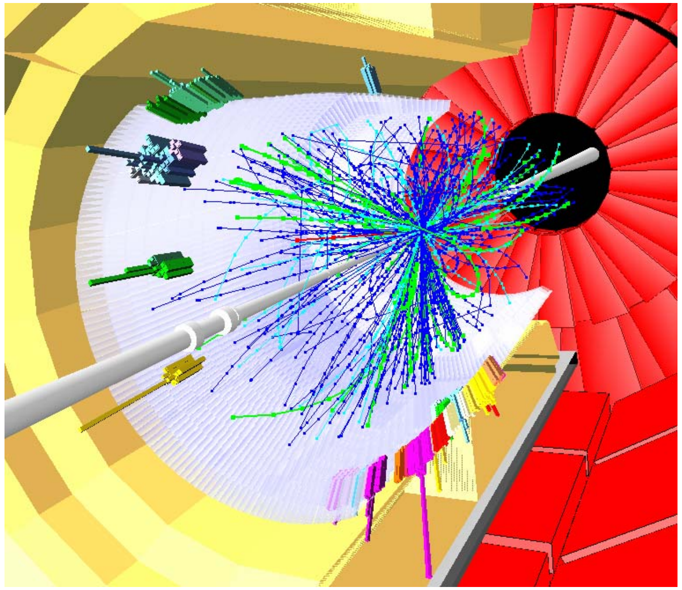
CMS: MC Experience and Needs

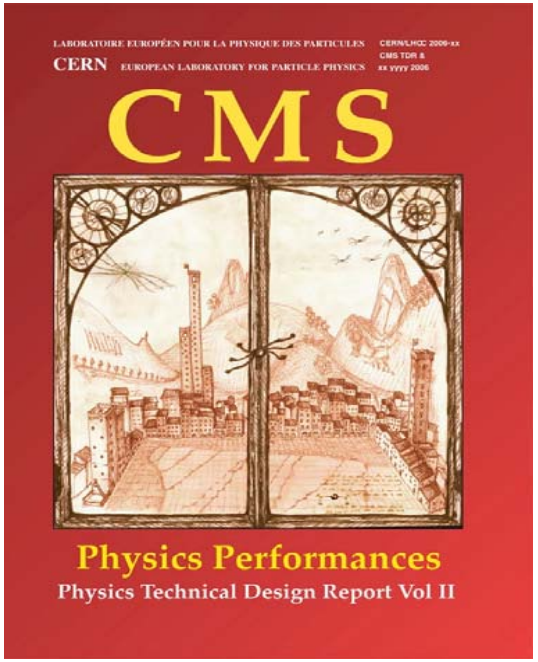
Albert De Roeck
CERN
MC4LHC Workshop

MC4LHC



Thanks to: P. Bartalini, I. Lokthin,F. Moortgat, A. Nikitenko,S. Slabospitsky, S. Spiropulu

Physics TDR Volume 2



20/6/06

2012 authors
650 pages
306 figures
211 tables
1.50 Kg

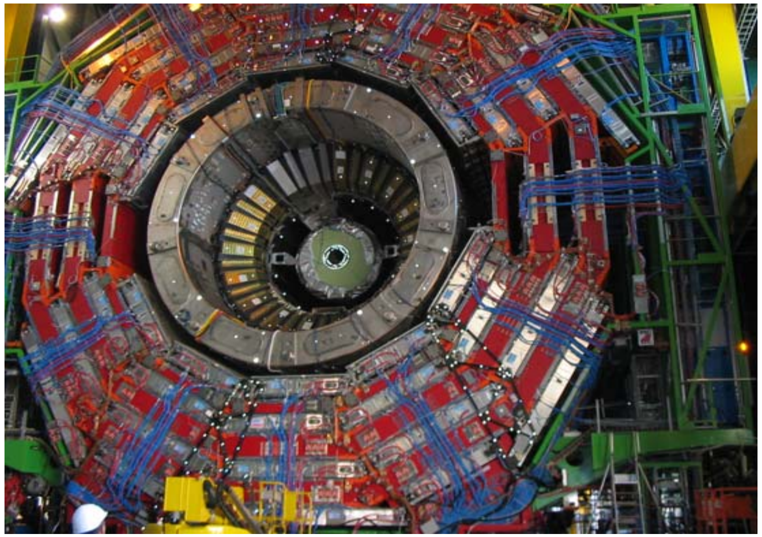
For almost all analyses: detailed detector simulation and reconstruction
- ~200 M events fully simulated for the Physics TDR

Fast simulation (FAMOS) used mainly for e.g. scans in SUSY space
- About a factor 1000 faster/includes parametrized showers etc.

Pile-up/trigger selection (L1/HLT) included for all studies
Background uncertainties from "data" and exp. systematics
Also generators "beyond PYTHIA": ALPGEN, MadGraph, MC@NLO,CompHEP,…

CMS schedule

- CSA06: Computing-Software-Analysis challenge: September/October 50 M simulated events/ MC generation close to PTDR settings
- Startup physics study: prepare for pilot run (low energy, 900 GeV, perhaps up to 2 TeV) in 2007 and first physics run in 2008. Physics samples range $100pb^{-1}$ -$1fb^{-1}$/ MC generation "first data" settings
- Cosmic challenge (combined detector test) starting now till end of August (September)
- CMS lowering in IP5 starting next month until early next year



Generators in Experiments

- No one generator adequately reproduces the physics for the complete program
  - Use parton shower MCs, Matrix Element MCs, Matching MC's, NLO MCs, Cross section calculators.
- Essential that experimentalists understand which techniques are applicable to which kinematic regimes

  $\Rightarrow$ Les Houches'03 write-up of used/available generators. ("old")

  $\Rightarrow$ This Workshop
- Uniform interface necessary (Generators $\rightarrow$ Experimental software)
- Generator tools should be accessible to whole collaboration and easy to use.
- Event Generation can become very time consuming (efficiencies?)

$\Rightarrow$ An event data base: MCDB

Generators in use in CMS

Workhorses so far

PYTHIA (6.2) and HIJING for Heavy Ions

Other MC's that are used

HERWIG, CompHep, HDECAY, FeynHiggs, ISASUGRA, ISASUSY, Prospino,ISAWIG,TAUOLA, PHOTOS, TopReX, SIMUB, ALPGEN, POMWIG, PHOJET, MadGraph, MadEvent, PYQUEN, HYDJET, ExHume, EDDE, DPEMC MC@NLO, MCFM, Charybdis, Truenoir, SHERPA, and private codes for BSM

Next:

EVTGEN, SOFTSUSY, SPHENO, SUSPECT, Cascade

Next: Startup Concerns

- Prime concern now is to get ready for the LHC startup (2007) 2008
    - Jets, W-Z-t(t)+ njets, WW-ZZ+njets,W-Zbb,ttbb,Wγ,Zγ, min bias…
- Strategy
  - Measure min-bias, QCD jet, W, Z, top production with first data.
    - Tune MC's to the data
  - Measure W, Z, top + njets in data in available control regions
    - Tune/Normalize MC's and extrapolate in new regions (tails)

  ⇒ Remember: early discoveries are possible!

- MC Production for startup physics for 2008
  - Choice of models and model versions (PYTHIA/HERWIG/Alpgen/…)
  - What settings/parameters? PDFs, underlying events, PS…
  - What processes are still missing?
  - LO/NLO importance?
  - Do we understand QCD sufficiently in the new LHC kinematic regime?
  - How to normalize the MC's

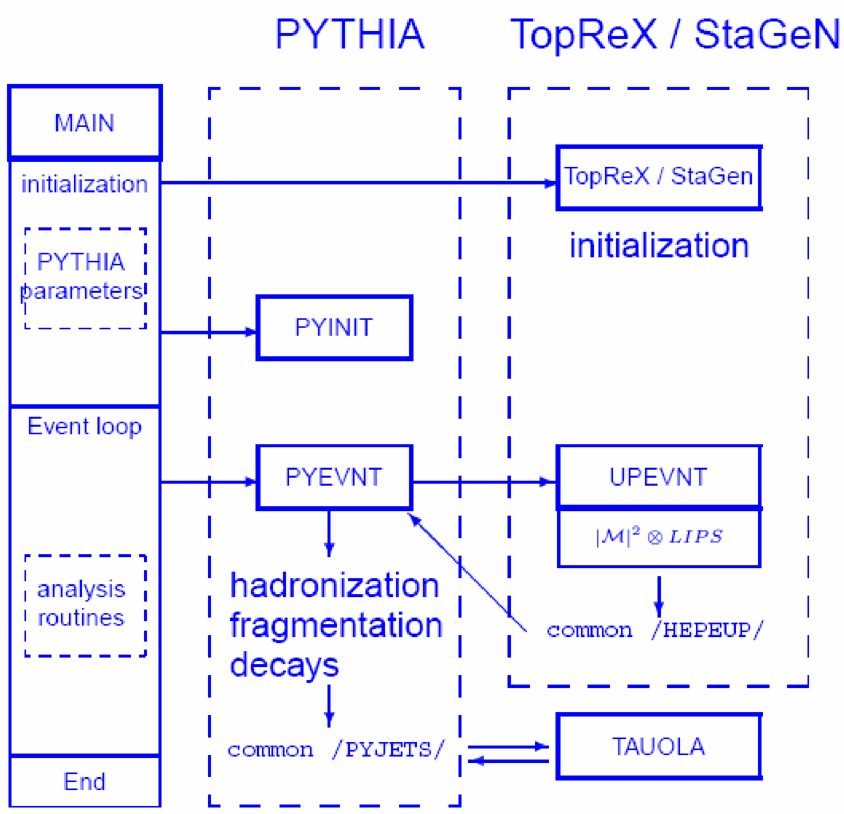
CMS: STAGEN for non-standard generators

S. Slabospitsky

"private" code for new processes

For the Physics TDR Studies

- Common interface package to include easily (for the user) private generators that use the PYTHIA external process option
- Can include new processes/code
  ADD EDs, Black Holes, …
- CMS software independent

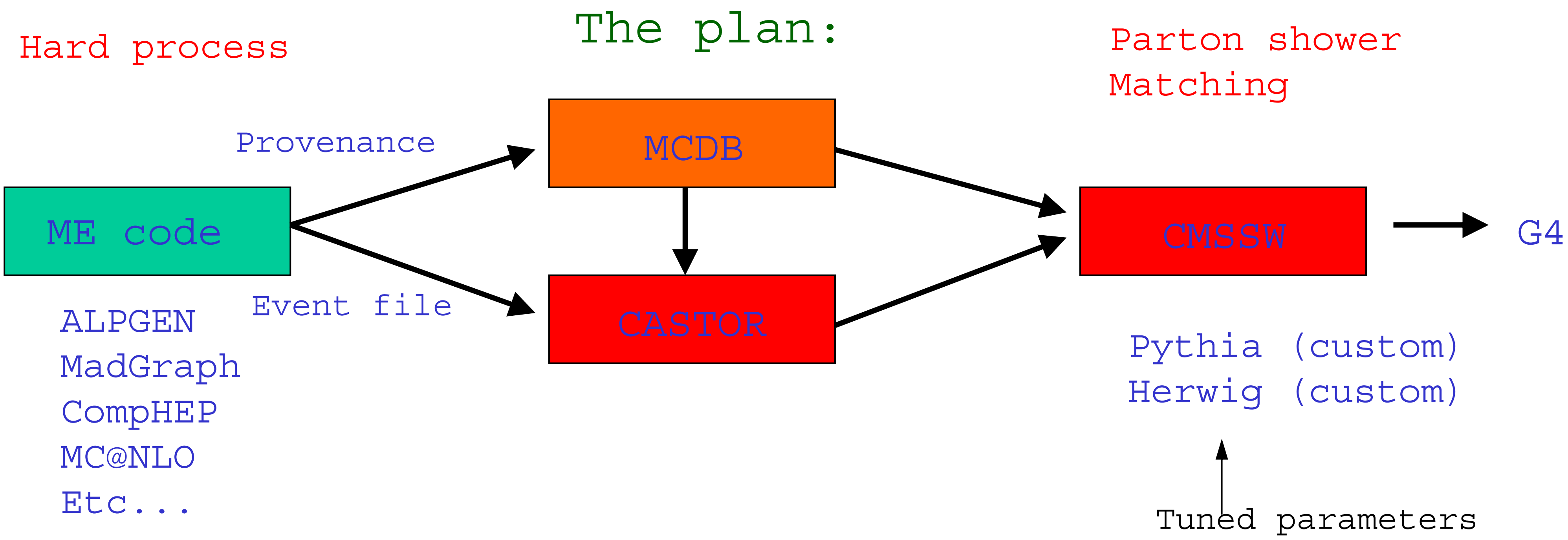


- specific (useful) features
  - ◇ unified interface to PYTHIA
  - ◇ meaning and treatment of parameters almost identical to PYTHIA
  - ◇ very easy to include new process
  - ◇ common routines for LIPS, color, mother/daughter information
  - ◇ very easy to include new top quark decay channel

Generator interfaces in CMS

CMSSW: direct interfaces for PYTHIA, HERWIG, SHERPA (via HepMC) to simulation.
Others via intermediate storage:

https://twiki.cern.ch/twiki/bin/view/CMS/GeneratorTaskList



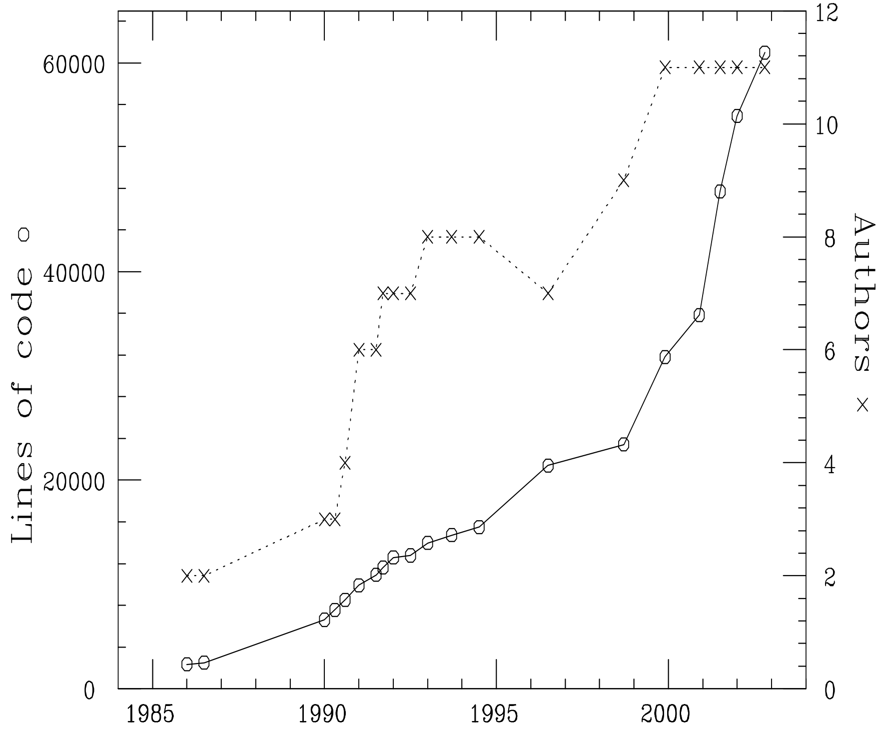
Event Data base: CMS MCDB for PTDR
LCG MCDB in future (see LCG generator meeting)

C++ Generators

- The existing generation of event generators
  - HERWIG
  - PYTHIA

  were highly successful.
- However they have reached the end of their lives.
- There are many reasons for this
  - Code structures prevent adding new physics features
  - Code hard to maintain
  - Students don't know FORTRAN anymore.

P. Richardson, Annecy 06



In CMS

- PYTHIA8 → a test interface to CMSSW exists
- HERWIG++/ThePEG → test interface to be done during/after this workshop

But unlikely to play a major role at the startup preparation studies

HepMC issues

HepMC moved into LCG Repository at experiments' request

- several improvements requested by CMS:
  - common heavy ion class agreed @ LCG level and implemented
    http://simu.cvs.cern.ch/cgi-bin/simu.cgi/simu/HepMC/HepMC/HeavyIon.h
  - printouts need improvement => implemented last week

- CMS software wants no dependency on CLHEP

→ MathCore vectors in HepMC?

→ requested at LCG Simulation forum; no action so far ☹ …

- to be discussed at this workshop: add possibility to add extra PDF information in GenEvent? (x1, x2, KF1, KF2, Q-scale, …)

HepPDT issues

Also HepPDT moved into LCG Repository

- The default PDG table in HepPDT is not adapted to our needs (does not contain hypothetical particles, BR not always saturated);
- using PYTHIA/HERWIG Particle data table instead

- A common Particle Data Table (framework) to be used by Generators, GEANT4 and experiment software would be still desirable, but maybe not realistic due to generator specific issues. Maybe worth one 'last discussion'?

We experienced some "small problems" with b mass differences in different tables

GENSER

- for interfacing with event generators, the CMS software will rely on the LCG GENSER repository
- contains various versions of large variety of generators
- new releases at regular times. Versioning of the software is very important.
- good communication with GENSER team and fast feedback

Generator Framework

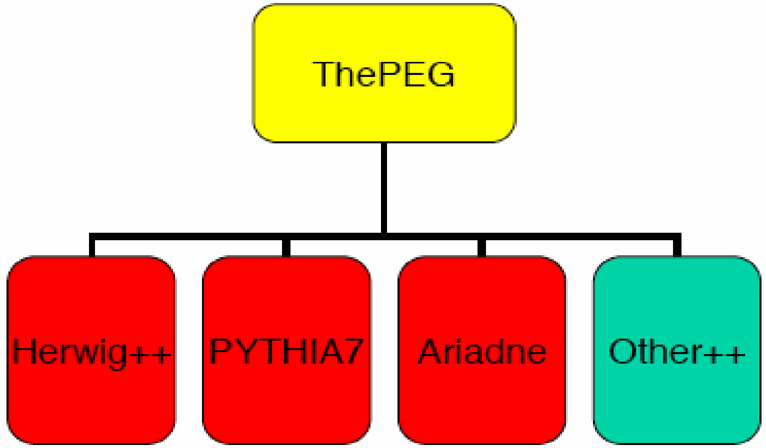
Example: ThePEG

- original idea: provide a general framework for the implementation of event generation models

- flexible: e.g. HERWIG shower could be run with PYTHIA hadronization

- due to complex structure etc. ThePEG is only used by HERWIG++

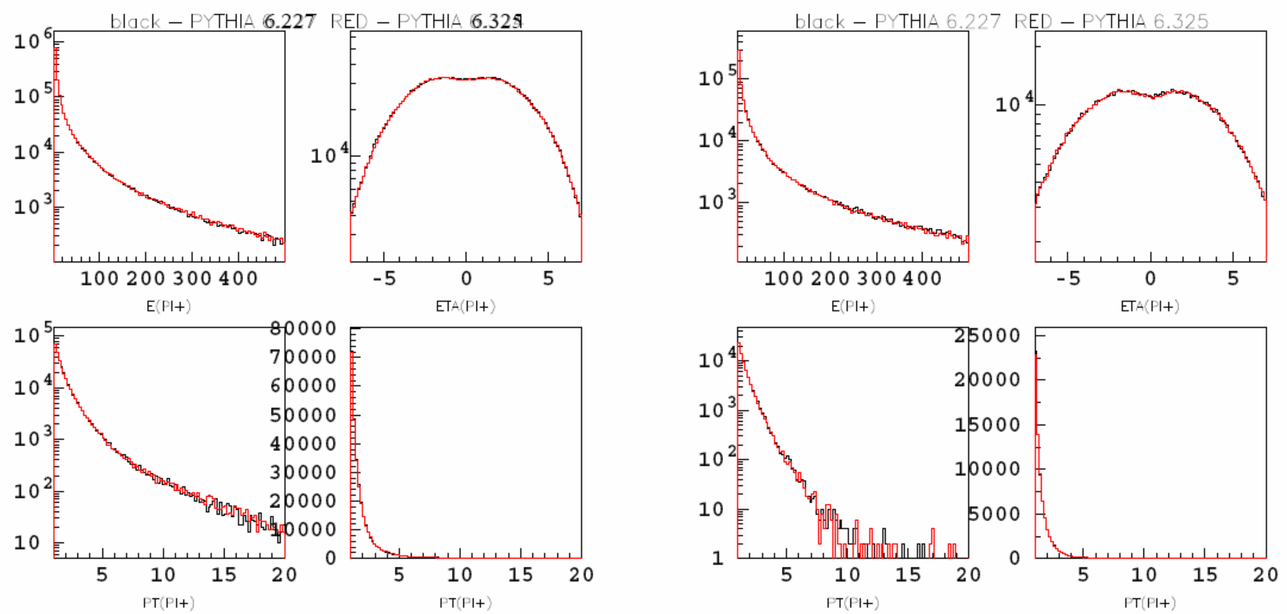
- Still worth the effort to try to get something such as the ThePEG in place, be it with a reduced scope. Discussion among experts at this workshop?

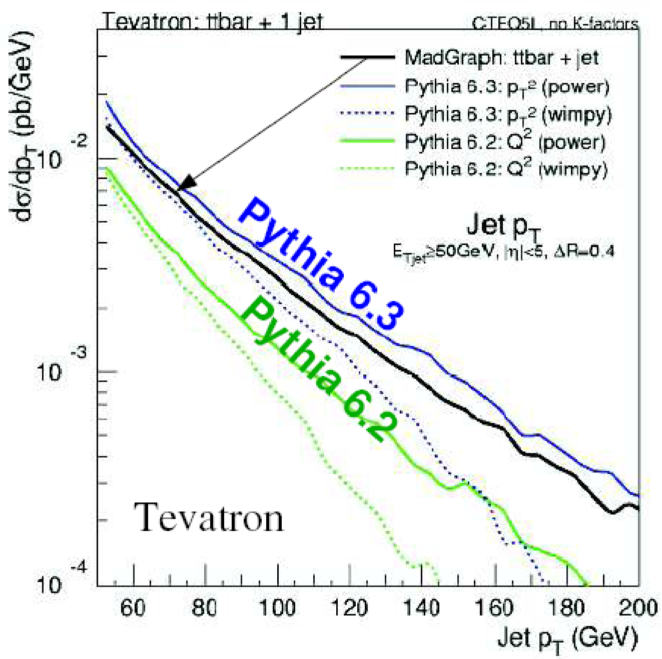


PYTHIA: Moving to V6.3 or V6.4

- two PYTHIA versions (6.227 and 6.325) with the same set of parameters (MSTJ, MSTP, PARP) were used for simulation: ◇ min-bias (MSEL = 1) and Drell-Yan pairs the differential distributions (on energy, transverse momentum and pseudorapidity) for the final hadrons ($\pi^\pm$, π^0, $K^\pm$, K^0), charged leptons ($\ell^\pm$) and photons were used

Drell-Yan pairs: $pp \to \ell^\top \ell^- X$ min-bias



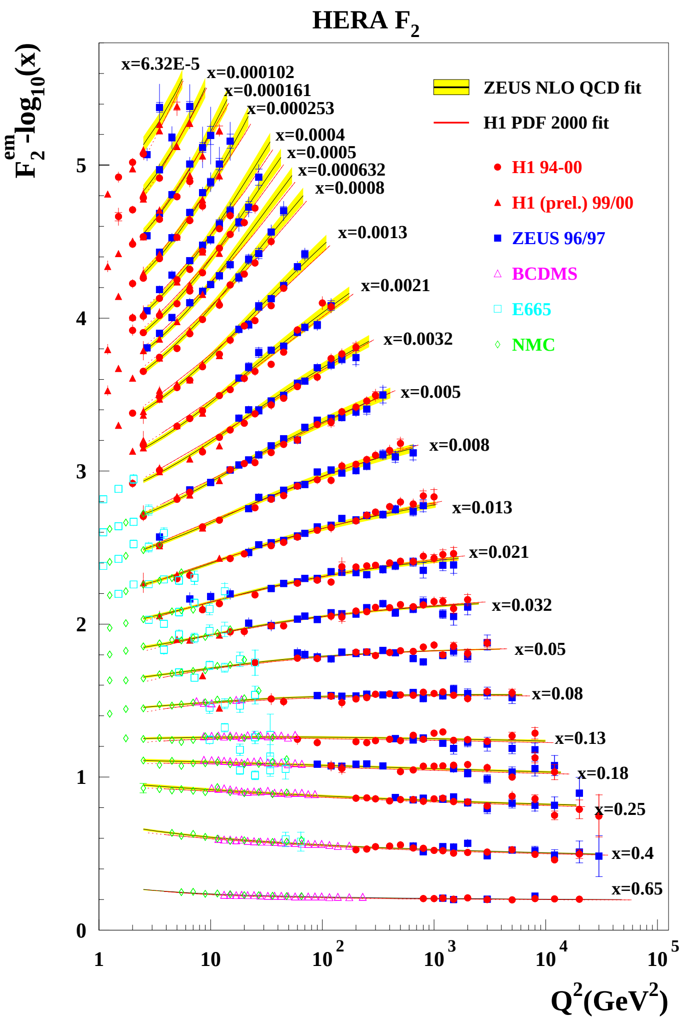


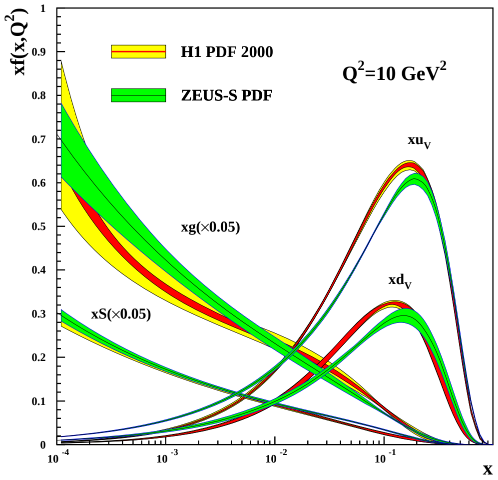
Validation of 6.3/6.4? Using the new parton showers and/or underlying event? Any recent PYTHIA/HERWIG comparisons?

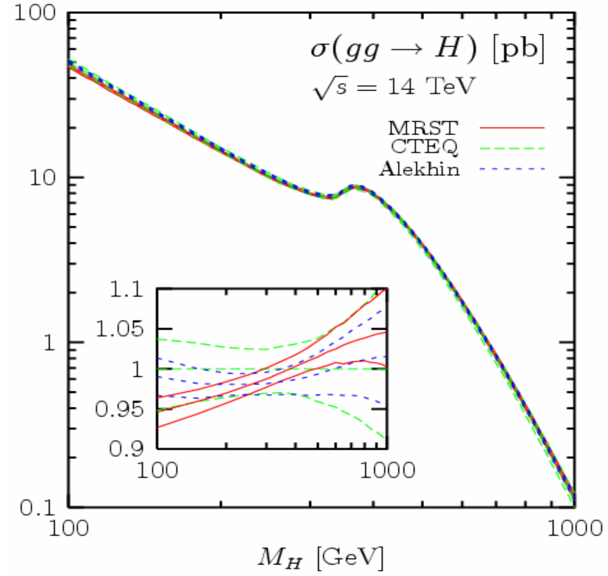
⇒ Feedback from this workshop welcome/needed!!

Parton Density functions

- Collinear PDFs







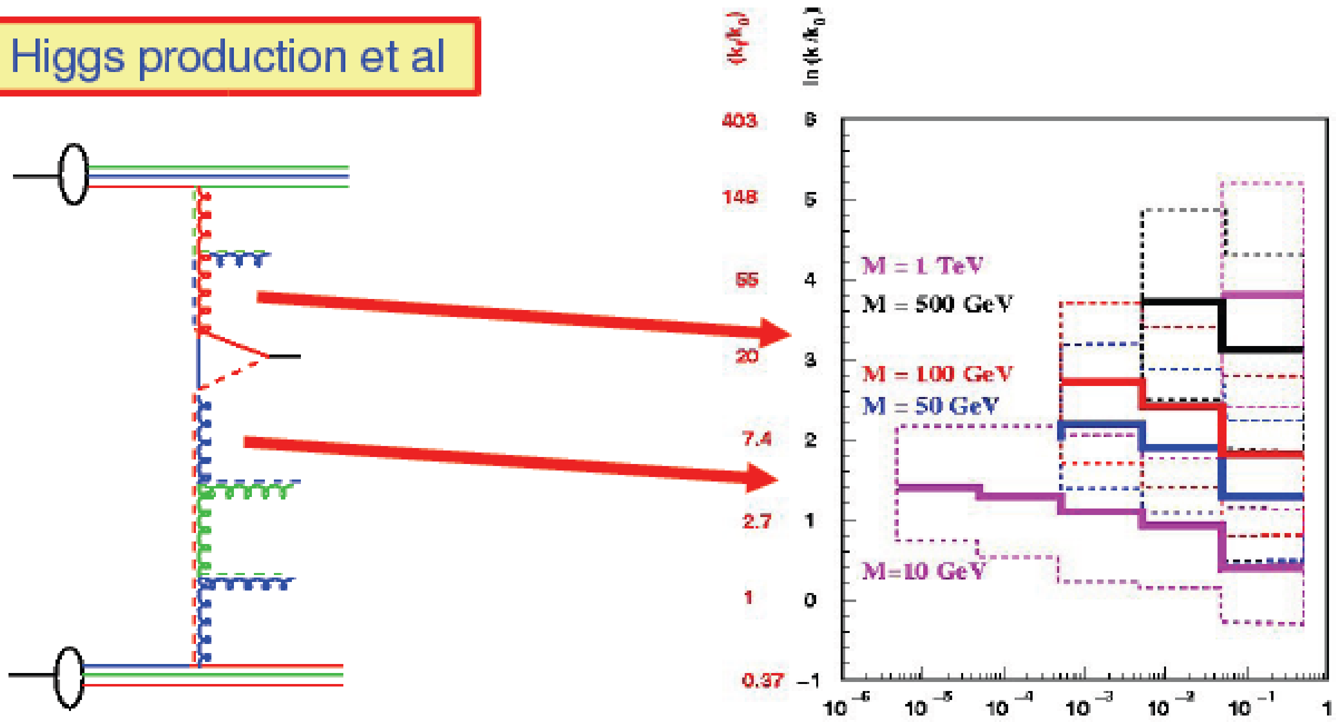
Simple spread of existing PDFs gives up to 10% uncertainty on Higgs cross section

Parton Density functions

- Collinear PDFs

- Unintegrated PDFs

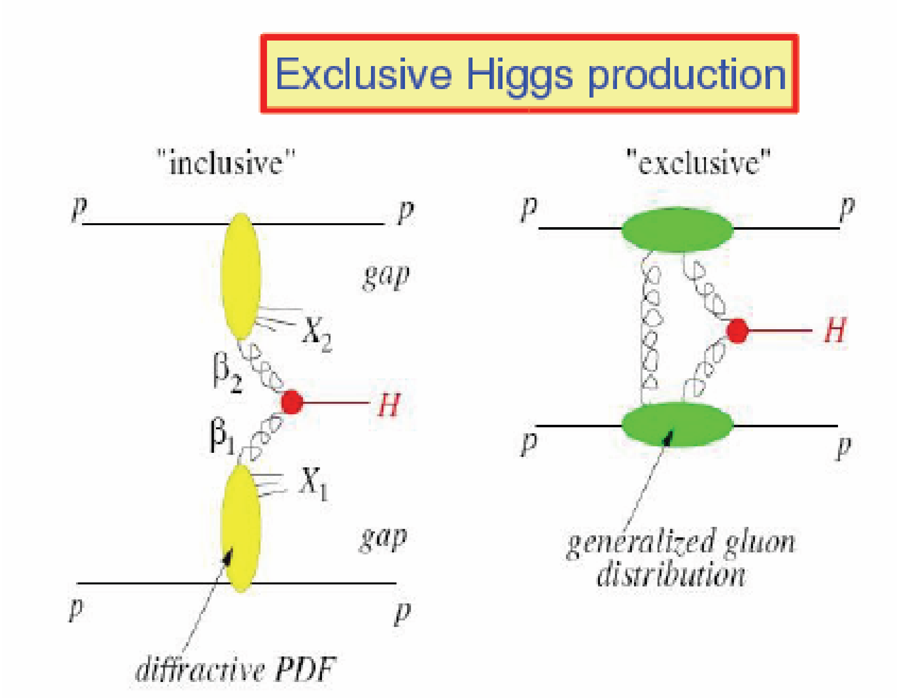
Higgs production et al



Large k_T effects may affect Higgs searches/measurements

Parton Density functions

- Collinear PDFs
- Unintegrated PDFs
- Difractive and Generalized PDFs



All these PDFs can be addressed at HERA via
- inclusive,
- semi-inclusive,
- diffractive,
- vector meson
- DVCS

measurements

Only collinear ones available in PDF libs

LHAPDF

Mike Whalley /Durham

LHAPDF generally adopted as the standard

CTEQ61 (cteq61m + errors)	41	cteq61.LHpdf
CTEQ6	41	cteq6.LHpdf
CTEQ6 Standard MSbar	1	cteq6m.LHpdf
CTEQ6 LO fit, with NLOrder alpha_S	1	cteq6l.LHpdf
CTEQ6 LO fit, with LOrder alpha_S	1	cteq6ll.LHpdf
CTEQ5m Standard MSbar	1	-
CTEQ5m1 updated CTEQ5m	1	-
CTEQ5d Standard DIS	1	-
CTEQ5l Leading Order	1	-
CTEQ4m Standard MSbar	1	-
CTEQ4d Standard DIS	1	-
CTEQ4l Leading Order	1	-
Fermi02	100	Fermi2002_100.LHpdf
Fermi02	1000	Fermi2002_1000.LHpdf
GRV98= LO	1	-
GRV98 NLO (msbar & dis)	2	-
H12000ms NLO msbar	1	-
H12000msE NLO msbar error sets	21	-
H12000dis NLO dis	1	-
H12000disE NLO dis error sets	21	-
H12000lo LO (evol+alphas)	1	-
H12000loE ditto error sets	21	-
H12000lo2 LO evol NLO alphas	1	-
H12000lo2E ditto error sets	21	-
MRST2004nlo - NLO -	1	MRST2004nlo.LHpdf
MRST2004nnlo - NNLO -	1	-
MRST2004FF3lo - LO -	1	-
MRST2004FF4lo - LO -	1	-
MRST2004FF3nlo - NLO -	1	MRST2004FF3nlo.LHpd
MRST2004FF4nlo - NLO -	1	MRST2004FF4nlo.LHpd
MRST2003c - NLO - restricted range	1	MRST2003cnlo.LHpdf
MRST2003c - NNLO - restricted range	1	-
MRST2002 - NLO	1	MRST2002nlo.LHpdf

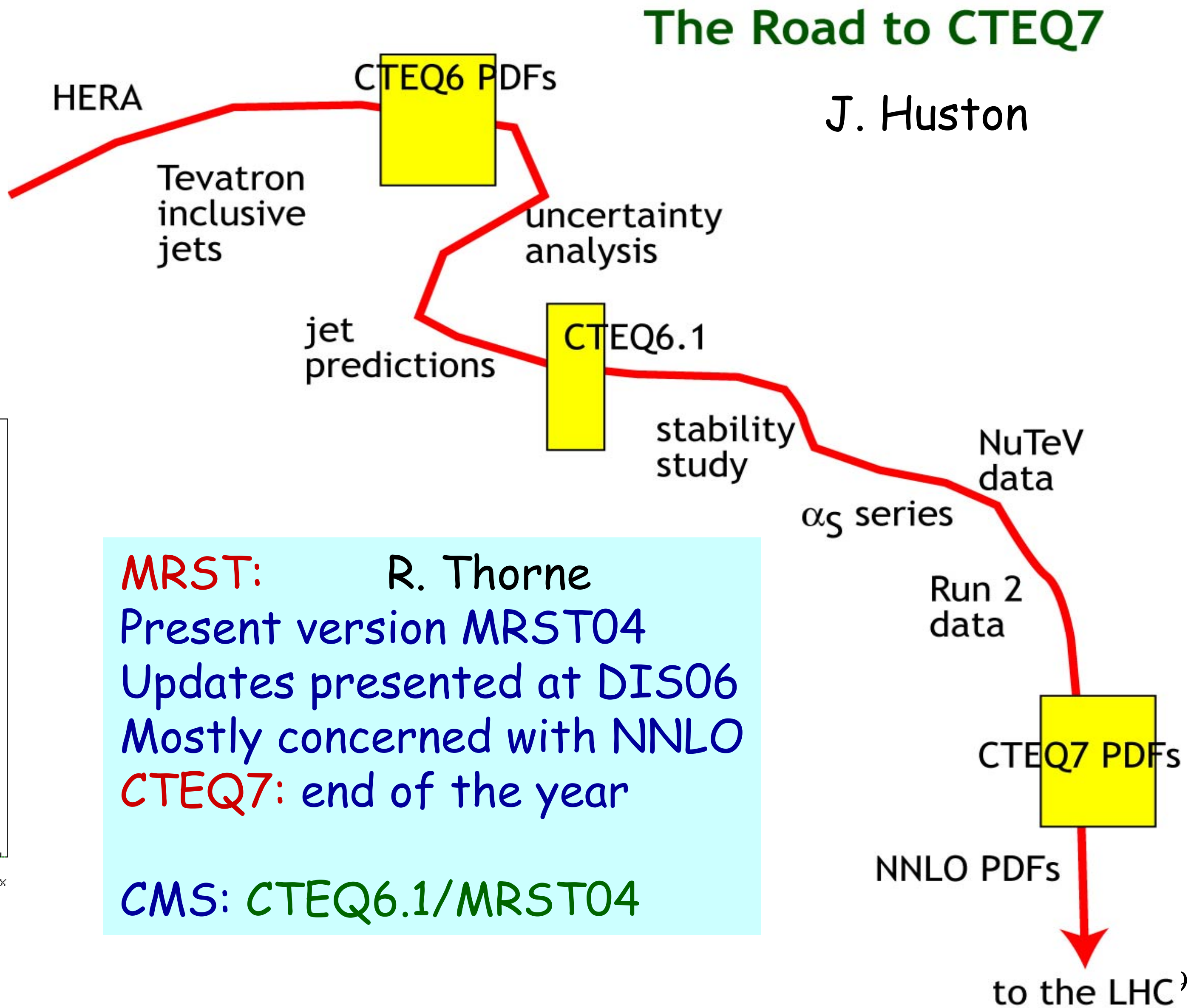
Note

α_s consistency between PDFs and eg used in processes?

In CMS we use a modified PYALPS routine to use α_s from LHAPDF library

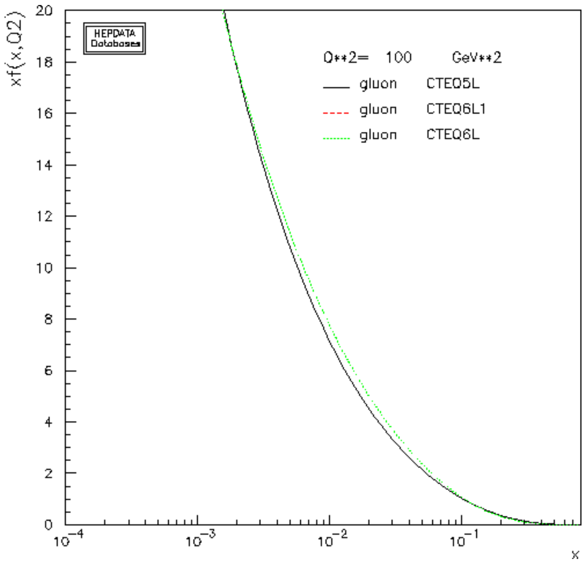
More common approach needed?

CTEQ/MRST



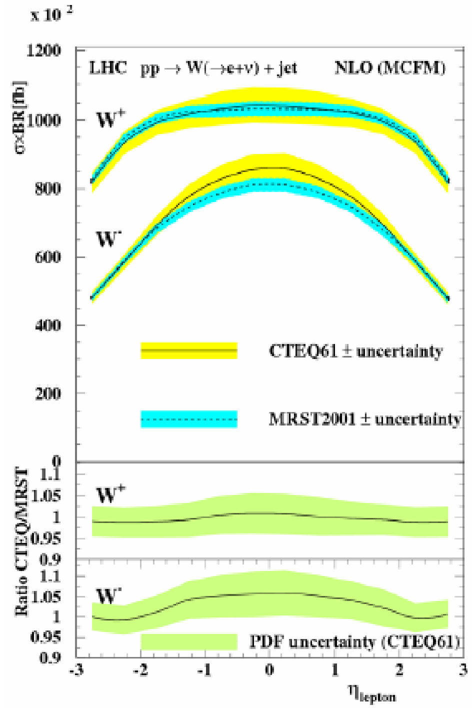
MRST: R. Thorne
Present version MRST04
Updates presented at DIS06
Mostly concerned with NNLO
CTEQ7: end of the year

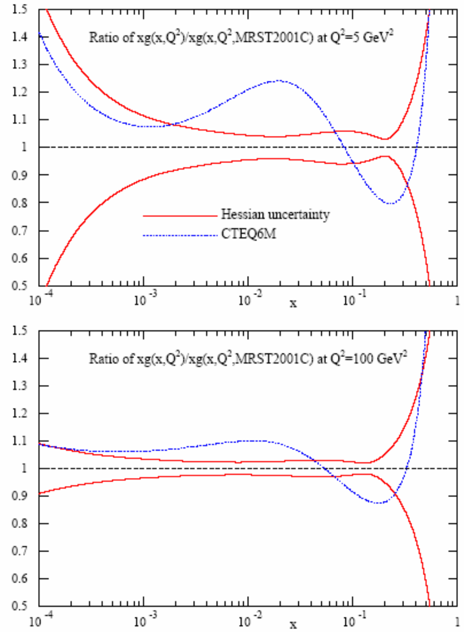
CMS: CTEQ6.1/MRST04



MRST/CTEQ differences

H. Stenzel





R. Thorne

Can we know more by the time of the LHC startup?

YES: F_L can referee the gluon distribution!
F_L is like F_2: little theoretical ambiguity (compared to e.g. F_2^c)

$$\sigma_r = F_2 - y^2/[1+(1-y)^2]\cdot F_L = F_2(x,Q^2) - f(y)\cdot F_L(x,Q^2)$$

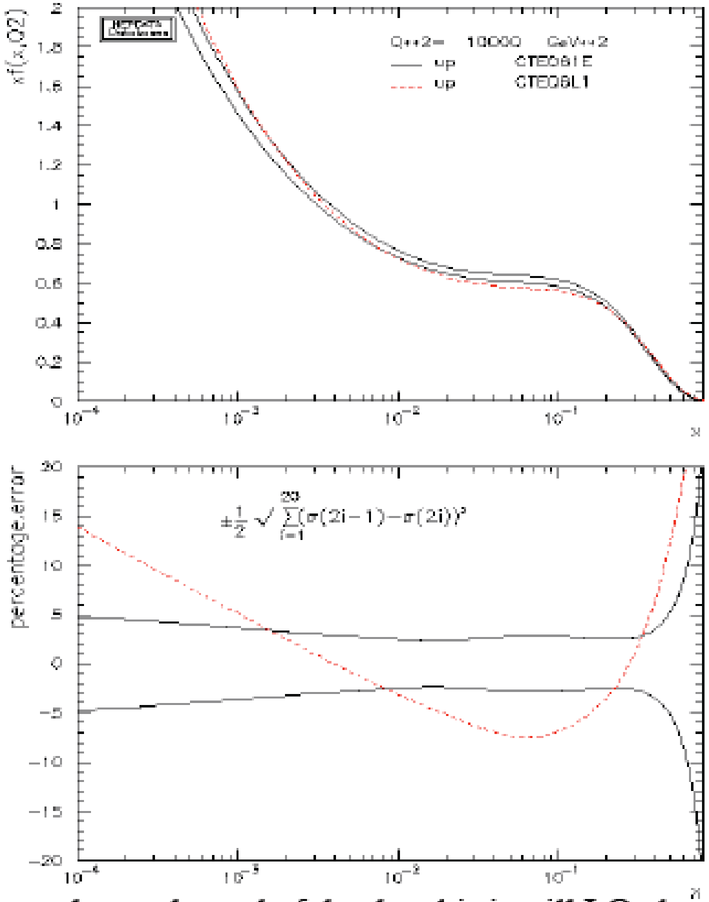
Need to lower the energy of proton or electron beam for this measurement

This is now scheduled for early 2007 at HERA!

Using NLO PDFs for (LO) MC's?

LO vs NLO pdf's for parton shower MC's

- For NLO calculations, use NLO pdf's (duh)
- What about for parton shower Monte Carlos?
  - somewhat arbitrary assumptions (for example fixing Drell-Yan normalization) have to be made in LO pdf fits
  - DIS data in global fits affect LO pdf's in ways that may not directly transfer to LO hadron collider predictions
  - LO pdf's for the most part are outside the NLO pdf error band
  - LO matrix elements for many of the processes that we want to calculate are not so different from NLO matrix elements
  - by adding parton showers, we are partway towards NLO anyway
  - any error is formally of NLO
- (my recommendation) use NLO pdf's
  - pdf's must be + definite in regions of application (CTEQ is so by def'n)
- Note that this has implications for MC tuning, i.e. Tune A uses CTEQ5L
  - need tunes for NLO pdf's



. . . but at the end of the day this is still LO physics;
There's no substitute for honest-to-god NLO.

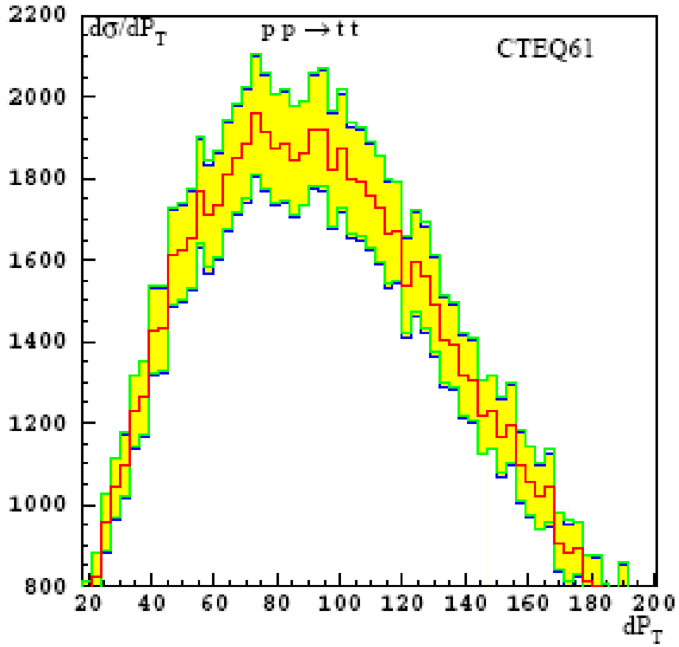
Proposal by
J. Huston et al

This calls for a discussion during this workshop!!

Tentatively Thursday pm

Uncertainties on PDFs

As applied for the PTDR



PDF uncertainty in CMS

- the additional information concerning PDFs
  - LHAPDF set, PDF subset number, N_{mem} – the number of PDF subsets
  - k_1, k_2: the KF-codes of the initial partons (from a hard process)
  - X_1 and X_2 of the initial partons, Q-scale
  - parton 'luminosity' for chosen subset (i.e. $F_{k_1}(X_1, Q) \times F_{k_2}(X_2, Q)$) (best-fit
  - the relative weights for all other PDF subsets (w_n^k)

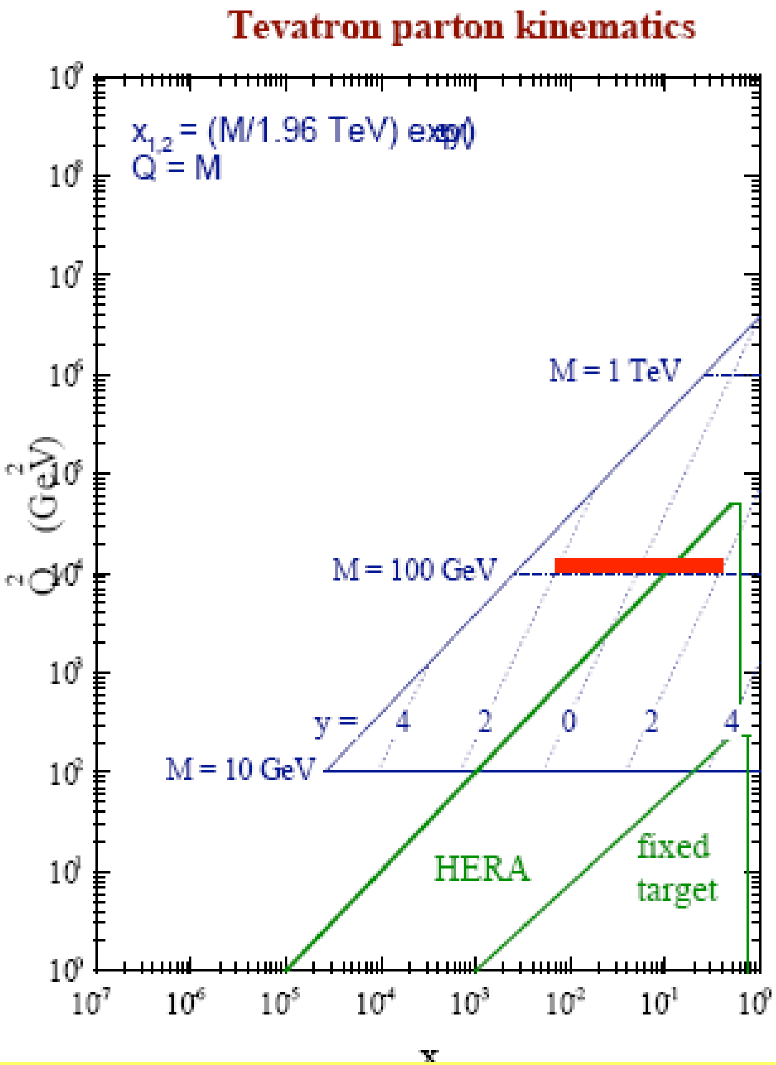
$$w_i^{\pm} = \frac{f^{\pm}_{1(i)}(x_1, Q) \times f^{\pm}_{2(i)}(x_1, Q)}{f^{(0)}_1(x_1, Q) \times f^{(0)}_2(x_1, Q)}$$

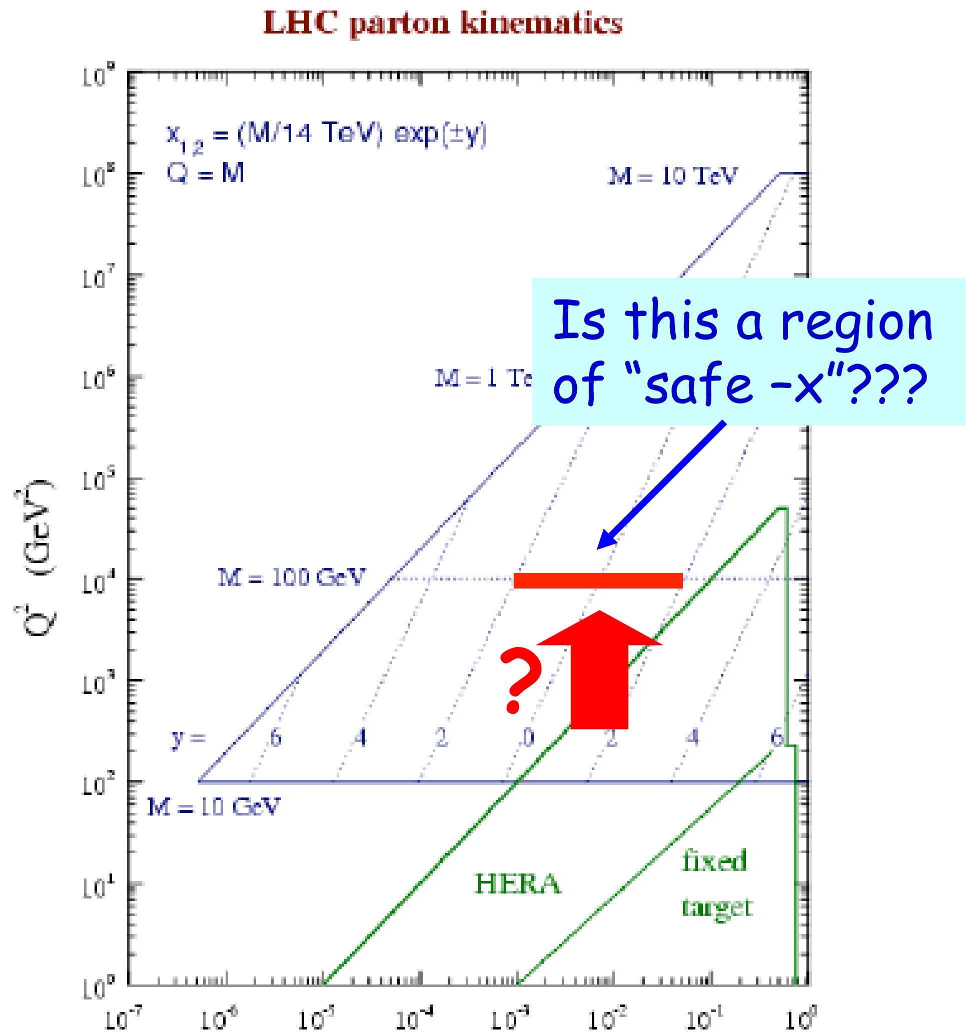
- we use (following Sullivan)

$$\delta X_+ = \sqrt{\sum_{k=1}^{d} \left(\max[D_k^+ \,,\ X_k^- - X_0 \,,\ 0]\right)^2}, \quad \delta X_- = \sqrt{\sum_{k=1}^{d} \left(\max[X_0 - X_k^+ \,,\ D_k^- \,,\ 0]\right)^2}$$

Same as the Tev4LHC Workshop proposal. New Standard?

LHC Kinematics/QCD evolution





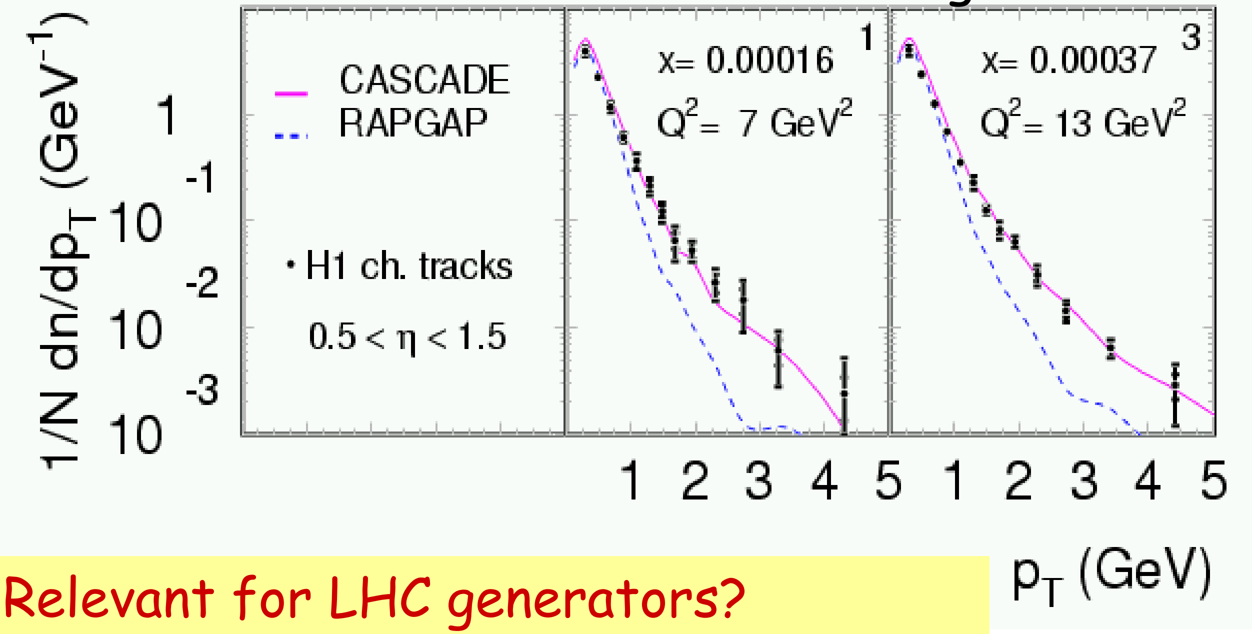
Evolution of PDFs to high Q2 & low x important at the LHC
Precision? Level of approximation? CCFM/BFKL?, non-linear effects?

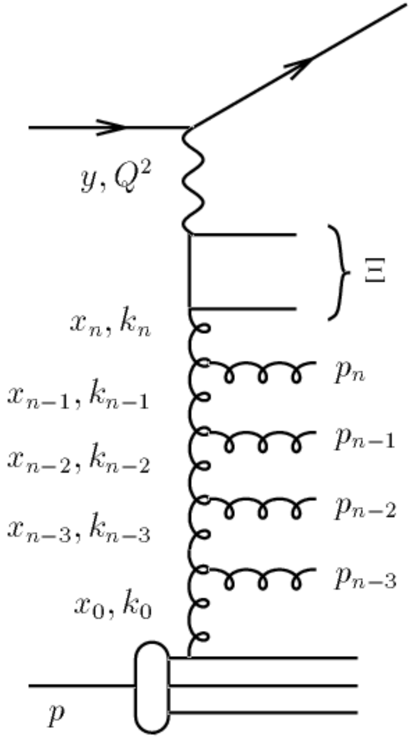
Low-x issues

HERA data at low-x (x ~10^{-3}-10^{-4})

- More pt in the event than predicted by DGLAP evolution based parton showers
- Good description using CCFM evolution (H. Jung)

H. Jung





Relevant for LHC generators?
NLO low-x: J. Andersen, A. Sabio Vera
Strikman: lots of mini-jets at the LHC

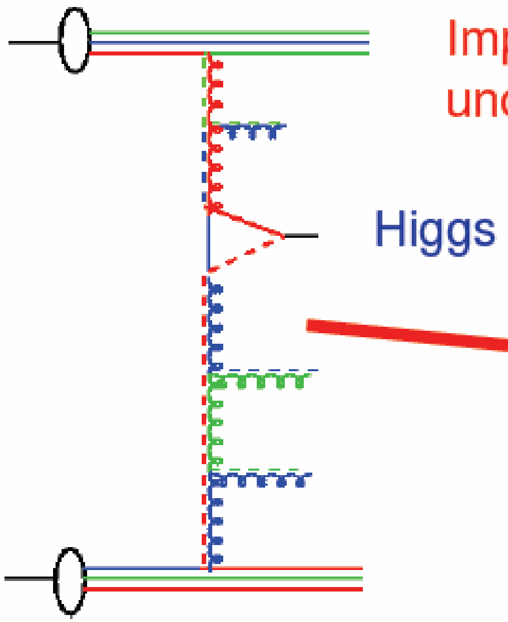
CCFM: Catani, Ciafaloni, Fiorani, Marchesini

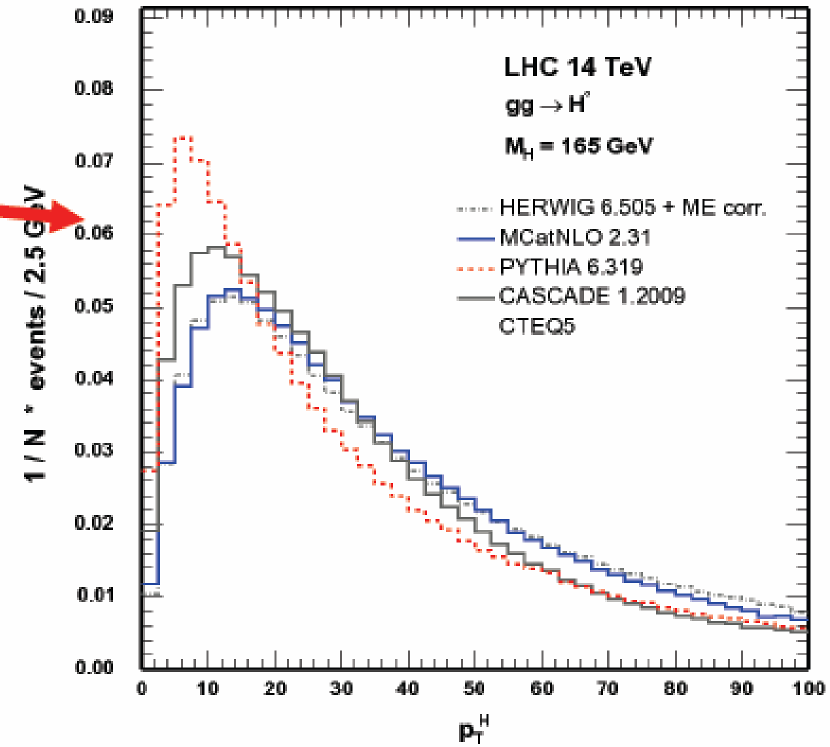
Eg. Pt Spectrum of the Higgs

H. Jung

Do we understand the p_t spectrum of Higgs at LHC?

Important for the *gg* → Higgs → *WW* → *lν lν* to understand the jet-veto for *tt* suppression...





$<k_t>$ large .... unintegrated parton PDFs will be needed

Need to be better constrained at HERA with final states

The HERA-LHC workshop


Many thanks to all conveners and authors !

CERN–2005–014
14 December 2005

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

HERA AND THE LHC
A workshop on the implications of HERA for LHC physics
March 2004 — March 2005

hep-ph/0601012
hep-ph/0601013

Proceedings
Editors: A. De Roeck and H. Jung

Available on request from CERN/DESY libs

GENEVA
2005

>650 pages

- Phase I of this workshop concluded with the proceedings
- However an important link between communities has been established.
- March 05': We should not just let it fade away, but strongly exploit it, to the benefit of both communities.
- Therefore keep momentum with one HERA/LHC meeting per year

2006	CERN:	6-9 June
2007	DESY	March or May/June 07
2008	CERN	(first LHC physics?)

- Keep also good contacts with TeV4LHC workshop activities (started Sept.2004)

June Workshop: 17 plenary talks
80 parallel talks
150 participants

Higher QCD corrections/K factors

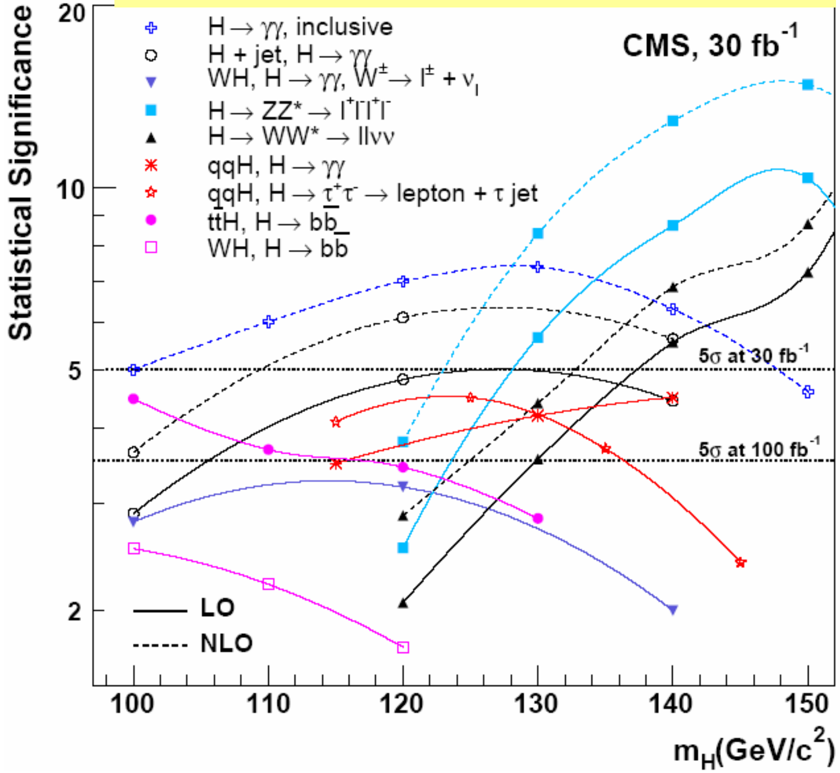
- Many cross sections now calculated to NLO
- K factors? Not always sufficient/can be huge in some phase space parts
- Reweighting Monte Carlo? Select key weighting variables

Complete NLO Monte Carlo! Quite some progress in the last years.
More processes!!

Table 42: The LHC "priority" wishlist for which a NLO computation seems now feasible.

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

Effect on Higgs 'discovery'



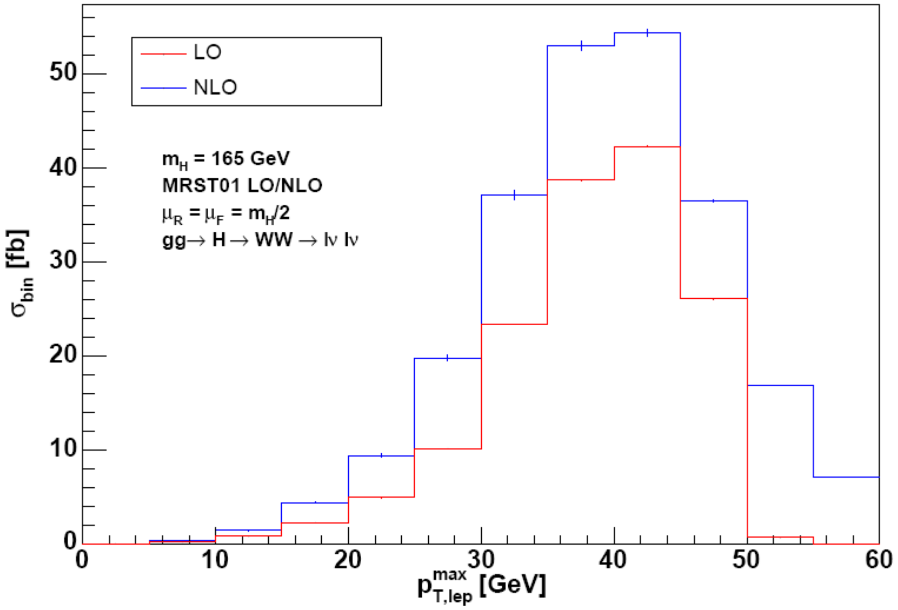
Priority wish list from the experiments
hep-ph/0604120 (Les Houches 05)

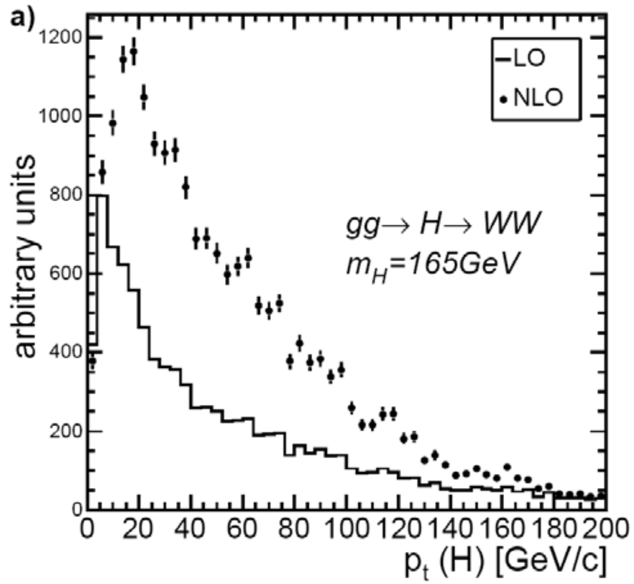
+ Zbb, Hbb

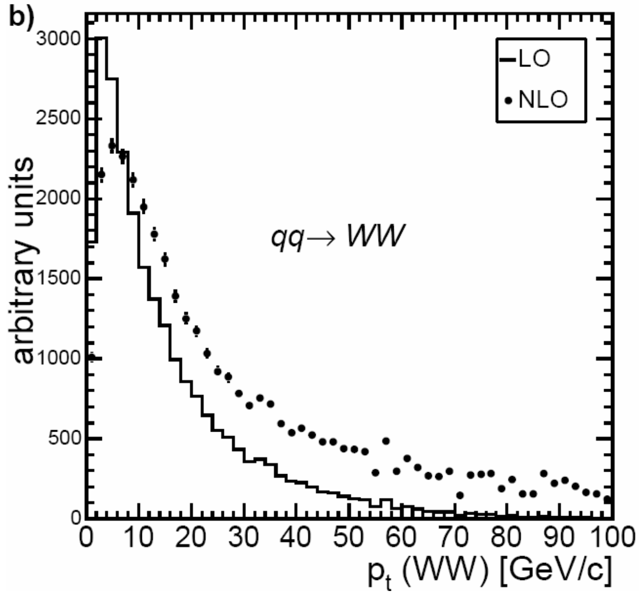
NLO/LO

Example H→WW study

Not just K-factors



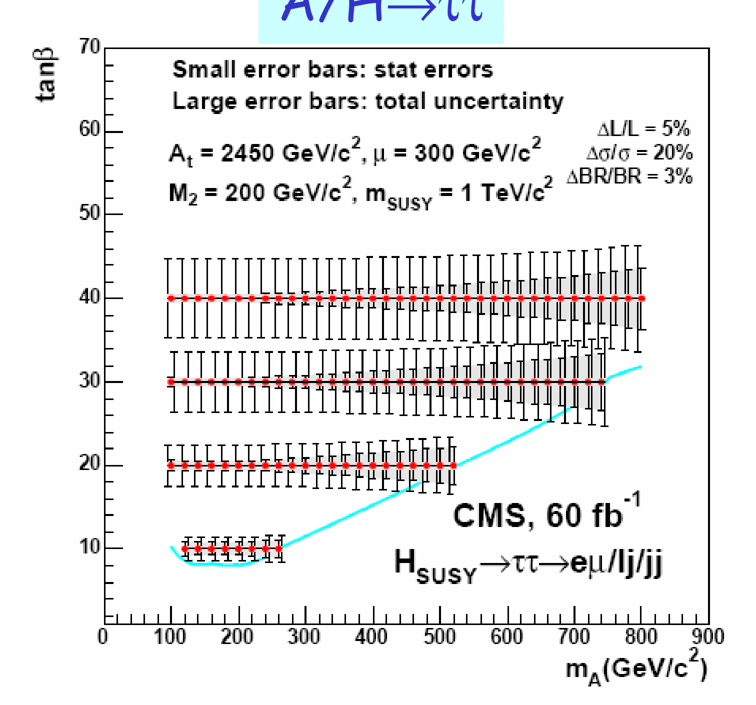




NOTE: MC@NLO with PYTHIA?

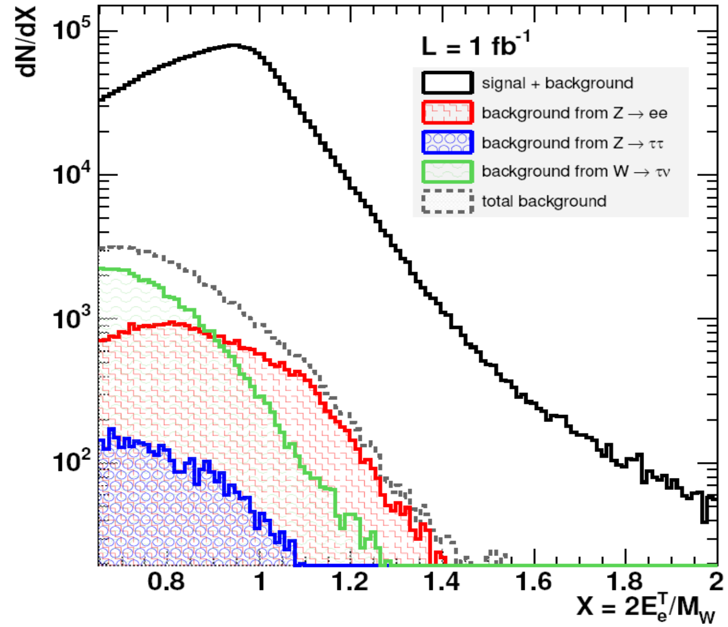
Theory (HO) limitations: examples

A/H→ττ



20% uncertainty on the cross section can limit the precision on tanβ extraction

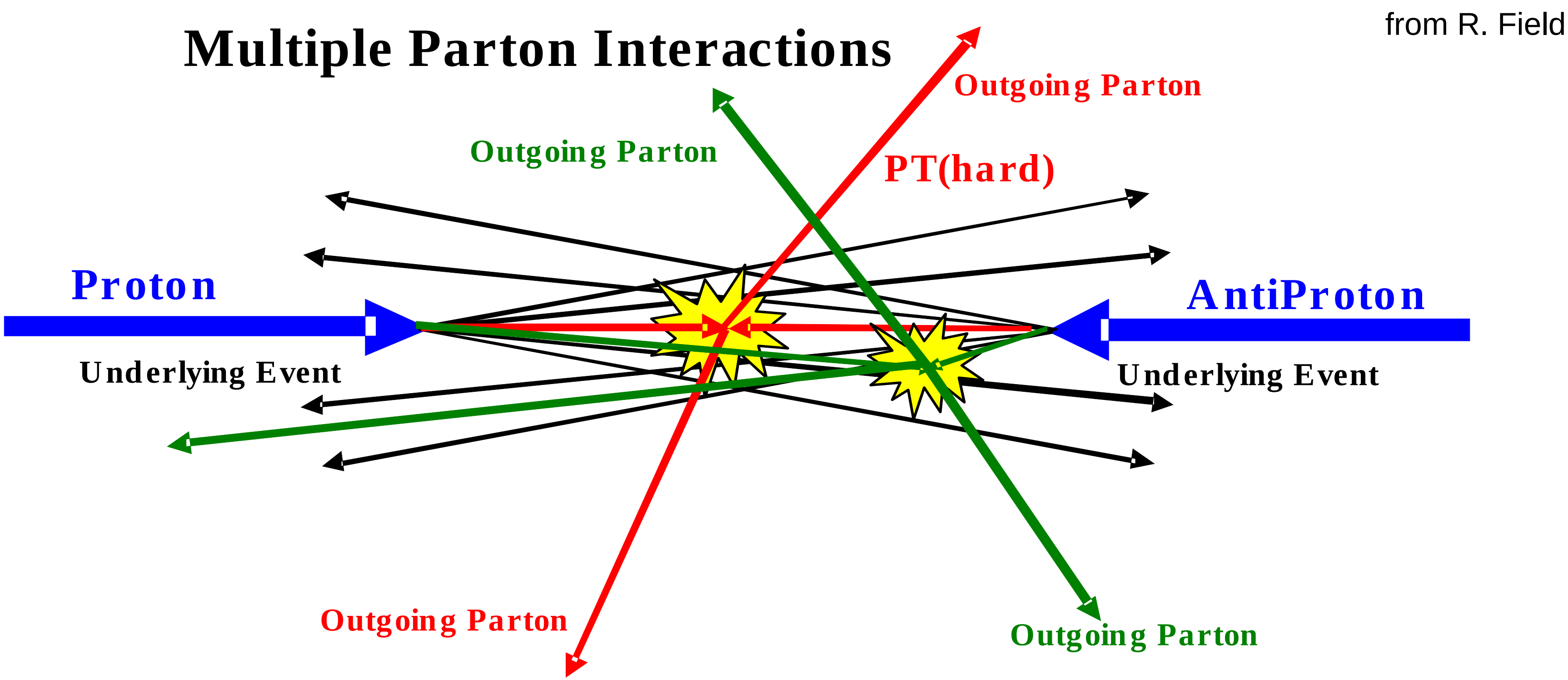
W → eν: Scaled observable method (E_T)



Source of uncertai				ΔM_W [MeV/c^2] with 10 fb^{-1}
statistics				15
background				2
electron energy sca				2
scale linearity				<10
energy resolution				2
MET scale				<10
MET resolution				< 5
recoil system				<10
total instrumental				**<20**
PDF uncertainties				<10
Γ_W		15		<15
p_T^W		30		30 (or NNLO)

Systematic errors for electrons (10 fb^{-1}): O(20) MeV exp+det.syst
Dominant error will be the understanding of the W-p_T spectrum. NNLO needed?

Underlying event/multiple interactions



- Studies and tunes made on Tevatron/lower energy data
  New models on the market that should be tested (new Pythia, Jimmy, Sherpa)

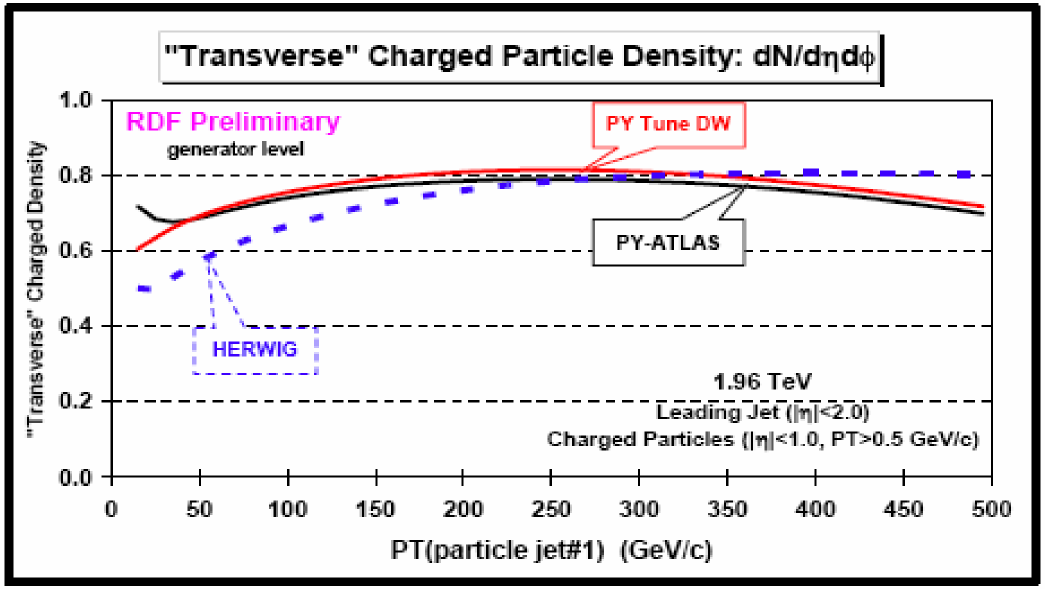
- ⇒ CMS so far used the ATLAS tune for the PTDR (A. Moraes et al/LH03)
- ⇒ Propose to move to a new tune (R. Field) ⇒ Discussion this Friday AM

PYTHIA 6.2 Tunes

PYTHIA 6.2 CTEQ5L

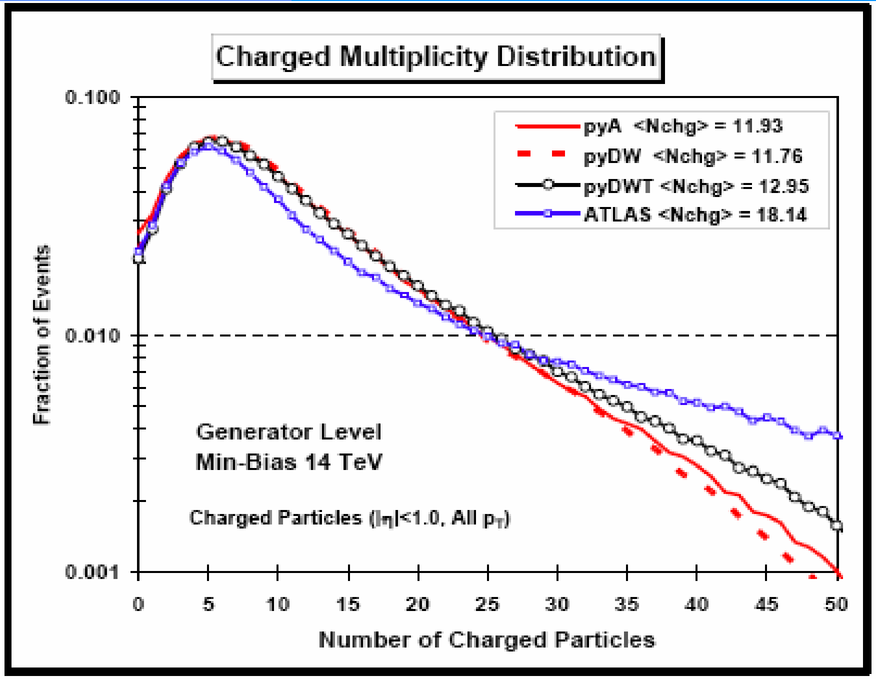
Parameter	Tune A	Tune DW	Tune DWT	ATLAS
MSTP(81)	1	1	1	1
MSTP(82)	4	4	4	4
PARP(82)	2.0 GeV	1.9 GeV	1.9409 GeV	1.8 GeV
PARP(83)	0.5	0.5	0.5	0.5
PARP(84)	0.4	0.4	0.4	0.5
PARP(85)	0.9	1.0	1.0	0.33
PARP(86)	0.95	1.0	1.0	0.66
PARP(89)	1.8 TeV	1.8 TeV	1.96 TeV	1.0 TeV
PARP(90)	0.25	0.25	0.16	0.16
PARP(62)	1.0	1.25	1.25	1.0
PARP(64)	1.0	0.2	0.2	1.0
PARP(67)	4.0	2.5	2.5	1.0
MSTP(91)	1	1	1	1
PARP(91)	1.0	2.1	2.1	1.0
PARP(93)	5.0	15.0	15.0	5.0

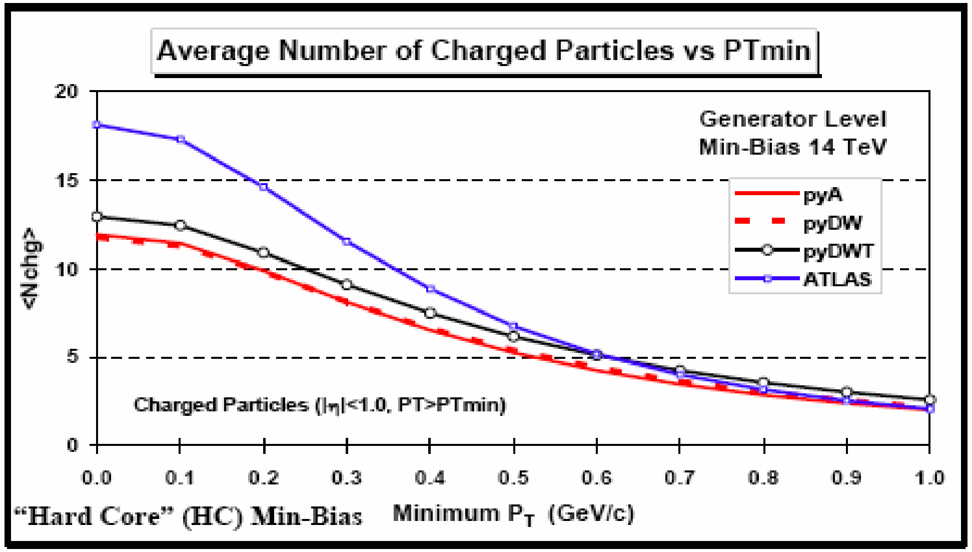
	σ(MPI) at 1.96 TeV	σ(MPI) at 14 TeV
Tune A	309.7 mb	484.0 mb
Tune DW	351.7 mb	549.2 mb
Tune DWT	351.7 mb	829.1 mb
ATLAS	324.5 mb	768.0 mb



- Shows the "transverse" charged particle density, dN/dηdϕ, versus P_T(jet#1) for "leading jet" events at 1.96 TeV for Tune DW, ATLAS, and HERWIG (without MPI).

PYTHIA 6.2 Tunes
LHC HC Min-Bias Predictions





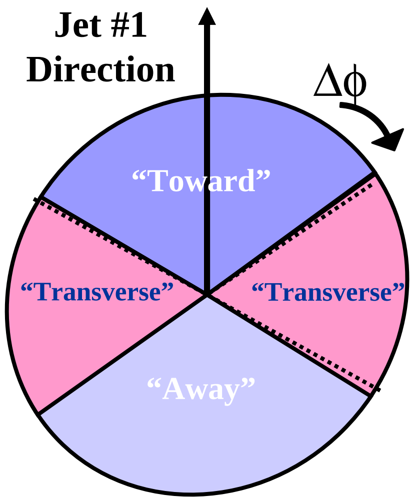
Note: depends on PDF choice!

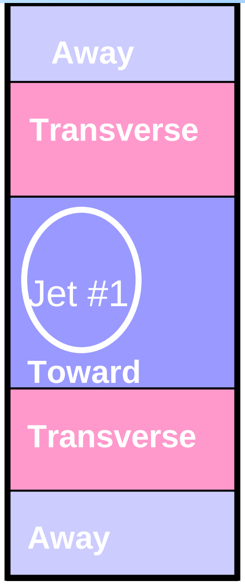
- Shows the predictions of **PYTHIA Tune A**, Tune DW, Tune DWT, and the ATLAS tune for the charged particle multiplicity distribution for "hard core" (HC) Min-Bias at 14 TeV ($|\eta| < 1$) and the average number of charged particles with $p_T > p_T^{min}$ ($|\eta| < 1$).
- The ATLAS tune has many more "soft" particles than does any of the CDF Tunes. The ATLAS tune has $\langle N_{chg} \rangle = 18.14$ ($|\eta| < 1$) while Tune A has $\langle N_{chg} \rangle = 11.93$ ($|\eta| < 1$).

DWT tune uses the "ATLAS" energy dependence

Basic Underlying Event Observables in Jet Events

CMS PTDR Studies

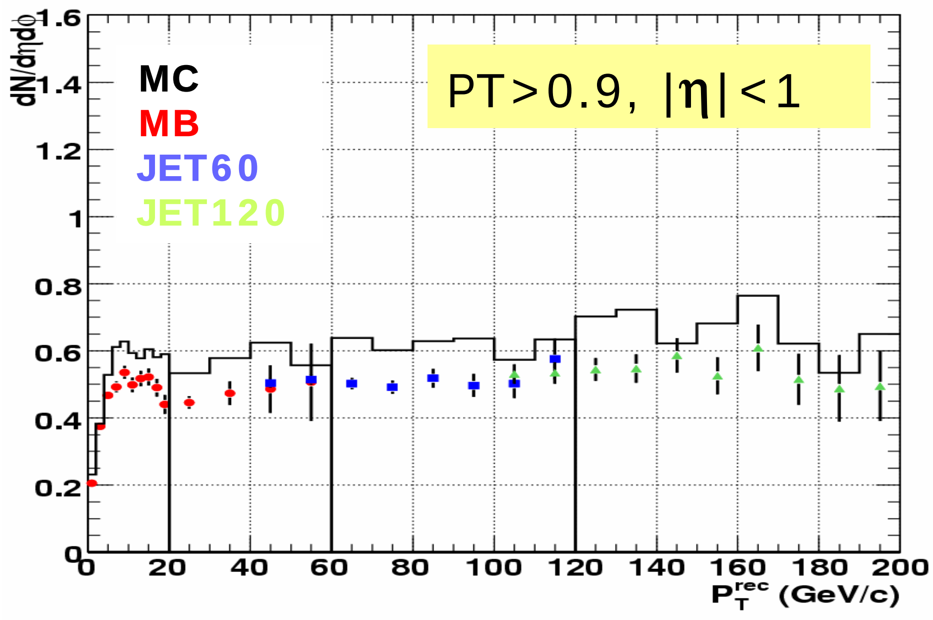


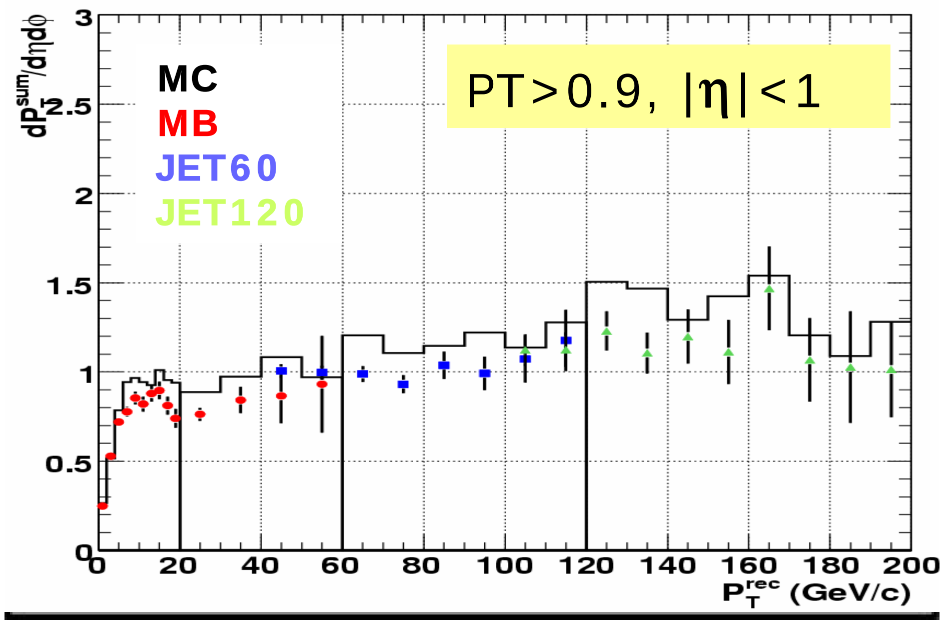


- "Charged jet" definition with R=0.7
- Assign all charged particles (P_T> 0.9 GeV/c) and |η|<1 to a jet

In the three different zones define:
- Charged Multiplicity
- Sum P_T (charged tracks)

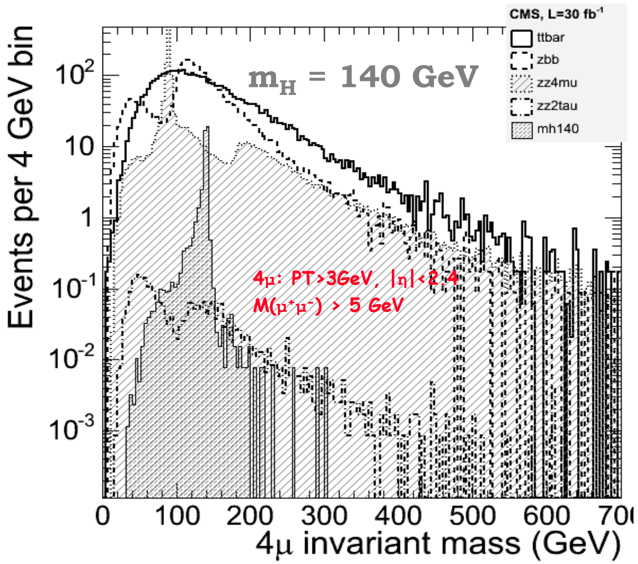
Transverse regions are expected to be sensitive to the Underlying Event

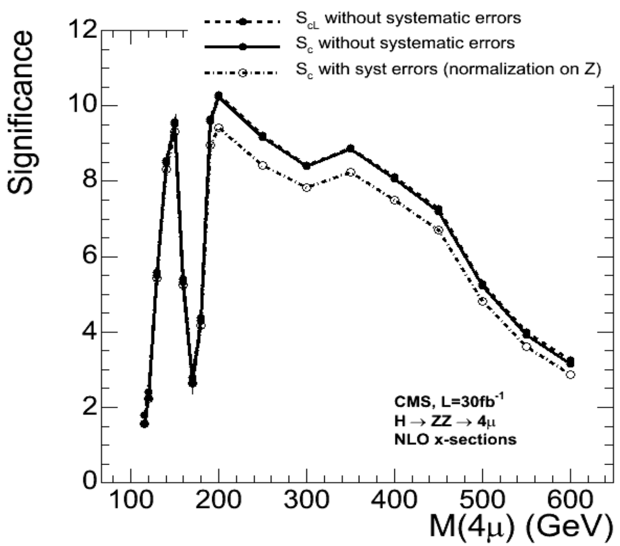




[CMS Note 2006/067] → Also Drell Yan

H→ 4μ Analysis. Emphasis on systematics

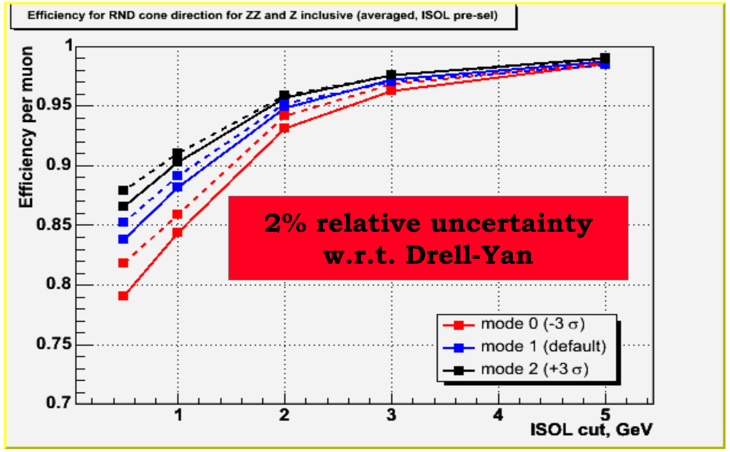




Sensitivity of the Muon Isolation Cut Efficiency to the Underlying Event Uncertainties

Experimental methodology: Calibration to Z→2m.

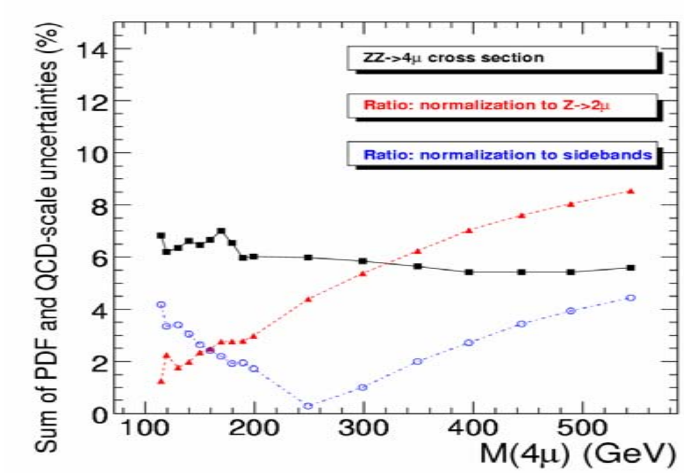
[CMS Note 2006/033]



Study of PDF and QCD scale Uncertainties for the Main Irreducible Background.

Experimental methodology: Normalization to Z→2μ and to Side-Bands.

[CMS Note 2006/068]



Additional Documentation:
Proceedings of the 2006 Les Houches Workshop.
CMS Notes 2006/ 057, 060, 106, 107, 122, 130

Heavy Ion Generators in CMS

There are two kind of MC HI simulations in CMS:

1. "Hard probes" signal event (jets, quarkonia, heavy quarks, Z) is generated with standard pp generator (PYTHIA,...) and superimposed on HI background
2. Global observables (particle spectra) and multiplicity background for "hard probes" are generated with HI event generator (HIJING,...)

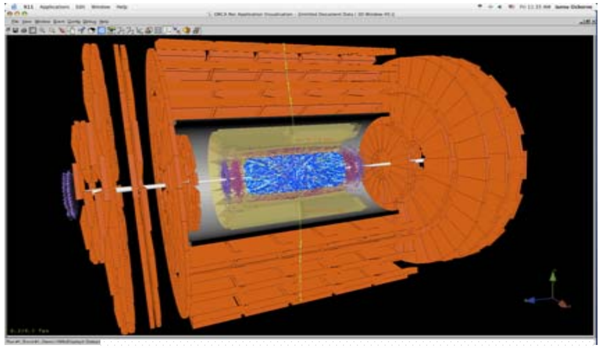
HIJING so far used for CMS HI analysis

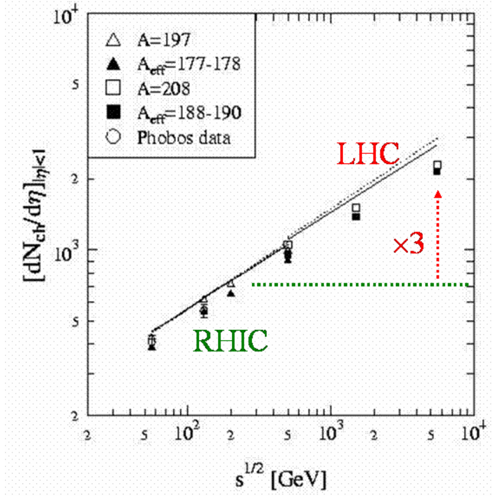
Problem: In most generators effects as jet quenching and flow are not included or implemented poorly

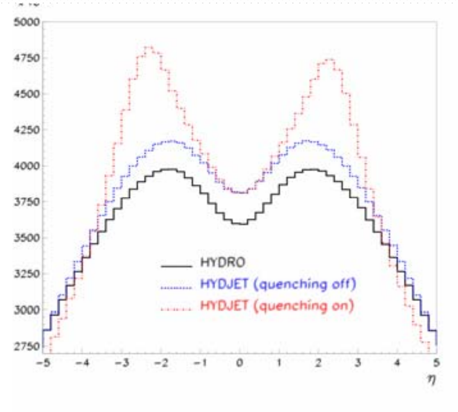
⇒Develop MC tools for adequate, fast simulation of physics phenomena

Eg PYQUEN - fast code to simulate jet quenching (modify PYTHIA6.4 jet event)

Wish: more tools/generators to describe HI phenomena eg. Quarkonia meltdown,...







BSM Tools

BSM Models

- (N)MSSM
- CPV, RPV
- Ext $H, \tilde{\chi}^0$ sectors
- NS Higgses
- Little Higgs
- Twin Higgs
- Higgsless,Z'
- Warped ED
- Warped/Comp. Pheno
- UED
- KK↔SUSY
- Top Partners
- ...

Spectrum Calc

- CPSuperH
- FeynHiggs ✓
- NMHDECAY ✓
- RGE Codes
  Isasusy ✓
  SoftSusy ✓
  Spheno ✓
  SuSpect ✓
- ...

Flavour Calc

- $(g-2)_\mu$
- $b \to s\gamma$
- $B_s \to \mu^+\mu^-$
- ...

Dark Matter

- micrOMEGAs ✓
- SloopS
- DARKSUSY
- NeutDriver ...

Cross Section Calc

- Tree-level, any
  CalcHEP, ✓
  CompHEP ✓
  Grace-SUSY
  FormCalc
- 1-loop, dedicated
  ILCslepton
  Prospino ✓
  hprod
- 1-loop/General
  Grace-SUSY
  FormCalc
  SloopS
- ...

Decay Codes

- FeynHiggs ✓
- HDECAY ✓
- NMHDECAY ✓
- SDECAY ✓
- SPHENO ✓
-

Event Generators

- Isajet
- Pandora
- Pythia ✓
- Herwig
- SUSY-MadGraph
- SUSYGEN - MCFM
- ALPGEN - VECBOS
- WHIZARD ✓ ...

Data Analysis Fitters

- Bard
- Fittino
- Sfitter
- NP-LHCFast
- Requs. from the exp.

Plenty of tools
Need Toolbox?
See ADR@Annecy

M. Muehlleitner

Collection of programs on http://www.ippp.dur.ac.uk/montecarlo/BSM/

SUSY Tools/SLHA Accord

SUSY Models

- MSSM √
- SUGRA √
- GMSB √
- AMSB √
- RPV
- CPV
- FLV
- NMSSM √
- ...

SLHA Input →

Spectrum Calc

- CPSUPERH
- FeynHiggs √
- ISASUSY √
- NMHDECAY √
- SOFTSUSY √
- SPHENO √
- SUSPECT √ ...

SLHA Input + Spectrum → (+ Decay Table)

Event Gen./ Cross Section Calc

- Calc/CompHEP √
- AF's SLEPTONS
- Grace
- HERWIG(++)
- ISAJET
- PROSPINO √
- PYTHIA √
- SHERPA
- SMadgraph
- SUSYGEN
- WHIZARD √ ...

SLHA Input + Spectrum → Dark Matter, Decay Codes

Dark Matter

- micrOMEGAs √
- DARKSUSY
- NeutDriver
- ...

Decay Codes

- FeynHiggs √
- HDECAY
- NMHDECAY √
- SDECAY √
- SPHENO √
- ...

SLHA Input + Spectrum + Decay Table → Event Gen./Cross Section Calc

M. Muehlleitner

SUSY Spectrum Calculations

	ISAJET 7.71	SOFTSUSY 1.9	SPHENO 2.2.2	SUSPECT 2.3
$\tilde\chi_1^0$	117.2	119.9	119.7	119.9
$\tilde\tau_1$	131.4	133.2	131.4	137.7
h^0	115.3	112.7	113.0	112.8
A^0	363.4	363.2	366.4	364.4
$\tilde\chi_3^0$	394.9	401.4	405.3	405.3
$m_{\tilde\tau_1} - m_{\tilde\chi_1^0}$	14.2	13.3	11.6	17.8
$m_A - 2m_{\tilde\chi_1^0}$	129	123	127	125
$\tilde\chi_1^0\tilde\chi_1^0 \to bb$	40%	38%	30%	49%
$\tilde\chi_1^0\tilde\chi_1^0 \to ee$	12%	10%	10%	14%
$\tilde\chi_1^0\tilde\chi_1^0 \to \tau\tau$	17%	14%	13%	19%
$\tilde\chi_1^0\tilde\tau_1 \to h\tau$	13%	16%	21%	7%
$\tilde\chi_1^0\tilde\tau_1 \to \gamma/Z\,\tau$	12%	14%	18%	7%
$\tilde\tau_1\tilde\tau_1 \to hh$	1%	2%	3%	–
Ω	0.120	0.107	0.094	0.142

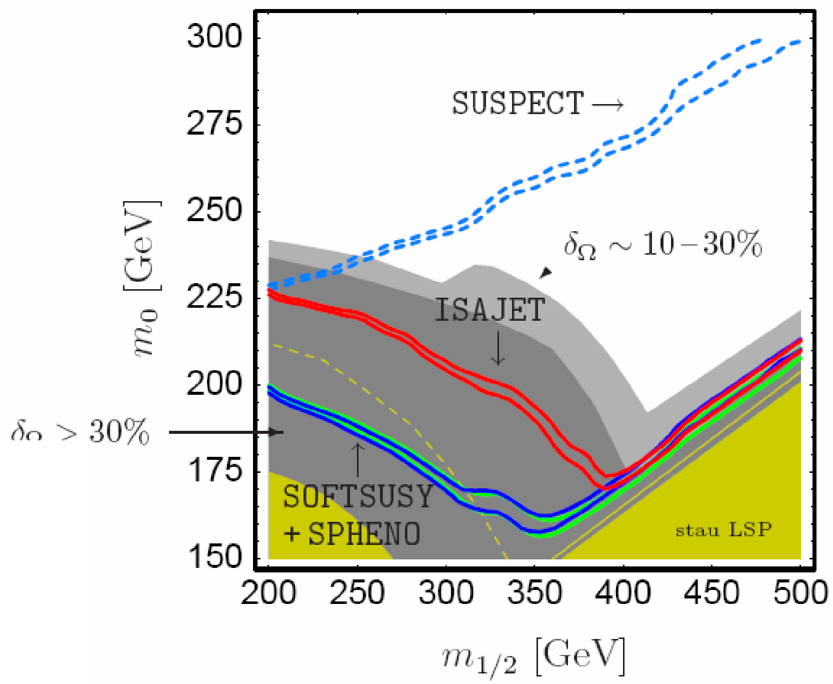
Table 3: Masses and mass differences (in GeV), the most important contributions, and the resulting Ω for $m_0 = 194$ GeV, $m_{1/2} = 300$ GeV, $A_0 = 0$, $\mu > 0$ and $\tan\beta = 40$. The higgsino fraction of $\tilde\chi_1^0$ is 1.8% in all cases.

	SOFTSUSY 1.9	SPHENO 2.2.2	SUSPECT 2.3
$\tilde\chi_1^0$	135.0	148.9	146.5
$\tilde\chi_1^\pm$	184.0	287.0	256.0
$\tilde\chi_2^0$	195.9	286.9	257.4
$\tilde\chi_3^0$	212.9	502.7	324.5
h^0	121.6	122.2	121.6
A^0	1200	1425	957
$f_H(\tilde\chi_1^0)$	30%	1.1%	4.3%
$\tilde\chi_1^0\tilde\chi_1^0 \to b\bar b$	5%	27%	44%
$\tilde\chi_1^0\tilde\chi_1^0 \to \tau\tau$	–	4%	6%
$\tilde\chi_1^0\tilde\chi_1^0 \to ZZ$	18%	7%	6%
$\tilde\chi_1^0\tilde\chi_1^0 \to WW$	61%	29%	21%
$\tilde\chi_1^0\tilde\chi_1^0 \to Zh$	8%	15%	10%
$\tilde\chi_1^0\tilde\chi_1^0 \to hh$	5%	15%	10%
Ω	0.125	18.6	2.15

Table 6: Relevant masses (in GeV), the higgsino fraction of the LSP, the most important contributions and the resulting Ω for $m_0 = 3450$ GeV, $m_{1/2} = 350$ GeV, $\tan\beta = 50$, $A_0 = 0$, $\mu > 0$.

Hep-ph/05/02079

$\tan\beta = 10,\ A_0 = -4m_{1/2}$



http://cern.ch/kraml/comparison

Several improvements since this comparison

Still large differences in the Focus point region

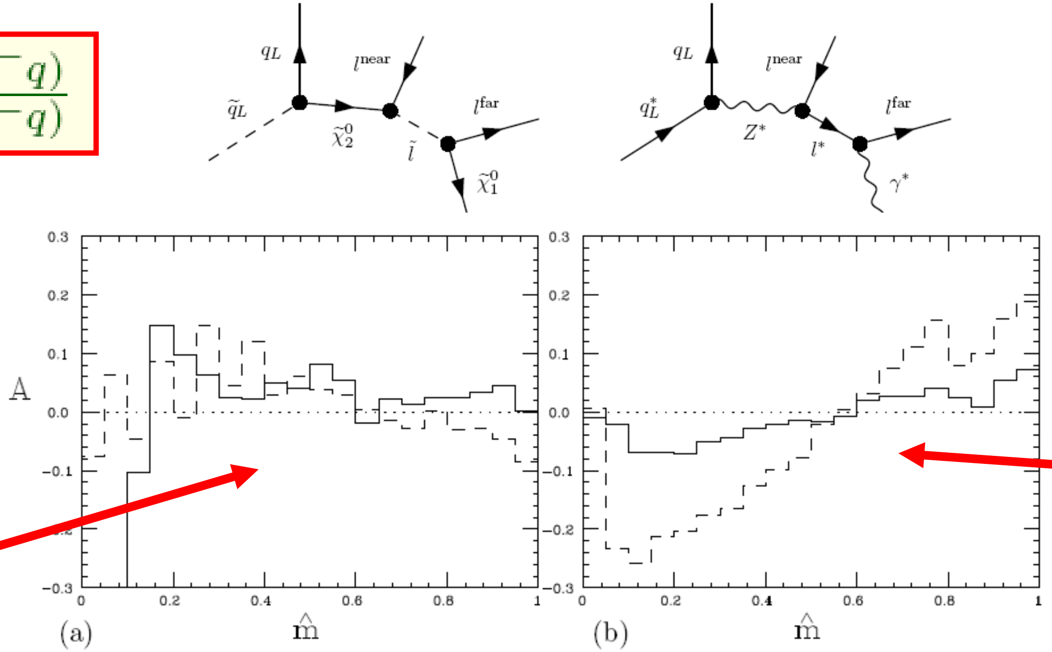
Is it SUSY? Spin in the generators

Can the LHC distinguish UED ↔ SUSY?

e.g. Cheng, Matchev, Schmaltz hep-ph/0205314

Look for variables sensitive to the particle spin eg. lepton charge asymmetries in squark/KKquark decay chains Barr hep-ph/0405052; Smillie & Webber hep-ph/0507170 Allanach & Mahmoudi hep-ph/0602198

$$A = \frac{(l^+q)-(l^-q)}{(l^+q)+(l^-q)}$$



KK like spectrum (small mass splitting)

SPS1a benchmark type spectrum

Method works better or worse depending on (s)particles spectrum

⇒ need spin correlations in decay chains of generators

SUSY+Njets

(S)MadGraph Numbers

Skands, TeV4LHC 05

sps1a

T = 600 GeV top

	$\sigma_{\rm tot}\,[\rm pb]$	$\tilde{g}\tilde{g}$	$\tilde{u}_L\tilde{g}$	$\tilde{u}_L\tilde{u}_L^*$	$\tilde{u}_L\tilde{u}_L$	TT
$p_{T,j} >$ 100 GeV	σ_{0j}	4.83	5.65	0.286	0.502	1.30
	σ_{1j}	2.89	2.74	0.136	0.145	0.73
	σ_{2j}	1.09	0.85	0.049	0.039	0.26
$p_{T,j} >$ 50 GeV	σ_{0j}	4.83	5.65	0.286	0.502	1.30
	σ_{1j}	5.90	5.37	0.283	0.285	1.50
	σ_{2j}	4.17	3.18	0.179	0.117	1.21

1) Extra 100 GeV jets are there ~ 25%-50% of the time!

2) Extra 50 GeV jets - ??? No control → We only know ~ a lot!

$\Rightarrow$ Additional jet contribution will be important

ALPGEN

- Getting the shapes right for njets final states → ALPGEN ME+matched PS for a number of channels, usually as a background study to Higgs or BSM searches
- Alpgen version 20x (mostly 205)
- Used parton shower matching CKKW with PYTHIA 6.25/6.35

Process
W+Njets, N=0,1,2,3,4,5,6+
Z+Njets, N=0,...,6+
tt+Njets, N=0,1,2,3,4,5,6+
WW,WZ,ZZ+Njets, N=0,1,2,3,4+
Z/W bb + Njets, N=0,1,2,3,4+
bb+Njets, N=0,1,2,3,4,5,6+
bbbb +Njets, N=0,1,2,3,4+
gamma+Njets, N=1,...,6+
Njets, N=2,3,4,5,6+
gamma gamma + Njets, N=0,...,6+
WWW,WZW,ZWZ,ZZZ + Njets, N=0,1,2,3+
Z+Mc+Njets, M=2, N=0,1,2+
t + Njets, N=0,1,2+

Subrocess	Cross section (pb)	Events generated	Submitted to full sim
tt + 0 j (excl)	190	incoming	-
tt + 1 j (excl)	170	3259500	1400000
tt + 2 j (excl)	100	331500	331500
tt + 3 j (excl)	40	125000	125000
tt + 4 j (incl)	61	186000	186000

Example tt+njets

ALPGEN: Procedure

- Interactive [preparatory for large scale production]
  - Build stable phase space .grid2
    - For subsequent use in same process larger scale production
  - Generate weighted,unweighted,matched events to extract:
    - Overall efficiency
    - Number of input events required for a requested yield of generated events [corresponding to X fb^{-1}]
    - CPU per jet multiplicity bin
- On the Grid, [large scale production]
  - Use stable phase space .grid2
  - Generate weighted,unweighted,matched events
  - Retrieve results in form of .tgz and store in castor
  - Stage the archives on disk/Uncompress and extract the final file

efficiencies	before matching (p_T>20 GeV)	Parton shower matching
0 jets	4%	80%
6 jets	3.10^{-5}	6%

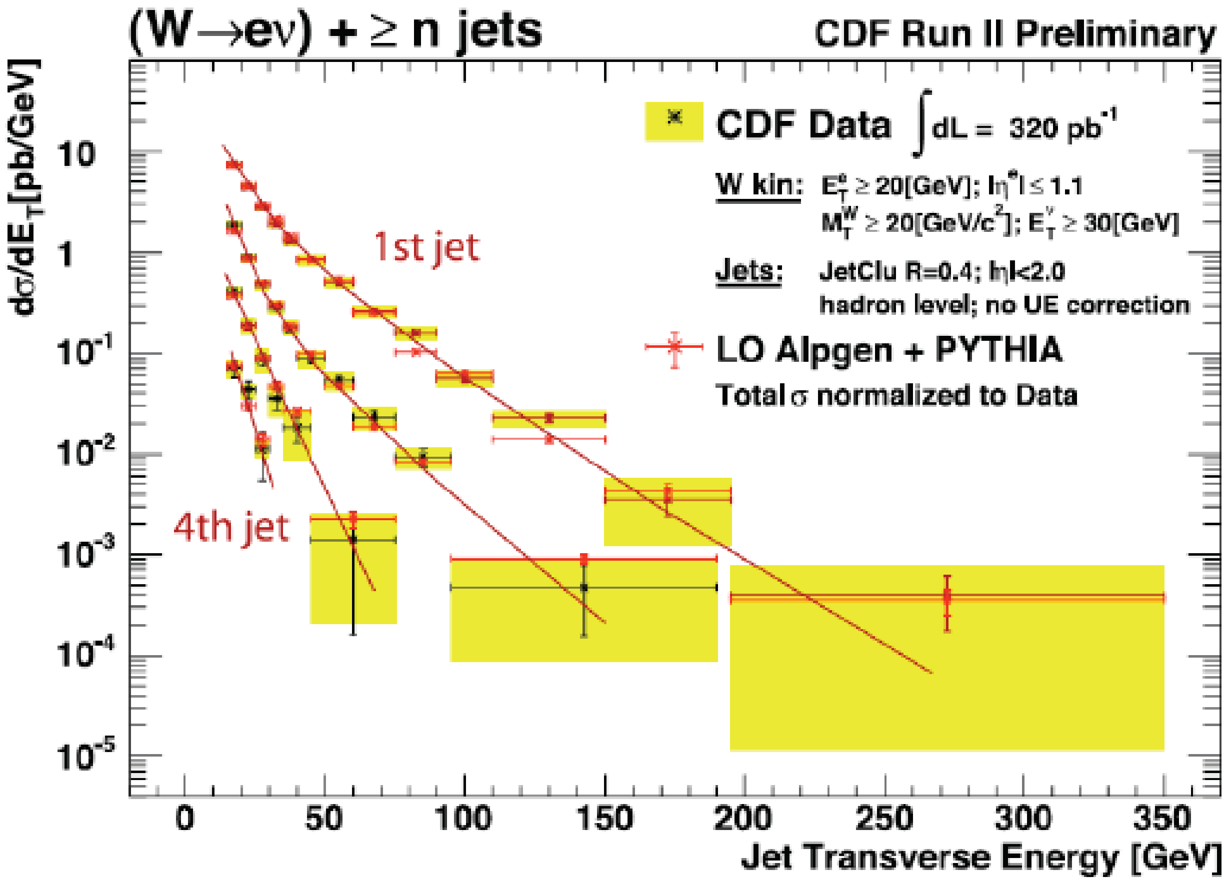
ALPGEN

- Mass production more tedious than wanted/lot of book keeping and computing resources needed
  - Unstable PS grids
    - Empirical solution: increase iterations and numbers of events to form stable grid2 as a function of jet bin
  - CPU (abortions/crashes for large Nj)
    - Empirical solution: decrease number of requested events as a function of jet bin
  - Disk space (staging the archives)
- Used cross section normalization procedure
  - Normalize each sample to the matched cross section
  - Add all samples
  - Normalize total sample to NLO cross section (e.g. from MCFM)
  - Care on the generator level requirements
  - Procedure needs to be thoroughly tested

Normalization procedure

Annecy 06

- How to normalise MC event generators especially in multi-leg hadronic final states (many jets beyond MC@NLO). Establish control sample of data for overall normalisation? Extrapolation to other final states/data sets possible ?



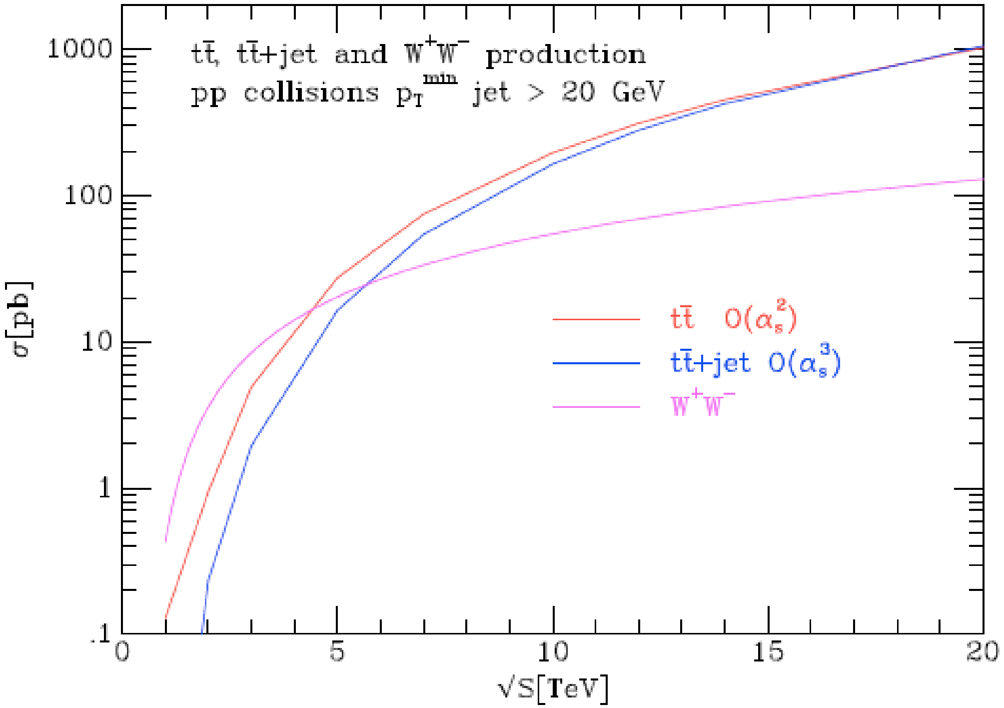
Normalize to data or to NLO total cross section?

Discussion Tuesday AM

Top, W, Z+ njet Production Normalization

Will be essential to understand properly for BSM searches: Eg Top

Top +jet production at LHC



MCFM prediction

K. Ellis

How to normalize tt+2jet or tt+3 jet?

- $t\bar{t}$+jet cross section same as $t\bar{t}$ cross section; Radiation probability is one.
- Note that a $p_T = 20$ GeV jet can be adequately described using the soft approximation.
- The W^+W^- cross section is also shown, (subject to gauge cancellation)

Example: QCD Njets ALPGEN

ALPGEN v201 $Q^2 = \Sigma P_T^2$(parton) PDFs CTEQ5L

Matching scheme CKKW (M Mangano impementation in Alpgen, see *http://mlm.home.cern.ch/mlm/alpgen*)- Interface with PYTHIA 6.227

Jet parameters for matching:

- E_T(jet) > 15 GeV
- R(jet) = 0.525,
- ΔR(parton-jet) < 0.7875

samples

2-to-2 : $N_{partons}$=2; P_T(parton)>20 (100) GeV; |eta|<5
ΔR(parton-parton) >0.7

2-to-3 : $N_{partons}$=3; P_T(parton)>20 (100) GeV; |eta|<5
ΔR(parton-parton) >0.7

2-to-4 : $N_{partons}$=4; P_T(parton)>20 (100) GeV; |eta|<5
ΔR(parton-parton) >0.7

samples cross sections

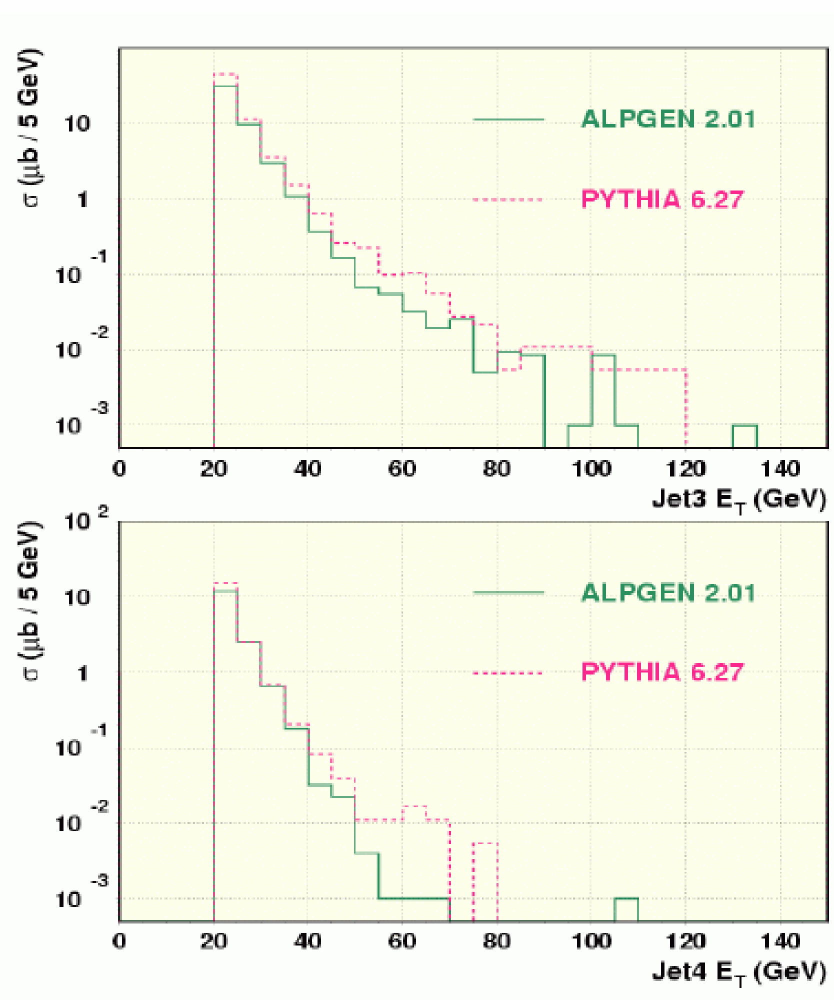
20 GeV

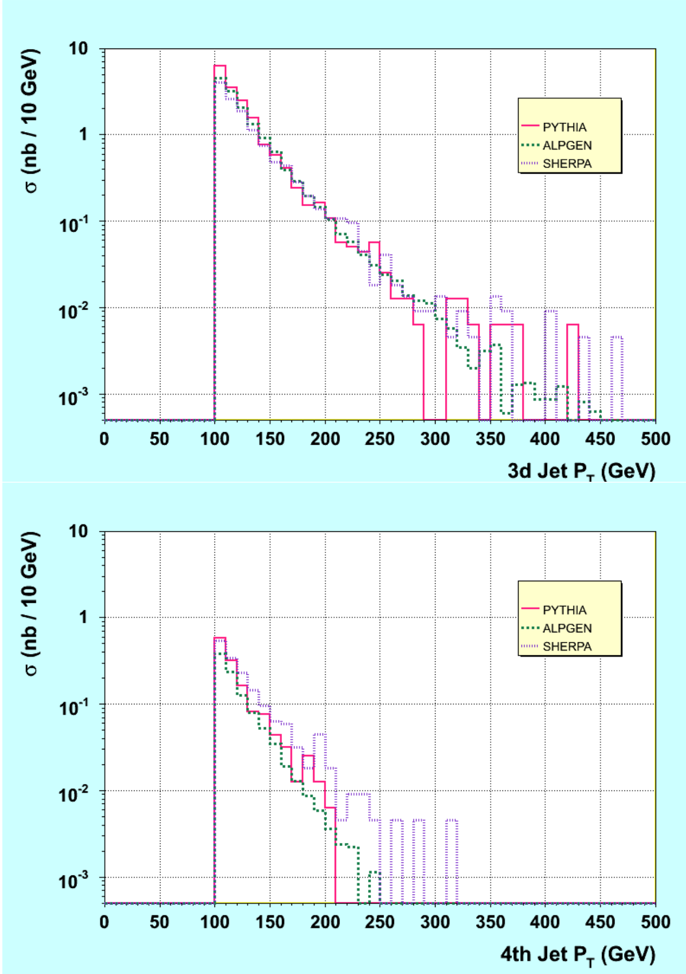
sample	σ(matched-alp)	σ(unw-alp)	matching ε	σ(pythia)
2-2	0.4 mb	0.8 mb	0.5	-
2-3	0.02 mb	0.06 mb	0.3	-
2-4	0.0024 mb	0.016 mb	0.15	-
total	0.45 mb	0.876 mb	-	0.83 mb

100 GeV

sample	σ(matched-alp)	σ(unw-alp)	matching ε	σ(pythia)
2-2	6×10^{-4} mb	0.0013 mb	0.45	-
2-3	1.5×10^{-5} mb	4×10^{-5} mb	0.38	-
2-4	1×10^{-6} mb	3.6×10^{-6} mb	0.27	-
total	6.16×10^{-4} mb	1.344×10^{-3} mb	-	6.3×10^{-4} mb

QCD Njets ALPGEN





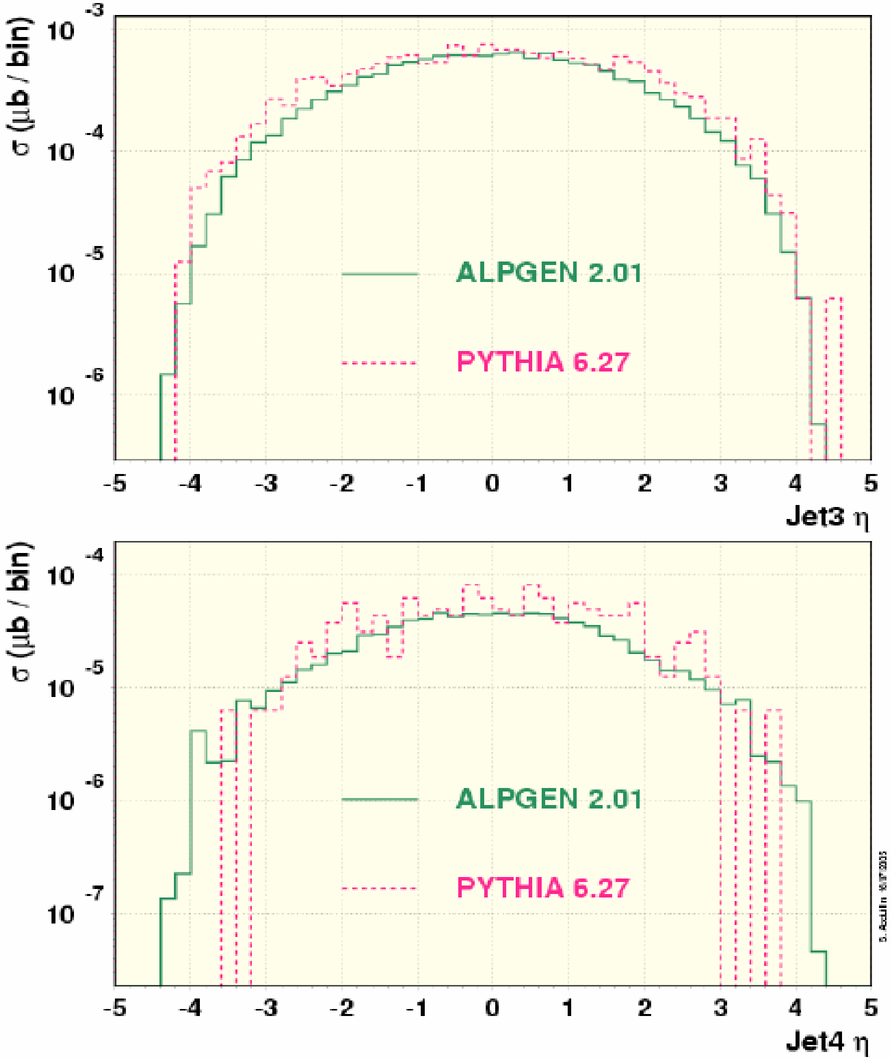
Low p_T range and up to 4 jets: No big difference observed

Effects of ALPGEN expected at high jet multiplicities and high parton p_T

QCD Njets ALPGEN

Pseudorapidity distributions

3d jet $E_T > 100$ GeV,
4^{th} jet $E_T > 100$ GeV



Note: Systematics from matching in progress !
Determine Inclusive/Exclusive usefulness (i.e: stop at 4 jets and tune the matching such that the 5th, 6th jets are predicted correctly?)

Similar observations for W,Z,tt+jets, see talk tomorrow morning

Summary

- Event generators will be very important for the LHC physics program
  - Important progress over the last years
- Workshop very timely in view of the LHC Startup
  - Prime concern now is to get ready for the LHC startup (2007) 2008
    - Jets, W-Z-t(t)+ njets, WW-ZZ+njets,W-Zbb,ttbb,Wγ,Zγ, min bias…
- A number of questions raised (here & particularly for parallel sessions)
  - What model versions (PYTHIA/HERWIG/Alpgen/…), parameters
  - PDFs NLO PDFs for LO MCs?
  - Underlying events, new tune
  - NLO processes wishlist
  - QCD in the new LHC kinematic regime? Special generators?
  - How to normalize the MCs
- Not discussed here but:
  - Projects like SPA, LHA accords etc. are very useful
  - Alternatives to QCD event simulation like SCET look interesting

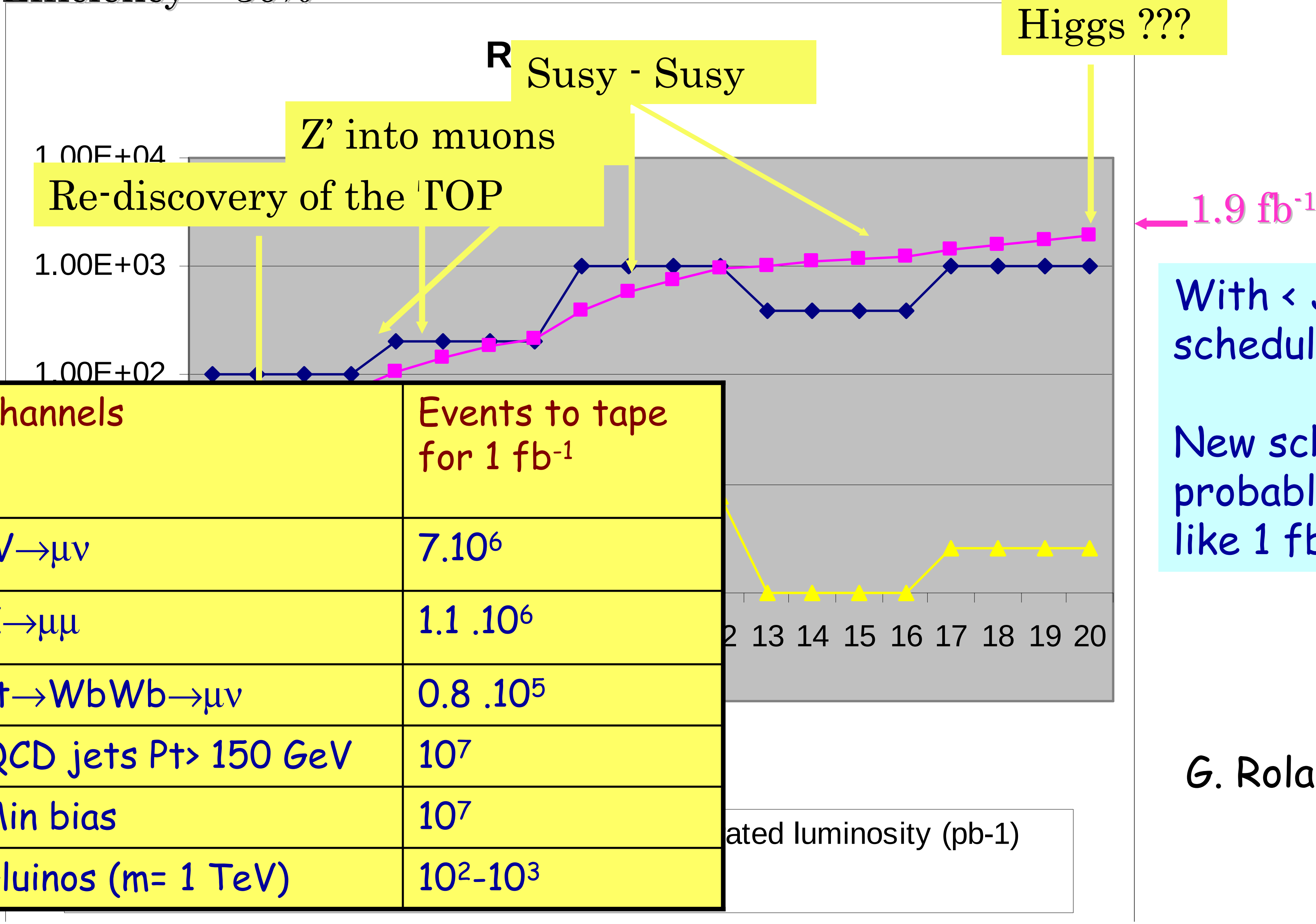
Backup

Extra processes wanted for Higgs Studies

- MC for gg$\rightarrow$ZZ including gamma* and Z width
- MC@NLO in PYTHIA, since HERWIG has the bad UE model (or improve HERWIG UEmodel)
- NLO MC for bbH (or bH) production and bbZ (or bZ) production.

The First Physics Run (2008)

Efficiency = 30%



Channels	Events to tape for 1 fb^{-1}
$W \to \mu\nu$	7.10^6
$Z \to \mu\mu$	$1.1\ .10^6$
$tt \to WbWb \to \mu\nu$	$0.8\ .10^5$
QCD jets Pt> 150 GeV	10^7
Min bias	10^7
Gluinos (m= 1 TeV)	10^2-10^3

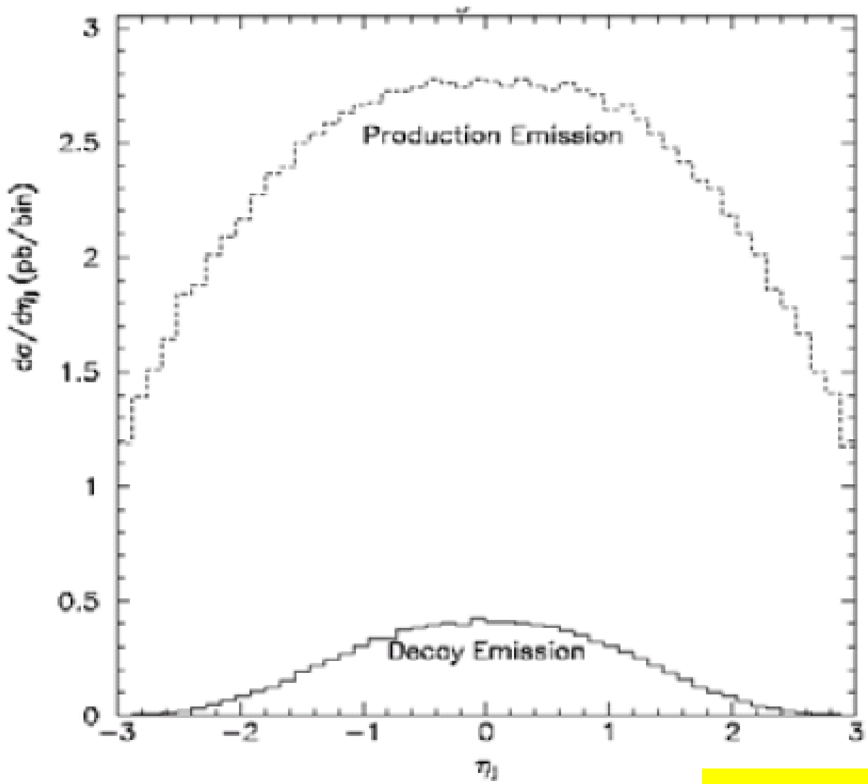
With < June06 schedule…

New schedule probably more like 1 fb^{-1}

G. Rolandi

Stability of PT at Tevatron & LHC

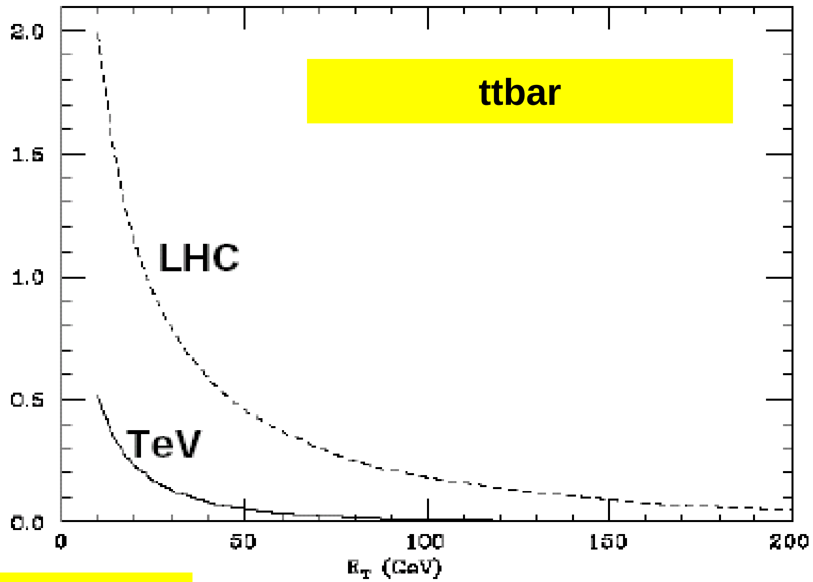
- Most radiation in production:



LHO, Stelzer, Stirling, PRD 1997

- And lots of it!

$$\frac{\sigma}{\sigma_0} = \frac{\sigma(tt j,\ E_T^{\,j} \geq E_T\ \mathrm{cut})}{\sigma_{(tt)}}$$



E_T, GeV

Slide from Lynne Orre

Top Mass Workshop

Requirements: tools and calculations

- Les Houches 05: What are the real uncertainty bands (from higher orders,scale uncertainties, PDFs). This has not yet been done even for some simple cases!

  We will obviously try to use our own data as much as possible (sidebands, independent measurements) but tuned Monte Carlos will play an important role in the analysis. Hence Standard Model processes will be important particulalry W,Z + jets, tt +jets , bb + jets, n-jets…

  ⇒ Calculations and generators; NLO, NNLO; ME+PS matching
- Upgrade MC@NLO for
  - WW, WZ with spin correlations, DY, W+jets
- MC@NLO+PYTHIA
- Event generator including EW effects
- Event generator based on Ariadne QCD treatement
- PYTHIA6.3 tuned version
- Underlying event/minimum bias event decriptions
- Toolkits for SM and BSM processes (via LH-accords)

Requirements: tools and calculations

- Specfic examples for Higgs Study
  - NLO predictions for ttbb and ttj(j)
  - NLO, NLLO for $gg \to H$; bbH; $H/A \to \tau\tau$
  - WbWb background to $H \to WW$
  - Gluon induce WW backgrounds to Higgs searches
  - $pp \to ZZ \to 4l$ with Z width and spin correlations
  - $tt \to WbWb$ with spin correlations

Time to repeat the MC@LHC workshop in summer 2006?

CERN Workshop on
Monte Carlo tools for the LHC

July 7 – Aug 1 2003

Organizing Committee :

N. Brook, A. de Roeck, F. Gianotti, E.W.N. Glover, I. Hinchliffe, S. Jadach, F. Krauss, M. Mangano, A. Morsch, F. Paige, W. Pokorski, A. Presland, A. Ribon, P. Richardson, E. Richter–Was, P. Skands, B. Webber

http://mlm.home.cern.ch/mlm/mcwshop03/mcwshop.html

QCD predictions: ALPGEN vs Data

QCD Multijets in D0

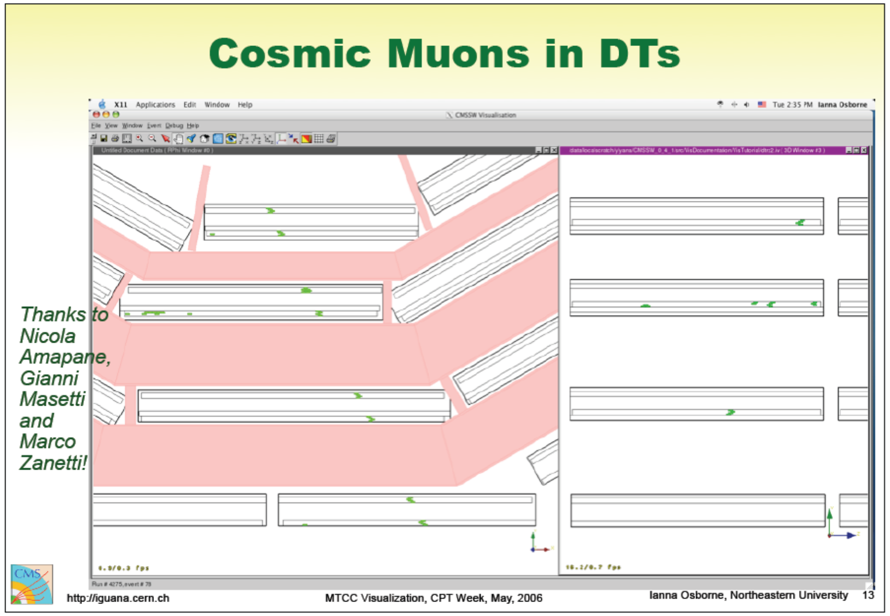
# jets	cuts	reference exp.	cross section exp. / pb	cross section theory / pb
3	A	[10]	38300 ± 200 (stat)	35000 ± 800 (stat)
3	B	[7]	6.7 ± 0.3 (stat)	16 ± 10 (stat)
4	A	[10]	6750 ± 75 (stat)	4500 ± 200 (stat)
6	C	[8]	48 ± 1 (stat)	89^{+25}_{-15} (stat)

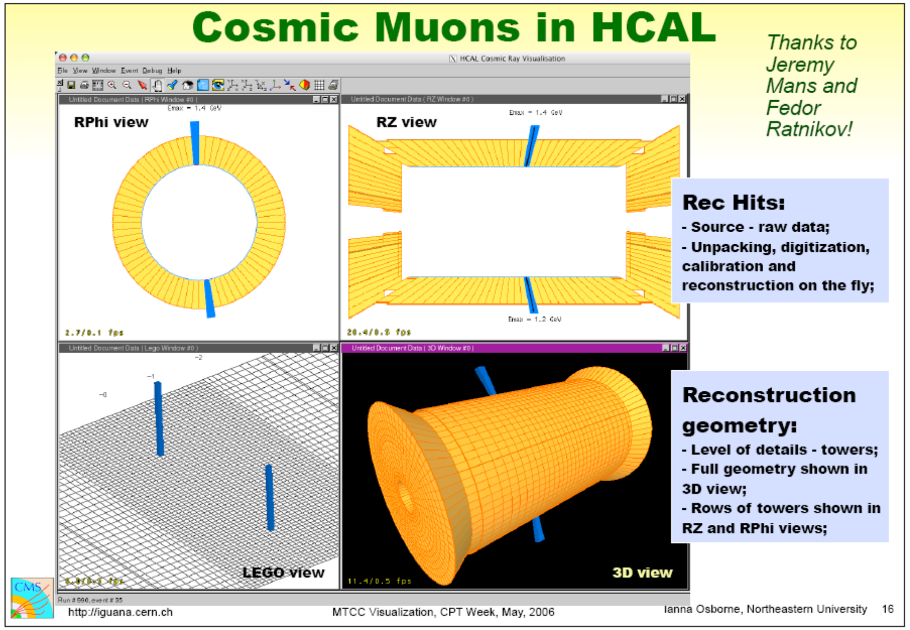
Table 2: Comparison of measured and calculated (Alpgen+Pythia) multijet cross sections.

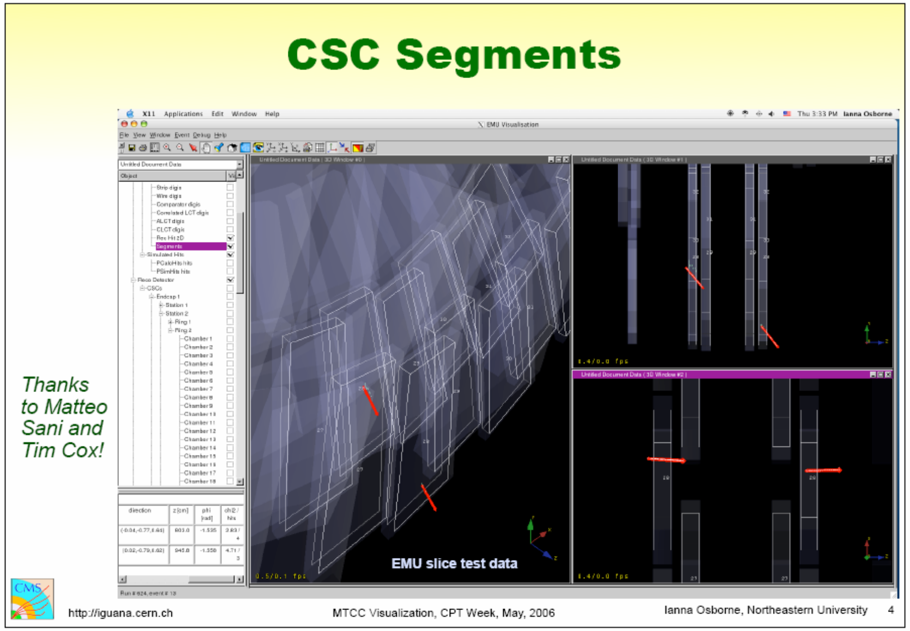
A	$E_T > 20\,\mathrm{GeV}, E_\perp(1st\ jet) > 60\,\mathrm{GeV}, \lvert\eta\rvert < 3, m > 200\,\mathrm{GeV}, R_{ij} > 1.4$
B	$E_T > 20\,\mathrm{GeV}, \lvert\eta\rvert < 3, \sum_j E_\perp > 420\,\mathrm{GeV}, m > 600\,\mathrm{GeV}$
C	$E_T > 20\,\mathrm{GeV}, \lvert\eta\rvert < 3, \sum_j E_\perp > 320\,\mathrm{GeV}$

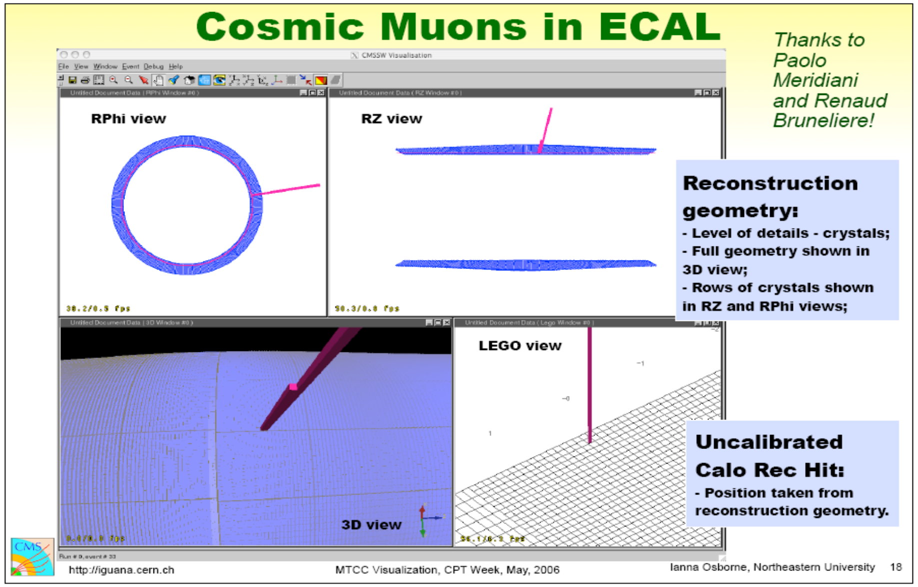
Table 3: Cuts used for multijet event selection

Cosmic events





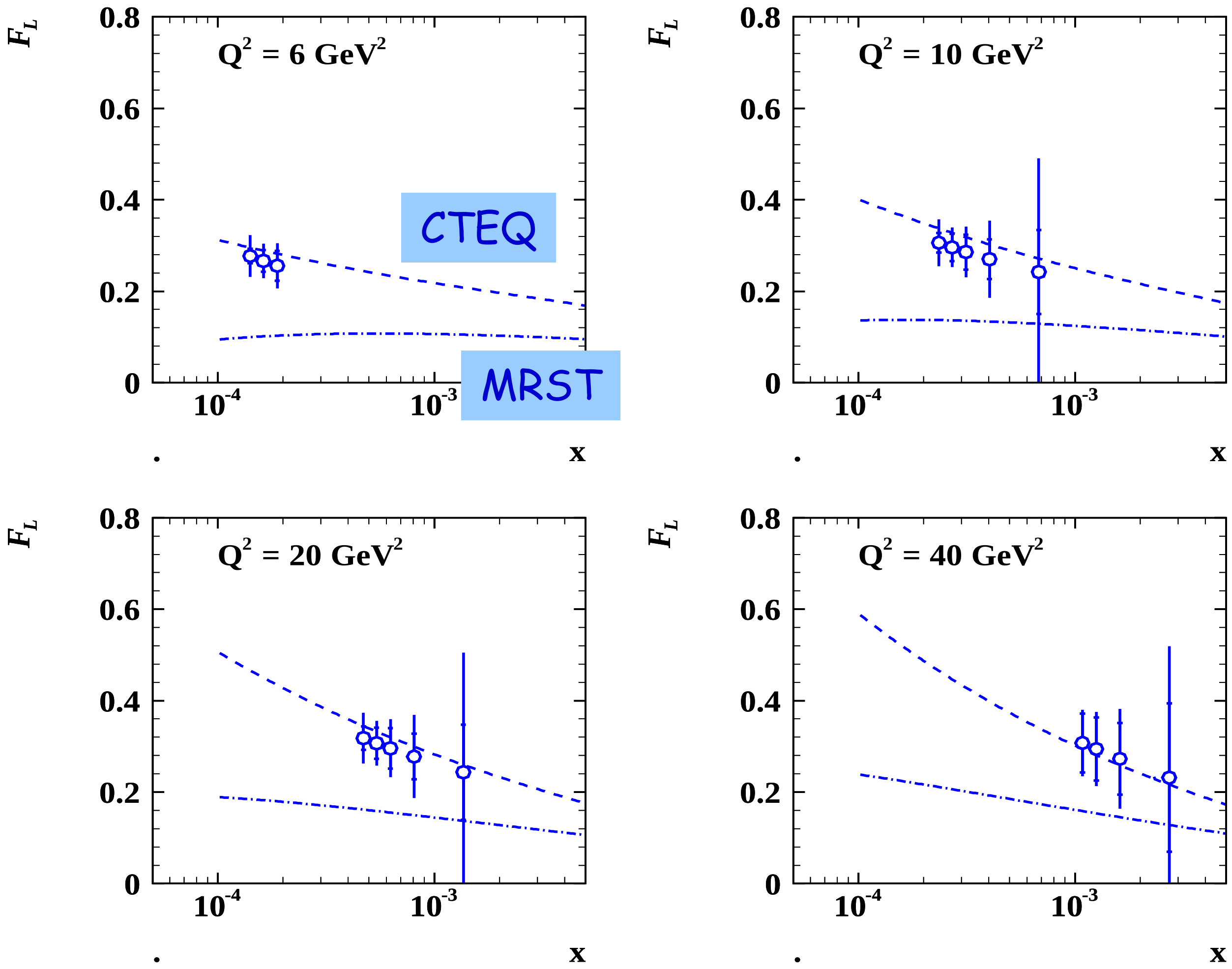




Measuring F_L

Detailed study for H1, with 2 lower proton beam energy settings

Feltesse/Klein et al



F_L can referee between MRST and CTEQ gluons

F_L is gluon driven

F_L measurement at HERA in 2007 !

General strategy toward understanding the underlying theory

(SUSY as an example …)

Discovery phase: inclusive searches … as model-independent as possible

First characterization of model: from general features: Large E_T^{miss} ? Many leptons ? Exotic signatures (heavy stable charged particles, many γ's, etc.) ? Excess of b-jets or τ's ? …

Interpretation phase:

- reconstruct/look for semi-inclusive topologies, eg.:
  - -- $h \to bb$ peaks (can be abundantly produced in sparticle decays)
  - -- di-lepton edges
  - -- Higgs sector: e.g. $A/H \to \mu\mu, \tau\tau \Rightarrow$ indication about tanβ, measure masses
  - -- tt pairs and their spectra $\Rightarrow$ stop or sbottom production, gluino $\to$ stop-top
- determine (combinations of) masses from kinematic measurements (e.g. edges …)
- measure observables sensitive to parameters of theory (e.g. mass hierarchy)

At each step narrow landscape of possible models and get guidance to go on:

- lot of information from LHC data (masses, cross-sections, topologies, etc.)
- consistency with other data (astrophysics, rare decays, etc.)
- joint effort theorists/experimentalists will be crucial

F. Gianotti
LP05

Towards the underlying theory

Next thoughts:

How can we go from the hadron collider data to the underlying theory?

- Can we map the measurements to theory phase space (e.g. SUSY)? Statistical techniques/Patterns? Interesting idea, encouraging result, but needs to go beyond inclusive variables. Endpoints etc. will be there early on and will be used to gain confidence that new particles have been produced.
- What variables/signals can be further looked at to reduce the degeneracy. Eg. to distinguish GDM & GMSB scenarios (both with semi-stable stau's) it appeared that the sparticle mass spectrum can help. Experimentalists will need guidance for this
- SUSY: measurements ⇔ parameters in the Langrangian Can we learn anything about underlying (string?) theory? Needs low scale predictions
- Are all the tools in place to do the exercise? Plethora of tools exist and almost all 'talk' via LHA-accord

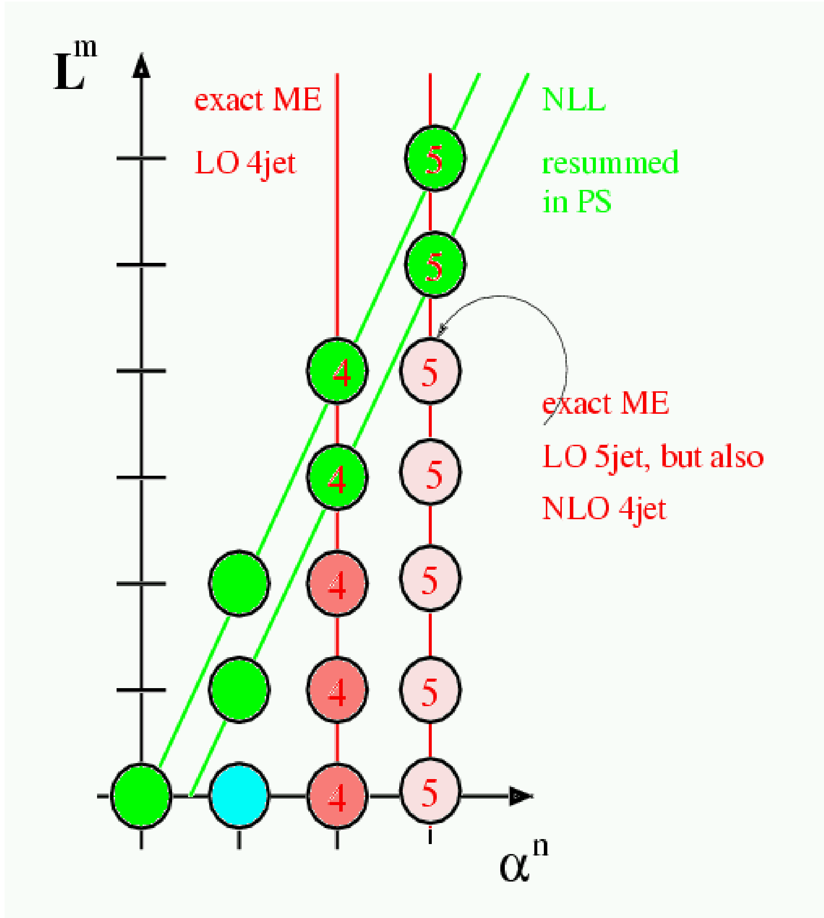
ME+PS Matching

Important topic:
Simulate both structure of jets and many high Pt jets

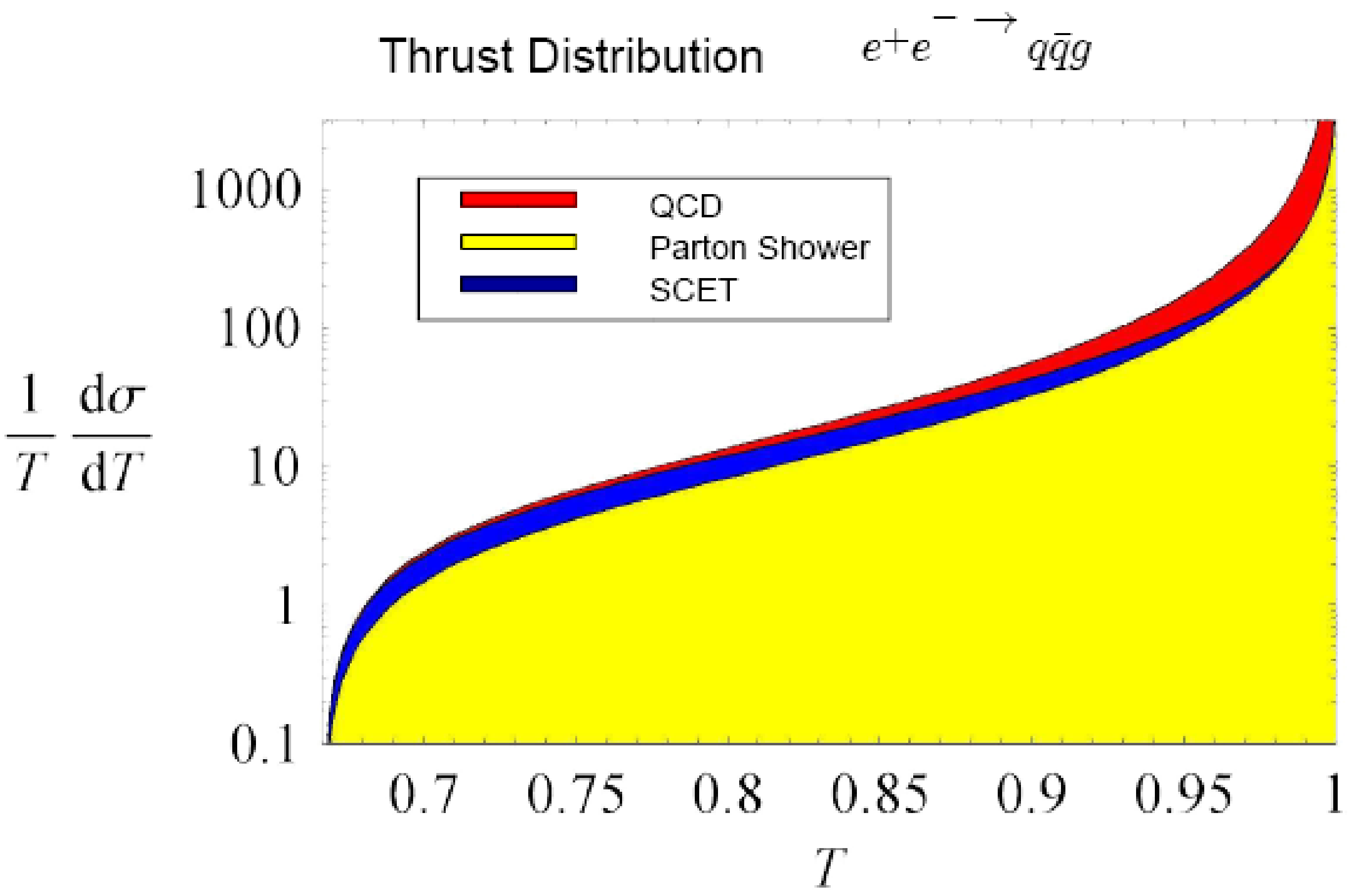
CKKWV (Catani-Krauss-Kuhn-Webber) prescription/now being implemented in HERWIG

The way to go?

Q: if LHC at startup sees a number of 8,9,10 jets events, how well do we the prediction...



SCET



Thrust Distribution
$e^+e^- \to q\bar{q}g$
QCD
Parton Shower
SCET
$\frac{1}{T}\frac{d\sigma}{dT}$
1000
100
10
1
0.1
0.7
0.75
0.8
0.85
0.9
0.95
1
T