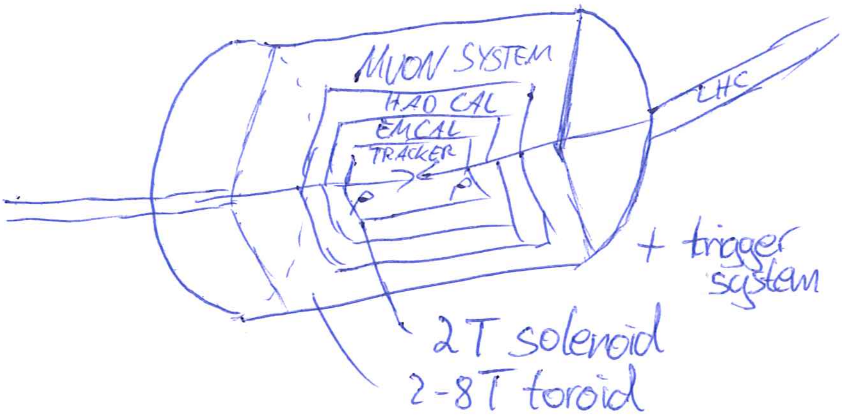
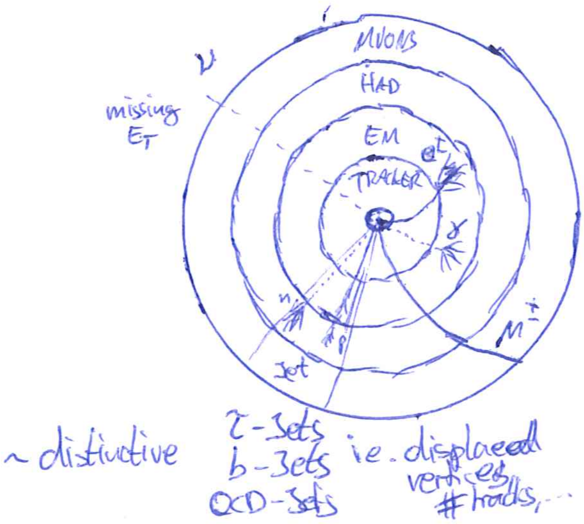
Di-Jet Searches with ATLAS

Introduction to ATLAS



- $\sqrt{s} = 13\,\mathrm{TeV}$
- $L \approx 10^{34}\,b^{-1}s^{-1}$
- 40 MHz bunch crossing rate
- $\sim 10^{11}$ protons per bunch
- 1 kHz event recording rate



Record event and reconstruct!

▷ Event variables:
- Particle content
- Total (transverse) energy
- Missing transverse energy
- # primary vertices
- sphericity
- ...

▷ Object variables:
- Transverse momentum, p_T
- Angle w.r.t beam
  - θ
  - $y = \frac{1}{2}\ln\frac{E+p_z}{E-p_z}$
  - $\eta = -\ln(\tan\frac{\theta}{2})$

  } L.I. with boost along beam
- Azimuthal angle, ϕ
- Invariant mass, m
- Energy, ...

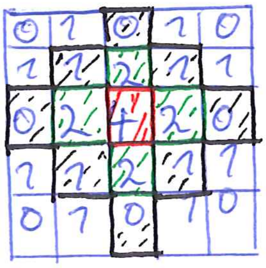
Jets

Jet: "A collimated spray of hadrons"

hard interaction	fragmentation hadronization	interaction with detector
10^{-18} m	10^{-15} m	10^{1} m
parton level	particle level	detector level

From energy deposits to reconstructed jets

Topological clustering algorithm: "420 scheme"



1. Select cell with $E_{cell} > E_{noise} + 4\sigma_{noise}$ as seed
2. Include neighboring cells with $E_{cell} > E_{noise} + 2\sigma_{noise}$
3. Include nearest neighbors

Jet algorithms:

$$d_{ij} = \min(p_{Ti}^{2p}, p_{Tj}^{2p}) \frac{\Delta R_{ij}^2}{R^2}$$

$$d_{iB} = p_{Ti}^{2p}$$

k_t: $p=1$ (soft clusters first)

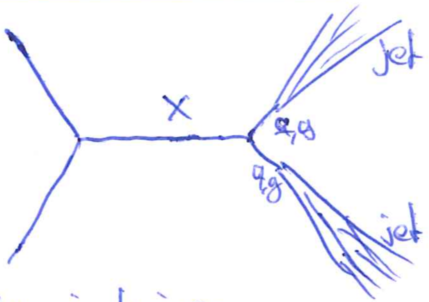
Cambridge/Aachen: $p=0$ (geometrically)

anti-k_t: $p=-1$ (hard clusters first)

1. Find minimum d_{ij}, d_{iB} among all possible pairs of clusters (i,j).
2. If $d_{ij}^{min} < d_{iB}^{min}$ combine 4-vectors of i and j into proto-jet.
3. If $d_{ij}^{min} > d_{iB}^{min}$ the 4-vector of i becomes a jet.
4. Repeat until $d_{ij}^{min} > d_{iB}^{min}$ for all clusters j.

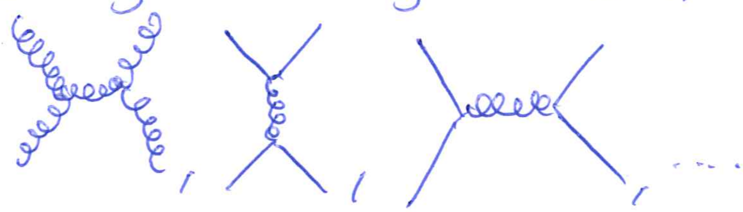
Jet calibration: Next lecture!

Di-Jet searches



(+) Very inclusive:
New particles produced at LHC must interact with partons of proton
⇒ They can also produce partons (jets) in final state!

(−) Largest SM background (QCD)



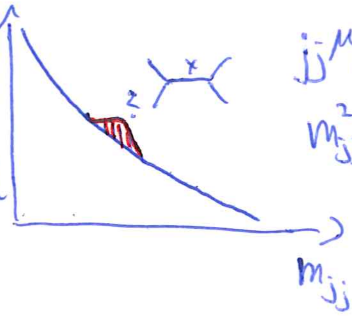
- SM $\sigma_{dijet} \sim 100nb$ ($\sigma_H \sim pb$)

⇒ employ data-driven background estimation techniques

Distinguish signals from QCD background

- QCD predicts smoothly and steeply falling dijet invariant mass spectrum

"Resonance Search" (i.e. for on-shell, s-channel mediator)



$jj^{\mu} = j_1^{\mu} + j_2^{\mu}$

$m_{jj}^2 = E_{jj}^2 - p_{jj}^2$

- QCD predicts most dijet production to occur at small angles w.r.t. beam

LO matrix elements for $2 \to 2$ scattering:

i.e.

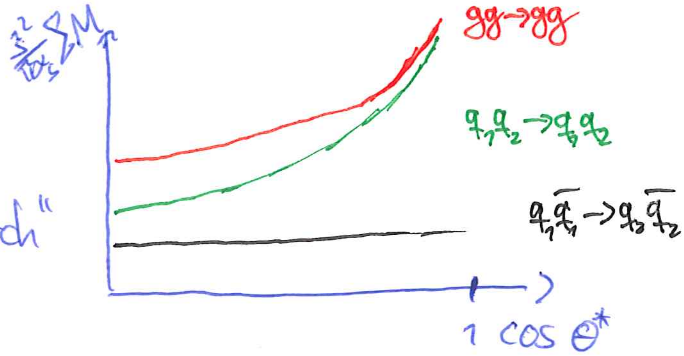
$q_1 q_2 \to q_1 q_2$: $\frac{4}{9}\frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2}$, $gg \to gg$: $\frac{9}{2}\left(3 - \frac{\hat{t}\hat{u}}{\hat{s}^2} - \frac{\hat{s}\hat{u}}{\hat{t}^2} - \frac{\hat{s}\hat{t}}{\hat{u}^2}\right)$

most subprocesses have $\hat{t}$-channel poles.

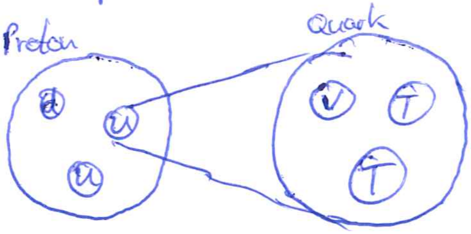
exception:

$q_1 \bar{q}_1 \to q_2 \bar{q}_2$: $\frac{4}{9}\frac{\hat{t}^2+\hat{u}^2}{s^2}$

"Angular Search"



- Example BSM scenario: Compositeness



e.g. charges $Q_T = +\frac{1}{3}$, $Q_V = 0$

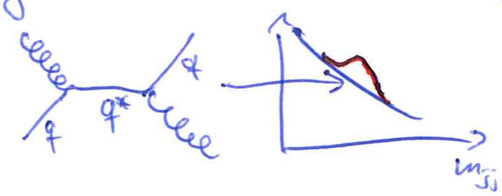
$\nu = VVV$, $u = VTT$

$\bar{d} = VVT$, $e^+ = TTT$, ...

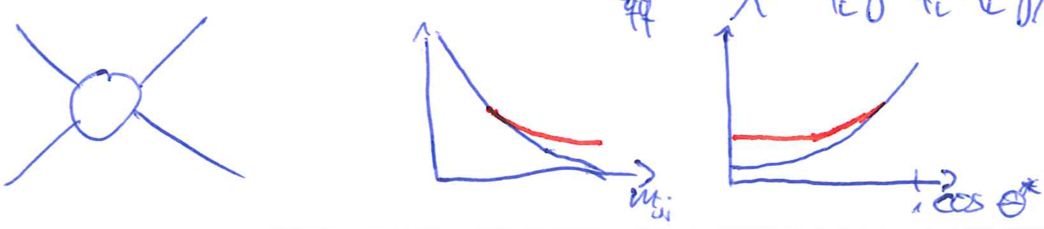
just one model among many!

Predictions (depending on details of model):

- Excited quarks



- Contact interactions, e.g. $\mathcal{L}_{qq} = \pm \frac{2\pi}{\Lambda^2} \bar{q}_L \gamma^{\mu} q_L \bar{q}_L \gamma_{\mu} q_L$



Di-Jet Search strategies

Event Selection (optimizing $\frac{S}{\sqrt{B}}$)

↓

Distribution of interesting observables
i.e. m_{jj}, angles, ..

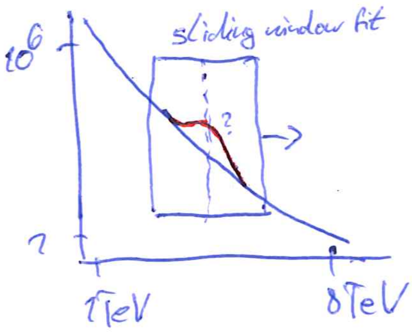
↓

Compare data to background estimate
i.e. "bumphunting"

see no deviations → Set limits

see deviations → Win Nobel prize

ATLAS High Mass Dijet Resonance Search:

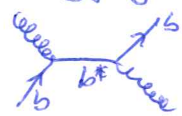


$p_{T_1} > 440$ GeV, $p_{T_2} > 60$ GeV

$M_{jj} > 1{,}1$ TeV

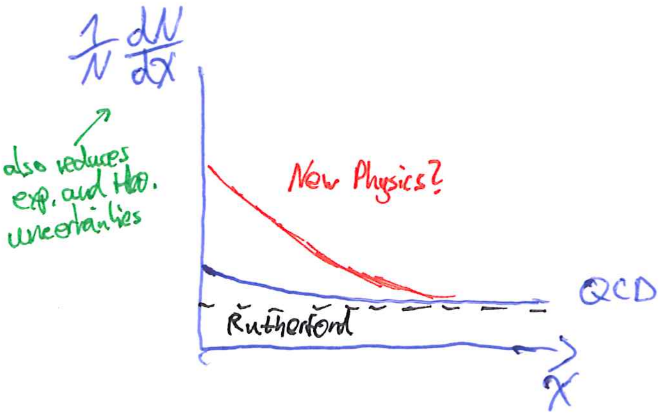
$y^* = \frac{1}{2}|y_1 - y_2| < 0{,}6$, 1.2

Optional: b-tagging



- M_{jj} spectrum fitted by empirical (historical) fit function: $f(z) = p_1(1-z)^{p_2} z^{p_3}$, $z = \frac{m_{jj}}{\sqrt{s}}$
- Fitting over many orders of magnitude of high statistics spectrum is challenging ⇒ Employ Sliding Window Fit (SWiFt)

ATLAS High Mass Angular Search:



$$\chi = e^{|y_1 - y_2|} \approx \frac{1 + \cos\theta^*}{1 - \cos\theta^*}$$

Compare data to QCD MC background estimate
(LO + NLO QCD and LO EW corrections)

large χ ≙ small angle
small χ ≙ large angle