Tree-level event generation and the Sherpa Monte Carlo

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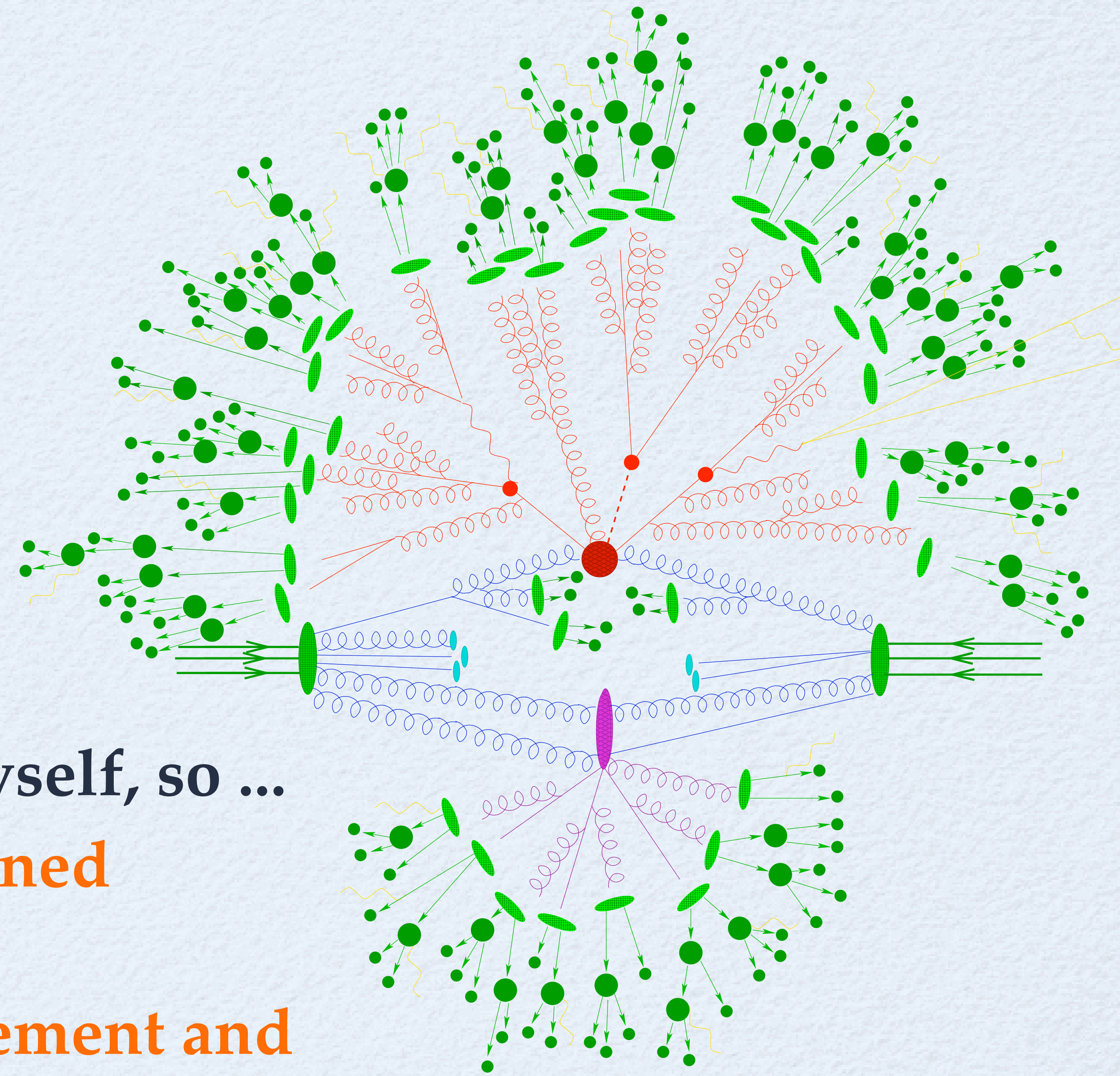
[1] and the other Sherpas T. Gleisberg, F. Krauss, M. Schönherr, S. Schumann, F. Siegert & J. Winter

Tree-Level Monte Carlos

How do they work ?

- Hard matrix elements
- Showers
- Multiple parton interactions
- Hadronisation
- Hadron decays



"Traditional" tree-level MC's like Pythia and HERWIG have been around for longer than myself, so ...

... are tree-level MC's old-fashioned and not up to the task ?

... is there still room for improvement and can this help to solve urgent experimental problems ?

Let's have a look and take Sherpa as an example

Matrix Element Generation

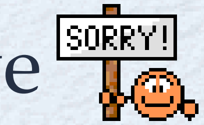
- The task is to generate events (weighted or unweighted) according to the differential cross section
  - ➜ Two steps:
    - Compute the matrix element
    - Sample the phasespace

Sounds trivial, everything is known, right ?
So why does it take us so long to build a tree-level ME generator ?

- The hard matrix element is rather tedious to compute for large final state multiplicities, even at tree-level ($pp \to W$+5jets has about 7000 diagrams)
- We have a high-dimensional phasespace with a most commonly sharply peaked integrand

The simple solution: restrict it to $2 \to 2$ and let showers do the rest
If we want something better, we have to try harder ...

Matrix Element Generation

Commonly used techniques to evaluate the ME (non-exhaustive 

)

- Pre-compute
  - Fast and easy
  - Lacks generality, low multis

  Pythia, HERWIG
- Diagrammatic techniques
  - Very flexible
  - Medium multis

  MadGraph, CompHEP, AMEGIC++
- Recursive techniques
  - Very flexible, high multis
  - Slow at low multis

  HELAC, Comix

part of Sherpa (AMEGIC++, Comix)

On top of that we have a choice ...

... sample or sum over colours ?

... sample or sum over helicities ?

... depends on what it costs ...

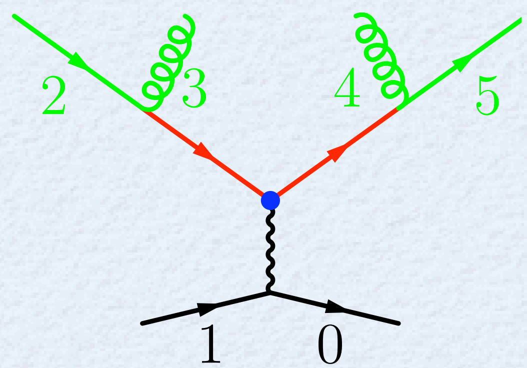
... the colour sum is tedious, because SU(3) is a nasty group

... the helicity sum is easy, because we can recycle subamplitudes

Matrix Element Generation

Commonly used technique to evaluate the multi-particle phasespace

- Guess the peak structure of the integrand from the dynamics of the process Nucl. Phys. B9 (1969) 568



$$\leftrightarrow \quad \mathbf{D}_{\mathrm{iso}}(\mathbf{23},\mathbf{45}) \otimes \mathbf{P}_0(\mathbf{23}) \otimes \mathbf{P}_0(\mathbf{45}) \otimes \mathbf{D}_{\mathrm{iso}}(\mathbf{2},\mathbf{3}) \otimes \mathbf{D}_{\mathrm{iso}}(\mathbf{4},\mathbf{5})$$

- Combine channels corresponding to single diagrams into a multi-channel and optimise CPC 83(1994)141
- Refine single integration channels with VEGAS CLNS-08/447 (1980)

Other, less optimal / general techniques exist, like Rambo & HAAG

The nasty part are correlation and interference effects in the ME, which often render the optimisation cumbersome !

Colour- and / or helicity-sampling introduces additional d.o.f.

Tree-level ME generators

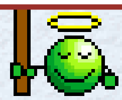
- Example: ME-Generator comparison in context of MC4LHC
  http://indico.cern.ch/categoryDisplay.py?categId=152 (2004)

X-sects (pb)	$e^-\bar{\nu}_e + n$ QCD jets						
Number of jets	0	1	2	3	4	5	6
ALPGEN	3904(6)	1013(2)	364(2)	136(1)	53.6(6)	21.6(2)	8.7(1)
AMEGIC++	3908(3)	1011(2)	362.3(9)	137.5(5)	54(1)		
CompHEP	3947.4(3)	1022.4(5)	364.4(4)				
GR@PPA	3905(5)	1013(1)	361.0(7)	133.8(3)	53.8(1)		
JetI	3786(81)	1021(8)	361(4)	157(1)	46(1)		
dEvent	3902(5)	1012(2)	361(1)	135.5(3)	53.6(2)		

cts (pb)	$e^+\nu_e + n$ QCD jets						
Number of jets	0	1	2	3	4	5	6
ALPGEN	5423(9)	1291(13)	465(2)	182.8(8)	75.7(8)	32.5(2)	13.9(2)
AMEGIC++	5432(5)	1277(2)	466(2)	184(1)	77.3(4)		
CompHEP	5485.8(6)	1287.5(7)	467.3(8)				
GR@PPA	5434(7)	1273 (2)	467.7(9)	181.8(5)	76.6(3)		
JetI	5349(143)	1275(12)	487(3)	212(2)			
MadEvent	5433(8)	1277(2)	464(1)	182(1)	75.9(3)		

Sherpa uses AMEGIC++

And we like to fill these, too !

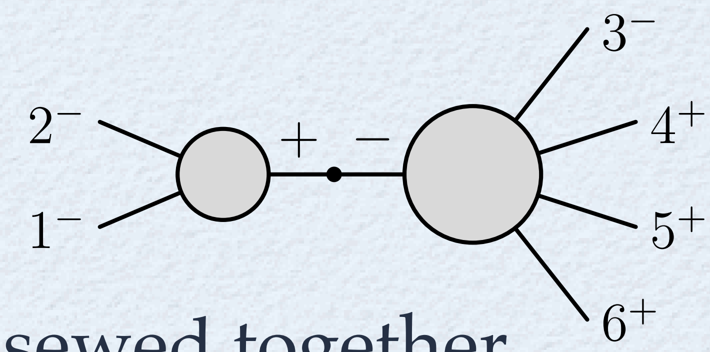


High-multi ME's with CSW

T. Gleisberg, SH, F. Krauss, R. Matyskiewicz; arXiv:0808.3672 [hep-ph]

For large multis we need something better than Feynman diagrams ...

- Twistor-inspired techniques (CSW rules) said to speed up calculation of high multiplicy pure QCD ME's



- Advantage: Up to $\mathbf{N_{out} = 7}$ only up to 3 MHV-amps sewed together

... sounds promising, so how far can we really go with it ?

$pp \to n$ jets gluons only	$n = 2$	$n = 3$	$n = 4$	$n = 5$	$n = 6$
MC cross section [pb]	$8.915 \cdot 10^7$	$5.454 \cdot 10^6$	$1.150 \cdot 10^6$	$2.757 \cdot 10^5$	$7.95 \cdot 10^4$
stat. error	0.1%	0.1%	0.2%	0.5%	1%
	integration time for given stat. error [s]				
CSW (HAAG)	4	165	1681	12800	$2 \cdot 10^6$
CSW (CSI)	-	480	6500	11900	197000
AMEGIC (HAAG)	6	492	41400	-	-
COMIX (RPG)	159	5050	33000	38000	74000
COMIX (CSI)	-	780	6930	6800	12400

Oops !

Why BG Recursive Relations ?

C. Duhr, F. Maltoni, SH: JHEP 08 (2006) 062

Apparently, for very large multis we need something even better ...

- QCD: Comparison with BCFW/CSW method shows superiority of CDBG/Dyson-Schwinger algorithms **for numerics**

Computation time $2 \to n$ gluon ME for 10^4 phase space points, sampled in helicity and colour

CO → colour ordered

CD → colour dressed

Final State	BG		BCF		CSW	
	CO	CD	CO	CD	CO	CD
$2g$	0.24	0.28	0.28	0.33	0.31	0.26
$3g$	0.45	0.48	0.42	0.51	0.57	0.55
$4g$	1.20	1.04	0.84	1.32	1.63	1.75
$5g$	3.78	2.69	2.59	7.26	5.95	5.96
$6g$	14.2	7.19	11.9	59.1	27.8	30.6
$7g$	58.5	23.7	73.6	646	146	195
$8g$	276	82.1	597	8690	919	1890
$9g$	1450	270	5900	127000	6310	29700
$10g$	7960	864	64000	-	48900	-

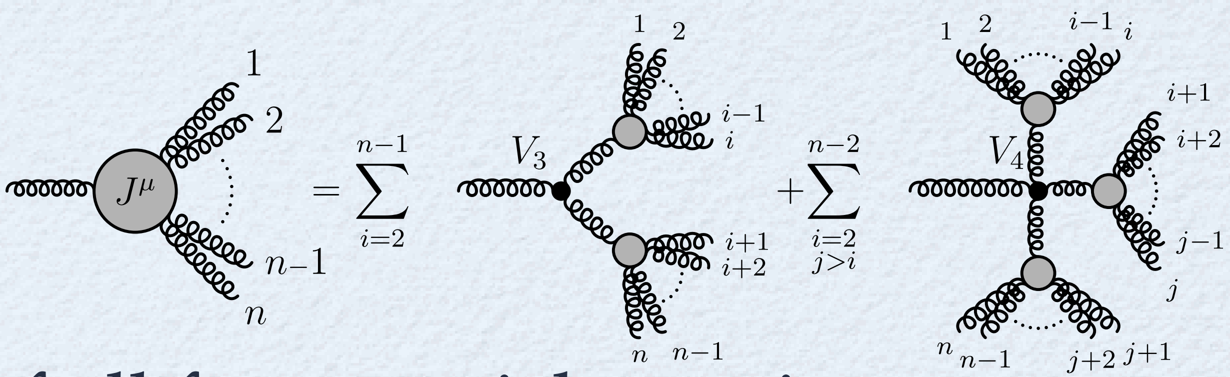
Factorial growth tamed !
Now exponential (~3^n)

Other methods much slower due to unsuitable natural color basis and/or large number of vertices

Very high-multi ME's: COMIX

T. Gleisberg, SH: JHEP12(2008)039

- BG recursion can be generalised
  - ➡ New ME generator **COMIX**



- Fully general SM implementation
- Key point: Vertex decomposition of all four-particle vertices

The growth in computational complexity is solely determined by the number of external legs at the model's vertices

- ME performance in QCD benchmark (2→n gluon)

World record ;-)

gg → ng	Cross section [pb]				
n $\sqrt{s}$ [GeV]	8 1500	9 2000	10 2500	11 3500	12 5000
Comix Phys. Rev. D67(2003)014026 Nucl. Phys. B539(1999)215	0.755(3) 0.70(4) 0.719(19)	0.305(2) 0.30(2)	0.101(7) 0.097(6)	0.057(5)	0.026(1)

Now the ME is really ticked off, but how about the phasespace ?

COMIX: Phasespace recursion

T. Gleisberg, SH: JHEP12(2008)039

- State-of-the art in phasespace generation: factorise PS using

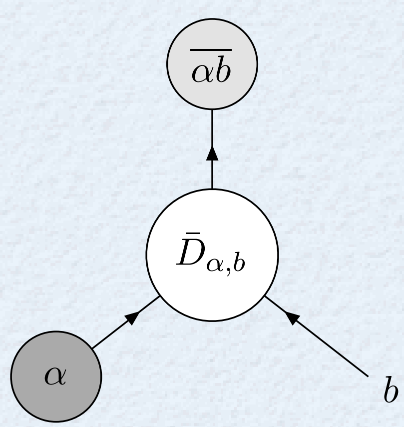
$$\mathrm{d}\boldsymbol{\Phi}_{\mathbf{n}}\left(\mathbf{a},\mathbf{b};\mathbf{1},\ldots,\mathbf{n}\right)=\mathrm{d}\boldsymbol{\Phi}_{\mathbf{m}}\left(\mathbf{a},\mathbf{b};\mathbf{1},\ldots,\mathbf{m},\bar{\pi}\right)\,\mathrm{d}\mathbf{s}_{\pi}\,\mathrm{d}\boldsymbol{\Phi}_{\mathbf{n-m}}\left(\pi;\mathbf{m}+\mathbf{1},\ldots,\mathbf{n}\right)$$

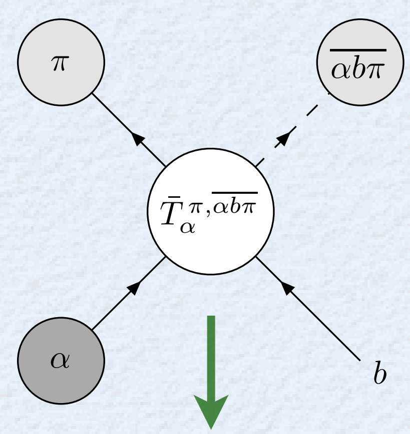
Remaining basic building blocks of the phasespace:

➔ "Propagators" $\mathbf{P}_{\pi}=\begin{cases}\mathbf{1} & \text{if } \boldsymbol{\pi} \text{ or } \overline{\boldsymbol{\pi}} \text{ external}\\ \mathbf{d}s_{\pi} & \text{else}\end{cases}$

➔ "Vertices"

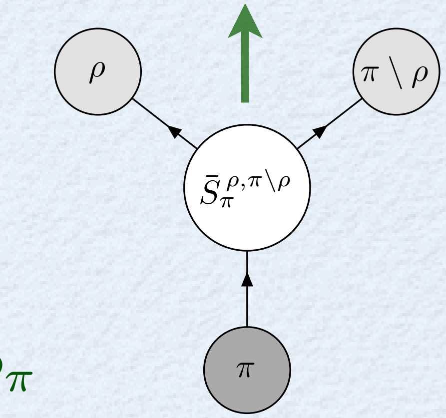
$$(2\pi)^4\,\mathrm{d}^4p_{ab}\,\delta^{(4)}(p_a+p_b-p_{ab})$$





$$\mathbf{T}_{\alpha}^{\,\pi,\overline{\alpha\mathbf{b}\pi}}=\frac{\lambda(\mathbf{s}_{\alpha\mathbf{b}},\mathbf{s}_{\pi},\mathbf{s}_{\overline{\alpha\mathbf{b}\pi}})}{\mathbf{8}\,\mathbf{s}_{\alpha\mathbf{b}}}\,\mathrm{d}\cos\theta_{\pi}\,\mathrm{d}\phi_{\pi}$$

$$\mathbf{S}_{\pi}^{\,\pi,\pi\setminus\rho}=\frac{\lambda(\mathbf{s}_{\pi},\mathbf{s}_{\rho},\mathbf{s}_{\pi\setminus\rho})}{\mathbf{8}\,\mathbf{s}_{\pi}}\,\mathrm{d}\cos\theta_{\rho}\,\mathrm{d}\phi_{\rho}$$



Arrows ➔ Momentum flow

COMIX: Phasespace recursion

T. Gleisberg, SH: JHEP12(2008)039

- Basic idea: Take above recursion literally and "turn it around"
  Example: s-channel phasespace recursion

$$\mathrm{d}\Phi_S(\pi) = \Big[\sum \alpha\left(S_\pi^{\rho,\pi\setminus\rho}\right)\Big]^{-1}$$

$$\times \Big[\sum \alpha\left(S_\pi^{\rho,\pi\setminus\rho}\right)\, S_\pi^{\rho,\pi\setminus\rho}\, P_\rho\, \mathrm{d}\Phi_S(\rho)\; P_{\pi\setminus\rho}\, \mathrm{d}\Phi_S(\pi\setminus\rho)\Big]$$

← Weights for adaptive multichanneling

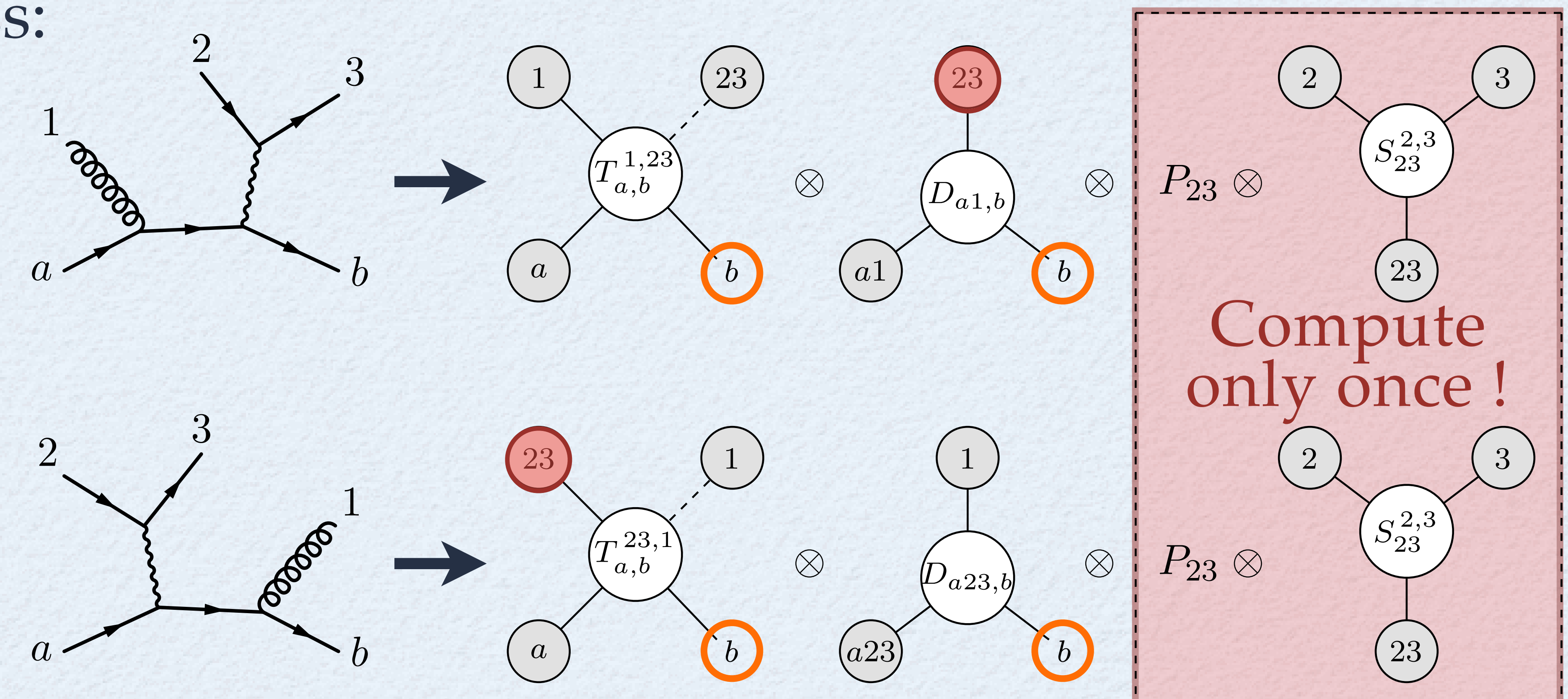
- Example process:
  $pp \to e^+e^-g$

"b" is fixed

↓

Every weight is unique !

(can be labeled by shaded blobs)



COMIX: Performance issues

T. Gleisberg, SH: JHEP12(2008)039

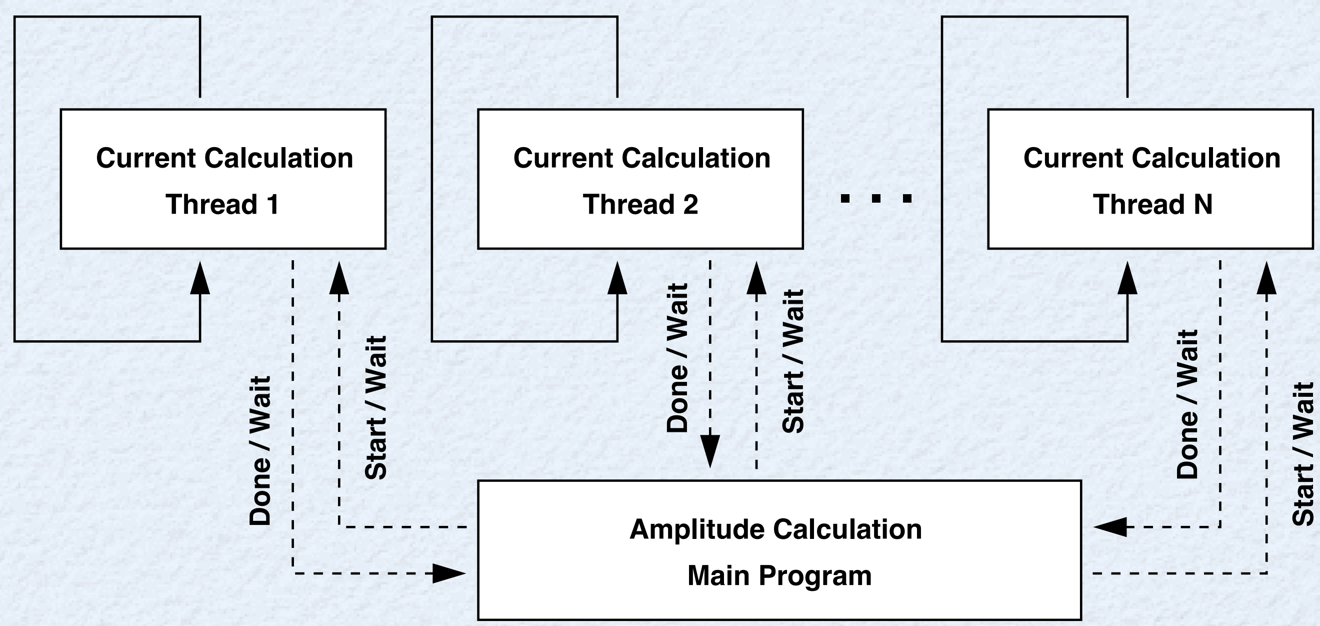
- General structure of recursion (ME and phasespace):

$$\mathcal{J}_\alpha\left(\pi\right) = P_\alpha\left(\pi\right) \sum_{\mathcal{V}_\alpha^{\alpha_1,\,\alpha_2}} \sum_{\mathcal{P}_2(\pi)} \mathcal{S}\left(\pi_1,\pi_2\right)\, \mathcal{V}_\alpha^{\alpha_1,\,\alpha_2}\left(\pi_1,\pi_2\right)\, \mathcal{J}_{\alpha_1}\left(\pi_1\right) \mathcal{J}_{\alpha_2}\left(\pi_2\right)$$

n-particle currents only depend on m<n-particle currents

➡ Straightforward multithreading algorithm

Now you can use as many processors / cores as you like !



Identical procedure for ME and phasespace due to same recursion

Comix: Performance

T. Gleisberg, SH: JHEP12(2008)039

- Example: Drell-Yan+b-pair+jets
  comparison with ALPGEN & AMEGIC++

σ [pb]	Number of jets					
$e^-e^+ + b\bar{b}$ + QCD jets	0	1	2	3	4	5
Comix	18.90(3)	6.81(2)	3.07(3)	1.536(9)	0.763(6)	0.37(1)
ALPGEN	18.95(8)	6.80(3)	2.97(2)	1.501(9)	0.78(1)	
AMEGIC++	18.90(2)	6.82(2)	3.06(4)			

All partons !

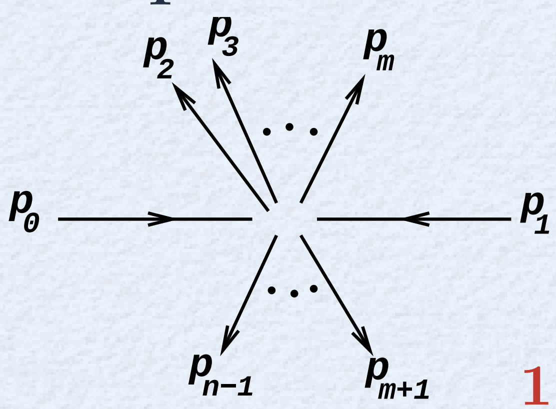
- Example: b-pair + jets
  comparison with ALPGEN & AMEGIC++

σ [μb]	Number of jets						
$b\bar{b}$ + QCD jets	0	1	2	3	4	5	6
Comix	471.2(5)	8.83(2)	1.813(8)	0.459(2)	0.150(1)	0.0531(5)	0.0205(4)
ALPGEN	470.6(6)	8.83(1)	1.822(9)	0.459(2)	0.150(2)	0.053(1)	0.0215(8)
AMEGIC++	470.3(4)	8.84(2)	1.817(6)				

COMIX: PURE QCD PHASESPACE

T. Gleisberg, SH: JHEP12(2008)039

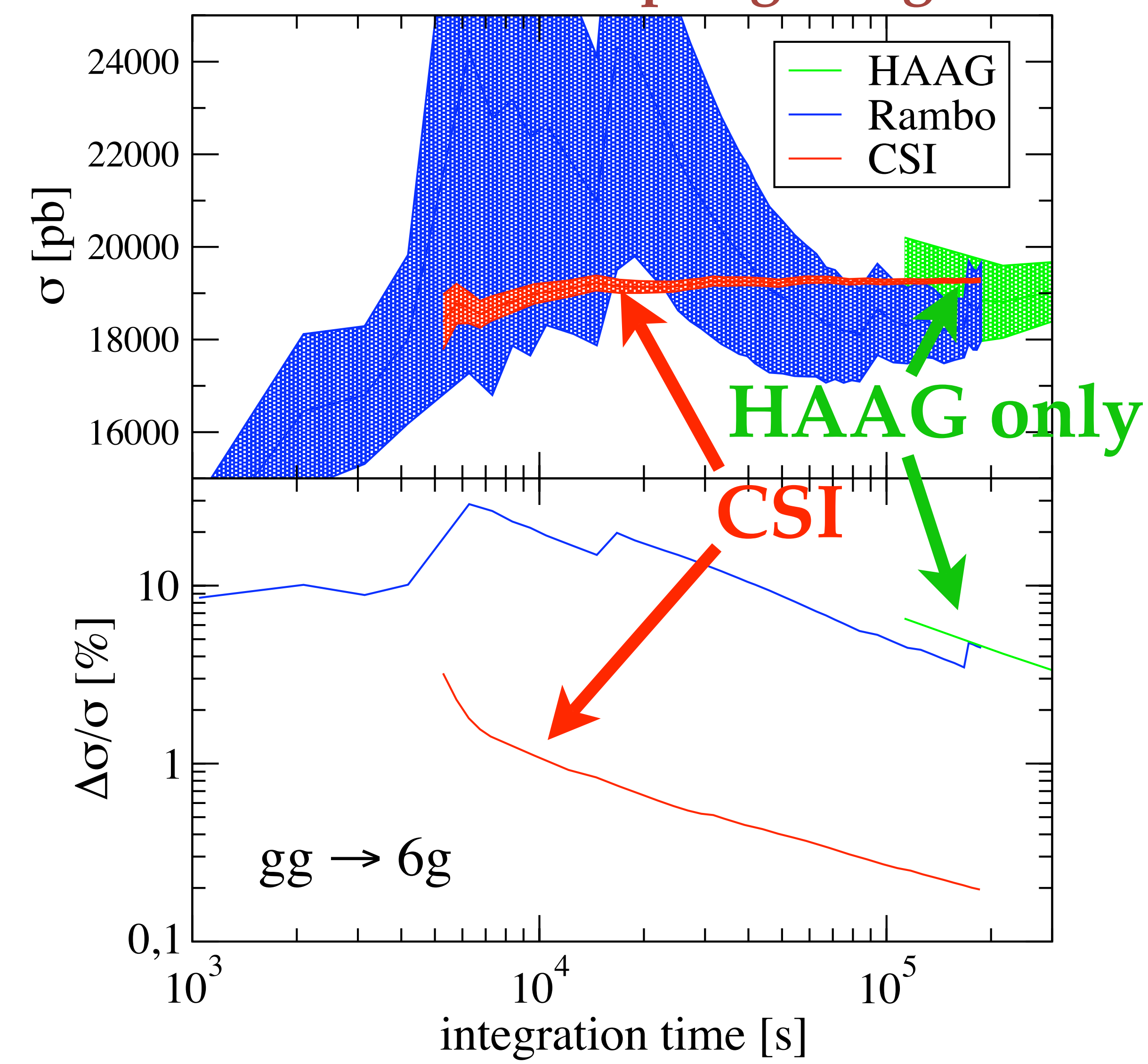
- QCD processes have typical & complicated antenna structure



$$\propto \frac{1}{(p_0p_1)(p_1p_2)\dots(p_{n-2}p_{n-1})(p_{n-1}p_0)}$$

- HAAG can generate momenta according to specific antenna
- Colour configuration defines which HAAG channels needed
- For every phasespace point a multichannel is constructed on the flight ➔ CSI

CSI - Colour Sampling Integrator



We can now generate high multiplicity ME's, so let's carry on ...

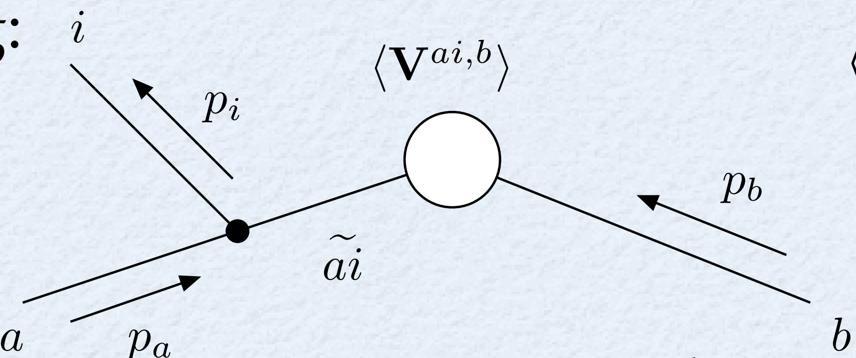
CS-Subtraction based Shower

F.Krauss, S.Schumann; JHEP03(2008)038

Next we need some shower algorithm ...

- Catani-Seymour subtraction terms
  - ➔ General framework for QCD NLO calculations
- Splitting of parton $\tilde{\mathbf{ij}}$ into partons $\mathbf{i}$ and $\mathbf{j}$, spectator $\mathbf{k}$
  - ➔ Momentum reshuffled locally, spectator enters splitting function !

e.g. initial-initial splitting:



$$\langle \mathbf{V^{ai,b}(x_{i,ab})} \rangle = \mathbf{P_{a \to \widetilde{ai}\, i}(x_{i,ab})}$$

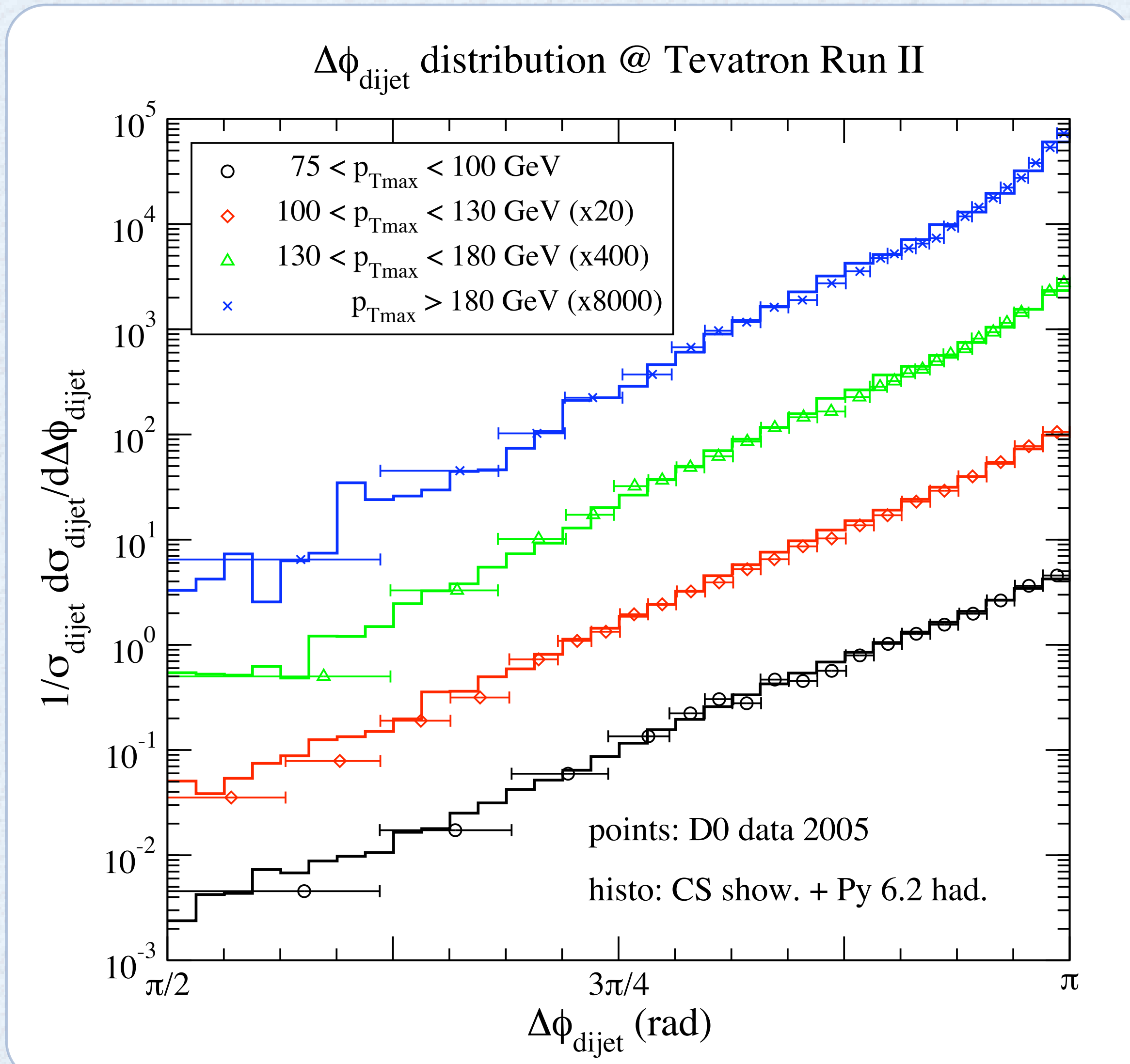
$$\mathbf{x_{i,ab}} = \frac{\mathbf{p_a p_b - p_i p_a - p_i p_b}}{\mathbf{p_a p_b}}$$

- Advantages over conventional Parton Shower
  - ➔ Excellent approximation of ME
  - ➔ Unambiguous kinematics
- Implemented into the Sherpa event generator in full generality (final-final, initial-final and initial-initial dipoles)

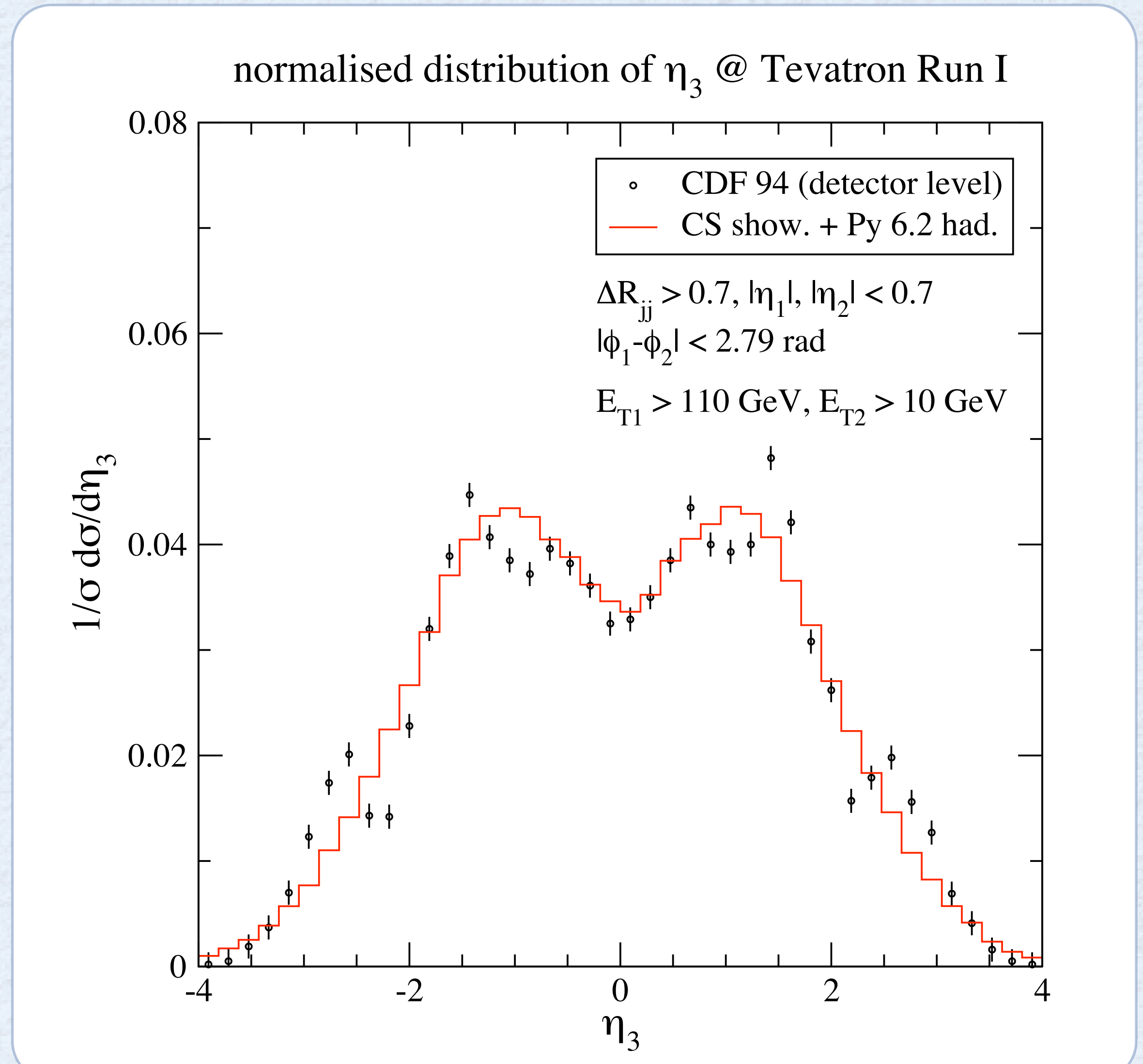
CS-subtraction based shower

F.Krauss, S.Schumann; JHEP03(2008)038

- pp→jets
  Phys. Rev. Lett. 94 (2005) 221801



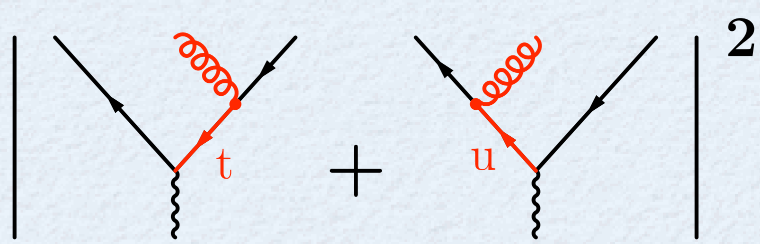
- pp→jets
  Phys. Rev. D50 (1994) 5562



ME+PS: why should we do it ?

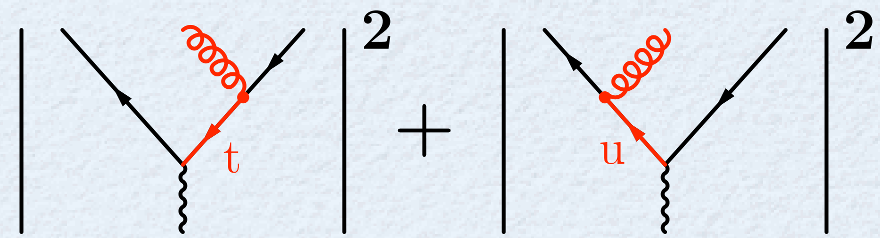
Now that we can compute high-multi ME's and generate showers, we need to combine the two in a sensible way ....

Matrix Elements



- Exact fixed order calculation

Parton Showers



- Resummation to all orders

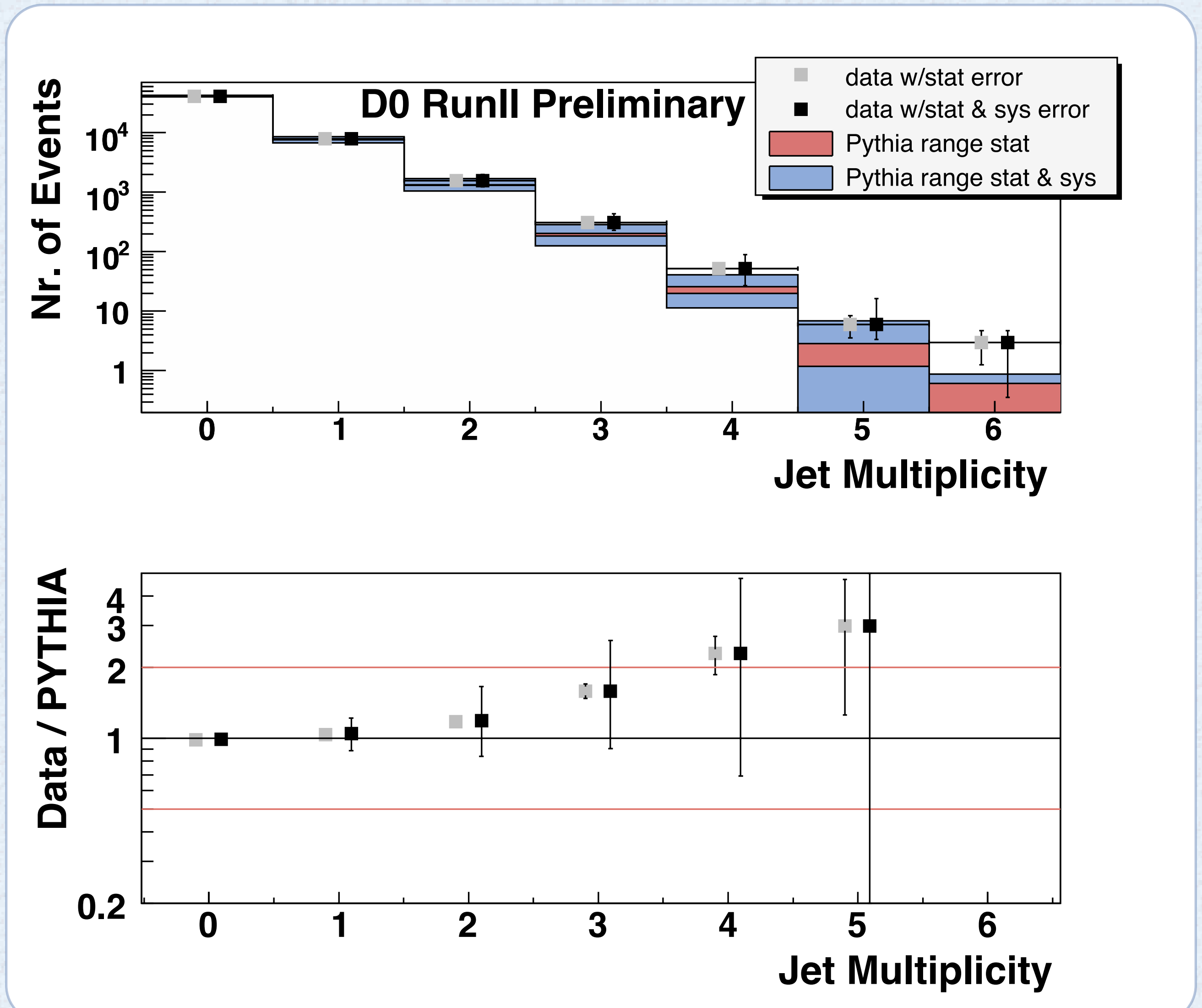
Combine the two: CKKW / CKKW-L / MLM

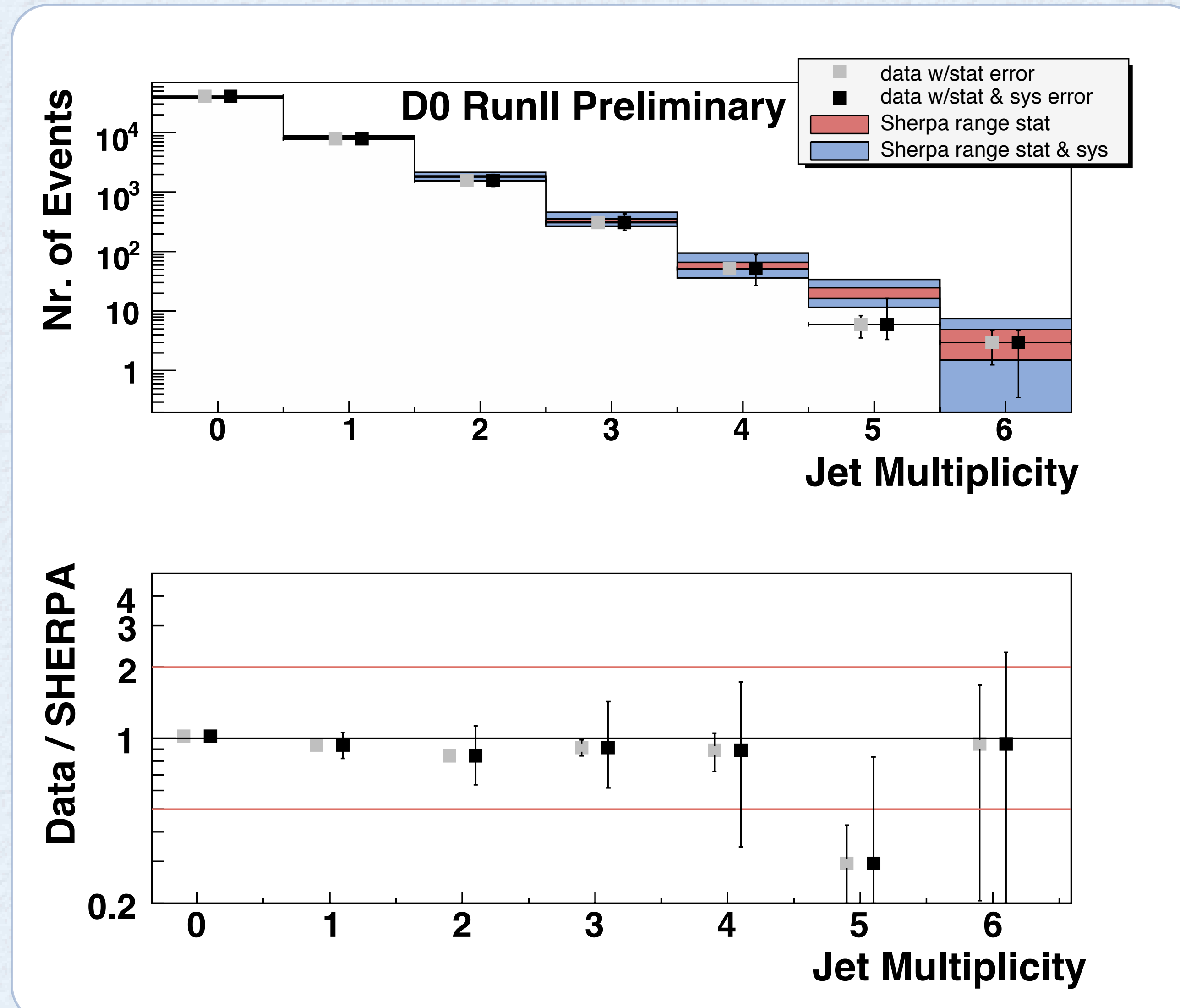
- Good description of hard radiation (ME)
  Correct intrajet evolution (PS)
- Strategy: Separate phase space
  - Jet production region → ME
  - Intrajet evolution region → PS
- **Free parameter: Separation cut Q_{cut}** ($Q \rightarrow K_T$-type jet measure)

CKKW: Z+jets @ Tevatron

The DØ collaboration, DØ note 5066-CONF

- Jet multiplicity





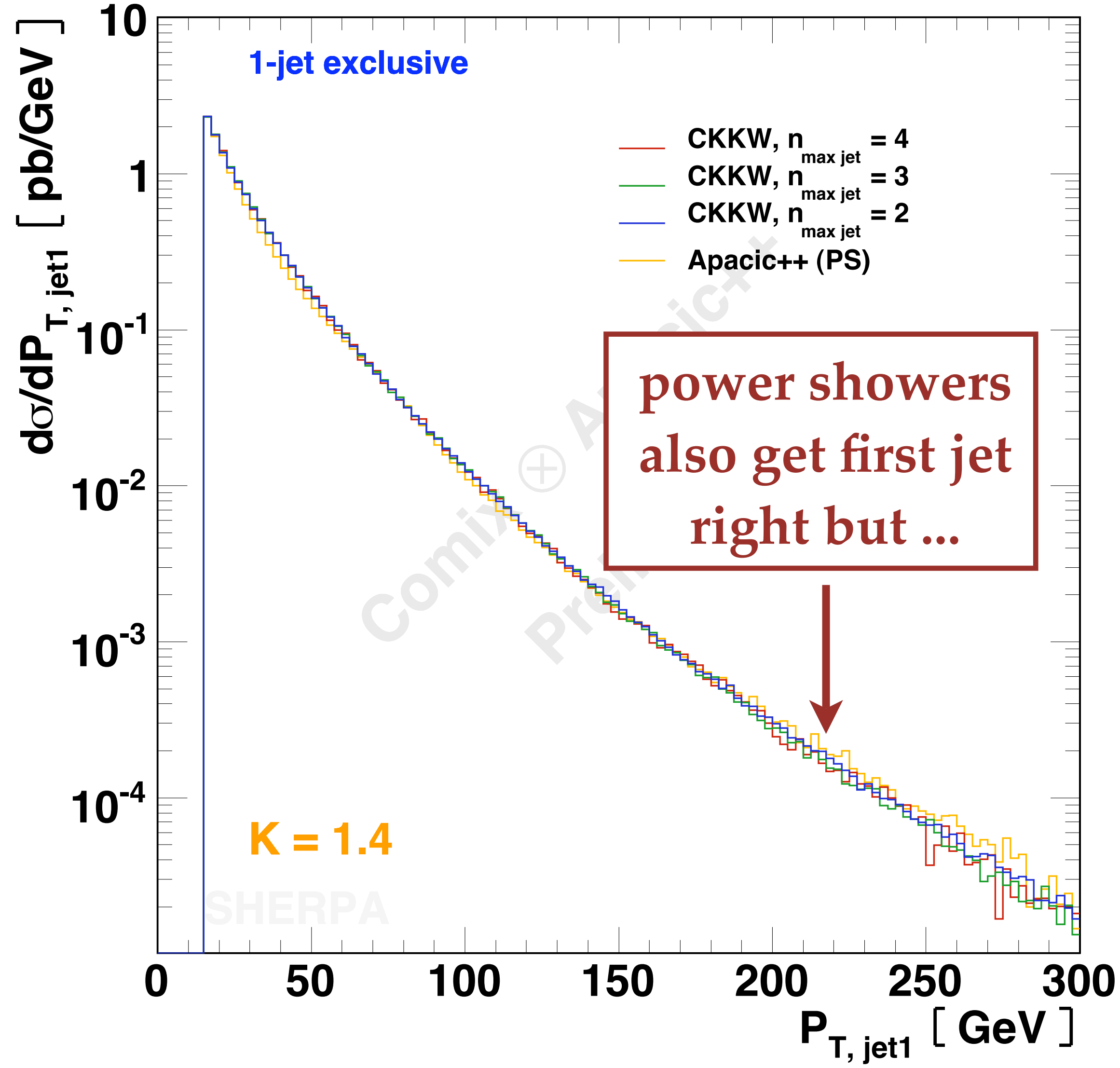
- Pythia 6.2
  normalized to data

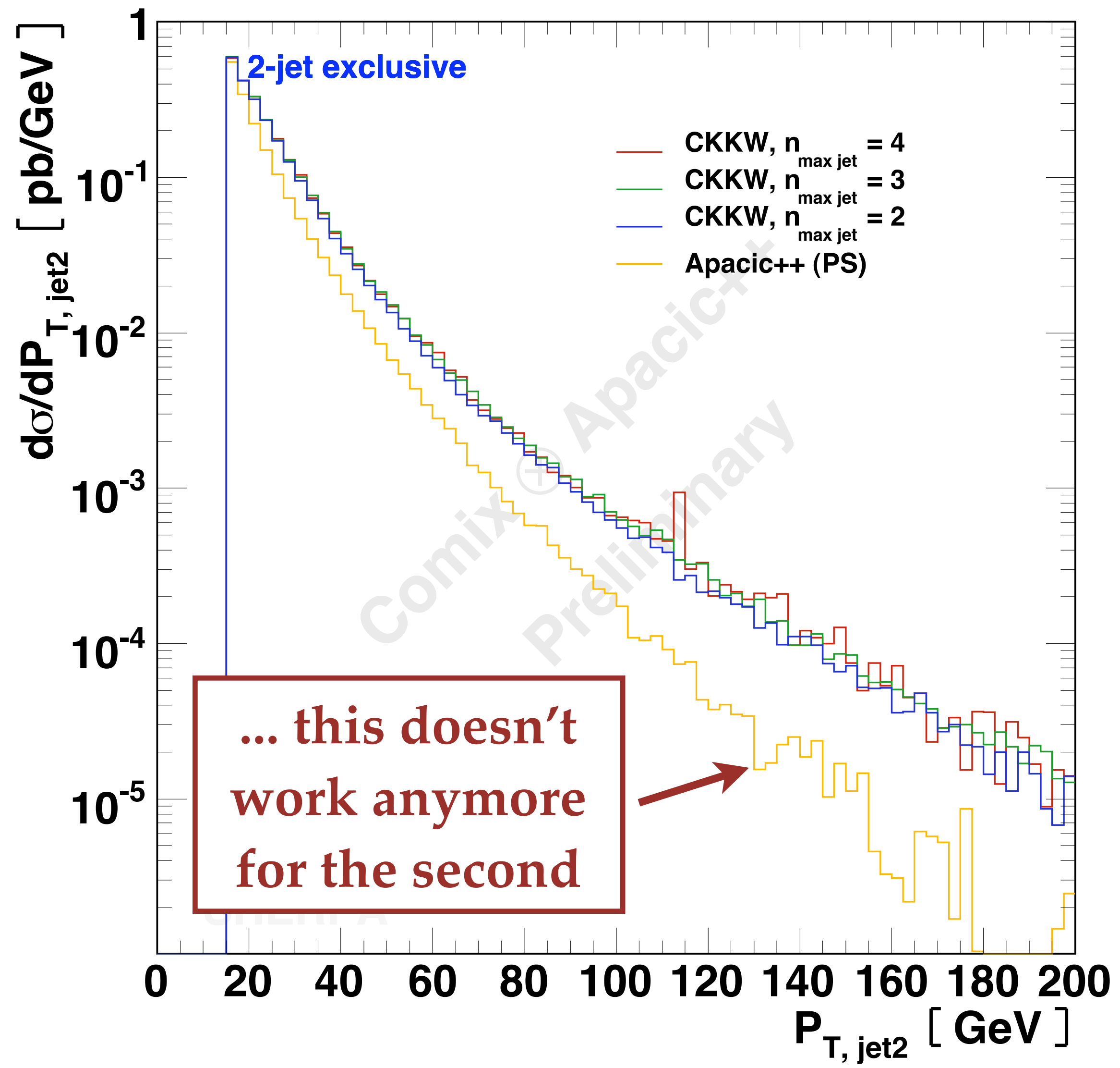
- Sherpa 1.0
  normalized to data

CKKW WITH COMIX

SH, F. Krauss, S.Schumann, F. Siegert: in preparation

- pp→ll+jets at the Tevatron
  exclusive jet-p_T , comparison vs. PS

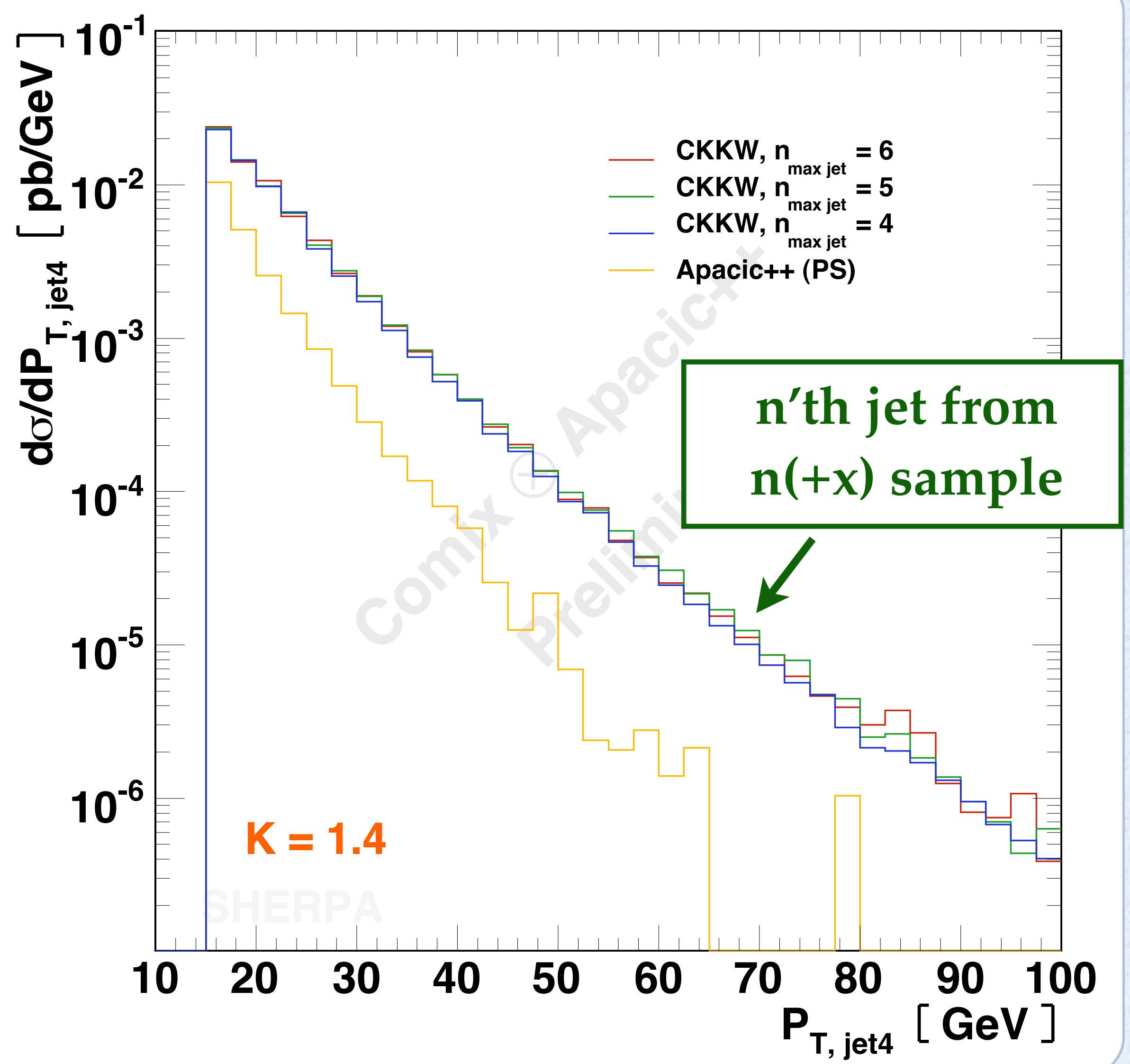


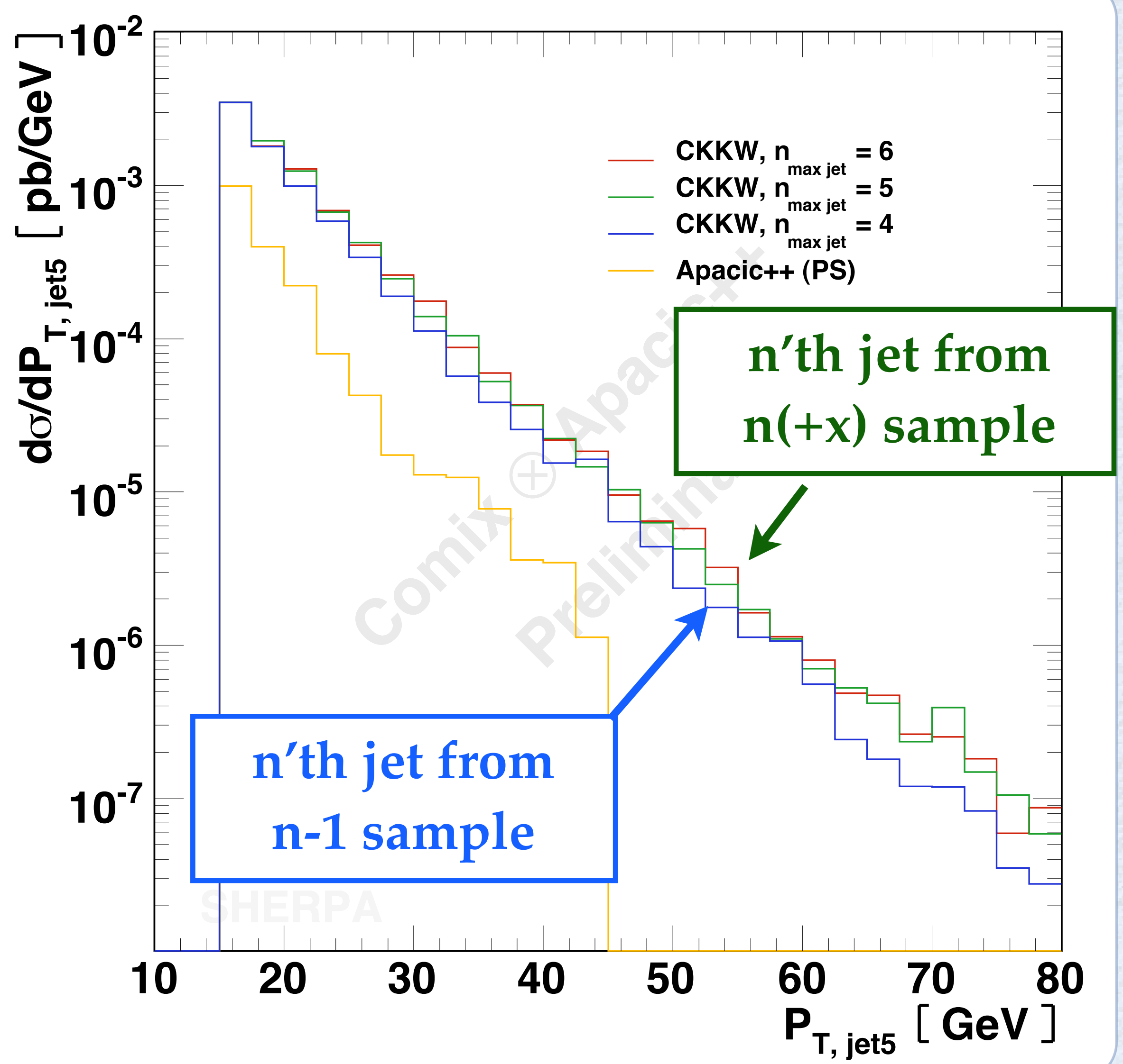


CKKW WITH COMIX

SH, F. Krauss, S.Schumann, F. Siegert: in preparation

- pp→ll+jets at the Tevatron
  inclusive jet-p_T , effect of N_{max} variation



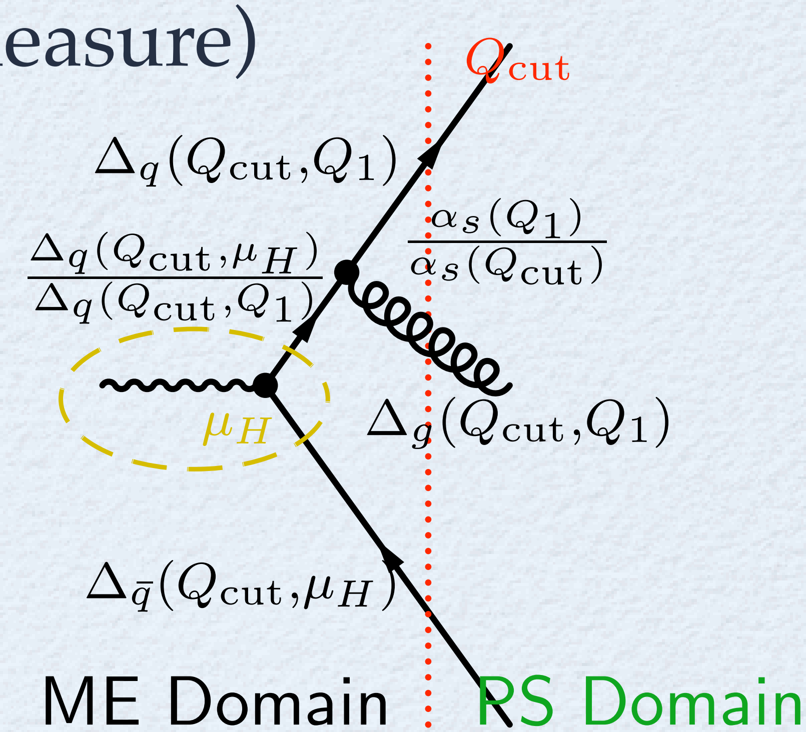


CKKW in a nutshell

JHEP 0111 (2001) 063, JHEP 0208 (2002) 015

Results look promising, but how does it actually work ?

- Define jet resolution parameter Q_{cut} (Q→jet measure)
  ➡ divide phase space into regions of jet production (ME) and jet evolution (PS)
- Select final state multiplicity and kinematics according to σ 'above' Q_{cut}
- K_T-cluster backwards (construct PS-tree) and identify core process
- **Reweight ME** to obtain exclusive samples at Q_{cut}
- Start the parton shower at the hard scale
  Veto all PS emissions harder than Q_{cut}



Procedure is essentially based on NLL-formalism in PLB 269(1991)432
A prominent criticism is the missing proof for initial state evolution, so we need to improve ...

How can we improve this ?

SH, F. Krauss, S.Schumann, F. Siegert: arXiv:0903.1219 [hep-ph]

Results l... ctually work ?

- Define ... →jet measure)
  → div... jet ... (PS)
- Select final state multiplicity and kinematics acc...
- K_T ... and ...
- Re... t Q_{cut}
- Start the parton shower at the hard scale
  ...ns harder th...

... ba... n in PL... ...)432

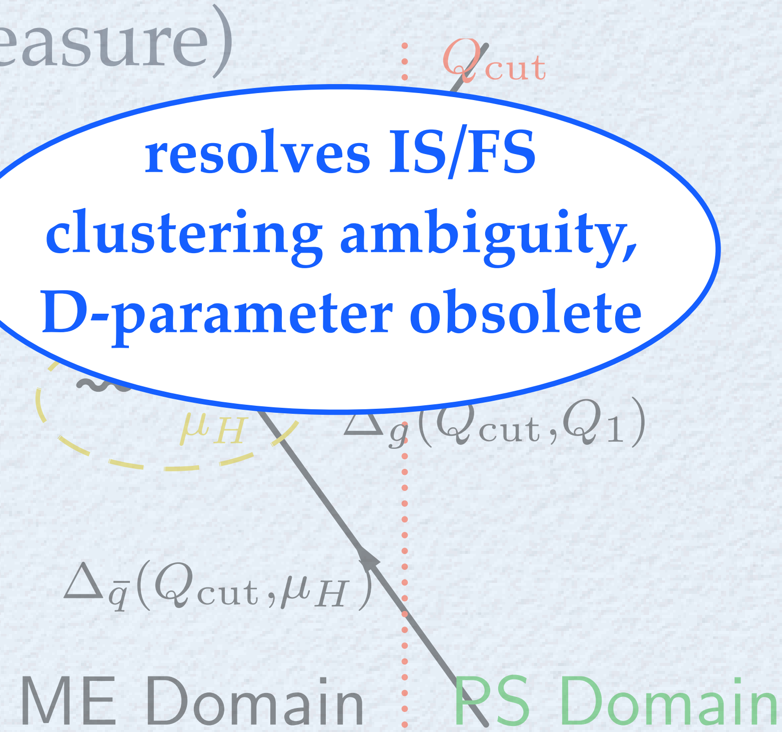
A pr... ...on is th... ...itial state evolution, so we need to improve ...

Usual K_T-type measure does not take beam assignment into account (possible solution in NPB 406 (1993) 187)

pQCD is crossing invariant and so the measure must be

Clustering does not necessarily reconstruct sensible history according to NLL formalism

NLL resummation is not the end of the story ordering must be guided by shower evolution



resolves IS/FS clustering ambiguity, D-parameter obsolete

decouples phasespace separation and shower history construction

Colour sampling in Comix allows easy large N_c projection

CS-based shower allows better control over jet veto

A new merging algorithm

SH, F. Krauss, S.Schumann, F. Siegert: arXiv:0903.1219 [hep-ph]

Let's try and formulate what we expect from a ME - shower merging

- The starting point is QCD evolution

$$\frac{\partial}{\partial\log(\mathbf{t}/\mu^2)}\,\frac{\mathbf{g_a}(\mathbf{z},\mathbf{t})}{\mathbf{\Delta_a}(\mu^2,\mathbf{t})}=\frac{\mathbf{1}}{\mathbf{\Delta_a}(\mu^2,\mathbf{t})}\int_{\mathbf{z}}^{\zeta_{\max}}\frac{\mathrm{d}\zeta}{\zeta}\sum_{\mathbf{b=q,g}}\mathcal{K}_{\mathbf{ba}}(\zeta,\mathbf{t})\,\mathbf{g_b}(\mathbf{z}/\zeta,\mathbf{t})$$

  This defines the backward no-branching probability for showers

$$\mathcal{P}^{(\mathbf{B})}_{\mathrm{no},\,\mathbf{a}}(\mathbf{z},\mathbf{t},\mathbf{t}')=\frac{\mathbf{\Delta_a}(\mu^2,\mathbf{t}')\,\mathbf{g_a}(\mathbf{z},\mathbf{t})}{\mathbf{\Delta_a}(\mu^2,\mathbf{t})\,\mathbf{g_a}(\mathbf{z},\mathbf{t}')}=\exp\left\{-\int_{\mathbf{t}}^{\mathbf{t}'}\frac{\mathrm{d}\bar{\mathbf{t}}}{\bar{\mathbf{t}}}\int_{\mathbf{z}}^{\zeta_{\max}}\frac{\mathrm{d}\zeta}{\zeta}\sum_{\mathbf{b=q,g}}\mathcal{K}_{\mathbf{ba}}(\zeta,\bar{\mathbf{t}})\,\frac{\mathbf{g_b}(\mathbf{z}/\zeta,\bar{\mathbf{t}})}{\mathbf{g_a}(\mathbf{z},\bar{\mathbf{t}})}\right\}$$

- Requirements for the ME - shower merging
  - ➜ Above equation for shower evolution is preserved
  - ➜ Hardest emissions are described by matrix elements, schematically:

$$\mathcal{K}_{\mathbf{ab}}(\mathbf{z},\mathbf{t})\;\to\;\frac{\mathbf{1}}{\sigma_{\mathbf{a}}^{(\mathbf{N})}(\mathbf{\Phi_N})}\,\frac{\mathrm{d}^{\mathbf{2}}\sigma_{\mathbf{b}}^{(\mathbf{N+1})}(\mathbf{z},\mathbf{t};\mathbf{\Phi_N})}{\mathrm{d}\log(\mathbf{t}/\mu^{\mathbf{2}})\,\mathrm{d}\mathbf{z}}$$

A new merging algorithm

SH, F. Krauss, S.Schumann, F. Siegert: arXiv:0903.1219 [hep-ph]

Now let's work it out ...

- Slice the phase space with a jet criterion Q

$$\mathcal{K}_{ab}^{\rm ME}(\xi,\bar{t}) = \mathcal{K}_{ab}(\xi,\bar{t})\;\Theta\left[Q_{ab}(\xi,\bar{t}) - Q_{\rm cut}\right]$$

$$\mathcal{K}_{ab}^{\rm PS}(\xi,\bar{t}) = \mathcal{K}_{ab}(\xi,\bar{t})\;\Theta\left[Q_{\rm cut} - Q_{ab}(\xi,\bar{t})\right]$$

- Veto the shower

$$\tilde{\mathcal{P}}^{(\mathbf{B})\,\rm PS}_{\rm no,\,\mathbf{a}}(\mathbf{z},\mathbf{t},\mathbf{t}') = \frac{\mathbf{\Delta}^{\rm PS}_{\mathbf{a}}(\mu^{\mathbf{2}},\mathbf{t}')\,\tilde{\mathbf{g}}_{\mathbf{a}}(\mathbf{z},\mathbf{t})}{\mathbf{\Delta}^{\rm PS}_{\mathbf{a}}(\mu^{\mathbf{2}},\mathbf{t})\,\tilde{\mathbf{g}}_{\mathbf{a}}(\mathbf{z},\mathbf{t}')} = \exp\left\{-\int_{\mathbf{t}}^{\mathbf{t}'}\frac{{\rm d}\bar{\mathbf{t}}}{\bar{\mathbf{t}}}\int_{\mathbf{z}}^{\zeta_{\max}}\frac{{\rm d}\zeta}{\zeta}\sum_{\mathbf{b}=\mathbf{q},\mathbf{g}}\mathcal{K}^{\rm PS}_{\mathbf{ba}}(\zeta,\bar{\mathbf{t}})\,\frac{\tilde{\mathbf{g}}_{\mathbf{b}}(\mathbf{z}/\zeta,\bar{\mathbf{t}})}{\tilde{\mathbf{g}}_{\mathbf{a}}(\mathbf{z},\bar{\mathbf{t}})}\right\}$$

It looks as if one obtains a different evolution
But this is easily corrected by adding the missing part

$$\mathcal{P}^{(\mathbf{B})}_{\rm no,\,\mathbf{a}}(\mathbf{z},\mathbf{t},\mathbf{t}') = \frac{\mathbf{\Delta}^{\rm ME}(\mu^{\mathbf{2}},\mathbf{t}')}{\mathbf{\Delta}^{\rm ME}(\mu^{\mathbf{2}},\mathbf{t})}\,\mathcal{P}^{(\mathbf{B})\,\rm PS}_{\rm no,\,\mathbf{a}}(\mathbf{z},\mathbf{t},\mathbf{t}')\;,\quad \mathcal{P}^{(\mathbf{B})\,\rm PS}_{\rm no,\,\mathbf{a}}(\mathbf{z},\mathbf{t},\mathbf{t}') = \frac{\mathbf{\Delta}^{\rm PS}_{\mathbf{a}}(\mu^{\mathbf{2}},\mathbf{t}')\,\mathbf{g}_{\mathbf{a}}(\mathbf{z},\mathbf{t})}{\mathbf{\Delta}^{\rm PS}_{\mathbf{a}}(\mu^{\mathbf{2}},\mathbf{t})\,\mathbf{g}_{\mathbf{a}}(\mathbf{z},\mathbf{t}')}$$

This works independent of the precise definition of Q !

A New Jet Criterion

SH, F. Krauss, S.Schumann, F. Siegert: arXiv:0903.1219 [hep-ph]

- New proposal for phasespace separation, CS - inspired
  ➡ Identify two-particle poles of real NLO ME through

$$Q_{ij}^2 = 2\,p_ip_j \min_{k\neq i,j}\left\{\frac{2}{C_{i,j}+C_{j,i}}\right\} \qquad C_{i,j} = \begin{cases} \dfrac{p_ip_k}{(p_i+p_k)p_j} - \dfrac{m_i^2}{2\,p_ip_j} & \text{if } j=g \\ 1 & \text{else} \end{cases}$$

min over colour partners

masses included

New separation criterion has better behaviour than conventional ones
(e.g. $Q_{ij}^2 = 2\min\{p_{\perp,i}^2, p_{\perp,j}^2\}\,[\cosh\Delta\eta_{ij} - \cos\Delta\phi_{ij}]$, $Q_{ib}^2 = p_{i\perp}^2$)

- Soft gluon limit (j→gluon)

$$\frac{1}{Q_{ij}^2} \to \frac{1}{2\,\lambda^2}\,\frac{1}{2\,p_i\,q}\left[\frac{p_ip_k}{(p_i+p_k)\,q} - \frac{m_i^2}{2\,p_iq}\right]$$

← correct part of eikonal

(Quasi-)Collinear limit

$$\frac{1}{Q_{ij}^2} \to \frac{1}{2\,\lambda^2}\,\frac{1}{\left|p_{ij}^2 - m_i^2 - m_j^2\right|}\left(\tilde{C}_{i,j}\,,\,\tilde{C}_{j,i}\right)$$

$$\tilde{C}_{i,j} = \begin{cases} \dfrac{z}{1-z} - \dfrac{m_i^2}{2\,p_ip_j} & \text{if } j{=}g \\ 1 & \text{else} \end{cases}$$

← leading term of DGLAP kernel

Truncated Showers

SH, F. Krauss, S.Schumann, F. Siegert: arXiv:0903.1219 [hep-ph]

What is a truncated shower and why is a standard shower not enough?

- Assuming we have a ME, predefining a branching at scale t with hard scale t′. Filling the remaining phase space means computing
$$\mathcal{P}^{(\mathbf{B})\,\mathrm{PS}}_{\mathrm{no},\,\mathbf{a}}(\mathbf{z},\mathbf{t},\mathbf{t}') \;=\; \frac{\mathbf{\Delta}^{\mathrm{PS}}_{\mathbf{a}}(\mu^{\mathbf{2}},\mathbf{t}')\,\mathbf{g}_{\mathbf{a}}(\mathbf{z},\mathbf{t})}{\mathbf{\Delta}^{\mathrm{PS}}_{\mathbf{a}}(\mu^{\mathbf{2}},\mathbf{t})\,\mathbf{g}_{\mathbf{a}}(\mathbf{z},\mathbf{t}')}$$

  ➔ We need a shower evolving between t′ and t, i.e. a “truncated” one

In a truncated shower, the predefined ME branching at t sets the evolution-, splitting- and angular variable of a predefined node to be inserted later
After any emission above t, this node must be reconstructed

ME+Shower: Results

SH, F. Krauss, S.Schumann, F. Siegert: arXiv:0903.1219 [hep-ph]

An immediate consequence is that the LO cross section is preserved

- $e^+e^- \rightarrow$ hadrons at LEP I, Total cross sections [nb]

6.4% variation

		$N_{\max}$				
		0	1	2	3	4
$\log_{10} y_{\text{cut}}$	-1.25	40.17(1)	39.65(3)	39.66(3)	39.66(3)	39.67(3)
	-1.75		39.38(5)	39.29(6)	39.13(5)	39.13(5)
	-2.25		39.27(8)	38.35(9)	37.89(11)	37.60(10)

- Drell-Yan at Tevatron Run II, Total cross sections [pb]

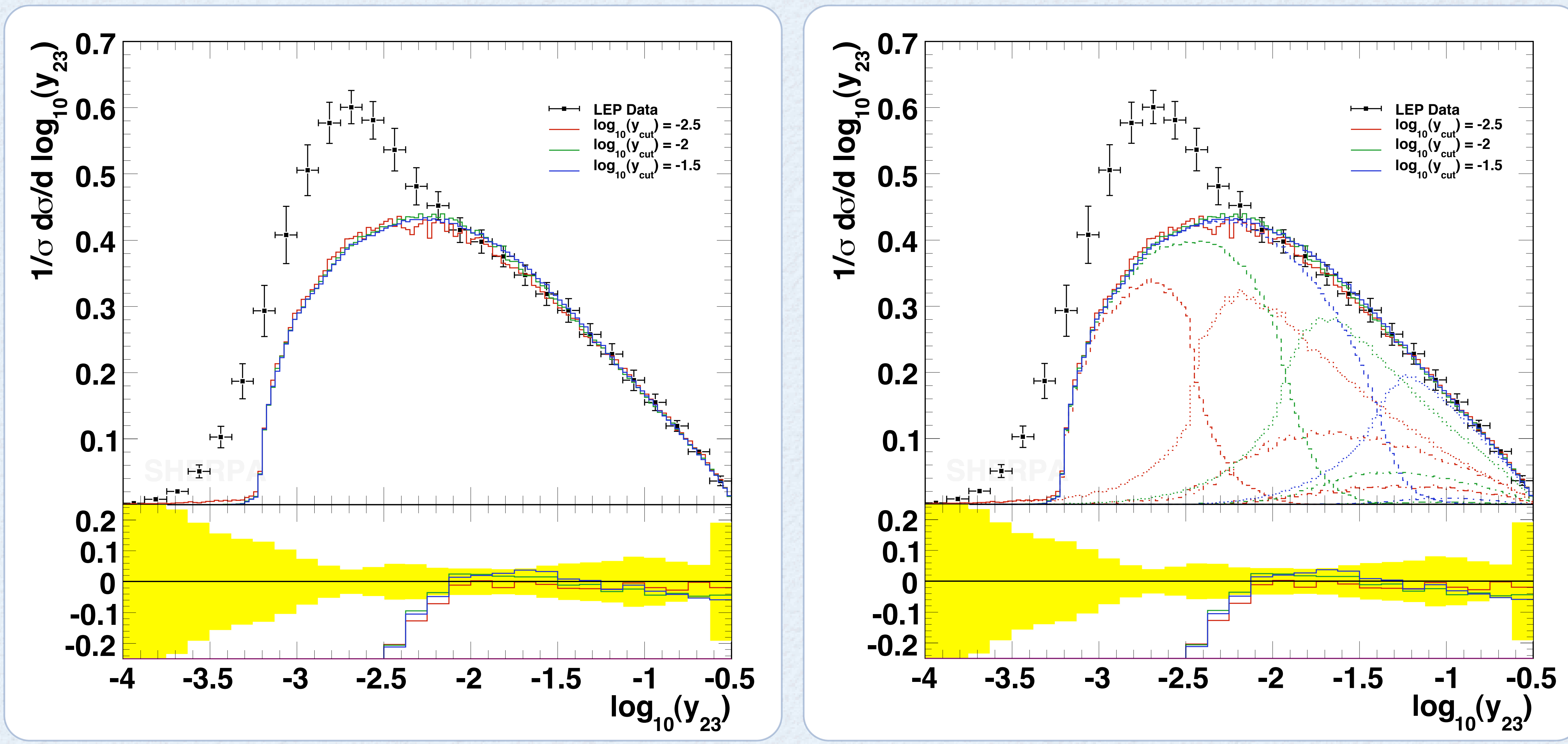
7.6% variation

		$N_{\max}$						
		0	1	2	3	4	5	6
Q_{cut}	20 GeV	192.6(1)	192.1(3)	194.0(5)	192.6(6)	191.9(7)	191.3(9)	207.4(14)
	30 GeV		193.3(2)	194.5(2)	194.6(3)	195.0(3)	194.7(3)	201.5(4)
	45 GeV		194.2(2)	194.9(1)	195.2(1)	195.3(2)	195.1(1)	197.7(1)

ME+SHOWER: RESULTS

SH, F. Krauss, S.Schumann, F. Siegert: arXiv:0903.1219 [hep-ph]

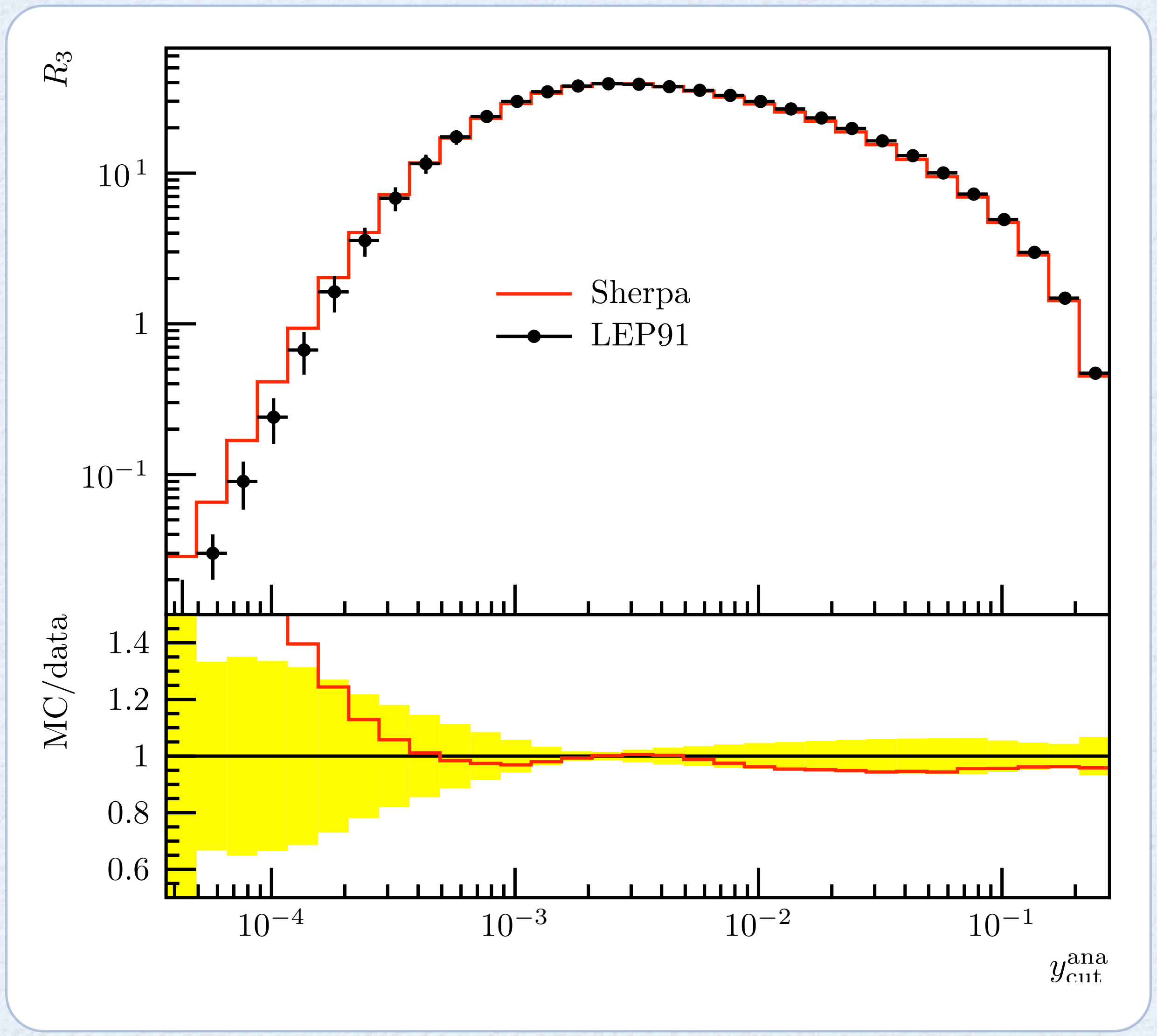
- $e^+e^- \to$ hadrons at LEP I
  Durham 2→3 jet rate (parton level)

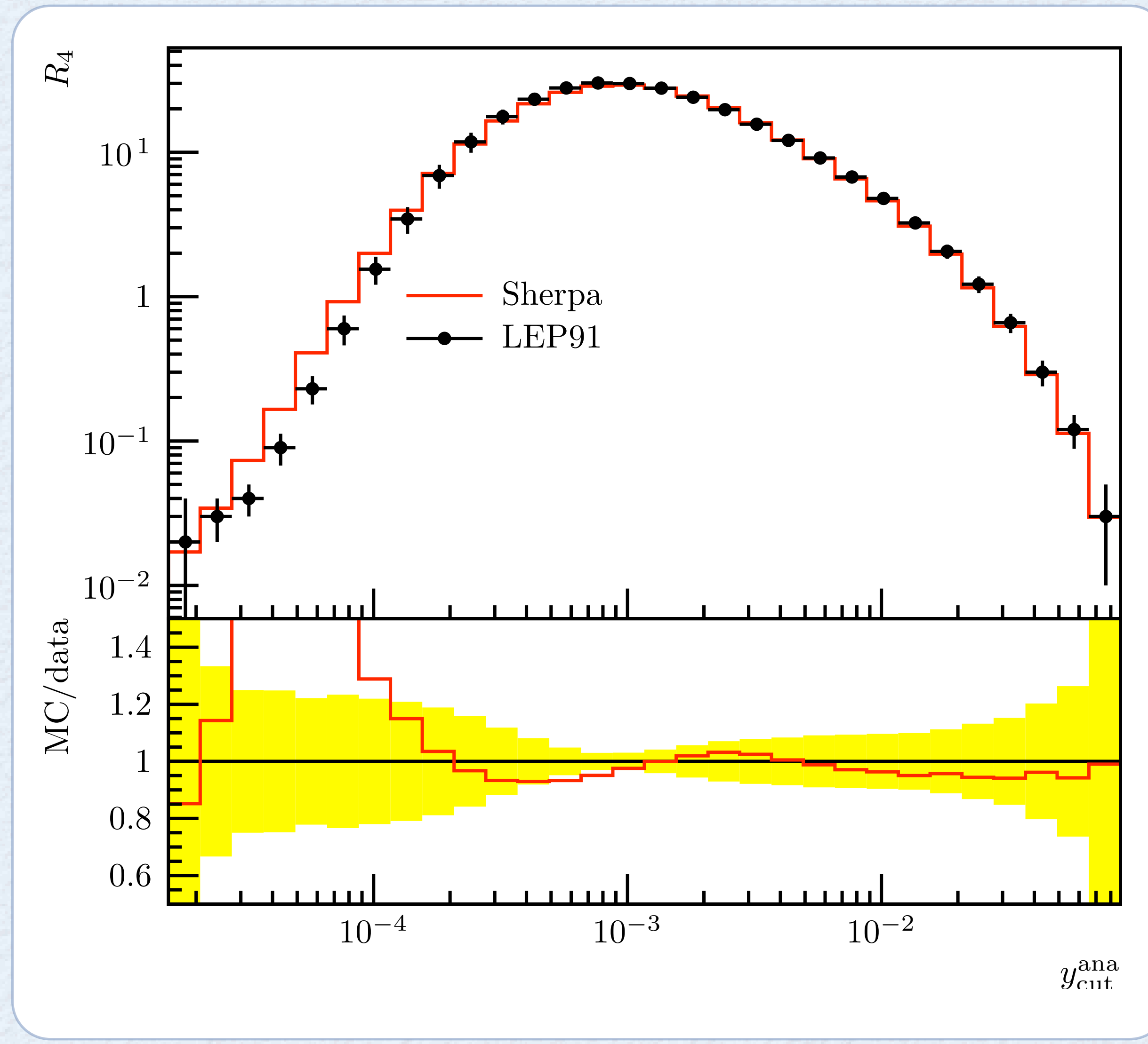


ME+Shower: Results

SH, F. Krauss, S.Schumann, F. Siegert: arXiv:0903.1219 [hep-ph]

- $e^+e^- \rightarrow$ hadrons at LEP I
  Durham jet rates (hadron level, untuned)

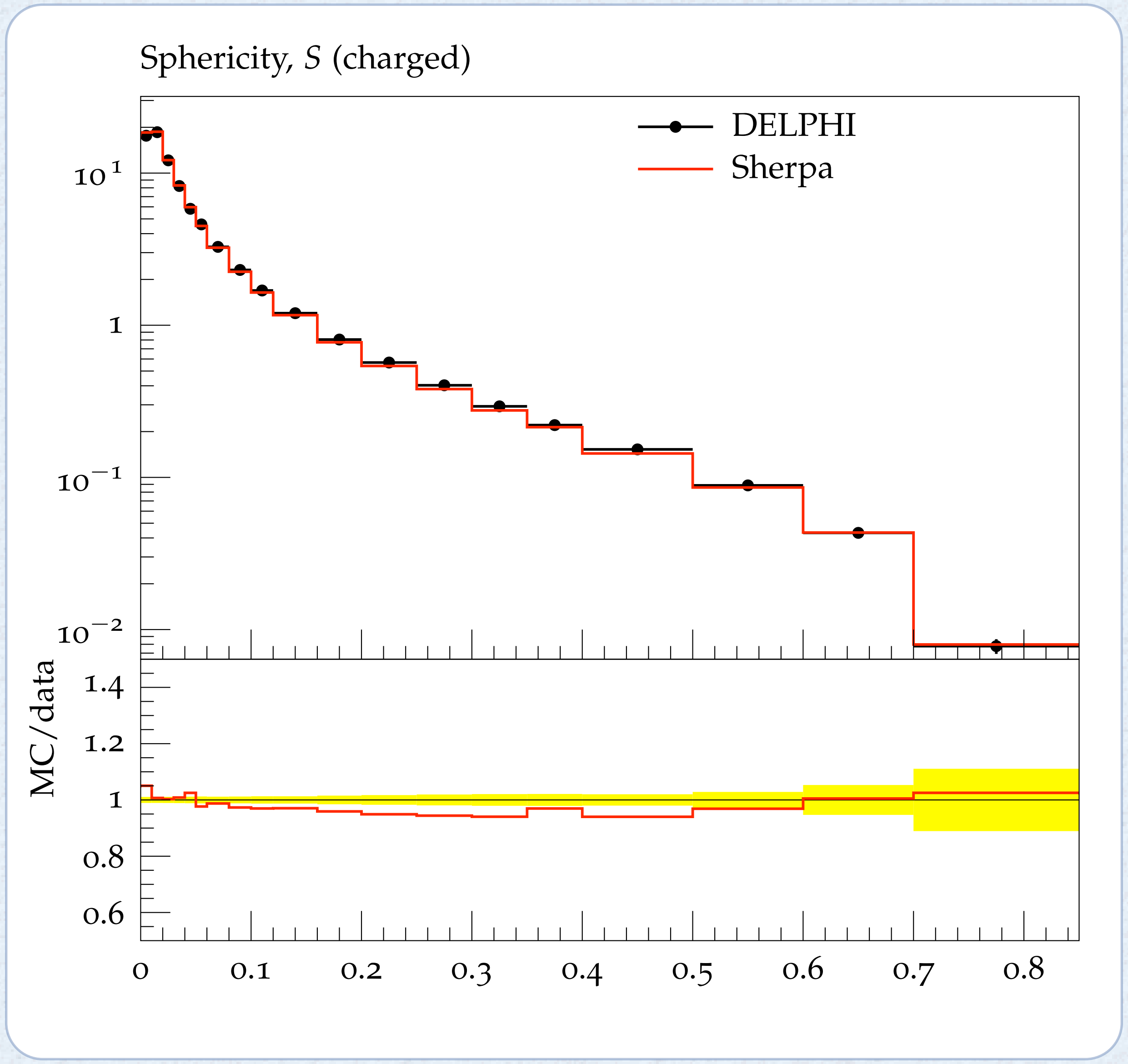


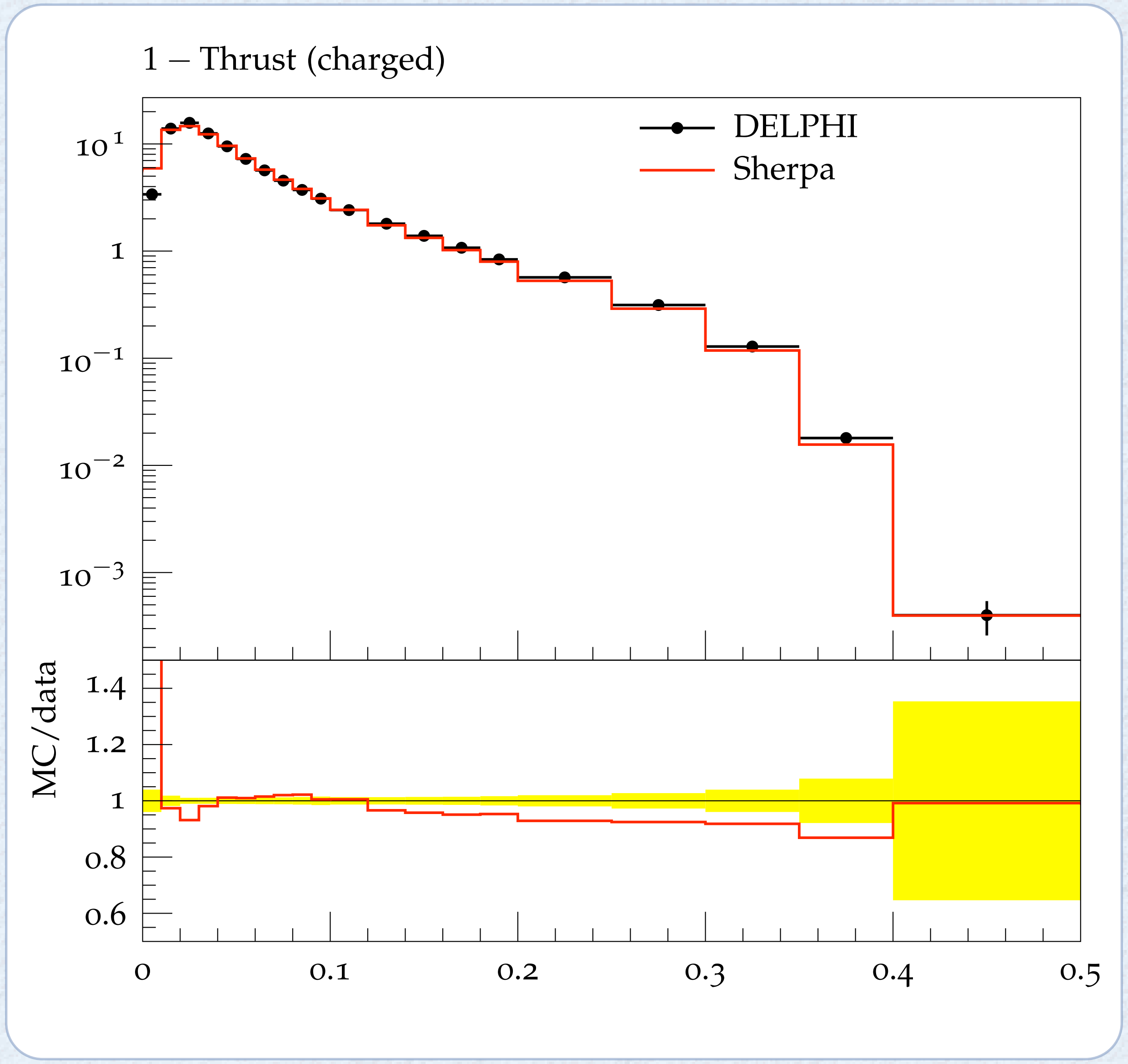


ME+Shower: Results

SH, F. Krauss, S.Schumann, F. Siegert: arXiv:0903.1219 [hep-ph]

- $e^+e^- \rightarrow$ hadrons at LEP I
  Shape observables (hadron level, untuned)

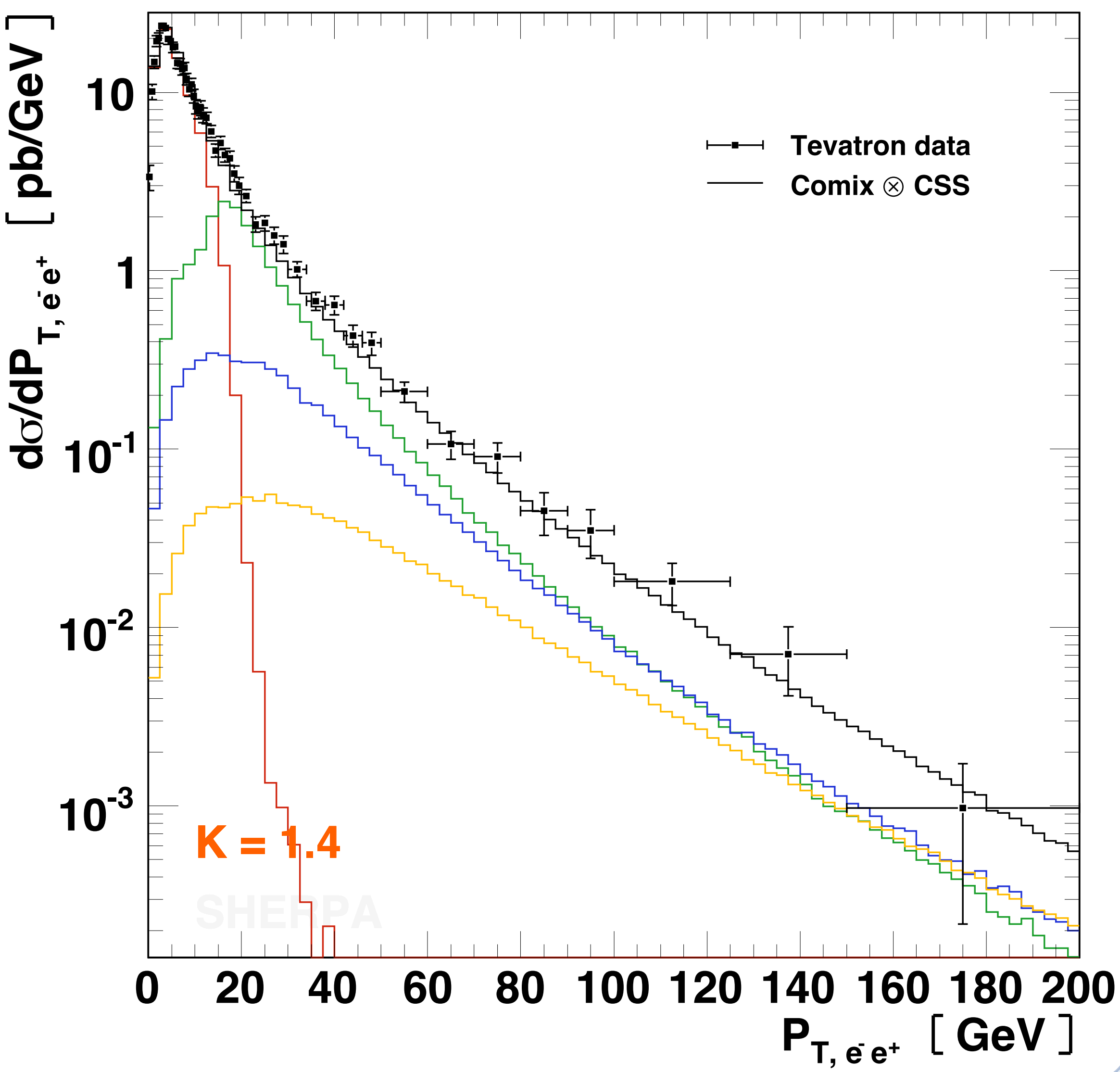


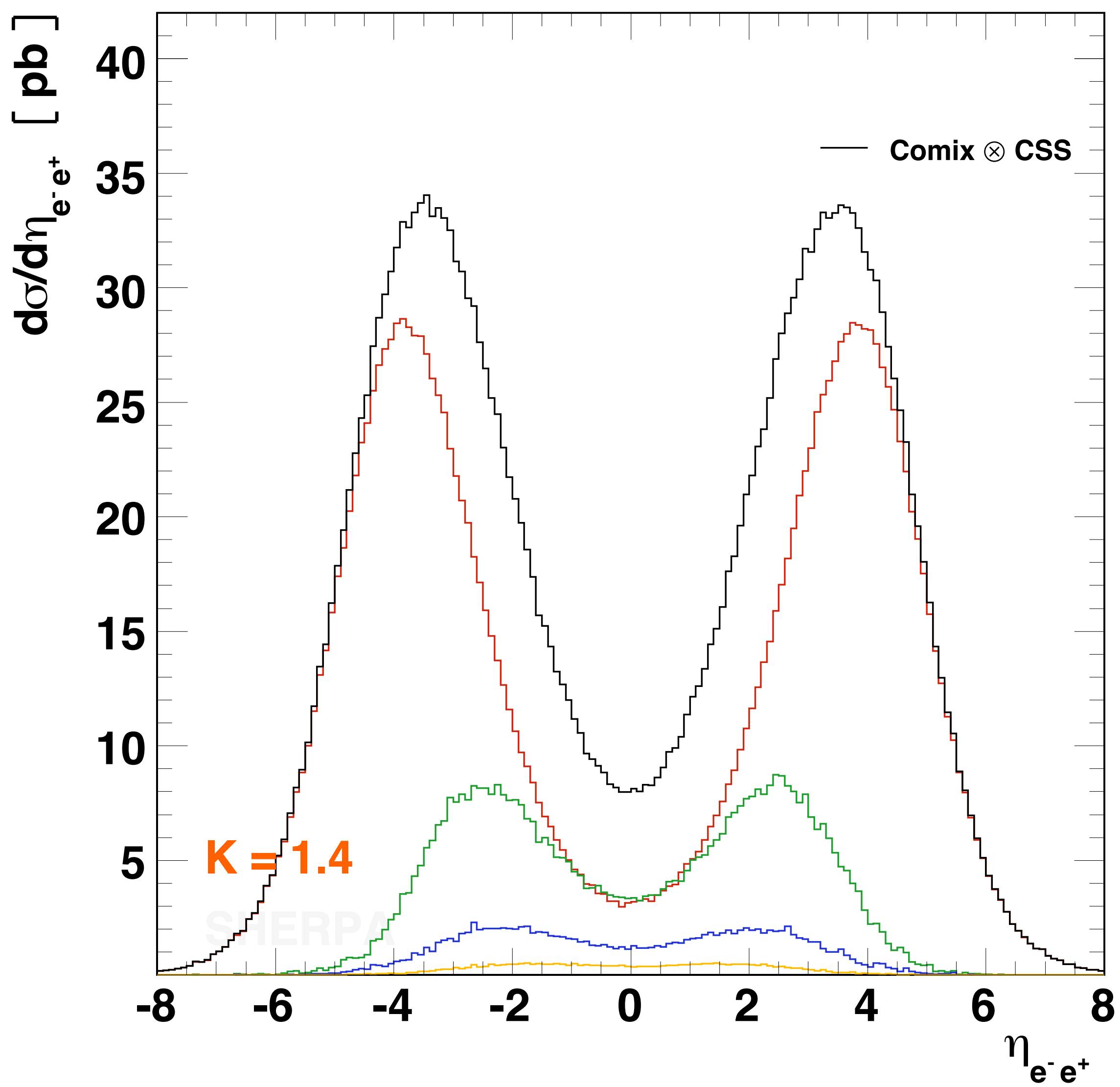


ME+SHOWER: RESULTS

SH, F. Krauss, S.Schumann, F. Siegert: arXiv:0903.1219 [hep-ph]

- Drell-Yan production at Tevatron Run I
  Lepton observables

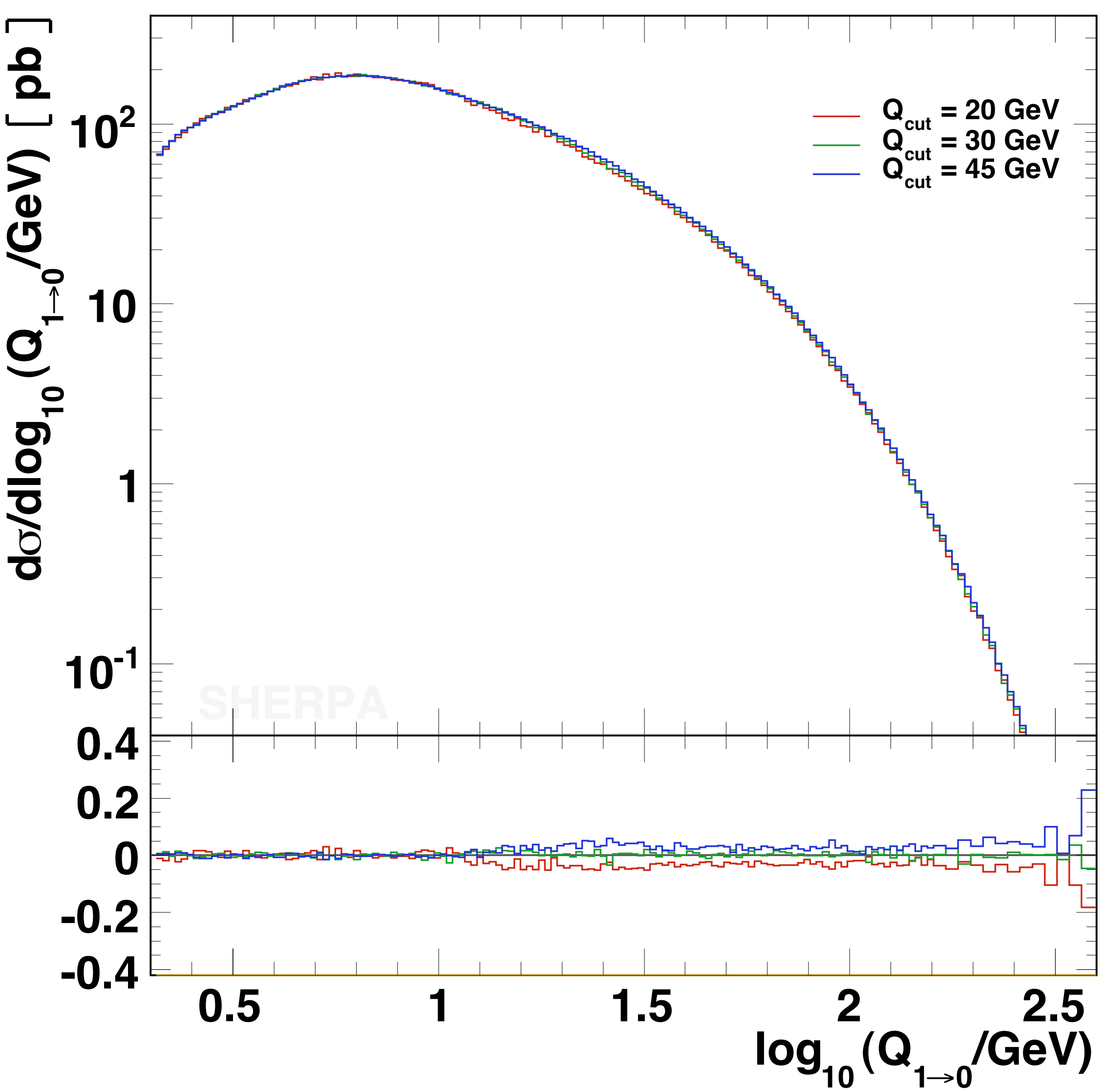


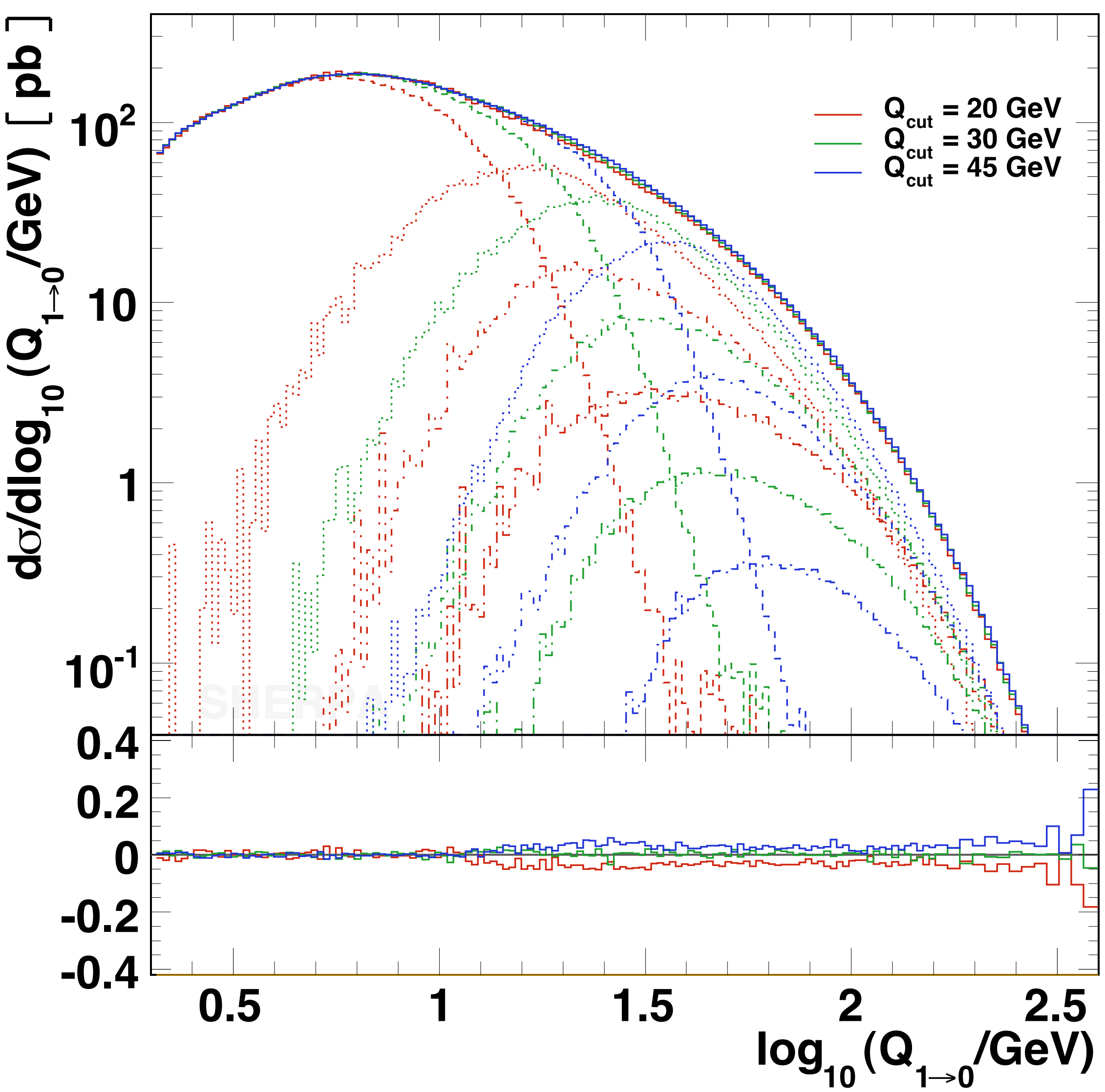


ME+SHOWER: RESULTS

SH, F. Krauss, S.Schumann, F. Siegert: arXiv:0903.1219 [hep-ph]

- Drell-Yan production at Tevatron Run I
  Differential jet rates (parton level)





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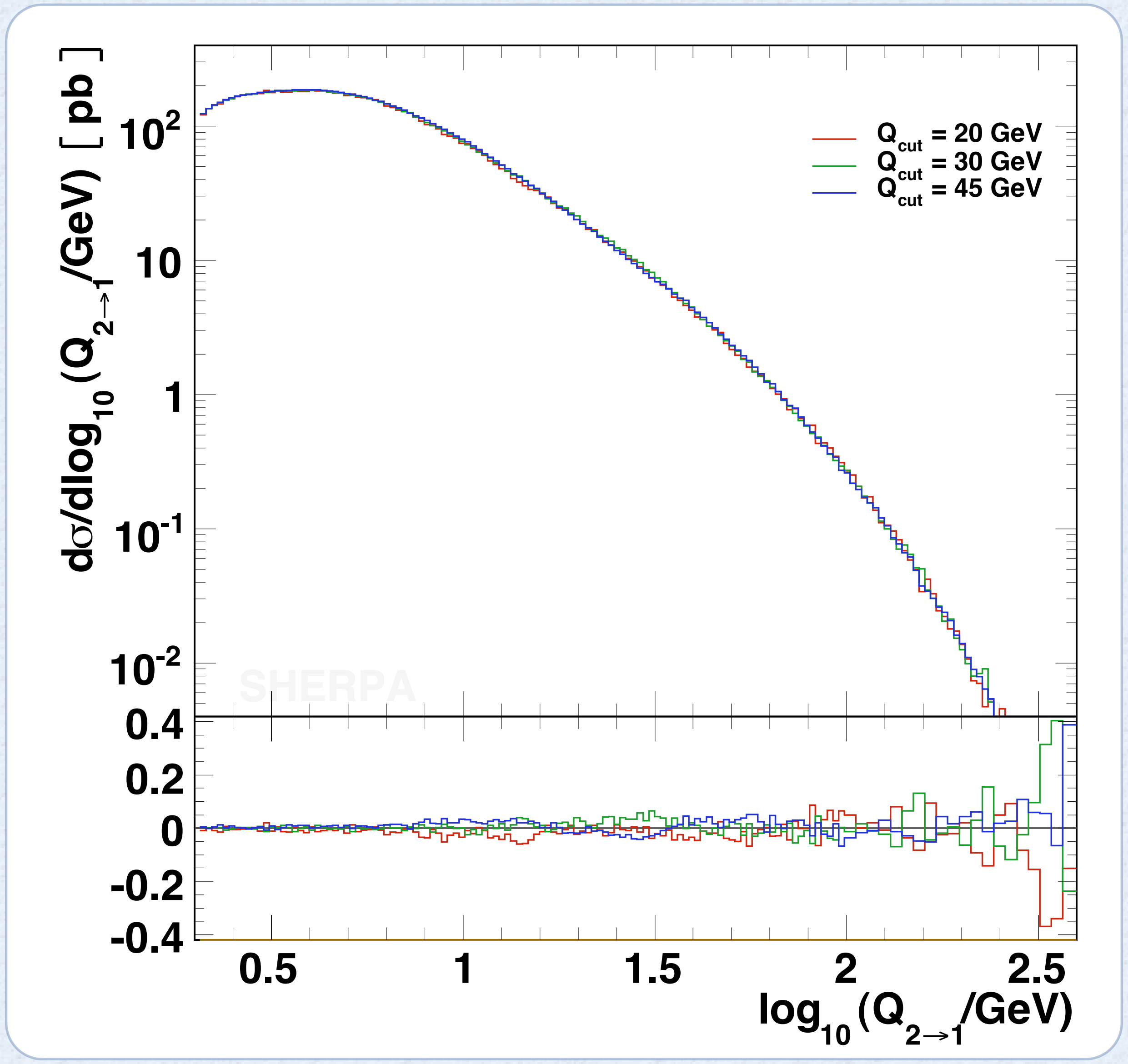
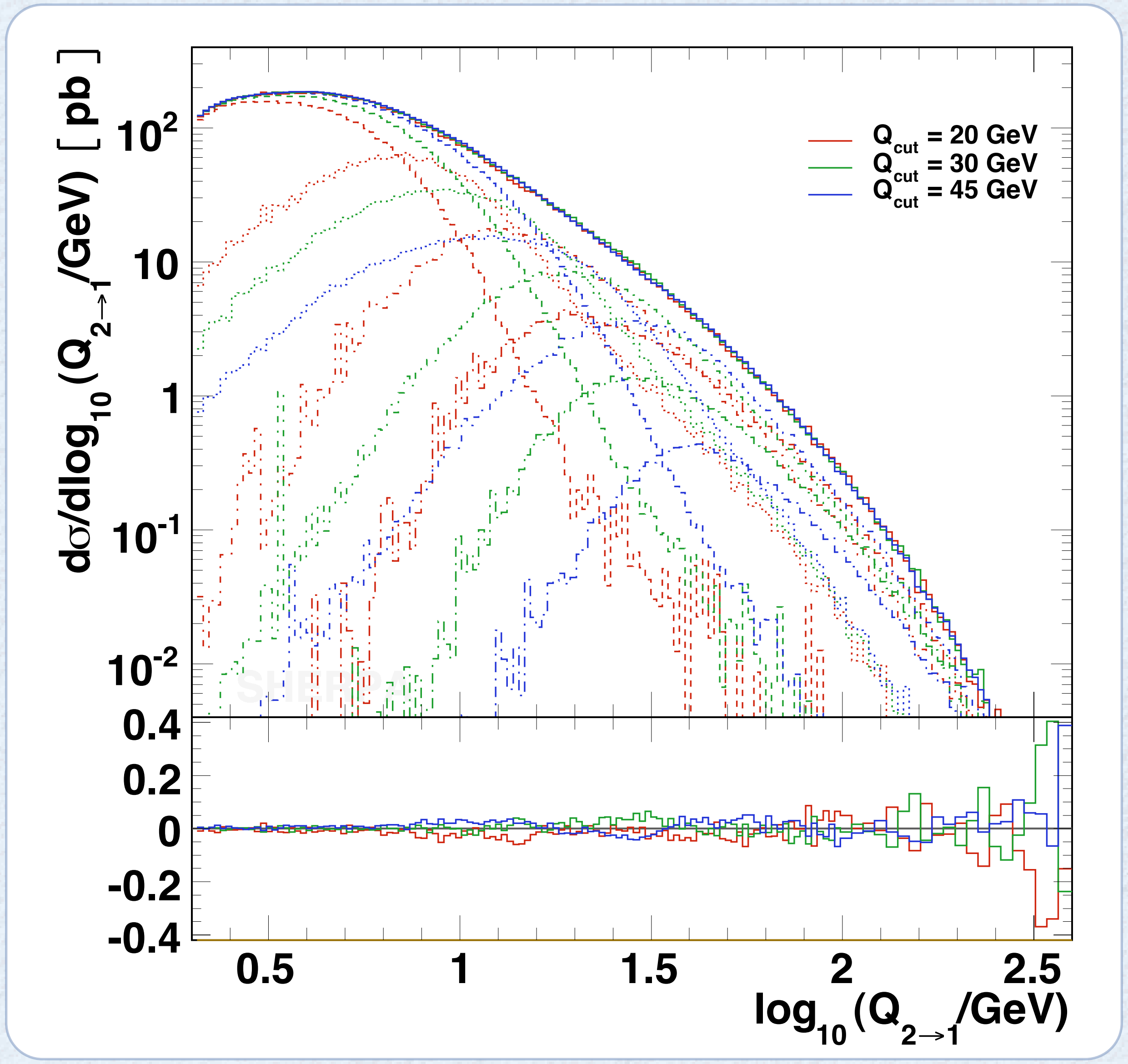
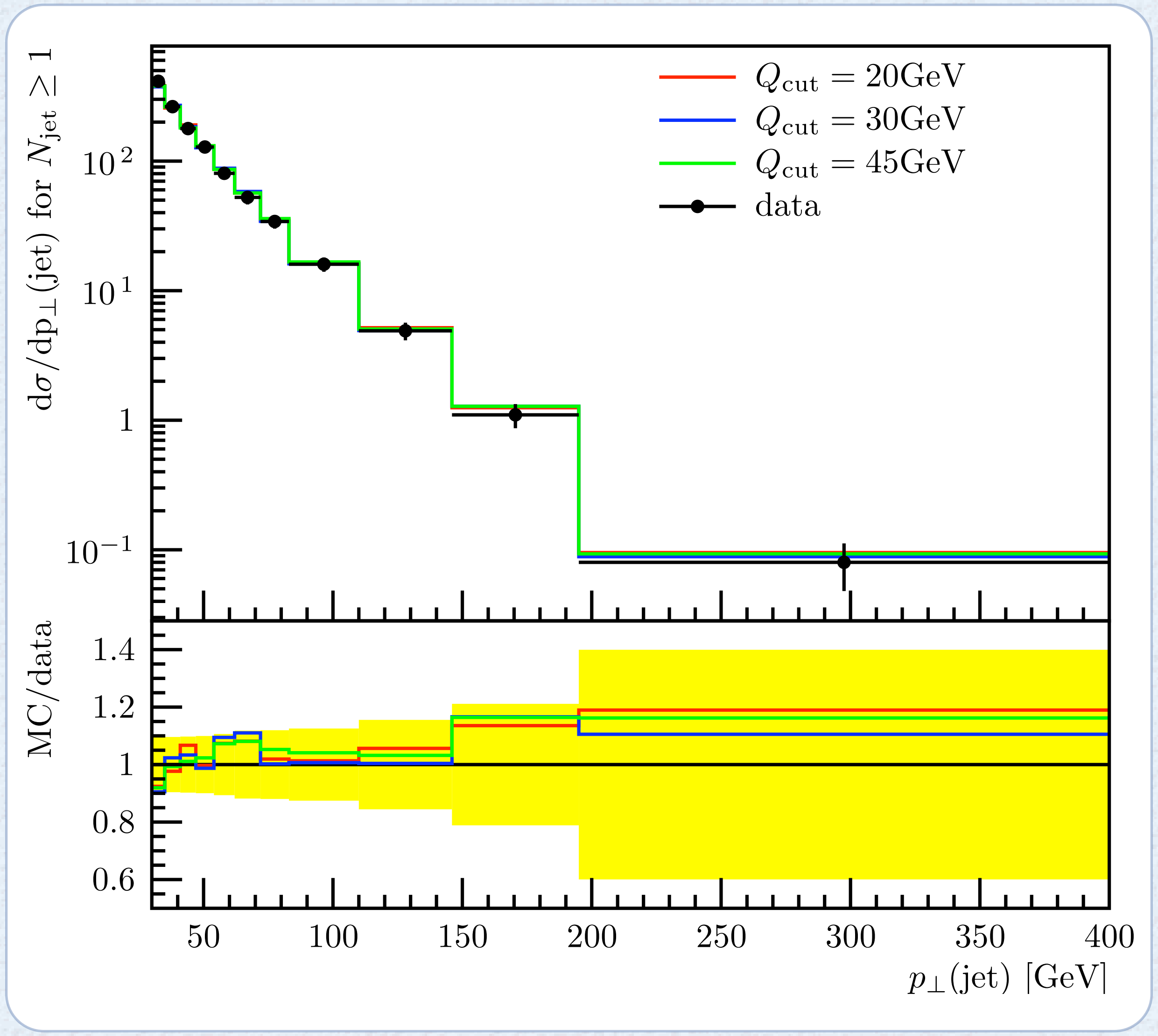


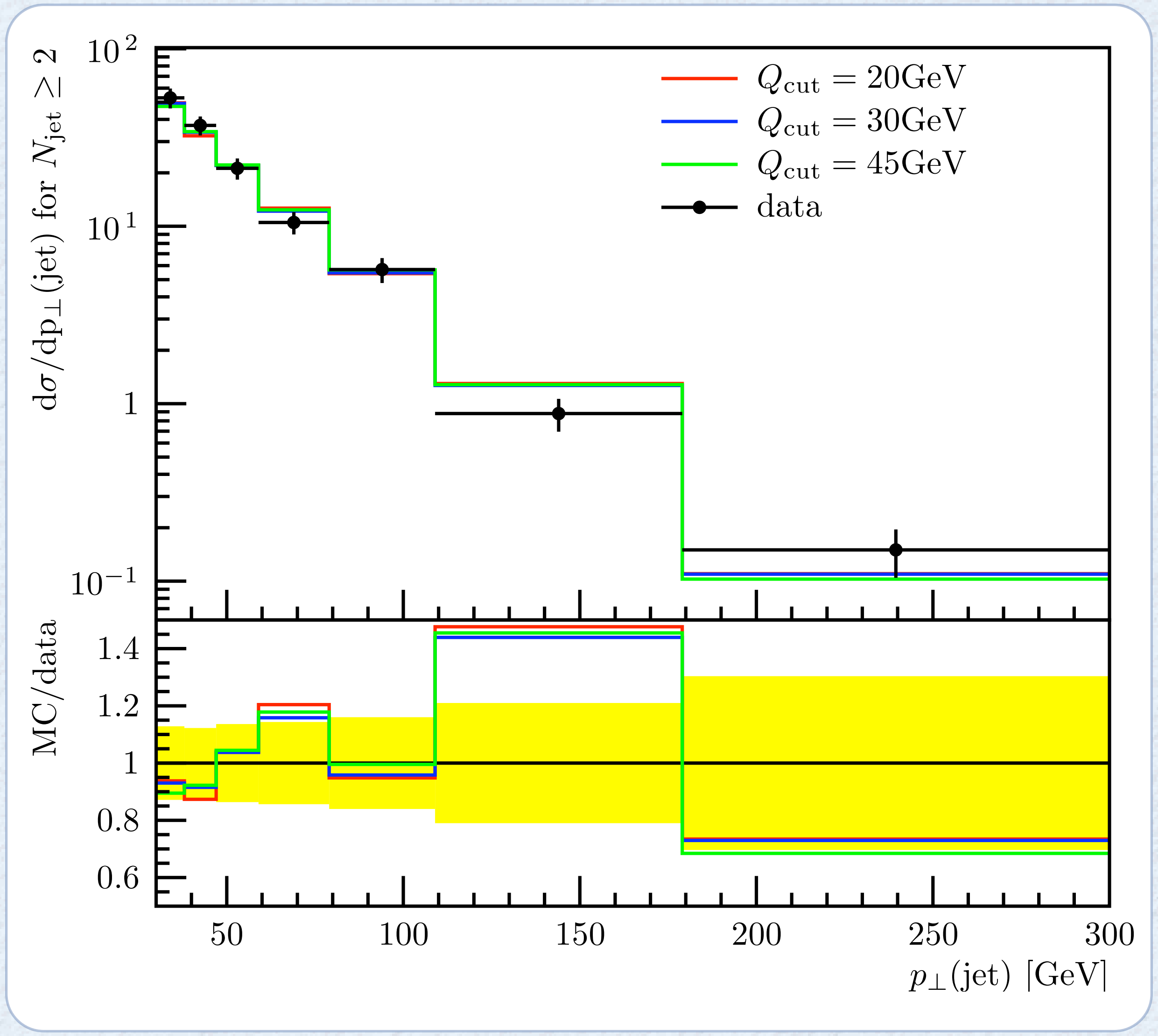


ME+SHOWER: RESULTS

SH, F. Krauss, S.Schumann, F. Siegert: arXiv:0903.1219 [hep-ph]

- Drell-Yan production at Tevatron Run II PRL 100(2008)102001
  Jet observables for $p_{T,jet} > 30$ GeV





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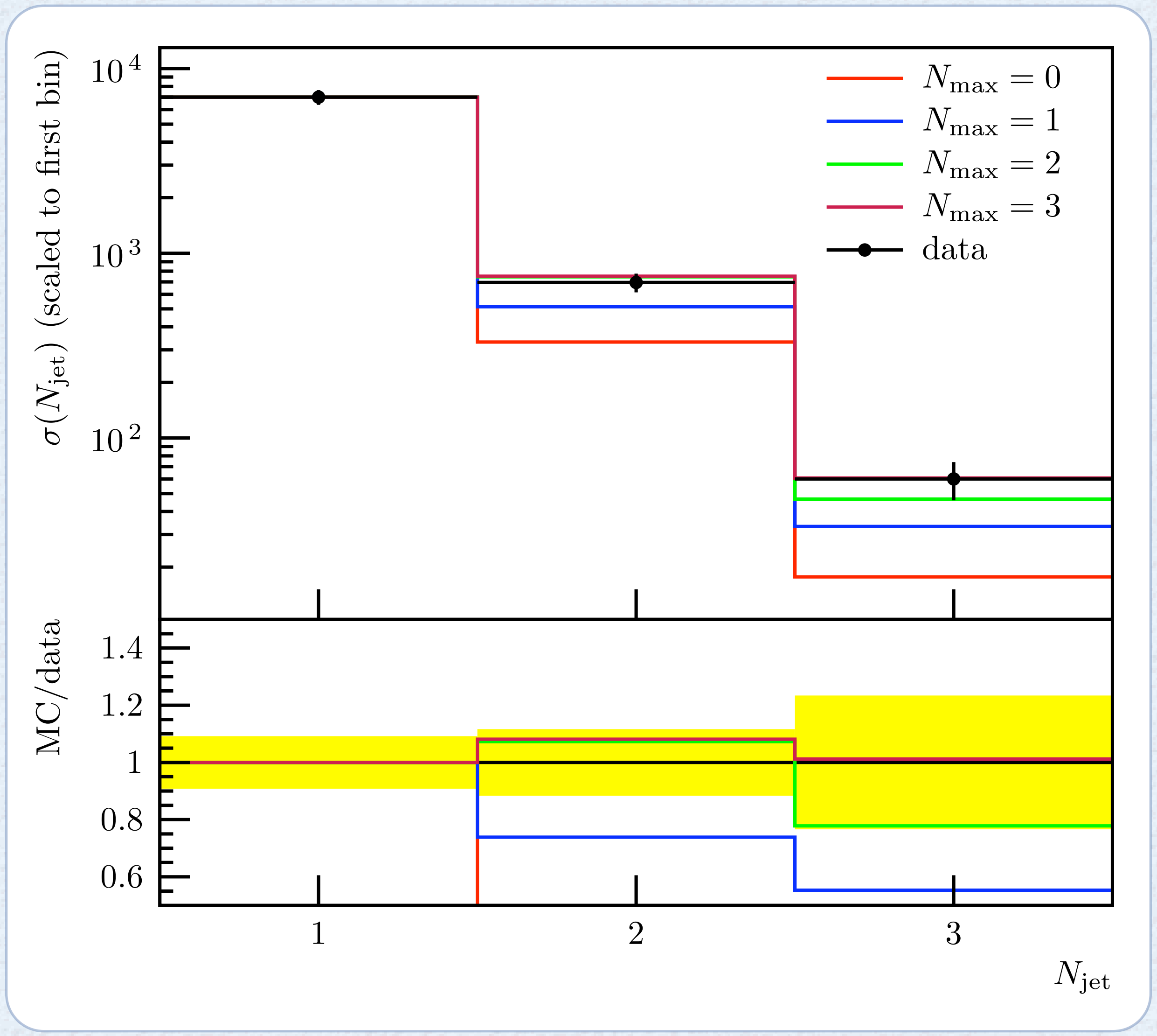

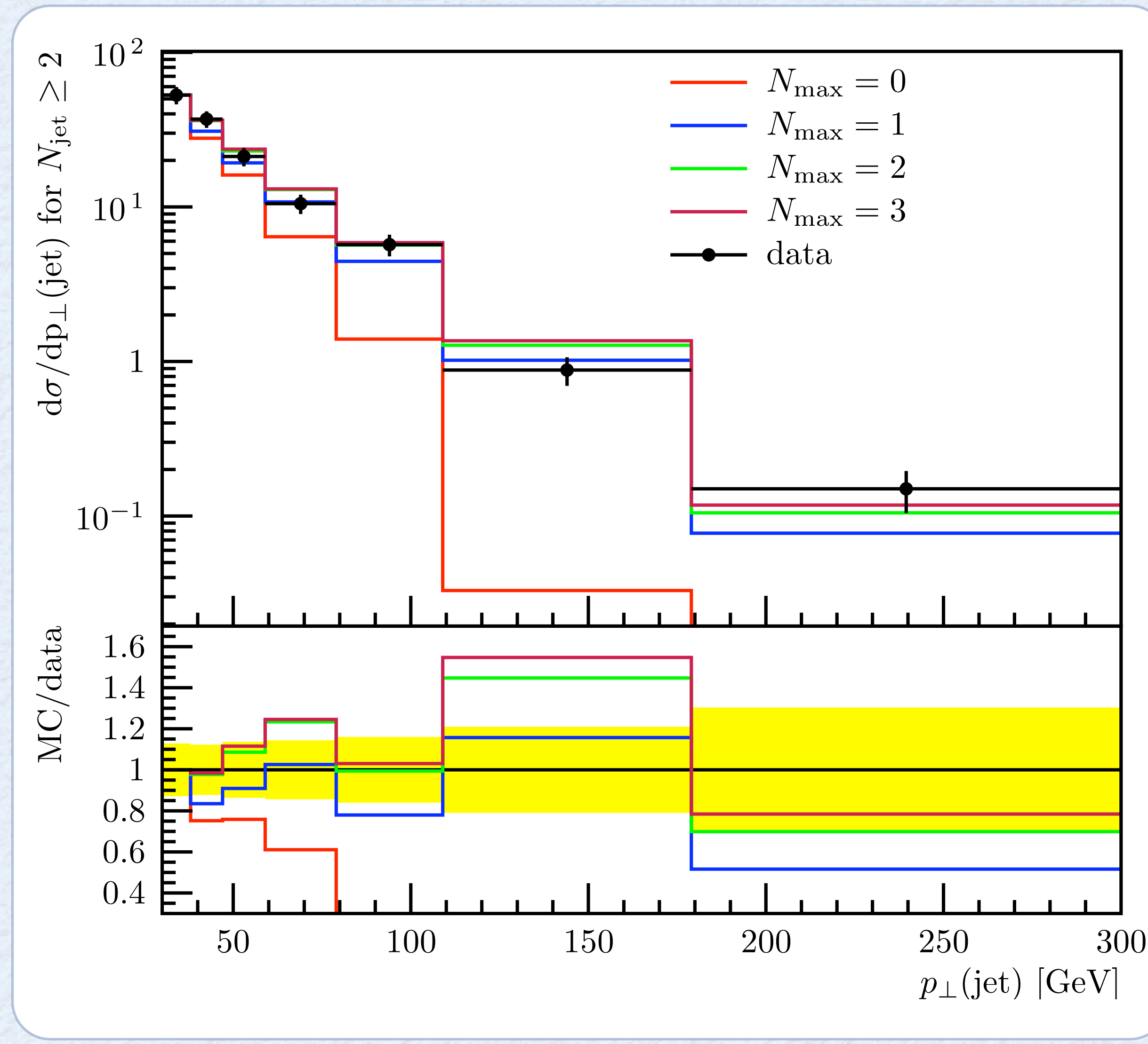

Seems we can finally say somthing about jets ...

Summary

Now we can generate ME's and showers and merge the two
Still, there is a lot to be done. We work in two directions

Loopy ...

- Automated POWHEG
- Interfaces to loop ME codes
- Extension to CKKW@NLO

... and down-to-earth

- Cross-checks with other codes
- Application to heavy quark and SUSY production
- Application to ep-scattering
- More phenomenology !

Summary

There is a whole lot of other stuff needed to build a full-fledged event generator

"Soft" physics ...

- Fragmentation
- Hadron decays
- QED radiation

"Hard" physics ...

- Inclusive decays
- Multiple parton interactions

Get the code to produce the plots in this talk ...

www.sherpa-mc.de

... and be a pain in the neck for its authors

info@sherpa-mc.de