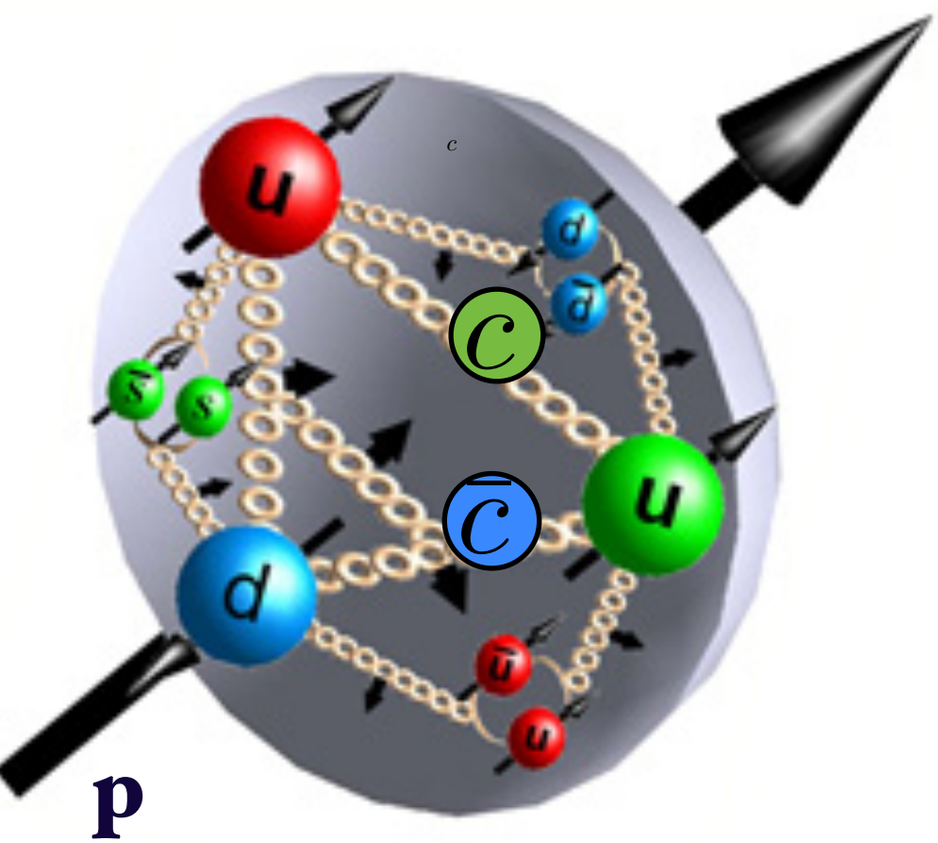
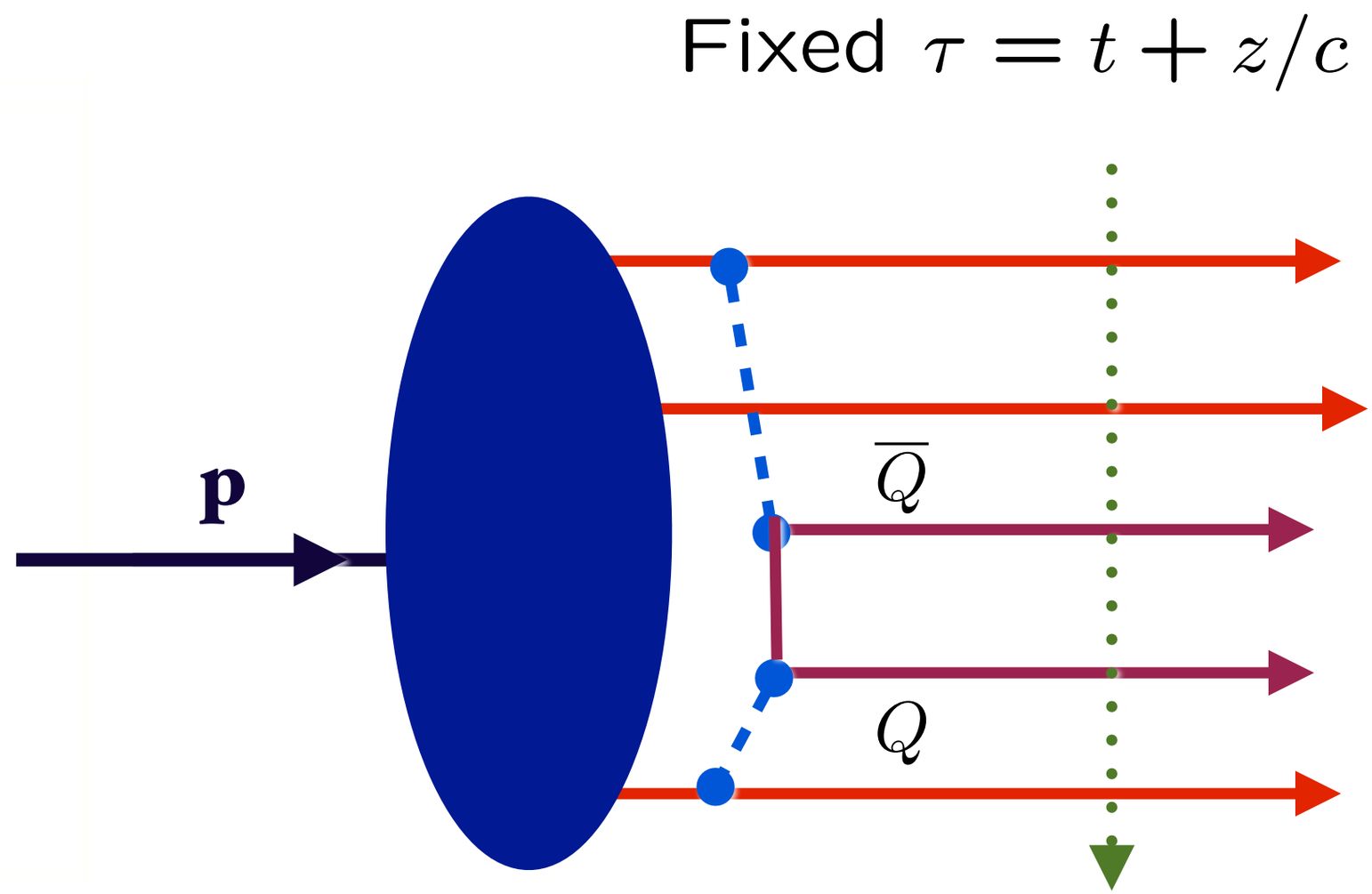
Novel Features of Quarkonium and Tetraquark Physics





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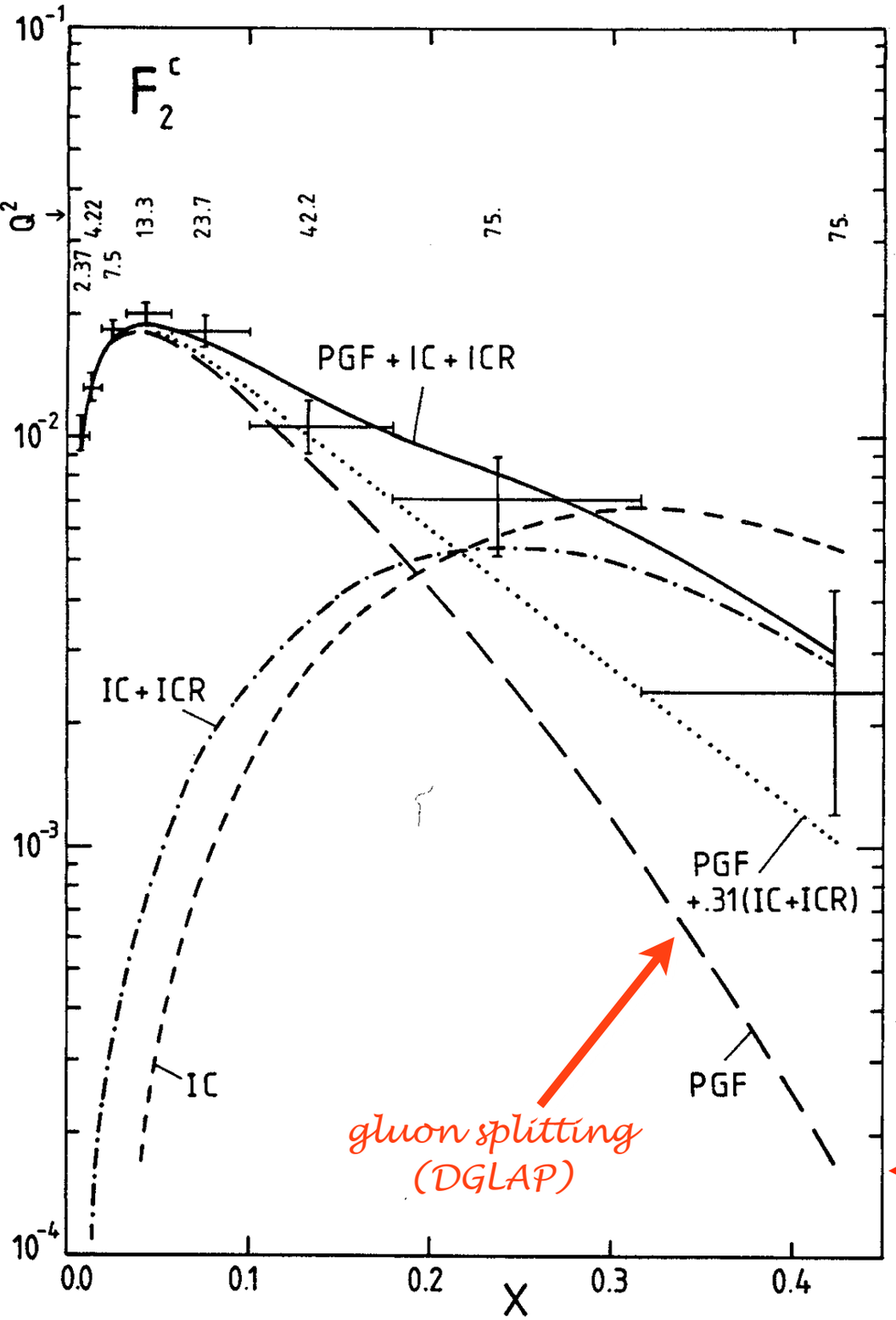
Measurement of Charm Structure Function!

J. J. Aubert et al. [European Muon Collaboration], "Production Of Charmed Particles In 250-Gev Mu+ - Iron Interactions," Nucl. Phys. B 213, 31 (1983).

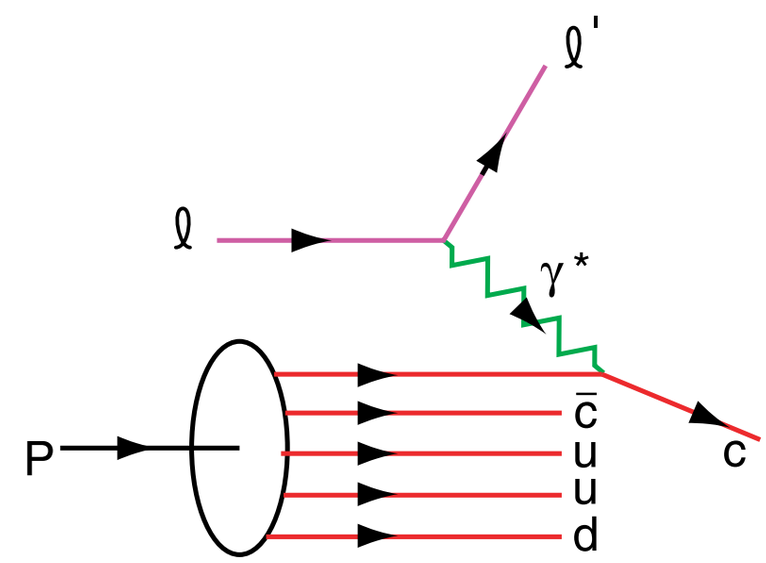


Evidence for Intrinsic Charm

$$< x_{c\bar{c}} >_p \simeq 1\%$$

Needs to be confirmed by COMPASS, EIC!

factor of 30 !



DGLAP / Photon-Gluon Fusion: factor of 30 too small

Two Components (separate evolution):

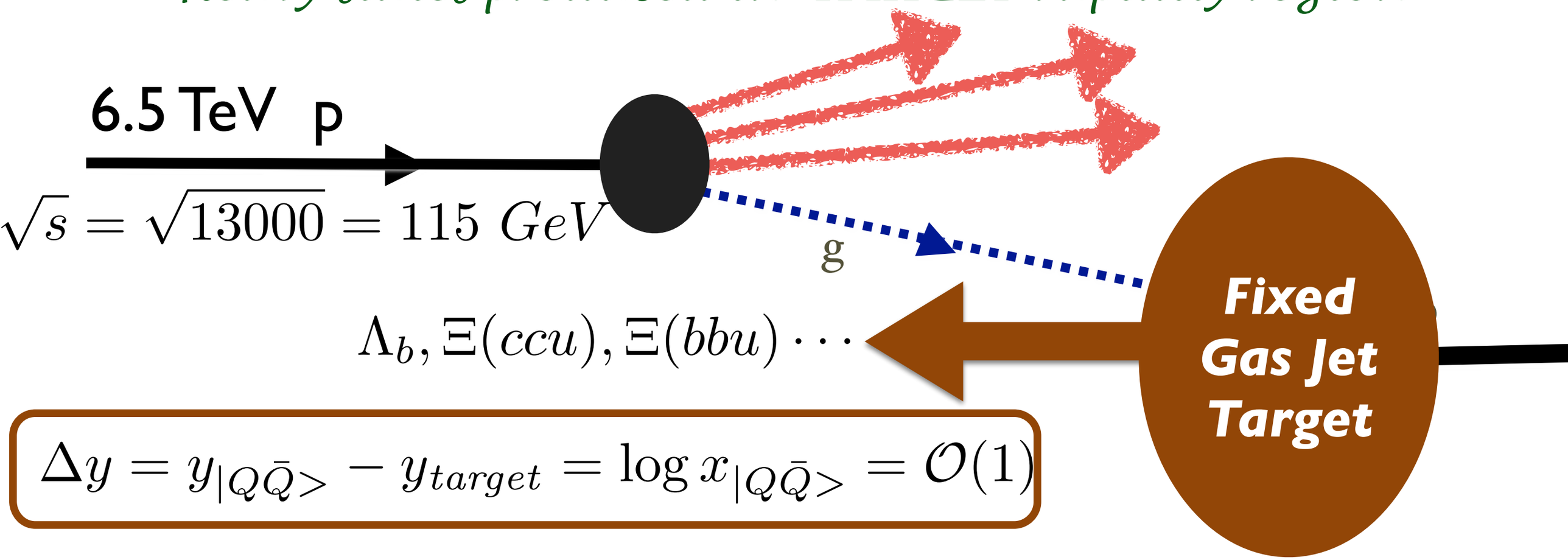
$$c(x, Q^2) = c(x, Q^2)_{\text{extrinsic}} + c(x, Q^2)_{\text{intrinsic}}$$

Excitation of Intrinsic Heavy Quarks in a Fixed Target

Amplitude maximal at minimal invariant mass, in target rapidity domain!

$$x_i \sim \frac{m_{\perp i}}{\sum_j^n m_{\perp j}} \qquad \frac{d\sigma}{dy_{J/\psi}}(pA \to J/\psi X)$$

Heavy states produced in **TARGET** *rapidity region*



$$\Delta y = y_{|Q\bar{Q}>} - y_{target} = \log x_{|Q\bar{Q}>} = \mathcal{O}(1)$$

Produce $J/\psi, \Upsilon, \Lambda_c, \Lambda_b, |ccu>, |cud\bar{c}>, |cuuddd u\bar{c}>, \cdots$

Test at LHCb!!

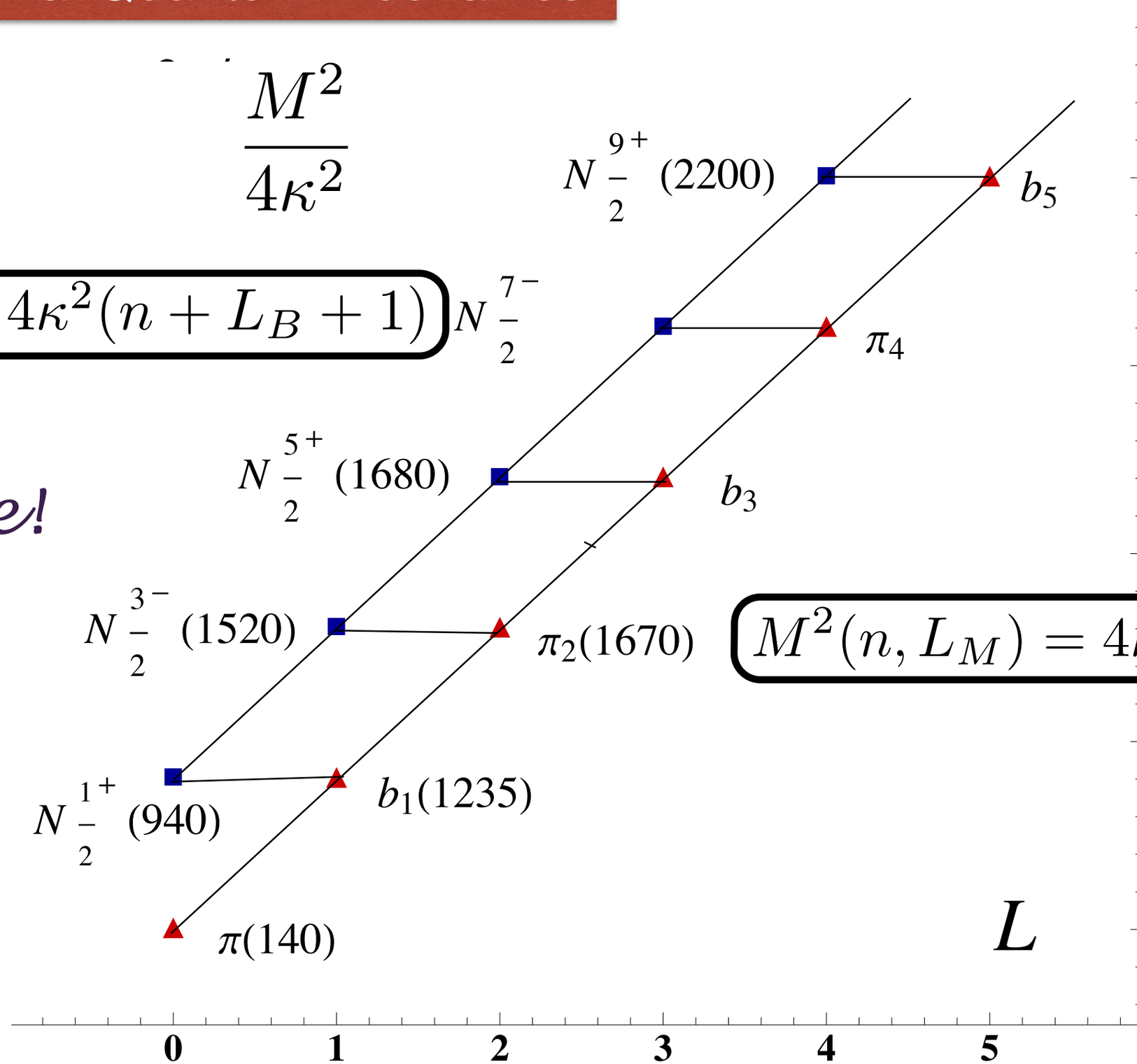
Superconformal Quantum Mechanics

de Tèramond, Dosch, sjb

$$\frac{M^2}{4\kappa^2}$$

$$M^2(n, L_B) = 4\kappa^2(n + L_B + 1)$$

Same slope!



$$M^2(n, L_M) = 4\kappa^2(n + L_M)$$

$$\frac{M^2_{meson}}{M^2_{nucleon}} = \frac{n + L_M}{n + L_B + 1}$$

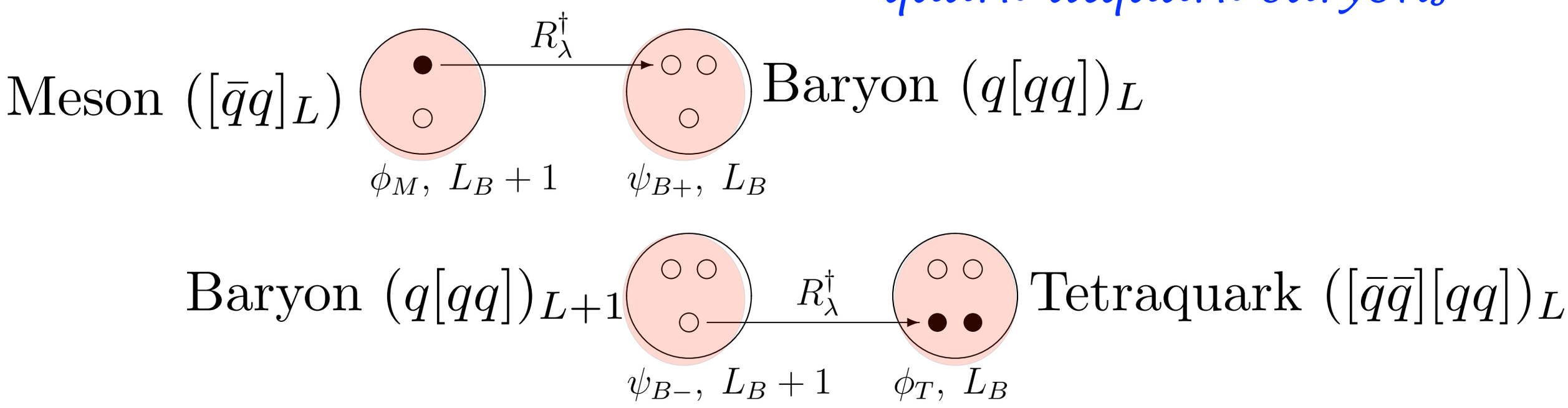
Meson-Baryon Mass Degeneracy for $L_M = L_B + 1$

Superconformal algebra

2 X 2 Matrix Representations: Mass-Degenerate Hadronic Eigensolutions

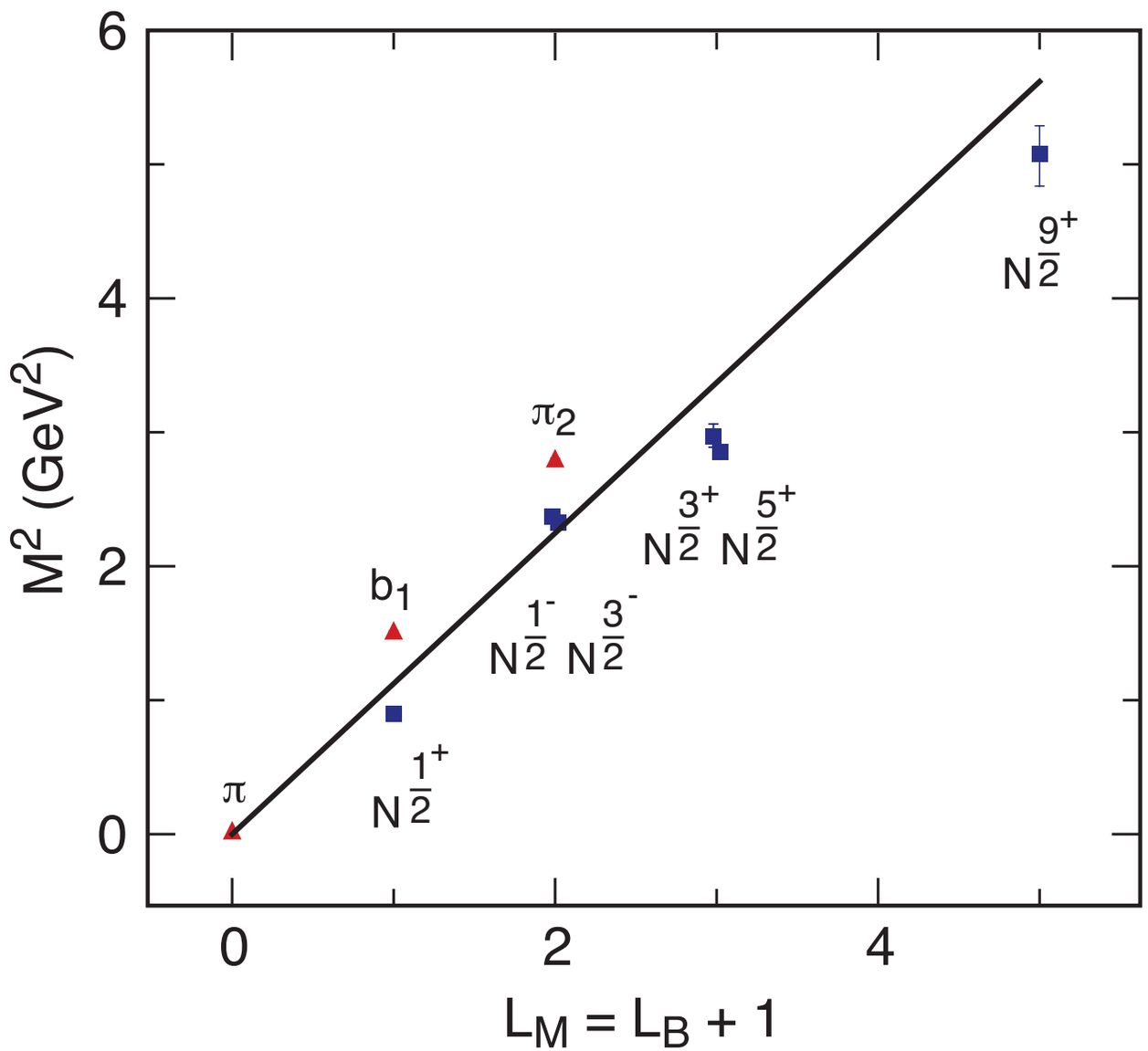
$$\begin{pmatrix} \phi_M(L_M = L_B + 1) & \psi_{B-}(L_B + 1) \\ \psi_{B+}(L_B) & \phi_T(L_T = L_B) \end{pmatrix}$$

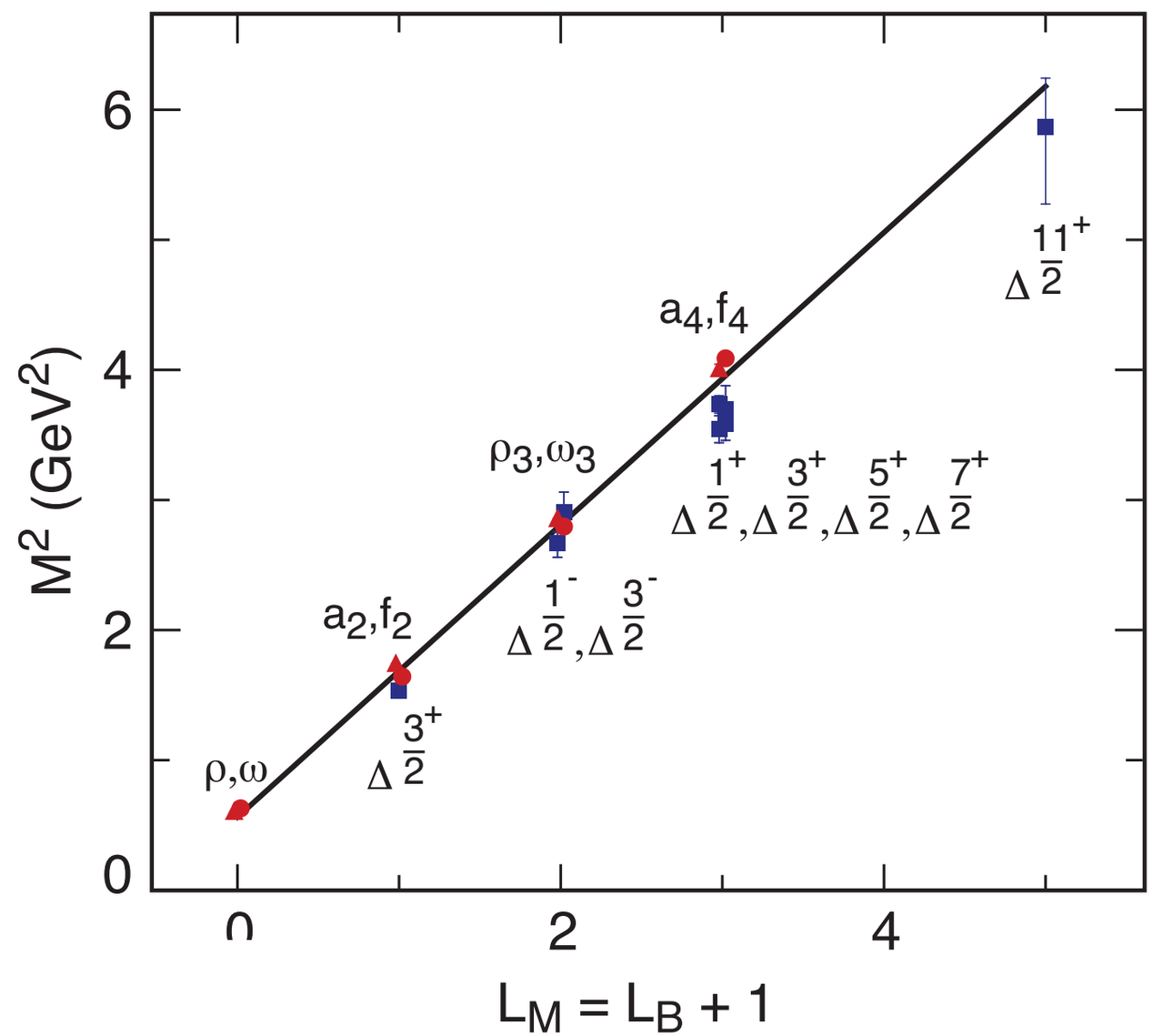
quark-diquark baryons



diquark-diquark tetraquarks

Solid line: κ = 0.53 GeV





Superconformal meson-nucleon partners

Tetraquark Candidates

$f_0(980) I = 0, J^P = 0^+$, partner of proton
$a_1(1260) I = 0, J^P = 1^+$, partner of $\Delta(1233)$

Mass Degenerate Tetraquarks *de Tèramond, Dosch, sjb*

de Tèramond, Dosch, Lorce, sjb

Diquark Clusters: Building Blocks of Exotic Hadrons

- Diquarks: Spin S=0, 1, all L $[qq]_{\bar{3}C}, [\bar{q}\bar{q}]_{3C},$
- Tetraquarks: $([qq][\bar{q}\bar{q}])$ Spin S =0,1,2, all L
- Regge trajectories, universal slope for mq=0
- All flavors possible $([cu][\bar{c}\bar{u}])$
- Pentaquarks $\left[([qq]_{\bar{3}_C}\bar{q}_{\bar{3}_C})_{3_C}[qq]_{\bar{3}_C}\right]_{1C}$
- Hexaquarks, Octoquarks! $(uuduudc\bar{c})$

diquark-diantiquark

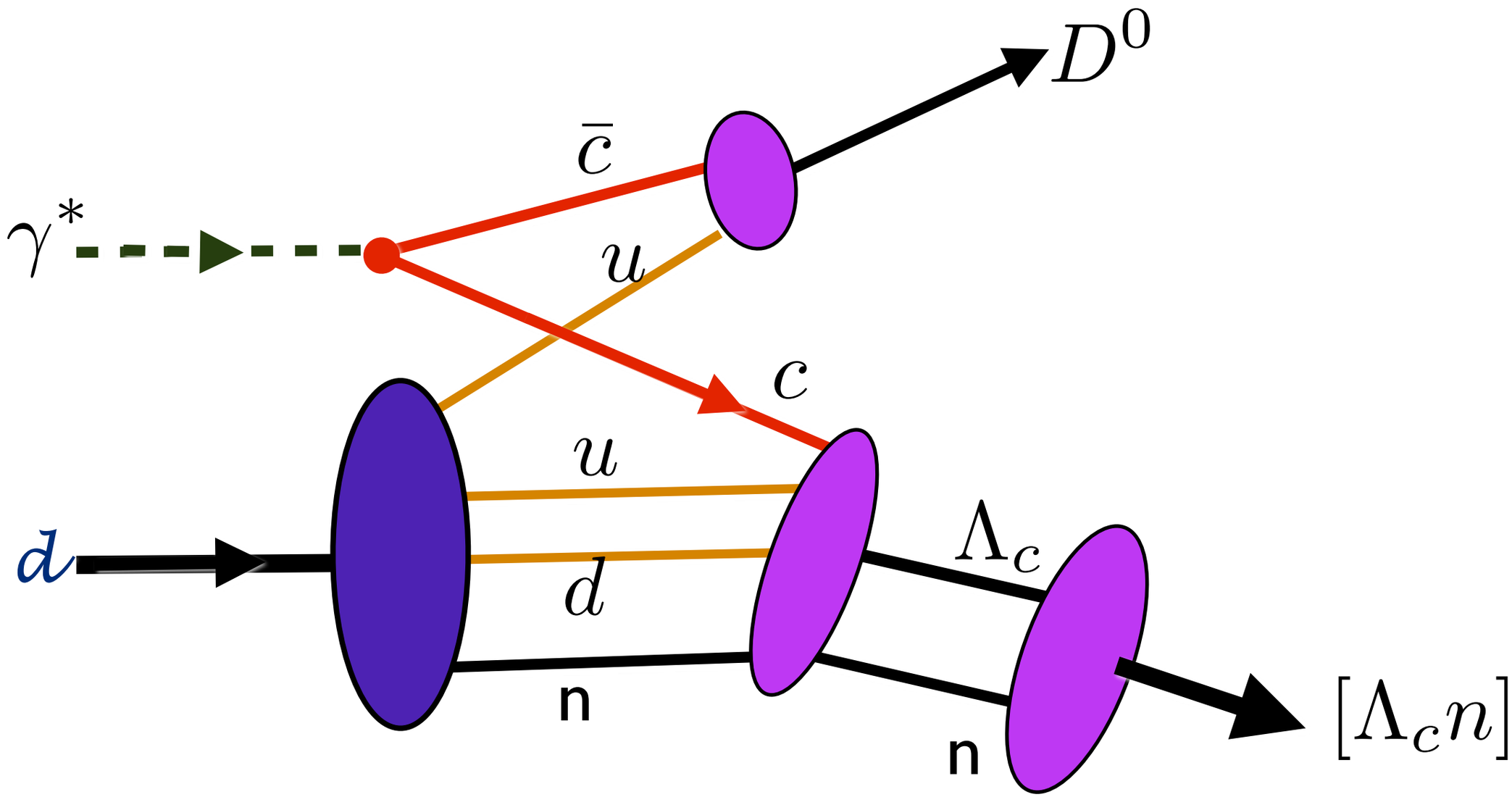
Lebed, Hwang, sjb

Tetraquark Candidates

$f_0(980) I = 0, J^P = 0^+$, partner of proton

$a_1(1260) I = 0, J^P = 1^+$, partner of $\Delta(1233)$

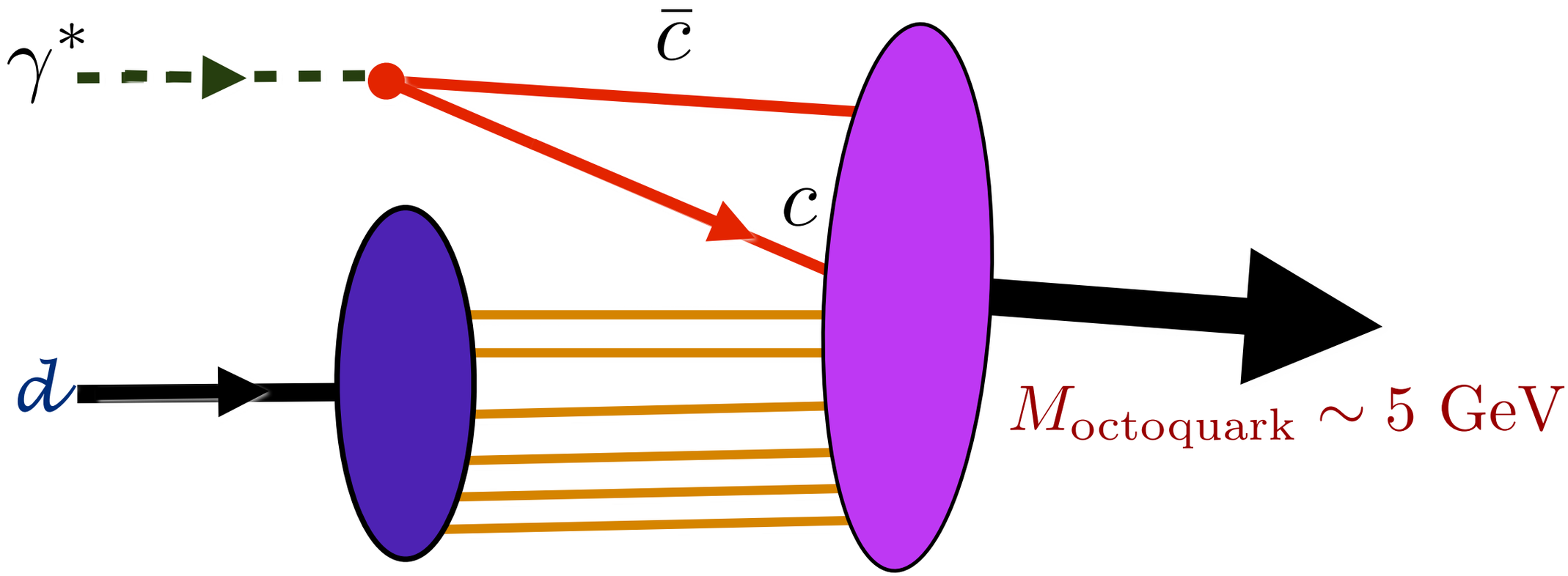
Nuclear binding at low relative velocity



$$\gamma^* d \to \overline{D}^0(\bar{c}u)[\Lambda_c n](cududd)$$

Possible charmed B= 2 nucleus

Octoquark Production at Threshold



$$\gamma^* d \to |uududdc\bar{c}>$$

Explains Krisch Effect!

Wish List

- ***Double-Charmed Baryons, ccu-ccd Isospin separation***
- ***tetraquarks, multi-flavors, Regge excitations, Q=2***
- ***Produce Heavy-Quark States at minimum y (Gas Jet Target LHCb)***
- ***JLab: Exotic Charm States***
- ***COMPASS: Charm Structure Function***

QCD Myths

- Anti-Shadowing is Universal
- ISI and FSI are higher twist effects and universal
- High transverse momentum hadrons arise only from jet fragmentation -- baryon anomaly!
- Heavy quarks only from gluon splitting
- Renormalization scale cannot be fixed
- QCD condensates are vacuum effects
- QCD gives 10^{42} to the cosmological constant
- Colliding Pancakes

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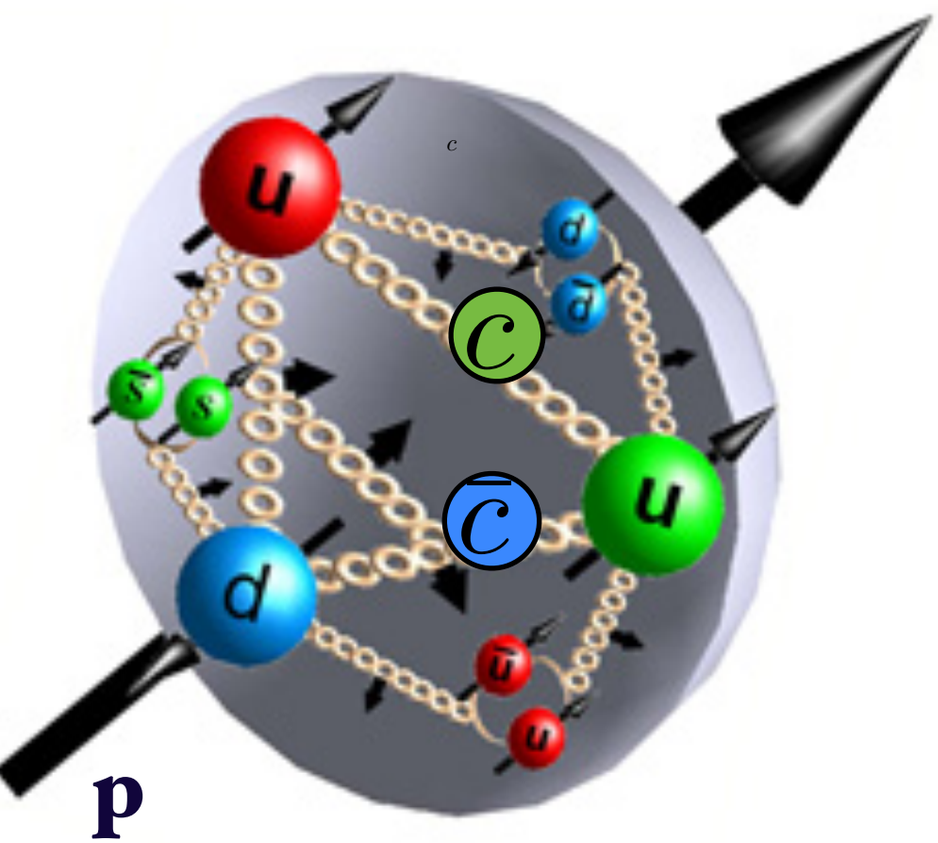

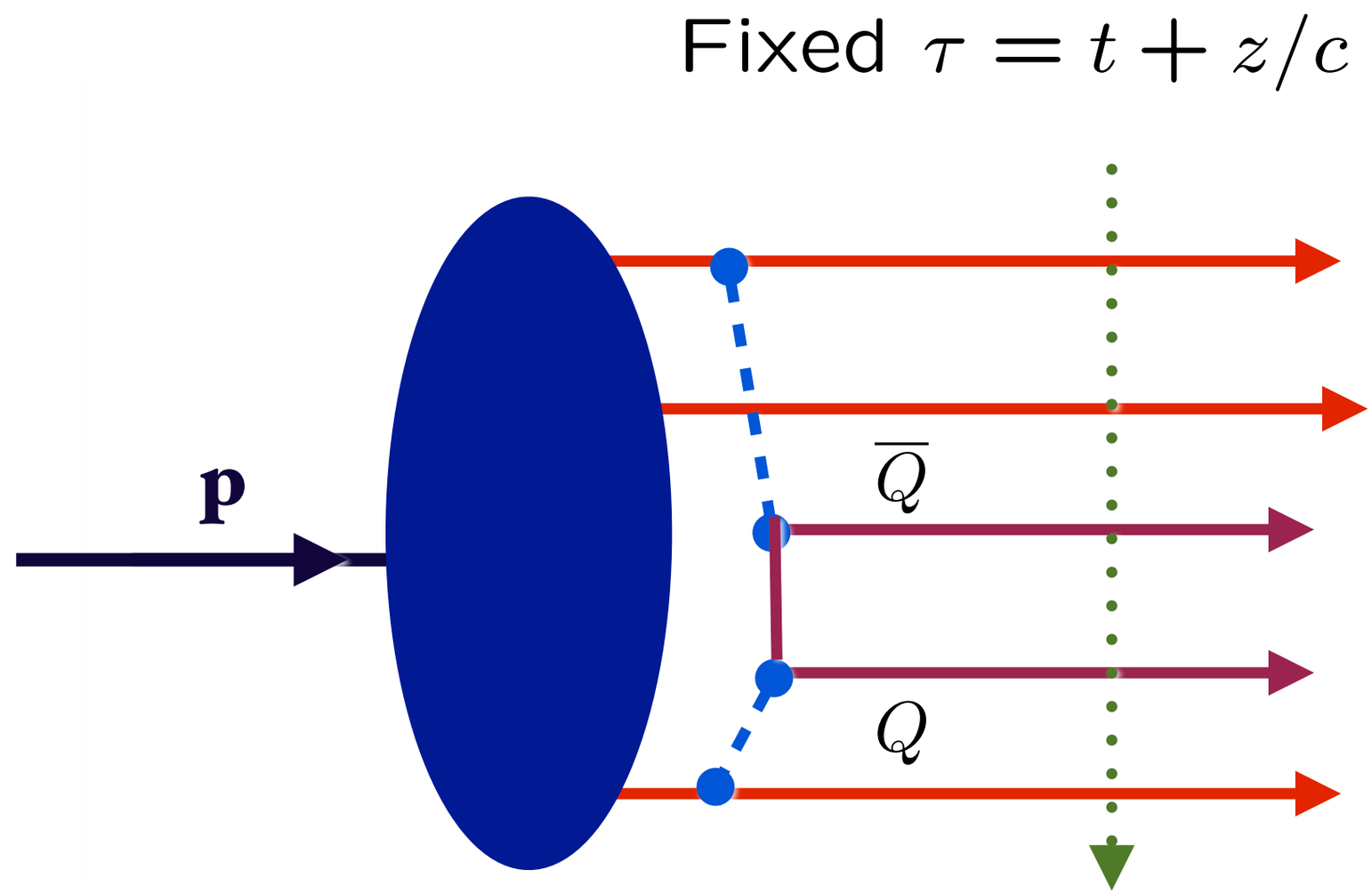

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