Modelling uncertainties

Alan Price, Marek Schönherr

IPPP, Durham University

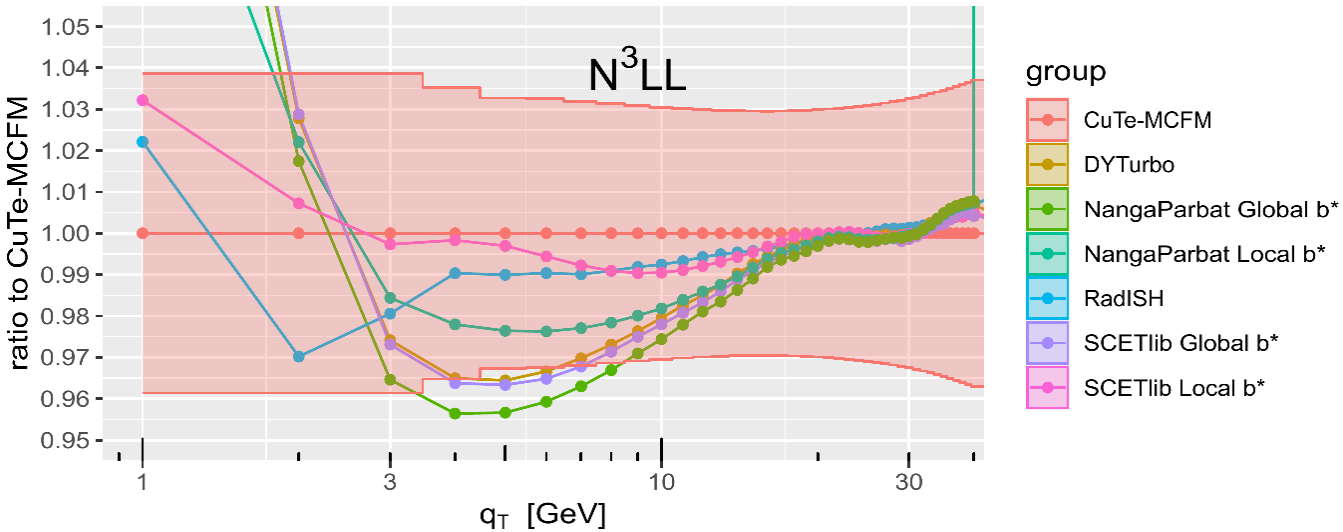
Modelling uncertainties

- algorithmic choices in perturbative physics
  - analytic resummation frameworks
  - numerical resummation frameworks (parton showers)
  - ...
- modelling of non-perturbative physics
  - hadronisation
  - hadron / photon / lepton substructure
  - multi-parton interactions
  - ...

Algorithmic uncertainties

Analytic resummation

- resummation formalism (CSS, SCET, ...)
- choices of representation (b-space, momentum space, ...)
- ...



LHC EW WG resummation comparison

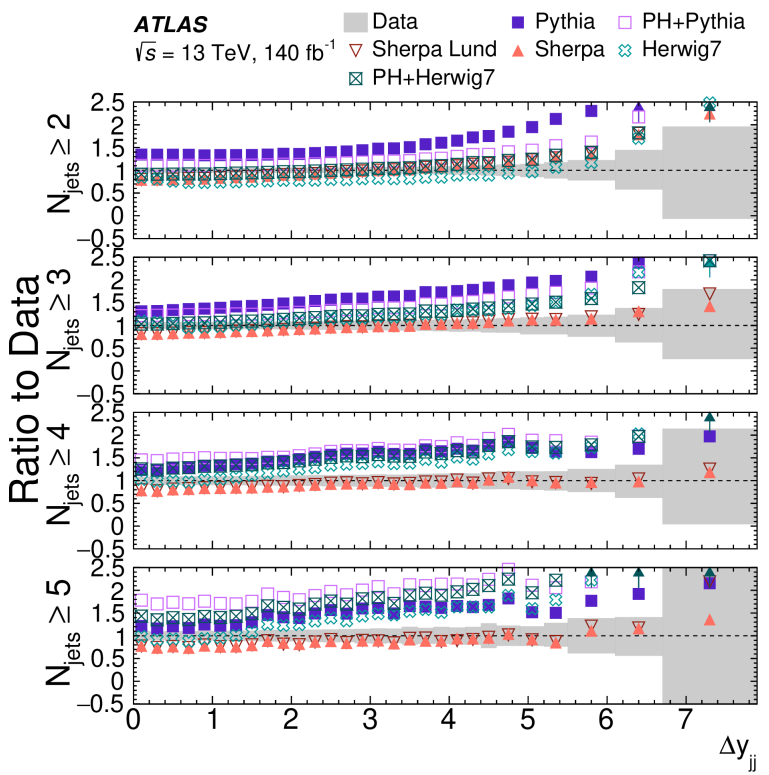
Algorithmic uncertainties

Numerical resummation / parton showers

- evolution variable (k_T^2, θ)
- momentum conservation / recoil (local, global)
- partial higher logs: which variant of CMW scheme?
- power corrections in splitting functions

⇒ **impact can be substantial even when matched to NLO**

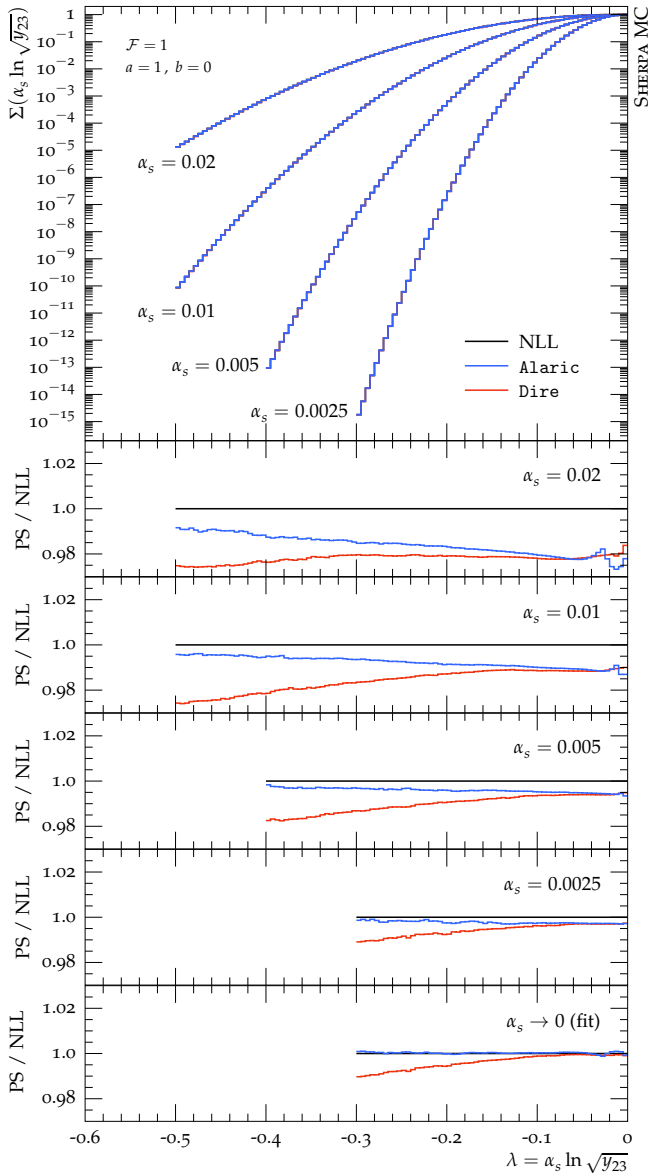
ATLAS '20



Algorithmic uncertainties

Numerical resummation / parton showers

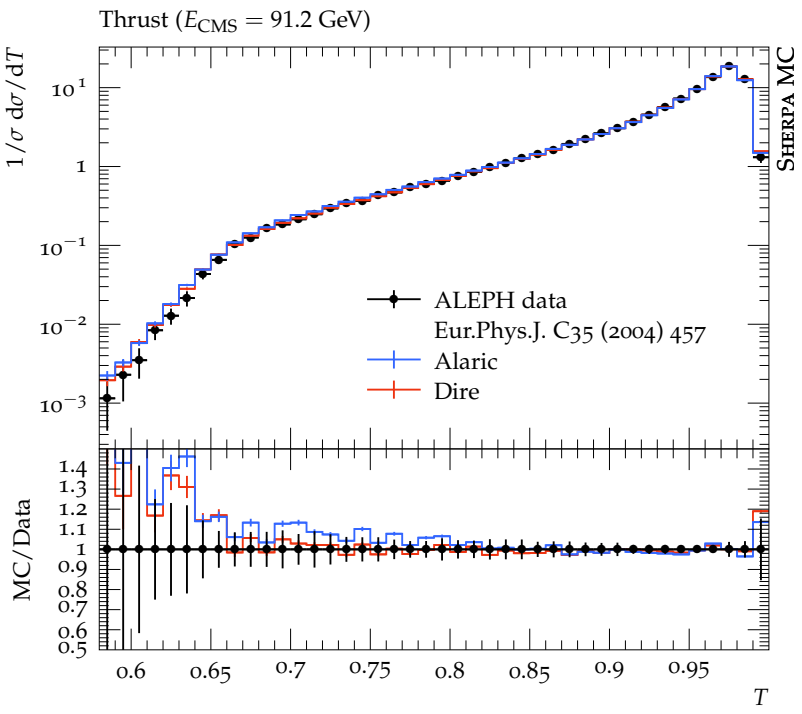
- some algorithmic uncertainties reduce at higher logarithmic accuracy
- others fixed through matching to fixed order
- NLL showers available, PanScales, Alaric
- but algorithmic choices remain at finite recoil

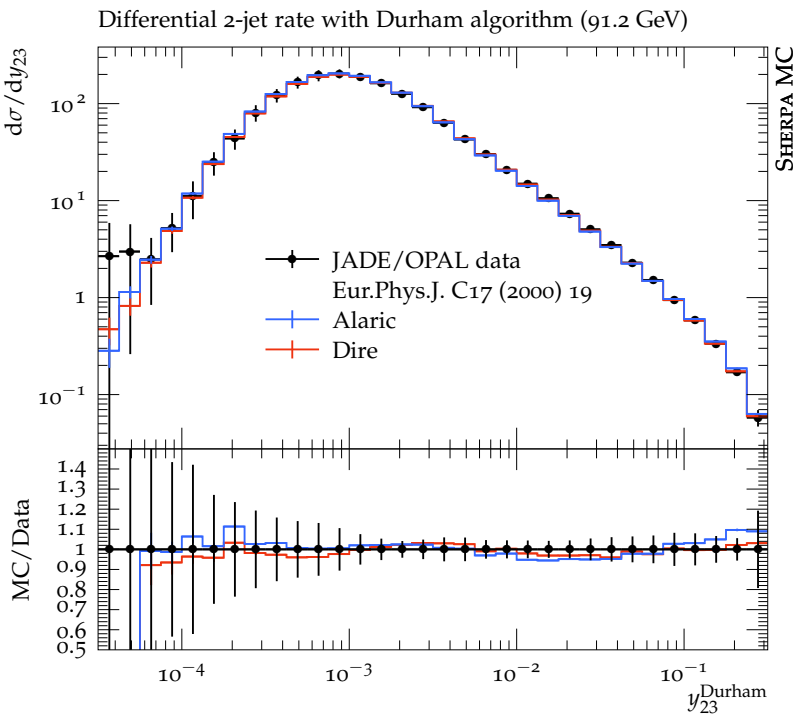


Herren, Höche, Krauss, Reichelt, MS '22

Algorithmic uncertainties

Herren, Höche, Krauss, Reichelt, MS '22





- higher-accuracy resummation mostly improves the distribution of soft gluons, but
- ALARIC (NLL acc.) vs. DIRE (not NLL acc.) w/ hadr. tuned to LEP

Non-perturbative modelling

Fragmentation

- perturbative component well-understood (DGLAP),
  but non-perturbative component not understood from first principles
  (yes, lattice, but need it phase-space-point-by-phase-space-point
  calculated in less than a second)
- phenomenological models / QCD-inspired parametrisations
  $\rightarrow$ need tuning of unphysical parameters
- similar problem to non-perturbative structure of proton / photon

Intrinsic transverse momentum

- Fermi motion, tuned values exceed theory expectation
  $\rightarrow$ possibly missing higher-order corrections

Multiple parton scattering

- mix of perturbative and non-perturbative aspects
- afflicts the proton and photon, but also e at high-enough order

Non-perturbative modelling

Fragmentation

- perturbative component well-understood (DGLAP),
  but non-perturbative component not understood from first principles
  (yes, lattice, but need it phase-space-point-by-phase-space-point
  calculated in less than a second)
- phenomenological models / QCD-inspired parametrisations
  $\rightarrow$ need tuning of unphysical parameters
- similar problem to non-perturbative structure of proton / photon

Intrinsic transverse momentum

- Fermi motion, tuned values exceed theory expectation
  $\rightarrow$ possibly missing higher-order corrections

Multiple parton scattering

- mix of perturbative and non-perturbative aspects
- afflicts the proton and photon, but also e at high-enough order

Non-perturbative modelling

Fragmentation

- perturbative component well-understood (DGLAP),
  but non-perturbative component not understood from first principles
  (yes, lattice, but need it phase-space-point-by-phase-space-point
  calculated in less than a second)
- phenomenological models / QCD-inspired parametrisations
  $\rightarrow$ need tuning of unphysical parameters
- similar problem to non-perturbative structure of proton / photon

Intrinsic transverse momentum

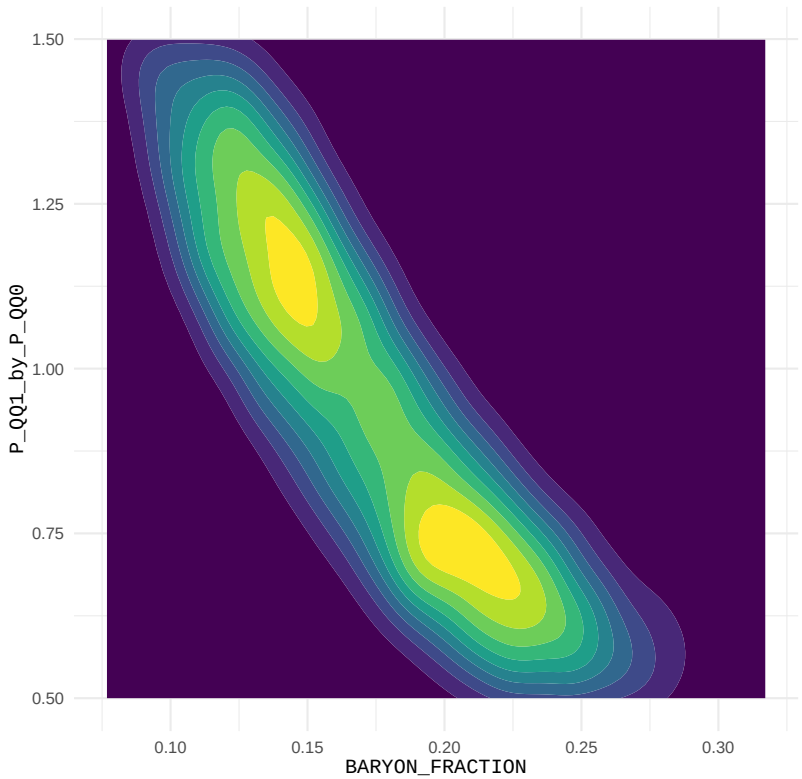
- Fermi motion, tuned values exceed theory expectation
  $\rightarrow$ possibly missing higher-order corrections

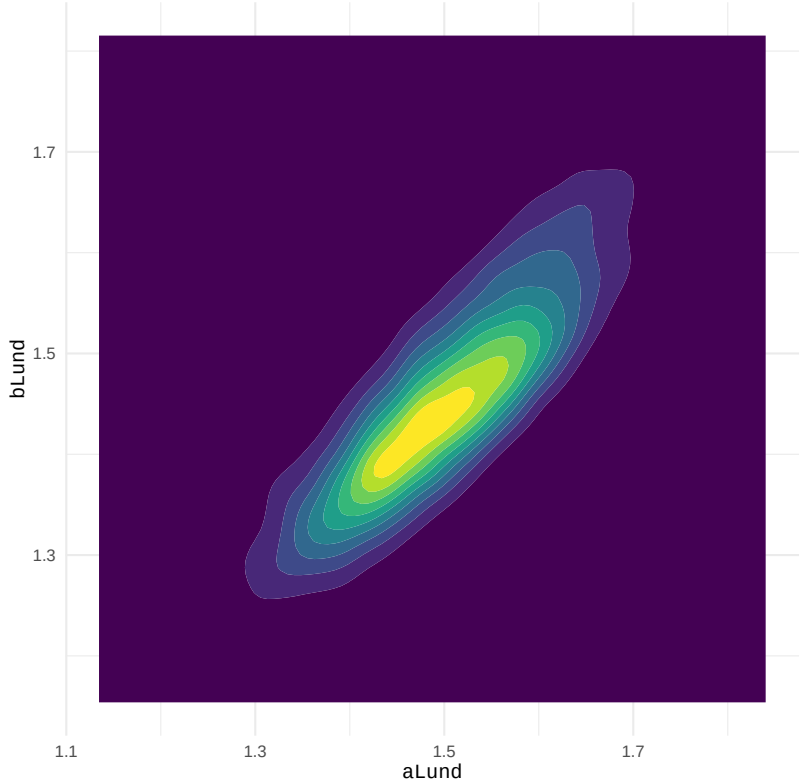
Multiple parton scattering

- mix of perturbative and non-perturbative aspects
- afflicts the proton and photon, but also e at high-enough order

Tuning and tuning uncertainties

Iskauskas, Knobbe, Krauss, Schumann '26

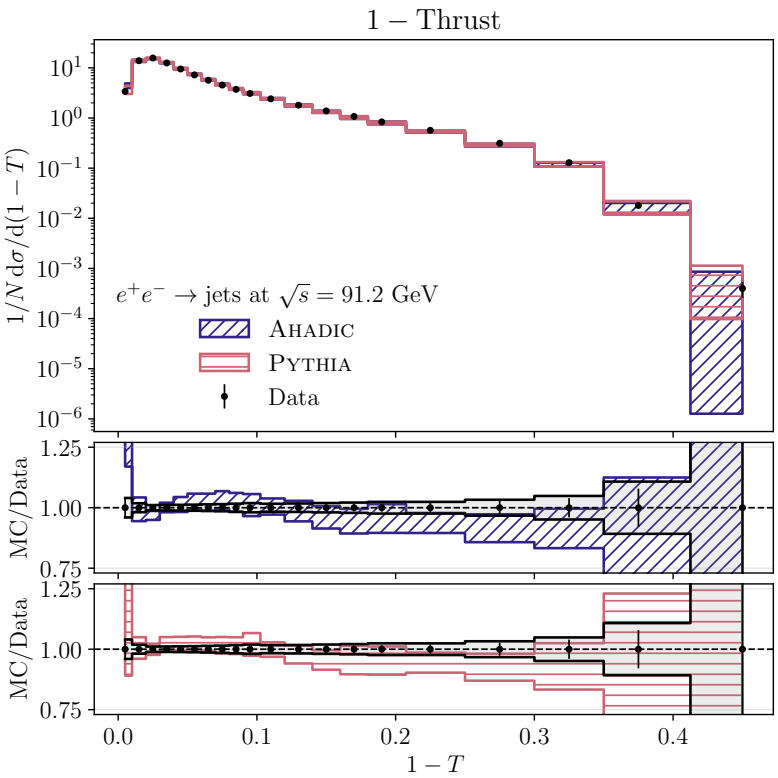


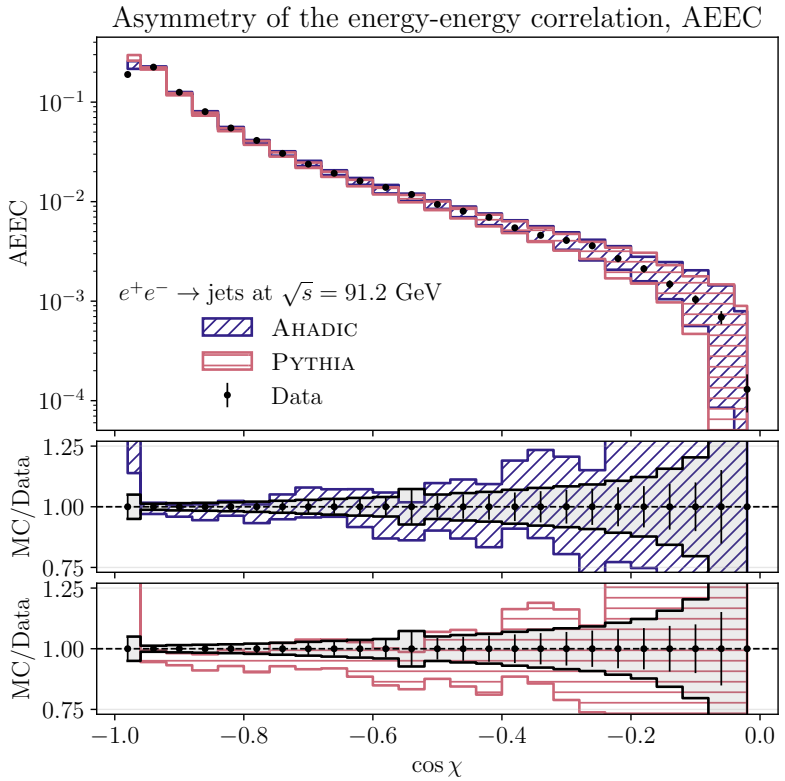


- parameter minimisation,
  best-fit (lowest χ^2) vs. not-implausible (region of low χ^2)
- uncertainty estimation through eigenvectors or replicas

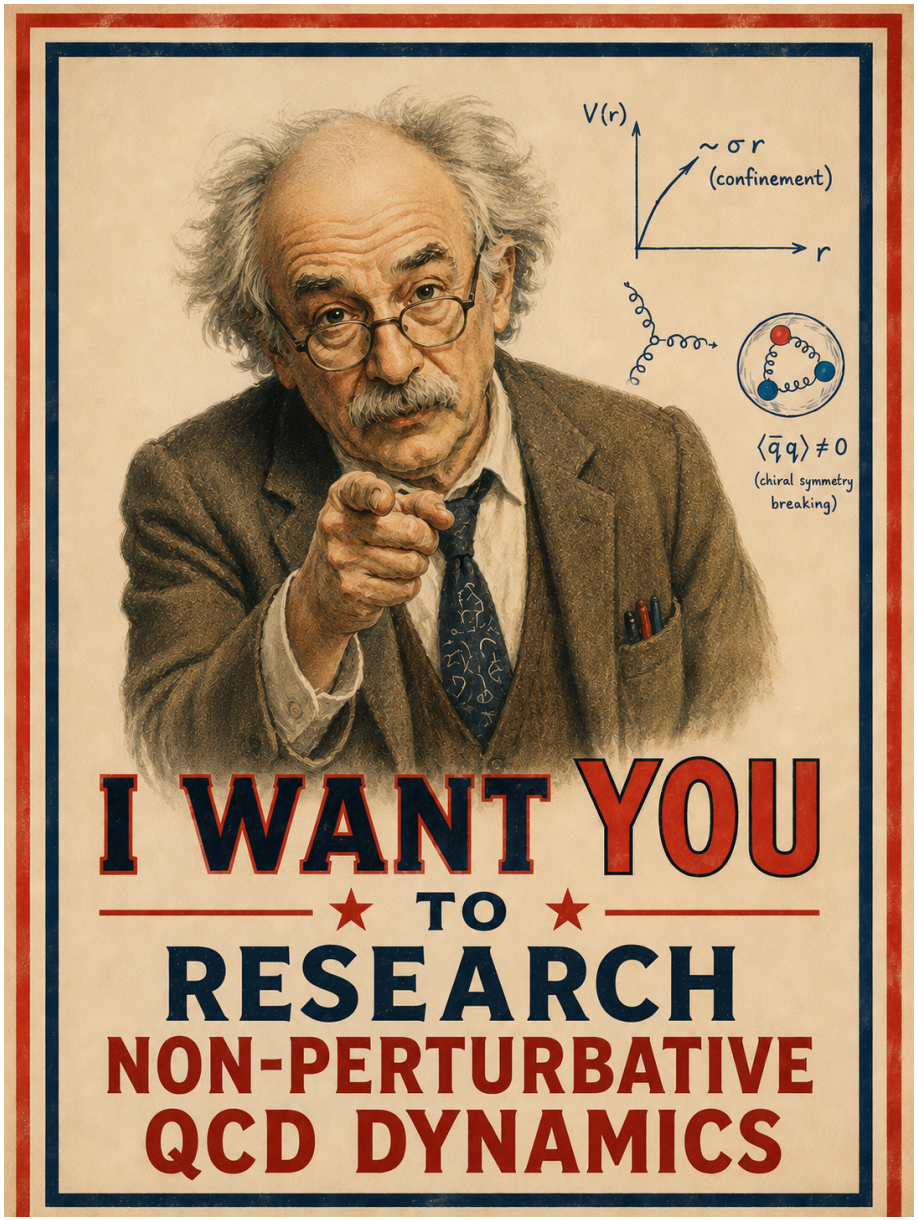
Non-perturbative modelling

Iskauskas, Knobbe, Kraus, Schumann '26





- modelling uncertainties usually not assessed
- dominate theory uncertainties already at LEP
  $\to$ **does not bode well for FCC-ee**



curtesy of ChatGPT

Conclusions

Algorithmic uncertainties

- part of every calculation with undefined components, eg. resummations, parton showers, etc.
- can be systematically eliminated in perturbation theory

Non-perturbative uncertainties

- insufficient understanding of non-perturbative dynamics, modelled through phenomenological QCD-inspired parametrisations
- non-perturbative uncertainties statistically well understood (how to calculate them effectively is not)
- **primary source of theory uncertainty in many precision QCD measurements**

Combination with other sources of uncertainties? → see Jonas' talk

Thank you!

Backup