SEARCH FOR MUON CATALYZED d^3He FUSION

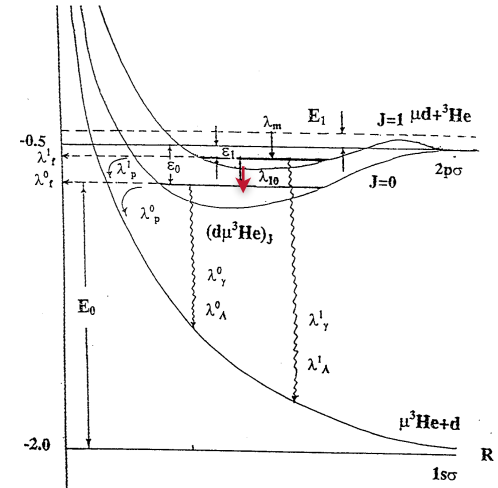
Addendum to the MuSun experiment
PSI Experiment R-08-01

Progress Report and Beam Request 2021

P. Kravchenko (PNPI, Russia)
for the MuSUN collaboration

BV52 User Meeting 27th of January 2021

Goal of project



L.N. Bogdanova,..Hyperfine Int., 118, 183 (1999)
D.I. Abramov,.. Hyperfine Int., 119, 1127 (1999)

To observe the muon catalyzed d^3He fusion

$$d^3He\mu \xrightarrow{\lambda_f} {}^4He + p + \mu$$

Formation of the $[d^3He\mu]_J$ molecules

$$\mu \rightarrow d\mu \xrightarrow{\lambda_{d3He}} [{}^3He\mu d]_J \xrightarrow{\lambda_{dec}} {}^3He\mu + d$$

λ_f (J=0) = $2\cdot10^5$ s^{-1}
λ_f (J=1) = $6.5\cdot10^2$ s^{-1}

λ_{d3He} = $1.48\cdot10^8$ s^{-1}

~1% precision, our experiments at PSI

λ_{dec} = $7.02\cdot10^{11} s^{-1}$

L.N. Bogdanova,.. PSI-PR-97-33 (1997)

Transfer the $[d^3He\mu]_{J=1}$ molecule from the J=1 state to the J=0 state

$$[(d^3He\mu)_{J=1}\, e]^+ + D_2 \rightarrow [(d^3He\mu)_{J=1}\, eD_2]^+ \rightarrow [(d^3He\mu)_{J=0}\, e]^+ + D_2 + e$$

$$\lambda_f = P_0\lambda_f(J=0) + P_1\lambda_f(J=1)$$

λ_f = $2.5\cdot10^4$ s^{-1}

M.P. Faifman (Hyperfine Int. 118, 187 (1999))

Theoretical interests

The observation of the muon catalyzed d^{3}He fusion is important for confirmation of the MFC theory.

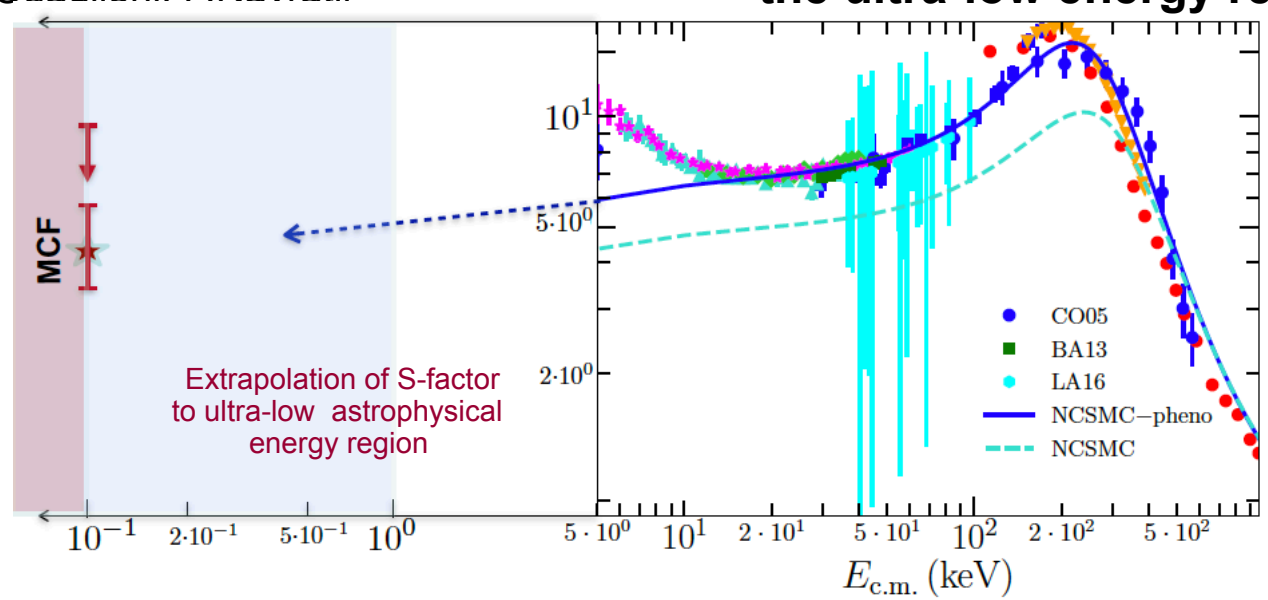
L.Bogdanova, M. Faifman, V.Korobov (Moscow , Russia)

Also, it has some astrophysical aspects, as this is a unique way to measure the fusion rate at ultra-low energies without the electron screening distortion.

R-matrix theory
R.S.de Souza, C.Iliadis, A. Coc

***Ab initio* many body calculations**
G. Hupin, S.Quaglioni, P.Navratil

The muon catalyzed fusion experiment provides the cross section for bare nuclei in the ultra-low energy region



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THM method
R.G.Pizzone, M.La Cognata, A.Tumino..
Direct and Indirect Measurements for a Better Understanding of the Primordial Nucleosynthesis
Frontiers in Astronomy and Space Sciences, 7, 560149(2020)

26 October 2020
PREFER meets AsFiN Workshop

Polarization REsearch for Fusion Experiments and Reactors (PREFER)
And
AsFiN (AstroFisica Nucleare)
merging interests

Future applications to Nuclear physics

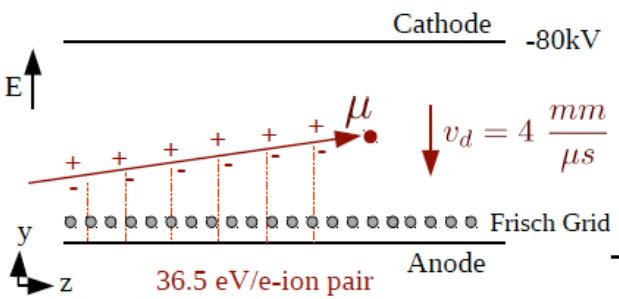
How nuclear astrophysics can benefit from lasers?

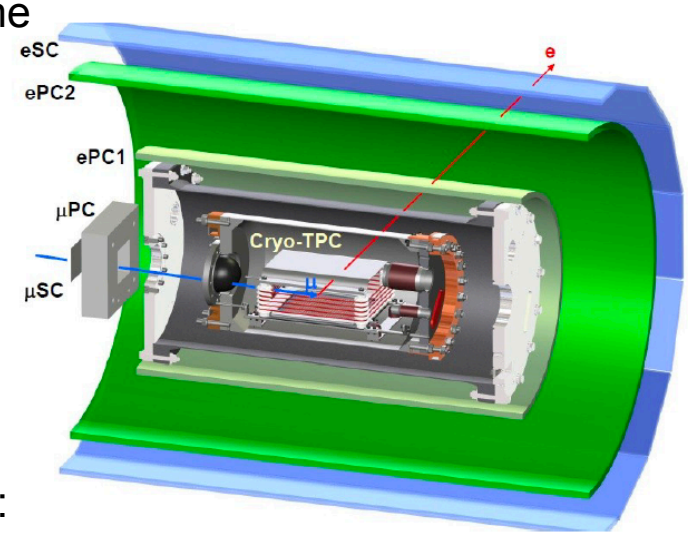
Alternative approach with applications to energy production in next generation clean nuclear power plants

Polarization effects on the cross-section of fusion reactions

Experimental strategy

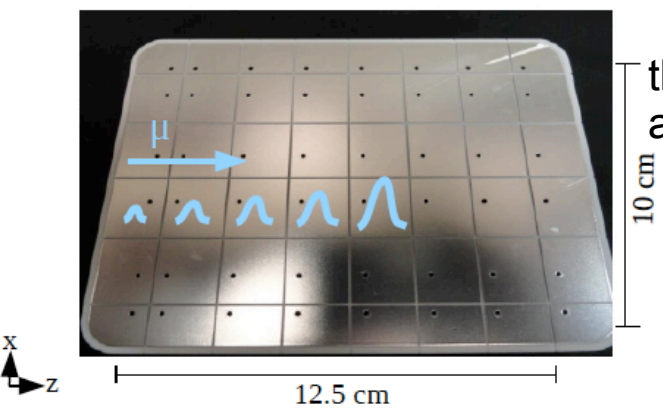
The **main goal** of the MuSun experiment was the life time measurement
of the muons stopped in ultra clean D2 gas

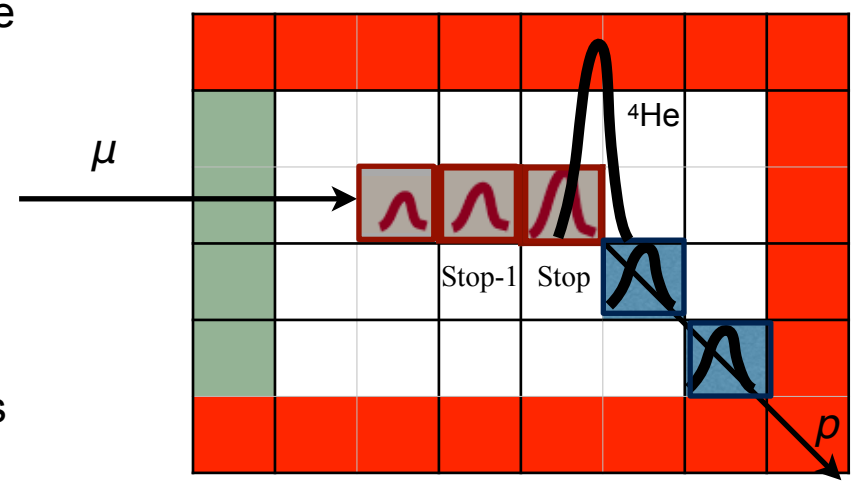




The **KEY ELEMENT** of the MuSun experimental setup:

the Cryogenic TPC operating at 31K, 5bar pressure





TPC detects all charged products following the muon stop, including products of the d^{3}He fusion reaction

$$d^3 + He \rightarrow {}^4He(3.66MeV) + p(14.64\ Mev)$$

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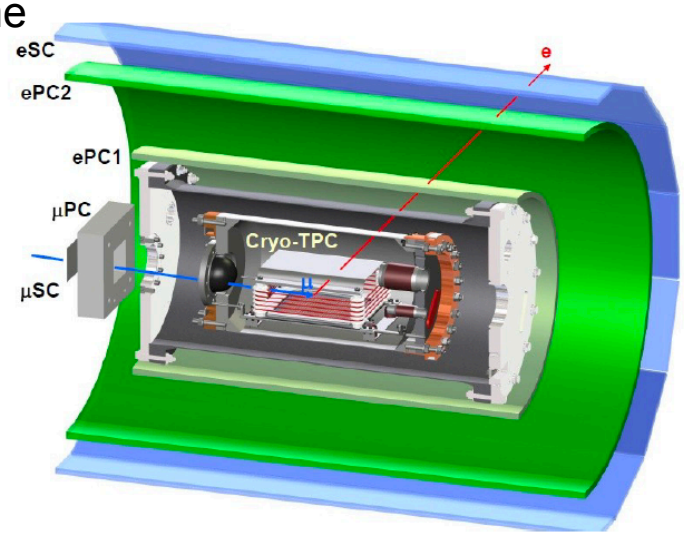


The MuSUN collaboration has a unique possibility
to observe for the first time the muon catalyzed d^{3}He fusion,
due to:

- high detection sensitivity and
- low and well controlled background.

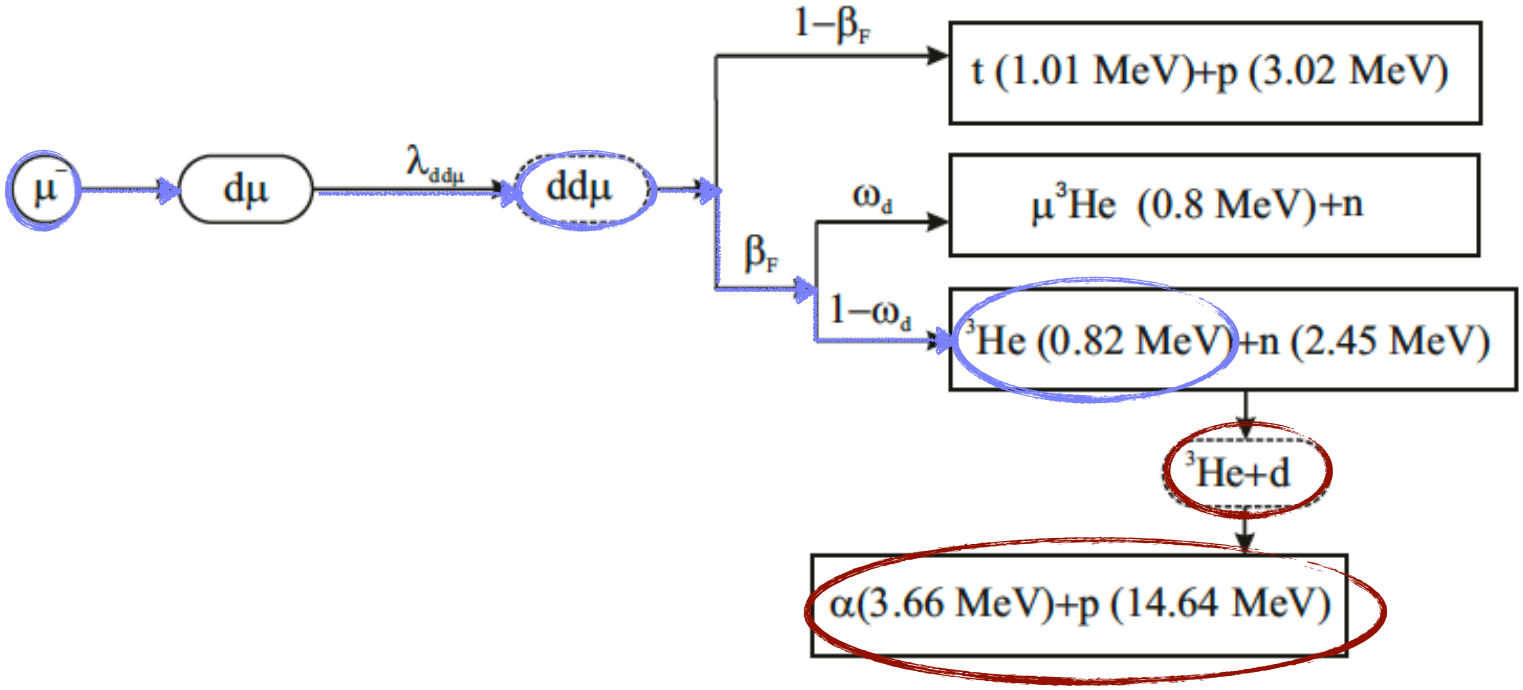
This statement is based on the results of the

- Run8 9 weeks MuSun experiment with pure D2 filled TPC and
- Run9 1 week test experiment performed with the D2 + ^{3}He gas mixture
  (new upper limit λ_f = < $6 \cdot 10^4$ s^{-1}).

Milestones

Run8 (2015)

Muon catalyzed fusion in D_2



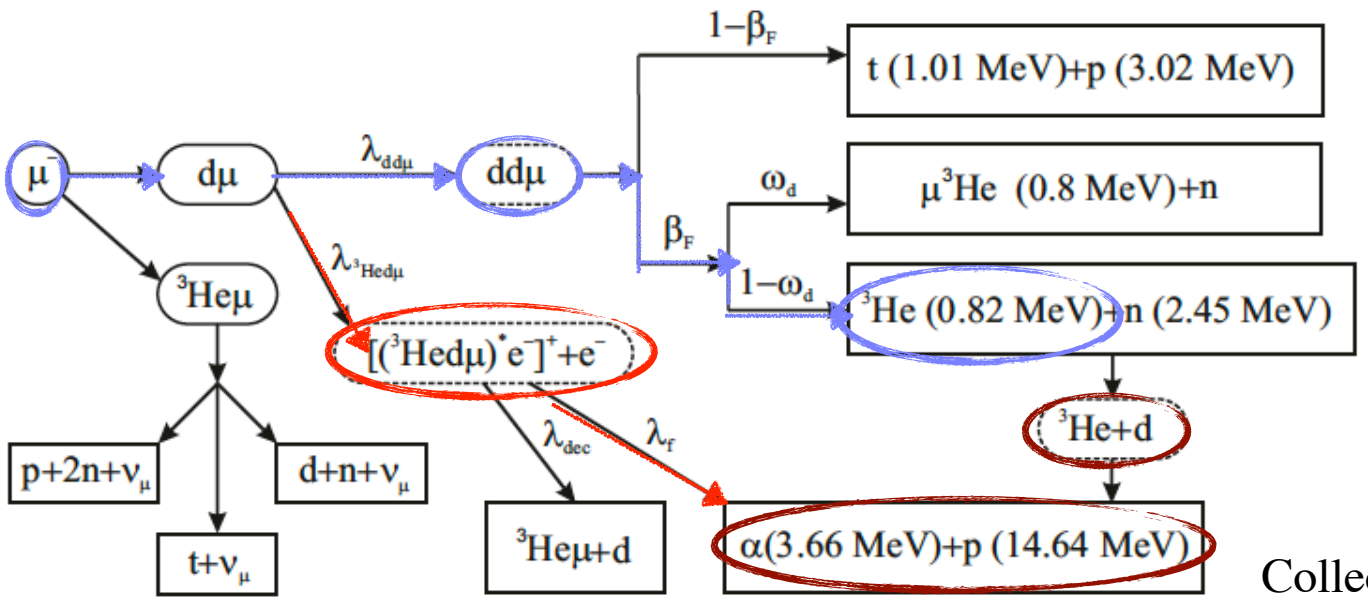
Fusion-in-flight

$$dd\mu \rightarrow d + {}^3He(0.82MeV) \rightarrow {}^4He(3.66MeV) + p(14.64MeV)$$

Milestones

Run9 (2016)

Muon catalyzed fusion in D2 + 5% ^{3}He



$$N_{d\mu^3He} = 1.4 \cdot 10^8$$

number of produced $d\mu^3He$ molecules

Collected Statistics

run	μ	Weeks	Ntot	NFinF/ Npileup
Run8	1.3E+10	9	99	77/22
Run9	1.0E+09	1	2	1.9/0.34

Milestones

Run9 (2016)

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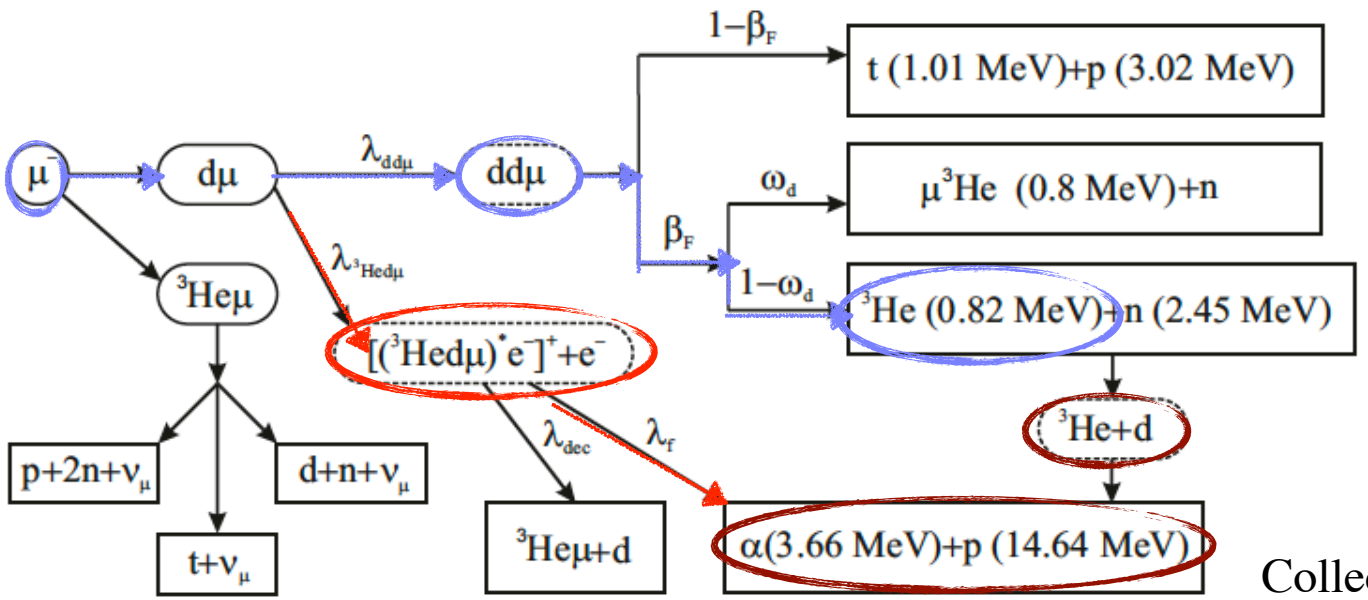

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$$N_{d\mu^3He} = 1.4 \cdot 10^8$$

number of produced $d\mu^3He$ molecules

upper limit for the probability of the fusion decay of the $d^3He\mu$ molecule

$$P_{fusion}(d^3He\mu) \leq 9.0 \cdot 10^{-8} \ at\ 90\%C.L.$$

decay rate

$$\lambda_{dec} = 7 \cdot 10^{11}\ s^{-1}$$

registration efficiency

$$\epsilon_f = 0.30$$

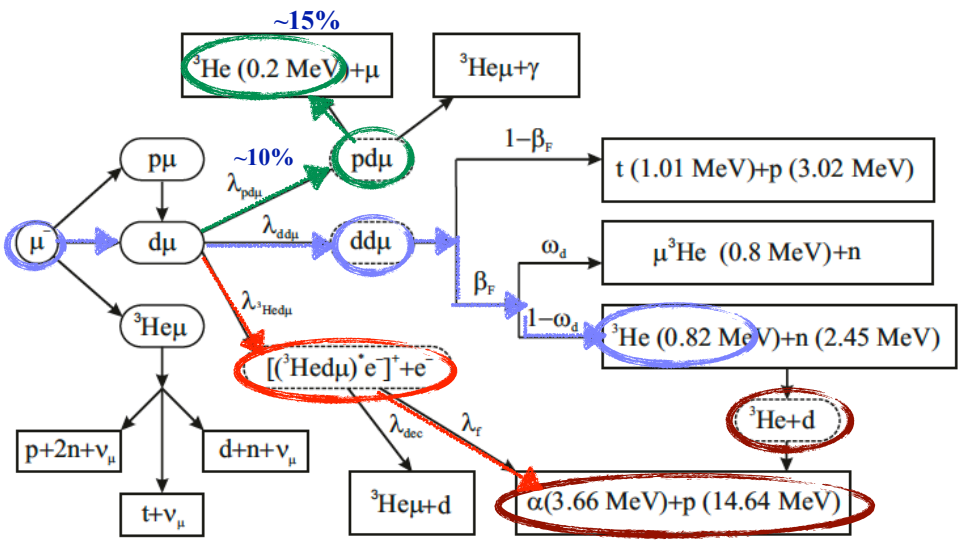
upper limit for the effective muon catalyzed d^3He fusion rate

$$\lambda_f \leq 6.3 \cdot 10^4\ s^{-1}\ at\ 90\%C.L.$$

Milestones

Run10 (2020)

Muon catalyzed fusion in HD + 5% ^{3}He



To increase the sensitivity for detection

- experiment with HD+5% 3He — x 1/4 — fusion-in-flight background
- modification of TPC electronics — x 3 — d3He Fusion
- 4 weeks of beam time — x 4

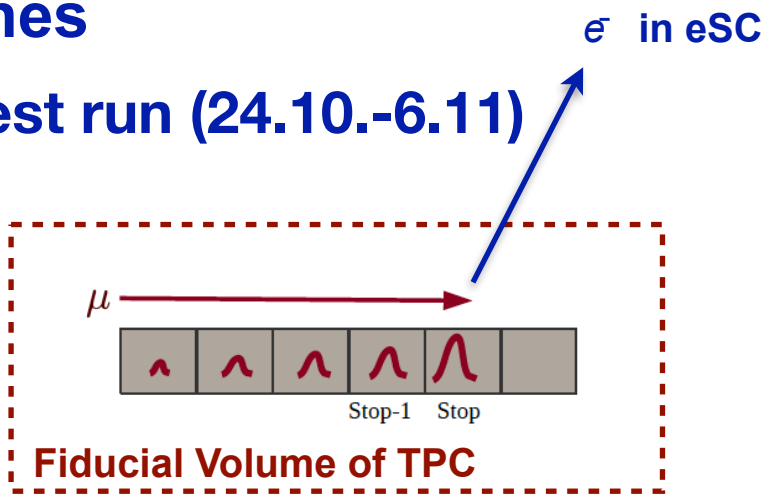
The BV51 User meeting 2020 PAC approval

Milestones

Run10 (2020) Preliminary results of test run (24.10.-6.11)

8 TB experimental data for analysis

run	μ stop	Weeks	Expectation
Run9	7.70E+08	1	
Run10	2.1E+08	1	2.0E+09



Objective difficulties

- No kicker factor more then 2 less

No time for technical work
in cooperation with colleagues from PSI
due to the new safety rules

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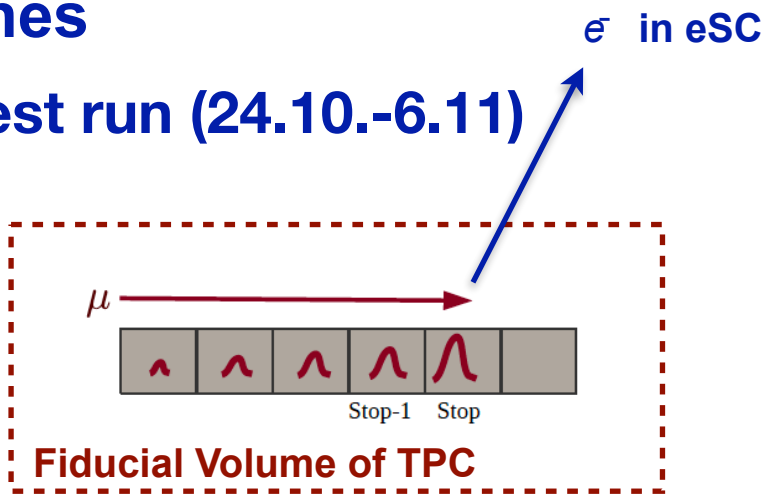

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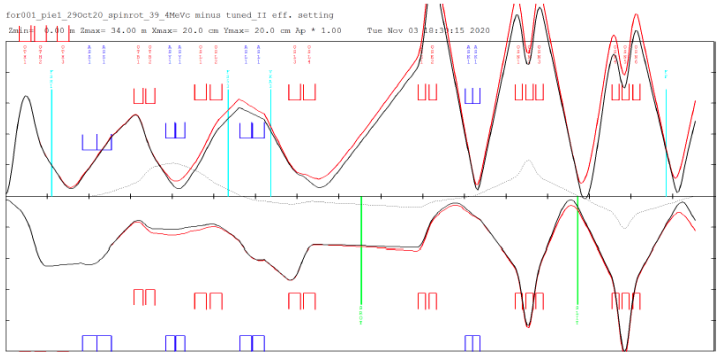
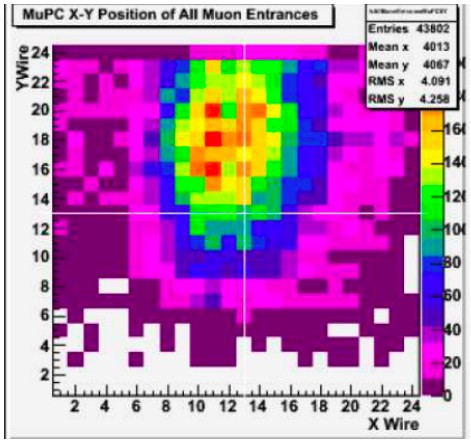
- Muon beam count rates 25% less





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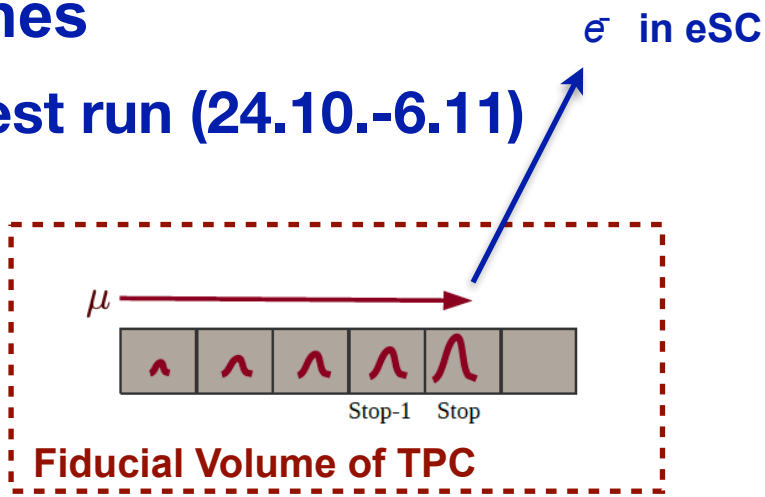

Objective difficulties

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- Produced volume of HD 25% less

No chromatography control

Development and application of the Rayleigh fractionation method for 3 components gas mixture

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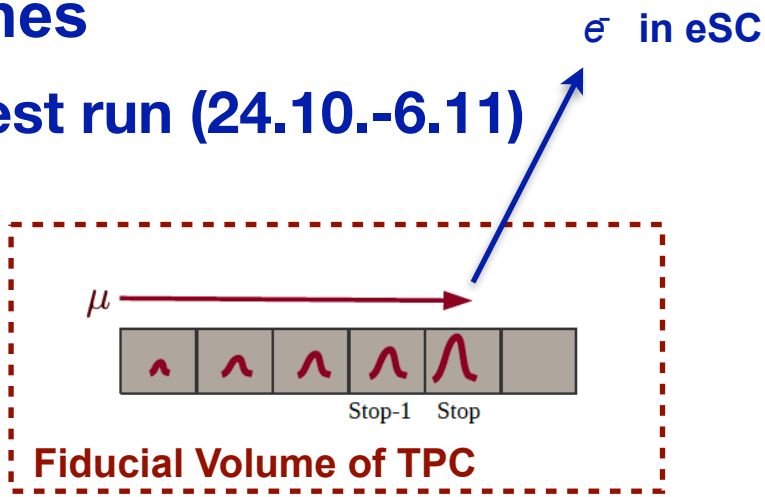

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….? (the analysis of the data is in progress)

Beam time requests

July-August… any time before the beam,
as soon as the travel restrictions will be removed

1-2 weeks for technical work with a kicker in cooperation with electricians from PSI with possibility to have a place in the hall for tests

September - November

2 weeks unrestricted access to the piE1-2 area
(HD production)

4 weeks beam time in piE1-2 area

We would like to say

THANK YOU FOR YOUR JOB AND SUPPORT!

Petitjean Claude Charles

Govaerts Van Loon Anita

Hildebrandt Malte

Bernhard Lauss