

Symposium on Dynamical Systems: A Celebration of Rosemary Mardling's Career

Beauty at Infinity

P. Skands, Monash University, August 2024

HST Image:
STAR CLUSTER NGC 602

Why do Science?

Scientia potentia est - knowledge is power

We can improve our lives with it

We can build new things with it

We can solve problems with it

The Real Reasons (?):

Curiosity and Fascination

The Universe is vast, beautiful, and full of mysteries

+ I believe that science is a force for civilisation, without which ...

“no knowledge of the face of the earth; no account of time, no arts, no letters, no society, and [...] the life of man solitary, poor, nasty, brutish, and short.”

Hobbes *Leviathan* (1651)

Superstition ain't the way

S. Wonder; *Superstition* (1974)

Inspiration

Astronomy & Astrophysics

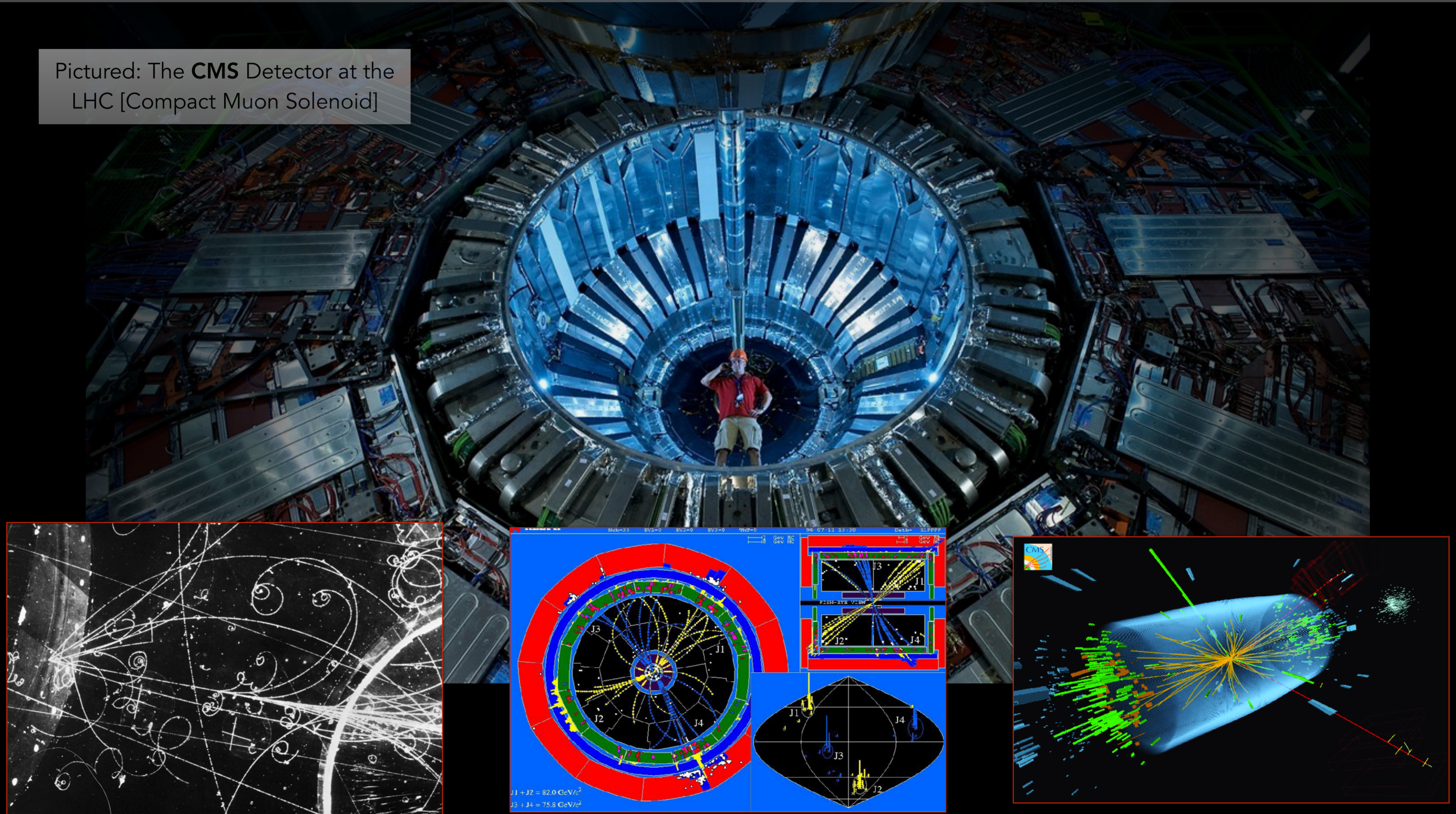
- ✓ Obvious visual appeal
- ✓ Fundamental: it's the universe!
- ✓ *Abstract beauty of science: the pictures we build in our minds*

Particle Physics

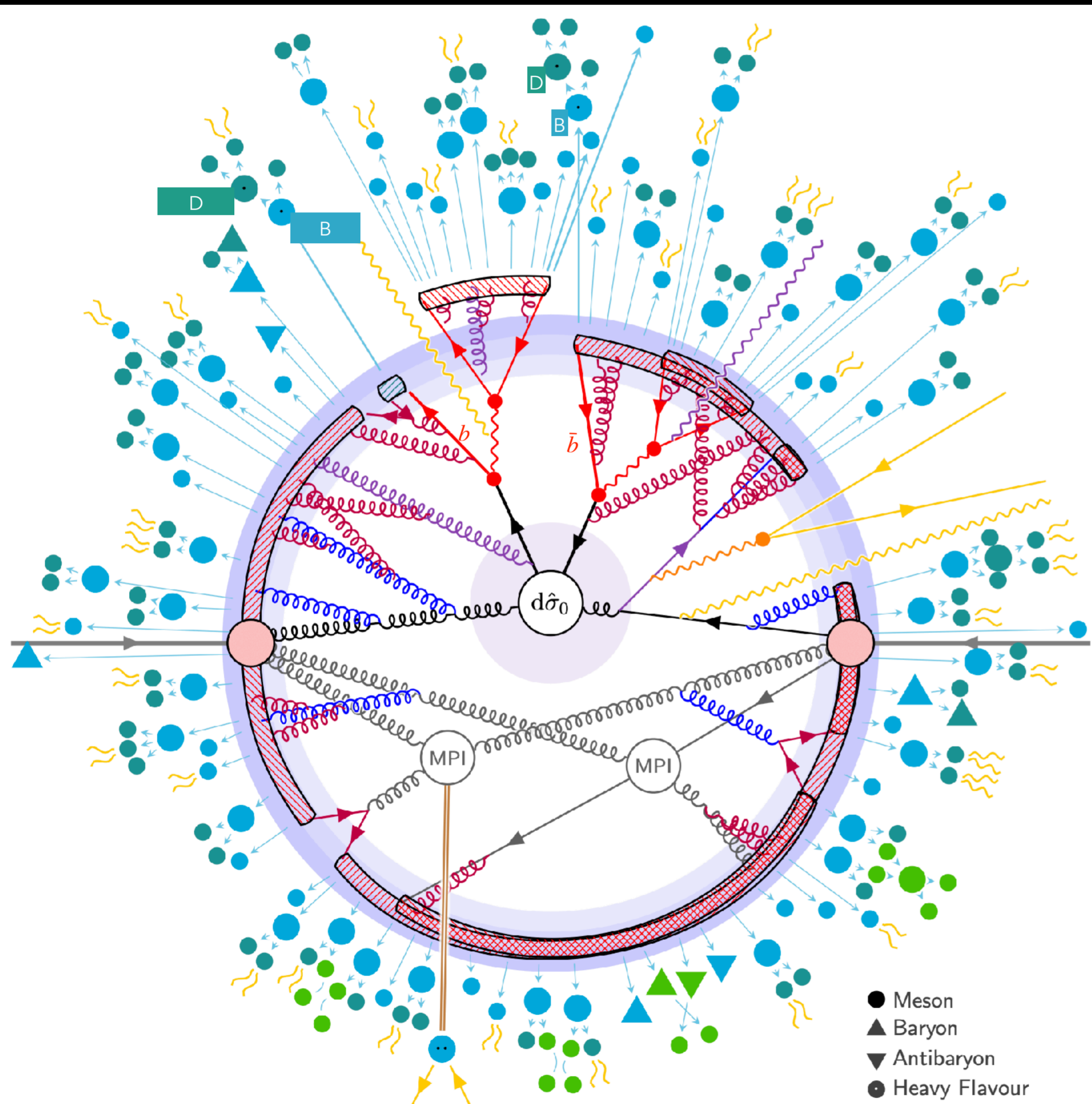
- ✓ Fundamental
- ✓ Abstract beauty
- 😞 Obvious visual appeal?

Beauty in Particle Physics?

Pictured: The **CMS** Detector at the LHC [Compact Muon Solenoid]



The *Abstract* Beauty — The Beauty of Theory?



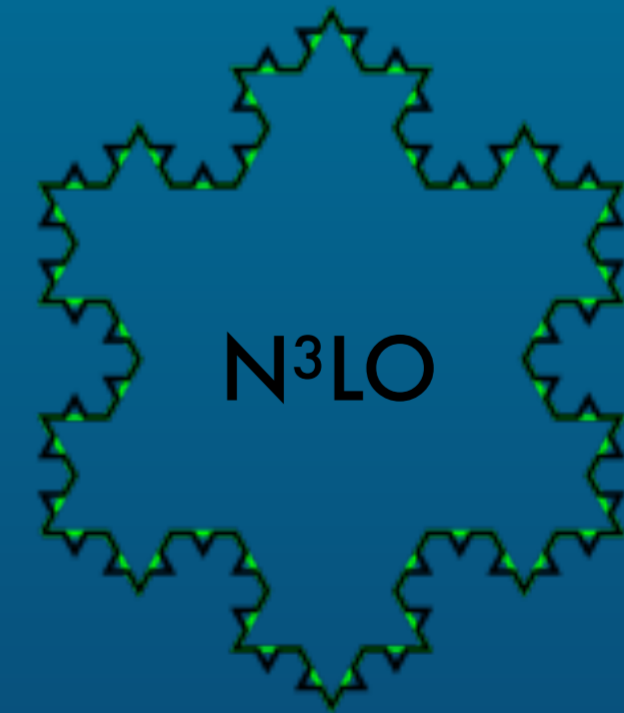
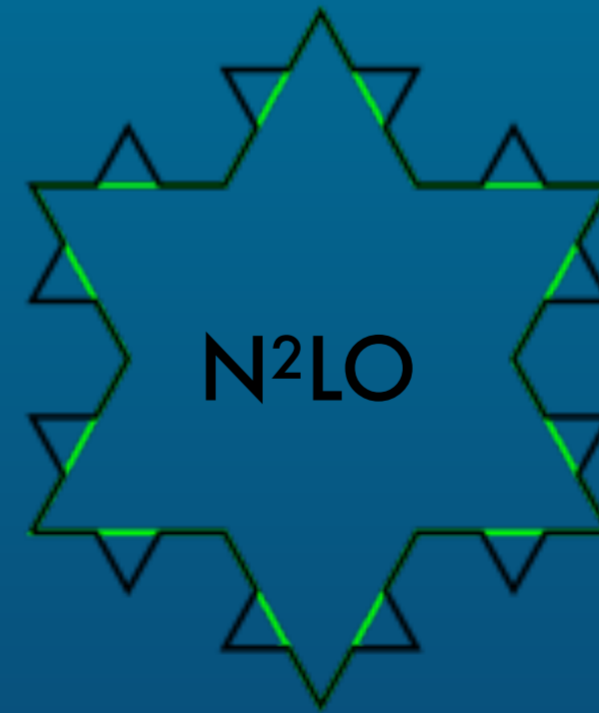
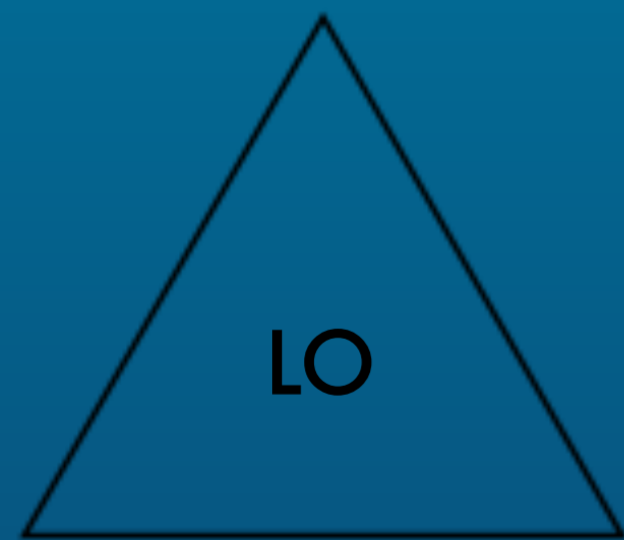
- Hard Process**
 - Hard Interaction
 - Resonance Decays
 - MECs, Matching & Merging
- Parton Showers**
 - QCD Final-State Radiation
 - QCD Initial-State Radiation*
 - Electroweak Radiation
- Underlying Event**
 - Multiparton Interactions
 - Beam Remnants*
- Hadronization**
 - Strings
 - Colour Reconnections
 - String Interactions
 - Bose-Einstein & Fermi-Dirac
- Hadron (& τ) Decays**
 - Primary Hadrons
 - Secondary Hadrons
 - Hadronic Reinteractions

The *Abstract* Beauty — Quantum Field Theory

Cross Sections ~ effective area of a shape ($d\sigma$)

Perturbation Theory: calculate $d\sigma$ with higher and higher detail
(power series in coupling)

Example: Koch Snowflake



Note: (over)simplified analogy, mainly for IR structure. More at each order than shown here.

Fractal (sub)structure → “Jet Clustering Sequences”

Jet Clustering Algorithms = main scientific tool to analyse (simplify) particle-physics collision events

E.g., via “**Sequential Recombination**”: For a given measure of QM resolution (like invariant mass, opening angle, ...), combine the two particles with the lowest value of the resolution measure.

Iterate this, until only a single “blob” remains => sequence of representations of the event, at different resolution scales.

Idea: Capture this way of looking at events

Not single events but **statistical samples** (~ long-time exposure).

In momentum space ~ More like how we actually look at the data

The *Abstract* Beauty — Quantum Field Theory

Gauge theories with massless quanta

Scale invariance → *fractal substructure*

(↔ universal QFT propagators)

⇒ **Bremsstrahlung Cascades**

~ Classical bremsstrahlung

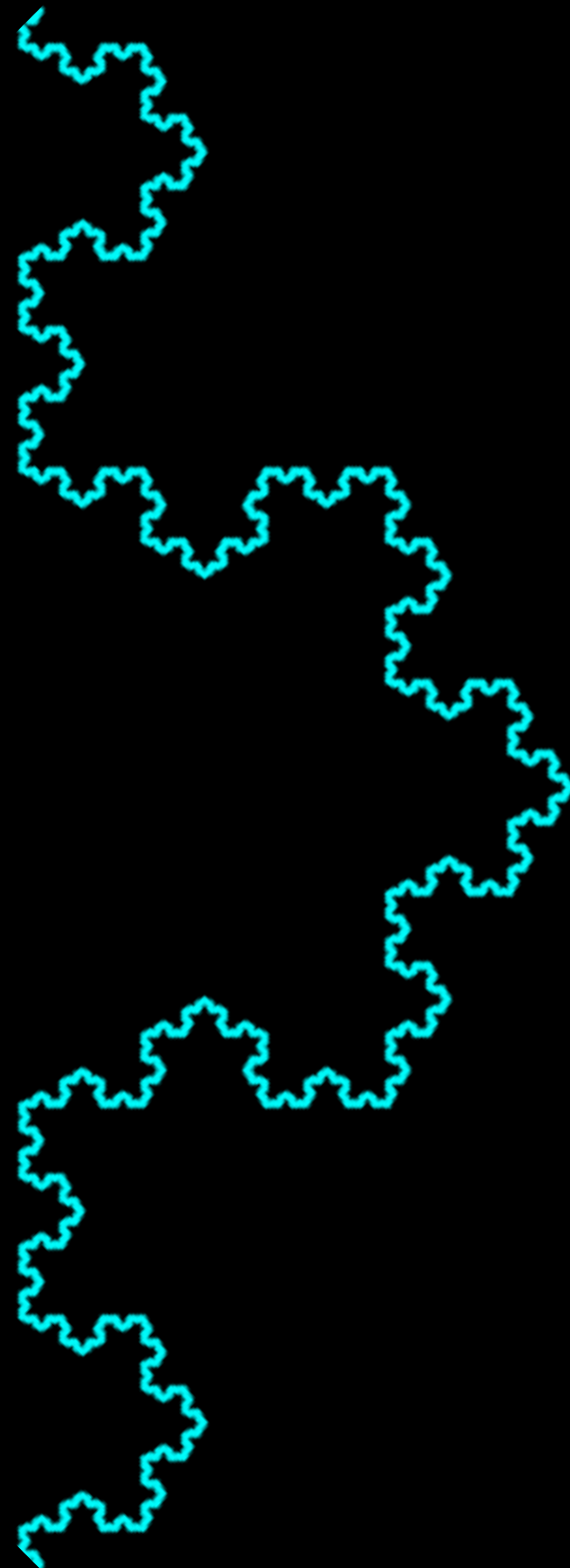
Formulated as differential evolution eqs

Stochastic (MC) solutions

⇒ **"Parton Showers"**

+ explicitly build in subleading "scaling violations"

— due to running coupling, masses, ...



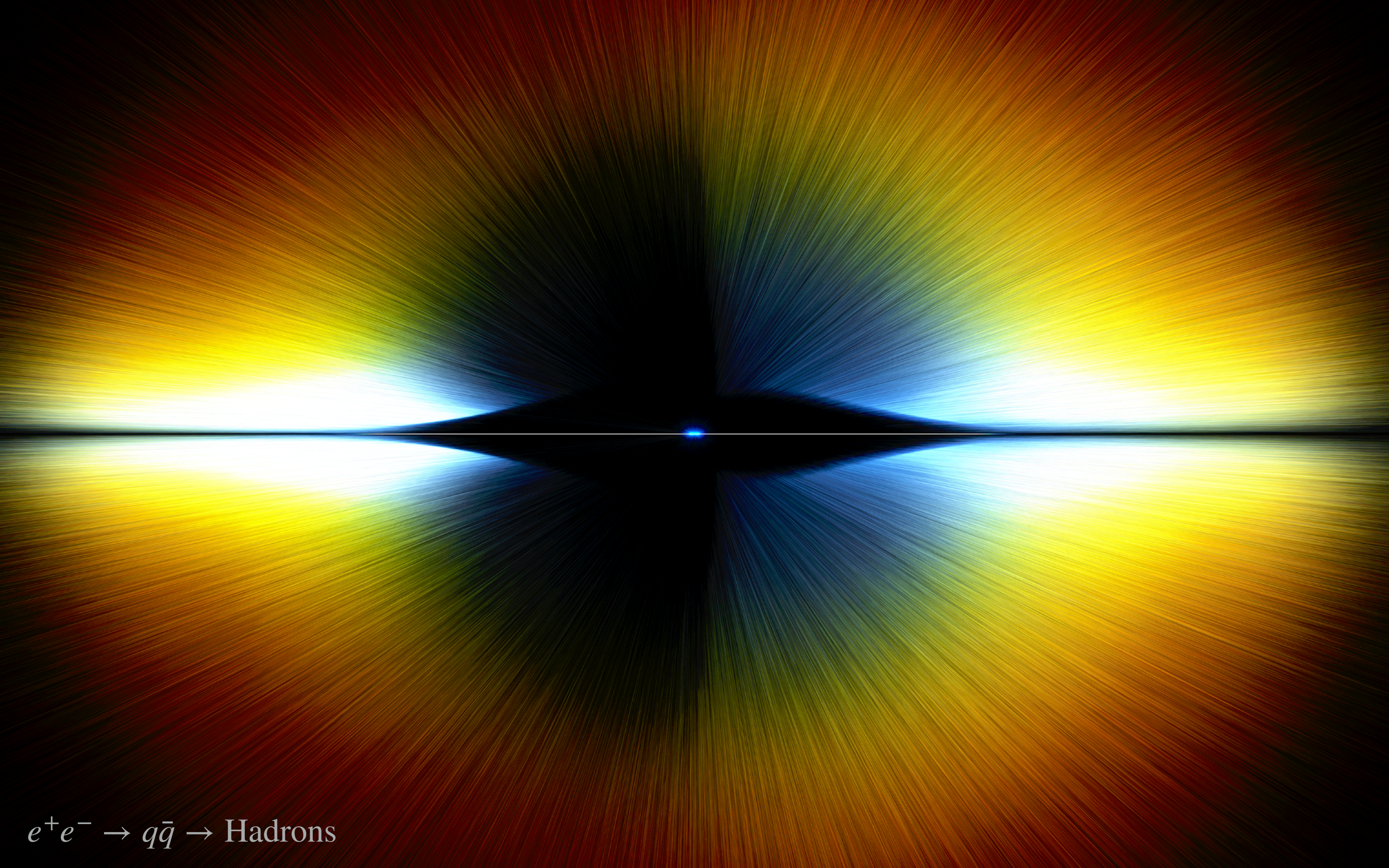
Astro-Inspired Long-Time Exposure

$$e^+e^- \rightarrow Z^0 \rightarrow q\bar{q} \rightarrow \text{Hadrons}$$

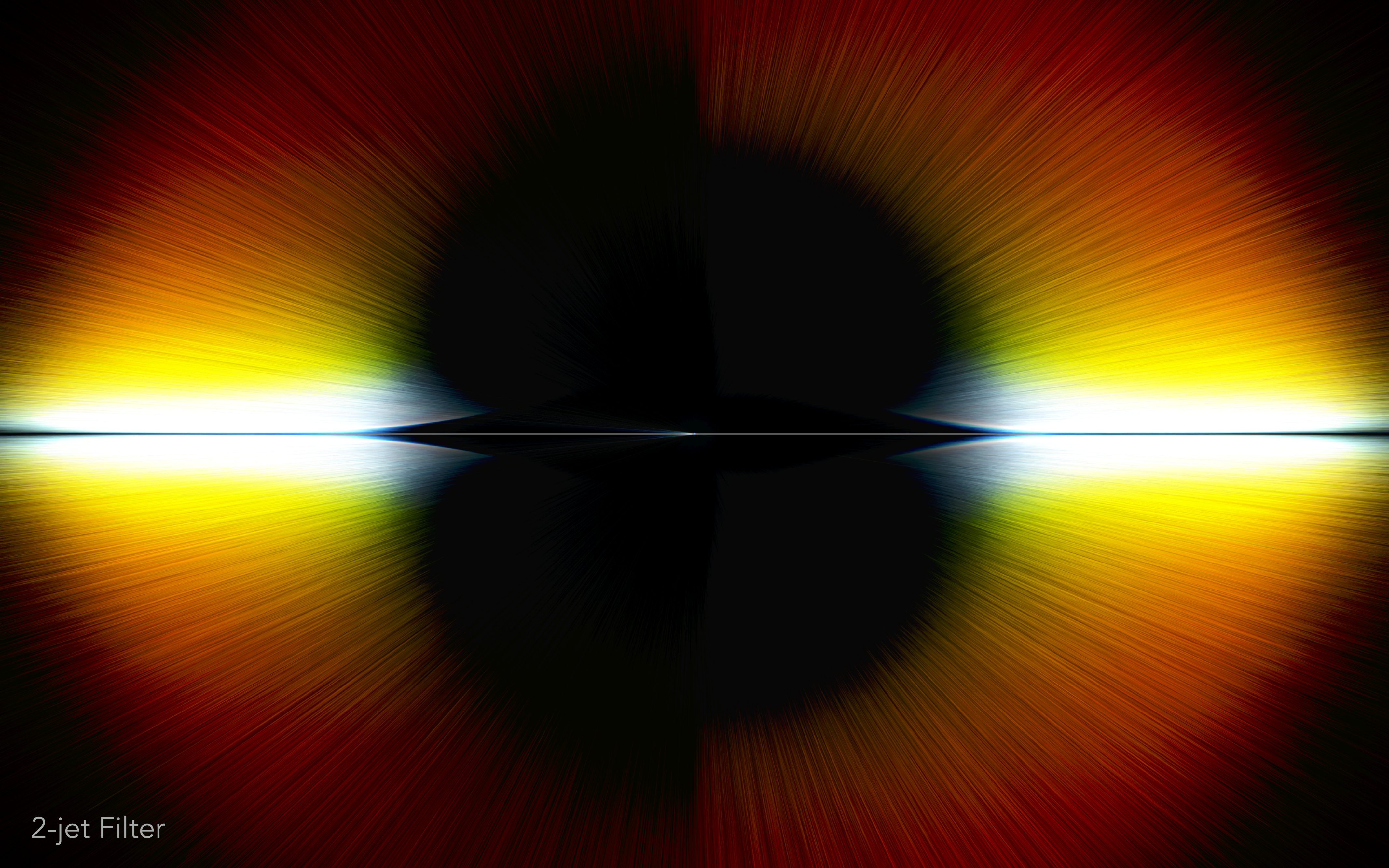
Radial Coordinate: Resolution Measure (Durham k_T) \sim Analogous to a Time or "Fractal Scale"

Angular coordinate: polar angle with respect to 2-jet axis

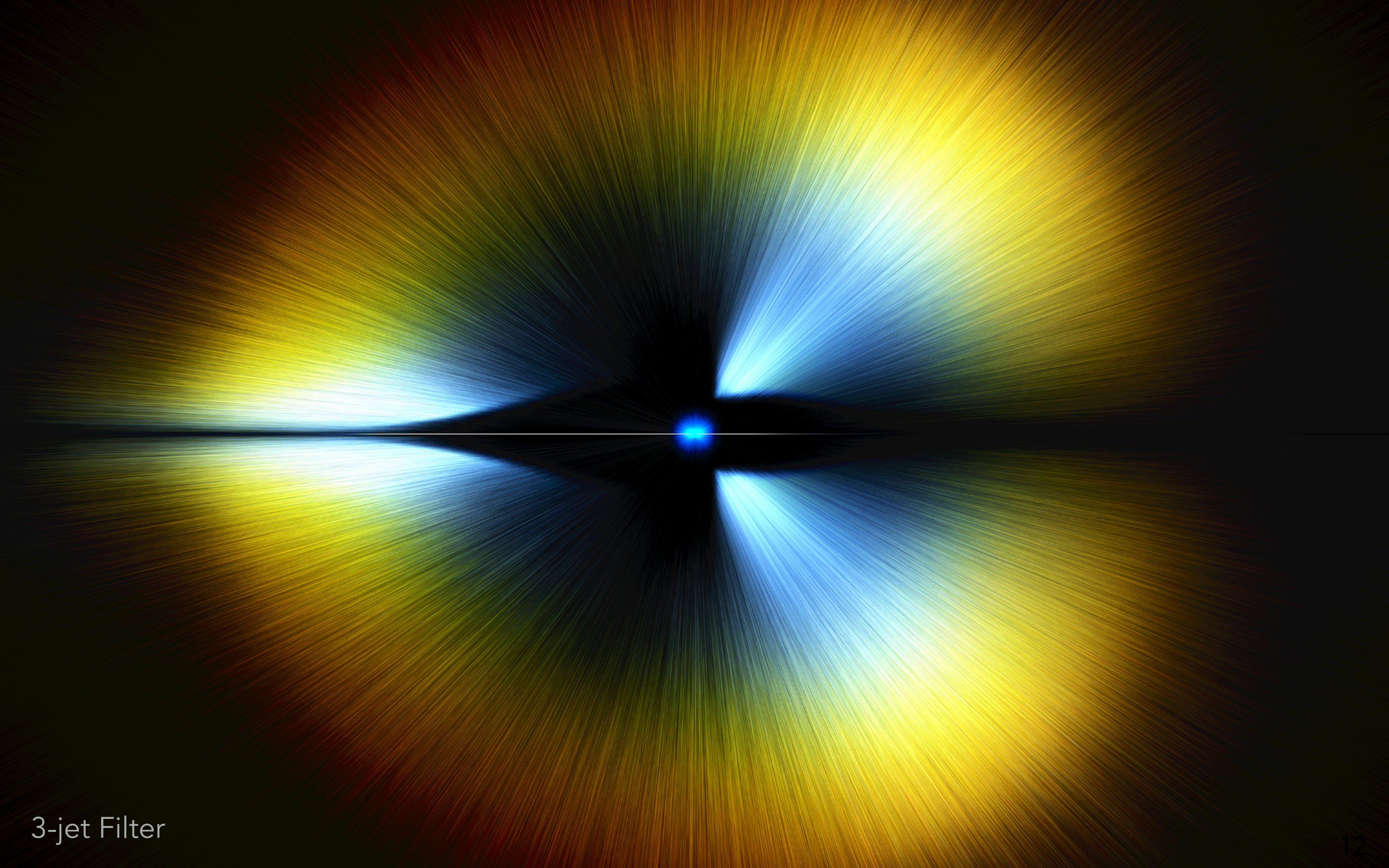
Colour scale: Energy \sim Frequency



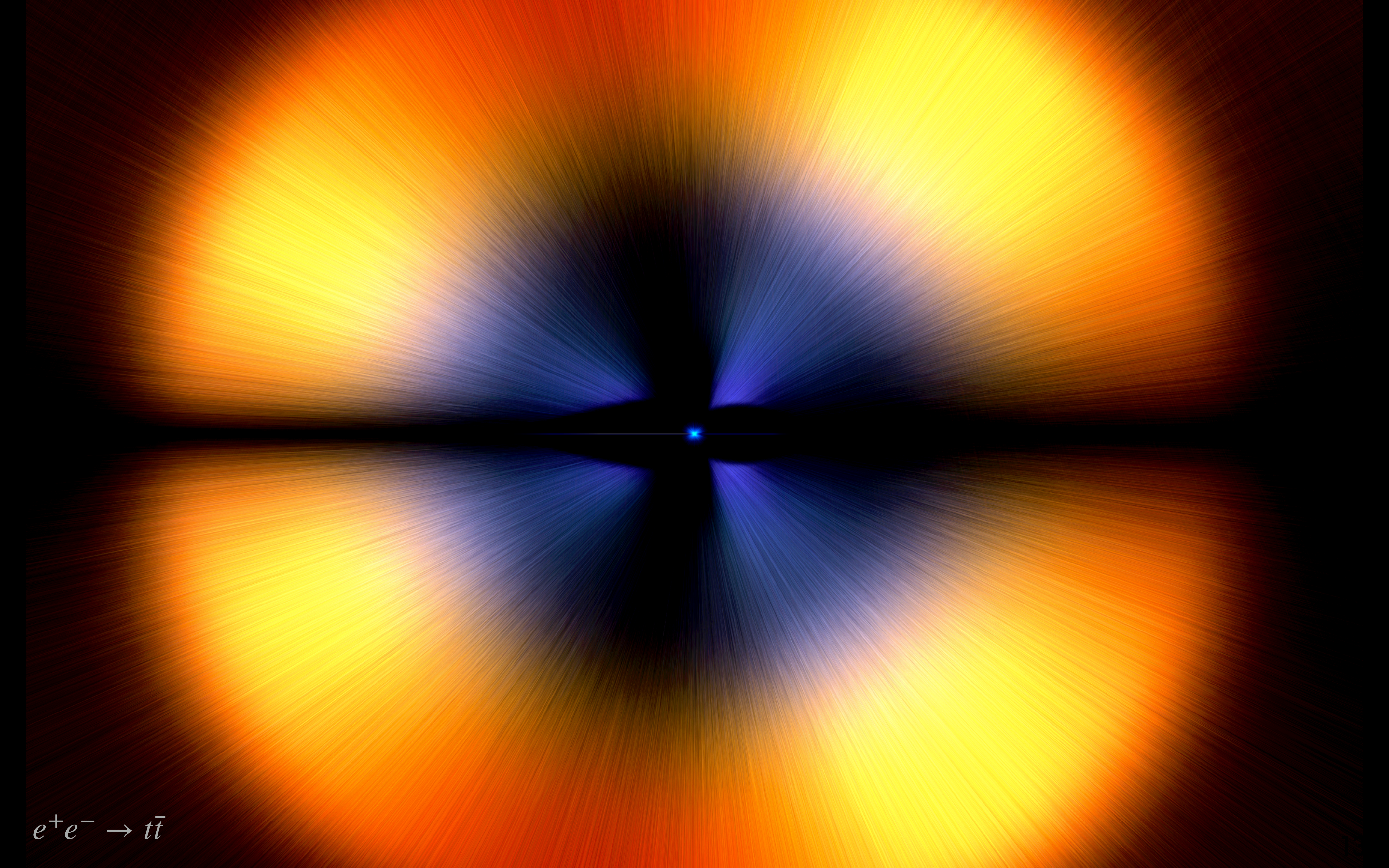
$e^+e^- \rightarrow q\bar{q} \rightarrow \text{Hadrons}$



2-jet Filter



3-jet Filter



$$e^+e^- \rightarrow t\bar{t}$$

Thank You, Rosemary

*Tout au long de ma vie, les
nouveaux visages de la nature
m'ont réjoui comme un enfant*

All my life through, the new
sights of Nature made me
rejoice like a child. — Marie Curie