Vector Bosons & Jets
Photon production

Several results on photon production
- Isolated, in association with up to 3 jets, di-photon at the LHC, direct photons at HERA
- Test of pQCD, in general successful
- Other approaches (k_T factorization) have problem with emissions of extra gluons
- Investigation of new variables to study parton radiation
  - Photons and jets show different QCD radiation pattern
Isolated photon production, transverse energy up to 1.5 TeV
- Good description by NLO MC; first NNLO calculations now available
Photon-pair production stringent test of pQCD
- NLO MC fails to describe data, whereas NNLO provides better match
Photons at HERA

Olena Hlushchenko

$k_T$-factorisation (BLZ) predictions show a fair agreement with the data with the exception of variables sensitive to gluon emission.
Associated production of W/Z and jets

V+jets are a test bench for perturbative QCD, in particular for matrix-element merging techniques
- Higher-order corrections improve theory/data agreement
- NLO merging gives a very satisfactory description of data

\[ Z+\text{jets} @ 7 \text{ TeV}, 1304.7098 \]

NLO used for shapes and normalisation
W/Z + Jets Highlights

Nataliia Kondrashova

\[ \sigma(Z/\gamma^* \rightarrow IT) + \text{jets} \]

13 TeV, 3.16 fb\(^{-1}\)
anti-\(k_t\) jets, \(R = 0.4\)
p_{T, \text{jet}} > 30 \text{ GeV}, |y| < 2.5

\[ \sigma(Z/\gamma^* \rightarrow IT) + \text{jets} \]

\[ Z + \text{up to 7 jets} \]

\[ W + \text{jets} @ 13\text{TeV} \]
- Stringent tests of pQCD
- Splitting scale measurement
- Probes QCD evolution

Qun Wang
Study of collinear W-jet topologies

V+jets make it possible to study the emission of vector bosons from quarks in events with hard jets
- Important contribution for V+jets at large $p_T$
- Impact also on vector-boson scattering, dijets at large $m_{jj}$, boosted top, and new physics searches

Best agreement found with predictions with higher-order QCD predictions
- Best: Njetti NNLO and Sherpa+OpenLoops
- NLO QCD+EWK
Inclusive $W \rightarrow e\nu$ production at 8 TeV

First measurement of $W \rightarrow e\nu$ at LHCb with 2 fb$^{-1}$

-Fiducial acceptance
  - single electron with $p_T > 20$ GeV, $2 < \eta < 4.25$
  - purity $\sim 60\%$
  - additional $\gamma \rightarrow ee$ background
  - softer $p_T$ spectrum compared to $W \rightarrow \mu\nu$
  - efficiencies data driven

$Wb\bar{b}$, $Wc\bar{c}$ and $t\bar{t}$ cross-section at 8 TeV

Analysis extended to one isolated lepton (muon or electron) and two heavy-flavour tagged jets using 2 fb$^{-1}$

- leptons:
  - isolated
  - $p_T > 20$ GeV
  - $2 < \eta < 4.5$ (4.25) for $\mu$ ($e$)
- jets:
  - $p_T > 12.5$ GeV
  - $2.2 < \eta < 4.2$
  - $\Delta R$ (lepton-jet) $> 0.5$

Good agreement between measured cross-section and theoretical predictions with different PDFs

Novel measurement of $W + cc$ production
LHCb Electroweak Programme

Inclusive $W \rightarrow e\nu$ production at 8 TeV

- First measurement of $W \rightarrow e\nu$ at LHCb with 2 fb$^{-1}$
- Fiducial acceptance:
  - single electron with $p_T > 20$ GeV, $2 < \eta_e < 4.25$
  - purity $\sim 60\%$
  - additional $\gamma \rightarrow ee$ background
  - softer $p_T$ spectrum compared to $W \rightarrow \mu\nu$
  - efficiencies data driven

NEW! (JHEP 10 (2016) 030)

Marcin Kucharczyk

$Wbb$, $Wcc$ and $t\bar{t}$ cross-section at 8 TeV

- MCFM NLO prediction with PDF set CT10
- Showering and hadronization using Pythia 8

Good agreement between measured cross-section and theoretical predictions with different PDFs

05-04-2017
Marcin Kucharczyk, DIS 2017

Good Agreement with NLO predictions
Theoretical progress highlights

Study of $Z$ production in association with $b$-jets, and comparison with different flavour schemes

- 4FS and 5FS agree in shape, 4FS normalisation undershoots data when one $b$-jet is outside the acceptance

Joint $q_T$ and threshold resummation for Drell-Yan available

- Unfortunately, power corrections remain large at the LHC because of $qg$-initiated channel
- OK for Tevatron and for heavy $Z'$
More theoretical progress

- Development of loop-tree duality techniques towards their application at realistic processes
- High-multiplicity loop integrals (up to 10 external legs) can be efficiently tackled
- Timings are quite competitive
- Will this change the way we do higher-order computations?

Grigoris Chachamis
Electroweak
Precision W mass result from ATLAS joins Tevatron(+LEP) combination
- Consistent within 2% uncertainty
Some highlights on painstaking analysis
- W sample, correction for detector effects, modeling of boson kinematic

Fabrice Balli
Electroweak Tevatron results

New results from D0 Collaboration
- Weak mixing angle in di-muon final state
- Direct measurement of top mass, full data sample
- Top pole mass from differential cross section

Preliminary combination of Tevatron weak mixing angle measurements

$$\sin^2 \theta_{\text{eff}} = 0.23002 \pm 0.00066$$

$$m_t = 174.9 \pm 0.75 \text{ GeV/c}^2$$

$$m_t = 169.1 \pm 1.4 \text{ (theo) } \pm 2.2 \text{ (exp) GeV/c}^2$$

Iain Bertram
Improvements on generators for top quark production

Proposed method to generate top states with full interference term at NLO
- Experimental precision reaching O(0.1GeV)
- Includes exact off-shell effects and interference of radiation from production and decay

Tomas Jezo

[arXiv:1404.1013]
Multi-boson final states: experimental updates

Very large scenario of measurements:
- Multi-boson final states; EWK production of vector bosons; VBS

Highlights:
- Fiducial cross sections sensitive to NNLO vs. NLO (WW)
- Differential cross sections challenge NLO predictions

Most recent results:
- ZZ in full 13 TeV data sample, WZ 8 TeV differential measurement
- VBF W, EW-produced Zγ, WWW production

Angela Burger (WZ)
Senka Duric (ZZ)
More multi-boson highlights

WZ cross section: 
MC/data normalization 10% off: consistent with expected NNLO QCD corrections

Search region for same-sign WW (above) and Zγ electroweak production (right)

Senka Duric

Chris Hays

VBF W: sensitive to EWK corrections

Christian Johnson

ATLAS Preliminary
Limits on anomalous gauge couplings

Not yet observed anomalies in electroweak gauge couplings (!)
- Larger sensitivity to anomalies due to increase in centre-of-mass energy
- Limits comparable to LEP results

Limits set using all multi-boson final states
- TGC (charged and neutral) in diboson production and VBF
- QCG in VBS and triple-boson final states

Senka Duric
Angela Burger
Christian Johnson
NLO electroweak corrections to di-boson production and vector-boson scattering
- Full set of NLO EW corrections to diboson production; dependence on different phase space selections evaluated (inclusive, Higgs analysis, TGC)
- First calculation of NLO EW corrections to VBS same-sign WW: they are large!
$\alpha_s$ and Double Parton Scattering
NNLO $\alpha_s$ fit using jets in DIS

- Recent NNLO computation of jet production in DIS (Currie et al, 1606.03991 and 1903.05977) makes it possible to extract $\alpha_s$ with a proper NNLO fit
- Sensitivity from hard matrix elements and from PDF separately studied
- Excellent experimental accuracy and improved theoretical errors. Scale uncertainties still the dominant source, followed by PDF
- Running confirmed between 7 and 90 GeV

$Fits$ to
- Inclusive jet or dijet data
- Separate fits to low-$\mu$ and high-$\mu$ data points
- Fits including PDF uncertainties in $\chi^2$ or not

$Fits$ with two free $\alpha_s$ parameters

$\sigma_i = f(\alpha_s(M_Z)) \otimes \hat{\sigma}_i(\alpha_s(M_Z)) \cdot c_{\text{had}}$

$Results$
- Most sensitivity arises from matrix elements
- Best-fit $\alpha_s$-values in PDF’s and ME’s are consistent
- Significant anti-correlation at lower scales -> Increased sensitivity if both $\alpha_s$-values identified to be identical
- PDF uncertainties do not yield significant shift -> PDF uncertainties with small correlation to $\alpha_{\text{PDF}}$
Global fit of $\alpha_s$ using jet cross sections

- Aim: extract $\alpha_s$ using the measurements of jet cross sections by various experiments, within an unified framework (ALPOS) and fitting procedure
- Old results are reproduced exactly. Possible improvements by including new theoretical predictions (NNLO)

**Unified fit result (2)**

**Add more datasets**

- K. Rabbertz
- Birmingham, UK, 05.04.2017
- DIS 2017 Workshop

---

**Simultaneous fit to H1, ZEUS, STAR, CDF, D0, and CMS**
- consistent result
- reduced experimental uncertainty
- scale uncertainty (NLO) dominating in full uncertainty breakdown

$$\alpha_s(M_Z) = 0.1187(\pm12)_{\exp} (\pm5)_{NP}$$

$$\pm6_{\text{PDF}} (^{+18}_{-3})_{\text{PDFset}} (^{+11}_{-8})_{\text{PDF}} \alpha_s$$

$$+59_{-38}\text{scale}$$

$$\chi^2_{\text{min/ndf}} = 0.87$$

**World average [2017]**

- H1 (HERA-II)
- ZEUS (HERA-I)
- STAR
- CDF (Run-II)
- D0 (Run-II)
- ATLAS (7 TeV)
- CMS (7 TeV)

**Common fit (excl. ATLAS)**

**Klaus Rabbertz**
Perturbative splitting can occur in both protons (1v1 graph) – gives power divergent contribution to DPS cross section!

\[ \int \frac{d^2 y}{y^4} = ? \]

DPS luminosities

\[ Q_A = Q_B = 80 \text{ GeV}, \sqrt{s} = 14 \text{ TeV} \]

Vary scale \( \nu \) between \( Q/2 \) and \( 2Q \)

Here: plot luminosities againsts rapidity of one hard system (other kept central):

2v2 much larger than others, with large \( \nu \) variation – need SPS contribution up to order containing double box, and subtraction!

Jonathan Gaunt

J. Gaunt, DPS in the UV
Perturbative splitting can occur in both protons (1v1 graph) – gives power divergent contribution to DPS cross section!

\[ \int \frac{d^2 y}{y^4} = ? \]

DPS luminosities

\[ Q_A = Q_B = \frac{1}{\sqrt{\alpha_s}} \]

Combining matching and evolution

- Cross section contribution given by

\[ W_{\text{large } y} = \sum_R \exp \left\{ \int_{\mu_1}^{\mu_2} \frac{d\mu}{\mu} \left[ \gamma_F(\mu, \mu^2) - \gamma_K(\mu) \log \frac{Q_1^2}{\mu^2} \right] + R_K(z_1, \mu_01) \log \frac{Q_1^2}{\mu_01^2} \right\} \]

\[ \times R C(\overline{x}_1', z_1; \mu_01, \mu_01^2) \otimes R C(\overline{x}_2', z_2; \mu_02, \mu_02^2) \otimes \]

\[ \times R C(x_1', z_1; \mu_01, \mu_01^2) \otimes R C(x_2', z_2; \mu_02, \mu_02^2) \otimes \]

\[ \times \left[ \Phi(\nu y) \right]^2 \exp \left[ R J(y, \mu_0 i) \log \frac{\sqrt{Q_1^2 Q_2^2}}{\zeta_0} \right] \]

\[ R F(\overline{x}_i, y; \mu_0 i, \zeta_0) R F(x_i, y; \mu_0 i, \zeta_0) \]

double box, and subtraction!

Actual \( \nu \) variation

Naive power counting expectation for \( \nu \) variation \( \propto \nu^2 \)
Event Shapes, Particle Correlations, Medium Effects
Underlying event tune in CMS

- Tuning of MC generators is needed to achieve a proper description of data
- A new Pythia8 tune is being developed by CMS
- UE tune improves the description e.g. of jets multiplicities in $t\bar{t}b$ar events
- Future plans to extend to HW++ and Sherpa

Results

\[
\alpha_{SR}^{IS} = 0.1108^{+0.0144}_{-0.0142} \quad h_{\text{damp}} = 1.581^{+0.658}_{-0.585}
\]

Performance of the new tune

Charged particle mult. in the MIN region and $dN/d\eta$ @13 TeV

The new tune has a better description of the plateau region

Rising part of the spectrum seems to prefer a double gaussian matter distribution profile
No tool can describe correlations both in 2 and 4 jets. Why? Can things be improved?

- Herwig++ exhibits the largest deviations.
- Pythia8 behaves better.
- Best description by MadGraph.

Armando Bermudez Martinez

Pythia8 and MadGraph fail to describe data.
Herwig++ provides a reasonable description of the data.
New ideas for jet physics

- A new framework ‘improved TMD’ for calculations of forward dijets has been developed, and phenomenological predictions can be obtained
- Forward-forward and forward-central di-jets studied
- Shall we use the jet mass to characterise jets and fragmentation functions?

**Suggestion**

Parametrise fragmentation functions as

\[ D \left[ x = \frac{2 P^\text{jet} P^\text{h}}{M^2_{\text{jet}}} \right], \quad Q^2 = M^2_{\text{jet}} \]

**Energy fraction the hadron takes away in the frame co-moving with the jet**

**Fragmentation scale:** jet mass

Krzystof Kutak

Kotko, K.K, Sapeta, van Hameren ’14

In DGLAP approach i.e. 2 → 2 + pdf one would get delta function

Observe suggested to study BFKL effects Sabio-Vera, Schwiening ‘06

Studied also context of RHIC Albacete, Marquet ’10
- Measurement of particle correlations and of the production of $J/\psi$ and vector bosons in heavy-ion collisions have been presented.
- Measurement of Fourier coefficient of correlations in heavy-ion collisions performed by ATLAS, lack of theoretical predictions to compare with.
- The measurement of the ratio $N_{J/\psi}/N_{Z}$ is independent of event activity and could be used as a benchmark for the nucleonic luminosity $T_{AA}$ and $N_{coll}$.
Two-photon contribution to elastic lepton-proton scattering

First results from OLYMPUS
- Experiment aims at measuring two-photon contribution to p-e scattering
- Measures size of two-photon contribution vs $Q^2$: up to 2% at high-$Q^2$
- Confirms VEPP-3 and CLAS measurements; smaller uncertainties of OLYMPUS measurement seem to identify disagreement with calculations

$$R_{2\gamma} = \frac{\sigma_{e^+p}}{\sigma_{e^-p}} = \frac{|M_{1\gamma}|^2 + 2R(M_{1\gamma}M_{2\gamma})}{|M_{1\gamma}|^2 - 2R(M_{1\gamma}M_{2\gamma})}$$

Dmitry Khaneft
Two-photon contribution to elastic lepton-proton scattering

First results from OLYMPUS

- Experiment aims at measuring two-photon contribution to $p$-$e$ scattering
- Measures size of two-photon contribution vs. $Q^2$: up to 2% at high-$Q^2$
- Confirms VEPP-3 and CLAS measurements; smaller uncertainties of OLYMPUS measurement seem to identify disagreement with calculations
Energy-loss Effects

E906/SeaQuest: measure **quark energy loss in cold matter with Drell-Yan**
- Baseline for understanding heavy-ion collision
- Key point w.r.t. E866: low \(x\)(target) minimizes shadowing effects

First results
- Sea PDF: disagreement with E866 being investigated
- Energy loss (Fe, W and C targets) \(~ A^{-1/3}\)

\[
\frac{d^2\sigma}{dx_b \, dx_t} = \frac{4\pi^2 \alpha^2}{9 x_b x_t s} \sum_q e_q^2 \left[ q_t(x_t) q_b(x_b) + \frac{x_t}{x_b} q_t(x_b) q_b(x_t) \right]
\]

-target sea quark at low/intermediate \(x\)
-beam valence quark at high \(x\)

Small in fix target exp. with very forward acceptance

**Po-Ju Lin**

**SeaQuest Preview**

30% of anticipated data

- Mass > 4.2 GeV
- \(x_{\text{Target}} > 0.15\)

Systematic uncertainty: \(~ 8\%\)
1952 E. Fermi
\[ \sim \exp\left(-\frac{E_T}{T}\right) \]

1983 R. Hagedorn
\[ \sim \left(\frac{p_0}{p_0 + p_T}\right)^N \]

1987 C. Tsallis
\[ \sim \left(\frac{1}{1 + \frac{E_T}{T\cdot N}}\right)^N \]

2010 ???

Further modification of existing approaches is needed.
Exponential contribution is related to the thermalized partons preexisted long before the interaction.

Power-law contribution is related to the QCD vacuum fluctuations described by exchange of Pomerons.

CMS Data pp $\sqrt{s} = 7$ TeV

Further modifications:

\[
\frac{d^2\sigma}{d y (d p_T^2)} = A_1 \exp\left(-\frac{E_{T\text{kin}}}{T_e}\right) + \frac{A_2}{\left(1 + \frac{p_T^2}{T^2N}\right)^N}
\]

1952 E. Fermi
\[\sim \exp\left(-\frac{E_T}{T}\right)\]

1983 R. Hagedorn
\[\sim \left(\frac{p_0}{p_0 + p_T}\right)^N\]

1987 C. Tsallis
\[\sim \left(\frac{1}{1 + \frac{E_T}{T\cdot N}}\right)^N\]

2010 A. Bylinkin & A. Rostovtsev
Light Mesons
Lattice studies on $\pi$ form-factors

- Aim to understand the transition to pQCD
- Lattice simulations very complicated. So far, results only for low values of $Q^2$ and high (unphysical) values of $m_{\pi}$
- Need for simulations with higher statistic and smaller spacing.

**Equation:**

$$F_a(Q^2) \rightarrow \frac{16\alpha_s(Q^2)f_{\pi}^2}{Q^2}$$

**Soft part** ($Q^2 < 1$ GeV$^2$):

- vector meson dominance with $F_a(0) = 1$,
- data fits well
Results: Branching fraction

\[
\text{BR}(K^\pm \rightarrow \pi^\pm \pi^0 e^+ e^-) = \frac{N_S - N_{BS}}{N_N - N_{BN}} \times \frac{A_N}{A_S} \times \frac{\varepsilon_{L1N} \times \varepsilon_{L2N}}{\varepsilon_{L1S} \times \varepsilon_{L2S}} \times \text{BR}(K^\pm \rightarrow \pi^+ \pi^0) \times \text{BR}(\pi_D^0)
\]

\(A_S = \text{weighted average of IB, DE, INT acceptances using expected relative contributions}\)

Radiative corrections taken into account by using PHOTOS in MC simulations and Prague group \(\pi_D^0\) generator [PRD 92(2015)054027] in MC for normalization mode

<table>
<thead>
<tr>
<th>Signal</th>
<th>Normalization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Candidates (N_S) 5076</td>
<td>Candidates (N_N) 16774613</td>
</tr>
<tr>
<td>Background (N_{BS}) 289</td>
<td>Background (N_{BN}) 25517</td>
</tr>
<tr>
<td>Accept(rad) (A_S) 0.666(1) %</td>
<td>Accept(rad) (A_N) 4.083(2) %</td>
</tr>
<tr>
<td>L1 eff. (\varepsilon_{L1S}) 99.73(1) %</td>
<td>L1 eff. (\varepsilon_{L1N}) 99.767(3) %</td>
</tr>
<tr>
<td>L2 eff. (\varepsilon_{L2S}) 99.46(2) %</td>
<td>L2 eff. (\varepsilon_{L2N}) 98.584(7) %</td>
</tr>
</tbody>
</table>

Preliminary result:

\[
\text{BR}(K^\pm \rightarrow \pi^\pm \pi^0 e^+ e^-) = (4.22 \pm 0.06_{\text{stat}} \pm 0.04_{\text{syst}} \pm 0.13_{\text{ext}}) \times 10^{-6}
\]

- Error is dominated by external error on \(\text{BR}(\pi_D^0)\)
- Good agreement with ChPT predictions [EPJ C72(2012)]:
  - without radiative and isospin breaking corrections: \(\text{BR}(\text{IB}) = 4.19 \times 10^{-6}\)
  - with isospin breaking: \(\text{BR}(\text{IB}) = 4.10 \times 10^{-6}\)
Results: Branching fraction

\[ \text{BR}(K^\pm \rightarrow \pi^\pm \pi^0 e^+ e^-) = \frac{N_S - N_{BS}}{N_N - N_{BN}} \times \frac{A_N}{A_S} \times \frac{\varepsilon_{L1N} \times \varepsilon_{L2N}}{\varepsilon_{L1S} \times \varepsilon_{L2S}} \times \text{BR}(K^\pm \rightarrow \pi^+ \pi^0) \times \text{BR}(\pi_0^D) \]

First observation of the $K^\pm \rightarrow \pi^\pm \pi^0 e^+ e^-$ decay

Results: signal and normalization $M_{ee}$ spectra

Signal: $\pi^+(\pi^0 \rightarrow \gamma\gamma)e^+e^-$

Normalization: $\pi^+(\pi_0^D \rightarrow \gamma e^+e^-)$
Results for the joint $K_{I3}$ analysis

- Quadratic fit: $\rightarrow \lambda'_+, \lambda''_+, \lambda'_0$
- Parameter correlation (1σ ellipses)
- black ellipse = NA48/2
- comparison to other experiments

$K^\pm \rightarrow \pi^0 f^\pm \nu$

NA48
Form-Factor Fits (Quadratic)

Andrea Bizzeti
Signal region definition

K⁺ events after the cut on fiducial region

$15\text{GeV} < p(\pi^+) < 35\text{GeV}$

**s-d transitions via FCNC loop**

- O(100) SM signal events
- 10% acceptance
- $10^{13}$ K⁺ decays
- background rejection $> 10^4$
- background yield < 20%
- background measurement with 10% precision

**Signal**

- Region 1: (0, 0.01) GeV²/c²;
- Region 2: (0.026, 0.068) GeV²/c²

$4m_{\pi^+}^2$

- $\pi\pi$ region
- $\mu^+\nu$ region
- $K^+\rightarrow\mu^+\nu$

Roberta Volpe

DIS 2017
Signal region definition

K⁺ events after the cut on fiducial region

15 GeV < p(π⁺) < 35 GeV

Expected signal and Bkg with 5% of 2016 sample

\[ N_{\pi\pi\nu}^{\text{exp}} = D_{\text{control}} \cdot N_{\pi\pi}^{\text{control}} \cdot \frac{BR_{\pi\pi\nu}}{BR_{\pi\pi}} \cdot \frac{A_{\pi\nu\nu}}{A_{\pi\pi}} \cdot \varepsilon_{\text{trig}} = 0.064 \]

normalisation: \( K^+ \to \pi^+\pi^0 \)
control trigger data passing the signal selection but the photon rejection
~ 0.6/0.86 from MC and cancellations
~ 85% (preliminary) measured with data

- O(100) SM signal events
- 10% acceptance
  - \( 10^{13} \) K⁺ decays
  - background rejection > 10 \%
- background yield < 20%
- background measurement with 10% precision

signal:

- Region 1: (0, 0.01) GeV²/c⁴
- Region 2: (0.026, 0.068) GeV²/c⁴
First observation of $\eta' \rightarrow \pi^+\pi^-\pi^+\pi^-$, $\pi^+\pi^-\pi^0\pi^0$

- $\eta' \rightarrow 4\pi$ suppressed by tiny phase space
- Only $\eta \rightarrow 4\pi^0$ is kinematically allowed
- ChPT: the amplitude goes to zero at leading order; non-zero contributions only at $O(p^6)$

$$B(\eta' \rightarrow 2(\pi^+\pi^-)) = (1.0 \pm 0.3) \times 10^{-4},$$
$$B(\eta' \rightarrow \pi^+\pi^-2\pi^0) = (2.4 \pm 0.7) \times 10^{-4}.$$ 

**PRL112, 251801(2014)**

$$B(\eta' \rightarrow \pi^+\pi^-\pi^+\pi^-) = (8.53 \pm 0.69 \pm 0.64) \times 10^{-5},$$
$$B(\eta' \rightarrow \pi^+\pi^-\pi^0\pi^0) = (1.82 \pm 0.35 \pm 0.18) \times 10^{-4}.$$ 

Good agreement between BESIII measurements and ChPT+VDM predictions
$e^+ e^- \rightarrow \gamma_{ISR} \pi^+ \pi^-$: cross section

\[
\sigma_{\pi\pi(\gamma_{FSR})}^{bare} = \frac{N_{\pi\pi\gamma} (1 + \delta_{FSR})}{L \cdot c_{\pi\pi\gamma}^\text{global} \cdot H(s) \cdot \delta_{\text{vac}}} \\
\sigma_{\mu\mu} = \frac{N_{\mu\mu\gamma}}{L} \cdot \epsilon_{\mu\gamma}^\text{global} \cdot \frac{1 + \delta_{FSR}^\mu}{1 + \delta_{FSR}^\mu} \cdot \sigma_{\mu\mu}^{bare}
\]

- Good agreement between two methods with relative difference (0.85±1.68)%
BESIII measurement agrees with KLOE

- Deviation on \((g-2)_{\mu}\) between experiment and SM has been confirmed.
Hadronic & Electroweak Observables

Thanks to all the presenters
# High $E_T$ Photons

**Claudia Glasman**

**Recent photon results from ATLAS**

**Inclusive isolated photon pairs @ 8 TeV ($\mathcal{L} = 20.2 \text{ fb}^{-1}$)**

- Photon selection: $E_T^{\gamma} > 40, 30 \text{ GeV and } |\eta^{\gamma}| < 2.37$, excluding the region $1.37 < |\eta^{\gamma}| < 1.56$
- Photon isolation: $E_{\text{iso}} > 11 \text{ GeV}; \text{signal purity: } \approx 75\% \ (60 - 98\% \ \text{depending on observable)}$

- **Main irreducible background to $H \rightarrow \gamma\gamma$**
- Theoretical predictions (uncertainty):
  - $(\mu_R = \mu_F (= \mu_f) = m_{\gamma\gamma}; \text{PDFs: CT10})$
  - $\rightarrow$ SHERPA 2.2.1: ME+PS merged at NLO ($10 - 40\%$)
  - $\rightarrow$ DIPHOX: DP+F at NLO, $gg \rightarrow \gamma\gamma$ at LO ($30\%$)
  - $\rightarrow$ RESBOS*: NLO + NNLL (* uncertainties not given)
  - $\rightarrow$ $2\gamma$NNLO: DP at NNLO ($20\%$) (Frixione isolation!)

- **PDF uncertainty:** $2\%$
- **NP uncertainty:** $< 5\%$
- The prediction from SHERPA 2.2.1 is in best agreement with the data

**$\sigma_{\text{meas}} = 16.8 \pm 0.8 \text{ pb}$**

**Experimental uncertainty:** $4.7\%$
- Major sources: $\gamma\text{ID} (2.5\%)$
- Modelling of $E_T^{\text{iso}} (2\%)$
- Luminosity (1.9%)
Cross-section ratios (fixed $y$ vs. fixed $y_{\text{ref}}$): 8TeV/7TeV

- Cross-section ratios between different c.m. energies

$$R_{8/7}^+ = \frac{d\sigma^W_+ (\sqrt{s} = 8 \text{ TeV})}{d\sigma^W_+ (\sqrt{s} = 7 \text{ TeV})}, R_{8/7}^- = \frac{d\sigma^W^- (\sqrt{s} = 8 \text{ TeV})}{d\sigma^W^- (\sqrt{s} = 7 \text{ TeV})},$$

and the double ratio $D_{8/7} = (R_{8/7}^+)/ (R_{8/7}^-)$:

- Define a scaling variable $\xi_1$,

$$\xi_1 = \frac{M_W}{\sqrt{s}} e^y \Rightarrow x_1^\pm \to \frac{M_W}{2p_T} \xi_1 \left[1 \mp \sqrt{1 - 4p_T^2/M_W^2}\right].$$

$\Rightarrow$ Cross-sections at fixed $\xi_1$ are sensitive to PDFs of $H_1$ at particular values of $x$ independently of $\sqrt{s}$.

- Compare charge asymmetry across various collision systems at various centre of mass energies
- Improve sensitivity

$\Rightarrow$ The PDF uncertainties partly suppressed when the ratios are formed at fixed $y_{\text{ref}}$.  

Hannu Paukkunen