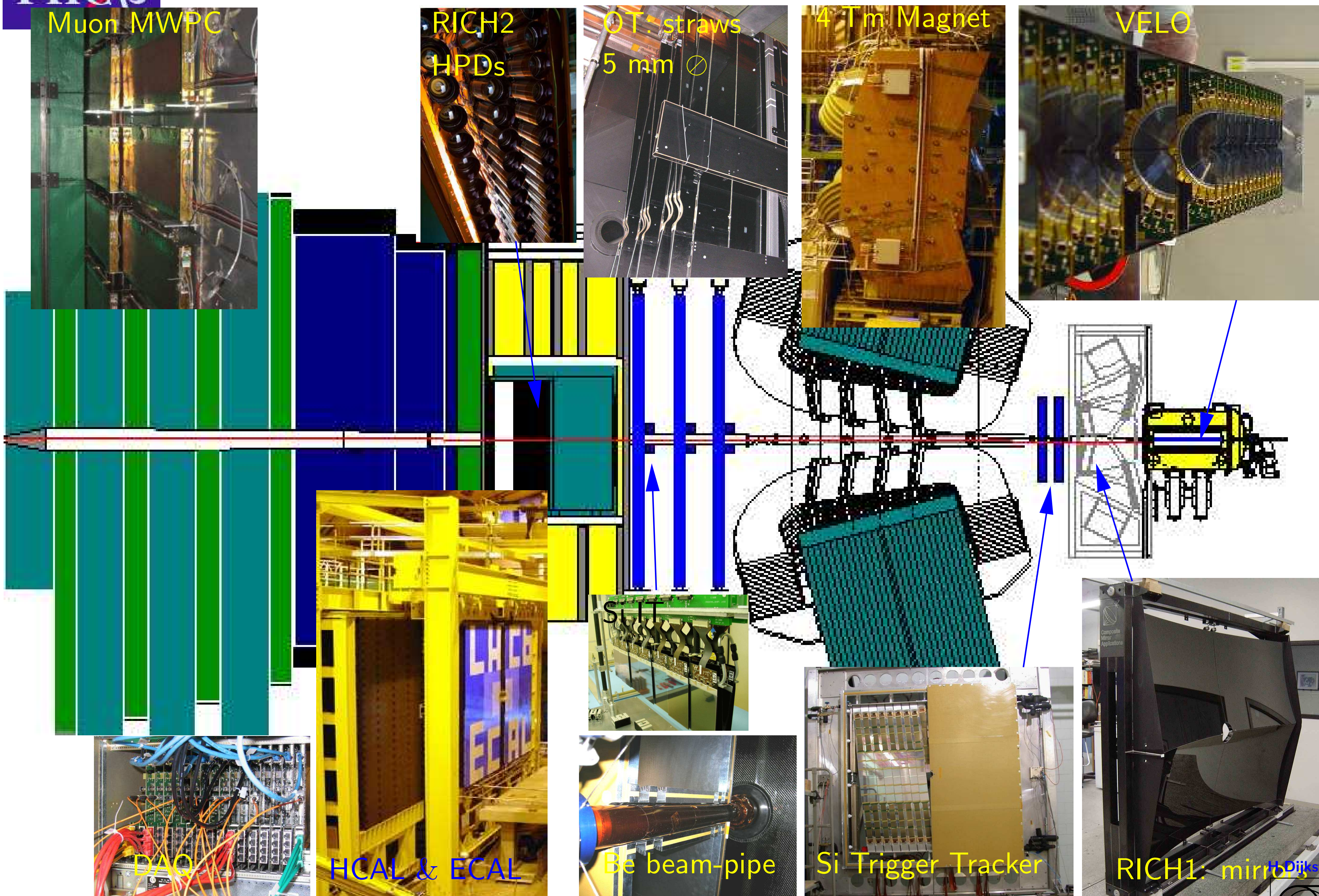
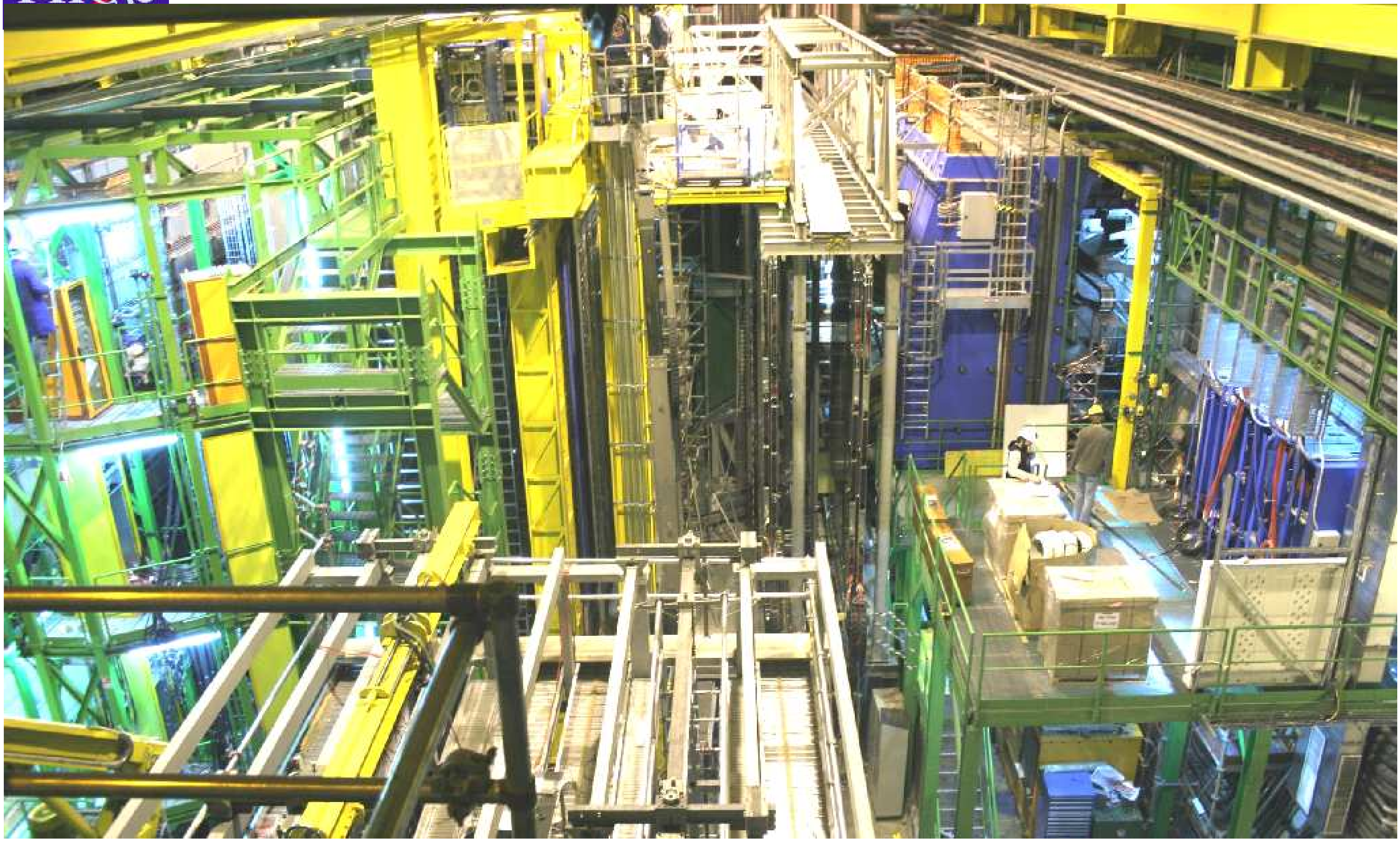
The LHCb Upgrade

- Status of LHCb
- The pre→upgrade years.
  - Running scenario
  - A few selected channels.
- The luminosity upgrade
  - The LHC machine and higher luminosities.
  - What is limiting LHCb to profit from larger L?
  - Base-line upgrade scenario.
- Projected yields of 'Super'LHCb
- Conclusions

H.Dijkstra


Muon MWPC
RICH2
HPDs
OT: straws
5 mm ∅
4 Tm Magnet
VELO
Si IT
DAQ
HCAL & ECAL
Be beam-pipe
Si Trigger Tracker
RICH1: mirrors



LHCb on schedule to complete installation/commissioning end 2007.

LHCb pre→upgrade years

- This year:
  - Engineering run @450 GeV/beam?
  - Commissioning/shake down detector
- Next year.
  - Expect 0.5 fb^{-1} @14 TeV.
  - Final shake down and Trigger commissioning.
  - First look for NP compatible with low $\int L$
- 2009-2012
  - Stable running at $L = 2 \rightarrow 5.10^{32}\ cm^{-2}s^{-1}$
  - Develop full physics program: $\int L \approx 10$ fb^{-1}.
- 2013-2020
  - Upgrade LHCb → SuperLHCb
  - Aim for $L = 2.10^{33}\ cm^{-2}s^{-1}$, $\int L \approx 100$ fb^{-1}.

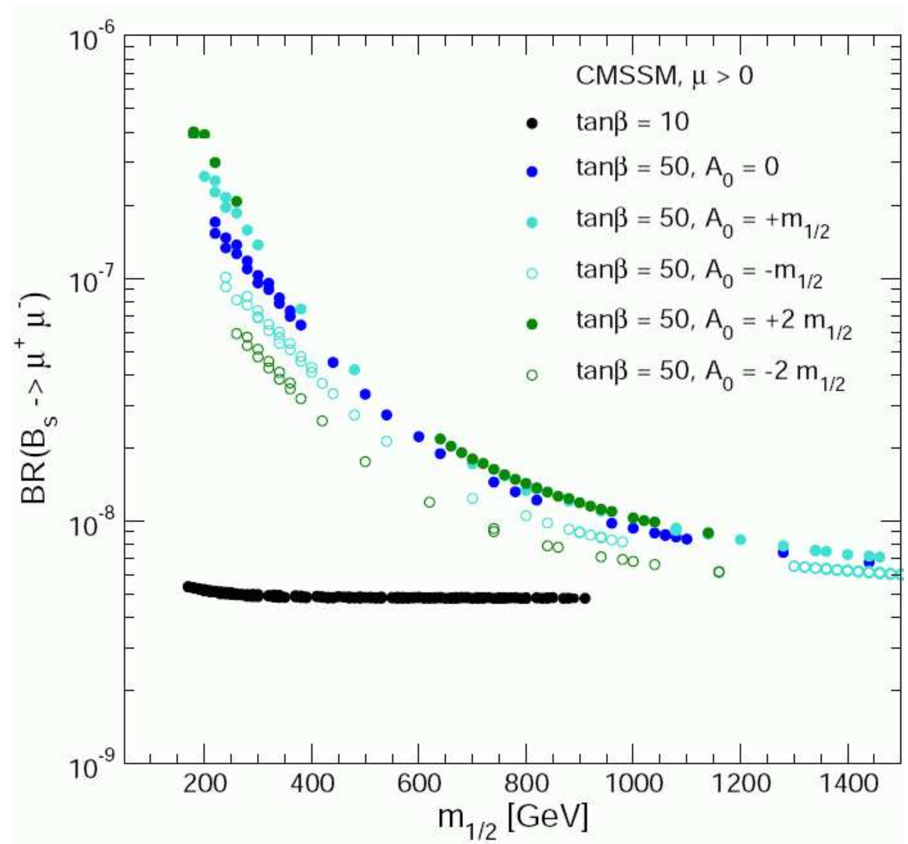
Next slides: expectations [a] of few typical channels:

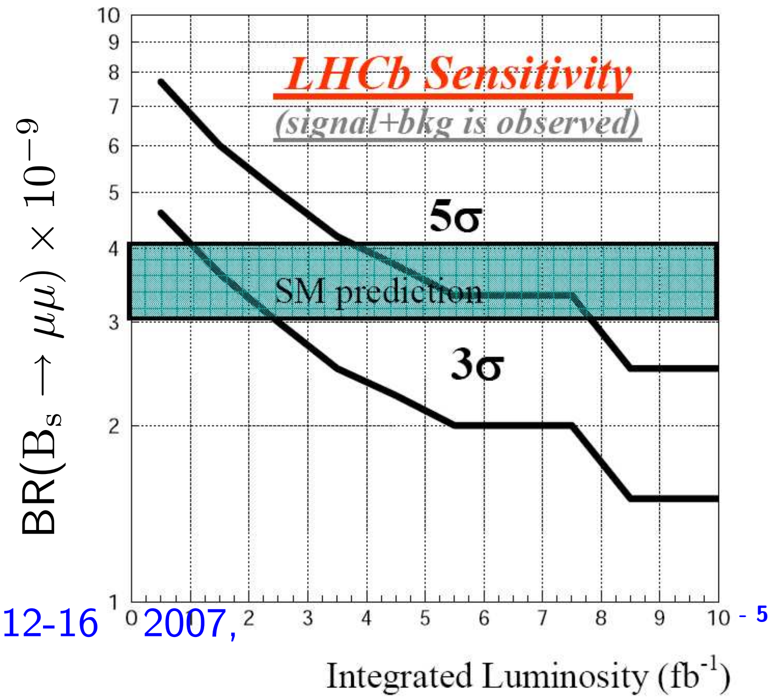
- $\mathrm{B_s} \rightarrow \mu\mu$, γ measurements, $\mathrm{B_s} \rightarrow \mathrm{J}/\psi\phi$, $\mathrm{B_s} \rightarrow \phi\phi$, $\mathrm{B} \rightarrow \mathrm{K}^*\mu\mu$

[a] Based on: full GEANT, spill-over, pile-up, LHCb PYTHIA tuning at 14 TeV (25 % larger multiplicity than CDF tuning @ 14 TeV), mean-$L = 2 \times 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

BR($B_s \to \mu\mu$)

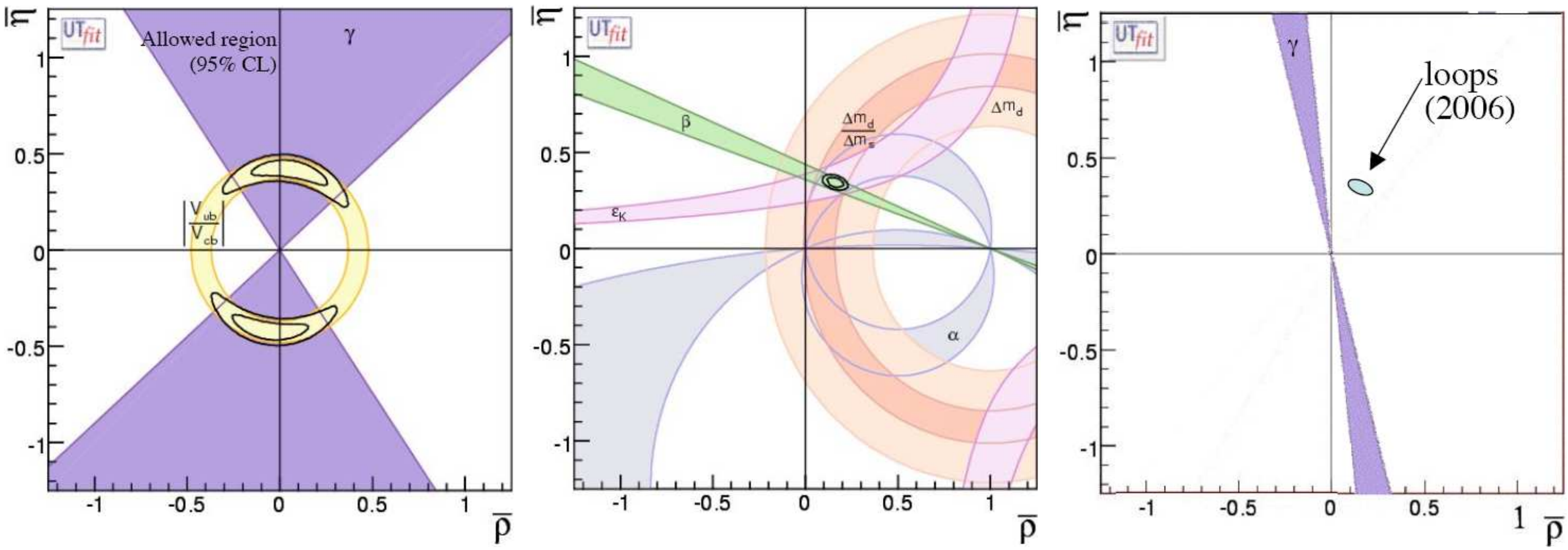
- Rare loop decay, sensitive to NP.
- Example CMSSM (hep-ph/0411216):
- SM: BR=$(3.4\pm0.4)10^{-9}$.
- Challenge: background rejection:
  - B_s mass-resolution: 18 MeV
  - Excellent vertex resolution→isolation.
- Trigger: $p_{\mathrm{T}}^{\mu} \gtrsim 1$ GeV





Unitary Triangle

γ measurements in $\mathrm{B}_{(s)}^{(\pm,0)} \rightarrow \mathrm{D}_{(s)}^{(*,0)}\mathrm{K}^{(\pm,*)}$

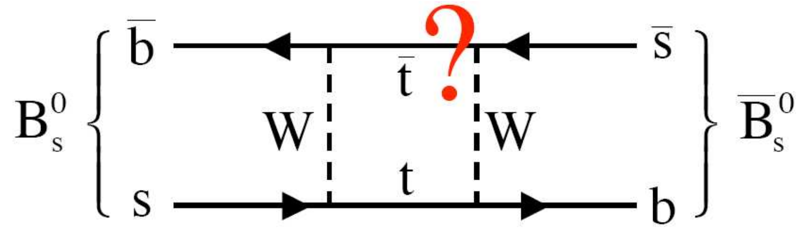


(a) 2006: Tree only, $\not N \not P$ (b) 2006: Loop, NP? (c) 2012: 10 fb^{-1}, $\gamma =$?

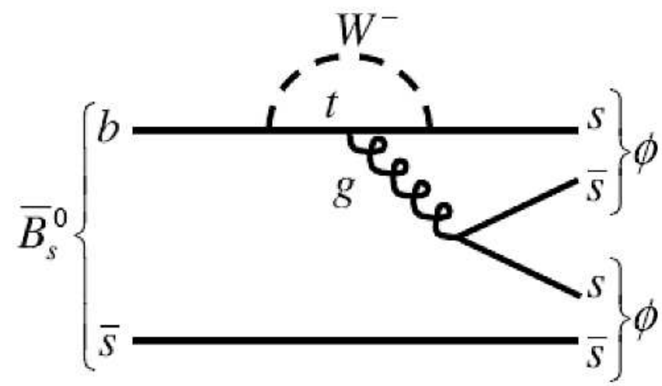
- Expect $\sigma(\gamma) \lesssim 3^\circ$ for 10 fb^{-1}.
- $\sigma(\gamma)$ from sides (UTFIT) $\sim 6^\circ$
- Lattice improvements could bring this down to $\sigma(\gamma)_{\mathrm{sides}} \lesssim 1^\circ$.
- While increasing statistics, have to resort to theoretically cleanest decays.

$B_s \to J/\psi(\mu\mu)\phi,\ \phi\phi$

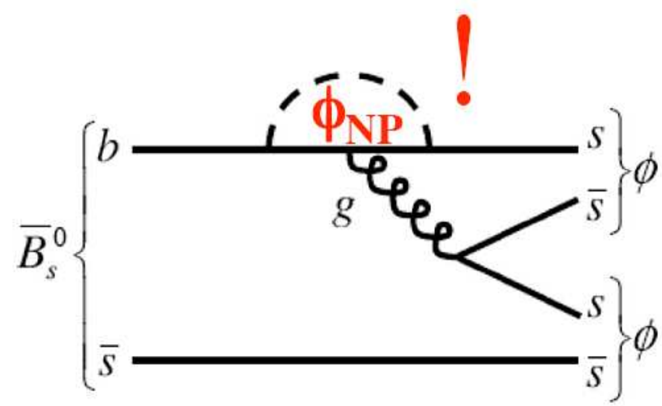
- Extract ϕ_s from golden mode: $J/\psi(\mu\mu)\phi$.
- $\phi_s^{SM} = -0.036 \pm 0.003$ (CKM-fitter).
- NP (?) in box could increase ϕ_s.
- 65k $J/\psi(\mu\mu)\phi$/fb^{-1}
- $\sigma(\phi_s) = 0.044$ with 0.5 fb^{-1}.



- Golden hadronic penguin counterpart: $\phi\phi$
- V_{ts} cancels in mixing-decay, hence: CPV-$\phi \neq 0 \to$ NP!
- 2k $\phi\phi$/fb^{-1} (with BR=1.4$\times 10^{-5}$)
- $\sigma(\phi_{NP}) = 0.042$ with 10 fb^{-1}

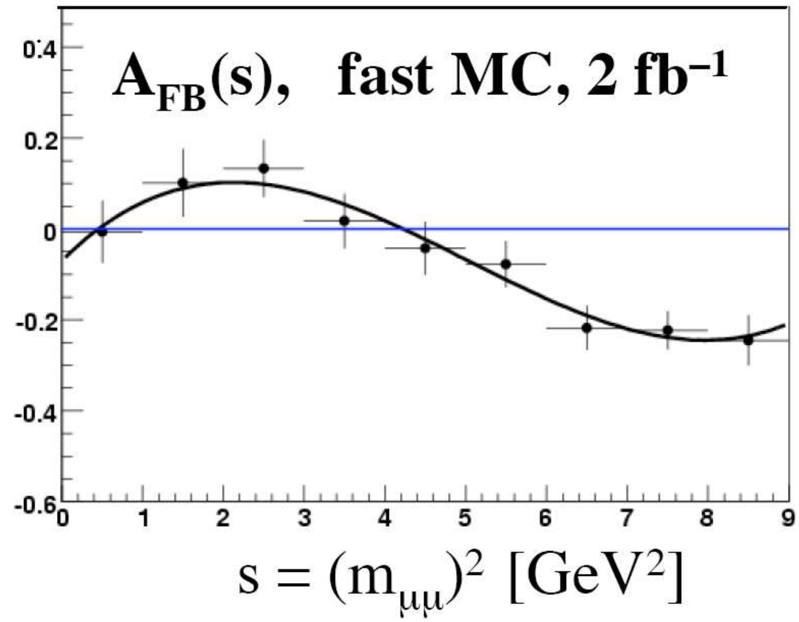


- Compare: 0.4k $B^0 \to \phi K_S/fb^{-1}$
- $\sigma(sin(2\beta)) = 0.14$ with 10 fb^{-1}
- Expect ± 0.12 with 2 ab^{-1} from B-factories.

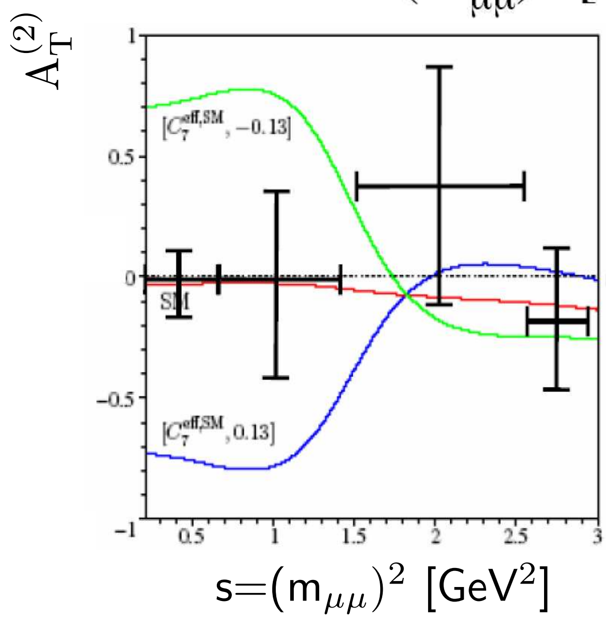


$B \to K^*\mu\mu$

- Suppressed loop decay, i.e. sensitive to NP.
- 3.8k events/fb^{-1}.
- $\sigma(A_{FB}(s) = 0)$: 0.28 GeV^2 for 10 fb^{-1}.



- Other symmetries:
  - $A_T^{(2)}$ for 2 fb^{-1}.
  - Sensitive to MSSM with tan(β)=5 (hep-ph/0612166), hence complementary to $B_s \to \mu\mu$.



- Investigating $B_s \to K^*\mu\mu$:
  - Potentially clean measurement of $\frac{V_{td}}{V_{ts}}$
  - $\sim$250 events/10 fb^{-1}

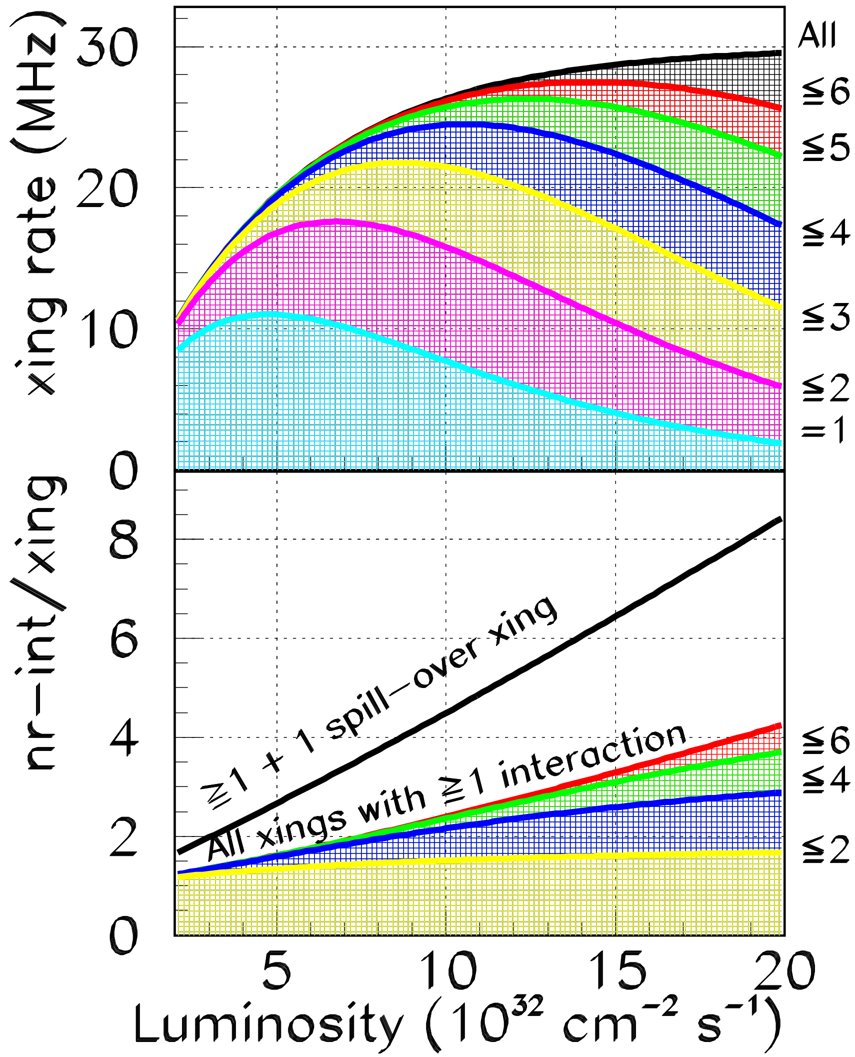
LHC and Luminosity

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

- $L_{\mathrm{LHC}}^{\mathrm{peak}} \approx 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$, $\geq 201n$
- Assume $\sigma_{\mathrm{visible}} = 63$ 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 $@10^{33}$, but spill-over goes linear with L!.

SLHC: LHCb does not need it but...

- $L_{\mathrm{SLHC}}^{\mathrm{peak}} \approx 8.10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$, $\geq 201n + 4$
- Baseline scheme 25 ns bunches, but:
  - 50 ns $I^{\mathrm{high}} \leftrightarrow I^{\mathrm{high}}$ bunches
  - Interleave with 50 ns $I_{\mathrm{low}} \leftrightarrow I_{\mathrm{low}}$ bunches
  - Atlas/CMS xings: $I^{\mathrm{h}} \times I^{\mathrm{h}}$, $I_{\mathrm{l}} \times I_{\mathrm{l}}, I^{\mathrm{h}} \times I^{\mathrm{h}}$
  - LHCb xing: $I^{\mathrm{h}} \times I_{\mathrm{l}}$, $I_{\mathrm{l}} \times I^{\mathrm{h}}, I^{\mathrm{h}} \times I_{\mathrm{l}}$ etc..



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LHCb and Luminosity

Trigger:

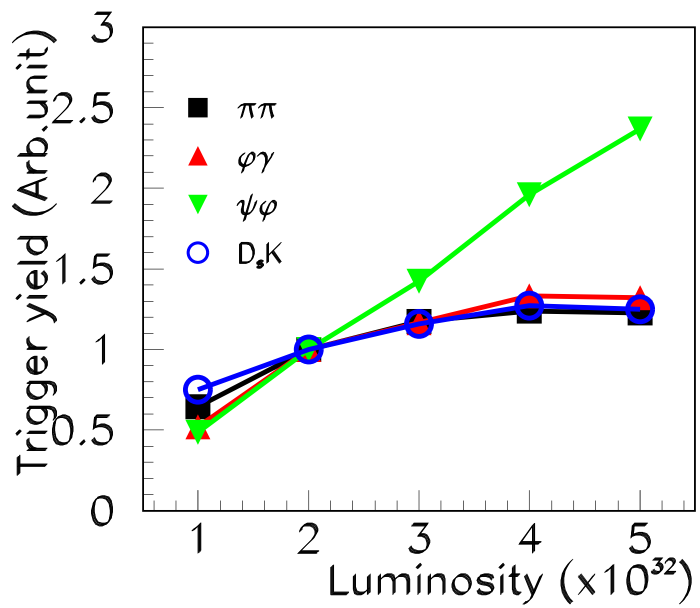
- $L^{\text{peak}} \geq 2 - 3.10^{32}$ no hadron-trigger gain.
  - hadronic-channels: yield $\propto \int (\text{time} \times 2.10^{32})$
  - μ-channels: yield $\propto \int L$

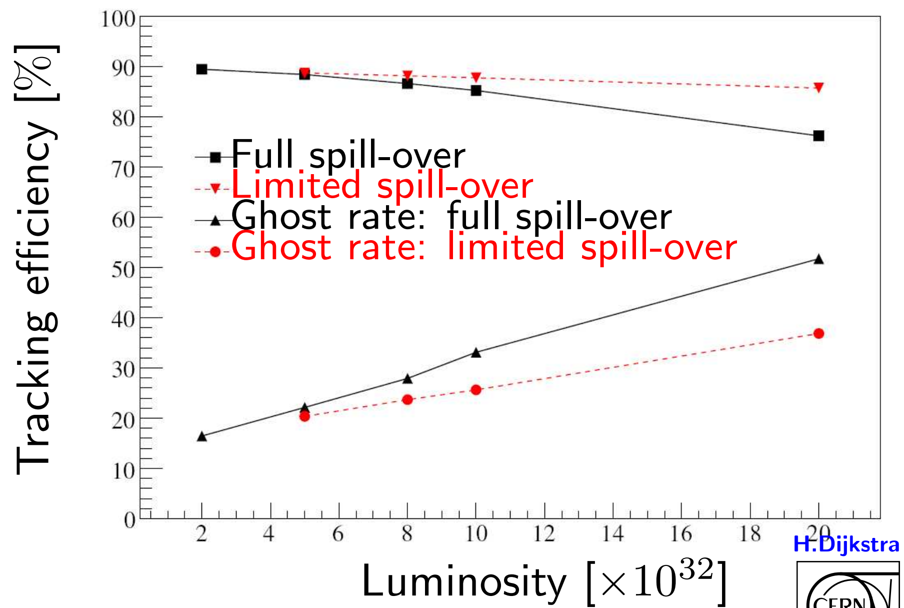
Radiation:

- designed for $\int L \leq 20\ \text{fb}^{-1}$ radiation damage.
  - Safety factor? Need first running.
  - Affects mainly large η.

Tracking & Particle-ID:

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





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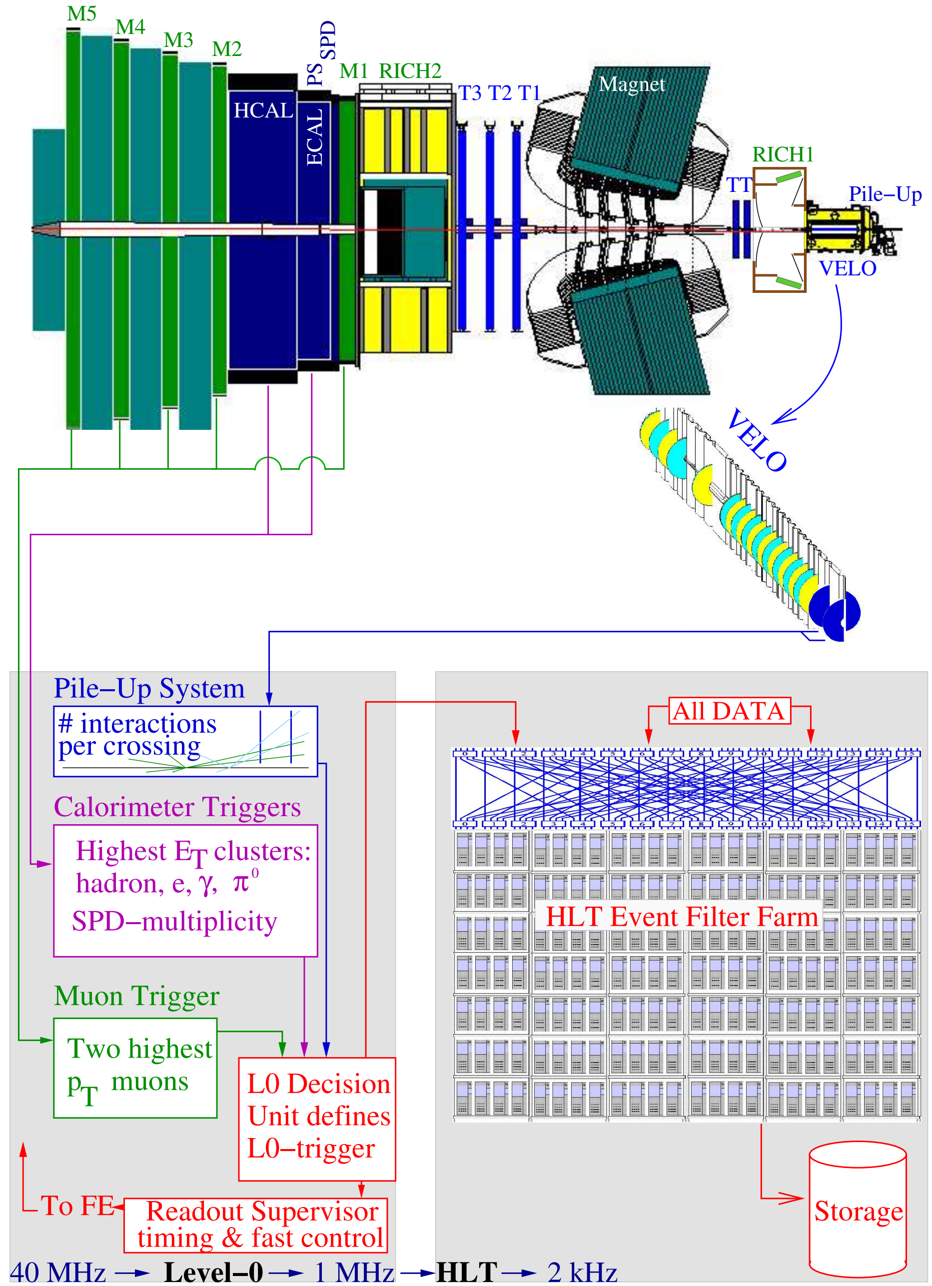
LHCb Trigger for pedestrians

Level-0:

- Largest E_T hadron, e(γ) and μ.
- Bottleneck: 1 MHz max-output rate.
- L0 limiting yield for larger L^{peak}:
  - $@L > 2.10^{32}$: L0-retention $\sim 10\%$
  - $@L > 10^{33}$: L0-retention $\sim 3\%$
  - $@L = 2.10^{33}$ ~ 4 pp/xing.
  - Result: E_T threshold $\gg \mathrm{M_B}$.

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 $\sim$3 years anyway.



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LHCb Trigger Performance ($@L = 2.10^{32}$)

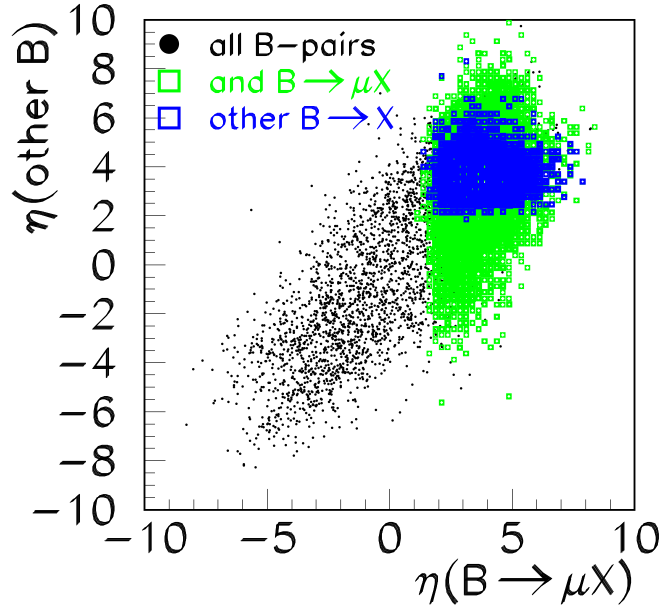
$\epsilon^{\text{Trigger}}$: % off-line reconstructed with good B/S:

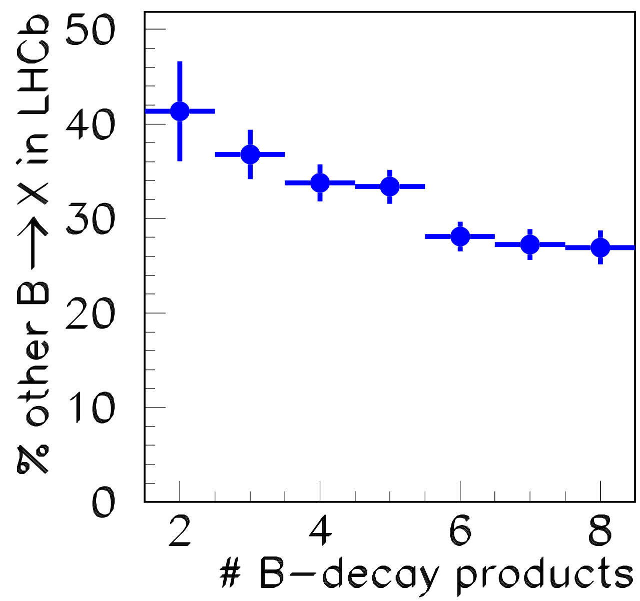
- $E_T^{\text{hadron}} \gtrsim 3.5$ GeV: ϵ(B →hadronic) $\sim 25 - 35\%$
- $E_T^{\gamma} \gtrsim 2.5$ GeV: $\epsilon(B \to \gamma X) \sim 30 - 40\%$
- $E_T^{\mu} \gtrsim 1.$ GeV: $\epsilon(B \to \mu\mu X) \sim 60 - 70\%$

Hence: increase lumi AND improve $\epsilon_{\text{trigger}}$!

Typical trigger→storage rates:

- 200 Hz exclusive B: core program.
- 600 Hz $M_{\mu\mu} > 2.5$ GeV: IP-unbiased B→ $J/\psi X$
- 300 Hz D*: Charm mixing&CPV.
- For "un-triggerable" channels:
  - 900 Hz inclusive B ($B \to \mu X$): Data mining. →
  - ~ 550 Hz of true $B \to \mu X$
  - $B \to \mu X$ trigger: tagging $\epsilon D^2 \approx 0.15$
  - $\sim 1.5 \times 10^9$ fully contained, μ-tagged, /2 fb^{-1}.





LHCb-upgrade base-line

Address trigger bottleneck:

- Perform whole trigger on CPU farm.
- Read-out all sub-systems at 40 MHz.
- Preliminary studies:

✓ Event building at 40 MHz, CPU power.

✓ Hadron trigger efficiency: $\propto L^{\rm peak}$, and $\epsilon_{\rm hadron} \times \sim 2$.

☹ Replace all FE-electronics → replace VELO/SiT and RICH-HPD, OT-FE, Cal-FE-boards.

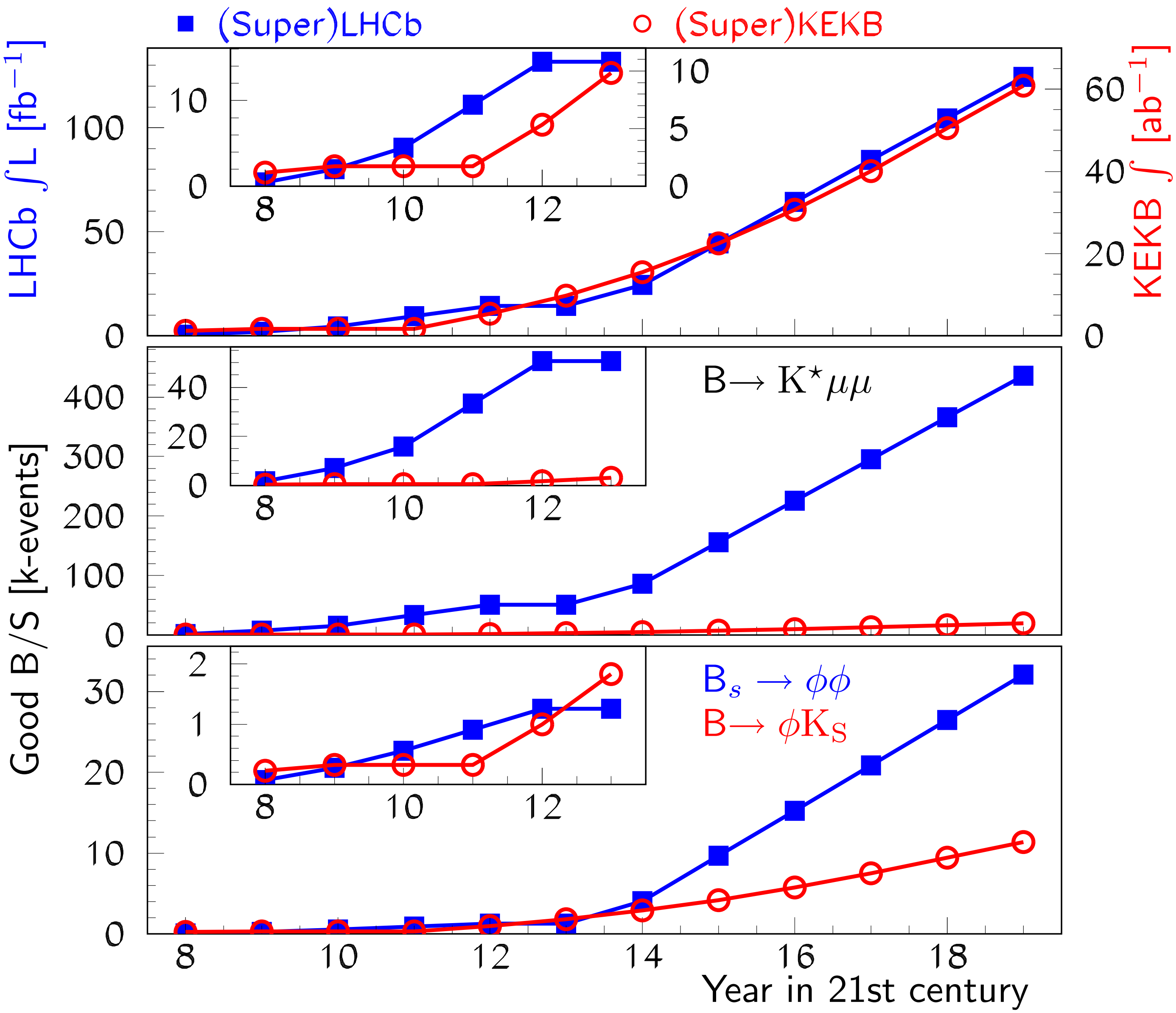
Address radiation $\int L$ 20→100 fb^{-1}.

- Need to replace VELO (anyway): rad-harder Si, pixels?
- Inner part of Shashlik Calorimeter: crystals?
- Inner part of Si-trackers.
- Remove μ-chamber before Calorimeter.

Address occupancy, especially at large η:

- OT straws-occ(no-spillover): 6(4.5)→ $25(10)\%$
  Hence: faster gas, increase Si-IT coverage, scintillating fibres?
- Tracking environment/algorithms in high(er) occupancy environment.

Projected Yield vs Time



LHCb$<$ 2013:

- $\int L \lesssim 15\text{fb}^{-1}$
- $L \cong 5.10^{32}$ $\geq$ 2010
- Yield$_{\text{h}}$: constant$> 2.10^{32}$

Upgrade:

- Assume $\epsilon_{\mu}^{\text{trigger}}$ unchanged
- Assume $\epsilon_{\text{h}}^{\text{trigger}}$ $30 \longrightarrow 60\%$
- $L \cong 2.10^{33} \geq$ 2015

Include tagging efficiency:

- LHCb $\times \epsilon D^2 = 0.07$
- Belle $\times \epsilon D^2 = 0.3$

Conclusions

- LHCb is (almost) ready to take over from first generation B-factories.
- Accumulate 10 fb^{-1} between 2008-2012.
- "1st LHCb Collaboration Upgrade Workshop" Jan/2007 in Edinburgh: well attended.
- Ramp up upgrade effort to be able to take decision ∼2010.
- Upgrade specs:
  - Accumulate ∼100 fb^{-1} by 2020
  - Increase $\epsilon_{\rm trigger}^{\rm hadron}$ by factor 2.
  - Maintain tracking and PID performance.
  - Start data-taking with SuperLHCb ∼2014.