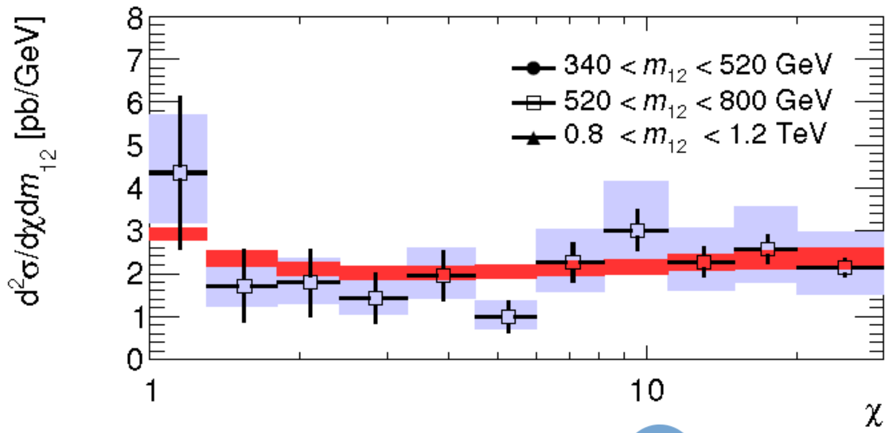
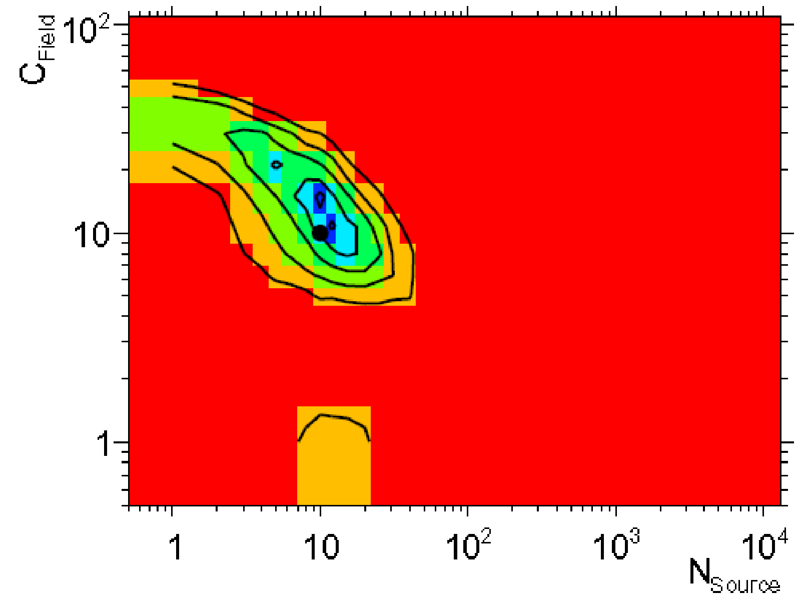
Analysis





Prof. Dr. Martin Erdmann

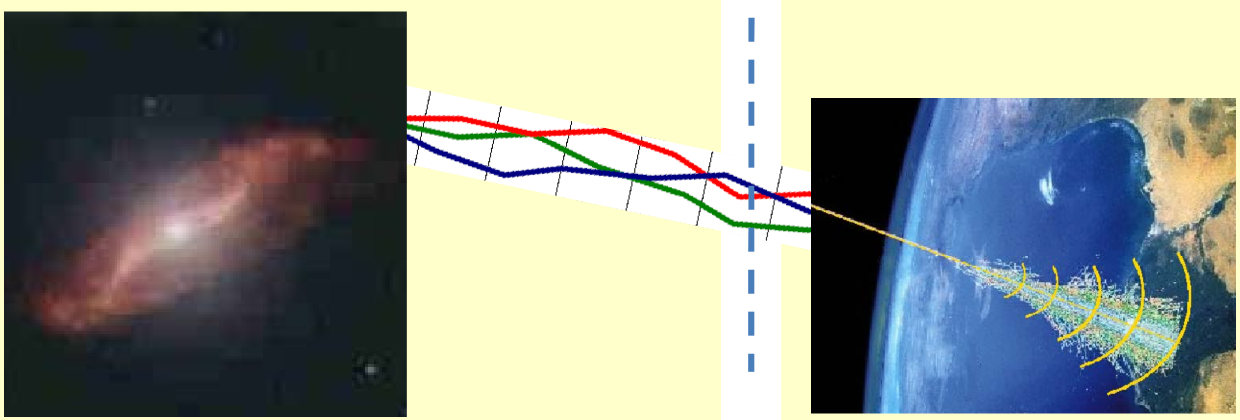
RWTH Aachen University

9-Oct-2010

Astroparticle Tasks

Theory

- Acceleration mechanism
- Sources
- Propagation
- Magnetic Fields



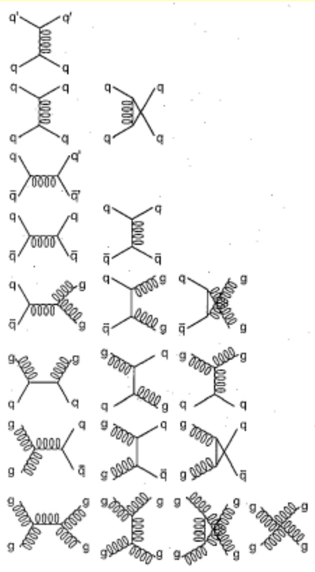
Experiment

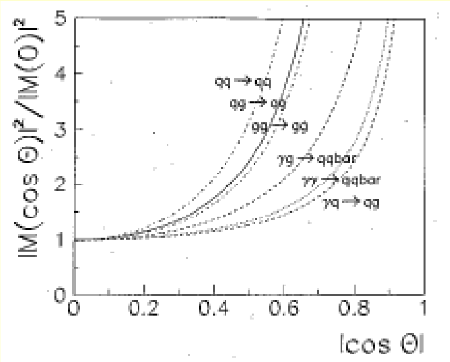
- UHECR detectors
- UHECR kinematics
- Data Distributions
- Observables

High Energy Physics

Theory

- Differential cross sections
- Monte Carlo Event Generators

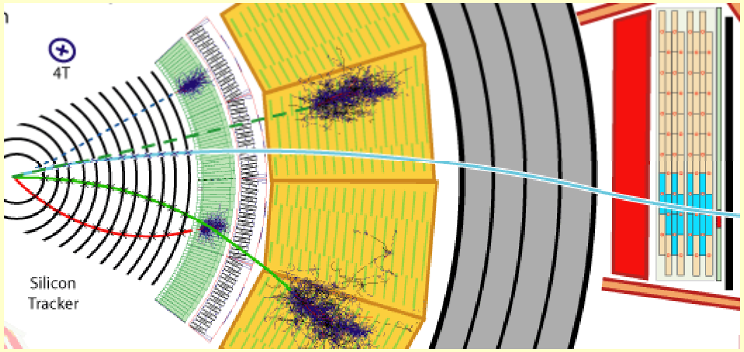




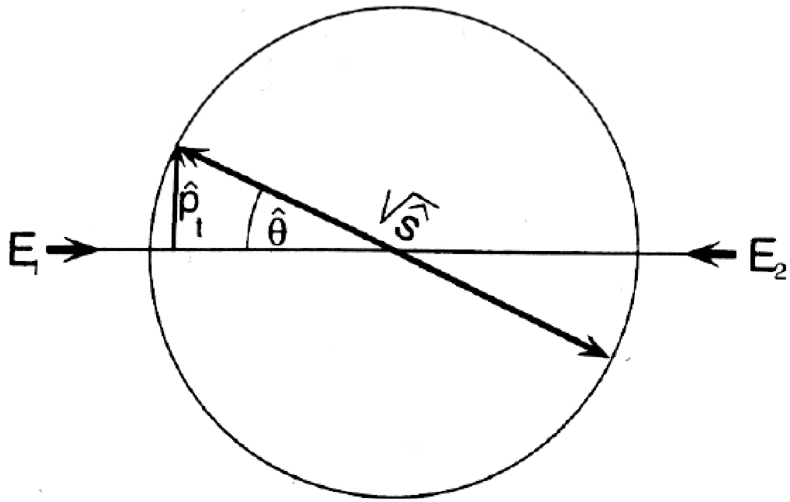
Interface C++ Classes

Experiment

- Accelerators
- Detectors
- Propagation
- Magnetic Fields



Distributions of Scattering Angle



Mandelstam Variables

$$\hat{s} = 4 \cdot E_1 \cdot E_2$$

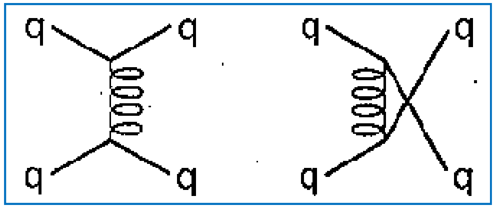
$$\hat{t} = -\frac{\hat{s}}{2}\left(1 - \cos\hat{\theta}\right)$$

$$\hat{u} = -\frac{\hat{s}}{2}\left(1 + \cos\hat{\theta}\right)$$

QCD: parton cross sections

-> angular distributions

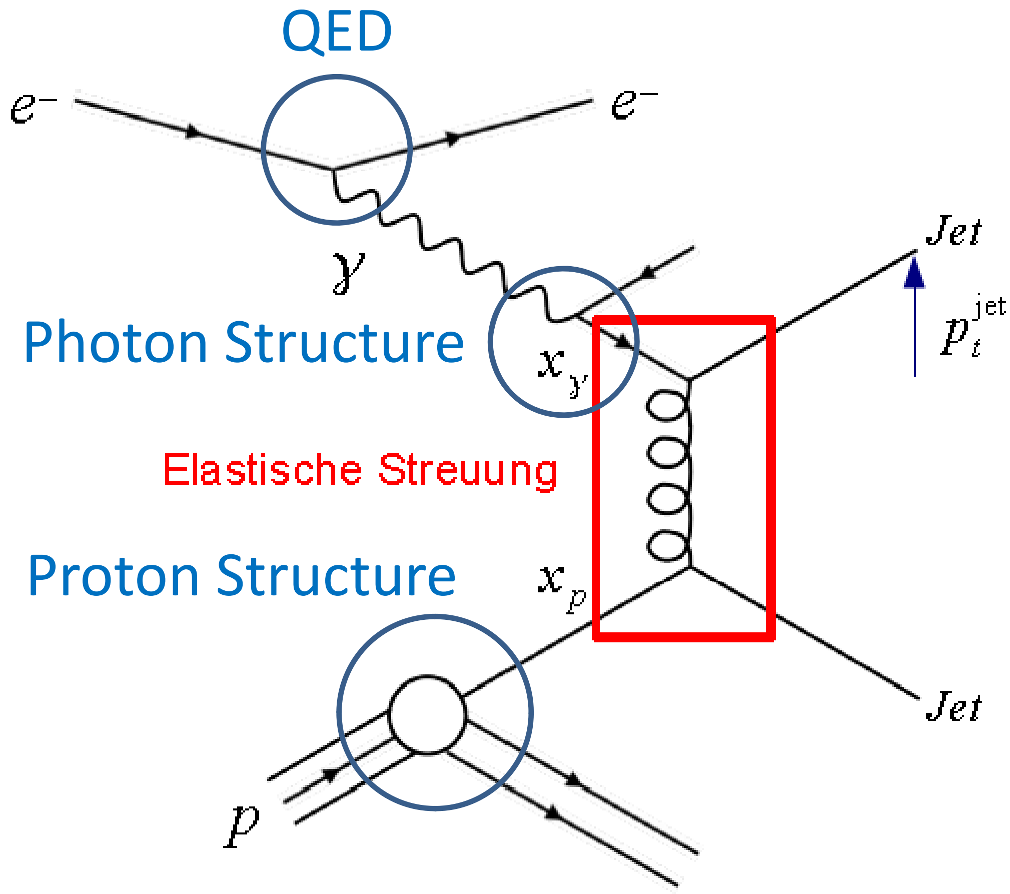
e.g.



$$\frac{d\hat{\sigma}}{d\hat{t}} = \frac{|M|^2}{16\pi\hat{s}^2}$$

$$\frac{|M|^2}{\pi^2} = \frac{64}{9}\alpha_s^2\left(\frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2} + \frac{\hat{s}^2+\hat{t}^2}{\hat{u}^2} - \frac{2}{3}\frac{\hat{s}^2}{\hat{u}\,\hat{t}}\right)$$

Calculation of γp Jet Cross Sections



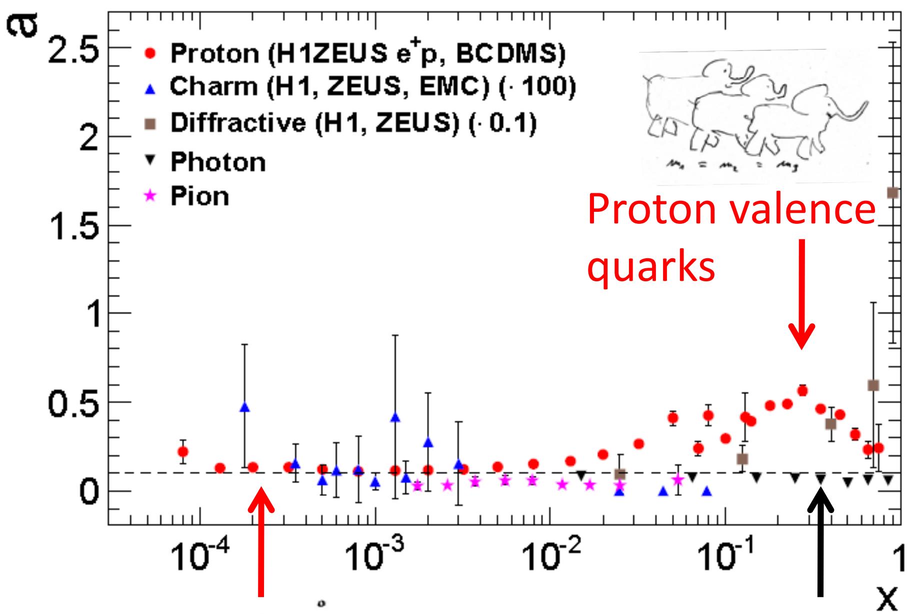
Blue marked ingredience: influence rate

Red: angular distributions are solid QCD predictions

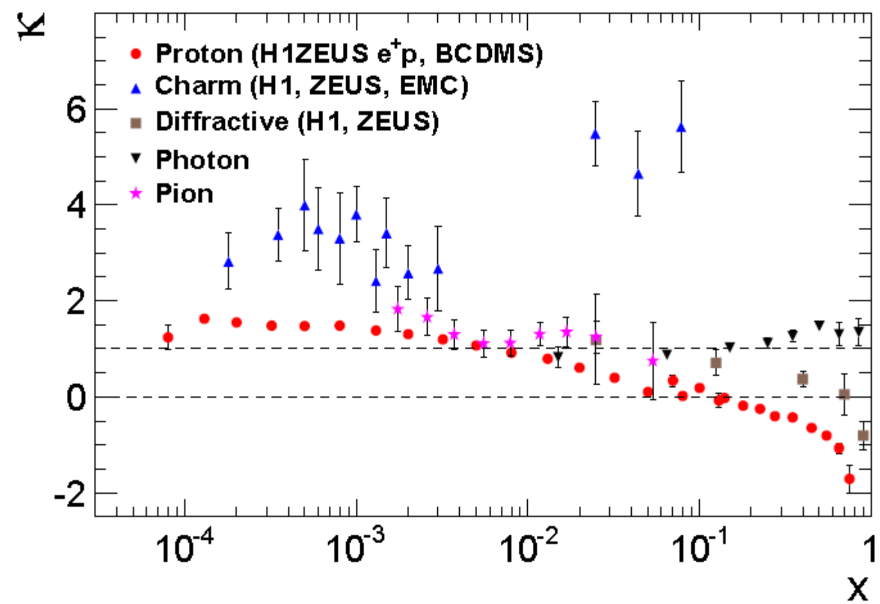
Proton & Photon Structure

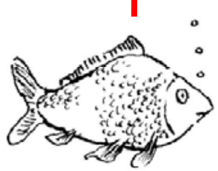
$$F_2(x,Q^2) = a(x)\left[\ln\left(\frac{Q^2}{\Lambda^2}\right)\right]^{\kappa(x)}$$

hadronic structure



scaling violations



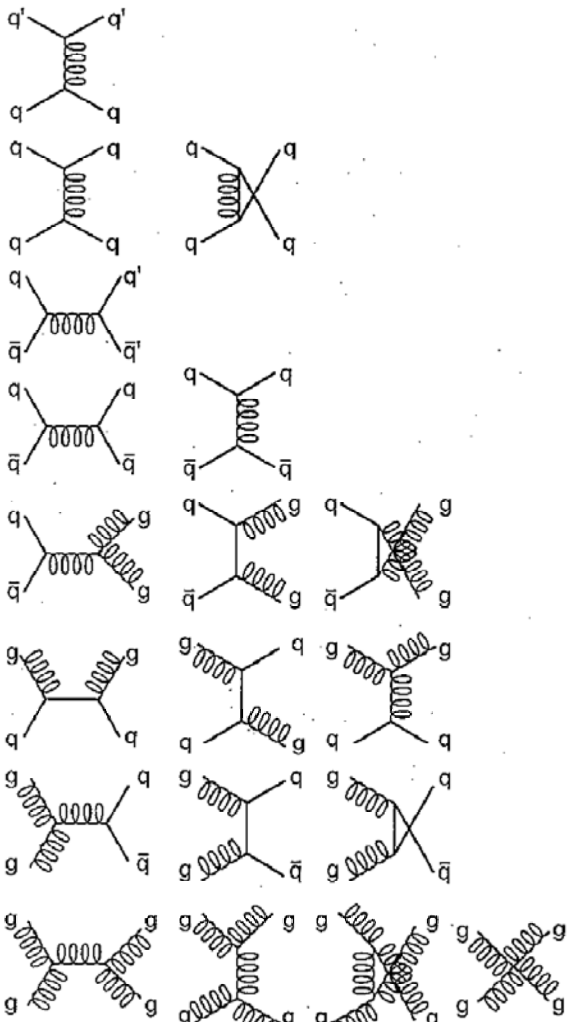


Photon sea quarks

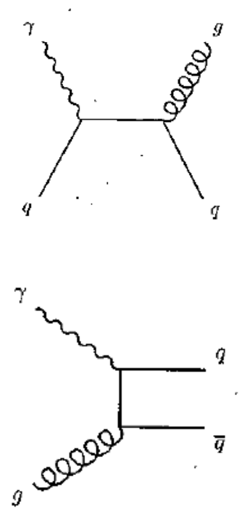
Proton sea quarks

Many parton processes possible:

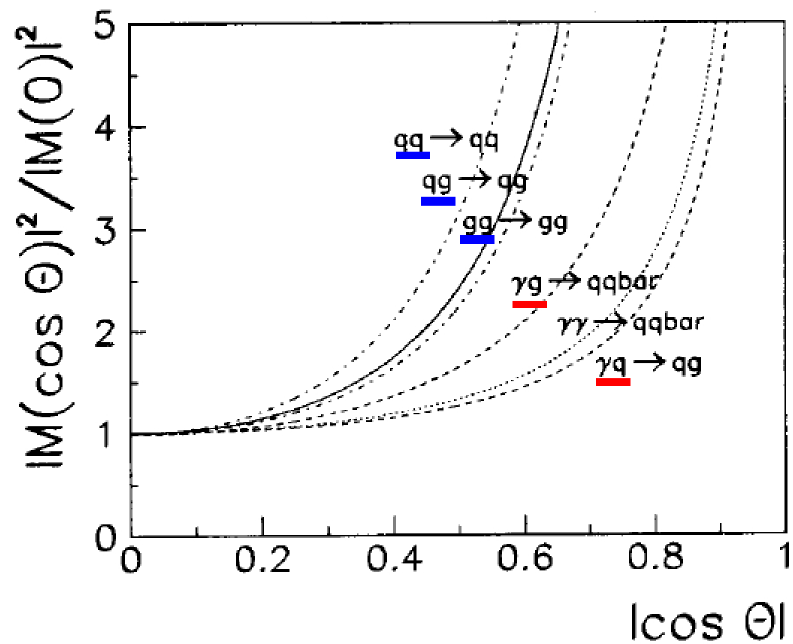
Resolved photon



Direct photon

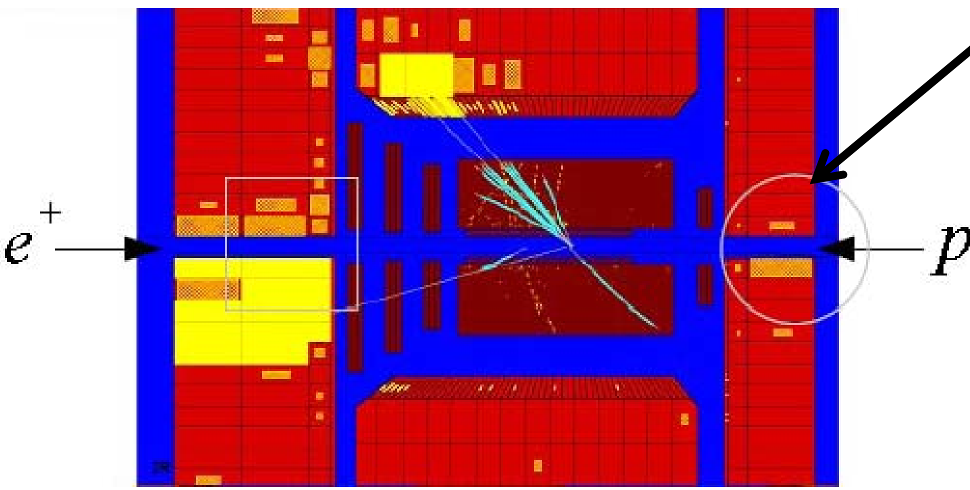


Angular Distributions

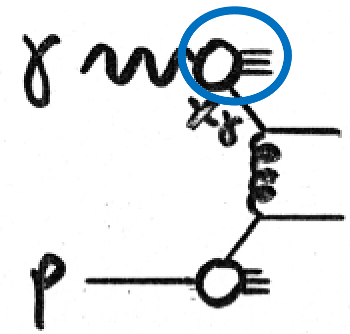


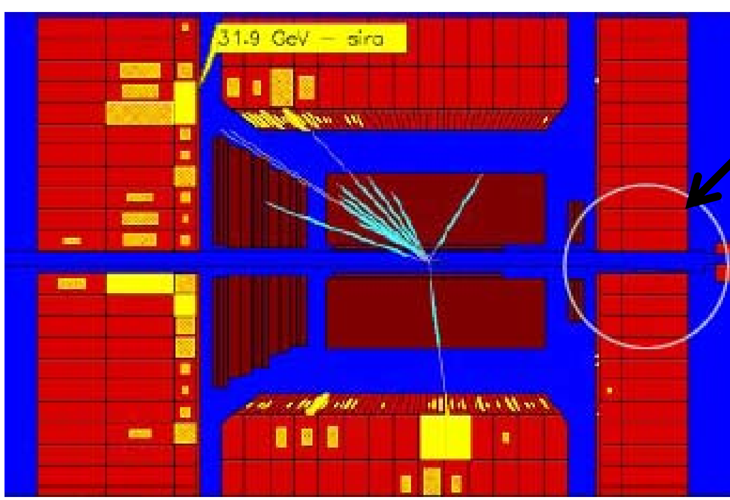
Direct / Resolved photon processes:
Resolved γ angular distribution expected to be more steep.

Direct/Resolved Photon Interactions

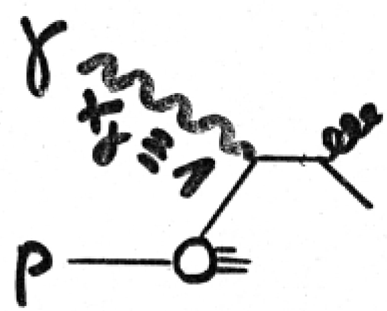


Energy from photon remnant

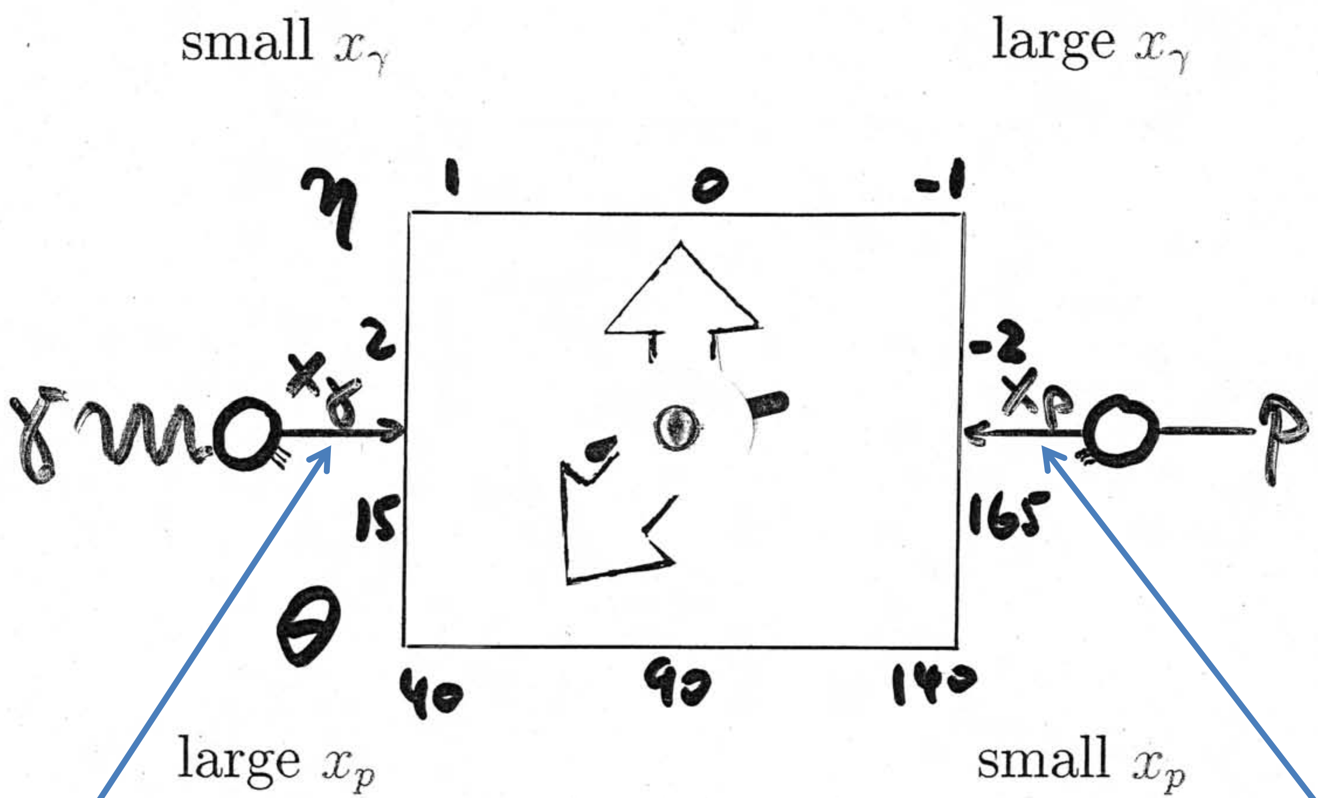


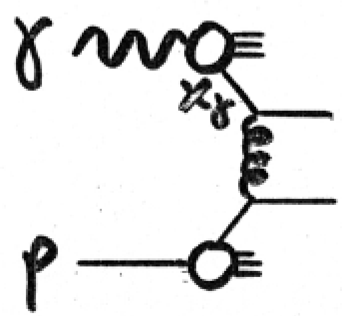


No energy in photon direction



Reconstruct initial Parton Momenta

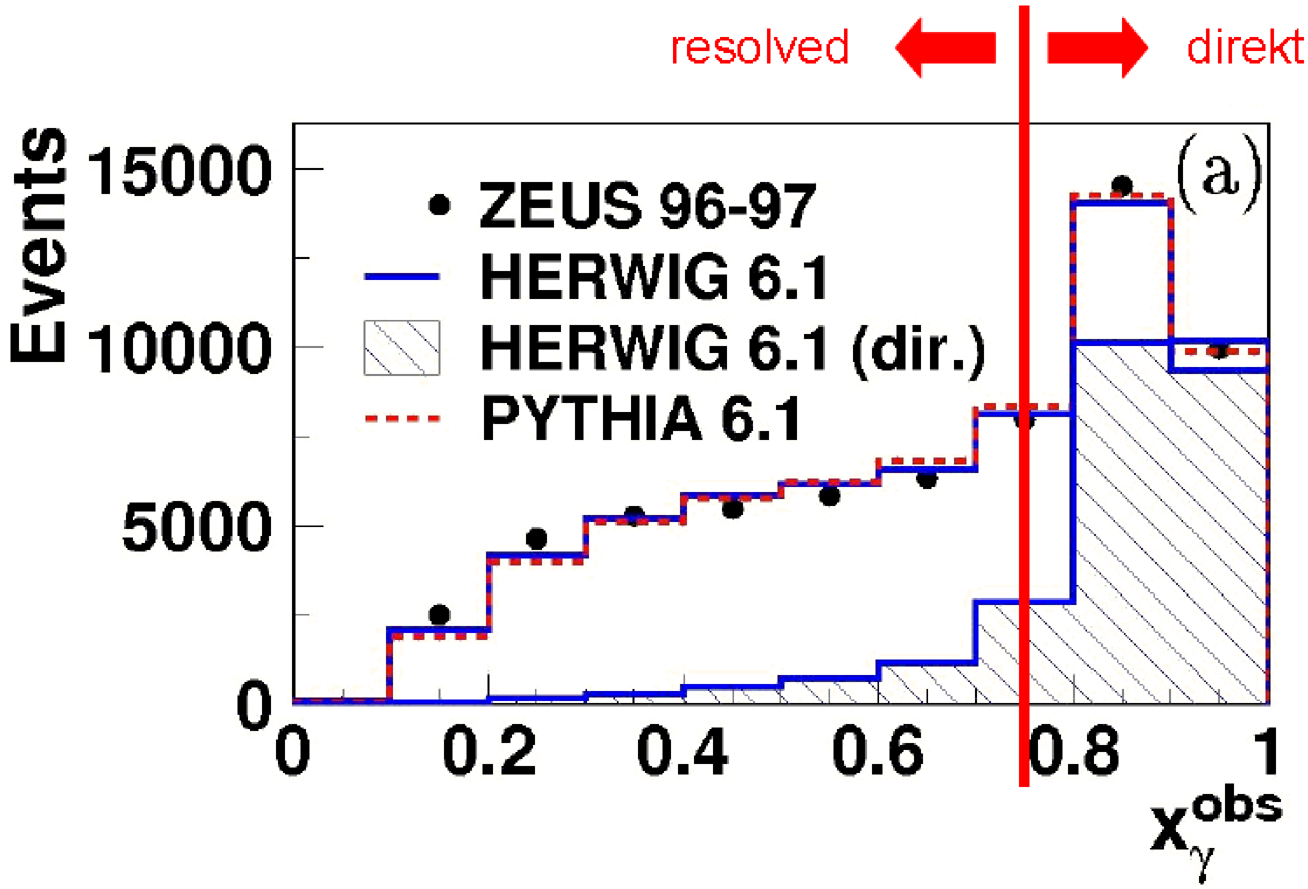




$$x_\gamma \;=\; E_t \, \frac{e^{-\eta_1} + e^{-\eta_2}}{2 \; E_\gamma}$$

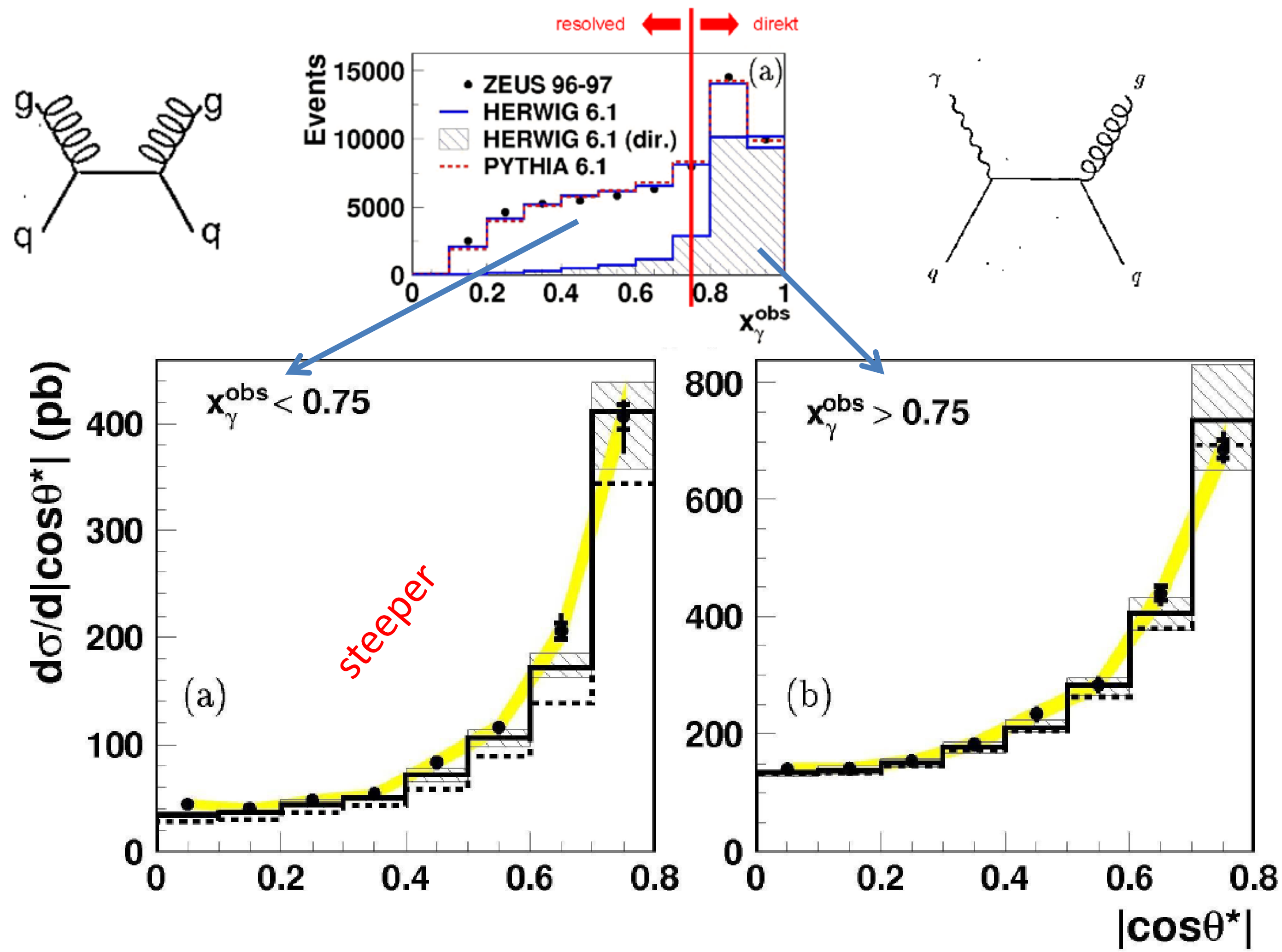
$$x_p \;=\; E_t \, \frac{e^{+\eta_1} + e^{+\eta_2}}{2 \; E_p}$$

Separate Direct/Resolved Photon Events



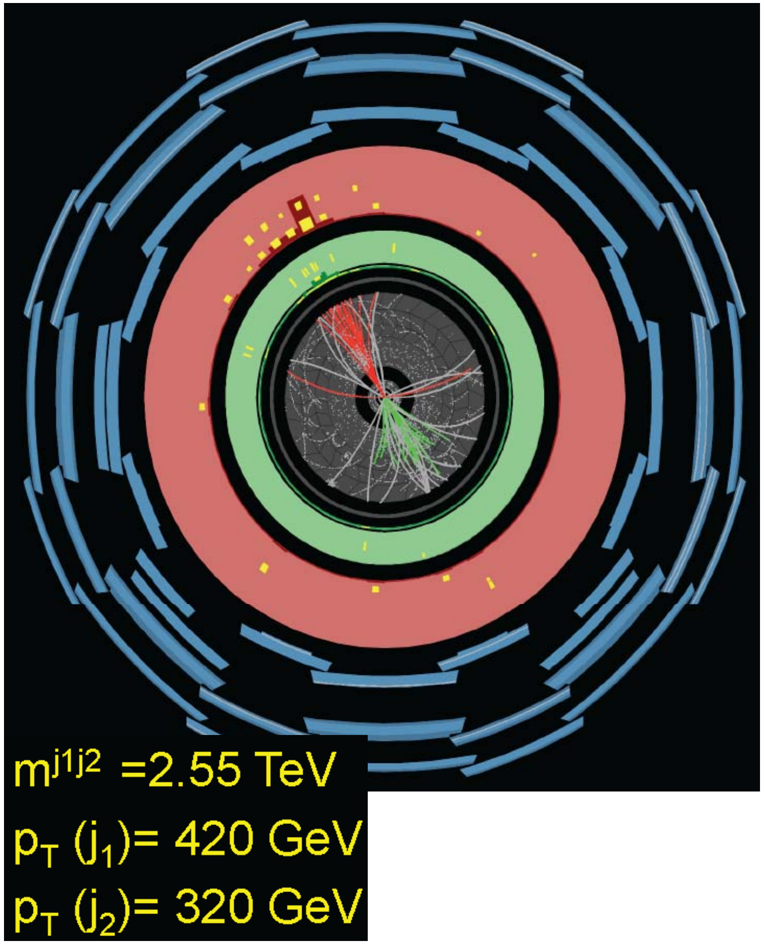
measure x_γ event-by-event

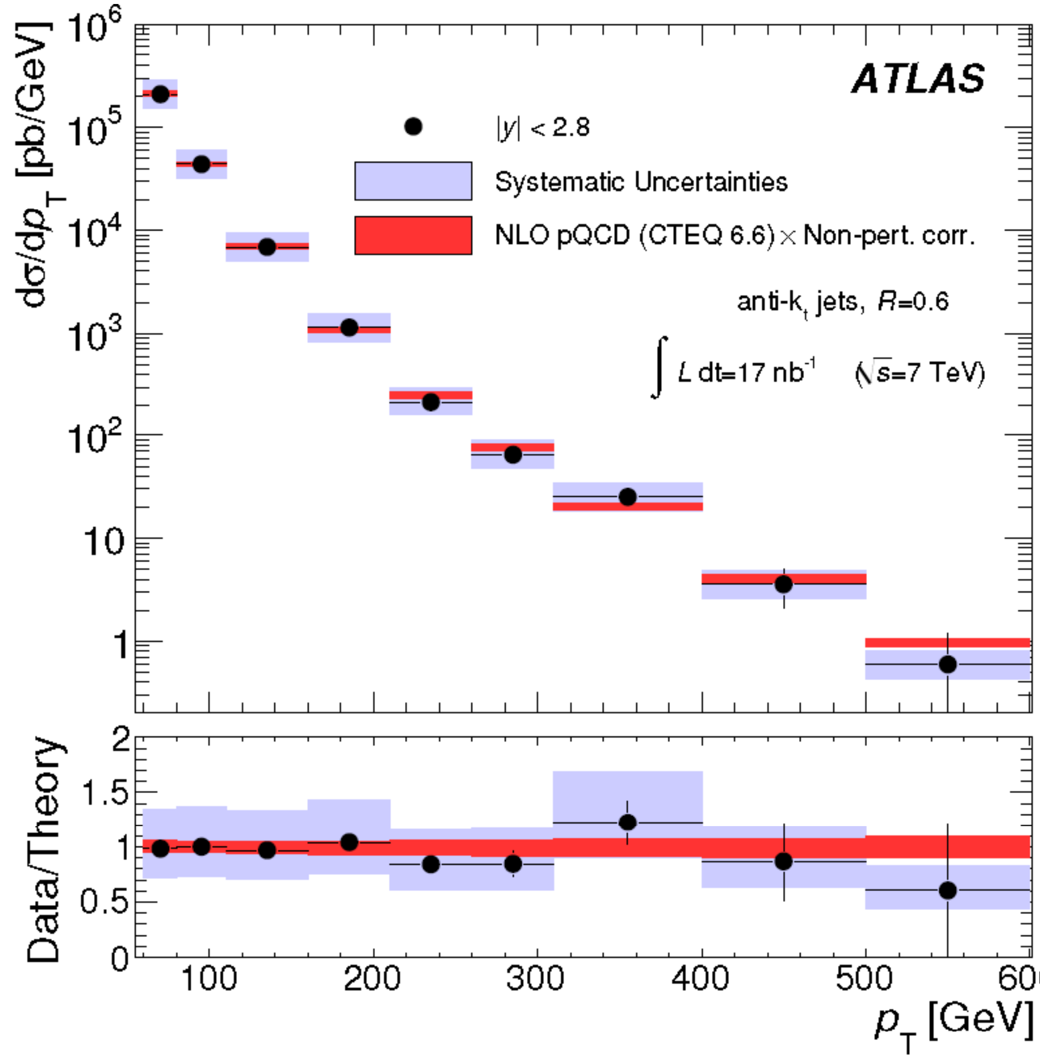
Measured Angular Distributions



QCD correctly predicts the angular distributions

Atlas: Jet Cross Section

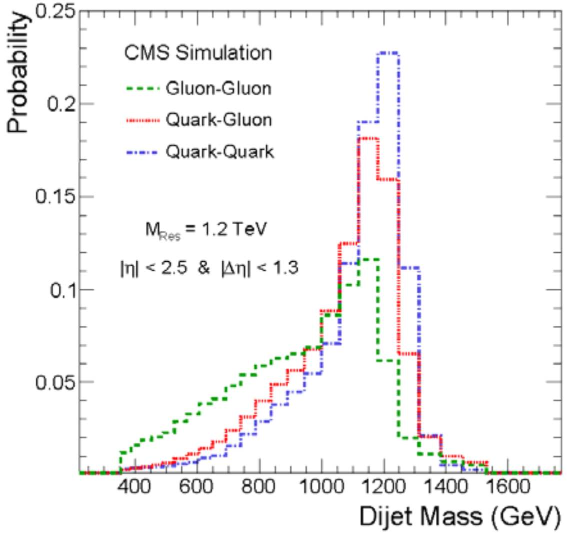




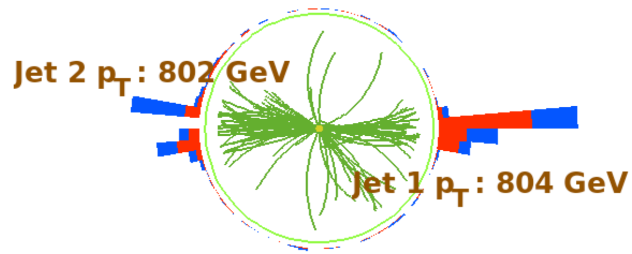
Good description of the NLO QCD calculations

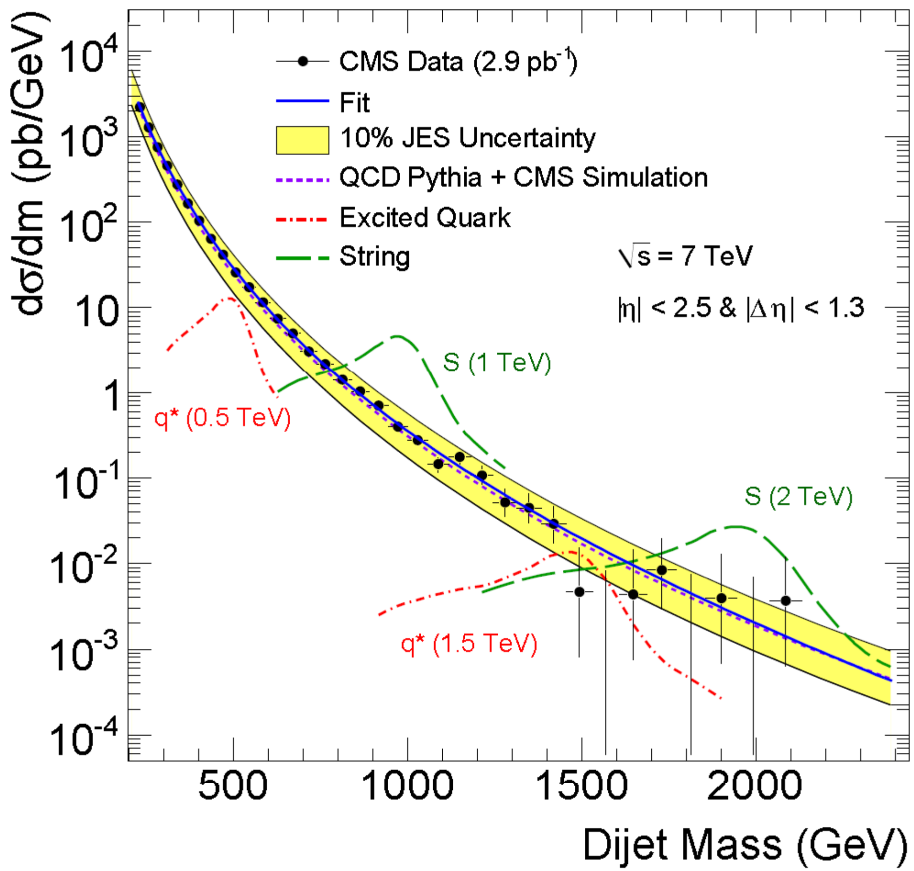
CMS: Search for New Heavy Particles

Simulation



Measurement

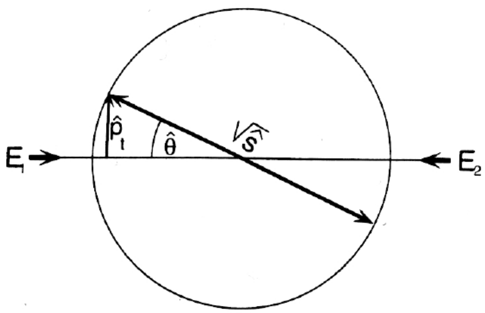


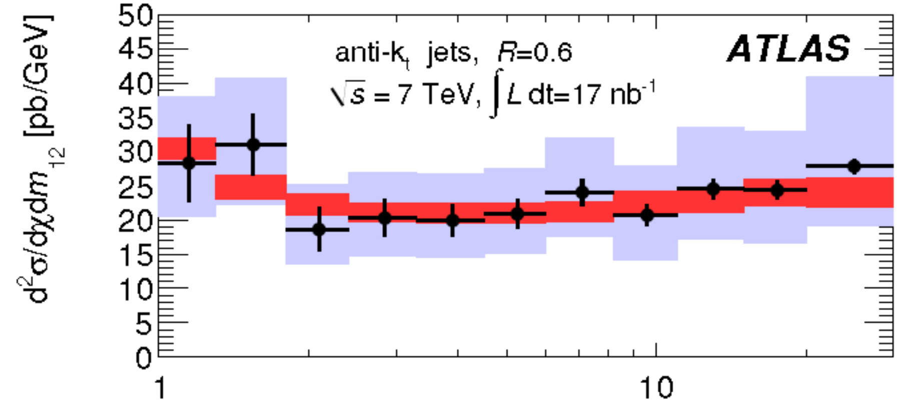


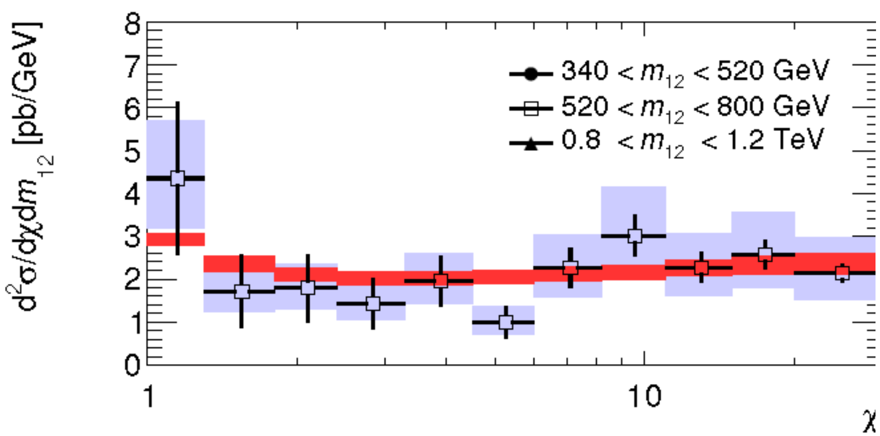
No resonance (yet)

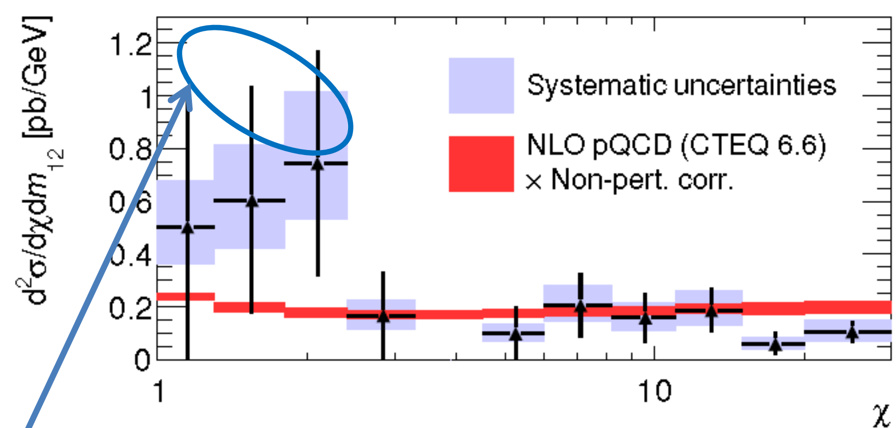
Atlas: Dijet Angular Distributions

$$\chi = \exp(|y_1 - y_2|) \approx \frac{1 + \cos\theta^*}{1 - \cos\theta^*}$$: Rutherford scattering appears flat





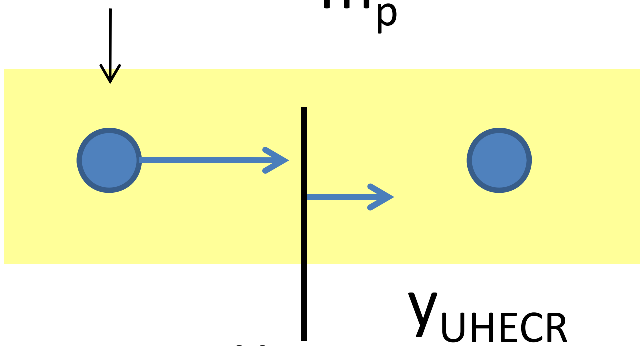




no sign (yet) of heavy particle decaying into two jets

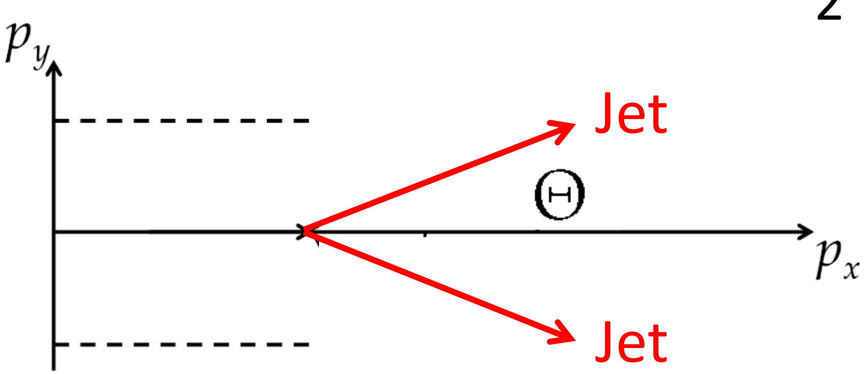
Jets from Air Showers?

$$y_{UHECR} = \ln \frac{E_p + p_p}{m_p} = \ln \frac{2\,10^{18}}{10^9} = \ln(2\,10^9)$$



$$y_{CM} = \frac{y_{UHECR}}{2} = \ln\sqrt{2\,10^9}$$

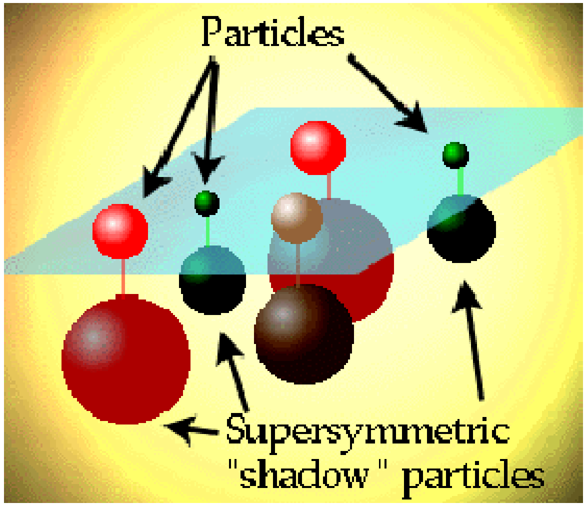
$$\gamma_{CM} = \cosh y_{CM} \sim \frac{e^{y_{CM}}}{2} = \frac{\sqrt{2\,10^9}}{2} \sim 2\,10^4$$

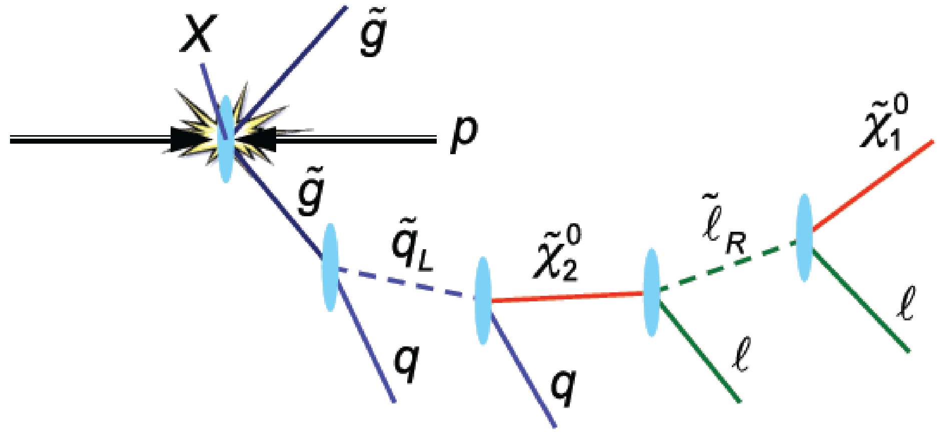


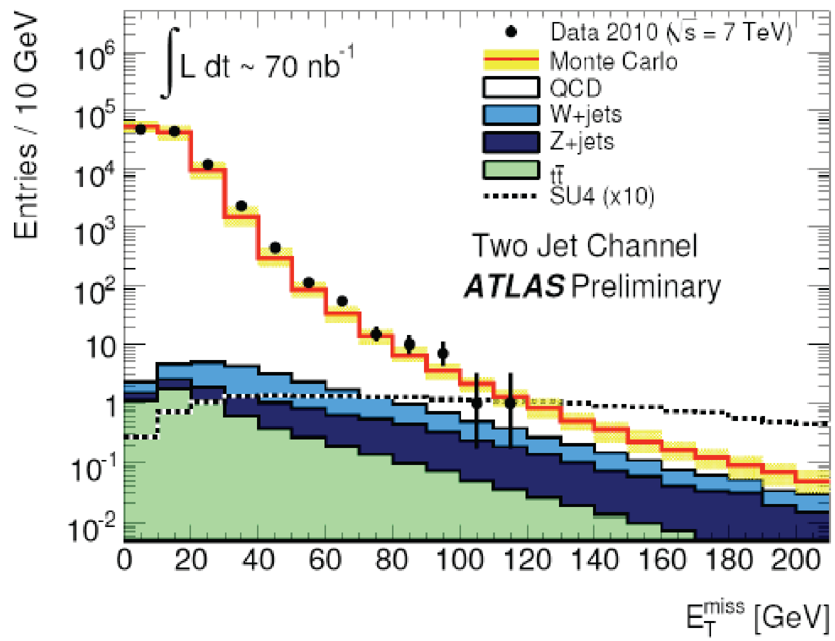
$$\Theta \approx \frac{1}{\gamma} = 0.5\,10^{-4} = \frac{0.5\text{ m}}{10\text{ km}}$$

impossible to separate the jets

Atlas: Searches for Supersymmetry

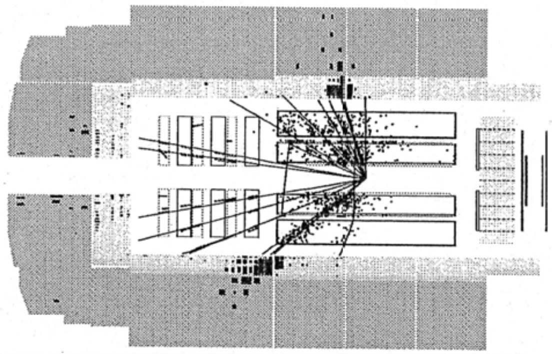


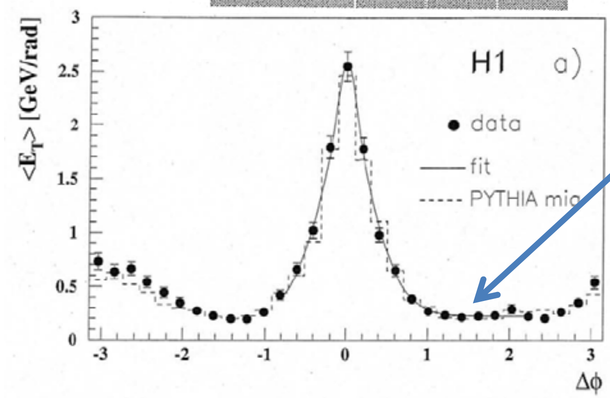


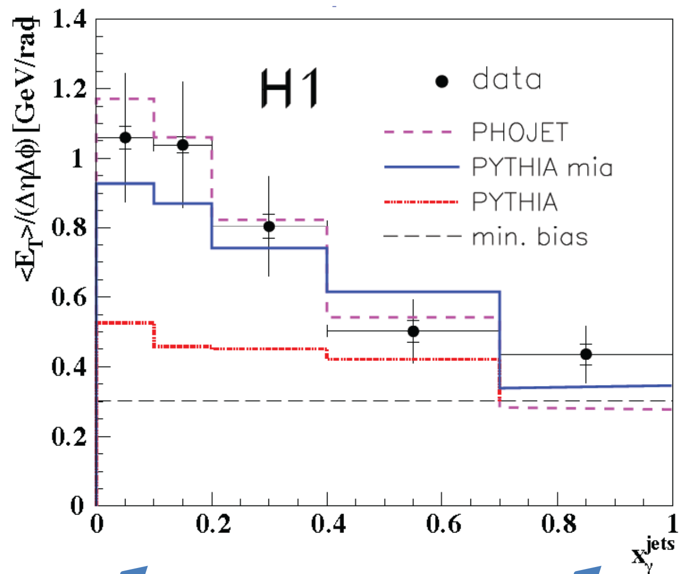


No sign (yet)

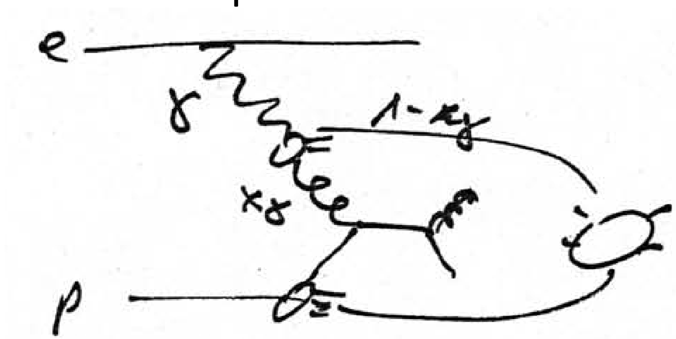
H1: Underlying Event Energy



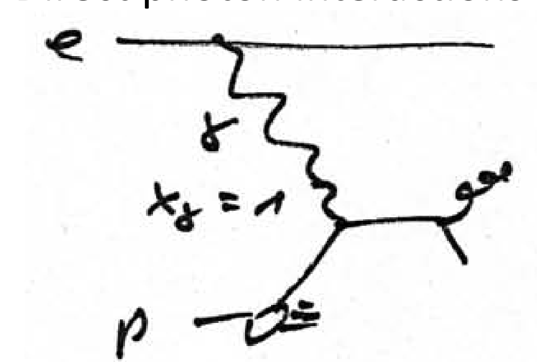




Resolved photon interactions



Direct photon interactions

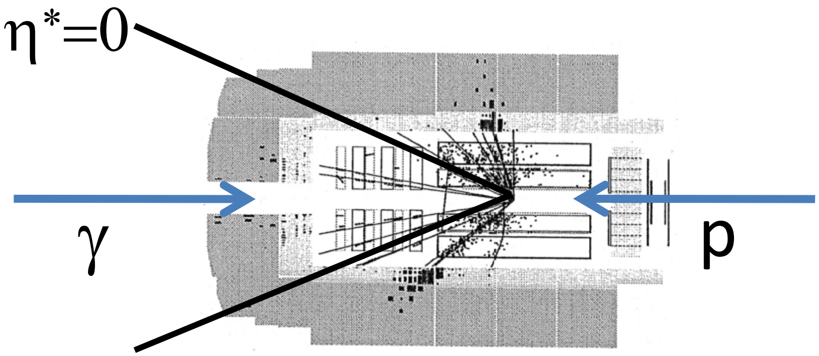


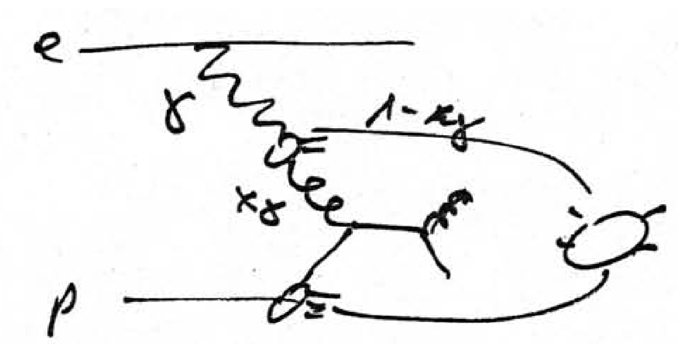
Multiple Parton Interactions

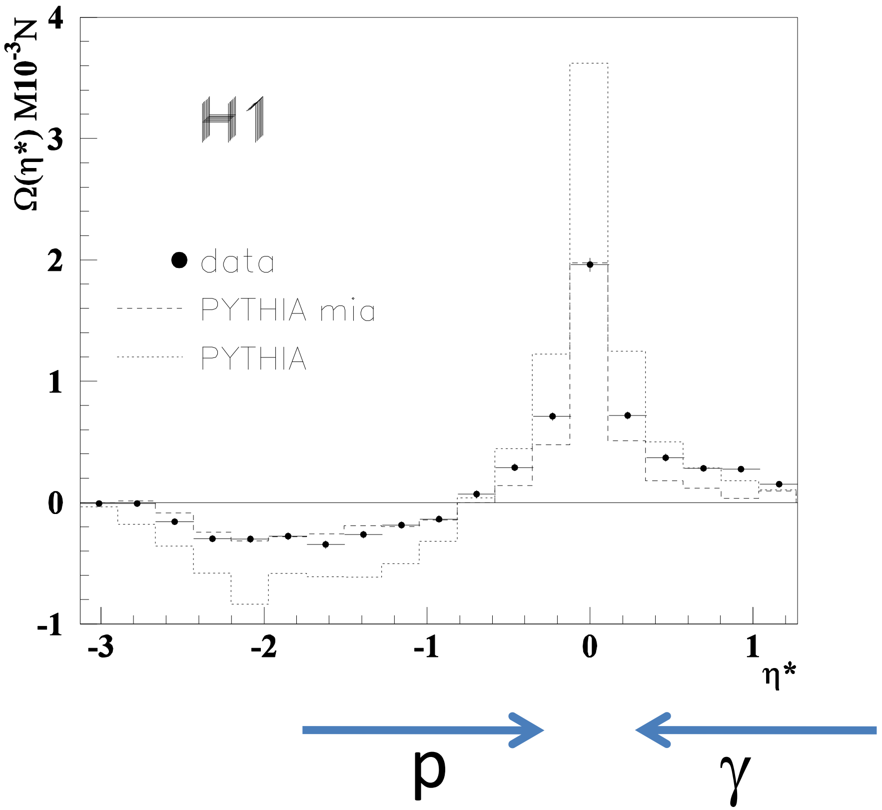
H1: Multiple Parton Interactions

$$\Omega(\eta^*) = \frac{1}{N_{ev}} \sum_{i=1}^{N_{ev}} \frac{\left(< E_{T,\eta^*=0} > - E_{T,\eta^*=0,i}\right)\left(< E_{T,\eta^*} > - E_{T,\eta^*,i}\right)}{(E_T^2)_i}$$

γp center-of-mass system

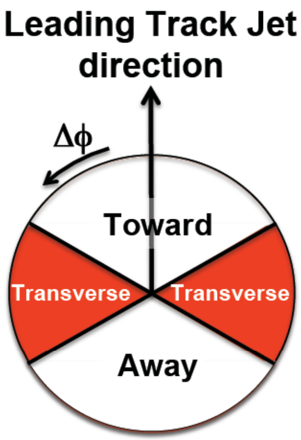


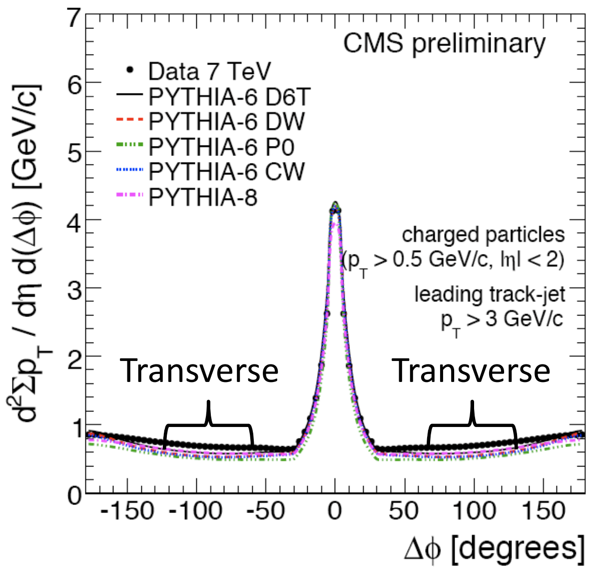




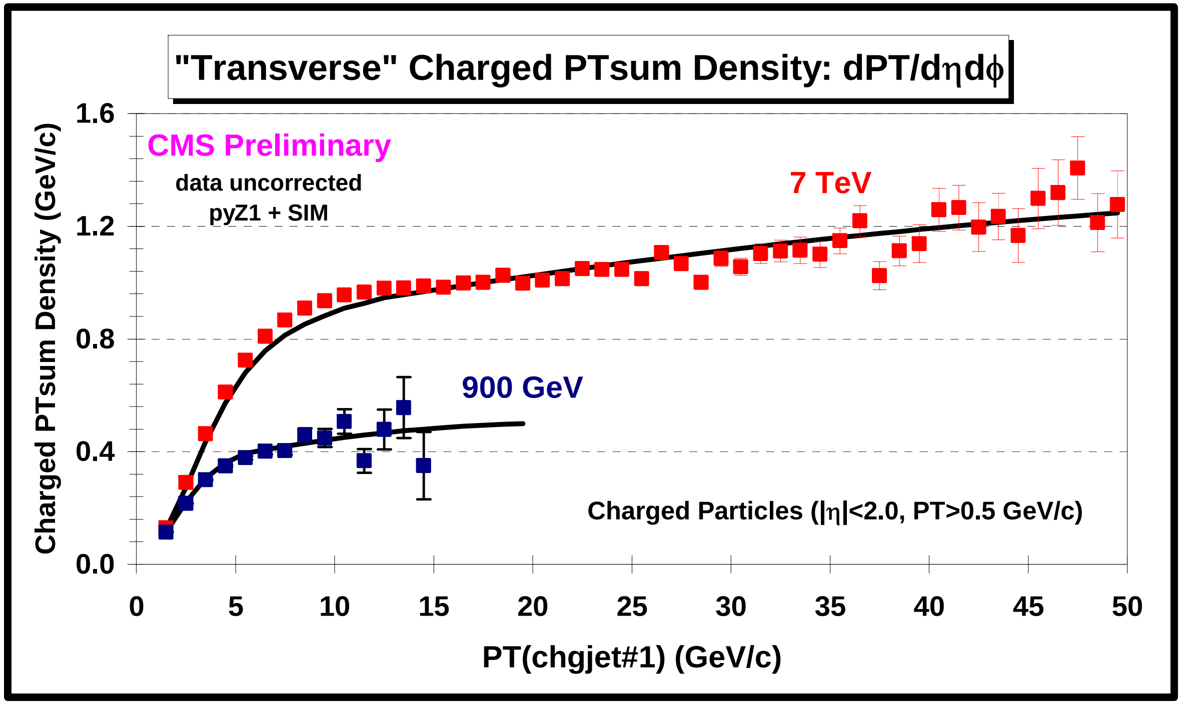
Uncorelated additional interactions next to the hard parton scattering

CMS: Underlying Event



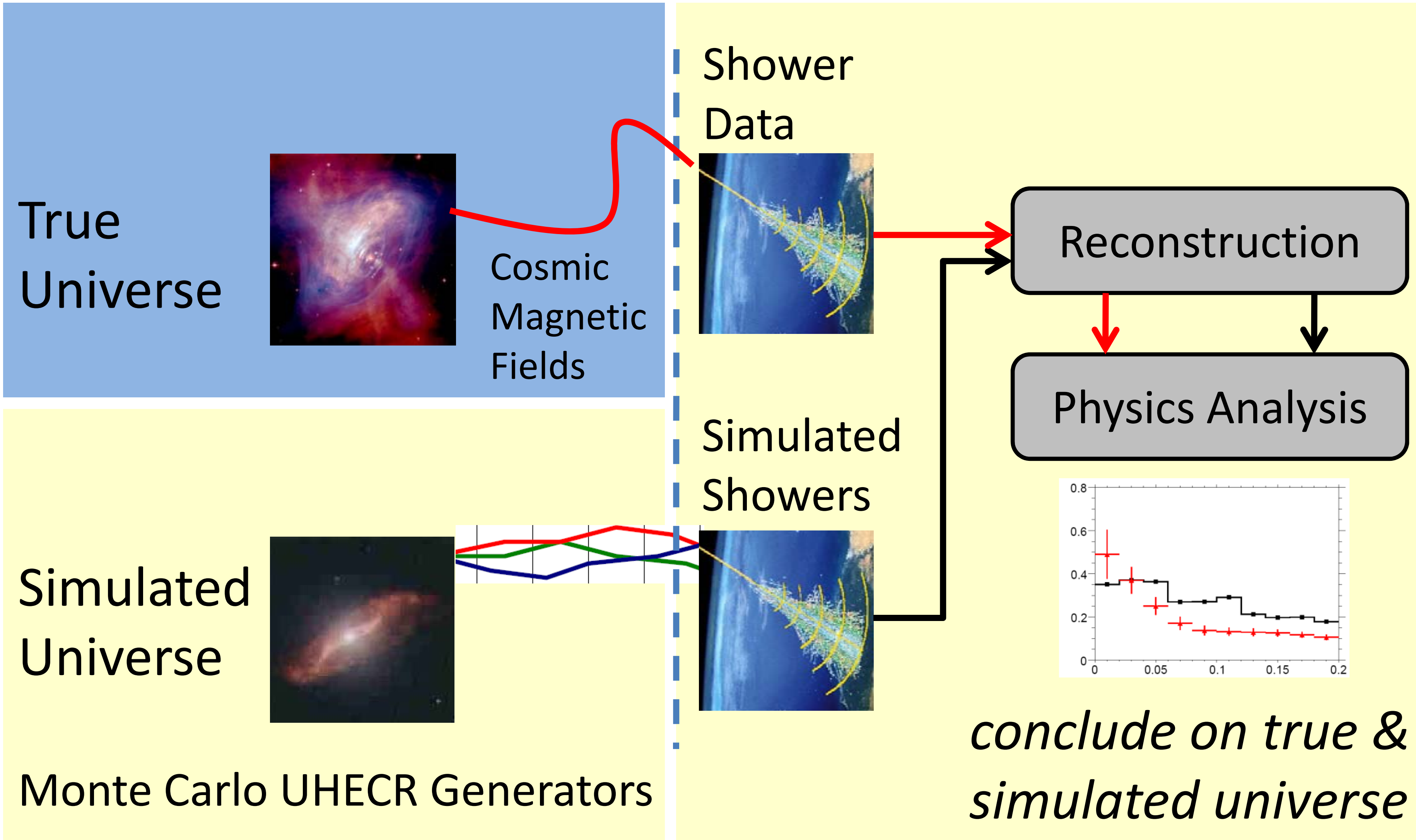


PYTHIA 6.4 tune p_T-ordered parton showers, new Multiple Parton Interaction model



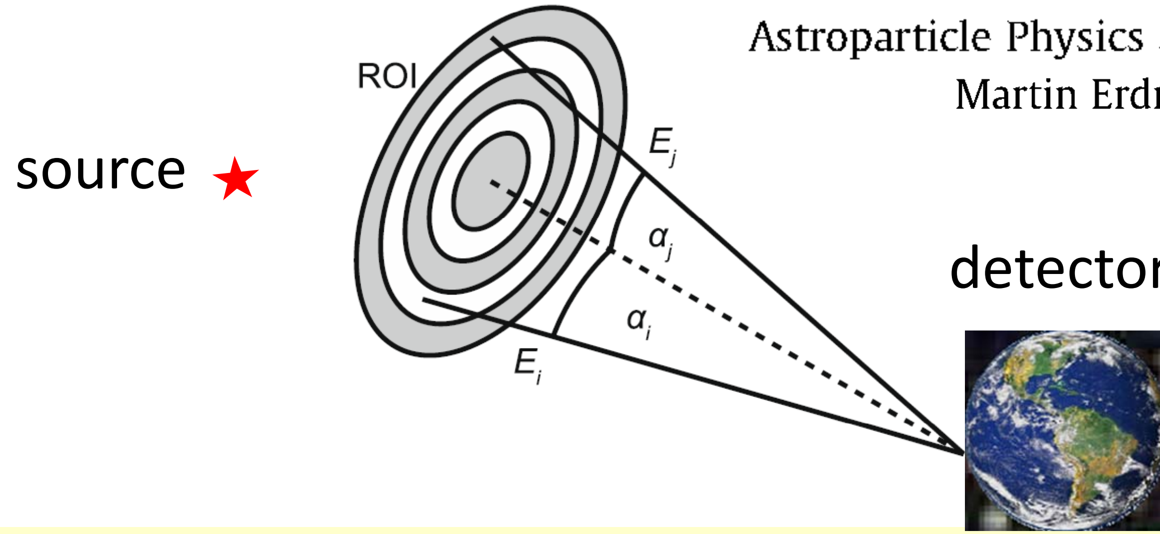
Charged energy
per unit rapidity-azimuth E_{UE} ~ 1 GeV

Astroparticle Physics Analysis



Advanced Autocorrelation Method

Astroparticle Physics 33 (2010) 201–205
Martin Erdmann, Peter Schiffer



Energy-Energy-Correlations

$$\boxed{\Omega_{ij} = \frac{\left(E_i(\alpha_i) - \langle E(\alpha_i)\rangle\right)\left(E_j(\alpha_j) - \langle E(\alpha_j)\rangle\right)}{E_i(\alpha_i)E_j(\alpha_j)}}$$

- Signal typically positive correlations $\langle\Omega\rangle > 0$
- Background typically (naive) $\langle\Omega\rangle = 0$

$\Big\}$ expect mixture

Analysis Flow

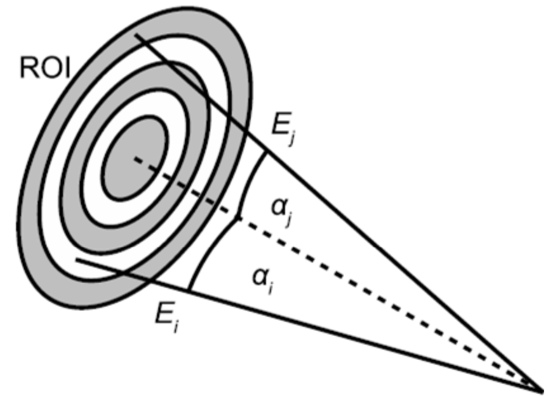
Input Data → **Jet Algorithm** (input / output)

Use UHECRs with E > 60 EeV as seed

Assign UHECRs within a 0.2 rad cone to ROI

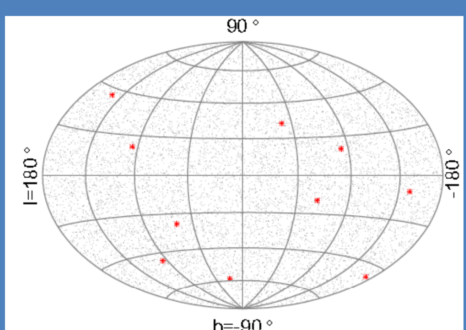
Calculate center of mass (CM) of the ROI

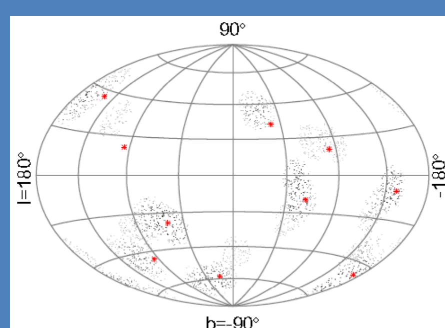
Use CM as new seed, 3 runs



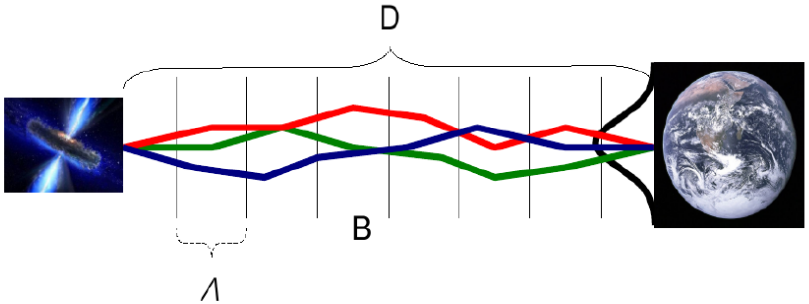
EEC Calculation (input / output)

$$\Omega_{ij}=\frac{\left(E_i(\alpha_i)-\langle E(\alpha_i)\rangle\right)\cdot\left(E_j(\alpha_j)-\langle E(\alpha_j)\rangle\right)}{E_i\cdot E_j}$$





Universe of Random Walk and coherent deflection



10 sources emitting
1000 protons each

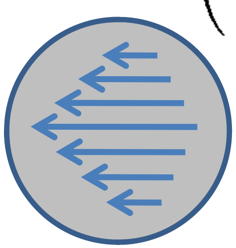
$$\sigma_\theta \simeq 0.025\,\mathrm{deg}\left(\frac{D}{\lambda}\right)^{1/2}\left(\frac{\lambda}{10\,\mathrm{Mpc}}\right)\left(\frac{B}{10^{-11}\,\mathrm{G}}\right)\left(\frac{E}{10^{20}\,\mathrm{eV}}\right)^{-1}$$

$$\sigma_\theta \simeq C_{RandomField}\left(\frac{E}{10^{18}\,\mathrm{eV}}\right)^{-1}$$

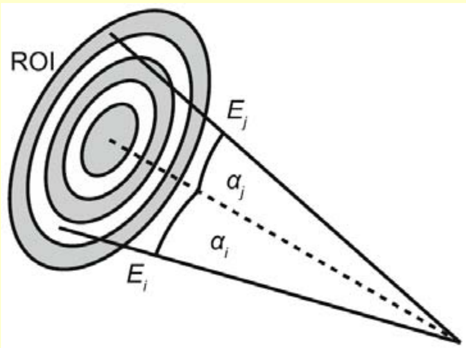
$C_{\text{Random Field}}$ =10 rad
scenario, e.g. D=50 Mpc, λ=1 Mpc, B=3 nG

$$\Delta\ell \simeq C_{CoherentField}\left(\frac{10^{18}\,\mathrm{eV}}{E}\right)$$

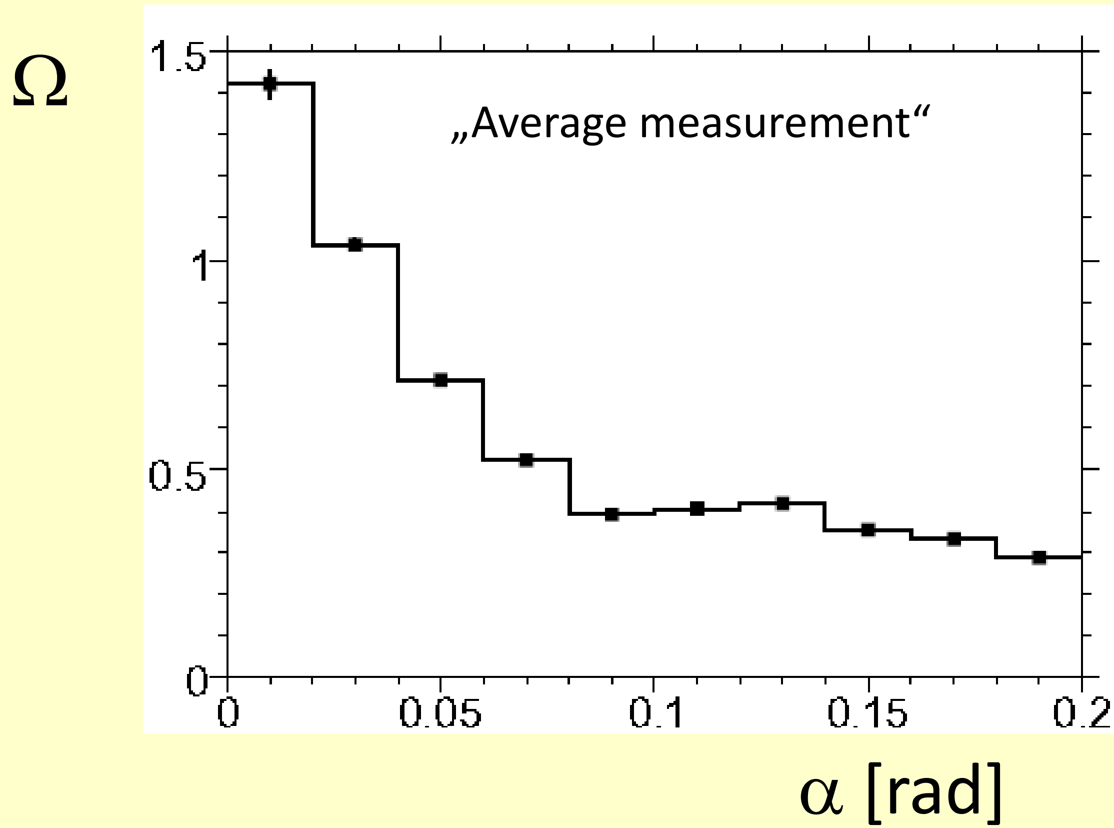
$C_{\text{Coherent Field}}$ =10 rad, for 60 EeV UHECR max. deflection 10deg, average deflection 7.5deg



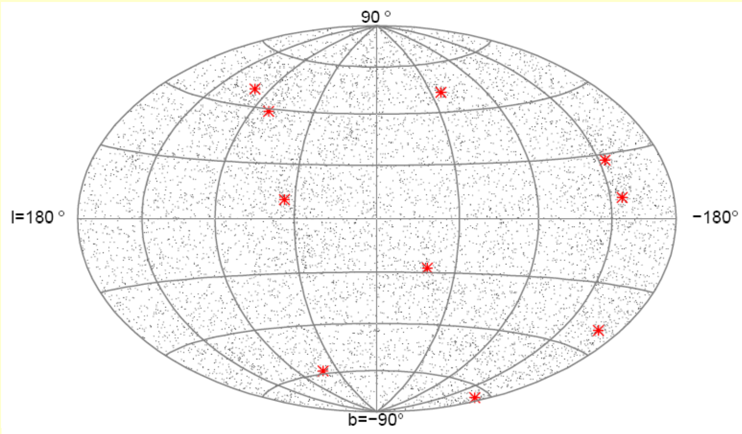
Energy-Energy-Correlation „Measurement“



$$\Omega_{ij} = \frac{\left(E_i(\alpha_i) - \langle E(\alpha_i)\rangle\right)\left(E_j(\alpha_j) - \langle E(\alpha_j)\rangle\right)}{E_i(\alpha_i)E_j(\alpha_j)}$$



Interpretation of Measurement



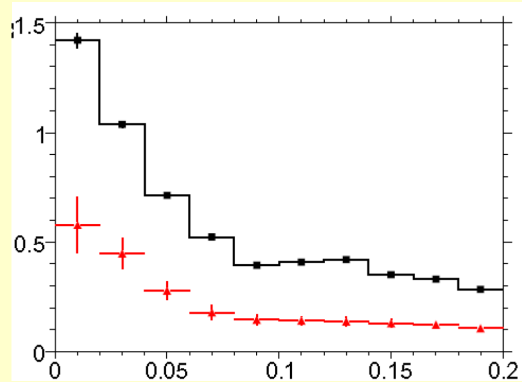
Calculate many universes:

- ***N*** **sources**

  each emits 10000/*N* UHECR

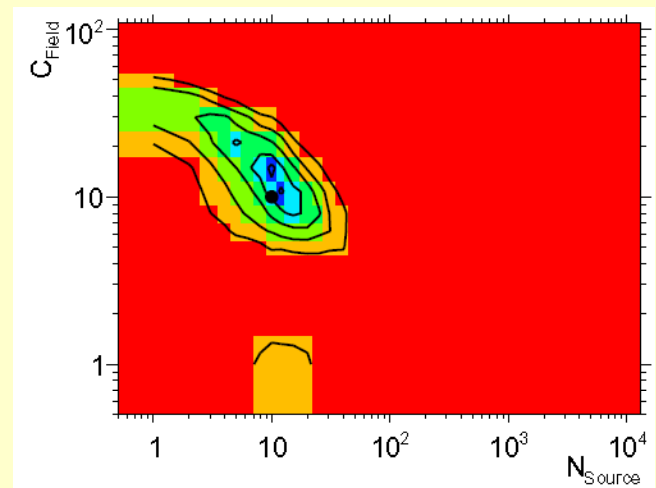
- Random Magnetic field **C**

Ω



α [rad]

$C_{\text{Random Field}}$ [rad]



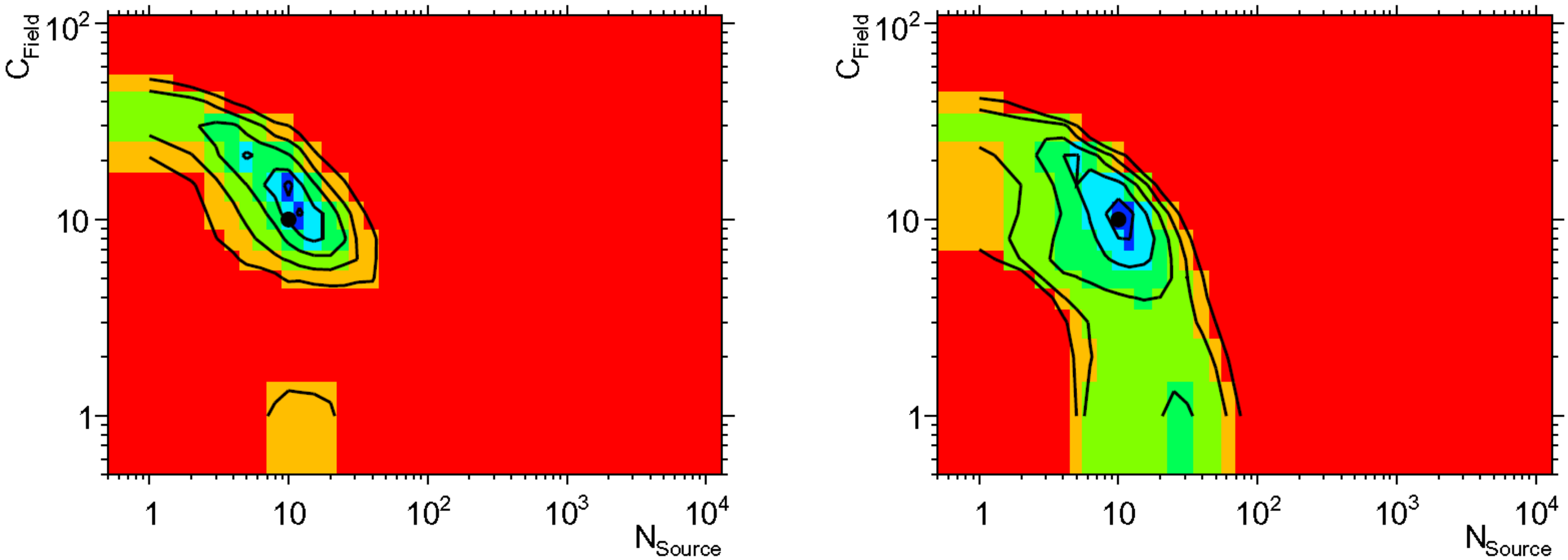
N

reject hypothesis in red region >5 σ

Sucessful reconstruction of universe $C_{\text{Random Field}}$=10 rad, N_{Source}=10

Systematic Check

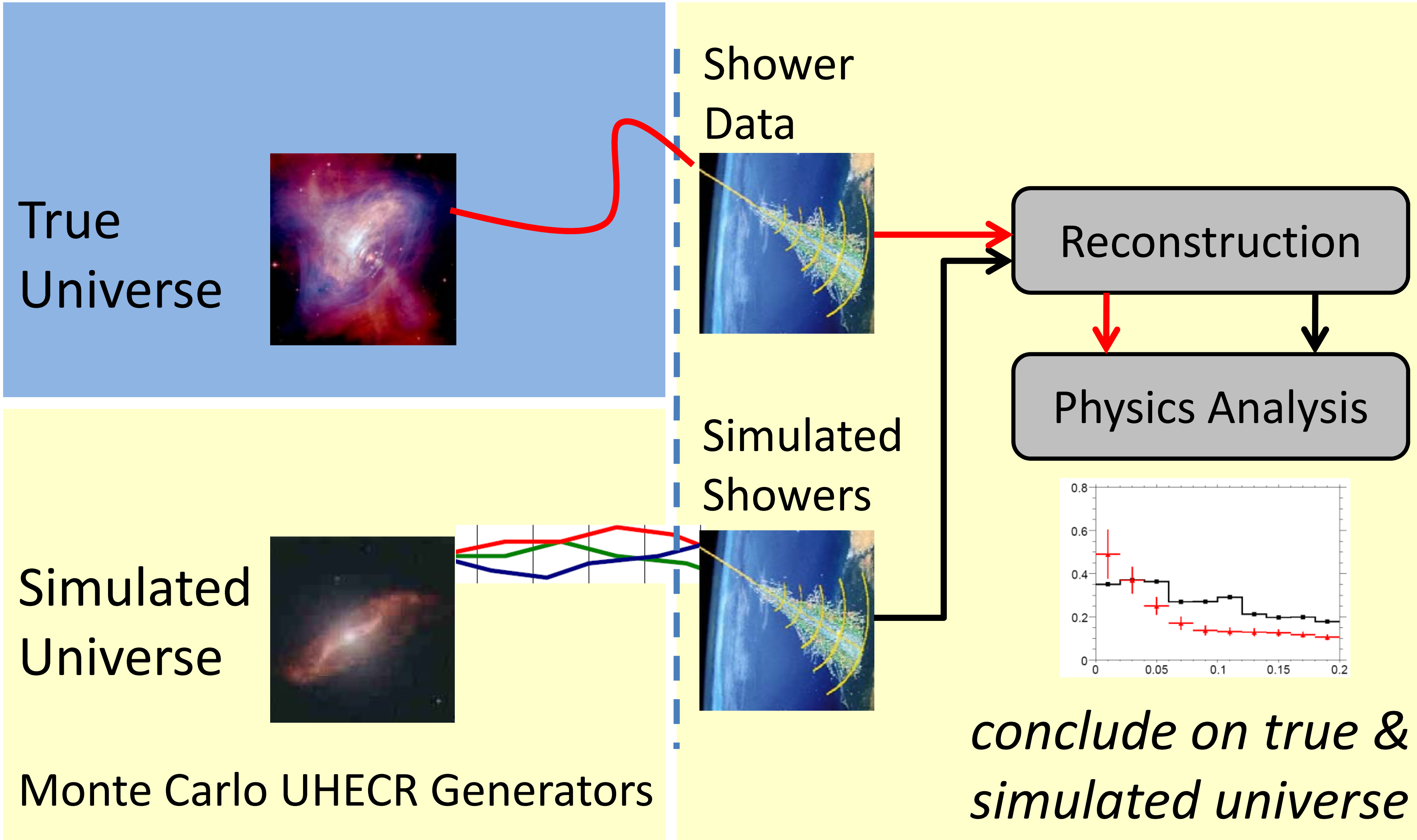
Original single realization   100 Realizations using original parameter



No significant shift caused by reconstruction method

Without knowing the sources: method constrains phase space of the parameters of a universe model

Astroparticle Physics Analysis



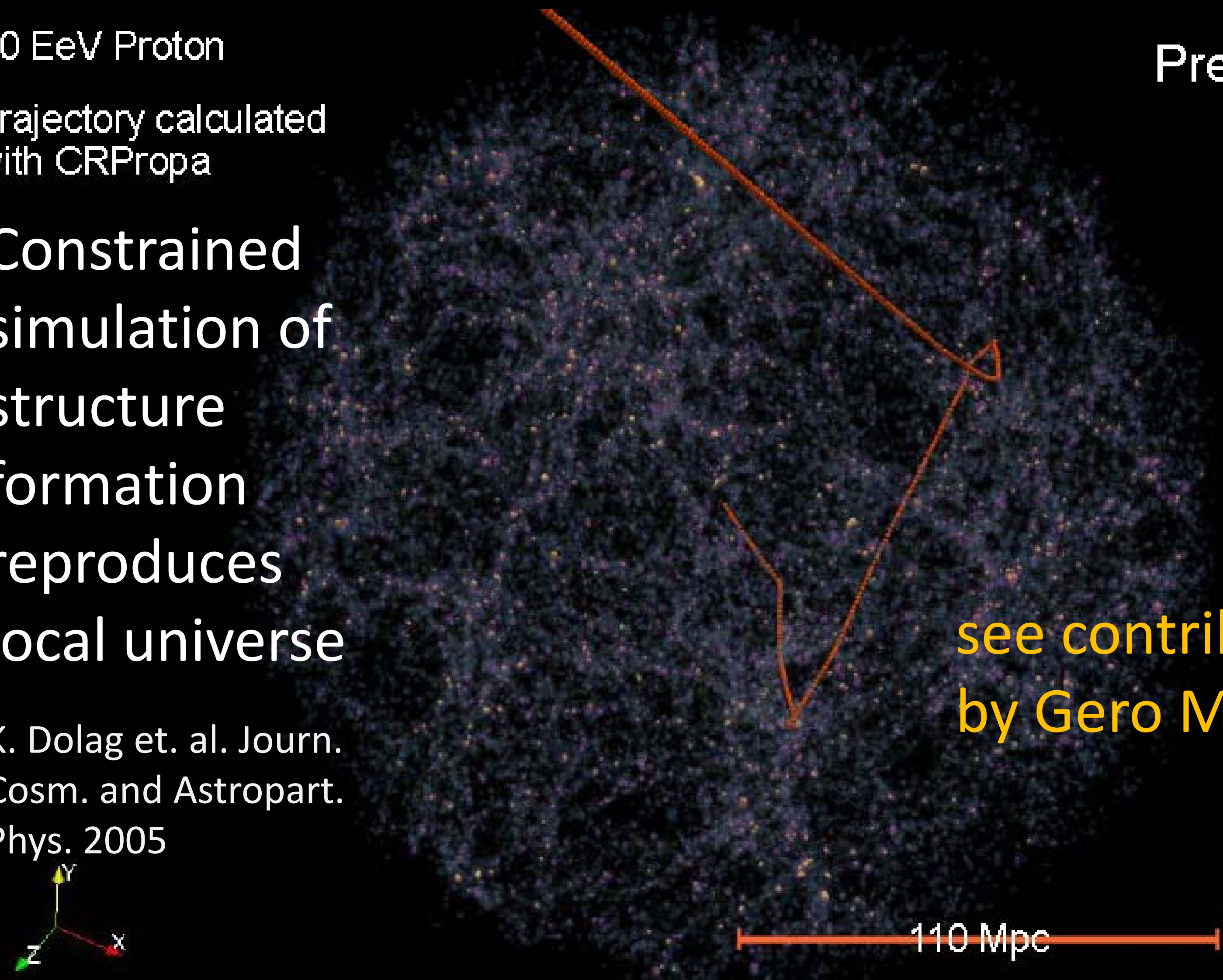
Simulation of More Realistic Universes

10 EeV Proton

Trajectory calculated with CRPropa

Constrained simulation of structure formation reproduces local universe

K. Dolag et. al. Journ. Cosm. and Astropart. Phys. 2005



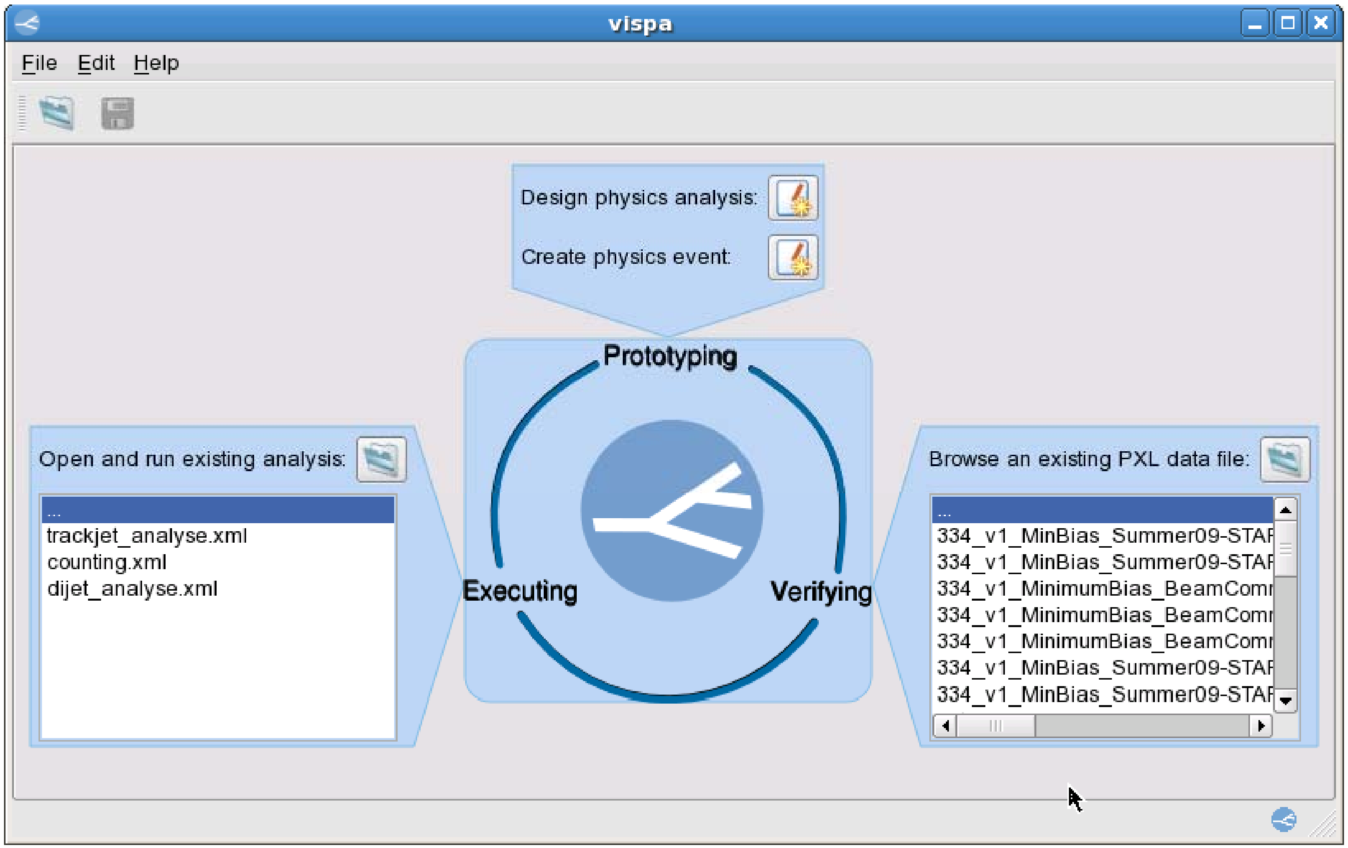
Preliminary

Gero Müller
Christoph Genreith
Tobias Winchen
David Walz
Peter Schiffer
Martin Erdmann

see contributed talk by Gero Müller

Visual Physics Analysis

Graphische Entwicklungsumgebung für Physik Analysen



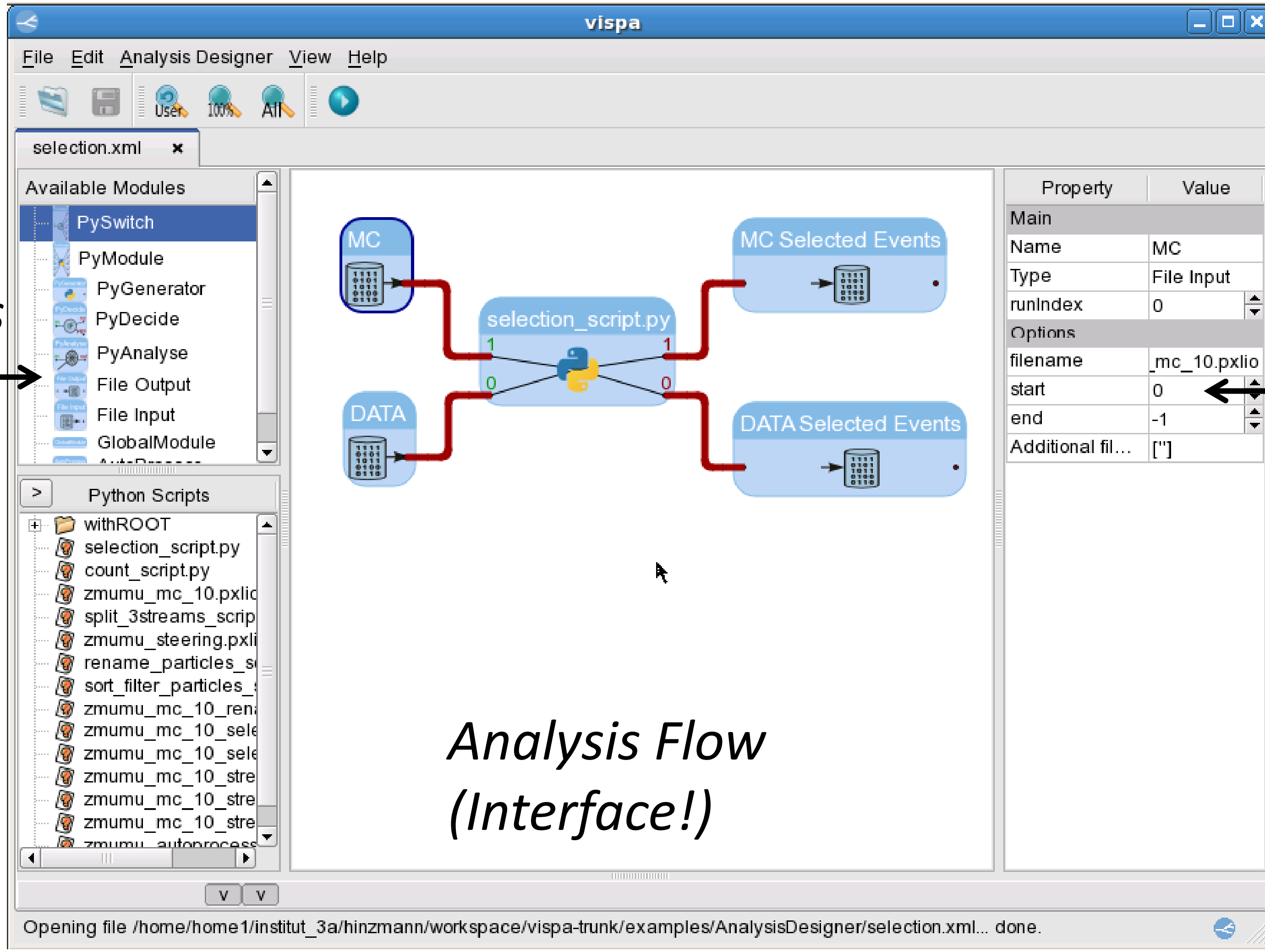
Astroteilchenphysik
Hochenergiephysik

Paradigmen
- Objektorientiert
- Datenflussbasiert
- Grafisch

Analysis Designer

Module Skeletons

Python
C++

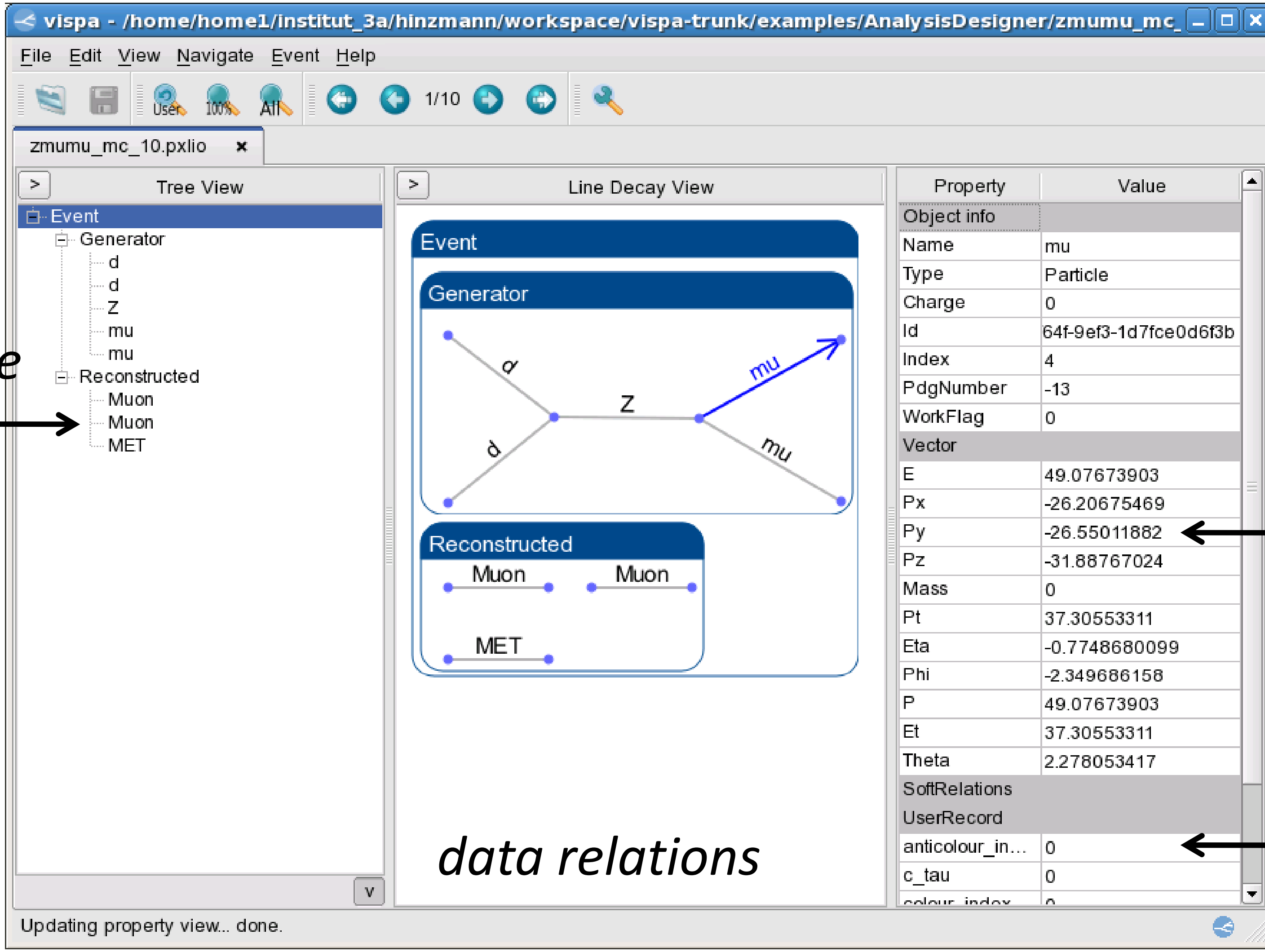


Analysis Flow (Interface!)

Module Configu-ration

Data Browser

data structure



inspect data

user invented data

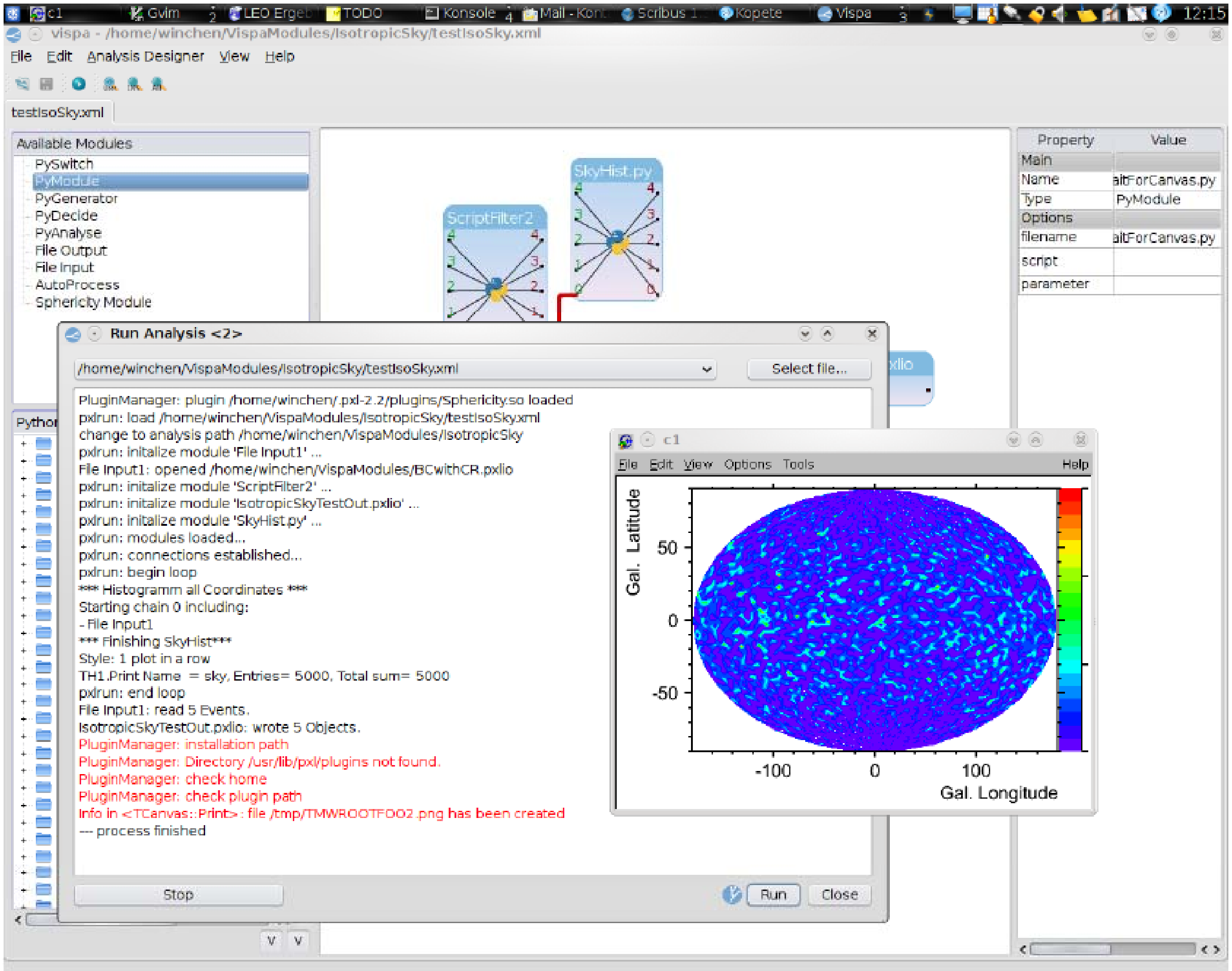
data relations

Application Astroparticle Physics

Excecute Analysis

→

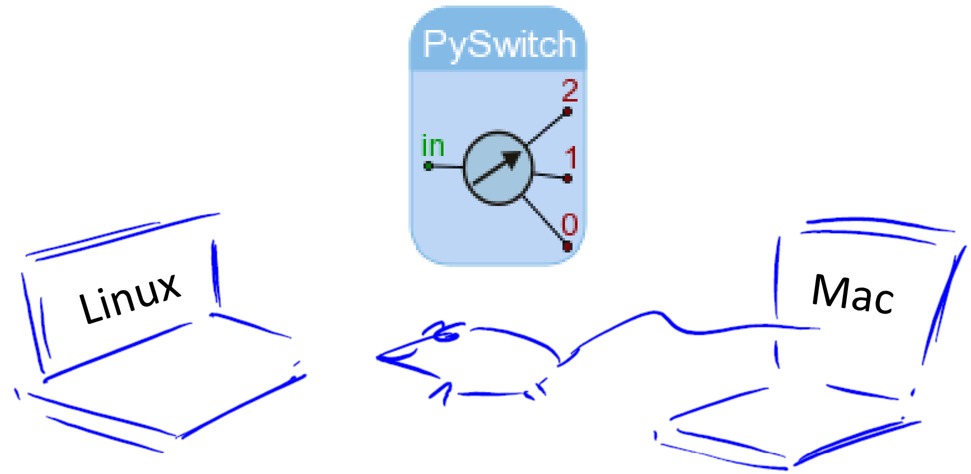
ROOT Connection



Team Work

Do you have
a module which...

Yes...



Drag-in-and-Play

M. Brodski, M. Erdmann, R. Fischer, A. Hinzmann, D. Klingebiel,
M. Komm, J. Lingemann, **Gero Müller**, J. Steggemann, T. Winchen

http://vispa.sourceforge.net

Summary

- Parton Scattering correctly predicted by QCD
- Data Analysis at LHC with enormous progress
- Information on Cosmic Magnetic Fields through Correlations
- You may want to try VISPA for developing your analysis