Experimental Summary

Katarzyna Klimek
ICHEP2002: Subjective Experimental Summary...

- Neutrino masses & mixing
- Quark matter
- Astrophysics & cosmology
- Electroweak physics
- QCD: hard interactions
- QCD: soft interactions
- CPV & CKM matrix
- Heavy quark hadrons
- Spectroscopy & exotics
- Beyond Standard Model
- Computational QFT
- String & math. QFT
- Future accel. & detectors

What to wear, what to wear?
CP Violation

talks by:
T.Baker, Y. Karyotakis, G. Unal, D. Wright, M. Yamauchi
Direct CPV in Kaon System: $\varepsilon' / \varepsilon$

$$R \equiv \frac{\Gamma(K_L \rightarrow \pi^0 \pi^0) \Gamma(K_S \rightarrow \pi^+ \pi^-)}{\Gamma(K_S \rightarrow \pi^0 \pi^0) \Gamma(K_L \rightarrow \pi^+ \pi^-)} = 1 - 6 \text{Re}(\varepsilon' / \varepsilon)$$

**NA31**: $(23.0 \pm 6.5) \times 10^{-4}$

**E731**: $(7.4 \pm 5.9) \times 10^{-4}$

**KTeV**: $(20.7 \pm 2.8) \times 10^{-4}$

(Preliminary)

**NA48**: $(14.7 \pm 2.2) \times 10^{-4}$

**World average**: $\varepsilon' / \varepsilon = (16.6 \pm 1.6) \times 10^{-4}$

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CP Violation: dominated by BaBar & Belle

**CKM Matrix**

\[
\begin{pmatrix}
    d' \\
    s' \\
    b'
\end{pmatrix} =
\begin{pmatrix}
    V_{ud} & V_{us} & V_{ub} \\
    V_{cd} & V_{cs} & V_{cb} \\
    V_{td} & V_{ts} & V_{tb}
\end{pmatrix}
\begin{pmatrix}
    d \\
    s \\
    b
\end{pmatrix}
\]

\( V^\dagger V = I \), and quark phases \( \Rightarrow 4 \) parameters

\[
\begin{bmatrix}
1 - \frac{1}{2} \lambda^2 & \lambda & A\lambda^3 (\rho - i\eta) \\
-\lambda & 1 - \frac{1}{2} \lambda^2 & A\lambda^2 \\
A\lambda^3 (1 - \rho - i\eta) & -A\lambda^2 & 1
\end{bmatrix} + O(\lambda^4)
\]

**Unitarity Triangle**

\[V_{ud} V_{ub}^* + V_{cd} V_{cb}^* + V_{td} V_{tb}^* = 0\]

**All angles related to \( \eta \) and \( \rho \)**

New physics, ex: coupling between super–symmetric and SM fields introduce new phases which may reshape UT

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$\sin^2 \beta = 0.755 \pm 0.074$

$\sin^2 \beta = 0.723 \pm 0.158$

$\eta_{cp} = -1$

$\eta_{cp} = +1$

$\sin^2 \beta = 0.741 \pm 0.067 \text{ (stat)} \pm 0.033 \text{ (syst)}$

$|\lambda| = 0.948 \pm 0.051 \text{(stat)} \pm 0.017 \text{ (syst)}$
New result of $\sin 2\phi_1$ -
BELLE–CONF–0201 (ABS688)

Belle, preliminary

$\sin 2\phi_1 =$

$= 0.719 \pm 0.074 \pm 0.035$

|\lambda|=0.950 \pm 0.049 \pm 0.026

Coherent picture of CP Violation in SM

No direct CPV signal yet

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The CKM people at work......

talks by:
M. Battaglia, A. Stocchi

H. Bosch  Players of GO
V_{cb} = (40.9 \pm 0.8) \times 10^{-3}

V_{ub} \text{ – work continues}

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Oscillations in B System

The probability that the meson $B^0$ produced (by strong interaction) at $t = 0$ transforms (weak interaction) into $\overline{B}^0$ (or stays as a $B^0$) at time $t$ is given by:

$$P_{B_q^0 \rightarrow B_q^0 (\overline{B}_q^0)} = \frac{1}{2} e^{-t/\tau} \left(1 \pm \cos \Delta m_q t\right)$$

$\Delta m_q$ can be seen as an oscillation frequency: $1 \text{ ps}^{-1} = 6.58 \times 10^{-4} \text{ eV}$

$$\frac{\Delta m_d}{\Delta m_s} \propto \frac{f_{B_d}^2 B_{B_d}}{f_{B_s}^2 B_{B_s}} \lambda^2 \left((1-\rho)^2 + \eta^2\right)$$

$\Delta m_d / \Delta m_s$ performant contraint for $\rho$ and $\eta$
Many new measurements: 4 from Belle and 3 from Babar

- **Hadronic** $\Delta m_d = 0.528 \pm 0.017 \pm 0.011 \text{ ps}^{-1}$
- **$D^*\pi$ partial** $\Delta m_d = 0.505 \pm 0.017 \pm 0.020 \text{ ps}^{-1}$
- **$D^*\psi$** $\Delta m_d = 0.494 \pm 0.012 \pm 0.015 \text{ ps}^{-1}$
- **Dileptons** $\Delta m_d = 0.503 \pm 0.008 \pm 0.009 \text{ ps}^{-1}$

Preliminary
$\Delta m_d = 0.498 \pm 0.013 \text{ ps}^{-1}$

LEP/SLD/CDF (2.6 %)

B–factories precision by a factor 2

$\Delta m_d = 0.503 \pm 0.006 \text{ ps}^{-1}$

LEP/SLD/CDF/B–factories: 1.2 %

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Measurement of $A$ at each $\Delta m_s$

At given $\Delta m_s$

$A = 0$ no oscillation

$A = 1$ oscillation

$\Delta m_s$ excluded at 95%CL

$A + 1.645\sigma_A < 1$

$P_{B^0 \rightarrow B^0_s (B_s)} = \frac{1}{2} e^{-t/\tau_s} (1 \pm A \cos \Delta m_s t)$
Constrains of UT

Constraints: \( V_{ub}, V_{cb}, \varepsilon_K, \Delta m_d, \Delta m_s, \sin 2\beta \)

\[
\begin{align*}
\rho & = 0.203 \pm 0.040 \\
\eta & = 0.335 \pm 0.027 \\
V_{cb} & = (40.4 \pm 0.8) \times 10^{-3} \\
\sin 2\beta & = 0.734^{+0.045}_{-0.034} \\
\gamma & = (59.5^{+6.5}_{-5.5})^\circ \\
\sin 2\alpha & = -0.20^{+0.23}_{-0.20} \\
\Delta m_s & = 17.6^{+2.0}_{-1.3} \text{ ps}^{-1}
\end{align*}
\]
Welcome to the world of charm and beauty

H. Bosch (1504)
The garden of Earthly Delights

Heavy Quark
Hadrons

talks by A. Stocchi, M. Yamauchi
New Results on Charmed Baryons

$\Xi^0_c \rightarrow \Xi^- \pi^+$ and $\Omega^- K^+$

$\tau(D^+) / \tau(D^0) = 2.53 \pm 0.02$
$\tau(D_s^-) / \tau(D^0) = 1.19 \pm 0.02$
$\tau(\Lambda_c) / \tau(D^0) = 0.49 \pm 0.01$
$\tau(\Xi^+_c) / \tau(\Lambda_c) = 2.11 \pm 0.14$

$\tau(\Omega_c) / \tau(\Xi^0_c) = 0.72 \pm 0.13$

in baryonic sector
expected hierarhy

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**BABAR**

$\bar{J}/\psi K_S^0 (\pi^\pm \pi^\mp)$

**BABAR 88 MB**

$B \bar{K}^+ \pi^-$

**BELLE**

$\phi K_S$ ($\pi^- K^+$)

$D_{S}^+ \pi^-$

$B^0 \rightarrow D^{(*)} D^{(*)} K$

**BABAR**

$\sigma S \ell^+ \ell^-$

**BELLE**

$\rho^+ \rho^0$

$M_{bc}$ (GeV)}
Measurement of $B \otimes X_S l^+ l^-$ model independent probe for new physics

$X_S : K^\pm$ or $K_S$ with 0~4 $\pi$'s (0 or $1\pi^0$) covers ~78% of $b \otimes sll$.

$B( B \otimes X_S l^+ l^- )$

$= (6.1 \pm 1.4^{+1.3}_{-1.1}) \times 10^{-6}$

for $M_{ll} > 0.2$ GeV/$c^2$
$M_{ll}$ and $M(X_S)$ distributions

Mass spectra assumed in MC

Model by A.Ali et al.

in agreement with SM
Beyond the Standard Model

talk by R. McPherson

LEP
Tevatron
HERA
Example: Leptoquark Limits

Q = 1/3, \( \text{BR}(LQ \rightarrow q\bar{q}) = 1/2 \)

LEP Indirect

HERA Indirect

HERA Direct

Tevatron Pair Prod.

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Multi-Lepton H1 Results

<table>
<thead>
<tr>
<th>selection</th>
<th>Data</th>
<th>SM</th>
</tr>
</thead>
<tbody>
<tr>
<td>2e $M &gt; 100$</td>
<td>3</td>
<td>$0.25 \pm 0.05$</td>
</tr>
<tr>
<td>3e $M &gt; 100$</td>
<td>3</td>
<td>$0.23 \pm 0.04$</td>
</tr>
</tbody>
</table>
Multi-Lepton ZEUS Results

ZEUS: 94–00, 130 pb$^{-1}$

<table>
<thead>
<tr>
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<th>SM</th>
</tr>
</thead>
<tbody>
<tr>
<td>2e $M &gt; 100$</td>
<td>2</td>
<td>$0.77 \pm 0.08$</td>
</tr>
<tr>
<td>3e $M &gt; 100$</td>
<td>0</td>
<td>$0.37 \pm 0.04$</td>
</tr>
<tr>
<td>Both</td>
<td>2</td>
<td>$1.14 \pm 0.09$</td>
</tr>
</tbody>
</table>

$\Rightarrow$ Good agreement with SM

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Searches for SM Higgs

still one particle of SM missing

1.7 \sigma excess (P=8\%) over expected SM background
One experiment (ALEPH, 2.8-3.0 \sigma), one channel (qqbb)
Final LEP-2 SM Higgs-boson mass limit (95\% C.L.):
M_{Higgs} > 114.4 \text{ GeV} \quad \text{(expected limit: 115.3 GeV)}
Do We Live in Perfect SM EW World?

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**NuTeV Neutrino-Nucleon Scattering**

Muon-(anti-)neutrino quark scattering:
- charged current (CC)
- neutral current (NC)

**Paschos-Wolfenstein relation (iso-scalar target):**

\[ R_- = \frac{\sigma_{NC}(\nu) - \sigma_{NC}(\bar{\nu})}{\sigma_{cc}(\nu) - \sigma_{cc}(\bar{\nu})} = 4g_{LV}^2 \sum_{q_f} \left[ g_{Lq}^2 - g_{Rq}^2 \right] = \rho_\nu \rho_{ud} \left[ \frac{1}{2} - \sin^2 \theta_W^{(on-shell)} \right] \]

+ electroweak radiative corrections

Insensitive to sea quarks
Charm effects only through $d_\nu$ quarks (CKM suppressed)
Need neutrino and anti-neutrino beam!
### NuTeV Results:

\[
\sin^2 \theta_{w}^{(on-shell)} = 1 - \frac{M_w^2}{M_Z^2} = 0.2277 \pm 0.0013 \text{(stat.)} \pm 0.0009 \text{(syst.)}
\]

\[
- 0.00022 \frac{M_{w}^2 - (175 \text{ GeV})^2}{(50 \text{ GeV})^2} + 0.00032 \ln \frac{M_{N_{e\nu}}}{150 \text{ GeV}} \quad \left[ \rho = \rho_{SM} \right]
\]

Factor two more precise than previous \( \nu N \) world average

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**Graph: World Average \( \sin^2 \theta_{w} \) (excl. NuTeV)**

\( 0.2277 \pm 0.0024 \text{(exp)} \pm 0.0019 \text{(th)} \)

\( \chi^2 / \text{DOF} = 4.79 / 4 \)

**Global SM analysis predicts: 0.2227(4) ** Difference of 3.0 \( \sigma \)!
**Possible Explanations**

**Strength of $\nu$ coupling $\rho_\nu$ (assuming $\sin^2\Theta_{\text{eff}}$ ok):**

- $1.00 \pm 0.05$
- $1.00 \pm 0.02$
- $0.995 \pm 0.003$
- $0.988 \pm 0.004$

$\chi^2/\text{dof} = 1.7/3$

- CHARM II et al.
- LEP I Direct
- LEP I Lineshape $\Gamma_{\text{inv}}$
- NuTeV

Neutrino NC Rate/Prediction

**Various explanations, old and new physics:**

- Theory uncertainty (LO PDFs)
- Isospin violating PDFs
- Strange (charm) sea asymmetry (quark-antiquark)
- Nuclear shadowing asymmetry ($W-Z$)

**New physics:**

- $Z'$, contact interactions, lepto-quarks, new fermions, neutrino oscillations, ...
QCD at High Energy

talks by: V. Chiochia, P. Kreuzer, K. Long, C. Paus, S. Roth, F. Wilczek
\[ \alpha_s = 0.1183 \pm 0.0009 \]

\( \alpha_s \) Measurements at ICHEP'02

- JADE power corr.
- LEP combined
- ALEPH 4-jets
- DELPHI RGI
- DELPHI power corr.
- CDF incl. jets
- ZEUS incl. jets
- ZEUS (prel.) Subjets
- ZEUS (prel.) Jet shape
- ZEUS dijets
- H1 incl. jets
- Photon Structure Function
- ZEUS NLO-QCD fit 2002
- H1 NLO-QCD fit 2000
- CTEQ-6 (2001)
- MRST–2001

\[ \alpha_s (M_Z) \]

\[ \alpha_s (Q) \]

**Data**

- Deep Inelastic Scattering
- \( e^+e^- \) Annihilation
- Hadron Collisions
- Heavy Quarkonia

**Theory**

- NLO
- NNLO
- Lattice

\[ \Lambda_{MS}^{(5)} \]

\[ \alpha_s (M_Z) \]

- QCD
- \( O(\alpha_s^4) \)

- 251 MeV --- 0.1215
- 213 MeV --- 0.1184
- 178 MeV --- 0.1153

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Beauty puzzle: does pQCD describe heavy quark production?

**LEP**: $\gamma\gamma$ events + $p_t^{rel}$ method

**Charm OK**

**Beauty too high**

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Updated theory:
- Peterson fragm. tuned for LL
- different parameter: $\varepsilon_b = 0.002$
- better even different fragm.
- theory update FONLL
- $\sigma_{data}/\sigma_{theory} = 1.7$
- data do not contradict theory

CDF

LEP: $\gamma\gamma$ events + $p_t^{rel}$ method

CTEQ5M1
$m_b = 4.75$ GeV
$f(b\rightarrow B) = 0.375$

Theory: FONLL with N=2 fit

$c = 0.006$

$\mu_0/2 < \mu_R, \mu_F < 2\mu_0$

$\sigma = \mu_R = \mu_F = \mu_0 = \sqrt{(m_b^2 + p_t^2)}$

$pp \rightarrow B^+ + X, \sqrt{s} = 1.8$ TeV, $|y| < 1$

dotted: Peterson

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Beauty puzzle: HERA

CASACADE (CFFM & unintegrated gluons) also describes ZEUS DIS data

HERA B: \( B \rightarrow J/\psi \ X \rightarrow l^+l^-X \)

agreement with recent calculations beyond NLO

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Inclusive jet cross section in $p\bar{p}$

**Tevatron jets:**
- QCD at very high scales
- Partons at high $x$ and very high $Q^2$

- **D0:** inclusive jet cross section as a function of pseudorapidity
  \[ \eta = -\ln \left[ \tan \left( \frac{\theta}{2} \right) \right] \]

- **NLO QCD** gives good description of $E_T$ and $\eta$ dependence

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Inclusive jets in $p\bar{p}$

- CTEQ/MRST groups: inclusion of D0 data in global fit to determine parton distributions

- Good description over full $p_t$ and $\eta$ range

- Main difference in new fits is enhanced gluon at high $x$
Physics at "Low" $Q^2$

Exploring Structures in Non-perturbative $QCD$ at (Relatively) Hard Scales

talk by N. Makins
Generalized Parton Distributions

Analysis of **hard exclusive processes** leads to a new class of parton distributions.

Four new distributions:
- helicity conserving $\rightarrow H(x, \xi, t), E(x, \xi, t)$
- helicity-flip $\rightarrow \tilde{H}(x, \xi, t), \tilde{E}(x, \xi, t)$

*Bjorken $x$* : average quark momentum fraction

"**skewing parameter**" $\xi$
- $\rightarrow$ mismatch between quark momenta
- $\Rightarrow$ sensitive to partonic **correlations**

N.C.R. Makins, ICHEP 2002, Amsterdam
DVCS: Beam-Spin Azimuthal Asymmetry

At intermediate energies, Bethe-Heitler cross-section $\gg$ DVCS ... explore interference, using polarized beams

Beam-Spin Asymmetry $\rightarrow$

$$A_{LU}(\phi_\gamma) = \frac{\sigma_\rightarrow - \sigma_\leftarrow}{\sigma_\rightarrow + \sigma_\leftarrow}$$

$\sim \text{Im} \left( \text{BH} \cdot \text{DVCS}^* \right) \sin \phi_\gamma$

Beam-Charge Asymmetry

$\sim \text{Re} \left( \text{BH} \cdot \text{DVCS}^* \right) \cos \phi_\gamma$

also measured, at HERMES

HERMES: $\langle Q^2 \rangle = 2.6 \text{ GeV}^2$

CLAS: $\langle Q^2 \rangle = 1.3 \text{ GeV}^2$
Precise new data have potential to constrain GPD's

- Calculations by Freund & McDermott, based on LO (solid) and NLO (dashed) PDF's
- explore correlation parameter $a$: $\sim x$-range over which quarks are correlated
Particle Astrophysics and Cosmology

talks by T. Gaisser, M. Kamionkowski
Neutrino Astronomy: Baikal, Amanda

South Pole

AMANDA

[Diagram showing the South Pole with AMANDA and schematic of neutrino detection setup.]
AMANDA: skyview

AMANDA: atmospheric ν

many ongoing & future projects

* neutrinos
  * atmospheric
  * from active gal.
  * from γ–ray bursts
  * WIMPS

...
$\chi^0$ Nucleus Recoils

$E_r \approx 10^{-3}$

Dense Energy Deposition $v/c$ small

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BOOMERanG Results

- flat Universe
- give primodial seeds for large scale struct.
  ⇒ inflation!
- verify BB nucleosyn.
- existance of nonbaryonic dark matter
- 70% negative presure dark energy

Current results:

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What is Universe made of?...

65% of dark energy!

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What is the Universe we live in like? A Summary?

- flat, after inflation
- ~65% dark energy
- CPV, no direct CPV yet
- full of objects to search for and mysteries to discover...

SM particles found (almost)
SM agrees (almost)
QCD works (almost)
no new physics (yet)

where do we go from here?...

keep going!
Quark–Gluon Plasma
Inclusive Diffraction

\begin{align*}
\gamma^* \rightarrow q_i^{\text{Diff}}(x_{IP}, t; \beta, Q^2) \otimes \hat{\sigma}^{\gamma*}_{q_i}(\beta, Q^2)
\end{align*}

Factorisation (Collins)

\begin{align*}
\sigma_i(x_{IP}, t; \beta, Q^2) & \sim q_i^{\text{Diff}}(x_{IP}, t; \beta, Q^2) \otimes \hat{\sigma}^{\gamma*}_{q_i}(\beta, Q^2)
\end{align*}

Data consistent with ‘Regge’ factorisation:

\begin{align*}
\sigma_r^{(3)} \sim f_{IP/p}(x_{IP}, t) \cdot F_2^{IP}(\beta, Q^2)
\end{align*}

\begin{align*}
f_{IP/p}(x_{IP}, t) = \frac{\exp(-b|t|)}{x_{IP}^{2\alpha(t)-1}}
\end{align*}

- Good description of data
- Positive scaling violations ($\beta < 0.6$) → diffractive PDFs are gluon dominated

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Diffractive parton densities

Predictive?

Diff. dijets

Diff. D*

First set of diffractive PDFs!
Standart Model Comparison

one solution for 2b in excellent agreement with measurements of UT

CP Violation

Very important in reducing the allowed region

Coherent picture of CP Violation in SM
**Hard Scales**

*pQCD applicable in presence of hard scale*

*example: Diffractive Vector Meson Production*

3 scales:

- $Q$: photon virtuality
- $m$: vector meson mass
- $t$: mom. transfer to target

**pQCD picture**: 2–gluon exchange

fast rise of xsec with $W$: $\sigma_L = W^{0.8}$
**Soft → Hard Transitions**

Photoproduction ($Q^2 = 0$)

onset of hard behavior: *charm mass* ($J/\psi$)

Diffractive $\rho$ production

onset of hard behavior: *high $Q^2$*

N.C.R. Makins, ICHEP 2002, Amsterdam
Diffractive Photoproduction

onset of hard behavior: large $t$

- power–like $d\sigma/dt$ behavior, not exponential!
- $d\sigma/dt$ described by BFKL calc.

$\alpha' \sim 0$ consistent with pQCD

$W$ dependance consistent with pQCD
Gluon Density from $\gamma p \rightarrow J/\psi p$

Diffractive $J/\psi$ production well described by pQCD 2-gluon exchange models

Should be possible to extract $g(x)$!

- $W = 250$ GeV $\rightarrow x = 10^{-4}$
- data precise enough to distinguish between different PDF sets
- ... but theoretical uncertainties make extraction impossible at present: higher-twist corrections and skewing ...

N.C.R. Makins, ICHEP 2002, Amsterdam
Where is matter???
What Can Be Dark Matter?

- ordinary matter – not enough
- massive neutrinos? not enough
- baronic MACHOS? not enough

- WIMPS?
  - axial?
  - LSP? neutralino?

\[ \sigma \approx 10^{20} \text{ higher – shield} \]

Nucleus Recoils
\[ E_r \]
Dense Energy Deposition
\[ v/c \approx 10^{-3} \]

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Success of SM in EW Sector

Example: W–Pair Production

Correlated average of:

\[ \frac{\sigma_{\text{meas}}}{\sigma_{\text{theory}}} : \]

0.997(11) YFSWW
0.999(11) RacoonWW

Test at the 1% level!

Uses O(\(\alpha\)) corrections:

-2.5(0.5)% on \(\sigma_{\text{theory}}\)

Effect on differential cross sections and on \(\gamma WW / ZWW\) gauge couplings?