Flavour Factories
-a personal view-

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What are “factories”?

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• Some energy frontier machines also function as or even become “factories”.
Physics of “factories”

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  - determination of the Standard Model parameters
  - comparison with the Standard Model predictions to search for deviations in rare and forbidden processes
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• Expected physics performance can be well predicted, for given accelerator and detector performances.
A lucky example in the past

• B factories (KEKB and PEP II)
  – With all the data available, observed CPV phenomena in the kaon system, described by a single complex parameter, $\varepsilon_K$, were “compatible” with the SM, but could not exclude that CPV was outside of the SM.
  – Large uncertainties for the SM prediction for CPV in $B \rightarrow J/\psi K_S$ decays (little idea on $m_t$ till late 80’s)
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Unitarity triangle in early 1990's

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“If the SM is the origin of CPV, an asymmetric B factory with $L \approx 10^{33}$ cm$^{-2}$s$^{-1}$ CPV in $B \to J/\psi K_S$ should be observed within a few years of data taking.”: **a strong justification!**
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And now: experiments improved but theory changed a lot as well….

CPV in $J/\psi K_S$ not too different

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• Expected physics performance can be well predicted, for given accelerator and detector performances.

• Primary goal is not look for “new particles”.
Factories provide

An alternative approach to experiments at high energy frontier machines: muon as an example
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An alternative approach to experiments at high energy frontier machines: muon as an example

- Class-A: undetectably small effect from the known physics,
  - Lepton flavour violating muon decays: $\mu \rightarrow e \gamma$: due to the neutrino oscillation $\Rightarrow Br \sim 10^{-54}$
  - Current limit $Br < 4.2 \times 10^{-13}$ (90% CL) (MEG)
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- Class-B: A discrepancy with the SM prediction
  - $\mu(g-2)$ (PDG 017, E821)

$$\Delta a_\mu = a_\mu^{\text{exp}} - a_\mu^{\text{SM}} = 268(63)(43) \times 10^{-11}$$

Improvements in both theory and experiment needed
Other on going examples

- **Class-A:**
  - Electric dipole moment: n, p, atoms, nuclei, e, μ
    (if seen only for hadron, could be due to strong CPV)
  - Lepton number violating processes in μ (μ→eγ, μ→e)
  - Lepton number and lepton flavour violation in b-, c- and s-hadron decays (intriguing phenomena in B decays)
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  – Deviation from the weak interaction Lorentz structure in semileptonic b-hadron decays (intriguing phenomena in B decays)
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  – Consistency test of the unitarity triangle
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Experimental progress makes a migration of A to B
An example of A to B migration

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- LHCb observation:
  
  $$CPV(D^0 \rightarrow K^-K^+) - CPV(D^0 \rightarrow \pi^-\pi^+) = (-1.57 \pm 0.29) \times 10^{-3}$$

"4.3\times10^7 KK  
1.7\times10^7 \pi\pi  
PRL2019"
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  - NB: CPV in $D^0 \rightarrow h^- h^+$ (h=K or \(\pi\))
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    = \text{CPV in } D^0 \leftrightarrow \bar{D}^0 \text{ + in } A_{h^- h^+} + \text{interplay of the two}
    \]
  - from the known properties of $D^0 \leftrightarrow \bar{D}^0$,
    if CPV(KK) $\neq$ CPV(\(\pi\pi\)), then due to CPV in $A_{h^+ h^-}$

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- In agreement with the SM predictions:
  now this becomes Class-B search: precisions in both experiments and theory becomes necessary
Present “factories”

- **PSI** p beam: \( \pi, n, \mu \)
- **FNAL** p beam: \( \mu, \nu \)
- **J-PARC** p beam: \( K, \mu, \nu \)
- **SPS (CERN)** p beam: \( K \)

- **VEP2000** \( e^+e^- \)
  \( \rho, \omega, \phi, \ldots \)
- **BEPC** \( e^+e^- \)
  \( D, \tau \)
- **VEP4M** \( e^+e^- \)
- **SuperKEKB** \( e^+e^- \)
  \( B, D, \tau \)
- **DAFNE** \( e^+e^- \)

Accelerator originally constructed as high energy frontier machine

Accelerator constructed as a “factory”

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New factories bing discussed

- Super-Tau-Charm factories: \( L \approx 10^{35} \text{ cm}^{-2}\text{s}^{-1} \)
  - BINP (Novosibirsk): approved but construction not funded, R&D
  - High Intensity Electron-Positron Accelerator in China: TDR in preparation, R&D
  (c.f. current BEPC II \( \sim 10^{33} \text{ cm}^{-2}\text{s}^{-1} \). No of D’s not more than LHCb or SuperKEKB but complementary and diversified programme)
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• $e^+e^-$ Higgs Factories
  – Circular options: CECP (CN), FCC-ee (CERN)
  – Linear options: ILC (JP), CLIC (CERN)
Circular option

- High luminosity
- Also super Z and W factories
- High energy pp collider could be installed later
- Initial cost would be high

Linear option

- Longitudinal beam polarizations
- Statistics for Z and W less than a circular option
- Extension to higher energies possible
- Initial cost would be lower than a circular option

Within the uncertainties of uncertainties, performance in the Higgs coupling measurements are comparable (Class-B case), while for, e.g., rare decays (Class-A case), luminosities do matter.
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No longer with a moderate cost: decision will have a profound impact on the community and field
And don’t forget

- LHC and HL-LHC also a factory: c, b, τ, t, W, Z, H
- There will be upgrades of
  - existing accelerators,
    - BEPC luminosity upgrade (IHEP), PIP-II (FNAL), possible SuperKEKB upgrade (polarization)?,…
  - beam lines
    - PSI new muon beam line (HIMB) for $10^{10}$ DC $\mu^+$/sec,…
  - and experiments
    - Many plans and ideas …

A cost effective way for the diversity, which is needed now in the field and should be exploited.
Final remarks

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• We have not yet the Standard Model of New Physics. A guidance from “flavour physics” is seriously required and interests in “flavour physics” are rapidly expanding, with many interesting ideas (as seen in this conference).
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• And we need to support “factories” for those activities.
Since I am the last speaker...

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• Thanks to the participants, in particular the hardcore ones who stayed till the end
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- Thanks to the participants, in particular the hardcore ones who stayed till the end
- And have a safe trip back home!