Physics Generators existing at BNL

Tobias Toll, BNL
EIC R&D Simulation Workshop
BNL 10/8/12

EIC computing at BNL

For information about generators,
on how to use, references etc.
https://wiki.bnl.gov/eic/index.php/Simulations

Information about how to get started and using
the EIC computing at BNL:
https://wiki.bnl.gov/eic/index.php/Computing

If you don't have an RCF account
https://www.racf.bnl.gov/docs/getstart/newuserform

To add EIC to existing RCF accoint:

▶ email John McCarthy & Elke

Why simulate?

Physics simulators crucial for IR design and predicting feasibility of making key EIC measurements.

Why simulate?

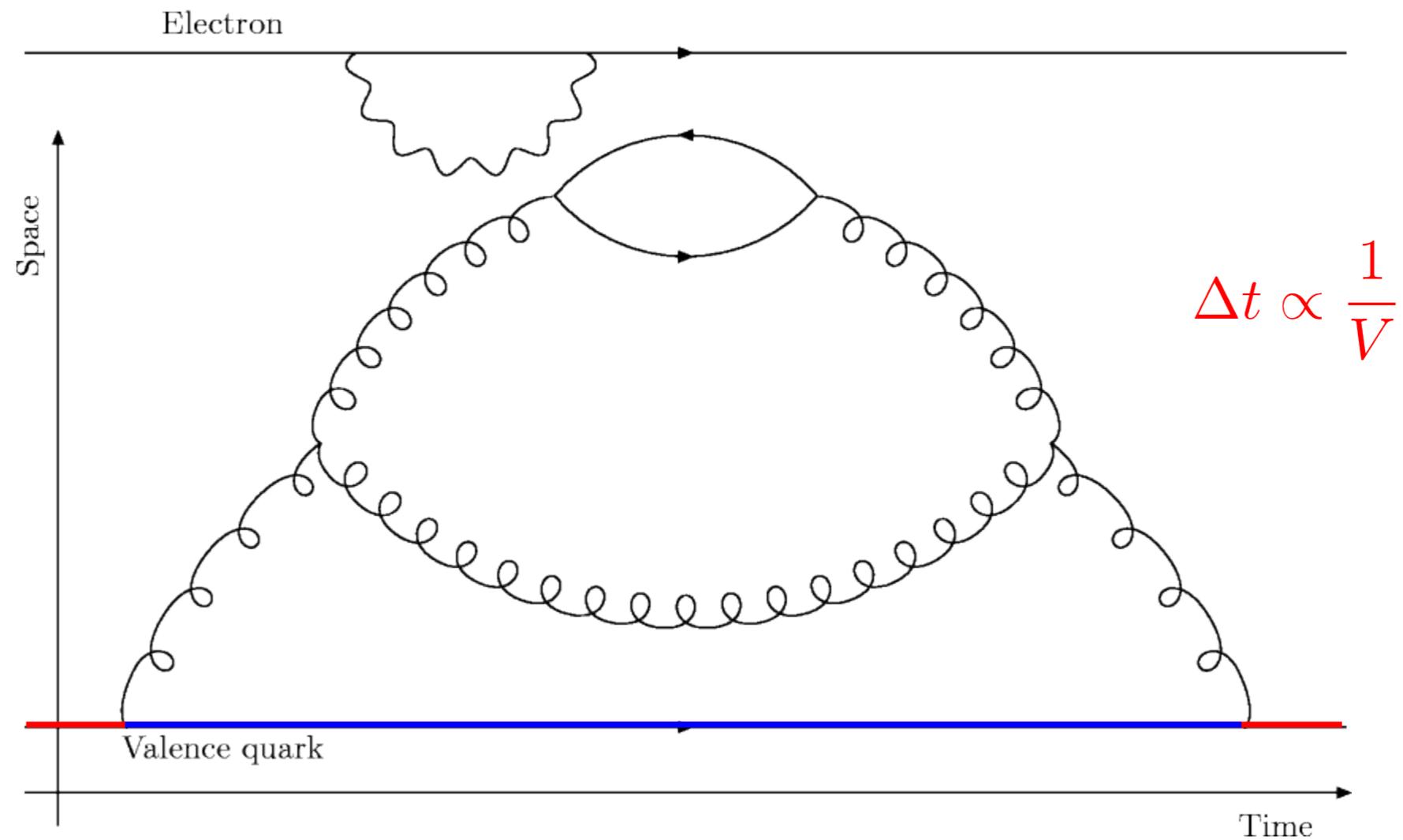## EIC *e+p* Physics Programme, Key measurements

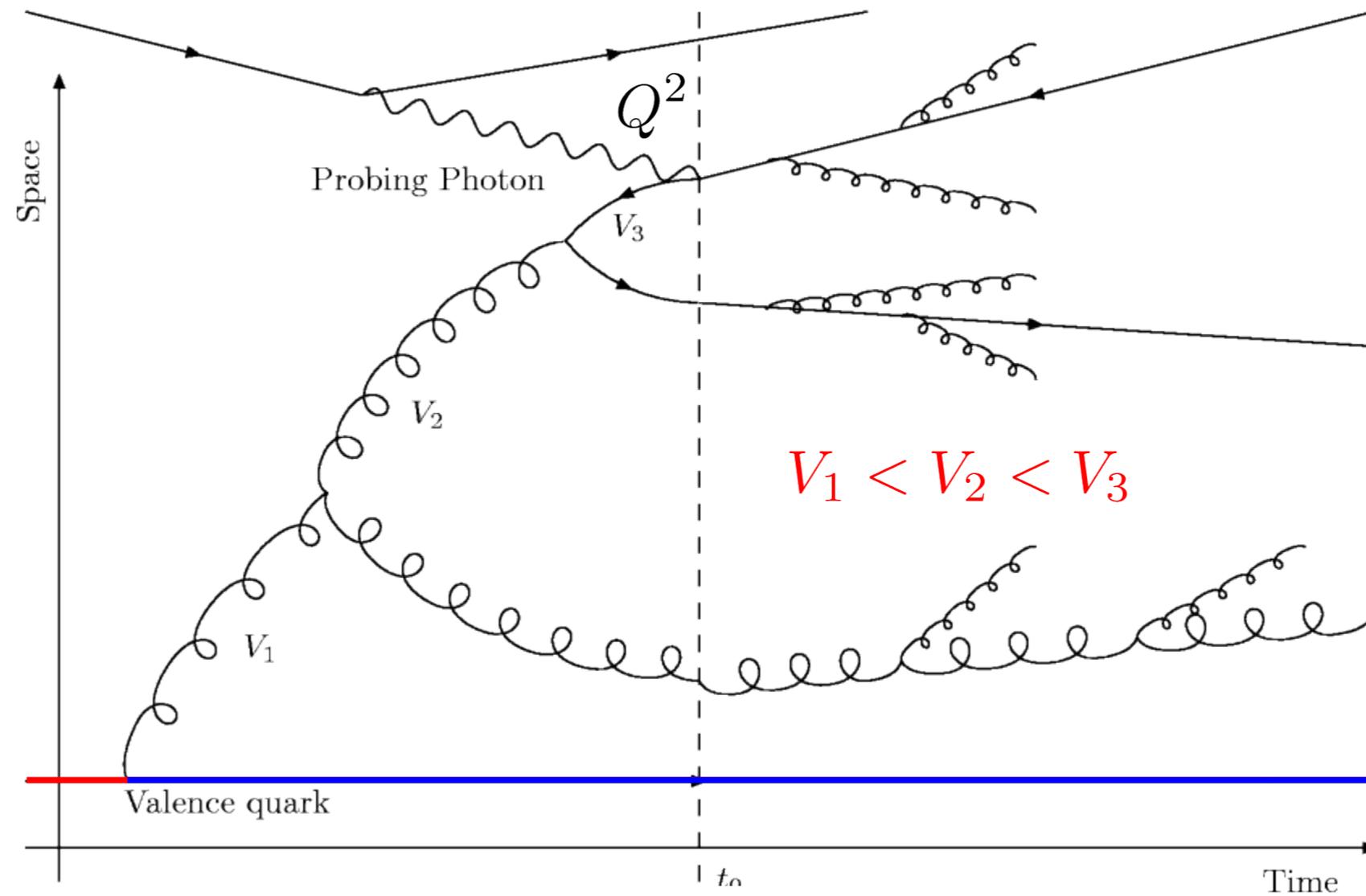| Deliverables	Obserables	MC generator
Polarised gluon distribution Δg	Scaling violation in inclusive DIS	PEPSI+LEPTO
Polarised quark and antiquark densities	semi-incl. DIS for pions and kaons	PEPSI+LEPTO
Sivers and unpolarised TMDs for quarks and gluon	SIDIS with transv. polarisation/ions; di-hadron (di-jet) heavy flavours	gmc_trans
GPDs, 3D structure of quarks and gluon in b-p_L space	Exclusive DIS: vector mesons and DVCS	MILOU

Monday, October 8, 2012

Why simulate?

EIC e+A Physics Programme, Key measurements

| Deliverables	Observables	MC generator
integrated gluon distributions	$F_{2,L}$	Pythia6+EPS09
kT dependent gluons; gluon correlations	di-hadron correlations	Pythia6/ DPMJetIII hybrid
b-dependence of gluon distribution and correlations	Diffractive VM production and DVCS, coherent and incoherent parts	Sartre

What is an MC generator?

Electron

Space

Valence quark

Time

$$\Delta t \propto \frac{1}{V}$$

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What is an MC generator?

Space

Q^2

Probing Photon

V_3

V_2

$V_1 < V_2 < V_3$

V_1

Valence quark

t_0

Time

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What is an MC generator?

Hard scattering pQCD or QED Matrix Element, at LO, NLO...

Initial state QCD radiations: collinear (DGLAP), non-collinear (CCFM, RCBK) ...
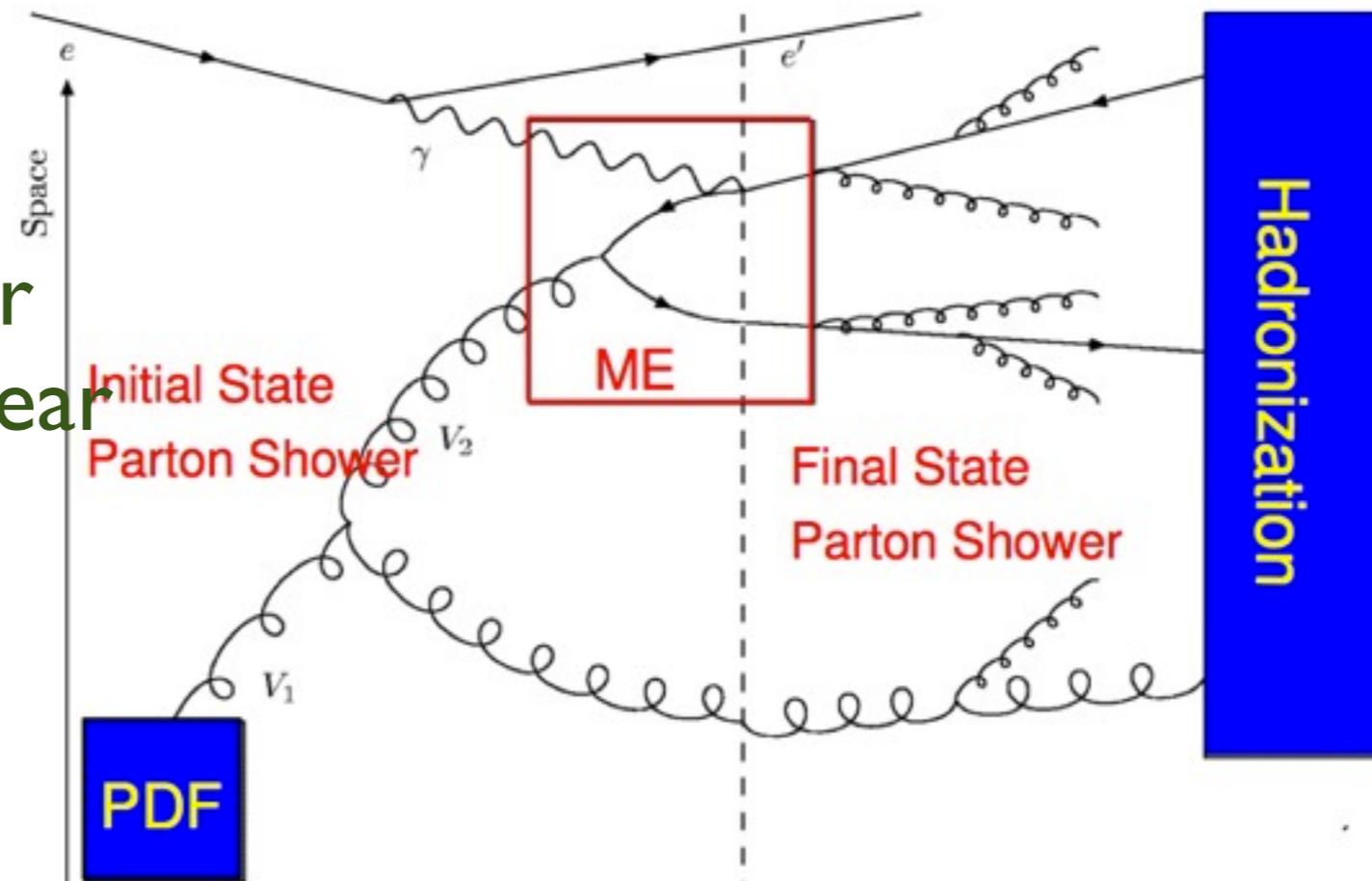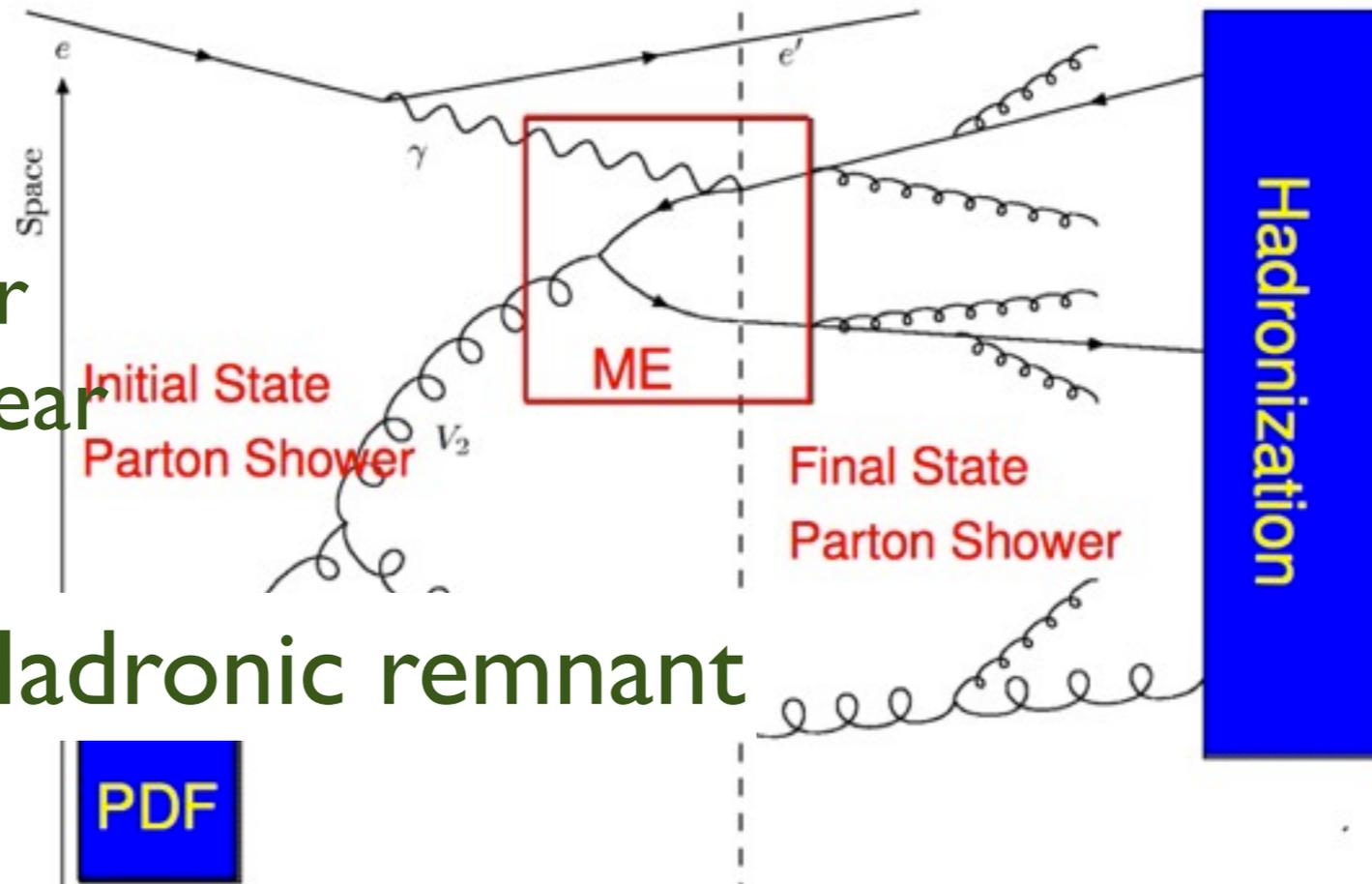
Lund Strings, Clusters, independent, medium ...
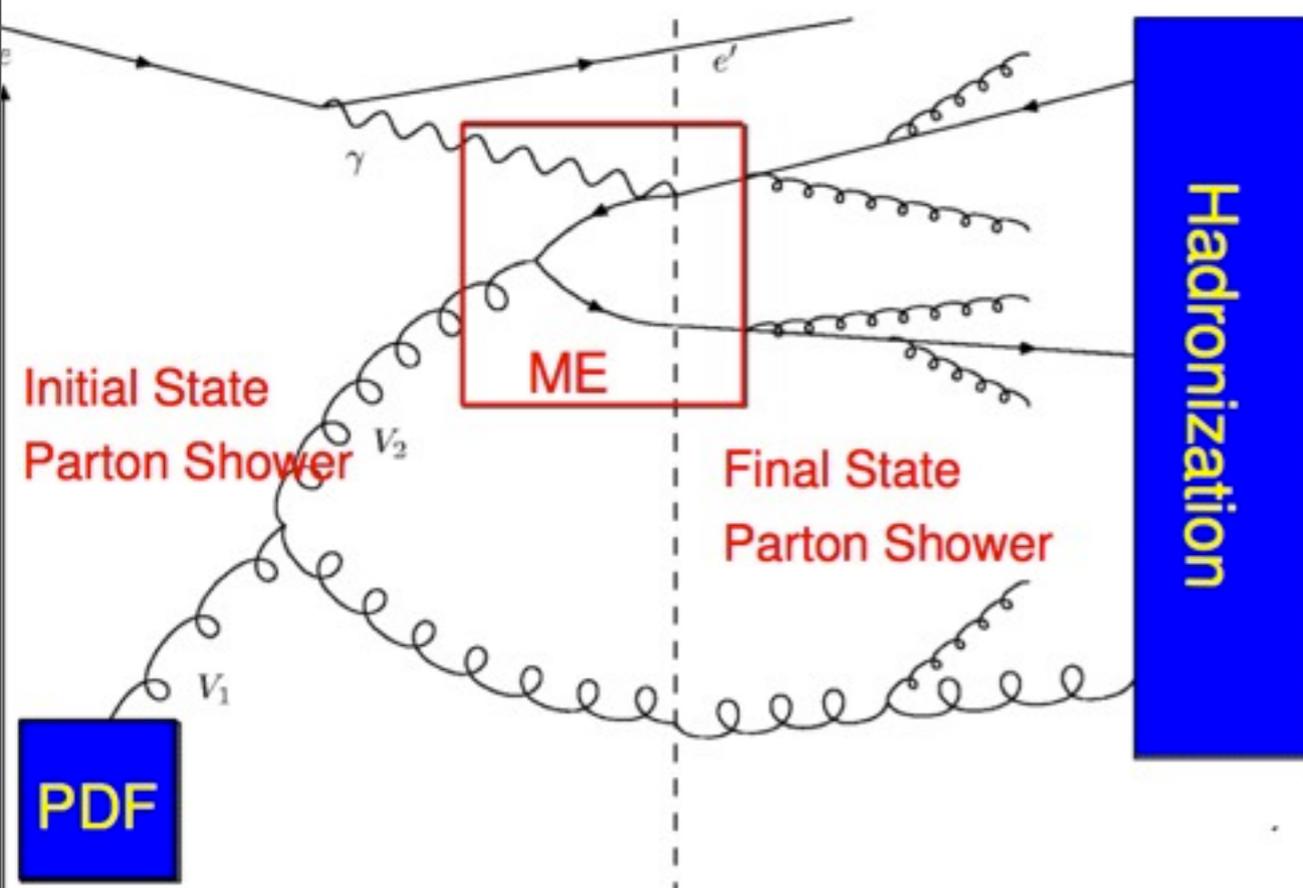
Input distribution: PDF, uPDF, GPD, TMD...

Final State bremsstrahlung PS, vacuum/medium

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What is an MC generator?

Radiative corrections (see Elke's talk)

Hard scattering pQCD or QED Matrix Element, at LO, NLO...

Initial state QCD radiations: collinear DGLAP), non-collinear (CCFM, RCBK) ...

Lund Strings, Clusters, independent, medium

...

Hadronic remnant

Input distribution: PDF, uPDF, GPD, TMD...

Final State bremsstrahlung PS, vacuum/medium

The Generators

Monday, October 8, 2012

Pythia6 by T. Sjöstrand

Multi-purpose generator in ep, all sorts of collinear LO ME

Collinear factorisation (DGLAP) PS

Lund fragmentation (JETSET)

Can simulate non-collinear effects with initial Gaussian gluon and quark k_T distributions.

Code modified to include radiative corrections via RADGEN (by Elke).

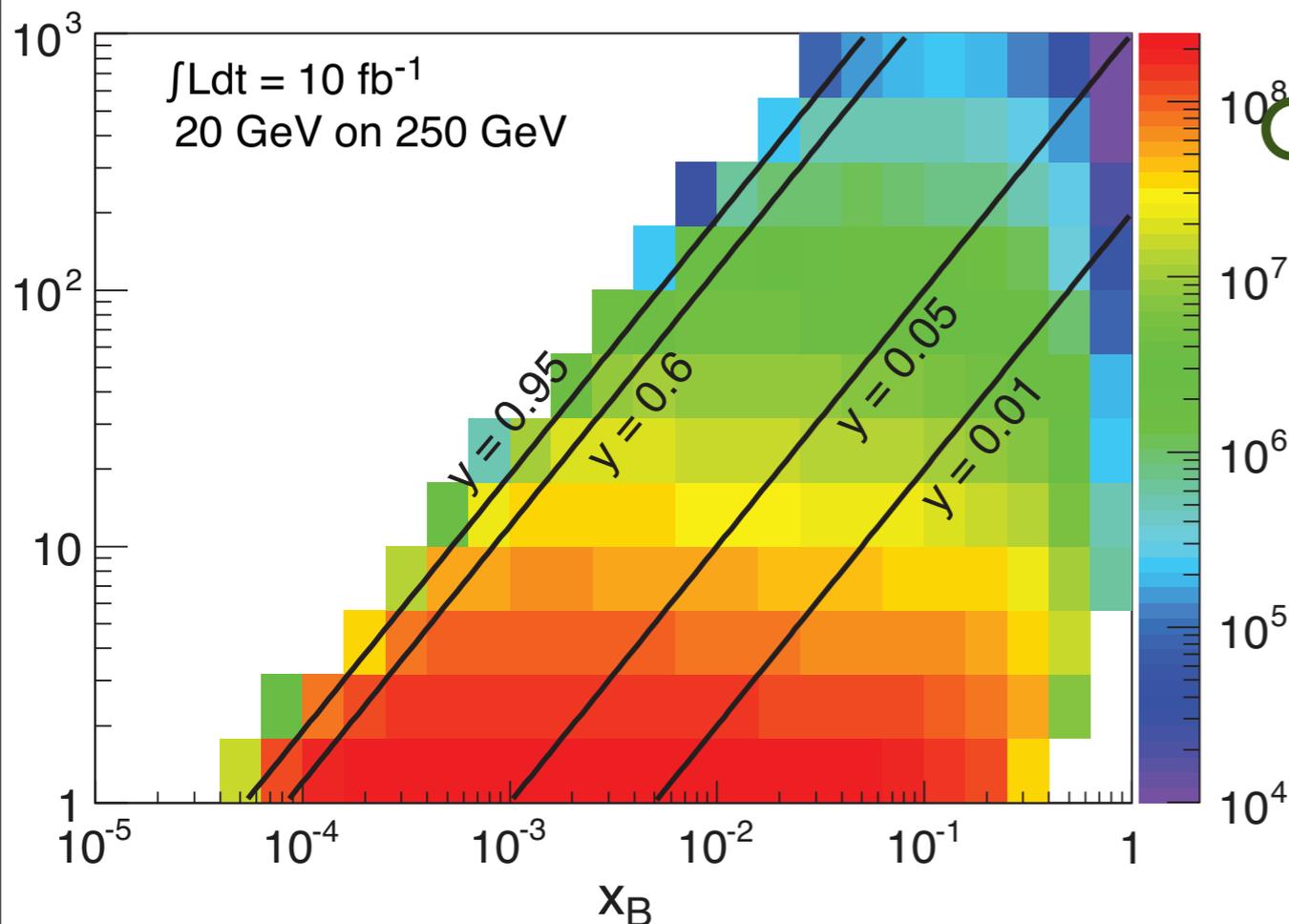http://home.thep.lu.se/~torbjorn/Pythia.html

Sjostrand, Torbjorn *et al.* JHEP 0605 (2006) 026 hep-ph/0603175 FERMILAB-PUB-06-052-CD-T, LU-TP-06-13

Pythia6 by T. Sjöstrand

Multi-purpose generator in ep, all sorts of collinear LO ME

$\int Ldt = 10 \text{ fb}^{-1}$
20 GeV on 250 GeV

$y = 0.95$
$y = 0.6$
$y = 0.05$
$y = 0.01$

x_B

Collinear factorisation (DGLAP) PS

Lund fragmentation (JETSET)

Can simulate non-collinear effects with initial Gaussian gluon and quark k_T distributions.

Code modified to include radiative corrections via RADGEN (by Elke).

http://home.thep.lu.se/~torbjorn/Pythia.html

Sjostrand, Torbjorn *et al.* JHEP 0605 (2006) 026 hep-ph/0603175 FERMILAB-PUB-06-052-CD-T, LU-TP-06-13

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LEPTO by G. Ingelman et. al.

Multi-purpose DIS generator. For ep: LO DIS, QCDC & PGF

Often used as part of other software packages,
e.g.: PEPSI & DJANGO

Initial state radiation from either DGLAP, or dipoles (ARIADNE)

Fragmentation from Lund model (JETSET)

Rapidity gaps simulated with soft colour interactions

Uses LHAPDF for PDF

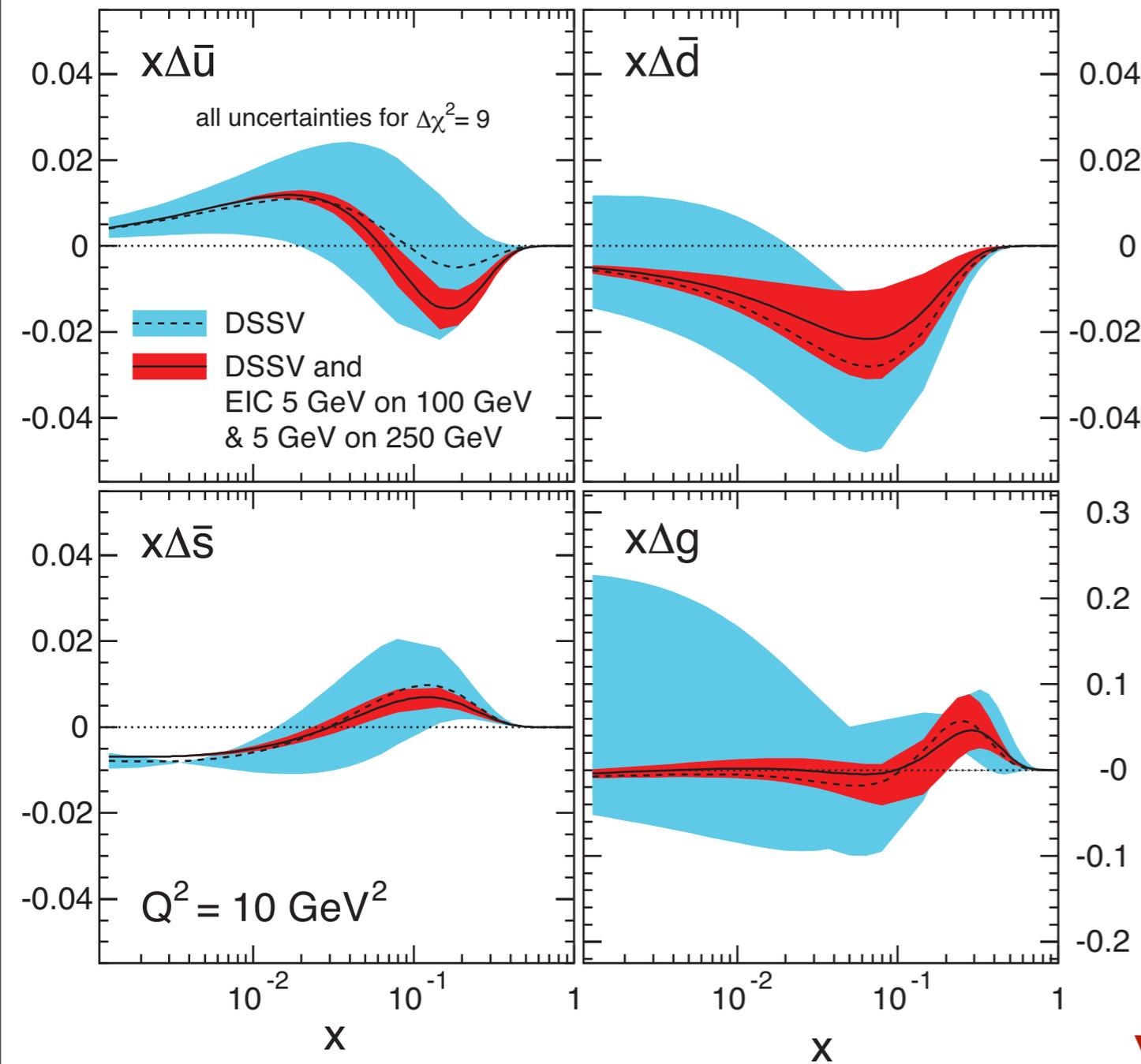Ingelman, G. *et al.* Comput.Phys.Commun. 101 (1997) 108-134 hep-ph/9605286 DESY-96-057

PEPSI

Uncertainty bands on helicity parton distributions, presently (blue) andwith EIC data (red), using projected inclusive and semi-inclusive EIC data sets

DIS generator with polarised proton, based on LEPTO 4.3.

Includes LO DIS, QCDC, PGF + electro-weak interactions

Polarised density functions are set in LEPTO

Code modified to include radiative corrections via RADGEN (by Elke)

Various parametrisations of Δq (x, Q^2) and $\Delta g(x, Q^2)$

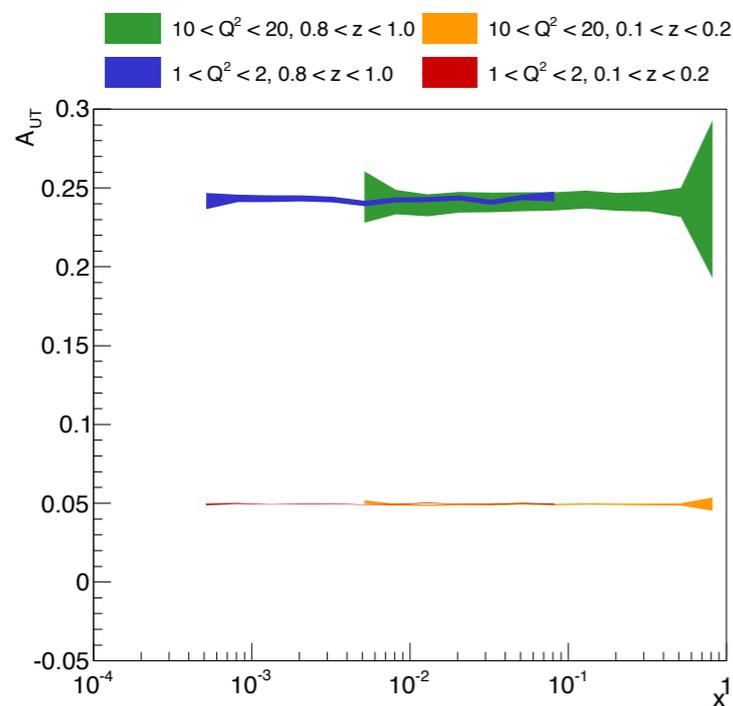L. Mankiewicz, A. Schäfer and M. Veltri, Comp. Phys. Comm. **71**, 305-318 (1992)

gmc_trans
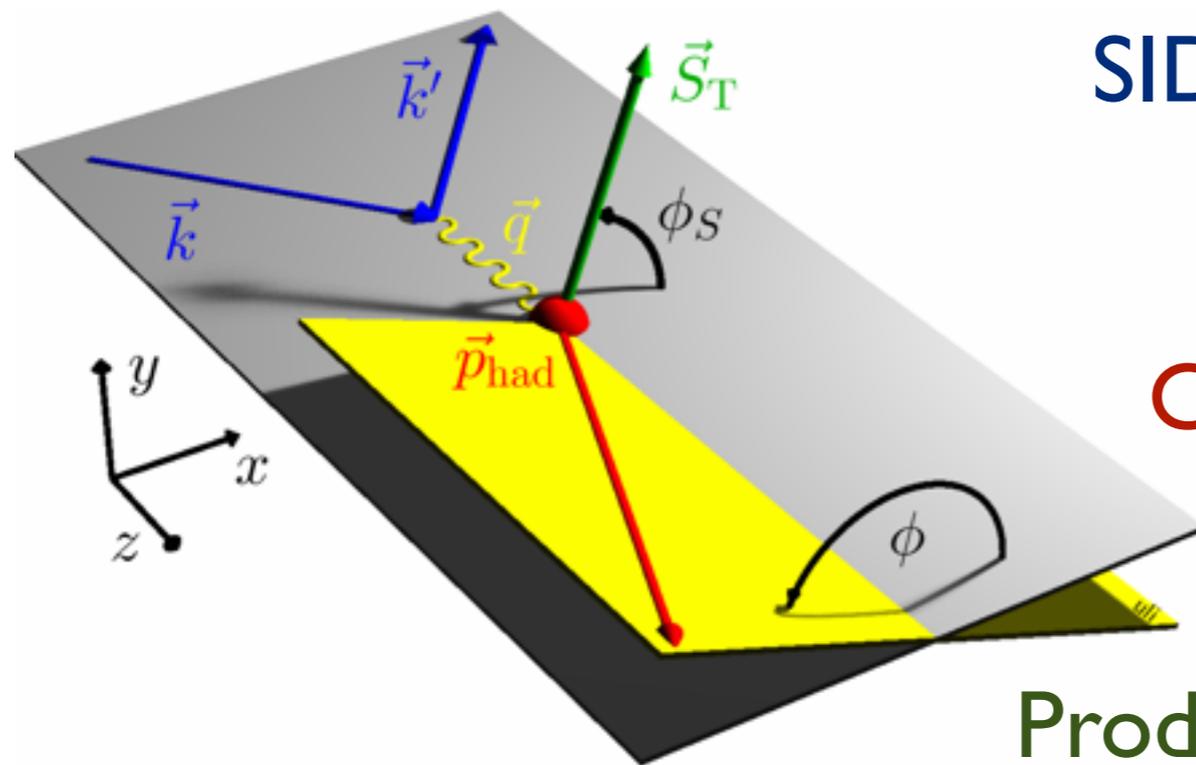
SIDIS generator for *ep* with polarized proton, with TMDs,
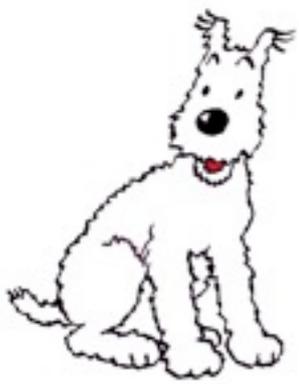
Choice of TMD parameterisations: Sivers, Collins, Boer-Mulders

Produces a single hadron, not a full event: e+p→e+h, h = π⁺, π⁻, π⁰, K⁺, K⁻

Polarized cross-section used to generate angular distribution of produced hadron

Sivers asymmetry as a function of *x* for different Q^2 and *z* values and integrated over p_T, at the positivity bound, showing the precision scaled for 10 fb⁻¹

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# MILOU

Maintained at BNL by Salvatore Fazio

A. Freund and M. McDermott [All ref.s in: http://durpdg.dur.ac.uk/hepdata/dvcs.html]

A DVCS generator: ep→eΥp, based on GPDs at evolved at NLO:
DVCS, Bethe-Heitler and interference

Optional: protons dissociation and initial-state QED radiative effects and radiative corrections

t-dependence parametrised as an exponential: $\dfrac{\mathrm{d}\sigma}{\mathrm{d}|t|} = e^{-B(Q^2)\cdot|t|}$
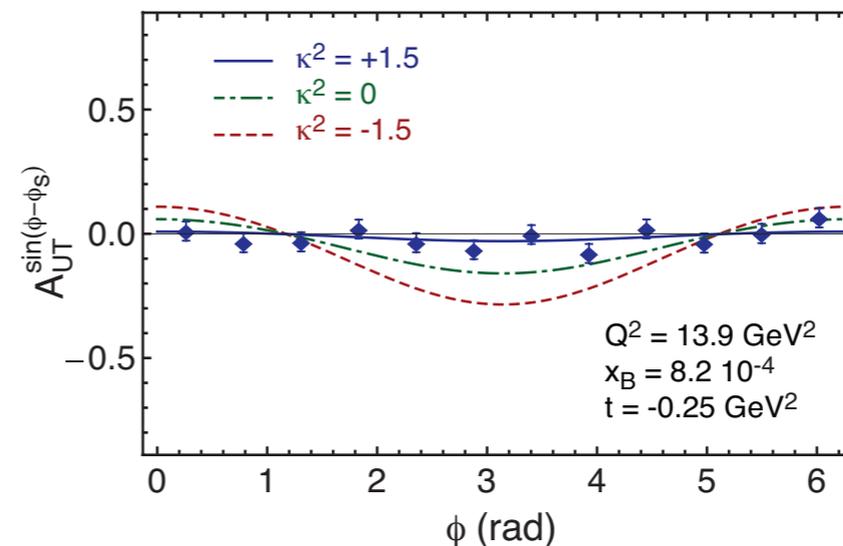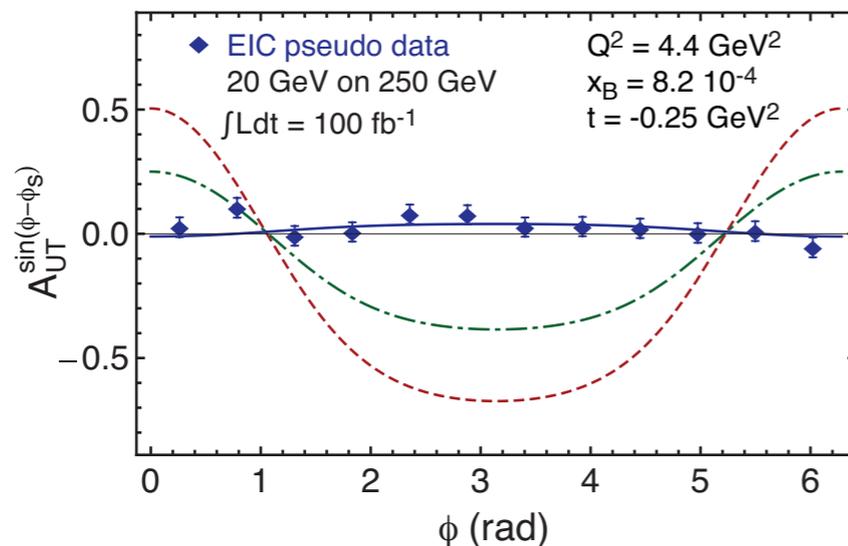
DVCS polarised asymmetry A_{UT} for T-polarised photons

DJANGOH by H. Spiesberger MZ–TH/05–15

Used by EIC primarily to simulate the effects of radiative corrections in both ep and eA

DIS generator with both QED and QCD radiative effects

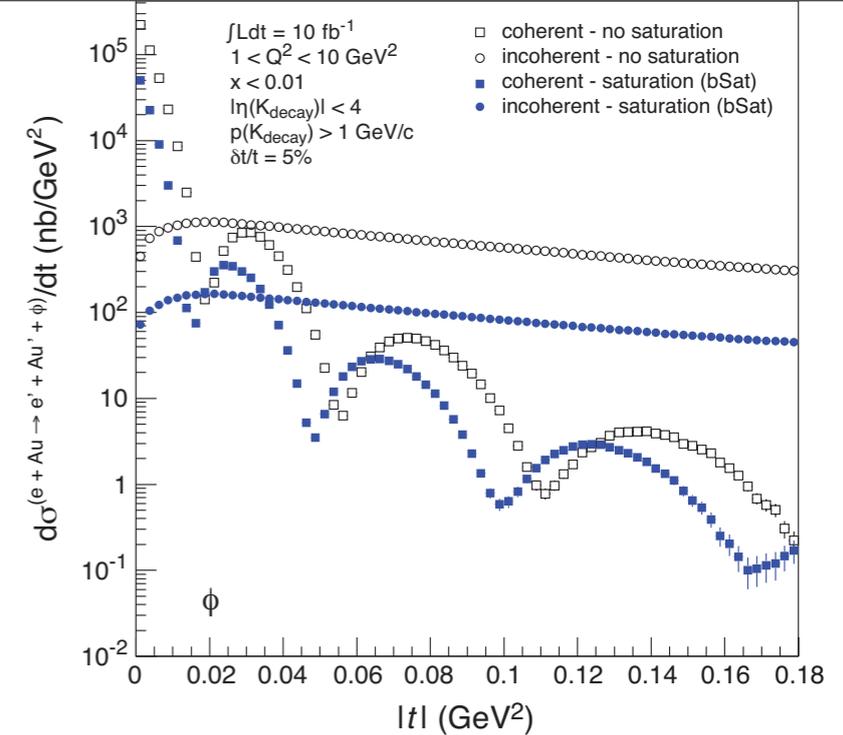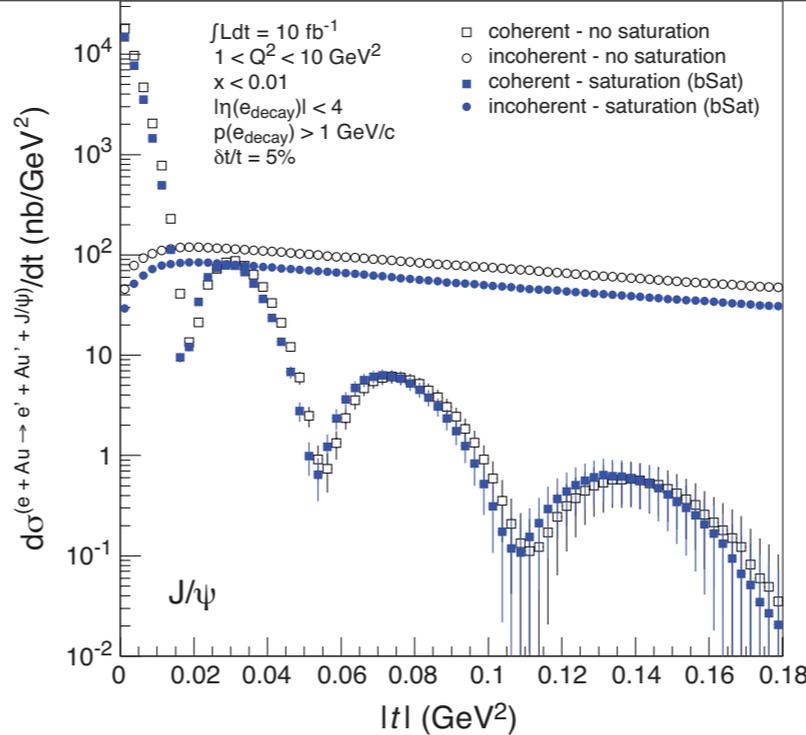Contains HERACLES MC for complete one-loop electroweak radiative corrections and scattering

For high hadronic mass HERACLES uses an interface to LEPTO, for low mass to SOPHIA

Fragments partons via the Lund model in JETSET.

Can be used with nuclear PDFs as well

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Sartre
T. Ullrich and TT

New event generator for exclusive diffractive vector meson and DVCS production in ep and eA (and UPC)

Uses the dipole models bSat and bNonSat

DGLAP gluon evolution, with Gaussian proton shape and Woods-Saxon nuclear shape

Uses Gemini++ for nuclear break-up

Outlook: Coherent inclusive diffraction

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DPM-JetIII

Based on Dual Parton Model, with soft and perturbative pomeron exchanges and AGK cutting rules

In *ee*, *ep*, *pp*, *p*A, *e*A, and AA. From a few GeV to highest cosmic ray energies
Only applicable for photo-production!
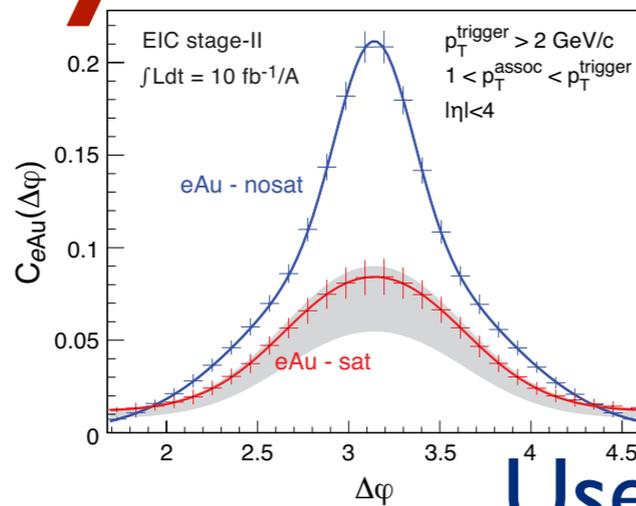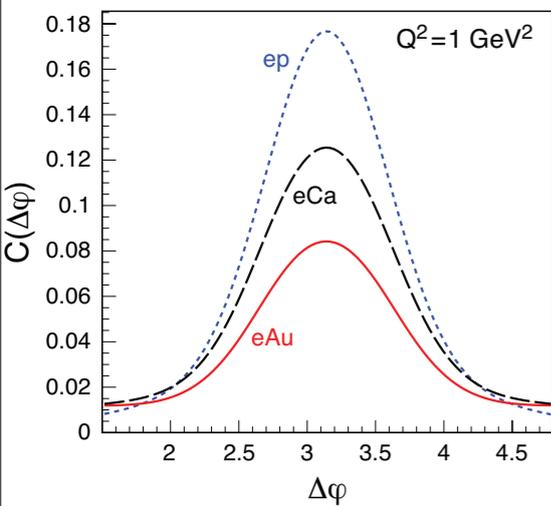
Uses FLUKA for intra-nuclear cascade and evaporation

Uses Lund model (JETSET) for fragmentation

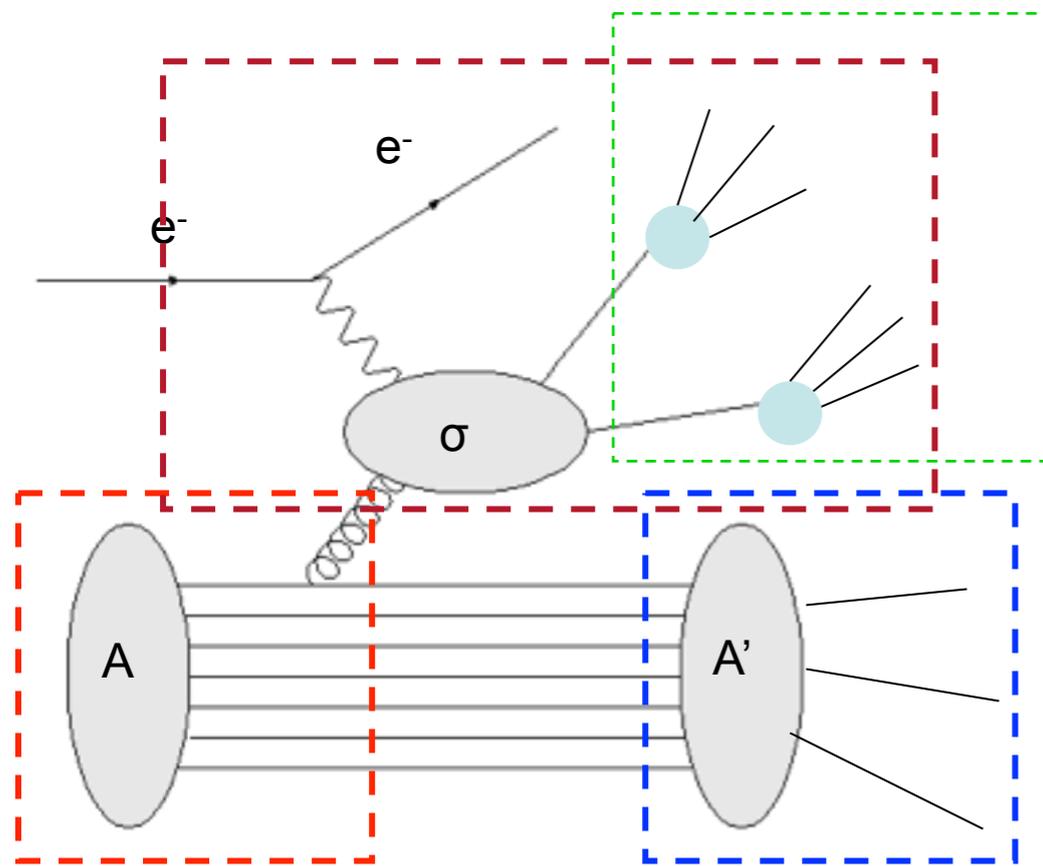Uses a Glauber model based on Woods-Saxon for initial nucleus

S. Roesler, R. Engel and J. Ranft, arXiv:hep-ph/0012252

New Pythia-DPM-JetIII hybrid

By Liang Zheng with Elke and J.H.
Used primarily by EIC to simulate dihadron correlations

Uses ME and PS from Pythia6, with nPDF EPS09

Nuclear geometry (WS) from DPMJet, as well as Nuclear evaporation/nuclear fission/fermi break-up

Energy loss effects to simulate fragmentation effects in cold nuclear matter (Salgado & Wiedermann)

Rad. Corr. in progress

New Pythia-DPM-JetIII hybrid

4 contributions to decorrelation:

1. Higher order effects, like
(a) initial state PS and
(b) NLO hard gluon+loop

2. Non-collinear effects, like
(a) intrinsic k_T of gluon. Also,
(b) combination, with non-collinear initial state radiations and Matrix Elements.
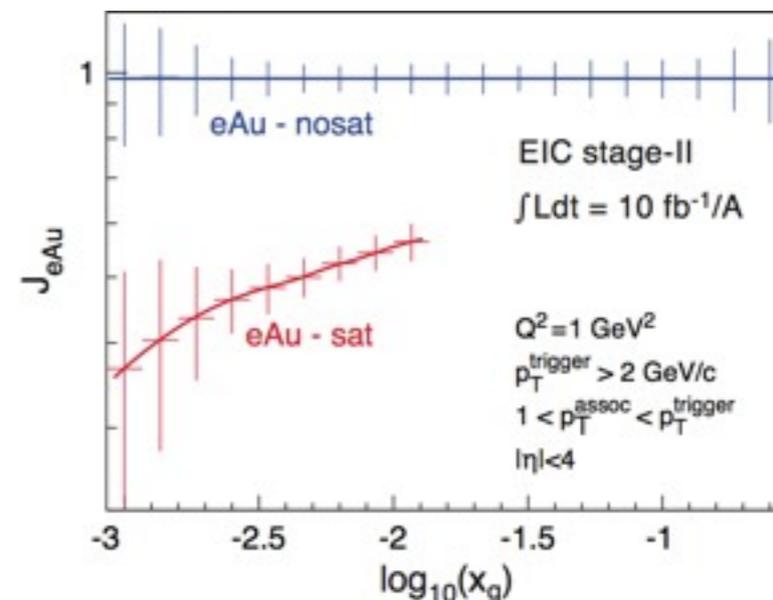
3. Saturation vs.
4. Multiple scattering (not in eA)

Can turn on/off 1(a), and has (crude) mechanism for 1(b) & 2(a)
CASCADE contains 1(a) & 2(a), (b)
Only for *ep* & *pp*
In progress: CASCADE for eA (H. Jung & TT)

eAu - nosat

EIC stage-II
∫Ldt = 10 fb^{-1}/A

eAu - sat

$Q^2 = 1$ GeV^2
$p_T^{trigger} > 2$ GeV/c
$1 < p_T^{assoc} < p_T^{trigger}$
$|\eta| < 4$

J_{eAu}

$\log_{10}(x_g)$

Other resources

- CASCADE (H. Jung et. al.)
  Multi-purpose DIS. k_T-factorised ME,
  CCFM evolution, uPDFs.
  Saturation included in initial state and by bound in evolution.
  Jung, H. *et al.* Eur.Phys.J. C70 (2010) 1237-1249 arXiv:1008.0152 [hep-ph] DESY-10-107

- MC@NLO (S. Frixione, TT)
  Only Heavy Quarks in photo-production for ep.
  Coll. ME calculated at NLO and matched with PS.
  LHAPDF.
  Toll, Tobias *et.al.* Phys.Lett. B703 (2011) 452-461 arXiv:1106.1614 [hep-ph] CERN-PH-TH-2011-128

- RAPGAP (H. Jung)
  Multipurpose. Simulates hard diffractive DIS. DGLAP.
  Jung, Hannes Comput.Phys.Commun. 86 (1995) 147-161