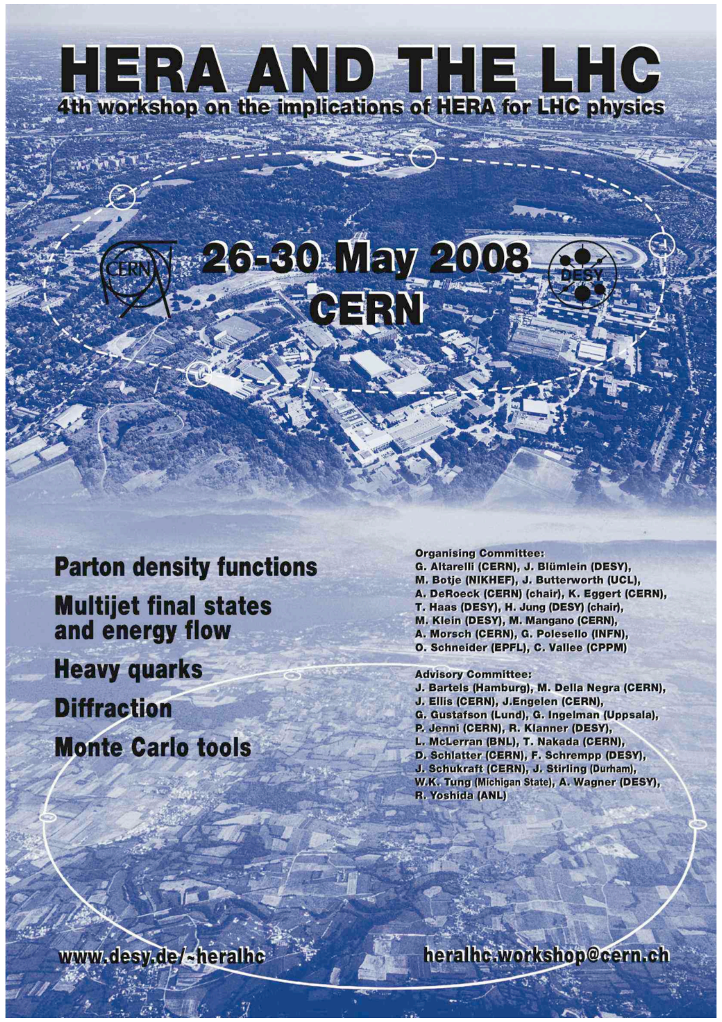
HERA LHC workshop

Workshop on the implications of HERA for LHC physics

Summary of the WG2

Hadronic final states and jet energy flow

Part I: Theory



Conveners: C. Gwenlan (ZEUS, ATLAS), L. Lönnblad (Lund),
E. Rodrigues (LHCb), G. Zanderighi (Oxford)

- Underlying event and minimum bias
- Rapidity gaps and survival probabilities
- Multi-jet topologies and multi-scale QCD
- Parton shower/ME matching

Outline

This is a special meeting:

- *it is the last meeting of this series*
- *it is the last meeting before the LHC startup*

➥ This summary:
not a complete summary of all the talks given here, rather an overview of progress reported at the Hera-LHC workshops since 2006

[Slides of all talks available on the web]

We had a large number of joint sessions:

- 2 joint sessions with WG on Diffraction
- 1 joint session with WG on PDFs
- 3 joint sessions with WG on MC tools [+3 in the working group week]

➥ strong interplay between the activities of the various working groups

QCD & LHC

The LHC will explore new ground and try to answer fundamental questions in particle physics

- Electroweak symmetry breaking: Higgs mechanism or what else?
- New physics at the TeV scale?

With the LHC we are finally moving from *indirect constraints* on BSM physics to *direct detection!*

The reach and physics potential of the LHC relies on our ability to provide accurate QCD predictions

- precise predictions of input parameter (α_s, m_t, parton densities)
- precise predictions of signal/backgrounds

Automation of perturbative calculations

Leading order: fully automated

- generation of tree level matrix elements
- phase space integration
- easy interface to parton showers

Treccani, Winter

At LO, very large scale dependences, sensitivity to kinematical cuts, poor modeling of jet structure. Why LO at all?

- always the fastest way and often the only one
- test quickly new ideas with fully exclusive description
- various working and well-tested approaches
- highly automated but lacks precision
  OK for qualitative studies, crucial as a tool to explore new ground

Automation & improving performance of NLO

Want Alpgen/Sherpa@NLO $\Rightarrow$ fully automated NLO calculations

- towards automation of NLO calculations
  Van Hameren
- NLO + parton shower
  Nagy
- duality between one-loop and single-cut phase space integrals
  Rodrigo
- automated one-loop N-gluon amplitudes via unitarity ➠ **Rocket**
  Zanderighi
- automated implementation of dipole-subtraction ➠ **TevJet**
  Seymour,Tevlin
- fast-NLO, NLOgrids, event weight grids
  Kluge,Clements,Sutton

When is NLO not good enough?

- when NLO corrections are large (NLO correction ~ LO)

  This may happens when

  - process involve very different scales → large logarithms of ratio of scales appear
  - new channels open up at NLO (at NLO they are effectively LO)
  - master example: Higgs production

- when extremely high precision is needed (not very often the case)

  - W/Z hadro-production, heavy-quark hadro-production, α_s from event shapes in e^+e^- ...

- when a reliable error estimate is needed

NNLO progress

- subtraction schemes at NNLO
  - antenna subtraction with initial state hadrons

    Daleo
  - subtraction scheme for jet-cross section at NNLO

    Somogyi
- charged current DIS scattering at three loops

  Moch
- SUSY QCD corrections to Higgs productions

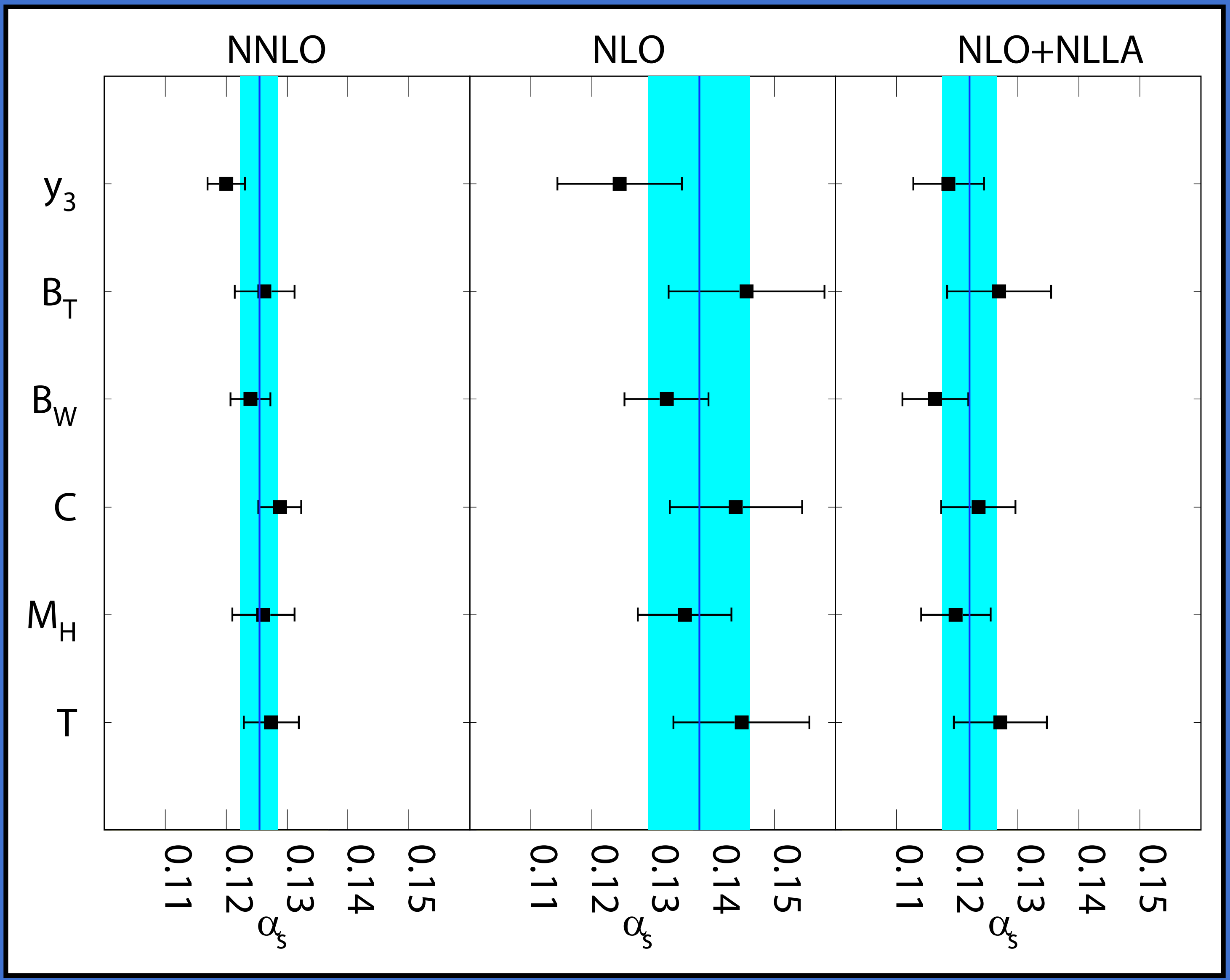
  Daleo
- NNLO 3 jets in e^+e^- and new α_S fits

  Luisoni

New NNLO α_S fits in e^+e^-

- $\alpha_S\,(M_Z)$
- consistent results at NNLO,
- scattering between variables much reduced.
- calculate weighted average for $\alpha_S\,(Q)$ from 6 variables

$$\bar{\alpha}_S = \sum_{i=1}^{6} w_i\, \alpha_S^i, \quad w_i \propto \frac{1}{\sigma_i^2}$$



$$\Rightarrow \quad \bar{\alpha}_S\,(M_Z) \;=\; 0.1240 \pm 0.0033$$

Luisoni

Not only NNLO QCD: "SUSY" corrections

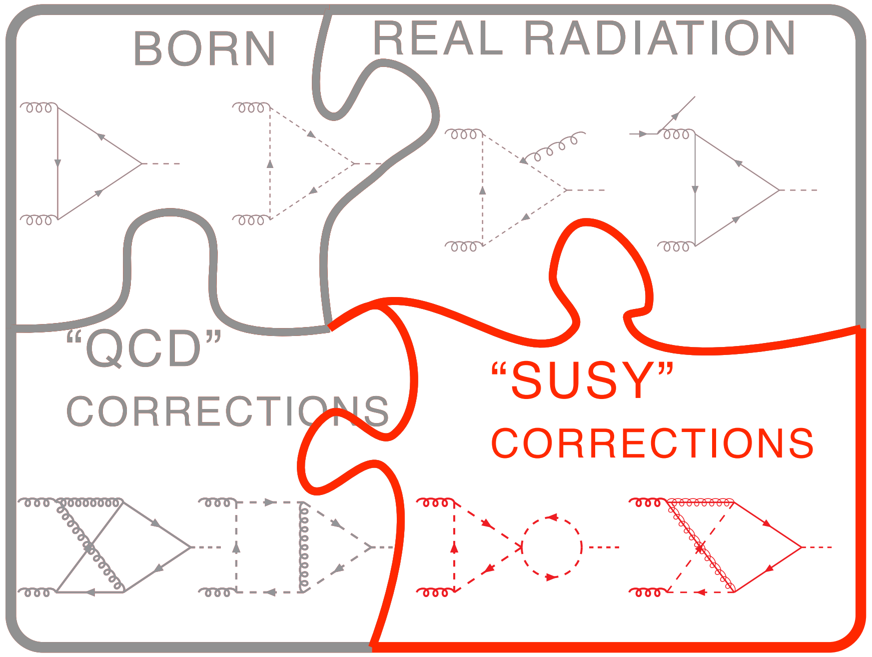
HIGGS SEARCHES ARE PRIORITY AT LHC

FOLLOWING DISCOVERY WE HAVE TO UNDERSTAND WHICH HIGGS WE FOUND

SIGNAL CROSS SECTION WILL BE MEASURED AT $\pm 10\%$ OR BETTER

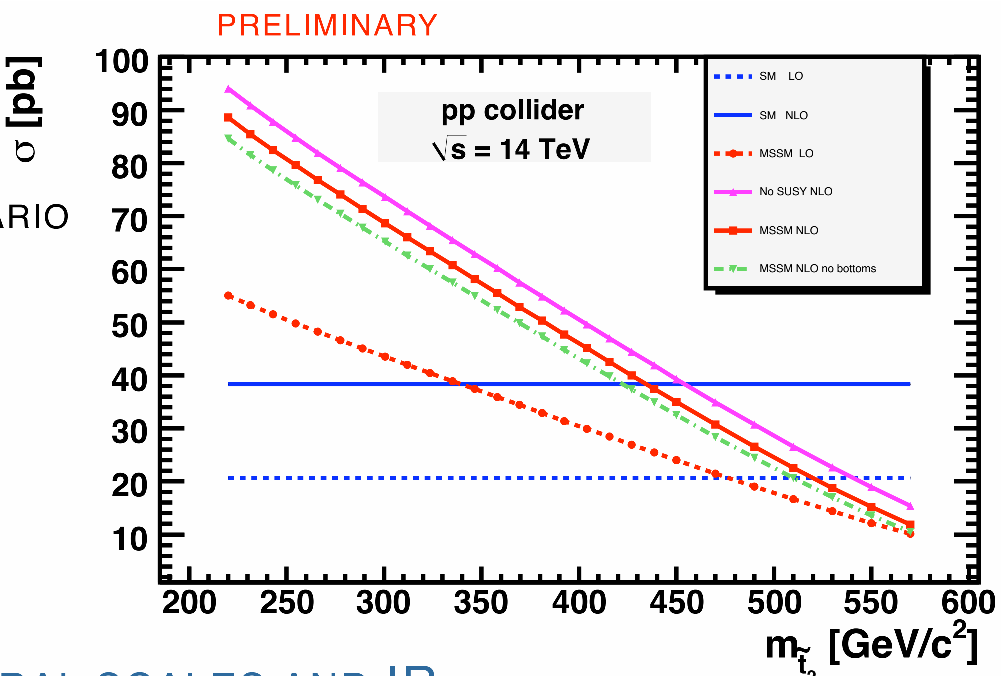
A PRECISION TEST OF THE STANDARD MODEL

IMPORTANT TO HAVE THEORETICAL PREDICTIONS MATCHING THIS PRECISION



EXTENSIONS OF THE SM MIGHT CHANGE THE PHENOMENOLOGY SIGNIFICANTLY

- NEW PARTICLES AFFECTING HIGGS PRODUCTION AND DECAYS
- COUPLING STRUCTURE MIGHT HIGHLIGHT CONTRIBUTIONS UNIMPORTANT IN THE SM
- EXTENDED HIGGS SECTORS COULD BE STUDIED AT THE LHC



MSSM IS A PROTOTYPICAL AND THOROUGHLY STUDIED BSM BENCHMARK SCENARIO

MANY INTERESTING FEATURES AFFECTING HIGGS PRODUCTION

- NEW COLORED PARTICLES, SQUARKS AND GLUINO, MEDIATING THE $gg \to h$ PROCESS
- CURRENT LIMITS DO NOT RULE OUT LIGHT $(100 - 200\,GeV)$ SQUARKS
- BOTTOM-HIGGS COUPLINGS ENHANCED AT LARGE $\tan\beta$
- HEAVY NEUTRAL HIGGS MIGHT BE ALSO SEEN AT THE LHC

- A NEW METHOD TO COMPUTE LOOP INTEGRALS INVOLVING SEVERAL SCALES AND IR SINGULARITIES
  - — GREAT POTENTIAL FOR MULTILOOP CALCULATIONS

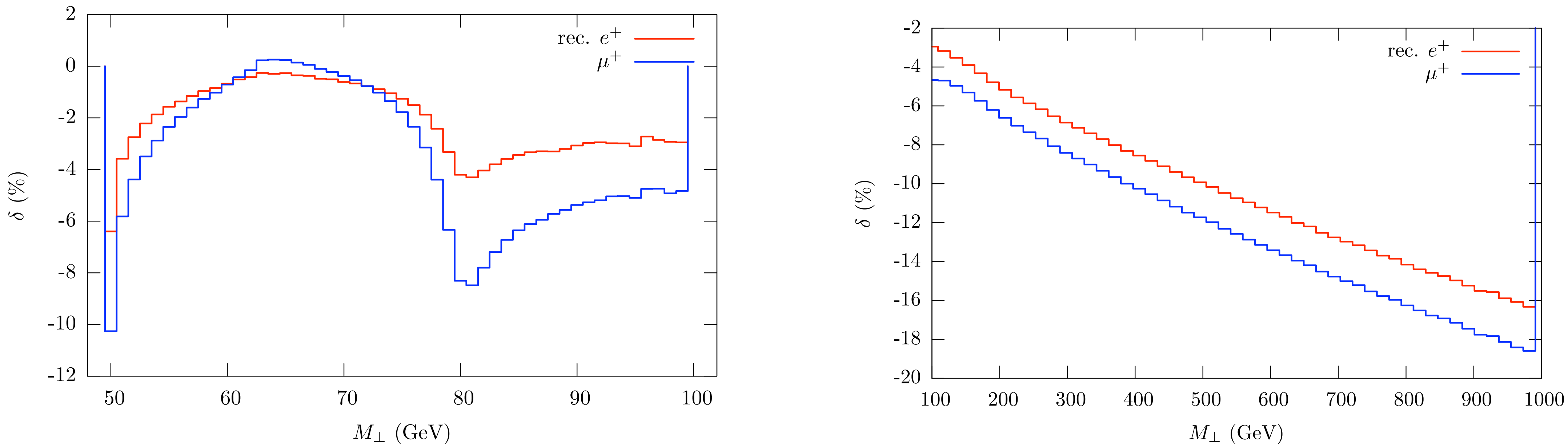
Daleo

Importance of EW effects

Electro-weak effects often believed to be irrelevant at the LHC

Recently: realized that this is not always the case

- LHC, $pp \to W^+ \to \ell^+ \nu_\ell$, $p_{\perp,\ell}$ and $p_{\perp,\nu} > 25$ GeV, $|\eta_\ell| < 2.5$
- $\mathcal{O}(\alpha)$ EW corrections to the M_T distribution



- $\mathcal{O}(\alpha)$ corrections at 5% - 10% level around the peak
- increasingly large in the M_T tail due to the presence of the EW Sudakov (logs)^2, $\alpha_W \log^2 \frac{s}{M_Z^2}$

Piccinini

Also: ongoing progress in QED*QCD resummation

Ward

A history of surprises ⇒ keep testing ideas!

- Apply e^+e^- ideas blindly to e.g. single hemisphere DIS event shapes – breakdown of techniques , need for non-global logarithms , large N_c approximation.

  Salam and MD 2002

- Look for non-global logarithms in gaps between jet studies in hadron -collisions using "well-known standard techniques" – find breakdown of naive coherence (super leading logarithm $\alpha_s^4 \ln^5 Q/Q_0$).

  Forshaw Kyrieleis and Seymour 2006

Kyrieleis

- Use well accepted resummation formulae in situations involving running of a jet algorithm – find extra logarithms that depend on algorithm parameters. Banfi and M.D. 2004, Banfi Delenda and M.D. 2006

Lesson – Important to keep testing "established" ideas in different contexts. Helps design better observables for future phenomenology - e.g. event shapes at hadron colliders. Banfi, Salam, Zanderighi 2005

Azimuthal dijet decorrelation: theoretically very rich observable (tests many ideas), practically very useful (e.g. MC tuning)

Dasgupta

A history of surprises ⇒ keep testing ideas!

- Apply e^+e^- ideas blindly to e.g. single hemisphere DIS event shapes – breakdown of techniques , need for non-global logarithms , large N_c approximation.

  Salam and MD 2002
- Look for non-global logarithms in gaps between jet studies in hadron -collisions using "well-known standard techniques" – find breakdown of naive coherence (super leading logarithm $\alpha_s^4 \ln^5 Q/Q_0$).

  Forshaw Kyrieleis and Seymour 2006

Kyrieleis

- Use well accepted resummation formulae in situations involving running of a jet algorithm – find extra logarithms that depend on algorithm parameters. Banfi and M.D. 2004, Banfi Delenda and M.D. 2006

Lesson – Important to keep testing "established" ideas in different contexts. Helps design better observables for future phenomenology - e.g. event shapes at hadron colliders. Banfi, Salam, Zanderighi 2005

Azimuthal dijet decorrelation: theoretically very rich observable (tests many ideas), practically very useful (e.g. MC tuning)

Dasgupta

Factorization:

- rigorous proofs of factorization assume color singlet in the initial state
- PT QCD calculations use IR-regulated PT with colored incoming lines. Act of faith?
- towards a new proof of cancellation of IR divergences in cross-sections with a light-like Wilson line in the initial state

Aybat

Specific kinematics regimes: small x

- Higgs via gluon fusion: new technique to approximate matrix elements with multi final state hard partons

White

- Forward jets at HERA and Mueller-Navalet jets at the LHC: BFKL NLL calculation (saddle point approximation removed)

Royon

- kt-factorization: incoming gluon not collinear to proton, but off-shell
  - CCFM-like equation for valence quarks in Cascade: results differ considerably from Pythia, both shape and normalization

Deak

  - W/Z+QQ production implemented in Cascade: large differences compared to MCFM

Deak

Specific regimes: large gluon density

- Multi-parton scattering, diffraction and effective cross-section: Poissonian model of hadronic interactions give too large effective cross-sections ⇒ dispersion of distribution larger than expected. Need to take fluctuations into account?

  Trelani

- Forward hadron production and high-gluon densities at the LHC: Reach black disk regime? Meaningful comparison of p-p at the LHC with Au-Au.

  Strikman

- In medium QCD and Cherenkov gluons: ring-like structure around away-side jets

  Dremin

Jets: *before 2006*

Cones are IR unsafe!

The Cone is too rigid!

IR unsafety affects jet cross-sections by less than 1%, so don't need to care!

kt collects too much soft radiation!

Cones has a well-defined circular area!

Jet area not well defined in kt: U.E. and pile-up subtraction too difficult!

What about dark towers??

After all, if D=1.35 R Cone and kt are practically the same thing....

Jets

The maturity in the description of jets reached a very high level
No space left for qualitative statements and for "bad jet-algorithms"

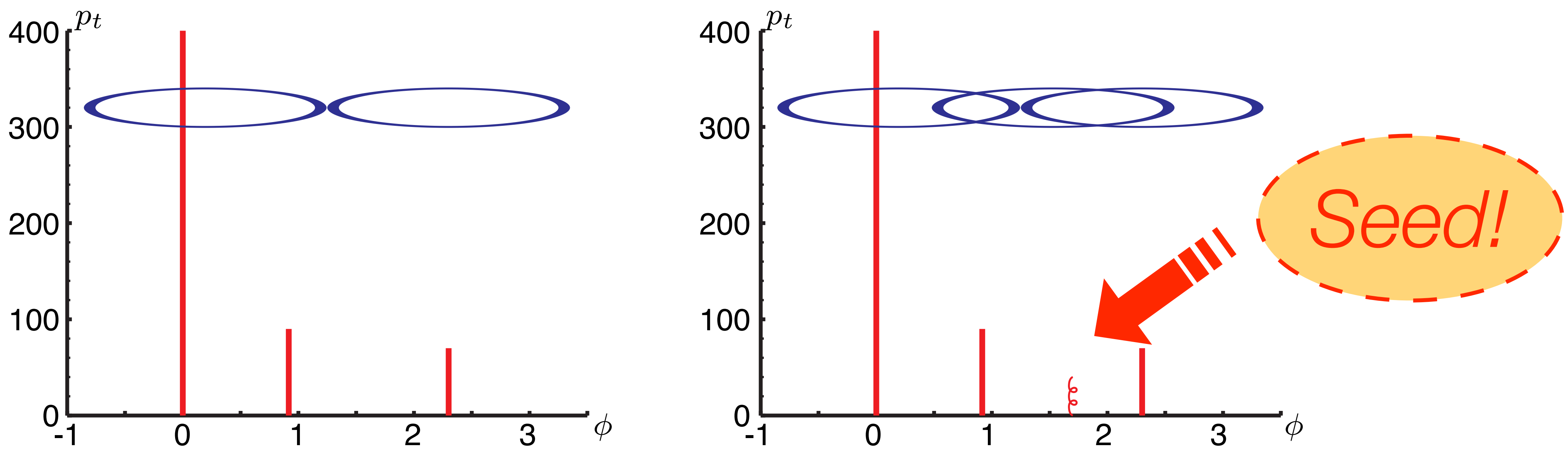
Progress and new concepts since 2006

- ✓ fast implementation of kt-algorithm fast-kt
- ✓ infrared safe cone algorithm SISCone
- ✓ new anti-kt algorithm with nice geometrical properties
- ✓ jet-areas and event-by-event pile-up subtraction
- ✓ systematic study of radius dependence of perturbative radiation, hadronization and underlying event

Infrared unsafety of seeded cone algorithms

Mid-point algorithm

Soyez



3 h ⇒ 2 stable cones

3 h + 1 s ⇒ 3 stable cones

Soft emission changes the structure of the jets ⇒ algorithm is IR unsafe

- Solution: use a seedless approach, find ALL stable cones
- Midpoint complexity: $\mathcal{O}\left(N^3\right)$
- Complexity: $\mathcal{O}\left(N^3\right)$, with improvements: $\mathcal{O}\left(N^2\log(N)\right)$

anti-kt

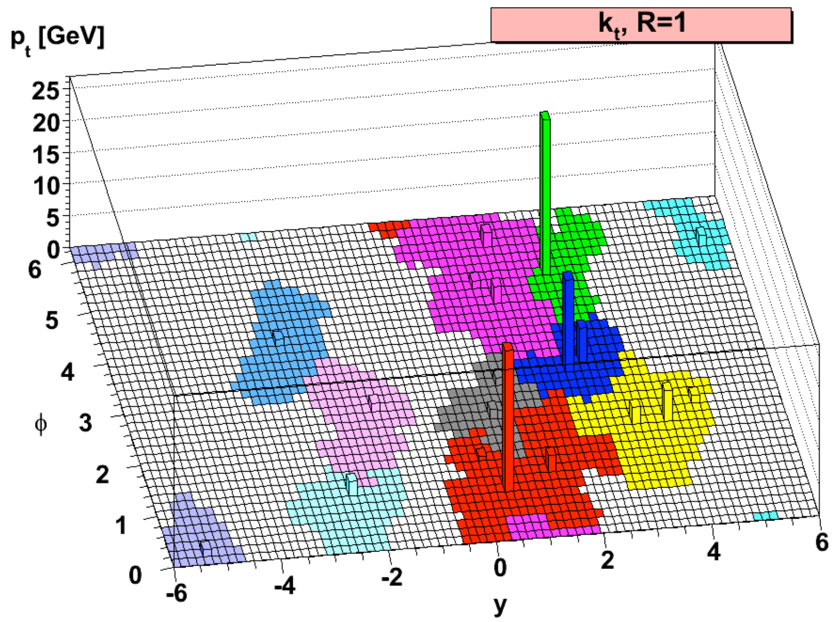
Come back to recombination-type algorithms:

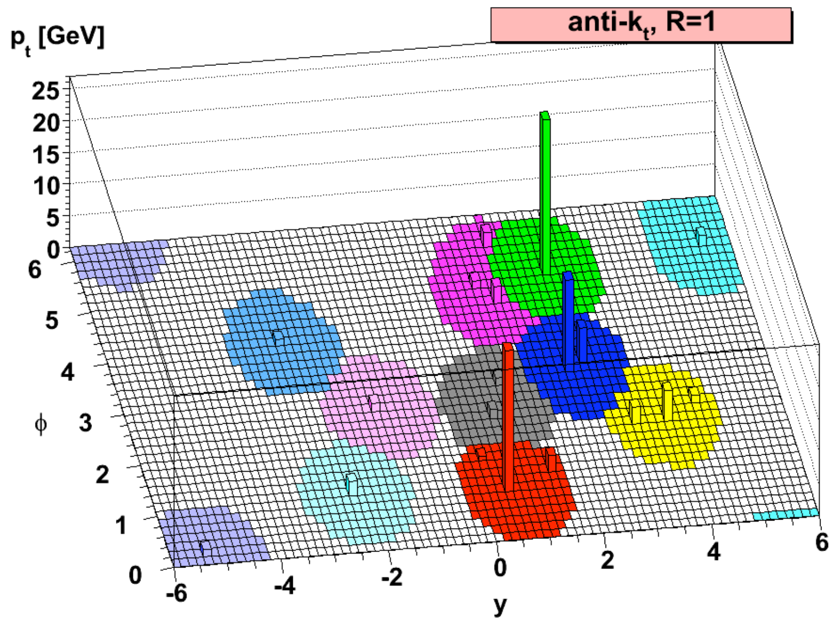
Soyez

$$d_{ij} = \min(k_{t,i}^{2p}, k_{t,j}^{2p})\ (\Delta\phi_{ij}^2 + \Delta\eta_{ij}^2)$$

- $p = 1$: k_t algorithm
- $p = 0$: Aachen/Cambridge algorithm
- $p = -1$: anti-k_t algorithm [M.Cacciari, G.Salam, G.S.,JHEP 04 (08) 063]

Hard event + homogeneous soft background





IR-safe jet-algorithms

Soyez

Observable	1st miss cones at	Last meaningful order
Inclusive jet cross section	NNLO	NLO
3 jet cross section	NLO	LO (NLO in NLOJet)
$W/Z/H$ + 2 jet cross sect.	NLO	LO (NLO in MCFM)
jet masses in 3 jets	LO	none (LO in NLOJet)

➡ IR-unsafety issue matters at the LHC
(the more exclusive the more it matters)

+ We do not want the theoretical efforts to be wasted

~~JetClu~~, ~~ATLAS Cone~~, ~~MidPoint~~ → SISCone
- ✓ as fast
- ✓ IRC safe

~~Iterative Cone~~ - - - → Anti-k_t
- ✓ regular
- ✓ IRC safe

Both available from FastJet (http://www.lpthe.jussieu.fr/∼salam/fastjet)

Jet area

MC, Salam, Soyez, arXiv:0802.1188 Cacciari

Active Area

Add **many** ghost particles in random configurations to the event.
Cluster many times.
Count how many ghosts on average get clustered into a given jet J.

$$A(J\,|\,\{g_i\}) = \frac{N_g(J)}{\nu_g}$$

- $A(J\,|\,\{g_i\})$: Active area of a single ghosts configuration
- $N_g(J)$: Number of ghosts in jet J
- ν_g: Ghost density

$$A(J) = \lim_{\nu_g \to \infty} \langle A(J\,|\,\{g_i\}) \rangle_g$$

- $A(J)$: **Active area**

Tools needed to implement it:

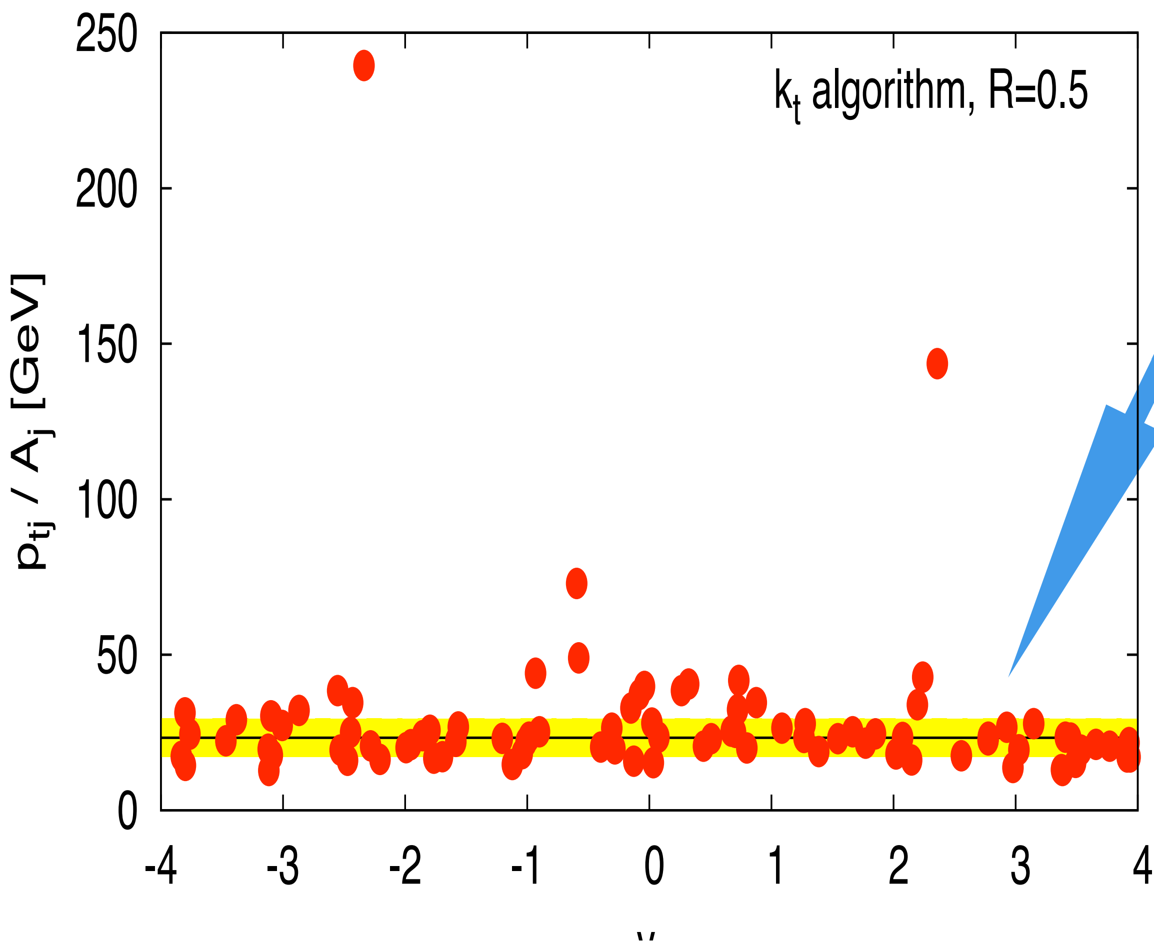
1. An **infrared safe jet algorithm** (the ghosts should not change the jets)
2. A reasonably **fast implementation** (we are adding thousands of ghosts)

Jet area: tool for UE & pileup subtraction

LHC: dijet event + high-lumi pilup

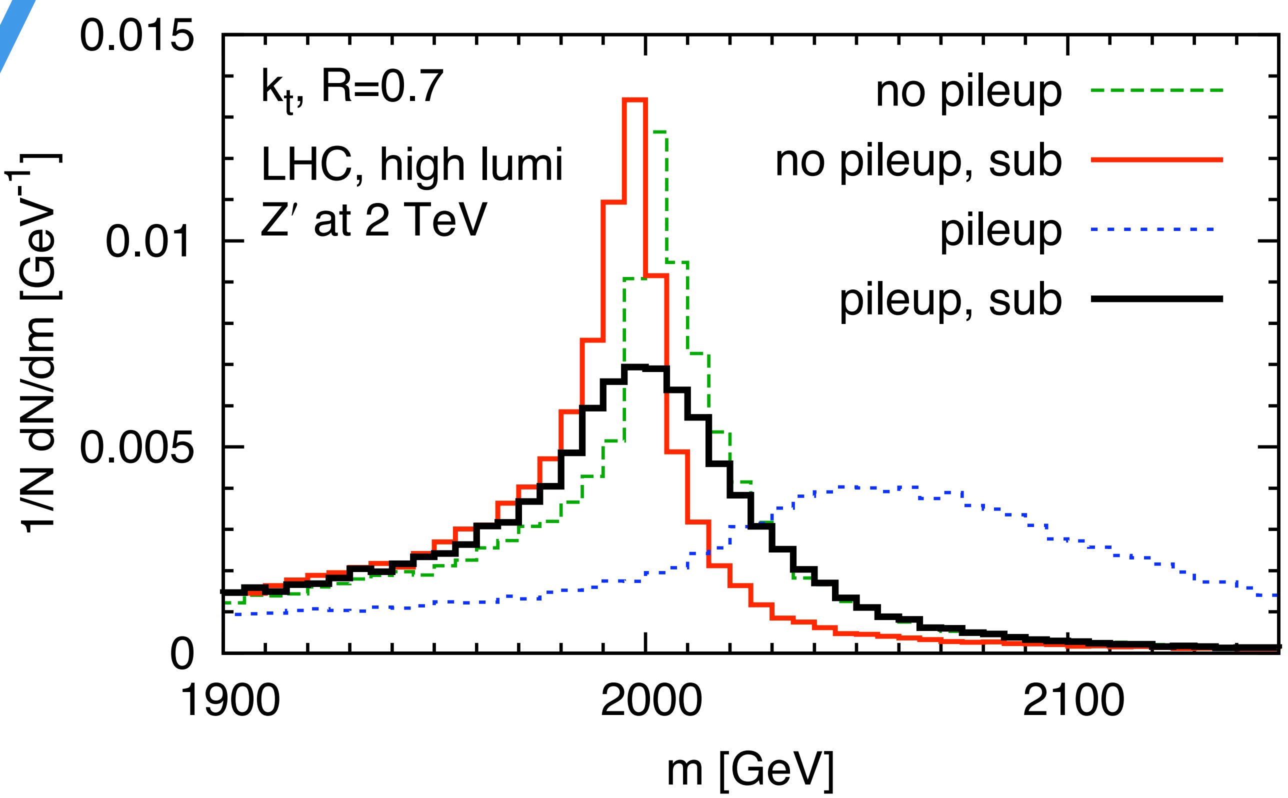
Cacciari

p_T/Area is fairly constant, except for the hard jets



The distribution of background jets establishes its own average momentum density **ρ**

(NB. this is true on an event-by-event basis)



Quantifying performance of jet algorithms

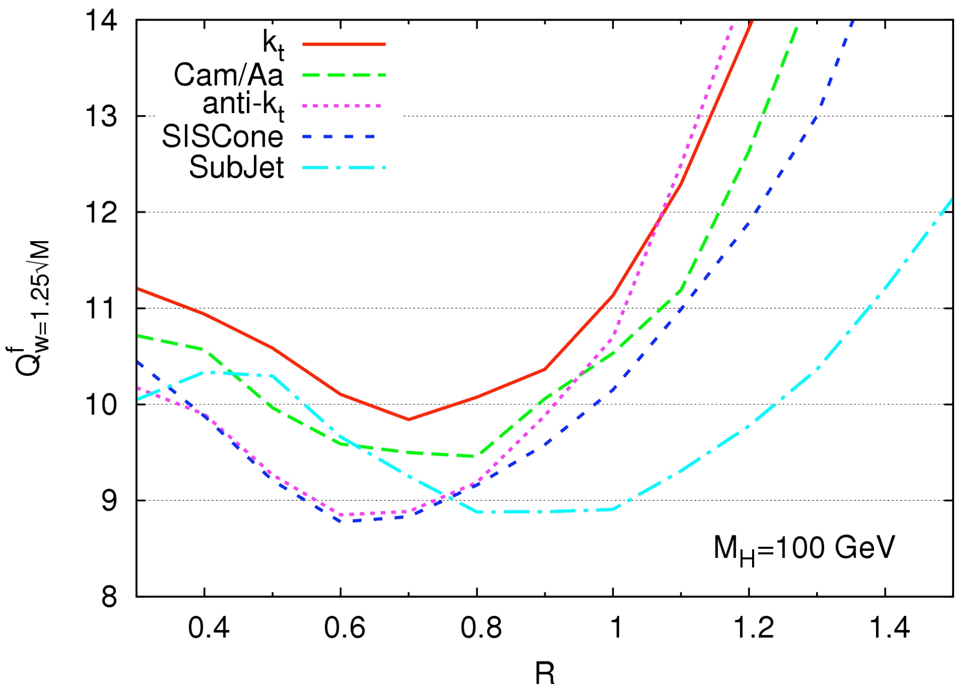
Rojo

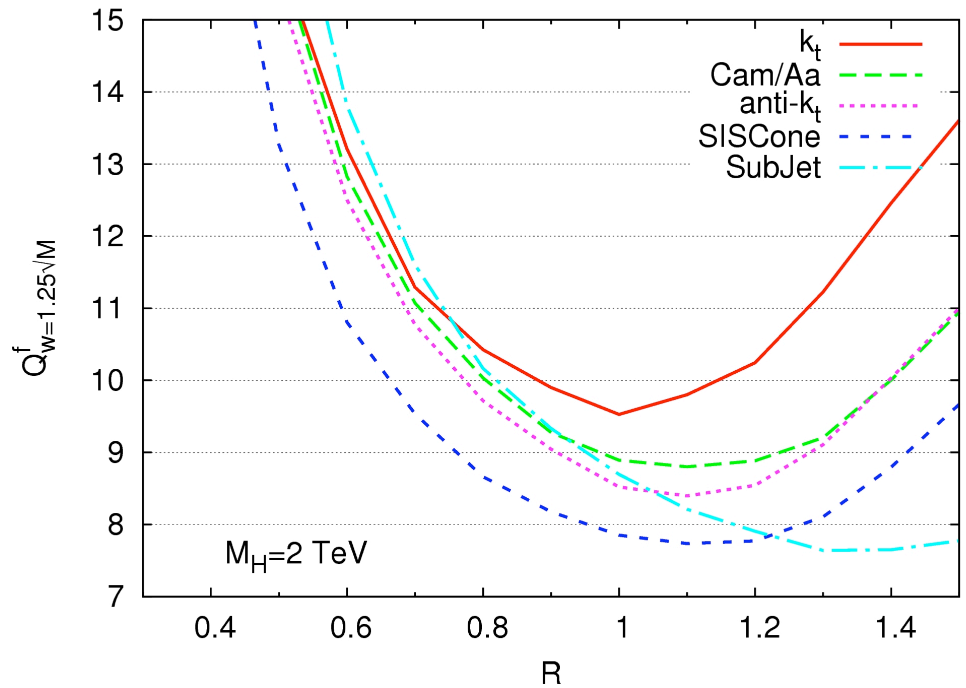
1. $Q^w_{f=z}(R) \to$ The **width of the smallest (reconstructed) mass window** that contains a fraction $f = z$ of the generated massive objects:

$$f = \left(\frac{\#\ \text{reco. massive objects in window of width } w}{\text{Total } \#\ \text{generated massive objects}} \right)$$

2. The **max. fraction of evs.** f in window of width $w = x\sqrt{M}$:

$$Q^f_{w=x\sqrt{M}}(R) \equiv \left(\frac{\text{Max } \#\ \text{reco. mass. obj. in width } w = x\sqrt{M}}{\text{Total } \#\ \text{generated massive objects}} \right)^{-1}$$





Less favored choices for the $M_H = 2$ TeV case:

1. Use SISCone, but $R^{100\ \text{GeV}}_{\text{best}} = 0.6$ instead of $R^{2\ \text{TeV}}_{\text{best}} = 1.1 \to \rho_{\mathcal{L}} \sim 0.55$
2. Use $R^{2\ \text{TeV}}_{\text{best}}$, choose not SISCone, SubJet/Filtering but $k_T \to \rho_{\mathcal{L}} \sim 0.6$

In both cases $\to$ Lose almost half effective discriminating power Σ^{eff}!

Optimizing R

Magnea

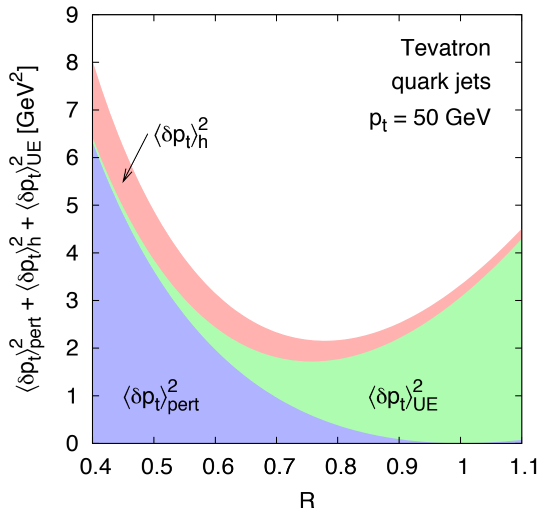
The change in p_t from the *hard parton* to the *hadronic jet* has *several sources*, each with its own *scale* and radius, energy and color dependence.

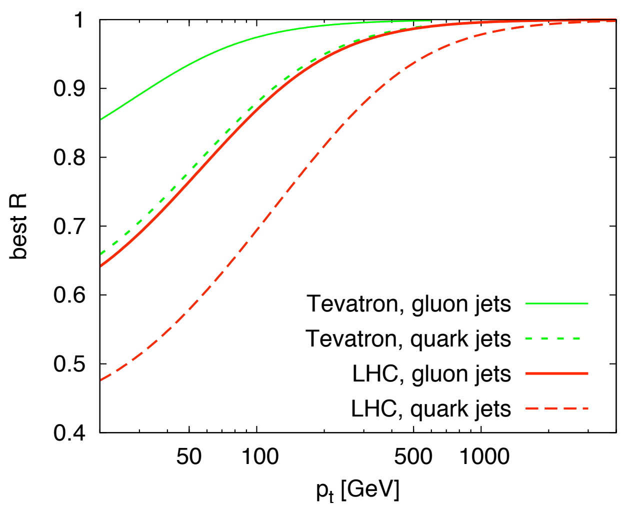
	Dependence of jet Δp_t on			
	scale	*colour factor*	R	$\sqrt{s}$
PT	$\alpha_s(p_t)\, p_t$	C_i	$\ln R + \mathcal{O}(1)$	–
H	$\mathcal{A}(\mu_f)$	C_i	$-1/R + \mathcal{O}(R)$	–
UE	Λ_{UE}	–	$R^2 + \mathcal{O}(R^4)$	s^{ω}

$\Rightarrow$ Different R dependence

a) disentagle different effects

b) choose an optimal R minimizing some (or all) effects





Take advantage of flexibility offered by modern jet tools: make flexible choices of jet-definitions and parameters!

Experimental status on jets

SM/QCD studies:
Both ATLAS and CMS implemented various IR safe jet-algorithms, and promise never to use IR-unsafe algorithms in physics analysis ever again

BSM studies:
Still older infrared unsafe algorithm being used?
Please convince your BSM collegues that a proper choice of the jet-algorithm does make a difference!

More on experimental progress on jets ➡ see Eduardo's talk

Part II
Experimental Summary
by
Eduardo Rodrigues