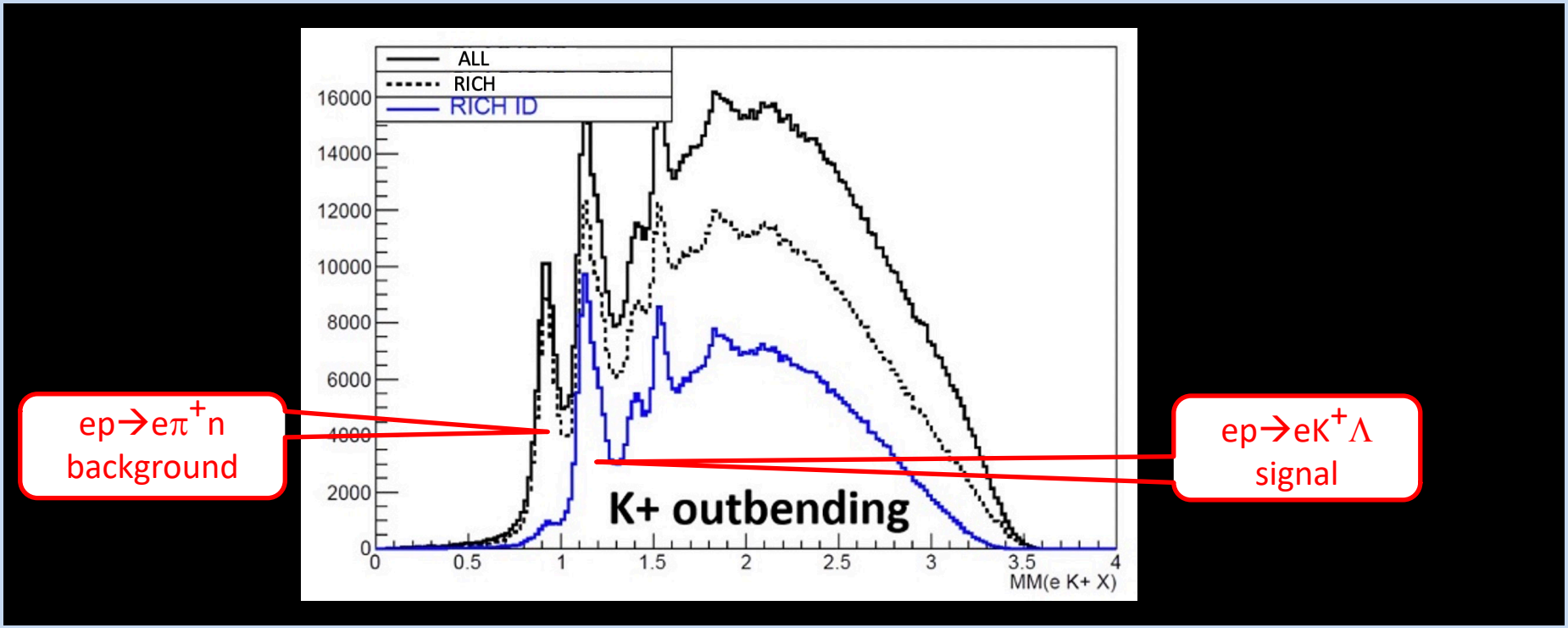
RICH Software

Pass1: direct photons and single reflection

Pass2: full acceptance (multiple reflections), RICH PID and 2nd module

all particle ID hypothesis, multi-thread safe, multi-particles, complete photon path tagging
likelihood PID for single photon and single particle



RICH Software

Features: large volume, > 50k readout channels, complicated topology

→ need large statistics for calibration

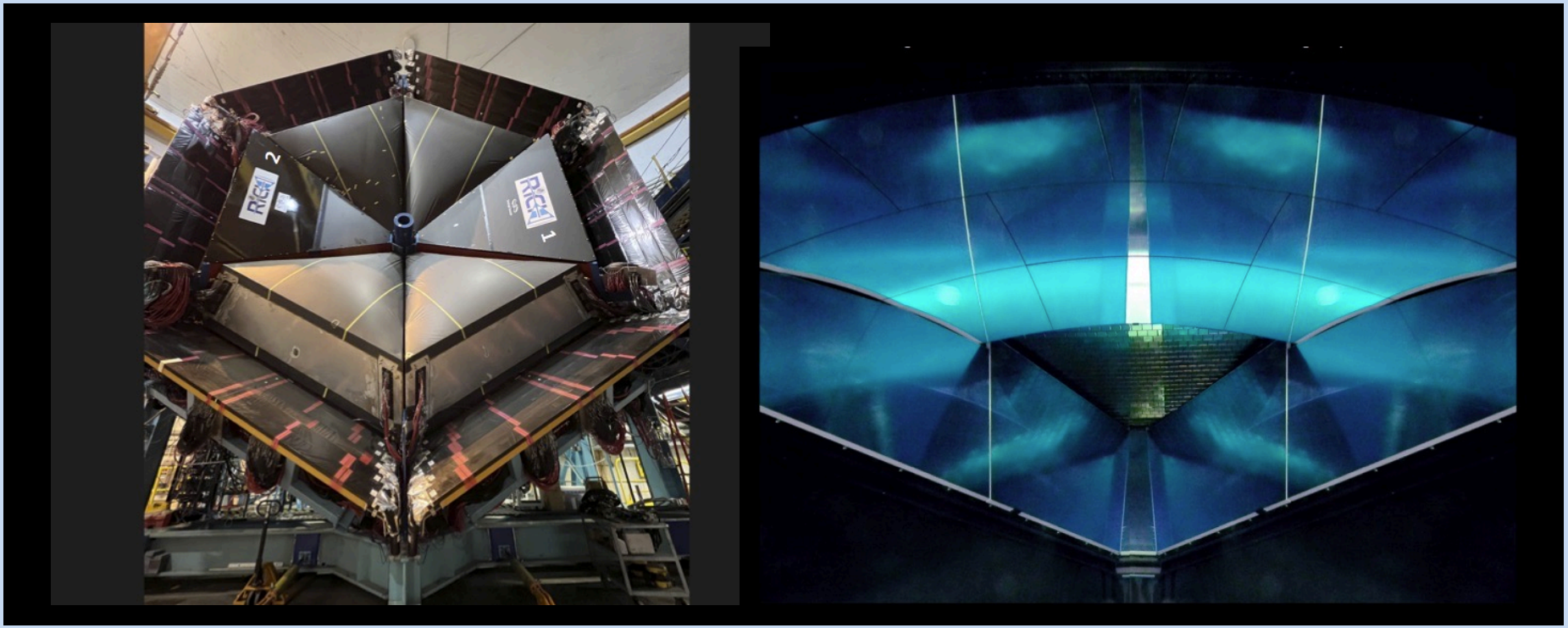
→ calibration possible from DSTs (not only calibration runs)

single photon reconstruction for high-level pattern recognition and PID

→ require DC track impact point and angle, use EB PID

→ interplay (merge) with EB only possible for two sectors and relevant for multi-particle events

→ post-process with specific hipo banks



Pass2

RICH Pass2 Package

RICH Engine:
reconstruction/rich/src/main/java/org/jlab/rec/rich/*

DataBank Reading:
common-tools/clas-reco/src/main/java/org/jlab/clas/detector/RingCherenkovResponse.java

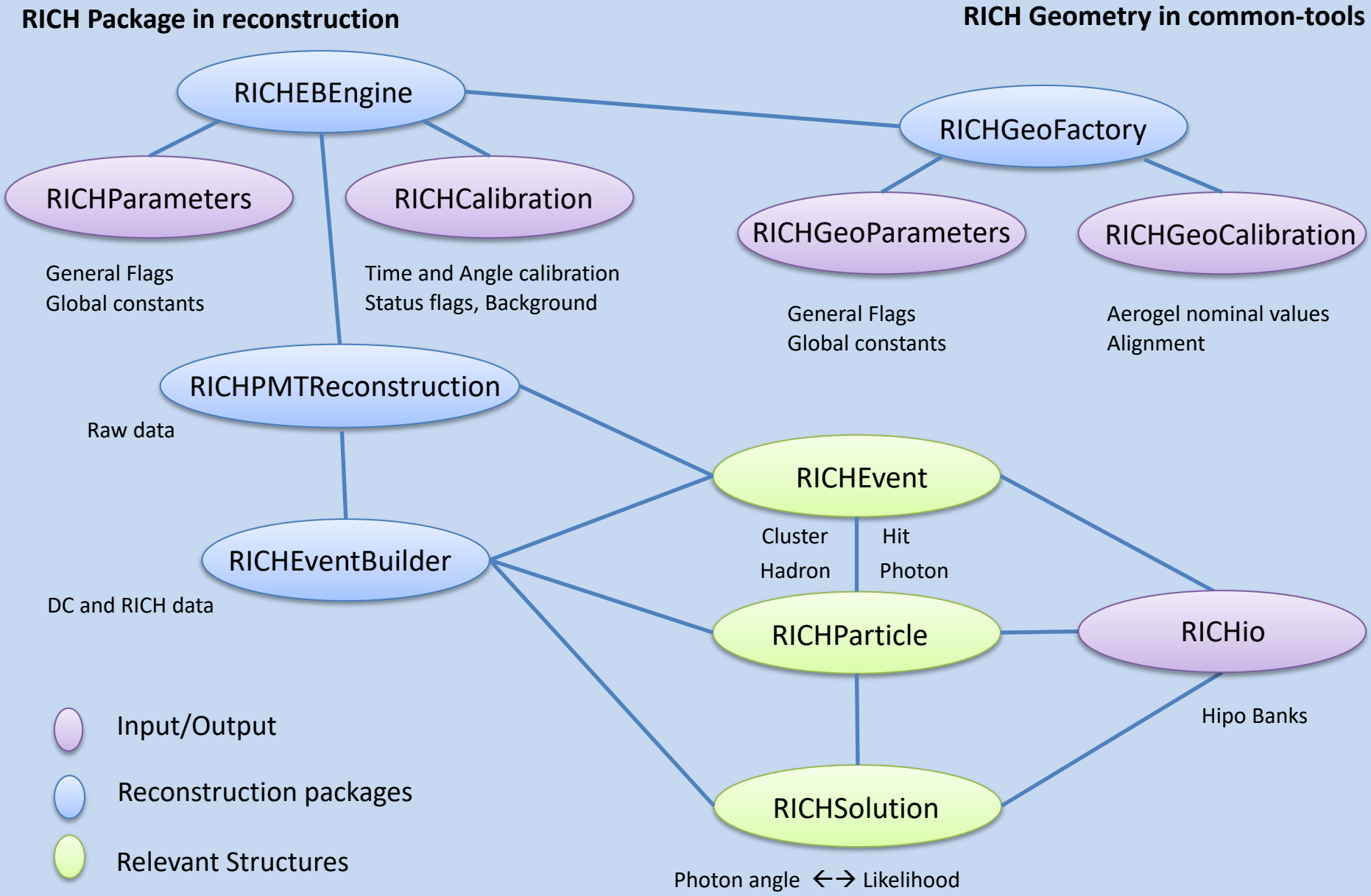
CSG Geometry:
common-tools/clas-jcsg/src/main/java/org/jlab/detector/geant4/v2/RICHGeant4Factory.java
common-tools/clas-jcsg/src/main/resources/rich/cad/*

Geometry Package:
common-tools/clas-jcsg/src/main/java/org/jlab/detector/geom/RICH/*

Hipo Banks:
coatjava/etc/bankdefs/hipo/RICH.json

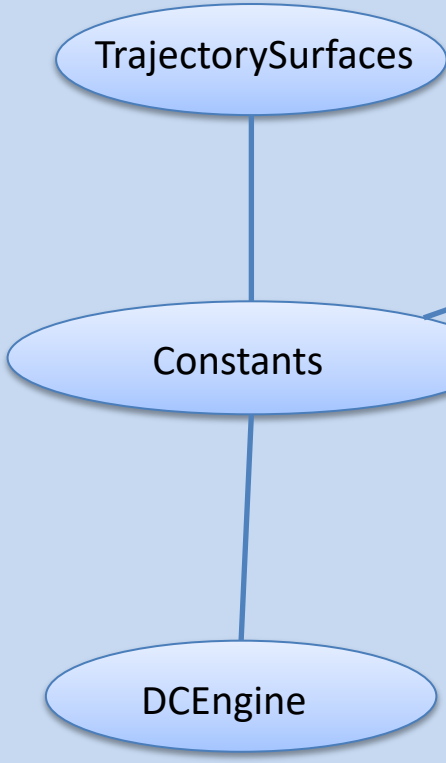
CCDB Tables:
geometry/rich
calibration/rich

Pass2

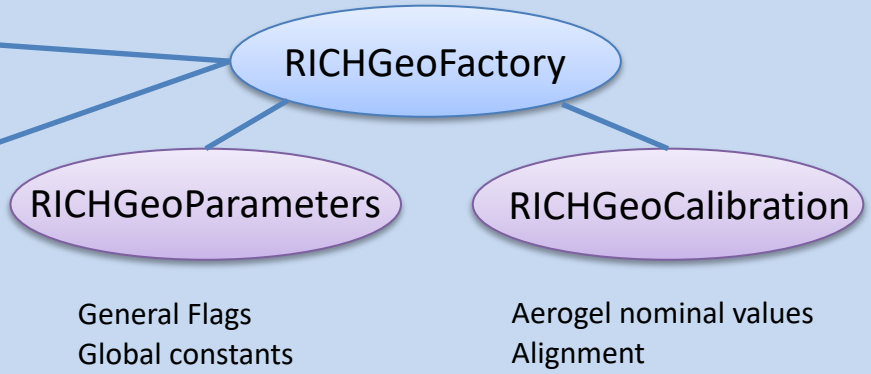

RICH Package in reconstruction
RICH Geometry in common-tools
RICHEBEngine
RICHGeoFactory
RICHParameters
RICHCalibration
RICHGeoParameters
RICHGeoCalibration
General Flags
Global constants
Time and Angle calibration
Status flags, Background
General Flags
Global constants
Aerogel nominal values
Alignment
RICHPMTReconstruction
Raw data
RICHEvent
RICHEventBuilder
Cluster
Hadron
Hit
Photon
DC and RICH data
RICHParticle
RICHio
Hipo Banks
RICHSolution
Photon angle ←→ Likelihood
Input/Output
Reconstruction packages
Relevant Structures

Pass2

DC Package in reconstruction

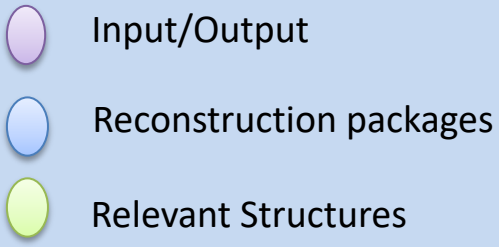


RICH Geometry in common-tools



General Flags
Global constants

Aerogel nominal values
Alignment




```
package org.jlab.detector.base;

public class DetectorLayer {

   public static final byte CND_INNER=1;
   public static final byte CND_MIDDLE=2;
   public static final byte CND_OUTER=3;

   ..........
   public static final byte RICH_MAPMT=1;
   public static final byte RICH_AEROGEL_B1=2;
   public static final byte RICH_AEROGEL_B2=3;
   public static final byte RICH_AEROGEL_L1=4;
}
```

RICH Geometry

Read CSG volumes from CAD stl files

Convert volumes into tracking surfaces (Shape3D) and spheres (Sphere3D) with given orientation

Each Sphere3D has an associated Shape3D to define its solid angle of acceptance

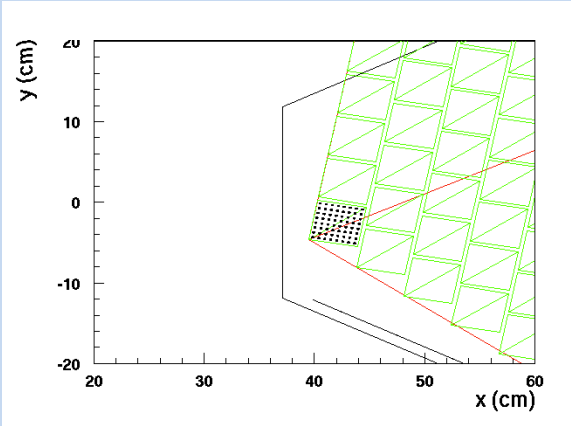
Misalign the tracking surfaces (as per mounting points)

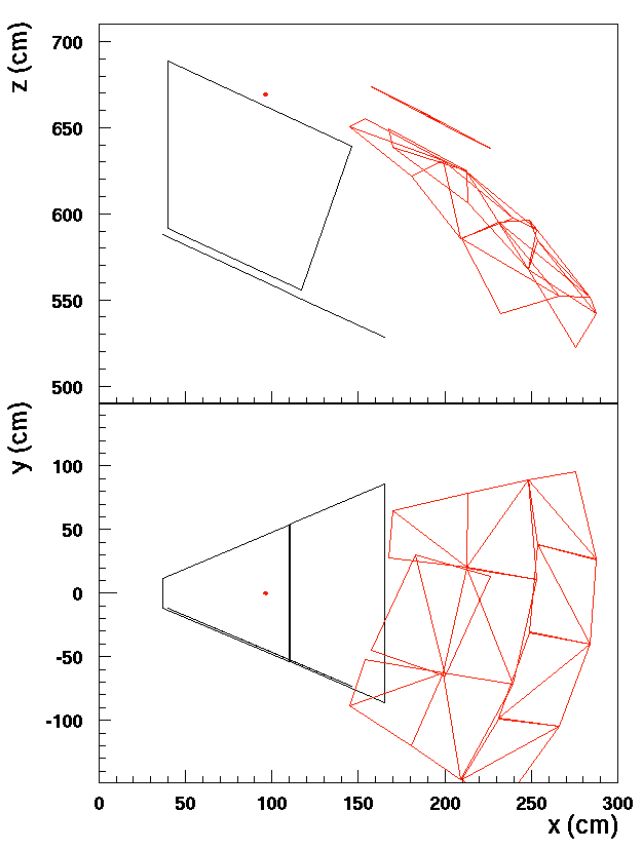
Global RICH

Layer (aerogel, MaPMTs, spherical mirror assembling)

Components (each single mirror, aerogel tile)

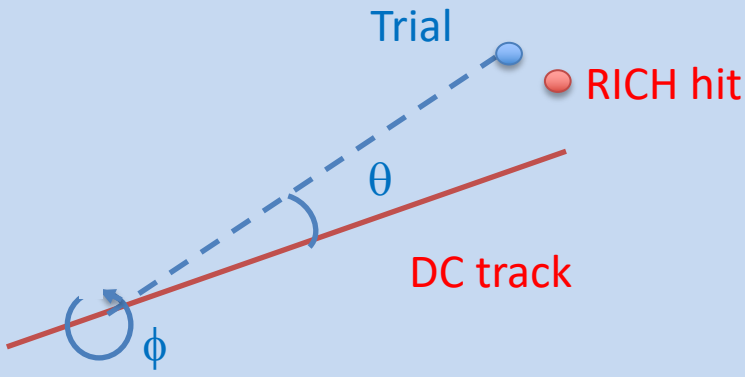
Detail MaPMT pixel geometry (on the misaligned plane)





Ray Tracing

Complex geometry with various photon paths (reflections) off the same particle



From CLAS12:

particle momentum
photon emission point

From RICH:

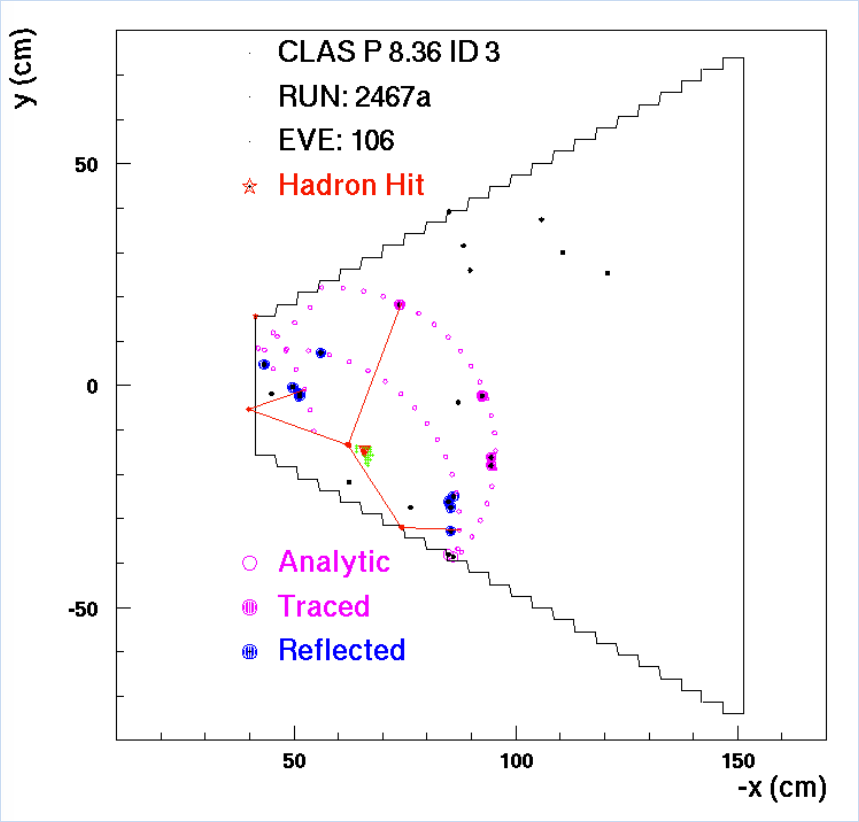
hit time and position

Direct ray-tracing:

ray-trace a limited sample of photon trials (selection of ϕ's for given θ)

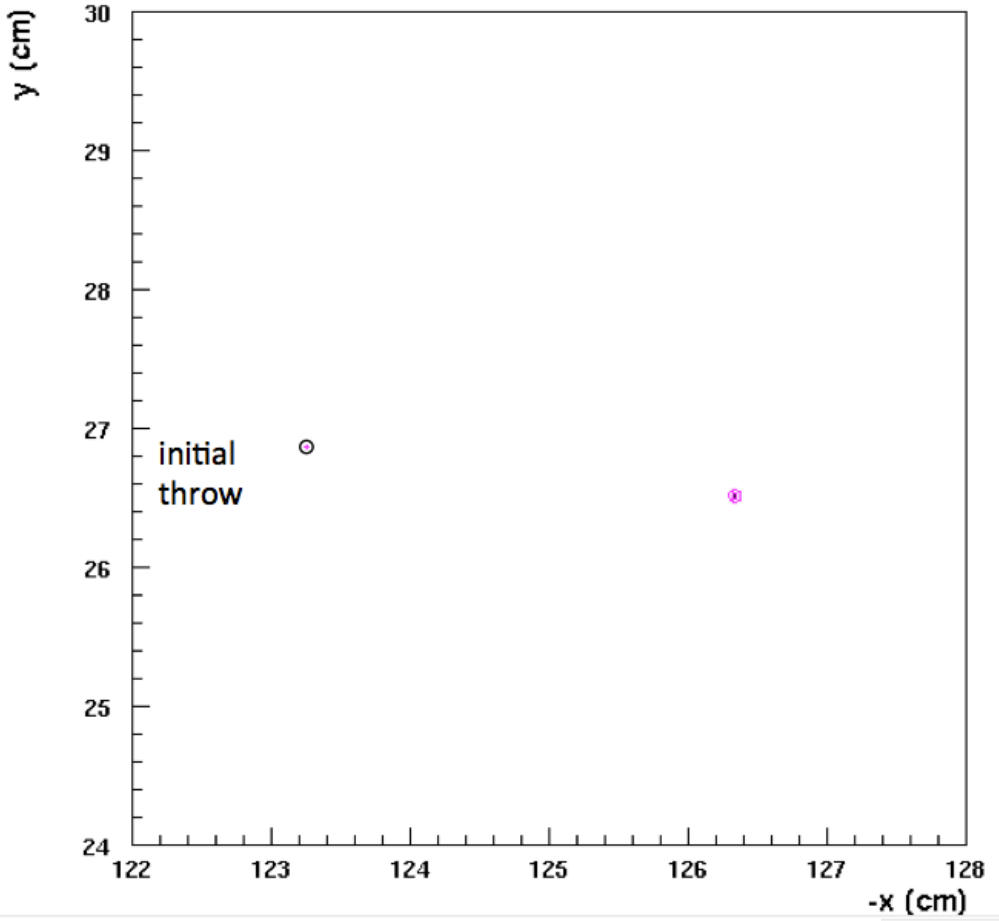
adjust the angles to match the hit starting from the closest trial (convergence in 2-3 iterations)

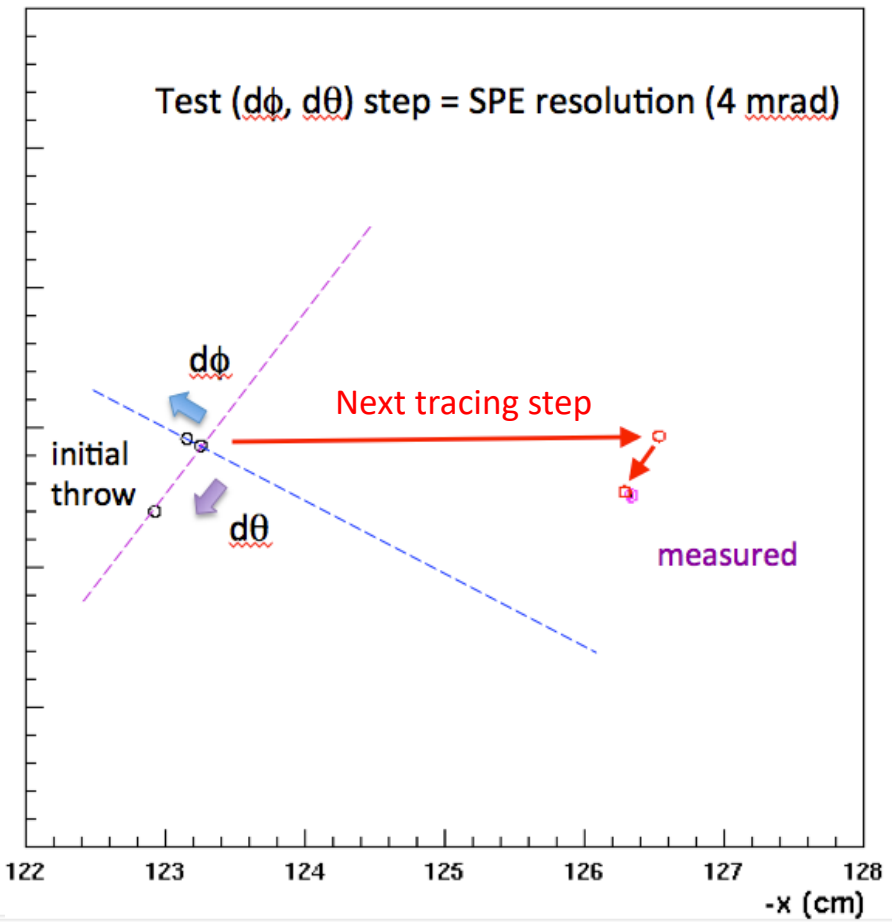
validate photon reconstructed Cherenkov angle and transit time



Ray Tracing

Stop when closer than half expected (angular) resolution

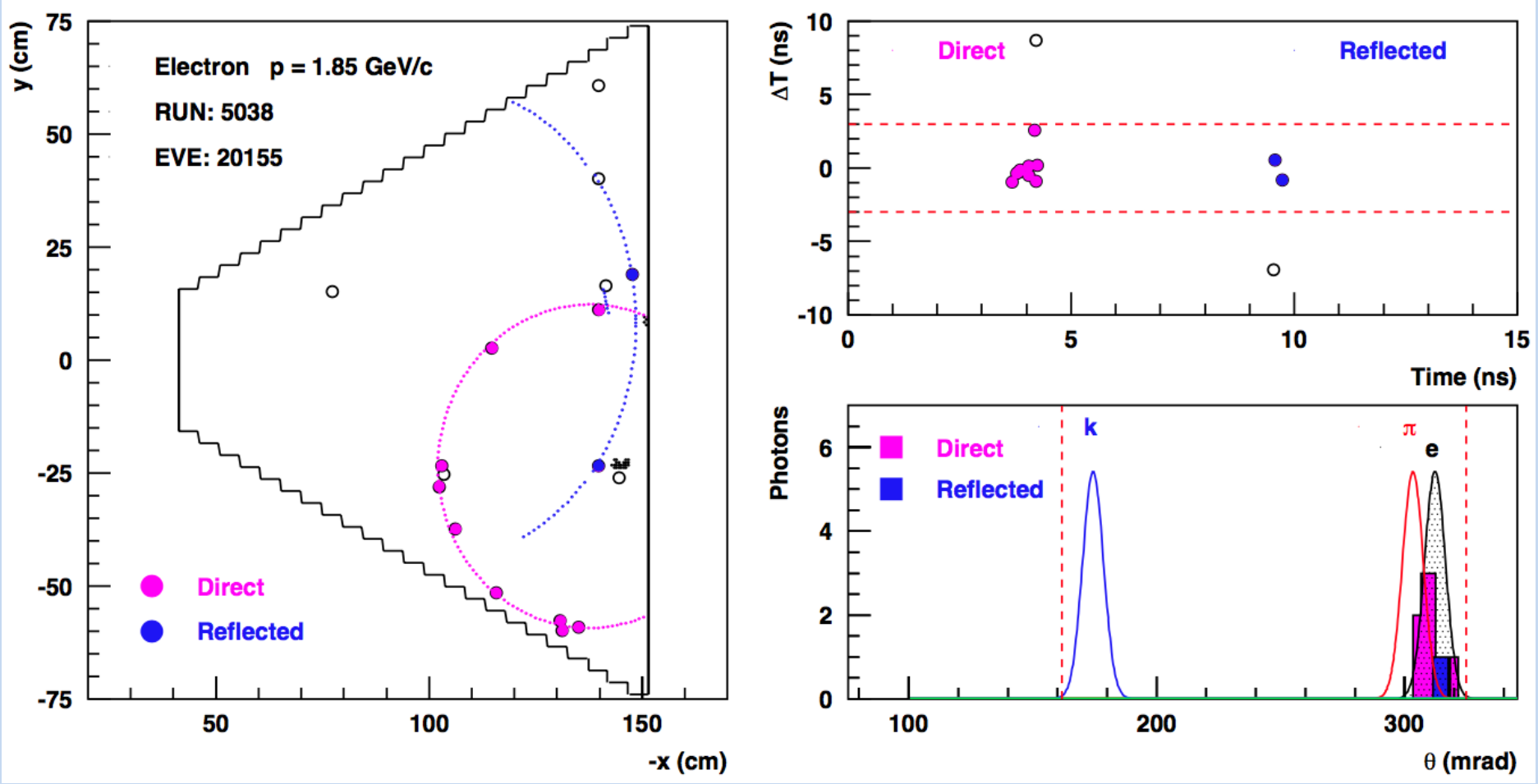




Ray Tracing

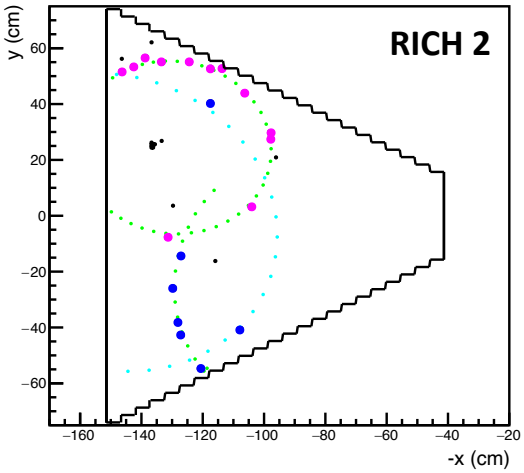
Photon path reconstruction allow to assign the photon to the most likely hypothesis:

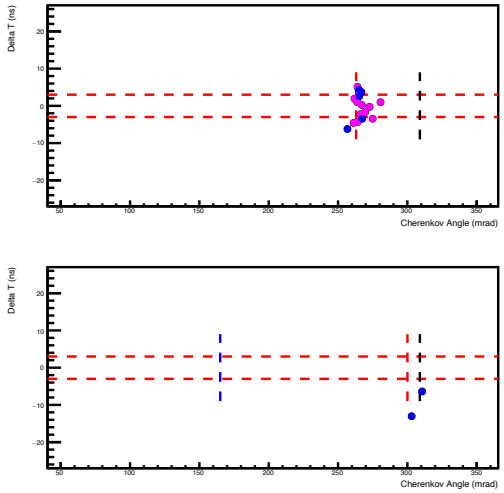
- be robust and easy to control (easy to handle multi-reflections, up to e.g. 5)
- discriminate background (hit far from trials, no solution foreseeable)
- provide full information (photon path, time, position and component of each reflection)
- allow relation with nominal optical components, resolution and efficiency

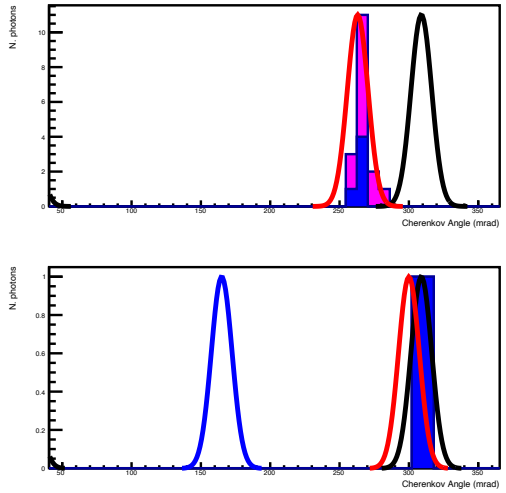


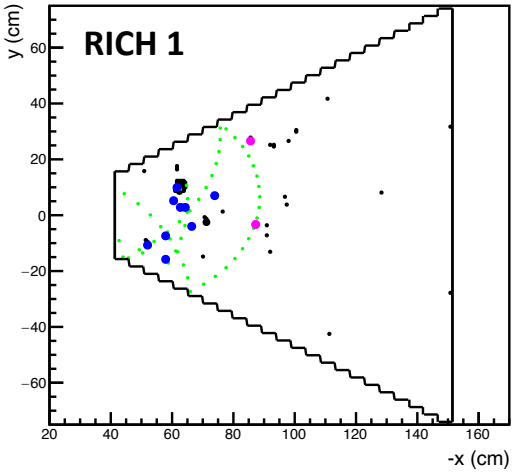
Run Group C

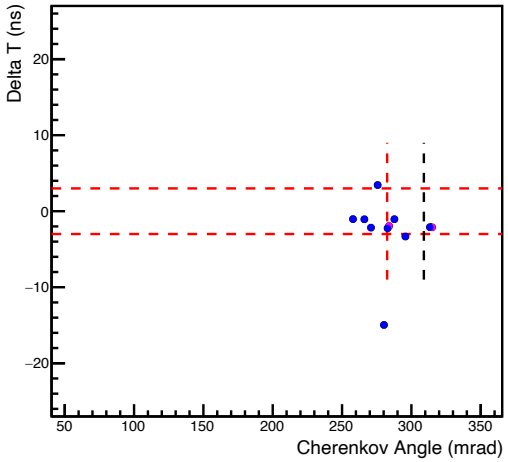
Example of 3 particle event into two RICHes (no calibration)

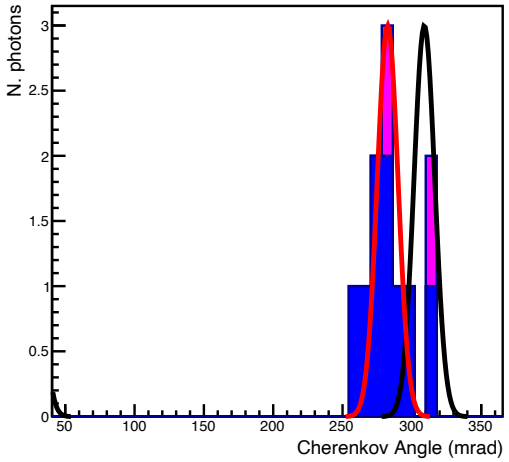












Process Time

Pass 1:

PHASE 0: INIT average over 1621 time 0.0051 ms
PHASE 1: CCDB average over 1621 time 6.9535 ms
PHASE 2: RAW-RICH average over 1621 time 10.2912 ms
PHASE 3: DC-RICH average over 1148 time 6.0564 ms
PHASE 4: HADRONS average over 1148 time 0.1729 ms
PHASE 5: ANALYTIC average over 1148 time 0.0042 ms
PHASE 6: TRACED average over 1148 time 5.0687 ms
PHASE 7: WRITE average over 1148 time 0.1452 ms
PHASE 8: CLOSE average over 1148 time 0.0004 ms
TOTAL : EVENT average over 1621 time 28.6975 ms

Pass 2:

PHASE 0: INIT average over 1621 time 0.0043 ms
PHASE 1: CCDB average over 1621 time 4.3222 ms
PHASE 2: RAW-RICH average over 1621 time 0.2077 ms
PHASE 3: DC-RICH average over 1148 time 1.8695 ms
PHASE 4: HADRONS average over 1148 time 0.3129 ms
PHASE 5: ANALYTIC average over 1148 time 0.0003 ms
PHASE 6: TRACED average over 1148 time 15.0577 ms
PHASE 7: WRITE average over 1148 time 0.1882 ms
PHASE 8: CLOSE average over 1148 time 0.0002 ms
TOTAL : EVENT average over 1621 time 21.9629 ms

CCDB: Geometry

✓ geometry/rich/setup [4 x 6 values] info per sector

sector	layer	component	module
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	1
5	0	0	0
6	0	0	0

Loaded with Engine init()

✓ geometry/rich/module1/alignment [9 x 126 values] info per component

sector	layer	component	dx	dy	dx	dthx	dthy	dthz
4	0	0	1.8	0.6	5.2	0.0	0.0	0.0
4	201	0	0.0	0.0	0.80	2.24	10.83	0
4	201	1	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4	201	2	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4	201	3	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4	201	4	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4	201	5	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

✓ geometry/rich/module1/aerogel [15 x 102 values] info per aerogel tile

sector	layer	component	thickness	n400	n_p1	n_p2	A0	L400	clarity	planarity	radius	xc	yc	zc
4	201	1	20	1.05054	0.09683	84.13	0.9772	44.92	0.0056990205	0.42	0.00000	0.00000	0.00000	0.00000
4	201	2	20	1.05164	0.09683	84.13	0.9842	53.00	0.0048301887	2.71	0.00000	0.00000	0.00000	0.00000
4	201	3	20	1.05227	0.09683	84.13	0.9717	48.45	0.0052837977	1.63	0.00000	0.00000	0.00000	0.00000
4	201	4	20	1.05175	0.09683	84.13	0.9863	54.13	0.0047293553	3.64	0.00000	0.00000	0.00000	0.00000
4	201	5	20	1.05214	0.09683	84.13	0.9863	53.71	0.0047663377	3.25	0.00000	0.00000	0.00000	0.00000
4	201	6	20	1.05208	0.09683	84.13	0.9812	44.89	0.0057028291	2.07	0.00000	0.00000	0.00000	0.00000
4	201	7	20	1.05096	0.09683	84.13	0.9737	49.99	0.0051210242	1.71	0.00000	0.00000	0.00000	0.00000
4	201	8	20	1.05110	0.09683	84.13	0.9540	57.20	0.0044755245	1.34	0.00000	0.00000	0.00000	0.00000
4	201	9	20	1.05158	0.09683	84.13	0.9866	54.65	0.0046843550	1.72	0.00000	0.00000	0.00000	0.00000
4	201	10	20	1.05189	0.09683	84.13	0.9832	48.36	0.0052936311	1.11	0.00000	0.00000	0.00000	0.00000
4	201	11	20	1.04943	0.09683	84.13	0.9501	60.04	0.0042638241	0.80	0.00000	0.00000	0.00000	0.00000

CCDB: Calibration

✓ calibration/rich/module1/time_offset [4 x 25024 values] info per pixel

sector	layer	component	offset
4	1	1	-9.27
4	1	2	-8.81
4	1	3	-8.78
4	1	4	-8.85
4	1	5	-8.64
4	1	6	-8.95
4	1	7	-9

Loaded with Engine
processDataEvent ()

✓ calibration/rich/module1/time_walk [7 x 391 values] info per readout chip

sector	layer	component	D0	m1	m2	T0
4	1	0	61.28	36.85	0.600	-0.155
4	2	0	59.52	34.44	0.575	-0.195
4	3	0	59.51	33.21	0.555	-0.143
4	4	0	60.38	33.42	0.550	-0.169
4	5	0	58.74	30.91	0.523	-0.165
4	6	0	59.56	33.07	0.554	-0.170
4	7	0	59.44	32.39	0.543	-0.155
4	8	0	57.84	29.83	0.506	-0.177

✓ calibration/rich/module1/cherenkov_angle [23 x 22950 values] info per aerogel quadrant

sector	layer	component	tile	quadrant	hp_npe_dir	hp_mean_dir	hp_sigma_dir	hp_npe_lat	hp_mean_lat	hp_sigma_lat	hp_npe_sphe	hp_mean_sphe	hp_sigma_sphe	hm_mean_dir	hm_sigma_dir	hm_npe_lat	hm_mean_lat	hm_sigma_lat	hm_npe_sphe	hm_mean_sphe	hm_sigma_sphe
4	201	1	1	1	6	0.305210	0.010000	9	0.307120	0.015960	0	0.311450	0.016000	6	0.305210	0.010000	9	0.307120	0.015960	0	0.311450	0.016000	6	0.305210	0.010000	9	0.307120	0.015960	0	0.311450	0.016000
4	201	2	1	2	6	0.305210	0.010000	9	0.307120	0.015960	0	0.311450	0.016000	6	0.305210	0.010000	9	0.307120	0.015960	0	0.311450	0.016000	6	0.305210	0.010000	9	0.307120	0.015960	0	0.311450	0.016000
4	201	3	1	3	6	0.305210	0.010000	9	0.307120	0.015960	0	0.311450	0.016000	6	0.305210	0.010000	9	0.307120	0.015960	0	0.311450	0.016000	6	0.305210	0.010000	9	0.307120	0.015960	0	0.311450	0.016000
4	201	4	1	4	6	0.305210	0.010000	9	0.307120	0.015960	0	0.311450	0.016000	6	0.305210	0.010000	9	0.307120	0.015960	0	0.311450	0.016000	6	0.305210	0.010000	9	0.307120	0.015960	0	0.311450	0.016000
4	201	5	1	5	6	0.305210	0.010000	9	0.307120	0.015960	0	0.311450	0.016000	6	0.305210	0.010000	9	0.307120	0.015960	0	0.311450	0.016000	6	0.305210	0.010000	9	0.307120	0.015960	0	0.311450	0.016000

CCDB: Calibration

✓ calibration/rich/module1/status_mirror [4 x 17 values] info per mirror

sector	layer	component	status
4	301	1	0
4	301	2	0
4	301	3	0
4	301	4	0
4	301	5	0

Loaded with Engine
processDataEvent ()

✓ calibration/rich/module1/status_aerogel [6 x 22950 values] info per aerogel quadrant

sector	layer	component	tile	quadrant	status
4	201	1	1	1	0
4	201	2	1	2	0
4	201	3	1	3	0
4	201	4	1	4	0
4	201	5	1	5	0
4	201	6	1	6	0

✓ calibration/rich/module1/status_mapmt [4 x 25024 values] info per pixel

sector	layer	component	status
4	1	1	0
4	1	2	0
4	1	3	0
4	1	4	0
4	1	5	0

✓ calibration/rich/module1/mapmt_pixel [9 x 25024 values] info per pixel

sector	layer	component	gain	effiiciency	dark-rate	N_t	mean_t	sigma_t
4	1	1	1.000	1.000	0.00000	22542	-0.147900	0.412800
4	1	2	1.000	1.000	0.00000	17944	-0.096900	0.437800
4	1	3	1.000	1.000	0.00000	18858	-0.123000	0.428400
4	1	4	1.000	1.000	0.00000	19807	-0.105300	0.443800
4	1	5	1.000	1.000	0.00000	23745	-0.135700	0.449900
4	1	6	1.000	1.000	0.00000	21598	-0.200500	0.411800

CCDB: Parameters

✓ geometry/rich/geo_parameter
[26 x 1 global constants]

N.	(type)	: (name)
0	int	: sector
1	int	: layer
2	int	: component
3	int	: do_align
4	int	: rich_ref
5	int	: pmt_pivot
6	int	: use_survey
7	double	: shift_scale
8	double	: angle_scale
9	double	: min_ray_dist
10	double	: min_sphe_dist
11	double	: xc_sphe_mir1
12	double	: yc_sphe_mir1
13	double	: zc_sphe_mir1
14	double	: rc_sphe_mir1
15	double	: xc_sphe_mir2
16	double	: yc_sphe_mir2
17	double	: zc_sphe_mir2
18	double	: rc_sphe_mir2
19	int	: debug_par
20	int	: debug_const
21	int	: spare_flag1
22	int	: spare_flag2
23	int	: spare_flag3
24	double	: spare_const1
25	double	: spare_const2
26	double	: spare_const3

✓ calibration/rich/reco_flag
[35 x 1 reconstruction options]

N.	(type)	: (name)
0	int	: sector
1	int	: layer
2	int	: component
3	int	: reco_raw
4	int	: reco_data
5	int	: use_sig_bank
6	int	: force_dc_match
7	int	: do_analytic
8	int	: do_traced
9	int	: throw_e
10	int	: throw_pi
11	int	: throw_k
12	int	: throw_pr
13	int	: throw_N2
14	int	: save_throws
15	int	: do_spher
16	int	: do_curved
17	int	: use_ecalib
18	int	: like_norm
19	int	: pixel_calib
20	int	: pixel_gain
21	int	: pixel_eff
22	int	: pixel_time
23	int	: pixel_back
24	int	: pass1_like
25	int	: pass2_like
26	int	: lhcb_like
27	int	: debug_reco_flag
28	int	: debug_reco_par
29	int	: debug_cal_const
30	int	: debug_CPUtime
31	int	: spare_flag1
32	int	: spare_flag2
33	int	: spare_flag3
34	int	: spare_flag4
35	int	: spare_flag5

✓ calibration/rich/reco_parameter
[24 x 1 reconstruction parameters]

N.	(type)	: (name)
0	int	: sector
1	int	: layer
2	int	: component
3	double	: global_time_off
4	double	: xtalk_frac
5	double	: dc_match
6	double	: trial_match
7	double	: hit_match
8	double	: direct_rms
9	double	: nsigma_cher
10	double	: nsigma_time
11	int	: quad_number
12	int	: N_trials
13	double	: ray_reso
14	int	: ray_steps
15	double	: ref_stime
16	double	: ref_back
17	double	: ref_Nele
18	double	: back_prob
19	double	: progess_delta
20	double	: spare_par1
21	double	: spare_par2
22	double	: spare_par3
23	double	: spare_par4
24	double	: spare_par5

Hipo Banks

Raw data:

"bank": "RICH::tdc"

RICH alone information

"bank": "RICH::hits"

"bank": "RICH::clusters"

RICH – CLAS12 Particle Matching

"bank": "REC::response"

RICH Cherenkov Analysis:

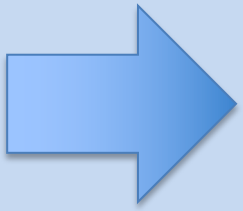
"bank": "RICH::hadrons"

"bank": "RICH::photons"

"bank": "REC::ringCher"

"bank": "REC::hadCher"

DST



Raw data:

"bank": "RICH::tdc"

RICH alone information

"bank": "RICH::Hit"

"bank": "RICH::Cluster"

RICH – CLAS12 Particle Matching

"bank": "REC::Response"

RICH Cherenkov Analysis:

"bank": "RICH::Hadron"

"bank": "RICH::Photon"

"bank": "REC::Ring"

"bank": "REC::Particle"

DST

RICH::Ring

Designed to allow: calibration from DST [sector, pmt, anode, dtime, etaC] } best ID, no status
alignment [layers, compos, etaC]

alternative likelihood [hypo, etaC, prob, use, dangle] } ID x 4, w. status

```
"name": "RICH::Ring",
  "group": 21800,
  "item" : 36,
  "info": "Reconstructed Cherenov information for single photon",
  "entries": [
       {"name":"id",          "type":"S", "info":"id" },
       {"name":"hindex",     "type":"S", "info":"related row in the RICH::hits bank"},
       {"name":"pindex",     "type":"B", "info":"related row in the REC::Particle bank"},

       {"name":"sector",      "type":"B", "info":"photon sector" },
       {"name":"pmt",         "type":"S", "info":"photon hit pmt" },
       {"name":"anode",      "type":"B", "info":"photon hit anode" },

       {"name":"hypo",        "type":"I", "info":"PID hypothesis for photon reconstruction"},
       {"name":"dtime",       "type":"F", "info":"time mismatch for traced solution" },
       {"name":"etaC",         "type":"F", "info":"Cherenkov angle as traced solution" },

       {"name":"prob",        "type":"F", "info":"probability for the given hypothesis"},
       {"name":"use",         "type":"B", "info":"flag for use in the likelihood"},
       {"name":"dangle",      "type":"F", "info":"angular range subtended by the pixel"},

       {"name":"layers",      "type":"S", "info":"sequence of hit layers (reflections)"},
       {"name":"compos",    "type":"S", "info":"sequence of hit components (reflections)"}
]
```

RICH::Particle

Providing best particle hypothesis (PID) with quality estimators


```
"name": "RICH::Particle",
  "group": 21800,
  "item" : 37,
  "info": "Reconstructed Cherenov information per track",
  "entries": [
        {"name":"id",          "type":"B", "info":"id"},
        {"name":"hindex",      "type":"S", "info":"related row in the RICH::clusters bank (if any)"},
        {"name":"pindex",      "type":"B", "info":"related row in the REC::Particle bank"},

        {"name":"emilay",      "type":"B", "info":"aerogel layer of photon emission"},
        {"name":"emico",       "type":"B", "info":"aerogel component of photon emission"},
        {"name":"enico",       "type":"B", "info":"aerogel component of photon entrance point"},
        {"name":"emqua",       "type":"S", "info":"aerogel quadrant of photon emission"},
        {"name":"mchi2",       "type":"F", "info":"track-cluster matching chi2 (if any)"},

        {"name":"best_PID",     "type":"S", "info":"most probable PID choice"},
        {"name":"RQ_prob",      "type":"F", "info":"goodness of hadron choice parameter (1=anambiguos, 0=random)"},
        {"name":"ReQ_prob",     "type":"F", "info":"goodness of elecgtron choice parameter (1=anambiguos, 0=random)"},
        {"name":"el_prob",      "type":"F", "info":"probability to be an electron"},
        {"name":"pi_prob",      "type":"F", "info":"probability to be an pion"},
        {"name":"k_prob",       "type":"F", "info":"probability to be an kaon"},
        {"name":"pr_prob",      "type":"F", "info":"probability to be an proton"},

        {"name":"best_ch",      "type":"F", "info":"Average etaC for best hypothesis"},
        {"name":"best_c2",      "type":"F", "info":"chi2 for best hypothesis"},
        {"name":"best_RL",      "type":"F", "info":"Likelihood ratio for best hypothesis"},
        {"name":"best_ntot",    "type":"F", "info":"Number of photon used for likelihood"},
        {"name":"best_mass",    "type":"F", "info":"Reconstructed mass for best hypothesis"}
  ]
```

DST Output

Dimensione banche (da hipo-utils)