Update on flavour facilities

Tim Gershon
University of Warwick

PPAP community meeting
Birmingham University – 5th July 2010

Thanks for input:
Adrian Bevan, Guennadi Borissov, Neville Harnew,
Cristina Lazzeroni, Franz Muheim,
Chris Parkes, Yoshi Uchida, Fergus Wilson
One year ago ...

**Flavour-changing physics + QCD**

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:30</td>
<td>coffee/tea</td>
</tr>
<tr>
<td>10:45</td>
<td>Welcome (05')</td>
</tr>
<tr>
<td>10:50</td>
<td>PPAN context (15')</td>
</tr>
<tr>
<td>11:05</td>
<td>Flavour-changing physics beyond the Standard Model (30')</td>
</tr>
<tr>
<td>11:50</td>
<td>CKM matrix elements and CP violation (40')</td>
</tr>
<tr>
<td>12:50</td>
<td>lunch</td>
</tr>
<tr>
<td>13:30</td>
<td>Lattice QCD (30')</td>
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<tr>
<td>14:15</td>
<td>Rare decays (30')</td>
</tr>
<tr>
<td>15:00</td>
<td>Lepton universality and lepton flavour violation (30')</td>
</tr>
<tr>
<td>15:40</td>
<td>tea/coffee</td>
</tr>
<tr>
<td>16:00-17:10</td>
<td>Required technologies</td>
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<tr>
<td>16:00</td>
<td>LHC Upgrades (LHCb + GPDs) (15')</td>
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<td>16:15</td>
<td>e+e- machines (SuperB, Belle upgrade, tau-charm factories) (15')</td>
</tr>
<tr>
<td>16:30</td>
<td>NA62 + kaons at JPARC/FNAL (10')</td>
</tr>
<tr>
<td>16:40</td>
<td>COMET + muons at FNAL (10')</td>
</tr>
<tr>
<td>17:10</td>
<td>Discussion (50')</td>
</tr>
</tbody>
</table>

Programme committee:
- Nigel Glover (IPPP) - Chair
- Tim Gershon (Warwick) - Deputy
- Christine Davies (Glasgow)
- Yal Gibson (Cambridge)
- Cristina Lazzeroni (Birmingham)
- Steve Playfer (Edinburgh)
- Chris Sachrajda (Southampton)
- Mara Smizanska (Lancaster)
- Guy Wilkinson (Oxford)

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Update on flavour facilities
Update on flavour facilities

- Will not try to cover everything
  - Please refer to the excellent talks on 13 July 2009
  - Theory covered by Mike Seymour today
  - Apologies for omissions

- Brief recap: why flavour?

- Physics highlights of last 12 months
  - a.k.a. “status of managed withdrawal”

- Update on global status and developments
  - Tevatron, LHC (GPDs & LHCb), LHCb upgrade, e+e− flavour factories, kaons, muons

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Update on flavour facilities
Why flavour?

- New physics usually shows up at precision frontier before energy frontier
  - GIM before discovery of charm
  - CP violation / CKM before discovery of bottom & top
  - Neutral currents before discovery of Z
- Particularly sensitive: loop processes
  - Standard Model contributions suppressed / absent
  - flavour changing neutral currents (rare decays)
  - CP violation
  - lepton flavour / number violation / lepton universality
But we haven't seen new physics yet


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<table>
<thead>
<tr>
<th>ELECTROWEAK STRUCTURE</th>
<th>FLAVOUR COUPLING:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$b \rightarrow s$ ($\sim \lambda^2$)</td>
</tr>
<tr>
<td>$\Delta F=2$ box</td>
<td>$\Lambda &gt; 100$ TeV from $\Delta m_{B_s}$</td>
</tr>
<tr>
<td>$\Delta F=1$</td>
<td>$\Lambda &gt; 80$ TeV from $B(B \rightarrow X_s \gamma)$</td>
</tr>
<tr>
<td>4-quark box</td>
<td></td>
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<tr>
<td>gluon penguin</td>
<td></td>
</tr>
<tr>
<td>$\gamma$ penguin</td>
<td>$\Lambda &gt; 150$ TeV from $B(B \rightarrow X_s \gamma)$</td>
</tr>
<tr>
<td>$Z^0$ penguin</td>
<td>$\Lambda &gt; 20$ TeV from $B(B \rightarrow X_s \ell^+\ell^-)$</td>
</tr>
<tr>
<td>$H^0$ penguin</td>
<td></td>
</tr>
</tbody>
</table>

Bounds on $\Lambda$ assuming $O(1)$ flavour-changing couplings

"New Physics flavour problem"?
But we haven't seen new physics yet


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Update on flavour facilities

hints of physics at very high scales?
But we haven't seen new physics yet


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Update on flavour facilities
Recent highlights
(exceptioning LHC start-up – discussed later)

- Main players in flavour over last decade
  - B factories, Tevatron, CLEOc, kaon experiments
- UK involvement in
  - BaBar, CDF, D0, CLEOc, NA48/NA62
- All now in (“managed”) withdrawal phase
- All continue to produce important and impressive results
  - UK involvement (leadership) highly evident
  - Punching above our weight despite minimal funding
\[ a_\mu^{\text{had,LO}}[e^+e^-] = (695.5 \pm 4.0 \text{ exp } \pm 0.7 \text{ QCD}) \times 10^{-10} \]

\[ a_\mu^{\text{SM}} = (11659183.4 \pm 4.9) \times 10^{-10} \]

\[ a_\mu^{\text{exp}} - a_\mu^{\text{SM}} = (24.6 \pm 8.0) \times 10^{-10} \]

3.1\sigma (assuming Gaussian statistics)

Many other new results including: \(|V_{ub}|, \gamma, \text{ rare decays, charm mixing and CP violation}\)
Forward-backward asymmetry in $B \rightarrow K^* \mu \mu$

Many other new results including:

$B_s \rightarrow \mu \mu$, $B_s \rightarrow \phi \phi$, $B$ hadron lifetimes
“Evidence for an anomalous like-sign dimuon charge asymmetry”
a.k.a. “The most interesting physics result of 2010” (J. Womersley)

Other new results include $B_s \rightarrow \mu \mu$
Future improvements

D0
(maybe Belle2 & SuperB)

D0
(maybe CDF & LHCb)

LHCb


BaBar, Belle
Belle2, SuperB

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CP violation and Nobel prizes

Nobel Mixing

- For neutral meson systems:

  Mixing → CP violation → Nobel Prize (~20 years)

- For 2 out of 4 mixing meson systems, we only just got started:

  - $B_s$: Mixing discovered in 2006, no CPV, yet.
  - $D^0$: Mixing discovered in 2007, no CPV, yet.

- In both systems, the prize is in finding non-SM CP violation (in the case of $D^0$, this is any CPV)

Observation of large CP violation in $B_s$ or $D$ oscillations would be Nobel-worthy
Update on global status and developments

- Tevatron
- LHC (GPDs & LHCb)
- LHCb upgrade
- $e^+e^-$ flavour factories (KEK & Italy)
- kaons (CERN, J-PARC, FNAL)
- muons (J-PARC, FNAL)
Tevatron

• Proposal to extend running until end 2014

• Arguments for this not based on flavour physics
  - LHCb will overtake Tevatron sensitivity
  - B physics triggers suffer at high luminosity
  - but still some unique potential (e.g. D0 A_{sl})
LHC (GPDs & LHCb)

- LHC operation at $\sqrt{s} = 7$ TeV, $L \sim 10^{32}$/cm$^2$/s
  - great news for flavour physics
  - even lower luminosities – opportunity for charm physics

- LHCC:
  “With current luminosity projections LHCb is the only detector capable to achieve almost completely its full physics potential during the 2010-2011 run”

http://indico.cern.ch/getFile.py/access?contribId=20&resId=1&materialId=slides&confId=92525
  - caveat: excellent LHCb potential for an upgraded programme
  - and competition from ATLAS & CMS in a few measurements
LHCb status

- Building up the ingredients for physics

- Only possible because the detector works well

VELO: best resolution of any LHC vertex detector
LHCb upgrade

- Upgrade schedule adjusted to fit LHC schedule
  - major upgrade during 2016 shutdown (independent of LHC upgrade)
    - new trigger scheme, new VELO(PIX), new electronics
    - RICH photon detectors replacement, TT & IT replacement
    - peak $L \sim 10^{32} \rightarrow 10^{33} / \text{cm}^2 / \text{s}$ (integrated $L \sim 10 \rightarrow 100 / \text{fb}$)
      - possible second stage upgrade for higher $L$ (PID, ECAL)

- UK leadership
  - physics, conceptual design (trigger), VELO(PIX), PID

- LOI in preparation (for LHCC December 2010)
  - cost minimisation exercise in progress – estimate 40 MCHF exploiting synergies with other experiments
LHCb upgrade – hot news

- At $2 \times 10^{32}$ cm$^{-2}$s$^{-1}$ (nominal conditions)
  - 30 MHz of crossings
  - Most crossings have no interaction
  - L0 reduces data to 1MHz
  - HLT output is 2kHz → on tape
- At $10^{33}$ cm$^{-2}$s$^{-1}$
  - On average 2.3 interactions/crossings

Current LHC operation ($\beta^*=3.5$ m, ~1.5 int./crossing) serves as a test beam for LHCb upgrade

Study effects on hadronic triggers
(precision CKM, charm, $B_s \to \phi\gamma$, $B_s \to \phi\phi$, $K^*\bar{K}^*$)

Confirm performance for leptonic modes
($B_{s,d} \to \mu\mu$, $B_d \to K^*\mu\mu$, $B_s \to J/\psi\phi$)

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Update on flavour facilities
e\(^+\)e\(^-\) flavour factories (I)

- SuperKEKB / Belle2 approved
  - 100 oku-yen (approx $110M) over three years
  - start data taking 2014
  - “nano-beam” scheme, large crossing angle, e\(^+\)/e\(^-\) 4/7 GeV
  - expected peak luminosity 8 \(10^{35}/\text{cm}^2/\text{s}\)
  - accumulate 50/ab by 2020, TDR to be published July 2010
  - main physics goals:
    - precision CKM, inclusive rare decays, B \(\rightarrow\tau\nu\), \(\tau\) lepton flavour violation

- BESIII / BEPCII running
  - charm / \(\tau\) physics near threshold
e^+ e^- flavour factories (II)

- **SuperB (Italy)**
  - more ambitious proposal than SuperKEKB / Belle2
    - higher lumi, polarised beam, flexible CM energy, 700M€
    - timescale: data taking 5-6 years after approval
  - INFN #1 priority, endorsed by the Italian Science and Economy Ministry, support pledged from Lazio regional government, waiting for cabinet approval
  - several international MOUs & agreements signed
  - physics white paper (SLAC-R-952) & TDR coming soon
    - accelerator design reviewed by MAC
  - UK involvement: physics, pixel vertex detector, computing
Kaons (I)

- **CERN NA62-Phase I**
  - preliminary measurement of Ke2/Kμ2 ratio (UK led)
  - 1.5σ tension with the SM prediction

- **CERN NA62-Phase II (K^+ → π^+νν decay in flight)**
  - approved at CERN; expect first data end 2012 (possibly with incomplete detector for first 6 months or so)
  - UK involvement
    - on hold until financial situation improves
    - UK progressing with conceptual design of CEDAR detector (very high rate particle id in the beamline)
  - potential for future upgrade (possibility to measure K^0 → π^0νν)
Kaons (II)

- **J-PARC KOTO** ($K^0 \rightarrow \pi^0 \nu \bar{\nu}$)
  - based on KEK E391a detector and experience
  - rebuilding calorimeter with KTeV crystals
  - fully approved; expect first data Autumn 2011
  - will reach SM prediction sensitivity in 3 years
  - possible further upgrade for precision measurement

- **FNAL P996**
  - proposal for $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ from stopped kaons
  - expecting ~200 events/year

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No UK involvement

arXiv:0911.4789
Muons (I)

- **PSI MEG experiment ($\mu \rightarrow e\gamma$)**
  - first preliminary results $< 3 \times 10^{-11}$
  - should reach $10^{-13}$ by 2013

- **FNAL mu2e ($\mu \rightarrow e$ conversion; $10^{-16}$ sensitivity)**
  - CD0 granted

- potential for future improvement using ProjectX

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Update on flavour facilities
Muons (II)

- J-PARC COMET ($\mu \to e$ conversion)
  - first (of two) stage approval received
  - schedule similar to mu2e
  - TDR in preparation
    - UK involvement: design studies, software
    - prototype pion capture solenoid (MUSIC, Osaka)
      - UK participation; students present on site
  - possible FFAG-based upgrade (PRISM)
    - major synergies with UK programme & UK led
Summary & Discussion

- Flavour physics is a field in which the UK has international leadership (experiment & theory)
- Both volume and breadth drastically reduced
  - excellence undiminished (but not sustainable)
- Physics case for flavour is compelling
  - best chance for NP discovery in next few years
  - long term physics reach beyond energy frontier
- Several positive developments internationally
  - opportunities for UK physics & for UK PLC
Back-up Material
LHC upgrade schedule

http://indico.cern.ch/conferenceOtherViews.py?view=standard&confId=95580
LHC upgrade schedule

2017 shutdown

LHC – 10 months

- Shutdown driven by the activities in the experiments and especially in ATLAS and ALICE.
- ATLAS; insert the new pixel layer. In parallel various systems will be upgraded and the LV1 will be sharpened.
- ALICE; installation of a smaller beam pipe and a new vertex detector. The outer detector will be upgraded in shorter shutdowns (Christmas breaks).
- LHCb; rebuild the vertex detector and increase the readout rate
- In the shadow, full maintenance as well as the preparation of magnets for crab cavities in IR4.

Injectors - (2 x 3.5 months)

- consolidations and upgrades

http://indico.cern.ch/conferenceOtherViews.py?view=standard&confId=95580
LHCb Upgrade

- We hope to see the effects of new particles observed by ATLAS & CMS in “flavor” variables in 10 fb^{-1}
- Upgrading will allow us to precisely measure these effects

Complementary to ATLAS & CMS

- cover different rapidity region
- “direct” discovery potential at high η

<table>
<thead>
<tr>
<th>Observable</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPV(B_s→φφ)</td>
<td>0.01-0.02</td>
</tr>
<tr>
<td>CPV(B_d→φK_s)</td>
<td>0.025-0.035</td>
</tr>
<tr>
<td>CPV(B_s→J/ψφ) (2β_s)</td>
<td>0.003</td>
</tr>
<tr>
<td>CPV(B_d→J/ψK_s) (2β)</td>
<td>0.003-0.010</td>
</tr>
<tr>
<td>CPV(B→DK) (γ)</td>
<td>&lt;1^o</td>
</tr>
<tr>
<td>CPV(B_s→D_sK) (γ)</td>
<td>1-2^o</td>
</tr>
<tr>
<td>B(B_s→μ^+μ^-)</td>
<td>5-10% of SM</td>
</tr>
<tr>
<td>A_{FB}(B→K^*μ^+μ^-)</td>
<td>Zero to ±0.07 GeV^2</td>
</tr>
<tr>
<td>CPV(B_s→φγ)</td>
<td>0.016-0.025</td>
</tr>
<tr>
<td>Charm mixing x'^2</td>
<td>2x10^{-5}</td>
</tr>
<tr>
<td>Charm mixing y'</td>
<td>2.8x10^{-4}</td>
</tr>
<tr>
<td>Charm CP y_{CP}</td>
<td>1.5x10^{-4}</td>
</tr>
</tbody>
</table>
Table 1: Sensitivities of the LHCb upgrade to key observables. For each observable the current sensitivity is compared to that expected after LHCb has accumulated 10 fb\(^{-1}\) and that which will be achieved by the upgraded experiment. Competing experiments are listed where they have potential sensitivities that are comparable to those of the LHCb upgrade (SFF indicates Super Flavour Factory).

<table>
<thead>
<tr>
<th></th>
<th>Measurement</th>
<th>Current precision</th>
<th>LHCb (10 fb(^{-1}))</th>
<th>LHCb upgrade (100 fb(^{-1}))</th>
<th>Irreducible theory error</th>
<th>Competition</th>
</tr>
</thead>
<tbody>
<tr>
<td>E/W Penguins</td>
<td>(S_0 A_{\text{FB}} (K^* \mu \mu))</td>
<td>Unmeasured</td>
<td>4%</td>
<td>1%</td>
<td>7%</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>(A_T^{(2)} (K^* \mu \mu))</td>
<td>Unmeasured</td>
<td>0.10</td>
<td>0.03</td>
<td>0.05</td>
<td>None</td>
</tr>
<tr>
<td>Right-handed currents</td>
<td>S ((B_s \rightarrow \phi \gamma))</td>
<td>Unmeasured</td>
<td>0.05</td>
<td>0.01</td>
<td>&lt;0.01</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>(A^{a\phi} (B_s \rightarrow \phi \gamma))</td>
<td>Unmeasured</td>
<td>0.10</td>
<td>0.02</td>
<td>0.02</td>
<td>None</td>
</tr>
<tr>
<td>Higgs penguins</td>
<td>(B(B_d \rightarrow \mu \mu) / B(B_s \rightarrow \mu \mu))</td>
<td>Unmeasured</td>
<td>Unmeasured</td>
<td>(-20%)</td>
<td>(-5%)</td>
<td>ATLAS, CMS</td>
</tr>
<tr>
<td>Gluonic penguins</td>
<td>(\beta_{s}^{NP} (B_s \rightarrow K^{0*} \overline{K}^{0*}))</td>
<td>Unmeasured</td>
<td>5°</td>
<td>1°</td>
<td>&lt;1°</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>(\beta_{s}^{NP} (B_s \rightarrow \phi \phi))</td>
<td>Unmeasured</td>
<td>5°</td>
<td>1°</td>
<td>(-1°)</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>(\beta^{NP} (B_d \rightarrow \phi K_s))</td>
<td>8°</td>
<td>8°</td>
<td>2°</td>
<td>(-1°)</td>
<td>SFF</td>
</tr>
<tr>
<td>SM benchmarks</td>
<td>(\gamma (B \rightarrow DK))</td>
<td>(-25°)</td>
<td>(-2°)</td>
<td>(-1°)</td>
<td>Negligible</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>(\beta (B_d \rightarrow J/\psi K_s))</td>
<td>1°</td>
<td>0.2°</td>
<td>0.1°</td>
<td>(-0.1°)</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>(\beta (B_d \rightarrow D \pi^+ \pi^-))</td>
<td>Unmeasured</td>
<td>1°</td>
<td>0.2°</td>
<td>Negligible</td>
<td>None</td>
</tr>
<tr>
<td>NP in Bs mixing</td>
<td>(\beta_s (B_s \rightarrow J/\psi \phi))</td>
<td>20°</td>
<td>0.3°</td>
<td>(\leq 0.1°)</td>
<td>(-0.1°)</td>
<td>None</td>
</tr>
<tr>
<td>CPV in charm</td>
<td>(A_r (D \rightarrow KK))</td>
<td>25 \cdot 10^{-4}</td>
<td>3 \cdot 10^{-4}</td>
<td>0.7 \cdot 10^{-4}</td>
<td>(-10^{-4})</td>
<td>None</td>
</tr>
</tbody>
</table>
Probe New Physics in

- Is there NP in $B_s^0 - \bar{B}_s^0$ mixing?
  - $B_s \rightarrow J/\psi\phi$ is golden mode at hadron colliders
  - Very precise SM prediction for small weak phase $\phi_s = -2\beta_s$
  - $\phi_s(J/\psi\phi) = -0.0368 \pm 0.0017$

- Current Results
  - From CDF and D0
  - Prefer non-zero $\phi_s$

- Weak Limits on new physics
  - Weak phase in $B_s$ mixing $\phi_s$ is not well measured yet
  - New Physics could be around the corner!

Re($\Delta_q$) + iIm($\Delta_q$) = $\frac{B^0|H^{\text{full}}|\bar{B}^0}{B^0|H^{\text{SM}}|\bar{B}^0}$
Prospects with $B_s \rightarrow J/\psi\phi$

- **Probe New Physics**
  - In box diagrams

- **Expected Sensitivity**
  - Yield: 117k in 2 fb$^{-1}$
  - $\sigma(\phi_s) \sim 0.07$ with 1 fb$^{-1}$

- **Exciting Prospects**
  - If $\phi_s$ at Tevatron central value
  - LHCb will make 5$\sigma$ discovery of new physics in this run

- **Additional measurements**
  - CP-eigenstate
    $B_s \rightarrow J/\psi f_0(980)$,
    $f_0(980) \rightarrow \pi^+\pi^-$

  - Precision required to establish $\phi_s = 0.7$ at 5$\sigma$

- **Probe New Physics**
  - in penguin diagrams
  - Best mode $B_s \rightarrow \phi\phi$

25 - 29 May 2010

FPCP, Torino, Italy
Prospect with $B_s \to \mu^+\mu^-$

- **Expected Sensitivity**
  - 200 pb$^{-1}$ to improve upon expected Tevatron limit with 8fb$^{-1}$
  - 3 fb$^{-1}$ for $3\sigma$ evidence and
  10 fb$^{-1}$ for $5\sigma$ observation of SM value @ 14TeV
Prospects with $B \rightarrow K^\ast \mu \mu$

With 1 fb$^{-1}$ LHCb expects 1200 events with $q^2 < 6$ GeV$^2$
At Belle central value, SM could be excluded at 4$\sigma$
$B^+ \rightarrow J/\psi K^+$ candidate

21 April 2010: LHCb observes first reconstructed Beauty Particle

All Observables far from cut values

XY Projection

Tracks from primary vertex

Primary vertex

$B^+ \rightarrow J/\psi K^+$, $J/\psi \rightarrow \mu \mu$

FPCP, Torino, Italy

25 - 29 May 2010
Probe New Physics in CP

Sensitivity with 10 fb$^{-1}$  Do we need 100 fb$^{-1}$?

- **NP in box diagrams**
  - $\phi_s$ from $B_s \rightarrow J/\psi \phi$  
    $\sigma(\phi_s) \sim 0.010$  
    $\sigma_{\text{theor}} \sim 0.002$  
    Yes

- **NP in hadronic penguins**
  - $\Delta S(\phi\phi)$ from $B_s \rightarrow \phi\phi$  
    $\sigma(\Delta S(\phi\phi)) \sim 0.05$  
    Yes
  - $\Delta S(\phi K_S)$ from $B_d \rightarrow \phi K_S$  
    $\sigma(\Delta S(\phi K_S)) \sim 0.10$  
    $\sigma_{\text{theor}} \sim 0.01$  
    Yes

- **NP in radiative penguins**
  - Photon polarisation in $B_s \rightarrow \phi \gamma$  
    $\sigma(A^{\Delta\Gamma}) \sim 0.09$  
    $\sigma(A^{\text{mix}}) \sim 0.05$  
    $\sigma_{\text{theor}} \sim 0.01$  
    Yes
Probe NP in Rare Decays

Sensitivity with 10 fb^{-1} | Do we need 100 fb^{-1}?
---|---
- NP in electroweak penguins
  - \(B_s \rightarrow K^*\mu\mu\) \(\sigma(A_T^{(2)}) \sim 0.16\) Yes
  - \(B_s \rightarrow \mu\mu\) \(>5\sigma\) observation if SM Yes
  - \(B_d \rightarrow \mu\mu\) - Yes

- Charm Physics
  - \(D^0 \rightarrow K\pi, KK, \pi\pi\) CP asymmetries Yes
  - \(D^0 \rightarrow K\pi\pi, KK\pi\pi\) \(A_T(D^0 \rightarrow KK) < 10^{-4}\) Yes

- Lepton Flavour Violation
  - \(\tau \rightarrow \mu\mu\mu\) \(BR \sim O(10^{-8})\) Yes

F. Muheim
**Probe New Physics in $B \rightarrow K^* \mu \mu$**

- **Asymmetries**
  - Excellent laboratory to explore NP
  - Sensitive to Wilson Coefficients C7 to C10, SUSY with low tan beta, 4th generation
  - SM predictions have small errors
  - Plots are for 10 fb-1
  - Blue band: SUSY model with large gluino mass, green band: SM

- **LHCb Upgrade**
  - Allows to discriminate between different NP models

F. Muheim

Egede et al., arXiv:0807.2589
**The VErtex LOcator**

- Present VELO has to be replaced (radiation)
- Precise measurement of the vertices
  - Aim is pattern recognition for the trigger
- The baseline is VELOPix, based on Medipix/TimePix readout chip
  - 256x256 pixels, 55μm square
  - 3 side buttable chip
  - TSV (Through Silicon Via) → dead side may be reduced to 0.8mm (Medipix3)

- Benefit from the 3D information
  - Less combinatorial for tracking reconstruction
  - Very low occupancy of the detector
  - But very high data rate (15Gbit/s/chip)
Rich (+TOF)

- Rich HPD tied to 1MHz readout → must be replaced
- Baseline candidate is the MA-PMT (Hamamatsu)
  - 8x8 pixels (of 2.0x2.0 mm²)
  - Characterisation of the chip shows good properties
    - Single photon response,
    - Uniformity,
    - Cross-talk,
    - Dark current.
  - Behaviour under magnetic field still to be checked
  - Temperature
- A front-end electronics is being designed
  - Target is
    - no pile-up (25ns)
    - Low consumption
- TOF (Torch)
  - TOF measurement could be coupled to the RICH for PID
  - 1 cm thick quartz plate at z=12m
  - 30ps resolution
  - Probably for the second upgrade phase
Electronics and readout completely re-design to permit readout @ 40MHz

- The events are zero-suppressed / packed at the front-end level
- The GBT technology is used to send the data from the FE to the readout syst.
- The readout boards are common to all the sub-detectors
- A throttling mechanism (Calo/Muon/Farm) is implemented to cope with
  - A staged DAQ which cannot handle the full rate
  - Unexpected high occupancies which prevent a full readout
Tracking

- Running at $2 \times 10^{33}$ is not acceptable for the present Outer tracker
  - Too high occupancy
  - Decide to limit the luminosity to $10^{33}$ for phase I of upgrade (2016)

- Still the OT electronics has to be changed to cope with the 40MHz readout
  - First prototypes are being designed

- Two options are still envisaged for the ST (TT and IT)
  1. Si options
     - Keep the existing modules unchanged
       - Need re-equip them with an upgraded electronics
       - Development of a new rad-hard FE chip @ 40MHz
     - Build new modules identical to the existing ones
  2. Fiber option
     - Several layers of scintillating fibers
     - Light collections with SiPM
     - Electronics is out of the acceptance (rad. tolerance)
     - First simulations show equivalent performances as Si
     - Requires important R&D but several labs are interested
Calorimeter and Muon system

- The front-end electronics of the calorimeter to be replaced (40MHz readout)
  - The PMT have to be operated at lower gain
  - The electronics will compensate but need to maintain the same noise as before
    - 2 directions: ASIC and discrete components → prototype being delivered
  - The L0 uses calo information (40MHz)
    - Plan is to keep on providing this to the farm to help software trigger (seeds)

- Radiation tolerance of the calorimeter inner modules
  - 2 modules irradiated at Protvino (Russia) and 2 other in the LHC tunnel

- Muon front-end electronics can basically be kept (already @ 40MHz)
  - The M1 chamber should be removed (background and upgraded L0)
  - The interface to the common readout has most probably to be adapted
  - The muon system should provide information to the throttling mechanism
    - Based on the present L0
### SuperKEKB Parameters as of Feb.15, 2010

<table>
<thead>
<tr>
<th>Parameter</th>
<th>KEKB Design</th>
<th>KEKB Achieved: with crab</th>
<th>SuperKEKB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (GeV) (LER/HER)</td>
<td>3.5/8.0</td>
<td>3.5/8.0</td>
<td>4.0/7.0</td>
</tr>
<tr>
<td>Crossing angle (mrad)</td>
<td>22</td>
<td>0 (crab)</td>
<td>83</td>
</tr>
<tr>
<td>$\beta y^*$ (mm)</td>
<td>10/10</td>
<td>5.9/5.9</td>
<td>0.27/0.41</td>
</tr>
<tr>
<td>$\varepsilon x$ (nm)</td>
<td>18/18</td>
<td>18/24</td>
<td>3.2/2.4</td>
</tr>
<tr>
<td>$\sigma y$ (µm)</td>
<td>1.9</td>
<td>0.94</td>
<td>0.059</td>
</tr>
<tr>
<td>$\xi y$</td>
<td>0.052</td>
<td>0.129/0.090</td>
<td>0.09/0.09</td>
</tr>
<tr>
<td>$\sigma z$ (mm)</td>
<td>4</td>
<td>~ 6</td>
<td>6/5</td>
</tr>
<tr>
<td>$I_{\text{beam}}$ (A)</td>
<td>2.6/1.1</td>
<td>1.64/1.19</td>
<td>3.6/2.62</td>
</tr>
<tr>
<td>Number of bunches</td>
<td>5000</td>
<td>1584</td>
<td>2503</td>
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<tr>
<td>Luminosity (10^34 cm^-2 s^-1)</td>
<td>1</td>
<td>2.11</td>
<td>80</td>
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</table>

Parameters presented at KEKB MAC Review Feb.15-17, 2010
# SuperKEKB Main Ring schedule

<table>
<thead>
<tr>
<th></th>
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<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Beam operation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>MR commissioning</strong></td>
</tr>
<tr>
<td><strong>Tunnel clear</strong></td>
<td>Remove magnets and beam pipes</td>
<td>Base plates</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Beam pipes (LER_wiggler)</strong></td>
<td>Fabrication</td>
<td>TiN coating</td>
<td></td>
<td></td>
<td>Install</td>
</tr>
<tr>
<td><strong>Beam pipes (LER_arc)</strong></td>
<td>Design</td>
<td>Fabrication TiN coating</td>
<td>Install</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Beam pipes (HER_arc)</strong></td>
<td>Design</td>
<td>Fabrication</td>
<td></td>
<td>Install</td>
<td></td>
</tr>
<tr>
<td><strong>Magnets &amp; Power supplies</strong></td>
<td>Design / Fabrication</td>
<td>Field measurement Install Cabling / Check</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>Beam monitors and Control</strong></td>
<td>R&amp;D / Fabrication</td>
<td>Test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>RF reinforcement</strong></td>
<td>Layout change / Add stations / Cavity improvements</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>IR hardware</strong></td>
<td>QCS R&amp;D</td>
<td>QCS fabrication</td>
<td></td>
<td>Install &amp; test</td>
<td></td>
</tr>
</tbody>
</table>

K. Akai KEKB Review Feb.2010
Cost estimation

1 (Oku-Yen) = 1.1 M USD = 0.8 M EUR (as of 12 Feb, 2010)

<table>
<thead>
<tr>
<th>Components</th>
<th>Cost (Oku-Yen)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linac upgrade and Damping Ring</td>
<td>31</td>
<td>e+ matching and L-band acc., RF-gun and laser system, Damping Ring components</td>
</tr>
<tr>
<td>Vacuum System</td>
<td>135</td>
<td>beam pipes (ante-chambers, electrodes, etc), pumps and other vacuum components for 3km x 2 rings</td>
</tr>
<tr>
<td>Magnet System</td>
<td>93</td>
<td>magnets, power supplies, cables</td>
</tr>
<tr>
<td>IR upgrade</td>
<td>20</td>
<td>QCS and other hardware</td>
</tr>
<tr>
<td>RF System</td>
<td>25</td>
<td>add 9 RF stations, improve cavities (coupler, HOM damper)</td>
</tr>
<tr>
<td>Beam monitor and control</td>
<td>32</td>
<td>BPM, SRM, feedback, control system, etc.</td>
</tr>
<tr>
<td>Belle upgrade</td>
<td>14.7</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>350.7</td>
<td></td>
</tr>
</tbody>
</table>

1 Cost for DR tunnel construction is not included in the list. Also cost for buildings and facilities for Linac, DR and MR is not included. These costs are about 30 Oku-Yen in total.

1 This list is what went to MEXT last year. According to recent estimation, cost for some components increases, but some others decrease.
SuperB Bullet points

- It is part of the European Strategy Forum on Research Infrastructures (ESFRI) forward look.
- SuperB is the #1 science priority for INFN.
- It is #1 flagship of the Italian National Research Plan.
- It has been endorsed by the Italian Science and Economy Ministry.
- Two possible funding streams: either as part of the Italian National Research Plan or stimulus package.
- Currently waiting for approval from cabinet committee.
- MOU's have been signed between France, Russia and US; letter of support from Canada.
- Berlusconi and Putin signed a joint agreement of mutual financial support of a fusion reactor research in Moscow and the SuperB project in Italy in May.
- Agreement between INFN/IN2P3 to hire people before approval.
- Likely to be one of the first European Research Infrastructure Consortiums, ERIC (no VAT).
- Time-scale: 5-6 years (based on Belle and BaBar experience) from approval.
- Site: Either Roma 2 University Camps at Tor Vergata or Frascati INFN site.
- Cost: ~700M€.
- 15 M€ already pledged by Lazio regional government.
- White Paper and CDR for Physics, Detector, Accelerator and Computing due out this month.
SuperB Bullet points

Accelerator:
• Design already reviewed by Machine Advisory Committee (MAC).
• Copious B, D and tau production (>10^{10} of each type per year).
• 80% polarized e- beam (important for LFV couplings in tau decays).
• Can run at energies from the Ψ(3770) to Υ(6S) and energies in between (g-2).
• Can achieve 100 x CLEO-c luminosity in 2 months.
• INFN needs accelerator physicists and has money to pay them.

Detector:
• UK contributing to design for INMAPS pixel silicon vertex detector (NIM paper in preparation).
• Many other possibilities. Highlights:
  - Forward PID: Focusing, TOF RICH.
  - Drift Chamber: Cluster counting could improve dE/dx by factor 2-3.
  - Forward Calorimeter: fast LYSO crystals
  - Trigger and DAQ: new design. Cannot reuse LHC design as some sub-detectors have high latency.
  - Muon Chamber: LSTs

Computing:
• LHC-like computing requirements. Need to log 25KHz of 75Kbyte events (~3 PetaBytes/year).
• Simulations running on the Grid.
• RAL and QMUL already contributing to production.
• Opportunity to design the complete system.
SuperB: Physics

- See white paper for details (on archive soon)
- Operate between Charm threshold and \( \Upsilon(6S) \).
- Is a Super-CLEO/B/\(\tau\)-charm (and more) rolled into one!

\[ \text{Precision CKM} \]

- All angles of UT: \( \alpha, \beta, \gamma \)
- |\(V_{us}\)|, |\(V_{ub}\)|, |\(V_{cb}\)|, |\(V_{ts}/V_{td}\)|

\[ \text{B & D CPT Violation} \]

\[ \text{CP Violation} \]

\[ \text{LFV} \]

\[ \text{Precision EW: } e.g. \sin^2\theta_W \]

\[ \text{Exotica (A0, DM, ...)} \]

\[ \text{Spectroscopy} \]

\[ \text{All areas are related to new physics} \]

Complementary impact on LHC physics in many areas.
SuperB: Physics

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B & D

CPT Violation

Polarisation

LFV

CP Violation

Exotica (A0, DM, ...)

Spectroscopy

Precision CKM

\(|V_{us}|, |V_{ub}|, |V_{cb}|, |V_{ts}/V_{td}|\)

Precision EW: e.g. \( \sin 2\theta_W \)

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Complementary impact on LHC physics in many areas.
Some examples
Kaons

- NA62-Phase I has produced a very precise measurement of $K_e^2/K_\mu^2$ ratio, which is currently in agreement with SM but shows a 1.5 sigma tension. Birmingham is leading this analysis.
- CERN NA62-Phase II ($K^+ \rightarrow \pi^+\nu\nu$) is progressing well. The aim is still to take first data at the end of 2012, but possibly with an incomplete detector for the first 6 months or so.
- UK (Birmingham, Bristol, Glasgow, Liverpool) involvement is on hold until the financial situation improves. Still, UK is progressing with conceptual design of modifications needed for the CEDAR detector (used to identify kaons in the beam line).
- JPARC KOTO ($K^0 \rightarrow \pi^0\nu\nu$) is approved & progressing. Expect first data taking Autumn 2011 & reach SM prediction sensitivity in 3 years.
- FNAL P996 proposed for $K^+ \rightarrow \pi^+\nu\nu$ with stopped kaons in target. Expecting $\sim$200 events/year, but not yet approved.
Lepton Flavour Violation

- We know that charged lepton flavour violation must occur (from neutrino oscillations)
- $\mu$FV experimental limits can be improved by several orders of magnitude, beyond many BSM predictions
- MEG ($\mu \rightarrow e + \gamma$, running since 2008 at PSI)
  - $<3 \times 10^{-11}$ in 2009; sensitive to $10^{-13}$ by 2013
- Muon-to-Electron Conversion (aim: factor 10,000 improvement, to $<10^{-16}$)
- COMET (J-PARC)
  - Stage-1 approval (of 2 stages) July 09
  - J-PARC preparatory work progressing
    - good inter-bunch extinction found in observations at the J-PARC Main Ring beam
- Mu2E (Fermilab)
  - CD0 at Fermilab in November 09
  - Tracker/Cosmic Veto/Extinction Monitor R&D this year
COMET/PRISM R&D

- COMET Prototype (MUSIC)
  - World’s first superconducting pion capture solenoid at Osaka
  - Part of wider programme of study with UK involvement
  - 2 UCL PG students on-site

- COMET Technical Design Report (in Preparation)
  - UK contributing design studies, software development, editorial leadership

- PRISM FFAG Task Force (Next Generation Muon-to-Electron Conversion)
  - International team (8 UK institutes) led by J Pasternak (Imperial/RAL)
  - Major synergies with UK programme
  - Progress in Injection/extraction, new lattice possibilities for scaling & non-scaling FFAGs, dispersion matching and kicker designs
  - CDR forthcoming