Boost 2011

Theory Summary

Michael H. Seymour
University of Manchester

May 26th 2011

Boost 2011 Theory Summary

- History
- Tools
- Observables
- Calculations
- Applications
- Summary/outlook

History

- Innovation = inspiration + perspiration !
- Butterworth, Davison, Rubin, Salam, Feb 2008, *Jet substructure as new Higgs search channel at the LHC*, Phys. Rev. Lett. 100 (2008) 242001
- Butterworth, Ellis, Raklev, Feb 2007, *Reconstructing sparticle mass spectra using hadronic decays*, JHEP 0705 (2007) 033
- Butterworth, Cox, Forshaw, Jan 2002, *WW scattering at the CERN LHC*, Phys. Rev. D65 (2002) 096014

Moriond 2000

History

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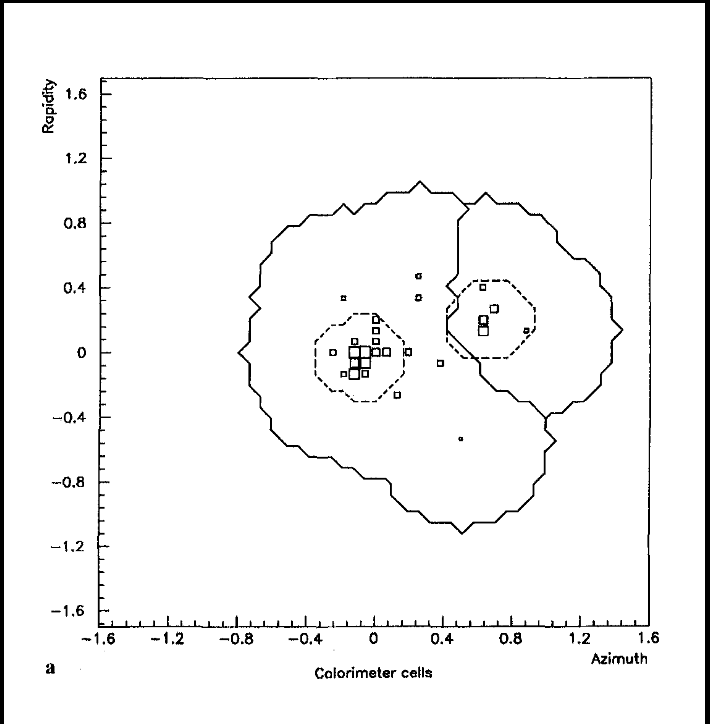

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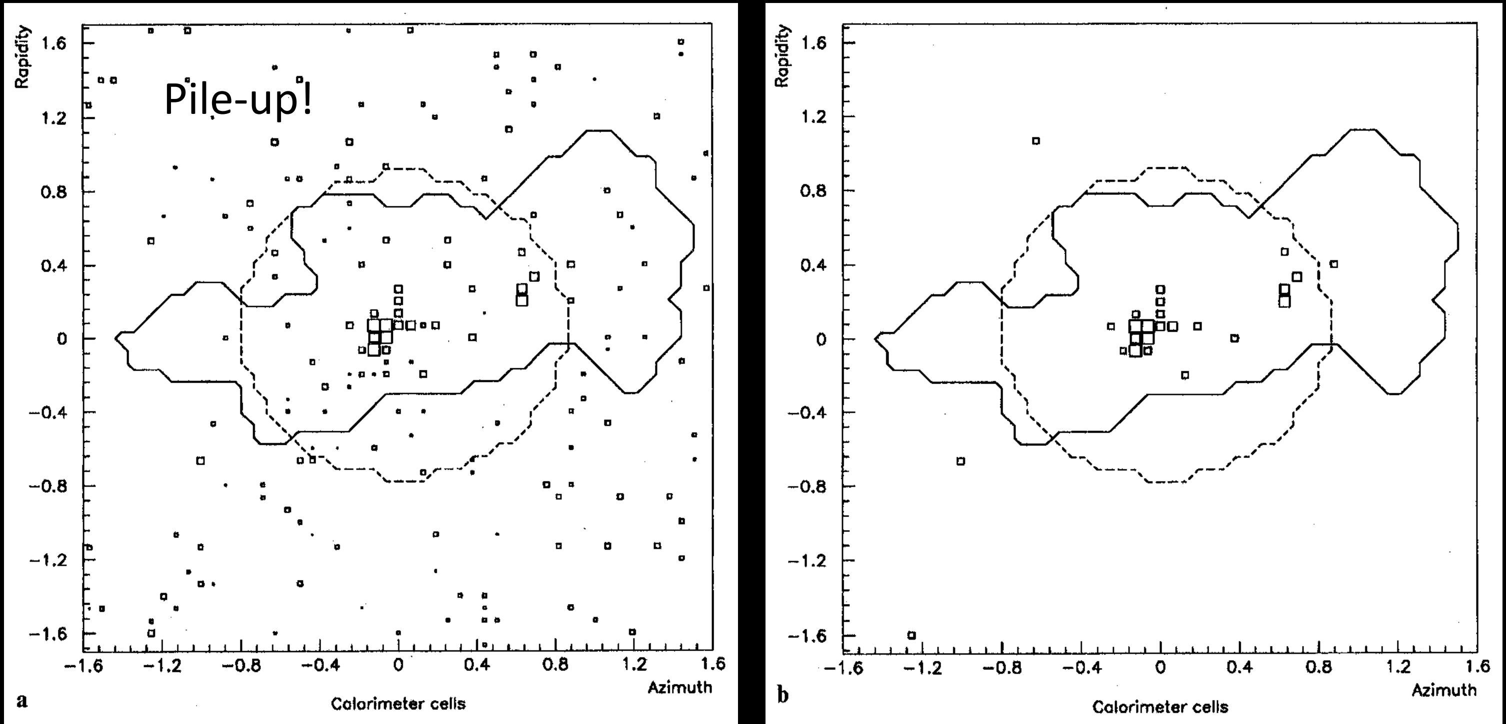
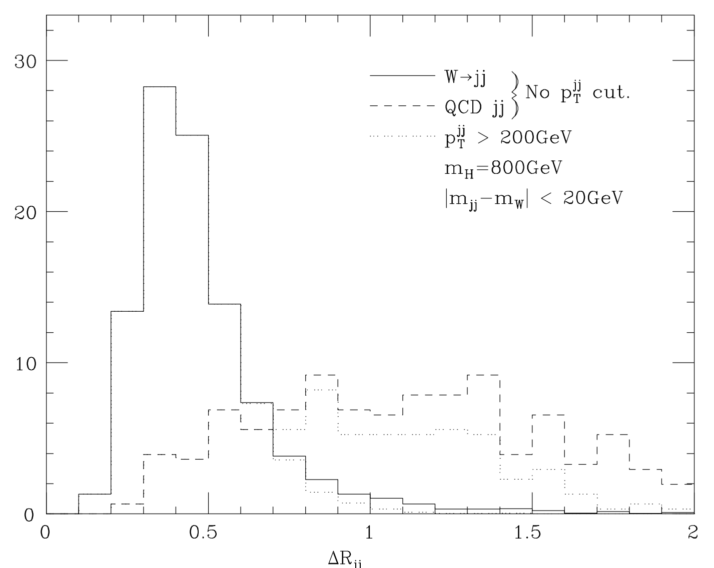

Pile-up!

History

- MHS, *Predictions for Higgs and Electroweak Boson Production*, Oct 1992, University of Cambridge PhD thesis
- *"Thus to search events for hadronic W decays we run a jet-finder twice, with a large cone size ΔR_1, and a smaller size ΔR_2."*



History

2) **Tagging a heavy Higgs boson.**
M.H. Seymour, (Cambridge U.) . CAVENDISH-HEP-90-25, Jan 1991. 16pp. Talk presented at the ECFA LHC Workshop, Aachen, Germany, Oct 4-9, 1990.
Published in Aachen ECFA Workshop 1990:0557-569 (QCD183:L25:1990:V.2)
References | LaTeX(US) | LaTeX(EU) | Harvmac | BibTeX | Keywords | Cited 1 time | More Info
CERN Library Record
Scanned Version (KEK Library)
Conference Info
Bookmarkable link to this information

"The W-finder used in this study utilises this cut by running a jet-finder twice, with cone sizes of ΔR=0.75 and ΔR=0.25, and then demands a big jet containing two small jets, with $|m_{jj}-m_W|$<10 GeV."

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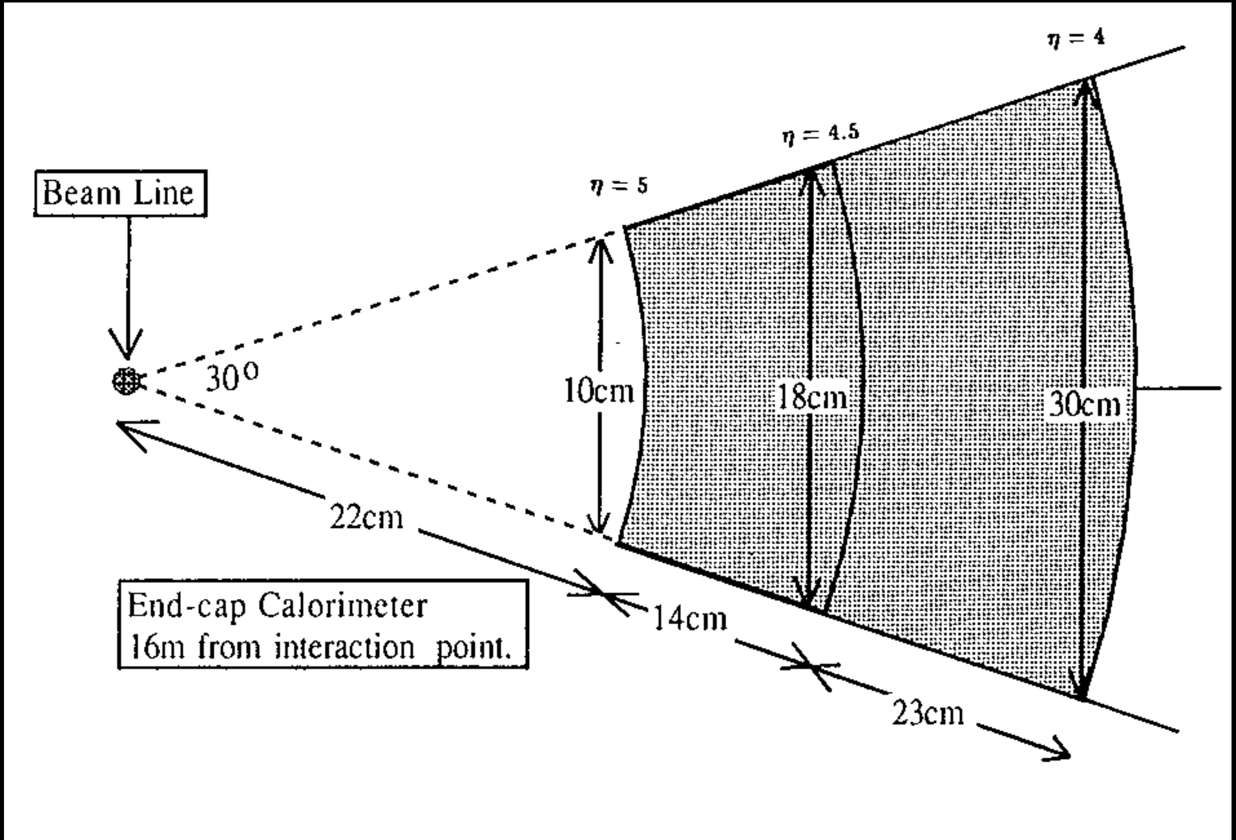
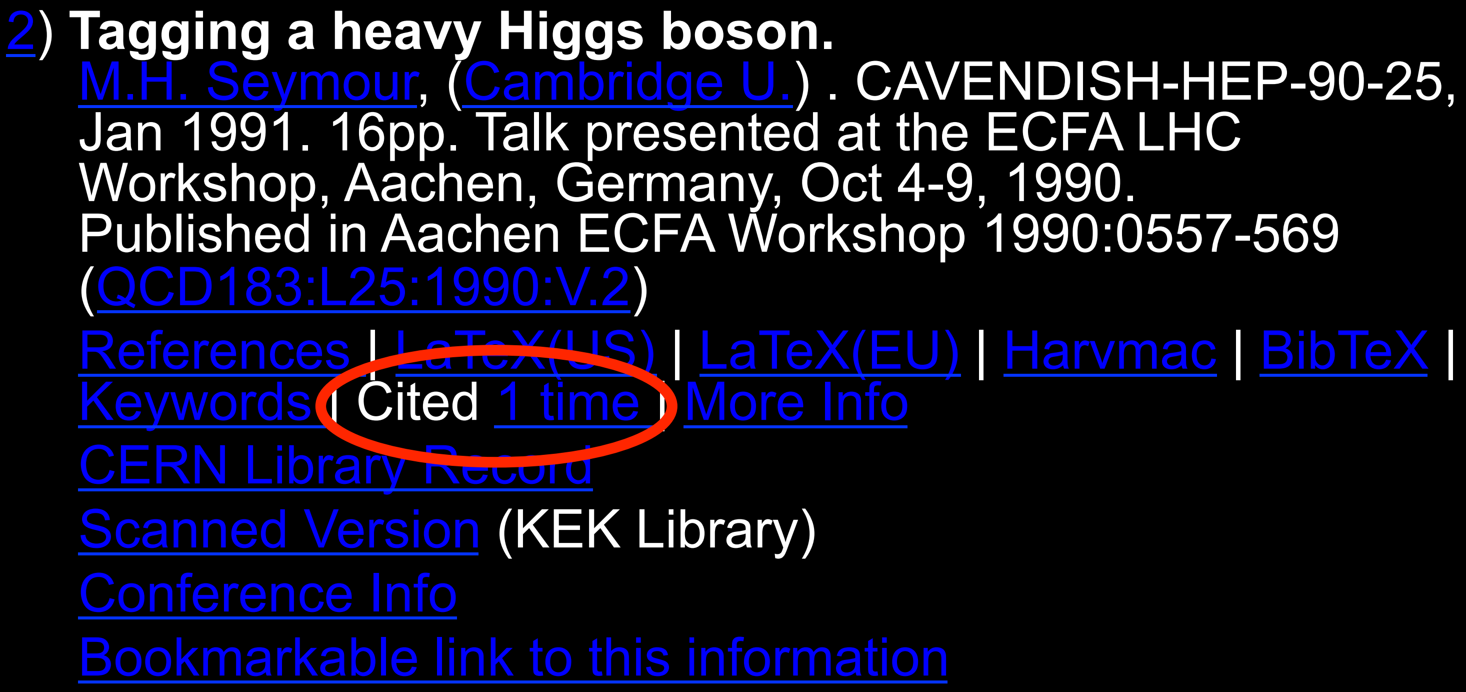


History



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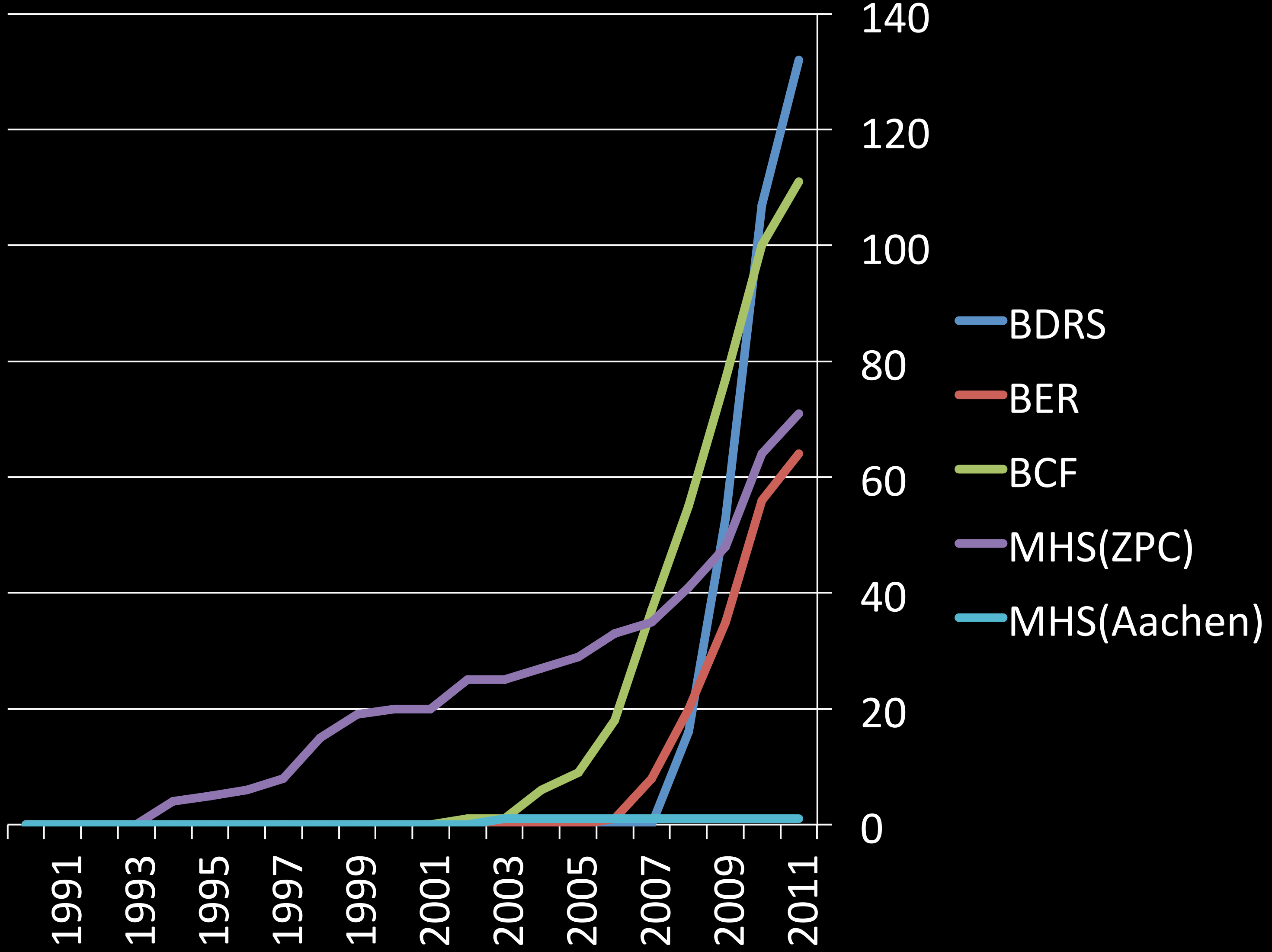
History

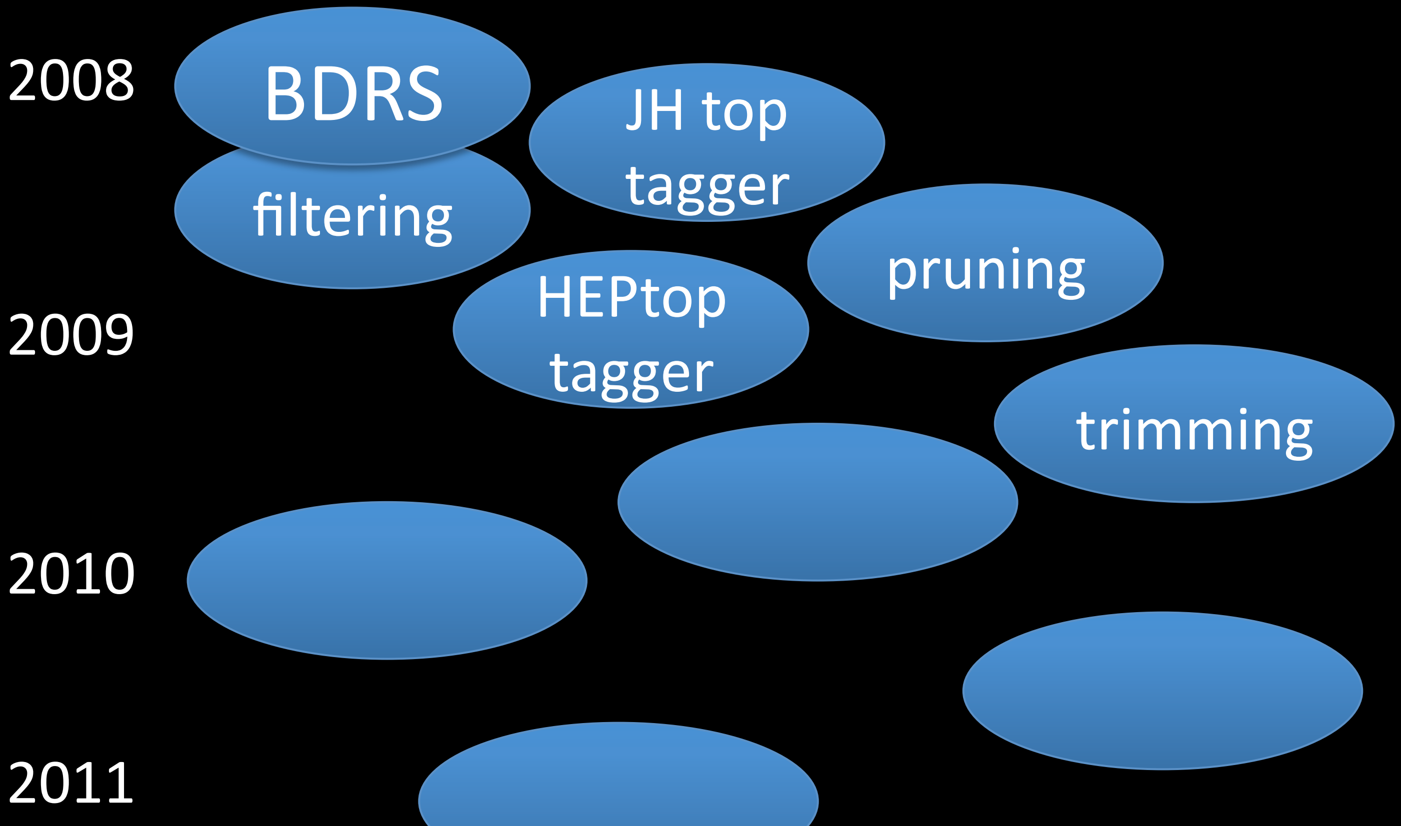
- Disclaimer: The next slide is for fun
  - I am really not a citation chaser!

Citations


140
120
100
80
60
40
20
0
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
BDRS
BER
BCF
MHS(ZPC)
MHS(Aachen)

History

- Seriously…
  - credit should go to those who see the importance of their idea, and do the work to make the case


2008

BDRS

JH top tagger

filtering

pruning

HEPtop tagger

2009

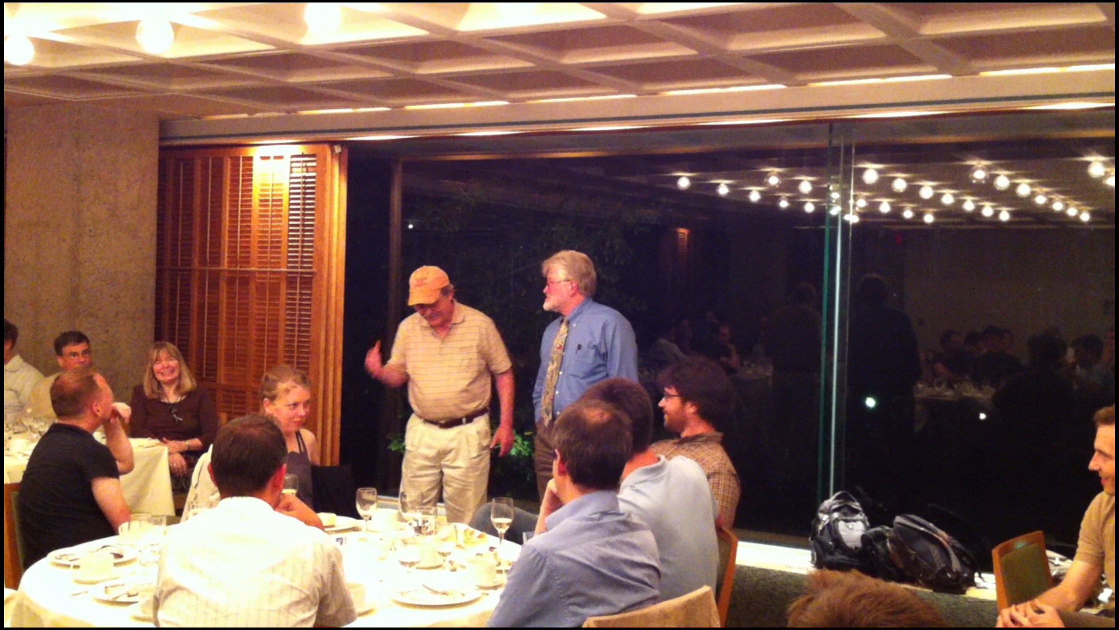
trimming

2010

2011

Boost 2011

- 44 talks over 4 days
  - 25 theory
  - 19 experiment
- Discussion sessions and report-backs
- and a double-act after-dinner speech!



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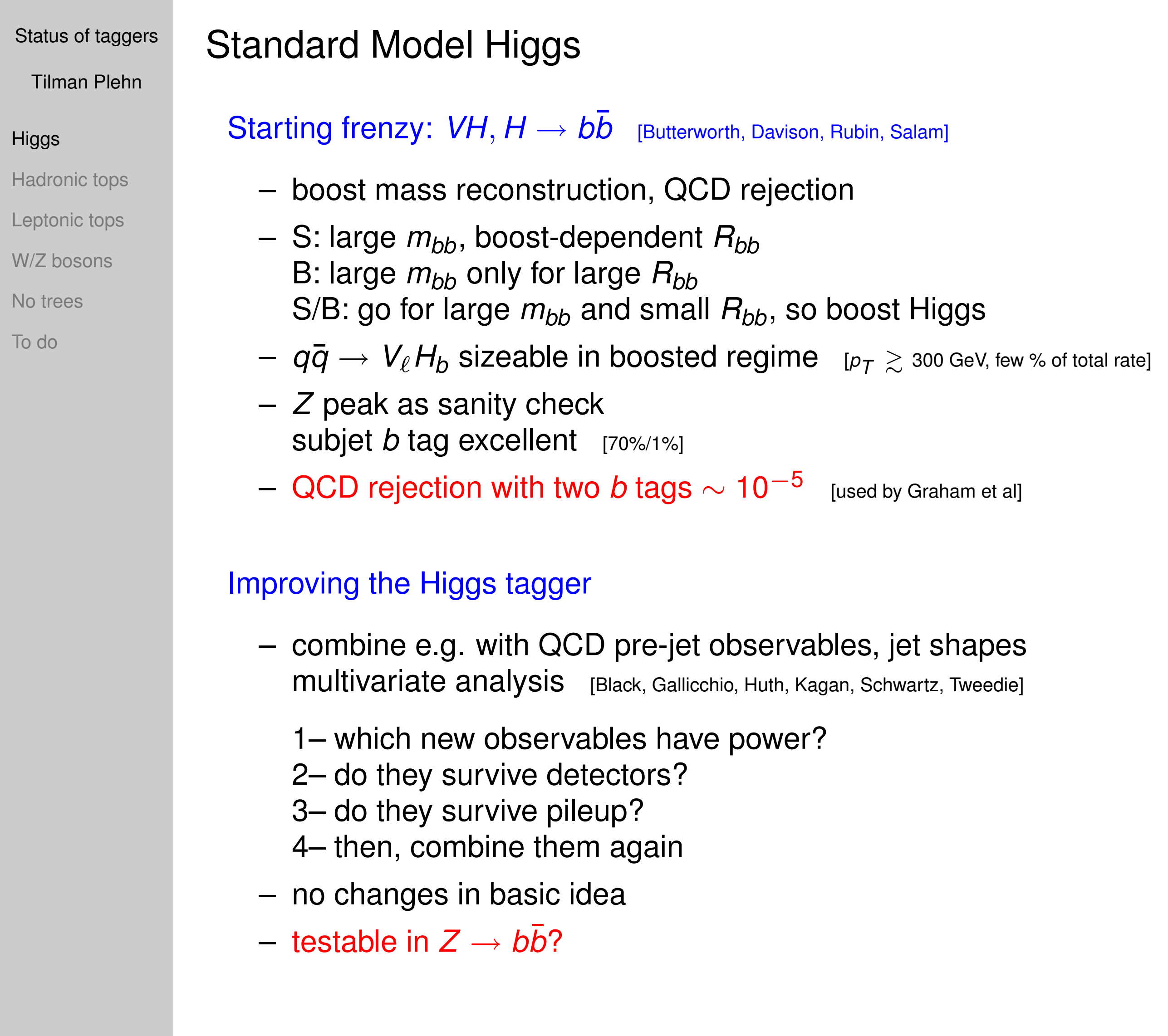
Tools

- PLEHN: Status of Higgs and Top taggers
- SALAM: Fastjet
- VERMILION: SpartyJet

Status of Higgs and top taggers



Standard Model Higgs

Starting frenzy: $VH, H \to b\bar{b}$ [Butterworth, Davison, Rubin, Salam]

- boost mass reconstruction, QCD rejection
- S: large m_{bb}, boost-dependent R_{bb}
  B: large m_{bb} only for large R_{bb}
  S/B: go for large m_{bb} and small R_{bb}, so boost Higgs
- $q\bar{q} \to V_\ell H_b$ sizeable in boosted regime [$p_T \gtrsim$ 300 GeV, few % of total rate]
- Z peak as sanity check
  subjet b tag excellent [70%/1%]
- QCD rejection with two b tags $\sim 10^{-5}$ [used by Graham et al]

Improving the Higgs tagger

- combine e.g. with QCD pre-jet observables, jet shapes
  multivariate analysis [Black, Gallicchio, Huth, Kagan, Schwartz, Tweedie]

  1– which new observables have power?
  2– do they survive detectors?
  3– do they survive pileup?
  4– then, combine them again
- no changes in basic idea
- testable in $Z \to b\bar{b}$?

Status of Higgs and top taggers

To do: jet algorithms and pileup

Filtering [BDRS, also used in HEPTopTagger]

- designed for C/A algorithm
- reduce effective fat-jet area
  zoom in on relevant final subjets
- number of jets and size negotiable

Pruning [Ellis, Vermillion, Walsh]

- designed for k_T algorithm
- extract relevant collinear splittings in splitting history
- soft/collinearity condition negotiable

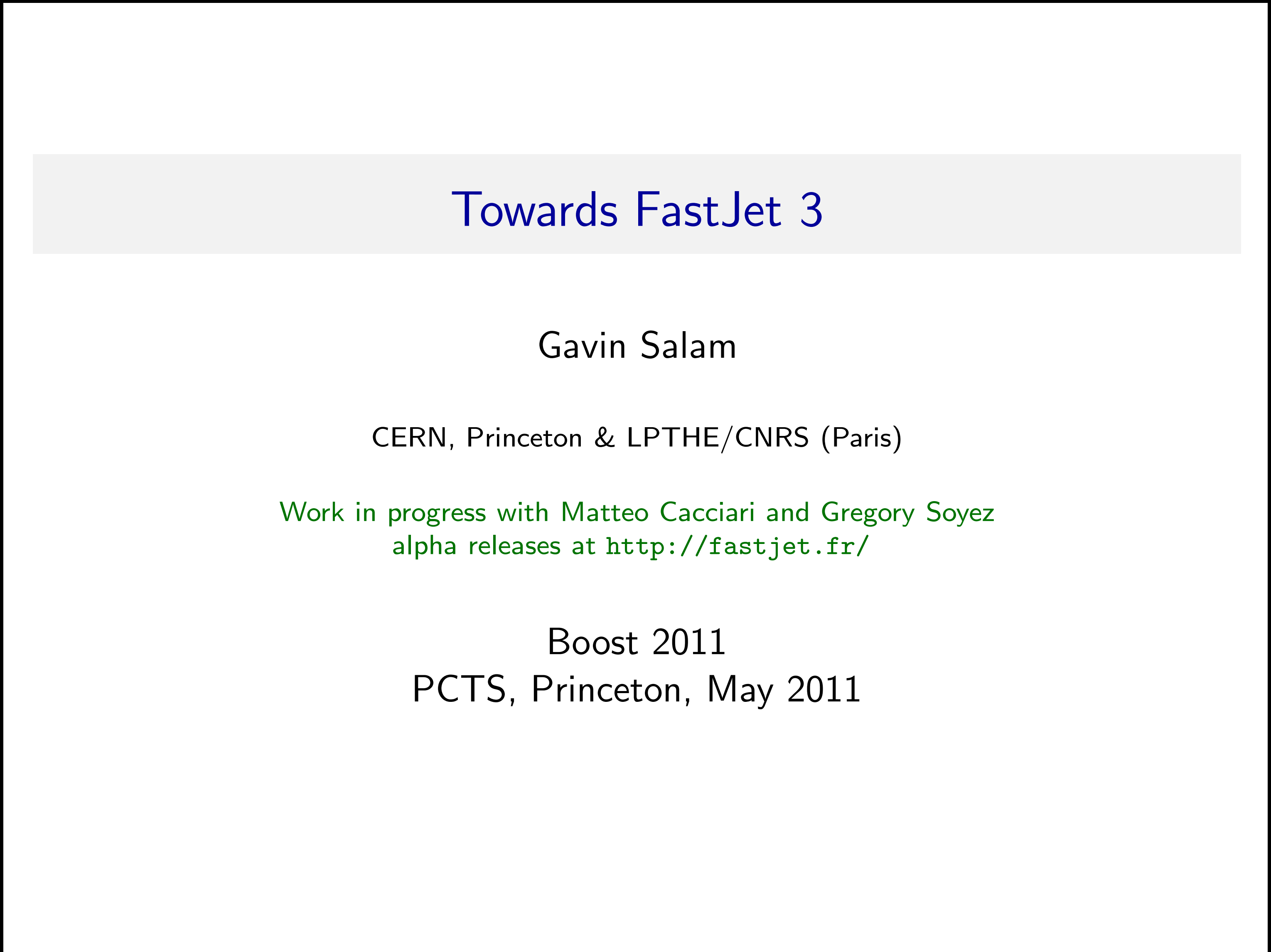
Trimming [Krohn, Thaler, Wang]

- designed for anti-k_T algorithm
- remove soft fat jet regions [inverse to filtering]
  slightly different interpretation for k_T algo

- filtering + pruning useful [Spannowsky & Soper]
- should we use more/less of the clustering history?
- and can we do this with pileup?

FastJet

Where would we be without FastJet???



Towards FastJet 3

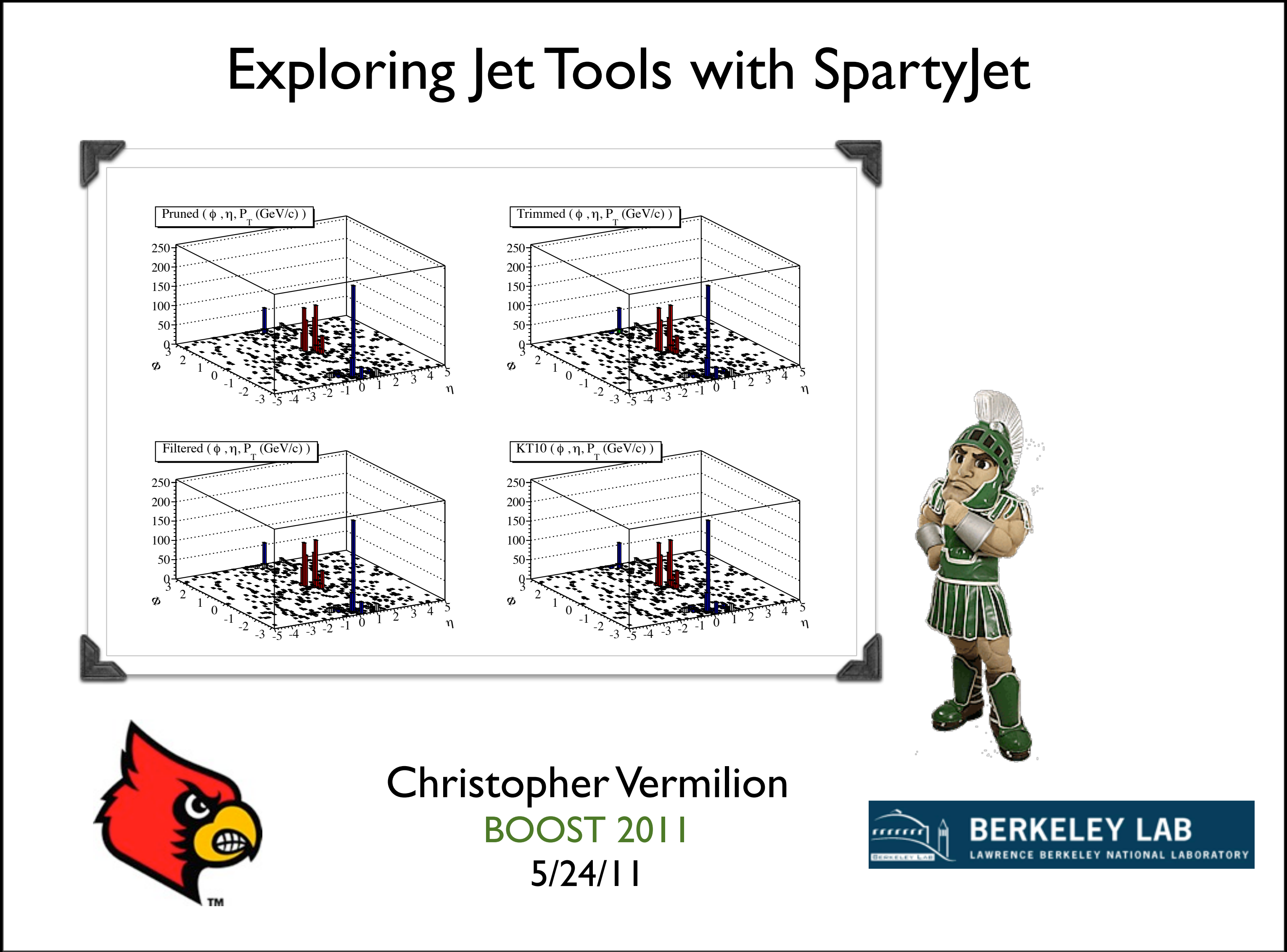
Gavin Salam

CERN, Princeton & LPTHE/CNRS (Paris)

Work in progress with Matteo Cacciari and Gregory Soyez
alpha releases at `http://fastjet.fr/`

Boost 2011
PCTS, Princeton, May 2011

SpartyJet



Exploring Jet Tools with SpartyJet

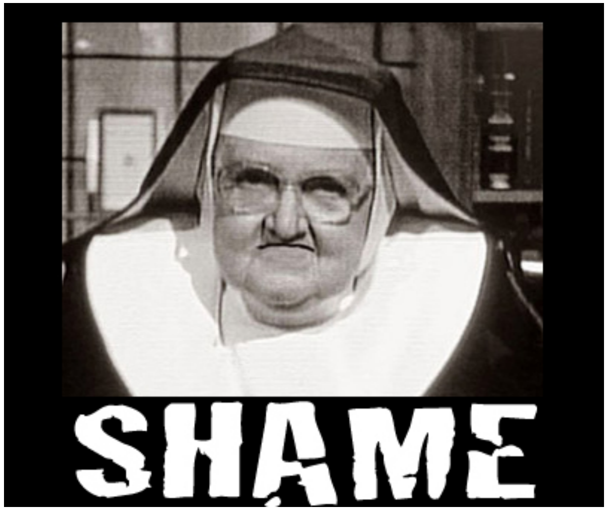
Christopher Vermilion
BOOST 2011
5/24/11

SpartyJet

SLIDE OF SHAME

An incomplete list of methods that do not, to my knowledge, have public, certified code

(I would be very happy to be corrected!!)



- [redacted]
- [redacted]
- [redacted]
- [redacted]”
- [redacted]
- [redacted]
- [redacted]
- Surely some I’ve missed...

If you build it, I will put it in SpartyJet!

FastJet vs SpartyJet

- Both are in danger of *mission creep*
- Serious danger of
  - duplication of effort?
  - confusion of roles and responsibilities?

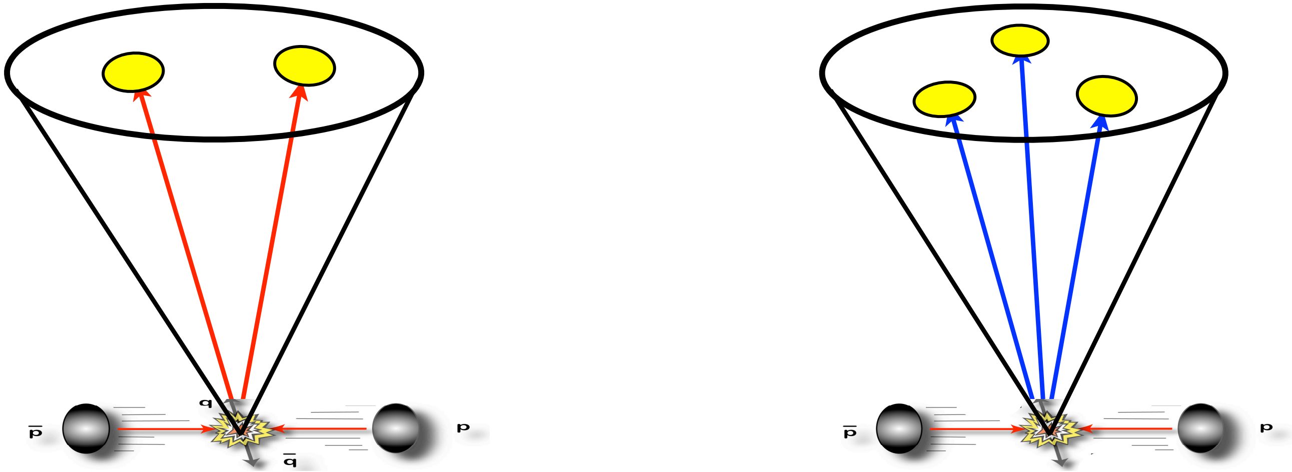
Observables

- S LEE: Template method and color flow for top
- LARKOSKI: Jet substructure without trees
- KROHN: ISR tagging
- SPANNOWSKY: Shower deconstruction
- THALER: N-subjetiness
- GALLICCHIO: Gluon tagging at the LHC
- JANKOWIAK: Dipolarity
- TWEEDIE: Top polarization
- SCHWARTZ: Multi-variate overview

Template method

Template overlap combined with jet shape

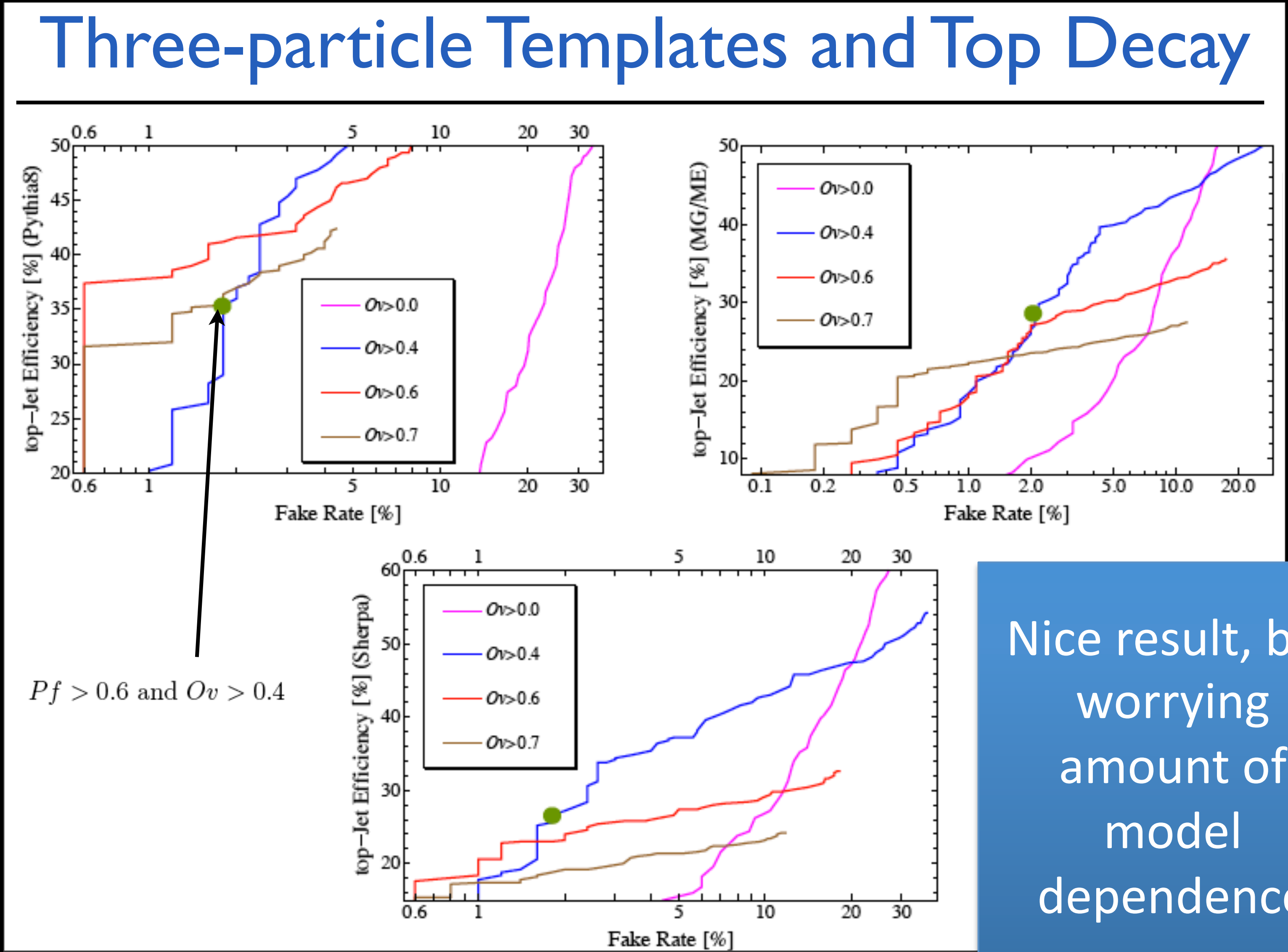
- Top-jet is 3 body vs. massive QCD jet <=> 2-body (our result)



QCD massive jet

top jet

Template method



Three-particle Templates and Top Decay

$Pf > 0.6$ and $Ov > 0.4$

Nice result, but worrying amount of model dependence

Jet substructure without trees

Angular Correlations

- For any IRC safe set of particles {*i*}:

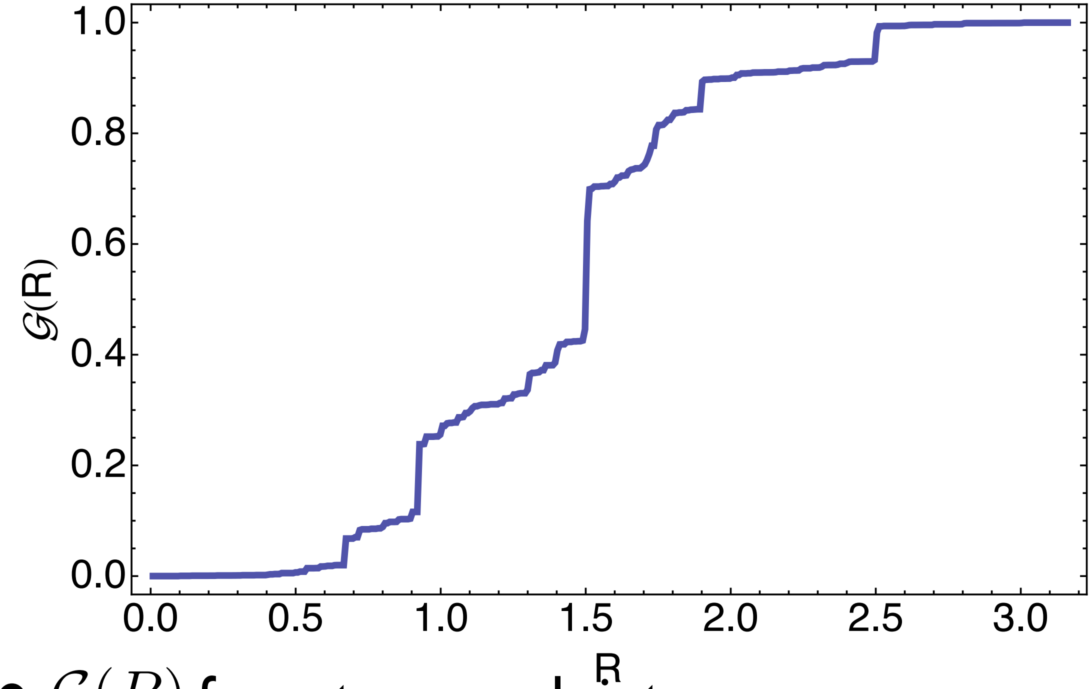
$$\mathcal{G}(R) \equiv \frac{\sum\limits_{i\neq j} p_{Ti}p_{Tj}\Delta R_{ij}^2\Theta(R-\Delta R_{ij})}{\sum\limits_{i\neq j} p_{Ti}p_{Tj}\Delta R_{ij}^2} \approx \frac{\sum\limits_{i\neq j} p_i\cdot p_j\Theta(R-\Delta R_{ij})}{\sum\limits_{i\neq j} p_i\cdot p_j}$$

- *R* is **not** measured wrt jet center
  - Distinct from angular profile
- Quantifies jet scaling in an IRC safe way

Jet substructure without trees

Angular Correlations

- Ledges in $\mathcal{G}(R)$ = separation of hard subjets



- $\mathcal{G}(R)$ for a top quark jet

Jet substructure without trees

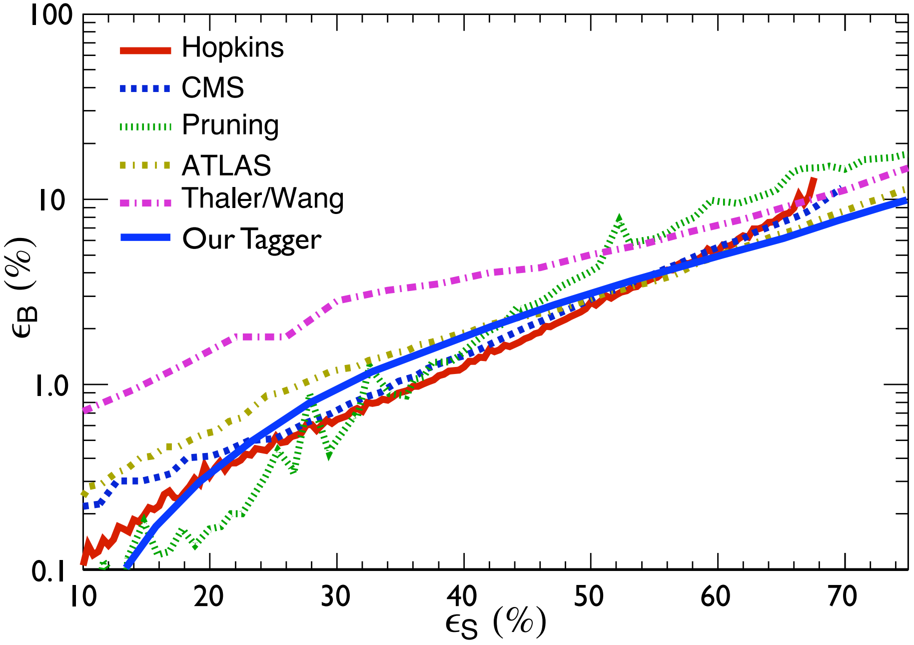
Angular Structure

- How to find ~~ledges~~ cliffs
  - Find peaks in the derivative!
  - Problem: really want ratio of masses
  - Take derivative of $\log \mathcal{G}(R)$
- QCD is ~scale invariant
  - Take derivative wrt log R
  - Reduces noise at small R

Jet substructure without trees

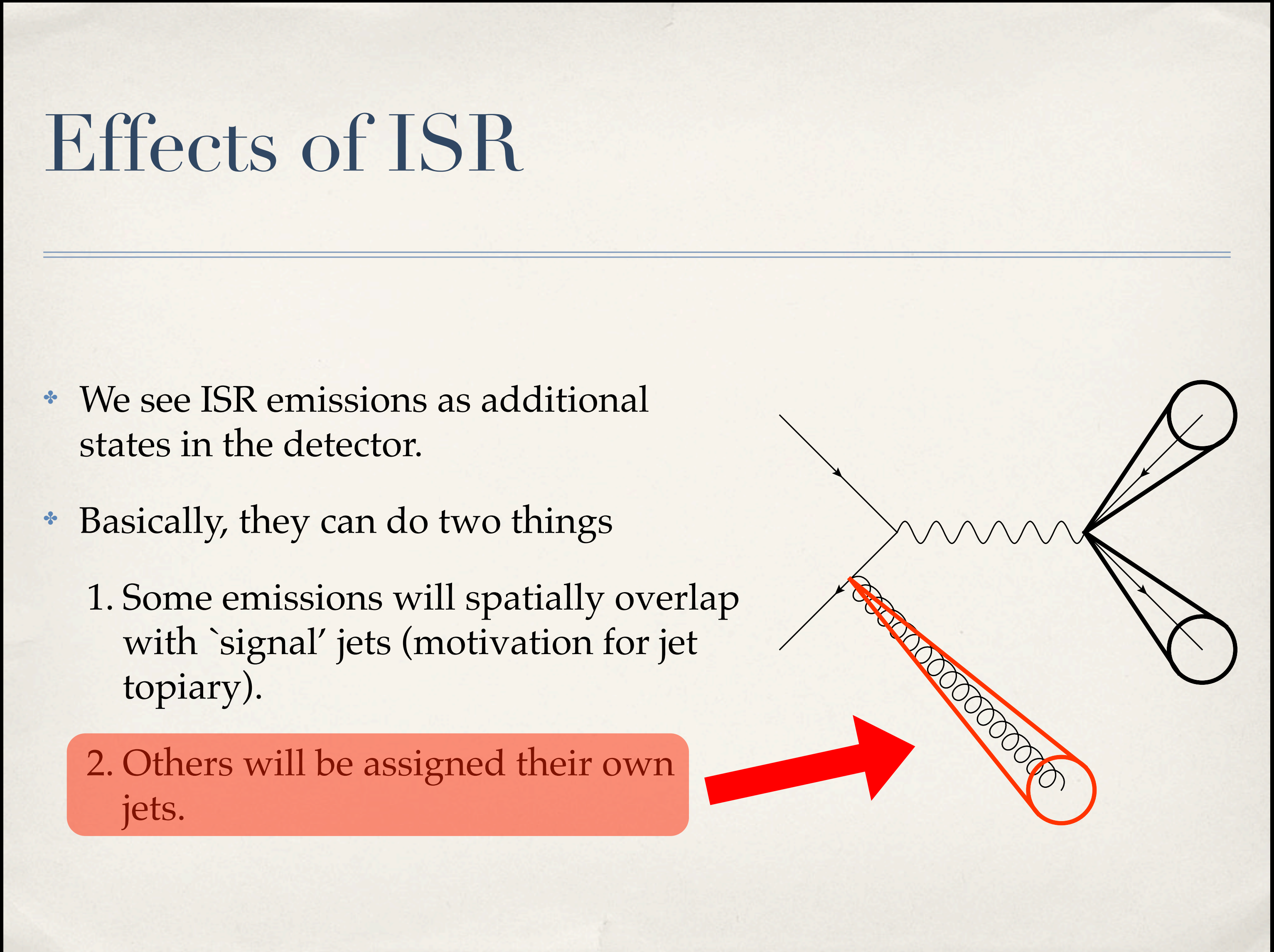
Current/Future Directions

- Constructed a top tagging algorithm competitive with others in the literature



anti-kT, R=1.0, 500 GeV < pT < 600 GeV

ISR tagging



Effects of ISR

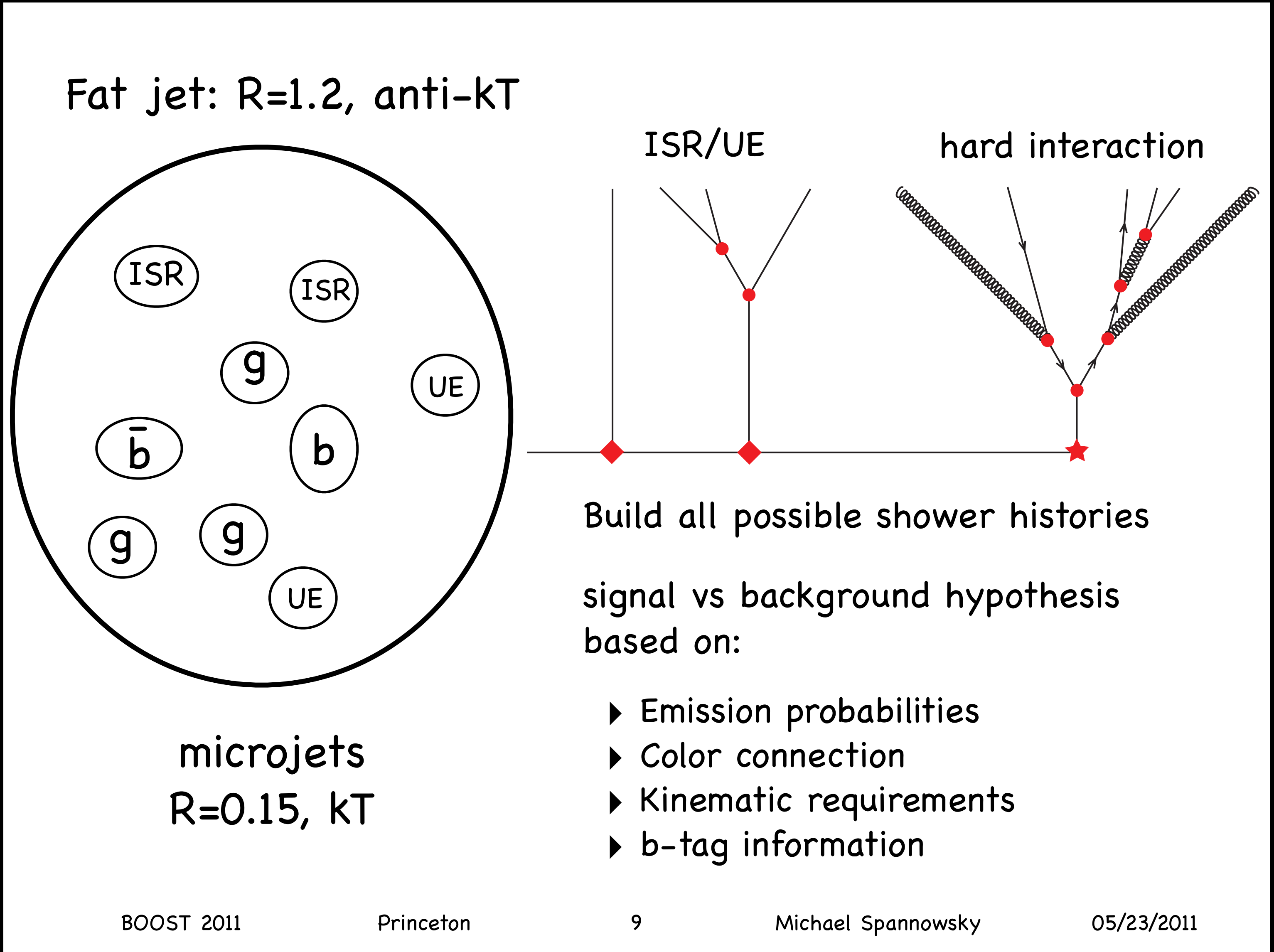
- We see ISR emissions as additional states in the detector.
- Basically, they can do two things
  1. Some emissions will spatially overlap with `signal' jets (motivation for jet topiary).
  2. Others will be assigned their own jets.

ISR tagging

- Just to emphasize what happened
  - On the previous page, for a 1 TeV gluino with a 900 GeV LSP we were able to infer the presence of 2.5 TeV physics from four dinky (p_T ~50 GeV) FSR jets and ISR. Not bad!

- Is ISR extraction event by event really well defined?
- But concept of event reconstruction from accompanying radiation very interesting.
- Can validate on SM processes?

Shower deconstruction



Fat jet: R=1.2, anti-kT

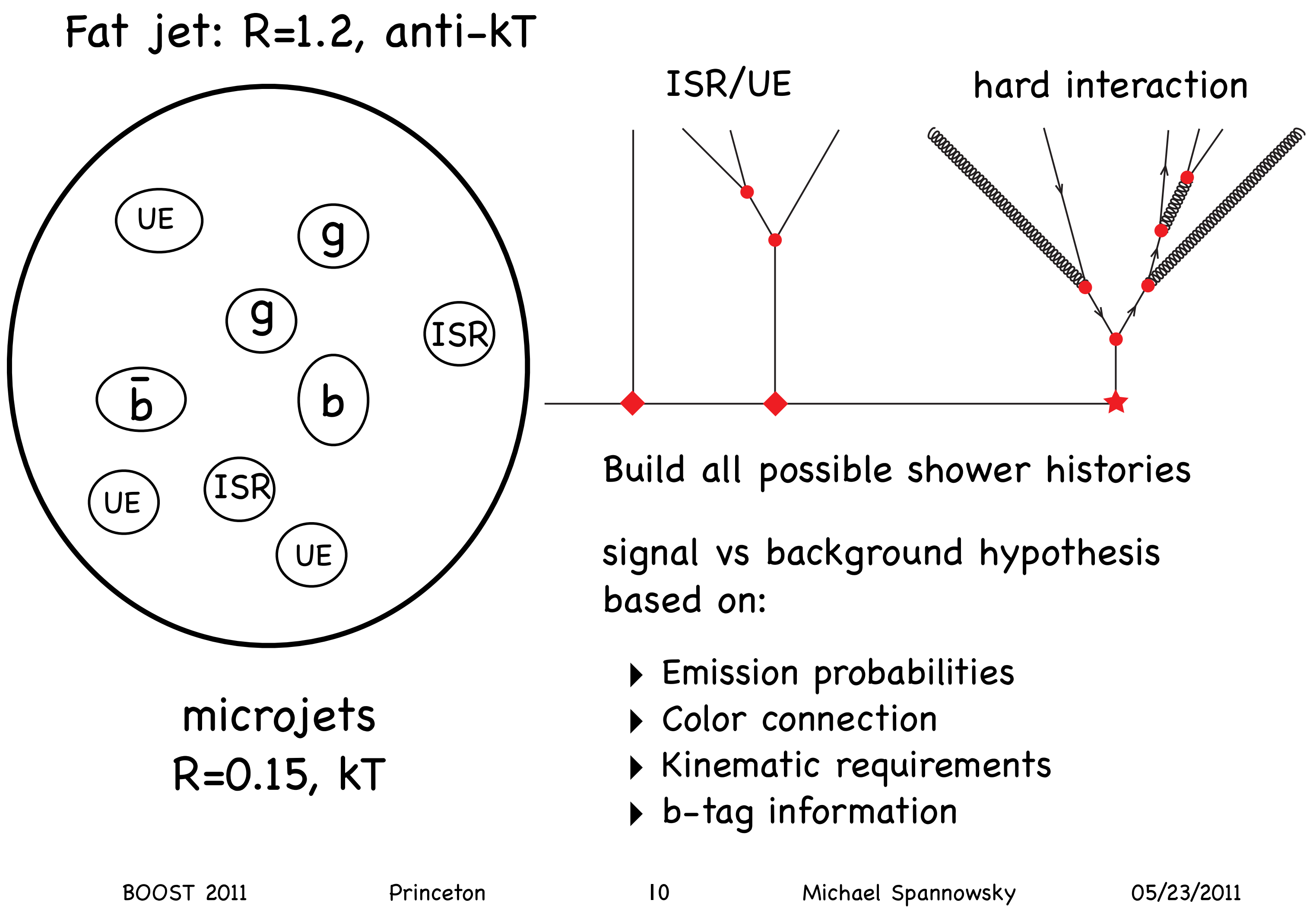
microjets
R=0.15, kT

Build all possible shower histories

signal vs background hypothesis
based on:

- Emission probabilities
- Color connection
- Kinematic requirements
- b-tag information

Shower deconstruction



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microjets
R=0.15, kT

Build all possible shower histories

signal vs background hypothesis based on:

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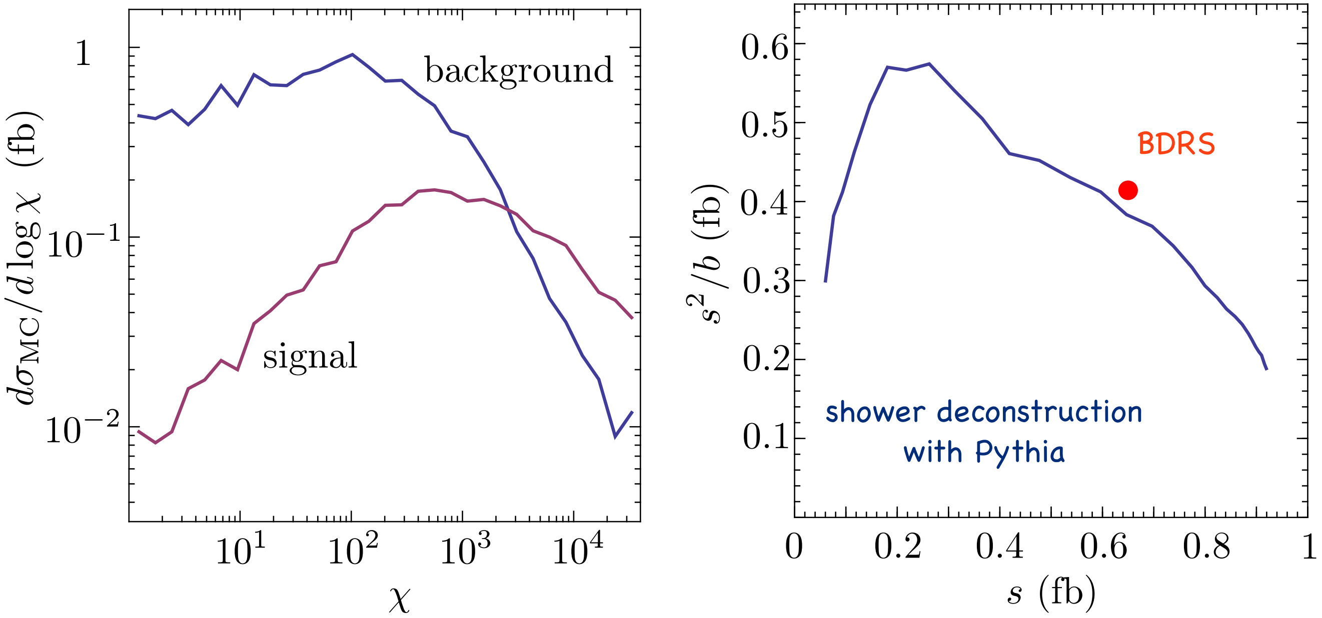
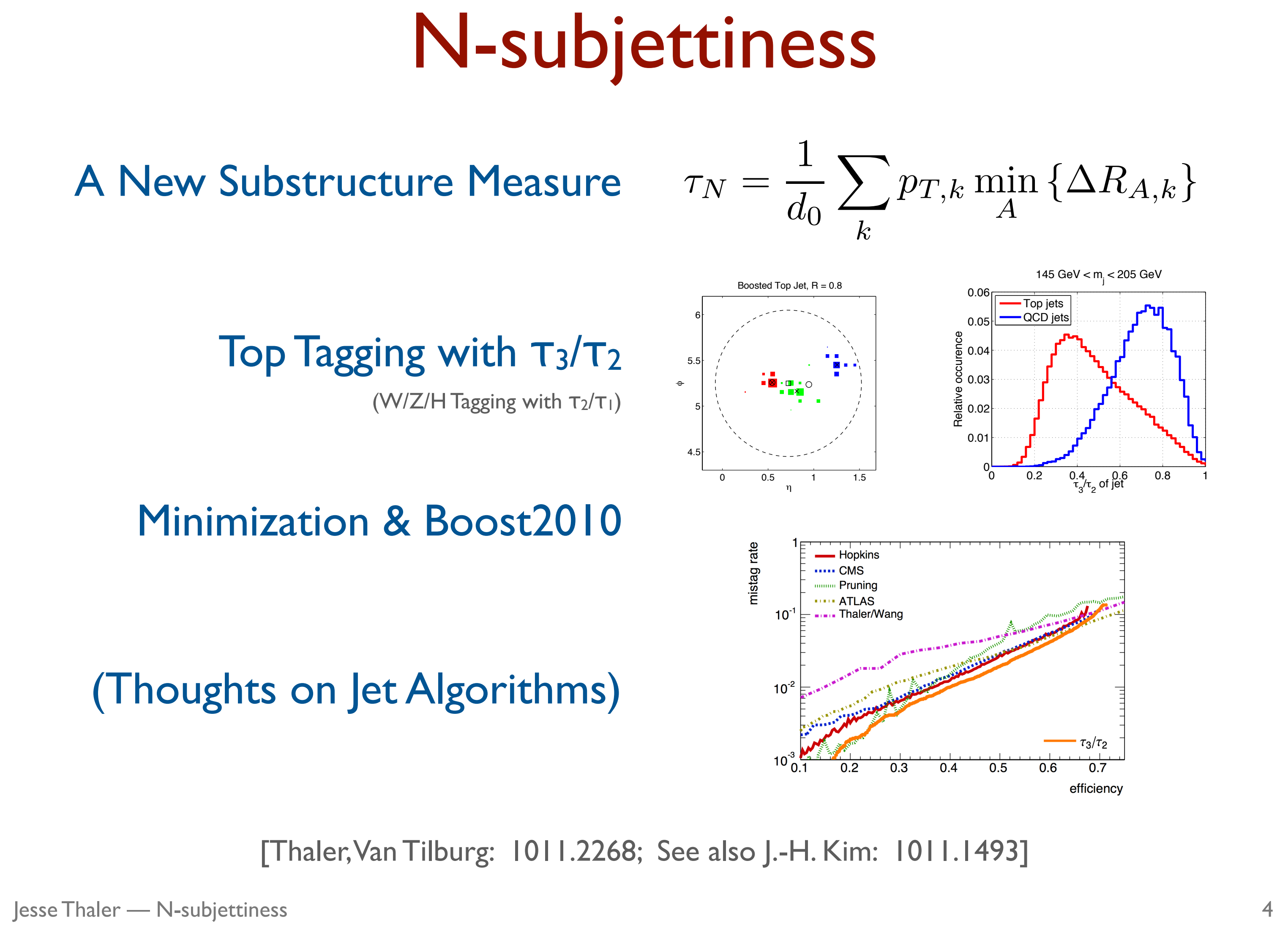
Shower deconstruction

perfect b-tagging 2 b-tagged microjets



- Profits more from information than BDRS, e.g. b-tagging

N-subjetiness



N-subjettiness

A New Substructure Measure

$$\tau_N = \frac{1}{d_0}\sum_k p_{T,k}\min_A\{\Delta R_{A,k}\}$$

Top Tagging with τ_3/τ_2

(W/Z/H Tagging with τ_2/τ_1)

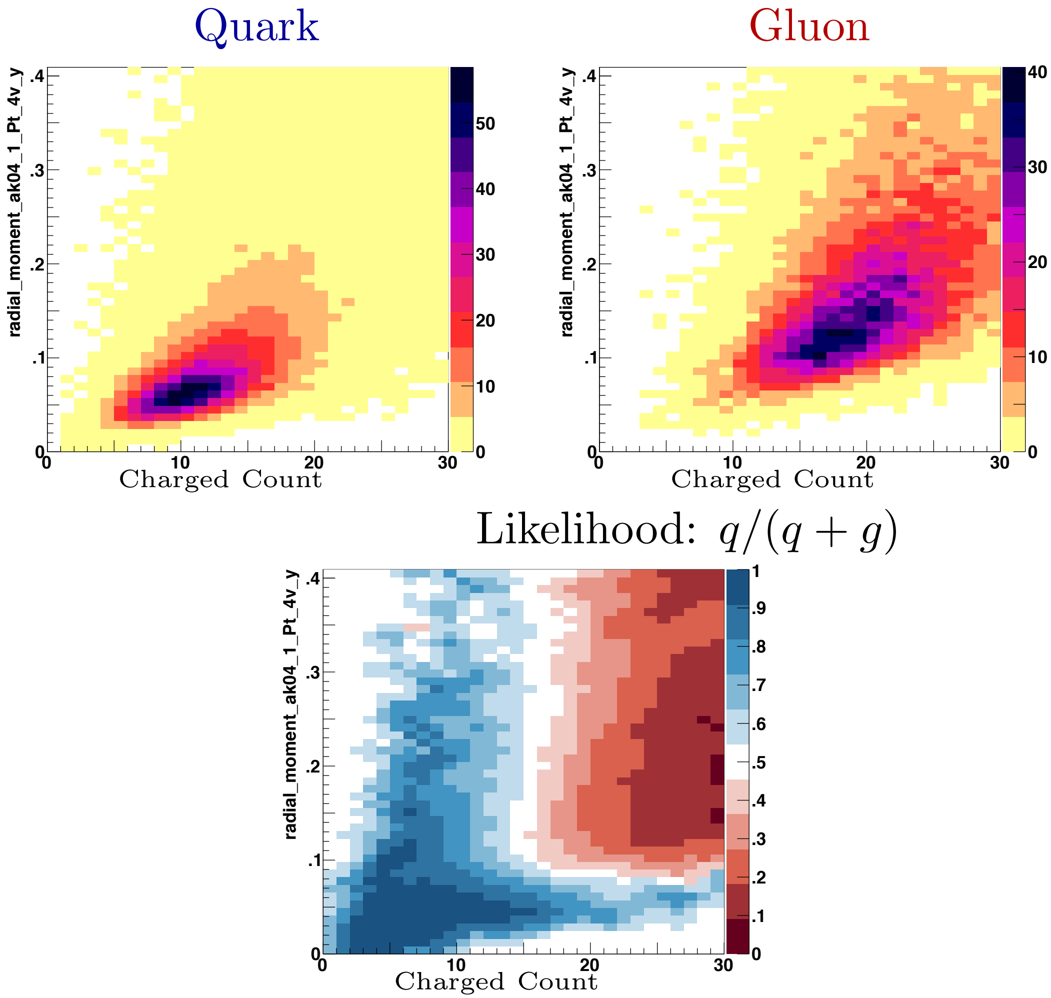
Minimization & Boost2010

(Thoughts on Jet Algorithms)

[Thaler, Van Tilburg: 1011.2268; See also J.-H. Kim: 1011.1493]

Gluon tagging at the LHC

Combining Variables: Girth vs Charged Count



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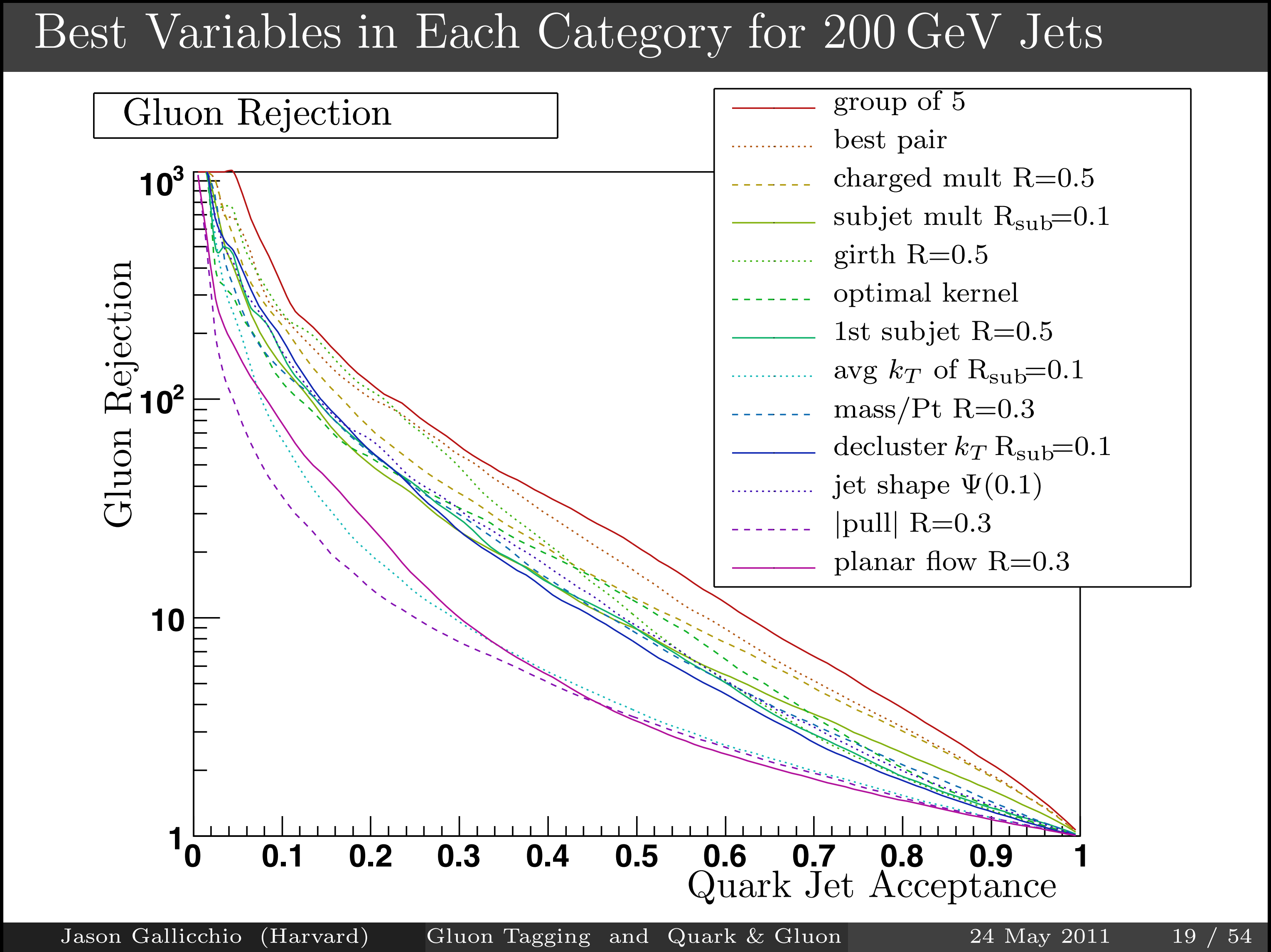
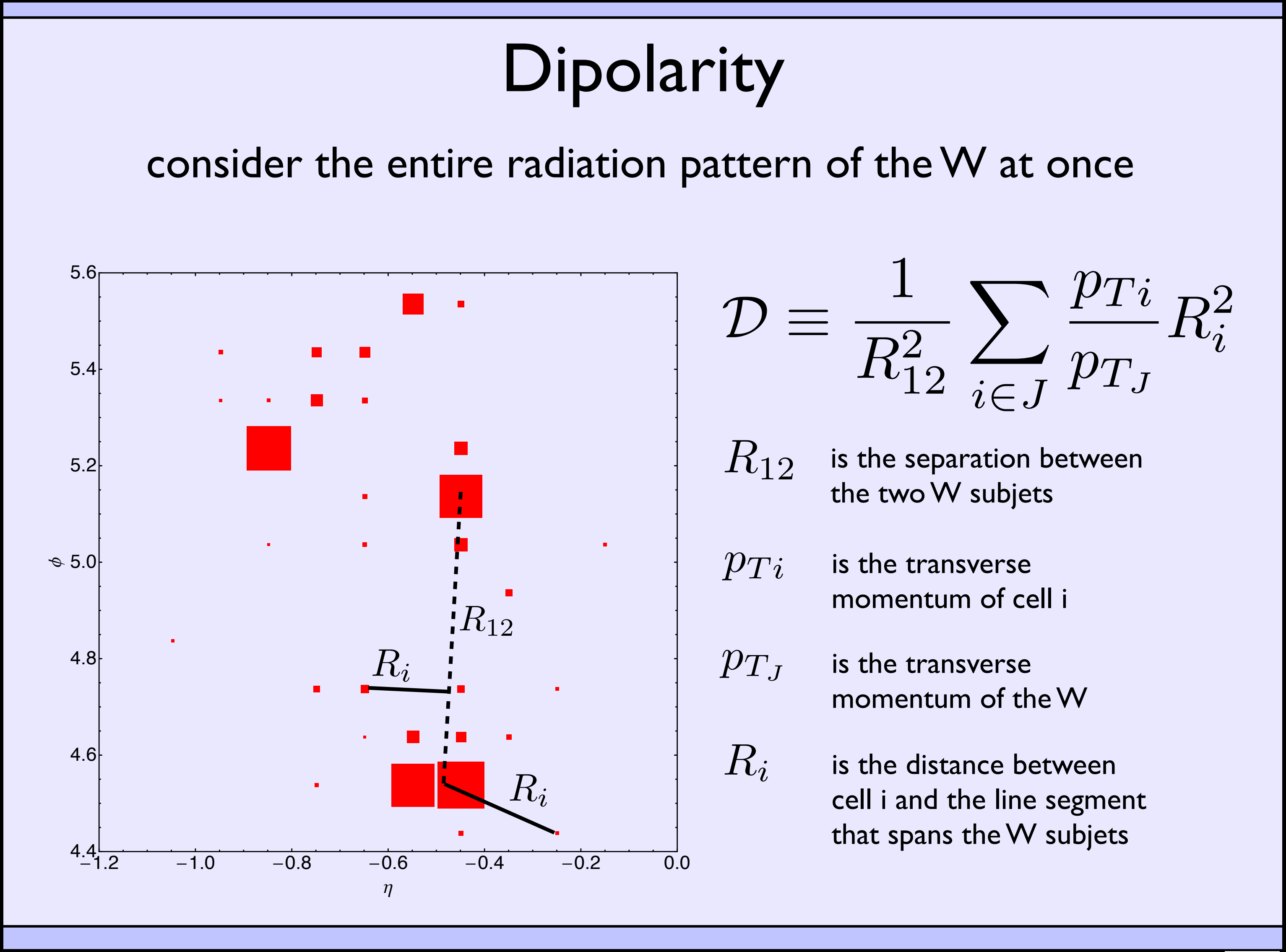


Best Variables in Each Category for 200 GeV Jets

Jason Gallicchio (Harvard) Gluon Tagging and Quark & Gluon 24 May 2011 19 / 54

Dipolarity



Dipolarity

consider the entire radiation pattern of the W at once

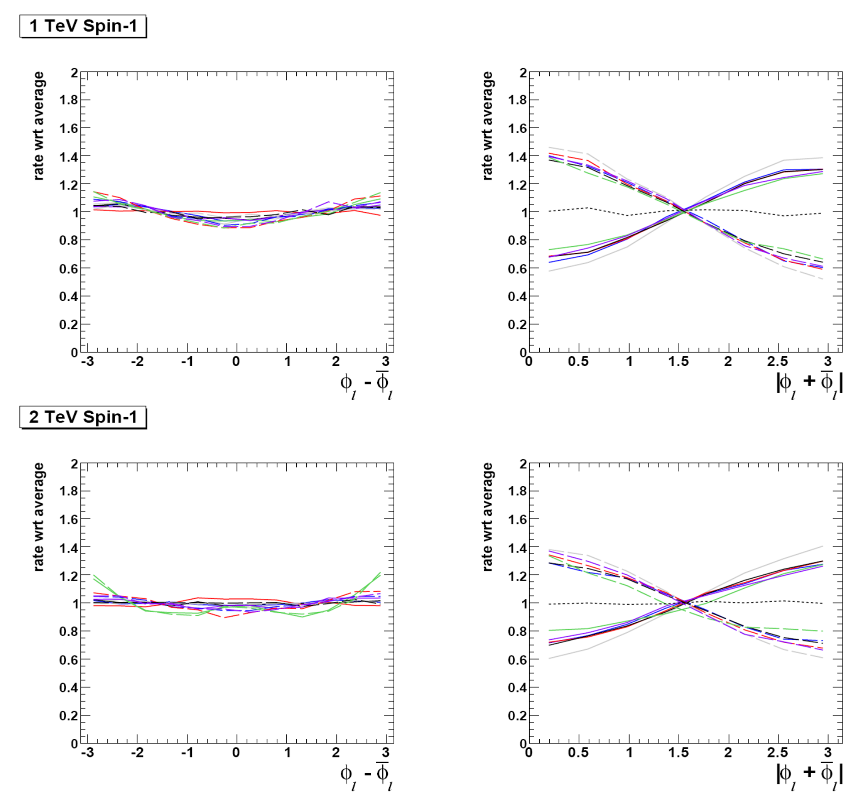
$$\mathcal{D} \equiv \frac{1}{R_{12}^2}\sum_{i\in J}\frac{p_{Ti}}{p_{T_J}}R_i^2$$

R_{12}	is the separation between the two W subjets
p_{Ti}	is the transverse momentum of cell i
p_{T_J}	is the transverse momentum of the W
R_i	is the distance between cell i and the line segment that spans the W subjets

Boosted top azimuthal correlations

Spin-1 Azimuthal Modulations

Application of boost beyond discovery



solid: pure vector, dashed: axial vector, dotted: LH chiral

Boosted top azimuthal correlations

Maybe Less Familiar: Z->ττ at LEP

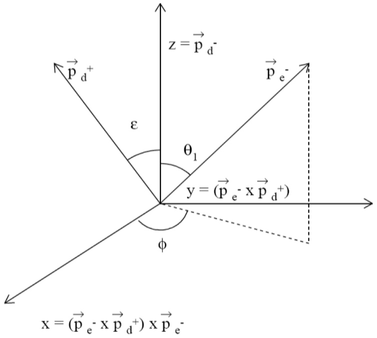


Figure 1: Coordinate system in the lab frame. $p_{d^\pm}$ is the direction of the $\tau^\pm$ decay product. p_{e^-} is the direction of the incident e^-.

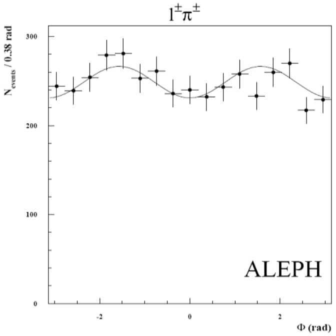
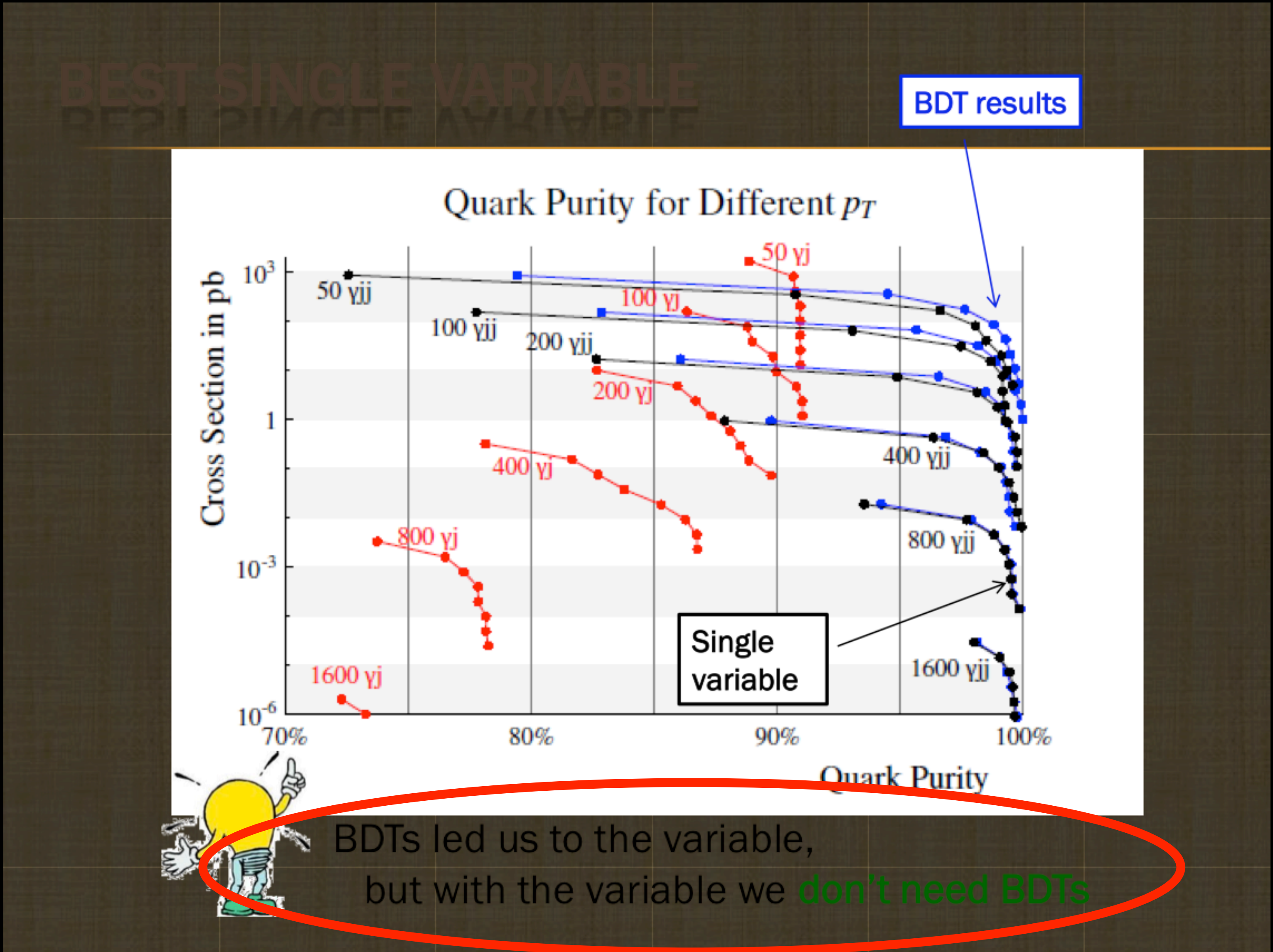


Figure 2: Comparison of the standard model $\cos(2\phi)$ asymmetry and the data for the $l^\mp\pi^\pm$ channel.

ALEPH, CERN OPEN-99-355

- Directly measured vector/axial admixture of Z coupling to taus
- Double one-prong events
  - no attempt to reconstruct neutrinos
  - know the CM frame, get to sit on resonance
- Azimuthal angle of one visible particle about the other follows cos(2ϕ) distribution

Multi-variate overview



BEST SINGLE VARIABLE

BDT results

Quark Purity for Different p_T

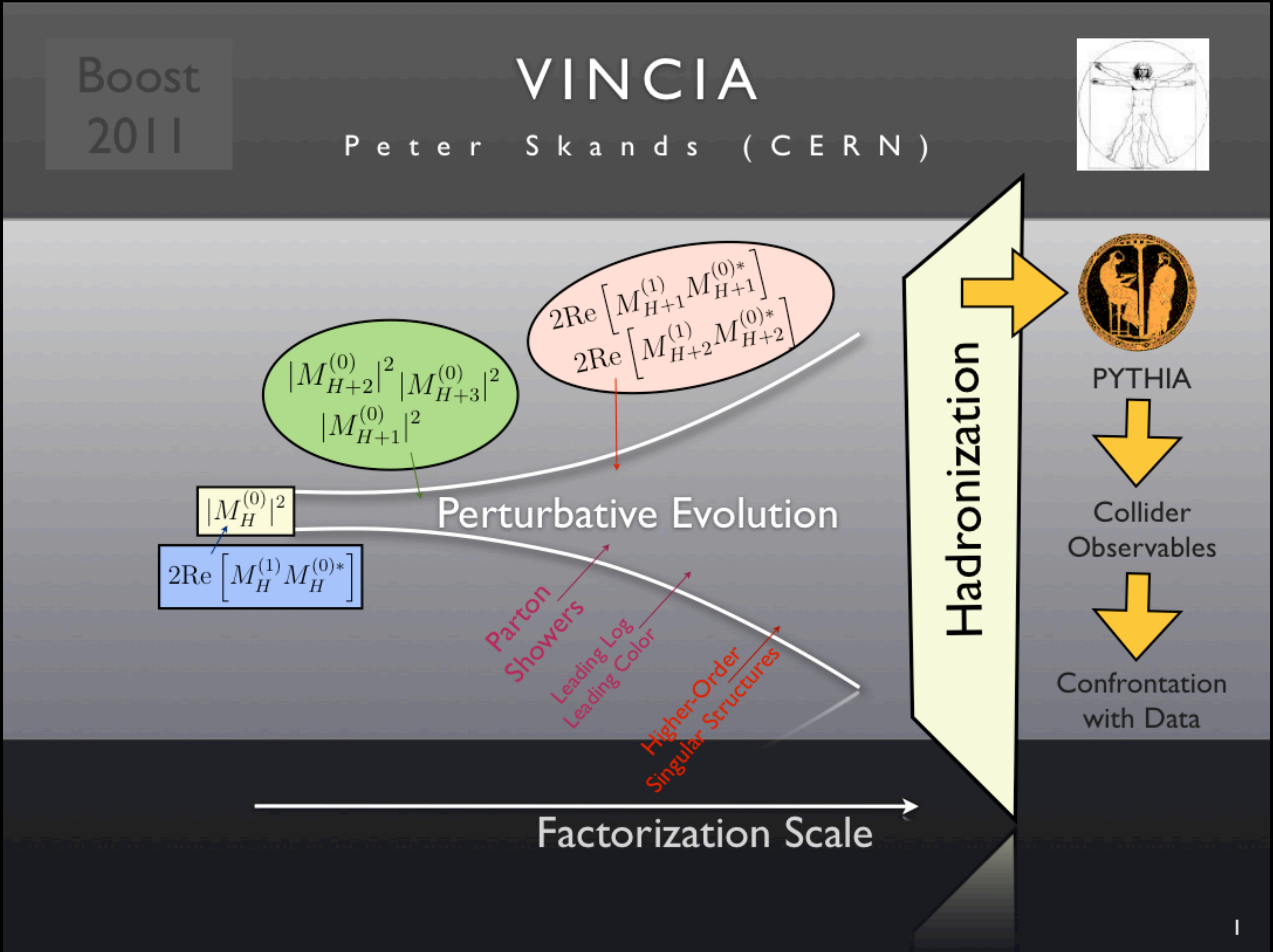
Single variable

BDTs led us to the variable,
but with the variable we don't need BDTs

Calculations

- SKANDS: Vincia
- ALTHEIMER: Jet merging
- DASGUPTA: Jet masses at the LHC
- STEWART: N-jettiness & jet masses at NNLL
- C LEE: Non-global logs etc in SCET
- WALSH: Controlling jets with SCET

Vincia



Boost 2011

VINCIA

Peter Skands (CERN)

$|M_{H+2}^{(0)}|^2 \, |M_{H+3}^{(0)}|^2$

$|M_{H+1}^{(0)}|^2$

$2\mathrm{Re}\left[M_{H+1}^{(1)} M_{H+1}^{(0)*}\right]$

$2\mathrm{Re}\left[M_{H+2}^{(1)} M_{H+2}^{(0)*}\right]$

$|M_H^{(0)}|^2$

$2\mathrm{Re}\left[M_H^{(1)} M_H^{(0)*}\right]$

Perturbative Evolution

Parton Showers

Leading Log Leading Color

Higher-Order Singular Structures

Hadronization

PYTHIA

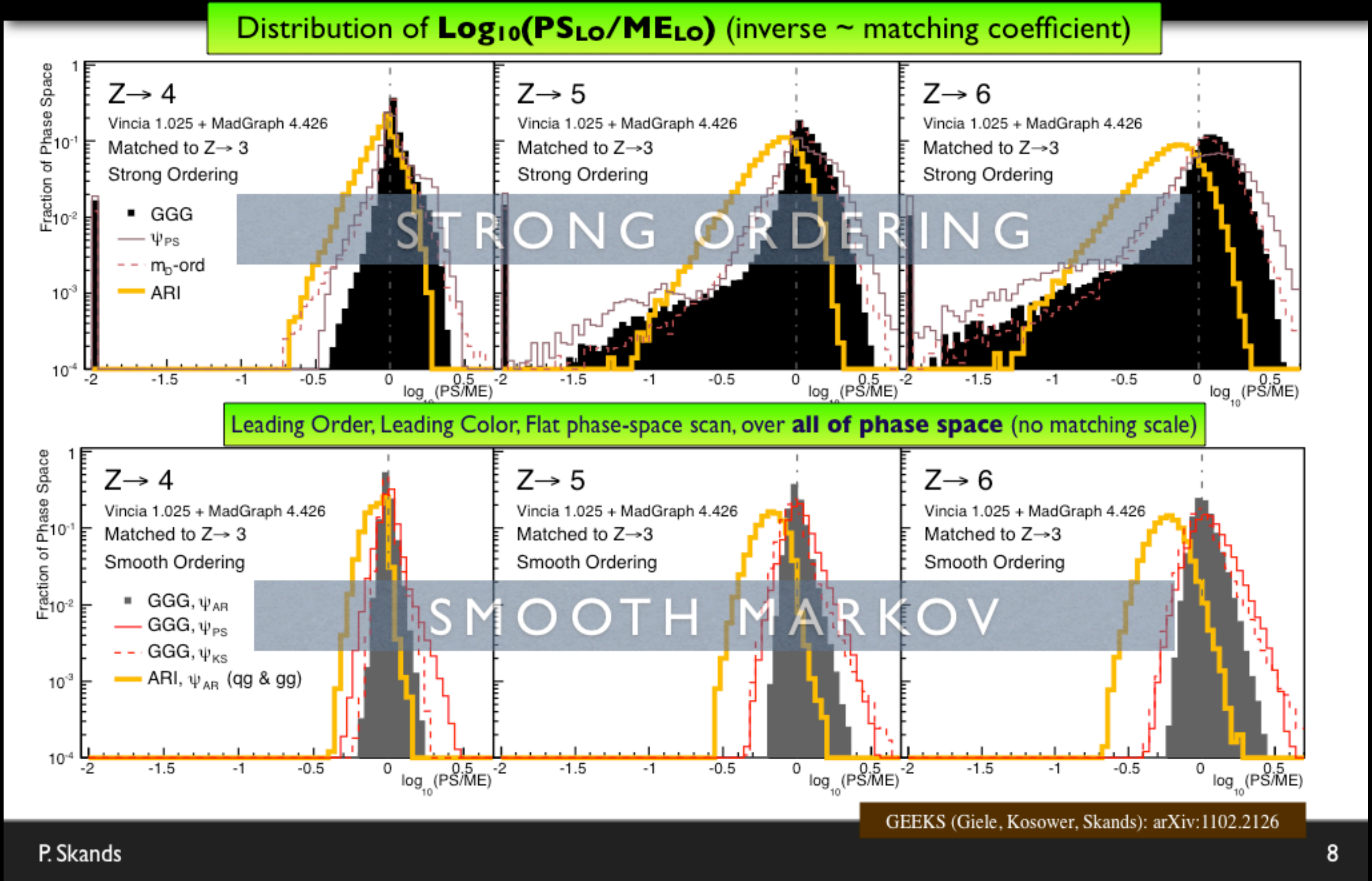
Collider Observables

Confrontation with Data

Factorization Scale

Vincia

→ Better Approximations



Distribution of **$\mathrm{Log}_{10}(\mathrm{PS}_{\mathrm{LO}}/\mathrm{ME}_{\mathrm{LO}})$** (inverse ~ matching coefficient)

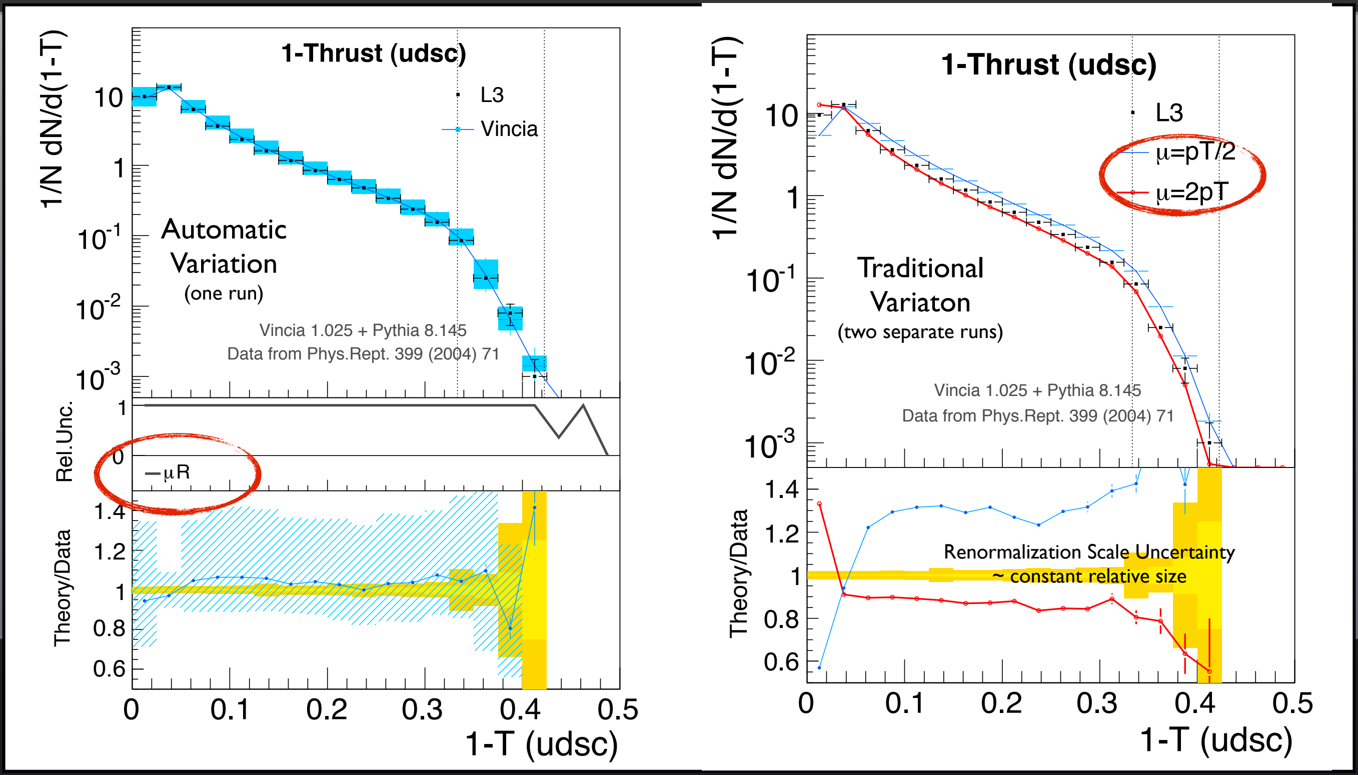
Leading Order, Leading Color, Flat phase-space scan, over **all of phase space** (no matching scale)

GEEKS (Giele, Kosower, Skands): arXiv:1102.2126

Vincia

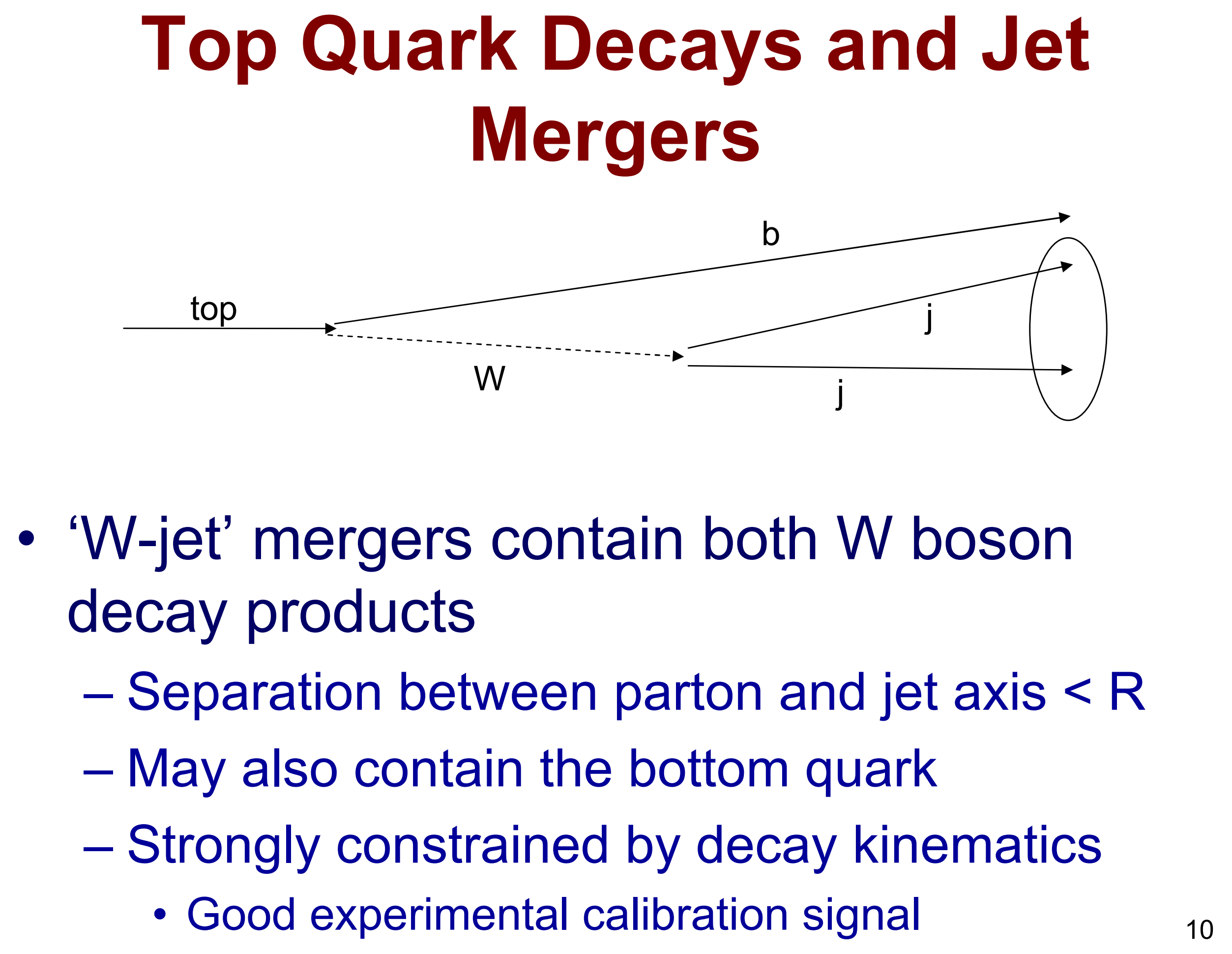
Automatic Uncertainties

Vincia:uncertaintyBands = on



Variation of renormalization scale (no matching)

Jet merging



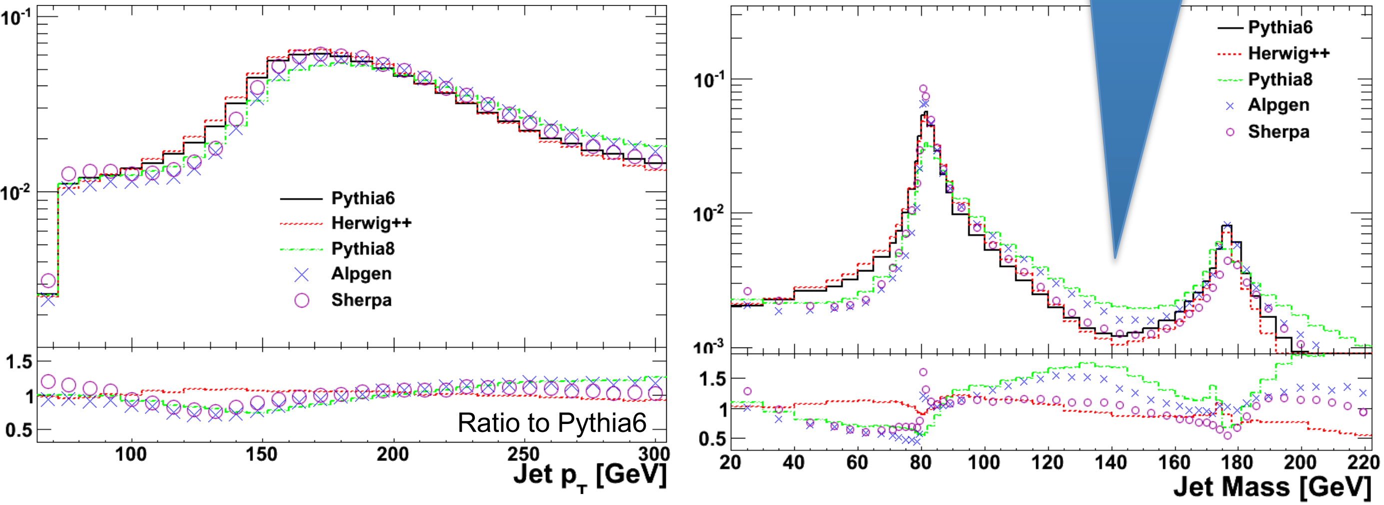
Top Quark Decays and Jet Mergers

- ‘W-jet’ mergers contain both W boson decay products
  - Separation between parton and jet axis < R
  - May also contain the bottom quark
  - Strongly constrained by decay kinematics
    - Good experimental calibration signal

Jet merging

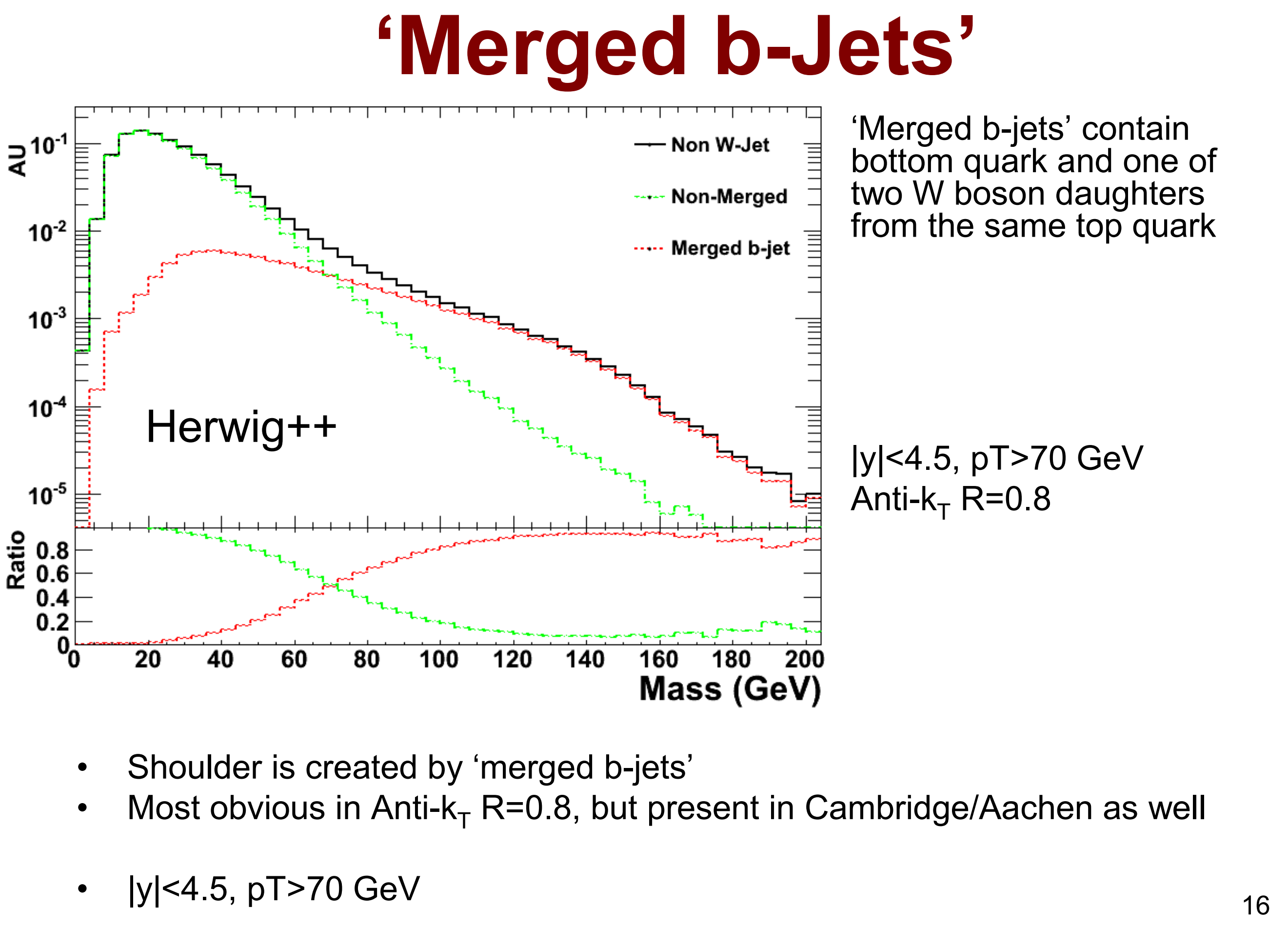
Really should be under perturbative control ?

‘Merged W-jets’



- Require both W boson decay products to be contained within the same jet
- $|y|<4.5$, $p_T>70$ GeV
- Cambridge/Aachen R=1.0

Jet merging



‘Merged b-Jets’

‘Merged b-jets’ contain bottom quark and one of two W boson daughters from the same top quark

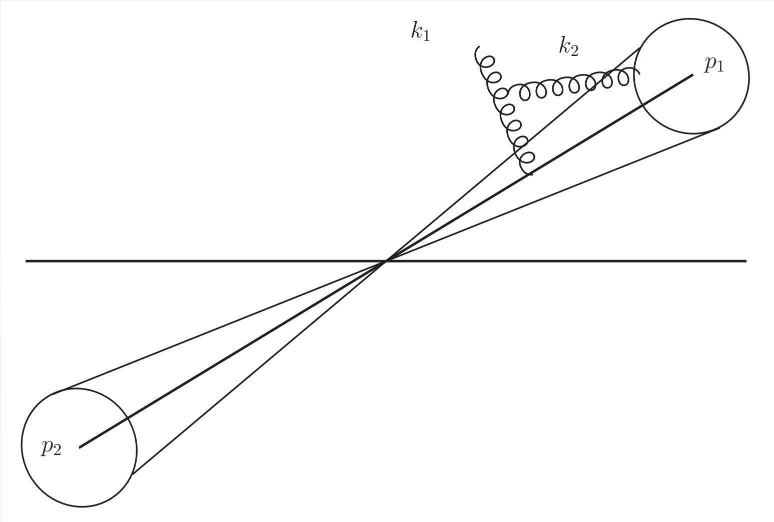
$|y|<4.5$, pT>70 GeV
Anti-k_T R=0.8

- Shoulder is created by ‘merged b-jets’
- Most obvious in Anti-k_T R=0.8, but present in Cambridge/Aachen as well

- $|y|<4.5$, pT>70 GeV

Jet masses at the LHC

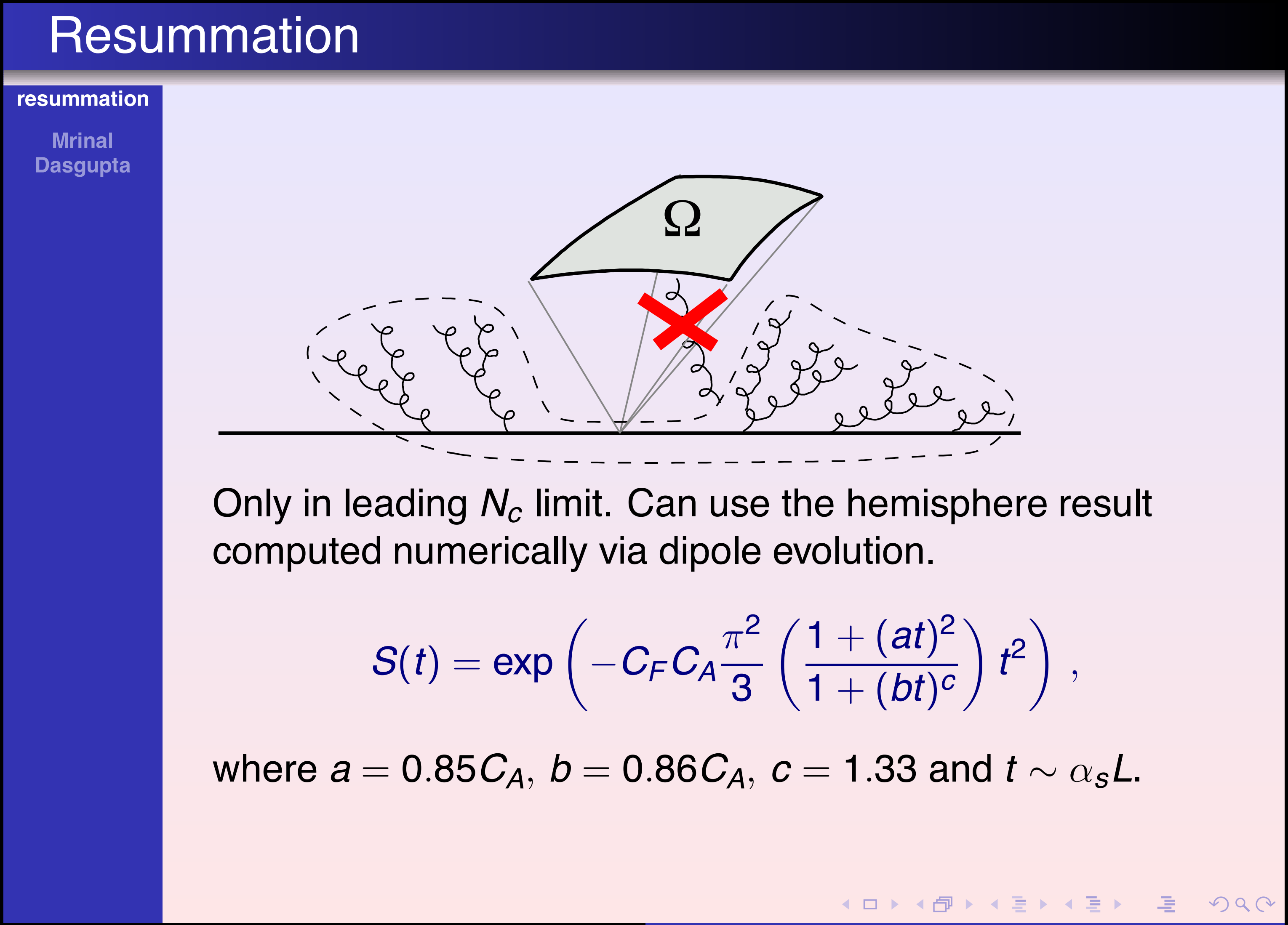
Soft wide-angle emissions beyond one-loop



The fun starts at two-loop level. Looking in the interior of jet corresponds to non-globalness. Can do explicit calculation with 2 soft energy ordered gluons $\omega_1 \gg \omega_2$.
Configuration would *cancel* to our accuracy in global observables.

MD and Salam, 2001, 2002

Jet masses at the LHC



Resummation

Only in leading N_c limit. Can use the hemisphere result computed numerically via dipole evolution.

$$S(t) = \exp\left(-C_F C_A \frac{\pi^2}{3}\left(\frac{1+(at)^2}{1+(bt)^c}\right)t^2\right) ,$$

where $a = 0.85C_A$, $b = 0.86C_A$, $c = 1.33$ and $t \sim \alpha_s L$.

N-jettiness & jet masses at NNLL

N-Jettiness Event Shape

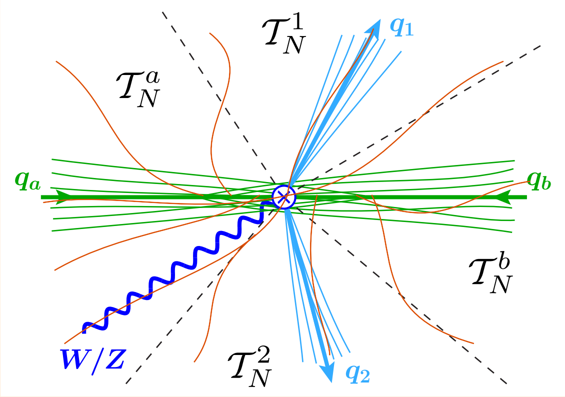
IS, Tackmann, Waalewijn
arXiv: 1004.2489

$$\mathcal{T}_N = \mathcal{T}_N(q_a, q_b, q_1, \ldots, q_N)$$

$$\mathcal{T}_N \to 0 \text{ for } N\text{-jets}$$

Factorization Friendly

$$\mathcal{T}_N = \mathcal{T}_N^a + \mathcal{T}_N^b + \mathcal{T}_N^1 + \ldots + \mathcal{T}_N^N$$



Want to calculate N-jet exclusive cross-sections.

eg. differential jet masses

$$\frac{d\sigma}{d\mathcal{T}_N^a \cdots d\mathcal{T}_N^N}$$

Jouttenus, IS, Tackmann, Waalewijn
arXiv: 1102.4344

How sensitive is N-jettiness to underlying event?

N-jettiness & jet masses at NNLL

Jet veto restricts ISR, gives double logs

Fixed Order to NNLO

Current recipe being used by experiments [Anastasiou et al., arXiv:0905.3529]

- Common scale variation for jet bins, e.g. for the Tevatron

$$\frac{\Delta\sigma}{\sigma} = \underbrace{66.5\% \times \binom{+5\%}{-9\%}}_{\text{0 jets}} + \underbrace{28.6\% \times \binom{+24\%}{-22\%}}_{\text{1 jet}} + \underbrace{4.9\% \times \binom{+78\%}{-41\%}}_{\geq 2\text{ jets}} = \binom{+14\%}{-14\%}$$

Proposed Fixed Order Solution [Tackmann, ...]

- The *inclusive* jet cross sections are considered uncorrelated

$\sigma_{\text{total}},\ \sigma_{\geq 1},\ \sigma_{\geq 2}$ for scale variation

- The covariance matrix for the *exclusive* jet cross sections follows from

$$\sigma_0 = \sigma_{\text{total}} - \sigma_{\geq 1}\,, \qquad \sigma_1 = \sigma_{\geq 1} - \sigma_{\geq 2}\,, \qquad \sigma_{\geq 2}$$

N-jettiness & jet masses at NNLL

Jet veto restricts ISR, gives double logs

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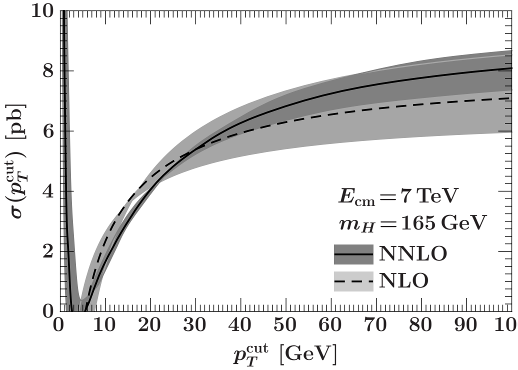
Proposed Fixed Order Solution

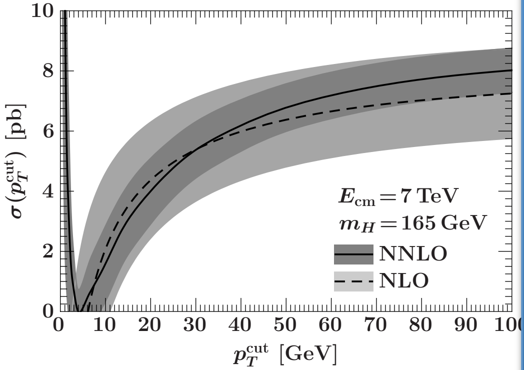
[Tackmann, ...]

Using naive scale variation for σ_0



$\Rightarrow$

Using above procedure for σ_0



Good proposal: worth looking at consequences for other cross sections/ observables

Logs, Non-Global Logs, and Non-Global Non-Logs in Dijet Observables

Momentum Space Result

Hornig, CL, Stewart, Walsh, Zuberi [1105.4628]

agrees exactly numerically with Kelley, Schabinger, Schwartz, Zhu [1105.3676]

For the double cumulant $\mathcal{S}_c(\ell_1^c, \ell_2^c; \mu) = \int^{\ell_1^c} d\ell_1 \int^{\ell_2^c} d\ell_2 \, S(\ell_1, \ell_2; \mu)$

Double NGL

Single NGL

$$\frac{1}{2} t_2^c(\ell_1^c, \ell_2^c, \mu) = \theta(\ell_1^c)\theta(\ell_2^c) \Big\{ -\frac{\pi^2}{3} C_F C_A \ln^2\Big(\frac{\ell_1^c}{\ell_2^c}\Big)$$
$$+ \ln\Big(\frac{\ell_1^c/\ell_2^c + \ell_2^c/\ell_1^c}{2}\Big) \Big[C_F C_A \frac{11\pi^2 - 3 - 18\zeta_3}{9} + C_F T_R n_f \frac{6 - 4\pi^2}{9} \Big]$$
$$+ C_F C_A \Big[f_N\Big(\frac{\ell_1^c}{\ell_2^c}\Big) + f_N\Big(\frac{\ell_2^c}{\ell_1^c}\Big) - 2 f_N(1) \Big] + C_F T_R n_f \Big[f_Q\Big(\frac{\ell_1^c}{\ell_2^c}\Big) + f_Q\Big(\frac{\ell_2^c}{\ell_1^c}\Big) - 2 f_Q(1) \Big]$$
$$+ C_F^2 \frac{\pi^4}{8} + \frac{1}{2} C_F C_A s_{2\rho}^{[C_F C_A]} + \frac{1}{2} C_F T_R n_f s_{2\rho}^{[n_f]} \Big\}$$

Non-Global Non-Logs:

$$f_Q(a) \equiv \Big(\frac{2\pi^2}{9} - \frac{2}{3(a+1)}\Big) \ln a - \frac{4}{3} \ln a \, \mathrm{Li}_2(-a) + 4\,\mathrm{Li}_3(-a) - \frac{1}{9}(3 - 2\pi^2) \ln\Big(a + \frac{1}{a}\Big),$$
$$f_N(a) \equiv -4\mathrm{Li}_4\Big(\frac{1}{a+1}\Big) - 11\,\mathrm{Li}_3(-a) + 2\mathrm{Li}_3\Big(\frac{1}{a+1}\Big) \ln\Big[\frac{a}{(a+1)^2}\Big]$$
$$+ \mathrm{Li}_2\Big(\frac{1}{a+1}\Big)\Big\{\pi^2 - \ln^2(a+1) - \frac{1}{2} \ln a \ln\Big[\frac{a}{(a+1)^2}\Big] + \frac{11}{3} \ln a\Big\}$$
$$+ \frac{1}{24}\Big\{22 \ln\Big[\frac{a}{(a+1)^2}\Big] - 6 \ln\Big(1 + \frac{1}{a}\Big) \ln(1+a) + \pi^2\Big\} \ln^2 a - \frac{(a-1)\ln a}{6(a+1)}$$
$$+ \frac{5\pi^2}{12} \ln\Big(1 + \frac{1}{a}\Big) \ln(1+a) - \frac{11\pi^4}{180}$$

$$a \equiv \ell_1^c/\ell_2^c$$

Logs, Non-Global Logs, and Non-Global Non-Logs in Dijet Observables

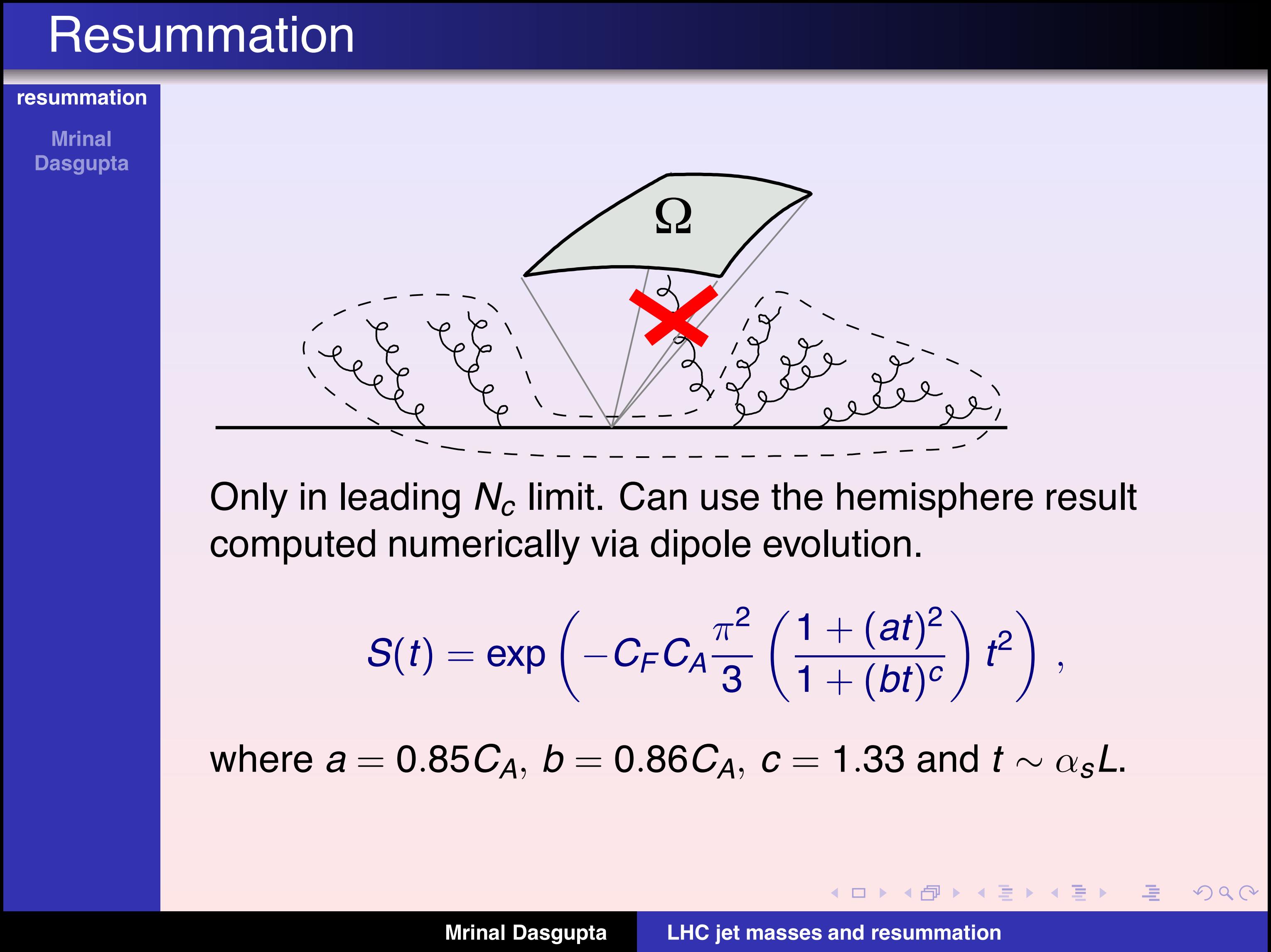
New Opportunities

- Understanding origin of fixed order NGLs in effective field theory opens door to RGE-based method to resum them
    - cf. nonlinear evolution equation, solution currently only known numerically in large-N_C limit.
- When NGLs are not large, our new results allow analytic resummation of global logs in dijet observables to NNNLL accuracy.
- Dijet soft function directly applicable to beam thrust or 0-jettiness in hadron collisions
- NGLs will appear in multijet/subjet observables, jet cross sections with jet energy vetoes, etc.

cf. Banfi, Dasgupta, Khelifa-Kerfa, Marzani (2010)
Rubin (2010): NGLs in Filtered Jet Algorithms

- Calculation and resummation of global and non-global logs bring us into the realm of precision jet physics.

Jet masses at the LHC



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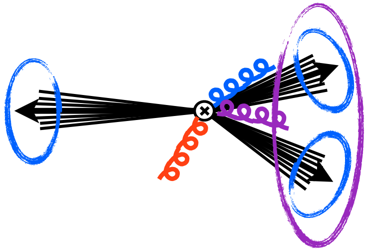
Controlling jets with SCET

Modes with Nearby Jets:
Collinear and Soft Modes



collinear: $p_c \sim E_J(1, \lambda^2, \lambda)$

csoft: $p_{cs} \sim E_J \frac{\lambda^2}{\lambda_t^2}(1, \lambda_t^2, \lambda_t)$

soft: $p_s \sim E_J(\lambda^2, \lambda^2, \lambda^2)$

$$\lambda = \frac{m_J^2}{Q^2}$$

$$\lambda_t = \frac{t}{Q^2}$$

$$\mathcal{T}_j(p) = n_j \cdot p$$

$$\mathcal{T}_j(p_c) = n_j \cdot p_c \sim E_J\lambda^2 \;\; \& \;\; p_c^2 \sim E_J^2\lambda^2 \;\Rightarrow\; p_c \sim E_J(1, \lambda^2, \lambda)$$

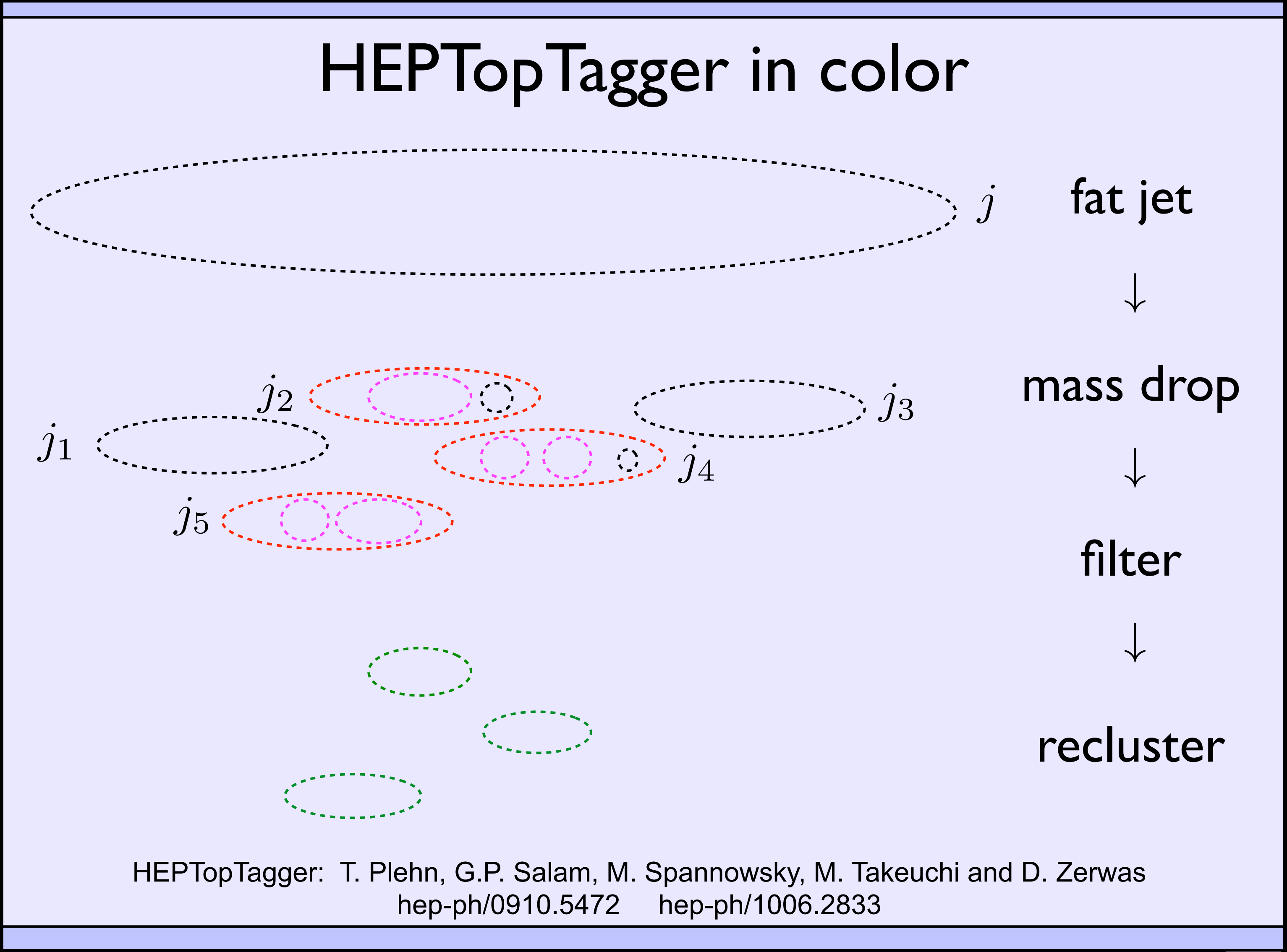
$$\mathcal{T}_j(p_{cs}) = n_j \cdot p_{cs} \sim E_J\lambda^2 \;\; \& \;\; \frac{p_{cs}^+}{p_{cs}^-} \sim \lambda_t^2 \;\Rightarrow\; p_{cs} \sim E_J \frac{\lambda^2}{\lambda_t^2}(1, \lambda_t^2, \lambda_t)$$

$$\mathcal{T}_j(p_s) = n_j \cdot p_s \sim E_J\lambda^2 \;\; \& \;\; p_s^2 \sim E_J^2\lambda^4 \;\Rightarrow\; p_s \sim E_J(\lambda^2, \lambda^2, \lambda^2)$$

Applications

- TAKEUCHI: stop with HEPTopTagger
- SHELTON: top FB asymmetry with HEPTT
- FAN: SUSY with unconventional signals
- YAVIN: Lepton jets
- KRIBS: Boosted Higgs from new physics

stop with HEPTopTagger



HEPTopTagger in color

fat jet

↓

mass drop

↓

filter

↓

recluster

HEPTopTagger: T. Plehn, G.P. Salam, M. Spannowsky, M. Takeuchi and D. Zerwas
hep-ph/0910.5472 hep-ph/1006.2833

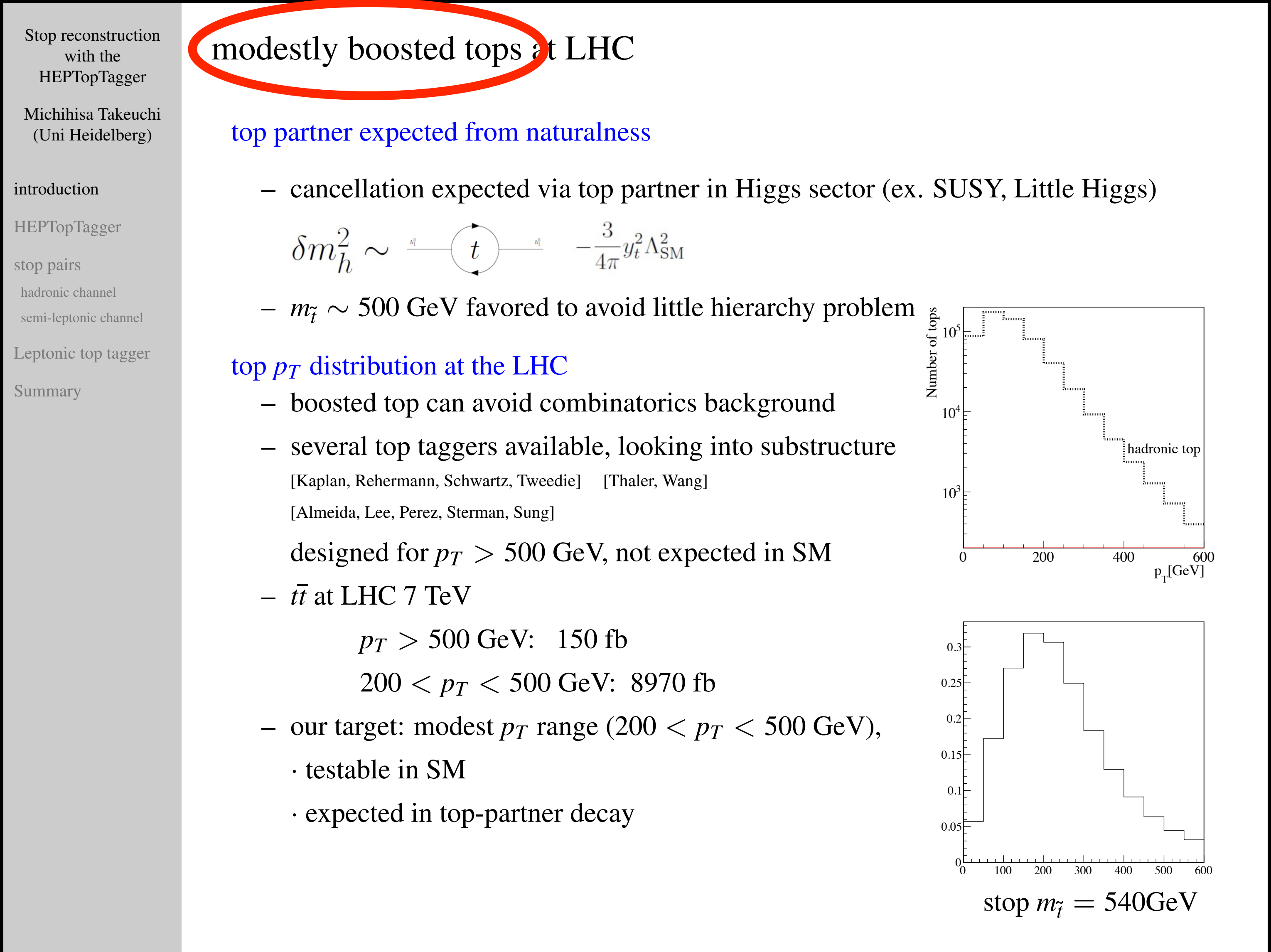
PRINCETON CENTER FOR THEORETICAL SCIENCE

Boost 2011

Boost 2011 Theory Summary

MANCHESTER 1824

stop with HEPTopTagger



Stop reconstruction with the HEPTopTagger

Michihisa Takeuchi (Uni Heidelberg)

introduction

HEPTopTagger

stop pairs

hadronic channel

semi-leptonic channel

Leptonic top tagger

Summary

modestly boosted tops at LHC

top partner expected from naturalness

- cancellation expected via top partner in Higgs sector (ex. SUSY, Little Higgs)

$$\delta m_h^2 \sim \; t \; -\frac{3}{4\pi} y_t^2 \Lambda_{\rm SM}^2$$

- $m_{\tilde{t}} \sim 500$ GeV favored to avoid little hierarchy problem

top p_T distribution at the LHC

- boosted top can avoid combinatorics background
- several top taggers available, looking into substructure

  [Kaplan, Rehermann, Schwartz, Tweedie] [Thaler, Wang]

  [Almeida, Lee, Perez, Sterman, Sung]

  designed for $p_T > 500$ GeV, not expected in SM
- $t\bar{t}$ at LHC 7 TeV

  $p_T > 500$ GeV: 150 fb

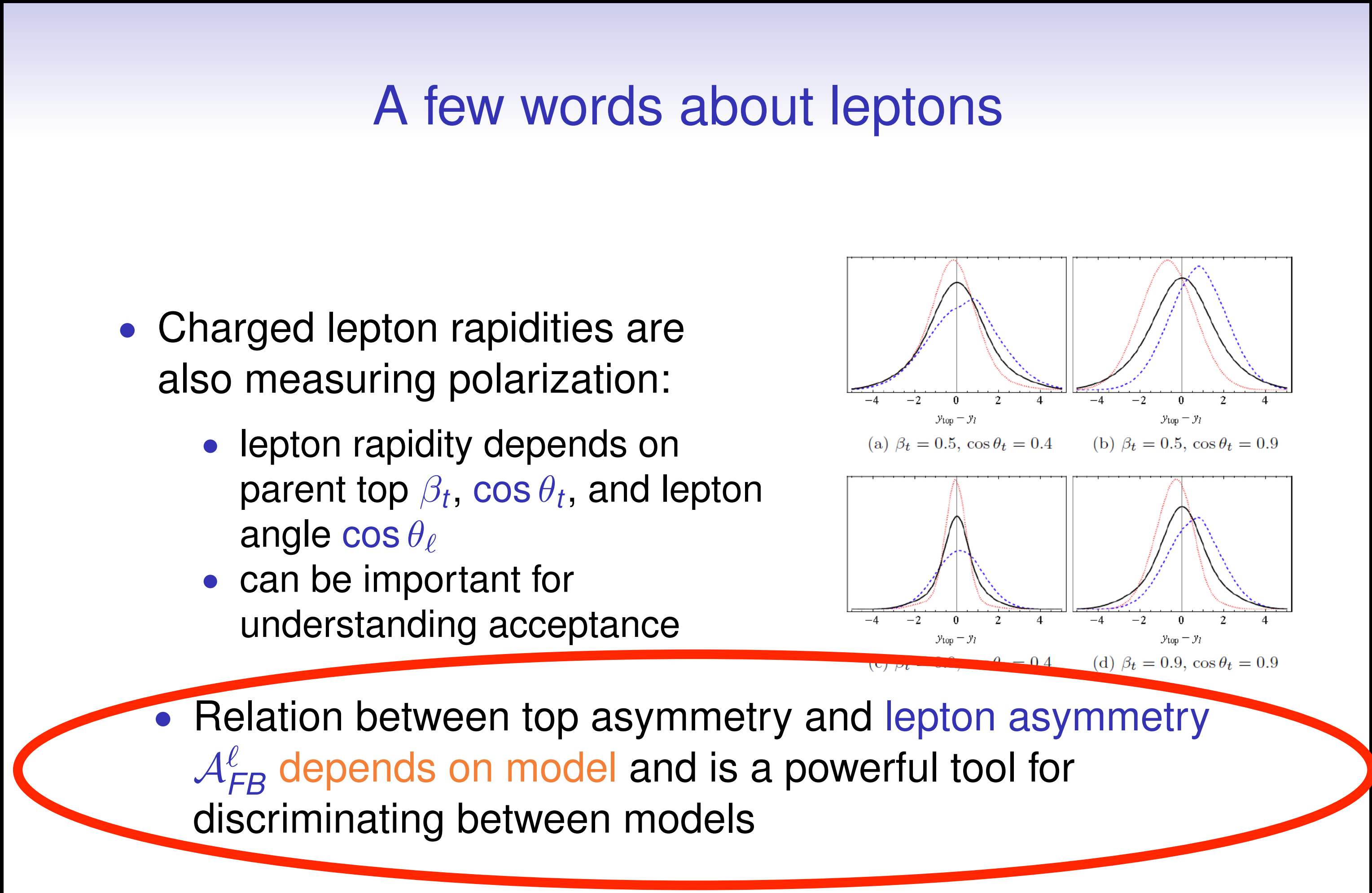
  $200 < p_T < 500$ GeV: 8970 fb
- our target: modest p_T range ($200 < p_T < 500$ GeV),

  · testable in SM

  · expected in top-partner decay

stop $m_{\tilde{t}} = 540$GeV

top FB asymmetry with HEPTopTagger



A few words about leptons

- Charged lepton rapidities are also measuring polarization:
  - lepton rapidity depends on parent top β_t, $\cos\theta_t$, and lepton angle $\cos\theta_\ell$
  - can be important for understanding acceptance

(a) $\beta_t = 0.5, \cos\theta_t = 0.4$

(b) $\beta_t = 0.5, \cos\theta_t = 0.9$

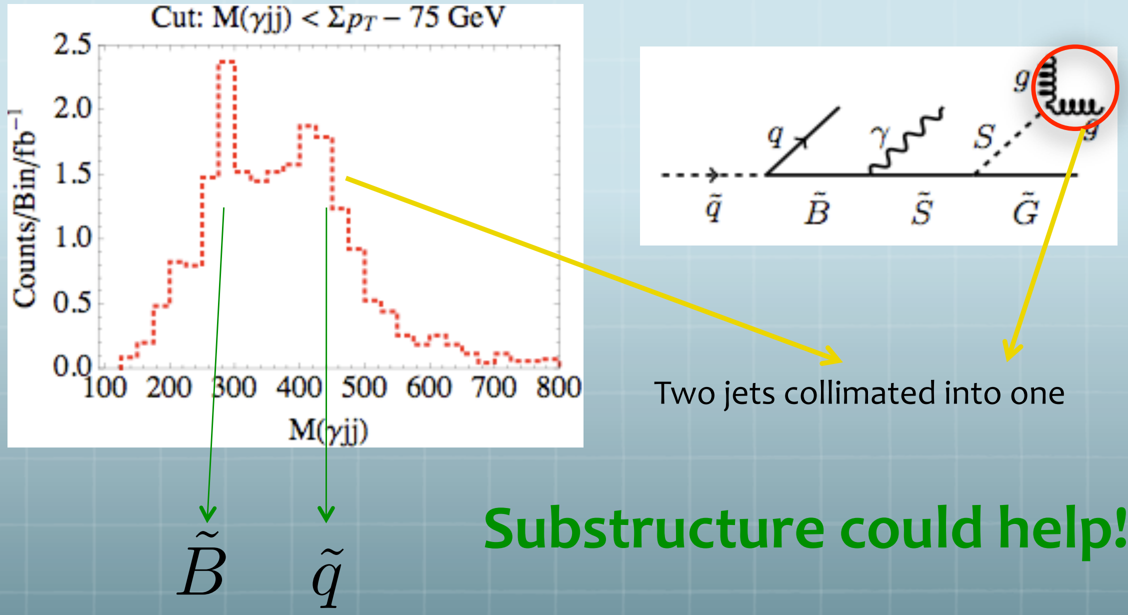
(c) $\beta_t = 0.9, \cos\theta_t = 0.4$

(d) $\beta_t = 0.9, \cos\theta_t = 0.9$

- Relation between top asymmetry and lepton asymmetry $\mathcal{A}^\ell_{FB}$ depends on model and is a powerful tool for discriminating between models

bias new physics reach by using too many features of top decay to tag it?

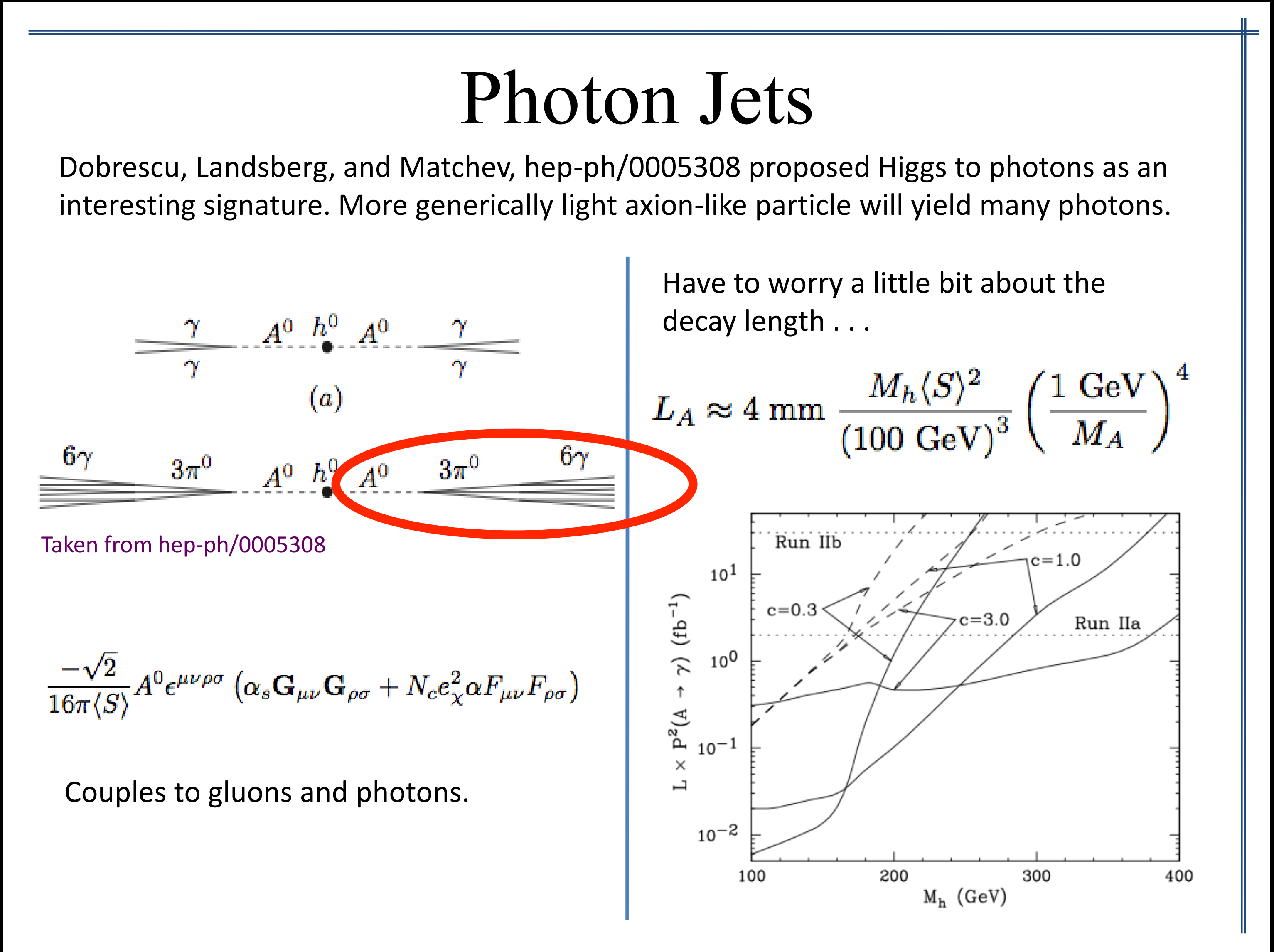
SUSY with unconventional signals



Two jets collimated into one

Substructure could help!

Lepton jets



Photon Jets

Dobrescu, Landsberg, and Matchev, hep-ph/0005308 proposed Higgs to photons as an interesting signature. More generically light axion-like particle will yield many photons.

Taken from hep-ph/0005308

$$\frac{-\sqrt{2}}{16\pi\langle S\rangle}A^0\epsilon^{\mu\nu\rho\sigma}\left(\alpha_s\mathbf{G}_{\mu\nu}\mathbf{G}_{\rho\sigma}+N_c e_\chi^2\alpha F_{\mu\nu}F_{\rho\sigma}\right)$$

Couples to gluons and photons.

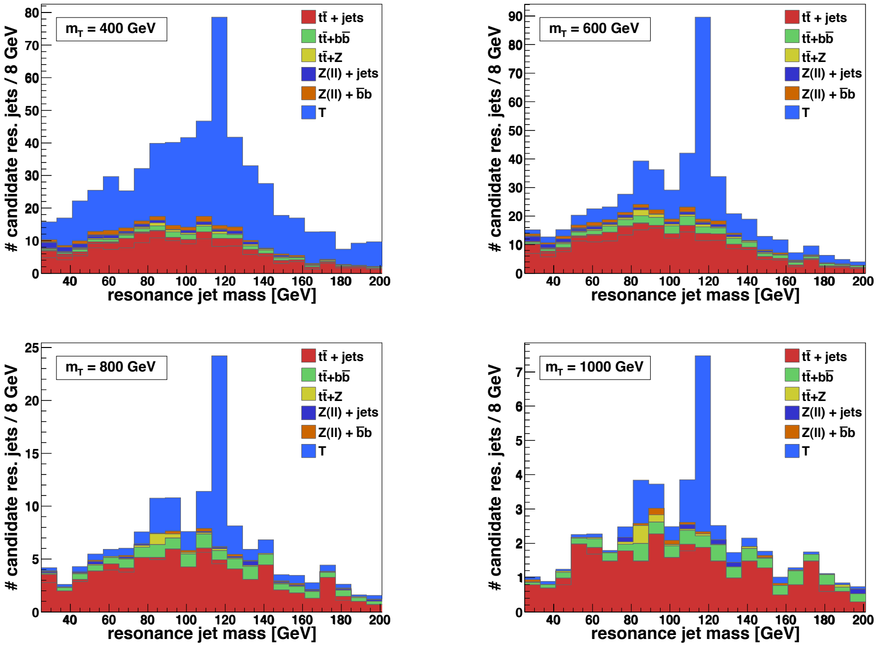
Have to worry a little bit about the decay length . . .

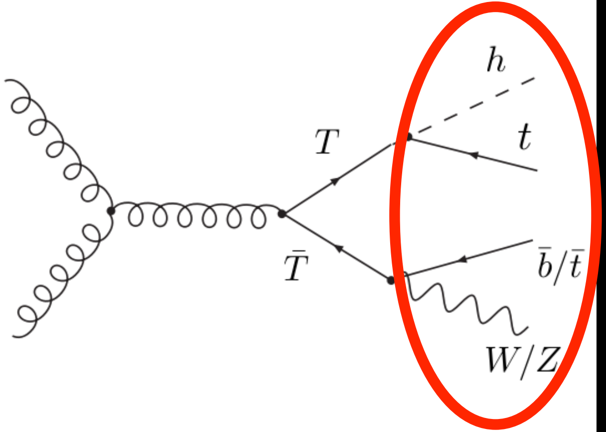
$$L_A \approx 4\ \mathrm{mm}\ \frac{M_h\langle S\rangle^2}{(100\ \mathrm{GeV})^3}\left(\frac{1\ \mathrm{GeV}}{M_A}\right)^4$$

Boosted Higgs from new physics

Top partner production & decay:

10 fb^{-1} @ 14 TeV





KMR 1012.2866

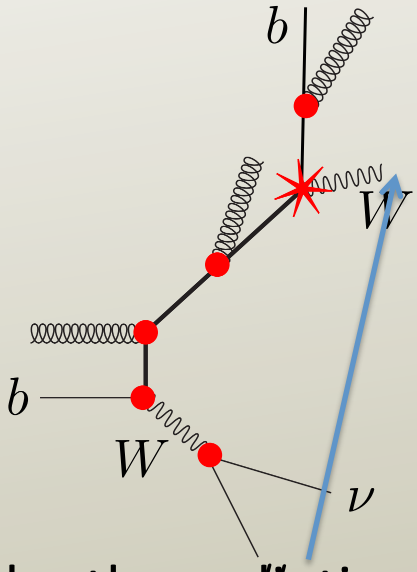
Miscellaneous

- SOPER: Introductory theory talk
- VOS: Overview of Boost 2010

Introductory theory talk

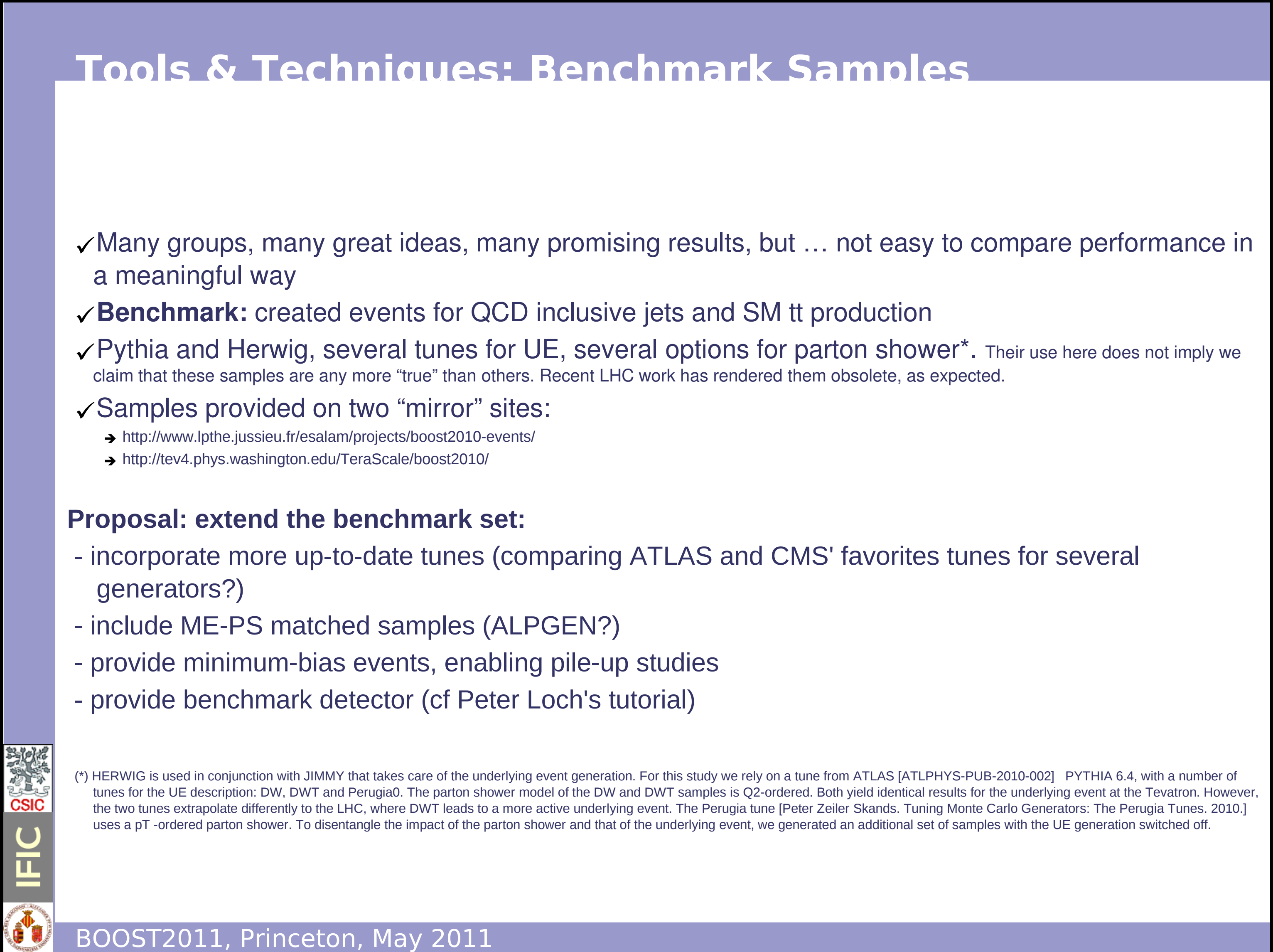
Where does the radiation go?

- The first radiation is from a color dipole of
  - The final state b-quark;
  - The "initial state" t-quark;
- Direction of g is likely collinear with the b.
- Direction of g is likely within angle $M/|\vec{P}_t|$ of the top.
- If the top is highly boosted, this is a narrow cone.



Maybe the radiation zero in the W direction is interesting/useful?

Overview of Boost2010



Tools & Techniques: Benchmark Samples

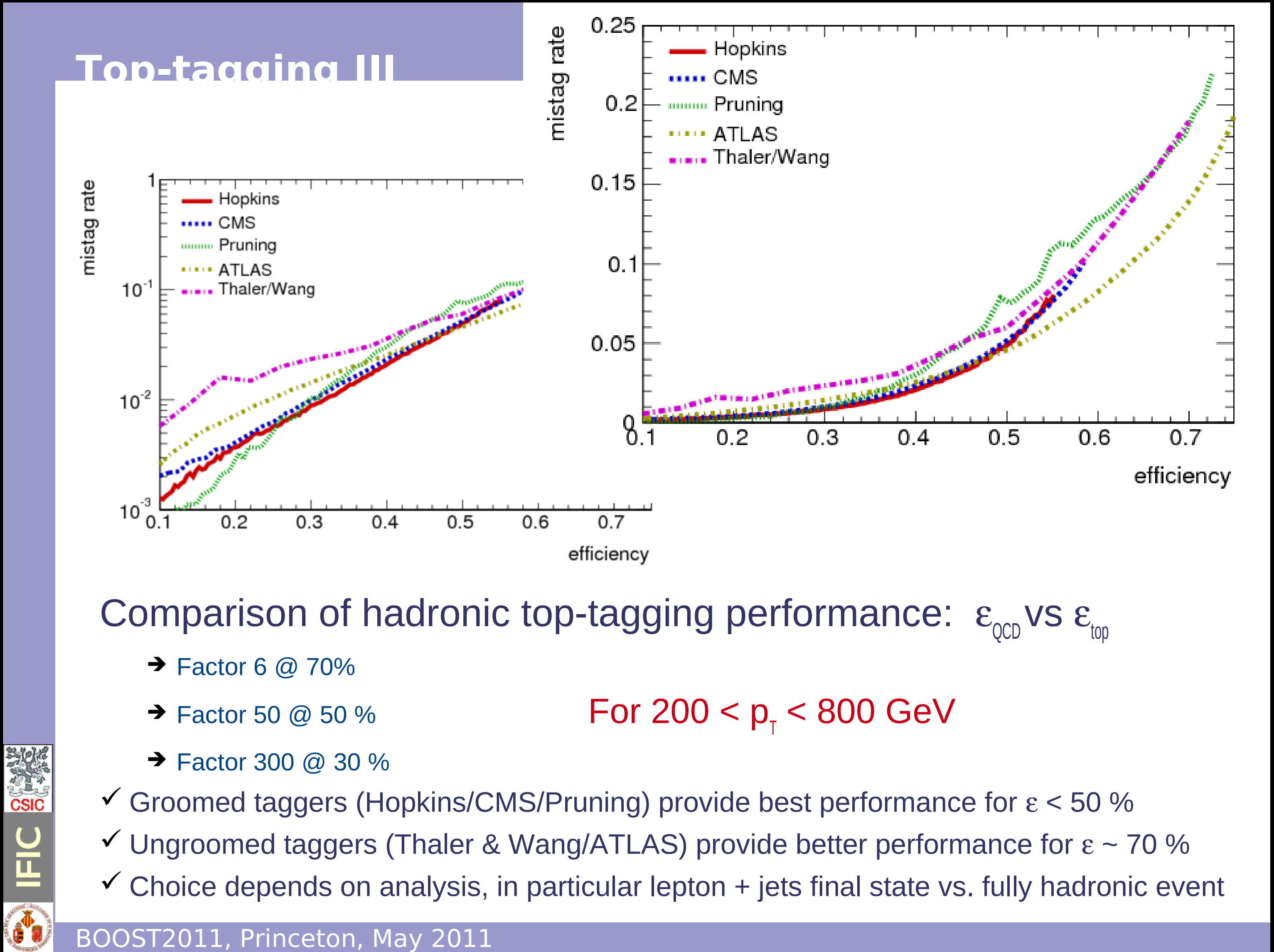
- ✓Many groups, many great ideas, many promising results, but … not easy to compare performance in a meaningful way
- ✓**Benchmark:** created events for QCD inclusive jets and SM tt production
- ✓Pythia and Herwig, several tunes for UE, several options for parton shower*. Their use here does not imply we claim that these samples are any more "true" than others. Recent LHC work has rendered them obsolete, as expected.
- ✓Samples provided on two "mirror" sites:
  - ➔ http://www.lpthe.jussieu.fr/esalam/projects/boost2010-events/
  - ➔ http://tev4.phys.washington.edu/TeraScale/boost2010/

Proposal: extend the benchmark set:

- incorporate more up-to-date tunes (comparing ATLAS and CMS' favorites tunes for several generators?)
- include ME-PS matched samples (ALPGEN?)
- provide minimum-bias events, enabling pile-up studies
- provide benchmark detector (cf Peter Loch's tutorial)

(*) HERWIG is used in conjunction with JIMMY that takes care of the underlying event generation. For this study we rely on a tune from ATLAS [ATLPHYS-PUB-2010-002] PYTHIA 6.4, with a number of tunes for the UE description: DW, DWT and Perugia0. The parton shower model of the DW and DWT samples is Q2-ordered. Both yield identical results for the underlying event at the Tevatron. However, the two tunes extrapolate differently to the LHC, where DWT leads to a more active underlying event. The Perugia tune [Peter Zeiler Skands. Tuning Monte Carlo Generators: The Perugia Tunes. 2010.] uses a pT -ordered parton shower. To disentangle the impact of the parton shower and that of the underlying event, we generated an additional set of samples with the UE generation switched off.

Overview of Boost2010



Top-tagging III

Comparison of hadronic top-tagging performance: ε_{QCD} vs ε_{top}

- ➔ Factor 6 @ 70%
- ➔ Factor 50 @ 50 %
- ➔ Factor 300 @ 30 %

For $200 < p_T < 800$ GeV

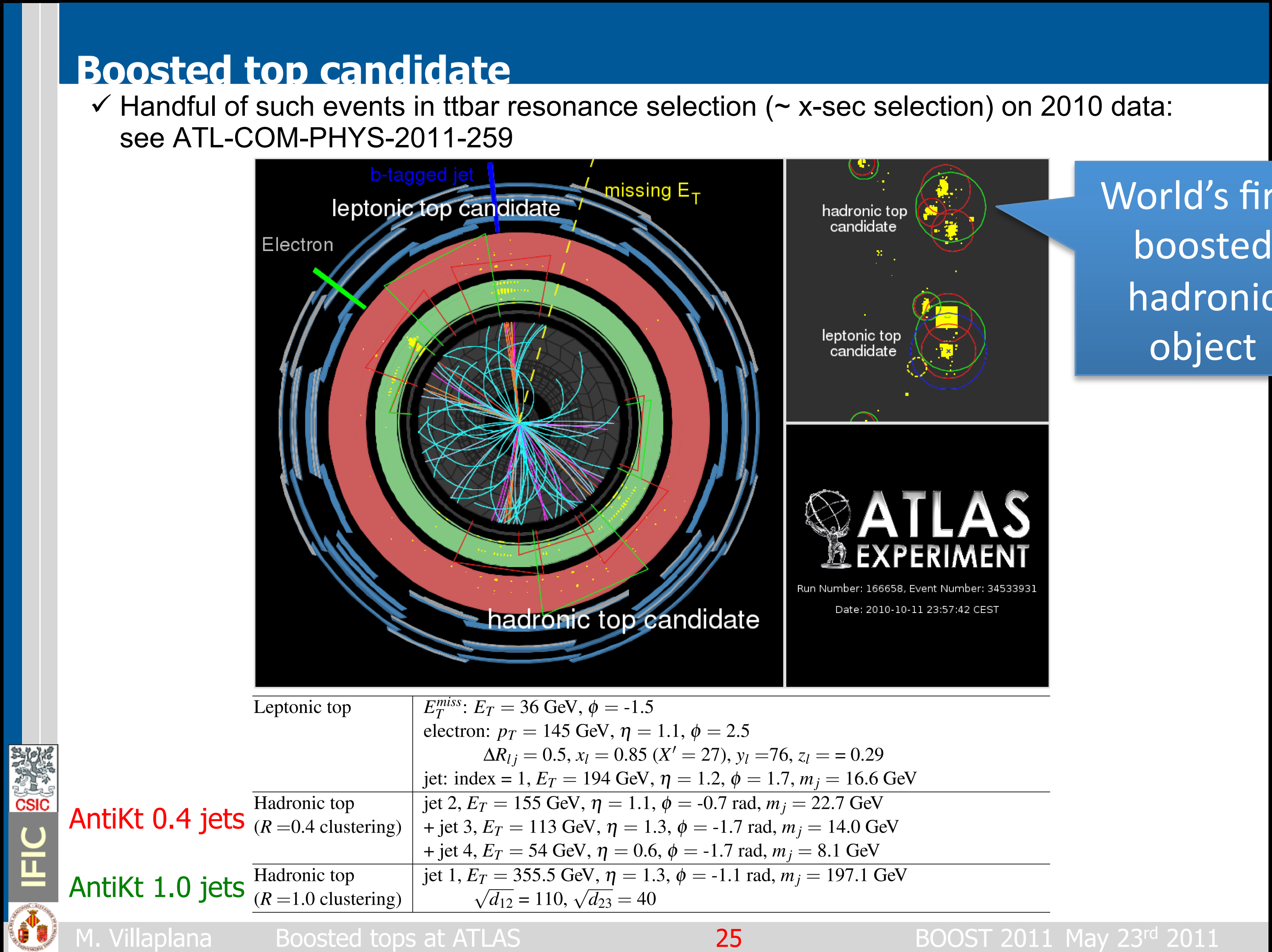
- ✓ Groomed taggers (Hopkins/CMS/Pruning) provide best performance for $\varepsilon < 50$ %
- ✓ Ungroomed taggers (Thaler & Wang/ATLAS) provide better performance for $\varepsilon \sim 70$ %
- ✓ Choice depends on analysis, in particular lepton + jets final state vs. fully hadronic event

BOOST2011, Princeton, May 2011

Summary/outlook

- The study of boosted objects is moving incredibly fast: some ideas 1990-2007 but truly revolutionised in 2008 and already a maturing field with its own conference series
- Much progress and understanding still needed
- But one important new feature this year…

Data!



Boosted top candidate

- ✓ Handful of such events in ttbar resonance selection (~ x-sec selection) on 2010 data: see ATL-COM-PHYS-2011-259

World's first boosted hadronic object

	Leptonic top	E_T^{miss}: $E_T = 36$ GeV, $\phi =$ -1.5 electron: $p_T = 145$ GeV, $\eta = 1.1$, $\phi = 2.5$ $\Delta R_{lj} = 0.5$, $x_l = 0.85$ ($X' = 27$), y_l =76, $z_l = = 0.29$ jet: index = 1, $E_T = 194$ GeV, $\eta = 1.2$, $\phi = 1.7$, $m_j = 16.6$ GeV
AntiKt 0.4 jets	Hadronic top (R =0.4 clustering)	jet 2, $E_T = 155$ GeV, $\eta = 1.1$, $\phi =$ -0.7 rad, $m_j = 22.7$ GeV + jet 3, $E_T = 113$ GeV, $\eta = 1.3$, $\phi =$ -1.7 rad, $m_j = 14.0$ GeV + jet 4, $E_T = 54$ GeV, $\eta = 0.6$, $\phi =$ -1.7 rad, $m_j = 8.1$ GeV
AntiKt 1.0 jets	Hadronic top (R =1.0 clustering)	jet 1, $E_T = 355.5$ GeV, $\eta = 1.3$, $\phi =$ -1.1 rad, $m_j = 197.1$ GeV $\sqrt{d_{12}} = 110$, $\sqrt{d_{23}} = 40$