32nd INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS

16-22 August 2004 Beijing China

120 talks in parallel sessions
28 talks in plenary sessions

Argomenti trattati nelle sessioni:

neutrino physics, astrophysics & cosmology, soft and hard QCD ints., CP violation, hadron spettroscopy, electroweak, heavy ions, heavy quarks, beyond SM and string theory, R&D in detector and accelerators.

Per ogni ulteriore approfondimento, tutti i talk sono in rete nel sito della conferenza
http://ichep04.ihep.ac.cn

Hadron Spettroscopy

…or the pentaquark saga

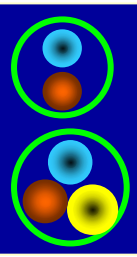
Multi-quark State, Glueball and Hybrid

- **Hadrons consist of 2 or 3 quarks?**

  Naive Quark Model?

  Meson? $q\ \bar{q}$?

  Baryon? q q q?



- **New forms of hadrons:**
  - **Multi-quark states ?Number of quarks >? 4**
  - **Hybrids ? $qq\bar{g}$?qqqg …**
  - **Glueballs ? gg? ggg …**

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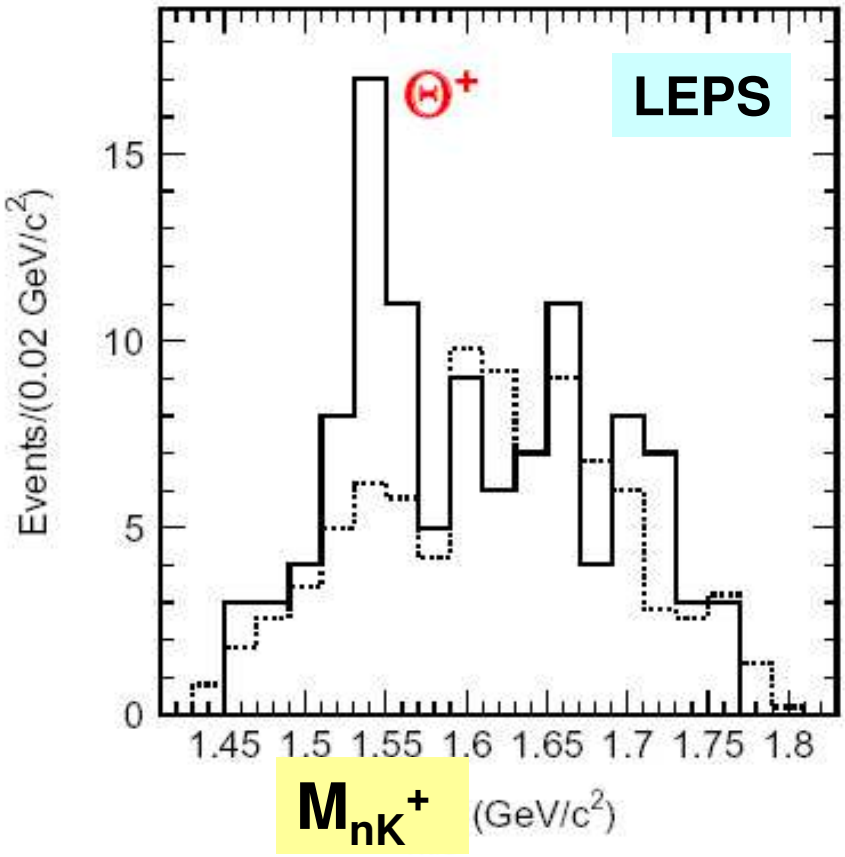
Θ+(1540)



- **First evidence of pentaquark was presented by LEPS in the process** $\gamma n \to K^+K^-n$ **:**

$$M = 1540 \pm 10 \pm 5 MeV$$

$$\Gamma < 25 MeV \quad \text{at 90\% CL}$$

N_{event}= 19 +/- 2.8

Significance: ~ 4.6 σ $(S/\sqrt{B})$

- **Minimum quark content: $uud\bar{d}s$**

Its mass and width are consistent with chiral soliton model prediction.

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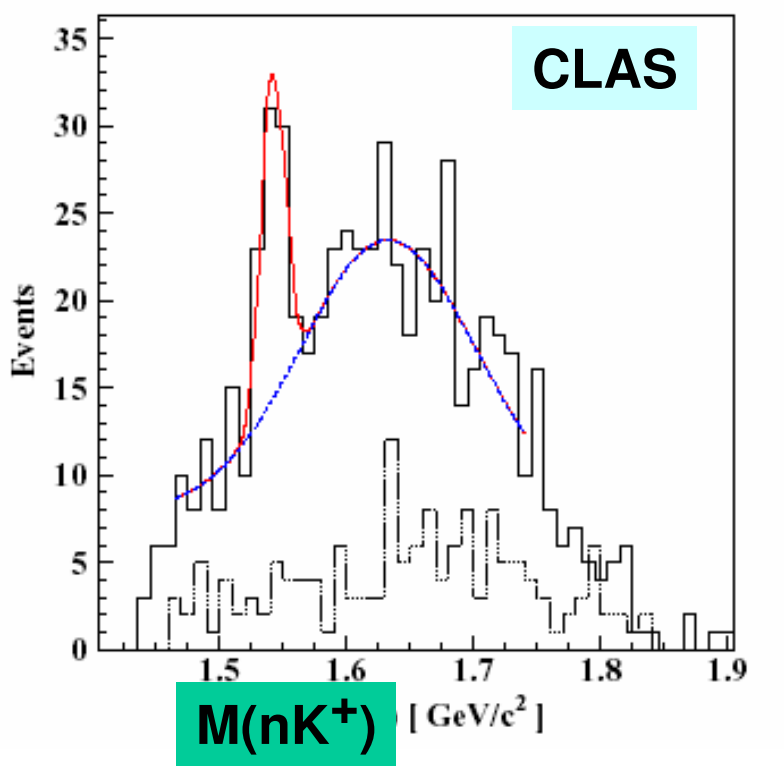
$$\gamma d \rightarrow pnK^+K^-$$



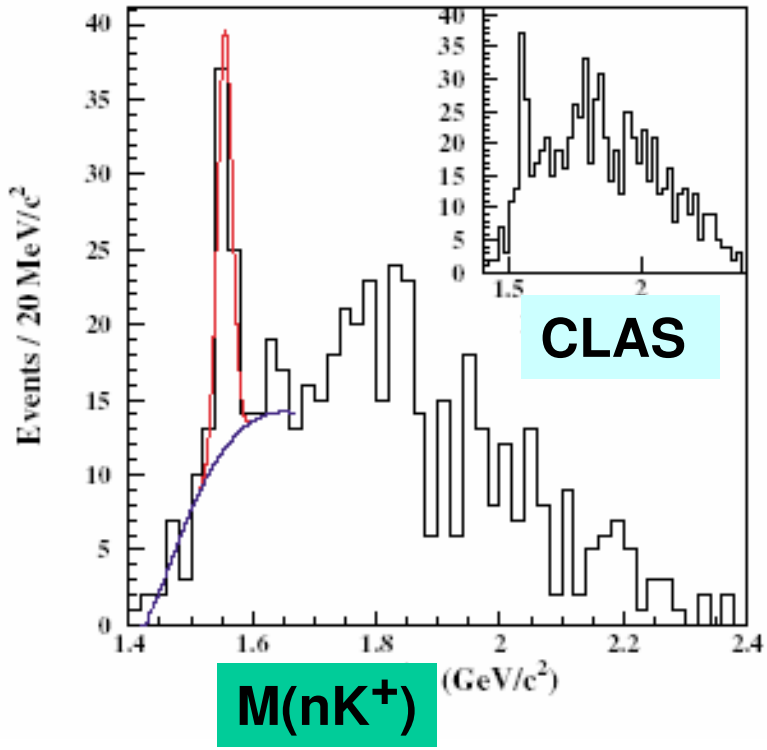
$$M = 1542 \pm 5 MeV$$

$$\Gamma < 21 MeV$$

$$N_{event} = 43$$

$$Significance :\sim 5.2\sigma \quad (S/\sqrt{B})$$

$$\gamma p \rightarrow nK^+K^-\pi^+$$

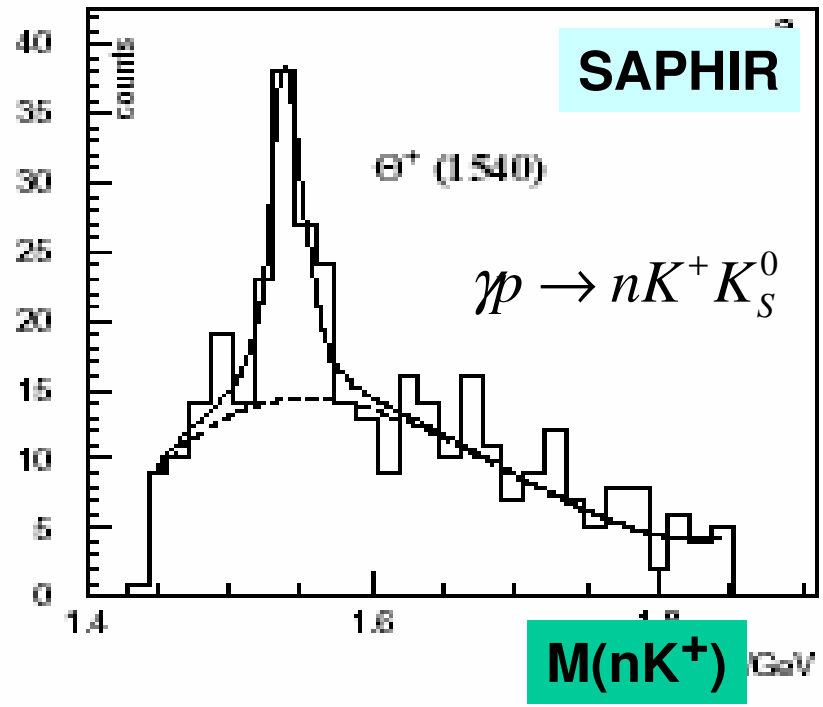


$$M = 1555 \pm 10 MeV$$

$$\Gamma < 26 MeV$$

$$N_{event} = 41$$

$$Significance :\sim 7.8\sigma \quad (S/\sqrt{B})$$



$$M = 1540 \pm 4 \pm 2 MeV$$

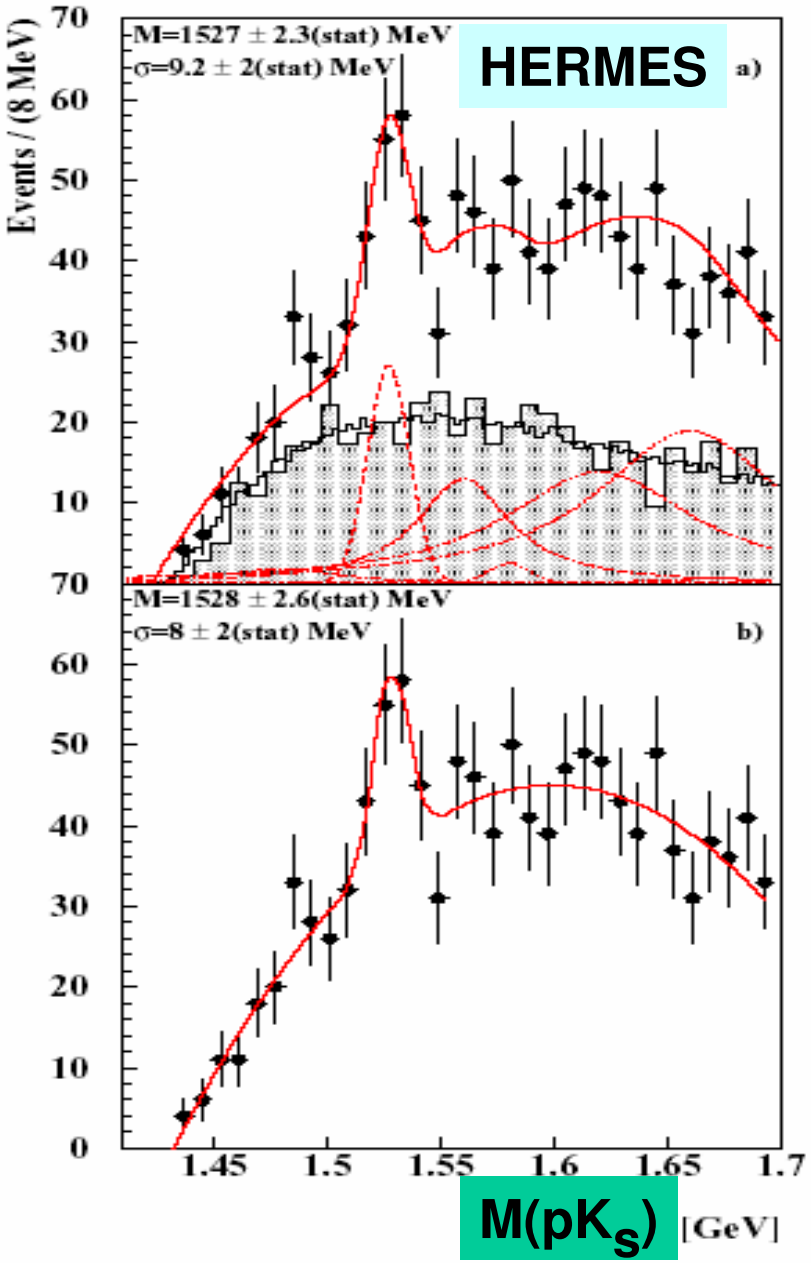
$$\Gamma < 25 MeV$$

$$N_{event} = 63 \pm 13$$

$$Significance: 4.8\sigma$$ **(fit)**

$$R_{\Lambda^*(1520)} = \sigma(\theta^+(1540)) / \sigma(\Lambda^*(1520)) \sim 0.3$$

Inclusive γ*- production



$$M = 1528 \pm 3 \pm 2 MeV$$

$$\Gamma = 17 \pm 9 \pm 3 MeV$$

$$N_{event} \sim 60$$

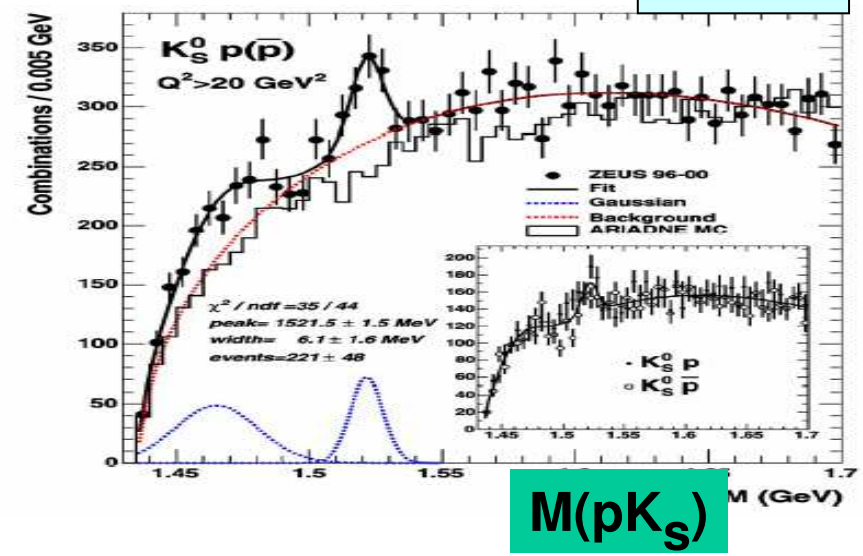
$$Significance: \sim 4 \sim 6\sigma \quad (S/\sqrt{B})$$

$$\sim 3 \sim 4\sigma \quad N_S / \delta N_S$$

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

Fragmentation

ZEUS



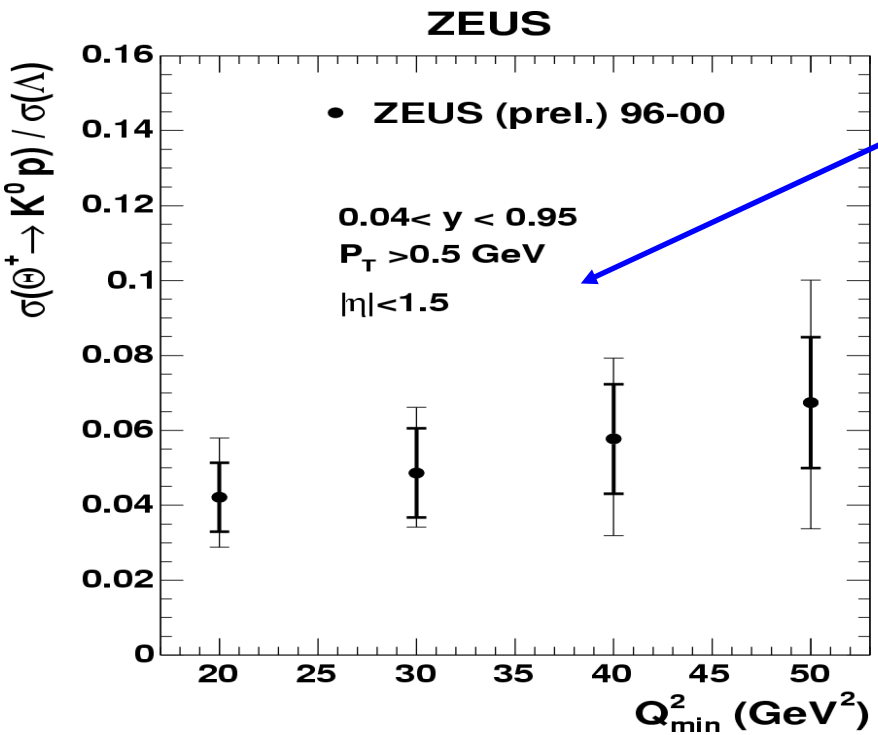
M(pK_S)

$$M = 1521.5 \pm 1.5 \pm^{2.8}_{1.7} MeV$$

$$\Gamma = 8 \pm 4 MeV$$

$$N_{event} = 221 \pm 48$$

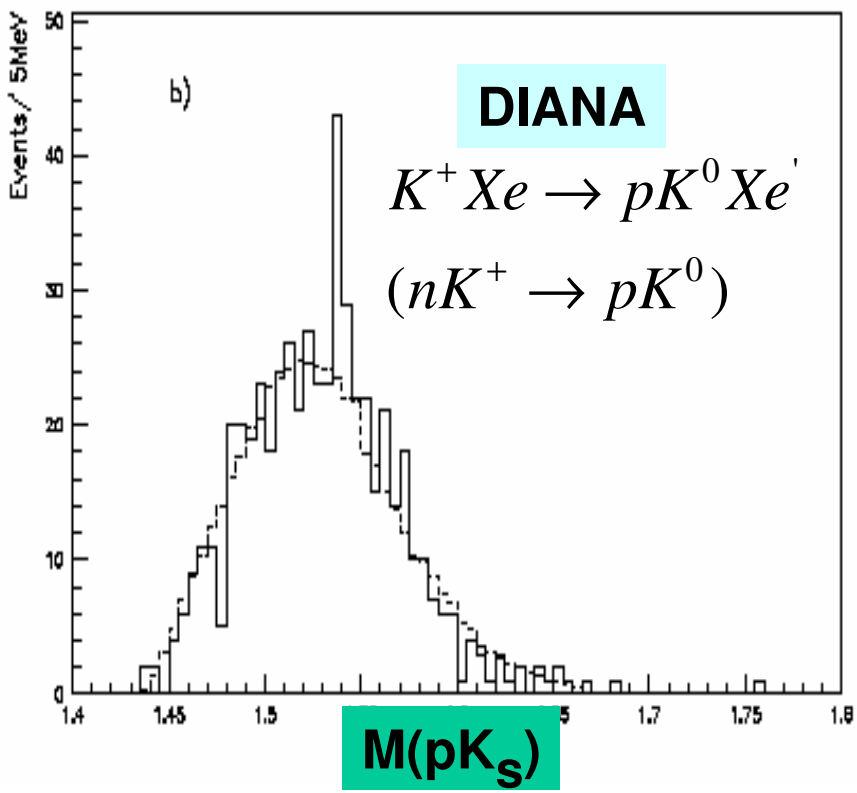
$$Significance :\sim 3.9 \sim 4.6\sigma$$ **(fit)**

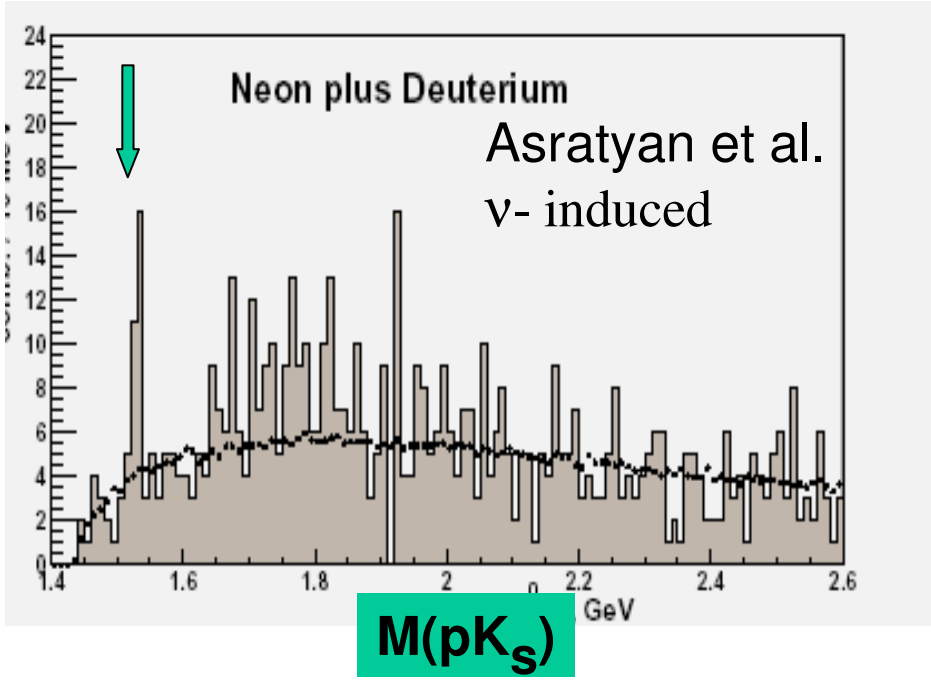


- **$R_\Lambda \sim 0.04$**

Assuming the production rate of Λ*(1520) is 5 times smaller than Λ, I estimated:

$R_{\Lambda^*(1520)} \sim 0.2$





$M = 1539 \pm 2 \pm 2 MeV$

$\Gamma < 9 MeV$

$N_{event} = 29$

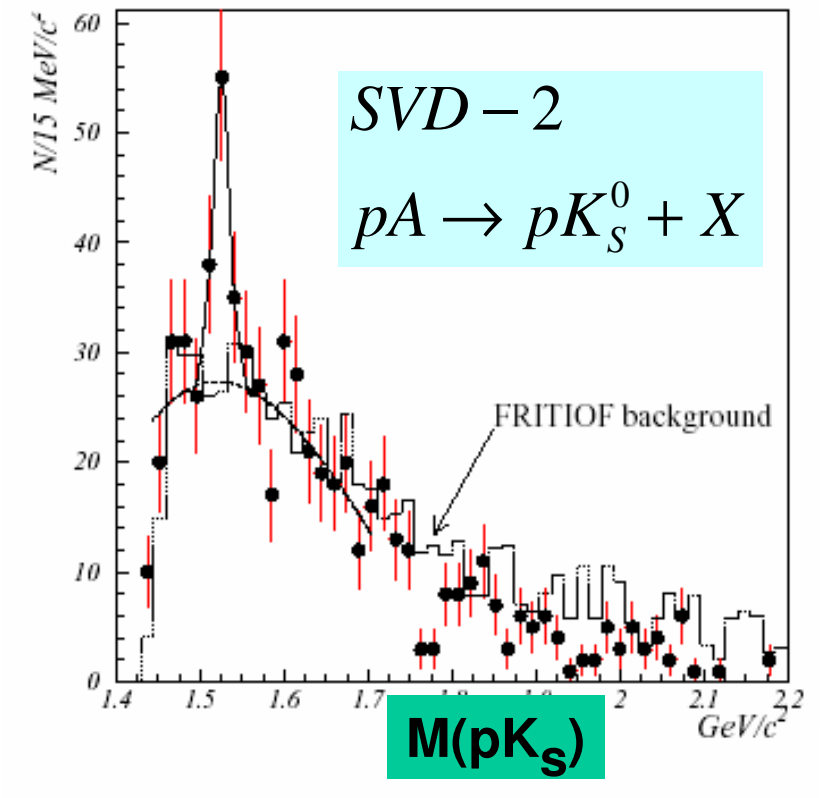
$Significance :\sim 4.4\sigma$ $(S/\sqrt{B})$

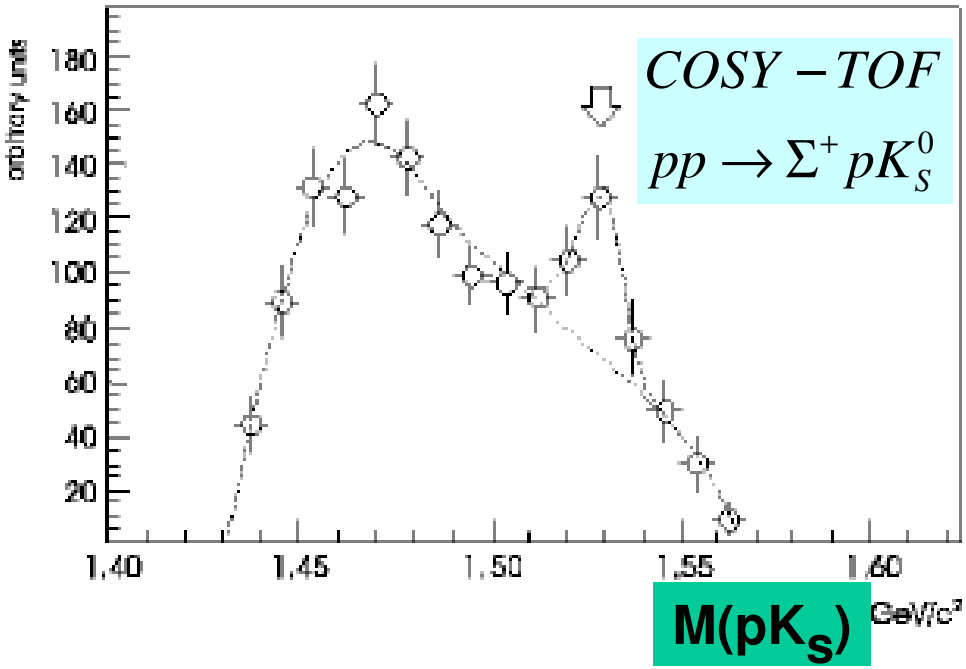
$M = 1533 \pm 5 MeV$

$\Gamma < 20 MeV$

$N_{event} = 27$

$Significance :\sim 6.7\sigma$ $(S/\sqrt{B})$





$M = 1526 \pm 3 \pm 3 MeV$

$\Gamma < 24 MeV$

$N_{event} = 50$

$Significance :\sim 5.6\sigma$ $(S/\sqrt{B})$

$\sigma(\theta^+) = 30 \sim 120 \mu b$

$M = 1530 \pm 5 MeV$

$\Gamma < 18 MeV$

$N_{event} \sim 120$

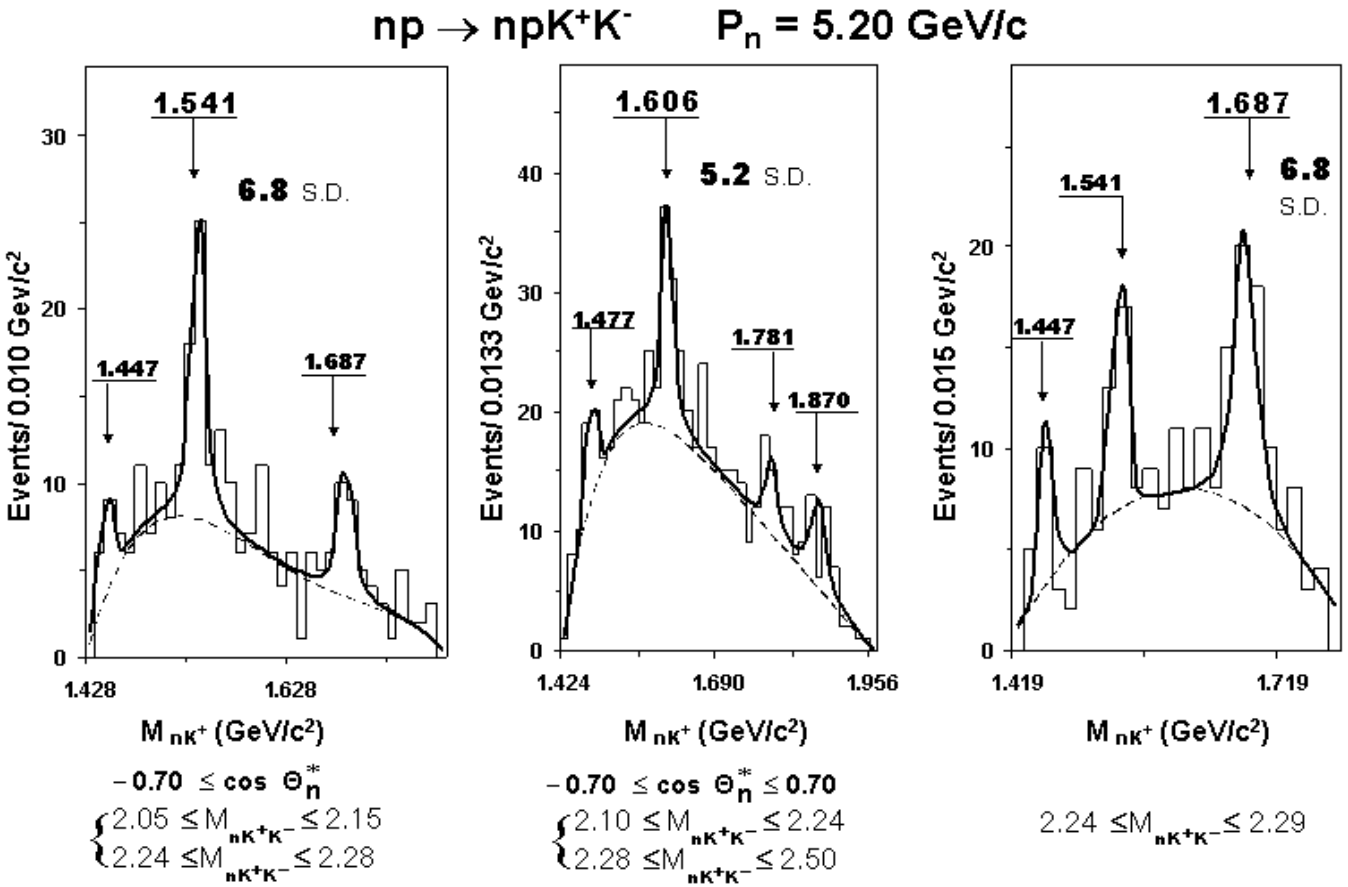
$Significance :\sim 3.7 \sim 5.9\sigma$

$\sigma(\theta^+) = 0.4 \pm 0.1 \pm 0.1 \mu b$

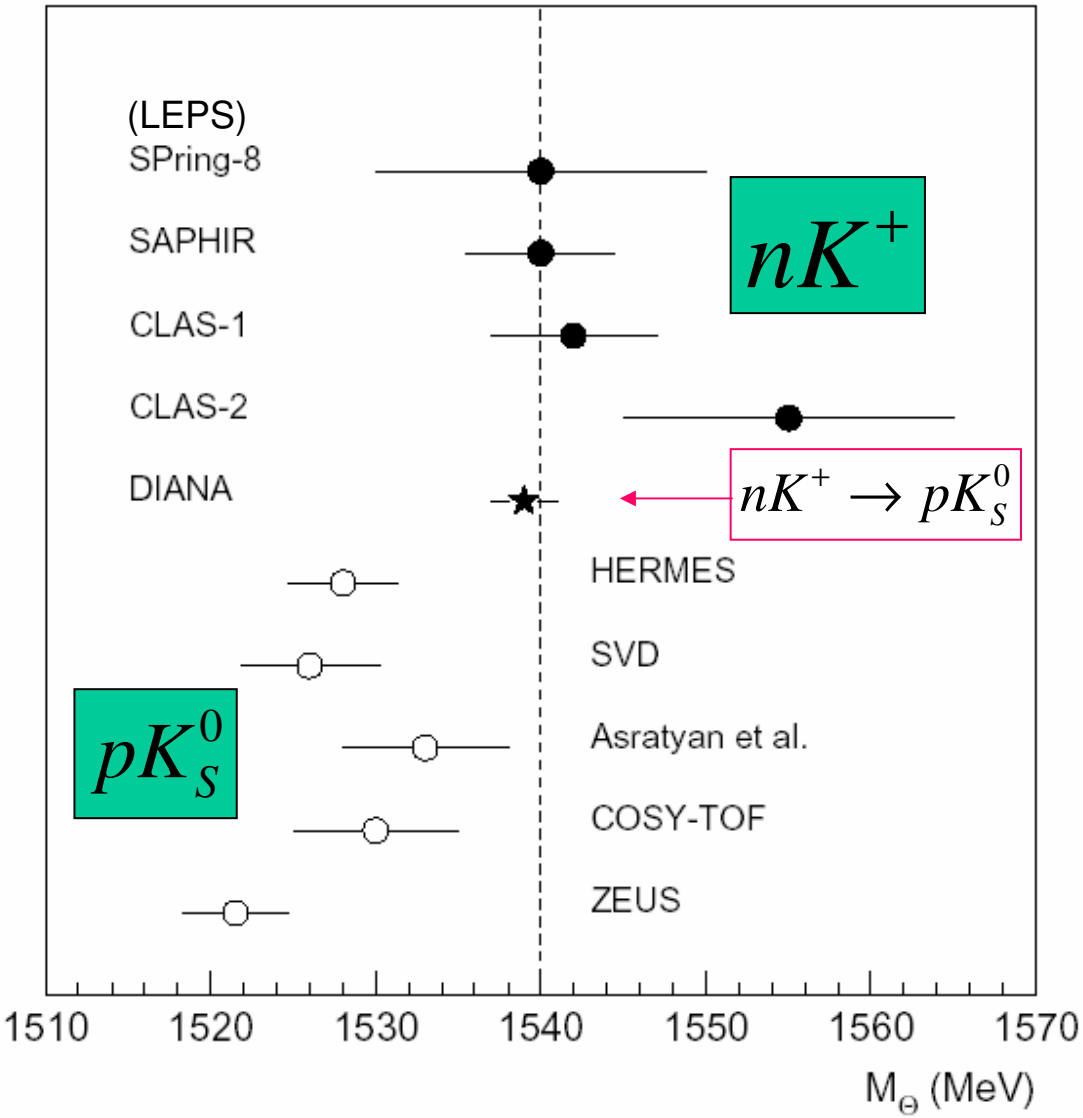
Pentaquarks at JINR

How many pentaquarks did they see?

M(nK⁺)



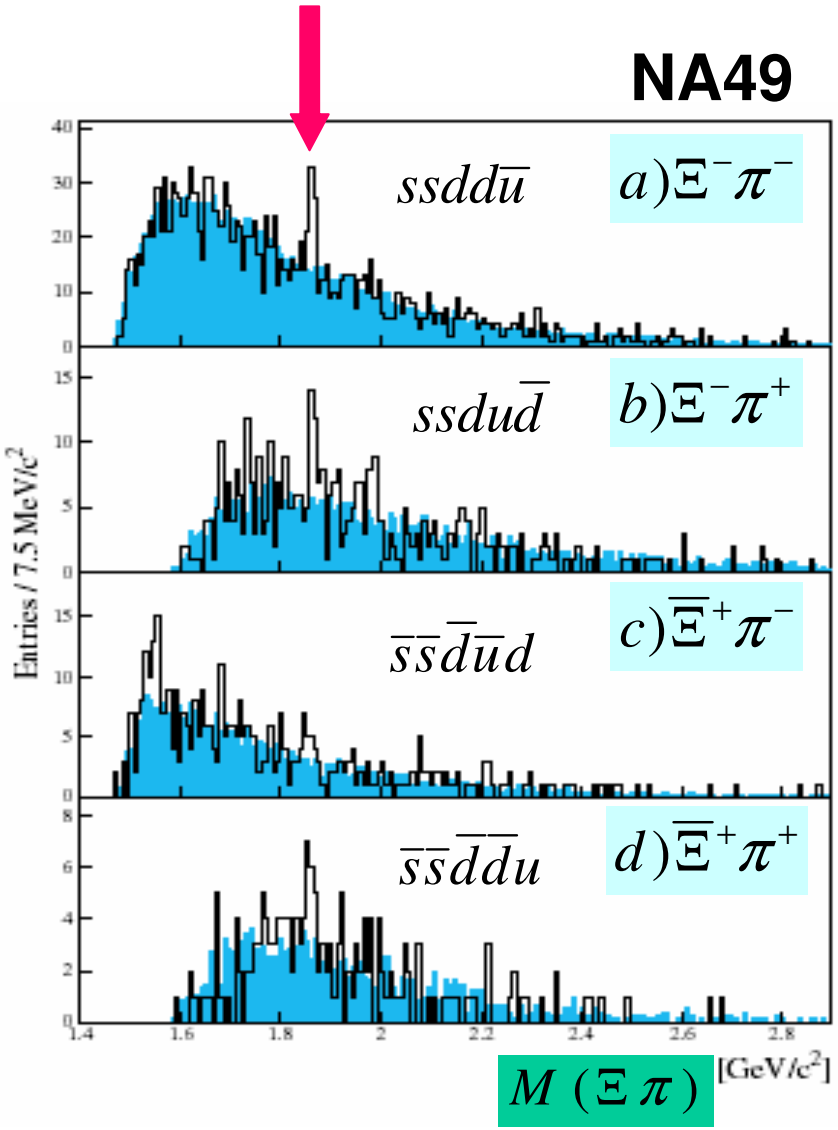
M_Θ



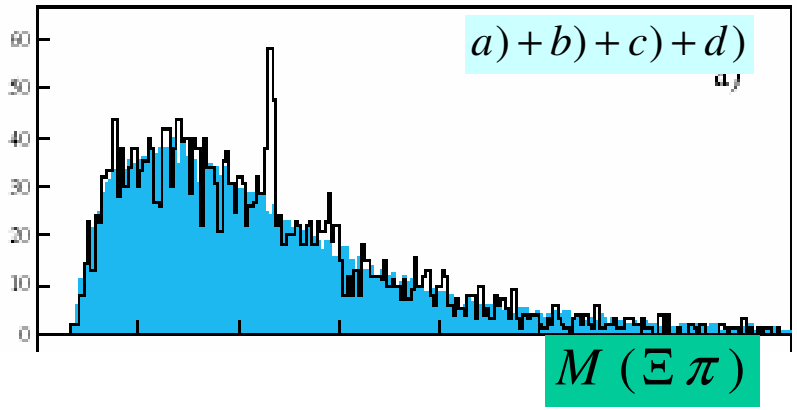
F. Close and Q. Zhao, hep-ph/0404075

$\Xi^{--}(1862)$

NA49



pp collision at E_{cm}=17.2GeV



$$M = 1862 \pm 2 MeV$$

$$\Gamma < 18 MeV$$

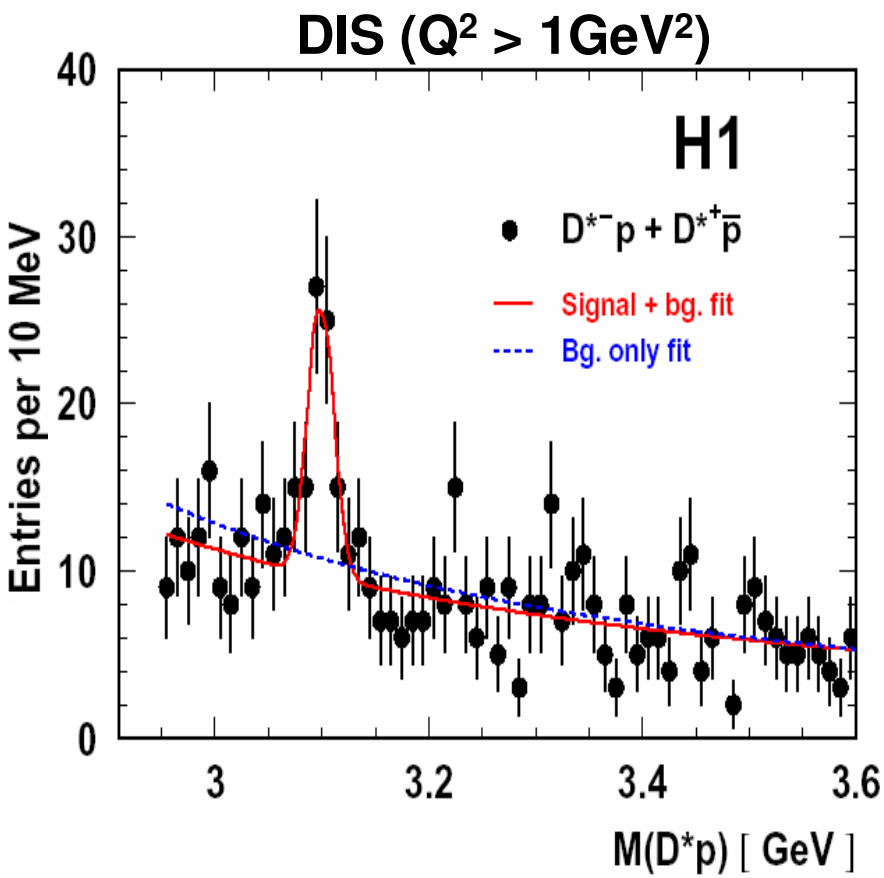
$$N_{event} = 69$$

$$Significance :\sim 5.8\sigma \quad (S/\sqrt{S+B})$$

- **Also evidence for $\Xi^0(1862)$**

  (I = 3/2)

$\Theta_c(3099)$



$$M = 3099 \pm 3 \pm 5 MeV$$

$$\Gamma < 12 MeV$$

$$N_{event} = 50.6 \pm 11.2$$

$$Significance :\sim 5.4\sigma$$

Poisson Prob.

- **Minimum quark content: uuddc**

$$\frac{N_{\Theta_c(3099)}}{N_{D^{*-}}} \cdot BR(\Theta_c(3099) \rightarrow D^{*-} p) \sim 0.01$$

Negative search results on pentaquarks

BES upper limits 90%C.L. BR ($\psi(2S) \rightarrow \Theta\,\Theta \rightarrow (K_S p)(K^- n) + (K_S p)(K^+ n)$) $< 0.84 \times 10^{-5}$

BR ($J/\psi \rightarrow \Theta\,\Theta \rightarrow (K_S p)(K^- n) + (K_S p)(K^+ n)$) $< 1.1 \times 10^{-5}$

ALEPH No evidence for $\Theta^+(1540)$, $\Xi^{--}(1862)$, $\Xi^0(1862)$, $\Theta_c(3100)$ in Z decays

DELPHI No evidence for $\Theta^+(1540)$, $\Theta^{++}(1540)$

L3 No evidence for $\Theta^+(1540)$ in two photon collisions.

CDF No evidence of $\Theta^+(1540)$, $\Xi^{--}(1862)$, $\Xi^0(1862)$ or $\Theta_c(3100)$

HERAB No evidence of $\Theta^+(1540)$, $\Xi^{--}(1862)$, $\Xi^0(1862)$

ZEUS $\Theta_c(3099)$ was not observed at ZEUS in a data sample which is 1.7 times of the H1 data sample

BABAR No evidence of $\Theta^+(1540)$, $\Xi^{--}(1862)$

BELLE $\Theta^+(1540)$ not seen, $\Theta_c(3100)$ was not seen either.

Inconsistencies

- Width of $\Theta^+(1540)$
  - Two "positive" experiments:

    HERMES: $\Gamma_\Theta = 17 \pm 9 \pm 2$ MeV

    ZEUS: $\Gamma_\Theta = 8 \pm 4$ MeV

  - K^+N PWA results indicates $\Gamma_\Theta < 1$ MeV
- Mass of $\Theta^+(1540)$
- Production rate

- **The "negative" experiments have much larger statistics, also are at relatively higher energies (but Babar and Belle are at low energy).**

  - **Pentaquarks do not exist, or**
  - **Pentaquarks have very exotic production mechanism.**

    via N*?

    Then why N* has much higher production rate at low energy?

- **Looking forward to more experimental results at low energy with high statistics, especially those photo-production experiments !**

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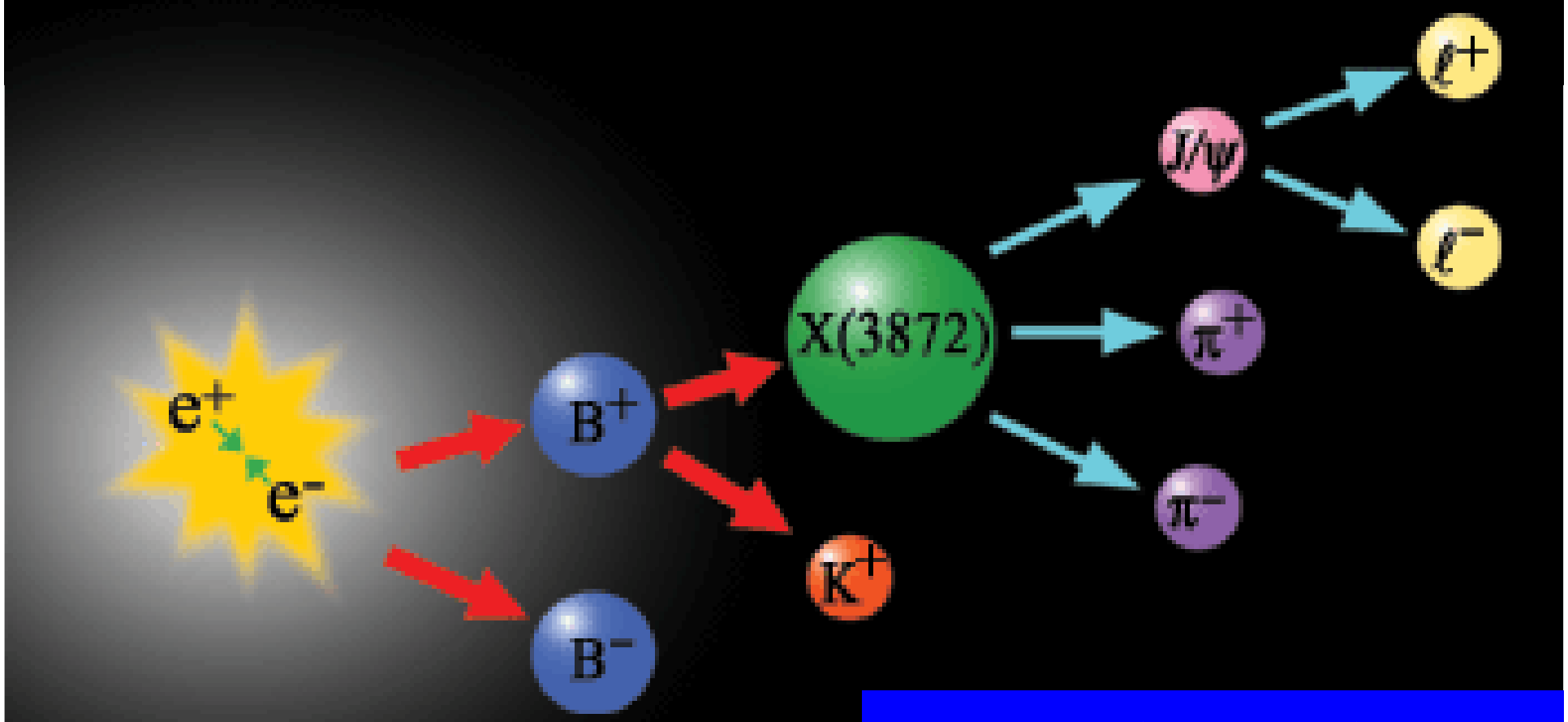
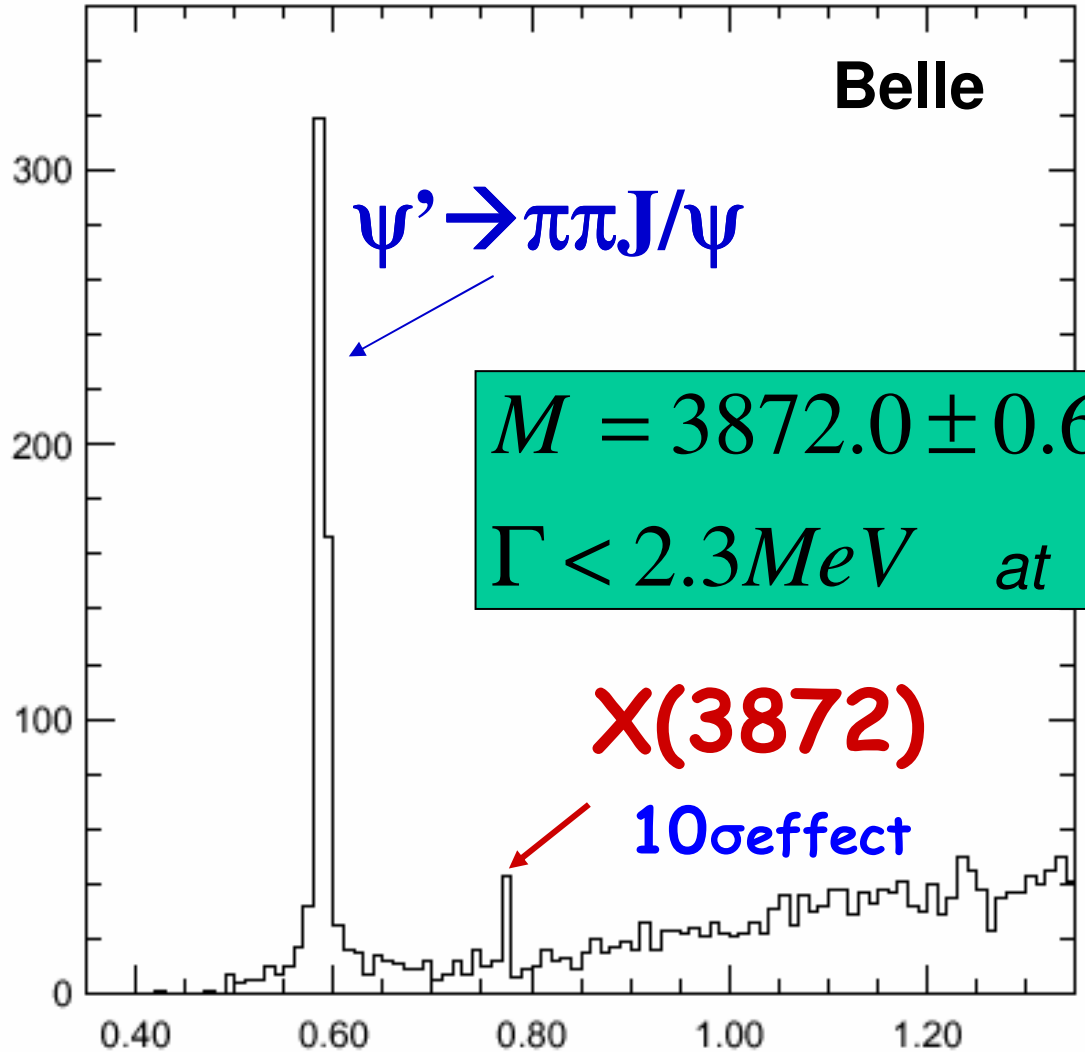
First observed by Belle Experiments in:



X(3872)

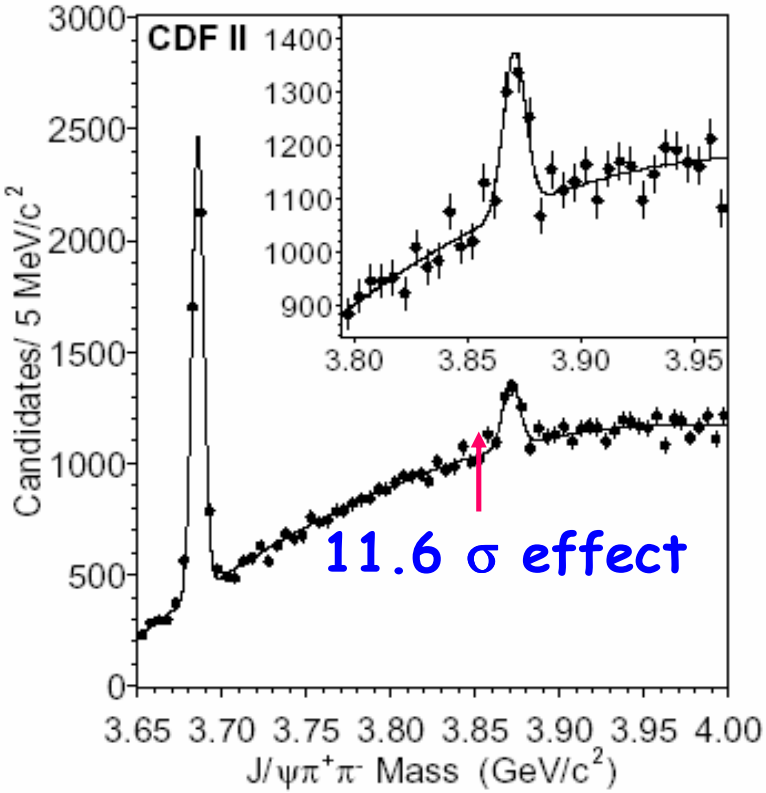
$M(\pi^+\pi^- J/\psi) - M(J/\psi)$

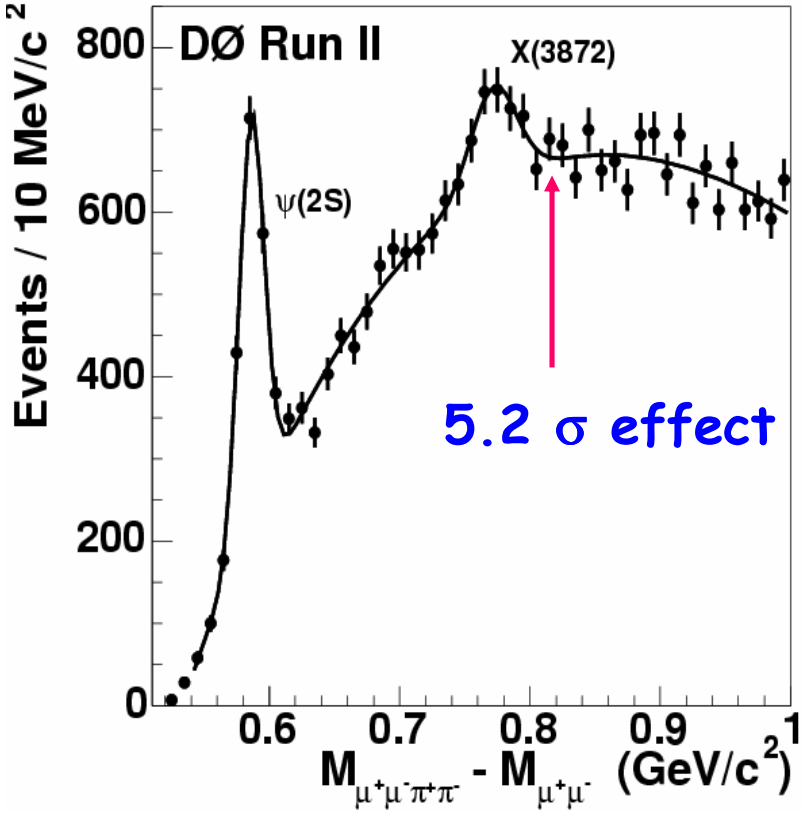


$$M = 3872.0 \pm 0.6 \pm 0.5 MeV$$

$$\Gamma < 2.3 MeV \quad \text{at 90\% C.L.}$$

X(3872) at CDF and D0





$$M_X = 3871.3 \pm 0.7 \pm 0.4 MeV$$

$$M_X - M_{J/\psi} = 774.9 \pm 3.1 \pm 3.0 MeV$$

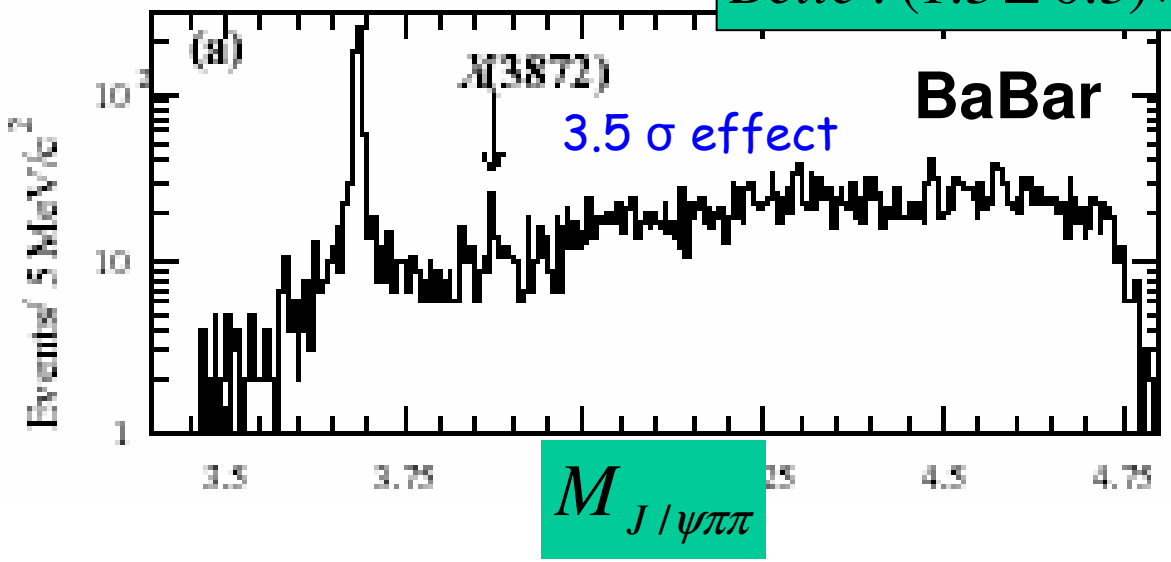
X(3872) at BaBar

- **The significance is low (about 3.5 σ), but its production rate is consistent with Belle:**

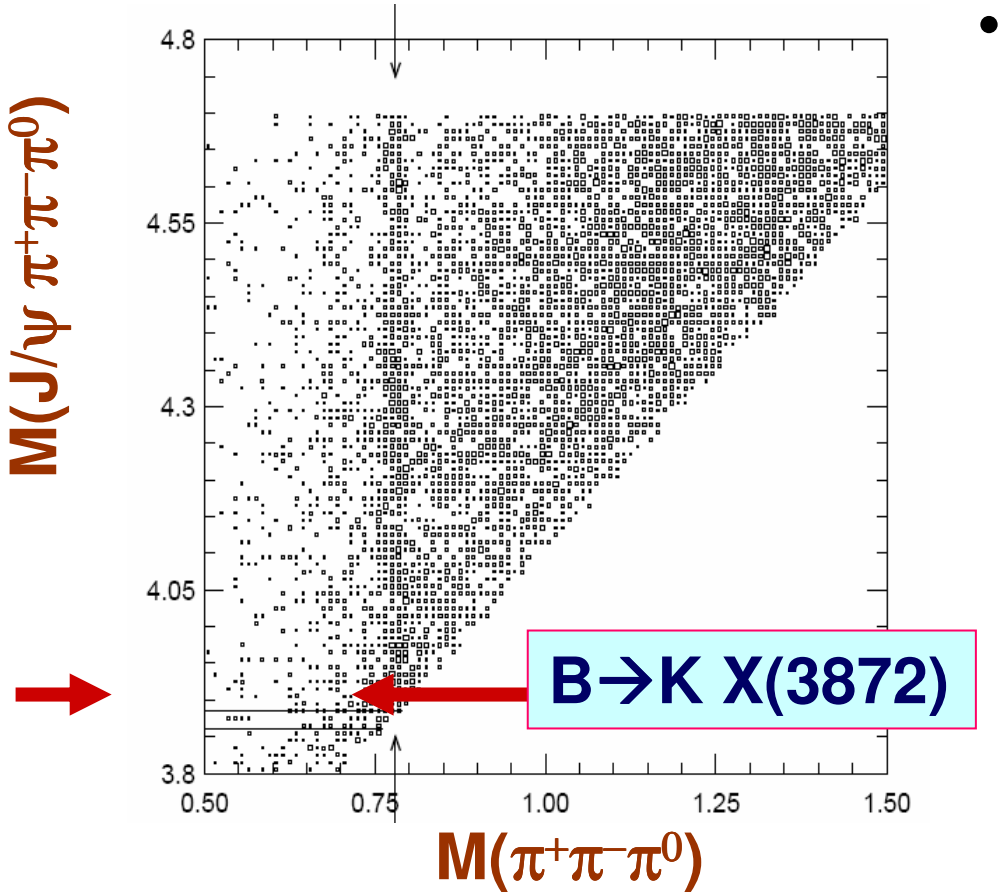
$$M_X = 3873.4 \pm 1.4 MeV$$

$$BR(B^- \to XK^-) \times B(X \to \pi\pi J/\psi) = (1.28 \pm 0.41) \times 10^{-5}$$

$$Belle: (1.3 \pm 0.3) \times 10^{-5}$$



New decay mode observed at Belle



- Belle observed a new decay mode of X(3872) → $\omega^* J/\psi \rightarrow \pi^+\pi^-\pi^0 J/\psi$

N_{evt}=10.0 ± 3.6
Signif = 5.8σ

$\Gamma(X \rightarrow \omega J/\psi)/\Gamma(X \rightarrow \pi^+\pi^- J/\psi) = 0.8 \pm 0.3 \pm 0.1$

Is X(3872) a Charmonium?

- **All possible charmonium assignments seem to have difficulties (S.L. Olsen, hep-ex/0407033):**

State	nickname	J^{PC}	comment
$1^3 D_2$	ψ_2	2^{--}	Mass wrong; $\Gamma_{\gamma\chi c1}$ too small
$2^1 P_1$	h'_c	1^{+-}	Ruled out by $\lvert\cos\theta_{J/\psi}\rvert$ distribution
$1^3 D_3$	ψ_3	3^{--}	Mass & width wrong; $\Gamma_{\gamma\chi c2}$ too small; Spin is too high
$2^3 P_1$	χ'_{c1}	1^{++}	$\Gamma_{\gamma J/\psi}$ too small
$1^1 D_2$	η_{c2}	2^{-+}	$B(\pi^+\pi^- J/\psi)$ expected to be very small
$3^1 S_0$	η''_c	0^{-+}	Mass and width are wrong

$D\bar{D}^*$ "Molecular State"?

- $M_{X(3872)}$ is very close to $M_D + M_{D^*}$.
- It was suggested that a $D\bar{D}^*$ multi-quark "molecular state" have large $BR(X \to D^0\bar{D}^0\pi^0)$. Belle observes:

$$\Gamma(X \to D^0\bar{D}^0\pi^0)/\Gamma(X \to \pi\pi J/\psi) < 6$$ at 90% C.L.

Some theoretical calculations predict the above ratio is small. (Swanson's talk in Session 10)

- Swanson also predicts:

$$\Gamma(X \to \omega J/\psi)/\Gamma(X \to \pi\pi J/\psi) \sim 0.6$$

Consistent with Belle new observation.

Prospects

- No matter what are the interpretations for the recent new surprising observations, **these discoveries certainly open a new window for understanding the strong interaction and hadron spectroscopy.**

- We need to have a global picture if there are new forms of hadrons beyond the naïve quark model —— any pentaquark, tetraquark, molecular state or other multiquark states cannot stay alone !

A lot of opportunities for BES III and other experiments working on hadron spectroscopy !!!

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CONCLUSION

Have Weird Multiquark Demons been found?

Is there a 1 MeV wide, S=+1 baryon at 1540 MeV?

If NO this is testament to the ingenuity of theorists whose models can explain it even if it doesn't exist.

Lattice QCD is almost unique in not having definitively disproved that such a state does not exist.

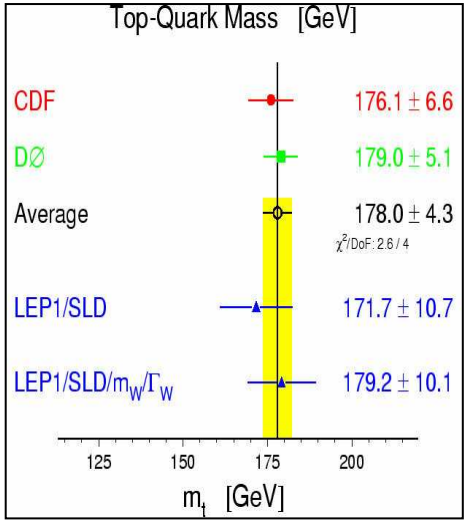
Frank Close
ICHEP04

Pespectives on Higgs searches

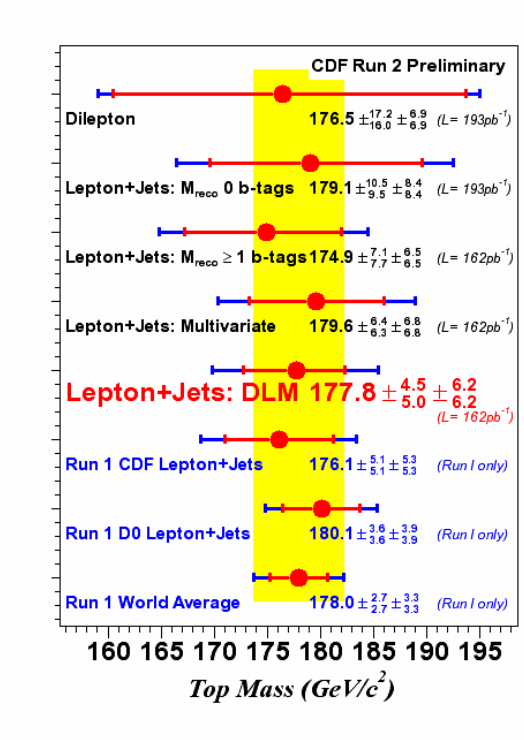
Tevatron Top Quark Mass Measurement

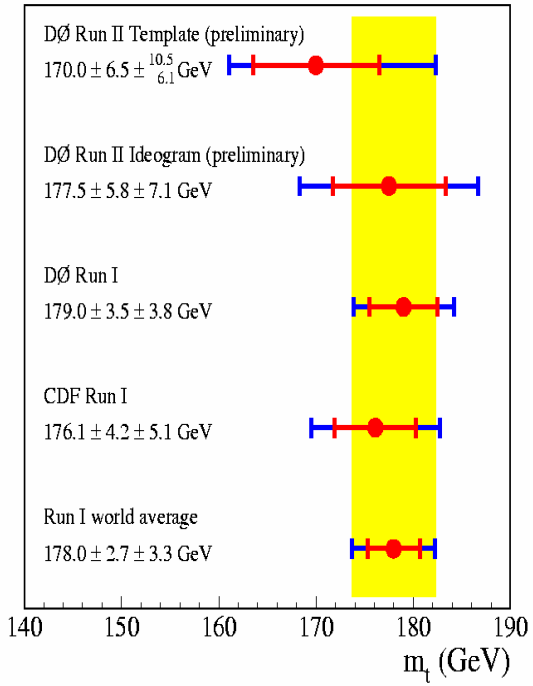
New combined Run I result →
(Was m_t = 174.3±5.1 GeV)

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

Dmitri Denisov, Fermilab

Experimental Limits on Higgs Mass

Available experimental limits

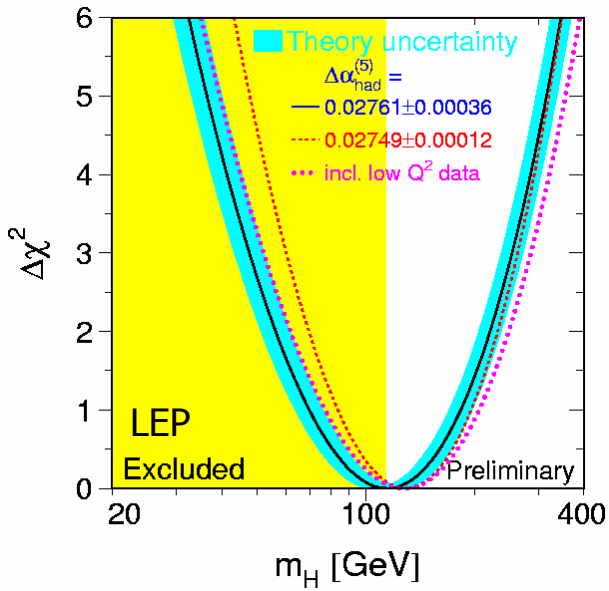
→direct searches at LEP
M_H >114 GeV at 95% C.L.

→precision EW fits

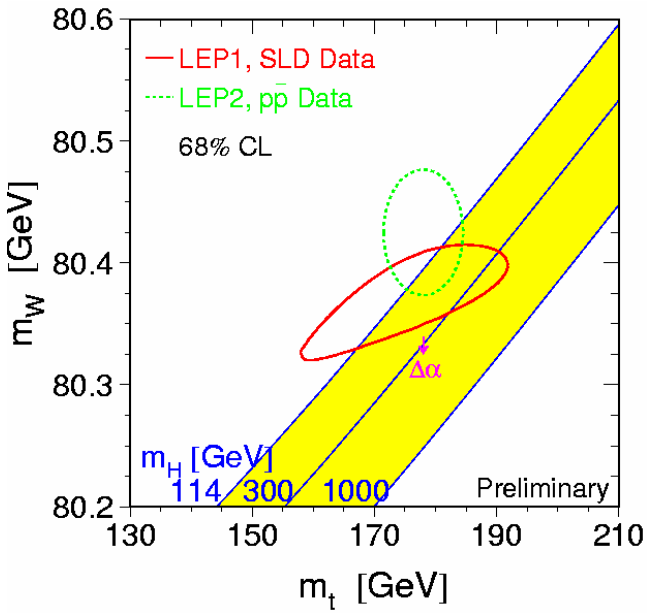
$$m_H = 114^{+69}_{-45} GeV$$

$$m_H \leq 260 GeV \quad \text{at 95\% C.L.}$$

Light Higgs favored

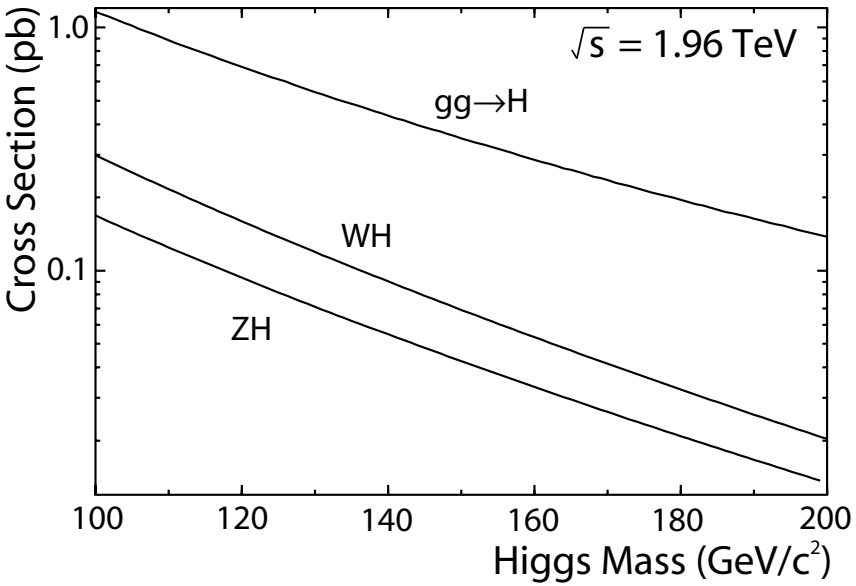


Tevatron provides:
Precision m_t and M_W measurements
Direct searches
→ SM Higgs
→ non-SM Higgs

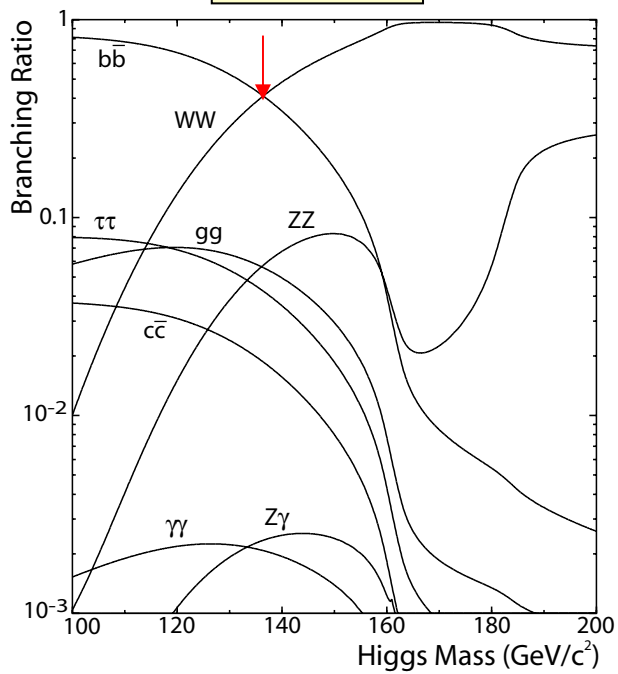


SM Higgs Production and Decays at Tevatron

Production



Decays



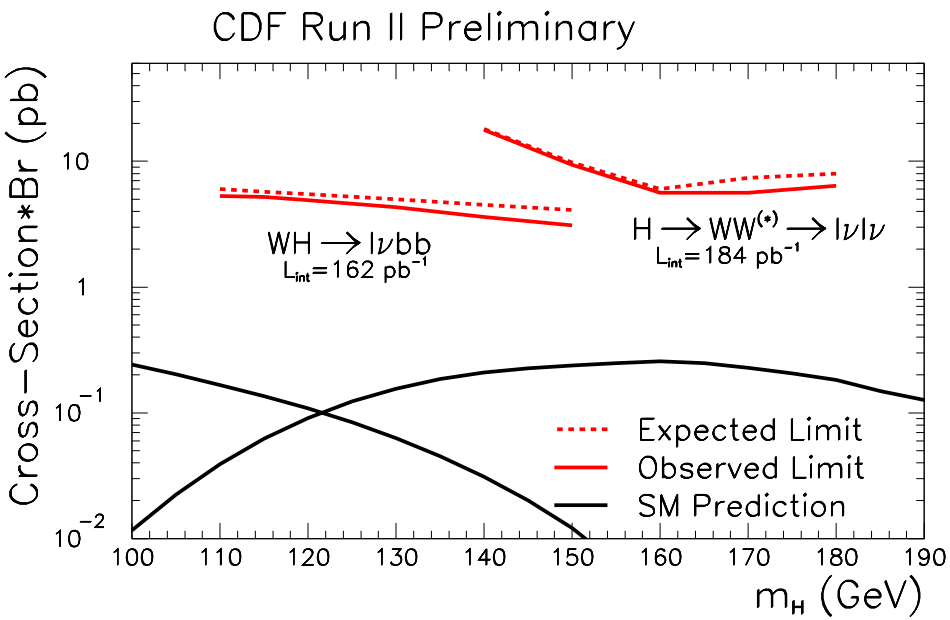
Production cross section
→ in the 1 pb range for gg → H
→ in the 0.1 pb range for associated vector boson production

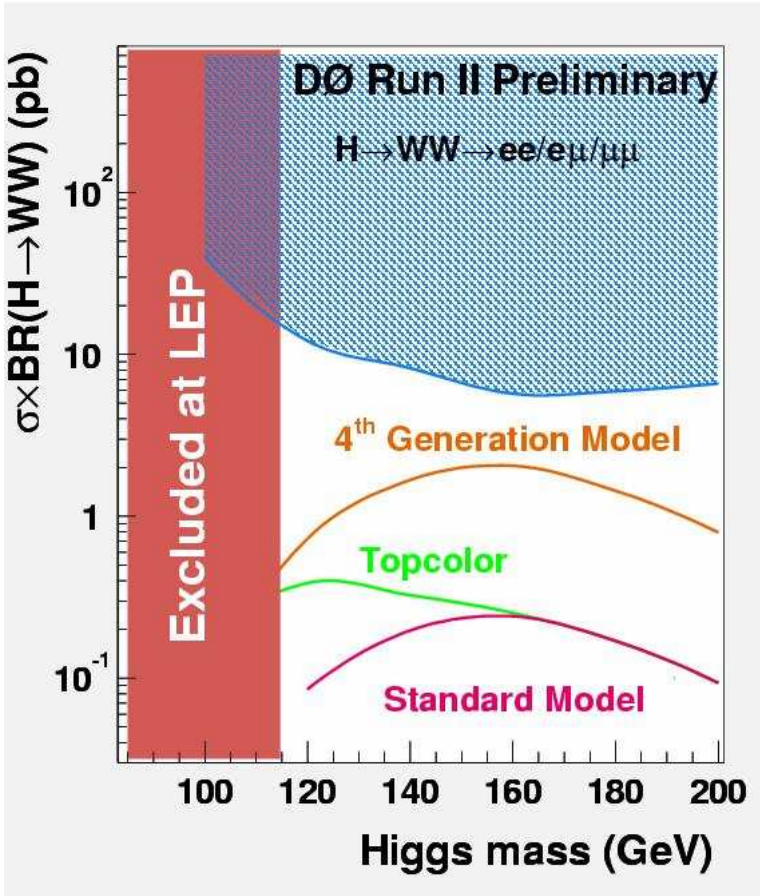
Decays
→ bb for M_H < 130 GeV
→ WW for M_H > 130 GeV

Search strategy:
M_H <130 GeV associated production and bb decay W(Z)H → lν(l) bb
Backgrounds: top, Wbb, Zbb…
M_H >130 GeV gg →H production with decay to WW
Backgrounds: electroweak WW production…

Current Limits on SM Higgs Search

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





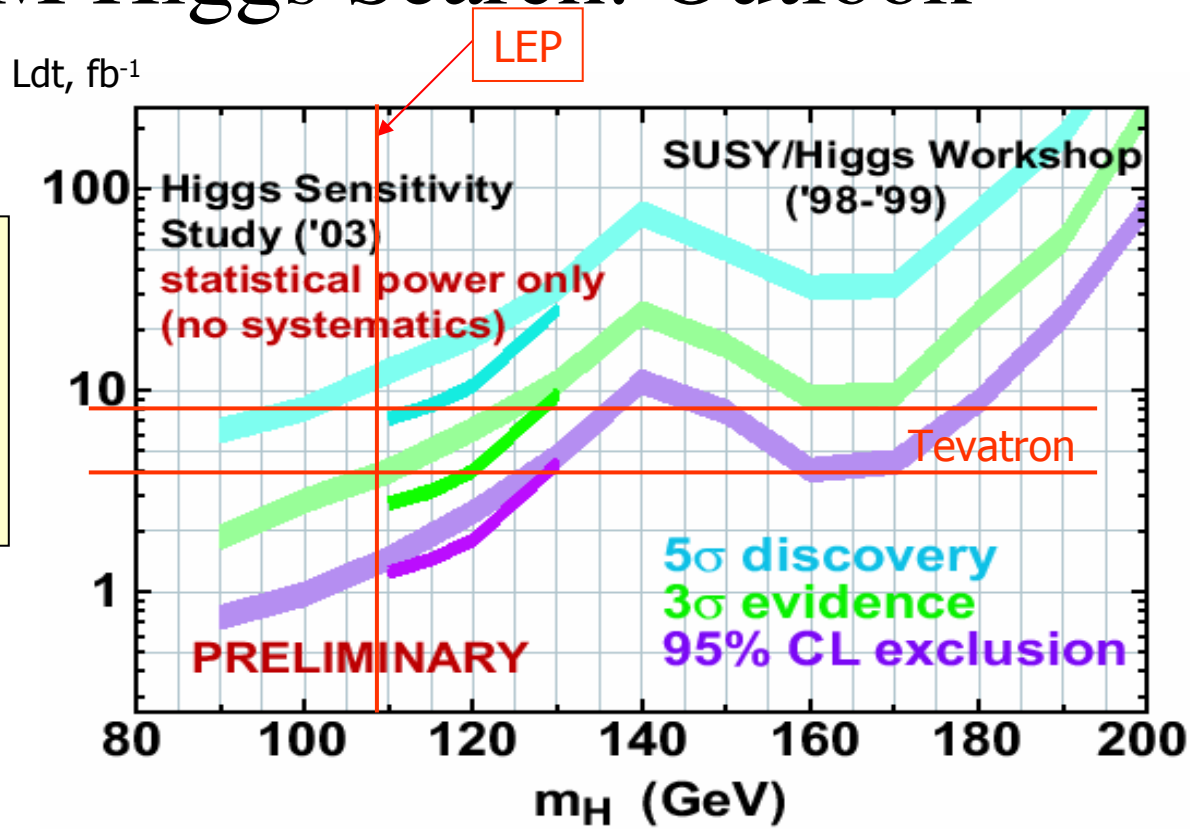
Limits already exceeding Run I results

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

Tevatron SM Higgs Search: Outlook

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

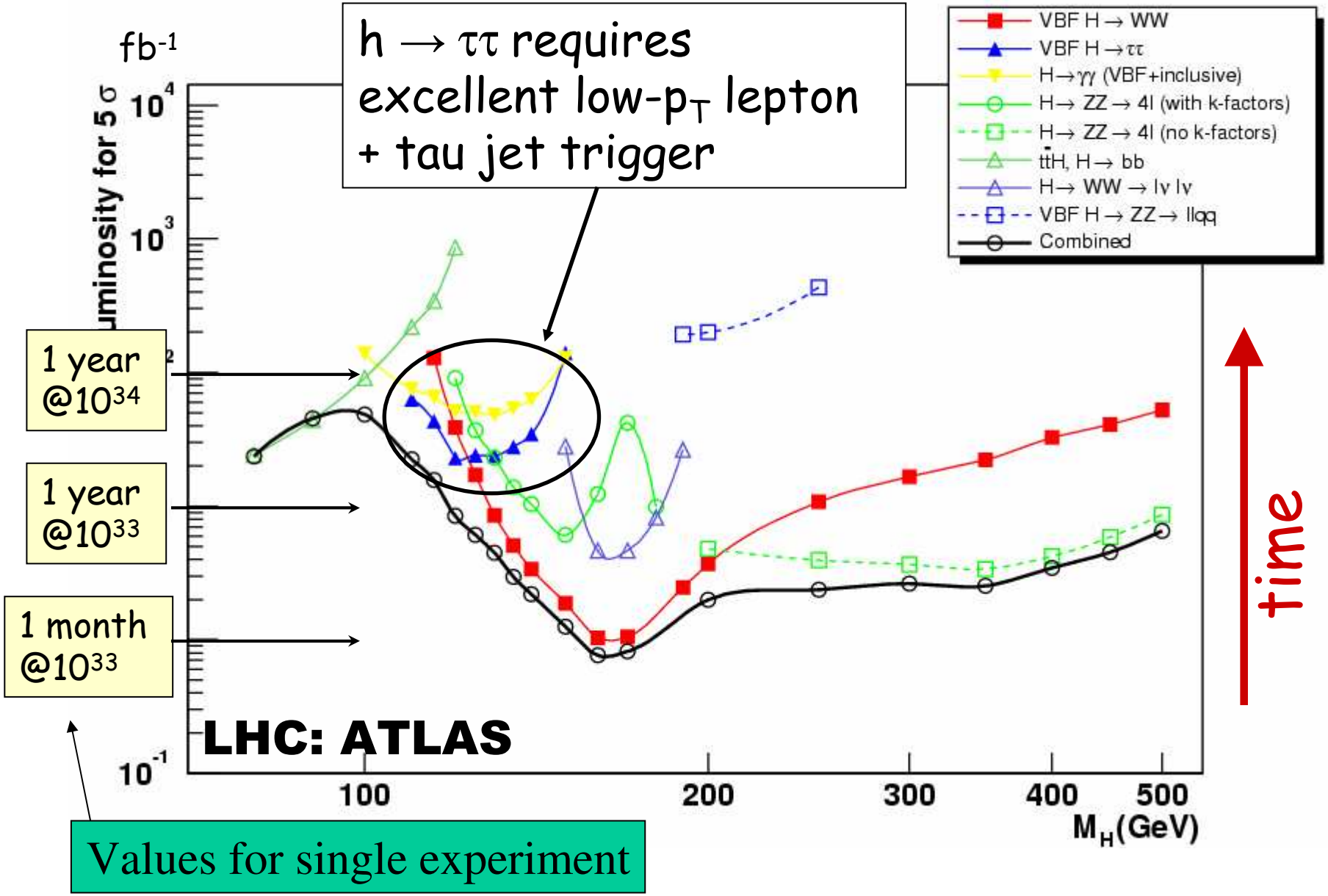
→ better detector understanding
→ optimization of analysis



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 at LHC


h → ττ requires
excellent low-p_T lepton
+ tau jet trigger
fb-1
uminosity for 5 σ
10^4
10^3
10^-1
1 year @10^34
1 year @10^33
1 month @10^33
LHC: ATLAS
100
200
300
400
500
M_H(GeV)
VBF H → WW
VBF H → ττ
H→γγ (VBF+inclusive)
H→ ZZ → 4l (with k-factors)
H→ ZZ → 4l (no k-factors)
tt̄H, H→ bb
H→ WW → lν lν
VBF H → ZZ→ llqq
Combined
time
Values for single experiment

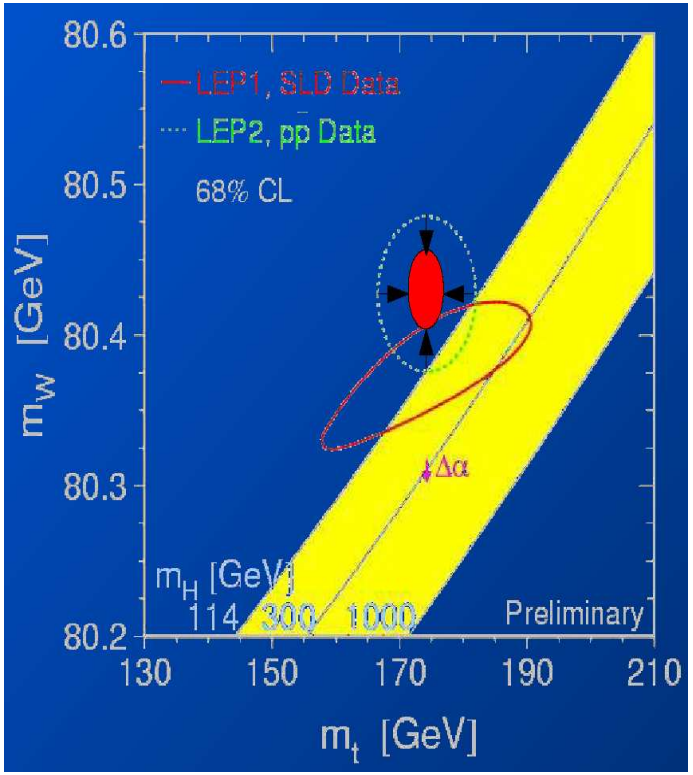
Tevatron Top and Higgs: Summary

Many excellent talks about top and Higgs studies at Tevatron are presented at ICHEP04
EW, Beyond SM, Heavy Quarks sessions

Top studies are actively progressing:
→ updated σ_{tt}, m_t , limits on single top production
→ studies of SM predictions and beyond SM models
→ W helicity studies
→ decay modes: Wq, WX, Xq...
→ tt resonances,…

No deviations from SM observed (yet)

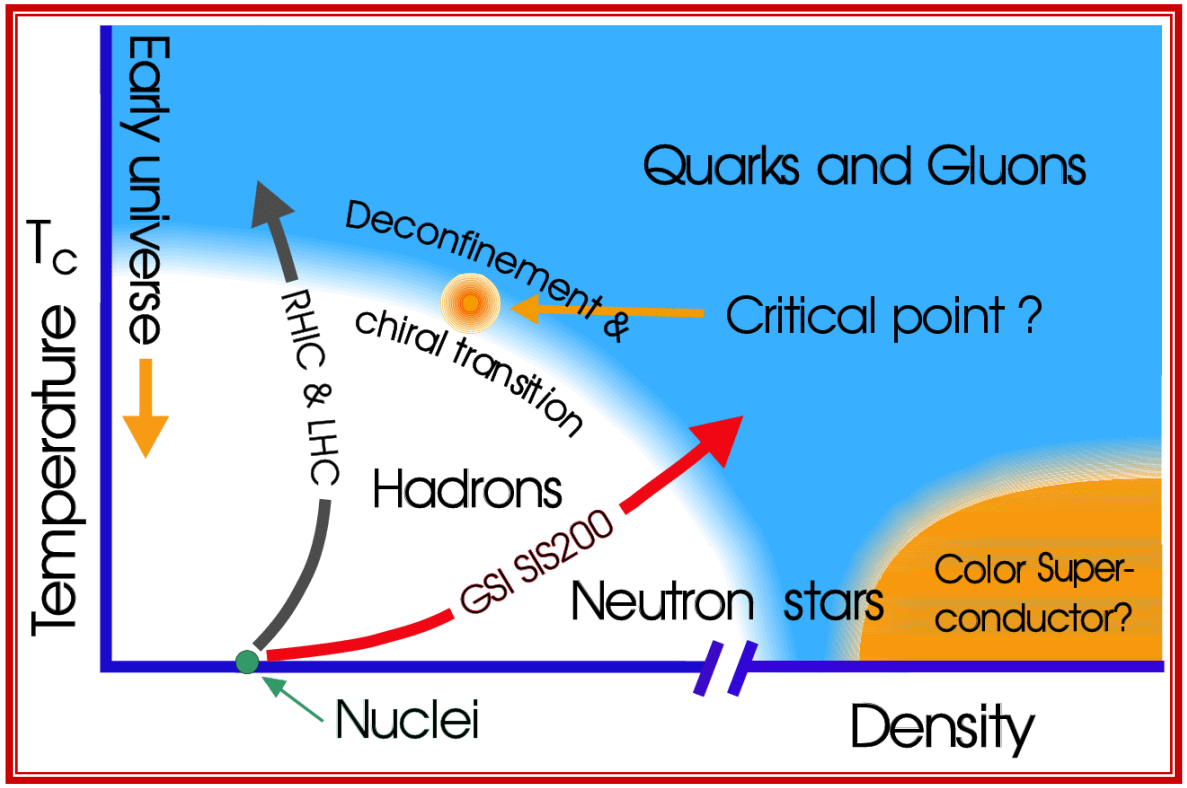
Higgs search is in progress:
→ SM Higgs
→ sensitivity (m_H >114 GeV) starts at ~2 fb^{-1}
→ non-SM Higgs
→ many different models tested
→ already see reduction in allowed phase space (Run I, LEP)



Expect substantial improvements in top studies, Higgs hunting with
~0.5 fb^{-1} already on tapes
~8 fb^{-1} expected in Run II

Heavy Ions

Quark Matter at High Density/Temperature



James C Dunlop

Brookhaven National Laboratory

Defining the question

Recent Definition from STAR for the Quark Gluon Plasma

QGP ≡ ***a (locally) thermally equilibrated state of matter in which quarks and gluons are deconfined from hadrons, so that color degrees of freedom become manifest over nuclear, rather than merely nucleonic, volumes.***

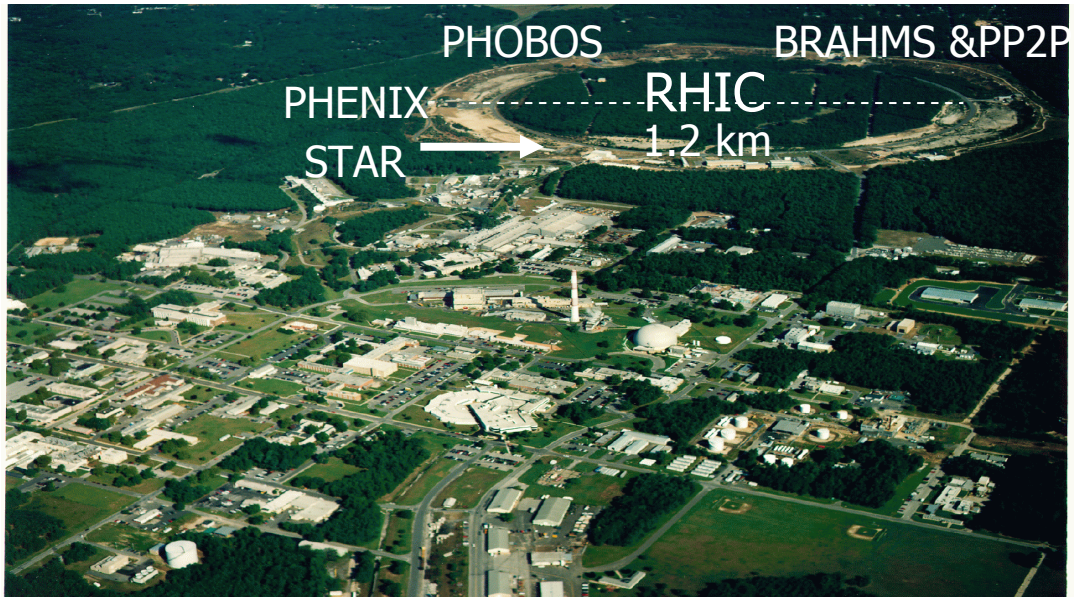
Contrast with other recent definition:

M. Gyulassy & L. McLerran

Approximately thermalized matter at energy densities so large that the simple degrees of freedom are quarks and gluons. This energy density is that predicted by LGT for the existence of a QGP, ≈ 2 GeV/fm^3.

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



RHIC Experiments

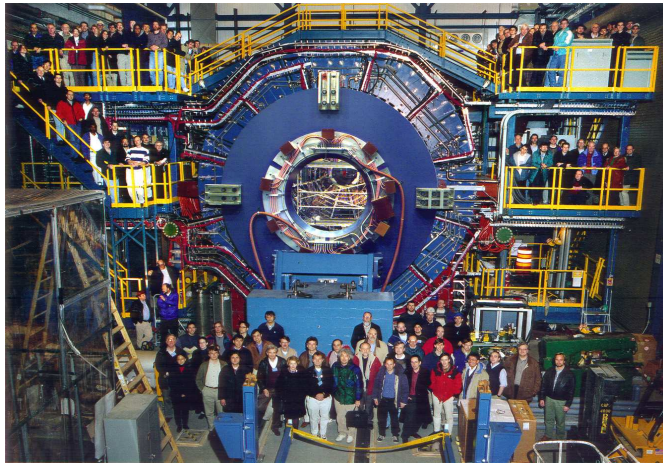
Four experiments, two large, two small:

STAR: Large acceptance ($\Delta\phi = 2\pi$, $\Delta\eta = 2–6$)
PHENIX: Electron/muon identification, high rate trigger, limited acceptance ($\Delta\phi = \pi$, $\Delta\eta = 0.5$ (central arm)

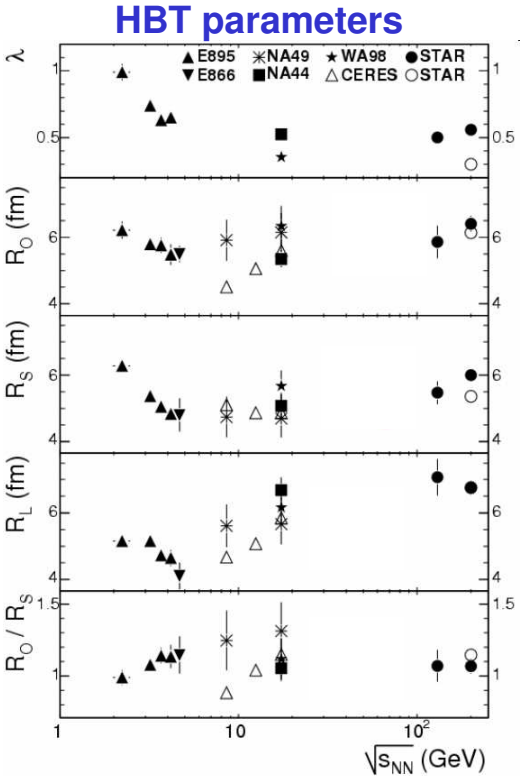
PHOBOS: Tabletop: limited tracking acceptance, largest multiplicity acceptance of all experiments
BRAHMS: Forward tracking in classical spectrometer

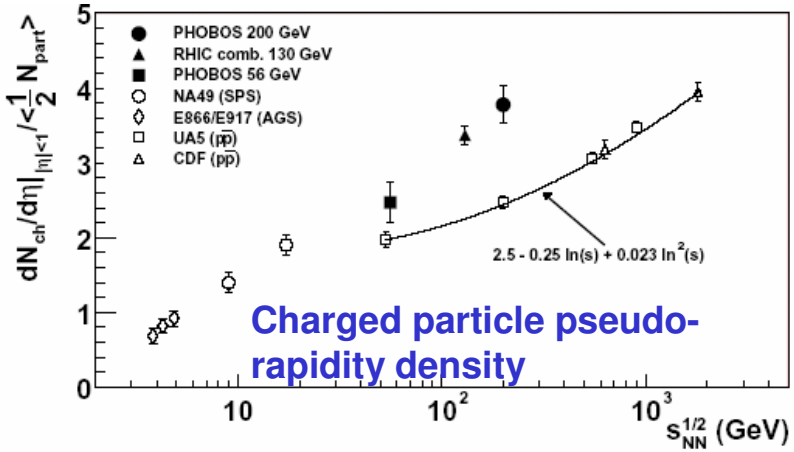
PHENIX

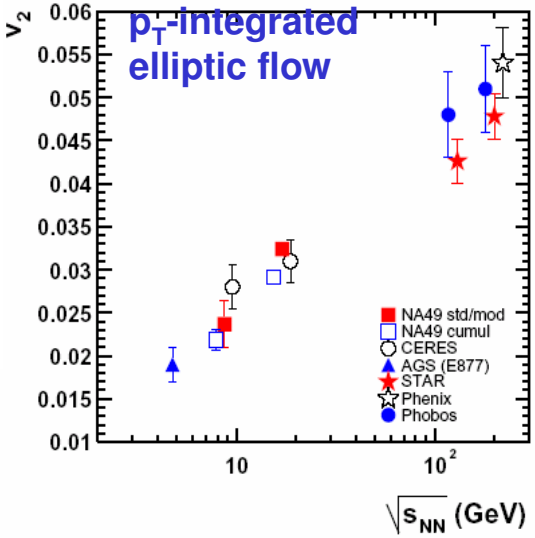
STAR

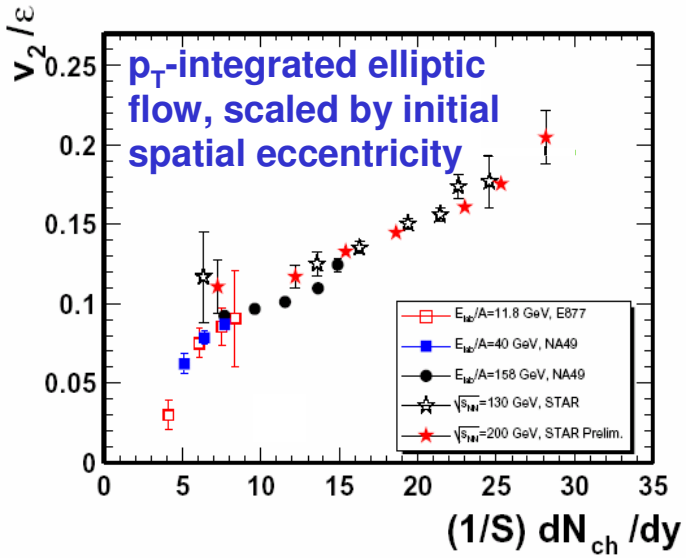


But only smooth behavior is observed



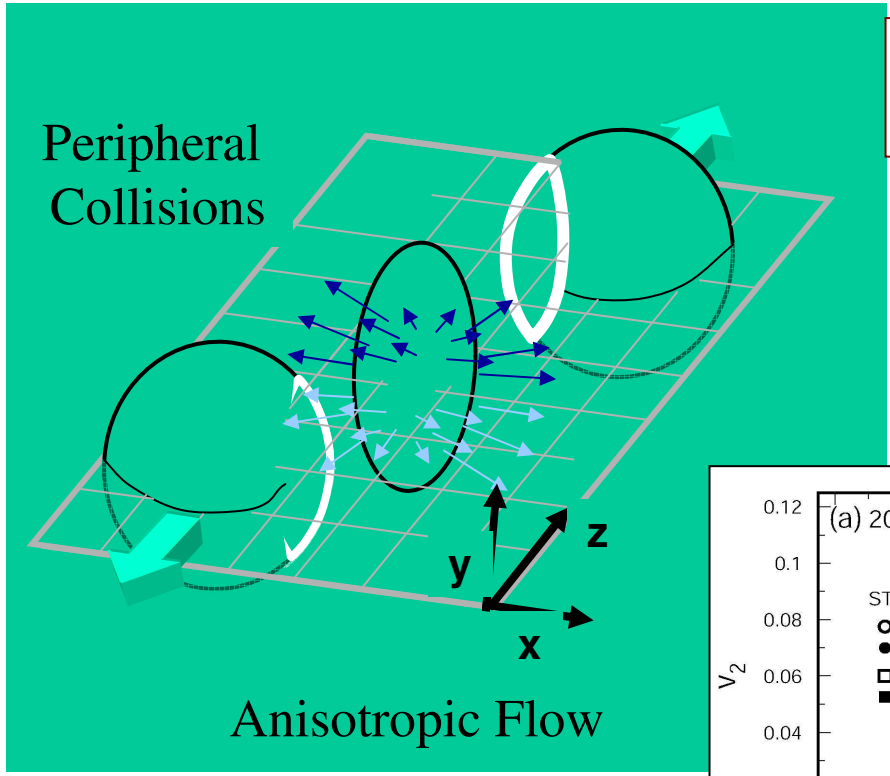






No exp'tal smoking gun! ⇒ Rely on theory-exp't comparison

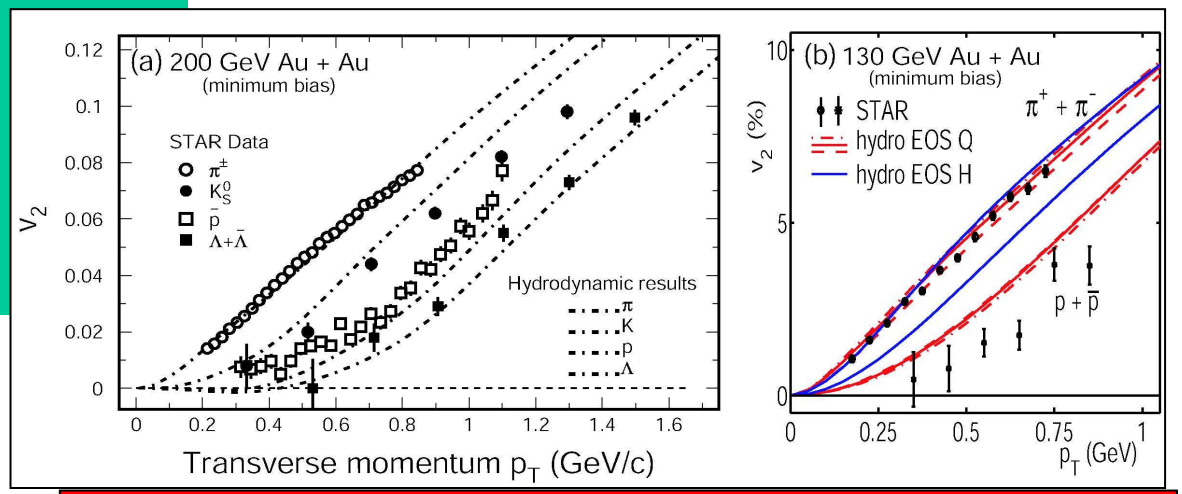
Elliptic Flow: the Shape of the Interaction Region at RHIC



$$\varepsilon = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle}$$

Shape parameter

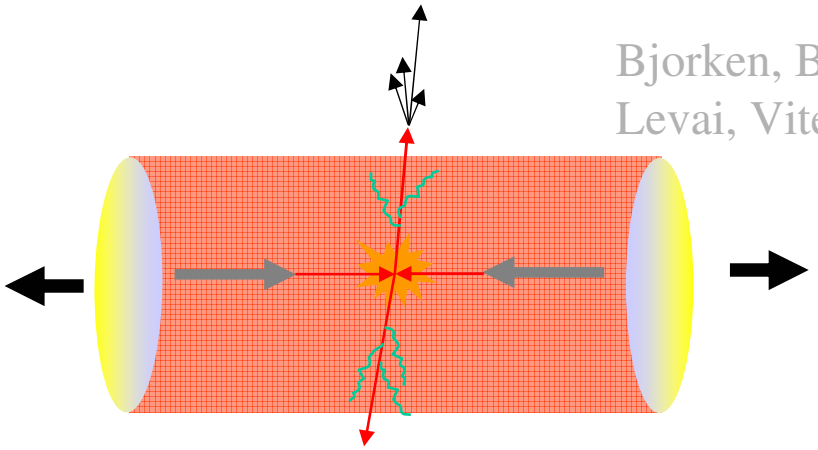
$$v_2 = \langle \cos 2\varphi \rangle, \quad \varphi = \tan^{-1}\left(\frac{p_y}{p_x}\right)$$



Reproduced well by hydrodynamic model

Partonic energy loss in dense matter: "Jet Tomography"

Bjorken, Baier, Dokshitzer, Mueller, Pegne, Schiff, Gyulassy, Levai, Vitev, Zhakarov, Wang, Wang, Salgado, Wiedemann,…



Gluon bremsstrahlung

Multiple soft interactions:

$$\Delta E \approx \frac{C_R \alpha_S}{4} \hat{q} L^2$$

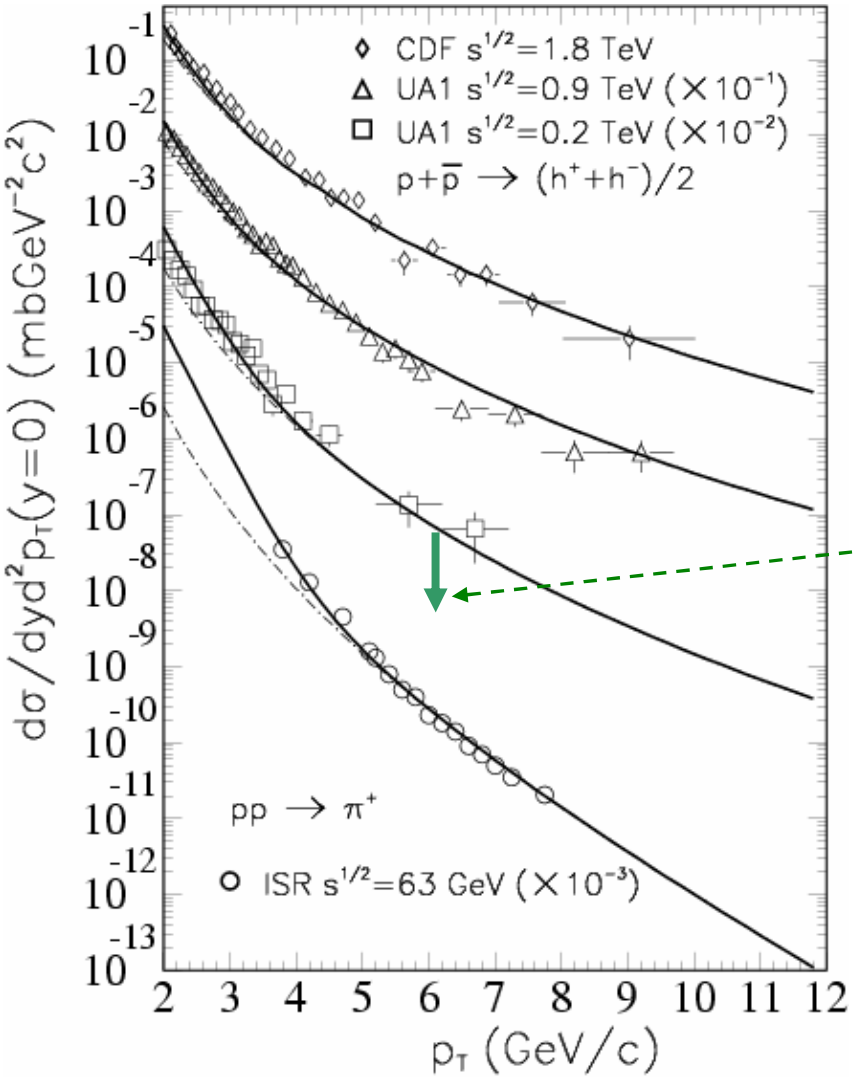
$$\hat{q} = \frac{\langle k_T^2 \rangle_{medium}}{\lambda} \propto \alpha_S \rho_{glue}$$

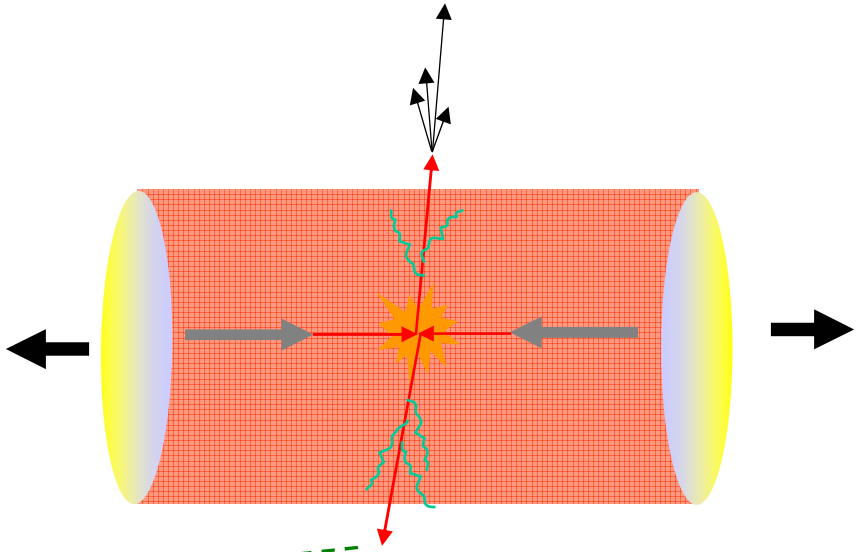
Opacity expansion:

$$\Delta E = \pi C_A C_a \alpha_S^3 \int d\tau \rho_{glue}(\tau, r(\tau)) \tau Log\left(\frac{2E_{jet}}{\mu^2 L}\right)$$

Strong dependence of energy loss on gluon density ρ_{glue}:
measure $\Delta E \Rightarrow$ color charge density at early hot, dense phase

Partonic energy loss via leading hadrons





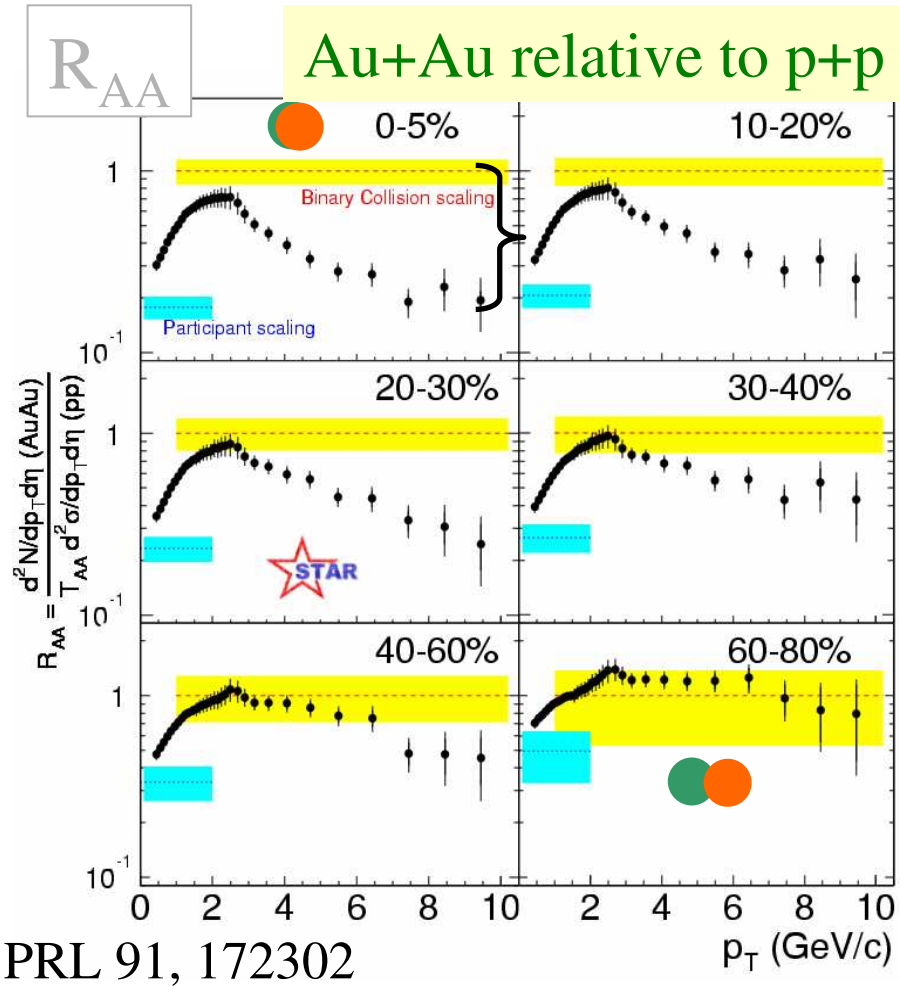
Energy loss $\Rightarrow$ softening of fragmentation $\Rightarrow$ suppression of leading hadron yield

$$R_{AA}(p_T) = \frac{d^2N^{AA}/dp_T d\eta}{T_{AA}\, d^2\sigma^{NN}/dp_T d\eta}$$

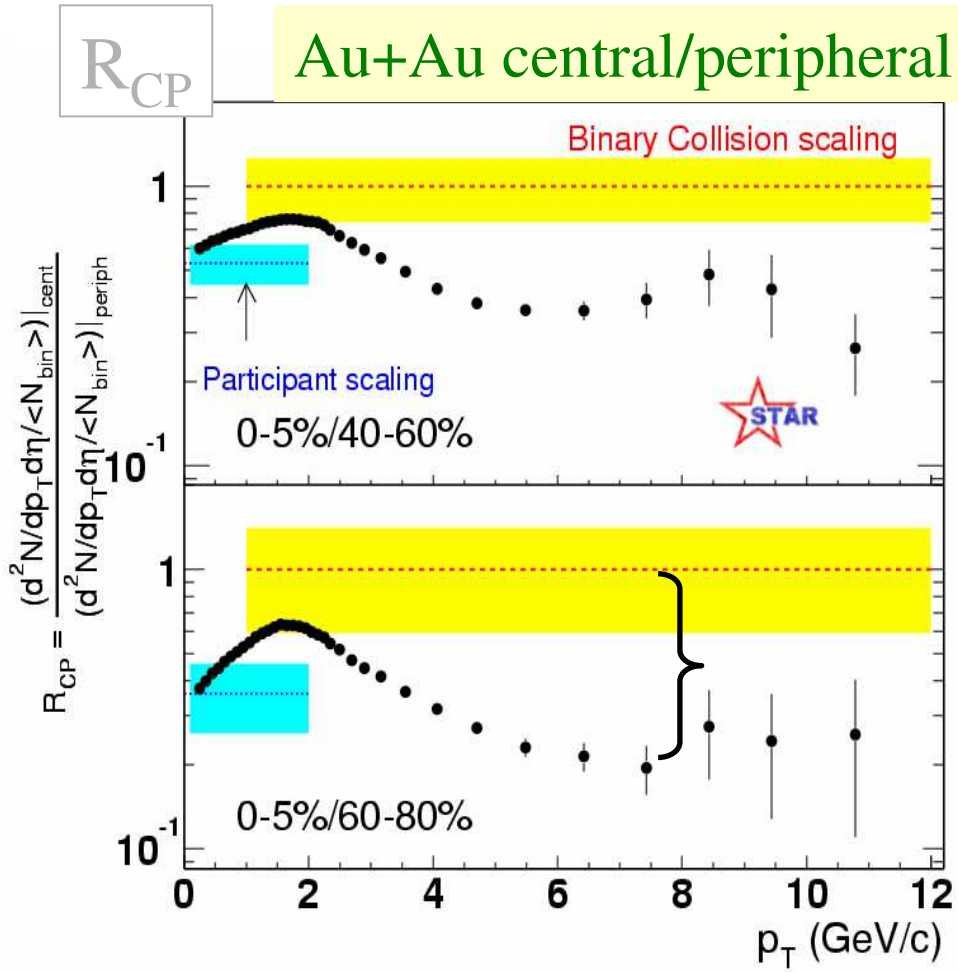
Binary collision scaling p+p reference

-

Suppression of inclusive hadron yield

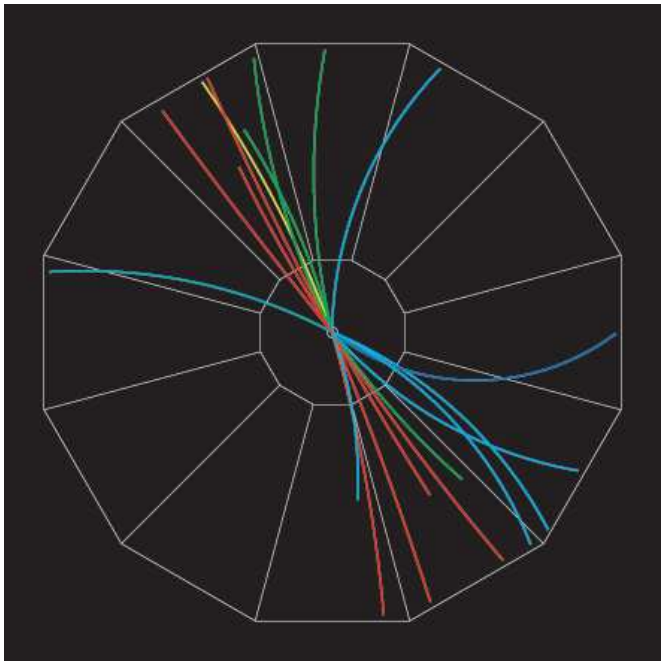


PRL 91, 172302

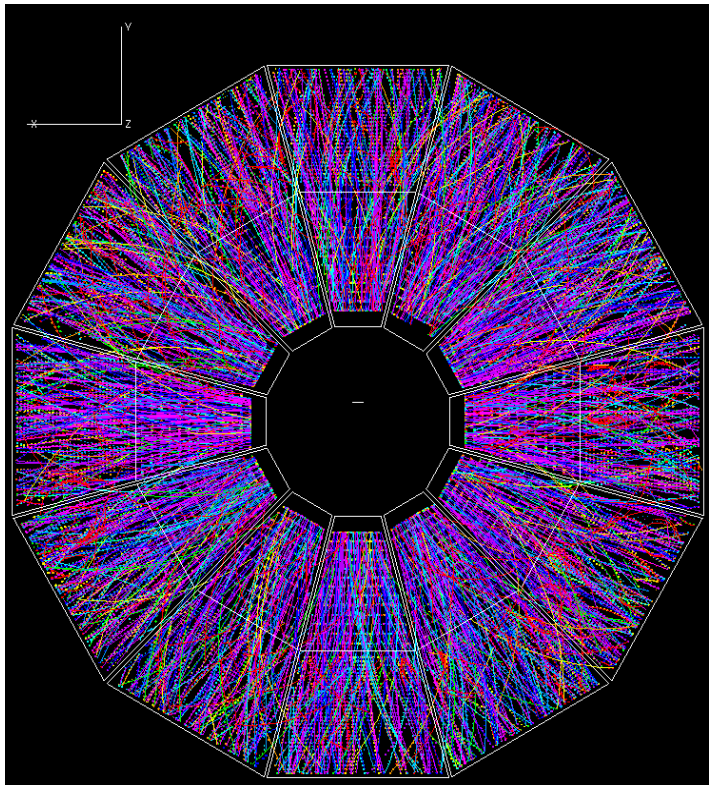


- central Au+Au collisions: factor ~4-5 suppression
- p_T>5 GeV/c: suppression ~ independent of p_T

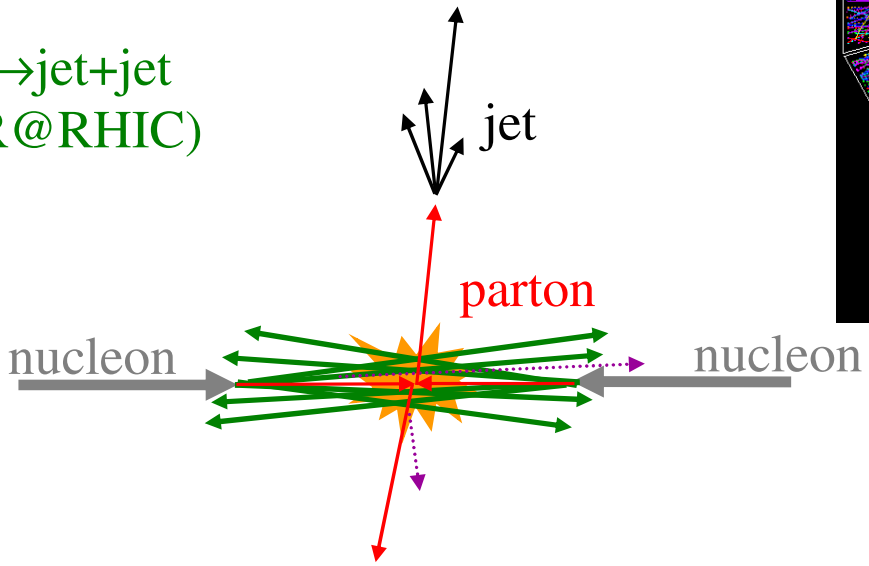
Jets at RHIC



Find this…….in this



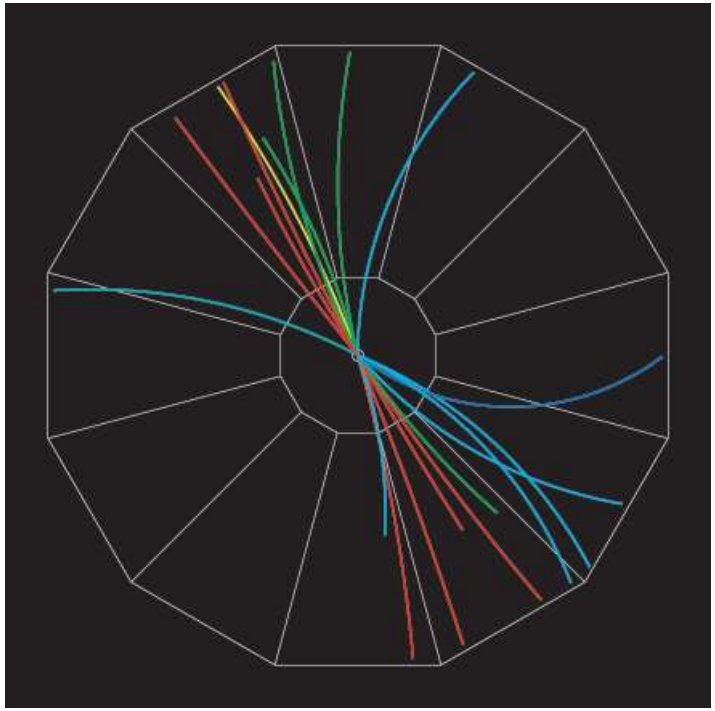
p+p →jet+jet
(STAR@RHIC)



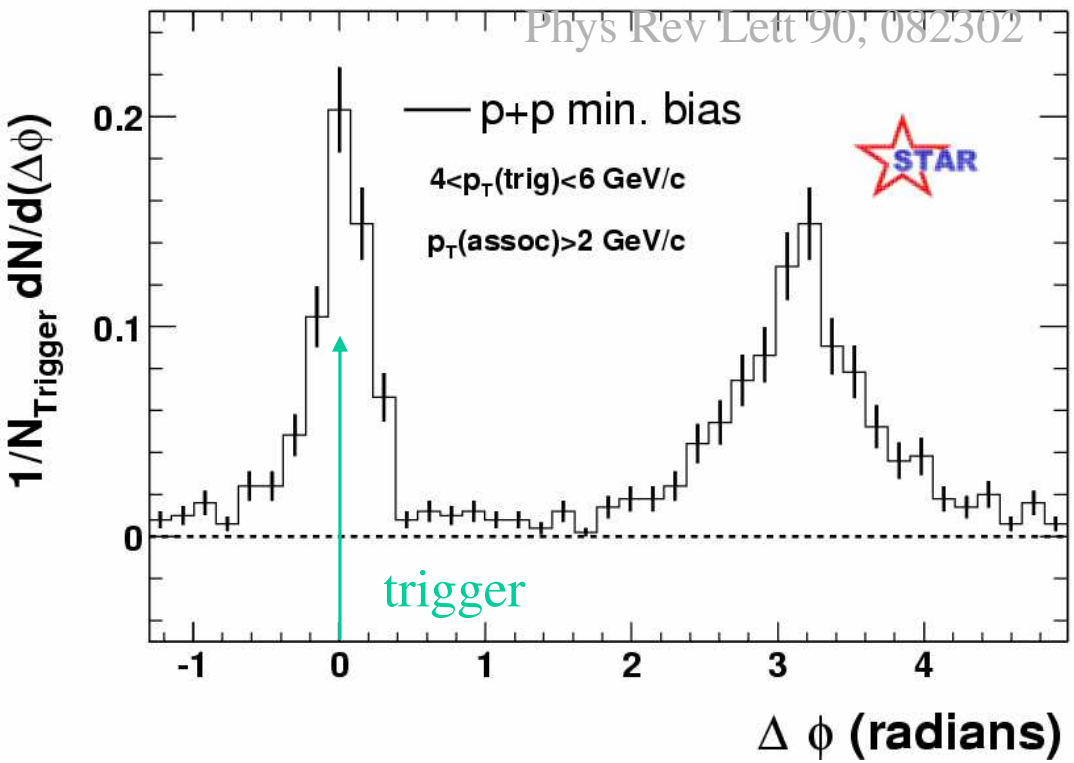
Au+Au →???
(STAR@RHIC)

Jets and two-particle azimuthal distributions

p+p → dijet



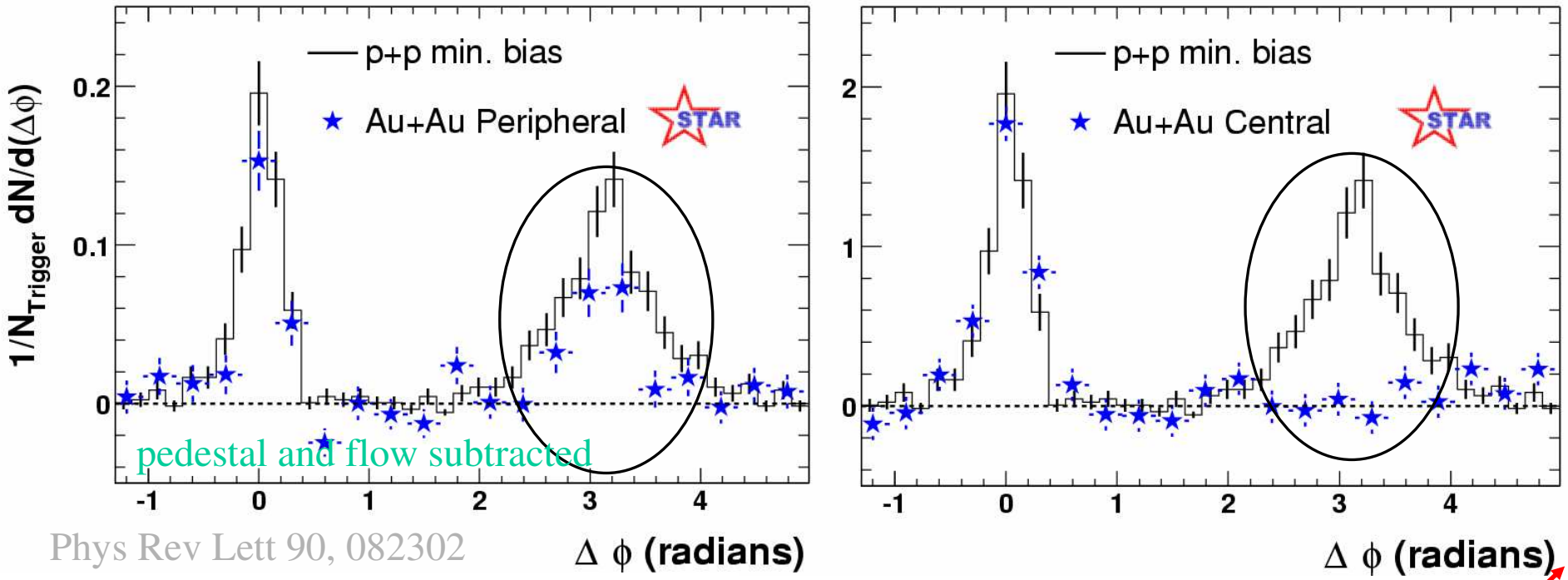
- trigger: highest p_T track, p_T>4 GeV/c
- $\Delta\phi$ distribution: 2 GeV/c<p_T<$p_T^{trigger}$
- normalize to number of triggers



Azimuthal distributions in Au+Au

Au+Au peripheral

Au+Au central

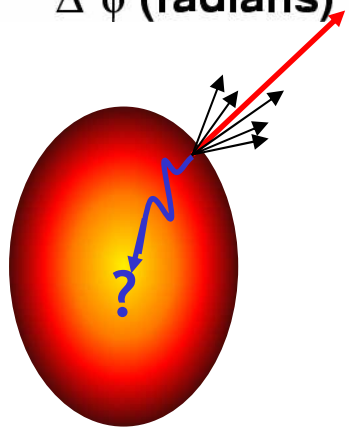


Phys Rev Lett 90, 082302

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

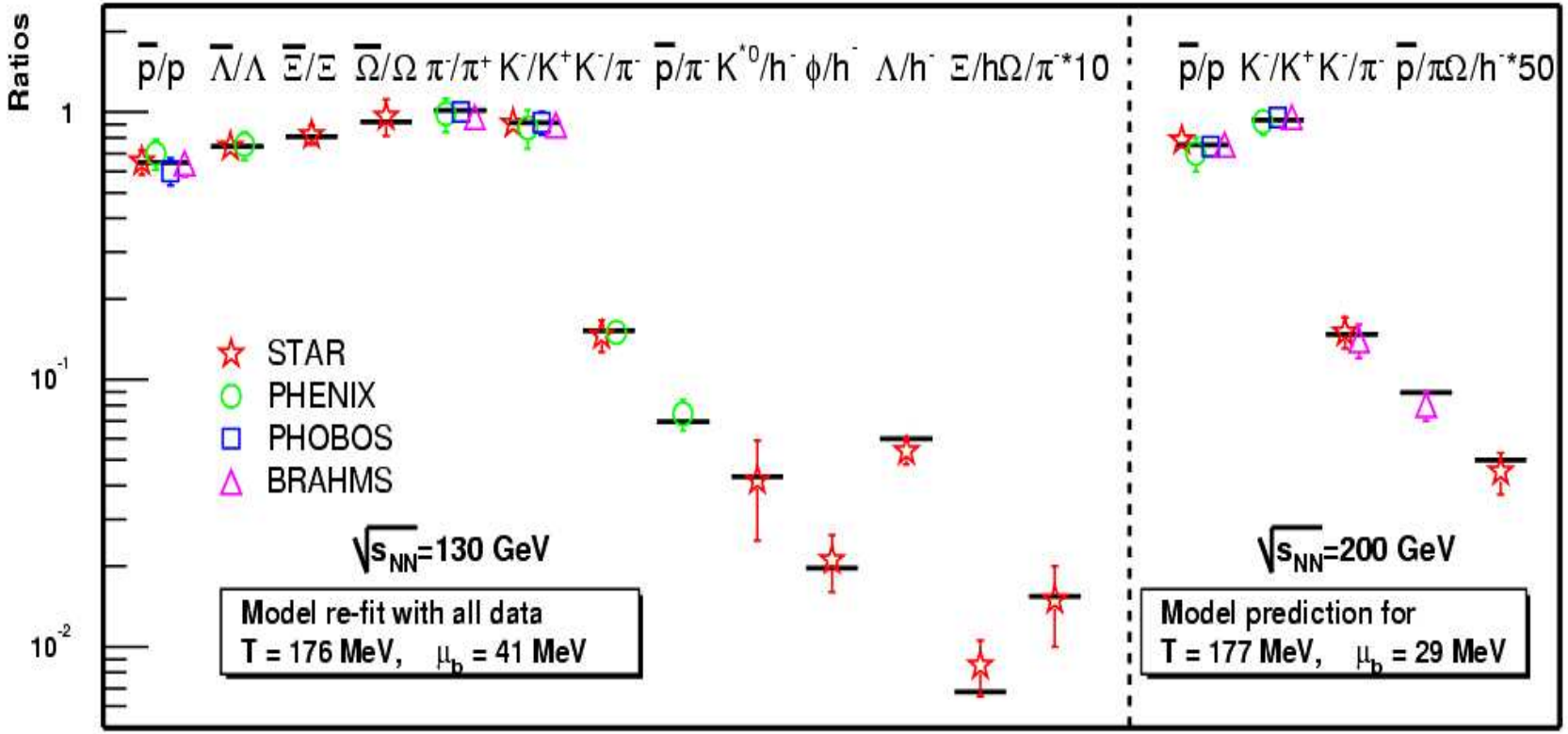
Strong suppression of back-to-back correlations in central Au+Au

Jet quenching?



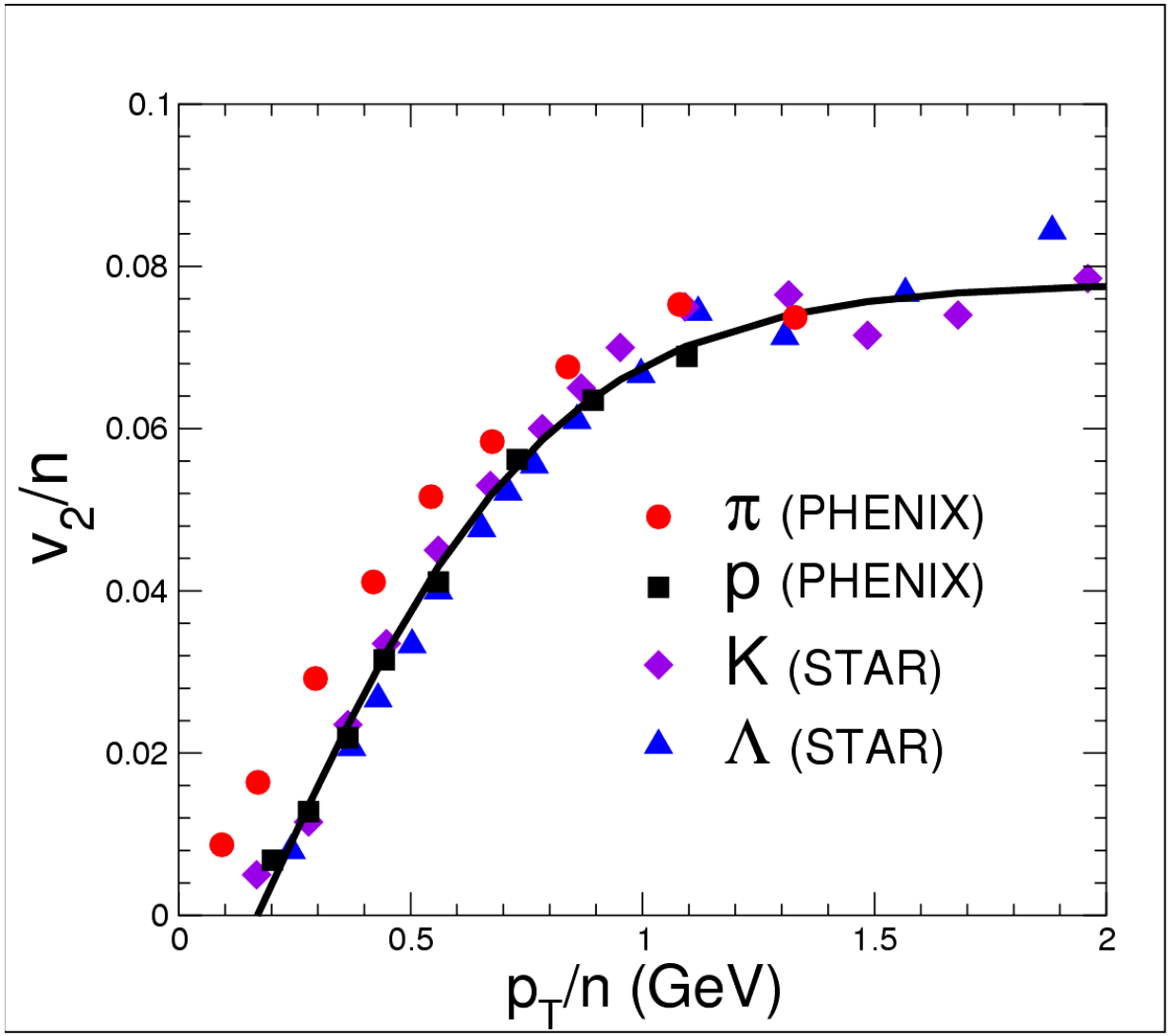
Particle Production Ratios

Well described by simple thermodynamic model, T ~ lattice …



… but could these just be phase space and statistics? (J.Ellis)

Hadron Elliptic Flows Scale with Quark Number



- Apparent scaling with number of constituent quarks in final-state hadron
- Explained currently by recombination/coalescence of constituent quarks at hadronization
- If better established, direct evidence of the degrees of freedom relevant at hadronization, and the existence of collective flow at the constituent quark level

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.***

James C Dunlop
Brookhaven National Laboratory

Neutrino Physics

Neutrino oscillations:

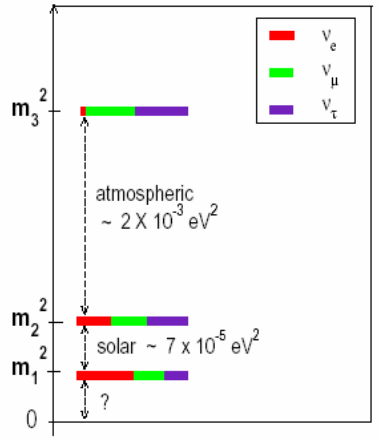
Pontecorvo-Maki-Nakagawa-Sakata Matrix

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} V_{e1} & V_{e2} & V_{e3} \\ V_{\mu 1} & V_{\mu 2} & V_{\mu 3} \\ V_{\tau 1} & V_{\tau 2} & V_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Mass eigenstates

$\neq$

Weak eigenstates



Atmospheric

CP phase

Solar

$$V = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13} \\ 0 & e^{-i\delta} & 0 \\ -s_{13} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} e^{i\rho} & 0 & 0 \\ 0 & e^{i\sigma} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$c_{ij}=\cos\theta_{ij}$, $s_{ij}=\sin\theta_{ij}$

Sub-dominant θ_{13} oscillations

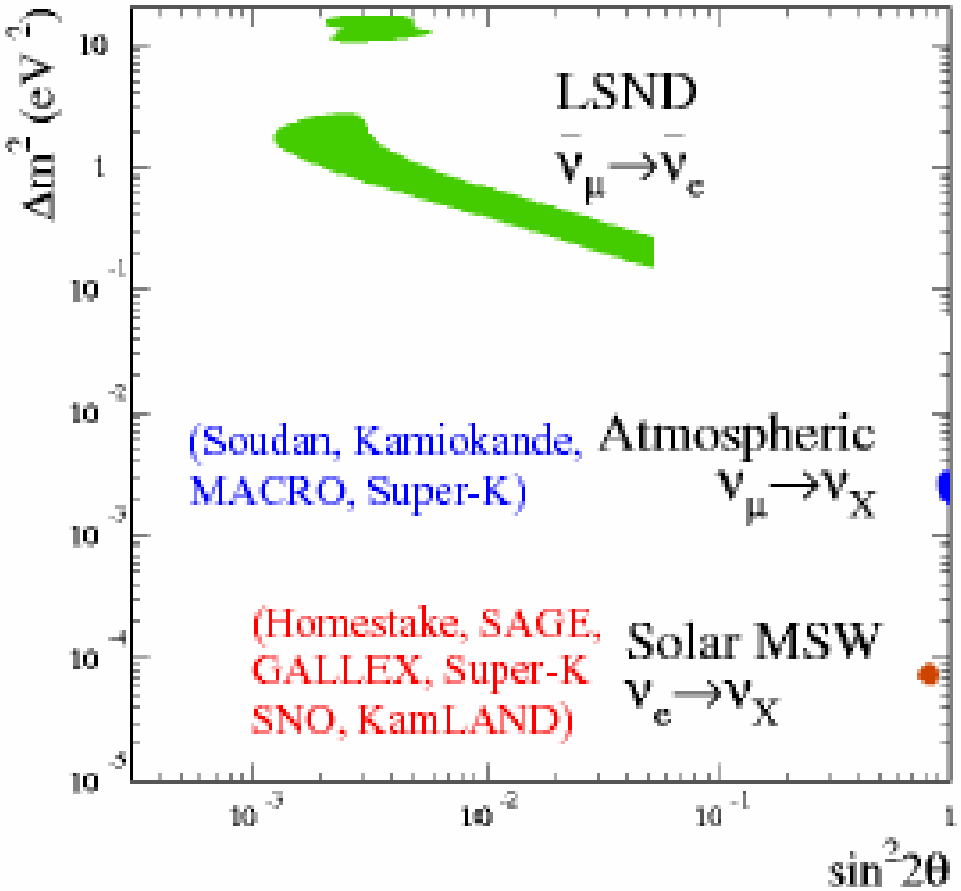
Majorana phases

Only appear in $0\nu\beta\beta$ decays

A total of 6 parameters: 2 Δm^2, 3 angles, 1 phases

+ 2 Majorana phases

Evidence of Neutrino Oscillations



Unconfirmed:

LSND:

$\Delta m^2 \sim 0.1\text{-}10\ eV^2$

Confirmed:

Atmospheric:

$\Delta m^2 \sim 2\times10^{-3}\ eV^2$

Solar:

$\Delta m^2 \sim 8\times10^{-5}\ eV^2$

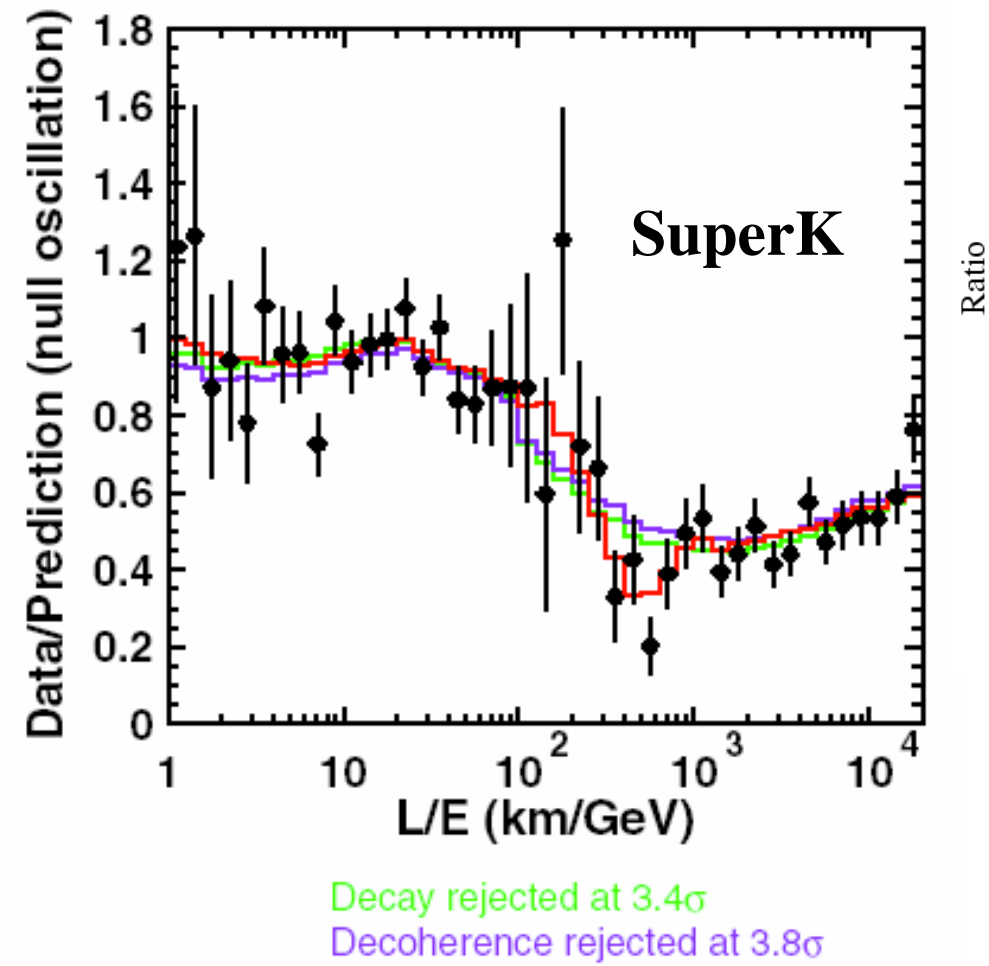
2 flavor oscillation in vacuum:

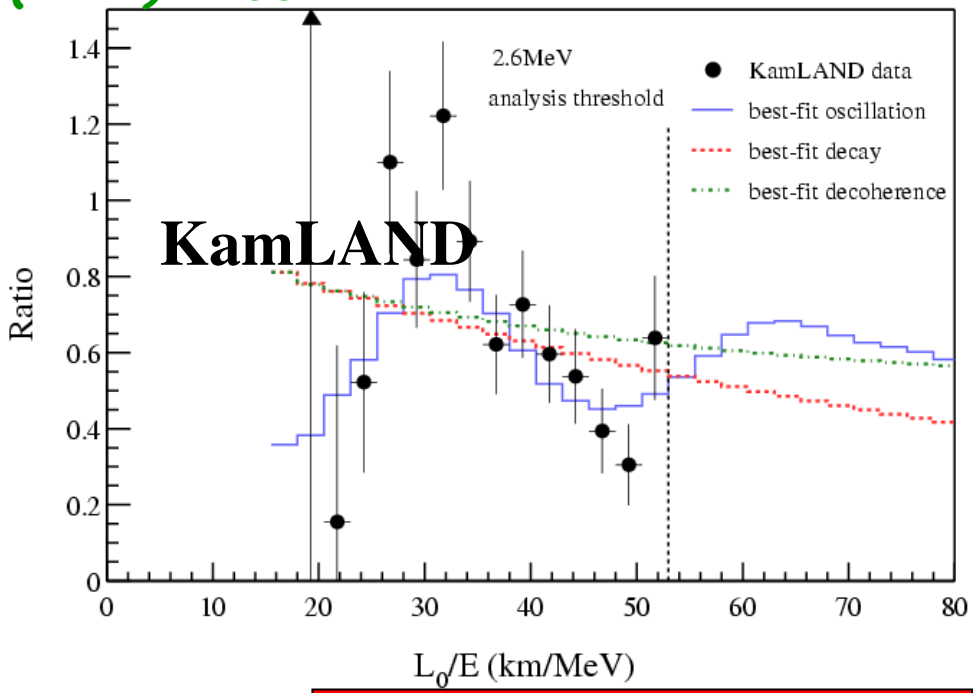
$$P(\nu_1 \rightarrow \nu_2) = \sin^2 2\theta \sin^2(1.27\Delta m^2 L/E)$$

Neutrino oscillations established

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

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





The dips in the data cannot be explained by other models

Preliminary K2K confirms Super-Kamiokande

Soon data from SNO, SKII,KamLand, Sudbury

To be measured

$\sin^2 2\theta_{13}$ δ, sign of Δm^2_{32}

at reactors:

$$P_{ee} \approx 1 - \sin^2 2\theta_{13} \sin^2 (1.27\Delta m^2_{13} L/E) - \cos^4\theta_{13} \sin^2 2\theta_{12} \sin^2 (1.27\Delta m^2_{12} L/E)$$

at accelerators (Minos, Opera, T2K):

$$P_{\mu e} \approx \sin^2\theta_{23} \sin^2 2\theta_{13} \sin^2(1.27\Delta m^2_{23} L/E) + \cos^2\theta_{23} \sin^2 2\theta_{12} \sin^2(1.27\Delta m^2_{12} L/E) - A(\rho) \bullet \cos^2\theta_{13} \sin\theta_{13} \bullet \sin(\delta)$$

Huge experimental program

To be measured

Absolute neutrino masses

- **β-decay:**

$$(m_{\nu_e})^{eff} = [\Sigma_i \, | U_{ei} |^2 \, m^2_{\nu_i}]^{1/2}$$

- **Endpoint of β decays**

$^3H \rightarrow {}^3He + e^- + \nu_e$

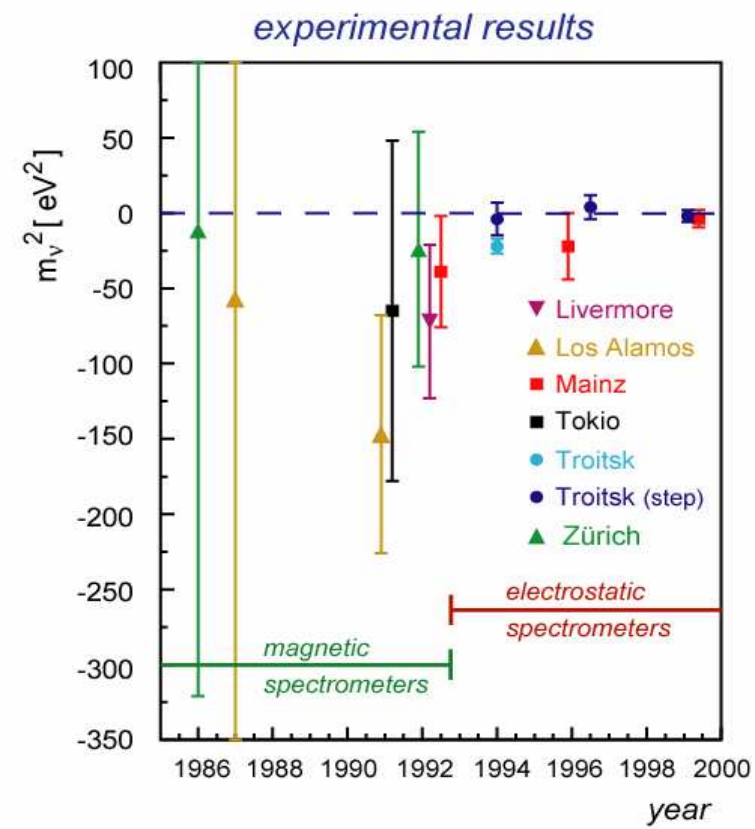
$E_0 = 18.574$ KeV

- **Currently the best limit:**

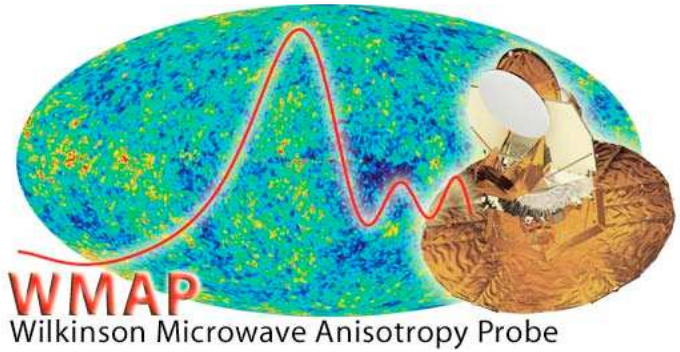
$m_\nu < 2.2$ eV @ 95% CL

- **Katrin expected:**

$m_\nu < 0.3$ eV @ 95% CL



Neutrino mass from Cosmology



Data	Σm_i (@95%CL)*	References
2dFGRS	< 1.8 eV	Elgaroy et al. PRL 89, 2002
WMAP+2dF+…	< 0.7 eV	Spergel et al. APJS 148,2003
WMAP+2dF	< 1.0 eV	Hannestad, JCPA 0305, 2003
XLF+WMAP+2dF+	$0.56^{+0.30}_{-0.26}$ eV	Allen et al. MNRAS346(2003)
SDSS+WMAP	< 1.7 eV	Tegmark et al. PRD 69,2004
WMAP+ACBAR+ 2dF+SDSS+…	< 1.0 eV	Crotty et al. PRD 69,2004

*With different assumptions, fitting constrains and datasets

A strong constraint to LSND and Heidelberg-Moscow ββ decay results

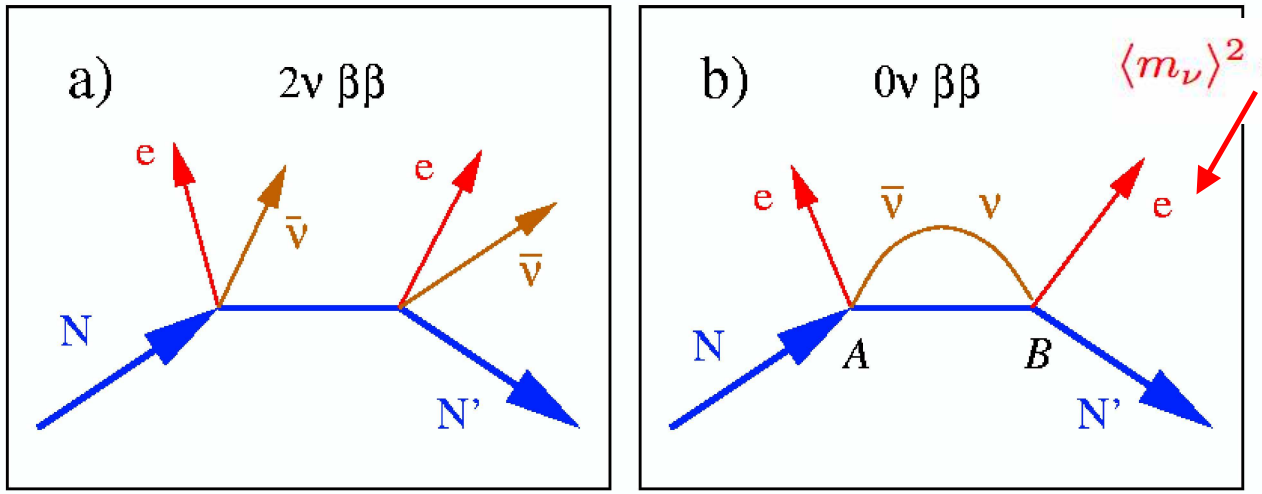
Majorana neutrino?

$$\beta\beta \text{ decays} : \langle M_{ee} \rangle = | \Sigma_i \ (U_{ei})^2 m_{\nu_i} |$$

2ν mode: a conventional 2nd order process in nuclear physics

0ν mode: a hypothetical process can happen only if:
- $M_\nu \neq 0$
- $\bar{\nu} = \nu$

Since helicity has to "flip"



$$\langle m_\nu \rangle^2 \propto \frac{1}{T_{1/2}}$$

Continuous β spectrum

Monochromatic β spectrum

Resolution and backgrounds are critical

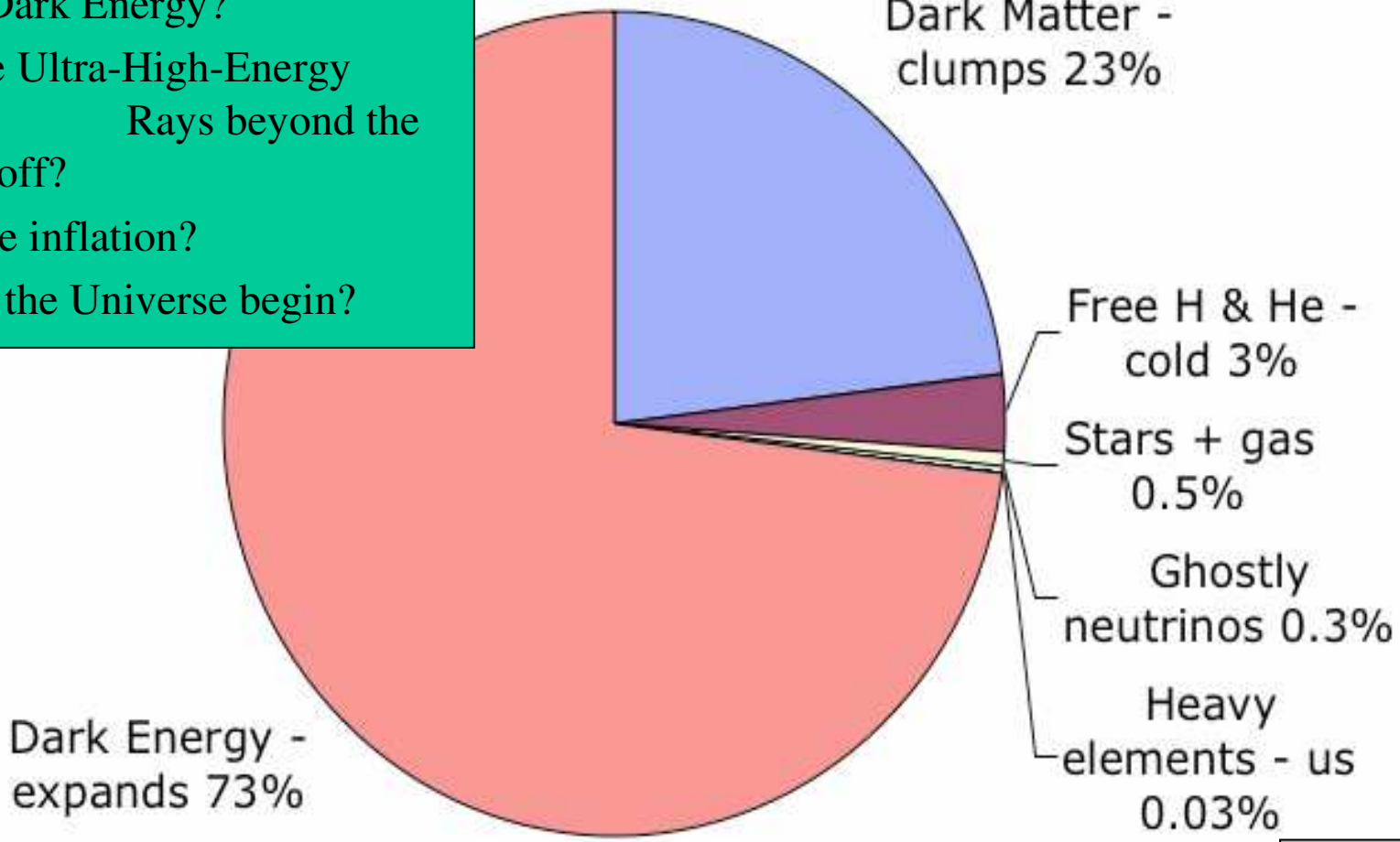
Future ββ-decay experiments

	Isotopes	enrichment	Mass (t)	Sensitivity (eV) (90%CL)
CUORE	^{130}Te	no	0.75	~ 0.03
GENIUS	^{76}Ge	yes	0.1-1.0	~ 0.01
Majorana	^{76}Ge	yes	0.42	~ 0.02
MOON	^{100}Mo	yes	3.0	~ 0.01
Super-NEMO	^{82}Se	yes	0.1	~ 0.03
EXO	^{136}Xe	yes	10.0	~ 0.01

Particle astrophysics and cosmology

Dark Matter in the Universe

- What is the Dark Matter?
- Is there Dark Energy?
- Are there Ultra-High-Energy Cosmic Rays beyond the GZK cutoff?
- Was there inflation?
- How did the Universe begin?



Binetruy

Candidates for Cold Dark Matter

- Axion?
- Lightest Supersymmetric Particle (LSP)?

  neutralino? gravitino?

  accelerators vs non-accelerator expts?
- Lightest Kaluza-Klein Particle (LKP)?

  in models with universal extra dimensions
- Superheavy (metastable) Particle?

  'WIMPzilla' produced at inflation?

J.Ellis CERN

Direct Search for Dark Matter

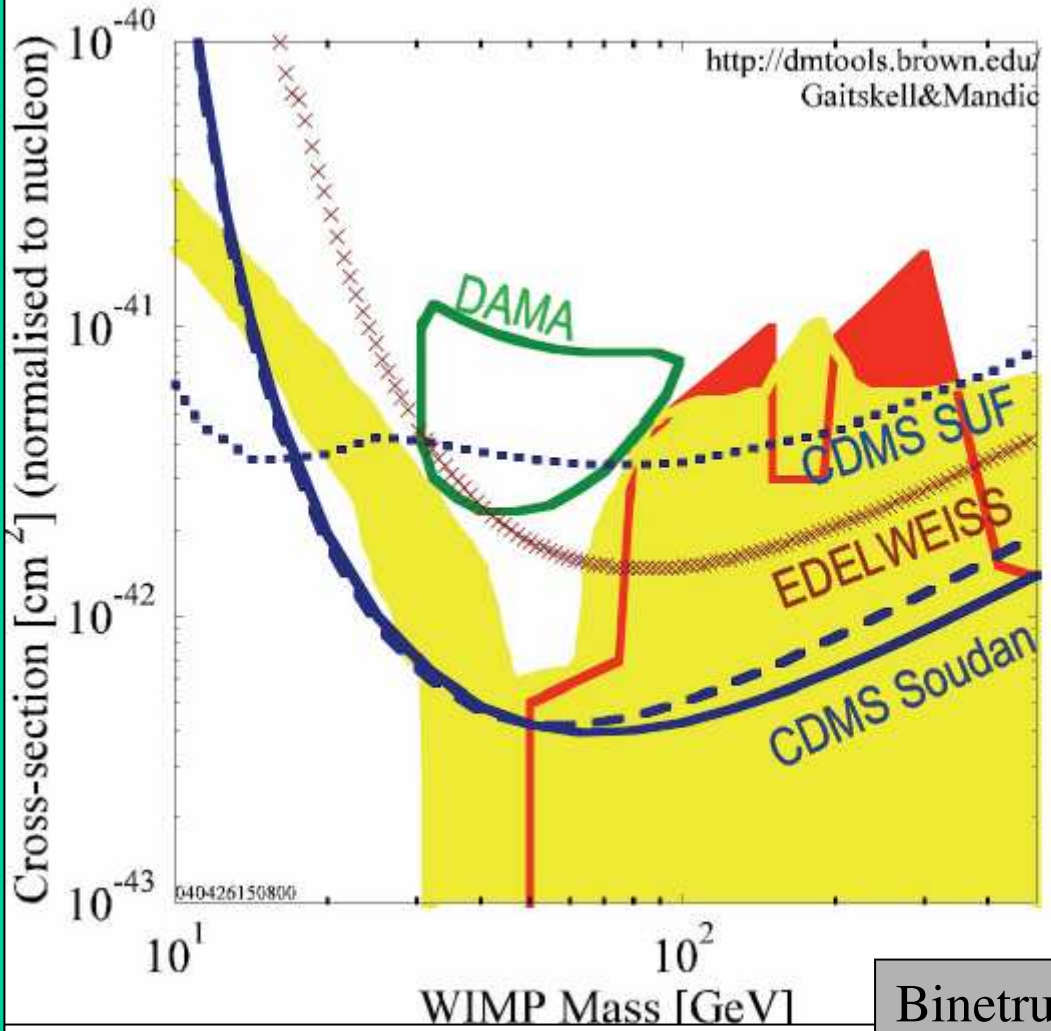
J.Ellis - CERN

- Look for elastic scattering on nuclei in low-background experiment

- DAMA modulation signal difficult to reconcile with other experiments, such as CDMS2

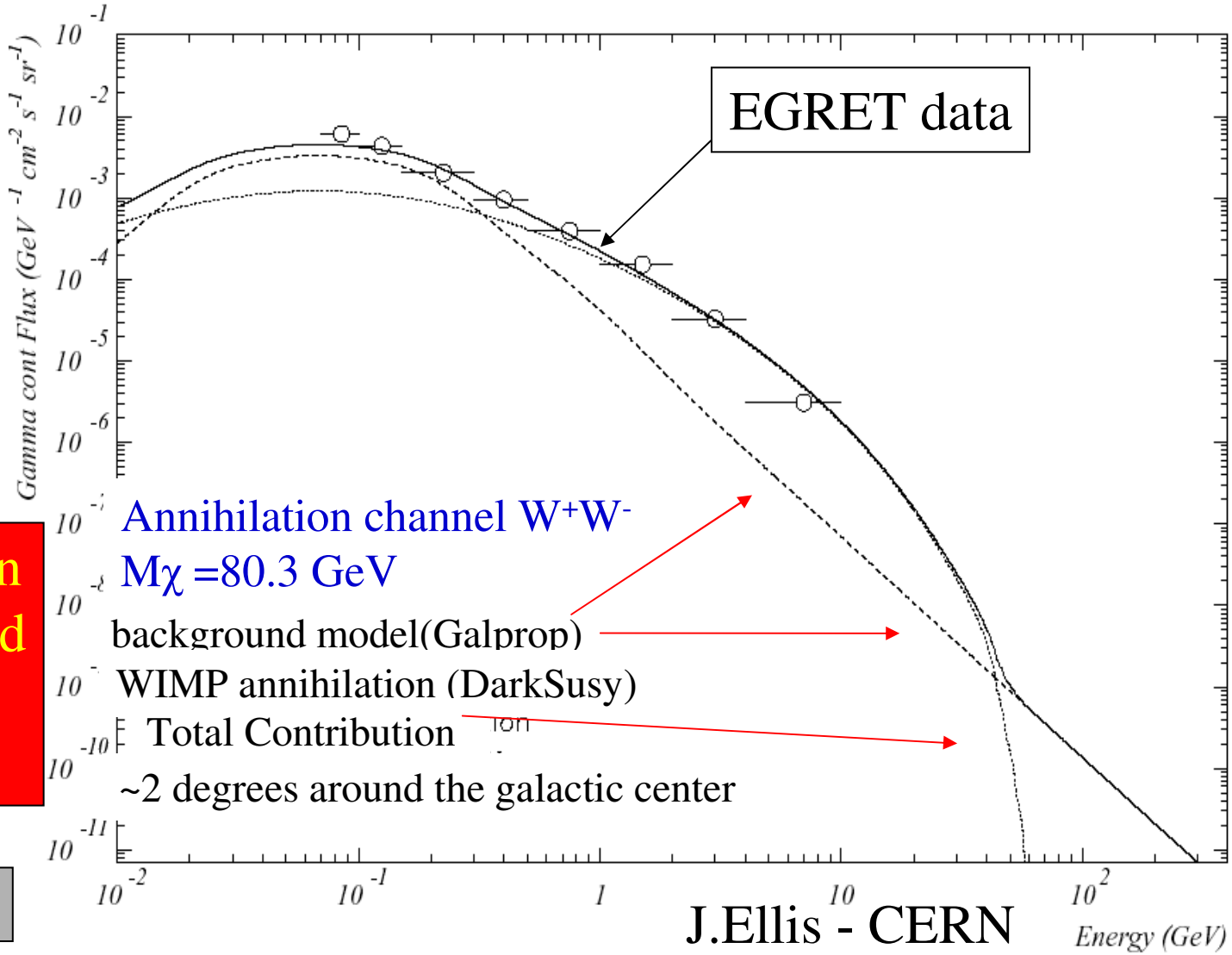
- Good prospects for improvement by factor ~ 20

- Starting to reach region expected in models



Binetruy

Gamma Rays from Neutralino Annihilations?



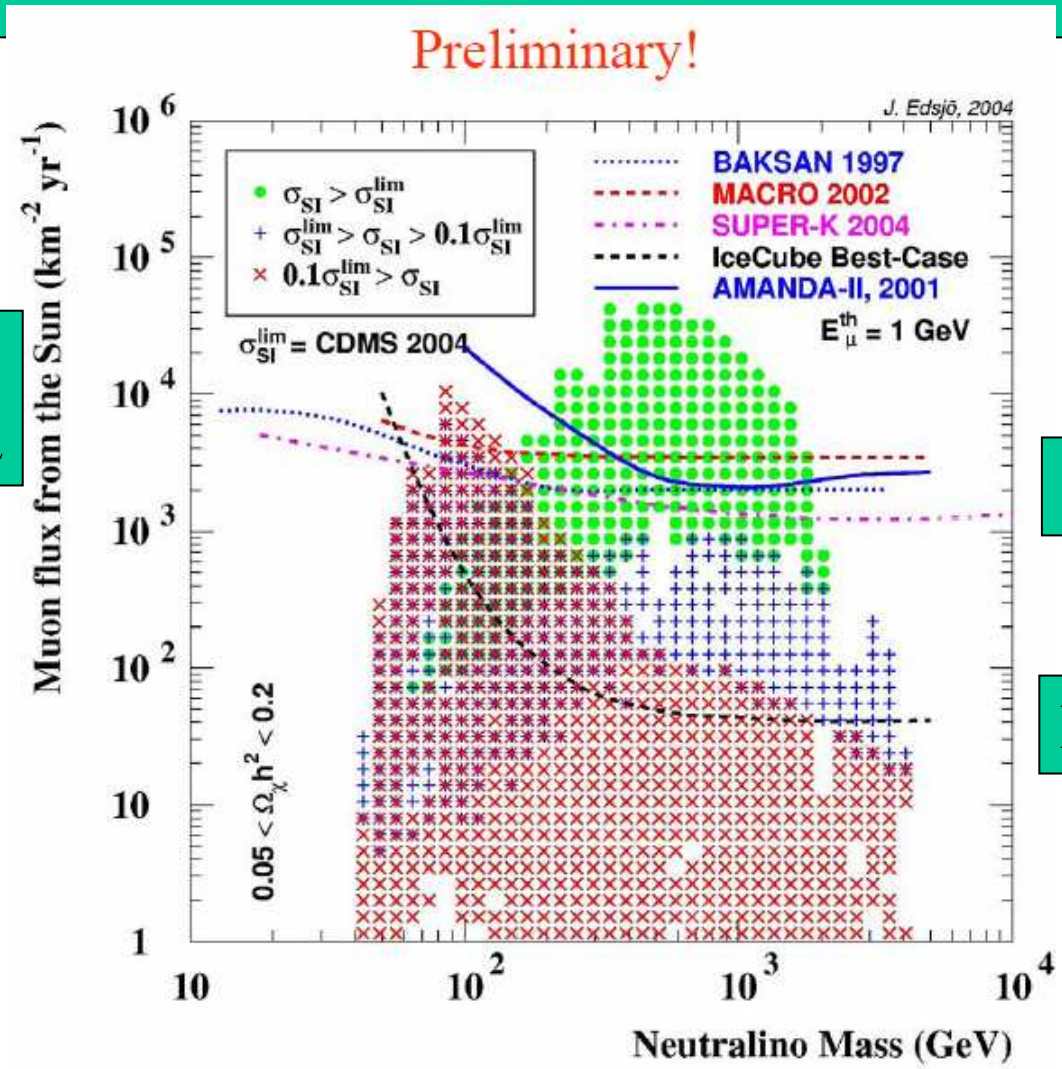
- Uncertainties in cosmic-ray bkgrd
- Also in signal normalization

Morselli, Sander //

J.Ellis - CERN

Neutralino Annihilations inside Sun?

Look for $\chi\chi \rightarrow \nu \rightarrow \mu$



Present

Future

J.Ellis - CERN

Summary of the Summary

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- QCD ever more quantitative
- Electroweak theory suggests new physics @ TeV scale: Higgs + ?
- Flavour physics becoming quantitative
- CKM looking better and better
- Neutrinos really do oscillate!
- Growing symbiosis with cosmology
- LHC on its way
- Good ideas for future accelerators
- ITRP has done its work

Lets get back to our work!