Piotr Krzysztof Skowroński

Tools For Simulation of HBT and Flow

CERN Workshop on Monte Carlo tools for the LHC July 2003

Introduction - HBT

- Hanburry-Brown and Twiss (HBT) interferometry
  - Technique developed in astrophysics for star diameter measuremant
  - Bases on Bose-Einstein symmetrization which leads to correlation function (CF) enhancement for particles with close momenta
  - Width of the correlation enhancemant and uncertainty relation allows to estimate size of the source

Introduction – Corr. Fctn.

Correlation Function is defined as

$$C(p_1, p_2) = N \frac{P_2(p_1, p_2)}{P_1(p_1)P_1(p_2)}$$

and under some assumptions is typically expressed as

$$1D: \; C(q, K) = 1 + \lambda e^{-R^2 q^2}$$

$$3D: \; C(q, K) = 1 + \lambda e^{-R_{long}^2 q_{long}^2 - R_{out}^2 q_{out}^2 - R_{side}^2 q_{side}^2}$$

$$K = \frac{1}{2}(p_1 + p_2) \quad q = p_1 - p_2$$

Introduction - HBT

Amplitude for 2 bosons with momenta p_1 and p_2,

emitted from points r_1 and r_2 and detected at x_1 and x_2 is

$$\Psi_{p_1 p_2}(x_1 x_2; r_1 r_2) = \frac{1}{\sqrt{2}}\left(e^{ip_1(x_1-r_1)}e^{ip_2(x_2-r_2)} + e^{ip_1(x_1-r_{21})}e^{ip_2(x_2-r_1)}\right)$$

or in general case of n particles

$$\Psi_{\{p\}}(\{x\};\{r\}) = \frac{1}{\sqrt{n!}}\exp\left(i\sum_{i=1}^{n} p_i x_i\right)\sum_{\sigma}\exp\left(-i\sum_{i=1}^{n} p_i r_{\sigma(i)}\right)$$

where σ denotes all $n!$ permutations

Final State Interactions (FSI)

- In heavy ion collisions FSI are unnegligible
  - They make fitting CF much more difficut since change significantly the shape of correlation function
  - But, correlations allows to study nature of strong interactions
  - One can perform complementary study of non-identical particles and correct than identical particle CF
  - They also give information about seqence of emission

POLITECHNIKA WARSZAWSKA

Generation

- The most direct way of HBT simulation seems to be use of symmetrized amplitudes for particle creation process.
- This is achieved within Lund String Model for particles coming from **single string** hadronization.
  - B. Andersson, M. Ringner, B-E correlations in the Lund model, Nucl. Phys. B 513 (1998) 627
- For any system containing more particles this approach is computationally unbarable

HBT generation - problems

- *„Bose – Einstein correlations arise from squaring production amplitudes*
- *Numerical event simulations are formulated via probabilities"*
  - *„The typical event generator output is a set of discrete phase-space points, lacking correlations due to Bose-Einstein symmetrization and other types of final state effects"*
- *„None of existing generators propagates properly symmetrized N-particle amplitudes from some initial condition"*
  - Not saying about Final State Interactions handling

Quotations above comes from Wiedemann and Heinz, Phys. Rep. 319 (1999) 145 (pages 177-180)

Remedy for a problem

- Exists two ways of handling HBT simulations for HI
  - Momentum shifts algorithms
  - Weighting prescriptions

Momentum shift algorithms

- Base on shifting particle momenta obtained from some input generator
- Few approaches exists differing in complexity (and limit number of particles where computing time stops to be permisive)
  - W. Zajc, Phys. Rev. D 35 (1987) 3396
  - Lonnblad and Sjostrand, Eur. Phys. J. C 2 (1998) 165
  - Fiałkowski, Wit and Wosiek, Phys. Rev. D 58 (1998) 94013
  - Ray and Hoffmann, Phys. Rev. C 54, 2582 (1996).
- First 3 of them are designed rather for pp, however authors claim a will for trial for ions as well
  - I Could not find any sign that it ever happened
- The last one works only for high multiplicities

Weighting algorithms

- In fact not an event generation techique but the way of obtaining correlation function from an output generator lacking BE effect.
  - For given particle (four-vector momenta and position) pair returns weight
- Two known to me programs are available
  - Scott Pratt, CRAB
    http://www.nscl.msu.edu/~pratt/freecodes/crab/
  - Lednicky and Lyuboshitz, Sov. J. Nucl. Phys. 35 (1982) 770
    - scan available at
      http://ccdb3fs.kek.jp/cgi-bin/img/allpdf?198110137

HBT simulation tools in Alice

- HBT-Processor
  - After-Burner that induces correlation effect by shifting particle momenta
- Lednicky – Lyuboshitz weighting procedure
  - Creates correlation function from events lacking correlation signal by weights assignment to pairs of particles

HBT Processor

- Developed by Lanny Ray for STAR experiment.
  - Ray and Hoffmann, Phys. Rev. C 54, 2582 (1996).
  - http://alisoft.cern.ch/people/skowron/hbtprocessor/index.html
- Shifts momenta of input events until required shape of correlator(s) is obtained
  - Most brutal from possible techniques but fastest
- Calculates background histograms on fly from input events
  - Needs more than one event at ones to work
  - As more events processed at ones as program is less prone for influence of statistical fluctuations

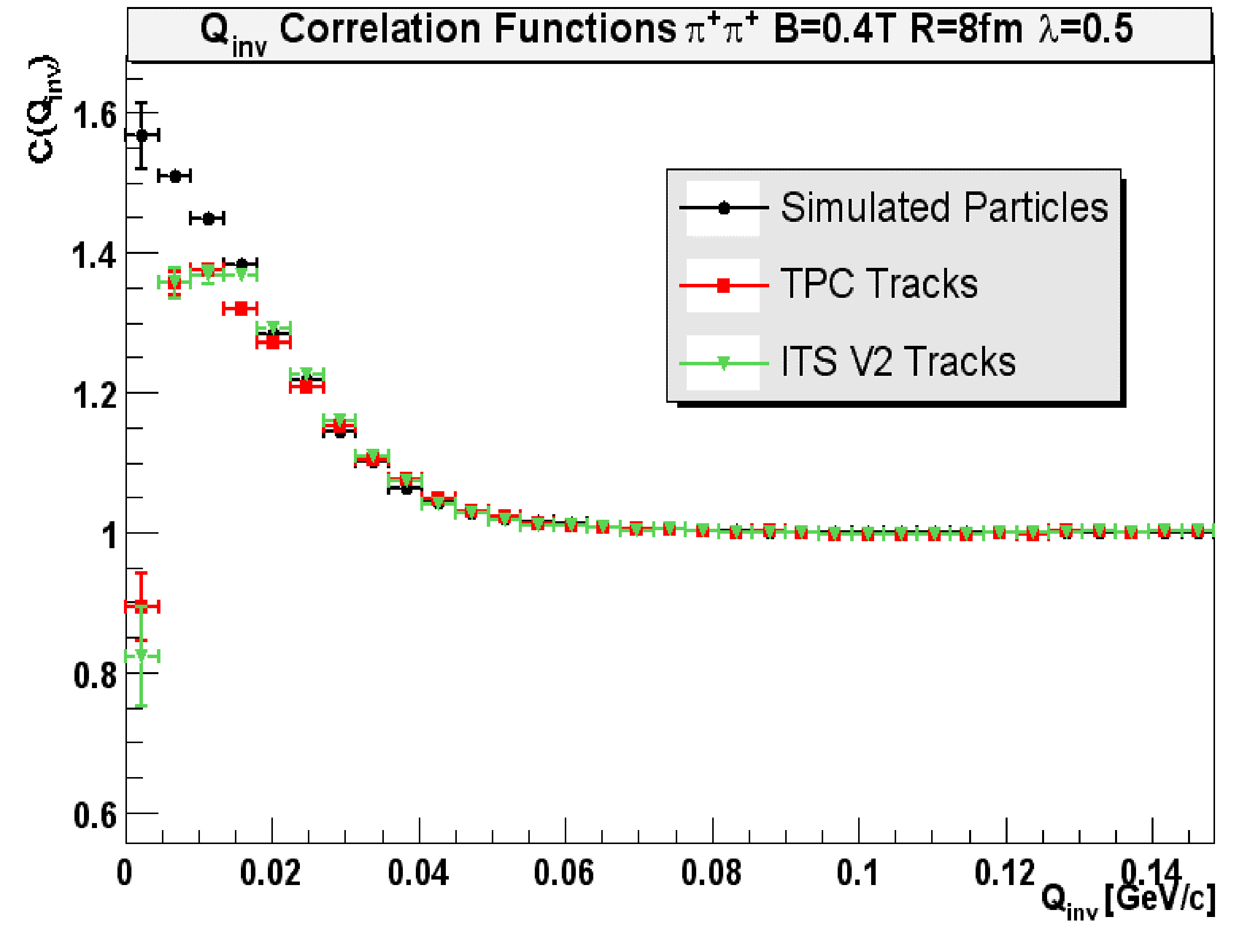
HBT Processor

- Works fine for high multiplicities
- For very high multiplicities events can be binned in p_t, pseudorapidity and ϕ.
  - Number of bins are tuneable parameters
- Does not reproduce pt dependence of radii
  - One can process the same input events several times for different p_t ranges, each time specifying proper radii

HBT Processor

- Coulomb Final State Interactions simulated by convoluting fitted histogram with
  - Gamov factor
  - „NA35" finite source size correction
  - Pratt/Cramer finite source size correction
- Strong interactions not taken to the account
  - Do not work for non-identical particle correlations

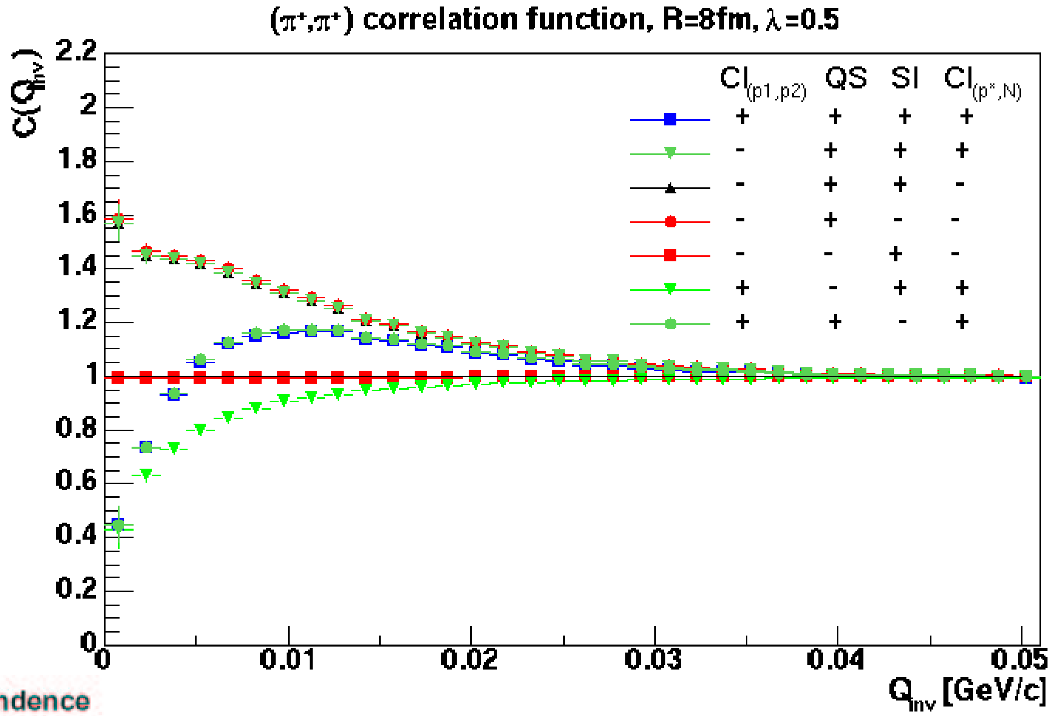
HBT Processor

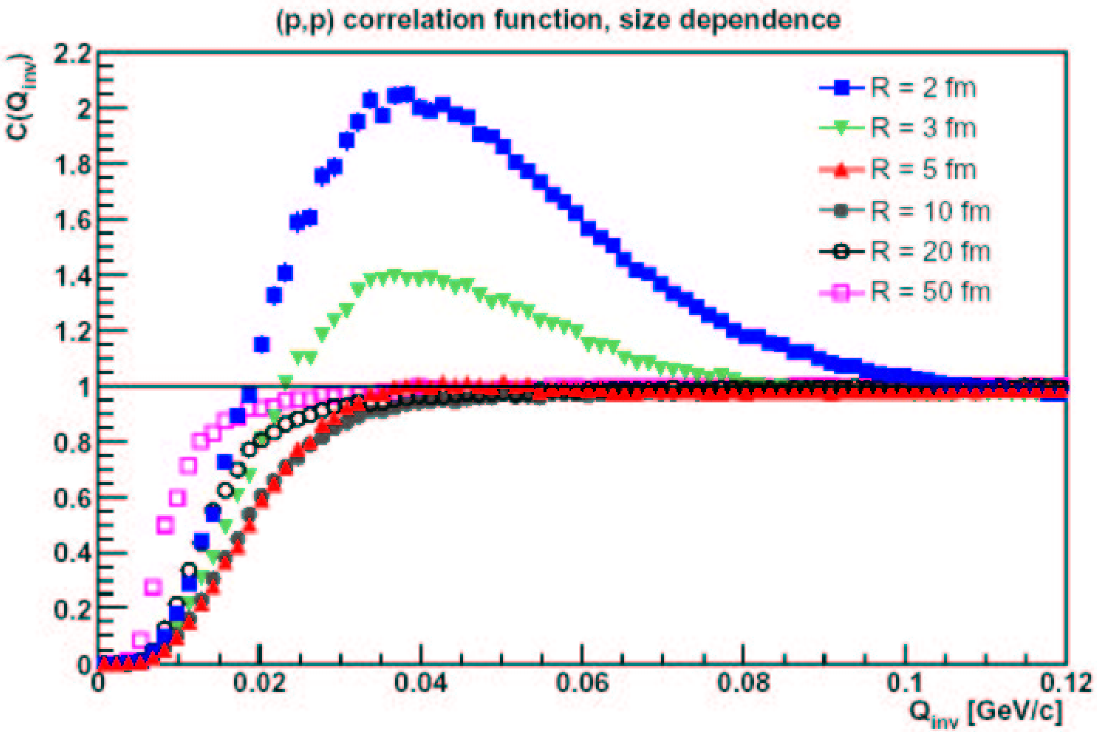


POLITECHNIKA WARSZAWSKA

LL Weights

- Strong FSI included as well as Coulomb interactions
- It is also feasible for detector performance study
  - CF is created by calculating weight for simulated particles, but filling histogram at bin corresponding to reconstructed particles
  - Can be studied this way influence of
    - Tracking efficiency
    - PID inefficiency influence
    - Momentum resolution
    - Double Track resolution





POLITECHNIKA WARSZAWSKA

Availablity

- Both packages are interfaced to C++ and integrated within AliRoot
  - HBT – Processor
    - AliGenHBTProcessor – AliRoot wrapper
    - THBTProcessor – Root wrapper
  - LL Weights
    - Integrated within HBTAN package

Cocktail After - Burner

- For purpose of HBT – Porocessor special wrapper generator was developed

POLITECHNIKA WARSZAWSKA

After Burner Cocktail Wrapper Generator

We have to generate **N** events (>1) and than run After Burner ones, everything before transport

AliStack1 AliStack2 .... AliStack **N**

Generator 1
Generator 2
•
•
•
Generator J

After Burner 1
After Burner 2
•
•
•
After Burner K

N times

1 time

Flow

- Flow is an anisotropy in distribution
  - Momentum
  - Multiplicity
- In our concern is momentum radial and elliptic transverse flow

$$\frac{d^3N}{dp_t\,dy\,d\varphi} = \frac{d^2N}{dp_t\,dy}\frac{1}{2\pi}\left(1 + 2v_1\cos(\varphi) + 2v_2\cos(2\varphi) + \ldots\right)$$

POLITECHNIKA WARSZAWSKA

Flow generation

- Contrary to HBT flow is very easy to simulate
  - Postkanzer and Voloshin presented a determinitic prescription for flow simulation
    - Phys. Rev. C 58 (1998) 1671

$$\varphi \rightarrow \varphi' = \varphi + \Delta\varphi$$

$$\Delta\varphi = \sum_n \frac{-2}{n} v_n \sin[n(\varphi - \psi_0)]$$

POLITECHNIKA WARSZAWSKA

AliFlowAfter and GeVSim

- This algorithm has been implemented within AliRoot by Sylwester Radomski in two ways, as
  - GeVSim event generator
  - Flow After Burner
    - Possibilty of adding flow to events generated by any generator
  - http://radomski.home.cern.ch/radomski

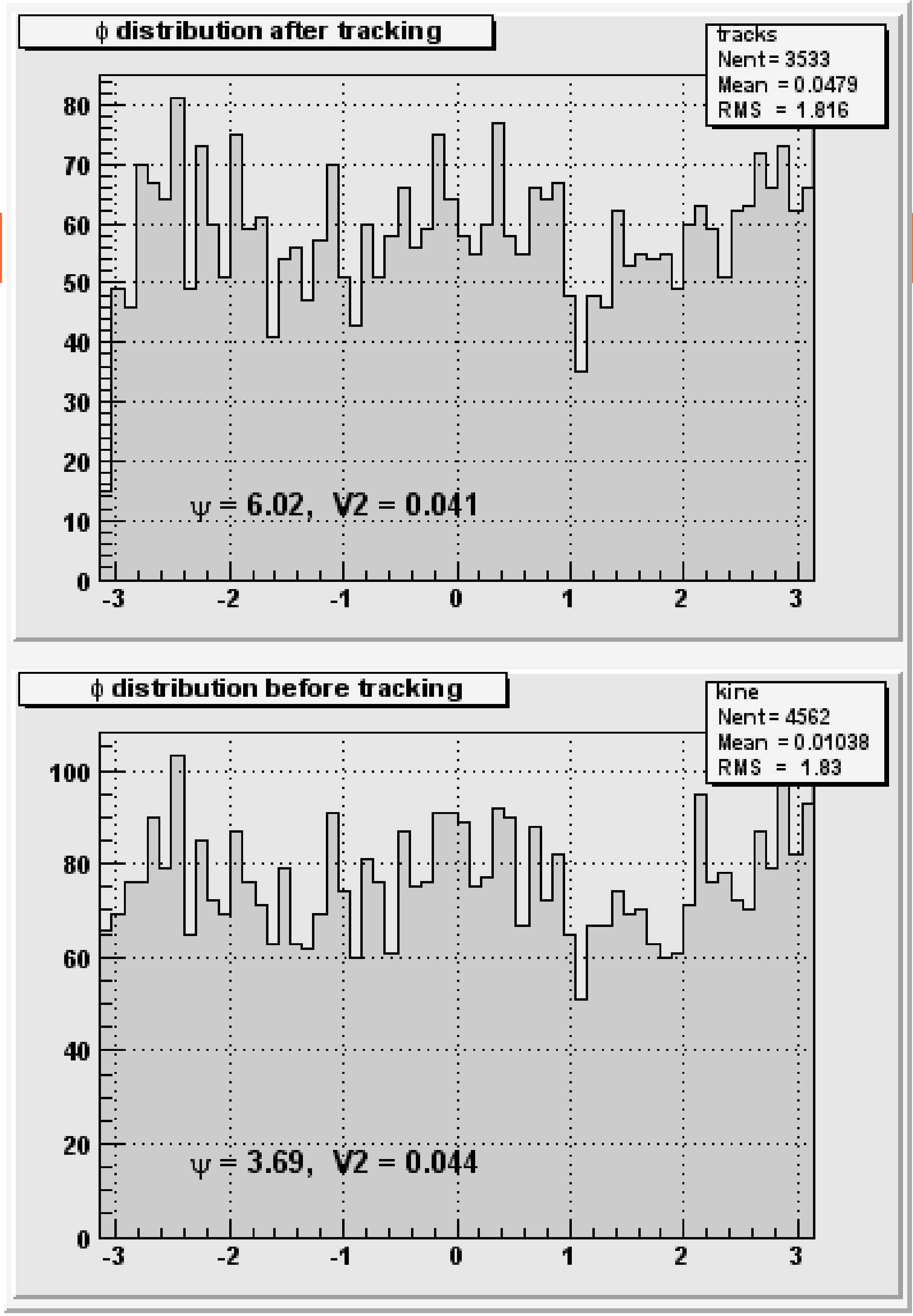
v_2 parametrization

- Two kindes of v_2 parametrization

$$V_2(p_t, Y) = (V_{21} + V_{22} p_t^2) \exp\left(-V_{23} Y^2\right)$$

$$V_2(p_t, Y) = \begin{cases} V_{21}(p_t / p_{t\max}) \exp(-V_{23} Y^2) & p_t < p_{t\max} \\ V_{21} p_{t\max} \exp(-V_{23} Y^2) & p_t \geq p_{t\max} \end{cases}$$

  - Second parameterization is made to reproduce the RHIC data
  - First parameterization is more suitable for heavier particles (protons, kaons) while second for pions
  - User can set arbitrary function in the program



POLITECHNIKA WARSZAWSKA