1) General problematics
2) Where pQCD works.
3) Where the pQCD is challenged.
4) Pushing pQCD to the limits.
5) Few words about the photons.
1.1) Common wisdom about QCD

- QCD is **ONE** theory: SU3 + free coupling parameter.
  - Well established in ee and ep colliders: $\alpha_s$ value and running, interaction mediator (gluon), SU3 gauge group, pQCD at NNLO, factorization theorem for hadrons PDFs...

- But **MANY** regimes with associated approximations:
  - NP regime (lattice QCD, phenomenology): spectroscopy
    - Common wisdom: complicated chemistry.
  - Intermediate (phenomenology): fragmentation functions, UE, Min bias collisions.
    - Common wisdom: “tuning and witchcraft”.
  - Hard interaction (pQCD): jets physics, inelastic hadrons PDFs.
    - Common wisdom: “well understood, just need to cross check it works”.

- At CMS: till now O(50) dedicated papers.
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMP
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFSQ
1.2) pQCD before the hadron colliders

- I would try to dispel the common wisdom that pQCD is so well understood and show where/why hadron colliders may and shall contribute.

- At LEP/HERA we got used that NLO (or NNLO when possible) contains most of the perturbative effects. UE and parton showering are minor corrections.

- It seems that this is not always true for the hadron colliders. Let's have a look on it.
1.3) Kingdom of the pQCD

- Factorization theorem: hard matrix element calculated at NLO factorized from proton PDFs, parametrized (mainly) in ep collision and evolved by DGLAP evolution at NLO (or NNLO).

“Higgs and SM region”

Terra incognita: forward physics

“Exotica searches region”
Where pQCD works
Central jets production and “Exotica region”
2.1.1) Inclusive hard jets production

- pp collisions: 2 ladders.
  - Central jets: symmetric collisions $x_1 \sim x_2$. DGLAP (strong $k_T$ ordering) expected to perform well.
  - Forward jets: asymmetric collisions $x_1 \ll x_2$. May need $\log(1/x)$ resummation and alternative evolution (BFKL, CCFM)

\[ x = \frac{2p_t}{\sqrt{s}} \exp(\pm y) \]
2.1.2) Experimental setup

- Central region $|\eta, y| < 2.5$: tracker + calorimeters. Particle Flow reconstruction allow very precise measurement by combining all detectors and allow pile-up (PU) removal.
- Forward region: $|\eta, y| > 3.0$: calorimeters only, but jets collimated and have large energy. Low handle on PU and large UE.
2.2.1) Measurement of inclusive jets

\[ \frac{d\sigma_{\text{Data}}^2}{dp_T dy} = \frac{d\sigma_{\text{Det}}^2}{dp_T dy} C_{\text{Det}} \]

\[ \frac{d\sigma_{\text{Thr}}^2}{dp_T dy} = \frac{d\sigma_{\text{NLO}}^2}{dp_T dy} C_{\text{NP}} \]

- Measurement: corrected for detector effect to “hadrons level” - $C_{\text{DET}}$.
- NLO calculation: corrected for hadronization and MPI effects estimated from LO+PS MC - $C_{\text{NP}}$. 

![Graph showing non-perturbative correction factor vs. Jet $p_T$](image-url)
2.2.2) Inclusive jets: 7 TeV with R=0.7

- Generally excellent agreement over 12 orders of magnitude with NLO+NP calculations.
- Let's look in more details.

Jets reconstructed with sequential anti-$k_T$ algorithm with R=0.7
2.2.3) Inclusive jets : 7 TeV with R=0.7

- Theory uncertainty : low pT - NP, middle/high pT – scales, PDF.
- Promising data to constraint proton PDF within DGLAP evolution.
2.3) Dijet angular correlation

- LO matrix element at LHC: dijet production.
- Anti-\( k_T \) with R=0.5 used.
- Each Mjj region normalised to 1.
- « Unfortunately » well described by pQCD in shape and no CI or resonances observed.
2.4) Inclusive jets : 7 TeV with R=0.5

- The results for anti-$k_T$ with $R=0.5$ are not so glorious:( Even if the difference is covered by uncertainties.
- Why?
Where pQCD is challenged
Small radius and/or forward jets
3.1) Dijet azimuthal decorrelation

- At LO 2 jets are back to back: $\Delta \phi \sim \pi$. True at large $p_T$.
- At low $p_T$ ISR and FSR play a significant rôlle. NLO+NP starts to fail to describe decorrelation. But LO+PS MC describe well.
- Simple evidence of importance of PS: large corrections beyond NLO!
3.2) POWHEG : NLO + PS + NP

- PS corrections are more important in forward direction and for smaller R (leaking out effect).
- Applying NP corrections from LO+PS MC to NLO is inconsistent when PS effects are large.
3.3) POWHEG vs NLO+NP

• POWHEG by itself describes better R=0.5 data than NLO+NP. PS represent part of the missing orders.
• Agreement not perfect at large $y$, but covered by systematics.
3.2 < |\eta| < 4.7

- JES dominating systematic.
- All models agree within systematics.
3.5) Inclusive jets: 7 TeV with R=0.7

- Access to very low x region. But sensitive to ISR there. To be understood.
- May be used to measure proton PDF?
Pushing pQCD to the limits large $|\Delta \eta|$
4.1) Inclusive to exclusive dijet ratio

- Jets with $p_T > 35$ GeV and $|y| < 4.7$, $R = 0.5$.
- Measure ration of inclusive dijets events to exclusive dijet events: cancelation of systematics
- $|\Delta y| \sim |\Delta \eta| < 9$ !!! between the two most external jets (Mueller-Navlett).
- Hope to see non DGLAP dynamics in the ladders between two jets.
- Strategic region for VBF physics: large $|\Delta y|$ and central jets veto !!!
4.2) Inclusive to exclusive dijet ratio

- Ratio only described by PYTHIA (surprising ?). Influence of the tune and MPI small.
- Deviation of most of the other models at large $|\Delta y|$.
- Cascade, HEJ: include elements of CCFM or BFKL like dynamics.
Few worlds about Photons production
5.1) Single photons production

- Predictions from the NLO pQCD (JETPHOX) agrees with Data except low $p_T$ photons where NLO predictions tends to overestimated data.
5.2) Double photons production

- Annihilation: $qq \rightarrow \gamma\gamma$
- Fusion: $gg \rightarrow \gamma\gamma$
- Fragmentation: $qg \rightarrow \gamma\gamma q$
- Calculation is done at NLO with DIPHOX, GAMMA2MC
- The overall agreement in diphoton mass spectrum.
  The theoretical predictions underestimate the measured cross section for $\Delta \phi_{\gamma\gamma} < 2.8$. 

![Graph showing CMS data and theoretical predictions.](image-url)
1) The understanding of QCD at LHC is a still challenging question even when considering simples observables as inclusive jets with low jet radius.
2) There are some QCD observables which are sufficiently well understood to use LHC data to contraint proton PDFs.
3) But for many others the NLO calculations are not sufficient in pp in contrary to ee, ep collisions. Parton Showers and other kind of leading log resummations seems to play an appreciable role.
4) This subject have to be understood since QCD is a background to non leptonic QCD searches and to the VBF production.
5) Photons program contrubuts/benefits but also suffers from the effort dedicated to the $H\rightarrow\gamma\gamma$. 
BACKUP
4) Dijets : 1 central jet + 1 forward jet

- All models fail. The closest is HEJ