Requirements from the Experiments

- Physics reach

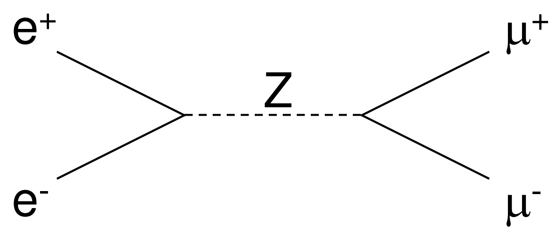
  => Integrated luminosity $\times$ cross section vs. energy

  - build on what was shown at Chamonix 2009
- Experiments requests
- Scheduling / scenarios

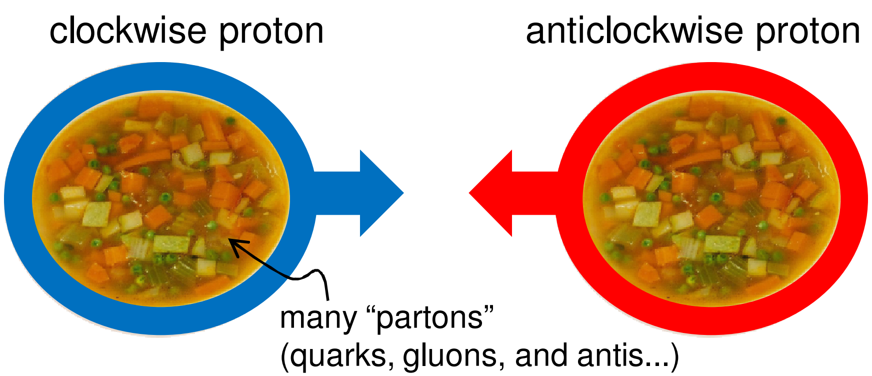
For complement, see talk at Chamonix 2009

LHC, a parton collider

- e^+e^- collider



- LHC



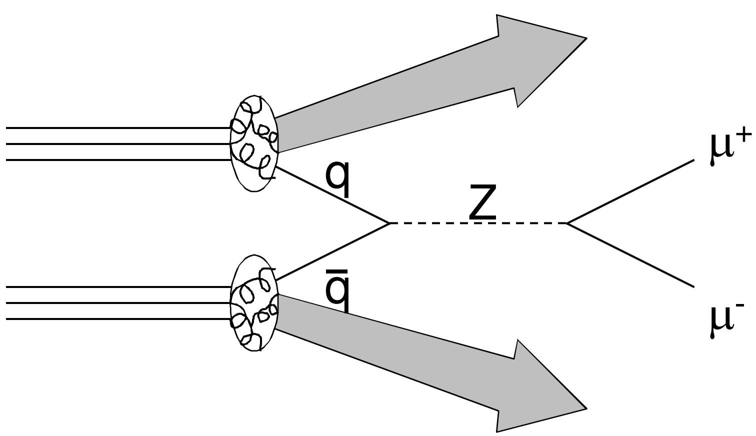
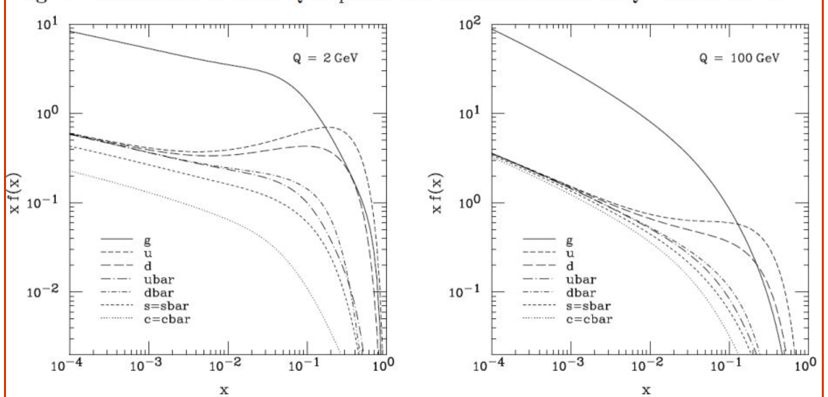


Fig. 1 : Overview of the CTEQ6M parton distribution functions at $Q = 2$ and 100 GeV.



Parton Distribution Functions

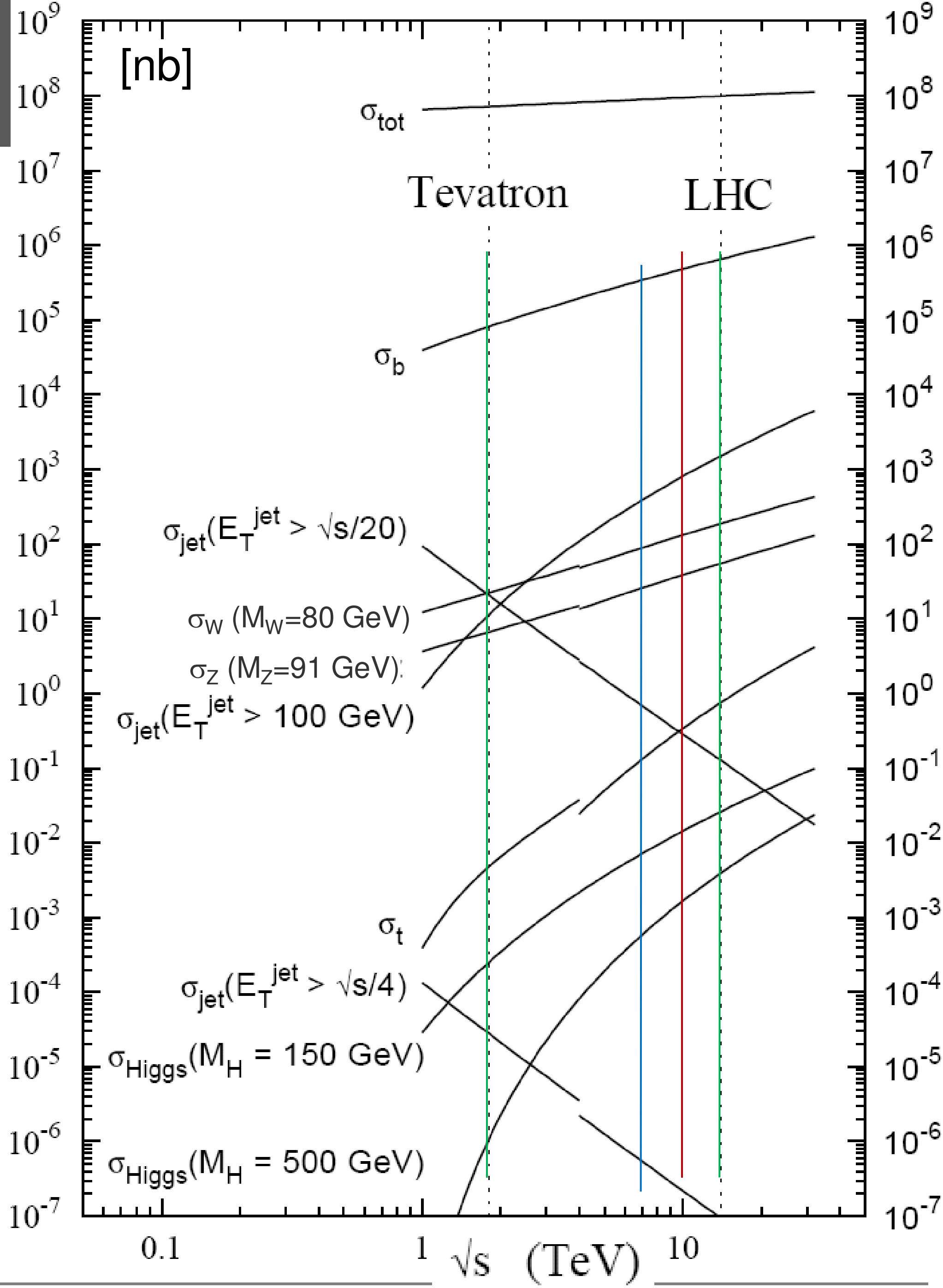
$$\frac{d\sigma}{dX} = \sum_{i,j}\sum_{\tilde{X}}\int dx_1 dx_2\, f_i(x_1,\mu^2) f_j(x_2,\mu^2)$$

$$\times \quad \hat{\sigma}_{ij}^{\tilde{X}}(\alpha_S(\mu^2),Q^2,\mu^2)\, F(\tilde{X}\rightarrow X,\mu^2)$$

the “Master Plot”

Simplified:

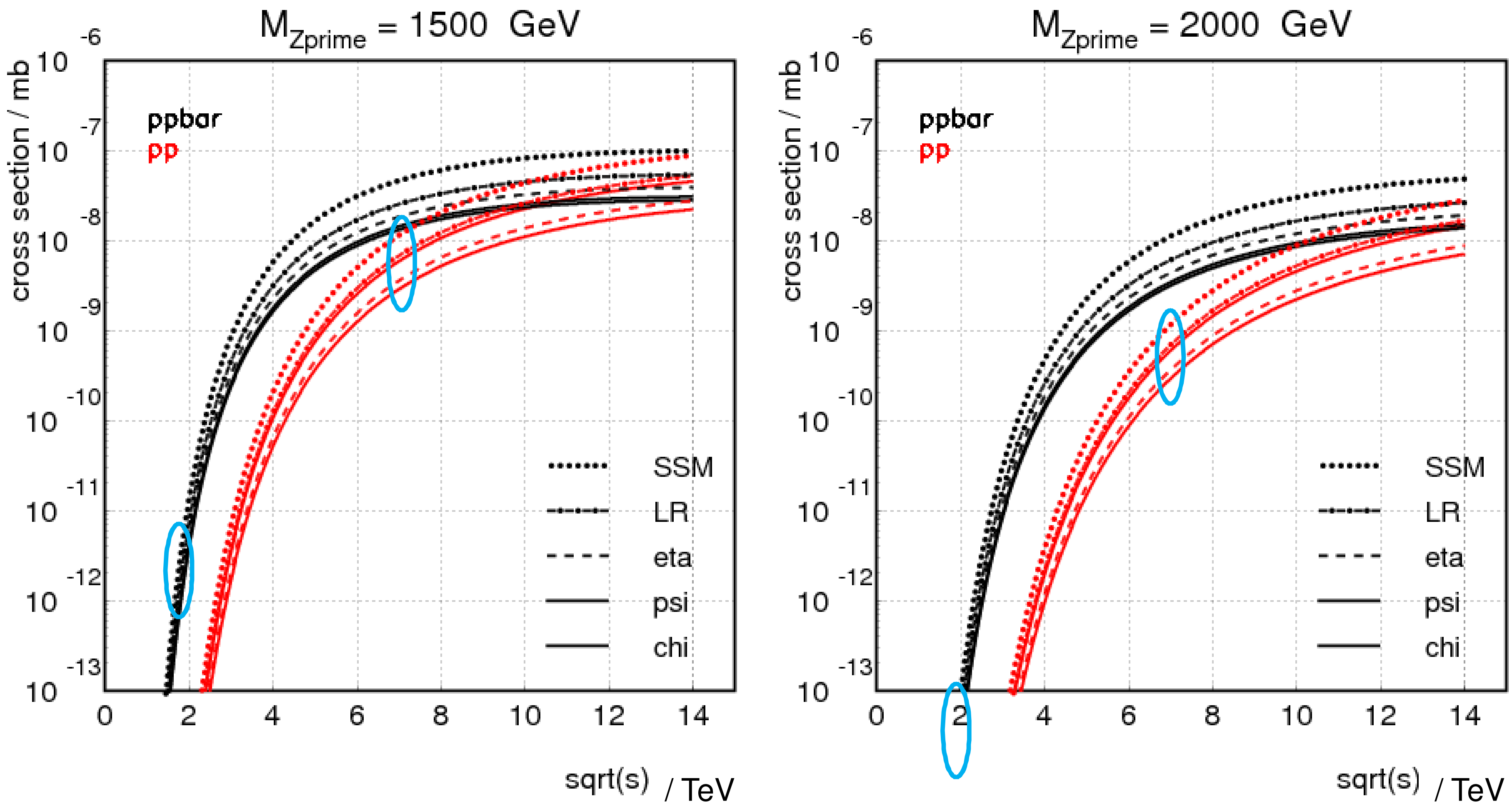
- For a given center-of-mass energy (√s), the larger the mass of the produced system, the steeper the curve
- Absolute cross section scales and details of √s-behaviour, depend on types of partons involved (gluons, quarks, antiquarks) and on couplings (strong, weak, etc.)
- NB: physics bkg typically increase less fast with √s than physics signal



Pedagogical example: Z'

Calculated from eq. (3.16) in arxiv:hep-ph/9805494v1 from A.Leike

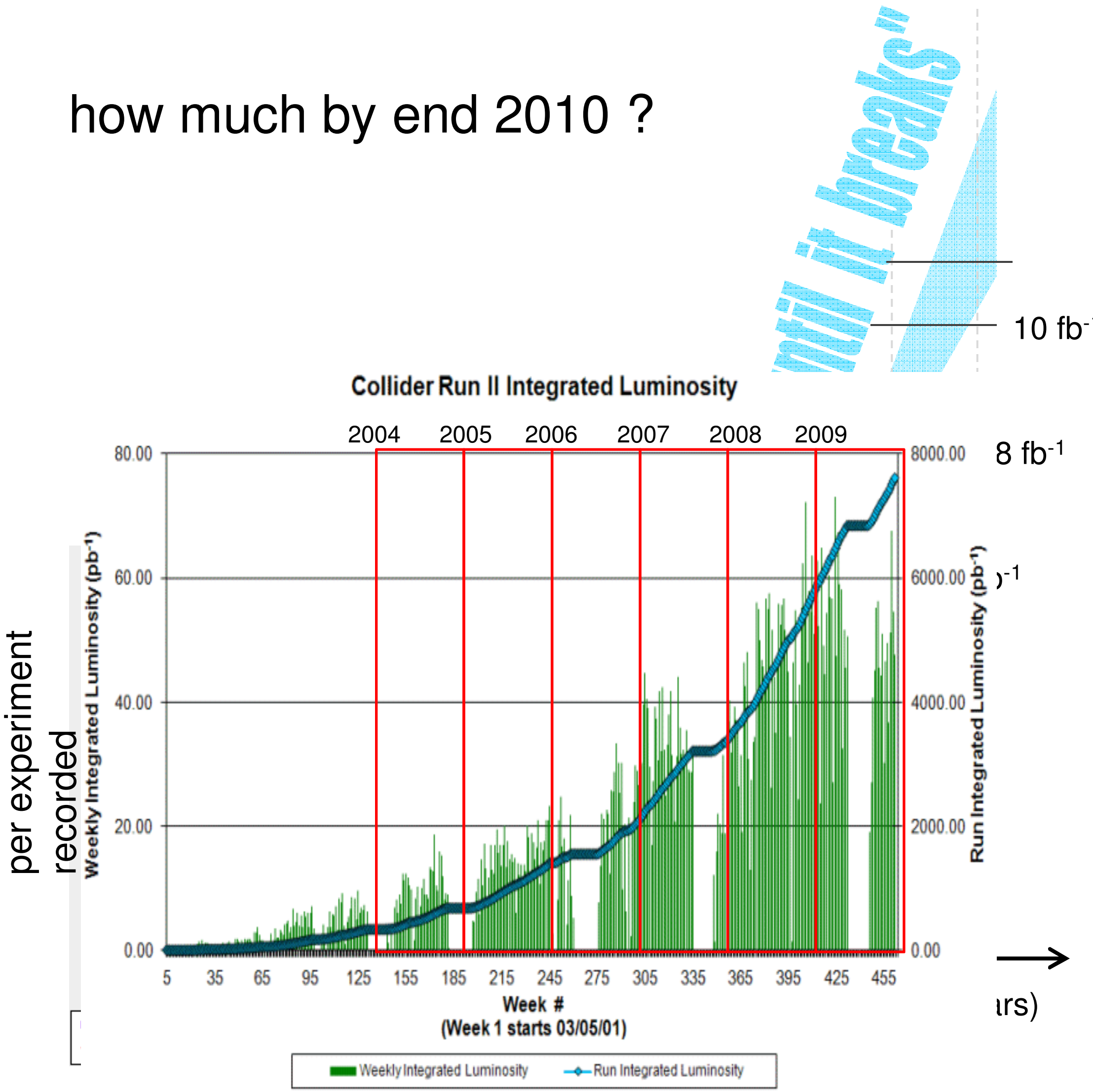
$$\sigma_T^\mu \equiv \frac{N_{Z'}}{L} \approx \frac{1}{s} c_{Z'} C \exp\left\{-A\frac{M_{Z'}}{\sqrt{s}}\right\} (\hbar c)^2$$



State of the Art: Tevatron

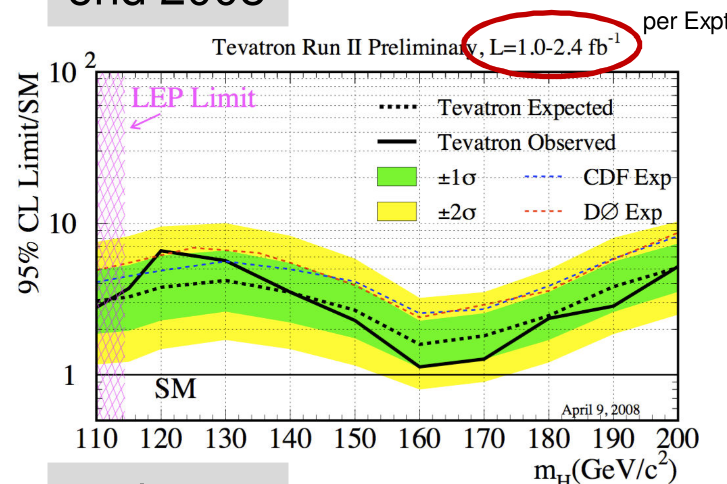
Projected integrated lumi

how much by end 2010 ?

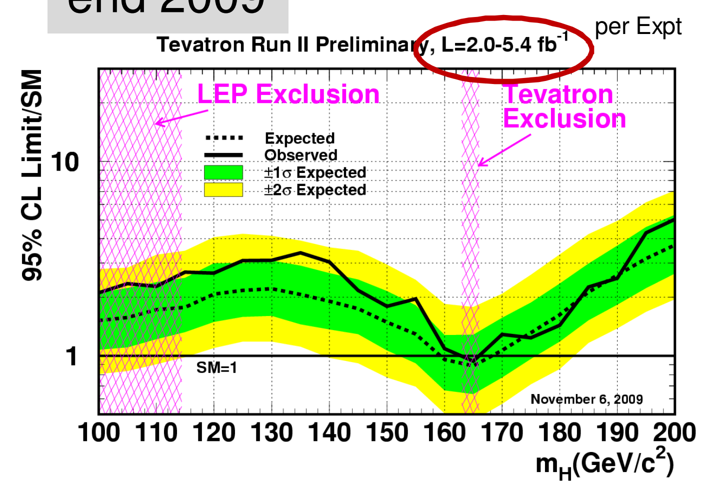


Higgs search

end 2008

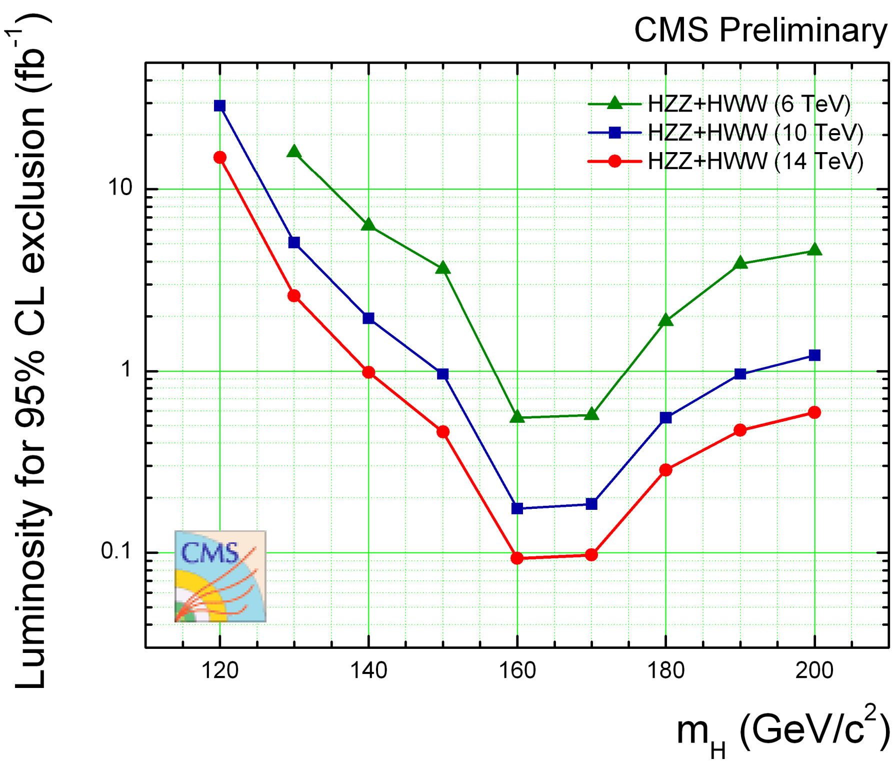


end 2009



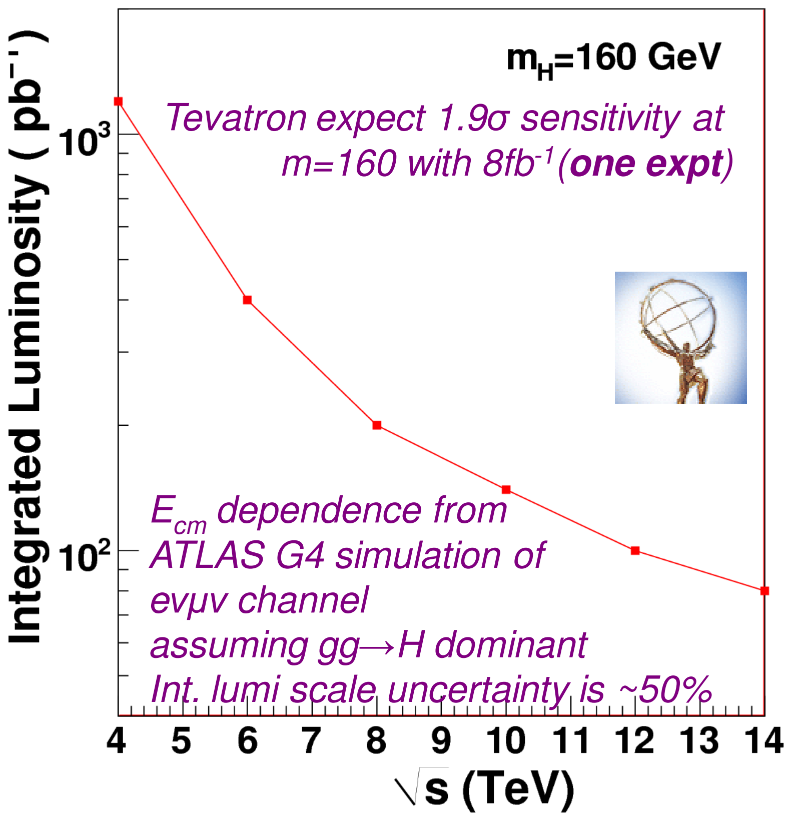
Higgs 95% CL at LHC, H→ weak bosons, indicative

Combined H→WW + H→ZZ: lumi for 95% CL



- Energy $s^{1/2}$ 14 → 10 → 6 TeV
- Lumi needed 0.1 → 0.2 → 0.6 fb^{-1}

Compare sensitivity to Tevatron with 8 fb^{-1} (only H→WW→ℓνℓν)



- Massive loss of sensitivity below 6 TeV

To challenge Tevatron at **$s^{1/2}$ = 7 TeV**, we need ~**500 pb^{-1} g.d.**

Z' resonance

Z': Heavy partner of the Z (SSM)

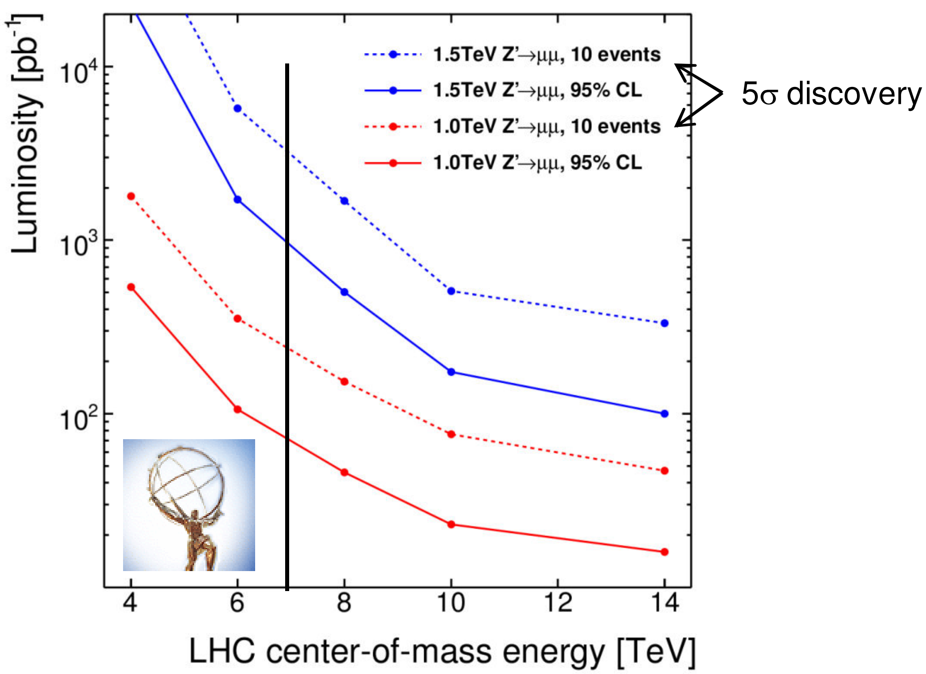
- Very clean experimental signal: Z'→ℓℓ
- Tevatron 95% CL limit at $m_{Z'}$ =1 TeV

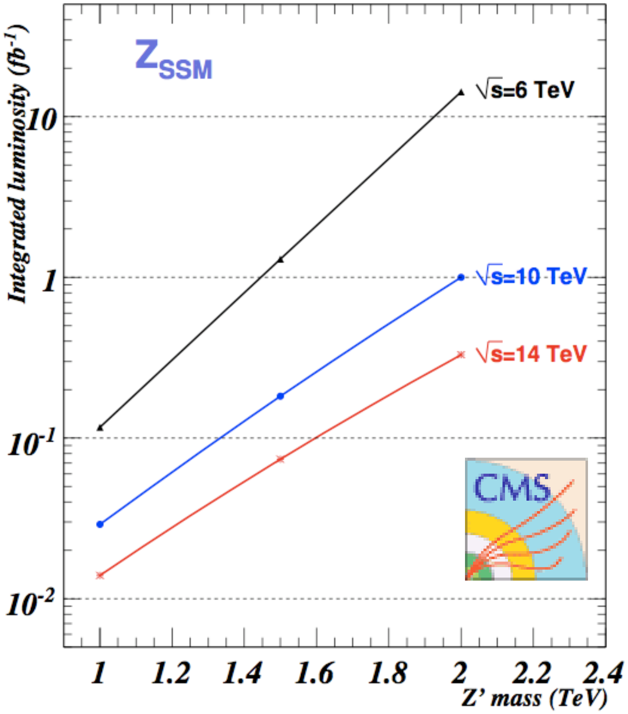
Needed luminosity for 95%CL exclusion at $m_{Z'}$ = 1 TeV :

$s^{1/2}$: 14 → 10 → 6 TeV

Lumi: 13 → 30 → 110 pb^{-1}

ATLAS fast simulation





for $m_{Z'}$ ~1TeV, with **$s^{1/2}$ = 7 TeV** <
95% CL limit with ~**100 pb^{-1} g.d.**
5σ discovery possible with ~**300 pb^{-1}g.d.**

ATLAS and CMS

- Operate at highest possible safe energy.

- Require the highest possible integrated luminosity. A value in excess of a 500 pb^{-1} at 3.5 TeV/beam would allow important first physics measurements.

- To achieve such values within less than 6 months of physics operation will probably require a peak luminosity in excess of 10^{32} $cm^{-2}s^{-1}$ (assuming a realistic operational efficiency).

- Pile-up will not be an issue for ATLAS and CMS (if, as expected, $\mu < 7$ in 2010). Hence, for IP1 and IP5 the highest possible peak luminosity, at reasonable operational efficiency, should be aimed at.

ALICE and *pp* running, in a few words

- ALICE not as strongly interested as ATLAS/CMS in reaching the highest possible energy for *pp*
- Not crucial at this stage, but yes ALICE interested in both
  - Short Tevatron energy run pp@1TeV/beam
  - *NN* equivalent in PbPb@3.5TeV/beam , i.e => pp@1.5TeV/beam
  - each about 1 or 2 x10^7 events on tape (few hours fill)
- Will collect data at ~10^{29} cm^{-2} s^{-1} (opt) or 3×10^{30} cm^{-2} s^{-1} (max)
- Use an (evolving) mix of two trigger configurations:
  - "*Minimum bias*" trigger: used among others to collect a sample of heavy flavour events, which drives requirements for beam conditions and stats. Beam size and pile-up as small as possible: $\sigma_{x,y}$ < ~50 μm ? μ < ~0.1 .
  - "*Rare triggers*" (e.g. high multiplicity evts, μ evts, etc.): here the pile-up requirements driven by high multiplicity evts, where μ < ~0.05 is needed.
- In all configurations, ALICE works better if spacing between colliding pairs at IP2 is >100 ns.
- ALICE intends to start with most of trigger bandwidth dedicated to MB trigger config => rapidly collect ~10^9 *Minbias triggers* (about 10^6 s). When approaching this number, ALICE intends to gradually increase the *Rare trigger* fraction and collect as much data as possible under these conditions.

ALICE (2)

- Optimal conditions for ALICE :

  large number of colliding pairs with small μ and small beam spot.
- For example, at 3.5 TeV/beam, using $\beta^* = \sim 3$ m and 24 bunches of $N = 1.5 \times 10^{10}$ p/b, one would fulfill all requirements:

  $\sigma_{x,y} = \sim 50\ \mu m$ $\mu = \sim 0.04$ $L = \sim 2 \times 10^{29}\ cm^{-2}s^{-1}$.
- This requires filling the LHC with bunches (or bunch trains) characterized by a different spacing and different population as the main bunches (which collide in the other IPs).

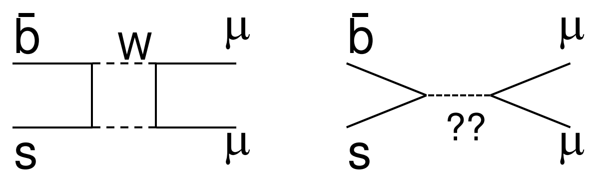
  => an injector MD (early 2010?) to prepare for such option. However, utilization of this option will be subject to an assessment of the consequences for LHC operation.
- Is it better to use same bunch charge, with squeeze, but in combination with offset collisions ?

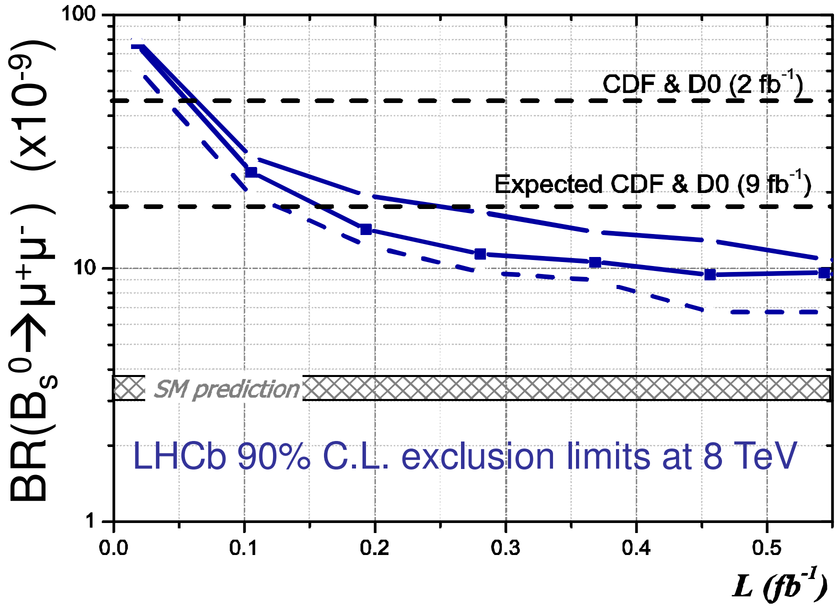
  (as long as the ALICE-dedicated bunches only collide at IP2 and no other bunch pair)

LHCb (1)

- B cross section does not vary as drastically as for high mass objects (b-bbar is “light“ , ~10 GeV). Thus, the request to go to highest possible energy is milder.

- Need ~**0.5 fb^{-1}** at **s$^{1/2}$** ≥ **7 TeV** to surpass Tevatron in B_s physics





LHCb (2)

- Require highest possible luminosity at minimum pile-up, i.e. the largest possible number of bunches.

  => strongly in favour of short-space bunch trains asap ($\alpha_{ext} \neq 0$).

- Pile-up becomes a worry when average number of visible interactions per bunch crossing, $\mu_{vis} = \sigma_{vis} N^2/4\pi\varepsilon\beta^*$, exceeds ~1 (although the degradation is gradual and only experience with real data will tell what pile-up is actually acceptable).

  Assuming σ_{vis} = ~50 mb at 3.5 TeV/beam, this translates into the request that $N^2/4\pi\varepsilon\beta^* \leq \sim 2\text{x}10^{25}\text{cm}^{-2}$.

- Given the expected performance of LHC in 2010, this implies that LHCb requests, like ATLAS and CMS, maximum luminosity until reaching a few 10^{32} $\text{cm}^{-2}\text{s}^{-1}$. After this point, LHCb will prefer minimum pile-up, while keeping such a luminosity level.

LHCb (3)

- Alternate between two dipole polarities during physics running.
- One of the dipole polarities not possible with 3.5 TeV beam $\alpha_{ext} \neq 0$ (already marginal at 5 TeV/beam).
- With $\alpha_{ext}=0$ (i.e. bunch spacing > 500 ns), both polarities are "equal" at any beam energy => utilize early physics periods (43x43 and 156x156) with $\alpha_{ext}=0$ to collect physics data with both polarities.
- Cycling the magnet should be reduced to the minimum needed, e.g. by keeping magnet always ON (no ramping) or by ramping down (if absolutely needed) to an intermediate value of the current, rather than to zero.
- Finally, worth to be noted that the VELO (Vertex Locator) cannot be fully closed if the beam energy is below ~2 TeV/beam (assuming no squeeze and no correction for the internal angle due to the dipole).

Spectrometer magnets: proposal for 2010 states

Proposals

- ATLAS+CMS solenoids: full field, fixed polarity, (a-priori) always on
- ALICE:
  - same polarity for dipole and solenoid,
  - start with [-,-] polarity, keep always at full field (i.e. no cycling/ramping)
  - reverse polarity [+,+] about once/month or less frequent
  - rather early on: short run with [0,0] at any energy, but such that can get about 10k muons in the muon system
    - get ~1 muon/300 mbias at 450 GeV, so as soon as mbias >50Hz, can do it in ~1 shift
- LHCb: here, good polarity is [-], B-field downward
  - start with [-] polarity, keep always at full field (i.e. no cycling/ramping)
  - while still $\alpha_{ext}=0$, reverse polarity between two fills [+]
  - rather early on: short run with [0] at nominal top energy
  - arriving at $\alpha_{ext}\neq0$, start with [-] polarity
  - later in 2010, possible request to introduce the [+] polarity with $\alpha_{ext}\neq0$
    - will depend on data analysis results
    - small MD needed (partial ramp of spectrometer ?)

TOTEM

- Core TOTEM physics program requires a lumi ~ 10^{29} $cm^{-2}s^{-1}$ with reduced number of bunches (43x43, 156x156) and special optics with β^*~1.5 km at IP5 => such scheme which will not be used in 2010.

- However, first physics results (in particular eleastic scattering) can be obtained in parallel with the settings used for CMS, but also with special optics settings with a reduced β^* of ~90m => requested by TOTEM for 2010.

- Requires to move the Roman Pots in with 'stable beams' (not closer than 15σ from the beams).

LHCf

- LHCf requires data taking at low lumi ~ few 10^{29} $cm^{-2}s^{-1}$ with $\mu < 1$.
  - best obtained with few circulating bunches (43x43, or less bunches)

- Detector must be dismounted when dose approaches 1 kGy.
  - replace with ATLAS ZDC-em after completion of LHCf data taking at 3.5 TeV/beam, e.g. at first subsequent technical stop (~5 hours to remove LHCf on both sides and ~9 hours to both remove LHCf and install the ATLAS EM module).

- To obtain complete data set: take data in three different vertical positions, with and without crossing angle.
  - The data taking time is of the order of one hour per setting.
  - Crossing angle such that momentum resultant points downward.

- The LHCf collaboration intends to re-install detectors in IR1 at a later time in order to take data at other center-of-mass energies.

Luminosity and Filling schemes

see Werner's talk in session 3

Requests

- ATLAS/CMS: highest possible luminosity
- ALICE: need ~10^{29} cm^{-2} s^{-1} (opt) or 3×10^{30} cm^{-2} s^{-1} (max)
- LHCb: highest possible till reaches ~5×10^{32} cm^{-2} s^{-1}, then prefer minimizing pile-up at same luminosity

Filling schemes wishes for 2010

- ATLAS/CMS: keep option to have 1 or 2 non-colliding bunches
  - automatic at 50 ns (ALICE bunches)
  - arrange 1 or 2 for 43x43 and 156x156

- ALICE:
  - can the special IP2 bunches be optimized ?
    - trunc. 50ns: spread more the few Alice bunches ?
    - adjust charge of the few Alice bunches ?
  - would like to test higher 1-turn pile-up (“stress” test of TPC)
    - one special fill at 43x43 with few 1e30 in IP2 ?

- LHCb:
  - prefer truncated 50ns to 156x156 (doubles # collisions in IP8)
    - skip 156x156 altogether ?
    - i.e, test crossing angles at 43x43, then move on to 50ns trains ?

Luminosities at $s^{1/2}$ = 7 TeV

$$L = \frac{f\, k_b\, N^2\, \gamma}{4\pi\, \varepsilon_N \beta^*} F$$

$$L_{int} = F \cdot T_{run} \cdot L_{peak}$$

Assume (somewhat arbitrarily) a "global efficiency factor" of F=0.2

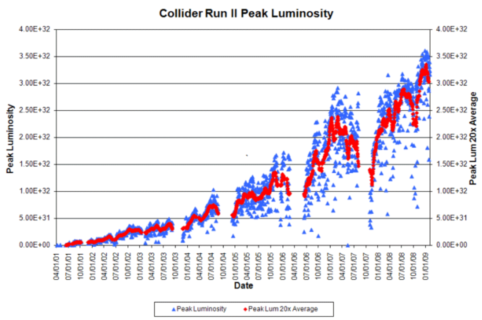
β^*=2m   N=7x10^{10}

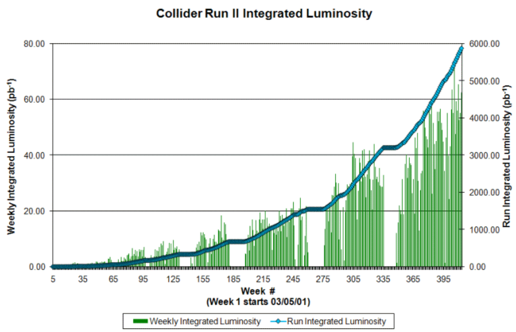
k_b=156 ⇒ 3.4×10^{31} cm^{-2} s^{-1} ⇒ ~ 0.6 pb^{-1} / day

β^*=3m   N=7x10^{10}

k_b=720 ⇒ 1.0×10^{32} cm^{-2} s^{-1} ⇒ ~ 1.7 pb^{-1} / day

$\alpha \neq 0$





Note: Tevatron is cruising at
~3×10^{32} cm^{-2} s^{-1}
(8 pb^{-1}/day , 2 fb^{-1} / year)
⇒ we need high energy!

3.5 TeV evolution, 2010

Zeroth parameter set – no crossing angle:
- few x few bunches, then squeeze

First parameter set - no crossing angle

number of bunches	N_b p/bunch)	β^* (m)	angle (μrad)	$\mathcal{L}_{peak}^{IP1,5}$ ($cm^{-2}s^{-1}$)	% I_{max} stored
taken from Werner					
43	$3\ 10^{10}$	4	-	$8.6\ 10^{29}$	2.6
43	$5\ 10^{10}$	4	-	$2.4\ 10^{30}$	4.3
43	$5\ 10^{10}$	2	-	$4.8\ 10^{30}$	4.3
156	$5\ 10^{10}$	2	-	$1.7\ 10^{31}$	16
156	$7\ 10^{10}$	2	-	$3.4\ 10^{31}$	22
156	$10\ 10^{10}$	2	-	$6.9\ 10^{31}$	31

skip ?

Parameter set with crossing angle

number of bunches	N_b p/bunch)	β^* (m)	half angle (μrad)	$\mathcal{L}_{peak}^{IP1,5}$ ($cm^{-2}s^{-1}$)	% I_{max} stored
144 (4)‡	$5\ 10^{10}$	3	±140	$1.0\ 10^{31}$	14
144 (4)‡	$7\ 10^{10}$	3	±140	$2.0\ 10^{31}$	20
288 (8)‡	$7\ 10^{10}$	3	±140	$4.1\ 10^{31}$	40
432 (12)‡	$7\ 10^{10}$	3	±140	$6.2\ 10^{31}$	60
720 (20)‡	$7\ 10^{10}$	3	±140	$10.2\ 10^{31}$	100

- assumption: next stable beams at 3.5 TeV
  - except perhaps some small amount at 450 GeV for warm-up
- move to multibunch transfer as soon as possible
  - even for few bunch scheme ?
- introduce $\alpha \neq 0$ at IP1 early on
  - short LHCf run

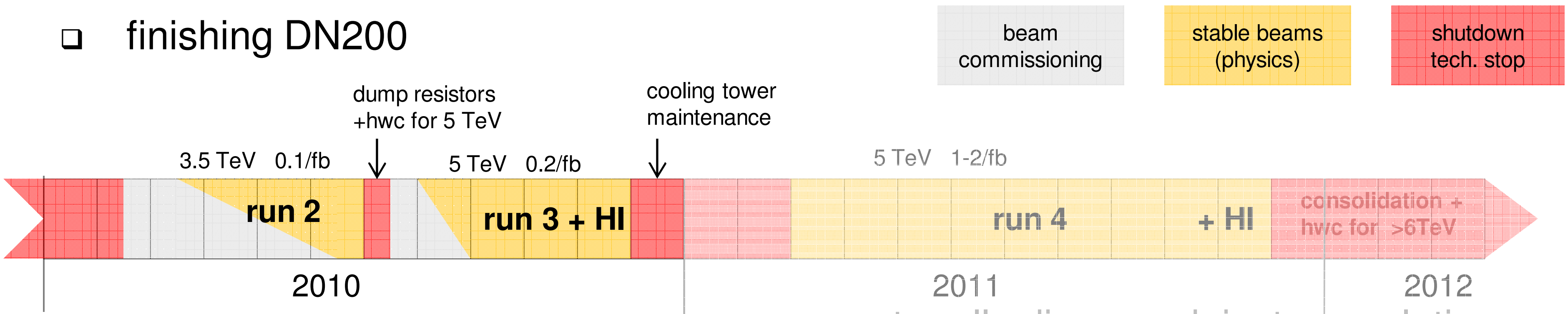
  then other IPs
  - already at 43x43 ?
- move to truncated 50ns asap

156x156 had a value in the cham'09 context (L>1e32 at 5 TeV).
Not so much now ?

Yearly scenario , as we had it round mid 2009...

Taking into account known facts about:

- copper stabilizer issue
- retraining of magnets
- finishing DN200

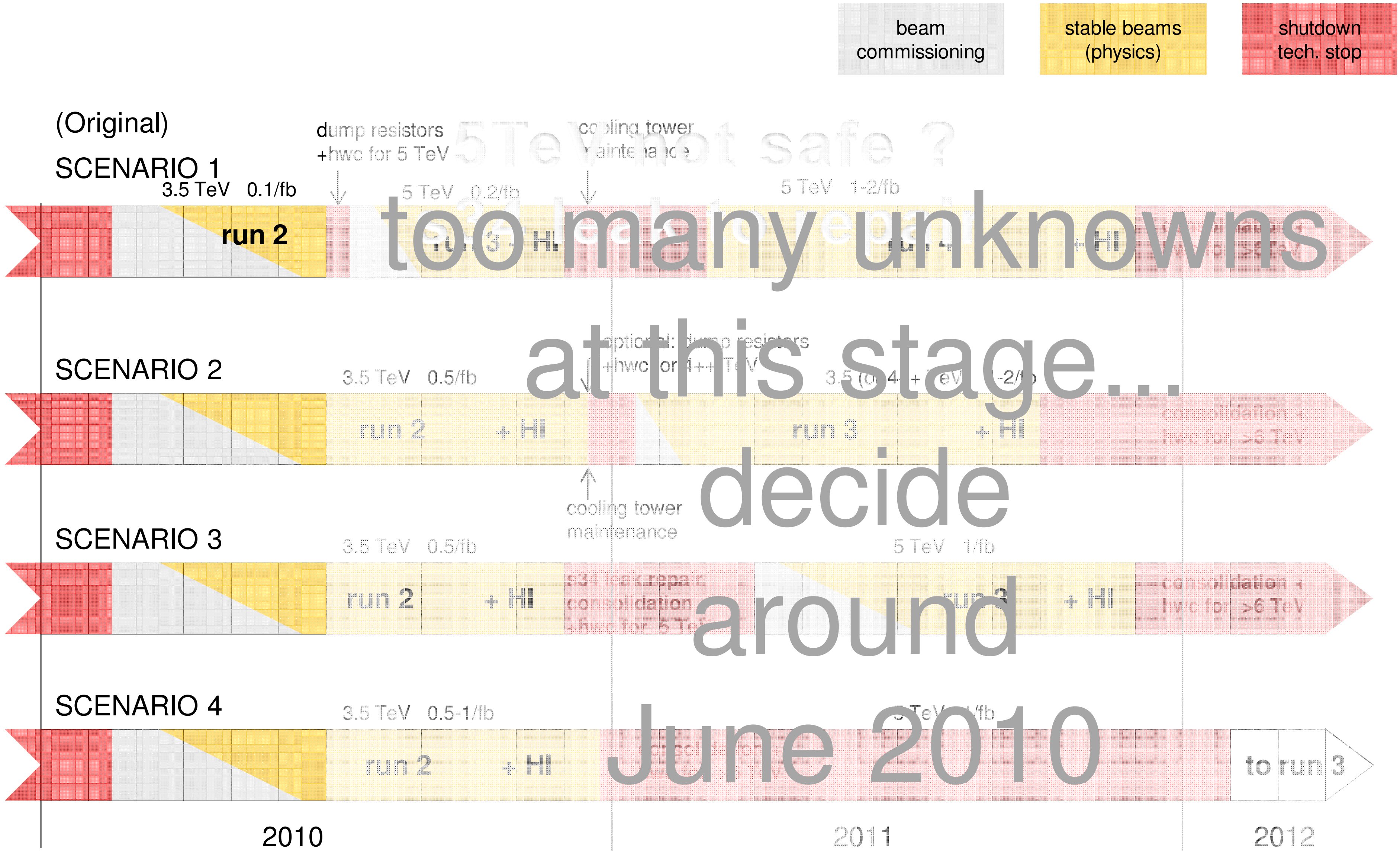


was not really discussed, just speculative

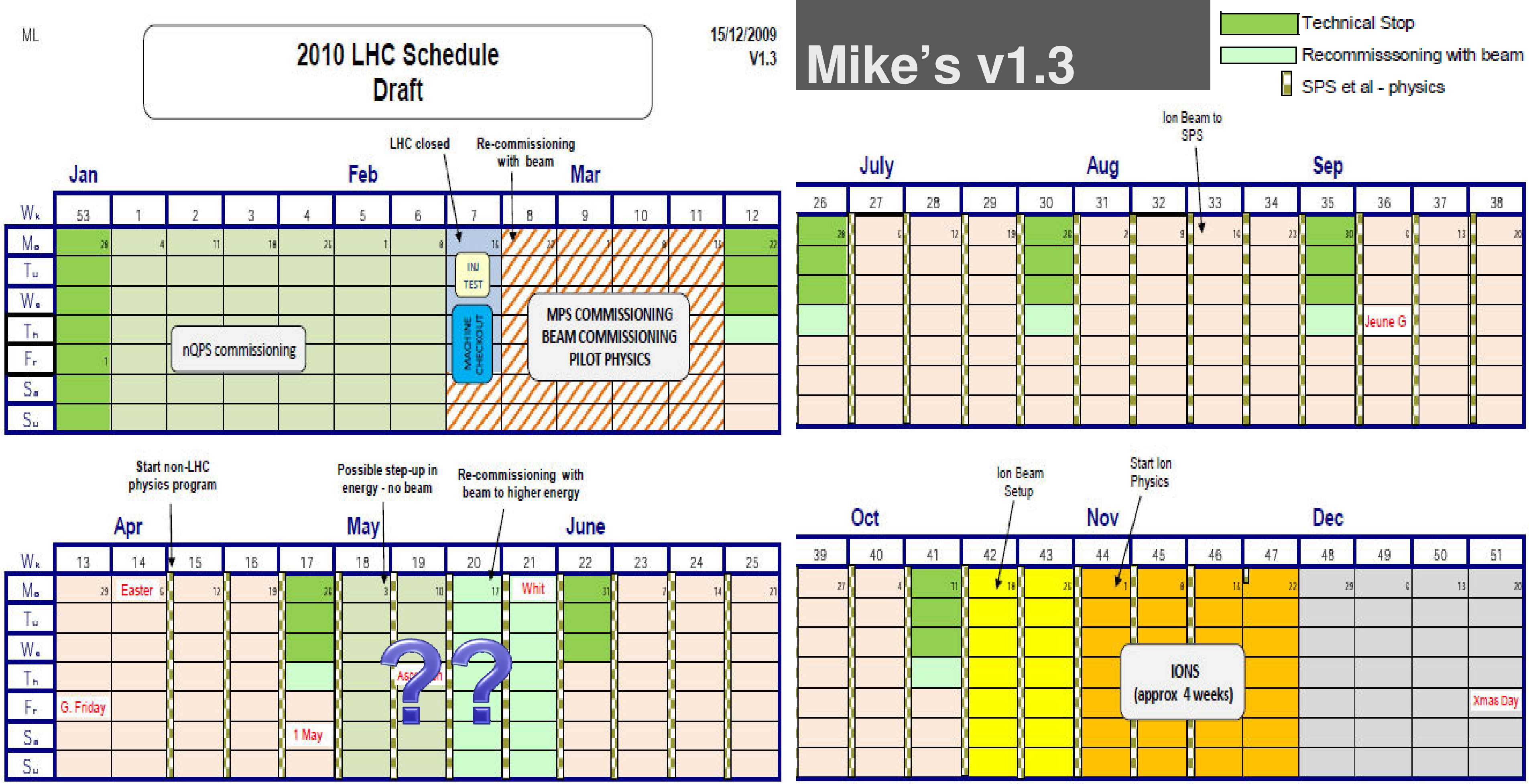
New information since then:

- copper stabilizer issue:
  - 5 TeV operation perhaps not safe enough ? => 4.5 ? 4... TeV ? => Cham'2010
  - and still three sectors not measured at warm (less constrained copper stabilizer resistance values)
- sector 34: vacuum leak
  - needs repair, rather sooner than later...

Scenarios



beam commissioning
stable beams (physics)
shutdown tech. stop
(Original)
SCENARIO 1
3.5 TeV 0.1/fb
run 2
dump resistors
+hwc for 5 TeV
5 TeV 0.2/fb
cooling tower maintenance
5 TeV 1-2/fb
5TeV not safe ?
s34 leak to repair
SCENARIO 2
3.5 TeV 0.5/fb
run 2
+ HI
optional: dump resistors +hwc for 4++ TeV
run 3
+ HI
consolidation + hwc for >6 TeV
cooling tower maintenance
SCENARIO 3
3.5 TeV 0.5/fb
run 2
+ HI
s34 leak repair consolidation +hwc for 5 TeV
5 TeV 1/fb
+ HI
consolidation + hwc for >6 TeV
SCENARIO 4
3.5 TeV 0.5-1/fb
run 2
+ HI
to run 3
2010
2011
2012
too many unknowns
at this stage...
decide
around
June 2010



- No specific technical stop requirements
  - i.e. OK with one 3-day stop about every month
  - work in line with machine stops
- LHCf⇔ZDC-em replacement , TOTEM RPs