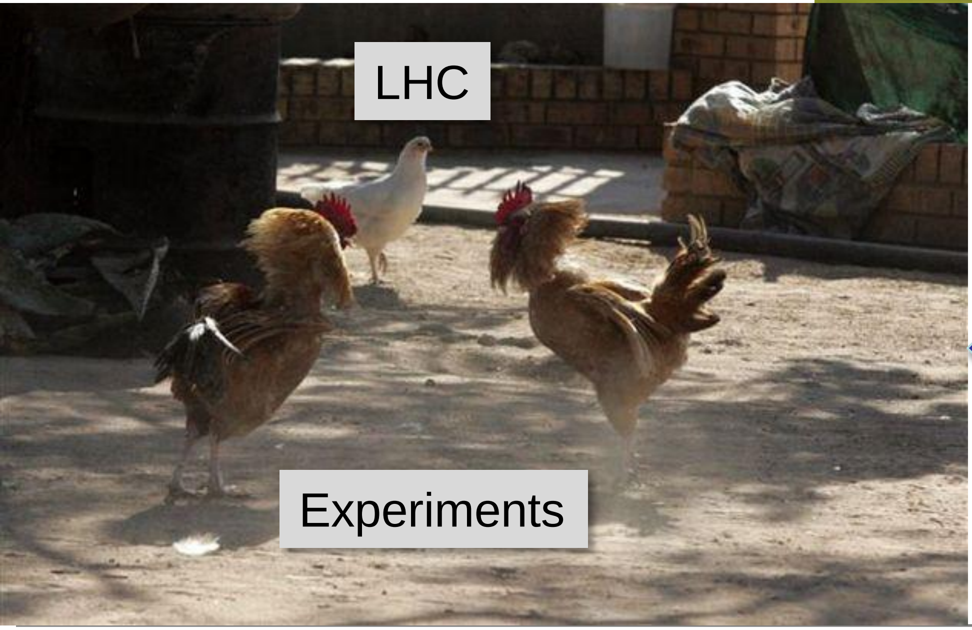
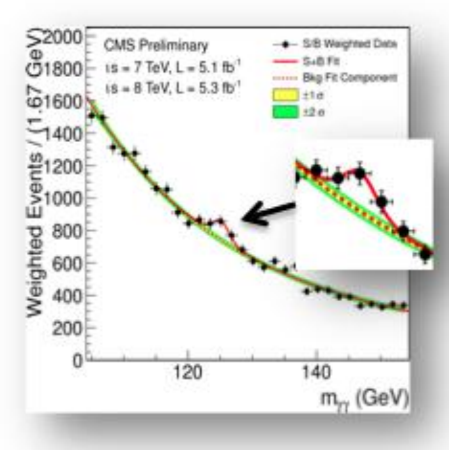
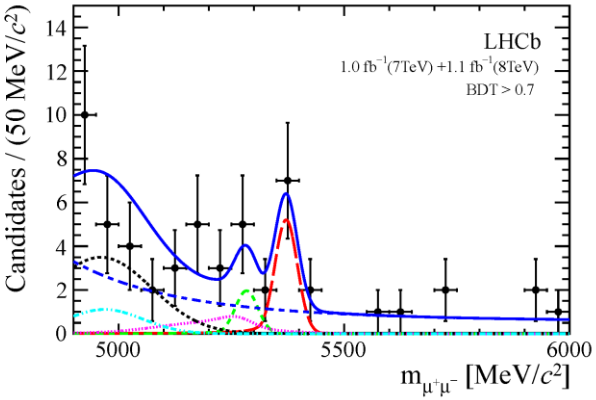
2012

Mike’s view



Our view

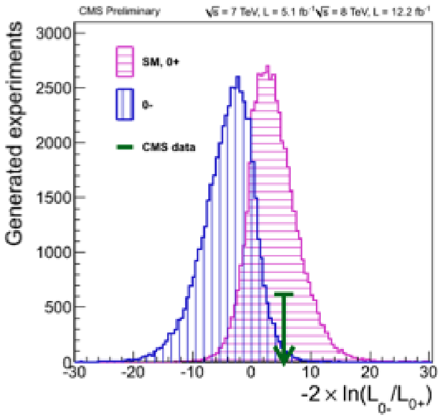




Experiments requirements and limitations for post-LS1 operation

Evian Workshop 20.12.2012

E Meschi, B Gorini



Summary

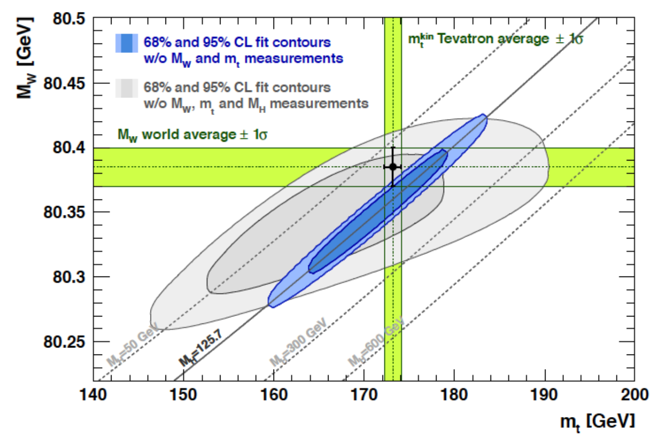
- Big achievements turn into a rich set of new physics goals
  - Difficult precision measurements of the properties of the newly found boson
  - Study of other important phenomena predicted by the standard model (or deviations thereof)
  - Higher energy: looking forward to the possibility of new physics **beyond** the standard model.
- Sometimes diverging demands on the experiments and the accelerator:
  - Running scenarios for the pp collider run after LS1
  - In particular with respect to the bunch spacing and related issues (pile-up, trigger and reconstruction efficiency)
  - Bunch length, filling schemes, β^* leveling, etc.
- Many experimental and technical challenges ahead of us in any of the different scenarios

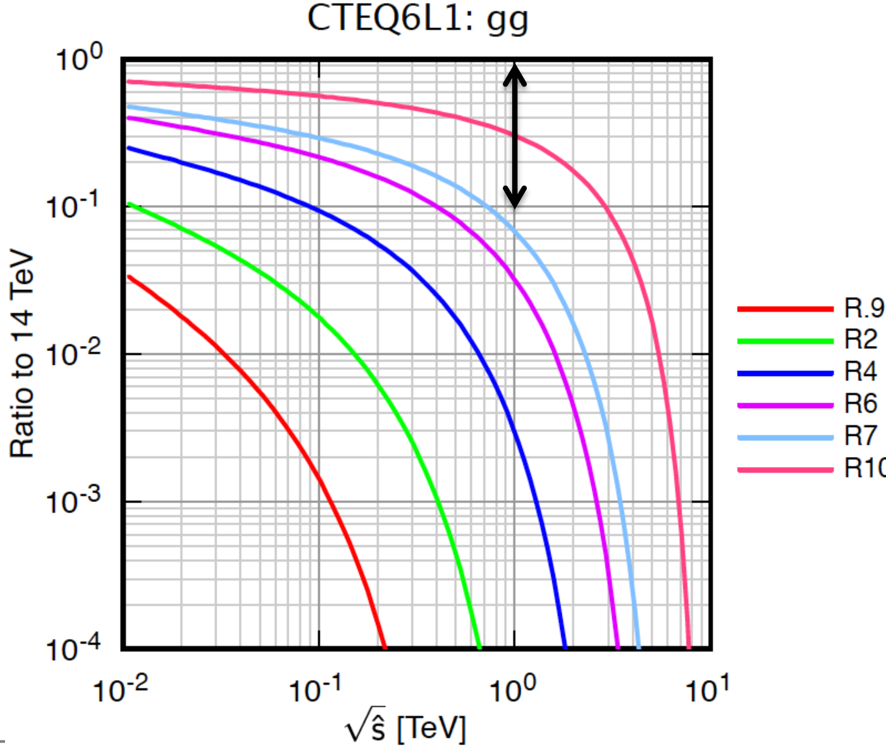
Physics: standard model and beyond

- ❑ Study of the “Higgs-like object at 126 GeV” (branching ratios, couplings, mass, spin/CP, ...) requires to cover a large range of modes:
  - H-> γγ, ZZ, WW, ττ
  - WH, ZH -> lvbb, llbb, vvbb
- ❑ Look for new physics

•At the mass scale of 1 TeV, the cross section for production of new particles is 10 times higher at 13 TeV relative to 8 TeV

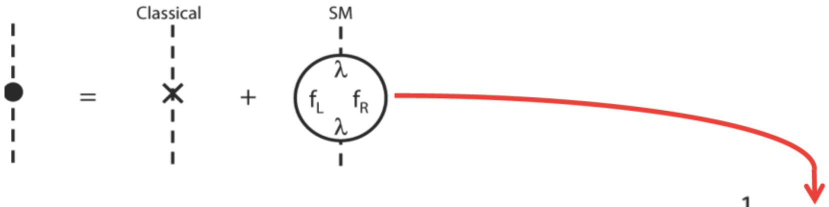
•30fb^{-1} in 2015 would allow to see a possible signal with 2.5 σ significance



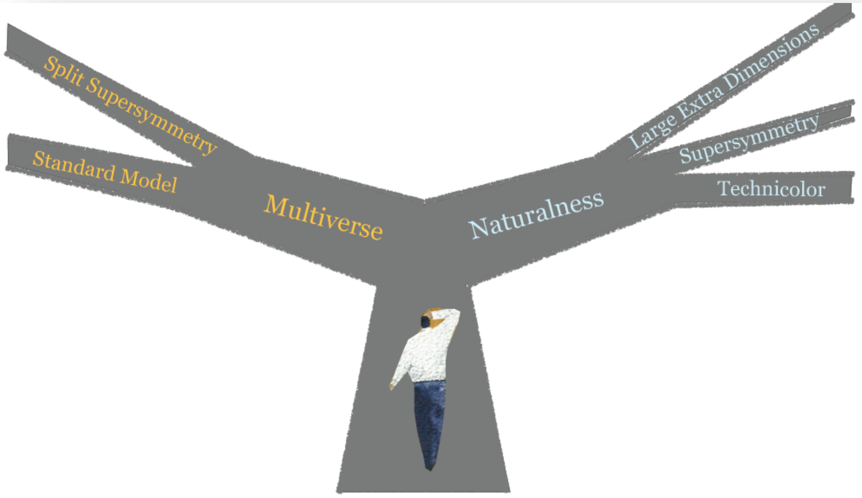


… and beyond ?

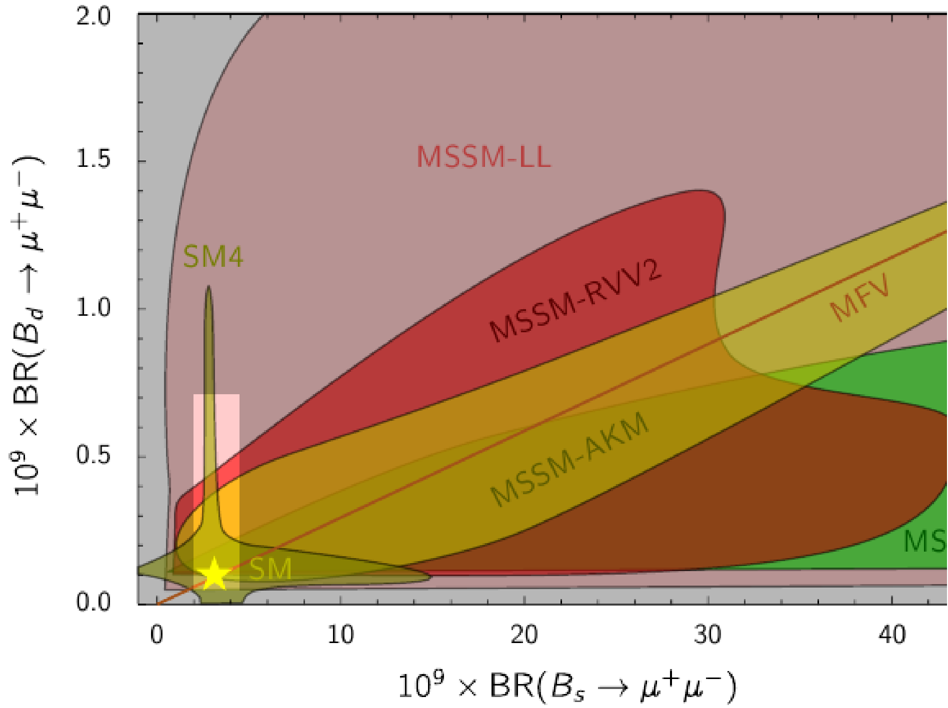
Miraculous cancelations needed to keep the Higgs mass < 1 TeV



$$m_h^2 = (m_h^2)_0 - \frac{1}{16\pi^2}\lambda^2\Lambda^2 + \ldots ,$$



Savas Dimopoulos, CERN Colloquium, Sep 20, 2012



BEAM PARAMETERS 2015

Bunch Spacing: ATLAS and CMS physics case

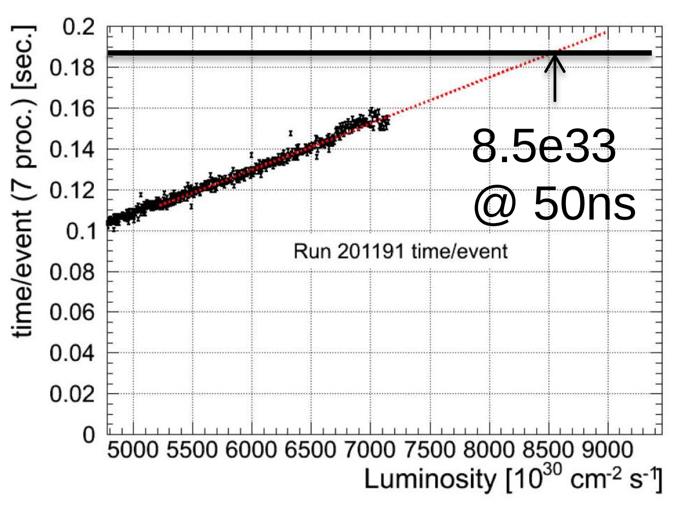
- **Obvious**: 50ns gives twice the in-time pileup for the same instantaneous luminosity, e.g. for 1e34 $cm^{-2}s^{-1}$ @14TeV:
  - μ=27 at 25ns
  - μ=54 at 50ns
- **Physics: Study of** the 'Higgs-like object at 126 GeV' is the highest priority
- H->©© and ZZ modes "relatively" straightforward to trigger and study
  - Even at high pile-up
  - Other modes require good resolution and small systematic uncertainties for jets and |-leptons -> much more difficult to achieve with high in-time pileup
    - H->||: requires low-threshold ||-triggers, which get spoilt by higher pile-up
    - ZH->ννbb relies on an E_T^{miss} trigger: higher pileup will require increased thresholds
  - In order to maximize acceptance, need to maintain or even lower those thresholds
  - **Requires operation at 25ns**

Detector Limitations with 50 and 25 (ATLAS&CMS)

- **2012 running conditions with 50ns beam already very close to limit**
- **Inner detector readout limitations** (Pixels and strips) due to increasing detector occupancy and fixed total bandwidth:
  - 50ns: with increased luminosity, leveling would become necessary
  - 25ns: detectors limitations start above 1e34 $cm^{-2}s^{-1}$
- **DAQ/Trigger & Computing:**
  - 50ns would require about twice the CPU capabilities of the high-level trigger farm, and a very significant increase of offline CPU and disk resources in comparison to 25ns, for the same amount of integrated luminosity
- **Reconstruction & Analyses:**
  - Effects on reconstruction and analysis become dramatic above 1e34 $cm^{-2}s^{-1}$ at 50ns
  - 25ns would give much more 'headroom' with respect to possible factors of two increase without going to pileup of $\mu>50$.
  - At 50ns fundamental changes to reconstruction and analyses would be required
    - e.g. raising track reconstruction p_T cut and rethinking the primary vertex determination strategy.

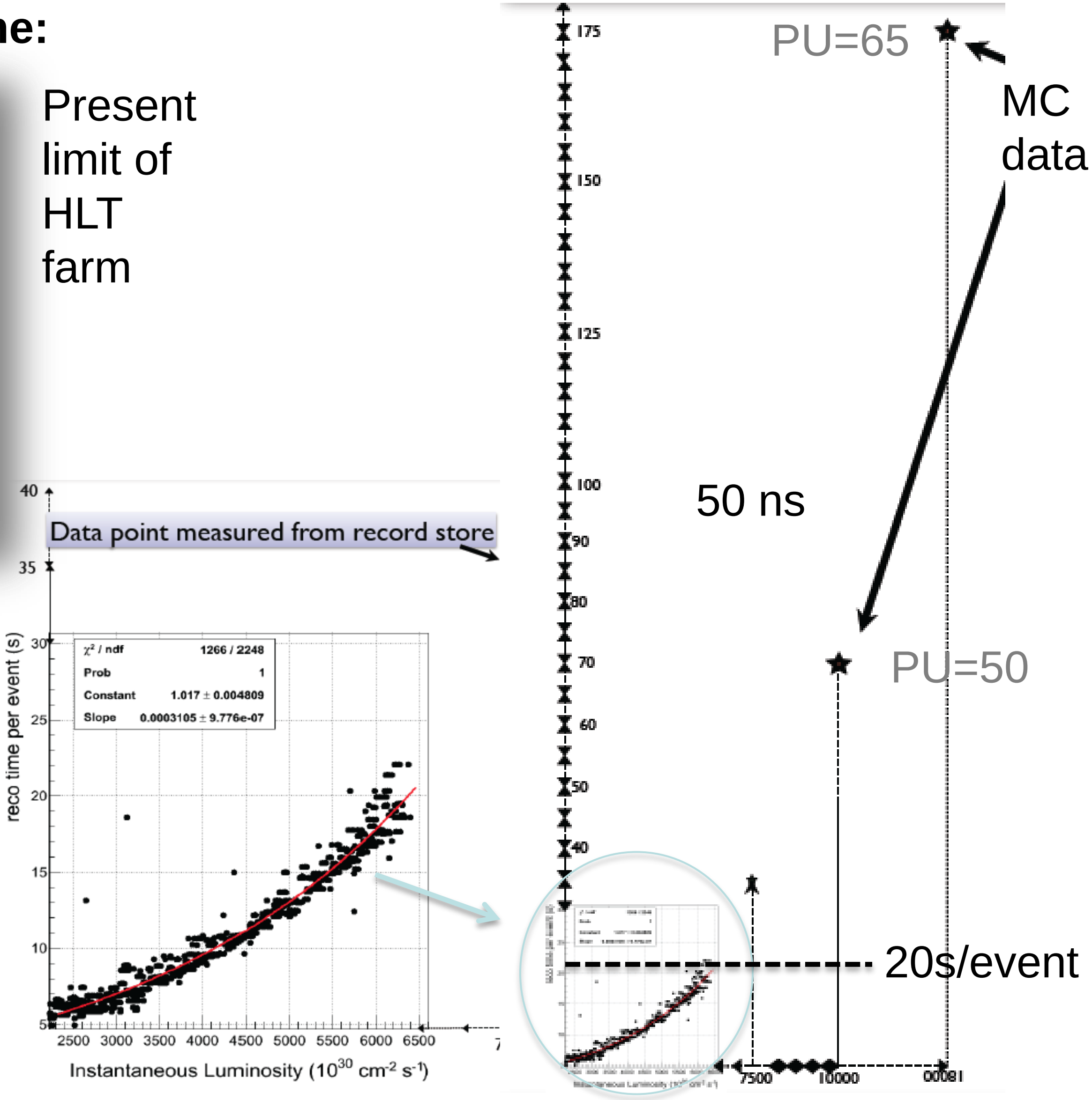
Example: Computing resources

High Level Trigger CPU time:



8.5e33 @ 50ns

Present limit of HLT farm



χ^2 / ndf	1266 / 2248
Prob	1
Constant	1.017 ± 0.004809
Slope	0.0003105 ± 9.776e-07

PU=65

MC data

50 ns

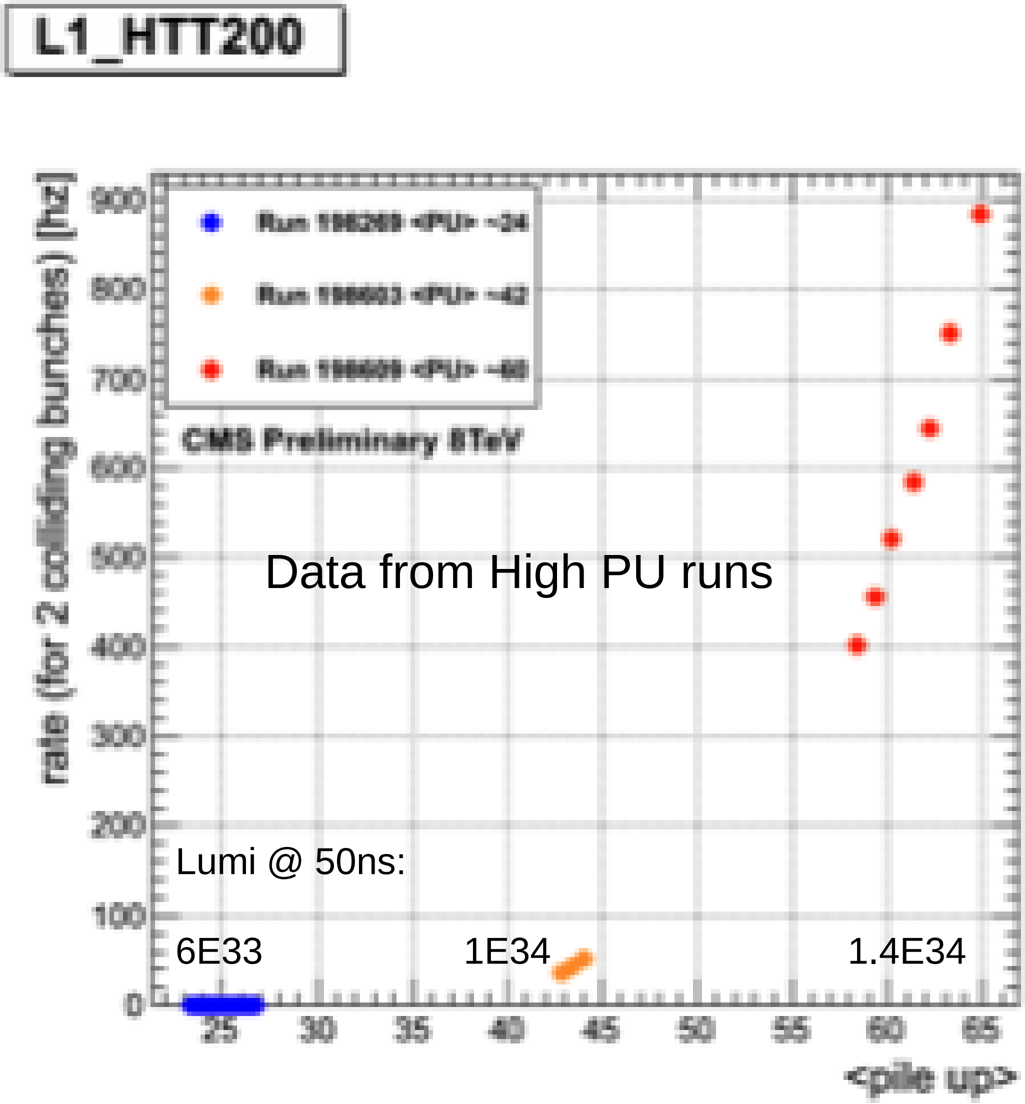
PU=50

20s/event

10^{34} 1.3 10^{34}

Offline reconstruction time/event: 20s

Example: trigger rates and thresholds



Data from High PU runs

Lumi @ 50ns:

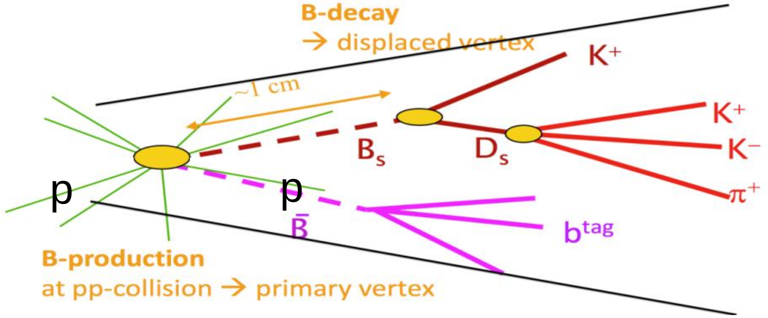
6E33

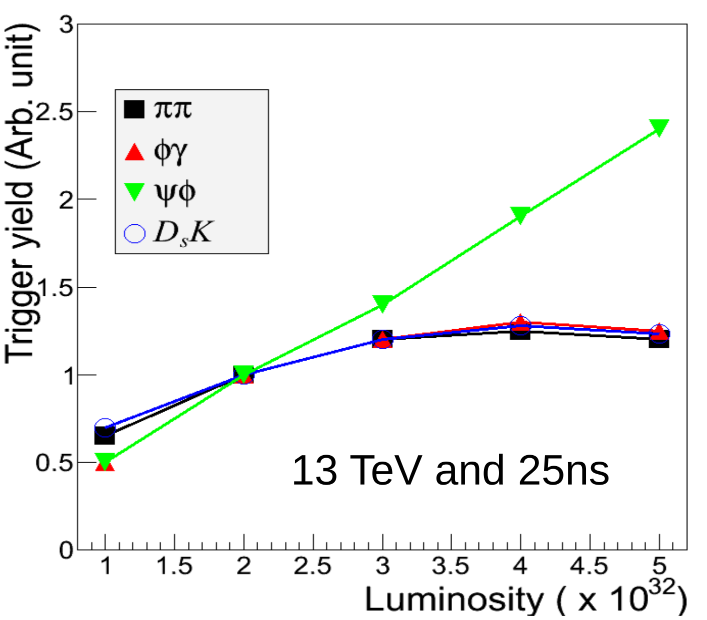
1E34

1.4E34

Bunch spacing: The LHCb case

- Precision measurements in charm and beauty physics
  - Look for complex, fully reconstructed decay chains
    - At both trigger and offline level
- High pileup means:
  - Ambiguities and ghost tracks
  - Worse vertex, momentum, and mass resolution
  - Ultimately degradation of signal/background
  - Increase in trigger CPU time
  - Increase in offline processing time





- Instantaneous luminosity
  - Running at 4x10^{32} cm^{-2}s^{-1} at 13 TeV and μ ~ 1.0
  - 25ns with 2200 LHCb bunches (high brightness, no private bunches)
  - Multiplicity increase 8 TeV → 13 TeV: ~20%
  - Detector particle flux equivalent to 5.5x10^{32} cm^{-2}s^{-1} 1 @ 8 TeV

The LHCb case

- 25ns low emittance option: 1.15×10^{11} ppb and emittance of 1.9 µm in LHC
  - IP8 peak luminosity with $\beta^*= 10$m and tilted crossing (resulting expected angle = 340microrad): 9×10^{32} cm^{-2}s^{-1}
- Leveling required !
  - Both for luminosity control and physics optimization (maximizing integrated luminosity, trigger stability)
  - Leveling “lifetime” (irrespective of technique):
    - 8.5h to exhaustion as compared to ~14h now assuming same luminosity lifetime of ~10h so…
    - $\beta^* < 10$m (at least square root of product of β^*_x and of β^*_y at the end…)
  - LHCb deems important to have dynamic β^* option available for 2015
    - Leveling is a physics yield and precision tool, yet transverse offset reduces head-on damping
  - Option: defocusing LHCb in vertical plane and dynamically reducing β^*_y ?

Luminous Region, Bunch Length, Crossing angles etc.

- ❑ Luminous region transverse size
  - In general:
    - As constant as possible across all the bunch crossings,
    - As small as possible in order to maximize the luminosity (assuming we are not in a pile-up regime that would force us to level the luminosity)
  - LHCb
    - Primary vertex reconstruction benefits from small transverse luminous region
      - Cut at 300 μm
      - (Luminous region about the same size (S~70 μm) with β^*= 10m and 13 TeV as with 3m and 8TeV…)
    - Maintain luminous region small (thin) in one plane !

Bunch Length, Luminous Region, Crossing angles etc.

- The critical parameter for experiments is the luminous region rather than the bunch length
  - Longer bunches will be partially compensated by larger crossing angles
- A short luminous region gives more 'merged vertices’
  - i.e. more difficult to reconstruct the primary event vertex
- A longer luminous region would benefit ATLAS and CMS (not LHCb) tracking and vertex reconstruction at high pile up **but**:
  - For CMS, it would also worsen the mass resolution in the H->$\gamma\gamma$ analysis (benefits vs drawbacks under study – will also depend on the pile up conditions)
  - For ATLAS and CMS: it can cause acceptance/efficiency losses for tracking and e/photons
  - For LHCb: despite VELO being ~1m, already some loss of “long-lived” B’s….
    - Contributes to 1/3 of the systematics in lifetime measurements…not an option to make the luminous region longer …!
    - Could even be beneficial to move current luminous region upstream a bit

Luminous Region, Bunch Length, Crossing angles etc.

- Ultimately, we should find a good compromise between 'longish beamspot' and 'large geometric factor' (crossing angle reduction of luminosity):
  - Luminous region length as stable as possible from fill to fill over the full running period.
  - value known in advance for correct generation of simulated samples.
- In general, current condition of (~45-50mm) OK for μ~30-35,
  - A 10% increase is probably tolerable (CMS) or even desirable (ATLAS)
- Crossing angle: LHCb
  - Vertical external crossing angle to **maintain tilted crossing** scheme
    - Same boost vector amplitude in both polarities
  - Polarity swaps as now
    - Essential to understand systematic effects in many analyses
- Increased crossing angles (for 25ns) will have no other effect on experiment
- Filling schemes
  - No “private bunches” colliding only in one (separated) IP envisaged in 2015
  - Isolated non-colliding bunches would still be useful for beam background studies

ALICE operation after LS1

ALICE goal for pp After LS1: Luminosity between 10^{30} and 10^{31} (by leveling)

- ❑ Main-satellite experience in 2012 pp
  - Decided for “natural” satellites in Chamonix 2012
    - Expected to provide sufficient luminosity and attractive to limit the pileup in the TPC
  - Several problems, including vacuum conditions around IP2 and unpredictable satellite population
  - Enhancing these satellites during the final phase provided peak luminosities of up to 18Hz/ub, which allowed ALICE to level the luminosity to the desired value.
- ❑ Drawbacks
  - Monitoring of satellite population in the injectors not possible
  - Luminosity decay very steep.
  - Beam with enhanced satellites is considered 'dirty' with many potential operational issues
- ❑ In the (remote) case of a 50ns beam, no interest in continuing with the main-satellite scheme after LS1
  - would like ~45 main-main collisions with leveling – β^* as large as possible – see below
- ❑ At 25ns (and ~2000 collisions) go back to at least 10m β^*
  - Larger β^* values (18-30), may not be beneficial (interplay of beam-beam effects and separation with broader beam - *P D Hermes, R Schicker ATS note, in preparation*)
  - Leveling by separation seems only option - Further analysis needed

Heavy Ion Operation

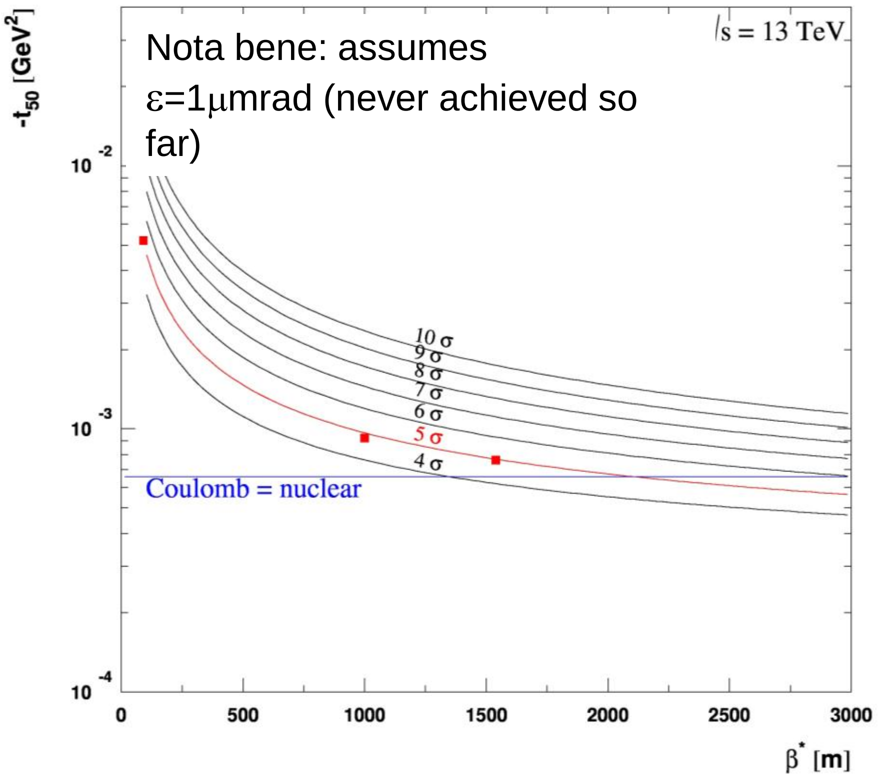
- HI requests for 2015 (and after)
  - So far, PbPb only at 13Z TeV
- Potential for 1-2 10^{27}
- ALICE working point after LS1: 1 10^{27} $cm^{-2}s^{-1}$
- We might be looking into leveling options in one or more IPs

SPECIAL RUNS

High β* plans for after LS1: TOTEM

Baseline: assume additional magnet cables installed during winter technical stop 2015/2016 **at the latest**.

- ❑ During the season without these cables:
  - Develop injection and ramp at β* = 90m
  - work with β* = 90m optics
  - should be possible to increase the number of bunches using crossing angles at 90 m
- ❑ After LS1: Low-|t| Elastic Scattering at 13 TeV


Nota bene: assumes ε=1μmrad (never achieved so far)

High β* plans for after LS1: ALFA

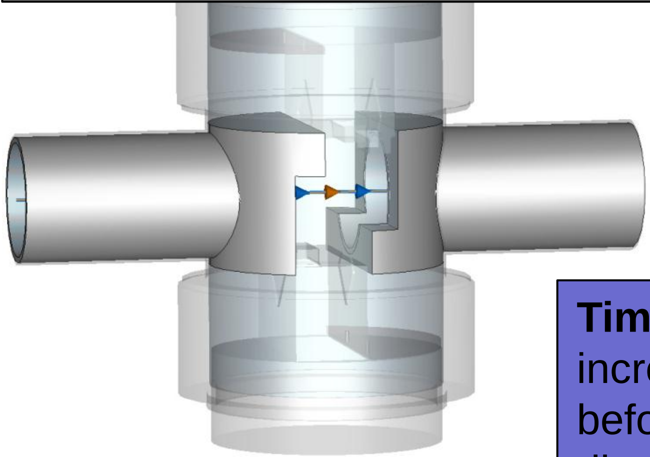
Long list of commissioning items:

- all old & standard ALFA functionalities
- commissioning of cooling with beams
- commissioning of high β*: → 90m → 1km → ~2.5km
- optimal collimator settings & low backgrounds
- standard beam based alignment

Data taking:

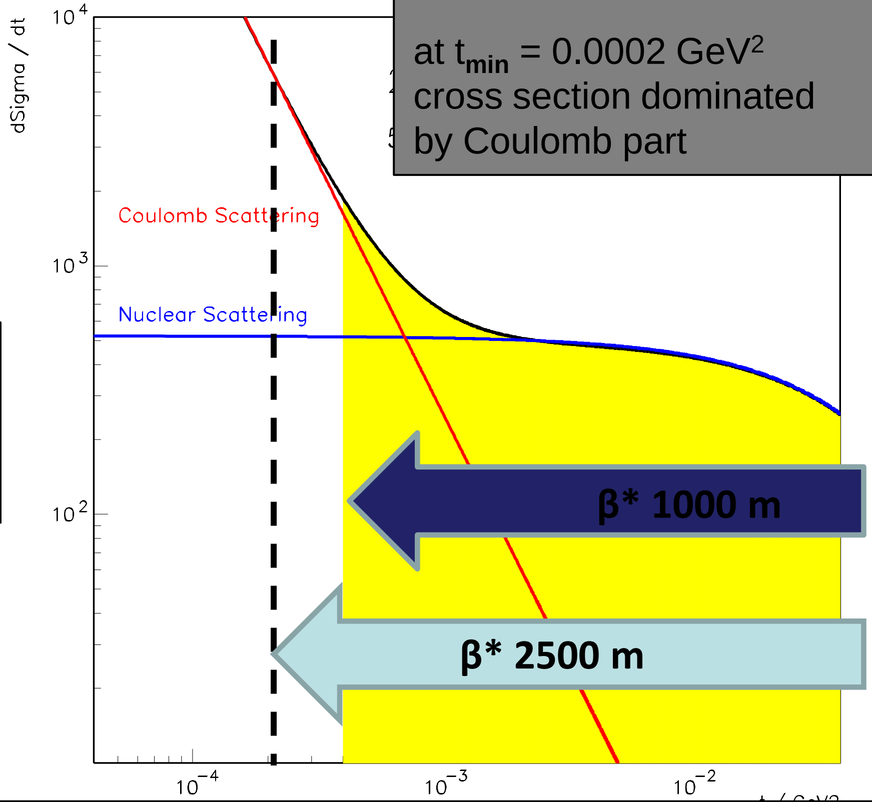
- Depend strongly on evolution of optics …
- data taking at β* 90m, 1km, 2.5 km

Cooling project:
Fixed insertion to close free openings and reduce RF losses to minimum (hope factor 10)
Alternative or in addition: active liquid cooling



Prospects for t-range
E_{beam} = 7 TeV, ε = 1.5 μm
RPs at 3 σ, β* = 2.5 km

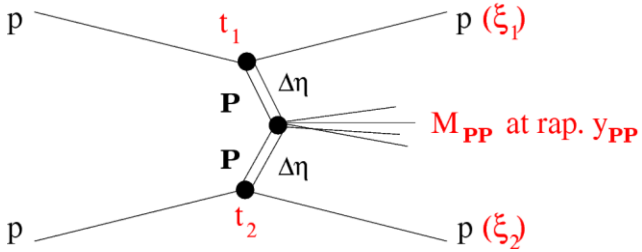
at t_{min} = 0.0002 GeV^2
cross section dominated by Coulomb part



Time line: Due to intensity-based heating and radiation increase the goal is to complete the ALFA physics program before LS2. The priority of these goals will have to be discussed with respect to the rest of the ATLAS program.

Miscellanea

- Roman Pots (ALFA/TOTEM) after LS1 besides high-β* program…
  - Still interested in doing diffraction physics with squeezed beams
  - Standard beam conditions or dedicated low-luminosity run



- TOTEM Roman Pot Configuration:
  - Vertical: 12 s (approach tested on 16 October without any problems)
  - Horizontal: 14 s (approach successfully tested on 15 November, but loss/vacuum problems afterwards)
  - Scenario only meaningful if all horizontal pots can be used
- LHCf: Upgraded for rad-hard GSO scintillators (no effect <1kGy -> 500 nb^{-1} @$\sqrt{s}$=13-14TeV)
  - Need >2μs event-to-event interval (<43 bunch) and μ<=0.01
  - Would like energy scan for extrapolation to CR energy (7 TeV. 3.5TeV,2.2TeV if possible) - N_b < 43, β^* = 11m, L < 10^{29} cm^{-2} s^{-1}, 10 nb^{-1}
  - Take clean data before 500 nb^{-1} -TBD

Machine Commissioning and ramp-up 2015

- ❑ During LS1 some detector will undergo non-minor modifications
  - E.g. CMS: new muon and calorimeter triggers, additional end cap muon chambers; ATLAS: additional innermost pixel layer
- ❑ Intensity ramp-up @ 25ns periods can be used, in general, to:
  - Commission the triggers
  - Commission new hardware
  - Study the detector performance at a new energy
  - Study Standard Model Physics at 13 TeV
- ❑ If an initial period at 50ns and 13 TeV should be deemed absolutely necessary
  - It will require an extra luminosity / trigger optimization
  - Should be as short as possible (<1 month ?)
  - Unavoidably less physics yield…

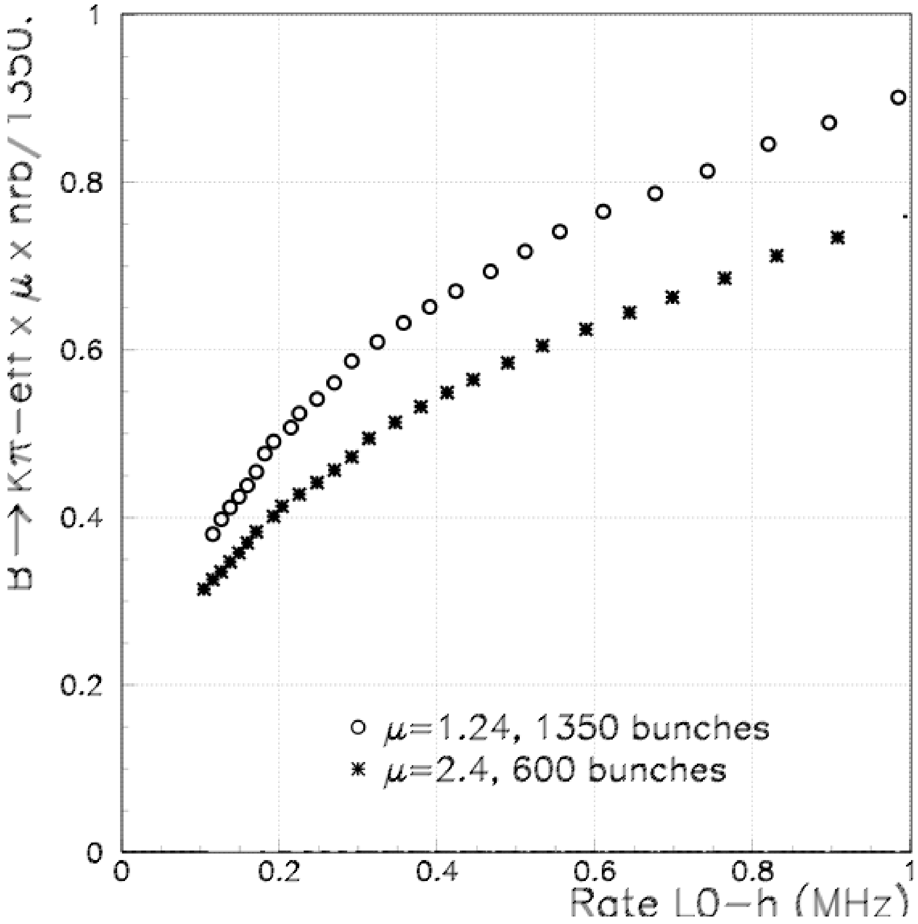
Conclusions

- 25 ns pp operation is a strong request of all the experiments
  - Cleaner environment for precision physics (trigger and reconstruction efficiencies, resolutions)
  - Less demanding in terms of resources (online and offline computing)
- 50 ns is an option only in case of major showstoppers
- Optimization of other parameters (bunch length, crossing angles) as needed
  - Clear demand for stable conditions
- Experiments accept that the commissioning period for 25ns operation may be longer than usual
- ALICE pp operation @ 25ns needs further studies
- Special runs program (RP, hi-β^*, LHCf) similar to 2012
- Heavy Ion in 2015: PbPb @ 13Z TeV

BACKUP

25ns Crucial for LHCb – One illustration

- Higher energy higher cross-sections and larger multiplicities combinatorics
- Example of pileup effect on trigger for B_d → Kπ
  - L0 trigger bandwidth reservation at the same luminosity: nbb x μ
  - E.g. yield of 0.6 with 1350 bunches @ m~1.24 ➔ L0 rate 300 kHz
  - Yield of 0.6 with 600 bunches @ m~2.4 ➔ L0 rate ~550 kHz
  - Increasing L0 cuts to maintain L0 bandwidth usage ➔ Yield 0.6 drops to <0.5



•Note 1: Readout load at 1 MHz: 4.0E32@8TeV with 1262 bunches eq. 4.5E32@13TeV with 2400 bunches (assume 20% increase in multiplicity from 8 → 13 TeV)
•Note 2: Equivalent bb-rate at 13 TeV as 4E32@8TeV: ~2.4E32 @ 2400 bunches ➔ μ~0.6

Implications for Physics

- ❑ Efficiencies, fake rates and resolutions of physics objects such as: tracks, leptons, jets and ETmiss depend on in-time pile up
- ❑ Tracking and flavour tagging
  - – Effects of high pile up studied in 2011 (up to <μ> of 32). Aim to get “stable” performance as a function of <μ>. The increase in fake tracks can be controlled by the imposition of ‘robust’ track quality cuts which do come with a loss of efficiency. The robust track quality cuts allow the PT cut to stay at 400MeV. For <μ> around 50 these cuts would be tightened again with another loss of efficiency.
  - – Primary track reconstruction would also be affected by high pile up with increased probability to merge vertices. The vertex of the hard scatter would be merged with close by vertices more frequently.
  - – Similar adverse performance penalties will show up in b-tagging.
- ❑ Electrons and Photons
  - – In time pile-up affects both electrons and photon shower shapes as well as Isolation (prompt electron identification). Electron/photon identification has (2012) already been optimized to be less sensitive to pile-up (some cost to performance) additional degradation is expected as we get closer to <μ> ~50.
- ❑ Jets and missing energy
  - – Resolutions strongly affected by pile-up, favouring 25ns over 50ns operation.

ATLAS Computing : Key Points

- Event sizes and CPU requirements strongly depend on in-time pile up.
- CPU requirements do not scale with <μ>, the exact details would depend on pile-up distribution in a fill. Estimates based on <μ> = 19 (25ns) and <μ> = 38 (50ns) are used in the models (70% of peak).
  - Increase of factors of 1.1 for tape (ratio 50ns/25ns)
- Assumptions:
  - Based on 2012 data and no assumption about speeding up of code in LS1. Some significant speed increases are anticipated. Some depend on emergent software technologies.

Trigger/DAQ System

- Analysing recent high luminosity runs (2e34 cm-2s-1 or <μ> =32)
  - A simple, and naïve extrapolation to <μ> of 100 would require an increase of a factor of 2-3 over current CPU capacity.
    - Ignores potential code improvements
  - As <μ> increases DAQ needs to cope with larger event sizes.
  - The real effect will depend on detailed estimates depend on these factors and the evolution of the menu
- Rates of triggers for multi-object items increase rapidly with inst. luminosity. Out-of-time pile effects seem to be worse than in-time pile-up effects
  - Missing energy and multi-jet rates thresholds will need to be increased
- Single lepton rates are less affected by in-time pile-up

diffractive protons detected in vertical pots
due to their t (acceptance for |t| > 0.02 GeV^2),
all ξ-values observed ($\xi \geq 0$),

resolution $\sigma(\xi)$ ~ 0.7% → $\sigma(M)$ ~ 40 GeV
(using CMS vertex: $\sigma(\xi) \sim 10^{-3}$ → $\sigma(M)$ ~ 5 GeV)

N of bunches limited to 156 since crossing angle = 0

Pileup reduced due to **β***

diffractive protons detected in horizontal pots,
acceptance for ξ depending on RP approach:
14 σ = 1.7 mm: ξ_{min} = 2.4 % → M_{min} = 200 GeV

good dispersion → $\sigma(\xi) \sim 10^{-3}$ → $\sigma(M)$ ~ 5 GeV

Advantage: 1400 bunches → higher lumi. and statistics

Pileup reduction via beam separation