News from Les Houches
“Physics at TeV Colliders”
(Session I)

Lance Dixon
SLAC ATLAS Forum
June 27, 2007

Three working groups

1. NLO Multileg
   a. New approaches (to one-loop amplitudes) (Sessions I & II)
   b. Improvements on standard techniques (Sessions I & II)
   c. (N)LO event generators (Session I)
2. SM Handles and Candles
   a. Comparison of existing tools for SM (Session I)
   b. Issues in jet physics (Session I)
   c. Higgs production and backgrounds (Session II)
3. New Physics
   a. SUSY (Session I)
   b. Beyond (instead of?) SUSY (Session II)

Plus “free-roaming” Monte Carlo group

WG3. New Physics [= SUSY for Session I]

G. Polesello for the conveners

Two main issues for SUSY studies with the impending arrival of the LHC data:

- Make sure that we will discover it, if it exists
- Once a deviation from the Standard Model is observed, develop a strategy for understanding the origin of the observed deviation

The first issue is dominantly an issue of being able to predict correctly the Standard Model backgrounds in the kinematic region where we expect SUSY to show up

These issues were mostly tackled in the SM group

During the workshop we had a stimulating meeting between ATLAS and CMS physicists with exchange of views of techniques for measuring Standard Model background from data

Work on simulation of top backgrounds together with top group (M. Tytgat, F. Moortgat)

PDF uncertainty on top background estimates studied by D. Tovey and C. Gwenlan

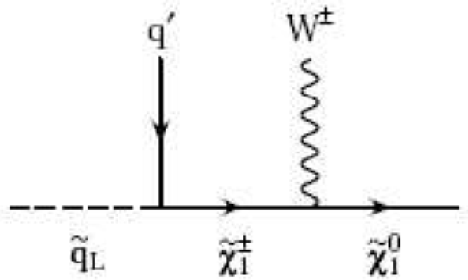
Work in BSM group mostly concentrated on what is sometimes referred to as the "inverse problem"

SUSY (cont.)

G. Polesello

Hadronic decays of massive bosons (MB) in SUSY

- The long neglected kid-brother of the di-lepton edge



Large backgrounds to reconstructing MB in SUSY events

Decay products in one jet:
Need to identify W and reject background

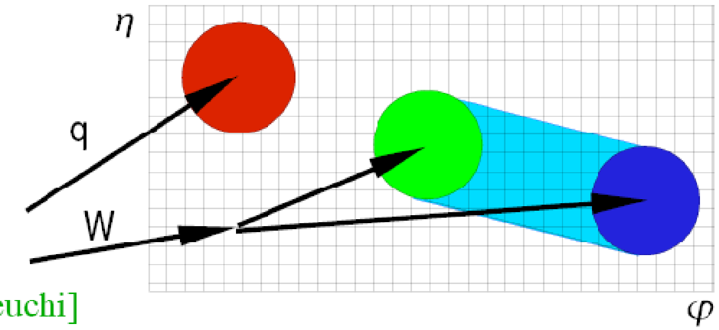
Structure of jets: mass, separation scale
Jet-algorithms: kT, Cambridge

[Butterworth, Raklev, Salam]

Decay products in two jets:
Need help in reducing SUSY combinatorics

Color connected jets:
Look at energy in region between jets

[Butterworth, Nojiri, Raklev, Takeuchi]



Focus Point

M. Consonni, R. Lafaye, T. Lari, T. Plehn, G. Polesello, M. Rauch, E. Turlay, D. Zerwas

mSUGRA FocusPoint region: heavy scalars (~3 TeV), 800 GeV gluino,
light neutralinos and charginos. Gluino decays mostly into χ^0 tt, χ^0 bb, $\chi^\pm$ tb

Project: How well can we constrain the gaugino sector parameters?
Can we distinguish from other scenarii with heavy scalars (split SUSY) ?

Possible LHC measurements (300 fb^{-1}):

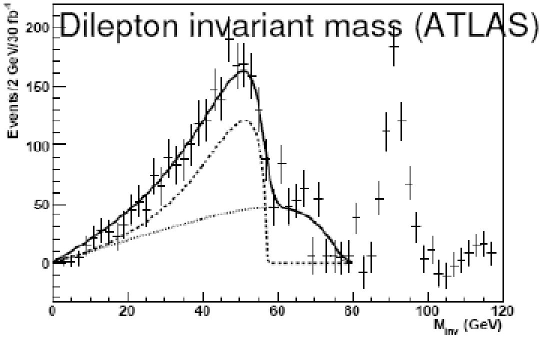
1) $m(\chi^0_3) - m(\chi^0_1)$
2) $m(\chi^0_2) - m(\chi^0_1)$
3) σ x BR ($\chi^0_2\, \chi^\pm_1$ -> 3 leptons)
4) A3/A2
5) AZ/(A2+A3)

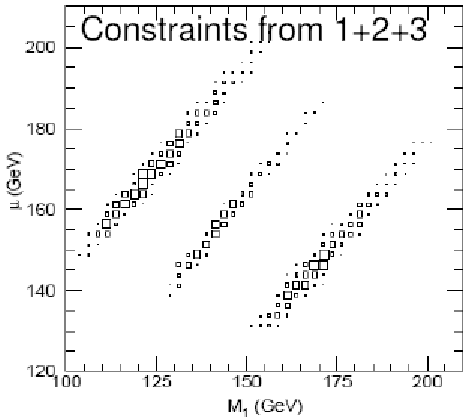
where

A2 = BR($g \to \chi^0_2 \to \chi^0_1$ ll)
A3 = BR($g \to \chi^0_3 \to \chi^0_1$ ll)
AZ = BR($g \to \chi^0_4 \to \chi^0_3$ Z) + BR(g -> $\chi^\pm_2$ -> $\chi^\pm_1$ Z)

6) Nb/Nq = BR(g -> b X)/BR(g -> qX) [including quarks from gaugino and top, W, Z decays]
7) m(h)

1+2+3+4: Already documented
5+6: investigated during this workshop





LHC Olympics + SM backgrounds =

Blind SUSY search

G. Polesello

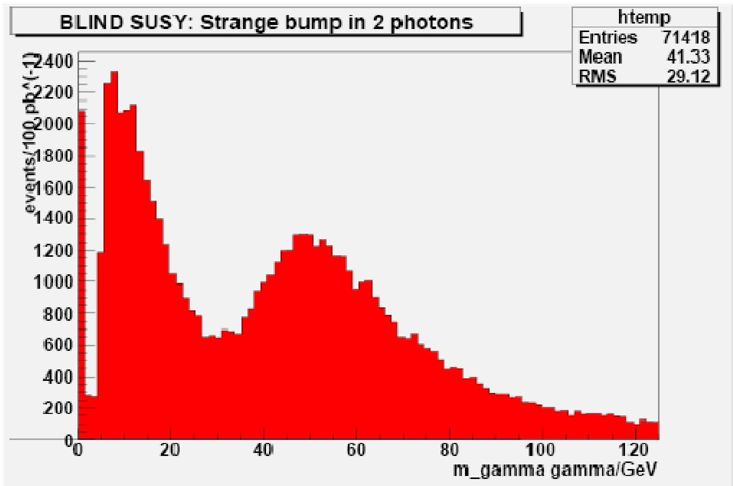
Analysis proposed by S. Muanza, who generated in fast simulation a full background set for 100 pb^{-1}

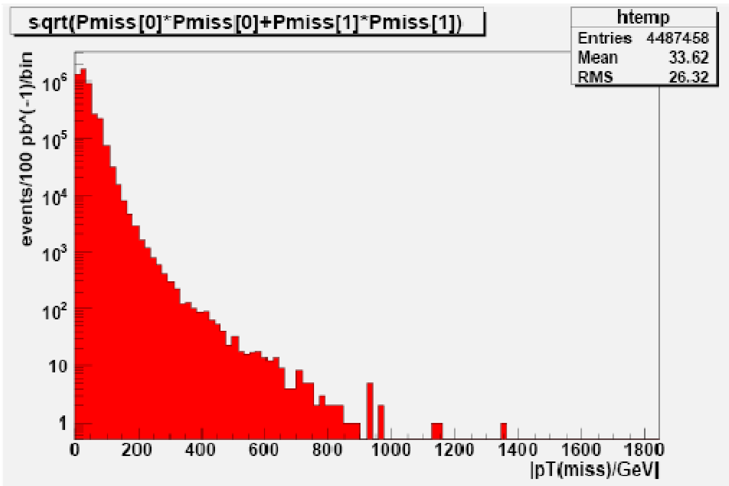
with a mystery SUSY model mixed in

Some preliminary plots produced during the workshop (B. Allanach):

Left: photon-photon invariant mass. Structure from generation cuts?

Right: ptmiss distribution. Seems larger than expected from SM





SUSY Renormalization Group Evolution Codes

Comparison of different SUSY codes

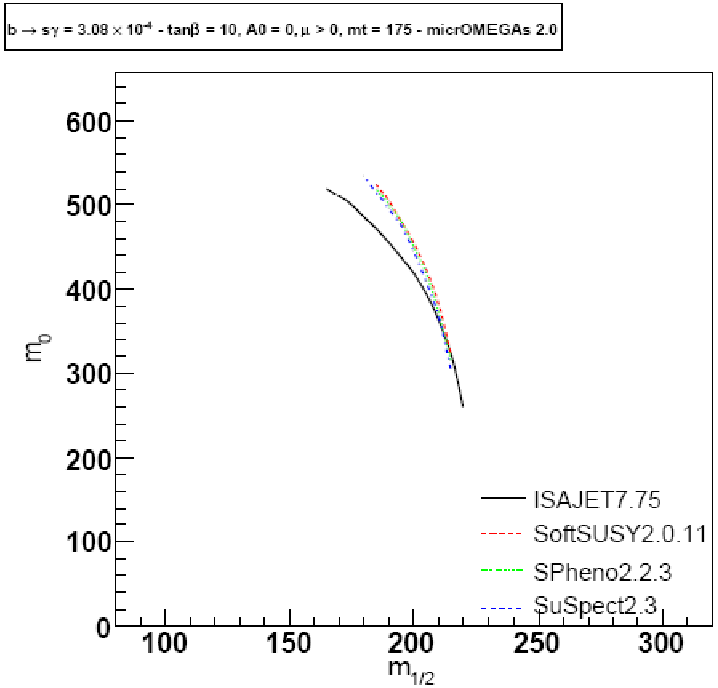
S. Kraml, S. Sekmen, B. Allanach, C. Lester, P. Zalewski

Input: $\mathrm{BR}(b \to s\gamma)$

+ fix some mSUGRA parameters at weak scale

run couplings up to GUT scale and compare

modern codes now all in pretty good agreement, after much comparison

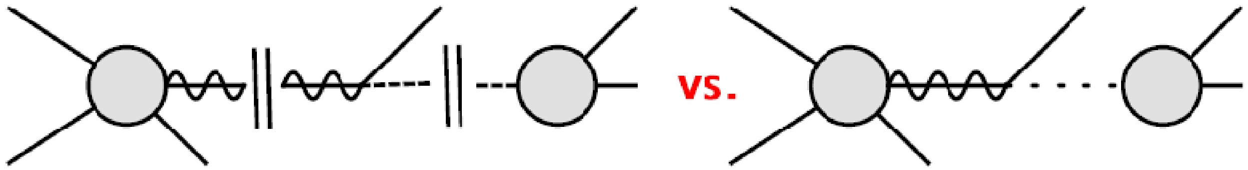


Models/tools

Off-shell effects

M. Gigg, N. Kauer (contact), T. Plehn, P. Richardson, C. Uhlemann

▶ **on- vs. off-shell intermediate states in SUSY cascades**



- study of processes with cascade decays in (modified) SPS scenarios
- off-shell vs. nonresonant and interference effects
- guidelines when off-shell effects can be important
- prescriptions for off-shell-improved predictions

More SUSY Tools

SLHAio, SFitter, Precision Constraints

(S. Kreiss, R. Lafaye, T. Plehn, M. Rauch, D. Zerwas)

- SLHAio: = Super-Les Houches Accord input/output format

  New library which provides

  - Easy-to-use implementation of reading/writing SLHA files (v1 and v2)
  - Direct mapping onto program-internal variables
  - Fast connection between linked programs
  - Bindings: C/C++, Fortran

- Precision Constraints for SFitter:

  - The usual set:

    Electro-weak Constraints: $g_\mu - 2$, M_W, $\sin^2\theta_W$, $\delta\varrho$, ...

    Flavour Constraints: $b \to s\gamma$, $B_s \to \mu\mu$, ...

    Dark Matter: Ωh^2
  - Fuzzy limits for observables with exclusion limits
  - Assess effect on constraining MSSM parameter space, when future LHC data is also taken into account

WG2. SM Handles and Candles
a. Existing tools

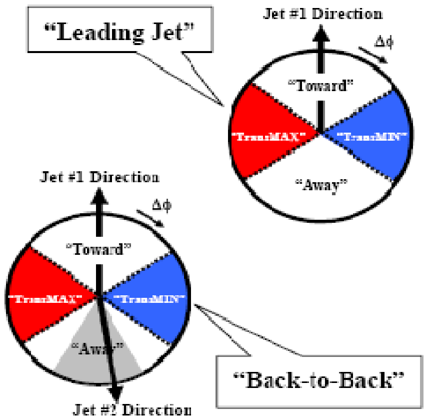
C. Buttar

1) **how to present LHC cross section results in 2008**
can we measure the luminosity precisely
should we quote absolute or relative cross sections
to which process we should normalize our cross sections
2) ***Soft physics: min bias and underlying event***
How to estimate trigger bias in minimum bias events
can we improve the tuning or is there a better way to get the diffractive part right?
Benchmark measurements to characterise the underlying event
Underlying event in EW processes
3) ***PDFs***
which cross-sections and/or distributions from the LHC will improve our knowledge of PDF's
how to estimate and the handle systematics
4) **real and virtual EW corrections for high Et QCD processes**
implementation in generators, check consistency
effect on distributions (p_t, m_t, m_ttbar, spin correlations, ...)
estimate the effect on measurements
issue of experimental v. theoretical event selection (whether inclusive or not wrt W/Z emission)
5) **Use of matrix elements and kinematic fitting in data analysis**
implementation of matrix elements techniques (comparison)
implementation of kinematic fit techniques (comparison)
benchmark cases for improvement
comparison between matrix elements and kinematic fit methods
6) Top
tt+jets
Spin correlations, colour reconnection
Top mass definitions

Many overlaps with jets, WG1 and WG3

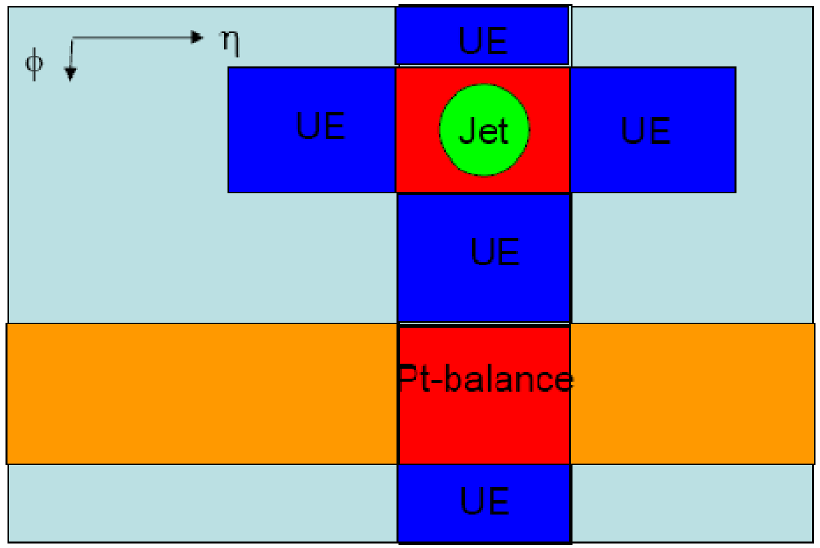
→ Twiki

Testing Models of the Underlying Event



In jet events (CDF, R Field)

C. Buttar



Shown by courtesy of Tate Gallery, London

- Traditionally have looked at transverse region
- With extended tracker can also look at longitudinal regions

Now studying UE in Drell Yan (T Todorov) and in Z + 2 jets at D0 (H Nilsen)

ttbar + jets

J. D' Hondt

- AlpGen – MadGraph comparison : ME⇔PS matching (MLM)
  - How and what to test with data: E_T, R_{ij}, M_{ij}^2, more ?
  - Double differential : $d\sigma/dp_T^j dp_T^{min}$ (min: smallest pT from top decays)
  - How does ttbar+jet compares with W+jets, can we learn something from a comparison ? Should we use the same matching criteria ?
- NLO vs LO (ttbar+0jet and ttbar+1jet): **hep-ph/0703120**
  - Which distributions to calculate: p_T^{top}, p_T^j, η^j, $\Delta R_{j,top}$, m_{ttbar}, ...
  - Also with cuts on p_T^{top}>50,100,200GeV: p_T^j, η^j, ...
  - More ... ?

  important SUSY background, missing E_T, jets, ...
- Is the comparison the same for different jet algorithms ? Can be done at hadron level within detector geometries...
- Other matching methods SHERPA (CKKW)

WG2. SM Handles and Candles
b. Jets

Better, faster jet algorithms wanted

Jets @LH (G. Salam, LPTHE) (p. 3)
└Background & motivation

LHC is not LEP

"I don't understand what all the fuss is about — why don't they [Tevatron] just use the k_t algorithm?"

by an ex-director of a large French particle-physics lab

LEP

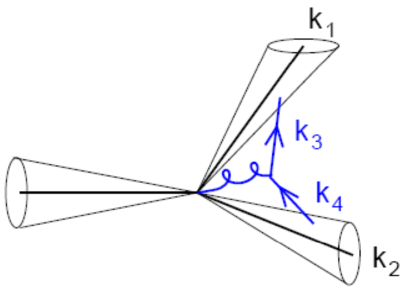
- $M_{BSM} \sim 1$ TeV
- $M_{EW} \sim 100$ GeV
- $p_{t,\text{pileup}} \sim 25 - 50$ GeV/unit
- $p_{t,\text{UE}} \sim 2.5 - 5$ GeV/unit ra
- $p_{t,\text{hadr.}} \sim 0.5$ GeV/unit rap.

LHC

- $M_{BSM} \sim 1$ TeV
- $M_{EW} \sim 100$ GeV
- $p_{t,\text{pileup}} \sim 25 - 50$ GeV/unit rap.
- $p_{t,\text{UE}} \sim 5 - 10$ GeV/unit rap.
- $p_{t,\text{hadr.}} \sim 0.5 - 1$ GeV/unit rap.

Better flavor jets

Less infrared sensitivity for jets with flavor (e.g., b jets)



Banfi, Salam, Zanderighi, hep-ph/0601139

Figure 2: A large-angle soft gluon splitting to a large-angle soft $q\bar{q}$ pair (k_3, k_4) with the q and $\bar{q}$ then clustered into different jets (k_1, k_2).

e^+e^- example based on k_T (Durham) algorithm

Applied to the k_t or cone algorithms, this procedure yields a jet flavour that is infrared (IR) safe at (relative) order α_s discussed in our example above. However at (relative) order α_s^2 a large-angle soft gluon can split into a widely separated soft $q\bar{q}$ pair and the q and $\bar{q}$ may end up being clustered into different jets, 'polluting' the flavour of those jets, see fig. 2. Because this happens for arbitrarily soft gluons branching to quarks, the resulting jet flavours are infrared unsafe from order α_s^2 onwards. We are not aware of this problem

$$y_{ij}^{(F)} = \frac{2(1-\cos\theta_{ij})}{Q^2} \times \begin{cases} \boxed{\max(E_i^2, E_j^2)}, & \text{softer of } i,j \text{ is flavoured,} \\ \min(E_i^2, E_j^2), & \text{softer of } i,j \text{ is flavourless,} \end{cases}$$

Fast k_T algorithm (FastJet)

Cacciari, Salam, hep-ph/0512210

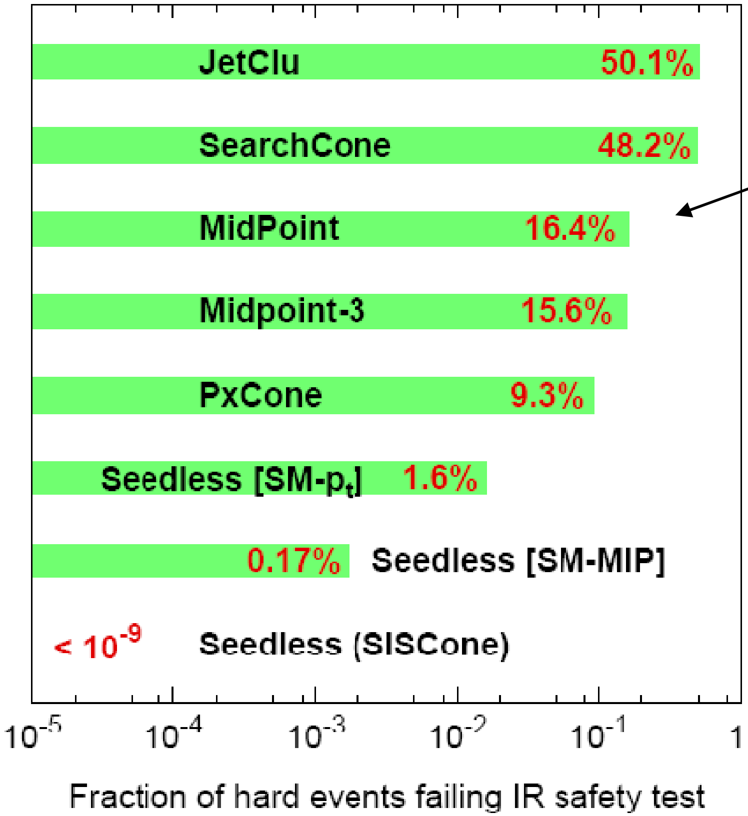
- Naively, cluster algorithms scale like N^3

(~ N(N-1)/2 pairs at first step, ~ N clustering steps)

- N = 2000 → 10 s CPU time!
- But the hard part of the problem can be mapped to a well-known problem in computational geometry with an N ln N solution
- Roughly, only have to find “distances” from each particle to its “nearest neighbor”, not to all other particles.

Seeded cone algorithms are Infrared Unsafe

Salam intro.



Tevatron Run I

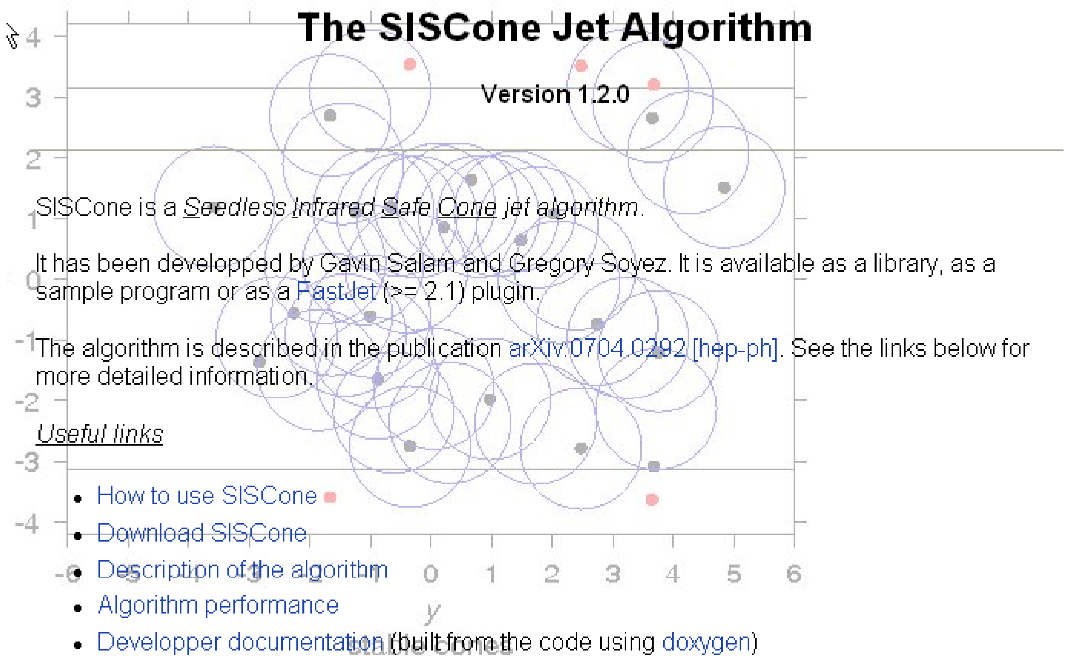
Run II

Last meaningful order	
Process	MidPoint alg.
Inclusive jets	NLO
$W/Z + 1$ jet	NLO
3 jets	LO
$W/Z + 2$ jets	LO
jet masses in $2j + X$	**none**

Fast seedless cone algorithm (SISCone)

Salam, Soyez, 0704.0292 [hep-ph]

Seedless cones better theoretically, but computation time was a possible issue, until SISCone.



Jet Algorithms

Salam

- Not yet clear if the LHC experiments will really use better jet algorithms
- Promising: It seems that ATLAS/CMS have ***experts*** in charge for implementing the jet algorithms in their software framework → aware of relevant issues
- Good News: experiments want standardized jet codes
  → take codes from external libraries fastJET, SpartyJet with version control
  → identical algorithms between experiments
  → Make it easy for beginners to use appropriate tools

All the jets you'll ever want in one package

http://www.pa.msu.edu/~huston/SpartyJet/SpartyJet.html

SpartyJet

SpartyJet is a framework intended to allow for the easy use of multiple jet algorithms in collider analyses.

So far this is a stub website in which only the tarball for SpartyJet (currently v1.0) is available. This will be developed further in the near future, allowing anonymous cvs to get the latest version. Included in the tarball is a README file that provides some useful information. An archive containing a jobOption for ATLAS users and a piece of code to extract topoclusters/truth particles from AOD's is given here. This will allow users to run SpartyJet with CSC data.

A history file including some known *features* and some future plans can be found here. The fixes and improvements will be incorporated into v1.1. One of the improvements will be the ability to read in STDHEP files as input to the jet finders.

Included in SpartyJet are the JetClu, Midpoint, CellJet algorithms and, through FastJet, the SISCone, inclusive and exclusive kT, and Cambridge/Aachen algorithms. The user is able to choose among a number of cuts/parameters for each algorithm.

WG1. NLO Multileg

NLO calculation priority list from Les Houches 2005: theory benchmarks

J. Huston summary

G. Heinrich and J. Huston

process ($V \in \{Z, W, \gamma\}$)	relevant for	
1. $pp \to VV$+jet	$t\bar{t}H$, new physics	+
2. $pp \to H + 2$jets	H production by vector boson fusion (VBF)	*
3. $pp \to t\bar{t}b\bar{b}$	$t\bar{t}H$	+
4. $pp \to t\bar{t} + 2$jets	$t\bar{t}H$	
5. $pp \to VVb\bar{b}$	VBF$\to H \to VV$, $t\bar{t}H$, new physics	
6. $pp \to VV + 2$jets	VBF$\to H \to VV$	
7. $pp \to V + 3$jets	various new physics signatures	+
8. $pp \to VVV$	SUSY trilepton	*

Table 2. The wishlist of processes for which a NLO calculation is both desired and feasible in the near future.

*completed since list
+people are working

- Additions in 2007
  - pp->4b (T. Reiter + advisor)
  - NLO gg->WW $W^{(*)}W^{(*)}$ and $Z^{(*)}Z^{(*)}$
    - add LO code to existing Monte Carlos   LO $gg \to Z(*)Z(*)$ presented by N. Kauer
  - NLO + EW VBF Higgs
- Interface issues
  - all NLO codes should be public and output 4-vectors in a convenient way
    - for example, in ascii or ROOT files
  - all experimenters should be encouraged to use the NLO codes (and to cite the proper papers when doing so) → indoctrinate the students early, for example in the ATLAS workbook

A day of showers (parton & H_2O)

- WG1 + MC (AdN): Parton Showers, Matrix Elements, and Matching:

  * 9:15 Morning:
    - o Introduction/Kickoff (Soper)
    - o Matrix element matching at LO and NLO (Richardson)
    - o Comparison of LO merging approaches (Schumann)
    - o Matching from an experimentalist's point of view (Nilsen)

  * Afternoon: beyond the present (each person to deliver a provocateur for discussion)
    - o SCET (Schwartz)
    - o VINCIA (Skands) ← shower based on dipoles (like ARIADNE) of sort used in newer NLO calculations
    - o ACOT-style Matching (Kersevan)
    - o Parton Shower with Quantum Interference (Nagy)
    - o BFKL at LHC (Andersen)
      + Update with comparison to CDF data
    - o LLL subtraction and PS kinematics (Odaka)
    - o Catani-Seymour shower (Schumann) ← shower based on standard NLO subtraction method

should make it easier to combine NLO calculations with parton shower MCs (i.e., easier than adding processes to MC@NLO)

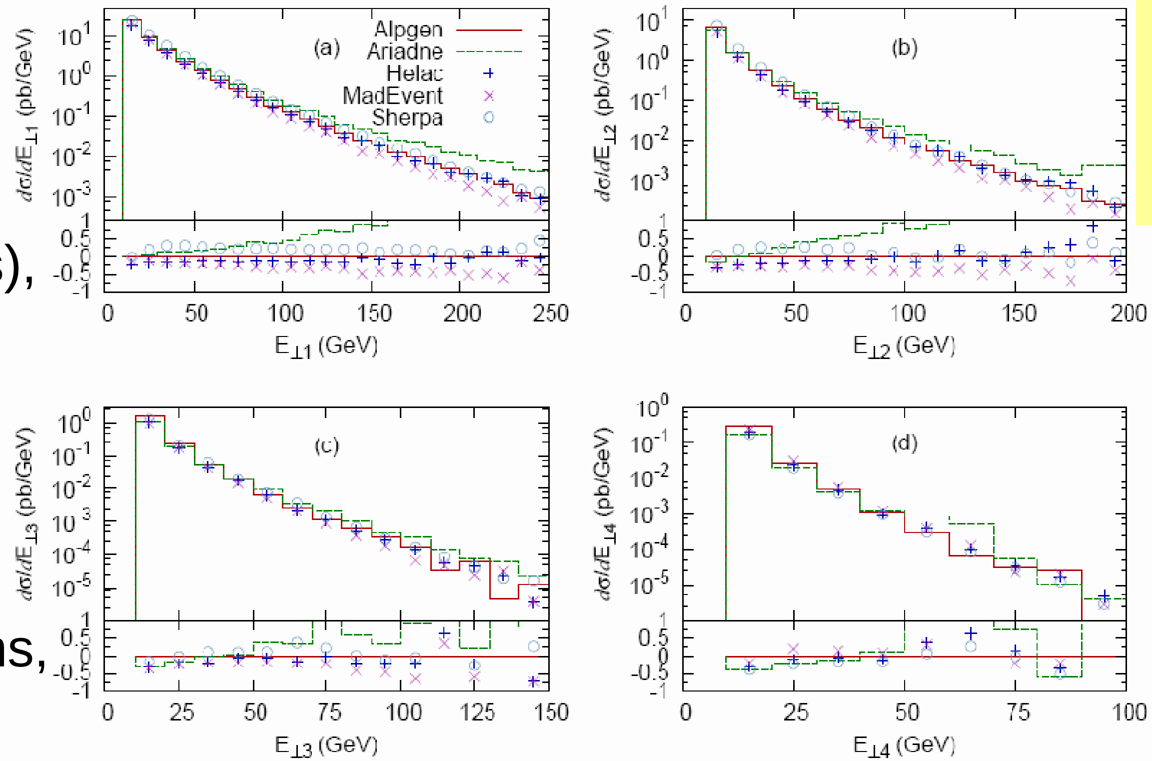
LO Matching Studies: W + multijet events

Comparing CKKW, L-CKKW, MLM @ Tevatron

➔ the jet-E_T spectra @ Tevatron (reference curve in lower panels is Alpgen)

S. Schumann. See also J. Alwall et al., 0706.2569 [hep-ph]

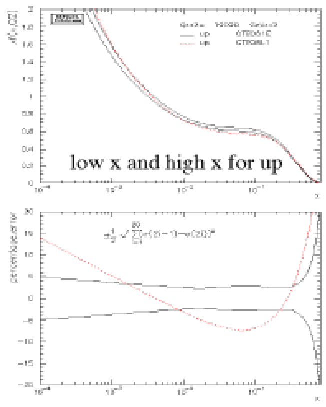
except for ARIADNE (ISR issues), quite good agreement between different matching prescriptions, showers



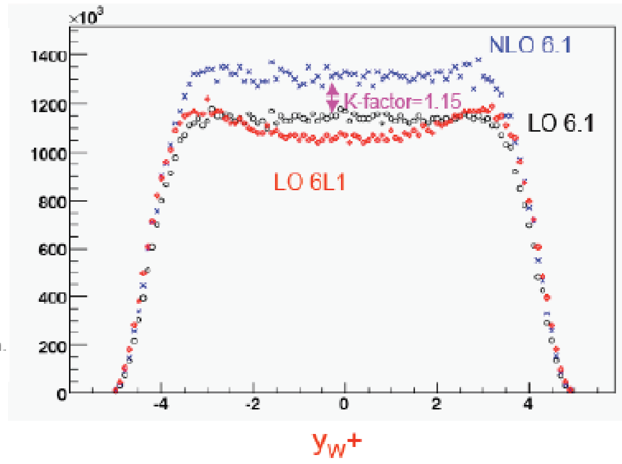
PDF's for Monte Carlos

J. Huston summary

- Experimenters tend to use LO Monte Carlos for everything, including for processes for which NLO information is available
  - see slide 2
- And what's worse, when they do use NLO tools, they reference the MC@NLO webpage rather than the original paper
- LO pdf's can create cross sections/acceptances that differ in both shape and normalization from NLO due to influence of HERA data
- Can we modify LO pdf's for Monte Carlos to reduce differences?



W+ rapidity distribution at LHC



WG1. a,b:
One-loop amplitudes for NLO

G. Heinrich
summary

progress

- change in philosophy:
  - more automatisation
  - more modular tools:
    - loop integrals: public database

      → "Les Houches Accord on master integrals"
    - real radiation: automated dipole subtraction
      (T. Gleisberg)

Fast, recursive trees

"new" approaches

Comparison for Born amplitudes

(Weinzierl)

n	4	5	6	7	8	9	10	11	12
Berends-Giele	0.00005	0.00023	0.0009	0.003	0.011	0.030	0.09	0.27	0.7
Scalar	0.00008	0.00046	0.0018	0.006	0.019	0.057	0.16	0.4	1
MHV	0.00001	0.00040	0.0042	0.033	0.24	1.77	13	81	—
BCF	0.00001	0.00007	~~0.0003~~	~~0.001~~	~~0.006~~	~~0.037~~	~~0.19~~	~~0.97~~	~~5.5~~
			0.00015	0.0005	0.003	0.015	0.085	0.45	2.25

CPU time in seconds for the computation of the n gluon amplitude on a standard PC
2 GHz Pentium IV), summed over all helicities.

I. Dinsdale, M. Ternick and S.W., JHEP 0603:056, (hep-ph/0602204);

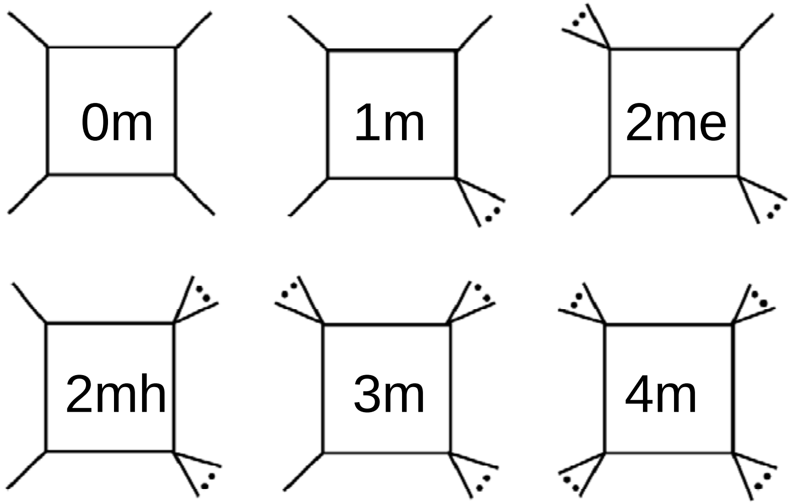
. Duhr, S. Höche and F. Maltoni, hep-ph/0607057.

BCF twice as fast using closed-form NMHV expression (LD)

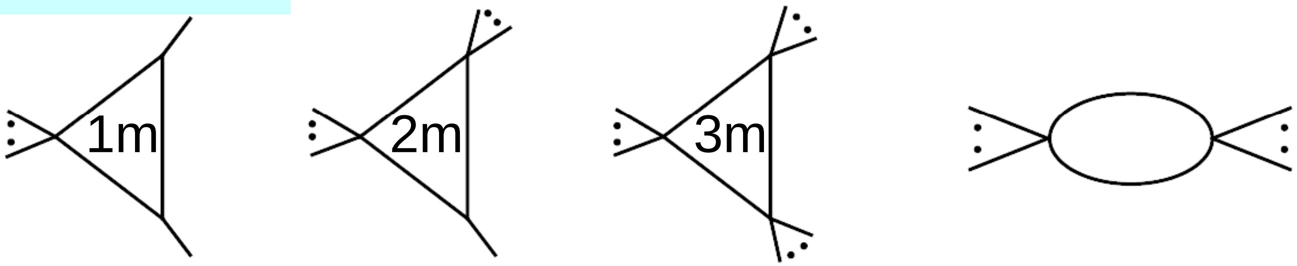
One-loop via unitarity-based methods: Rely on a general decomposition of 1-loop amplitudes

Bern, LD, Dunbar, Kosower (1994)

Boxes



Triangles & bubbles



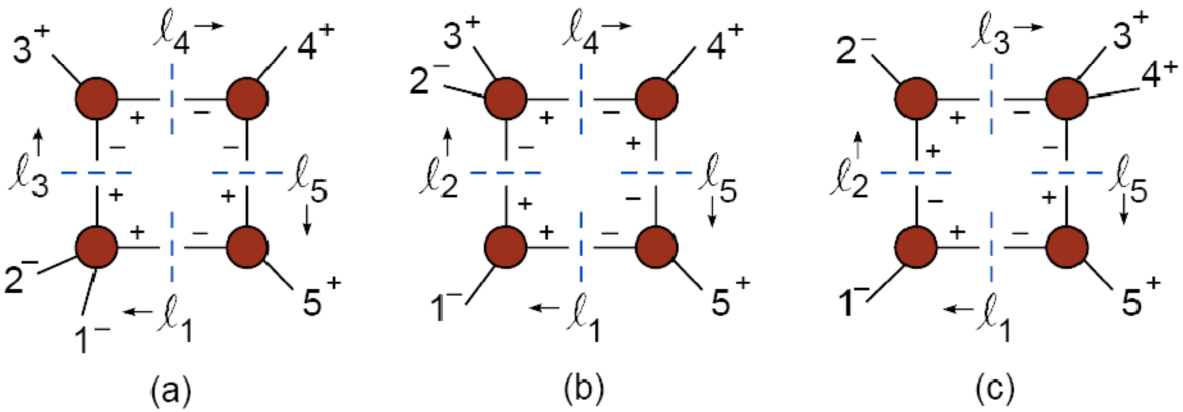
"Just" need to work out the coefficients of each integral

(Generalized) unitarity can be used to determine coefficients of integrals

- Boxes determined by quadruple cuts.
- Four constraints determine all four components of loop momenta

→ coefficients obtained by simple substitution

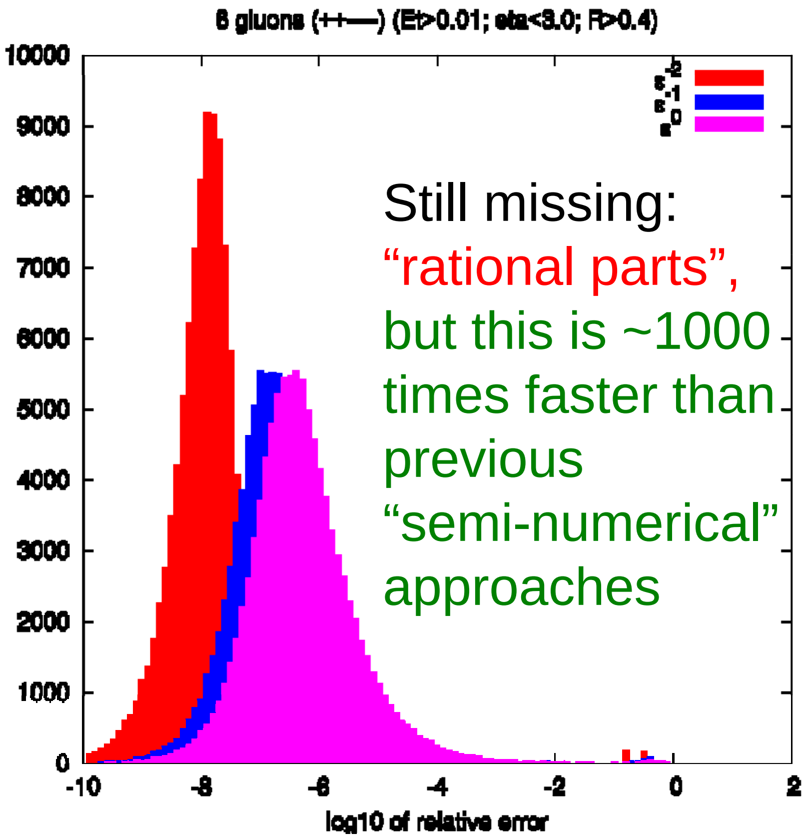
Britto, Cachazo, Feng, hep-ph/0412103



Numerical Implementation of These Methods – Comparison: 6 gluons

Ellis, Giele, Kunszt

- Time: 107 secs/10,000 events



Still missing: "rational parts", but this is ~1000 times faster than previous "semi-numerical" approaches

- All other PT-helicity combinations identical results. (3+,3-) helicity amplitudes checked for singular contributions
- 3.0* slower as 5 gluons
- 11.0*slower as 4 gluons
- Increase in computer time is determined by growth of the number of coefficients.
- This is still development code with lots of internal checks, the final code will be faster
- On the other hand the (D-4)-part inclusion will double the cpu time

Rational Parts

- Unitarity cuts are simplest to evaluate in four dimensions, because of many simplifications from helicity basis for intermediate states.
- However, in this case rational parts are missed.
- Three basic ways proposed to recover rational parts:
  - Feynman diagrams (many don't contribute)

    Xiao, Yang, Zhu, hep-ph/0607017; Binoth, Guillet, Heinrich, hep-ph/0609054
  - Unitarity in $D = 4\text{-}2\varepsilon$ Bern, Morgan, hep-ph/9511336;

    Bern, LD, Kosower, hep-ph/9602280;
    Bern, LD, Dunbar, Kosower, hep-ph/9611127;
    Brandhuber, McNamara, Spence, Travaglini, hep-th/0506068;
    Anastasiou, Britto, Feng, Kunszt, Mastrolia, hep-ph/0609191, hep-ph/0612277;
    Britto, Feng, hep-ph/0612089
  - Recursive approach

    Bern, LD, Kosower, hep-th/0501240, hep-ph/0505055, hep-ph/0507005;
    Berger, Bern, LD, Forde, Kosower, hep-ph/0604195, hep-ph/0607014;
    Berger, Del Duca, LD, hep-ph/0608180 [*Hgggg*];
    Badger, Glover, Risager, arXiv:0704.3914 [hep-ph] [*Hgggg*];
- All three methods could use more development and/or automation

Fully numerical methods

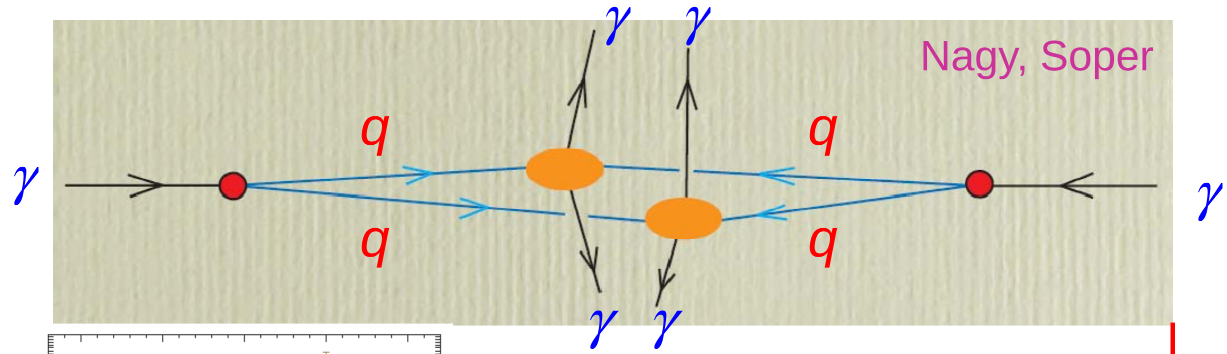
- It is possible to proceed **fully numerically**,
  e.g. 6-photon 1-loop amplitude, $\gamma\gamma \rightarrow \gamma\gamma\gamma\gamma$
  Nagy, Soper, hep-ph/0308127, hep-ph/0610028

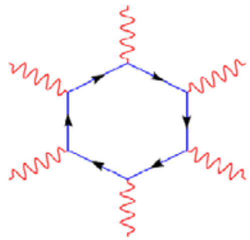
- and $pp \rightarrow ZZZ$ at NLO
  Lazopoulos, Melnikov, Petriello, hep-ph/0703273

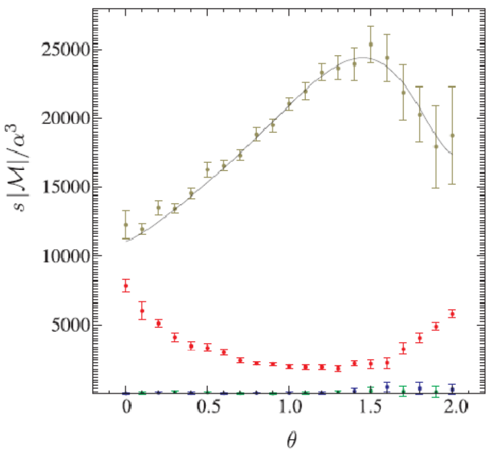
- Requires paying attention to the singularity structure of the one-loop integrand
- Important to see if this technique can be extended to cases with additional partons in the final state

Numerical stability
& “double parton scattering”

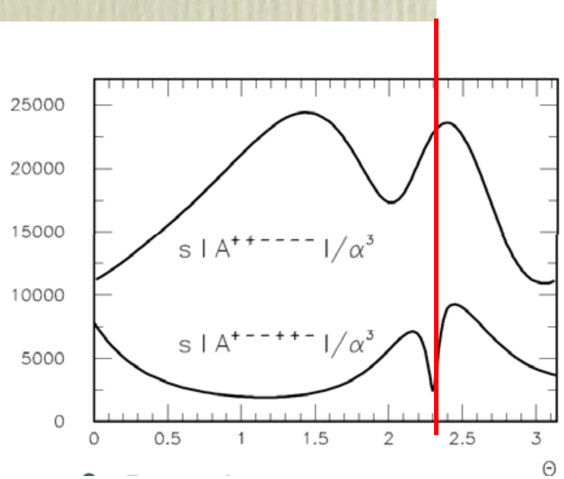
Beginning with 2 → 4 processes, like $\gamma\gamma \to \gamma\gamma\gamma\gamma$ or $gg \to \gamma\gamma\gamma\gamma$ through a quark loop. Physical singularity when $p_T(\gamma\gamma) \to 0$.







Nagy, Soper (numerical)



Binoth et al., (analytical)

Summary

- No Les Houches Accord this year, but Les Houches A'cold is almost universal

LES HOUCHES 2007

for more information see

http://lappweb.in2p3.fr/conferences/LesHouches/Houches2007/program07.html
(talks at beginning & end of sessions)

and

http://www.lpthe.jussieu.fr/LesHouches07Wiki/index.php/Preliminary_Programme

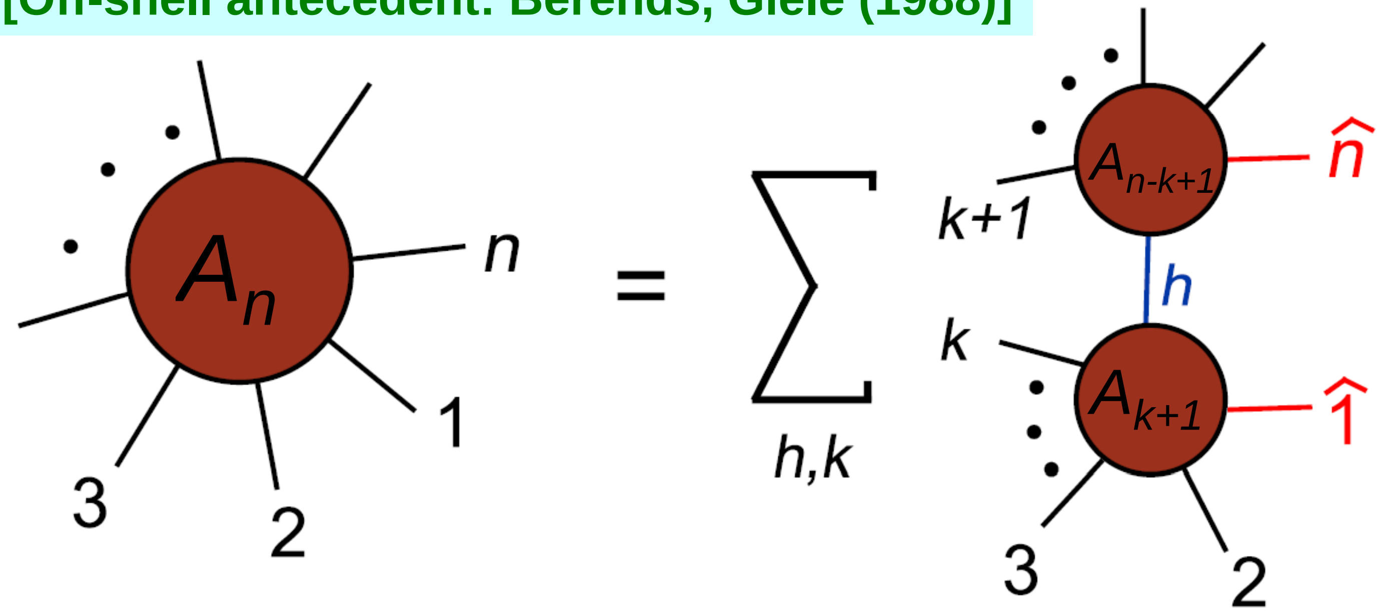
(wiki page with activities & talks during sessions; use "history" to get to Session I)

Extra slides

Tree-level on-shell recursion relations

Britto, Cachazo, Feng, hep-th/0412308

[Off-shell antecedent: Berends, Giele (1988)]



A_{k+1} and A_{n-k+1} are on-shell tree amplitudes with fewer legs, evaluated with momenta shifted by a **complex** amount

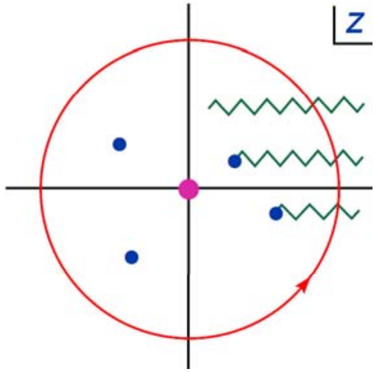
Trees are recycled into trees!

Loop amplitudes with cuts

Generic analytic properties of shifted 1-loop amplitude, $A_n(z)$

Cuts and poles in z-plane:

$$\ln(s_{23}) \Rightarrow \ln[(\langle 2\,3\rangle + z\langle 1\,3\rangle)[3\,2]]$$



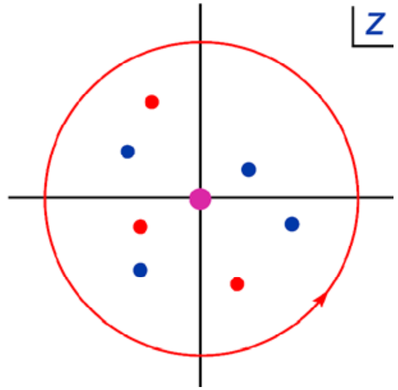
But if we know the cuts (*via* unitarity in D=4), we can subtract them: $R_n \equiv A_n - C_n$

rational part → R_n; full amplitude → A_n; cut-containing part → C_n

Shifted rational function $R_n(z) = A_n(z) - C_n(z)$

has no cuts, but has spurious poles in z because of C_n:

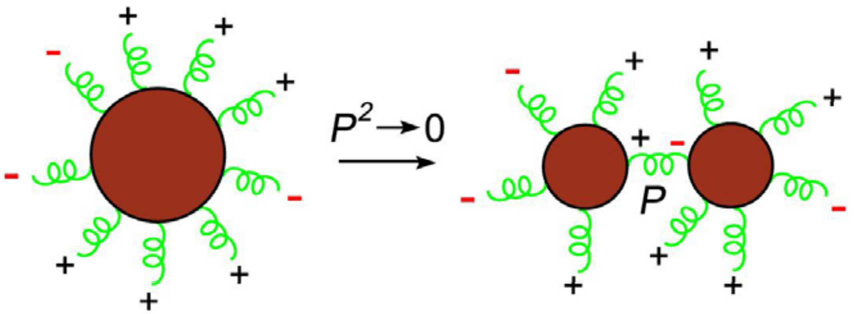
$$C_n \rightarrow \frac{\ln(r) + 1 - r}{(1-r)^2} \leftarrow R_n$$



Revenge of the Analytic *S*-matrix

Reconstruct scattering amplitudes **directly** from **analytic properties**

- Poles



- Branch cuts