SCOPES activities
Detector, algorithms and analysis

Ferenc Siklér
Wigner RCP, Budapest

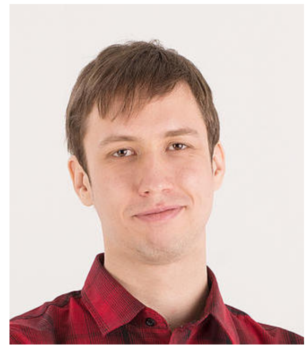
SCOPES 152601

SCOPES Annual Meeting
ETH Zürich, Apr 28, 2017

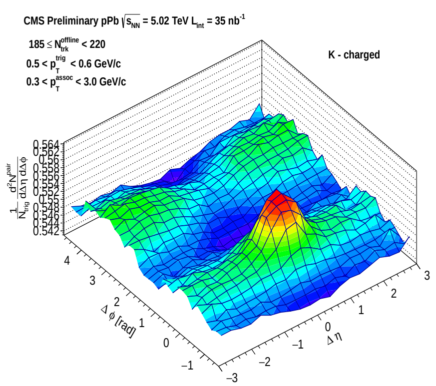
The Budapest group (Wigner RCP) now

Ferenc Siklér
DSc, group leader
new methods, particle spectra and correlations

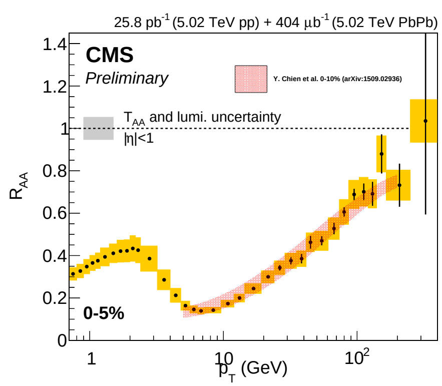
Viktor Veszprémi
PhD, group leader
new pixel detector, calibrations



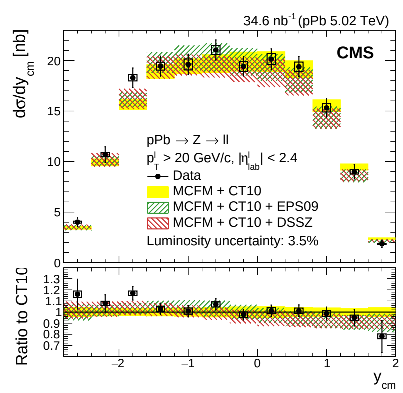
Olivér Surányi
PhD student at Eötös U
exclusive production, ZDC analysis
$\rightarrow$ stays @ Budapest



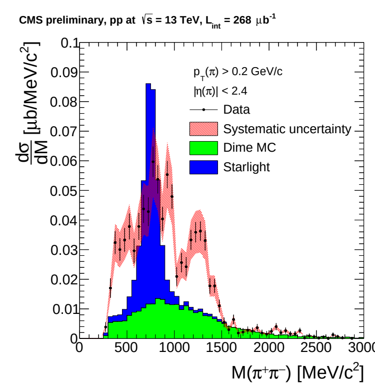
CMS PAS HIN-15-007



CMS PAS HIN-15-015



CMS PAS HIN-15-002



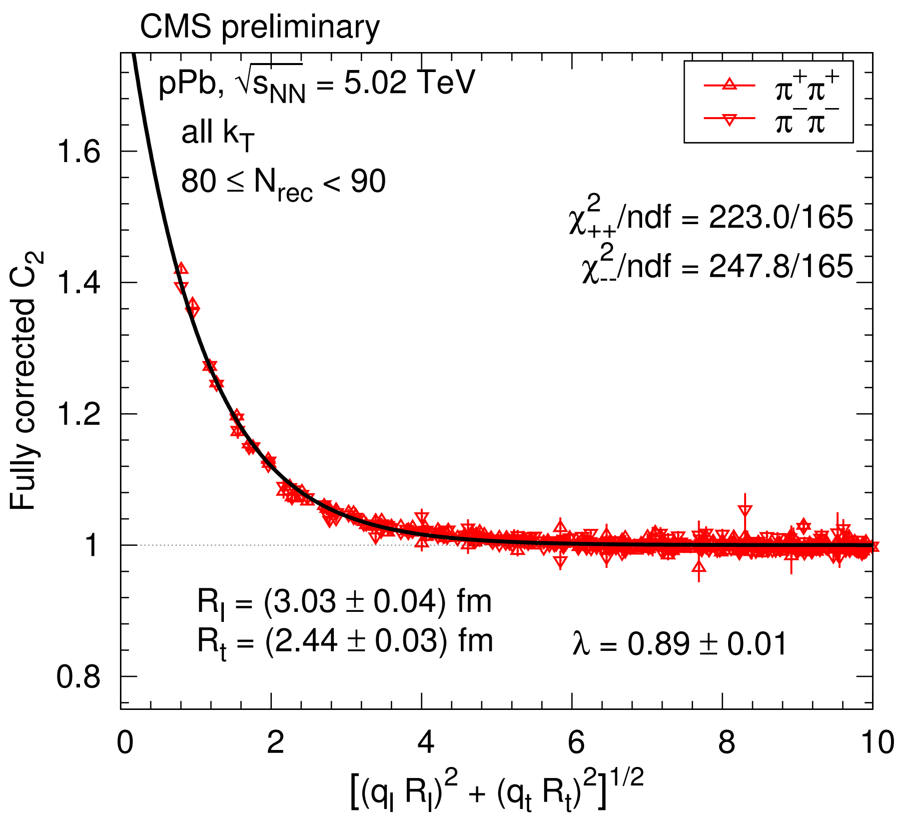
CMS AN-2015/288

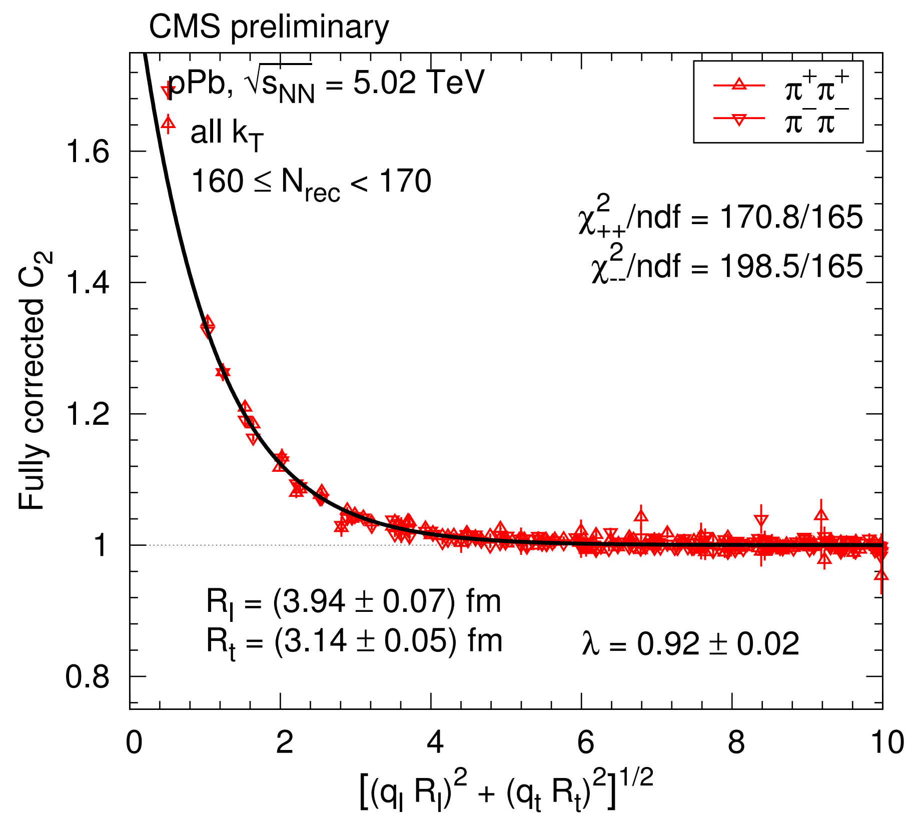
The Budapest group (Wigner RCP)

- Contents – activities in the past year
  - **Quantum correlations of identified hadrons (Ferenc)**
    FSQ-14-002, paper in CWR ($\rightarrow$ PRC)
  - **Spectra of identified hadrons from pp at 13 TeV (Ferenc)**
    FSQ-16-004, paper in FR ($\rightarrow$ PRD), abstract to EPS HEP
  - **Installation and operation of the new pixel detector (Viktor)**
    some selected plots
  - **New tracking algos for very high multiplicity events (Ferenc)**
    CTD/WIT17 talk and proceedings, paper draft ($\rightarrow$ EPJA)
  - **Exclusive production in pp (Olivér)**
    FSQ-16-006, pre-approved
  - **Participation in p-Pb data taking (Olivér)**
    calibration of the zero degree calorimeter, physics with neutrons

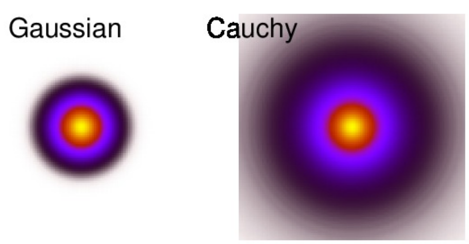
The last two topics will be shown in Olivér's talk

Quantum correlations (FSQ-14-002)





$$C_{2,\mathrm{BE}}(q_l, q_o, q_s) = 1 + \lambda \exp\left[-\sqrt{(q_l R_l)^2 + (q_o R_o)^2 + (q_s R_s)^2}\right]$$

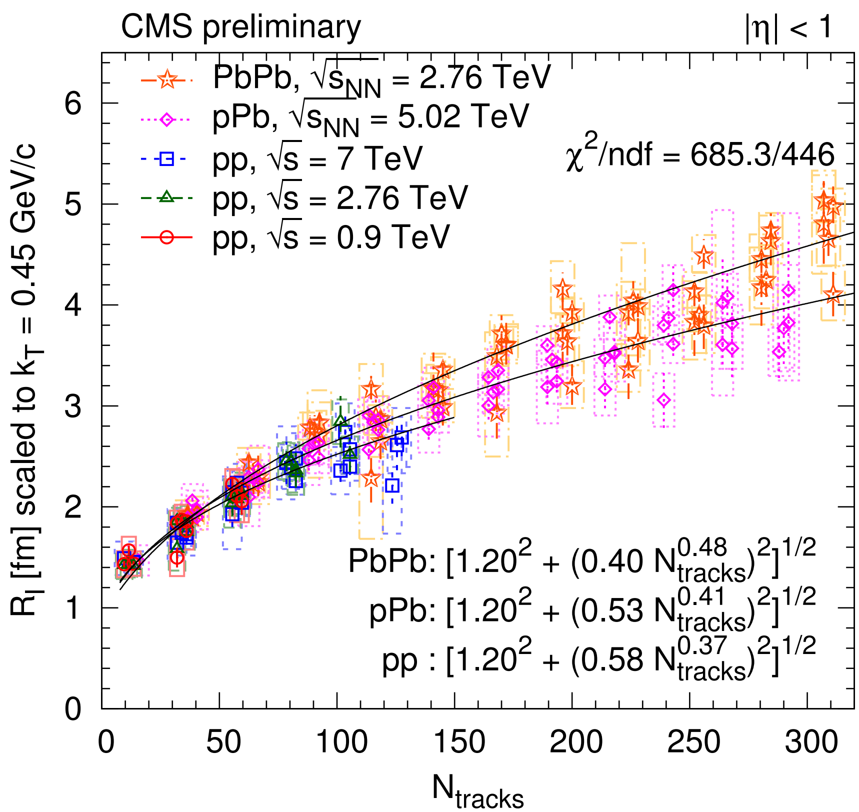


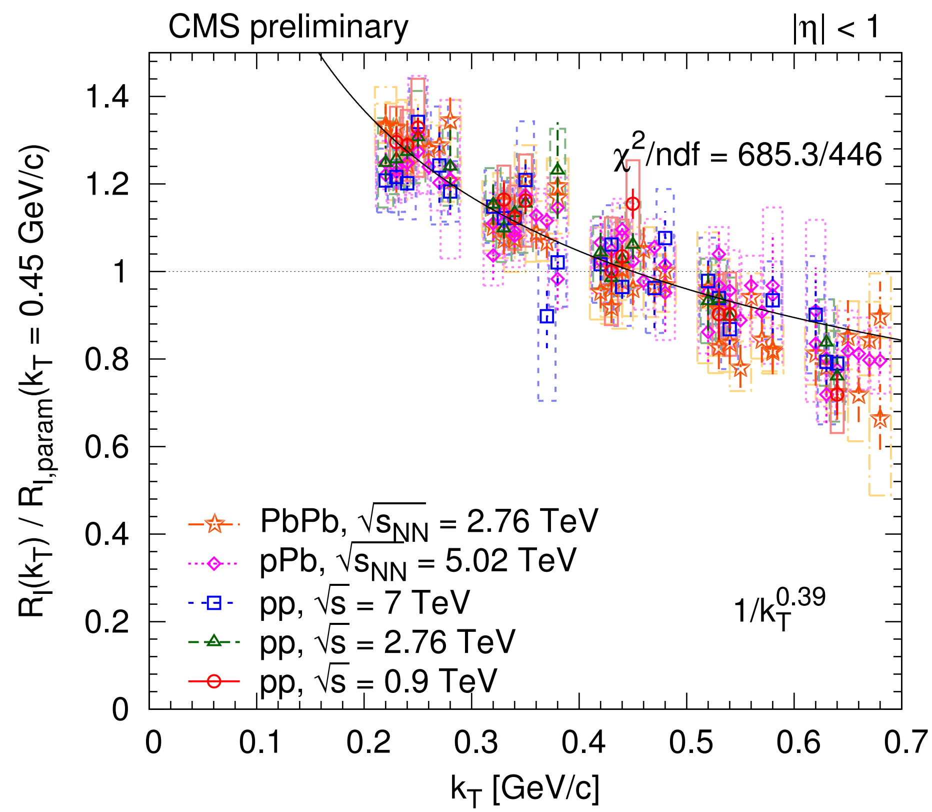
Exponential parametrisation, Cauchy-type source

Dimensions depend on multiplicity

Critical hadron density – last collisions

Quantum correlations (FSQ-14-002)

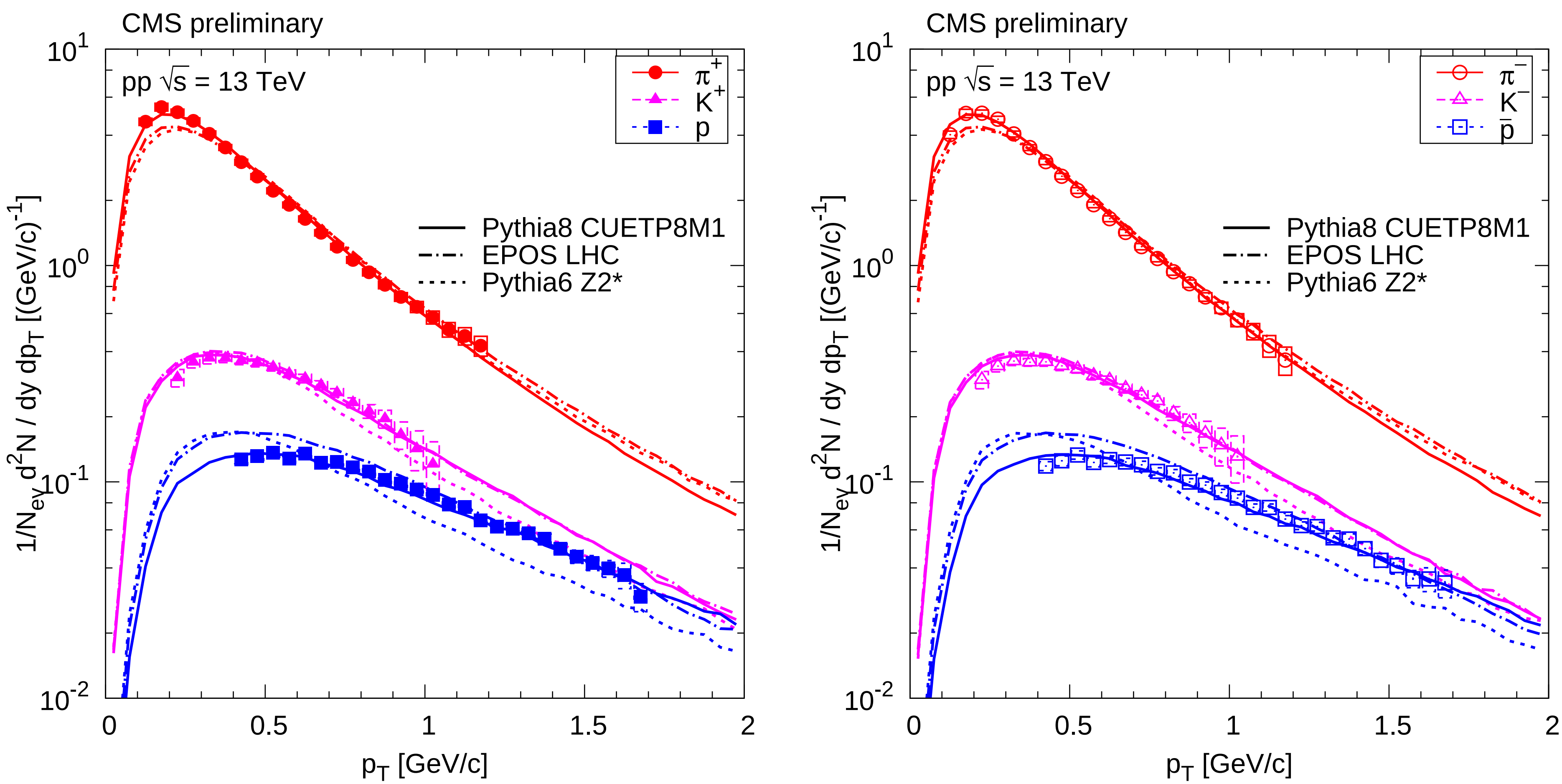




Took a lot of time to harmonize two analyses, delays

ARC agreed to go to CWR, the target is PRC (53 pages)

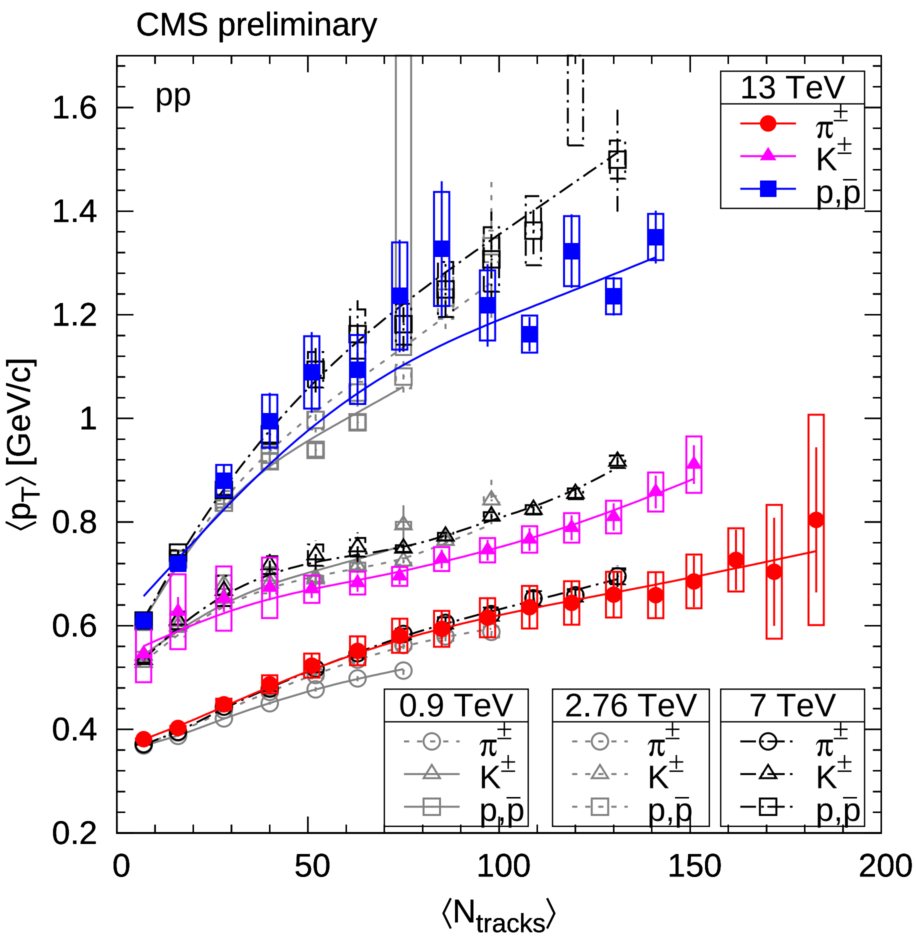
PID spectra (FSQ-16-004)

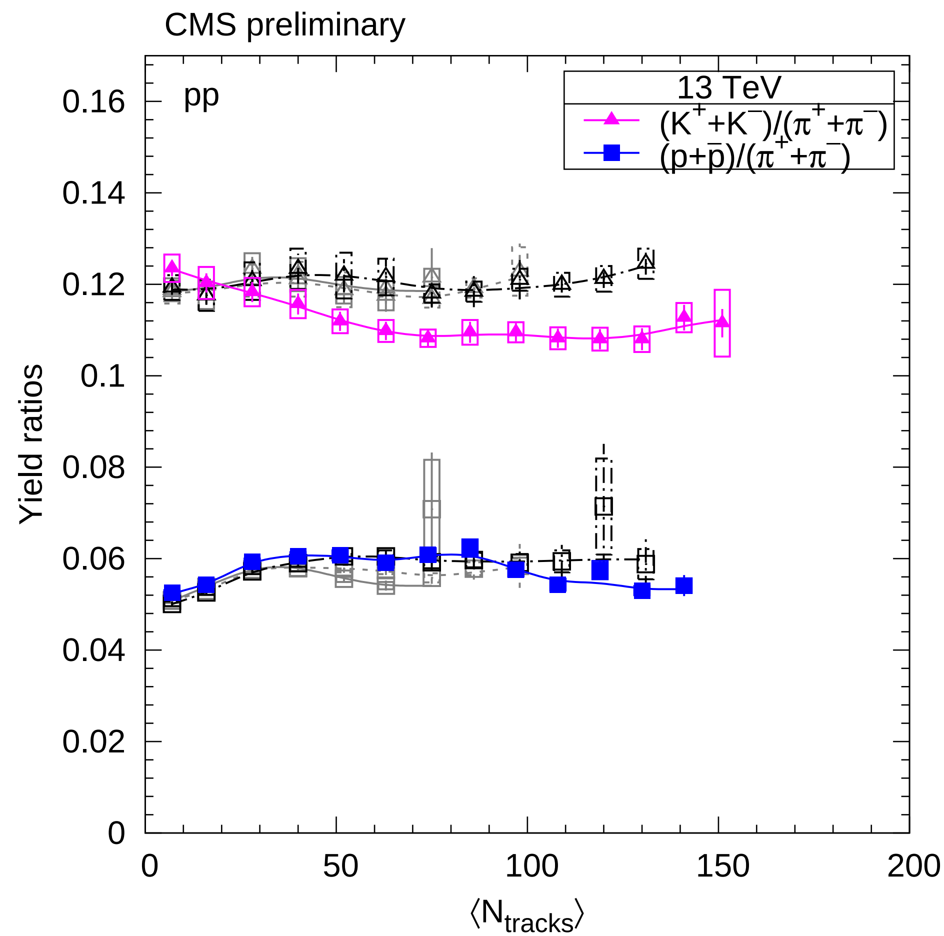


Logarithmic scale

Reasonable job from generators, but Pythia8 CUETP8M1 is by far the best

PID spectra (FSQ-16-004)





What primarily matters is the number of produced particles

Resonates with recent ALICE hype

After several iterations with the ARC, the paper is in FR next week

CMS PAPER FSQ-16-004

DRAFT
CMS Paper

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2017/04/13
Head Id: 399055
Archive Id: 399055P
Archive Date: 2017/04/13
Archive Tag: trunk

Measurements of the production of charged pions, kaons, and protons in proton-proton collisions at $\sqrt{s} = 13$ TeV

The CMS Collaboration

Abstract

Transverse momentum spectra of identified charged hadrons are measured in proton-proton (pp) collisions at $\sqrt{s}$ = 13 TeV with the CMS detector at the LHC. Charged pions, kaons, and protons in the transverse-momentum range $p_T \approx$ 0.1–1.7 GeV/c and for laboratory rapidities $|y| < 1$ are identified via their energy loss in the CMS silicon tracker. The p_T spectra and integrated yields are compared to lower center-of-mass energy pp results and to Monte Carlo simulations. The average p_T increases with particle mass and the charged-particle multiplicity of the event. A comparison with previously published CMS results shows only a moderate dependence of the average p_T on the center-of-mass energy.

This box is only visible in draft mode. Please make sure the values below make sense.

PDFAuthor:	Ferenc Sikler
PDFTitle:	Study of the production of charged pions, kaons, and protons in pp collisions at sqrts = 13 TeV
PDFSubject:	CMS
PDFKeywords:	CMS, physics, energy loss, hadron spectra

Please also verify that the abstract does not use any user defined symbols

Paper draft in FR

CMS PAPER FSQ-14-002

DRAFT
CMS Paper

The content of this note is intended for CMS internal use and distribution only

2017/04/21
Head Id: 397396
Archive Id: 400266P
Archive Date: 2017/04/03
Archive Tag: trunk

Bose-Einstein correlation results for pp, pPb, and PbPb collisions at LHC energies

The CMS Collaboration

Abstract

Two-particle, quantum-statistical (Bose-Einstein) correlations are measured in pp collisions at $\sqrt{s}$ = 0.9, 2.76 and 7 TeV, as well as in pPb and peripheral PbPb collisions at 5.02 and 2.76 TeV center-of-mass energy per nucleon, respectively. The analysis is carried out using all charged particles, as well as pions and kaons identified via their energy loss in the silicon tracker. The characteristics of the one-, two-, and three-dimensional correlation functions are studied as functions of the pair transverse momentum (k_T) and the charged-particle multiplicity of the event. The extracted correlation radii are in the range 1–5 fm, the largest values corresponding to very high multiplicity pPb interactions and for similar multiplicity in PbPb collisions. For all systems, the radii steadily increase with the event multiplicity and decrease with increasing k_T. It is also observed that the dependences of the radii on multiplicity and k_T largely factorize. At the same multiplicity the radii are relatively insensitive to the choice of colliding system and center-of-mass energy.

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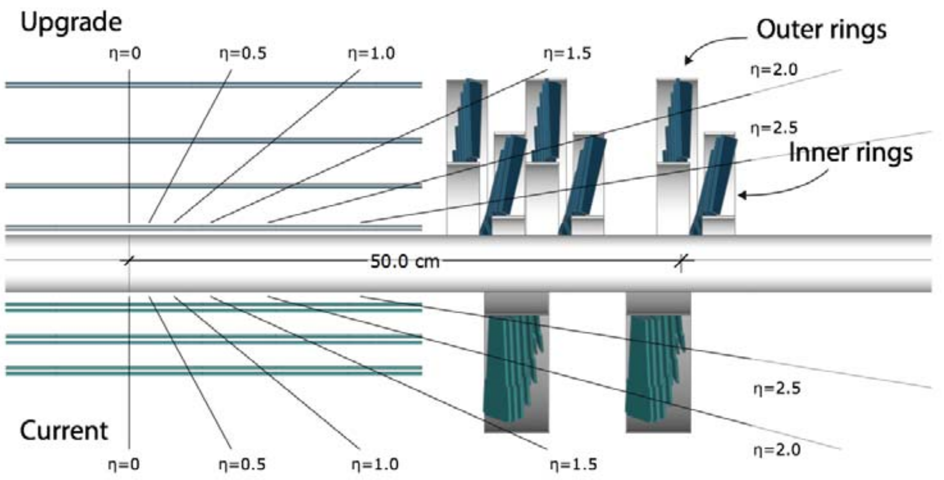
PDFAuthor:	Ferenc Sikler, Sandra Padula, Sunil M. Dogra
PDFTitle:	Bose-Einstein correlations in various collision systems and energies
PDFSubject:	CMS
PDFKeywords:	CMS, physics, femtoscopy, hadrons, HBT, particle identification

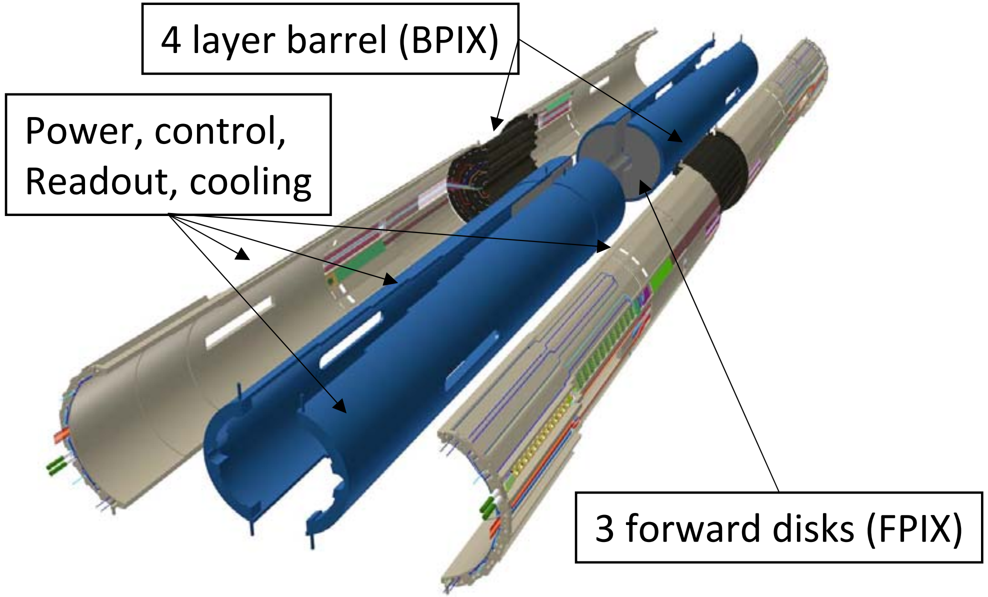
Please also verify that the abstract does not use any user defined symbols

Paper draft in CWR

The New Phase 1 Pixel

- 4 layers/3 disks
- CO_2 cooling
- DCDC converters (higher power transfered)
- Reduced material budget



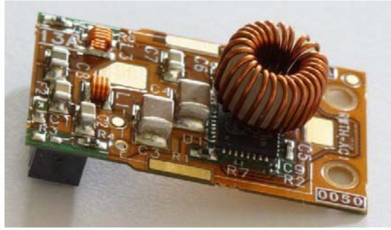


- New readout ASIC(s)
  - PSI46dig (BPIX L2-L4, FPIX)
  - PROC600 (BPIX L1)
- New back-end electronics (uTCA)
  - Fully digital read out (400 MHz)

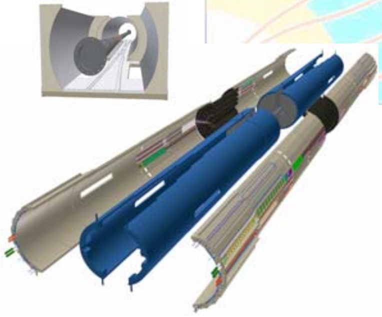
→**Readout inefficiency negligible up to $2*10^{34}cm^{-2}s^{-1}$, PU~70-100**

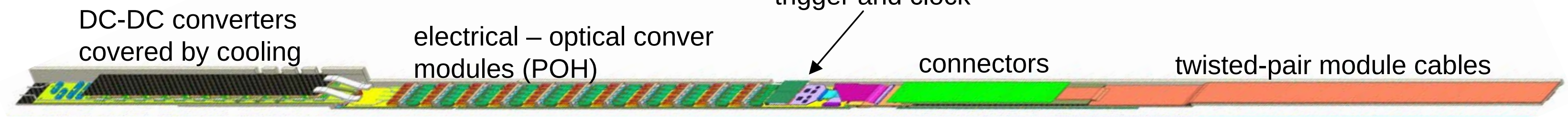
Supply tube: powering and read-out

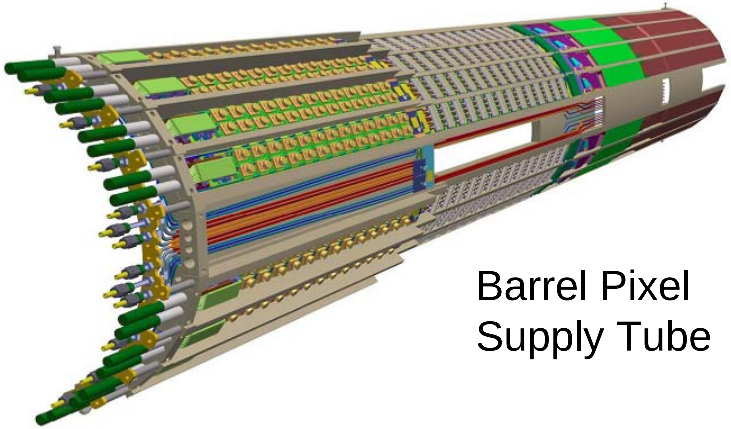
- More modules (x2), need more power
- Analog 3.0V and digital 2.5 V by DC-DC converters (eff. of 80%) from 10 V input



DCDC converter with AMIS5 ASIC
(RF shield not mounted)







- Front-end auxiliary electronics
  - Distributes clock signal synchronized to TOF within 1 ns
  - Equally distributes data-load among back-end FPGA-s
- 8 slots per half-shell, servicing a sector of up to 39 modules
  - 6 layers of 20 mm wide PCB-s and a bundle of 56 fiber optic cables stacked within a 20 mm deep slot

Constructing the supply tube

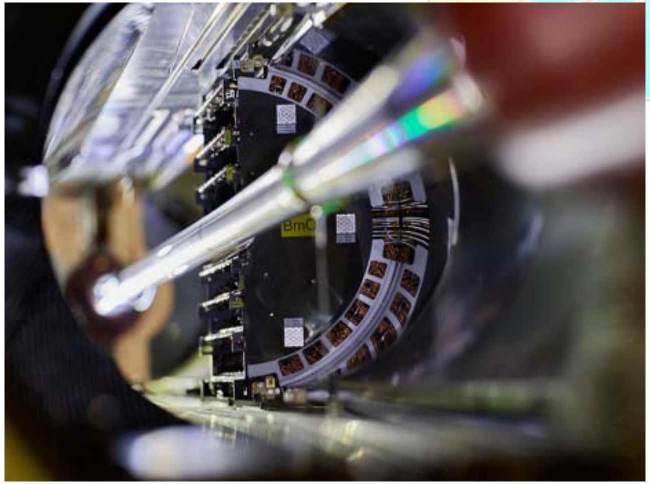
- Three participating institutes
  - Powering developed at University of Aachen
  - Control and read-out electronics by Wigner (**Tivadar Kiss, Tamás Tölyhi, Viktor Veszpremi**)
  - Mechanical and cooling structure by University of Zürich
- Prototype design and production cost was covered by Wigner – about 1.5 million Ft
  - Local test was developed by **Viktor Fisch**, MSc at Universiy of Debrecen, and Wigner engineers
- Final production cost ~100 kCHF
  - Parts after local tests are shipped to University of Zurich
  - Chain test and assembly of the full detector is done there

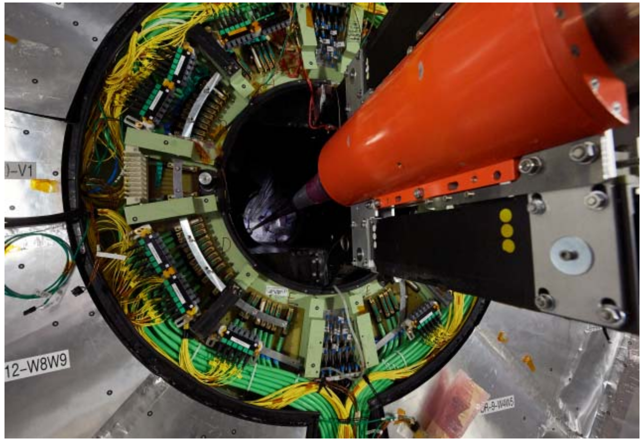
Production test at Wigner

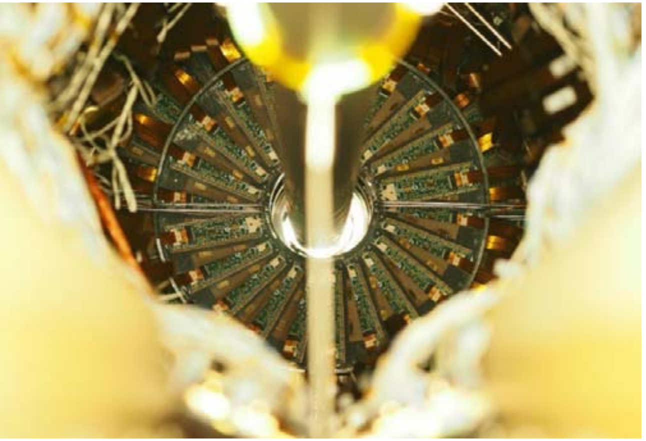
Slice test at Universiy of Zürich

Insertion of the Pixel

- Insertion of barrel pixel (top left)
- Half of the BPix (BmO) in its envelope (top right)
  - Detector is cut in half vertically and installed separately on both sides of the beampipe
- Full BPix installed and connected to Patch Panel0 (bottom left)
- FPix installed covering BPix





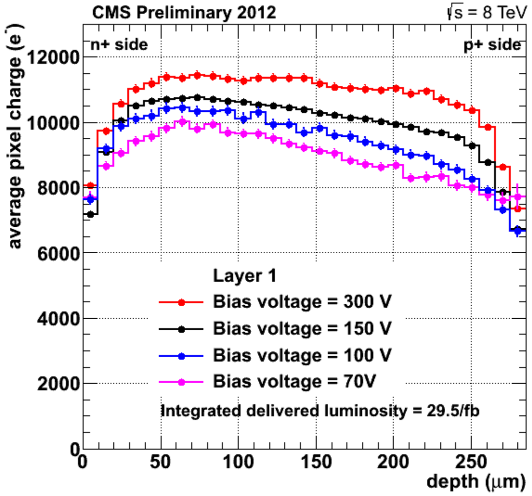


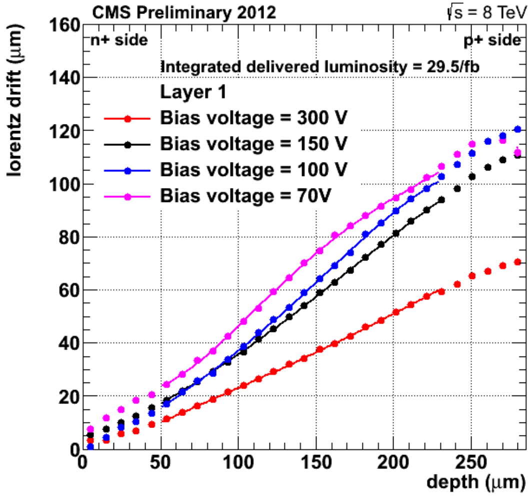
Pixel calibration and preparation

- Online check-out, calibration (by Operation team)
  - Establish mapping between modules and back-end readout channels
  - Verify programmability of all modules
  - Initialize communication between front-end and back-end (timing for digital communication, voltages, laser driver levels, and gains)
  - Configure modules (timing, voltage levels, ROC settings, bias voltage)
  - Calibrate thresholds, signal height
  - Perfrom gain calibration

- Offline calibrations (by Offline team – **that is us**)
  - Establish mapping between back-end readout channels and 3D modelling of detectors in CMS software
  - Initial settings for gain calibration, temperature and bias voltage dependent charge-sharing, cluster position measurement
  - Setting up Monte Carlo framework for detector-simulation

- Prepare offline software for initial data-taking, tracker alignment, track reconstruction

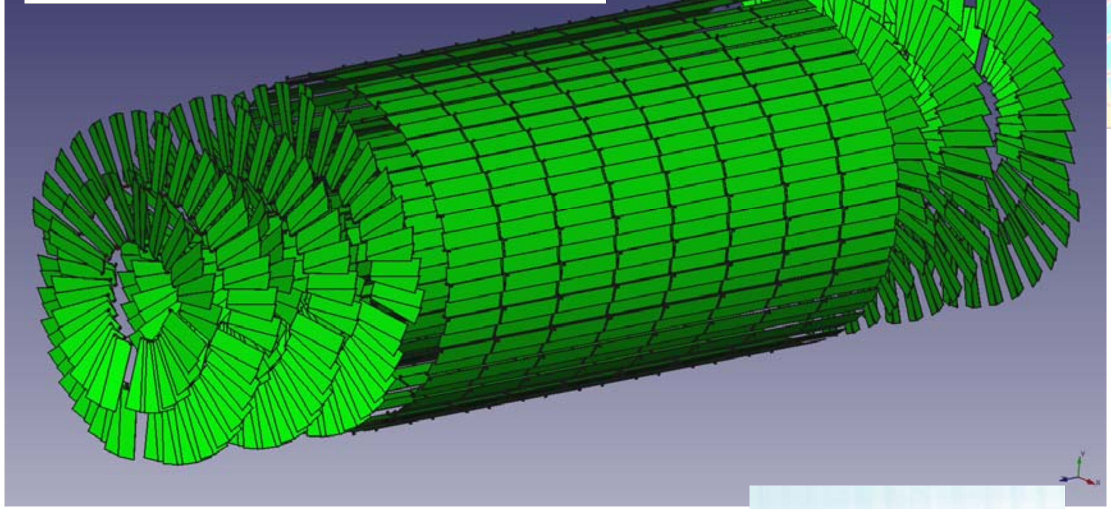


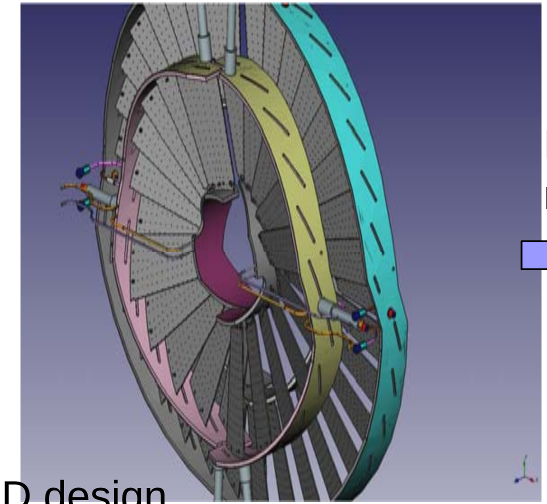


Geant description

- Geometric description of detectors in the CMS software
  - Describes passive and sensitive material in Geant4 simulation
  - Maps 2D local (sensor) measurement into 3D space for tracking
- Description was finalized in March (V. Veszpremi)
- Placement of sensors are expected to be within ~100 um of design
- Passive material compositions mostly follow engineering design
  - Sensor module description ~5% accuracy
  - Support structure agreement within ~10%...
- Direct measruement based on identification by Nuclear Interaction is being prepared

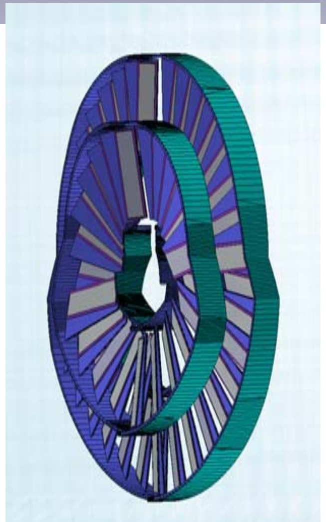
CMSSW definition of sensors





CAD design

Passive materials



CMSSW model

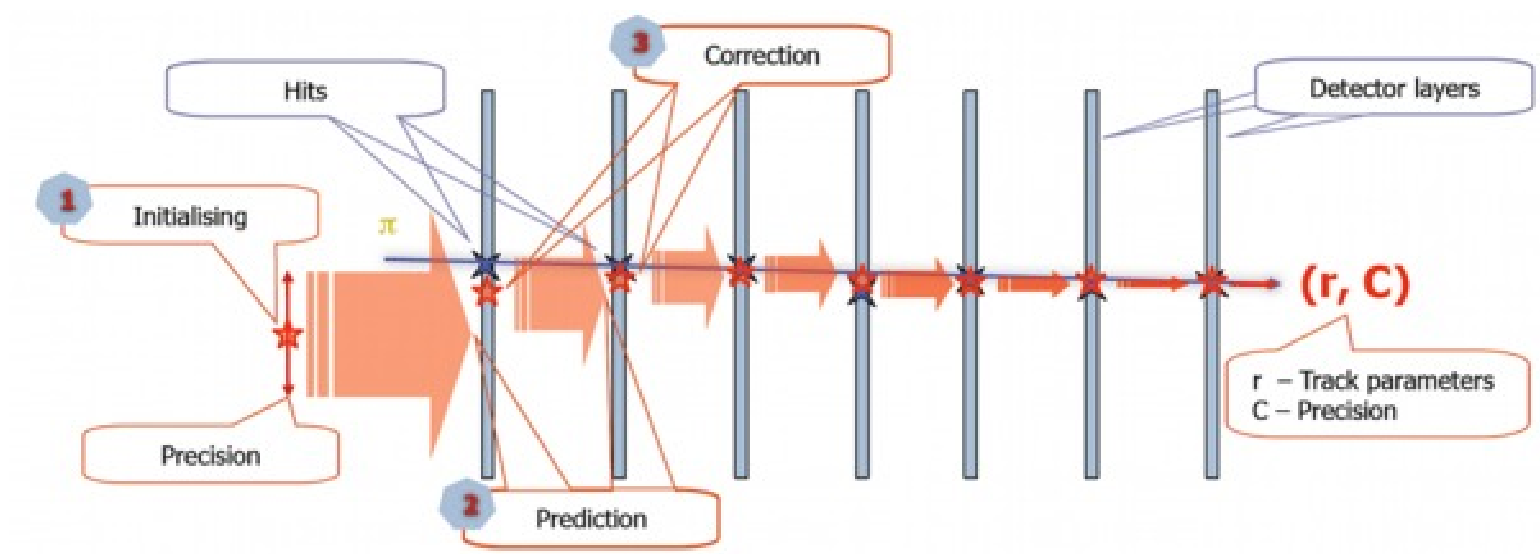
Combination of data analysis techniques for efficient track reconstruction in high multiplicity events

Ferenc Siklér
Wigner RCP, Budapest

Orsay, 8 Mar 2017

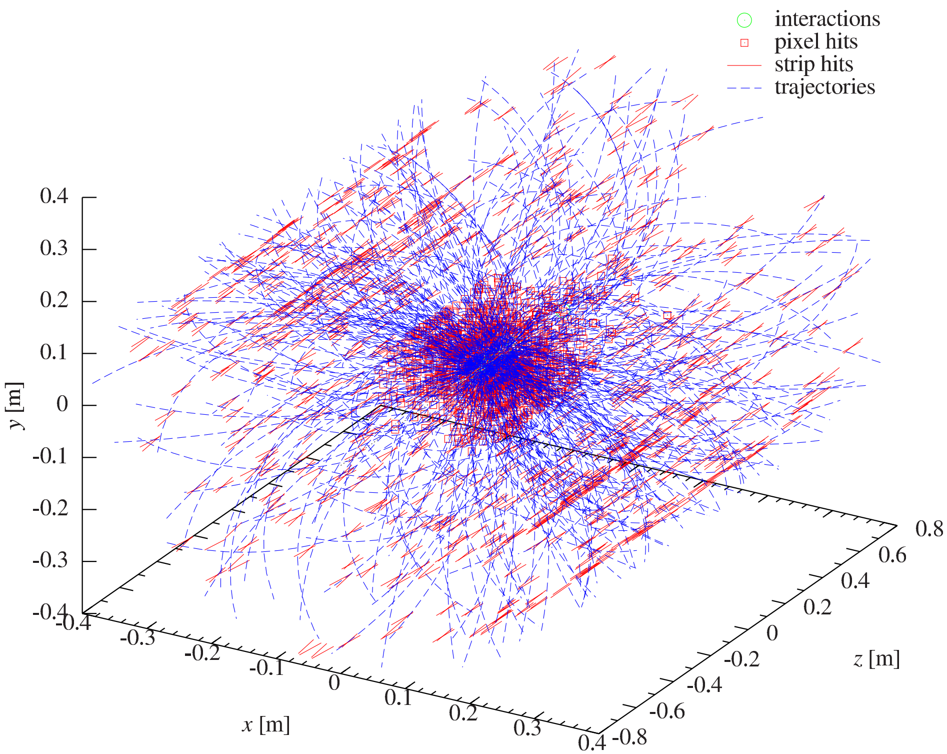
Track reconstruction

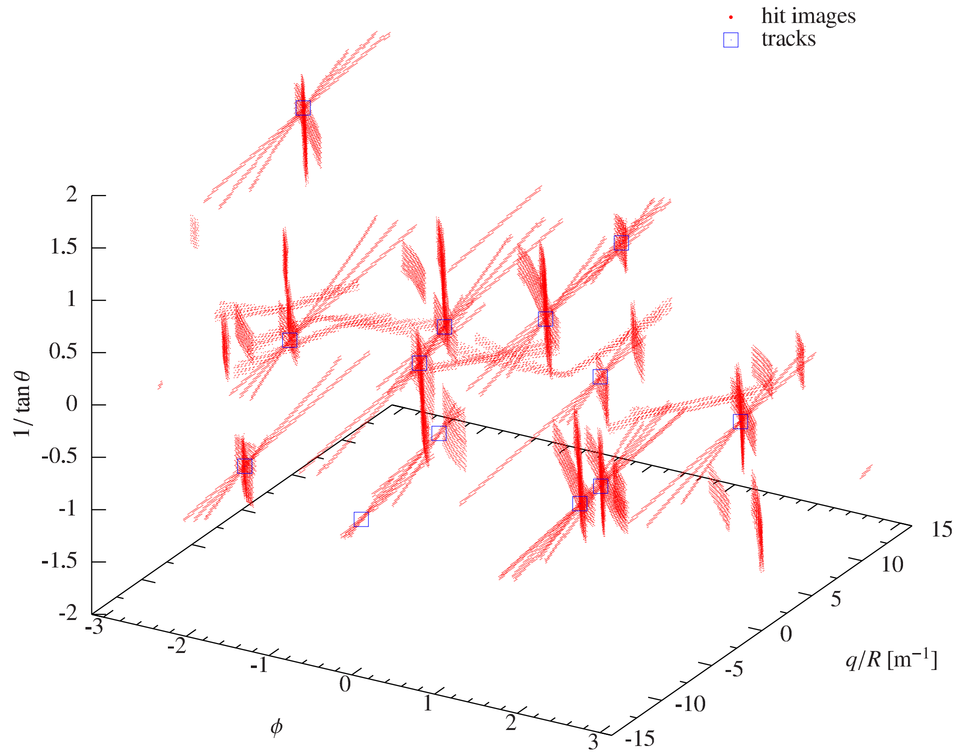
- Pattern recognition
  - find a track seed (usually two or three compatible hits)
  - try to extend that, pick up compatible points, build a trajectory
  - ☹ mostly uses **local information**
  - ☹ number of trajectory candidates **must be limited** at each step
  - ☹ keeping some of the best hit-candidates biases the result
  - ☹ decisions are **made too early**
  - ☹ trajectories are **treated separately**



Executive summary – some thoughts

- How to identify track candidates?
  - try to use all available information
  - ☺ collect information globally and not locally
  - ⇒ **image transformation (Hough transformation)**
  - several physics effects: multiple scattering, energy loss
  - ⇒ **use templates (with translational and rotational invariance)**





Executive summary – some thoughts

- How to select the best set of tracks?

☺ keep concurrent choices open; several hit-track assignments

⇒ **treat the hits and track candidates as a (bipartite) graph**

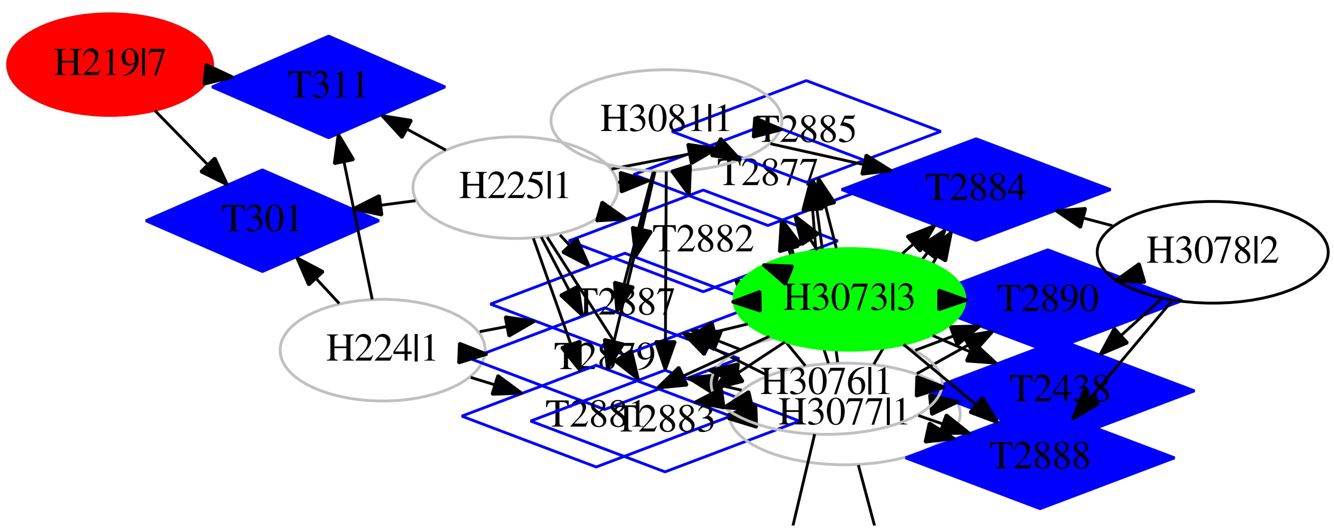
– the graph can be highly connected; but has vulnerable components

☺ disconnect it by looking for *bridges* and *articulation points*

– in the end each hit must belong to at most one track

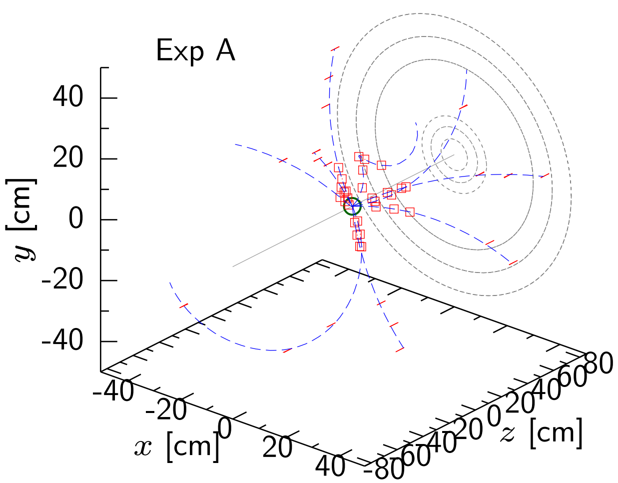
⇒ **solve subgraphs, decision tree, deterministic single-player**

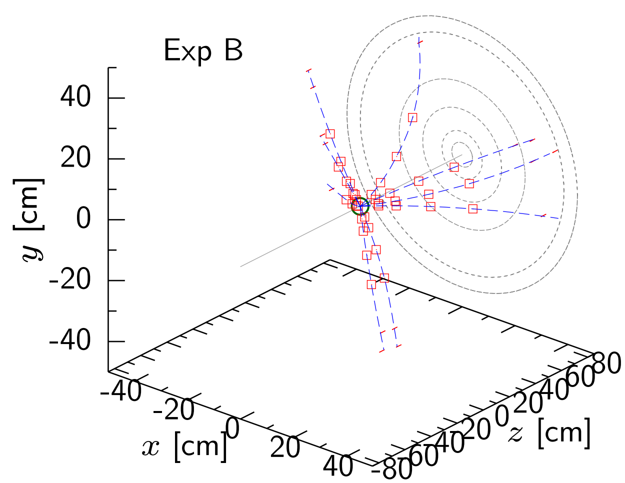
– maximize the number of hits on track, then minimize $\sum \chi^2$

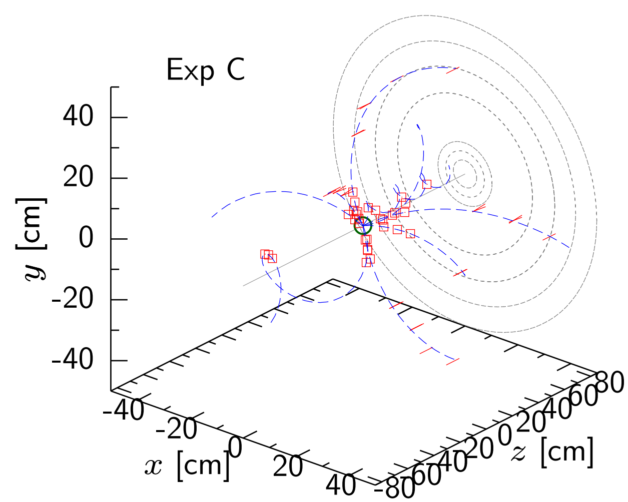


Simulation – inner barrel detectors

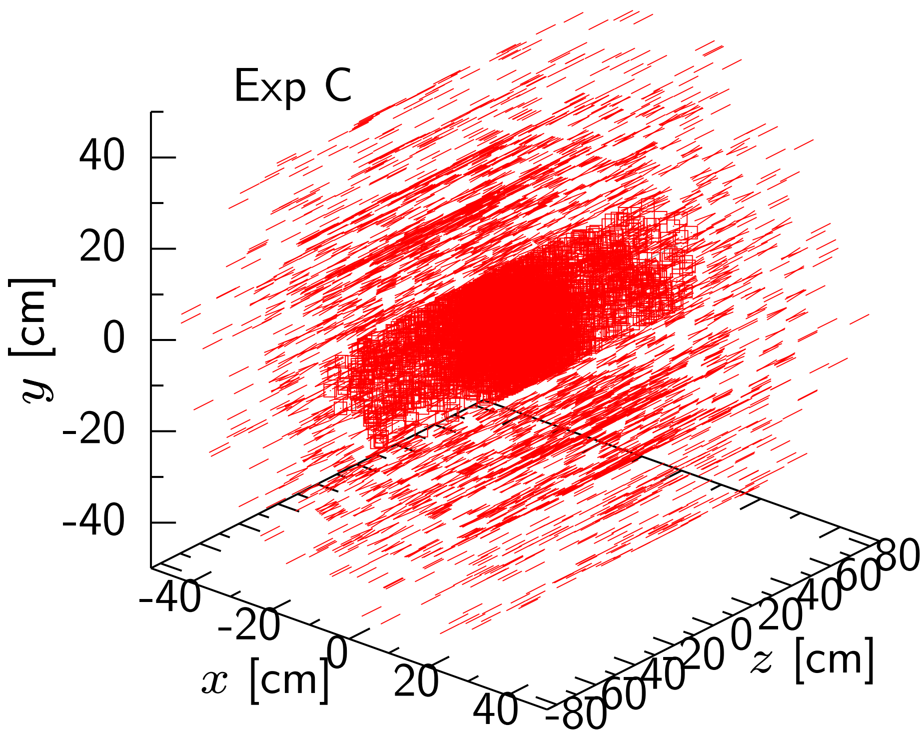
	B_z [T]	Layer type	Radii [cm]	Tilt [mrad]	$\sigma_{r\phi}$	σ_z (l_z)	x/X_0 [%]
Exp A	2.0	pixels (barrel)	5.0, 8.8, 12.2	–	10 μm	115 μm	4
		strips (SCT)	29.88, 29,92	± 20	17 μm	(6.4 cm)	2
		strips (SCT)	37.08, 37,12	± 20	17 μm	(6.4 cm)	2
		strips (SCT)	44.28, 44,32	± 20	17 μm	(6.4 cm)	2
Exp B	0.4	pixels (SPD)	3.9, 7.6	–	12 μm	100 μm	1
		drifts (SDD)	14.9, 23.8	–	35 μm	25 μm	1
		strips (SSD)	38.48, 38.52	$+7.5, -27.5$	20 μm	(4 cm)	0.5
		strips (SSD)	43.58, 43.62	$+7.5, -27.5$	20 μm	(4 cm)	0.5
Exp C	3.8	pixels (PXB)	4.4, 7.3, 10.2	–	15 μm	15 μm	3
		strips (TIB)	25.48, 25,52	± 50	23 μm	(10 cm)	2
		strips (TIB)	33.88, 33.92	± 50	23 μm	(10 cm)	2
		strips (TIB)	41.8	0	35 μm	(10 cm)	2
		strips (TIB)	49.8	0	35 μm	(10 cm)	2



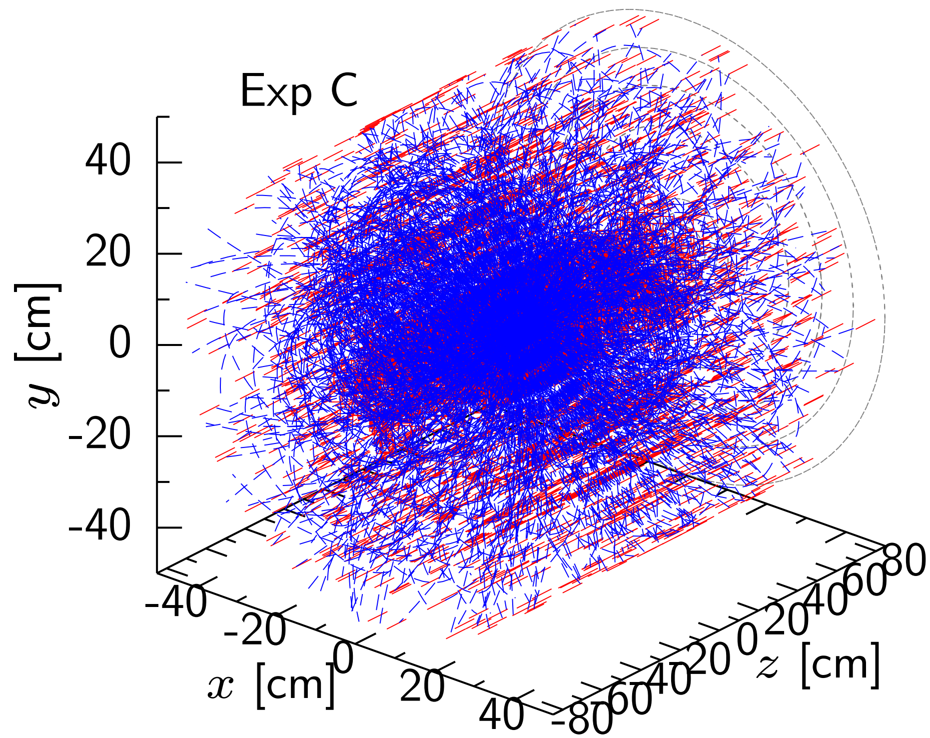




Simulated events – multiple pp



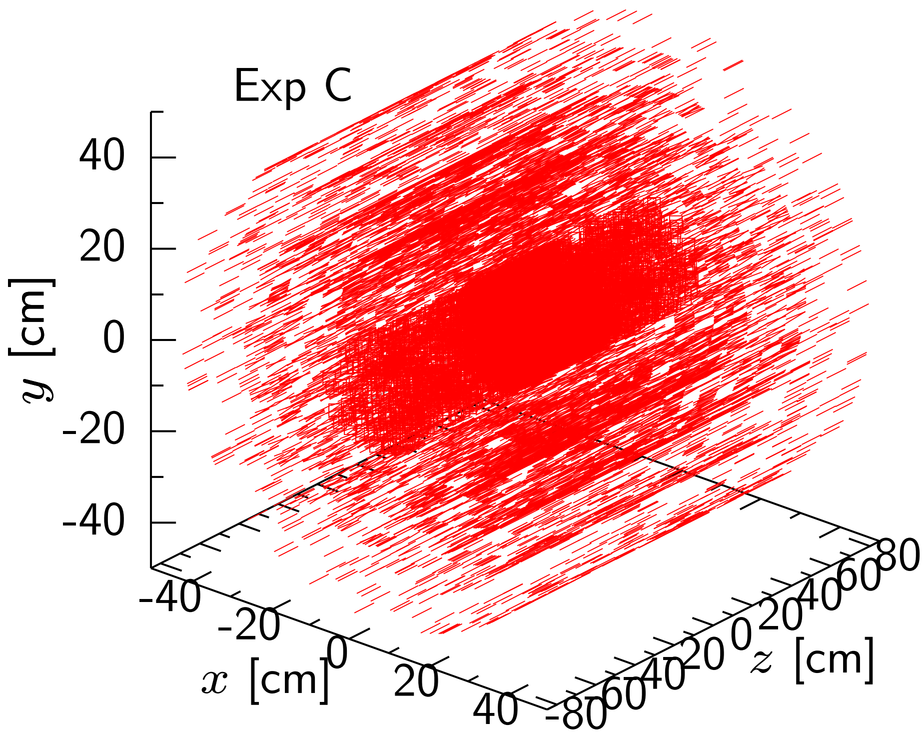
Hits



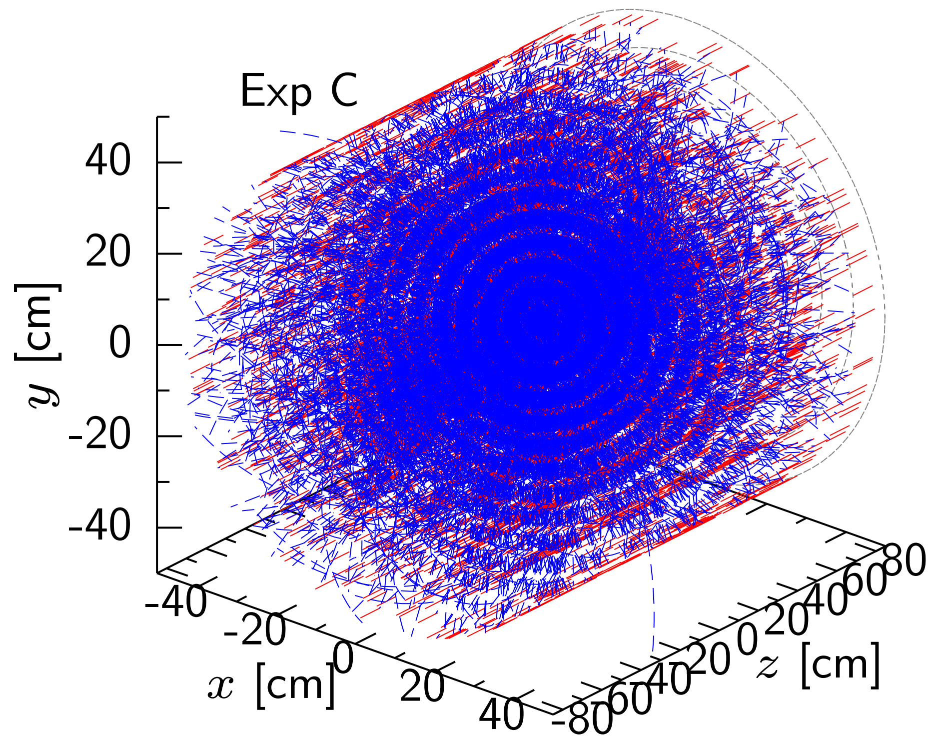
Hits+trajectories

40 simultaneous inelastic pp collisions at $\sqrt{s} = 14$ TeV from the PYTHIA8 MC event generator (version 219)

Simulated events – single Pb-Pb



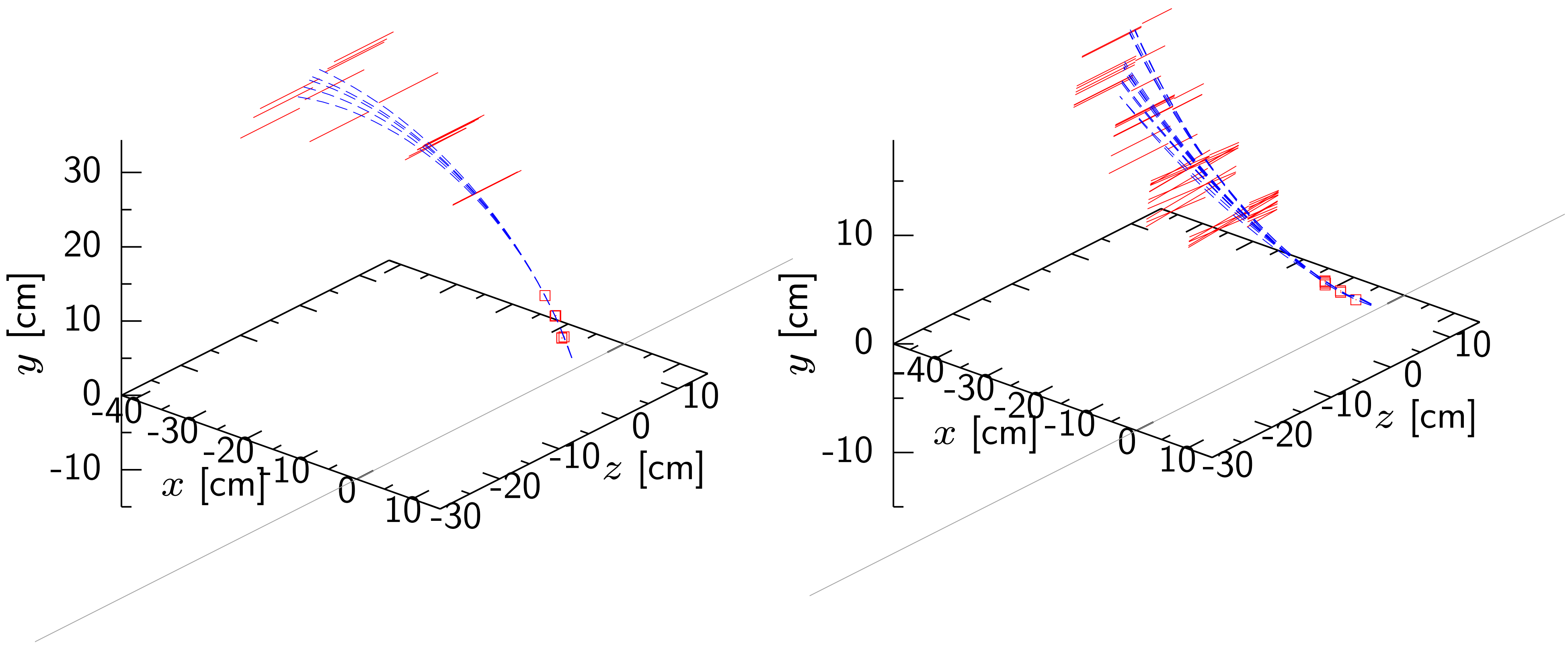
Hits



Hits+trajectories

Single semi-central Pb-Pb collision at $\sqrt{s_{NN}} = 5$ TeV
from the HYDJET MC event generator (version 1.9)
$dN/d\eta \approx 1100$, equivalent to about 200 pp

Hit family in an accumulator bin



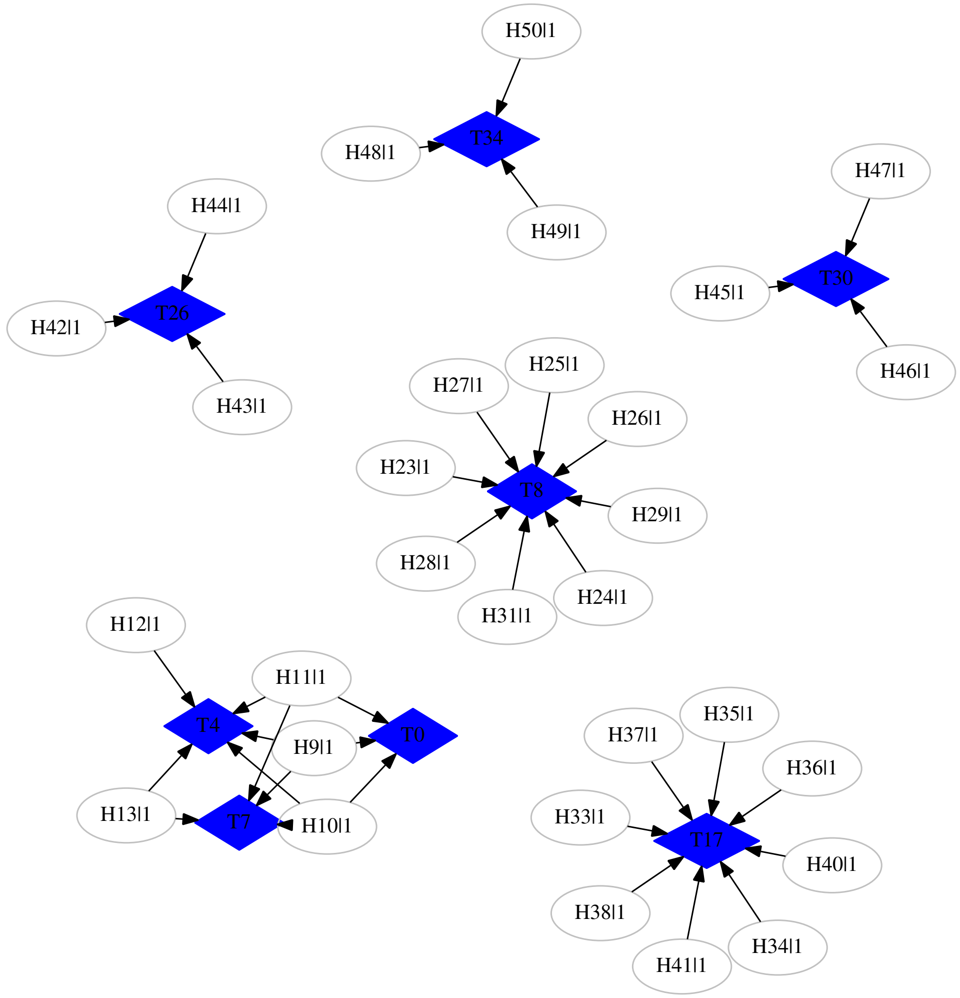
How to select track candidates? Inner strip layers are crowded

Take first two (pixel) hits with beamspot constraint, fit helix

Add third (pixel) hit, **propagate to** a (strip) hit on the **outermost** layer

Use **smoothing step to select** compatible (strip) hits in between

Convert to graph – single p-p

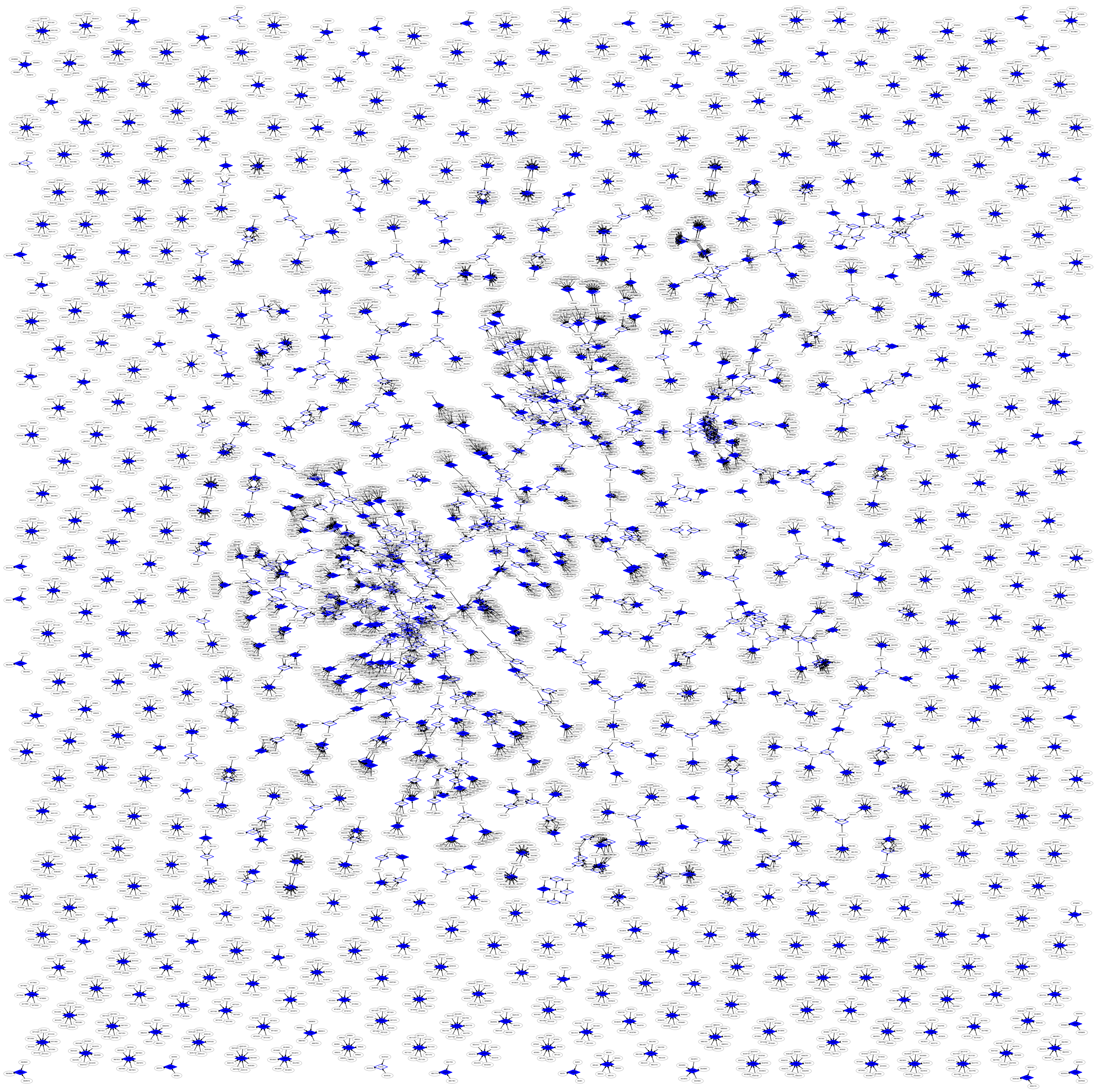


Nodes: hits (ellipses) and track candidates (blue diamonds)

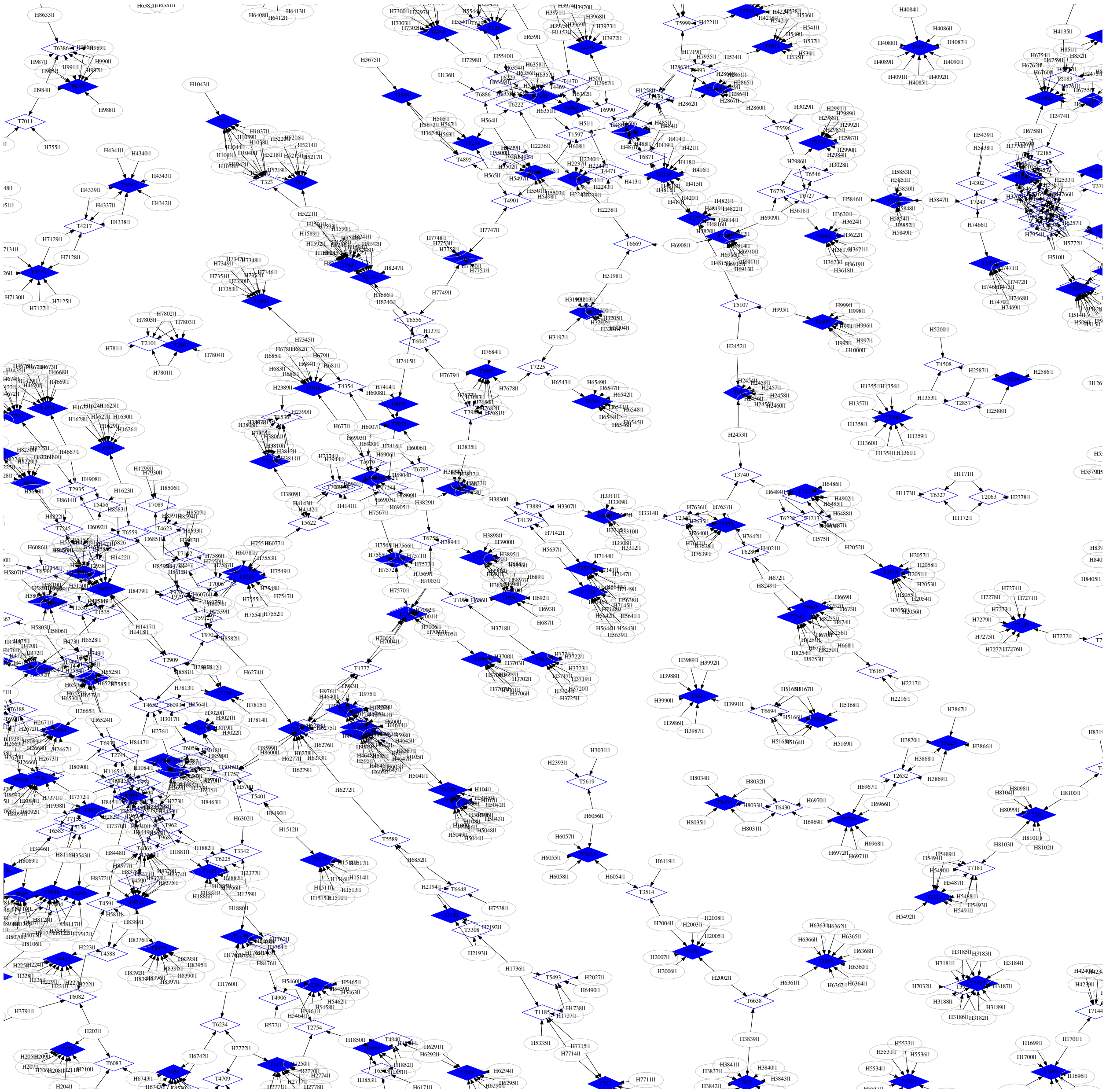
Edges: hits can belong to one or more track candidates

Ambiguity, hit confusion; **optimal packing** problem

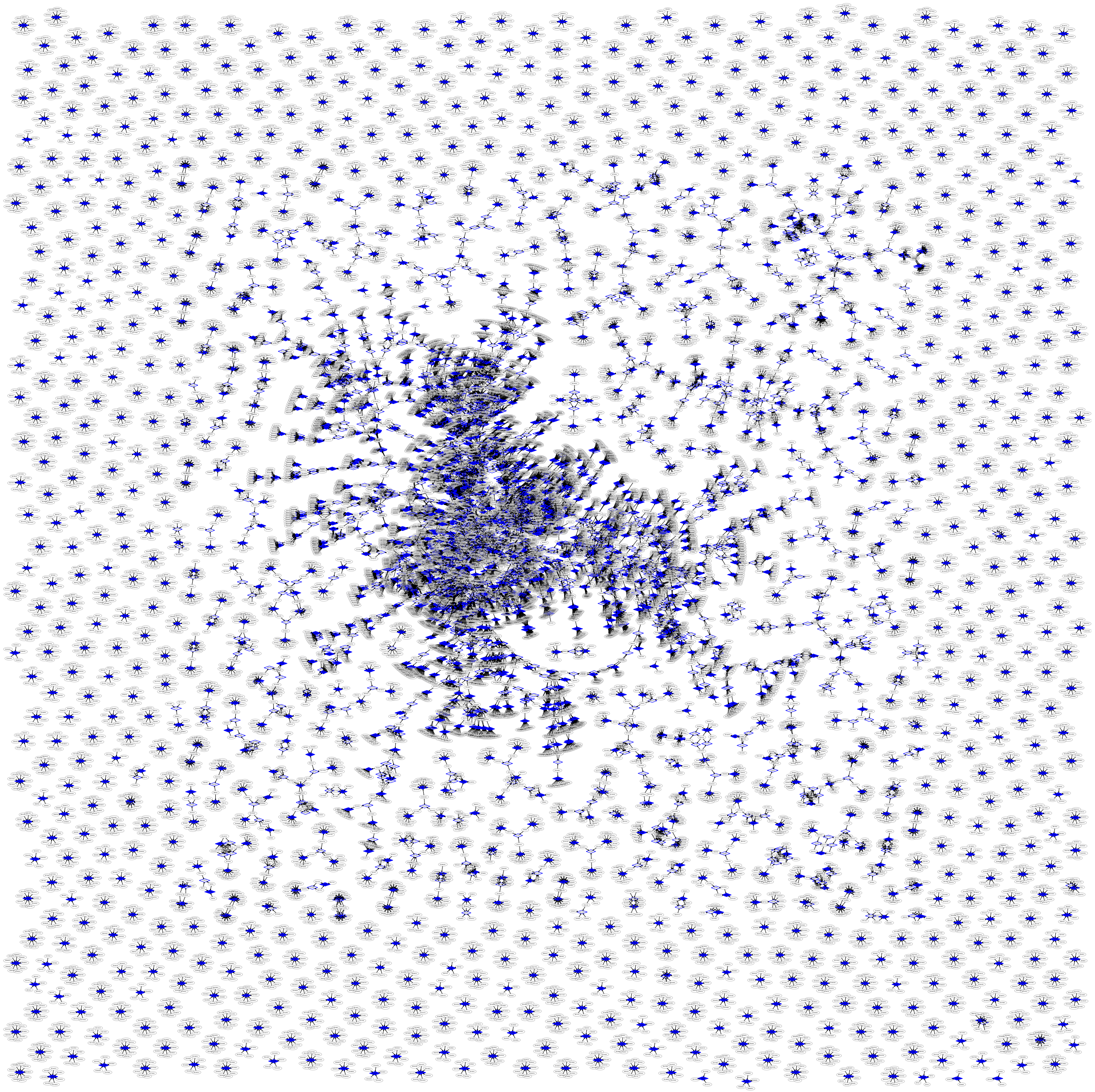
Disconnecting the graph – 40 p-p



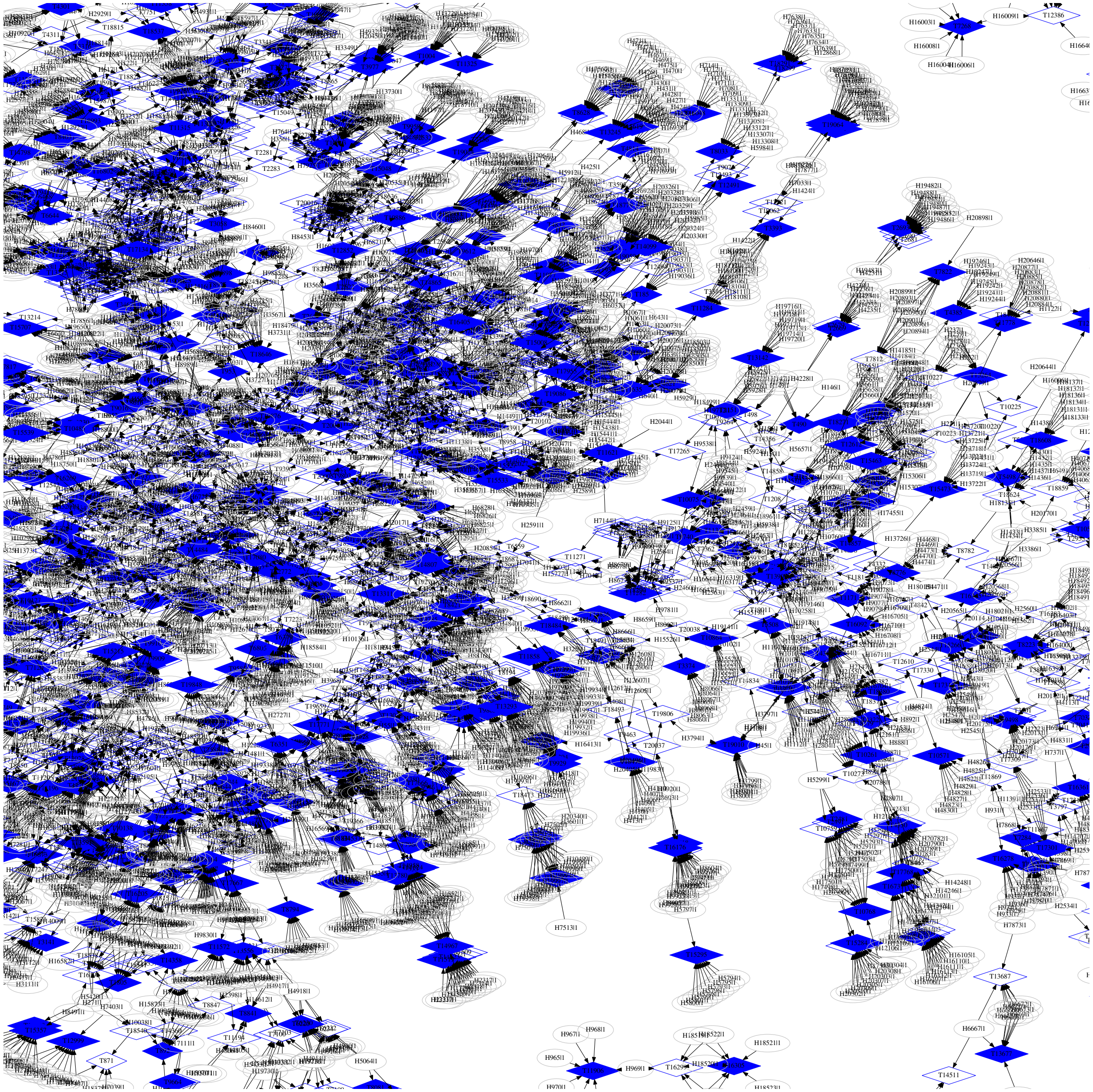
Disconnecting the graph – 40 p-p – zoom



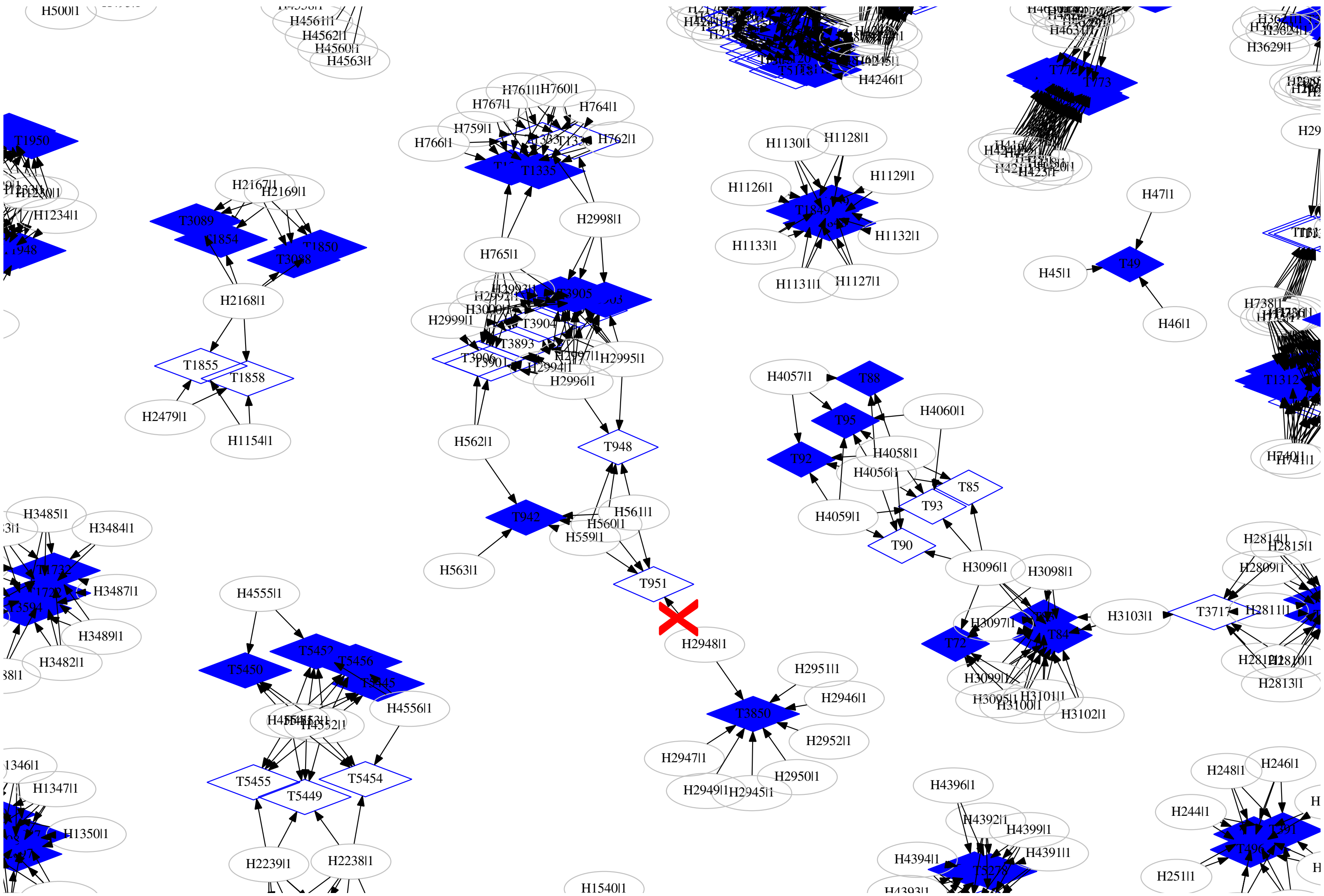
Disconnecting the graph – single Pb-Pb



Disconnecting the graph – single Pb-Pb – zoom



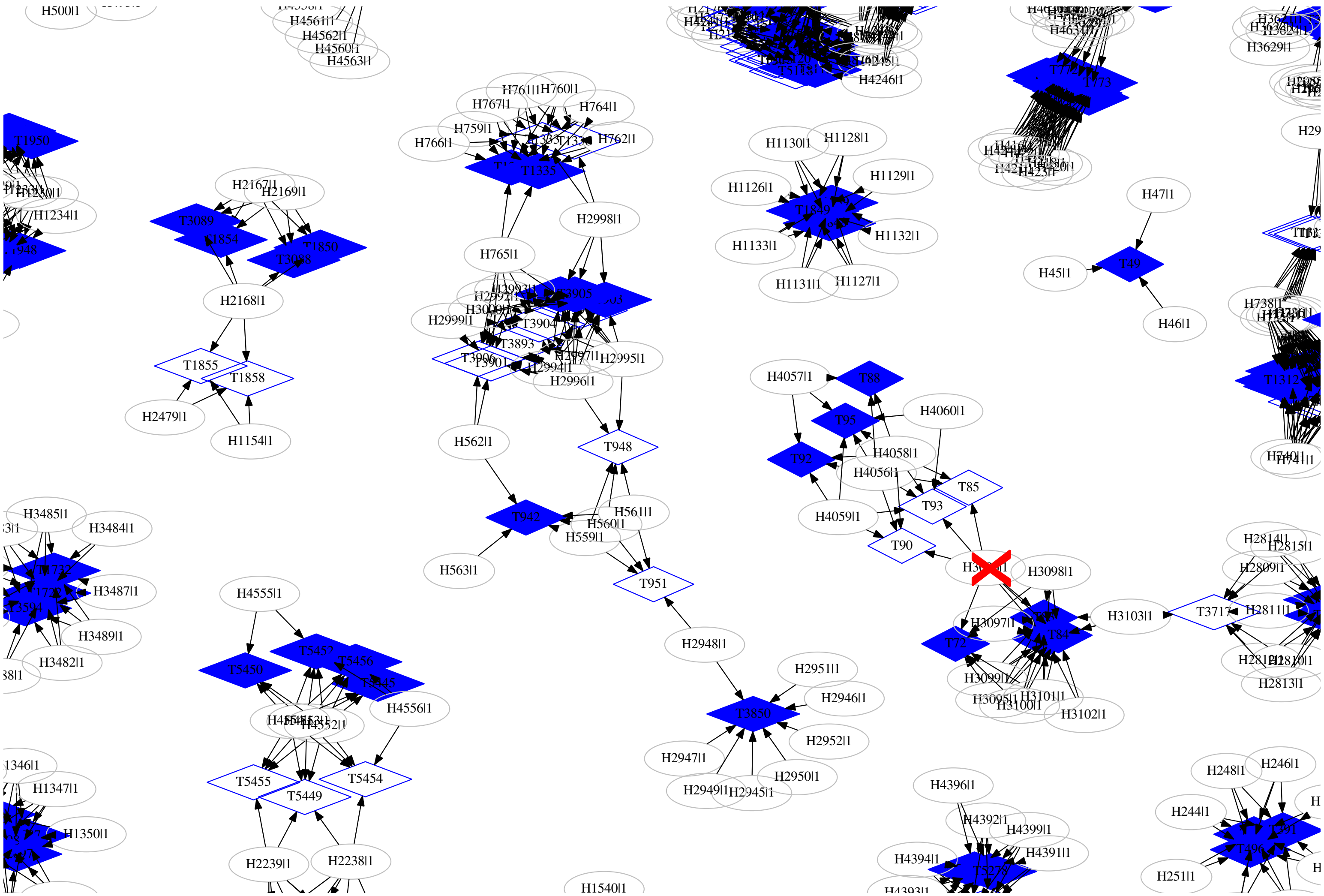
Disconnecting the graph – bridges



Its deletion increases the number of connected components

The children of its node do not have a back-edge

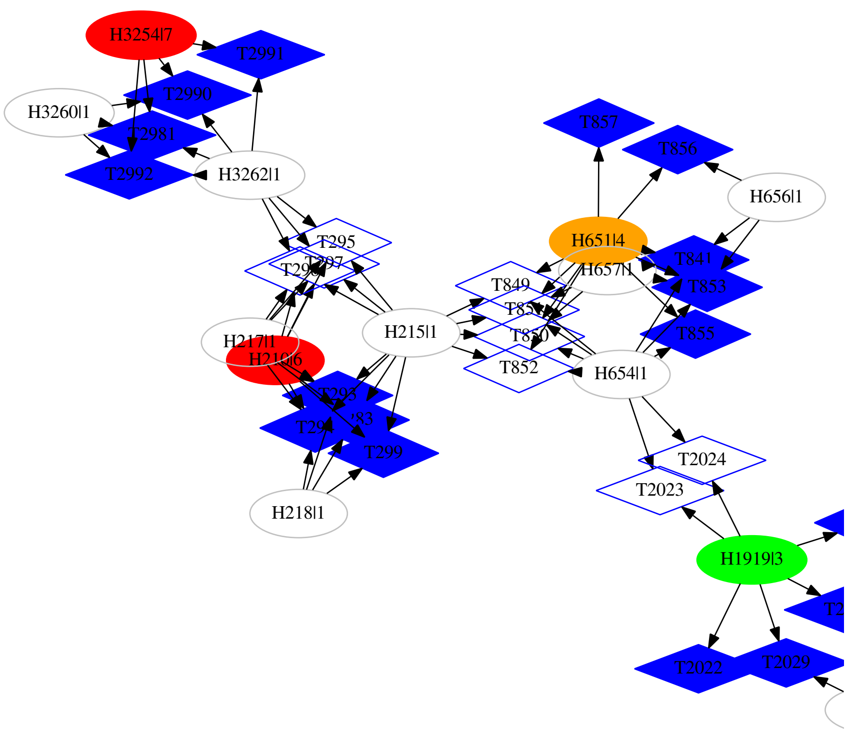
Disconnecting the graph – articulation points



Its removal increases the number of connected components

Might look for double-edges (2-edge connectivity) as well

Solve the subgraphs – decision tree



- Explore the decision tree

1. choose the **most wanted hit**
2. assign it to a track (loop over)
3. store tracks w at least three lonely hits; not requested by others
4. remove tracks with too few hits
5. if there are hits left, go to → 1.
6. **evaluate** # of hits on track, $\sum \chi^2$
7. if best score so far → take note

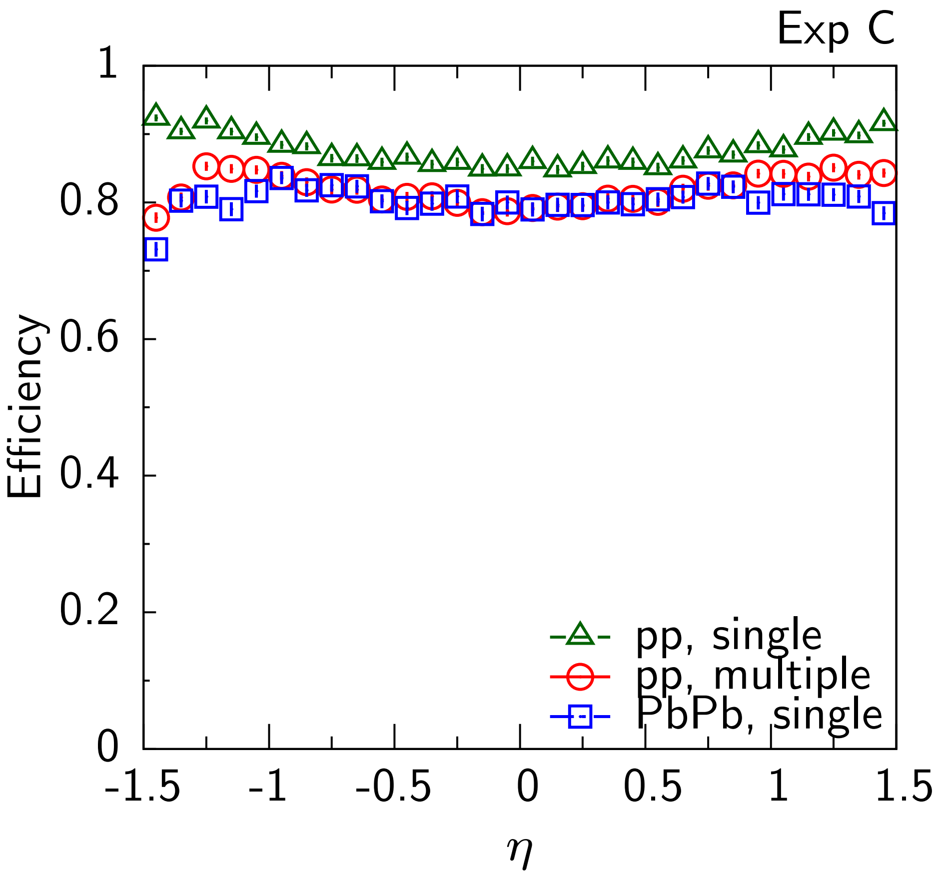
Recursive

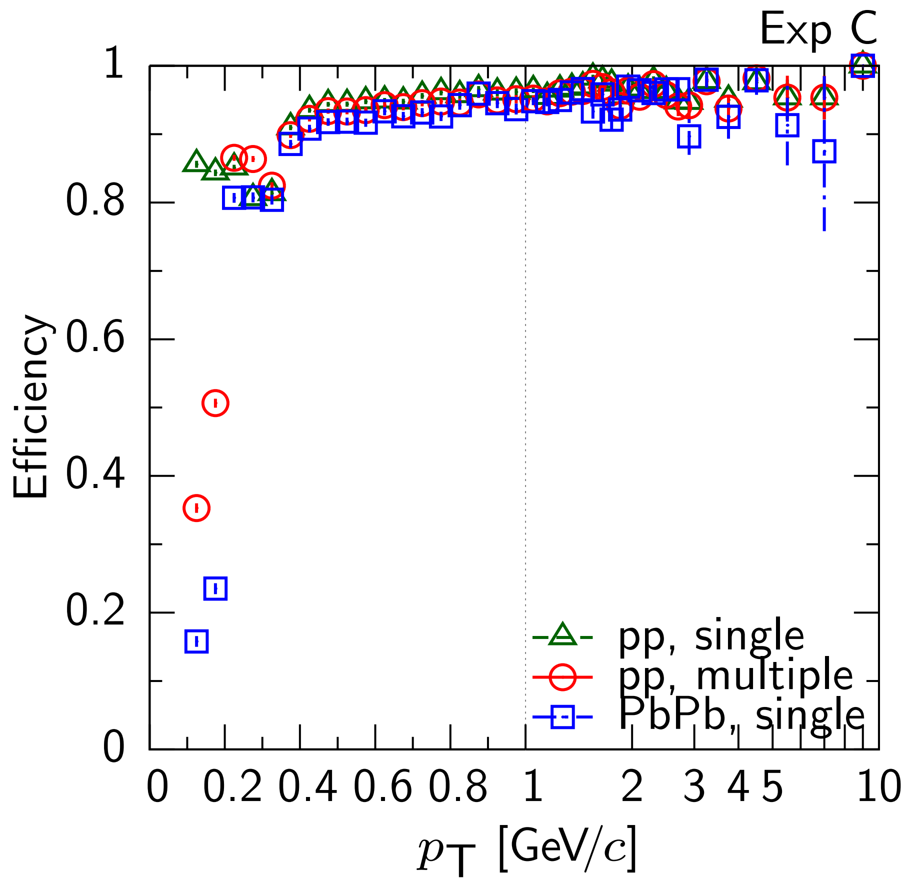
Depth-limited, horizon (∼chess)

Less depth → better solution (∼pruning)

Gives **optimal distribution** of hits

Performance – track finding efficiency

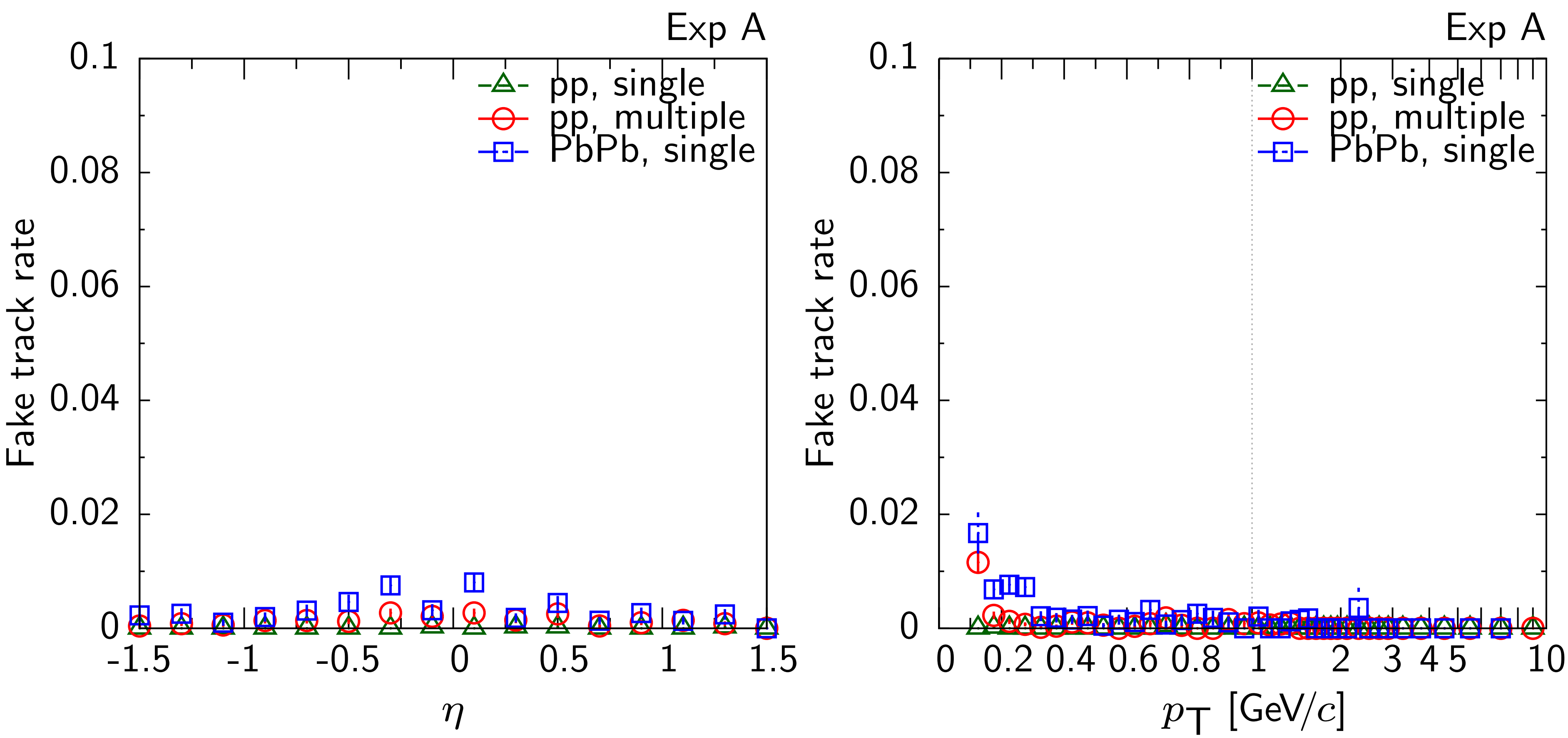




Simu-reco matched: all hits match or at most one is not in place

Looks good

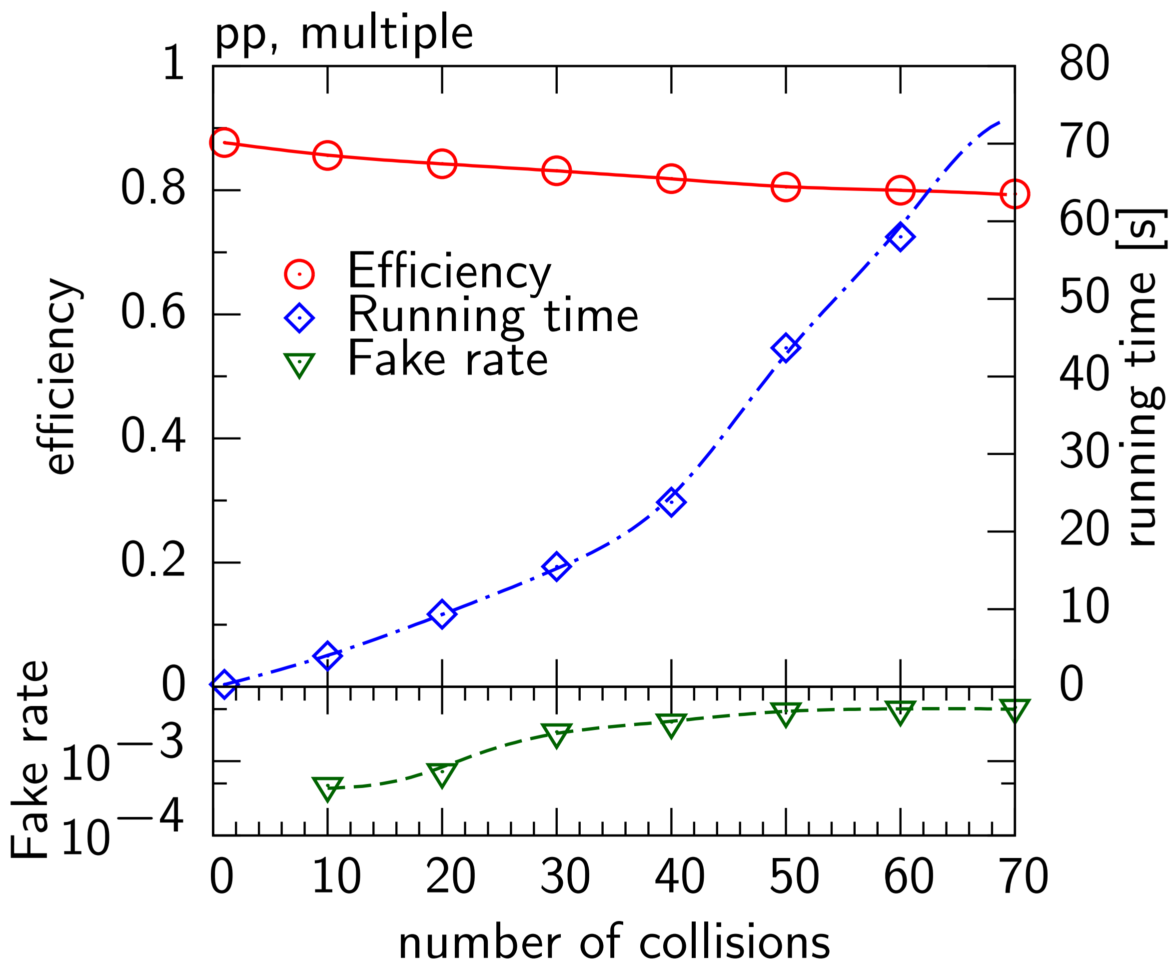
Performance – fake track rate



Nice, event at low p_T

Permille level

Performance – dependence on pileup



Efficiency between 80-90% taking into account all charged particles

Running time has piecewise linear dependence on pileup

Fake track rate is around permille level

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Combination of various data analysis techniques for efficient track reconstruction in very high multiplicity events

Ferenc **Siklér**[1,a]

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Abstract. A novel combination of established data analysis techniques for reconstructing charged-particles in high energy collisions is proposed. It uses all information available in a collision event while keeping competing choices open as long as possible. Suitable track candidates are selected by transforming measured hits to a binned, three- or four-dimensional, track parameter space. It is accomplished by the use of templates taking advantage of the translational and rotational symmetries of the detectors. Track candidates and their corresponding hits usually form a highly connected network, a bipartite graph, where we allow for multiple hit to track assignments. In order to get a manageable problem, the graph is cut into very many minigraphs by removing a few of its vulnerable components, edges and nodes. Finally the hits distributed among the track candidates by exploring a deterministic decision tree. A depth-limited search is performed maximizing the number of hits on tracks, and minimizing the sum of track-fit χ^2. Simplified but realistic models of LHC silicon trackers including the relevant physics processes are used to test and study the performance (efficiency, purity, timing) of the proposed method in the case of single or many simultaneous proton-proton collisions (high pileup), and for single heavy-ion collisions at the highest available energies.

1 Introduction

Traditional methods of track reconstruction can be scaled to work in high multiplicity events, namely in many simultaneous collisions (pileup) of elementary particles [1, 2] and in high multiplicity single heavy-ion collisions. Nevertheless the performances are not optimal, efficiency and purity are reduced, especially at low momentum. That is why present data taking conditions and further upgrades of high energy particle colliders, as well as those of detector systems, call for new ideas.

Image transformation methods and neural networks [3] are often used in gas detectors (time projection chambers [4, 5] and transition radiation trackers [6, 7]). In the case of silicon trackers the combinatorial track finding methods employed for trajectory building mostly use local information [8, 9]. They start with a trajectory seed and build a trajectory by extending the seed through the detector layers, picking up compatible hits. In the case of very many compatible hits the number of concurrently built trajectory candidates must be limited. Only some of the best candidates are kept that biases the final result. In this sense decisions are made too early. In addition, trajectories are mostly treated separately, there is no interaction between their assigned hits.

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PACS. 29.40.Gx Tracking and position-sensitive detectors – 29.85.-c Computer data analysis

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In this study a combination of established data analysis techniques for charged-particle reconstruction is proposed. It uses all information available in an event while keeping competing choices open as long as possible. Details of silicon detectors, relevant physical effects and tracking with Kalman filter are introduced in Sec. 2. Suitable track candidates are selected by transforming measured hits to a binned, four-dimensional, track parameter space (Sec. 3). It is accomplished by the use of templates taking advantage of the translational and rotational symmetries of the detectors. Track candidates and their corresponding hits usually form a highly connected network, a bipartite graph, where we allow for multiple hit to track assignments (Sec. 4). In order to get a manageable problem, the graph is cut into very many subgraphs by removing a few of its vulnerable components, edges and nodes (k-connectivity). Finally, the hits of a subgraph are distributed among the track candidates by exploring a deterministic single-player game tree. A depth-limited search is performed with a sliding horizon maximizing the number of hits on tracks, and minimizing the sum of track-fit χ^2.

Simplified but realistic models of silicon trackers (Sec. 5) utilized in detector systems at particle colliders are used to test the performance (efficiency, purity, timing, parallelization) of the proposed methods. These studies are performed in the case of numerous simultaneous proton-proton collisions (high pileup), and for single ion-ion collisions at the highest available energies (Sec. 6).

Paper draft to EPJA

SCOPES support indicated in both

The Budapest group (Wigner RCP)

- Contents – activities in the past year
  - Quantum correlations of identified hadrons (Ferenc)
    FSQ-14-002, paper in CWR ($\rightarrow$ PRC)
  - Spectra of identified hadrons from pp at 13 TeV (Ferenc)
    FSQ-16-004, paper in FR ($\rightarrow$ PRD), abstract to EPS HEP
  - Installation and operation of the new pixel detector (Viktor)
    some selected plots
  - New tracking algos for very high multiplicity events (Ferenc)
    CTD/WIT17 talk and proceedings, paper draft ($\rightarrow$ EPJA)
  - Exclusive production in pp (Olivér)
    FSQ-16-006, pre-approved
  - Participation in p-Pb data taking (Olivér)
    calibration of the zero degree calorimeter, physics with neutrons

Big thanks for SCOPES for the continuous support during years!