Tracking of low p_T charged particles

Ferenc Siklér[*]

KFKI Research Institute for Particle and Nuclear Physics
Budapest, Hungary

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Abstract

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[*]E-mail: <sikler@rmki.kfki.hu>. Twiki: CMS/TrackerSoftware.

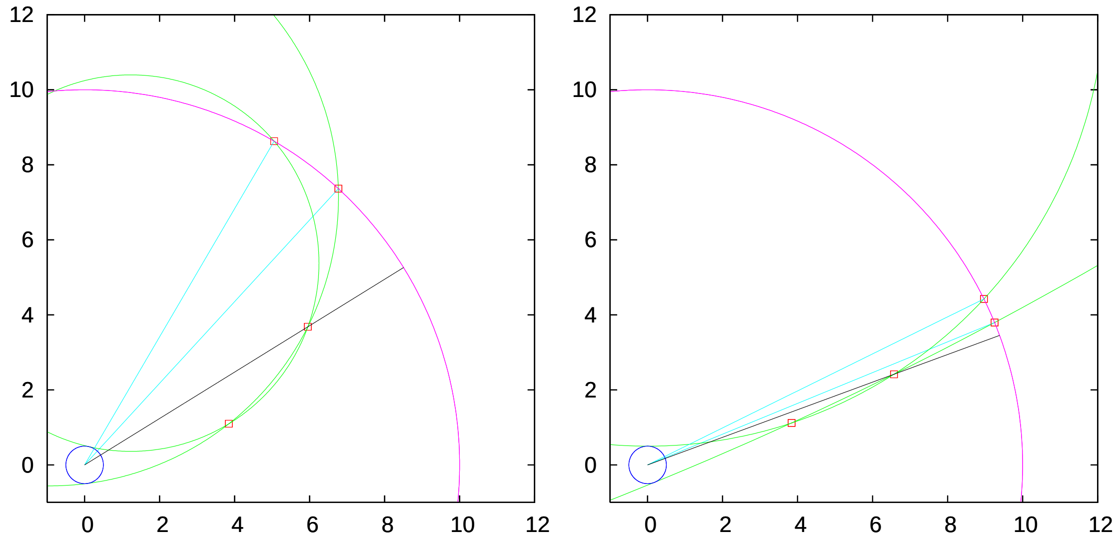

Figure 1: Setting the search range for the third pixel hit, here ϕ range on the third barrel cylinder. The cylinder of origin is shown by the blue circle. The third barrel cylinder is given by the magenta arc. The inner and outer members of the pixel pair are indicated by the two red boxes. The default straight line prediction is illustrated by the thick black line. The two green limiting circles cut out the arc of possible third hits from the third barrel cylinder. The resulted ranges of ϕ are given by the two light blue lines.

1 Introduction

Reconstruction of low p_T charged particles is crucial for hadron physics where measured particle yields, spectra and correlations have to be compared to model predictions. It can also be important for high energy physics in general.

In CMS the high occupancy of silicon strips in central A+A collisions renders their inclusion into charged particle tracking difficult. The use of silicon pixels alone allows to use the same analysis for low multiplicity p+p, p+A and high multiplicity A+A events. At the same time it enables the reconstruction of very low p_T particles, down to 200 MeV/c.[1]

The default pixel tracker algorithm first finds pixel hit pairs, then for each pair it predicts the range of position of the corresponding third pixel hit. The prediction uses straight line for the r and z coordinates. In case of ϕ the prediction is simply the corresponding value of the outer hit. Tolerances are set to take in account the effects of multiple scattering. When going to lower p_T, the nature of the prediction sets back (and below $p_T \approx 500$ MeV/c even disables) the reconstruction of particles.

2 Modified hit triplet finding

Low p_T particles can be found if the search for the third pixel hit is modified, keeping the logic of pixel track finding intact. In the small volume of the pixel detector the magnetic field is practically constant, the charged particles propagate on helices. Their projections onto the transverse plane are circles. During the search for the third hit the following requirements must be fulfilled:

- the track comes from the cylinder of origin
- its p_T is above the minimal value $p_{T,min}$
- track is able to reach the third barrel/forward layer

[1] A particle can reach the third pixel barrel layer if $p_T \geq 0.3B\frac{R_3}{2} = 0.3 \cdot 4 \cdot 0.10/2 \approx 60\text{MeV}/c$

With a given circle of origin and two points, every requirement defines a pair of so called limiting circles (see Fig. 1). Details on their geometry are given in Appendix A. Every pairs of limiting circles cut out an the arc from the third barrel cylinder/endcap disk where potential thirds hits may be located. The ϕ range it then given by intersection of these arcs. The z or r range can be calculated, as well.

Third hit candidates in the predicted (ϕ, r) or (ϕ, z) ranges are collected next. The combination of the members of the original pair and a candidate gives three spatial points. They define unambiguously a circle on the transverse plane. Due to the nature of the helix, there is a linear relationship between the azimuthal angle with respect to the center of the circle and the z coordinate. This way the z coordinate of the third hit can be predicted. The prediction is compatible (and the third hit is accepted) if it falls within 4 standard deviations expected from multiple scattering. In the low momentum range multiple scattering behaves as $\theta_0 \propto 1/(\beta p)$, where θ_0 is the standard deviation. Note that θ_0 is roughly inverse proportional to the mass of the particle, so protons scatter much more than pions.

The constructed hit triplets, pixel tracks, can be already passed to the usual momentum fitting procedure.

3 Triplet cleaning

While high p_T tracks are relatively clean, pixel hits can often be combined to form fake low p_T tracks. It is therefore important to filter out this unwanted background. Two tools have been developed.

3.1 Shape of the pixel cluster

This tool checks whether the shape of the pixel hit (cluster) is compatible with the predicted thrust of the track. The shape of the cluster and the measured ADC values contain exploitable information.[2] 10 million particles with random angle of incidence have been generated and their energy deposits collected in the pixels of a model silicon unit (pitches 155 μm, 101 μm and thickness 300 μm). A pixel was filled if the deposited energy reached the threshold $5 \cdot 3.7 = 18.5$ ADC. A pixel cluster can be described by the dimension of the rectangular envelope, in pitch units. As a result of the simulation, for a given size of envelope the region of compatible angles can be provided.

The hit might also be skipped if it is at the boundary of a silicon unit or its shape is not compatible with a single particle hit (e.g. it has "legs" due to δ-electrons or multiple hits).

3.2 Lost points

This tool checks if the track has lost point(s) along its path.

4 Results

Most of the following plots are done using 1000 minimum bias p+p events with reconstruction parameters (`ptMin` = 0.075 GeV/c; `originRadius` = 0.2 cm; `originHalfLength` = 15 cm; `originZPos` = 0 cm). Note that in case of p+p no assumption is made on the position of the primary vertex.

For central Pb+Pb collisions the low p_T limit was increased and the particles have been required to come from the neighborhood of the previously determined primary vertex (`ptMin` = 0.175 GeV/c; `originRadius` = 0.1 cm; `originHalfLength` = 0.1 cm). Pixel clusters at the boundary of silicon unit or clusters with shape not compatible with a single particle hit are not used.

[2] Often the parameters of the track (q, p_T, η) can be calculated with good precision. They can also be used for the determination of the specific energy loss (dE/dx) of the particle.

all simulated	40294
reconstructable	27834
reconstructed	195371
filtered	14718
resolved	10937

Table 1: Number of tracks at different stages of reconstruction in a central Pb+Pb event.

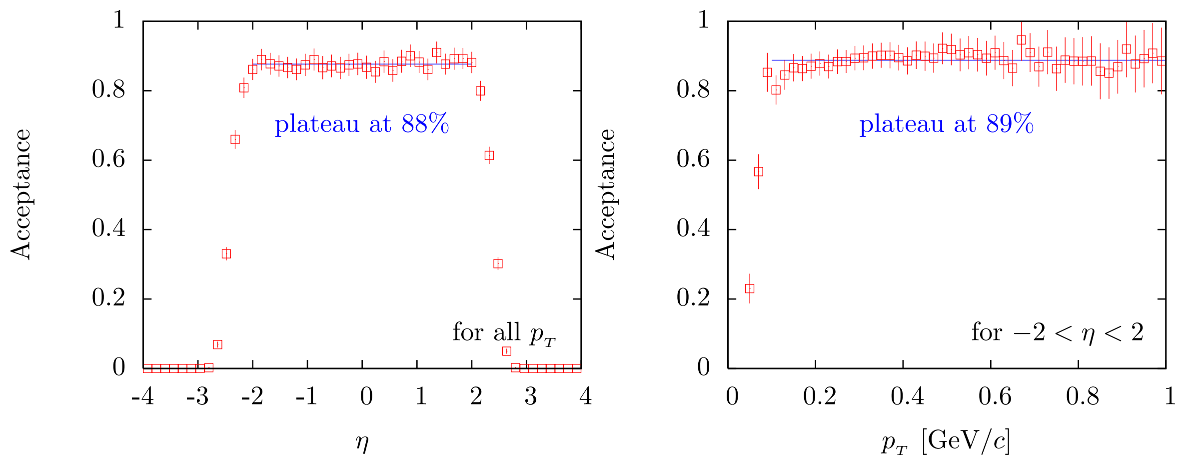

Figure 2: Acceptance for charged particles as function of pseudo-rapidity η and transverse momentum p_T.

4.1 Geometrical acceptance

A track is reconstructable if its vertex is the cylinder of origin and if it has at least three hits in the five different groups of pixel layers (first, second and third barrel; closer and farther endcaps).

4.2 Algorithmic efficiency

Multiple counting.

4.3 Fake rate

Acknowledgement

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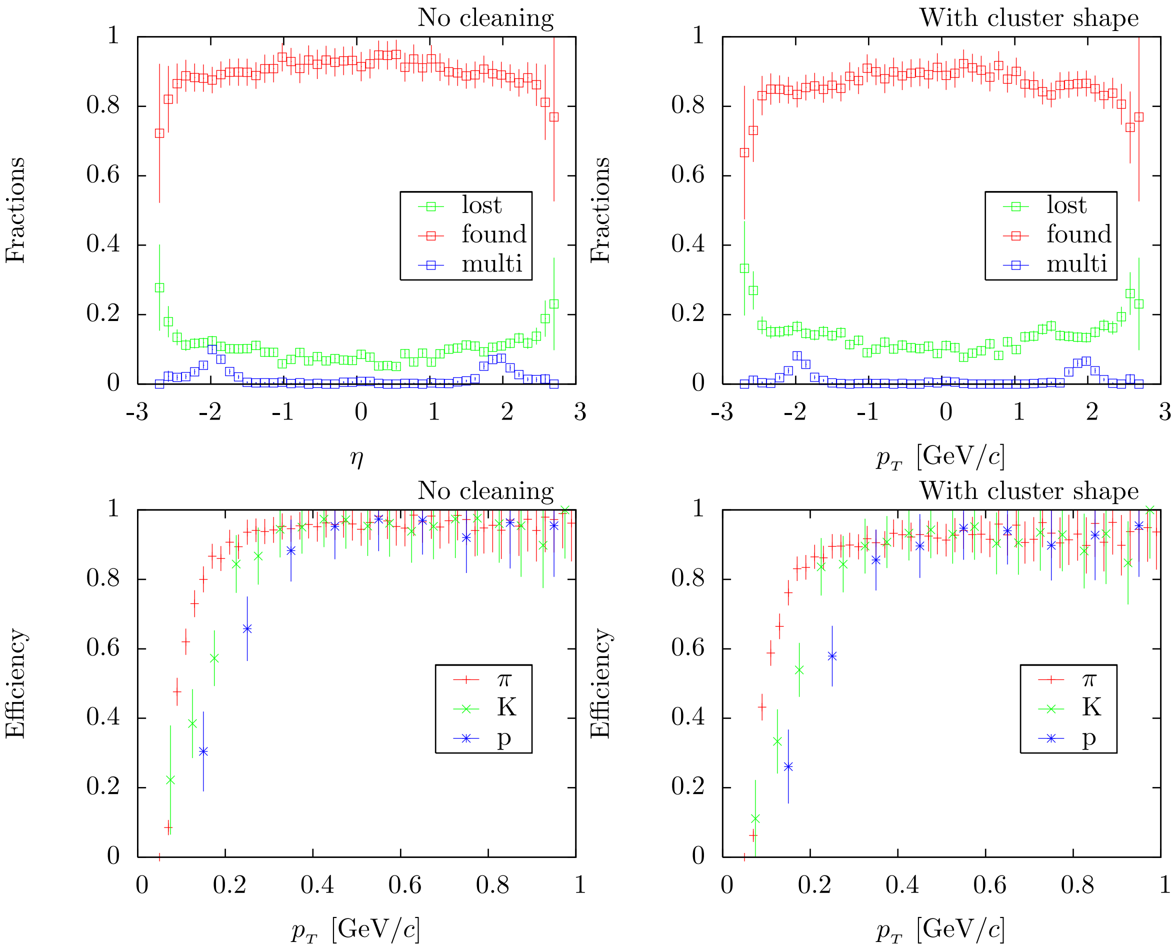

Figure 3: Efficiency as function of pseudo-rapidity η and transverse momentum p_T without triplet cleaning and with switching on checks for cluster shape.

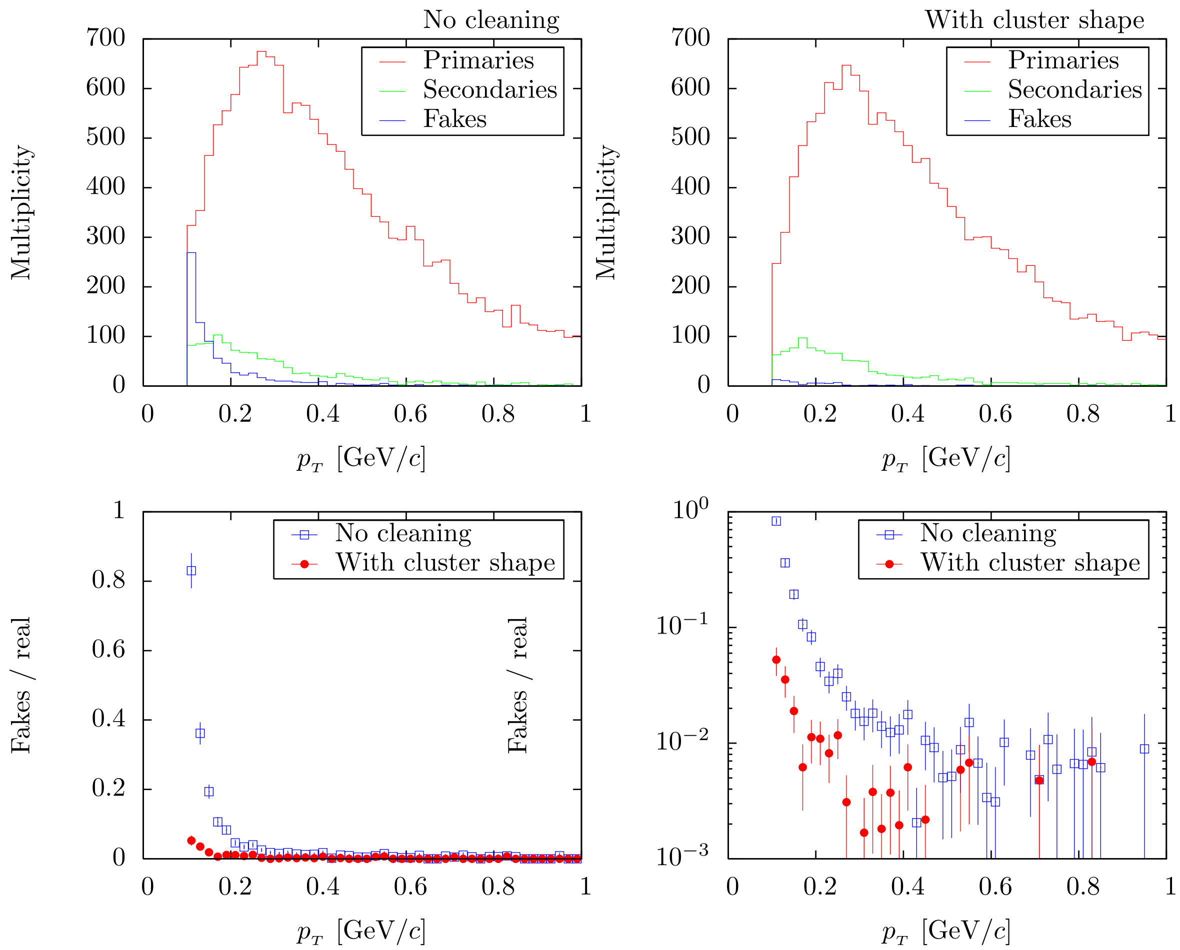

Figure 4: The upper plots give the p_T distribution of reconstructed primaries, reconstructed secondaries and fakes, without triplet cleaning and with switching on checks for cluster shape. The lower plots show the ratio of fakes to real (primary and secondary) tracks, in linear and in logarithmic scale.

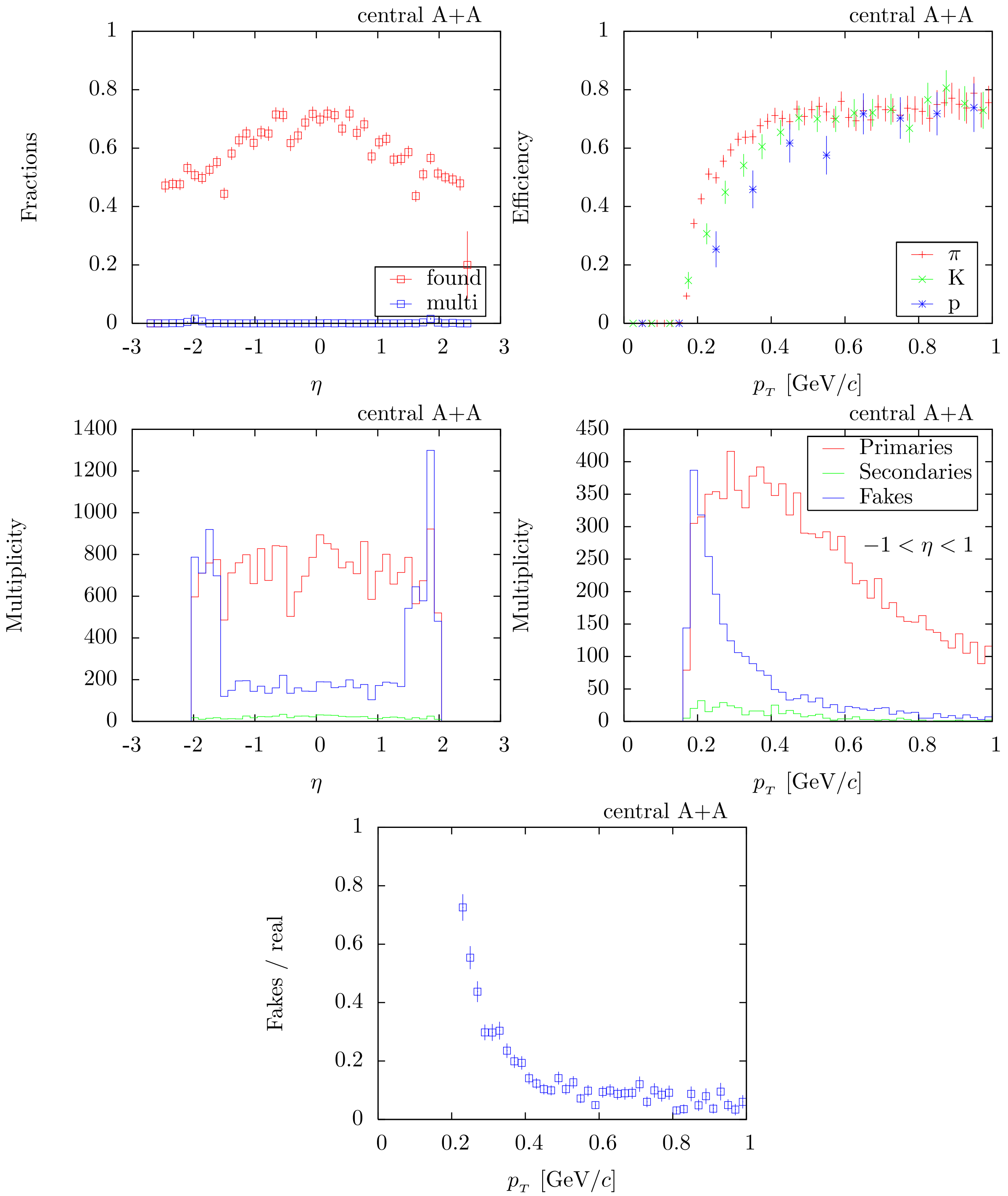

Figure 5: Upper plots: efficiency as function of η and p_T. Lower plots: distribution of reconstructed primaries, reconstructed secondaries and fakes; the ratio of fakes to real (primary and secondary) tracks, in linear and logarithmic scale.

P_1	inner hit, center of the inversion
P_2	outer hit
P_3	hypothetical third hit
k	radius of the inversion circle, P_1P_2
c_0	circle of origin, with center O and radius r_0
c_3	circle on which P_3 lies, with center O and radius r_3

Table 2: Some notations relevant to the discussion of geometry.

A Geometrical supplement, details

Some notations are summarized in Table 2. The relevant problems and solutions are listed below. Most of them use an inversion with center P_1 and radius $k = P_1P_2$. The inverse of P_2 is itself. A circle passing through both P_1 and P_2 is inverted into a line touching P_2.

1. Find a circle which passes through the points P_1 and P_2 and touches c with center O and radius r.

   The circle c will be inverted into another circle c' with center $O' = P_1 + s(O - P_1)$ and radius $r' = |s|r$, where $s = k^2/(OP_1{}^2 - r^2)$.

2. There are two lines tangent to the circle c' and passing though the point P_2. Calculate the angle χ between $\mathbf{P_2O'}$ and the lines with as few as possible function calls.

   Let R denote the distance P_2O'.

   $$\sin\chi = \frac{r'}{R} \qquad\qquad \chi = \frac{1}{2}\arccos\left(1 - \frac{2r'^2}{R^2}\right) \tag{1}$$

   Here the identity $\sin^2\chi = (1 - \cos 2\chi)/2$ was used.

3. A circle c_m with radius r_m passes through the points P_1 and P_2. c_m is inverted into the line l_m. Calculate the angle χ_m between $\mathbf{P_2P_1}$ and l_m with as few as possible function calls.

   Similarly

   $$\sin\chi_m = \frac{k}{2r_m} \qquad\qquad \chi_m = \frac{1}{2}\arccos\left(1 - \frac{k^2}{2r_m^2}\right) \tag{2}$$

4. A central angle can be given by a pair: its center α and half width χ. Find the common part, intersection, of two central angles (α_1, χ_1) and (α_2, χ_2).

   Spin α_2 by adding or subtracting 2π until $|\alpha_1 - \alpha_2| < \pi$. The lower and upper limits are

   $$\text{lower} = \max(\alpha_1 - \chi_1, \alpha_2 - \chi_2) \qquad \text{upper} = \min(\alpha_1 + \chi_1, \alpha_2 + \chi_2) \tag{3}$$

   If lower < upper, the resulting intersection (α, χ) is

   $$\alpha = \frac{\text{upper} + \text{lower}}{2} \qquad\qquad \chi = \frac{\text{upper} - \text{lower}}{2} \tag{4}$$

   Otherwise there two angles do not have an intersection.

5. The inverse of a circle c passing through both P_1 and P_2 is a line c'. It is given by one of its points P_2 and a unit vector v parallel to the line. There is another circle c_3 with center at O and radius r_3. Determine the intersection point P_3 of the circles c and c_3 which is closer to P_2.

   The inverse of c_3 is another circle c_3' with center O_3' and radius r_3' (see point 1). Let $\delta = O_3' - P_2$. The closer intersection point P_3' of the line c' and the circle c_3' is at

$$P_3' = P_2 + \lambda v \qquad\qquad \lambda = \delta v - \sqrt{r_3'^2 + (\delta v)^2 - \delta^2} \tag{5}$$

   The inverse of P_3' gives the wanted point P_3.

6. Determine the center C of the circle c, using results from the previous point.

   The antipodal point of P_1 is A_1. Its inverse A_1' satisfies

$$A_1' = P_2 - v[v(P_2 - P_1)] \qquad\qquad C = \frac{P_1 + A_1}{2} \tag{6}$$

7. Given two points P and Q on a circle c with center C and radius r. Calculate the length of the arc PQ.

$$PQ = r \arcsin\left[\frac{|(P - C) \times (Q - C)|}{r^2}\right] \tag{7}$$