The LHCb Upgrade

- Physics aims.
- Upgrade the trigger.
  - Present LHCb trigger for pedestrians.
  - What is limiting LHCb trigger to profit from larger L?
  - The luminosity upgrade: full software trigger.
- Upgrade schedule(s).
- Progress reports/sub-system.
- Conclusions.

Physics Aims

Search & Study of New Physics at LHC are the main objectives of the current LHCb physics program as well as the motivations for the upgrade.

Strategy: measure experimental observables sensitive to NP through their interference effects with well studied objects, b-quarks, in processes mediated by box ($\mathrm{B_{d,s}}$ oscillations) diagrams and radiative ($\mathrm{B_s} \to \phi\gamma$), electroweak ($\mathrm{B} \to \mathrm{K}^*\mu\mu$), strong ($\mathrm{B_s} \to \phi\phi$) penguin diagrams.

There are many observables[a] where we are far away from being limited by theoretical (or systematic [b]) uncertainties.

LHCb data collection strategy:

- Collect $\sim 10\ \mathrm{fb}^{-1}$ with present detector.
- Upgrade detector to be able to collect $\sim 100\ \mathrm{fb}^{-1}$ with double hadron-trigger efficiency to either study/distinguish between NP models, or push the discovery potential to higher masses and/or smaller couplings.

---

[a] see LHCb-EOI, CERN/LHCC/2008-007, April 2008

[b] Study to determine systematics in ϕ_s by fitting toys for $10\ \mathrm{fb}^{-1}$ shows σ systematics$< 10\%$ of statistics, hence at 20x statistics this should still be the case. But not all possible biases included yet, nor exploiting all control channels.

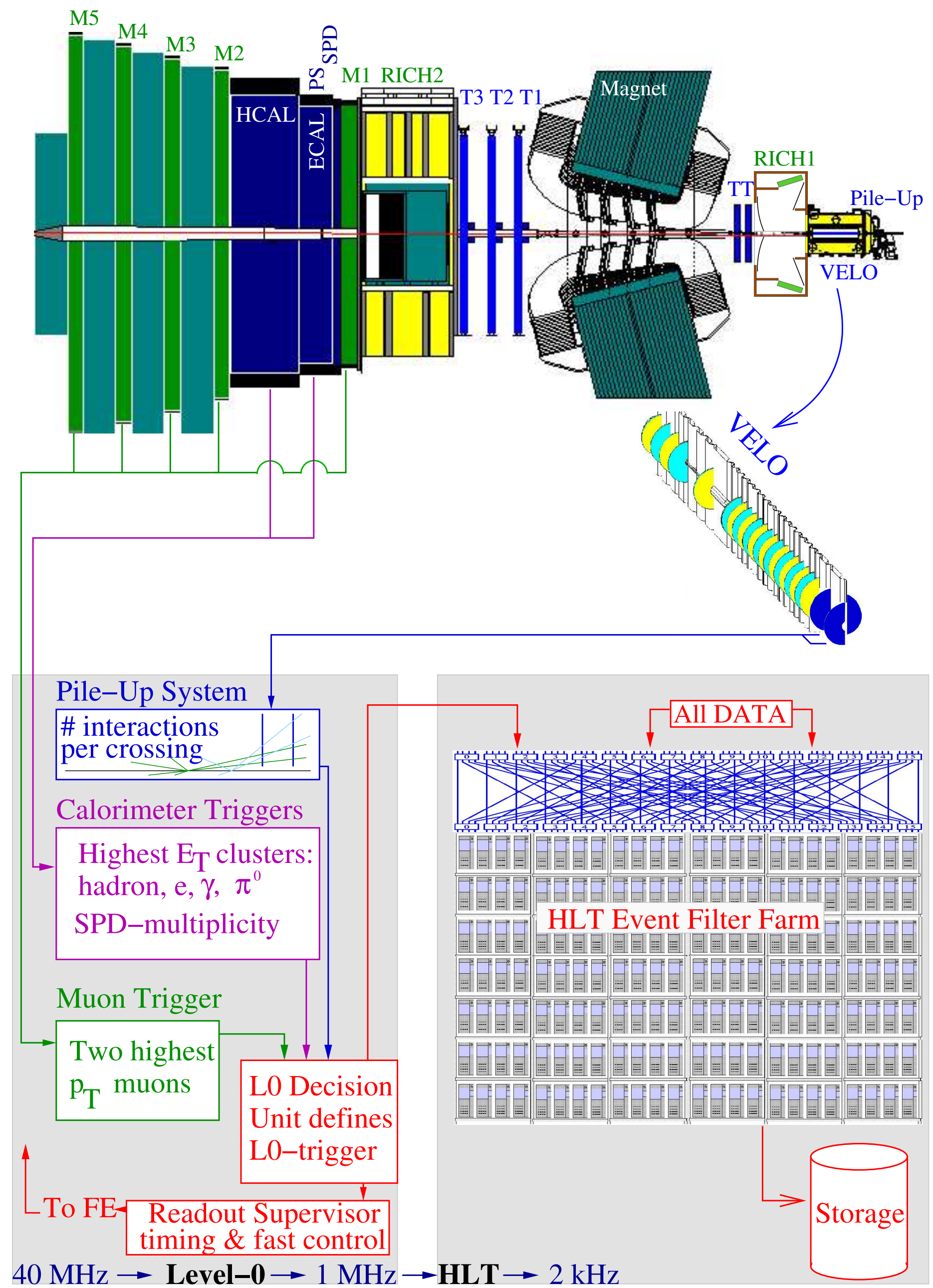
Present LHCb Trigger for Pedestrians

Level-0 (hardware based):

- Largest E_T hadron, e(γ) and μ.
- $@L > 2 - 5.10^{32}$:
  L0-retention $\sim 10 - 5\%$
- Hardwired bottlenecks:
  - 1 MHz max-output rate.
  - Latency: 2.5 μs for trigger

High Level Trigger:

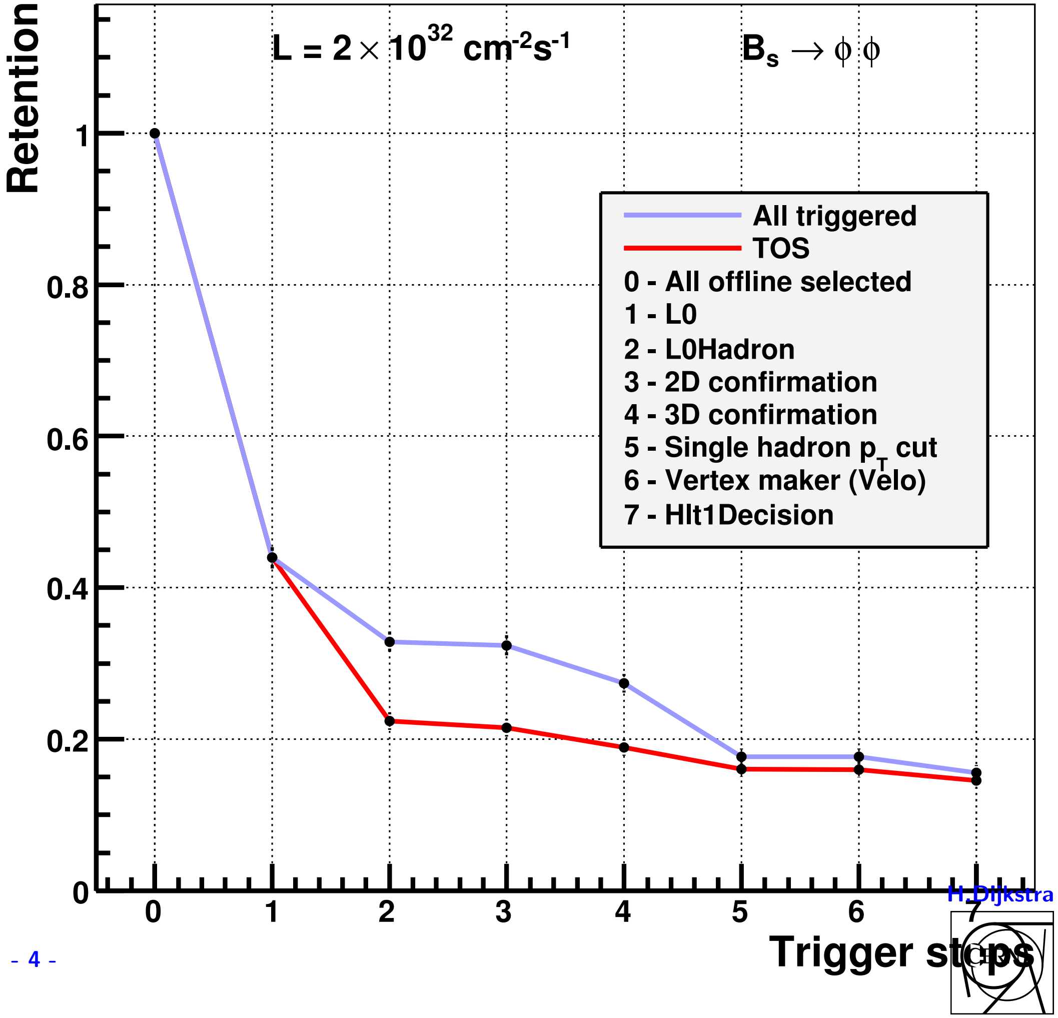
- Access to all detector info from day 1.
- Limitation: CPU (brain?) power.
- Will improve with Moore's law "automatically": plan to replace CPU boxes every ~3 years anyway.



H.Dijkstra

Hadron Trigger Example

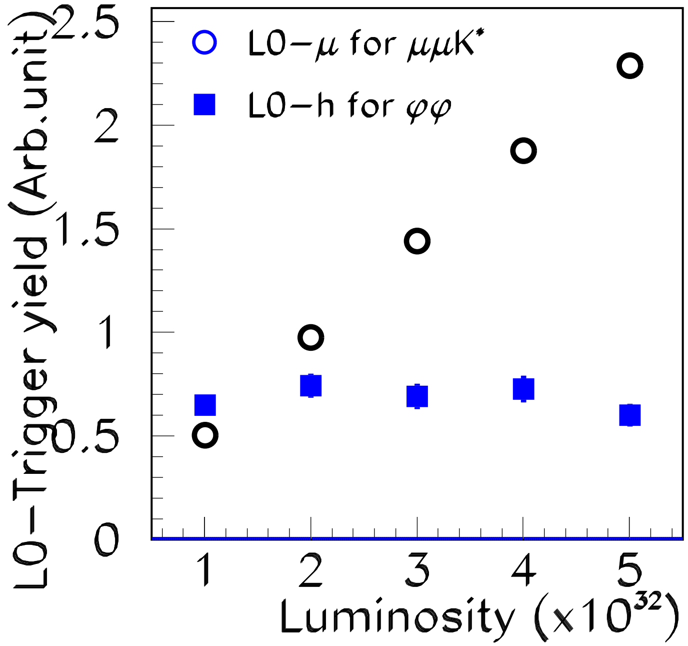
- L0-Hadron: 1.3 clusters/event with $E_T^{hadron} > 4$ GeV. (TOS=Trigger on Signal)
- 2D/3D Confirmation: Match Clusters→VELO, IP$> 100\ \mu$m: 2.2 tracks/event.
- Single hadron p_T cut: Forward tracking to T-stations: $p_T > 2.$ GeV: 1.2 tracks/event.
- Velo Vertex: Vertex with other VELO tracks with IP$> 100\ \mu$m (12/event): 4 vertexes/event.
- Hlt1Decision: 2nd track in vertex →T1-T3, $p_{T_2} > 1.$ GeV.



- "Few" tracks/event: $\sim$ 5000 events/CPU-box/s.
- Minimum Bias reduction rate L0×Hlt1 > 1000.
- $B_s \to \phi\phi$ efficiency: L0×Hlt1$=23\% \times 70\% = 16\%$.

Present Trigger and Luminosity

- $L^{\text{peak}} \geq 2 - 3.10^{32}$: no hadron-trigger gain.
  - 1 MHz bottleneck→$\mathrm{E_T}$-cut⇑
  - hadronic-channels: yield $\propto \int(\text{time} \times 2.10^{32})$
  - μ-channels: yield $\propto \int L$



Aim of the Trigger Upgrade:

- Improve hadron trigger efficiency by at least factor two.
- h(e/γ)-triggers yield $\propto \int L$

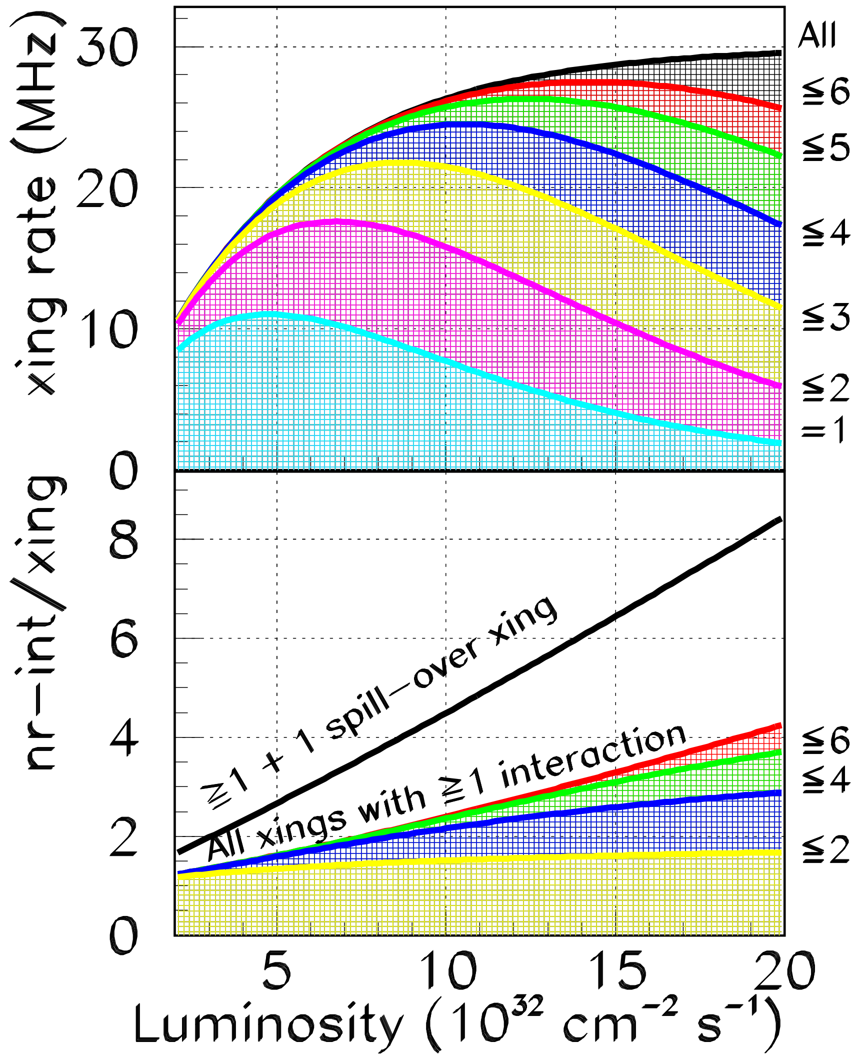
LHC and Luminosity

LHC: we (will..) have the machine!

- $L_{\rm LHC}^{\rm peak} \approx 10^{34}\ {\rm cm^{-2}s^{-1}}$, $\geq 201n$
- Assume $\sigma_{\rm visible} = 63$ mb.
- $@2.10^{32}$: ~ 10 MHz xings with ≥ 1 int.
- $@10^{33}$: ~ 26 MHz xings with ≥ 1 int.
- nr-int/xings:
  only factor 2 increase up to $@10^{33}$

SLHC: LHCb does not need it but:

- relies on 25 ns structure!
- optics $L_{\rm LHCb}^{\rm peak} \approx 0.5 - 5 \times 10^{33}\ {\rm cm^{-2}s^{-1}}$



H.Dijkstra

Trigger Upgrade Conclusions

Studies show that:

- Larger efficiencies at higher luminosities: requires adding impact parameter (IP) information in first level.
- Measuring p_{T} and IP takes more than the 2.5 μs allowed in present system.

Trigger upgrade (and its consequences for the rest of LHCb...):

- Execute whole trigger in software on a CPU farm. $\longrightarrow$ next slide

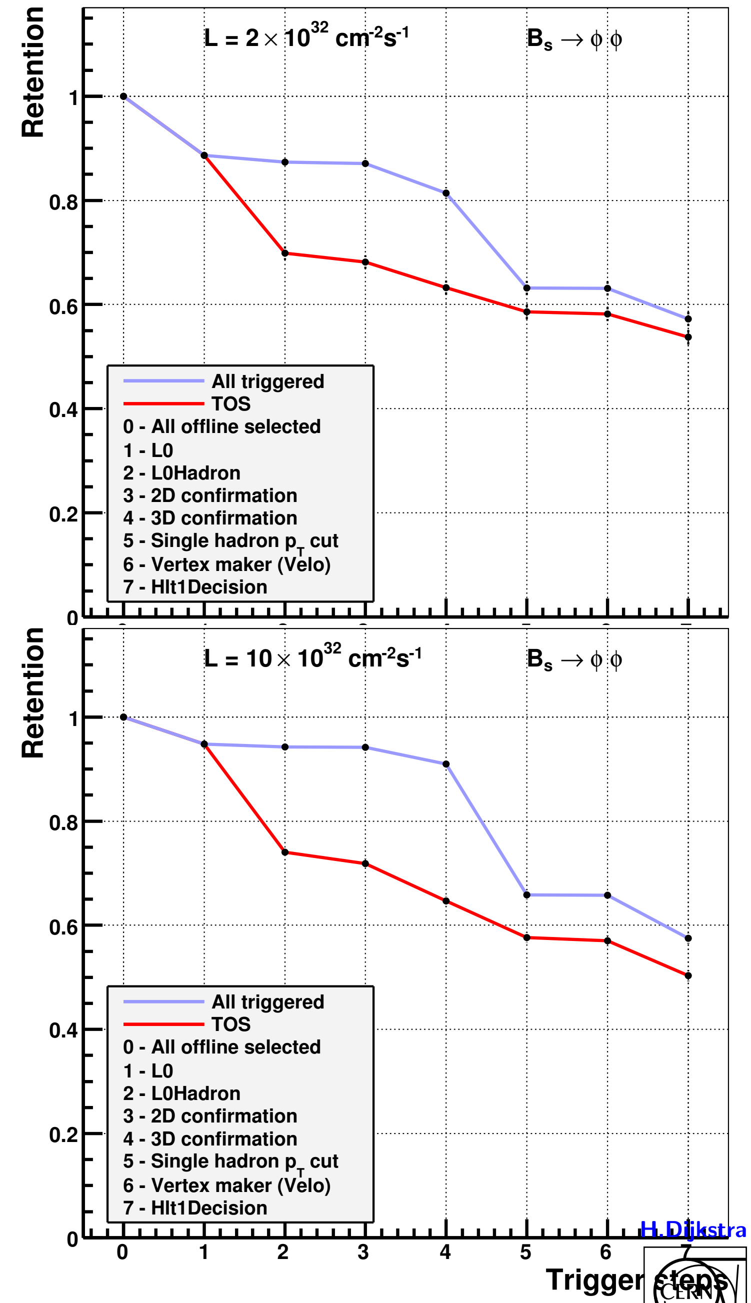
☹ replace all FE electronics with 40 MHz read-out electronics.

☺ create a flexible trigger, able to adapt to the needs in the next decade.

Upgraded Hadron Trigger and $\mathrm{B_s} \to \phi\phi$

(Algorithm as "now", no high-L tuning, preliminary:)

- $@2.10^{32}$: get $> 2\times$ efficiency:
  - at 4 MHz rate:
    $\sim 70\%$ events have HCAL cluster > 2 GeV from $\mathrm{B_s} \to \phi\phi$.
  - $\mathrm{B_s} \to \phi\phi$ efficiency $16\% \to\sim 55\%$.

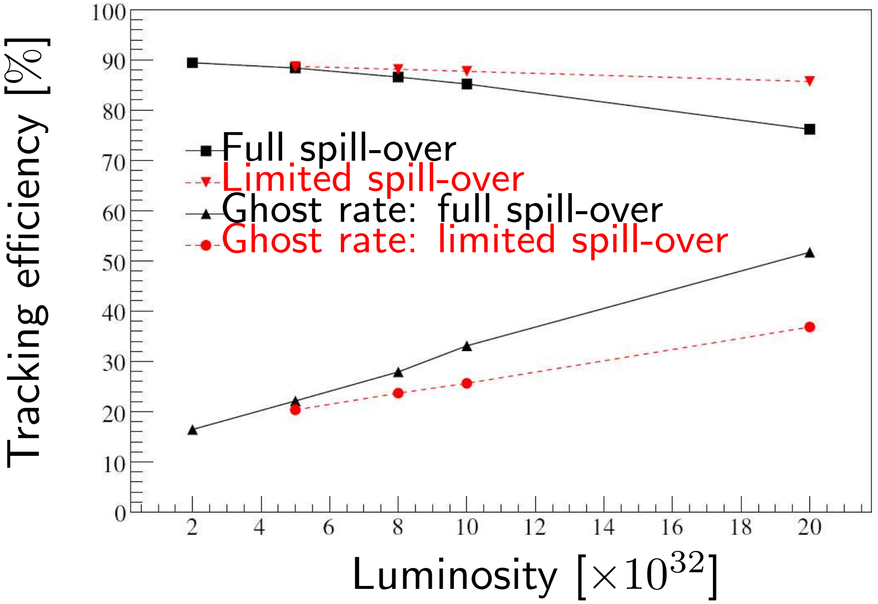


- Increase luminosity: $10^{33}\ \mathrm{cm^{-2}s^{-1}}$
  - Input rate 15 MHz, similar signal efficiency,
    i.e.: $> 10\times$ better signal yield for $5\times$ increase in L.
  - Trigger-rate: 500 kHz, without tuning. $\longrightarrow$
  - "Tuned" to get rate down: ~ 30 kHz for 45% eff.

Other High-L Limitations

Tracking $\&$ Particle-ID:

- VELO tracking not a problem.
- Straws: $L^{\rm peak} \geq 10^{33}$ spillover is a problem.
- PID: OK for $L^{\rm peak} \leq 5.10^{32}$, then linear and smooth degradation.
- Tagging: no deterioration $L^{\rm peak} \leq 6.10^{32}$



Radiation:

- designed for $\int L \leq 20\ \rm fb^{-1}$ radiation damage, apart from VELO.
  - Safety factor? Need first running.
  - Affects only large η.

Conclusion:

- Below $L^{\rm peak} \sim 10^{33}$: only trigger needs upgrade.
- Above $L^{\rm peak} \sim 10^{33}$: tracking, PID, Calo, watch radiation.

For the upgrade logistics the shutdown schedule is very important input!

Upgrade Schedule

LHCb will have to upgrade synchronized with LHC and GPD schedule:

- shutdown 10/2012-6/2013: new GPD-triplets.
- shutdown 2017-6/2018: GPD Inner Detectors.

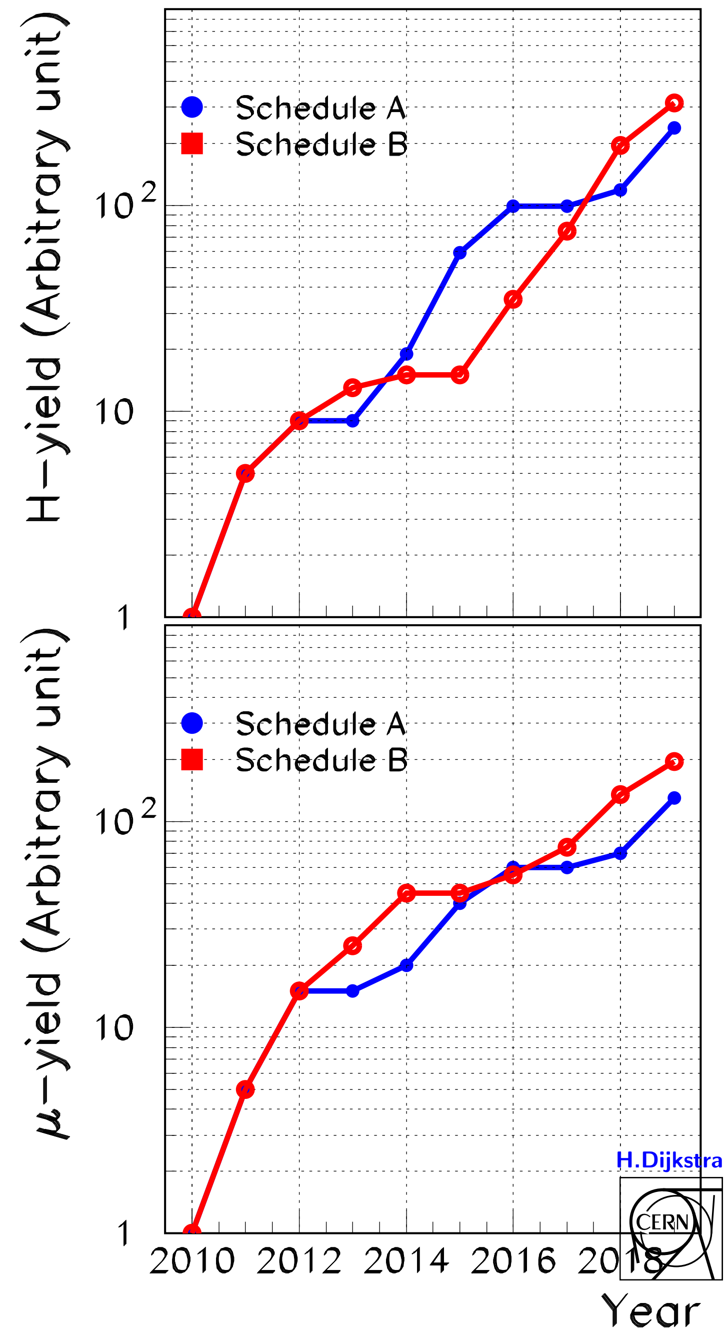
Schedule-A: consider two upgrade phases:

I Trigger upgrade in first longer shutdown:
- 10/2012-3/2014 (12 months access): all FE to 40 MHz.
- $< L^{\rm peak} > \sim 10^{33}$ till 2017.

II 1/2017-6/2018 upgrade for $< L^{\rm peak} > \geq 3.10^{33}$

Schedule-B:

- Suppose GPD triplets 2015-2016: then combine two phases.
- Run with L0-μ trigger only 2013-2014 @10^{33}.



What can/cannot be Staged?

Trigger Upgrade:

- Including VELO in first level trigger $\rightarrow$ ALL FE MUST be able to run at 40 MHz read-out due to hardwired 1 MHz and 2.5 μs bottlenecks!
- Rate-control trigger (copy of L0) allows reducing input rate for switch& trigger-farm to any acceptable rate: hence can stage switch&CPUs.

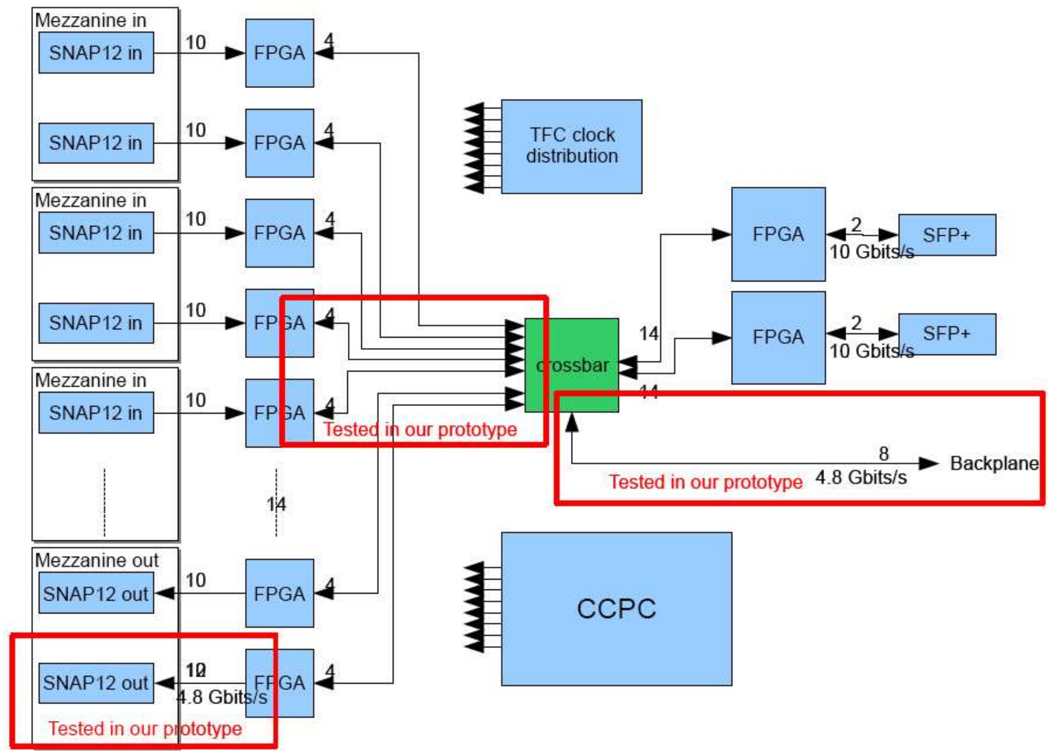
Sub-detector Upgrades: some sub-detectors address very specific part of physics, and could be included at a later stage if not ready in time (very preliminary list!):

- TT: provides 70% of K^0_S, and improves dp/p.
- Stage PID of low-momentum tracks.
- Crystals for inner part of ECAL, which is now not instrumented.

FE&DAQ 40 MHz Upgrade

Electronics working group has:

- Collected the required BW /sub-system, and evaluating with/without 0-suppression in FE to size the system.
- Basic specification of Si-ASICS in progress.



- Started R&D on the common Readout board (interface between all FE and the DAQ).

DAQ:

- Keep basic (push) architecture.
- Produced timing and fast-control (TFC) architecture note.
- Controls evaluation board design starts this year.
- Gaining experience with high speed technologies: 10,100 Gb Ethernet, 10,40 Gb Infiniband.

H.Dijkstra

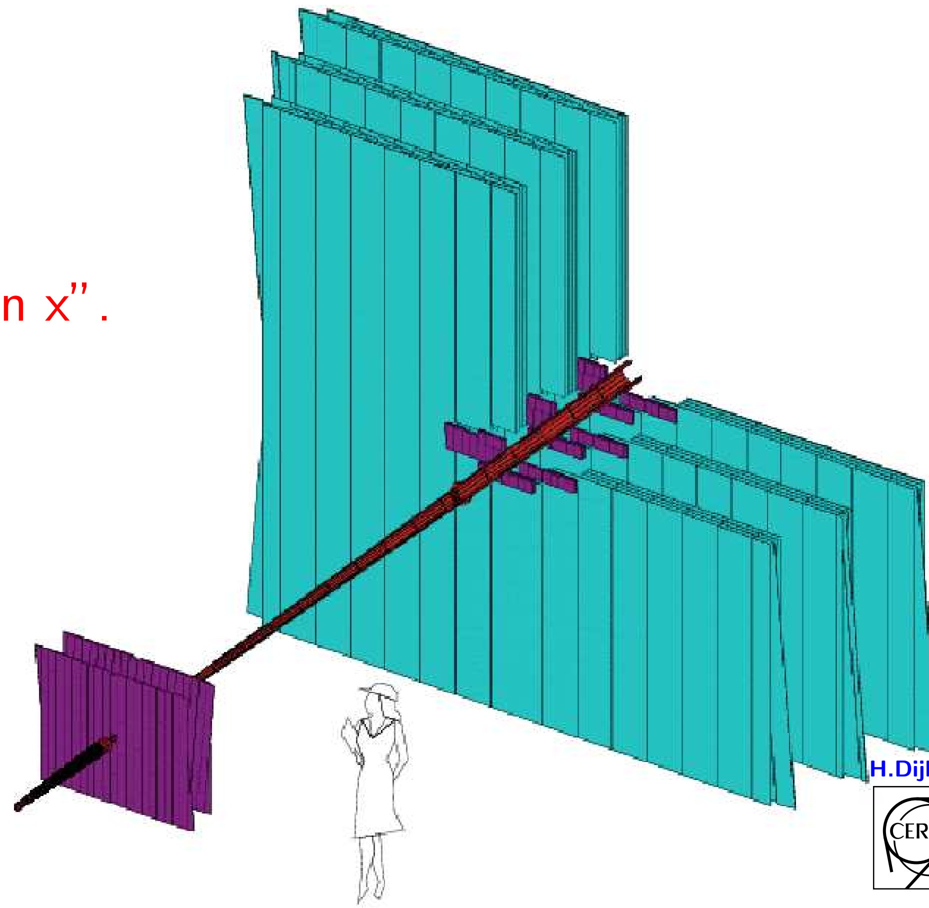
Tracking Detectors

Velo:

- Radiation: have to replace present VELO to sustain 10-15 fb^{-1}. Replacement under construction.
- Want only one upgrade to cover 100 fb^{-1}.
- Demonstrator pixel module planning worked out.
- Working on detailed R&D plan, expected before summer.

ST and OT: two main solutions:

- Keep Si+straw system:
  need to define IT-size, and path to
  either have one upgrade, or a "growing IT in x".
- Alternative: fiber tracker (with SiPM),
  several groups interested.



H.Dijkstra

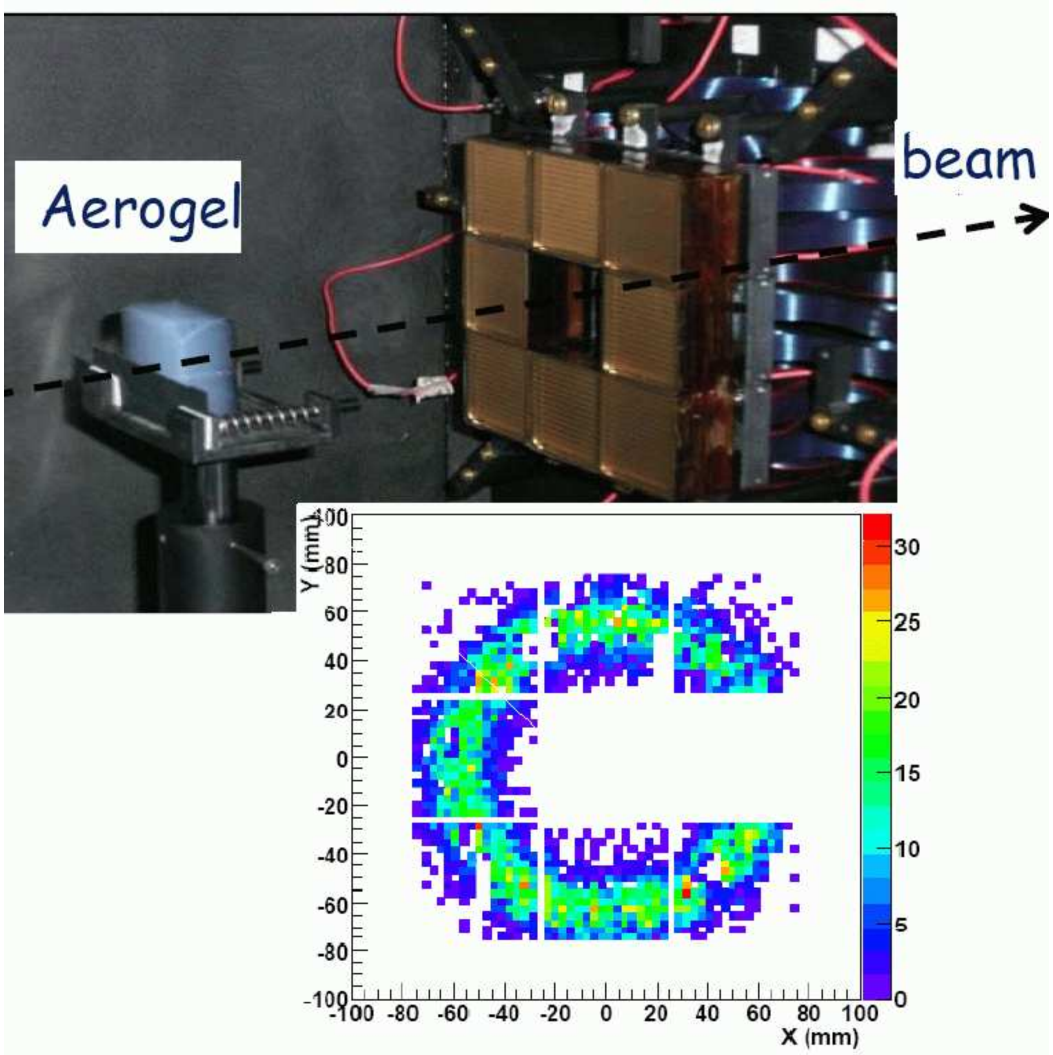
RICH

Photo-detector: this is the critical item.

- Flat-panel PMT is a very strong contender, first tests done, agreed to start intensive R&D program for this solution. Manpower has been found.
- HPDs: possibility to re-use large part of present infrastructure.

Phase II RICH:

- Proposal to replace two RICH system with one Super-RICH behind OT to cover full angular acceptance.
- Could include a TOF system to cover low momentum range.



Calorimetry

Scintillating Pad detector and Pre-shower:

- Not sure they are still necessary for the upgrade.
- Manpower has been identified to study MC samples for some typical channels in the upgrade environment.

ECAL/HCAL

- Will design small scale prototype of FE-boards, no ASICS design necessary.
- Able to keep present L0 as "rate-control" trigger at little extra cost.
- Inner region radiation dose needs to be addressed for Phase II, but anticipate this in electronics design for Phase I.

Muon Chambers

- M1 to be removed, too high occupancy, and trigger will use T3 for confirmation.
- If new-TFC is backward compatible, could re-use present Off-Detector-Electronics, else...
- Now provides TDC info for calibration, needs to be sent at low rate after upgrade, ideas on how to achieve this.
- For Phase II luminosity need to study high rate regions, also requires first real data performance (safety factors etc..).

Conclusions

- All sub-systems have identified manpower to prepare the upgrade, and have made an initial outline of the R&D work necessary, and some already on construction effort/time schedule.
- Detailed R&D plans are being worked out.
- Schedule:
  - Use the first longer shutdown (GPD triplet replacement) to at least upgrade the trigger! Assumed to be 2013.
  - If this is 2015++, can already now plan to upgrade many of the sub-detectors for their final high luminosity upgrade.