LHC Detectors and Early Physics

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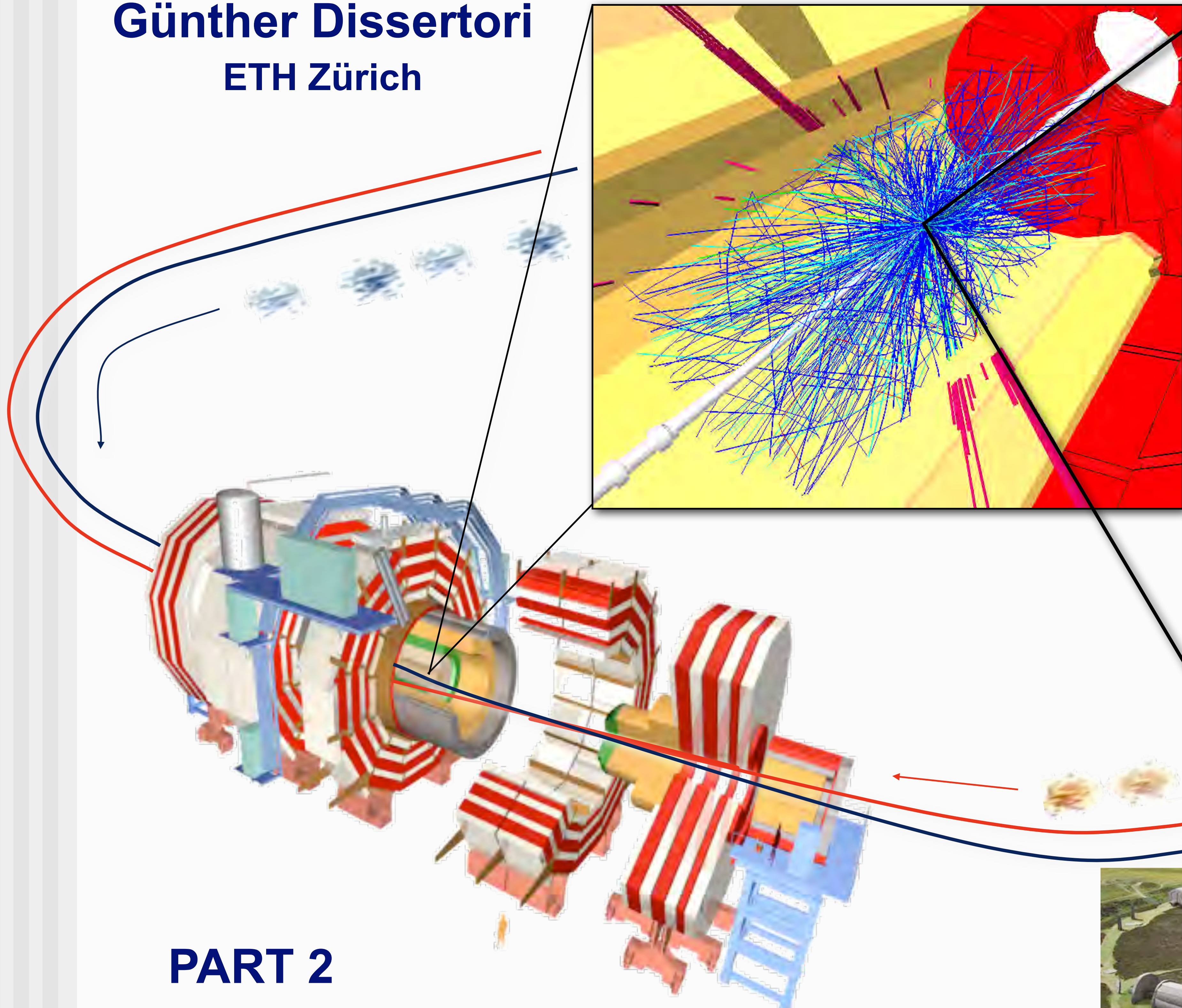
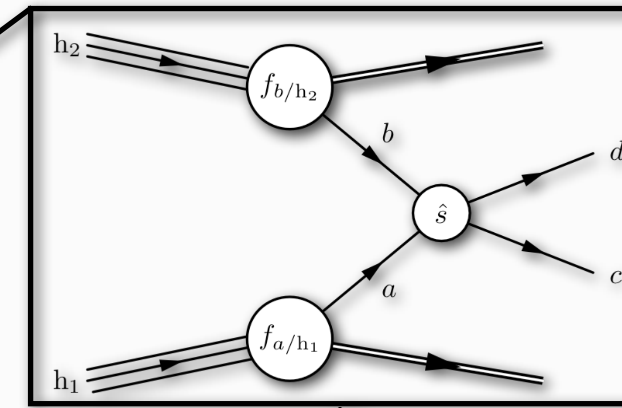
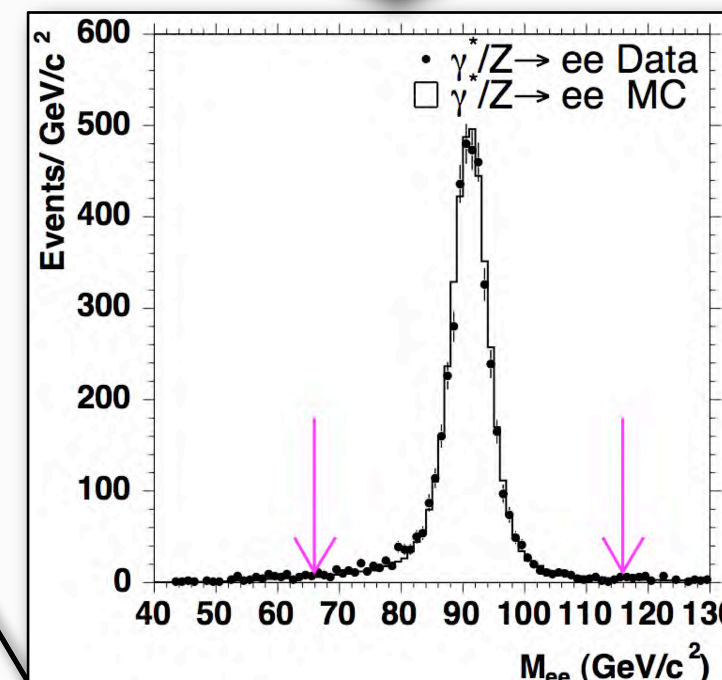


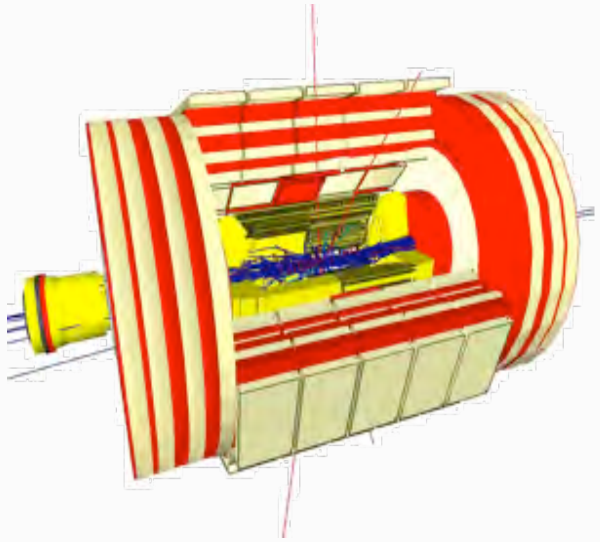


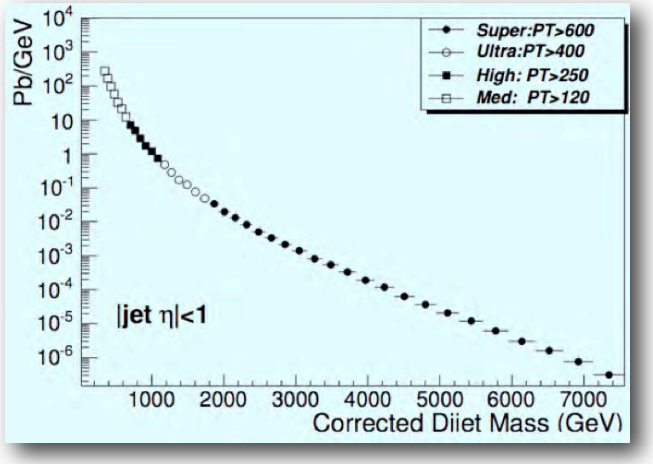


PART 2

Outline Part 2

- Introduction
  - Basic processes, rates
- Low-pT and QCD
  - Minimum Bias, UE, MPI
  - Jet cross sections
- Electroweak Physics
  - W and Z production
  - + jets
- Top Physics
- Further Issues





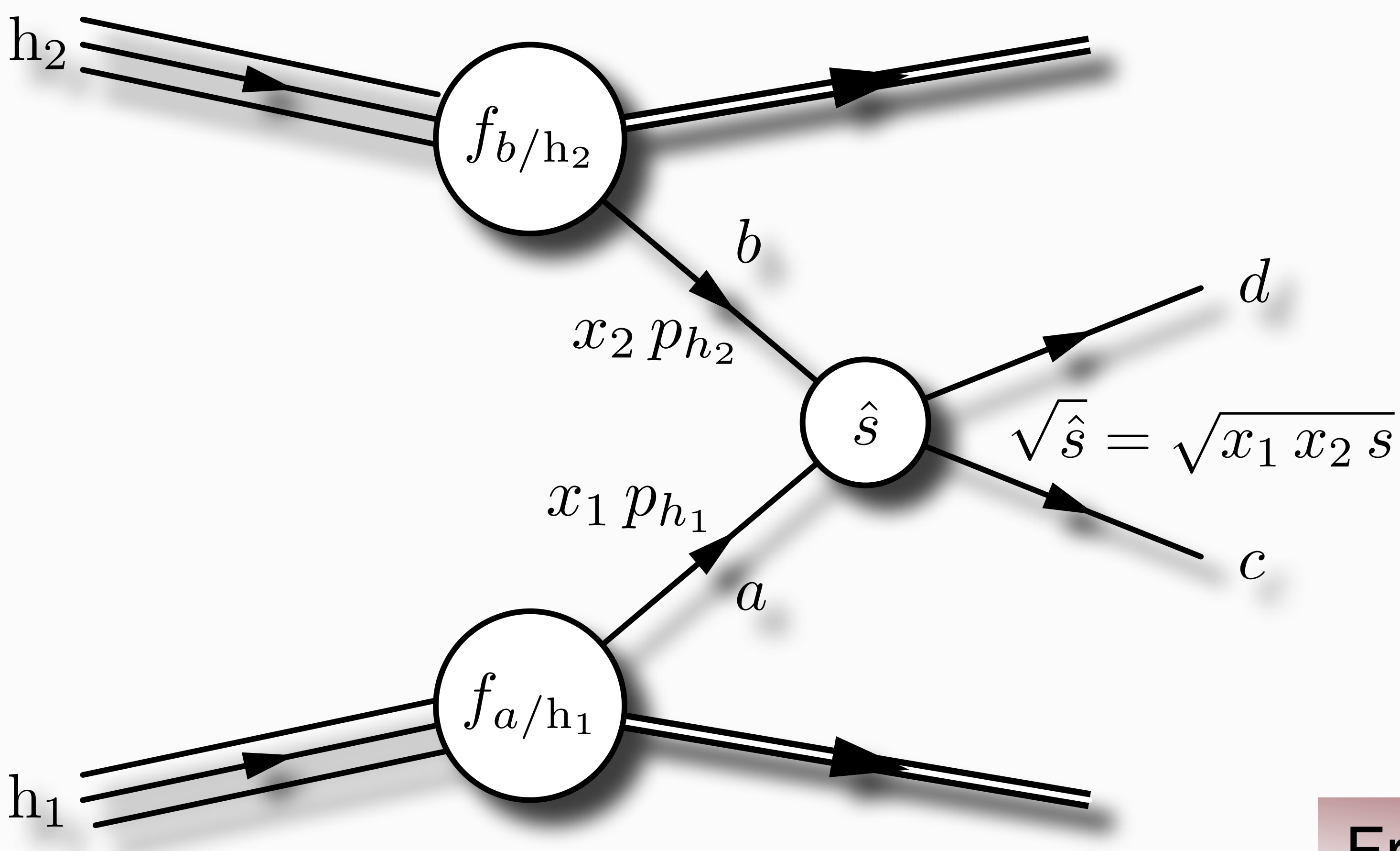
Disclaimer 1 : I concentrate on multi-purpose detectors ATLAS and CMS and high-p_T physics. Some bias towards CMS, for practical reasons only ;-) Nothing on LHCb and ALICE....

Disclaimer 2 : Some slides or slide content taken from seminars/lectures/write-ups of other LHC colleagues, eg. K. Jakobs, O. Buchmüller, L. Dixon, M. Dittmar, D. Froidevaux, F. Gianotti, D. Green, J. Virdee, ...

Excellent resources : CMS Physics TDR, CMS-TDR-008-1; ATLAS Overview: arXiv:0901.0512; https://twiki.cern.ch/twiki/bin/view/CMS/PhysicsResults

Introduction : Measurements of hard processes

The hard scattering



To produce (at central rapidity, ie. $x_1 \sim x_2$) a mass of

	LHC	TEVATRON
100 GeV	x~0.007	0.05
5 TeV	x~0.36	--

From where do we know these?

$$d\sigma(h_1 h_2 \to cd) = \int_0^1 dx_1 dx_2 \sum_{a,b} f_{a/h_1}(x_1, \mu_F^2) f_{b/h_2}(x_2, \mu_F^2) d\hat{\sigma}^{(ab\to cd)}(Q^2, \mu_F^2)$$

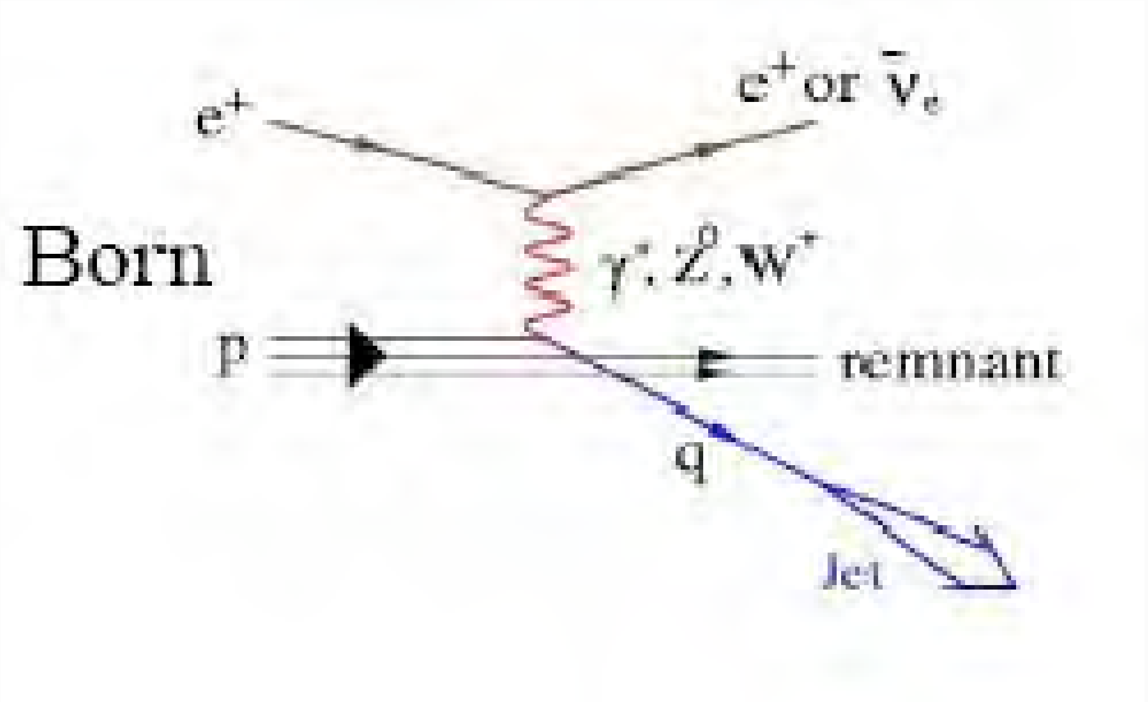
Hard Scattering = processes with large momentum transfer (Q^2)

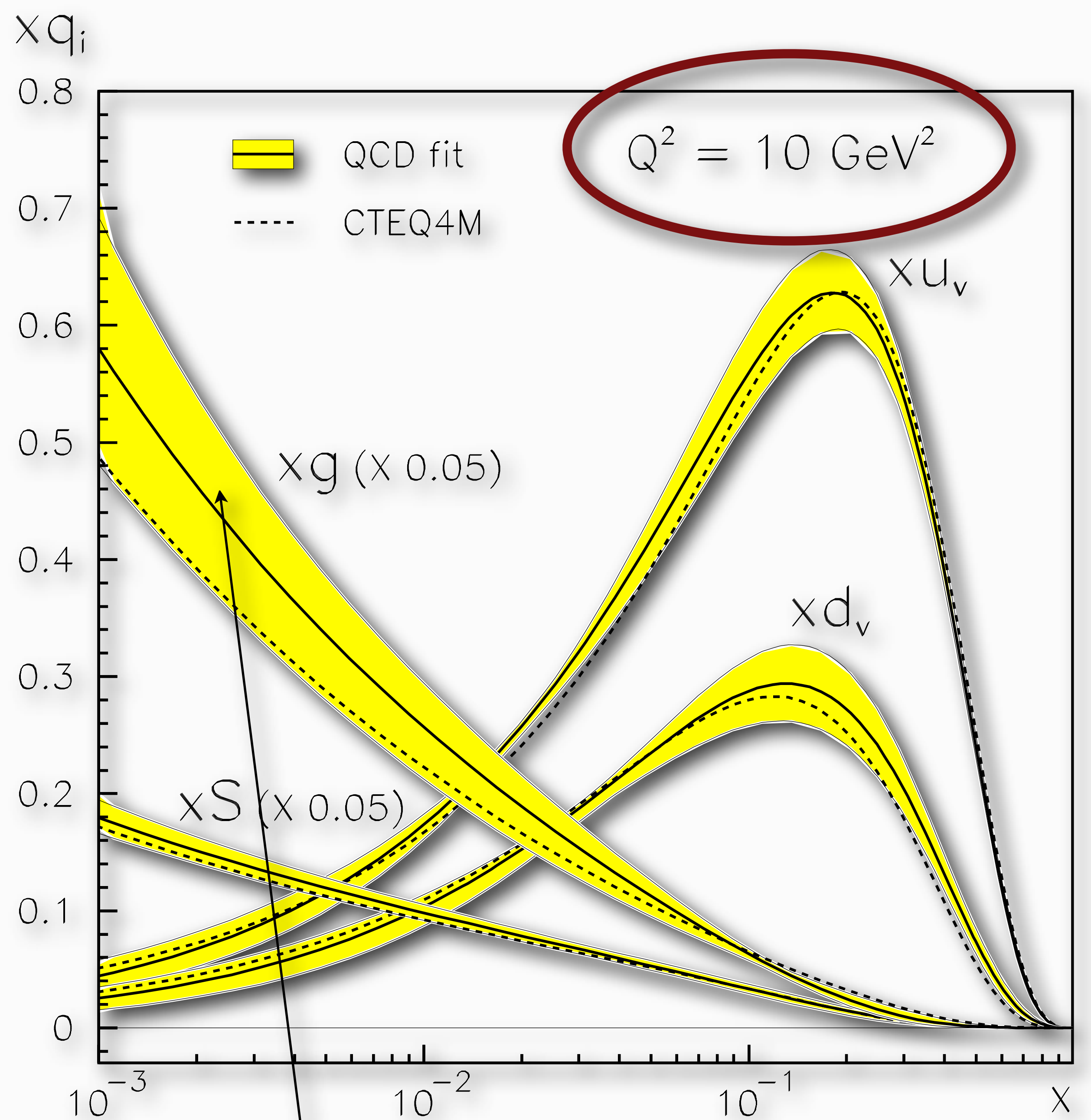
Represent only a tiny fraction of the total inelastic pp cross section (~ 70 mb)

eg. $\sigma(pp \to W+X) \sim 150$ nb $\sim 2 \cdot 10^{-6}\ \sigma_{tot}(pp)$

Parton Distribution functions

HERA ep accelerator, 6.3 km circumference





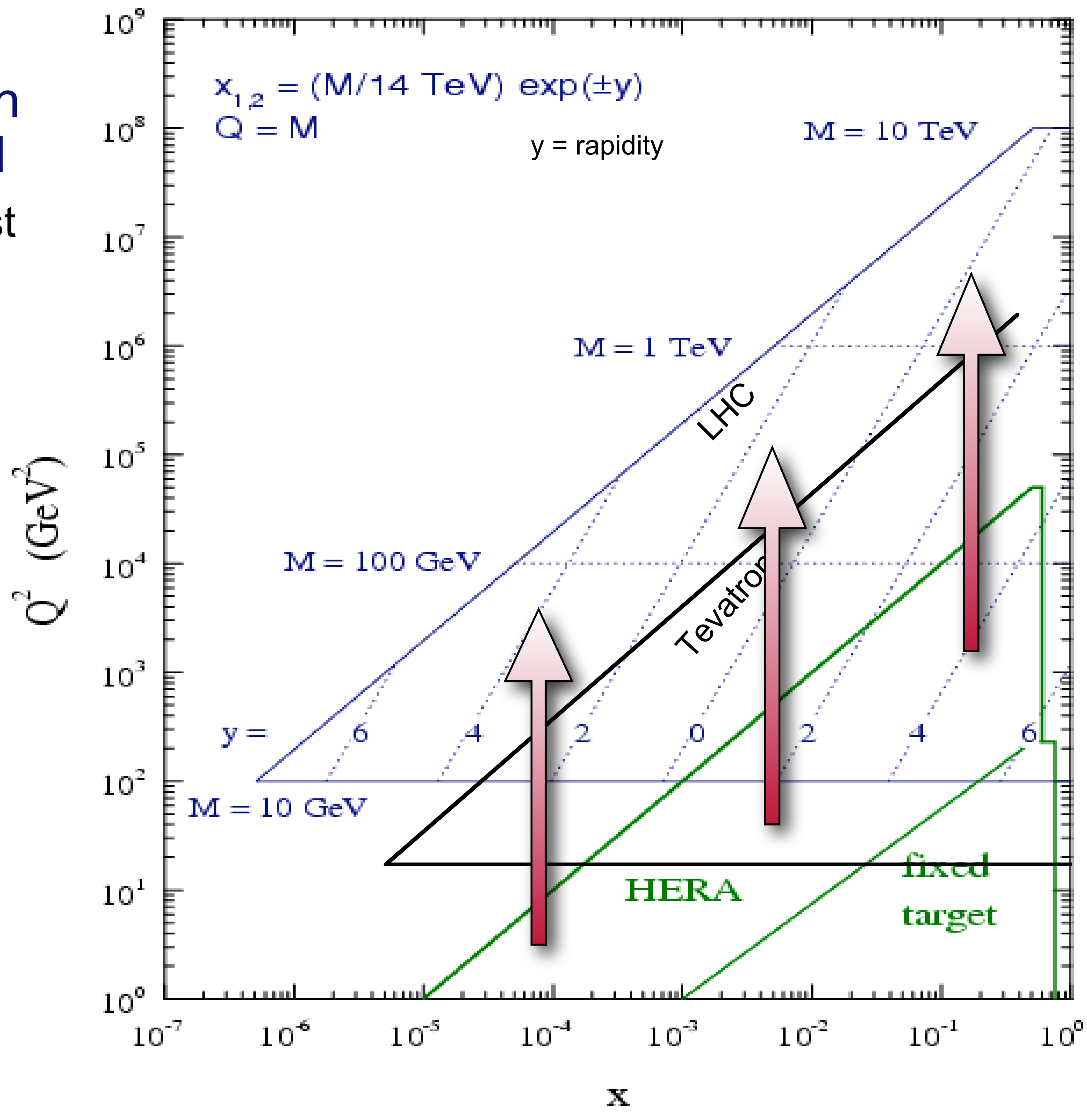
gluons dominate at low x !

Scattering of 30 GeV electrons on 900 GeV protons:
→ Test of proton structure down to 10^{-18} m

→ the LHC is a gluon-gluon collider !

Parton Distribution functions

- Kinematic regime for LHC much broader than currently explored
  - for example, HERA covers most of the relevant x range, but at much smaller values of Q^2
- Is NLO DGLAP evolution sufficient for LHC?
- Have to propagate correctly the uncertainties of PDF determinations into predictions of LHC processes
  - important when comparing to data
- Have to determine / constrain the pdfs at LHC itself
  - what are useful processes for this?



Event rates (at 14 TeV....)

Event production rates at $L=10^{33}$ cm^{-2} s^{-1} and statistics to tape

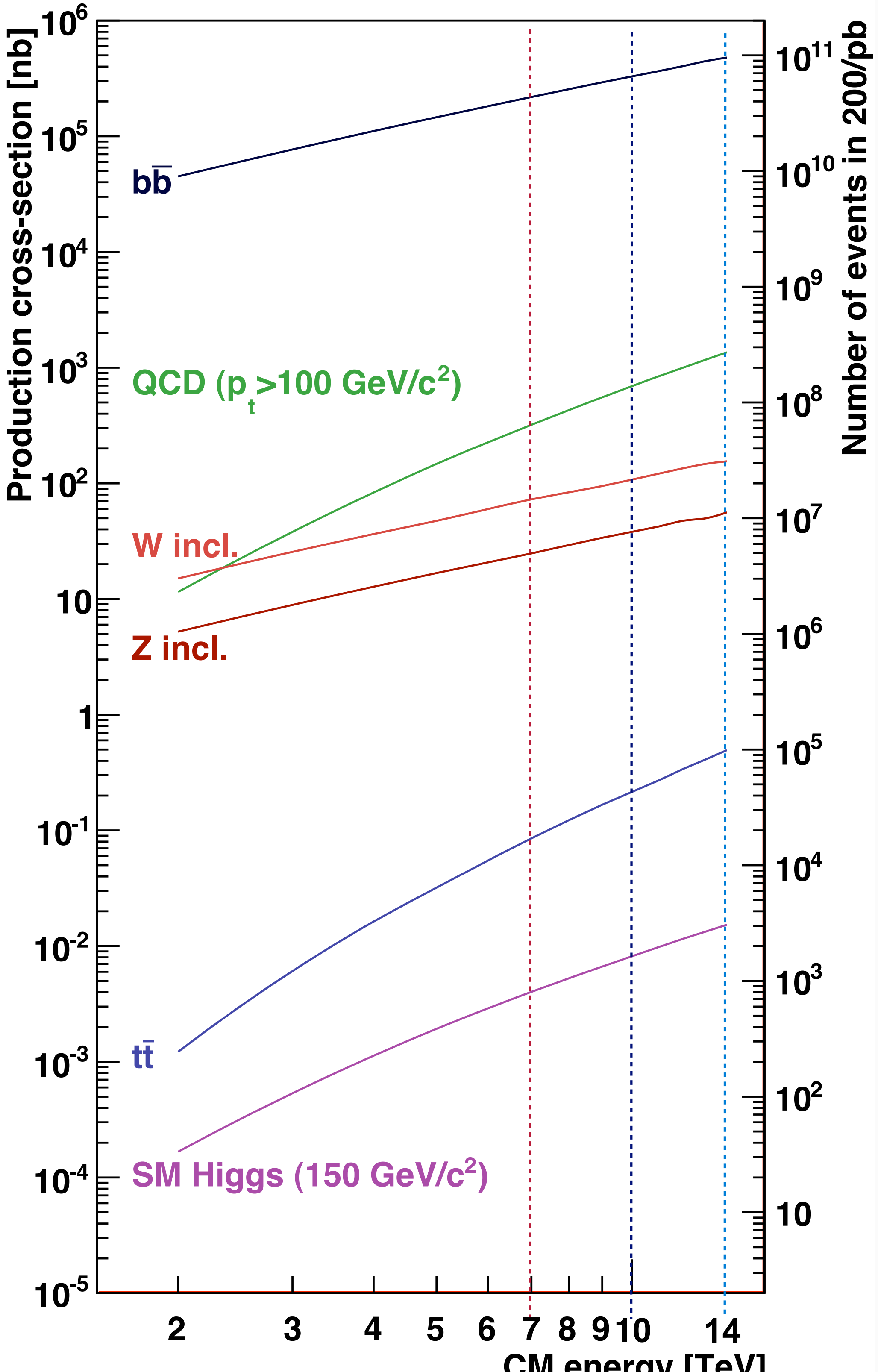
Process	Events/s	Evts on tape, 10 fb^{-1}
$W \to e\nu$	15	10^8
$Z \to ee$	1	10^7
$t\bar{t}$	1	10^6
Minimum bias	10^8	10^7
QCD jets p_T>150 GeV/c	10^2	10^7
$b\bar{b} \to \mu X$	10^3	10^7
gluinos, m=1 TeV	0.001	10^3
Higgs, m=130 GeV	0.02	10^4

assuming 1% of trigger bandwidth

10^7 events to tape every 3 days, assuming 30% data taking efficiency, 1 PB/year/exp

statistical error negligible after few days (in most cases) !
dominated by systematic errors (detector understanding, luminosity, theory)

We will start at a lower E_{cm}



thanks to F. Ronga

LO cross sections in pb, inclusive

E_{cm} [TeV]/ Process	7	10	14	Evts (7 TeV) in 200/pb	Ratio 7/14
QCD pt>100 GeV	3.2E+05	6.8E+05	1.4E+06	6.4E+07	0.2
Z incl	2.5E+04	3.6E+04	5.7E+04	5.0E+06	0.4
W incl	9.5E+04	1.4E+05	2.1E+05	1.9E+07	0.5
ttbar	8.4E+01	2.2E+02	4.8E+02	1.7E+04	0.2
H(150 GeV)	4.0	8.2	16.0	8.0E+02	0.3

no branching ratios included !

- Thus: Early physics at E_{cm} = 7 TeV means
  - QCD (low and high-pT)
  - Exclusive B production
  - EWK (Z,W) physics
  - some top (not too much, but should be ok)
  - no SM Higgs
  - some surprise ?

First Physics runs (2010 …)

- After first "good" 10 pb^{-1}
  - plenty of Min Bias events, many jets...
  - ~20000 W, decaying to lepton + neutrinos
  - ~2500 Z, decaying into two leptons
  - ~200 semi-leptonic top-pair events
    - Measure rates, align and calibrate better

- After first "good" 100 pb^{-1}
  - W(Z)+jets rates well measurable
    - Jet calibration, MET calibration (for SUSY)
  - Inclusive leptons, di-leptons, photons, di-photon triggers (for Higgs)

- From 100 pb^{-1} to 1 fb^{-1} (part of it not in 2010)
  - Standard model candles
    - Top pair prod., W/Z cross sections, PDF studies, QCD studies, b-jet production
    - Do extensive MC tuning
  - Early Higgs boson search, exclusions
    - $H \rightarrow \gamma\gamma$,WW,ZZ
  - Early SUSY-BSM searches
    - MET + anything, di-jet, di-leptons, di-photon, resonances….

Why SM physics?

- Interesting in its own right
  - measure (calculable) event rates, cross sections
  - establish (dis)agreement with SM, constrain SM
  - challenge theoretical calculations at high Q^2
  - demonstrate “working” experiment with well known processes
- Understanding, commissioning, calibration of detector and the software. eg. well suited : $Z \rightarrow \ell^+\ell^-$
- Backgrounds to many searches : check MC simulations
  - eg. W/Z+jets, Multi-Jets, top-pair events
- Constrain (relative) PDFs
- Alternative measurements of luminosity

Our Master Equation

Event rates (absolute, relative, differential)
Stat vs syst errors, backgrounds from data or MC?
Resolution, Energy Scale, Signal Significance

$$\sigma_{\mathrm{meas}} = \frac{N_{\mathrm{obs}} - N_{\mathrm{bkg}}}{\varepsilon \quad L}$$

Proton-Proton Luminosity uncertainty ~ 5% ? Do better?

Experimental issues : Triggers, reconstruction, isolation cuts, low-p_T jets (jet veto)
efficiency determination (tag&probe)

Theoretical issues : p_T distributions at NLO + resummation;
differential calculations for detectable acceptance.

$$\sigma_{\mathrm{theo}} = PDF(x_1, x_2, Q^2) \otimes \hat{\sigma}_{\mathrm{hard}}$$

constrain, define uncertainties

HO calculations, implement in MC

Goal : test SM (in)consistency : $\sigma_{\mathrm{exp}} \pm \Delta_{\mathrm{exp}} \stackrel{?}{=} \sigma_{\mathrm{SM}} \pm \Delta_{\mathrm{th}}$

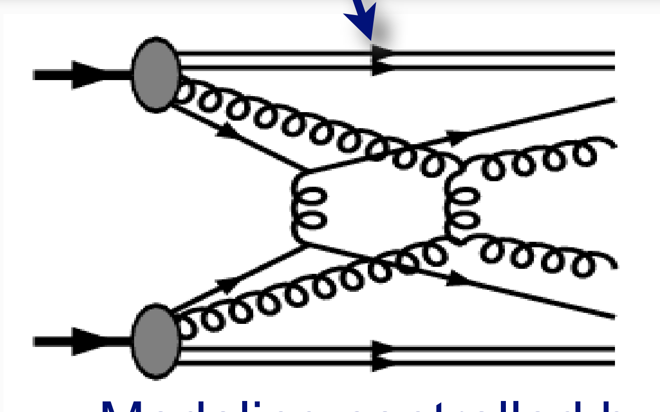
Measurements of "soft" processes (low p_T)

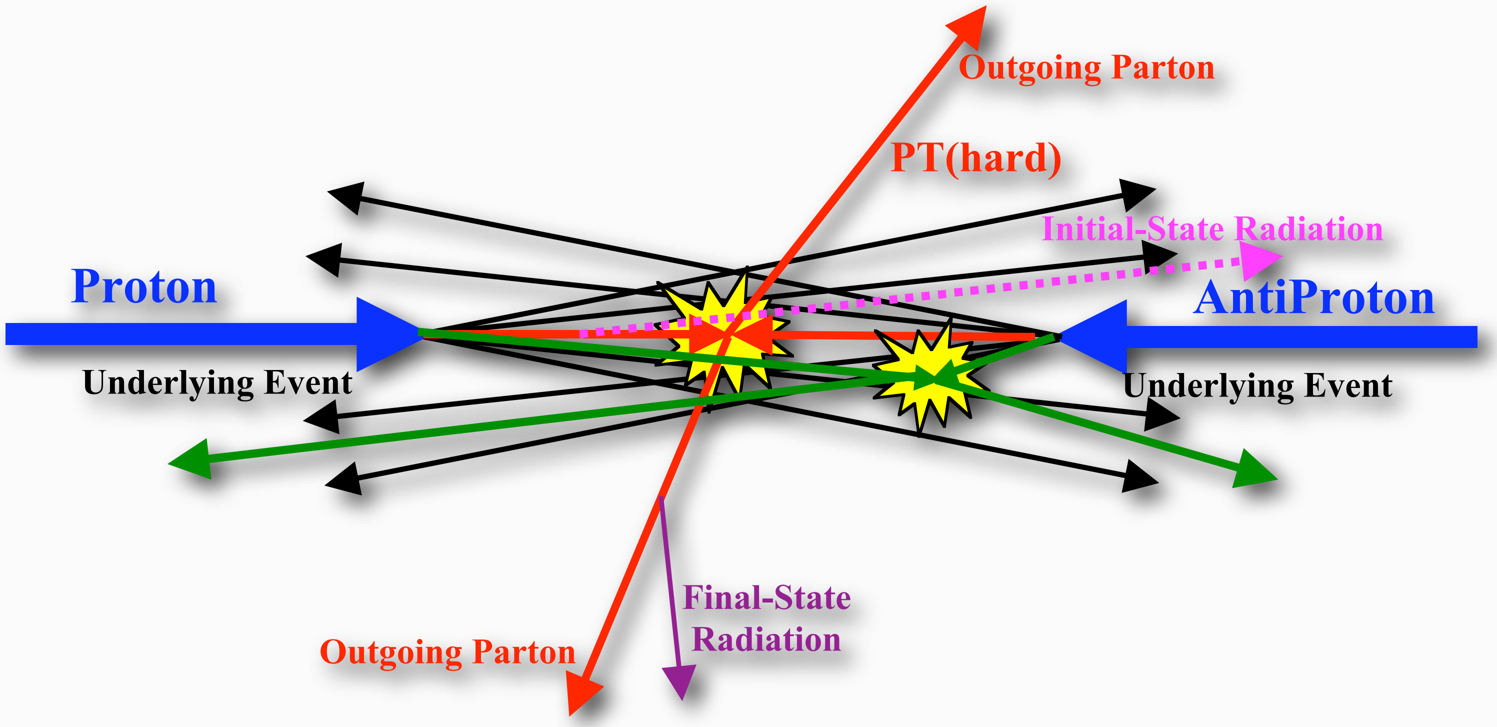
Underlying Event : Definition

The Underlying Event:

Everything except the hard scattering component of the collision:

ISR, FSR,
spectators,
beam-beam remnant
multiple-parton interactions





Modeling controlled by p_T cut-off parameter:
Controls number of interactions

$$< N_{\rm int} >= \frac{\sigma_{\rm parton-parton}}{\sigma_{\rm proton-proton}}$$

and hence the multiplicity.

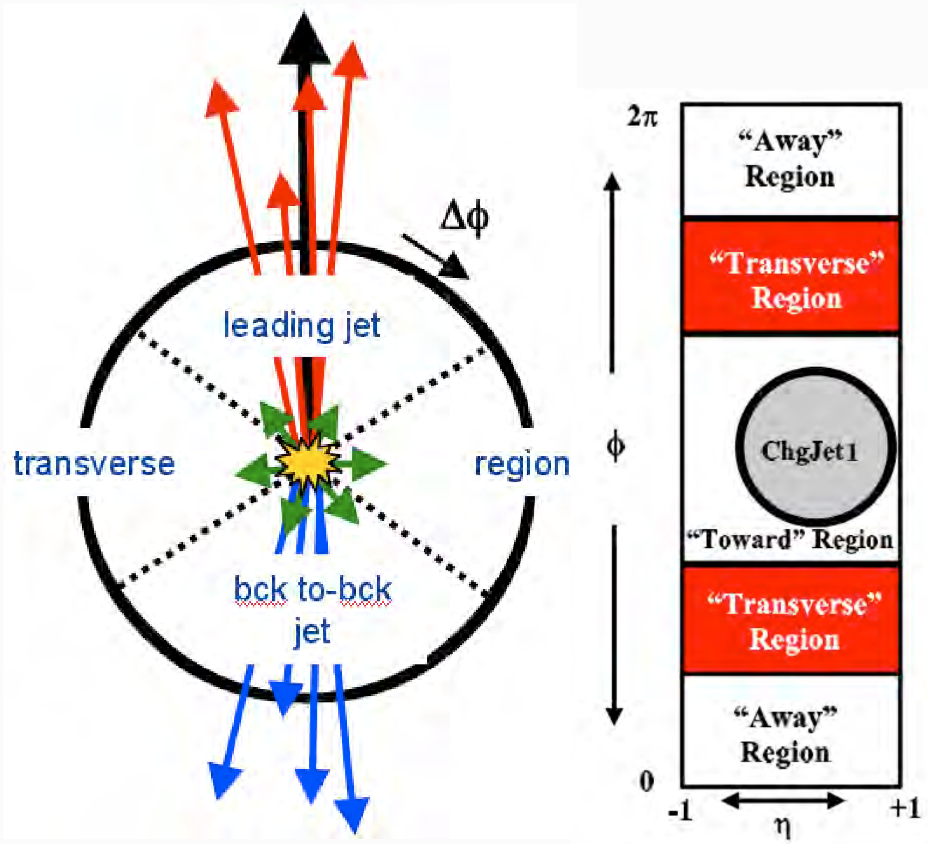
Tuning for LHC: issue is the energy dependence of the parameters

Issues / interesting questions / Motivations:

- Note : UE != MB
- Structure of hadrons, factorization of interactions
- Tuning of MC models, extrapolation to LHC energies
- Detector commissioning
- impact on selection efficiencies (isolation), jet energy scale, MET, low-pT jets, jet vetos

UE studies : Observables

see CDF study, R. Field et al.



Using Charged Jets (using MB and jet triggers)

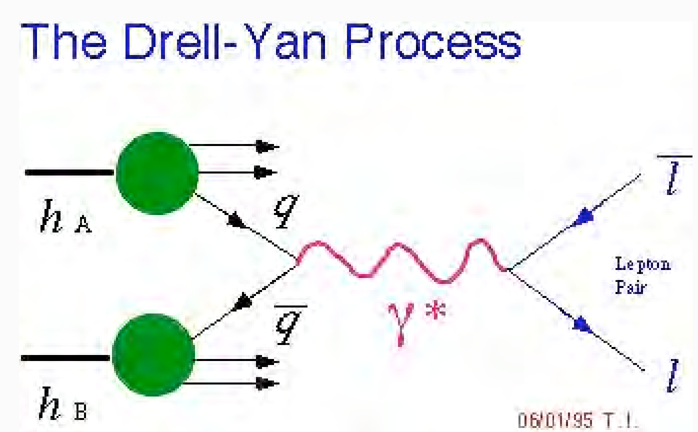
- Topological structure of p-p collision from charged tracks
- Jets found with massless charged tracks as input
- The leading Ch_jet1 defines a direction in the phi-plane
- The transverse region is particularly sensitive to the UE

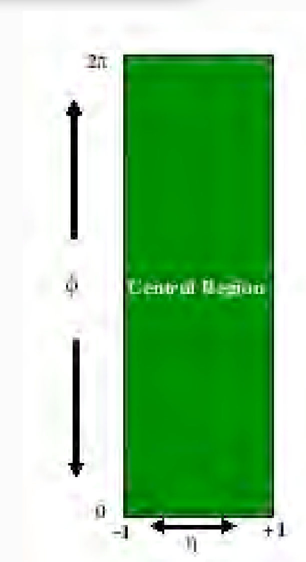
Main observables:

$dN/d\eta d\Phi$	charged density
$d(PT_{sum})/d\eta d\Phi$	energy density

From DY muon-pair production (using muon triggers)

- defined in all the phi-plane
- after removing the muon pairs, everything else is UE





Minimum Bias

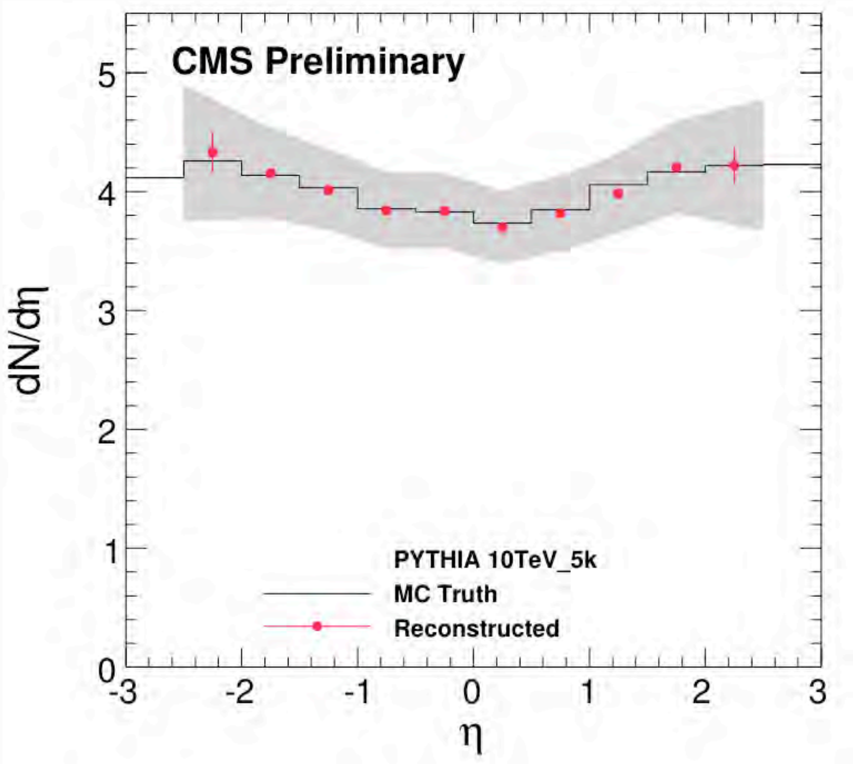
- chg. tracks : multiplicity, p_T, rapidity distributions
- chg. multiplicity versus effective energy = E_{beam} - $E_{leading\ baryon}$

Note :

need corrections for
track reco eff. and acceptance

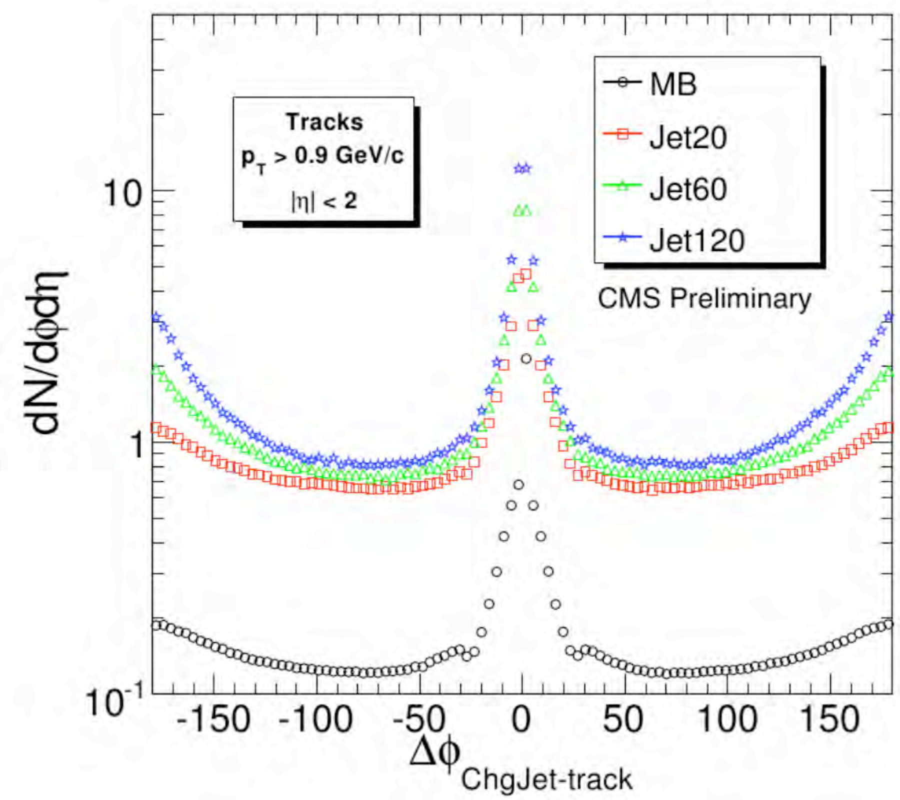
Examples of "Measurements"

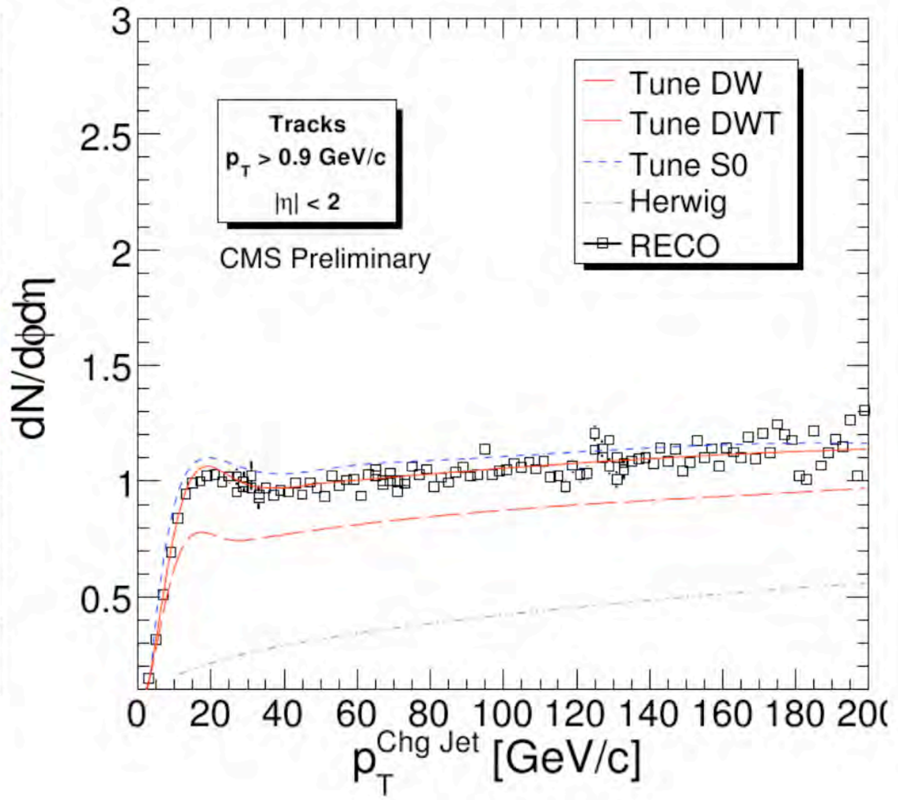
Inclusive charged particle production



Remarks / Issues

- Only a few thousands good events needed !
- try to go to lowest p_T possible (even to 100 MeV!), eg. just using pixel hit triplets
- have to carefully extrapolate to full acceptance
- systematic uncertainties at the level of 7 - 10 %

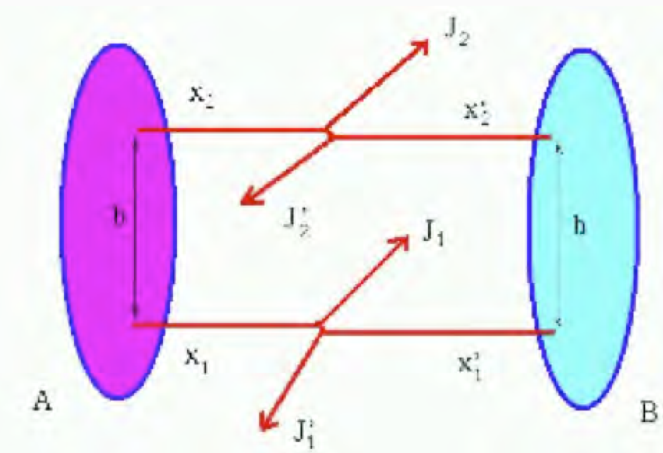




- UE tests: sensitive to various models and tunings...

Multiple Parton Interactions

- New handles to estimate
  multiple partonic interaction rates
  - count pairs of mini-jets in MB interactions, reconstructed using charged tracks
  - same-sign W-pair production
    - based on D. Treleani, Phys. Rev. D72, 034022(2005)



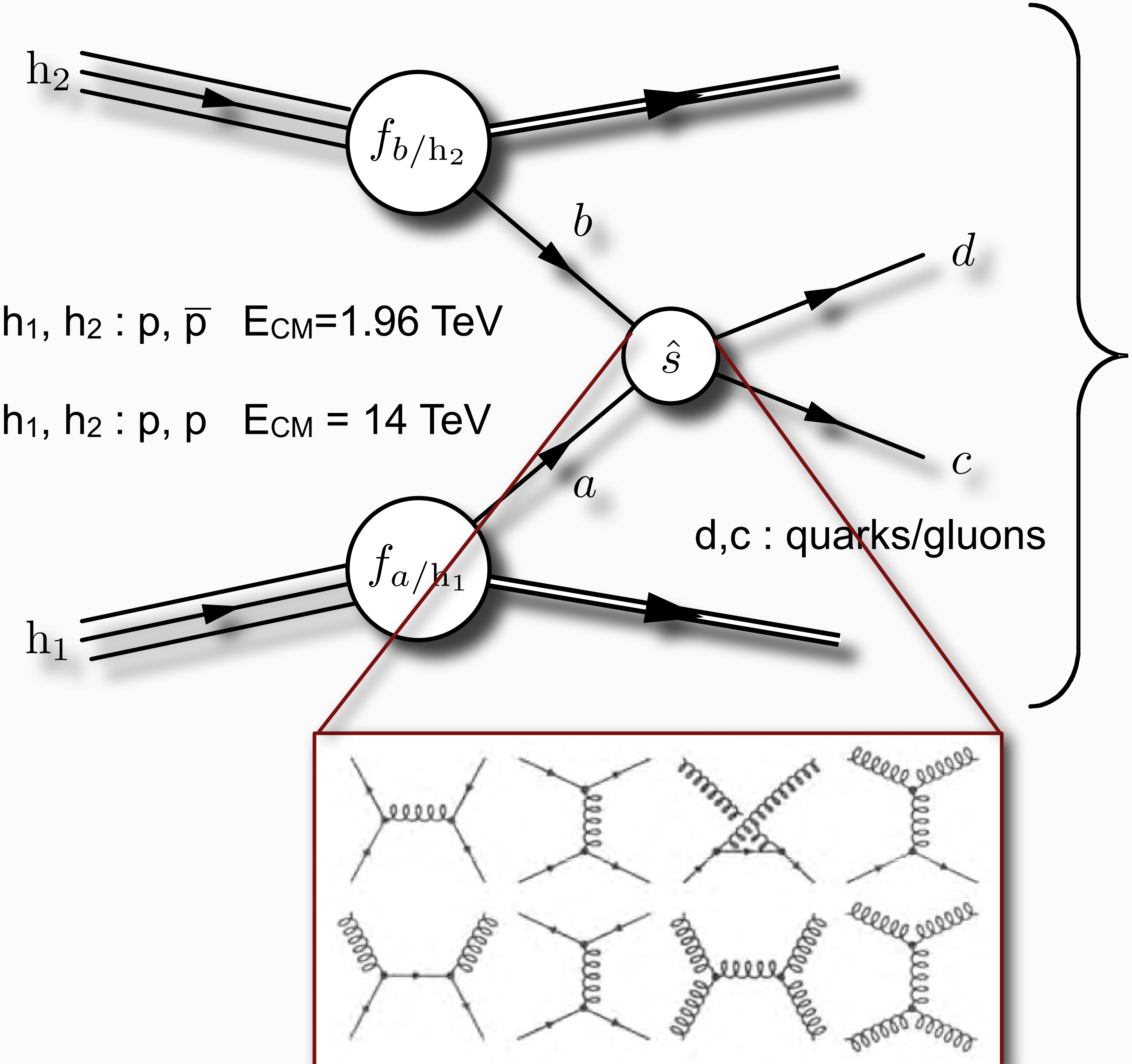
- new MPI models in PYTHIA
  - impact on jet cross sections studied
  - models have to be tuned on data

- should we be worried?
  - a surprise in the rate of additional jets above 20-30 GeV because of MPI could have considerable impact on jet vetos...

Jets

JET production at hadron colliders

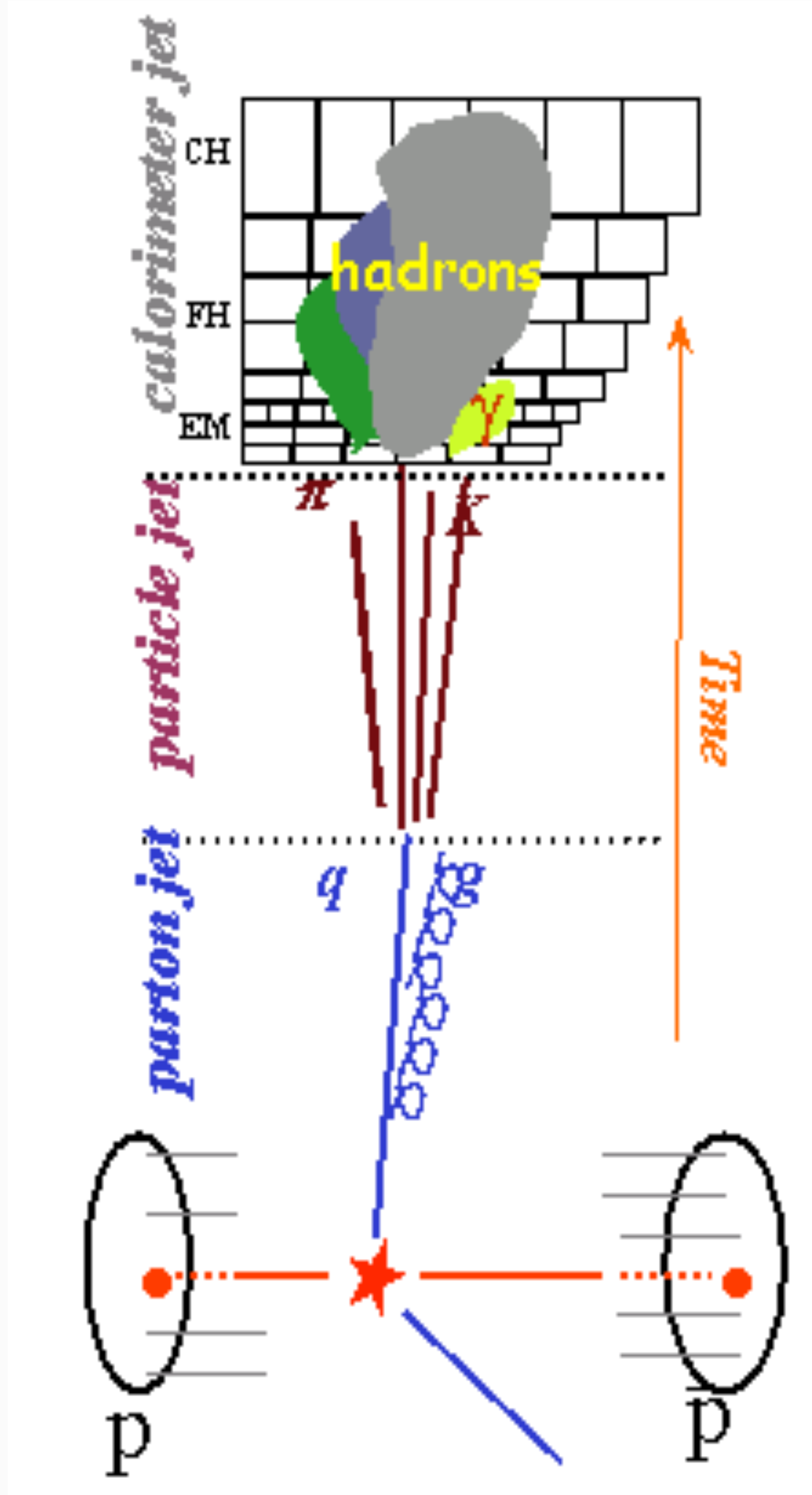
- at the Tevatron, or in the future at the LHC



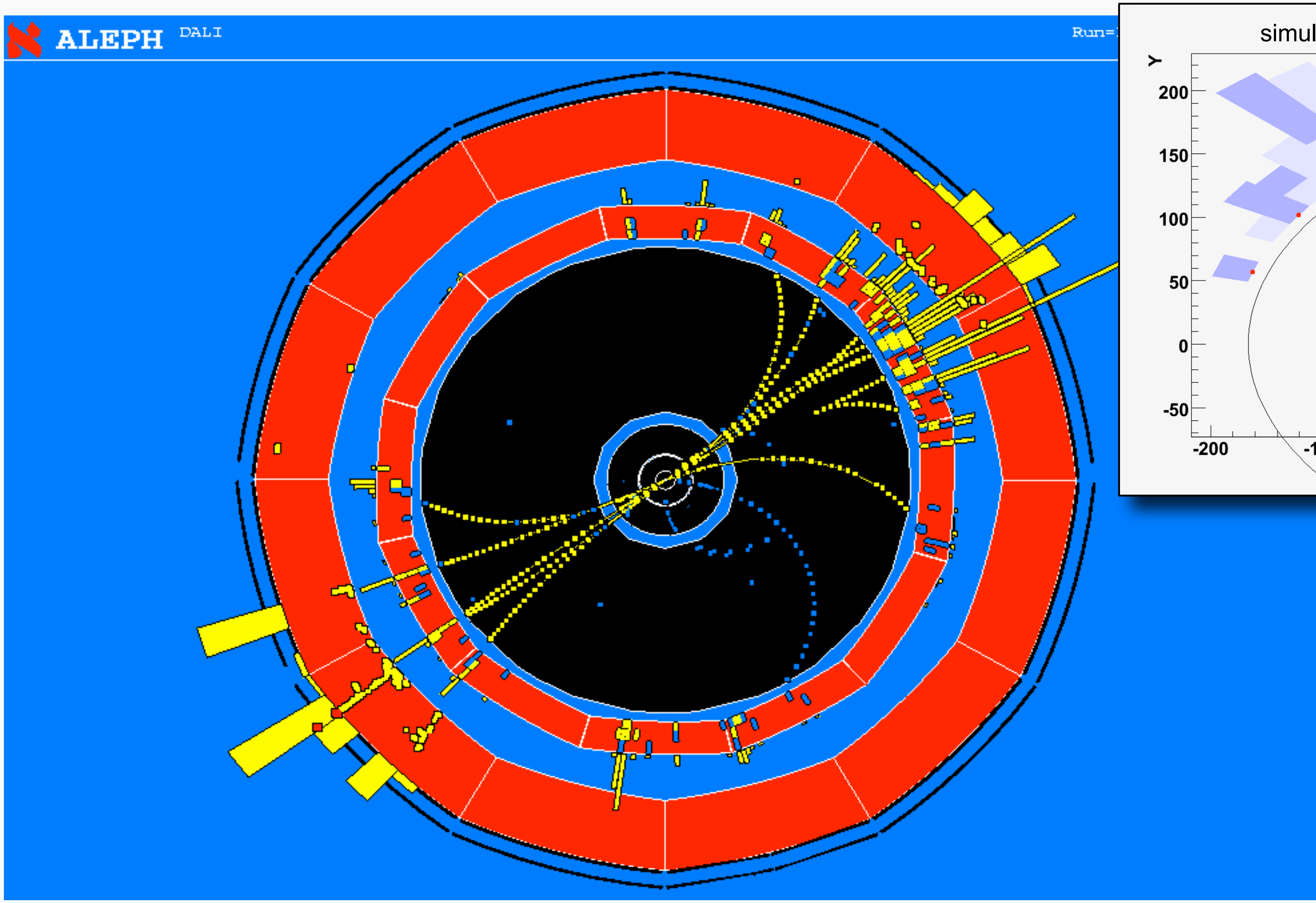
h_1, h_2 : p, $\bar{p}$ E_{CM}=1.96 TeV

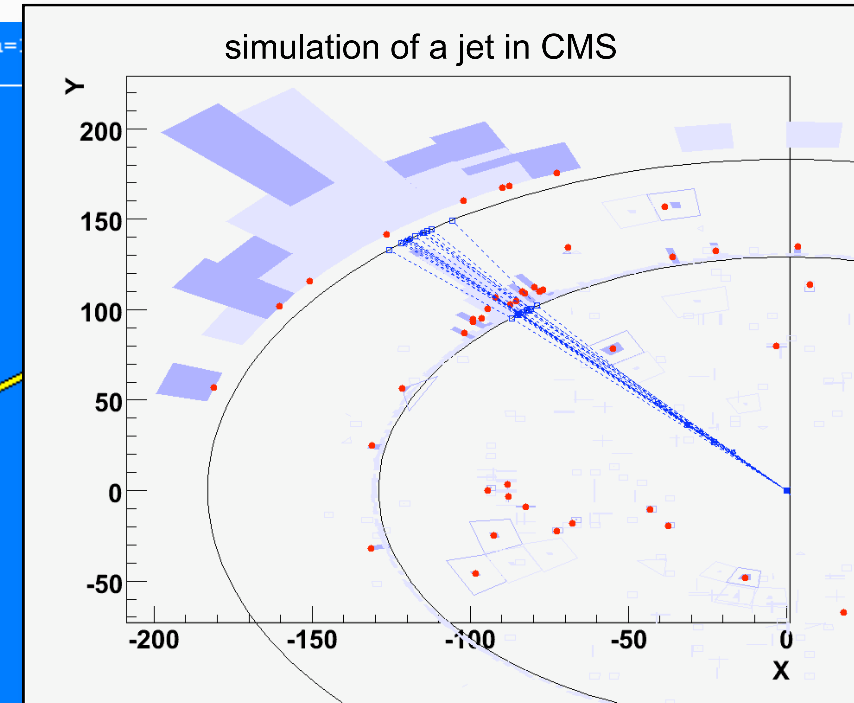
h_1, h_2 : p, p E_{CM} = 14 TeV

d,c : quarks/gluons



What is a jet?





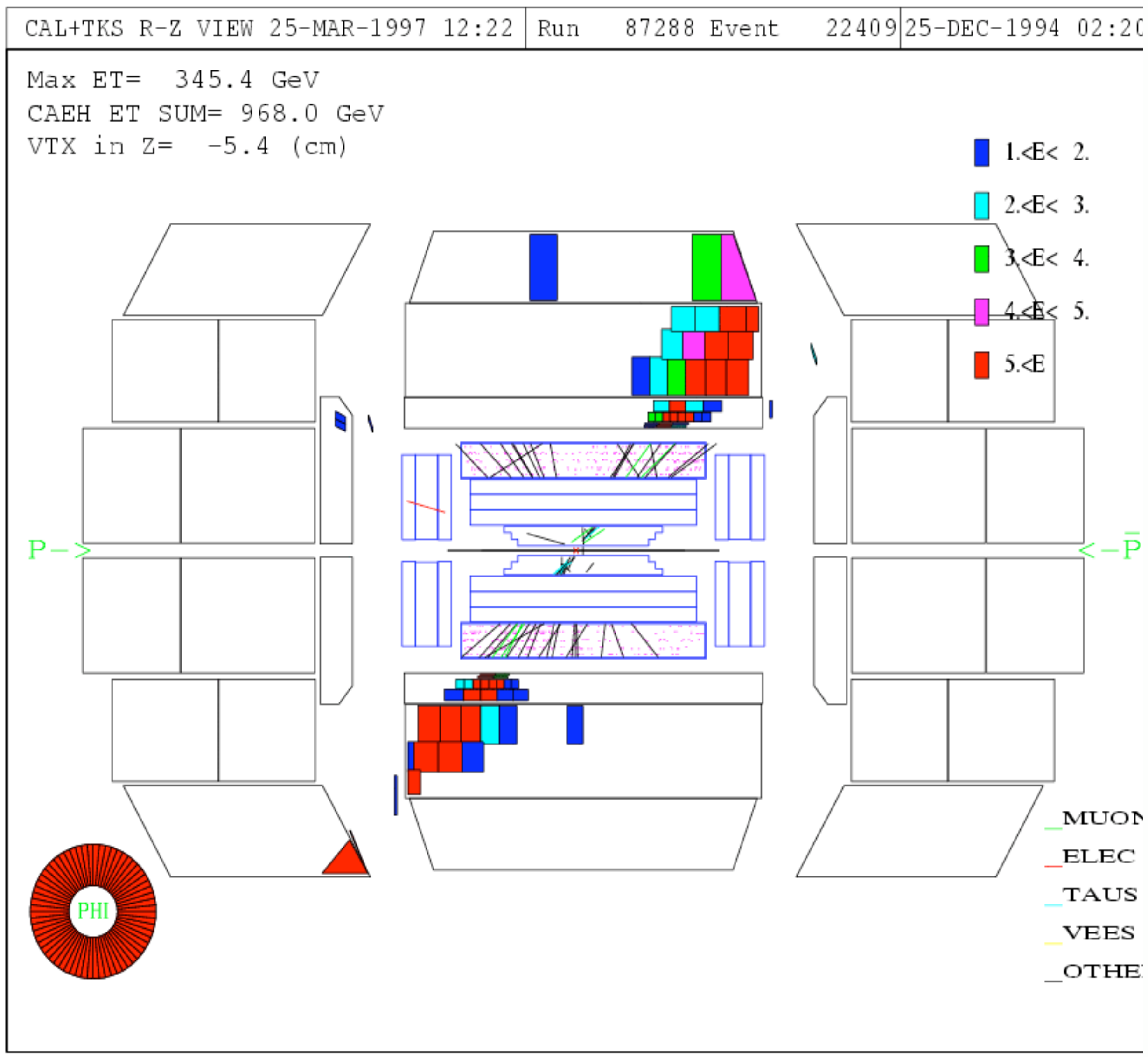
“cluster/spray of particles (tracks, calorimeter deposits) or flow of energy in a restricted angular region”

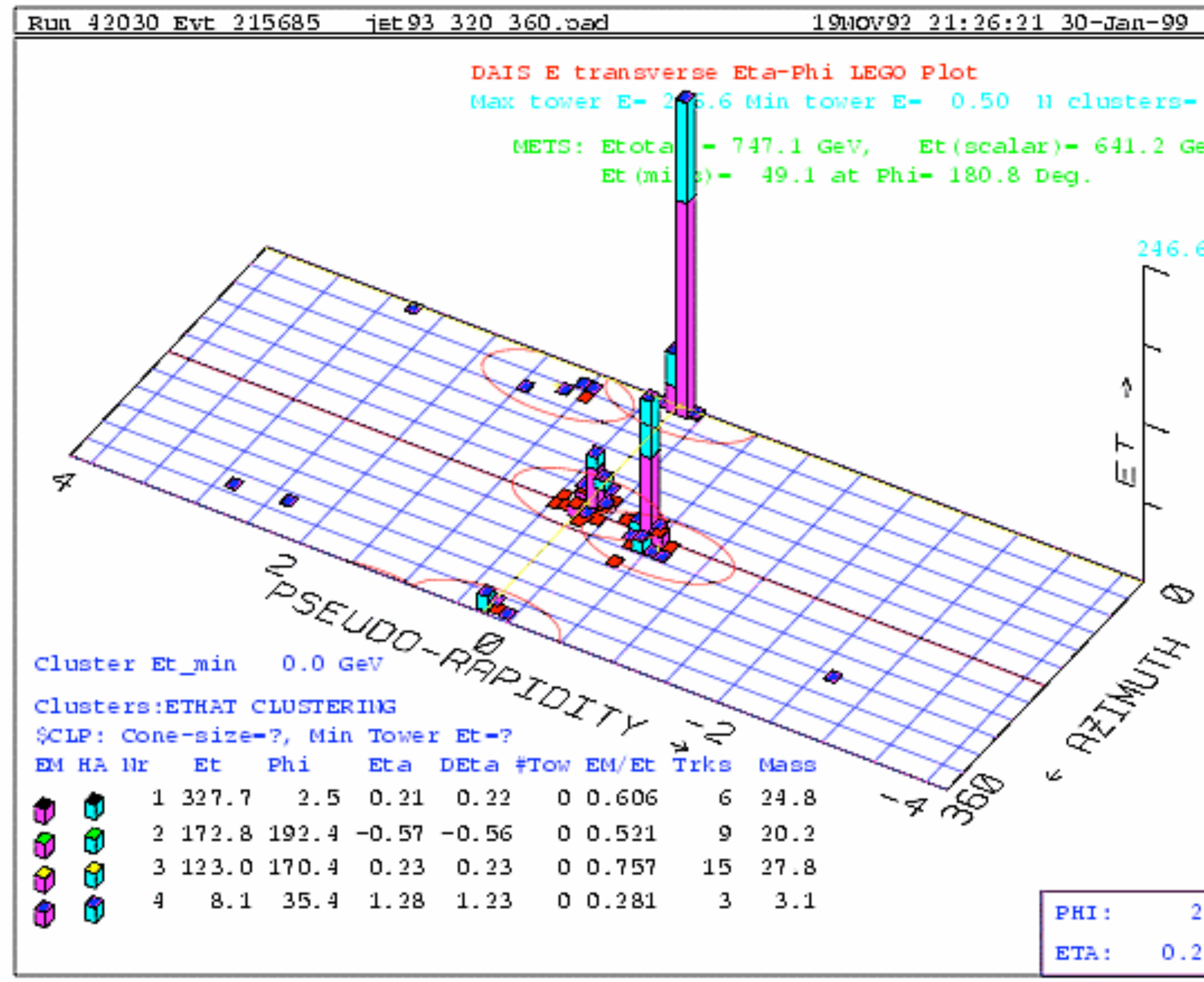
- clear : need some algorithmic definition

A short digression: Jet Algorithms

Jets in Hadron Collider Detectors

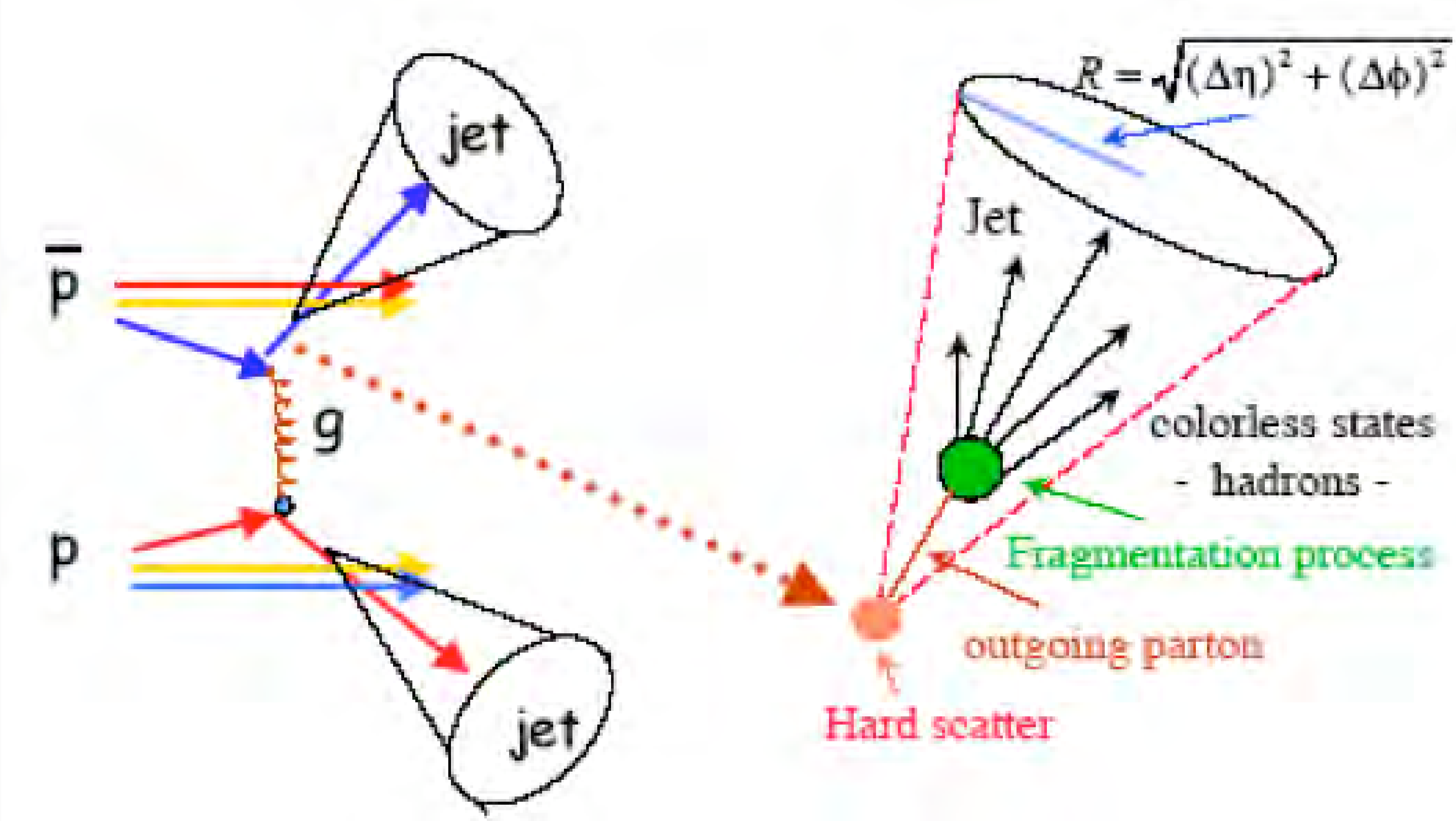
Jets in DØ CDF





- Introducing a cone prescription seems “natural”...
- But how to make it more quantitative?
    - don’t want people “guessing” at whether there are 2,3, ... jets

Cones...



The natural (?) definition of a jet in a hadron collider environment

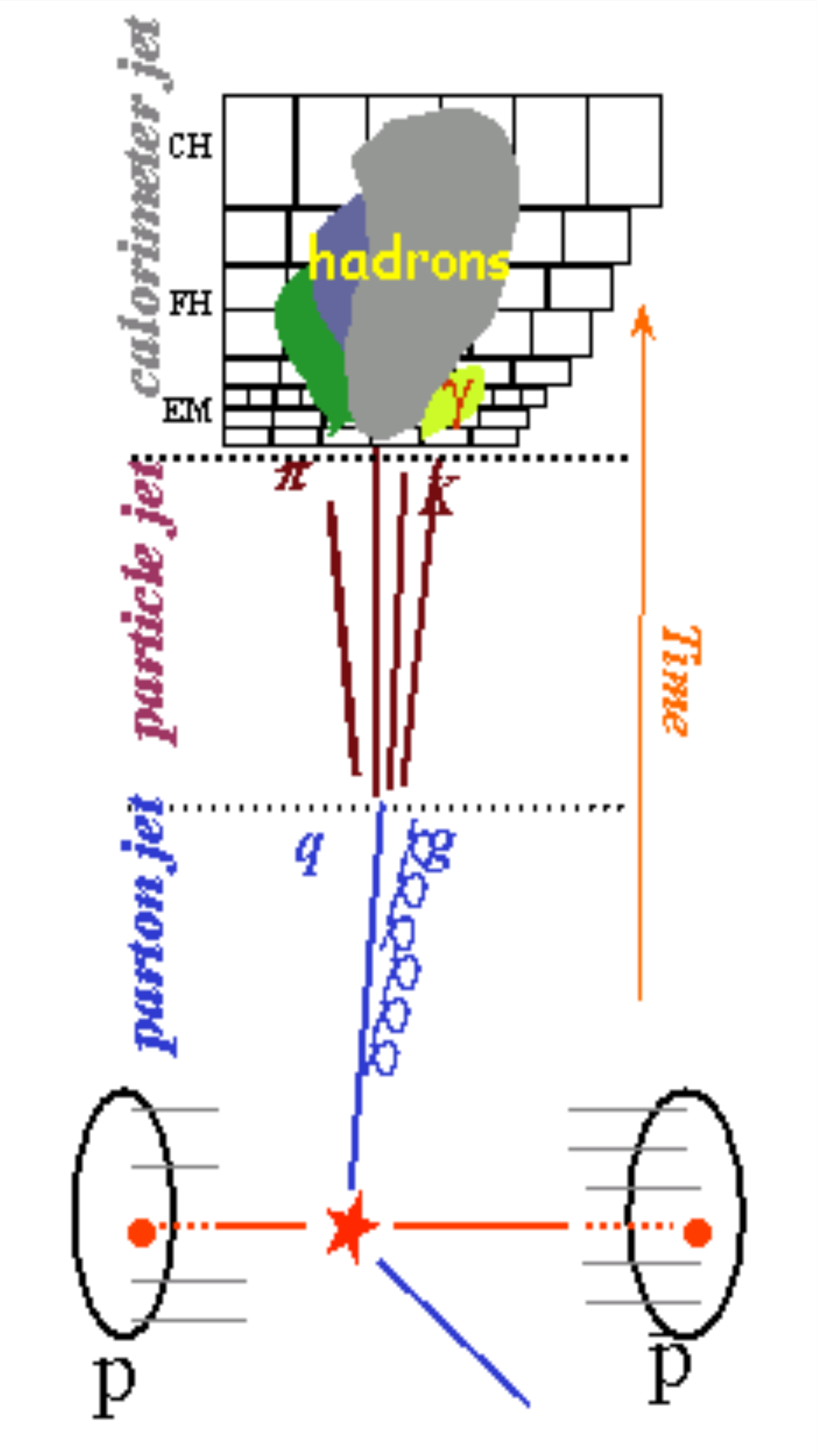
from J. Huston, CTEQ summer school 2004

Requirements

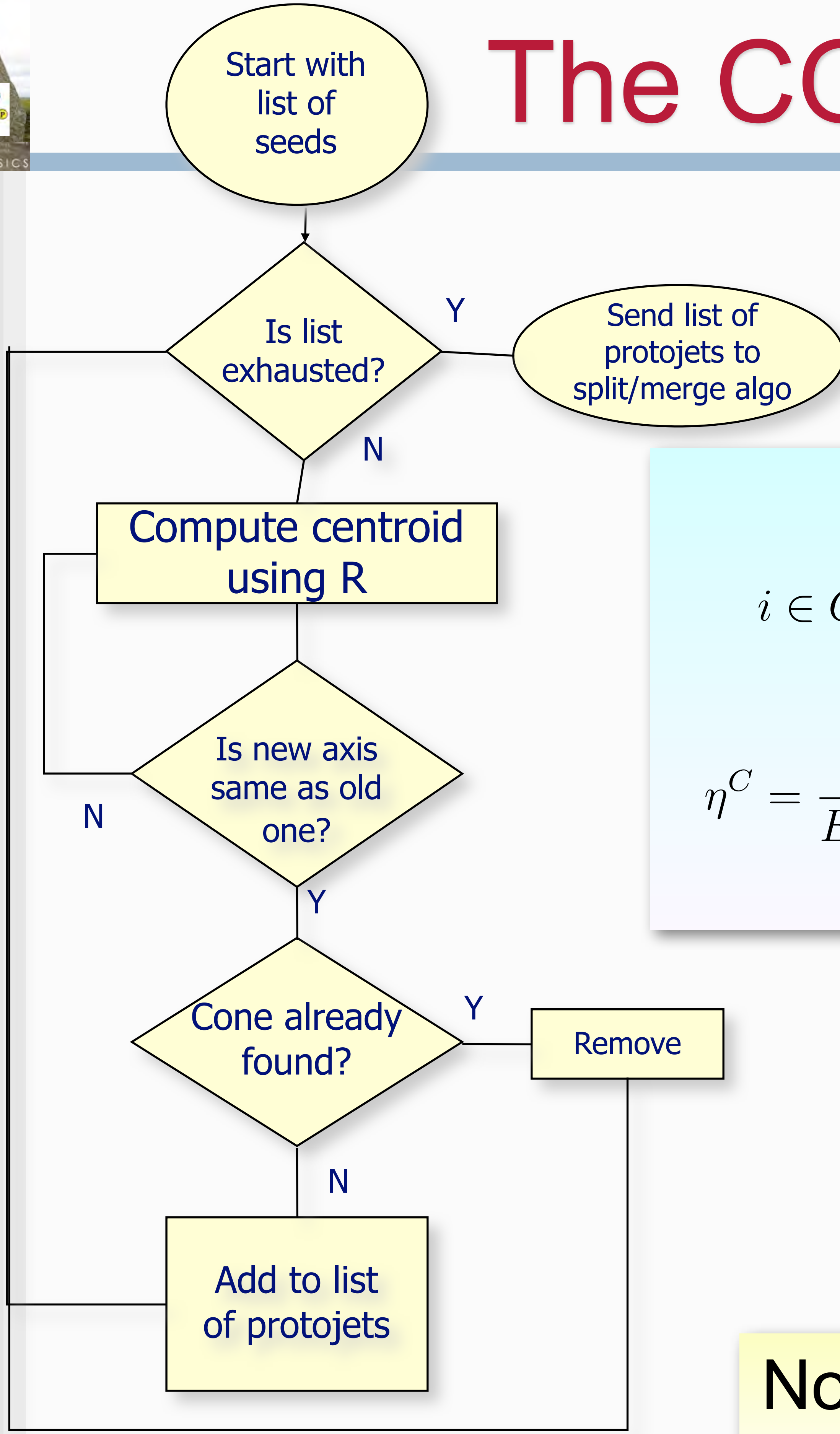
- Applicable at all levels
  - partons, stable particles
    - for theoretical calculations
  - measured objects (calorimeter objects, tracks, etc)
  - and always find the same jet
- Independent of the very details of the detector
  - example : granularity of the calorimeter, energy response,...
- Easy to implement !
- Infrared and Collinear safe!
- Close correspondence between

$$P_{parton} \Longleftrightarrow P_{jet}$$

Energy
Momentum
angle



The CONE algorithm

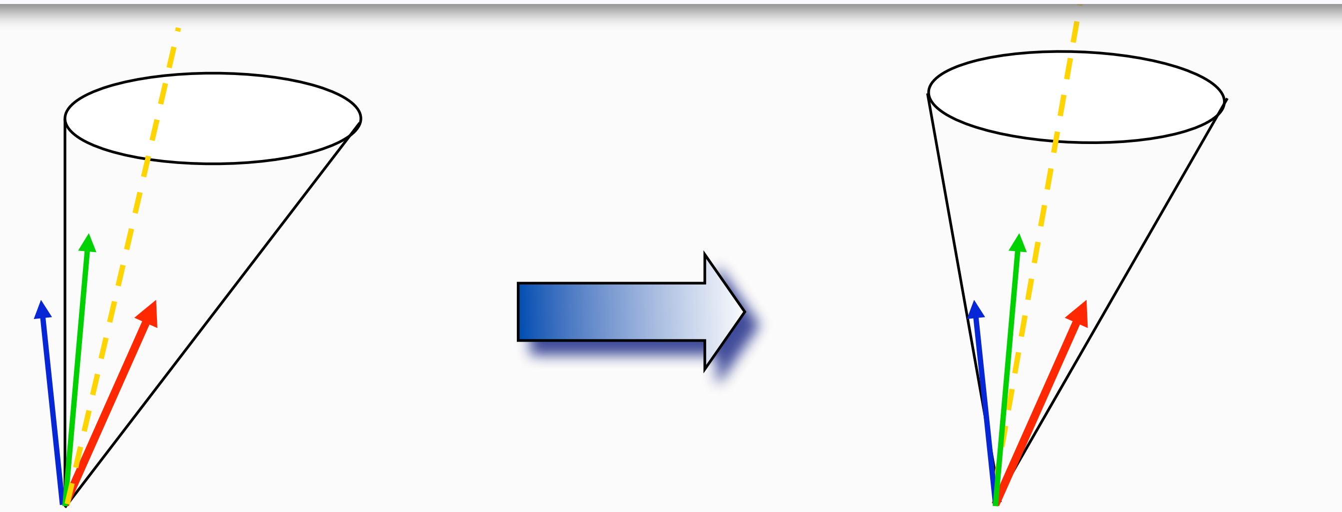


Seeds: for example, energy deposits with transverse energy ($E_T = E \sin\theta$) > 2 GeV in a tower of the calorimeter

Centroid (one possible def) :

$$i \in C \quad : \quad \sqrt{(\eta^i - \eta^C)^2 + (\Phi^i - \Phi^C)^2} \leq R \quad \text{cone radius}$$

$$\eta^C = \frac{1}{E_T^C} \sum_{i \in C} E_T^i \eta^i \quad ; \quad \Phi^C = \frac{1}{E_T^C} \sum_{i \in C} E_T^i \Phi^i \quad ; \quad E_T^C = \sum_{i \in C} E_T^i$$

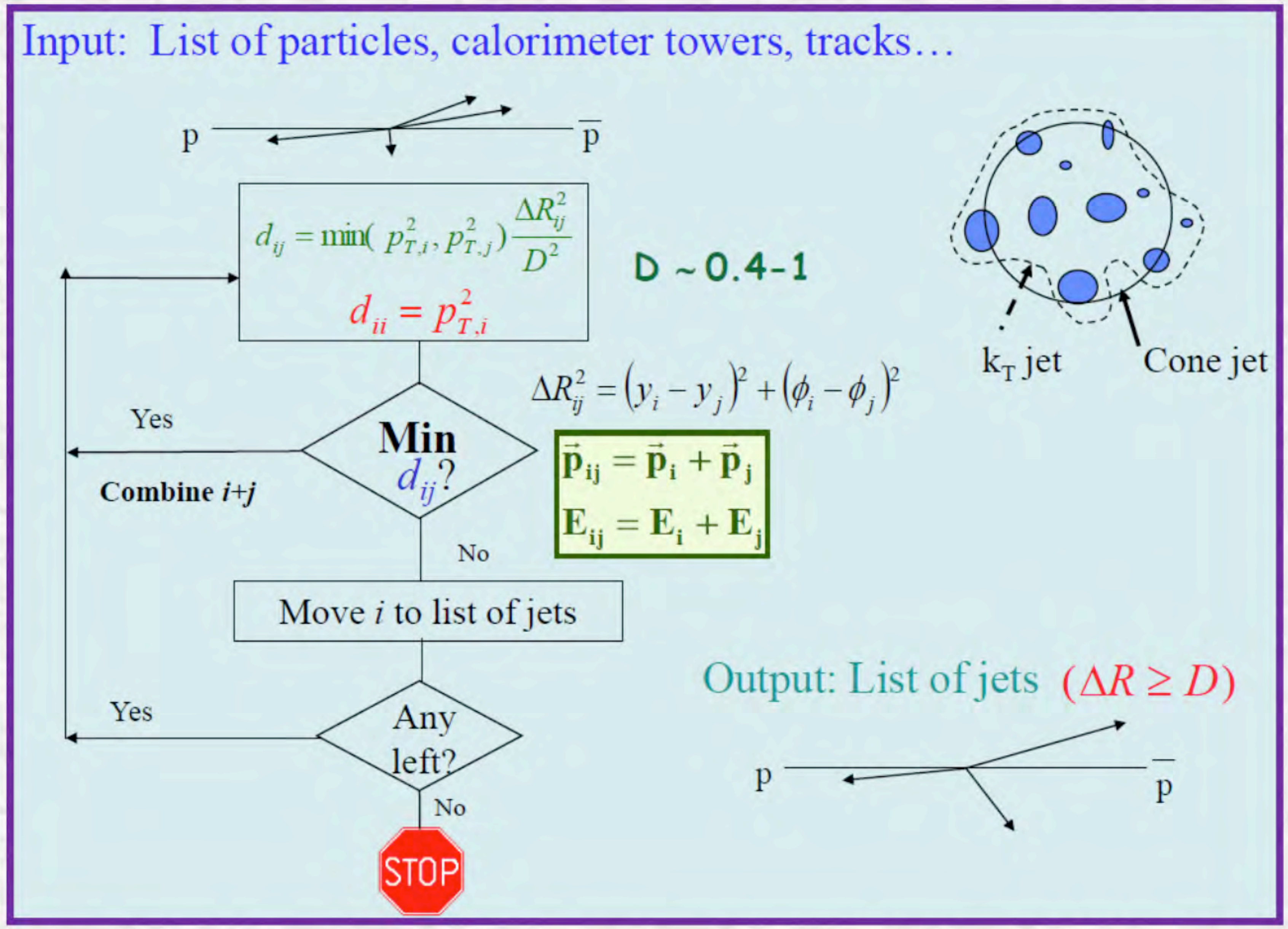


Now : new seedless cone algorithm

SISCone : IR and Collinear Safe !

Recombination algorithms (k_T type)

- **k_T jets are infrared and collinear safe**
- **There are no overlapped jets**
- **Every particle, or detector tower is unambiguously assigned to a single jet**
- **No biases from seed towers**
- **k_T jets are sensitive to soft particles and area could depend on pile-up**



S.D.Ellis, D.Soper, PRD 48, 3160 (1993)

N. Varelas

Recent developments

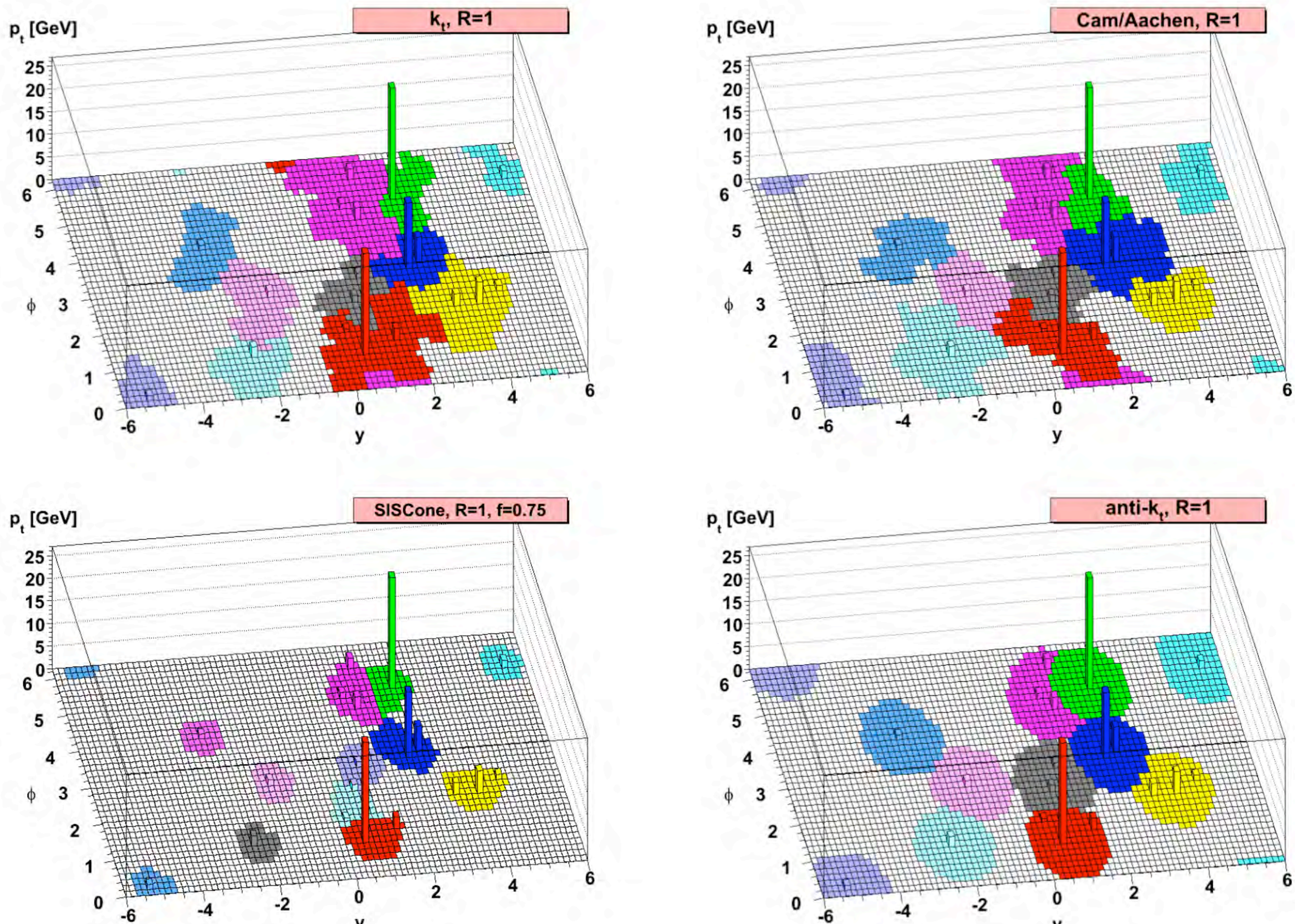
- **Fast kT Algorithm improves speed from $O(N^3)$ to $O(N \ln N)$**
  - **G.Salam, M.Cacciari, Phys. Lett. B641, 41 (2006)**
  - **Add ghost particles to determine the area of jets**
    - **Could be used to subtract pile-up contributions**
  - **Already adopted as the default k_T algorithm at LHC**
- **Other recombination algorithms:**

$$d_{ii} = p_{T,i}^{2p} \qquad d_{ij} = \min(p_{T,i}^{2p}, p_{T,j}^{2p}) \frac{\Delta R_{ij}^2}{D^2}$$

  - **p=1 → regular k_T jet algorithm**
  - **p=0 → Cambridge/Aachen jet algorithm**
    - **Dokshitzer, Leder, Moretti, Webber '97 (Cambridge) – Wobisch, Wengler '99 (Aachen)**
  - **p=-1 → "Anti-k_T" jet algorithm**
    - **Cacciari, Salam, Soyez '08**
    - **Soft particles will first cluster with hard particles before among themselves**
    - **Almost a cone jet near hard partons**
      - **No merge/split**
      - **Currently under consideration by CMS (already adopted by ATLAS)**

N. Varelas

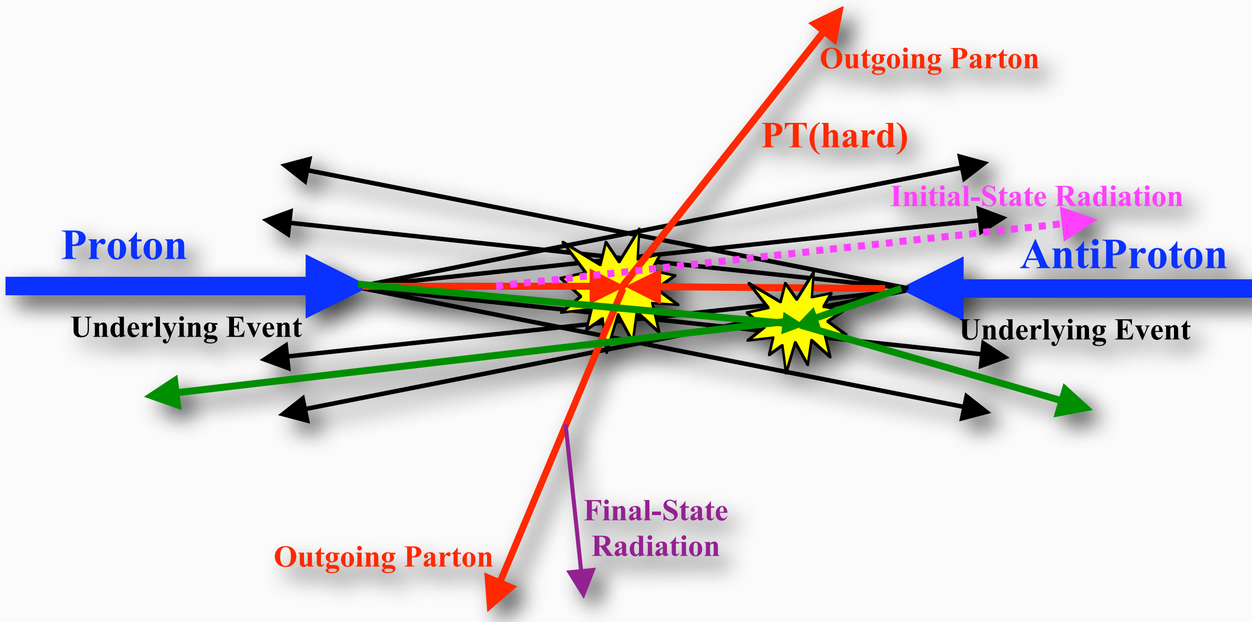
Jet areas



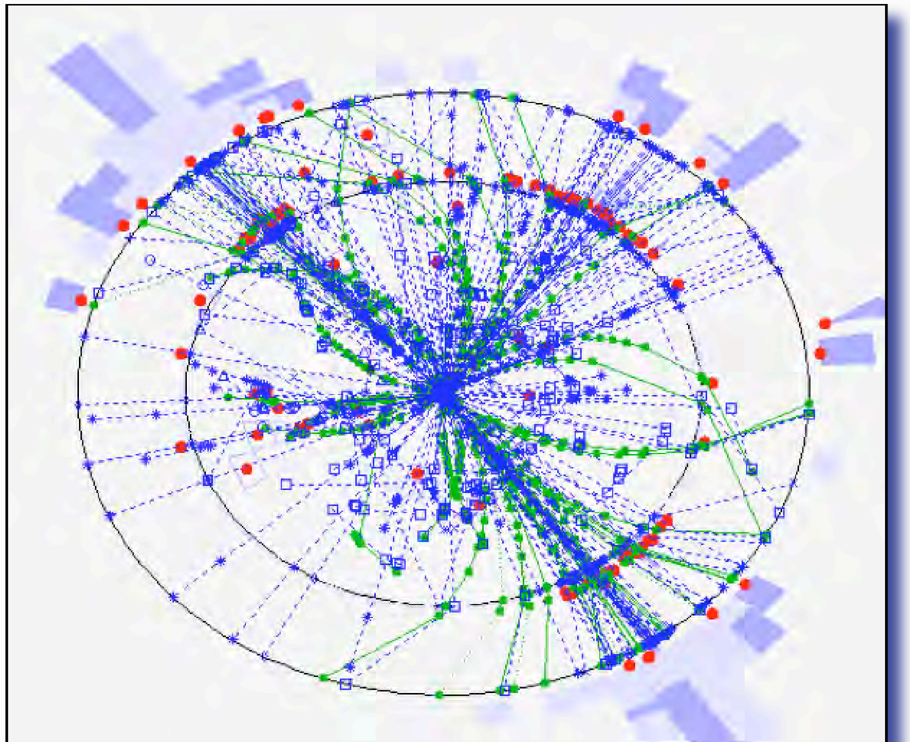
G. Salam, "Towards Jetography"

Further difficulties

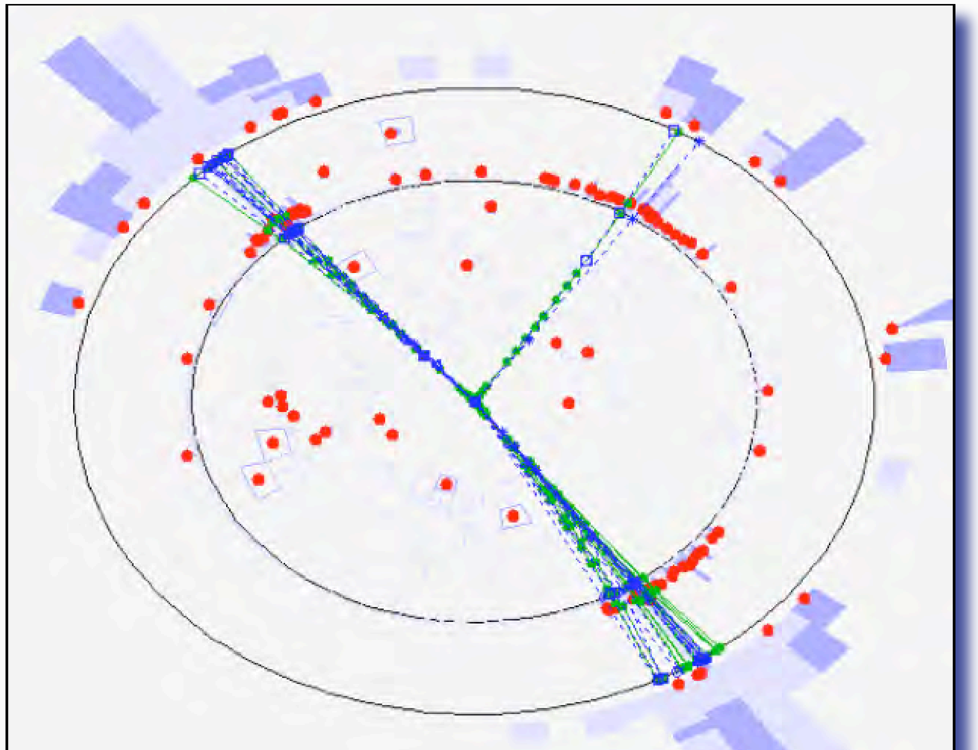
- Pile Up : many additional soft proton-proton interactions
  - up to 20 at highest LHC luminosity
- Underlying event
  - beam-beam remnants, initial state radiation, multiple parton interactions
  - gives additional energy in the event



- **Note** : contributions from UE and from hadronization effects tend to cancel
- All this additional energy has nothing to do with jet energies
  - **have to subtract it**



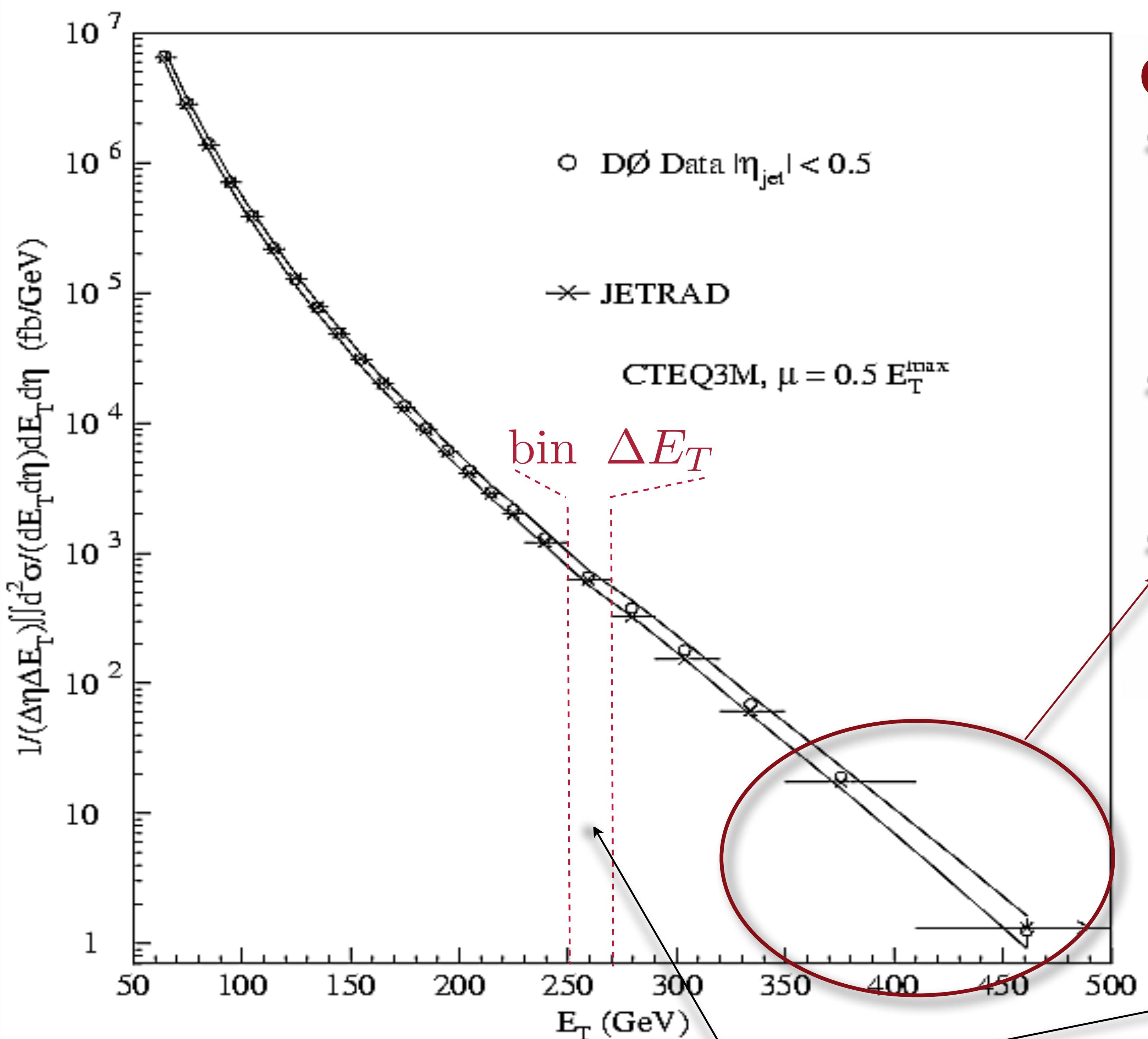
no cut on track momenta



minimum track p_T = 10 GeV/c

End of the digression

What do we have to measure?



Goal

- measure cross section inclusively for jets that are produced with a certain transverse energy E_T, within a certain rapidity range
- Test of perturbative QCD, over many orders of magnitude!
- Look at very high energy tail, new physics could show up there in form of excess (eg. sub-structure of quarks?)

can be calculated in pert. QCD

$$\left\langle \frac{d^2\sigma}{dE_T d\eta} \right\rangle = \frac{N}{\Delta E_T \Delta\eta\, \epsilon\, \mathcal{L}}$$

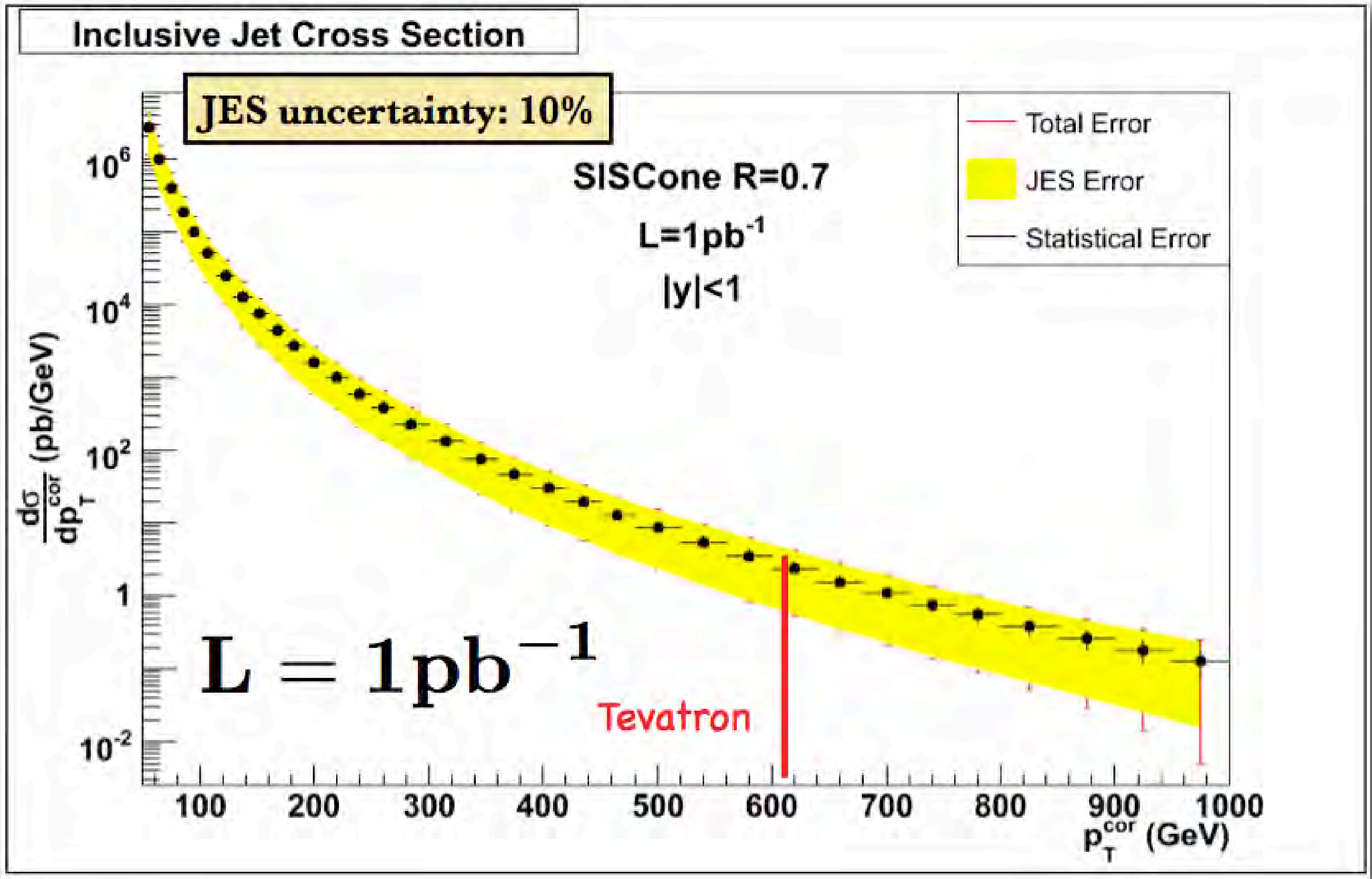
- count number of events, N, in this bin
- for a certain range in rapidity (angle) $\Delta\eta$

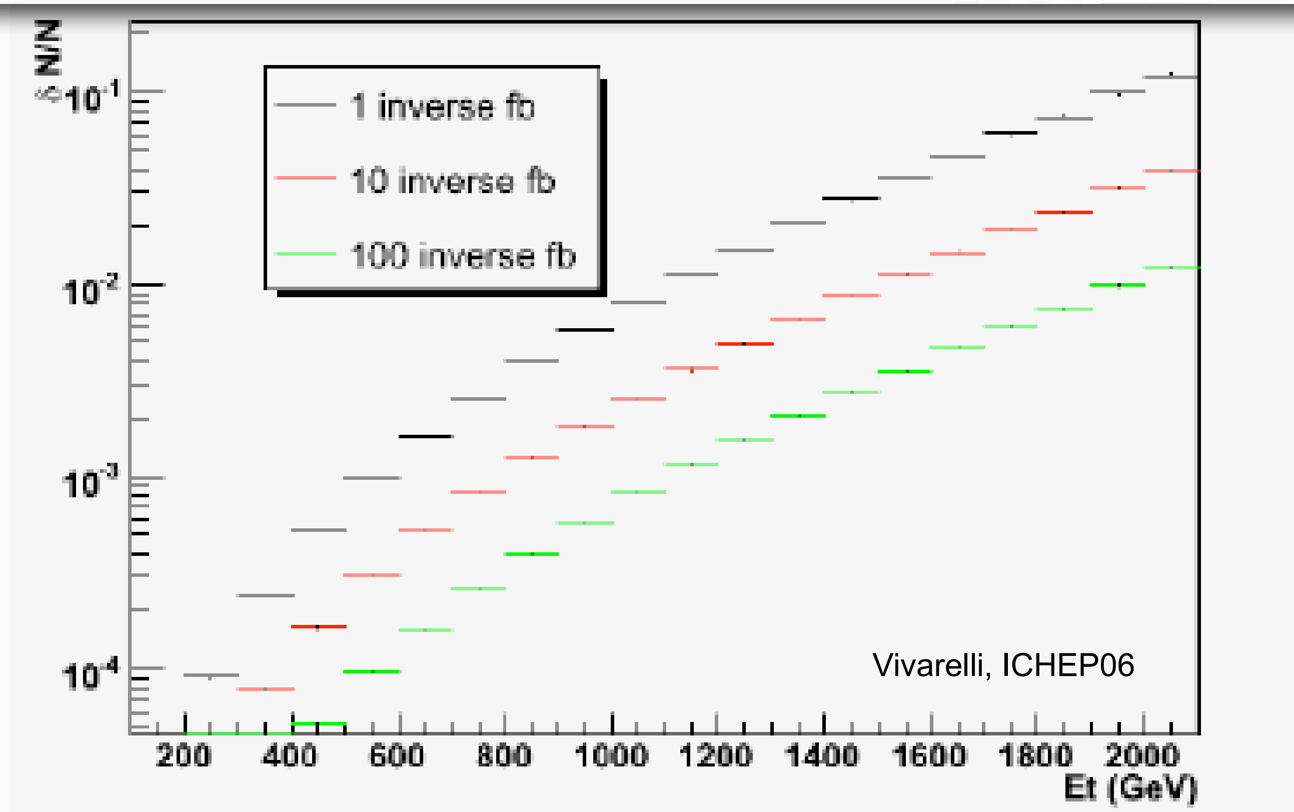
efficiency to reconstruct jets

integrated luminosity

Inclusive Jet cross section at the LHC

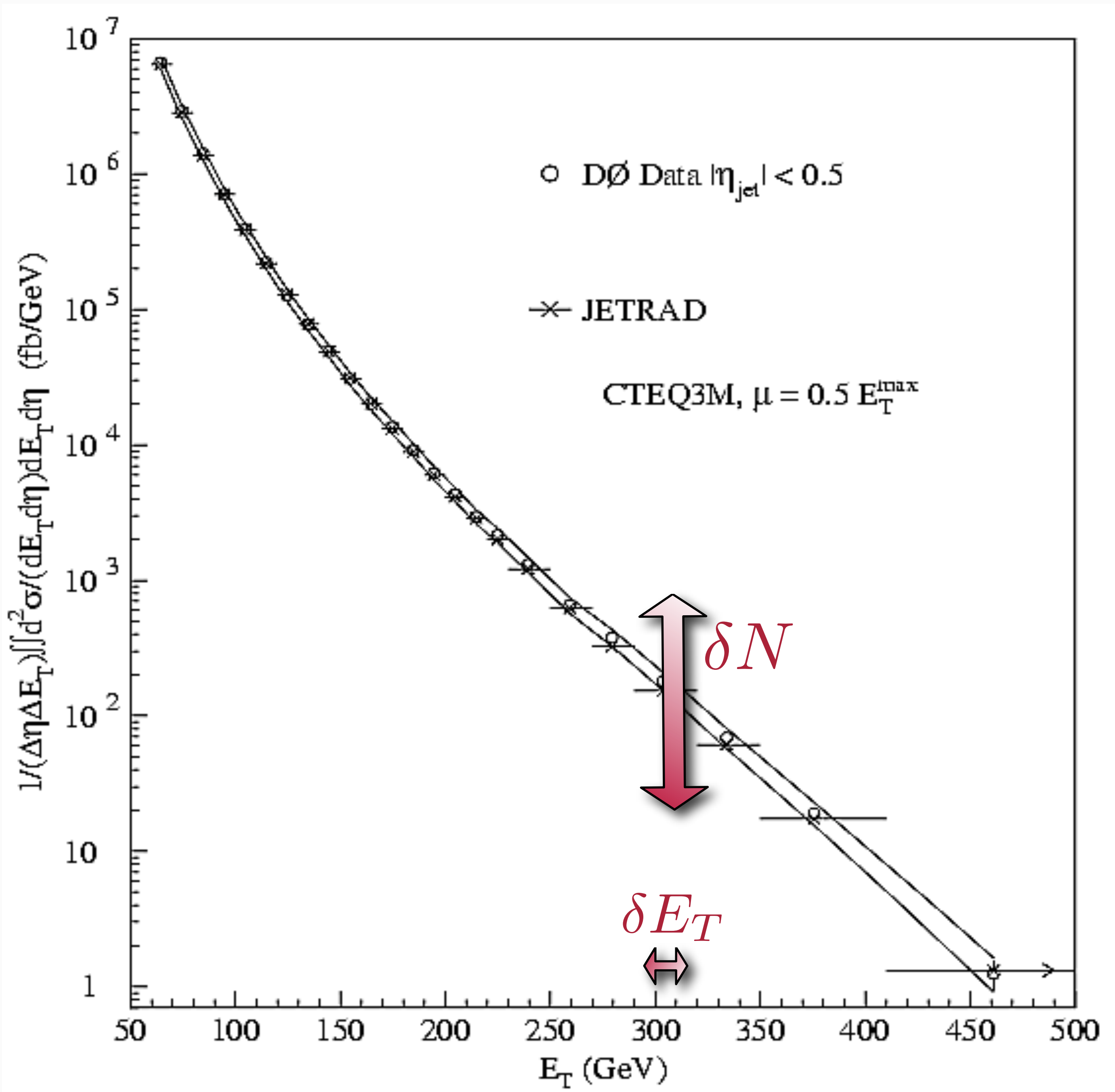
- After MB studies, jets will be the first objects seen and measured
- Enormous cross section, so statistical errors quickly negligible
  - 1% at p_T=1 TeV for 1 fb^{-1} (central)
  - 10% for $3 < \eta < 5$
- Steeply falling cross section : energy scale knowledge most relevant





Problem 1 : Energy scale

- Question : how well do we know the energy calibration?
- Critical because of very steeply falling spectrum!



$$\frac{d^2\sigma}{dE_T d\eta} \approx \text{const} \cdot E_T^{\,-6}$$

relative uncertainties

$$\frac{\delta N}{N} \approx 6 \cdot \frac{\delta E_T}{E_T}$$

so beware:

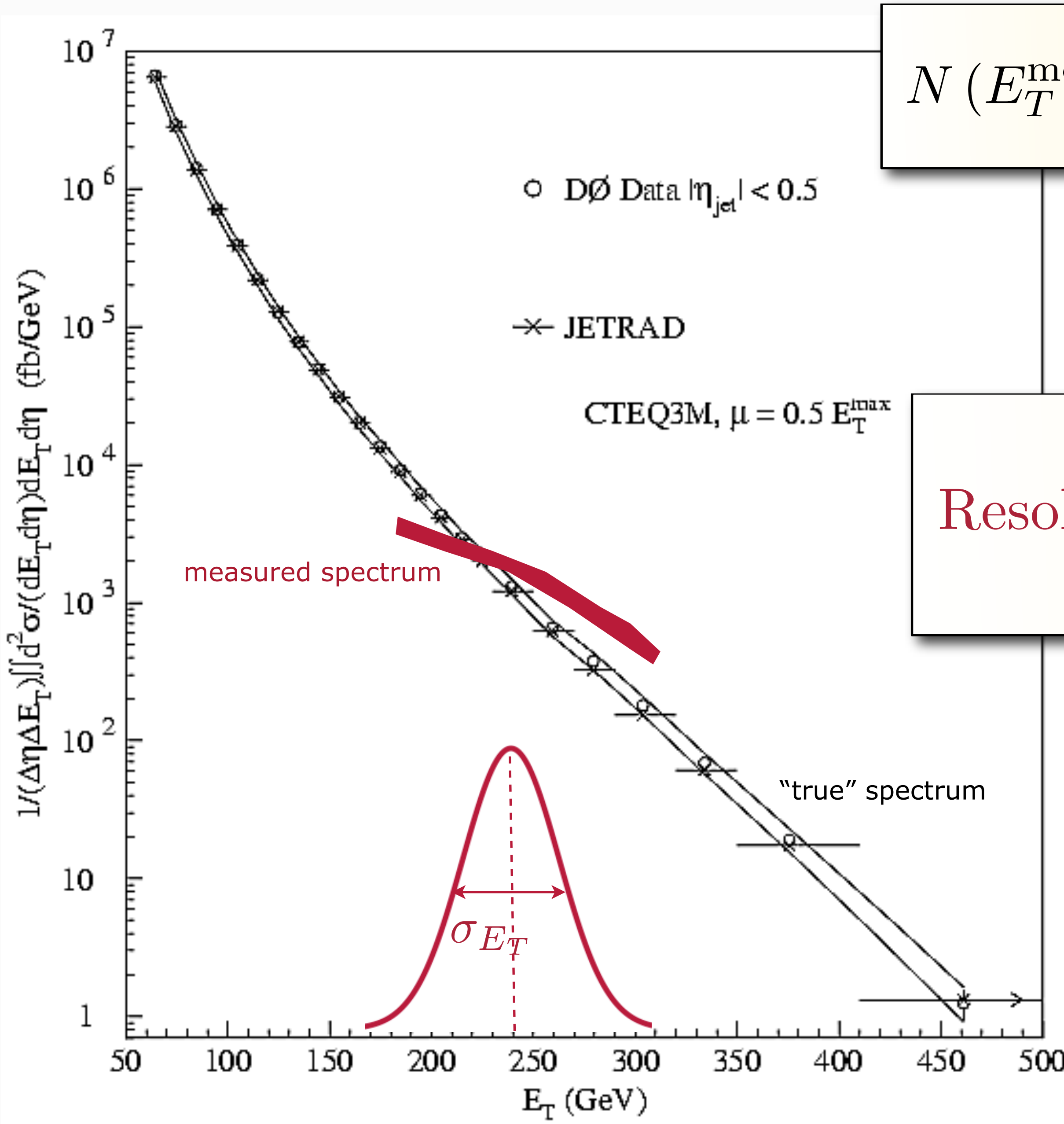
eg. an uncertainty of **5%** on absolute energy scale (calibration)

➔ an uncertainty of **30%** (!) on the measured cross section

Problem 2 : Energy resolution

ETH Institute for Particle Physics

- The energy resolution can distorts the spectrum
- Again : Critical because of very steeply falling spectrum!



$$N\left(E_T^{\mathrm{meas}}\right) = \int_0^{\infty} N\left(E_T^{\mathrm{true}}\right) \cdot \mathrm{Resol}\left(E_T^{\mathrm{meas}}, E_T^{\mathrm{true}}\right) \mathrm{d}E_T^{\mathrm{true}}$$

eg. Gaussian resolution function

$$\mathrm{Resol}\left(E_T^{\mathrm{meas}}, E_T^{\mathrm{true}}\right) \propto \exp\left[-\frac{\left(E_T^{\mathrm{meas}} - E_T^{\mathrm{true}}\right)^2}{\sigma_{E_T}^2}\right]$$

so beware:

A bad energy resolution can distort the true spectrum

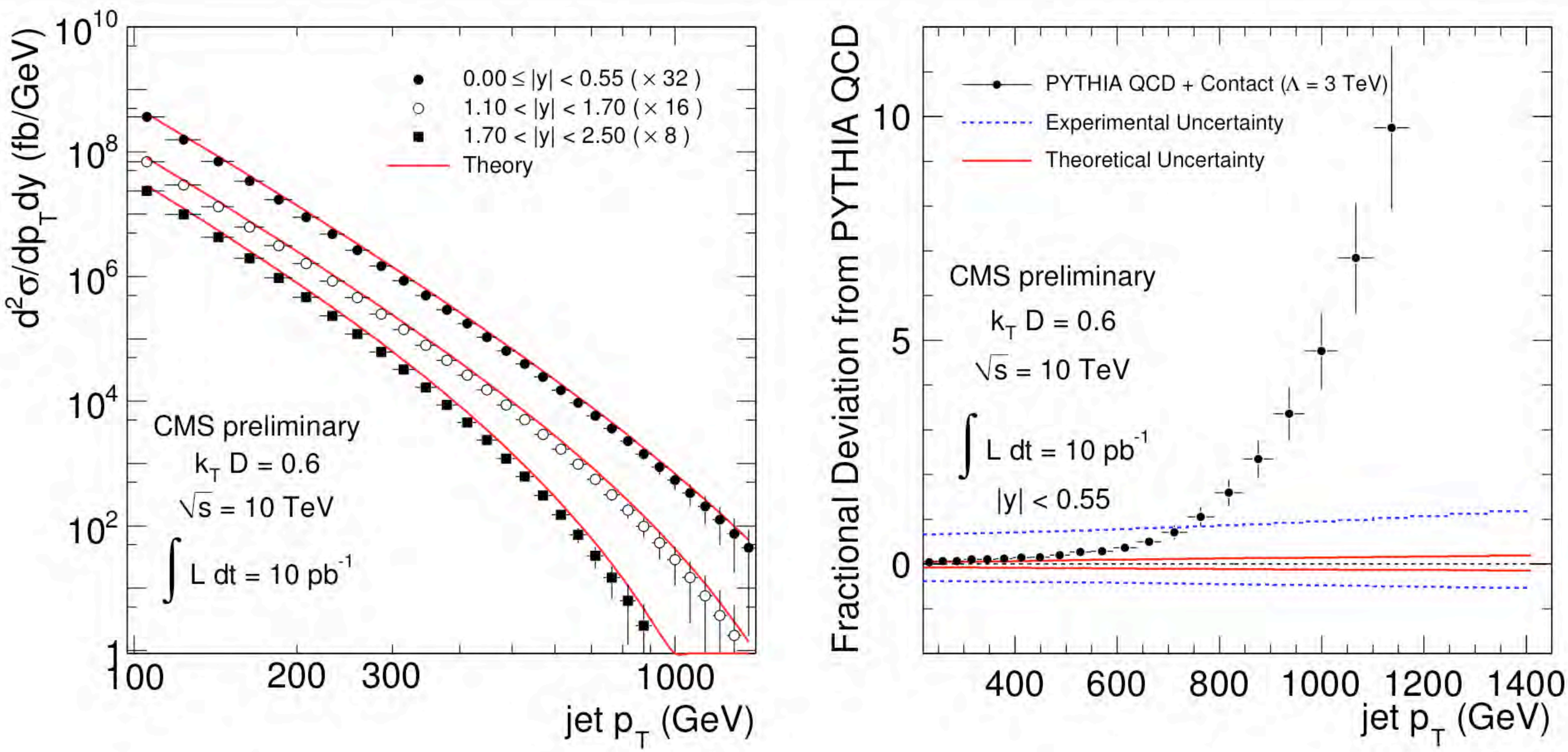
➔ have to determine the energy resolution

➔ have to "unfold" the measured spectrum

➔ problem is minimized if bin width ~ σ_{E_T}

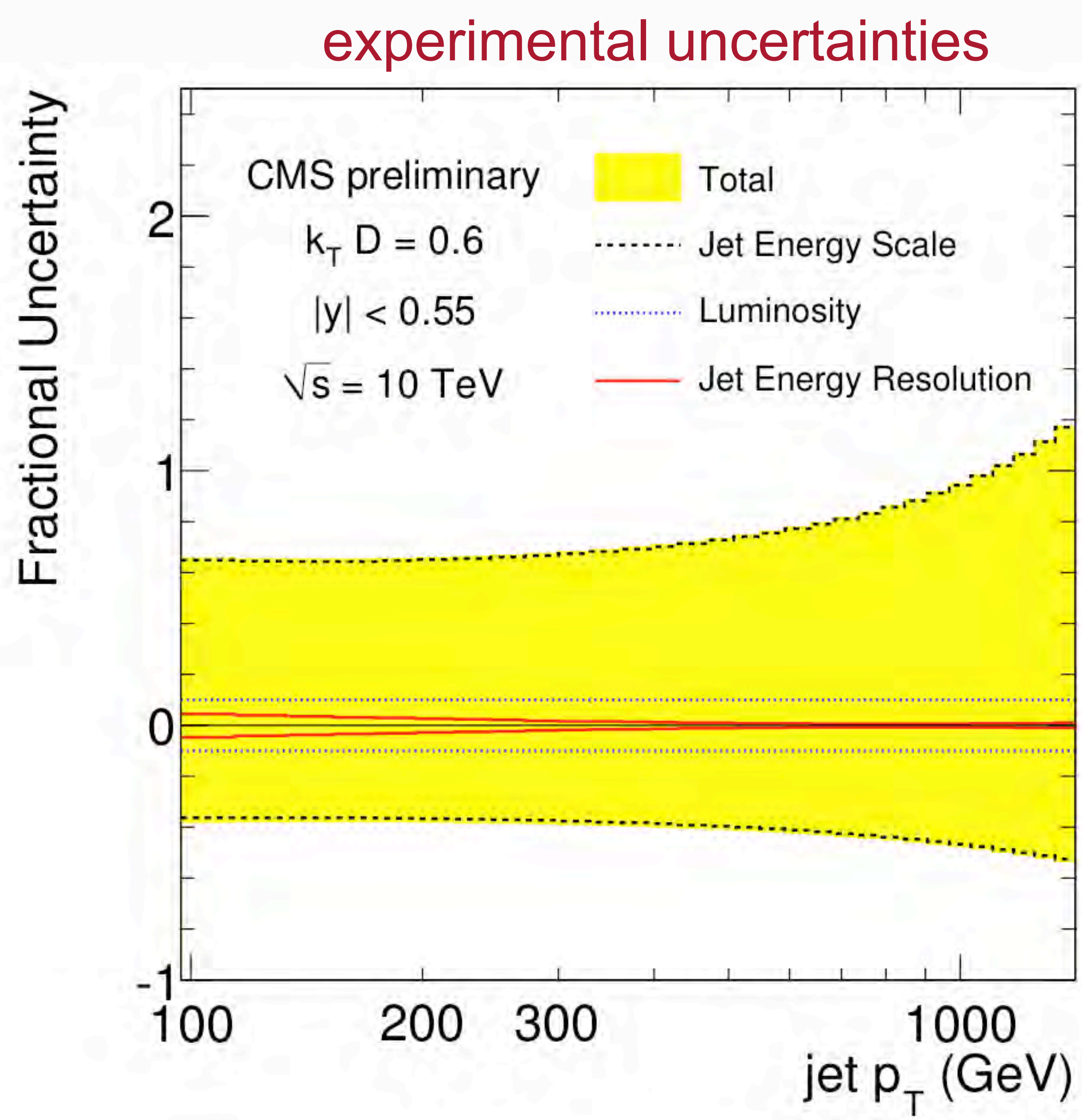
Inclusive Jets : Projections

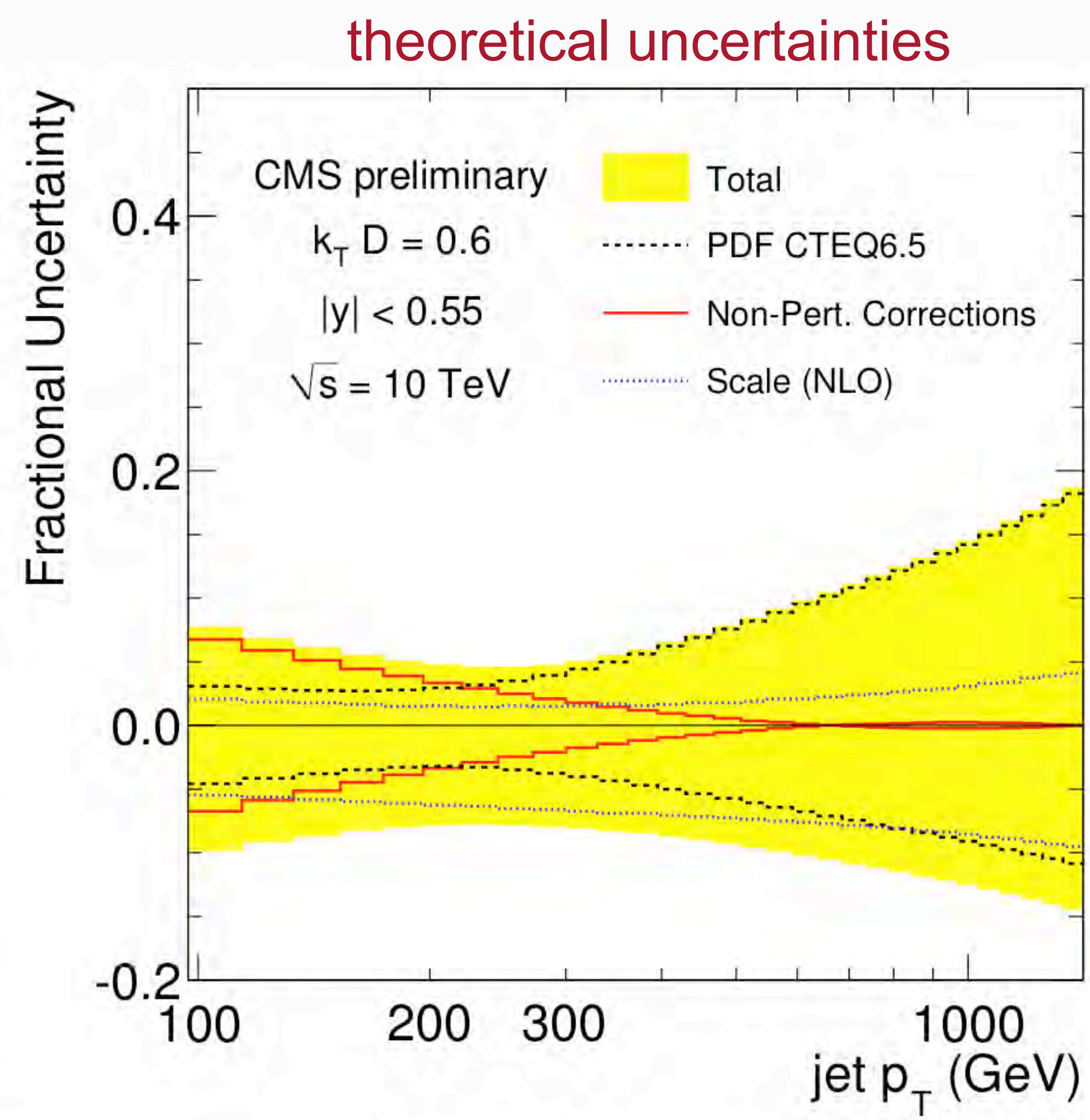
CMS Physics Analysis Summary CMS-PAS-QCD-08-001



Note : left plot : "data points" are from PYTHIA, but "theory" is a NLO calc. !
right plot : also shown : hypothetical contribution from new contact interactions

Inclusive Jets : Systematics

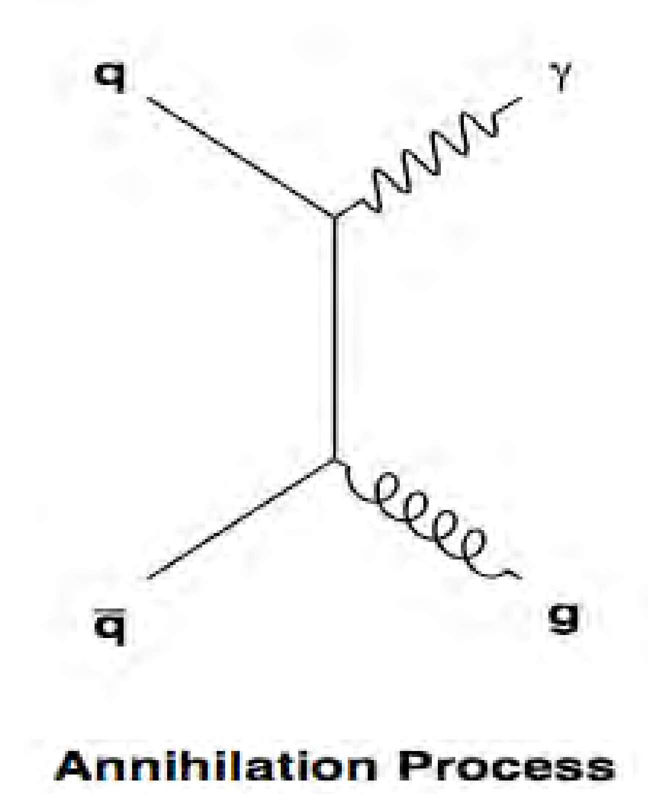


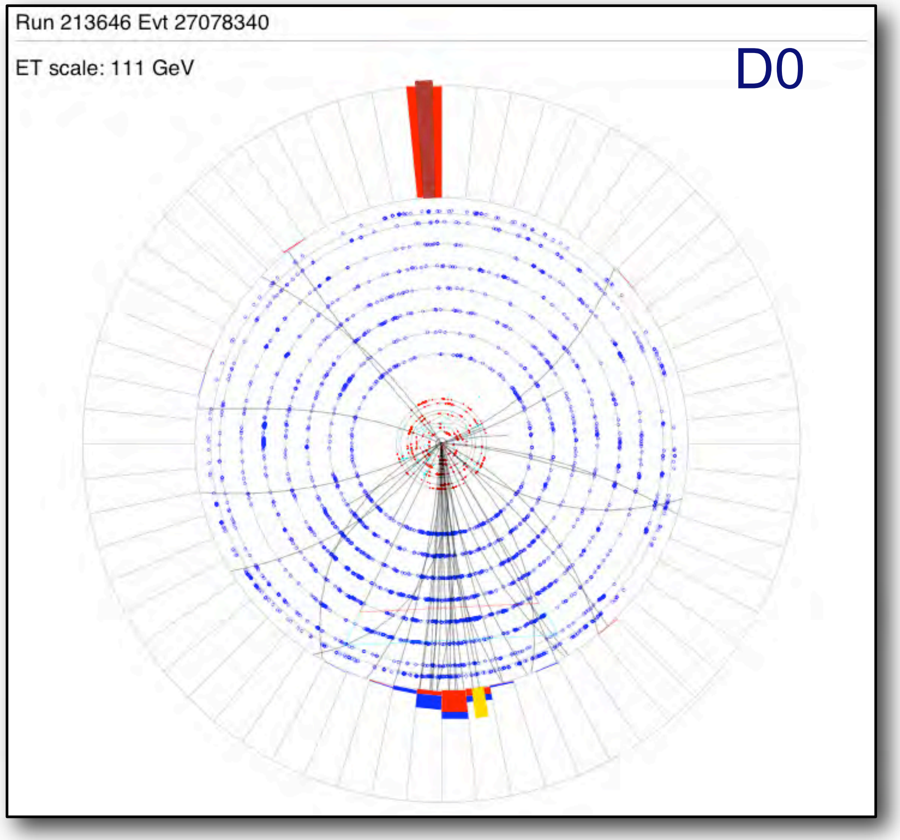


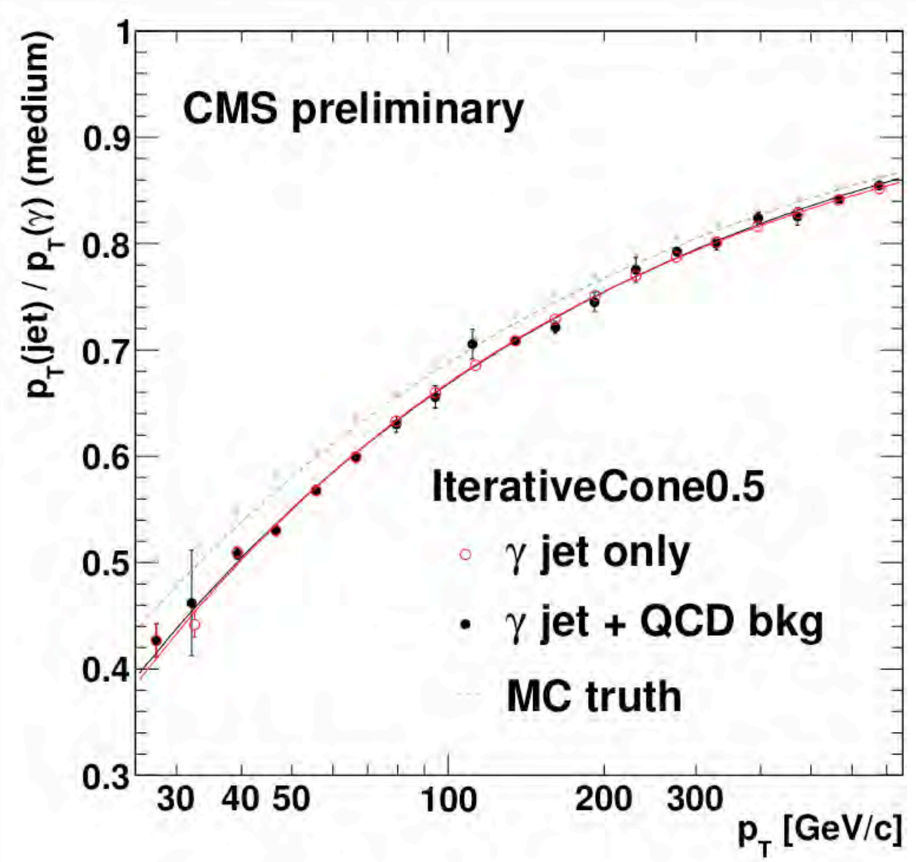
- a **10% jet energy scale** uncertainty (which is realistic at start-up) gives a **60% error** on the cross section!
- Control in-situ with : photon/Z+jets and W➔ JJ in top decays
- Other sources : jet corrections (det ➔ had ➔ part), UE subtraction

Jet+Photon and Jet Energy Scale (JES)

- Jet calibration using p_T **balance** in Jet+Photon events
  - Selection : isolated photons, no high-p_T secondary jet, photon and jet well separated in transverse plane
  - 10% (5%) precision expected for 100 pb^{-1} (1 fb^{-1})







Jet Energy Scale

- procedures for obtaining data-driven jet energy corrections
- Factorized Approach :

reco jet → **L1** corr *offset* → **L2** corr *rel. η* → **L3** corr *abs.* → **L4** corr *flavour* → **L5** corr *UE* → **L6** corr *parton* → **calib. jet** parton level model dep.

L3 corr *abs.* → calib. jet at particle level, corr. for det. effects

- Possible approaches
  - L2 : di-jet balance and/or photon+jets
  - L3 : photon+jets, data-driven MC corrections

Possible time-line:

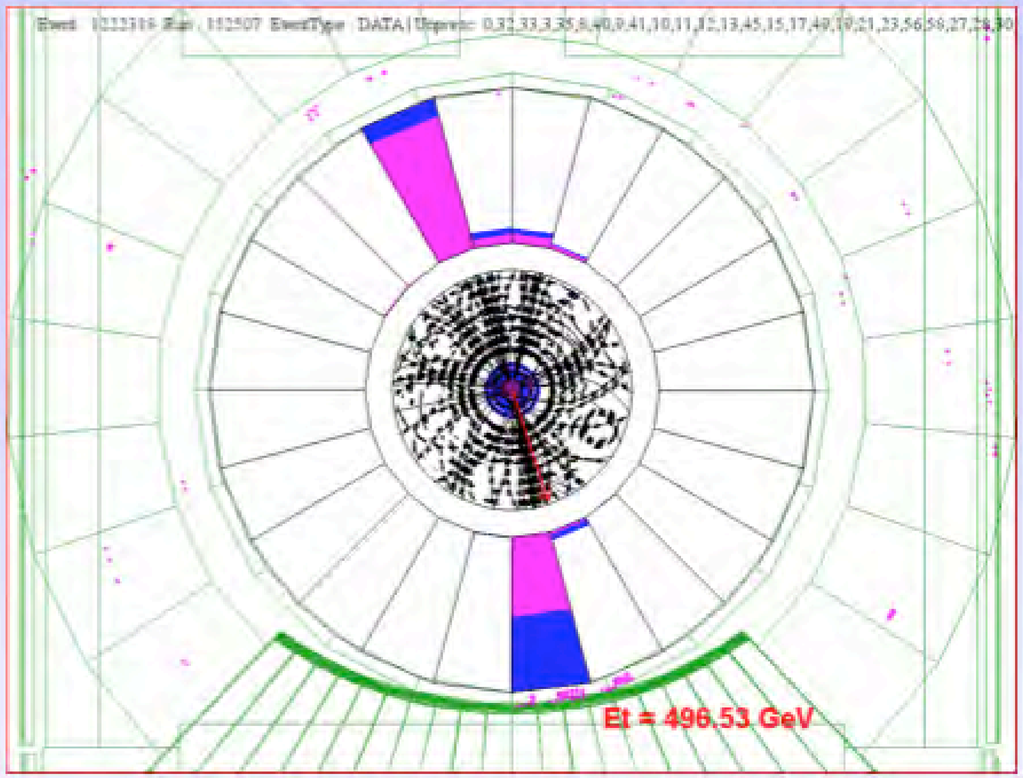
Day one:
Test-beam tuned MC simulation to provide corrections, backed up by the first pass to data based corrections.

Intermediate:
More developed data-based corrections. Use data-driven MC (re-tuned with collider data) to understand biases, extend to more particle types and algorithms

Long term:
A combination of a very accurate data-driven MC and well understood data methods would allow to achieve ultimate errors and support a large number of jet types and algorithms.

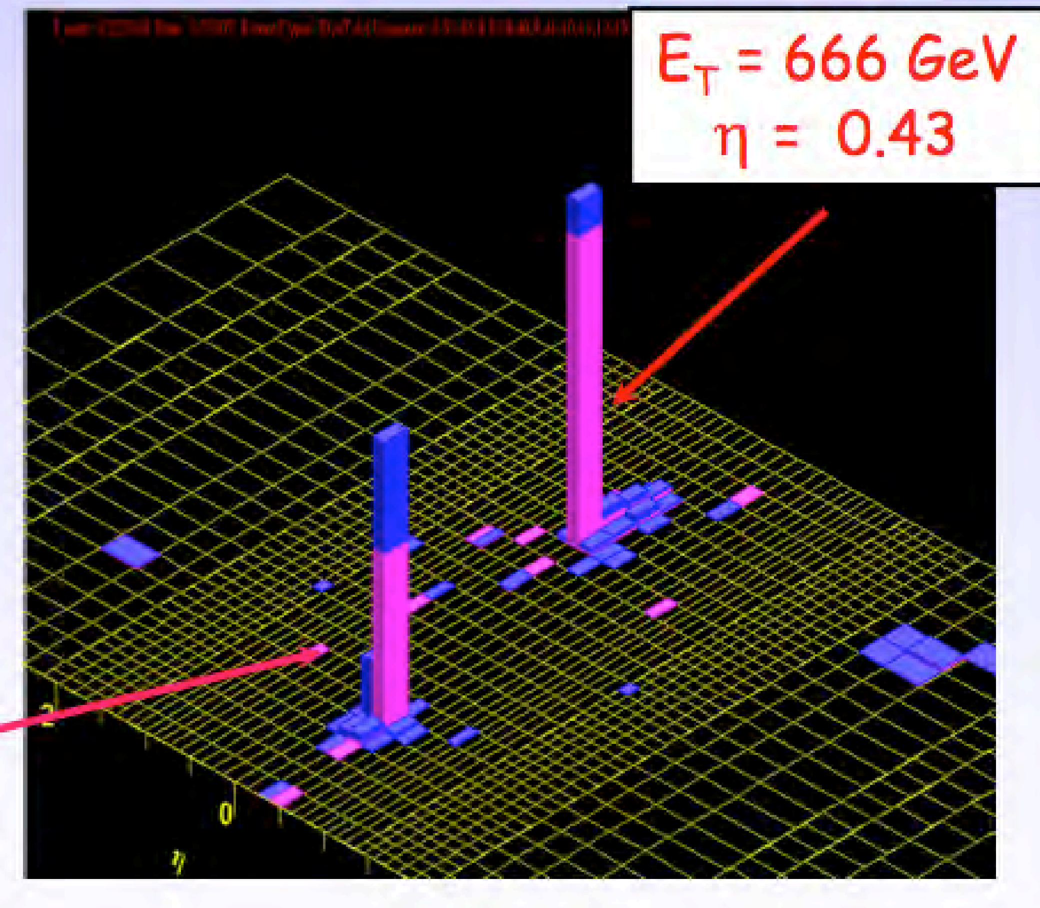
Di-Jets

A two jet event at the Tevatron (CDF)

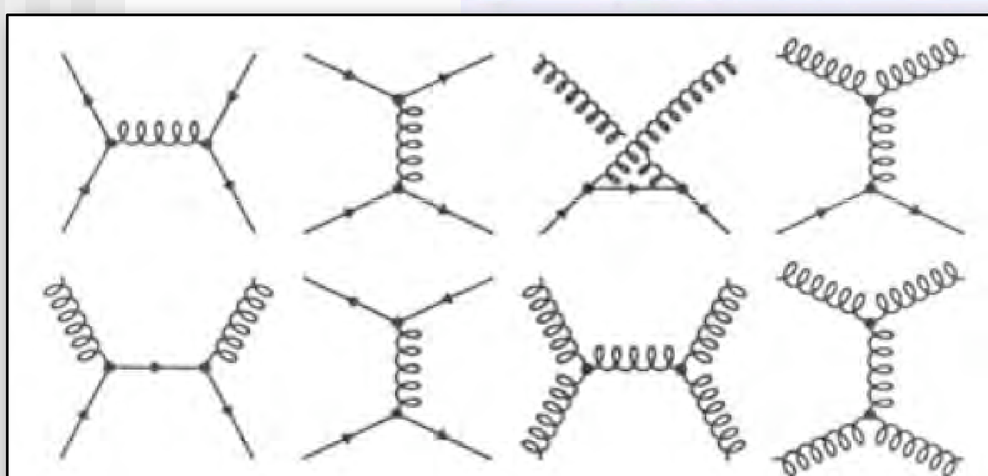


CDF (ϕ-r view)

Dijet Mass = 1364 GeV/c^2



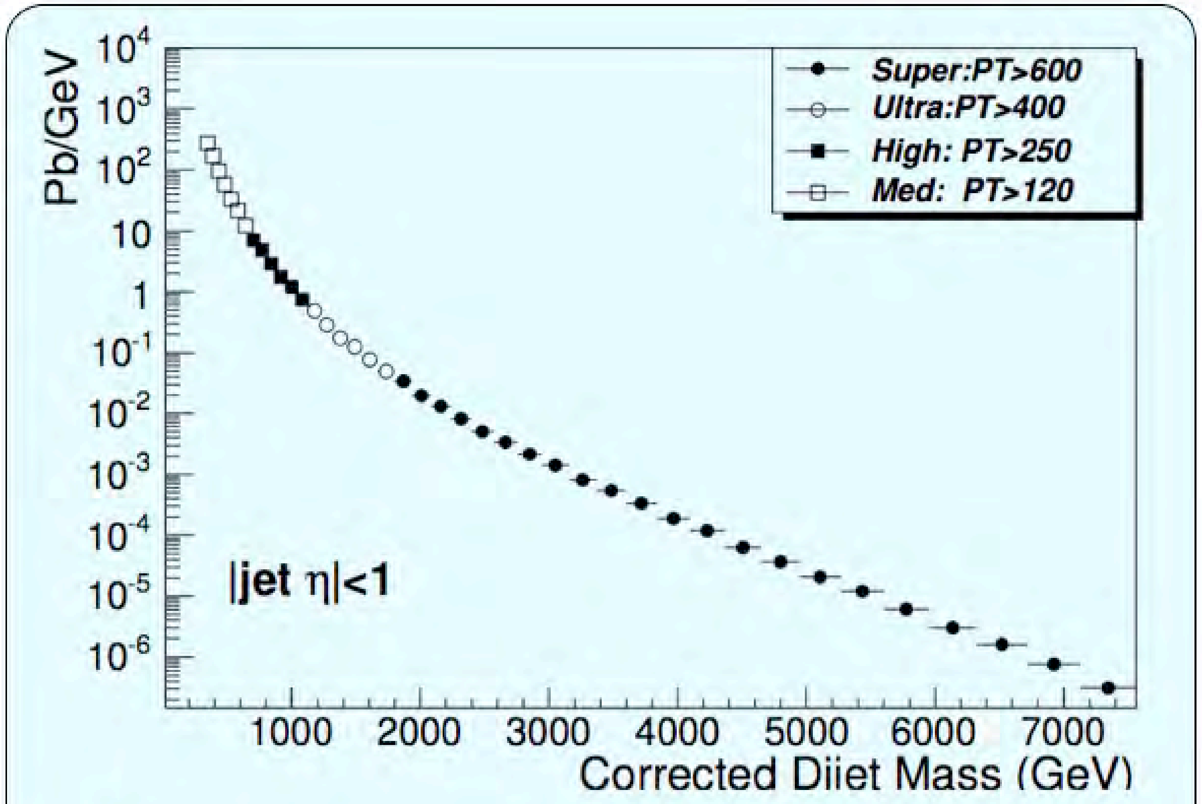
K. Jakobs, CSS07

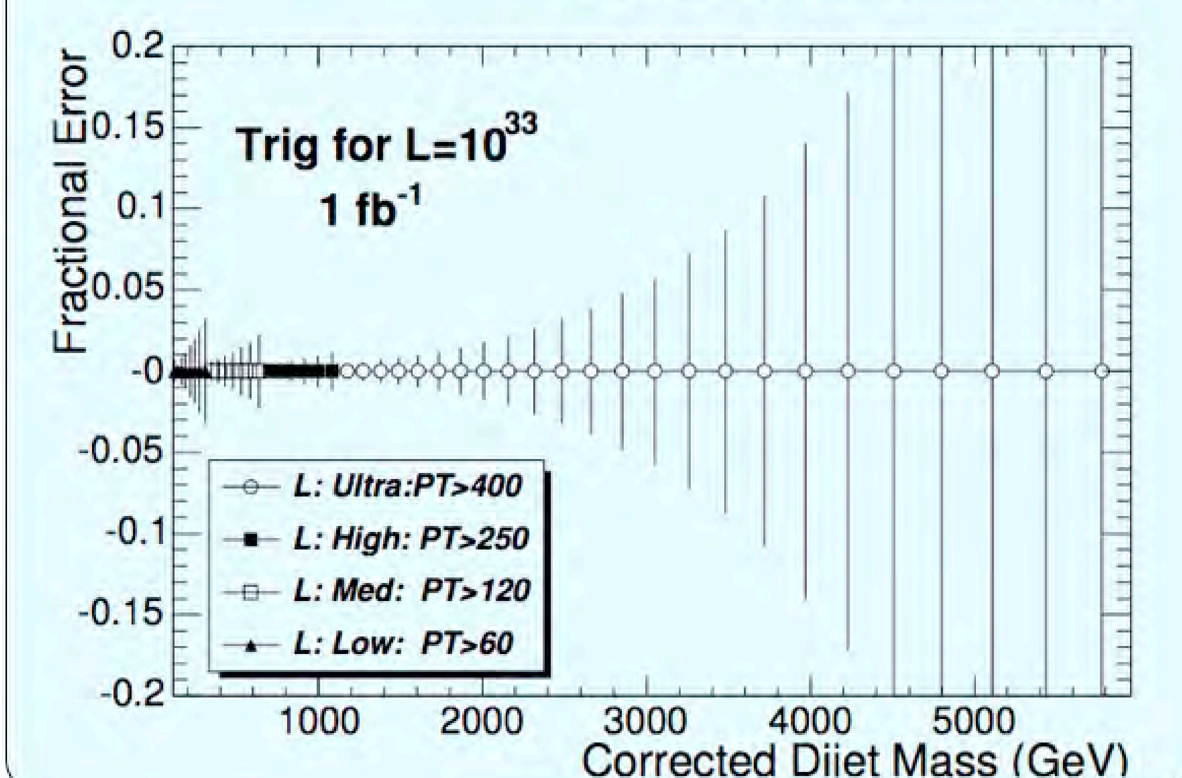


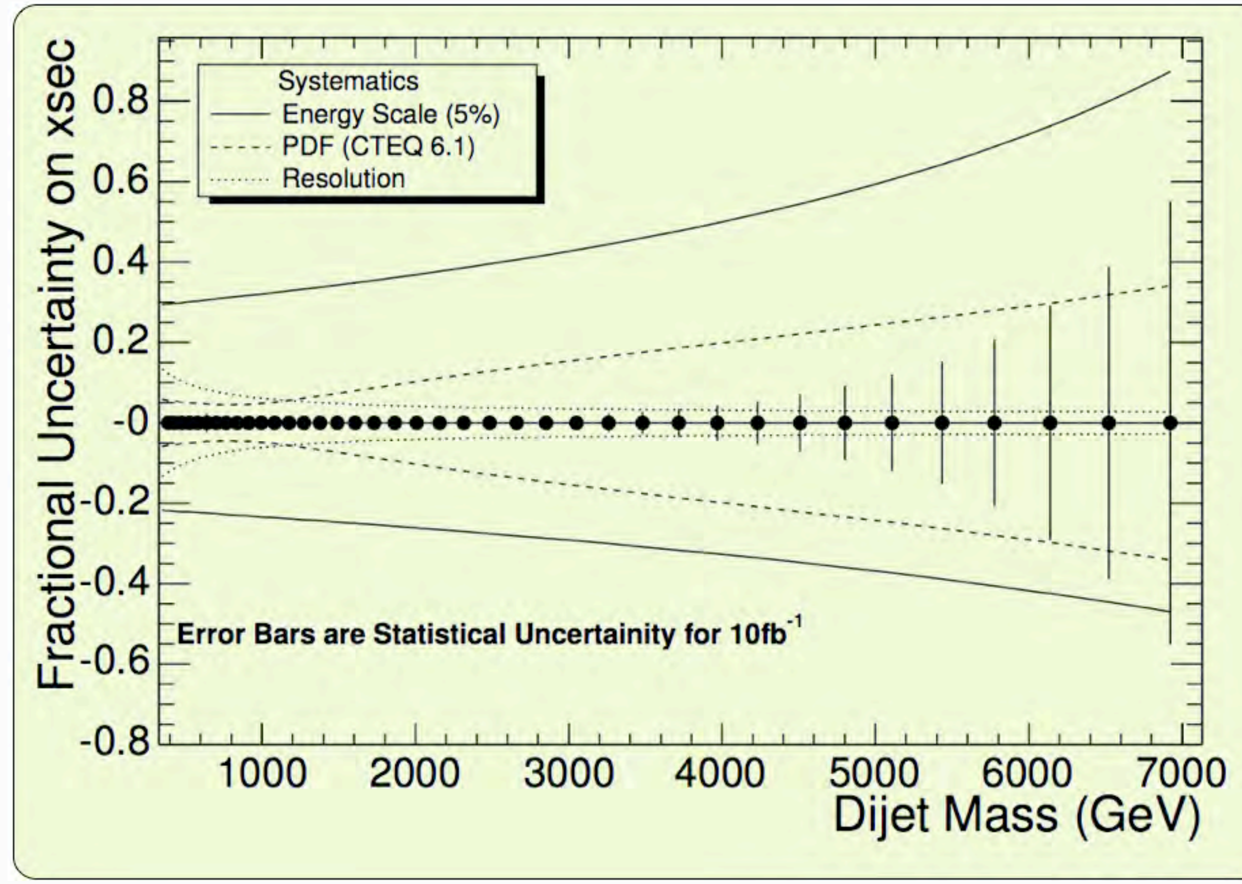
Goal : Measure cross section as function of invariant mass of the two jets.
Test QCD predictions and look for resonances at high invariant mass.

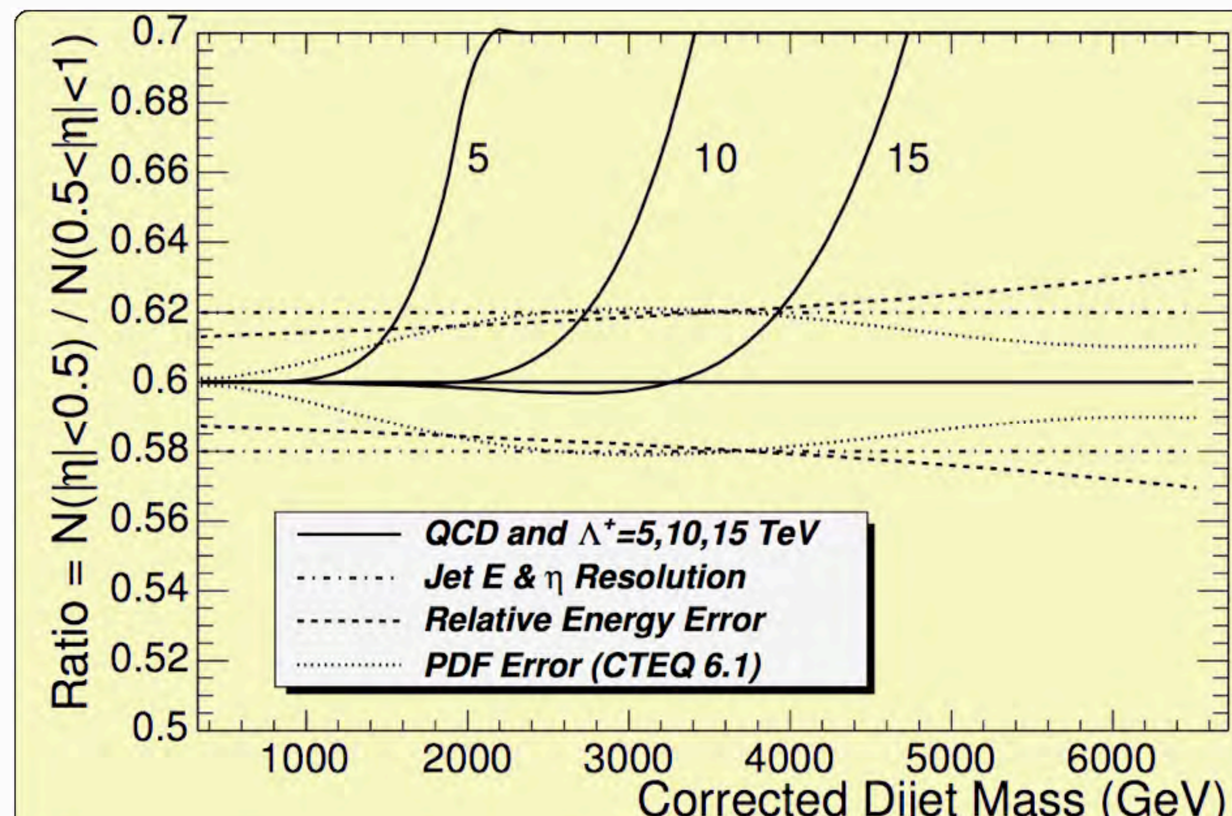
Also : **di-jet angular correlations**, largely independent on JES and luminosity cancels out

Di-Jets (CMS PDTR)





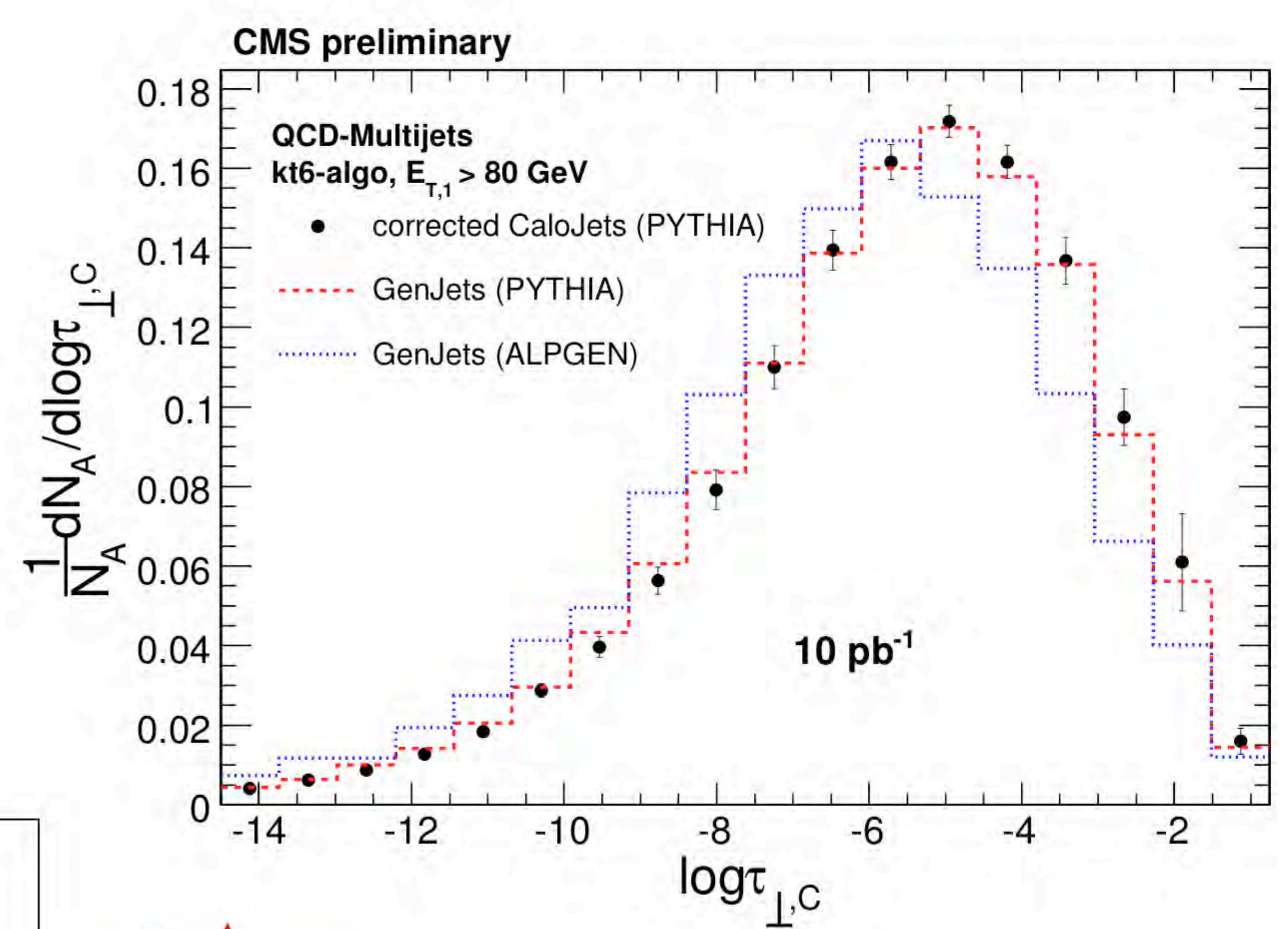




Note : Ratio of cross-section central / forward !

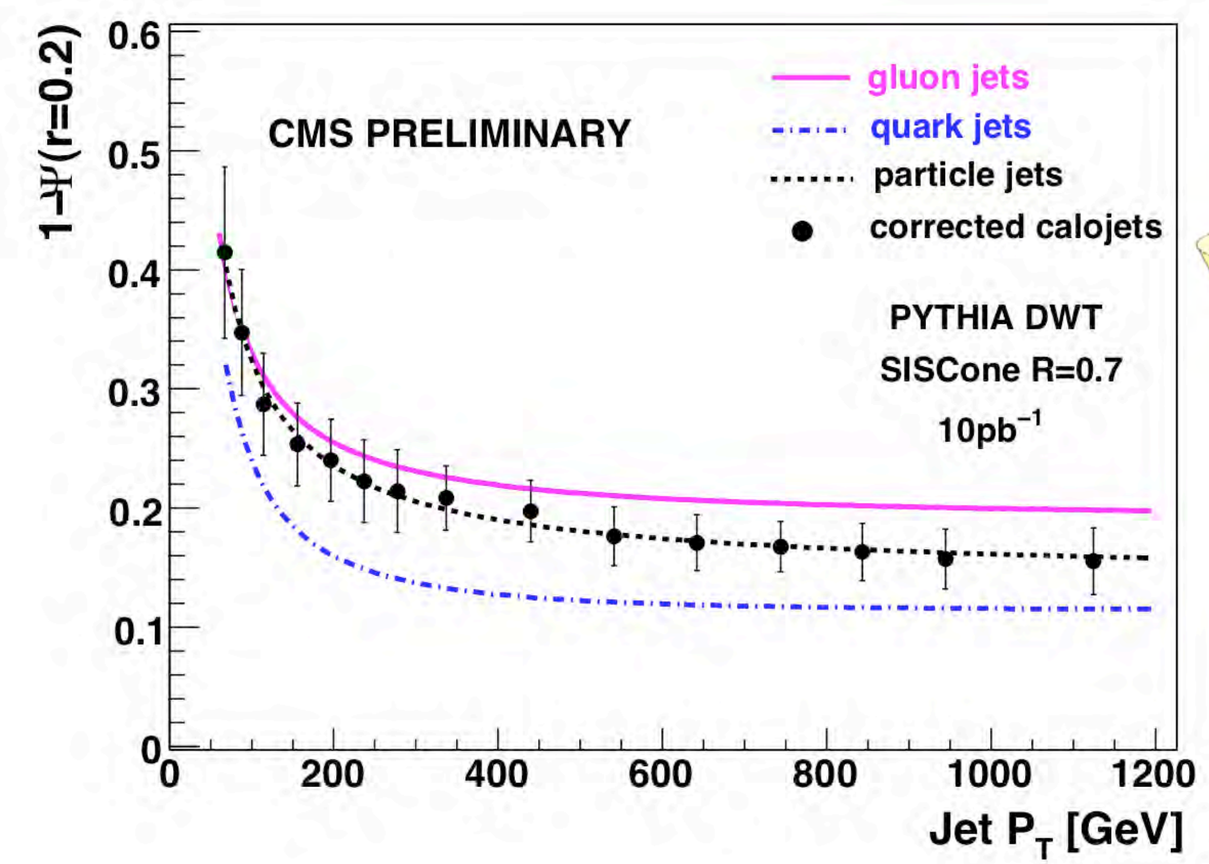
Further (early) jet observables

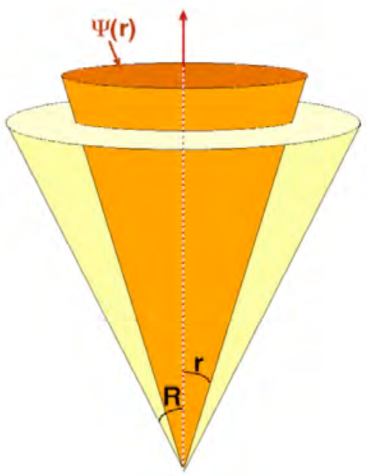
- Event shapes
- di-jet (azimuthal) angular correlations
- jet shapes



Transverse Thrust

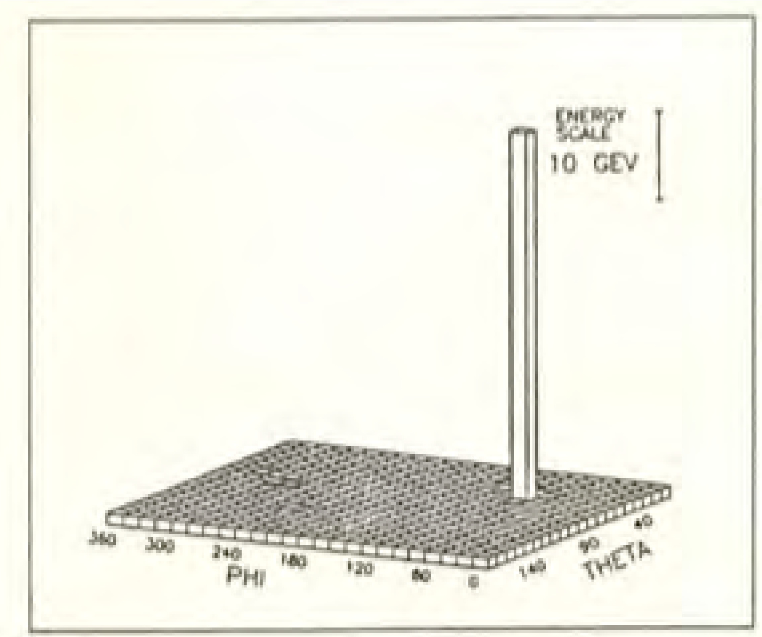
$$1 - \tau_\perp = \max_{\vec{n}_T} \frac{\sum_i |\vec{p}_{\perp,i} \cdot \vec{n}_T|}{\sum_i |\vec{p}_{\perp,i}|}$$

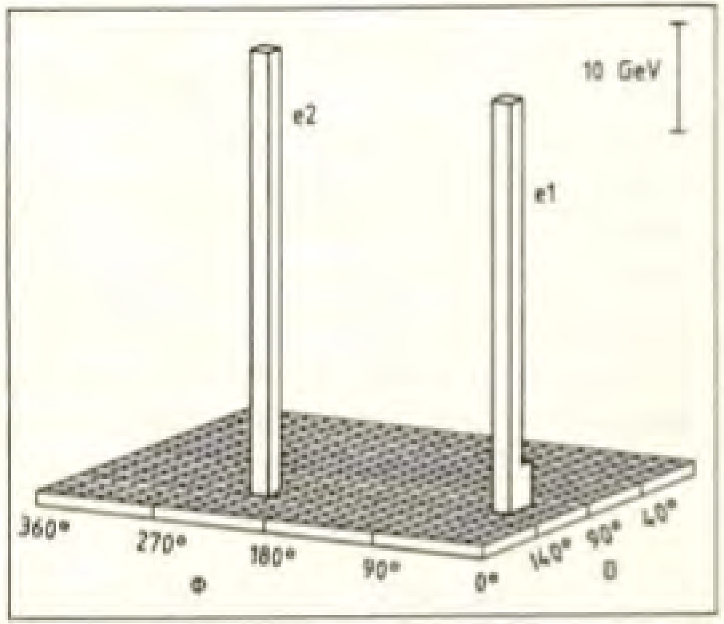




Jet shape (fractional momentum inside cone)

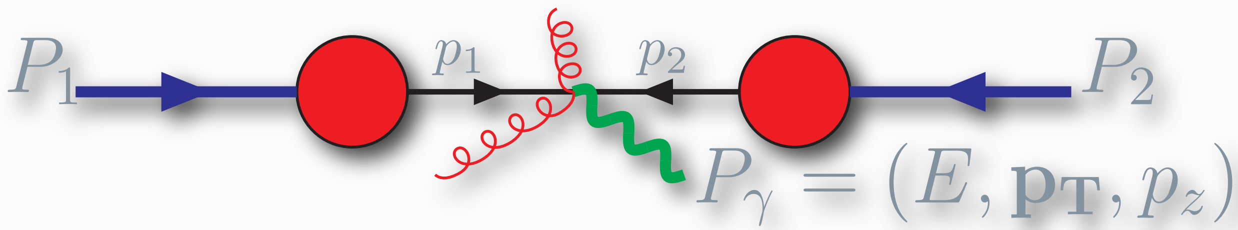
W and Z production



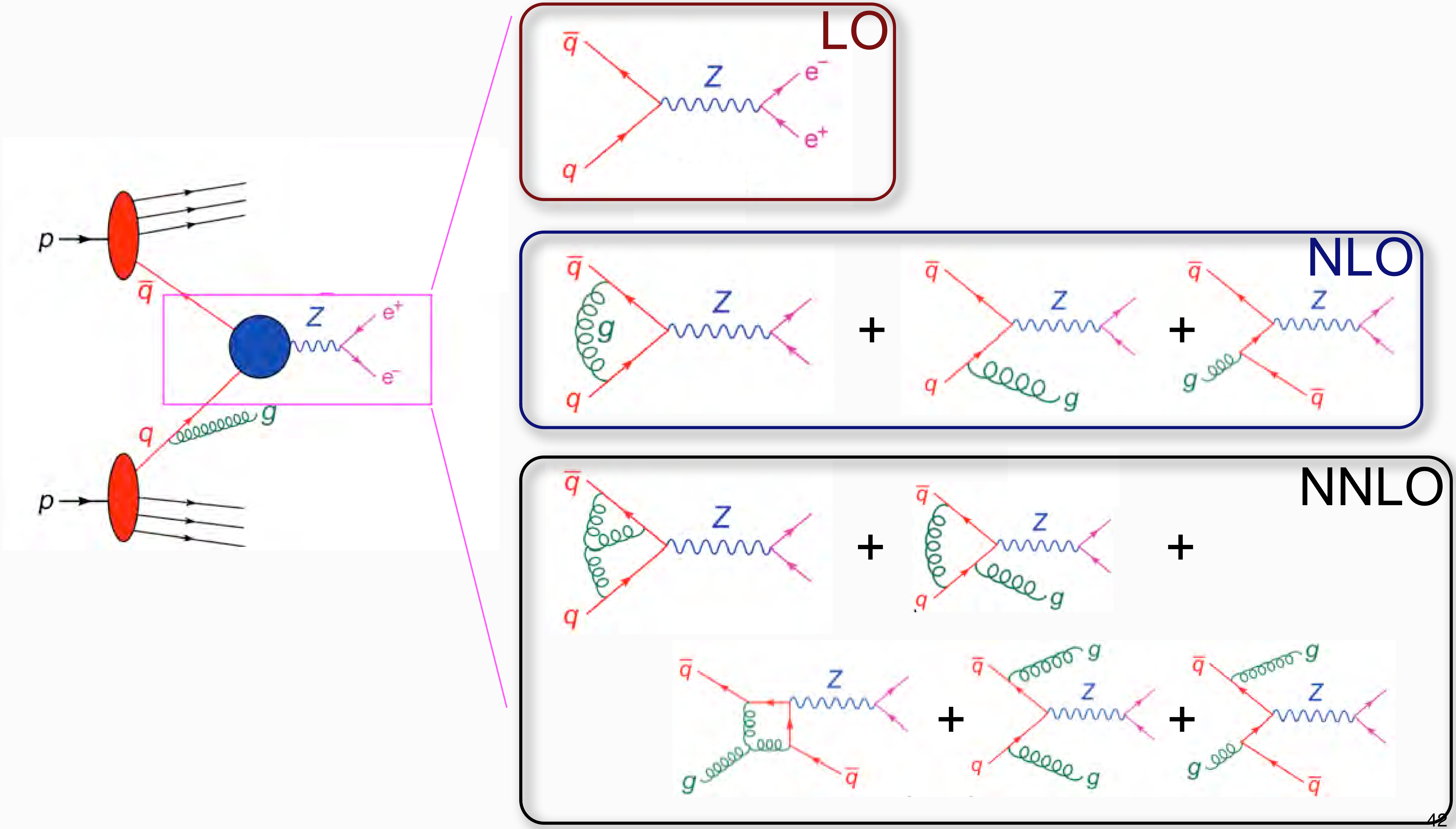


... one of the first W and Z's in UA1/2

Predictions

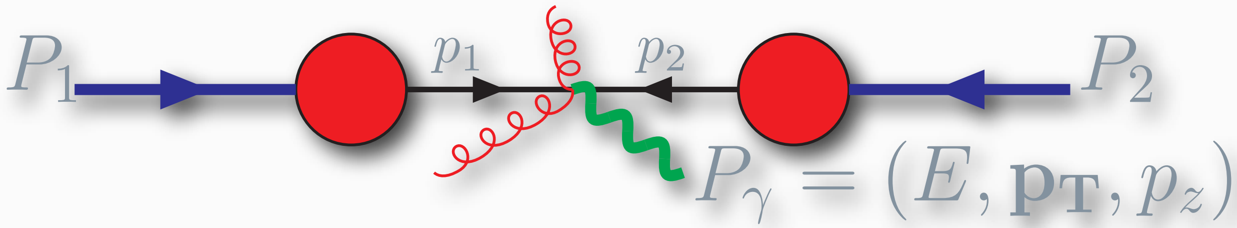


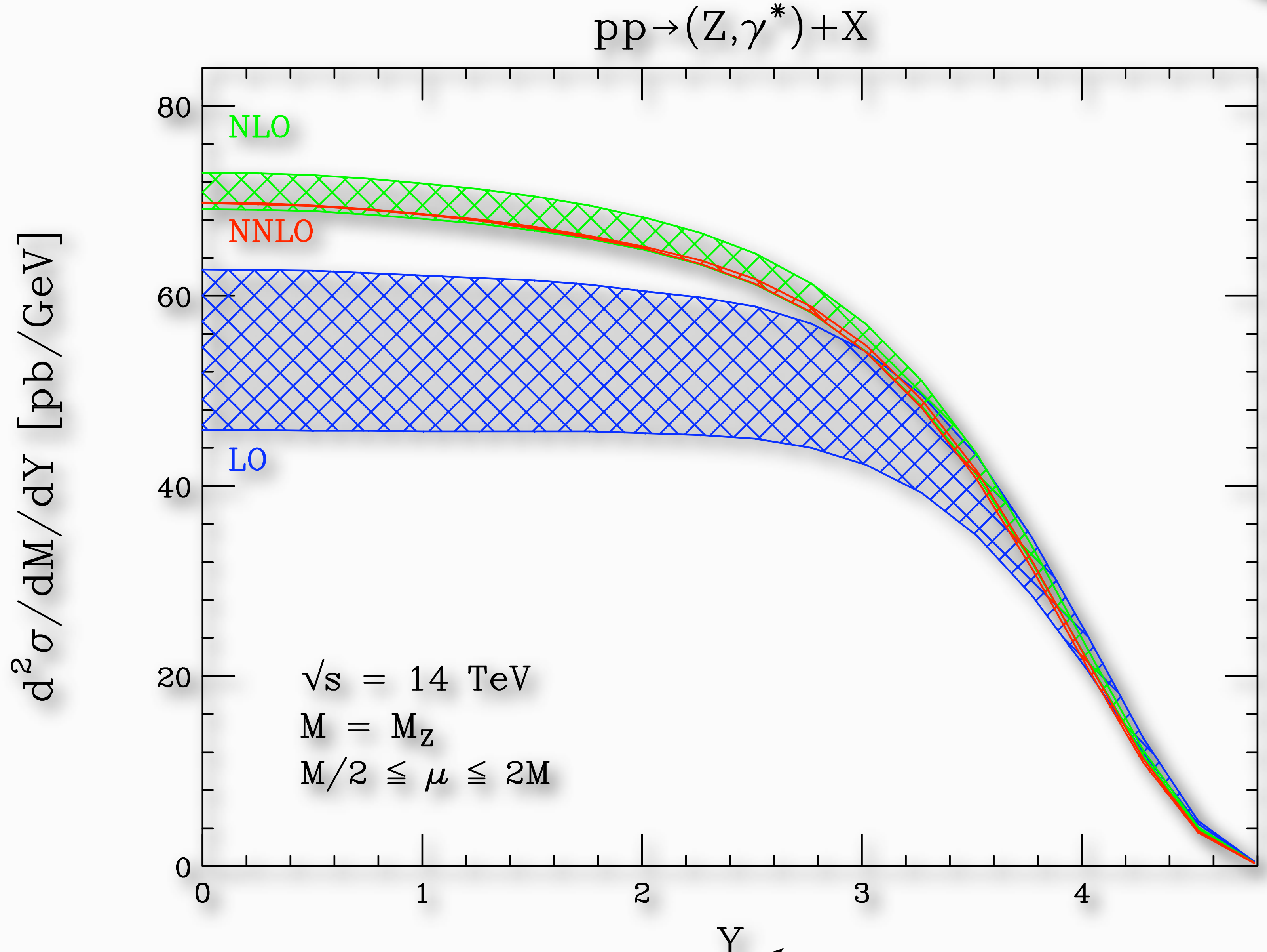
known up to NNLO in pert. QCD!



Predictions

- Probably best known cross section at LHC, NNLO, differentially
- a well suited normalization process





small NNLO scale uncertainty:

LO : 25% - 30%
NLO : 6%
NNLO : 0.1 % (Y=0) -

1% (Y<3) -

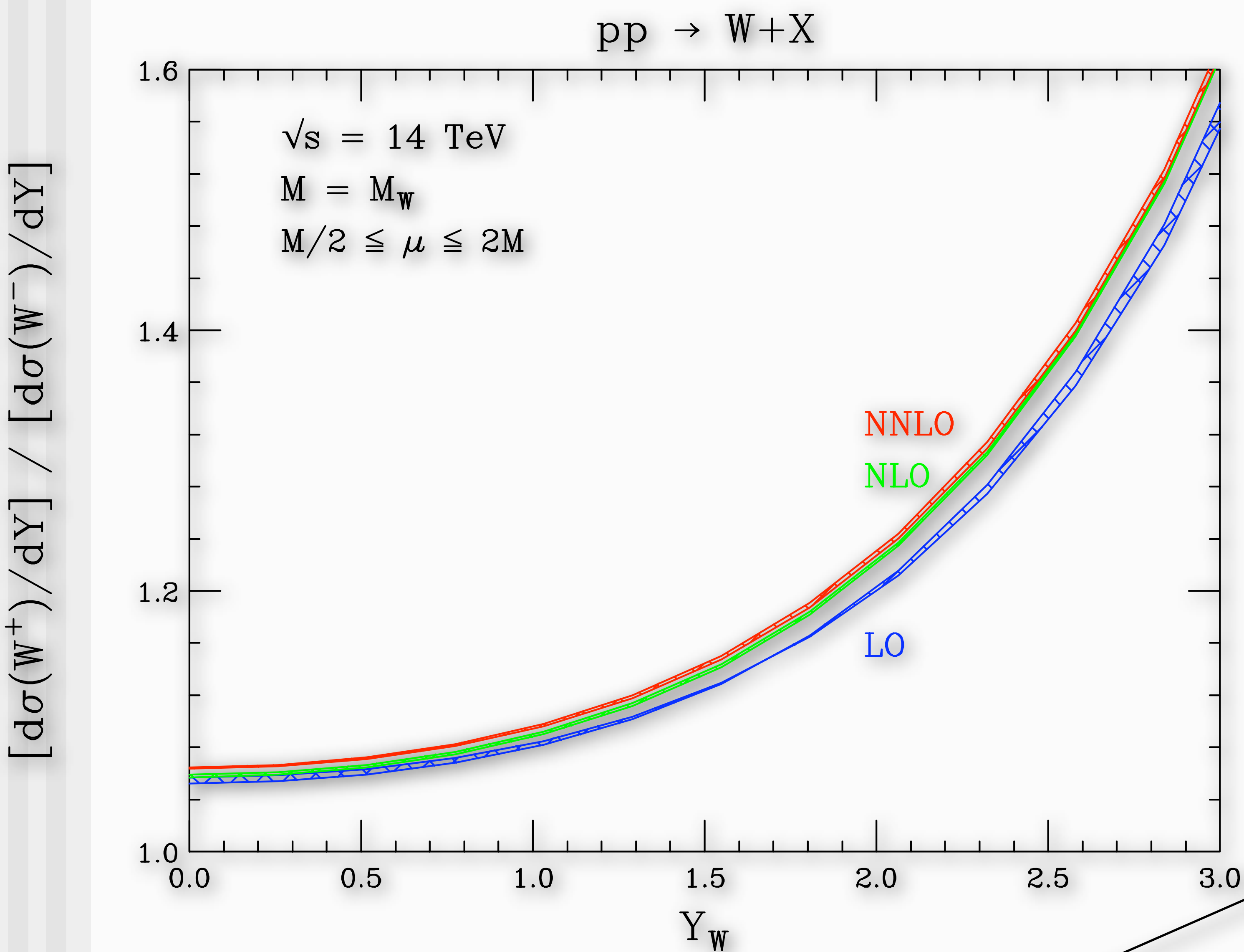
3% (Y ~ 4)

shape stabilizes at NNLO

Anastasiou, Dixon, Petriello, Melnikov : differential in W/Z rapidity
Petriello, Melnikov : fully differential in lepton momenta

Predictions

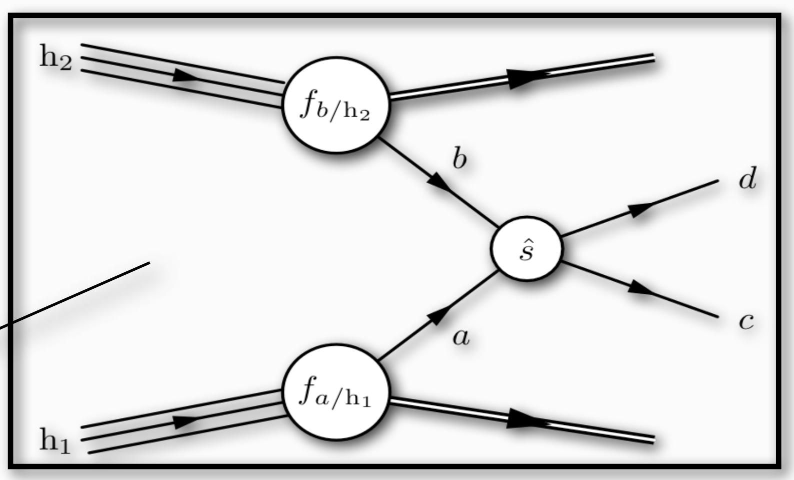
similarly for W^+/W^- : very small
NNLO scale uncertainty: 0.5 - 0.7 %



However : dominant uncertainty for absolute W and Z cross section:

PDFs : 4 - 5 %

remember:

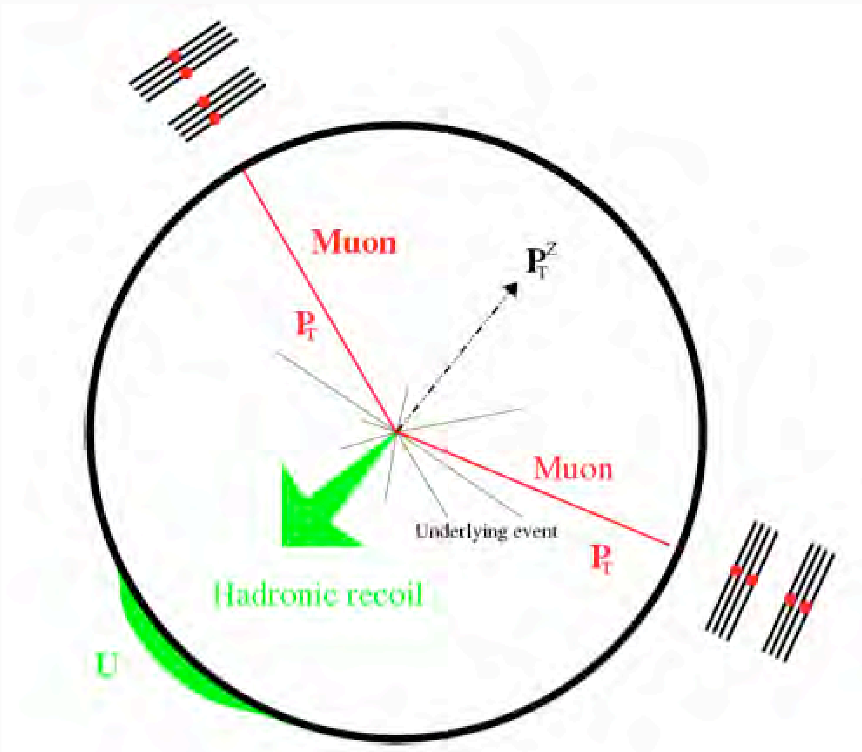


$$d\sigma(\mathrm{h}_1\mathrm{h}_2 \to cd) = \int_0^1 dx_1 dx_2 \sum_{a,b} f_{a/\mathrm{h}_1}(x_1,\mu_F^2) f_{b/\mathrm{h}_2}(x_2,\mu_F^2) d\hat{\sigma}^{(ab\to cd)}(Q^2,\mu_F^2)$$

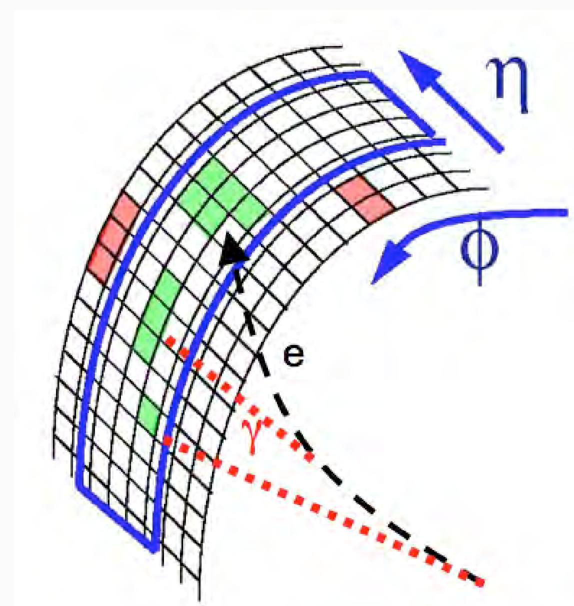
so : if we measure precisely this, can we constrain this?

known precisely up to NNLO

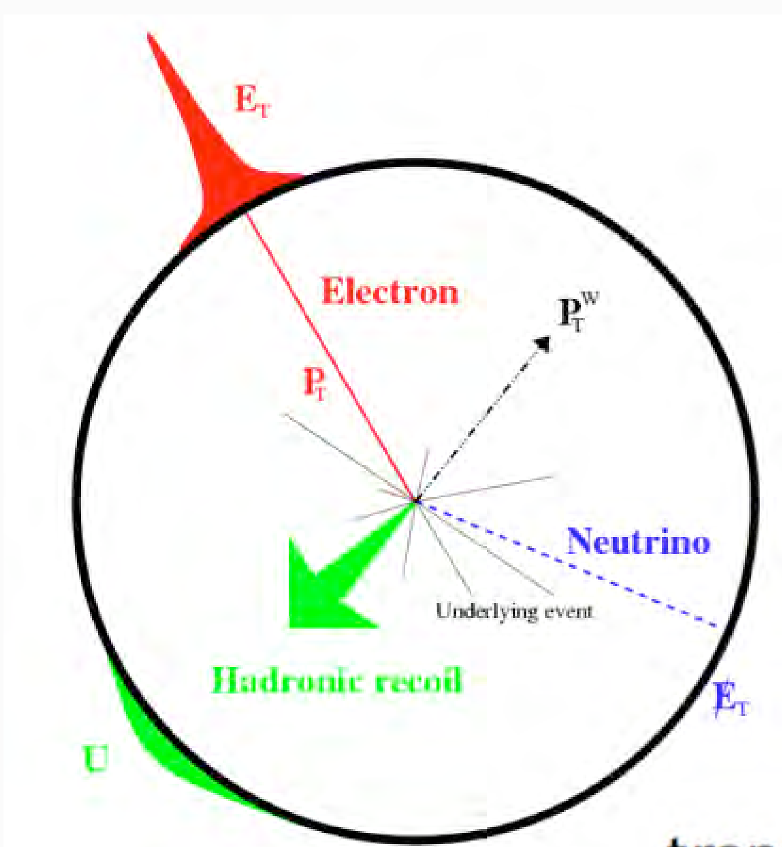
Experimental signature



Z: pair of charged leptons
- high-p_T
- isolated
- opposite charge
- ~70 < m_{ll}< ~110 GeV



Example: electron reconstruction
- isolated cluster in EM calorimeter
- p_T > 20 GeV
- shower shape consistent with expectation from electrons
- matching charged track



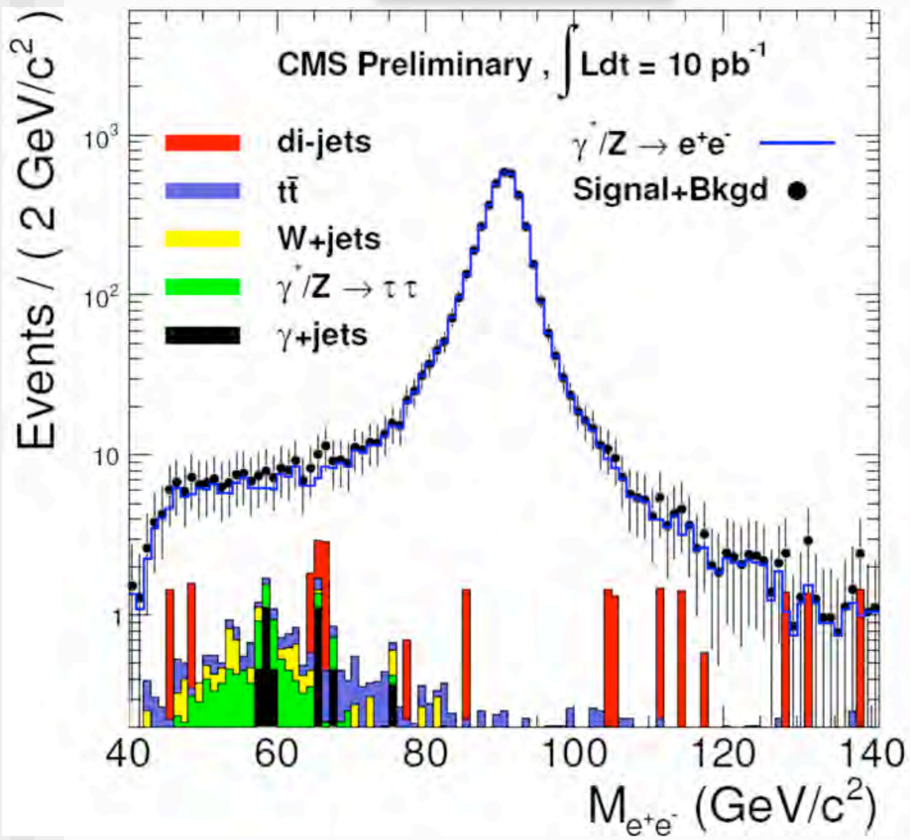
W: single charged leptons
- high-p_T
- isolated
- $E_{T,miss}$ (from neutrino)

transverse mass: $M_W^T = \sqrt{2 \cdot P_T^l \cdot P_T^\nu \cdot (1 - \cos\Delta\phi^{l,\nu})}$

Example: W, Z (σ.BR)

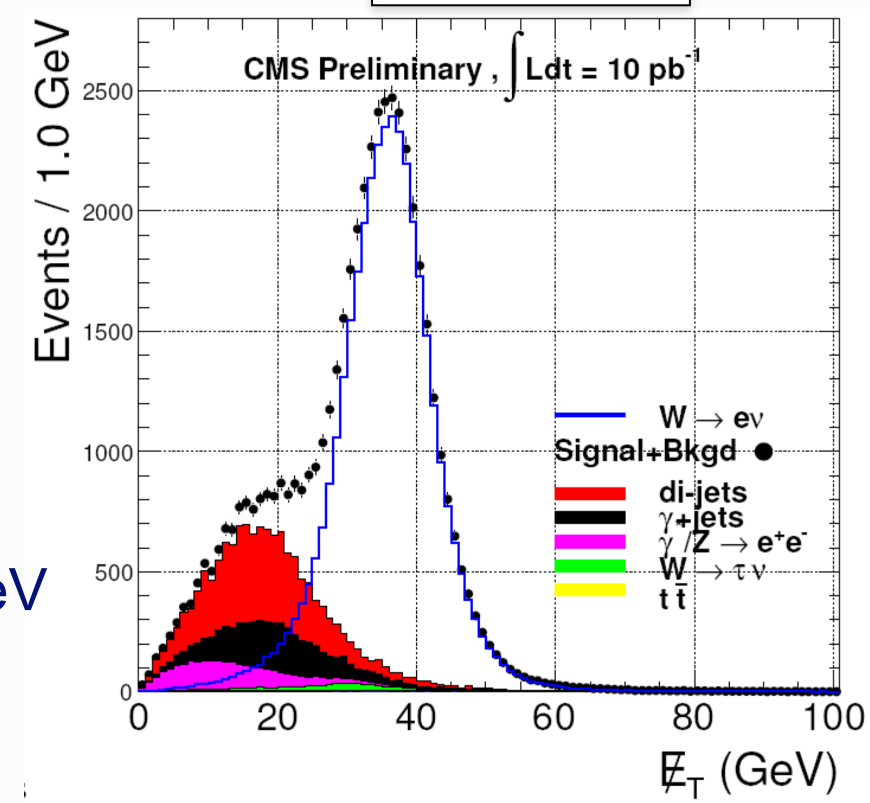
Virdee, EPS09

$Z \rightarrow ee$ (10 pb^{-1} at 10 TeV) **$W \rightarrow e\nu$**



Z Selection
$E_T > 20.0$ GeV
both e isolated
$70 < M_{e,e} < 110$ GeV

W Selection
$E_T > 30.0$ GeV
Isolated e



$N_{selected}$	4273 ± 65
N_{bkgd}	assumed 0.0
Tag&Probe $\varepsilon_{offline}$	90.4 ± 0.3 %
Tag&Probe $\varepsilon_{trigger}$	99.88 ± 0.02 %
Tag&Probe ε_{total}	81.6 ± 0.5 %
Acceptance	40.4 ± 0.2 %
Int. Luminosity	$10\ pb^{-1}$
$\sigma_{Z/\gamma^*} \times BR(Z/\gamma^* \rightarrow e^+e^-)$	1300 ± 20 pb
$\sigma_{Z/\gamma^*} \times BR(Z/\gamma^* \rightarrow e^+e^-)$ (MCtruth)	1296 pb

Use data driven methods e.g. tag and probe method to work out efficiencies from “data”

$N_{selected} - N_{bkgd}$	37500 ± 453
Tag&Probe $\varepsilon_{offline}$	74.4 ± 0.6 %
Tag&Probe $\varepsilon_{trigger}$	97.2 ± 0.3 %
Tag&Probe $\varepsilon_{offline \times trigger}$	72.3 ± 0.6 %
Acceptance	36.6 ± 0.1 %
Int. Luminosity	$10\ pb^{-1}$
$\sigma_W \times BR(W \rightarrow e\nu)$	14200 ± 200 pb
$\sigma_W \times BR(W \rightarrow e\nu)$ (MCtruth)	13865 pb

Systematic uncertainty
2.4% + 10% for ∫Ldt

Systematic uncertainty
4.0% + 10% for ∫Ldt;

Tag and Probe

- Take well reconstructed object (eg. electron after tight cuts), as well one with looser cuts (=Probe)
- Use further constraint (eg. Z mass) to define a Tag (ie. tight selection + mass constraint)
- Now measure efficiency of applying further cuts on probe object!

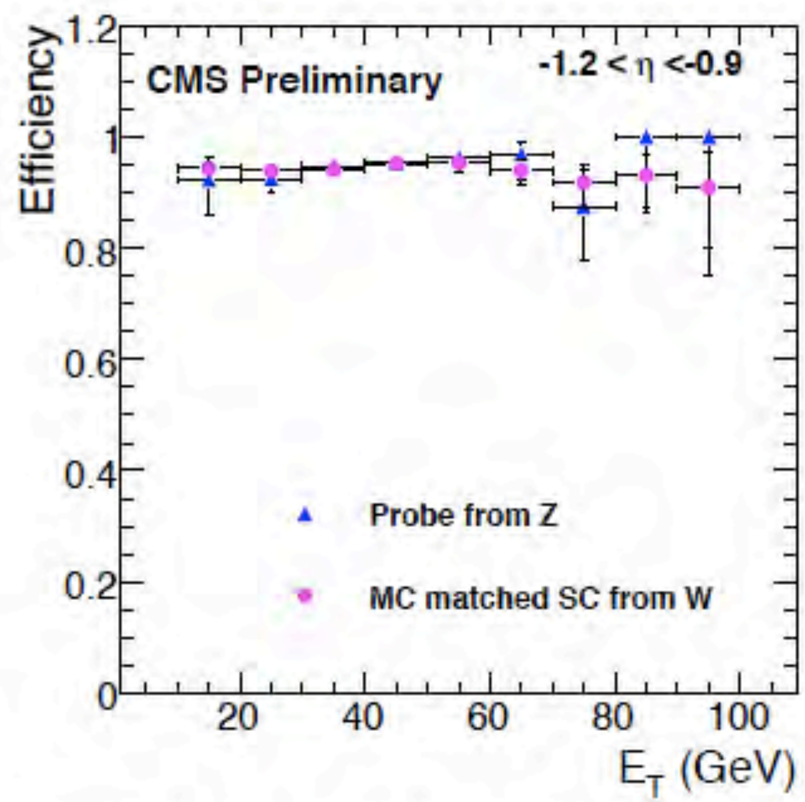


Figure 1: Track matching efficiency as a function of supercluster E_T for $-1.2 < \eta < -0.$

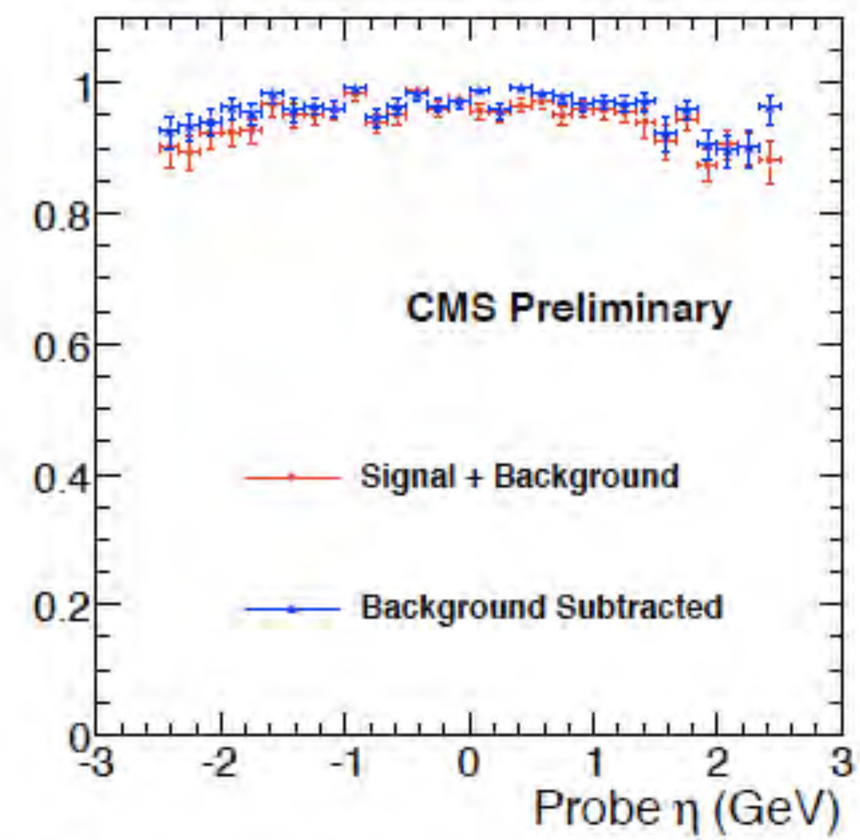
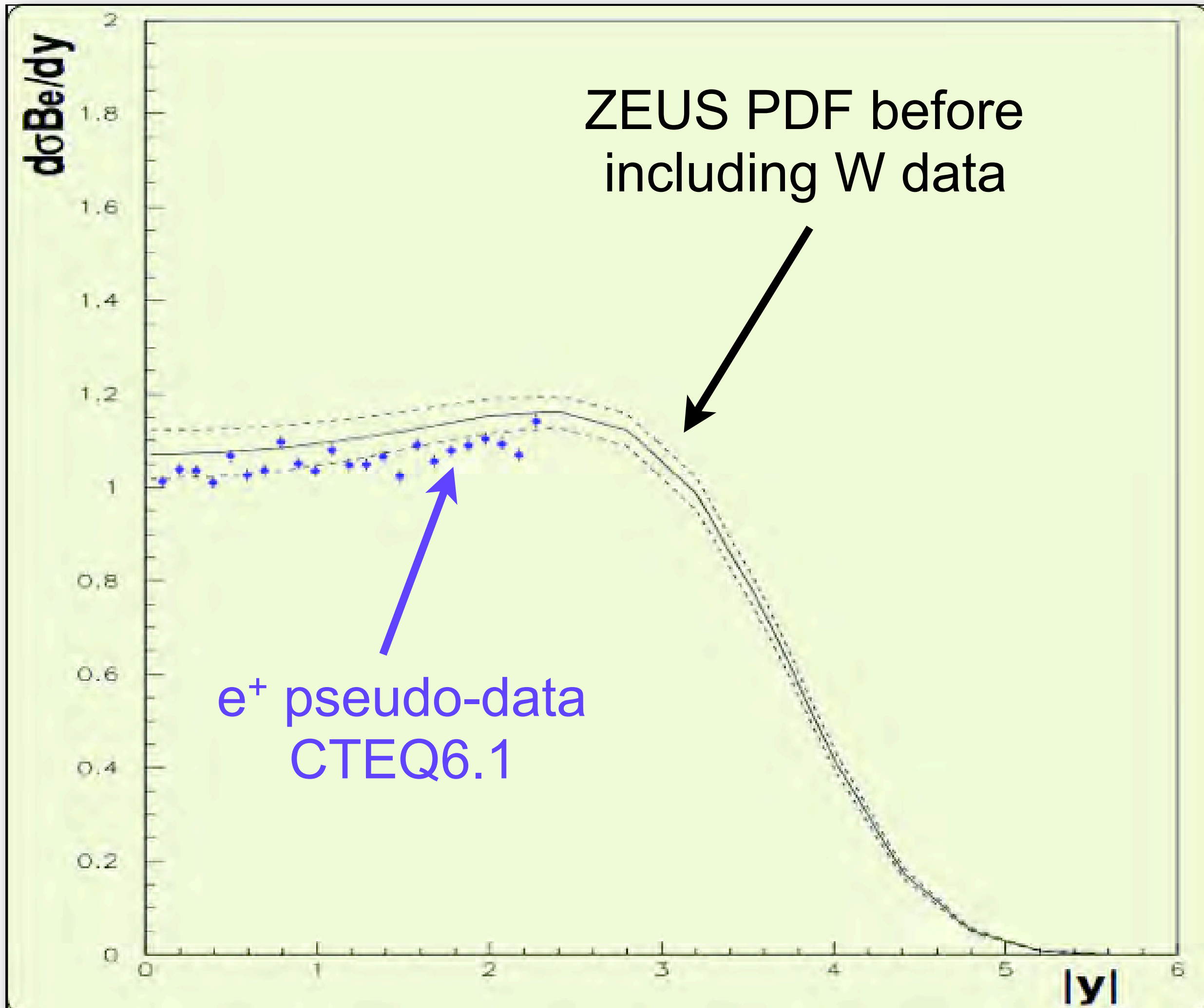
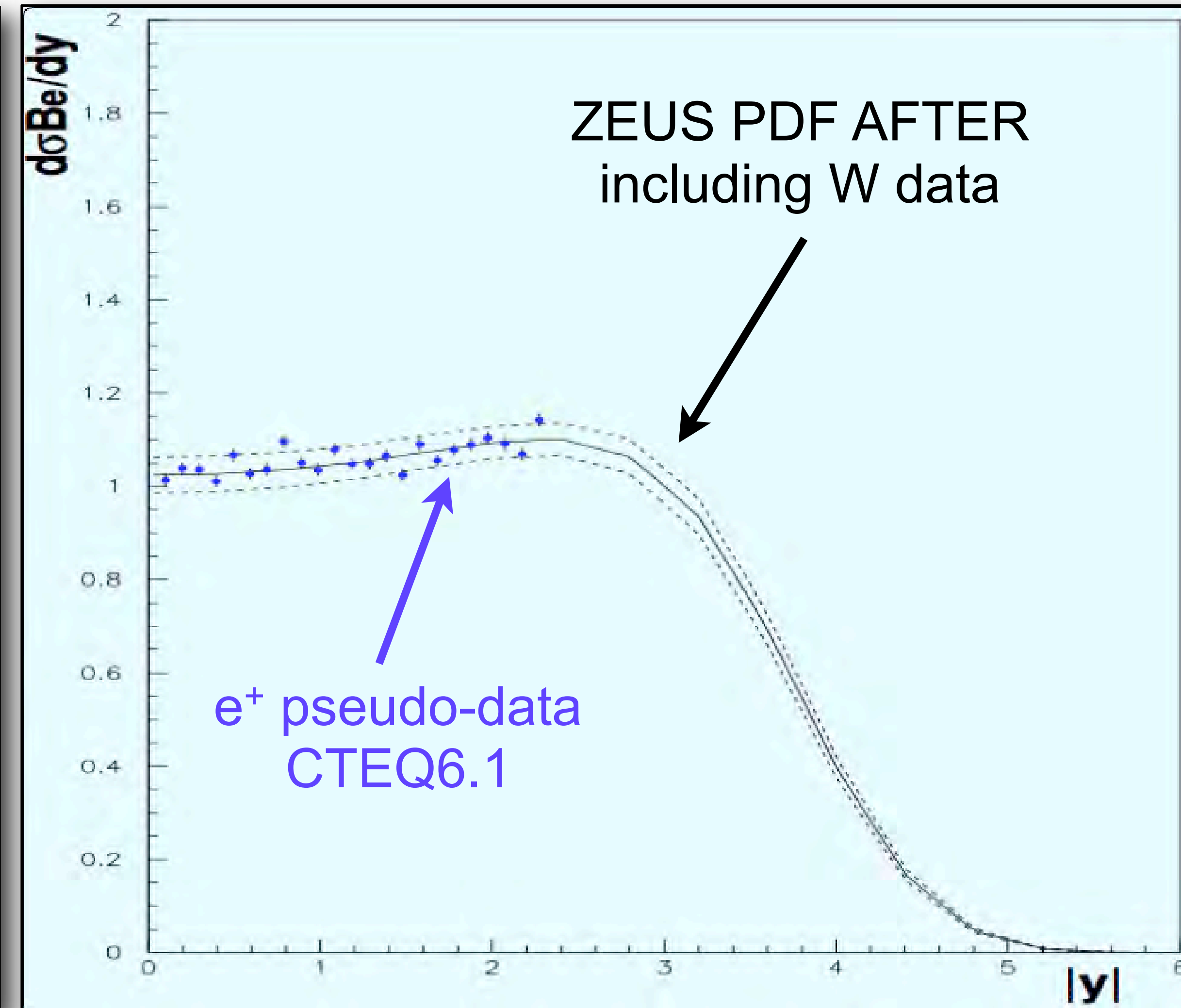


Figure 6: Electron preselection efficiency versus probe η.

W/Z and PDF constraints





- Fast simulation study by ATLAS (HERA-LHC workshop, hep-ph/051119)
  - produce W sample with CTEQ6.1 pdf set, using a random 4% error on “data”
  - correct back for detector acceptance, using ZEUS-PDFs and include these data into the ZEUS fit
  - Fit shows : error on parameter λ ($x\,g(x) \sim x^{-\lambda}$) reduced by 35 %

Luminosity Measurement

Expected uncertainty from luminosity monitors ≈ 10 - 5% (?)

Alternative : use W/Z counting as luminosity monitor Dittmar et al.

$$N_{pp\to Z} = L_{pp} \cdot PDF(x_1, x_2, Q^2) \cdot \sigma_{q,\bar{q}\to Z}(+HO)$$

count extract as inputs

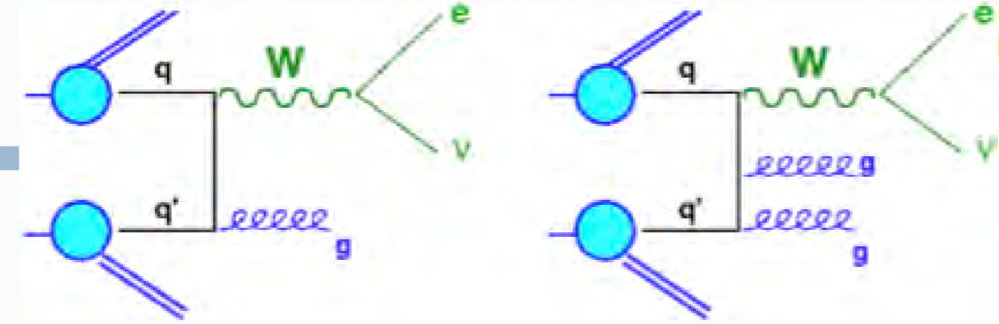
or better : normalize processes to number of Zs (parton-parton luminosity)

$$N_{pp\to WW} = N_{pp\to Z} \cdot \frac{\sigma_{q,\bar{q}\to WW}}{\sigma_{q,\bar{q}\to Z}} \cdot \frac{PDF(x_1', x_2', Q'^2)}{PDF(x_1, x_2, Q^2)}$$

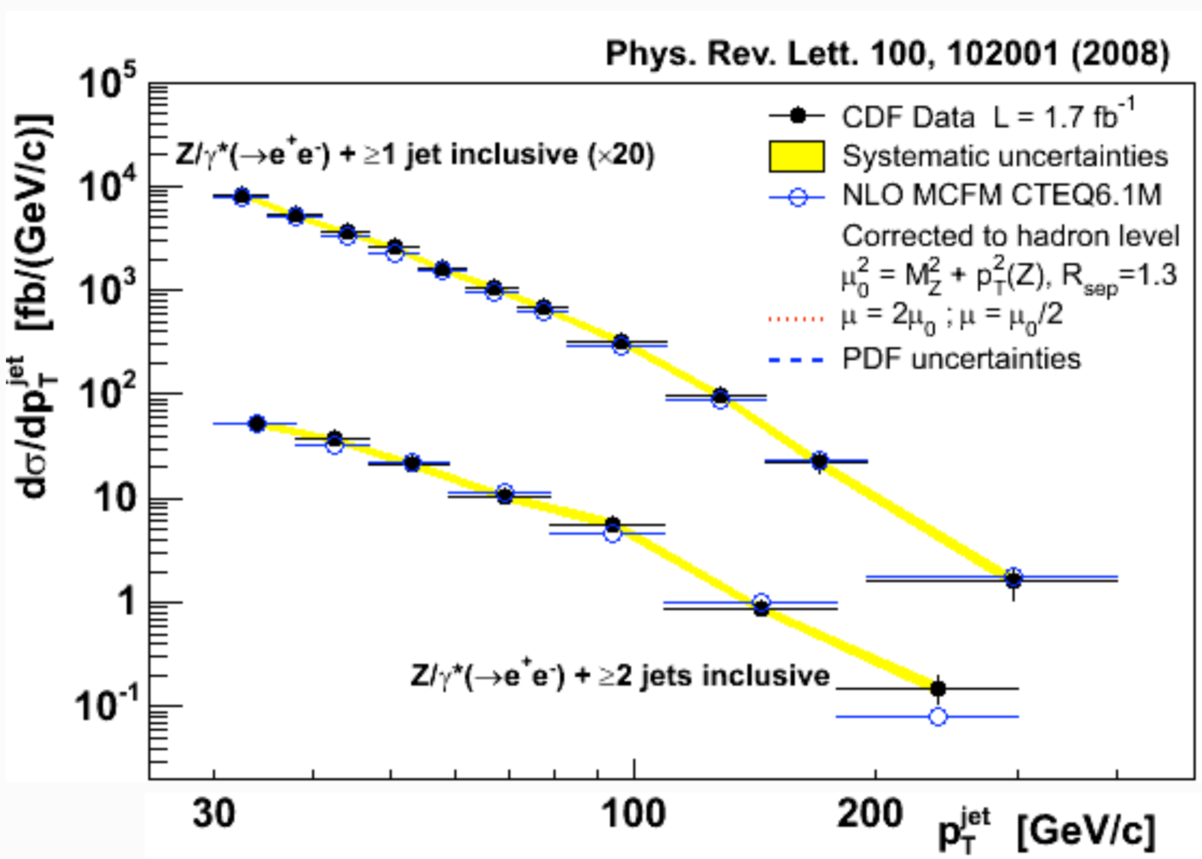
$\Delta L_{pp} = 0!$

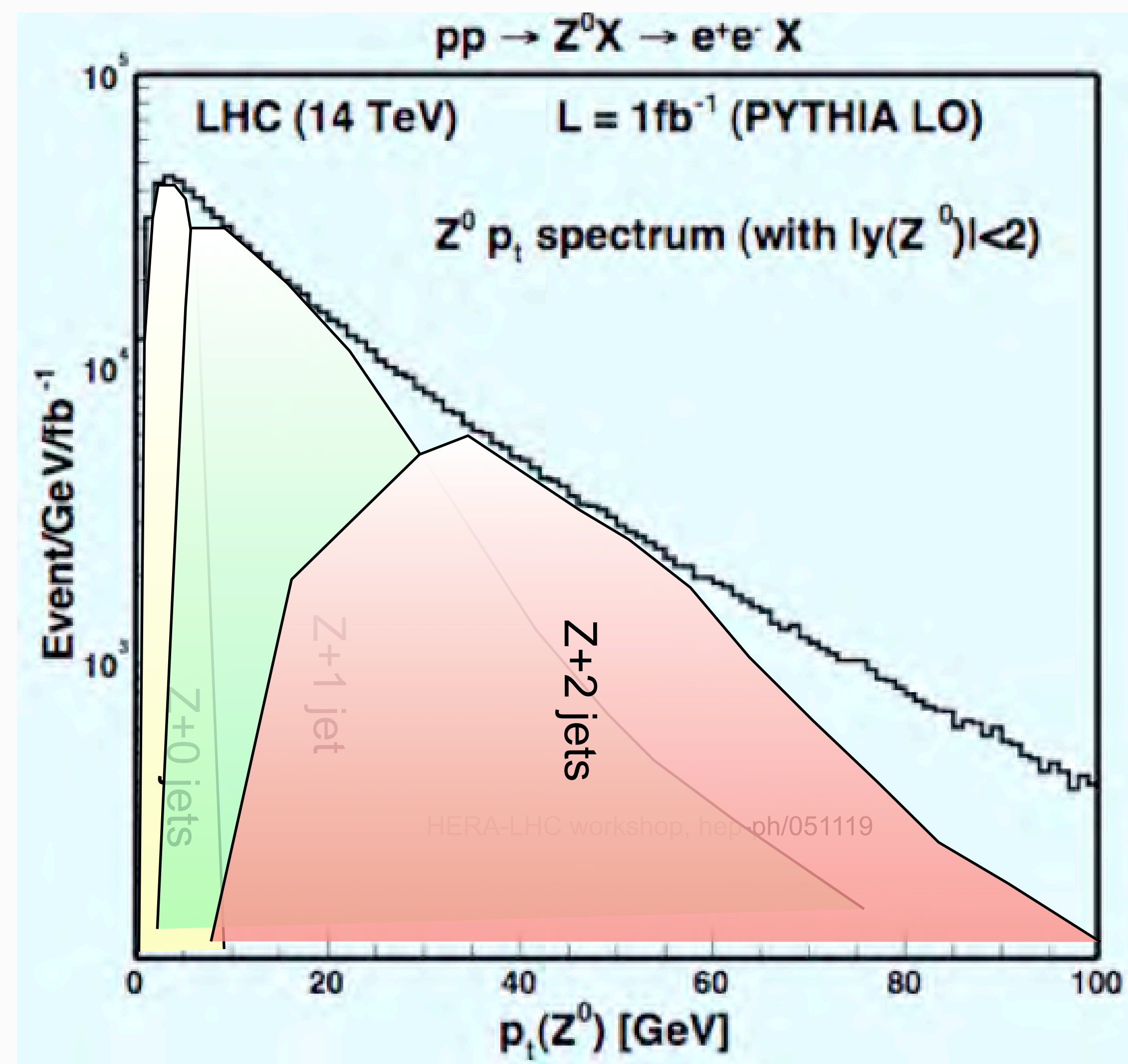
Calculate ratios.
Reduced uncertainties(?)
Extend also to gluon-quark case....
eg. by going to large p_T (more gluon induced) ?

W/Z + jets



- Extremely important background for many searches
  - in particular for SUSY searches in the “jets+lepton+E_{Tmiss}” channel
- Remember : Jet scale uncertainty extremely important (xsec as function of jet p_T), also here
  - can expect some 30 % uncertainty from that. Probably less in case of rate measurements.
- Should also have a more “inclusive” look at it : Measuring the Z p_T can be done with a relative precision at the per-cent level (leptons (!) again), will be invaluable for checking predictions and tuning MCs

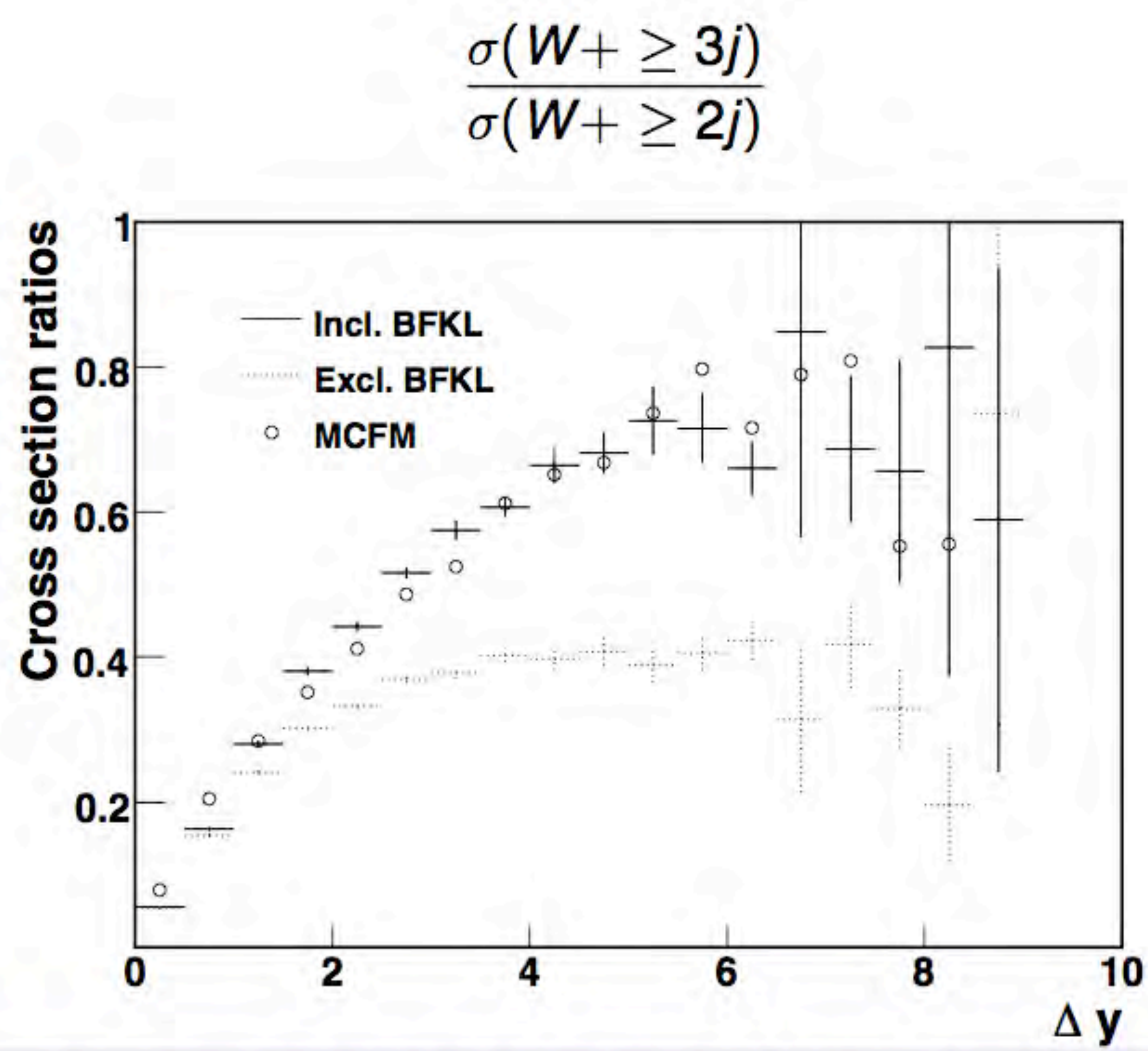




Again, look at ratios!

- Useful to test QCD, look for deviations
- and many uncertainties cancel

- Jeppe Andersen, Les Houches 09



$k_\perp$-jet, $R = .4$, $p_\perp > 40$GeV; incl: $W+ \geq 3$ jets, excl: $W+" = "3$jets

Interesting example of newly proposed "**ratio observable**":

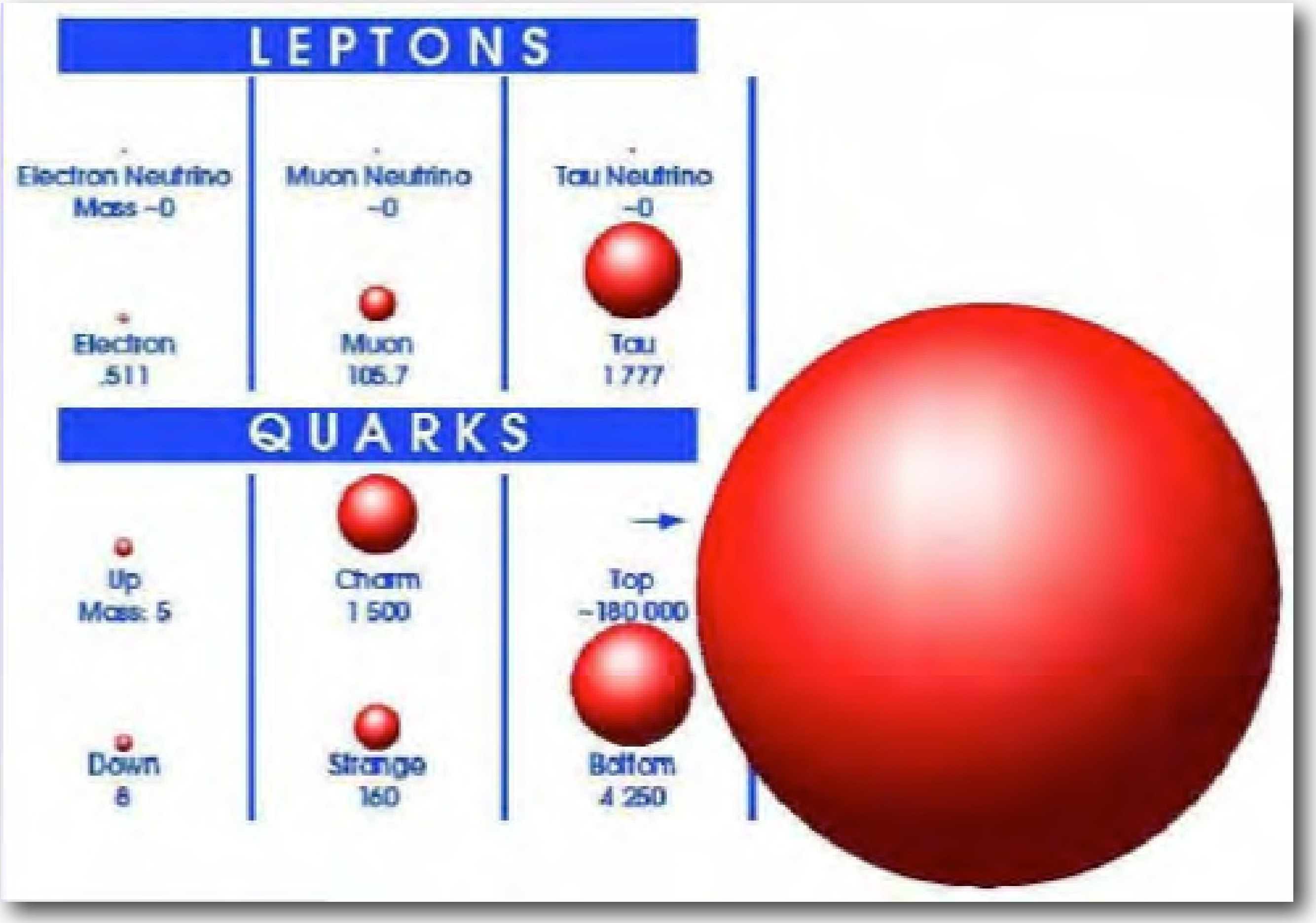
>= 3rd jet production as function of rap.diff. of 2 leading jets.

Reduced sensitivity to exp. uncert?

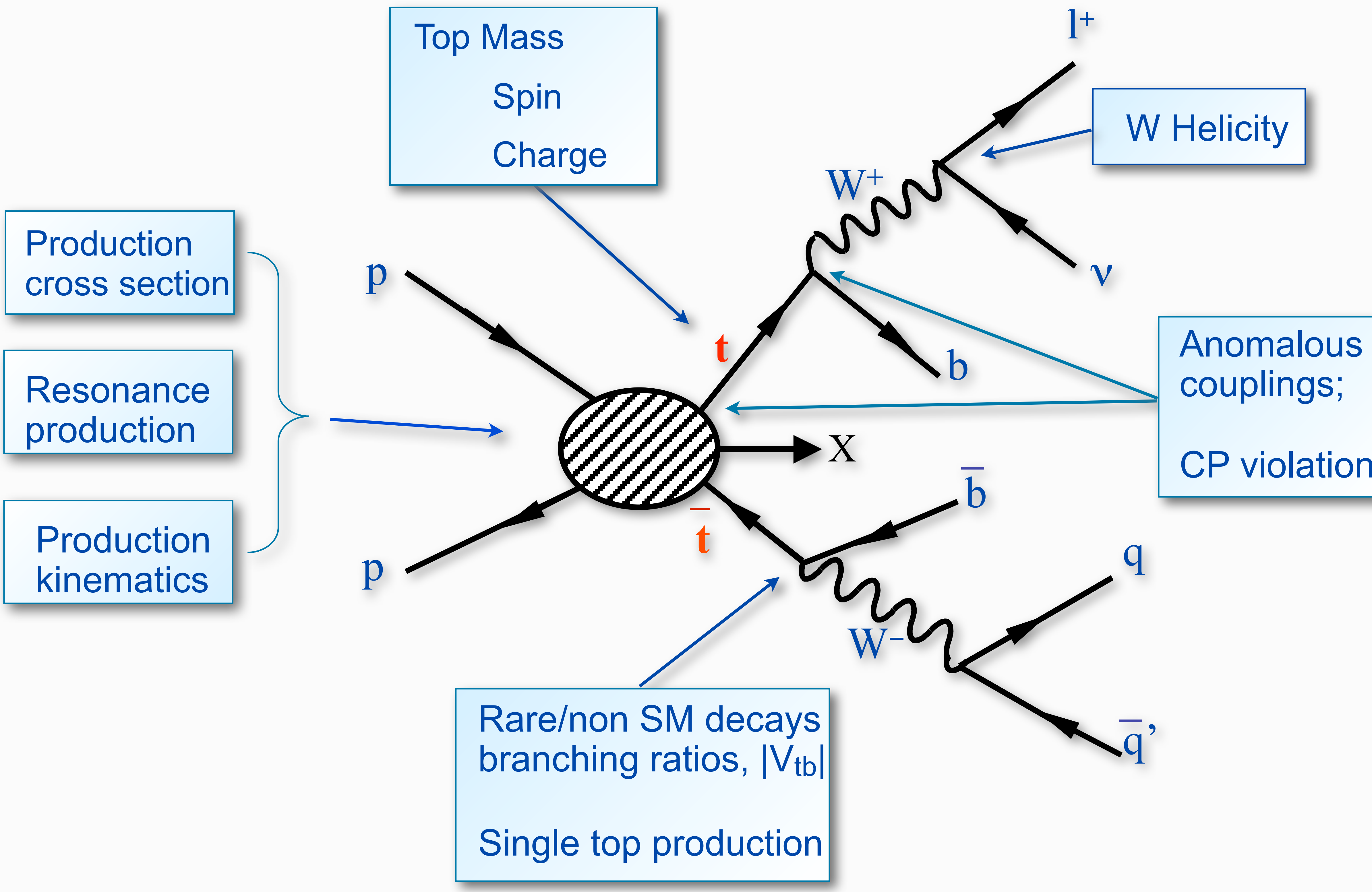
Useful to test MC models!
Shower MC need "help" of extra hard partons!

- Other interesting observables:
  - $\sigma(W+n)/\sigma\ (Z+n)$
  - $\sigma(W^+)/\sigma\ (W^-)$ vs <n jet> ⇒ pdf's

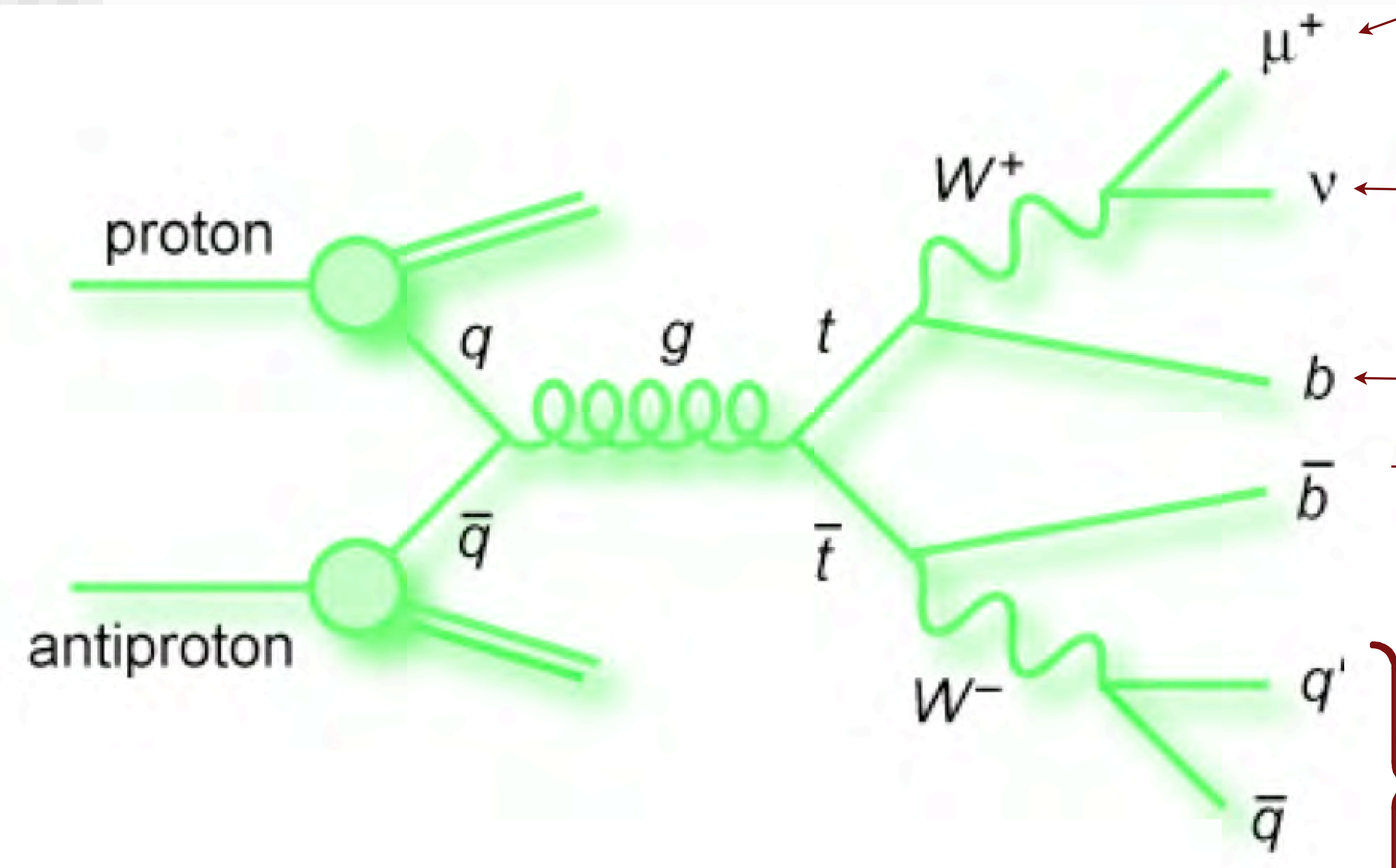
Top production



Top Quark Physics



Top as a "Tool"



Tag and Lepton study tool

Missing E_T study tool

b-tag study tool

Light quark:
jet energy
scale from
M_W constraint

b quark:
jet energy
scale from
M_{top} constraint

Top decays

BR (t→Wb) ~ 100%

Both W's decay via W→ ℓν (ℓ=e or μ; 5%)

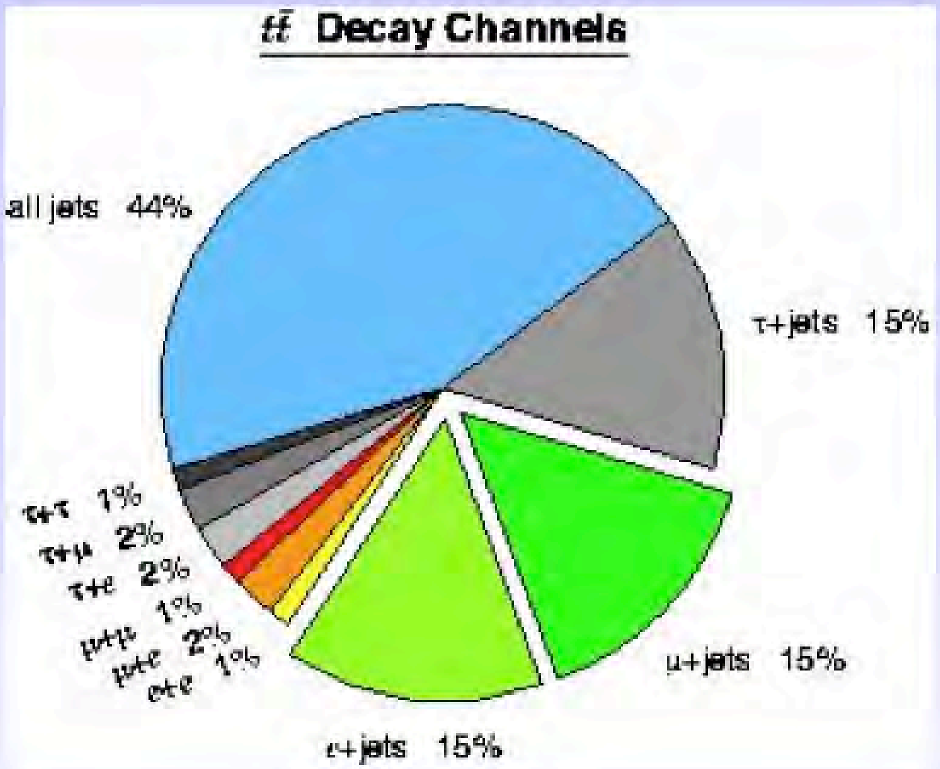
dilepton channel

One W decays via W→ℓν (ℓ=e or μ; 30%)

lepton + jet channel

Both W's decay via W→qq (44%)

all hadronic, not very useful



Important experimental signatures: : - Lepton(s)

- Missing transverse momentum
- b-jet(s)

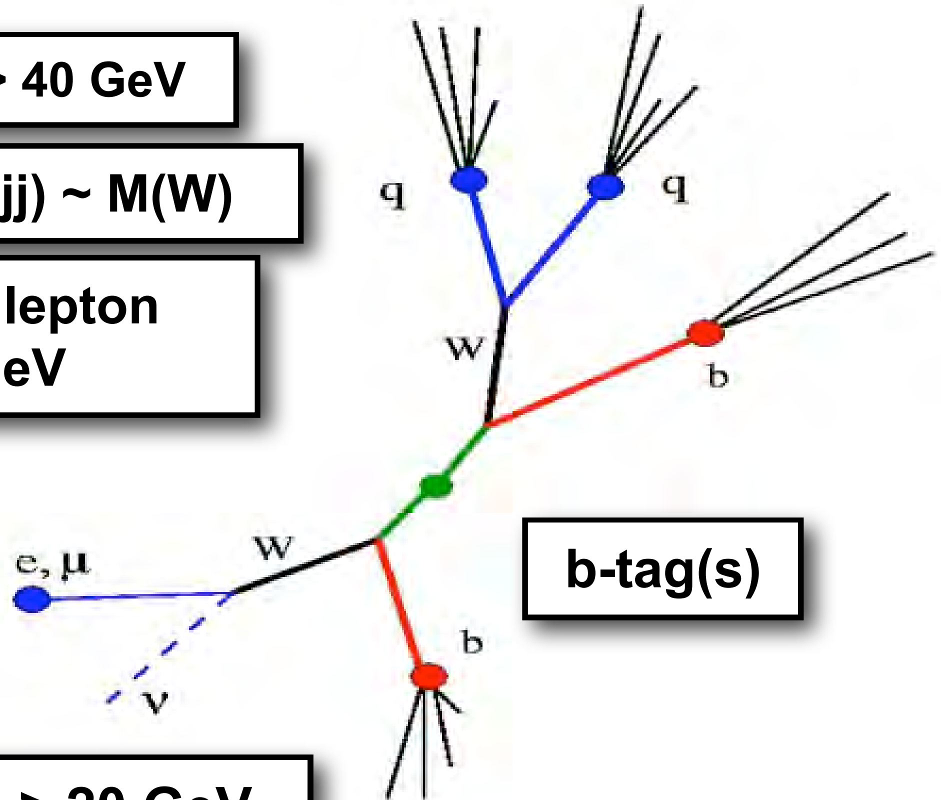
K. Jakobs, CSS07

Top identification

4 jets p_T> 40 GeV

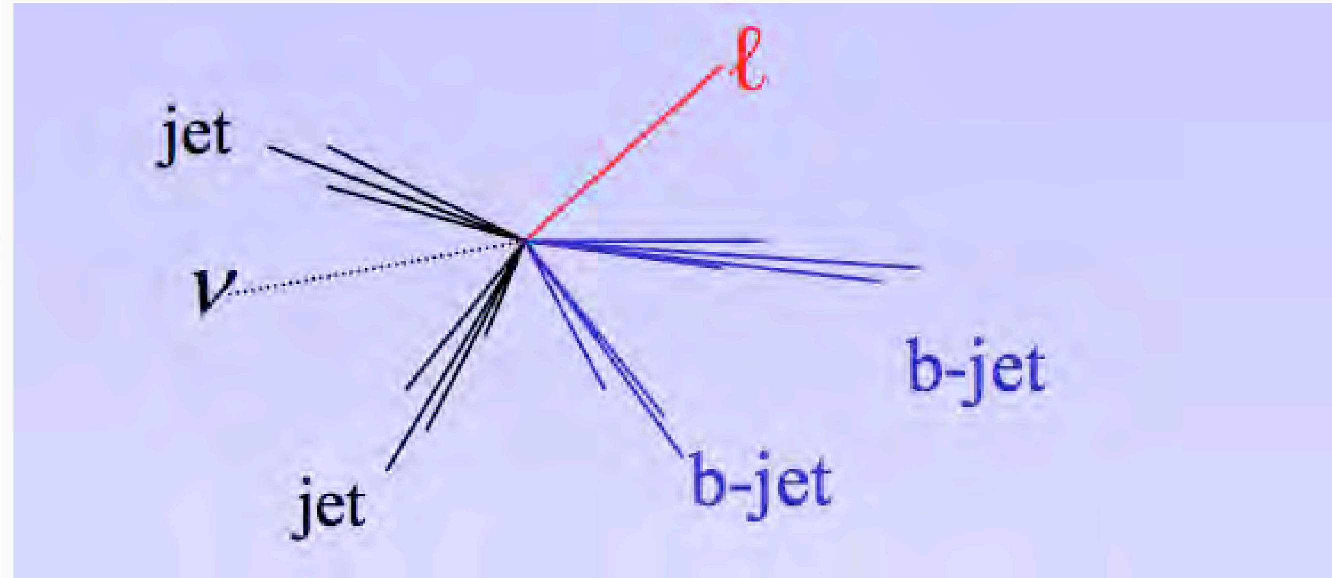
2 jets M(jj) ~ M(W)

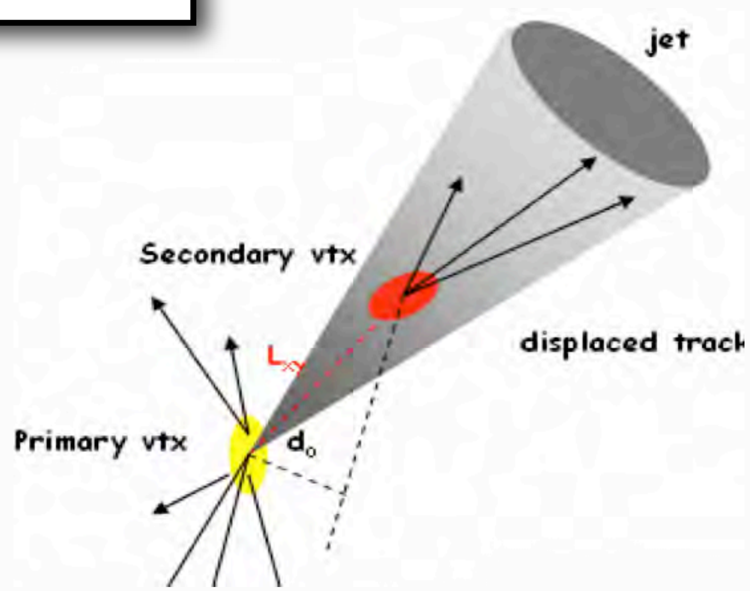
Isolated lepton p_T> 20 GeV

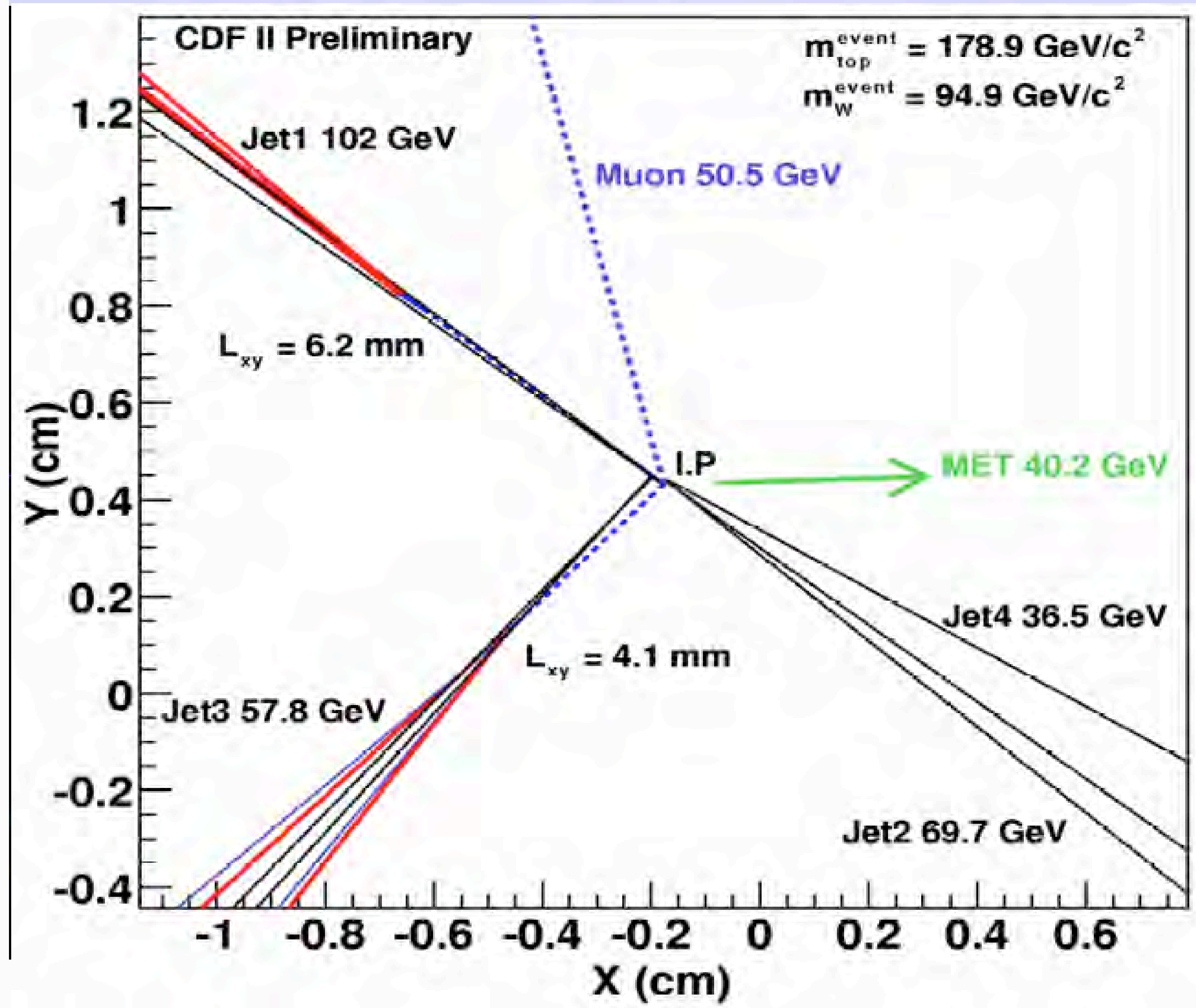


b-tag(s)

E_T^{miss} > 20 GeV







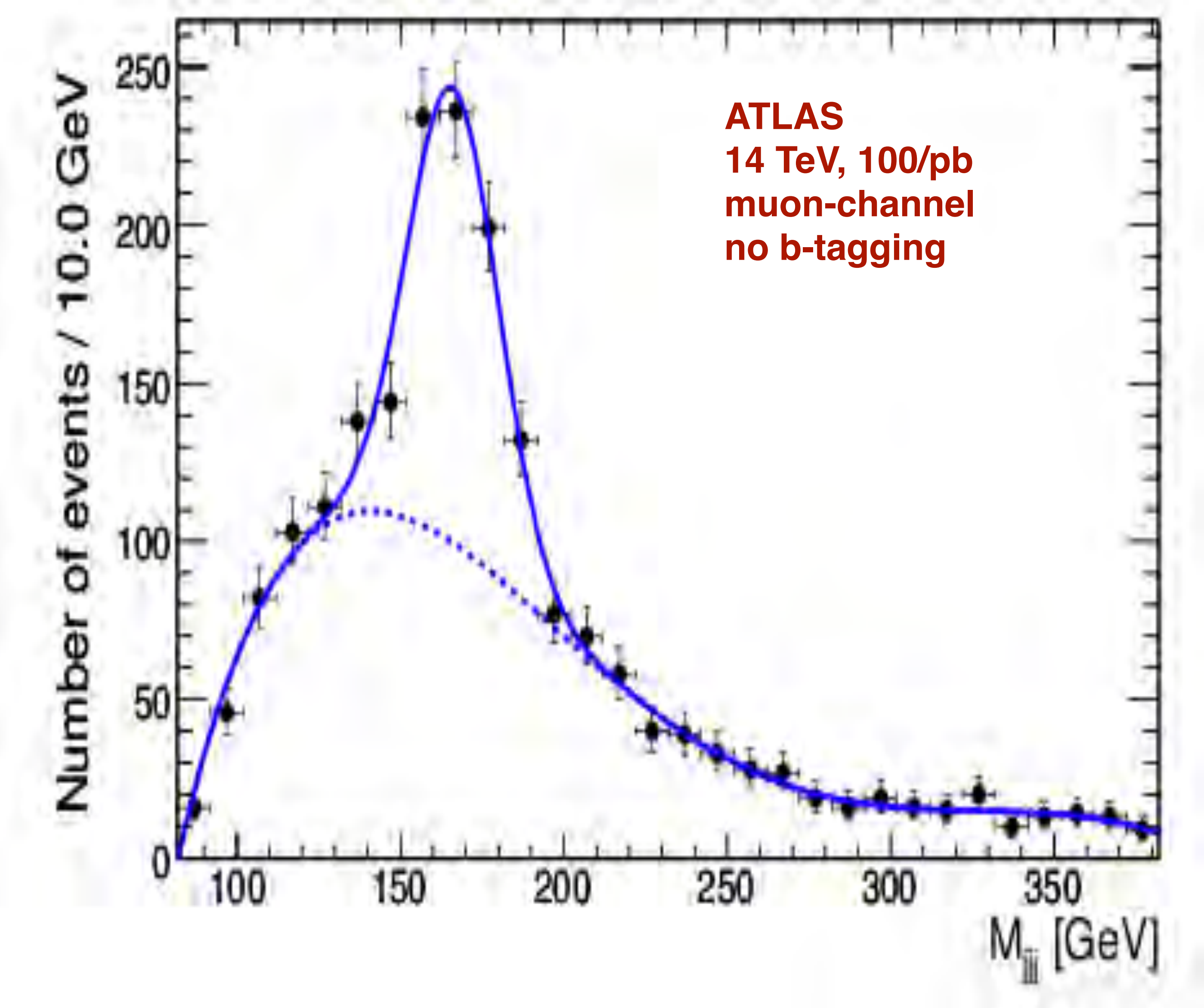
b-tagging important:
Need excellent Silicon Vertex and Pixel Detectors

Top Production (example : semi-leptonic case)

See the top immediately with simple selection :
Missing E_T, 1 lepton, ≥4 jets ,
even without b-tag (!),
cut on hadronic W mass

Example (ATLAS study, 14 TeV):

- Observe it with 30 pb^{-1}
- σ(tt) to 20 % with 100 pb^{-1}
- M(t) to 7-10 GeV



Once b-tagging is understood:
Very high S/B achievable ~ 27 !

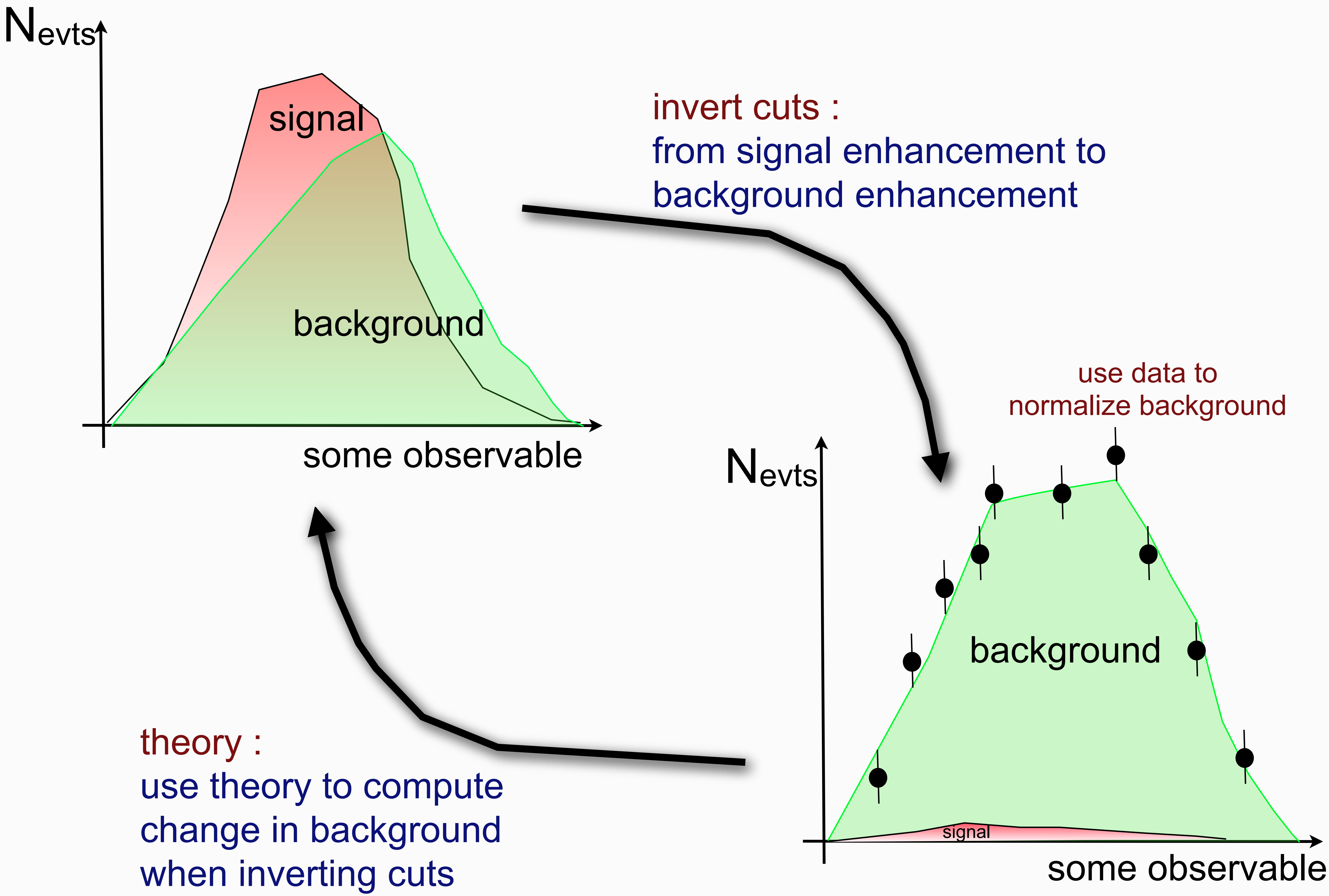
Backgrounds :
W+4j, Wbb+2j(3j) (minor here)

relevant also for single-top

Study the top quark properties
mass, charge, spin, couplings, production and decay,
ΔM_{top} ~ 1 GeV ?
important background for searches
Jet energy scale from W→jet jet,
commission b-tagging

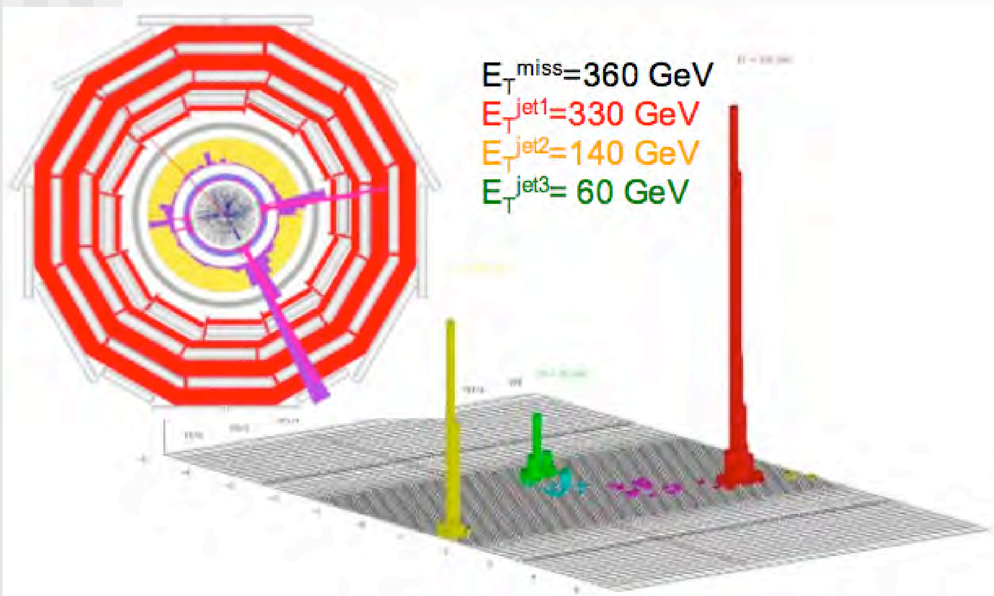
Further issues...

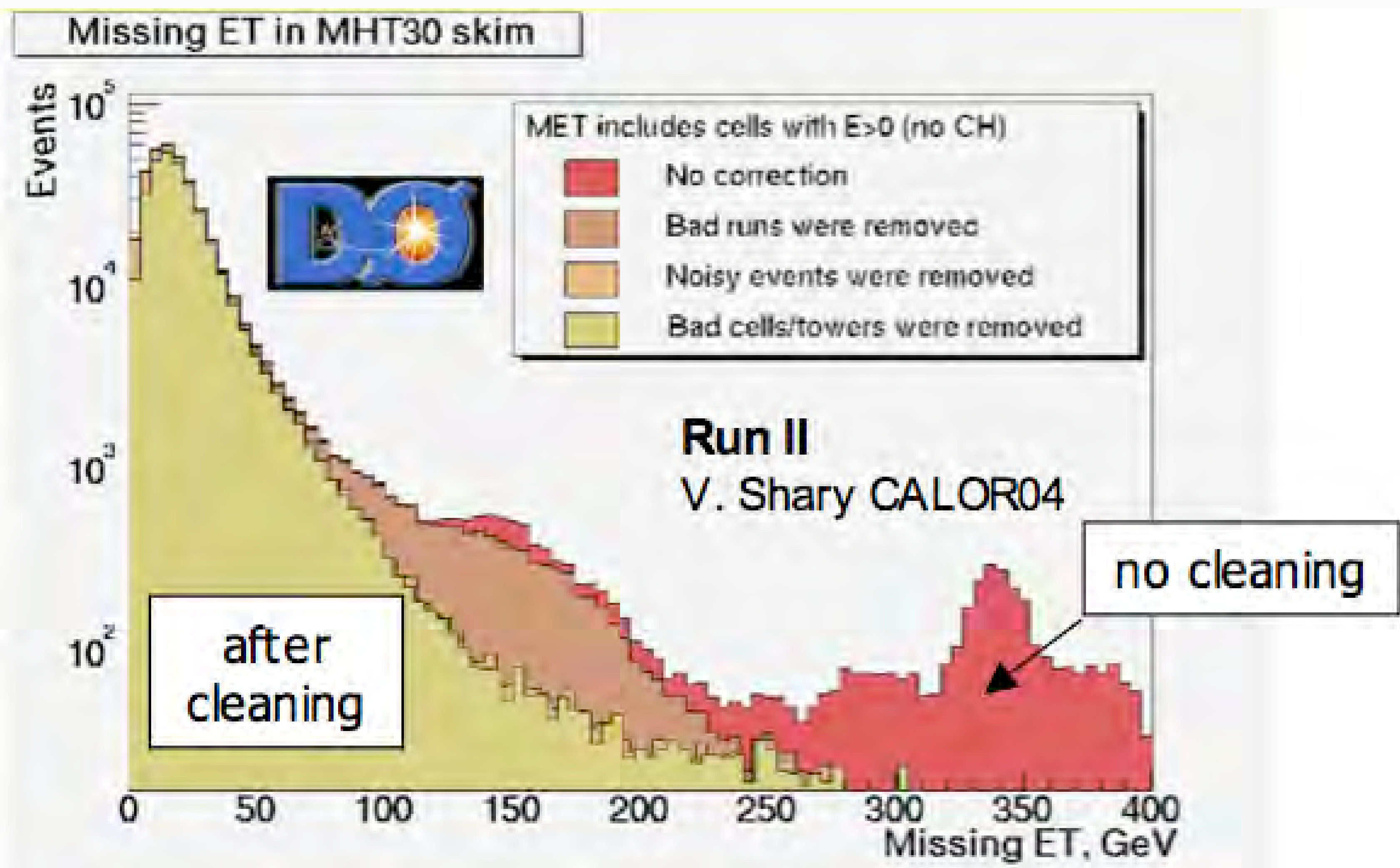
Background extrapolation



Importance of “Cleaning”

- during very early days we will have to be careful
- will not yet understand “perfectly” some “noise” contributions, from detector, the machine, cosmics
- Example : Missing transverse Energy





$E_{T,miss}$ is a very tricky variable to measure. Mis-measurements can easily fake “signals”.
Have to fight backgrounds, noise, use control samples, eg. Z+jets

Warnings…

- Always try to be as independent from the Monte Carlo as possible!
  - eg. find a “Standard Model candle” for calibration
  - Obtain backgrounds from the data whenever possible
    - Easy if we have mass peak (from sidebands)
    - More difficult in case of excess in high-energy tails, in particular in relation to MET or high-E_T jets
  - Study carefully the validity of a Monte Carlo, and what it is exactly based on
    - eg. LO 2-to-2 process + parton shower, or 2-to-n + parton shower, or NLO+parton shower, or …
- Worry in particular about systematic errors in your search analysis when S/B << 1 !!
    - be careful with calculation of significance

Summary of Part 2

"The only place where success comes before work is the dictionary"

Summary

- SM physics at the LHC:
  we will have to re-discover the SM before going to other discoveries

- Test the SM at an unprecedented energy scale
  - lots of highly exciting and interesting physics
    - Jets, Ws and Zs, tops, ...

- These are also important tools to
  - understand, study, calibrate and improve the detector performance
  - constrain physics input (pdfs, underlying event)
  - necessary input for all other measurements

- We are getting ready now to be able to perform all these measurements and run these tools as early as possible, once the data start flowing in....


END