顶夸克和新物理

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（1）粒子物理的标准模型
（2）寻找顶夸克：漫长的旅程
（3）顶夸克和超出标准模型之外的新物理

部分借用袁简鹏老师报告

千年之问：
"世界基本组成成分为何？"
和
"它们如何相互作用？"

基本粒子物理
或
高能物理

研究自然界的
基本相互作用（力）

自然界中四种力

1 重力

牛顿

2 电磁

法拉第

3 弱相互作用

Beta 衰变
Muon 衰变

时间尺度: $10^{-12} \sim 10^{3}$ 秒

4 强相互作用

将核子仅仅结合起来
粒子对撞

时间尺度: 10^{-23} 秒

轻子

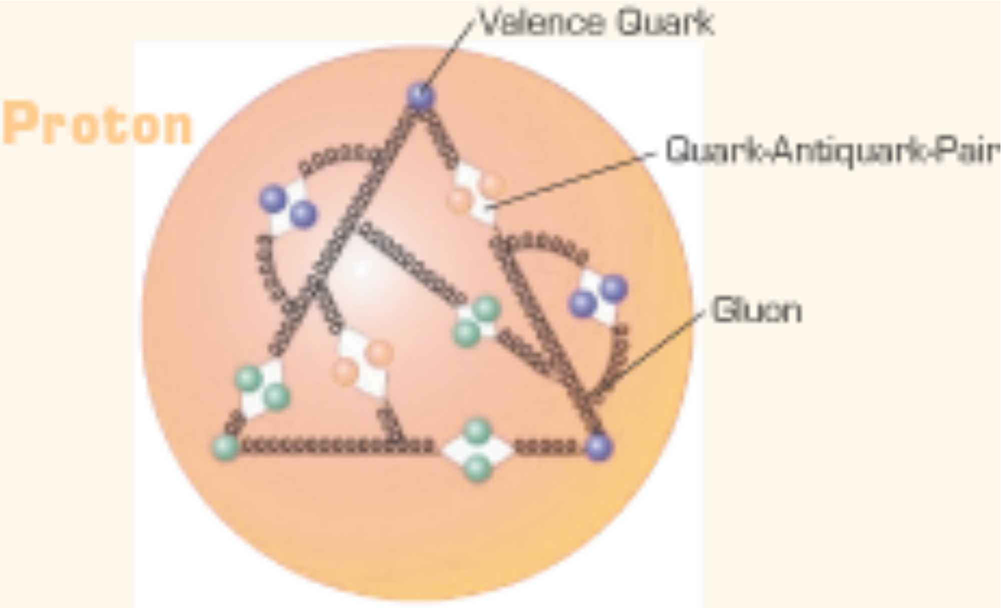
- 不参与强相互作用
- 整数或零电荷
- 味:

e^-	“电子”	(1897)	在原子中
μ^-	“Muon” (206 m_e)	(1937)	在宇宙射线中首次观测到
τ^-	“Tau” (17 m_μ)	(1975)	在SLAC观测到 (Stanford Linear Accelerator Center)
ν_e	“electron 中微子”	(1956)	
	泡利以之解释Beta衰变中能动量不守恒 (1930)		
ν_μ	“Muon 中微子”	(1962)	
ν_τ	“Tau 中微子”	(2000)	

夸克

- 参与强相互作用
- 带分数电荷

$$Q = \begin{Bmatrix} 2/3 \\ -1/3 \end{Bmatrix} \times \text{Proton charge}$$



- 质子和中子的组成成分

(udd) (uud)

$$\begin{pmatrix} \text{u} \\ \text{d} \end{pmatrix}$$

“up”
“down”

- 第一次实验证据:

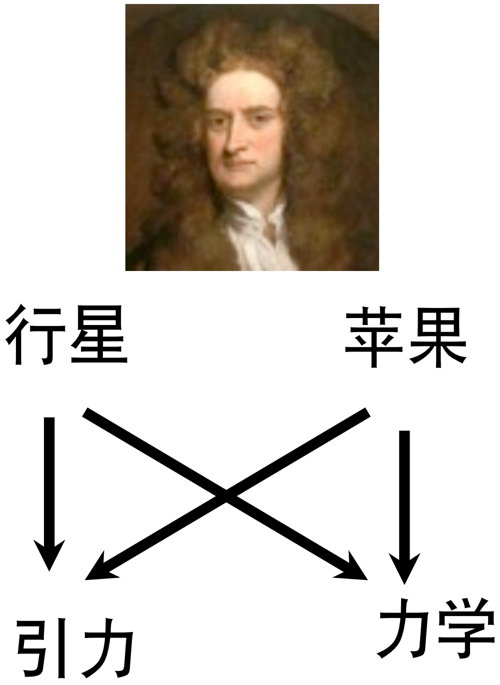
Stanford Linear Accelerator Center
(Giant Electron Microscope)

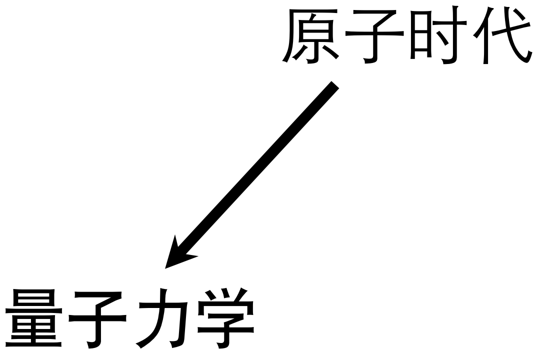
- 味:

u	“up”		
d	“down”		
s	“strange”		
c	“charmed”	(1974)	
b	“bottom”	(1977)	“Beauty”
t	“top”	1995	“Truth”

@ Fermilab (Tevatron)

统一之路



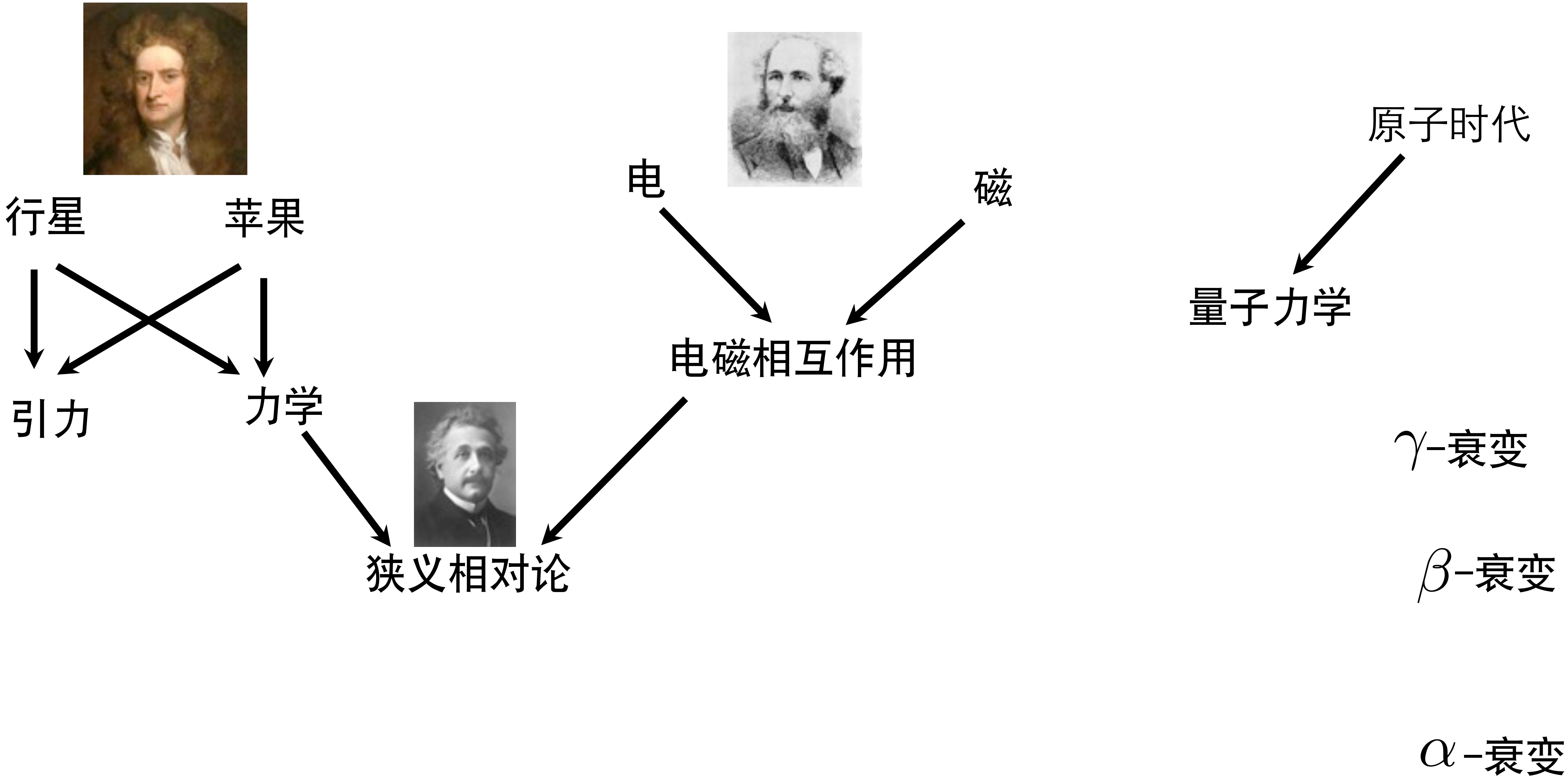


γ-衰变

β-衰变

α-衰变

统一之路



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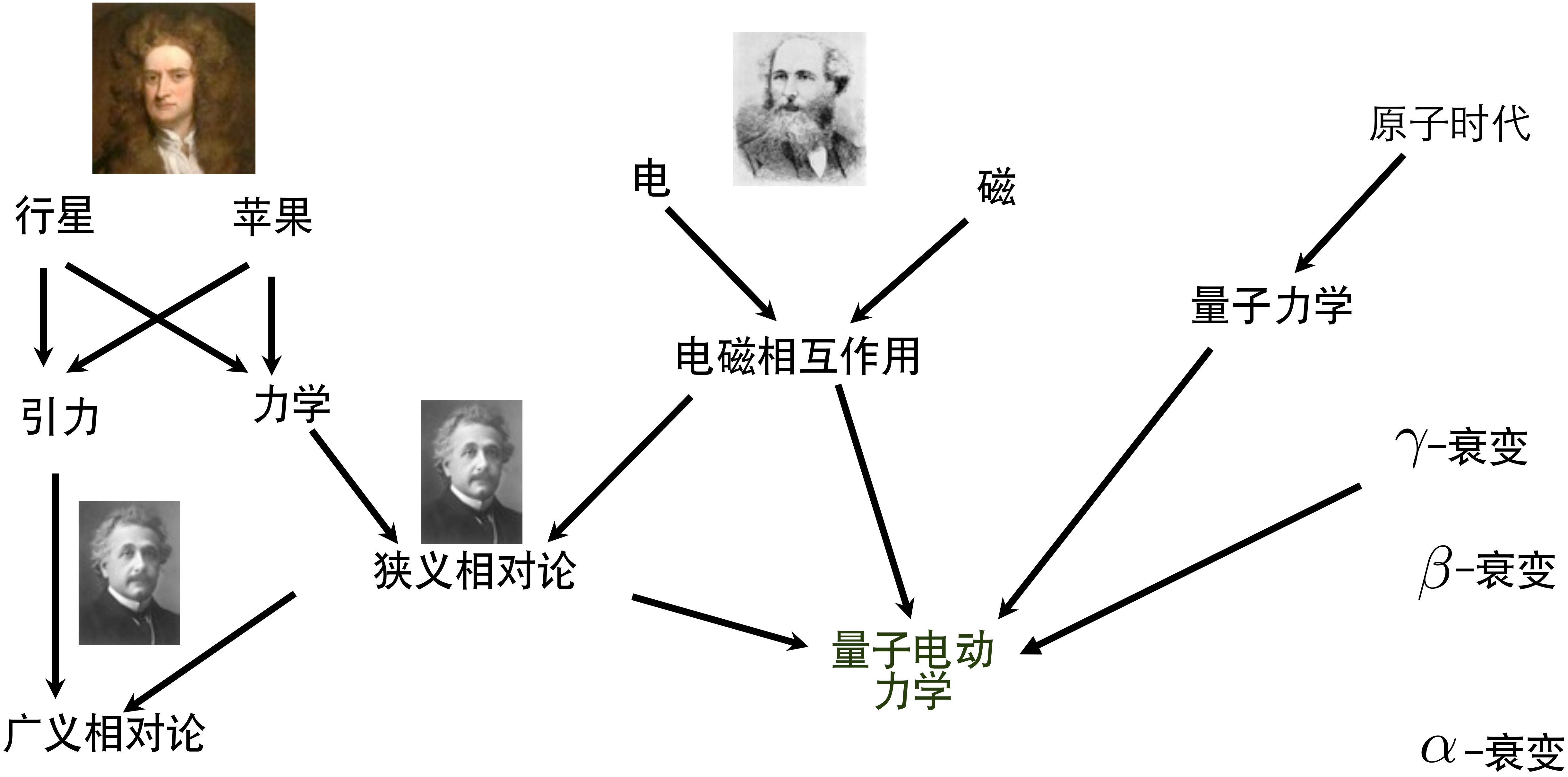

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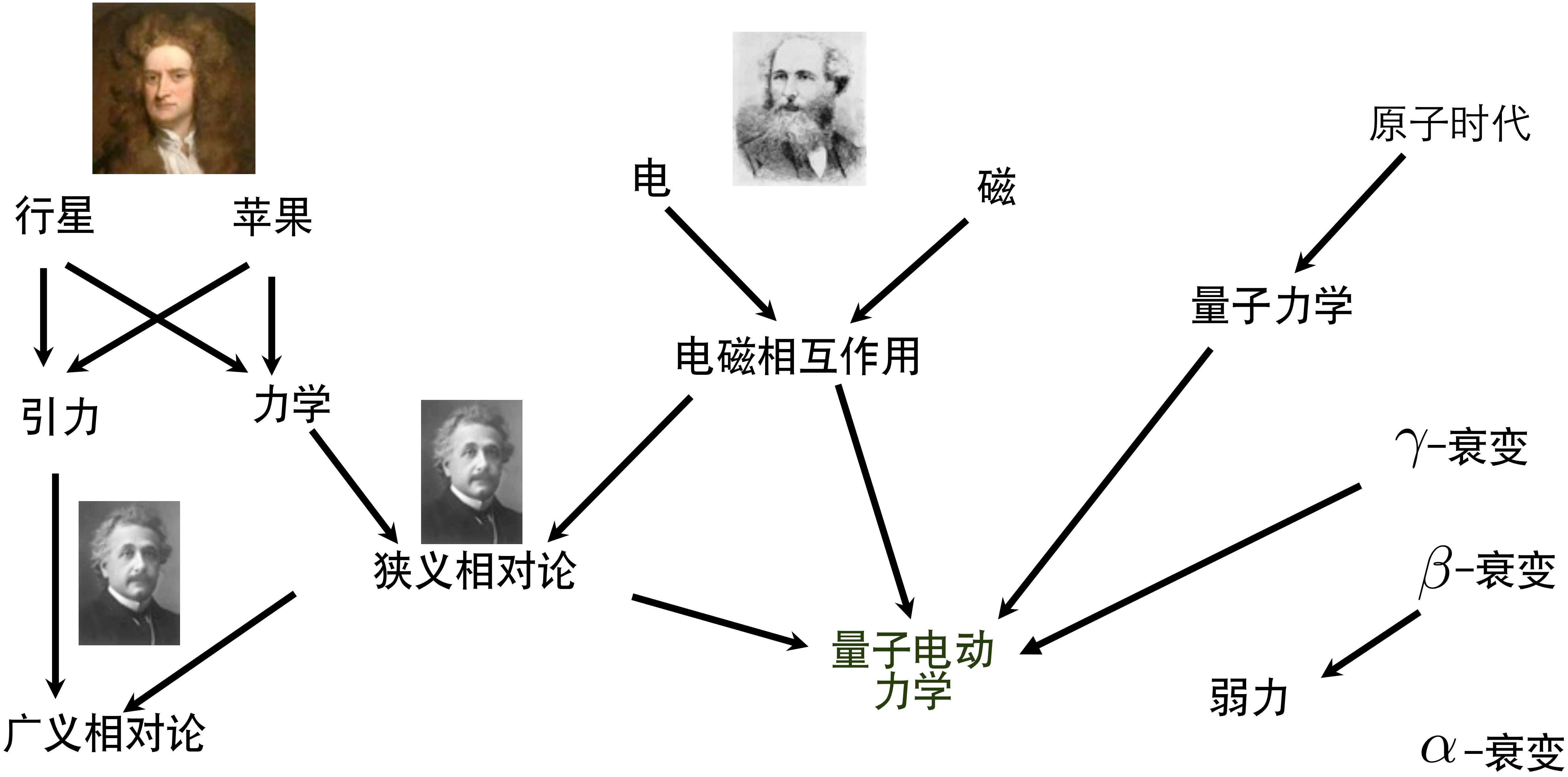

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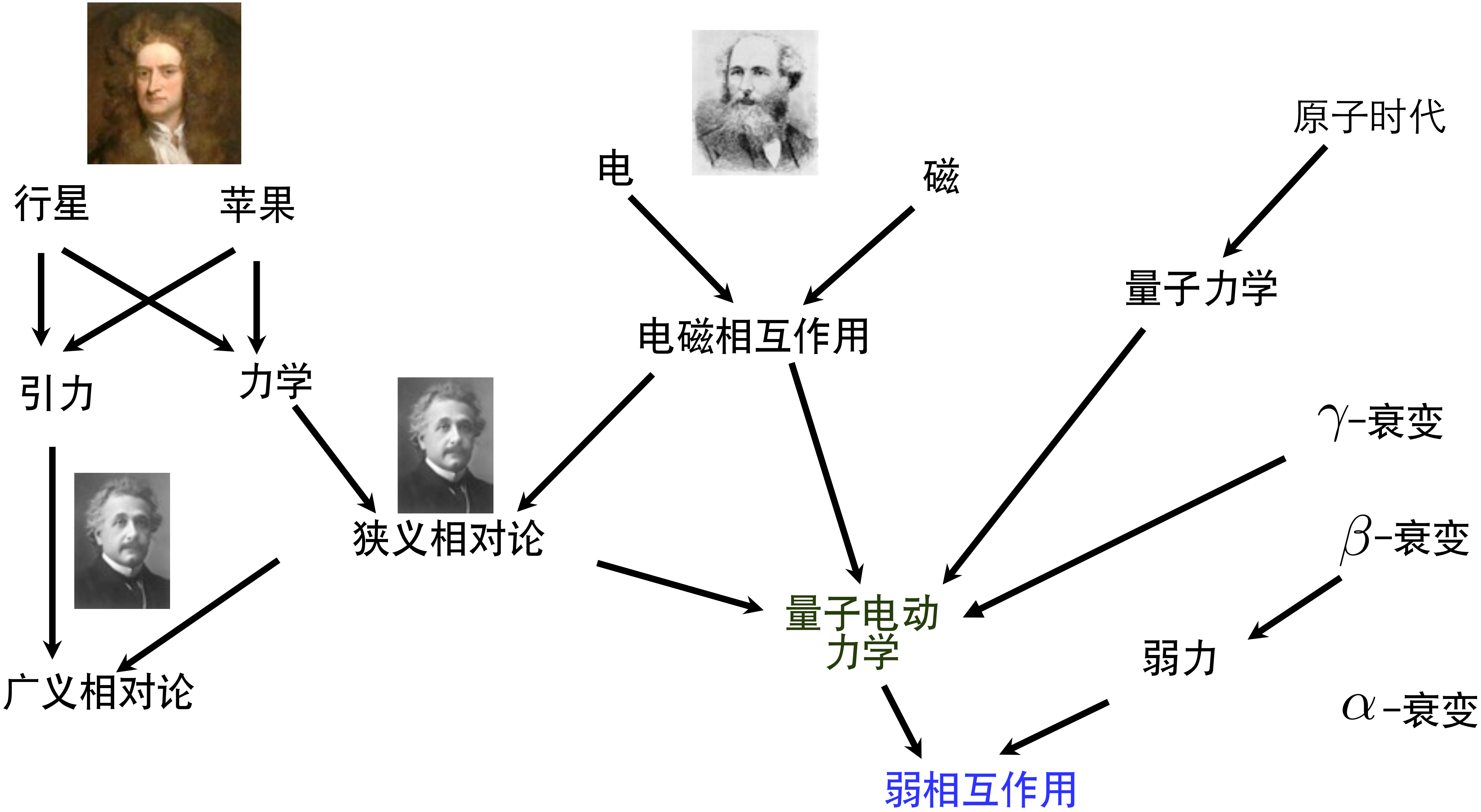

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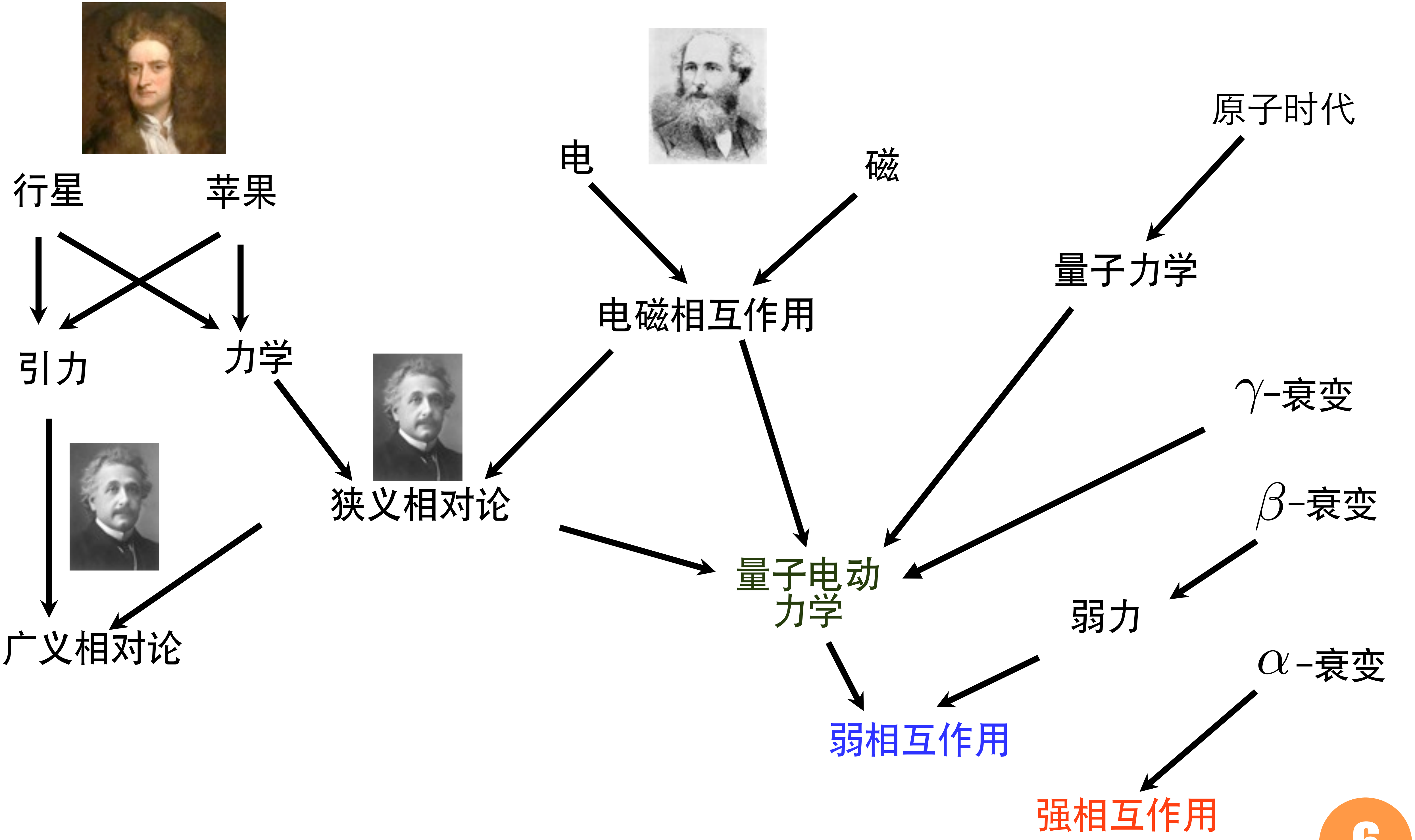

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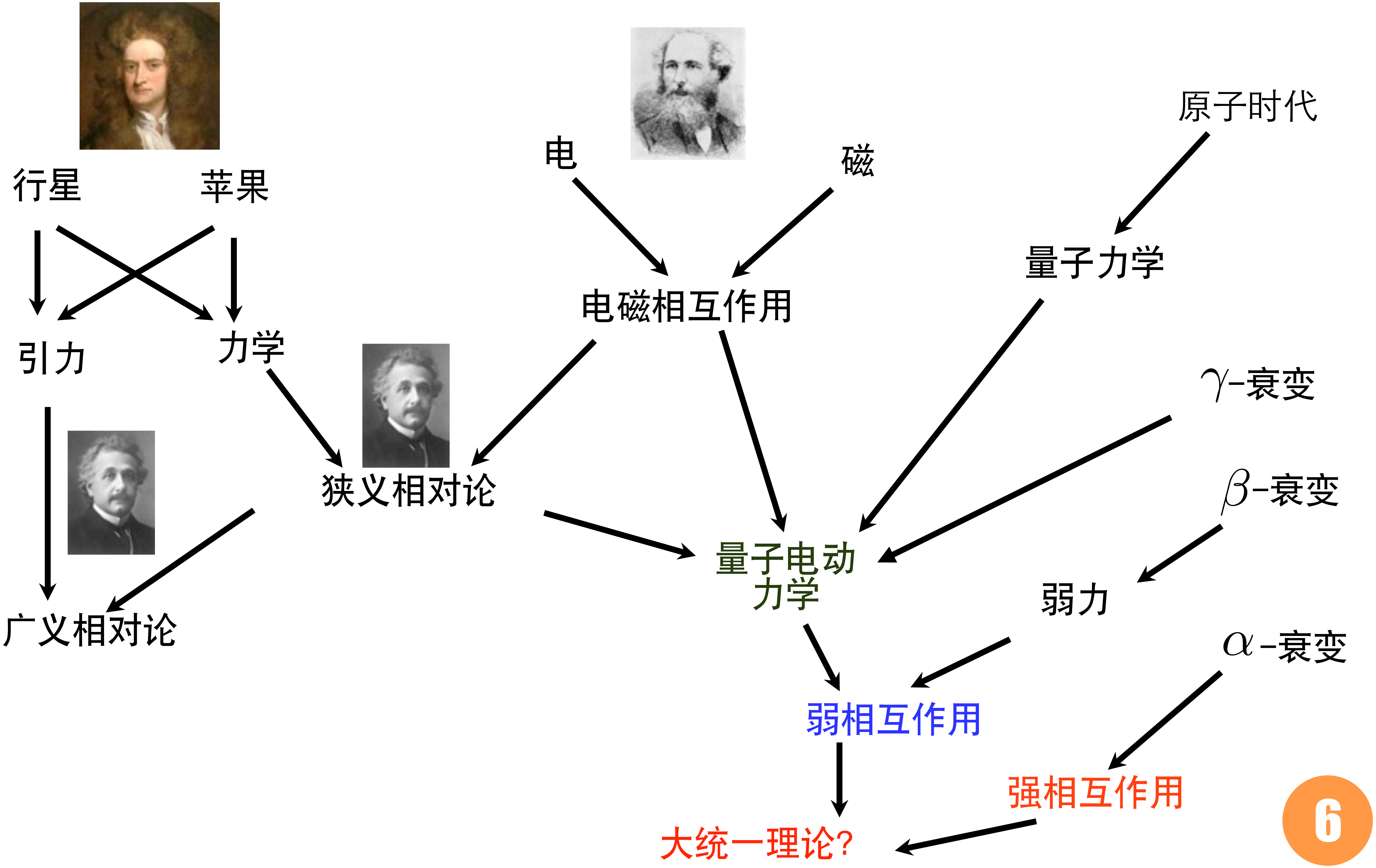

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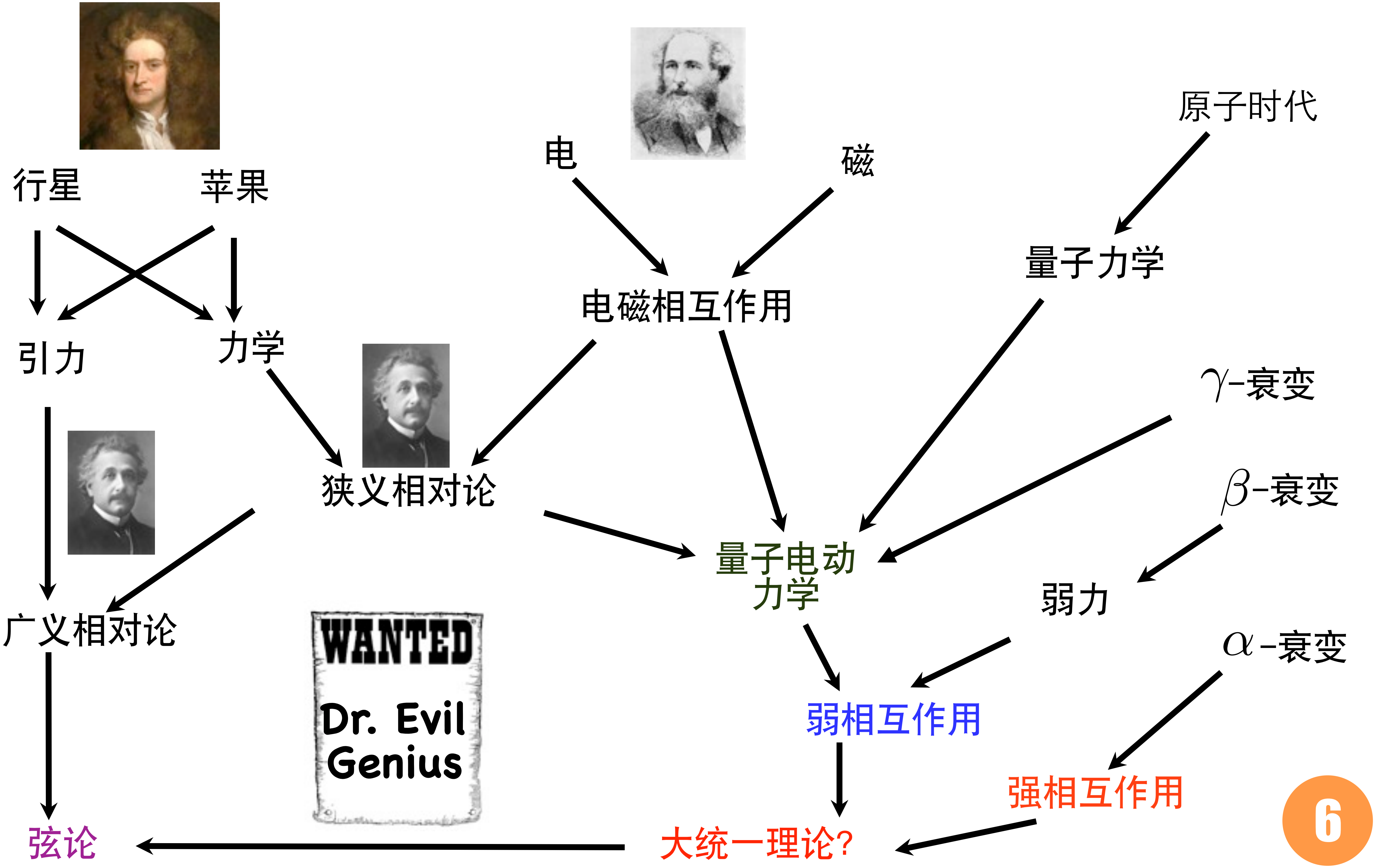
大统一理论?

统一之路



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强相互作用

大统一理论?

WANTED

Dr. Evil Genius

如何实现统一：对称性

1）不可观测

无法观测的物理量

绝对位置 $\vec{p}$

绝对时间 E

绝对方位 $\vec{L} = \vec{r} \times \vec{p}$

绝对左右 P

绝对未来 T

绝对电荷 C

2）无法区分

一个物体变换为另一个物体

整体对称性：同位旋

时空对称性

⟶ 等价性

⟶ 完美但却无聊的世界

如何实现统一：对称性

1）不可观测

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整体对称性：同位旋

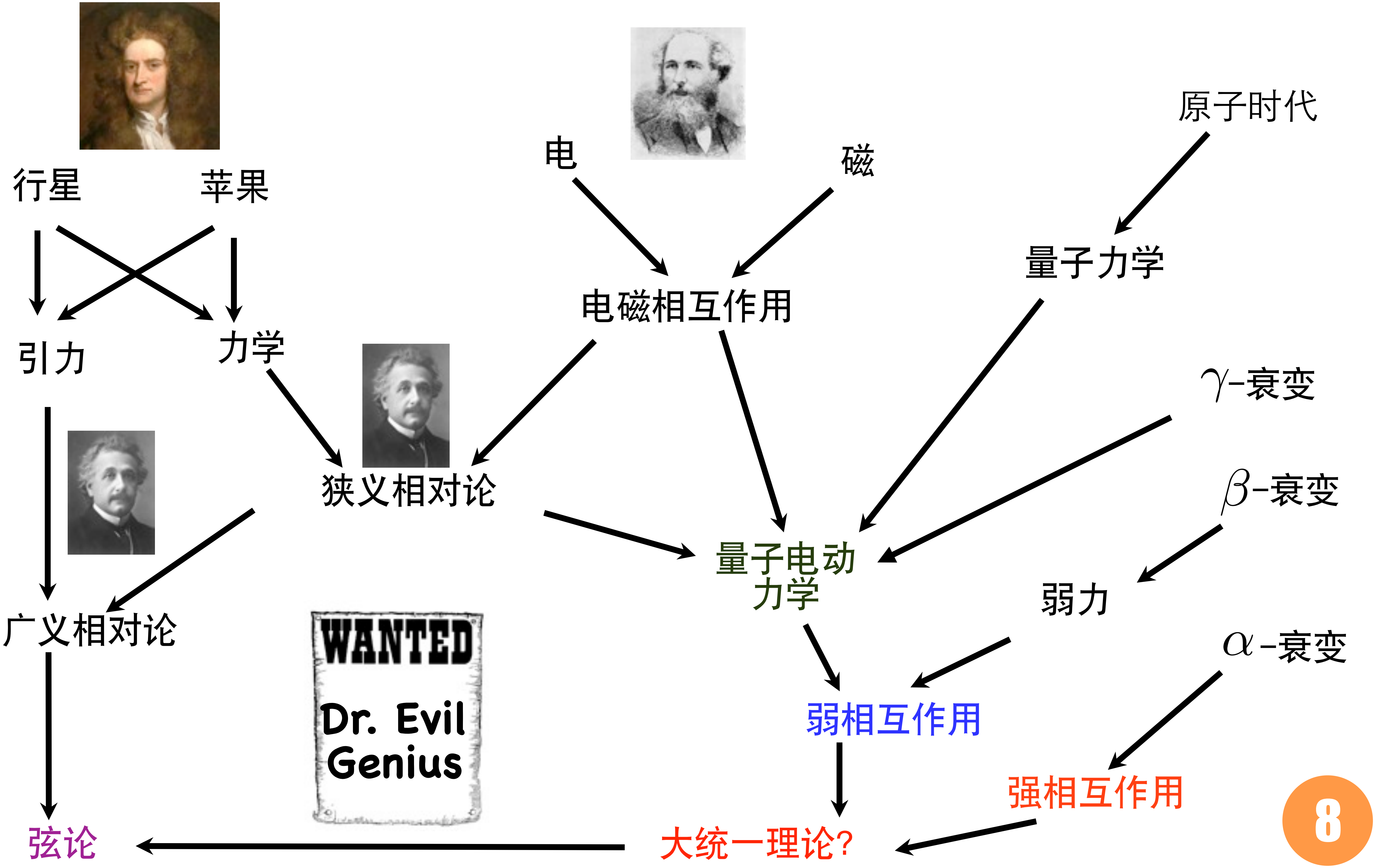
时空对称性

→ 等价性

→ 完美但却无聊的世界

在微观世界中，
等价的相互作用，力的载体为无质量的粒子

统一之路和对称性破缺



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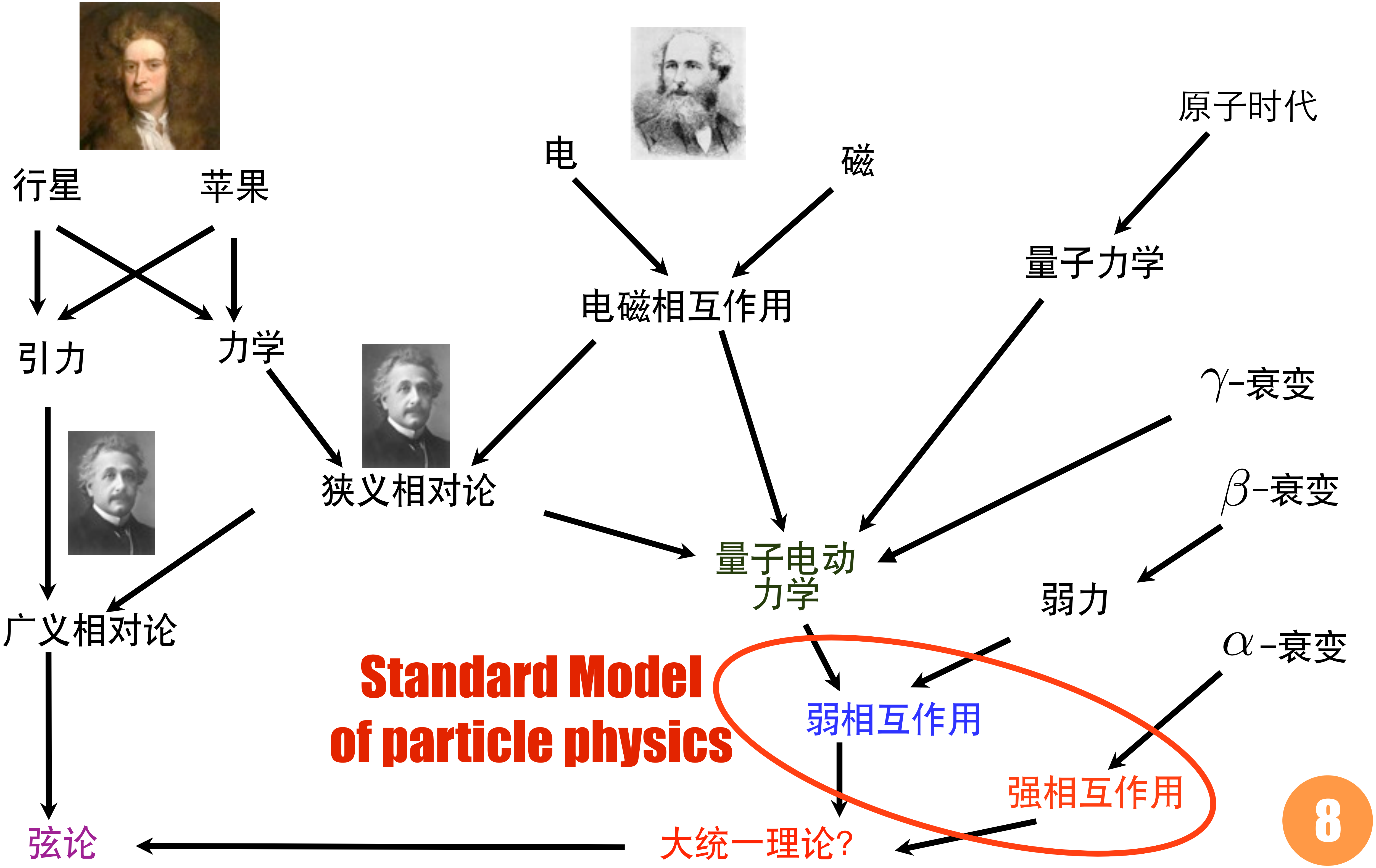

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Standard Model of particle physics

弱相互作用

强相互作用

弦论

大统一理论?

粒子物理的标准模型

❖ 规范对称性

$$\underbrace{SU(3)_{\text{Color}}}_{\text{QCD}} \otimes \underbrace{SU(2)_{\text{Left}} \otimes U(1)_{\text{Hyper charge}}}_{\text{WEAK} \oplus \text{QED}}$$

(Strong Interaction)

(Unification of Weak and Electromagnetic)

对称性自发破缺
（希格斯机制）

$$\Big\downarrow$$

$U(1)_{\text{E.M.}}$

量子电动力学
（电磁相互作用）

粒子物理的标准模型

物质场:

- 费米子 (自旋1/2)

轻子

(无强相互作用)

$$\begin{pmatrix}\nu_e\\ e^-\end{pmatrix}_L$$

$$e^-_R$$

夸克

(q)

$$\begin{pmatrix}u\\ d\end{pmatrix}_L \quad \begin{pmatrix}u\\ d\end{pmatrix}_L \quad \begin{pmatrix}u\\ d\end{pmatrix}_L$$

$$u_R \quad u_R \quad u_R$$

$$d_R \quad d_R \quad d_R$$

粒子物理的标准模型

- **物质场:**
  - 费米子 (自旋1/2)

轻子

(无强相互作用)

$$\begin{pmatrix}\nu_e\\ e^-\end{pmatrix}_L \qquad \begin{pmatrix}\nu_\mu\\ \mu^-\end{pmatrix}_L \qquad \begin{pmatrix}\nu_\tau\\ \tau^-\end{pmatrix}_L$$

$$e^-_R \qquad \mu^-_R \qquad \tau^-_R$$

夸克

(q)

$$\begin{pmatrix}u\\ d\end{pmatrix}_L \begin{pmatrix}u\\ d\end{pmatrix}_L \begin{pmatrix}u\\ d\end{pmatrix}_L \qquad \begin{pmatrix}c\\ s\end{pmatrix}_L \begin{pmatrix}c\\ s\end{pmatrix}_L \begin{pmatrix}c\\ s\end{pmatrix}_L \qquad \begin{pmatrix}t\\ b\end{pmatrix}_L \begin{pmatrix}t\\ b\end{pmatrix}_L \begin{pmatrix}t\\ b\end{pmatrix}_L$$

$$u_R \quad u_R \quad u_R \qquad c_R \quad c_R \quad c_R \qquad t_R \quad t_R \quad t_R$$

$$\underbrace{d_R \quad d_R \quad d_R \qquad s_R \quad s_R \quad s_R \qquad b_R \quad b_R \quad b_R}_{3代}$$

粒子物理的标准模型

❖ 物质场:

- 费米子 (自旋1/2)

轻子

(无强相互作用)

$$\begin{pmatrix}\nu_e\\ e^-\end{pmatrix}_L \qquad \begin{pmatrix}\nu_\mu\\ \mu^-\end{pmatrix}_L \qquad \begin{pmatrix}\nu_\tau\\ \tau^-\end{pmatrix}_L$$

$$e^-_R \qquad \mu^-_R \qquad \tau^-_R$$

夸克

(q)

$$\begin{pmatrix}u\\ d\end{pmatrix}_L \begin{pmatrix}u\\ d\end{pmatrix}_L \begin{pmatrix}u\\ d\end{pmatrix}_L \qquad \begin{pmatrix}c\\ s\end{pmatrix}_L \begin{pmatrix}c\\ s\end{pmatrix}_L \begin{pmatrix}c\\ s\end{pmatrix}_L \qquad \begin{pmatrix}t\\ b\end{pmatrix}_L \begin{pmatrix}t\\ b\end{pmatrix}_L \begin{pmatrix}t\\ b\end{pmatrix}_L$$

$$u_R \; u_R \; u_R \qquad c_R \; c_R \; c_R \qquad t_R \; t_R \; t_R$$

$$\underbrace{d_R \; d_R \; d_R \qquad s_R \; s_R \; s_R \qquad b_R \; b_R \; b_R}_{3代}$$

- 标量场 (自旋为0)

希格斯波色子： 唯一知道不同代的粒子间不同之处的粒子

(希格斯机制 —— 对称性自发破缺)

(2012年7月24日在CERN发现)

粒子物理的标准模型

❖ **相互作用（通过交换自旋为1的规范玻色子）**

1) 电磁相互作用 (QED)

光子 (无质量)

2) 强相互作用 (QCD)

胶子 (无质量) (1979)

3) 弱相互作用

$W^{\pm}$ 和 Z 规范玻色子 (1983)

(有质量 $M_W = 80.4\ \text{GeV}$

$M_Z = 91.187\ \text{GeV}$ $1\ \text{GeV} = 10^9\ \text{eV}$)

标准模型中，规范玻色子（$W^{\pm}$ 或 Z）的质量起源于希格斯机制

⇨ 探测戈德斯通玻色子的相互作用

⇨ 探测纵向极化的W波色子的相互作用

标准模型是如何做理论预言的?

◆ 量子力学

薛定谔方程:

$$i\frac{\partial\Psi}{\partial t}=H\Psi$$

1. 找出描述系统的哈密顿量 H

2. 将H代入薛定谔方程

3. 做理论就算

标准模型是如何做理论预言的?

◆ 量子力学

薛定谔方程:

$$i\frac{\partial \Psi}{\partial t} = H\Psi$$

1. 找出描述系统的哈密顿量 *H*
2. 将*H*代入薛定谔方程
3. 做理论就算

◆ 相对论性量子场论

标准模型给出描述相互作用的拉格朗日量$\mathcal{L}$

$\mathcal{L}$

⇓

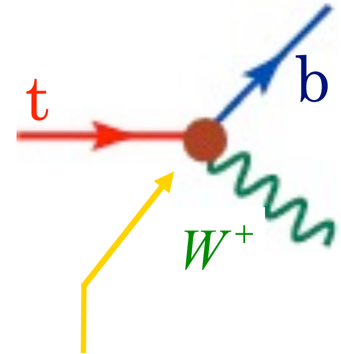
费曼规则
费曼图

⇓

S-矩阵元

⇓

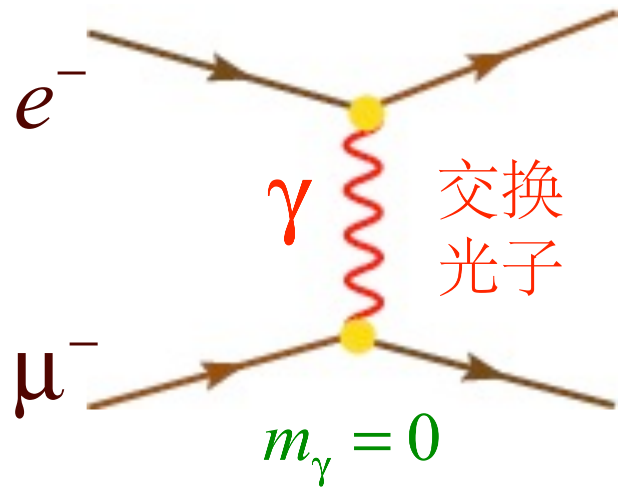
理论预言



Vertex; coupling

弱电相互作用统一

电磁相互作用（QED）



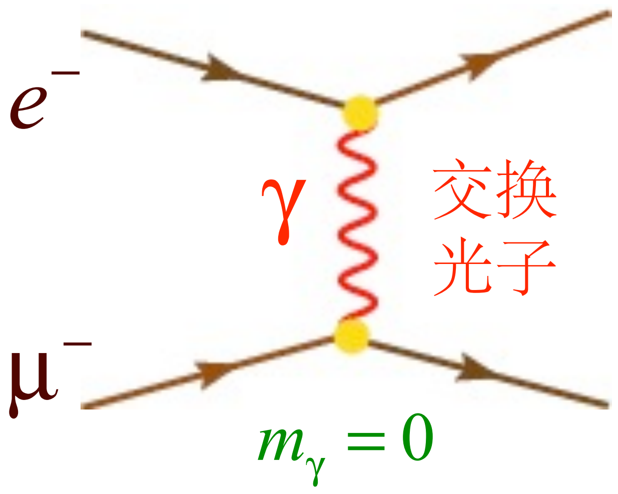
Beta 衰变（Weak）

费米理论
（四费米子模型）

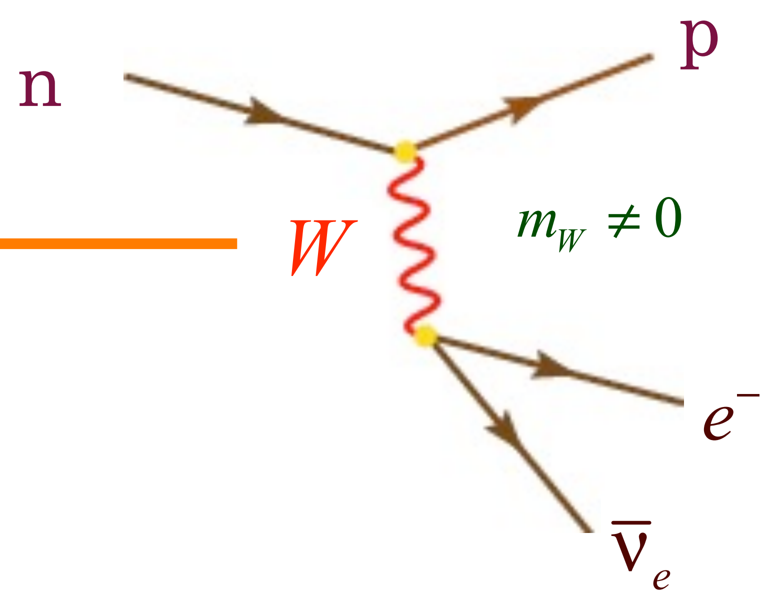
（理论不自洽, 在高能散射极限下破坏幺正性.）

弱电相互作用统一

电磁相互作用 (QED)



Beta 衰变 (Weak)



高能区的自洽理论，
微扰论也适用

代价：

1) $W^\pm$ 必须存在 1983
2) 最简单模型还要求有质量的电中性的 Z^0 1983

全新的弱荷守恒的相互作用理论 1973

⟹ $SU(2)\times U(1)$

标准模型的希格斯机制

电弱理论的两个疑难:

- 电弱对称性破缺的起源　　$(M_W = 80\ \mathrm{GeV},\ M_Z = 91\ \mathrm{GeV})$
- 味对称性破缺的起源　　(夸克和轻子质量差异悬殊)

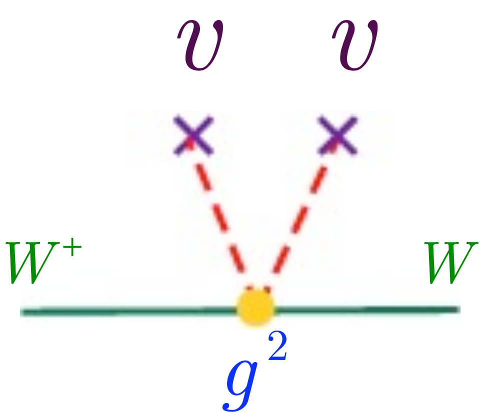
在标准模型中，这两种对称性破缺是通过引入一个基本的标量场（希格斯玻色子）来实现：

$$\Phi = \frac{1}{\sqrt{2}}\begin{pmatrix} \phi_1 + i\phi_2 \\ \phi_3 + i\phi_4 \end{pmatrix}$$

- 产生 M_W 和 M_Z

$$\mathcal{L}_\Phi = \left(D_\mu \Phi\right)^\dagger \left(D^\mu \Phi\right) - \mu^2 \Phi^\dagger \Phi + \lambda \left(\Phi^\dagger \Phi\right)^2$$

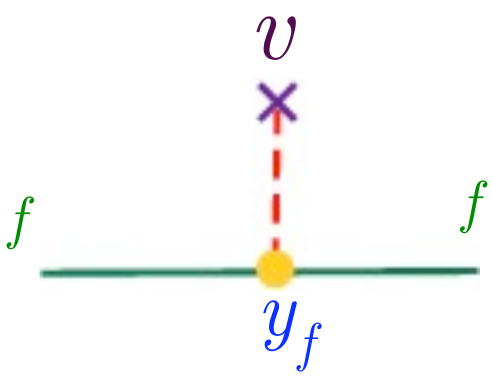
$$\langle \Phi \rangle_{\min} = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v \end{pmatrix}$$



$$\Rightarrow \quad M_W = \frac{1}{2} g v$$

- 产生 m_f

$$y_f \overline{F}_L \Phi f_R + h.c.$$



$$\Rightarrow \quad m_f = y_f \frac{v}{\sqrt{2}}$$

标准模型的自由参数

$SU(3)_{\text{color}} \times SU(2)_{\text{Left}} \times U(1)_{\text{Hypercharge}}$

g_3, g_2, g_1
λ, μ

$$\left\{ \begin{array}{l} \alpha_S, \alpha_{\text{em}}, \theta_{\text{Weak mixing}} \\ V\text{(vacuum expectation value)} \\ m_H\text{(Higgs Boson mass)} \end{array} \right\}$$

This set can be traded by

$\alpha_S, \alpha_{\text{em}}, G_F, m_Z, m_H$

(3) 轻子质量

(e, μ, τ) m_ν's=0

(6) 夸克质量

(u, d, s, c, b, t)

夸克的弱相互作用本征态和质量本征态之间的混合 → 3个混合角和1个相位

CP破坏

(1) 强CP相位

→ 总共19个自由参数。
迄今为止，所有物理实验数据都和标准模型预言相符。

To include neutrino masses (suggested by Neutrino Oscillation data) in the SM

- For Dirac Neutrinos
- For Majorana Neutrinos

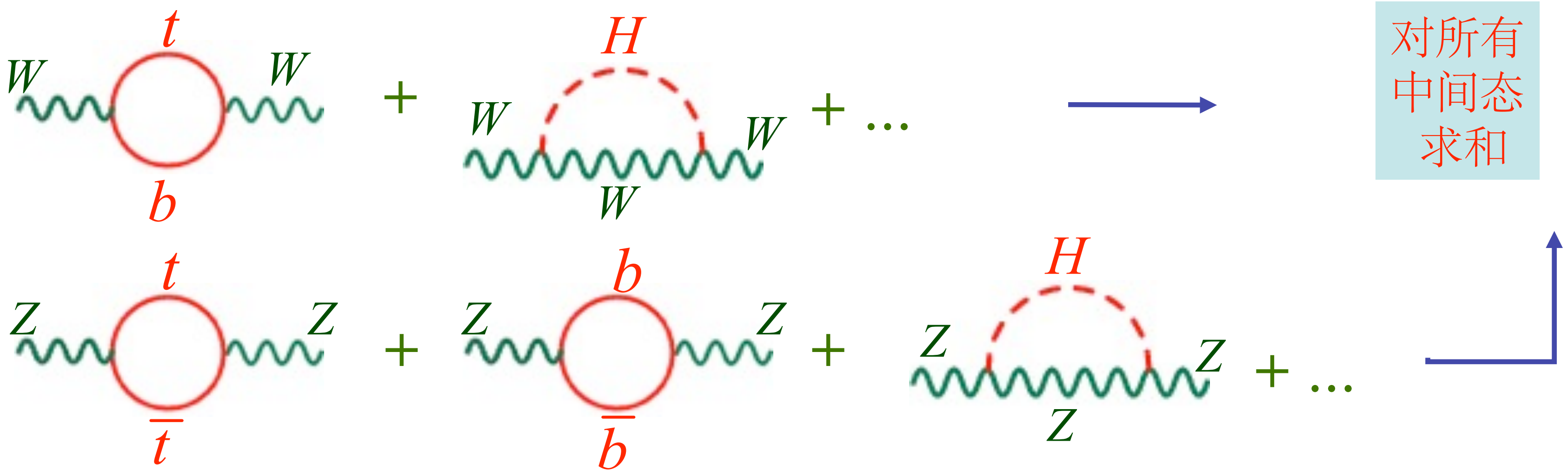
→ Add 3 masses and
3 mixing angles with
1 CP violation phase

→ Add 3 masses and
3 mixing angles with
3 CP violation phase

圈图量子辐射修正示例

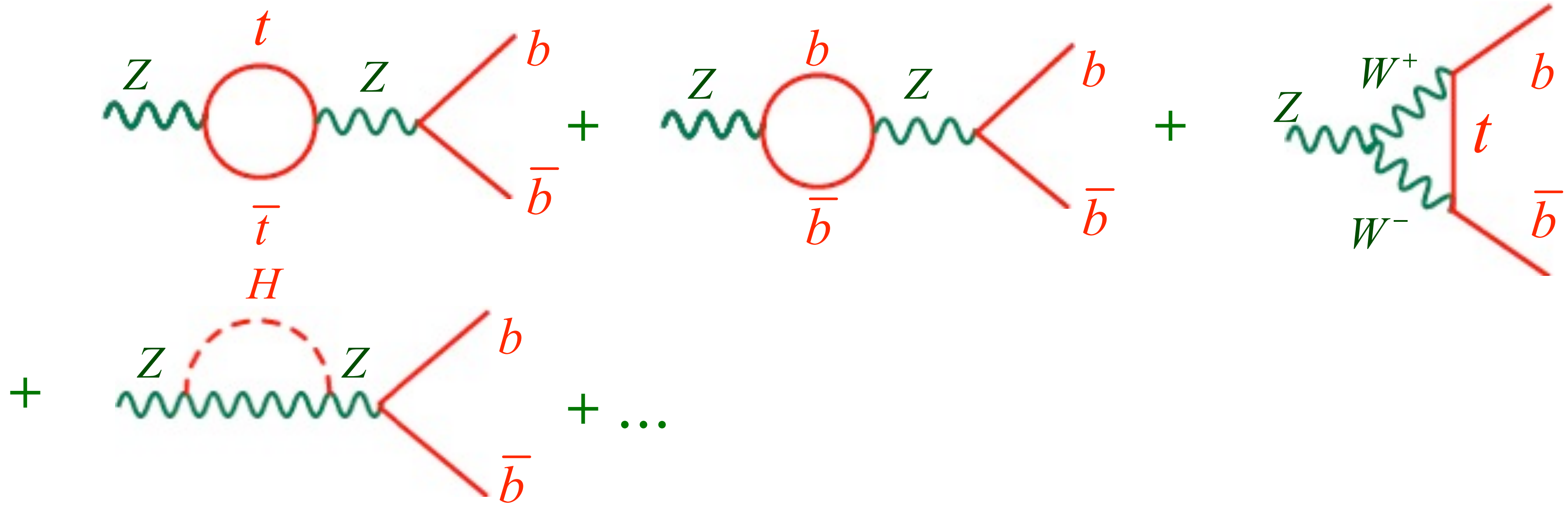
1) $m_W \sim$

$m_Z \sim$

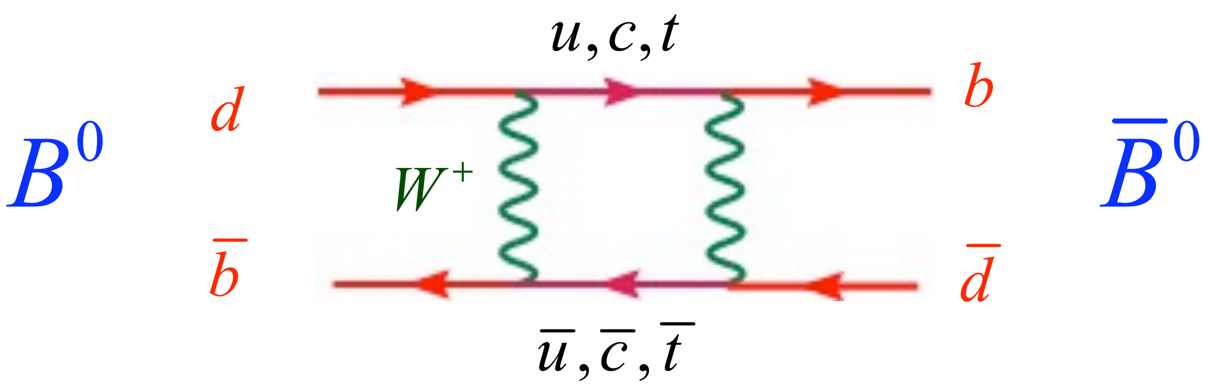


对所有中间态求和

2) $\Gamma_{Z\to b\bar{b}} \sim$



3) $B_d - \bar{B}_d$ 混合



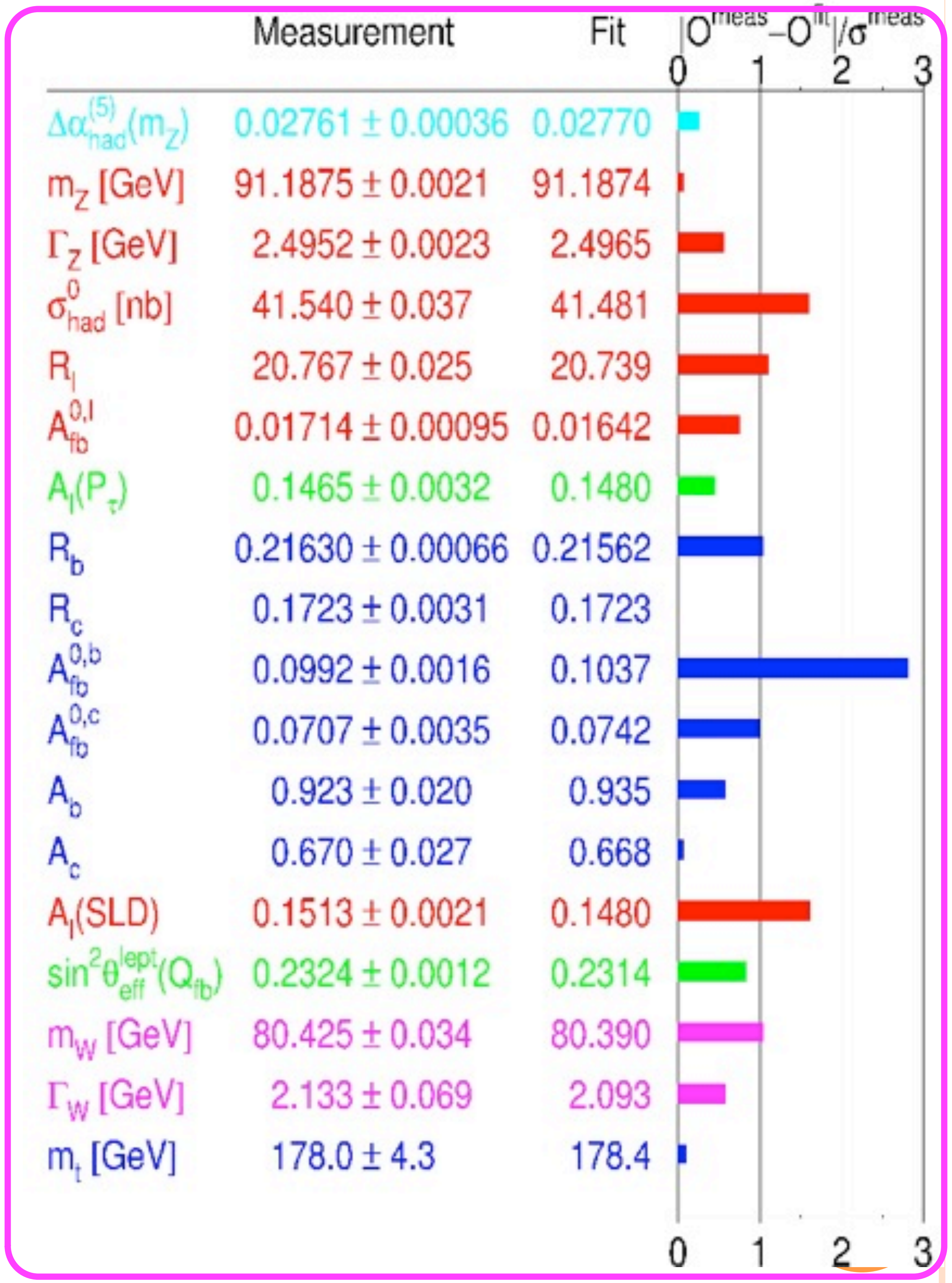
标准模型的精确测量

研究可以精确观测的诸电弱物理量，
对比理论预言和具体的实验测量值

- 标准模型的电弱部分已经在
  量子辐射级别上被检验

- 标准模型的自洽性通过比较
  直接的观测物理量
  和
  各个理论输入参数来获得

- 可以限制超出标准模型之外的新物理模型的参数空间.



	Measurement	Fit
$\Delta\alpha_{had}^{(5)}(m_Z)$	0.02761 ± 0.00036	0.02770
m_Z [GeV]	91.1875 ± 0.0021	91.1874
Γ_Z [GeV]	2.4952 ± 0.0023	2.4965
σ_{had}^0 [nb]	41.540 ± 0.037	41.481
R_l	20.767 ± 0.025	20.739
$A_{fb}^{0,l}$	0.01714 ± 0.00095	0.01642
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1480
R_b	0.21630 ± 0.00066	0.21562
R_c	0.1723 ± 0.0031	0.1723
$A_{fb}^{0,b}$	0.0992 ± 0.0016	0.1037
$A_{fb}^{0,c}$	0.0707 ± 0.0035	0.0742
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1480
$\sin^2\theta_{eff}^{lept}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.425 ± 0.034	80.390
Γ_W [GeV]	2.133 ± 0.069	2.093
m_t [GeV]	178.0 ± 4.3	178.4

寻找顶夸克

一段漫长的旅程

1977年：顶夸克是存在的！

（从底夸克的实验数据推断出）

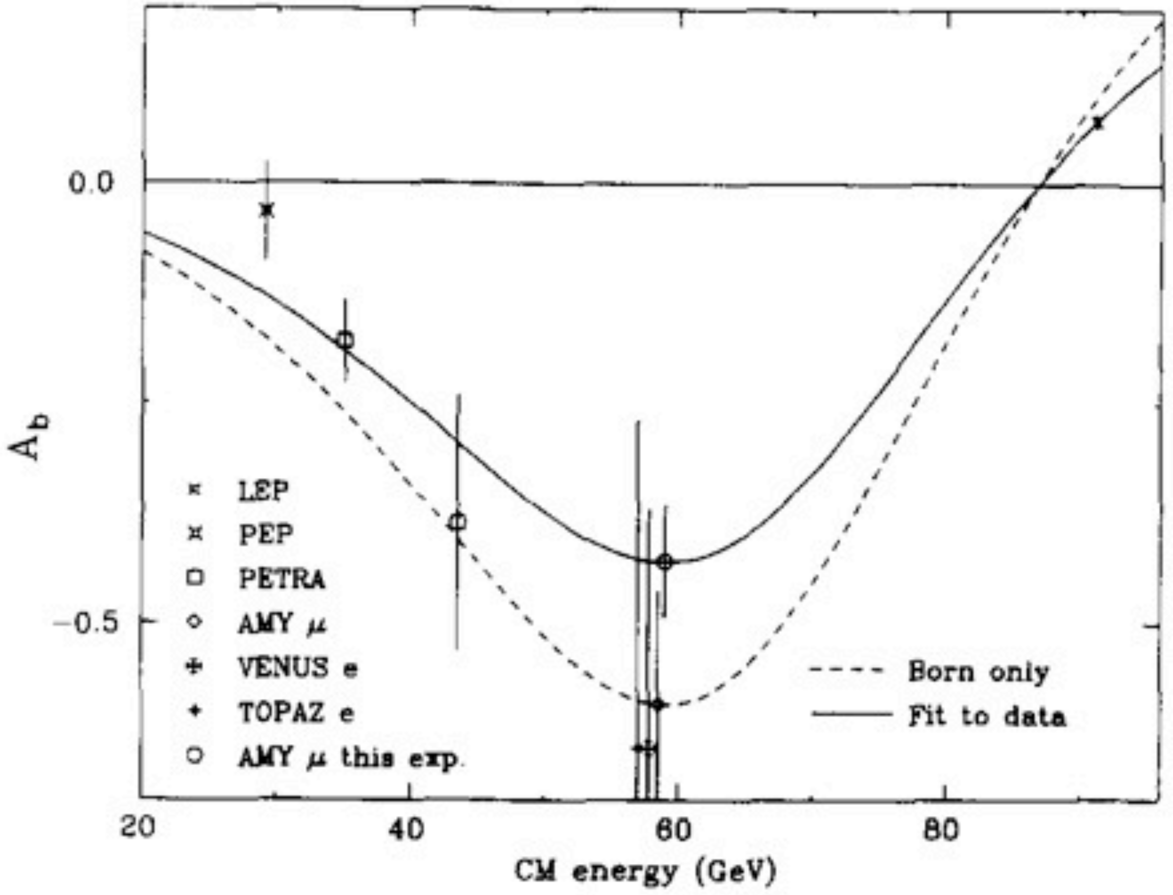


Fig. 5. The present measurement of the asymmetry A_b together with other experiments. The statistical and systematic errors are added in quadrature. The two curves are the Born term prediction without mixing (broken line) and the fit to the data (solid line) with mixing parameter χ. See the text.

Forward-Backward Asymmetry of bottom quark (A_b) in

$$e^+e^- \to b\bar{b}$$

confirmed weak isospin of **b**

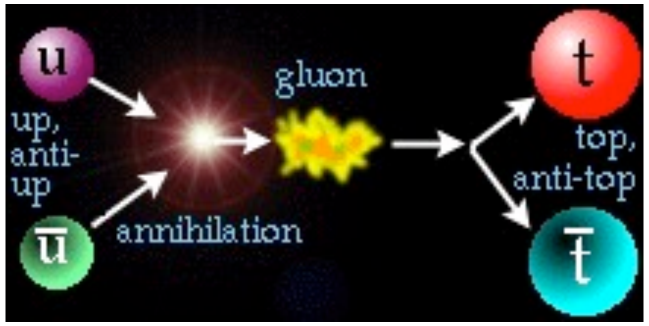
$$T_3 = -\frac{1}{2}$$

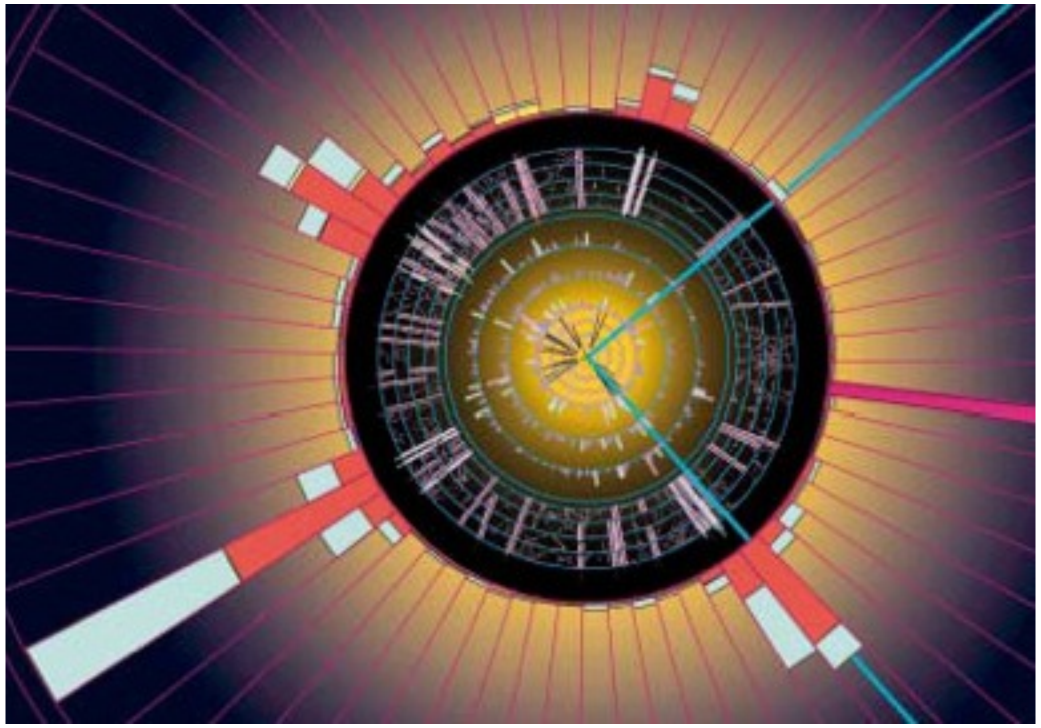
⇨ $T_3 = \dfrac{1}{2}$ state must exist, which is called

TOP.

然而，顶夸克的发现之路却是如此漫长！

1995年3月2日





高能物理学家高举

香槟

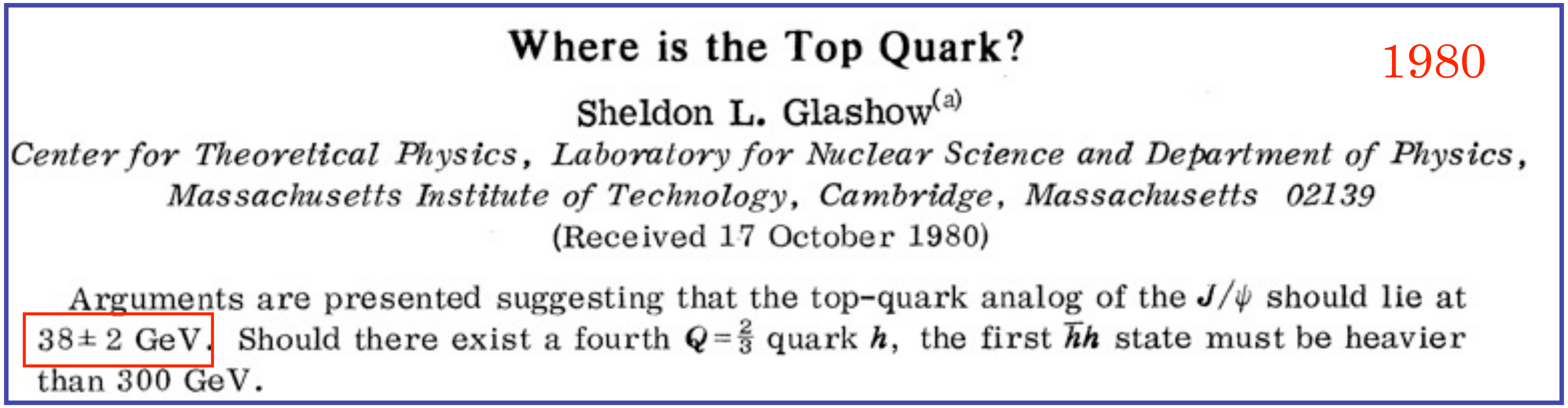
欢庆发现顶夸克

（美国费曼国家实验室的D0和CDF实验组）

最近实验结果,

$$m_t = (173.1 \pm 1.0)\ \text{GeV}$$

顶夸克年表



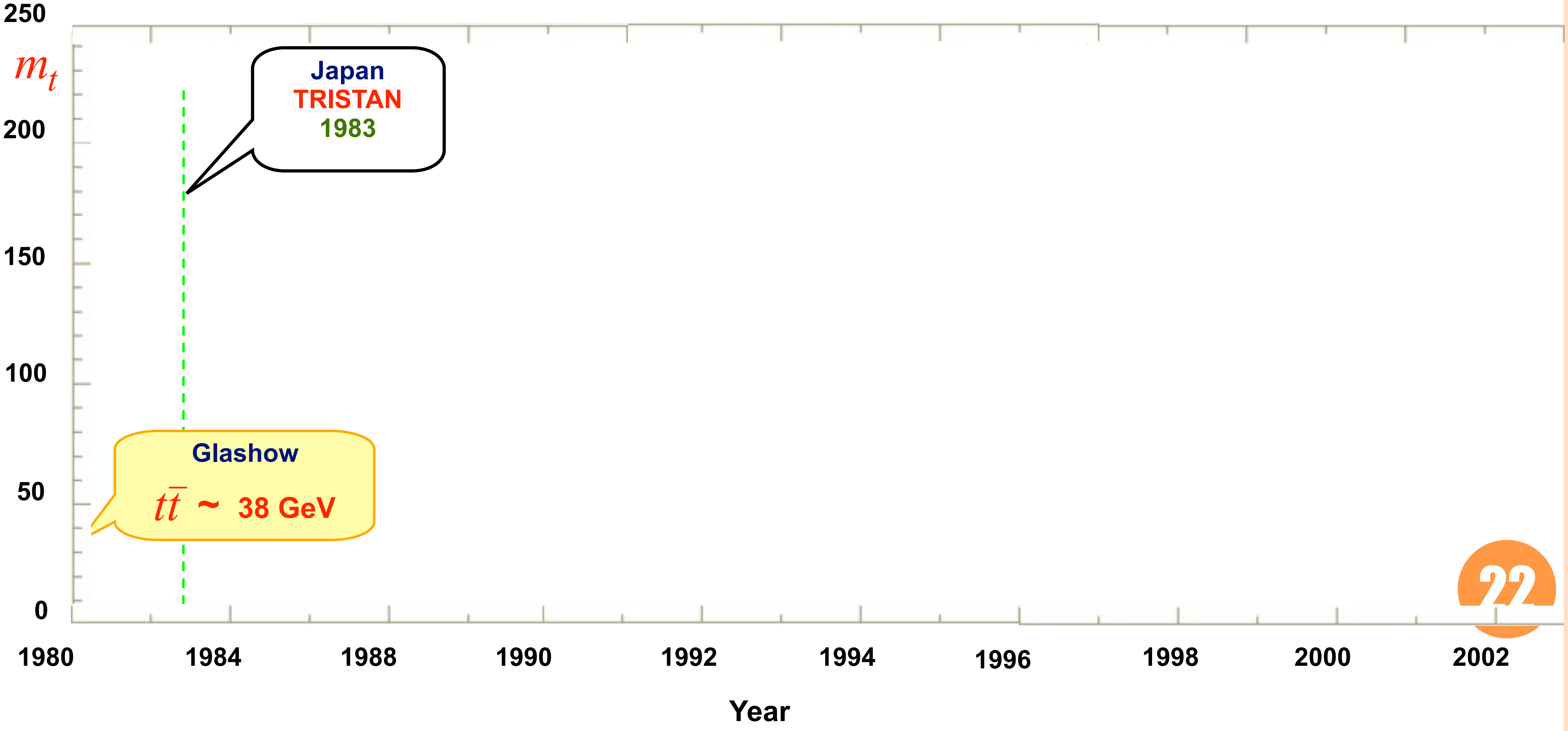
1980

Where is the Top Quark?

Sheldon L. Glashow(a)
Center for Theoretical Physics, Laboratory for Nuclear Science and Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

(Received 17 October 1980)

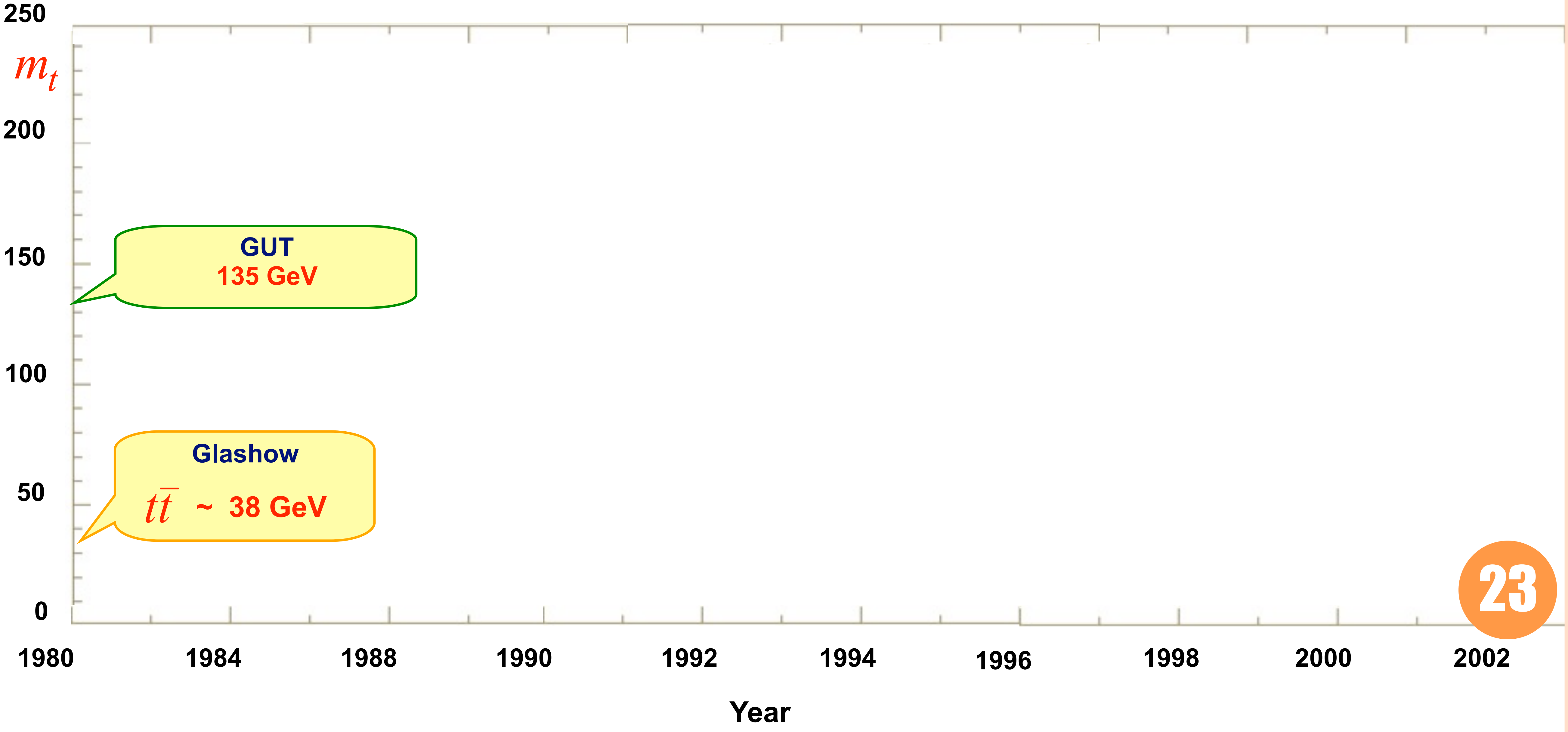
Arguments are presented suggesting that the top-quark analog of the J/ψ should lie at 38± 2 GeV. Should there exist a fourth $Q=\frac{2}{3}$ quark h, the first $\bar{h}h$ state must be heavier than 300 GeV.



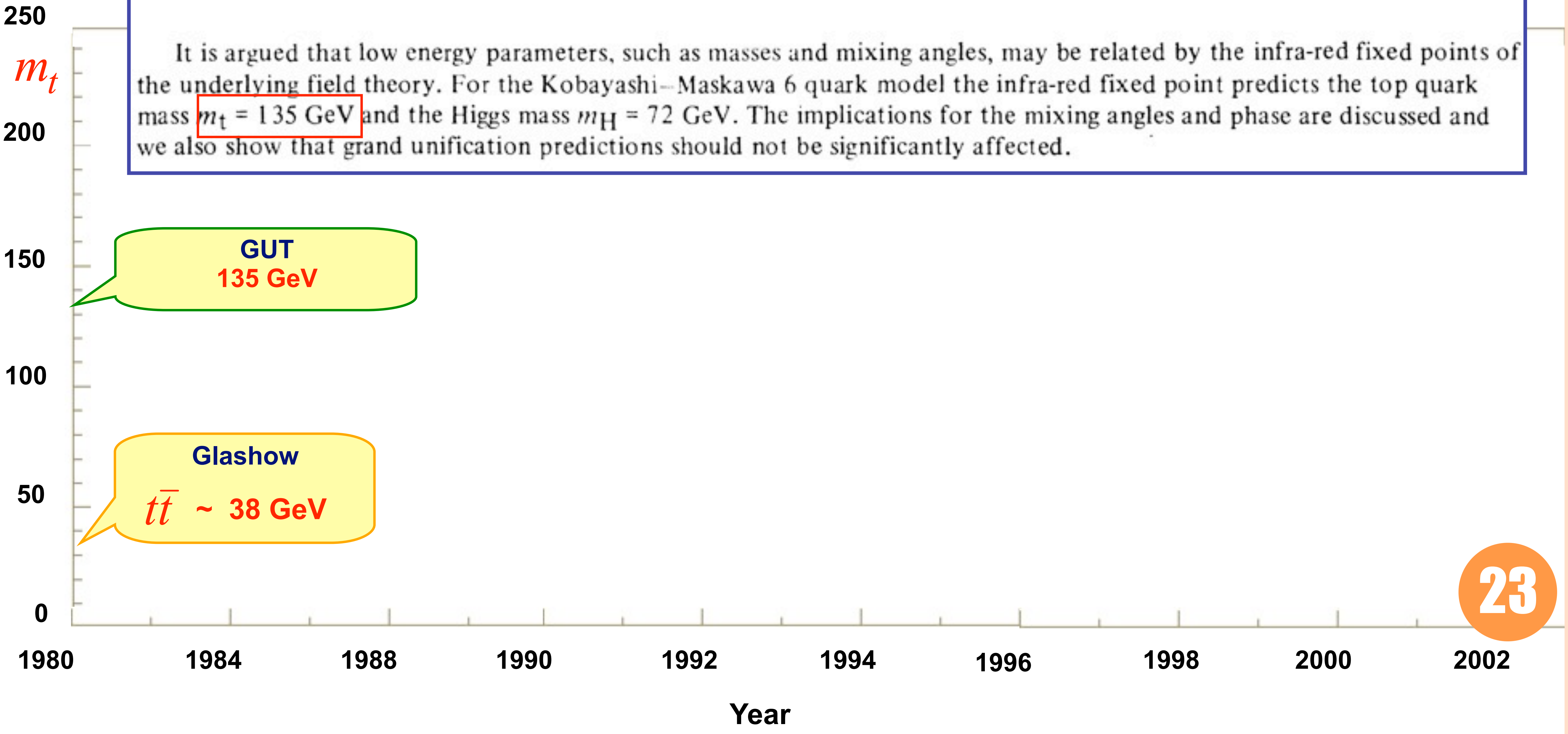
Japan
TRISTAN
1983

Glashow
$t\bar{t}$ ~ 38 GeV

顶夸克年表


250
m_t
200
150
100
50
0
GUT
135 GeV
Glashow
$t\bar{t}$ ~ 38 GeV
1980
1984
1988
1990
1992
1994
1996
1998
2000
2002
Year

顶夸克年表



MASS AND MIXING ANGLE PREDICTIONS FROM INFRA-RED FIXED POINTS

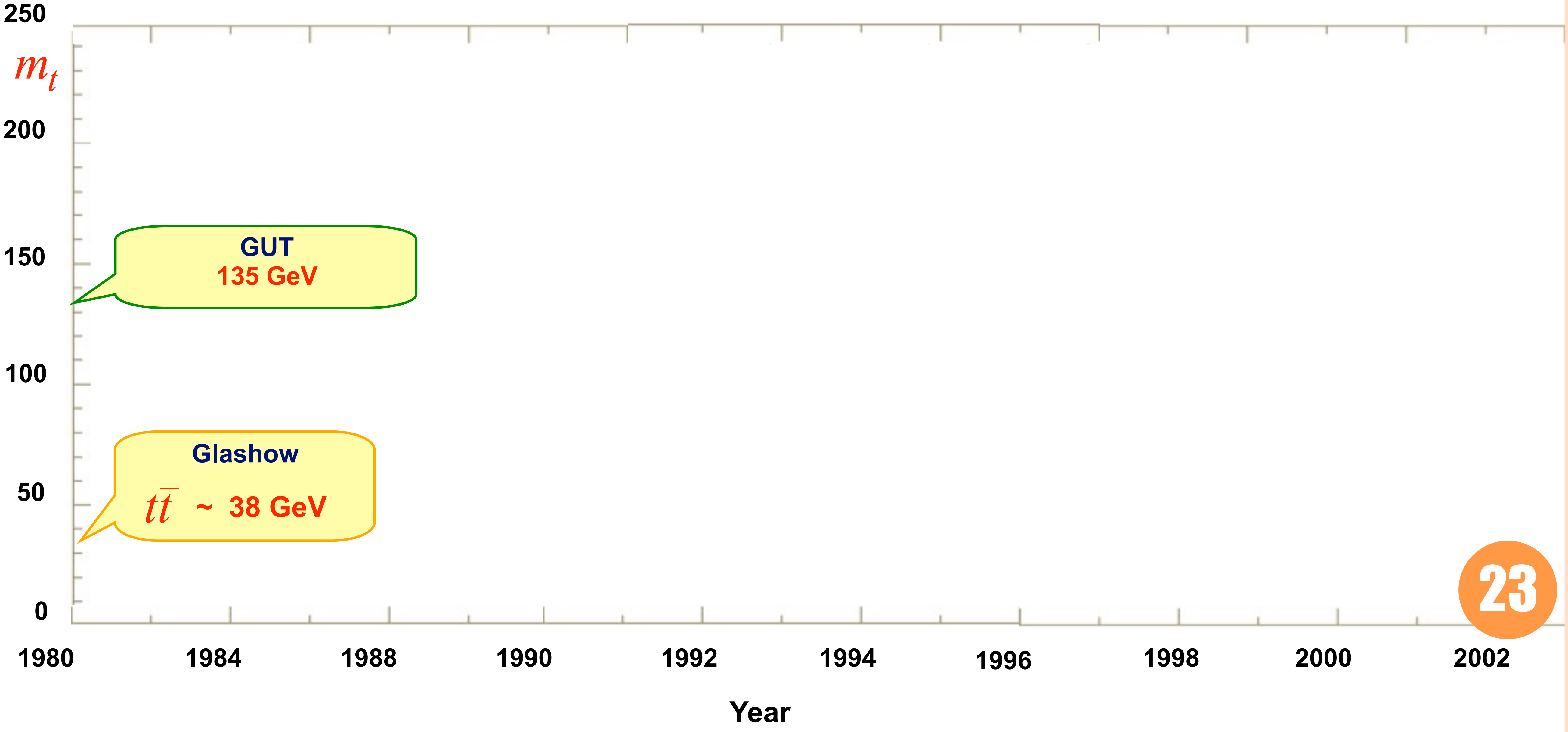
1980

B. PENDLETON and G.G. ROSS
Theoretical Physics Department, Oxford OX1 3NP, UK

Received 15 July 1980
Revised manuscript received 3 November 1980

It is argued that low energy parameters, such as masses and mixing angles, may be related by the infra-red fixed points of the underlying field theory. For the Kobayashi–Maskawa 6 quark model the infra-red fixed point predicts the top quark mass $\boxed{m_t = 135\ \mathrm{GeV}}$ and the Higgs mass $m_H = 72$ GeV. The implications for the mixing angles and phase are discussed and we also show that grand unification predictions should not be significantly affected.

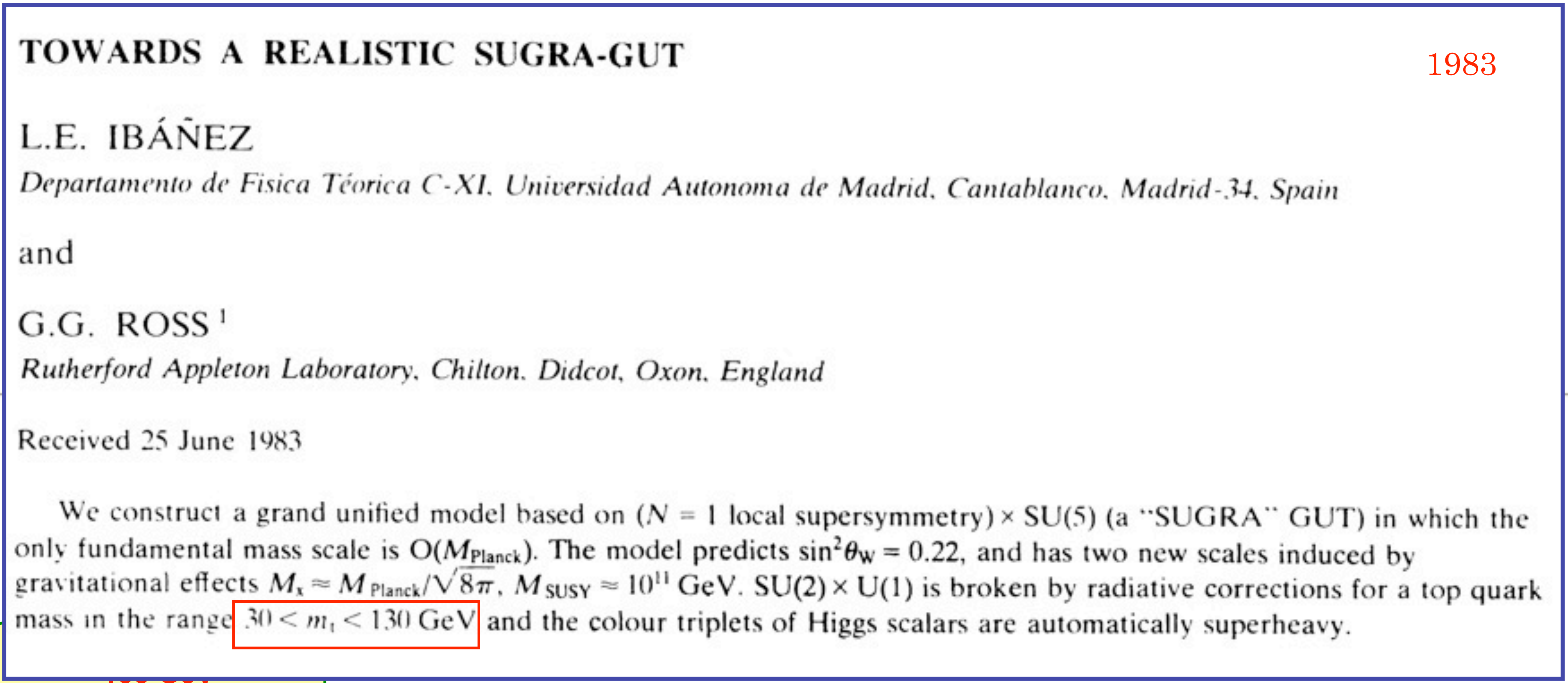
顶夸克年表



GUT
135 GeV

Glashow
$t\bar{t}$ ~ 38 GeV

顶夸克年表



TOWARDS A REALISTIC SUGRA-GUT

1983

L.E. IBÁÑEZ

Departamento de Fisica Téorica C-XI, Universidad Autonoma de Madrid, Cantablanco, Madrid-34, Spain

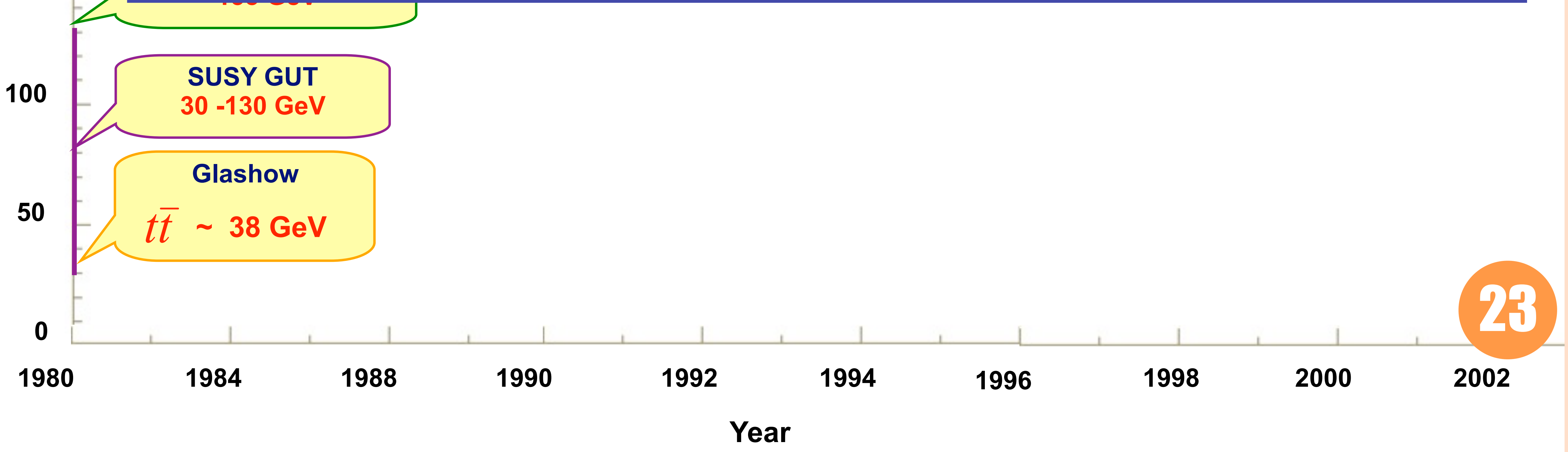
and

G.G. ROSS[1]

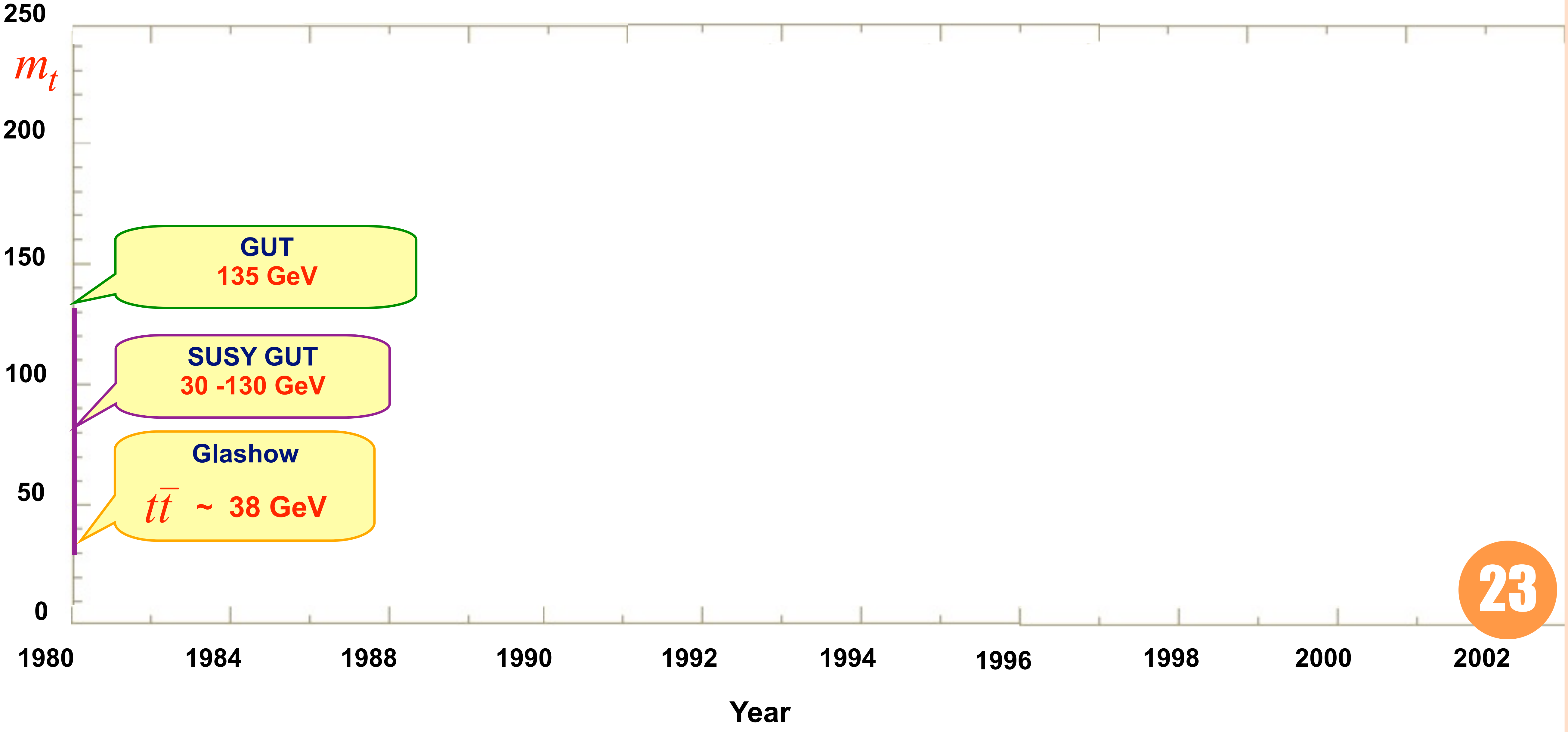
Rutherford Appleton Laboratory, Chilton, Didcot, Oxon, England

Received 25 June 1983

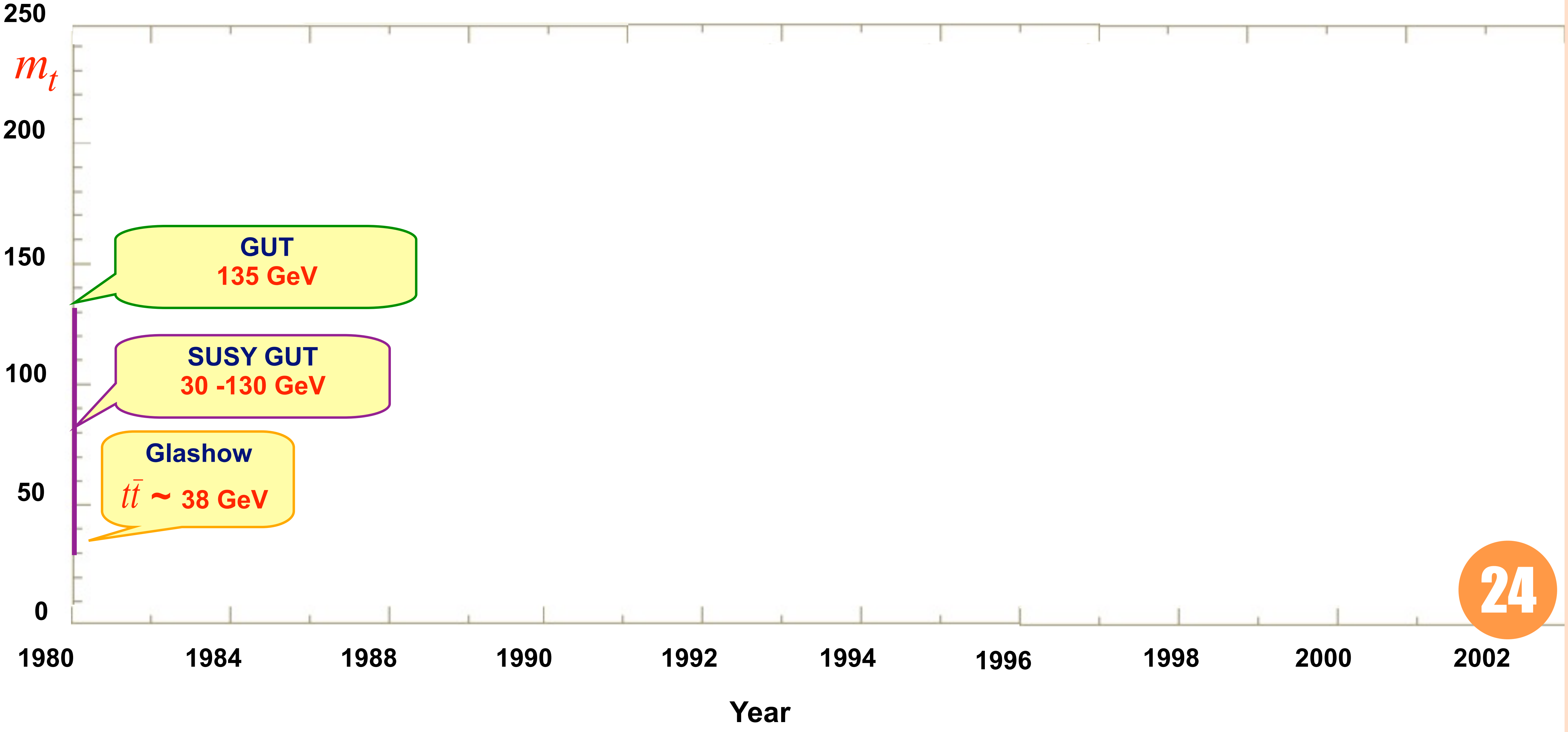
We construct a grand unified model based on ($N = 1$ local supersymmetry) × SU(5) (a "SUGRA" GUT) in which the only fundamental mass scale is $O(M_{\text{Planck}})$. The model predicts $\sin^2\theta_W = 0.22$, and has two new scales induced by gravitational effects $M_x \approx M_{\text{Planck}}/\sqrt{8\pi}$, $M_{\text{SUSY}} \approx 10^{11}$ GeV. SU(2) × U(1) is broken by radiative corrections for a top quark mass in the range $\boxed{30 < m_t < 130\ \text{GeV}}$ and the colour triplets of Higgs scalars are automatically superheavy.



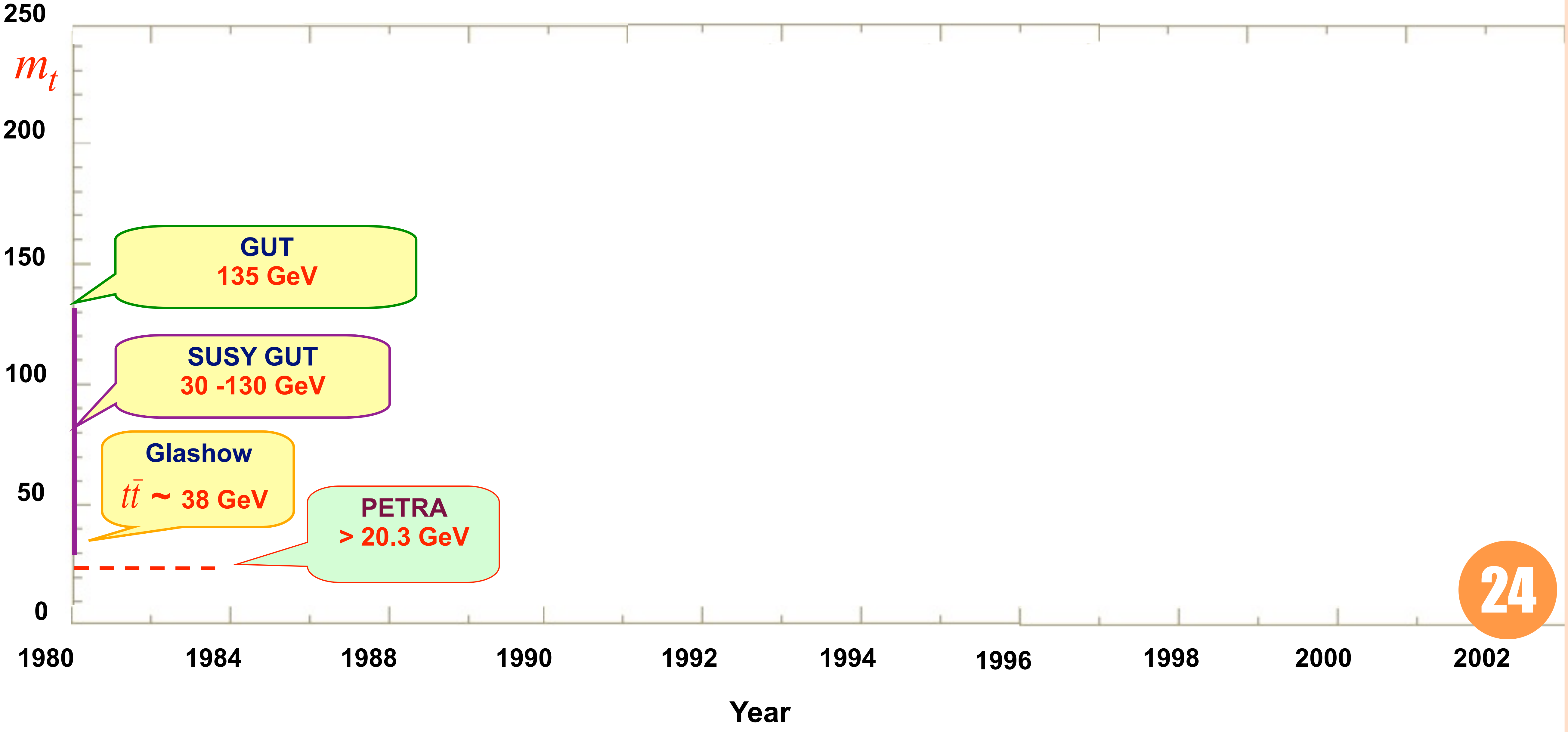
顶夸克年表


250
m_t
200
150
100
50
0
GUT
135 GeV
SUSY GUT
30 -130 GeV
Glashow
$t\bar{t}$ ~ 38 GeV
1980
1984
1988
1990
1992
1994
1996
1998
2000
2002
Year

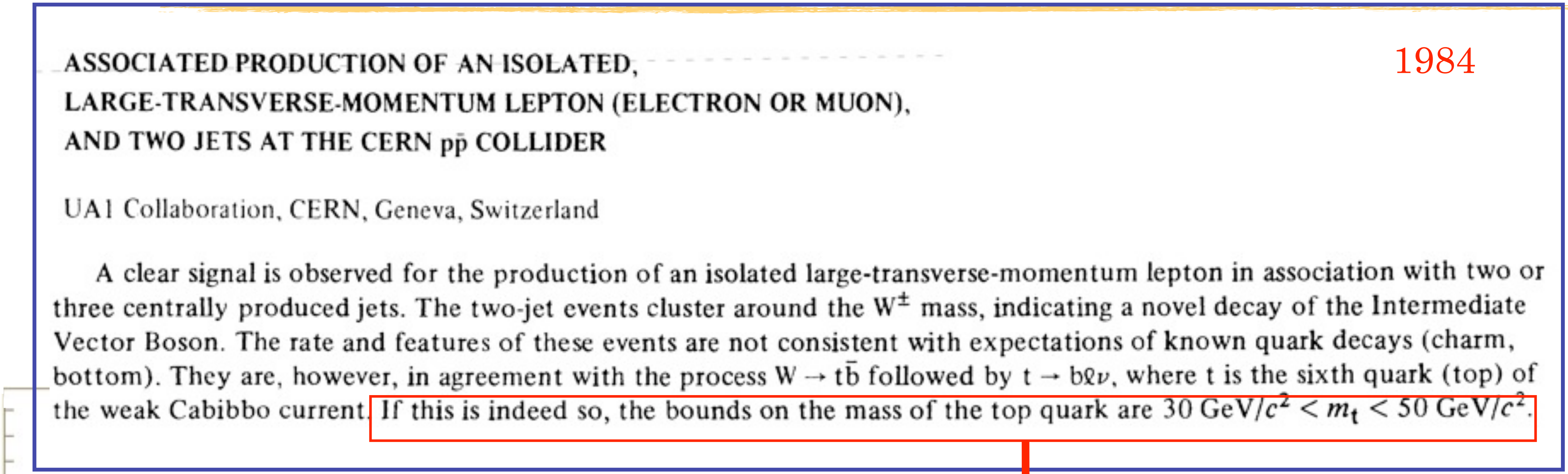
顶夸克年表


250
m_t
200
150
100
50
0
GUT
135 GeV
SUSY GUT
30 -130 GeV
Glashow
$t\bar{t}$ ~ 38 GeV
1980
1984
1988
1990
1992
1994
1996
1998
2000
2002
Year

顶夸克年表


250
m_t
200
150
100
50
0
1980
1984
1988
1990
1992
1994
1996
1998
2000
2002
Year
GUT
135 GeV
SUSY GUT
30 -130 GeV
Glashow
$t\bar{t}$ ~ 38 GeV
PETRA
> 20.3 GeV

顶夸克年表

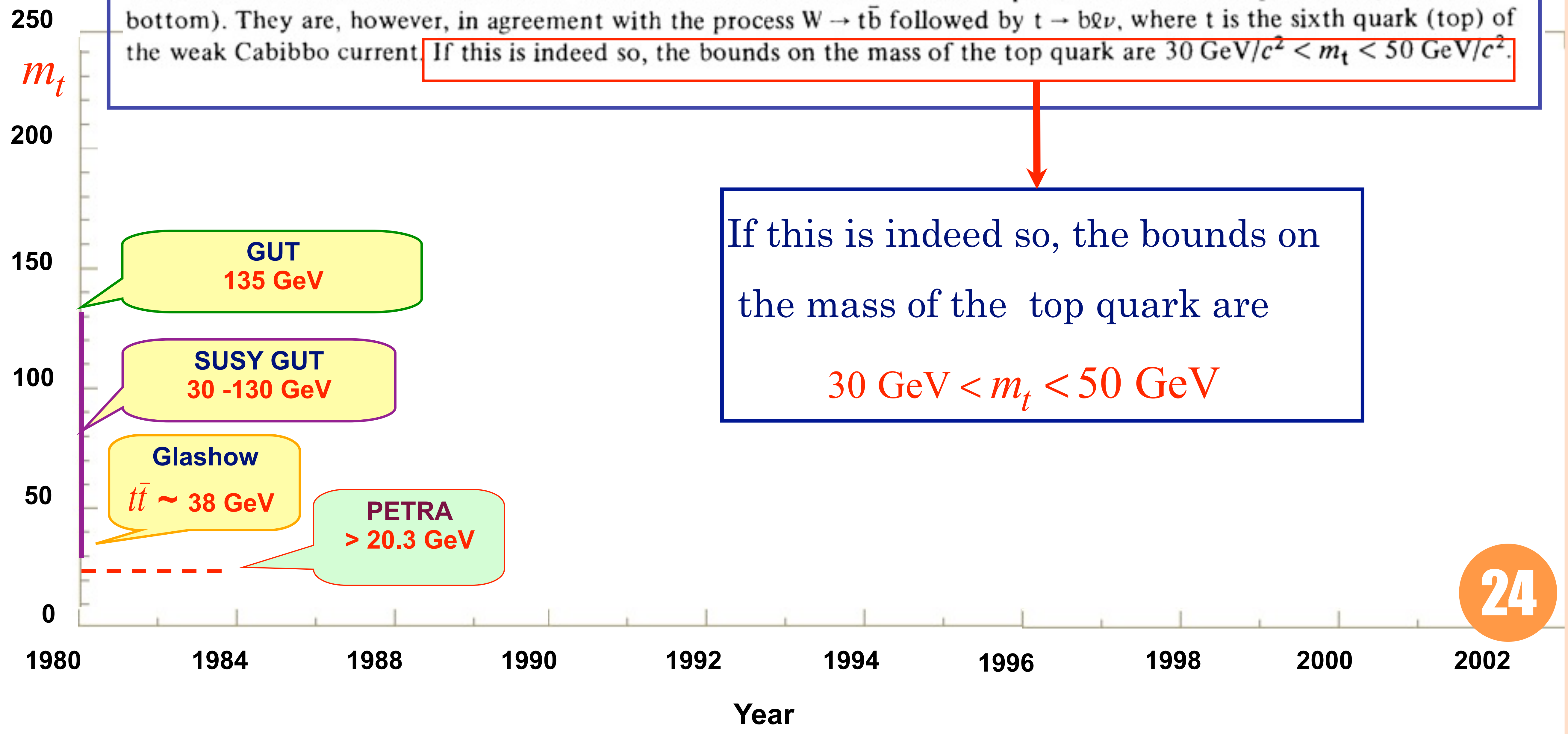


1984

ASSOCIATED PRODUCTION OF AN ISOLATED,
LARGE-TRANSVERSE-MOMENTUM LEPTON (ELECTRON OR MUON),
AND TWO JETS AT THE CERN $p\bar{p}$ COLLIDER

UA1 Collaboration, CERN, Geneva, Switzerland

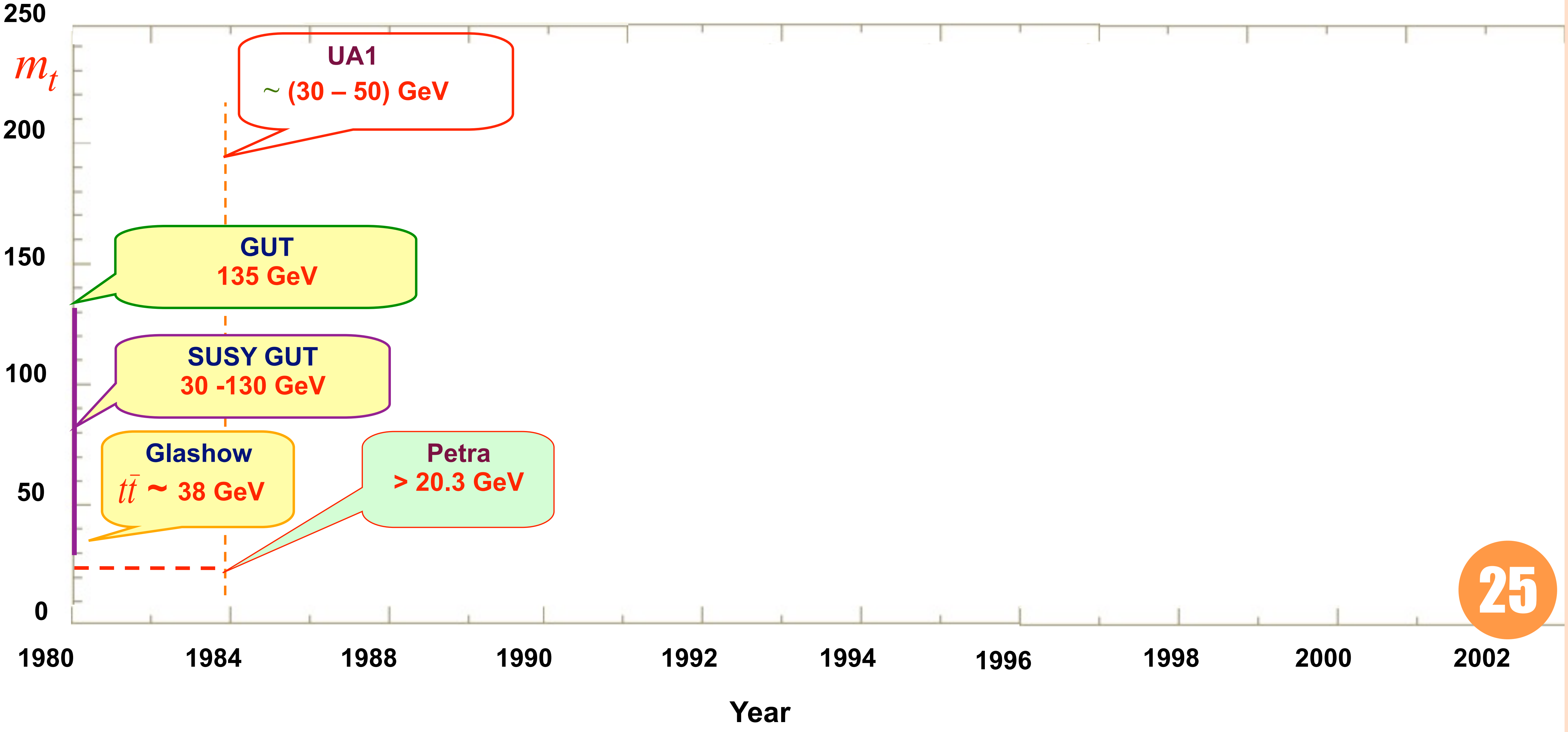
A clear signal is observed for the production of an isolated large-transverse-momentum lepton in association with two or three centrally produced jets. The two-jet events cluster around the $W^{\pm}$ mass, indicating a novel decay of the Intermediate Vector Boson. The rate and features of these events are not consistent with expectations of known quark decays (charm, bottom). They are, however, in agreement with the process $W \to t\bar{b}$ followed by $t \to b\ell\nu$, where t is the sixth quark (top) of the weak Cabibbo current. If this is indeed so, the bounds on the mass of the top quark are $30\ \mathrm{GeV}/c^2 < m_t < 50\ \mathrm{GeV}/c^2$.



If this is indeed so, the bounds on the mass of the top quark are

$$30\ \text{GeV} < m_t < 50\ \text{GeV}$$

顶夸克年表

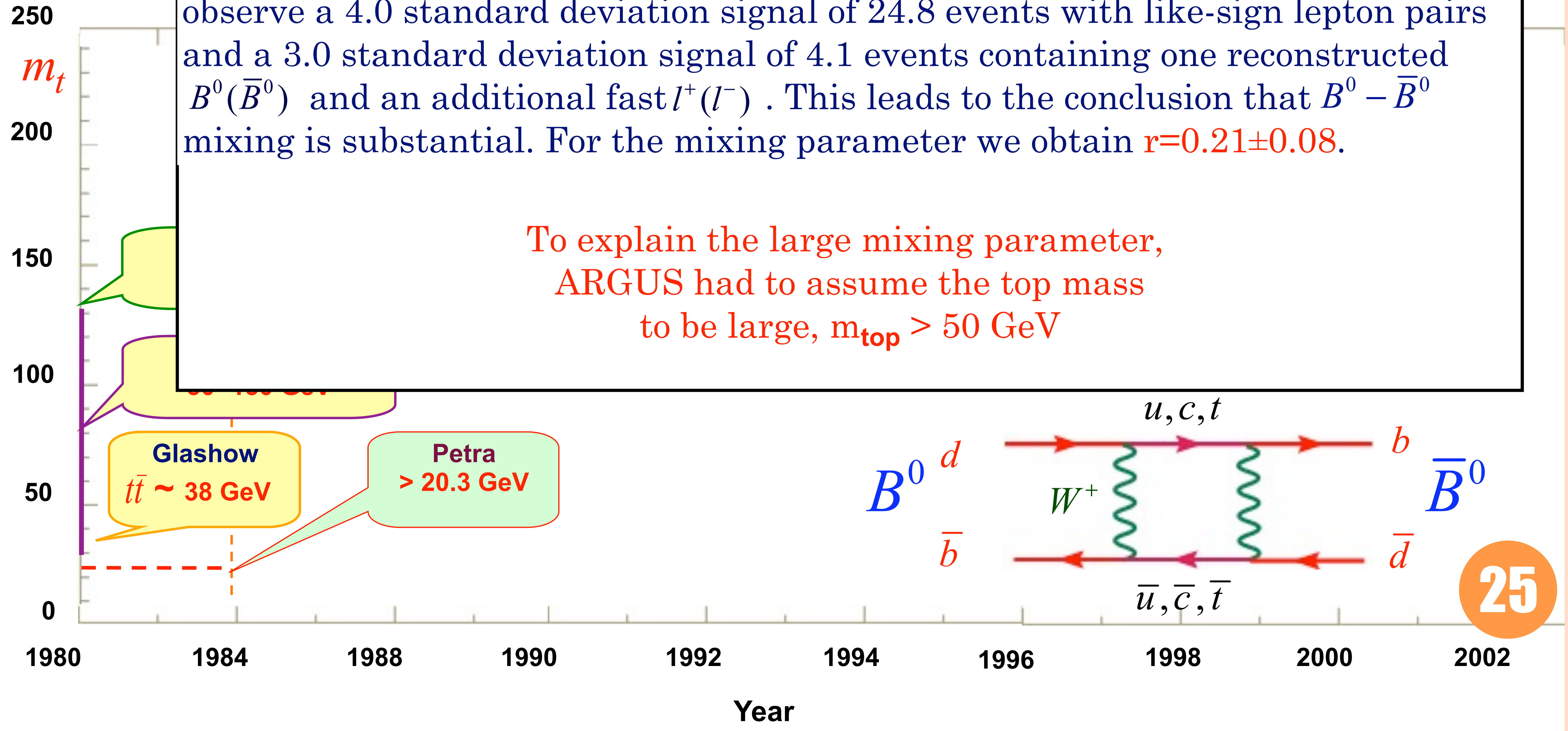

250
m_t
200
150
100
50
0
UA1
~ (30 – 50) GeV
GUT
135 GeV
SUSY GUT
30 -130 GeV
Glashow
$t\bar{t}$ ~ 38 GeV
Petra
> 20.3 GeV
1980
1984
1988
1990
1992
1994
1996
1998
2000
2002
Year

顶夸克年表

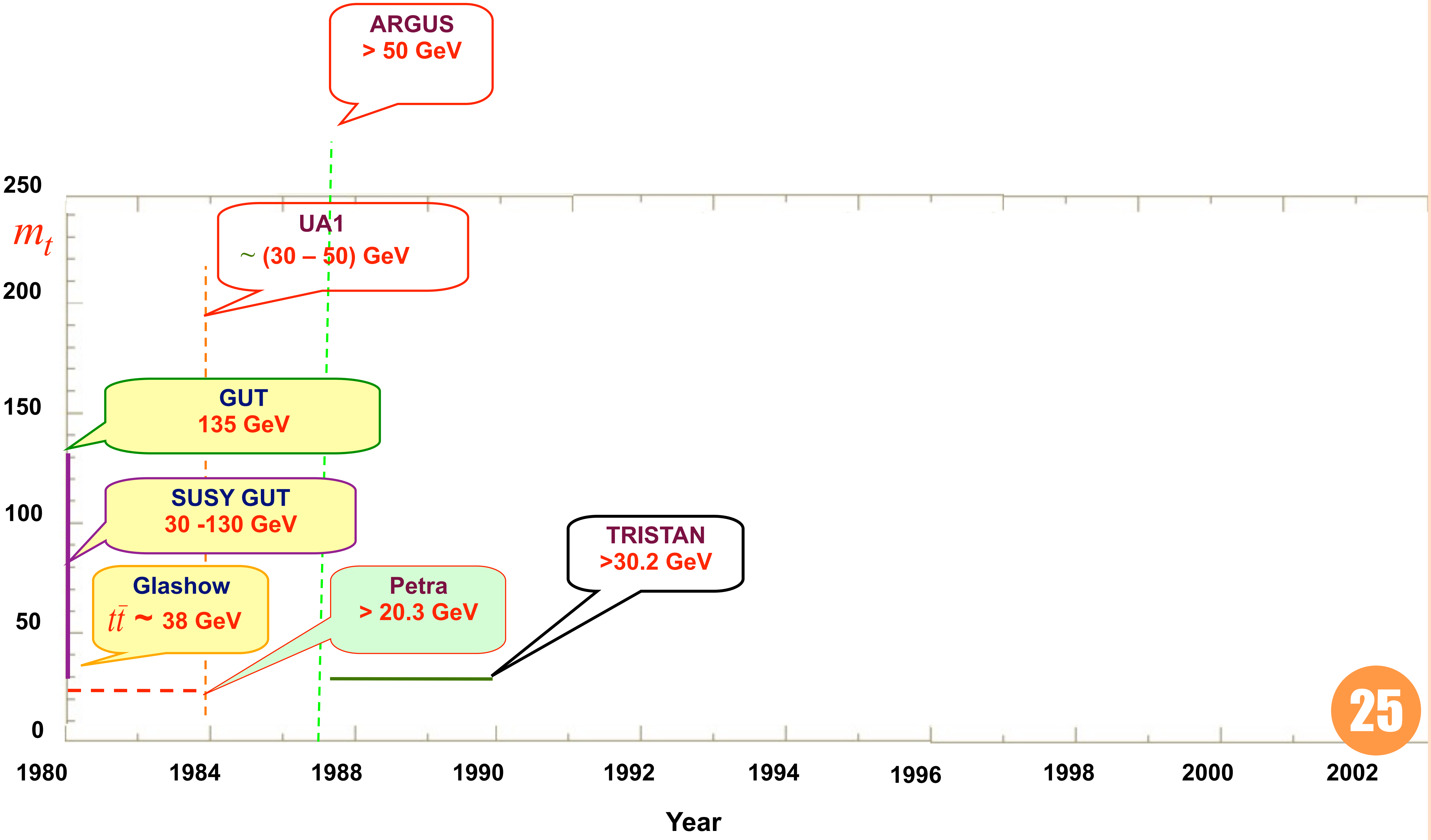
Observation of $B^0-\bar{B}^0$ mixing
ARGUS Collaboration
Received 9 April 1987

Using the ARGUS detector at the DORIS II storage ring we have searched in three different ways for $B^0-\bar{B}^0$ mixing in Υ(4S) decays. One explicitly mixed event, a decay $\Upsilon \to B^0\bar{B}^0$, has been completely reconstructed. Furthermore, we observe a 4.0 standard deviation signal of 24.8 events with like-sign lepton pairs and a 3.0 standard deviation signal of 4.1 events containing one reconstructed $B^0(\bar{B}^0)$ and an additional fast $l^+(l^-)$. This leads to the conclusion that $B^0-\bar{B}^0$ mixing is substantial. For the mixing parameter we obtain r=0.21±0.08.

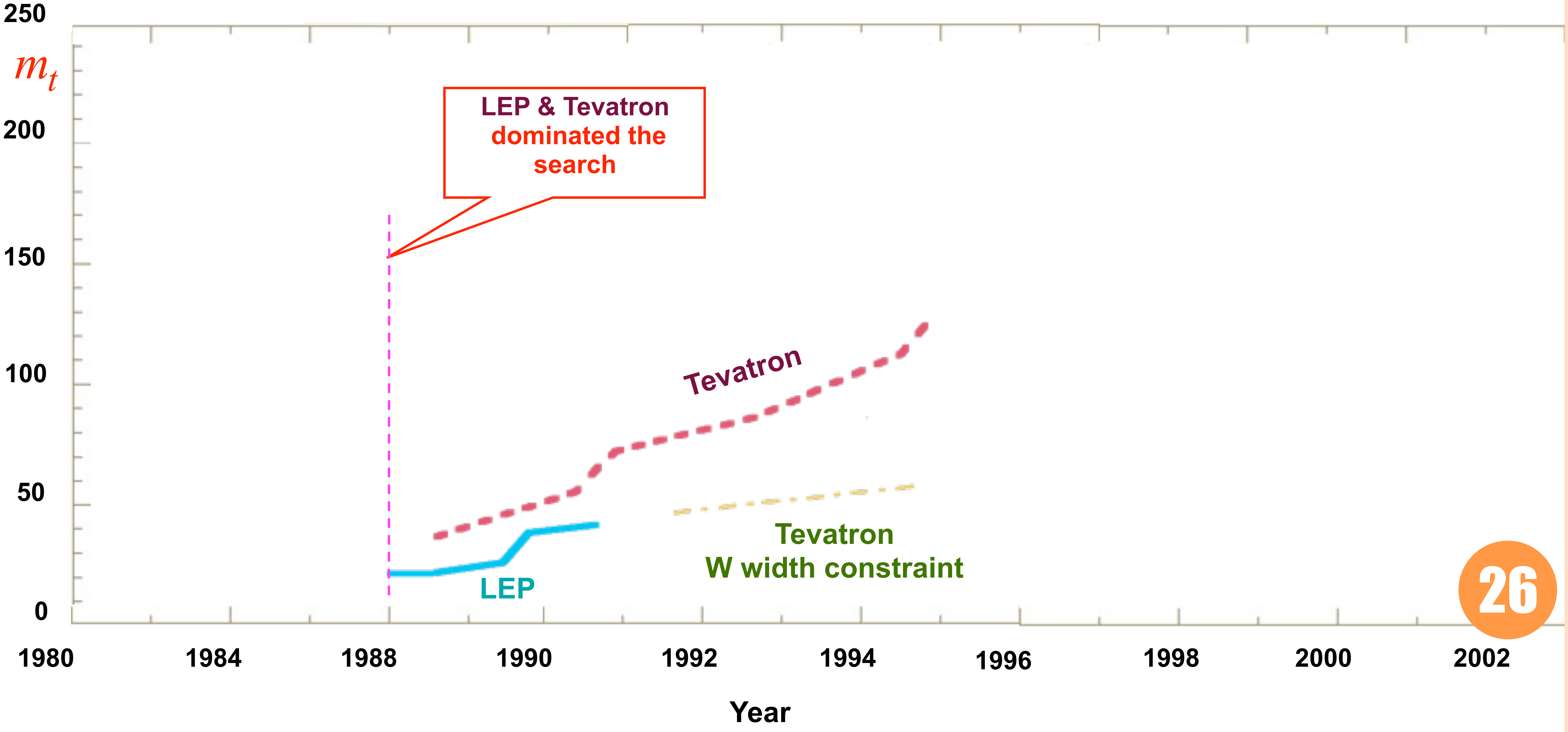
To explain the large mixing parameter,
ARGUS had to assume the top mass
to be large, m_{top} > 50 GeV



顶夸克年表

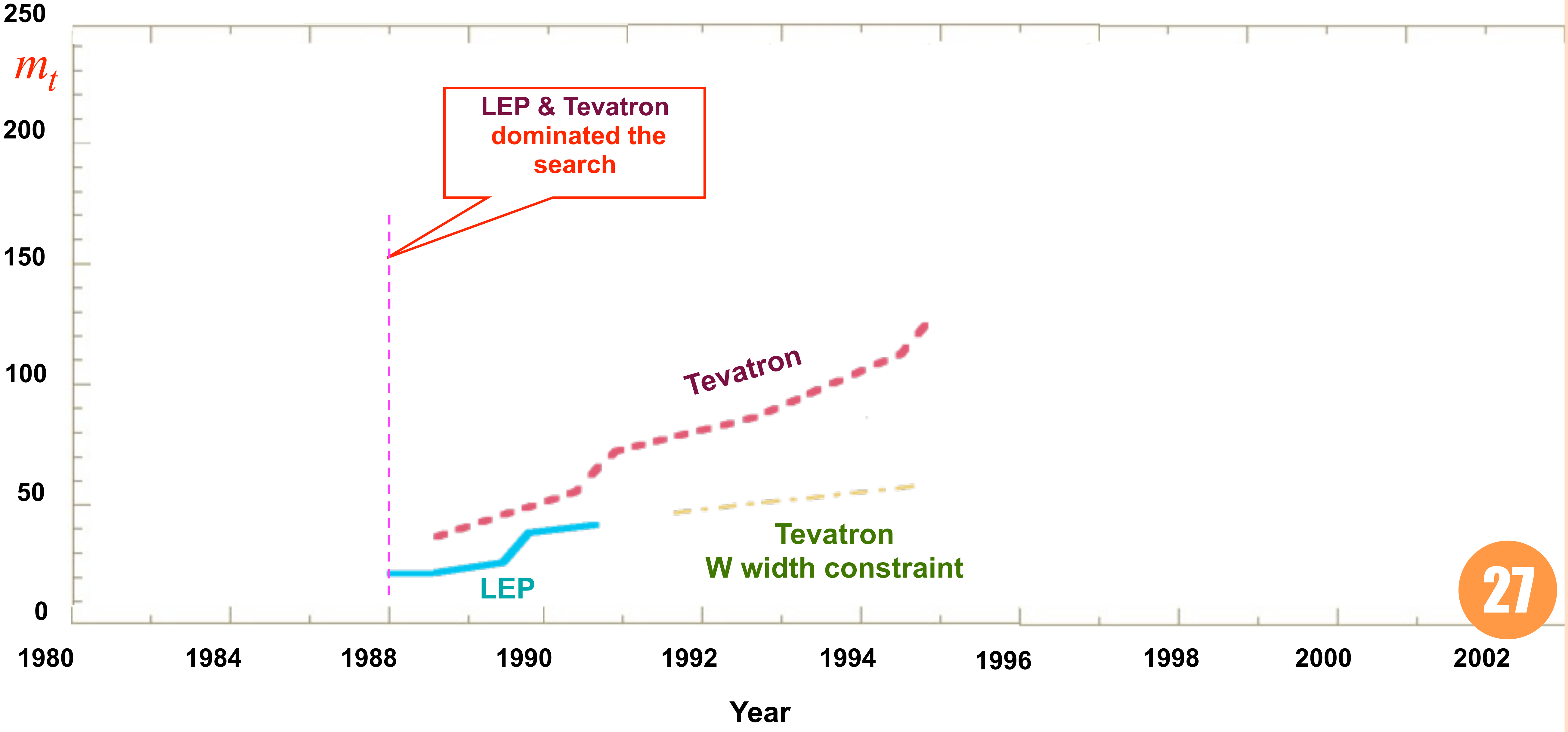

ARGUS
> 50 GeV
250
m_t
UA1
~ (30 – 50) GeV
200
150
GUT
135 GeV
100
SUSY GUT
30 -130 GeV
TRISTAN
>30.2 GeV
Glashow
$t\bar{t}$ ~ 38 GeV
Petra
> 20.3 GeV
50
0
1980
1984
1988
1990
1992
1994
1996
1998
2000
2002
Year

顶夸克年表



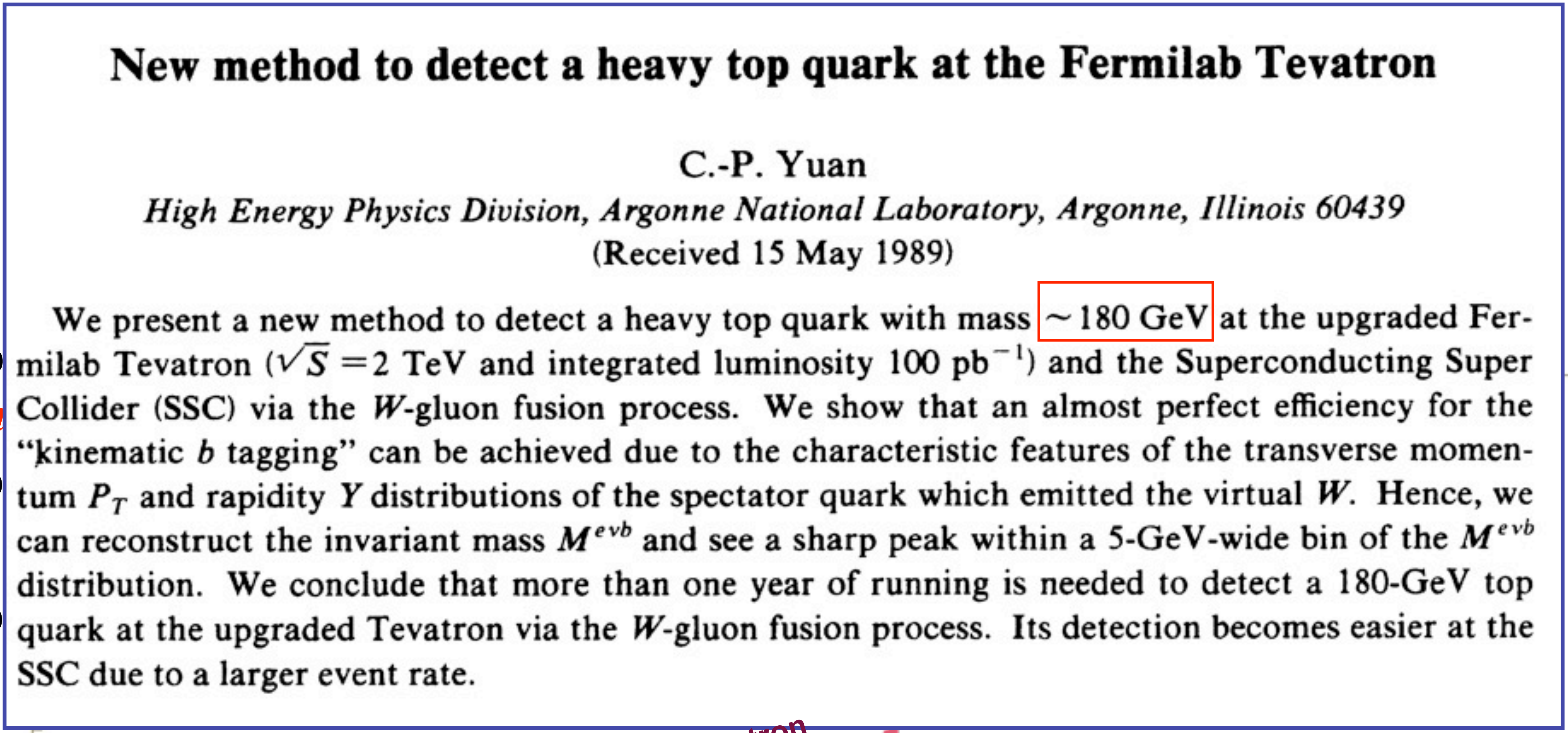
LEP & Tevatron dominated the search

顶夸克年表



LEP & Tevatron dominated the search

顶夸克年表

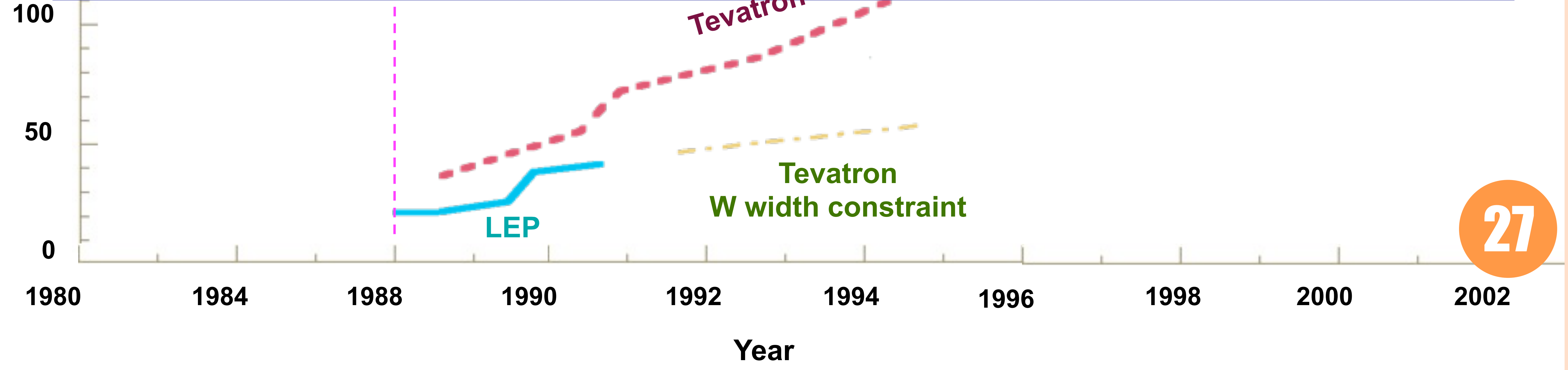


New method to detect a heavy top quark at the Fermilab Tevatron

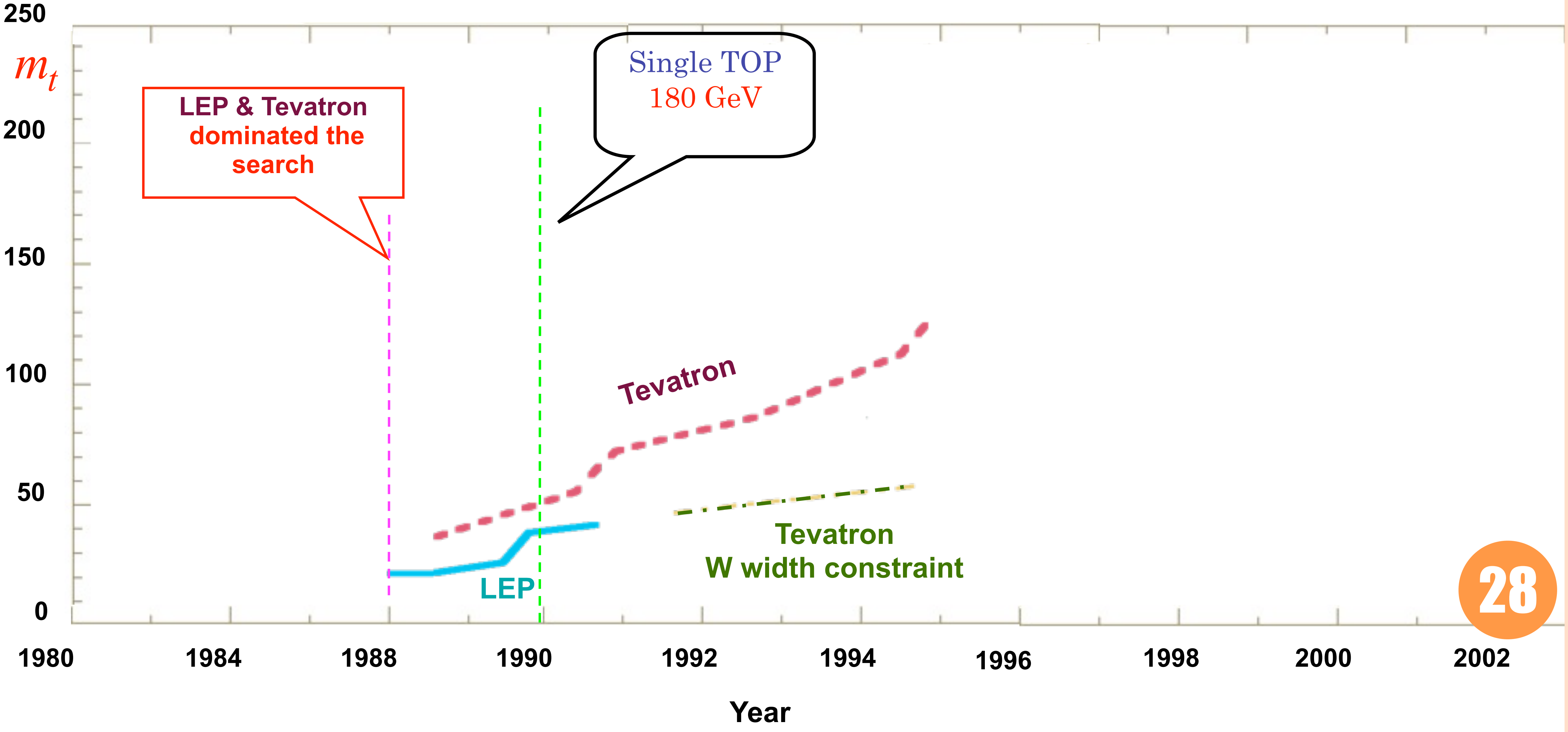
C.-P. Yuan
High Energy Physics Division, Argonne National Laboratory, Argonne, Illinois 60439

(Received 15 May 1989)

We present a new method to detect a heavy top quark with mass $\boxed{\sim 180\text{ GeV}}$ at the upgraded Fermilab Tevatron ($\sqrt{S} = 2$ TeV and integrated luminosity 100 pb^{-1}) and the Superconducting Super Collider (SSC) via the W-gluon fusion process. We show that an almost perfect efficiency for the "kinematic b tagging" can be achieved due to the characteristic features of the transverse momentum P_T and rapidity Y distributions of the spectator quark which emitted the virtual W. Hence, we can reconstruct the invariant mass $M^{e\nu b}$ and see a sharp peak within a 5-GeV-wide bin of the $M^{e\nu b}$ distribution. We conclude that more than one year of running is needed to detect a 180-GeV top quark at the upgraded Tevatron via the W-gluon fusion process. Its detection becomes easier at the SSC due to a larger event rate.



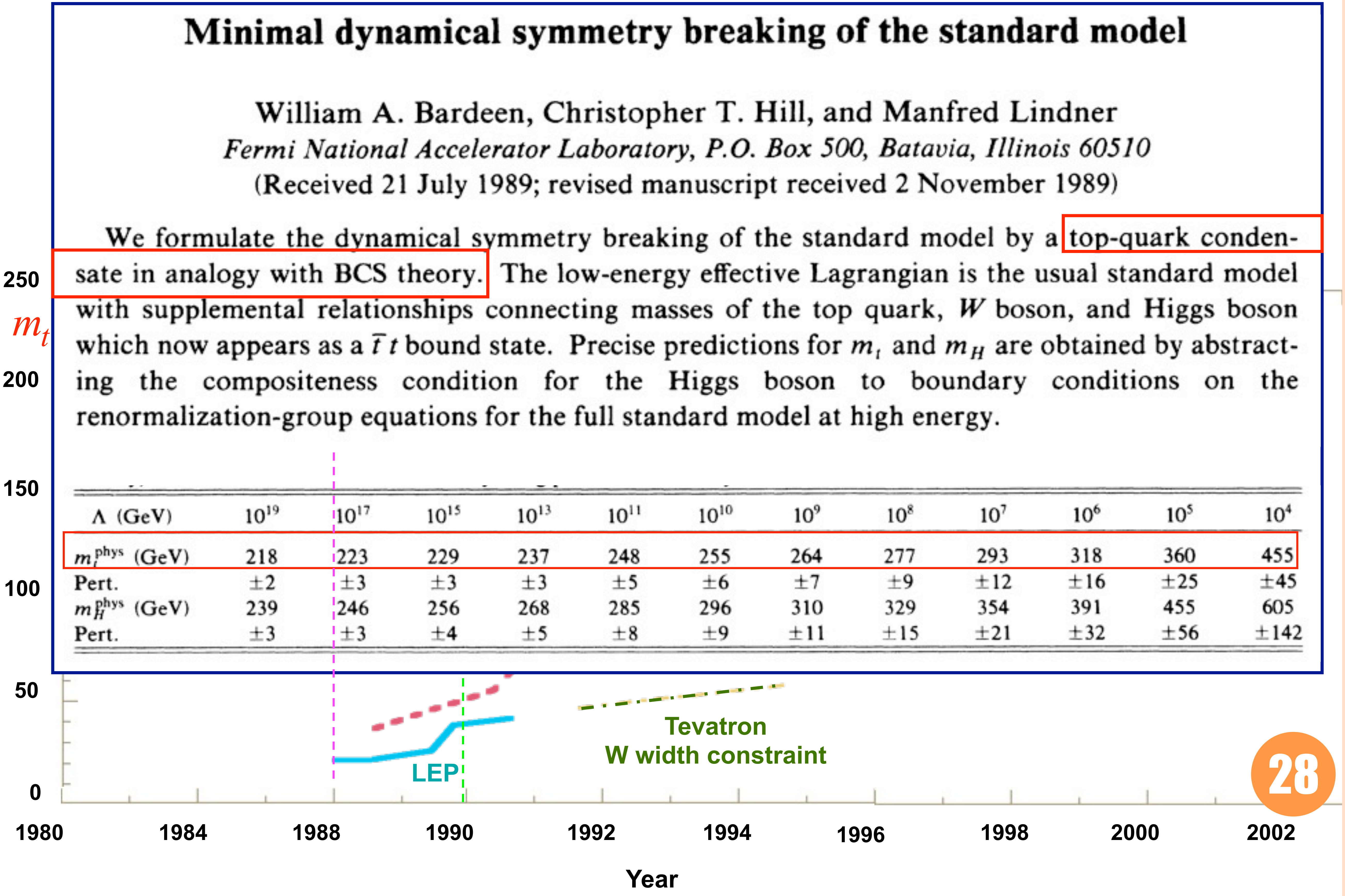
顶夸克年表



LEP & Tevatron dominated the search

Single TOP
180 GeV

顶夸克年表



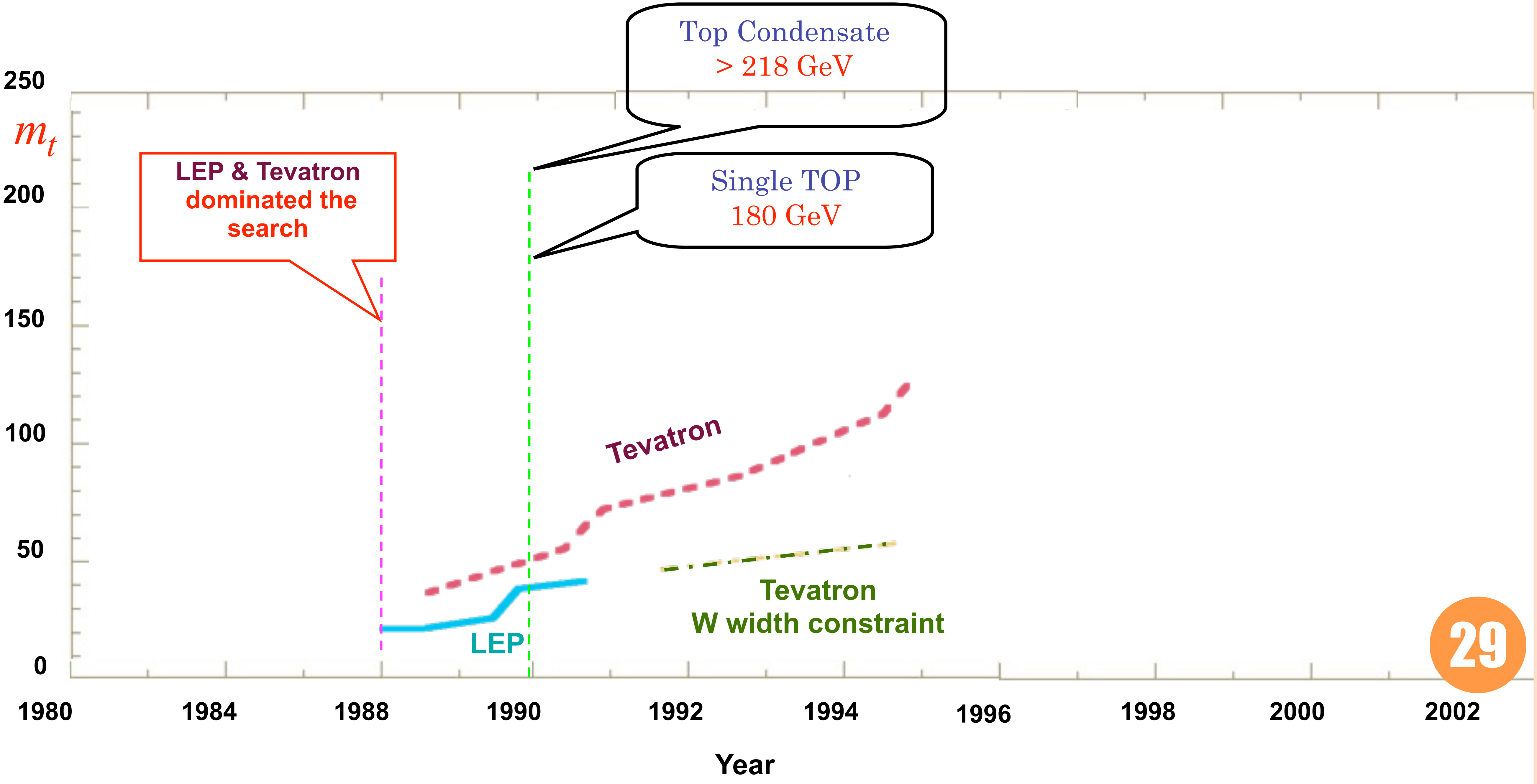
Minimal dynamical symmetry breaking of the standard model

William A. Bardeen, Christopher T. Hill, and Manfred Lindner
Fermi National Accelerator Laboratory, P.O. Box 500, Batavia, Illinois 60510
(Received 21 July 1989; revised manuscript received 2 November 1989)

We formulate the dynamical symmetry breaking of the standard model by a top-quark condensate in analogy with BCS theory. The low-energy effective Lagrangian is the usual standard model with supplemental relationships connecting masses of the top quark, W boson, and Higgs boson which now appears as a $\bar{t}\,t$ bound state. Precise predictions for m_t and m_H are obtained by abstracting the compositeness condition for the Higgs boson to boundary conditions on the renormalization-group equations for the full standard model at high energy.

Λ (GeV)	10^{19}	10^{17}	10^{15}	10^{13}	10^{11}	10^{10}	10^{9}	10^{8}	10^{7}	10^{6}	10^{5}	10^{4}
m_t^{phys} (GeV)	218	223	229	237	248	255	264	277	293	318	360	455
Pert.	±2	±3	±3	±3	±5	±6	±7	±9	±12	±16	±25	±45
m_H^{phys} (GeV)	239	246	256	268	285	296	310	329	354	391	455	605
Pert.	±3	±3	±4	±5	±8	±9	±11	±15	±21	±32	±56	±142

顶夸克年表

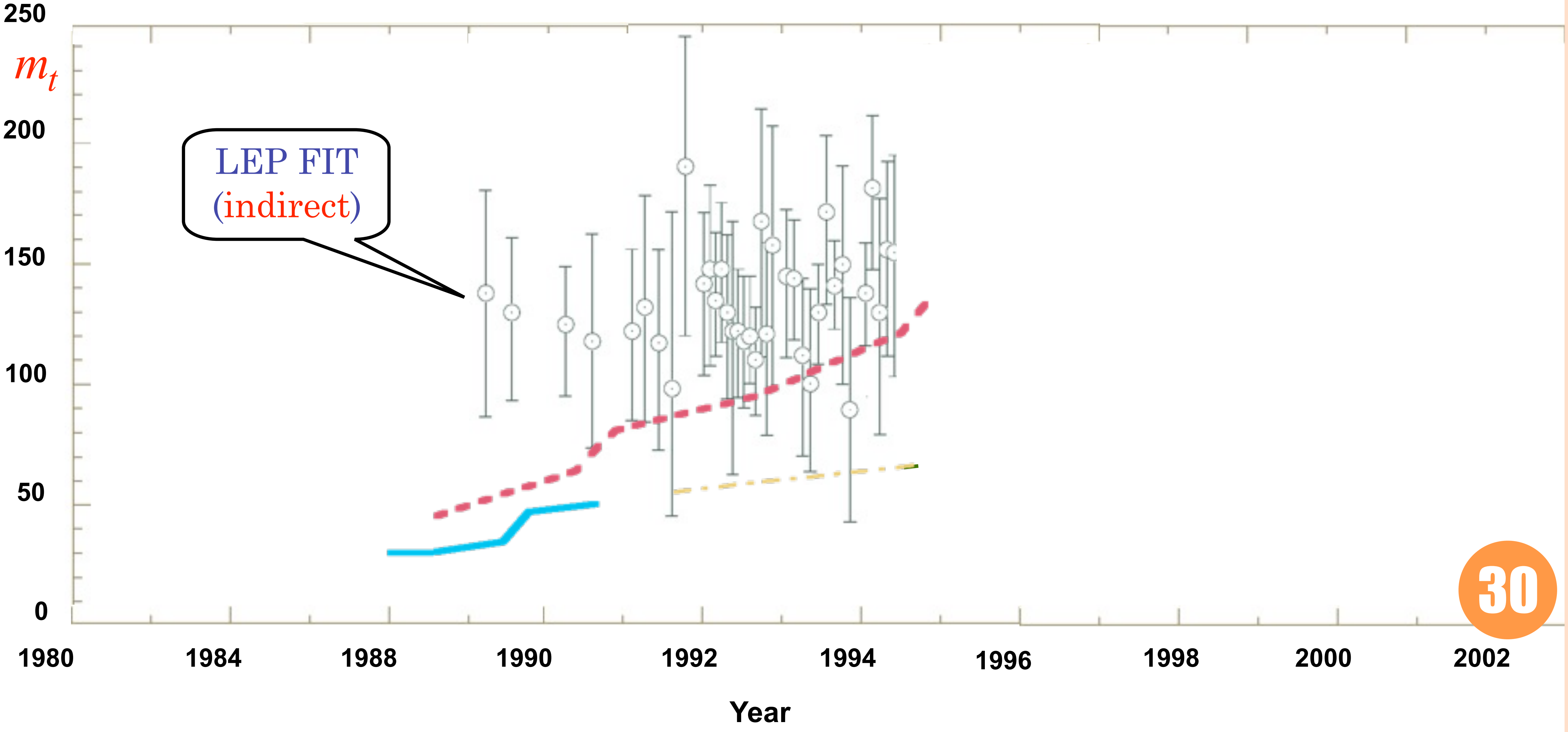


LEP & Tevatron dominated the search

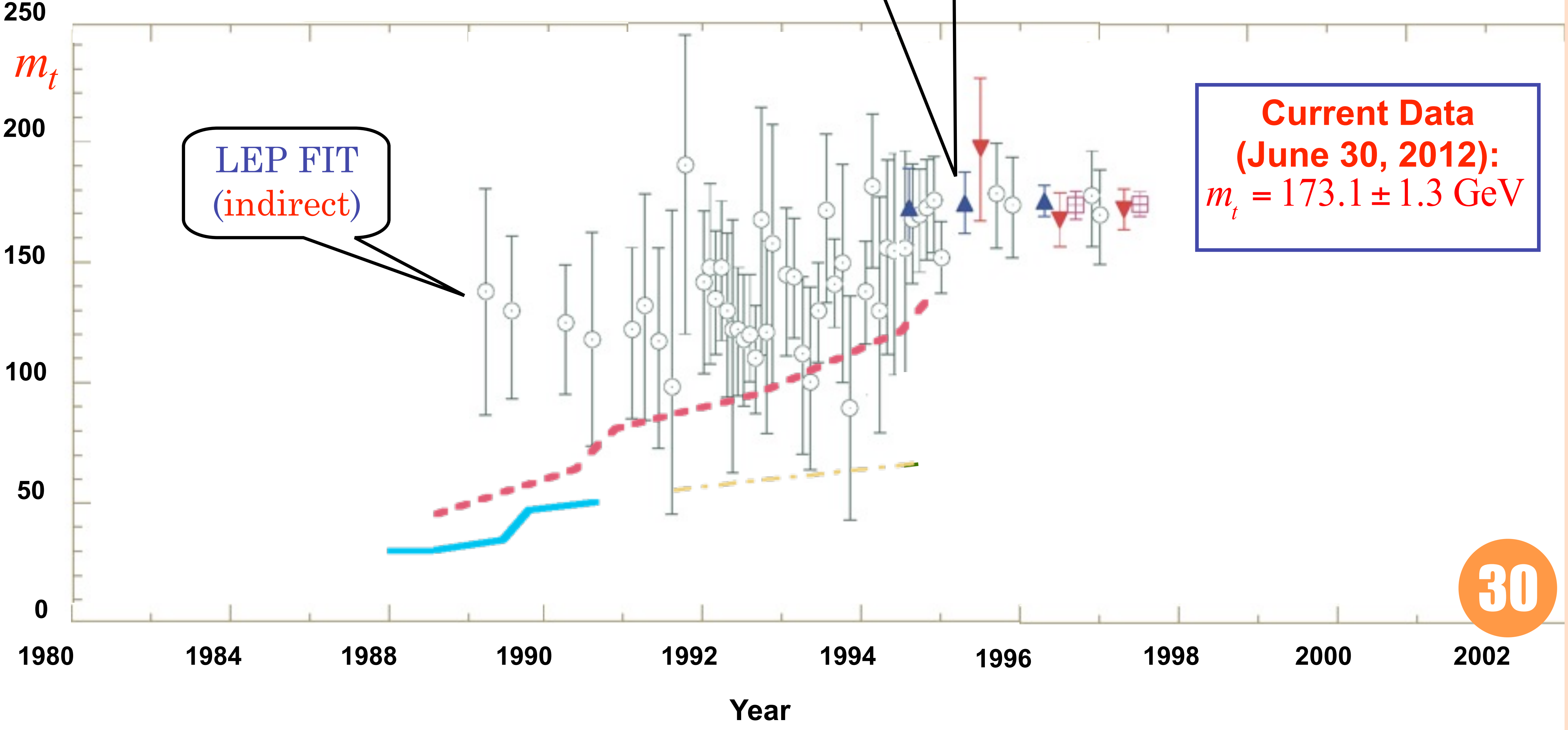
Top Condensate
> 218 GeV

Single TOP
180 GeV

顶夸克年表


250
m_t
200
150
100
50
0
1980
1984
1988
1990
1992
1994
1996
1998
2000
2002
Year
LEP FIT
(indirect)

顶夸克年表



LEP FIT
(indirect)

Discovery of TOP
@Tevatron

Current Data
(June 30, 2012):
$m_t = 173.1 \pm 1.3$ GeV

<u>顶夸克和</u>
<u>新物理</u>

大型强子对撞机时代

- 物理学和各种能标尺度紧密相关

弱相互作用

TeV

大统一能标

普朗克能标

能标等级

电弱对称性破缺
暗物质

超对称

规范统一
中微子跷跷板机制

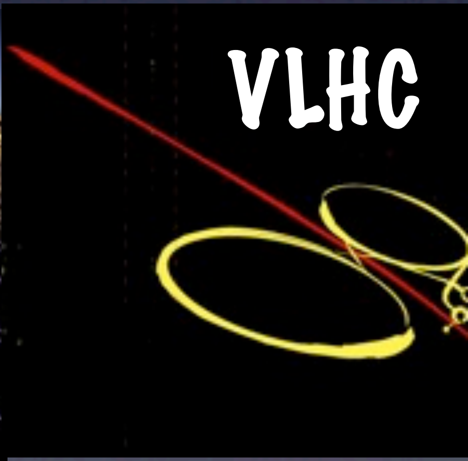
量子引力

- 大型强子对撞机探测TeV能区的新物理

大型强子对撞机时代

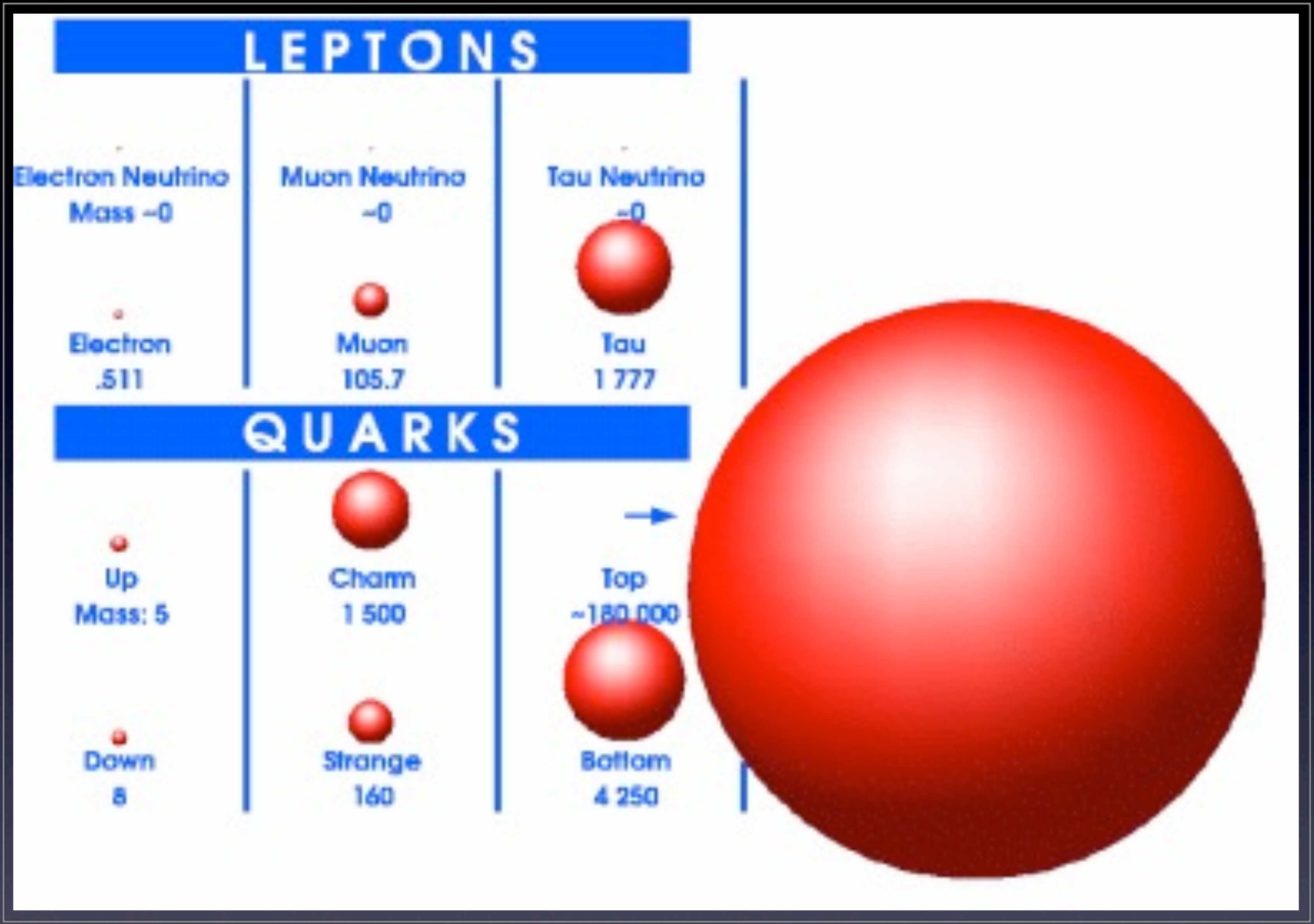
- 物理学和各种能标尺度紧密相关


弱相互作用
TeV
大统一能标
普朗克能标
能标等级
电弱对称性破缺
暗物质
超对称
规范统一
中微子跷跷板机制
量子引力



- 大型强子对撞机探测TeV能区的新物理

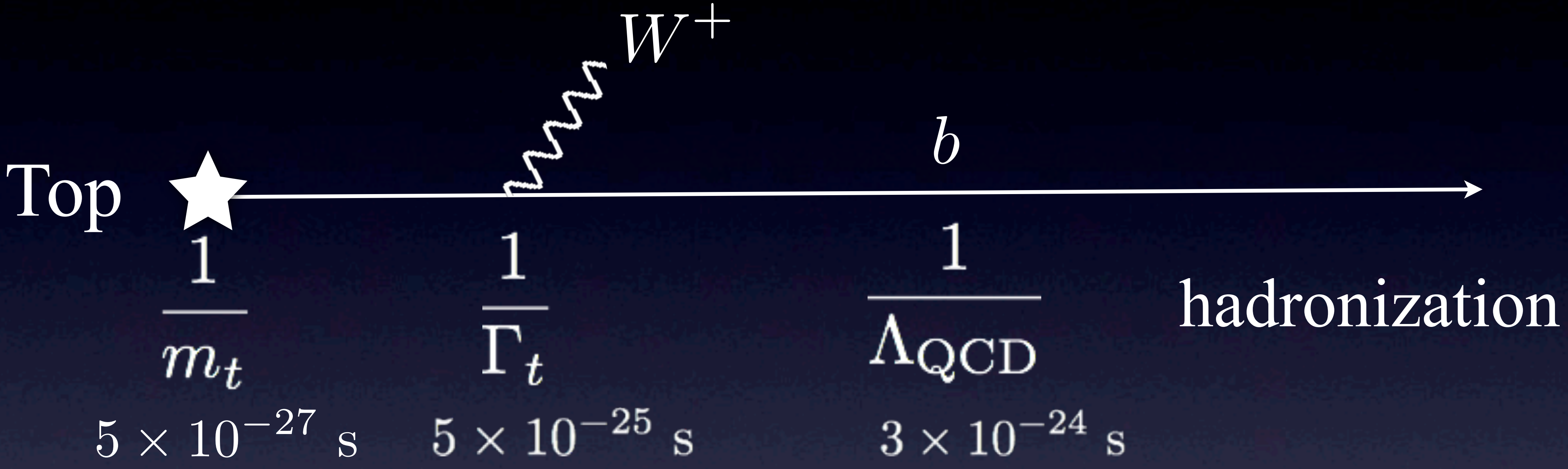
顶夸克：标准模型的国王



- 标准模型中最重的夸克（探测对称性破缺）
- 具有“自然”的Yukawa耦合常数的唯一夸克

顶夸克是如此特殊

- 寿命极短：



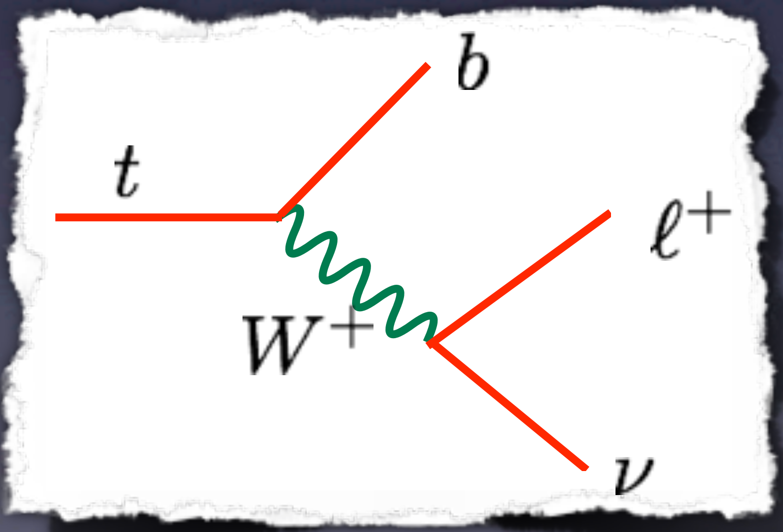
$\frac{1}{m_t}$ 5×10^{-27} s

$\frac{1}{\Gamma_t}$ 5×10^{-25} s

$\frac{1}{\Lambda_{\rm QCD}}$ 3×10^{-24} s

- “裸”夸克：

  自旋信息完好地保存在其衰变产物中



顶夸克是探测新物理的有效探针

新规范波色子

Z'　W'　G'

新夸克

top

色奇异态

Vector-like Quark

第四代

Gluino

带电
希格斯
粒子

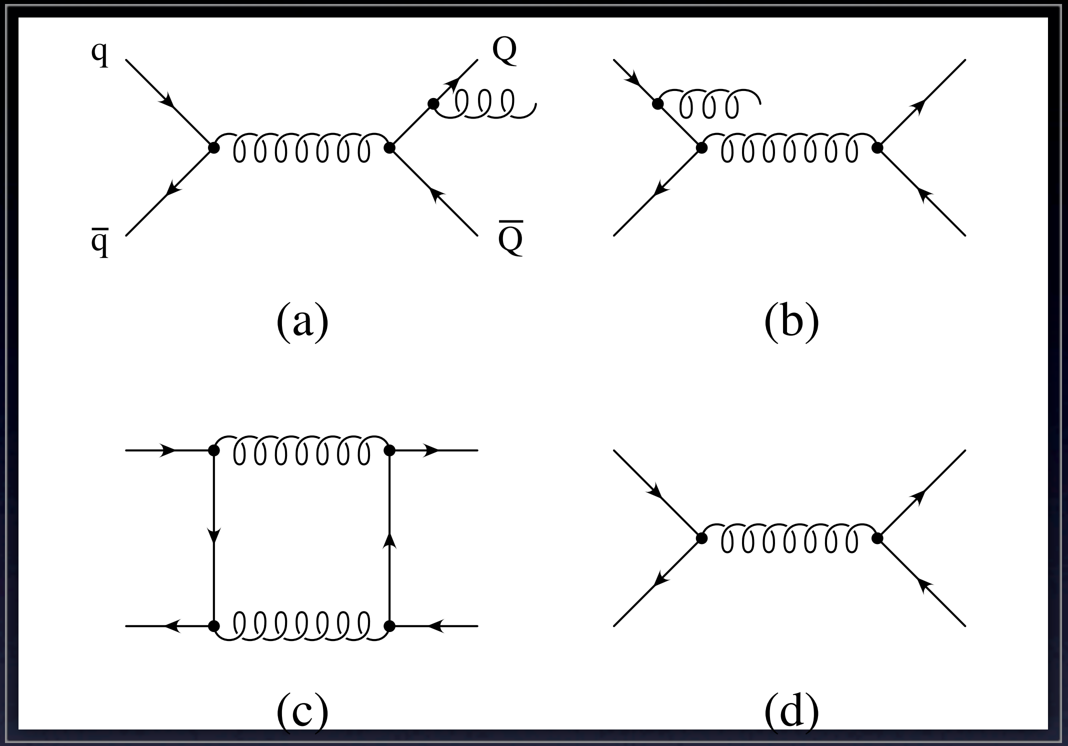
重夸克产生的
微扰QCD预言

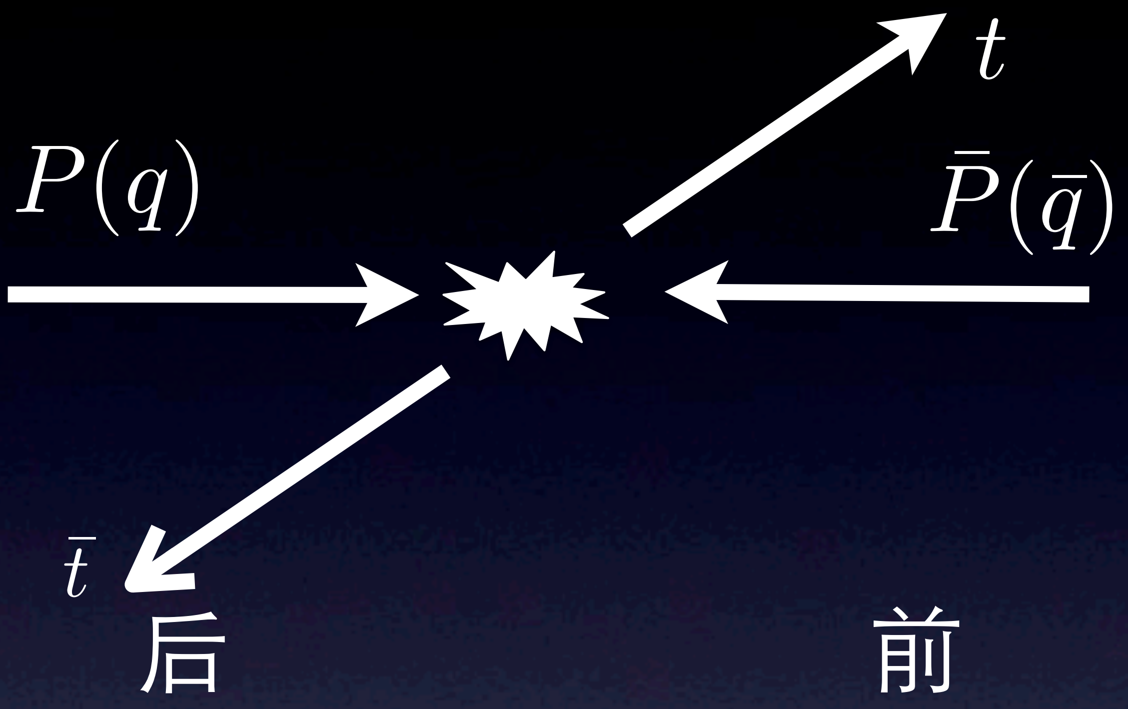
味改变中性流

A_{FB}　$\cancel{CP}$

标准模型中顶夸克前后不对称

- A charge asymmetry arises at NLO



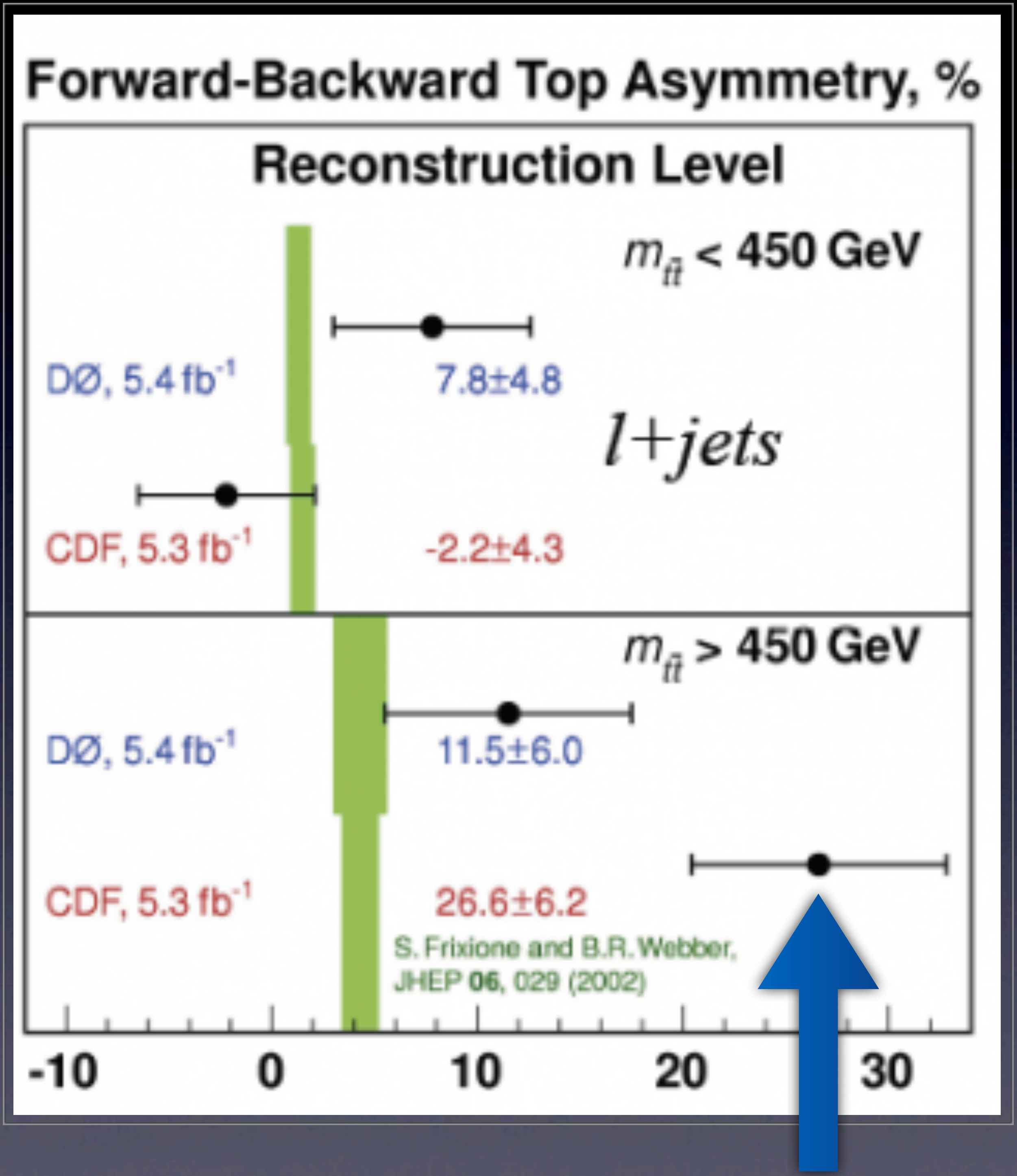


Top quarks are produced along the direction of the incoming quark

$$A^{p\bar p} = \frac{N_t(y>0) - N_{\bar t}(y>0)}{N_t(y>0) + N_{\bar t}(y>0)} = 0.051(6)$$

$$A^{t\bar t} = \frac{N(\Delta y>0) - N(\Delta y<0)}{N(\Delta y>0) + N(\Delta y<0)} = 0.078(9) \quad \Delta y = y_t - y_{\bar t}$$

Top-quark A_{FB} at the Tevatron

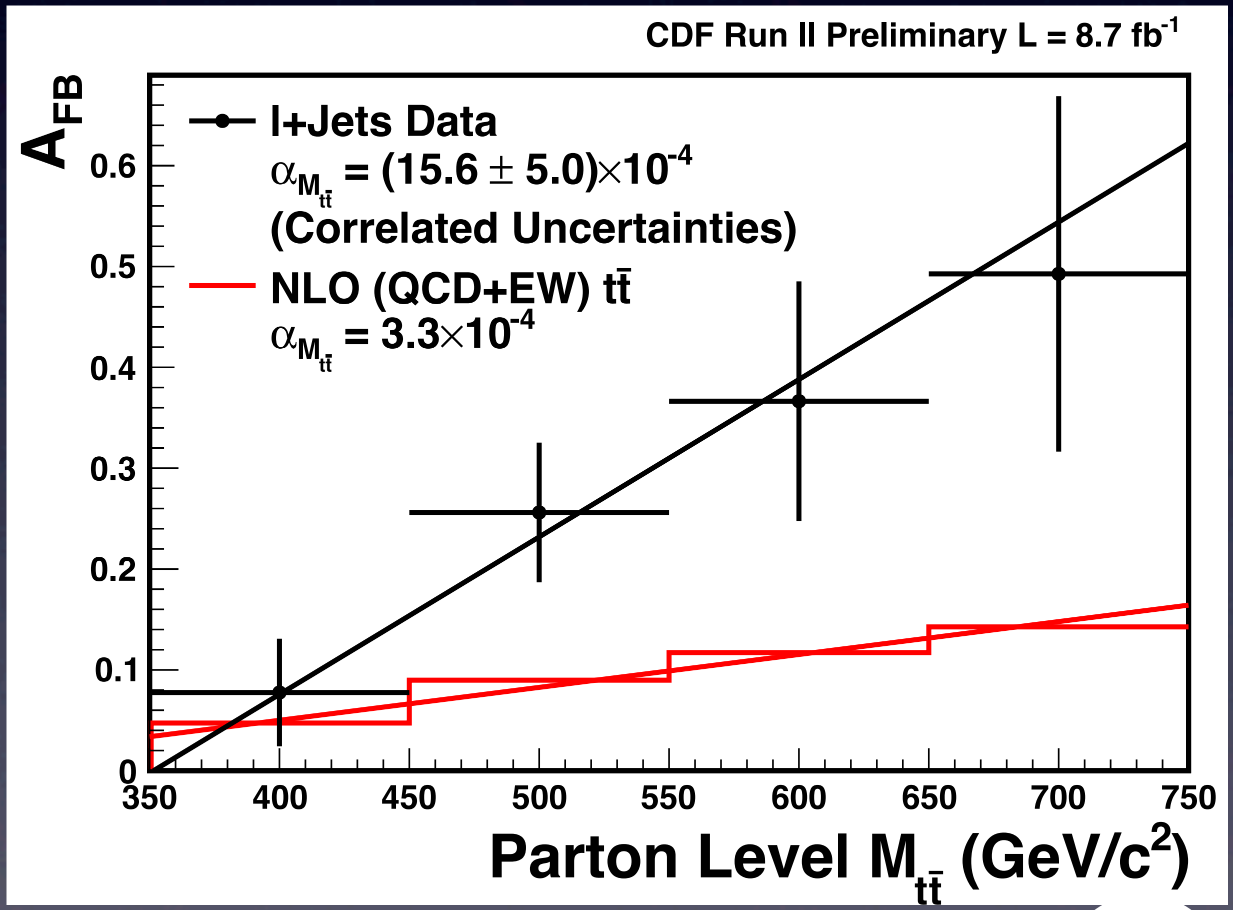


1101.0034 (cited > 240)

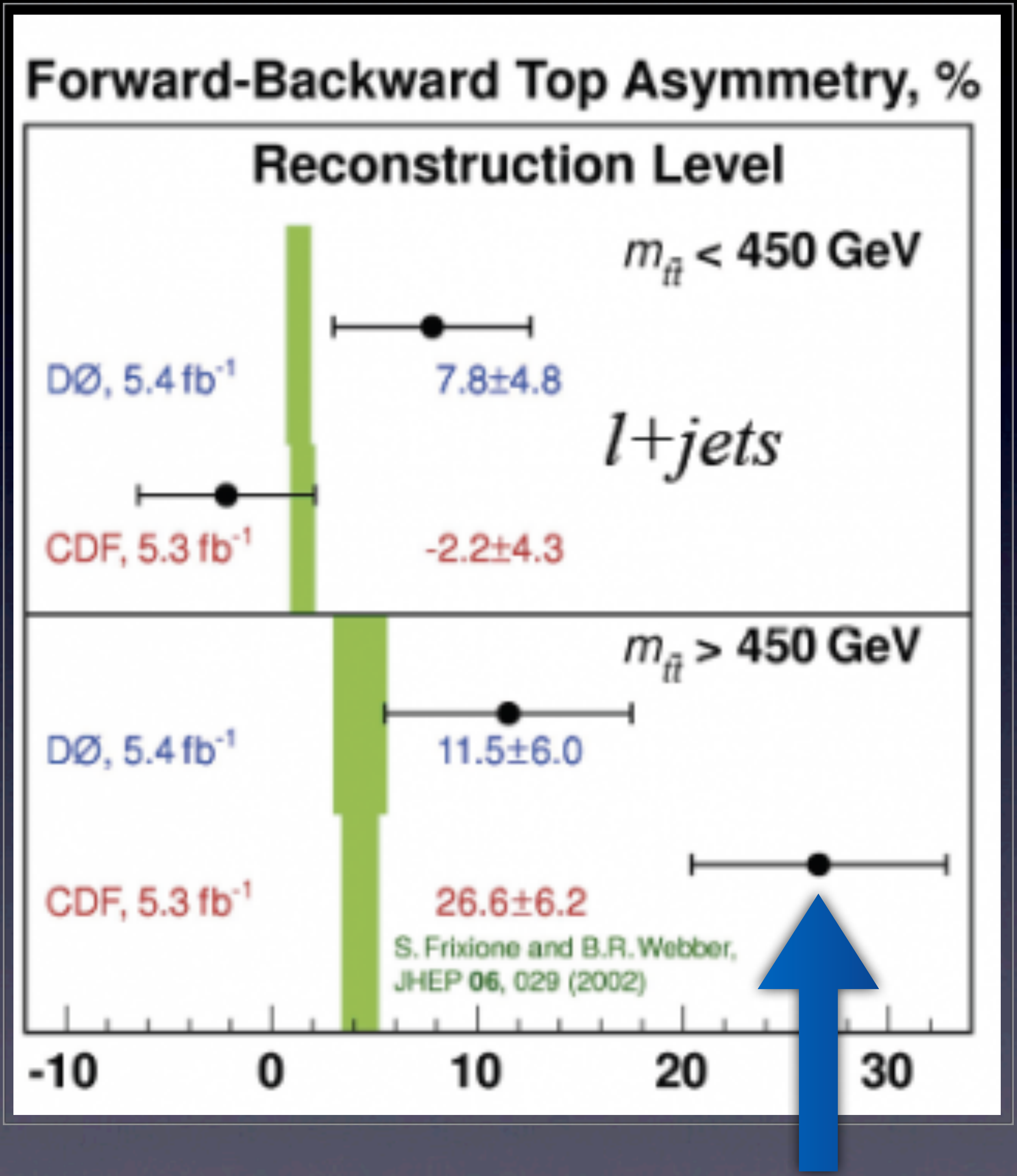
CDF new data (8.7fb^{-1}):

$$A_{FB}^{\text{inclusive}} = 0.162 \pm 0.041 \pm 0.022$$

$$A_{FB}^{\text{NLO+EW}} = 0.066$$



Top-quark A_{FB} at the Tevatron

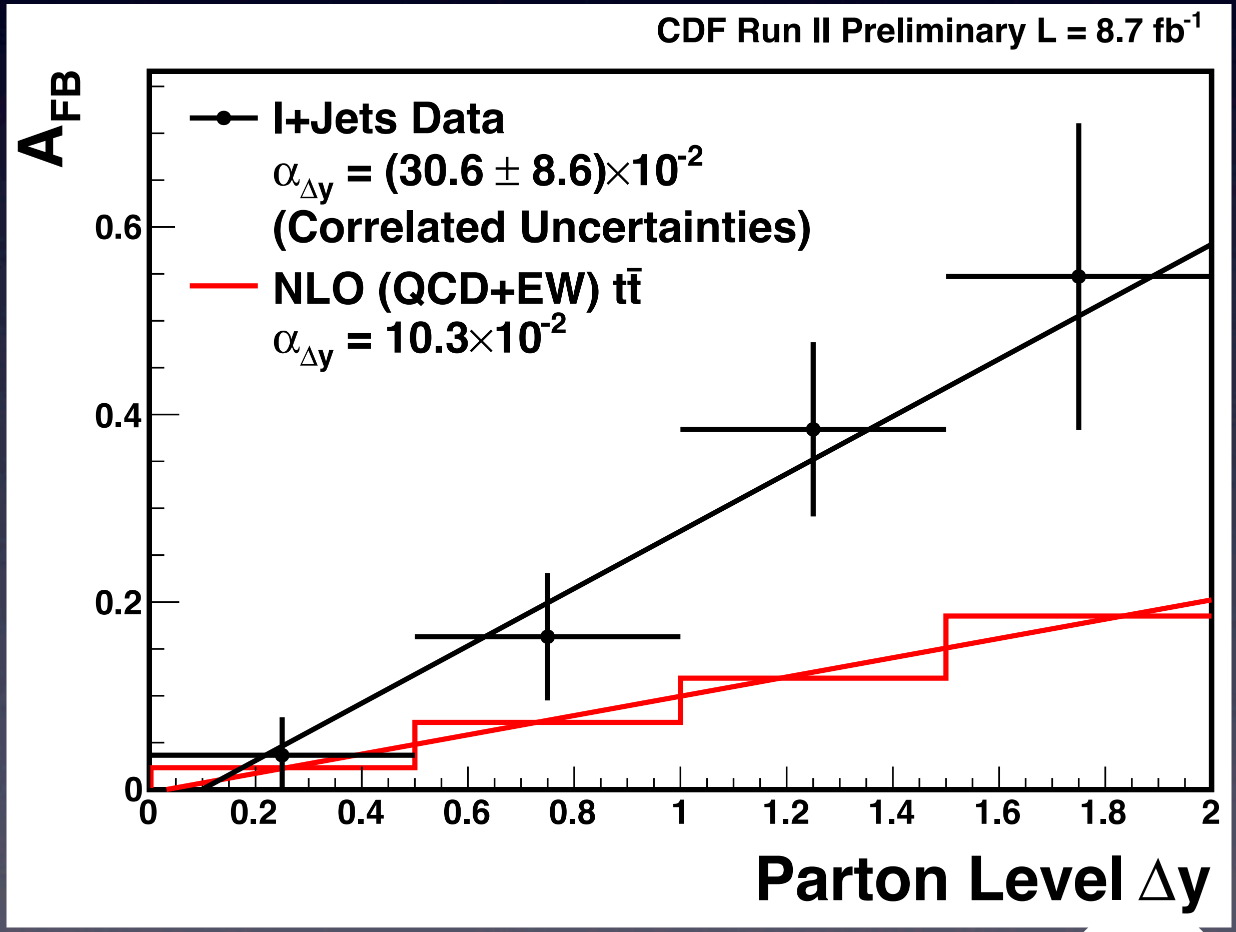


1101.0034 (cited > 240)

CDF new data (8.7fb^{-1}):

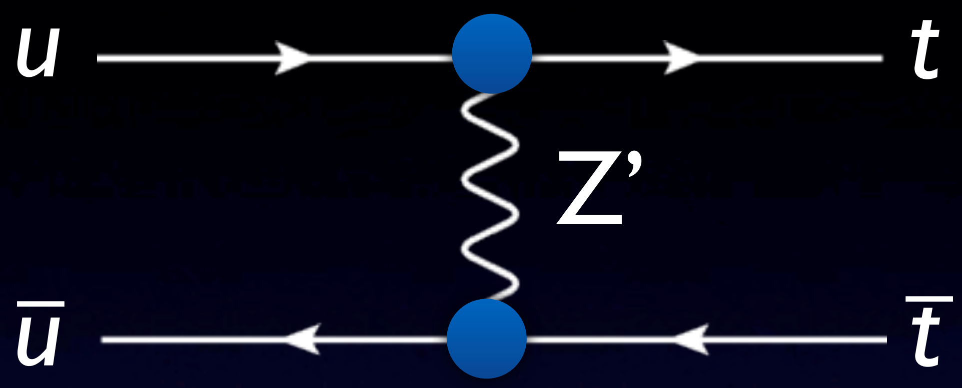
$$A_{FB}^{\text{inclusive}} = 0.162 \pm 0.041 \pm 0.022$$

$$A_{FB}^{\text{NLO+EW}} = 0.066$$



Minimal FCNC Z' is disfavored

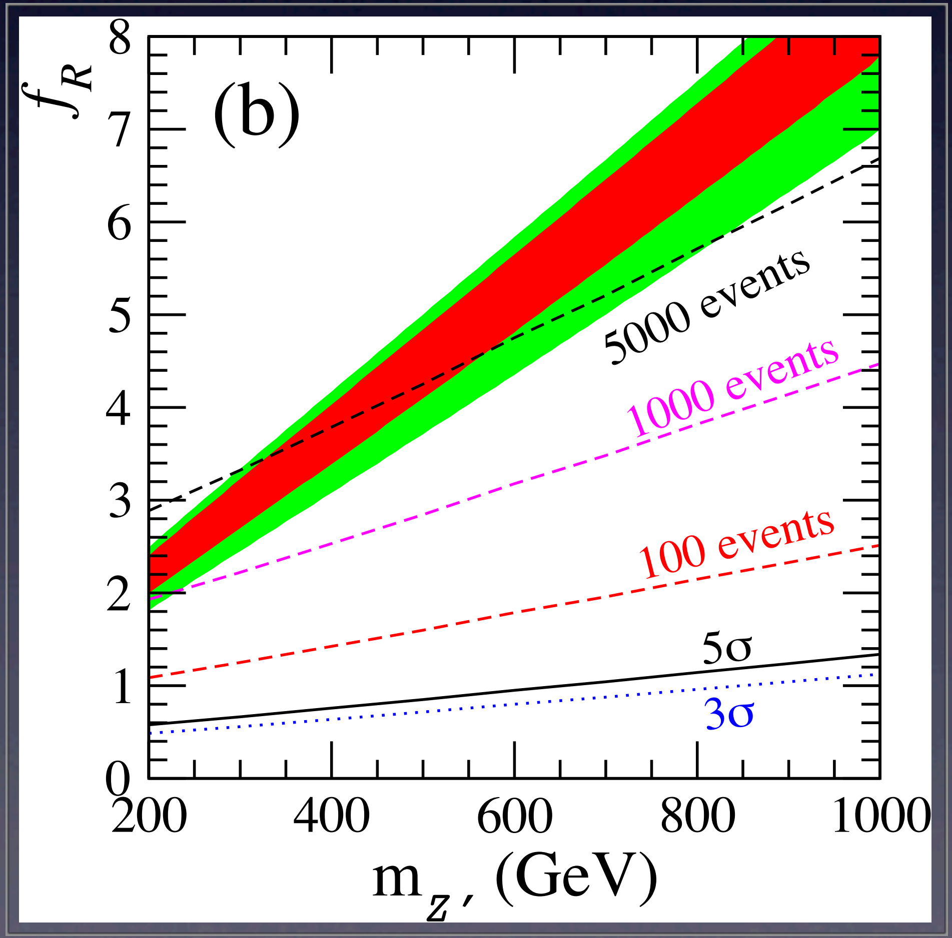
Berger, *Qing-Hong Cao*, Chen, C. S. Li, Zhang, PRL 106 (2011) 201801



$$\mathcal{L} = g\bar{u}\gamma^{\mu}(f_L P_L + f_R P_R)tZ'_{\mu} + h.c.$$

Left-handed coupling is highly constrained by B_d-$\overline{B}_d$ mixing.

A_{FB} prefers a LARGE f_R.



Minimal FCNC Z' is disfavored

Berger, *Qing-Hong Cao*, Chen, C. S. Li, Zhang, PRL 106 (2011) 201801

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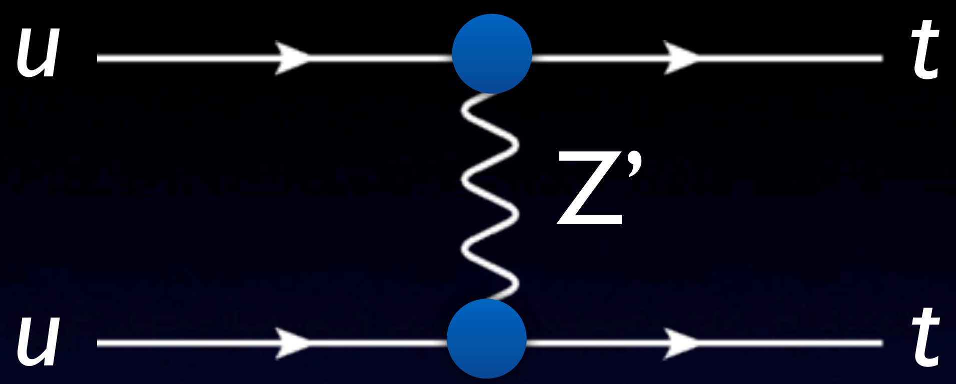

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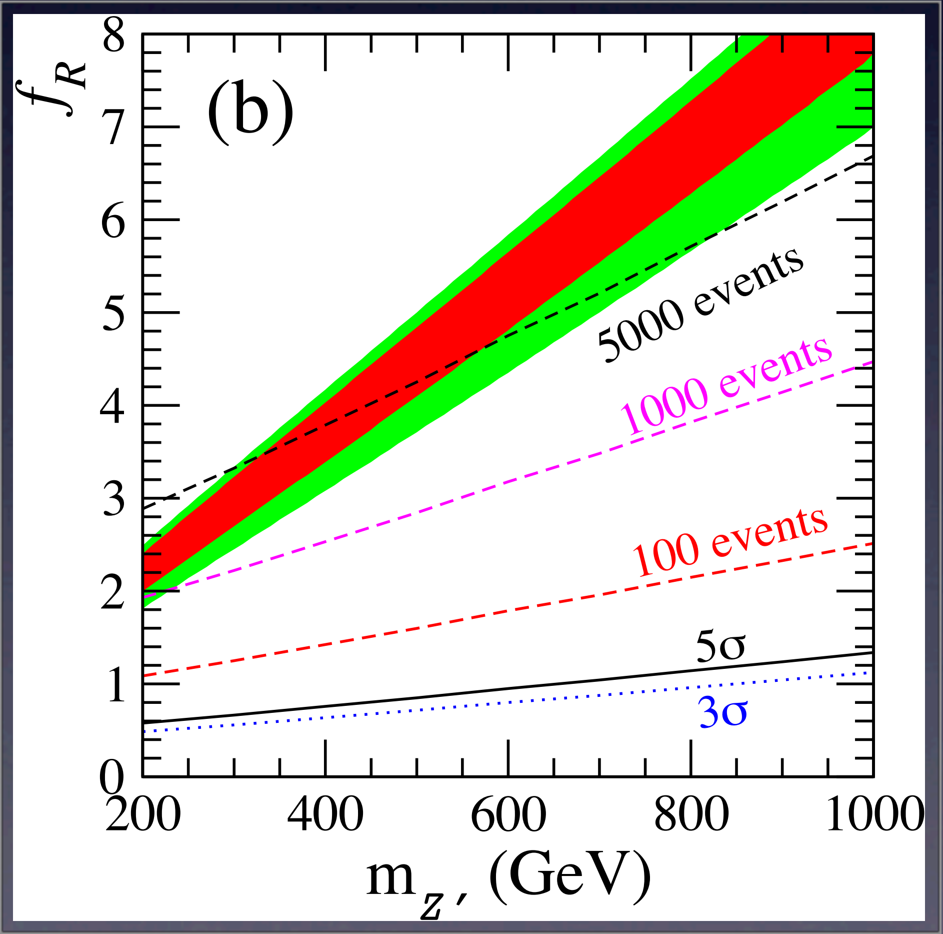
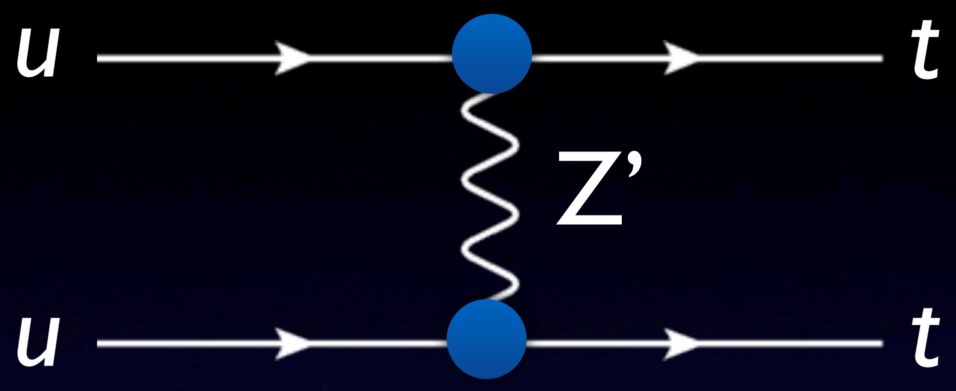


Minimal FCNC Z' is disfavored

Berger, *Qing-Hong Cao*, Chen, C. S. Li, Zhang, PRL 106 (2011) 201801

$$\mathcal{L} = g\bar{u}\gamma^{\mu}(f_L P_L + f_R P_R)tZ'_{\mu} + h.c.$$



Left-handed coupling is highly constrained by B_d-$\overline{B}_d$ mixing.

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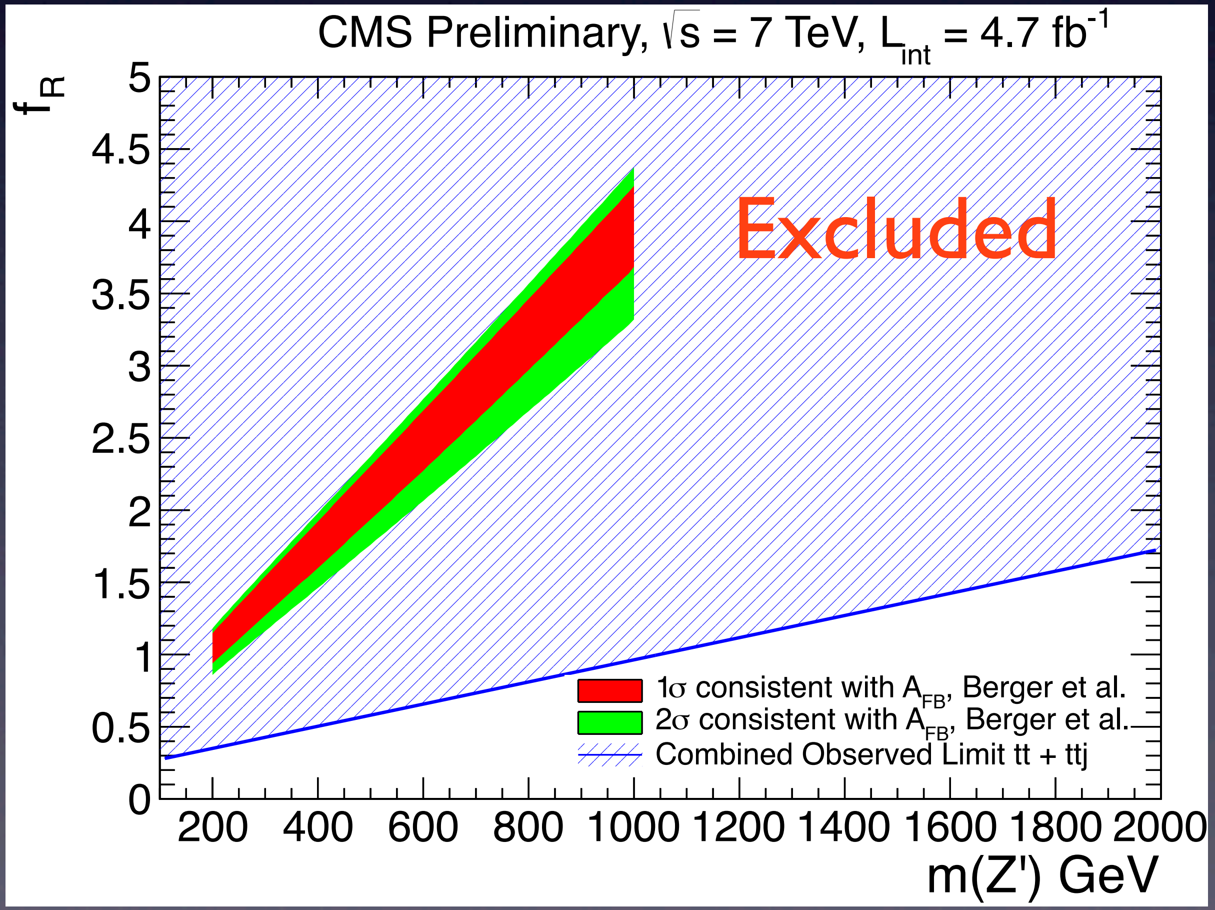
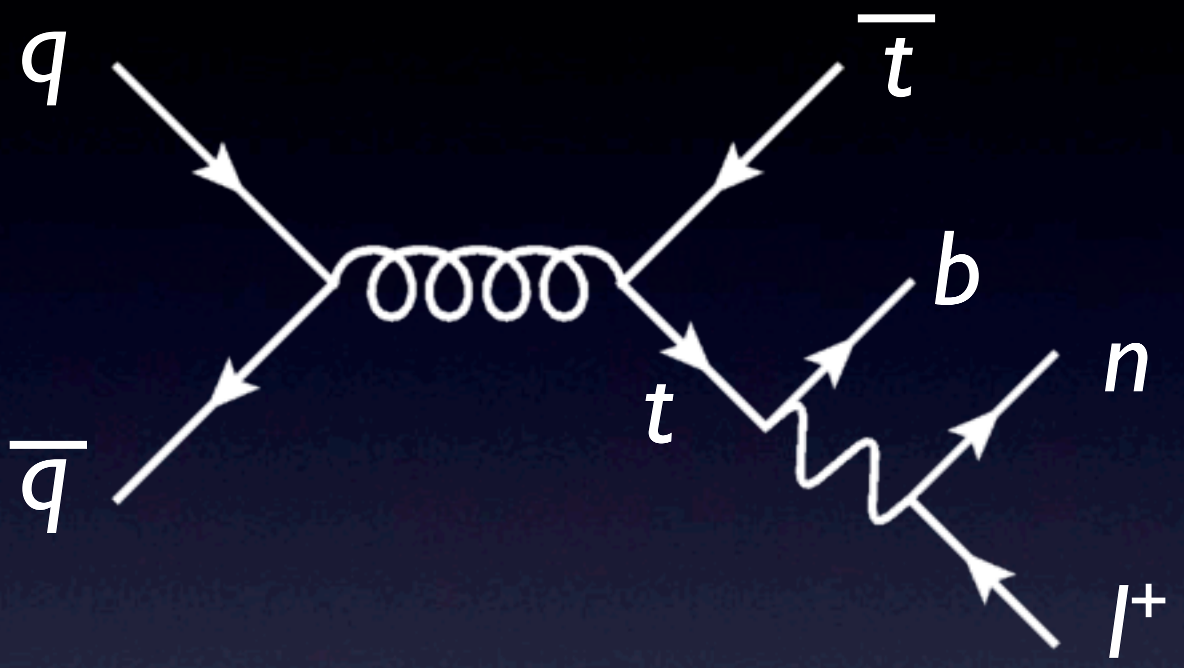


A^{ℓ}_{FB} versus A^{t}_{FB}

- Charged lepton is maximally correlated with top-spin.



Bernreuther, Zong-Guo Si, NPB837 (2010) 90

SM: $A^{t}_{FB} = 0.051 \pm 0.001$

$A^{\ell}_{FB} = 0.021 \pm 0.001$

$$\left.\frac{A^{\ell}_{FB}}{A^{t}_{FB}}\right|_{\rm SM} \sim \frac{1}{2}$$

D0: $A^{t}_{FB} = 0.196 \pm 0.065$

$A^{\ell}_{FB} = 0.152 \pm 0.040$

$$\left.\frac{A^{\ell}_{FB}}{A^{t}_{FB}}\right|_{\rm D0} \sim \frac{3}{4}$$

CDF: $A^{t}_{FB} = 0.085 \pm 0.025$

(8.7fb^{-1}) $A^{\ell}_{FB} = 0.066 \pm 0.025$

(Before unfolding)

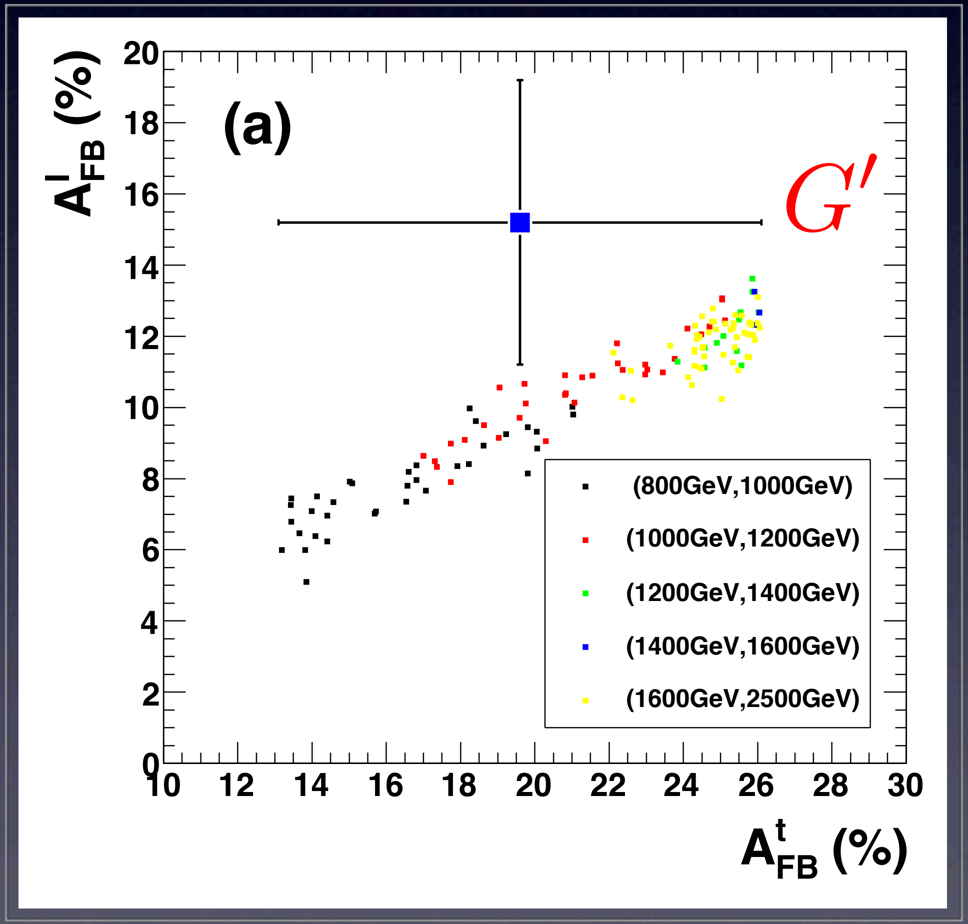
$$\left.\frac{A^{\ell}_{FB}}{A^{t}_{FB}}\right|_{\rm inc} \sim \frac{3}{4} \qquad \left.\frac{A^{\ell}_{FB}}{A^{t}_{FB}}\right|_{>450} \sim \frac{3}{5}$$

A^{ℓ}_{FB} versus A^{t}_{FB}

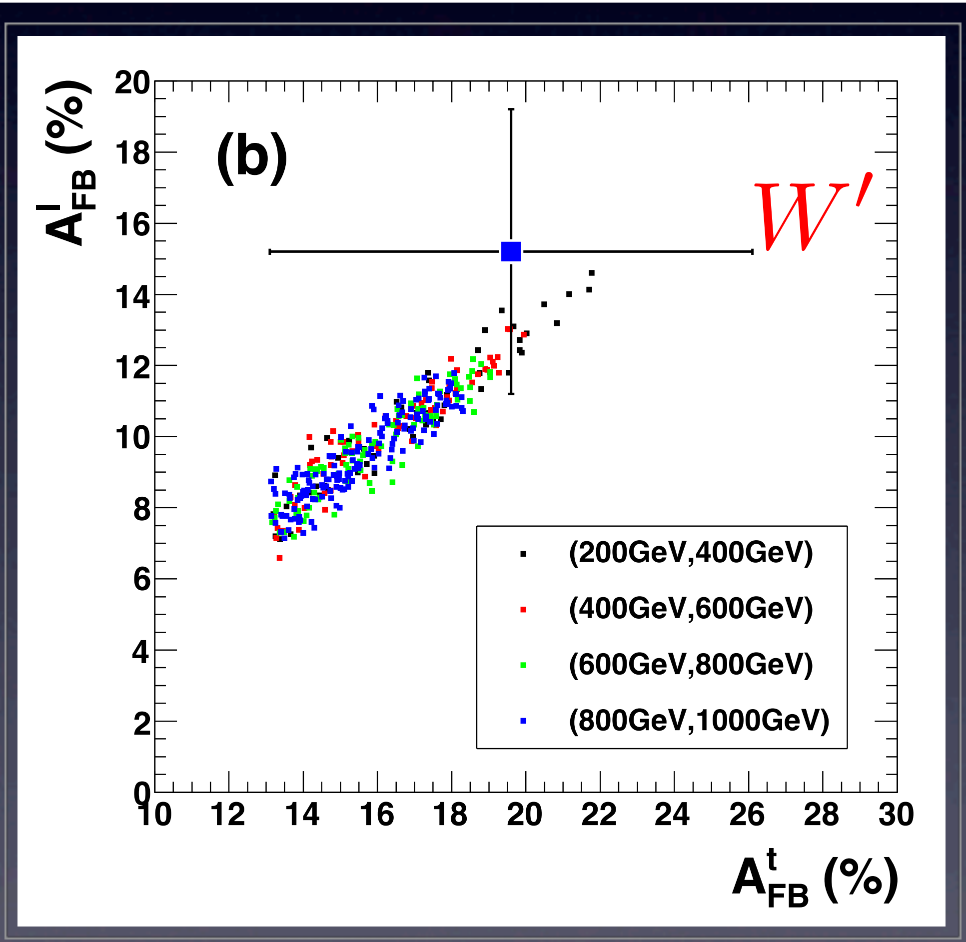
Berger, *Qing-Hong Cao*, Chen, Yu, Zhang, PRL 108 (2012) 072002

- A^{t}_{FB} and A^{ℓ}_{FB} is connected by the top-quark and charged lepton spin correlation.

$$\boxed{A^{\ell}_{FB} \approx \rho_{t_L} A^{t_L}_{FB} \times \left(2\mathcal{R}^{t_L}_{F} - 1\right) + \rho_{t_R} A^{t_R}_{FB} \times \left(2\mathcal{R}^{t_R}_{F} - 1\right)}$$



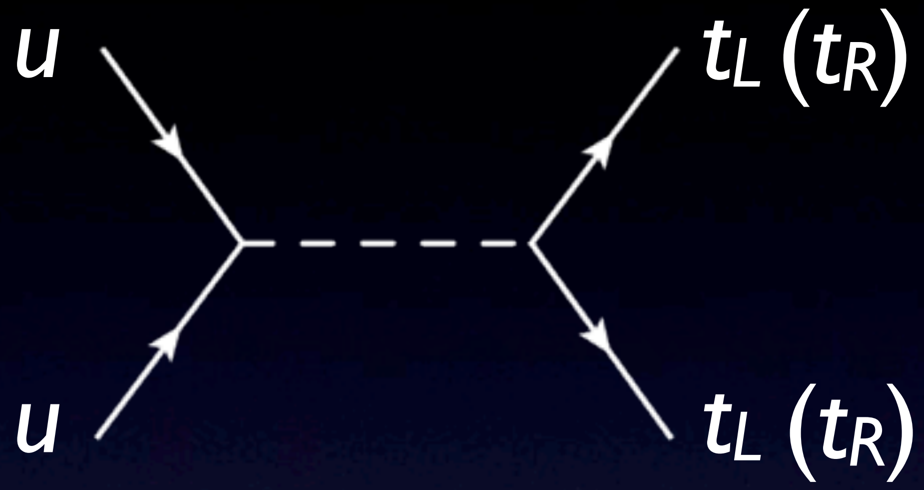
$$A^{\ell}_{FB} \simeq 0.47 \times A^{t}_{FB} + 0.25\%$$



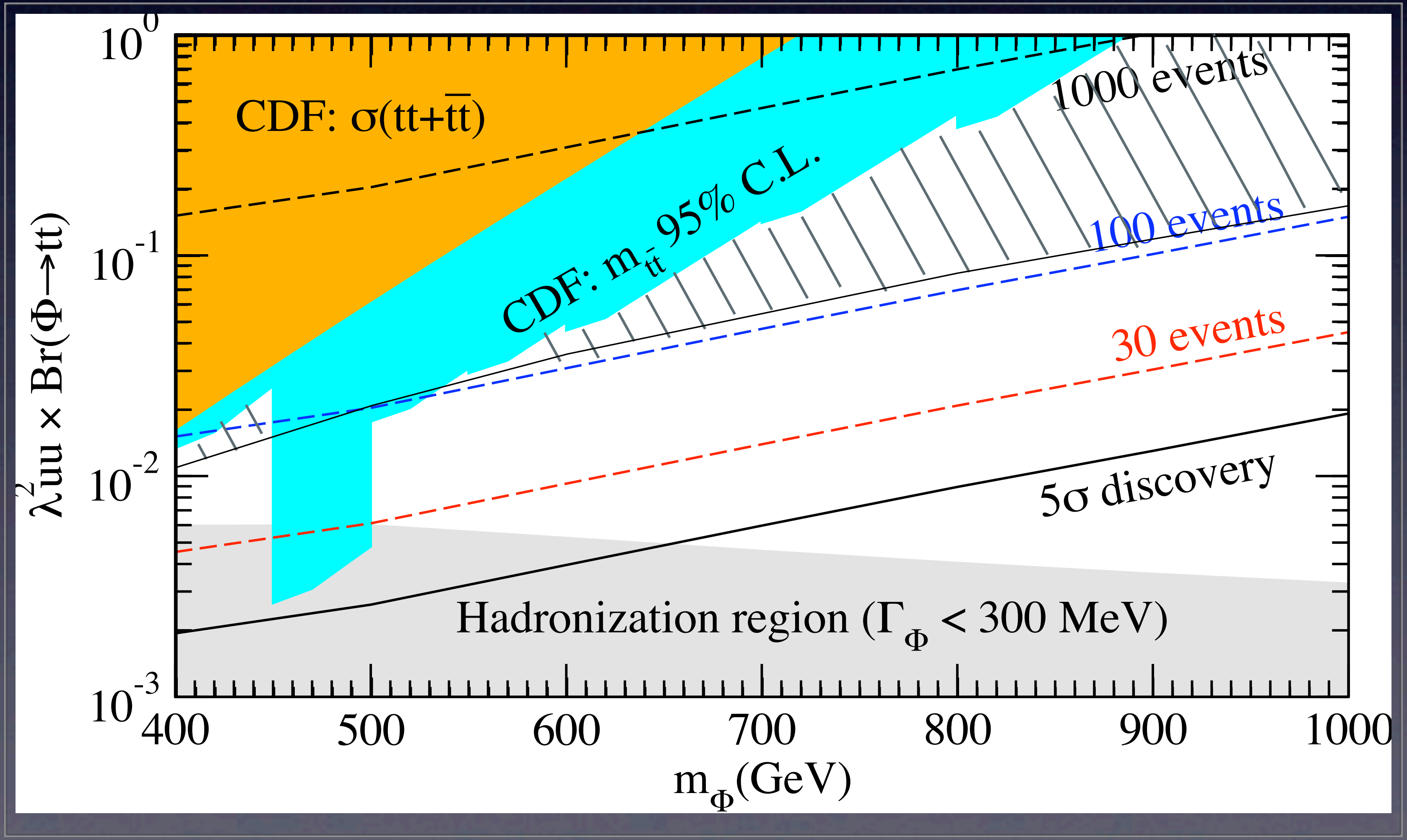
$$A^{\ell}_{FB} \simeq 0.75 \times A^{t}_{FB} - 2.1\%$$

Color sextet scalar and same-sign top pair

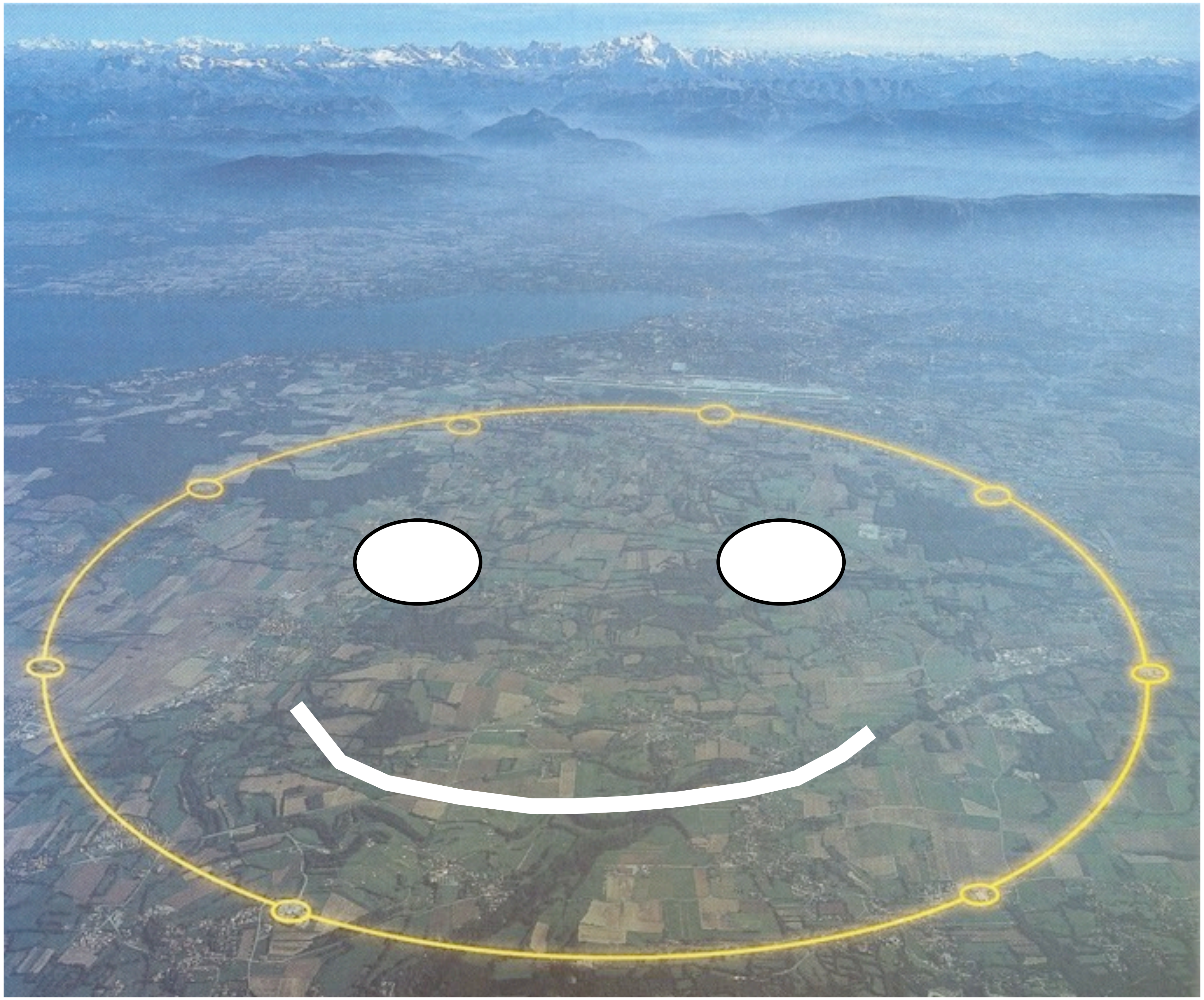
Berger, *Qing-Hong Cao*, Chen, Shaughnessy, Zhang, PRL 105 (2010) 181802



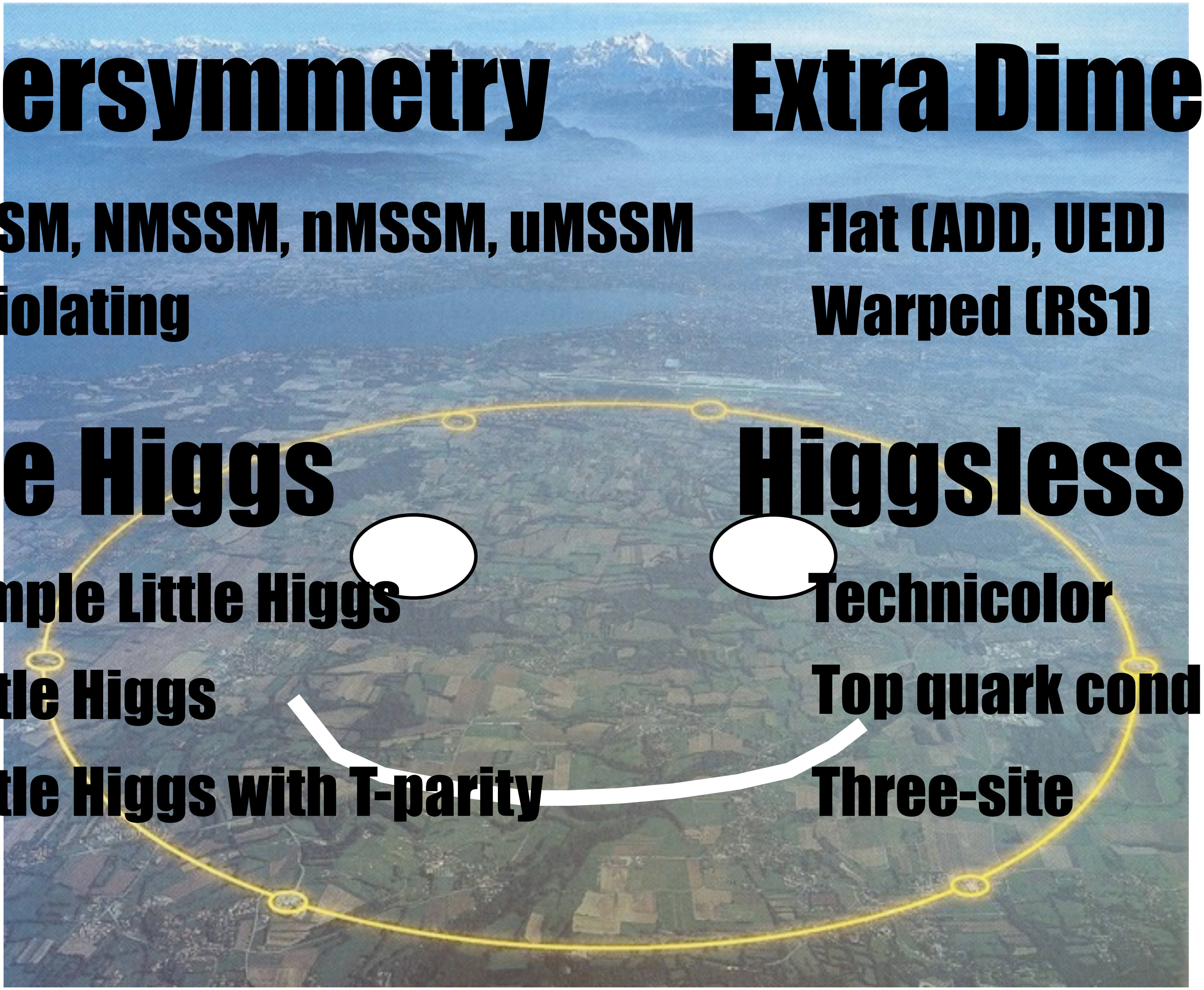
$$3 \otimes 3 = 6 \oplus \bar{3}$$



总结：粒子物理新时代



总结：粒子物理新时代



Supersymmetry

MSSM, NMSSM, nMSSM, uMSSM

R-violating

Extra Dimension

Flat (ADD, UED)

Warped (RS1)

Little Higgs

Simple Little Higgs

Little Higgs

Little Higgs with T-parity

Higgsless

Technicolor

Top quark condensate

Three-site

谢谢！