Introduction:
Moriond (Electroweak)
Real 'physics' conference

Calorimetry 2004
Real 'hardware' conference.

Disclaimer:
Most of the sheets are taken directly from the talks given at Moriond.
Small and very nice conference, but still: 90 talks!

**Experiment:**
- EW results & precision measurements
- B-physics
- Searches and SUSY
- Discovery of new particles
- Dark matter
- Neutrinos

**Theory:**
- Large extra dimensions

- top quark mass, $g-2$, $s \sin^2(\theta_w)$
- Babar & Bell + frustrating sheet
- Higgs at Tevatron
- Penta-quarks

Discovery claim
What is happening

why and how can we see it
top quark
Top quark production

production

Final states

$\sigma(t\bar{t}) \approx 8 \text{ pb}$

$W\rightarrow qq \ (2/3) \text{ and } l\nu \ (1/3)$

Lepton + jets. Most sensitive

Di-lepton. Small statistics

Large QCD background
Tevatron run 2: CDF

**di-lepton**

CDF Run II Preliminary

126/102 pb$^{-1}$

6 events (0.5 background)

**Lepton + jets**

CDF Run II Preliminary

Reconstructed Top Mass, Tagged Events (GeV/c$^2$)

22 events (6 background)

Run II data, $\sim$126 pb$^{-1}$

$m_t = 175.0_{-16.9}^{+17.4} \pm 8.4$ (syst) GeV/c$^2$

Run II data, $\sim$102 pb$^{-1}$

$m_t = 177.5_{-12.7}^{+7.9} \pm 7.1$ (syst) GeV/c$^2$
Tevatron run 2: D0

“First we have something to say on our run 1 result.”
New D0 analysis technique:

- **Compute event-by-event probability**
  Match measured 4-momenta to expectations for signal ($m_{\text{top}} = 170, 175, 180$ etc) and background.

- **Use only 4 jet (clean) events (22 events instead of 77 previously)** & all combinations

Basicallly same as difference between:

\[
< m > = \frac{\sum_i \left( \frac{1}{\sigma_i} \right)^2 m_i}{\sum_i \left( \frac{1}{\sigma_i} \right)}
\]

instead of

\[
< m > = \frac{1}{n} \sum_i m_i
\]

Can it be so important?? YES!!
Improvement in statistical error is roughly 1.5 (comparable to 2.4 times more data)

\[ m_{\text{top}} = 173.3 \pm 5.6 \text{ (stat)} \pm 5.5 \text{ (syst)} \text{ GeV} \quad \text{91 events} \]

\[ m_{\text{top}} = 180.1 \pm 3.6 \text{ (stat)} \pm 3.9 \text{ (syst)} \text{ GeV} \quad \text{22 events} \]

\( M_{\text{top}} \) moves up by \( \sim 7 \text{ GeV} \) !!!

As if you had 2.4 times more data
Tevatron

New top quark mass averages

TEVATRON RUN1 (old) \( m_{\text{top}} = 174.3 \pm 5.1 \, \text{GeV} \)

RUN1 (new) \( m_{\text{top}} = 178.0 \pm 4.3 \, \text{GeV} \)

RUN2 (l+jets) \( m_{\text{top}} = 177.8^{+4.5}_{-5.0} \pm 6.2 \, \text{GeV} \)

Influence on rest of EW physics results
Another example: Influence new top mass on $\tan(\beta)$ exclusion region from LEP:

In MSSM benchmarks: $m_{\text{top}} = 175$ GeV $\rightarrow$ Maximum $m_h$: in the MSSM < 135 GeV

- Computation of $m_h$-max:
  
  Loop corrections $\propto m_{\text{top}}^4$
  
  FeynHiggs:
  
  higher order corr. $\rightarrow \Delta m_h \approx 3$ GeV
  
  $\Delta m_{\text{top}} \approx 5$ GeV $\rightarrow \Delta m_h \approx 5$ GeV

- LEP-excluded $\tan(\beta)$ region will shrink

<table>
<thead>
<tr>
<th>Scenario</th>
<th>$m_h$</th>
<th>$m_A$</th>
<th>Excluded $\tan(\beta)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M_h$-max</td>
<td>&gt;91.0</td>
<td>&gt;91.9</td>
<td>0.5 &lt; $\tan(\beta)$ &lt; 2.4</td>
</tr>
</tbody>
</table>
Impact new top mass on the electroweak fit

- Example: $W$ mass. contributions from:

$$\delta_{M_W} \propto m_t^2 \ln(m_h)$$

Example: $W$ mass. contributions from:

$\text{Old (new): } m_h = 96 \ (117) \text{ GeV}$

$\text{Old (new): } m_h < 219 \ (251) \text{ GeV @ 95\% CL}$
Electroweak

$g-2$
Anomalous magnetic moment of the muon
g-2 collaboration final results

“Compare to SM prediction: there is a 1.4/2.7 sigma deviation”

Depends on e+e- data or tau data
Theoretical computation of $a_\mu \ [ (g-2)/2 \] \ and \ part \ (1)$

- $a_\mu^{SM}$ can be expressed in terms of its various contributions:

$$a_\mu^{SM} = a_\mu^{QED} + a_\mu^{EW} + a_\mu^{HLBL} + a_\mu^{HVP} + a_\mu^{HOHVP}$$

<table>
<thead>
<tr>
<th>SM Term</th>
<th>$a_\mu \times 10^{-10}$</th>
<th>$\Delta a_\mu \times 10^{-10}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_\mu^{QED}$</td>
<td>11658471.94</td>
<td>0.18</td>
</tr>
<tr>
<td>$a_\mu^{EW}$</td>
<td>15.1</td>
<td>0.4</td>
</tr>
<tr>
<td>$a_\mu^{HLBL}$</td>
<td>12.0</td>
<td>3.5</td>
</tr>
<tr>
<td>$a_\mu^{HVP,e+e-}$</td>
<td>694.4</td>
<td>7.2</td>
</tr>
<tr>
<td>$a_\mu^{HOHVP}$</td>
<td>-10.1</td>
<td>0.6</td>
</tr>
</tbody>
</table>

(1) light by light scattering: theory!
Tedious work. Done by 1 guy basically.
Sign flip found in 2002 (PhD student from Marseille ??)
(2) Hadronic vacuum polarization: experiment (2 ways to extract it)

(1) CMD: $e^+e^-$ results:
- Claim 0.6% uncertainty, but new rad corr shifted cross section by 3%
- Region < 1.8 GeV dominates
- They were alone (check needed)

Now confirmed by KLOE (radiative events). Maybe BaBar and Cleo can do something as well

(2) Tau decay
- Gives different $e^+e^- \rightarrow$ hadrons

\[
\alpha_{HVP} \propto \int_{4m_e^2}^{\infty} \frac{R(s)}{s} K(s) ds, \text{ where } R(s) = \frac{\sigma(e^+e^- \rightarrow \text{hadrons})}{\sigma(e^+e^- \rightarrow \mu^+\mu^-)}.\]
Muon g-2: new results

Brookhaven, January 2004: $\mu^-$ measurement.

\[ a^\text{exp}_\mu - a^\text{SM}_\mu = 270 \pm 100 \cdot 10^{-11} \]
\[ \rightarrow 2.7\sigma \text{ (again...)} \]
(based on Davier et al., 2003, e+e-)

\[ a^\text{exp}_\mu - a^\text{SM}_\mu = 123 \pm 89 \cdot 10^{-11} \]
\[ \rightarrow 1.4\sigma \]
(tau)

Arkady Vainshtein: new analysis
Electroweak
\[ \sin^2 \theta_w \]
SLAC E-158
Measuring Parity Violation in \( n \)øller Scattering

\[
E = 48 \text{ GeV}, \quad Q^2 = 0.03 \text{ GeV}^2
\]

For a polarized electron beam and an unpolarized electron target,

\[
A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}
\]

\[
A_{PV} \propto (1 - 4 \sin^2 \theta_W)
\]

tree level: \(-3 \cdot 10^{-7}\)

**E158 Goal**: \( \delta \sin^2 \theta_W = +/- 0.001 \)

Best measurement of \( \theta_W \) away from the Z-pole
$A_{PV} = -160 \pm 21 \pm 17$

Significance of parity non-conservation is 6.3 sigma !!

Translate to $\sin^2(\theta_W)$

Still the old NuTeV 'discrepancy'
NuTeV: neutrino-nucleus deep inelastic scattering

Measure $\sin^2 \theta_W$ through NC CC cross section ratio:

Paschos-Wolfenstein:

$$\frac{\sigma^{\text{NC}}(\nu N) - \sigma^{\text{NC}}(\bar{\nu} N)}{\sigma^{\text{CC}}(\nu N) - \sigma^{\text{CC}}(\bar{\nu} N)} = \frac{1}{2} - \sin^2 \theta_W$$

Probe strange sea
$v$ and anti-$v$ beam
Clean events

For and against PWR
PWR is based on isospin symmetry
It is stable against $\Delta g$ and HT corrections
PWR holds for both diff. and tot. $x$-sections.

PWR holds for an isoscalar target (e.g. D)
and must be corrected for non-isoscalarity eff.
in heavy nuclei. PWR is violated if $s \neq \bar{s}$.
PWR is violated if isospin symmetry is not exact.
Extracting $\sin^2(\theta_W)$ from DIS cross sections:

$$R = \frac{1}{2} - \sin^2 \theta_W + \delta_R$$

Nuclear effects due to target corrections

More precise corrections:

1. $Z$ protons and $N$ neutrons (10 x experimental error)

2. QCD radiative corrections

$$\delta(\sin^2(\theta_W)) = -0.5 \sigma_{\text{NuTeV}} \text{ (towards SM value)}$$

3. Fermi-motion and nuclear binding effects from target

$$\delta(\sin^2(\theta_W)) = -0.5 \sigma_{\text{NuTeV}} \text{ (towards SM value)}$$

NuTeV shifts towards SM value (almost 1 sigma)!
BABAR and Belle attacking the CKM matrix from all sides

2 odd things

Do they agree on everything ??
Are there anomalies left ??

CP violation in $B^0 \to \pi^+ \pi^-$

Belle $B \to \phi K_s$ $3.5\sigma$ deviation from SM
Belle $B \to \phi K_s$ 3.5 $\sigma$ deviation from SM

**Difference between $J/\psi K_s$ and $\phi K_s$**

$\bar{B}^0 \rightarrow J/\psi K^0$

$\bar{B} \rightarrow \phi K$

NP contributions to $B^0 \rightarrow \phi K_s$ penguin can result in

$\sin(2\beta)_{J/\psi K_s} \neq \sin(2\beta)_{\phi K_s}$

Babar : $\sin(2\beta)_{J/\psi K_s} = 0.73 \pm 0.06$

: $\sin(2\beta)_{\phi K_s} = 0.5 \pm 0.5$

Belle : $\sin(2\beta)_{\phi K_s} = -1.0 \pm 0.6$

$\Delta t$ decay time between tag-B and decay-B

**Old numbers**

Diff!
**CP violation in $B^0 \rightarrow \pi^+ \pi^-$**

Fit asymmetry to:

$$A_{\pi \pi}^C(t) = A_{\pi \pi}(t) \cos(\Delta m \Delta t) + S_{\pi \pi}(t) \sin(\Delta m \Delta t)$$

For no $B^\pm$, $B^0$ and $\bar{B}^0$ decays no CP-violation is observed (except Belle in $B^0 \rightarrow \pi^+ \pi^-$).

**SUMMARY (BABAR/Belle):** doing well, some mysteries left.
Most frustrating slide in the conference!!

$B_s \to \mu^+ \mu^-$ is a promising window on possible physics beyond the SM.

In the SM, the expected branching ratio is small:

$$\text{Br}(B_s \to \mu^+ \mu^-) = (3.4 \pm 0.5) \cdot 10^{-9}$$

Quite a few talks on theoretical aspects of rare B decays as well.

**B_s \to \mu^+ \mu^- sensitivity study**

Optimised cuts using Random Grid Search [Prosper, CHEP’95; Punzi, CSPP’03] based on the mass sidebands.

**After optimisation:**

- Expect $7.3 \pm 1.8$ background events in signal region

The analysis has not been *unblinded* yet (signal region still hidden).

**Expected limit (Feldman/Cousins):**

- $\text{Br}(B_s \to \mu^+ \mu^-) < 9.1 \cdot 10^{-7}$ @ 95% CL (stat only)
- $\text{Br}(B_s \to \mu^+ \mu^-) < 1.0 \cdot 10^{-6}$ @ 95% CL (stat + syst)

(expected signal has been normalised to $B^\pm \to J/\Psi K^\pm$)

Published CDF Run I result (98 pb$^{-1}$):

- $\text{Br}(B_s \to \mu^+ \mu^-) < 2.6 \cdot 10^{-6}$ @ 95% CL
Tevatron running
&
Higgs
Nothing new on the Higgs front & SUSY searches (updates from HERA, LEP, Tevatron)

Higgs cross section exclusion

Tevatron accelerator review:
- 4.4 fb\(^{-1}\) at FY 09 feasible
- 8.5 fb\(^{-1}\) at FY 09 very challenging

Expected Higgs boson mass exclusion

Factor 50

SM cross section

Tevatron operation

started bad, now ok
Penta-quarks & other new particles
'New' particles are discovered all the time:

- two new extremely narrow mesons containing $c$ and $\bar{s}$ quarks (BaBar, CLEO, BELLE)
- new very narrow resonance precisely at $D^{0*}D^0$ threshold (Belle, CDF)
- exotic 5-quark resonances: $\Theta^+ (KN)$, $\Xi^{*-}$
Last summer, Belle announced a new particle at $\approx 3872$ MeV/c$^2$, observed in $B^+$ decays:

$$B^+ \rightarrow K^+ X(3872),$$

$$X(3872) \rightarrow J/\Psi \pi^+ \pi^-.$$  

Belle’s discovery has been confirmed by CDF and DØ.

DØ preliminary:

300 ± 61 events

4.4σ effect

$$\Delta M = 0.768 \pm 0.004 \text{ (stat)} \pm 0.004 \text{ (syst) GeV/c}^2$$

Could have seen it in Run1 I guess. Now studying decay properties. Seems like charmonium state.
The discovery of $\Theta^+$

**Pentaquarks: $\Theta^+$ and $\Xi^-$**

# K+n-invariant mass

## Penta-quark

**New particle**

**World average: $m = 1530.5 \pm 2.0$ MeV**

### $m_{\Theta^+}$ = 1542 ± 5 MeV, $\Gamma_{\Theta^+}$ ≤ 20 MeV

<table>
<thead>
<tr>
<th>Experiment</th>
<th>$m_{\Theta^+}$</th>
<th>$m_{\Xi^-}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>COSY: $pp \rightarrow \Sigma^+ K_0 \pi$</td>
<td>1542 ± 5</td>
<td>1592 ± 50</td>
</tr>
<tr>
<td>SVD-2: $pA$</td>
<td>1542 ± 5</td>
<td>1592 ± 50</td>
</tr>
<tr>
<td>ZEUS: $\gamma^* p$</td>
<td>1542 ± 5</td>
<td>1592 ± 50</td>
</tr>
<tr>
<td>CLAS 2: $\gamma p$</td>
<td>1542 ± 5</td>
<td>1592 ± 50</td>
</tr>
<tr>
<td>HERMES: $\gamma^* D$</td>
<td>1542 ± 5</td>
<td>1592 ± 50</td>
</tr>
<tr>
<td>ITEP: $pA, \bar{p}A$</td>
<td>1542 ± 5</td>
<td>1592 ± 50</td>
</tr>
<tr>
<td>SAPHIR: $\gamma p$</td>
<td>1542 ± 5</td>
<td>1592 ± 50</td>
</tr>
<tr>
<td>CLAS: $\gamma D$</td>
<td>1542 ± 5</td>
<td>1592 ± 50</td>
</tr>
<tr>
<td>DIANA: $K^+ Xe$</td>
<td>1542 ± 5</td>
<td>1592 ± 50</td>
</tr>
<tr>
<td>LEPS: $\gamma^{28}C$</td>
<td>1542 ± 5</td>
<td>1592 ± 50</td>
</tr>
</tbody>
</table>

$\frac{1}{2}$

P-wave diquark-triquark molecule.

Trying to understand the structure
New particle
Penta-quark

A 3\textsuperscript{rd} penta-quark??
(NA49)

\textbf{BUT}

Not confirmed by CDF

**Pentaquarks**

Looking for $\Xi(1860) \rightarrow \Xi^- \pi^\pm$

2\textsuperscript{nd} Step: Combine $\Xi^-$ with $\pi^\pm$

- Don't see any $\Xi(1860)$
- It's not statistics: ($18 \times$ as many $\Xi^-$ as NA49).
- Unknown bias due to Trigger? Re-check with Jet20 data ($2 \times$ NA49). Still no $\Xi(1860)$

95\% UL relative to $\Xi(1530)$:

$\Xi^- \pi^+ \text{ (search)} / \Xi(1530) \ 0.07$

$\Xi^- \pi^- \text{ (control)} / \Xi(1530) \ 0.04$
Extra dimensions
Many theory talks on this subject, a hot topic

e.g. Randall-Sundrum Models

Apprecently I was not the only one who was surprised!
Why Consider Extra D?

- **String theory**: at least six unseen dims
- **General Relativity**: why 4?
- **New ways of approaching old problems**
  - Cosmology: still many unanswered questions
  - Hierarchy, flavor, GUTs
**XD for EW Hierarchy**

*or why is gravity sooo small?*

- **ADD**: all forces & particles localized on one brane, only gravity in large, flat XD \( \Rightarrow \)
  - monojet+missing \( E_T \) (graviton KK modes)
- **RS1**: “warped” XD, with second (EW or TeV) brane, where gravity exp. suppressed
  - TeV resonances on EW brane \( \Leftrightarrow \) KK modes (also for gauge)
- You will see heavy partners of all particles
- Partners of the electron will be fermions
- Not bosons as in SUSY
- Partners should all have similar masses

**Experimental Signal**

- Kaluza-Klein particles
- Definite mass spectrum and "spin"-2

Tevatron (direct) and LEP (indirect)

- **Gravity strong near the EW scale**
  \[ M_{pl}^2 \sim M_{\text{eff}}^{2+n} r^n \]
  n extra (space) dimensions of radius r

- **Virtual graviton exchange affects:**
  \[ \frac{d}{d\cos(\theta)} \left[ \sigma_{\ell^+\ell^-\rightarrow\ell^+\ell^-} \right] \]

- We haven’t seen additional charged particles up to m~TeV

**SUMMARY:**

- No branes: 10^{-17} cm
- With branes, 0.2 cm
- With branes and curvature: infinite!
XD & EWSB: no Higgs

- Boundary conditions can break 4D gauge symmetry (e.g. Dirichlet forbids $n=0$)
- Unitarity (without scalar) recovered iff all KK modes included, and 5d gauge invariant lagrangian; there are massive KK gauge bosons with $m_{KK} < 1.8$ TeV
- Warped XD + more symmetries needed to suppress oblique corrections $S, T, U$
- Fermion masses: possible except for top
Dark matter
What is dark matter? 

Axion 

WIMP (SUSY stable LSP, $\chi_1^0$) 

$\Omega_{\text{matter}} > \Omega_{\text{baryon}}$ --> Non baryonic dark matter 

$\Omega_{\text{total}} > \Omega_{\text{matter}}$ --> Dark Energy 

Dark matter halo around galaxies 

Baryon density: $\Omega_b = 0.044 \pm 0.004$ 

Dark Matter: $\Omega_m = 0.23 \pm 0.04$ 

Dark Energy: $\Omega_\Lambda = 0.73 \pm 0.04$ 

$\Omega_{\text{matter}} > \Omega_{\text{baryon}}$ --> Non baryonic dark matter 

$\Omega_{\text{total}} > \Omega_{\text{matter}}$ --> Dark Energy
II. Direct detection of Neutralino WIMP

- Local Dark Matter density
  \[ \rho_{\text{local}} \approx 0.3 \text{GeV} / \text{cm}^3 \]

- Maxwellian velocity distribution
  \[ \bar{v} \approx 270 \text{km} / \text{s} \]

- Local Flux of Dark Matter
  \[ \Phi_{\text{local}} \approx \frac{100 \text{GeV}}{m_\chi} \cdot 10^5 \text{cm}^{-2} \text{s}^{-1} \]
Principles of WIMP detection

- Elastic scattering of a WIMP on a nucleus inside a detector

- The recoil energy of a nucleus with mass $m_N$

$$E_{\text{recoil}}(\text{max}) = 2v_{\chi}^2 m_N \frac{m_{\chi}^2}{(m_N + m_{\chi})^2}$$

For $v_{\chi} \approx 10^{-3} c \quad \Rightarrow \quad E_{\text{recoil}} \approx 10^{-6} m_N \approx 10\text{keV}$

- This recoil can be detected in some ways:
  - Electric charges released (ionization detector)
  - Flashes of light produced (scintillation detector)
  - Vibrations produced (phonon detector)
Sensitive underground detectors, but need large \((\text{mass} \times \text{exposure time})\)
## WIMPS

<table>
<thead>
<tr>
<th>Discrim.</th>
<th>Name</th>
<th>Location</th>
<th>Technique</th>
<th>Material</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>CUORICINO</td>
<td>Gran Sasso</td>
<td>Heat</td>
<td>41 kg TeO2</td>
<td>running</td>
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<td></td>
<td>GENIUS-TF</td>
<td>Gran Sasso</td>
<td>Ionization</td>
<td>42 kg Ge in N2</td>
<td>running</td>
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<tr>
<td></td>
<td>HDMS</td>
<td>Gran Sasso</td>
<td>Ionization</td>
<td>0.2 kg Ge diodes</td>
<td>stopped</td>
</tr>
<tr>
<td></td>
<td>IGEX</td>
<td>Canfranc</td>
<td>Ionization</td>
<td>2 kg Ge Diodes</td>
<td>stopped</td>
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<tr>
<td>Statistical</td>
<td>DAMA</td>
<td>Gran Sasso</td>
<td>Light</td>
<td>100 kg NaI</td>
<td>stopped</td>
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<tr>
<td></td>
<td>LIBRA</td>
<td>Gran Sasso</td>
<td>Light</td>
<td>250 kg NaI</td>
<td>running</td>
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<tr>
<td></td>
<td>NaIAD</td>
<td>Boulby mine</td>
<td>Light</td>
<td>65 kg NaI</td>
<td>running</td>
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<td></td>
<td>ZEPLIN-I</td>
<td>Boulby mine</td>
<td>Light</td>
<td>4 kg Liquid Xe</td>
<td>running</td>
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<tr>
<td>Event-by-event</td>
<td>CDMS-I</td>
<td>Stanford</td>
<td>Heat + Ionization</td>
<td>4 Kg Ge + Si</td>
<td>stopped</td>
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<tr>
<td></td>
<td>CDMS-II</td>
<td>Soudan mine</td>
<td>Heat + Ionization</td>
<td>2 to 7 kg Ge + Si</td>
<td>running</td>
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<tr>
<td></td>
<td>CRESST-I</td>
<td>Gran Sasso</td>
<td>Heat + Light</td>
<td>0.262 kg Al2O3</td>
<td>stopped</td>
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<tr>
<td></td>
<td>CRESST II</td>
<td>Gran Sasso</td>
<td>Heat + Light</td>
<td>0.6 to 9.9 kg CaWO4</td>
<td>running</td>
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<td>EDELWEISS-I</td>
<td>Modane</td>
<td>Heat + Ionization</td>
<td>1 kg Ge</td>
<td>running</td>
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<tr>
<td></td>
<td>ROSEBUD</td>
<td>Canfranc</td>
<td>Heat + Light</td>
<td>1 kg BGO</td>
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<td></td>
<td>SIMPLE</td>
<td>Rustrel</td>
<td>Superheated droplets</td>
<td>Freon</td>
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</tbody>
</table>

**DAMA & Edelweiss**
Investigating the presence of a WIMP component in the galactic halo by the model independent WIMP annual modulation signature.

- $v_{\text{sun}} \approx 232$ km/s (Sun velocity in the halo)
- $v_{\text{orb}} = 30$ km/s (Earth velocity around the Sun)
- $\gamma = \pi/3$
- $\omega = 2\pi/T$  \( T = 1 \text{ year} \)
- $t_0 = 2^{nd}$ June (when $v_\odot$ is maximum)

$$v_\odot(t) = v_{\text{sun}} + v_{\text{orb}} \cos \gamma \cos[\omega(t-t_0)]$$

$$S_k[\eta(t)] = \int_{\Delta E_k} \frac{dR}{dE_R} \approx S_{0,k} + S_{m,k} \cos[\omega(t-t_0)]$$

Expected rate in given energy bin changes because of the Earth’s motion around the Sun moving in the Galaxy.

**Requirements of the annual modulation**

1) Modulated rate according cosine  
2) In a definite low energy range  
3) With a proper period (1 year)  
4) With proper phase (about 2nd June)  
5) For single hit in a multi-detector set-up  
6) With modulated amplitude in the region of maximal sensitivity $\leq 7\%$ (larger for WIMP with preferred inelastic interaction, PRD 48 (1994) 1435-39)

To mimic this signature, spurious effects and side reactions must (not only - obviously - be able to account for the whole observed modulation amplitude, but also) satisfy contemporaneously all these 6 requirements.
Investigating the presence of a WIMP component in the galactic halo by the model independent WIMP annual modulation signature

**Talks from DAMA 95% the same:**

They see something!!
Latest results: DAMA

- Data taking completed in July 2002
- Total exposure of 107,731 kg.d
- See annual modulation at $6.3\sigma$
- Claim model-independent evidence for WIMPs in the galactic halo

- WIMP candidate under standard halo parameters:
  $M_\chi = (52^{+10}_{-8})$ GeV and $\sigma_{\chi-N} = (7.2^{+0.4}_{-0.9}) \times 10^{-6}$ pb

- Checking this result remains important

- 2nd phase 250 kg LIBRA running...
- NaIAD 65kg NaI in Boulby mine
EDELWEISS-I (Frejus, ionization-heat measurement, small)

Current exclusion limits

- 99.8% CL incompatibility with DAMA modulation signal claimed by:
  - CDMS at low masses
  - EDELWEISS above 50 GeV
- Exclusion resists to a variation of halo parameters *

* Copi & Krauss, astro-ph/020810
* Kurylov & Kamionkowski, hep-ph/0307185

Plans: $10^{-6}$ pb (now), $10^{-8}$ (soon), $10^{-10}$ (10 years)

However, DAMA claims that no model independent comparison is possible...
Axions can be produced in the sun.

Interact with magnetic field ($\propto B^2 L^2$) and produce X-rays ($a \rightarrow \gamma$)

$L = 10 \text{ m}, B = 9 \text{T}$

100 times more $a \rightarrow \gamma$ conversions than any other experiment

$\pm 8^\circ$, so shifts only at sunrise(set)

X ray telescope.

2005: Probe higher axion masses (fill magnet with helium)
Other underground experiments: proton decay  Explore lifetimes $>10^{35}$ years

Ambitious:

74 sheets in 30 minutes
100,000,000 kg liquid argon

Experiments for CP violation: a giant liquid Argon scintillation, Cerenkov and charge imaging experiment.

Neutrinos
Neutrino: mass and mixing parameters

Puzzles and experimental tasks:

- Do neutrinos really oscillate? ← OK, evidence from Super-K
- Are there only 3 neutrino species? ← LSND / MiniBooNE
  Are there sterile neutrinos?
- What is the mass hierarchy pattern? (Sgn $\Delta m_{23}^2$?)
  \[
  \begin{array}{c}
  \text{NORMAL} \\
  \hline
  \Delta m^2 \\
  \hline
  m_1 \\
  m_2 \\
  m_3 \\
  \text{INVERTED} \\
  \Delta m^2 \\
  m_1 \\
  m_2 \\
  m_3 \\
  \end{array}
  \]
- What is absolute mass scale? ← Neutrinoless double beta-decay
- Are neutrinos Dirac or Majorana? ← Neutrinoless double beta-decay
- Measure $\theta_{13}$ and $\delta$
How do we probe the neutrino sector of the SM:

Mass eigenstates are mixture of flavour eigenstates (a la CKM matrix)

\[
| \nu_{\text{flavour}} \rangle = U_{\text{PMNS}} | \nu_{\text{mass}} \rangle \\
| q_{\text{flavour}} \rangle = U_{\text{CKM}} | q_{\text{mass}} \rangle
\]

2-3 mixing

1-3 mixing

1-2 mixing

Atmospheric

Superkamiokande

Reactor (CHOOZ)

Solar (KAMLAND)

\( \Delta(m_{23})^2 = 2-3 \text{ eV}^2 \)

\( \Theta_{23} = 45^\circ \)

\( \Delta(m_{13})^2 = ?? \)

\( \Delta(m_{12})^2 = 5-7 \text{ eV}^2 \)

MNS = Maki-Nakagawa-Sakata

April 2004

Ivo van Vulpen
Do they really oscillate??

Super Kamiokande

- Atmospheric Neutrinos
  \( \nu_e \leftrightarrow \nu_x \)
  2 flavor oscillations from
  I. Zenith angle analysis
  II. L/E analysis

\[
\chi^2_{\text{min}} = 170.8/170 \text{ d.o.f}
\]
\[\Delta m^2 = 2.0 \times 10^{-3} \text{ eV}^2, \sin^2 2\theta = 1.00\]
\[1.3 \times 10^{-3} < \Delta m^2 < 3.0 \times 10^{-3} \text{ eV}^2\]
\[0.90 < \sin^2 2\theta \quad \text{at 90\% C.L.}\]

2 allowed regions are compatible

Is disappearance really caused by oscillations??

First evidence that neutrino transition probability obeys sinusoidal function as predicted in neutrino oscillation

April 2004

Ivo van Vulpen
Are there 3 families??

Sterile neutrinos

Excess ($\bar{\nu}_\mu \rightarrow \bar{\nu}_e$, appearance): 87.9 $\pm$ 22.4 $\pm$ 6.0

Close to 4 $\sigma$

KARMEN excludes part of it

$\nu$ oscillation signals:
- Solar: $\Delta m^2 \sim 10^{-5}$ eV$^2$
  (SNO, KamLAND, ...)
- Atmospheric: $\Delta m^2 \sim 10^{-3}$ eV$^2$
  (Super-K, K, ...)
- Accelerator: $\Delta m^2 \sim 10^0$ eV$^2$
  (LSND)

What to do?
1. An experiment or interpretation is wrong
2. Add sterile neutrinos: 1, 2, 3 ...
3. Violate CPT

(confirmation needed): --> miniBOONE
miniBOONE energy spectrum requires more precise cross section data

**Physics goals**

- **Systematic study of HAdRon Production:**
  - Beam energy: 2-15 GeV
  - Target: *from hydrogen to lead*

- **Motivation:**
  - Pion/kaon yield for the design of the proton driver of *neutrino factories* and SPL-based *super-beams*
  - Input for precise calculation of *atmospheric neutrino flux*
  - Input for prediction of neutrino fluxes for the *MiniBooNE* and *K2K* experiments
  - Input for *Monte Carlo* generators (GEANT4, e.g. for LHC, space applications)
  - Use identical targets at HARP

*miniBOONE will cross-check LSND result*
What about the absolute mass scale and hierarchy??

We only know mass differences squared $\Delta(m^2)$:

$$m_3 \quad \quad \quad m_2 \quad \quad \quad m_1$$

$m_2 \quad \quad \quad m_1 \quad \quad \quad ?

NEMO:

Neutrinoless double beta decay

$\beta\beta 0v$: beyond the SM $T_{1/2} \geq 10^{25}y$

$n \rightarrow p + e^- + \nu$

Lepton number violation

Very preliminary calibration!!!
I will leave CERN on the 1st of June
Moriond 2004