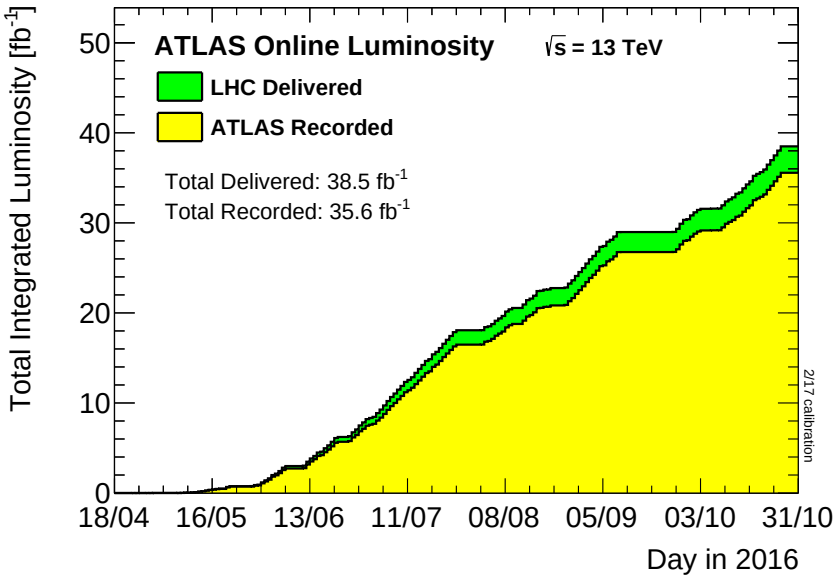
Standard Model Physics

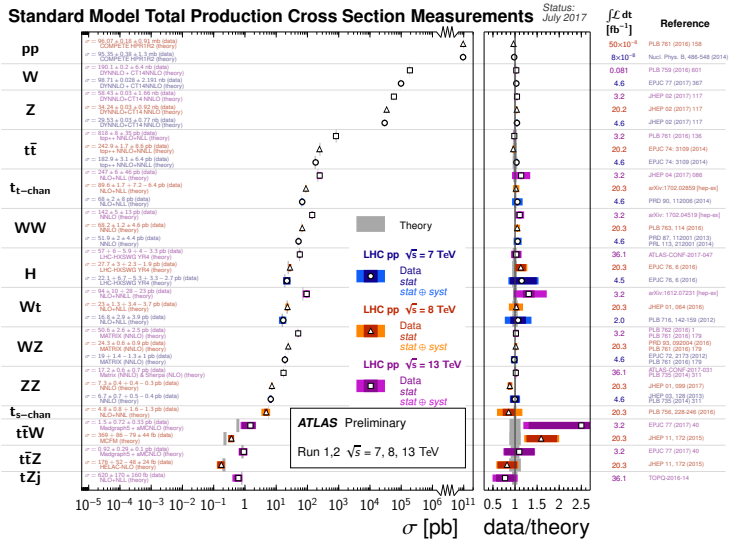
Peter Richardson

CERN TH & IPPP

TH Retreat: 15th November

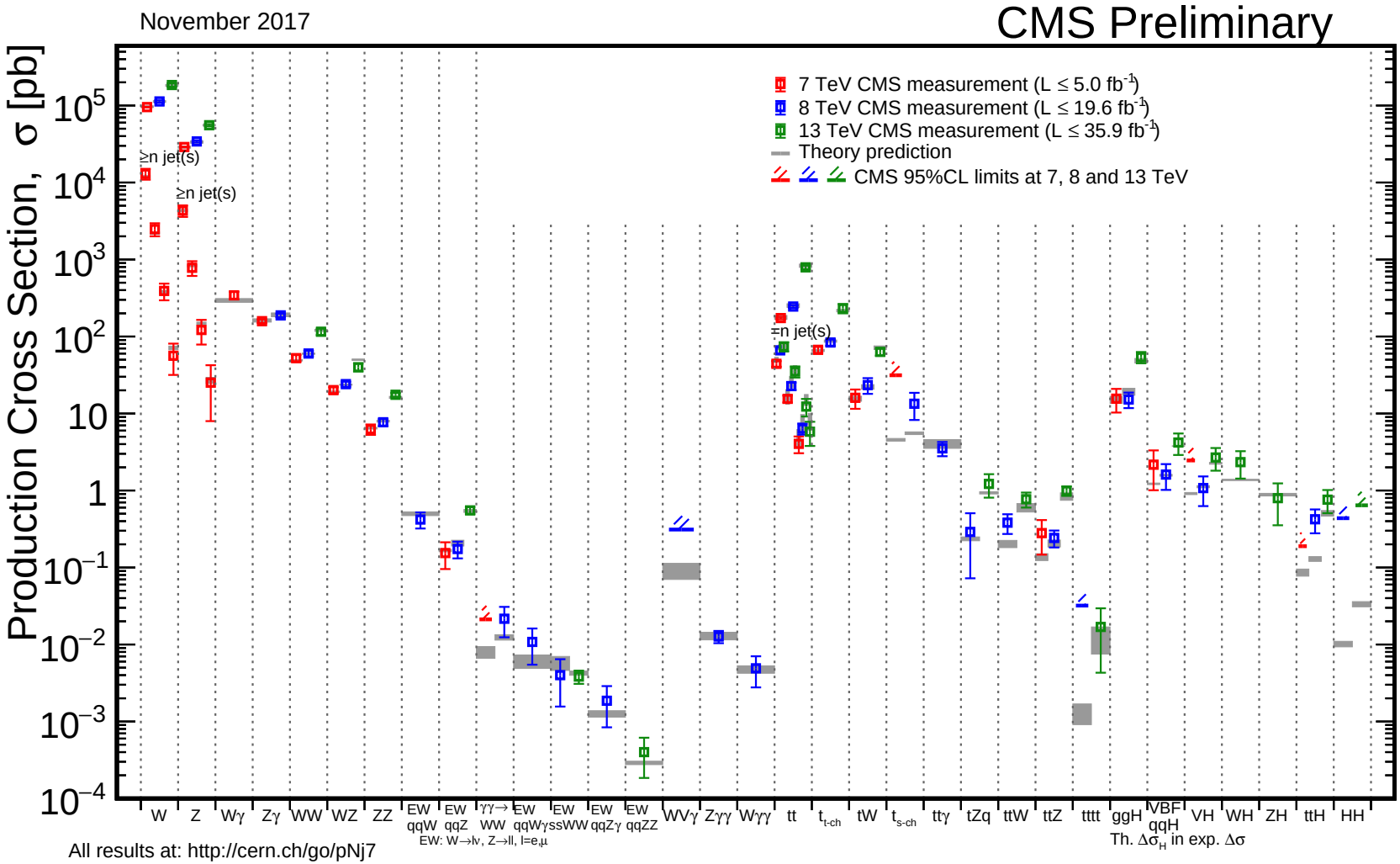
The LHC





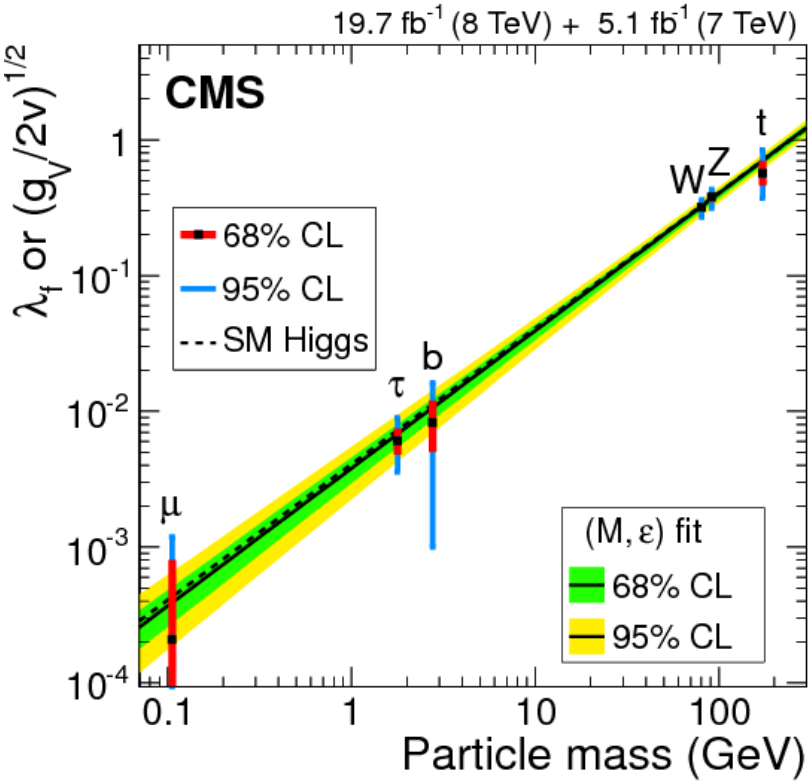
- The LHC goes on delivering unprecedented integrated luminosities.
- So far consistent with SM predictions.
- In many cases small experimental uncertainties.

The LHC

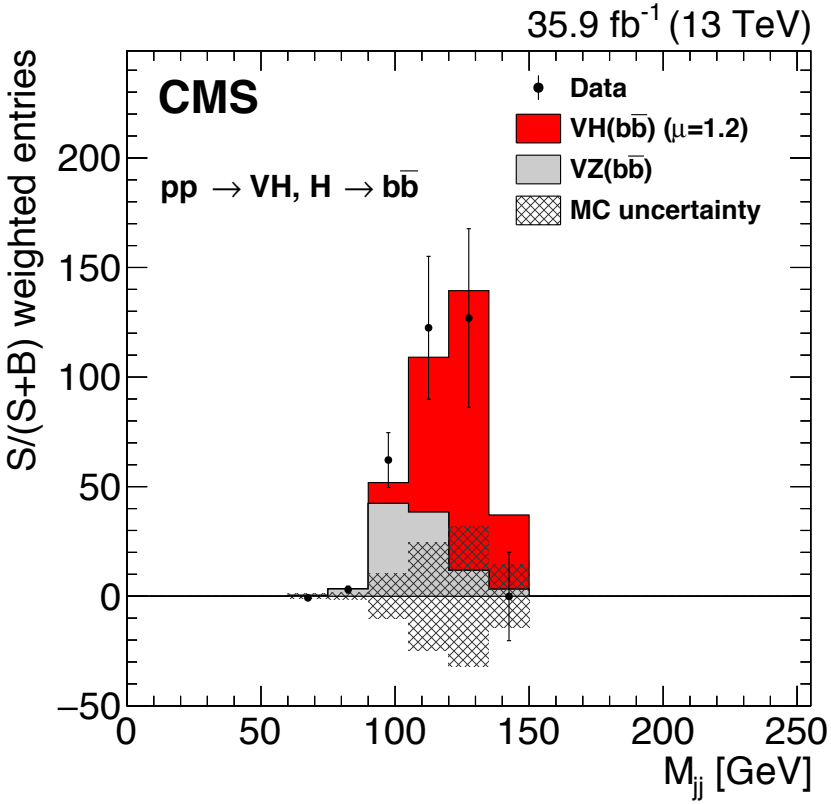

November 2017
CMS Preliminary
Production Cross Section, σ [pb]
7 TeV CMS measurement (L ≤ 5.0 fb-1)
8 TeV CMS measurement (L ≤ 19.6 fb-1)
13 TeV CMS measurement (L ≤ 35.9 fb-1)
Theory prediction
CMS 95%CL limits at 7, 8 and 13 TeV
≥n jet(s)
≥n jet(s)
≥n jet(s)
W Z Wγ Zγ WW WZ ZZ EW qqW EW qqZ γγ→WW EW qqWγssWW EW qqZγ EW qqZZ WVγ Zγγ Wγγ tt t t-ch tW t s-ch ttγ tZq ttW ttZ tttt ggH VBF qqH VH WH ZH ttH HH
EW: W→lν, Z→ll, l=e,μ
Th. Δσ_H in exp. Δσ
All results at: http://cern.ch/go/pNj7

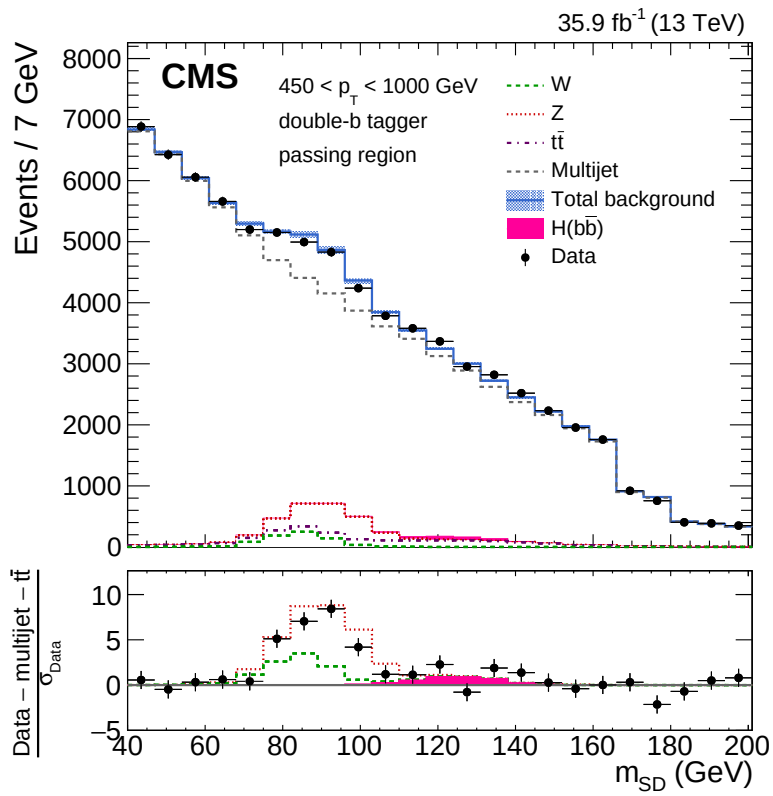
The LHC

- New physics may still show up via small deviations.
- In such scenarios we need precise SM predictions!



$h^0 \to b\bar{b}$

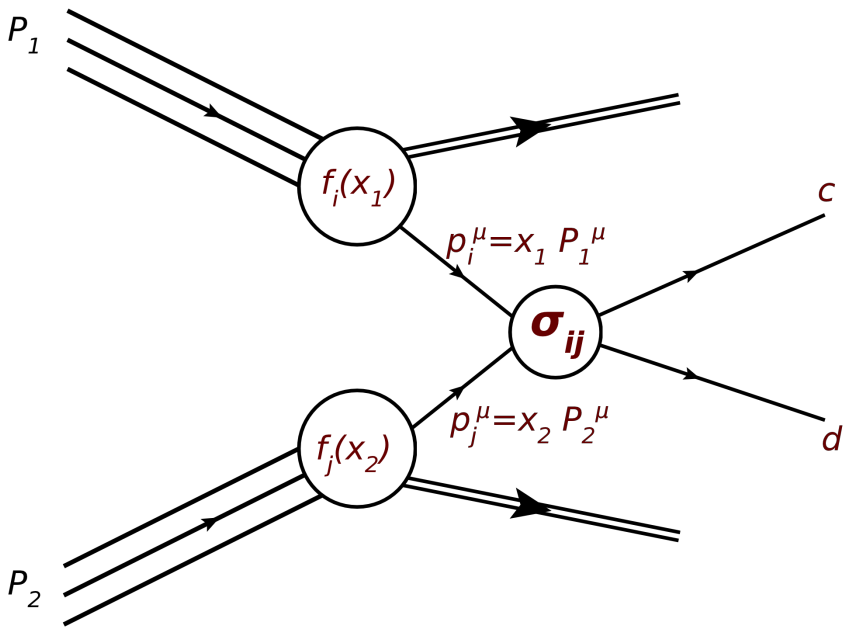




Many things which were thought challenging, if not impossible, before the start of the programme are starting to be measured. Using better analysis techniques and phenomenological ideas.

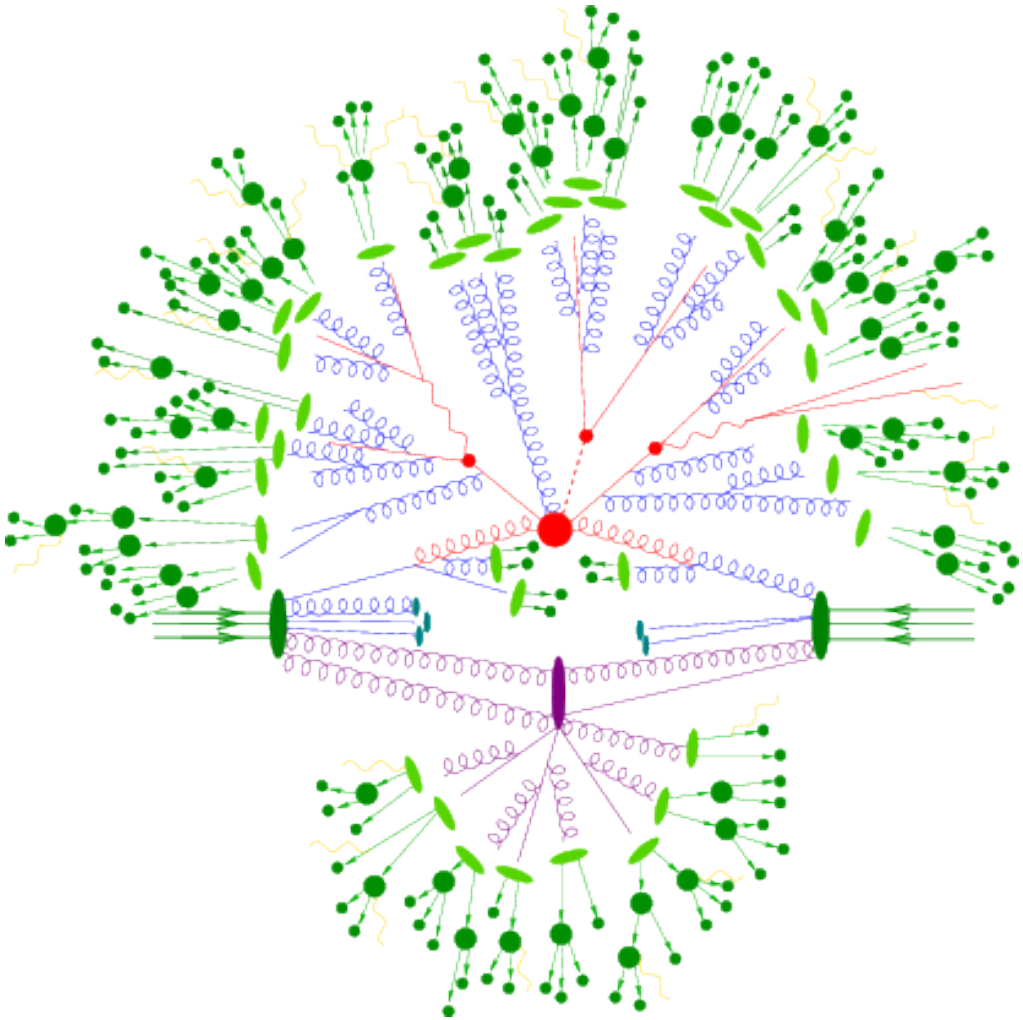
Precision

$$\mathrm{d}\sigma = \sum_{ij} \int_0^1 \mathrm{d}x_1 \mathrm{d}x_2 f_i(x_1, \mu_F^2) f_j(x_2, \mu_F^2) \mathrm{d}\hat{\sigma}_{ij}(\mu_F^2)$$



- Parton Distribution Functions (PDFs) $f_i(x_1, \mu_F^2)$, $f_j(x_2, \mu_F^2)$ extracted from data.
- $\mathrm{d}\hat{\sigma}_{ij}(\mu_F^2)$ computed in perturbation theory.

Reality Much More Complicated



Approaches

- Fixed order: Compute higher-order corrections to $\mathrm{d}\sigma_{ij}$. Usually restricted to low orders.
- Resummation Work in a limit, but to all orders in perturbation theory.
- Parton Shower Combine fixed order and resummation with non-perturbative models (hadronization and underlying event) to give a fully exclusive description of the final state.

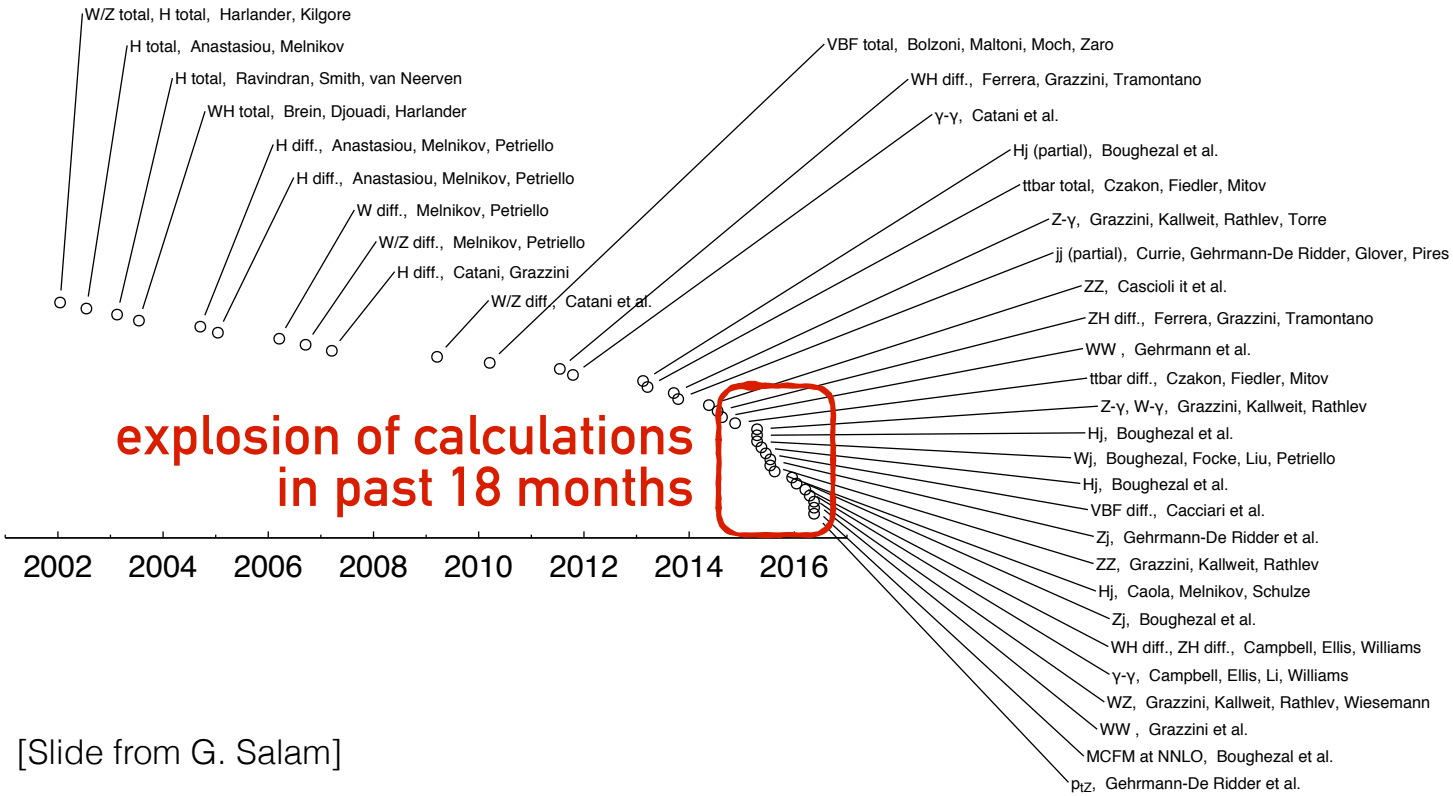
Also lots of phenomenology, need new ideas in jet reconstruction, substructure, ...

Progress

Tremendous progress in all areas:

- Automation of one-loop QCD and electroweak corrections;
- Explosion of NNLO calculations;
- N^3LO for Higgs production;
- New PDF sets with reduced uncertainties;
- New parton shower codes;
- Automation of NLO + parton shower;
- First results for NNLO + parton shower;
- Better understanding of jet substructures.

NNLO revolution



[Slide from G. Salam]

Staff

Claude Duhr

Michelangelo Mangano

Peter Richardson

Gavin Salam

Giulia Zanderighi

Associates

Christian Bauer

Uli Haisch

Keith Hamilton

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Mike Seymour

Fellows

Sophia Borowka

Stefano Carrazza

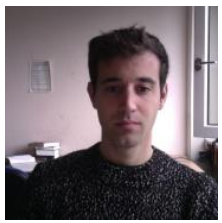
Celine Degrande

Jonathan Gaunt

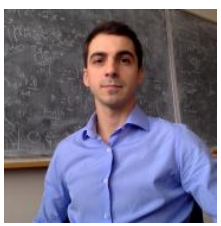
Martin Gonzalez-Alonso

Alexander Huss

Stefan Kallweit



Bernard Mistlberger



Pier Monni

Emanuele Re

Marek Schönherr

Dingyu Shao

Lorenzo Tancredi

Riccardo Torre

Eleni Vryonidou

Marius Wiesemann

$\sim \frac{1}{2}$ funded by ERC/Marie Currie

Activities in the group

Precise determination of the structure of the proton (PDFs):
Bauer, Carrazza, Gaunt, Mangano, Salam, Zanderighi, ...

- New precise determinations of PDFs;
- PDFs for photons;
- PDF & heavy flavours;
- Electroweak effects;
- Double parton scattering;
- Fragmentation functions.

Activities in the group

Precise description of collider events:
Bauer, Hamilton, Mangano, Monni, Nason, Re, Richardson, Seymour, Schönherr, Wiesemann, Zanderighi, . . .

- Development of parton shower simulations;
- Matching parton showers & fixed order;
- Tuning, hadronization, underlying event, ...

Activities in the group

Precise fixed-order computations:

- Matrix elements & scattering amplitudes: Duhr, Mangano, ...
- NLO: Borowka, Carrazza, Zanderighi, ...
- NNLO & beyond: Borowka, Duhr, Gaunt, Huss, Kallweit, Mistlberger, Salam, Zanderighi, ...
- EW corrections: Kallweit, Schönherr, Mangano, ...
- Multi-loop integrals: Borowka, Duhr, Mistlberger, ...

Activities in the group

Resummation of large logarithms:

- Event shapes in e^+e^- collisions: Monni, Salam, Shao, Zanderighi ...
- Soft gluon resummation in hadron collisions: Mangano, Monni, Re, Salam, Wiesemann, Zanderighi...
- DGLAP evolution: Carrazza, Salam, ...
- Soft Collinear Effective Theory: Bauer, Shao ...

Activities in the group

Observable dependent projects:

- Higgs: Borowka, Duhr, Mistlberger, Monni, Kallweit, Re, Salam, Schönherr, Wiesemann, Zanderighi, ...
- Vector bosons: Kallweit, Re, Schönherr, Wiesemann, Zanderighi
- Top: Haisch, Mangano, Schönherr...
- Flavour physics & quarkonium: Haisch, Mangano ...
- EFTs: Gonzalez-Alonso, Haisch, Vryonidou ...

Connections & Overlaps

- Close connection & interaction between SM group and experimental community!
- Development of codes that are used by experiments and other areas of TH: aMCSusHi, Alpgen, Apfel, APPLgrid, FastJet, FeynRules, Herwig, Hoppet, JetVHeto, LoopSim, MadGraph5_aMC@NLO, MoReSusHi, QCDLoop, SecDec, SuShi, NNPDF, Powheg, ...
- This year major workshop Physics of HL-LHC, and perspectives at HE-LHC

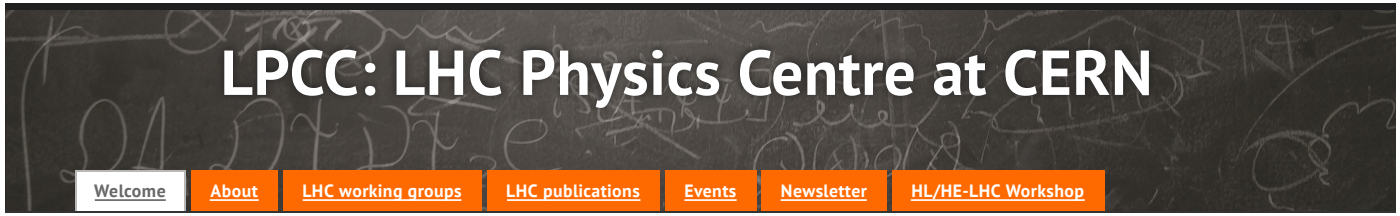
Connections & Overlaps

Connections with other TH groups:

- BSM: Degrande, Haisch, Mangano, Richardson, Salam, Vryonidou, Torre...
- Heavy Ions: Mangano, Salam, ...
- Strings/Field Theory: Duhr, Mistlberger, ...

Group activities

- CERN-LHC seminar: Tuesday 11am (not strictly TH)
- TH colloquium: Wednesday 2pm (Duhr, Kurkela, McCullough, Rychkov)
- Collider Cross Talk: Thursday 11am (Nardecchia, Re, + exp. organisers)
- QCD lunch: Tuesday 12.45pm (Salam)
- Particle & Astro-particle seminar: Friday 2pm (Patella, Richardson, Sibiryakov)
- TH Institute planned in summer 2018



Welcome to the LPCC website

LPCC forthcoming events

IML Machine Learning Working Group: common benchmark datasets (https://indico.cern.ch/event/670021/)
Machine Learning - 01/12/2017 - 15:00 to 18:00 - 222-R-001 (https://maps.cern.ch/mapsearch/mapsearch.htm?n=%5B%27222/R-001%27%5D)

LHC Working Group on Forward Physics and Diffraction (https://indico.cern.ch/event/673941/)
Forward Physics and Diffraction - 07/12/2017 - 09:00 to 08/12/2017 - 18:20 - 4-S-030 (https://maps.cern.ch/mapsearch/mapsearch.htm?n=%5B%274/S-030%27%5D)

LHC Electroweak WG meeting (https://indico.cern.ch/event/678694/)
Electroweak precision measurements - 13/12/2017 - 09:00 to 14/12/2017 - 13:00 - TH Conference Room (https://maps.cern.ch/mapsearch/mapsearch.htm?n=%5B%274/3-006%27%5D)

- Initiatives related to the LHC physics program.
- Michelangelo Mangano is responsible.
- Sign up for the mailing list: lpcc.web.cern.ch

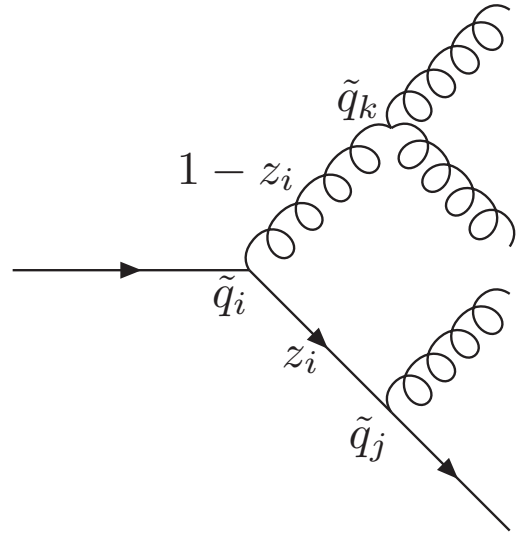
Me

- Two years into a 5 year staff position (on leave from the IPPP, Durham).
- Main interest is collider phenomenology, both Standard Model (SM) and Beyond the Standard Model (BSM) physics.
- That lead to an interest in Monte Carlo event generators the best methods to study collider physics.

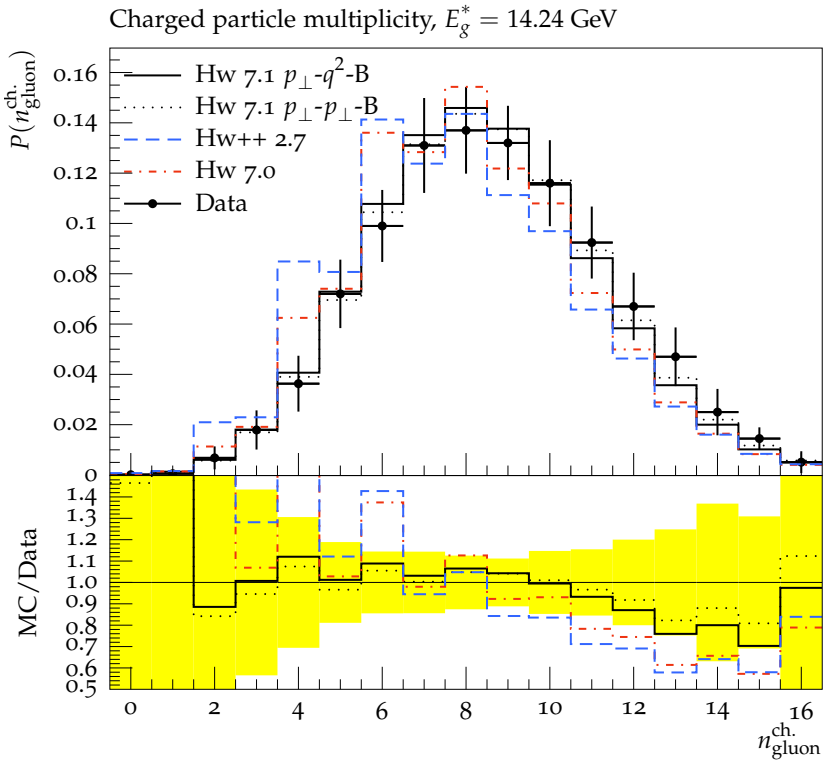
Me

- Historically I was mainly interested in the search for BSM physics and simulation of BSM processes.
- In recent years mainly working on improving the accuracy of simulations, primarily for the SM but also still some BSM physics.

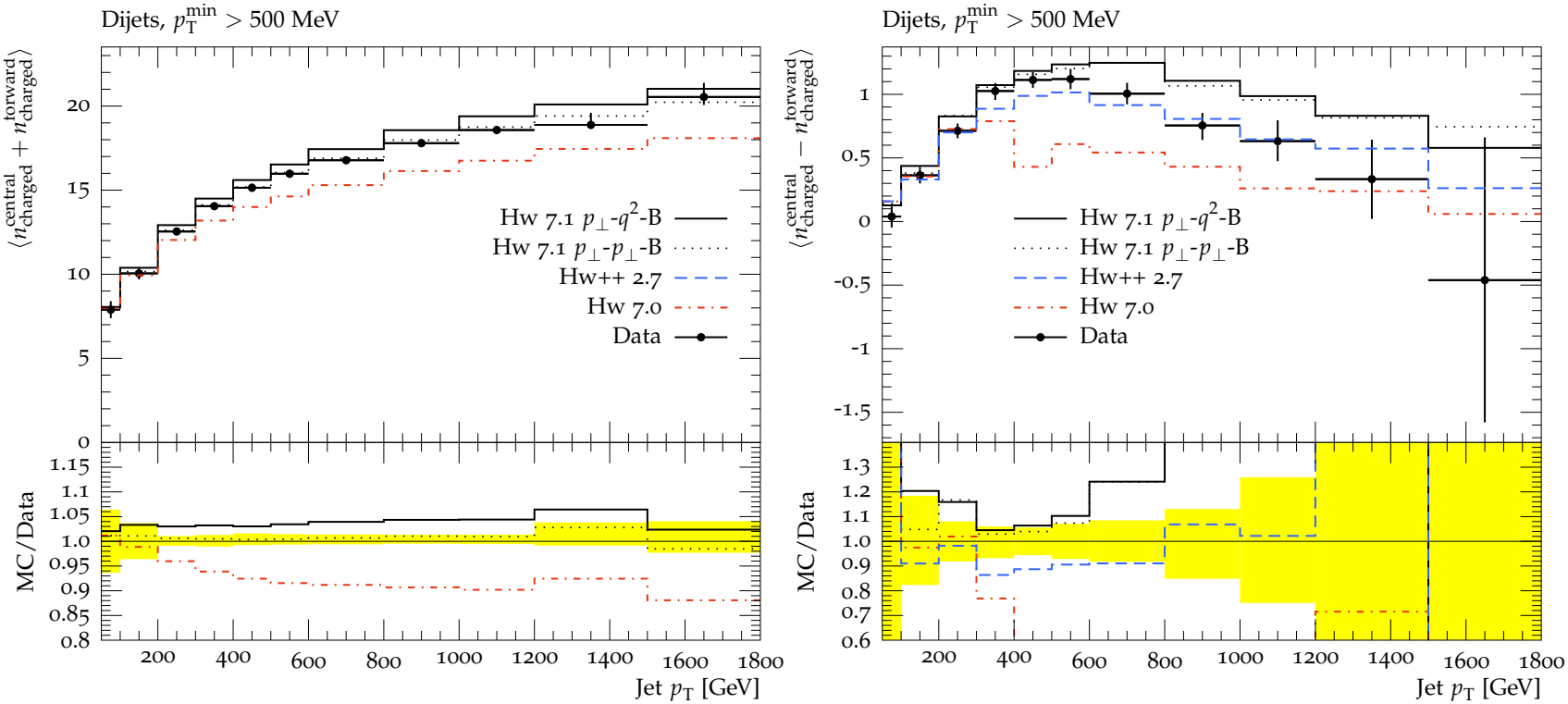
Quark and Gluon Jets



- Lot of experimental interest, but usable few LHC results.
- Use old LEP results and some LHC data to improve the models.

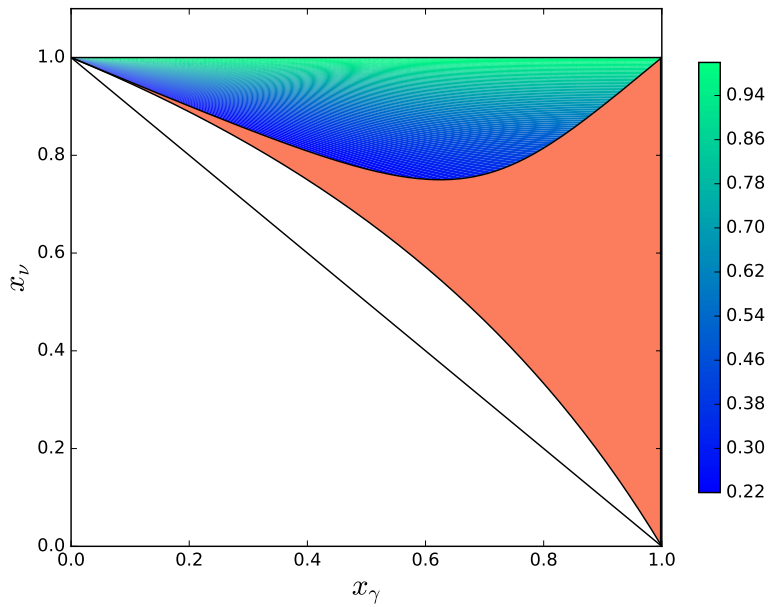


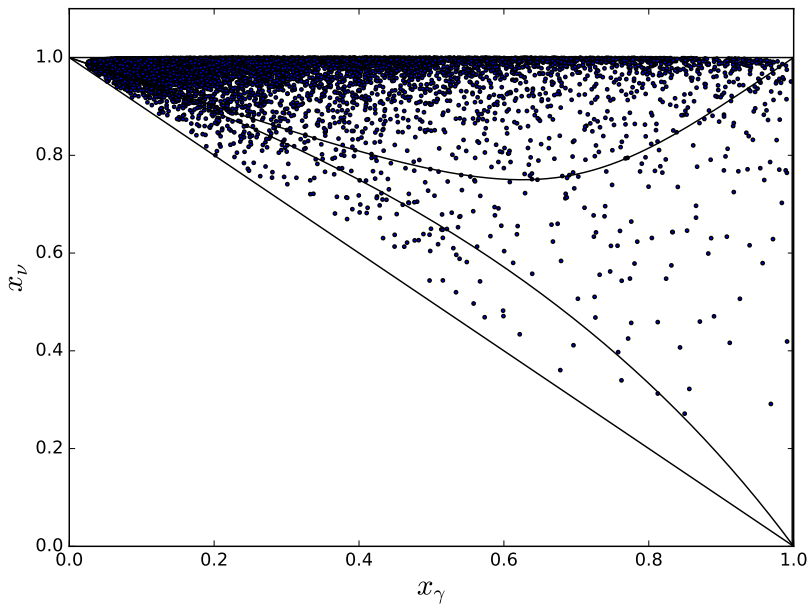
Quark and Gluon Jets



data from ATLAS Eur.Phys.J. C76 (2016) no.6, 322

QED Radiation e.g. $W \to \ell\nu$





- Parton shower overestimates the matrix element in the region filled by the shower, and doesn't fill the full phase space.
- Apply a POWHEG correction to improve the simulation, e.g. of top quark decays.