GAMBIT and semileptonic decay using the Recursive Jigsaw Reconstruction

Paul Jackson

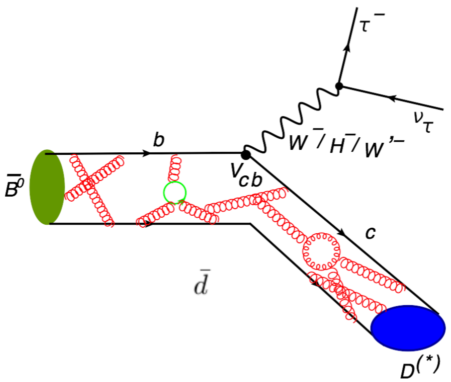
THE UNIVERSITY of ADELAIDE

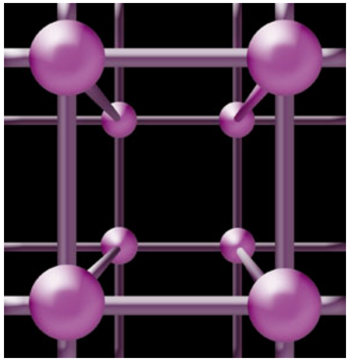
Nagoya University, March 28th 2017

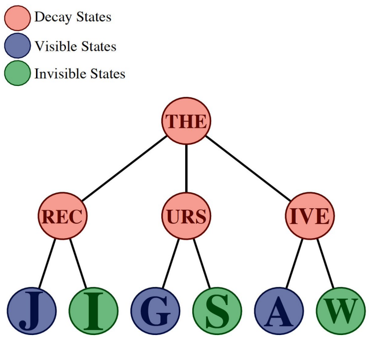
Mini Workshop on D(*)taunu and related topics

Overview

- Brief introduction to the Recursive Jigsaw Reconstruction
  - potential application to semileptonic B decays
- Introduction to GAMBIT
  - application to constraints on new physics from various sources, including flavour
- Lattice efforts in Adelaide

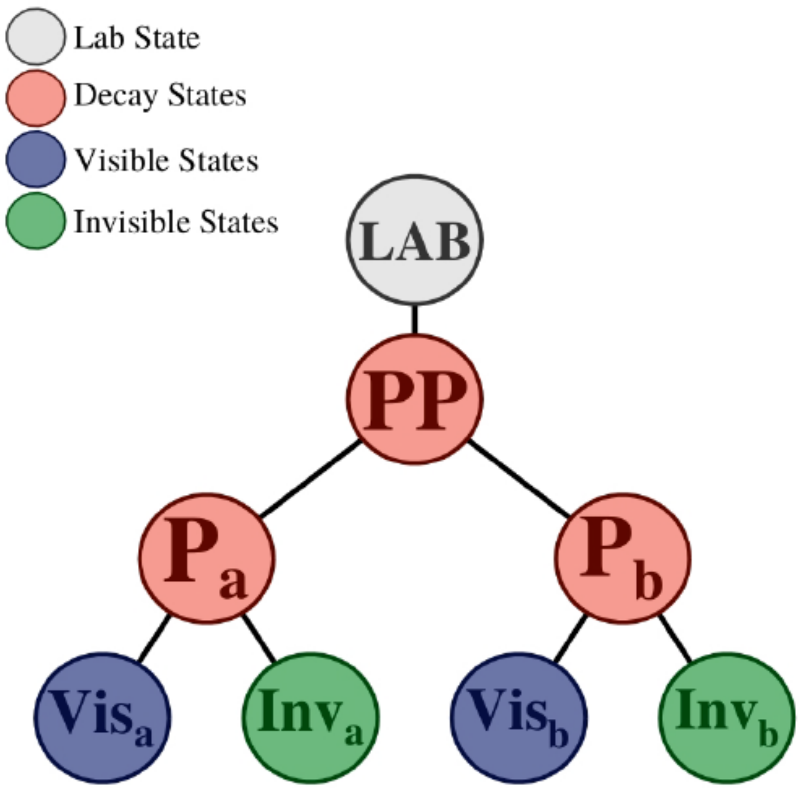






Recursive Jigsaw Reconstruction technique

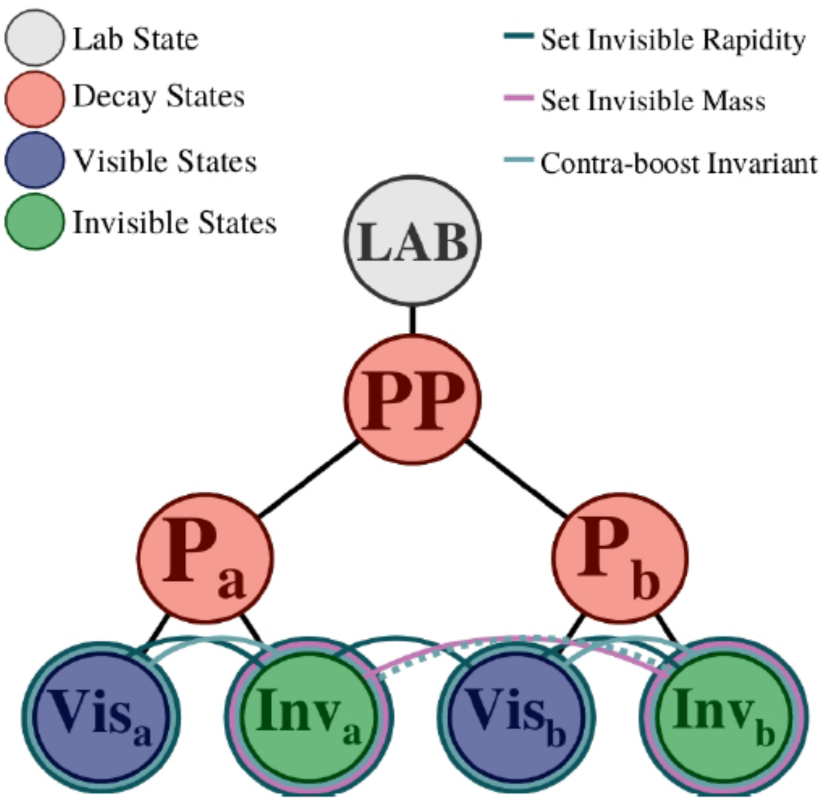
- Original method to **reconstructing** final states with weakly interacting particles.
- Transform observable momenta reference-frame to reference-frame
- **Jigsaw rules**: specify the unknown d.o.f. relevant to the transformation (customizable-interchangeable like jigsaw puzzle pieces)
- The procedure is repeated **recursively**, travelling through each of the reference frames relevant to the topology



- Rather than obtaining one observable, get a complete basis of useful variables *diagonalized* with physical observable: angles, energies, masses ...

RJR technique

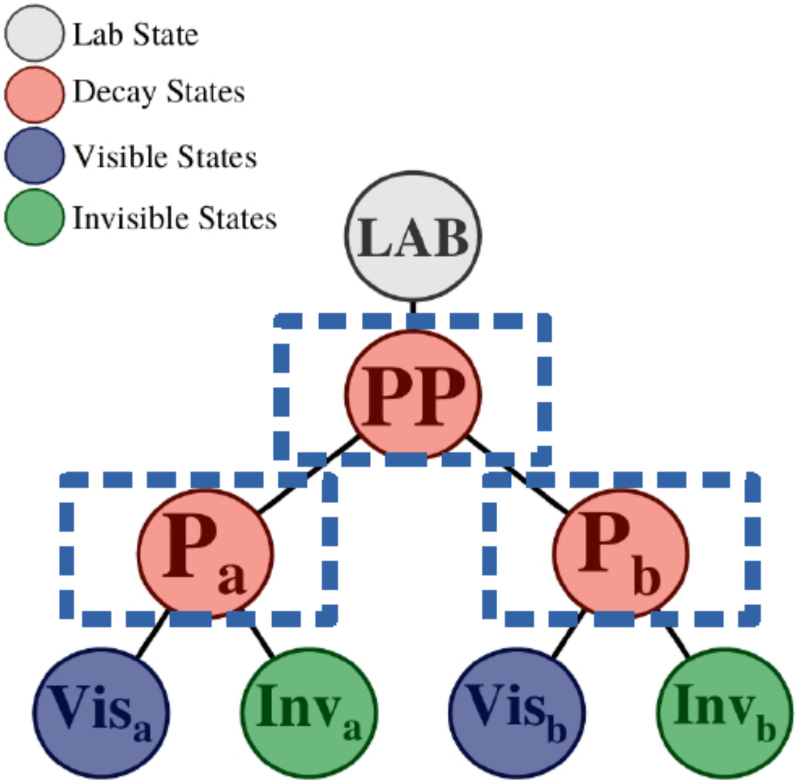
- Original method to **reconstructing** final states with weakly interacting particles.
- Transform observable momenta reference-frame to reference-frame
- **Jigsaw rules**: specify the unknown d.o.f. relevant to the transformation (customizable-interchangeable like jigsaw puzzle pieces)
- The procedure is repeated **recursively**, travelling through each of the reference frames relevant to the topology



- Rather than obtaining one observable, get a complete basis of useful variables *diagonalized* with physical observable: angles, energies, masses ...

RJR technique

- Original method to **reconstructing** final states with weakly interacting particles.
- Transform observable momenta reference-frame to reference-frame
- **Jigsaw rules**: specify the unknown d.o.f. relevant to the transformation (customizable-interchangeable like jigsaw puzzle pieces)
- The procedure is repeated **recursively**, travelling through each of the reference frames relevant to the topology

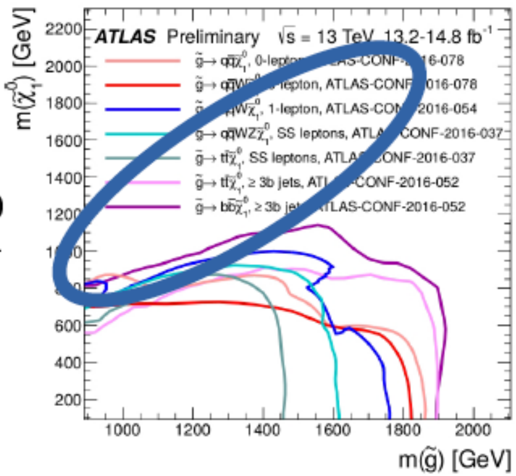


- Rather than obtaining one observable, get a complete basis of useful variables *diagonalized* with physical observable: angles, energies, masses ...

RJR technique – compressed decays

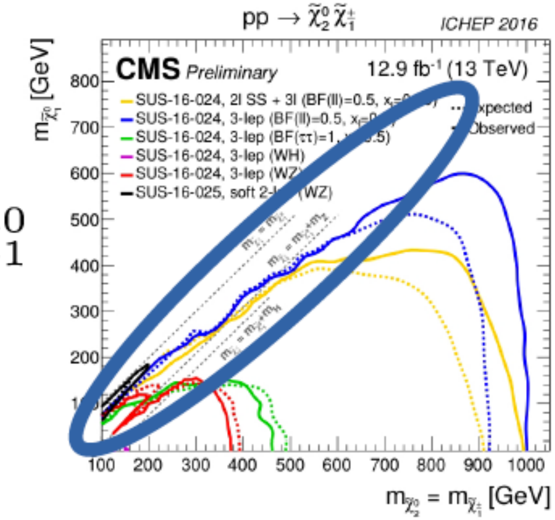
- **Compressed** scenarios refer to **small mass-splittings** $M_{\tilde{P}} - M_{\tilde{\chi}_1^0}$ between the parent superparticle $\tilde{P}$ and the lightest supersymmetric particle (LSP) $\tilde{\chi}_1^0$

$M_{\tilde{\chi}_1^0}$



$M_{\tilde{P}}$

$M_{\tilde{\chi}_1^0}$



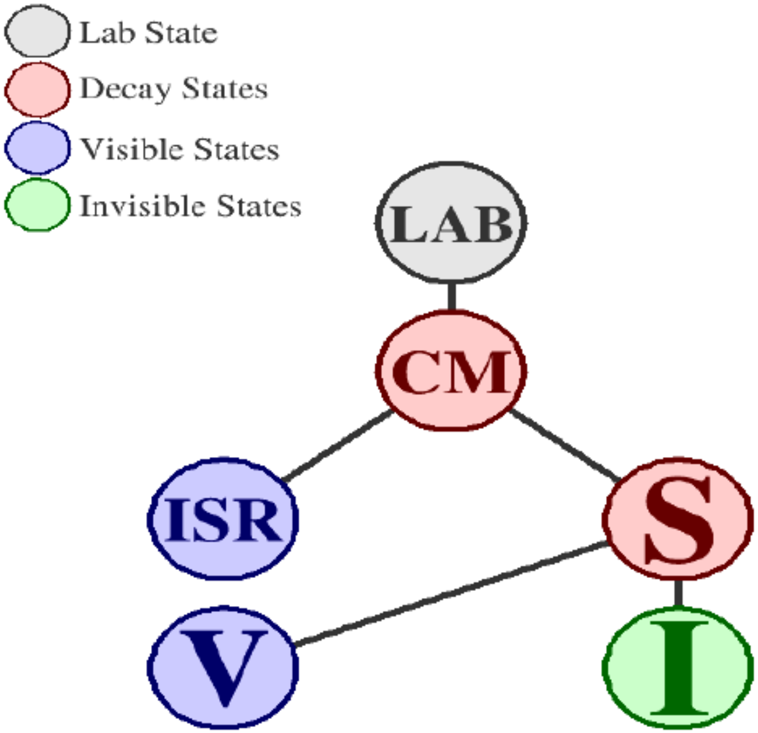
$M_{\tilde{P}}$

- **Challenge**
  - Low momentum decay products are hard to detect
  - The LSPs result in a low value of the transverse missing momentum $\vec{\not{E}}_T$
- To separate signal from BGs, consider only events with a **high momentum ISR-system**
- In the limit where the LSPs receive no momentum from their parents' decays

$$\vec{\not{E}}_T \sim -\vec{p}_T^{\,\mathrm{ISR}} \times \frac{M_{\tilde{\chi}_1^0}}{M_{\tilde{P}}}$$

- How do we separate initial state radiation from the other decay products?

- The RJR algorithm to separate **ISR** from "*sparticle objects*"
- Accomplished with a simple ***transverse*** decay view of the event
- **CM**: centre-of-mass system including all visible objects and MET
- **ISR** radiation not coming from sparticle decays
- **S** is the Signal/SUSY system decaying in
- **V**: Visible system
- **I**: Invisible system = missing transverse momentum

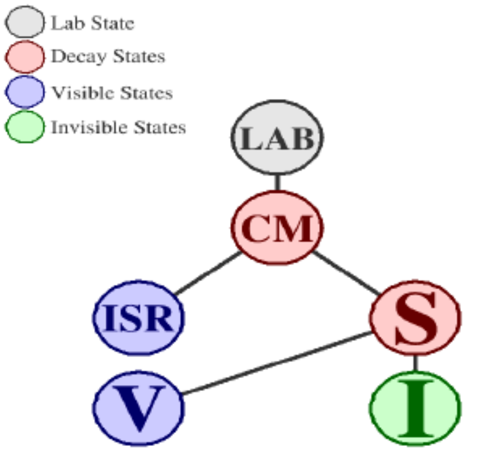


Kinematics observables to probe SUSY in the compressed regime

$p^{\mathrm{CM}}_{\mathbf{ISR},T}$ Magnitude of the jets vector-sum transverse momentum of **ISR**-system evaluated in the CM frame ($\vec{p}^{\,\mathrm{CM}}_{\mathbf{ISR},T} = -\vec{p}^{\,\mathrm{CM}}_{\mathbf{S},T}$)

$R_{\mathrm{ISR}} \equiv \left| \vec{p}^{\,\mathrm{CM}}_{\mathbf{I},T} \cdot \hat{p}^{\mathrm{CM}}_{\mathbf{ISR},T} \right| / p^{\mathrm{CM}}_{\mathbf{ISR},T}$ Variable sensitive to the mass ratio $\frac{M_{\tilde{\chi}^0_1}}{M_{\tilde{P}}}$

M^{S}_{T} Transverse mass of **S** system (**V**+**I**)



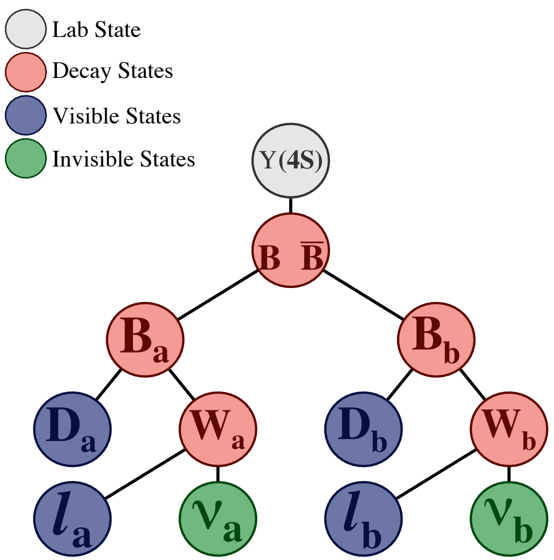
N^{V}_{jet} Number of jets assigned to the **V** system (i.e. not associated with the ISR system)

$\Delta\phi_{\mathbf{ISR},\mathbf{I}}$ Opening angle between the ISR system and the I system, evaluated in the CM frame.

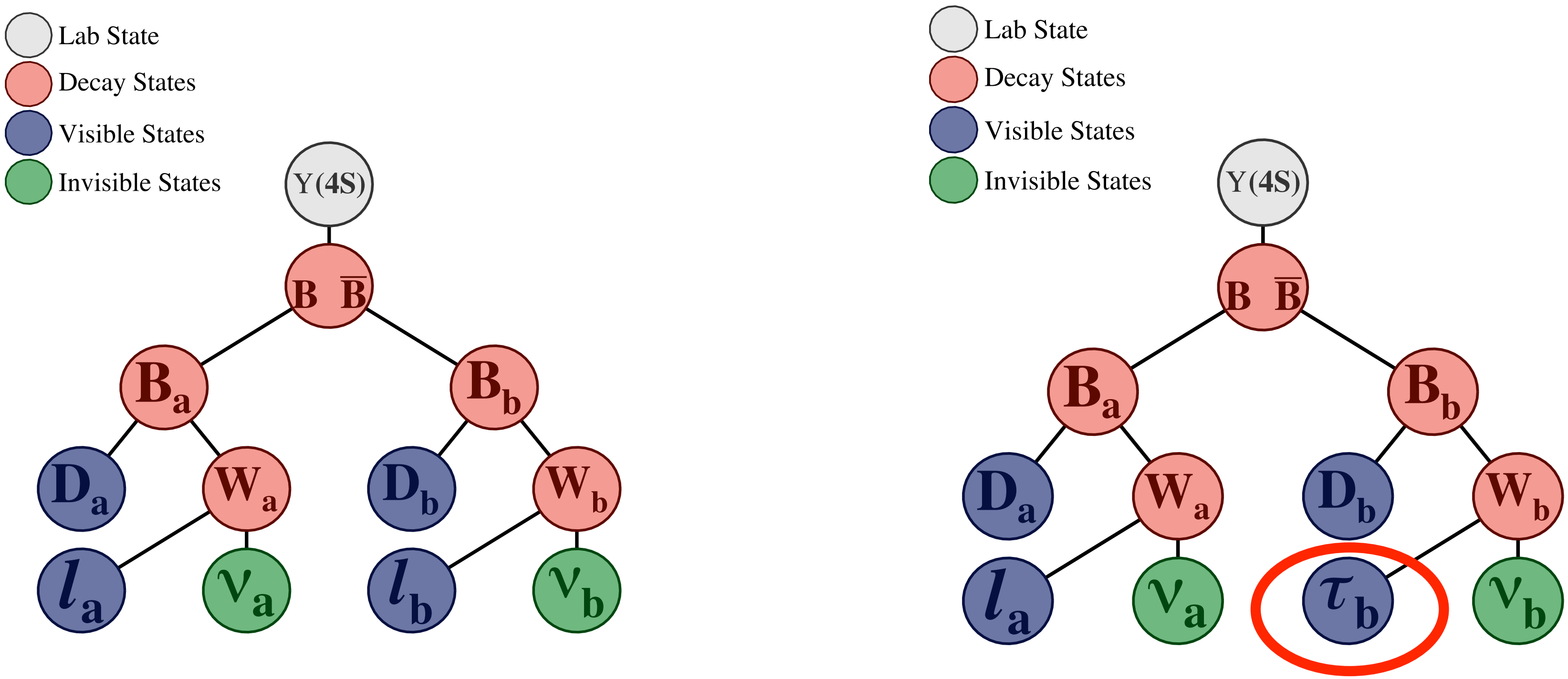
PRD 95, 035031 (2017)

Using Recursive Jigsaw Reconstruction for SL tagged B->Dτν

- The technique develops physics sensitive discriminants in events with multiple missing final state particles.
- Been applied at the LHC to various searches for new physics, and studies of Higgs (H->WW->lνlν)
- We've been making the first attempts to look at how this may contribute to the semileptonic tagged measurements in Belle II – in principle it should be easier than at a proton collider, given the knowledge of the CM frame.
- We start by partitioning our events via a "decay tree" (see right) and use this as both an organising principle and a method of measuring angular and mass difference properties
- These variables can provide the added benefit of distinguishing SM from other models



Applying RJR SL tagged B->Dτν



Where "D_a" and "D_b" correspond to the X_c (D^0, $D^{\pm}$, D^{*0}, $D^{*\pm}$) system.
The "l_a" and "l_b" are the $e^{\pm}$ or $\mu^{\pm}$.

Of course, the tau decays, and will contribute additional missing momentum to the signal B.

The idea is to partition this event-by-event, using the recursion principles of the jigsaw algorithm (currently work in progress for B decays)

GAMBIT

GAMBIT: The Global And Modular BSM Inference Tool

gambit.hepforge.org

- Fast definition of new datasets and theoretical models
- Plug and play scanning, physics and likelihood packages
- Extensive model database – not just SUSY
- Extensive observable/data libraries
- Many statistical and scanning options (Bayesian & frequentist)
- *Fast* LHC likelihood calculator
- Massively parallel
- Fully open-source

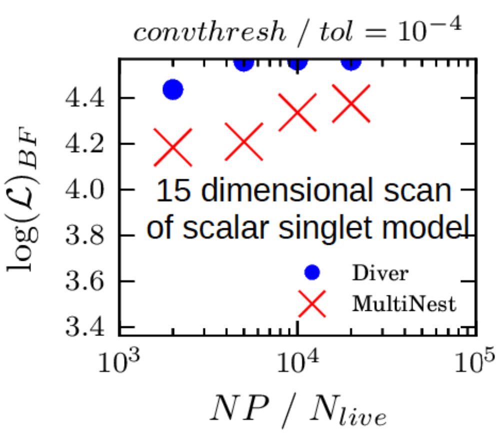
ATLAS	A. Buckley, P. Jackson, C. Rogan, M. White
LHCb	M. Chrząszcz, N. Serra
Belle-II	F. Bernlochner, P. Jackson
Fermi-LAT	J. Conrad, J. Edsjö, G. Martinez, P. Scott
CTA	C. Balázs, T. Bringmann, J. Conrad, M. White
HESS	J. Conrad
IceCube	J. Edsjö, P. Scott
XENON/DARWIN	J. Conrad, B. Farmer, R. Trotta
Theory	P. Athron, C. Balázs, T. Bringmann, J. Cornell, J. Edsjö, B. Farmer, A. Fowlie, T. Gonzalo, J. Harz, S. Hoof, F. Kahlhoefer, A. Kvellestad, F.N. Mahmoudi, J. McKay, A. Raklev, R. Ruiz, P. Scott, R. Trotta, C. Weniger, M. White, S. Wild

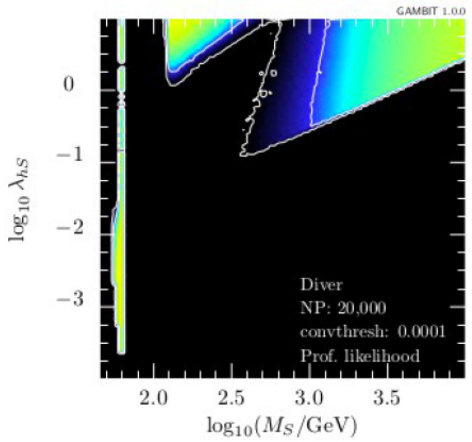
29 Members, 9 Experiments, 5 major theory codes, 11 countries

Global

- Complete global statistical fit framework
- Can be Bayesian, Frequentist or other (random, grid, etc)
- Interfaced to the best + fastest scanners available:

  Multinest, MCMC, Diver (new differential evolution scanner)

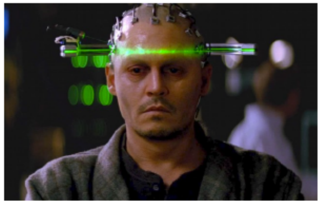




Publication ready plots available using *pippi* plotting code on the GAMBIT HDF5 output

Global and Modular

- **ColliderBit:** collider observables including Higgs + SUSY Searches from ATLAS, CMS, LEP
- **DarkBit:** dark matter observables (relic density, direct & indirect detection)
- **FlavBit:** including $g-2$, $b \to s\gamma$, B decays (new channels), angular obs., theory unc., LHCb likelihoods
- **SpecBit:** generic BSM spectrum object, providing RGE running, masses, mixings
- **DecayBit:** decay widths for all relevant SM and BSM particles
- **PrecisionBit:** precision EW tests (mostly via interface to FeynHiggs or SUSY-POPE)
- **ScannerBit:** manages stats, sampling and optimisation



THE UNIVERSITY *of* ADELAIDE

CoEPP ARC Centre of Excellence for Particle Physics at the Terascale

What's in a module?

- Module functions (actual bits of GAMBIT C++ code)
- These can depend on other module functions
- Or can they can depend on *backends*(external codes)
- Adding new things is ***easy*** (detailed manual)
- Hooking up new backends or swapping them is ***easy***
- Module functions are **tagged** according to what they can calculate $\rightarrow$ plug and play!

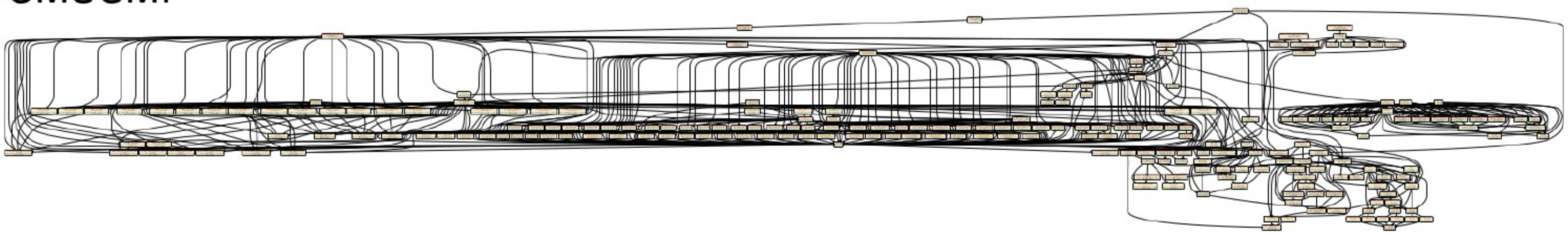
How does GAMBIT work?

- You specify what to calculate and how (yaml input file)
- GAMBIT checks to see which functions can do it
- A dependency resolver stitches things together in the right order, and calculations are also ordered by speed
- GAMBIT performs the scan and writes output
- Pippi makes the plots
- You(r student) write(s) the paper

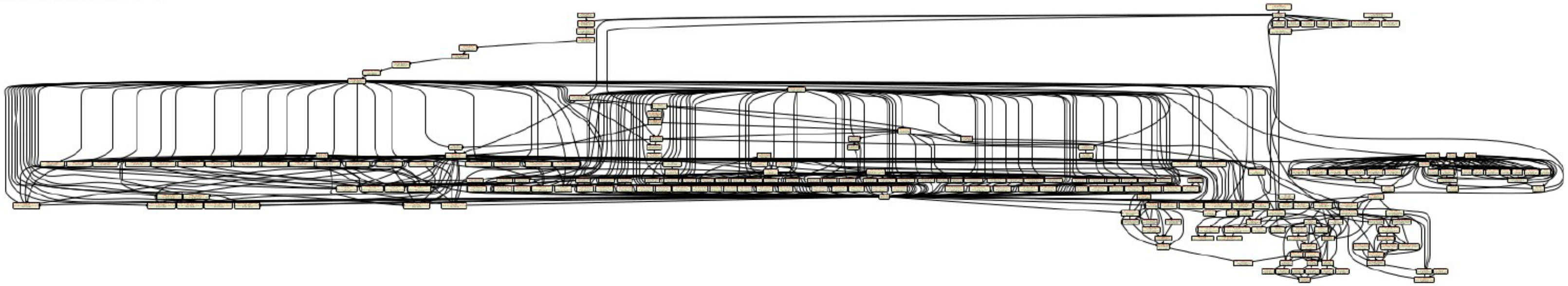
Cornell University Library
arXiv.org

Dependency resolution in action

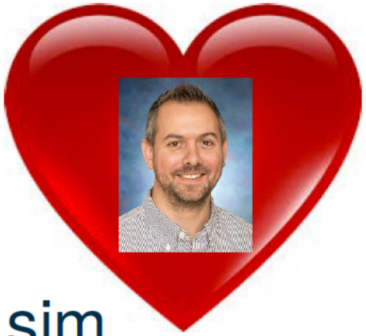
CMSSM:



MSSM7:



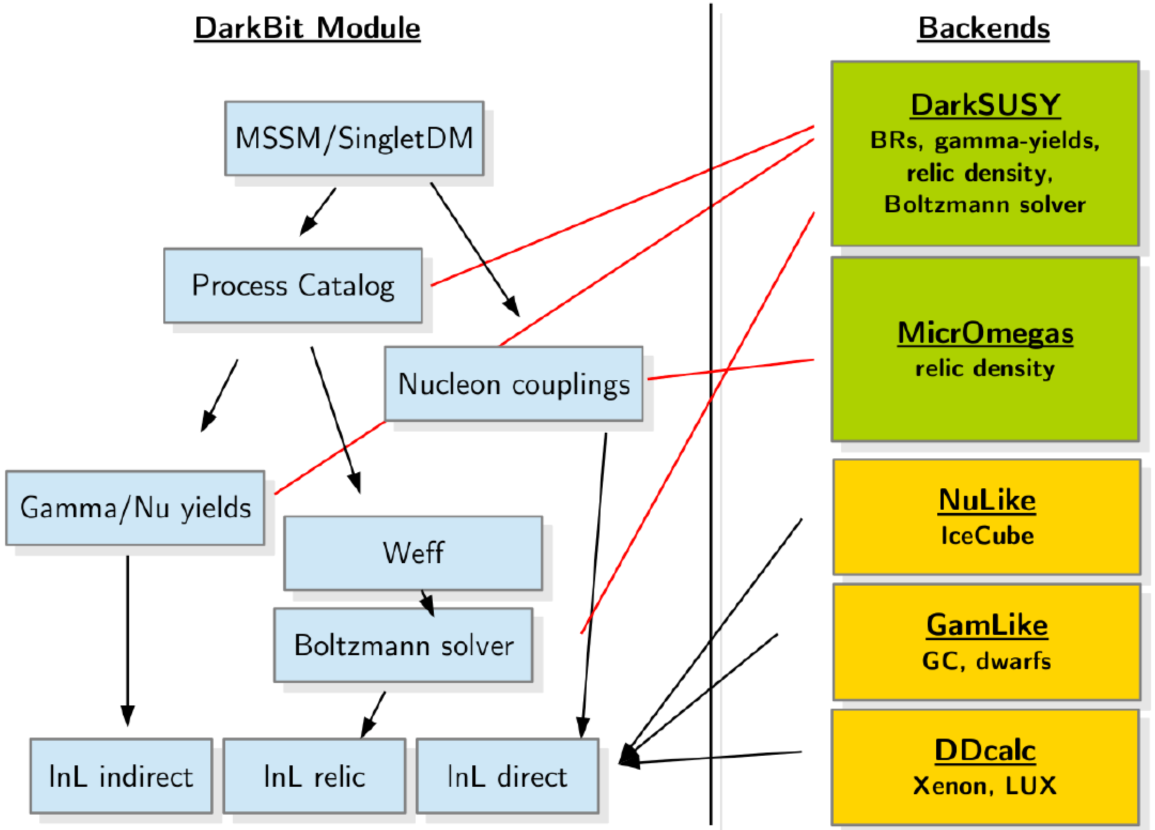
Model independent LHC limits



- Custom parallelised Pythia MC + custom detector sim
- Can generate 20,000 events on 12 cores in < 5 s
- Then apply Poisson likelihood with nuisance parameters for systematics
- Combine analyses using best expected exclusion
- The best you can do without extra public info from the experiments. CMS are getting better at this:

  https://cds.cern.ch/record/2242860/files/NOTE2017_001.pdf

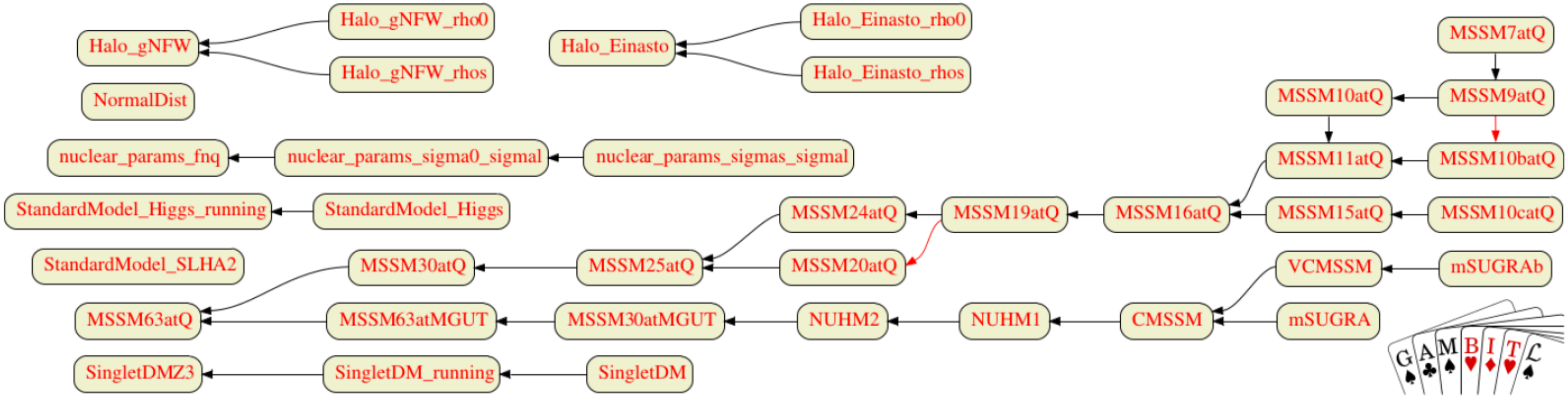
Astro limits: the GAMBIT solution



- **Event level neutrino telescope and gamma ray likelihoods!**
- **First principles treatment of direct search limits → easily extendable to non-trivial operators**
- **Very large range of experiments included (includes future, e.g. CTA)**

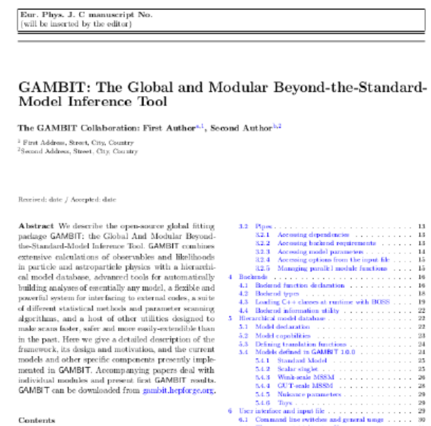
Global and Modular BSM

- Models are defined by their parameters and relations to each other
- Models can inherit from parent models, easy translation between relations
- We have so far scanned SUSY + Higgs portal + axion + two Higgs doublet models



Global and Modular BSM Inference Tool

- GAMBIT will be released next month as an ***open source public tool***


Eur. Phys. J. C manuscript No.
(will be inserted by the editor)

GAMBIT: The Global and Modular Beyond-the-Standard-Model Inference Tool

The GAMBIT Collaboration: First Author[a,1], Second Author[b,2]

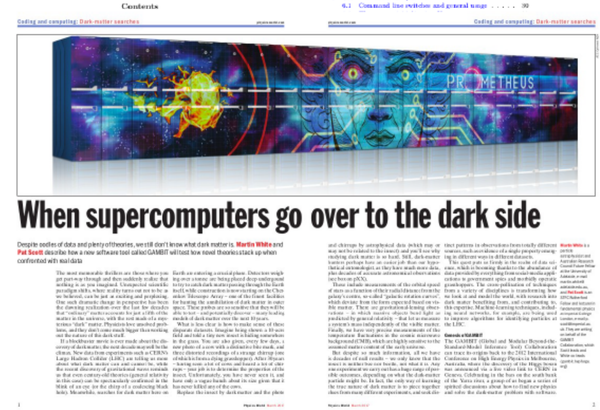
[1] First Address, Street, City, Country
[2] Second Address, Street, City, Country

Received: date / Accepted: date

Abstract We describe the open-source global fitting package GAMBIT: the Global And Modular Beyond-the-Standard-Model Inference Tool. GAMBIT combines extensive calculations of observables and likelihoods in particle and astroparticle physics with a hierarchical model database, advanced tools for automatically building analyses of essentially any model, a flexible and powerful system for interfacing to external codes, a suite of different statistical methods and parameter scanning algorithms, and a host of other utilities designed to make scans faster, safer and more easily-extendible than in the past. Here we give a detailed description of the framework, its design and motivation, and the current models and other specific components presently implemented in GAMBIT. Accompanying papers deal with individual modules and present first GAMBIT results. GAMBIT can be downloaded from gambit.hepforge.org.

Contents

- 9 papers to be published in EPJC (design, manual + first physics results) *First 6 papers already submitted!*


When supercomputers go over to the dark side

- Feature article in *Physics World* March 2017 issue if you want a gentler introduction

Talks lined up with physics working groups in collaborations.

THE UNIVERSITY *of* ADELAIDE

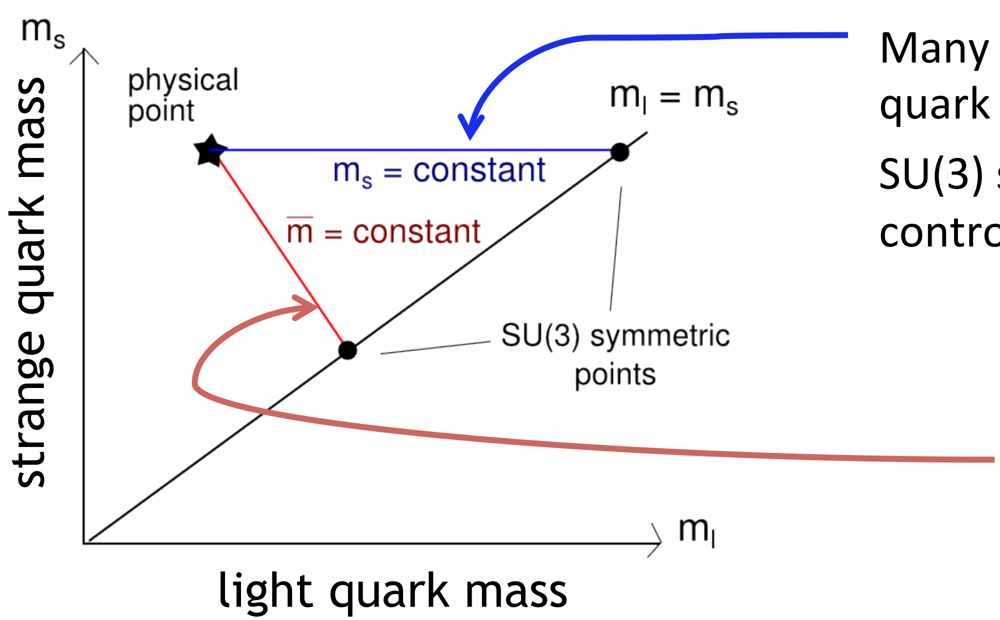
CoEPP ARC Centre of Excellence for Particle Physics at the Terascale

Lattice

- There are two main methods for generating *b*-quarks on the lattice:
  - Use anisotropic lattices
  - Use anisotropic quark actions

Work of Sophie Hollitt with Ross Young and James Zanotti

- We choose to modify the *b*-quark action, as generating new lattices is computationally expensive.
- Focus on SU(3) symmetry breaking effects on B mesons by varying the mass of the strange quark



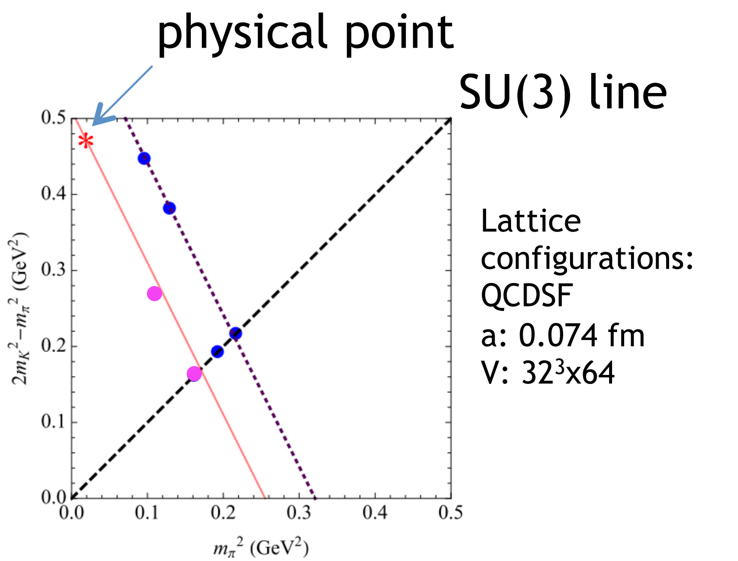
Many groups choose to keep the strange quark mass constant.

SU(3) symmetry breaking is not necessarily controlled

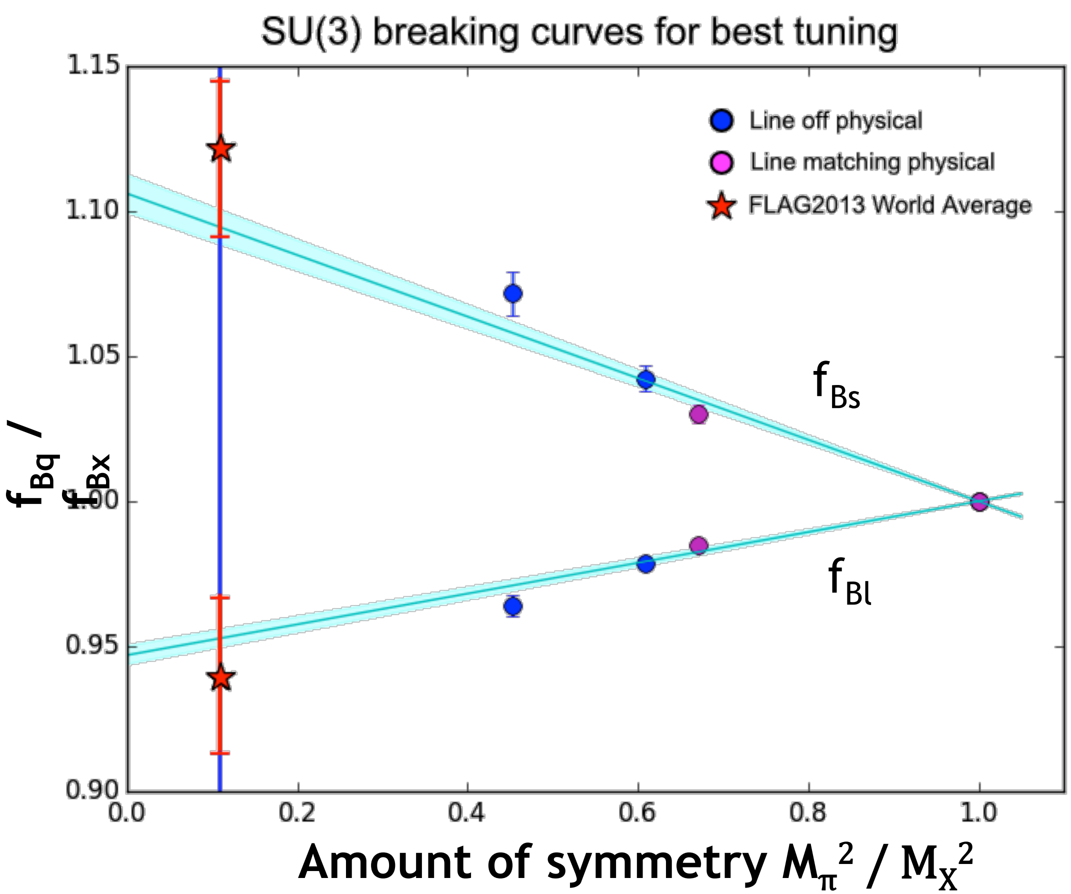
QCDSF collaboration (inc Adelaide): focus on symmetry breaking effects with constant average mass
$m = m_u + m_d + m_s$

SU(3) breaking of decay constant f_{Bq}

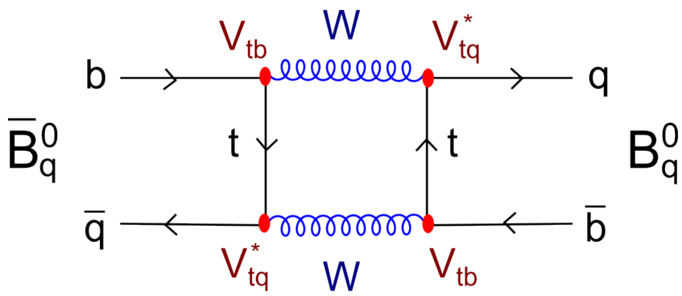
- Compare f_B and f_{Bs} to the "average" decay constant $f_{Bx} = 2f_B + f_{Bs}$ as the light and strange quark masses vary.
- Good agreement with FLAG collaboration world average: we target reduced uncertainty in calculation of f_{Bs}/f_B



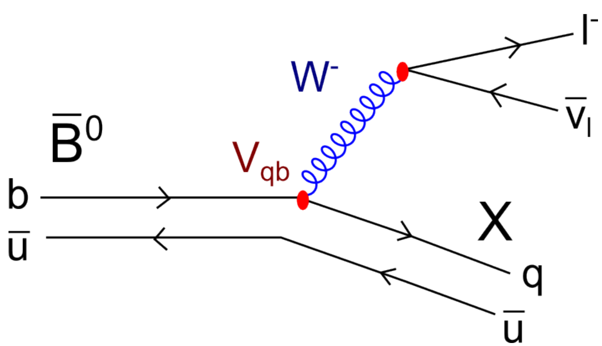
Lattice configurations:
QCDSF
a: 0.074 fm
V: 32^3x64



- In the short term:
  - Continue collecting lattice measurements of f_B and f_{Bs} for different lattice spacings and lattice sizes to quantify systematic uncertainty

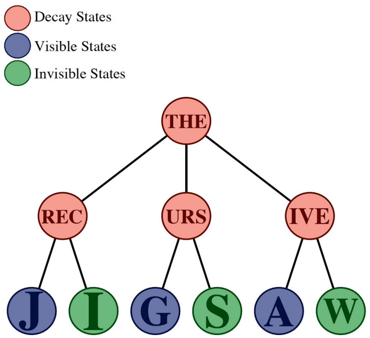


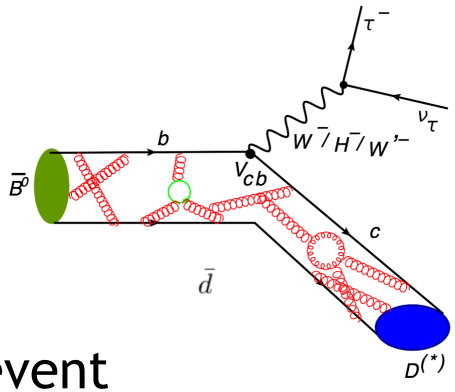
- In the long term:
  - Use this framework for generating b-quarks/B mesons to investigate other B-physics observables
  - Current target: form factors of weak B meson decays
  - Suggestions or ideas welcome!



Summary

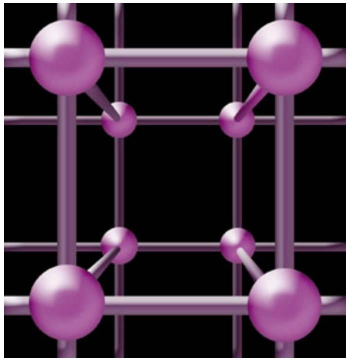
Summary





We have ongoing studies of:

- kinematics variables for event reconstruction methods
- global fitting tool - GAMBIT
- Lattice QCD



That all have some relation to our interest in semitauonic B-decays

Thanks! Some backup slides may follow

p.jackson@adelaide.edu.au

There’s nothing useful written in this box

RJR technique – compressed decays

from M. Santoni

- **Consider the worst scenario: final states with only light jets and MET**

- We want to **separate** the jets between the visible system (**V**) and those recoiling against it (**ISR**)

- *Transverse* view of the event $(\vec{P}_z\,(jet_i) = 0)$

- Zero mass for **I** system

- $\vec{P}_T(\mathrm{CM}) = \vec{\not{E}}_T + \sum_i \vec{P}_T\,(jet_i)$

  Boost in the *estimated* **CM** frame

- Combinatoric jigsaw rule based on the minimization of the masses

  In CM frame $M_{\mathrm{CM}} = \sqrt{M_{\mathrm{ISR}} + p^2} + \sqrt{M_{\mathrm{S}} + p^2}$

  Equivalent to maximize p or find the thrust axis in the CM frame