Status report of the OPERA experiment

SPSC Meeting 102

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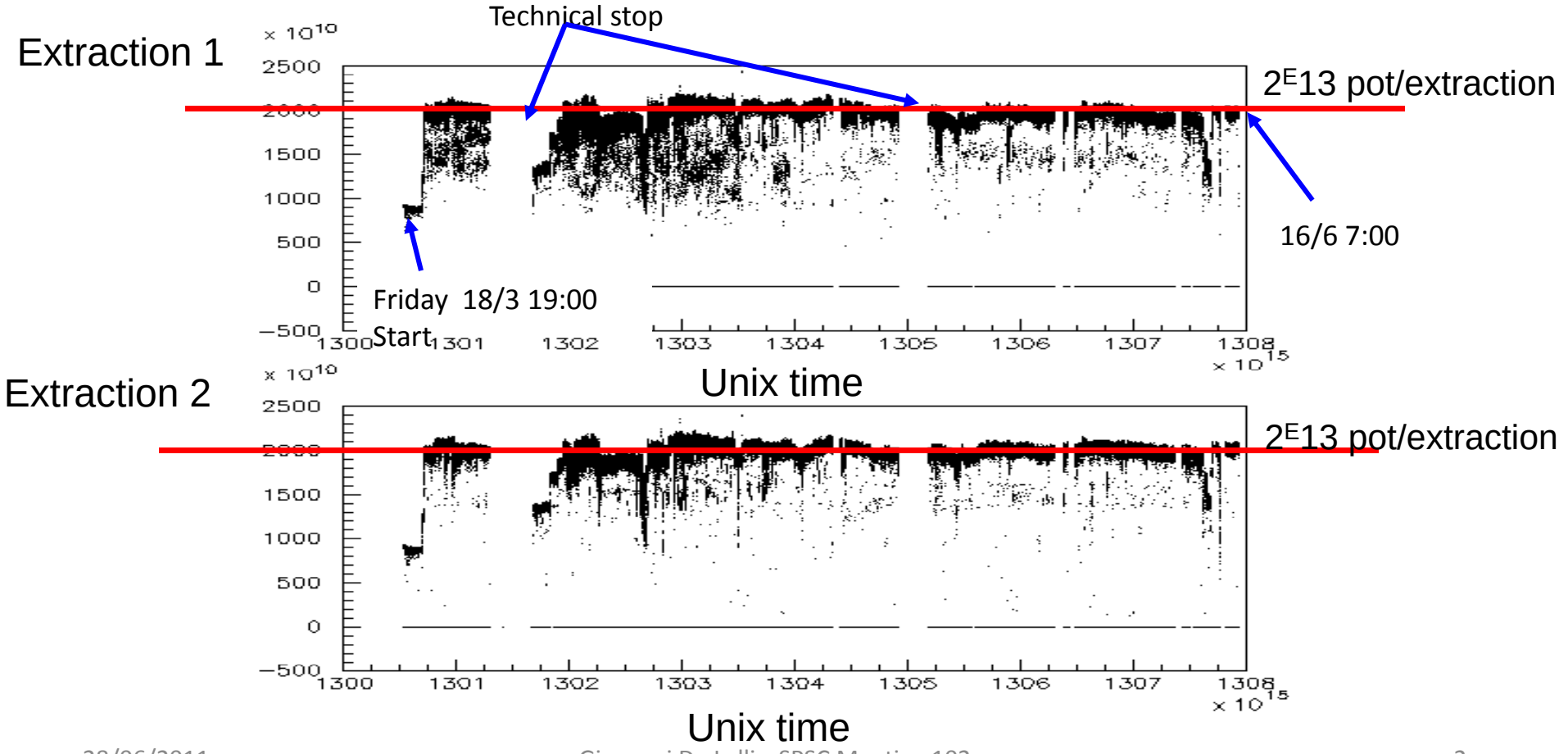
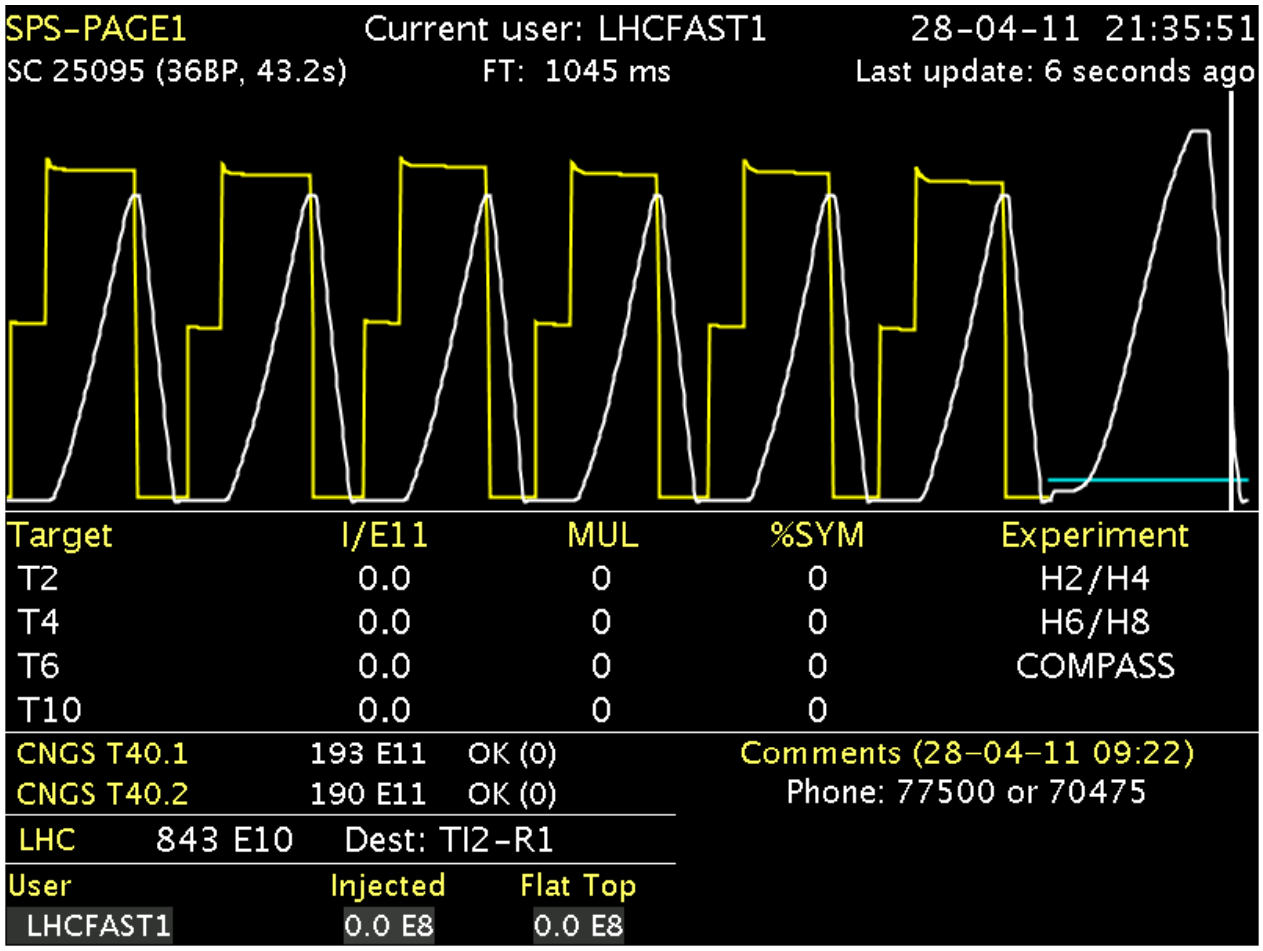
On behalf of the OPERA Collaboration

CNGS in 2011

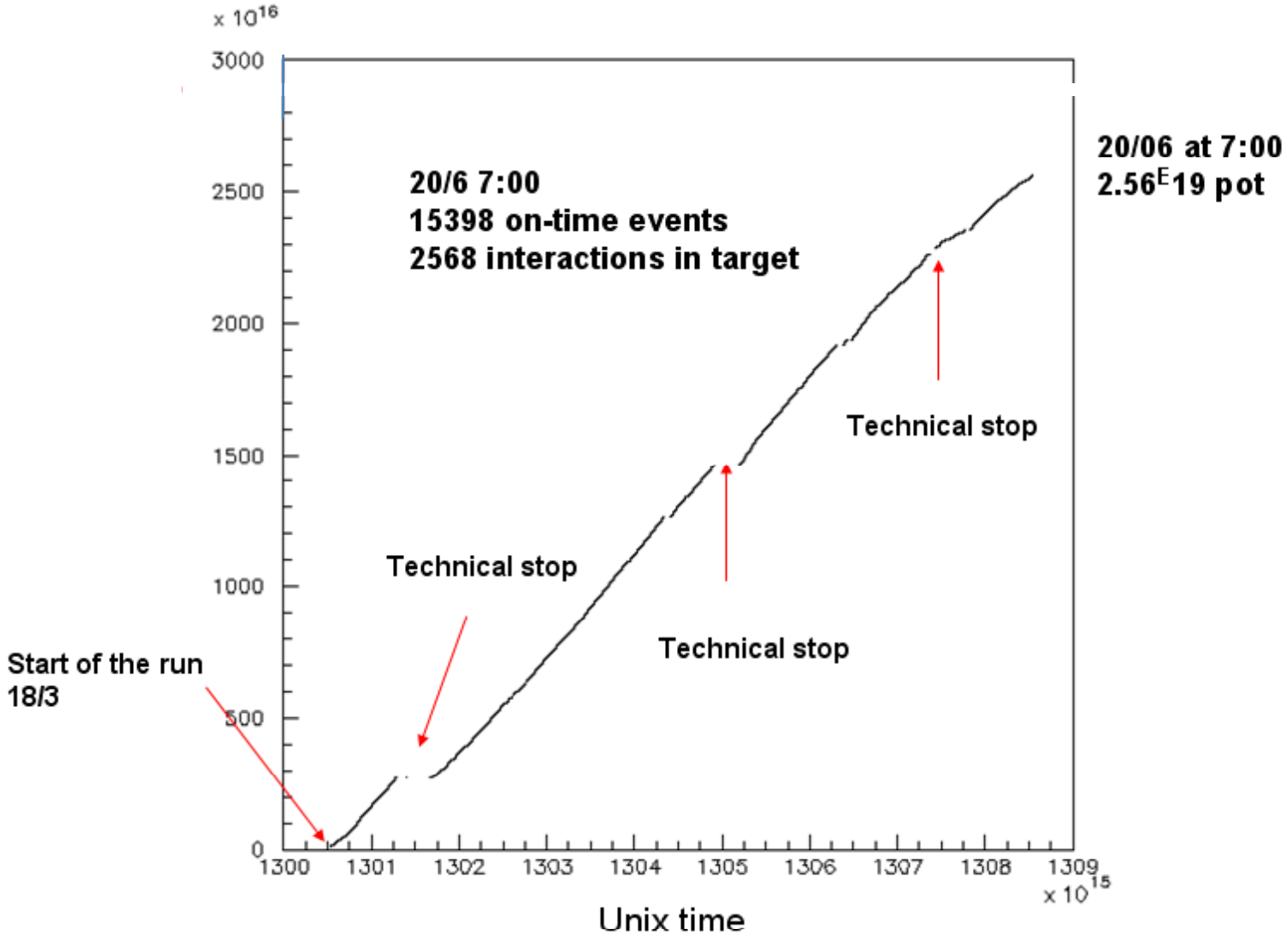
- CNGS in dedicated mode (CNGS + LHC) since March 18th until June 7th (4 additional weeks due to North Area problems)
- Expected to run for 223 days (till November 20th) → > 5 x 10^{19} pot
- Integral (2008÷2011) → ~14.5 x 10^{19} pot ~ 65% of 5 nominal years



SPS super-cycle with 6 CNGS cycles + LHC in dedicated mode



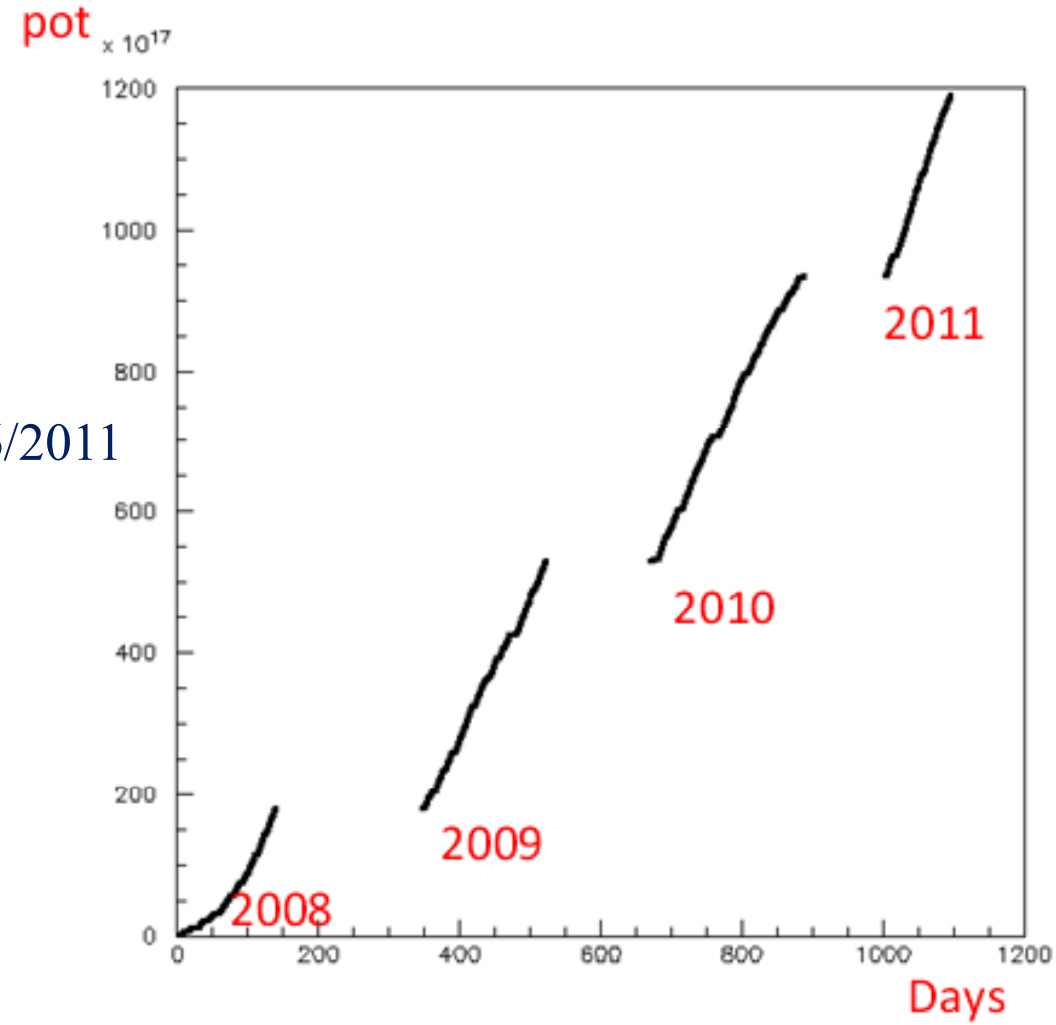
2011 run: integrated pot so far



CNGS beam performance

Year	Beam days	P.O.T. (10^{19})
2008	123	1.78
2009	155	3.52
2010	187	4.04
2011	101	2.69
Total	**566**	**12.03**

As of 27/06/2011

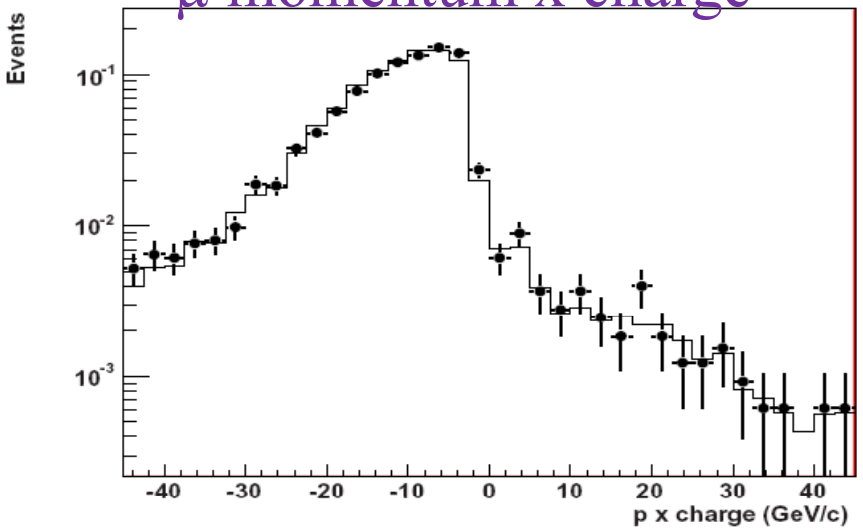


Detector and facilities performance

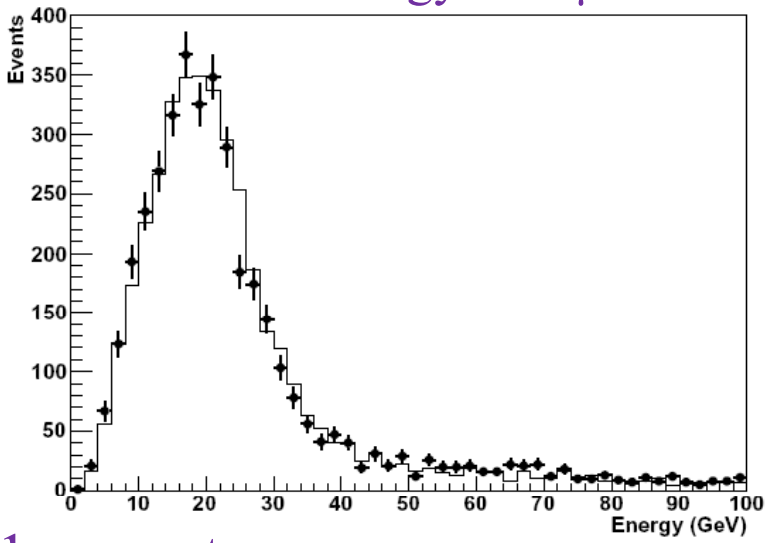
Improvements in the understanding of the electronic detector

New Journal of Physics 13 (2011) 053051

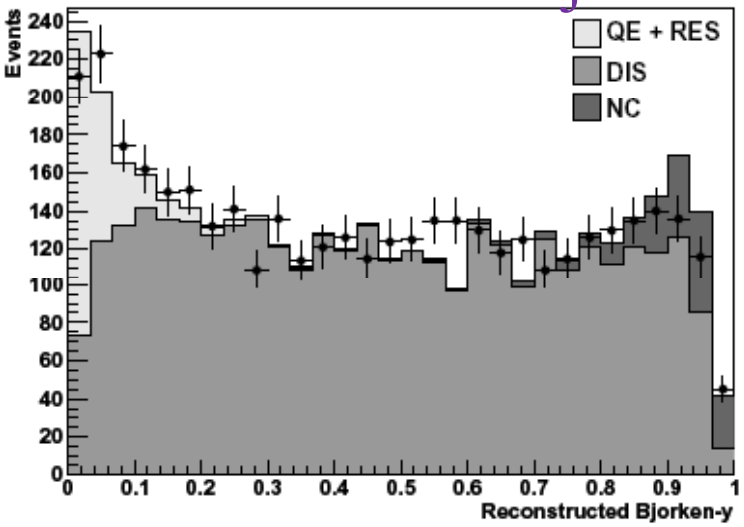
μ momentum x charge

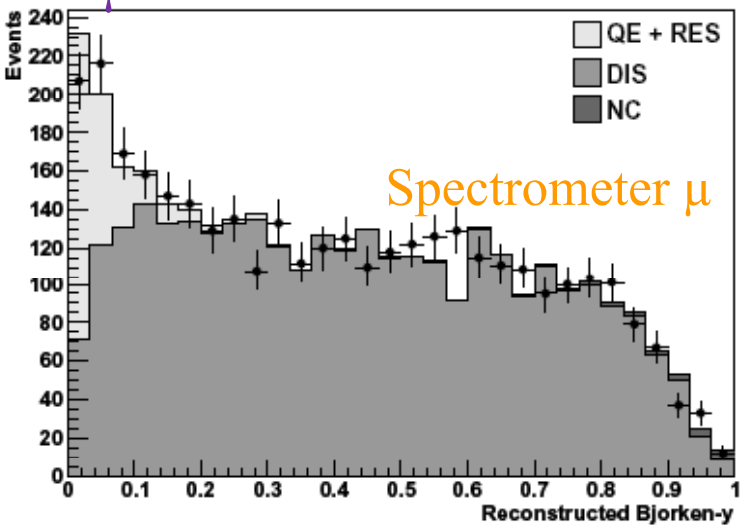


Reconstructed energy for 1μ events



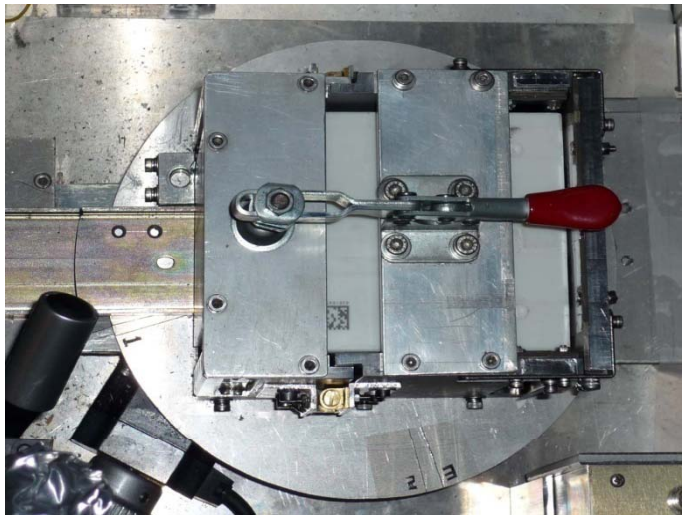
Y- Bjorken for 1μ events

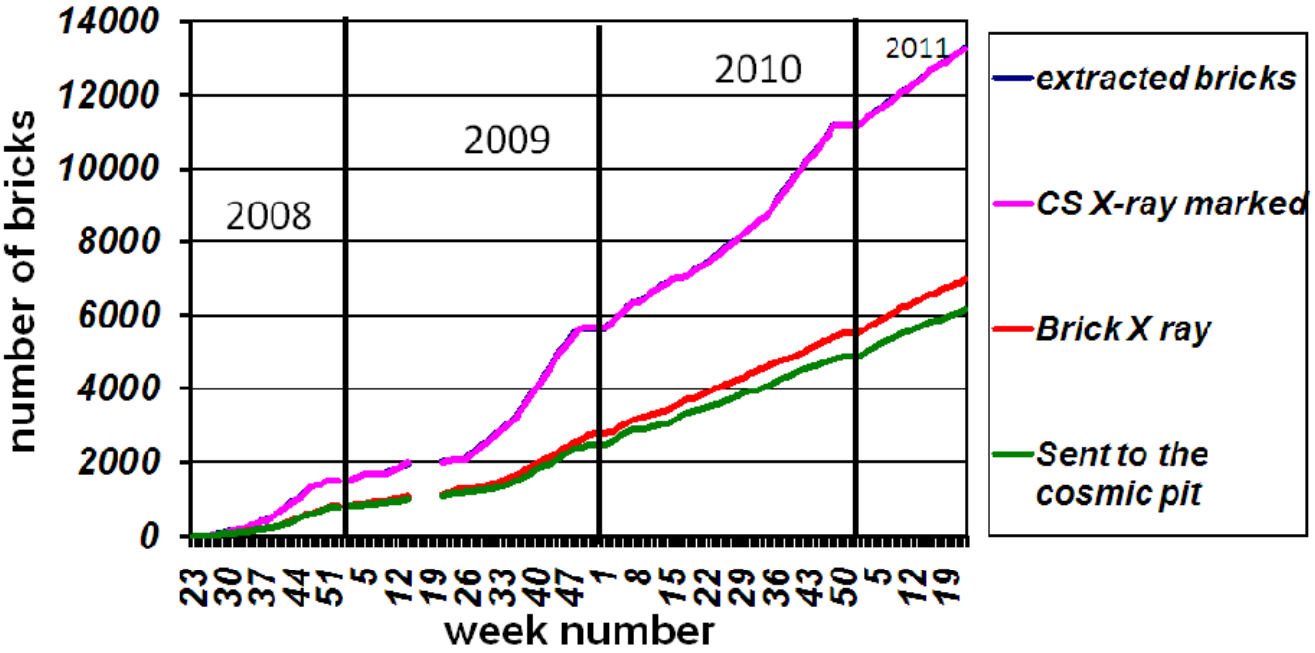




Brick manipulator system

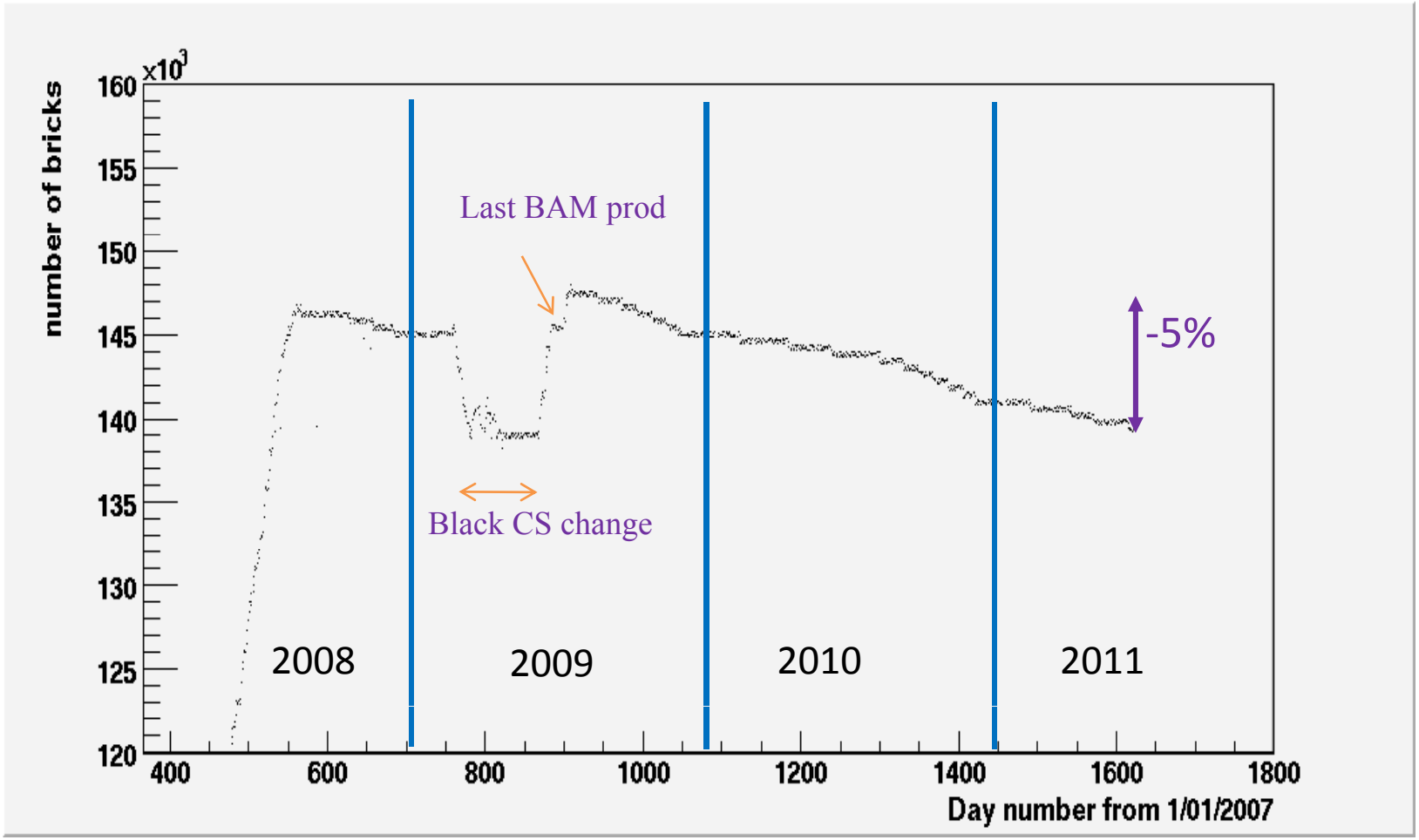
X-ray marking





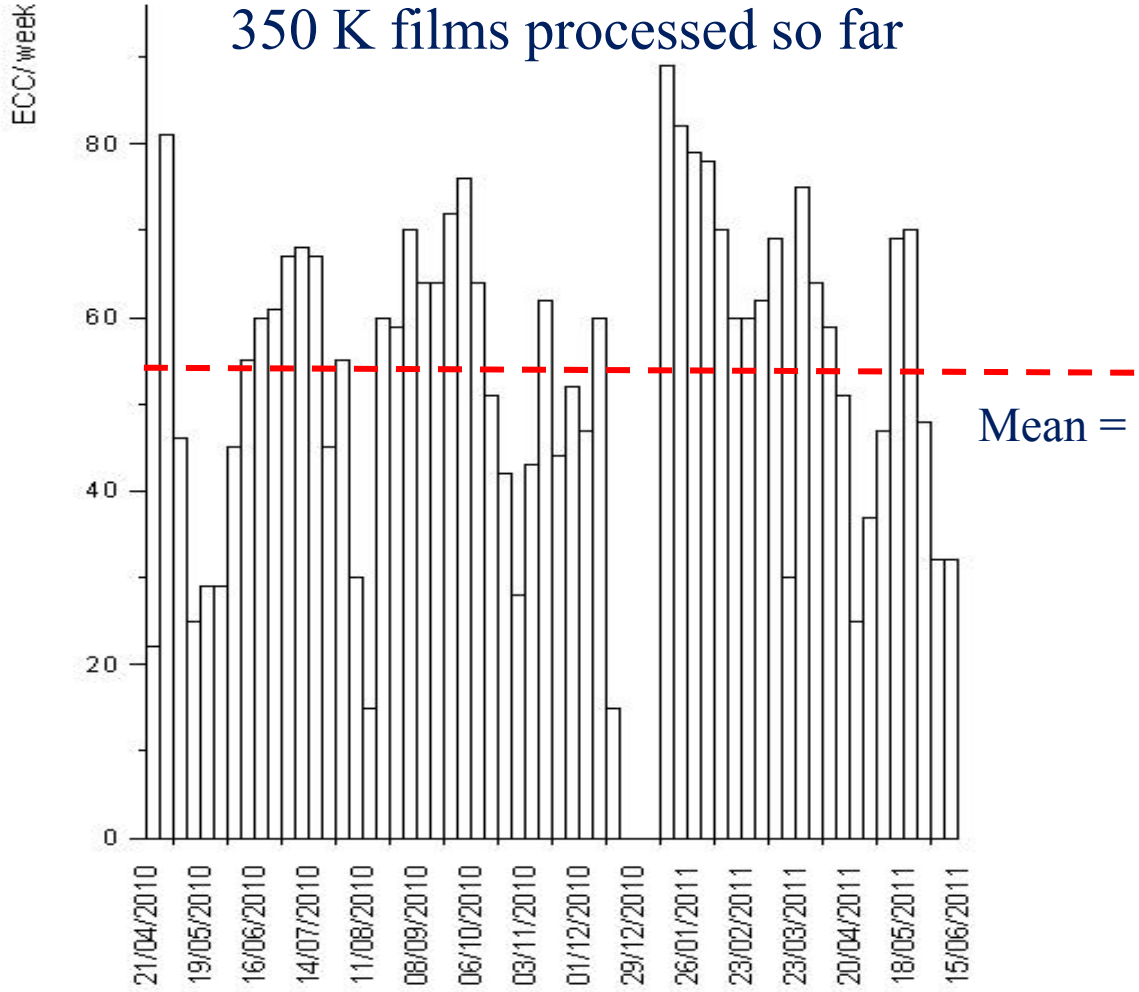
13312 extracted bricks (2008÷2011)

Target mass evolution



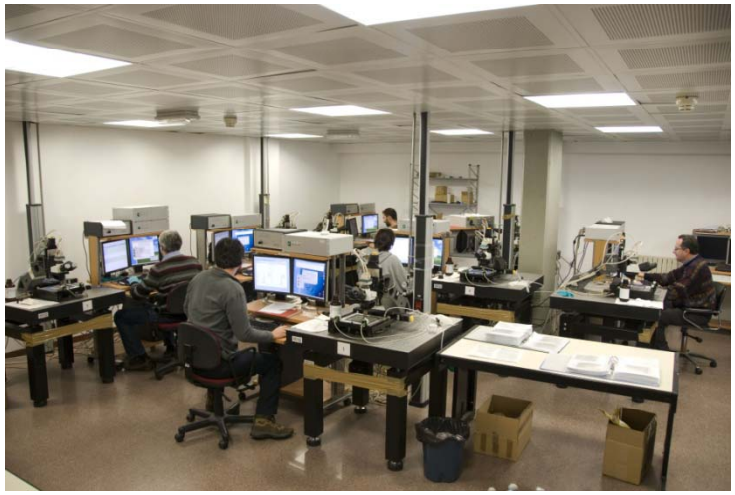
Emulsion development facility

350 K films processed so far



Mean = 55 bricks/week

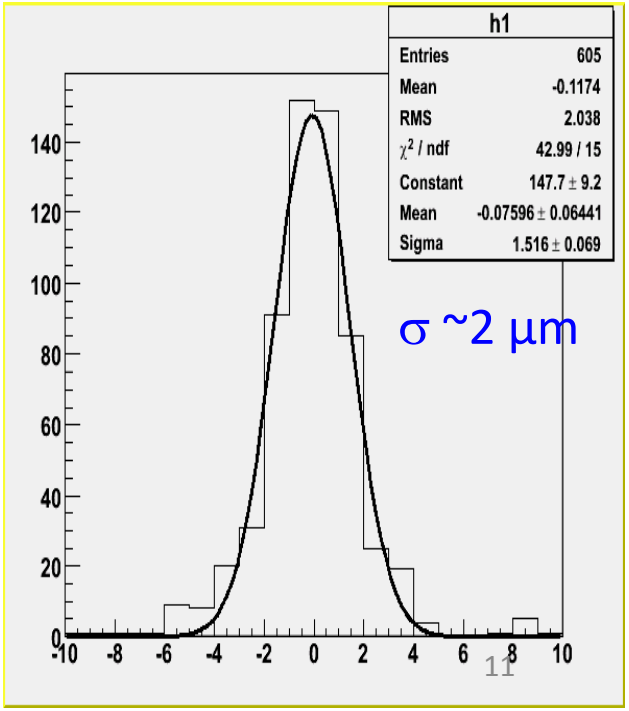
Scanning of Changeable Sheets: several tasks accomplished



LNGS: 11 microscopes, 220 cm^2/h

Nagoya: 5 S-UTS, 220 cm^2/h

So far ~ 1000000 cm^2 analyzed



Improvements in the emulsion analysis

Speed up CC event analysis: likelihood to replace visual inspection

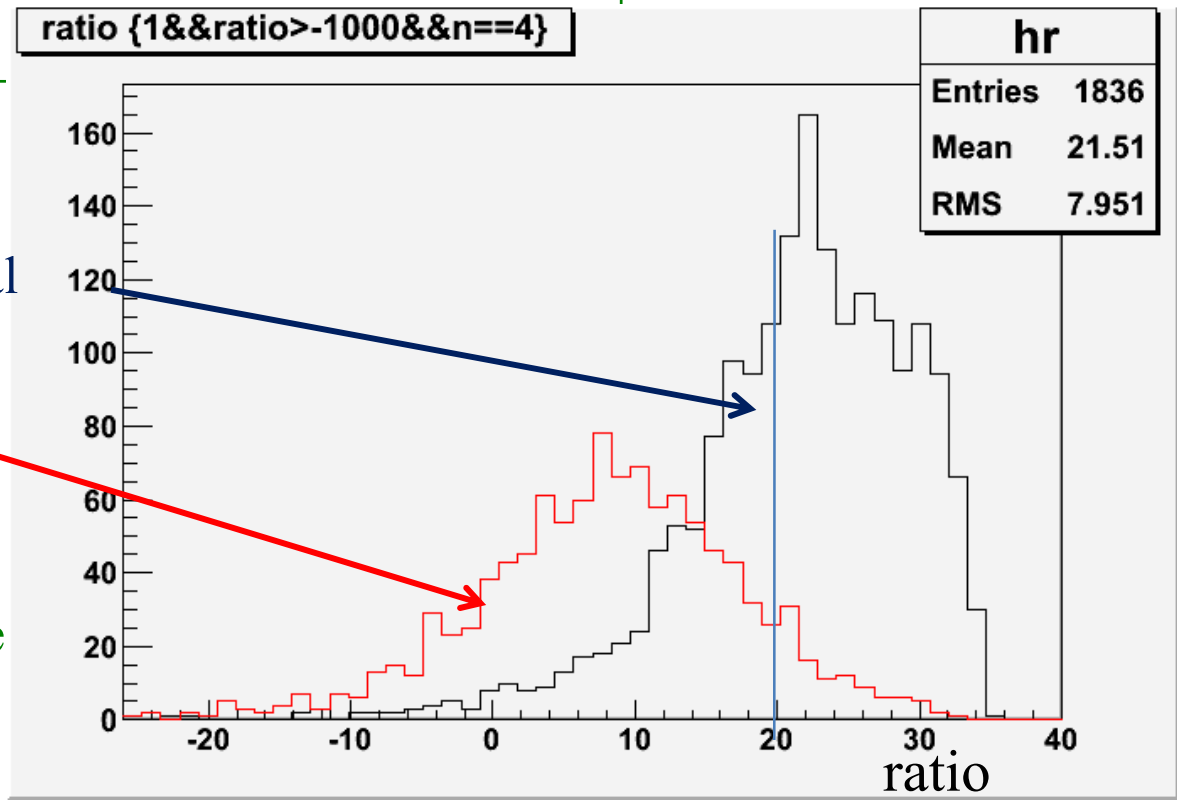
$$L^{signal} = \prod_{i=1}^{4} g_i^{signal}(\theta) * \prod_{i=1}^{8} ds_{\mu tr\,i}^{signal}(\theta) * \prod_{i=1}^{2} \Delta S_{base\,i}^{signal}(\theta)$$

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

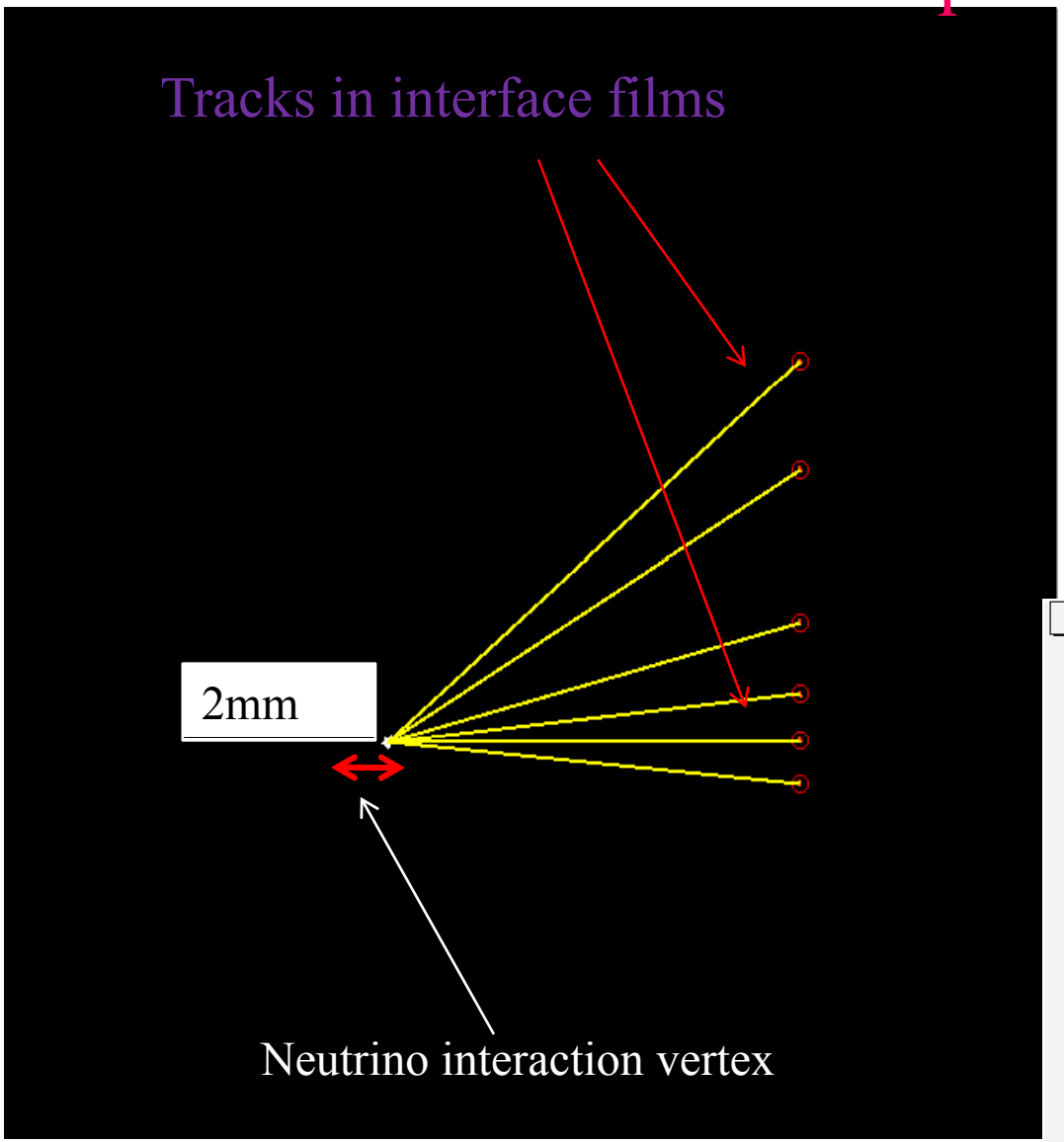
$$ratio = \ln \frac{L^{signal}}{L^{noise}}$$

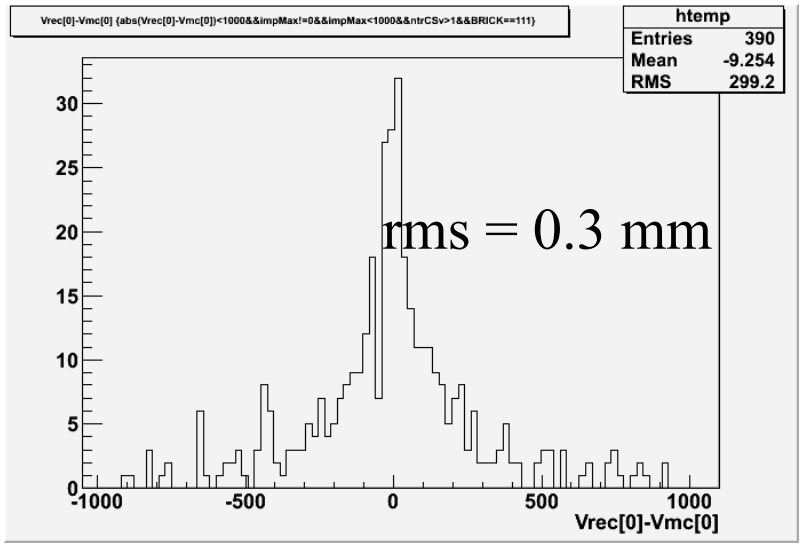
- Tracks validated through visual inspection
- Background tracks

- 40% of CC events validated without visual inspection since 2010

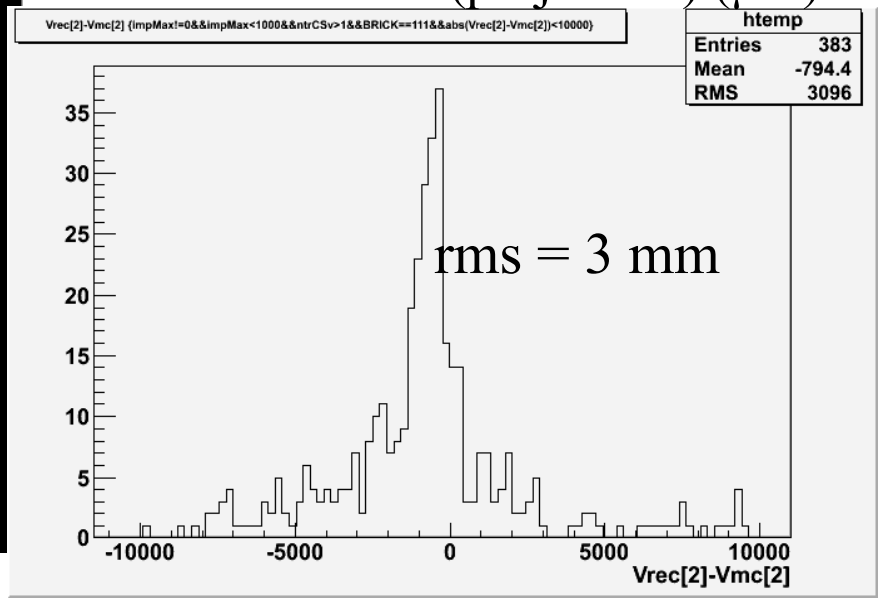


Speed up the analysis of events without μ in the final state: vertex pre-definition



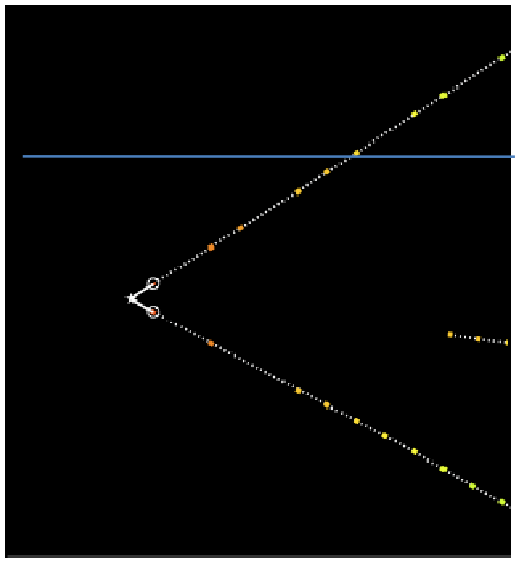


Transverse distance(projection) (μm)



Longitudinal distance (μm)

Study of CS tracks as seen in the brick



BRICK

CS

AT PRIMARY VERTEX 33%

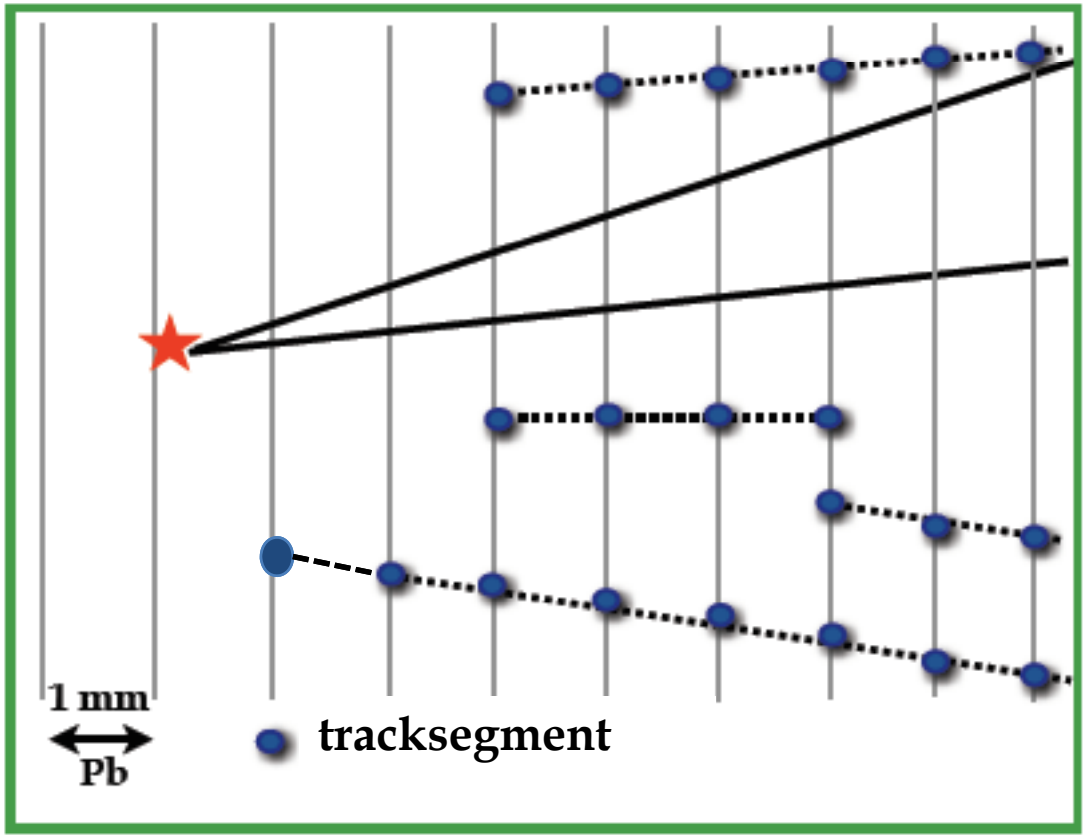
PENETRATING (cosmic rays, rock μ, ν_μ upstream) 7%

LOST (secondary particles, electrons) 22%

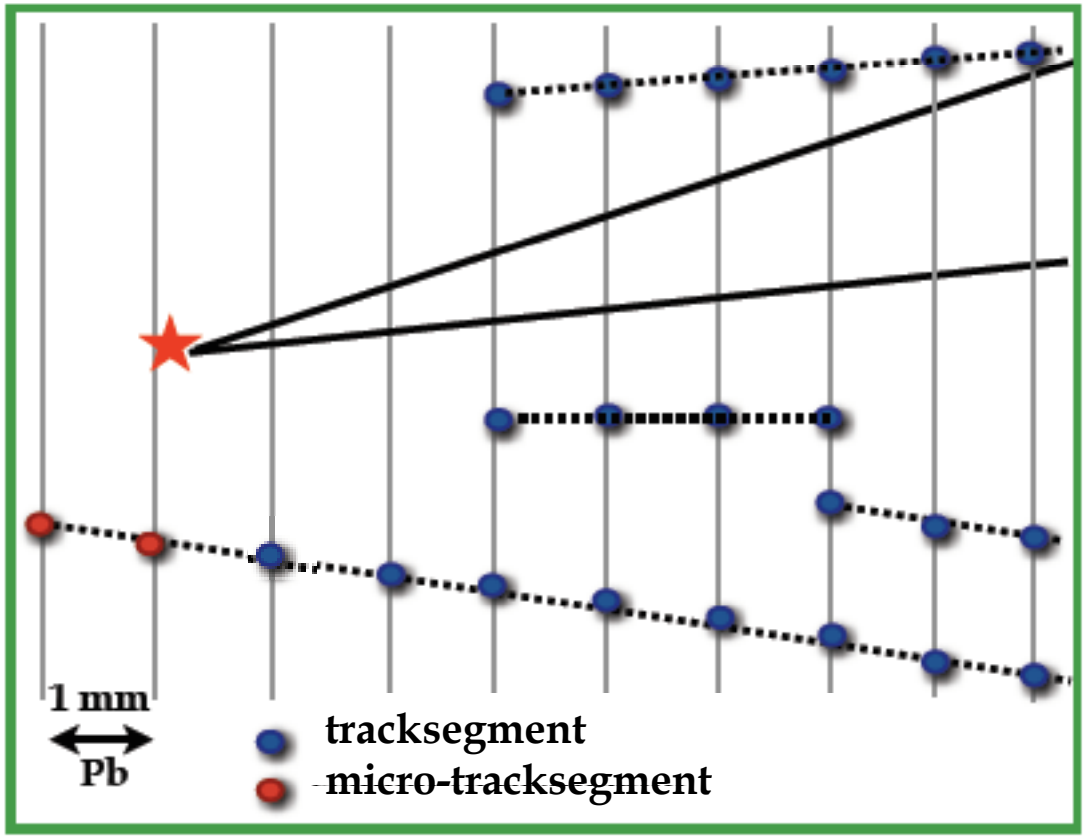
NOT CONNECTED (soft electrons, spurious tracks) 38%

AT PRIMARY VERTEX

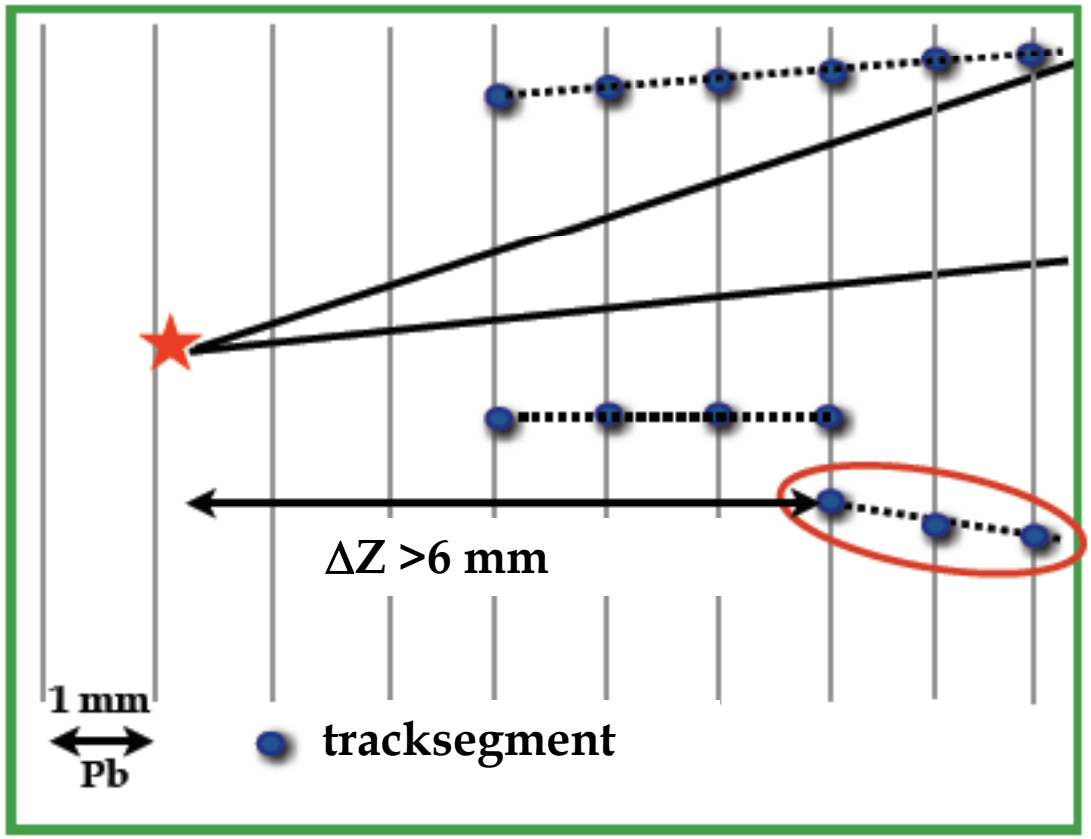
Improved decay search procedure



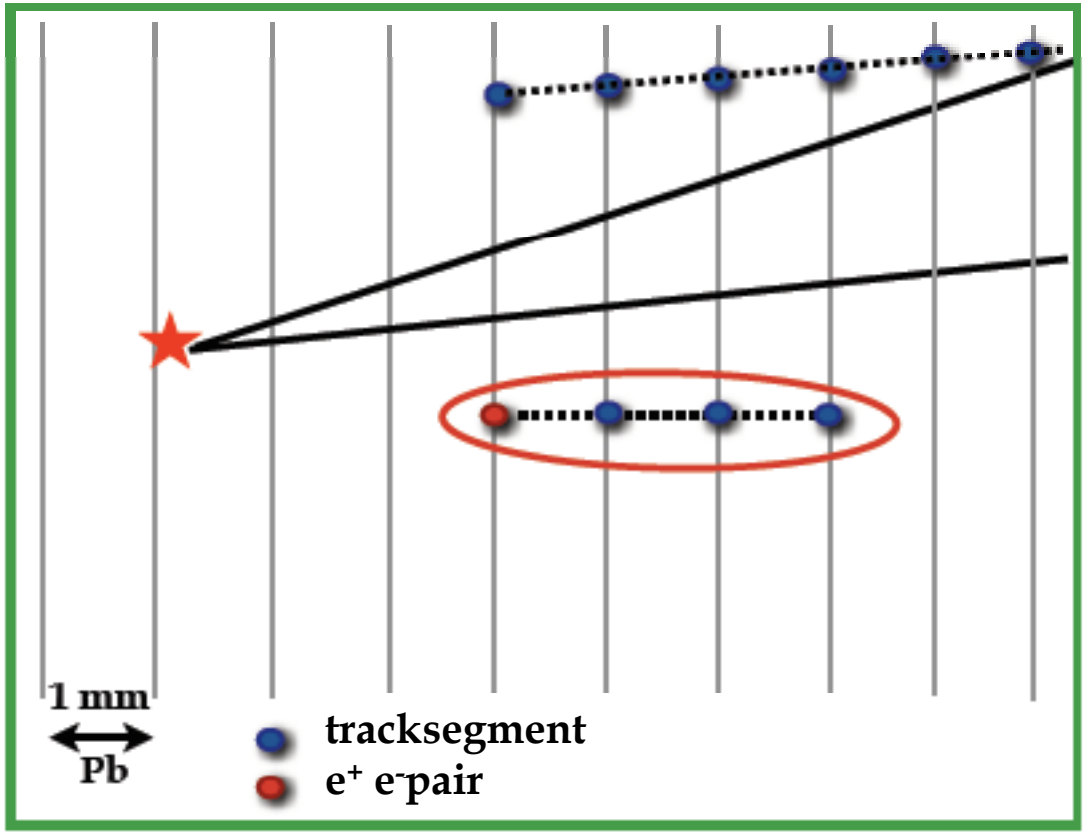
Decay search: penetrating tracks discarded



Decay search: track selection

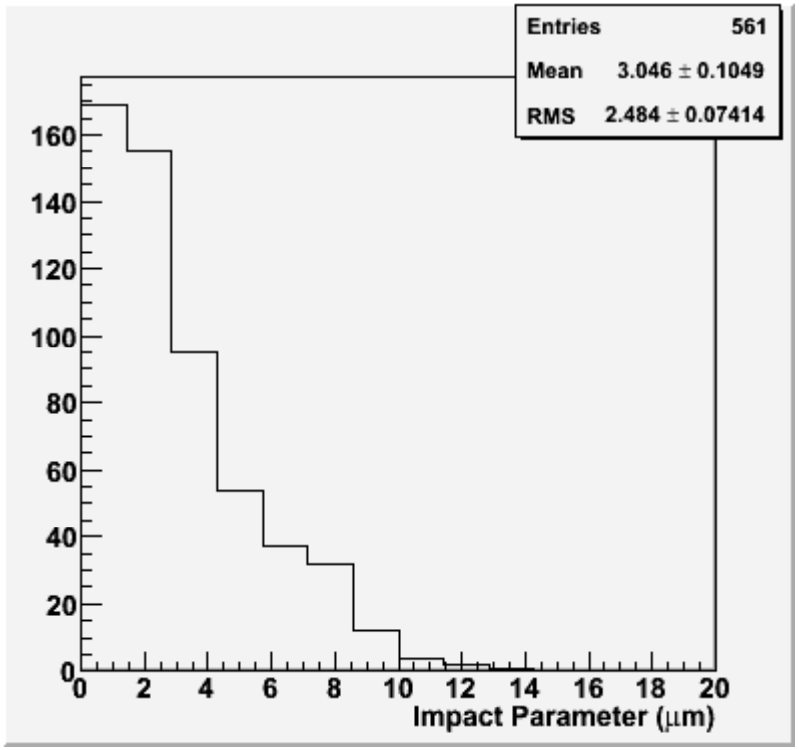


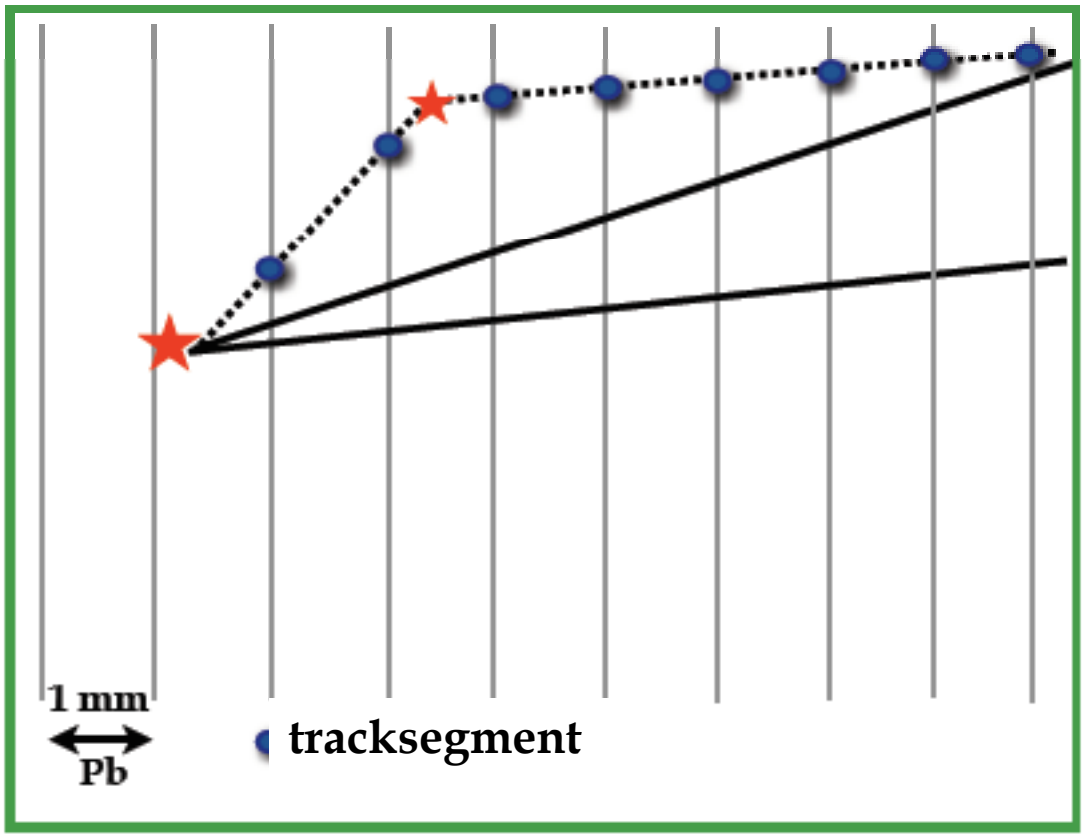
Decay search: electron pair



Decay search: kink topology detected

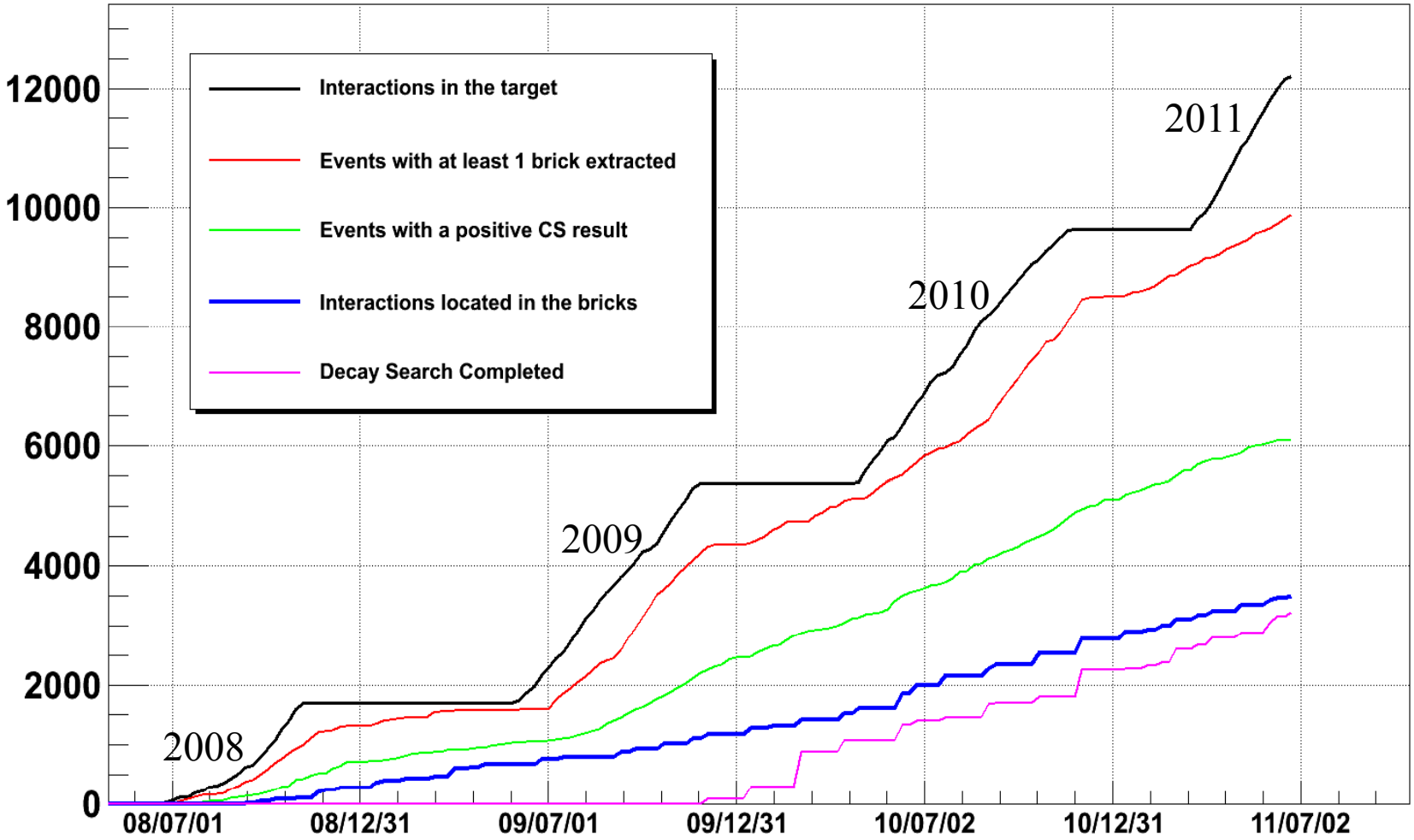
Impact parameter distribution of tracks associated to primary vertices





Current status of the data analysis

Performance plot



3513 interactions located in the bricks,
3232 “decay searched” events

Our strategy: analysis of 2008/09 runs

	0mu	1mu	All
Events predicted by the electronic detector	1503	3752	5255
Interactions located in ECC	519	2280	2799
Located in dead material	54	245	299
Decay search performed	494	2244	2738

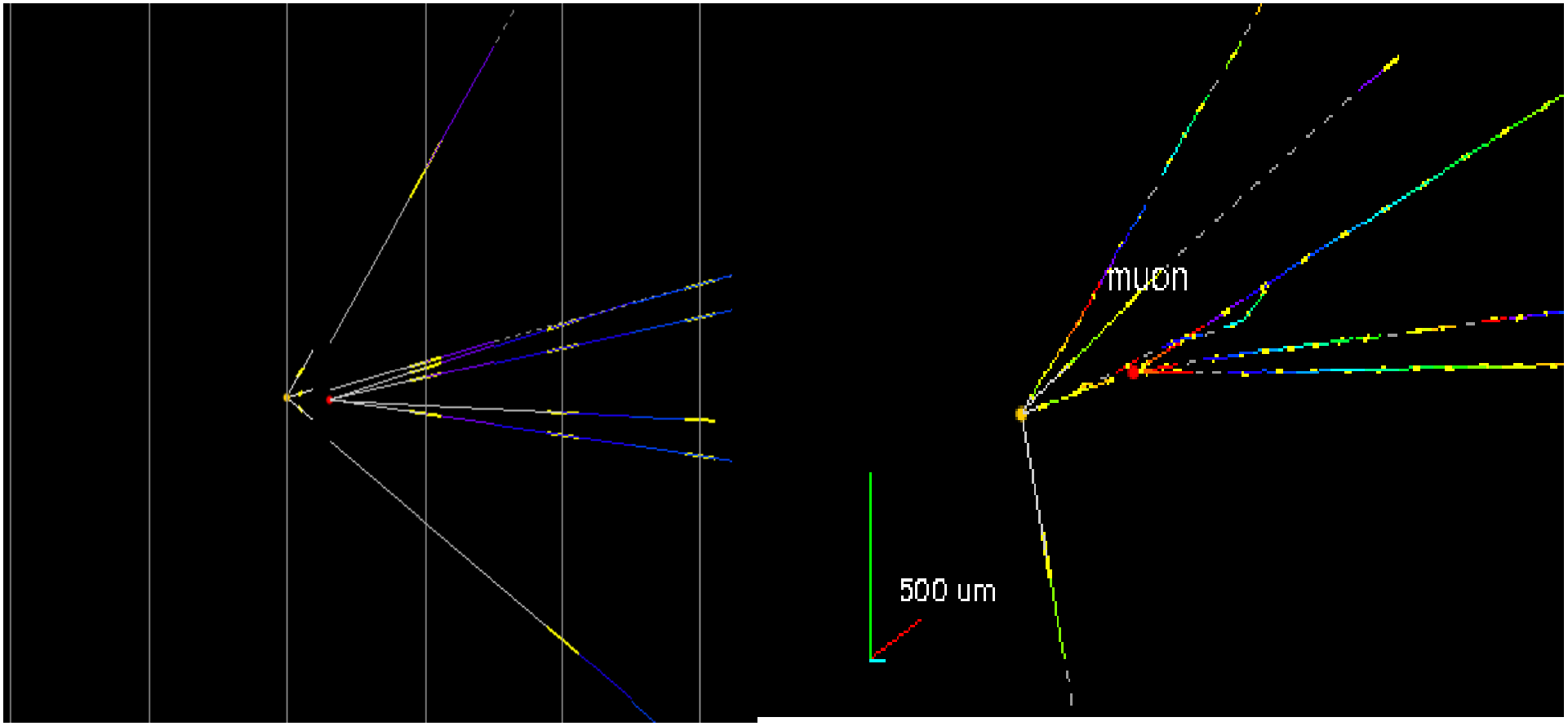
1088 in Phys. Lett. B691 (2010) 138

Results of the decay search: neutrino induced charmed hadron production

- Charm topology analogous to τ (similar lifetime)

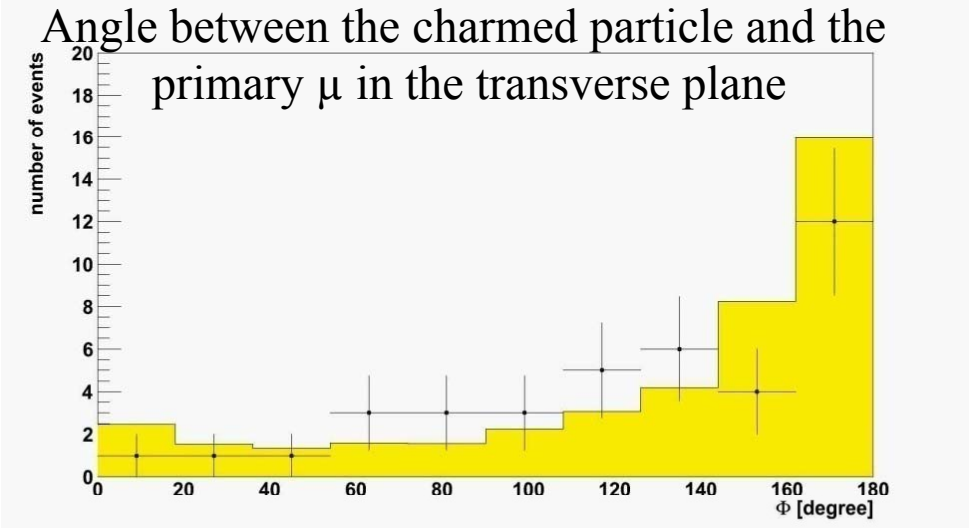
D0 → 4 prong

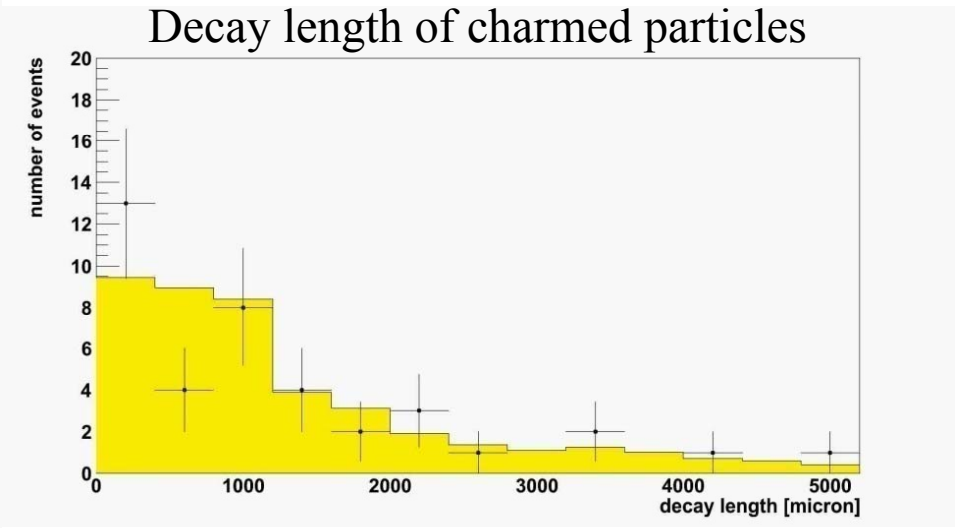
Charged charm → trident



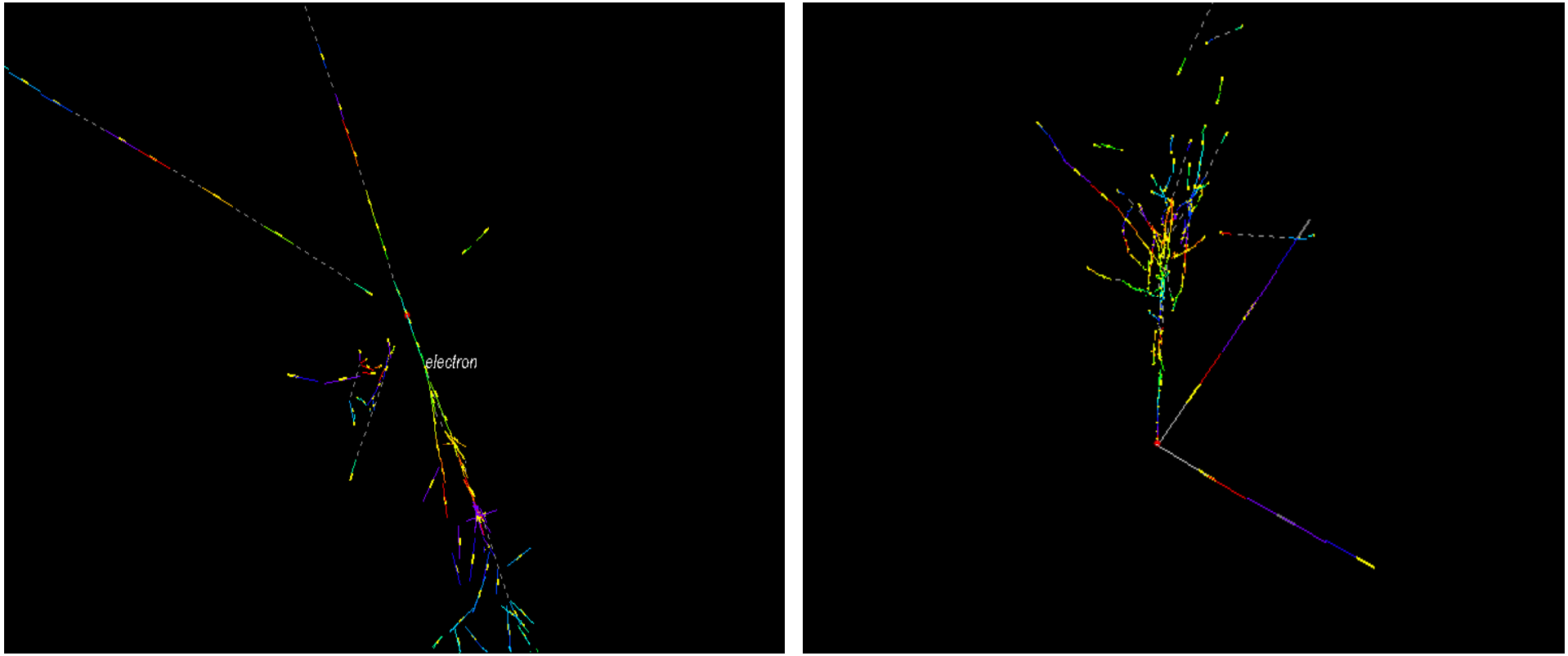
Charm events as a control sample (data versus MC)

Topology	Observed events	Expected events		
		Charm	Background	Total
Charged 1-prong	13	15.9	1.9	17.8
Neutral 2-prong	18	15.7	0.8	16.5
Charged 3-prong	5	5.5	0.3	5.8
Neutral 4-prong	3	2.0	<0.1	2.1
Total	39	39.1±7.5	3.0±0.9	42.2±8.3





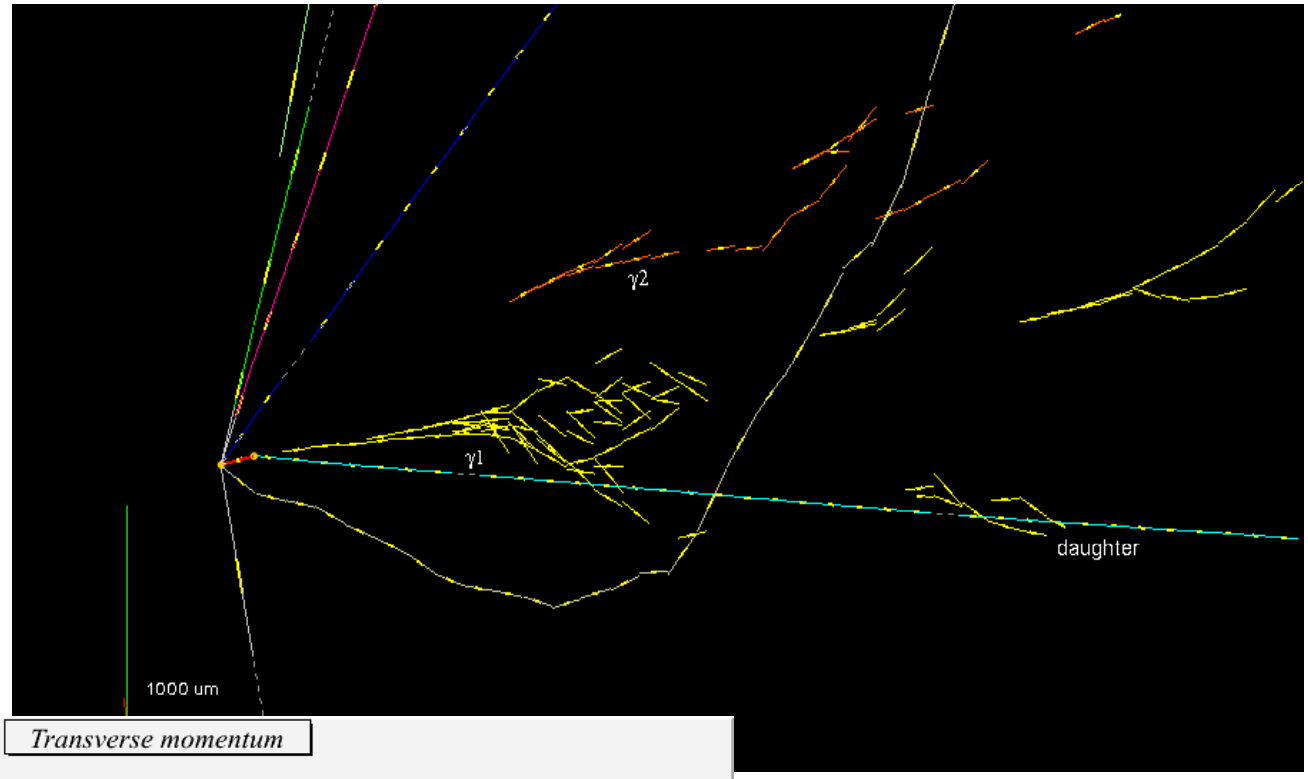
Interesting by-product of the analysis chain: detection of ν_e in muonless events

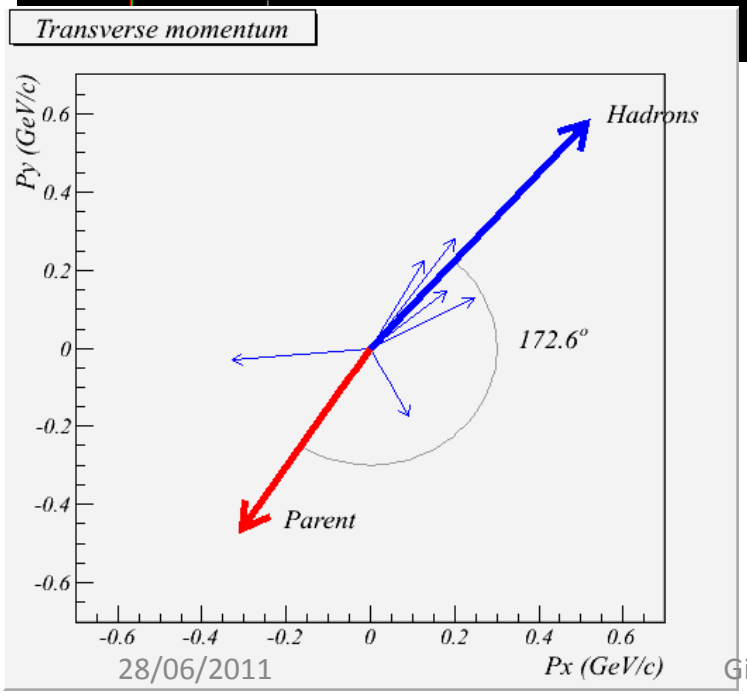


14 events in the analyzed sample

$\nu_\mu \rightarrow \nu_e$ analysis ongoing

Detection of the first ν_τ candidate event PLB691 (2010) 138





Variable	Value
kink (mrad)	**41 ± 2**
decay length (μm)	**1335 ± 35**
P daughter (GeV/c)	**$12\ ^{+6}_{-3}$**
Pt (MeV/c)	**$470\ ^{+230}_{-120}$**
missing Pt (MeV/c)	**$570\ ^{+320}_{-170}$**
ϕ (deg)	**173 ± 2**

While analyzing 2008/09: analysis of 2010 and 2011 runs in progress

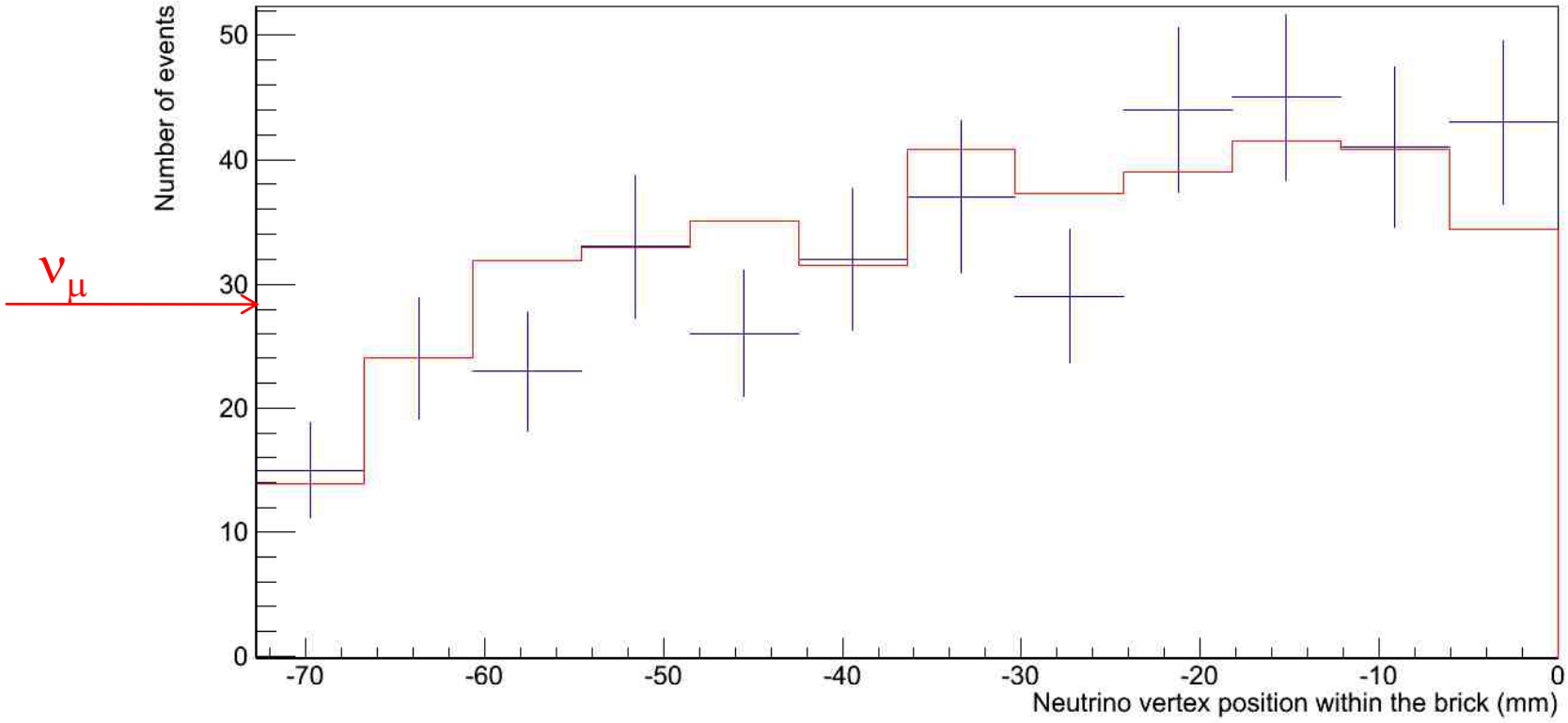
Status of the 2010 run

	0mu	1mu	All
Events predicted by the electronic detector	1165	2747	3912
Extracted CS	1146	2700	3846
CS Scanned	1043	2517	3560
Found in CS	479	1420	1909
Interactions located in ECC	156	558	714
Decay search	113	381	494

Improvements in the data analysis

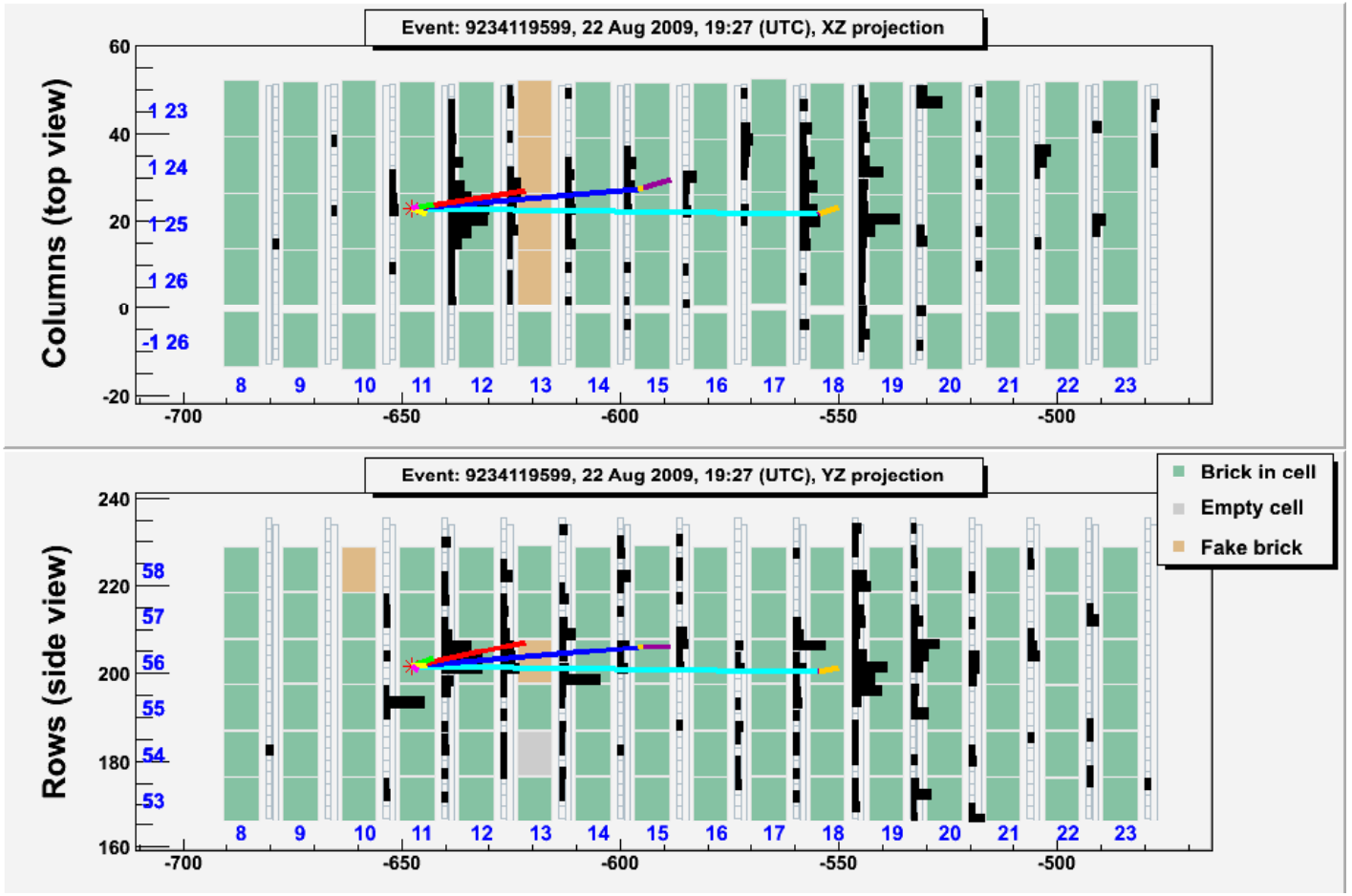
Full emulsion simulation
OpEmurec code

Vertex position distribution within the brick:
Located interactions for events without μ in the final state are compared with OpEmurec simulation



Background reduction: systematic track follow-up for muon detection

Tested in the analysis of the first ν_τ candidate



BG sources:

- Charm
- Hadronic interactions in ν_μ CC with misidentified μ ($\tau \rightarrow h$ channel)
- Hadronic interactions in ν_μ CC and NC ($\tau \rightarrow \mu$ channel)

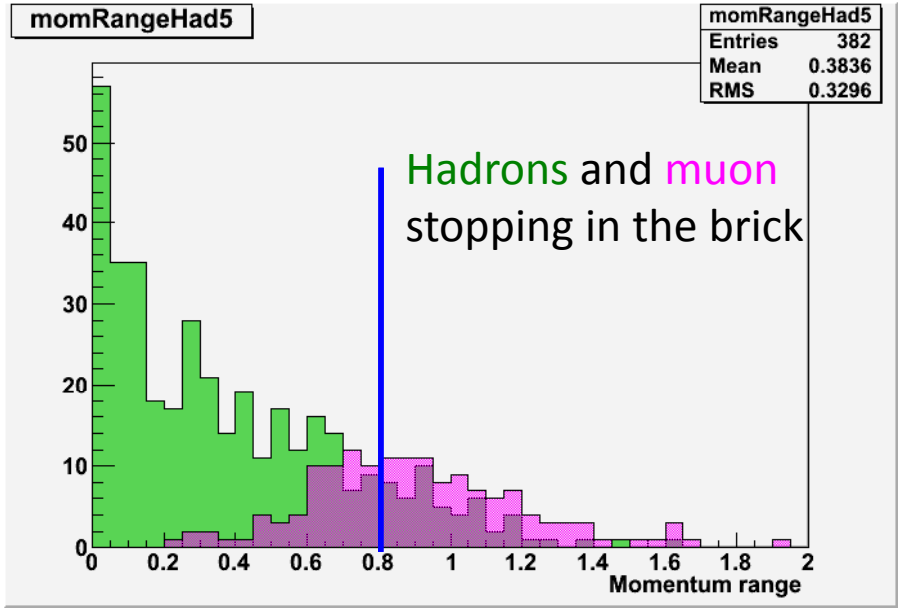
Track follow-down analysis

- ✓ Interaction visible in the brick
- ✓ Momentum/range correlation

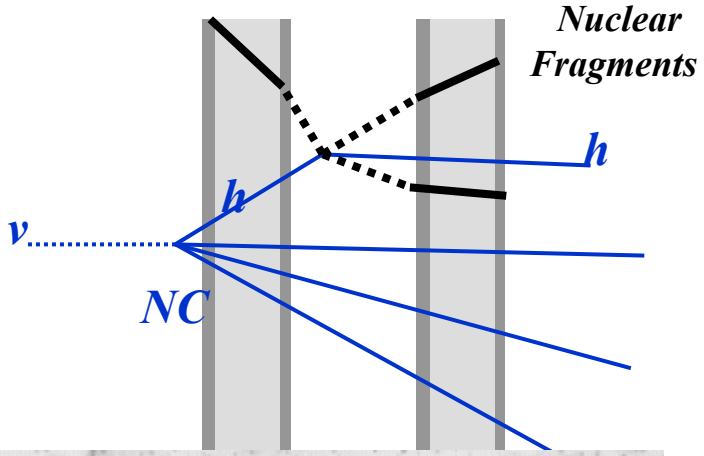
Discriminating variable $$D = \frac{L}{R_{lead}(p)} \frac{\rho_{lead}}{\rho_{average}}$$

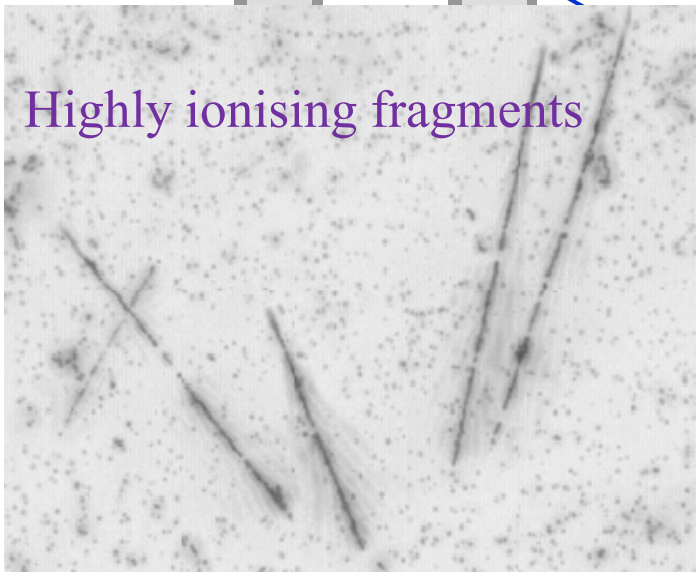
L = track length
R_{lead} = μ range
$\rho_{average}$ = average density along the path
ρ_{lead} = lead density
p = momentum measured in emulsion

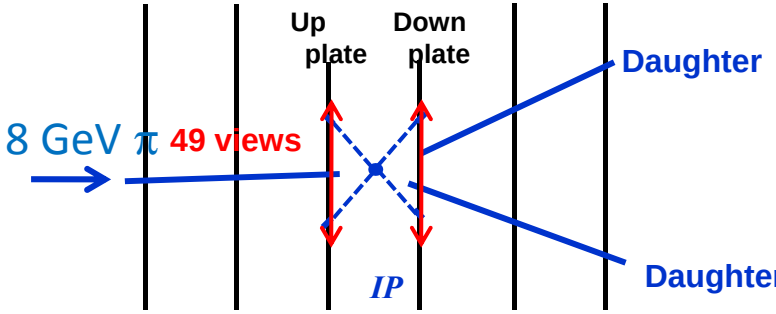
- Mis-ID muons in charm events 3.28% (was 5%)
- 2 orders of magnitude reduction of the τ→μ background due to μ mis-match in CC and NC events

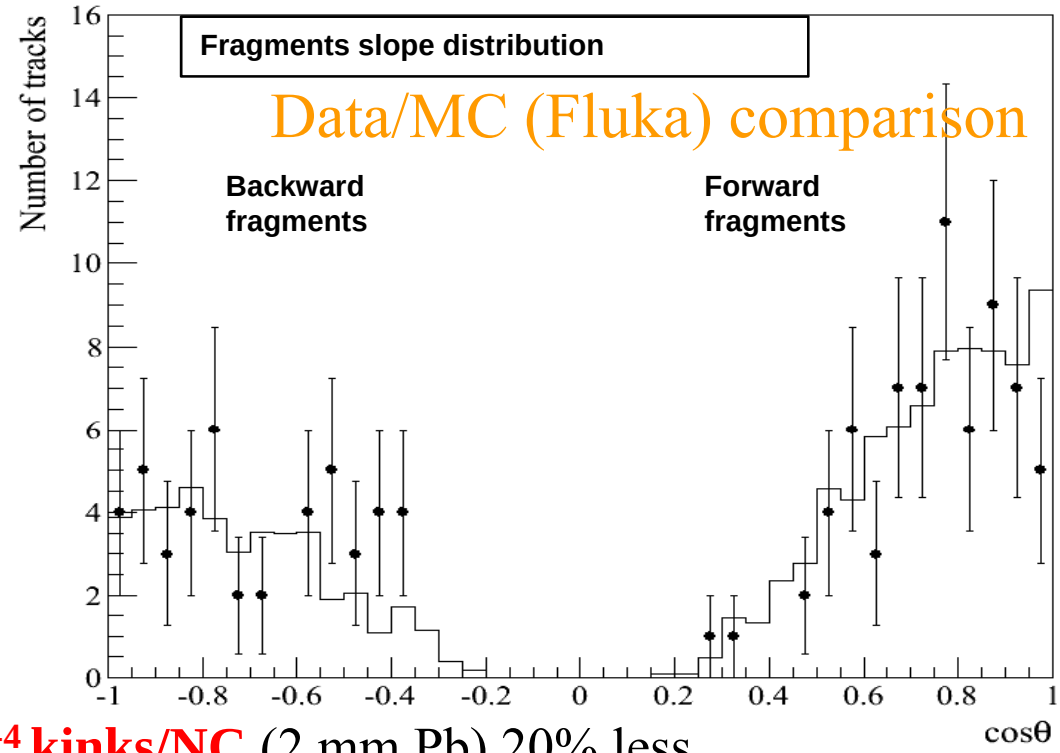


Further background reduction: detect highly ionising particles produced in hadron interactions







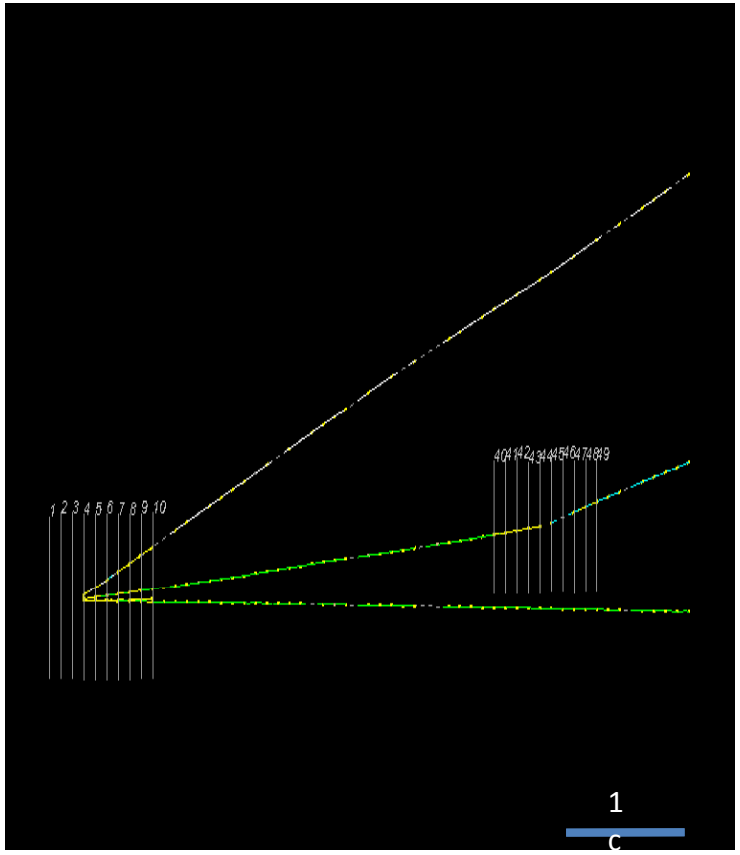


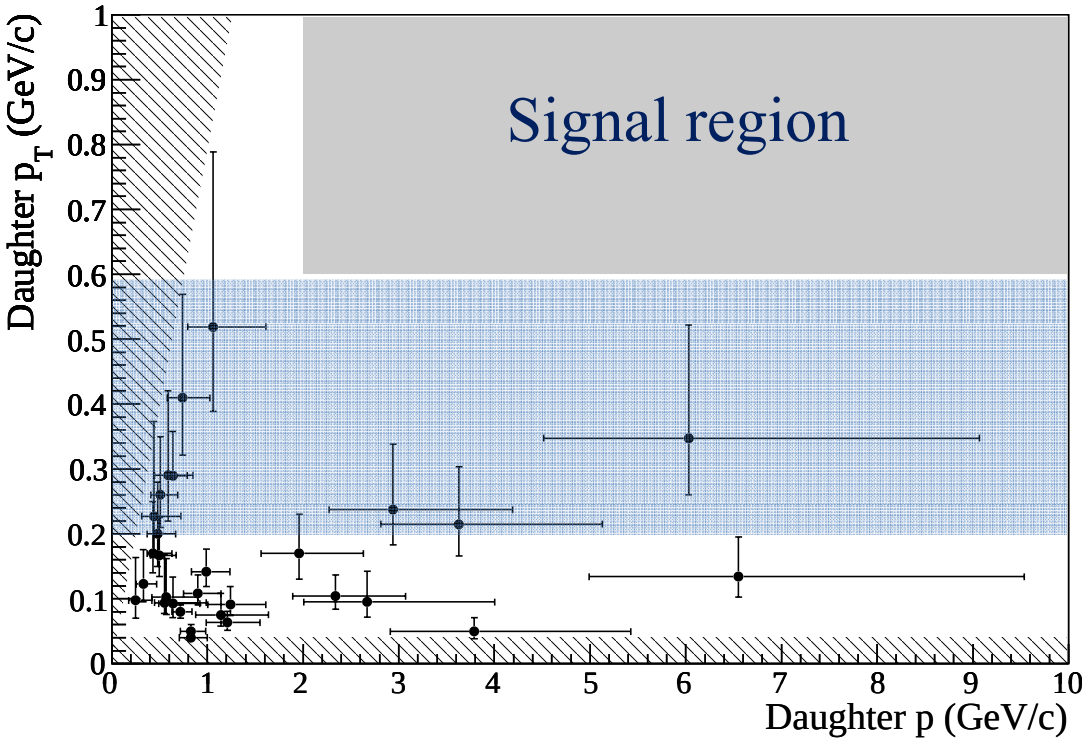
kink probabilities: **(1.53 ± 0.10) x 10^{-4} kinks/NC** (2 mm Pb) 20% less

The first ν_τ candidate survives this cut

Measure interactions far from the τ decay region

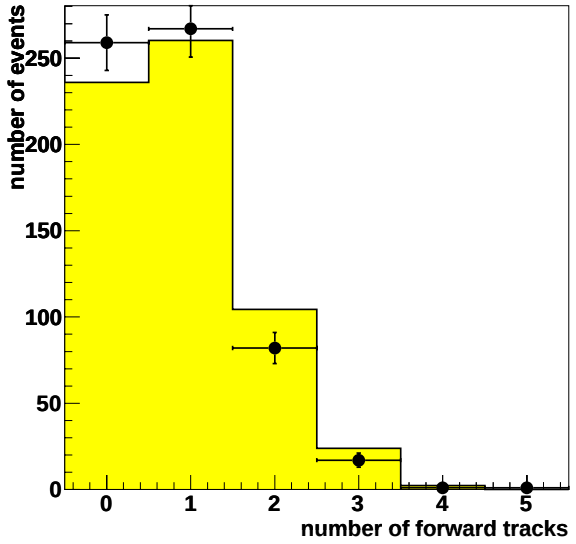
- Search for interactions and "kinks" along 14 m of hadron tracks in neutrino events. 5 times larger than the so far scanned track length for NC events
- No events in the signal region
- 90% CL upper limit of 1.0×10^{-3} kinks/NC event
- In the boundary region ($P_{\perp} > 200$ MeV/c) 10 observed events (10.8 expected)

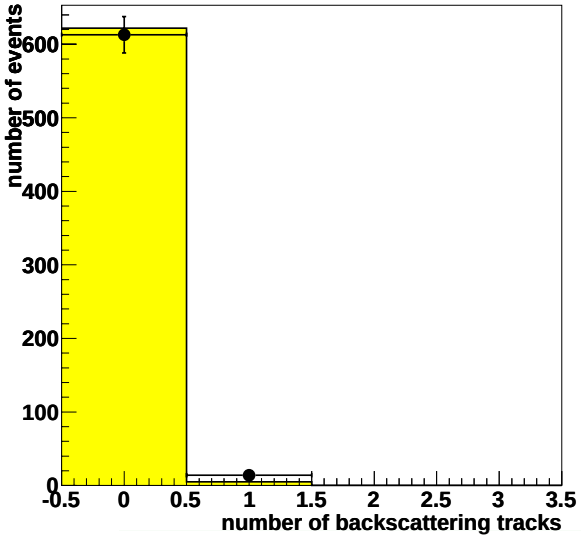


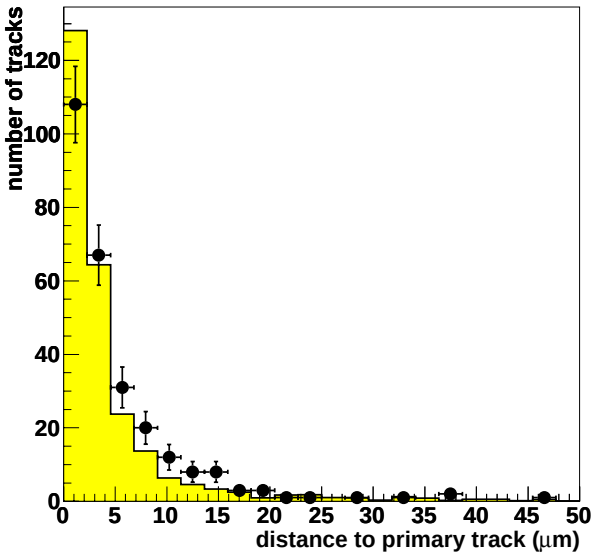


MC validation by π beam test

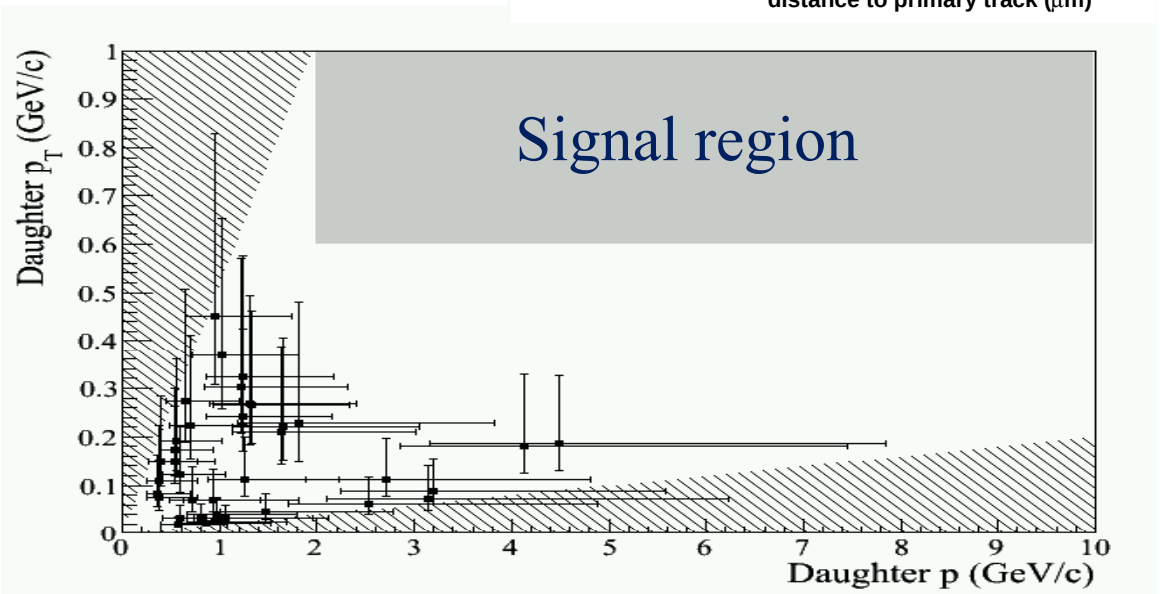
Two 4 GeV/c π beam exposures: KEK and CERN







- ~ 190 m of tracks
- one order of magnitude larger
- 534 interactions detected
- 214 kinks detected
- No events in the signal region



Summary of physics background

- Production and decay of charmed particles
- Hadron re-interactions
- Large angle μ scattering

Decay channel	Number of background events for:							
	22.5×10^{19} p.o.t.				Analysed sample			
	Charm	Hadron	Muon	Total	Charm	Hadron	Muon	Total
$\tau \rightarrow \mu$	0.025	0.00	0.07	0.09 ± 0.04	0.00	0.00	0.02	0.02 ± 0.01
$\tau \rightarrow e$	0.22	0	0	0.22 ± 0.05	0.05	0	0	0.05 ± 0.01
$\tau \rightarrow h$	0.14	0.11	0	0.24 ± 0.06	0.03	0.02	0	0.05 ± 0.01
$\tau \rightarrow 3h$	0.18	0	0	0.18 ± 0.04	0.04	0	0	0.04 ± 0.01
Total	0.55	0.11	0.07	0.73 ± 0.15	0.12	0.02	0.02	0.16 ± 0.03

- Charm production cross-section increased (last CHORUS data)
- Fragmentation fraction into D^+ increased from 10% to 22%
- Improvements due to the track follow-down
- Significant reduction of the background in the $\tau \rightarrow \mu$ channel

Signal events

Decay channel	Number of signal events expected for	
	22.5×10^{19} p.o.t.	Analysed sample
$\tau \rightarrow \mu$	1.79	0.39
$\tau \rightarrow e$	2.89	0.63
$\tau \rightarrow h$	2.25	0.49
$\tau \rightarrow 3h$	0.71	0.15
Total	7.63	1.65

- One ν_τ candidate observed in the $\tau \rightarrow$ h channel where 0.49±0.12 events are expected with a background of 0.05±0.01 event
- The probability for the event not to be due to a background fluctuations is 95%

Conclusions

- CNGS is performing well for the 2011 run. Chance to go beyond the CNGS nominal year (4.5 x 10^{19} pot)
- Thanks to the CNGS team and to CERN for the strong support
- Improving performance of the OPERA detector and of its ancillary facilities
- Analysis of the 2008/09 data sample: better knowledge of experimental features, background and efficiencies. Several notable improvements
- One ν_τ candidate observed with a significance of 95% in the hadronic channel
- These results are being submitted for publication to Phys. Lett. B
- In parallel: scanning and analysis of 2010 and 2011 in progress
- Next goal: high statistics study of $\nu_\mu \rightarrow \nu_\tau$ by next year
- Working on $\nu_\mu \rightarrow \nu_e$ search. Exploit the peculiar capabilities of OPERA in identifying electrons. Aim at contributing soon to the international effort