Lecture: Elementary Particle Physics (SS 2005) Part II

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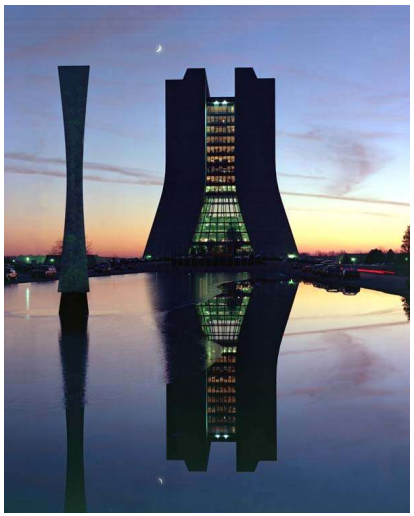
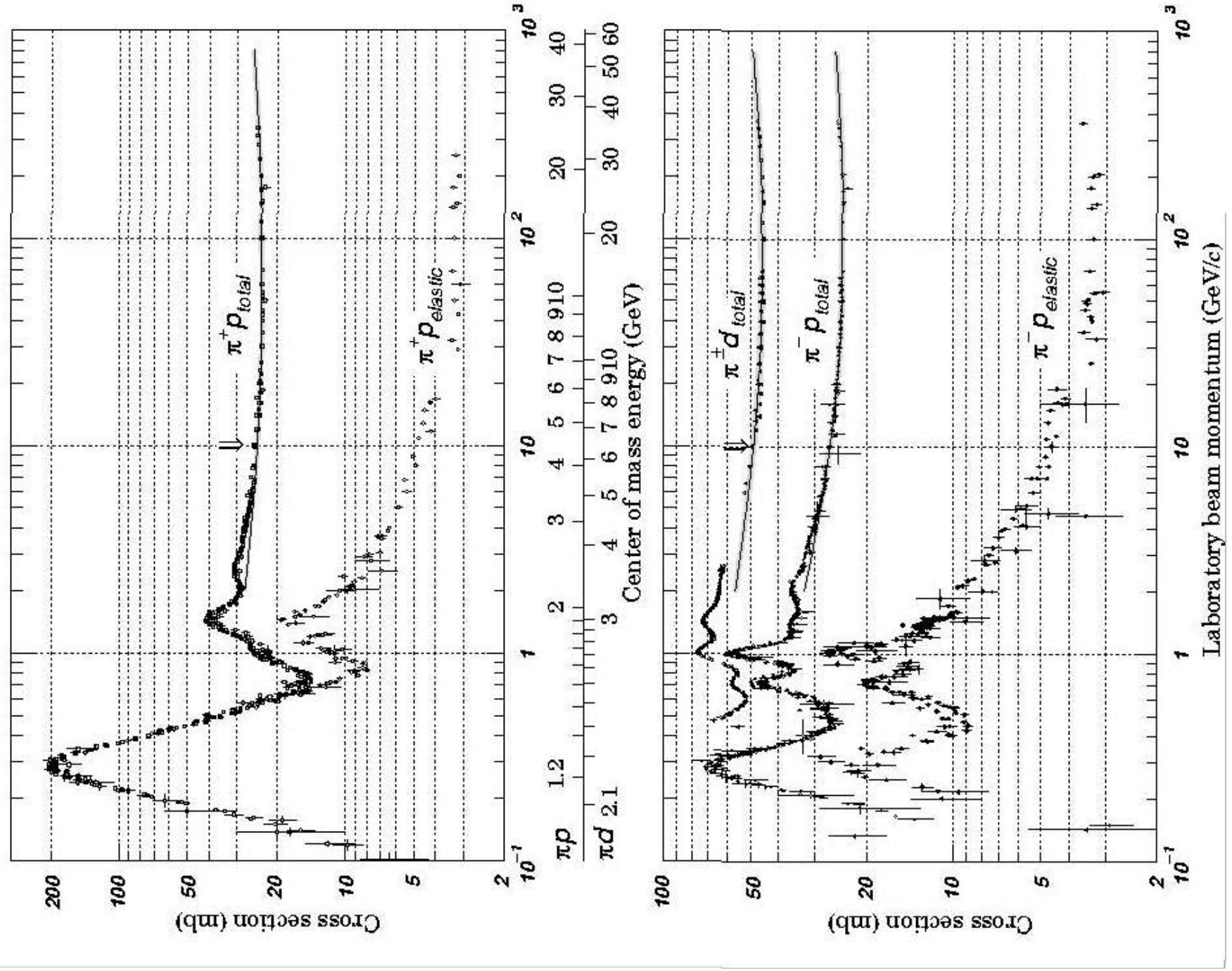


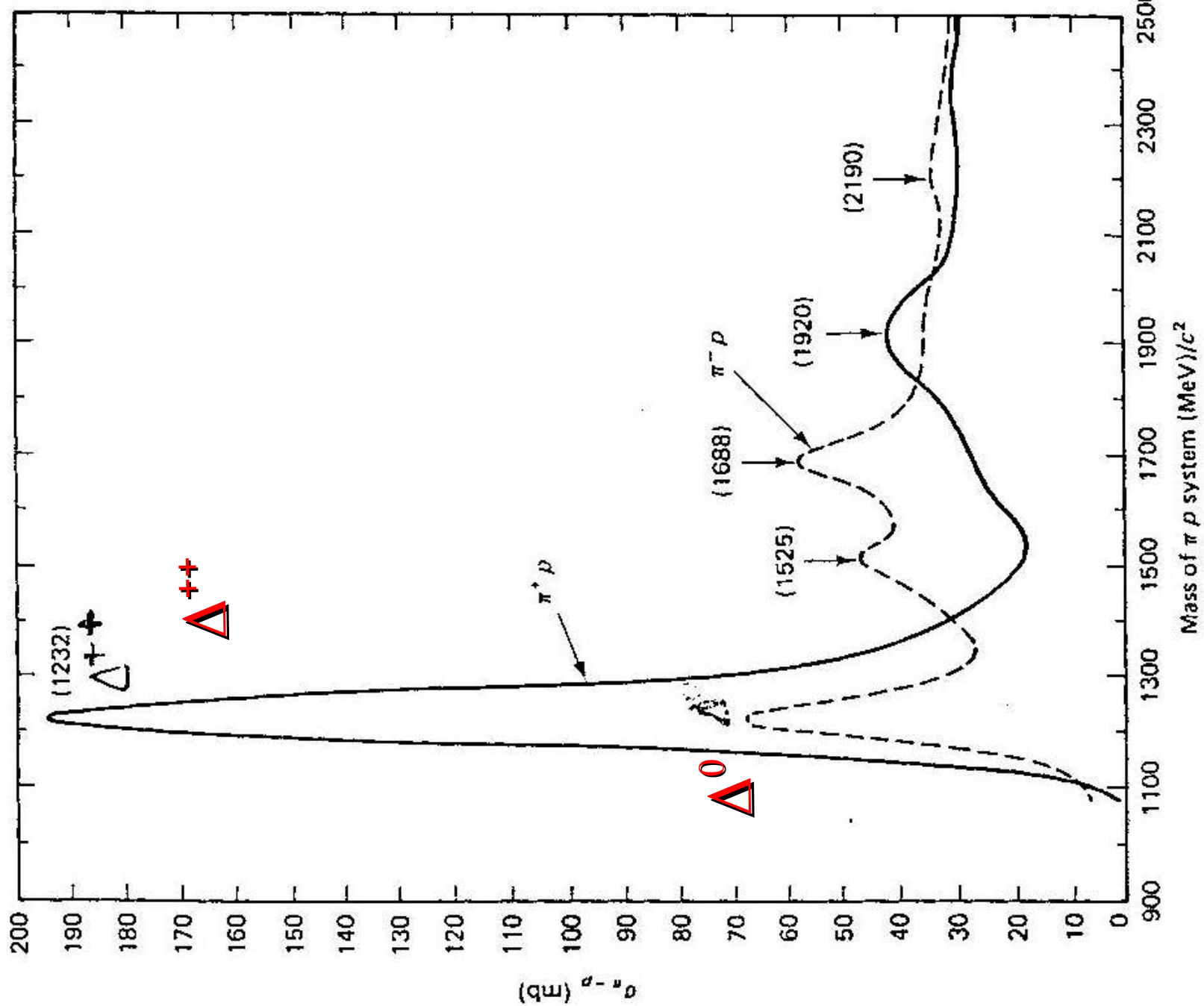
Transparencies

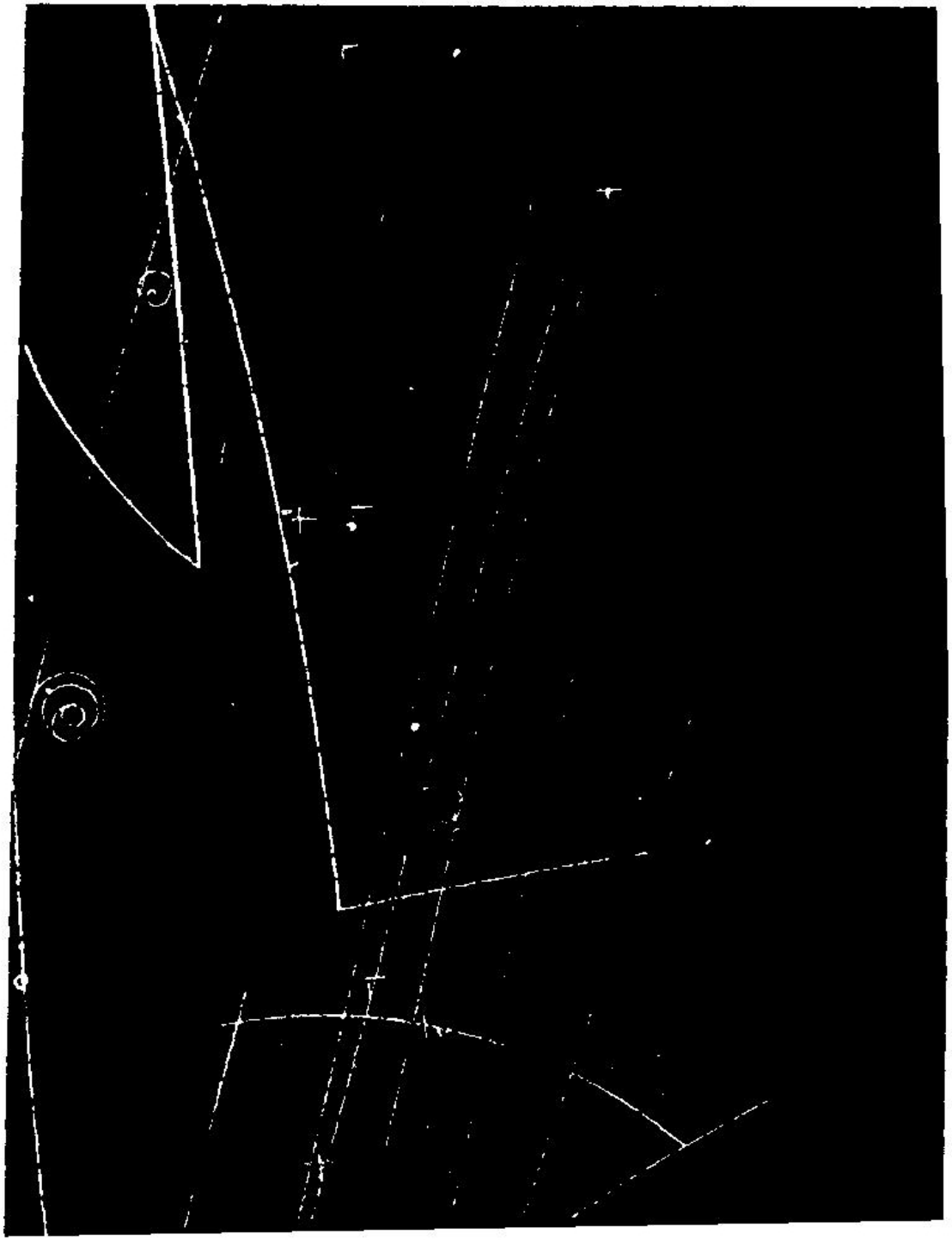
VII: Quarks and Hadrons

Cross Sections for $\pi^{\pm}$p and $\pi^{\pm}$d Scattering



Cross Sections for $\pi^{\pm}$p Scattering





Cloud chamber reaction:

$\pi^- p \rightarrow K^0 \Lambda$

with subsequent decay

$K^0 \rightarrow \pi^+ \pi^-$ and $\Lambda \rightarrow p \pi^-$

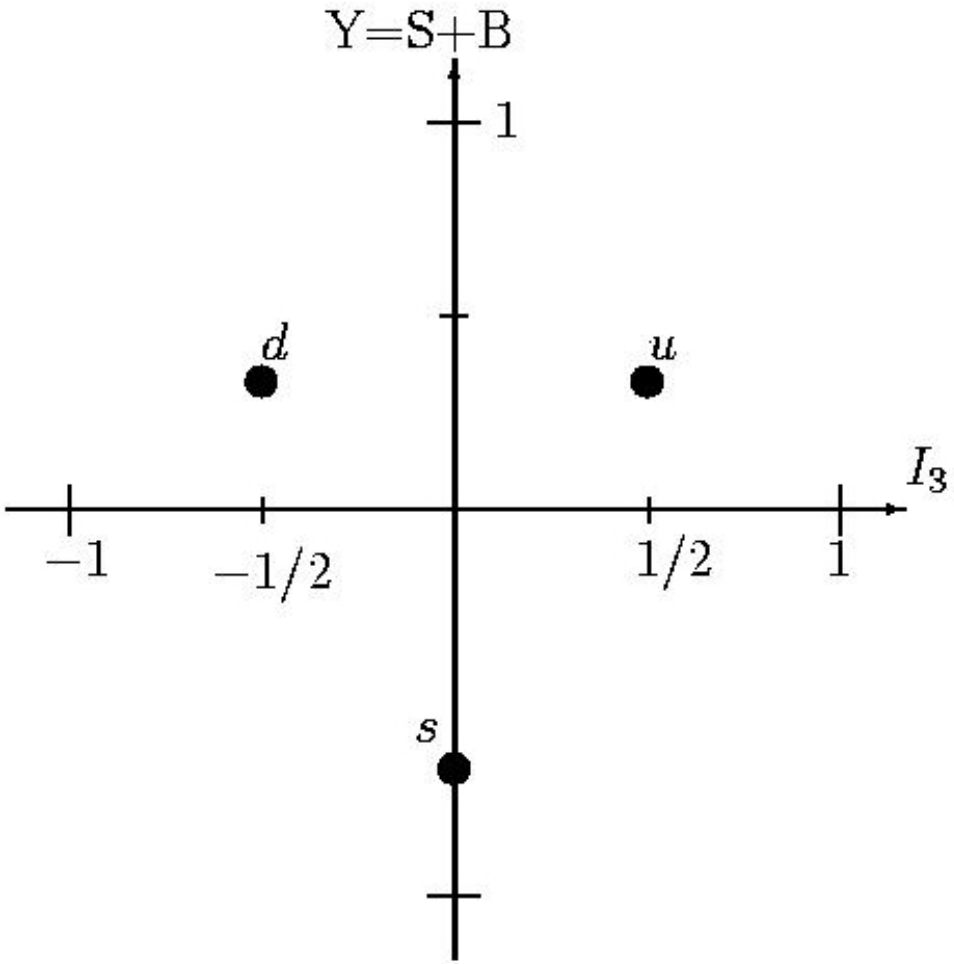
Multiplett	Isospin	Teilchenmultipletts			
Singulett	$I = 0$	η	Λ	Ω^-	
Dublett	$I = 1/2$	K^0, K^+	$K^-, \bar{K}^0$	(n, p)	(Ξ^-, Ξ^0)
Triplett	$I = 1$	(π^-, π^0, π^+)	$(\Sigma^-, \Sigma^0, \Sigma^+)$		
Quartett	$I = 3/2$	$(\Delta^-, \Delta^0, \Delta^+, \Delta^{++})$			

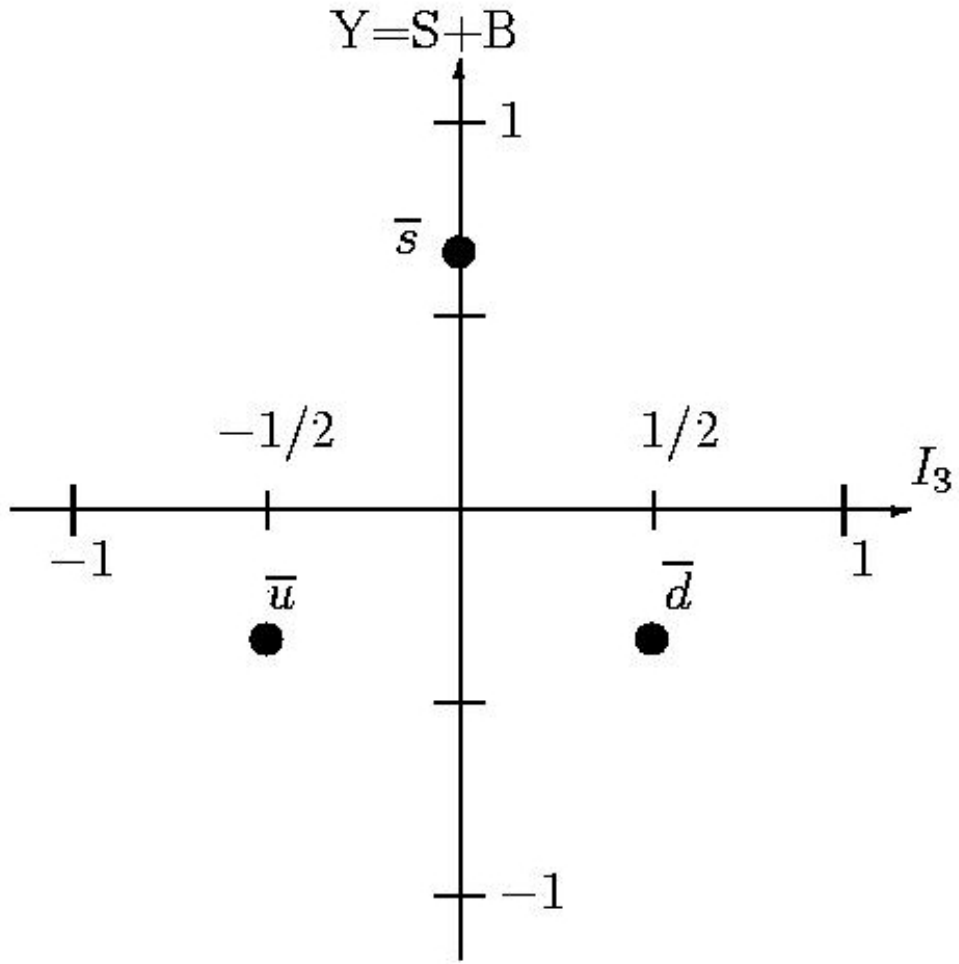
I_3 = -3/2, -1/2, +1/2, +3/2

Multipletts of Hadrons

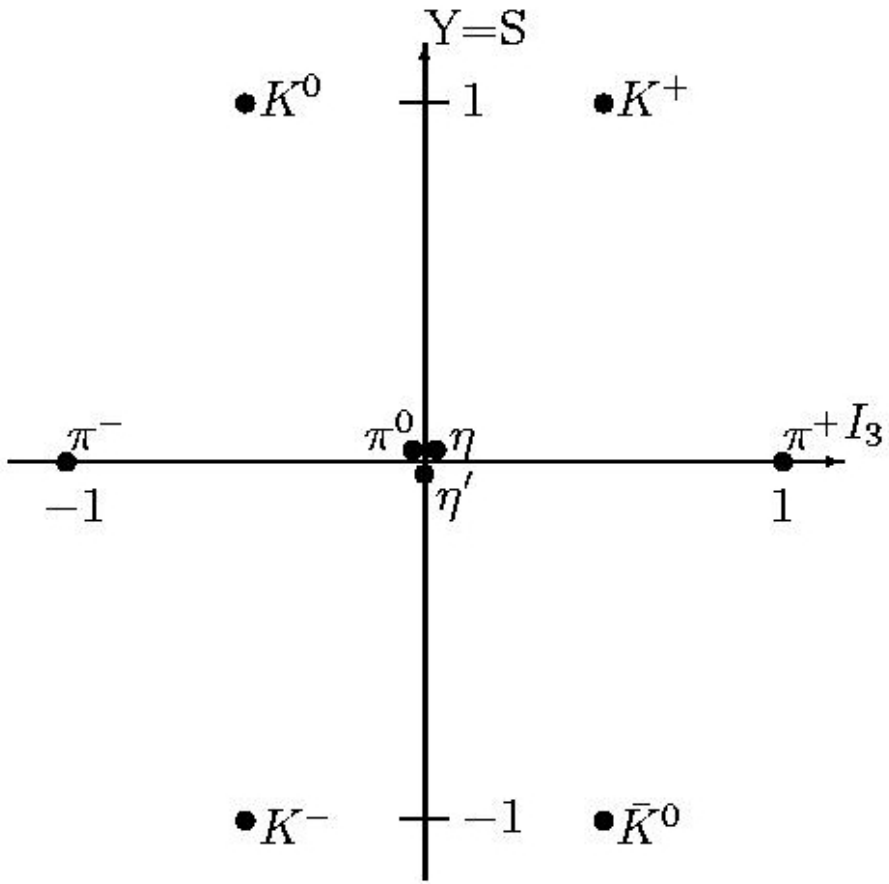
Quark	Baryonzahl B	Spin J	Isospin I	I_3	Seltsamkeit S	el. Ladung Q $[e]$
u	$+1/3$	$1/2$	$1/2$	$+1/2$	0	$+2/3$
d	$+1/3$	$1/2$	$1/2$	$-1/2$	0	$-1/3$
s	$+1/3$	$1/2$	0	0	-1	$-1/3$
$\overline{u}$	$-1/3$	$1/2$	$1/2$	$-1/2$	0	$-2/3$
$\overline{d}$	$-1/3$	$1/2$	$1/2$	$+1/2$	0	$+1/3$
$\overline{s}$	$-1/3$	$1/2$	0	0	$+1$	$+1/3$

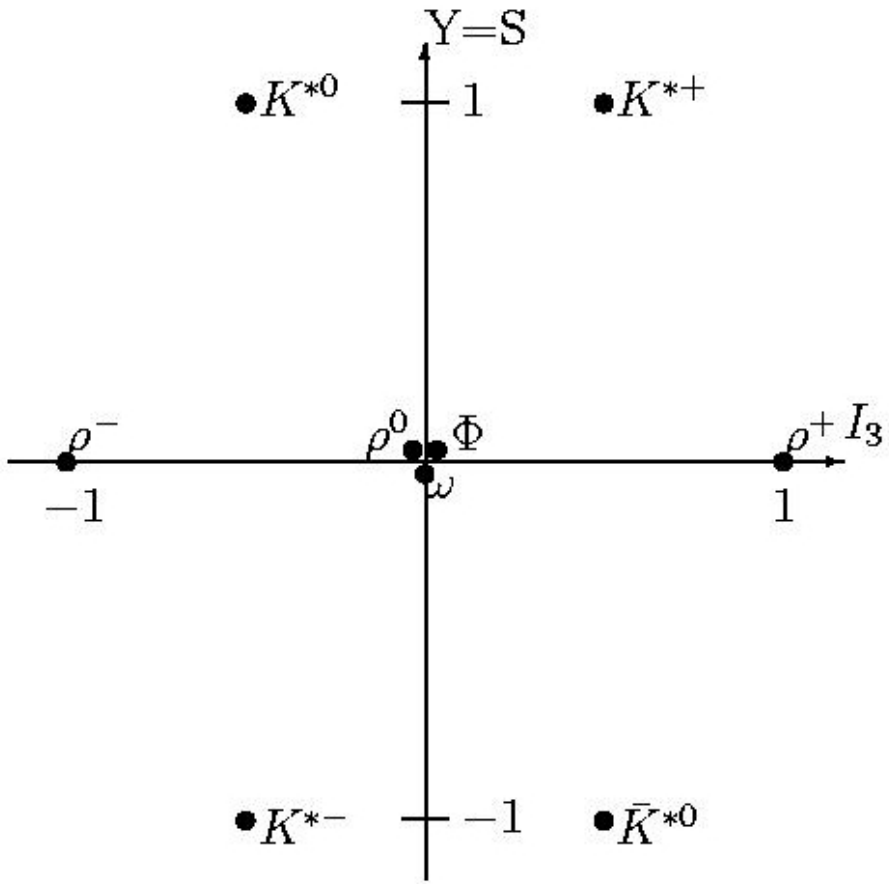
Isospin and Quarks





Weight Diagram for Quark and Antiquark Triplett

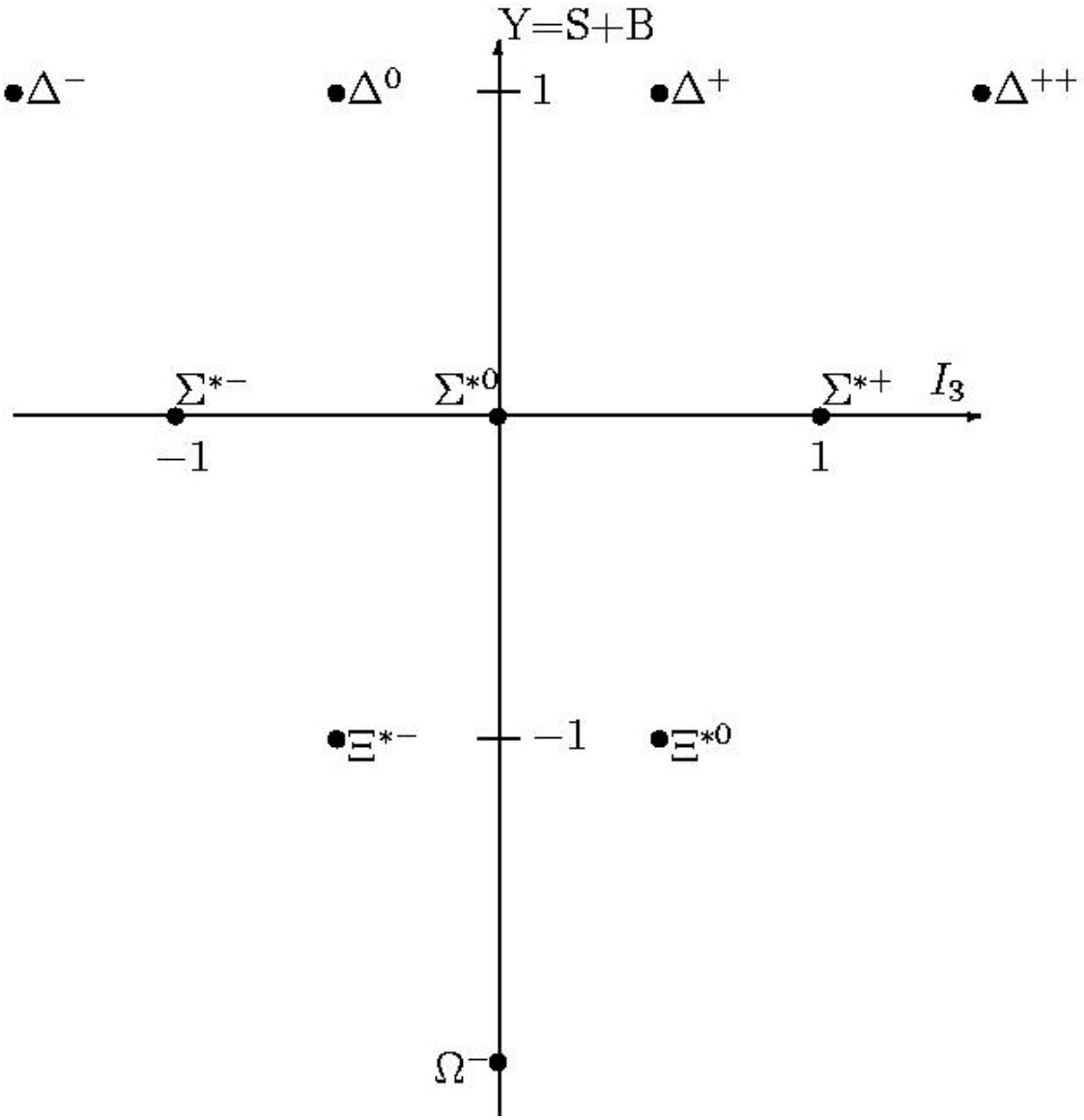


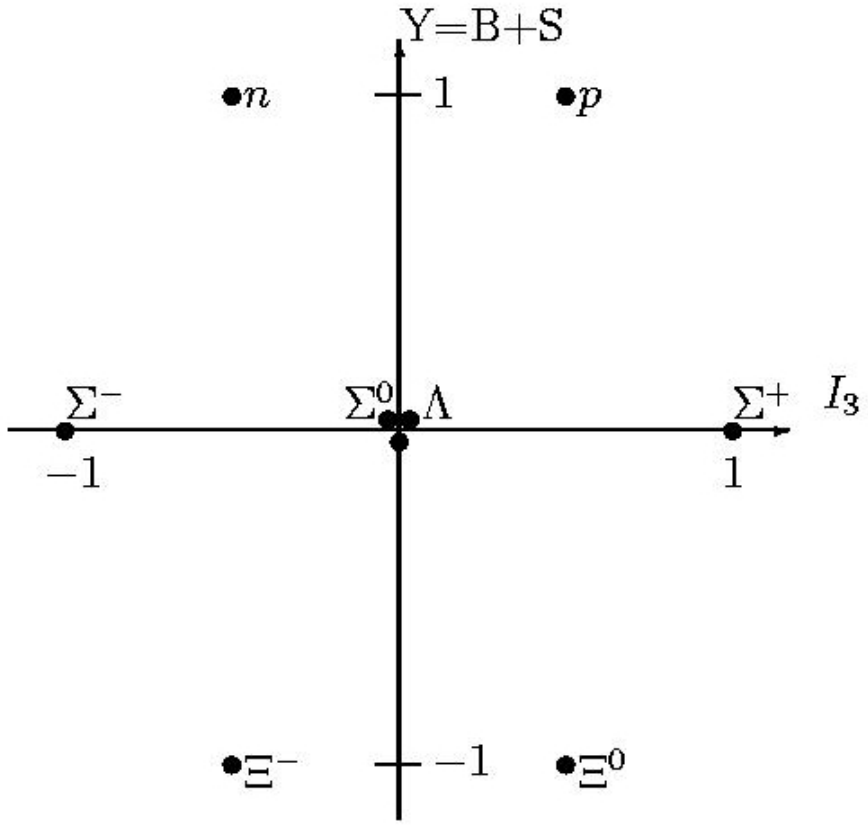


Weight Diagram for 0^- and 1^- Meson Singlet+Octet

Quarkinhalt	0^- Zustand	1^- Zustand	I_3	I	$Y = S$
$u\bar{s}$	$K^+(494)$	$K^{*+}(892)$	$1/2$	$1/2$	1
$d\bar{s}$	$K^0(498)$	$K^{*0}(896)$	$-1/2$	$1/2$	1
$u\bar{d}$	$\pi^+(140)$	$\rho^+(769)^a$	1	1	0
$\frac{u\bar{u} - d\bar{d}}{\sqrt{2}}$	$\pi^0(135)$	$\rho^0(769)^a$	0	1	0
$d\bar{u}$	$\pi^-(140)$	$\rho^-(769)^a$	-1	1	0
$s\bar{d}$	$\overline{K}^0(498)$	$\overline{K}^{*0}(896)$	$1/2$	$1/2$	-1
$s\bar{u}$	$K^-(494)$	$K^{*-}(892)$	$-1/2$	$1/2$	-1
S. Text	$\eta(547)$	$\omega(782)$	0	0	0
S. Text	$\eta'(958)$	$\phi(1019)$	0	0	0

Quark Content and Quantum Numbers for Mesons





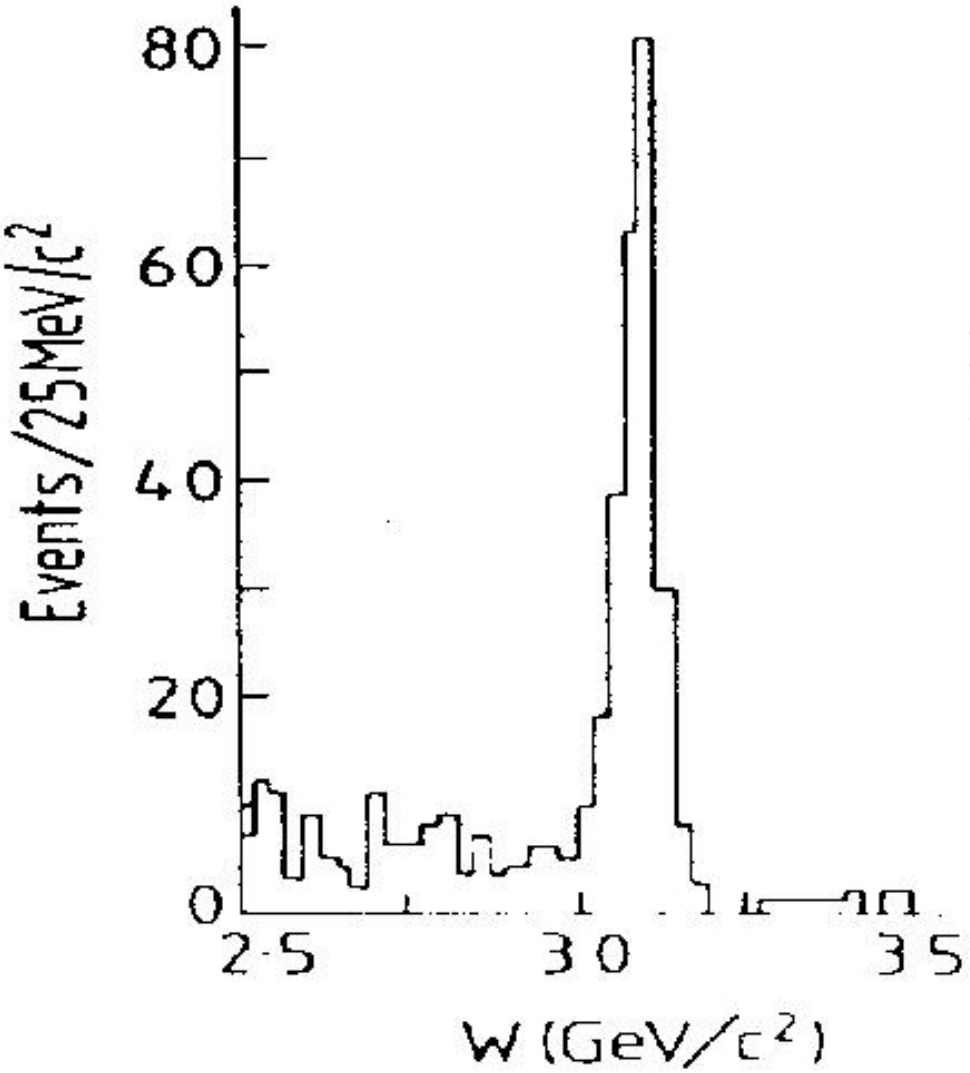
Weight Diagram for $3/2^+$ and $1/2^+$ Baryon Multiplets

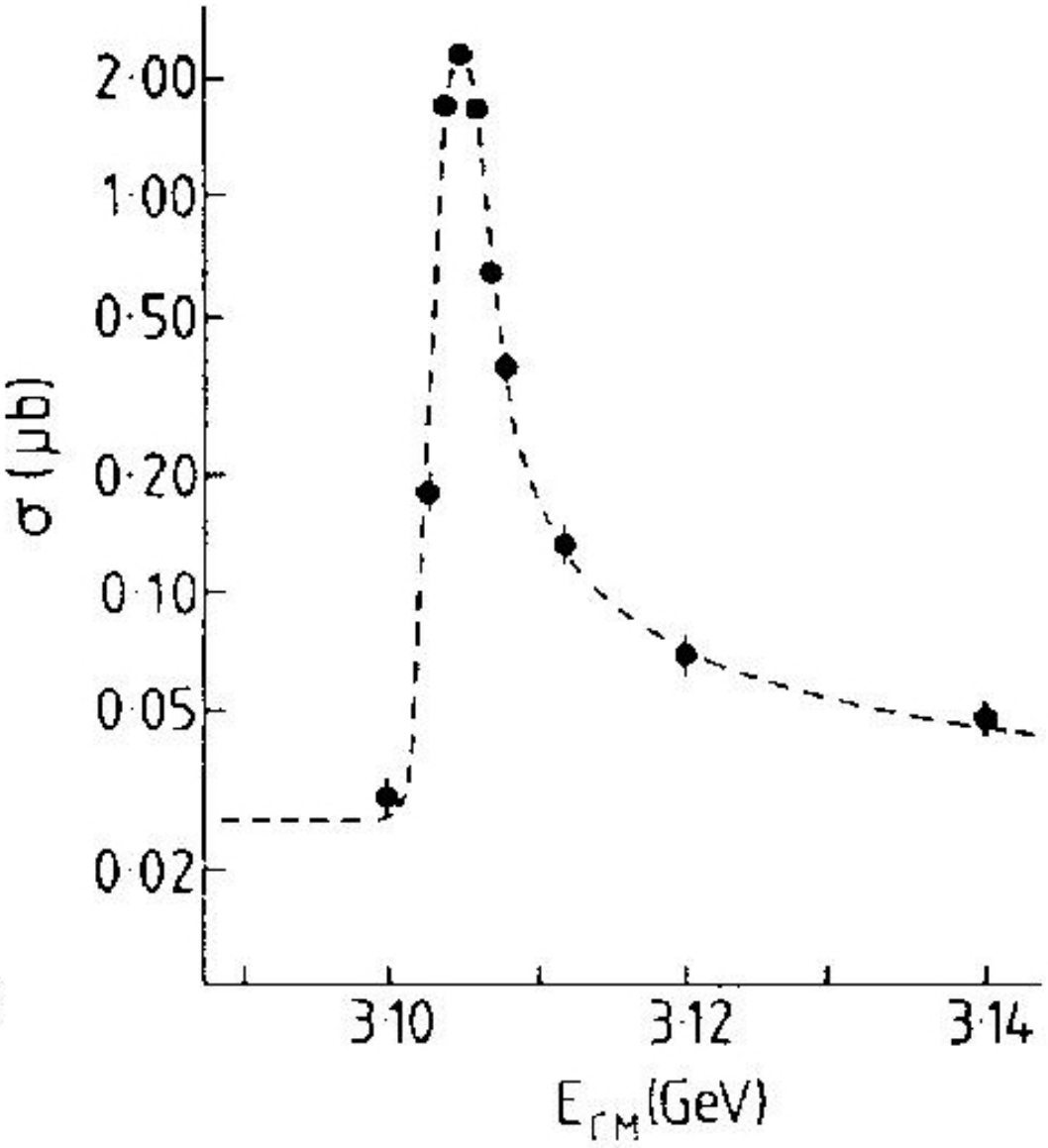
Quark Inhalt	Zustand	I_3	I	S
uud	p(938)	$1/2$	$1/2$	0
udd	n(940)	$-1/2$	$1/2$	0
...	...	...	...	...
uds	$\Lambda(1116)^a$	0	0	-1
...	...	...	...	...
uus	$\Sigma^+(1189)$	1	1	-1
uds	$\Sigma^0(1193)^a$	0	1	-1
dds	$\Sigma^-(1197)$	-1	1	-1
...	...	...	...	...
uss	$\Xi^0(1315)$	$1/2$	$1/2$	-2
dss	$\Xi^-(1321)$	$-1/2$	$1/2$	-2

Quark Content and Quantum Numbers for $1/2^+$ Baryon Octet

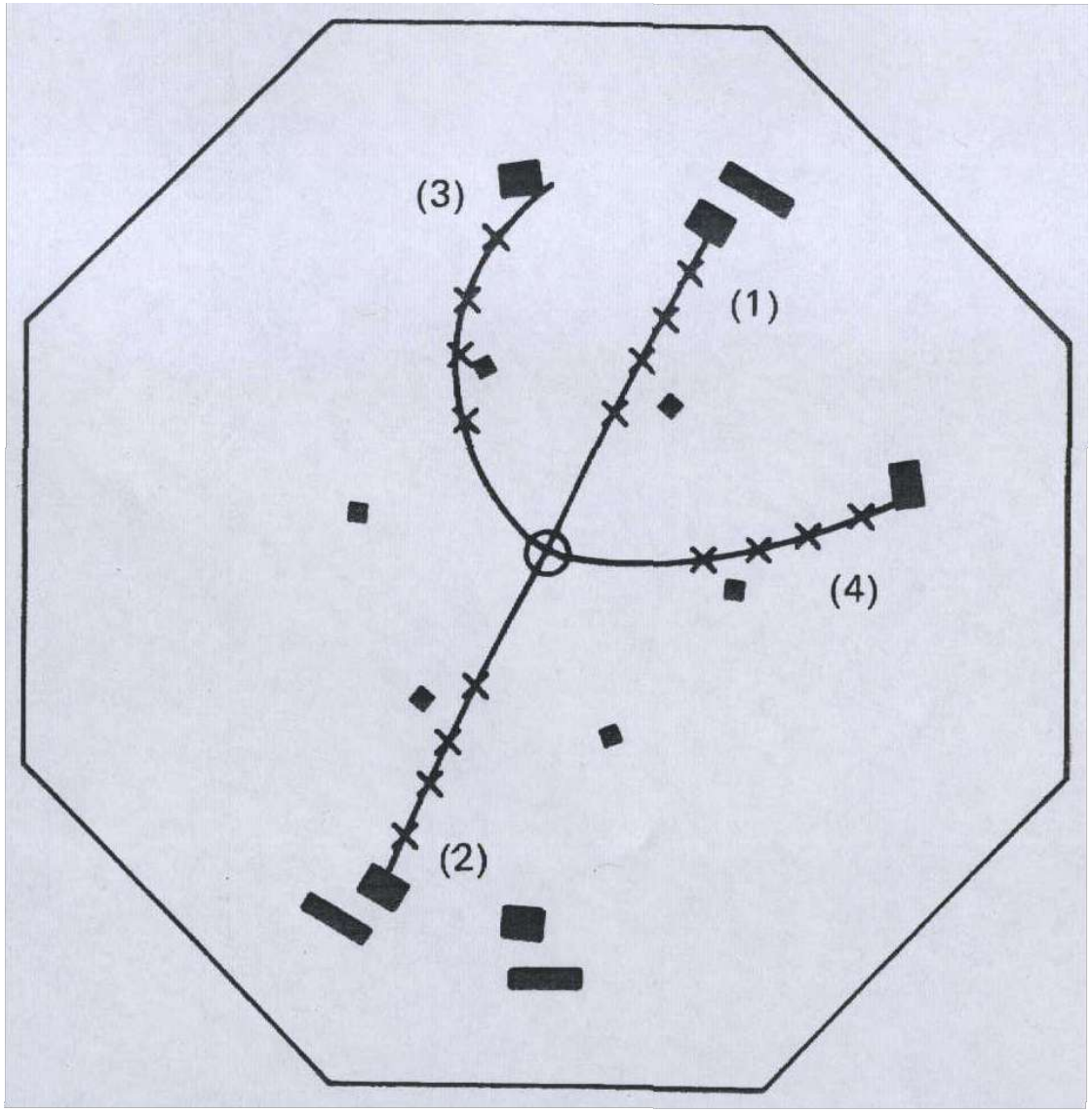
Quark Inhalt	Zustand	I_3	I	S
uuu	$\Delta^{++}(1232)^a$	$3/2$	$3/2$	0
uud	$\Delta^{+}(1232)^a$	$1/2$	$3/2$	0
udd	$\Delta^{0}(1232)^a$	$-1/2$	$3/2$	0
ddd	$\Delta^{-}(1232)^a$	$-3/2$	$3/2$	0
.....				
uus	$\Sigma^{+}(1383)$	1	1	-1
uds	$\Sigma^{0}(1384)$	0	1	-1
dds	$\Sigma^{-}(1387)$	-1	1	-1
.....				
uss	$\Xi^{0}(1532)$	$1/2$	$1/2$	-2
dss	$\Xi^{-}(1535)$	$-1/2$	$1/2$	-2
.....				
sss	$\Omega^{-}(1672)$	0	0	-3

Quark Content and Quantum Numbers for $3/2^+$ Baryon Decuplet



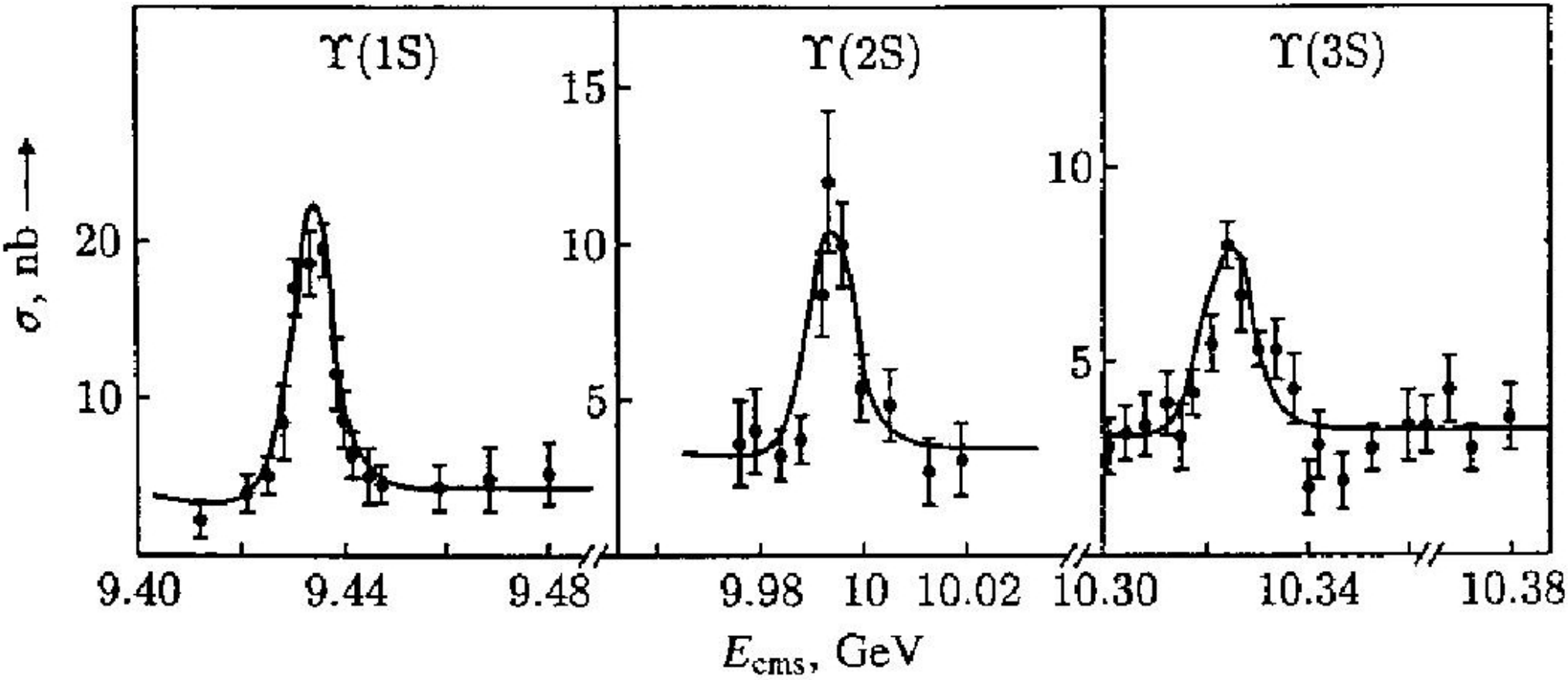


Discovery of J/ψ:
pp- (Brookhaven) and e⁺e-scattering (SLAC)



$\psi'(3.7) \rightarrow \psi(3.1)\ \pi^+\pi^- \rightarrow e^+e^-\ \pi^+\pi^-$

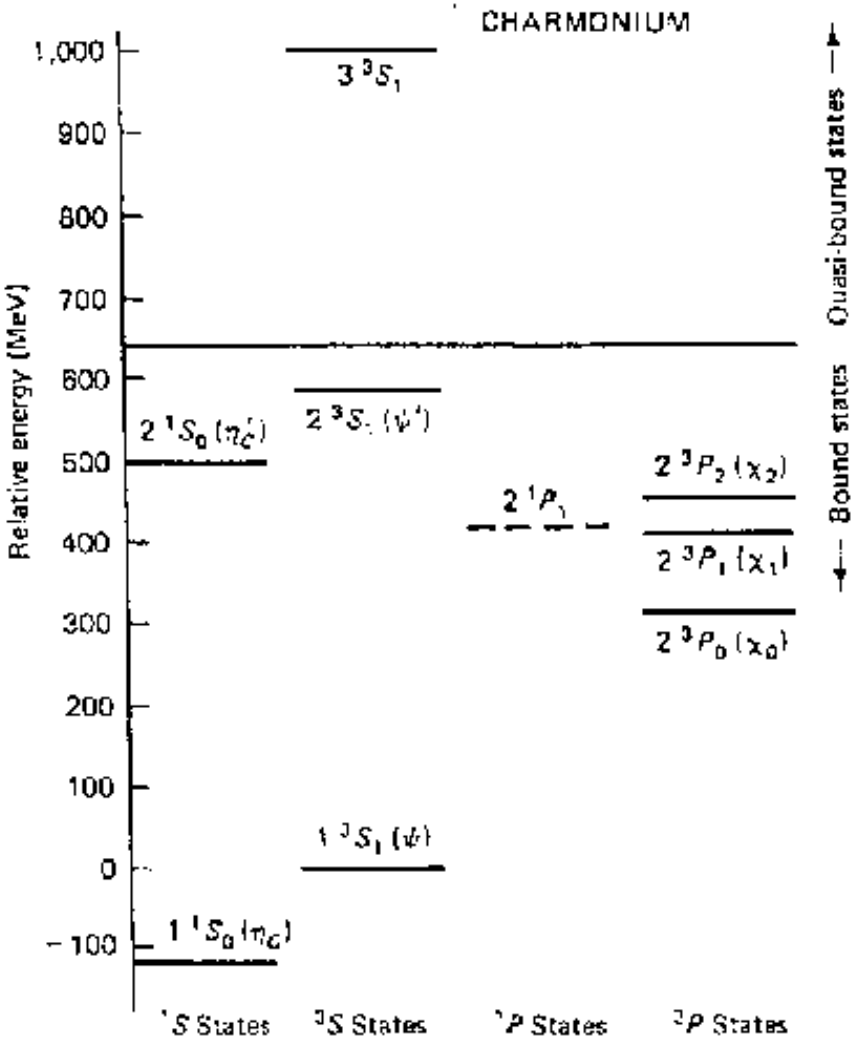
in a spark chamber detector

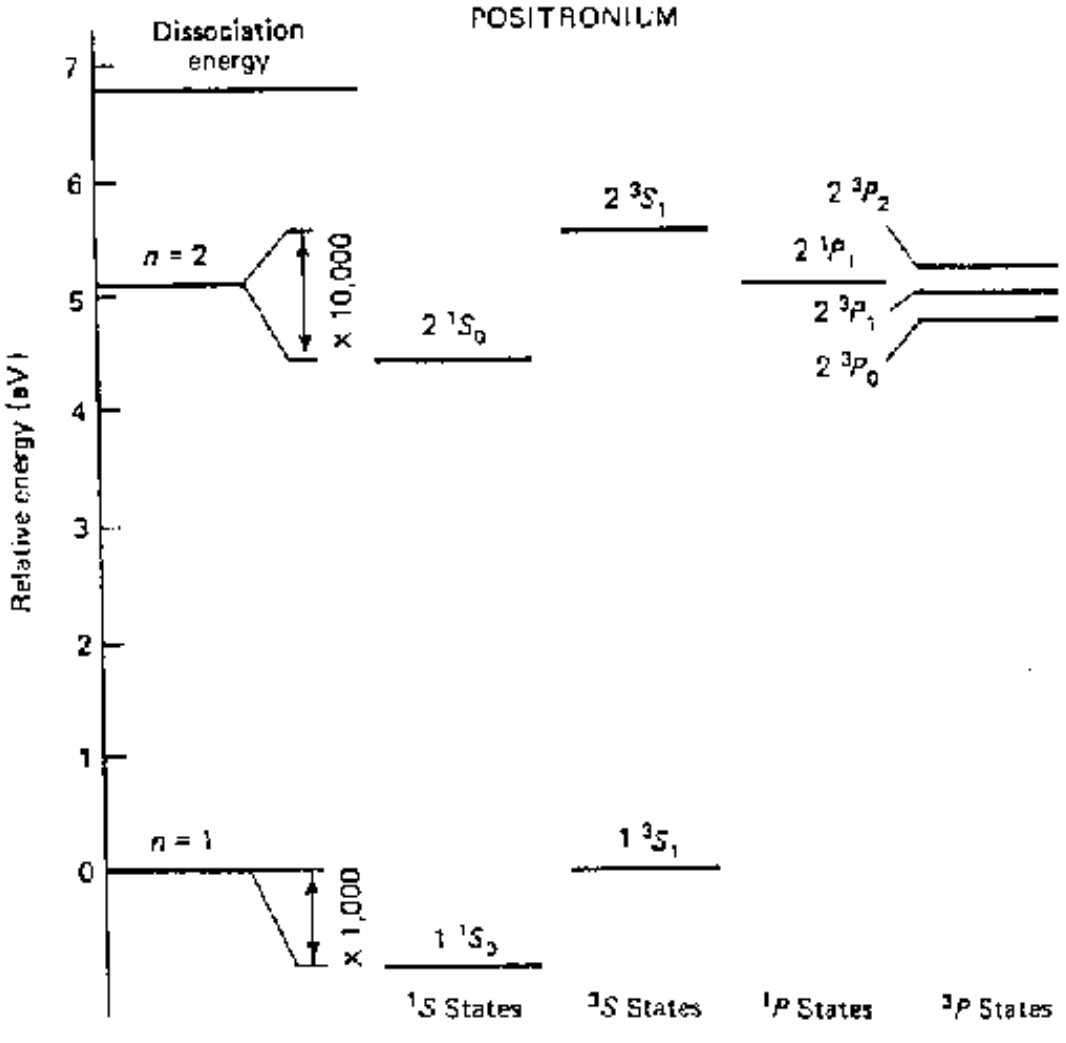


Measurements of lowest Υ resonances

Hauptquanten-zahl	$^{2S+1}L_J$	J^{PC}	$c\bar{c}$ Zustand	$b\bar{b}$ Zustand
$n=1$	$^1S_0$	0^{-+}	$\eta_c(2980)$	–
$n=1$	$^3S_1$	1^{--}	$J/\psi(3097)$	$\Upsilon(9460)$
$n=2$	$^1S_0$	0^{-+}	–	–
$n=2$	$^3S_1$	1^{--}	$\psi(3686)$	$\Upsilon(10023)$
$n=2$	$^3P_0$	0^{++}	$\chi_{c0}(3415)$	$\chi_{b0}(9860)$
$n=2$	$^3P_1$	1^{++}	$\chi_{c1}(3511)$	$\chi_{b1}(9892)$
$n=2$	$^3P_2$	2^{++}	$\chi_{c2}(3556)$	$\chi_{b2}(9913)$
$n=2$	$^1P_1$	1^{+-}	–	–

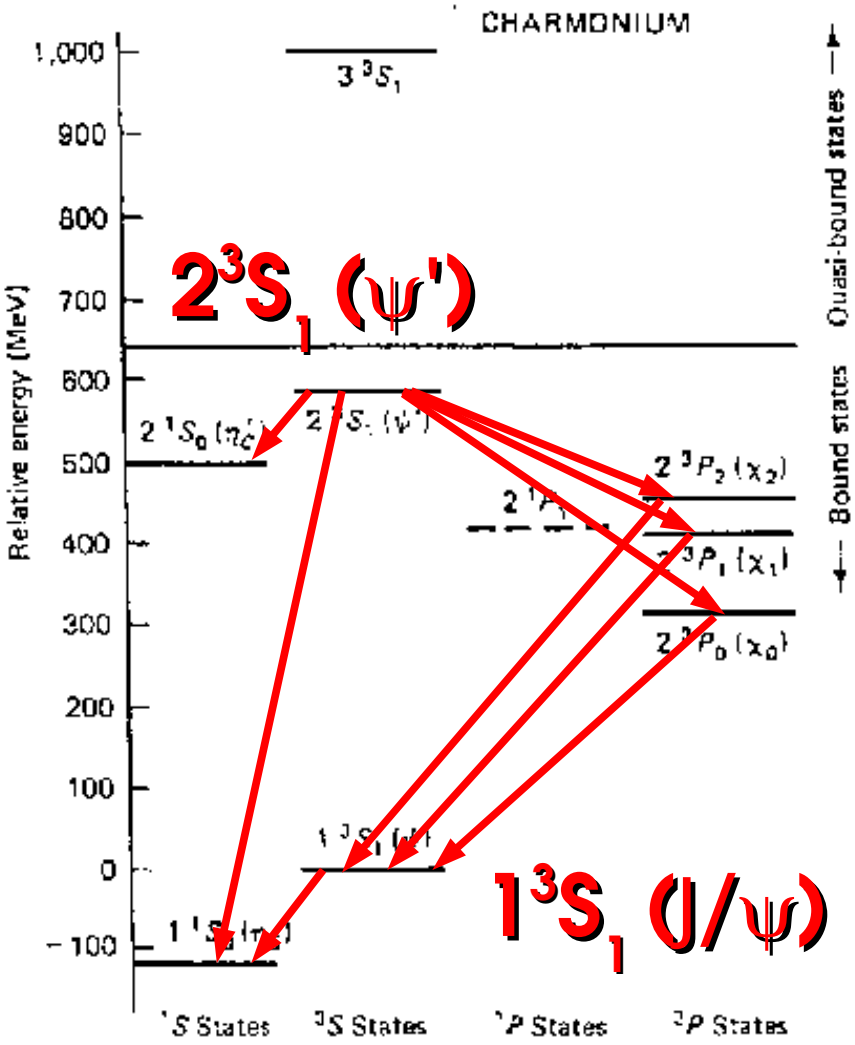
$c\bar{c}$ and $b\bar{b}$ states (Masses in MeV)

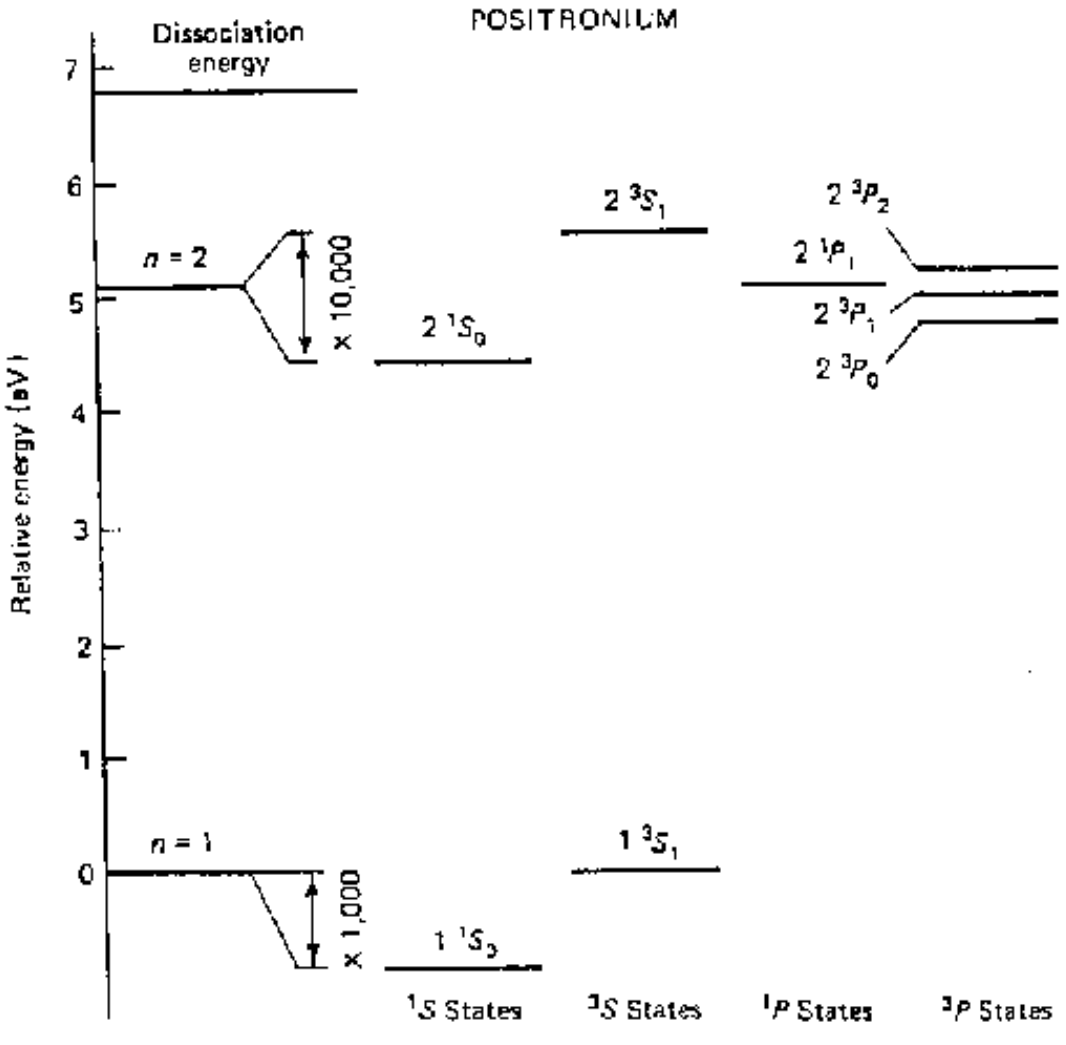




$c\bar{c}$

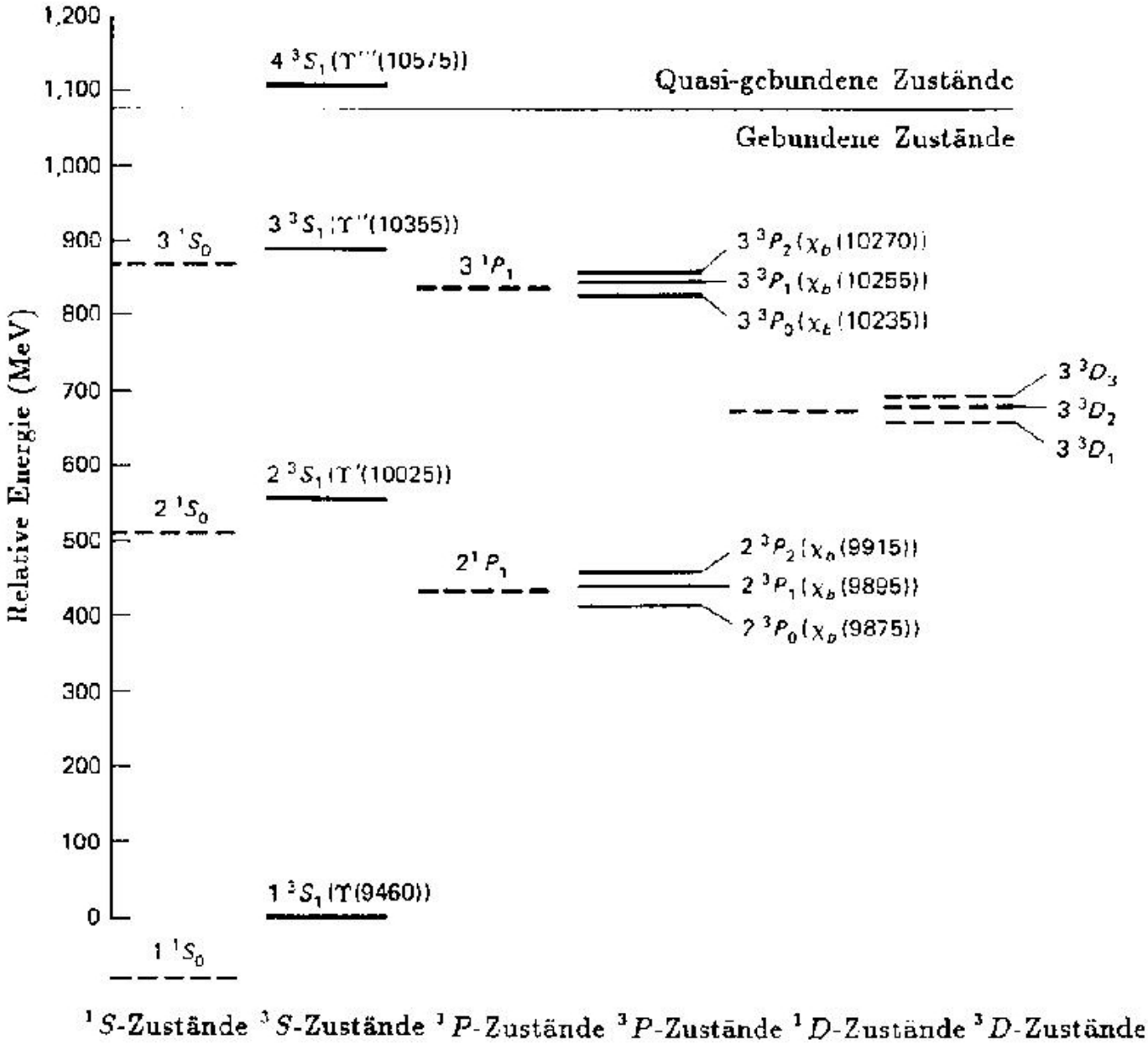
Energy niveaux for Charmonium and Positronium



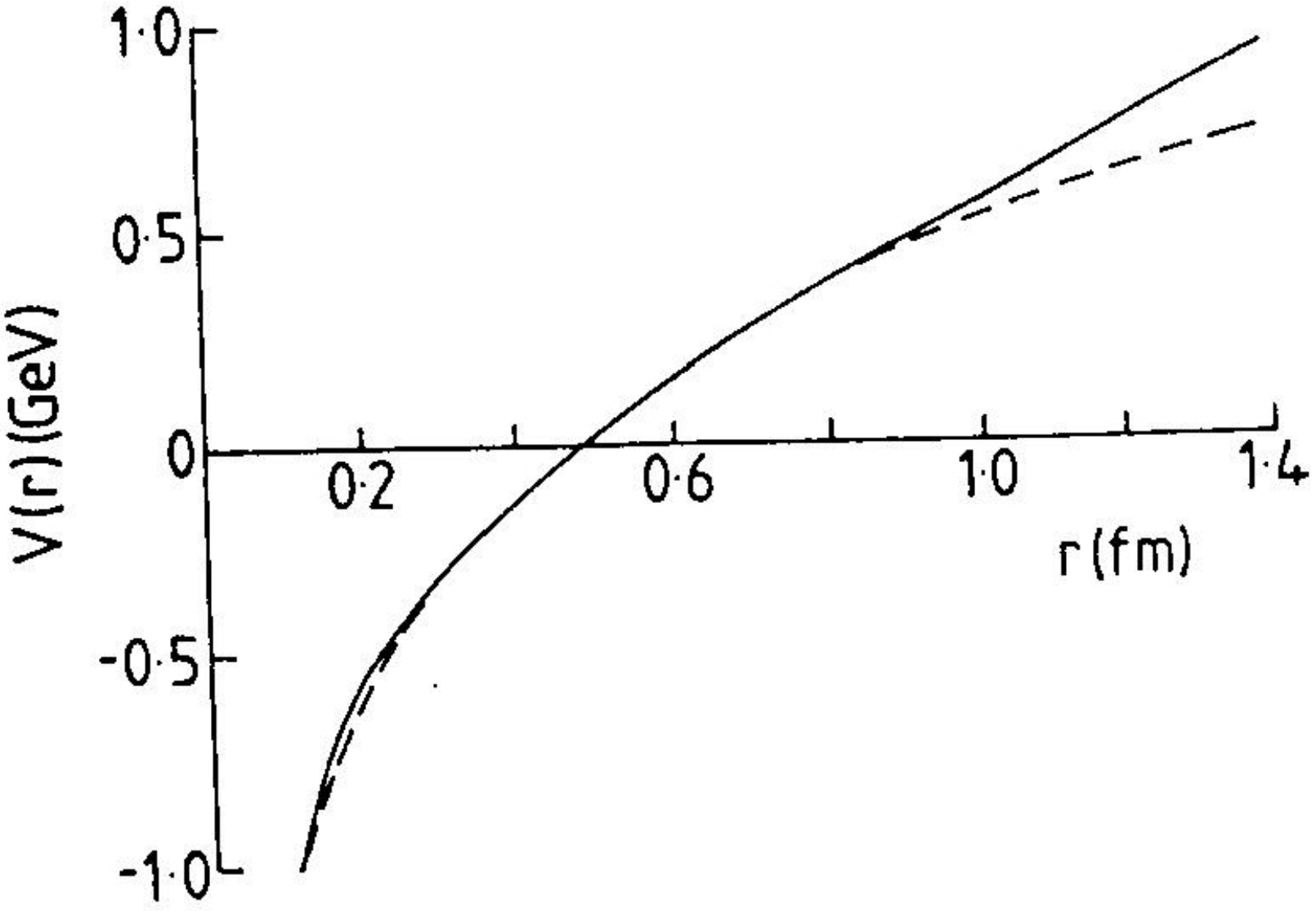


$c\bar{c}$

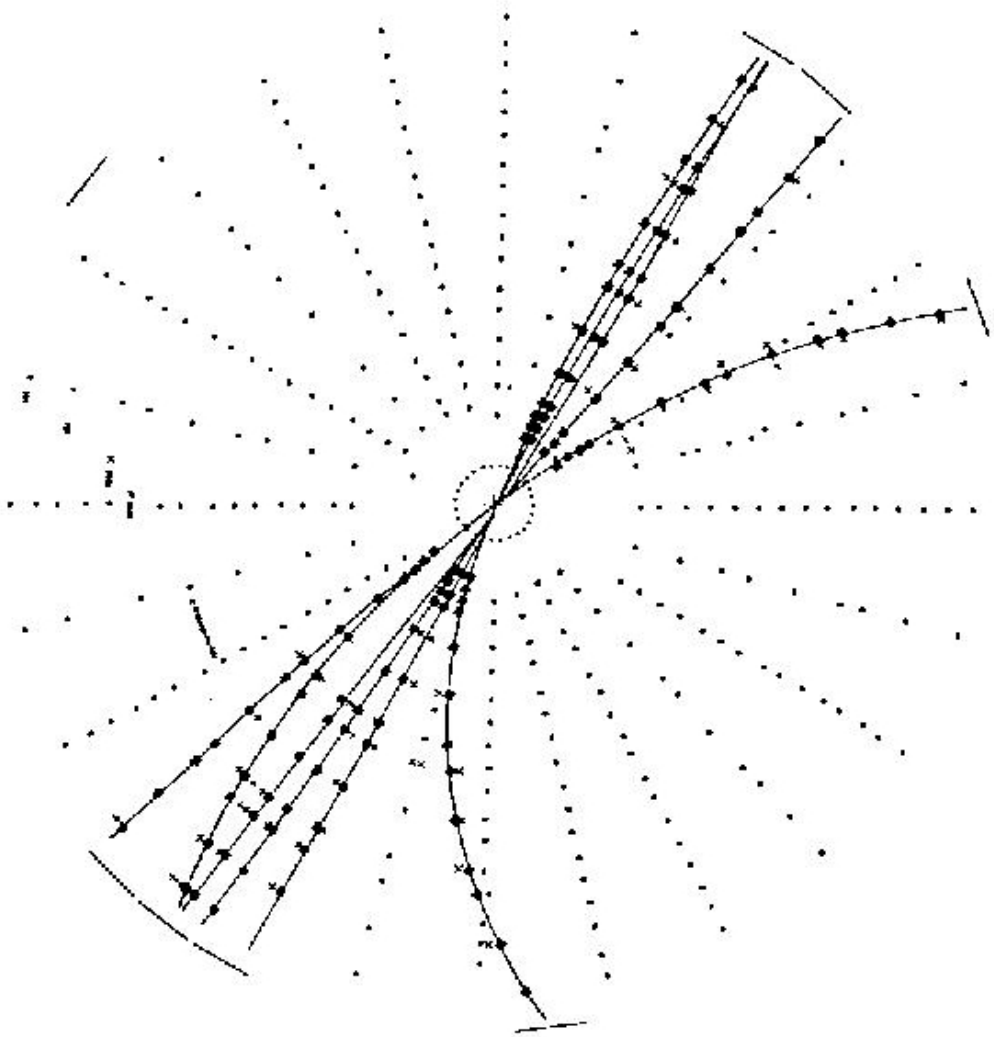
Energy niveaux for Charmonium and Positronium

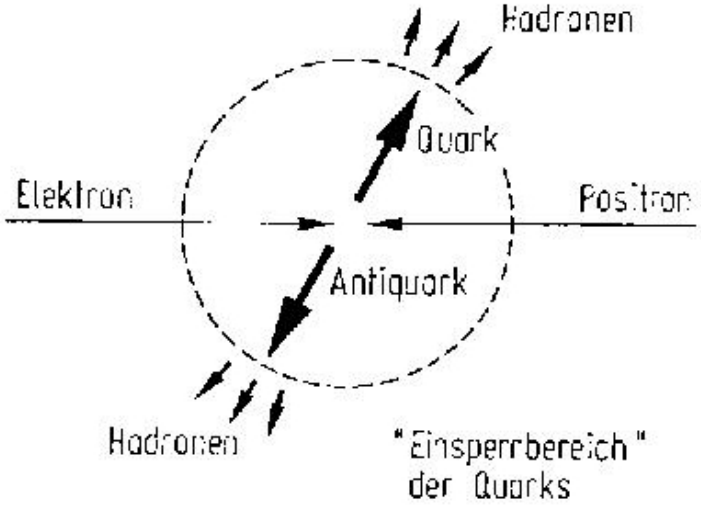


Energy Niveaux for Bottomonium

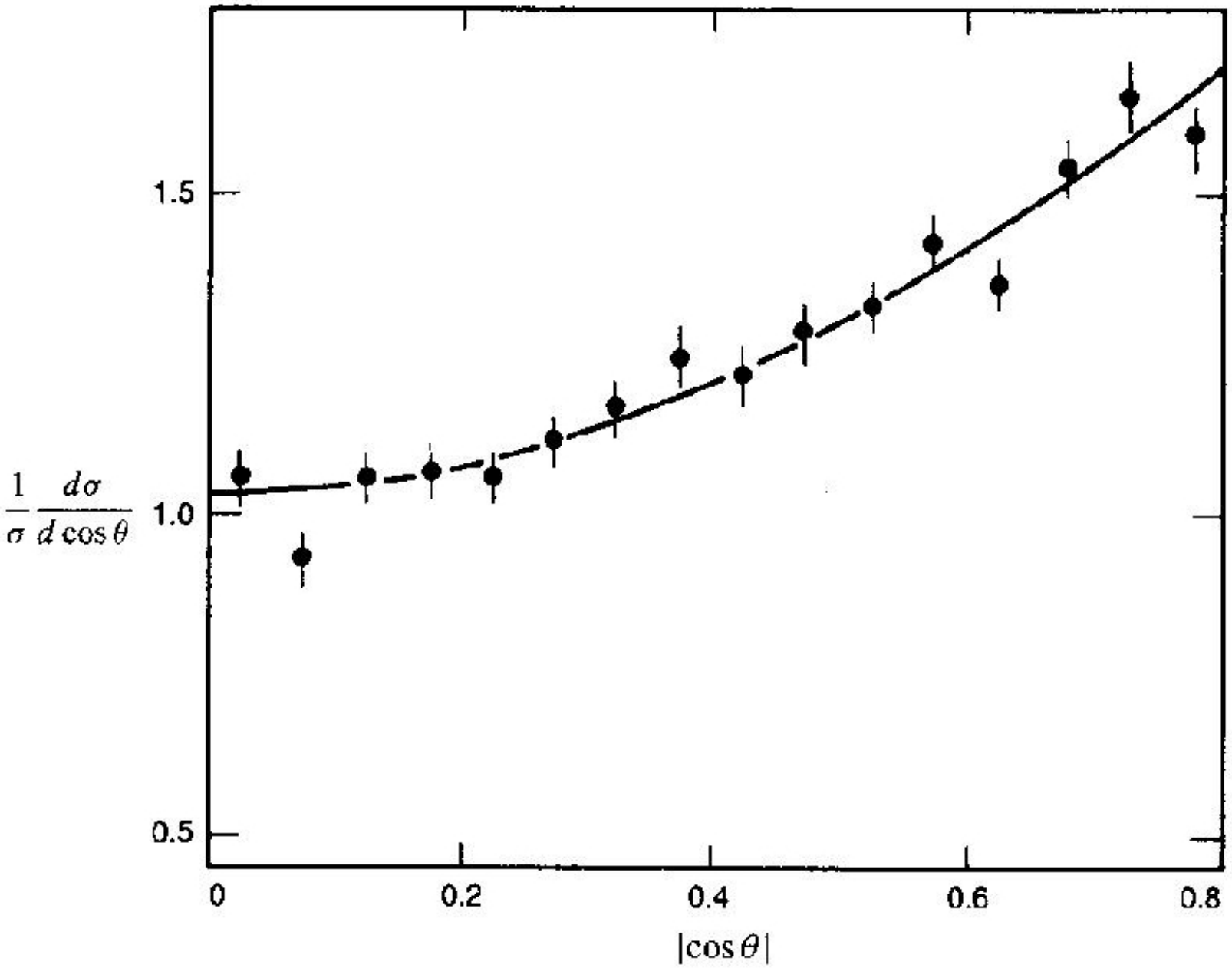


Potential of strong quark interaction from charmonium and bottomium data



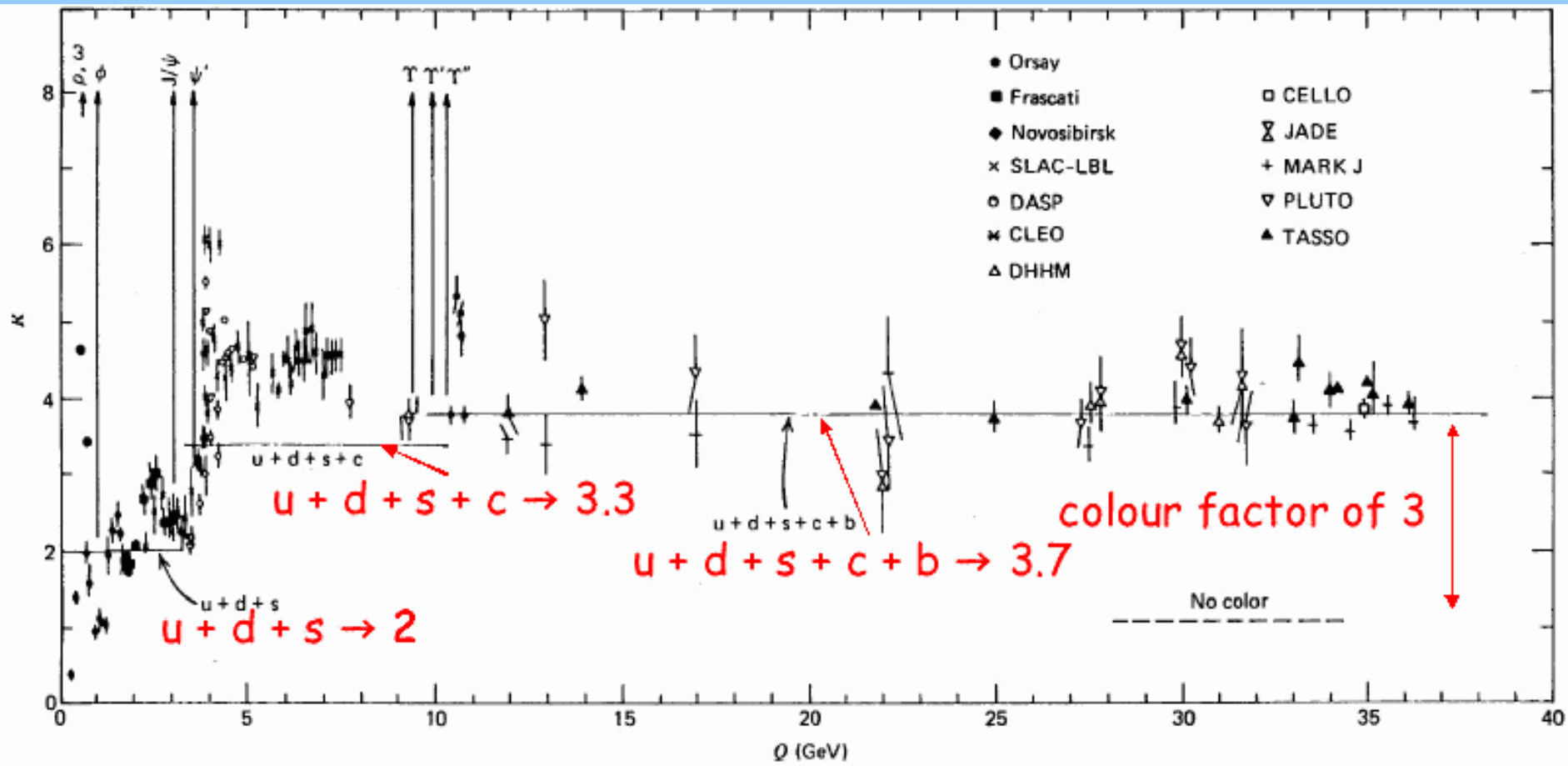


2 jet event at e^+e^- accelerator PETRA

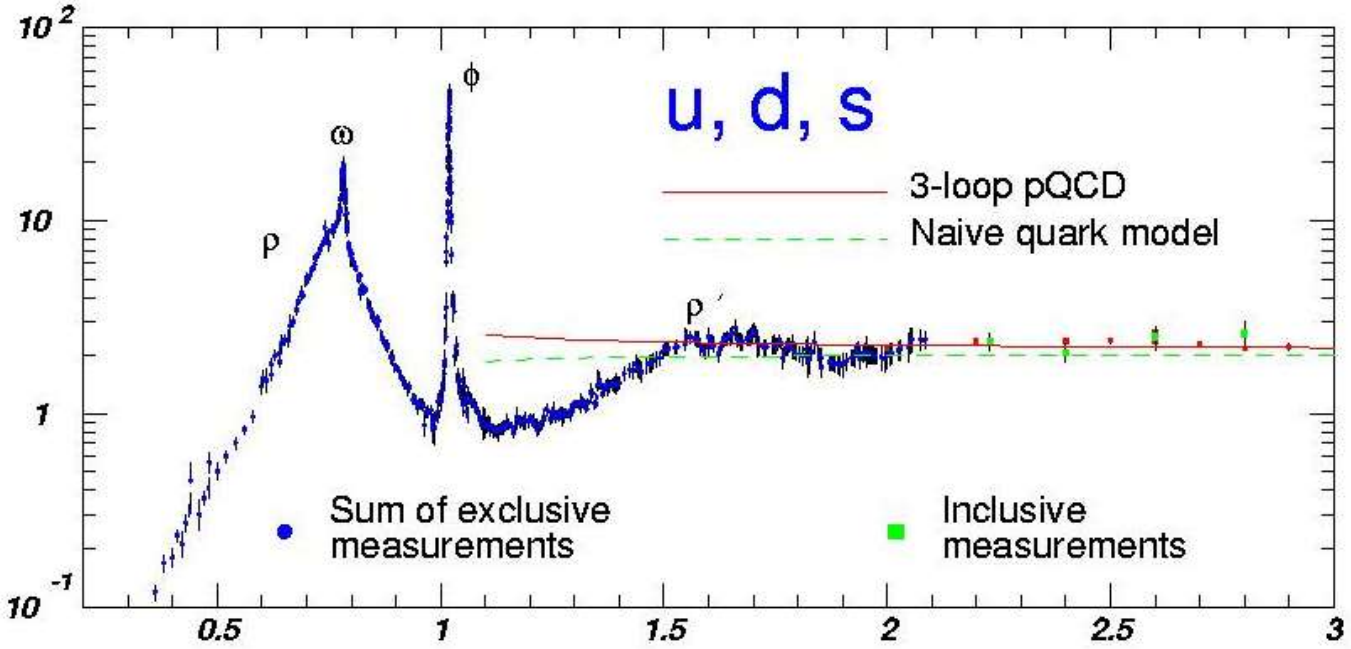


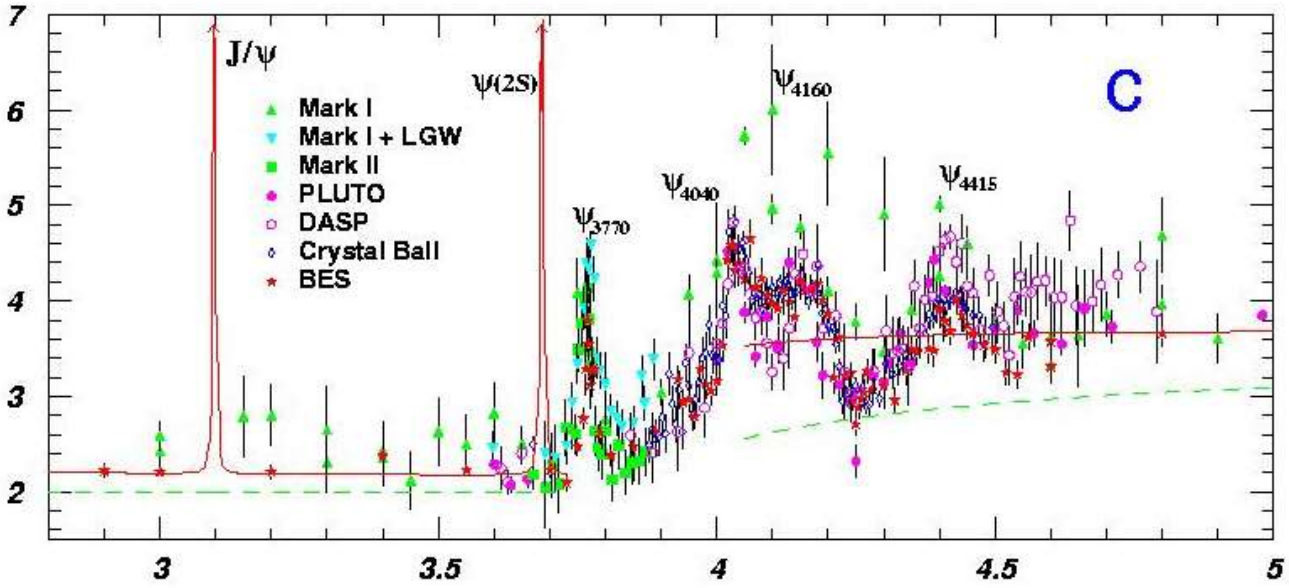
polar angle of jets in 2 jet events

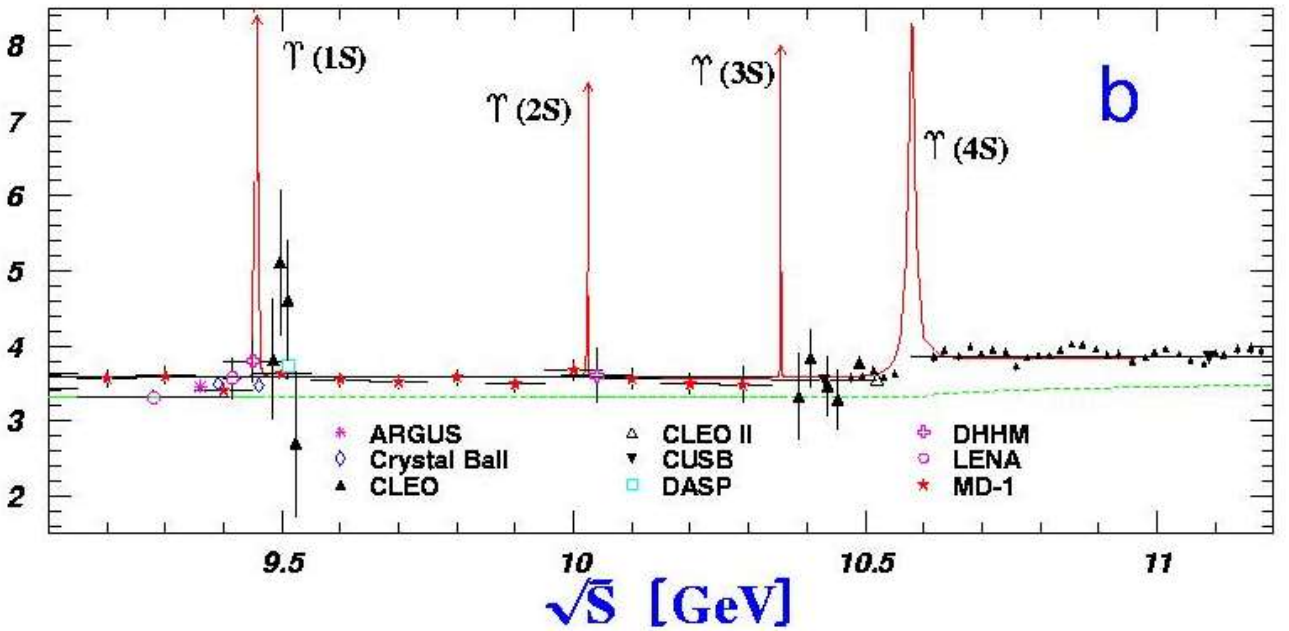
$$R = \frac{\sigma(e^+ + e^- \to hadrons)}{\sigma(e^+ + e^- \to \mu^+ + \mu^-)} = \frac{3\sum(quark\ charge)^2}{1^2}$$

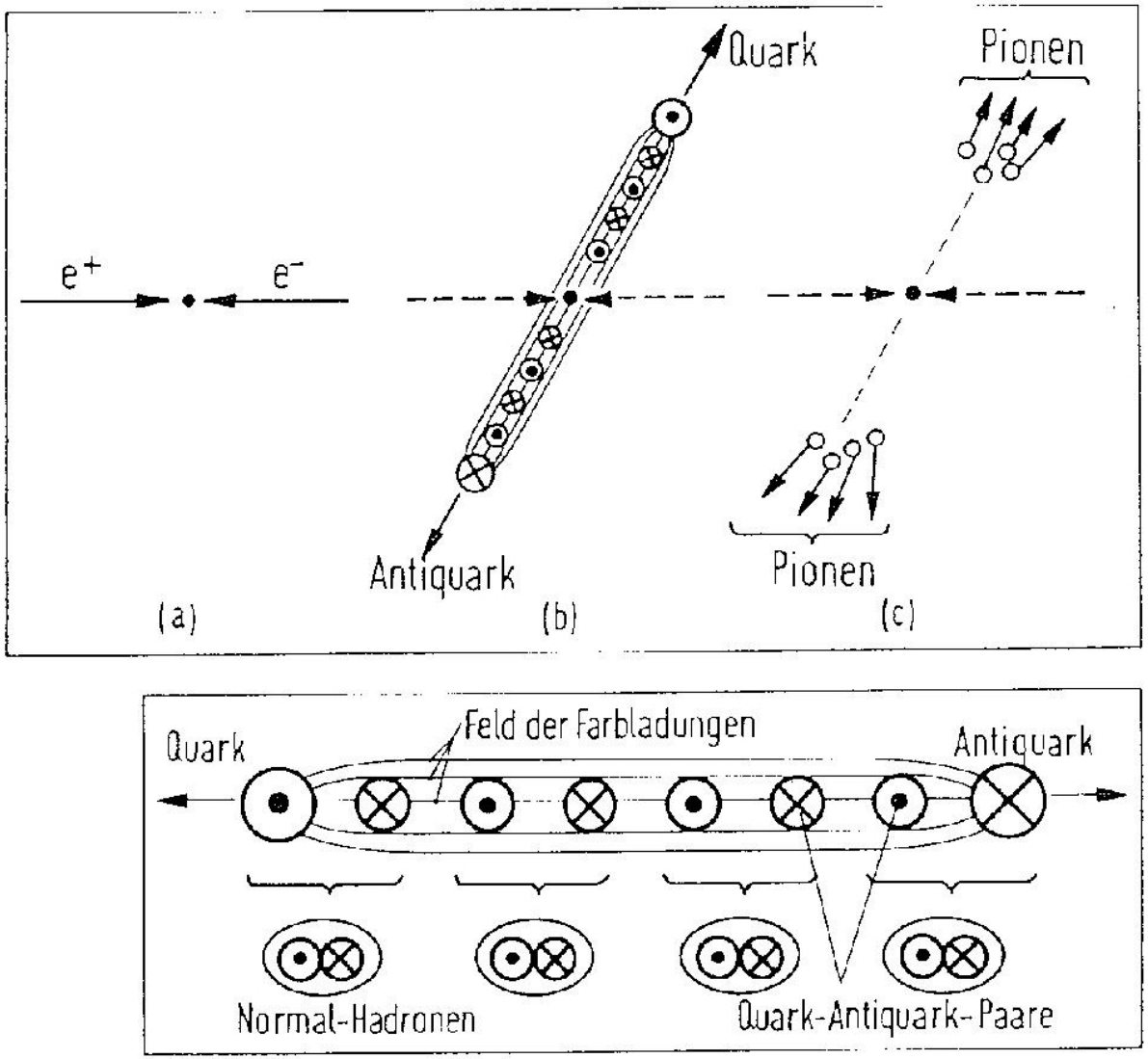


R in Light-Flavour, Charm, and Beauty Threshold Regions

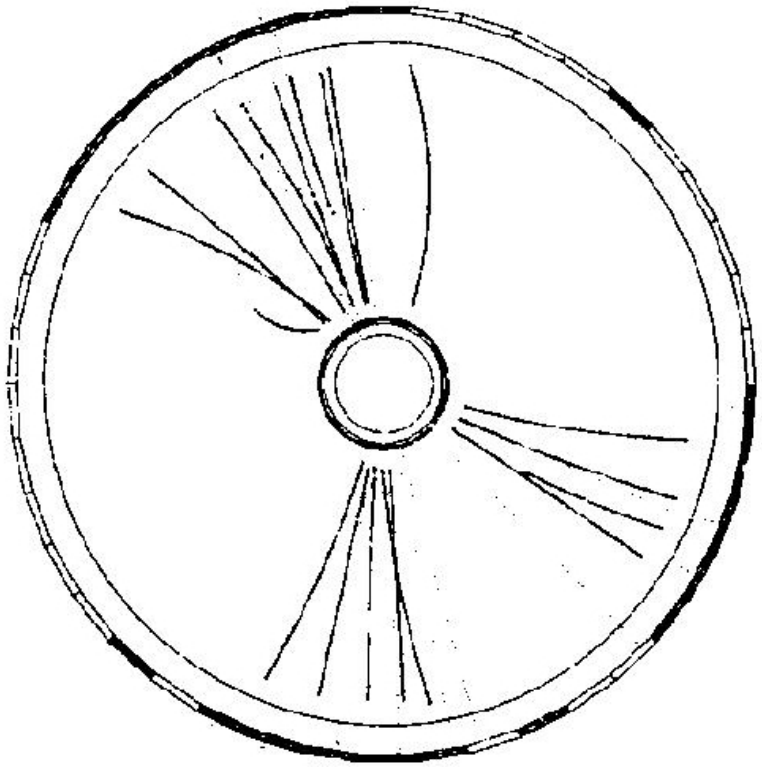


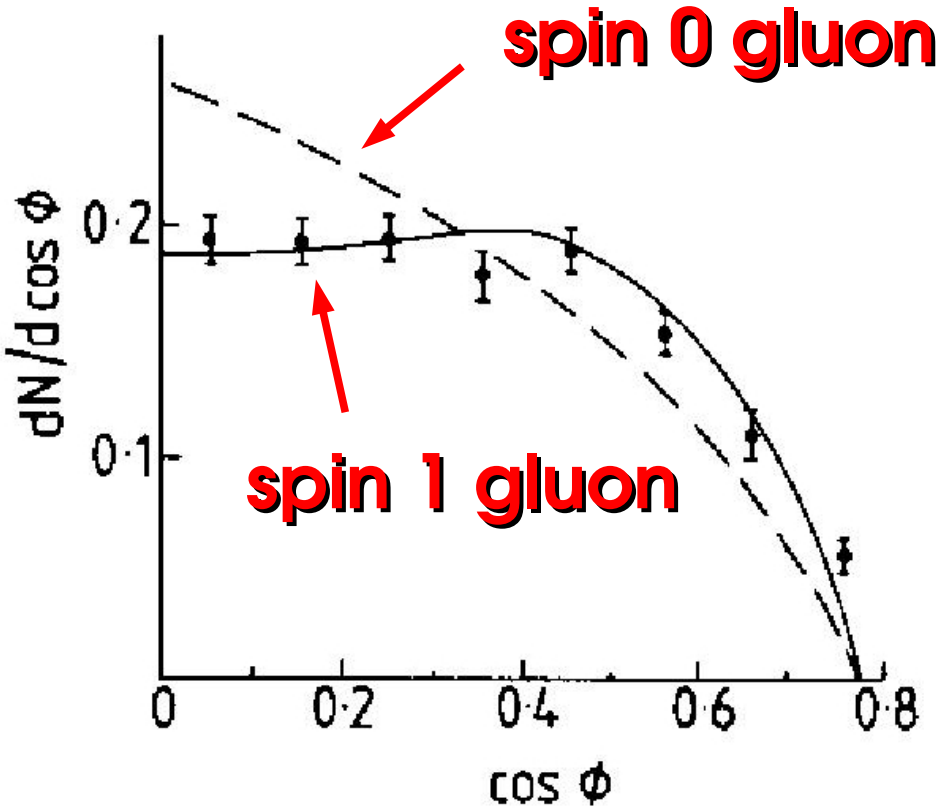




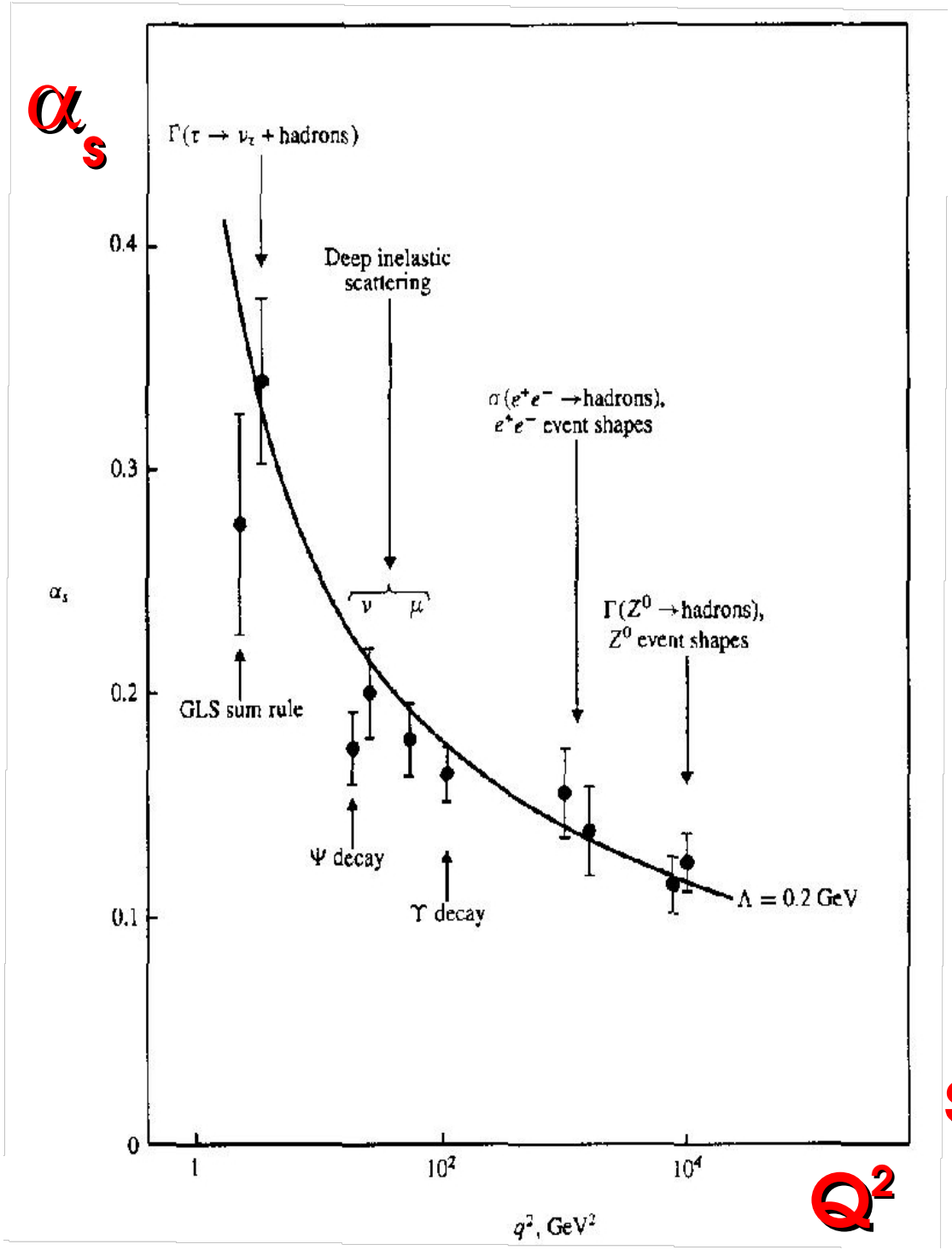


Schematic Hadronisation



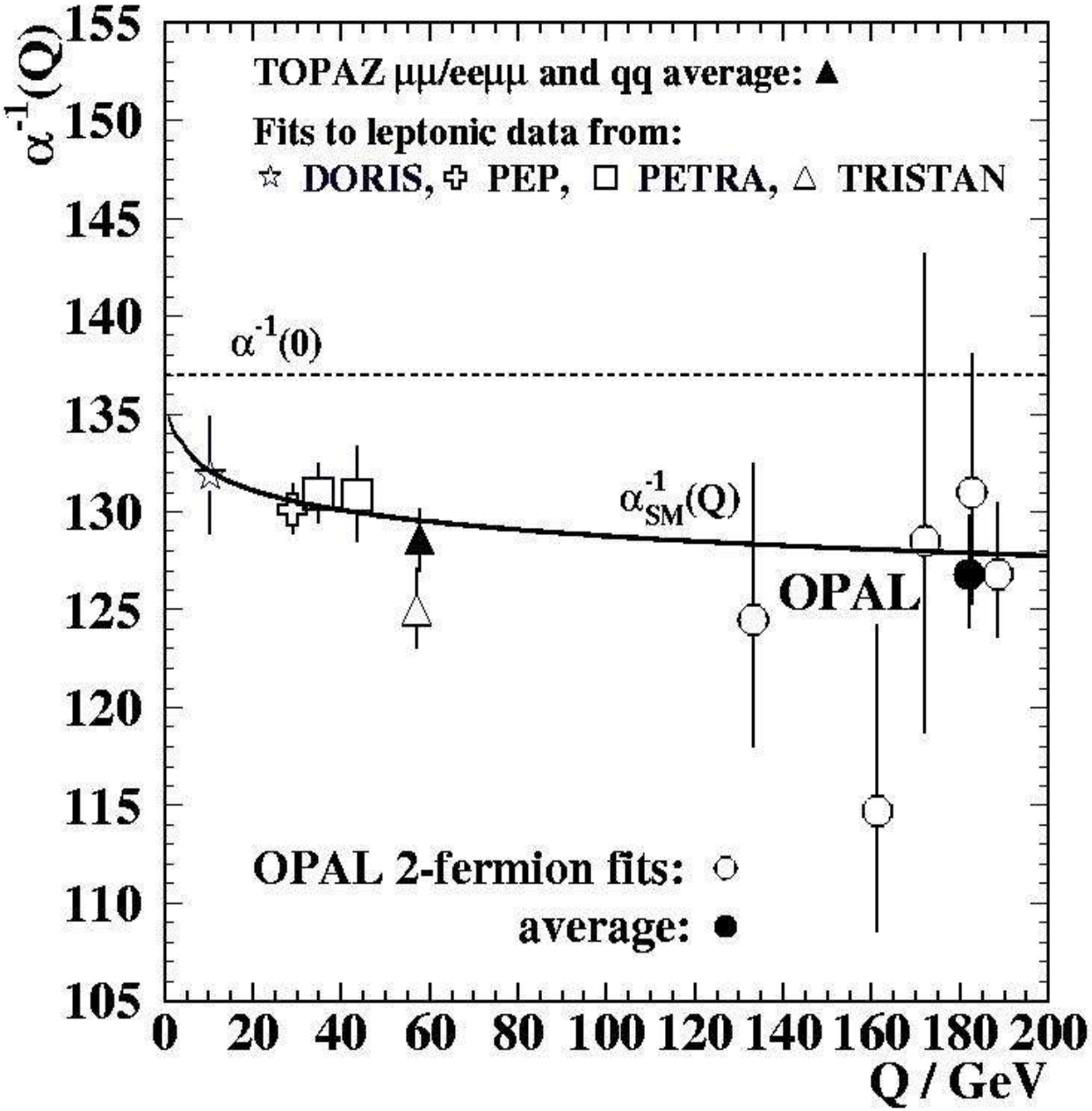


3 jet event and angular distribution at e^+e^- accelerator PETRA



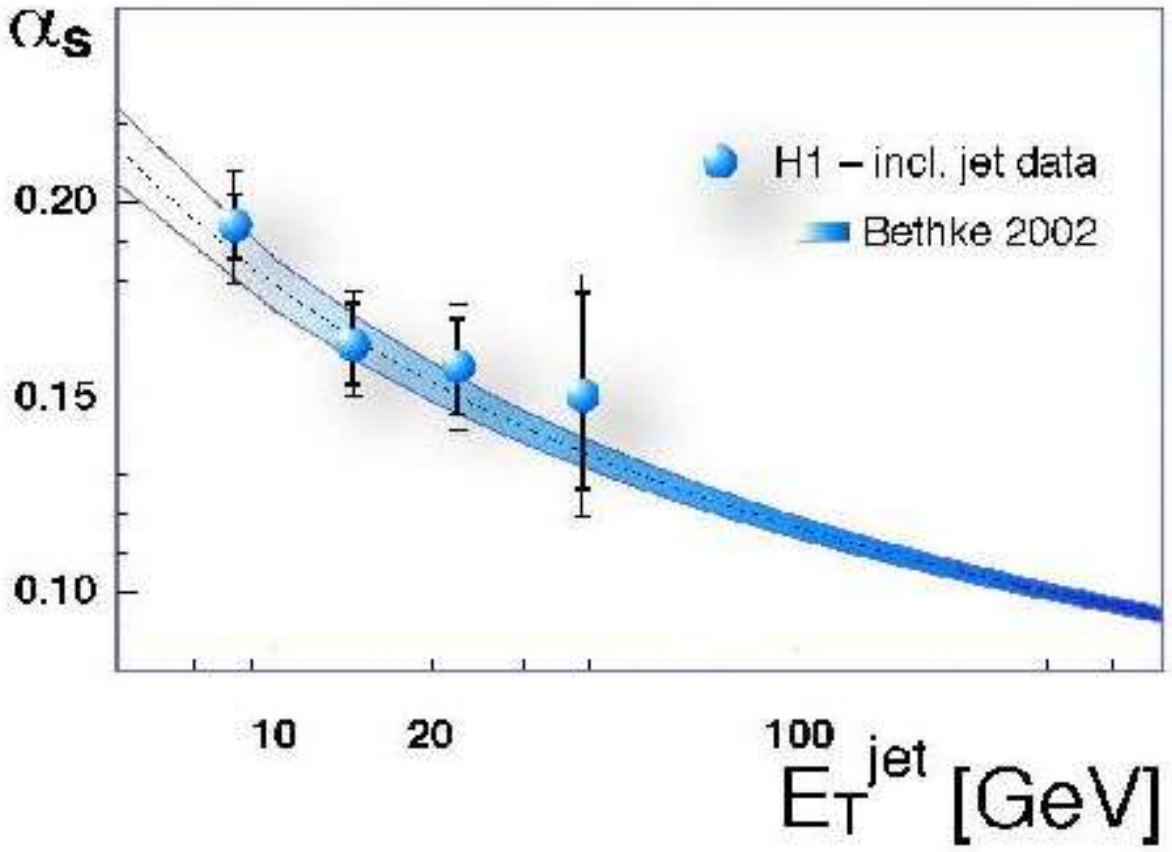
strong coupling $\alpha_s(Q^2)$

α^{-1}



α^{-1}_{QED} as function of √s in e^+e^- annihilation

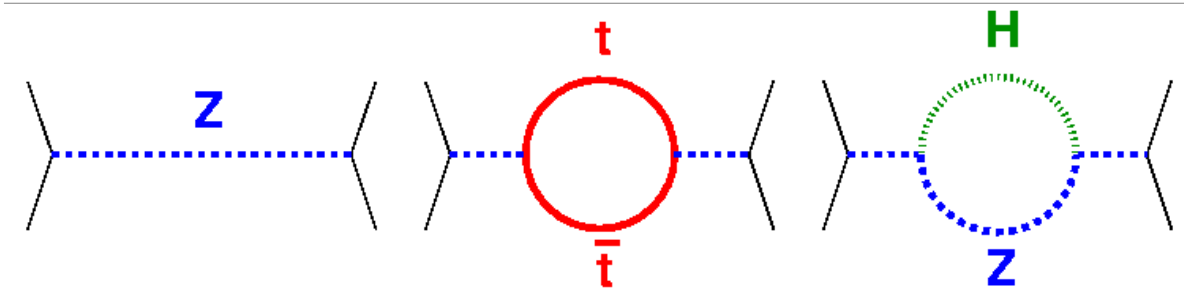
David Gross, David Politzer and Frank Wilczek awarded the 2004 Nobel Prize in Physics for the discovery of asymptotic freedom



Twenty years ago, David Gross, David Politzer and Frank Wilczek discovered **asymptotic freedom** in the theory of the strong interactions. Measurements published by **H1** in the year 2000 beautifully illustrate this effect: the strong coupling a_s is seen to decrease as the energy at which it is measured, E_T^{jet}, increases.

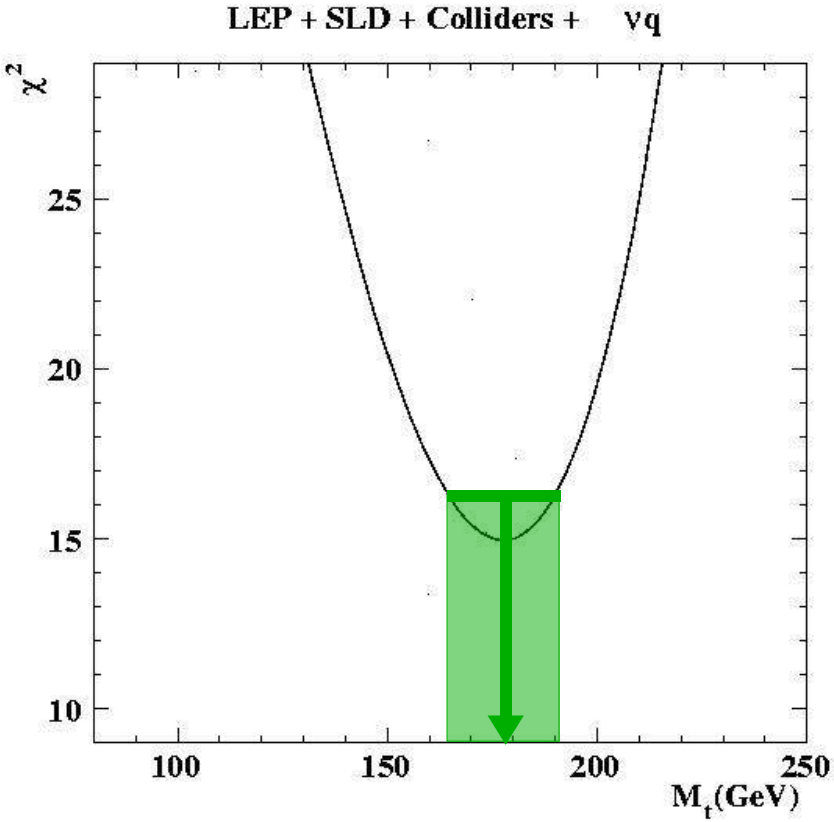
Noble Prize 2005 for running of strong coupling α_s

Top-Quark Mass Prediction



$$M_Z^2 = M_Z^{2\ 0.order} / (1 - \Delta)$$

$$\Delta \approx \ldots m_t^2 \ldots + \ldots \ln m_h \ldots$$

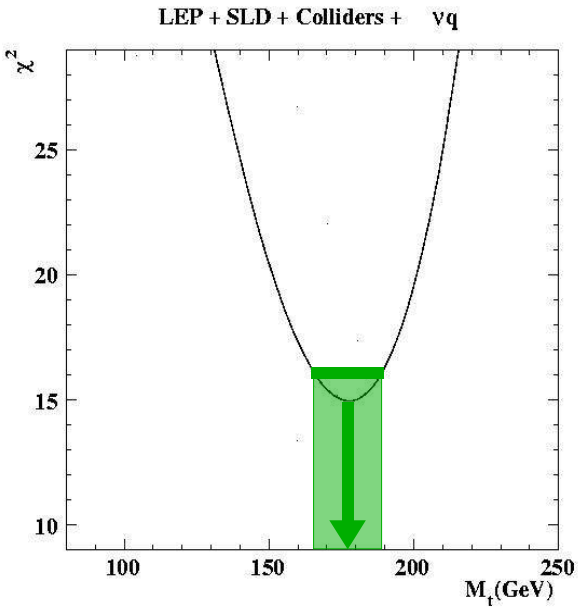


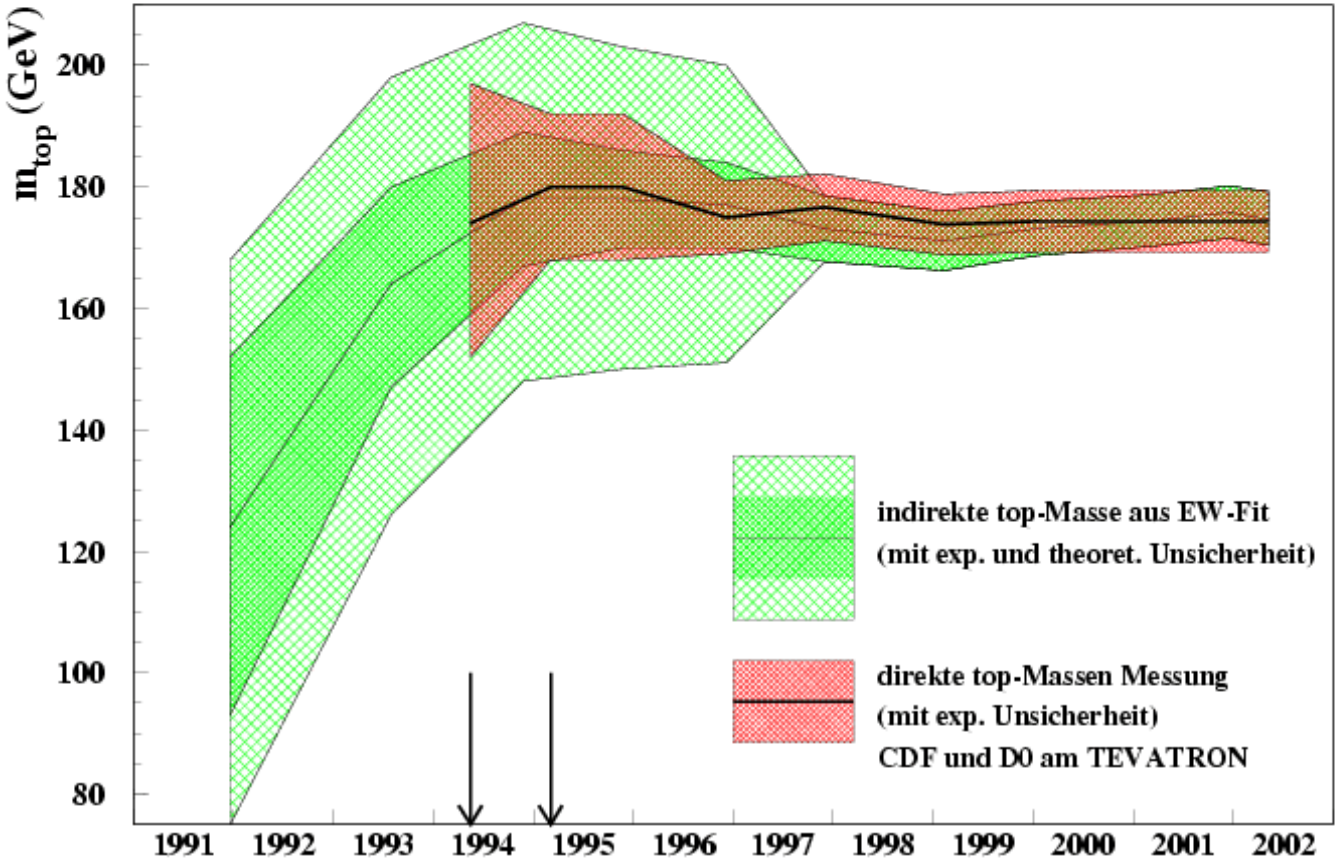
comparison :

precision measurement ⇔ correction

⇨ top quark mass prediction

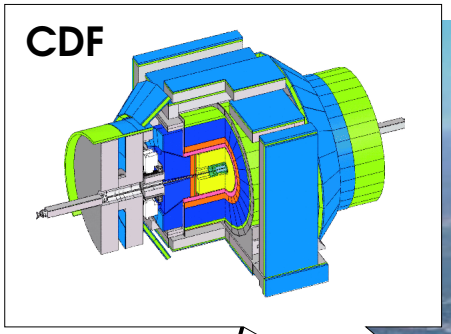
Discovery of the Top Quark

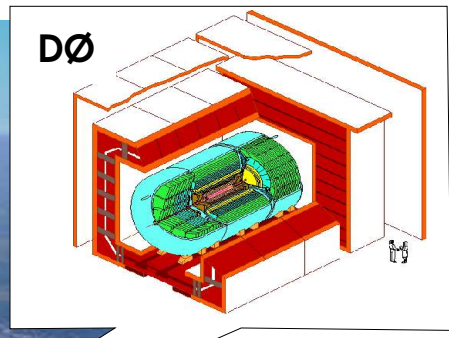


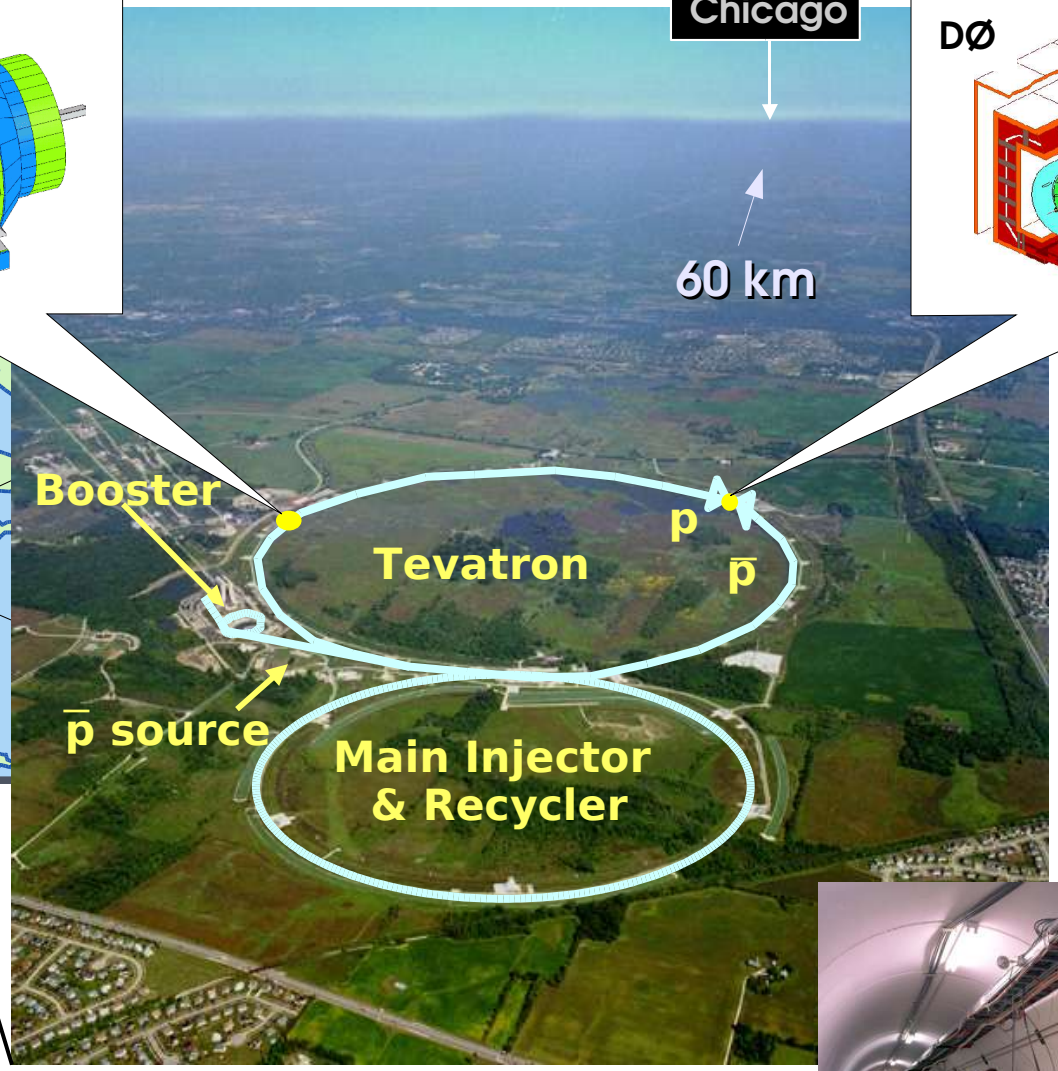


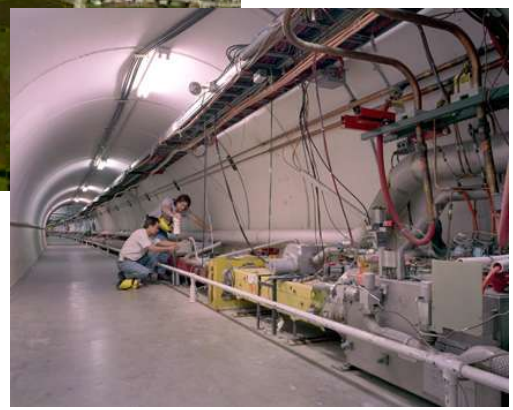
... discovered the top exactly where it was expected ...

The TEVATRON at Fermilab









p $\bar{p}$

$\sqrt{s} = 1.96$ TeV

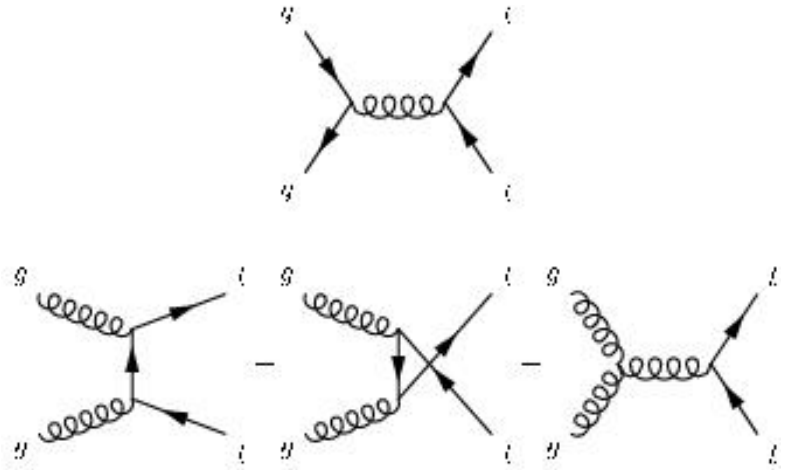
$\Delta t = 396$ ns

Run I 1987 (92)-95 L_{int} ~ 125 pb^{-1}

Run II 2001-09(?)

> 40- to 90-times larger dataset at increased energy

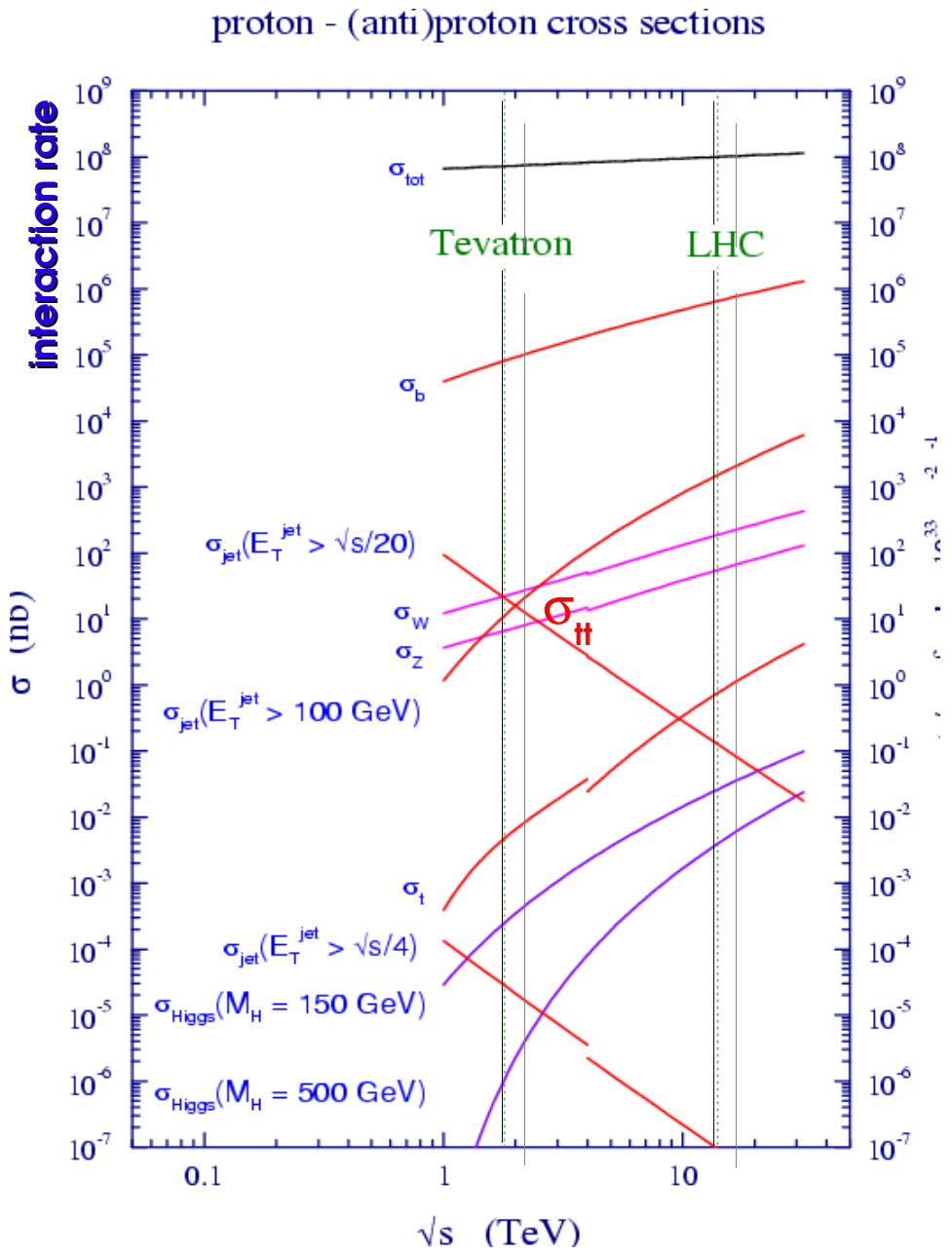
Strong Top Quark Production



qq ~ 85 %

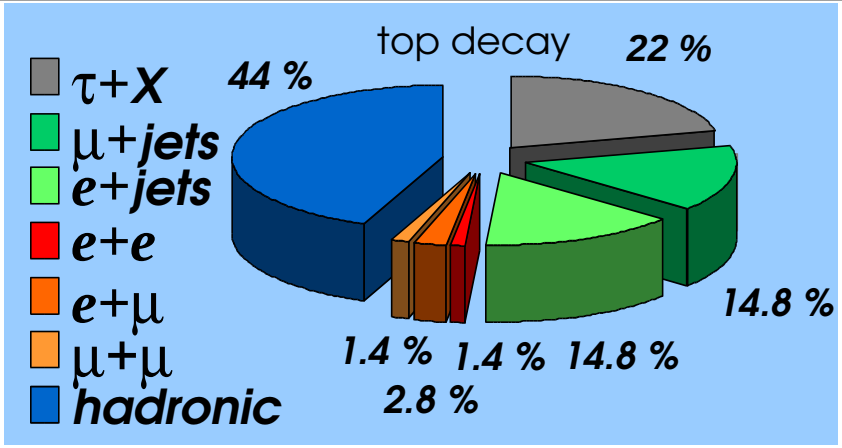
gg ~ 15 %

	Run I	Run II ($2\ fb^{-1}$)	LHC ($10\ fb^{-1}$)
no ttbar (m_t sample ≥1 b-tag)	20	800	$8 * 10^6$



Decay Topology in TbarT

Top quarks decay predominantly (~100%) to a W-Boson and a b-quark

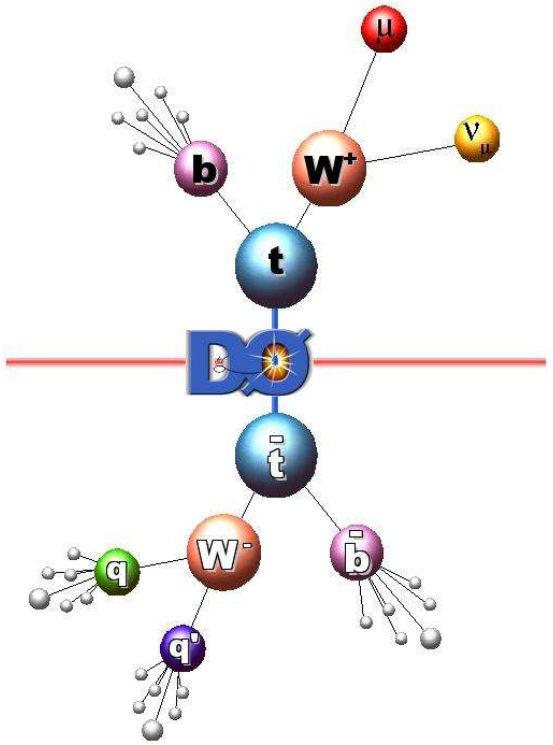


Top-Antitop Signatures:

`dilepton channel'
5% : 2 jets, 2 charged leptons, 2 ν

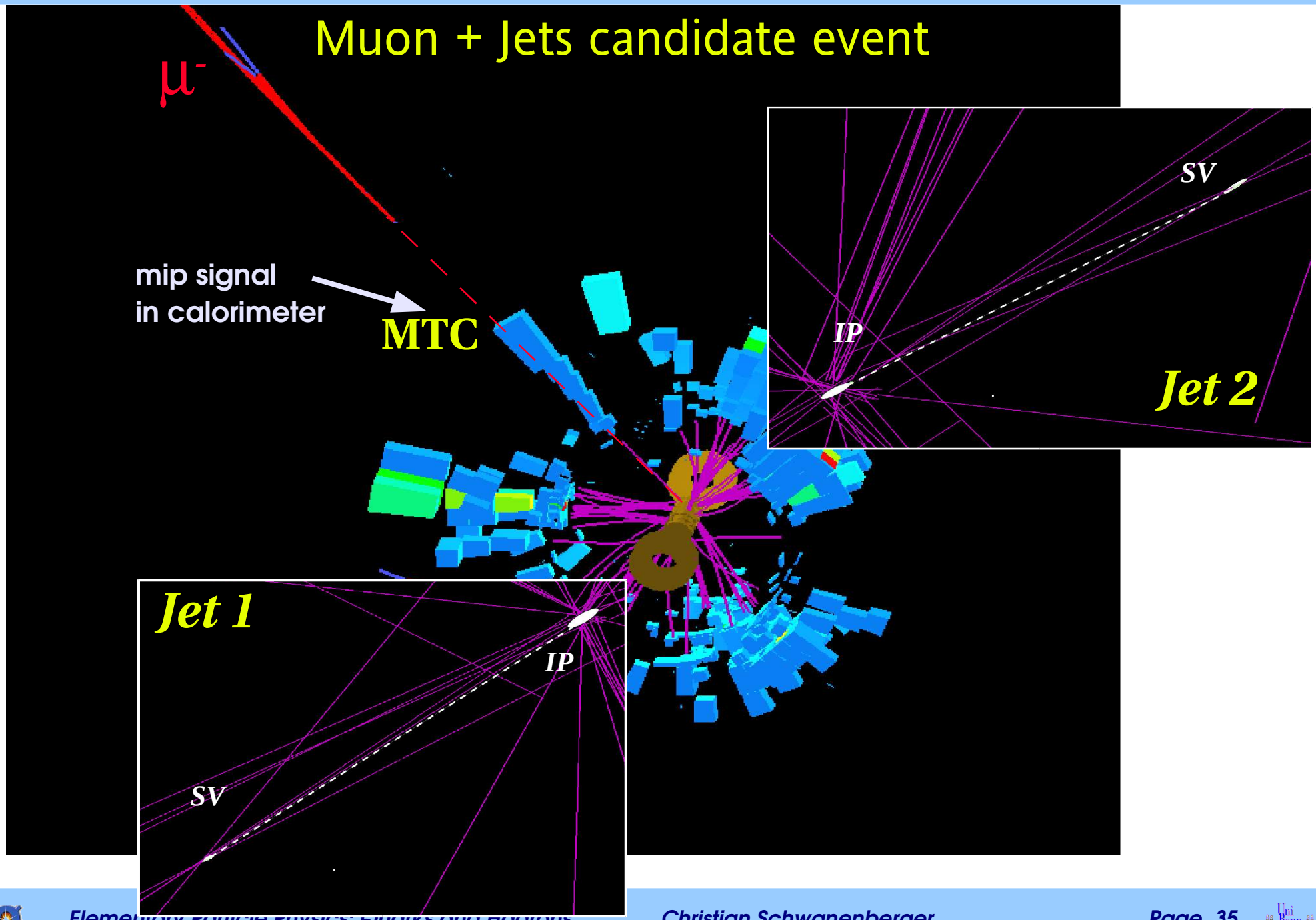
'lepton+jets channel'
30%: 4 jets, 1 charged lepton, 1 ν

'all-jets channel'
40%: 6 jets



always 2 jets are b-jets

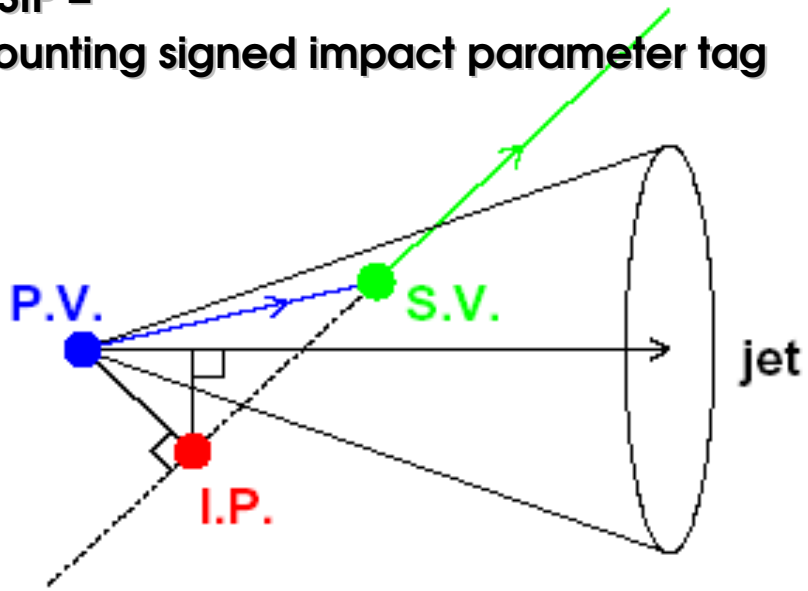
Lepton+Jets: A Typical μ+Jets Event



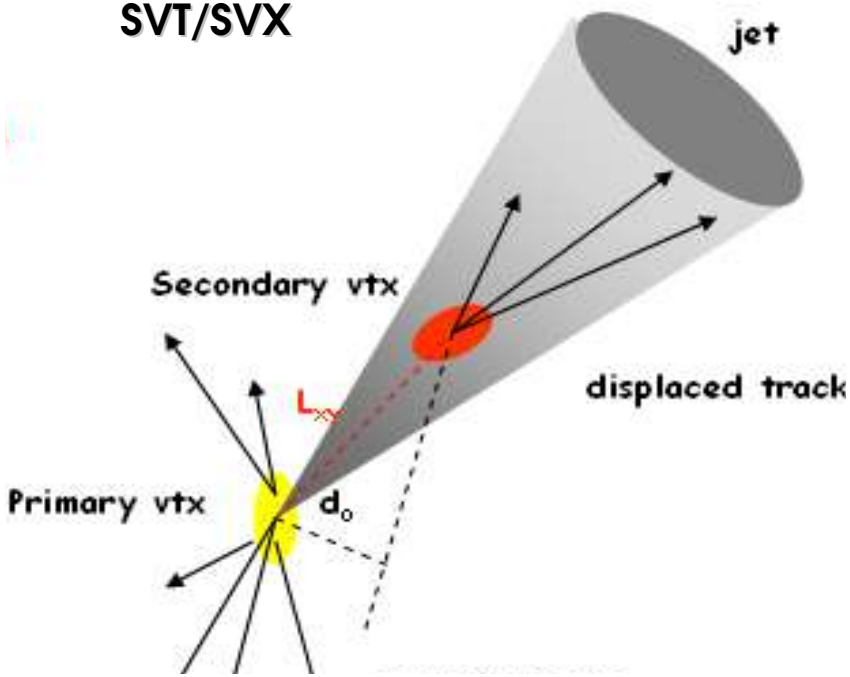
b-tagging in CDF and DØ

- b-quark lifetime $c\tau \sim 450\ \mu m$
- b-hadrons travel $L_{xy} \sim 3$ mm before decay

CSIP =
counting signed impact parameter tag



SVT/SVX

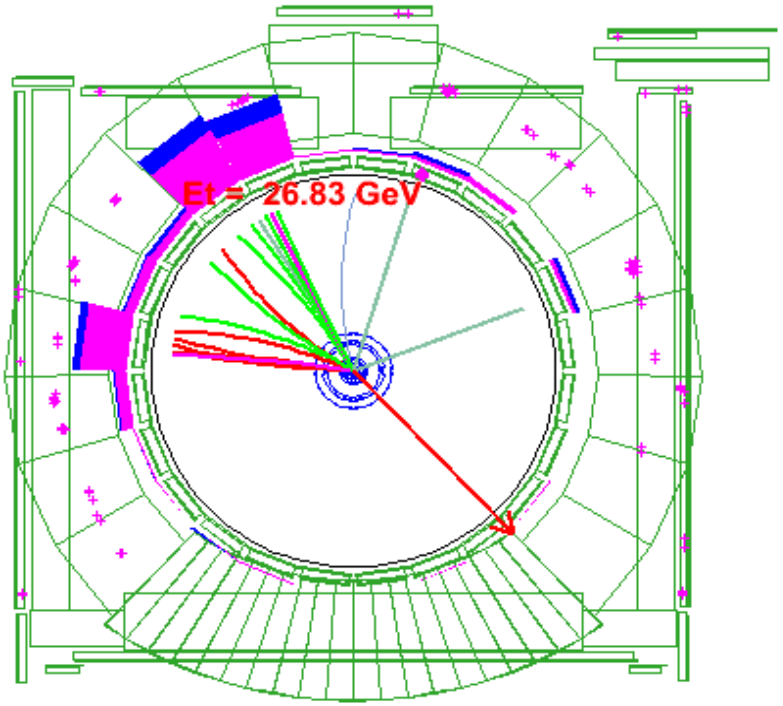


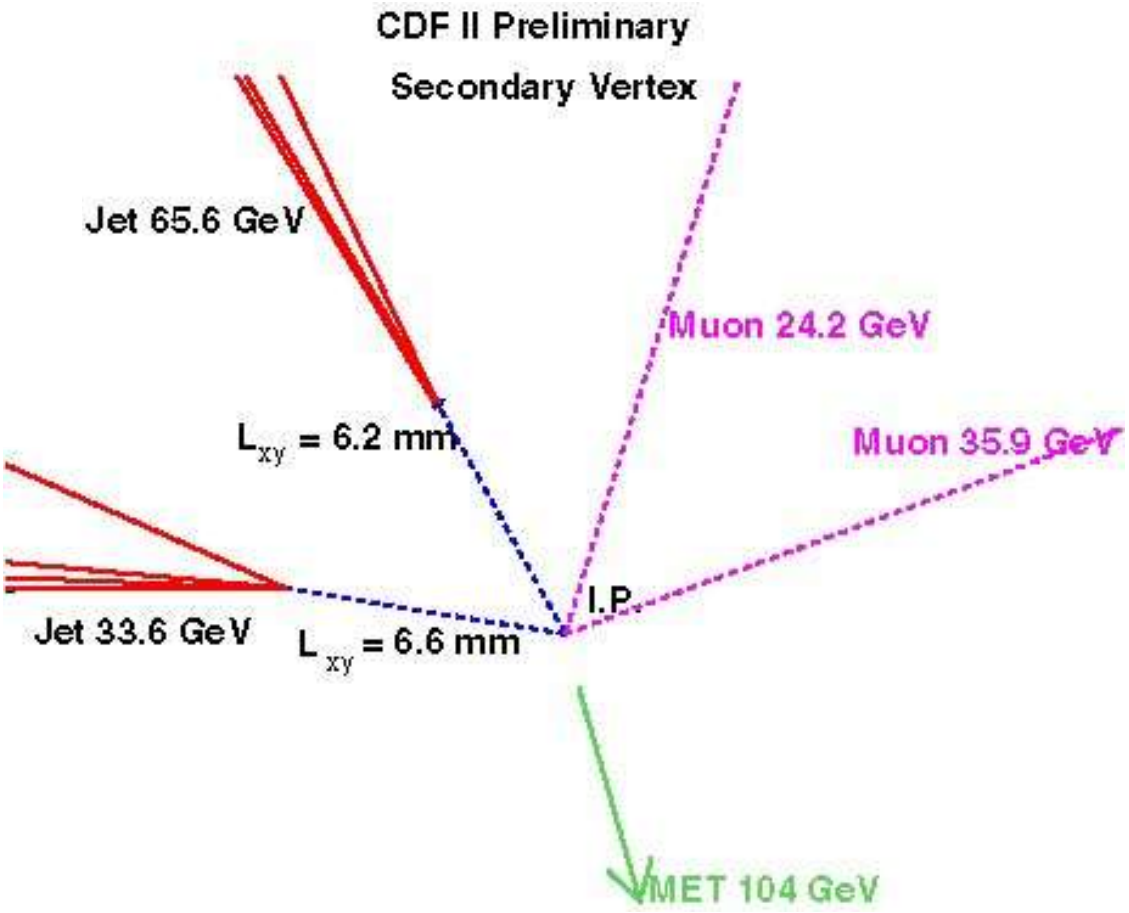
- count the number of track with large positive DCA significance σ
- jet is tagged if
  $N_{tr}(\sigma>2)>3$ or
  $N_{tr}(\sigma>3)>2$

- explicitely reconstruct 3D vertices out of track jets
- cut on decay length significance
- tagging eff. ~50%

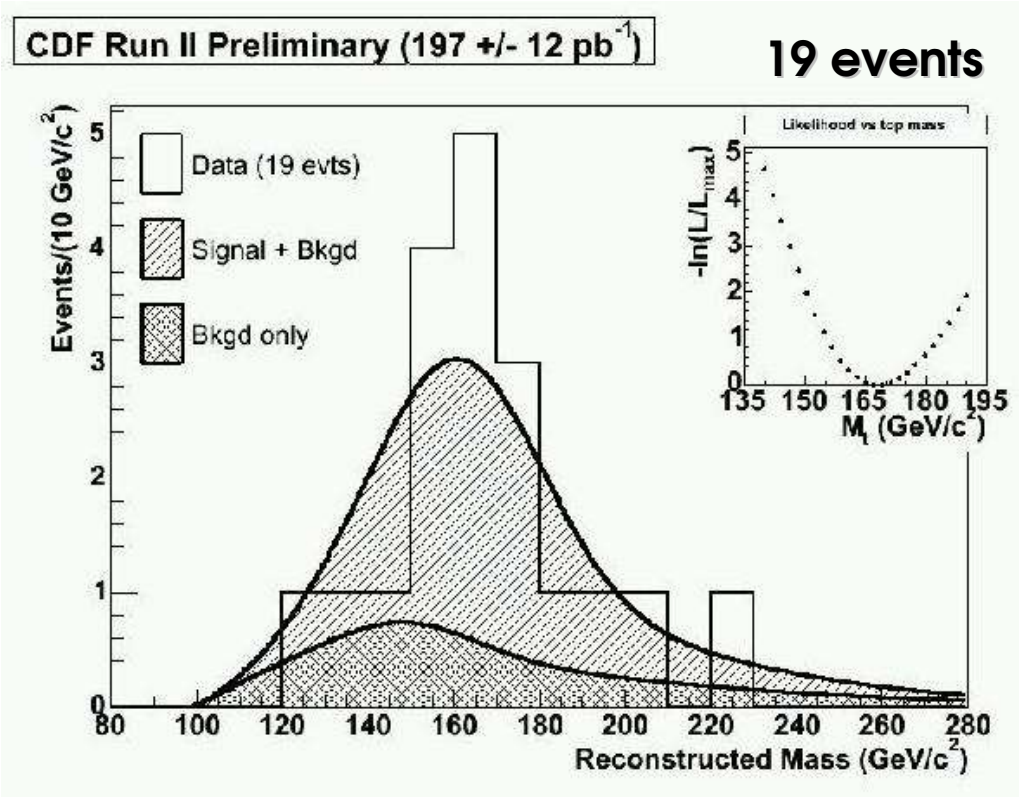
⇨ can also tag muon in jet from soft-lepton decay

Dilepton: An Example μμ-Event





CDF-II – m_{top} Dilepton from Neutrino Weighting



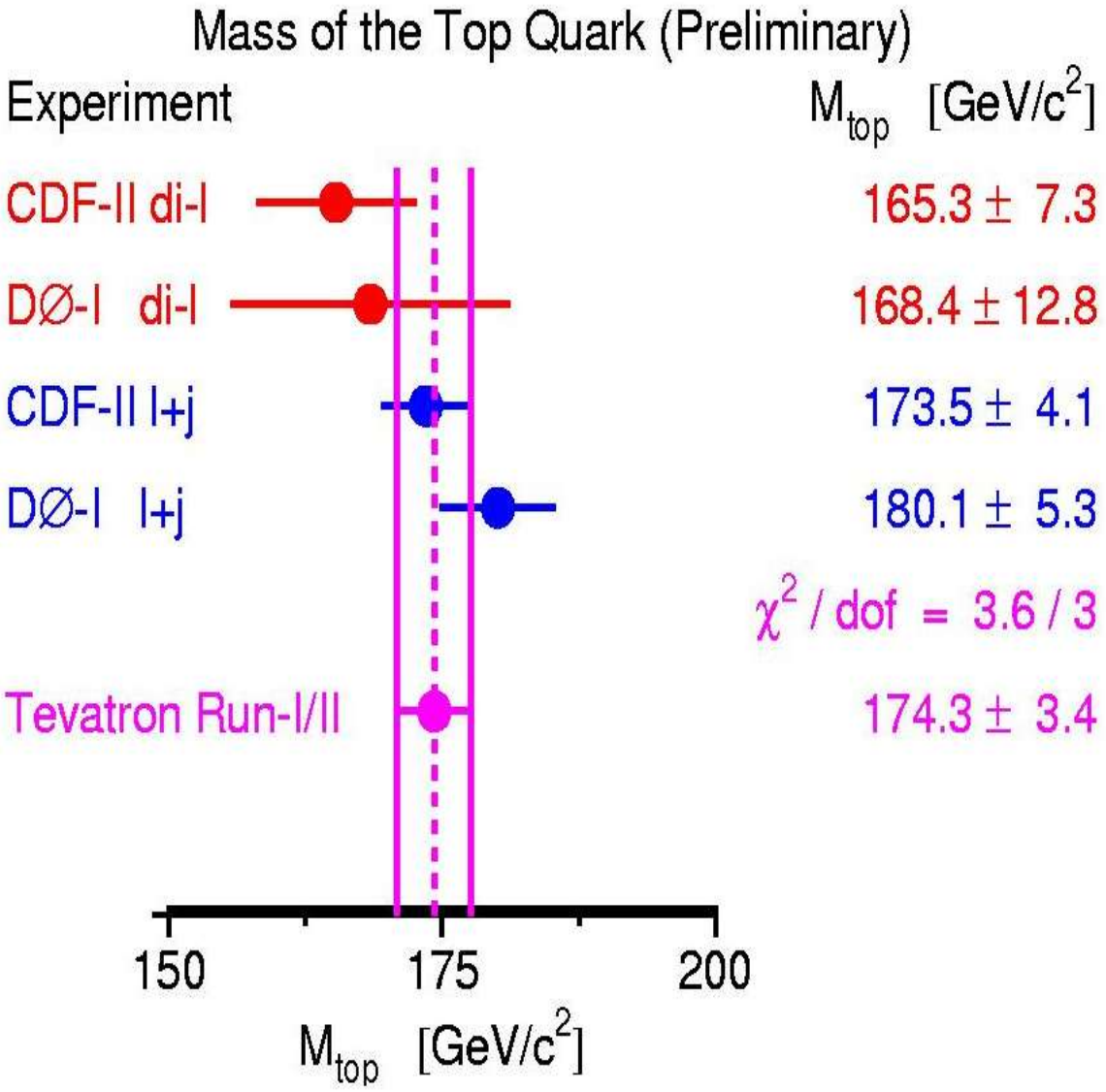
CDF II Preliminary	
Systematic	Uncertainty (GeV/c^2)
Jet energy scale	7.4
Background shape	2.8
Signal template statistics	0.3
Background template statistics	1.3
Signal Monte Carlo generators	0.6
Parton Distribution Functions	0.8
Initial State Radiation	2.5
Final State Radiation	1.3
$\not\!\!E_T$ resolution	0.3
Total	8.6

$$m_{top} = 168.1^{+11.0}_{-9.8} \pm 8.6\, GeV/c^2$$

... other methods based on kinematic templates or MINUIT fitter ...

World Average m_{top}

hep-ph/0507006



new world average

(TeV EW/TOP working group, July-1 '05):

174.3 ± 3.4 GeV/c^2