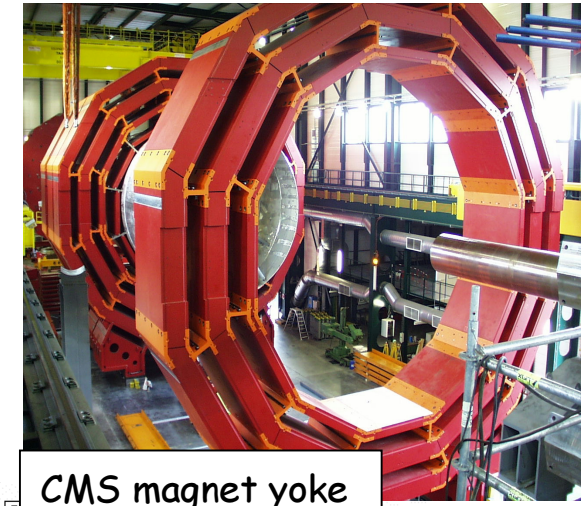
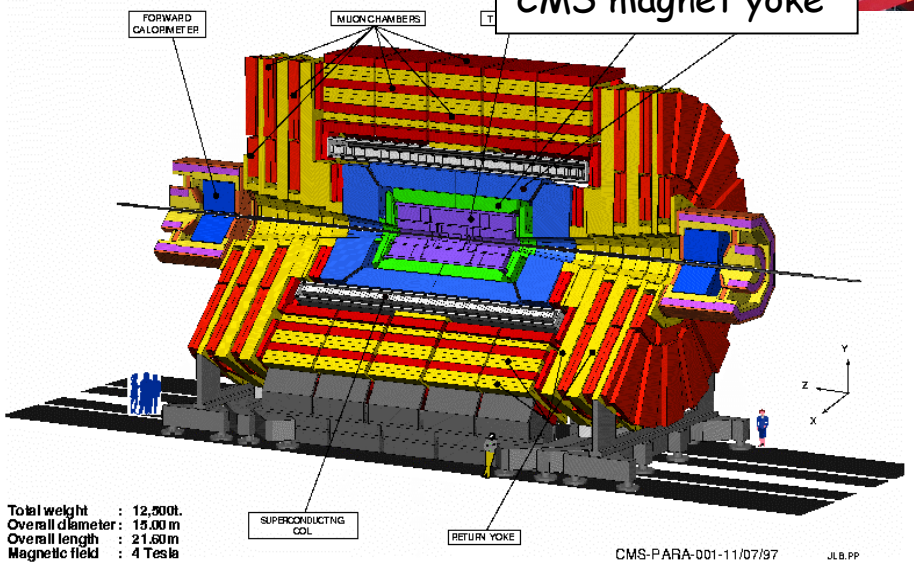
Monte Carlo Tools in CMS

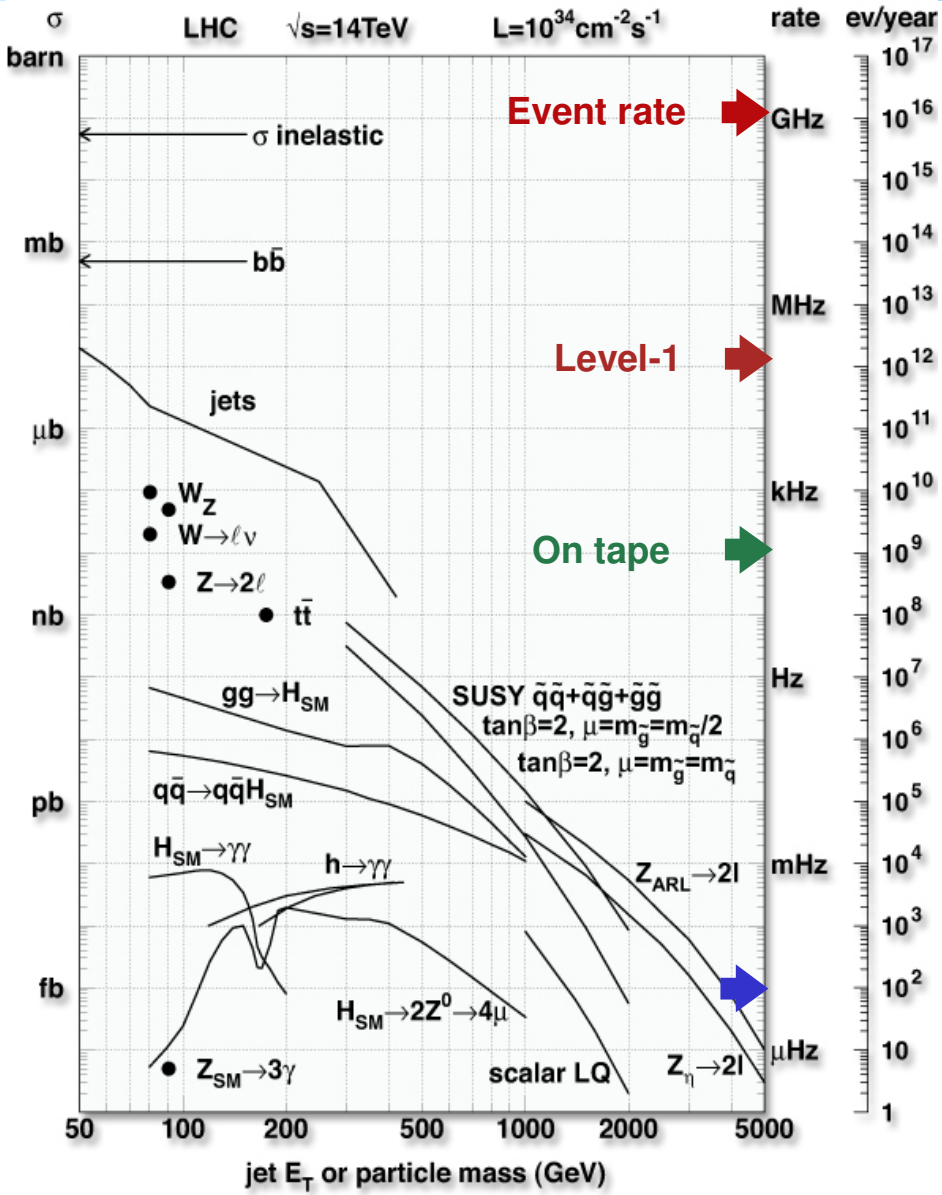
Albert De Roeck
CERN
MC4LHC Workshop



CMS magnet yoke

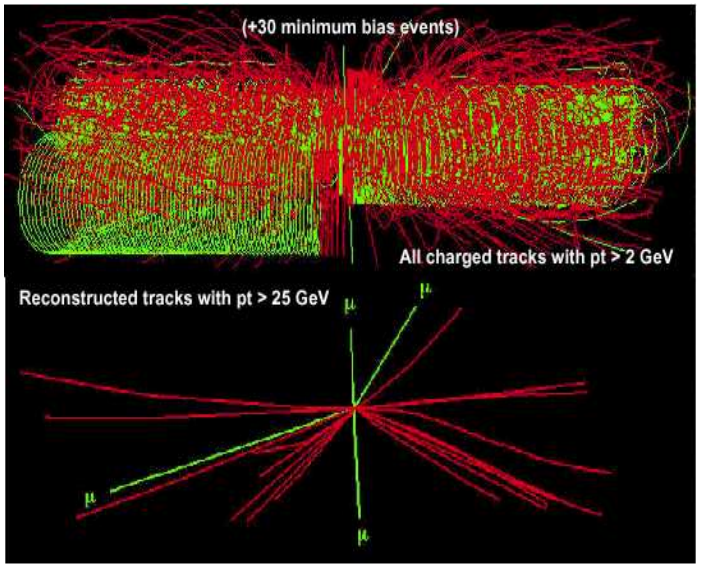


Physics @ CMS (pp collisions at 14 TeV)

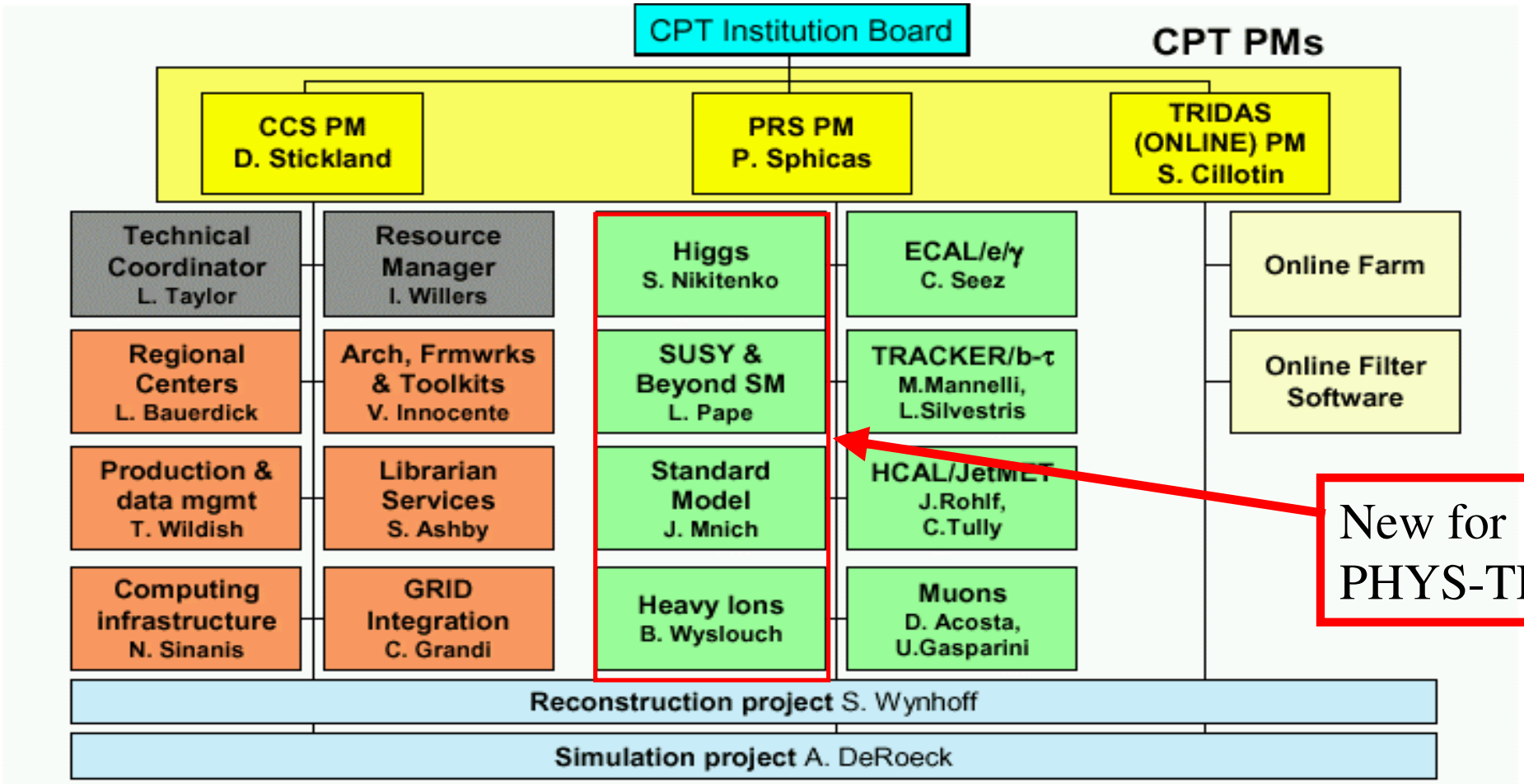


- Higgs physics
- SUSY or other new physics
- Precision measurements
- B-physics
- QCD & diffraction
- Heavy ion physics
- …

E.g pp→H→ZZ→μμμμ

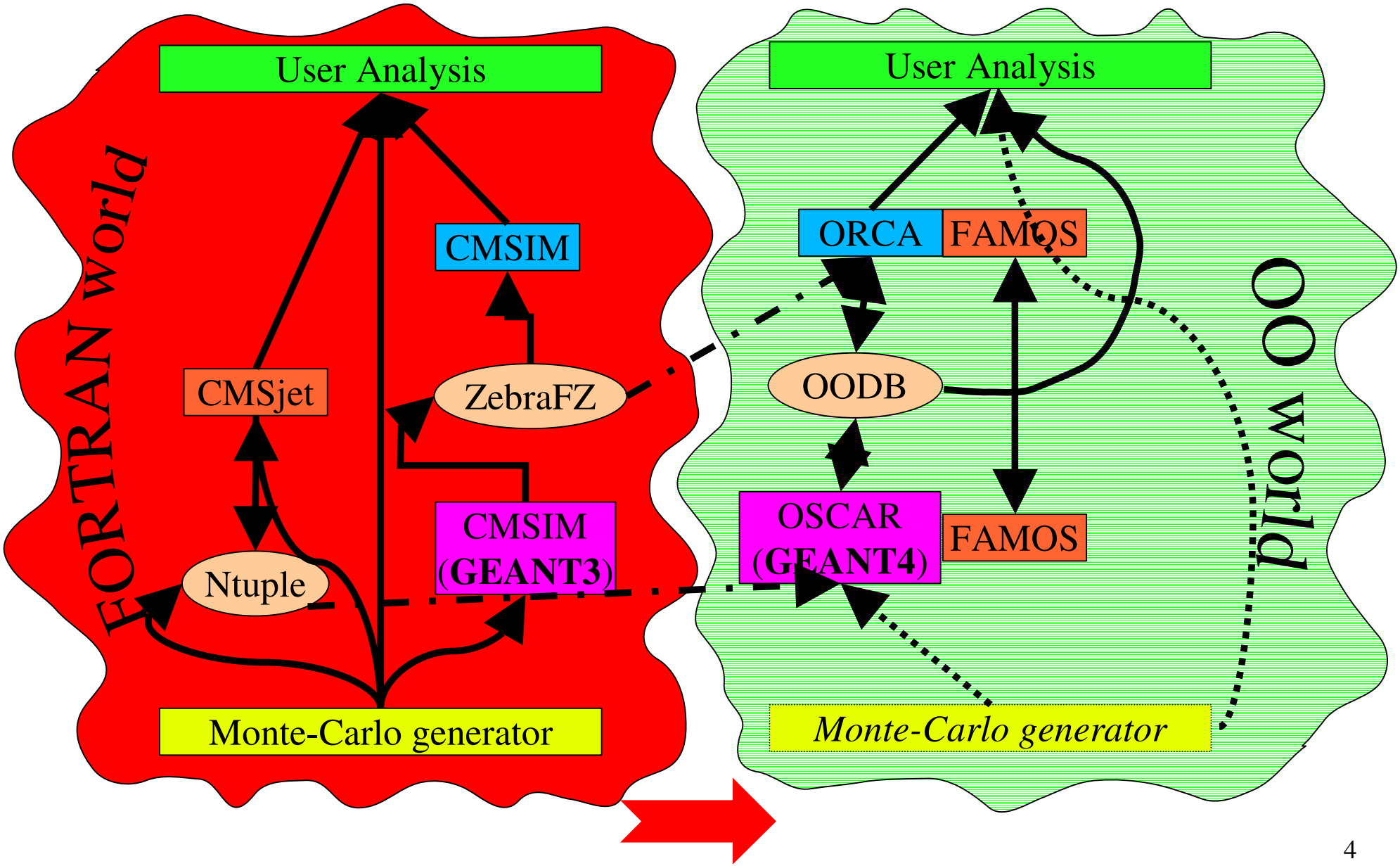


Organization



CMS Physics TDR: Start May '03 until end '05 (T0-1.5 years)
Generators presently part of Simulation Project
Future: part of a phenomenology group

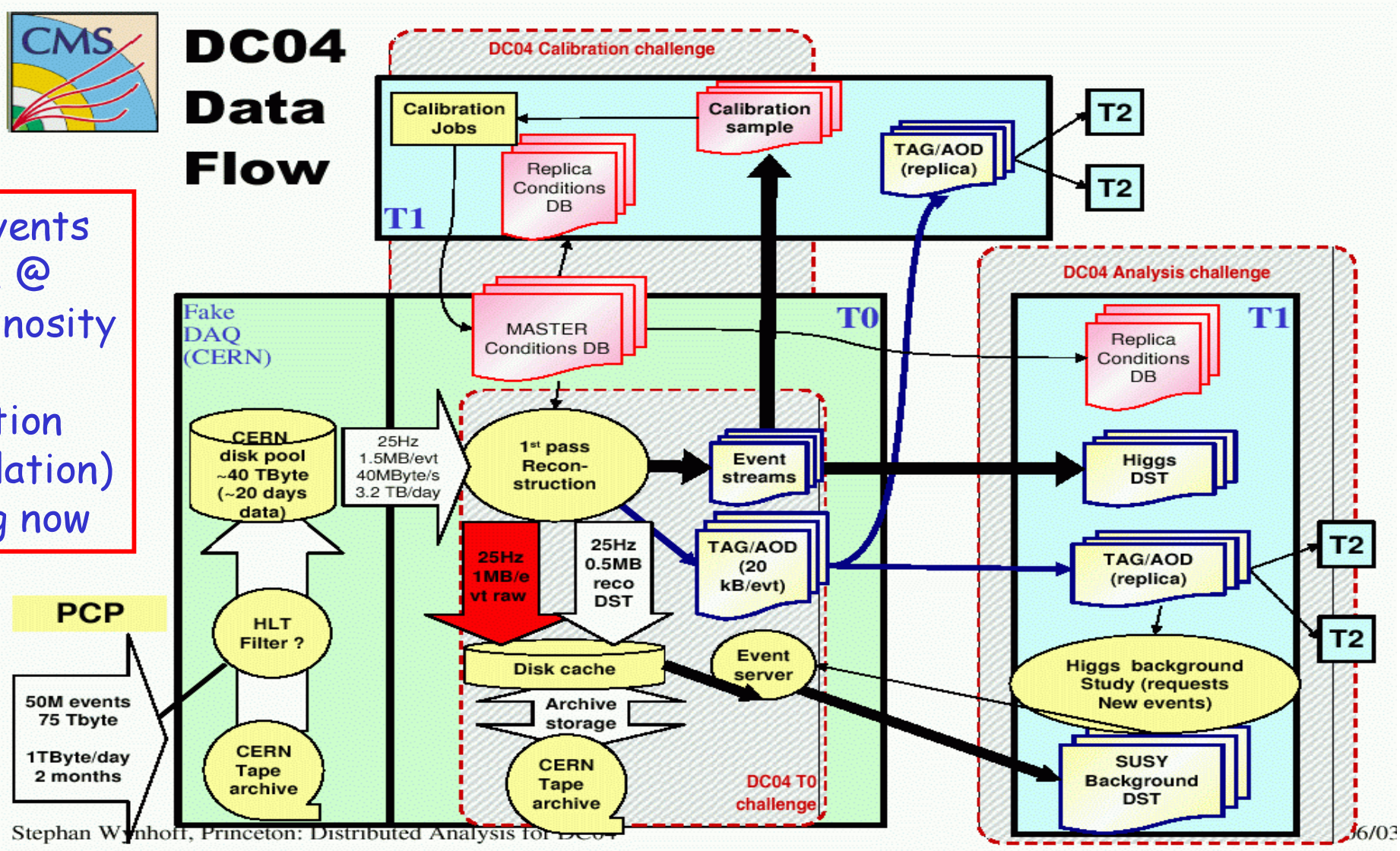
CMS Simulation and Reconstruction: C++



CMS Data Challenge DC04

50 M events
1 month @
low luminosity

Generation
(& simulation)
starting now



Generators

- Monte Carlo Generators essential for
  - Simulation of physics signals
  - Determination of backgrounds
  - Calculation of acceptances and efficiencies
  - Determination of (some) systematic errors
    - Higgs,W-Z+njets,WW-ZZ+njets,Wbb,Zbb,Hbb,Abb,tt+njets,ttbb,Wγ,Zγ...

    (will not repeat arguments/issues just made by ATLAS)
- Presently used for benchmarks for detector evaluation or design (e.g. forward region), trigger and analysis strategies. QCD important (e.g. factor 1000 suppression needed for τ triggers)

The QCD effect: 1-4 jet thresholds (PYTHIA based)

Table 15-13 Jet rate summary table. The table gives the generator-level jet E_T where the cut (in GeV) on the reconstructed jet E_T gives 95% efficiency for this generator-level jet E_T and also gives by itself a rate of 1 kHz (Level-1) and 1 Hz (HLT). The actual value of the cut on E_T that corresponds to the 95% efficiency points is given in parentheses.

	1-jet trigger	2-jet trigger	3-jet trigger	4-jet trigger
low luminosity Level-1	177 (135)	140 (104)	85 (57)	70 (45)
high luminosity Level-1	248 (195)	199 (153)	112 (79)	95 (64)
low luminosity HLT	657 (571)	564 (489)	247 (209)	149 (122)
high luminosity HLT	860 (752)	748 (652)	326 (275)	199 (162)

Generators in Experiments

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

  $\Rightarrow$ Les Houches'03 initiative to produce overview of used/available generators.

  $\Rightarrow$ This Workshop
- Uniform interface necessary (Generators $\rightarrow$ Experimental software)
- Generator tools should be accessible to whole collaboration and easy to use.
- However in practice advanced cases are better handled by experts, providing generated files

  $\Rightarrow$ An event data base

Generator Handling in CMS

- CMKIN package – wraps around the generators
  - Allows event pre-selection
  - Produced n-tuple (HEPEVT common)
  - Add additional information (Pt-hat etc.)
  - CMS production stores used version and all parameters in MySQL data base (fully reproducible at any time)
- Event access in C++
  - Implement exact copy of HEPEVT
  - Class RawHepEvent() $\rightarrow$ RawHepEventParticle()… etc.
  - Implemented in 1999/used to date
- Future: plans for change (when DC04 well on the way)
  - Use HepMC event container. Is this the HEP choice?
  - POOL for persistency…

A propos C++

Experiment code in C++
Very few generators in C++
Progress not as fast in e.g. converting PYTHIA/HERWIG into C++ as perhaps originally planned (quite understandably C++ also not immediately accepted in experiments)
⇒Have to see on this workshop where we are

But
Generators are reasonably well factorized in present experimental software. Important if there can be a common stable event record, e.g. HepMC – and perhaps data tables (HepPDT?)

More important to have functional event generators than generators in C++

May have to live with Fortran generators even at data taking

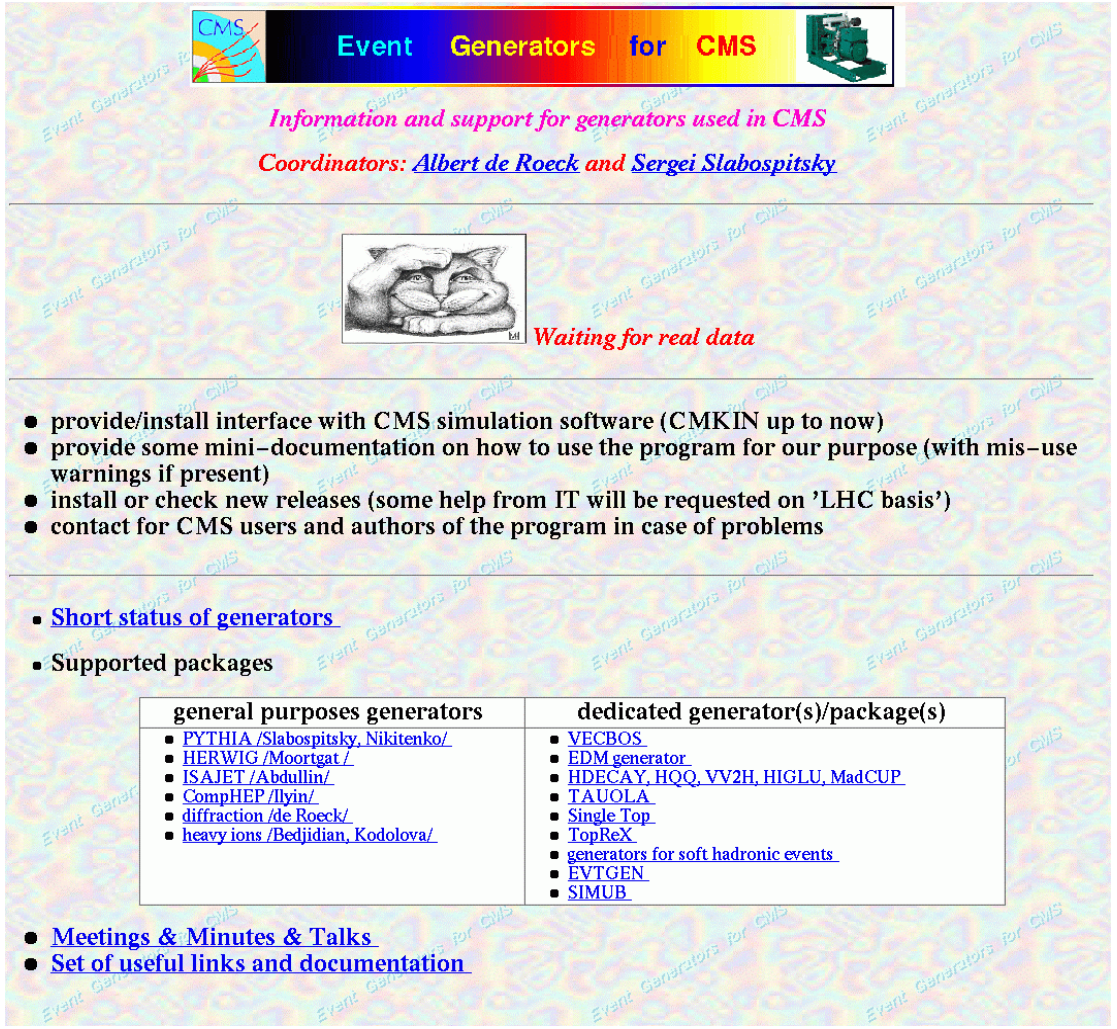
Event generator information in CMS

S. Slabospitsky and ADR

URL= http://cmsdoc/cern.ch/cms/generators/

- Interface with CMS simulation software
- Mini-documentation on how to use program @LHC in CMS
- Install/check new releases (contact for each main generator)
- Example jobs

- Future: Integration with LCG generator initiative (GENSER)



Generators in use in CMS

Workhorses

PYTHIA (6.2) and HERWIG , HIJING for HI

(ISAJET fragmentation part not used anymore)

Further being used

CompHep, HDECAY, ISASUGRA, ISASUSY, ISAWIG,TAUOLA, PHOTOS, TopReX, HardDif, SIMUB, AlpGen,POMWIG, PHOJET, MadGraphII, MadCup, GR@PPA

Next:

MC@NLO, AMEGIC++, EVTGEN, SOFTSUSY, MCFM, SPHENO, SUSPECT, PROSPINO, ADD, Black Holes, Diffractive Higgs, Cascade,low-x,…

Heavy Ions

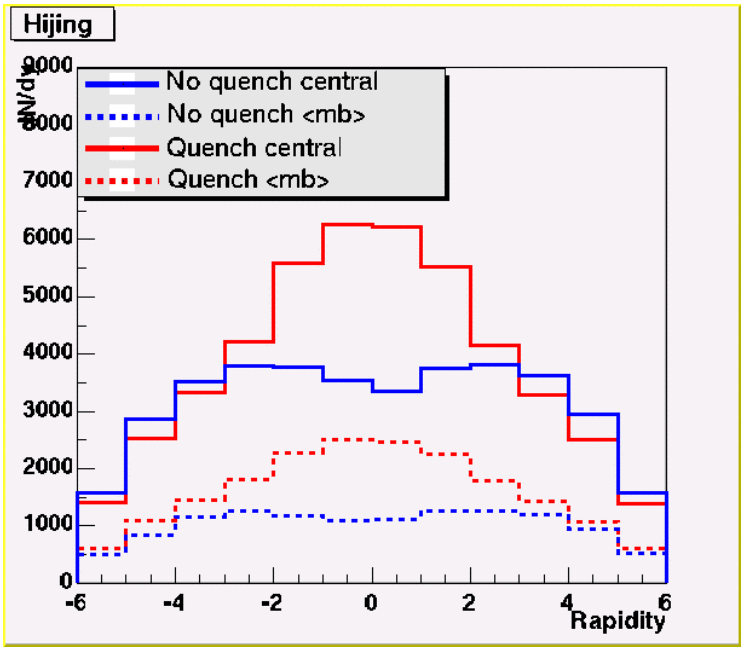
CMS has also a Heavy Ion Program

- Monte Carlo' s used: (see also talk of I. Lokhtin)
  - PYTHIA for the hard probes
  - HIJING for the underlying event
  - HYBRID (home-made) elliptic energy flow

- Typical overlay PYTHIA event on HIJING event

- Rice database contains 1000 PbPb collisions

- Validation: RHIC data



- Wish: generator with correct description of QCD production, nuclear geometry, shadowing, jet quenching, anisotropic flow etc.

Generator Validation

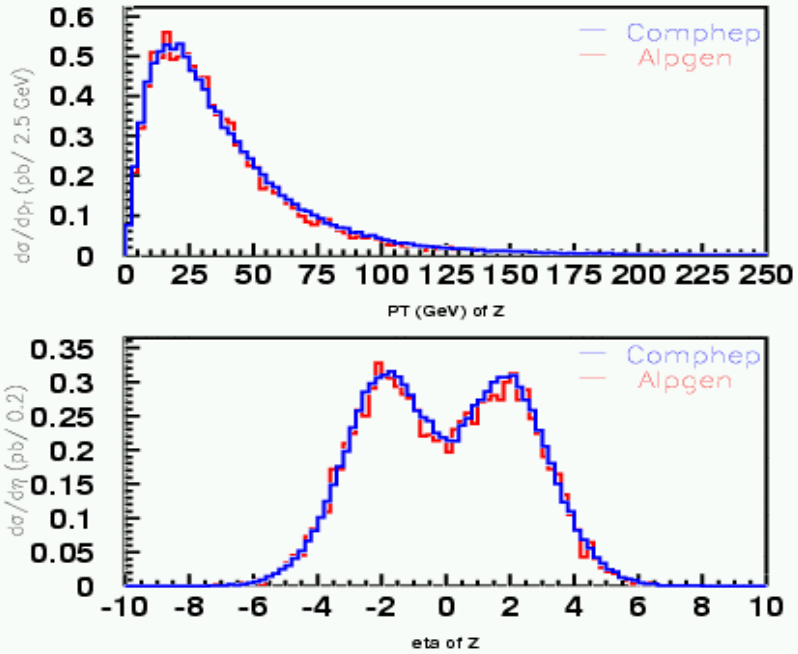
- Comparison of Generators:

ALPGEN vs. COMPHEP (K. Mazumdar)

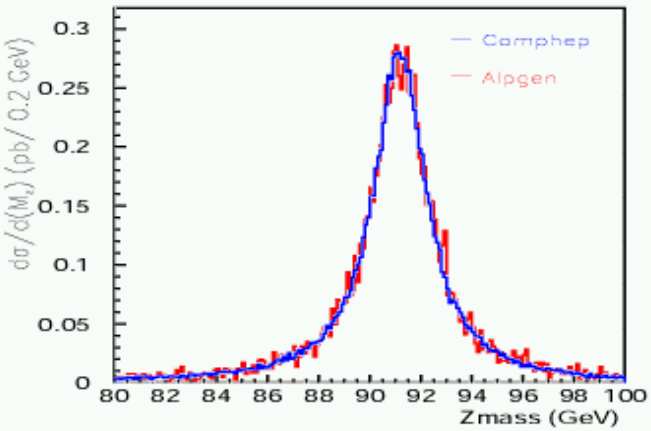
$$p\,p(gg, u\bar{u}, d\bar{d}) \rightarrow Zb\bar{b},\ Z \rightarrow e^+e^-$$

$$\sigma(\text{ALPGEN}) = 11.15 \pm 0.016 \text{ pb}$$

$$\sigma(\text{COMPHEP}) = 10.36 \text{ pb}$$



- No systematic validation or general tools developed
- Count on LCG generator project & CERN generator workshop
- Some studies ongoing e.g on comparison between generators



MC event data base

L. Dudko, A Sherstnev (← details)

Motivation:

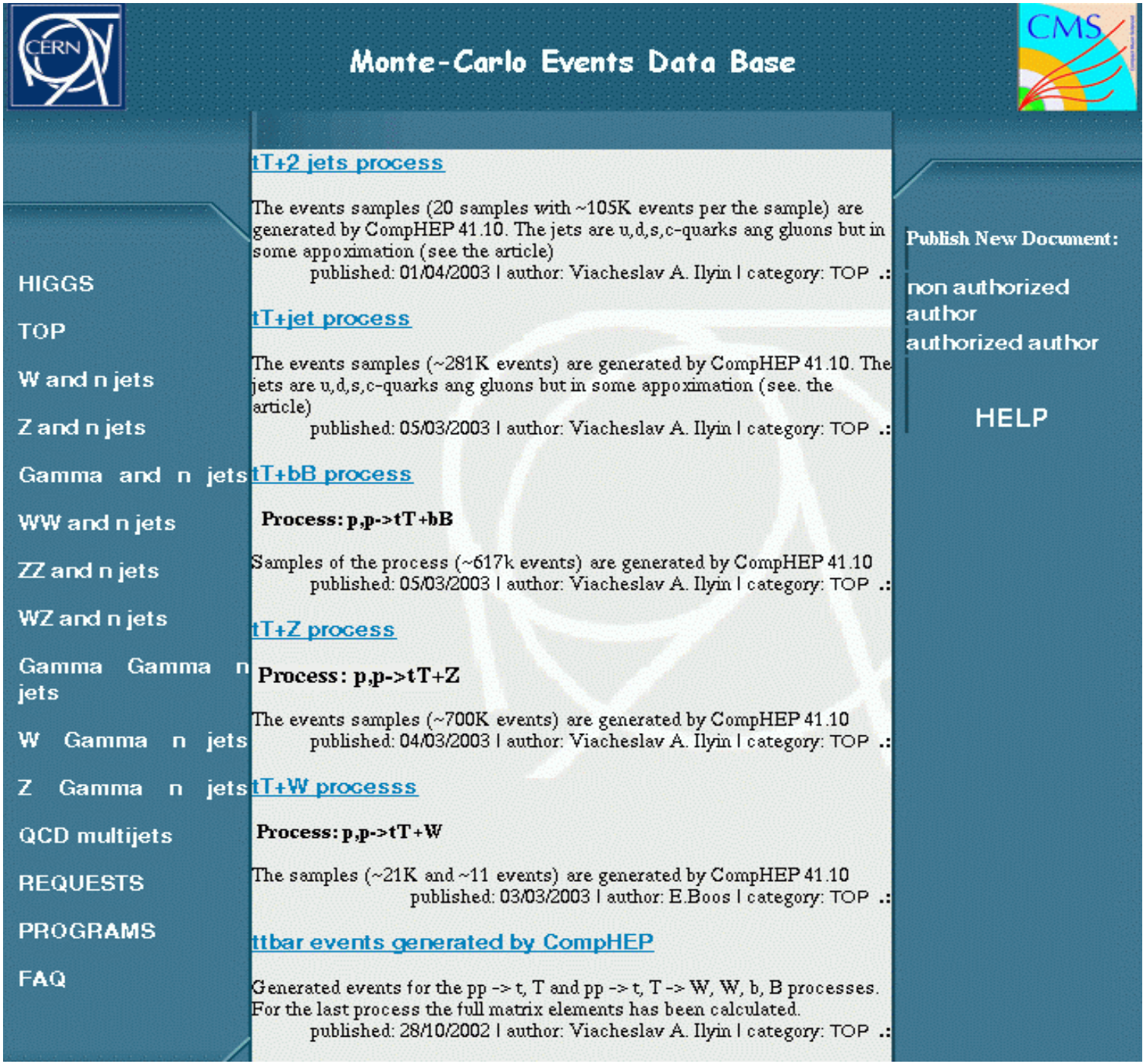
Experts/authors prepare MC files.

Experimental collaborators want to use (correct) files

CMS: PEVLIB example of a MC data base (based on model used at FNAL: FNAL MCDB)
/afs/cern/ch/cms/physics/PEVLIB with directory structure.

Used by some physics groups in CMS already.

Expect increase as Physics-TDR progresses


Monte-Carlo Events Data Base
HIGGS
TOP
W and n jets
Z and n jets
Gamma and n jets
WW and n jets
ZZ and n jets
WZ and n jets
Gamma Gamma n jets
W Gamma n jets
Z Gamma n jets
QCD multijets
REQUESTS
PROGRAMS
FAQ
tT+2 jets process
The events samples (20 samples with ~105K events per the sample) are generated by CompHEP 41.10. The jets are u,d,s,c-quarks ang gluons but in some appoximation (see the article)
published: 01/04/2003 | author: Viacheslav A. Ilyin | category: TOP .:
tT+jet process
The events samples (~281K events) are generated by CompHEP 41.10. The jets are u,d,s,c-quarks ang gluons but in some appoximation (see. the article)
published: 05/03/2003 | author: Viacheslav A. Ilyin | category: TOP .:
tT+bB process
Process: p,p->tT+bB
Samples of the process (~617k events) are generated by CompHEP 41.10
published: 05/03/2003 | author: Viacheslav A. Ilyin | category: TOP .:
tT+Z process
Process: p,p->tT+Z
The events samples (~700K events) are generated by CompHEP 41.10
published: 04/03/2003 | author: Viacheslav A. Ilyin | category: TOP .:
tT+W processs
Process: p,p->tT+W
The samples (~21K and ~11 events) are generated by CompHEP 41.10
published: 03/03/2003 | author: E.Boos | category: TOP .:
ttbar events generated by CompHEP
Generated events for the pp -> t, T and pp -> t, T -> W, W, b, B processes. For the last process the full matrix elements has been calculated.
published: 28/10/2002 | author: Viacheslav A. Ilyin | category: TOP .:
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HELP

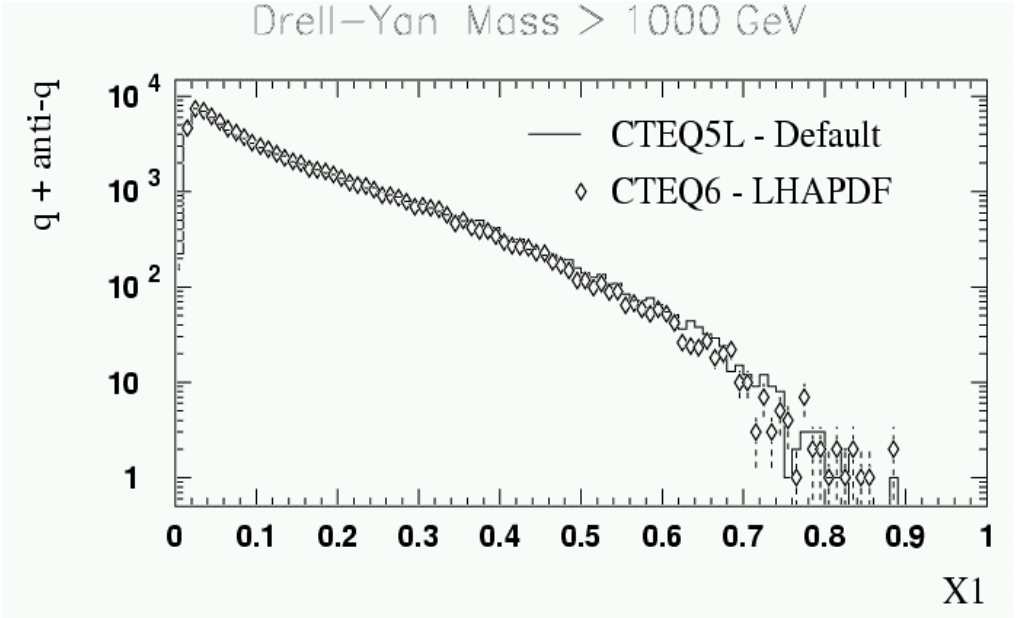
PDF's

Transition from PDFLIB to LHAPDF (now taken care of by Durham)

Drell-Yan production

PDF set	Comment	xsec
$81 < M < 101$ GeV		
CTEQ5L	PYTHIA internal	1516 ± 5 pb
CTEQ5L	PDFLIB	1536 ± 5 pb
CTEQ6	LHAPDF	1564 ± 5 pb
MRST2001	LHAPDF	1591 ± 5 pb
Fermi2002	LHAPDF	1299 ± 4 pb
$M > 1000$ GeV		
CTEQ5L	PYTHIA internal	6.58 ± 0.02 fb
CTEQ5L	PDFLIB	6.68 ± 0.02 fb
CTEQ6	LHAPDF	6.76 ± 0.02 fb
MRST2001	LHAPDF	7.09 ± 0.02 fb
Fermi2002	LHAPDF	7.94 ± 0.03 fb

D. Bourilkov



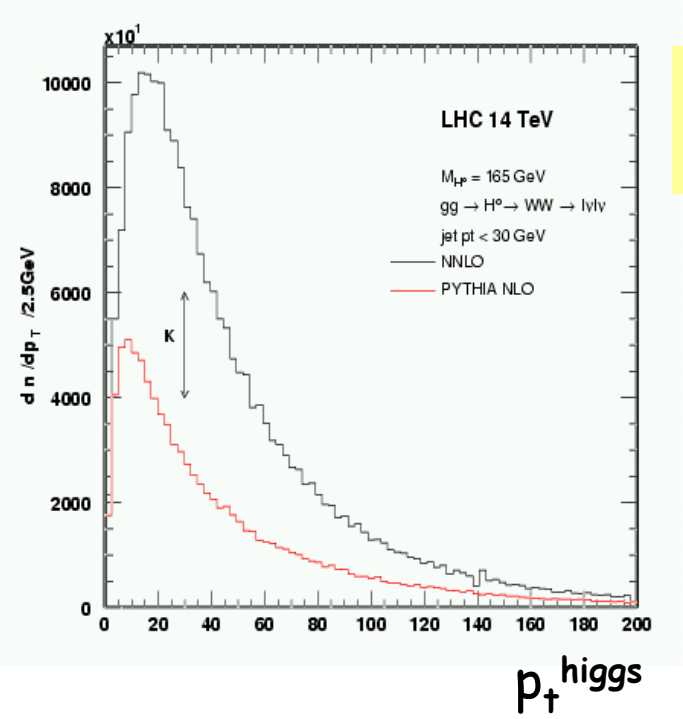
Private CMS interface to PYTHIA exists

LHAPDF the new accepted standard?
Will all generators adapt it?

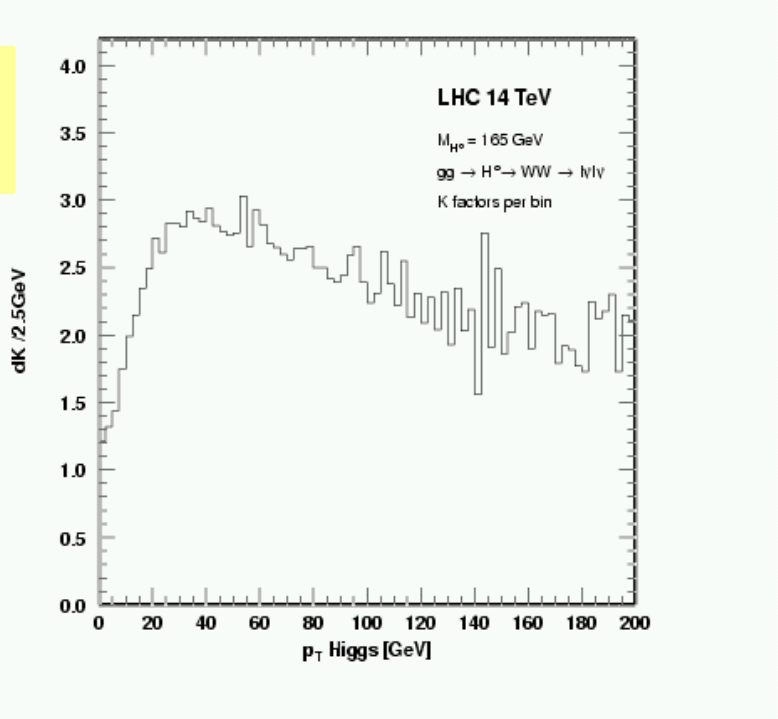
PDF knowledge crucial for LHC: HERA-II→ errors of a few % at large scales

NLO

- Many cross sections now calculated to NLO
- Les Houches03 message: "effects can be significant so experiments better start thinking in NLO"
- K factors? Not always sufficient/can be huge in some phase space parts
- Reweighting Monte Carlo? Select key weighting variables (e.g. M. Dittmar et al.)
- Complete NLO Monte Carlo? Ideal but balance of effort and gain

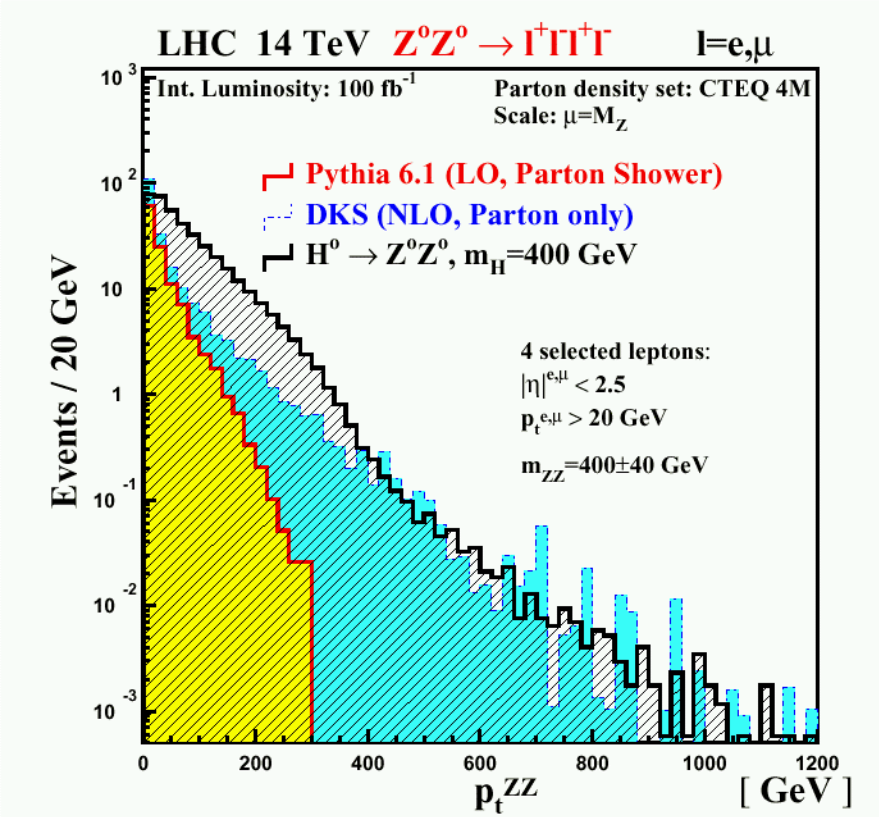


Eg. p_t^{higgs} spectrum



NLO Contributions

- Have to go beyond e.g PYTHIA



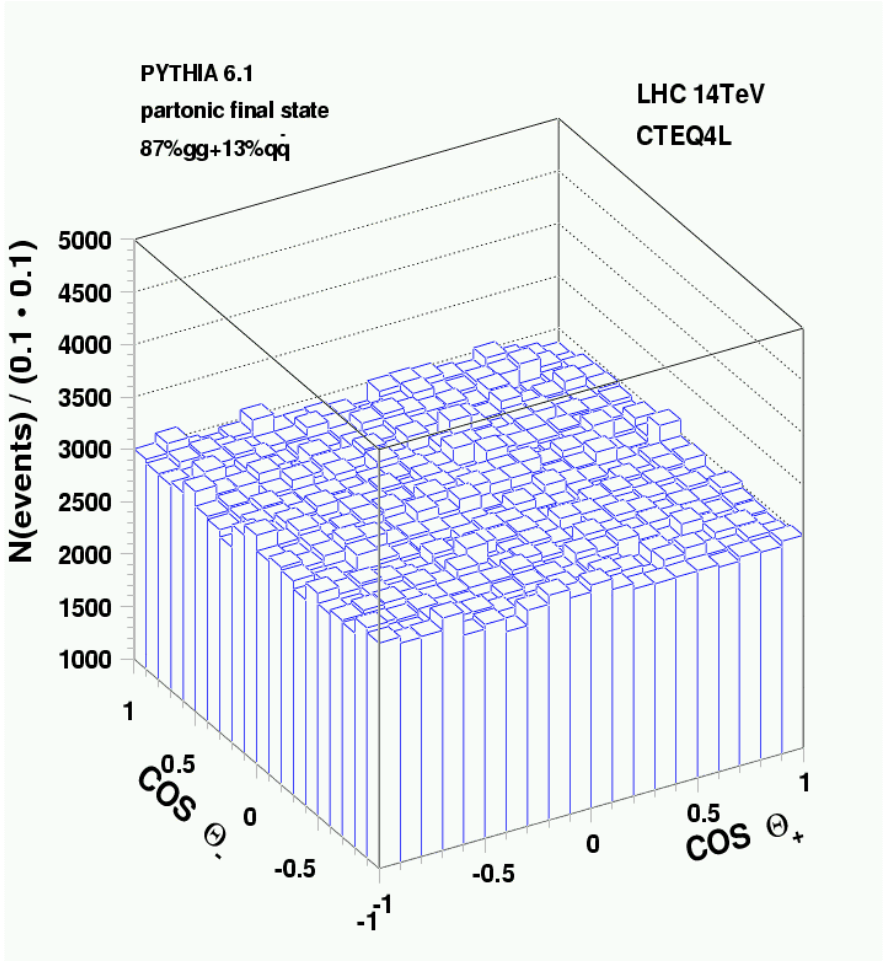
NLO important for many studies, not just the Higgs

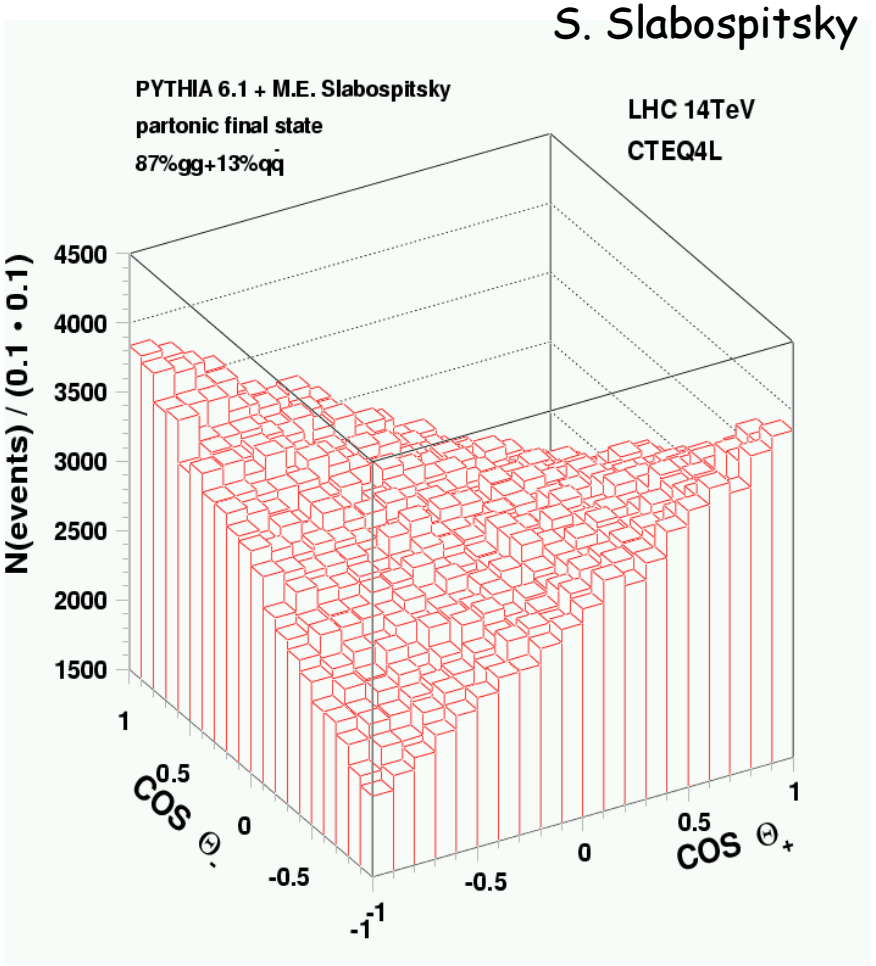
What is exactly available in MC's/ planned developments?
Can one improve in e.g. PYTHIA?

Matrix elements

Example: spin correlations between leptons in pp $\rightarrow$tt $\rightarrow l^+l^-\nu\nu bb$

S. Slabospitsky





CMS: use TopRex

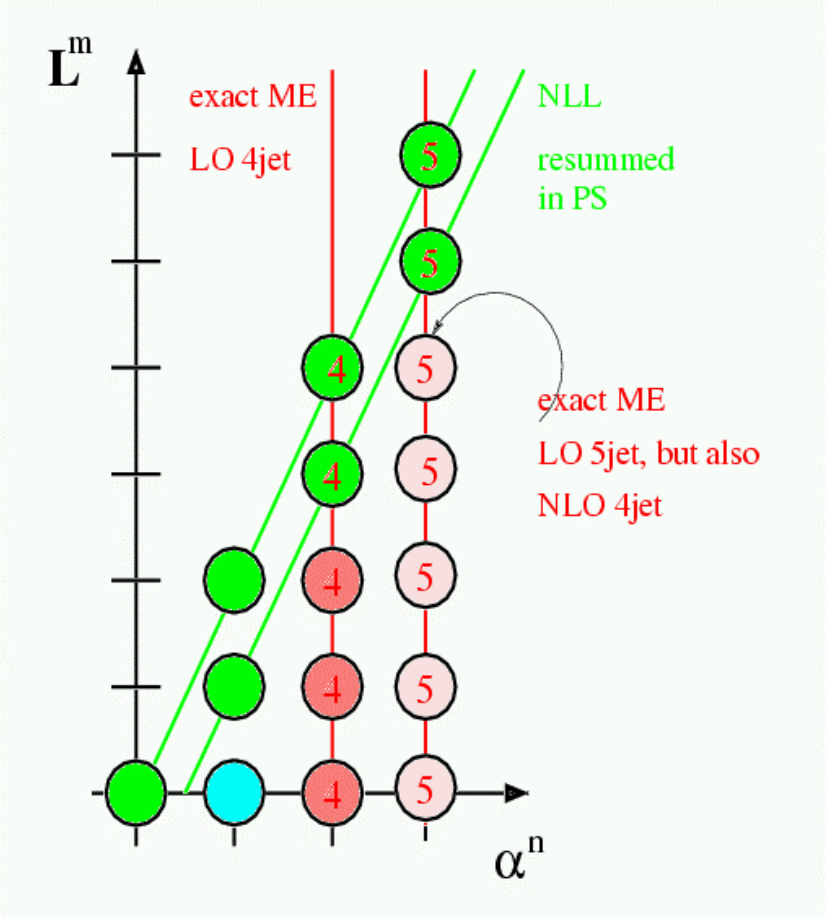
ME+PS Matching

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

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

The way to go?

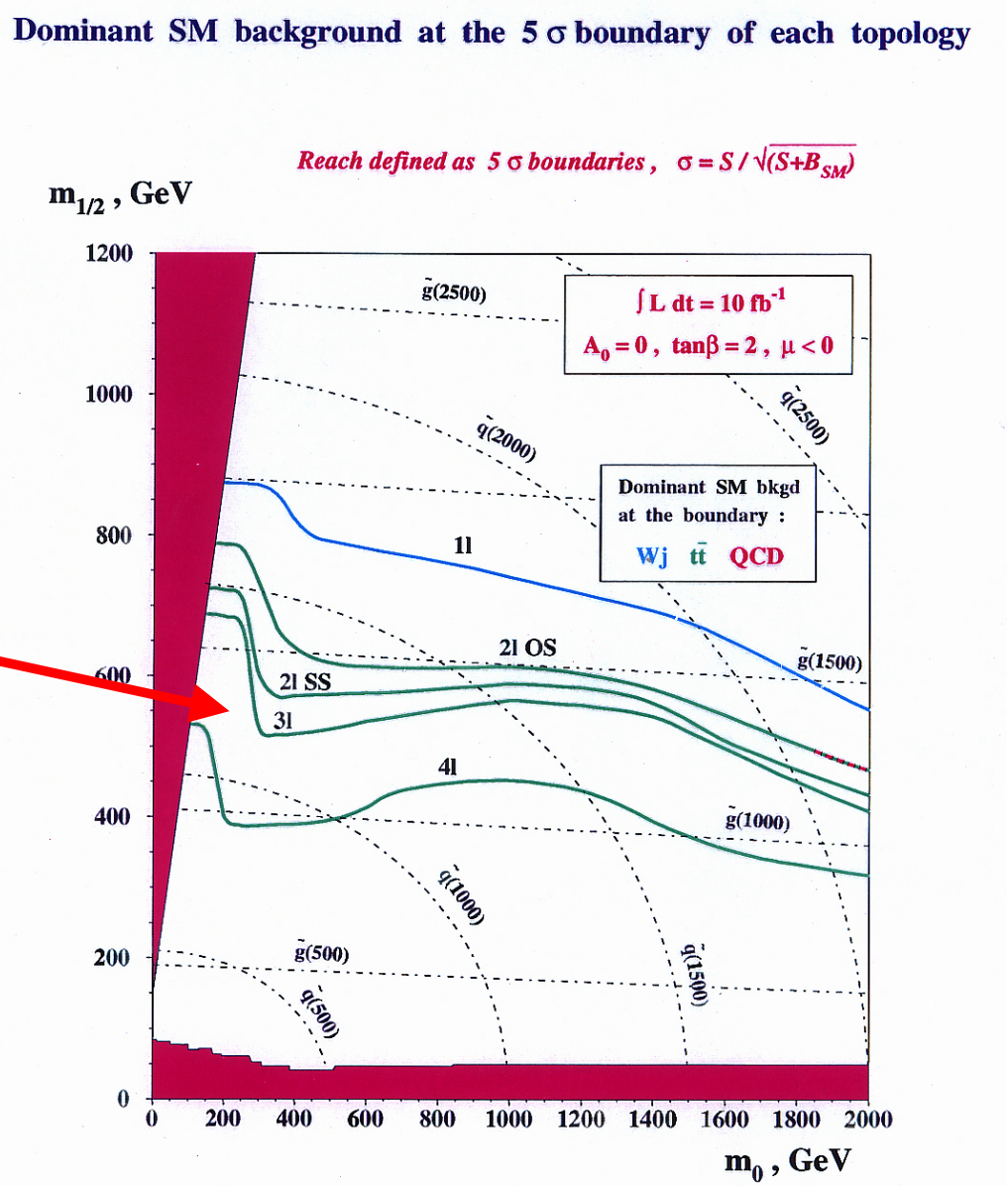
Q: if LHC at startup sees a number of 8,9,10 jets events, how well do we the prediction…



Backgrounds to New Physics

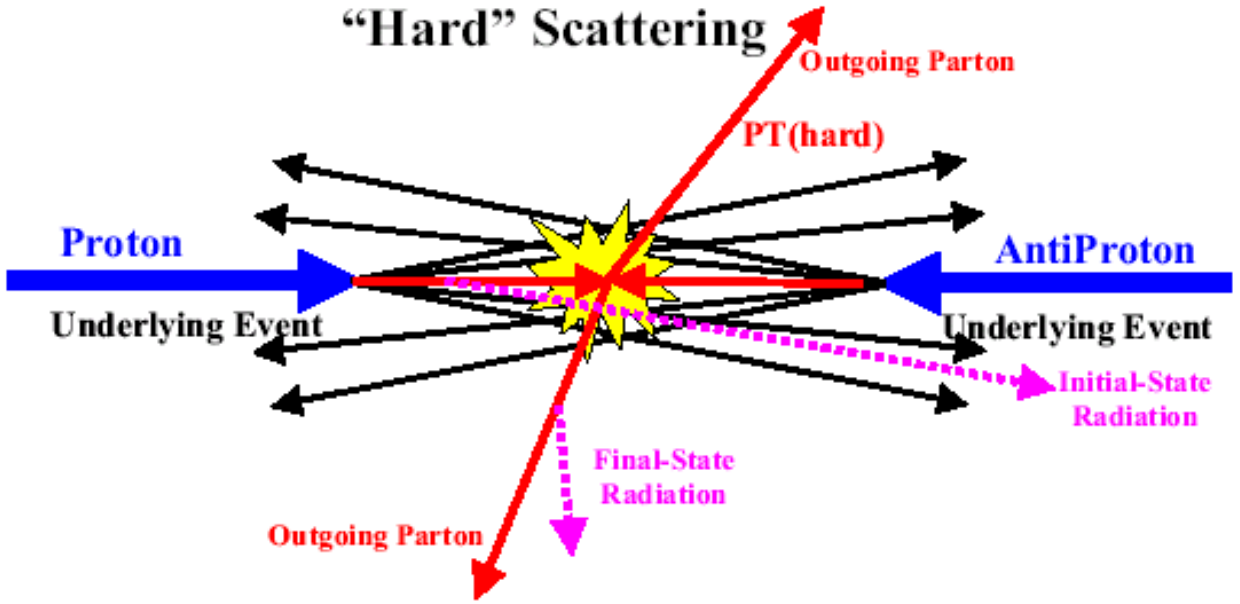
- LHC can discover SUSY already with O(1) fb^{-1}, ie. in the first month(s)
- Important to control the backgrounds well from day-1.
  tt+jets,W+jets,Z+jets,
  Wtb, WW+jets, ZZ+jets
  QCD …

- How well do we control X+njets today? Prospects?



Minimum bias/underlying event

Important: Affects E_T^{miss} resolution , trigger, detector occupancy…



Phenomenological implementations in models (e.g. PYTHIA)
Several tunes exist (e.g. R. Field, A. Moraes et al. (Durham03))

One common tune for LHC? More data needed (Tevatron)?
Extrapolation from Tevatron to LHC?
Different/new models (JIMMY/new model in PYTHIA)

Parameter	PY 6.2 DEFAULT	R.F. TUNE A	A.M. TUNE
MSTP(81)	1	1	1
MSTP(82)	1	4	4
PARP(82)	1.9	2.0 GeV	2.2/1.9 GeV
PARP(83)	0.5	0.5 (D)	0.5 (D)
PARP(84)	0.2	0.4	0.2/0.4
PARP(85)	0.33	0.9	0.33 (D)
PARP(86)	0.66	0.95	0.66 (D)
PARP(89)	1 TeV	1.8 TeV	1 TeV (D)
PARP(90)	0.16	0.25	0.16 (D)
PARP(67)	1.0	4.0	1.0 (D)

- $Pt_{cut} = Pt_0 \times (\sqrt{s} / Ecm)^{\varepsilon}$

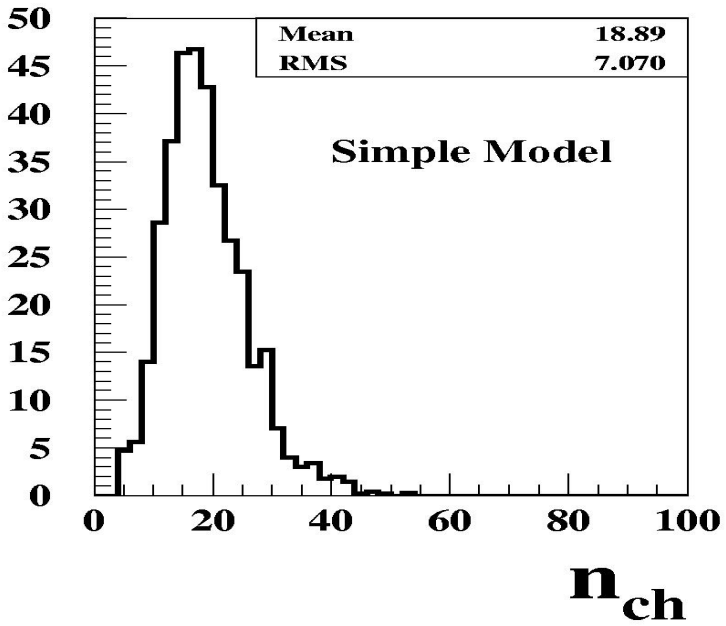
Pt_0 = PARP(82)
Ecm = PARP(89)
ε = PARP(90)

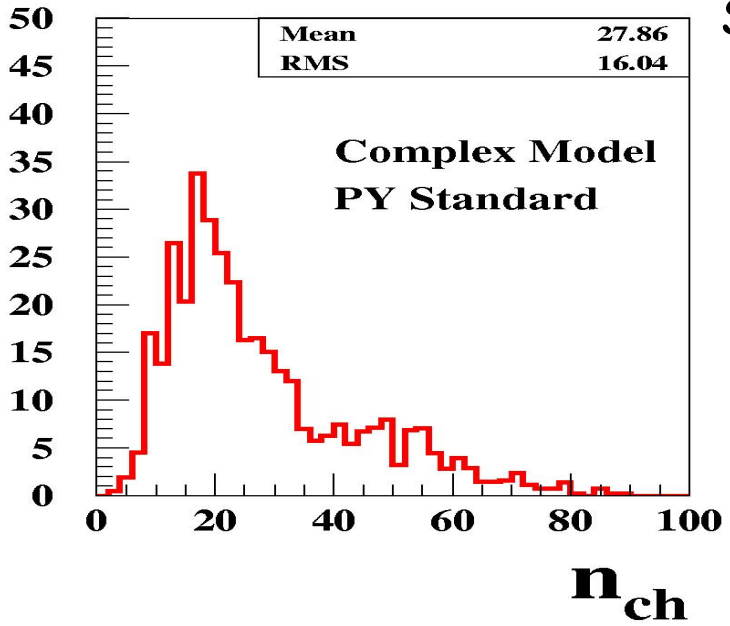
- PARP(83,84) regulate the double-gaussian parton distribution (core density and size)

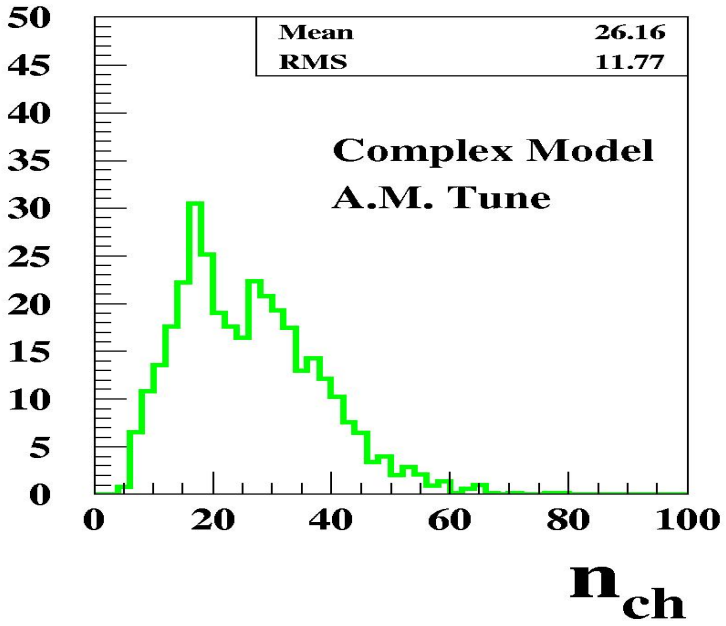
- PARP(85,86) regulate 2-gluon production in MPI, PARP(67) influences QCD ISR

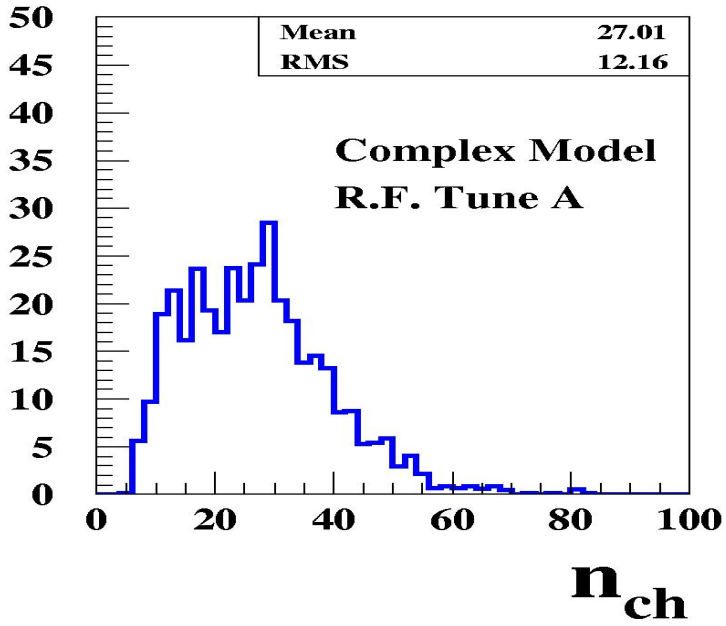
MB bb, charged multiplicity for tracks in $|\eta| < 2.4$ and $P_t > 1$ GeV

S. Arcelli

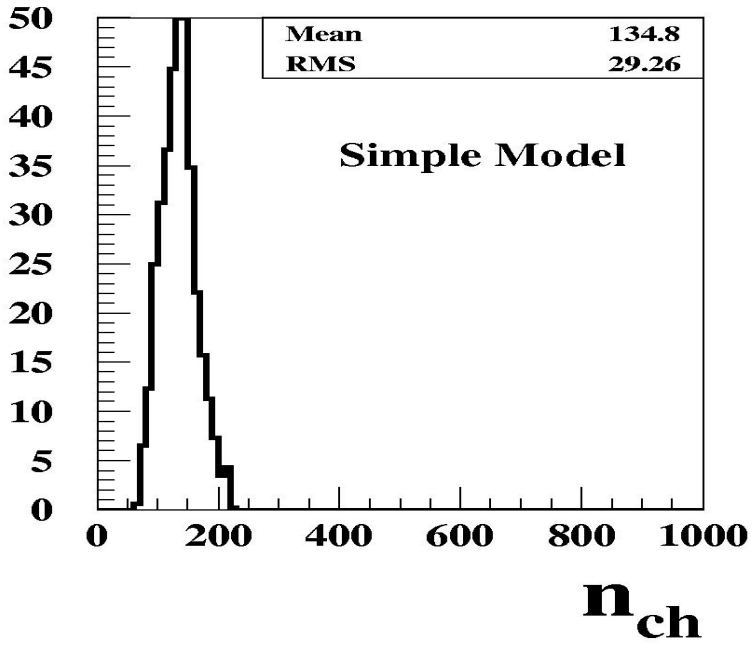


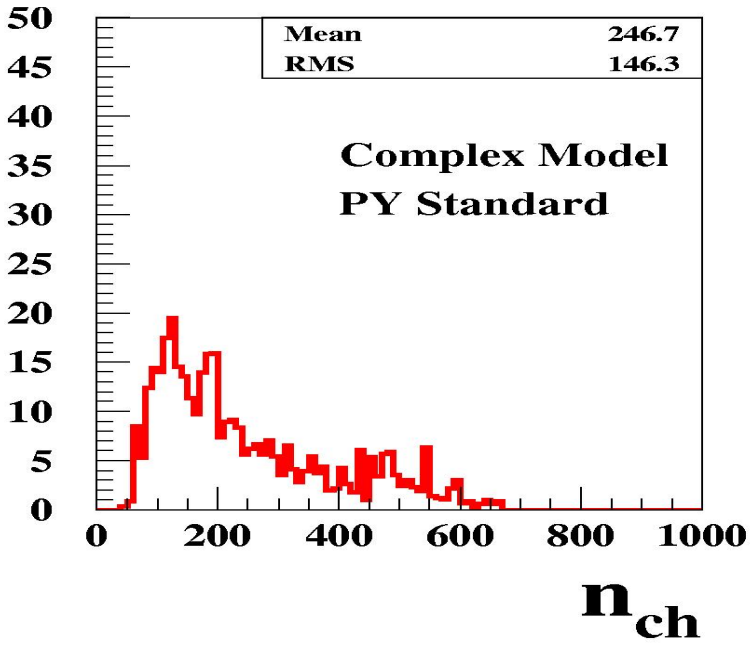


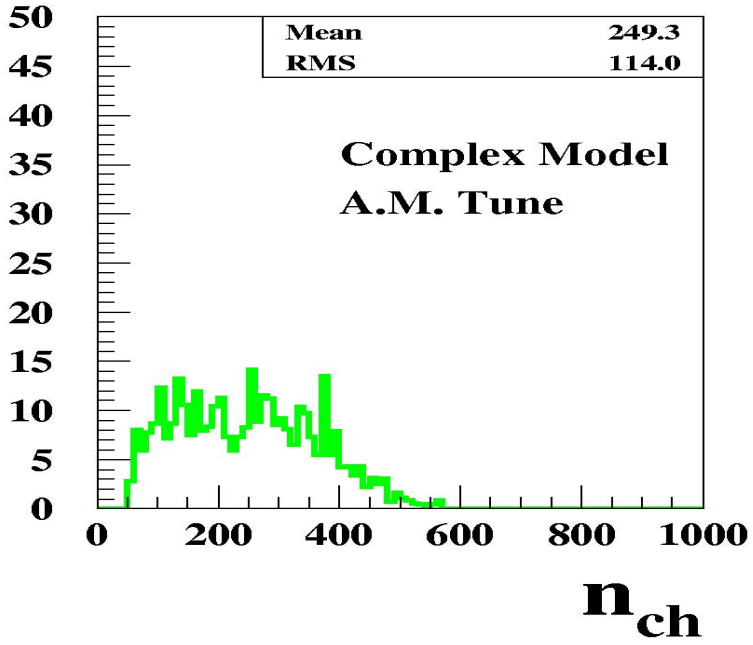


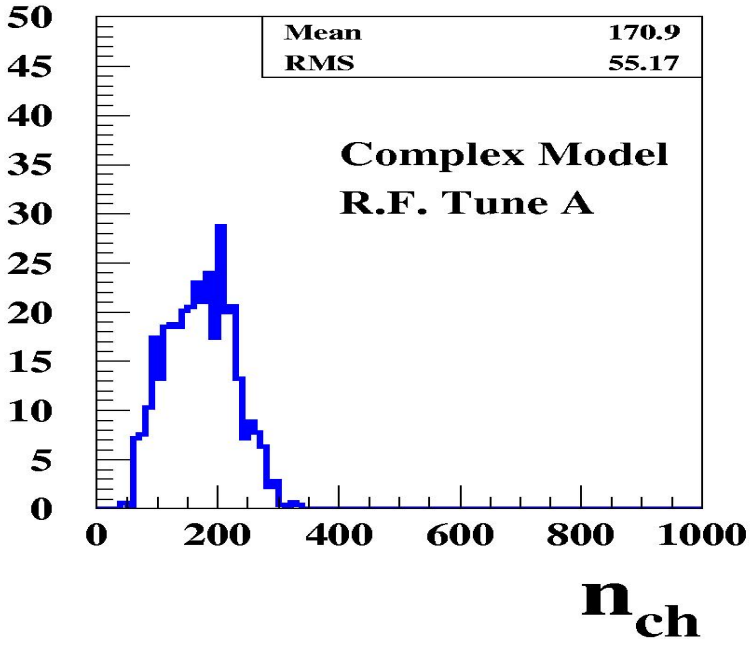


MB bb, Charged multiplicity , no η and Pt cuts







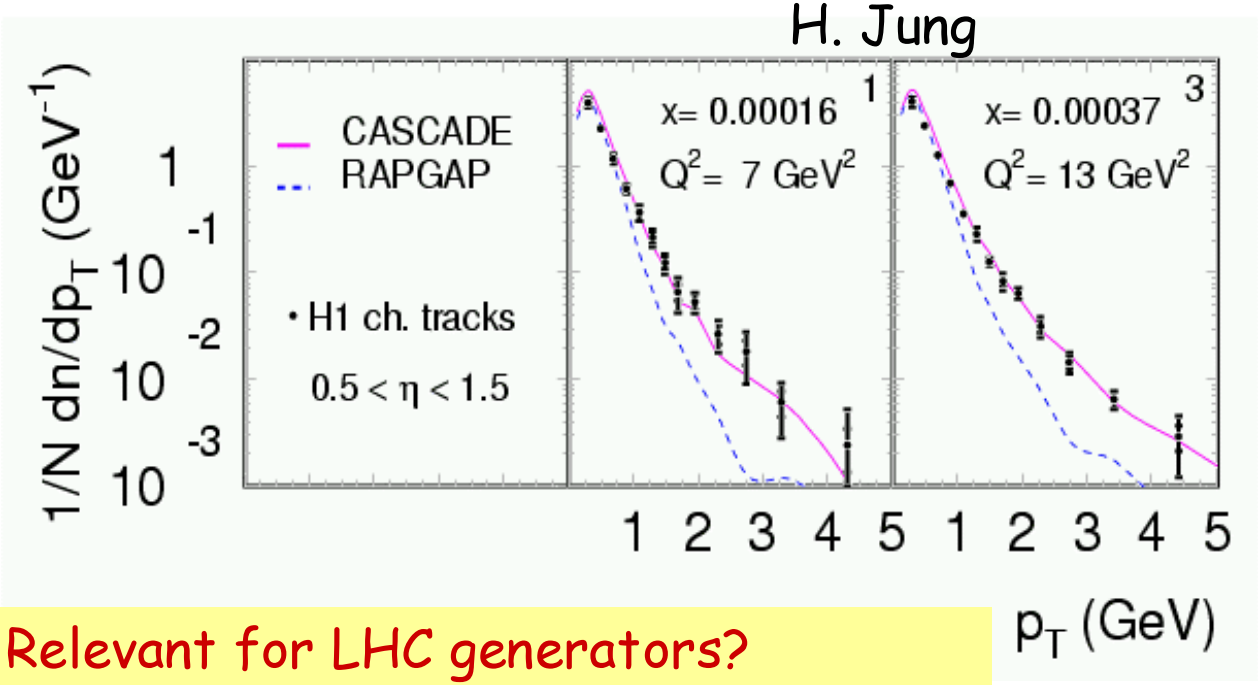


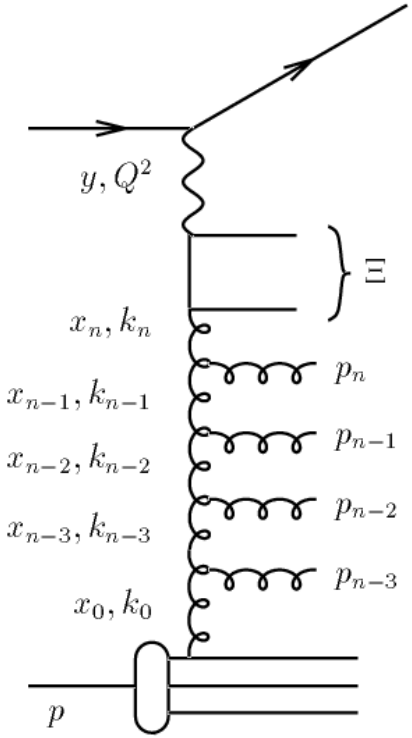
Low-x & Diffraction issues

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

- More pt in the event than predicted by Altarelli-Parisi 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

CCFM: Catani, Ciafaloni, Fiorani, Marchesini

SUSY generators & codes

- Different codes
- Different procedures
- Different corrections

Taken into acount

⇒ Different masses for the same SUSY parameters

- Example for the 10 Snowmass 2001 Benchmark points

- Experiments: can use one program/version (e.g. SPS points: ISAJET 7.58)

Improvement with Les Houches accord '03?

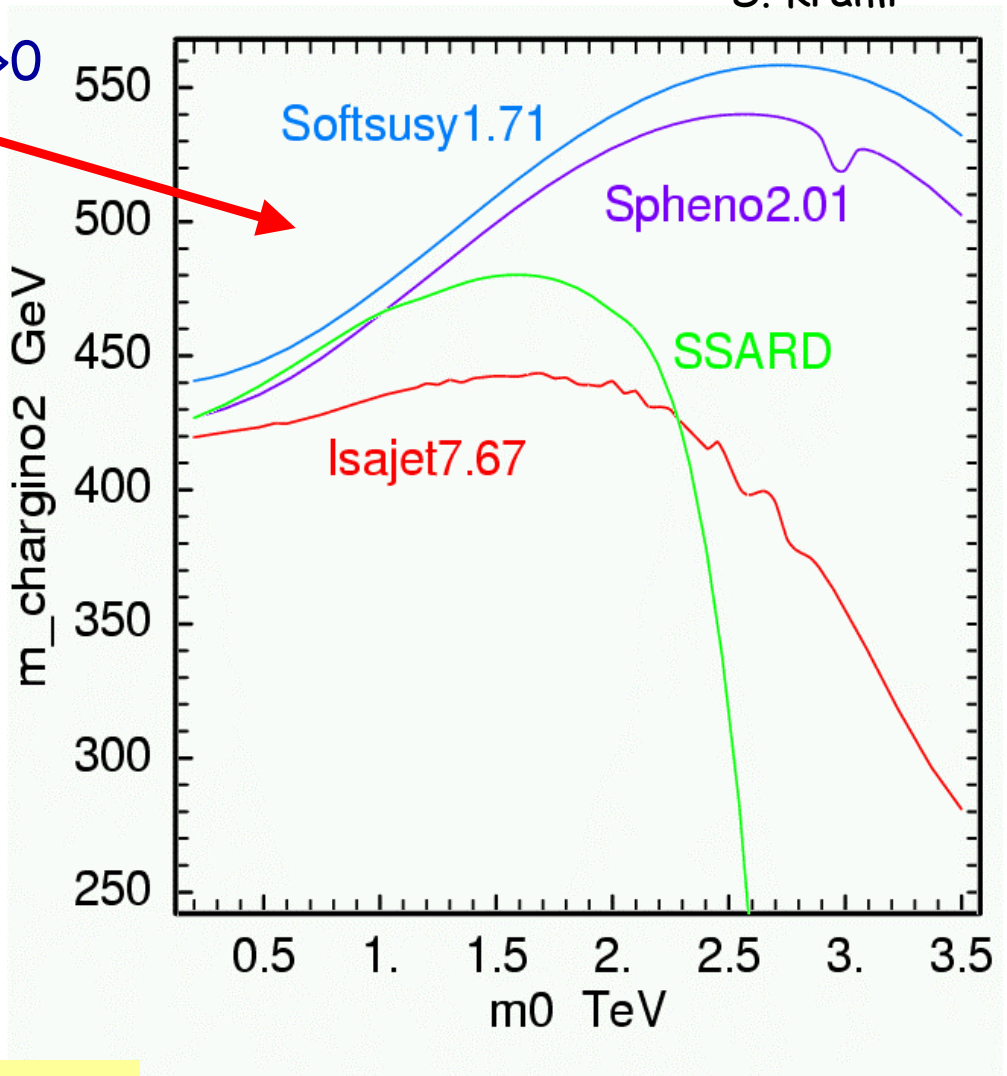
Allanach, Kraml, Porod

mass	code	1a	1b	2	3	4	5	6	7	8	9
$\tilde{g}$	ISAJET	607	936	794	932	732	719	718	944	835	1296
	SOFTSUSY	614	949	802	946	743	730	729	964	852	1306
	SPHENO	594	917	782	914	719	705	704	940	836	1232
	SUSPECT	626	964	870	959	761	730	742	986	902	1395
	error	13	20	40	19	18	12	16	22	31	67
$\tilde{u}_L$	ISAJET	536	835	1532	817	730	642	640	858	1079	1233
	SOFTSUSY	549	851	1582	831	753	657	662	876	1083	1291
	SPHENO	565	876	1563	859	764	676	674	910	1127	1314
	SUSPECT	570	886	1595	867	775	681	680	910	1138	1502
	error	15	23	27	23	19	18	18	26	30	116
$\tilde{u}_R$	ISAJET	520	807	1529	788	714	622	626	830	1033	1242
	SOFTSUSY	569	884	1592	866	774	681	679	914	1142	1297
	SPHENO	548	847	1552	828	746	655	659	880	1080	1266
	SUSPECT	550	852	1585	832	754	656	662	880	1092	1492
	error	20	32	29	32	25	24	22	35	45	114
$\tilde{t}_1$	ISAJET	379	633	947	621	523	236	476	774	951	998
	SOFTSUSY	398	658	974	645	544	232	497	813	987	951
	SPHENO	398	658	964	646	545	248	497	813	982	986
	SUSPECT	410	676	1004	663	560	243	513	831	1015	1140
	error	13	18	24	17	16	7	15	24	26	83

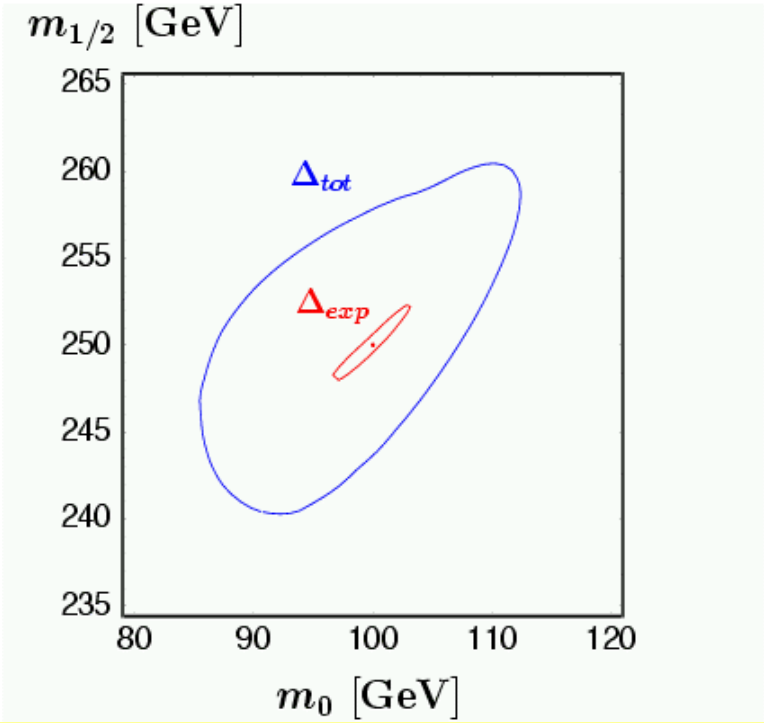
SUSY generators & codes

Chargino mass prediction for
$M_{1/2}$ = 300 GeV A=0 Tanβ=10 μ>0

S. Kraml



Fit of mSUGRA to
"LHC measurements" for SPS1a

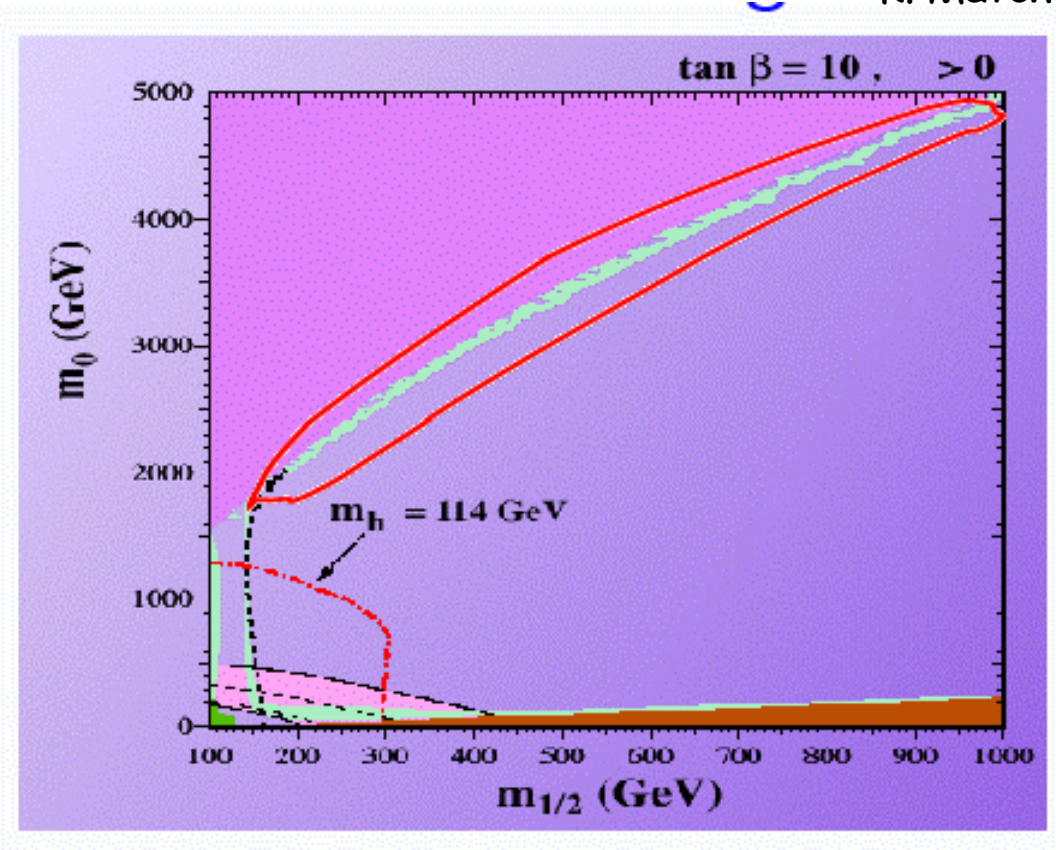


Dominated by the "theoretical error"

Focus Point Region

- Interesting region (phenomenolically)
- But ill determined by present codes

K. Matchev



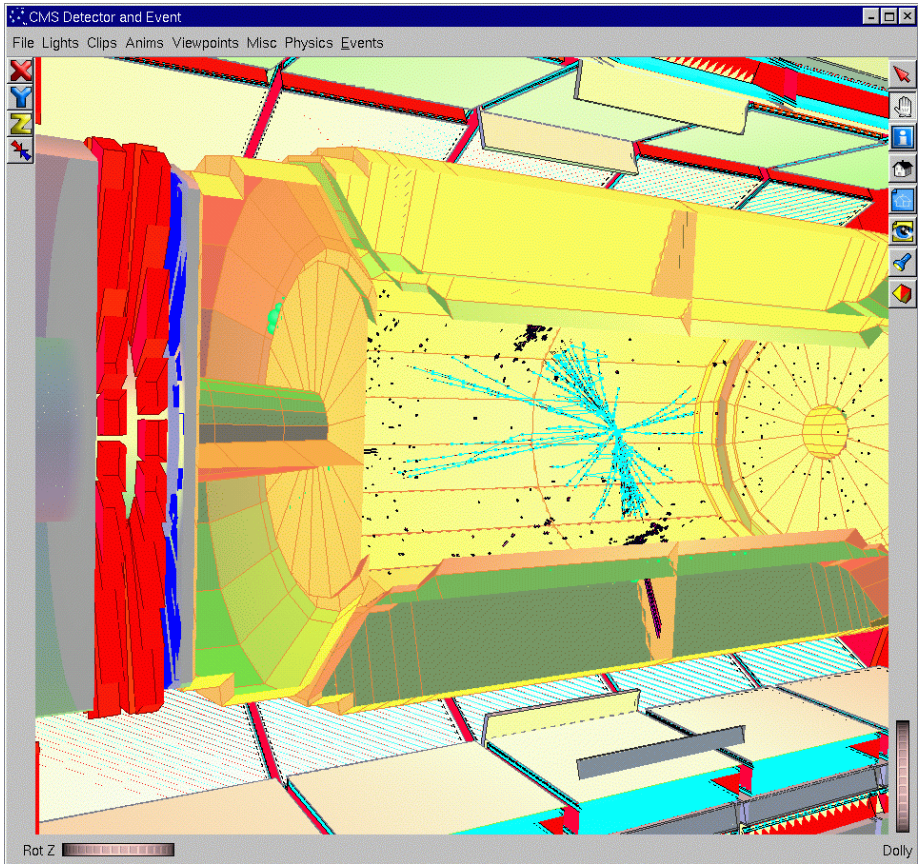
Can one get a stable prediction for this region?

Generators for (non-susy) BSM

This area may need some cleaning-up

- Many private codes, mostly as patches on PYTHIA and HERWIG exist for the new BSM phenomena such as ED's and black holes (E.g. K. Matchev code for ADD extra dimensions, TrueNoir,…)

- Codes for even newer ideas such as the little Higgs models (heavy 'top' or gauge bosons with proper couplings)
  Radions
  H CP mixing
  …



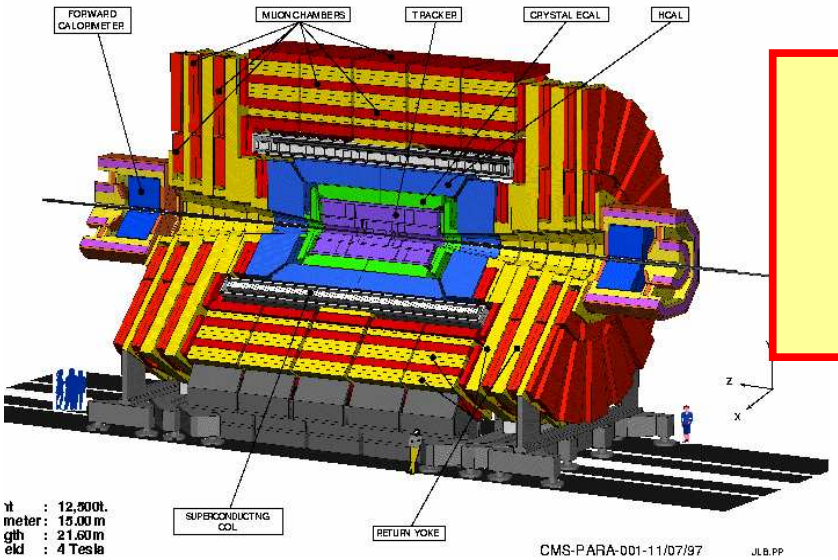
Black hole in CMS with the Harris/Richardson generator

Summary

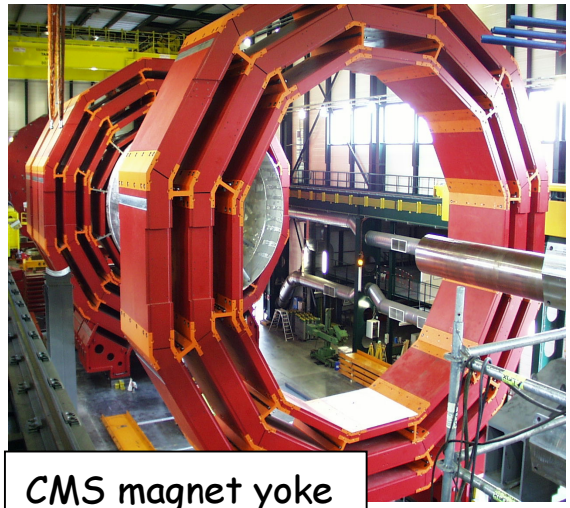
- Event generators will be very important for the LHC physics program
  - Certainly important progress over the last years
- Workshop very timely in view of the CMS TDR
  - Question which will need addressing is the required precision of event generators.
  - E.g W,Z,tt+njets and Higgs pt spectra, NLO effects will be important issues
- CMS moving towards HepMC (HepPDT) and LHAPDF, if these choices are not challenged during the workshop
  - Looking forward to LCG tools & collaboration
- A number of issues raised (here & particularly parallel sessions).
  - Expect for progress/strategy developing during this workshop
- Hope this workshop to be a starting point for a MC forum until and during LHC data taking

Thanks to: S. Abdoulin, S. Arcelli, D. Borilkov, D. Denegri, M. Dittmar, H. Jung, O. Kodolova, S. Kraml, F. Krauss, I. Lokhtin, J. Mnich, F. Moortgat, A. Nikitenko, S. Slabospitsky, S. Wynhoff

Monte Carlo Tools in CMS



Albert De Roeck
CERN
MC4LHC Workshop


CMS magnet yoke

Introduction: Monte Carlo tools in CMS