顶夸克极化和TeV能区新物理

曹庆宏

理论物理研究所

报告基于以下工作:

Phys. Rev. Lett. 109 (2012) 152004
Phys. Rev. Lett. 108 (2012) 072002
Phys. Rev. Lett. 106 (2011) 201801

合作者:

Ed Berger, Chuan-Ren Chen, Chong Sheng Li, Jiang-Hao Yu, Hao Zhang

粒子物理的标准模型

已知基本粒子谱

夸克

轻子

u c t γ 电磁

d s b g 强

ν_e ν_μ ν_τ W 弱

e μ τ Z

自旋1/2 自旋1

希格斯粒子

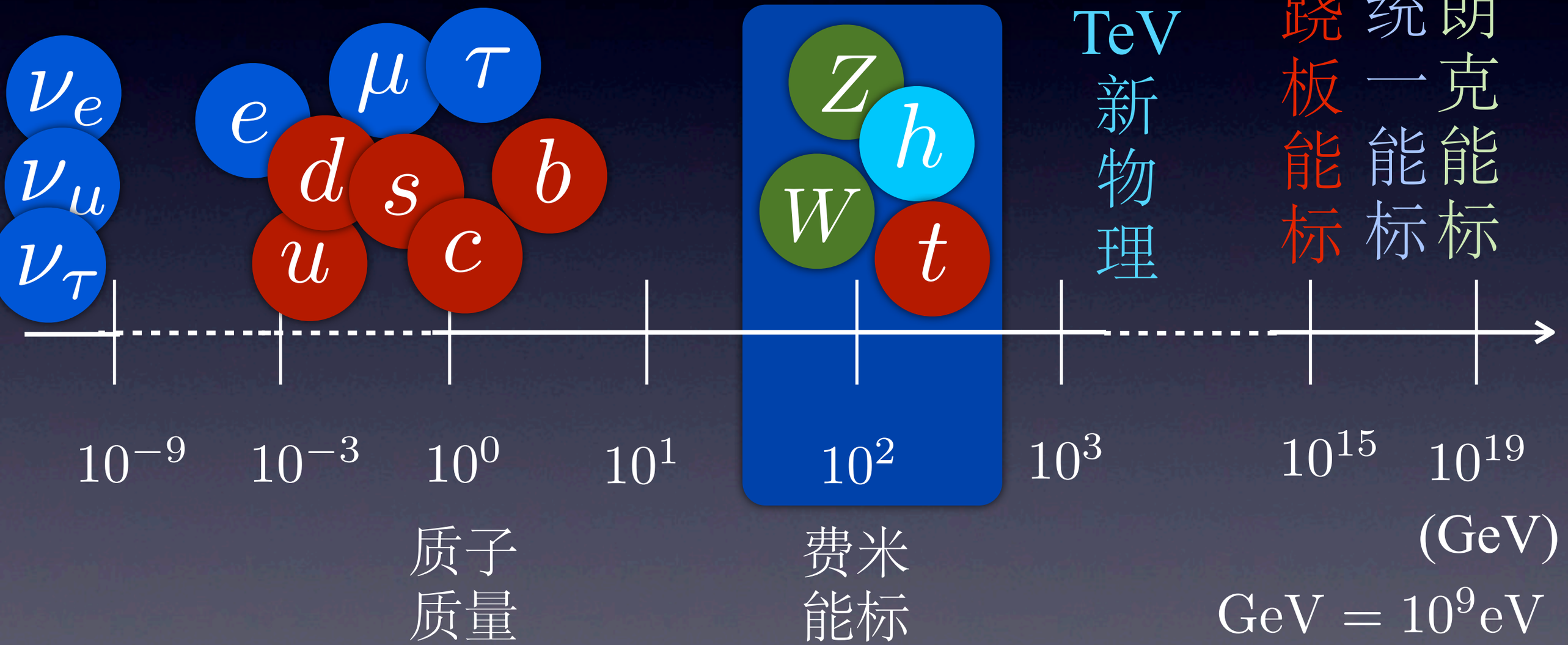
h 自旋0

SU(3) x SU(2) x U(1)
规范对称性

标准模型的两大疑难

<u>电弱对称性破缺起源</u> 和 <u>味对称性破缺起源</u>

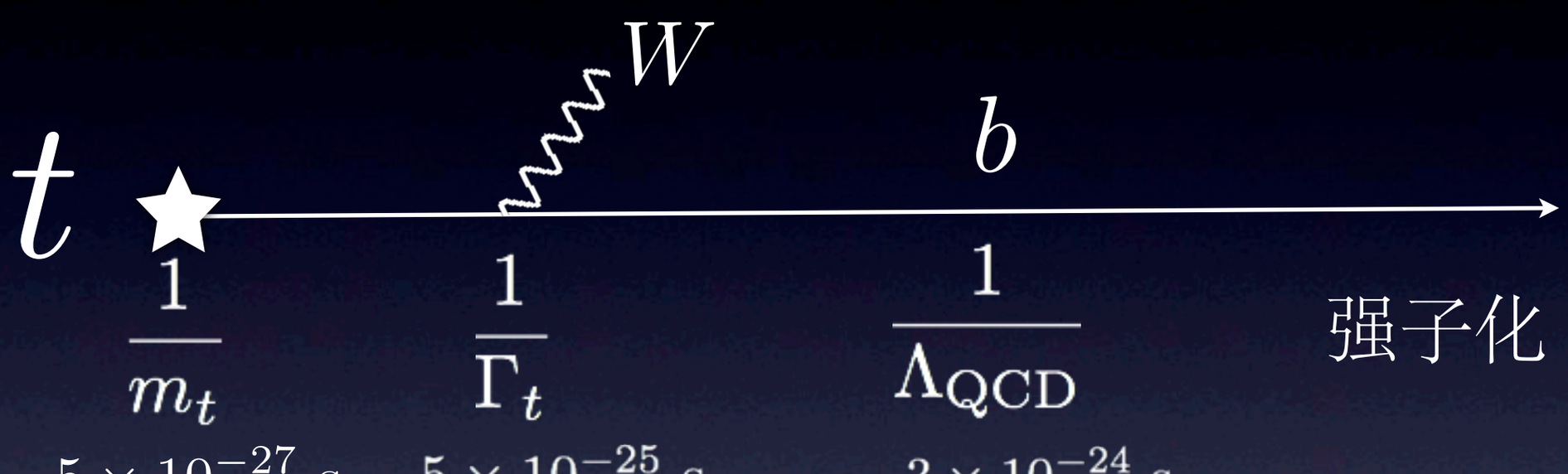
（W 和 Z 质量）　　（费米子质量）



顶夸克或许是我们和新物理间的唯一联系

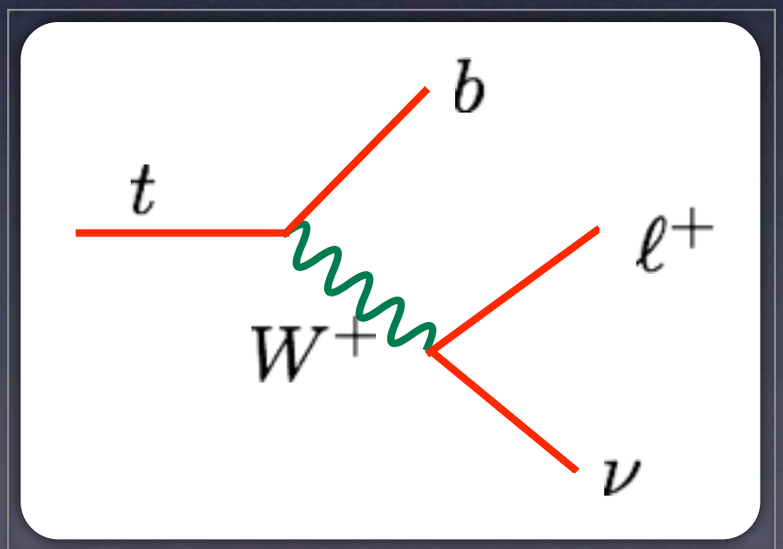
顶夸克: 标准模型中唯一裸夸克

顶夸克寿命非常短



5×10^{-27} s　　5×10^{-25} s　　3×10^{-24} s

顶夸克的自旋信息
完好地保存在
顶夸克衰变产物中

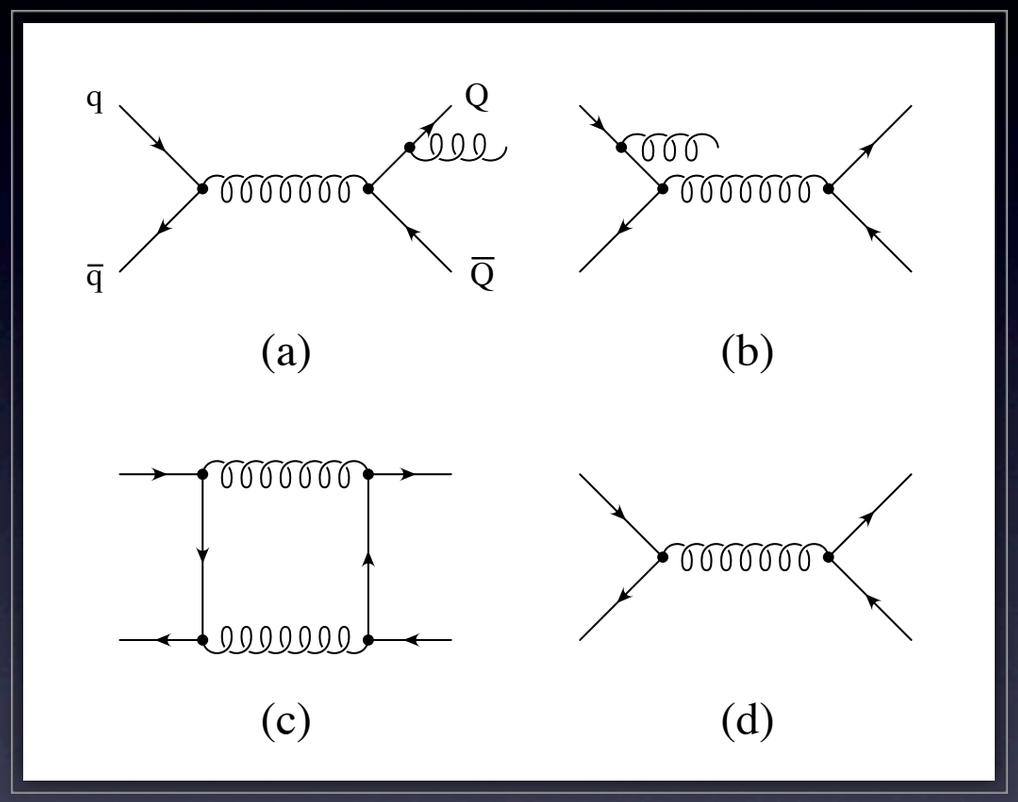


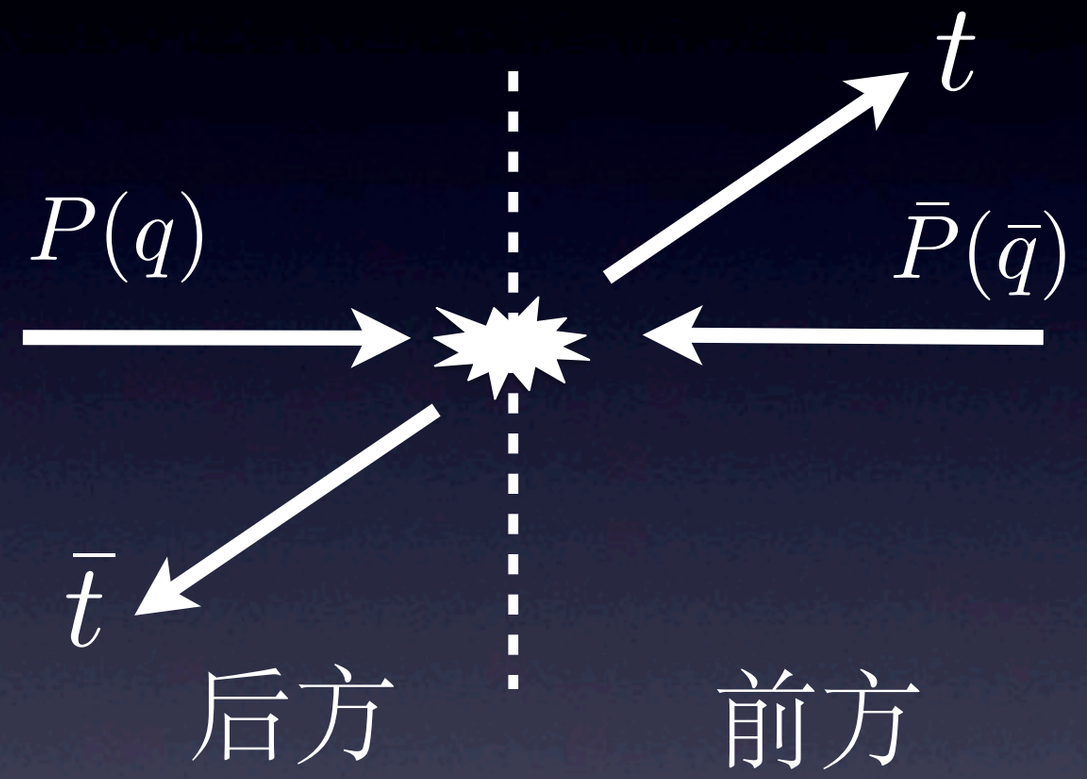
带电轻子倾向于沿着顶夸克自旋方向出射

Tevatron的顶夸克前后不对称性

2011年国际热点

在标准模型中仅在量子辐射修正水平上出现

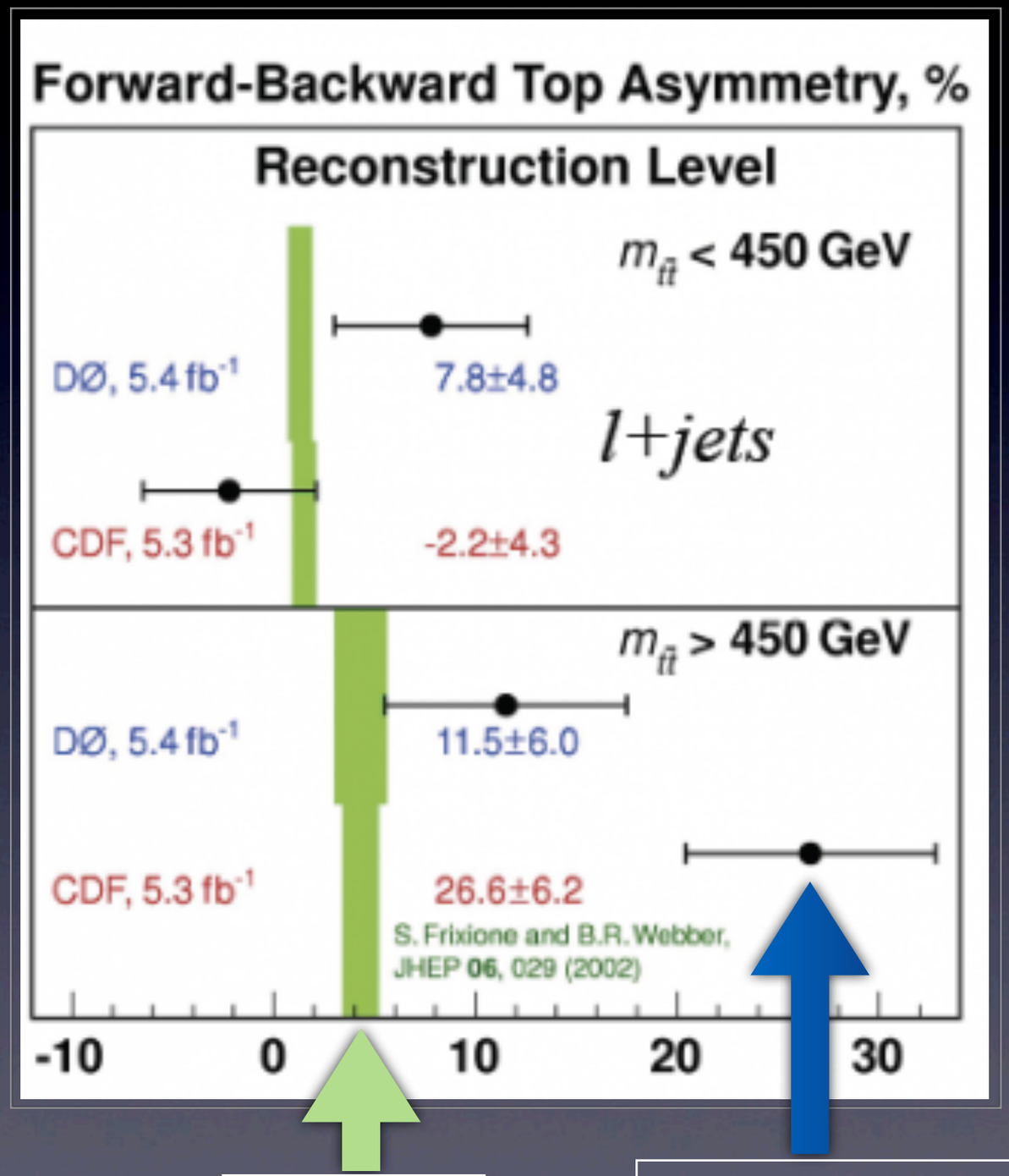




$$A^{p\bar{p}} = \frac{N_t(y>0) - N_{\bar{t}}(y>0)}{N_t(y>0) + N_{\bar{t}}(y>0)} = 0.051(6)$$

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

Tevatron的顶夸克前后不对称性



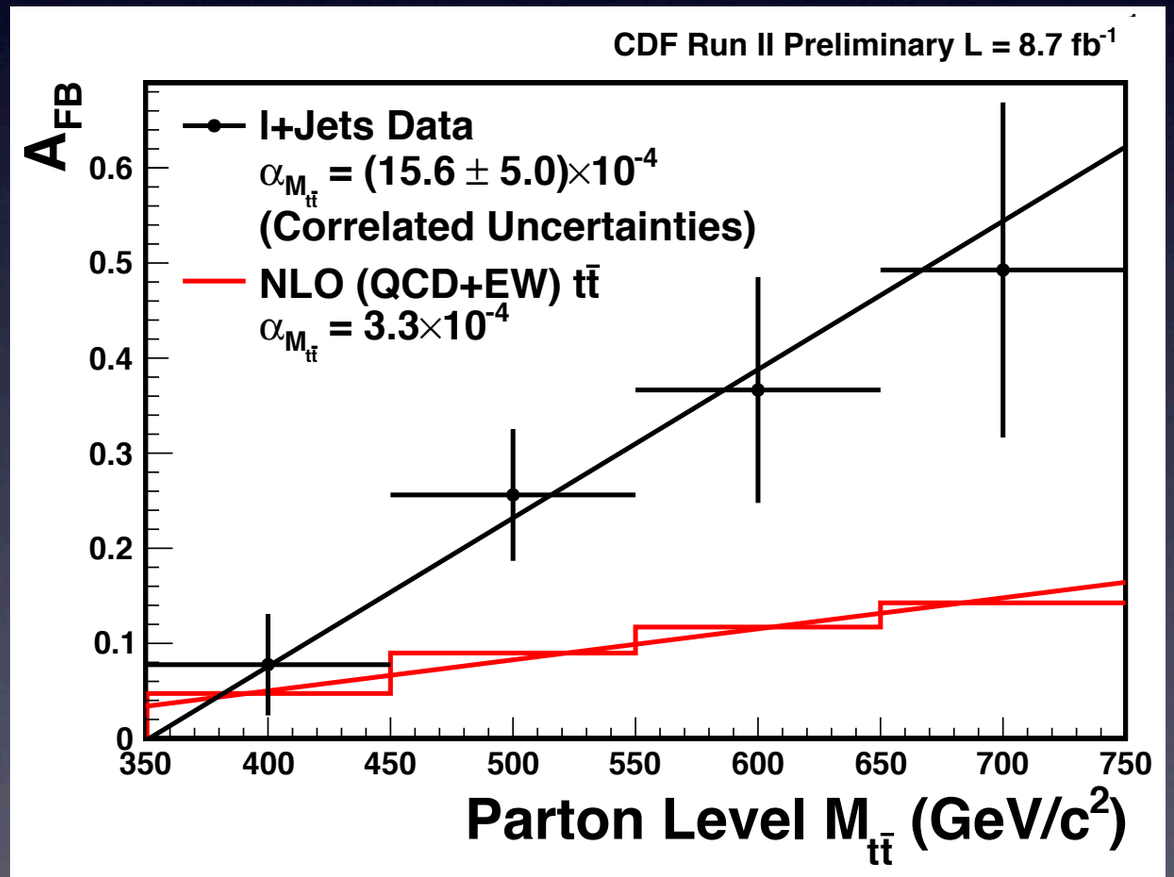
标准模型预言值

CDF: 1101.0034

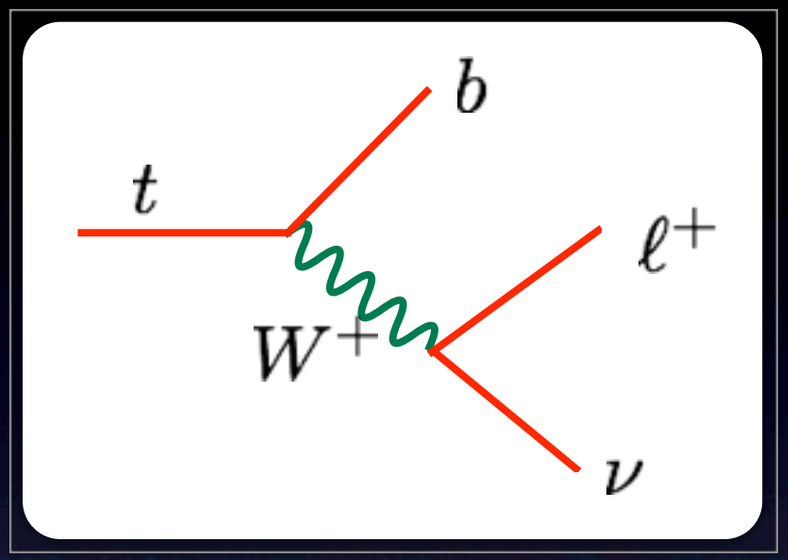
CDF (8.7fb^{-1}):

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

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



带电轻子的前后不对称性A_{FB}^{ℓ}



A^t_{FB}和A^ℓ_{FB}的关联

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: $A^t_{FB} = 0.085 \pm 0.025$

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

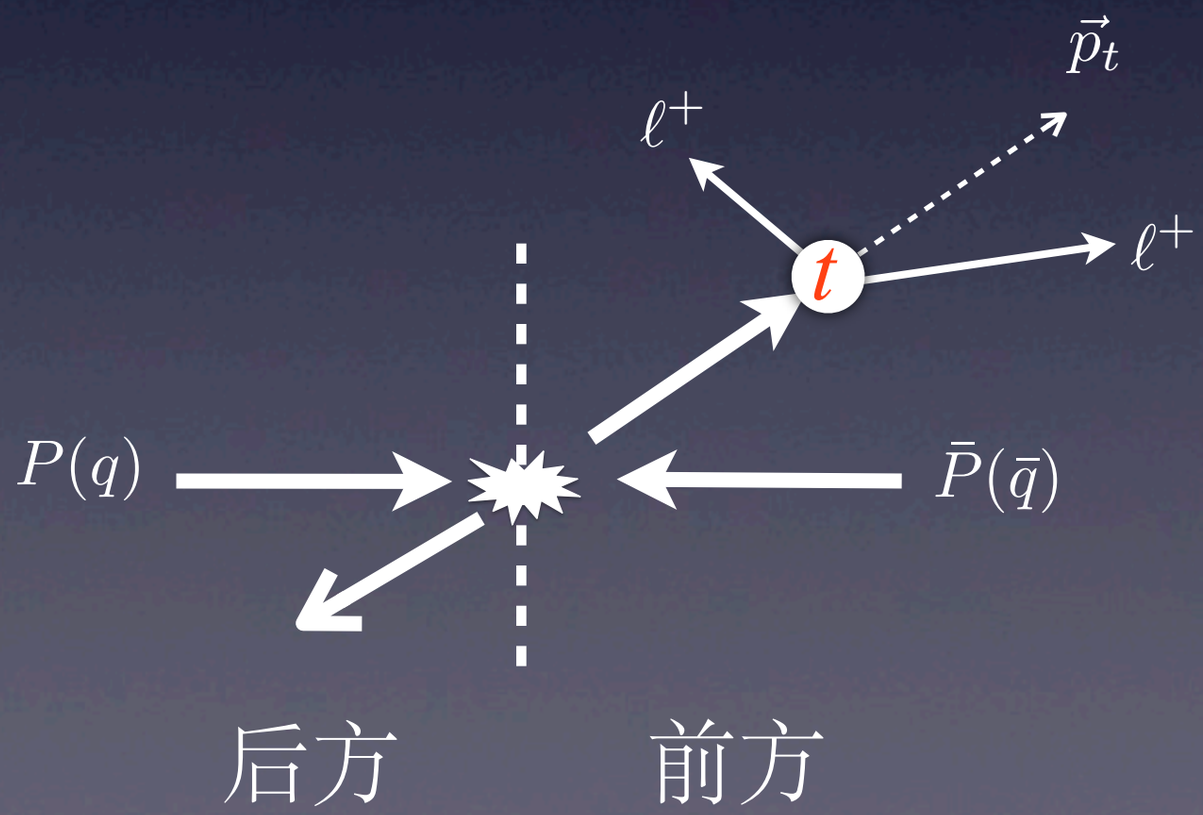
$$\left.\frac{A^\ell_{FB}}{A^t_{FB}}\right|_{\rm inc} \sim \frac{3}{4} \qquad \left.\frac{A^\ell_{FB}}{A^t_{FB}}\right|_{>450} \sim \frac{3}{5}$$

标准模型理论预言:

$A^t_{FB} = 0.051 \pm 0.001$

$A^\ell_{FB} = 0.021 \pm 0.001$

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



A_{FB}^{t} 和 A_{FB}^{ℓ} 的关联

源于顶夸克极化和带电轻子的自旋关联效应

Phys. Rev. Lett. 108 (2012) 072002

$$A_{FB}^{\ell} \approx \rho_{t_L} A_{FB}^{t_L} \times \underbrace{\left(2\mathcal{R}_C^{t_L} - 1\right)}_{0} + \rho_{t_R} A_{FB}^{t_R} \times \underbrace{\left(2\mathcal{R}_C^{t_R} - 1\right)}_{1}$$

$$A_{FB}^{t} \approx \left[\rho_{t_L}\ A_{FB}^{t_L} + \rho_{t_R}\ A_{FB}^{t_R}\right]$$

标准模型：$\rho_{t_L} = \rho_{t_R} = \frac{1}{2}$

$$A_{FB}^{t_L} = A_{FB}^{t_R}$$

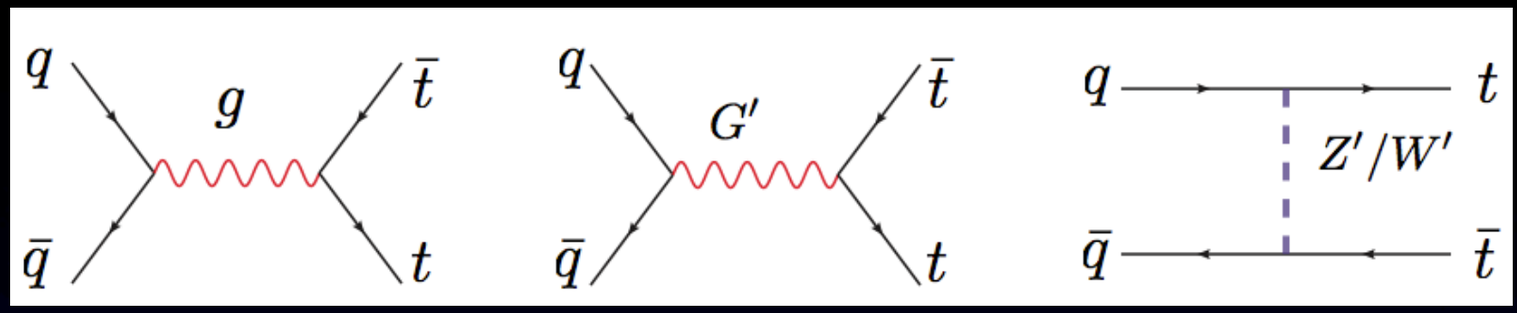
$$\rightarrow \left.\frac{A_{FB}^{\ell}}{A_{FB}^{t}}\right|_{\mathrm{SM}} \sim \frac{1}{2}$$

精简的解析表达式

$$R_F^{\lambda_t}(\beta, y_t) = \begin{cases} \dfrac{1}{2} + \dfrac{1}{2\left(1+\gamma^{-2}\coth^2 y_t\right)^{1/2}} + \dfrac{\lambda_t \coth^2 y_t}{4\beta\gamma^2\left(1+\gamma^{-2}\coth^2 y_t\right)^{3/2}}, & (y_t > 0) \\ \dfrac{1}{2} - \dfrac{1}{2\left(1+\gamma^{-2}\coth^2 y_t\right)^{1/2}} - \dfrac{\lambda_t \coth^2 y_t}{4\beta\gamma^2\left(1+\gamma^{-2}\coth^2 y_t\right)^{3/2}}, & (y_t < 0) \end{cases}$$

顶夸克A_{FB}的新物理解释

三类
新物理
模型

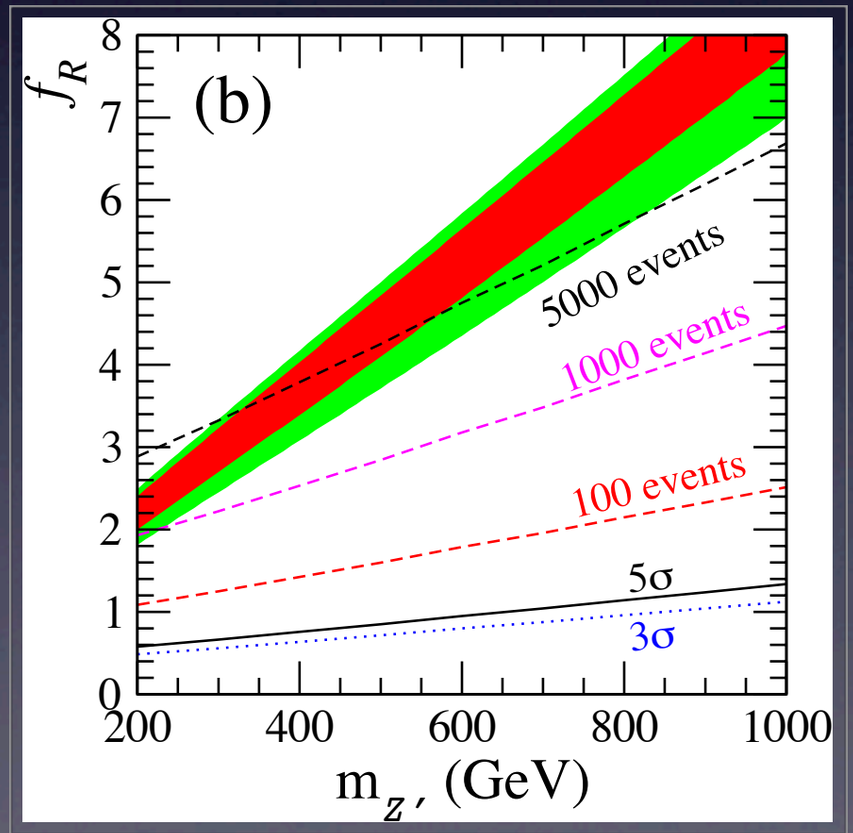


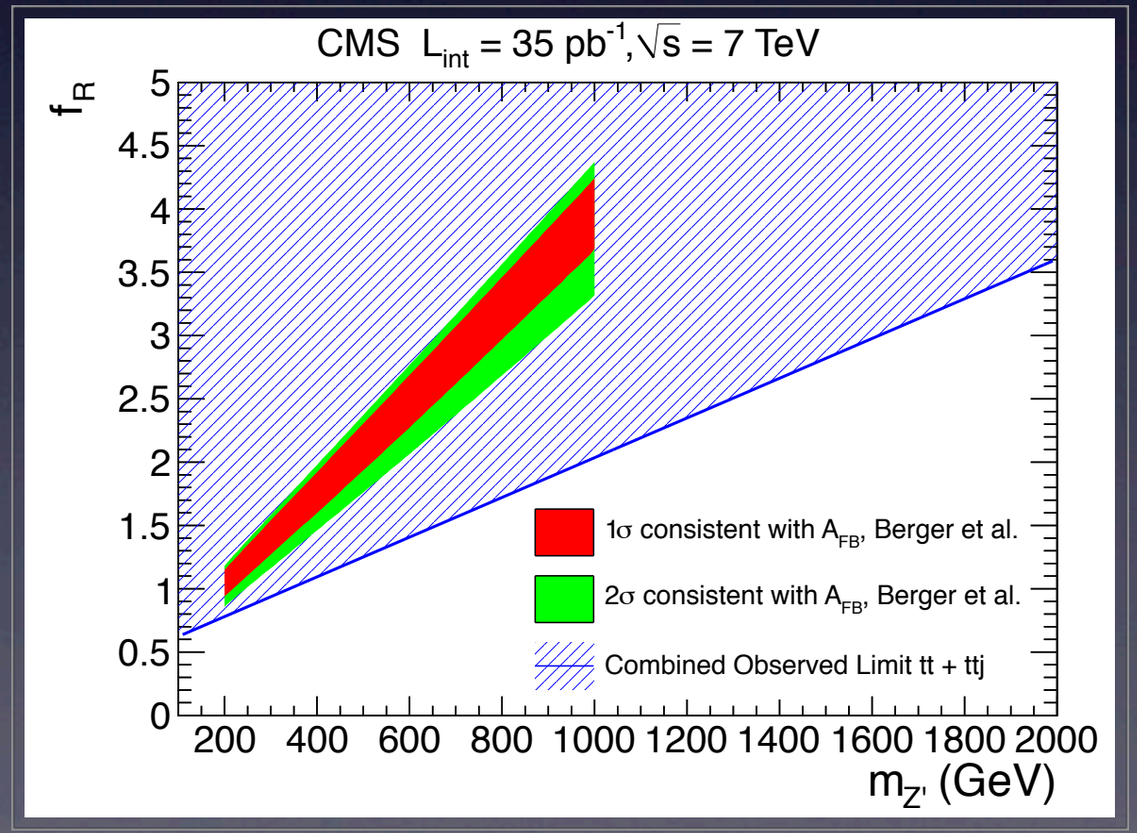
标准模型
胶子

味守恒的
新轴矢胶子

味改变的
新玻色子

味改变中性流
Z-prime
已被CMS
实验排除





Phys. Rev. Lett. 106 (2011) 201801

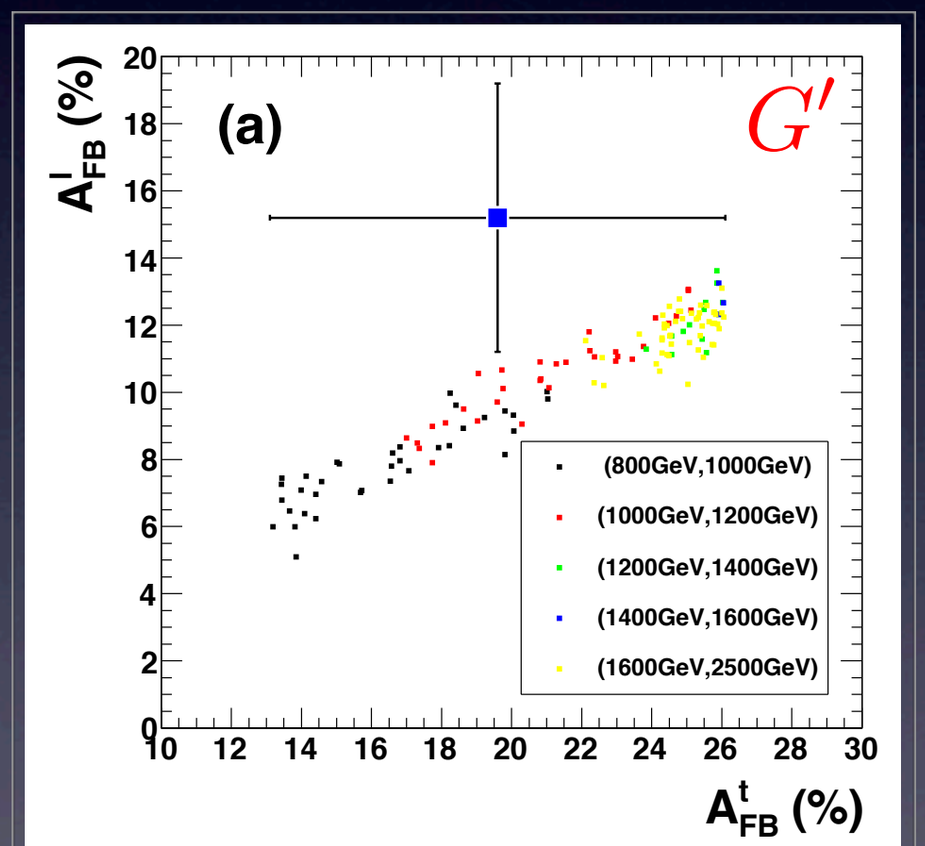
CMS实验组
JHEP 1108 (2011) 005

A^t_{FB} 和 A^ℓ_{FB} 的关联

源于顶夸克极化和带电轻子的自旋关联效应

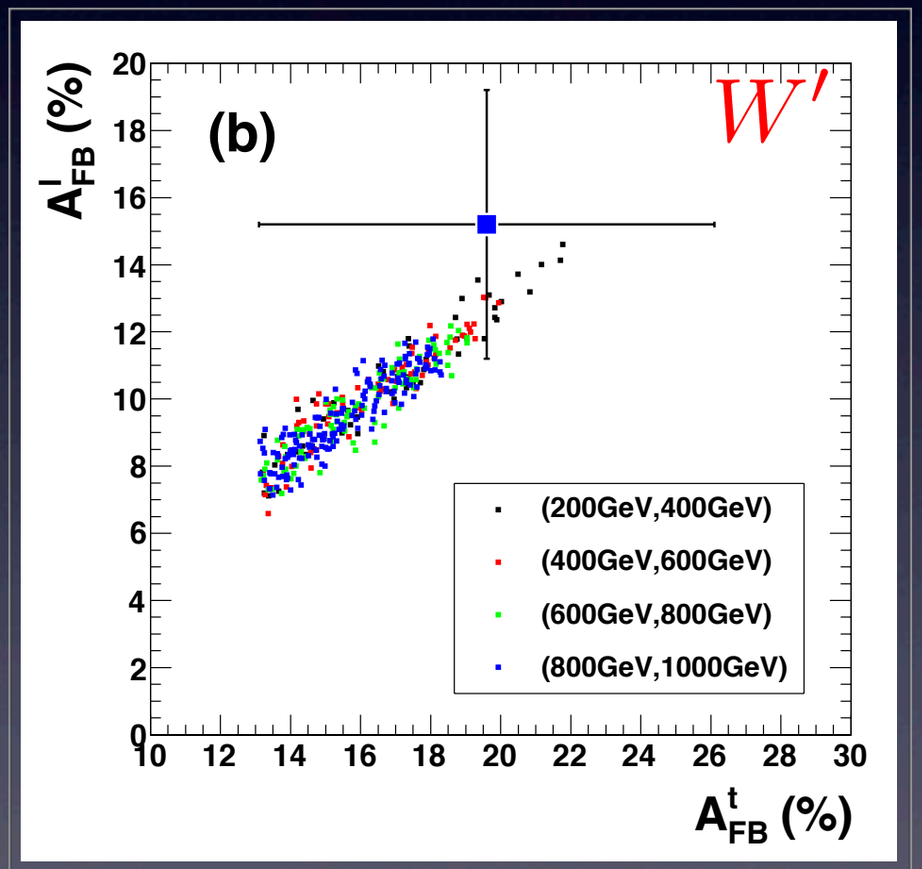
Phys. Rev. Lett. 108 (2012) 072002

无极化的顶夸克



$$A^\ell_{FB} \simeq \frac{1}{2} \times A^t_{FB}$$

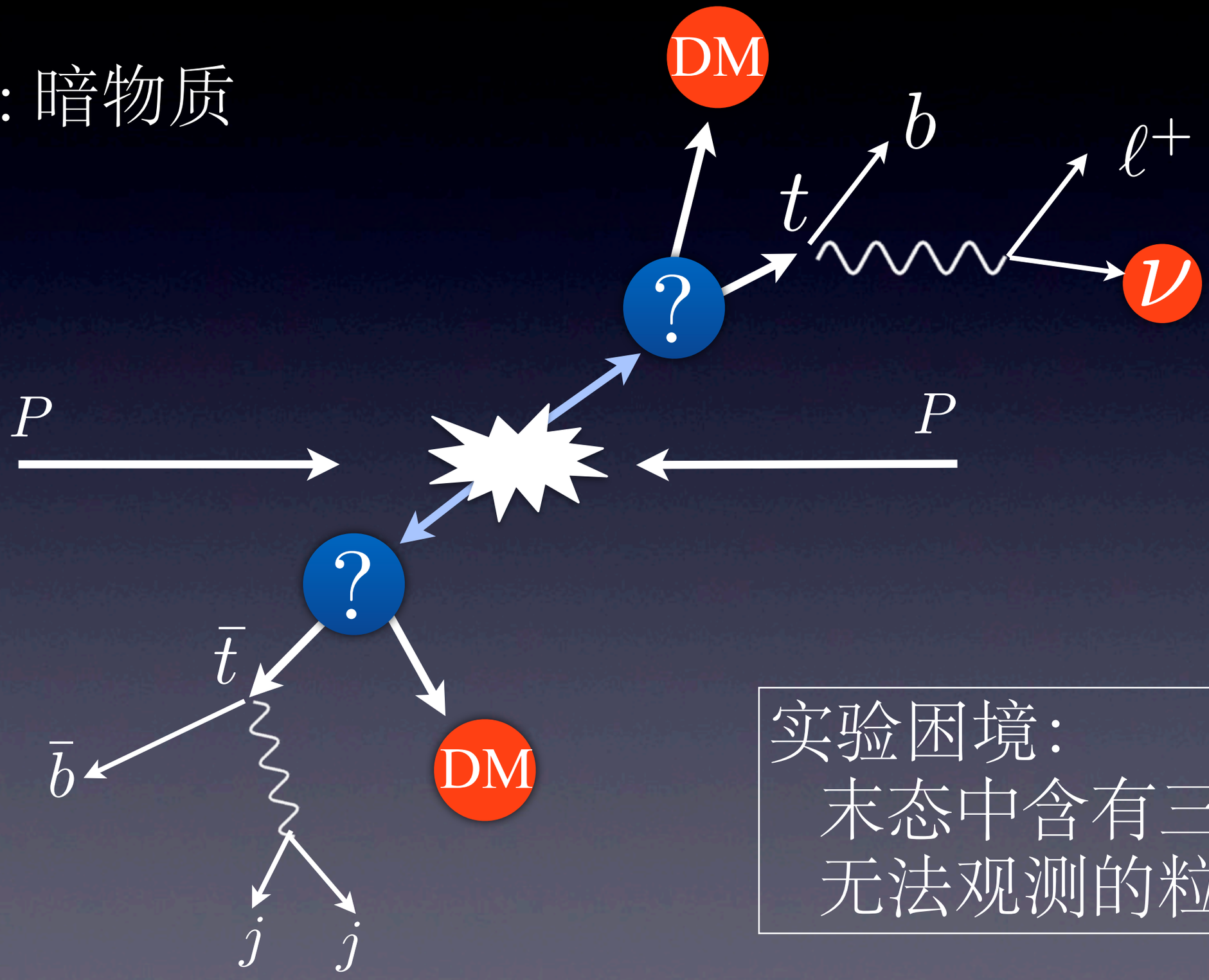
右手极化的顶夸克



$$A^\ell_{FB} \simeq \frac{3}{4} \times A^t_{FB}$$

顶夸克对和暗物质联合产生

DM: 暗物质



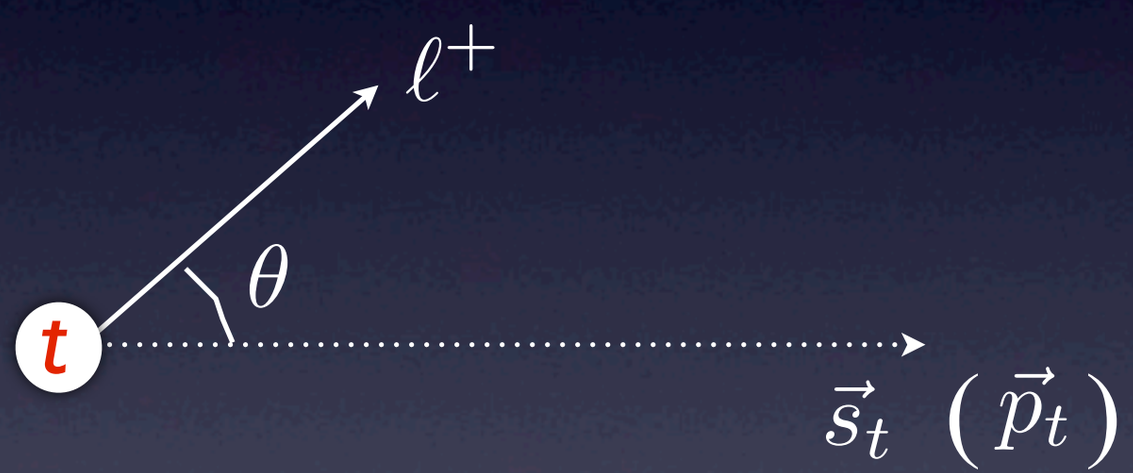
实验困境：
末态中含有三个
无法观测的粒子

带电轻子的能量和空间角分布

在顶夸克静止系中

$$\frac{d\Gamma}{dx\,d\cos\theta} = \frac{\alpha_W^2 m_t}{32\pi AB} x(1-x)\,\mathrm{Arctan}\left[\frac{Ax}{B-x}\right] \frac{1+s_t\cos\theta}{2}$$

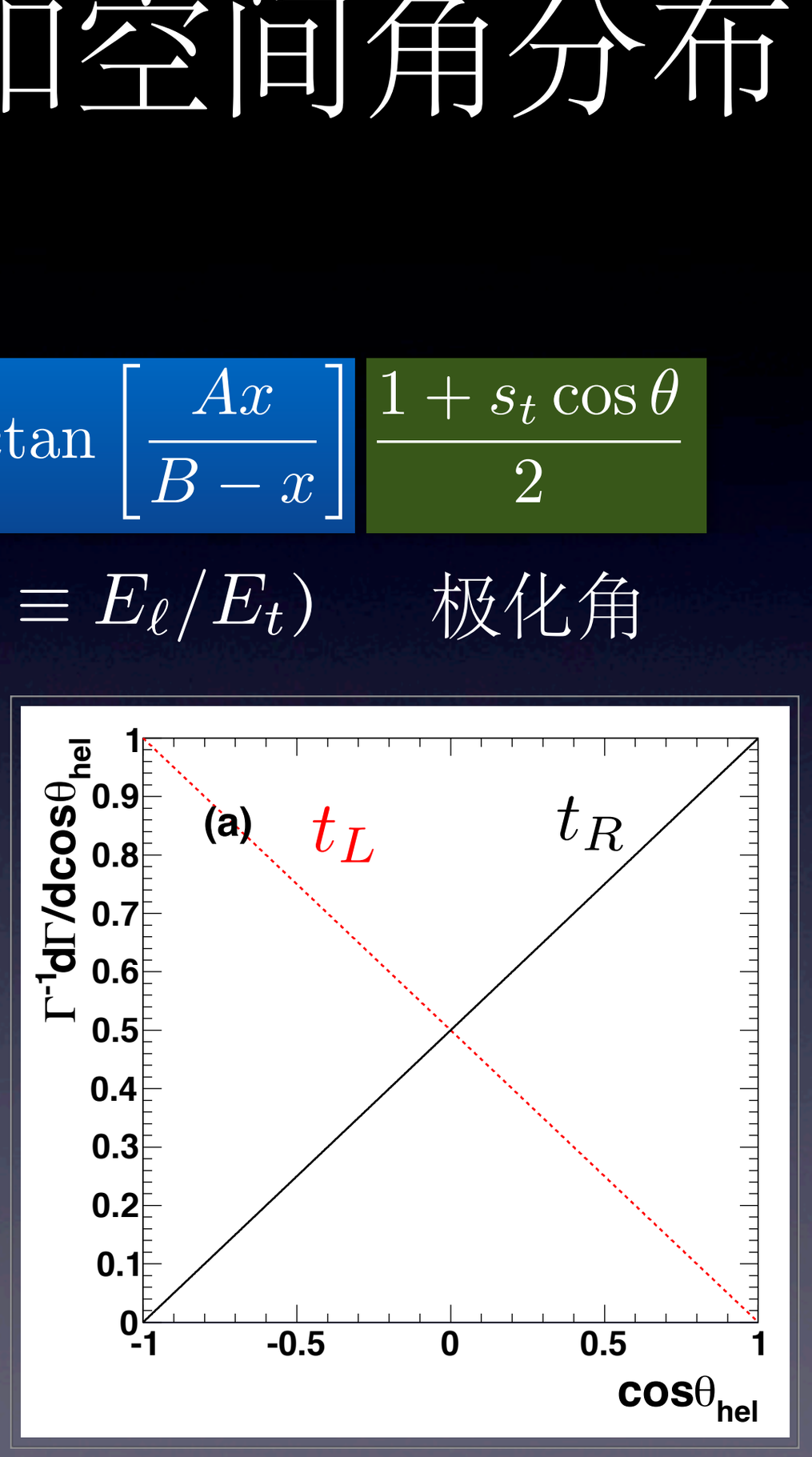
能量 $(x \equiv E_\ell/E_t)$　　极化角



$\lambda_t = +$ 右手顶夸克

$\lambda_t = -$ 左手顶夸克

当顶夸克运动时，带电轻子的能量和空间角纠缠起来。



带电轻子的能量敏感依赖于顶夸克极化性质

Phys. Rev. Lett. 109 (2012) 152004

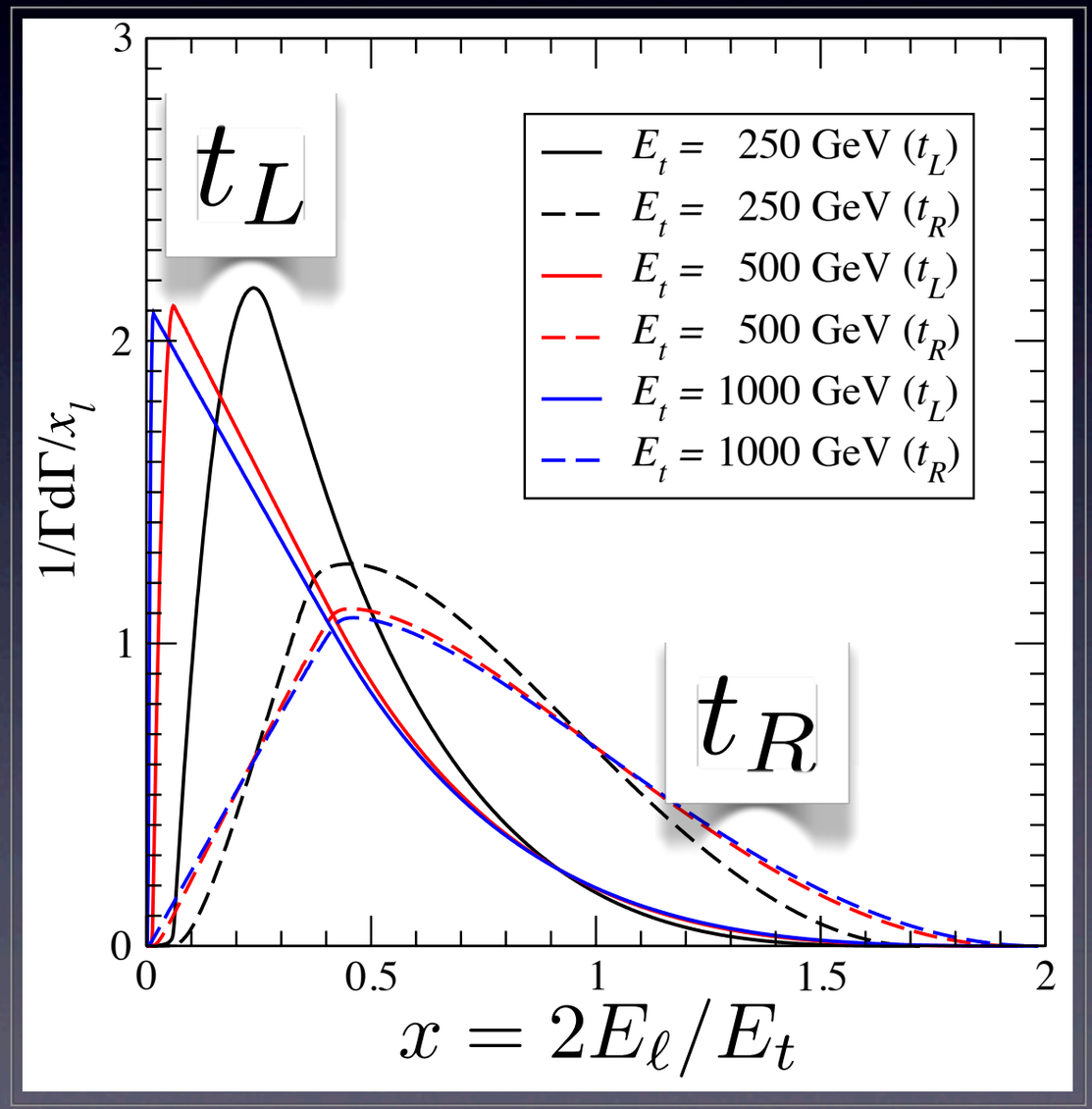
$$\frac{d\Gamma(\hat{s}_t)}{dx} = \frac{\alpha_W^2 m_t}{64\pi AB} \int_{z_{\min}}^{z_{\max}} x\gamma^2[1 - x\gamma^2(1 - z\beta)] \times \left(1 + \hat{s}_t \frac{z - \beta}{1 - z\beta}\right) \mathrm{Arctan}\left[\frac{Ax\gamma^2(1 - z\beta)}{B - x\gamma^2(1 - z\beta)}\right] dz$$

$$A = \frac{\Gamma_W}{m_W} \qquad B = \frac{m_W^2}{m_t^2} \approx 0.216$$

$$\gamma = \frac{E_t}{m_t} \qquad \beta = \sqrt{1 - 1/\gamma^2}$$

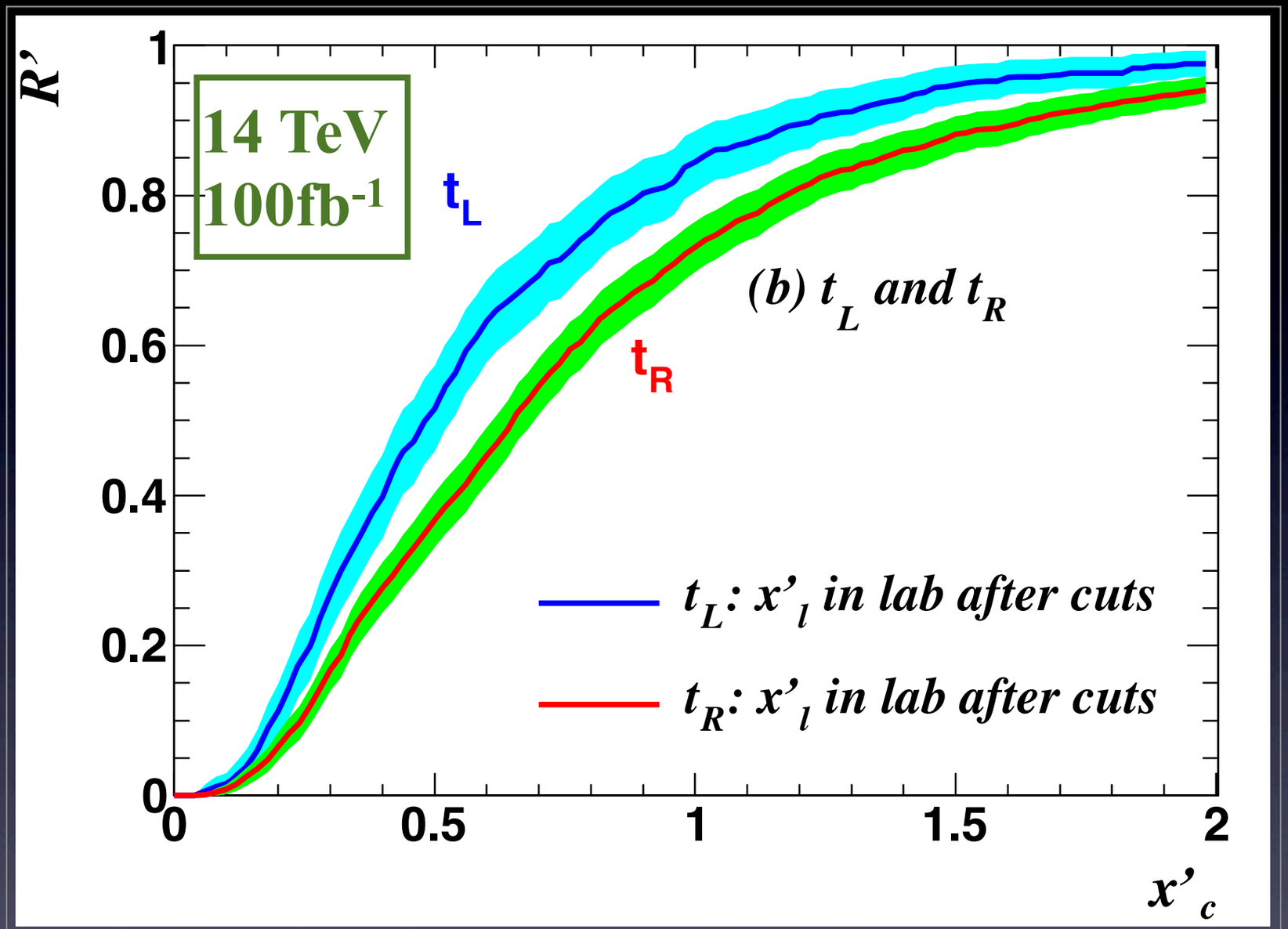
$$z_{\min} = \max[(1 - 1/\gamma^2 x)/\beta, -1]$$

$$z_{\max} = \min[(1 - B/\gamma^2 x)/\beta, 1]$$



此方法被人们忽视了近20年

$\mathcal{R}'$分布可以区分t_L和t_R

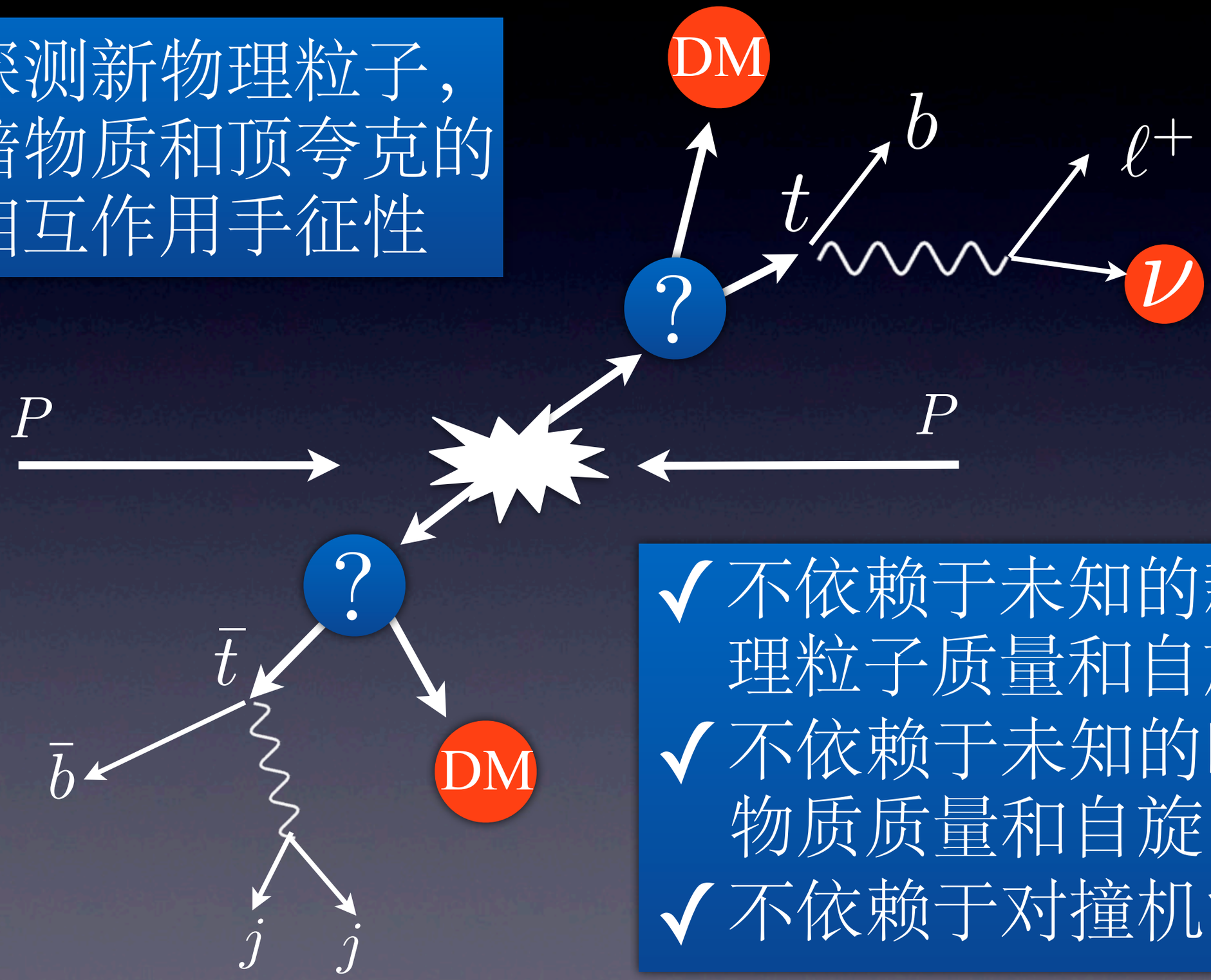


最小超对称模型：$pp \to \tilde{t}\bar{\tilde{t}} \to t\bar{t}\tilde{\chi}_0\bar{\tilde{\chi}}_0 \to b\bar{b}jj\ell^+ \not{E}_T$

T-宇称守恒的小希格斯模型：$pp \to T\bar{T} \to t\bar{t}A_H A_H \to b\bar{b}jj\ell^+ \not{E}_T$

顶夸克对和暗物质联合产生

探测新物理粒子，暗物质和顶夸克的相互作用手征性



- ✓ 不依赖于未知的新物理粒子质量和自旋
- ✓ 不依赖于未知的暗物质质量和自旋
- ✓ 不依赖于对撞机能量

顶夸克和TeV能区新物理展望

Extra gauge bosons

Z’ W’ G’

New heavy quarks

Vector-like Quark

4th Gen

Gluino

顶夸克

Exotic colored states

Heavy quark production via pQCD

Charged Higgs

FCNC

A_{FB}

~~CP~~

谢谢！