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生命の科学で未来をつなぐ

Automated analysis of nuclear emulsions using new tracking technique

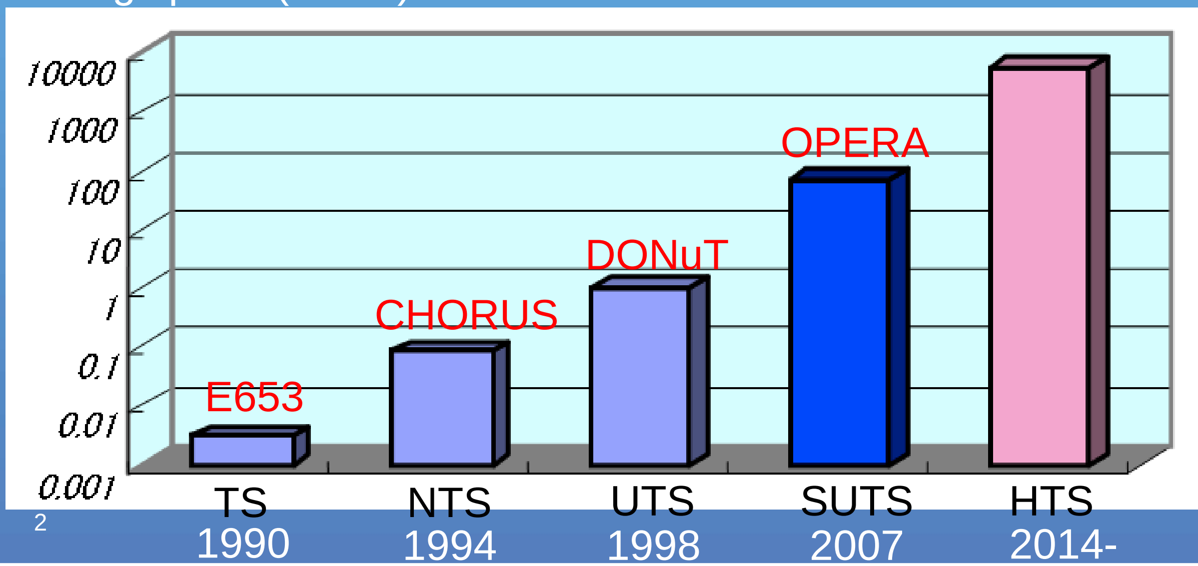
presented by Tsutomu Fukuda
(Toho University)

Workshop on Nuclear Track Emulsion and its Future, 15 Oct 2013, Predeal Romania

History of automated analysis of nuclear emulsion in Japan

- **Modern applications of nuclear emulsions in the field of high energy physics has been progressed with development of automated track recognition technology.**
- **In 1970's, K. Niwa designed an automated tracking algorithm, then S. Aoki and T. Nakano developed practical and high speed systems (Track Selector : TS).**
- **These systems were applied for Fermi lab-E653, CHORUS, DONuT and OPERA in success.**

Scanning speed (cm^2/h)



Next generation high speed System, Hyper-TS (HTS),
→ Yoshimoto's talk

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Introduction for new tracking technique

- Nowadays the technique of high speed emulsion scanning has made a major progress.
- On the other hand, new development which is qualitatively different from conventional strategy is also important to open up new possibility for the future.
- We have been developing the automatic track recognition technique of nuclear emulsion on basis of new concept, i.e. "Large angle tracking" and "High discriminated tracking".
- I will introduce pioneer works of developing such new tracking technique and its application for scientific analysis.

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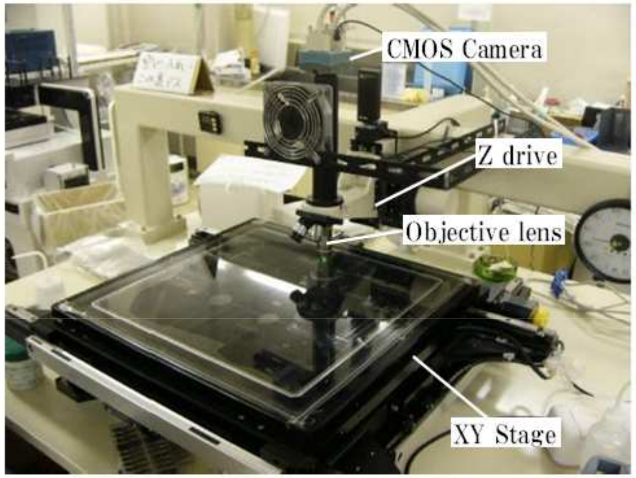
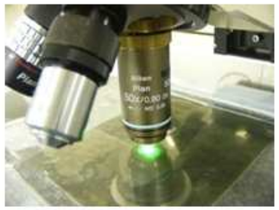
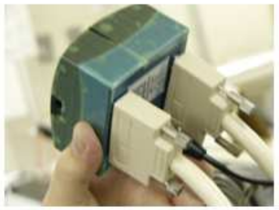
Fine Track Selector (FTS) at Toho univ.

- **system overview**



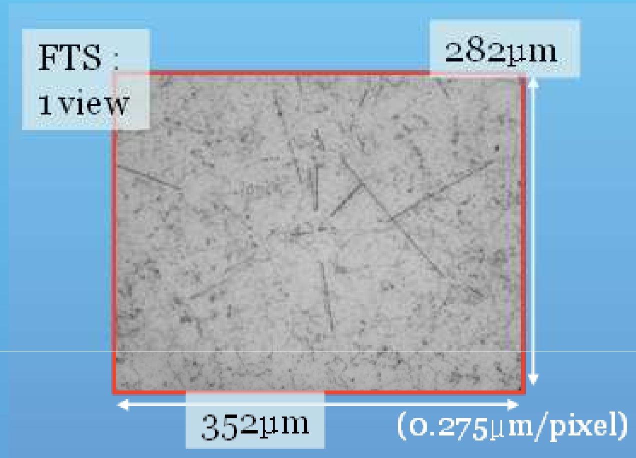


Objective lens
Nikon CFI Plan x50
oil immersion lens



CMOS Camera
Mikrotron
Eosens MC 1362

Graphics Processing Unit (GPU)
NVIDIA Tesla C2050



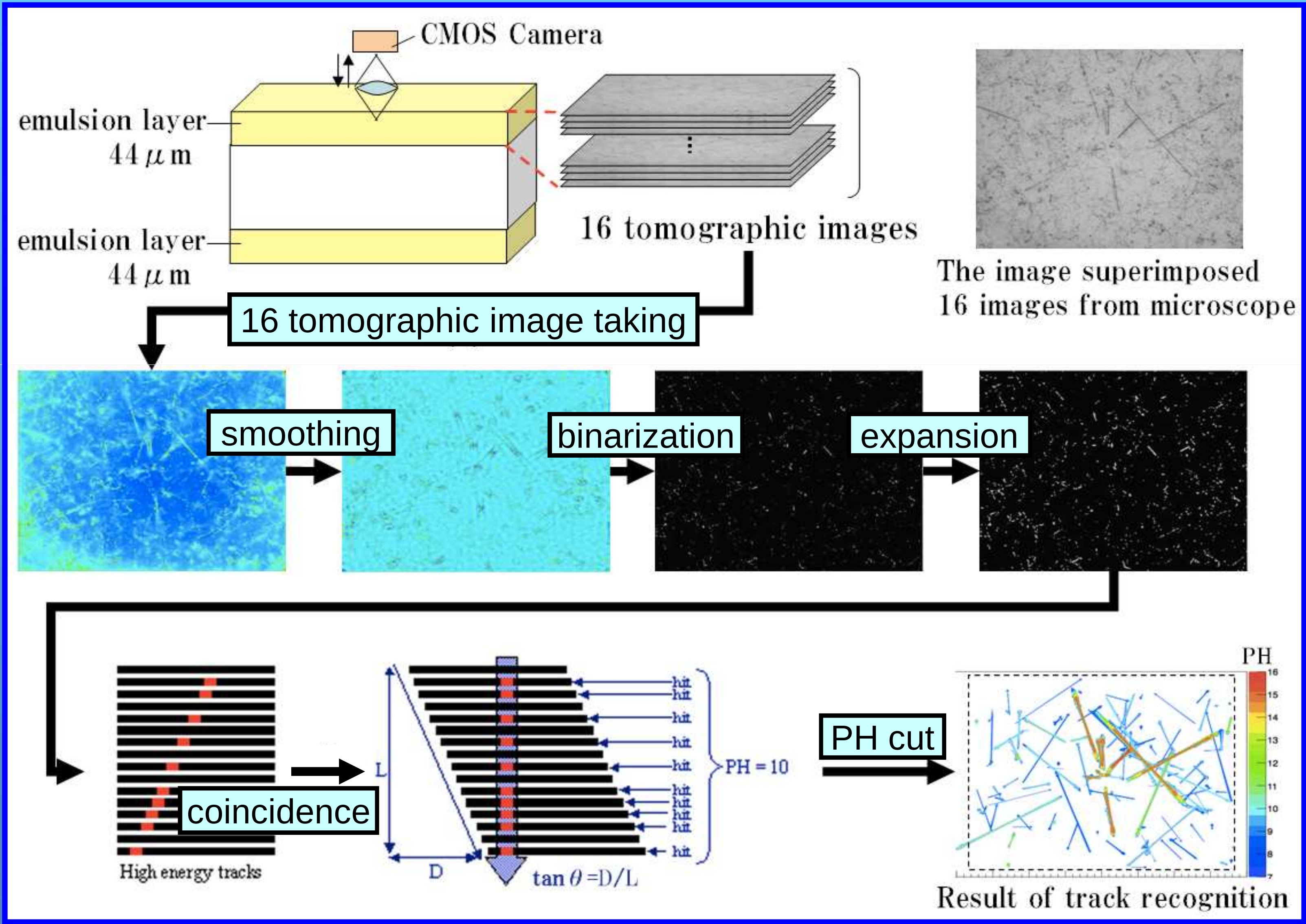
Large view size
→ enough size for large angle track within one view.

Tracking at GPU
→ good flexibility to improve tracking algorithm.

Large angle tracking

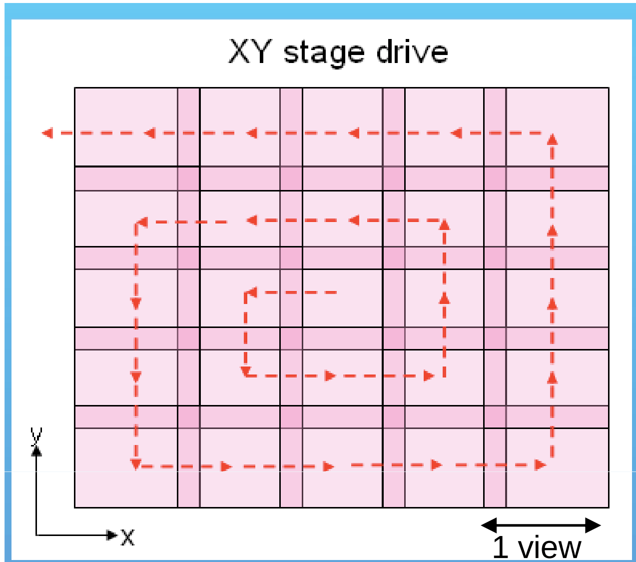
Large angle tracking

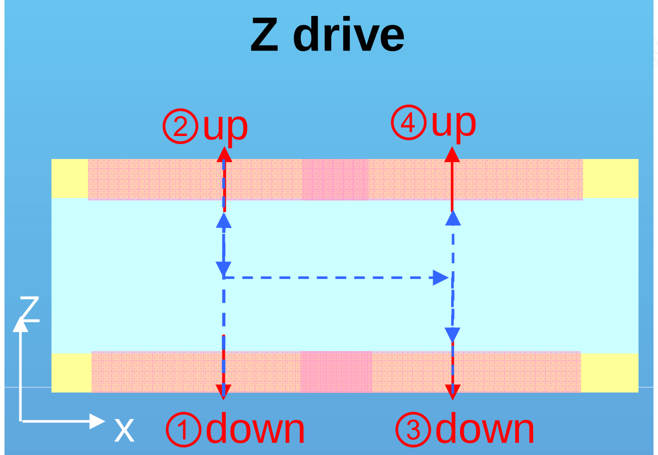
Conventional Tracking algorithm

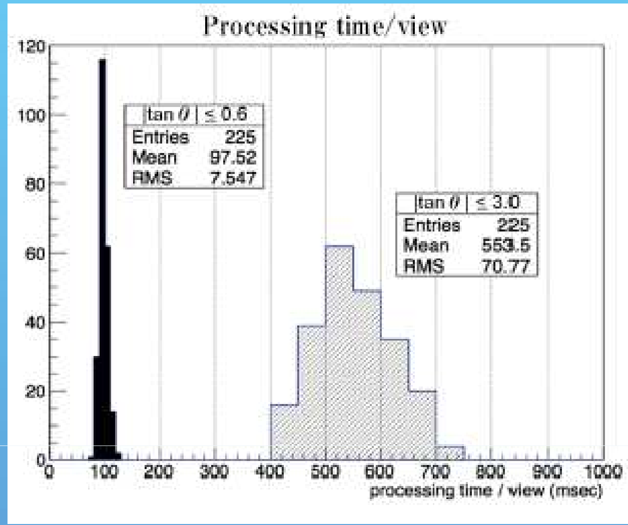


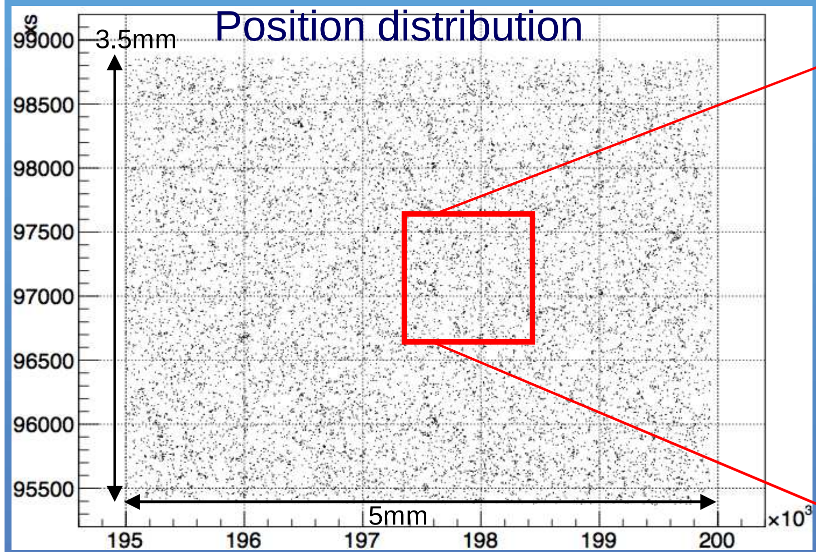
Large angle tracking

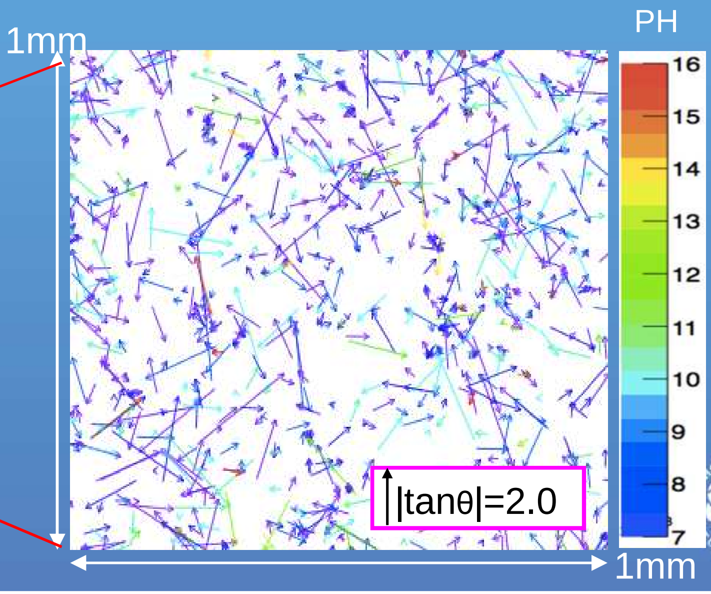
Large angle track scanning

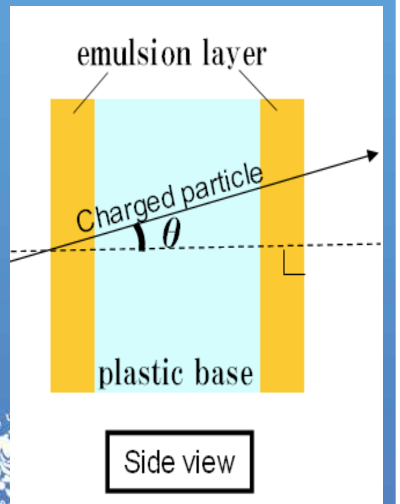








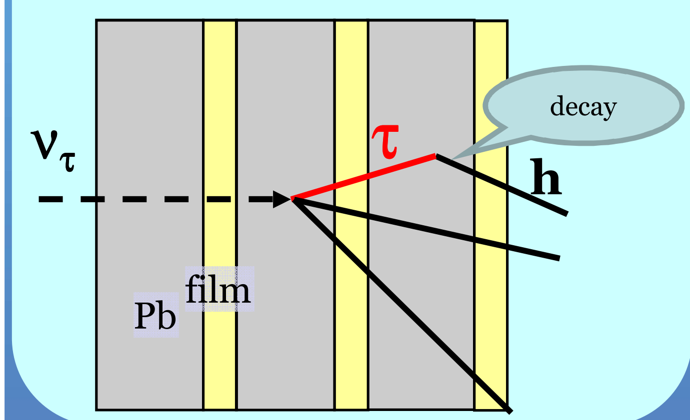


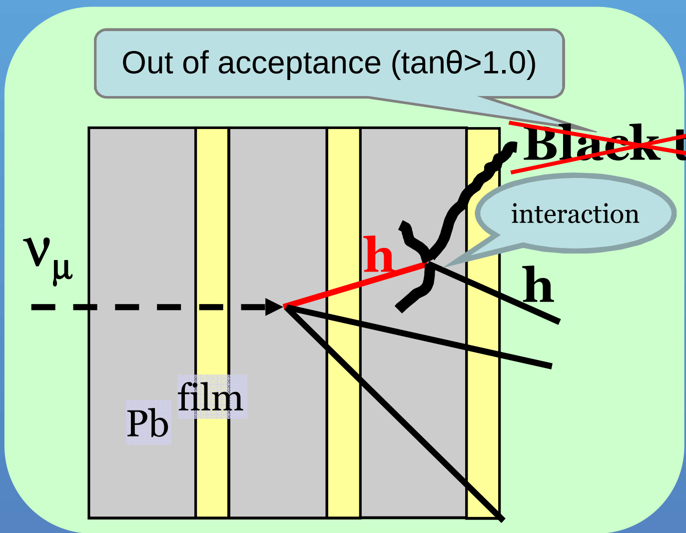


Physics motivation with large angle scan

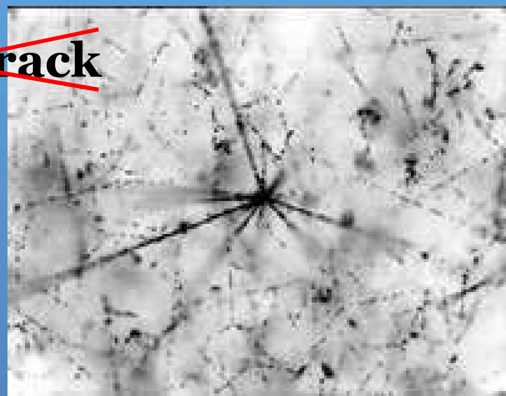
- Hadron interaction analysis is very important for verification of MC to estimate $\tau \rightarrow$ hadron decay channel background in the OPERA experiment. We also want to reduce this background.
- Nuclear fragment from vertex is very strong proof of Hadron interaction.
- Nuclear fragments are produced in the nuclear evaporation process caused by an excitation of the nucleus and they are emitted almost isotropically.
- Therefore the scanning system with wide-angle acceptance is required for the systematic nuclear fragment search in hadron interaction analysis.

ν_τ CC interaction





Background of ν_τ CC interaction



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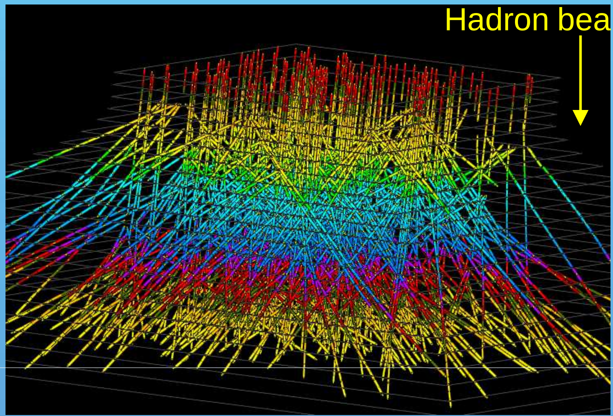
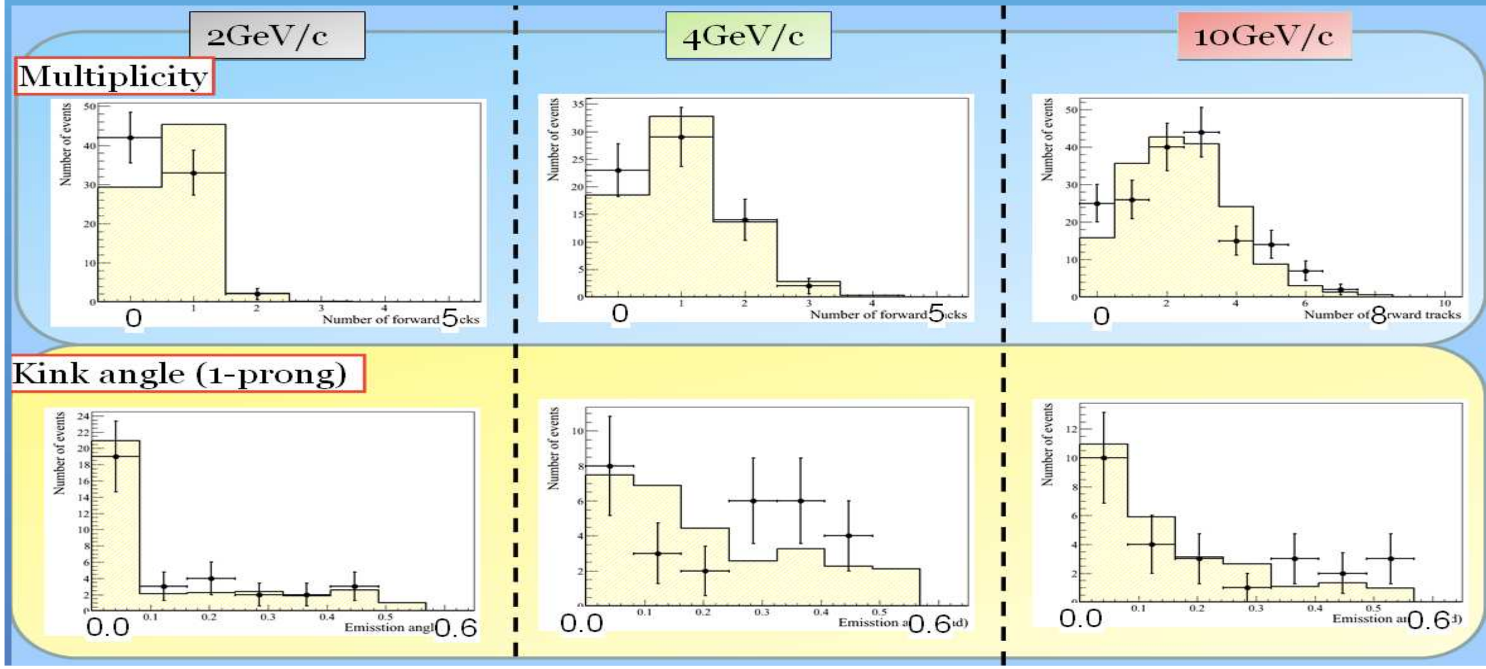
Systematic hadron int. analysis in OPERA type ECC

We have been studied hadron int. in the OPERA ECC.



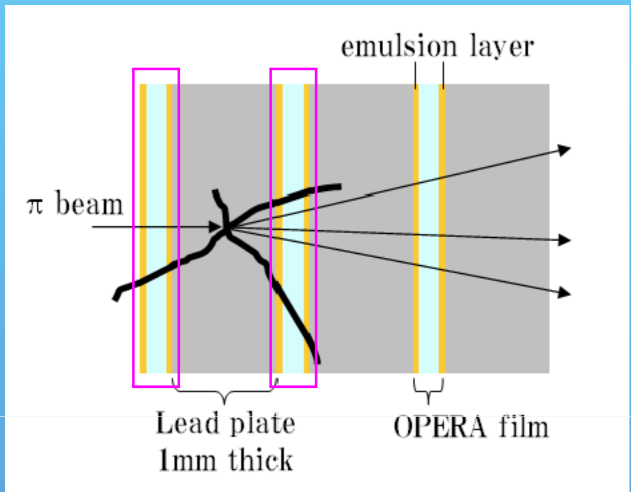
CERN	10GeV π^-	4GeV π^-	2GeV π^-
Reconstructed tracks	2205 tracks	913 tracks	584 tracks
Total track length in ECC	38.5 m	12.6 m	8.5 m
Interactions in ECC	173 events	68 events	77 events



Scanned at normal angle acceptance. (|tan|≤0.6)

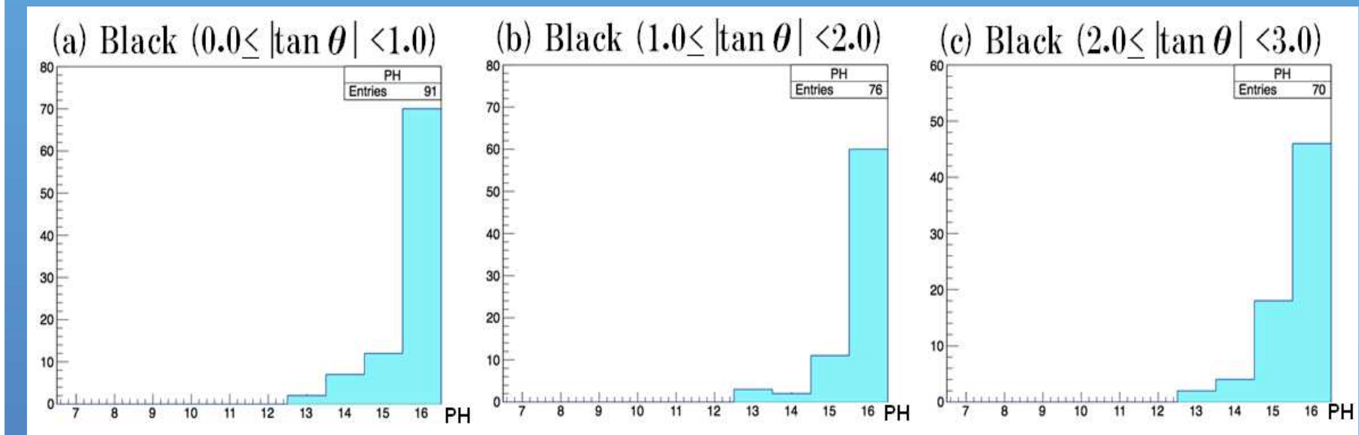
Data and MC is good agreement.

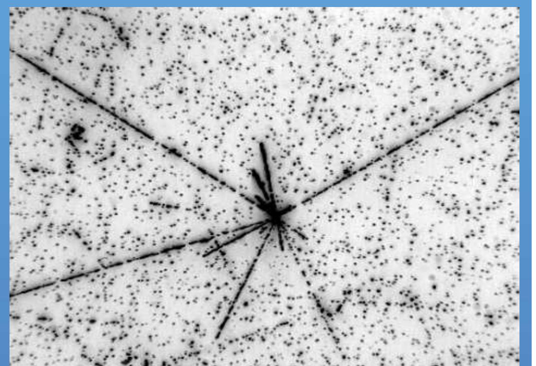
Search for Black Track



- Scanned area : 3.5 x 2.5 mm^2, upstream and downstream films of the vertex
- Angular acceptance : |tanθ| ≤ 3.0
- Impact parameter < 100(50) mm + 0.01 x depth (@ 2, 4 (10) GeV/c)
- Estimated number of background tracks : 0.035 tracks/event
- Eye check confirmation after selecting candidates.

PH distribution of Black Track on each angle





Hadron int. found in emulsion layer

eff = 99.8% @ 90%C.L (PH≥13; 2.0≤|tanθ|<3.0)

T. Fukuda et al., 2013 *JINST* 8 P01023 , [arXiv:1301.1768]

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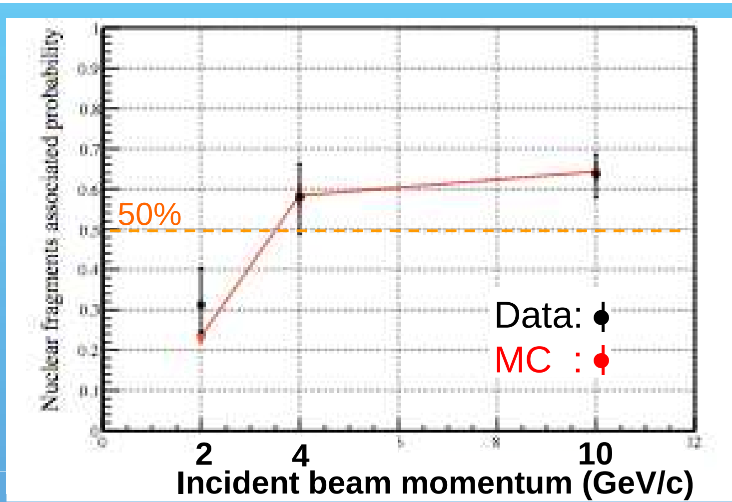
Large angle tracking

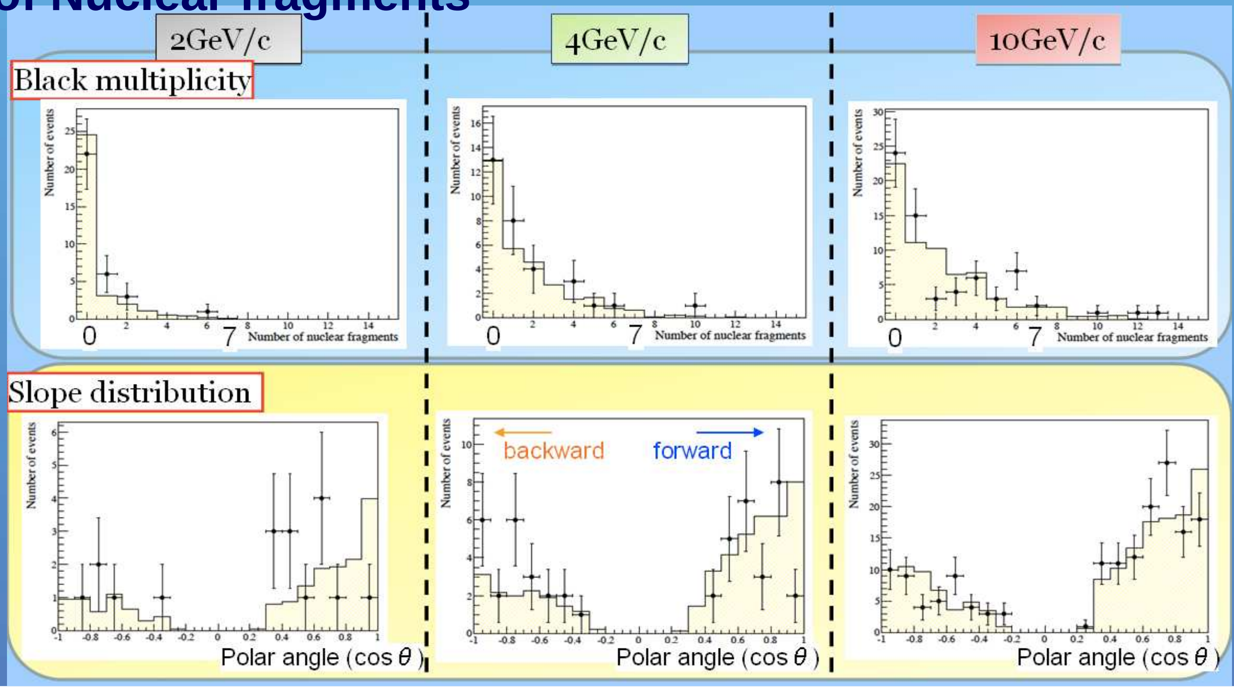
Analysis result for Nuclear fragments in hadron int.

Associated probability of nuclear fragments

Beam momentum [GeV/c]	2	4	10
Events	32	31	66
Fragment associated events	10	18	42
Fragment associated probability [%]	$31.3^{+9.1}_{-6.9}$	$58.1^{+8.1}_{-9.1}$	$63.6^{+5.0}_{-5.7}$



Topological aspects of Nuclear fragments



- Data and MC is good agreement.
- This result allowed to reduce 30% hadorn BG in OPERA.

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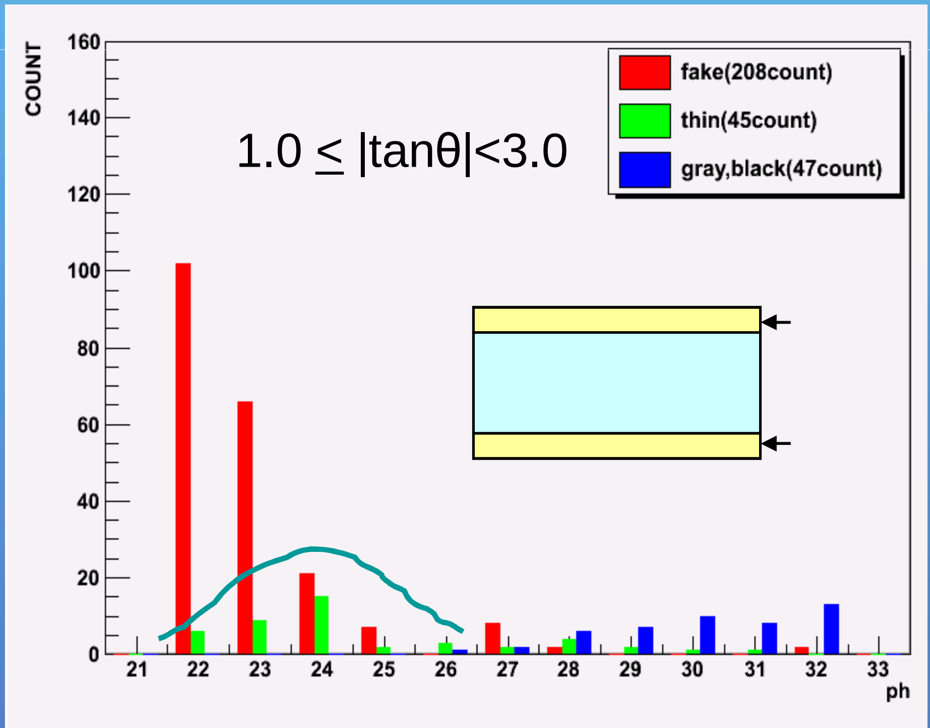
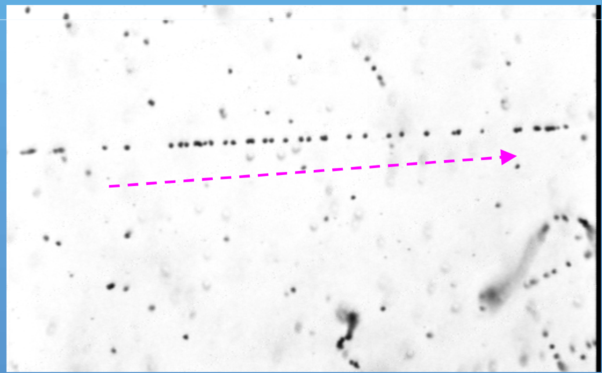
Large angle scan for minimum ionizing particles

- We found the tracking efficiency of large angle MIPs is kept sufficiently high in large angle Black Track analysis.
- PH distribution of large angle MIPs also make mountain as PH distribution of small angle MIPs.

PH sum on both side tracks





MIP at OPERA film
G.D. ~ 34

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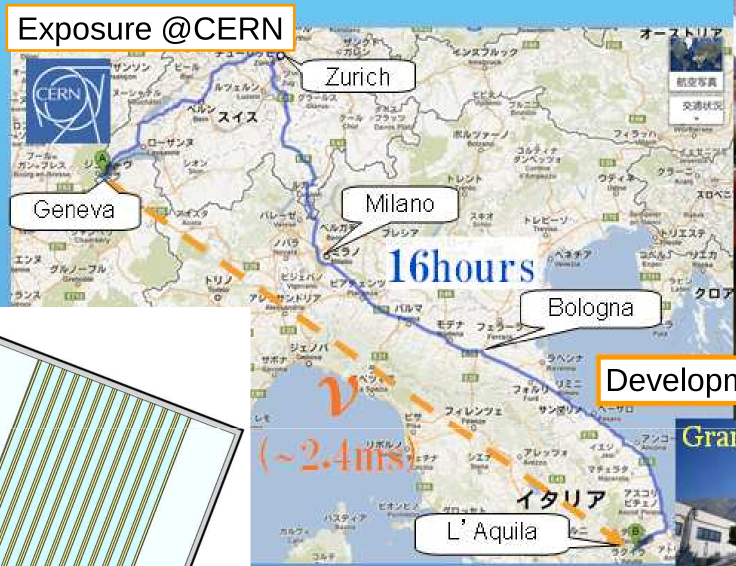
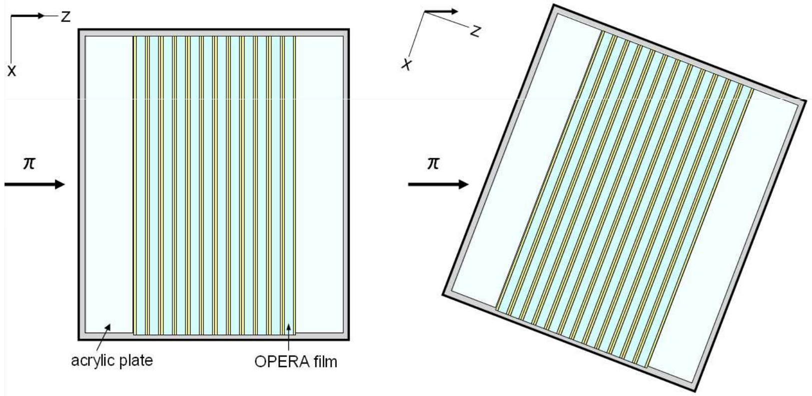
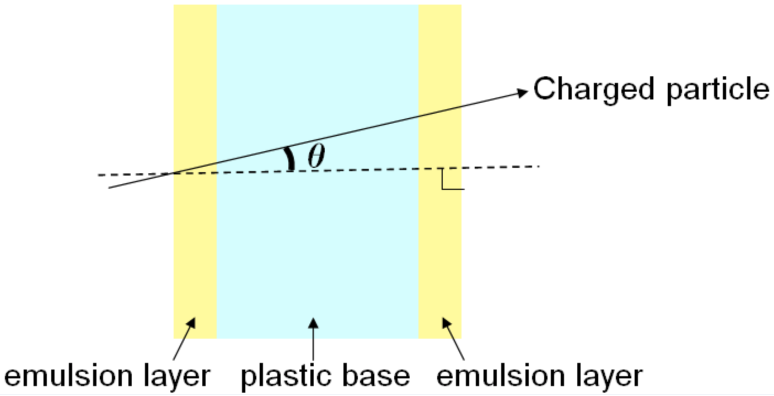
Beam exposure at CERN to make sample for evaluation of large angle scan

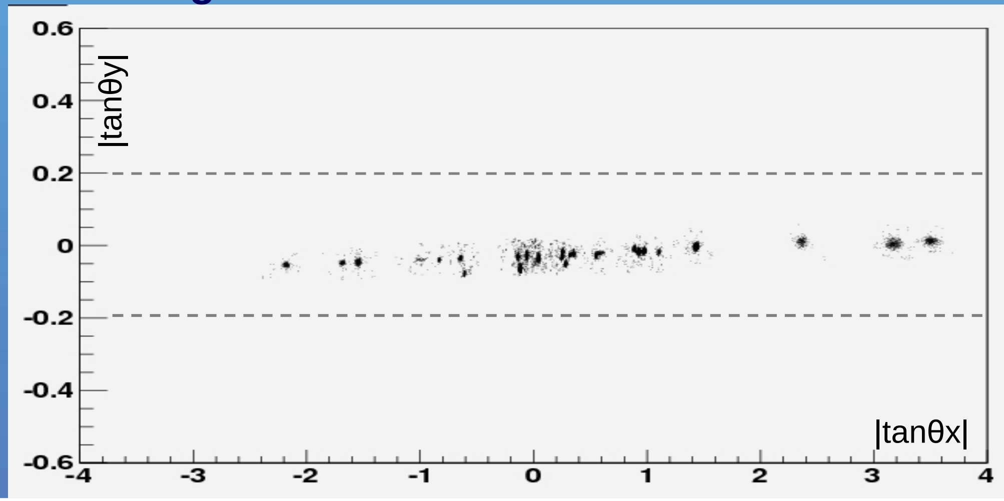


Sample were developed at Gran Sasso Lab.



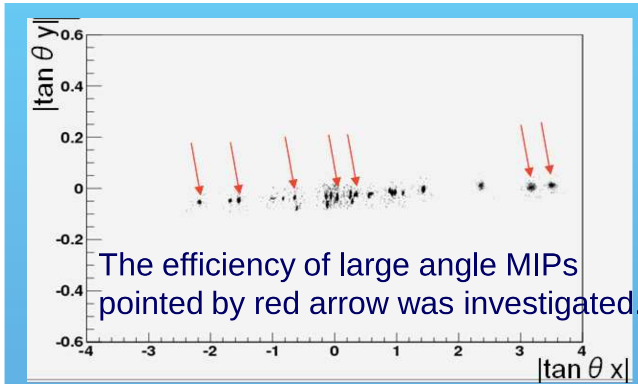


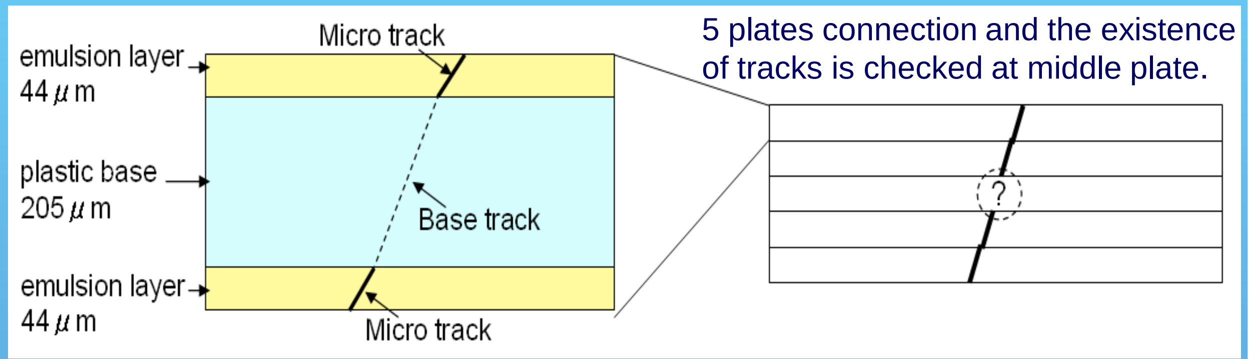
Beam angle distribution

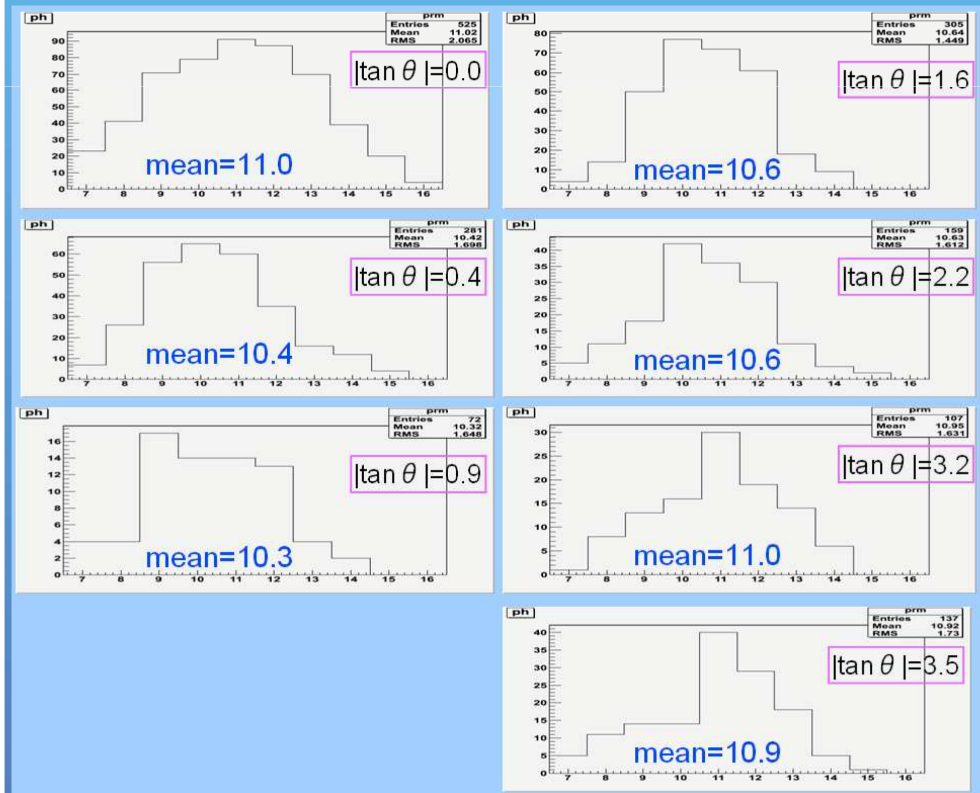


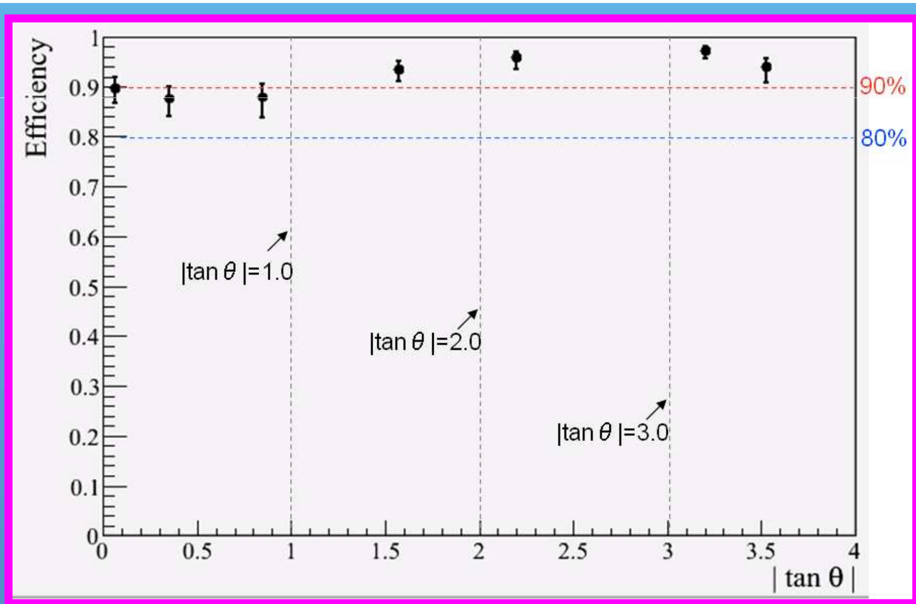
Analysis and results of automatic scanning for large angle MIP

Large angle tracking









The high efficiency for large angle MIPs is confirmed by test experiment.

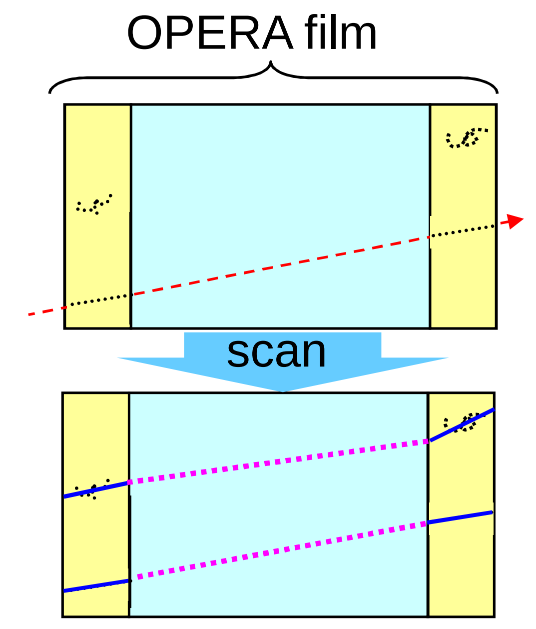
Short summary

- We developed an technique for automatic large angle tracking.
- This technique was applied for hadron analysis and also BG reduction for OPERA.
- The HIGH automatic recognized efficiency for large angle MIPs is found in our work.
- Currently, there is many other trial and update for large angle tracking.
  (see Ariga's talk and Valeri's poster)

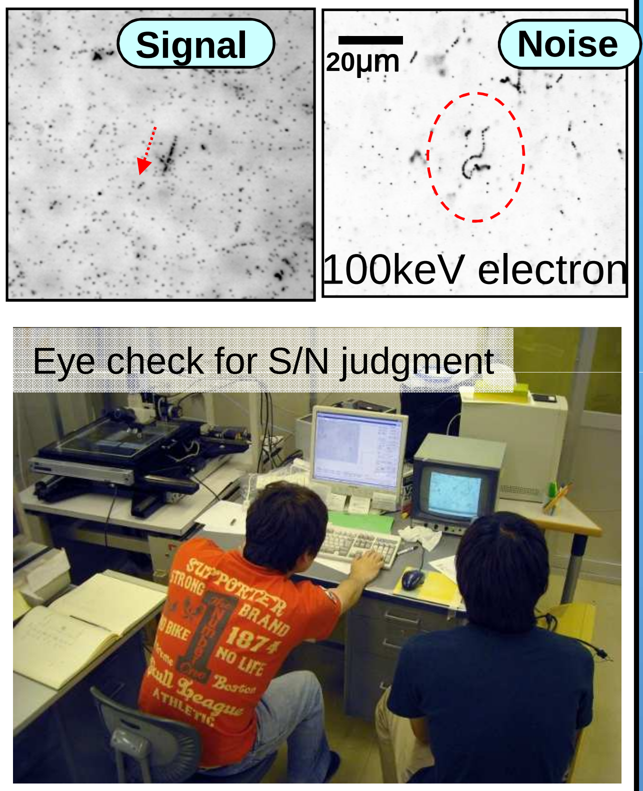
High discriminated tracking

Current emulsion analysis in OPERA film

Current strategy of analysis



Chance coincidence of Noise is also picked up as track in normal scan.



- **After reconstructing tracks in normal scan, there is many chance coincidence of Noise track. so we must judge signal/noise by eye for OPERA film.**
- **We want to reduce eye check process because it's heavy work.
  This is the motivation for development of high discriminated (S/N) tracking.**

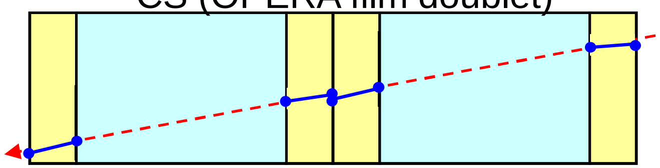
Past progress for high S/N tracking

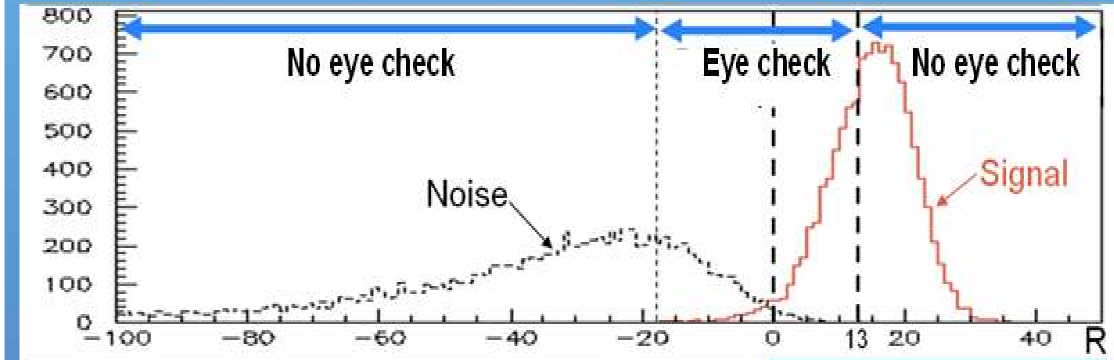
- We developed a high discriminated method on basis of log-likelihood for CS analysis in OPERA. [Track Ranking method: T.Fukuda et al., 2010 *JINST* 5 P04009]
- Selection parameter is linearity and blackness of track data.

$$L^{signal} = \prod_{i=1}^{4} P_{VPH_i}^{signal}(\theta) * \prod_{i=1}^{8} P_{dAmicro_i}^{signal}(\theta,\ ph) * \prod_{i=1}^{2} P_{dAbase_i}^{signal}(\theta) * \prod_{i=1}^{2} P_{dXbase_i}^{signal}(\theta)$$

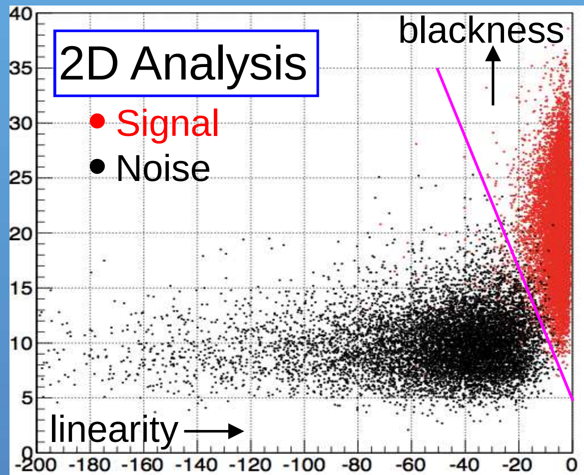
$$L^{noise} = \prod_{i=1}^{4} P_{VPH_i}^{noise}(\theta)$$

$$Track\ \ Ranking\ \ Score\ (R) = \log \frac{L^{signal}}{L^{noise}}$$





Signal	<0.1%	2%	34%	64%	98%
Noise	77%	22%	1%	<0.1%	



Selection parameter from normal scan is finish up.
So tracking algorithm itself should be improved for furthermore S/N improvement.

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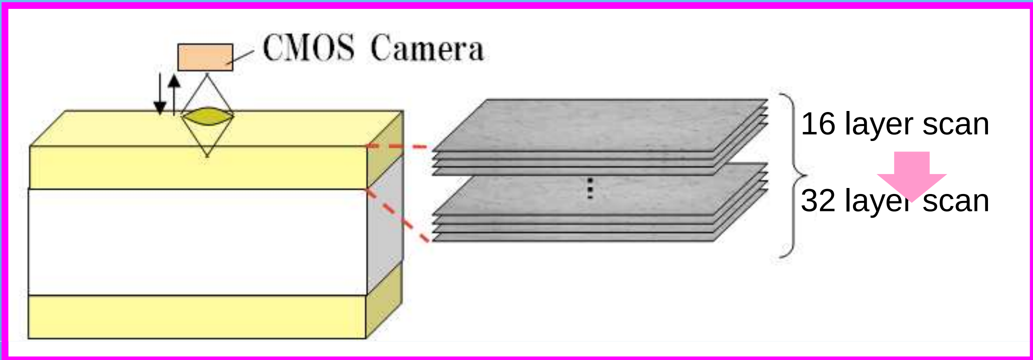
Tracking in FTS

High S/N tracking

1. increasing image information
   (16 layer scan → 32 layer scan)

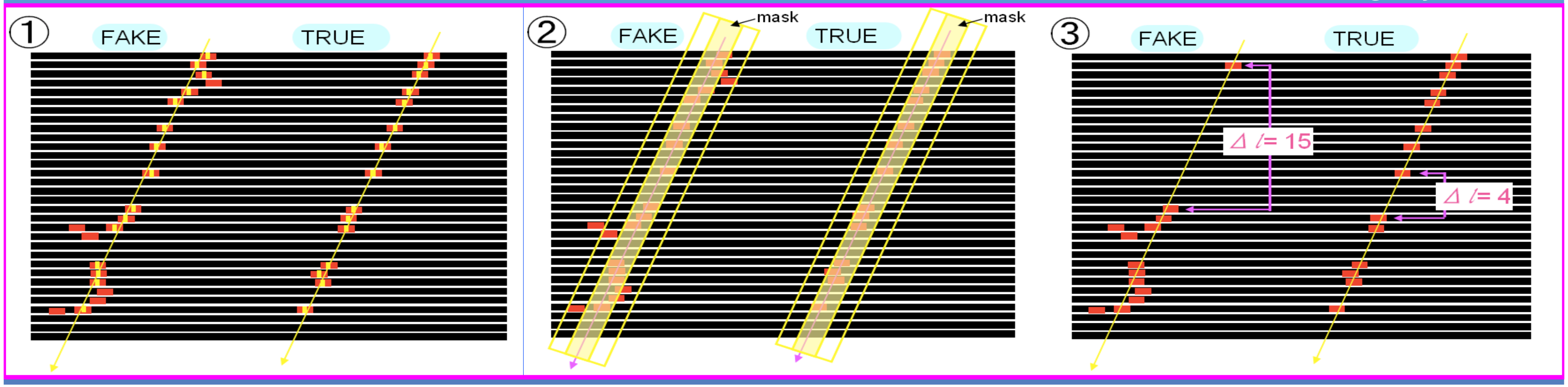


2. additional judgment for micro track
   (pick up new selection parameters)

Linearity of grains

Number of grains around track

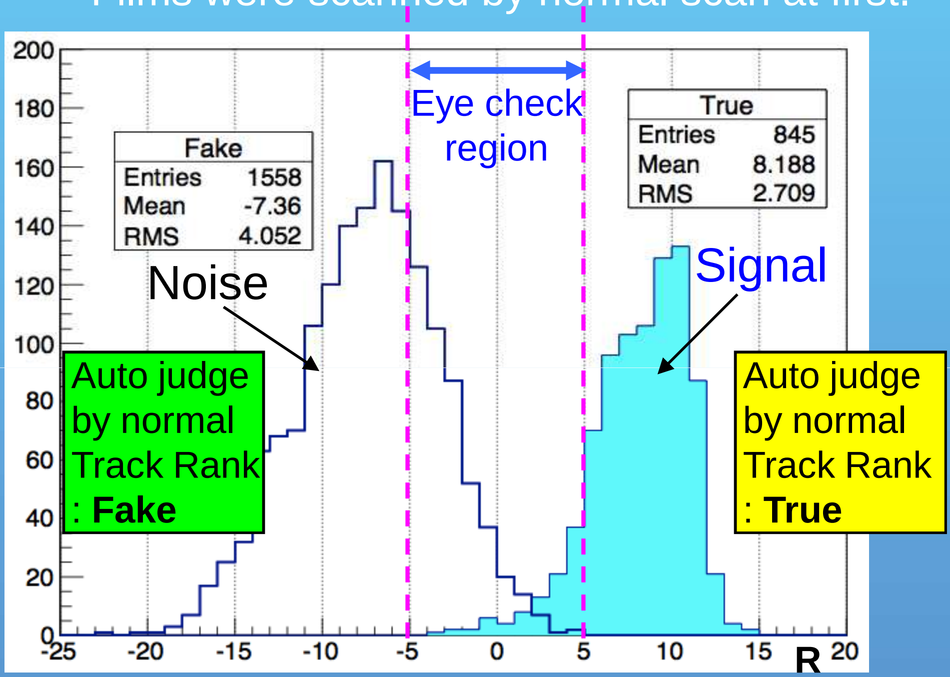
Maximum gap
between hitting layer



High S/N tracking

Evaluation of noise reduction rate

- Sample films were exposed beam.
- Films were scanned by normal scan at first.



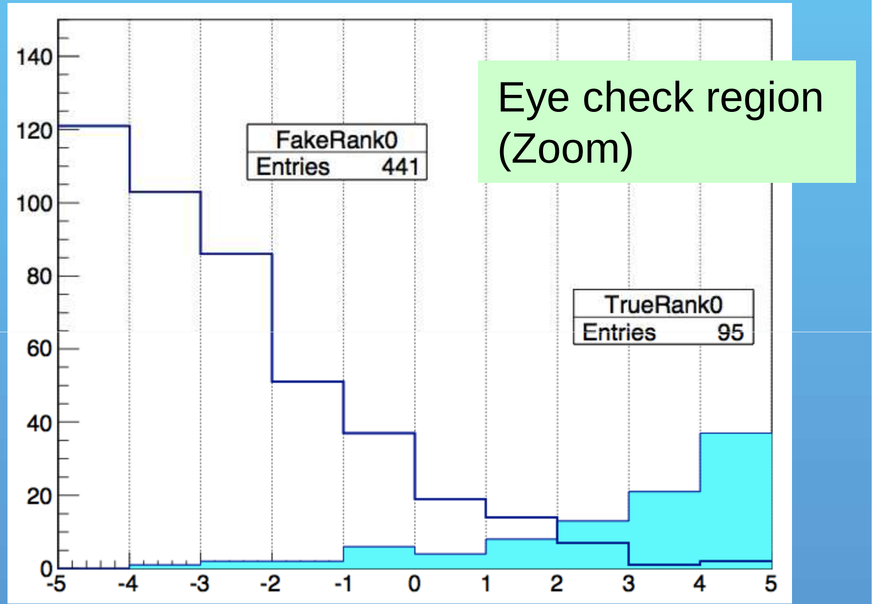
Normal Track Ranking score

$$L^{signal} = \prod_{i=1}^{2} P_{ph_i}^{signal}(\theta) * \prod_{i=1}^{4} P_{dAmicro_i}^{signal}(\theta, ph)$$

$$L^{noise} = \prod_{i=1}^{2} P_{ph_i}^{noise}(\theta)$$

Track Ranking score (R_0) $= \log \frac{L^{signal}}{L^{noise}}$

The sample for evaluation



Sample (|tanθ|<0.2) were checked by eye (-5≤R<5).

- Signal track → 95 base tracks
- Noise track → 441 base tracks

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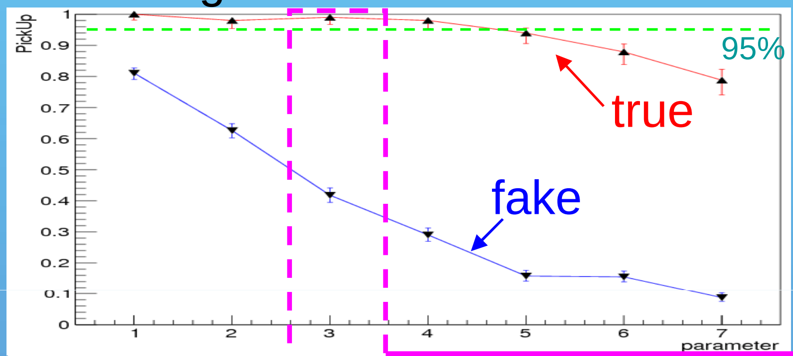
Effect of 32 layer scan

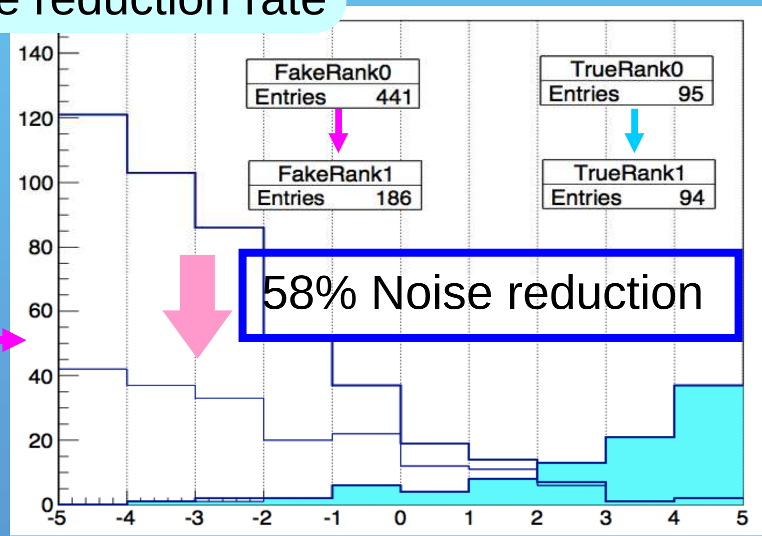
All micro tracks were re-measured by FTS.

Re-recongized rate in FTS



	Prm1	Prm2	Prm3	Prm4	Prm5	Prm6	Prm7
True	1.000	0.980	0.989	0.980	0.939	0.879	0.788
Fake	0.811	0.626	0.422	0.290	0.158	0.155	0.087

Noise reduction rate



- **Scanning condition :**
  The brightness filter for binarization and the expansion filter is changed.
- **The selection parameter [99% re-recongized rate for True tracks] is chose.**
- **If we reject tracks which are not re-recognized on both side, 58% Noise track is reduced.**

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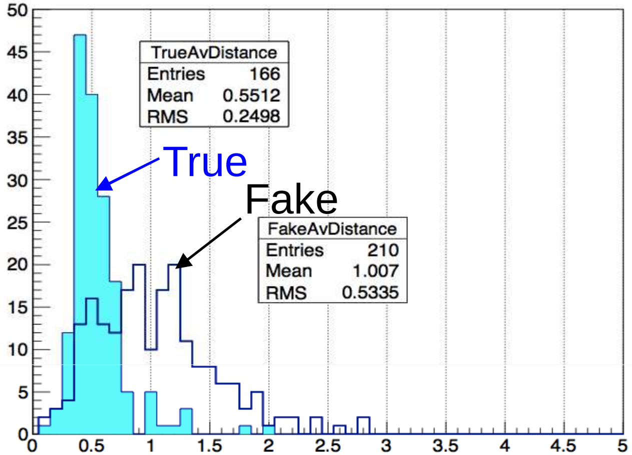
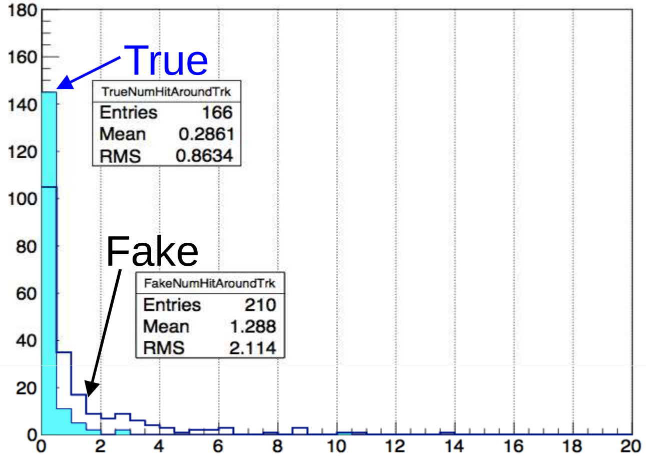
Track Ranking using new selection parameters

- The status of new selection parameter for True tracks and Fake Tracks.

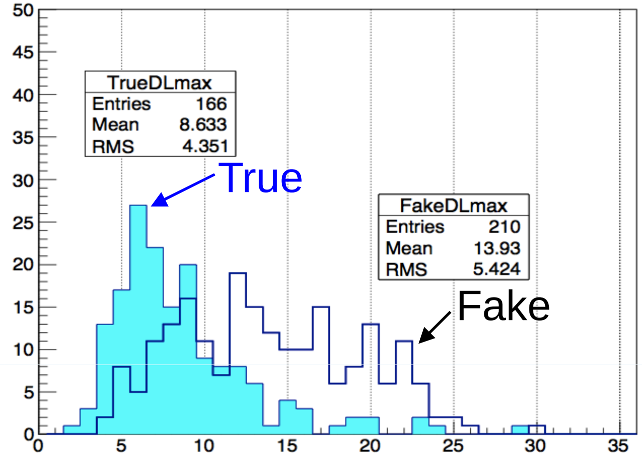
[1] Linearity of grains



[2] Number of grains around track



[3] Maximum gap between hitting layer

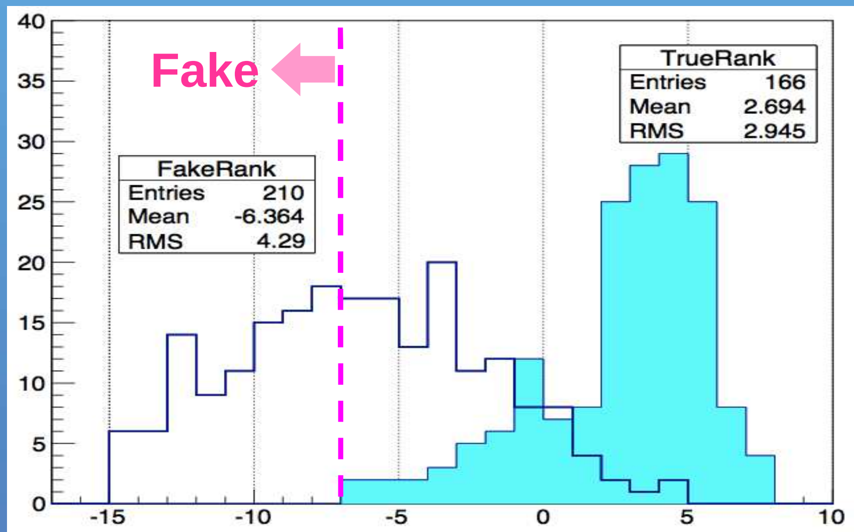


new TRank score is calculated based on the PDF of new selection parameters.

$$L^{signal} = P_{[1]}^{signal} \times P_{[2]}^{signal} \times P_{[3]}^{signal}$$

$$L^{noise} = P_{[1]}^{noise} \times P_{[2]}^{noise} \times P_{[3]}^{noise}$$

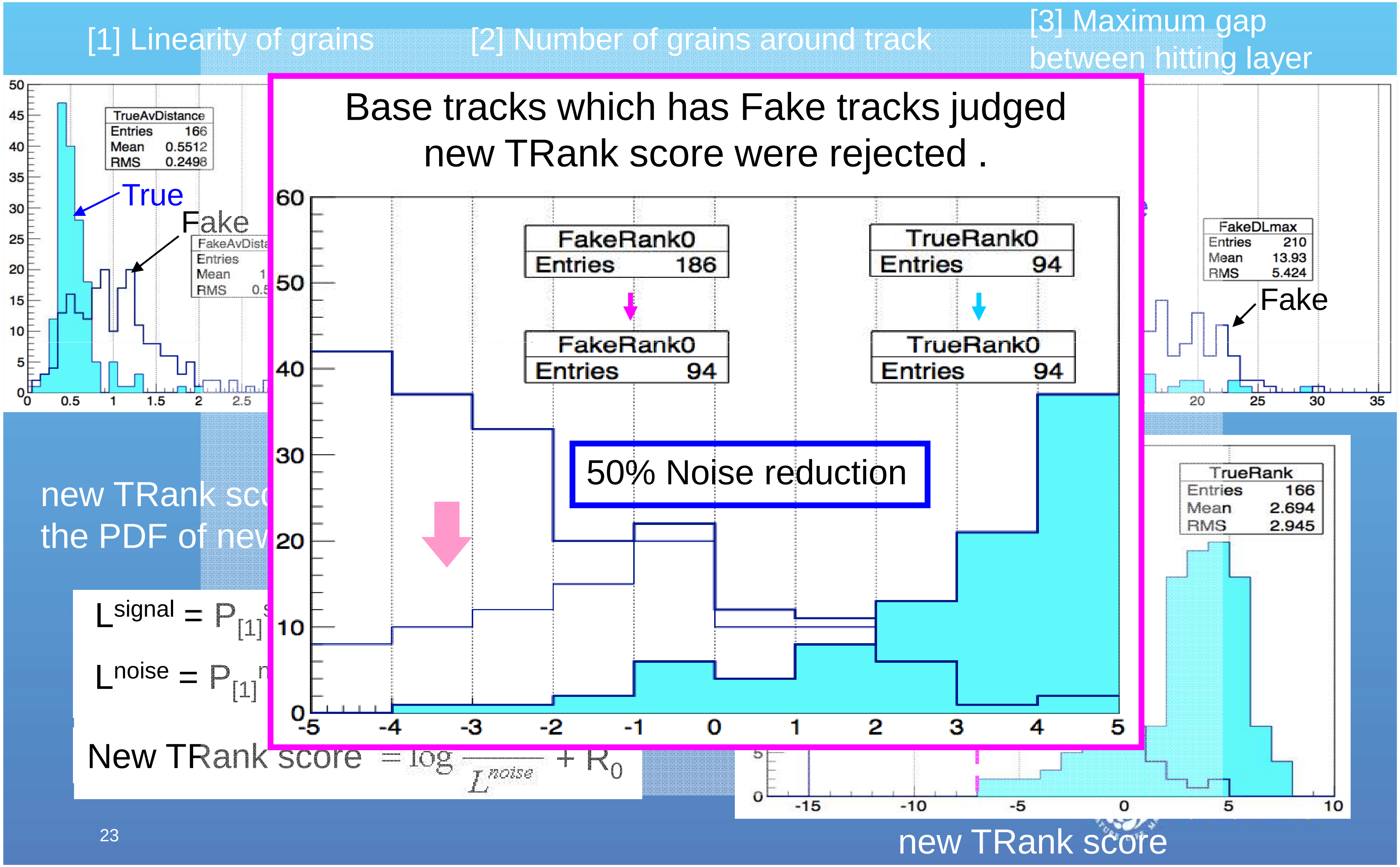
$$\text{New TRank score} = \log \frac{L^{signal}}{L^{noise}} + R_0$$



new TRank score

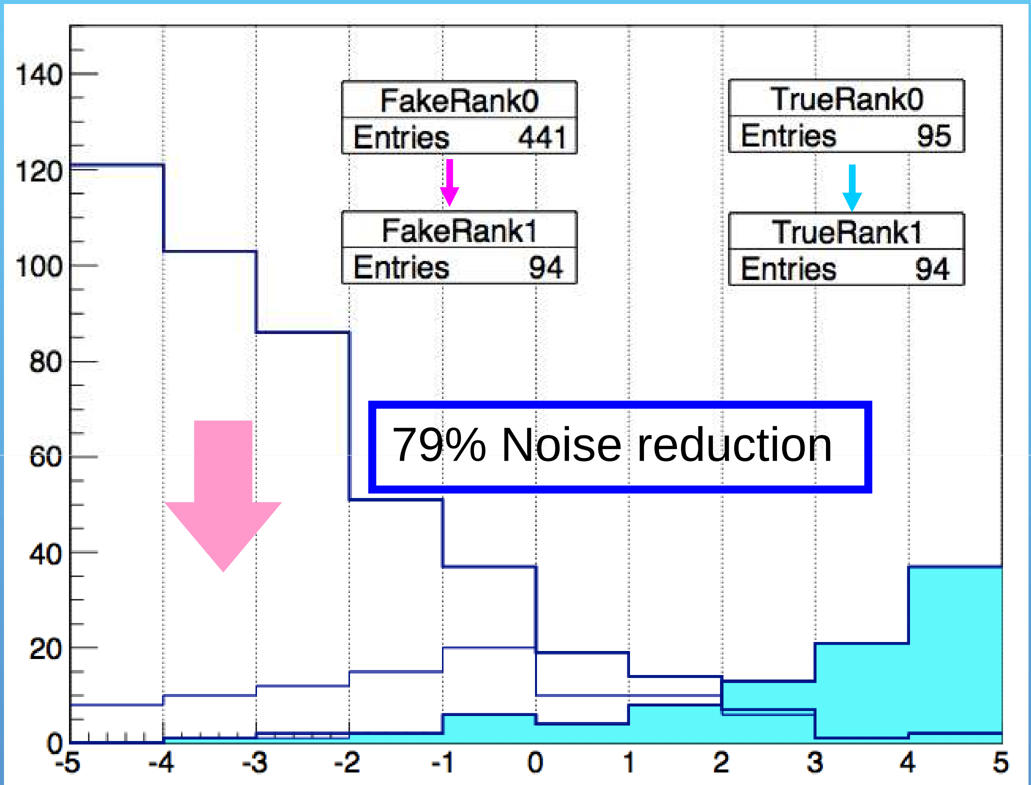
Track Ranking using new selection parameters

- The status of new selection parameter for True tracks and Fake Tracks.



High S/N tracking

Current noise reduction rate by FTS



The efficiency of True tracks were kept on 99% and 21% Fake tracks were survived.

In the case of CS (OPERA film doublet), 98% true tracks are survived and 95% fake tracks are rejected additionally.

	FTS:32layer scan	FTS: new prm	for OPERA film	for OPERA film doublet
Signal	95 → 94	94 → 94	94/95 = 0.99	0.98
Noise	441 → 186	186 → 94	94/441 = 0.21	0.05

Summary

- We have been developing High discriminated tracking method.
- This will allow an automation of emulsion analysis.
- We also developed an technique for automatic large angle tracking.
- This technique was applied for hadron analysis and also BG reduction for OPERA.
- The HIGH automatic recognized efficiency for large angle MIPs is found in our work.
- In this talk, I introduced pioneer works which is qualitatively different from conventional development strategy [speed up]. I hope many kind of improvement for scanning is done.

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