QCD Physics
Potential of CMS

On behalf of the CMS Collaboration
Klaus Rabbertz
University of Karlsruhe
Outline

- What is QCD?
- Tracks and Hadrons
- Jets
- Photons
- Summary
What is QCD?
What is QCD?

First of all … it is 98% of us (our mass) as we have heard yesterday from Raphael! So we should better know it.

**In Formulae:**

\[
\mathcal{L} = -\frac{1}{4} F^A_{\alpha \beta} F^{\alpha \beta}_A + \sum_{\text{flavours}} \bar{q}_a (i \not{D} - m)_{ab} q_b + \mathcal{L}_{\text{gauge-fixing}}
\]

**In Words:**

- QCD is the theory of the strong interaction, one of the four fundamental forces of nature, describing especially
- the hard interactions between the coloured quarks and gluons
- but also how they bind together to form hadrons.
What is QCD?

In Pictures:

Initial State Radiation

Hadronization

Final State Radiation

PDF, Proton structure

Hard Process (ME)

Decay

Not shown for simplicity:

- Beam Remnants
- Multiple Interactions
- FSR off the hard partons

S. Gieseke
What is QCD?

**Zoomed in:**

**High \( P_T \) Jet Production**

- **Initial-State Radiation**
- **Underlying Event**
- **Outgoing Parton**
- **Multiple Parton Interaction**
- **Final-State Radiation**
- **Outgoing Parton (or photon)**
- **PT(hard)**

\[ \text{à la R. Field} \]
QCD in CMS

CMS QCD Group:

Everything … not excluded:

- New particles, exotics, SUSY (Higgs, Exotica, SUSY)
- Weak bosons (EWK)
- Heaviest quarks (Top, B Physics)
- Very forward topology (Forward Physics)
- Colliding hadrons other than protons (Heavy Ions)

Three subdivisions:

- Low $p_T$ measurements (tracker, hadrons)
- High $p_T$ measurements (calorimeter, jets)
- Measurements with photons (ECAL, photons)

Plus common efforts (PDFs, …)
QCD at Startup

Still enough events/sec left 😊

- **Startup with QCD:**
  - Not statistically limited
  - First measurements at multi TeV energy scale
  - Re-establishment of Standard Model, i.e. test extrapolations from Tevatron energies
  - Background to be understood for almost everything
  - Physics commissioning of CMS
  - But be prepared for surprises ...

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Isfahan, Iran, 24.04.2009
1st IPM Meeting on LHC Physics
Tracks and Hadrons
First Observations

... just a bunch of hadrons!

- Charged particle rapidity density
- Charged hadron spectra
- Underlying event from transverse region

Track based analyses:

Phys. Lett. Vol. 107B, no. 4
First UA1 Publication
QCD
17. December 1981

Recall:

SOME OBSERVATIONS ON THE FIRST EVENTS
SEEN AT THE CERN PROTON–ANTIPROTON COLLIDER

\[ \langle n^\pm \rangle / \Delta \eta = 1 \]
\[ |\eta| < 1.3: \ 3.9 \pm 0.3 \]
(1 track min.)

Average multiplicity of charged particles per unit of rapidity

\[ \sqrt{s} = 540 \text{ GeV} \]

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Isfahan, Iran, 24.04.2009
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Hadron Trigger at Startup

At low luminosity want to collect “ideal” data meaning exactly one collision per bunch crossing.

Regions of ideal data for different bunch patterns:
- p+p - √s = 14 TeV (σ = 79 mb)
- Too many collisions per event
- Too many empty events with ZeroBias trigger

Need trigger (Pythia):
- 69% non-diffractive
- 18% single-diffractive
- 13% double-diffractive

Possibilities:
- single or double-sided HF Trigger Tower #
- others like PixelTracks under examination

Efficiencies single:
- 81% non-diffractive
- 15% single-diffractive
- 15% double-diffractive

Double kills differ. events!

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**Strategy (used by Phobos at RHIC):**

- **No tracking,** just count clusters in the pixel barrel layers (4, 7 and 10 cm radii)
- Use cluster size to estimate z vertex and to remove hits at high $\eta$ from non-primary sources
- Correction for loopers, secondaries; systematic uncertainty expected below 10%
**CMS Pixel Triplets**

**Expect:**

- ~ 2 million events assuming one month with 1 Hz allocated bandwidth

**Strategy:**

- Still “no” tracking, Pixel Triplets

**CMS pixel detector:**

- 3 barrel layers (4, 7 and 10 cm radii) and 2 end caps on each side
- 100 × 150 μm² pixels

**Hit triplets:**

- Use pixel hit triplets instead of pairs, loss of acceptance but lower fake rate
- Reconstructing down to $p_T = 0.075$ GeV
**Charged Particle Rapidity Density from Triplets**

Simulation result from CMS:
- Charged particle pseudo-rapidity distribution
- Pythia tune DWT

**Model expectations for charged particles at $|\eta| = 0$ vs. $\sqrt{s}$:**
- Pythia: $\sim \ln^2(s)$
- Phojet: $\sim \ln(s)$

Assumes trigger efficiencies:
- $\sim$ SD 60%, DD 70%, ND 99%

**Simulated tracks**

**Will be able to differentiate**

CMS PAS QCD-07-001

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Charged Hadron Spectra

**Technique:**
Tracks from pixel triplet seeding
→ Tracking down to $p_T$ of 75 MeV

**Systematic:**
Trigger, feed-down, geom. acceptance, alg. efficiency

**Events:** ~ 2M
One month with 1 Hz allocated bandwidth

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**The Underlying Event**

The Underlying Event is everything but the hard scatter.

**High P_T Jet Production**

Measurement possibility:
- Charged particle and $p_T$ sum densities in transverse region of leading jet of charged particles

**Leading jet**

**Balancing jet**

Other “stuff” but the hard scatter

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The Underlying Event

Mix of contributing MinBias and calorimetric jet triggers

Decomposition of trigger contributions to charged particle density in $\Delta\Phi$ plane

14 TeV

Tracks $p_T > 0.9$ GeV/c

$|\eta| < 2$

CMS Preliminary

CMS PAS QCD-07-003
The Underlying Event

Charged particle density in transverse plane vs. leading charged jet $p_T$

Extrapolation to LHC from CDF data

Comparison of different Pythia tunes

Tracks: $p_T > 900\text{MeV}$ $|\eta| < 2$

Statistics as for 100/pb

14 TeV

Different Pythia tunes

CMS PAS QCD-07-003

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The Underlying Event

Increase sensitivity with tracks from $p_T > 0.5$ GeV instead of $> 0.9$ GeV

Decrease systematic effects with ratio, but with similar systematic $\rightarrow 0.9 / 1.5$

14 TeV

CMS PAS QCD-07-003
Jets
Theory Picture

Measured (or simulated) Event

Add. Collisions
Minimum Bias (MB) → Pile-up (PU)

Multiple Parton Interactions (MPI Models)

Hard Interaction ME (LO, NLO)

Parton Shower (perturbative QCD) + Hadronization (non-pert. Model)

For Jets: “splash in”

Parton Shower (perturbative QCD) + Hadronization (non-pert. Model)

For Jets: “splash out”

Hadronic Final State, colourless Particles
Experimental Picture

\[ \frac{d^2 \sigma}{d p_T dy} = \frac{N_{jets}}{\epsilon \cdot L \cdot \Delta p_T \cdot \Delta y} \times C_{unsm} \]

All jets in the event satisfying the selection criteria

⇒ Jet Efficiency
⇒ Event Efficiency

Bins of corrected Jet Pt and Jet rapidity

The JES dominates the total uncertainty of the measurement

Unsmearing correction (due to the finite detector Pt resolution)
Generic Jet Analysis

Requires:

- PDFs
- LO & NLO MC
- Det. simulation
- Jet energy scale and resolution
- Calorimeter calibration
- Jet triggers
- Luminosity
- and ...
- Data, of course!
Jet Analysis Uncertainties

Theoretical Uncertainties (~ in order of importance):
- PDF Uncertainty
- pQCD (Scale) Uncertainty
- Non-perturbative Corrections
- PDF Parameterization
- Electroweak Corrections
- Knowledge of $\alpha_s(M_Z)$
- ...

Experimental Uncertainties (~ in order of importance):
- Jet Energy Scale (JES)
- Noise Treatment
- Pile-Up Treatment
- Luminosity
- Jet Energy Resolution (JER)
- Trigger Efficiencies
- Resolution in Rapidity
- Resolution in Azimuth
- Non-Collision Background
- ...

Recall: Jet Algorithms used by CMS:
- Iterative Cone $R = 0.5$
- SISCone $R = 0.5, 0.7$
- $k_T$ $D = 0.4, 0.6$
QCD Jet Analyses

Jet analyses at high transverse momenta:

- Dijet azimuthal decorrelation
  - Less sensitive to JES, not dependent on luminosity
- Event shapes
  - Reduced sensitivity to JES & JER, not dependent on luminosity
- Dijet production ratios & angles
  - Reduced sensitivity to JES, not dependent on luminosity
- Jet cross section ratios (3-jet / all, R=0.7 / R=0.5, SISCones / kT)
  - Reduced sensitivity to JES, not dependent on luminosity
- Jet shapes
- Multi-jet studies
- Inclusive jet cross section
  - Most complicated, requires all uncertainties to be under control!
Inclusive Jets at the Tevatron

CDF Incl. $k_T$ jets, $D=0.7$
Theory: NLO with CTEQ6.1M

arXiv:0802.2400 [hep-ex]

D0 Incl. MidPoint cone jets, $R=0.7$
Theory: NLO with CTEQ6.5M

$\sqrt{s} = 1.96$ TeV
$L = 0.70$ fb$^{-1}$
$R_{\text{cone}} = 0.7$

CTEQ6.5M $\mu_R = \mu_F = p_T$

$|y| < 0.4$ (x32)
$0.4 < |y| < 0.8$ (x16)
$0.8 < |y| < 1.2$ (x8)
$1.2 < |y| < 1.6$ (x4)
$1.6 < |y| < 2.0$ (x2)
$2.0 < |y| < 2.4$
Inclusive Jets at the LHC

- $k_T$, $D=0.6$, 10 TeV

- Tevatron limit 600 GeV

- Bands are PDF uncertainties from CTEQ6.5

- LHC reach 3 x 600 GeV with 100/pb

- SISCones, $R=0.7$, 10 TeV

- Log Scale

- fastNLO/NLOJet++ NLO
- incl. $k_T$, $D=0.6$
- CTEQ6.5 PDF uncertainties

- fastNLO, hep-ph/0609285
Cross Section Ratios

Cross section ratios in 6 bins in rapidity $y$

**SISCone 0.7 / $k_T$ 0.6 @ 10 TeV**

- $k_T$ 0.6 10 TeV / 14 TeV

**Change pre-scales**

*About 14 – 8% higher cross section than $k_T$*

**Loss in $p_T$ reach**

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“The data are compared with QCD predictions for various sets of parton distribution functions. The cross section for jets with $E_T > 200$ GeV is significantly higher than current predictions based on $O(\alpha_S^3)$ perturbative QCD calculations. ..."

Explained by change in gluon density which then can be constrained by jets!

Today:

Much better estimates of PDF uncertainties

But beware ...

PDF and Scale Uncertainties

PDF uncertainties from CTEQ 6.5
At 4 TeV in $p_T$ about -20% to +35%

SISCone: Similar result
PDF uncertainties from CTEQ 6.5
At 4 TeV in $p_T$ about -20% to +35%

SISCone: Up to twice as large!
Scale variation of $p_{T,jet}$ to
$0.5 \cdot p_{T,jet}$ and $2 \cdot p_{T,jet}$
Forward Jets and PDFs

\( p_{T,jet} > 35 \text{ GeV} \)

\( \Delta \text{JES} = 5\% \)

Forward jets relative yields: 14 TeV

CMS PAS FWD-08-001
Non-perturbative Corrections

To compare with data correct NLO for:
- Multiple Parton Interactions (MPI)
- Hadronization & Decays (Lund, Cluster)

Less compensation of these effects for $k_T$ than for SISCone, not negligible in both cases. Need MC tunes for UE with first LHC data!

Compared 3 different tuned MC:
- Pythia Tune D6T
- Herwig++
- Herwig/Jimmy with Tune from ATLAS
Take correction as average of Pythia and Herwig++ and half the spread as uncertainty
JES and New Physics

- Dominating experimental uncertainty: JES (assumed ± 10% at startup)
- More data and improved JES knowledge needed to start constraining PDFs
- Sensitive to Contact Interactions beyond Tevatron reach (2.7 TeV) with 10 pb⁻¹
Jet Energy Resolution

Jet energy resolution from CMS performance study
JER usually parameterized by:

$$\sigma(p_T) = p_T \cdot \sqrt{C^2 + \frac{S^2}{p_T} + \frac{N^2}{p_T^2}}$$

Finite detector resolution on a steeply falling jet $p_T$ spectrum leads to strongly asymmetric bin migrations!

Can be derived from dataMC with dijet asymmetry method

Derived from MC comparison
Fairly independent of jet algo

CMS PAS JME-07-003
Unsmearing Applied

Artificially smear jets by Gaussian with an arbitrary but reasonable $p_T$ dependent width.

Apply ansatz method

Method corrects $p_T$ smearing effects on steeply falling spectrum
Unsmearing Steps

Motivation

The observed cross section is higher than the true one due to the falling shape of the spectrum and the finite $p_T$ resolution. More events migrate into a bin of measured $p_T$ than out of it.

Unsmearing steps:

Analytical expression of the $p_T$ resolution

Ansatz function with free parameters to be determined by the data

Fitting the data with the Ansatz function smeared with $p_T$ resolution.

Unsmearing correction calculated bin by bin.

\[
R(p'_T, p_T) = \frac{1}{\sqrt{2\pi}\sigma(p'_T)} \exp \left[ -\frac{(p'_T - p_T)^2}{2\sigma^2(p'_T)} \right]
\]

\[
f(p_T) = N \cdot p_T^{-a} \cdot \left( 1 - \frac{2 \cosh(y_{min})}{\sqrt{s}} p_T \right)^b \exp(-\gamma p_T)
\]

\[
F(p_T) = \int_0^\infty f(p'_T)R(p'_T, p_T)dp'_T
\]

\[
C_{bin} = \frac{\int_{bin} f(p_T)dp_T}{\int_{bin} F(p_T)dp_T}
\]
JER Uncertainty

Good knowledge of the resolution required!
A wrong assumption can shift the final spectrum easily by some percent ...

**Two scenarios studied:**

- **Very pessimistic:**
  - Resolution in unsmearing is “real” resolution (in %) - 1 %: 1% better (-)
  - Resolution in unsmearing is “real” resolution (in %) + 4%: 4% worse (+)

- **Optimistic:**
  - Resolution in unsmearing is 0.95 times “real” resolution (in %): 5 % better (*)
  - Resolution in unsmearing is 1.05 times “real” resolution (in %): 5 % worse (*)
Jet Shapes

Measurement of the average integrated (differential) energy flow inside jets.

Jet shape measurements can be used to test the showering models in the MC generators.

Jet shape measurements can be used to discriminate between different underlying event models.

Can be used to distinguish gluon originated jets from quark jets.
**Event Shapes**

**Definition:**
Transverse global Thrust
\(k_T\) jets, \(E_{T,1} > 80\text{ GeV}, E_{T,\text{all}} > 60\text{ GeV})

\[
T_{\perp,g} \equiv \max_{\vec{n}_T} \frac{\sum_i |\vec{p}_{\perp,i} \cdot \vec{n}_T|}{\sum_i p_{\perp,i}}
\]

Similar as Event Shapes in e⁺e⁻ and ep
- In praxis, need to restrict rapidity range:
  \(|\eta| < 1.3\) → Transverse central Thrust
- Less sensitive to JES & JER uncertainty
- No luminosity uncertainty
- Useful for MC tuning

\[\tau_{\perp,g} \equiv 1 - T_{\perp,g}\]

**CMS PAS QCD-08-003**

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Event Shapes

- Distributions get more peaked at higher $E_T$
- Corrected pseudo-data follow behaviour of original Pythia MC
- Alpgen makes different predictions

Distributions get more peaked at higher $E_T$.
Photons (and Jets)
**Photons**

**Photon processes:**
- Direct photon production
- Di-photons
- Photon + n jets

**Photon rate estimations:**
- Photon $p_T > 20\text{GeV}$
- Photon $|\eta| < 2.5$

<table>
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<th># bunches</th>
<th>$\beta^*$ (m)</th>
<th>$I_b$</th>
<th>$L$ (cm$^{-2}$s$^{-1}$)</th>
<th>Pileup</th>
<th>Photons/hour ($p_T &gt; 20\text{GeV}$)</th>
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<td>$9 \cdot 10^{10}$</td>
<td>$1.1 \cdot 10^{32}$</td>
<td>3.9</td>
<td>$3.6 \cdot 10^{5}$</td>
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</table>

Not taken into account
Photon Isolation

Gauge boson production gives important additional information:
- Luminosity measurement
- Detector calibration
- PDFs
- Background for new physics :

Important steps:
- Good efficiency including photon conversions
- Proper photon isolation to suppress background

CMS photon study:
- Photon $p_T$ spectrum for $1/fb$
- Background QCD jets in blue
- After photon isolation cuts
- Improves S/B > 2 orders of magnitude


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Outlook

- CMS is preparing (again) for first LHC data in autumn
- LHC will explore unknown territory in QCD
- First measurements, even at 900 GeV, will be QCD
- Some tough experimental systematics to deal with, but combining detector parts may help in certain phase space regions (jets+tracks, particle flow)

- Measurements of jets and photons are important tests of QCD:
  - Angular distributions, inclusive jets, di-jets, photon+jets, di-photons, forward jets
  - Calibration of the calorimeters
  - Better understanding of dominant background to many new physics channels
  - Constraints on PDFs

- New physics might be just ahead!

Thanks to all colleagues helping in preparing this presentation!
Backups
CMS Electromagnetic Calorimeter

Barrel (EB):
- \( \eta \) segments: 2x85
- \( \phi \) segments: 360
\( \rightarrow 61200 \) crystals
\( (\text{PbWO}_4, 26 \, X_0) \)
\( \rightarrow \Delta \eta \times \Delta \phi \approx \)
\( 0.0174 \times 0.0174 \)

End caps (EE):
- (x,y) grid on two halves
- front face 28 x 28 mm\(^2\)
\( \rightarrow 2 \times 2 \times 3662 \) crystals = 14648
\( (\text{PbWO}_4, 25 \, X_0) \)

Energy resolution from test beam:
\( S = 3.63\%, \, N = 124 \, \text{MeV}, \, C = 0.26\% \)

\[
\left( \frac{\sigma}{E} \right)^2 = \left( \frac{S}{\sqrt{E}} \right)^2 + \left( \frac{N}{E} \right)^2 + C^2
\]
CMS Hadronic Calorimeter

HCAL (tower structure):
- Barrel (HB): $|\eta| < 1.4$, 2304 towers
- End caps (HE): $1.3 < |\eta| < 3.0$, " towers
- Outside coil (HO): $|\eta| < 1.26$ (tail catcher)
  $\rightarrow$ 4608 towers (Plastic scintillator tiles, $\approx 10 \lambda_N$)
  $\rightarrow$ $\Delta \eta \times \Delta \phi \approx 0.087 \times 0.087 \rightarrow 0.350 \times 0.175$
- Forward (HF): $2.9 < |\eta| < 5.0$ (not shown)
  $\rightarrow$ 2 x 900 towers (Quartz fibers, $\approx 10 \lambda_N$)
  $\rightarrow$ $\Delta \eta \times \Delta \phi \approx 0.111 \times 0.175 \rightarrow 0.302 \times 0.350$

CASTOR calorimeter (not shown):
- $5.1 < |\eta| < 6.5$, $\approx 22 X_0$, $\approx 10 \lambda_N$
# Hadron Spectra Systematics

CMS Pixel triplets

\[
\Delta N_{\text{corrected}} = \frac{(1 - \text{fakeRate}) \cdot (1 - \text{feedDown})}{\text{geomAcc} \cdot \text{algoEff} \cdot (1 - \text{multiCount})} \cdot \Delta N_{\text{measured}}
\]

<table>
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<th>Corr.</th>
<th>Syst.</th>
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<td>mult</td>
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<td>Trigger</td>
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<tr>
<td>Feed-down</td>
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<tr>
<td>Total</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
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</table>
Tracking Performance

Comparison of tracking performance for:
- Ideal conditions
- Start-up (misaligned)
- Alignment Position Error application

Track reconstruction efficiency

Fake rate

- Recover efficiency
- Increased fake rate

The price to pay
**Dijets in pp collisions:**

\( \Delta \phi \text{ dijet} = \pi \rightarrow \)
- Exactly two jets, no further radiation

\( \Delta \phi \text{ dijet} \) small deviations from \( \pi \rightarrow \)
- Additional soft radiation outside the jets

\( \Delta \phi \text{ dijet} \) as small as \( 2\pi/3 \rightarrow \)
- One additional high-pT jet

\( \Delta \phi \text{ dijet} \) small – no limit →
- Multiple additional hard jets in the event

hep-ex/0409040
PRL 94, 221801 (2005)
Partonic Subprocesses

For $hh \rightarrow \text{jets}$ there are **seven** relevant partonic subprocesses:

1) $gg \Rightarrow \text{jets} \propto H_1(x_1, x_2)$

2) $qg, \bar{q}g \Rightarrow \text{jets} \propto H_2(x_1, x_2)$

3) $gq, g\bar{q} \Rightarrow \text{jets} \propto H_3(x_1, x_2)$

4) $q_i q_j, \bar{q}_i \bar{q}_j \Rightarrow \text{jets} \propto H_4(x_1, x_2)$

5) $q_i q_i, \bar{q}_i \bar{q}_i \Rightarrow \text{jets} \propto H_5(x_1, x_2)$

6) $q_i \bar{q}_i, \bar{q}_i q_i \Rightarrow \text{jets} \propto H_6(x_1, x_2)$

7) $q_i \bar{q}_j, \bar{q}_i q_j \Rightarrow \text{jets} \propto H_7(x_1, x_2)$

**Seven linear combinations $H_i$ of PDFs**
Decomposition of the total pp, pp → jets cross section (NLO) into subprocesses At central rapidity against the scaling variable $x_T = 2p_T/\sqrt{s}$

- Subprocess Decomposition

![Graph showing subprocess contributions](image-url)
**New Physics from Dijets**

**New Physics with Jets:**

- **Contact interactions**
- **Resonances**
  - $W'$ & $Z'$ (Grand Unified Theory)
  - $E_6$ diquarks (D) (Superstrings & GUT)
  - Excited quarks ($q^*$) (Compositeness)
  - RS Gravitons (G) (Extra Dimensions)
  - Colorons (C) & Axigluons (A) (Extra Color)

### CMS

#### Need $E_{CMS} > M$

| Model | J  | Color | $|\eta| < 1$ | $|\eta| < 1.3$ | $|\eta| < 1$ | $|\eta| < 1.3$ | $|\eta| < 1$ | $|\eta| < 1.3$ |
|-------|----|-------|-------------|-------------|-------------|-------------|-------------|-------------|
| $q^*$ | 1/2| Triplet| $7.95 \times 10^4$ | $1.27 \times 10^9$ | $9.01$ | $1.36 \times 10^1$ | $1.82 \times 10^{-2}$ | $2.30 \times 10^{-2}$ |
| A,C   | 1  | Octet | $3.22 \times 10^2$ | $5.21 \times 10^2$ | $5.79$ | $8.82$ | $1.55 \times 10^{-2}$ | $2.04 \times 10^{-2}$ |
| D     | 0  | Triplet| $8.11 \times 10^1$ | $1.26 \times 10^2$ | $4.20$ | $5.97$ | $4.65 \times 10^{-2}$ | $5.75 \times 10^{-2}$ |
| G     | 2  | Singlet| $3.57 \times 10^1$ | $5.47 \times 10^1$ | $1.83 \times 10^{-1}$ | $5.31 \times 10^{-1}$ | $1.76 \times 10^{-4}$ | $1.17 \times 10^{-3}$ |
| $W'$  | 1  | Singlet| $1.46 \times 10^1$ | $2.37 \times 10^1$ | $3.49 \times 10^{-1}$ | $5.31 \times 10^{-1}$ | $1.76 \times 10^{-4}$ | $1.17 \times 10^{-3}$ |
| $Z'$  | 1  | Singlet| $8.86$ | $1.44 \times 10^1$ | $1.81 \times 10^{-1}$ | $2.77 \times 10^{-1}$ | $5.50 \times 10^{-4}$ | $7.26 \times 10^{-4}$ |

### Contact Interactions

- Sensitive to Scale $\Lambda >> \sqrt{s}!$

**Contact Interaction**

$L_{qq} = \frac{Ag^2}{2\Lambda^2}(\bar{q}L\gamma\mu qL)(\bar{q}L\gamma\mu qL)$

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Klaus Rabbertz  
Isfahan, Iran, 24.04.2009  
1st IPM Meeting on LHC Physics
New Physics from Dijets

Search for deviation from expected event rate:

- QCD from PYTHIA (here) or NLO
- Contact interaction: PYTHIA or LO

Cross section ratios

Search for resonances

Possible signals of $q^*$ relative to QCD prediction, visible for $<2$ TeV
(statistical uncertainty only!)

One means to avoid systematics is by looking into cross section ratios in $\eta$
Recent Limits

Tevatron limit on contact interaction scale (qqqq): $> 2.4 - 2.7$ TeV

Dijet resonance search

CDF Preliminary 03/2008

Exclusion limits for $W'$ and $Z'$
Dijet Ratios

- Sensitivity to new physics from dijet x section ratios in pseudo-rapidity
- Reduced sensitivity to jet energy scale

CMS PAS SBM-07-001

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Jet Shapes

A possibility to look into details of QCD and jet structure!

Norm. transverse energy distribution:

$$\rho(r) = \frac{\sum p_T (r - \Delta r/2, r + \Delta r/2)}{\Delta r \sum p_T^{Jet}}$$

Good reproduction of general properties (central region $|\eta| < 1$, matched jets)

Jets from generator particles

Jets from calorimeter towers

Iterative Cone

CMS PRELIMINARY

80 < $P_T^{Jet}$ < 120 GeV/c

Icone uses $\eta$, $\Delta r$ employs $\gamma$!

MidPointCone

SISCono

CMS PAS JME-07-003

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Multiple Parton Interactions

Phase space:
- As low as possible in pT:
  - photon pT > 10 GeV
  - jet pT > 20 GeV for calojets
=> could consider jets from tracks

- **Double-parton-scattering**
  - four-jet production (→ AFS, UA2, CDF)
  - like-sign W production
  - γ + 3-jet production (→ CDF)

- Need double-parton component to describe the data

CDF 16 GeV γ/π⁰ 3 jets
1-Vertex-Events
- Data
- DP component from Two-Dataset-Method (52.6 %)
  - Monte Carlo admixture:
    - 52.6 % DP + 47.4 % Pythia

σ_{eff}(CDF) = 11 mb
→ no x-dependence found!
Influence of $\alpha_s(M_Z)$

Cross section ratios at central rapidity $\alpha_s(M_Z)$ varies from 0.112 to 0.125

With CTEQ6.6 central PDF

PDG Value $\alpha_s(M_Z) = 0.1176 \pm 0.0020$
Would lead to 2 to 4% variation

With CTEQ6.6A $\alpha_s$ PDF series

Only $\alpha_s$ different already in PDF fit
Some UA1 Quotations

- Quotations from Phys. Lett. Vol. 107B, no. 4:
  - ... dipole magnet which produces a field of 0.7 T over a volume of 7m x 3.5m x 3.5m ...
  - ... yields space points at centimetre intervals on the detected tracks
  - ... two short accelerator development periods in October and November 1981 ...
  - The events were scanned by physicists on a Megatek display.
  - ... was examined independently by all physicists who participated in the scanning. The combined effect of the scanner variations ...