Working at 5 ns bunch spacing?

Very first ideas to stimulate discussion…

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Beam conditions

Parameter	LHC	HL-LHC		HE-LHC	VHE-LHC
c.m. energy [TeV]	14			33	100
circumference C [km]	26.7				80
dipole field [T]	8.33			20	20
dipole coil aperture [mm]	56			40	≤ 40
beam half aperture [cm]	2.2 (x), 1.8 (y)			1.3	< 1.3
injection energy [TeV]	0.45			>1.0	≥3.0
no. of bunches	2808	2808	1404	2808	8420
bunch population [10^{11}]	1.125	2.2	3.5	0.81	0.80
init. transv. norm. emit. [μm]	3.73,	2.5	3.0	1.07	1.70
initial longitudinal emit. [eVs]	2.5			3.48	13.6
no. IPs contributing to tune shift	3	2	2	2	2
max. total beam-beam tune shift	0.01	0.021	0.028	0.01	0.01
beam circulating current [A]	0.584	1.12	0.089	0.412	0.401
RF voltage [MV]	16			16	22
rms bunch length [cm]	7.55			7.55	7.55
IP beta function [m]	0.55	$0.73 \rightarrow 0.15$		0.3	0.9
init. rms IP spot size [μm]	16.7	$15.6 \rightarrow 7.1$	$24.8 \rightarrow 7.8$	4.3	5.3
Stored energy [MJ]	362	694		601	4573
Peak luminosity [10^{34} cm^{-2}s^{-1}]	1	(7.4)		5	5

- Starting parameters driven by design pileup of ~140
  - Based on 25 ns bunch spacing
  - Can we get better conditions with smaller spacing?

5ns spacing

- Different approaches
  - Keep total current constant
    - Same peak luminosity, 5 times smaller pileup
    - Beware:
    - $$L \propto \frac{N^2 \times n_b}{\varepsilon \beta}$$
    - One needs to compensate with smaller beams (acting both on emittance and optics)
  - Increase current to get higher luminosity for same pileup
    - Theoretically up to a factor 5 in peak luminosity
    - But linear increase in stored energy:
      - How many dumps/abort gaps would we need?
      - Can we build injection protection devices?
      - All this could result in a much more inefficient fill schemes…
  - Anything in between

Some realistic estimates

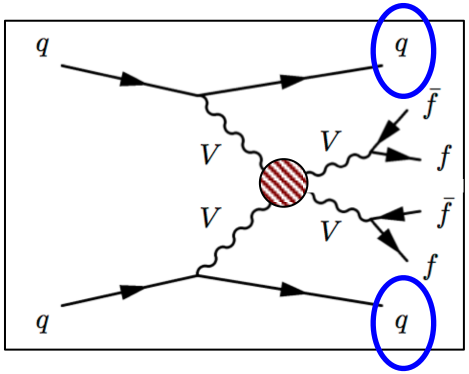
- Assuming the limits in the injection chain (after all upgrades)
  - Max charge ~2.5e11 per 25 ns interval
  - Min emittance ~1 μm

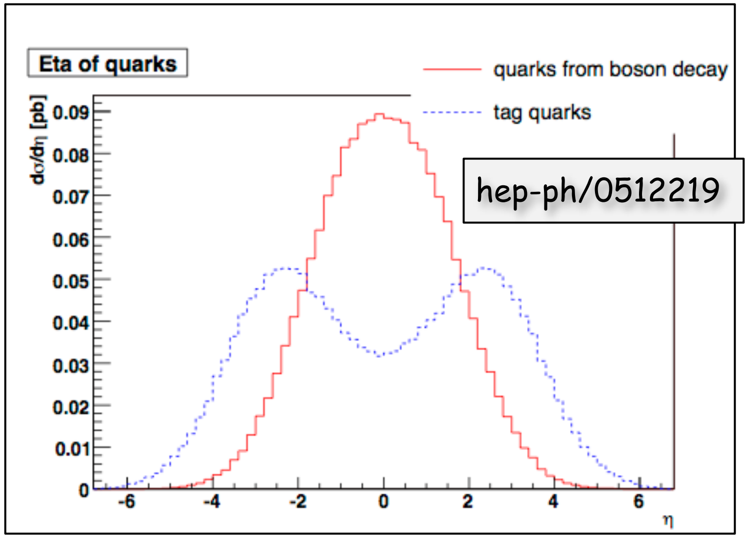
- We would probably have to marginally increase the current to keep luminosity constant
- We could probably get not more than a factor 2 in total luminosity

Experiments perspective

- Smaller bunch spacing useful only if able to distinguish bunches
- Few aspects identified so far
  - DAQ/Trigger electronics: OK!
    - Modern FPGAs can be clocked today at 400 MHz
      - Electronics dead time scales in clock cycles rather than absolute time
    - Buffer occupancies depend on Trigger rate rather than bunch spacing
  - Detector
    - Rate capability
      - Depending mostly on luminosity (low pileup vs high lumi approach)
    - Online resolution for first level trigger
      - Can we distinguish between close bunches?
    - Offline performance
      - Effect of out of time pileup from close bunches

L1 Trigger approach

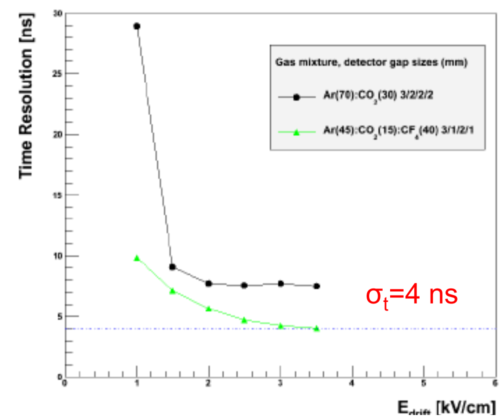


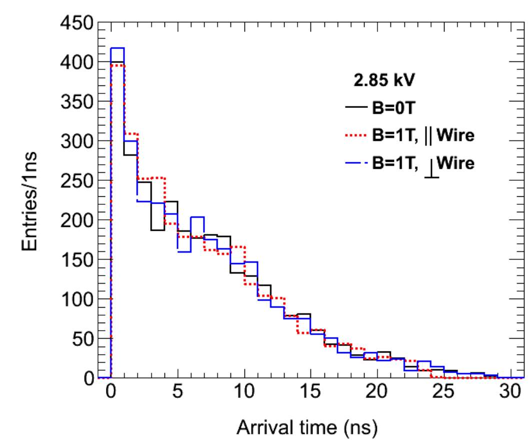


- For VBF/VV scattering we need to cover up to η~4 but
  - Do we need to trigger on jets at all?
  - Up to which η do we need to trigger on VV decay products?
    - ⇒ acceptance vs occupancy and fake rate
  - To be studied

Muons

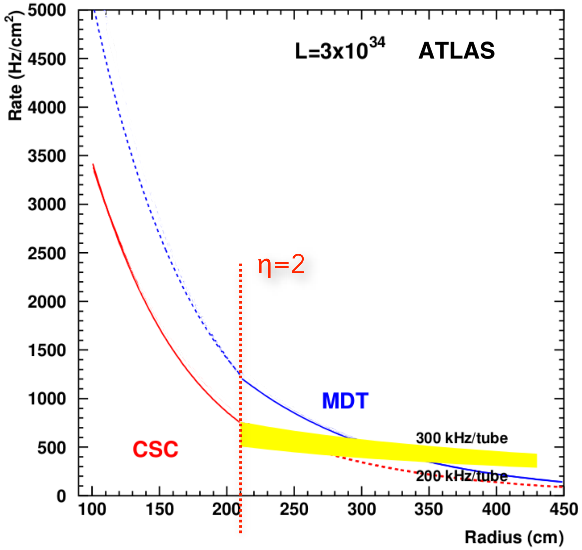
- Offline performance should be OK with existing technologies
- Online time resolution of ~1ns needed to distinguish crossings at L1 trigger level
  - RPC: OK with strips not longer than ~1m; double with double ended readout and mean timer
    - Question is rate capability/η coverage
  - Micro pattern detectors: time resolution dominated by fluctuations on primary cluster formation
    - Depending on drift length: GEMs better than MM
  - TGC: time response not adequate
    - Hits not contained within 5ns
    - Using TGCs in the forward region would imply no effective pileup reduction at trigger level





Muon trigger coverage

- Rate capability is the crucial parameter
  - We need studies to extrapolate rates to higher η and higher lumi/energy
- Improved RPCs
  - Expected rate limit ~10 kHz/cm^2 (proven already up to 7 kHz/cm^2)
  - Up to which η can they stand hit rate?
- Micro-pattern or TGCs for triggering at higher η?
  - Lose pileup mitigation effect because it's hard to resolve BCs



Calorimeters

- Trigger time resolution shouldn't be critical but need to be studied in detail
  - Getting to ~ns even with slow LAr calorimeter
  - Trigger may set requirements on detector technology
- Technologies:
  - Scintillation calorimeters: concerns on radiation hardness for the endcap region (η> 2.5)
  - Liquid noble gas detectors are intrinsically slow:
    - Influence on measured energy fluctuations from all crossings occurring within typical peaking time (~40 ns)
      - Limited effective pileup reduction with smaller bunch spacing
    - Reduced shaping time implies higher noise: possible impact on trigger of low p_T objects
      - Thinner gaps?
      - With higher Z liquid (Kr,Xe) to compensate for sampling ratio?
- Silicon sampling calorimeters? Can we afford cost? Rad hardness?
- We should be thinking of an heterogeneous approach vs η
- Other ideas?

Initial conclusions

- So far we haven't identified a showstopper against running with short bunch spacing
- On the other hand the detector technology to fully benefit from the spacing need to be investigated further
  - Limited effective pileup reduction for slow detectors
  - Trigger limitations not allowing to distinguish close crossings

Next steps

- So far only limited effort
- Complete list of questions to address
- Produce some reasonable occupancy simulations
- Address inner tracker
- Evaluate different scenarios
  - Peak lumi vs beam parameters
  - Possible intermediate spacings between 5 and 25
- Let us know if you are interested in contributing to the discussions