Report from the TeV4LHC Workshop

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HERA and the LHC Workshop

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Workshop Goals / Organization

- bring together the Tevatron and LHC experimental groups and the theoretical community
  to make best possible use of data and experience from the Tevatron
  in preparing for the LHC experimental program
- includes understanding how to use Tevatron data to improve event modeling
  and theoretical understanding of cross sections for the signals and backgrounds at LHC
  also how to use experience with real problems at the Tevatron
  to best prepare for the challenges of doing analysis at the LHC

Four Meetings: (plus add. group meetings)

- Fermilab, 16-18 September, 2004
- Brookhaven National Lab., 3-5 February, 2005
- CERN, 28-30 April, 2005
- Fermilab, Fall, 2005

Four Working Groups:

- QCD
- Top and Electroweak
- Higgs
- Physics Landscape

http://conferences.fnal.gov/tev4lhc/

TeV4LHC $\Longleftrightarrow$ HERA and the LHC

many issues in common (see talks: theory, PDFs, Event Generators, ...)

different situation:
HERA and LHC physics is complementary
most significant: HERA has unique access to PDFs – fundamentally relevant!
all universal output: α_s(??!), PDFs, NP limits

huge overlap of Tevatron and LHC physics $\rightarrow$ similar: physics/challenges/(solutions?)

- **TeV4LHC:**
  how to use Tevatron experience for LHC
- **LHC4LHC:**
  theoretical developments for LHC / dedicated LHC studies
- **TeV4TeV** (and LHC4TeV)
  improving methods for the analysis of Run II data
  opportunity for discussions between experiment and theory / between CDF and DØ

TeV4LHC workshop still in progress – we had two out of four meetings
so far: not many results – but: identify the right questions

Working Groups and Topics (1)

QCD

- PDFs and Event Classification:
  - Extraction of PDFs purely at high-momentum transfers
  - Establishment of Jet Contracts between experiments and theorists
  - Subtleties and practicalities of jet algorithms
- Hard Scattering and Hadronization:
  - Testing of Matrix Element - Parton Showering matching
  - Underlying Event tunes and model development
  - Test of hadronization and tunes
  - Debate on universality of tunes

Top and Electroweak

- top production and decay
- analysis techniques
- Improved tagging strategies

huge overlap!!!

Working Groups and Topics (2)

Higgs

- Wh, Zh with $h \rightarrow bb$: can we use what we have learned at the Tevatron to make these modes more easily accessible at the LHC?
- **b-tagging: what have we learned at the Tevatron about tagging b's and rejecting charm and light-quarks and gluons?**
- bb invariant mass resolution: how can we use our experience at the Tevatron to improve this at the LHC?
- Associated production of Higgs and tt : can we use our experience with top at the Tevatron to optimize this at the LHC?
- **Associated production of SUSY Higgs and b's (at large tan beta):** what have we learned from the Tevatron searches that can be applied to the LHC?
- Vector-boson fusion: what have we learned about forward jets that can help us tag vector-boson-fusion processes at the LHC?
- Higgs decay to two photons: what have we learned about photons at the Tevatron that can help us at the LHC?
- Higgs decay to WW $\rightarrow$leptons: can the Tevatron search help us optimize this at the LHC?
- Higgs decay to tau's: what have we learned about taus at the Tevatron?
- Advanced analysis techniques - how can our experience at the Tevatron be used for Higgs at the LHC?
- **Theory: what calculations can we do to improve our predictions of signals and backgrounds at the Tevatron/LHC, as well as to improve our modeling?**
- Are there signals for standard model and non-standard Higgs that we have overlooked?

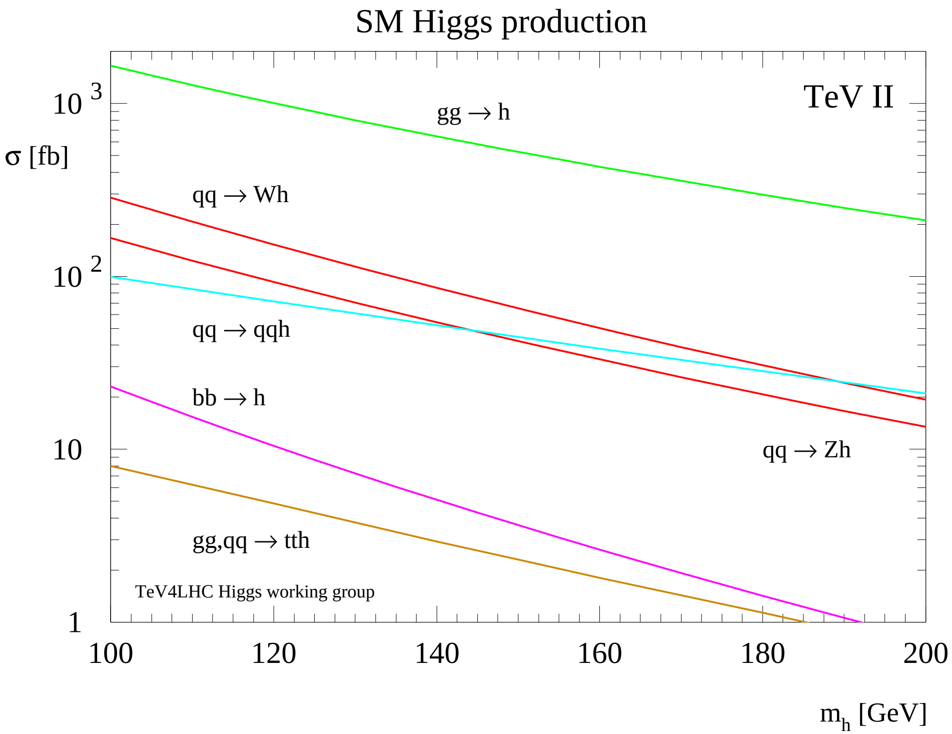
Working Groups and Topics (3)

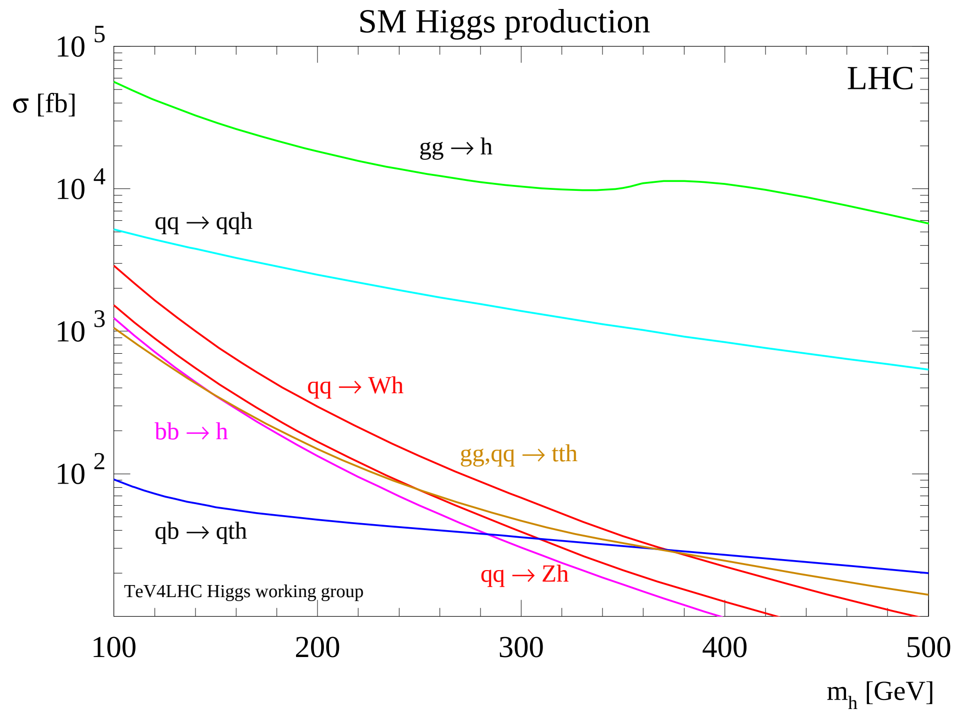
Physics Landscape

- How do the solutions to analysis problems for searches at the Tevatron generalize to the LHC?
  - are current Tevatron background techniques adequate for the LHC?
  - can new analysis ideas (NN, specialized jet reconstruction, energy flow) be employed at the LHC?
  - how about pure signature-based searches?
- How will measurements and searches at the Tevatron impact theoretical predictions for the LHC?
  - impact of searches for Z-primes and W-primes?
  - constraints from SUSY searches
  - impact of better measurements of Mtop and MW?
  - How are the Tevatron and the LHC complementary?

SM Higgs Cross Sections

collection of most recent theory predictions: (for details see WG webpage)





process	order in perturbative expansion	uncert.
gg → h + X: gluon fusion	NNLO pQCD + soft gluon resumm. @ NNLL	$\approx 10\%$
qq → qqh + X: vector boson fusion	NLO pQCD (MCFM)	$< 10\%$
qq → Wh + X, qq → Zh + X: W,Z assoc. production	NNLO pQCD and NLO EW	$< 5\%$
bb → h + X: bottom fusion	NNLO pQCD (5 flavor scheme)	
qq, gg → tth + X: t-tbar assoc. production	NLO pQCD	
qb → bth : single-top assoc. production	LO pQCD	

Higgs: Major Experimental Issues

ttH, H→bb	$80 < M_H < 120$	b-tagging, jet calibration
H→ $\gamma\gamma$ (+0,1,2 jets)	$100 < M_H < 150$	γ calibration, γ/jet separation
H→ZZ*, Z→4l	$120 < M_H < 180$	Lepton isolation, effi ciency
H→ τ, τ, τ →l,h (+1,2 jets)	$110 < M_H < 150$	$\tau\tau$ reconstruction VBF issues, Ptmiss
H→WW* W→ lν,qq (0,1,2 jets)	$110 < M_H < 180$	Lepton isolation VBF issues, Ptmiss
H→ZZ, Z→4l	$180 < M_H < 600$	Lepton isolation, effi ciency
H→ZZ, Z→ll	$500 < M_H < 1000$	Lepton isolation, Ptmiss, forward jets
H→WW* W→l,qq (+2 jets)	$180 < M_H < 1000$	Lepton isolation VBF issues, Ptmiss
H→ZZ, Z→ llqq (+2 jets)	$180 < M_H < 500$	Lepton isolation VBF issues

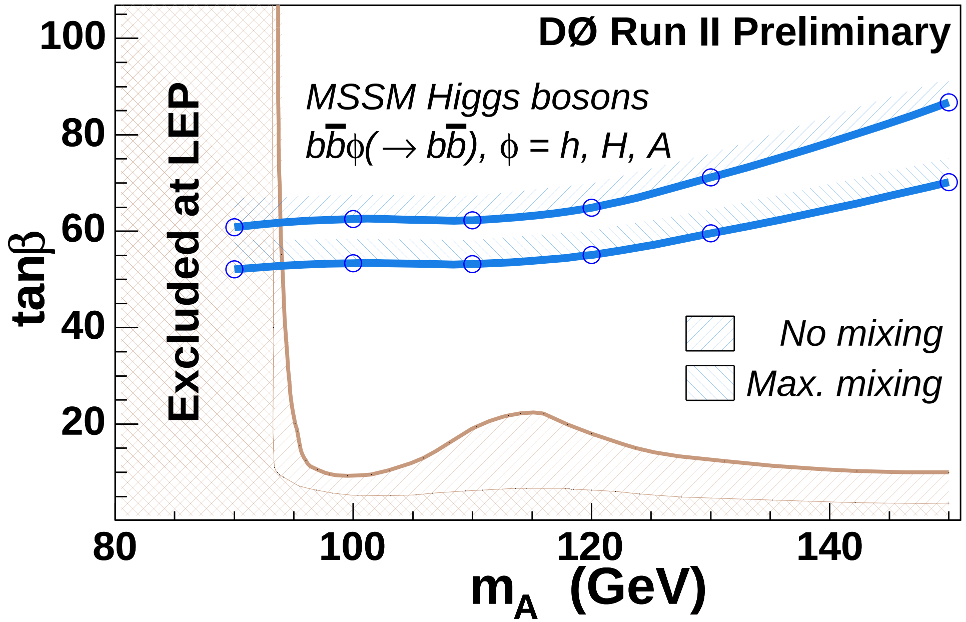
Tevatron will help understand faster experimental and theoretical issues at the LHC:

- Lepton ID, Jet Algorithm, missing E_T reconstruction, b-tagging, τ reconstruction, etc. ..
- Background studies:
  - better theoretical understanding of $\gamma\gamma$ continuum
  - W/Z production + jets, jet veto (Zeppenfeld plots) - Top production, tt+jet, flavor content of jet associated with tops
  - underlying event, pile up
- PDFs

current workshop projects – where Tevatron can add information:

MSSM scenarios where Higgs production is enhanced:

- production of neutral Higgs boson (in association with b quarks) DØ ⟶
- CP-violating Higgs



study experimental methods:

- add tracking information to jet reconstruction in calorimeter:
  use ATLAS method / so far: tested in Tevatron MCs / next step: test in DØ data

- test CMS b-tagging algorithm

TeV4LHC

Physics Landscape WG

many models of new physics at the TeV scale

despite various severe phenomenological and theoretical constraints:
testing all is challenging

Missing ET is undoubtedly one of the most powerful experimental tools at the LHC:

Unambiguous detection of MET 200-300 GeV essential for first discoveries at LHC

Missing E_T: SUSY & Extra Dim.

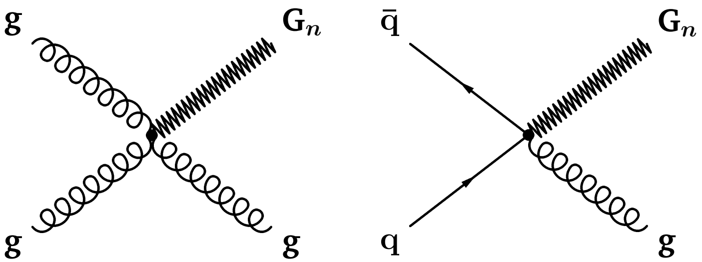
Search for SUSY

$p\bar{p}$ collider: strong production of Squarks/Gluinos ($\rightarrow$ large cross section)
$\tilde{q}\tilde{q} \rightarrow q\tilde{\chi}_1^0 q\tilde{\chi}_1^0$ (Neutralino LSPs escape detection $\Rightarrow$ 2 jets + miss. E_T)

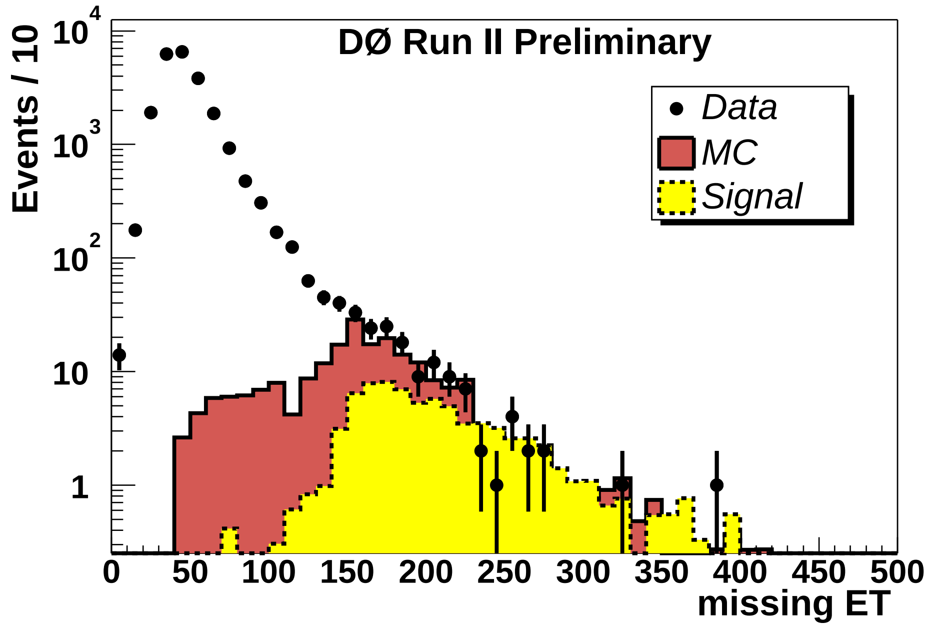
Search for large extra dimensions:

gravitons produced recoiling against q/g
- small gravitational coupling

but: large No. of kinematically accessible states



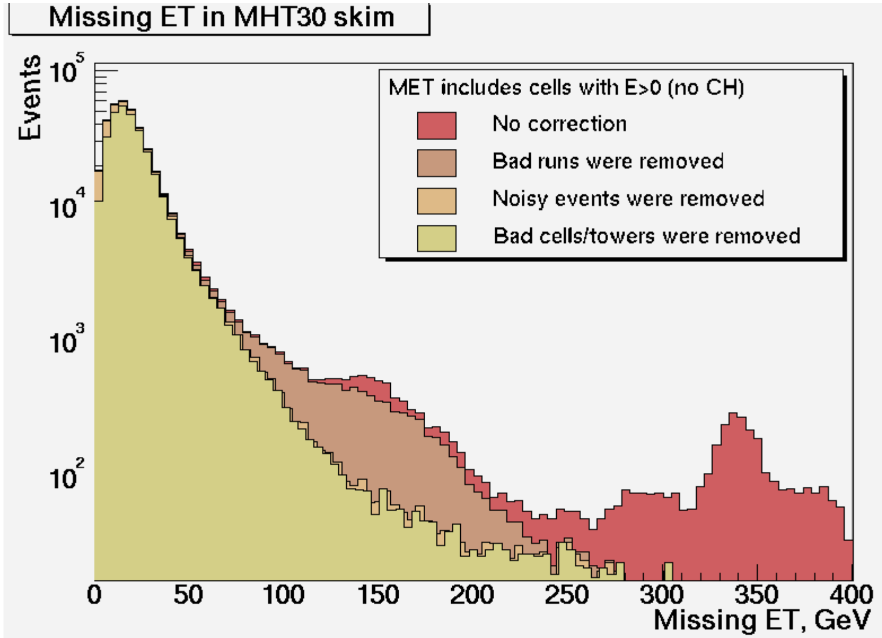
gravitons escape $\rightarrow$ search for monojets



typical analysis cuts:
- miss. E_T and jet $p_T > 150$ GeV (monojets) / miss. $E_T > 175$ GeV, $\sum_{\text{jets}} p_{T,i} > 275$ GeV

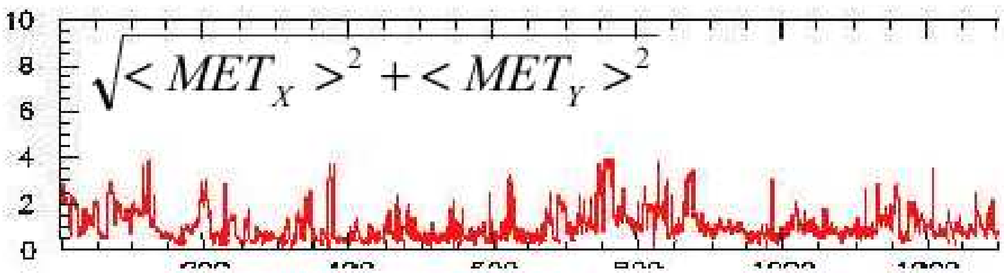
Missing E_T – Calorimeter Noise

A trigger on missing E_T provides an excellent test sample for data quality control



use mean missing E_T (mean and width)

for data quality monitoring:
- online: run-by-run
- offline: for each 1-minute block
  to detect intermittent problems



Large Variety of (rare) problems detected by monitoring tools and physics analysis:
- hot cells
- external noise
- gain variations (hardware failures)

Parton Density Functions

Standard Candle:
$\sigma(W)$ and $\sigma(Z)$:
precision predictions
and measurements at
Tevatron Run II and LHC

Uncertainties in Predictions:

LHC	$\boldsymbol{\sigma}_{\text{NLO}}(\boldsymbol{W})$ **(nb)**	error definition
CTEQ6	205 ± 8 (expt)	$\Delta\chi^2 = 100$
MRST2002	204 ± 4 (expt)	$\Delta\chi^2 = 50$
Alekhin02	215 ± 6 (tot)	$\Delta\chi^2 = 1$!!!

- uncertainties:
  - CTEQ/MRST consistent (different error definitions!)
  - only Alekhin uses statistically correct definition $\Delta\chi^2 = 1$ ... and gets similar error!
  - ➤ Why do different error definitions give same error?

- predictions:
  - Alekhin predictions are significantly different
  - ➤ reason: only using structure function data?? — missing some input?
  - ➤ but PDFs supposed to be universal ... (should agree within uncertainties)

personal opinion: still unresolved issues in PDF fits – current uncertainties not realistic

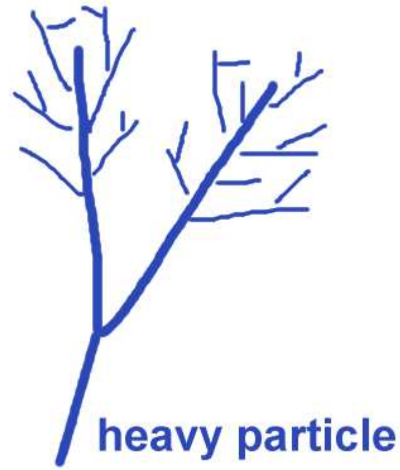
Jet Algorithms (= Jet Definitions)

used for very different purposes:

jets ... to reconstruct underlying "truth"

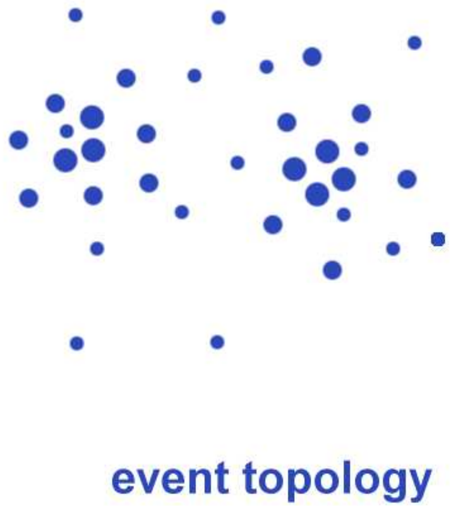
heavy particle decaying into jets:
reconstruct dijet mass (= particle mass)

⇒ jet definition / resolution parameter:
optimize mass resolution for physics environment
⇒ jets are **a tool**



jets ... to classify event topologies

measure production rates of certain topologies:
- inclusive jet-, dijet-, three-jet cross sections
and compare with (low-order) pQCD
⇒ jet definition / resolution parameter:
- minimize non-perturbative physics
⇒ jets are **the observable**



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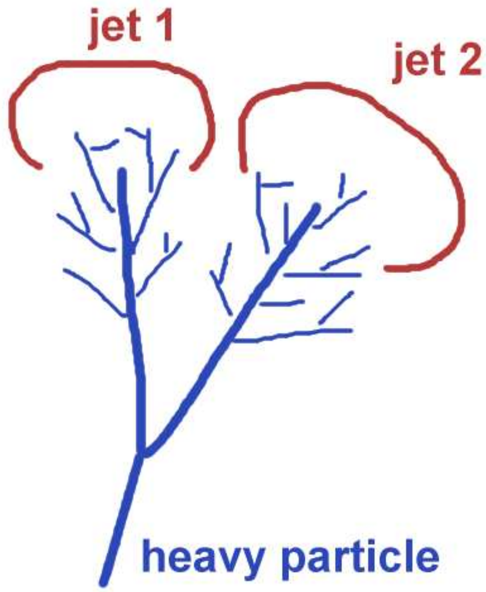

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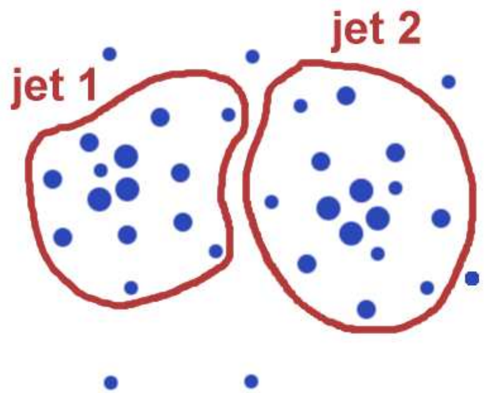


event topology

TeV4LHC

Jet Algorithms

criteria to choose a jet algorithm:

- theoretical and experimental considerations:
- infrared/collinear safety
- close correspondence: partonic final state $\leftrightarrow$ particle final state $\leftrightarrow$ detector

Tevatron Run I: jet algorithms were not infrared safe
- Tevatron Run II $\longrightarrow$ improved jet algorithms
- iterative midpoint cone algorithm / k_T algorithm (successive recombination)

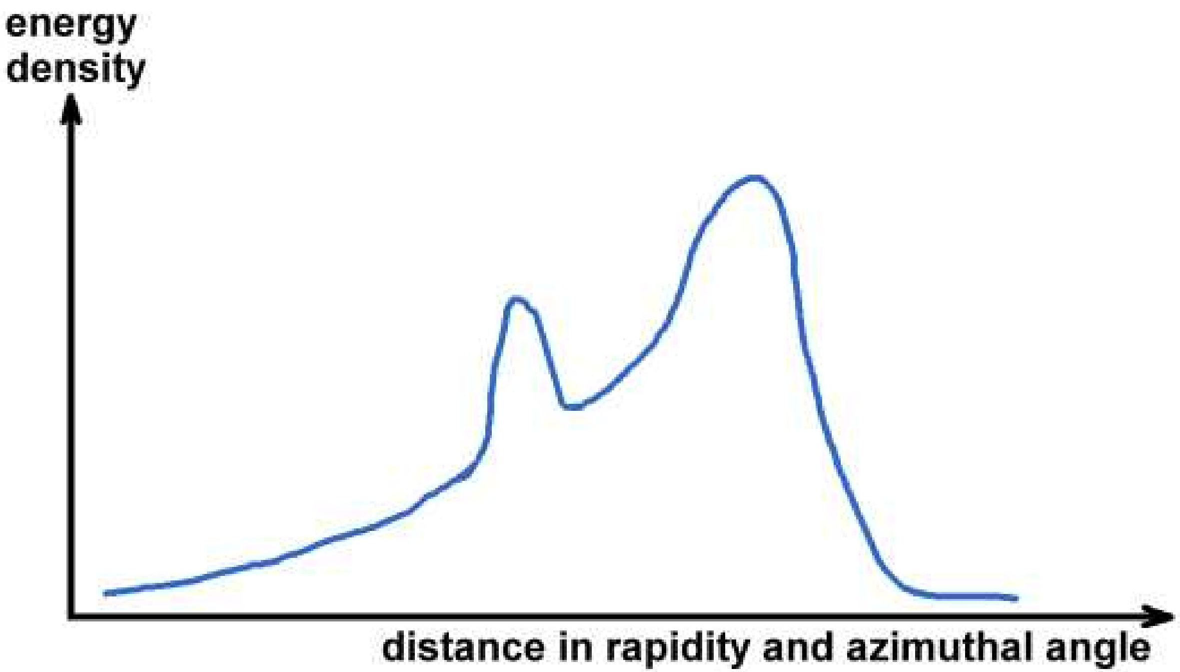
$\Rightarrow$ different criteria for different purposes?

better variables:

Run I: E_T scheme: $E_{T\,\text{jet}} = \sum_i E_{T\,i}$ $\quad M_\text{jet} = 0$
defined quantity! – not a real property of the event! – possible: $E_{T\,\text{jet}} > \sqrt{s}/2$

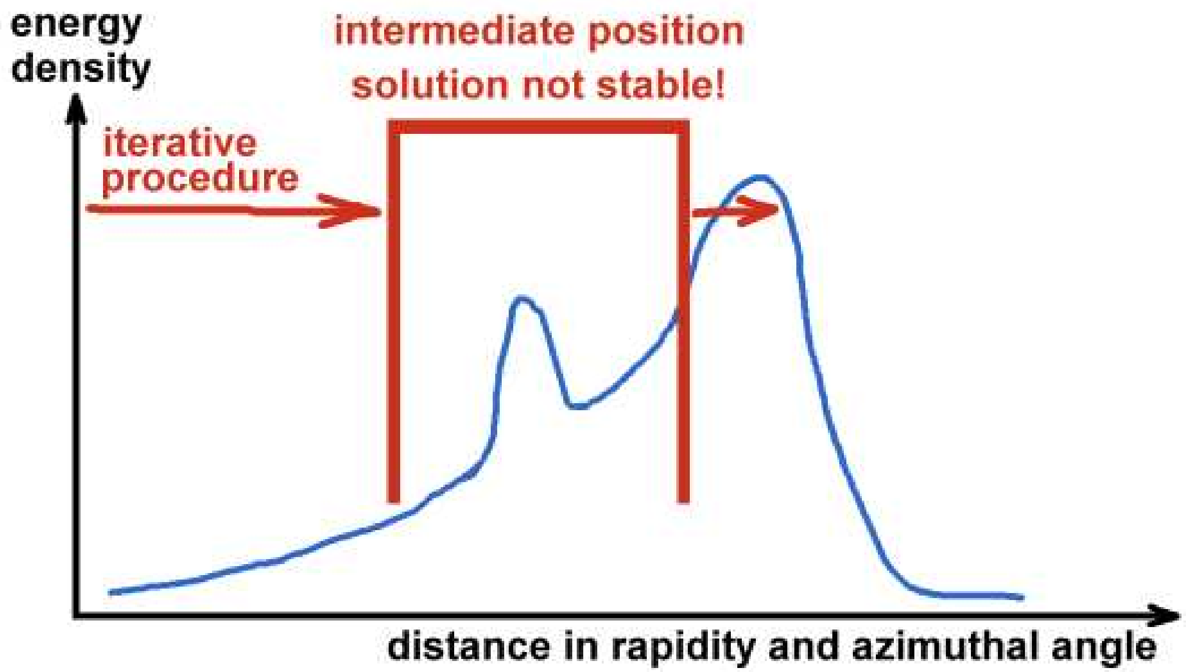
Run II: E-scheme: $p_\text{jet} = \sum_i p_i$ true inv. jet-mass, true jet energy/momentum
kinematic limit: $p_{T\,\text{jet}} < \sqrt{s}/2$ $\Rightarrow$ resummation at phase space boundaries

Feature of Cone Algorithm



energy density in an event

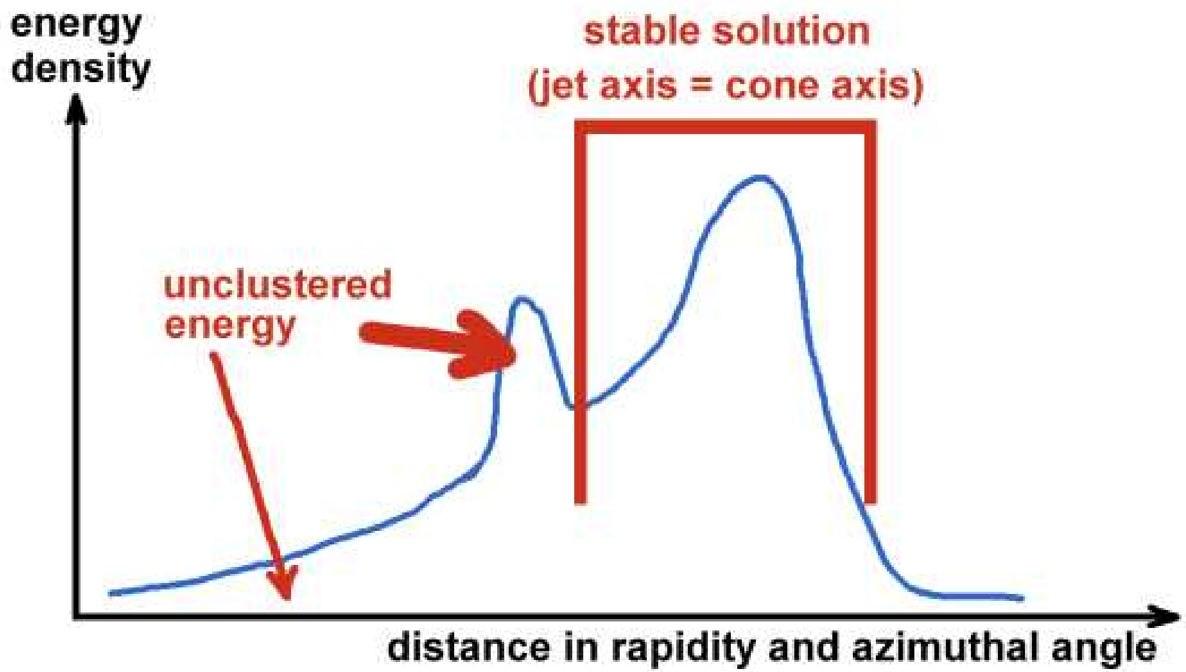
Feature of Cone Algorithm



energy density in an event

iterative cone algo ...

Feature of Cone Algorithm



energy density in an event

iterative cone algo ...
finds maximum

but no stable solution
for 2_{nd} local maximum

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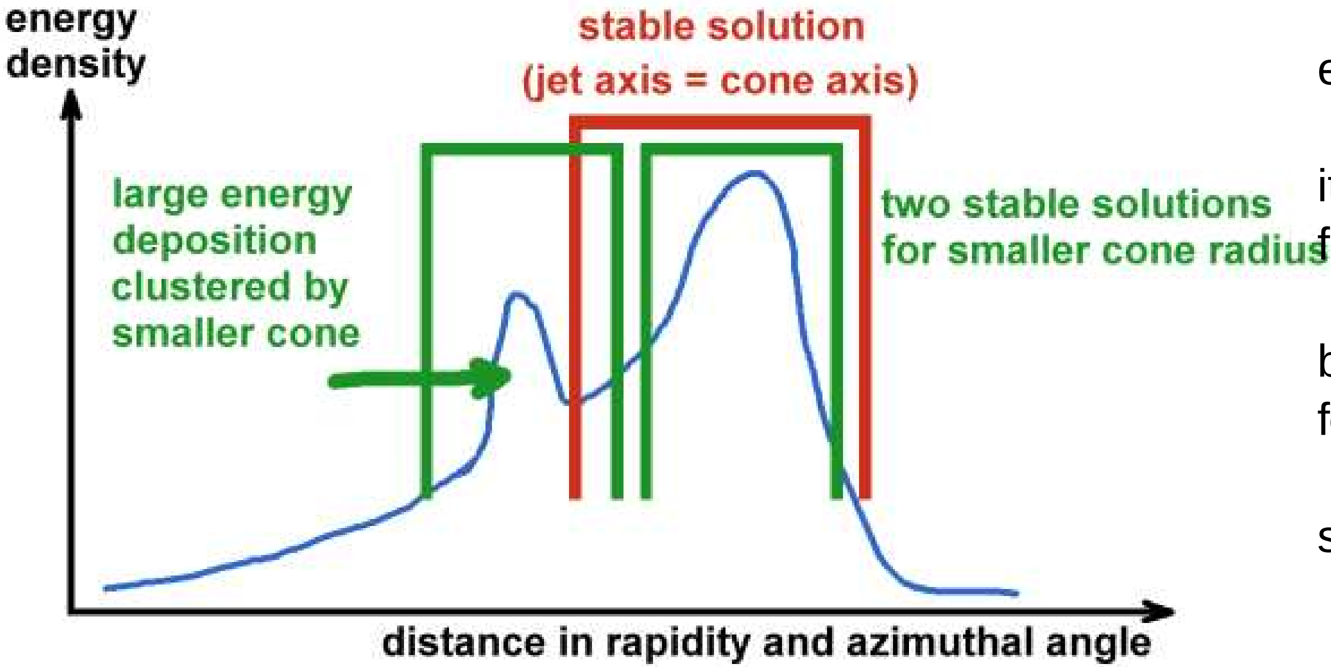

energy density in an event

iterative cone algo ...
finds maximum

but no stable solution
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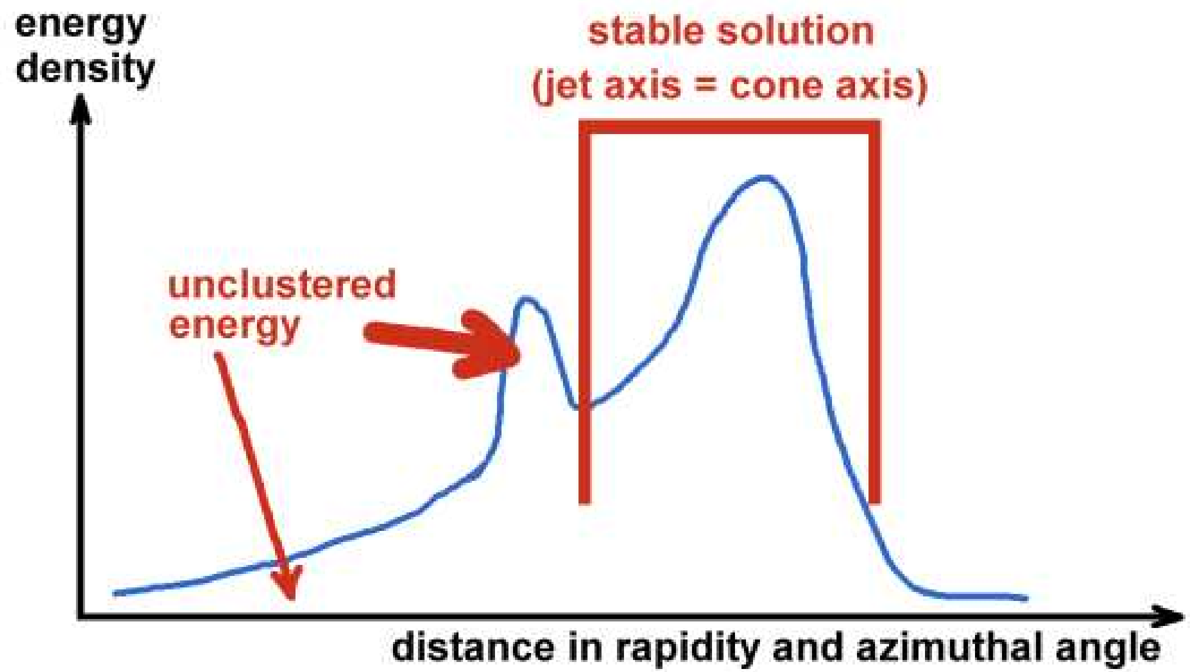
smaller cone finds both!

TeV4LHC

Feature of Cone Algorithm



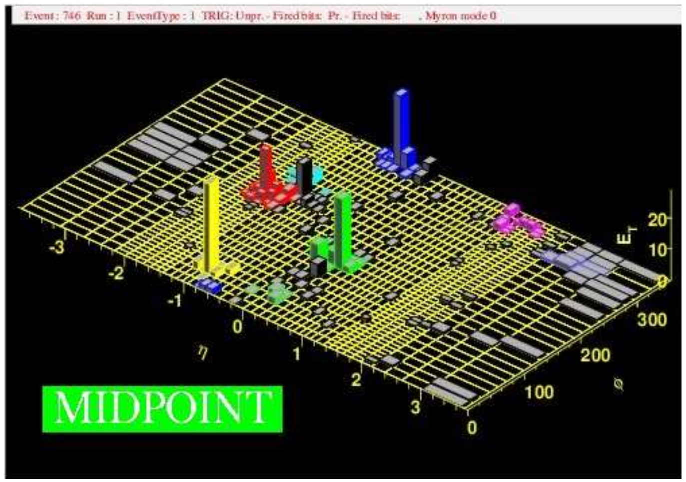
energy density in an event

iterative cone algo ...
finds maximum

but no stable solution
for 2_{nd} local maximum

CDF observes large unclustered E_T close to jets
$\longrightarrow$ introduce smaller "search cone" in iterative procedure
$\Rightarrow$ stable jet solutions can be closer

$\Rightarrow$ Overlap treatment may merge many nearby jets
$\Rightarrow$ results in merged jets with huge spacial extension



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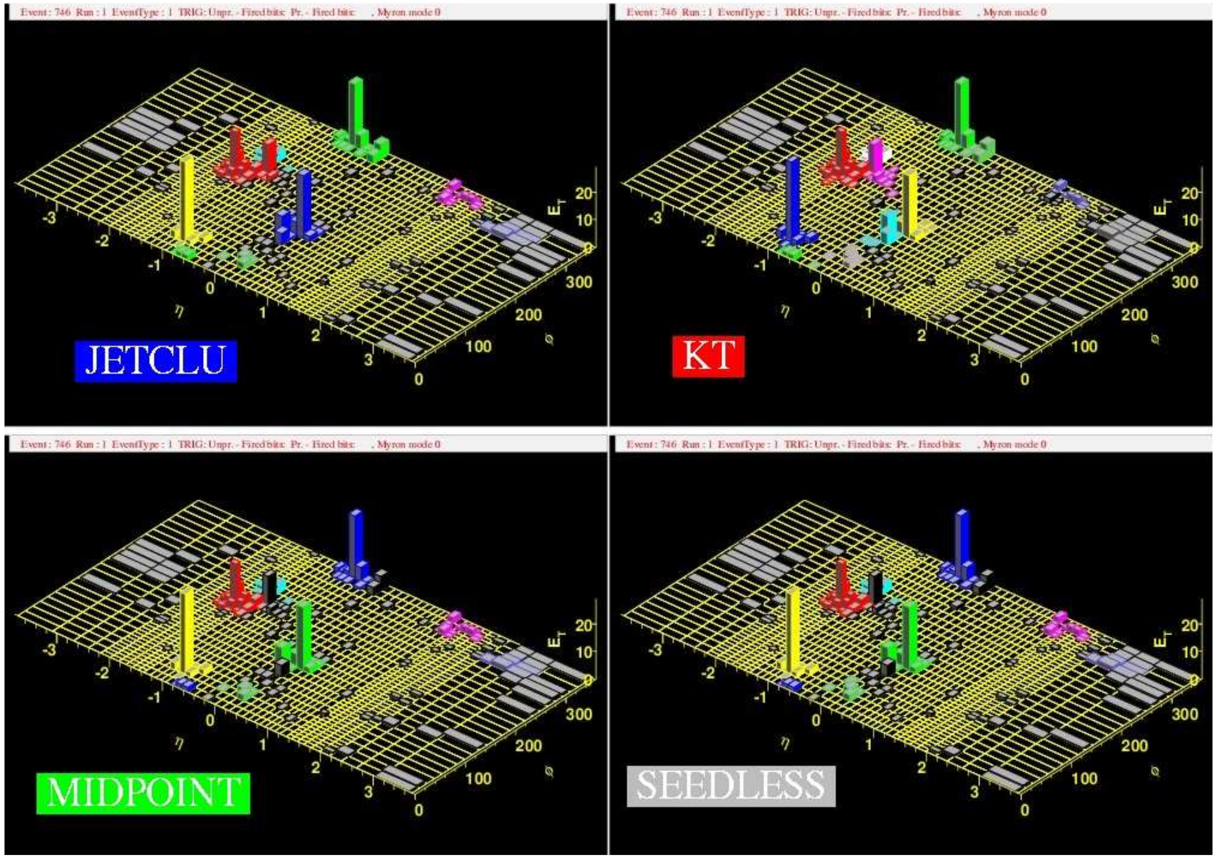

no unclustered E_T for k_T jets!

... and neither for Run I jets
(but these are not infrared safe!)

this feature is currently under discussion:

- ✓ no fundamental problem for QCD analyses — well-defined (and the same for theory)
- ✗ but a problem for particle reconstruction?? (decay products are not reconstructed)

Conclusions

- **TeV4LHC** workshop is now coming into the final phase
- transition: reviewing work → producing results
- next meeting: 28-30 April, 2005 at CERN
- great opportunity to reach more LHC experimenters
  more discussions TeV ↔ LHC
- LHC experiments can benefit a lot from the experience gained at the Tevatron
- on the other hand: also the Tevatron will benefit a lot from this exchange! – and for the next two years the energy frontier is still at the Tevatron!!

➤ join us http://conferences.fnal.gov/tev4lhc/