LHCb upgrade

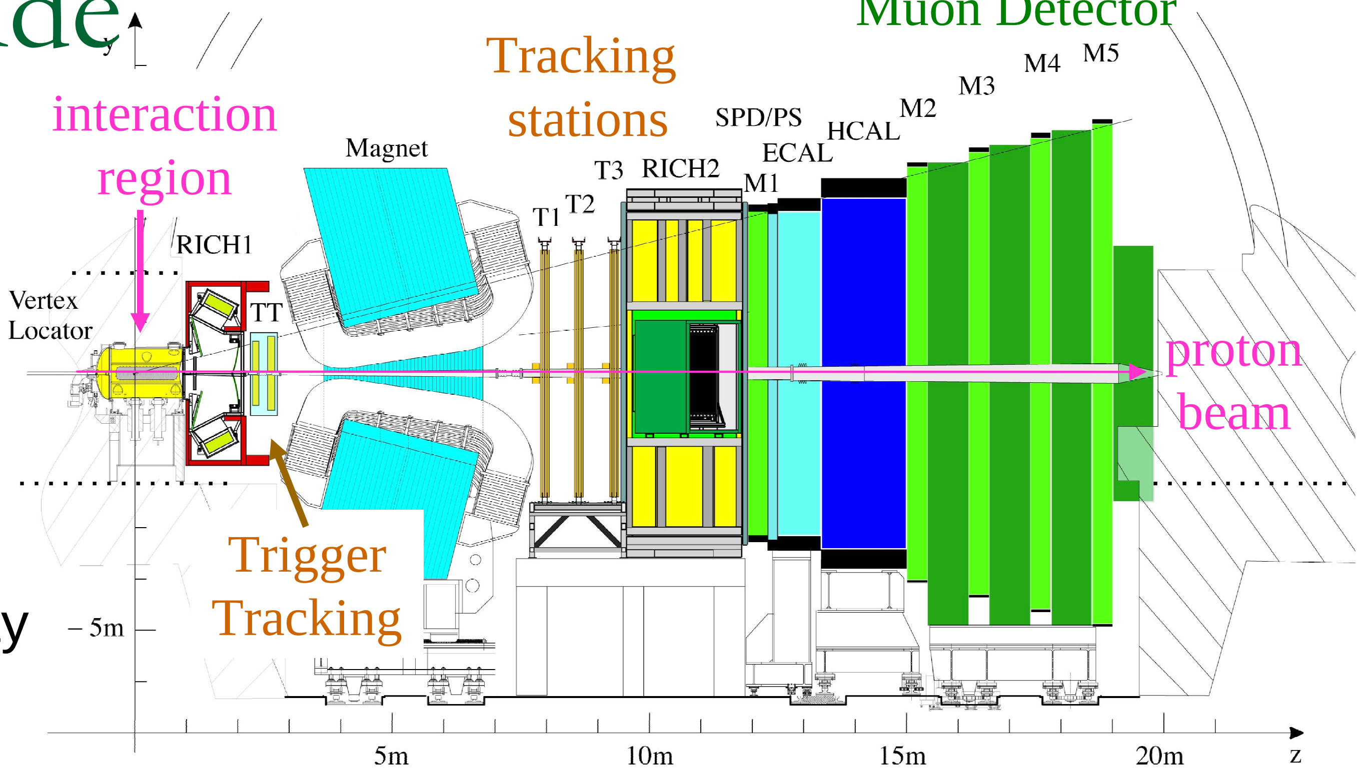
Jim Libby (University of Oxford) on behalf of the LHCb collaboration

Outline

- **LHCb**
  - Reminder of what is planned by 2013
- **The upgraded LHCb physics programme**
  - Unitarity triangle and CPV
  - FCNC decays
- **Upgraded LHCb**
  - Luminosity goals
  - Technical requirements and desires
- **Conclusion**
  - Including comments on time-scale

LHCb in a slide

- Forward geometry:
  - 10^{12} $b\bar{b}$/2 fb^{-1} produced
  - both B hadrons in acceptance for tagging
  - excellent proper time resolution (40 fs)
  - RICHs for hadron ID from 1 to 100 GeV/c
- Instantaneous luminosity (2-5)×10^{32} cm^{-2}s^{-1}
  - Factor 50 to 20 below peak design luminosity for GPDs



- Level-0: high p_t $l^{\pm}$, hadron or γ hardware trigger 40→1 MHz
  - effectively 10 → 1 MHz
- Software Higher Level Trigger (HLT):
  - ensure high-p_t Level-0 object associated with large impact parameter tracks
  - inclusive and exclusive selections to reduce storage rate to 2 kHz

LHCb programme and goals

Marcel Merk [Monday]

- **Highlights of the physics programme with 10 fb^{-1}**
  - $B_s \to \mu^+\mu^-$ observed
    - BR measured to ~15% if SM

Mitesh Patel [Tuesday]

  - B_s mixing phase (β_s) measured with an uncertainty 0.01 rad
    - Current CKMFitter prediction $\sin 2\beta_s = -0.037 \pm 0.002$
    - Tevatron 'favours' non-SM values
      - D0: arXiv:hep-ex/0701012 [hep-ex]
      - CDF: arXiv:0712.2397v1 [hep-ex]

Olivier Leroy [Wednesday]

  - γ measured to a few degrees
    - $B \to DK$, $B_s \to D_s K$ and $B \to D\pi$ [Tree-level determination]
    - $B_{(s)} \to h^+h^-$ exploiting U-spin [Loop-level determination]

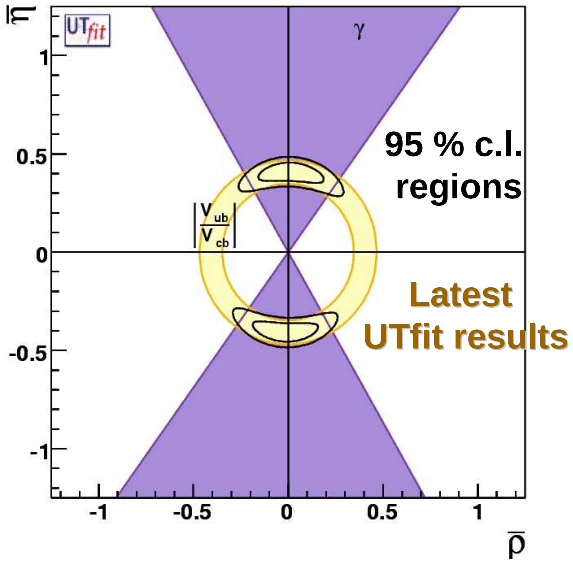
Angelo Carbone [Wednesday]

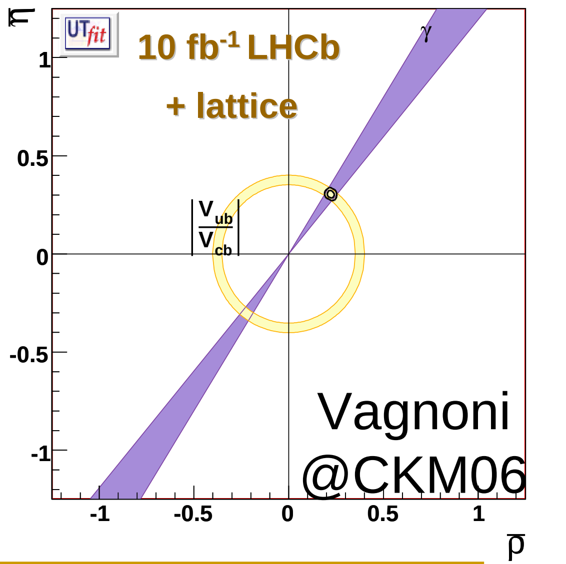
  - $B \to K^* \mu^+\mu^-$: 38k events with B/S<0.5
    - angular analyses sensitive to Beyond the Standard Model (BSM) physics

Mitesh Patel [Tuesday]

The particle physics landscape in 2013?

- All measurements listed on previous slide very sensitive to BSM effects
- Three tangible scenarios in 2013
  1. BSM at GPDs and LHCb
  2. BSM at LHCb but not at GPDs
  3. BSM at GPDs not at LHCb
     - But maybe a few 2-3σ effects
- **Trivial to motivate upgrade in first two**
- **Also straightforward with scenario 3:**
  - **New physics at TeV scale must influence flavour observables even with MFV**
- There is a scenario 4 (LHC wasteland)
  - No one wants this!
  - However, virtual effects will be the only way to set scale of BSM





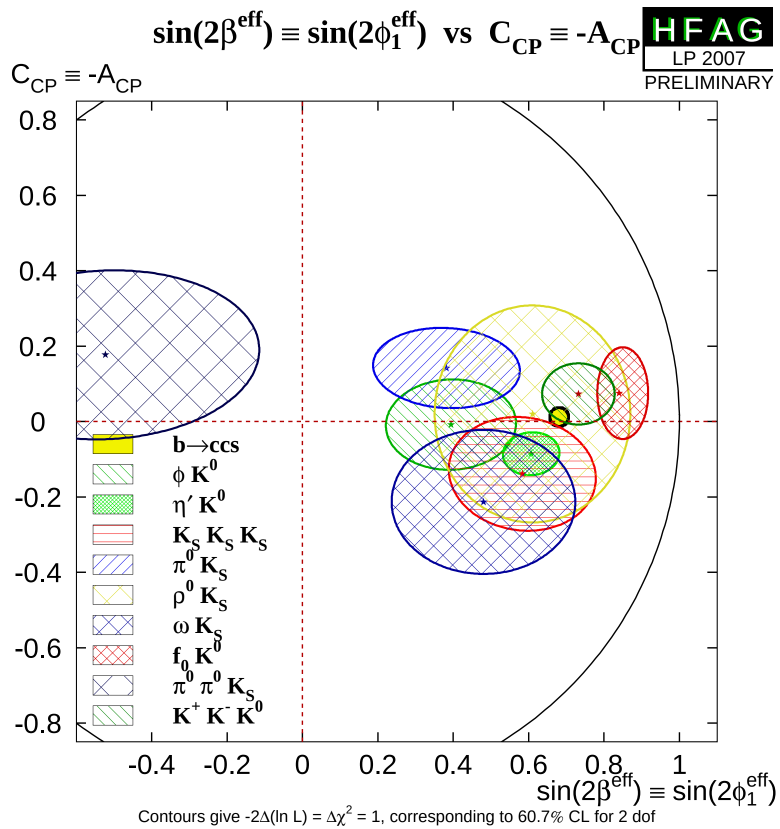
The LHCb upgrade

- Three aims:
  1. Collect an integrated luminosity of 100 fb^{-1}
     - A factor ten increase in data sample size
  2. Increase hadron trigger efficiency by ×2
     - Currently 25-35% for fully hadronic modes compared to 75-80% for modes containing muons
  3. At least maintain original LHCb performance
     - Hopefully some areas can be improved:
       - Material, electromagnetic calorimetry…..
- Will discuss the potential physics of such a data set before returning to the instrumentation

Examples of LHCb upgrade physics

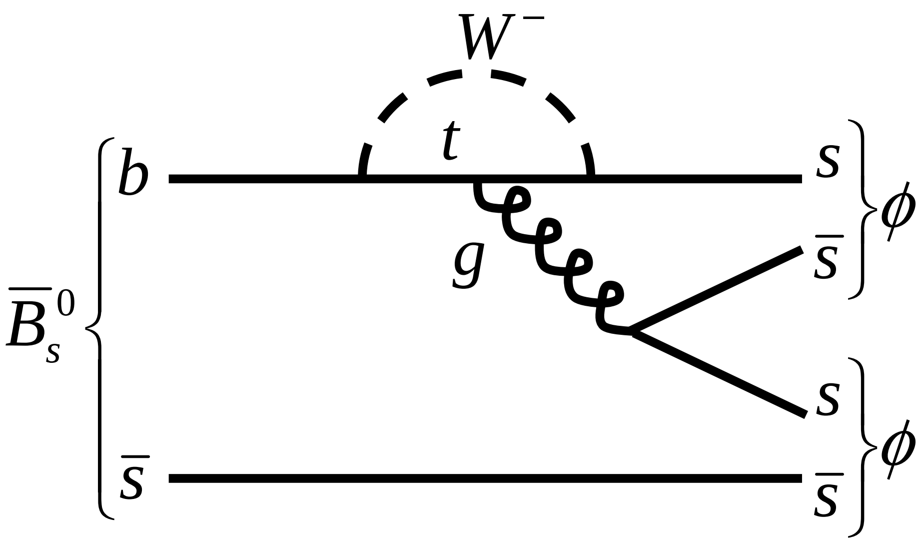
CPV in gluonic penguin

- One of the poster children of a SFF
  - For good reason given the tantalising hints of a discrepancy with sin2β from b→ccs
- Concentrate on the cleanest modes $B_d \to \phi K^0, \eta' K^0$ and $K^0 K^0 K^0$
  - **Average discrepancy 0.10±0.06**
    - No attempt to add theory
  - 5σ with current central value an important goal i.e. sin $2\beta^{eff}$
- $B_d \to \phi K^0$ most promising at current LHCb
  - Precision at end of LHCb 0.1
  - **End of SLHCb 0.025**
    - assuming $2\times\varepsilon_{trigger}$
    - same as a SFF but they have the other important modes…..



$B_s \rightarrow \phi\phi$

- B_s analogue of $B_d \rightarrow \phi K^0, \eta' K^0$ etc
- Dependence on V_{ts} in both the decay and B_s mixing amplitudes leads to the SM CPV being < 1%
  - for example M. Raidal, PRL 89, 231803 (2002)
- $P \rightarrow VV$ decay requires full angular analysis to extract CP info
- Simulation studies with background and detector effects
  - 2000(4000) events/fb^{-1} @ (upgraded) LHCb
  - BSM phase sensitivity of 0.05 at current LHCb
  - **Upgraded LHCb sensitivity 0.01 rad.**



$$\lambda_{\phi\phi}^{SM} = \frac{q}{p}\frac{\overline{A}_{\phi\phi}}{A_{\phi\phi}} = \underbrace{\frac{V_{tb}V_{ts}^*}{V_{tb}^*V_{ts}}}_{\text{mixing}}\underbrace{\frac{V_{tb}^*V_{ts}}{V_{tb}V_{ts}^*}}_{\text{decay}} = 1$$

Toward a sub-degree error on γ

- Extrapolating to 100 fb^{-1} only consider strategies which are theoretically clean

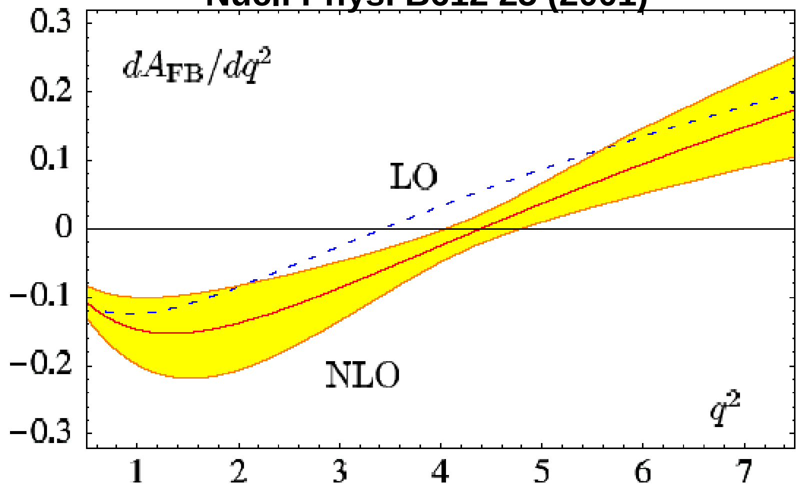
Mode	LHCb (10 fb^{-1})	**Upgraded-LHCb (100 fb^{-1})**
D_sK	27 k	**540k**
$D(K_s\pi\pi)K$	$\leq$25k	**0.5M**
$D(K\pi)_{fav}$ K	280k	**5.6M**

- $B_s \to D_sK$: statistical scaling leads to **1° uncertainty** for 100 fb^{-1}
- $B \to D(K_s\pi\pi)K$: statistical scaling leads to **1.2 °** for 100 fb^{-1}
  - need to consider model independent method (Bondar & Poluektov) exploiting $\psi'' \to DD$ data with $K\pi\pi$ vs CP and $K\pi\pi$ vs $K\pi\pi$
  - 3-5° with final CLEO-c statistics BES-III (×20 stat.) coming soon
- $B \to D(hh)K$: ADS/GLW **1-1.5° uncertainty**
  - largest systematic from detector asymmetry - measured in data

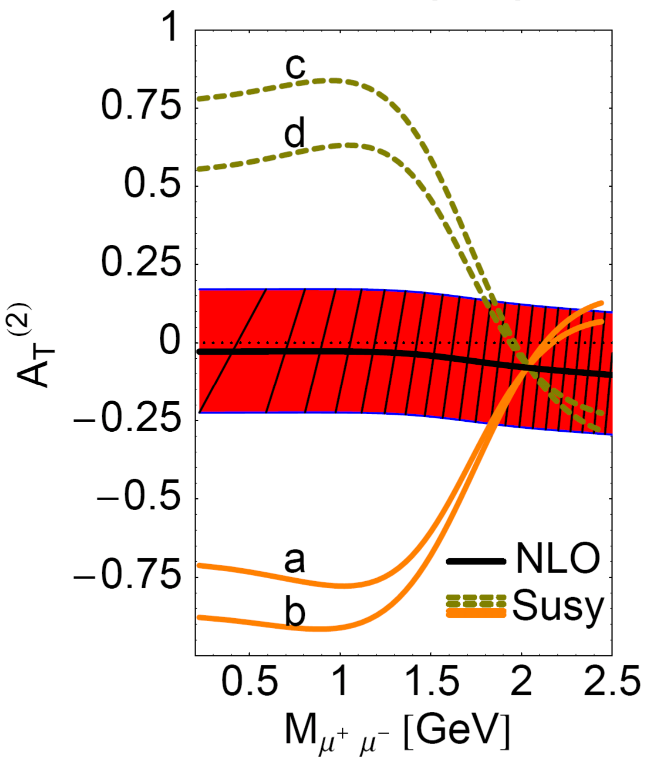
B→K*μμ

- $A_{FB}(s_0)=0$ is not enough:
  - SLHCb $\sigma_{s0}/s_0=2.1\%$
  - Exclusive NLO theory today $\sigma_{s0}/s_0=9\%$
  - But similar $1/m_b$ corrections must be included
  - Not unreasonable to expect exclusive error to improve by 2020
- However, transversity angle asymmetry analysis looks extremely promising
  - $A^{(2)}_T=|A_\perp - A_\parallel| / |A_\perp + A_\parallel|$
  - $\sigma\,(A^{(2)}_T)=0.06$ with upgraded LHCb
  - Theoretically clean
  - Constrains small tanβ

M. Beneke, T. Feldmann, D. Seidel
Nucl. Phys. B612 25 (2001)

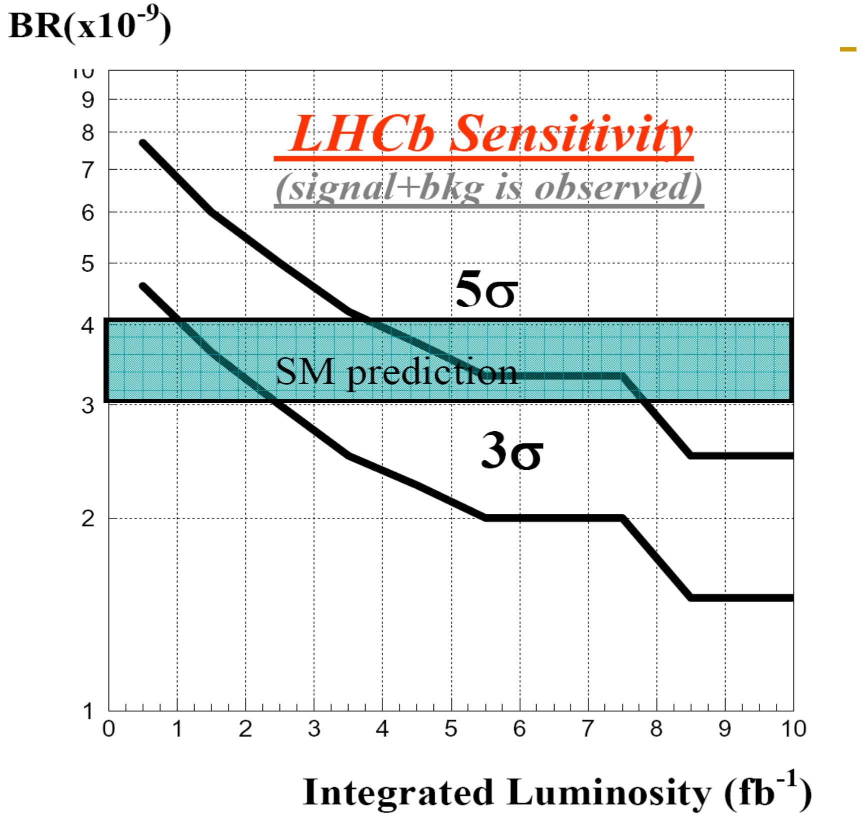


Lunghi and Matias
JHEP 0704 (2007) 058.

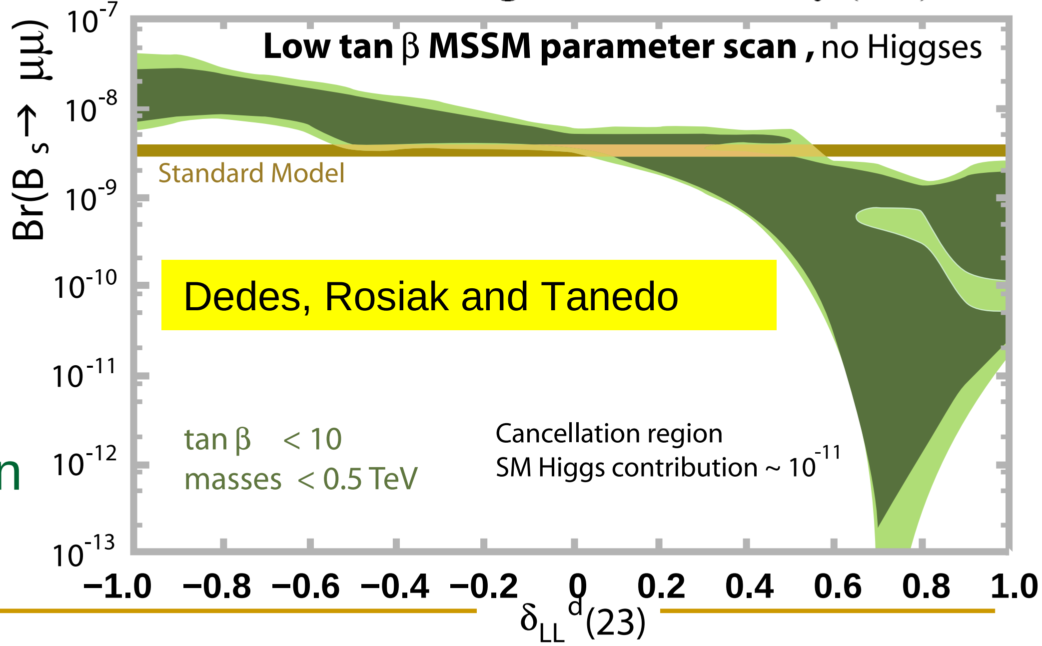


$B_{s(d)} \to \mu\mu$

- **5σ observation expected at current LHCb even if value of BF is SM**
- Theory prediction already at ~10%
- More precise determination at upgraded LHCb would be constraining of BSM models with large tanβ
  - Precise determination will be sensitive to low tanβ MSSM

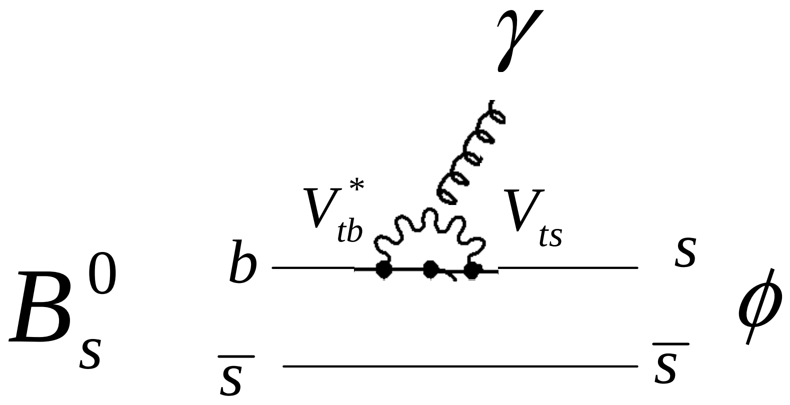


- $B_s \to \mu\mu / B_d \to \mu\mu = 32.4 \pm 1.9$ tightly constrained in SM and MFV
  - a magic number of CMFV (Buras)
- Matching theory precision is impossible with 100 fb^{-1}
  - observation possible as long as PID can cope with misidentification backgrounds i.e. $B_d \to \pi\pi$



TDCPV in $B_s \rightarrow \phi\gamma$

- **$B_s \rightarrow \phi\gamma$ is sensitive to right-handed currents**
- Upgraded LHCb sensitivity to $S(B_s \rightarrow \phi\gamma)$ is 0.02
  - But unless $2\beta_s$ large the senstivity to RH currents limited
- However, sensitivity via hyperbolic-sine term in decay width:
  - **$A^{\Delta} \sinh(\Delta\Gamma\, t / 2)$**
  - $\Delta\Gamma$ Negligible in B_d decays
  - Upgraded LHCb sensitivity to $A^{\Delta\Gamma}$ is 0.03
  - Reaches the level of theoretical uncertainties



$$A_{CP}(t) = \frac{\Gamma[\bar{B}_q \rightarrow \phi\gamma] - \Gamma[B_q \rightarrow \phi\gamma]}{\Gamma[\bar{B}_q \rightarrow \phi\gamma] + \Gamma[B_q \rightarrow \phi\gamma]}$$

$$A_{CP}(t) = -\frac{C\cos(\Delta m_q t) \quad + \quad S\sin(\Delta m_q t)}{A^{\Delta}\sinh(\Delta\Gamma_q t/2) + \cosh(\Delta\Gamma_q t/2)}$$

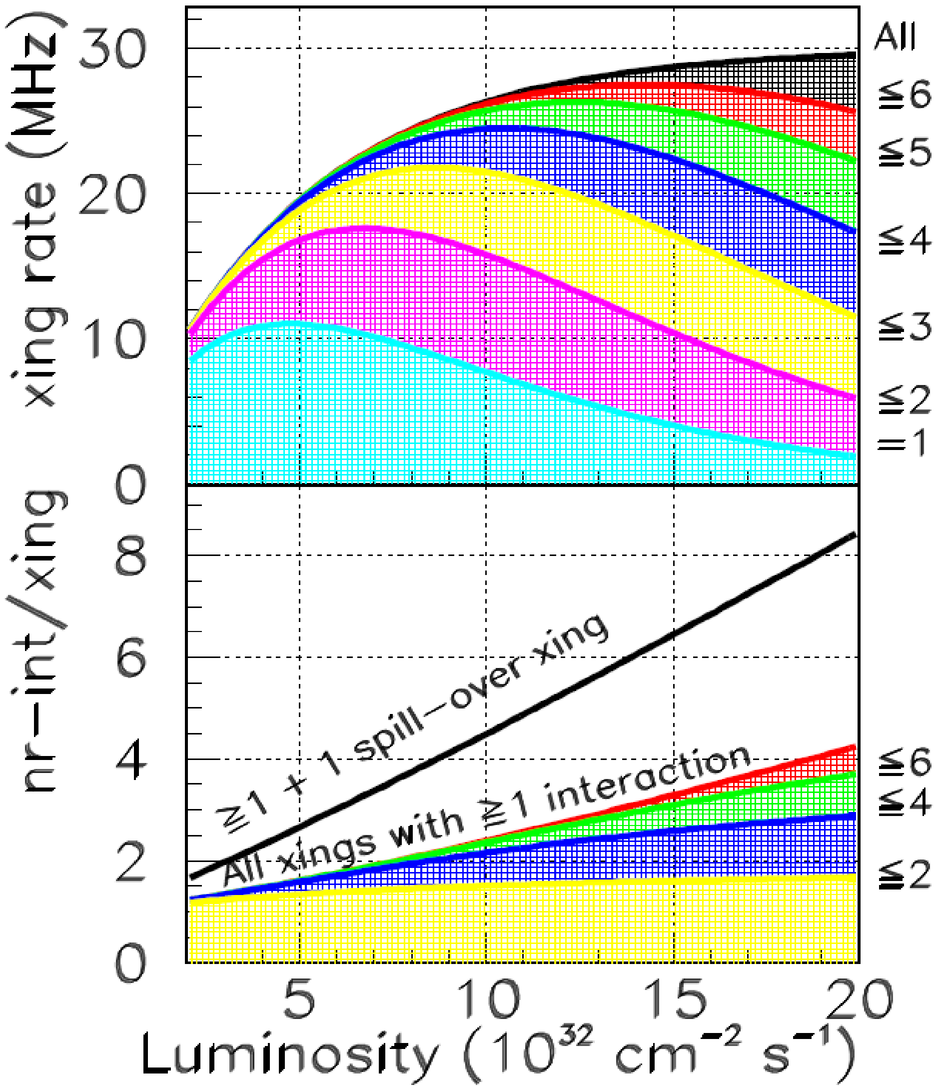
In SM,
C=0 (direct CPV)
$S = \sin 2\psi \sin 2\beta_s$
$A^{\Delta} = \sin 2\psi \cos 2\beta_s$
where ψ fraction of “wrong” polarization

Technical considerations

LHC and luminosity

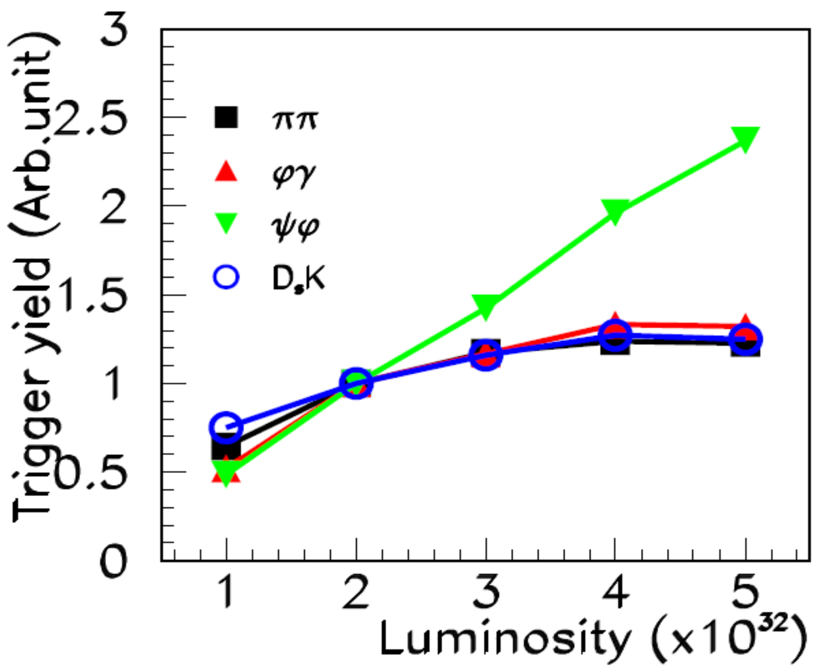
- Peak LHC luminosity 10^{34} cm^{-2}s^{-1}
- LHC operating at 2×10^{32} cm^{-2}s^{-1}
  - 10 MHz of crossings with ≥ 1 int.
- LHC operating at 2×10^{33} cm^{-2}s^{-1}
  - 30 MHz of crossings with ≥ 1 int.
  - Number of int./crossing increased by factor of two
  - **BUT** with spill-over (int. from previous crossing) increased by factor 3
- SLHC peak luminosity ~8×10^{34} cm^{-2}s^{-1}
- Not needed by LHCb, but
  - Possible scheme 25 ns bunches with alternating high (I^H) and low (I_L) current
  - GPDs: $I^H\times I^H$, $I_L\times I_L$, $I^H\times I^H$, $I_L\times I_L$,……
    - Effective 20 MHz crossing rate
  - LHCb: $I^H\times I_L$, $I_L\times I^H$, $I^H\times I_L$, $I_L\times I^H$,…….
    - Select I_L for desired luminosity

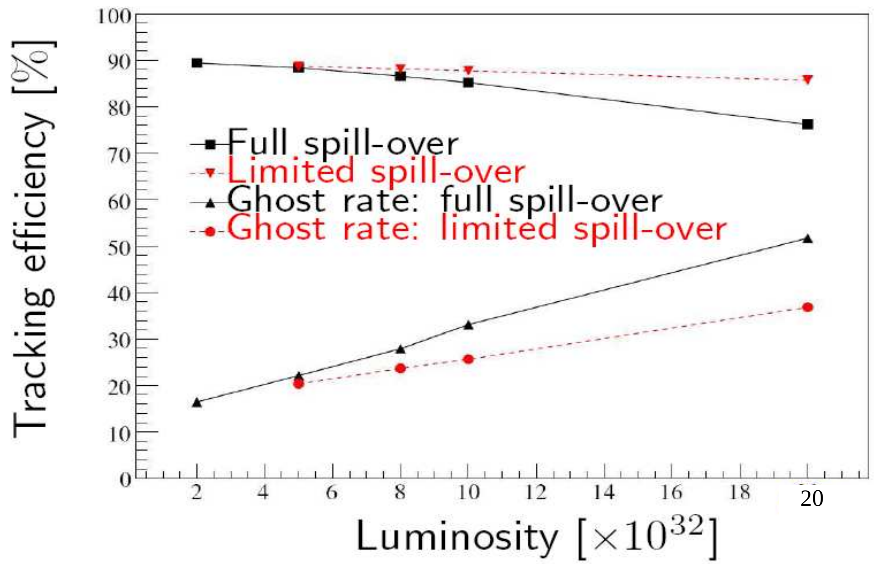
Assumes $\sigma_{visible}$=63 mb



Current LHCb and increased luminosity

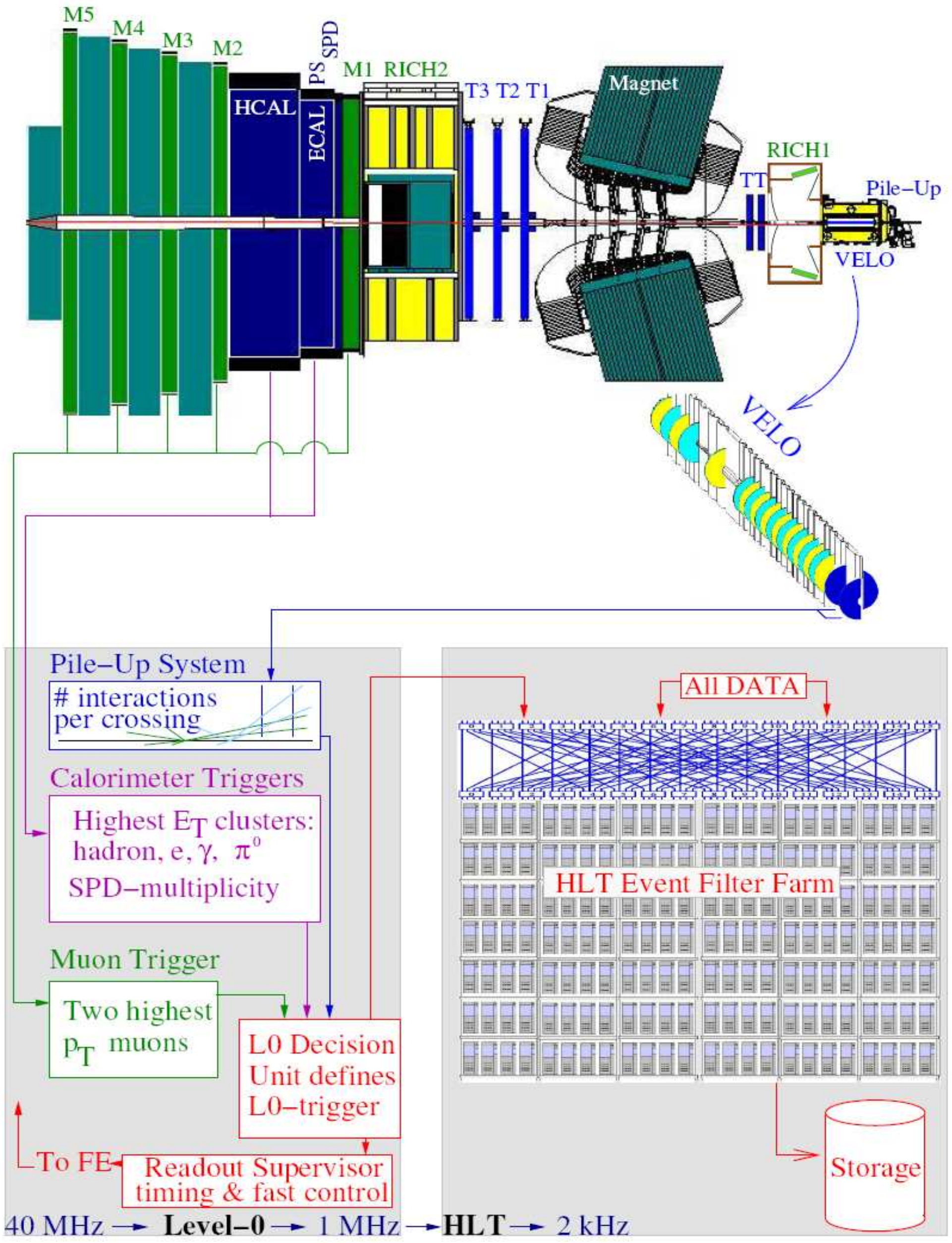
- Current LHCb no gain for hadron modes when lumi goes above 2×10^{32} cm^{-2}s^{-1}
  - **Limitation from L0 trigger**
- Radiation damage
  - Spec was for less than 20 fb^{-1}
  - Principally affects large η
- Tracking and particle ID:
  - **Straws: significant problems from spill-over above 10^{33} cm^{-2}s^{-1}**
  - Hadron PID and tagging OK to ~5×10^{32} cm^{-2}s^{-1} but degrades with reduced tracking performance
  - Si tracking fine





Current trigger limits

- Level-0 largest E_T hadron, e(γ) and μ
- Bottleneck is 1 MHz output rate
  - Thresholds tuned to match this
- At L>10^{33} $cm^{-2}s^{-1}$
  - interactions @ 30 MHz so only 3% can be retained
  - Number of int./crossing 2-4
  - **Leads to E_T threshold >> M_B!**
- Furthermore, desire to improve efficiency for hadrons and photons
  - $\varepsilon_{trigger}(B\rightarrow hadronic)$ ~ 25-35%
  - c.f. $\varepsilon_{trigger}(B\rightarrow \mu\mu X)$ ~ 60-70%
- Higher Level Trigger
  - Only limitation is CPU and our algorithmic ingenuity
  - (Former) improves with Moore's Law



Hardware path to upgrade

- **Address trigger bottleneck:**
  - Perform whole trigger in CPU farm ∴ **read out 40 MHz**
  - Preliminary studies:
    - Event building at 40 MHz OK with suitable CPU
    - Hadron trigger efficiency can be increased by incorporating vertex and coarse momentum early (c.f. BTeV)
    - **However, all subsystems front-end electronics need to be replaced**
      - New RICH photon detectors
      - Do we want have a single RICH to reduce X_0?
- **Radiation:**
  - Vertex detector replacement already required after ~6 fb^{-1}
    - **Upgrade to rad. hard Si strixels/pixels – R&D already begun**
  - Inner region of calorimeter:
    - increase segmentation of current Shaslik technology
    - move to crystals→improved σ(E)/E
- **Occupancy ×4 in outer tracker**
  - Only two fold without spillover → faster gas?
  - Increase inner Si tracker coverage
  - More radical: SciFi tracker!

MUCH R&D TO BE DONE

Conclusion

- There is a strong case to continue flavour physics even without clear NP signatures by 2013

- To operate at 10 × luminosity LHCb requires significant upgrades to:
  - Trigger and front-end
  - Silicon vertex detector
  - Straw tracking stations
- Does not require any luminosity upgrade
  - compatible with SLHC running

- Schedule
  - 2008: EoI submitted to LHCC
    - CERN/LHCC/2008-007
    - R&D started
  - 2010 decisions on upgrade instrumentation and write TDR
  - ~2013 upgrade detector
  - 2015-2020 gather 100 fb^{-1}