Joint JINR–INFN project
(collaboration since 1969...)

DUBTO $\Longrightarrow$ PAINUC

A study of pion interactions with the ^{4}He nucleus

topic: Physics of light mesons

PAINUC

PAINUC institutions

1 **Joint Institute for Nuclear Research (JINR), Dubna, Russia**
2 **Institute of theoretical and experimental physics, (ITEP), Moscow, Russia**
3 **Institute of nuclear physics, (INR), Sophia, Bolgaria**
4 **Dipartimento di Fisica Generale "A. Avogadro" Universitá di Torino, INFN Sezione di Torino I-10125 Torino, Italy**
5 **Universitá del Piemonte Orientale and INFN, Gruppo collegato di Alessandria, Alessandria, Italy**
6 **Universitá di Brescia and INFN, Gruppo collegato di Brescia, Brescia, Italy**
7 **Centro Studi e Ricerche "Enrico Fermi", Roma, Italy**

Plan

1. History
2. Results
3. PAINUC: state of affairs

What is DUBTO

TOFRADUBP $\Longrightarrow$ DUBTO (1968 – 1980-ies – 1990-ies):

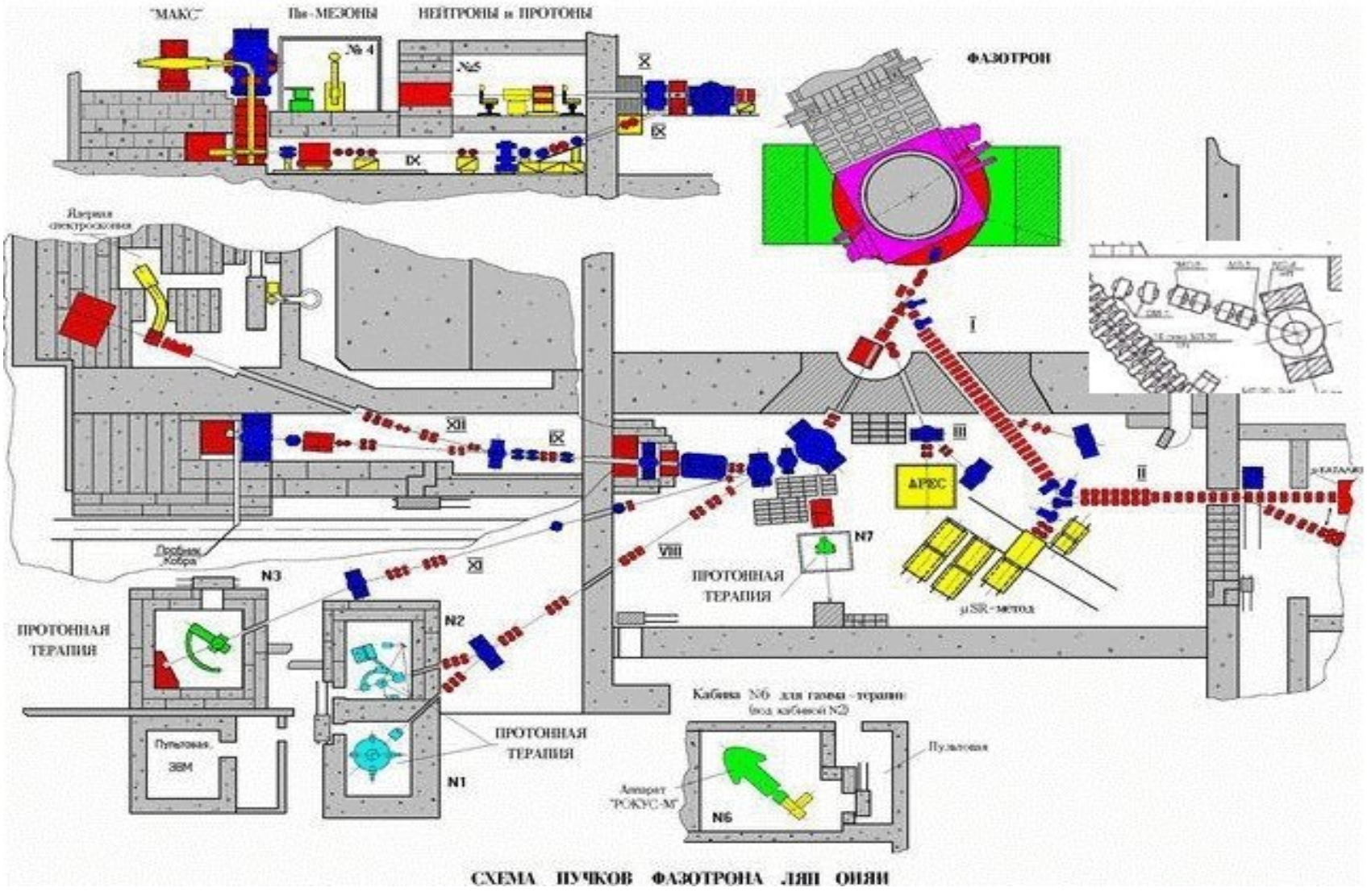
$\pi^{\pm 4}$He, $\pi^{\pm 3}$He, $\bar{p}^{\pm 4}$He, $\bar{p}^{\pm 3}$He, $\bar{p}^{\pm 20}$Ne

JINR: Yu.A.Scherbakov, M.M.Kulyukin

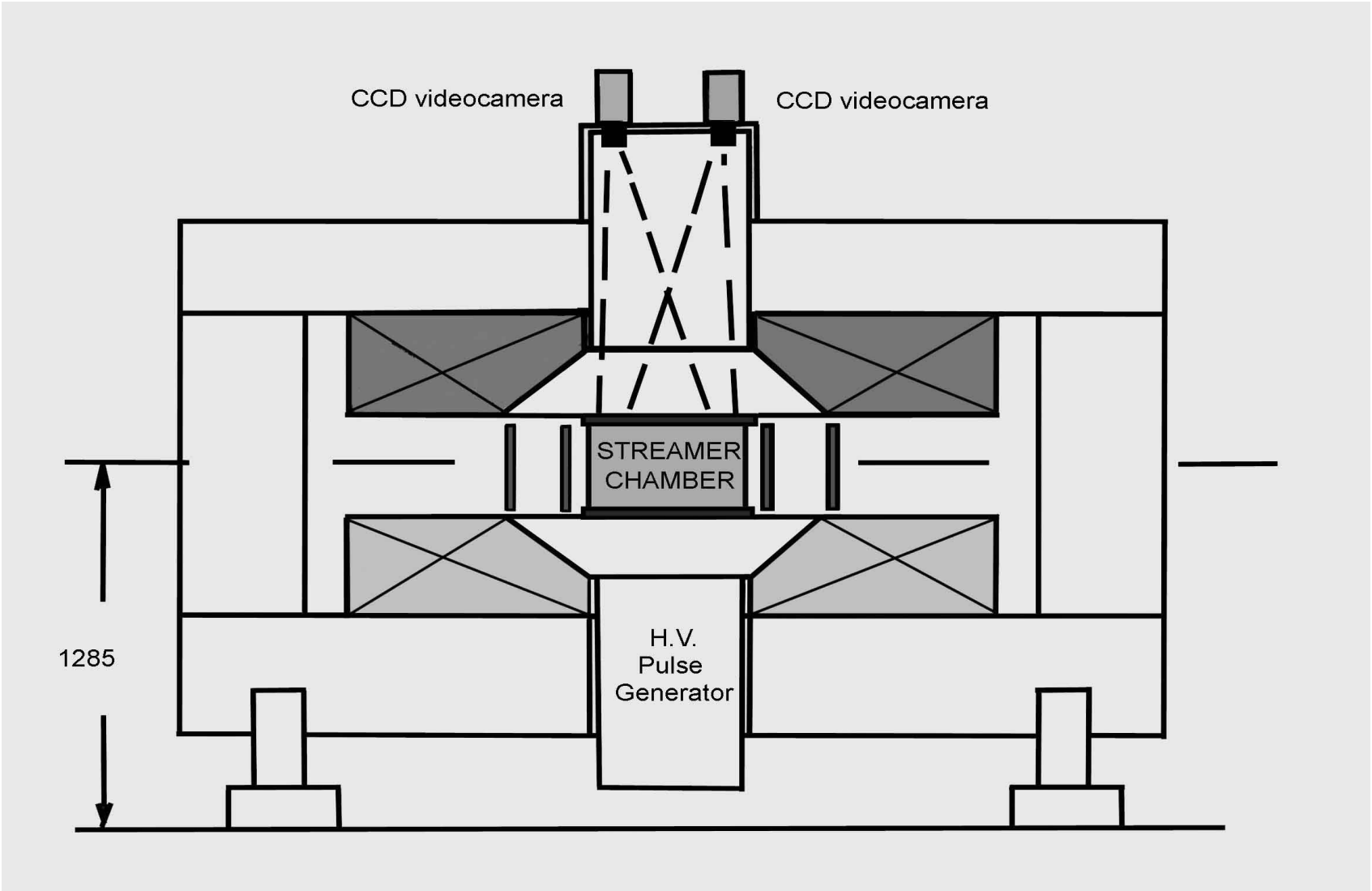
INFN, Torino: G.Piragino

Self-shunted streamer chamber: V.P.Dzhelepov LNP (1970-ies)

Experimental hall of LNP phasotron



Scheme of streamer chamber



Self-shunted streamer chamber filled with ^{4}He at 1 atm –

- **little matter:**
  $\rho_{^4He}$=0.17 mg/cm^3,
  $R_{^4He,\ 5MeV}$=20.cm
- **triggerable track detector;**
- **controllable memory time:**
  $\tau \sim 1\ \mu s$, $l_\pi \leq 10^6\ s^{-1}$.
- **Relatively inexpensive: no blumlein for pulse shaping.**

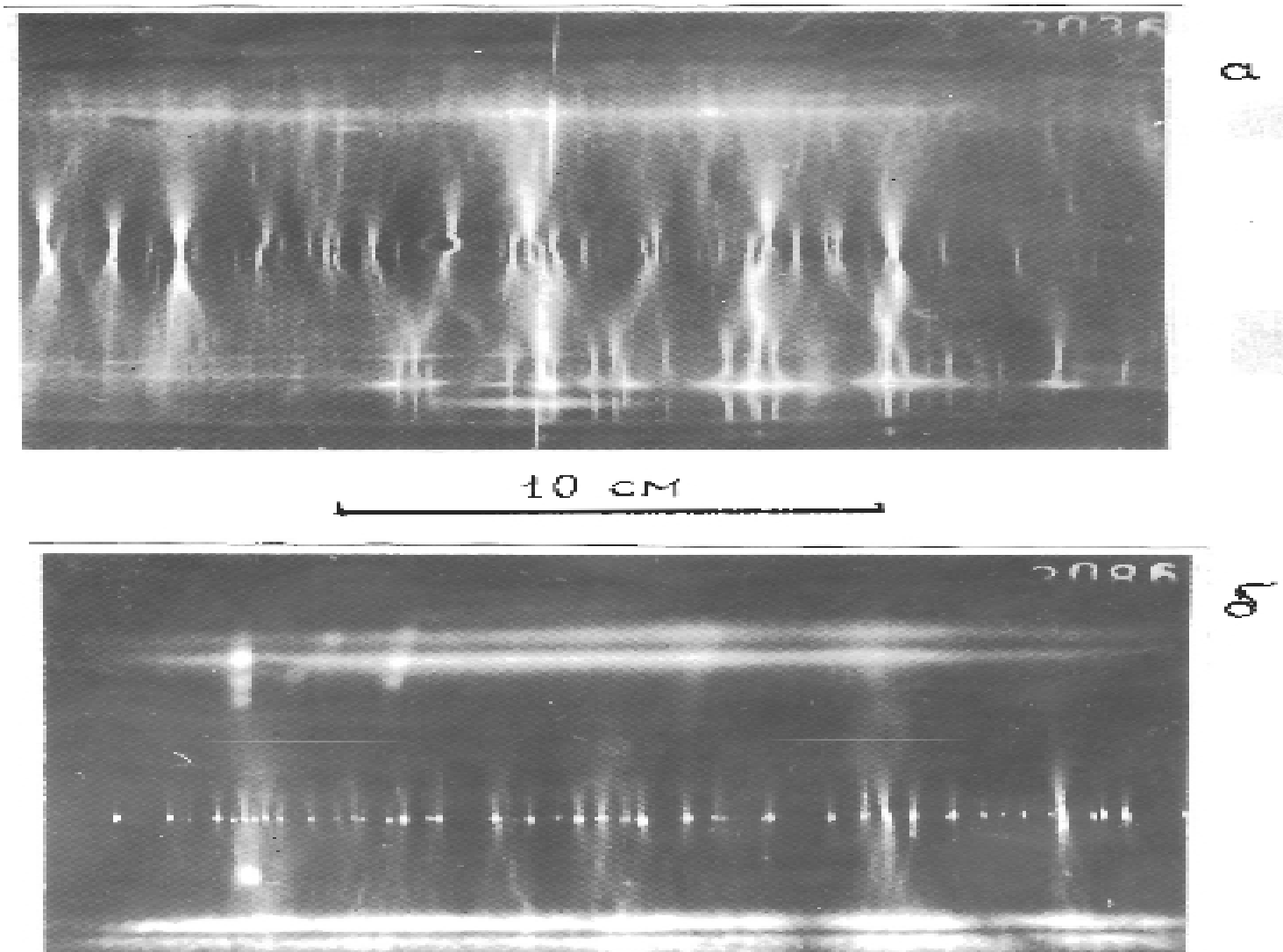
Range–energy

Range (cm) – energy (MeV) (helium at NTP)

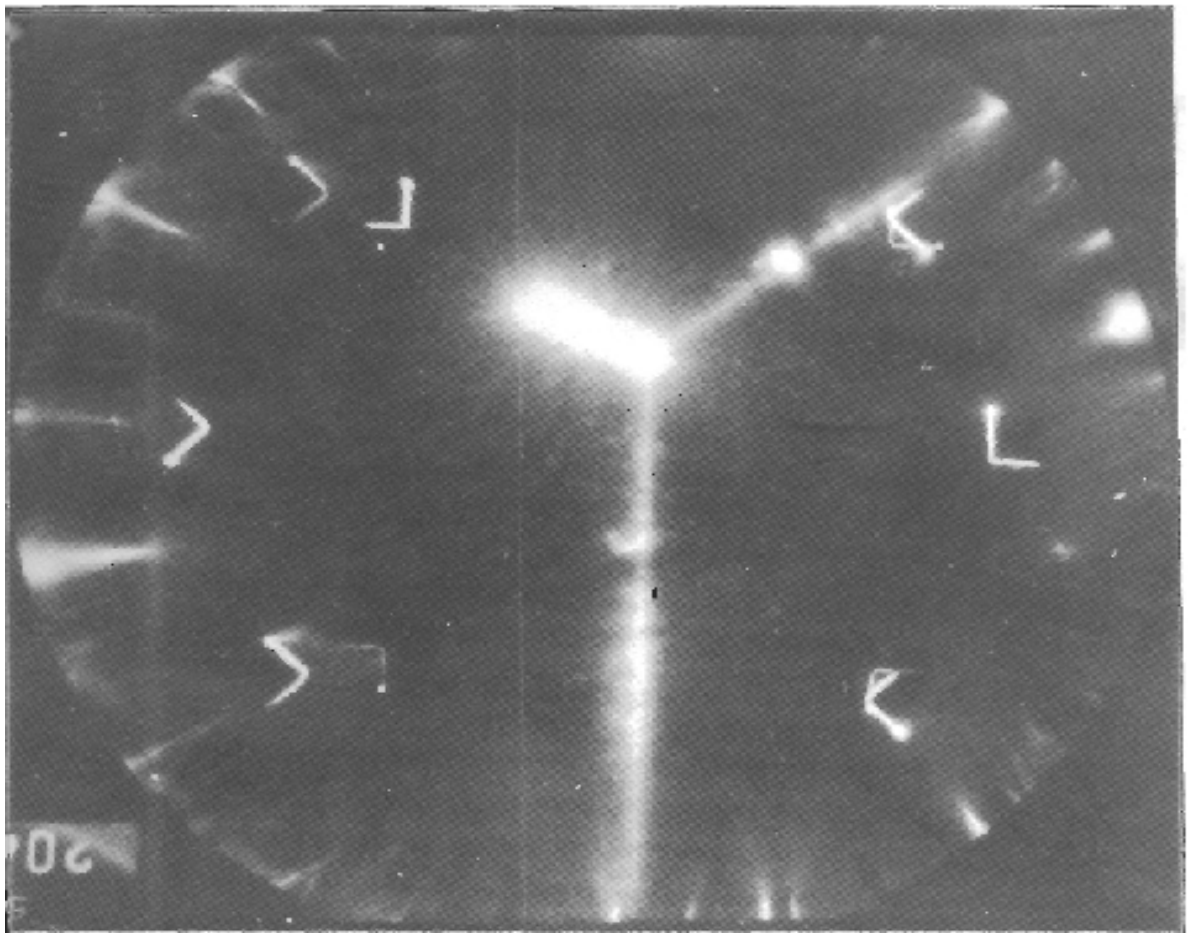
R		π	p	d	t	^{3}He	α
1.0		0.16	0.17	0.17	0.14	0.25	0.3
5.0		0.27	0.55	0.70	0.75	1.70	1.8
10.0	He	0.40	0.85	1.20	1.30	2.90	3.3
	Ne	1.40	3.40	4.20	5.50	11.10	12.9
20.0		0.57	1.30	1.70	1.90	4.50	5.0

Electron tracks in: a – ; b – $+10^{-4}\alpha$-pinene

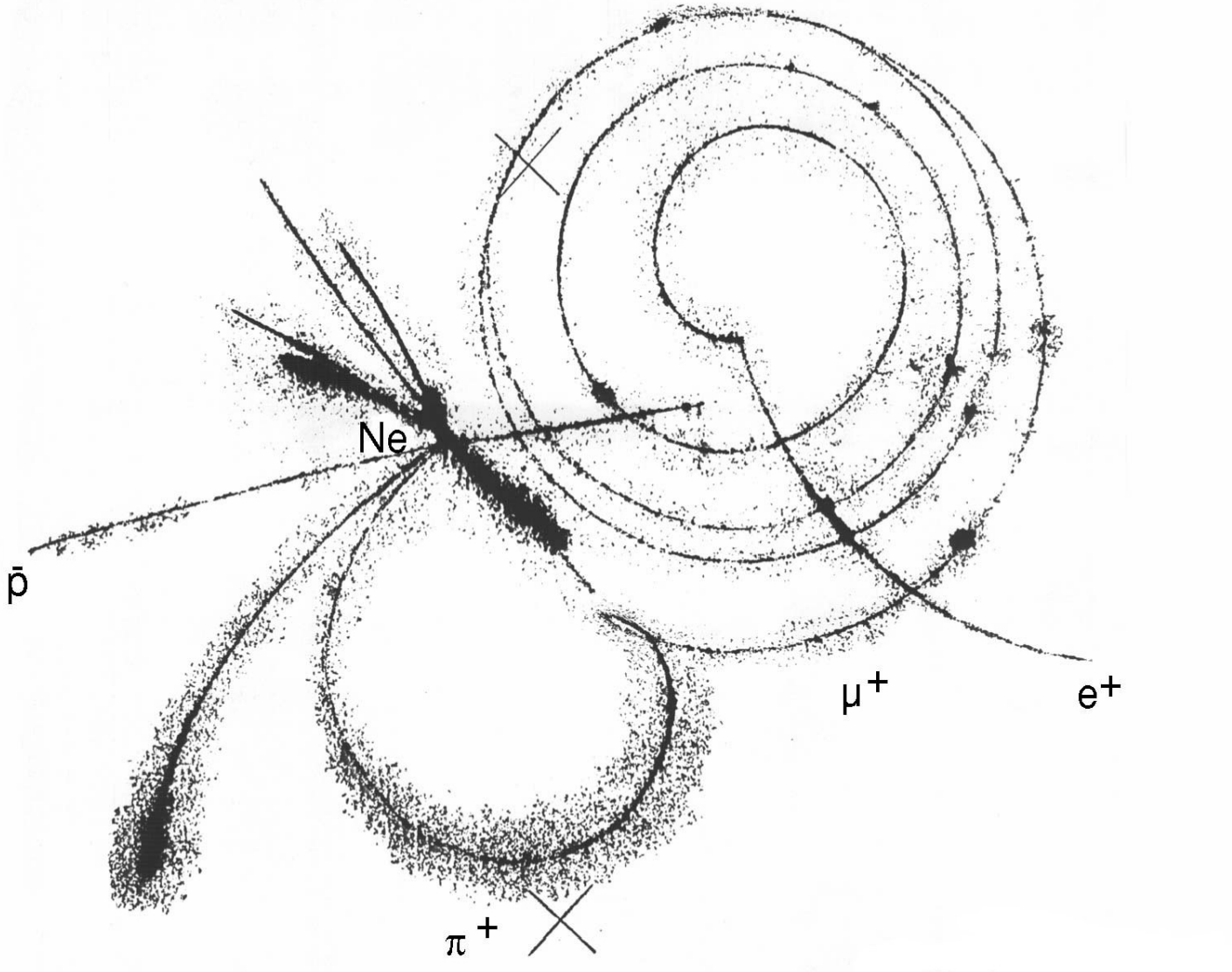
Nucl. Instr. and Meth. 53 (1967) 266.



Elastic scattering



Elastic π^{+4} scattering, $= 4$ atm,
$D_{fiduc} = 30$ cm, $T_\alpha \approx 3. \div 4.$ MeV.



PS179 ($\bar{p}Ne$): $\pi^+ \to \mu^+\nu_\mu$, $\phi_{\pi\mu}$=(163.0±1.0)°, T_{π^+}=1.98±0.02 MeV

Big Bang $\Longrightarrow \sum m_{\nu_i} \leq 150\,\text{eV}$

Cosmology $\Longrightarrow \sum m_{\nu_i} \leq 0.3\,\text{eV}$

- **K.Assamagan et al., Upper limit of muon-neutrino mass ..., Phys. Rev. D53 (1996) 6065:**

  $$m_{\nu_\mu} \leq 0{,}17 \ \text{(C.L.=0,9)}$$

- **N.Angelov et al., On the m_{ν_μ} ..., Nucl. Phys. A780 (2006)78:**

  $$m_{\nu_\mu} \leq 2{,}2 \ \text{(C.L.=0,9)}$$

- **MINOS. Measurement of ν velocity ..., Phys. Rev. D76 (2007) 072005:**

  $$m_{\nu_\mu} \leq 50 \ \text{(C.L.=0,9)}$$

CERN PS179

WELCOME

CERN Courier – digital edition

Welcome to the digital edition of the September 2015 issue of *CERN Courier*.

It is now 60 years since the antiproton was discovered at Berkeley in September 1955 and 20 years since the first antihydrogen atoms were made at CERN. Over the decades, antiprotons have become a standard tool in particle physics, and antihydrogen is now a miniature laboratory for investigations in fundamental physics, as this month's anniversary feature describes. Recently, the BASE collaboration at the Antiproton Decelerator reported on a new comparison of the proton and antiproton to test a basic symmetry. Also at CERN, the ALICE experiment is investigating how loosely bound objects, including antinuclei, can survive the hot and dense heavy-ion collisions at the LHC.

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CERNCOURIER

VOLUME 55 NUMBER 7 SEPTEMBER 2015

In the steps of the antiproton

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LHCb observes two exotic new particles **p5**

INTERVIEW
Massimo Tarenghi: telescope builder extraordinaire **p31**

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New results from the LHC experiments **p8**

CERNCOURIER
VOLUME 55 NUMBER 7 SEPTEMBER 2015

IOP Publishing

Antiproton-Ne interaction, = 1 atm.

DUBTO — PAINUC

DUBTO —
NIM A489 (2002) 99

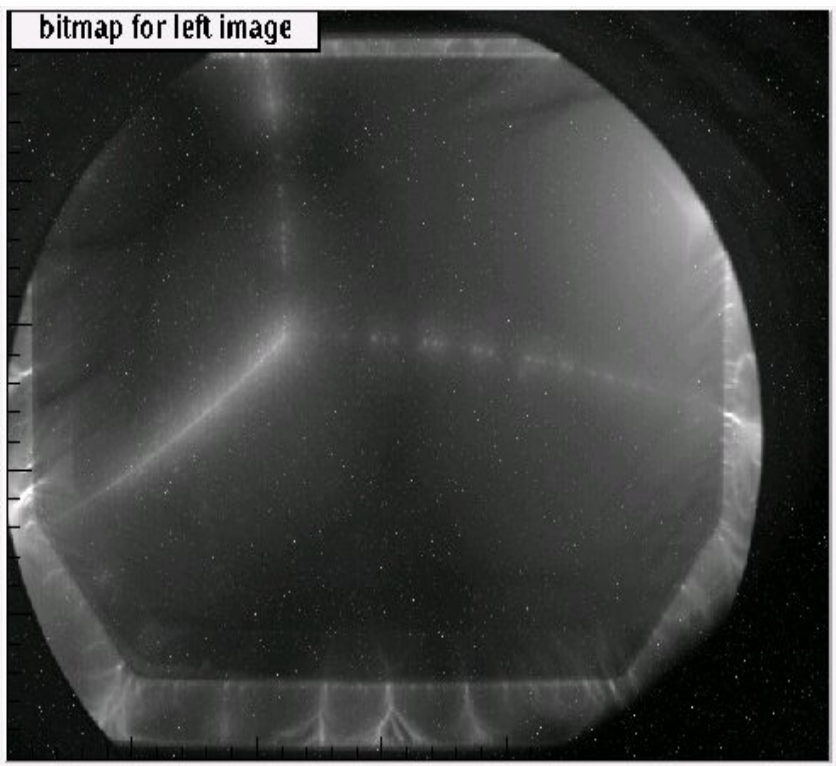
- **triggerable track detector;**
- $\rho_{^4He}$**=0.17 mg/cm**^{3}**;**
- 4π**-registration in space;**
- **control.** $\tau \sim$**1** μ**s ,** $I_\pi \leq 10^6$ **s**$^{-1}$**.**
- **Magnetic field: = 0.8 T;**
- **2 CCD video cameras;** ~ 2.0 **s;**
- **Software for data handling.**

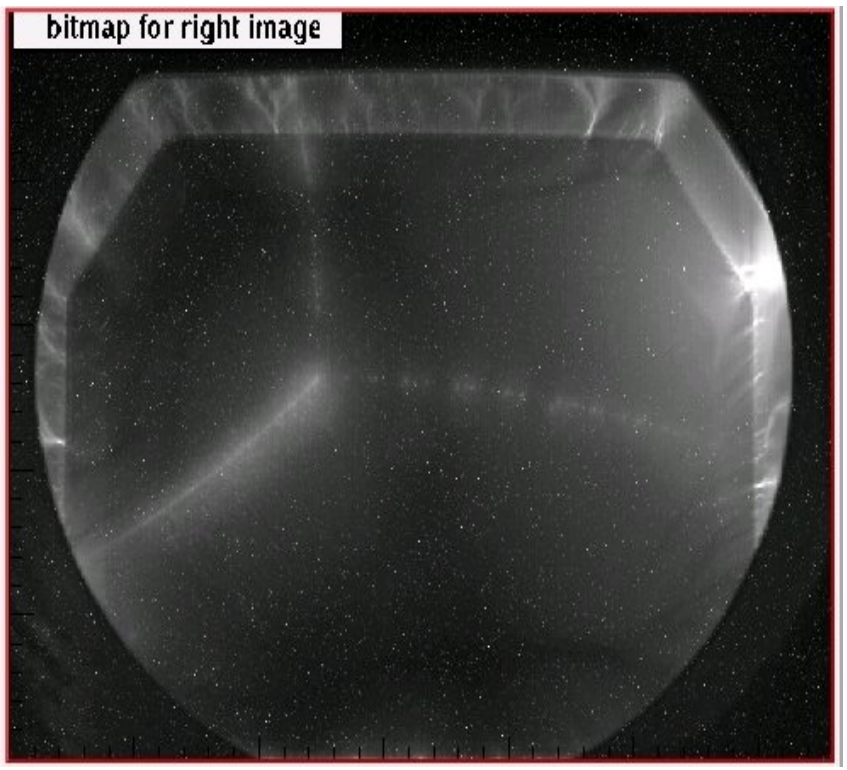
30000 events of $\pi^{\pm}{}^4$He interaction

	2-prong evs.			
1.	$\pi^{\pm} + {}^4\mathbf{He}$	$\rightarrow$	$\pi^{\pm} + {}^4\mathbf{He}$	
2.		$\rightarrow$	$\pi^{\pm} + {}^4\mathbf{He} + \gamma$	
3.		$\rightarrow$	$\pi^{\pm} + \mathbf{n} + {}^3\mathbf{He}$	
4.	$\pi^{+} + {}^4\mathbf{He}$	$\rightarrow$	$\pi^{0} + \mathbf{p} + {}^3\mathbf{He}$	**(SCX)**
5.		$\rightarrow$	$\mathbf{p} + {}^3\mathbf{He}$	**(absorp.)**
	3-prong evs.			
1.	$\pi^{\pm} + {}^4\mathbf{He}$	$\rightarrow$	$\pi^{\pm} + \mathbf{p} + {}^3\mathbf{H}$	
2.		$\rightarrow$	$\pi^{\pm} + \mathbf{2n} + \mathbf{2p}$	
3.		$\rightarrow$	$\pi^{\pm} + \mathbf{d} + \mathbf{d}$	
4.	$\pi^{+} + {}^4\mathbf{He}$	$\rightarrow$	$\mathbf{3p} + \mathbf{n}$	**(absorp.)**
	5-prong evs.			
1.	$\pi^{+} + {}^4\mathbf{He}$	$\rightarrow$	$\pi^{-} + \mathbf{4p}$	**(DCX)**

DUBTO: 2-prong events (with π^-)

1. $\pi^- + {}^4\mathrm{He} \rightarrow \pi^- + {}^4\mathrm{He}$
2. $\rightarrow \pi^- + {}^4\mathrm{He} + \gamma$
3. $\rightarrow \pi^- + {}^3\mathrm{He} + \mathrm{n}$

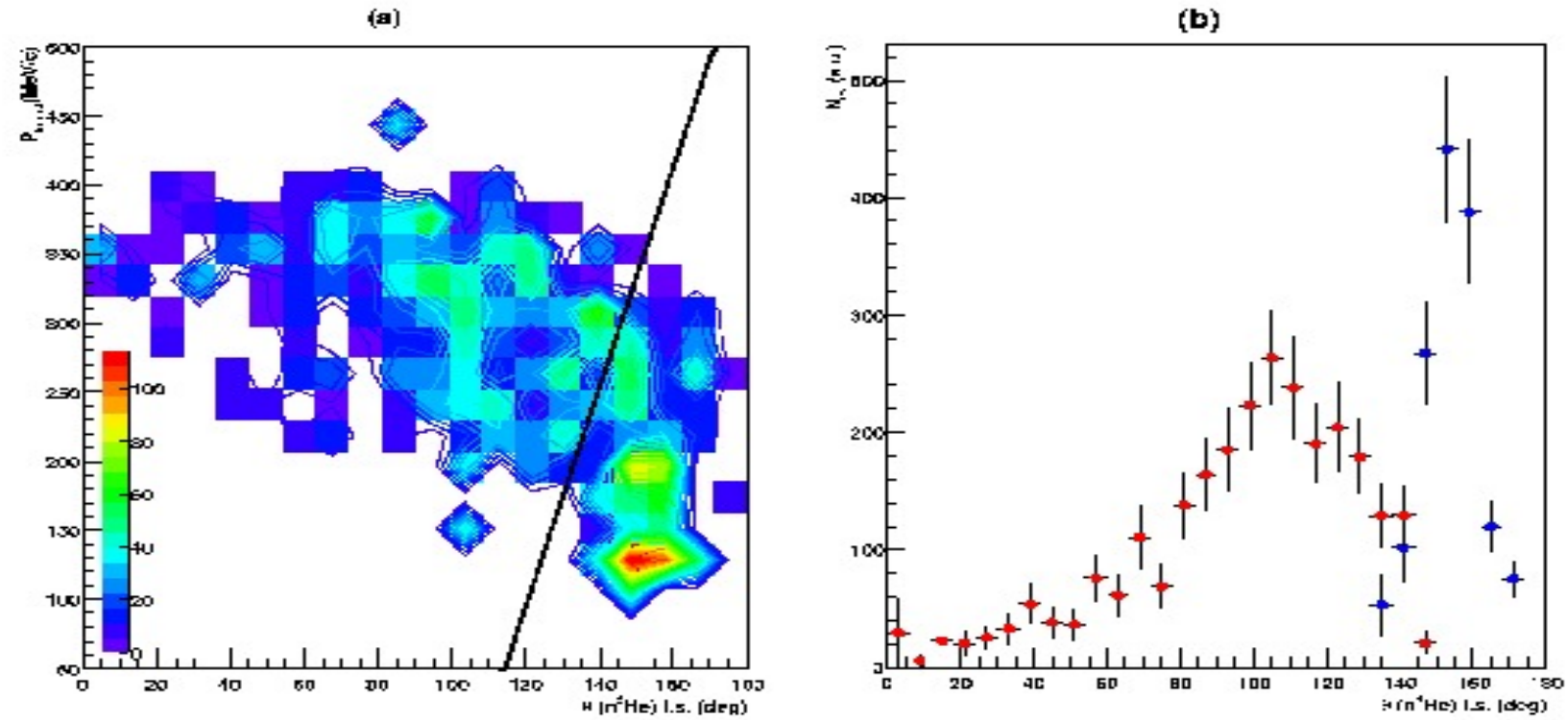




angle(n-He3), M(π^--n), ANN for identification

$\pi^- + {}^4\mathbf{He} \rightarrow \pi^- + {}^3\mathbf{He} + \mathbf{n};$
$\rightarrow \Delta^- + {}^3\mathbf{He};\ \Delta^- \rightarrow \pi^- + \mathbf{n};$ **(1160)**

$\mathbf{P}_{transfer}\mathbf{.vs.}\theta_{n^3He}$ θ_{n^3He}



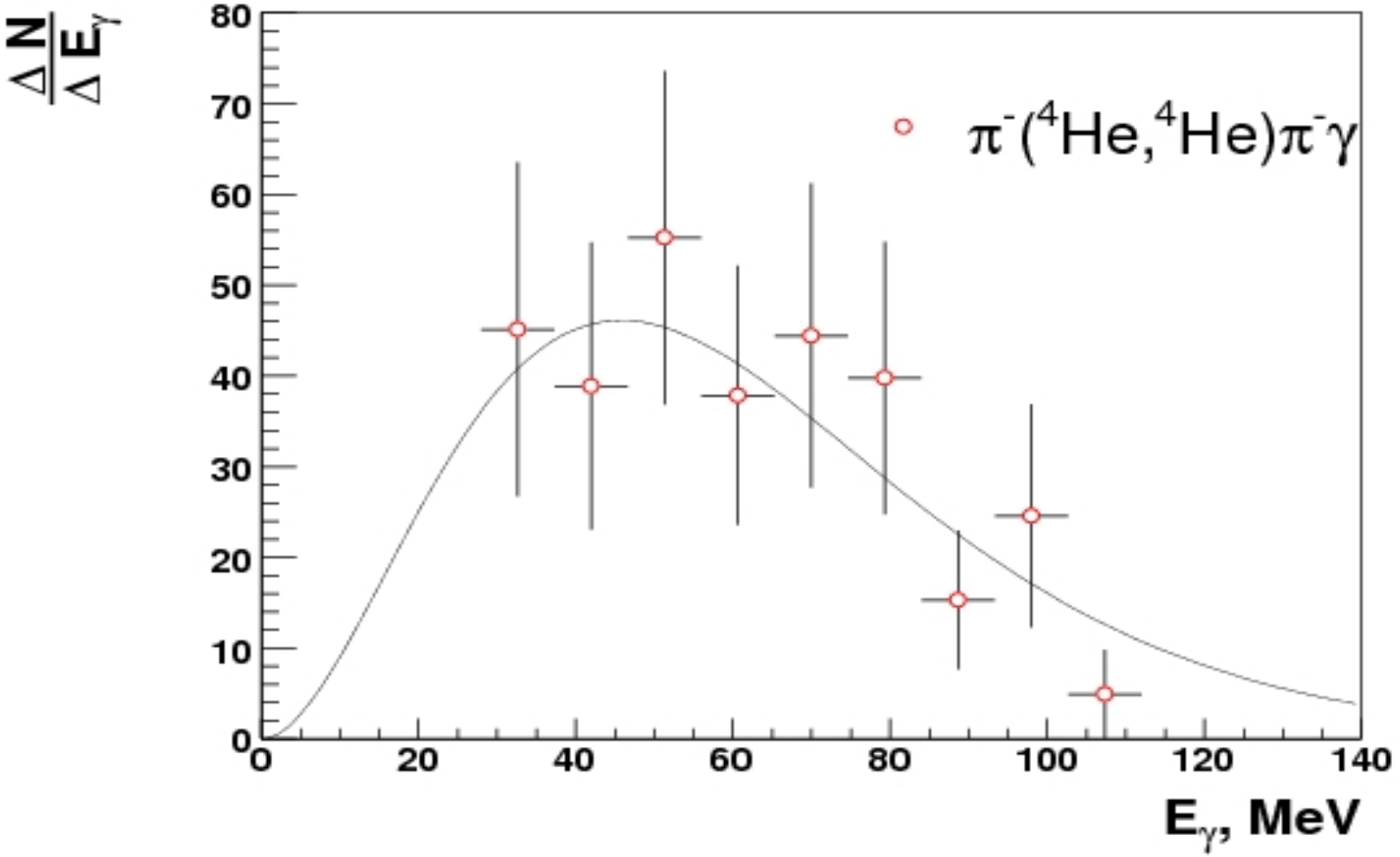
Branching ratios: ANN

BR for π^{-4}He reaction channels

	Channel	BR, π^-	events
1.	π^{-4}He	0.51±0.02	911±34
2.	π^{-4}Heγ	0.05±0.01	97±10
3.	π^-n^{3}He	0.44±0.02	790±29

Gamma energy

Energy spectrum of γs – Planck distribution: E_0=14.4$\pm$1.6 MeV; $T_{\pi^-} = 106$ MeV.

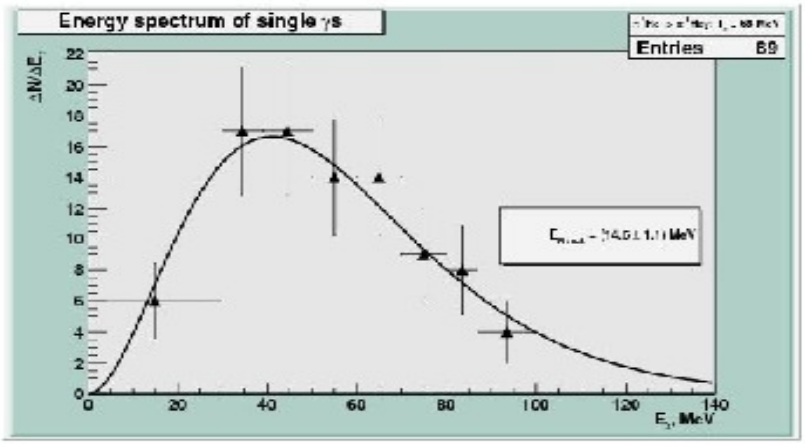


Spectrum of γ-quanta, T_{π^-}= 68 MeV, E_0=14.6±1.1 MeV; Prompt γs ?

Nuclear physics

PAINUC project

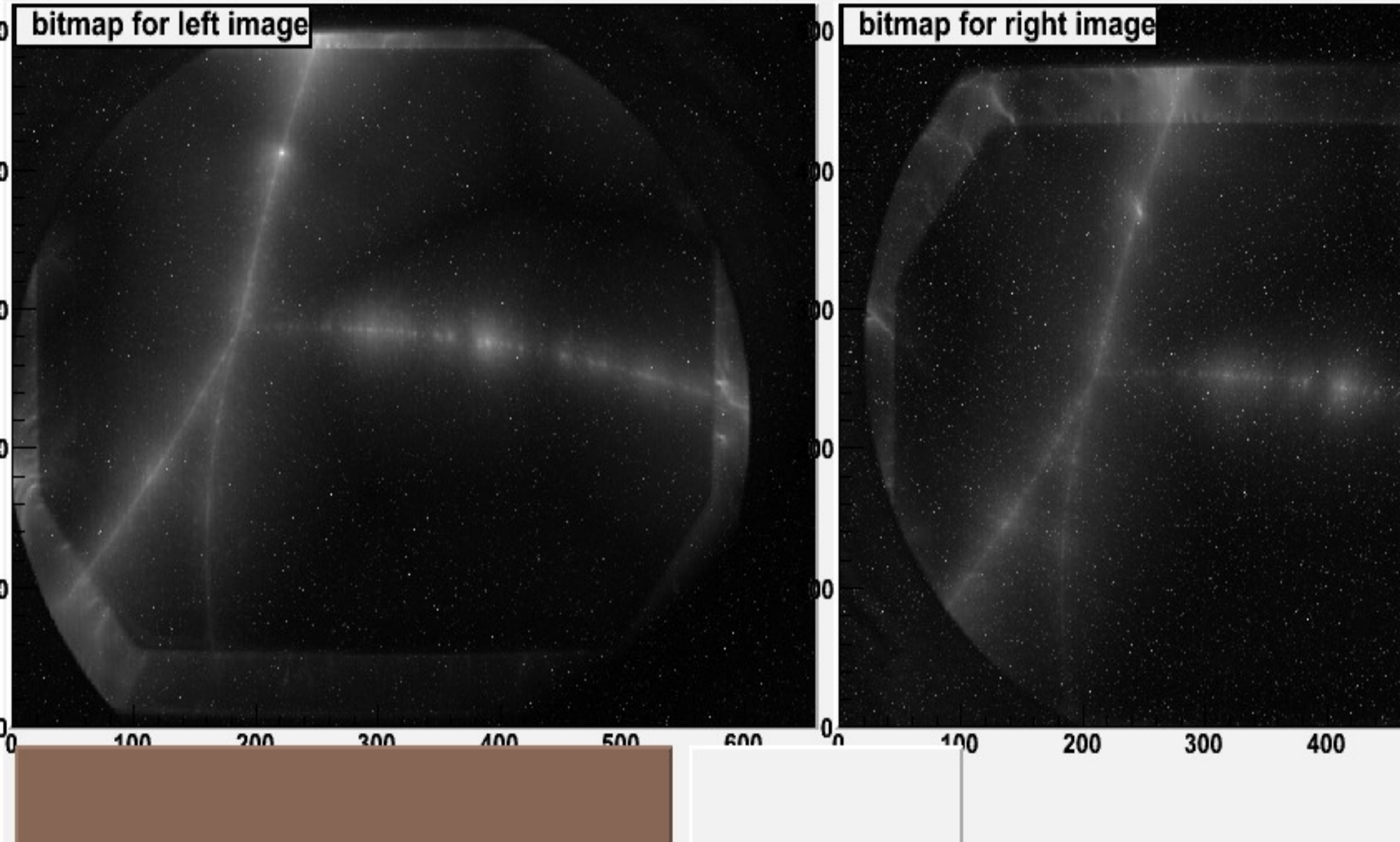
The JINR-INFN (Italy) experiment PAINUC has observed single γ-quantum production in "elastic" π^{-4}He → π^{-4}He γ interaction at 106 and 68 MeV.



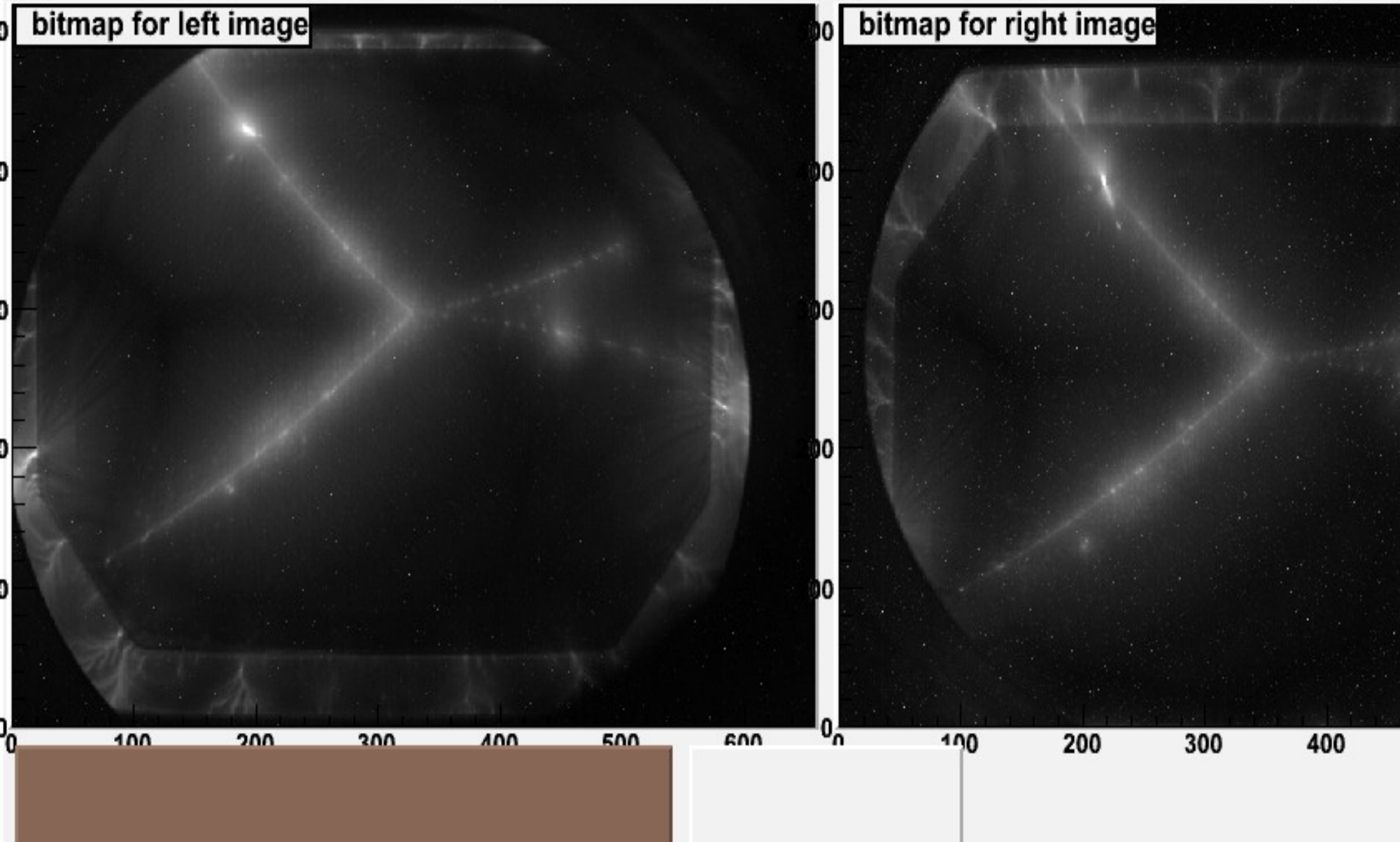
Preliminary results at 68 MeV also reveal single γ-production.

If the excited ^{4}He nucleus is a Planck radiator, one obtains the respective Planck temperatures E_{Planck}=14.4±1.6 and 14.6±1.1 MeV for 106 and 68 MeV.

3-prong event: ^{4}He $\rightarrow$ *ppnn* ?

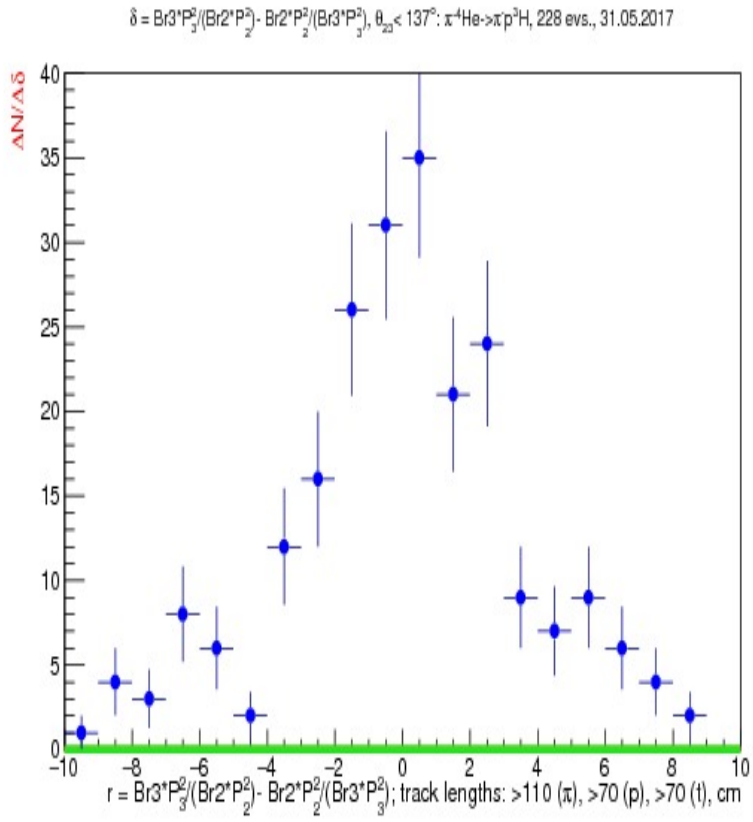


3-prong event: $^4\mathrm{He} \rightarrow DD$?

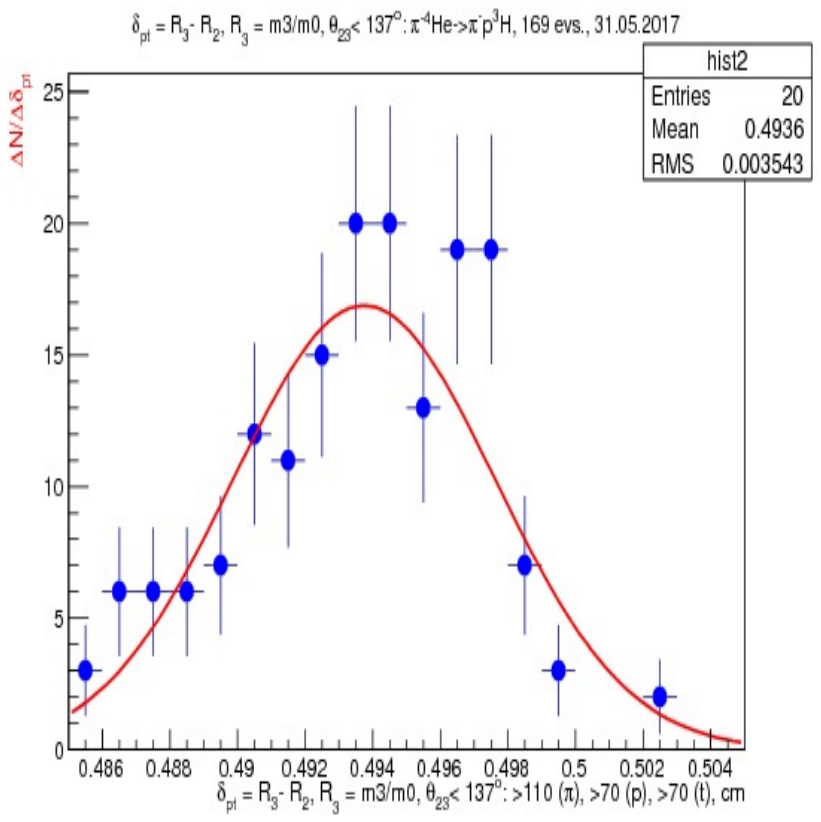


Particle identification: $Br \times p^2 \propto m^2$, kinematics

$m_3^2/m_2^2 - m_2^2/m_3^2$



$m_3/m_0 - m_2/m_0$

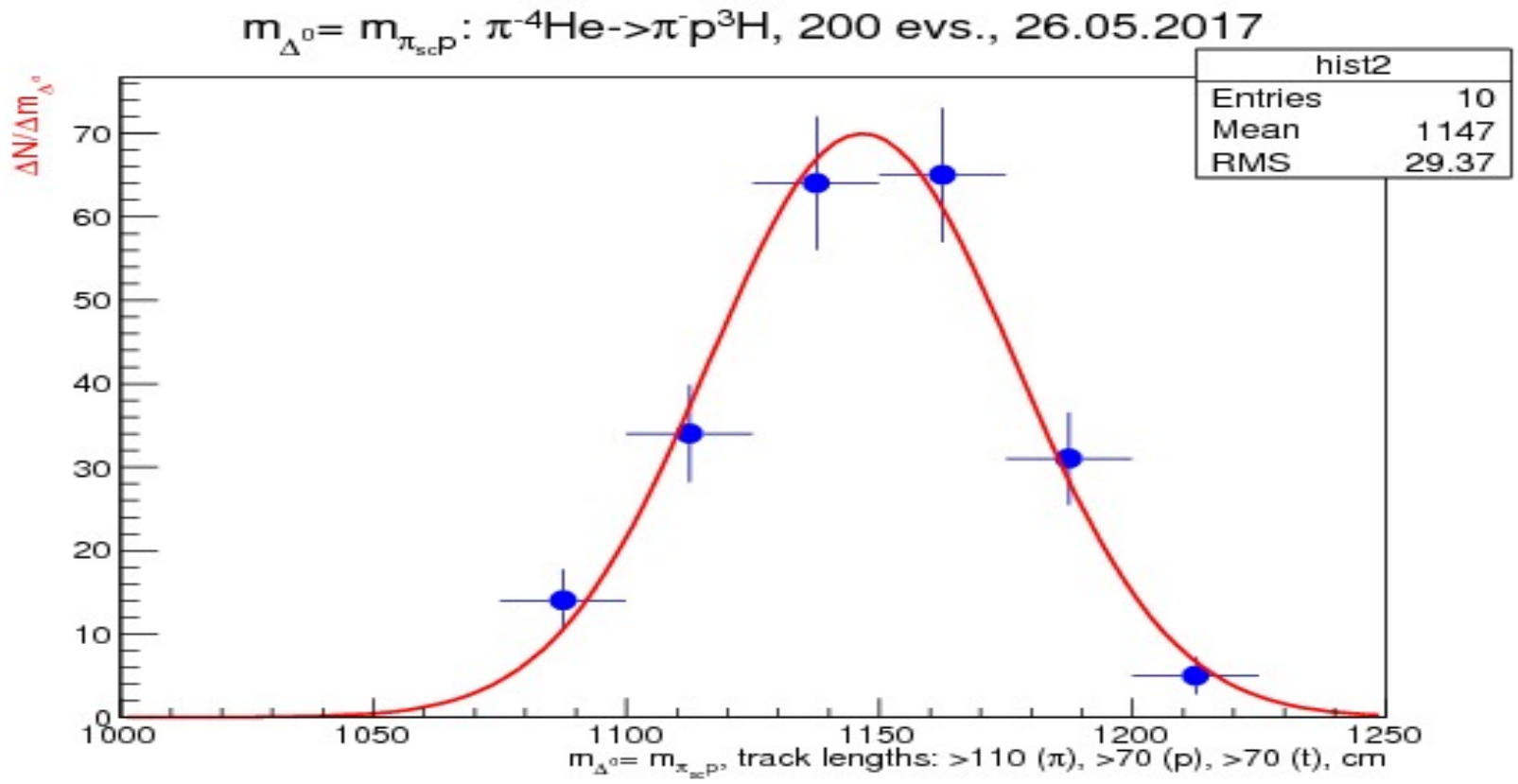


M_{Δ^0}

$\pi^- + {}^4\mathbf{He} \rightarrow \pi^- + {}^3\mathbf{H} + \mathbf{p};$

$\rightarrow \Delta^0 + {}^3\mathbf{H};\ \Delta^0 \rightarrow \pi^- + \mathbf{p};$ **(1147)**

M_{Δ^0}

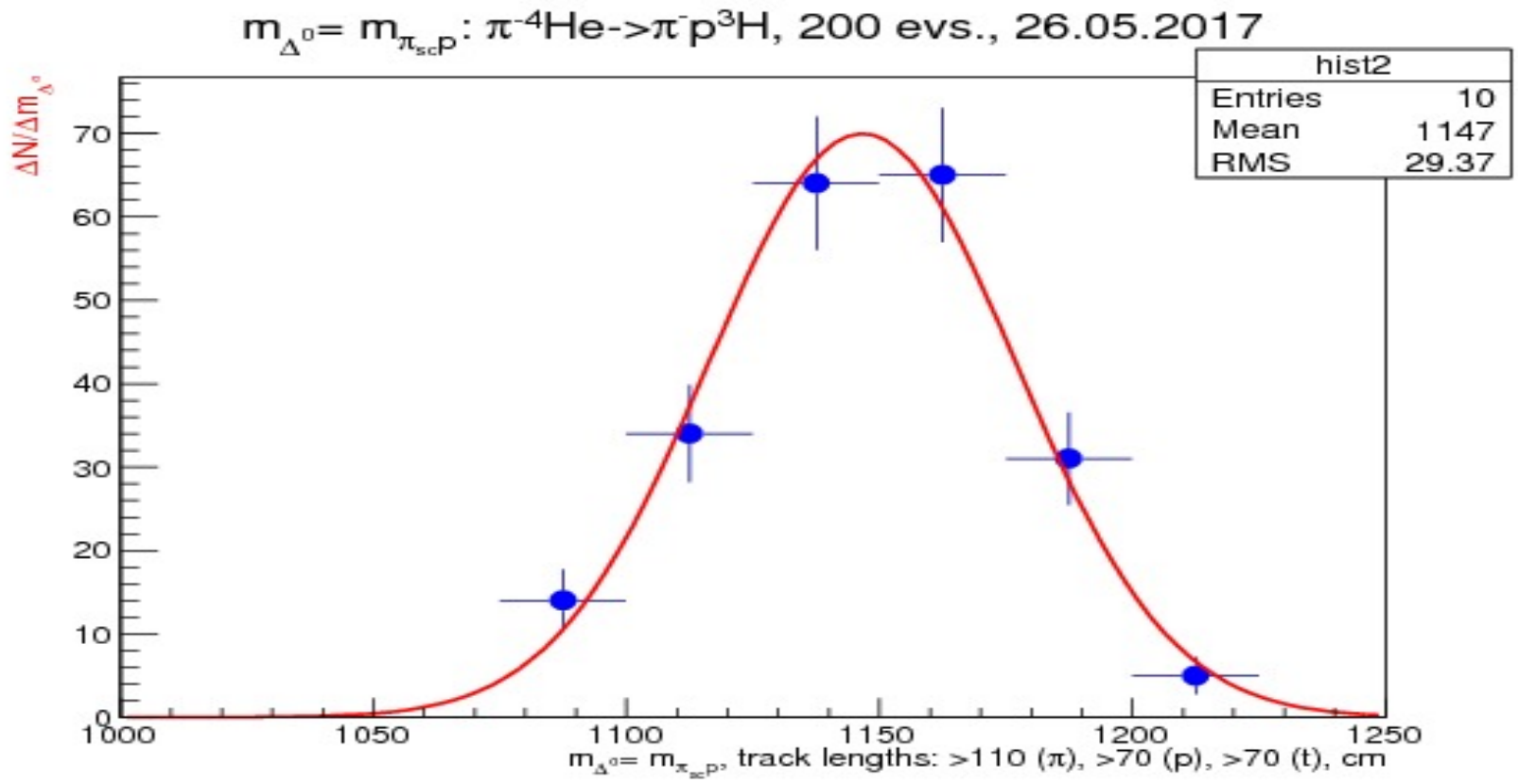


M_{Δ^0}

$\pi^- + {}^4\mathbf{He} \rightarrow \pi^- + {}^3\mathbf{H} + \mathbf{p};$

$\rightarrow \Delta^0 + {}^3\mathbf{H};\ \Delta^0 \rightarrow \pi^- + \mathbf{p};$ **(1147)**

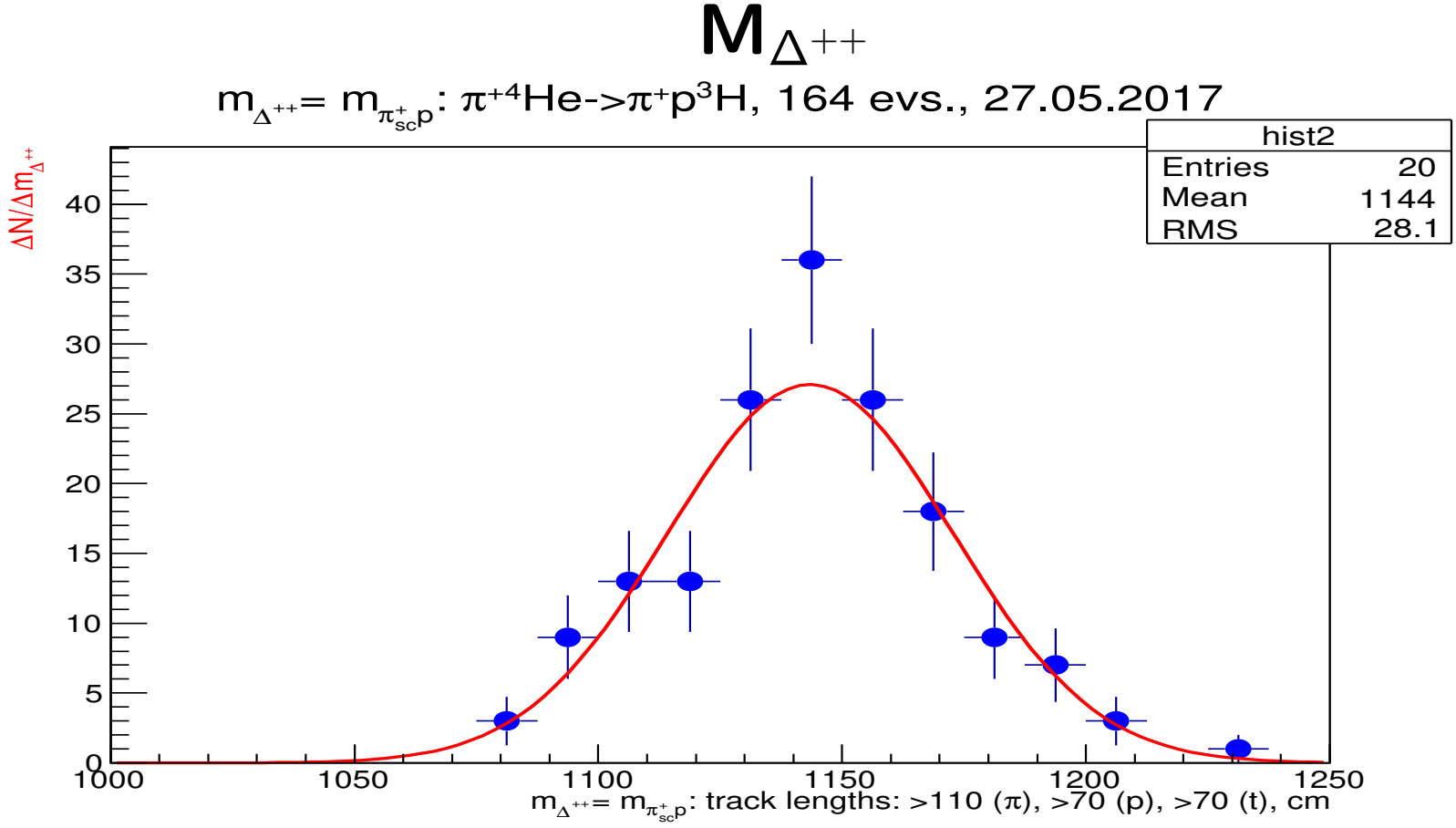
M_{Δ^0}



$M_{\Delta^{++}}$

$\pi^+ + {}^4\mathbf{He} \rightarrow \pi^+ + {}^3\mathbf{H} + \mathbf{p};$

$\rightarrow \Delta^{++} + {}^3\mathbf{H};\ \Delta^{++} \rightarrow \pi^+ + \mathbf{p};$ **(1144 MeV)**



M_{Δ^-}, M_{Δ^0}, $M_{\Delta^{++}}$ in ^{4}He

Phys.Rev.Lett. 67 (1991) 1982:
pC and pH; 1.5 GeV/c

C $M_{\Delta^{++}}$**=1207 MeV;** $\Gamma/2$ **= 190 MeV**

H $M_{\Delta^{++}}$**=1225 MeV;** $\Gamma/2$ **= 115 MeV**

^{4}**He,** $\pi^{\pm}$**, 106 MeV:**

M_{Δ^-}**= 1160** $\pm$ **40 MeV (PAINUC)**
(Eur. Phys. J. A 34, 255–269 (2007))

M_{Δ^0}**= 1147** $\pm$ **59 MeV**

$M_{\Delta^{++}}$**= 1144** $\pm$ **56 MeV**

M_{Δ^+}**= ???**

Branching ratios

BR for $\pi^{\pm}{}^4$He 3-prong reaction channels

	Channel	BR, π^-	BR, π^+
1.	$\pi^{\pm}$p^{3}H	0.30±0.05	0.24±0.04
2.	$\pi^{\pm}$DD	0.40±0.05	0.47±0.06
3.	$\pi^{\pm}$ppnn	0.17±0.04	0.21±0.04
4.	$\pi^{\pm}$pDn	0.13±0.03	0.09±0.03

Conclusion: BR

Table 1: Branching ratios of 3-pr $\pi^{\pm}{}^4$He reaction channels observed in diffusion chamber (π^+, 1980) and self-shunted streamer chamber ($\pi^{\pm}$, 2017)

reaction	Diff.ch.: 15 atm π^+, 120 MeV	Str.ch.: 1 atm π^-, 106 MeV	Str.ch.: 1 atm π^+, 106 MeV
$\pi^{\pm}$pt	0.66	0.30	0.24
$\pi^{\pm}$dd	–	0.40	0.47
$\pi^{\pm}$ppnn	0.34	0.17	0.21
$\pi^{\pm}$pdn	–	0.13	0.09

Conclusion: m_{Δ}

Table 2: Δ_{1232}-resonance masses

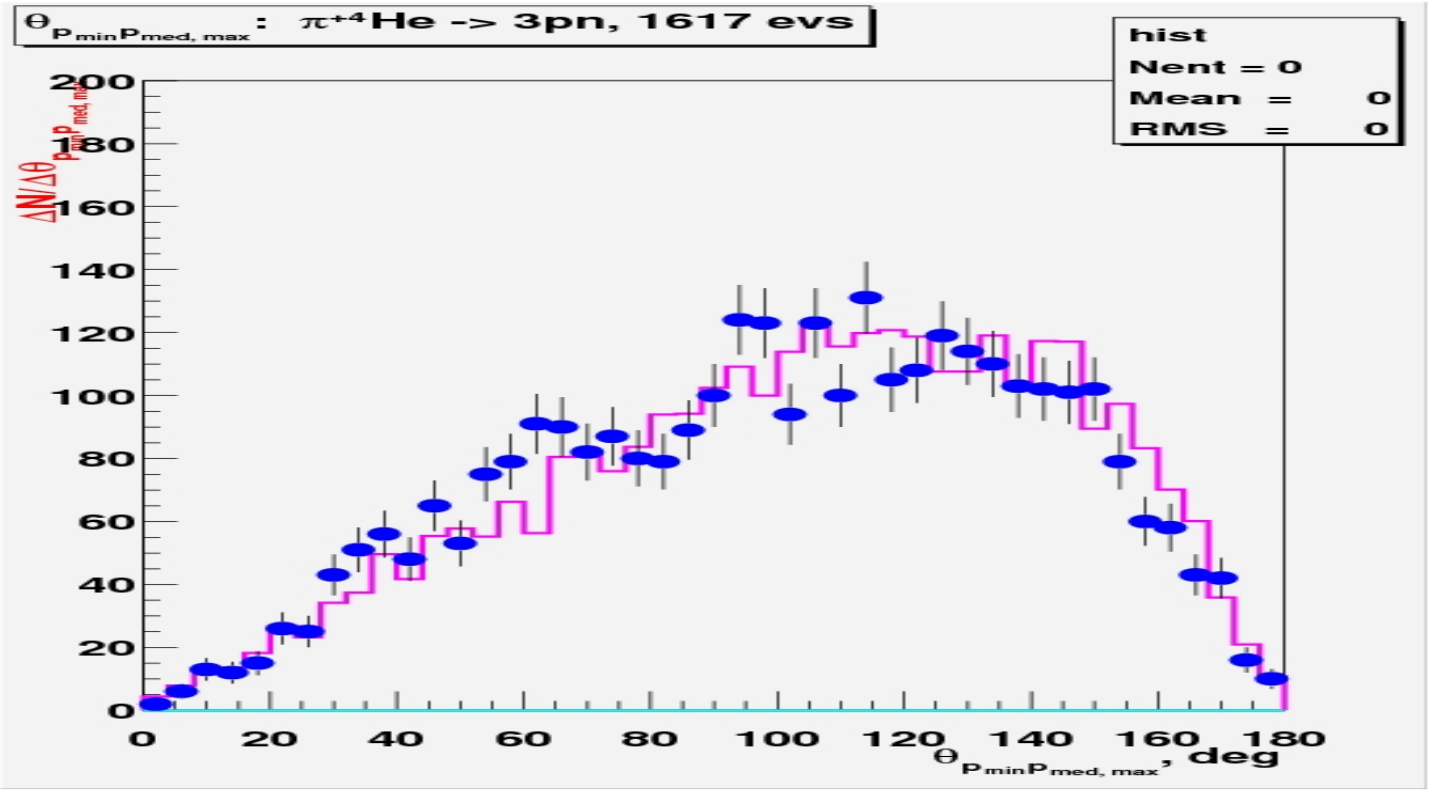
Pions	Nucleus	Δ mass, MeV	Reference
π^+, 1.5 GeV/	^{1}H	Δ^{++}, 1225	PRL 67 (1991) 1982
" "	^{12}C	Δ^{++}, 1207	" "
π^-, 106 MeV	^{4}He	Δ^-, 1160	EPJ. A 34, 255 (2007)
" "	" "	Δ^0, 1147	PAINUC, prelim.
π^+, 106 MeV	" "	Δ^{++}, 1144	" "
" "	" "	Δ^+, ???	

Conclusion

About 10 physicists are involved (not full time) in PAINUC; STREAMER is in working condition; $<$ 20% of the $\approx$ 30000 $\pi^{\pm}$^{4}He evs ($T_{\pi^{\pm}}$= 106 and 68 MeV) have been measured, so our plans would include the following:

- **Sustaining STREAMER.**
- **Measuring and analyzing $\pi^{\pm}$^{4}He events including those involving γs, absorption, π-induced collective resonances etc.**
- **Enhancement of $I_{\pi^{\pm}}$ up to $10^4 \div 10^5 \pi/s$.**
- **Future runs at different pion beam energies (new Project: financial support required).**

Absorption, angle slow–fast



Distribution of angles between slow and the 2 fast protons in absorption π^{+4}He$\rightarrow$pppn. MC histogram takes into account experimental measurement errors.