

DELPHI

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CERN

On behalf of the DELPHI Collaboration

LEP Jamboree

6 March 2003

Outline

- EW
 - $\sigma(WW)$ and $\sigma(ZZ)$
- QCD/ $\gamma\gamma$
 - α_s from event shapes
 - Coherence
- B-physics (LEP I)
 - b branching fractions
 - b -hadron lifetimes
 - B_s^0 oscillations
- Higgs Searches
 - SM Higgs
 - Invisible Higgs
- SUSY/EXOTICA Searches
 - Resonant $\tilde{\nu}$ production
 - $\gamma + \cancel{E}$
- Unless stated
 - Limits 95% C.L.
 - Results to be published
 - y -axis: Number of event/bin

Status of EW Measurements

DRAFTS

$\sigma(\mathbf{WW})$ $\sigma(\mathbf{ZZ})$
WW γ production

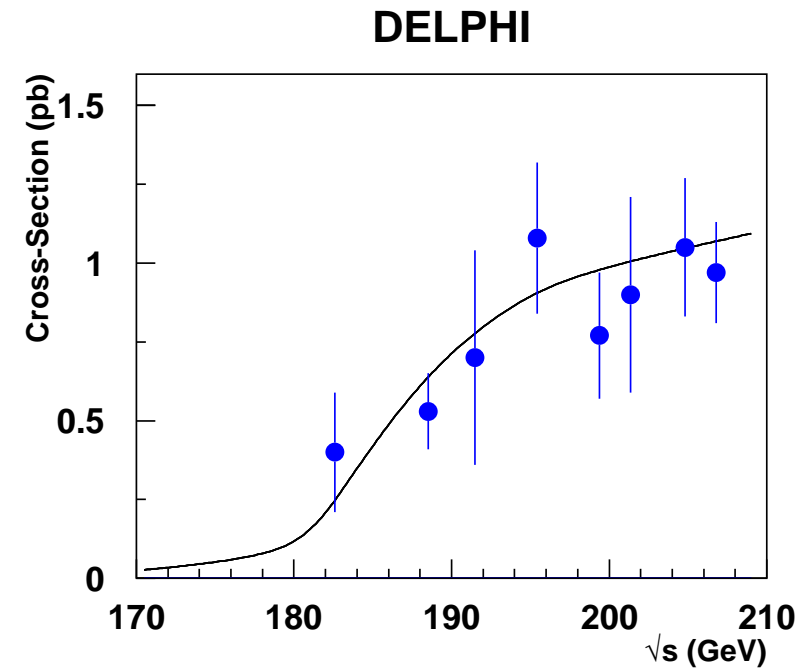
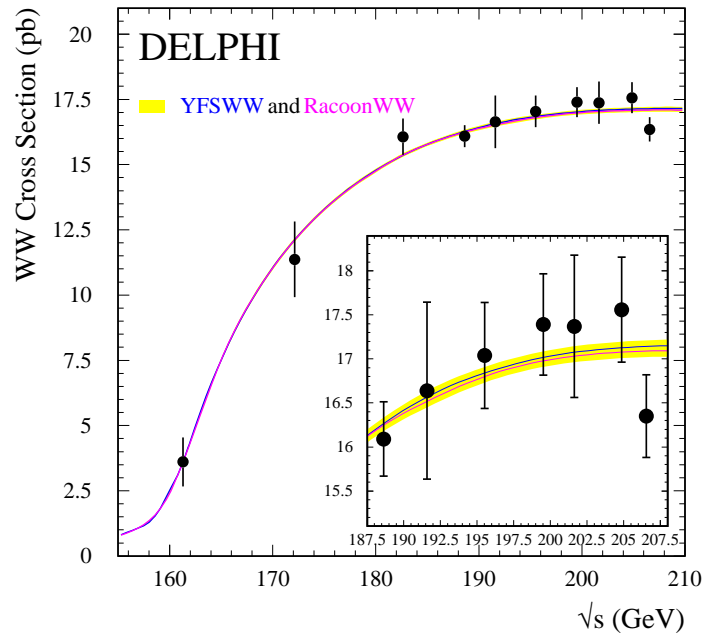
$A_{\text{FB}}(\text{b})$ inclusive $A_{\text{FB}}(\text{b})$ with leptons

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W mass and Width Z γ^*
Single-boson production Spin Density Matrix
Charged TGCs Neutral TGCs

$f\bar{f}$ production at LEP II $\gamma\gamma$ production at LEP II
 $Q\bar{Q}$ production at LEP II

WW/ZZ cross-sections



$$\mathcal{R}_{WW} = 1.001 \pm 0.012(\text{stat}) \pm 0.011(\text{syst}) \quad \mathcal{R}_{ZZ} = 0.91 \pm 0.08(\text{stat}) \pm 0.02(\text{syst})$$

Average over energies $\mathcal{R} = \left\langle \frac{\sigma_{\text{measured}}}{\sigma_{\text{predicted}}} \right\rangle$ include correlations

Status of QCD/ $\gamma\gamma$ Measurements

PUBLISHED

Energy evolution of event shapes

DRAFTS

α_s from event shapes

hadr. γ struct. func.

f_1 production

$\gamma\gamma \rightarrow J/\psi$

Ξ^\pm production

$\gamma\gamma \rightarrow \eta_c$

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BEC in WW

CR in WW

Transverse radii in BEC

W hadronic decays

Gluon fragm.

$\gamma\gamma \sigma(\text{total})$

no-tag high- p_t jets

double-tag σ

single-tag σ

Mult. in 3-jet events

Charged part. mult. at 206 GeV

Mult. in b and light quark events

Fragm. functions and α_s

Running m_b

$\gamma\gamma \rightarrow c\bar{c}/b\bar{b}$

$\gamma\gamma \rightarrow \pi\pi/KK$

$\gamma\gamma \rightarrow p\bar{p}$

$\gamma\gamma \rightarrow \rho\rho$

Running m_b in 4-jet events

α_s in 4-jets events

Angular distr. in 4-jet events

Soft photon excess in qq

QCD overview paper

$\gamma\gamma \rightarrow \eta_b$

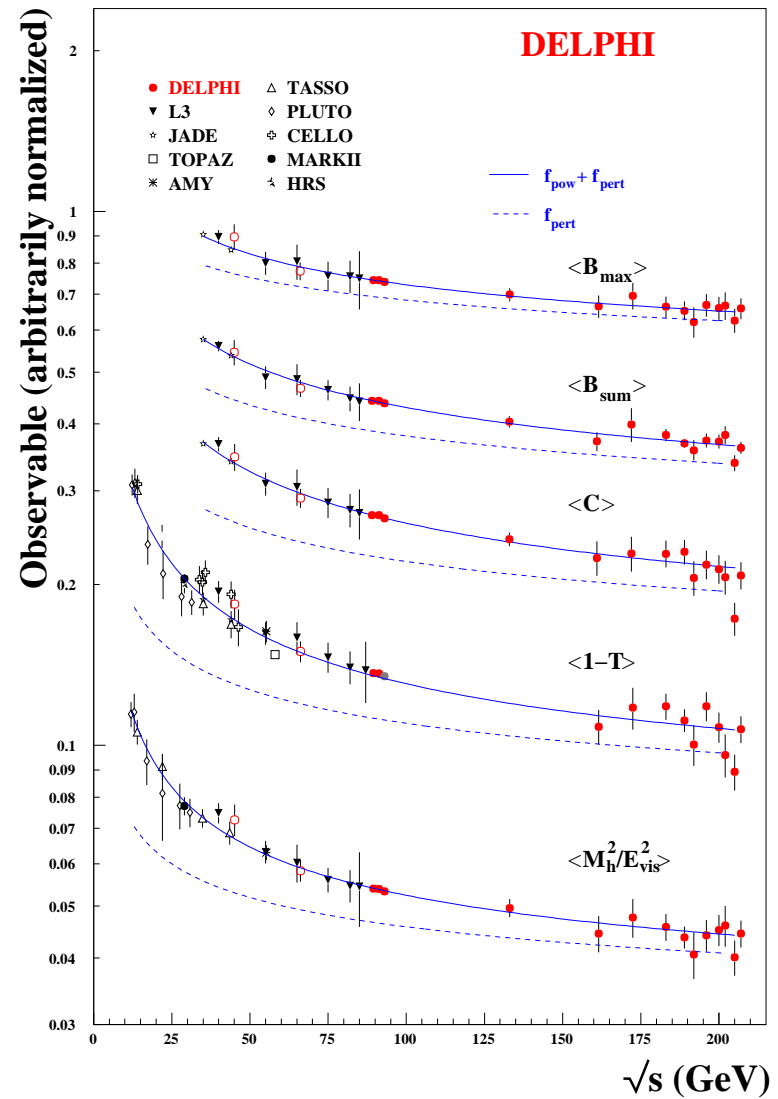
$\gamma\gamma \rightarrow 4\pi$

$\gamma\gamma \rightarrow KK\pi$

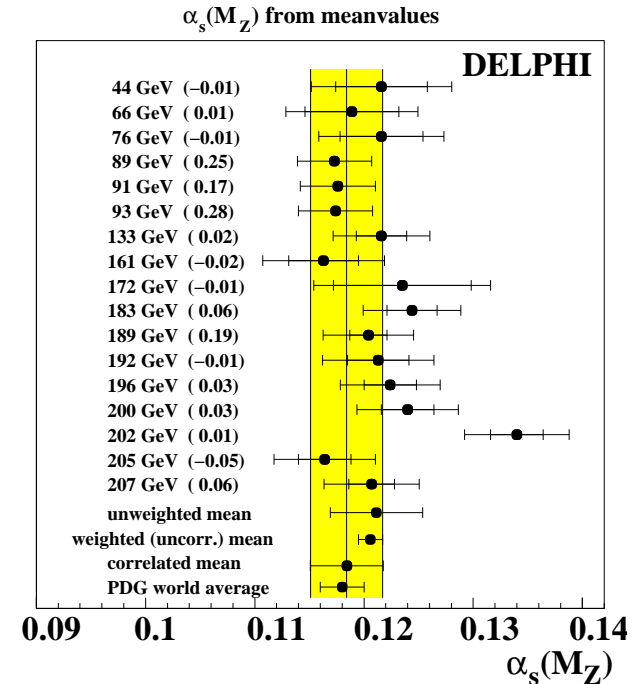
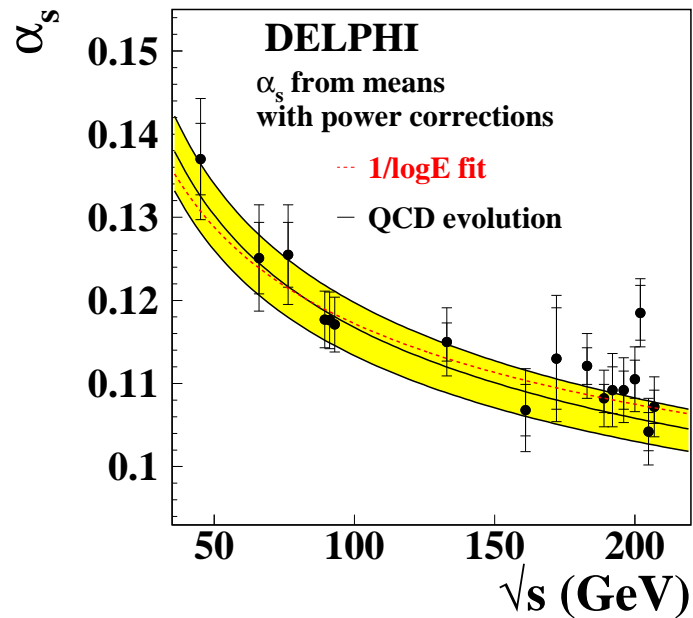
electron struct. func.

Determination of α_s

- Fit means of 5 event shapes including power corrections
 - Fit means vs \sqrt{s} to obtain non-perturbative contribution to each event shape and $\alpha_s(s)$



Determination of α_s (II)



- Check running of $\alpha_s(s)$

– Fit $b = \frac{d\alpha_s^{-1}}{d\log\sqrt{s}}$

$b = 1.11 \pm 0.09(stat) \pm 0.19(syst)$

[QCD(5 flavours) 1.27]

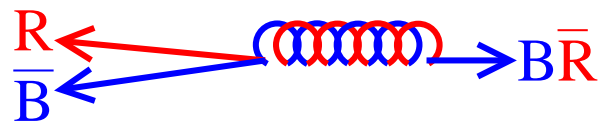
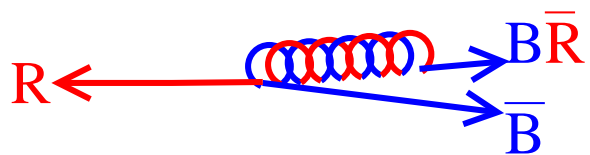
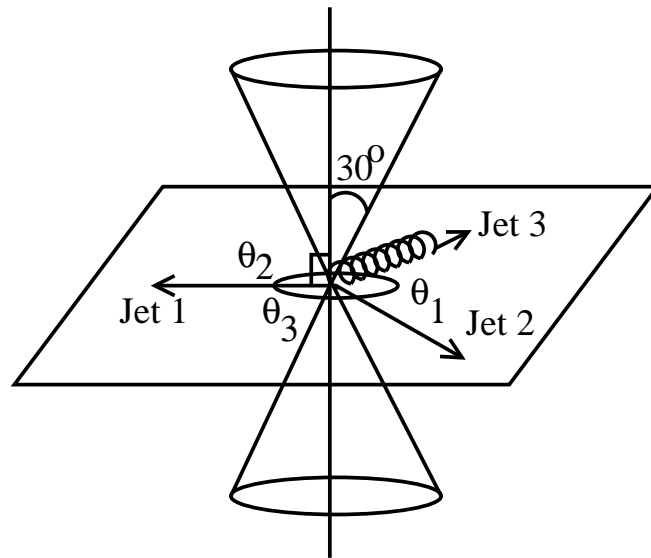
- Extrapolate all measurements to $\alpha_s(M_Z)$

$\alpha_s(M_Z) = 0.1184 \pm 0.0004(stat) \pm 0.0033(syst)$

- LEP II/LEP I weights similar
 LEP II smaller had. and scale errors
- Scale uncertainty dominates

Coherence

NEW ANALYSIS

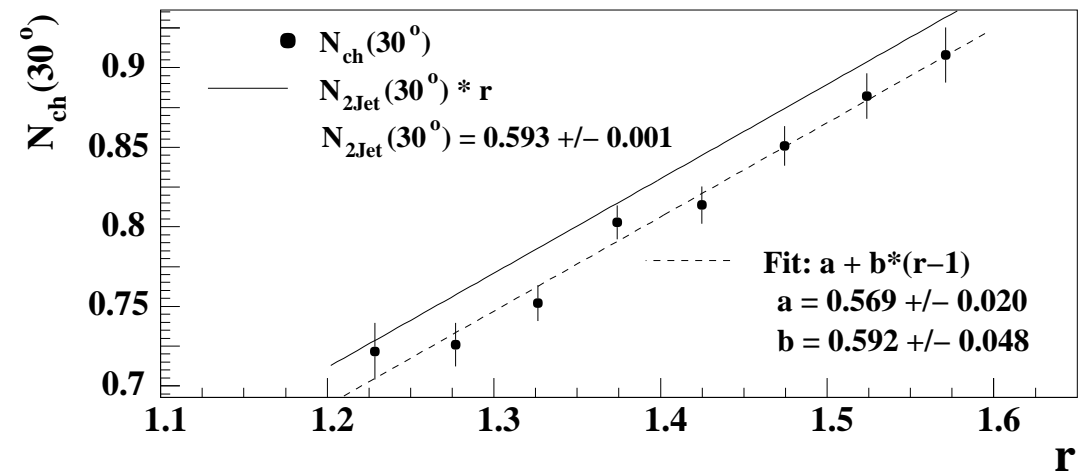
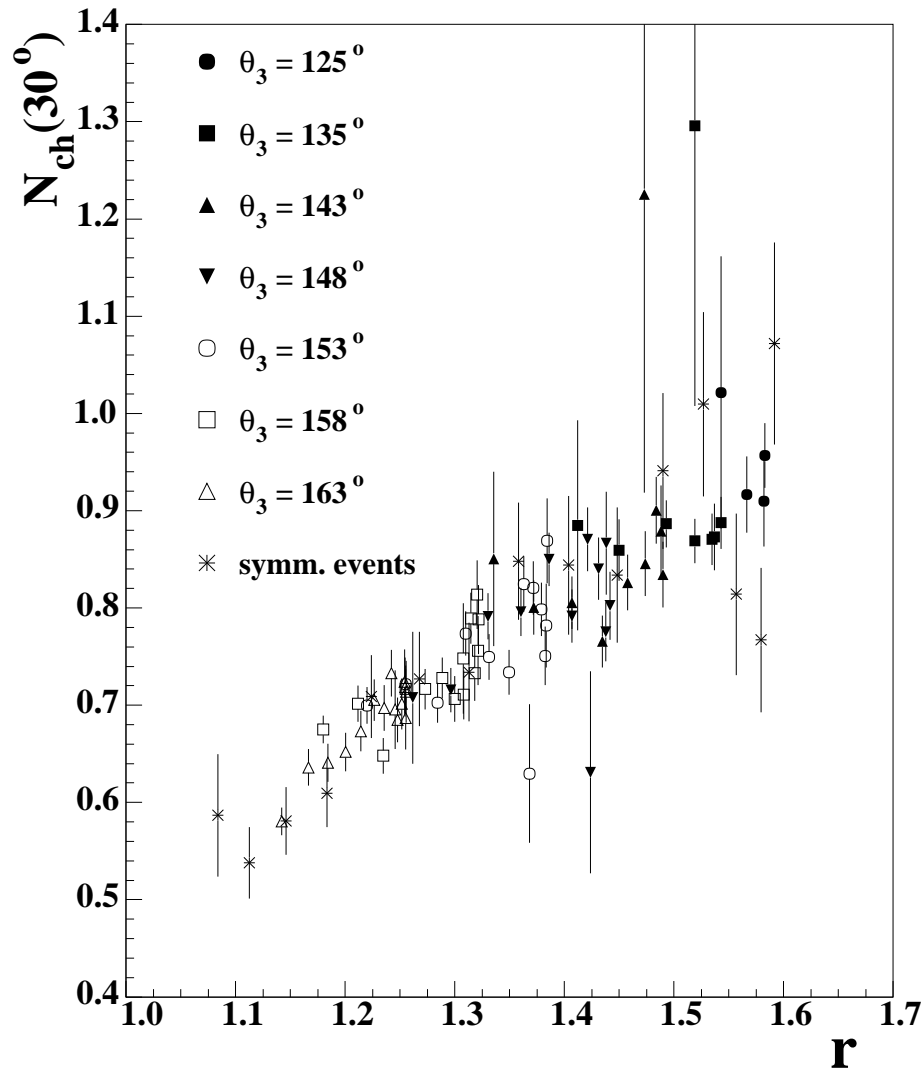


- Test coherence in different topologies of $q\bar{q}g$ events
- Use rate of production of hadrons at 90° to the plane of the $q\bar{q}g$ events
 - Measure $\langle N_{ch} \rangle$ /event in cone at 90°
- Prediction

$$\frac{\langle N_{ch}(3j) \rangle}{\langle N_{ch}(2j) \rangle} = r(\theta_2, \theta_3)$$

- 2 jet events
Gluon soft and collinear
 $r = 1$
- Y-events:
2 COLOUR – $\overline{\text{COLOUR}}$ sources
 $r = C_a/C_f$

Coherence (II)



- $\langle N_{ch} \rangle / \text{event}$ depends only on r
- Slope of $\langle N_{ch} \rangle / \text{event}$ vs r as expected

Status of Heavy Flavour Measurements

PUBLISHED

B_s osc. with incl. vertex $b \rightarrow$ wrong sign charm

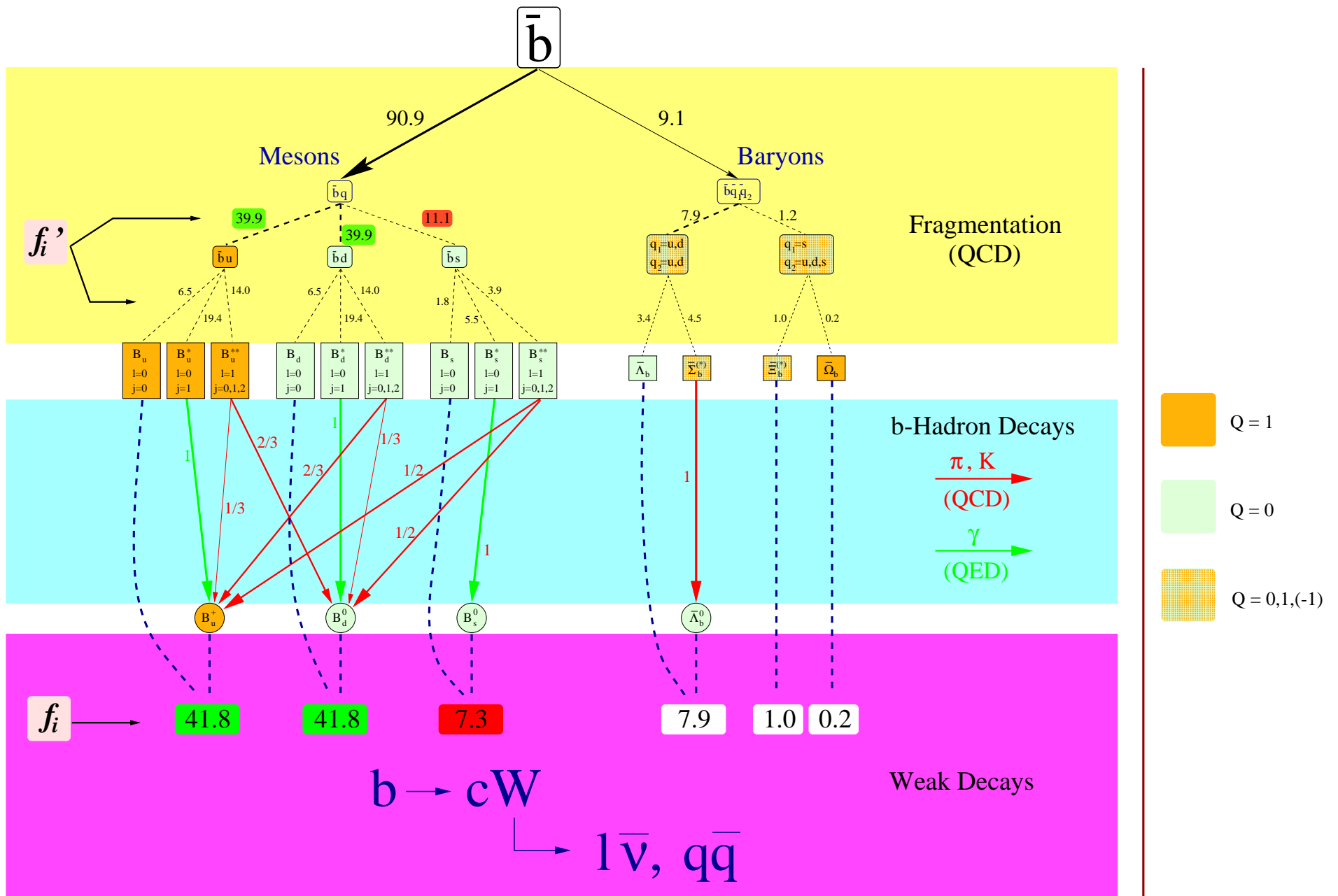
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b branching fractions B_s osc. with incl. $l/D_s l$
 B^0/B^+ lifetimes Λ_b form factor
B decays V_{cb}

BR($\tau \rightarrow$ had) τ lifetime
 $\gamma\gamma \rightarrow \tau^+\tau^-$

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b fragmentation Moments analysis
 $B^{*(*)}$ Ξ_c



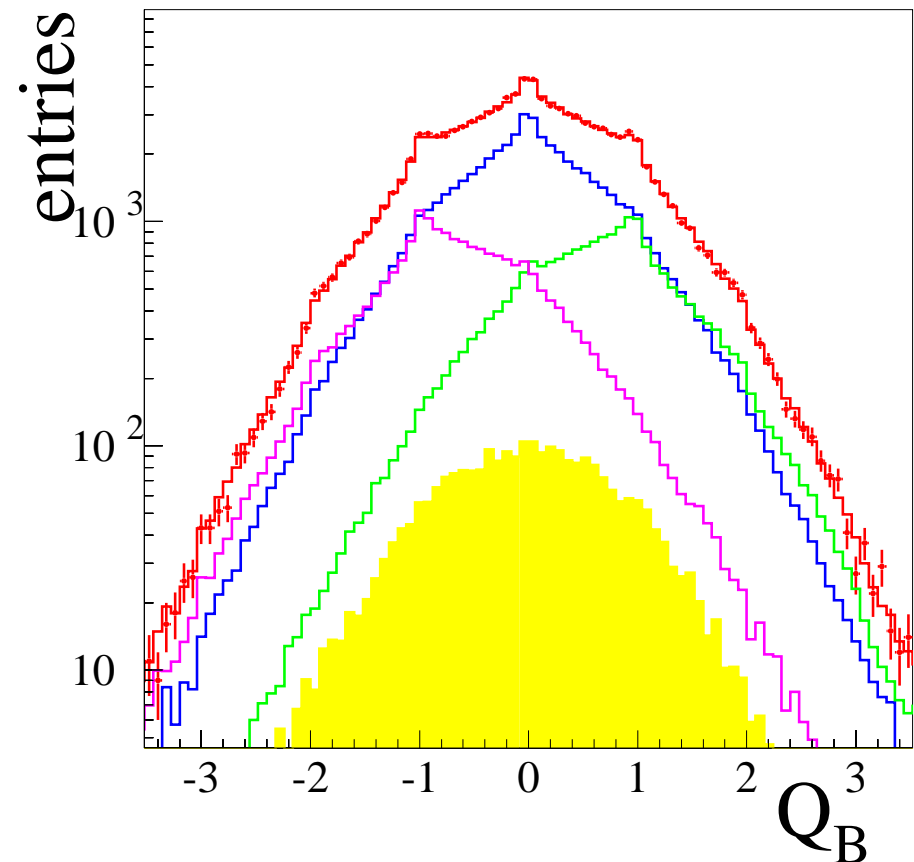
(numbers from simulation)

b branching fractions (II)

- First direct measurement of b fragmentation rates into weakly decaying charged and neutral b -hadrons
- Probability that a track comes from a b -decay given by a **Neural Net**
- Compute b hadron charge

$$Q_b = \sum_{hem} Q_i \cdot P_b^i$$

- Calibrate Q_b distributions from data by comparing opposite hemispheres
 - Fraction of events with opposite sign Q_b



b branching fractions (III)

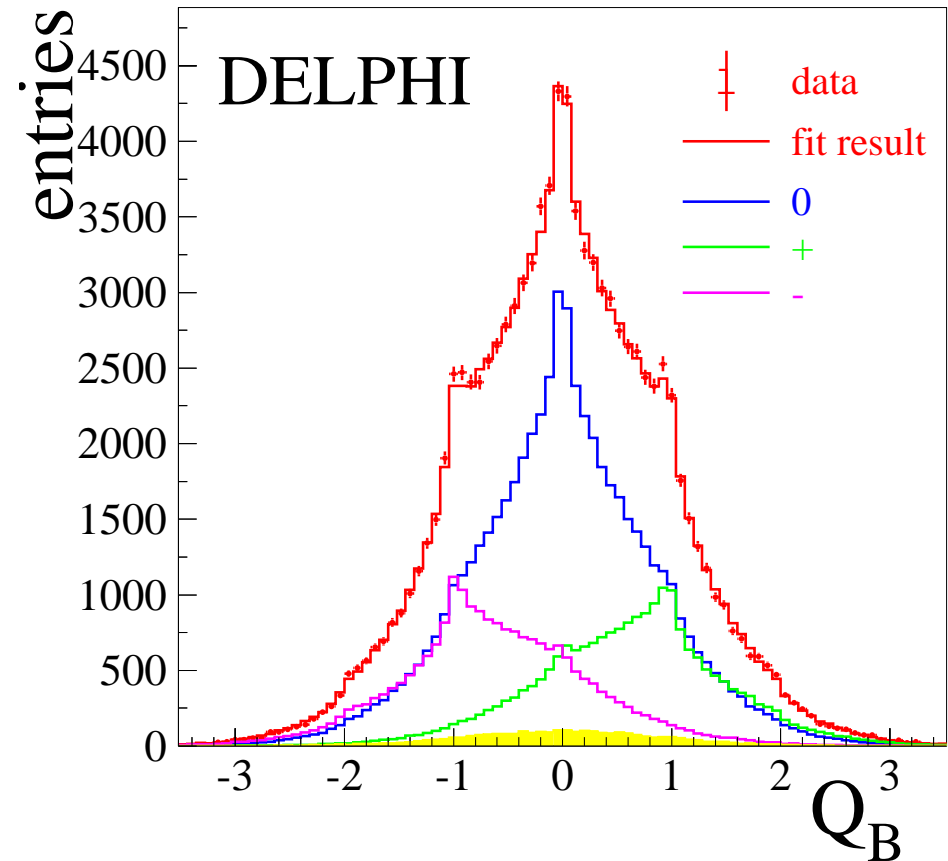
- Fit Q_b in data to expected shapes for charged and neutral b -hads.

$$f^+ = 42.06 \pm 0.81(\text{stat.}) \pm 0.91(\text{syst.})\%$$

- Subtract b -baryons

$$f_{B_u} = 40.96 \pm 0.81(\text{stat.}) \pm 1.14(\text{syst.})\%$$

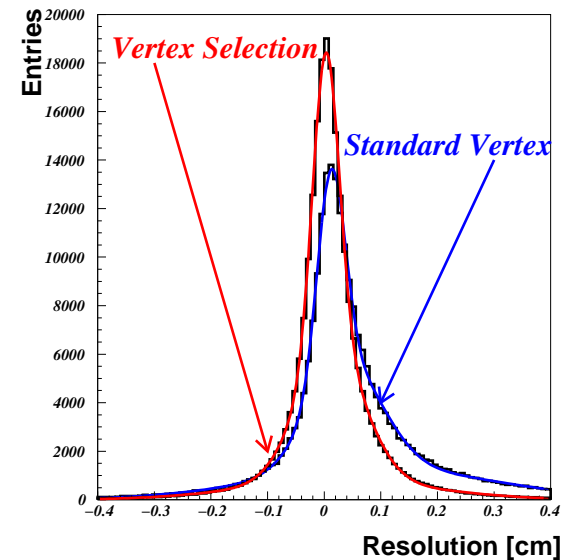
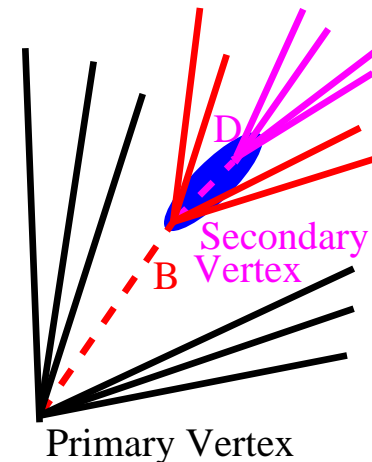
- Dominant systematic comes from calibration of Q_b
- Single most precise measurement of f^+



Precise b -hadron lifetimes

- Measure $\langle \tau_{b\text{-hadron}} \rangle$ and τ_{B^+} , τ_{B^0}
- Reduce bias from cascade D decays
- **Neural Nets** used to
 - Order tracks from B decay/D decay for reconstruction of B vertex
 - Weight tracks from b decays/primary vertex
 - Estimate of the B hadron momentum
 - Select B^0 and B^+ events for τ fits
- Binned χ^2 fit to proper time distribution
- Weight events in MC for, *e.g.*
 - B_s^0 and B^+ fractions

best model of hadronisation and decays



Precise b -hadron lifetimes (II)

- Reweight MC events for different lifetimes

- don't need many samples with different lifetimes

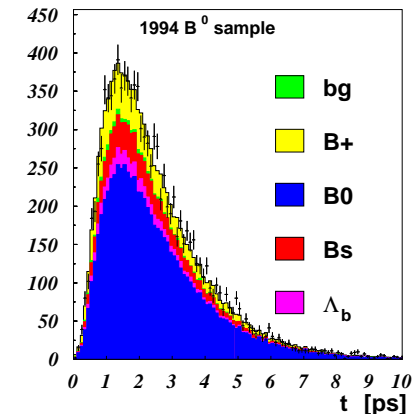
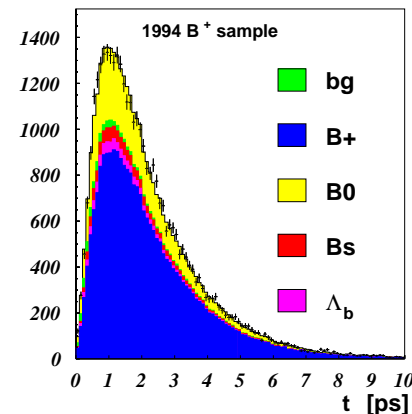
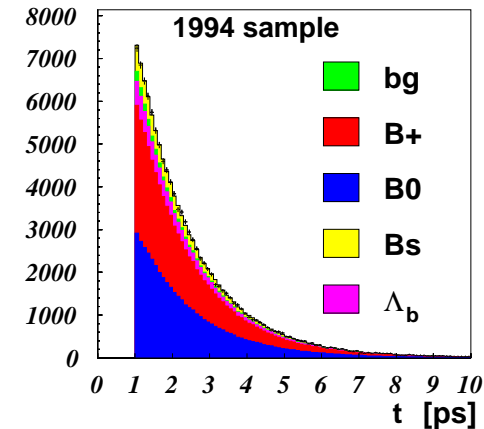
- Results

$$\begin{aligned} \langle \tau_b \rangle &= 1.568 \pm 0.005 \pm 0.009 \quad [\text{ps}] \quad (170\text{k } b) \\ \tau_{B^+} &= 1.625 \pm 0.013 \pm 0.017 \quad [\text{ps}] \quad (54\text{k } B^+) \\ \tau_{B^0} &= 1.543 \pm 0.020 \pm 0.033 \quad [\text{ps}] \quad (16\text{k } B^0) \\ \frac{\tau_{B^+}}{\tau_{B^0}} &= 1.051 \pm 0.019 \pm 0.024 \end{aligned}$$

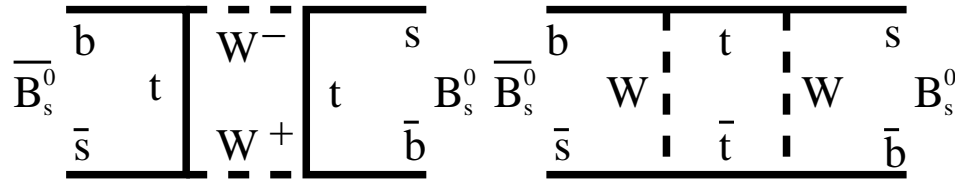
- Main sources of systematic errors

- NN cuts to separate B^0/B^+
- Detector resolution

Preliminary

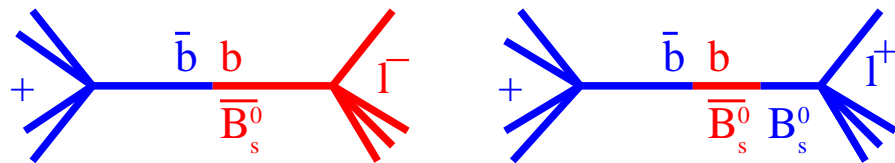


$B_s^0 - \bar{B}_s^0$ Oscillations



- Oscillation

$$\mathcal{P}^{\frac{unmix}{mix}} = \frac{1}{2\tau} e^{-\frac{1}{\tau}} [1 \pm \cos(\Delta m_s t)]$$



No Oscillation

Oscillation

- Fit fractions of *like/unlike-sign* events vs t

- Inclusive leptons *New*

- High statistics ($\sim 68k$ events)
- Use NN to improve B_s^0 purity

- D_s -lepton *Update*

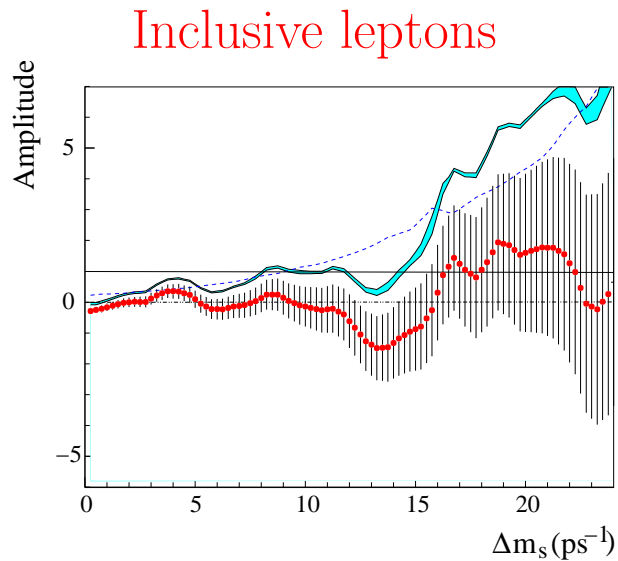
- Exclusive reconstruction of the D_s
- Low stats (~ 400 events)
- High B_s^0 purity

- For rapid oscillations (large Δm_s)
Need good control of t resolution

- Separate events with good t resolution
- Good decay length resolution
- Good B_s^0 energy resolution

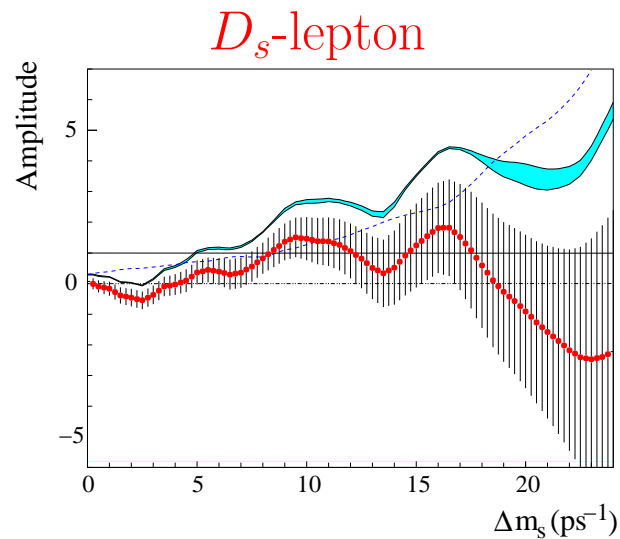
$B_s^0 - \overline{B}_s^0$ Oscillations (II)

- Fit using the *amplitude method*
- $\mathcal{P}_{mix}^{unmix} = \frac{1}{2\tau} e^{-\frac{1}{\tau}} [1 \pm \mathcal{A} \cos(\Delta m_s t)]$
- $\mathcal{A} = 1 \rightarrow$ mixing at Δm_s
- $\mathcal{A} = 0 \rightarrow$ no mixing at Δm_s



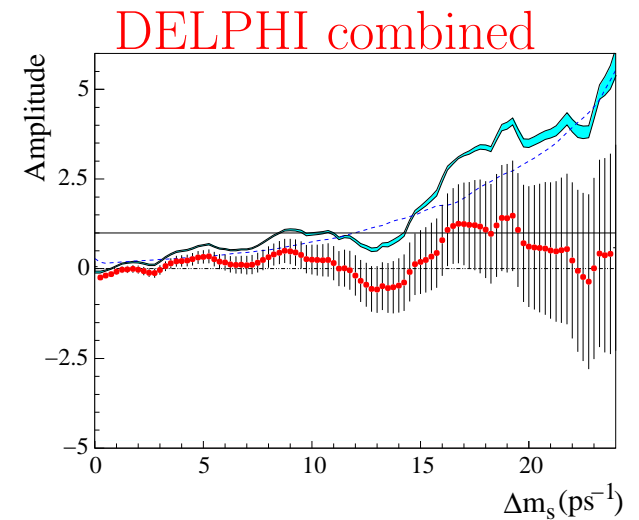
$$\Delta m_s > 8.0 \text{ ps}^{-1}$$

$$\text{Sensitivity } \Delta m_s = 9.1 \text{ ps}^{-1}$$



$$\Delta m_s > 4.9 \text{ ps}^{-1}$$

$$\text{Sensitivity } \Delta m_s = 8.6 \text{ ps}^{-1}$$



$$\Delta m_s > 8.5 \text{ ps}^{-1}$$

$$\text{Sensitivity } \Delta m_s = 12.0 \text{ ps}^{-1}$$

Status of Higgs Searches

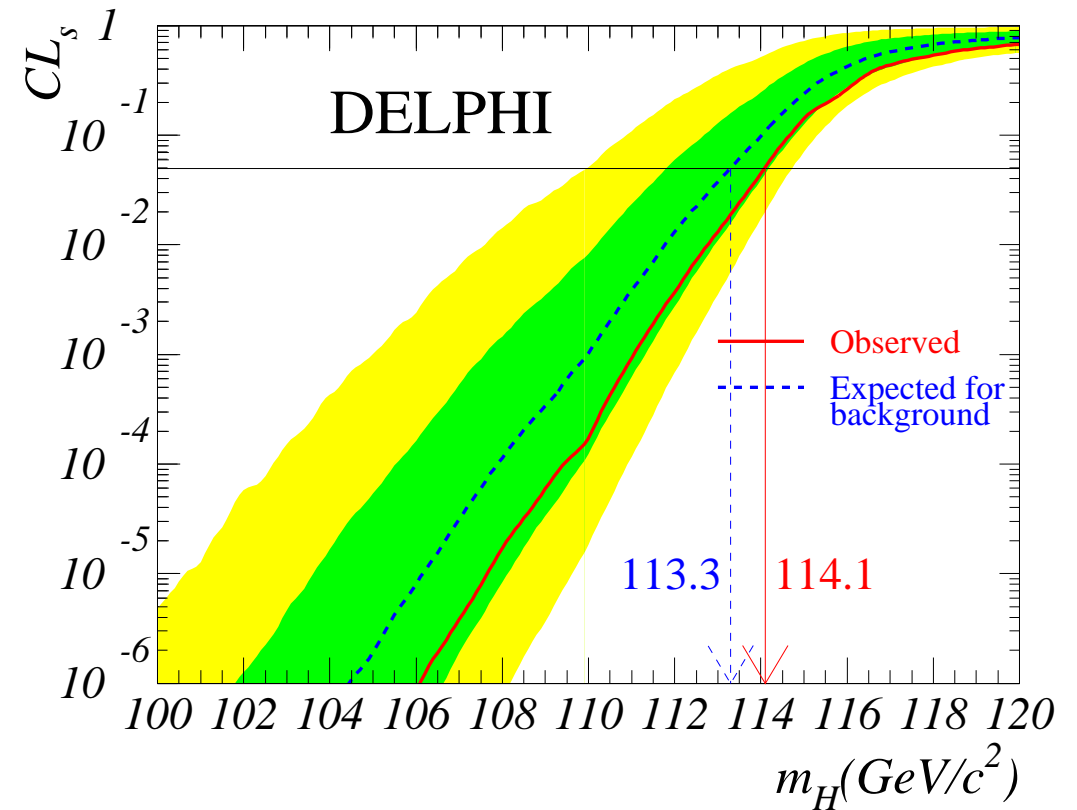
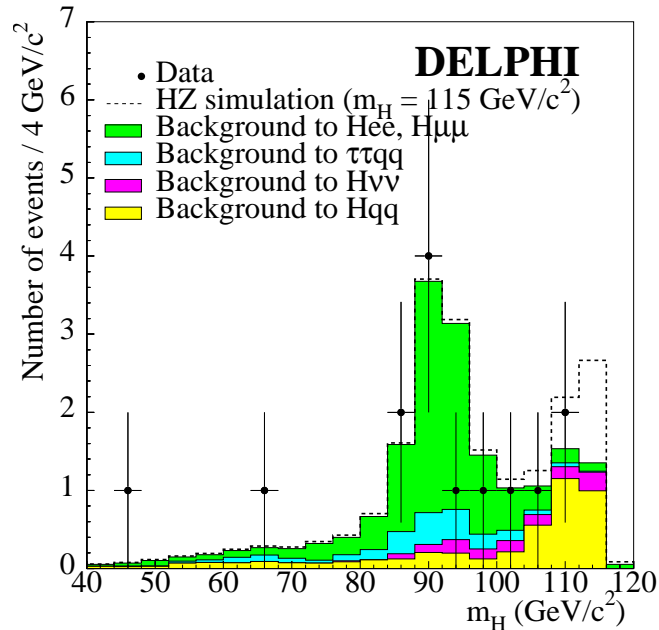
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SM+MSSM Neutral Higgs Invisible Higgs
Charged Higgs 2HDM Extended Models

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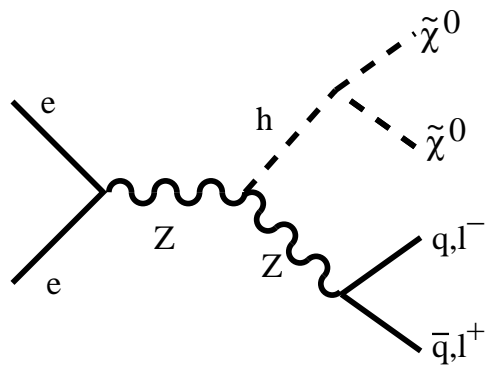
Extensions to the MSSM Neutral Higgs Searches

SM Higgs

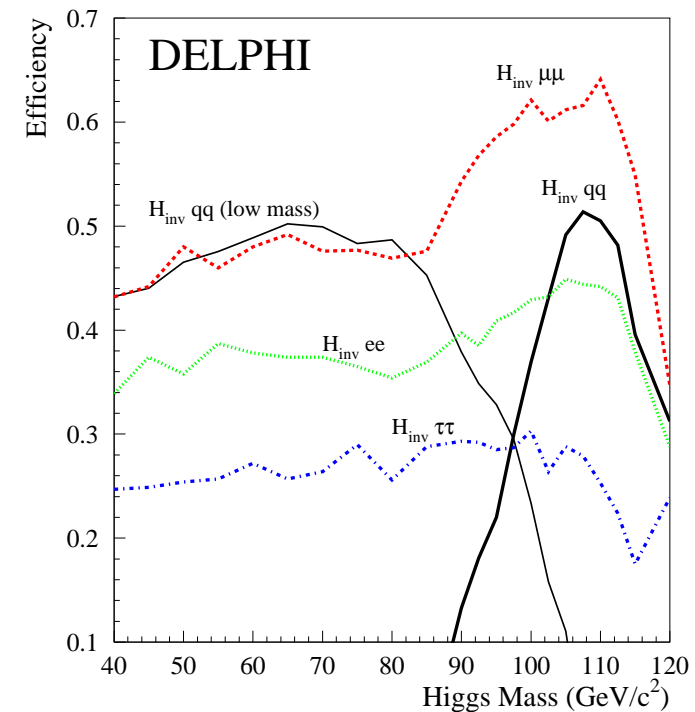


- Result unchanged since summer 2002
- Limit: $M_H > 114.1 \text{ GeV}/c^2$
(expected $113.3 \text{ GeV}/c^2$)
- Paper with EP referee

Invisible Higgs



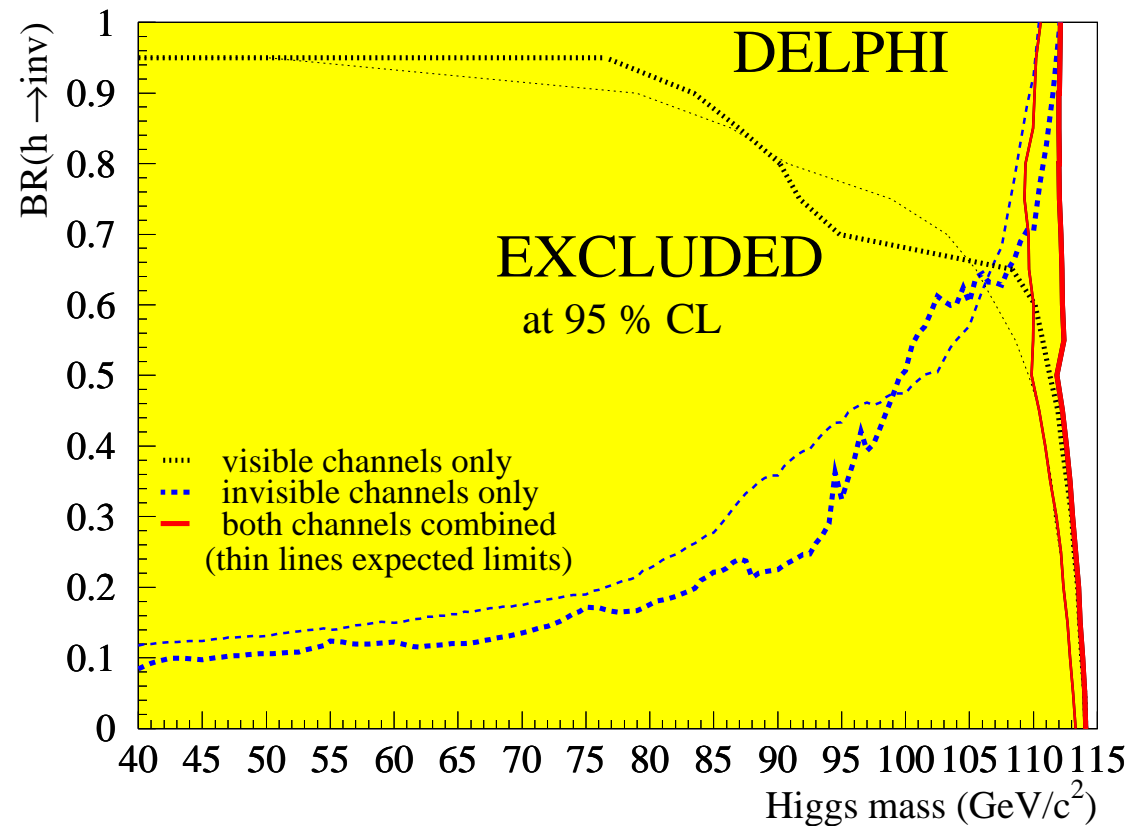
- Signatures: $m_{vis} \sim M_Z$; \cancel{E}
- 5 search channels
 - $q\bar{q}$: high Higgs mass; low Higgs mass
use IDA tuned for different M_H
 - l^+l^- : e^+e^- $\mu^+\mu^-$ $\tau^+\tau^-$
use cuts ; no overlap in samples



| Channel | Obs | Expected |
|-------------------|-----|-----------------|
| $q\bar{q}$ (high) | 153 | 160.6 ± 8.1 |
| $q\bar{q}$ (low) | 213 | 226.8 ± 5.6 |
| $\mu^+\mu^-$ | 18 | 25.7 ± 0.9 |
| e^+e^- | 20 | 29.7 ± 1.1 |
| $\tau^+\tau^-$ | 37 | 43.9 ± 1.6 |

Invisible Higgs (II)

- Limit $BR(h \rightarrow \text{inv}) = 1$
 $M_H > 112.1 \text{ GeV}/c^2$
 (expected 110.5 GeV)
- Combine with SM Higgs search
 $M_H > 112.0 \text{ GeV}/c^2$
 For any $BR(h \rightarrow \text{inv})$



Status of SUSY and Exotica searches

PUBLISHED

Resonant $\tilde{\nu}$ production Doubly charged Higgs,
Glauino as LSP GMSB
SUGRA

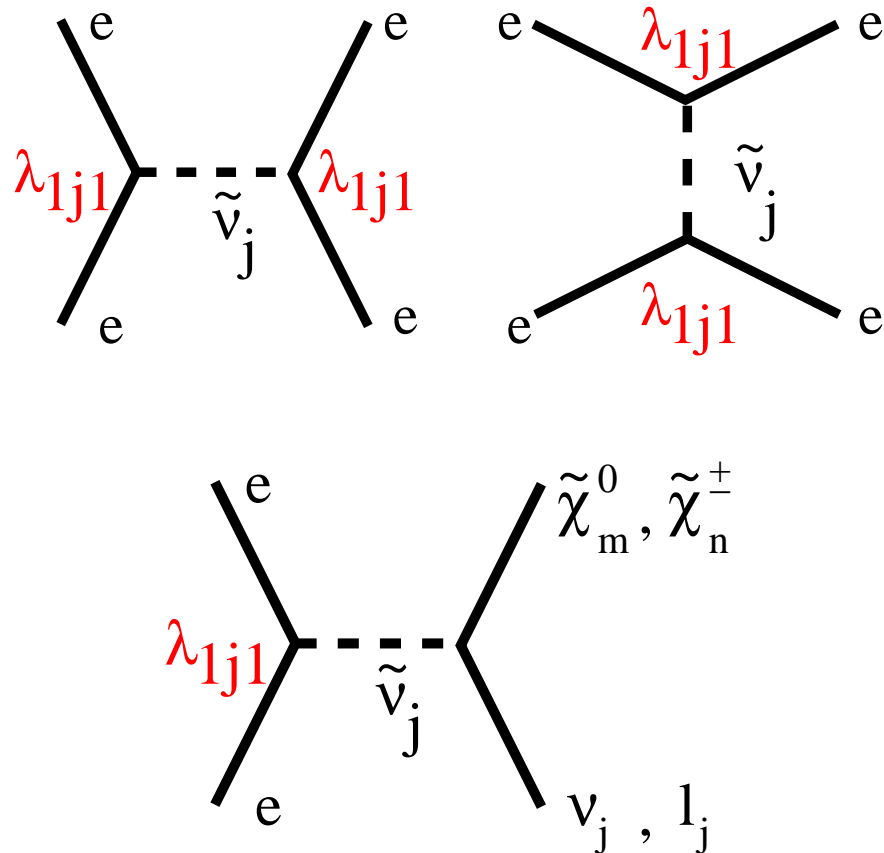
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AMSB RPV
 $\gamma \tilde{E}$ Single top via FCNC

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2HDM SUSY Searches Flavour indep. Higgs
Single top production Single top via contact int.
Leptoquarks Fermiophobic Higgs
Excited leptons b'

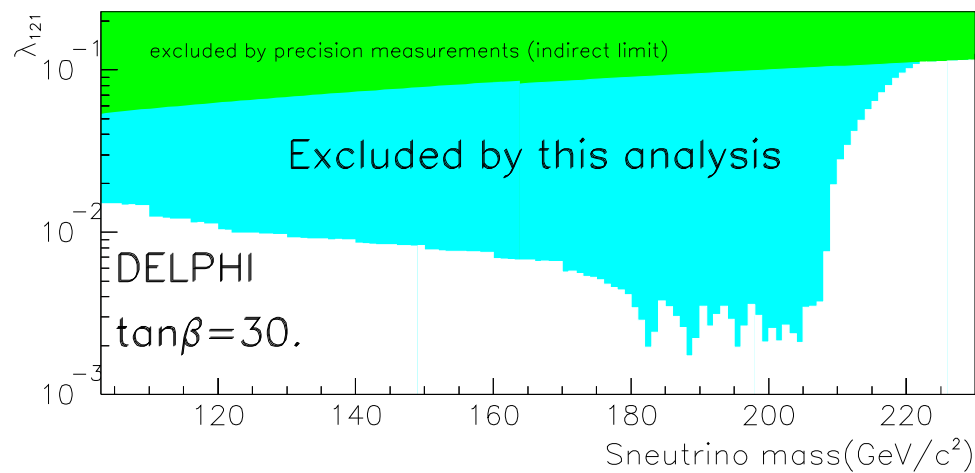
Resonant $\tilde{\nu}$ Production



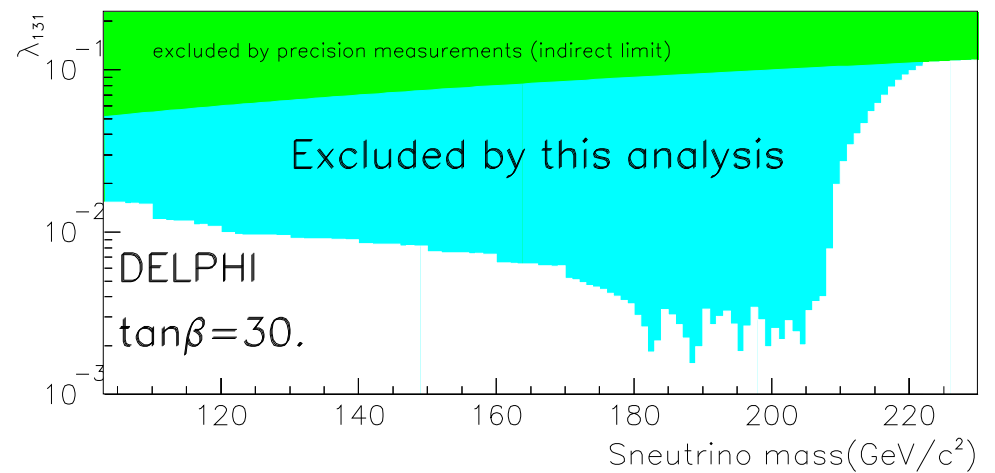
- \mathcal{R} - superpotential $\lambda_{ijk} L_i L_j \bar{E}_k$
- For $M_{\tilde{\chi}} < M_{\tilde{\nu}}$ indirect decay of $\tilde{\nu}$ possible
- For small λ may dominate over direct decay
 - $\sigma \sim \Gamma(ee)\Gamma(X)$
 - Direct decay $\sim \lambda_{1j1}^4$
 - Indirect decay $\sim \lambda_{1j1}^2$
- 3 topologies - depending on $\tilde{\chi}$ decay modes
 - 2 leptons + \cancel{E}
 - 4/6 leptons with/without \cancel{E}
 - ≥ 2 leptons + ≥ 2 jets
 - Semi-leptonic analyses different for $j = 2, 3$ due to l_j

Resonant $\tilde{\nu}$ Production (II)

FINAL RESULT

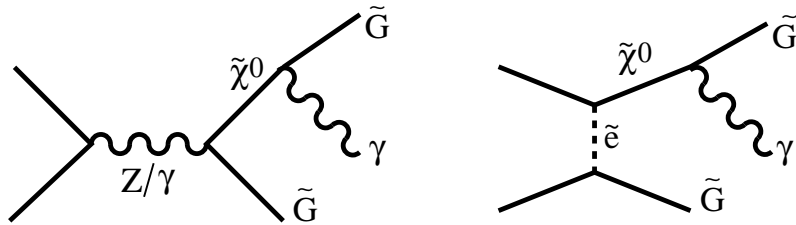
 λ_{121}


Total expected 155.6 ± 1.6 events
 Total observed 150 events
 Limits for $\Gamma_{\tilde{\nu}} = 150$ MeV

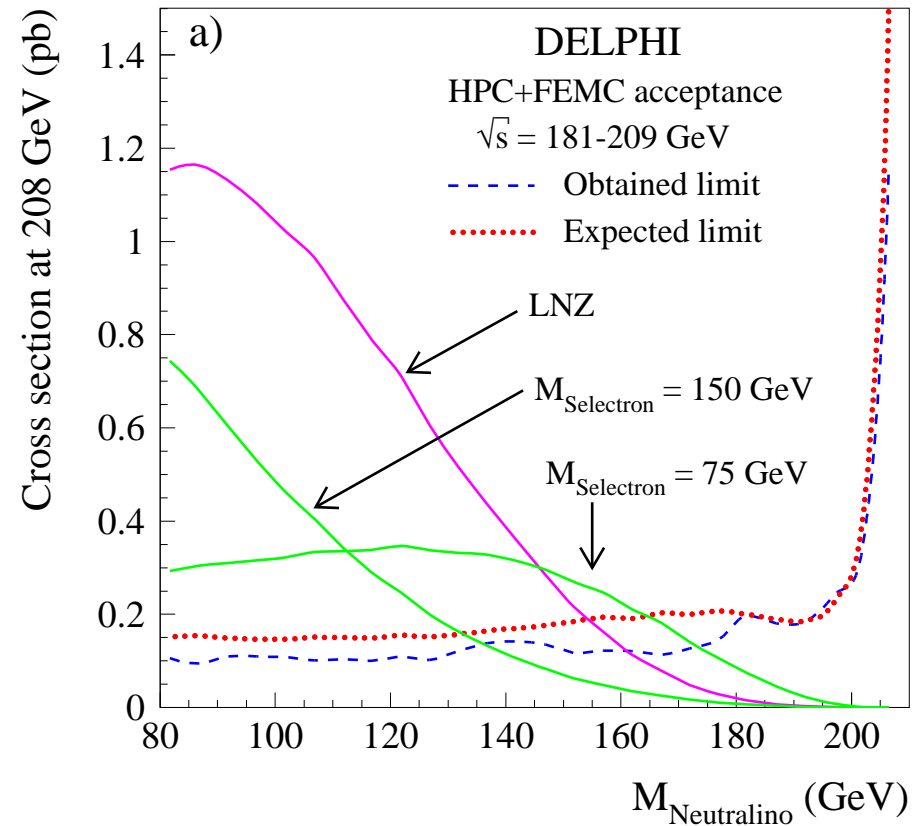
 λ_{131}


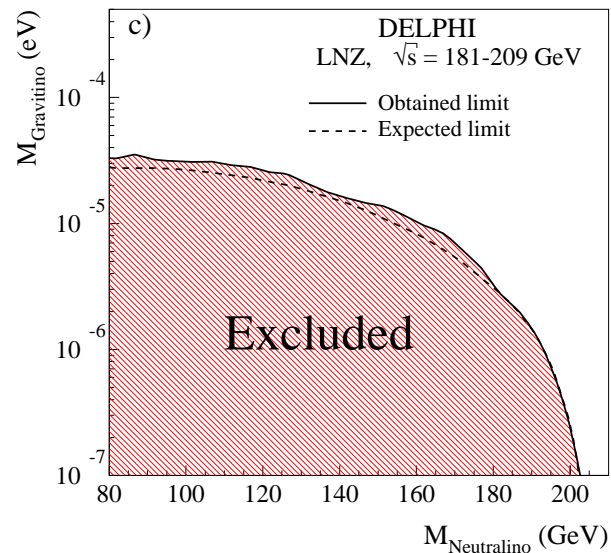
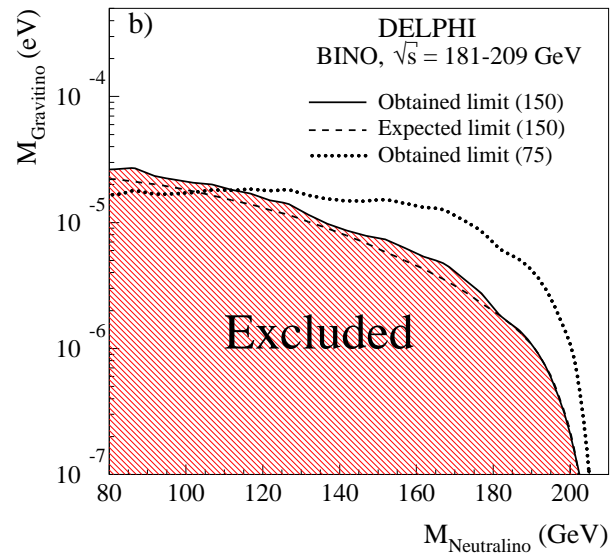
Total expected 154.3 ± 1.6 events
 Total observed 129 events
 Limits for $\Gamma_{\tilde{\nu}} = 150$ MeV

$$\gamma + \cancel{E}$$



- Cross-section depends on
 - Composition of the $\tilde{\chi}^0$
 - $M_{\tilde{\chi}}$ and $M_{\tilde{G}}$
 - $M_{\tilde{e}}$
- Obtain σ limits at 208 GeV vs $M_{\tilde{\chi}}$
 - \sqrt{s} and $\cos\theta_\gamma$ dependence of limits only weakly model dependent

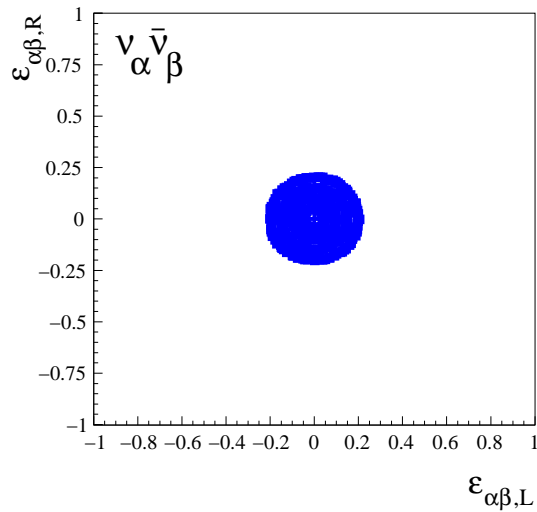
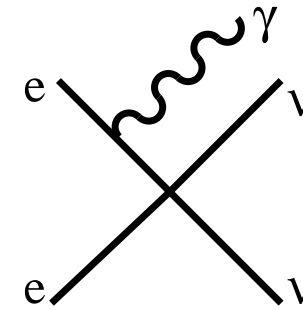
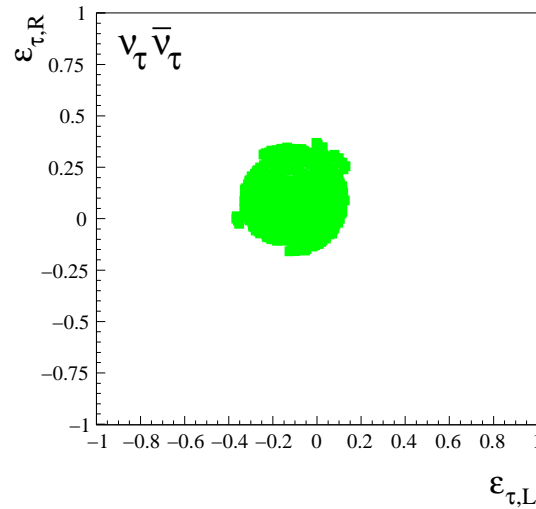
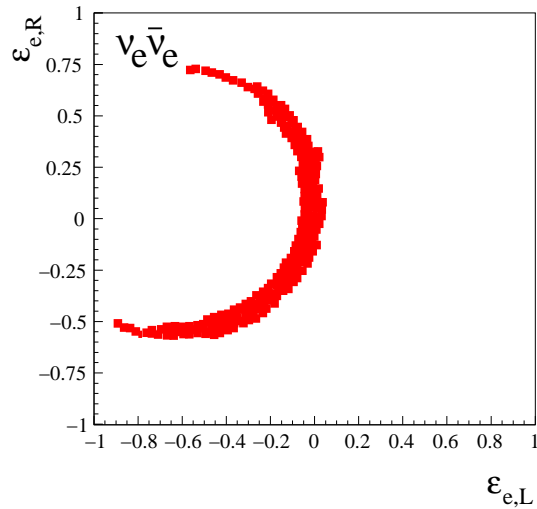


$\gamma + \cancel{E}$ (II)


- For $\tilde{\chi}^0$ bino-like, obtain limits on $M_{\tilde{\chi}}$ vs. $M_{\tilde{G}}$
 - for given $M_{\tilde{e}}$

- LNZ model of SUSY breaking
 - only 2 free parameters $M_{\tilde{G}}$ and $M_{\tilde{\chi}}$
 - These fix the composition of the $\tilde{\chi}^0$
 - Favourable for significant σ

$\gamma + \cancel{E}$ (III)



- Search for C.I. between e and ν

- Put limits on $\epsilon_{L/R} = g_{L/R}^2 / \Lambda_{L/R}^2$

- 3 different interpretations

Consider coupling to

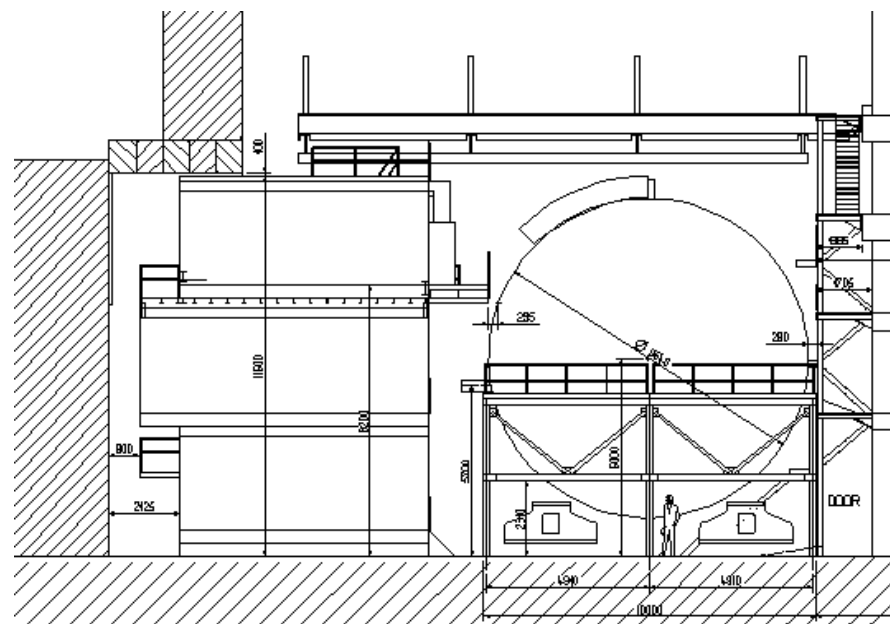
- $\nu_e \bar{\nu}_e$ - interf. with s/t -chan. SM
- $\nu_\mu \bar{\nu}_\mu / \nu_\tau \bar{\nu}_\tau$ - interf. with s -chan. SM
- $\nu_\alpha \bar{\nu}_\beta$ ($\alpha \neq \beta$) - no interf. with SM

Data archiving: a reminder

- Data are stored in **/castor**
 - To allow access to low level information in case features need to be investigated in detail
 - Raw data from the pit: 6003 GB in 58186 files
 - Real data DSTs: 7370 GB in 76292 files
 - MC DSTs: 10043 GB in 215915 files
- We have produced a CD with all DELPHI analysis software
- Would like longterm support for **FORTRAN**
- Have developed an **OO** framework for data access
 - Less well used/tested within DELPHI
- Starting internal discussion about who will be given access to data
 - Existing collaboration members only
 - ↓
 - The whole world

Status of DELPHI

- Dead - but not buried
- DELPHI will be reopened to the general public in Summer
 - Thanks to our friends on LHCb
- DELPHI has been moved to rear/side of UX8
- Civil engineering
 - Erection of a platform
 - Discussing creation of extra elevator stop



Conclusions

- Status of Physics Analysis
 - Since July 2002 Published 8 papers
 - Currently 28 drafts in circulation
 - Expect to produce ~ 30 additional publications
 - *i.e.* ~ 60 publications to come
- Support now will ensure
 - High quality final publications on complete DELPHI data set
 - Combination of results between LEP experiments
 - Maximising the scientific return on the total investment in DELPHI and LEP