QCD at LHC with the ATLAS Detector

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(on behalf of the ATLAS Collaboration)

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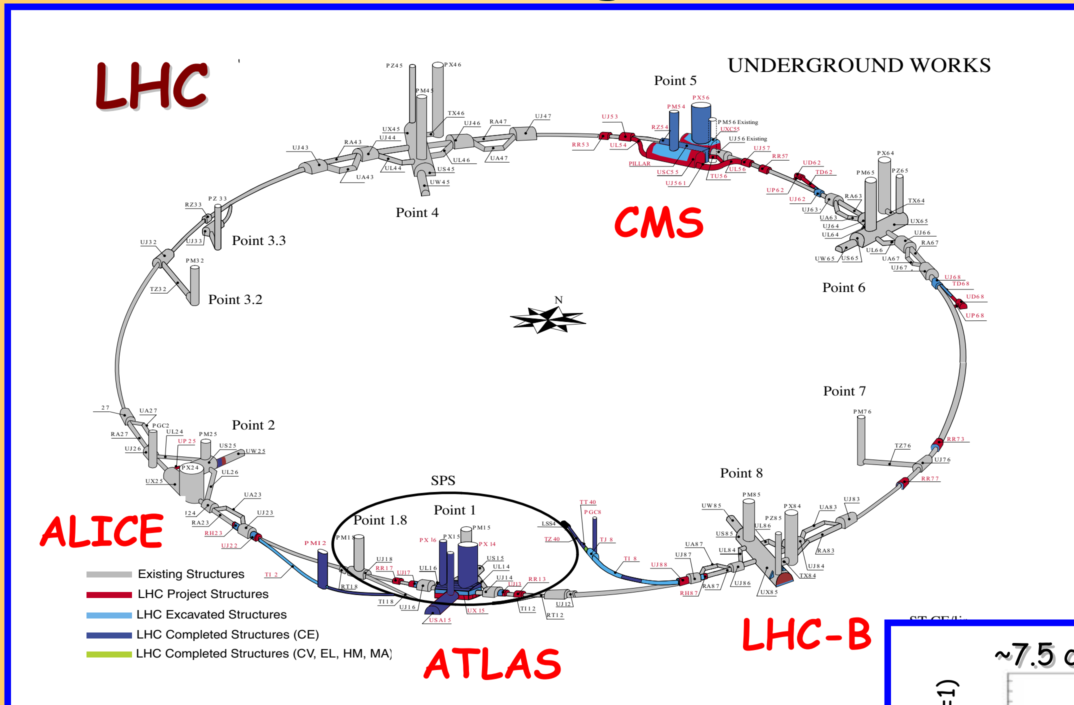
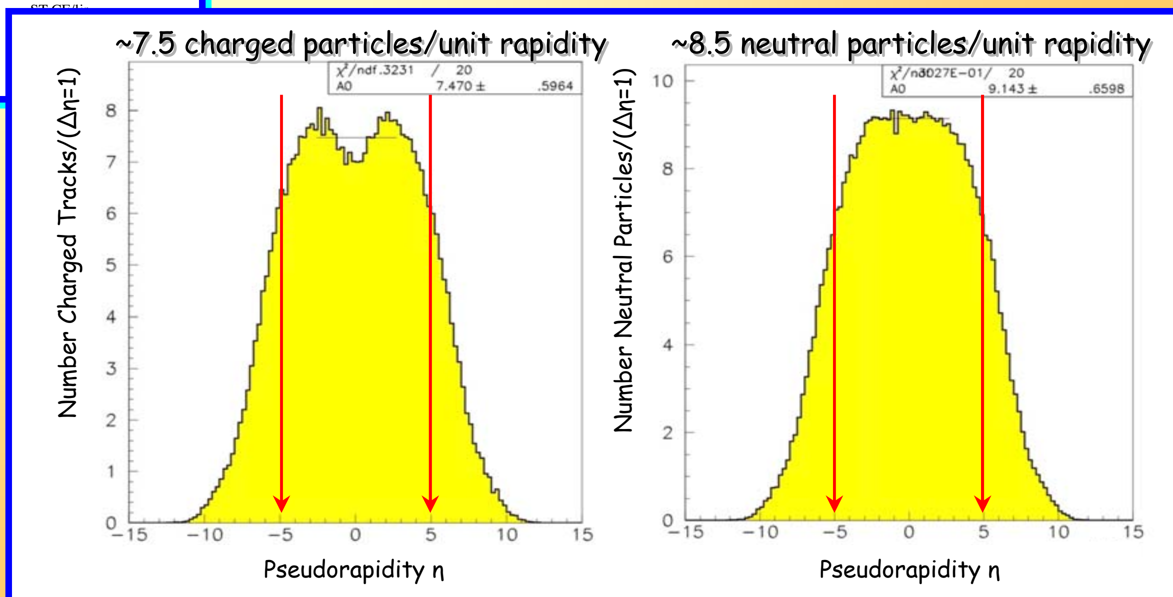
The Large Hadron Collider (LHC) @ CERN:



- pp collider with $\sqrt{s}$ = 14 TeV, located in the LEP tunnel at CERN, Geneva, Switzerland;
- design L=10^{34} $cm^{-2}s^{-1}$ ($\mathcal{L}$ = 100 fb^{-1}), initial ~2×10^{33} $cm^{-2}s^{-1}$ ($\mathcal{L}$ = 20 fb^{-1});
- bunch crossings every 25 ns (40 MHz);
- high lumi, large $\sigma_{incl} \approx 80$ mb -> ~23 min bias events/bunch crossing, with ~75 charged tracks/event within typical detector acceptance |η|<5;
- mass reach mare than 5 TeV;



ATLAS Calorimeter Performance Technical Design Report CERN/LHCC 96-40

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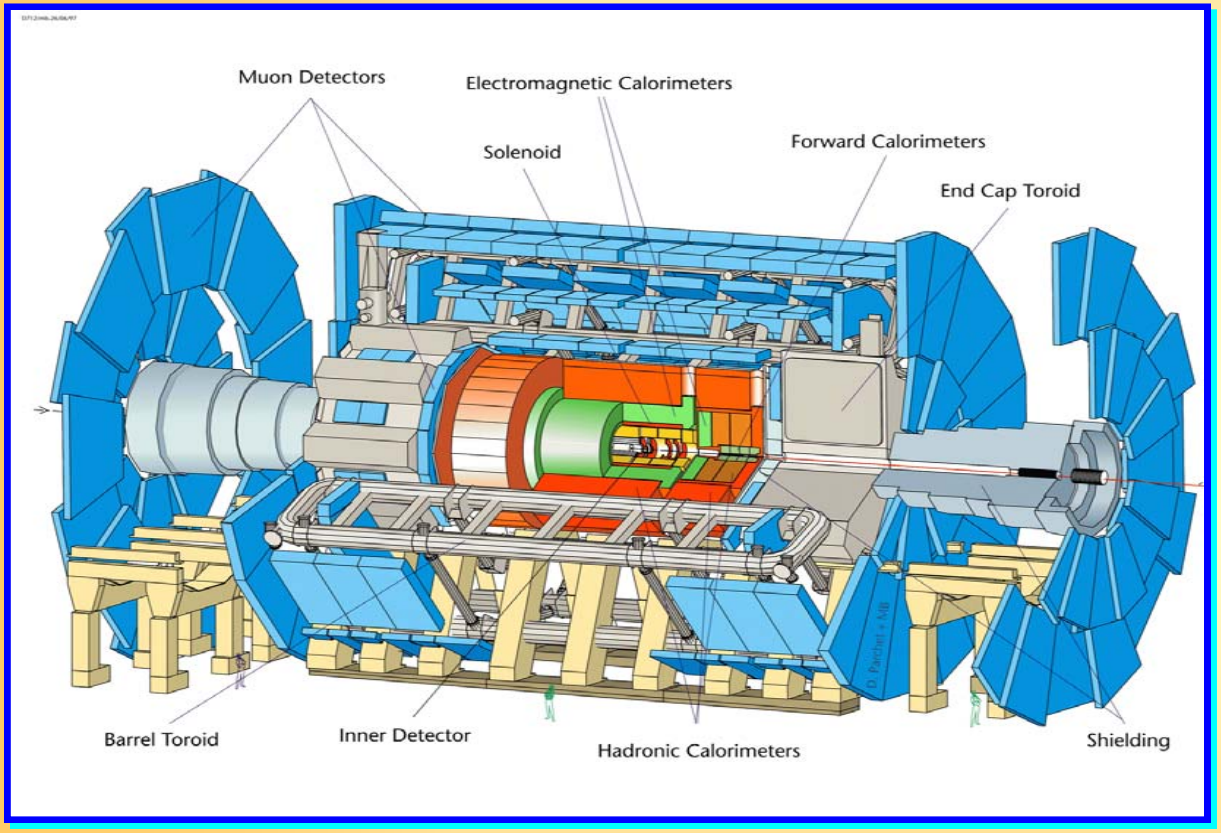
The ATLAS Detector



Length ~45 m, height ~22 m, weight ~7000 tons

- Inner Detector (2T solenoid, $|\eta|<2.5$):

  $\sigma_{p_t}/p_t \simeq 0.05\%/\mathrm{GeV} \times p_t \oplus 1\%$

- Calorimetry:
  * electromagnetic, $|\eta|<3.2$

    $\sigma_E/E \simeq 10\,\%\sqrt{\mathrm{GeV}}/\sqrt{E} \oplus 0\%$
  * hadronic (central, $|\eta|<1.7$)

    $\sigma_E/E \simeq 50\,\%\sqrt{\mathrm{GeV}}/\sqrt{E} \oplus 3\%$
  * hadronic (endcaps, $1.7<|\eta|<3.2$)

    $\sigma_E/E \simeq 60\,\%\sqrt{\mathrm{GeV}}/\sqrt{E} \oplus 3\%$
  * hadronic (forward, $3.2<|\eta|<4.9$)

    $\sigma_E/E \simeq 100\,\%\sqrt{\mathrm{GeV}}/\sqrt{E} \oplus 5\%$

- Muon system (~4T toroid, $|\eta|<2.7$):

  $\sigma_{p_t}/p_t \simeq 10\%$ for $p_t(\mu) \approx 1$ TeV/c

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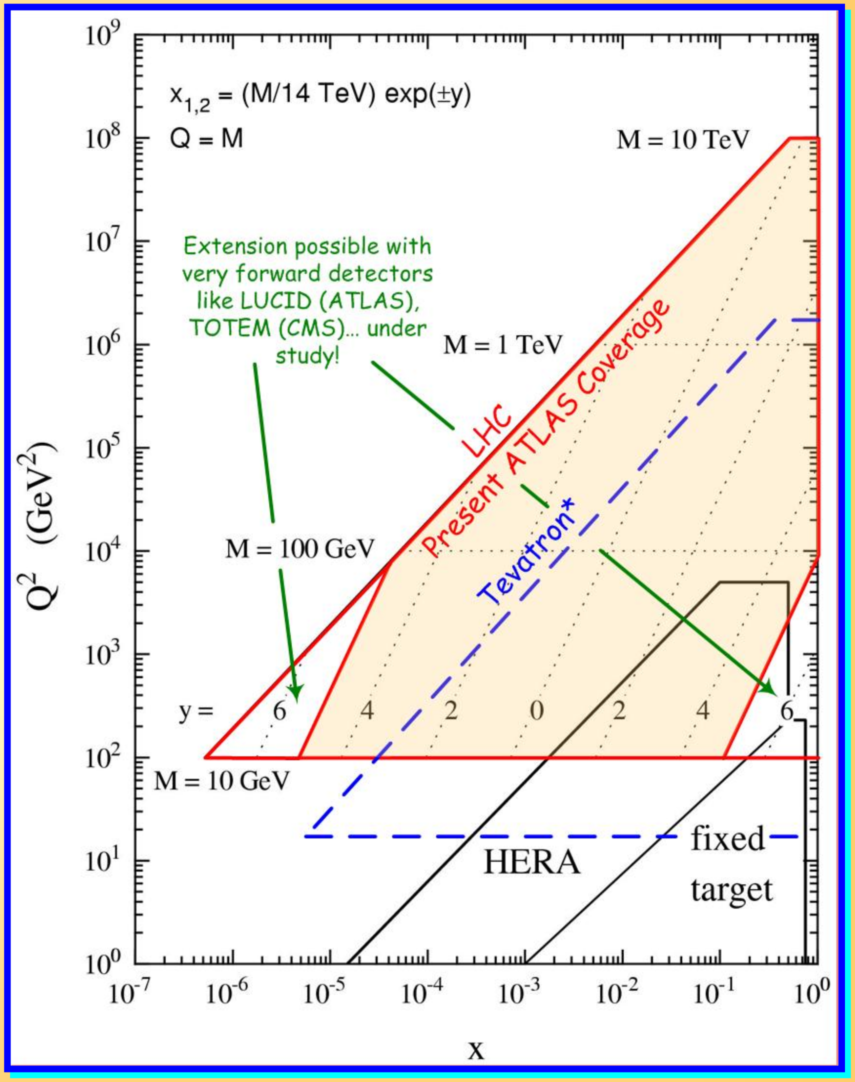
QCD at LHC

- nearly all LHC physics is connected to the interaction of quarks and gluons -> QCD provides the underlying dynamics for basically everything!
- large event rate reduces statistical errors quickly and allows precision measurements of Standard Model cross sections over a yet unexplored kinematic regime;
- access to quark and gluon structure functions, strong coupling at high momentum transfers, compositeness scales…
- QCD provides background for nearly all searches (direct photon production for low mass Higgs, multi-jet production for SUSY…);
- (non-pertubative) QCD determines shapes and rates for minimum bias events -> important limitation on precision measurements at design luminosity!



W. Stirling, LHCC Workshop “Theory of LHC Processes” (1998)
*annotation from J. Huston, Talk @ ATLAS Standard Model WG Meeting (Feb. 2004)

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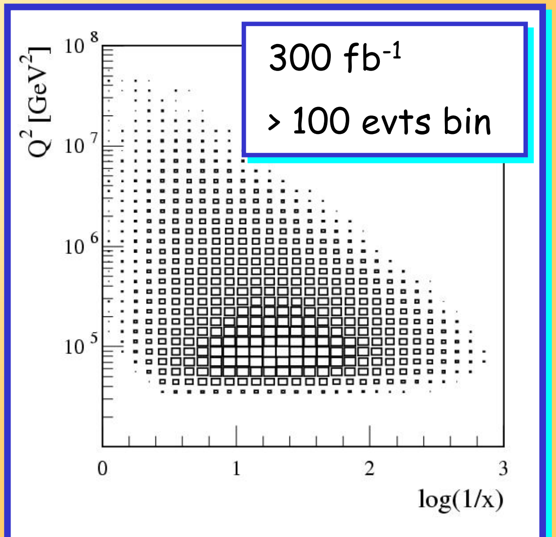
Jet Physics in ATLAS

- jet cross section measurements allow tests of pertubative QCD in unexplored kinematic regions;
- statistical errors are small -> systematic uncertainties from jet algorithm & trigger efficiency, jet energy scale (mostly linearity of calorimeter response), contributions from underlying event and pile-up, and luminosity (~5%);

Process		σ (nb)	Evts/year ($\mathcal{L}$=10 fb^{-1})
$W \rightarrow e\nu$		15	~10^8
$Z \rightarrow e^+ e^-$		1.5	~10^7
$t\bar{t}$		0.8	~10^7
Inclusive Jet Production	p_t > 200 GeV	100	~10^9
	p_t > 1 TeV	0.1	~10^6
	p_t > 2 TeV	10^{-4}	~10^3
	p_t > 3 TeV	1.3×10^{-6}	~10

- several "calibration channels" for jets (W->jj, Z+jj) available with high statistics -> ~1% systematic error on energy scale possible;
- measurements best done in initial low luminosity running to minimize effects from pile-up events;
- ATLAS measures jets with $\sigma_E/E \approx 50(60)\%/\sqrt{E(\mathrm{GeV})} \oplus 1.5(3)\%$ in the central (endcap) calorimeters;

$d\sigma/dQ^2 d(\log(1/x))$



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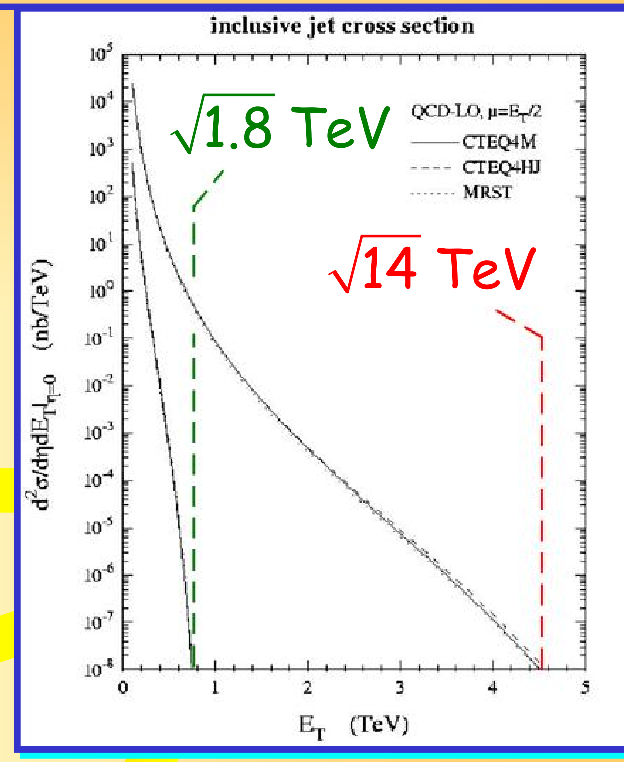
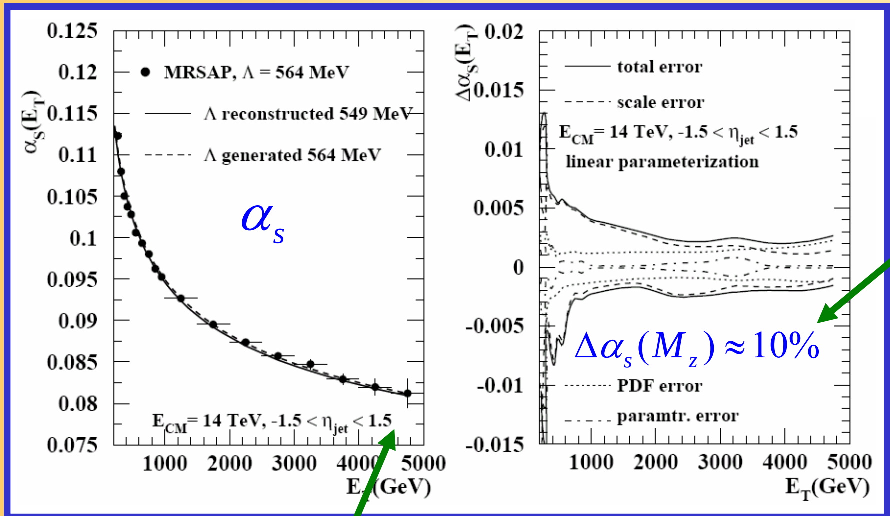
From the Inclusive Jet Cross-Section:



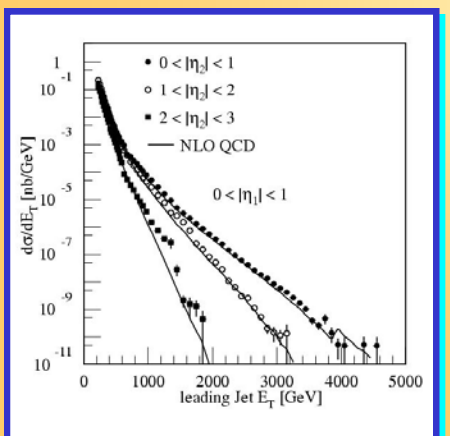
Strong Coupling



just from cross-section, can be improved by 3/2 jet ratio, but no competition for LEP/HERA!

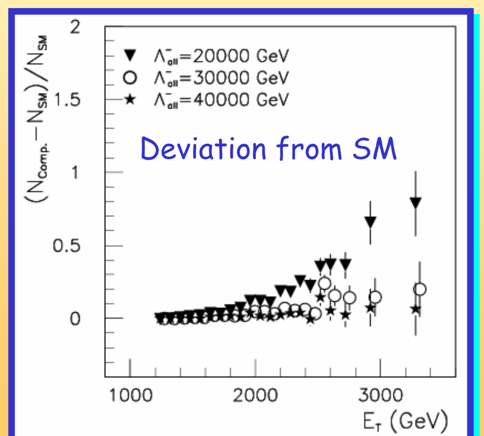
test of QCD at very small scale ($\alpha_s \approx 0.08$)

PDFs



di-jet cross section and properties (E_T,η_1,η_2) constrain parton distribution function

Compositeness



sensitivity to compositeness scale Λ up to 40 TeV @ 300 fb^{-1} (all quarks are composites)

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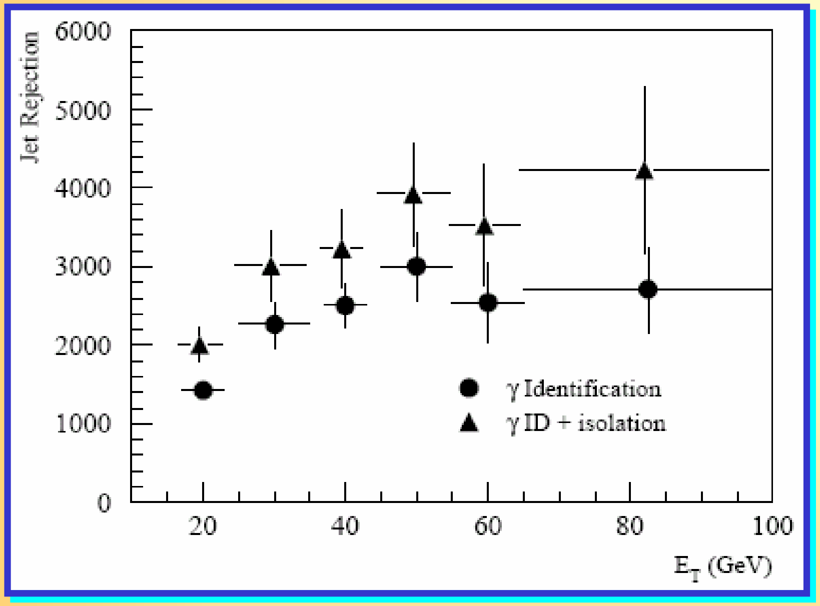
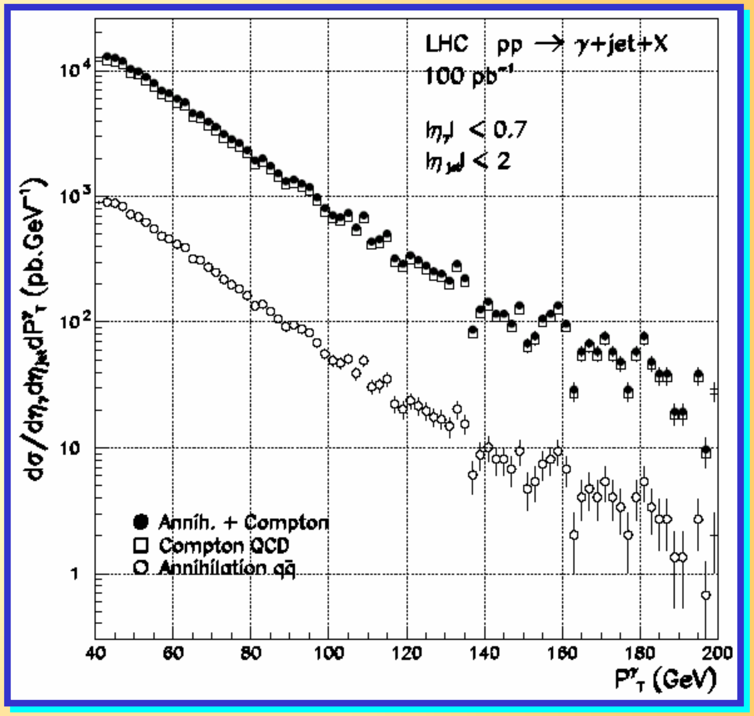
Exclusive Final State: Direct Photon Production

- interesting: major contribution to direct photon production ($qg \rightarrow \gamma q$, QCD Compton) provides access to gluon density function (requires good knowledge of α_s);
- needs good photon/jet separation -> ATLAS has highly granular calorimeters providing this;

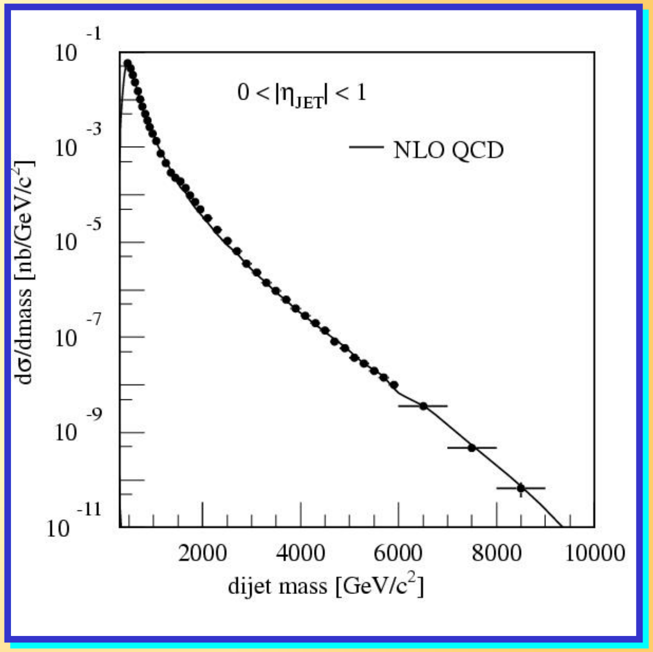


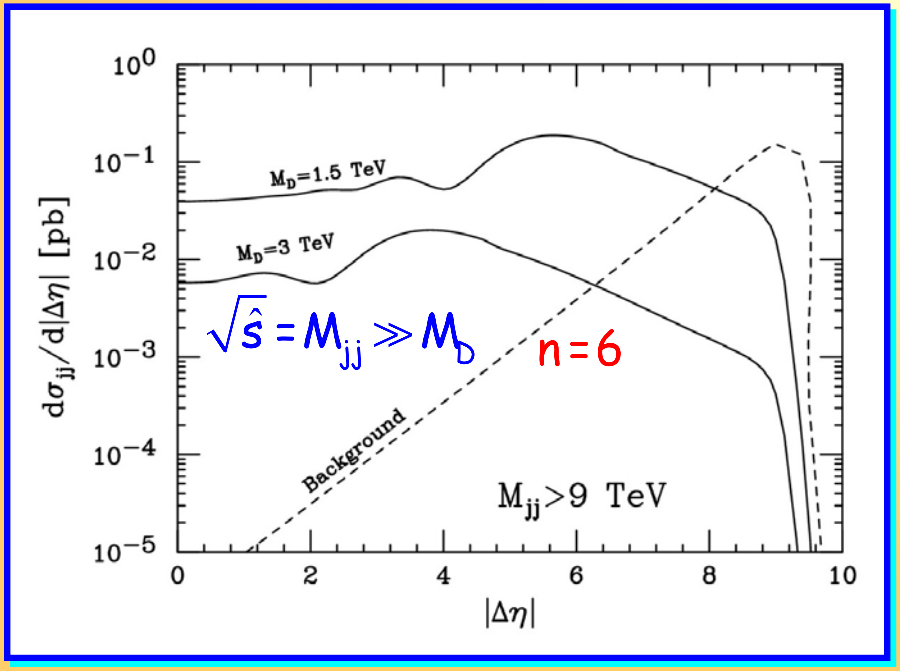


- irreducible background from jets with leading π^0, expected total systematics 10-22% (mostly from *xG(x)* parametrization uncertainties);
- also Drell-Yan processes (no final state QCD radiation!) help to constrain the proton structure at $Q^2 \approx m_{\ell\ell}^2$

QCD as Background

- QCD provides background signals for almost all new signals expected at LHC: Higgs (di-photon production), SUSY (multi-jet events), exotics (large transverse momentum jets, high mass systems) -> need to understand QCD production mechanisms over a large kinematic range;
- especially high mass reach of the (QCD) di-jet system and the large coverage |η|<5 of the ATLAS detector allow studies models with widely separated jets in very heavy hadronic final states;





G.F.Giudice, R.Rattazzi, J.D.Wells, hep-ph/0112161

di-jet separation |Δη| for a model with a large number n of (flat) extra dimensions, indicating graviton exchange contributions to the (very small) cross-section

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Conclusions

- LHC allows precision tests of QCD in yet unexplored kinematic domains, including but not limited to constraints on PDFs in (high Q^2,low x), strong coupling at very small distances, and limits of compositeness;
- Other large cross-section QCD channels not discussed in this talk, mainly W/Z and heavy quark production, provide measurements of masses and couplings;
- Good understanding of soft (non-pertubative) QCD required to understand contributions from the underlying (hard initial/final state radiation, proton remnants) and minimum bias ("pile-up", non-single diffractive) events at high luminosity;
- The ATLAS detector can reconstruct QCD events over the whole kinematic range within very good resolution and acceptable systematics, even in the presence of high luminosity pile-up;