

# Monash University — Status & Plans

Peter Skands (Monash U)



**German Valencia**  
Professor



**Csaba Balazs**  
Professor



**Peter Skands**  
A/Prof



**Peter Athron**  
Future Fellow

Theory / Phenomenology



Experimental HEP



**Ulrik Egede**  
Professor



**Jordan Nash**  
Professor, Dean



**Helen Brooks**  
Post Doc



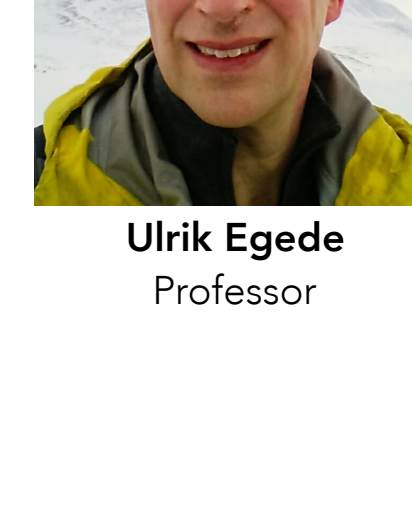
**Ursula Laa**  
Post Doc



**Tomas Gonzalo Velasquez**  
Post Doc



**Yang Zhang**  
Post Doc



**Yuki Fujii**  
Post Doc

(& Students)

(& Students)



Australian Meeting on Accelerator-Based High-Energy Physics

Monash University, February 2019

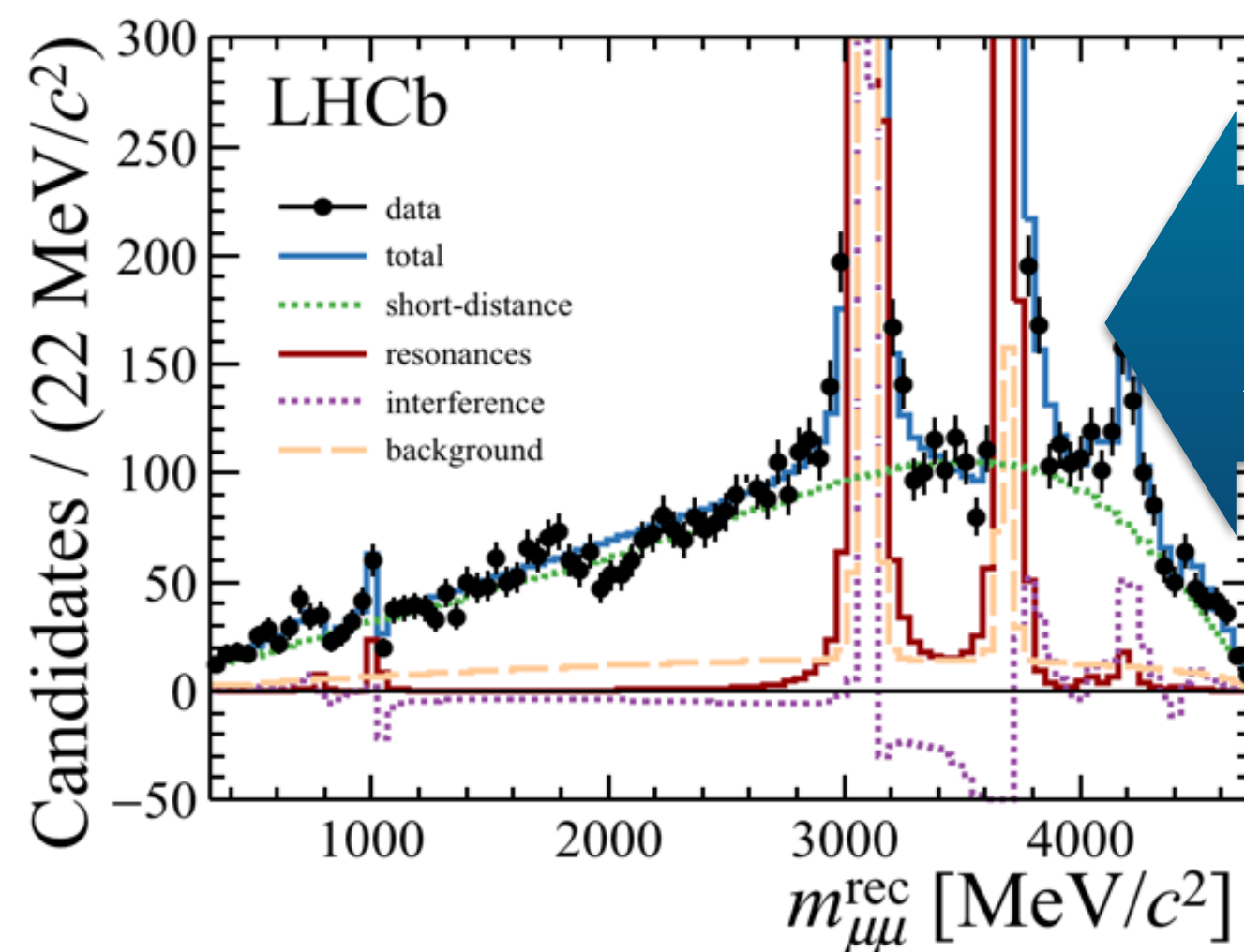


# EXPERIMENTAL HEP: LHCb

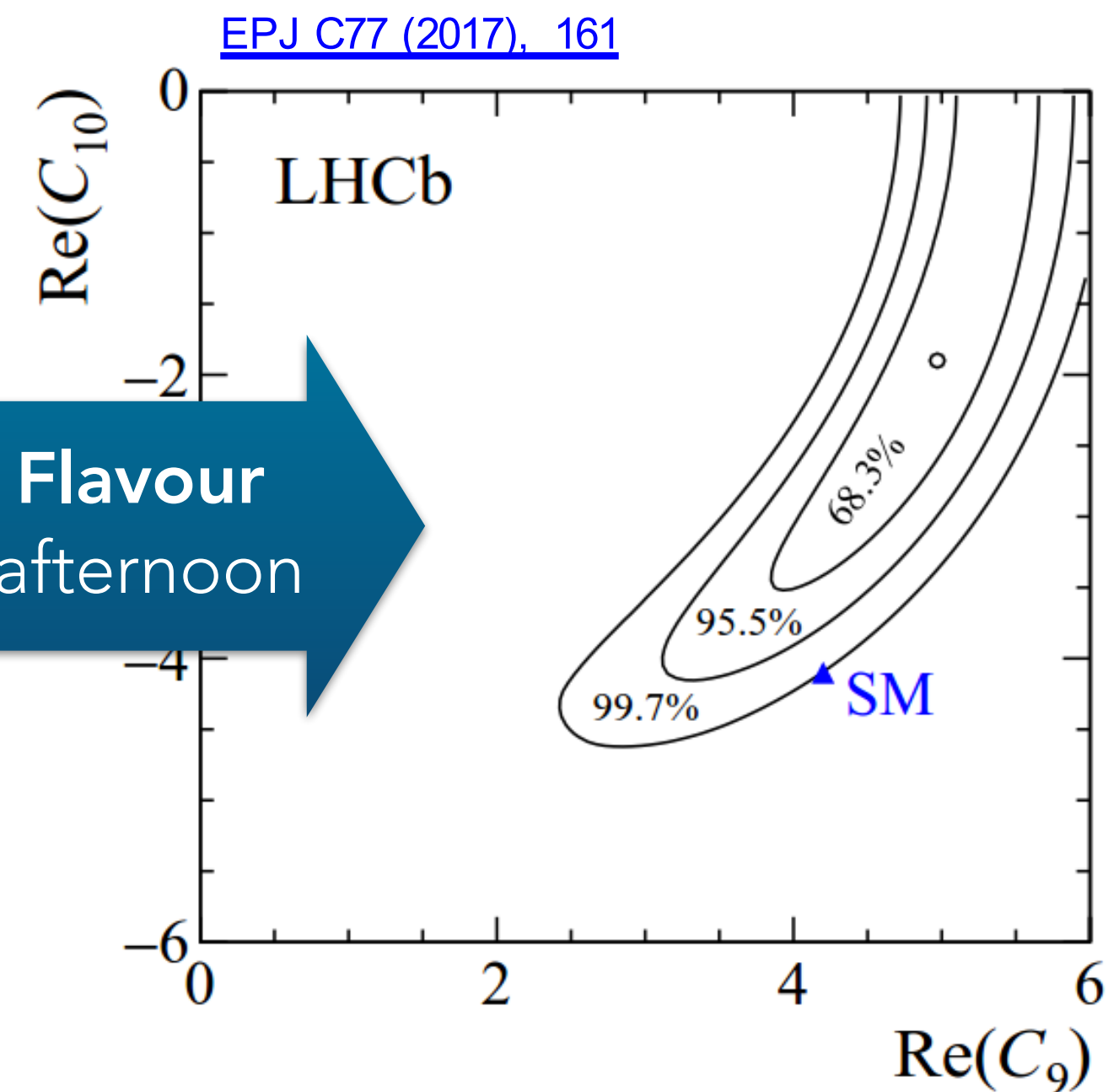
*Ulrik Egede* joined the Monash HEP group on 1-Feb-2019

## Experimental heavy flavour physics

- Detector development for **Upgrade-II of LHCb**
- **Data analysis** in electroweak penguins and semileptonic decays
- **Phenomenology cooperation** to develop new measurements
- **Distributed computing** user interface software



More in the **Flavour Session** this afternoon



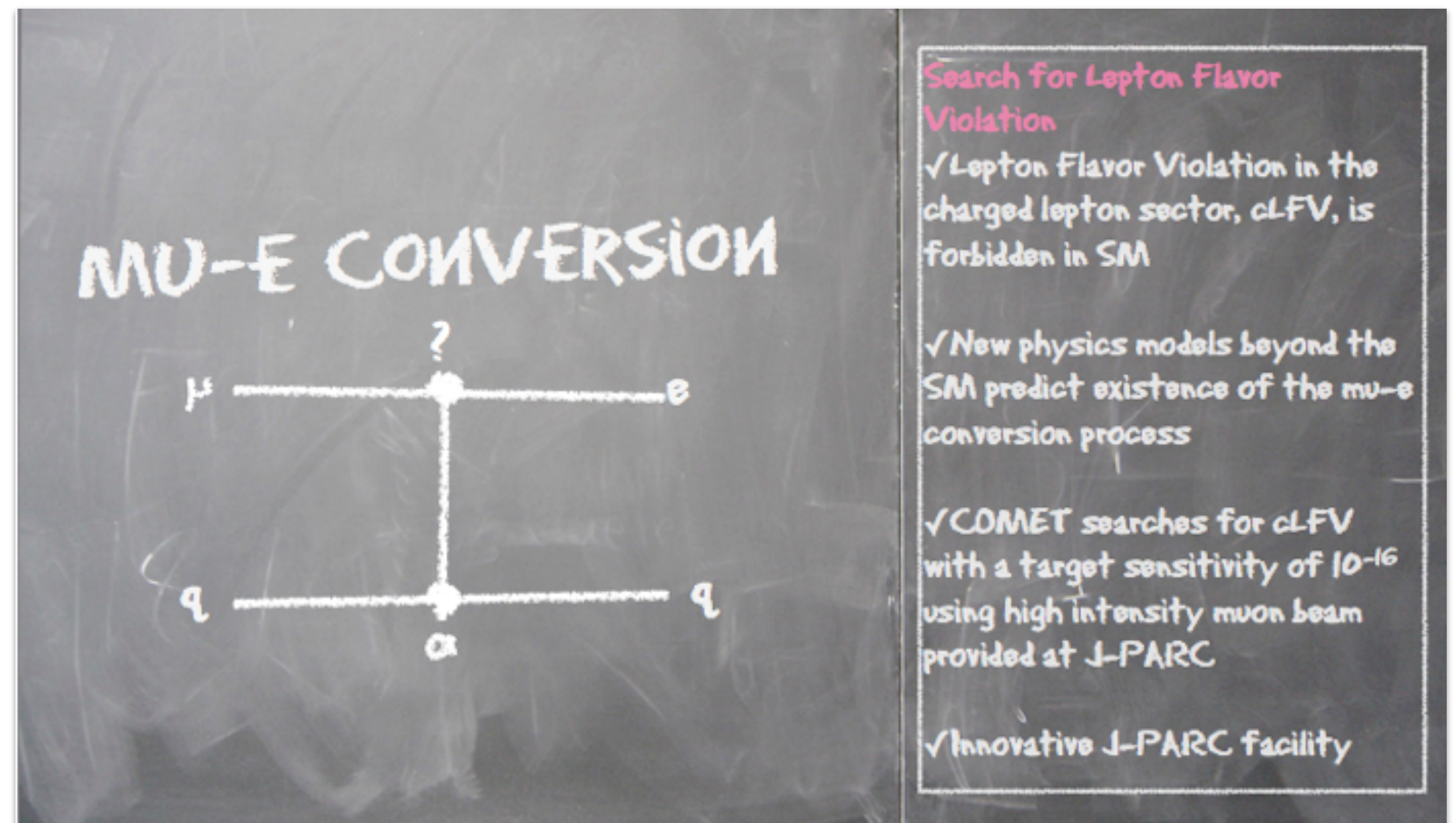


*Jordan Nash & Yuki Fujii* joined the Monash HEP group in 2018

## Muon to Electron Conversion

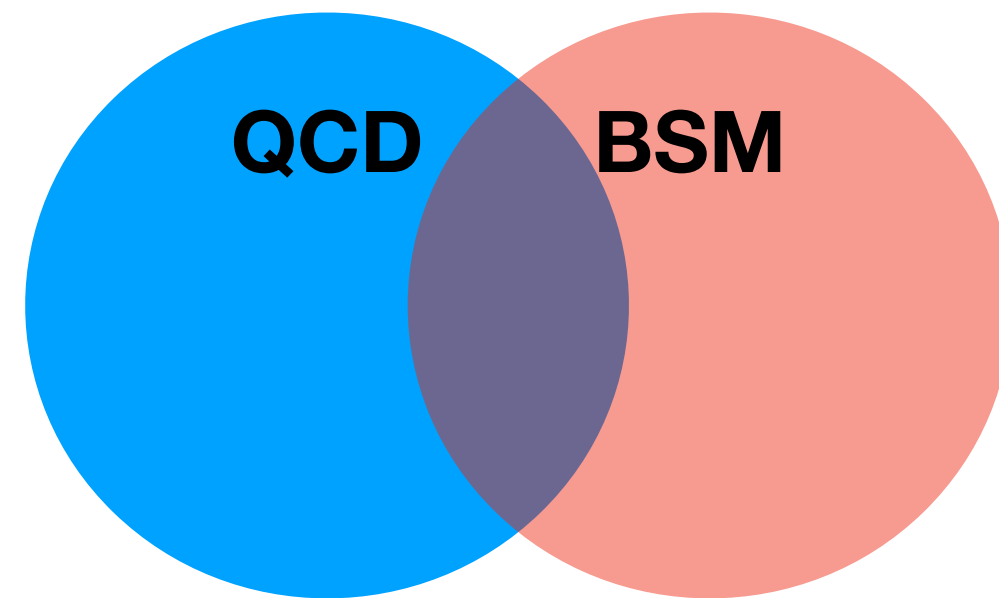


- Forbidden transition in SM (BR  $\sim 10^{-54}$ )
- Any **observation** of a signal  $\Rightarrow$  clear herald of new physics (new mediators)
- COMET targets **sensitivity below  $10^{-16}$**  (four orders of magnitude better than current limit)
- First phase ( $10^{-15}$ ) now being readied at J-PARC in Tokai, Japan
- Main ring  $\Rightarrow$  8 GeV bunched proton beam (spaced by about a muon lifetime  $\sim 2\mu\text{s}$ ) with extremely clean bunch separation (interpulse extinction  $\sim 10^{-9}$ )  $\rightarrow$  window for COMET to look between pulses.



*German Valencia (joined 2015):*

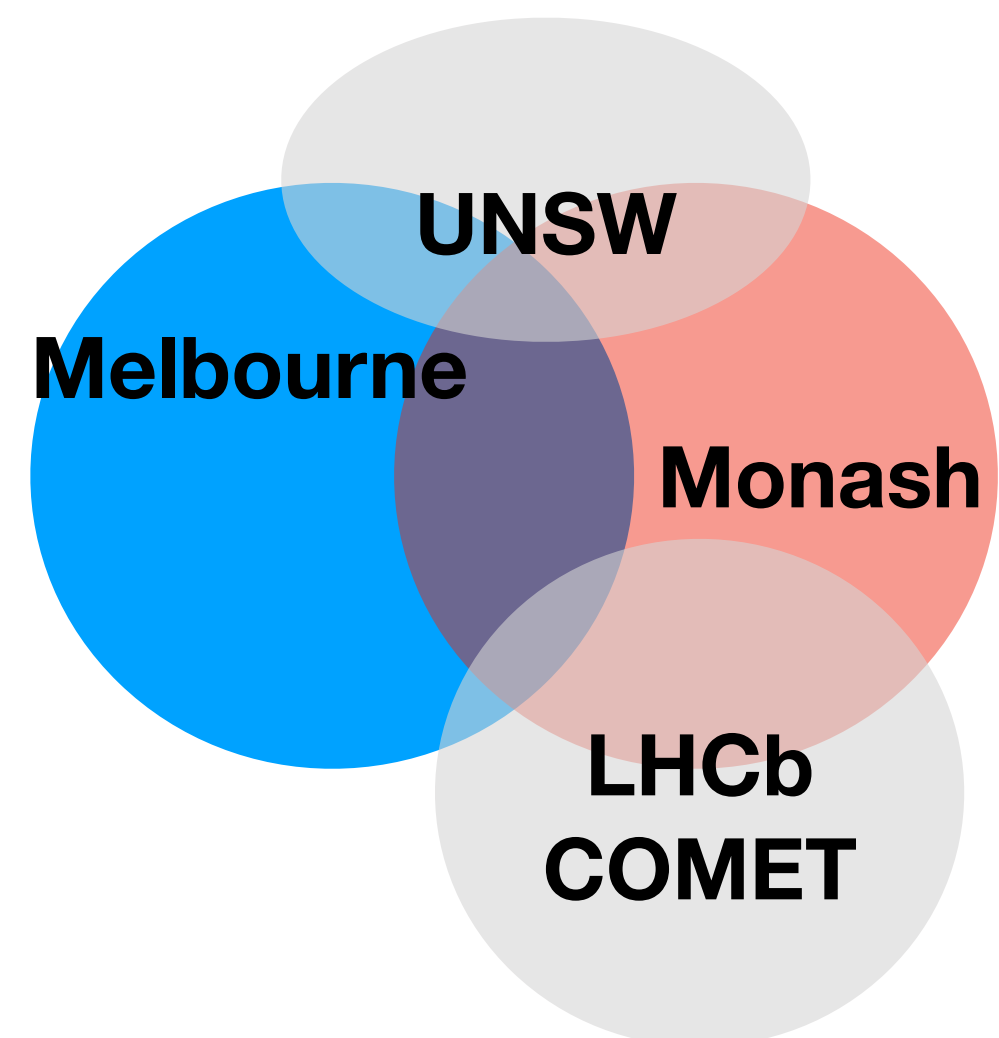
## Phenomenology of SM and BSM at both the high-energy and intensity frontiers



### Applications of effective field theory

- NP or higher order QCD (LHC) that may be kinematically separated from SM: (w Haitao Li)
- NP in the scalar sector
- baryon chiral perturbation theory
- heavy quark effective theory

model building with additional coloured scalars

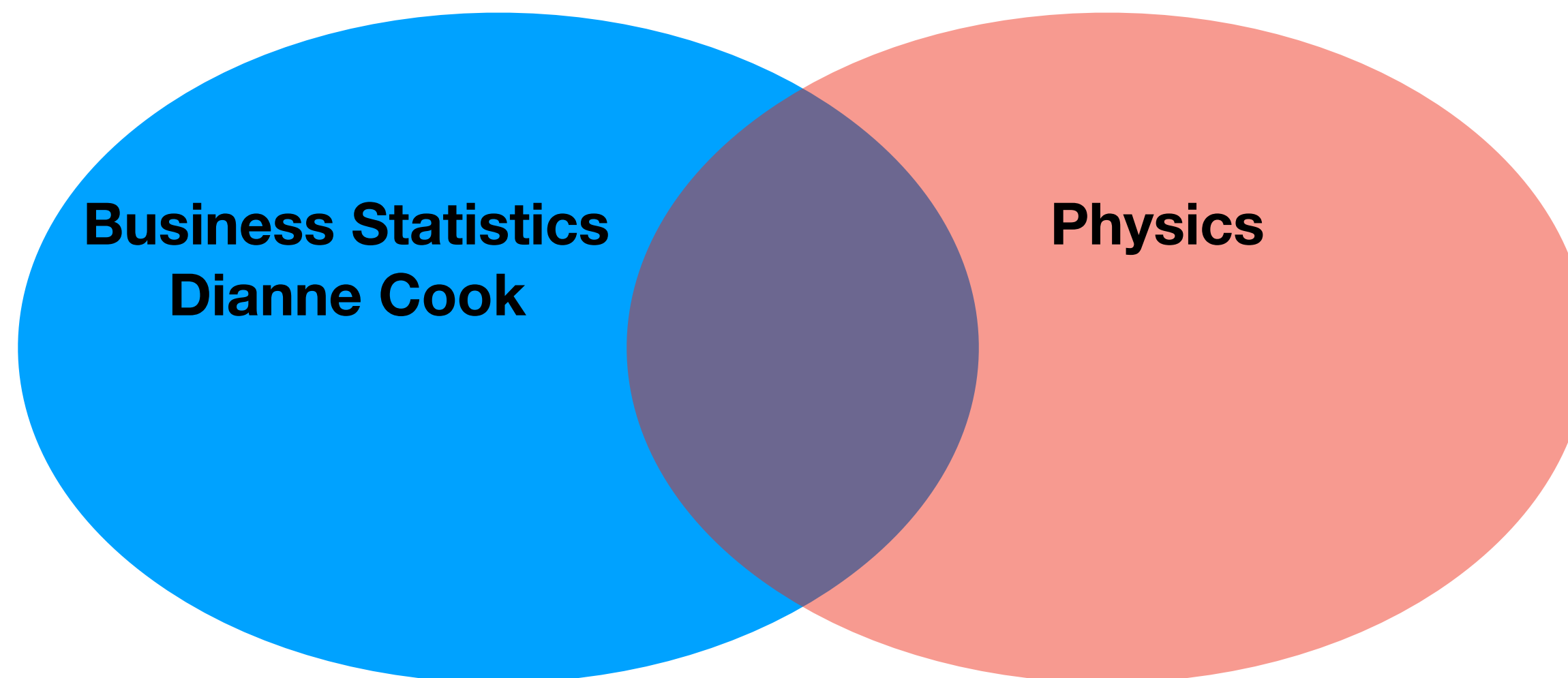


### Flavour Physics

- Lepton universality violation
- Rare decays with additional light (sterile) neutrinos
- charged LFV (w Yi Cai, Michael Schmidt)
- new proposal (w Michael Schmidt, Ray Volkas)
- future collaboration - Ulrik Egede, Jordan Nash



Applications and development of statistical methods for visualisation of high dimensional data in physics: this is **mostly done by Ursula Laa.**



- Sensitivity of hadronic experiments to nucleon structure: PDF fits
- Fit to flavour measurements in 6d NP parameter space to understand in detail the structure of any deviations from the SM. (see talk tomorrow)
- Visualisation methods complementary to machine learning

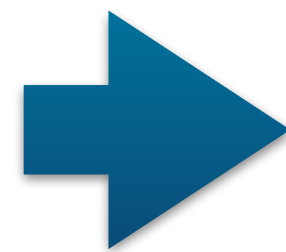


# PHENOMENOLOGY: FlexibleTools

*Peter Athron (ARC future fellow)* joined Monash HEP (as CoEPP post doc) in 2014

State-of-the-art calculation of **Masses and Couplings** in *any* BSM model

$$\mathcal{L} = \mathcal{L}_{\text{SM}} + \dots$$



Spectrum of physical particles, masses, mixings, couplings  
+ many derived quantities (eg decay branching fractions)

- *International collaboration involving Australia, Czech Republic, Germany and South Korea*
- *Leadership from Monash*
- *Originally 4 members, expanded with 12 new contributors and still growing*

## General Strategy

At least

- full two-loop RGEs
- one loop self-energies and tadpoles

Many model specific corrections to ensure most precise predictions in *all* models

+ Focus on **precision Higgs mass calculations**

## Current Projects (non-exhaustive)

- Anomalous **muon magnetic moment** (w *C Balazs, D Jacob*)  
+ other flavour-related observables
- **LHC** searches/analysis/**reinterpretation** (*Y Zhang, G Pozzo*)
- From realistic **GUTs** to phenomenology (*T Gonzalo*)
- **Phase transitions** and electroweak symmetry breaking  
(w *C Balazs, M Bardsley, G Pozzo, Y Zhang*)





*Balazs, Athron, Zhang, and Gonzalo* are all part of the GAMBIT collaboration, which has a significant presence in Australia — see also other group talks

- open source global fitting code: **from Lagrangian to likelihood**
- extendable database of models and measurements: **from collider to cosmology**
- **massively parallel**, plug&play physics backends,
- 40+ participants in 11 experiments and 14 major theory codes

## Goals and vision

- **Finding** traces of new physics in *all available data* from collider, through precision to cosmology,
- **Covering** the most *comprehensive set of models* from particle physics, through nuclear to astrophysics
- **Automating** tools to calculate the *widest range of observables* starting from a Lagrangian
- **Calculating plausibility** of a model via *sophisticated sampling of parameter spaces*

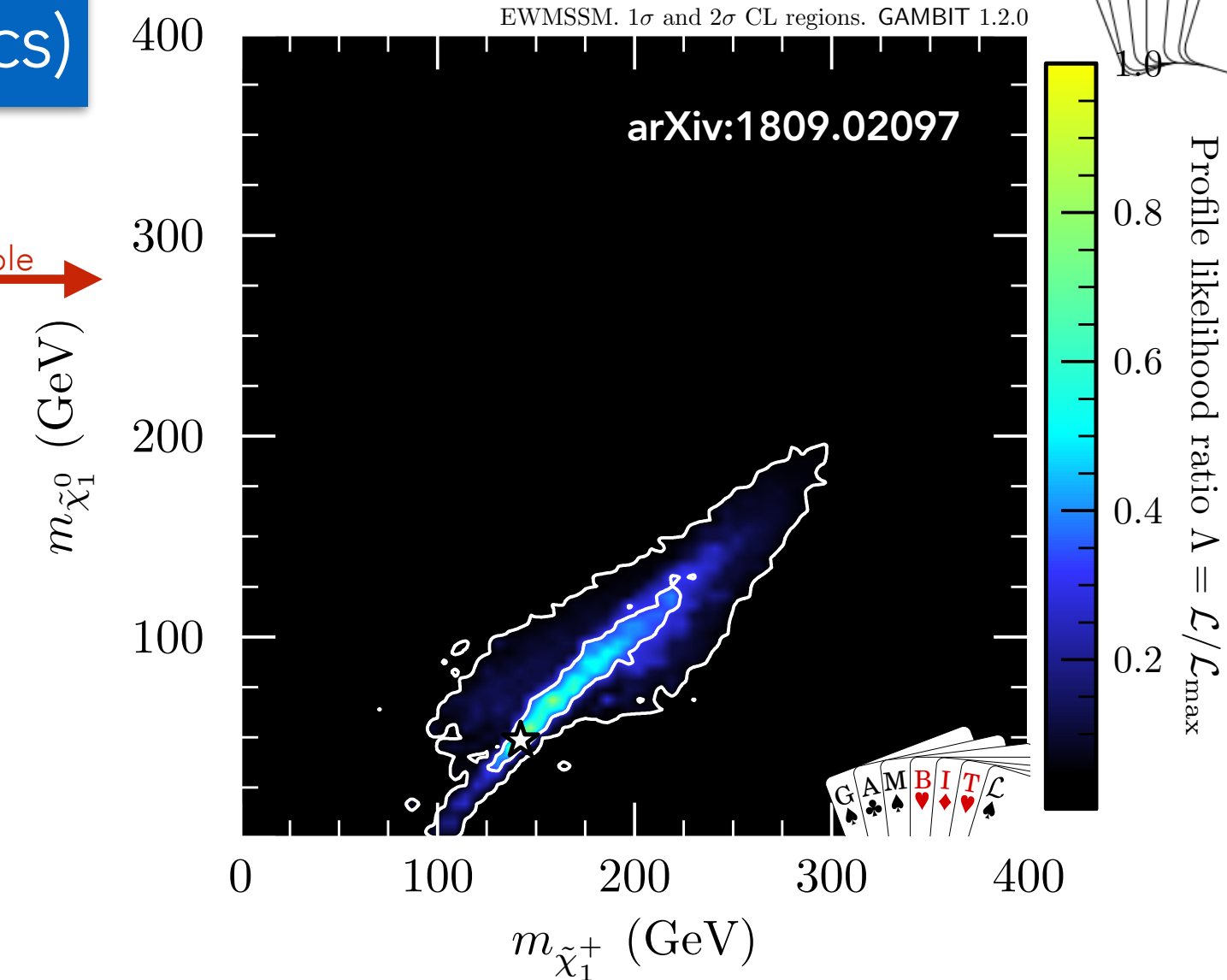




## Current Projects (relevant to accelerator-based physics)

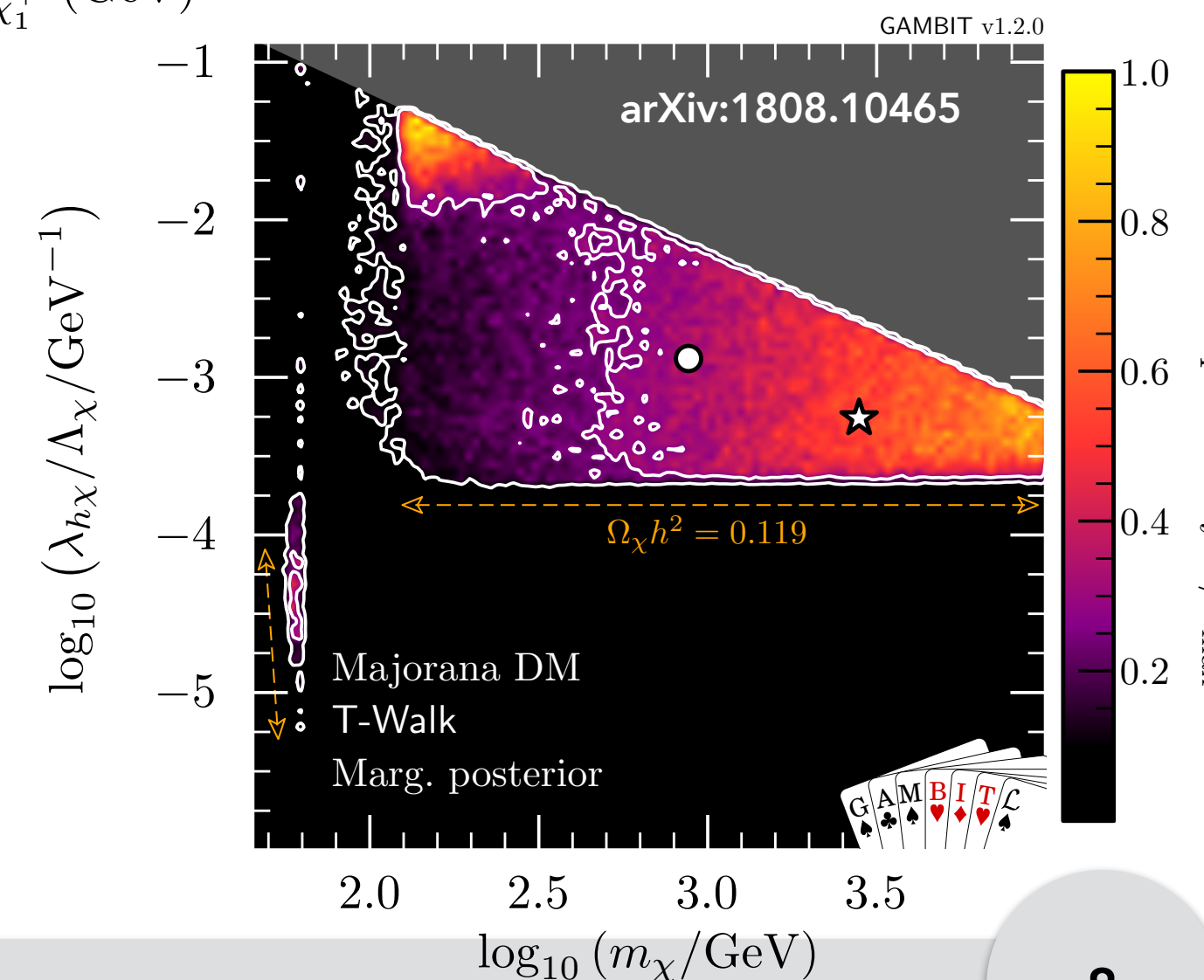
- Combining collider constraints on neutralinos and charginos in the (N)MSSM,
- Global **leptoquark fits to flavour anomalies**
- Assessing the viability of various MSSM models (gravitino, MSSM-9, ...),
- Global fits for various dark matter models incl. collider and flavour observables.

example →



## Near future projects (relevant to accelerator based physics)

- The new physics reach of **future colliders** (HL/E-LHC, FCC, ILC, CEPC, CLiC...)
- Global fits to **lepton flavour violating models** and flavour EFTs, to 2HDM, RHN, and various SUSY and *dark matter models*. example: status of majorana Higgs portal dark matter →



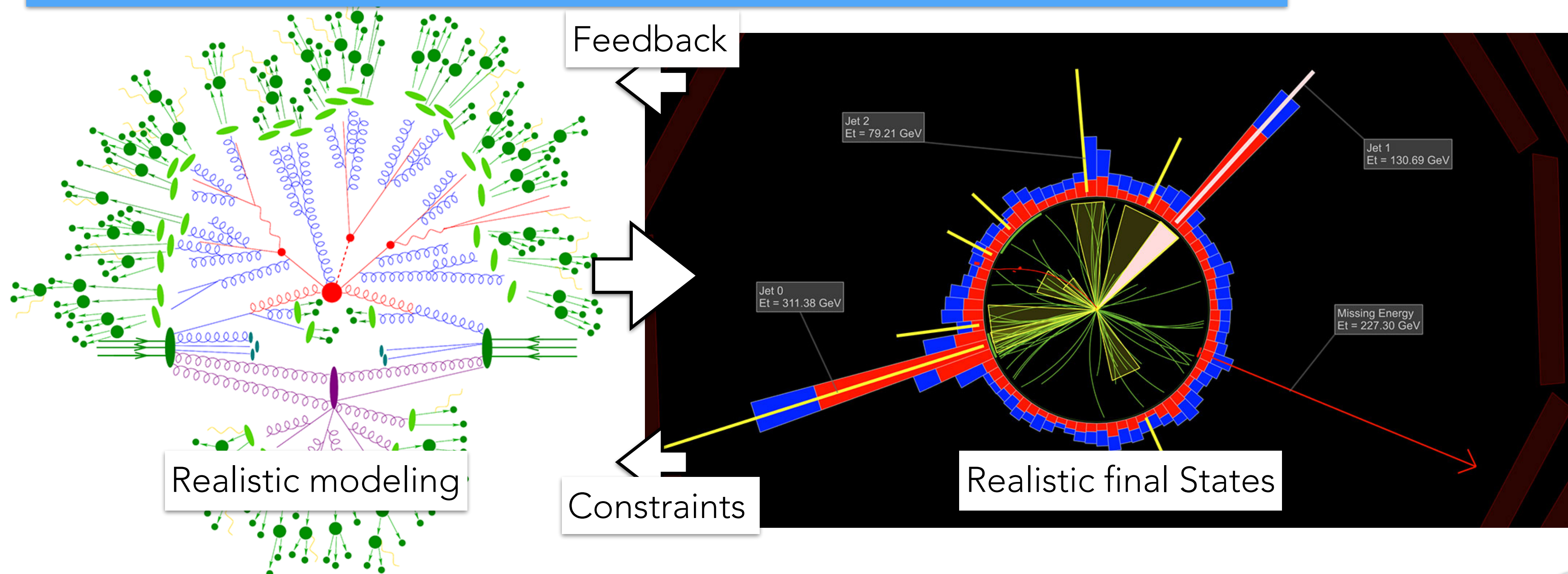




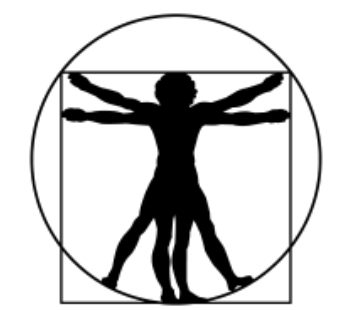
Theoretical modeling of high-energy physics processes (via Monte Carlo simulations)

- Combining fixed-order and infinite-order (resummed) **perturbative calculations**.
- **String fragmentation**, Multi-parton interactions, Hadron and Tau Decays

**Detailed models of complex physics** — crucial in modern day particle physics



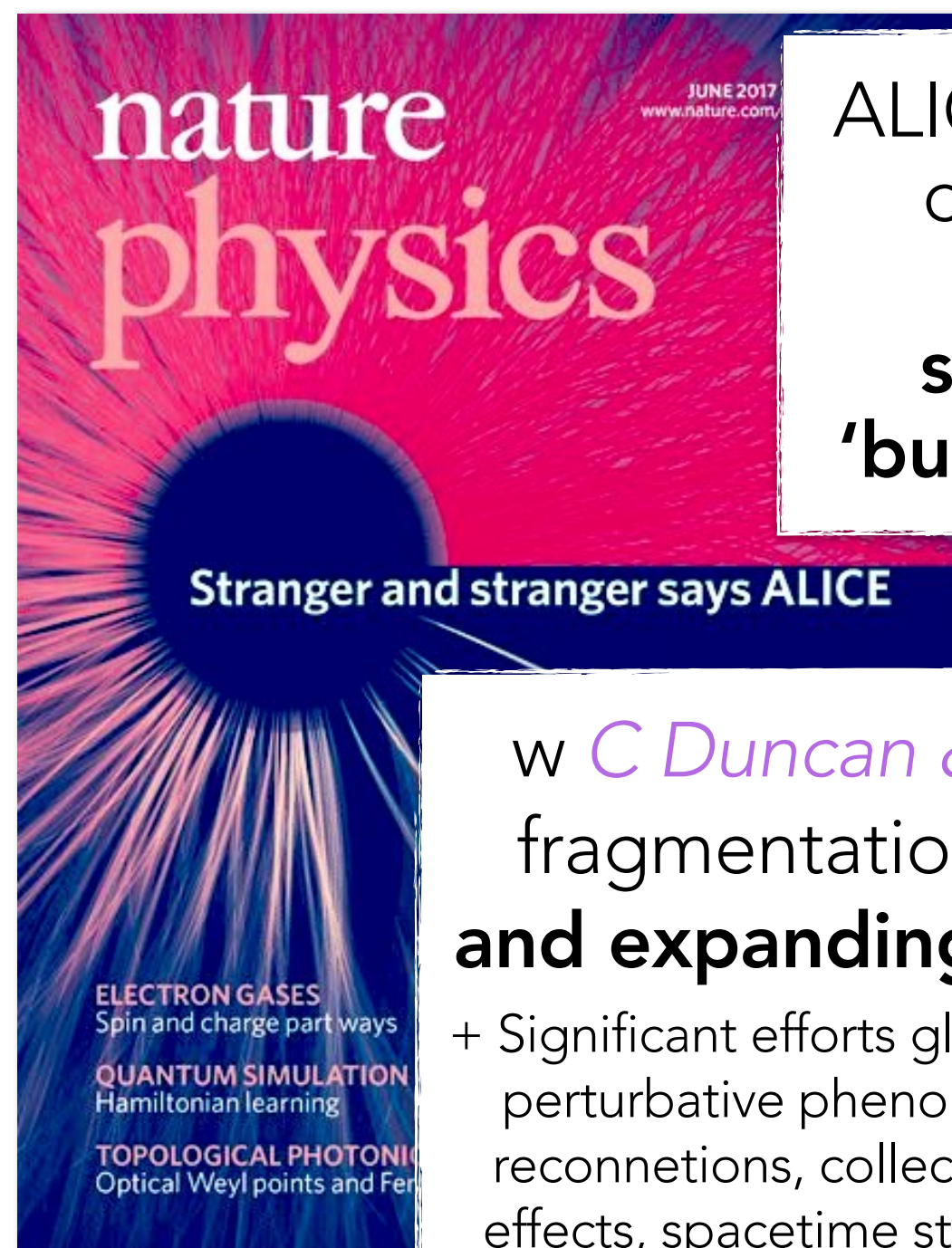




*Skands, Brooks & Students* explore solutions to (real-world) QFT & models of non-perturbative dynamics. Using **Pythia** + **Vincia** to transfer successful ideas to the wider community

## A few recent projects:

### Non-perturbative QCD Dynamics



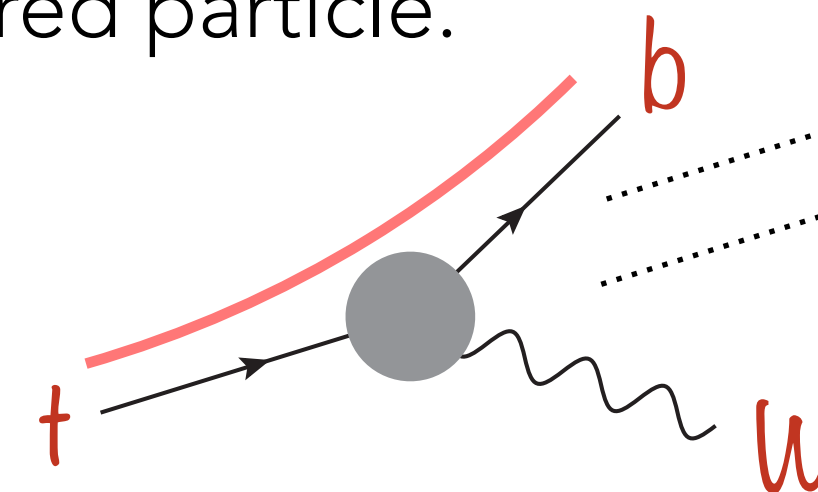
ALICE has observed clear signals of increased **strangeness** in 'busy' pp collisions

w *C Duncan & N Hunt-Smith*: fragmentation of **interacting and expanding strings** in Pythia  
+ Significant efforts globally to understand non-perturbative phenomena in pp; MPI, colour reconnections, collectivity / ridges / QGP-like effects, spacetime structure, rescatterings, ...

### Top-Quark and High-Precision Physics

Top quark unique (in SM): decay of a (very) massive coloured particle.

Very high statistics at LHC



The go-to reference case (& background) for many BSM searches

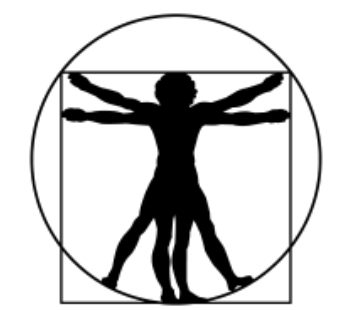
*H. Brooks*: new approach to radiation: modelled as initial-final QCD antenna/dipole in Vincia

*R. Verheyen (Nijmegen)*: fully coherent QED multipole showers ( $\rightarrow$  EW showers) in Vincia

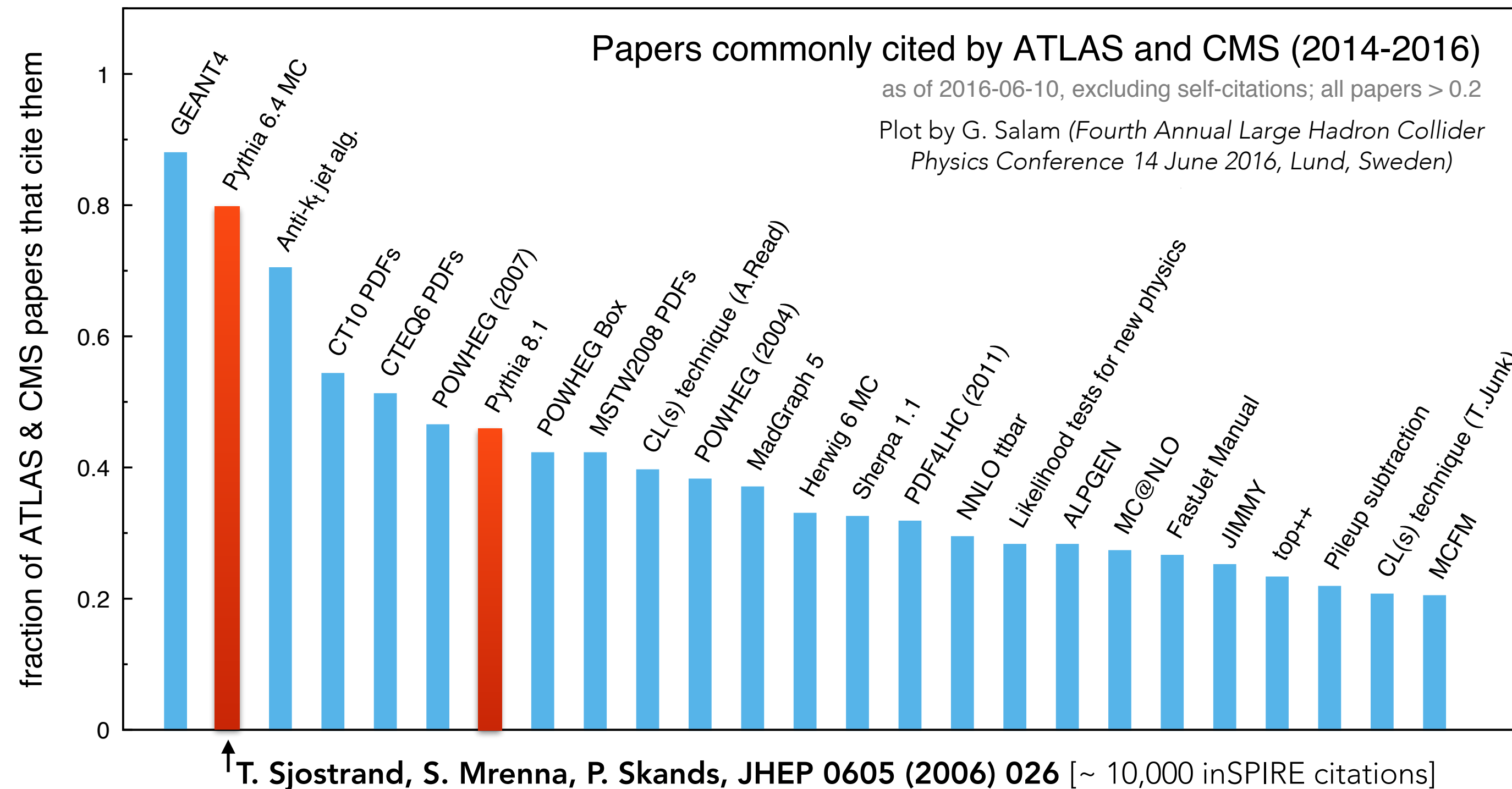
+ Further projects with *C Preuss, C Duncan, B Wong*







## Calculations with Impact



MC generators heavily relied upon ...

- For the **design** of existing experiments ATLAS, CMS, LHCb
- To devise **new strategies for analyses** and new experiments
- For the **interpretation of data**

## International collaborations

- **MCnet** EU Horizon 2020 ITN (w/ Manchester, **Lund**, UCL, Durham, Heidelberg, Göttingen, CERN, Louvain-la-Neuve, Karlsruhe KIT)
- + Recent student exchange agreement with Bologna (**F. Maltoni**, MadGraph)

\*Many of the 20% which do not cite Pythia directly, cite "Atlas generation framework and references therein", are hardware specific, or PRLs with results obtained with Pythia, but 'short of space' for references.



# Outlook: accelerator-based particle physics at Monash

## 1. Focus on flavour

**LHCb** represents a long-term program, including *upgrades*, engagement with *CERN*  
+ Collaboration with Japan (*J-PARC*) via **COMET**

Substantial **Theory** / Phenomenology engagement & support for flavour physics  
Collaborations at both national and international levels,  
(not least Australian **Belle II** groups)

## 2. Precision SM & BSM phenomenology

**High-Lumi LHC** → 2030ies (+ Future Colliders): also an *intensity frontier* → precision & accuracy

Sophisticated and reliable translations of SM (**Pythia + Vincia**) and BSM (**FlexibleTools**,  
FeynRules+MadGraph+**Pythia**) physics models into real-world observables.

+ Engagement with experimental/user communities → new measurements and searches.

Sophisticated **global fits** (GAMBIT) including ↔ **flavour sector**