R. Yoshida, ANL
7 September 2004 at DESY

A summary of experimental results at ICHEP04

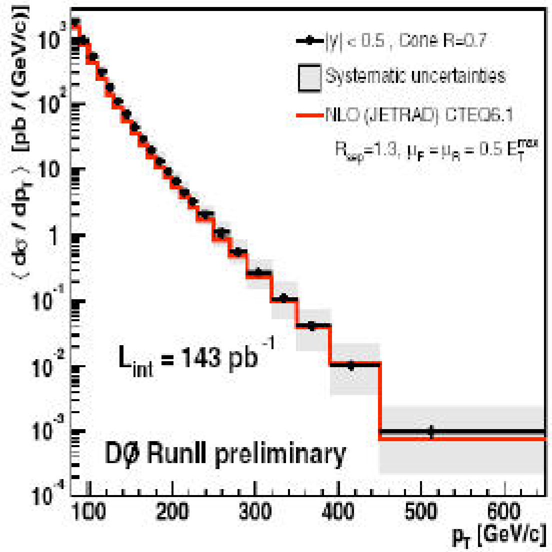
- QCD at Tevatron II
- Hadron spectroscopy
- Quark-Gluon plasma
- Quark mixing
- Neutrino mixing
- Electroweak (top mass)
- Higgs search
- Particle astrophysics and cosmology
- Final remarks
    - Not summarized: results from HERA, future colliders, detectors.. and many others.

Most slides taken from plenary talks:

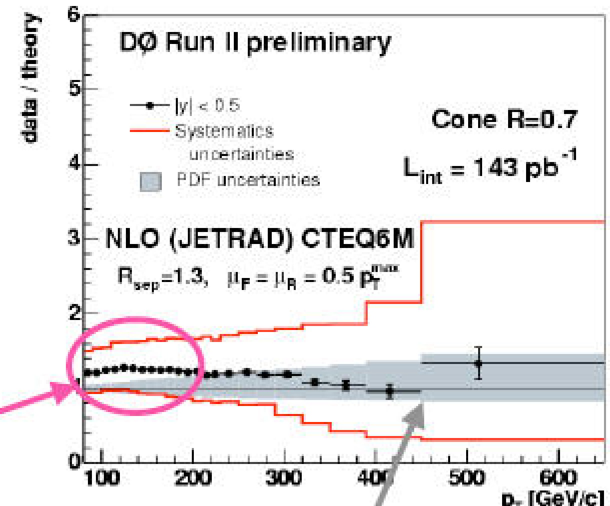
My comments are in red boxes

Apologies in advance for oversimplifications, omissions and mistakes.

Inclusive Jet P_T Cross section



Agreement with theory within systematic uncertainties (dominated by jet-energy scale)



Hadronization correction needed?

NLO uncertainty due to gluon @ high x

First jet cross-section results from the Tevatron II: Jet-energy scale unc. still large (should improve with more data)

Inclusive Jet Cross section: K_T algorithm

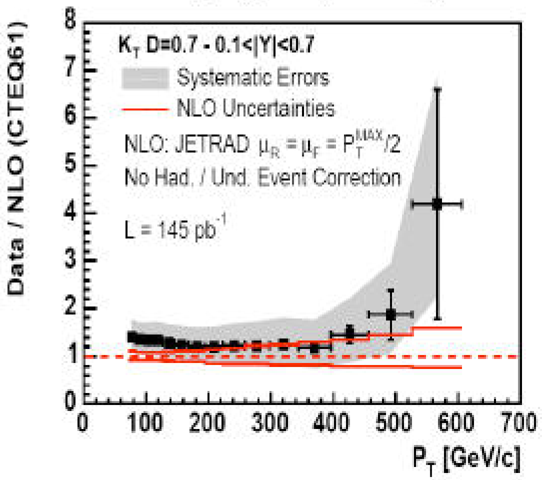
- Inclusive K_T algorithm

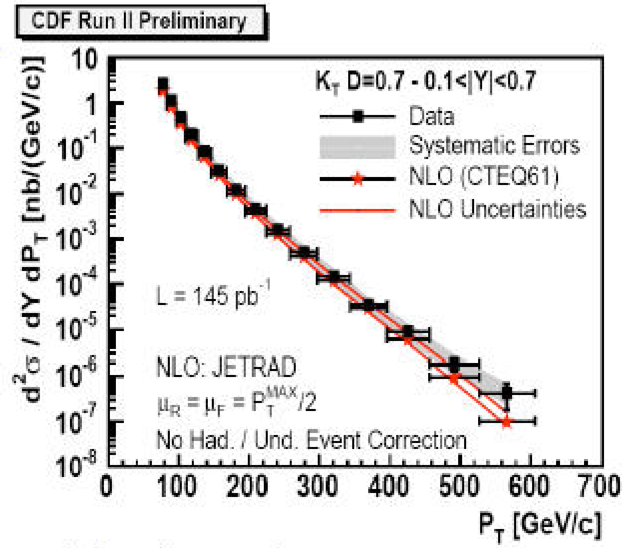
$$d_{ij} = \min(P^2_{T,i}, P^2_{T,j}) \frac{\Delta R^2}{D^2} \quad \Delta R^2 \rightarrow (y_i - y_j)^2 + (\varphi_i + \varphi_j)^2$$

$$d_i = (P_{T,i})^2$$

$D^2 \rightarrow$ jet size

- Infrared and collinear safe
- No merging / splitting





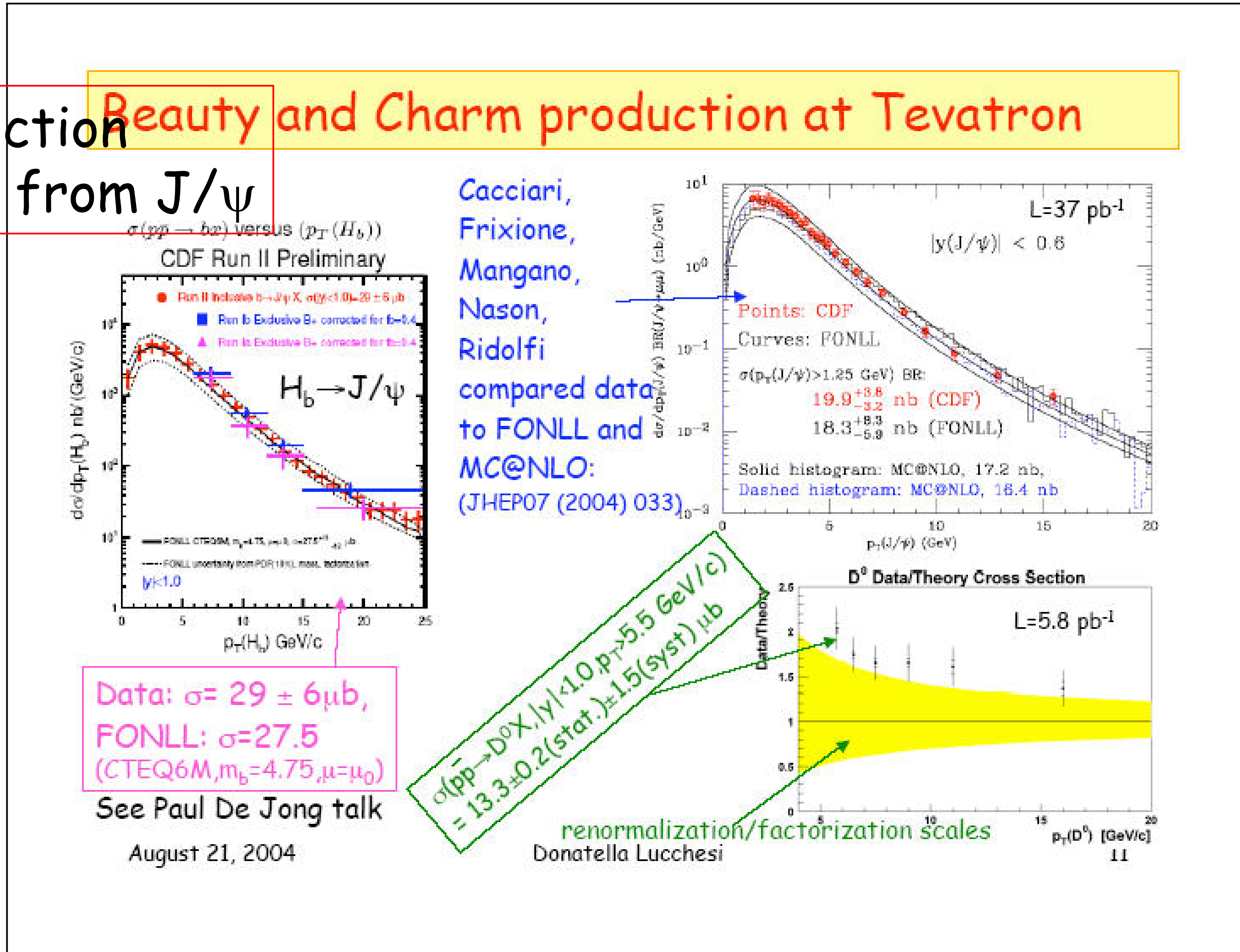
- Reasonable data-theory agreement
- NLO still needs to be corrected for Hadronization /Underlying Event

August 21, 2004 Donatella Lucchesi 7

Tevatron is starting to use modern jet algorithms

QCD

B production derived from J/ψ



Beauty and Charm production at Tevatron: agree with latest theory. Consistent picture with LEP and HERA?

Summary of Θ^+ pentaquark reports

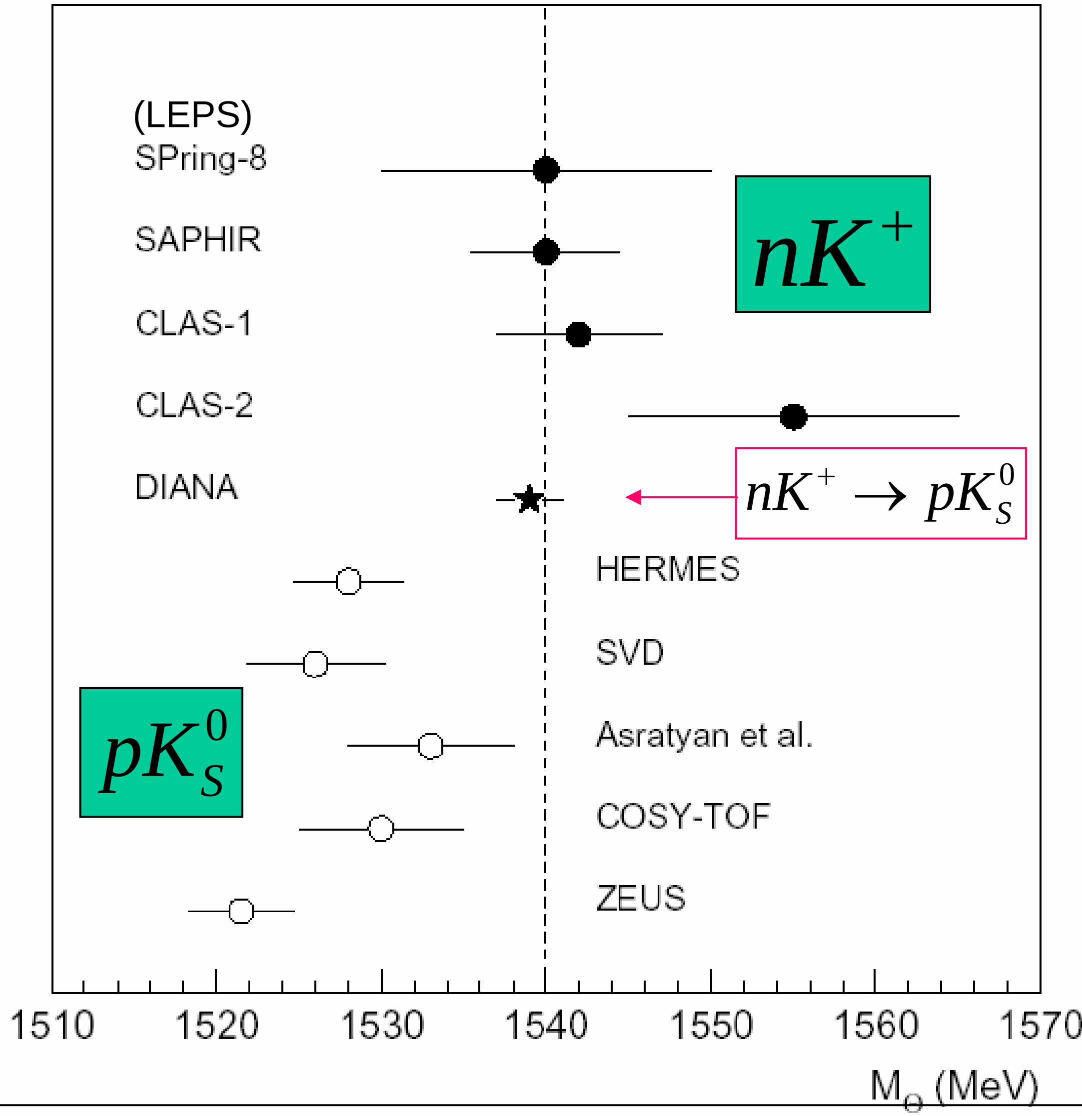
Jin

Experiment	Mass(MeV)	Width(MeV)	Reaction	Production
SPring-8	1540±10	< 25	γn	nK^+
DIANA	1539±2	< 9	K^+Xe	$nK^+ \to pK_s^0$
CLAS-1	1542±5	< 21	γd	nK^+
SAPHIR	1540±4 ± 2	< 25	γp	nK^+
ITEP	1533±5	< 20	$\nu CC, \overline{\nu} CC$	pK_s^0
CLAS-2	1555±10	< 26	γp	nK^+
ALICE	1532±-	$< -$	CC	pK_s^0
HERMES	1528±2.6±2.1	$17 \pm 9 \pm 3$	γd	pK_s^0
COSY-TOF	1530±5	$< 18 \pm 4$	pp	$\Sigma^+ pK_s^0$
SVD-2	1526±3±3	< 24	pN	pK_s^0
JINR-1	1545.1±12.0	16.3 ± 3.6	pC_3H_3	pK_s^0
ZEUS	$1521.5 \pm 1.5^{+2.8}_{-1.7}$	$\cancel{6.1 \pm 1.6^{+2.0}_{-1.4}}$ 8±4 MeV	ep	$pK_s^0, \overline{p}K_s^0$
JINR-2	1541±4	8 ± 4	np	nK^+
NA49	1535±-	$-$	pp	pK_s^0

Some speakers commented on a "width" inconsistency of Θ^+ (<1 MeV from partial wave analysis of nK results. See review in PDG by Trilling.)
Hermes and ZEUS see significantly wider width than other positive expts. (?)

Close and Zhao

M_Θ



Masses of "two decay modes" appear to be inconsistent

Summary of negative pentaquark reports

Jin

Experiment	$\Theta^+(1540)$ $(uudd\bar{s})$	$\Xi^{--}(1862)$ $(ddss\bar{s})$	$D^{*-}p(3100)$ $(uudd\bar{c})$	Reaction
HERA-B	NO	NO		$pA \to \Theta^+ X,\ \Xi^{--} X$
E690	NO	NO		$pp \to \Theta^+ X,\ \Xi^{--} X$
CDF	NO	NO	NO	$p\bar{p} \to \Theta^+ X,\ \Xi^{--} X,\ \Theta^c X$
HyperCP	NO			$\pi, K, p \to \Theta^+ X$
BaBar	NO	NO		$e^+e^- \to \Theta^+ X,\ \Xi^{--} X$
ZEUS	yes	NO	NO	$ep \to \Theta^+ X,\ \Xi^{--} X,\ \Theta^c X$
ALEPH	NO	NO	NO	$e^+e^- \to \Theta^+ X$
DELPHI	NO			$e^+e^- \to \Sigma^+ K^0 p$
PHENIX	NO			$AuAu \to \Theta^+ X$
FOCUS			NO	$\gamma A \to \Theta^c X$
BES	NO			$e^+e^- \to J/\Psi \to \Theta^+ \overline{\Theta^-}$

- **Production rate (e.g. for $\Theta^+(1540)$)**

Jin

  - **"Positive" experiments:**

SAPHIR: $R_{\Lambda^*(1520)} \sim 0.3$

HERMES: $R_{\Lambda^*(1520)} \sim 1.6 \sim 3.5$

ZEUS: $R_{\Lambda^*(1520)} \sim 0.2$ (I estimated from $R_\Lambda \sim 0.04$)

SVD-2: $R_{\Lambda^*(1520)} > 0.2$ (estimated by SPHINX, hep-ex/0407026)

  - **"Negative" experiments:**

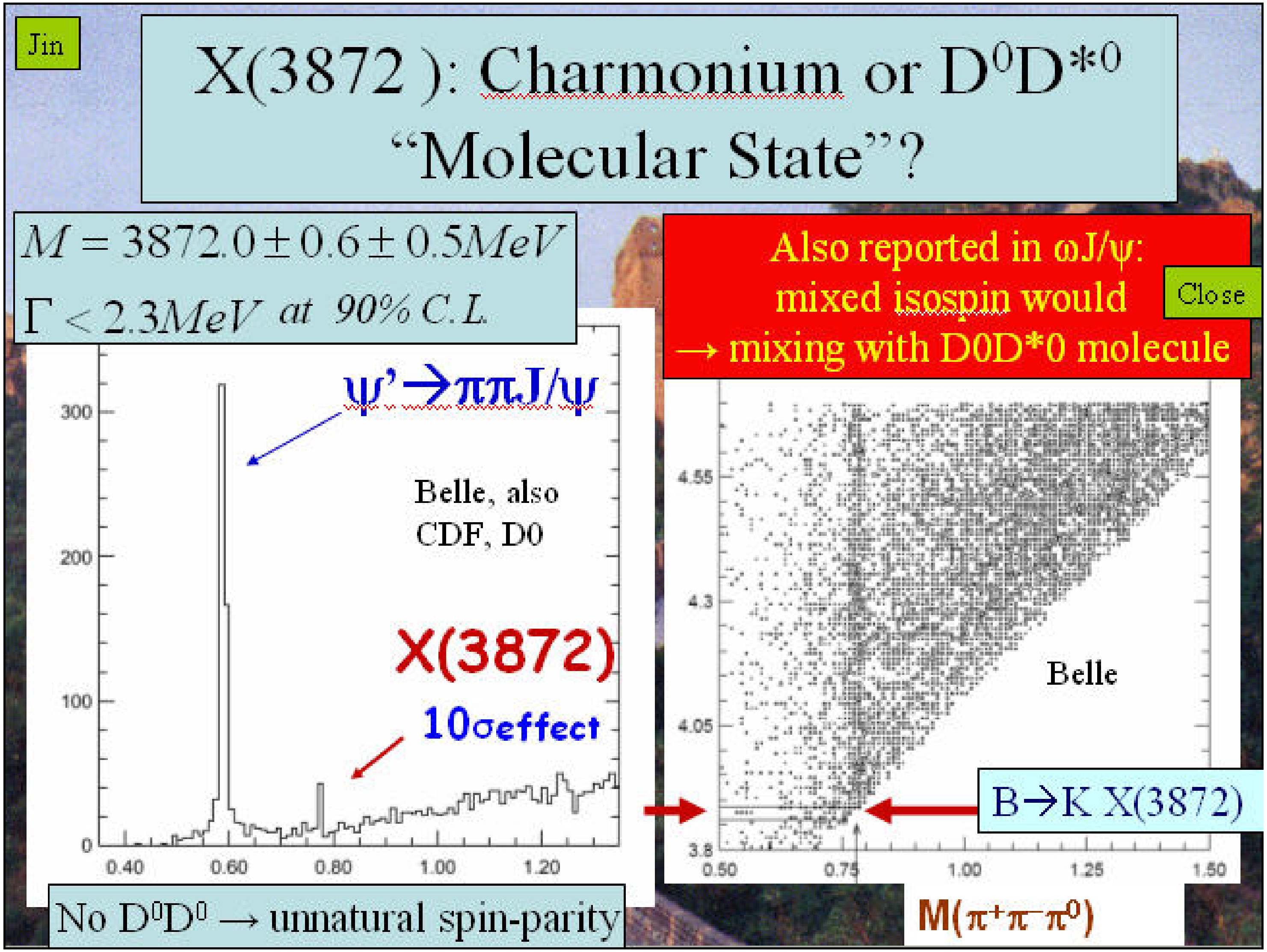
ALEPH: $R_{\Lambda^*(1520)} < 0.1$

BaBar: $R_{\Lambda^*(1520)} < \sim 0.01$ Belle: <0.02

HERA-B: $R_{\Lambda^*(1520)} < 0.027 \sim 0.16$

SPHINX: $R_{\Lambda^*(1520)} < 0.02$

Quantitative comparisons difficult.
(ZEUS-H1 should be one of the few possible)



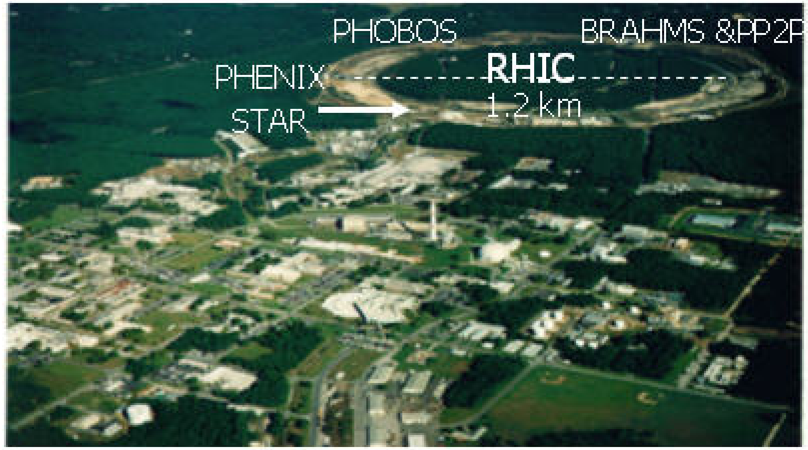
Mass, width, angular dist, etc. disfavor charmonium:
On the other hand DD* molecule models also have difficulties

Quark-gluon plasma?

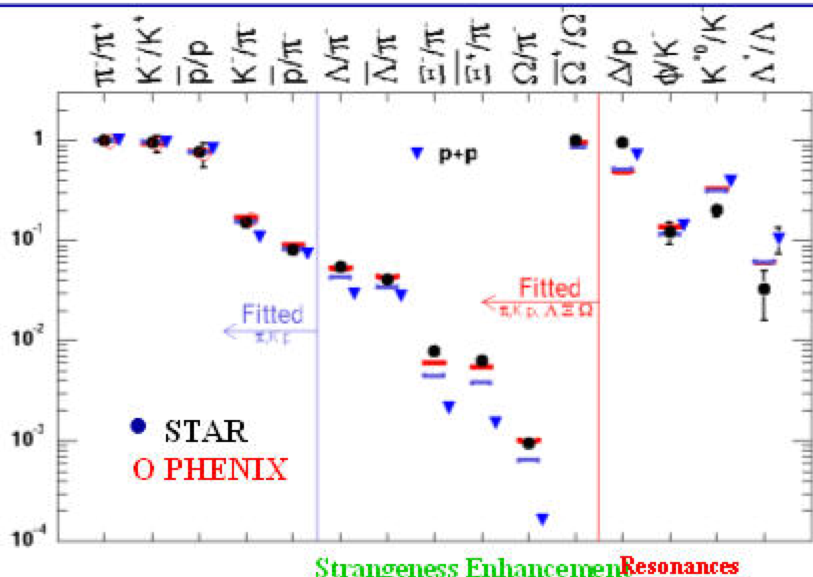
Dunlop

RHIC Implementation

- Flexibility is key to understanding complicated systems
  - Polarized protons, sqrt(s) = 50-500 GeV
  - Nuclei from d to Au, sqrt(s_{NN}) = 20-200 GeV
- Physics runs to date
  - Au+Au @20,62,130,200 GeV
  - Polarized p+p @200 GeV
  - d+Au @ 200 GeV



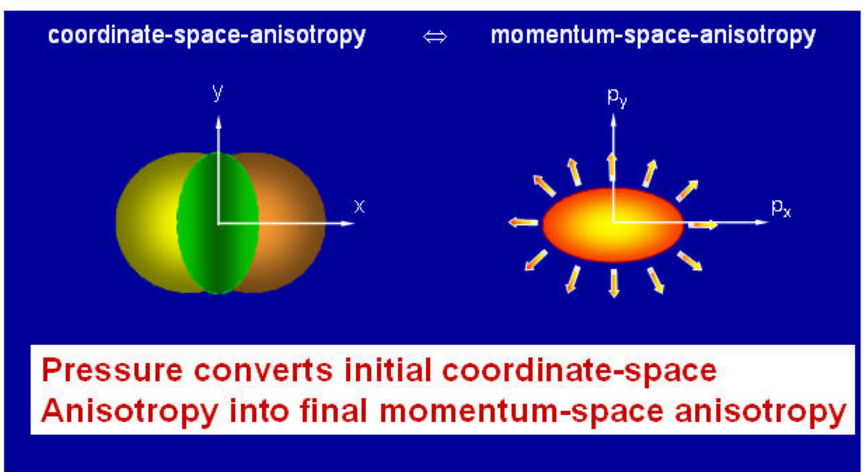
Chemical Equilibration? Hadron Yield Ratios



Some quark-gluon plasma models give good descriptions of data...

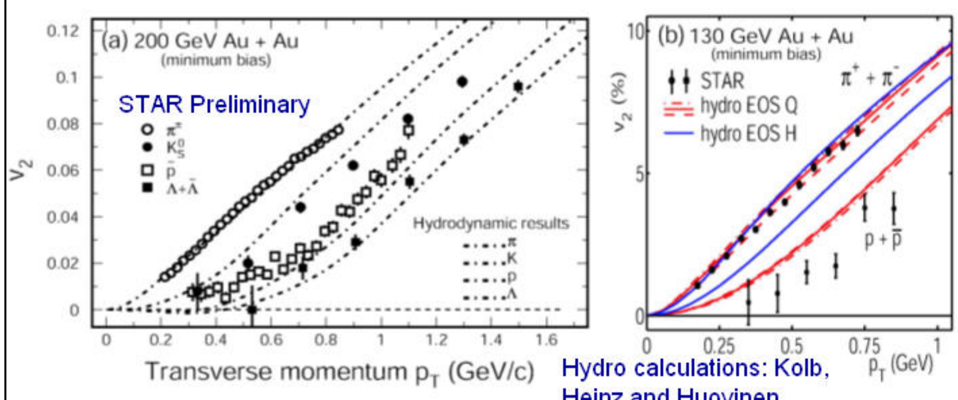
Dunlop

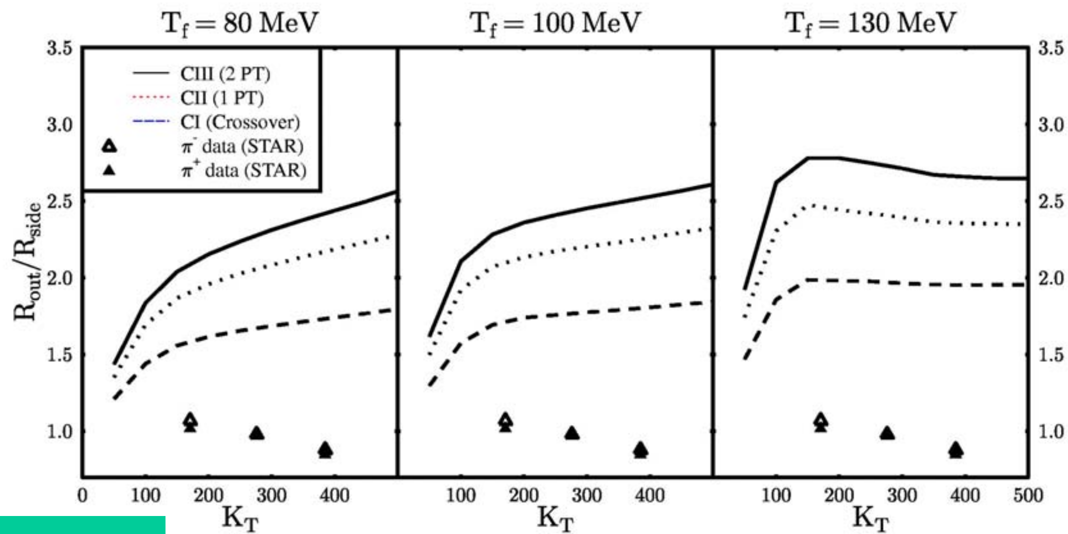
Collective Behavior: Azimuthal Anisotropy v_2



$$\varepsilon = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle} \qquad v_2 = \langle \cos 2\varphi \rangle, \quad \varphi = \tan^{-1}\left(\frac{p_y}{p_x}\right)$$

v_2 vs. Ideal Hydrodynamics





But doesn't work sometimes:

←source size compared to hydrodynamic model

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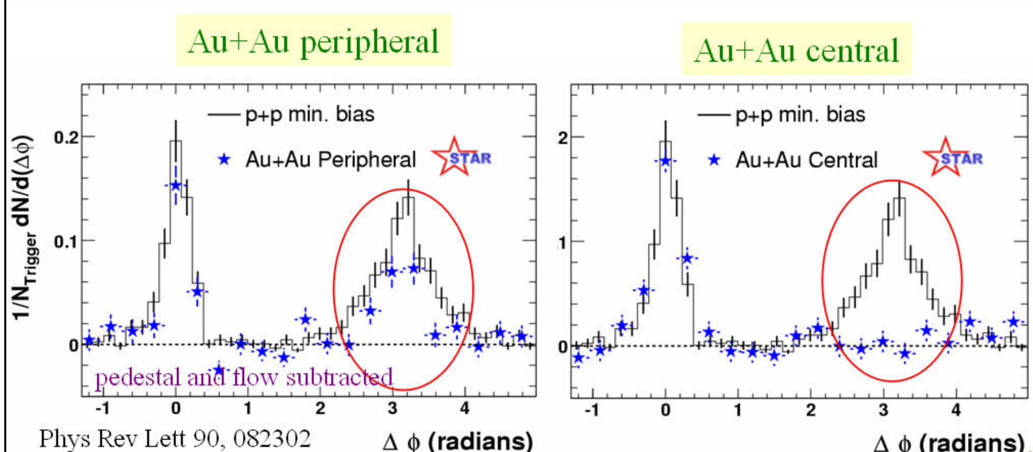
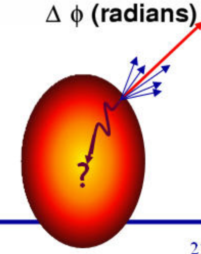
Azimuthal distributions in Au+Au



Phys Rev Lett 90, 082302

Near-side: peripheral and central Au+Au similar to p+p

Strong suppression of back-to-back correlations in central Au+Au



Jet-quenching measurements look impressive: Quantitative predictions?

QGP summary by Dunlop

Summary

RHIC has made major advances in runs 1-3, leading to an appealing picture of bulk, dense, highly interacting matter.

1) ***Extended reach in energy density appears to reach simplifying conditions in central collisions --*** **~ideal fluid expansion; approx. local thermal equilibrium.**

2) ***Extended reach in p_T gives probes for behavior difficult to access at lower energies –*** **jet quenching; ~constituent quark scaling.**

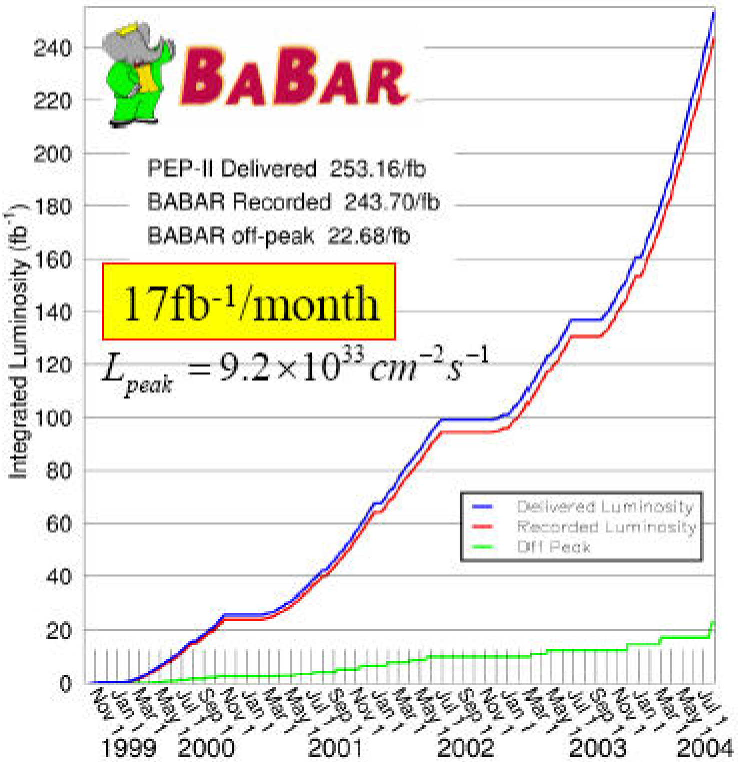
However: ***In the absence of a direct "smoking gun" signal of deconfinement revealed by experiment alone, a QGP discovery claim must rest on the comparison with a promising, but still not yet mature, theoretical framework. In this circumstance, clear predictive power with quantitative assessments of theoretical uncertainties are necessary for the present appealing picture to survive as a lasting one.***

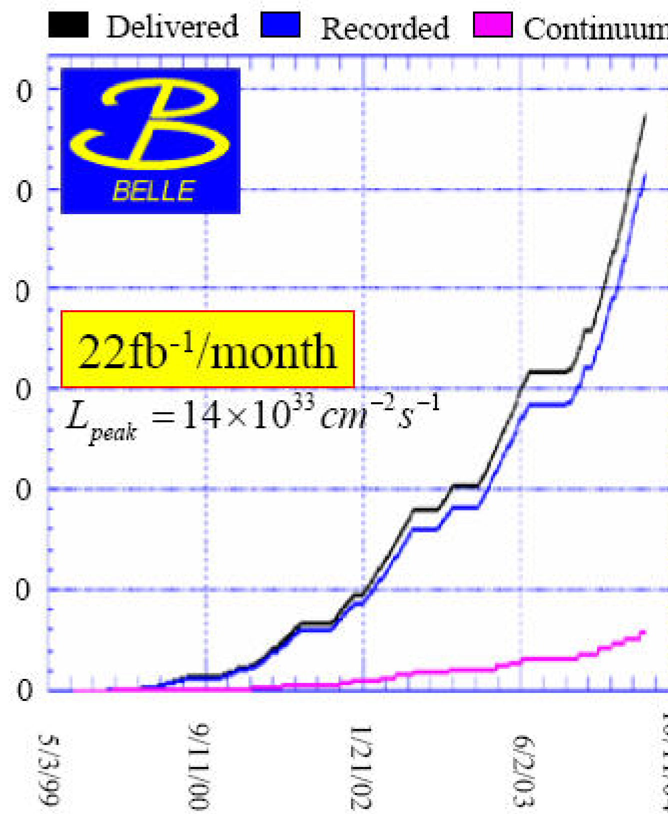
J/ψ suppression measurements yet to come

Quark mixing

Current luminosities and data samples

Total 244 + 286 fb^{-1} = 0.530 ab^{-1}!!





B-factories are doing spectacularly well.
project 1.5 ab^{-1} (each !) end 2009.

CPV in decay amplitudes

First observation of Direct CPV in *B* decays

$B^0 \to K^+\pi^-$

BABAR *hep-ex/0408057, submitted to PRL*

$A_{CP} = -0.133 \pm 0.030 \pm 0.009$

4.2σ

Belle **Confirmation at ICHEP04**

Signal (274M $B\bar{B}$ pairs): 2140 ± 53

$A_{CP} = -0.101 \pm 0.025 \pm 0.005$

3.9σ

Average $A_{CP} = -0.114 \pm 0.020$

$B^0 \to K^+\pi^0$

B⁺

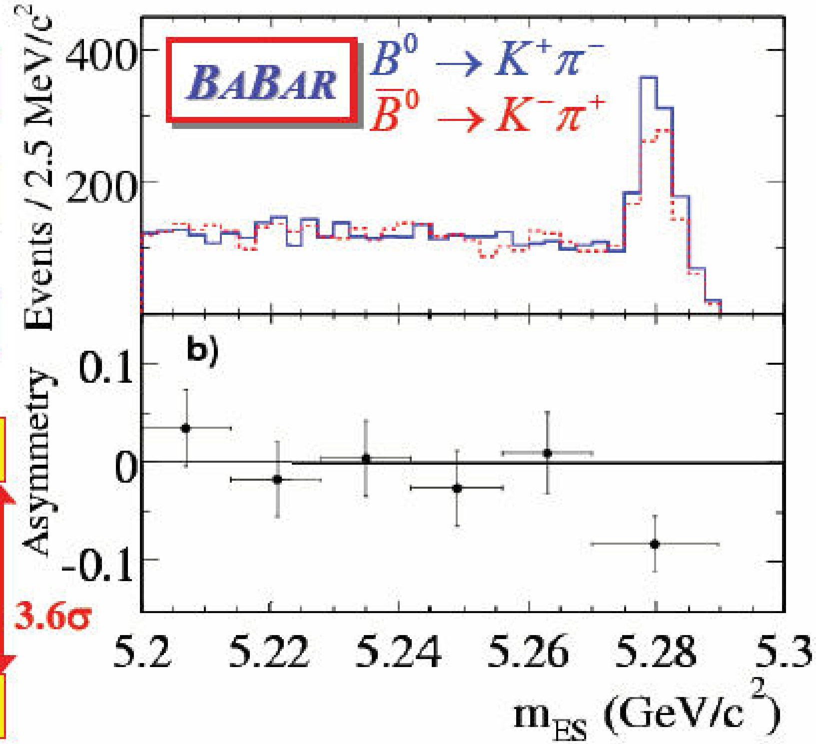
$A_{CP} = +0.06 \pm 0.06 \pm 0.01$ *BABAR*

$A_{CP} = +0.04 \pm 0.05 \pm 0.02$ Belle

3.6σ

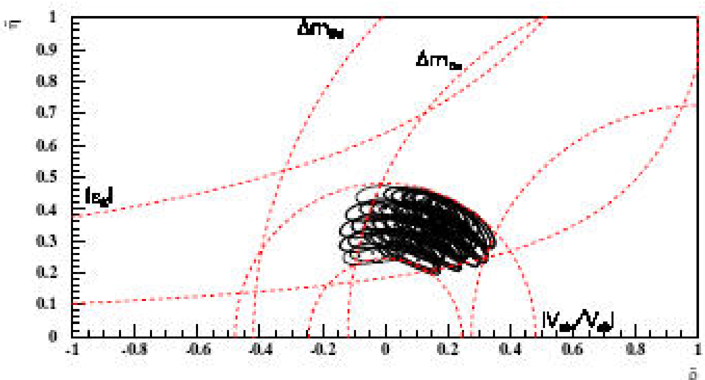
Average $A_{CP} = +0.049 \pm 0.040$

Signal (227M $B\bar{B}$ pairs): 1606 ± 51

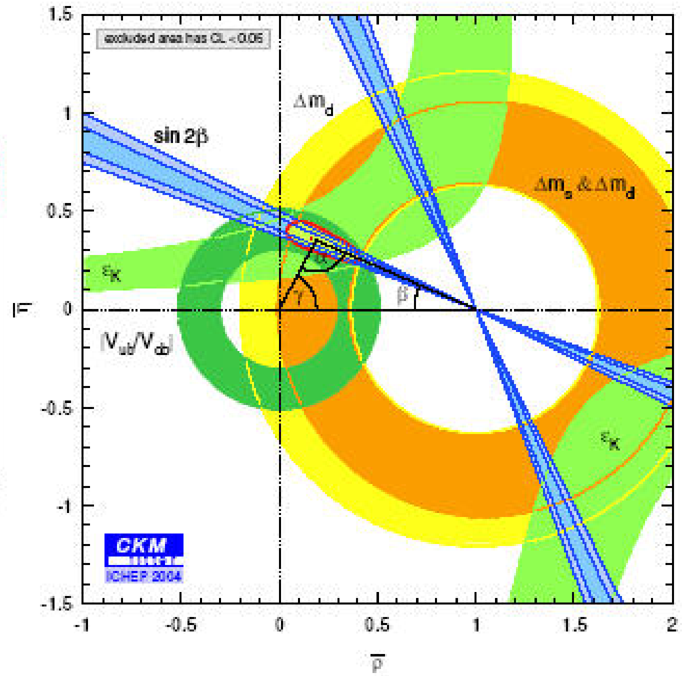


Testing the flavor sector

- For 35 years, untill 1999, the only unambiguous measurement of CPV was ϵ_K



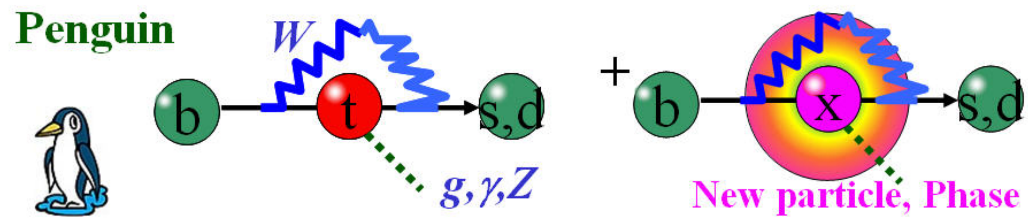
(BABAR Physics Book, 1998)

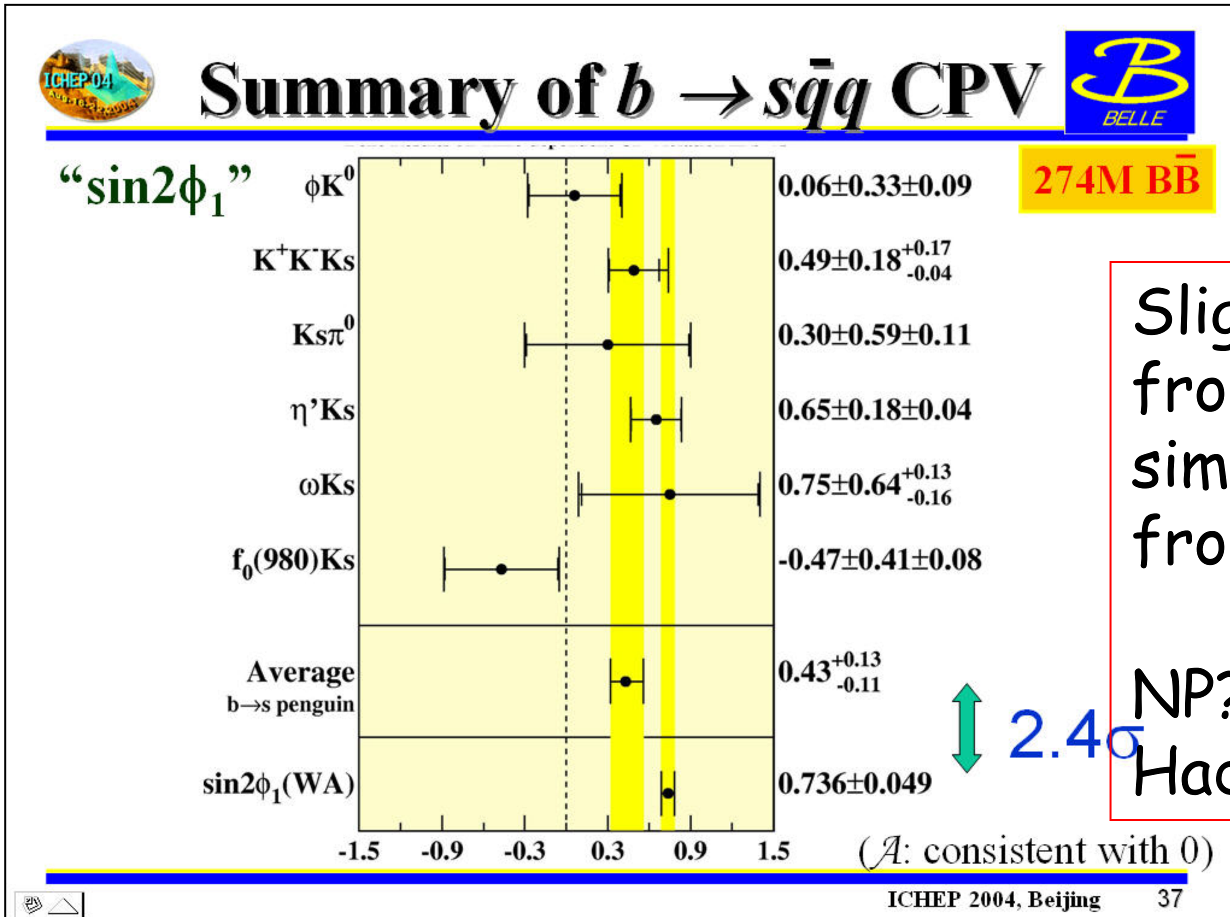


$\boxed{\sin 2\beta = 0.726 \pm 0.037,}$ order of magnitude smaller error than first measurements

From B -> J/ψ Ks ; other modes are (mostly) consistent

Penguins are sensitive to new physics





Slight deviation from expectations: similar results from Babar (2.7 σ)

NP?

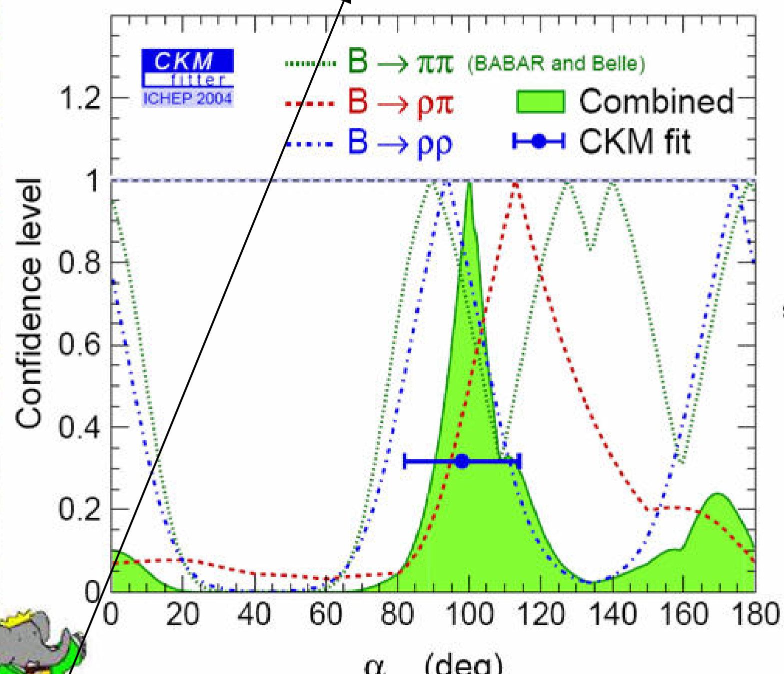
Hadronic corrections?

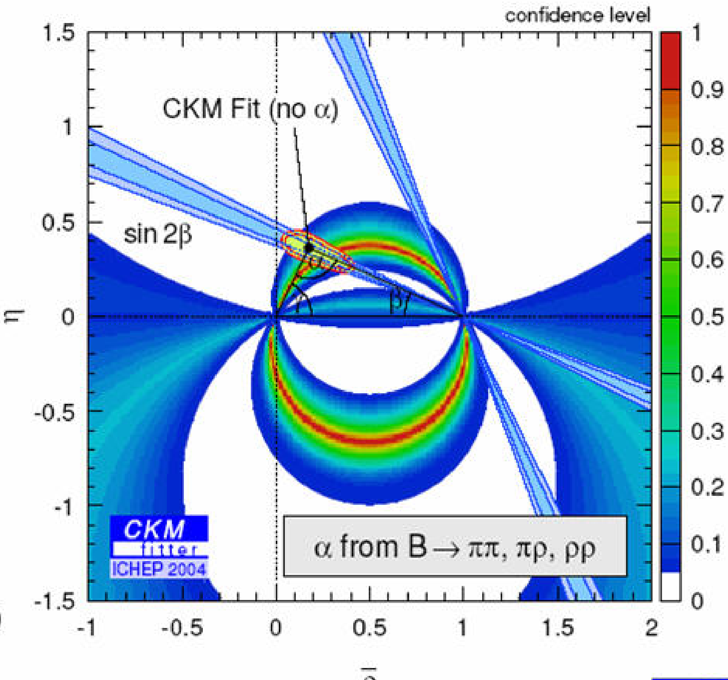
Inconsistent result from Belle and BaBar

Measuring α with B⟶ ππ, ρπ and ρρ Decays

Sensitivity mainly from $S_{\rho^+\rho^-}$ and $\rho\pi$ Dalitz, $\pi\pi$ has small effect at present

Combined result: $\alpha = 100^{+12}_{-10}{}^{\circ}$ ($103 \pm 11^{\circ}$ w/o $\pi\pi$); better than indirect fit $98 \pm 16^{\circ}$





Excellent agreement with global CKM fit

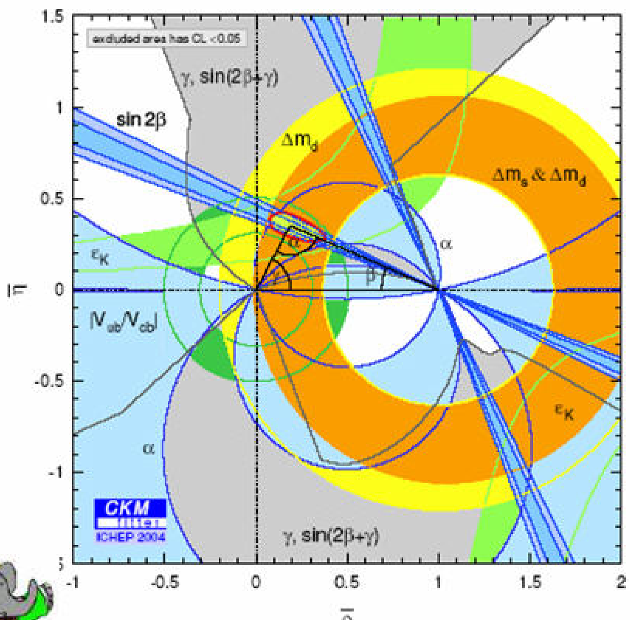
I only saw this in Ellis' summary.

Fit allowing for new physics in $B\bar{B}$ mixing amplitude

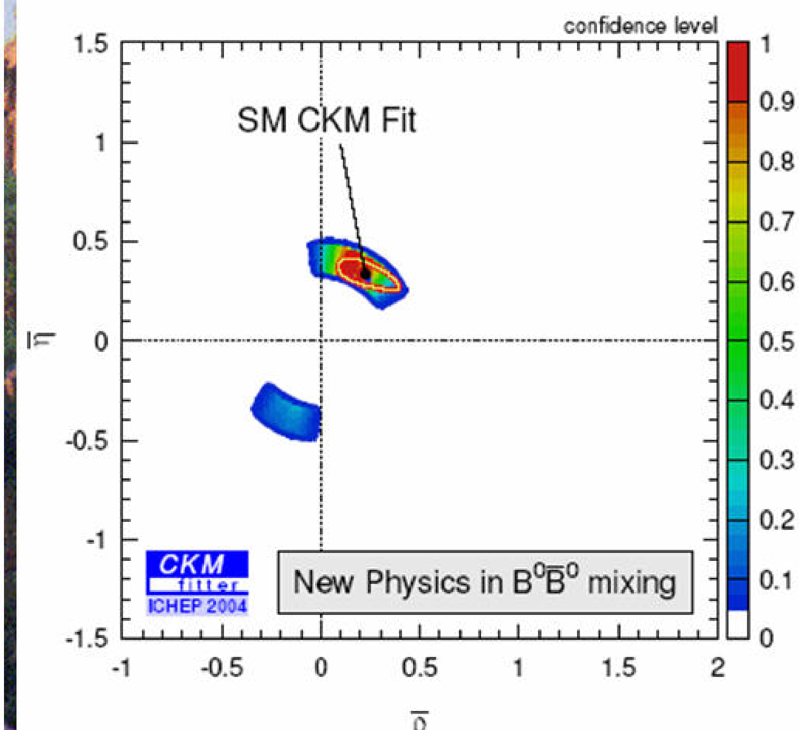
Putting all the Information Together

- α from $B \to \rho\rho$ and $\rho\pi$ Dalitz
- $2\beta + \gamma$ from $B \to D^{(*)\pm}\pi^{\mp}$
- γ from $B \to DK$ (with D Dalitz)
- $\cos 2\beta$ from ψK^* and A_{SL} (for NP)

Fit with above included



Is there room for NP?



Sakai, Ali, Giorgi, Ligeti

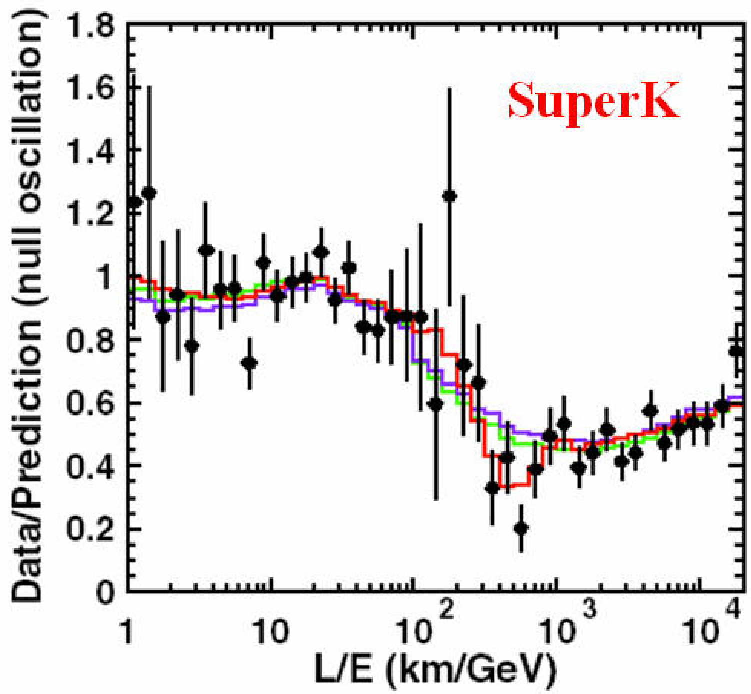
Not much room for NP

Neutrino sector

Neutrino oscillations established

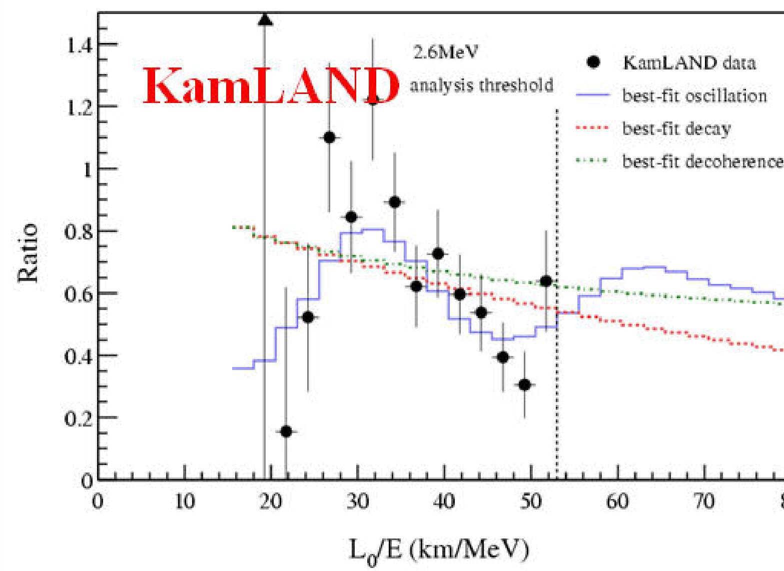
[*] V.Barger et al. Phys. Rev. Lett. 82 (1999) 2640

[†] E.Lisi et al., Phys. Rev. Lett. 85 (2000) 1166



Decay rejected at 3.4σ

Decoherence rejected at 3.8σ



Decay[*] excluded at 95% CL

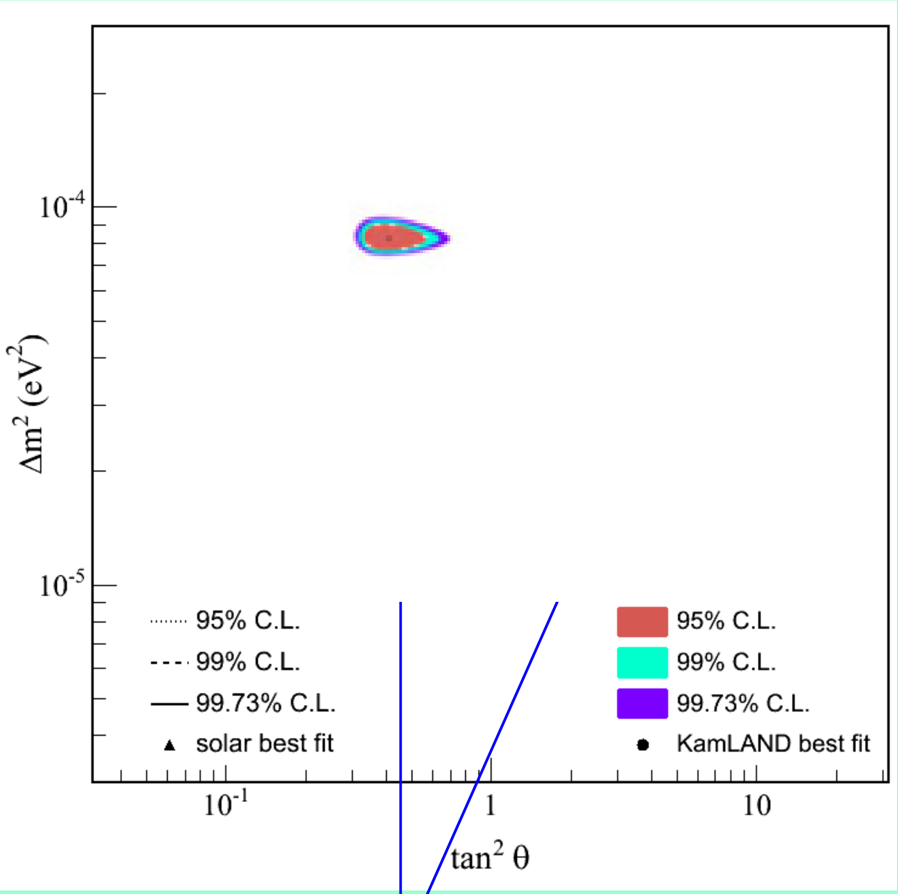
Decoherence[†] excluded at 94% CL

L/E analyses from atmospheric (Θ_{23}) and reactor(Θ_{12}): oscillation favored over other exotic explanations

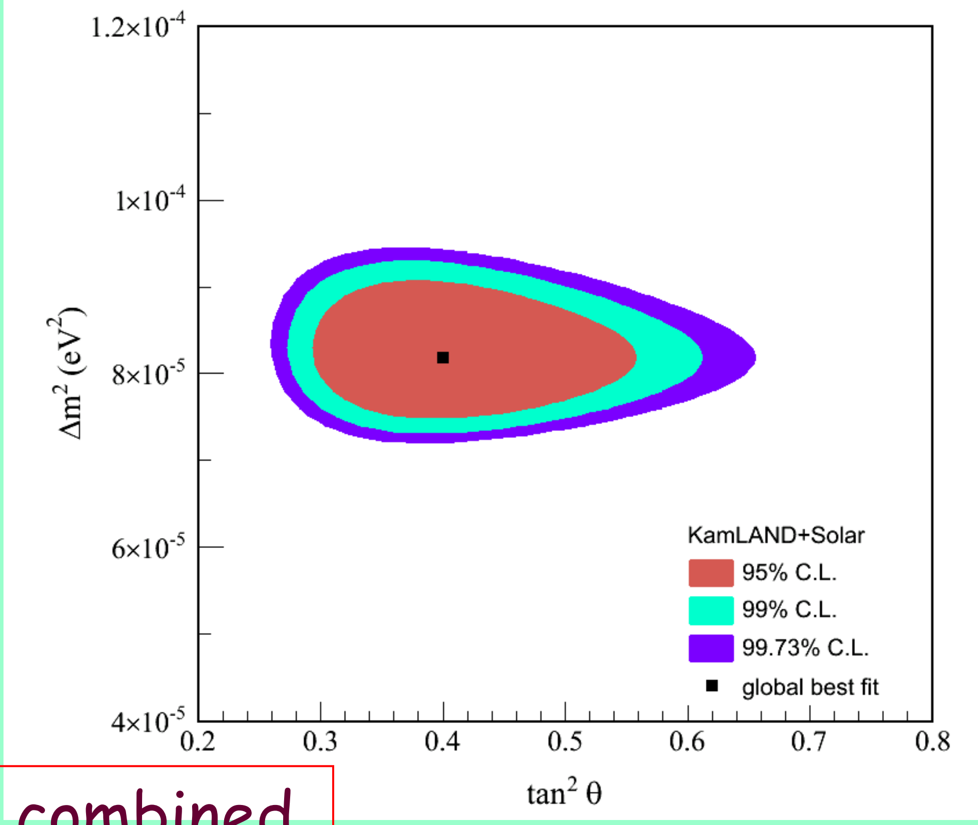
Combined solar ν - KamLAND 2-flavor analysis

$$\Delta m_{12}^2 = 8.2^{+0.6}_{-0.5} \times 10^{-5}\, eV^2$$

$$\tan^2\theta_{12} = 0.40^{+0.09}_{-0.07}$$



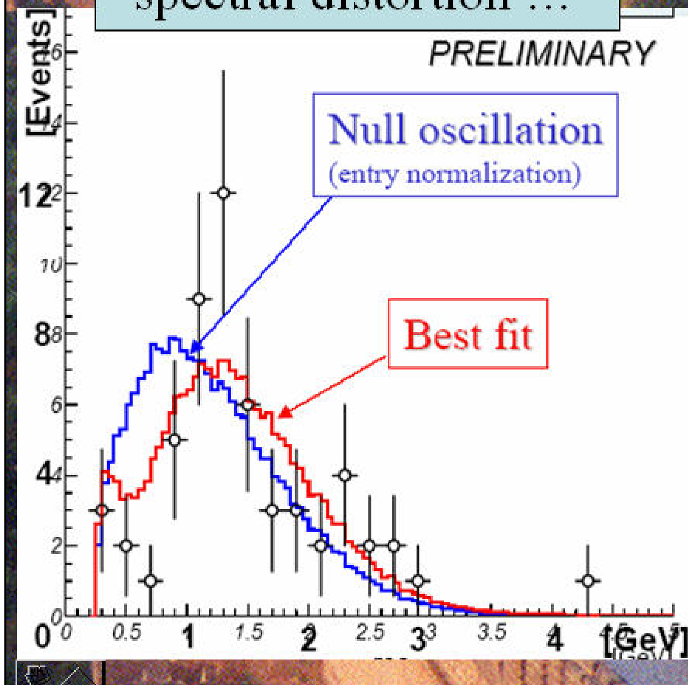
Includes (small) matter effects



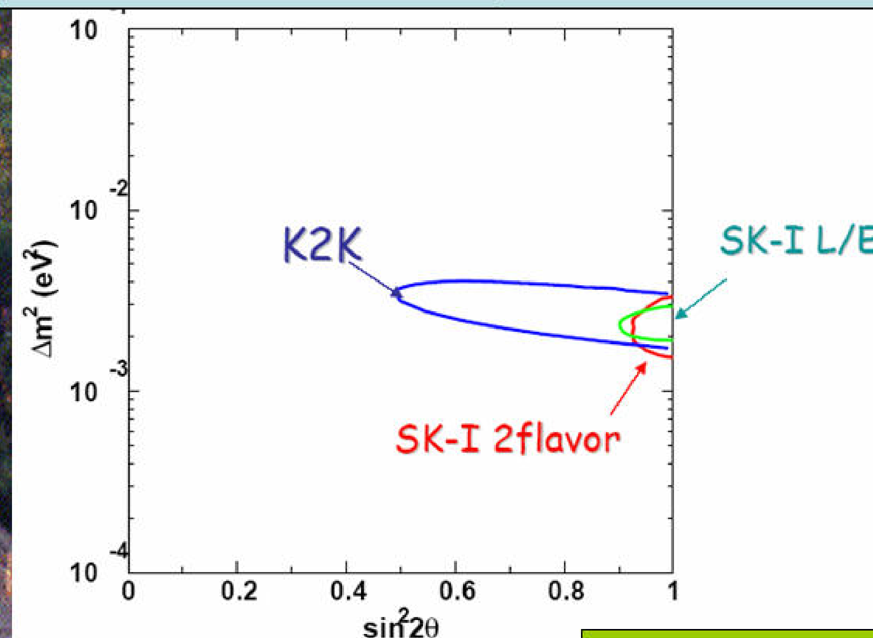
Solar(SK,SNO) and KamLAND combined

K2K confirms Super-Kamiokande

K2K Rate suppression
and
spectral distortion …



… agree with SK azimuthal distributions
and
L/E analysis



McGrew, Wang

Atmospheric and acclerator-based (Θ_{23}) consistent

Wang: summary

Summary

- **Neutrino oscillations established**
  - Solar: $\Delta m^2_{12} = (8.2^{+0.6}_{-0.5})\times 10^{-3}$ eV^2
    $\tan^2\theta_{12} = 0.40^{+0.09}_{-0.07}$ large but not maximal
  - Atmospheric: $\Delta m^2_{23} = (2.4\pm 0.4)\times 10^{-3}$ eV^2
    $\sin^2 2\theta_{23} > 0.92$ @ 90%CL maximal
  - From global fit: $\sin^2 2\theta_{13} < 0.09$ @ 90%CL
- **Our next goal:**
  - Absolute neutrino masses β-decay experiments
  - Dirac or majorana ? 0νββ-decay experiments
  - θ_{13}, CP and Mass hierarchy
    Reactor, Long baseline accelerator based experiments

➔ A great success in the past
A long way to go in the future

Current limit: 2.2 eV
soon down to 0.5 eV?

Sensitivity of
next exp: 0.01 eV

Sensitivity of
proposed exp: ~0.01

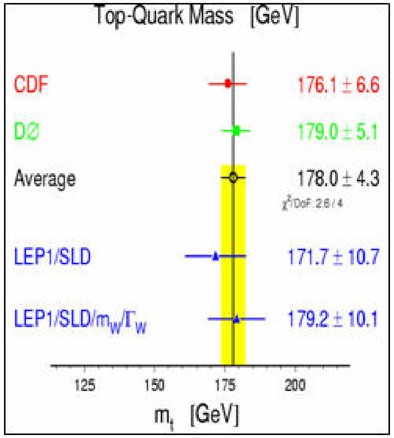
MiniBooNE should clarify LSDN result (2005?)
MINOS start in 2005
CNGS(OPERA) start 2006
T2K, Nova on the horizon

Electro-weak fits: Improved top mass from the Tevatron

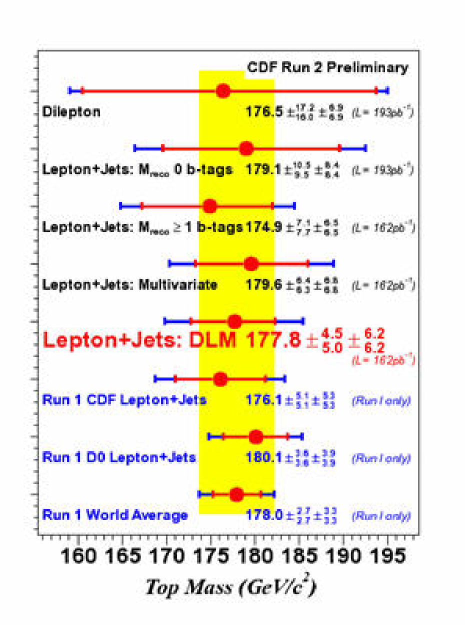
Tevatron Top Quark Mass Measurement

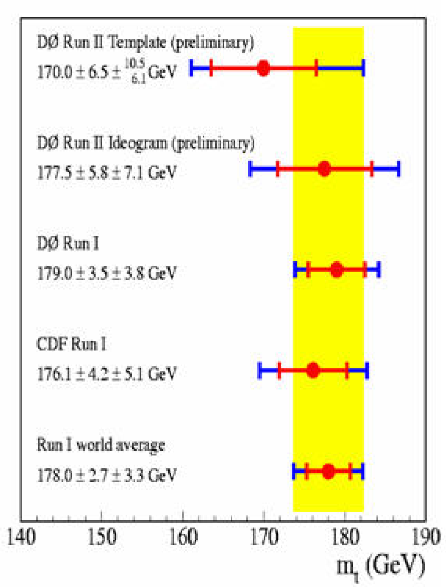
New combined Run I result →
(Was m_t = 174.3±5.1 GeV)

m_t = 178.0±4.3 GeV



Run II top quark mass results from both detectors are available





Systematic error
(mainly jet energy scale)
is becoming limiting accuracy
factor

TeV EWWG is working on combining Run II top mass measurement from CDF and DØ

Experimental Limits on Higgs Mass

Available experimental limits

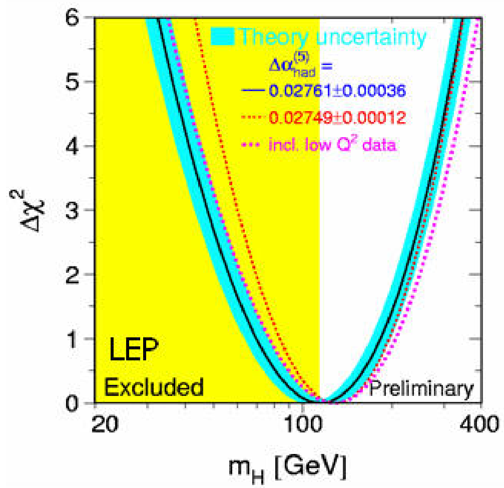
→direct searches at LEP
M_H >114 GeV at 95% C.L.

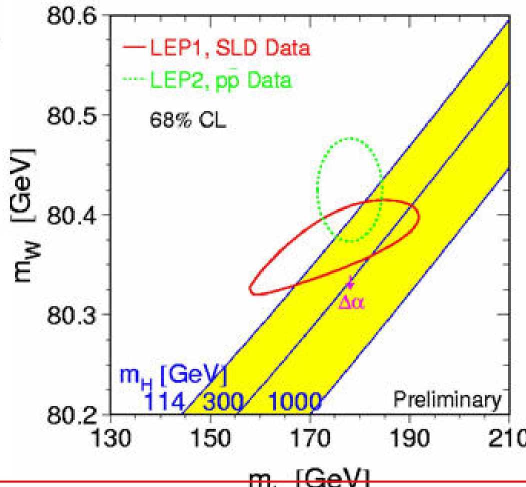
→precision EW fits

$$m_H = 114^{+69}_{-45}\, GeV$$

$$m_H \le 260 GeV$$ at 95% C.L.

Light Higgs favored





Tevatron provides:
Precision m_t and M_W measurements
Direct searches
→ SM Higgs
→ non-SM Higgs

Leads to a Higgs mass which is the same as that of the limit from the direct search as LEP…

How Good is the Global Electroweak Fit?

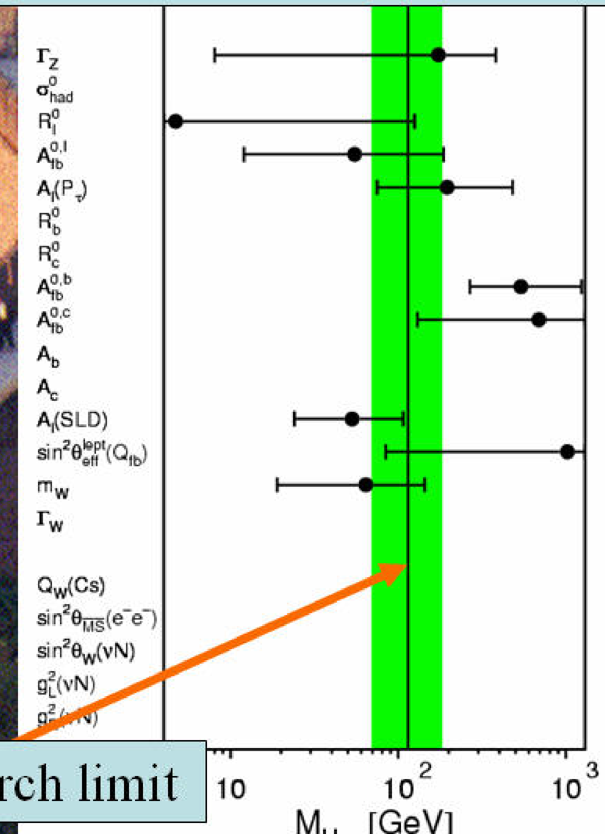
Teubert

Pulls on Global Fit

	Measurement	Fit
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02761 ± 0.00036	0.02769
m_Z [GeV]	91.1875 ± 0.0021	91.1874
Γ_Z [GeV]	2.4952 ± 0.0023	2.4966
σ^0_{had} [nb]	41.540 ± 0.037	41.481
R_l	20.767 ± 0.025	20.739
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01650
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1483
R_b	0.21630 ± 0.00066	0.21562
R_c	0.1723 ± 0.0031	0.1723
$A^{0,b}_{fb}$	0.0998 ± 0.0017	0.1040
$A^{0,c}_{fb}$	0.0706 ± 0.0035	0.0744
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.026	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1483
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.425 ± 0.034	80.394
Γ_W [GeV]	2.133 ± 0.069	2.093
m_t [GeV]	178.0 ± 4.3	178.2

$|O^{meas} - O^{fit}|/\sigma^{meas}$: 0 1 2 3

Higgs mass from individual measurements



Direct search limit

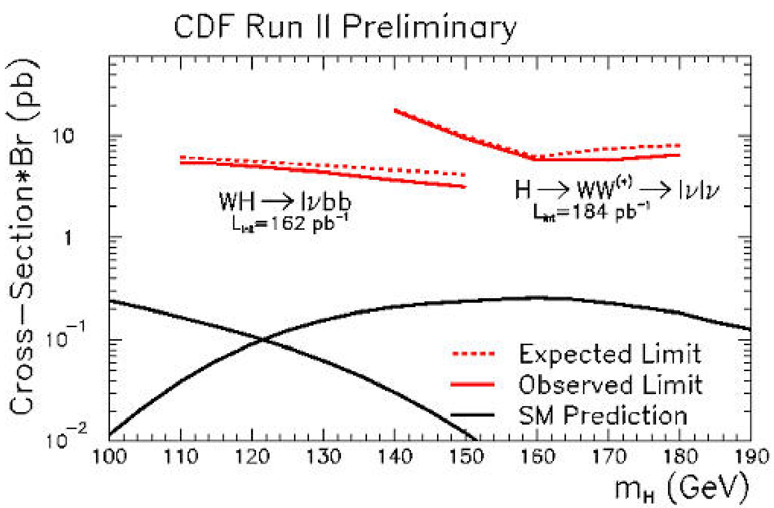
Heavy flavours ≠ leptons, m_W

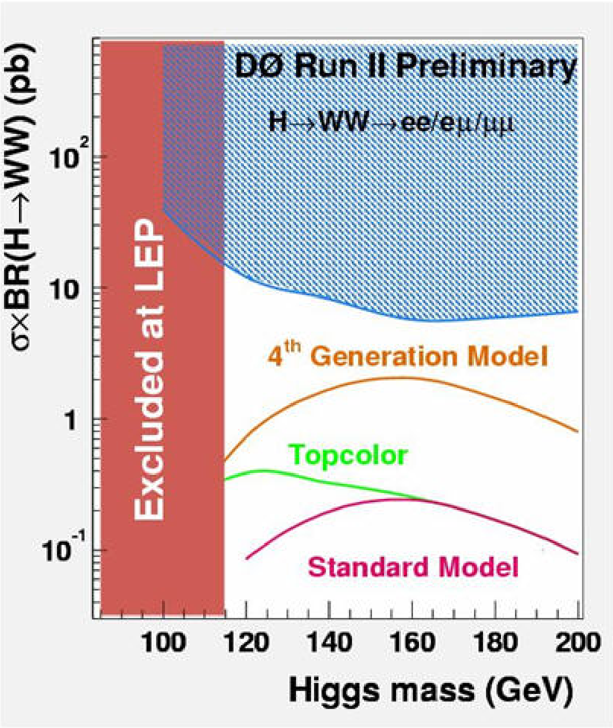
Electroweak fits give satisfactory results:
g-2, $\sin^2\Theta$ from NuTeV (theory issues: see S-O. M. talk)

Higgs search at the Tevatron

Current Limits on SM Higgs Search

Both experiments set 95% C.L. on SM Higgs cross section x Br





Limits already exceeding Run I results

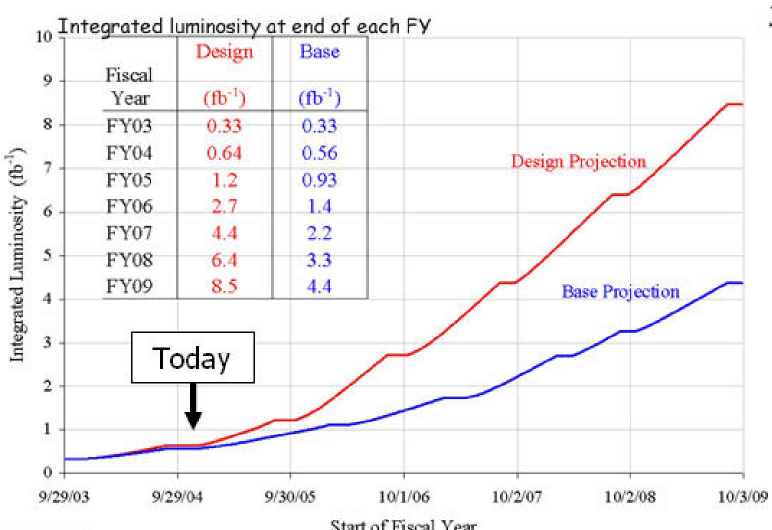
DØ light (115 GeV) Higgs search limit
$\sigma(WH) \times BR(H \rightarrow bb) < 12.4\ pb^{-1}$ at 95% C.L.

Tevatron Long Term Luminosity Plan

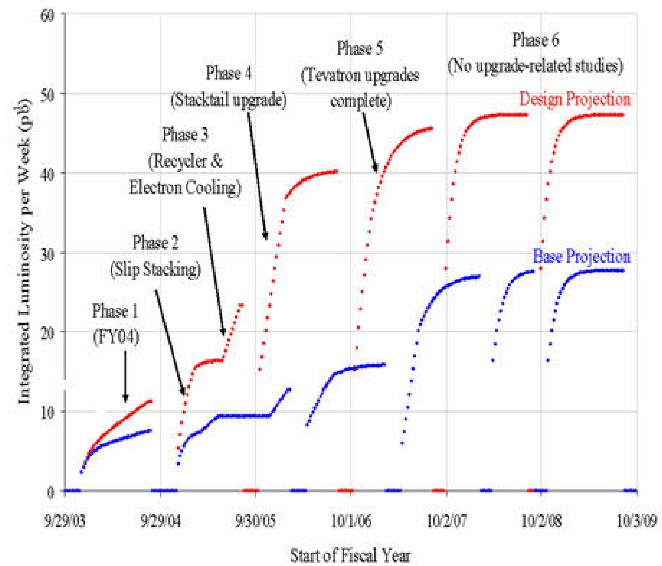
To reach higher masses with the same energy
→ higher luminosity

Increase in number of antiprotons
→ the key for higher luminosity

Expected peak luminosity
→ $3 \cdot 10^{32}$ cm^{-2}sec^{-1} by 2007



Fiscal Year	Design (fb^{-1})	Base (fb^{-1})
FY03	0.33	0.33
FY04	0.64	0.56
FY05	1.2	0.93
FY06	2.7	1.4
FY07	4.4	2.2
FY08	6.4	3.3
FY09	8.5	4.4



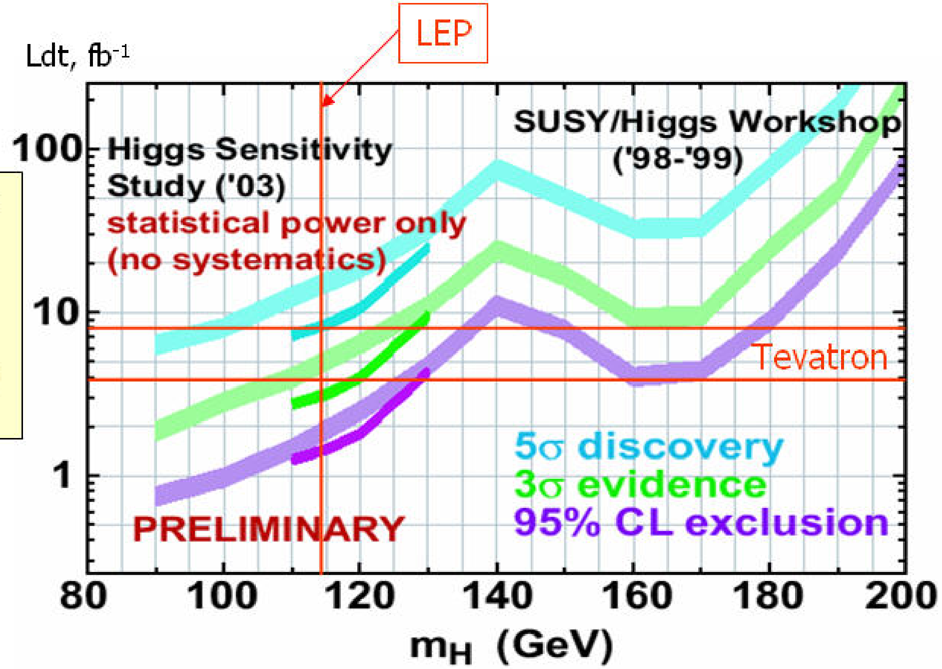
Currently expecting delivered
luminosity to each experiment
→ 4-8 fb^{-1}
by the end of 2009

Tevatron projection is 4-8 fb^{-1} by 2009

Tevatron SM Higgs Search: Outlook

Updated in 2003 in the low Higgs mass region W(Z)H→lν(νν,ll)bb to include

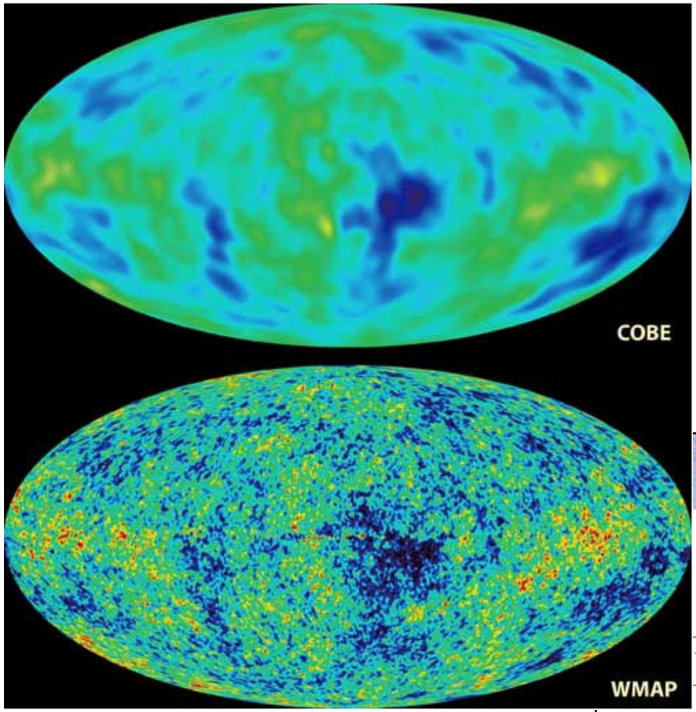
→ better detector understanding
→ optimization of analysis



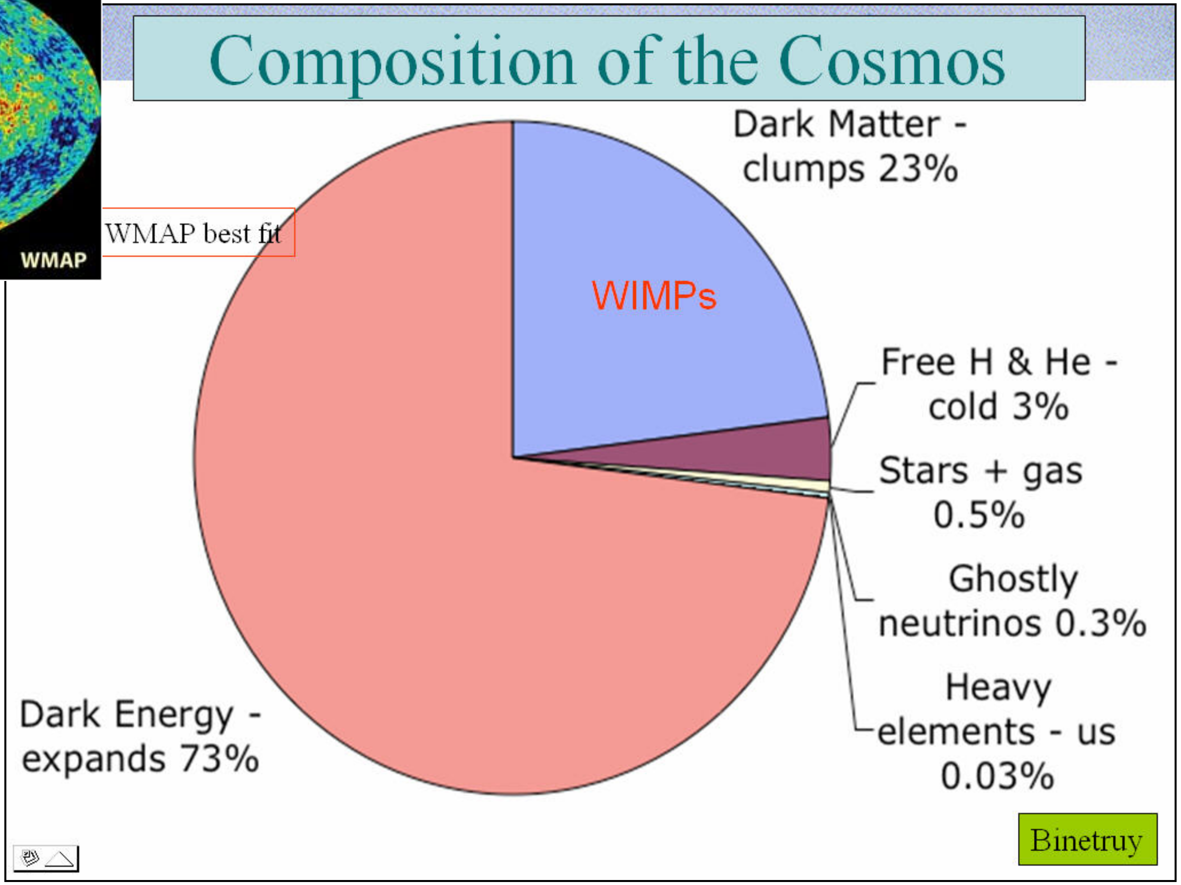
Sensitivity in the mass region above LEP limit starts at ~2 fb^{-1}

Meanwhile
→ optimizing analysis techniques
→ understanding detectors better
→ searching for non-SM Higgs with higher production cross sections or enhanced branching into modes with lower backgrounds

Higgs prospects at the Tevatron

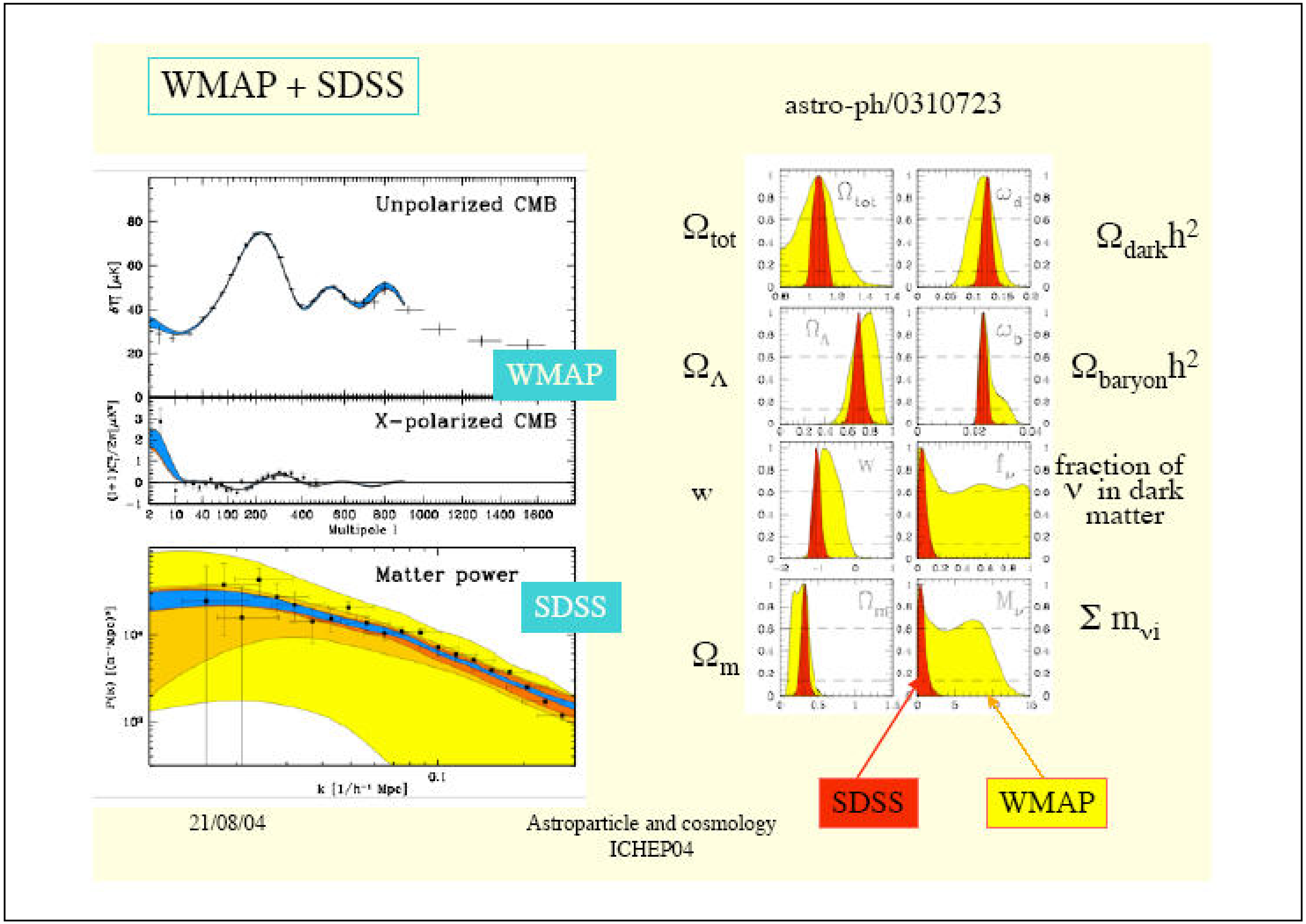


"New" standard cosmology



CMB anisotropy measurements from WMAP

SDSS (Sloan Digital Sky Survey): clustering of galaxies



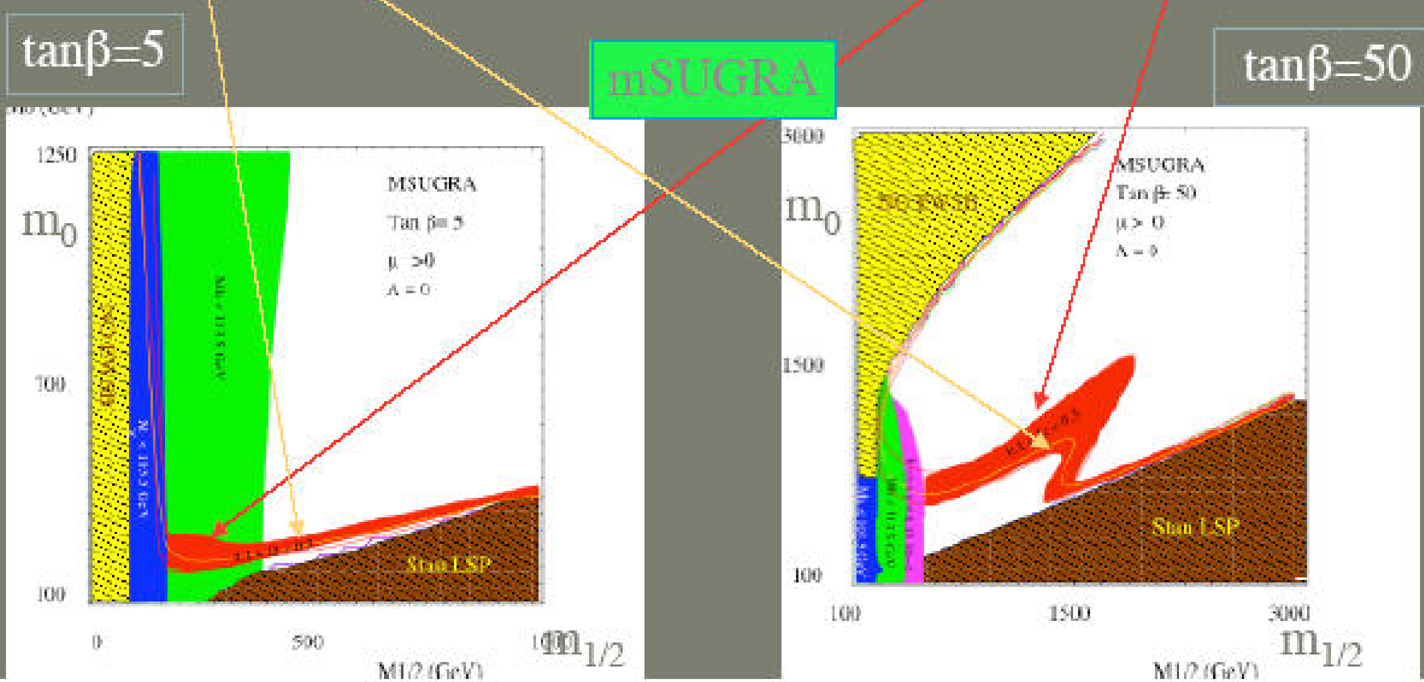
Strong constraints on cosmological parameters

Which, in turn, puts constraints on, e.g. SUSY

In the context of supersymmetric models, the constraint on dark matter severely constrains the parameter space :

$\Omega_{CDM} = 0.1126 {}^{+0.0161}_{-0.0181}$

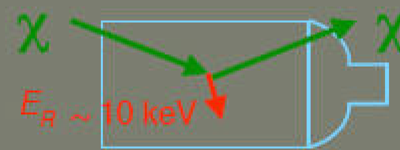
$0.03 < \Omega_{CDM} < 0.3$



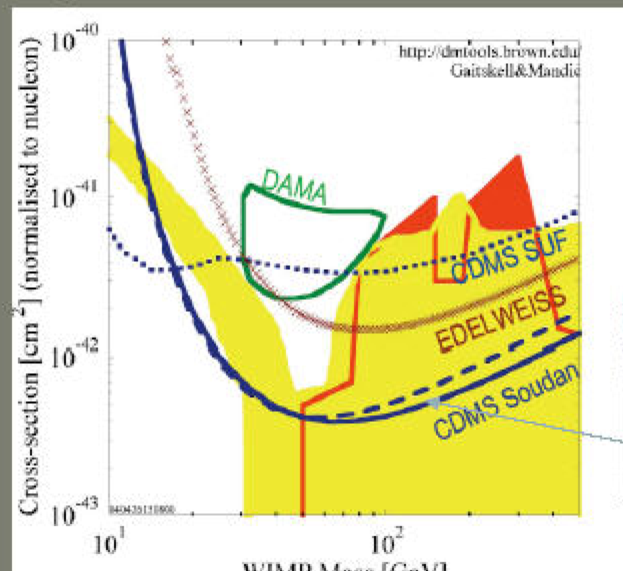
Binetruy

Experimental search for dark matter

Dark matter : direct detection



New results presented by CDMS of the first data run in the Soudan mine



P. Cushman

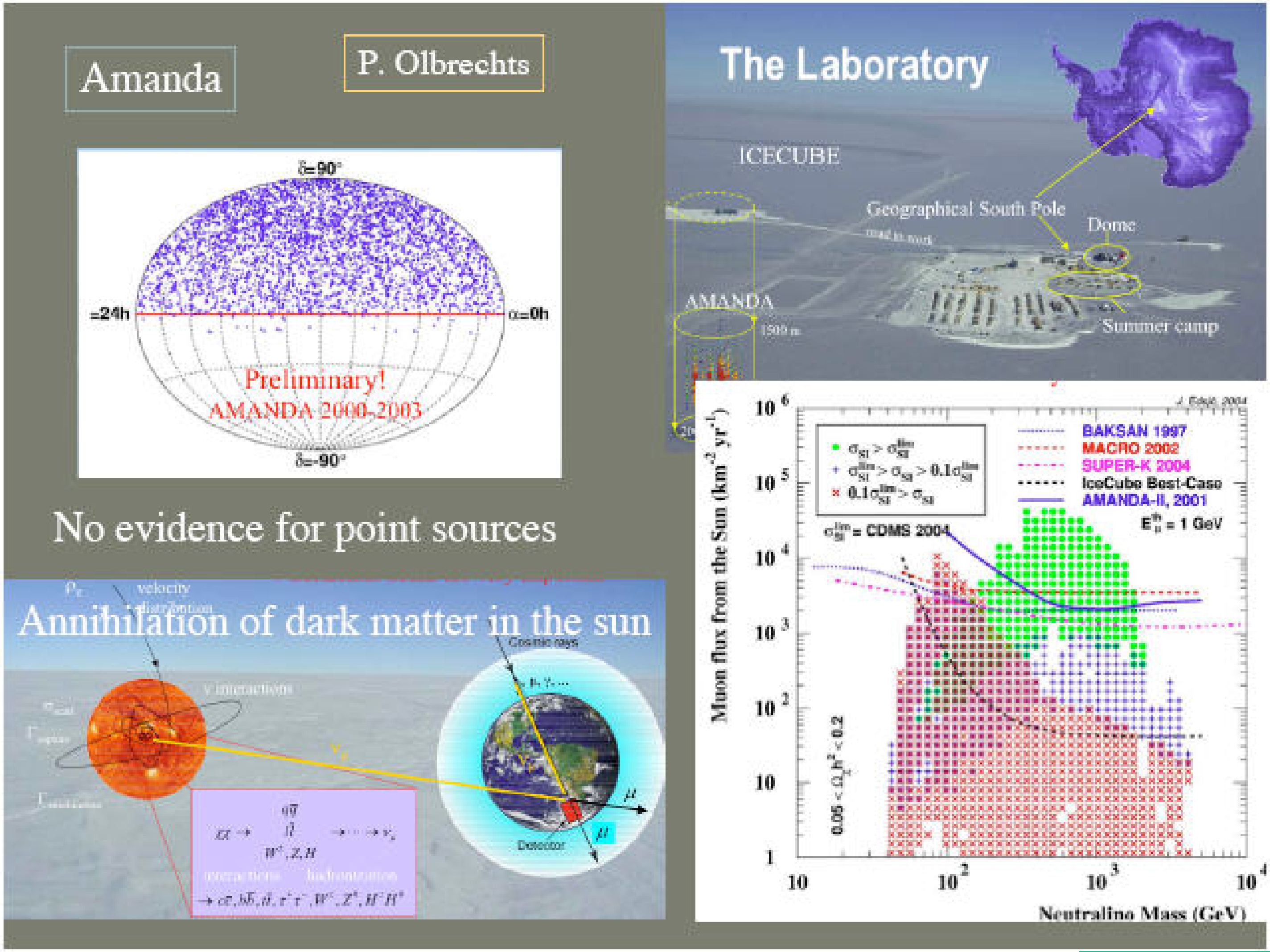
C. Sander

indirect detection

Connect EGRET excess in GeV cosmic γ rays with the presence of a halo of susy dark matter.

Binetruy

CDMS limit now contradicts DAMA positive result



Binetruy

Dark matter search at neutrino observatories

Final Remarks

- Many confirmations of Standard Model.
  - QCD becoming ever more precise. Deeper understanding of QCD essential in understanding many other results.
  - CKM description is now becoming very solid; no room for big deviations.
  - Neutrino oscillation also seems solid.
  - EW fits (despite some small deviations) work well -> light Higgs
  - SM + neutrino mixing appears to be a very good description of nature.
- On the other hand, as the precision of B and neutrino sector measurements increase, one is stuck more and more by the large number of apparently random parameters in the SM.
  - SM looks more and more like a description than an explanation.
  - E.g. Why does the quark and neutrino mixings look so different?
    - Several speakers commented on $\Theta_{12}+\Theta_{cabbibo}\approx\pi/4$
- Many reasons to be optimistic
  - B factories
  - Many new neutrino experiments on horizon
  - Strong connection with astroparticle physics and cosmology
  - LHC on the way
  - Linear Collider technology decision taken
  - Ideas for future (>30 years) accelerators (talk by Yokoya)