Study of $Ds1(2460)^+ \to Ds^+ + \pi^+ + \pi^-$

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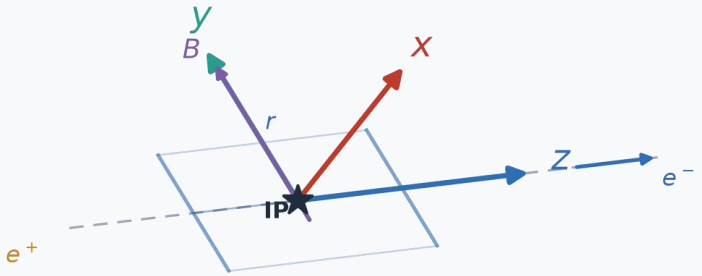
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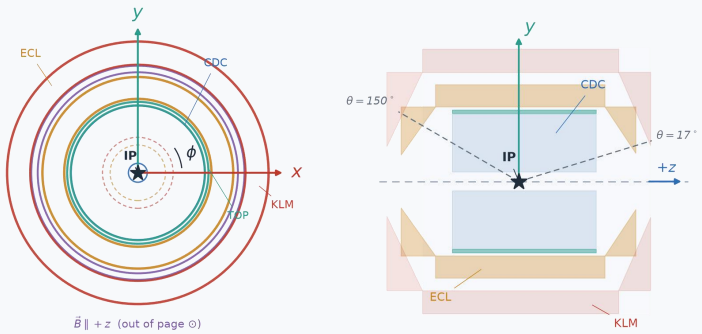
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Introduction-Frame

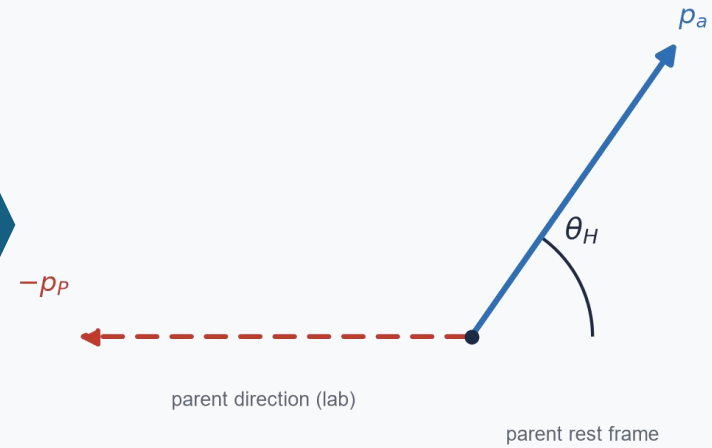
1 From the 3D detector



2 To the lab frame



3 To the helicity angle



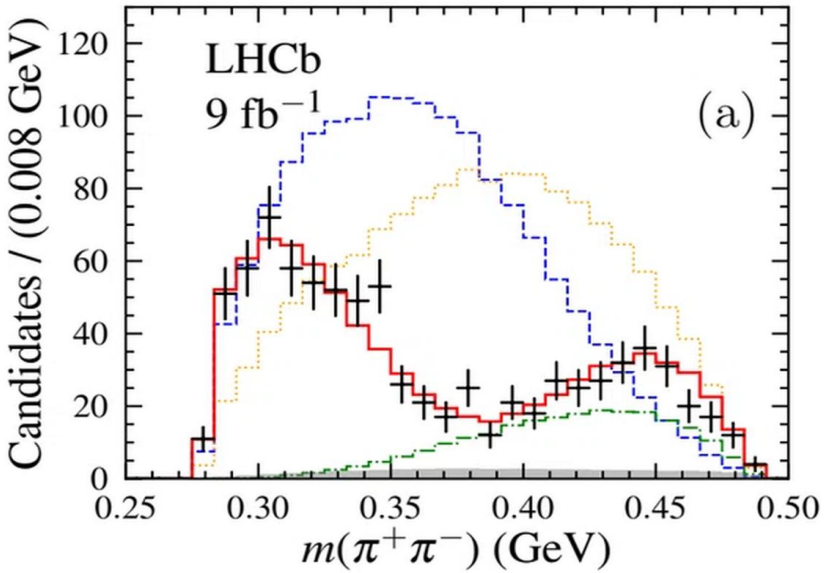
cylindrical, $B \;//\; z$

$$r = \sqrt{x^2 + y^2}$$
$$\varphi = atan2(y, x) \in (-\pi, \pi]$$
$$\theta \in [0, \pi],\; p_T = p\sin\theta$$

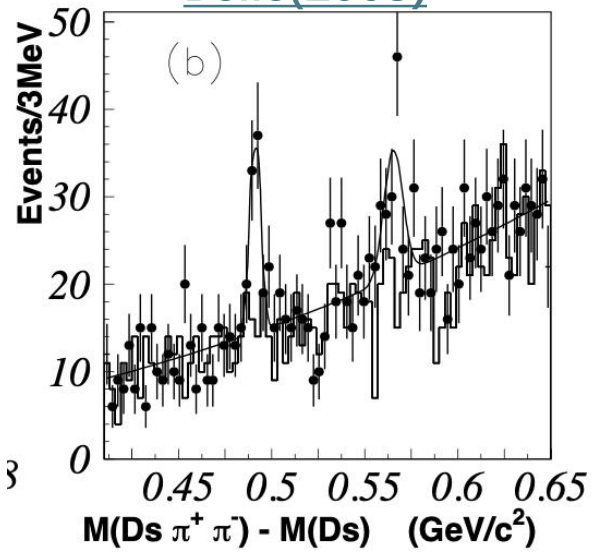
$$\cos\theta_H = p_a \cdot (-p_p)/(|p_a||p_p|)$$

Motivation

HADRONIC · LHCb, 9 fb⁻¹, 2025



Belle(2003)



Puzzle

- $D_{s1}^{+}(2460)$ masses are much lower than the expectation in the quark mode, very narrow, sitting just under the D*K threshold.
- Theoretical calculations predict a double bump lineshape in the $\pi^+\pi^-$ invariant-mass spectrum in this decay if the $D_{s1}^{+}(2460)$ meson is a D^*K hadronic molecule

Data sets

Software:

basf2 + b2bii,

Generate: release-09-00-15

Run: light-2607-kasei

Generic MC:

Belle generic MC, 711 fb^{-1}

Signal MC:

2×10^5 Ds1 events

Decay mode:

$Ds1(2460)^+ \rightarrow Ds^+\pi^+\pi^-$, $Ds^+ \rightarrow K^+K^-\pi^+$

Decay card:

```
Decay vpho
1.0 PYCONT 0 0 0 1 0 0   0 0 0 0 0 0;
Enddecay
Decay D'_s1+
1.000   MyDs+  pi+ pi-   PHOTOS  PHSP;
Enddecay
Decay D'_s1-
1.000  MyDs-  pi+ pi-   PHOTOS  PHSP;
Enddecay
Decay MyDs+
1.000 K- K+  pi+ PHOTOS  D_DALITZ;
Enddecay
Decay MyDs-
1.000 K+ K- pi- PHOTOS  D_DALITZ;
Enddecay
```

Event Selections

Tracks

K^+ π^+

$|dr| < 0.4$ cm,
$|dz| < 4.0$ cm

K/π PID:
K: L(K/ π)>0.6
π : L(K/ π)<0.4

D_s^+

| m(KKπ) − 1.968 | < 70 MeV

then a tree fit

$D_{s1}^+(2460)$

$M(D_{s1}^+(2460) - D_s^+) < 700$ MeV

and $xp > 0.5$

then a tree fit

Five tracks, two mass windows, one candidate — one number per event. Every page after this one is a histogram of it.

Event selection

The same Ds1. The Ds inside it can decay two ways, so we keep two samples.

Channel 1

$$D_s^+ \to \varphi\pi^+$$

$$\varphi \to K^+K^-$$

mass window
$|\, m(K^+K^-) - 1019.5\ \text{MeV}\,| < 15\ \text{MeV}$

Channel 2

$$D_s^+ \to K^{*-}K^+$$

$$K^{*-} \to K^-\pi$$

mass window
$|\, m(K^-\pi^+) - 895.6\ \text{MeV}\,| < 50\ \text{MeV}$
and outside the φ window

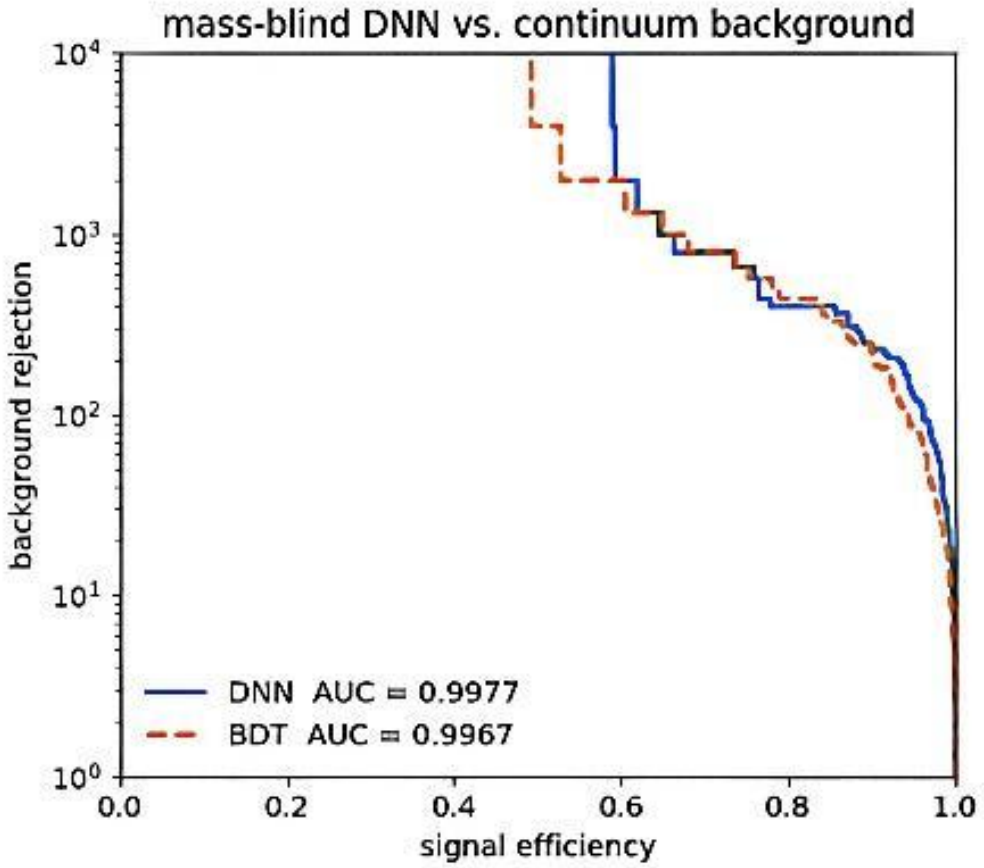
A candidate belongs to exactly one of the two — never both — so the samples can be added once the split has been checked.

Why split: φπ and K*K probe different Ds dynamics — and together they hold 8.7% of the truth-matched signal, as expected from B(Ds → φπ, K*K).

MVA Analysis

A mass-blind network: 42 inputs, and neither InvM nor Ds_InvM is one of them.

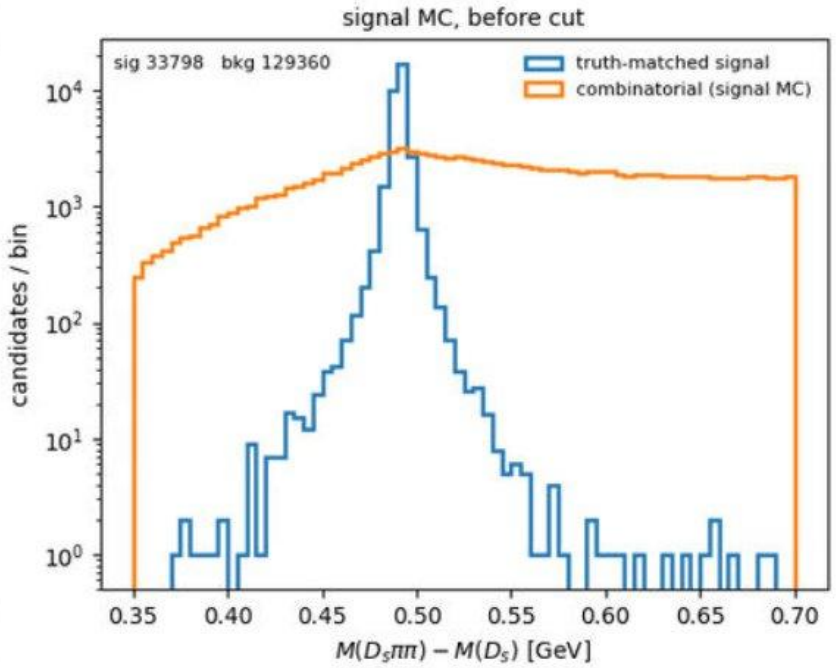
	DNN 42 inputs	BDT 42 inputs
Test AUC	**0.9977**	**0.9967**
background rejection, $\boldsymbol{\varepsilon_s}$ = 90%	**248×**	**233×**
background rejection, $\boldsymbol{\varepsilon_s}$ = 80%	**396×**	**496×**
best $\boldsymbol{\varepsilon_s/\sqrt{\varepsilon_b}}$	**9.45**	**9.39**

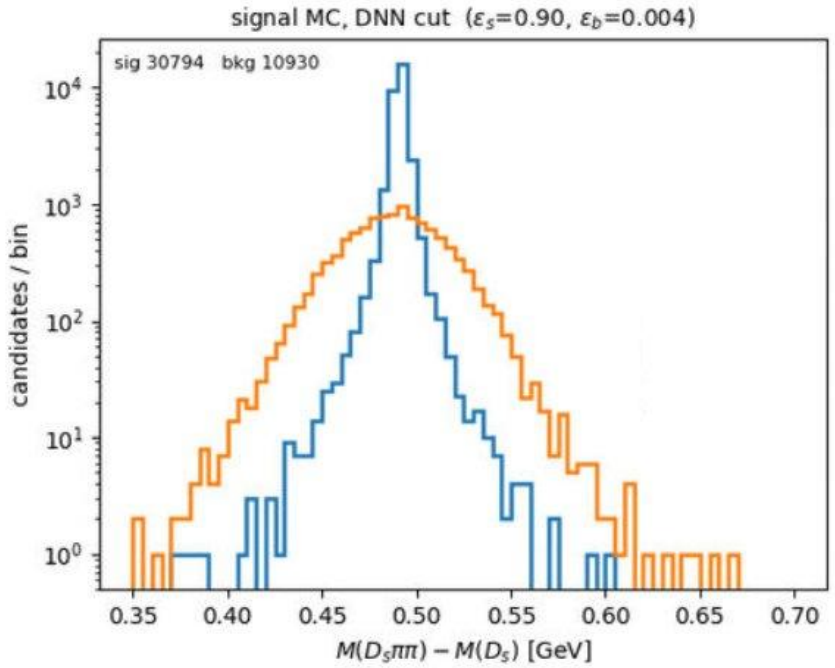


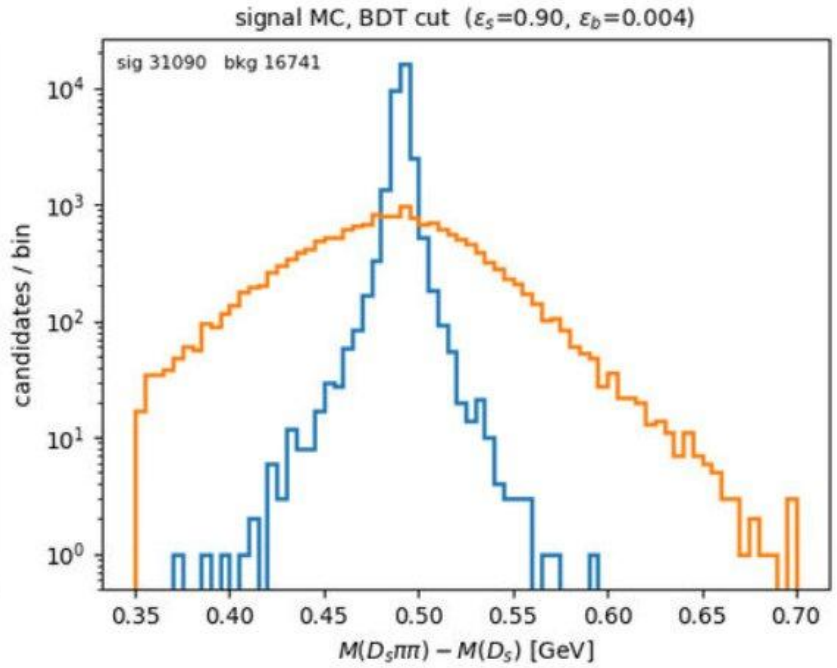
Same 90% signal efficiency: the DNN rejects 248 times the background, the BDT 233 — a 6% gap, and the BDT takes over at looser points.

Results

Signal MC, 90% working point: truth-matched signal vs the combinatorial candidates in the same sample.







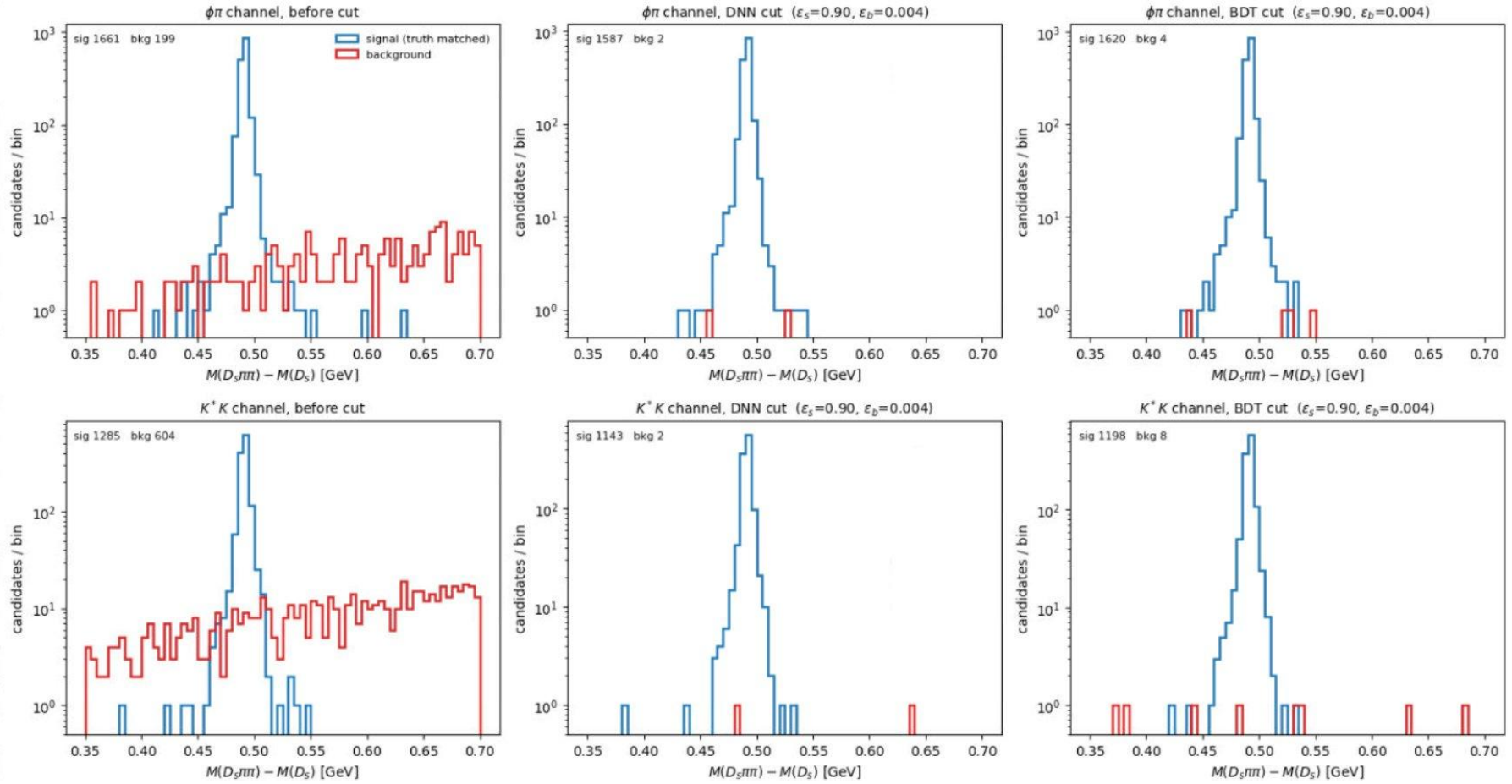
91% **of the true signal kept**
33,798 → 30,794

92% **of the combinatorial background removed**
129,360 → 10,930

What survives is no longer flat: the remaining combinatorial candidates pile up at 491 MeV. So the cut is a preselection — the peak is still the fit's job.

Results

The two channels separately: each keeps its signal and loses its background.



φπ channel

1,661 → 1,587

signal candidates

199 → 2

background candidates

K*K channel

1,285 → 1,143

signal candidates

604 → 2

background candidates

Signal MC, after the DNN cut at $\varepsilon_s = 90\%$: the same $D_{s1}^{+}(2460)$ peak in both channels, with clear background.

Summary

A complete chain.

Belle 711 fb^{-1} of data, generic MC at 1:1, 2×10^5 signal events — reconstructed through $\mathrm{Ds1(2460)^+} \to \mathrm{Ds^+} + \pi^+ + \pi^-$, $D_s^+ \to K^+K^-\,\pi$.

Two channels, one state.

φπ and K*K are mutually exclusive, and both reconstruct the same $D_{s1}^+(2460)$ peak.

Background suppression.

Apply MVA analysis with DNN and BDT framework that suppress the background efficiently .

Next to do.

Fit $D_{s1}^+(2460)$with the residual background shaped from sidebands and generic MC; then the m(ππ) spectrum — that is where the molecule question is settled.

Thanks for listening!

Back up - MVA 训练输入变量

运动学与事件环境

母粒子与 Ds 动量、反冲质量及事件径迹数

xp · ps · mRecoil
Ds_xp · Ds_ps
nTracks

顶点与飞行信息

顶点拟合质量、飞行距离及其测量误差

chiProb · chisq
fl · flerr
Ds_chiProb · Ds_chisq
Ds_fl · Ds_flerr

粒子鉴别 PID

额外 π 与 Ds 末态的 K/π 鉴别信息

pipkid · pimkid
Ds_p0kid · Ds_p1kid
Ds_p2kid

子系统不变质量

ππ、Dsπ 及其他子系统的质量信息

mpipi · mdspip · mdspim
m3pi · mpipif
Ds_m02 · Ds_m12

螺旋度角信息

母粒子衰变及 Ds 子共振的角信息

coshelids · coshelipi
Ds_cosheliphi
Ds_cosheliks

末态径迹运动学

五条末态径迹的动量与极角余弦

Kp_p · Kp_cosTheta
Km_p · Km_cosTheta
pip_p · pip_cosTheta
pi1_p · pi1_cosTheta
pi2_p · pi2_cosTheta
pi1p · pi2p