

Flavour Physics at LHC and B factories

PLHC 2011: Physics at LHC
Perugia, Italy, 6-11 June 2011

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EPFL-LPHE
Lausanne, Switzerland



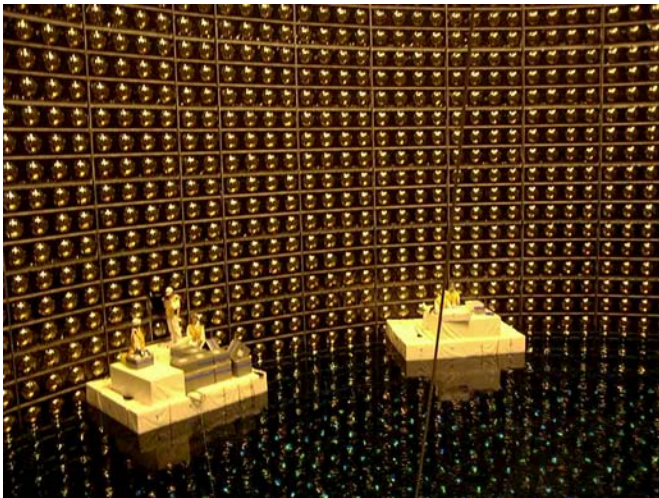
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- There exists solid observations for physics beyond the Standard Model

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Neutrino oscillations

S-KAMIOKANDE



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Dark matter

Bullet Galaxy Clusters



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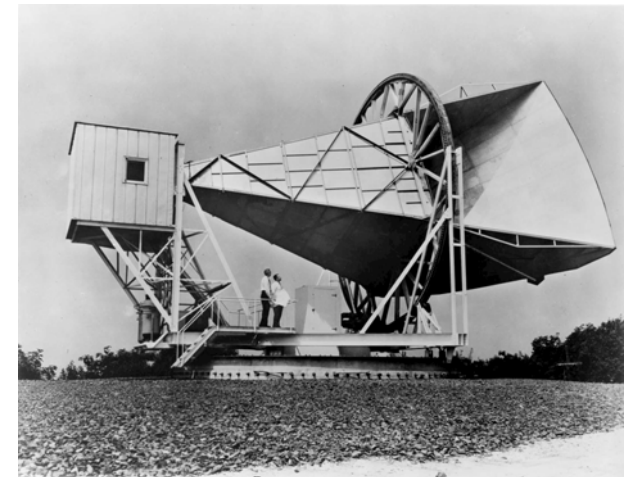
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$$N_B / N_\gamma = 10^{-10}$$

The Horn Antenna
Bell Telephone Laboratory



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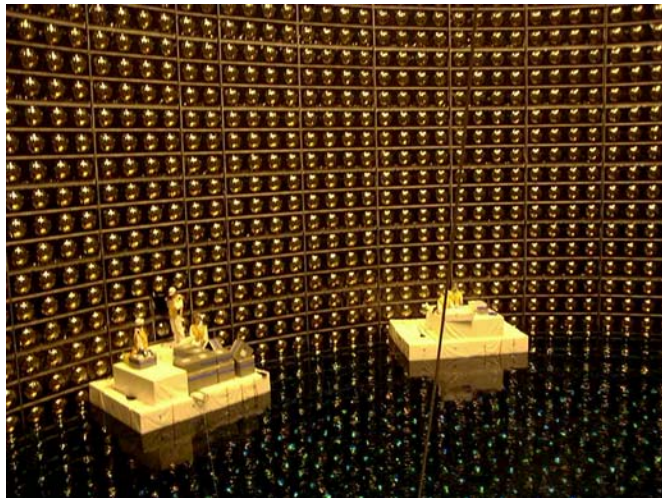
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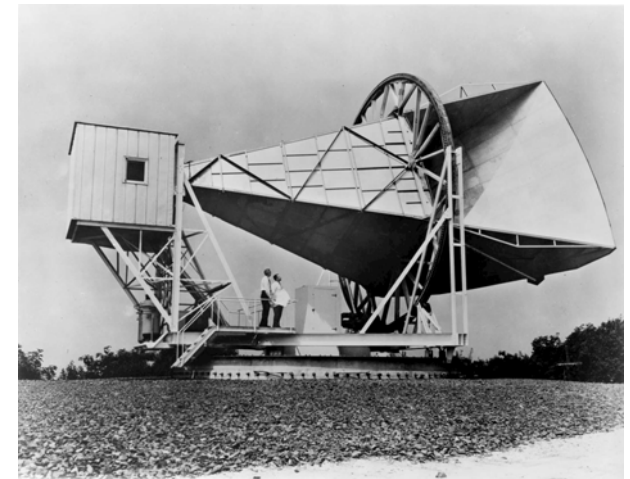
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also more philosophical/theoretical/esthetical arguments...

Introduction (II)

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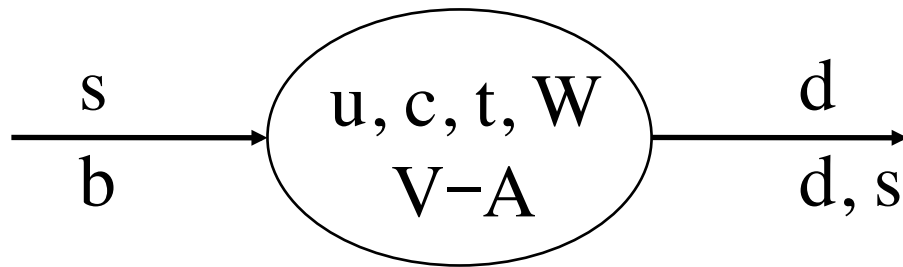


The hope is, once new particles were discovered at LHC, then LC would be built to make detailed studies.

- But there exists a complementary approach...

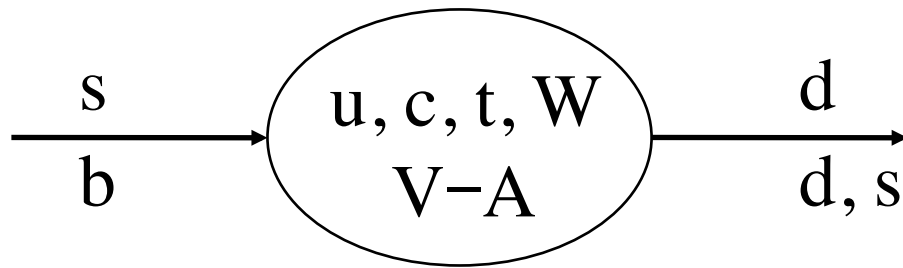
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$\Delta s = 1$ $s \rightarrow d$: K decay with u or d as a spectator

$\Delta s = 2$ $s \rightarrow d$: K^0 - \bar{K}^0 oscillations

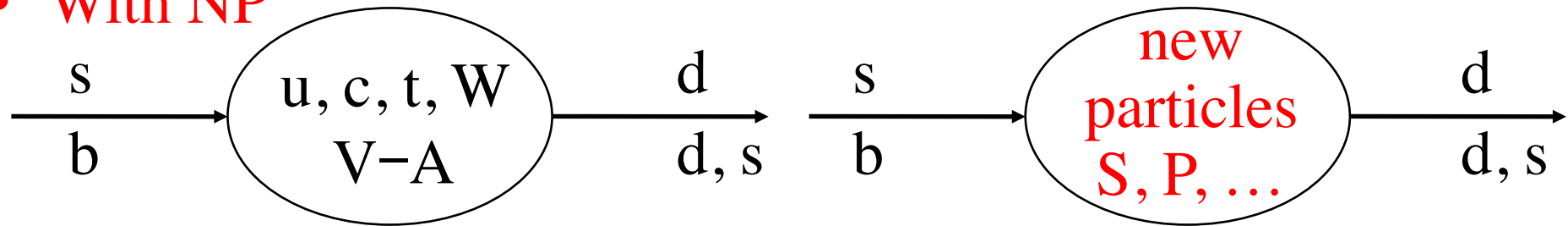
$\Delta b=1$ $b \rightarrow s$: and $b \rightarrow d$ B decays with u, d, and c as a spectator

$\Delta b=2$ $b \rightarrow s$: B_s - \bar{B}_s oscillations $b \rightarrow d$: B^0 - \bar{B}^0 oscillations

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- With NP**

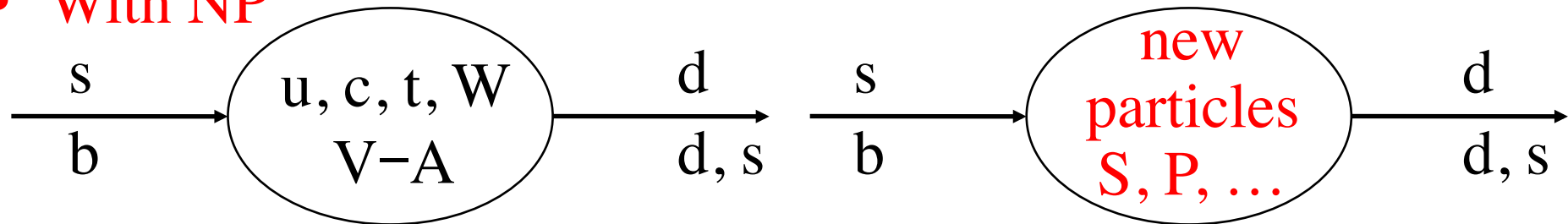


amplitude: $A = A_{\text{SM}} + A_{\text{NP}}$ for Δs or $\Delta b = 1$ and 2

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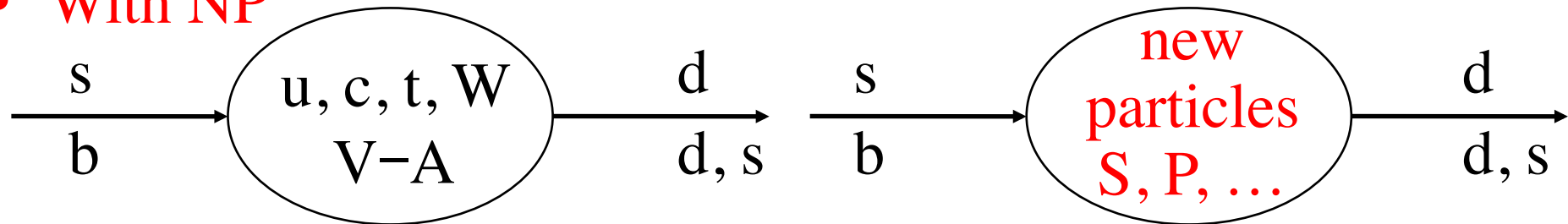
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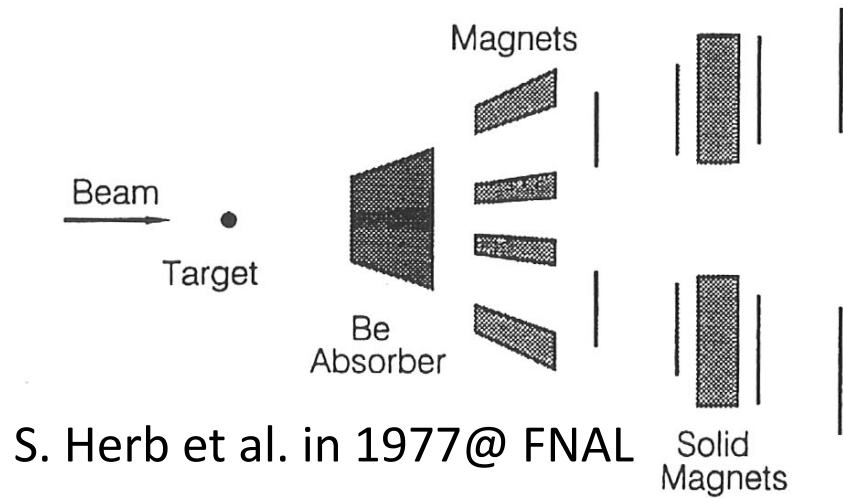
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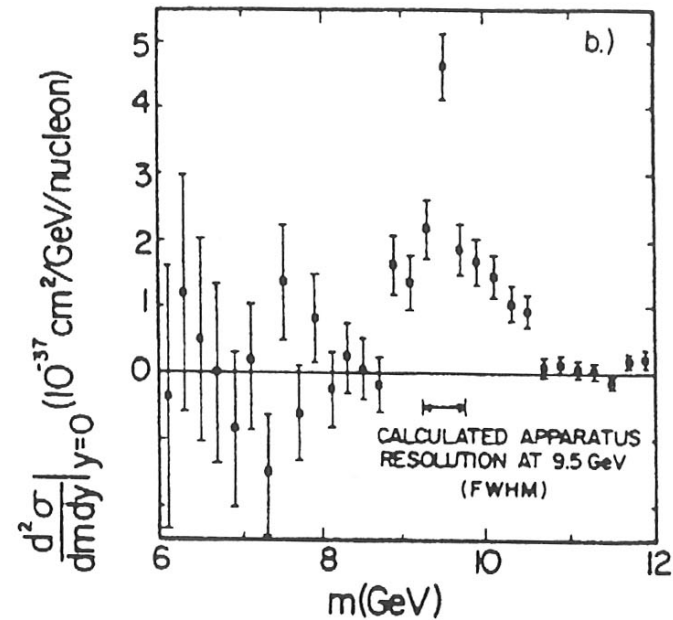
(NP could appear also in the tree level but A_{SM} is usually large)

Hadron machine to start,

- First discovery of b-quark by a fixed target experiment

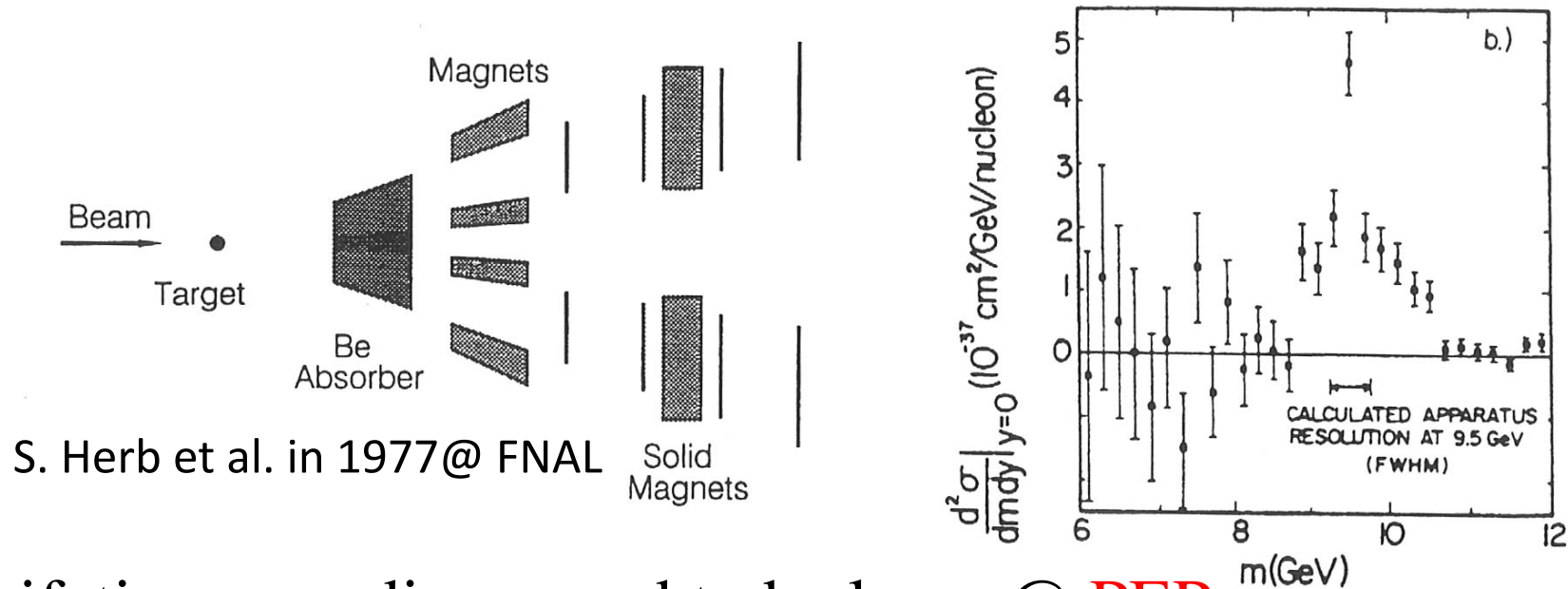


S. Herb et al. in 1977@ FNAL



Hadron machine to start, then...

- First discovery of b-quark by a fixed target experiment



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- Lifetime was discovered to be large @ **PEP**

Theoretical prejudice:

e.g. V. Barger et al. $0.8 \times 10^{-14} < \tau < 1.4 \times 10^{-13}$ s, J. Phys. G5, L147 (1979)

MAC: Phys. Rev. Lett. 51, (1983) 1022

Mark II: Phys. Rev. Lett. 51, (1983) 1316

b lifetime is $\sim 10^{-12}$ sec, $|V_{cb}| \sim 0.05$, i.e. $\ll \sin\theta_{\text{Cabibbo}} \sim 0.2$

Successful stories at $Y(4S)$ I

- DORIS-II @ DESY ARGUS experiment
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– $B_d-\bar{B}_d$ oscillations giving $\Delta m_d \approx 100 \times \Delta m_K: m_t > 50 \text{ GeV}/c^2$
(NB, top was considered to be just around the corner, $\sim 50 \text{ GeV}$, in
80's UA1, PEP, PETRA, TRISTAN) ARGUS: Phys. Lett. B, 192 (1987) 245

Δm_d and ε_K allowed m_t independent SM prediction for

~~CP~~ in $B^0 \rightarrow J/\psi K_S$ Z. Phys. C 36 (1987) 503

\Rightarrow setting a bench mark luminosity of $\text{few} \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$

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for B-factory ideas in 90's to really test \cancel{CP} in the SM
- And stimulated theory community how to extract $|V_{ij}|$

Successful stories at Y(4S) II

- PEP-II @ SLAC BABAR experiment
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KEKB @ KEK Belle experiment
with a notable discovery
 - \cancel{CP} in $B_d \rightarrow J/\psi K_S$ as expected from the $|V_{ij}|$ measurements and ϵ_K :
Validation of the KM mechanism to be the major source for
 \cancel{CP} in particle physics
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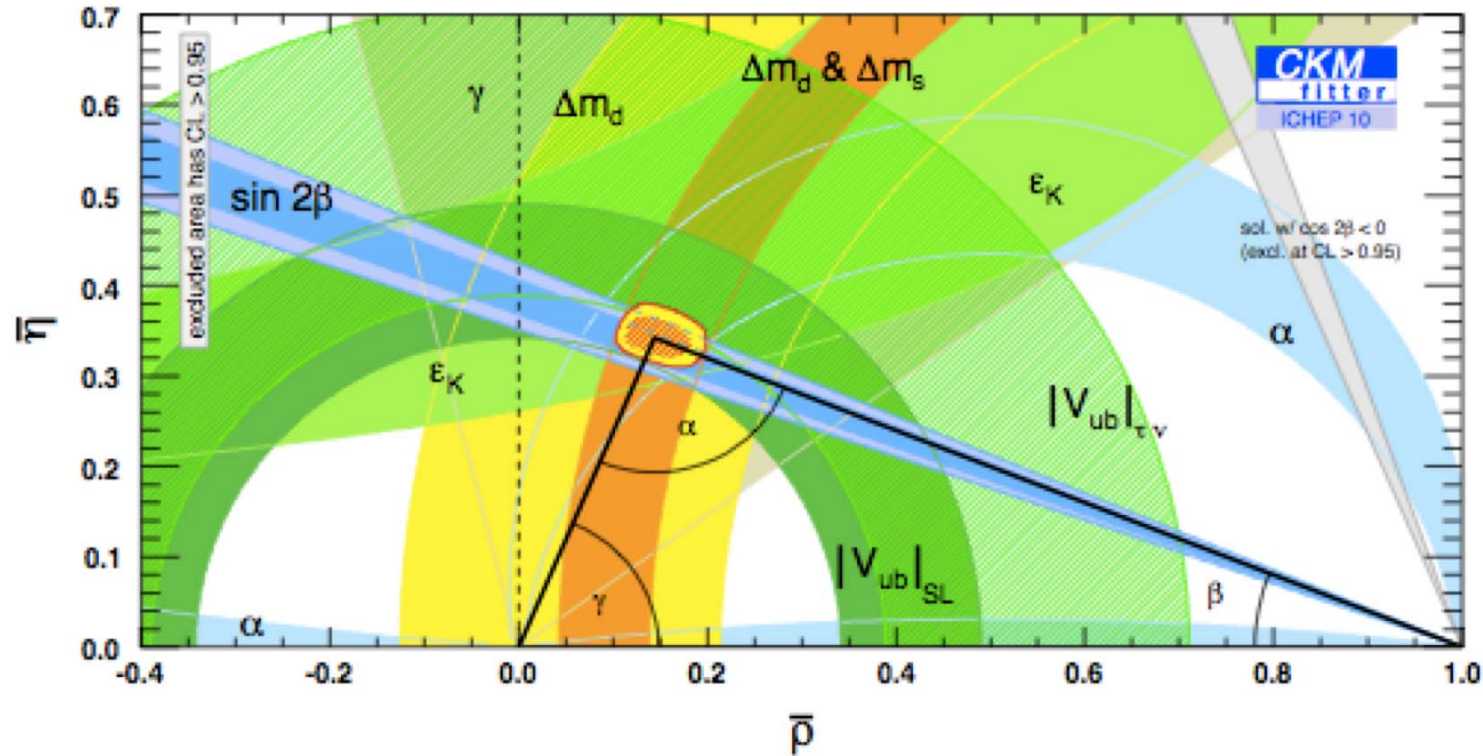
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- And a very comprehensive study of Flavour Structure with B_d and B_u mesons **establishing the complete Flavour Structure of the Standard Model**. CP violation is no longer “special”! They also made an exploratory work in B_s , **excellent contributions for establishing D- \bar{D} oscillations**, spectroscopy of “exotic” charm particles, and rare τ decay studies.

Some contributions from the LEP experiments as well.

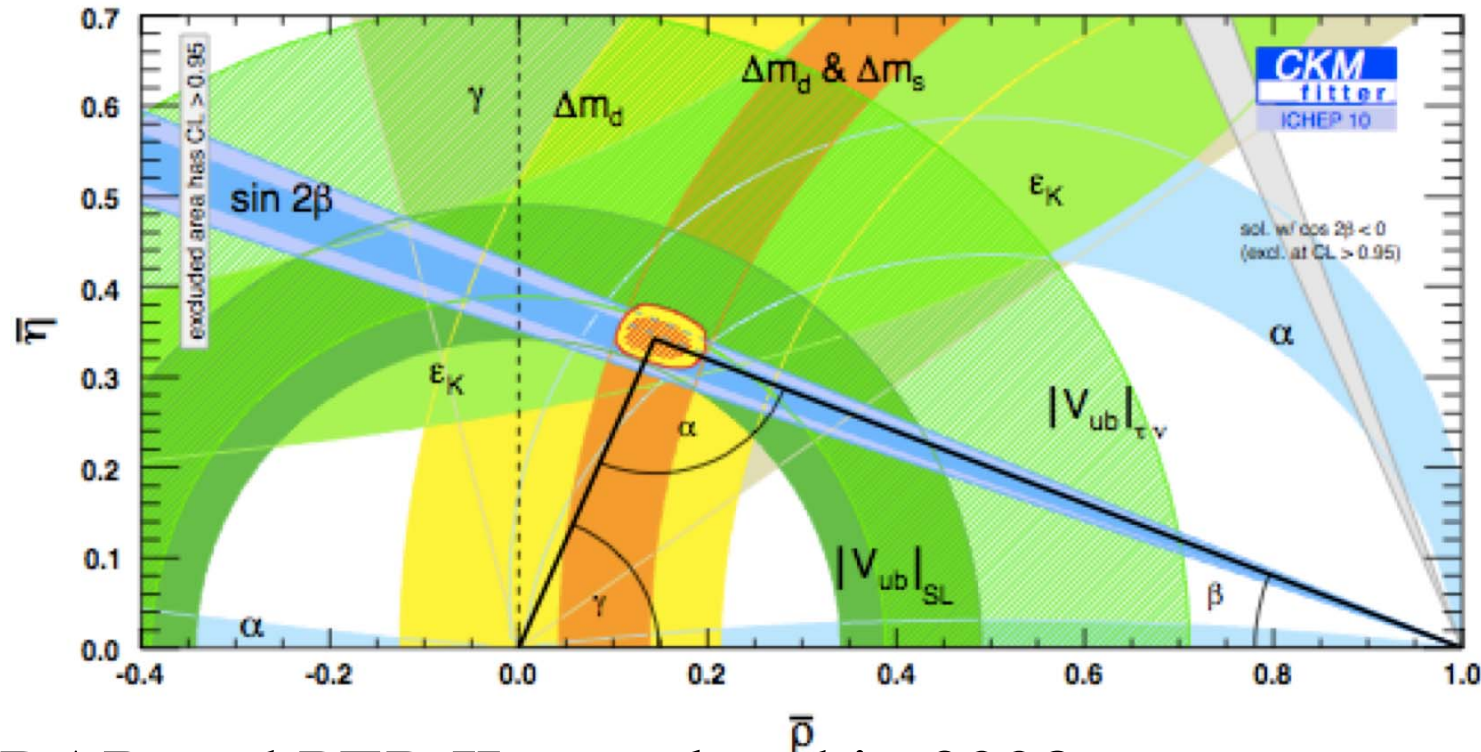
Successful stories at Y(4S) II

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Successful stories at Y(4S) II

- All input from B factories, except ε_K and Δm_s



- BABAR and PEP-II completed in 2008
 Belle and KEKB completed in 2010
 with a total of $\sim 1.2 \text{ ab}^{-1}$ data, i.e. $\sim 1.3 \times 10^9 \text{ B}\bar{\text{B}}$!
 → Looking forward to seeing many key results with full statistics data in the coming conferences.

PEP-II and KEKB

	PEP-II		KEKB	
	High E-beam	Low E-beam	High E-beam	Low E-beam
Energy [GeV]	9.0	3.1	8.0	3.5
Beam current [A]	1.9	3.0	1.3	1.7
Bunch current [mA]	1.1	1.7	1.0	1.2
ϵ_x [nm]	48	24	24	18
$\sigma_x(\text{IP})/\sigma_y(\text{IP})$ [μm]	155 / 4.2		110 / 1.9	
beam-beam x	0.059	0.009	0.070	0.117
beam-beam y	0.074	0.058	0.056	0.110
Crossing angle [mr]	0		± 11	
Peak L [$10^{34}\text{cm}^{-2}\text{s}^{-1}$]	1.2		1.7	

PEP-II = high current and head-on collision

KEKB = small beam and crossing angle collision

$\int L dt @ Y(4S)$ is somewhat higher for KEKB: 720 fb^{-1} (800 M $B\bar{B}$)

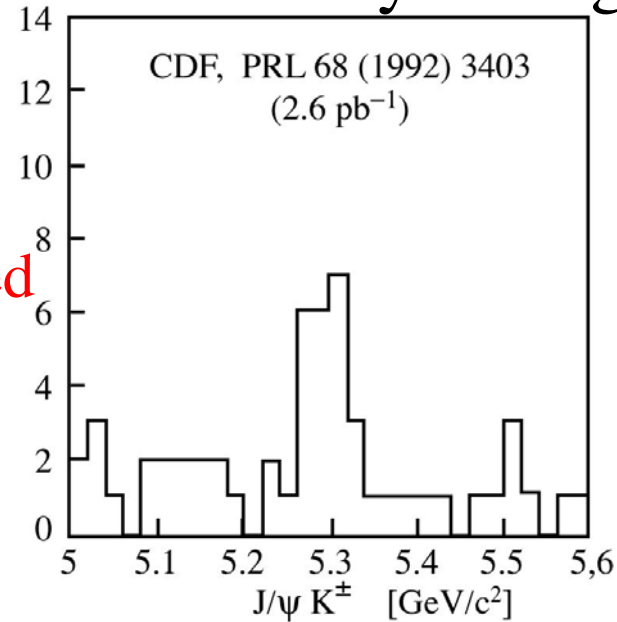
Very comparable physics achievements by BELLE and BABAR

(KEKB achieved $2.1 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ with crab crossing and less beam current in 2009)

Contribution from the hadron machine

- fixed target contribution had been marginal: i.e. σ_{bb}
- Tevatron showed its potential already during Run I, thanks to large σ_{bb}

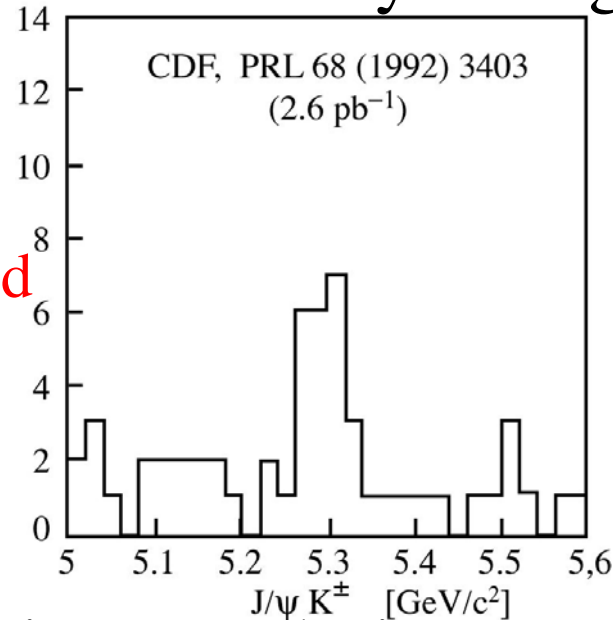
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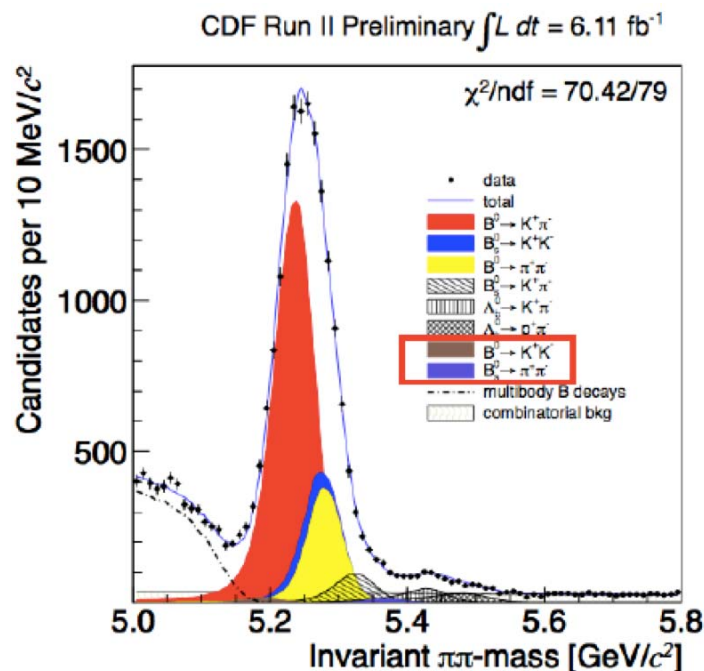
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- But significant contributions are during Run II: due to improved L , good vertex detectors, and trigger (DCF): b-baryon spectroscopy, lifetimes, $B_s - \bar{B}_s$ oscillation (Δm_s), and \mathcal{CP} in $B \rightarrow J/\psi \phi$, \mathcal{CP} in $B_s - \bar{B}_s$ oscillations, $B^0 \rightarrow K^{*0} \mu^+ \mu^-$, $B_s \rightarrow \mu^+ \mu^-$, and D physics... see talk by P. Squillacioti

Contribution from the hadron machine

- CDF and D0 demonstrated that
 - Exclusive b-hadron decay modes (with charged particles, including semileptonic decays) can be well reconstructed
 - b-baryon and B_s : very unique and B_s oscillation can be resolved
 - B_d : for some decay modes as good as B factories or even better



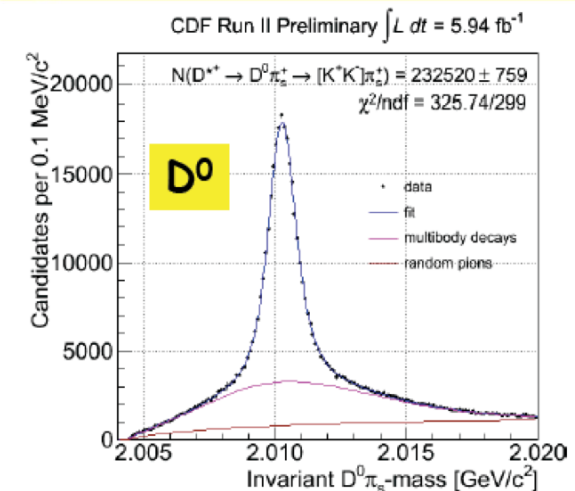
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CDF-Pub-10296

$$A_{CP}(D^0 \rightarrow \pi^+ \pi^-) = [+0.22 \pm 0.24 \pm 0.11]\%$$

$$A_{CP}(D^0 \rightarrow K^+ K^-) = [-0.24 \pm 0.22 \pm 0.10]\%$$



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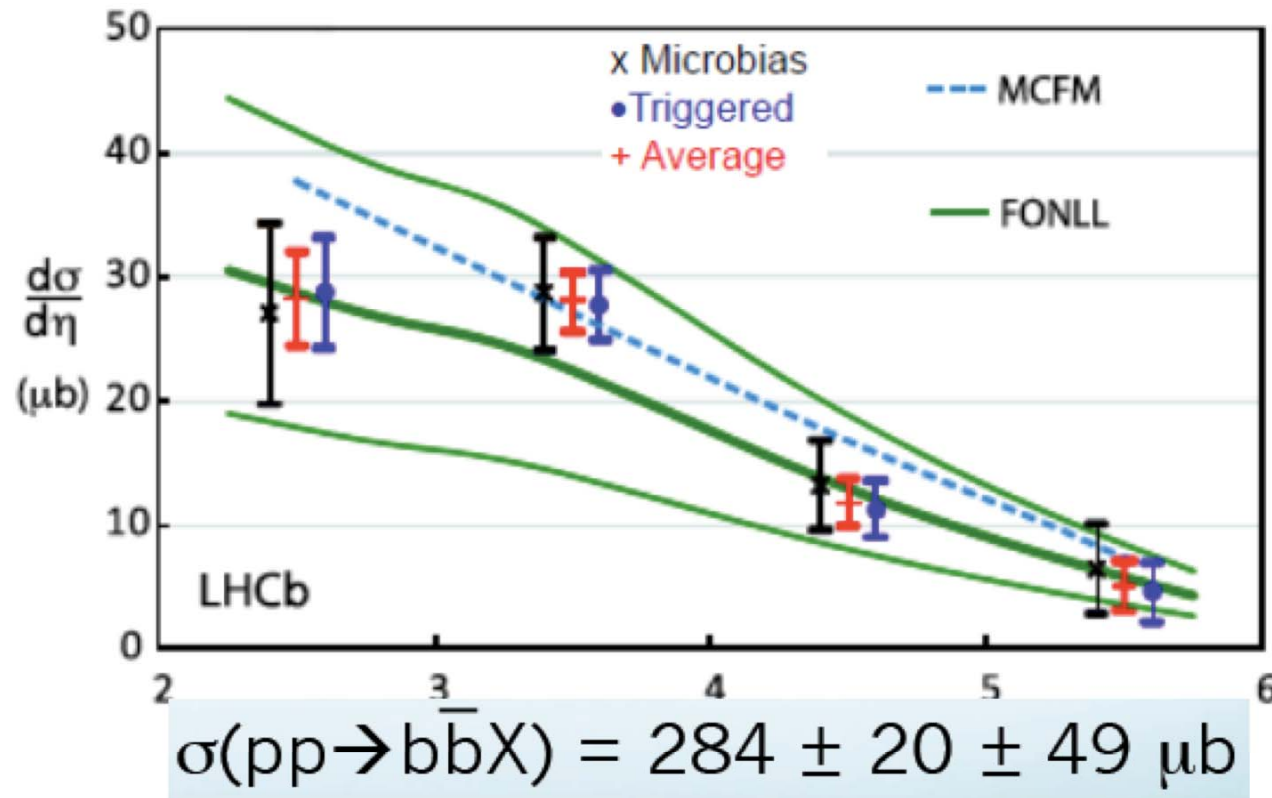
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- CDF and D0 will stop data taking this year with $\sim 10 \text{ fb}^{-1}$ /experiment. More results will come with improved sensitivities, but most probably not enough to unambiguously establish new effect

But LHCb has started

- May results with 2010 data, $\sim 36 \text{ pb}^{-1}$, detector performance and B yields very close to the expectation

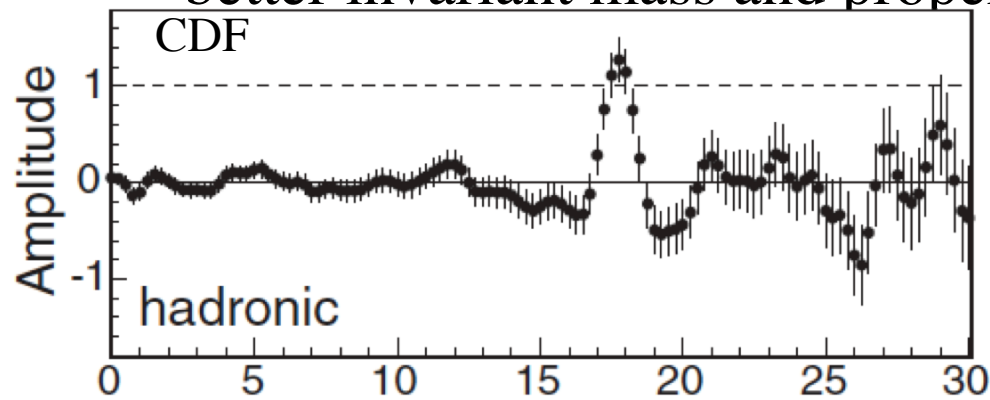
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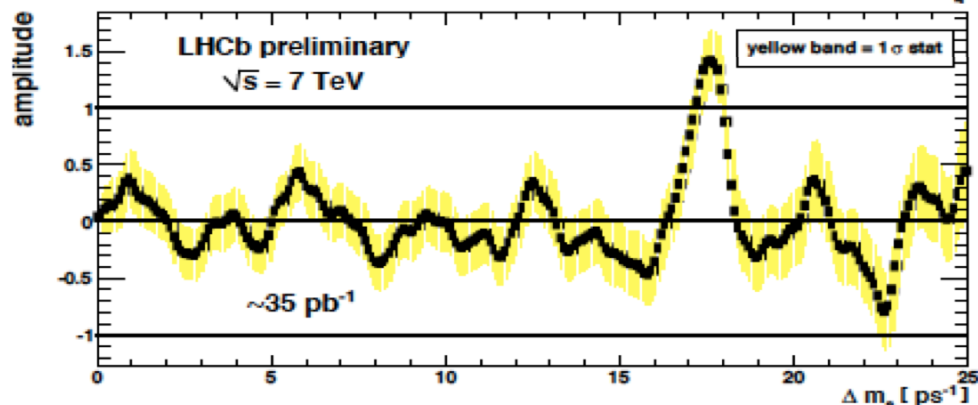


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 - better invariant mass and proper time resolutions



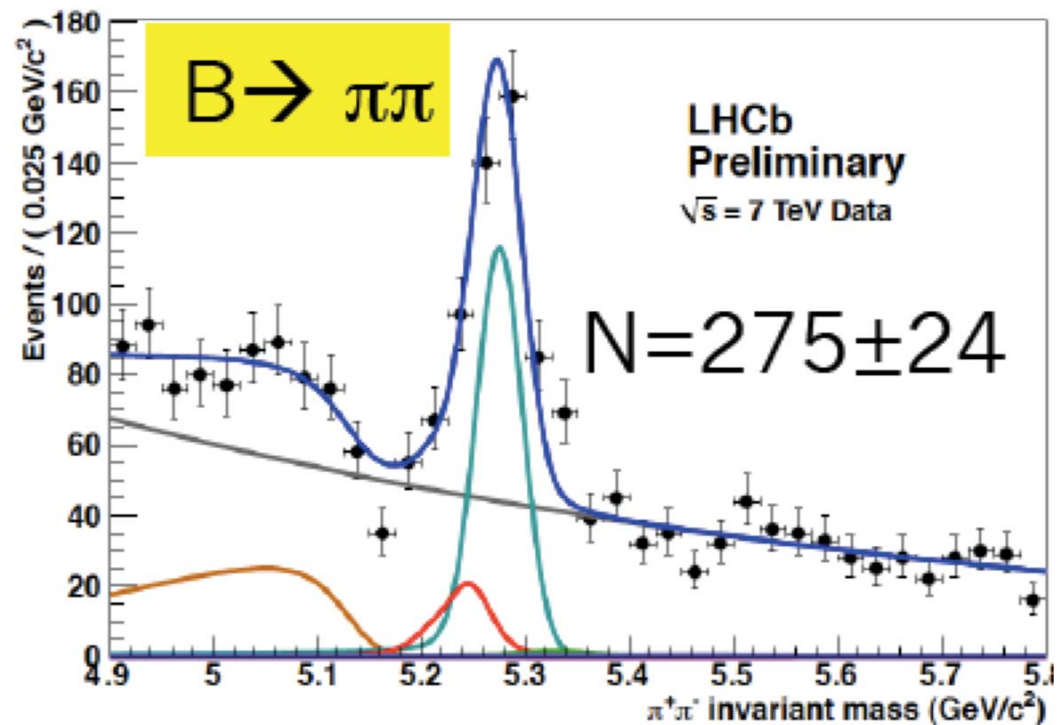
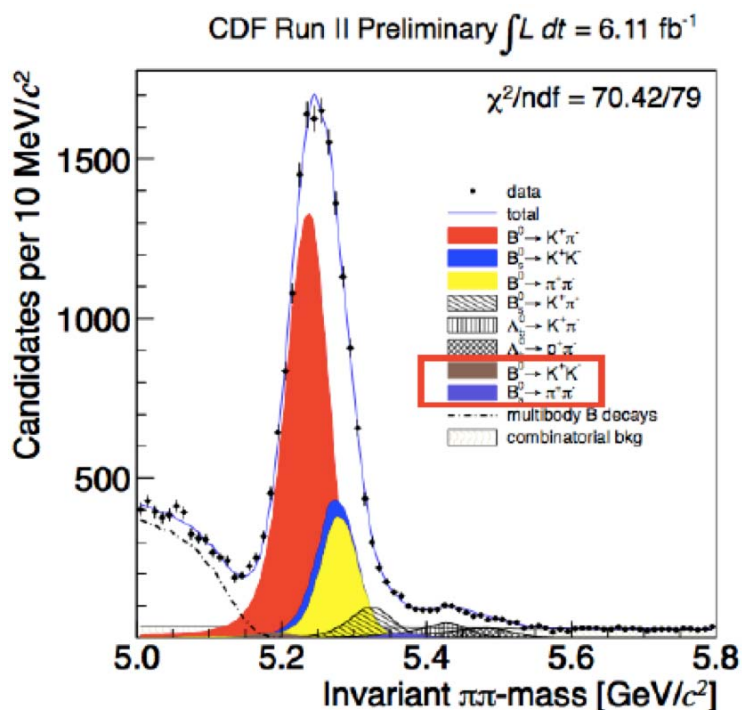
CDF: $\Delta m_s = 17.77 \pm 0.10 \pm 0.07 \text{ ps}^{-1}$
5600 signal, $\sigma_\tau = 87 \text{ fs}$



LHCb: $\Delta m_s = 17.63 \pm 0.11 \pm 0.04 \text{ ps}^{-1}$
1350 signal, $\sigma_\tau = 36 \text{ or } 44 \text{ fs}$

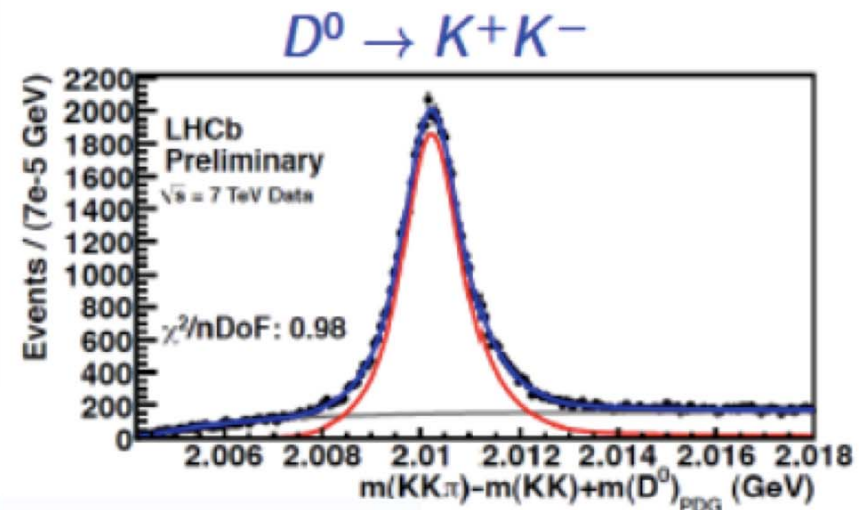
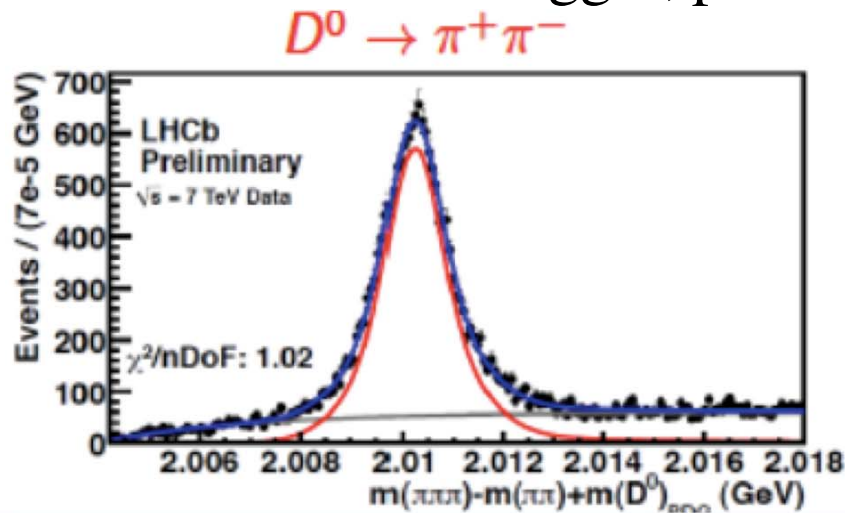
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 - hadron PID
 - more efficient trigger, particularly for hadronic final states



$$\Delta A_{CP} = A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-) = A_{CP}^{\text{raw}}(K^+K^-) - A_{CP}^{\text{raw}}(\pi^+\pi^-)$$

$$= (-0.28 \pm 0.70 \pm 0.25)\%$$

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 - more efficient trigger, particularly for hadronic final states
- Hope to catch-up and even overtake CDF and D0 by the summer 2011.

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- An evidence of Low mass Higgs and/or SUSY candidates at below ~ 1 TeV with ATLAS/CMS?

LHC by the end of 2012 (my own view)

- An evidence of Low mass Higgs and/or SUSY candidates at below ~ 1 TeV with ATLAS/CMS?
- LHCb will correct $\gtrsim 2 \text{ fb}^{-1}$ of data
 - Exclude NP physics contribution to $B_s \rightarrow \mu^+ \mu^-$ up to a level of SM (currently up to ~ 10 times SM) or find an evidence of NP
 - CPV in $B_s \rightarrow J/\psi \phi$ to be measured with $\sigma(\phi_s) \approx 0.1$ (current most probable value ~ -0.6 but less than 2σ effect and SM expectation -0.036 ± 0.002)
 - A_{FB} for $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ with $\sim 2\text{k}$ events. (currently ~ 400 events with all experiments. With the current value $> 5\sigma$ deviation from SM expected where q^2 between 1 to 6 GeV^2)
 - CP asymmetry in $D \rightarrow hh$ decays to a level of 10^{-3}
 - CP asymmetry $\sigma(B \rightarrow K\pi) = 4 \times 10^{-3}$ (current world average 0.01), $\sigma(B_s \rightarrow \pi K) = 0.025$ (CDF will be ~ 0.047)

LHCb by the end of 2017 (my own guess)

- LHCb will correct $> 5 \text{ fb}^{-1}$ of data
assuming data taking in 2015-2017 before the LHC upgrade shutdown
Close to the proposed final precisions could be achieved:
- From LHCb we will know
 - $\sigma_{2\beta_s} \approx 0.02$
 - $\sim 20\%$ accuracy measurement of SM $\text{Br}(B_s \rightarrow \mu^+ \mu^-)$
 - With $> 5\text{k } K^{*0} \mu^+ \mu^-$, A_{BF} and complete decay angular distribution analysis.
 - $\sigma_\gamma = 2 \sim 3^\circ$
 - ~~CP~~ in $B_s \rightarrow \phi\phi$, $B_s \rightarrow \phi\gamma$, $D \rightarrow K^+ K^- \rightarrow \pi^+ \pi^-$ ($< 10^{-3}$) and many other decay modes

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- There is an intention then to upgrade LHCb to implement full software trigger scheme for working at ~ 5 times higher L , with much enhanced efficiency for hadronic decay modes: SLHCb. Could start taking data in ~ 2020

And also

- KEK has started to upgrade their B factory: SuperKEKB
 - low energy ring dismantled, high energy ring reused
 - damping ring construction started
 - BELLE in parking position and all the inner detectors dismantled
 - hope to get back the beams by ~2015
 - $L_{\text{design}} = 0.8 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}$, 50 ab^{-1} by 2020~2021

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- Recently, Italian government decided to allocate 250 M€ over 5 years to INFN to build a Super B-factory
 - Site has been decided@the Univ. of Rome Tor Vergata, ~4.5 km from the Frascati Laboratory, “green field” now.
 - Organization being worked out: proposed name “Cabibbo Laboratory”
 - Reuse PEP-II components
 - $L_{\text{design}} > 10^{36} \text{ cm}^{-2}\text{s}^{-1}$ with polarization, start ~2016, 75 ab^{-1} in 2021

“LHC” vs “B Factories”

- Inclusive processes are unique to “B factories”
exclusive $B\bar{B}$ state with one B fully reconstructed
very hermetic detector (smaller boost would be better)

SM predictions tend to be cleaner for
inclusive processes.

At LHC:
too many additional particles
and
too small detector acceptance

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very hermetic detector (smaller boost would be better)
 - $b \rightarrow s(d) + g, +\gamma, +Z^0$: inclusive $X_{s(d)}, X_{s(d)} + \gamma$
 - $b \rightarrow u(c) + W^-$: inclusive $X_{u(c)}, X_{u(c)} l^- \nu$

SM predictions tend to be cleaner for inclusive processes.

- $b \rightarrow s(d) + Z^0$: exclusive hadrons + $\nu\bar{\nu}$ final states: e.g. $K\nu\bar{\nu}$
- $B \rightarrow \tau\nu$: currently slightly larger than the SM prediction and cannot be studied by LHCb ($B \rightarrow D^*\tau\nu$ could be an alternative?)

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large B_s production and excellent decay time resolution

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large B_s production and excellent decay time resolution
 - CPV in oscillations using hadronic final states, equivalent to “ a_{SL} ”
 - Oscillation-decay induced CPV: $J/\psi\phi$
 - $b \rightarrow s(d)+g, +\gamma, +Z^0$:
exclusive final states: hadronic, semileptonic and radiative
 $b \rightarrow s$: $\phi\phi, \phi l^+ l^-, \phi\gamma$ $b \rightarrow d$: $\phi K_S, K^{*0} l^+ l^-, K^{*0}\gamma$
 - $b \rightarrow u(c)+W^-$: exclusive hadronic and semileptonic decays
($b \rightarrow d$ may deserve more attention?)

“LHC” vs “B Factories”

- Time dependent studies of B_s decays are unique to “LHC”
large B_s production and excellent decay time resolution
 - CPV in oscillations using hadronic final states, equivalent to “ a_{SL} ”
 - Oscillation-decay induced CPV: $J/\psi\phi$
 - $b \rightarrow s(d)+g, +\gamma, +Z^0$:
exclusive final states: hadronic, semileptonic and radiative
 $b \rightarrow s$: $\phi\phi, \phi l^+ l^-, \phi\gamma$ $b \rightarrow d$: $\phi K_S, K^{*0} l^+ l^-, K^{*0}\gamma$
 - $b \rightarrow u(c)+W^-$: exclusive hadronic and semileptonic decays
- With triggerless-readout and a CPU based online filter farm, statistics on exclusive decays with charged hadrons for B_u, B_d, B_s and D at LHC would likely to be higher than those at “super” B factories.

Slowly to conclude

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- LHCb may soon have somewhat lonely few years. Hopefully the two big brothers will soon inject some stimulation.
- By ~ 2017 LHCb would achieve the best results in many areas including CPV in D decays, except inclusive decay modes and decays such as $B \rightarrow \tau \nu$, $B \rightarrow \pi^0 \pi^0$

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- Italian government allocated 250 M€ for INFN to construct Super B Factory in a green field. The site has been selected to be Tor Vergata.
- Both projects aim at starting with beams in 2016, achieving 50 to 75 fb^{-1} by 2021, respectively.

Very exciting period has started!



Photos by
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