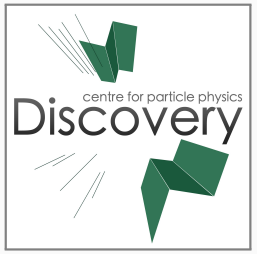
Rivet for Heavy Ions

features and prospects for EIC

Christian Bierlich, bierlich@thep.lu.se
University of Copenhagen
Lund University

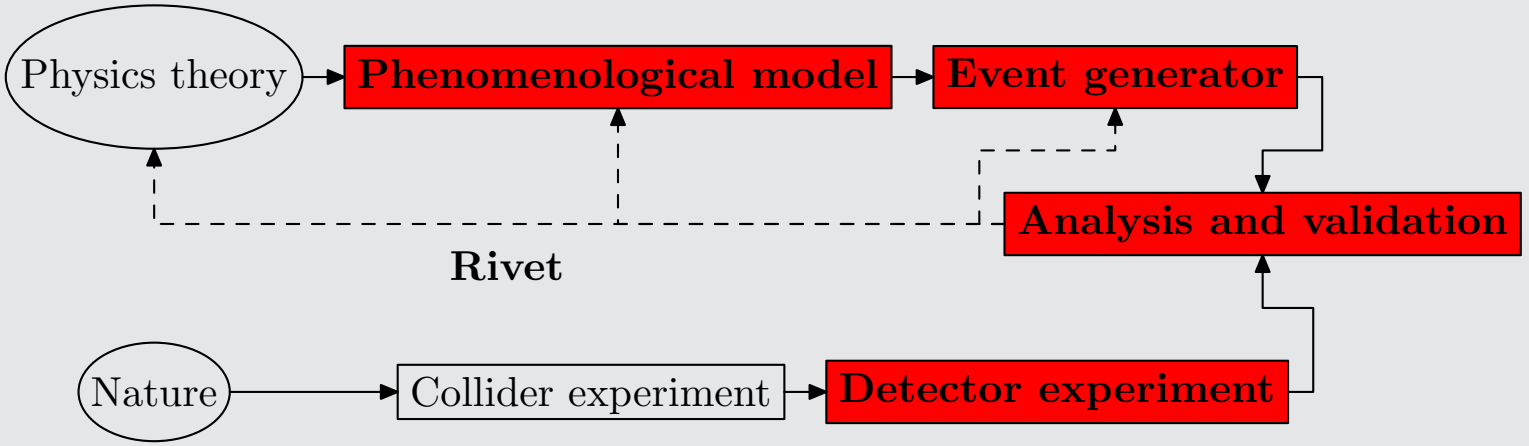
November 22 2019, MCEG for EIC, Vienna



Rivet

- Analysis system for Monte Carlo events. (Buckley *et. al.*: arXiv:1003.0694.)
  1. Data preservation.
  2. Monte Carlo validation.
- Generator independent, HepMC events.
- C++ library with analyses as "plugins", optimally written by the analyser.

The biggger picture



LHC Coverage

- Main LHC pp and LEP analyses.
- Standard tool @ LHC, fair coverage...

Rivet analysis coverage

Rivet analyses exist for 418/5667 papers = 7%. 176 priority analyses required.

Total number of Inspire papers scanned = 7216, at 2019-11-16

Breakdown by identified experiment (in development):

Key	ALICE	ATLAS	CMS	LHCb	B-factories	HERA	LEP	Other
Rivet wanted (total):	197	258	351	160	1391	445	1393	1054
Rivet REALLY wanted:	35	37	71	9	3	13	7	1
Rivet provided:	**23/220 = 10%**	**156/414 = 38%**	**80/431 = 19%**	**12/172 = 7%**	**59/1450 = 4%**	**9/454 = 2%**	**60/1453 = 4%**	**19/1073 = 2%**

LHC Coverage

- Main LHC pp and LEP analyses.
- Standard tool @ LHC, fair coverage...
- ...but not for heavy ions! (http://rivet.hepforge.org)

Rivet analysis coverage (heavy ion only)

Rivet analyses exist for 15/570 papers = 3%. 30 priority analyses required.

Total number of Inspire papers scanned = 617, at 2019-11-16

Breakdown by identified experiment (in development):

Key	ALICE	ATLAS	CMS	LHCb	B-factories	HERA	LEP	Other
Rivet wanted (total):	146	41	72	6	0	0	1	289
Rivet REALLY wanted:	19	1	10	0	0	0	0	0
Rivet provided:	**10/156 = 6%**	**2/43 = 5%**	**0/72 = 0%**	**0/6 = 0%**	**0**	**0**	**0/1 = 0%**	**3/292 = 1%**

Why no heavy ions?

- Heavy Ions have not been prioritized.
  - Lack of common interest (few MCs for HI).
  - Lack of specialized functionality $\rightarrow$ High threshold.

Why no heavy ions?

- Heavy Ions have not been prioritized.
  - Lack of common interest (few MCs for HI).
  - Lack of specialized functionality $\rightarrow$ High threshold.

That has changed!

- ◇ Joined effort by LHC experimentalists and MC authors.
- ◇ Features from v. 2.7.0, more polished in the 3.X series
- ◇ Dedicated paper, est. ultimo 2019.

Relevance for EIC?

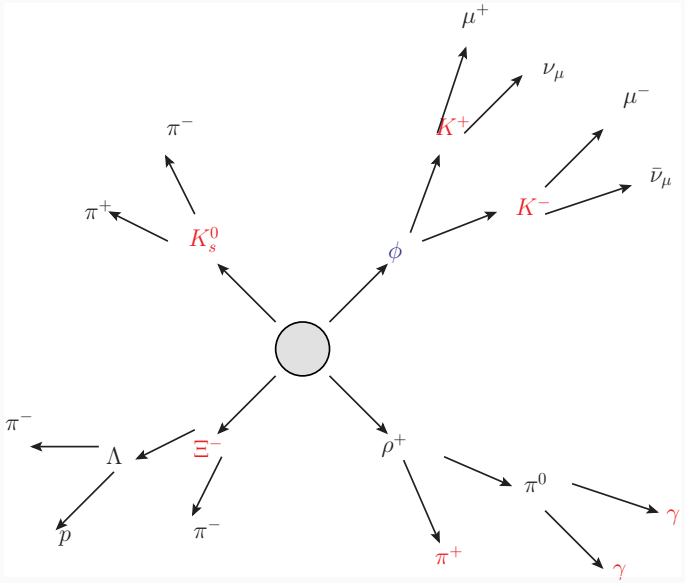
- No data to preserve... yet!
- But!
  1. Older datasets and analyses needs implementation for MC tuning.
  2. Rivet can work as "communication tool" for MCEGs.
  3. Experiments can easily communicate desired predictions.
  4. For data preservation, best to get in on the ground floor.
- What we need: A strong message from MCEG community that this is our preferred collaboration tool!

The rest of this talk

1. Technical additions:
   - 1.1 Experimental particle definitions.
   - 1.2 Re-entrant finalize.
   - 1.3 Analysis options.
   - 1.4 Event mixing.
2. Physics motivated additions:
   - 2.1 Centrality selection.
   - 2.2 Flow observables.
3. Open discussion: What is needed for EIC?

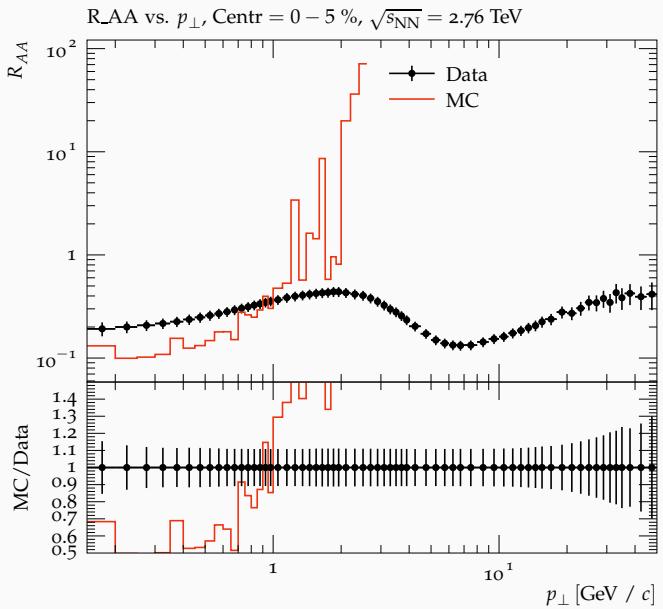
Experimental particle definitions

- The projection system includes standard tools.
- ...but correct decay corrections a larger problem for soft QCD/HI analyses.
- Easier to implement with `PrimaryParticles` projection – just provide a list.



- Example: `ALICE::PrimaryParticles`.

Re-entrant finalize: `rivet-merge`



1. Read in histogram files, and re-generate analysis objects.
2. Run `void finalize()` again.
3. Enables statistically correct merging of difficult objects (ratios, scatters, ...).
4. Merge different physics runs to a single figure (AA/pp ratios, $\sqrt{s}$ dependance, ...)

Analysis options

- Implant option (number, selection, ...) in analysis code at run-time.
- More flexible analyses, versatile code can be re-used.

Analysis options

- Implant option (number, selection, ...) in analysis code at run-time.
- More flexible analyses, versatile code can be re-used.

```
1          // A double.
2          double f = getOption<double>("foo", 1.0);
3          // A string.
4          string s = getOption<string>("bar", "");
5          // A custom object.
6          A a = getOption<A>("baz", A());
7          cout << "foo = " << f << endl;
8          cout << "bar = " << s << endl;
9          cout << "baz = " << a << endl;
```

- Use:

  `rivet events.hempc -a AnalysisName:foo=1:bar=a:baz=42`.

Event mixing

- Correlation analyses important for soft/collective physics.
- Experimental corrections for limited *pair acceptance* involves event mixing.

$$S(\Delta p_1, \Delta p_2, ..., \Delta p_n) = \frac{1}{N_{\mathrm{trig}}} \frac{d^n N}{\mathrm{d}\Delta p_1 \mathrm{d}\Delta p_2 ... \mathrm{d}\Delta p_n}.$$

$$B(\Delta p_1, \Delta p_2, ..., \Delta p_n) = \frac{1}{N_{\mathrm{trig}}} \frac{\mathrm{d}^n N^{\mathrm{mixed}}}{\mathrm{d}\Delta p_1 \mathrm{d}\Delta p_2 ... \mathrm{d}\Delta p_n}.$$

$$C(\Delta p_1, \Delta p_2, ..., \Delta p_n) = B(0, 0, ..., 0) \frac{S(\Delta p_1, \Delta p_2, ..., \Delta p_n)}{B(\Delta p_1, \Delta p_2, ..., \Delta p_n)}.$$

- Dedicated projection for mixed final states. Cache of previously generated events.
- Correct handling of weighted events.

Centrality selection

- Centrality is ubiquitous, but not directly measurable.
- Experiment: Forward particle production/energy flow as proxy. Cannot always be unfolded.
- MC: Not always feasible to fold prediction with "forward central" correlation.

Centrality selection

- Centrality is ubiquitous, but not directly measurable.
- Experiment: Forward particle production/energy flow as proxy. Cannot always be unfolded.
- MC: Not always feasible to fold prediction with "forward central" correlation.

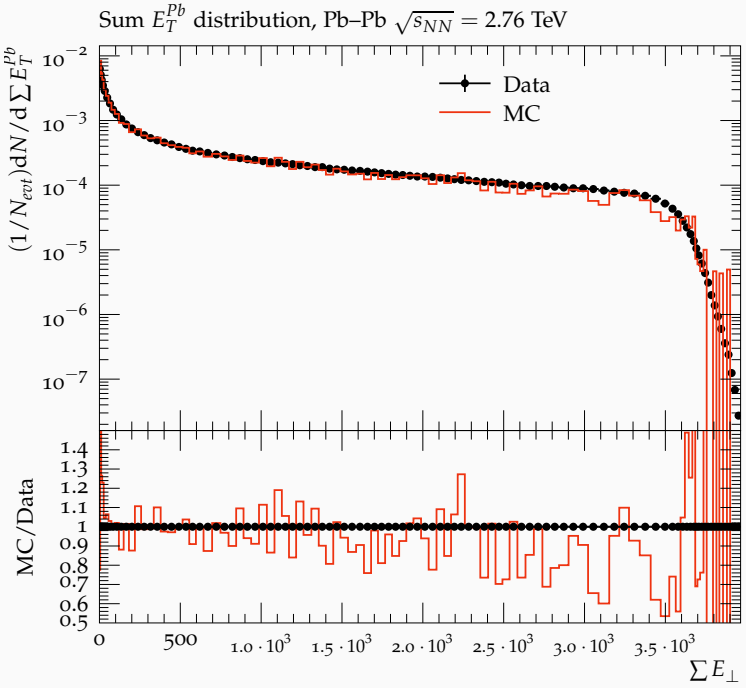
Solution: Users' choice between several options

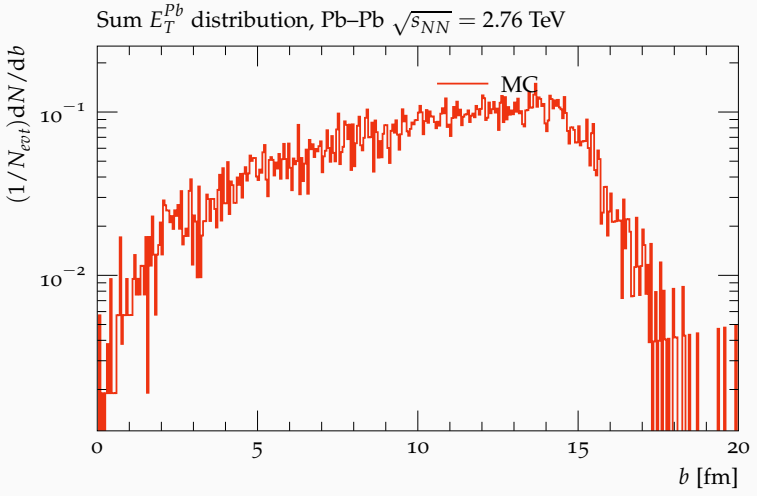
1. Experimental measure (if existing).
2. Generated version of experimental measure.
3. Impact parameter distribution.
4. MC supplies centrality number.

- Three latter requires a "calibration run".

Centrality selection, calibration

- Example calibration: `ATLAS_PBPB_CENTRALITY`.
- (data points extracted from paper, not unfolded).

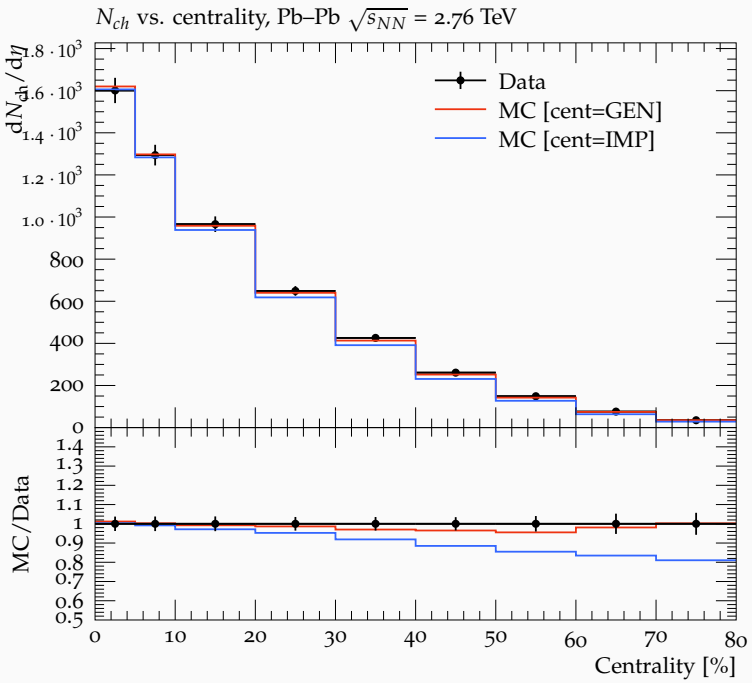


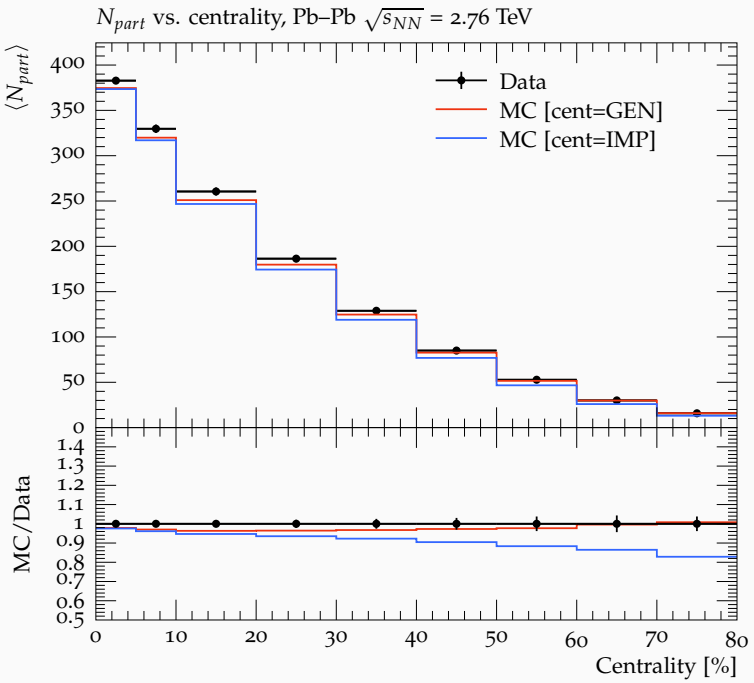


- Generated histograms are preloaded into Rivet: new `preload` option.

Centrality and Rivet options

- Run the same analysis, with different options.
- Example: `ALICE_2010_I880049`





Flow observables

- Key heavy ion observables:

$$E\frac{\mathrm{d}^3N}{\mathrm{d}^3p} = \frac{1}{2\pi}\frac{\mathrm{d}^2N}{p_\perp \mathrm{d}p_\perp \mathrm{d}y}\left(1 + 2\sum_{n=1}^{\infty} v_n \cos([n(\phi - \Psi_n)])\right).$$

- Naively, but cumbersome:

$$\langle v_n^2 \rangle \approx \langle \cos(n(\phi_1 - \phi_2)))\rangle = \langle \exp(in(\phi_1 - \phi_2))\rangle$$

- Rewrite with $Q_n = \sum_{k=1}^{M} w_k \exp(in\phi_k)$, it turns out that all harmonics to all orders can be rewritten like this, eg.

$$\langle 2 \rangle_n = \frac{|Q_n|^2 - M}{M(M-1)}.$$

- Non-flow reduced by increasing orders, or requiring event gaps.

Flow observables – generic framework implementation

- Generic framework (the flow equivalent of FastJet!) and add-ons implemented. (1010.0233, 1312.4572).
- Functionality, calculate any $\langle\langle M \rangle\rangle_{m,n}$.
- Automatic subtraction of lower orders and error calculation.

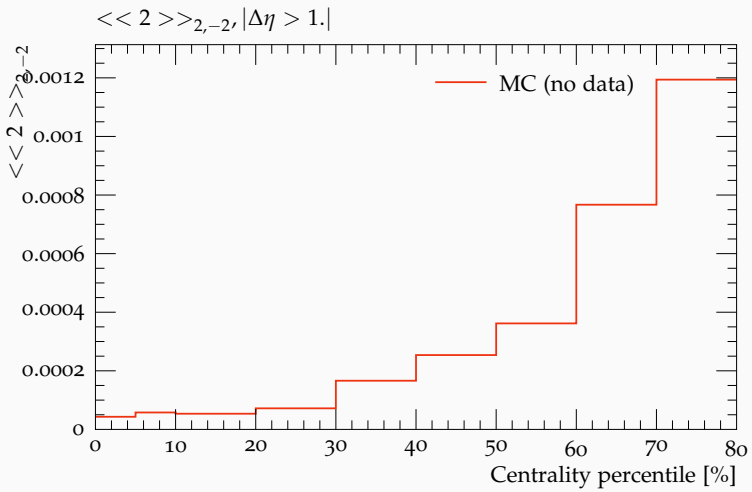
Flow observables – generic framework implementation

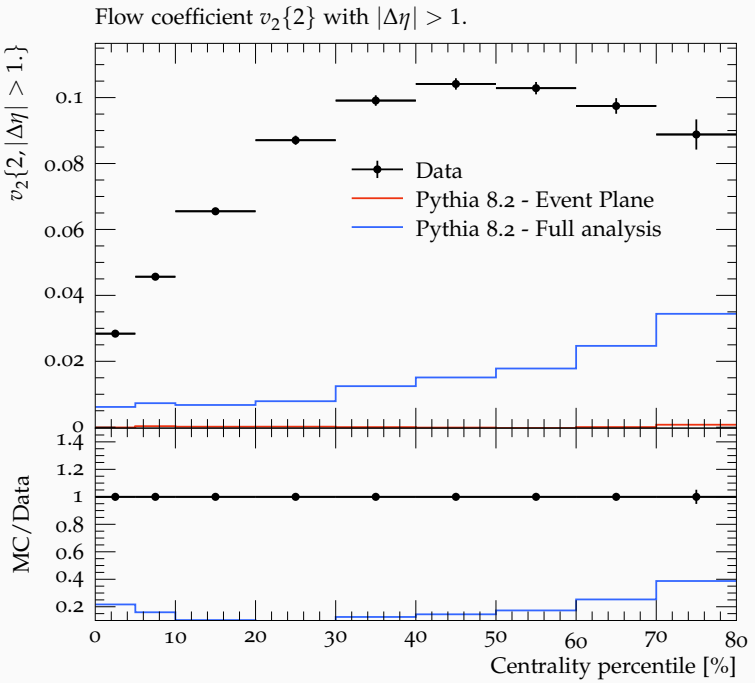
- Generic framework (the flow equivalent of FastJet!) and add-ons implemented. (1010.0233, 1312.4572).
- Functionality, calculate any $\langle\langle M \rangle\rangle_{m,n}$.
- Automatic subtraction of lower orders and error calculation.

```
1        hc24 = bookScatter2D("c24",120,0,120);
2        ec22 = bookECorrelator<2,2>("ec22",hc22);
3        ec24 = bookECorrelator<2,4>("ec24",hc24);
4        ...
5        ec22->fill(...);
6        ec24->fill(...);
7        ...
8        // c_n{4} = <<4>>_{n,-n} - 2 * <<2>>_{n,-n}
9        cnFourInt(hc24, ec22, ec24);
```

Sample results

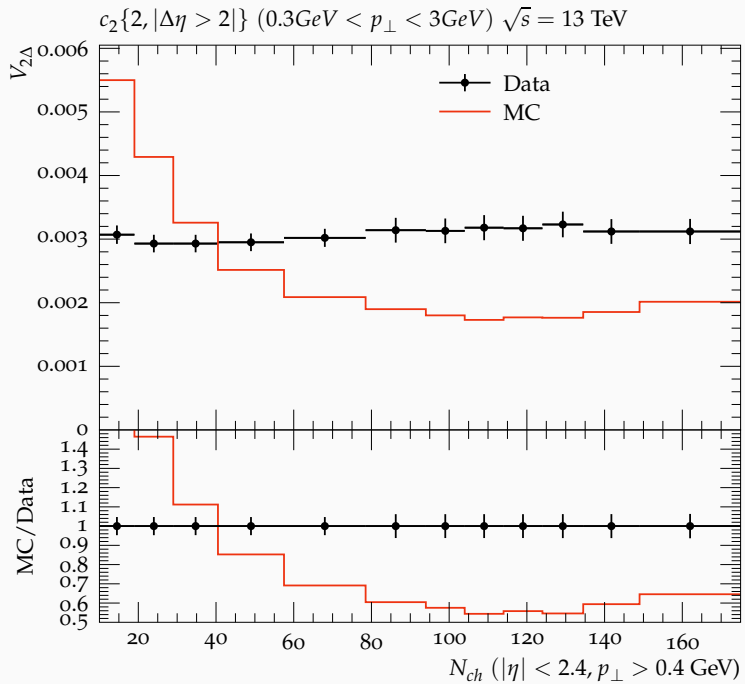
- Some HI analyses implemented, here: `ALICE_2016_I1419244`.
- Correlators and cumulants can be plotted, also without data.

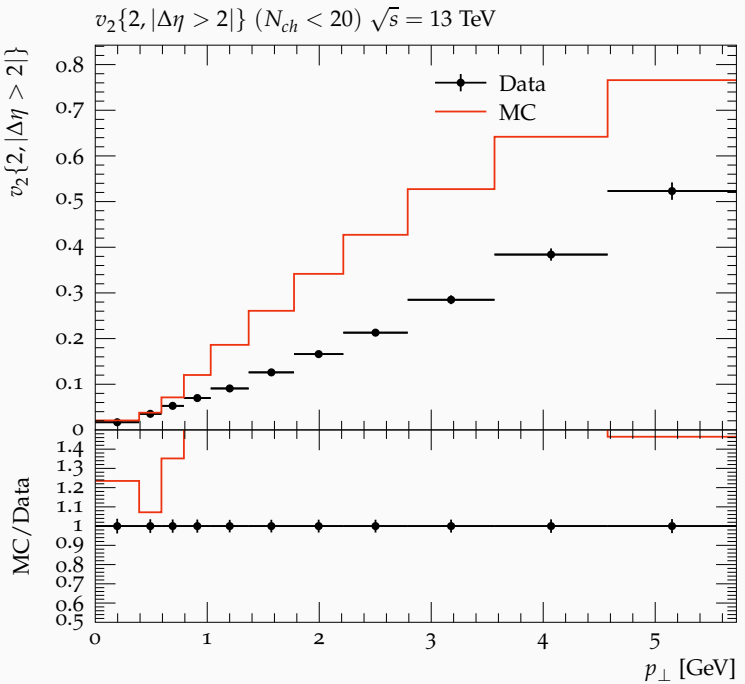




HI methods in pp (CMS: Evidence for collectivity in pp collisions at the LHC)

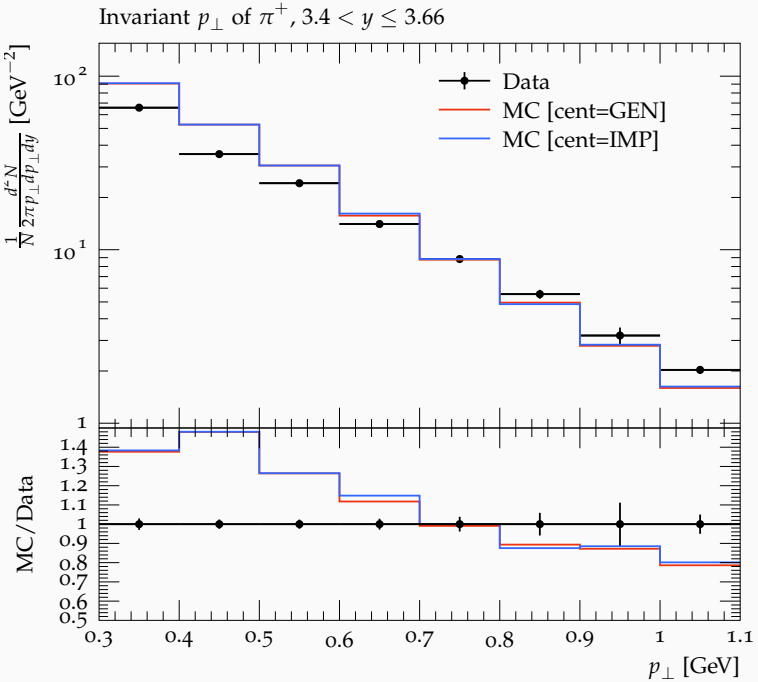
- Heavy ion methods also available for pp analyses.
- Allows for new types pp analyses in Rivet.
- Example: `CMS_2017_I1471287`.

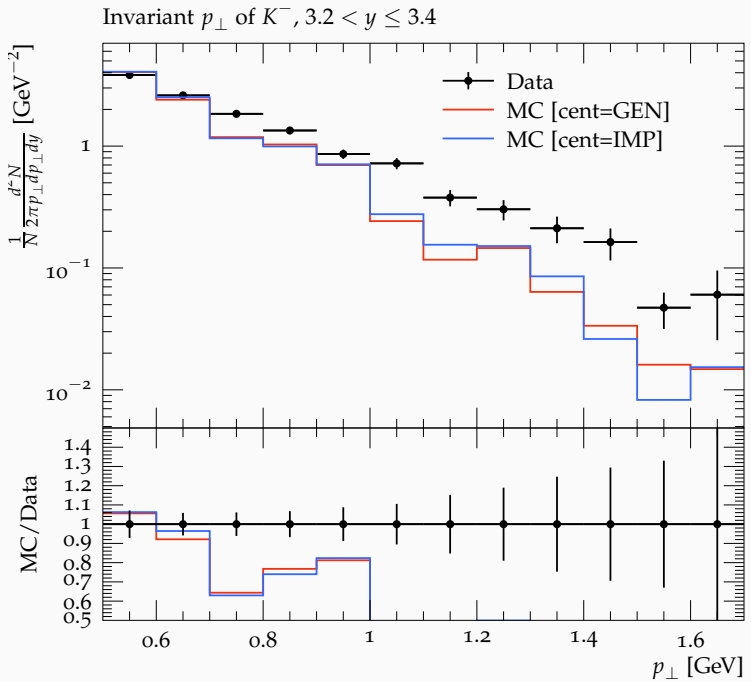




Data preservation, older experiments

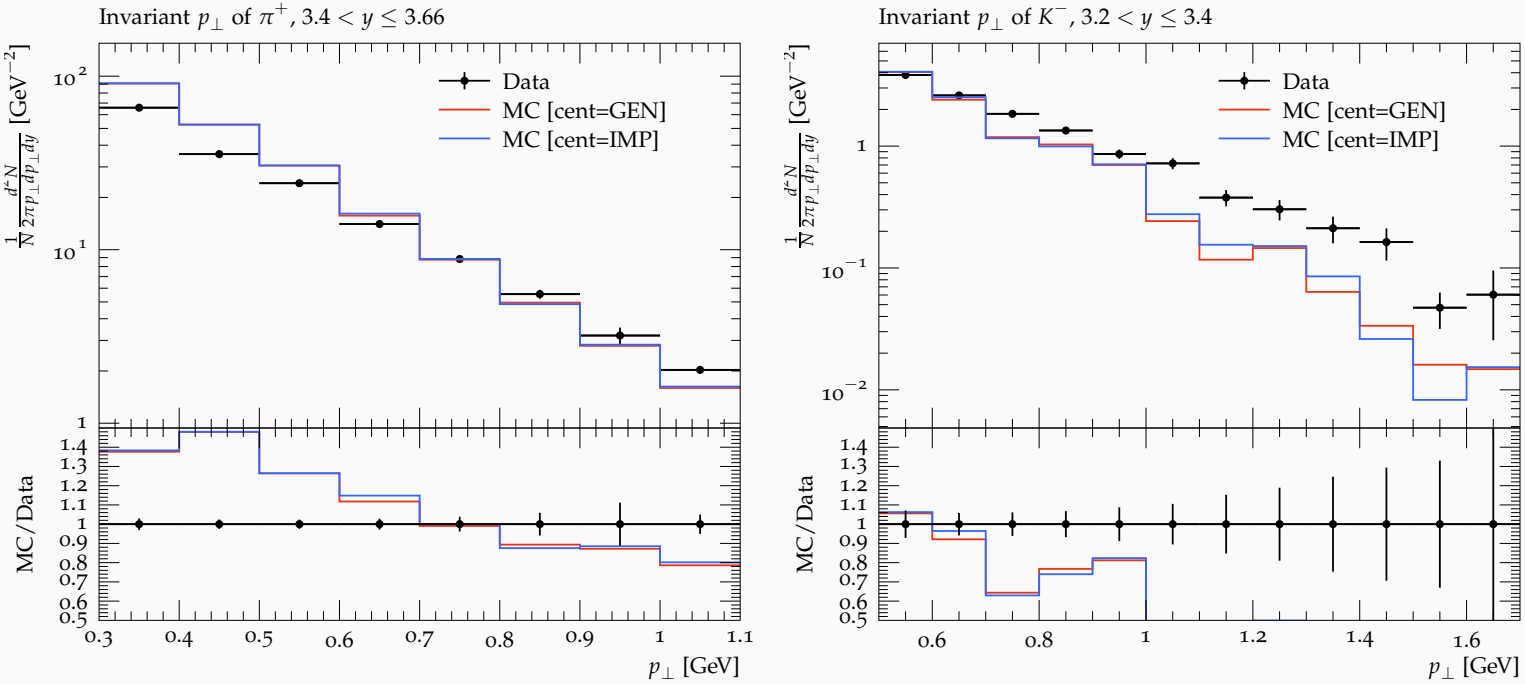
- Older data still exist – but not forever!
- Example: `BRAHMS_2004_I647076`





Data preservation, older experiments

- Older data still exist – but not forever!
- Example: `BRAHMS_2004_I647076`



WANTED: Other collaborations!

Ongoing work with STAR members.

Discussion ongoing with GSI.

Several NA-XX results implemented.

Discussion

- Several technical and physics motivated additions for HI physics.

  1) Experimental particle definitions, 2) Re-entrant finalize, 3) Analysis options 4) Event mixing, 5) Centrality selection, 5) Flow observables.
- Way forward for EIC?
  1. Wanted feedback: Features missing? wanted?
  2. More analyses: LHC, RHIC, HADES, other? how? who?
  3. Other venues – νA (CCFR, νTeV, other?), interest? how? who?
  4. Other venues – Very forward production, LHCb velo?, Cosmics (Auger? Other?), interest, how? who?
  5. More compatible generators? (PHSD, SMASH in contact), $>$400 analyses strong selling point, others?
  6. Other comments?