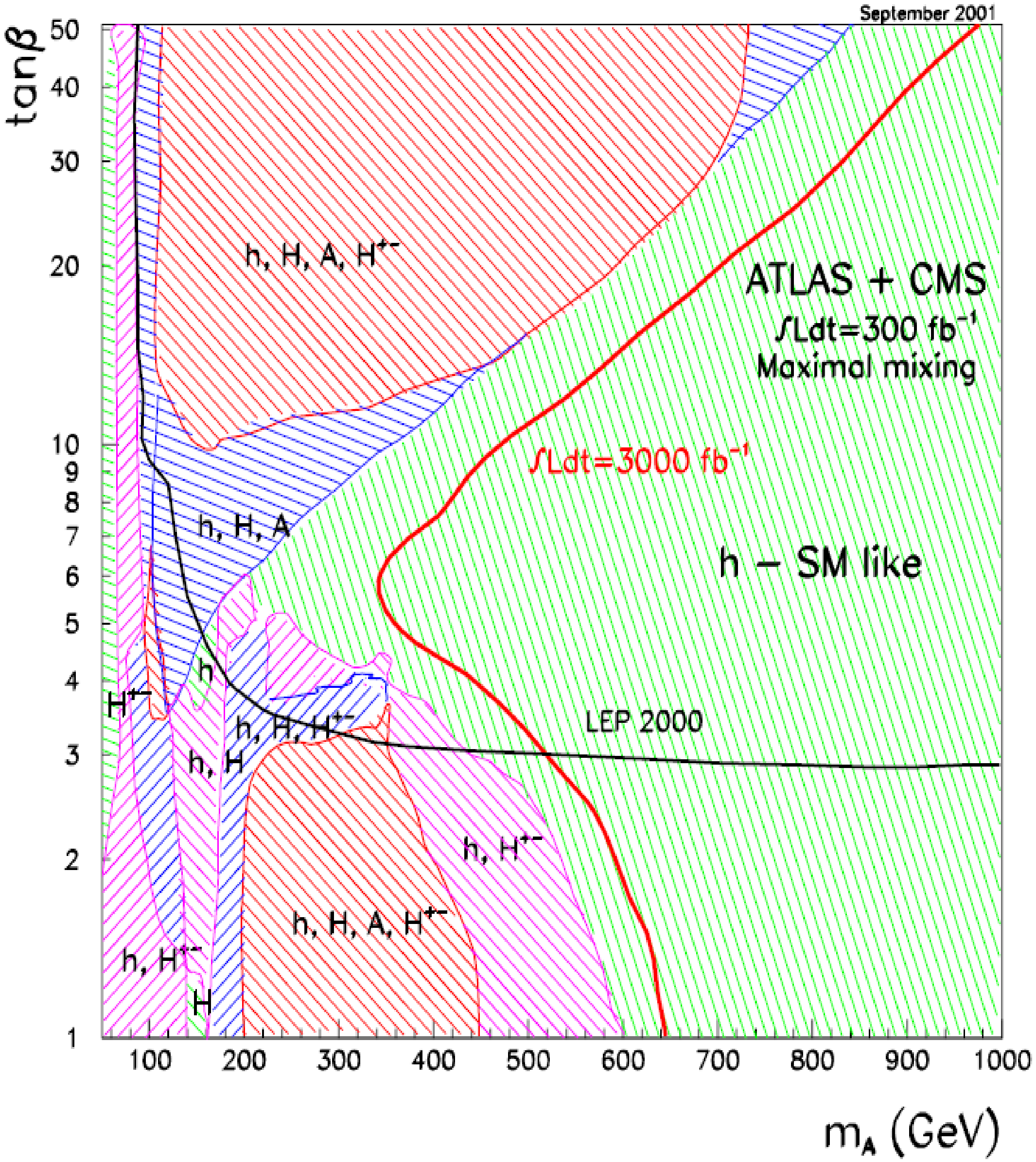
- CERN
  - → POFPA (Physics Opportunities for Future Proton Accelerators)
    - http://pofpa.web.cern.ch/pofpa/
  - → PAF (Proton Accelerators for the Future)
    - http://paf.web.cern.ch/paf/

- Machine upgrade
  - → CARE-HHH network
    - High energy High intensity Hadron beams
    - http://care-hhh.web.cern.ch/care-hhh
  - → CARE-NED joint activity
    - Next European Dipole
    - http://lt.tnw.utwente.nl/research/HCS/Projects/CARE-NED/
  - → US.LARP
    - Large hadron collider Accelerator Research Program
    - http://uslarp.org/

- Detector upgrades
  - → ATLAS
    - http://atlas.web.cern.ch/Atlas/GROUPS/UPGRADES/
  - → CMS:
    - Expression of Interest CERN/LHCC 2007-014

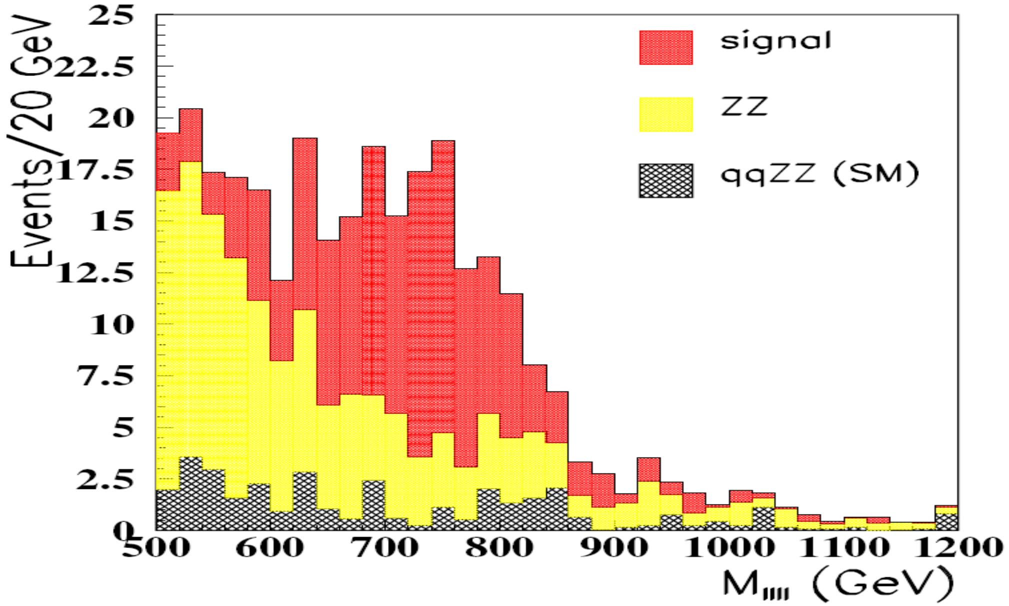
Backup

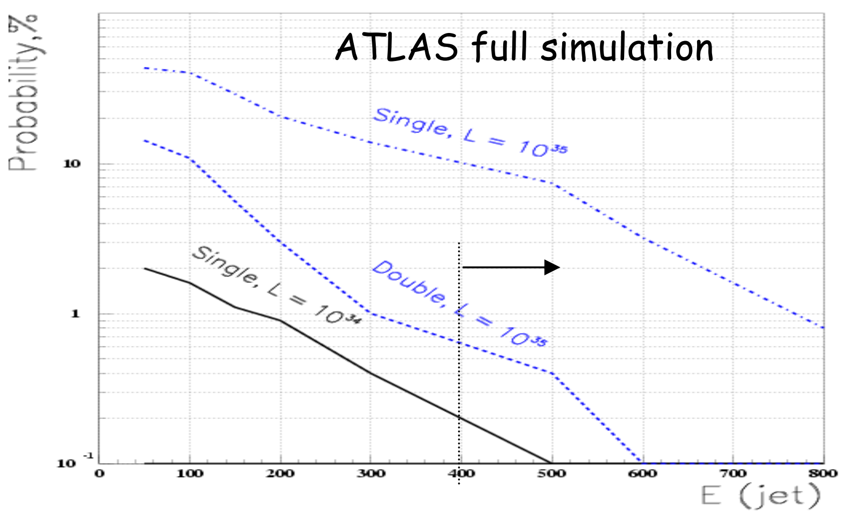
Example: MSSM Higgs bosons



- difficult region:
  - → large m_A values
  - → only one SM like Higgs boson observable
- increased SLHC luminosity
  - → coverage in m_A extended by about 100 GeV
    - especially around $\tan\beta \approx 5$

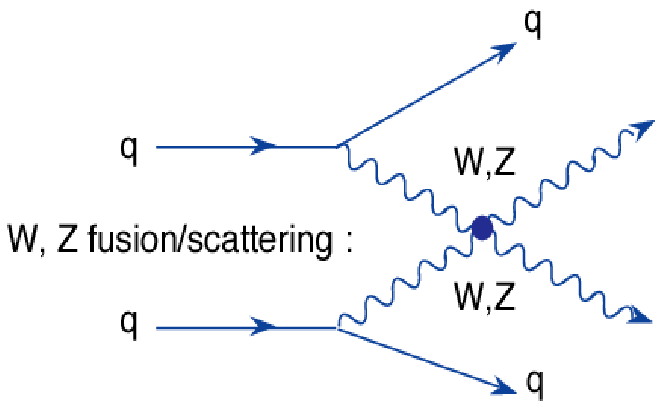
Example: strong V_L-V_L scattering





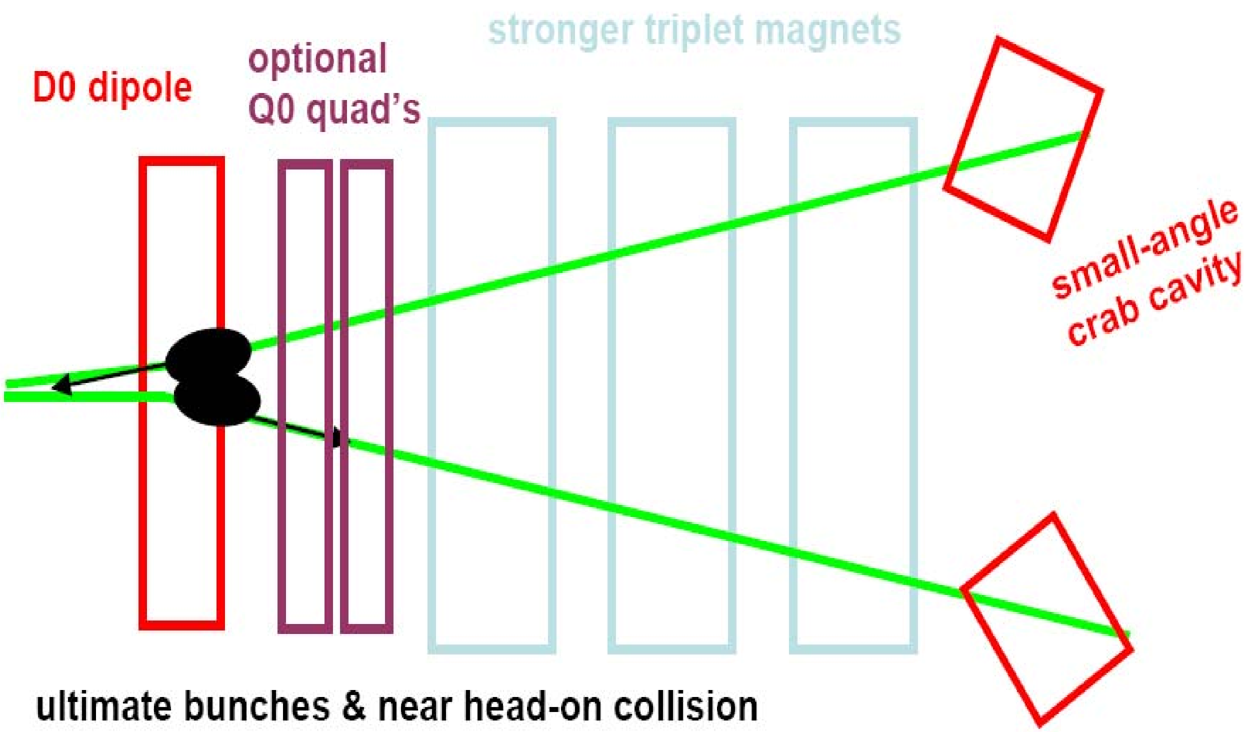
Fake fwd jet tag probability (|η| > 2) from pile-up (preliminary ...)

- if no Higgs found



- $Z_L Z_L$ resonance at mass of 750 GeV
  - → decay to 4 leptons
  - → L_{int} = 3000 fb^{-1}
  - → not detectable at LHC
- requirement of forward jet tagging

Early separation scenario (ES)

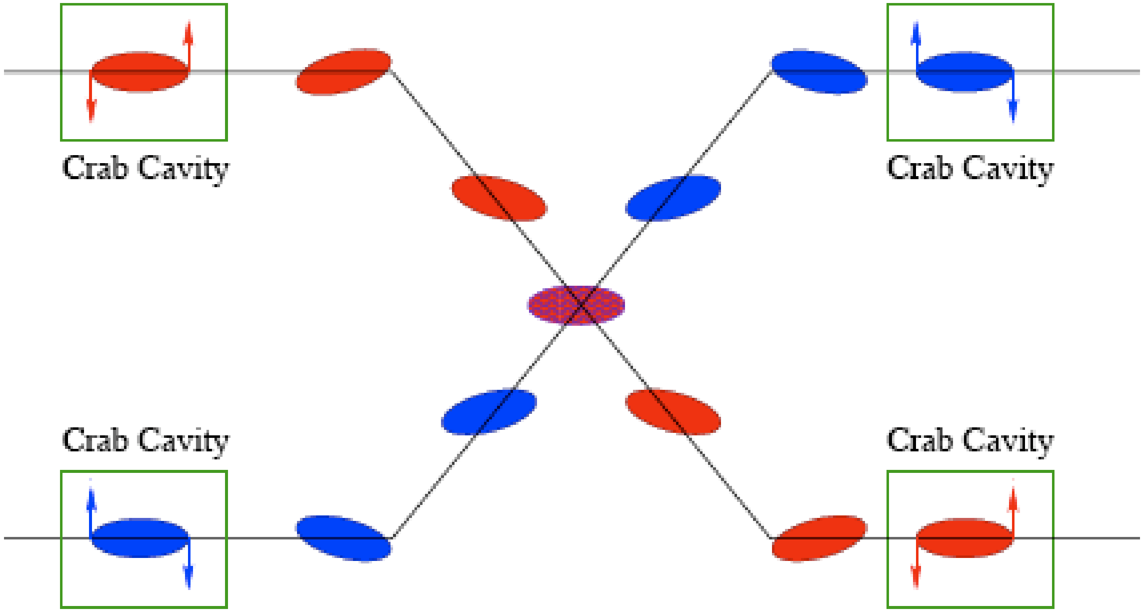


- ultimate beam
- stronger focusing
- early separation dipoles
- crab cavities

- challenges
  - → new machine elements (deep) inside the detectors
  - → crab cavities for hadron beams
  - → poor beam and luminosity lifetime

- e.g. F. Zimmermann, talk at PAC07

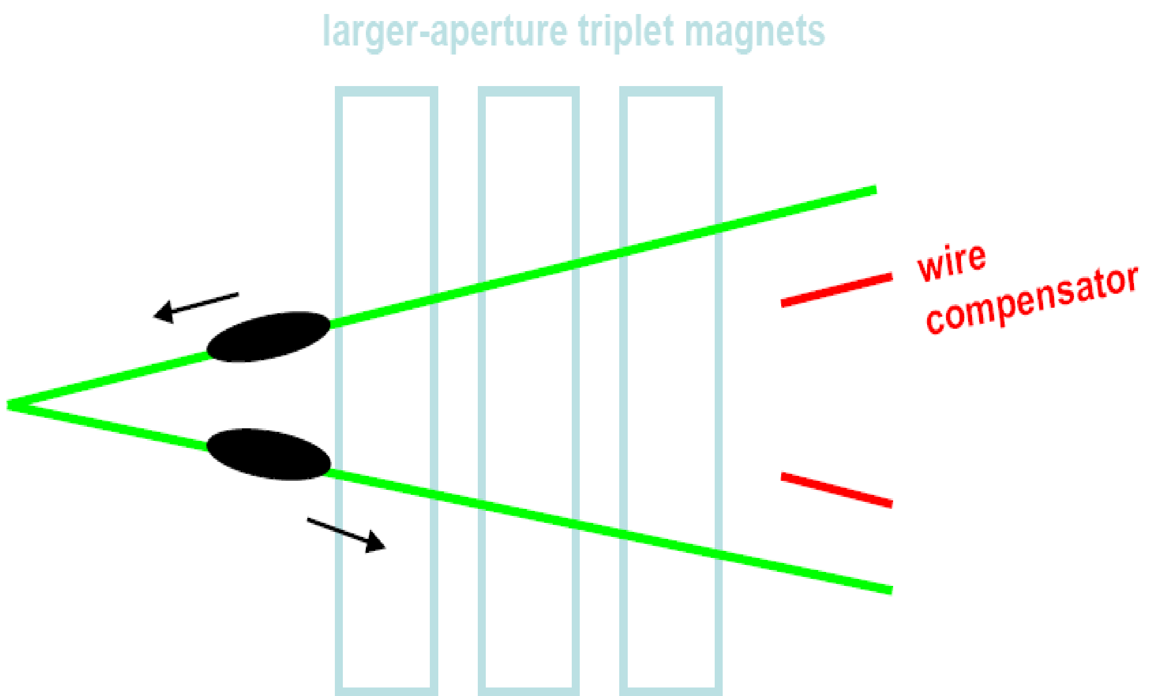
Crab cavities



- RF cavities
  - → local around IP
  - → global placement at 2 locations

- first results obtained in electron beams at KEK
  - → no experience at a hadron collider
- commitments from various labs for R&D effort
  - → could be a magic solution

Large Piwinski angle scenario (LPA)

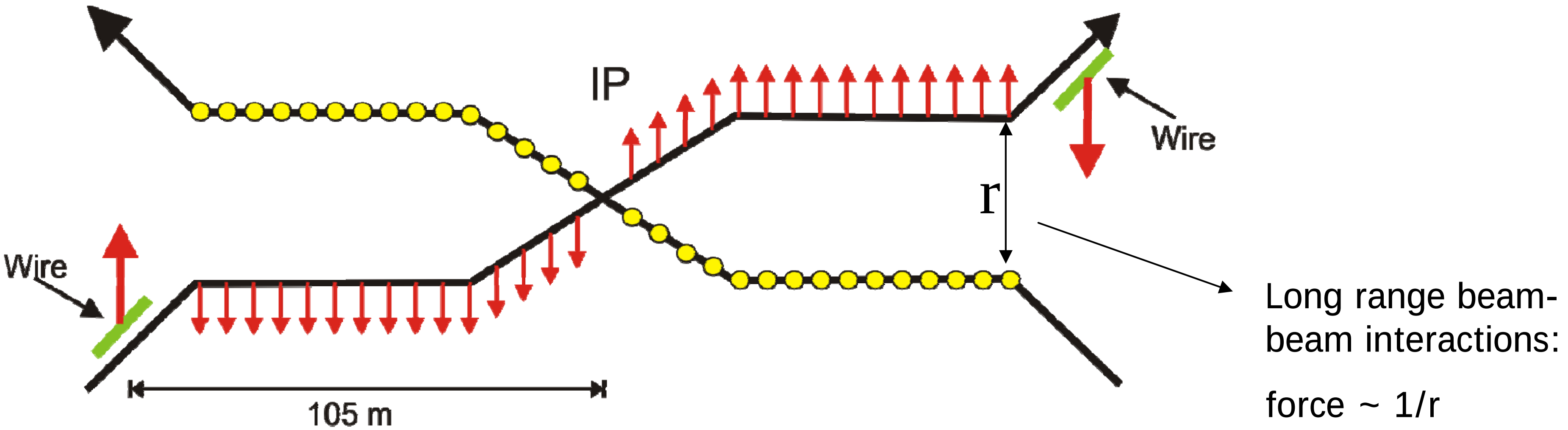


- double bunch spacing
- more intense bunches
- wire compensation
  → of long range beam-beam interactions

- challenges
  → high bunch charge, larger beam current
  → operate with large Piwinski parameter (unproven)
  → wire compensation (almost established)

- e.g. F. Zimmermann, talk at PAC07

Wire compensation



- install wire on each side of interaction point
  - → similar force (~ 1/r) but opposite sign to beam-beam force
- requirements
  - → current of few 100 kA in pulsed mode
    - not easy, R&D required

LHCb upgrade plans

- plan to operate 5 years at $2*10^{33}$ cm^{-2} s^{-1}
  - → accumulate 100 fb^{-1}
- some of the physics goals
  - B_s physics 'unique' to LHCb
  - → weak mixing phase ϕ_s (from $B_s \rightarrow J/\psi\ \phi$)
  - → b→s transition using $B_s \rightarrow \phi\phi$
  - → CKM angle γ from $B \rightarrow DK$, $B_s \rightarrow D_s K$
- experimental upgrade independent of LHC upgrade
  - → replace VELO with more radiation hard variant
  - → add first level trigger on detached vertices
  - → further components under study

ALICE upgrade plans

- present physics program extends until 2017
  - → Pb Pb, p p and p ion running
  - → later low mass ions and lower energies
- present plans for further installation
  - → 2010 electromagnetic calorimeter
  - → 2012-2015 thinner beam pipe, new pixel detector, improved high p_T particle ID, improved forward instrumentation
- request for accelerator R&D to increase PbPb luminosity to $5*10^{27}$ cm^{-2} s^{-1}
  - → need modification to TPC, TPC electronics and DAQ