

Waving a **Red** Rag to a Pull

Investigating Jet Pull's Soft and Collinear Behavior in Three-jets Final State

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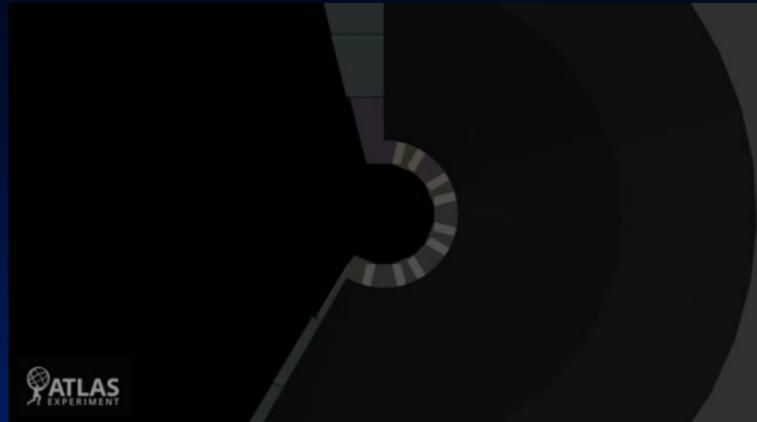
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Observable: What is jet pull?



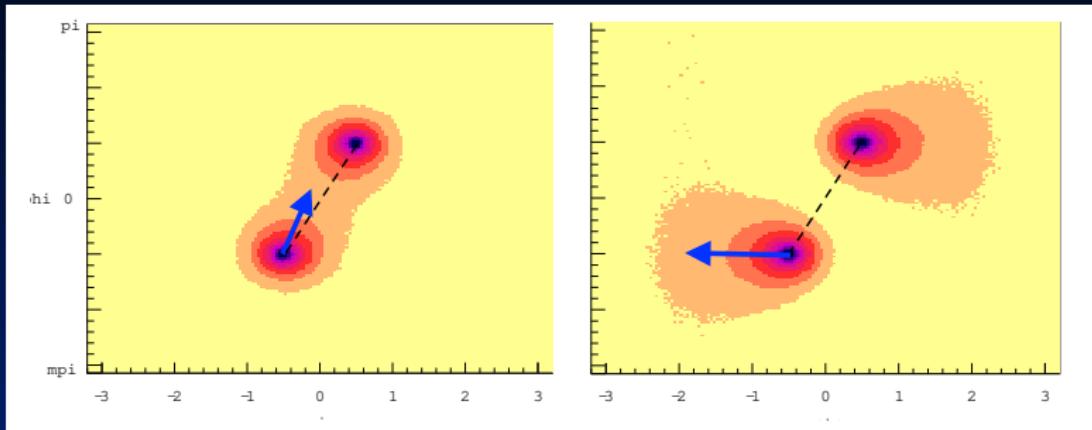
An event display of a pp collision recorded by ATLAS on 3 June 2015. [Credit: CERN]

Example of observables:

- energy
- momentum
- trajectory
- electric charge
- color?

Observable: What is jet pull?

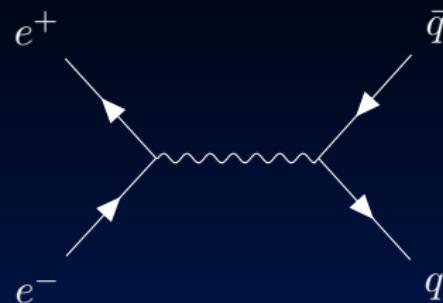
Pull: An observable designed to capture the color flow between jets.



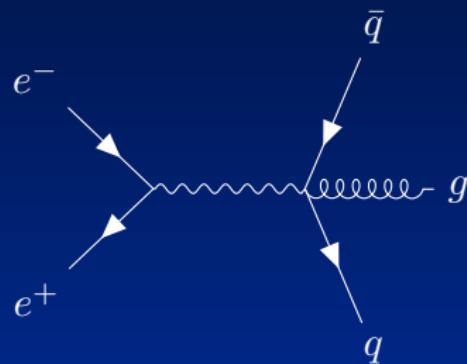
[Gallicchio and Schwartz, arXiv:1001.5027]

$$\mathbf{t} \triangleq \sum_{i \in J} \frac{p_{\perp i} |\mathbf{r}_i|}{p_{\perp J}} \mathbf{r}_i, \quad \mathbf{r}_i \triangleq (y_i - y_J, \phi_i - \phi_J).$$

Physics: Which three-jet final state?



⇓



Physics: Why soft and collinear?



$$P(e^+e^- \rightarrow q\bar{q}g) \propto \frac{1}{E_g^2} \rightarrow \infty.$$

Map Physics to Observable: Massaging the observable

Splitting function & Change of variable \implies Jet/Soft function

- Splitting function:

$$\frac{d^2\sigma}{dx d\phi} = \left| q' \xrightarrow{\quad} \text{wavy line} \xrightarrow{\quad} g \right|^2 = P(q \rightarrow gq)$$

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- Change of variable:

$$\mathbf{t} \rightarrow \mathbf{t}_{\text{collinear}}, \quad |\mathbf{t}| = t(x, \phi) \text{ and } \arg \mathbf{t} = \phi_p(x, \phi).$$

- Jet function:

$$J = \frac{d^2\sigma}{dt d\phi_p} = \frac{\partial x}{\partial t} \frac{\partial \phi}{\partial \phi_p} \frac{d^2\sigma}{dx d\phi}.$$

Map Physics to Observable: Mapping the physics Jet/Soft function & Summing over cases \implies Full PDF

- Jet function:

$$J \sim P(\text{collinear})$$

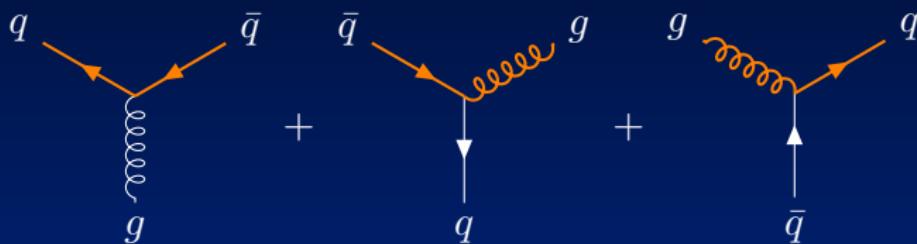
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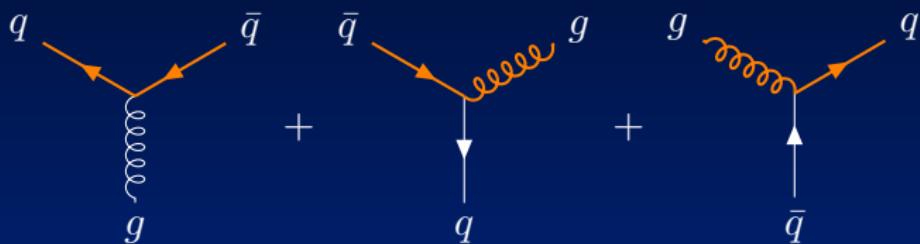
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Jet/Soft function & Summing over cases \implies Full PDF

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- Full PDF, $P(e^+e^- \rightarrow q\bar{q}g)$ AND (collinear OR soft)):

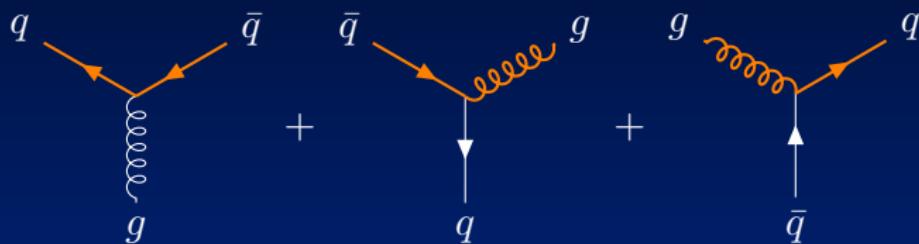
Map Physics to Observable: Mapping the physics

Jet/Soft function & Summing over cases \implies Full PDF

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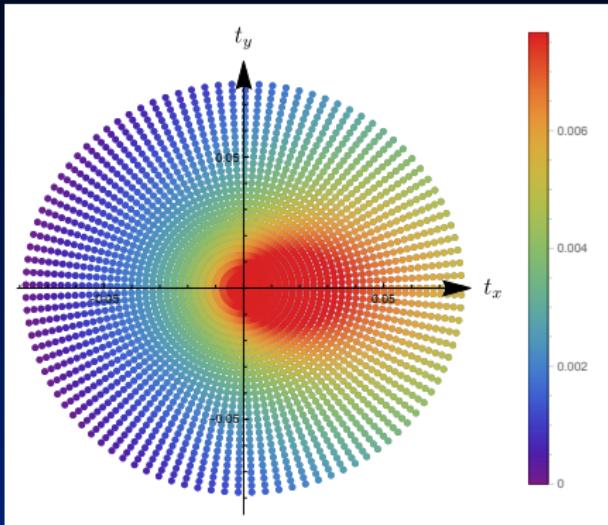


- Full PDF, $P(e^+e^- \rightarrow q\bar{q}g)$ AND (collinear OR soft)):

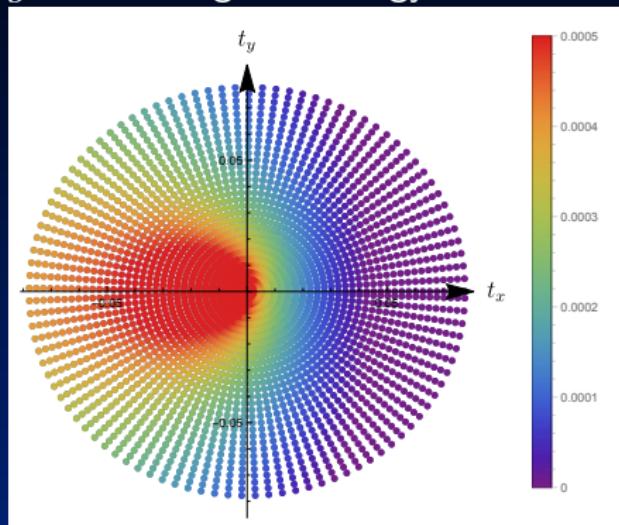
$$P(e^+e^- \rightarrow q\bar{q}g)[J + S].$$

Discoveries: Results

Summed over all cases:

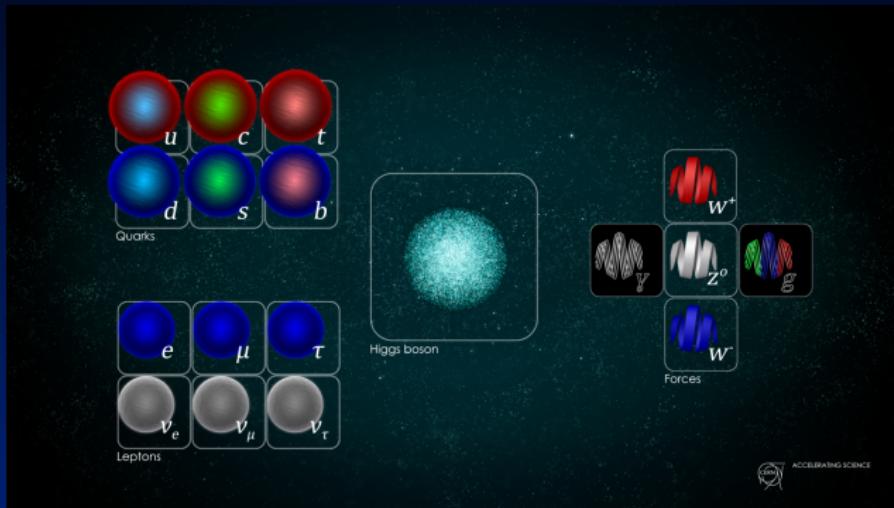


g has the highest energy:



Thank you! Questions?

We are pullfighters, waving the red rag to a pull¹, and gradually tease out the beautiful colors in an experiment.



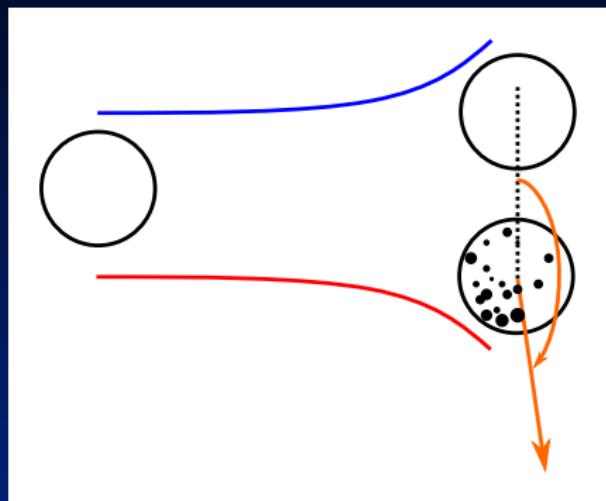
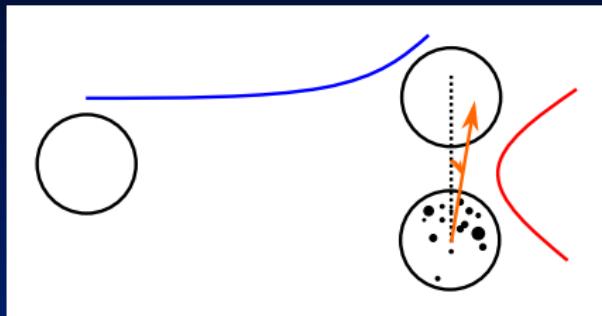
[Credit: Daniel Dominguez, CERN]

¹No pull was harmed in the making of this collision.

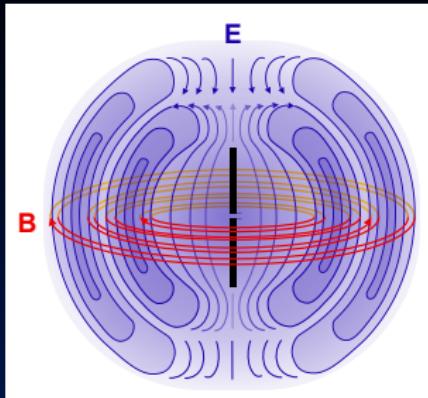
Discoveries: Detailed Explanation

g has the highest energy:

Summed over all cases:



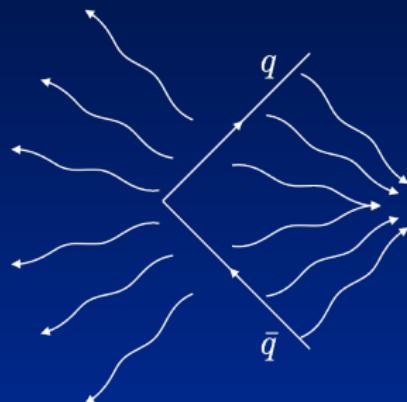
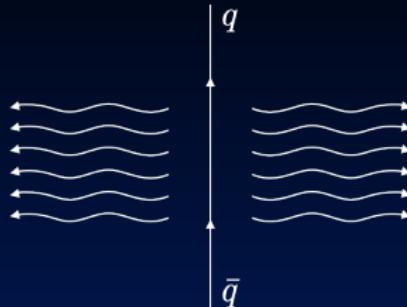
Observable: What makes pull sensitive to color flow?



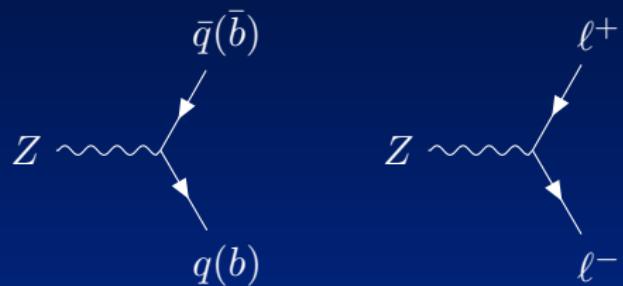
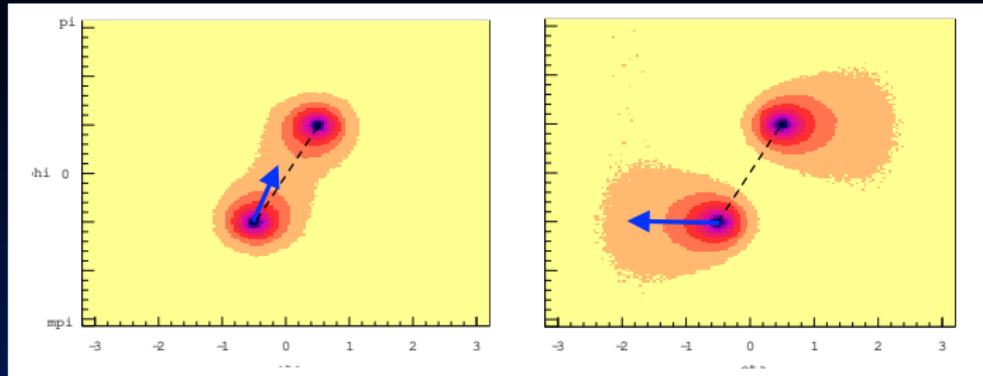
Dipole radiation pattern in E&M

[Credit: Wikipedia users]

More radiations appear
between
color-connected dipoles

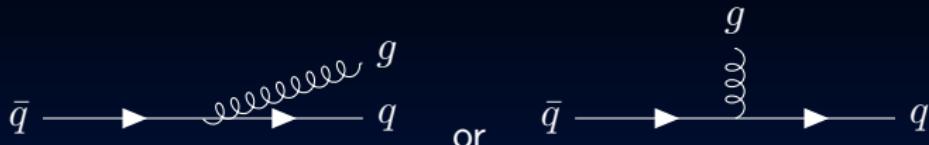


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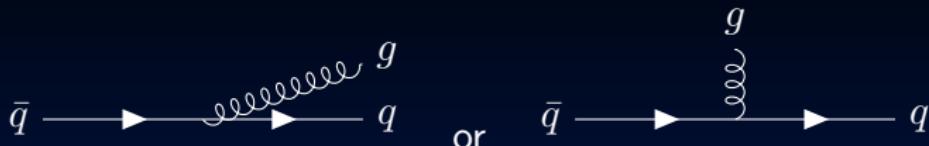
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Physics: Why soft and collinear?

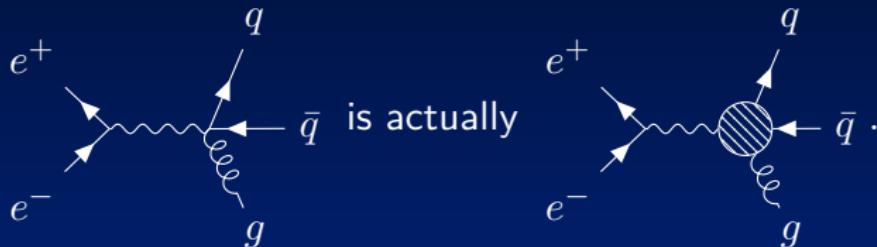


$$P(\text{collinear or soft}) \propto \frac{x_q^2 + x_{\bar{q}}^2}{(1 - x_q)(1 - x_{\bar{q}})} \rightarrow \infty, \quad x_i \triangleq \frac{2p_i \cdot Q}{Q^2}$$

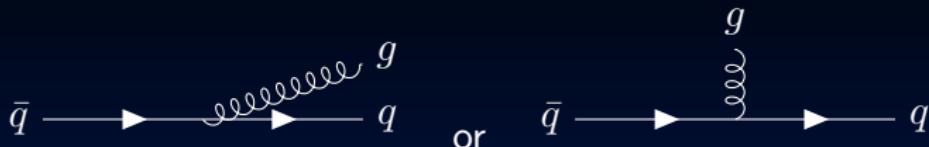
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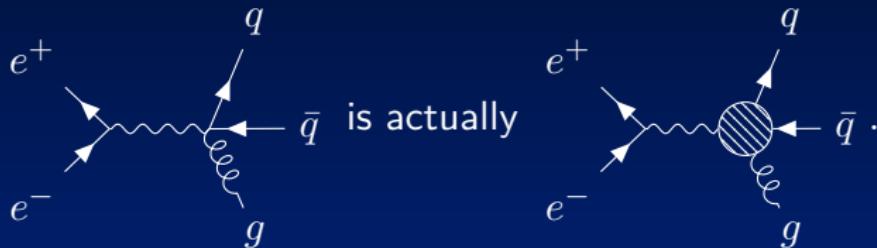
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Physics: Why soft and collinear?



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Map Physics to Observable: Dimensional Regularization

- $\int d\Pi_4 P(\Pi_4)$ diverges, but $\int d\Pi_{4-2\epsilon} P(\Pi_{4-2\epsilon})$ converges (for positive ϵ).
- Insert an energy scale μ such that $\mu^{2\epsilon} \int d\Pi_{4-2\epsilon} P(\Pi_{4-2\epsilon})$ still has the right dimension.

Map Physics to Observable: Change of variable

Delta function is our friends!

$$\begin{aligned} J &= \frac{d^2\sigma}{dt d\phi_p} = \left(\frac{\partial t}{\partial x} \right)^{-1} \left(\frac{\partial \phi_p}{\partial \phi} \right)^{-1} \frac{d^2\sigma}{dx d\phi} \\ &= \int dx d\phi \frac{d^2\sigma}{dx d\phi} \delta(t - t(x, \phi)) \delta(\phi_p - \phi_p(x, \phi)). \end{aligned}$$

Make the phase space integral more explicit, and we can control the integral bound to phase space of interest.

Future Developments

- Distinguish $H \rightarrow q\bar{q}$ from $g \rightarrow q\bar{q}$
- Extend into more complicated non-singlet multi-jet configurations
- Resum the cross section
- Compare with experiments to improve the model

Physics: What are non-singlet jets?

