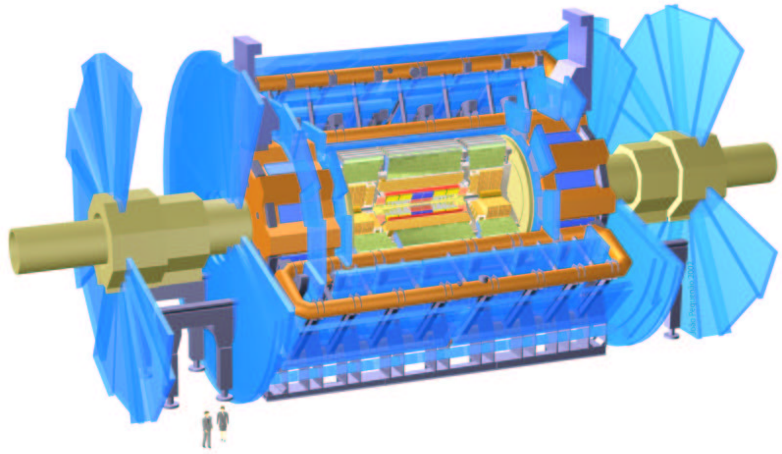
Monte Carlo tools in ATLAS

ATLAS: general purpose experiment
14 TeV pp collisions

main objectives:

-> search for Higgs, SUSY, new Physics
-> precision measurements: m_W, m_t, TGC's,
-> B-physics
-> (heavy ions)
-> etc.

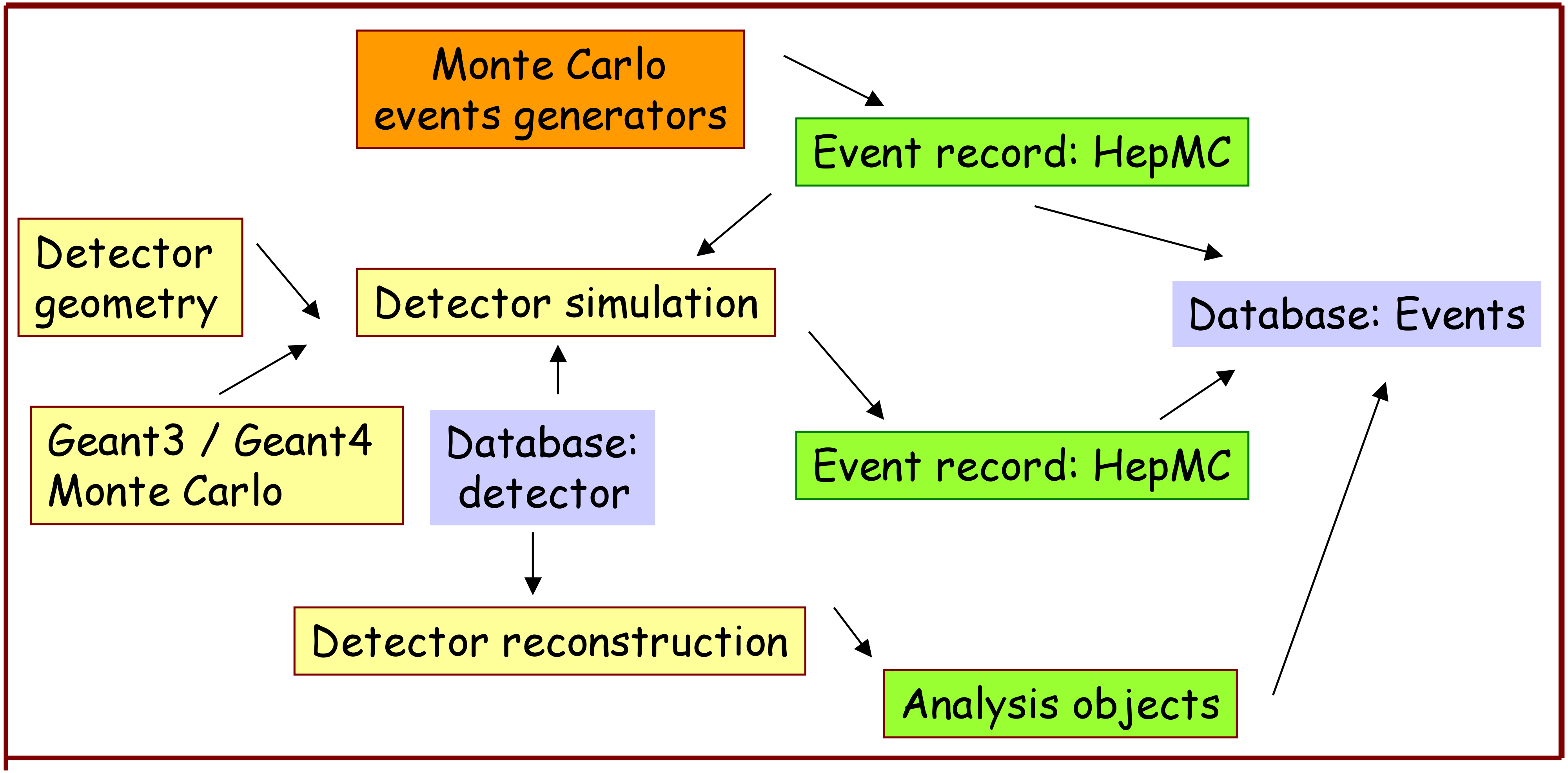


Outline of the talk

- Status of MC tools in the ATLAS-wide framework
- Other packages used frequently
- Strategy for event generation and few examples of open issues.

This talk covers event generation tools, but not tools for detector simulation.

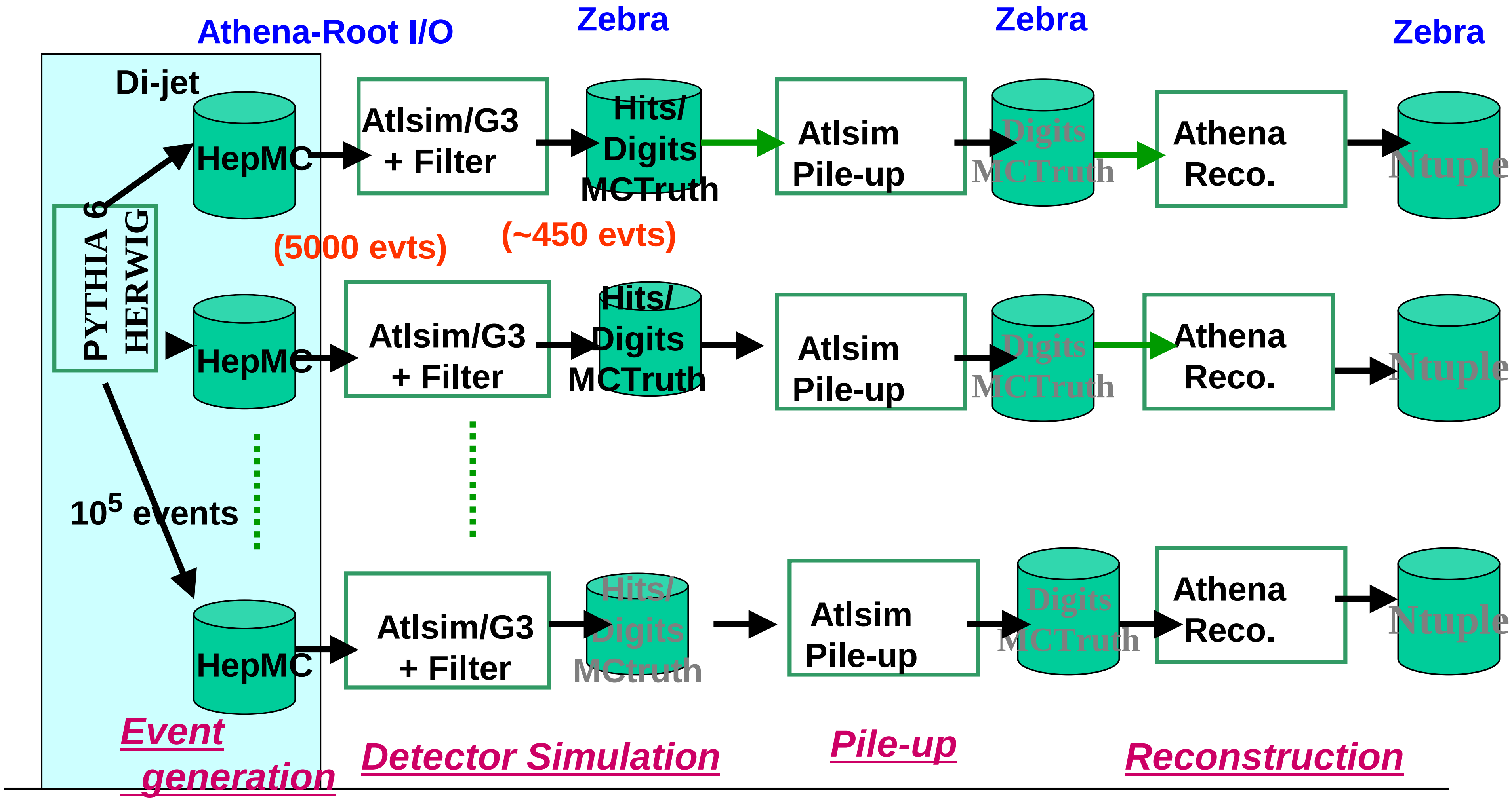
Overal ATLAS simulation framework



Monte Carlo generators are an important component of the general simulation framework, ATHENA (some components are not yet implemented)

Large scale production in ATHENA framework: Data Challenge 1 (2002/2003 year)

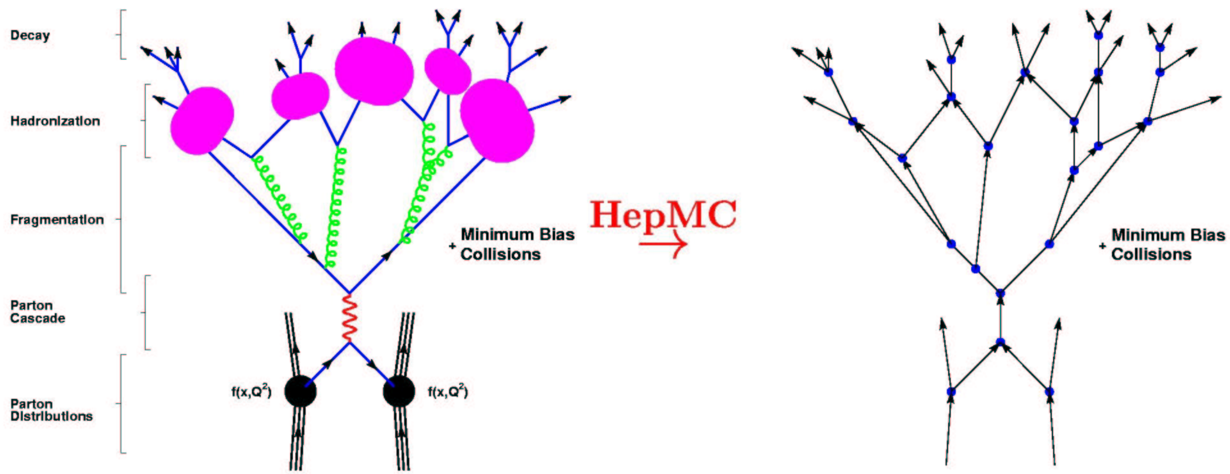
- Event generation: 1.5 x 10^7 events in 150 partitions
- Detector simulation: 3000 jobs



Event record: HepMC

Stores information in graph-like structure, the only possible relations are of „mother-daughter" type.

Requires dedicated „interpreters" for each Monte Carlo generator.
Translates PYJETS->HepMC,
HEPEVT->HepMC, ...



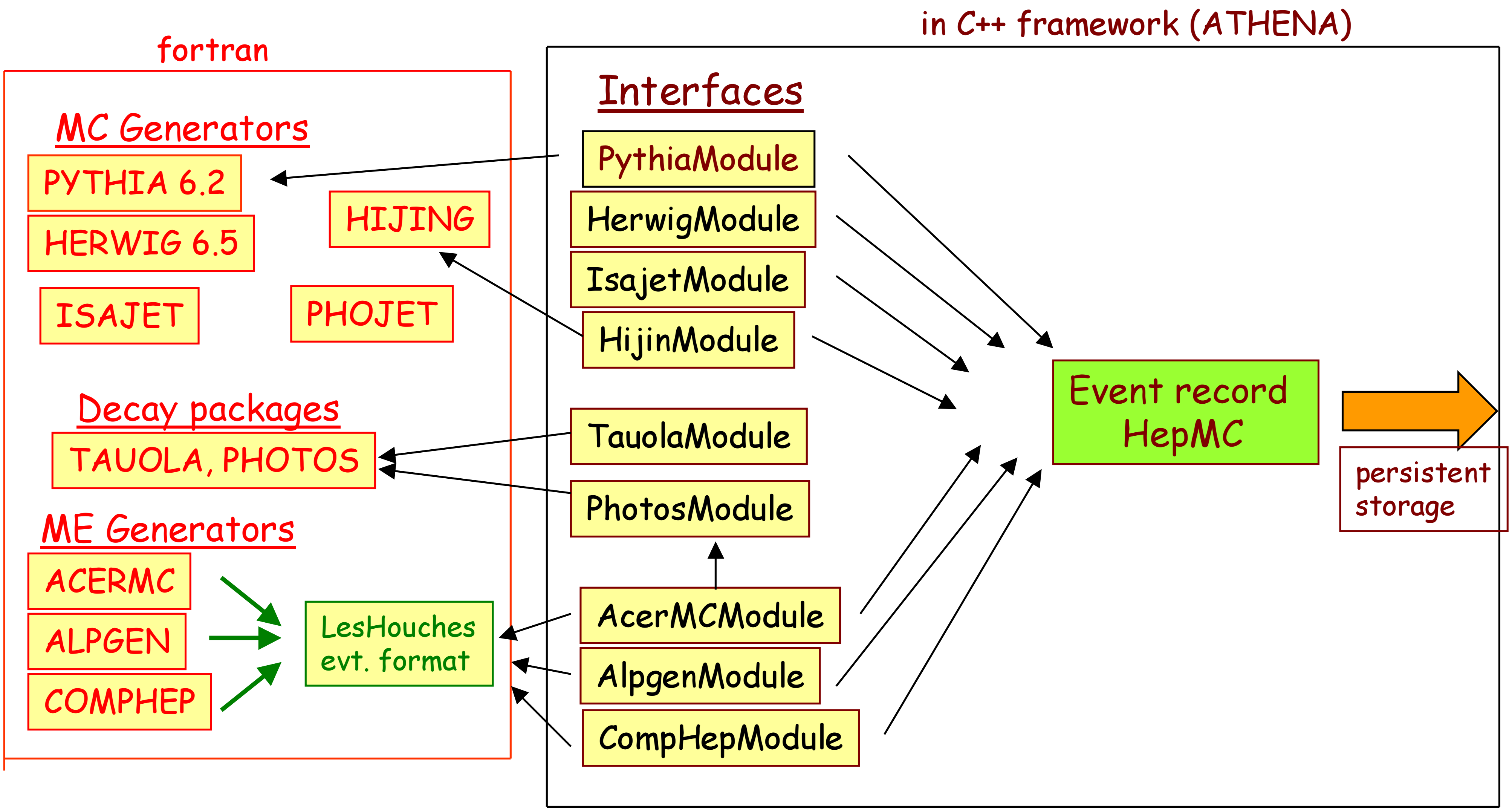
Need further evaluation of whether the structure is adequate for the long term:

=> accommodate all information provided by event generator; preserve information about QM effects: interferences spin-correlations, ISR/FSR evolution, colour flow, etc.

=> accommodate Geant-produced particles, minim.-bias, pile-up events, interaction position may be moved, whole event may be rotated, overlapping vertices may be merged, etc. etc.

Format of the event record has to be one of the „most stable" components of the software framework.

Monte Carlo event generators in ATLAS



We work with coexisting FORTRAN and C++ codes

Toolbox for physics studies in ATLAS

Use the „fortran box" shown previously .... and many more other packages

For event generation (4-momenta):

-> „Complete" Monte Carlo generators: hard process, ISR/FSR, hadronisation decays =>
PYTHIA, HERWIG, ISAJET,....

-> Matrix-element Monte Carlo generators: hard process only
(+ direct interface to PY/HW or LesHouches accord.) =>
AcerMC, ALPGEN, COMPHEP, MADGRAPH II, MadCUP, MadEvent,...

-> MC@NLO: next-to-leading log calculations + parton shower (hard emission ME, soft with PS)
fully exclusive events are generated, rates with NLO precision, smooth matching
between „soft" and „hard" parts.

-> Decay packages: TAUOLA, PHOTOS, EVTGEN

For comparison studies:

-> „Semi-inclusive" Monte Carlo generators: eg. hard process, resummation => ResBOS
4-vectors only for Higgs/W/Z, eg. accomp. hadronic products (jets) not available.

-> „Distribution provider": only certain inclusive distributions available => MCFM,....

For evaluation of xsec or BR:

-> „Integrators": only total xsection or branching ratio available => HIGLU, QQH, VVH,
HDECAY, FEYNHIGGS,....

-> „Published" numbers, plots or formulas for LO, NLO, NNLO calculations.

Physics simulations in ATLAS: complexity of planned analyses and few examples...

- LEP legacy
- „LHC legacy"... what we have learned so far
- Some frequently simulated processes
- Few current problems:
  - -> heavy flavour jet content
  - -> NLO, NNLO calculations:
    why we cannot use them for most of the analyses
  - -> Pythia tuning and B-events
  - -> Minimum bias and underlying event

LEP1 legacy: precision theoretical calculations were late.....

„The luminosity is determined by comparing the measured rate at low angle Bhabha scattering with the cross-section predicted by the Standard Electroweak Model.."

With very first data (January 1990) :

exp. error 1.1%

theor. error ~ 0.7% (no event generator available)

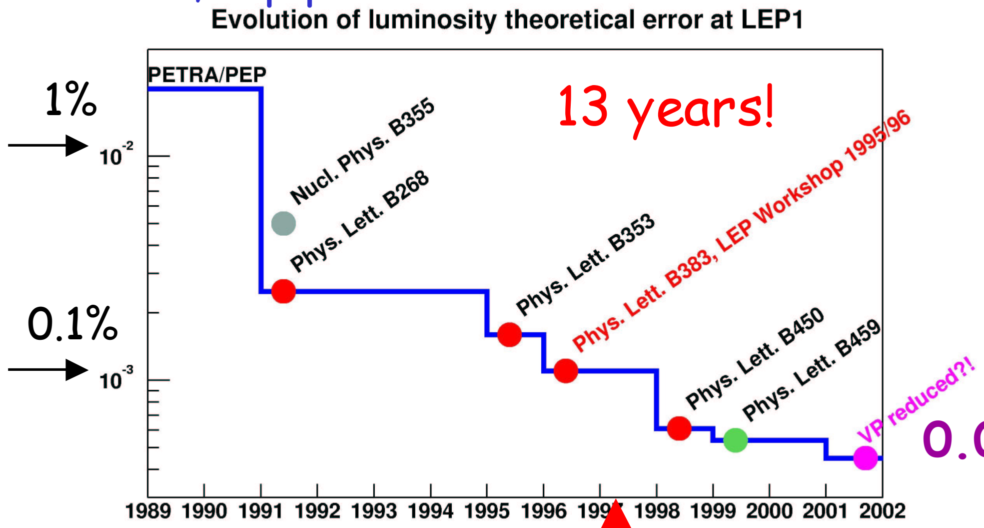
End of 1990: enormous progress, ALEPH going to 0.4%, still no event generator available

Published results (ALEPH, CERN-PPE/91-129, August 1991):

exp. error 0.6%

theor. error 0.3% (only LL $O(\alpha3)$ generator available + complicated procedure with anal. calc.)

S. Jadach, hep-ph/0306083



0.045%

end of LEP1 data taking

It was recognised very soon that detector granularity too good to say that we don't care about photons with $E_\gamma < 1\% \, E_{beam}$.

achieved with $O(\alpha^1$+h.o.LL)exp

soft and collinear resummation was the key element, more important than expanding into finite higher orders!

„LHC legacy": almost 15 years experience already with physics simulation.

LHC detectors have very high granularity and excellent reconstruction and identification efficiencies. Very exclusive analyses are feasible.
Inclusive techniques for theoretical estimates insufficient to fully explore potential of LHC physics.

Detectors will be sensitive to „soft" electrons/jets/photons:
jets reconstructed down to $p_T \sim 15$ GeV (~ 0.2% E_{beam})
photons reconstructed down to $p_T \sim 5$ GeV (~ 0.1% E_{beam})
electrons reconstructed down to $p_T \sim 1$ GeV (~ 0.1% E_{beam})

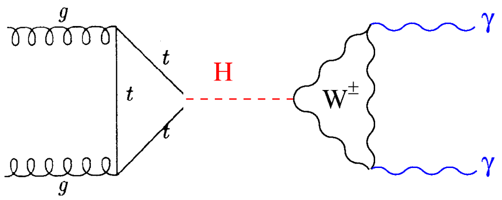
Exclusive selections:

-> lepton multiplicity and angular correlations (spin correlations), inv. mass
-> total energy balance (off-shell decays)
-> jet multiplicity and angular separation
-> jet presence or absence in defined regions of phase-space (forward, central)
-> identification of heavy flavour jets, tau-leptons is an important tool

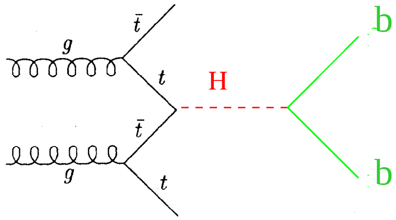
Rich spectrum of analyses planned.
Analyses will be very exclusive!

Three examples

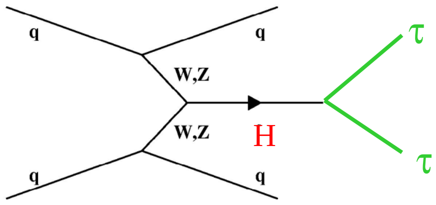
$H \to \gamma\gamma$



$t\bar{t}H \to t\bar{t}\, b\bar{b} \to b\ell\nu\ bjj\ b\bar{b}$



$qqH \to qq\tau\tau$



Inclusive analysis:

irreducible bgd: $\gamma\gamma$ production
reducible bgd: γj, jj production
(PYTHIA, DIPHOX)

Exclusive analysis:

irreducible bgd: ttbb
reducible bgd: ttjj,ttcb
(PYTHIA, AcerMC)
require fully reconstructed final state
-> sensitive to :
jet topology /multiplicity
heavy flavour content (b,c)

VERY exclusive analysis:

irreducible bgd: EW Zjj, EW WWjj
reducible bgd: tt, QCD Zjj , QCD WWjj
(MadCUP, PYTHIA)
require tight selection:
-> tag jets with large η separation
-> leptons between tag jets
-> central jet-veto
-> kinematical constraints for $\tau \to l\nu$
using assumption of collinear approx.
-> reconstruction of $m_{\tau\tau}$
-> sensitive to EVERYTHING

LHC will be a factory of QCD jets, W, Z, ttbar, bbar events....

In many physics areas we will work with high event rates (negligible statistical error) or high background rejection. In both cases good understanding on precision of Monte Carlo prediction needed.

Example: needed rejection against top-pair bgd.
(each represents a very different accep. topol.)

Signal	tt bgd rejection (topology+kinematics)
H->WW*->lνlν	$3\ 10^4$
ttH, H->inv	$3\ 10^4$
qqH, H->WW*->lνlν	10^4

Signal	Bgd. rejection (detector)
<u>for H->γγ</u>	
jj, γj	$2\ 10^7$, $8\ 10^3$ (identification)
<u>for H->ZZ->4l</u>	
tt bgd	$1.2\ 10^3$ (isolation, impact parameter)

Can theory predict top-pair topology to 10^{-4} or jj to 10^{-7} ?
NO (?).....

Data will need to be used to estimate background at this level of accuracy.
- -> For H->γγ this works well (measure Σ all bgds.)
- -> For H->WW* works less well.
- -> For WH, H->bb doesn't work.

LHC will be a factory of QCD jets, W, Z, ttbar, bbar events....

In many physics area ... ogy
statistical error) or
understanding on pre

Example: needed rejection o
(each represents a very dif

Signal	Bgd r (topo
H->WW*->lνlν ttH, H->inv qqH, H->WW*->lνlν	

Signal	Bgd
for H->γγ	
jj, γj	2 10
for H->ZZ->4l	
tt bgd	1

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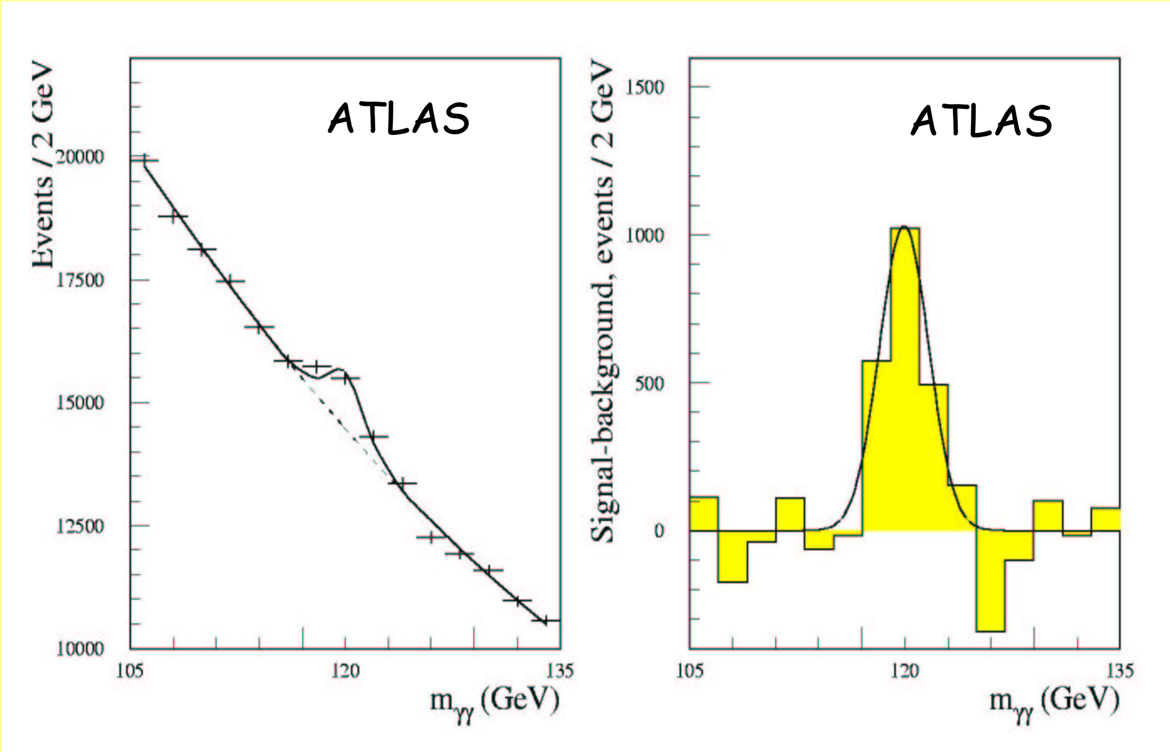
H->γγ with $100fb^{-1}$



$m_{\gamma\gamma}$ (GeV)

LHC will be a factory of QCD jets, W, Z, ttbar, bbar events....

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LHC ents....

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Example: neede
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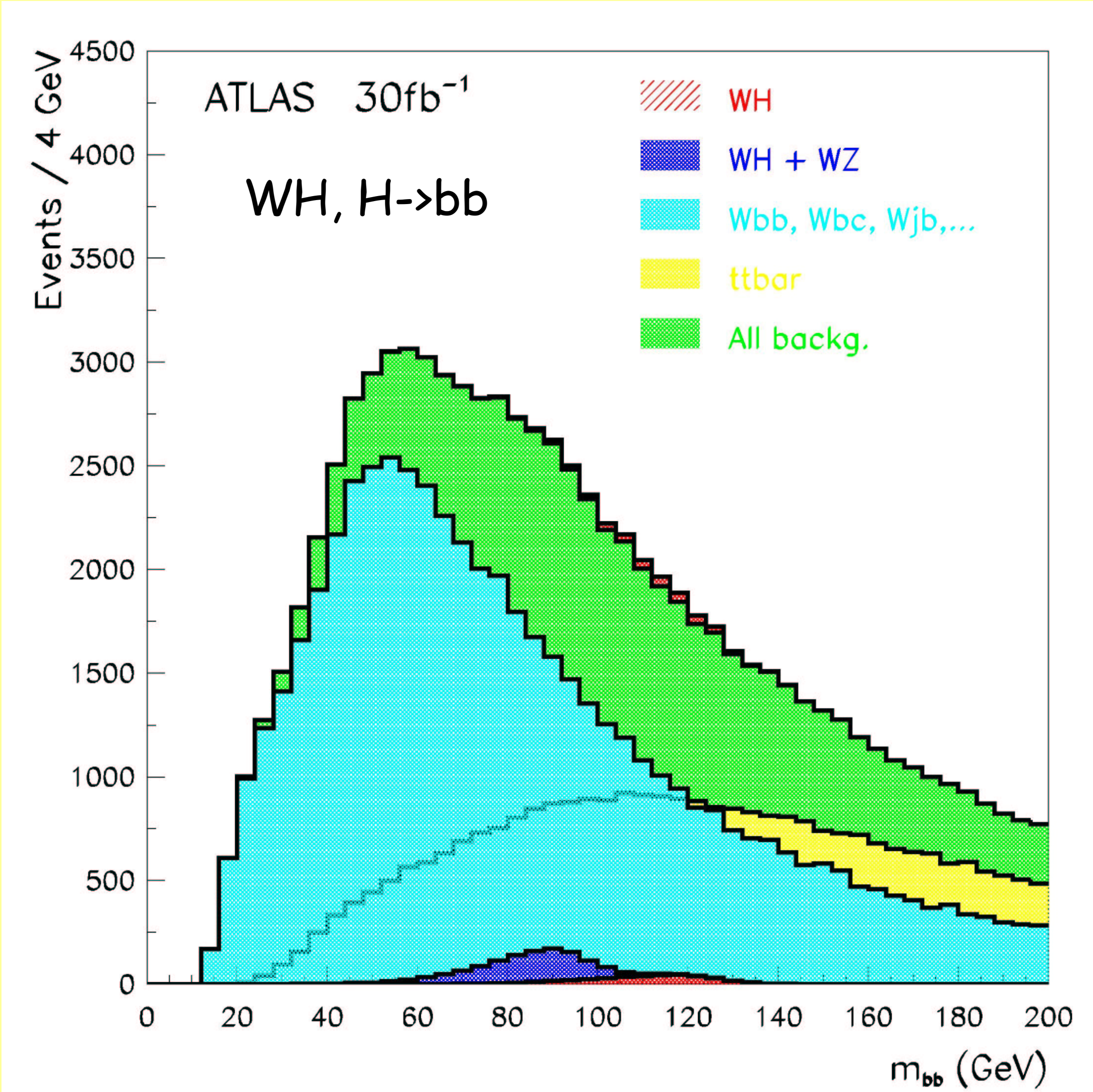
Signal

H->WW*->lνlν
ttH, H->inv
qqH, H->WW*-

Signal

for H->γγ
jj, γj

for H->ZZ->4l
tt bgd



m_{bb} (GeV)

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sn't work.

Some frequently simulated processes

Process	Measurement	Comments
qq->W and qq->Z/γ^* (10^8 W->eν, 10^7 Z->ee for $10fb^{-1}$)	-> m_W (15 MeV)	needed th error < 10 MeV (p_T^W, radiative corrections,PDF's)
	-> σ_{ll} for Z/γ^*->ll (< 5% for m_{ll} = 1500 GeV)	needed theory error ~ 1%(?)
	-> luminosity measuring tool (< 5%)	needed theoretical error on xsection ~ % (PDF's)
	-> measur. of $\sin^2(\theta_{eff}^{lep})$ (error ~ 10^{-4})	main systematic error from PDF's , can the uncertainties match exp. precision?
QCD Wbb, QCD Zbb	Bgd. to Higgs, techni-rho	mandatory to estimate also Wbc, Wcj, Wbj, Wcc, Wjj
QCD W+2j, QCD Z+2j EW W+2j, EW Z+2j	Bgd. to VBF H production	Rejection 10^3 with very exclusive selection
QCD W+4j, EW W+4j	Technicolour, strong sym. breaking,non-resonant WW	

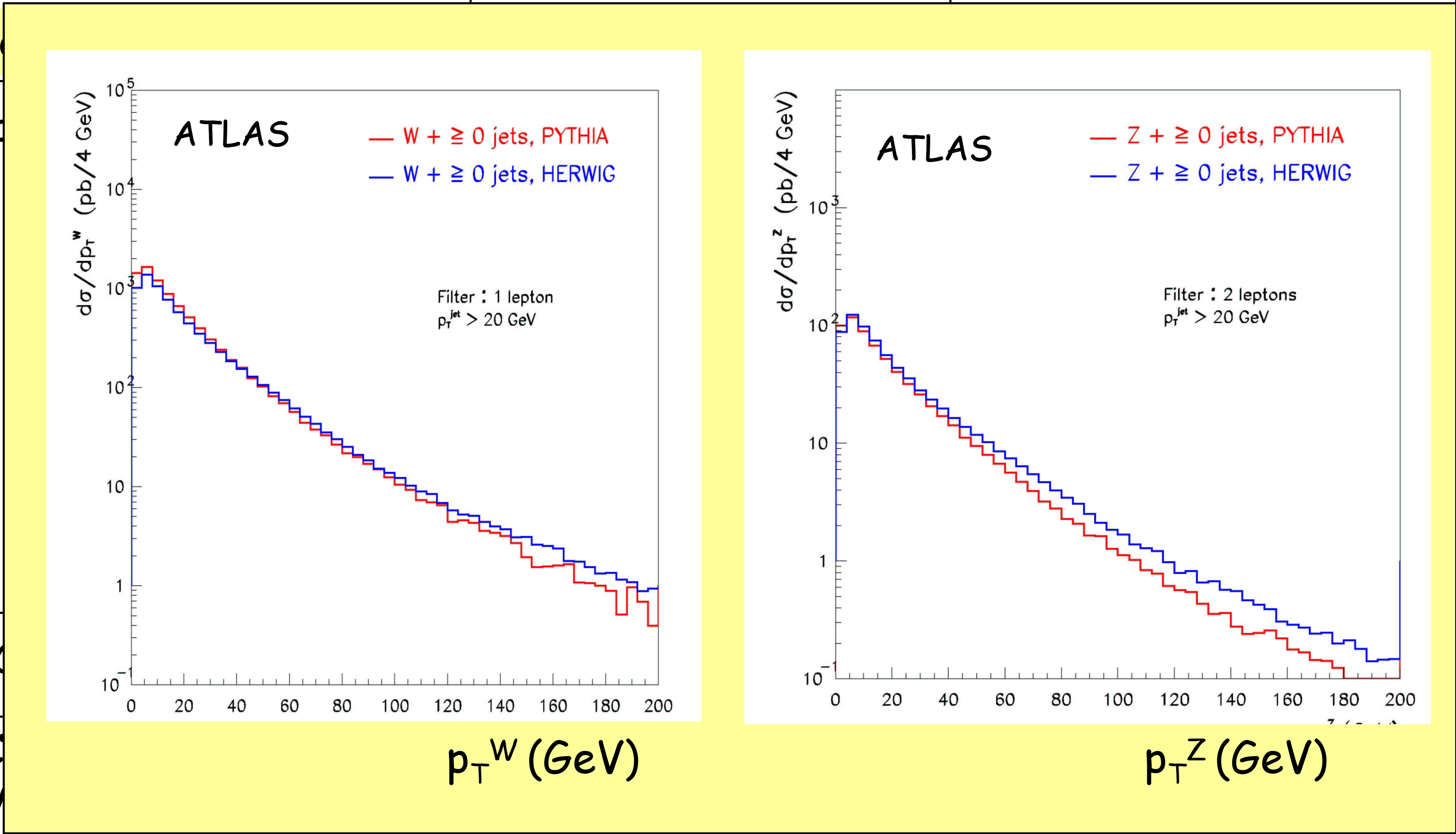
Some frequently simulated processes

Pr

qq

(10^8

F's)



QC

QC
EW

QCD W+4j, EW W+4j	Technicolour, strong sym. breaking,non-resonant WW	

Some frequently simulated processes

Process	Measurement	Comments
qq->W and qq->Z/γ* (10[8] W->eν, 10[7] Z->ee for 10fb[-1])	-> m_W (15 MeV)	needed th error < 10 MeV (p_T^W, radiative corrections,PDF's)
	-> σ_{ll} for Z/γ*->ll (< 5% for m_{ll} = 1500 GeV)	needed theory error ~ 1%(?)
	-> luminosity monitoring/ measuring tool (< 5%)	needed theoretical error on xsection < 1% (PDF's)
	-> measur. of $\sin^2(\theta_{eff}^{lep})$ (error ~ 10^{-4})	main systematic error from p_T^Z PDF's , can the uncertainties match exp. precision?
QCD Wbb, QCD Zbb	Bgd. to Higgs, techni-rho	mandatory to estimate also Wbc, Wcj, Wbj, Wcc, Wjj
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Some frequently simulated processes

Process	Measurement	Comments
top-pair production	top-mass measurement (error 1 GeV)	p_T^{top} predictions from theory, FSR, underlying event.
	bgd. to H->WW*	modelling of off-shell production, spin correlations
tt+1j, tt+2j	bgd. to VBF H production;	
QCD ttbb, EW ttbb	bgd to ttH, H->bb;	
ttW, ttWW	bgd to ttH, H->WW*;	
$W\gamma$, $Z\gamma$, WZ	bgd to TGC's	at least NLO control on the differential spectra
$W\gamma\gamma$, $Z\gamma\gamma$, $tt\gamma\gamma$	bgd to WH, ZH, ttH,H->$\gamma\gamma$	

Some frequently simulated processes

Process		
top-pair proc		
tt+1j, tt+2j		
QCD ttbb, EV		
ttW, ttWW		
Wγ, Zγ, WZ		
Wγγ, Zγγ, ttγγ	bgd to WH, ZH, ttH,H->γγ	

qqH → qqWW* → qq l ν l ν

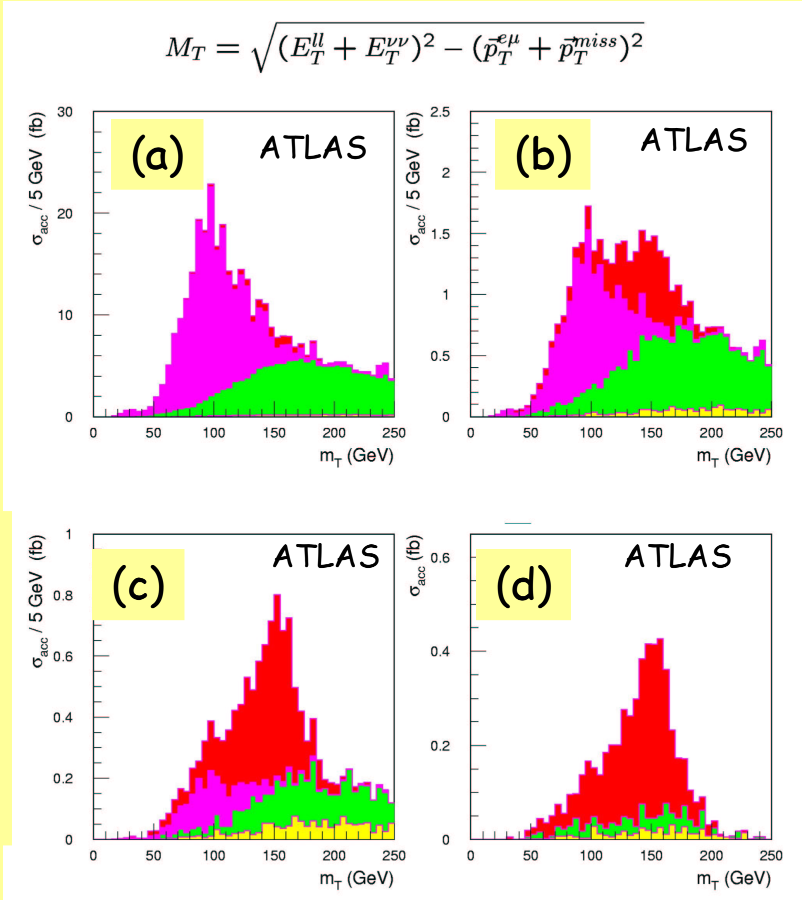
signal: **Higgs (m_H = 160 GeV)**

backgrounds: **tt background**

γ* / Z + jets

el.weak WW jj

(a) Lepton P_T cuts and
tag jet requirements ($\Delta\eta$, P_T)
(b) Require large mass of tag jet system
(c) Jet veto
(d) Lepton angular and mass cuts



Some frequently simulated processes

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top-pair production	top-mass measurement (error 1 GeV)	p_T^{top} predictions from theory, FSR, underlying event.
	bgd. to H->WW*	modelling of off-shell production, spin correlations
tt+1j, tt+2j	bgd. to VBF H production;	
QCD ttbb, EW ttbb	bgd to ttH, H->bb;	
ttW, ttWW	bgd to ttH, H->WW*;	
Wγ, Zγ, WZ	bgd to TGC's	at least NLO control on the differential spectra
Wγγ, Zγγ, ttγγ	bgd to WH, ZH, ttH,H->γγ	

Some frequently simulated processes

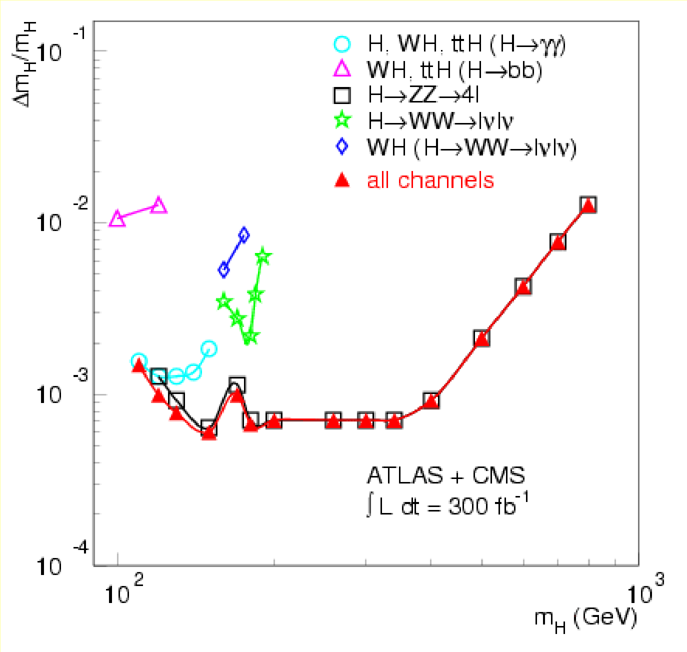
Process	Measurement	Comments
Higgs production gg->H, qqH ttH, WH, bbH,	evidence, mass measur. (~ 0.1%), coupling measur. (~ 20%), width measur. (~ 20%),	exclusive topologies very important NLO calculations not very helpful NLO MC generator would be most welcome

Such a list could continue over many pages ......

Some frequently simulated processes

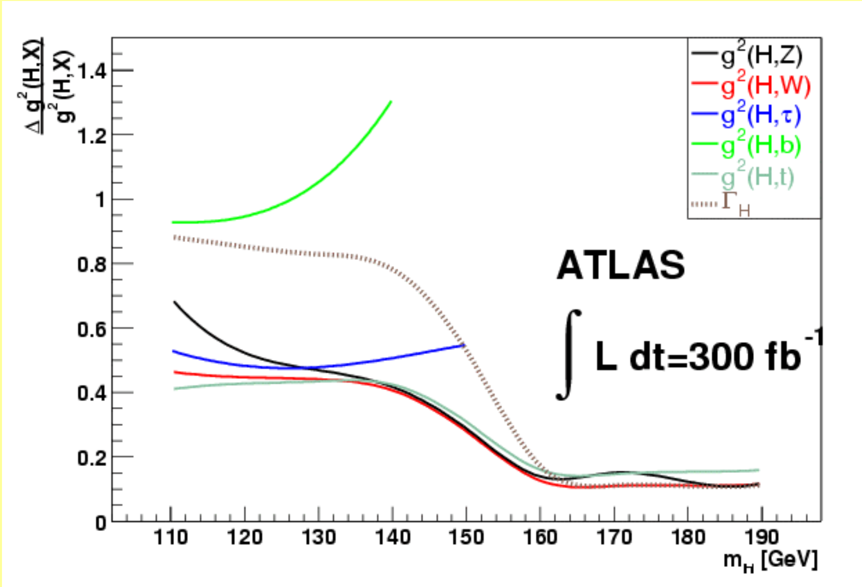
Process | Measurement | Comments

Measurement of the SM Higgs mass at the LHC (ATLAS study)



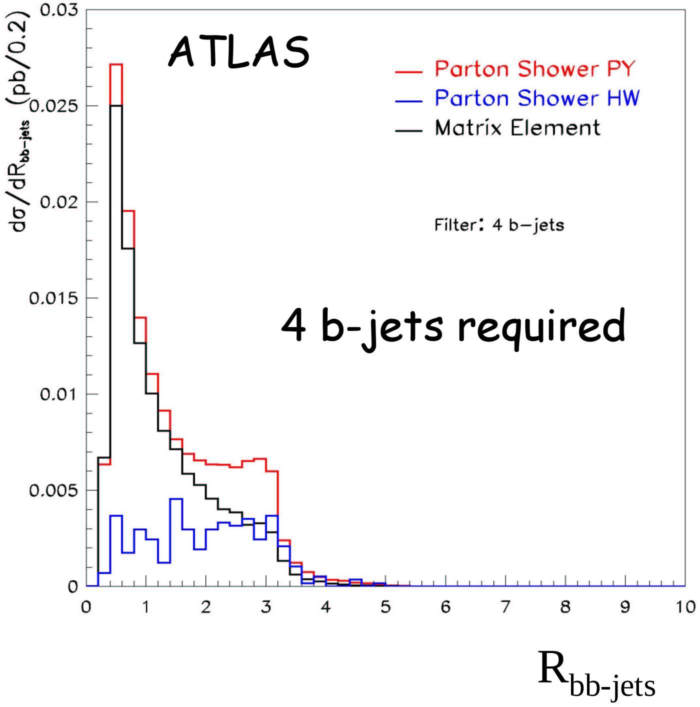
Expected experimental systematic errors included.
No theoretical uncertainty

Measurements of the Higgs couplings and Higgs width in ATLAS



Systematic uncertainties included

Heavy flavour production in QCD cascade....



<u>Example: irreducible ttbb backgd. to ttH</u>
comparison of the differential distributions for b-jets not originating from top-quark decays.

black: ME calculations (AcerMC)
red: PYTHIA
blue: HERWIG

⇒ understand what is missing in HERWIG
⇒ improve consistency between different approaches

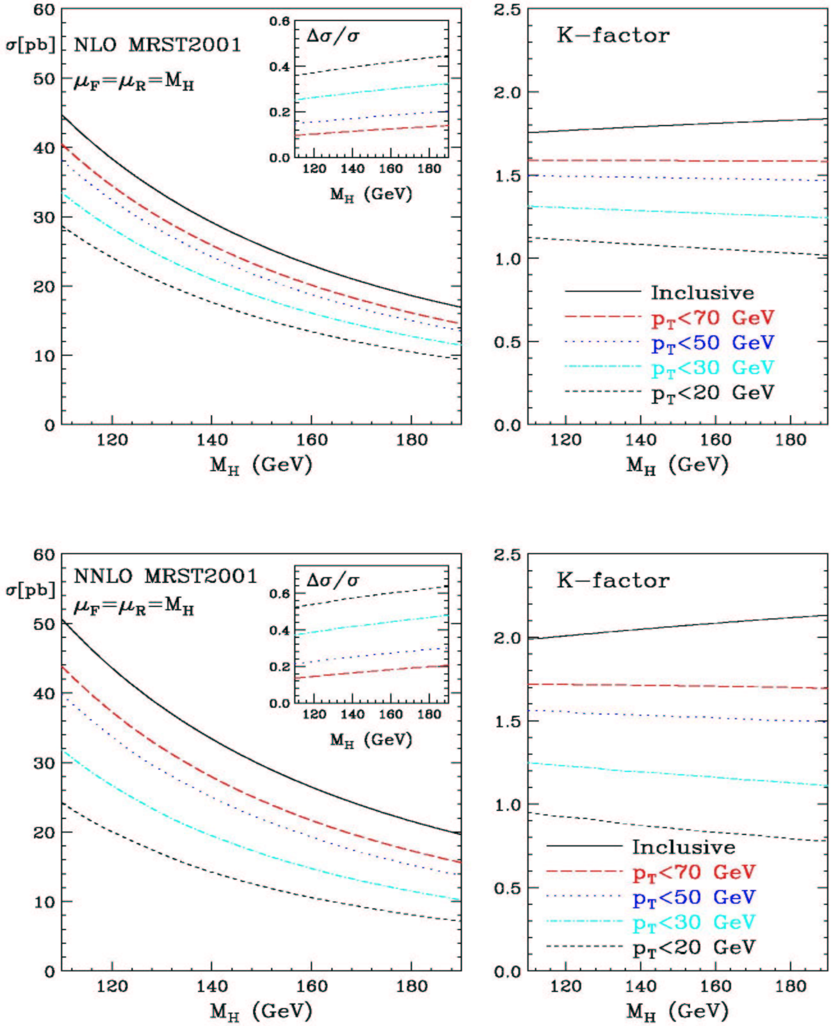
Important to validate baseline MC generators (Pythia++, Herwig++, ??) versus
- LEP data (known)
- Tevatron data (2fb-1 will add a lot)

➔need to agree on this process: how?, who?
(automatic tool like JetWeb could provide a technical solution)

NLO, NNLO calculations for gg->H

S. Catani et al., hep-ph/0206052

K-factor with jet-veto



gg-> H->γγ almost inclusive selection

gg->H->WW*->lνlν tight jet-veto to reject tt background.

Inclusive xsection

⇒K-factor ~ 1.7 for NLO
~ 2.1 for NNLO

Applying jet-veto implies „loss" in the xsection. The dominant part of QCD corrections is due to soft collinear radiation.

With veto p_T^{jet} >20 GeV

⇒K-factor ~ 1.1 for NLO
~ 0.9 for NNLO

Full-fledged NNLO Monte Carlo will probably be needed (most difficult part will be background not signal).

NLO, NNLO calculations for bbH

Example: bbH, bbA Yukawa production in MSSM.

NNLO calculations (Harlander, Kilgore,hep-ph/0304035):
- up to two-loops: bb->H
- up to one-loop: bb->Hg, gb->Hq
- at tree level: bb->Hgg, bb->Hqq, bb->Hbb, gb-Hgb, bb->Hbb, bq->Hbq, gg->Hbb,qq->Hbb

[fb] for tanβ=1

m_H	120 GeV	300 GeV	800 GeV
σ_{LO}	480	22	3.4
σ_{NLO}	690	30	4.1
σ_{NNLO}	720	30	4.4
$\sigma_{NNLO} / \sigma_{LO}$	1.5	1.35	1.30

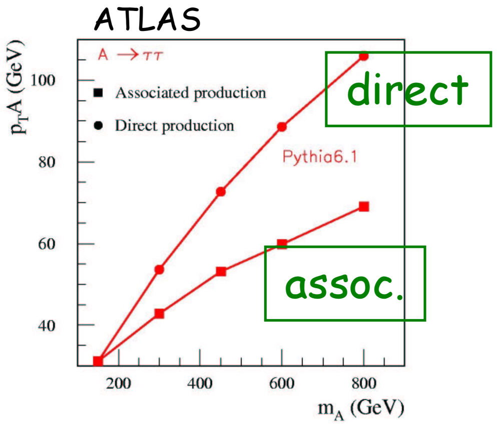
Available for event generation:
- bb->H lowest order + improved PS
- bb->Hg, gb->Hq + simple PS
- gg->bbH, qq->bbH + simple PS

What are the sources/sizes of theoretical uncertainties on those predictions:
μ_R, μ_F, PDF's, $m_b(Q^2)$, resummation,.... ??

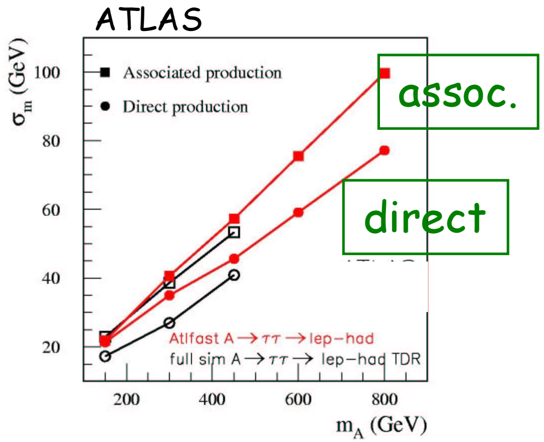
ongoing discussion on VFS versus FFS approaches

Is it a problem that „only" calculations are available?
=> Yes, because analysis is very exclusive

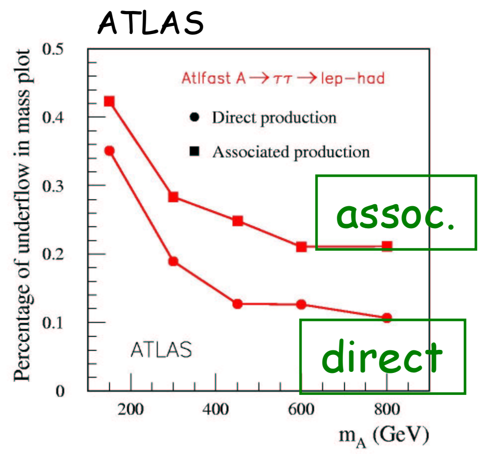
Higgs transverse momenta



H->ττ mass resolution



Fraction of events for which H->ττ cannot be reconstructed



direct: gg->H
associated: gg,qq -> bbH

reconstruction effic. & accept. differ by factor 2!

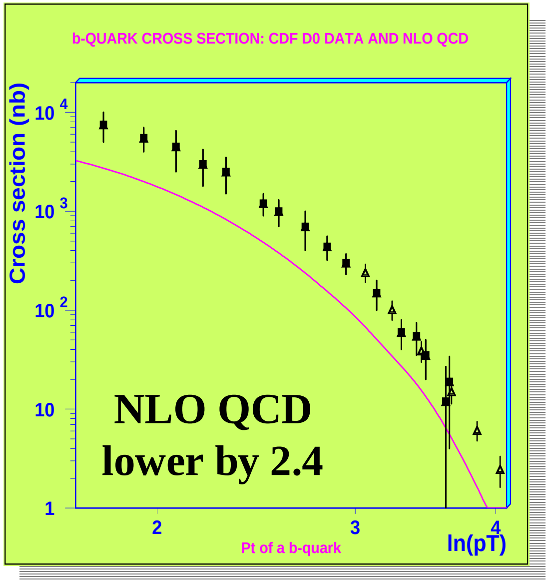
a) reco efficiency + resolution for A/H->ττ reconstruction depends (factor 100%) on event topology (p_T^H plays main role)
b) single b-jet or b-jet veto required (p_T^{jet} ~ 20 GeV , a rather soft cut for LHC), combine statisticaly evidence for both sample.
c) dominant bgds: tt, incl. Z, incl. W

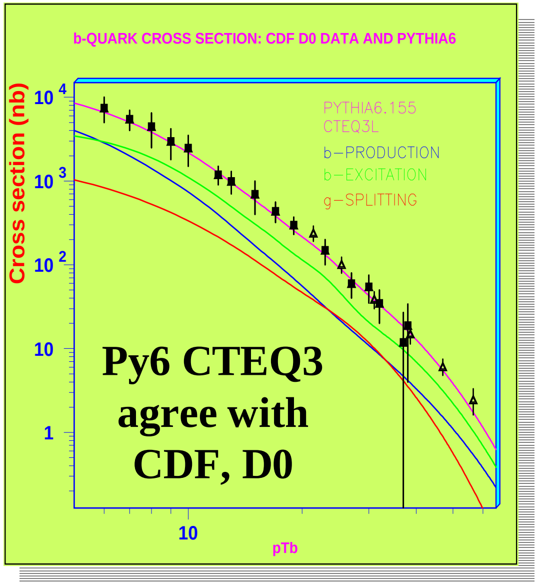
Full-fledged Monte Carlo generator mandatory!

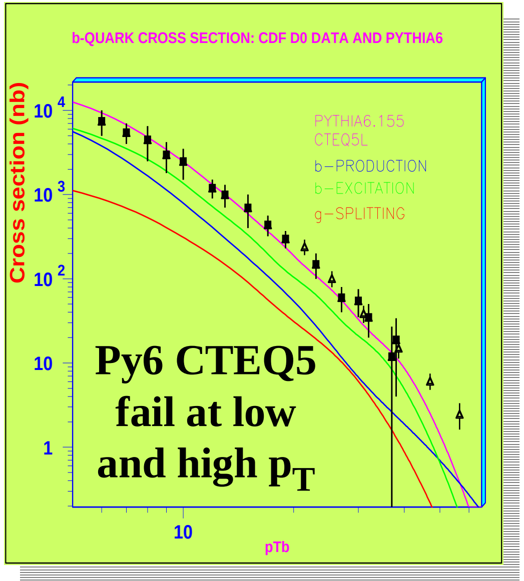
Pythia tuning and B events

Even if full NLO QCD calculation available – need whole event, need hadronization and decays.

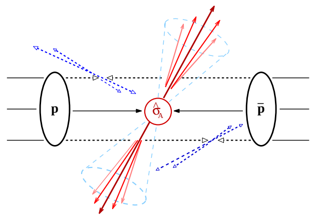
Use Pythia tuned to CDFD0 b-production and underlying event. Many parameters involved – some of them correlated, ambiguities…







Currently tuned 'set of Py6 parameters' works better with CTEQ3 than with CTEQ5 for b-production CDF+D0. We can move to CTEQ5 only if the whole set re-tuned. Non-trivial: need Py6 team involvement.



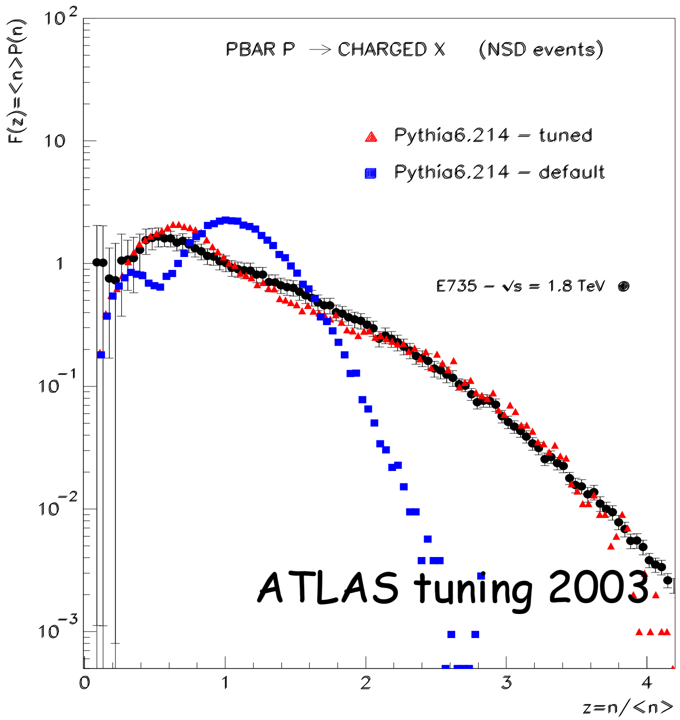
Minimum bias event and underlying event

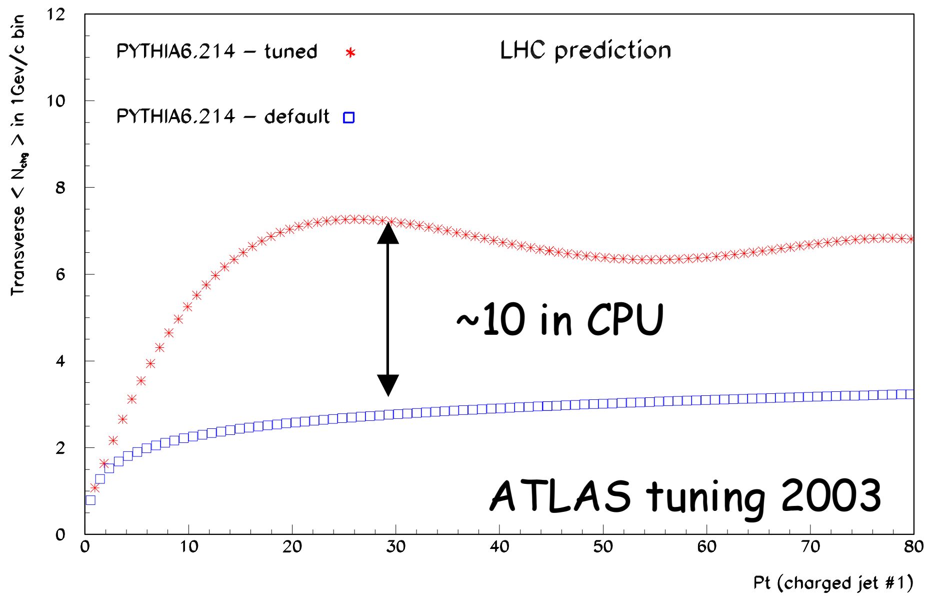
Multiple parton interactions give a natural way of explaining
the event activity for both minimum bias and the underlying event.

Fluctuations in charged particle multiplicities

default – „simple" scenario
tuned - „complex" scenario

Strong impact on:
- E_T^{miss} resolution,
- soft-jet multiplicities,
- radiation levels;
- detector occupancy,
- etc.





Conclusions

EVENT GENERATORS are mandatory to fully explore the potential of the detector and machine, and the complexity of the planned analyses.

LEP experience has shown that one can easily underestimate the time needed to match the precision of the theoretical predictions with the analysis potential of the experiments.

There has been enormous progress over the last twenty years in the availability of NLO, NNLO calculations („integrated over full phase-space") and matrix-element tree-level event generators.

It is however rather clear that, given the experimental goals the fixed order and/or „cut-off" dependent generators will often not be sufficient. (It was already the case for LEP analyses).

As a result of this workshop, we would like to HAVE A CLEAR WORKPLAN for getting in time adequate Monte Carlo tools (missing background processes, NLO generators) with better precision (factor 10?)with respect to what we have now.

Many thanks to: D. Froidevaux, G. Azuelos, B. Craig, M. Dobbs, F. Gianotti, I. Hinchliffe,B. Kersevan,A. Mor
R. Harlander, S. Jadach, Z. Was