Outline

• Lecture 1: Jets and QCD
  • The physics of jets
    • Including brief history
  • Jets from perturbative QCD
  • Jet algorithms
  • Some data

• Lecture 2: Modern jet physics
  • Jet substructure
  • Jet grooming
  • Jet properties
  • The future of jets
THE PHYSICS OF JETS
What happens in a collision?

Colliding water droplets – what happens?
What happens in a collision?

Colliding water droplets – what happens?
What happens in a collision?

Colliding water droplets – what happens? Produces radially symmetric distribution
Colliding protons
Colliding protons
Colliding protons
Jets and the LHC

• The LHC has much **higher energy** than any collider ever
  • More jets
  • Harder (more energetic) jets
  • More jet-like (collimated) jets

• LHC experiments can **measure jets really well**
  • Better **energy resolution** than Tevatron
  • Better **spatial resolution** than Tevatron
  • Can identify individual particles!!

Jet physics is entering a **Golden Era**
Revolution in the last 4 years

- New experimental techniques
- New theoretical methods
- New ideas and algorithms
BRIEF HISTORY
Nuclear physics begins

Rutherford’s Experiment (1910)

- $\alpha$ particles from $^{214}\text{Po}$ on 0.5 $\mu$ thick sheet of gold
- $\alpha$ particle speed = $10^7$ m/s

Rutherford concluded:

- Most of the gold foil is empty space
- Mass is concentrated in a hard central nucleus
- Size of nucleus is approximately $3 \times 10^{-14}$ m (very close to correct)
Electron-positron (e⁻ P⁺) scattering

In general, the cross section depends on the momentum transfer $q^2$

$$d\sigma = d\sigma_{\text{point}} F(q^2)$$

Form factor $\sim$ scattering potential

$$F(q^2) = 1 \Leftrightarrow V(r) = \frac{1}{r}$$

Pure Coulomb potential $\rightarrow$ no structure

Pointlike elastic collisions
Electron-positron ($e^- \, P^+$) scattering

1950s at the Mark III linear collider at Stanford
• Energies of order 200-500 MeV

Proton has size: $r = 10^{-15} \text{m}$
Higher energy $e^- P^+ \text{ scattering}$

1960s at Stanford Linear Accelerator (SLAC)

Proton breaks apart – inelastic scattering!
Very high energy $e^- P^+ \text{ scattering}$

1960s at SLAC

Hard scattering off of 
pointlike weakly interacting constituents in the proton

What happens to the proton?

**Hard to tell** -- DIS experiments of the 50s and 60s were fixed-target experiments

-- not designed to measure the “hadronic” part, just the electron

Now $F(q^2) = \text{constant again!}$
Intersecting Storage Rings (ISR) at CERN

First hadron (pp) collider

From T. Schörner-Sadenius

- Unexpected rise in the total pp cross section
- Large number of particles produced at high \( p_T \)
- Consistent with (early) expectations from QCD
Spear at SLAC

Mark I -- first 4π detector (1973-1977)
• Confirmed jet models with event shapes

PETRA at DESY (Hamburg)

HISTORY OF JETS

\( e^+ + e^- \) collisions at SPEAR
Geschonke et al., "Physics at the Terascale," Wiley 2011

\( \sqrt{s} = 3.0 \text{ GeV} \)
\( \sqrt{s} = 6.2 \text{ GeV} \)
\( \sqrt{s} = 7.4 \text{ GeV} \)

Mark-I PRL 35 (1975) 1609

\[ S = \frac{3 \left( \sum_i p_{T,i}^2 \right)}{2 \left( \sum_i p_i^2 \right)} \]

Measured Sphericity (event shape)

PETRA (DESY) 1979

Gluon jets
quark jet
antiquark jet

From T. Schörner-Sadenius
THE PHYSICS OF JETS
Colliding protons
Colliding protons
Size is $1 \text{ fm} \sim \Lambda_{\text{QCD}}^{-1}$. 

- $u$ quarks
- $d$ quarks
- QCD (Quantum Chromodynamics)
Interaction length
0.01 fm $\sim 100 \text{ GeV}^{-1} \ll \Lambda_{\text{QCD}}^{-1}$
Special relativity
Special relativity

Length contraction

- Longitudinal size of proton is much smaller than transverse size
Special relativity

Time dilation

- Hadronization occurs well outside of proton radius
- For 100 GeV collision, $R_{\text{had}} \sim 100$ fm

Length contraction

Longitudinal size of proton is much smaller than transverse size
at **short distances**

QCD is like QED

- Electrons in, electrons out

at **long distances**

QCD is a mess

- Nuclei in, hadrons out

Proton-proton collisions are just right intermediate between QED and a mess
QCD predicts jets

1. Quarks and gluons (partons) are produced at short distance, where QCD is weak.

2. As they propagate outward, they radiate more partons.

3. At distances $\sim \Lambda_{\text{QCD}}^{-1}$ they form uncolored hadrons. Hadrons leave the proton and do not interact strongly until detected.

$d\sigma = \text{[PDFs]} \times \text{[production]} \times \text{[parton shower]} \times \text{[hadronization]}$

• Physics at different length scales can be calculated separately and then combined.
$$d\sigma = [\text{PDFs}] \times [\text{production}] \times [\text{parton shower}] \times [\text{hadronization}]$$

Subject of my lectures
Factorization

- Partons produced at short distances

- Radiation and hadronization cannot change parton momentum by much

Short distance physics imprinted on jets!
JETS FROM PERTUBUATIVE QCD
Why jets?

Leading order: \( R=0, \text{Energy} = E \)

Propagator factor:

\[
\frac{1}{(p + q)^2} = \frac{1}{2p \cdot q} = \frac{1}{E_p E_q (1 - \cos \theta)} = \frac{1}{2E_q E_p \sin^2 \frac{\theta}{2}}
\]

Blows up when \( E=0 \) (soft divergence)

Or \( \theta = 0 \) (collinear divergence)

\[ d\sigma \sim \alpha_s \int_0^R d\theta \frac{dE}{\theta} \frac{dE}{E} \sim \alpha_s \ln R \ln E \]

Sudakov double logarithms
Collinear limit

In the **collinear** limit, cross sections factorize

\[
\frac{k_T^{(2)}}{\lambda} = \frac{k_T^{(1)}}{\lambda} \times \frac{k_T^{(1)}}{\lambda}
\]

when \( k_T^{(2)} \ll k_T^{(1)} \ll E_{\text{jet}} \)

In the collinear limit, cross sections given by **DGLAP splitting functions**

\[
z = \frac{E_1}{E_1 + E_2}
\]

\[
\begin{align*}
    \times P_{q \rightarrow qg} &= \frac{4}{3} \frac{\alpha}{2\pi} \frac{1 + z^2}{1 - z} \frac{1}{k_T^2} \\
    \times P_{g \rightarrow gg} &= \frac{3}{2\pi} \frac{\alpha}{1 - z + \frac{1 - z}{z}} \frac{1}{k_T^2}
\end{align*}
\]
Parton shower

Probability of finding a gluon with energy fraction $z$ and transverse momentum $k_T$

$$dP = \frac{4}{3} \frac{\alpha}{2\pi} \frac{1 + z^2}{1 - z} \frac{1}{k_T^2} \, dk_T^2 \, dz$$

- Start with the largest scale ($k_T \sim Q$)
- Is there an emission?
- If not, try lower scales.

Parton “evolves” from hard scale to $\Lambda_{QCD}$
Sudakov factors

\[ d\sigma = \frac{\alpha_s}{2\pi} \frac{1}{t} \left( 1 + \frac{z^2}{1 - z} \right) dt \, dz \]

Integrate over \( z \)

\[ d\sigma = P(t) \, dt = C_F \frac{\alpha_s}{2\pi} \frac{1}{t} \left( \ln \frac{t}{Q^2} + \frac{3}{2} \right) \]

Probability of finding a gluon with energy fraction \( z \) and transverse momentum \( t \sim k_T^2 \)

Probability of finding a gluon at this \( t \)

What is the scale for the hardest gluon?
- Should correspond to scale of the second hardest jet

Sudakov factor \( \Delta(t_0, t) \) is the probability of finding no gluons between \( t_0 \) at \( t \)

\[
\begin{align*}
\Delta(t_0, t + \delta t) &= \Delta(t_0, t) \left( 1 - \int_{t}^{t+\delta t} dt' P(t') \right) = \Delta(t_0, t) - P(x) \delta x \Delta(t_0, t) \\
\Delta(t_0, t + \delta t) &= \Delta(t_0, t) + \delta x \frac{d}{dx} \Delta(t_0, t)
\end{align*}
\]

Thus, \( \Delta(t_0, t) = \exp \left( -\int_{t}^{t_0} P(t') dt' \right) \sim \exp \left[ -\frac{2\alpha_s}{3\pi} \left( \ln^2 \frac{t}{Q} + \frac{3}{2} \ln \frac{t}{Q} \right) \right] \)

And so, the cross section for the hardest gluon is

\[ d\sigma = \Delta(Q, t) P(t) \, dt \approx e^{-\frac{2\alpha_s}{3\pi} \ln^2 \frac{t}{Q} \frac{dt}{t}} \]

Sudakov factor = semi-classical resummation of the leading Sudakov logarithm
Parton shower

- Probability of emission at some $t$
  \[ d\sigma = P(t)dt = C_F\frac{\alpha_s}{2\pi}\frac{1}{t}\left(\ln\frac{t}{Q^2} + \frac{3}{2}\right) \]

- Agrees with cross section for hardest parton in QCD including leading log resummation

- Formally correct at this order for many scale choices

- Common scale choices motivated by soft physics

**Probability that hardest emission is at $t$**

\[ d\sigma = \Delta(Q,t)P(t)dt \approx e^{-\frac{2\alpha_s}{3\pi}\ln^2\frac{t}{Q^2}\frac{dt}{t}} \]

Leading log resummation

\[ k_T^2 = tz(1 - z) \Rightarrow \frac{dk_T^2}{k_T^2} = \frac{dt}{t} \]

\[ d\sigma \approx e^{-\frac{2\alpha_s}{3\pi}\ln^2\frac{k_T^2}{Q^2}} \frac{dk_T^2}{k_T^2} \]

\[ d\sigma \approx e^{-\frac{2\alpha_s}{3\pi}\ln^2\theta} \frac{d\theta}{\theta} \]

\[ d\sigma \approx e^{-\frac{2\alpha_s}{3\pi}\ln^2\frac{t}{Q^2}} \frac{dt}{t} \]

\[ t = (p_q + p_g)^2 \]

(transverse momentum)

(angle)

(invariant mass)
Parton shower

- Semi-classical model which agrees with perturbative QCD in collinear limit at leading-logarithmic level

\[ d\sigma = e^{-\int dP dP} \sim e^{-\alpha \ln^2 \left( \frac{\mu_1}{\mu_2} \right)} \left( \frac{\alpha_s}{2\pi} \frac{1 + z}{1 - z^2} \right) dz \]

- Formally correct at this order for many scale choices

- Common scale choices motivated by soft physics
In soft limit (large distance limit), field from + and – charges cancel. Coherent destructive interference.
Soft limit

QCD

3 quark color dipoles

Gluons act like ends of 2 dipoles

Accurate up to $1/N^2 \sim 10\%$ effects

Destructive interference

Constructive interference

Color coherence

Angular ordering

Pythia simulation
Dipole shower

Dipole showers in its rest frame

• Boost $\rightarrow$ string showers in dipole-momentum direction
• Alternative to angular ordering
Parton shower summary

- Semi-classical model which agrees with perturbative QCD in **collinear limit** at leading-logarithmic level

\[
d\sigma \approx e^{-\int \frac{dP}{dP} dP} e^{-\frac{2\alpha_s}{3\pi} \ln^2 \frac{\mu^2}{Q^2} \frac{d\mu}{\mu}}
\]

  Suadkov factor
  (leading log resummation)

- Formally correct at **leading log** in the **collinear limit**

\[ d\sigma \approx e^{-\int \frac{dP}{dP} dP} e^{-\frac{2\alpha_s}{3\pi} \ln^2 \frac{\mu^2}{Q^2} \frac{d\mu}{\mu}} \]

Herwig uses an angle ordered shower

\[ \theta^{(1)} \quad \theta^{(2)} \]

Pythia uses a \( k_T \) ordered dipole shower

\[ k_T^{(1)} \quad k_T^{(2)} \]

- Both incorporate **color coherence**
- Neither gets soft limit exactly right
- Parton showers give **amazingly accurate** simulations of complicated final states
JET ALGORITHMS
We want to see quarks and gluons:

We observe jets:

Jet-parton-map

Parton shower

How can we invert?

- Find jet momenta
- Set quark momenta = jet momenta

missing energy
Jet algorithms

- Construct jet 4-momentum from observed particle 4-momenta

Desirable properties
- Good match between jet and parton momenta
- Insensitive to hadronization
- Calculable in perturbative QCD = infrared safe
- Experiment friendly
  - Easy to calibrate
  - Insensitive to pileup
- Fast

Cone algorithms
- Conceptually simple
- Difficulties with infrared safety

Iterative algorithms
- Popular
- Efficient
Sterman-Weinberg jets (1977)

- $e^+ e^-$ to 2 or 3 jets
- 3 jets if:
  - Angles greater than $\delta$
  - Energies greater than $\epsilon$

\[
\sigma_{2\text{jet}} = \sigma_0 \left[ 1 - \frac{\alpha_s}{2\pi} \left( \ln \delta \ln \epsilon + \ln \delta - \frac{3}{4} + \cdots \right) \right]
\]

- This jet definition is infrared safe (finite in perturbation theory)
# Cone jets

**Generalizations to hadron colliders**

- Where are the cones centered
  - Seeded cones, Fixed cones, Midpoints
- Is it still infrared safe
  - Maybe, maybe not. Does it matter?

<table>
<thead>
<tr>
<th>Finding cones</th>
<th>Processing</th>
<th>Progressive Removal</th>
<th>Split–Merge</th>
<th>Split–Drop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seeded, Fixed (FC)</td>
<td>GetJet</td>
<td>CellJet</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seeded, Iterative (IC)</td>
<td>CMS Cone</td>
<td></td>
<td>JetClu (CDF)†</td>
<td>ATLAS cone</td>
</tr>
<tr>
<td>Seeded, It. + Midpoints (IC&lt;sub&gt;mp&lt;/sub&gt;)</td>
<td></td>
<td></td>
<td>CDF MidPoint</td>
<td>D0 Run II cone</td>
</tr>
<tr>
<td>Seedless (SC)</td>
<td></td>
<td></td>
<td></td>
<td>SIScone</td>
</tr>
</tbody>
</table>

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G. Salam
Iterative jet algorithms

• Start with input 4-vectors
  • e.g. stable particles, topoclusters, calorimeter cells, etc.

• Calculate the pairwise distances

\[ R_{ij} = \sqrt{(\theta_i - \theta_j)^2 + (\eta_i - \eta_j)^2} \]
Iterative jet algorithms

• Start with input 4-vectors
  • e.g. stable particles, topoclusters, calorimeter cells, etc.

• Calculate the pairwise distances

\[ R_{ij} = \sqrt{(\theta_i - \theta_j)^2 + (\eta_i - \eta_j)^2} \]

• Merge the two closest particles
Iterative jet algorithms

- Start with input **4-vectors**
  - e.g. stable particles, topoclusters, calorimeter cells, etc.

- **Calculate** the pairwise distances
  \[ R_{ij} = \sqrt{(\theta_i - \theta_j)^2 + (\eta_i - \eta_j)^2} \]

- **Merge** the two closest particles
- **Repeat** until no two particles are closer than \( R \)
Iterative jet algorithms

• Start with input 4-vectors
  • e.g. stable particles, topoclusters, calorimeter cells, etc.

• **Calculate** the pairwise distance

\[ R_{ij} = \sqrt{(\theta_i - \theta_j)^2 + (\eta_i - \eta_j)^2} \]

• **Merge** the two closest particles
• **Repeat** until no two particles are closer than R

Two R=1.0 Jets
Different distance measures

Cambridge/Aachen algorithm

\[ d_{ij} = \left( \frac{R_{ij}}{R_0} \right)^2 \]

- Clusters closest radiation first

\[ R_{12} \]
\[ R_{13} \]

\[ \begin{align*}
\text{Inversion of } \text{Herwig shower}
\end{align*} \]

\[ \begin{align*}
\text{Inversion of } \text{Pythia shower}
\end{align*} \]

\[ \begin{align*}
\text{Inversion of } \text{Pythia shower}
\end{align*} \]

k_T algorithm

\[ d_{ij} = \min(p_{T_i}^2, p_{T_j}^2) \left( \frac{R_{ij}}{R_0} \right)^2 \]

- Clusters hard collinear radiation first

anti k_T algorithm

\[ d_{ij} = \min(p_{T_i}^{-2}, p_{T_j}^{-2}) \left( \frac{R_{ij}}{R_0} \right)^2 \]

- Clusters farthest first
- No inverse parton-shower interpretation

- Produces round jets
- Almost exclusively used by ATLAS and CMS

August 25, 2012
Matthew Schwartz
Jet algorithms

- popular at Tevatron
- Good for QCD theory
- Non-compact regions – hard to calibrate

\( k_T \)

**Cambridge/Aachen**

- Based on angles
- Closer to cones

**SICcone**

- Infrared safe cone algorithm
- Not cones at all

**Anti \( k_T \)**

- Very round jets
- No parton shower interpretation
- Great for calibration
What R is best?

Goal: reconstruct parton momentum in Monte Carlo

- Include all final state radiation (FSR)
- Include little initial state radiation
- Include little pileup

Bigger R

<table>
<thead>
<tr>
<th></th>
<th>Tevatron</th>
<th>LHC (14 TeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>quark jets</td>
<td>0.56</td>
<td>0.41</td>
</tr>
<tr>
<td>gluon jets</td>
<td>0.73</td>
<td>0.54</td>
</tr>
</tbody>
</table>

Table 6: \( R \) values that minimise the two non-perturbative contributions in various circumstances for Tevatron and LHC running, based on eq. (53), with \( \frac{\alpha_s}{\pi} \mu_I^2 / \pi = 0.19 \) GeV and \( \Lambda_{UE} = 4 \) GeV at the Tevatron (LHC).

\[
\langle \delta p_T \rangle^2_{\text{pert}} + \langle \delta p_T \rangle^2_{\text{UE}}
\]

In practice
- \( R \sim 0.4-0.7 \) works best
- Must optimize for each study
Resonance peak various $R$

$R = 0.3$

$qq$, $M = 100$ GeV

SISConet, $R=0.3$, $f=0.75$

$Q_{f=0.24} = 24.0$ GeV

from G. Salam

http://www.lpthe.jussieu.fr/~salam/jet-quality/
Resonance peak various $R$

$$R = 0.3$$

$qq, M = 100 \text{ GeV}$

$SIS\text{Cone}, R=0.3, f=0.75$

$Q_w^{f=0.24} = 24.0 \text{ GeV}$

from G. Salam
http://www.lpthe.jussieu.fr/~salam/jet-quality/
Resonance peak various $R$

$R = 0.4$

$qq$, $M = 100$ GeV

SIS Cone, $R=0.4$, $f=0.75$

$Q_{f=0.24}^w = 22.5$ GeV

from G. Salam

http://www.lpthe.jussieu.fr/~salam/jet-quality/
Resonance peak various $R$

$R = 0.5$

$qq, M = 100$ GeV

SISCon, $R=0.5, f=0.75$

$Q_{f=0.24}^W = 22.6$ GeV

Resonance $X \rightarrow$ dijets

from G. Salam

http://www.lpthe.jussieu.fr/~salam/jet-quality/
Resonance peak various $R$

$R = 0.6$

$qq, M = 100 \text{ GeV}$

SISCon, $R=0.6, f=0.75$

$Q^w_f=0.24 = 23.8 \text{ GeV}$

Jet mass histogram

Resonance $X \rightarrow \text{dijets}$

From G. Salam

http://www.lpthe.jussieu.fr/~salam/jet-quality/
Resonance peak various R

\[ R = 0.7 \]

qq, \( M = 100 \text{ GeV} \)

SISCon, \( R=0.7, f=0.75 \)

\( Q_f^{25.1 \text{ GeV}} = 0.24 \)

from G. Salam
http://www.lpthe.jussieu.fr/~salam/jet-quality/
Resonance peak various $R$

$R = 0.8$

$qq, M = 100 \text{ GeV}$

SISConE, $R=0.8, f=0.75$

$Q_{f=0.24} = 26.8 \text{ GeV}$

from G. Salam

http://www.lpthe.jussieu.fr/~salam/jet-quality/
Resonance peak various $R$

$R = 0.9$

$qq, M = 100 \text{ GeV}$

SISCon, $R=0.9$, $f=0.75$

$Q_f^{W}=28.8 \text{ GeV}$

from G. Salam

http://www.lpthe.jussieu.fr/~salam/jet-quality/
Resonance peak various $R$

$\mathbf{R = 1.0}$

$qq, M = 100 \text{ GeV}$

SIS Cone, $R=1.0, f=0.75$

$Q_f^{w}= 31.9 \text{ GeV}$

Resonance $X \rightarrow \text{dijets}$

from G. Salam
http://www.lpthe.jussieu.fr/~salam/jet-quality/
Resonance peak various R

$R = 1.1$

qq, $M = 100$ GeV

SISCon, $R=1.1$, $f=0.75$

$Q_{f=0.24}^W = 34.7$ GeV

from G. Salam

http://www.lpthe.jussieu.fr/~salam/jet-quality/
Resonance peak various R

\[ R = 1.2 \]

qq, \( M = 100 \text{ GeV} \)

\[
\frac{1}{N} \frac{d\eta}{dbin} / 2
\]

SISCon, \( R=1.2, f=0.75 \)

\( Q_w^{f=0.24} = 37.9 \text{ GeV} \)

Resonance \( X \rightarrow \text{dijets} \)

from G. Salam

http://www.lpthe.jussieu.fr/~salam/jet-quality/
Resonance peak various R

**R = 1.3**

qq, M = 100 GeV

SISConE, R=1.3, f=0.75

Q_f=0.24 = 42.3 GeV

from G. Salam

http://www.lpthe.jussieu.fr/~salam/jet-quality/
DATA
RHIC, Hera and Tevatron

- Excellent agreement between NLO theory and data (10% level)
- Using same PDF set (CTEQ6.1M) and same 
  \[ \alpha_s(m_Z) = 0.118 \]

THE GLOBAL PICTURE
Putting things together
Summary on jets production in hadron collisions
– with transverse energies from 5 to 600 GeV.
– from different colliders: pp, ppbar, ep
  (would be nice to add e^+ + e^- / 2photon data, HERA PHP, …)
– simultaneously described by ONE NLO calculation with ONE PDF set on the level of 10%.

\[ \Rightarrow \text{Excellent test of pQCD.} \]

Great success !!!
– Hopefully soon: LHC data points!
– And more detailed tests?

- Excellent agreement between NLO theory and data (10% level)
- Using same PDF set (CTEQ6.1M) and same 

PDG

- Consistent values from different machines, energy scales and processes!
- Consistent picture of QCD, QCD as a precision theory!

\[ \alpha_s = 0.1184 \pm 0.0007 \]
LHC data: dijet invariant mass

Atlas dijet invariant mass (anti-\(k_T\) R=0.4)

\[ \frac{dN}{dm_{12}} [1/(\text{GeV}/5.8 \text{fb}^{-1})] \]

- Data \(\sqrt{s} = 8 \text{ TeV}, \int L \, dt = 5.8 \text{ fb}^{-1}\)
- Yellow: Pythia 8 \(\sqrt{s} = 8 \text{ TeV}\)
- Scaled to 5.8 fb\(^{-1}\):
  - Blue: Data \(\sqrt{s} = 7 \text{ TeV}, \int L \, dt = 4.8 \text{ fb}^{-1}\)
  - Red: Pythia 6 \(\sqrt{s} = 7 \text{ TeV}\)

**ATLAS** Preliminary

- anti-\(k_T\) jets, \(R = 0.4\)
- \(y^* < 1.5, |y| < 2.8\)
Tri-jet invariant mass

\[ \int L \, dt = 4.7 \text{ fb}^{-1}, \sqrt{s} = 7 \text{ TeV} \]

Events / 20 GeV

**ATLAS Preliminary**

- $t \bar{t}$
- Single Top
- $V (V) + \text{jets}$
- $t \bar{t} + V$
- MC Stat Error

$(m_t, m_{\chi_t}) = (400, 1) \text{ GeV}$

Data 2011
Multijets

Multijet data
Agrees very well with theory
Summary

- Jets exist because QCD is weakly coupled at short distances and strongly coupled at long distances.
- Collinear and soft regions dominate cross sections.
- Semi-classical approximation “Sudakov factors and splitting-functions” works excellently.
- Jet algorithms reconstruct parton momenta from jets.
- Different algorithms: Cone algorithms, Cambridge/Aachen, $k_T$, Anti-$k_T$.
- Different goals: Reconstruct parton momenta, Infrared safe, Insensitive to pileup, Easy to calibrate experimentally.
- Excellent agreement of theory with data.