Heavy Quark Production with SHERPA

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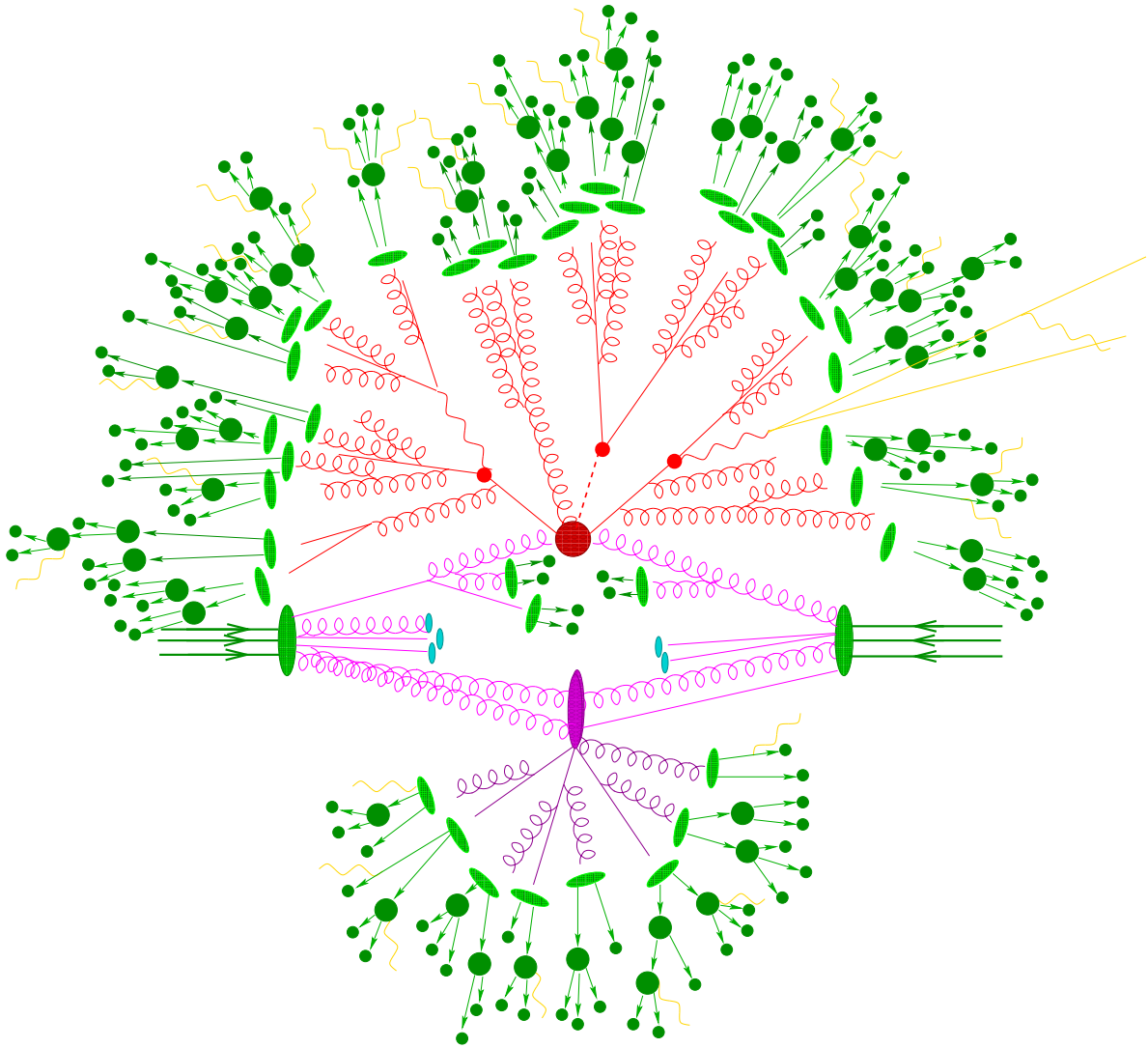
outline

- Initial state parton shower (QCD)
- Underlying event
- Signal process
- Final state parton shower (QCD)
- Fragmentation
- Hadron decays
- QED radiation



SHERPA is the framework steering these event phases.

- new physics version SHERPA-1.1 released in April '08
- current bugfix version SHERPA-1.1.2

Physics modules

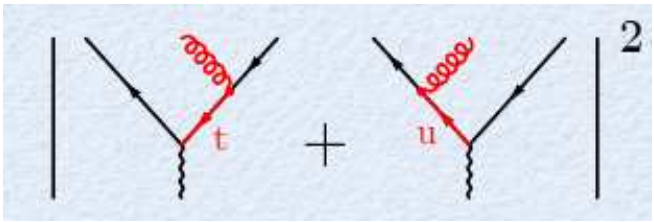
- AMEGIC++: tree level ME generator
- APACIC++: parton shower
- AMISIC++: multiple parton interactions

New physics modules (introduced in SHERPA-1.1)

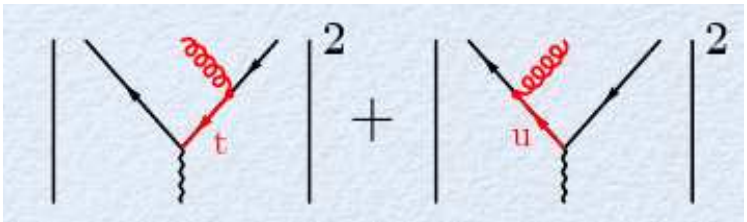
- AHADIC++: cluster fragmentation
- HADRONS++: hadron and τ decay module
- PHOTONS++: higher order QED corrections

CKKW ME-PS merging

ME



PS



\+ Exact fixed order
\+ All interference terms
− Calculable only for low FS multiplicities (n $\leq$ 6-8)

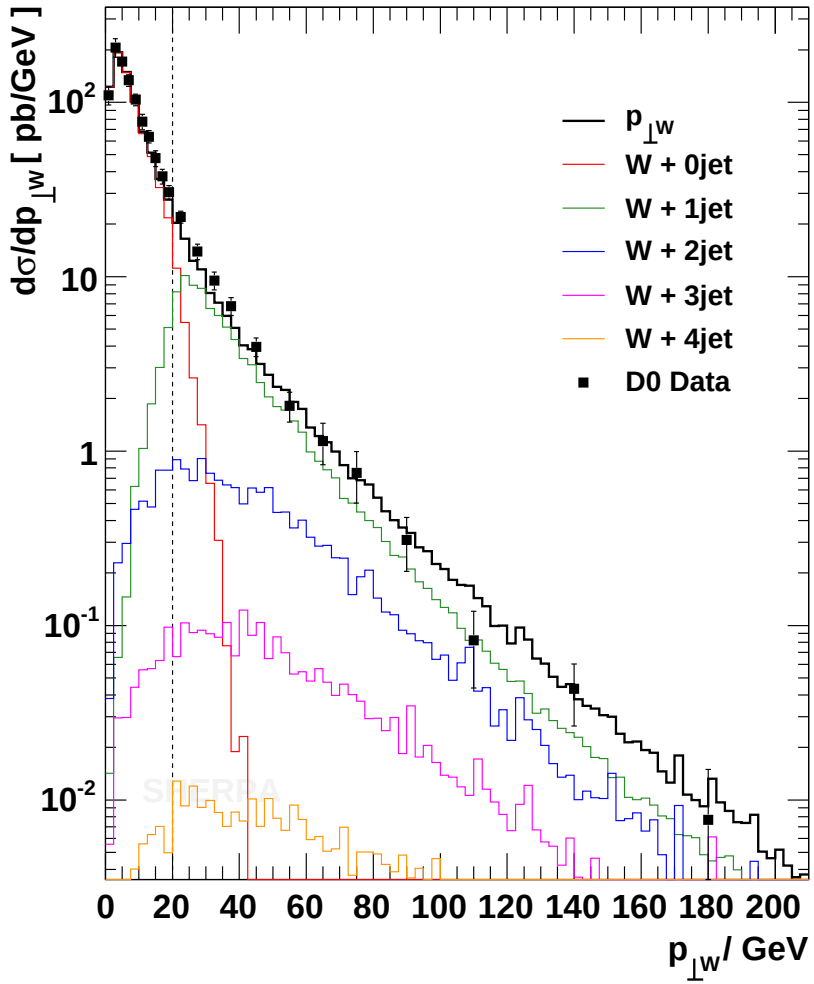
\+ Resum all (next-to) leading logs to all orders
− Interference effects only through angular ordering

Combine advantages of both approaches

- Good description of hard emission (ME)
- Correct intrajet evolution (PS)

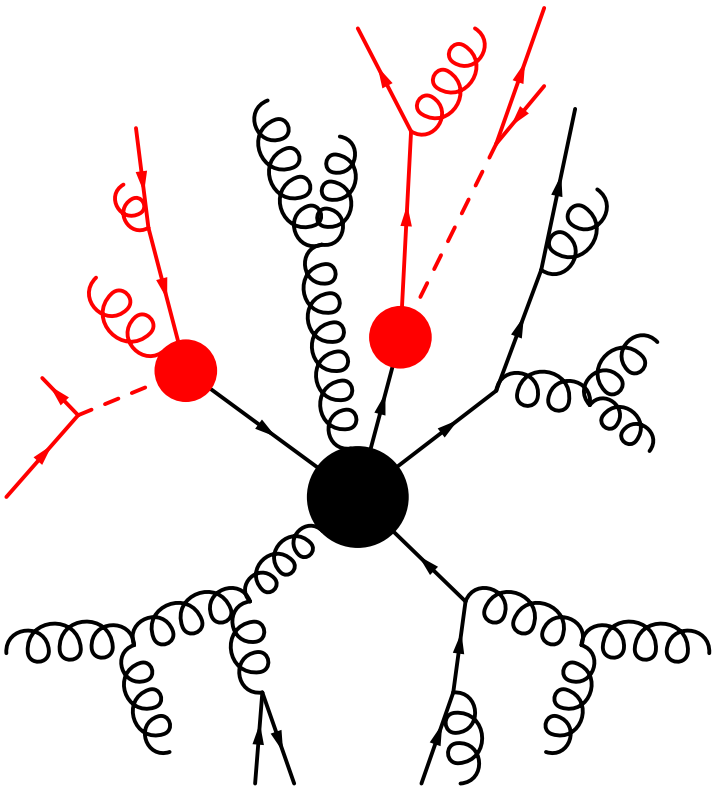
Strategy

- Separate phase space:
  $\longrightarrow$ ME region $k_\perp > Q_{cut}$
  $\longrightarrow$ PS region $k_\perp < Q_{cut}$
  (for $n_{Jet} \leq N$)
- Select final state multiplicity and kinematics according to σ_i
- Create shower history by backwards clustering (in $k_\perp$) and identify $2 \longrightarrow 2$ core process
- Reweight ME to obtain exclusive sample
- Start shower at hard scale and veto emission above Q_{cut}



$p_\perp$ of W in W+Jets at DØ

$\longrightarrow$ **Free parameter Q_{cut}**



- In ME with resonant structure
  $\Rightarrow$ (Breit-Wigner improved) Narrow width approximation

$$\mathcal{A}^{(n)} = \mathcal{A}_{\text{prod}}^{(\mathbf{n}_{\text{prod}})} \otimes \prod_i \mathcal{A}_{\text{dec},i}^{(n_i)}$$

- AMEGIC++ provides diagrams for decay chains (full chain and projections on production and decay subamplitudes)
- APACIC++ provides production and decay shower off heavy partons
- **CKKW merging** is applied separately and independently in production and decay

Implemented fully general and applicable e. g. in SUSY decay chains.

- Determine kinematics according to full resonant ME
- Add parton evolution of intermediate heavy quark

PS in production

- Heavy quark keeps its mass
- On-shell daughter partons
  $\longrightarrow$ new decay kinematics via Lorentz boost into new rest frame of heavy quark

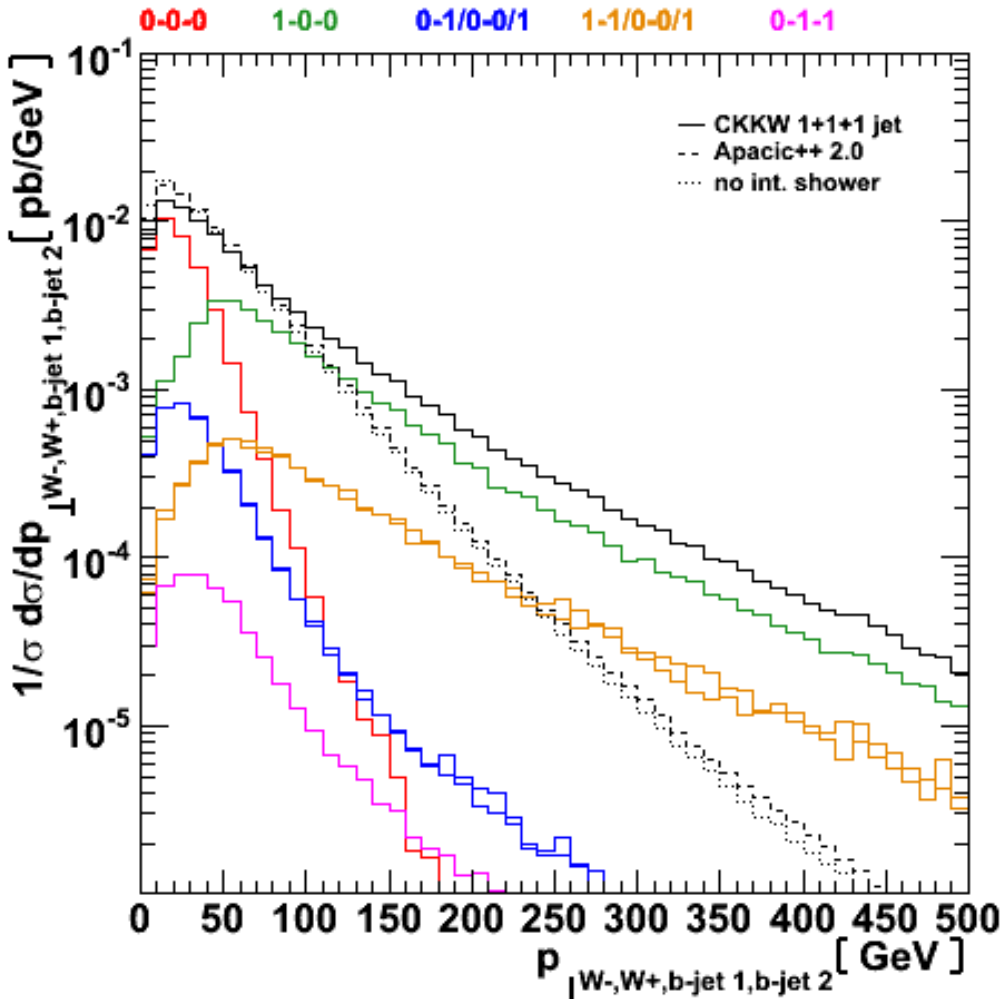
PS in decay

- Heavy quark mass reduced
- Off-shell daughter partons
  $\longrightarrow$ reconstruction of daughter kinematics by scaling their momenta

- Apply CKKW seperately and independently to production and each decay
  $\longrightarrow$ yields all combinations of parton multiplicities in ME up to

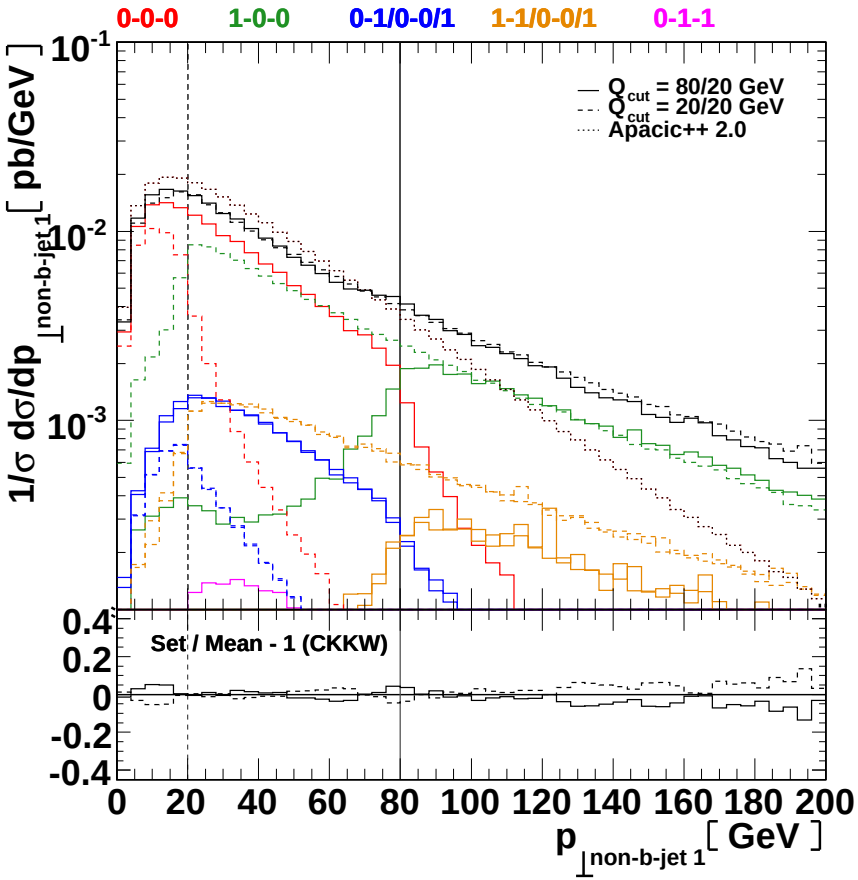
$$\mathrm{N} = \mathrm{N}_{\mathrm{prod}} \otimes \prod_i \mathrm{N}_{\mathrm{dec},i}$$

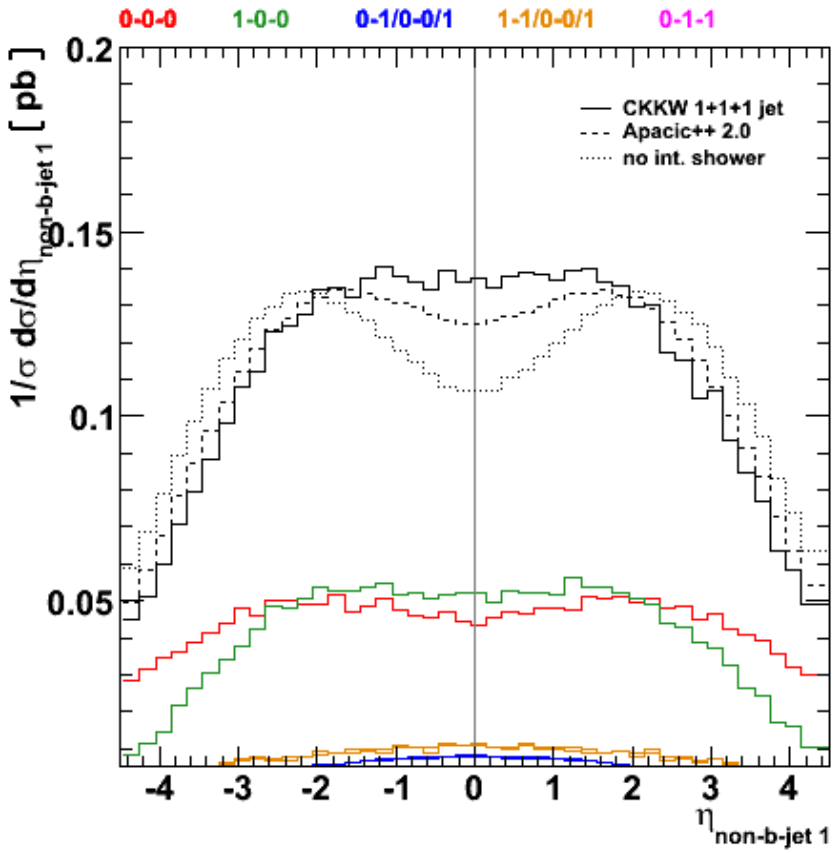
ttbar production at LHC (dileptonic)



- $p_\perp$ of reconstructed ttbar pair using the b-jets and lepton-neutrino pairs

ttbar production at LHC (dileptonic)



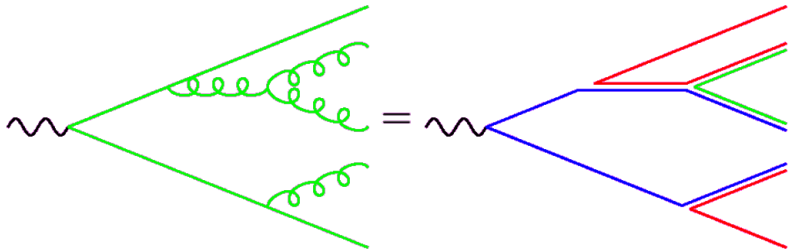


New features of SHERPA-1.1

- new physics version SHERPA-1.1 released in April '08
- current bugfix version SHERPA-1.1.2
- new physics modules introduced:
  - AHADIC++: cluster fragmentation
  - HADRONS++: hadron and τ decay module
  - PHOTONS++: higher order QED corrections
- next physics release will be SHERPA-1.2 ($\sim$ end of 2008)

AHADIC++: cluster fragmentation

- Large N_C-limit, gluons split non-perturbatively into $q\bar{q}$
- Colour connected pairs form colourless clusters



- After evolution in parton showers: colour singlets close in phase space
- Clusters ($\approx$ excited hadrons) decay into clusters or hadrons
- Splittings $\propto \alpha_s(p_\perp)/p_\perp^2$ with non-perturbative α_s (tunable)
- Limit allowed $p_\perp$ in gluon splitting
- Include diquarks throughout
- Use dipole splitting kinematics

HADRONS++: hadron and τ decays

- Decay kinematics according to matrix elements with form factors
- Kinematical corrections for spin correlations
- Treatment of neutral meson mixing and related CP violation

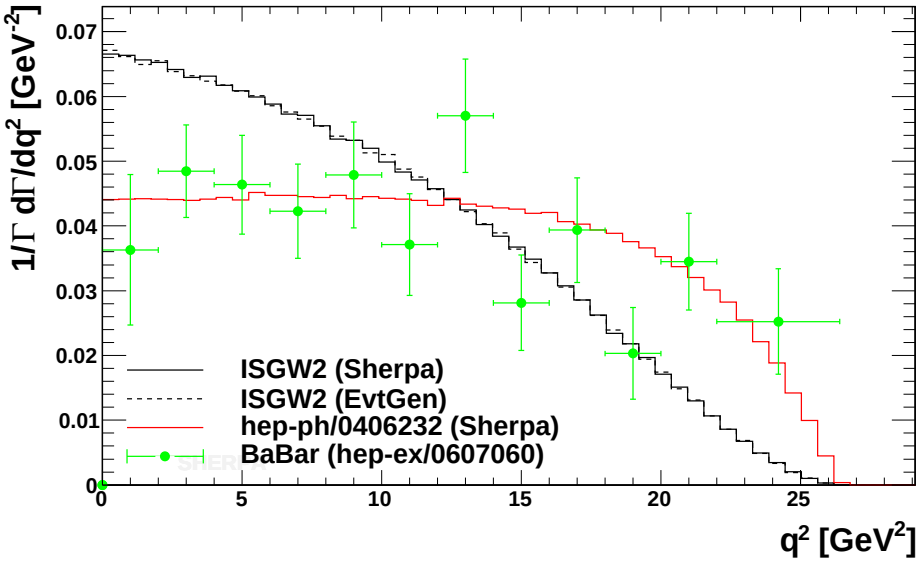
Other features

- Mass smearing of unstable resonances
- Partonic decays for incomplete decay tables

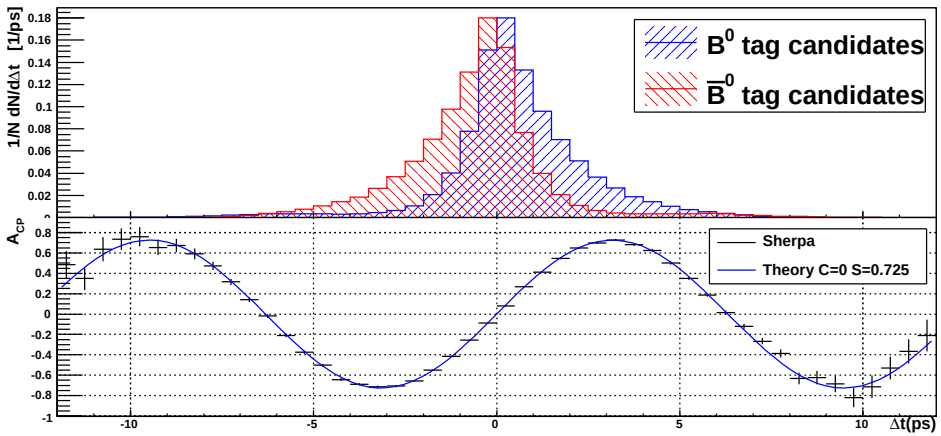
Status

- Decay tables for $\approx$ 400 particles
- $\approx$ 2500 decay channels
- $\approx$ 400 decay channels with form factors

HADRONS++: results



inv. mass of ℓ-ν pair in $B^+ \to \pi^0 e^+ \nu_e$

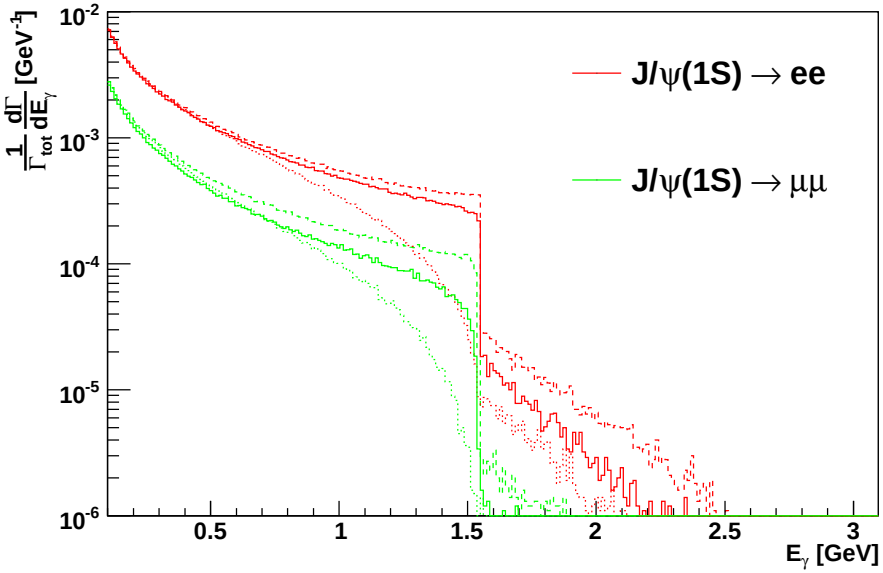


CP violation in the interference $B^0 \to J/\psi K_S$ and $\bar{B}^0 \to J/\psi K_S$

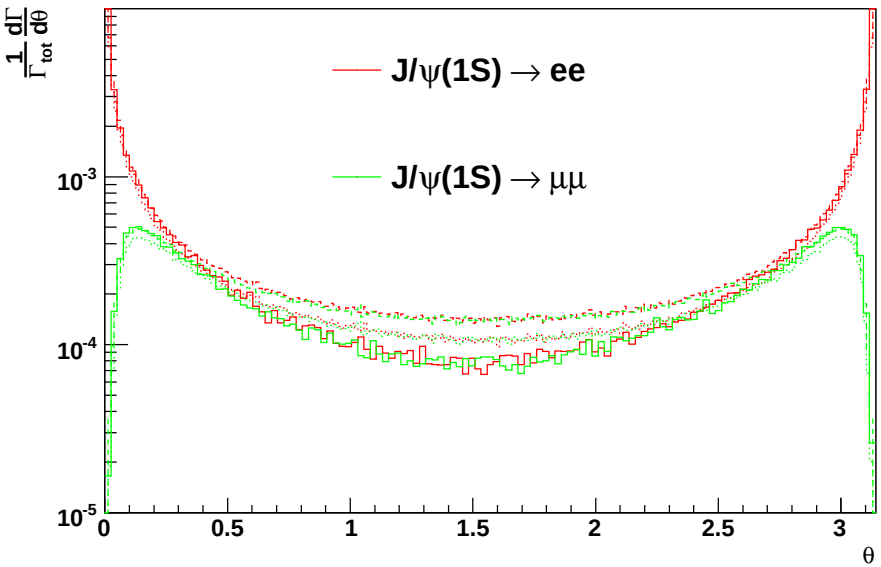
PHOTONS++: Corrections for higher order QED effects

- Sums all contributions of soft photon radiation (real and virtual) using the Yennie-Frautschi-Suura-Formalism (YFS) Ann.Phys.13(1961)379-452
  $\Rightarrow$ exact as $k \to 0$, perturbative series for hard emission effects
- Hard emission effects up to $\mathcal{O}(\alpha)$ incorporated generally via approximated matrix elements in the quasi-collinear limit
- Important cases with $\mathcal{O}(\alpha)$ real and/or virtual exact matrix elements $V^0 \to FF$, $V^0 \to SS$, $S^0 \to FF$, $S^0 \to SS$, $\tau \to \ell\nu_\ell\nu_\tau$, $W \to \ell\nu_\ell$
- ME corrections for radiative semi-leptonic meson decays $(1 \to 3 + \gamma)$ $S \to V/S\ell\nu$ in near future
- Implemented for hadron and τ decays
- No limitation on final state complexity
- Hadrons treated as point-like, improvement needs form factor models $\to$ process dependent

PHOTONS++: results, example $J/\psi \to \ell\ell$



total energy radiated
in J/ψ rest frame



angular radiation pattern
in ℓ-ℓ rest frame

—— ME corrected $\mathcal{O}(\alpha)$

- - - coll. approx. $\mathcal{O}(\alpha)$ correction

····· soft resummation only

PHOTONS++: comparison to data

	$\frac{\Gamma(\mu\to e\nu_e\nu_\mu\gamma)}{\Gamma(\mu\to e\nu_e\nu_\mu,incl.)}$	$\frac{\Gamma(\tau\to e\nu_e\nu_\tau\gamma)}{\Gamma(\tau\to e\nu_e\nu_\tau,incl.)}$	$\frac{\Gamma(\tau\to \mu\nu_\mu\nu_\tau\gamma)}{\Gamma(\tau\to \mu\nu_\mu\nu_\tau,incl.)}$
PDG	0.014(4)	0.09(1)	0.021(3)
PHOTONS++	0.0147(1)	0.0999(3)	0.0233(2)

A comparison of the branching ratios of the radiative leptonic μ and τ decay mode ($E_\gamma > 10$MeV) in relation to their inclusive leptonic mode calculated by PHOTONS++ and the PDG world avarage. The number in brackets reflects the absolute error on the last digit.

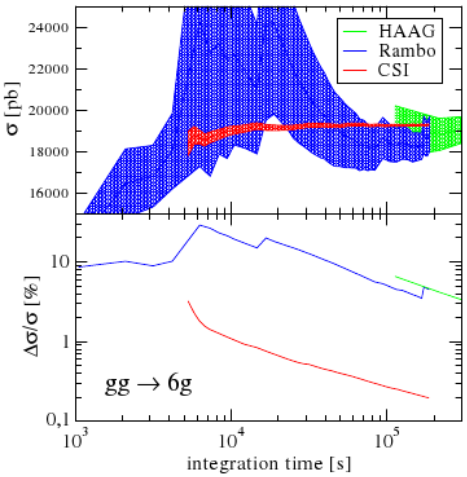
High multiplicity matrix elements: COMIX

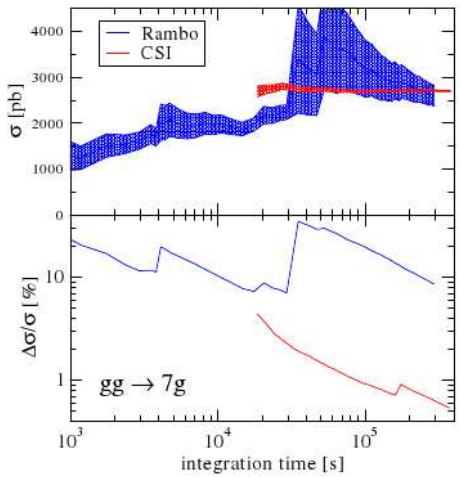
- Revisited Berends-Giele recursion: JHEP08(2006)062
  $\Rightarrow$ new matrix element generator COMIX
- Fully general implementation of SM interactions, e. g.
  - pp $\longrightarrow W/Z +$ N jets (N up to 6, all partons)
  - pp $\longrightarrow$ N jets $+ t\,[W^+b +$ M jets$]\;\bar{t}\,[W^-\bar{b} +$ M jets] (N/M up to 2/1)
  - pp $\longrightarrow$ N gluons (N up to 12)
  - pp $\longrightarrow$ N jets (N up to 8, all partons)

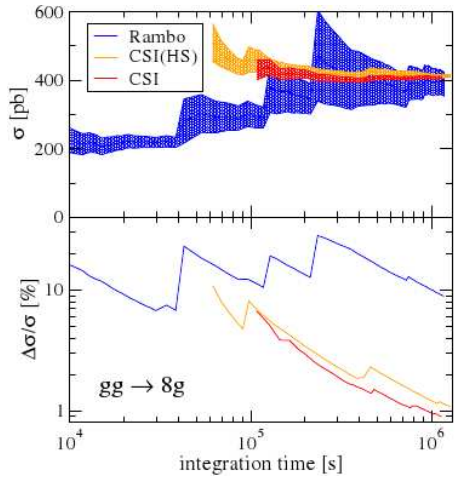
Example from MC4LHC comparison vs. COMIX

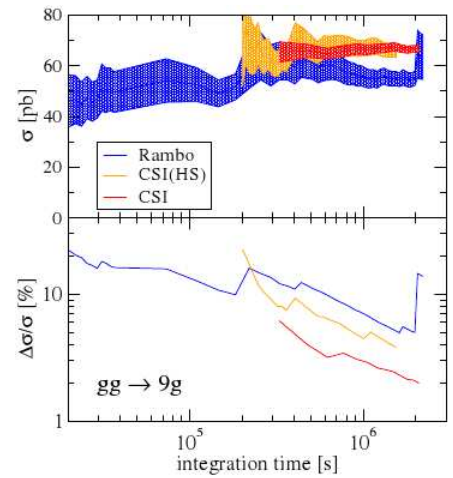
σ [pb]	Number of jets						
$e^-e^+ +$ QCD jets	0	1	2	3	4	5	6
COMIX	723.5(4)	187.9(3)	69.7(2)	27.14(7)	11.09(4)	4.68(2)	2.02(2)
ALPGEN	723.4(9)	188.3(3)	69.9(3)	27.2(1)	10.95(5)	4.6(1)	1.85(1)
AMEGIC++	723.0(8)	188.2(3)	69.6(2)	27.21(6)	11.1(1)		

COMIX: Colour Sampling Integrator (CSI)









Overall integration performance for multi-gluon scattering.

HAAG with colour- and helicity-summed ME's with CSW recursion relations - arXiv:0808.3672

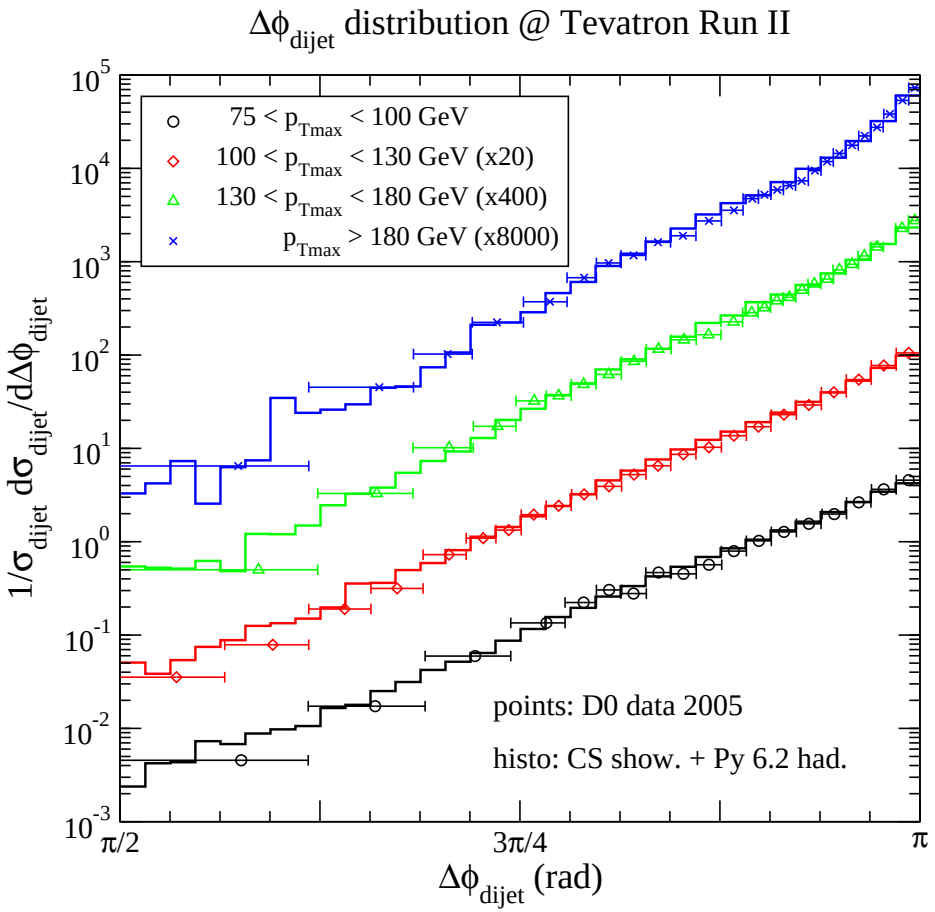
Rambo with colour- and helicity-sampled ME's

CSI with colour-sampled and helicity-summed ME's

CSI(HS) with colour- and helicity-sampled ME's

CSSHOWER++

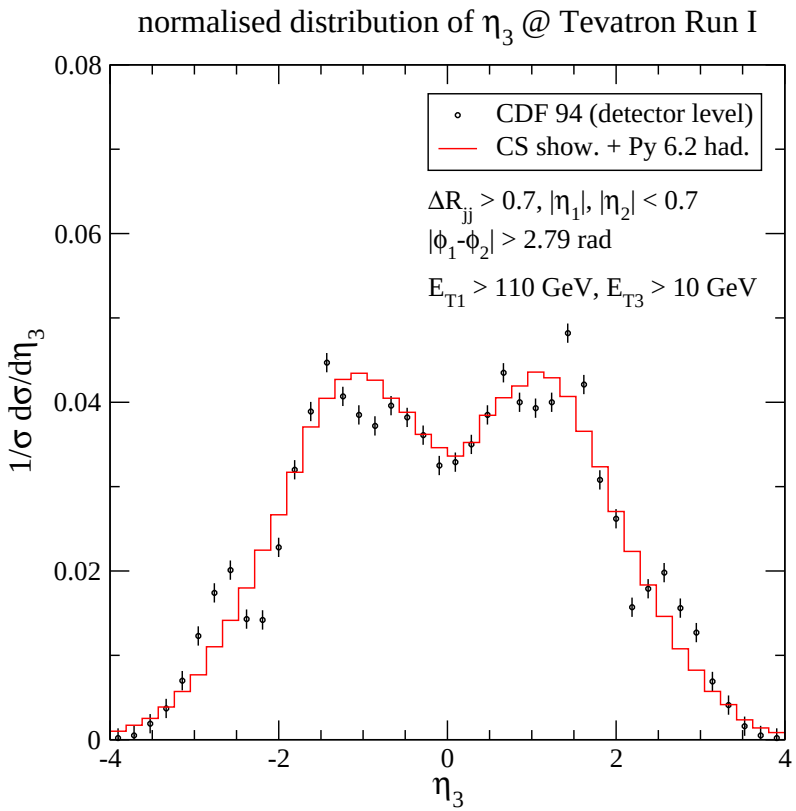
- Based on Catani-Seymour dipole subtraction
- Dipole terms can be used to describe splittings
- Correct soft & collinear limits, better treatment of colour coherence

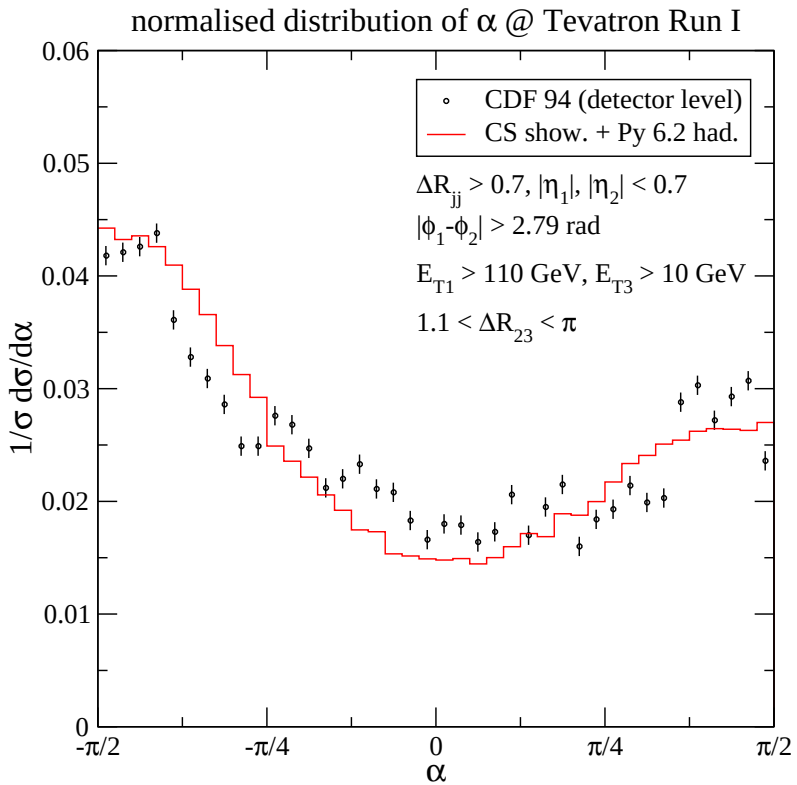


Azimuthal decorrelation in dijet events with DØ data (Run II)

CSSHOWER++: colour coherence

$$\alpha = \arctan\left[\mathrm{sign}(\eta_2)\,\frac{\eta_3-\eta_2}{\phi_3-\phi_2}\right]$$





η_3 and α distribution of third hardt jet in inclusive QCD three-jet production with CDF data at Tevatron Run I. Experimental errors are statistical only.

SHERPA-1.2

- More flexible signal process handling, combine multiple ME generators for different subprocesses in same run
- Merging between all combinations of shower and matrix element generators

AMEGIC++ / COMIX $\Longleftrightarrow$ APACIC++ / CSSHOWER++

- Inclusive decays, including spin correlations, finite width treatment

Conclusion

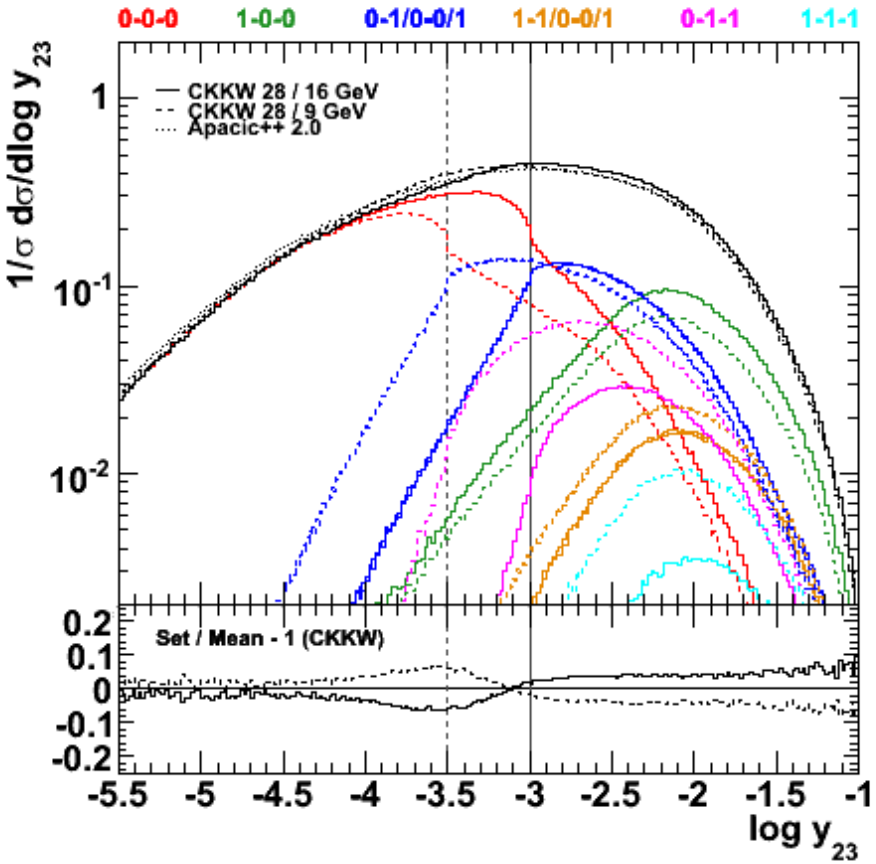
- CKKW implementation generalised for production and decay of heavy strongly interacting resonances
  $\longrightarrow$ more elaborate ttbar simulation
- New physics modules make SHERPA complete hadron level event generator
- New ME generator will make high FS multiplicities available
  $\longrightarrow$ needed especially for SM background to BSM physics
- New parton shower and generalised CKKW merging will allow for improved ME-PS merging

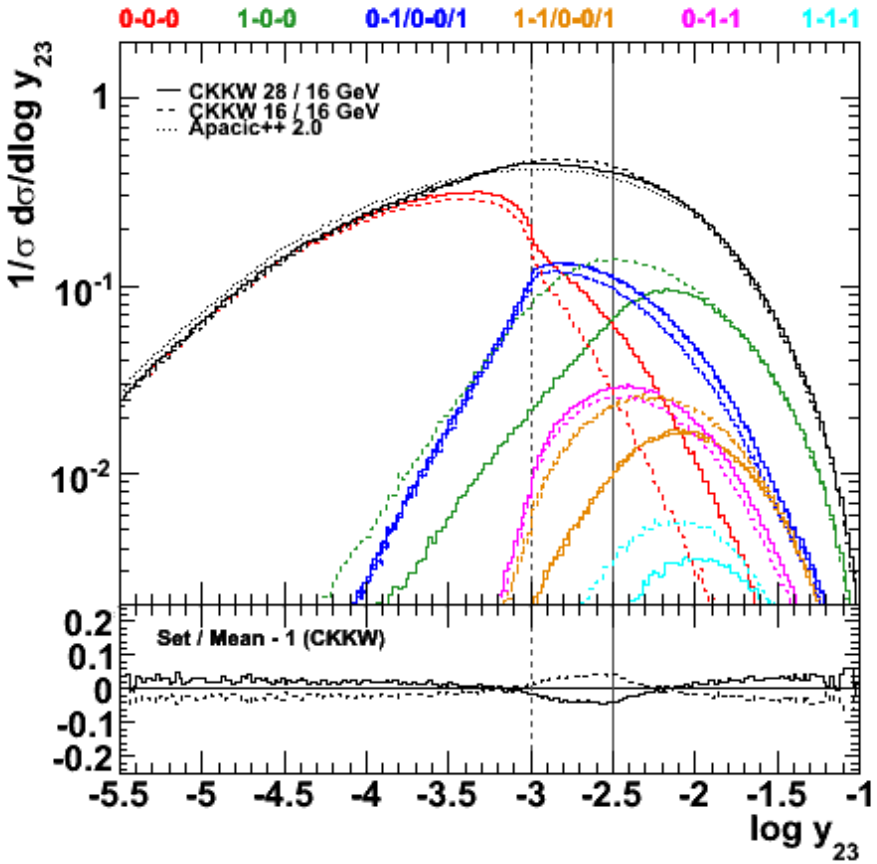
`http://sherpa-mc.de`

- Downloads, updates, documentation, announcement mailing list
- Support at `sherpa@projects.hepforge.org`

appendix

Differential jet rates for ttbar in e^+e^-





ttbar production at LHC (dileptonic)