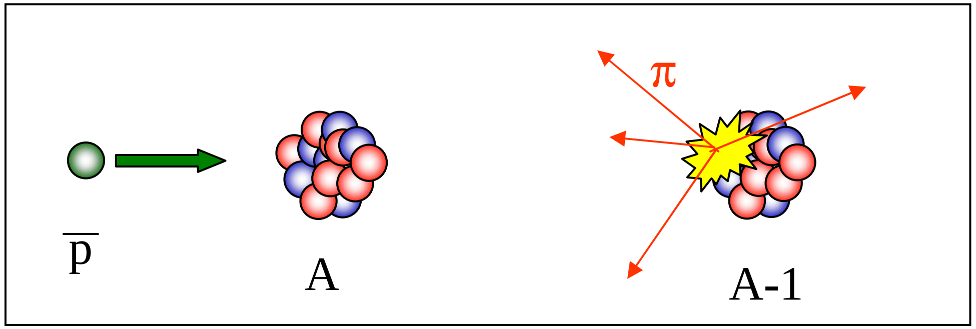
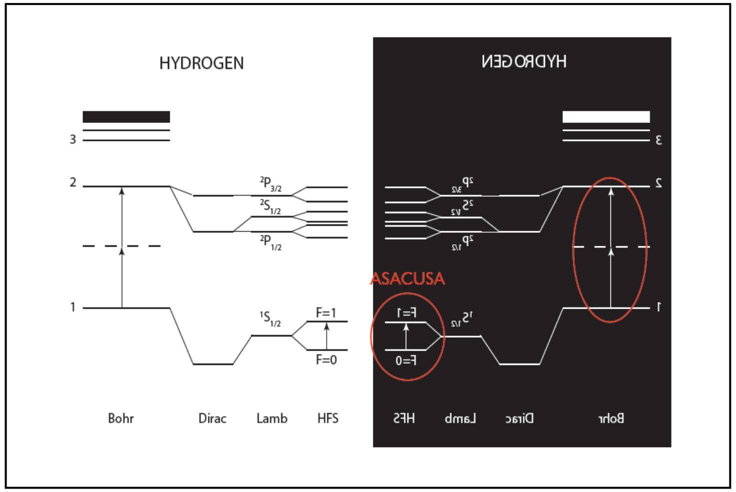
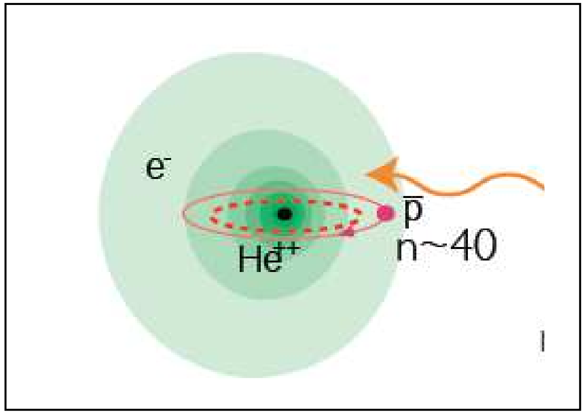
ASACUSA

Luca Venturelli

Università di Brescia & INFN Gruppo Collegato di Brescia







ASACUSA

Atomic Spectroscopy And Collisions Using Slow Antiprotons

Asakusa, Tokyo

Austria - SMI Vienna

Denmark - University of Aarhus

Germany - Max-Planck Institute for Quantum Optics

Hungary - KFKI Budapest, ATOMKI Debrecen

Italy - INFN Brescia

Japan - University of Tokyo, RIKEN Saitama

United Kingdom - University of Swansea, Queens University of Belfast

7 countries, 10 institutions, 40 researchers
Started in 1997 by merger of PS194, PS205, etc. collaborations.
Members active in CERN's antiproton programme since >20 years.

$\bar{p}$He & $\bar{H}$ spectroscopy
→CPT, fundamental const.

100 keV $\bar{p}$s (RFQD)
100 eV $\bar{p}$s (“MUSASHI” trap)

ASACUSA

Atomic Spectroscopy And Collisions
Using Slow Antiprotons

D. Barna[1,6], M. Charlton[2], M. Corradini[3], A. Dax[1], S. Federmann[8], M. Fink[8], S. Friedreich[8], J. Handsteiner[8], R.S. Hayano[1], H. Higaki[5], M. Hori[1,10], D. Horváth[6,9], C.A. Hunniford[9], B. Juhász[8], Y. Kanai[5], H. Knudsen[7], H-P. Kristiansen[7], T. Kobayashi[1], N. Kuroda[4], M. Leali[3], E. Lodi-Rizzini[3], V. Mascagna[3], O. Massiczek[8], Y. Matsuda[4], K. Michishio[5], S.P. Møller[7], D. Murtagh[5] W. Pirkl[1], M. Rihl[8], A. Sótér[10], K. Todoroki[1], K. Tőkési[9], H.A. Torii[4], U. Uggerhøj[7], S. Ulmer[5] L. Venturelli[3], E. Widmann[8], Y. Yamazaki[5], P. Zalán[6], J. Zmeskal[8], N. Zurlo[3]

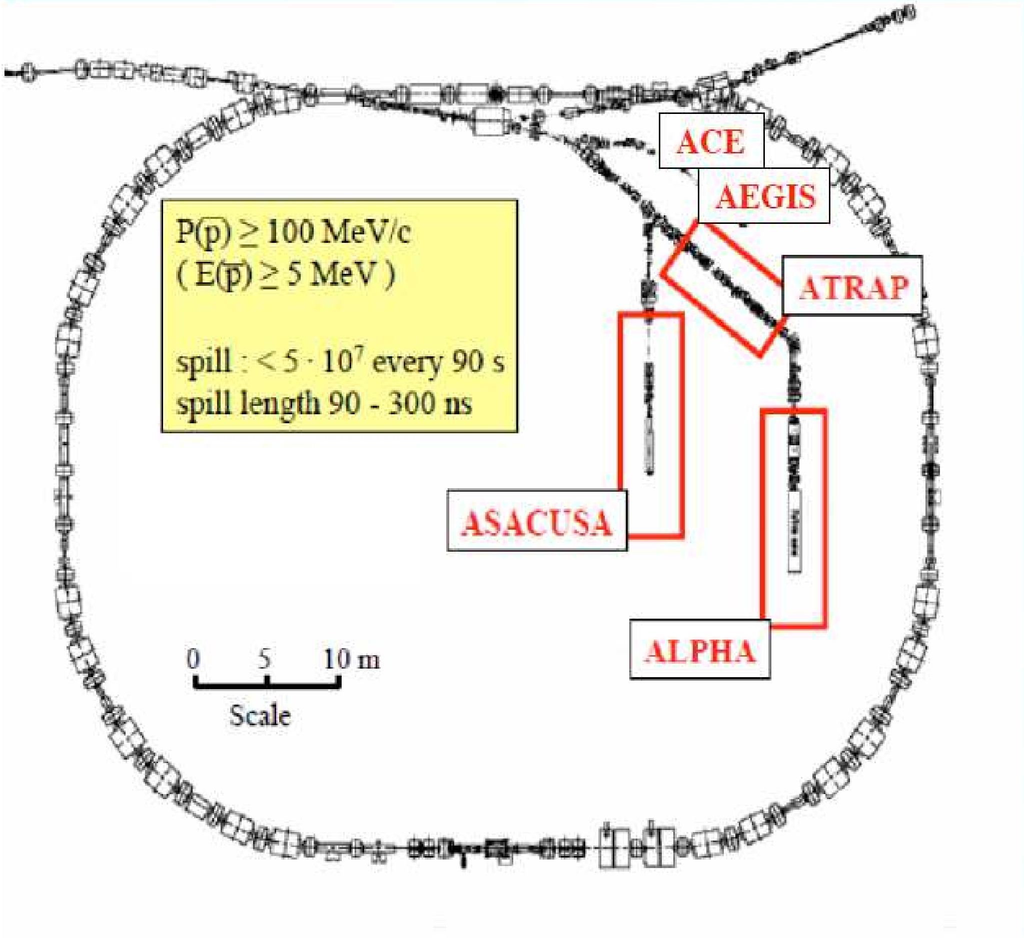
1. The University of Tokyo (JP), 2. University of Swansea (GB), 3. Università di Brescia and INFN (IT), 4. The University of Tokyo, Komaba (JP), 5. RIKEN (JP), 6. KFKI (HU), 7. University of Aarhus (DK), 8. Stefan Meyer Institute (AT), 9. ATOMKI (HU), 10. Max-Planck-Institut für Quantenoptik (DE)

ASACUSA Italia

cognome nome		TIPO	Ricercatori	Tecnologi	FTE
Corradini Maurizio	assoc	Ricercatore			80
Leali Marco	assoc			x	100
Lodi Rizzini Evandro	assoc	Prof. Ordinario			
Mascagna Valerio		Assegnista			100
Mazzotta Cristina	da assoc	Ric. ENEA			50
Venturelli Luca	assoc	Prof. Associato			100
Zurlo Nicola	assoc	Ricercatore			100
Di Govambattista Giorgio	tecnico				100

+ collaboratori Universita' dell'Insubria-Como INFN Trieste

Antiproton Decelerator (AD) @ CERN



- **Started operation** July 6, **2000**

  Antiproton capture, deceleration, cooling 100 MeV/c (5.3 MeV)
- **Pulsed extraction**
- **Many Experiments**
  - ASACUSA
  - ATRAP
  - ALPHA
  - AEGIS
  - Free Fall
  - ~~PAX~~
  - ACE
  - .....

Antiprotonic atom formation and spectroscopy;

Antihydrogen formation and spectroscopy;

Atomic collisions;

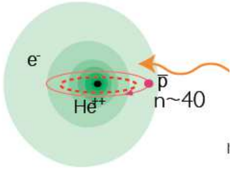
Nuclear collisions

- **Request for more and better antiproton beams**
  - To speed up progress
  - To boost accuracy

⇒ **ELENA**

AD is the only low-energy $\bar{p}$ source

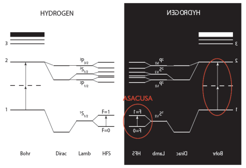
Studies of *CPT symmetry* by atomic spectroscopy



1) • Two-photon laser spectroscopy of antiprotonic helium :
→Antiproton mass with $<10^{-10}$ precision.

• ~~Microwave spectroscopy of antiprotonic helium (completed)~~
~~→Antiproton magnetic moment with 0.3% precision~~

NO INFN



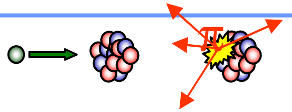
2) • Microwave spectroscopy of antihydrogen :
→Ground-state hyperfine structure with 10^{-6} precision.

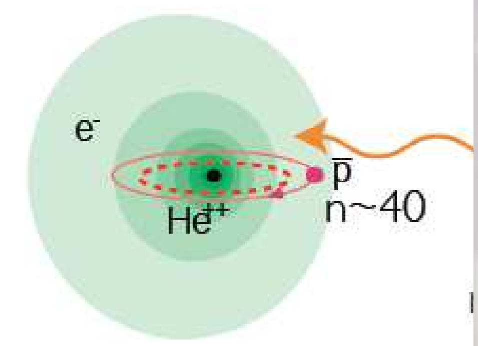
~~Atomic collisions with antiprotons~~

NO INFN

Nuclear collisions with antiprotons

3) • total annihilation cross-section σ at 5 MeV completed. 0.1 MeV ongoing

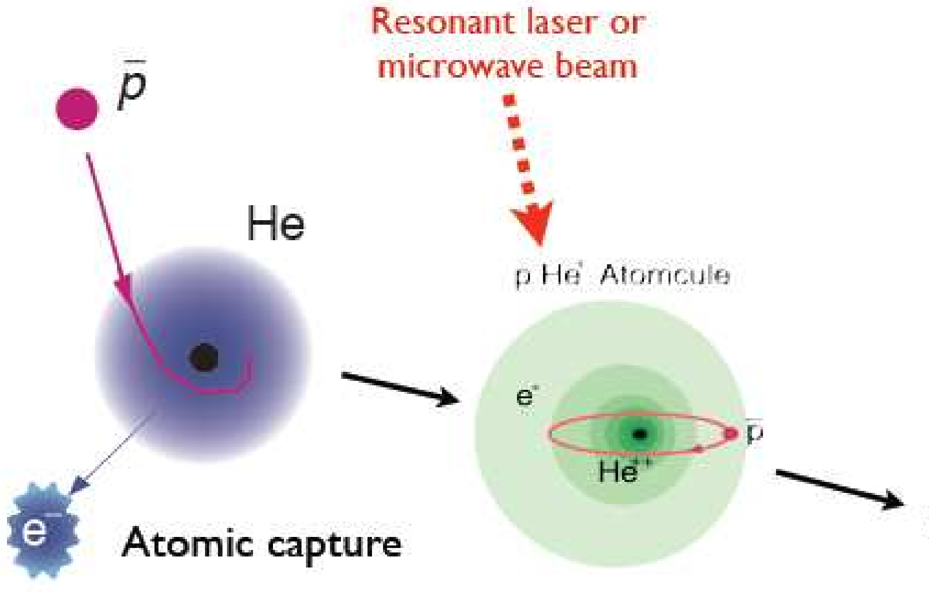


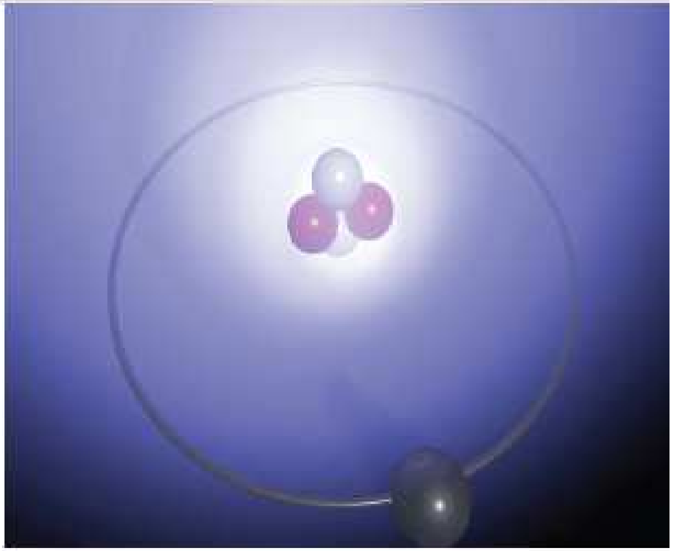


1. $\bar{p}$He laser spectroscopy

$m_{\bar{p}}/m_e$

Spectroscopy of antiprotonic helium

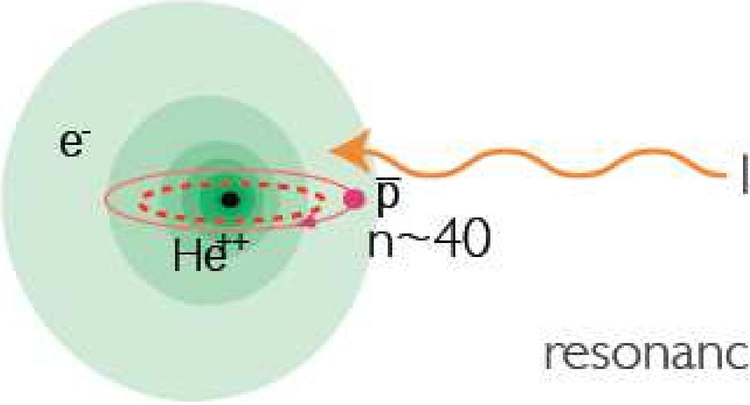




Forced annihilation and detection

- 3-body atom made of antiproton, He, and electron.
- Survives for >10 microseconds.
- >1 billion atoms synthesized per day.
- Amenable to high-precision laser and microwave spectroscopy.

$\bar{p}$He laser spectroscopy contributes to m_p/m_e



laser pulse changes the $\bar{p}$ orbit

resonance detection via $\bar{p}$ annihilation

Frequency

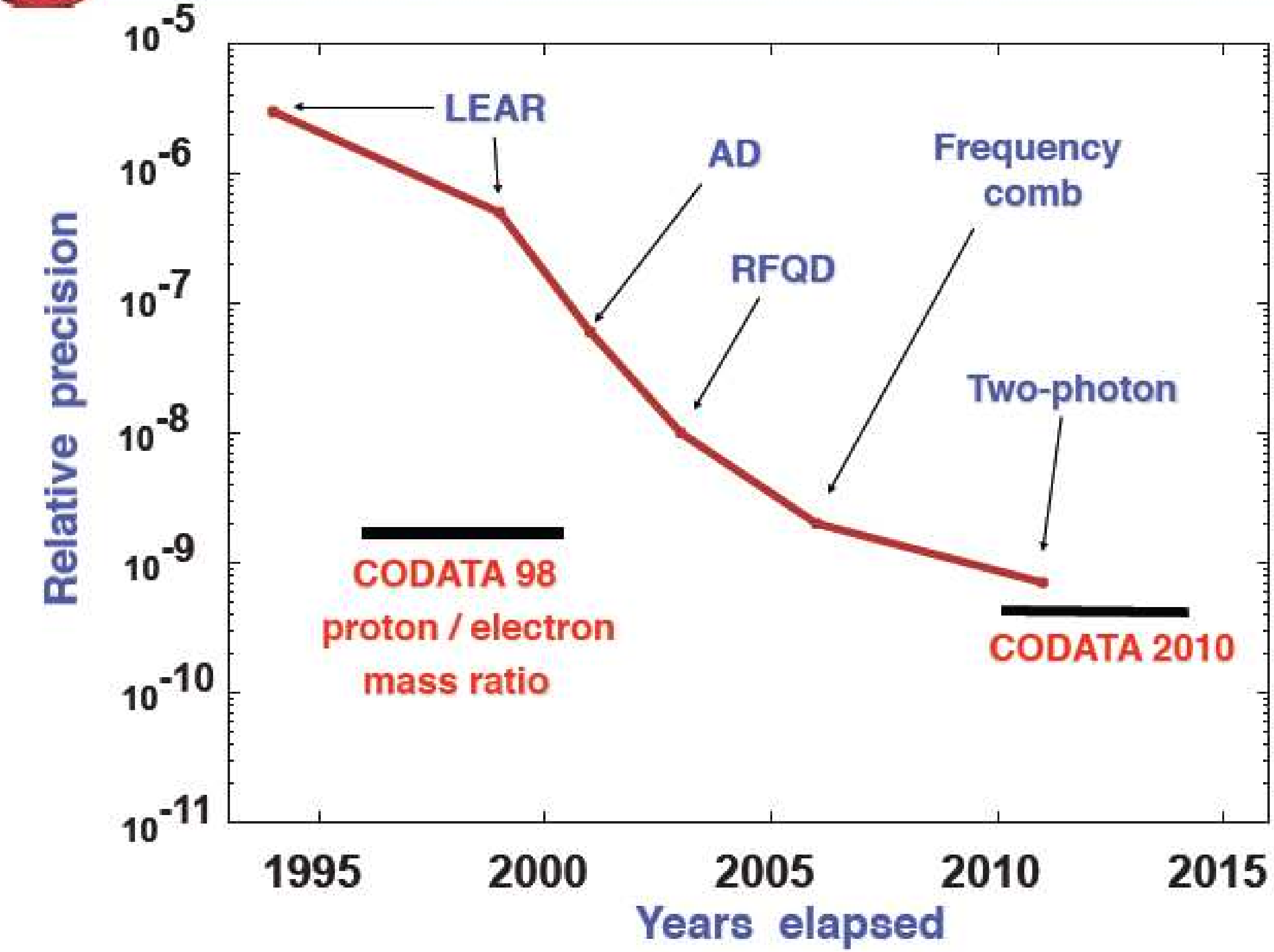
$$\boxed{\nu_{n,\ell\to n',\ell'}} = Rc\boxed{\frac{m^*_{\bar{p}}}{m_e}} Z^2_{\text{eff}}\left(\frac{1}{n'^2}-\frac{1}{n^2}\right) + QED$$

$\bar{p}$ (p) - e mass ratio

Theory

Korobov

Antiproton mass measurement



$\bar{p}$He laser spectroscopy - 2011 highlight

M. Hori et al., Nature 475, 484 (2011).

+ L.Venturelli, N.Zurlo

Press Release

PR10.11
28.07.2011

CERN experiment weighs antimatter with unprecedented accuracy

Geneva, 28 July 2011. In a paper published today in the journal Nature, the Japanese-European ASACUSA experiment at CERN[1] reported a new measurement of the antiproton's mass accurate to about one part in a billion. Precision measurements of the antiproton mass provide an important way to investigate nature's apparent preference for matter over antimatter.

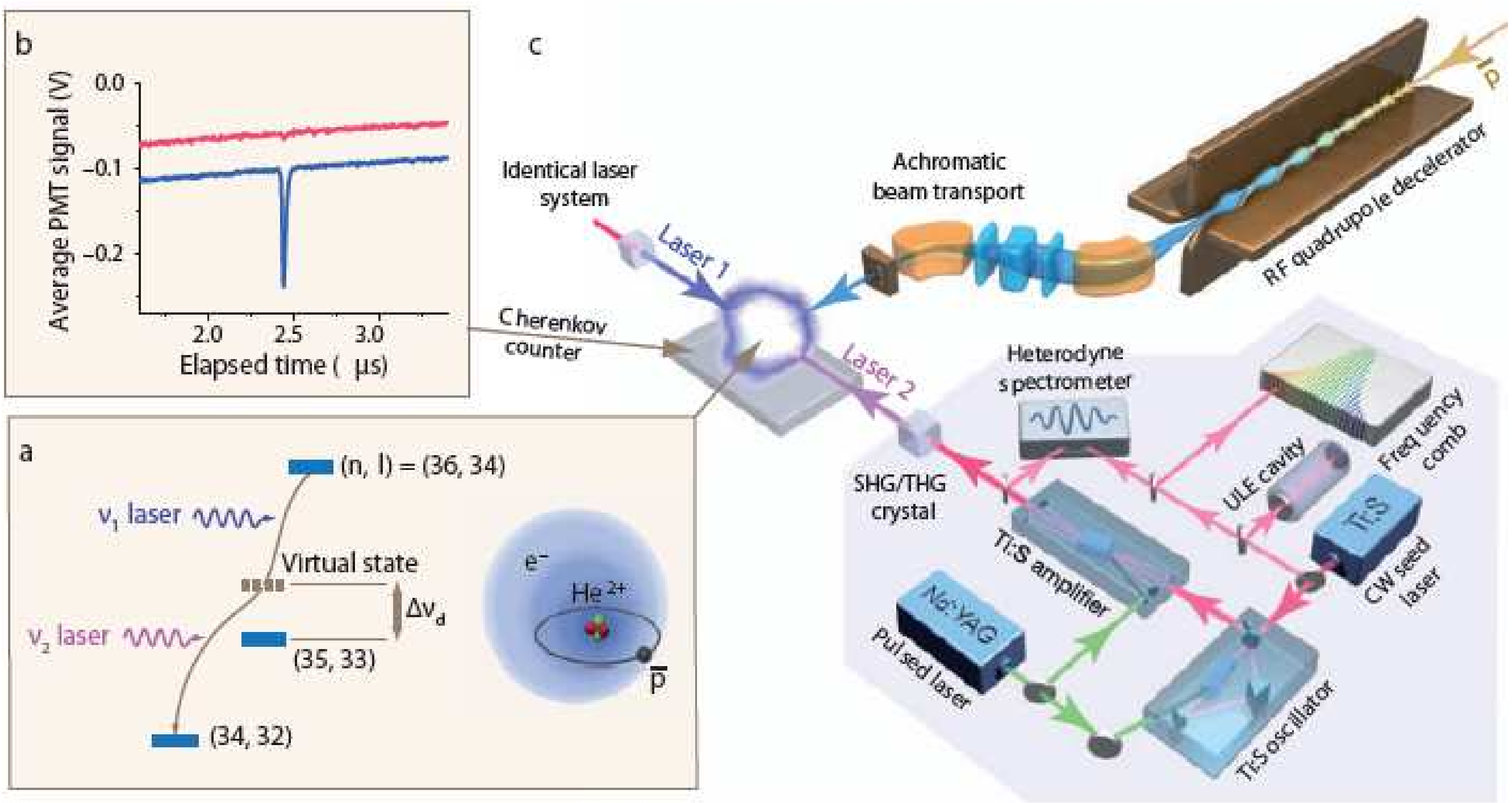
"This is a very satisfying result," said Masaki Hori, a project leader in the ASACUSA collaboration. "It means that our measurement of the antiproton's mass relative to the electron is now almost as accurate as that of the proton."

The ASACUSA experiment.
More photos: 1 - 2.

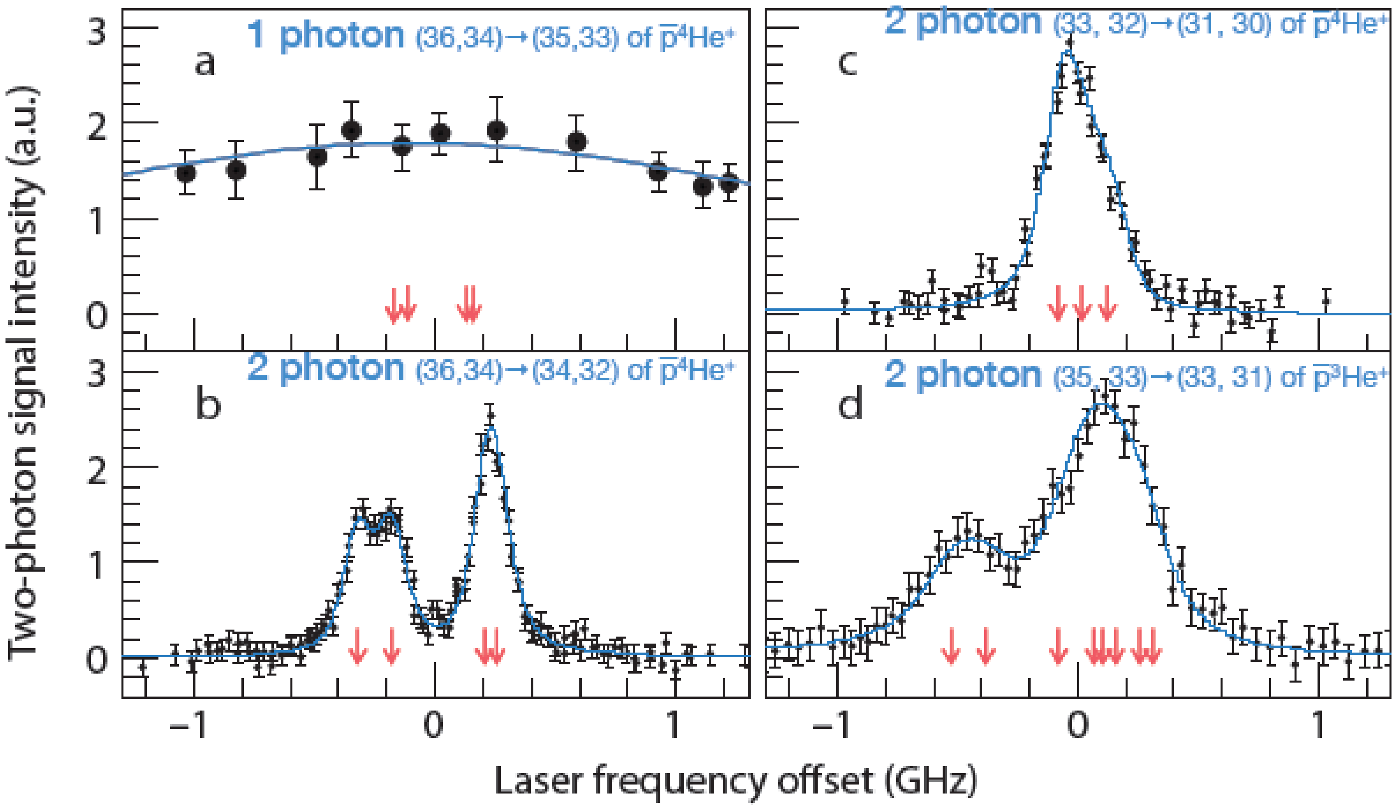
Ordinary protons constitute about half of the world around us, ourselves included. With so many protons around it would be natural to assume that the proton mass should be measurable to greater accuracy than that of antiprotons. After today's result, this remains true but only just. In future experiments, ASACUSA expects to improve the accuracy of the antiproton mass measurement to far better than that for the proton. Any difference between the mass of protons and antiprotons would be a signal for new physics, indicating that the laws of nature could be different for matter and antimatter.

To make these measurements antiprotons are first trapped inside helium atoms, where they can be 'tickled' with a laser beam. The laser frequency is then tuned until it causes the antiprotons to make a quantum jump within the atoms, and from this frequency the antiproton mass can be calculated. However, an important

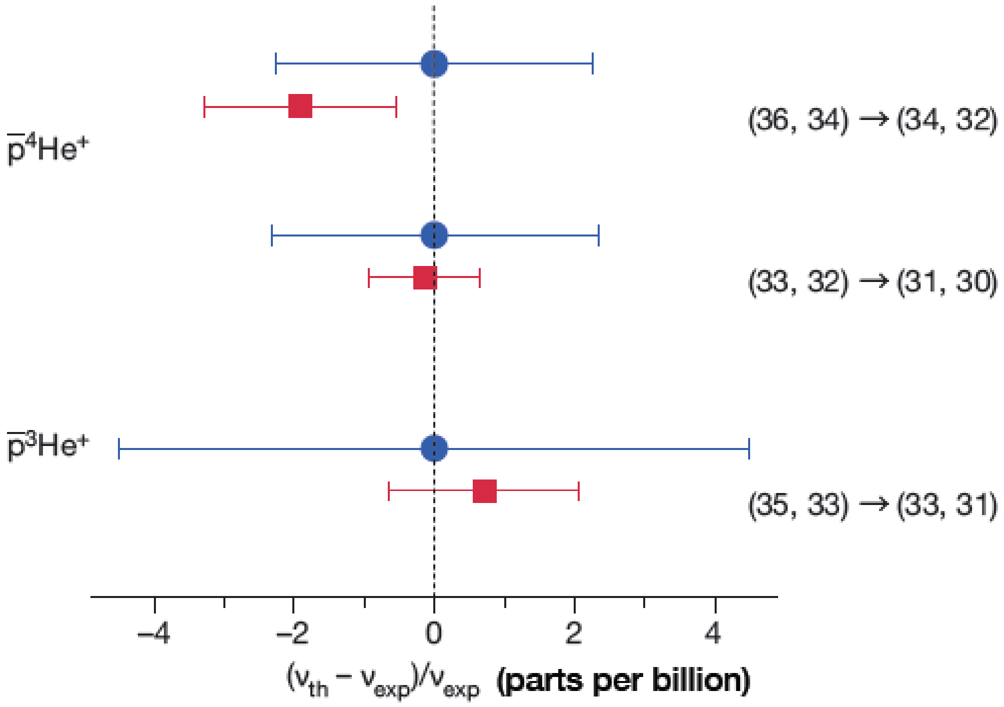
$\bar{p}$He sub-Doppler 2-photon spectroscopy



sub-Doppler two-photon resonances



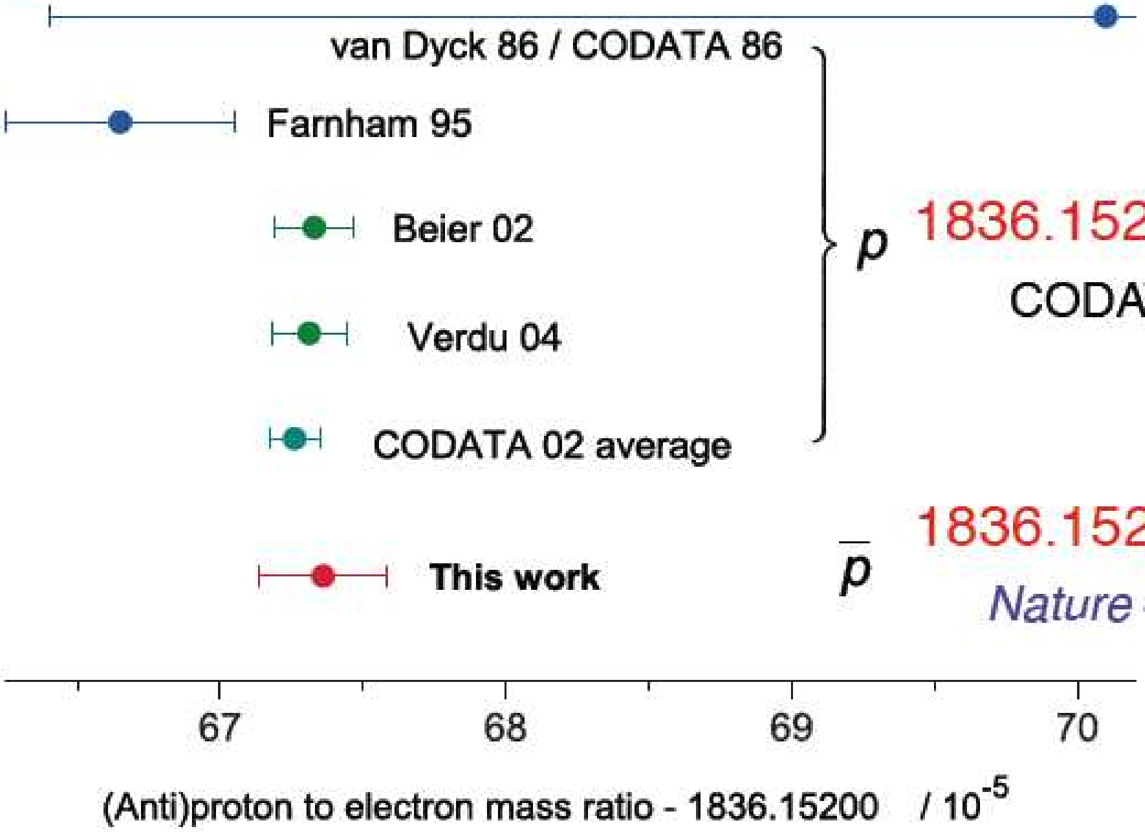
ν_{theory} vs $\nu_{experiment}$



$\bar{p}$He : statistics limited

Datum	Error (MHz)
Experimental errors	
Statistical error, σ_{stat}	3
Collisional shift error	1
A.c. Stark shift error	0.5
Zeeman shift	< 0.5
Frequency chirp error	0.8
Seed laser frequency calibration	< 0.1
Hyperfine structure	< 0.5
Line profile simulation	1
Total systematic error, σ_{sys}	1.8
Total experimental error, σ_{exp}	3.5
Theoretical uncertainties	
Uncertainties from uncalculated QED terms	2.1
Numerical uncertainty in calculation	0.3
Mass uncertainties	< 0.1
Charge radii uncertainties	< 0.1
Total theoretical uncertainty, σ_{th}	2.1

Antiproton mass measurement



p 1836.15267245(75)

CODATA 2010

$\bar{p}$ 1836.1526736(23)

Nature 475, 484 (2011).

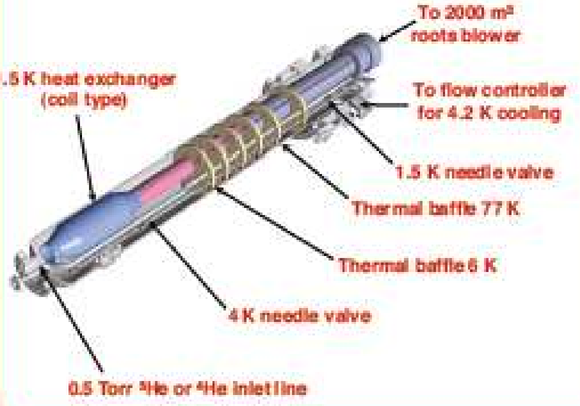
- Compare laser frequency with 3-body QED calculations.
- Antiproton-to-electron mass ratio measured to 1.3 ppb

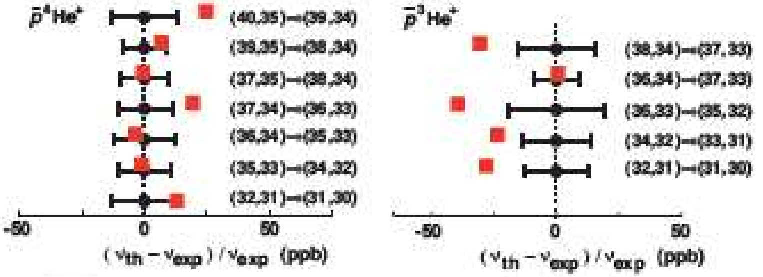
spectroscopy of “cold” $\bar{p}$He

2011

- “cold” $\bar{p}$He :
  (1) less Doppler
  (2) improve S/N
  (3) less collisional broadening
- start with 1-photon transitions

cool $\bar{p}$He$^+$ to T = 1.5 K

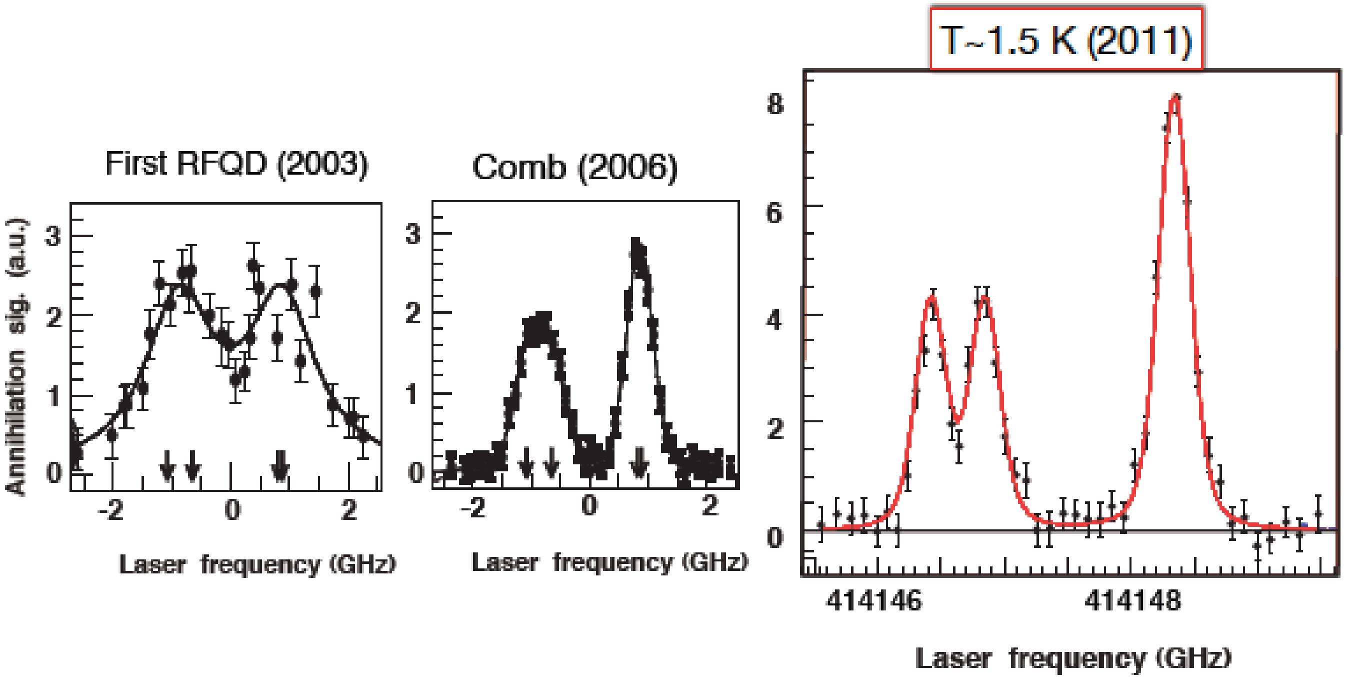




Problem with
ASACUSA 2006

measurement of 11 transitions completed in 2010-2011

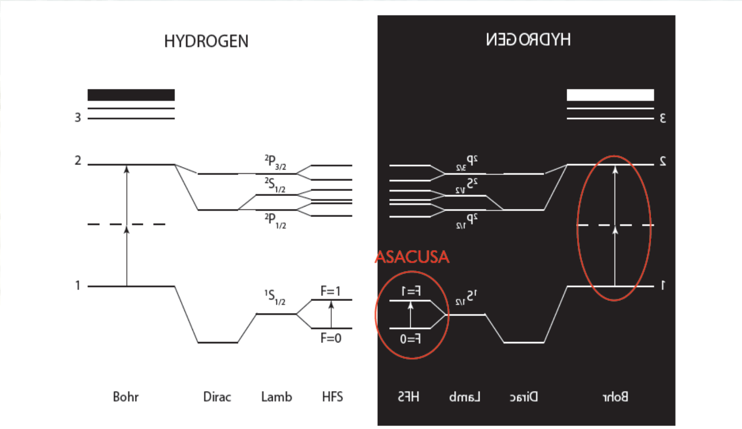
example (36,34)→(37,33) in $\bar{p}^3He^+$ (wavelength ~ 723 nm)



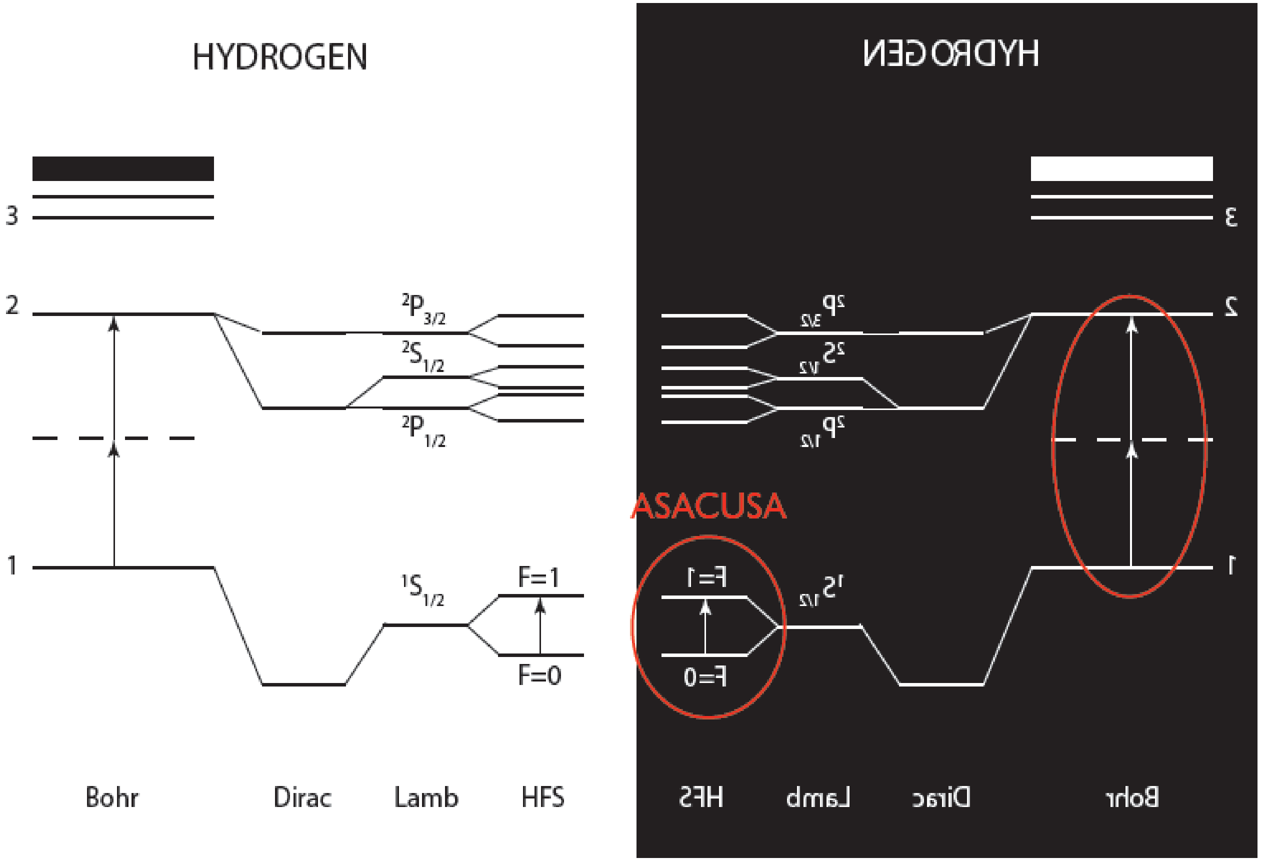
soon to be published (almost as precise as the 2-photon results)

Next: 2-photon spectroscopy of “cold” $\bar{p}$He → 2012

2. $\bar{H}$ formation & GS HFS spectroscopy

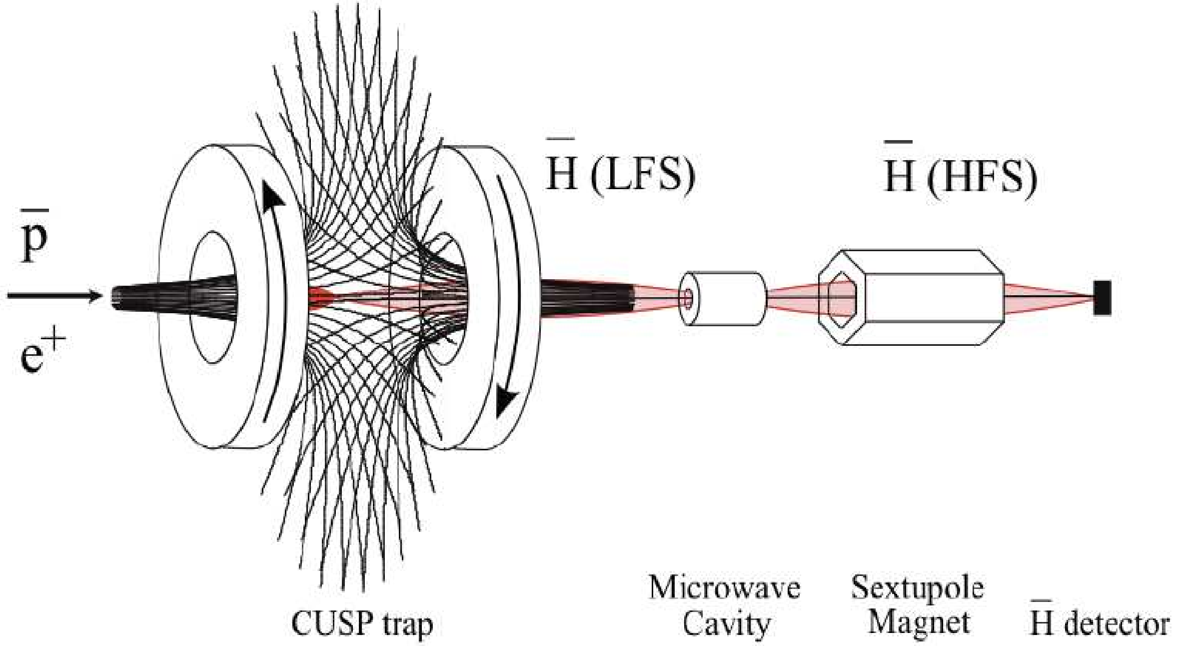


$\bar{H}$ ground-state HFS

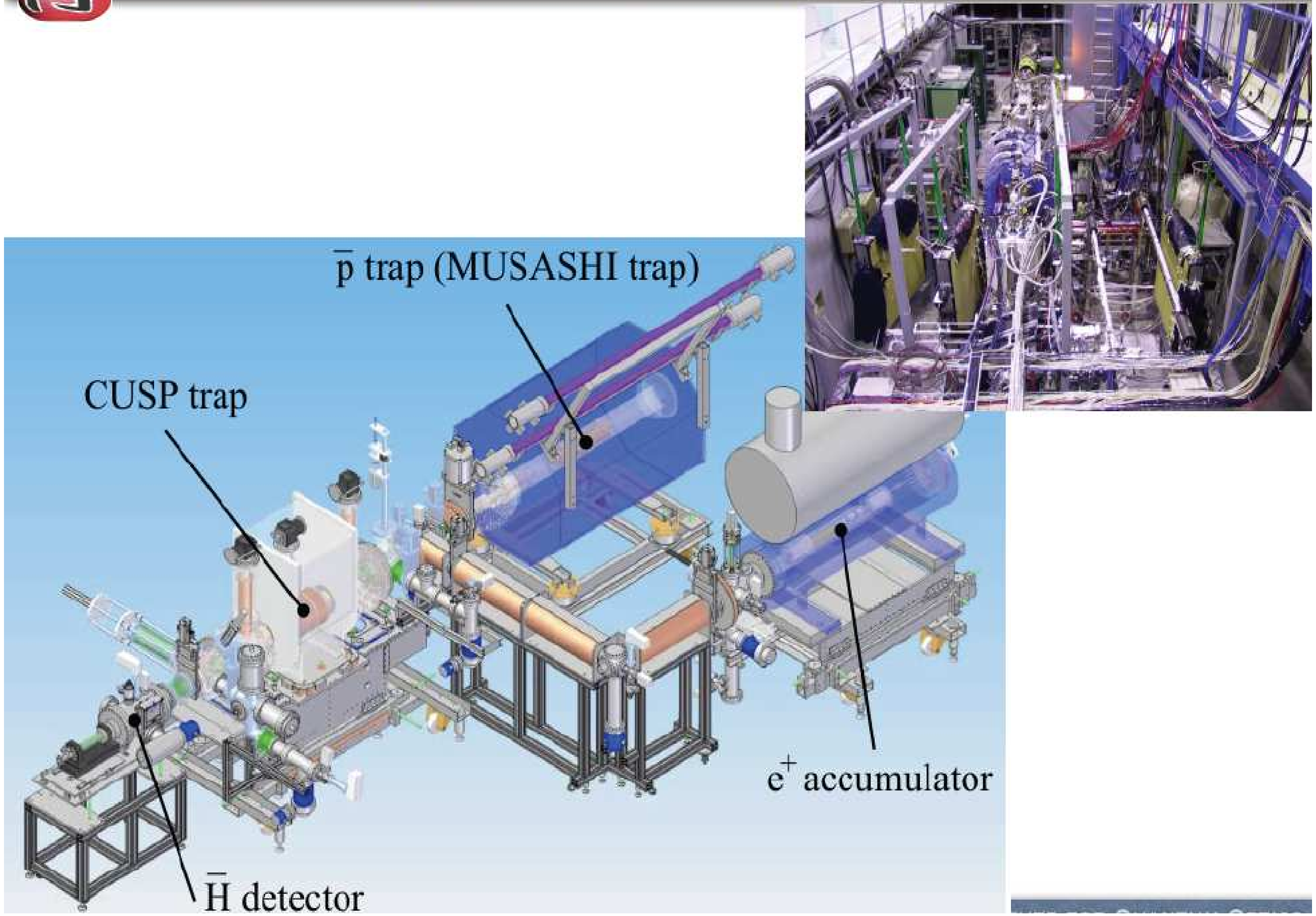


Ground-state hyperfine structure of antihydrogen

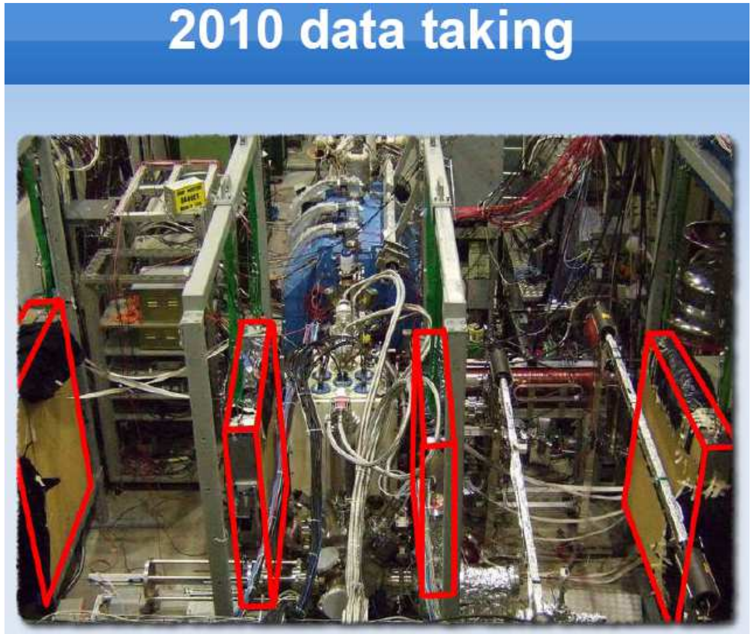
- Measured to 0.6 ppt in hydrogen case: 1.420405751 7667(9) GHz.
- Sensitive to magnetic radius and polarizability of antiprotons.
- Classic atomic-beam spectroscopy with polarized antihydrogen beam, microwave cavity, and sextupole magnet.
- Precision 1 part per million (typical for this type of experiment).



Toward production of antihydrogen beams

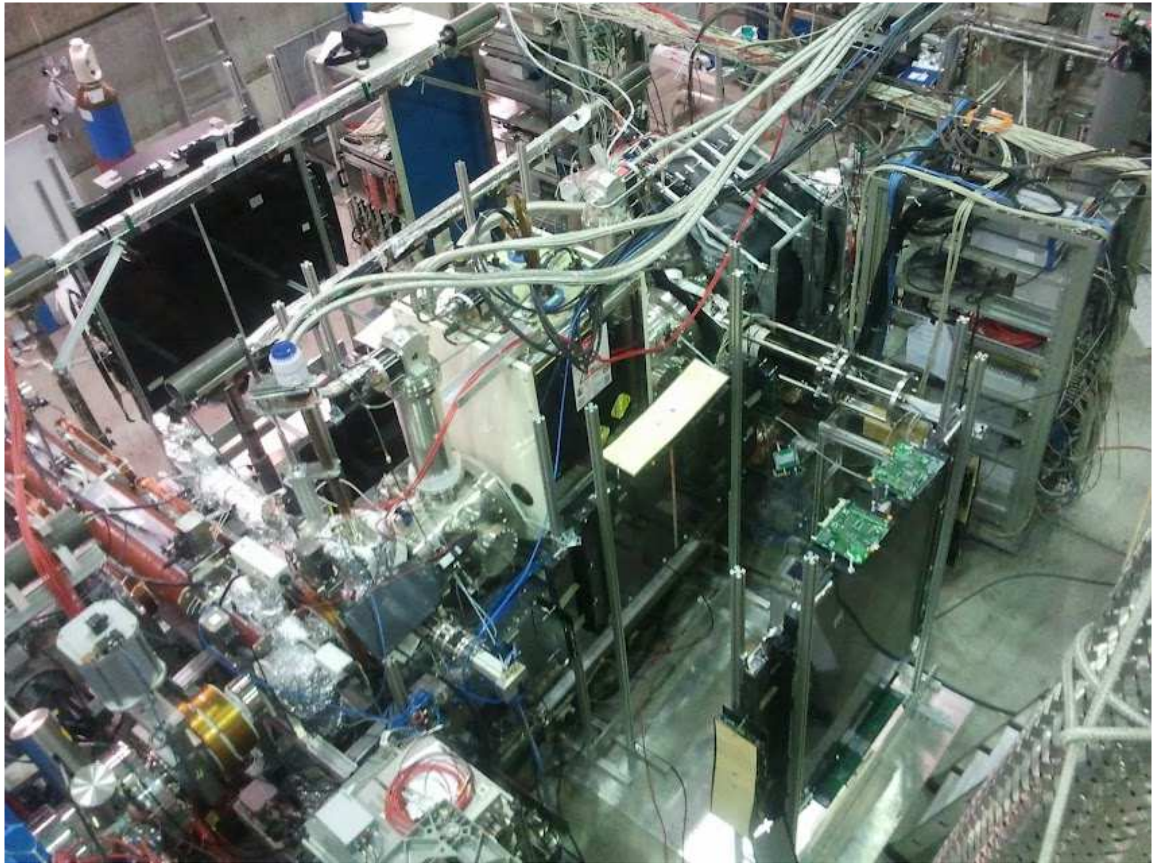


3D detector



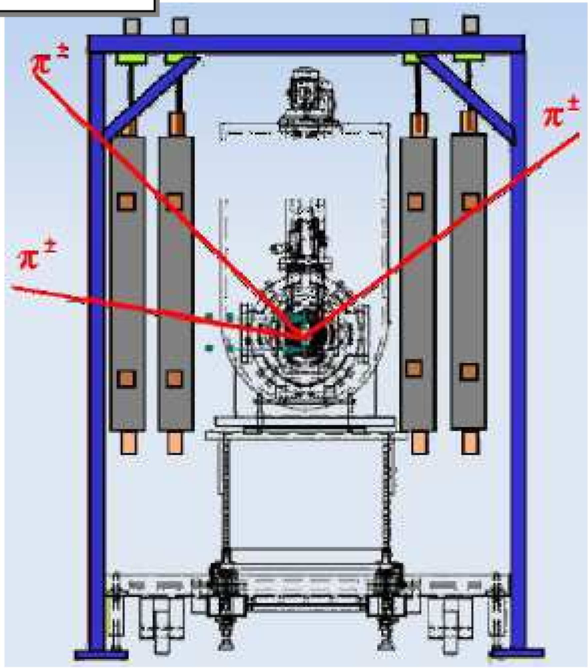
2010 data taking

2011 data taking



3D detector

before 2011



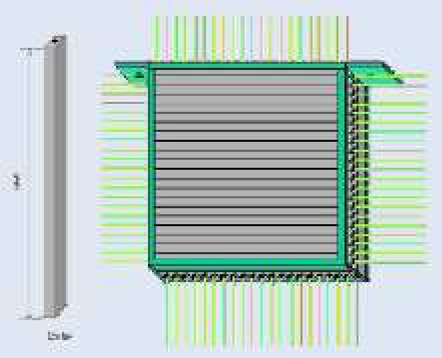
since 2011

Lighter modules

3D detector

4 modules

1 modules = 2 layers

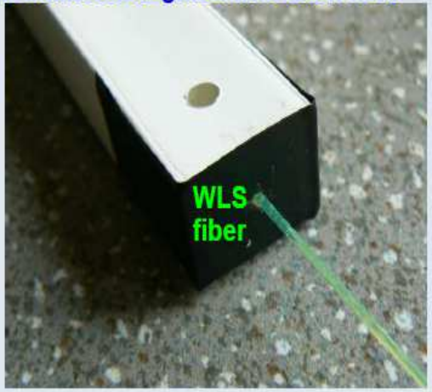


1 layer = 64 scintillator bars (96 cm long)

Polystyrene Dow, Styron 663 W + 1% PPO + 0.03% POPOP, white capstocking (TiO_2) 15 x 19 x 960 mm (by Fermilab)

central hole of diameter 2 mm

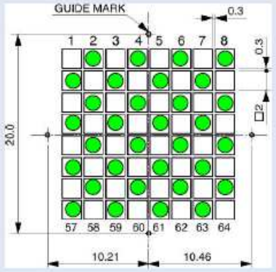
1 WLS Kuraray Y-11 green fiber 1 mm in diameter is glued into each hole



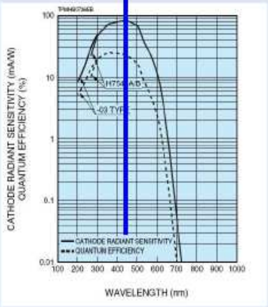
64 bars -> two 64-ch multi-anode PMTs

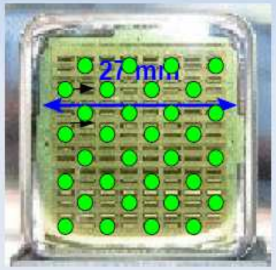
64 channel MULTIANODE PHOTOMULTIPLIER:

- Hamamatsu H7546B
- Q.E. @ 420 nm = 20%
- Anode = 2x2 mm^2
- Gain @ -800 V = 3 10^5
- Rise time = 1.0 ns
- Gain uniformity = 1-2.5
- Crosstalk (opt.+ele.) = 1-2%



WLS fiber emission peak 432 nm





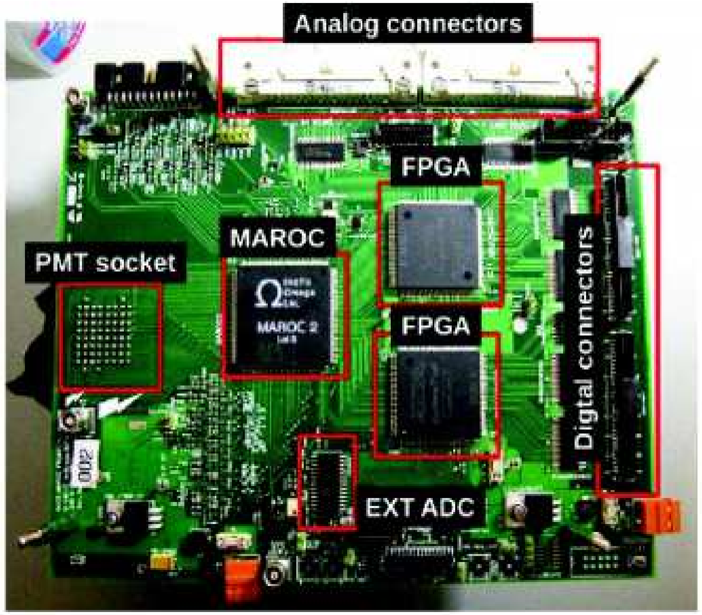
32 fibers / PMT to avoid cross-talk

New frontend board

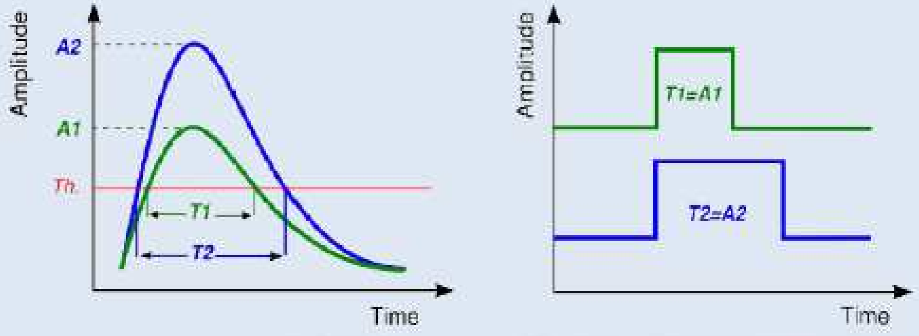
since 2011

MAROC ASIC

calibration input
1 single ASIC (plastic packaging)
Single power rail
Gain and offset uniformity < 2%
Both ANALOG and DIGITAL readout



Time over threshold digital sampling

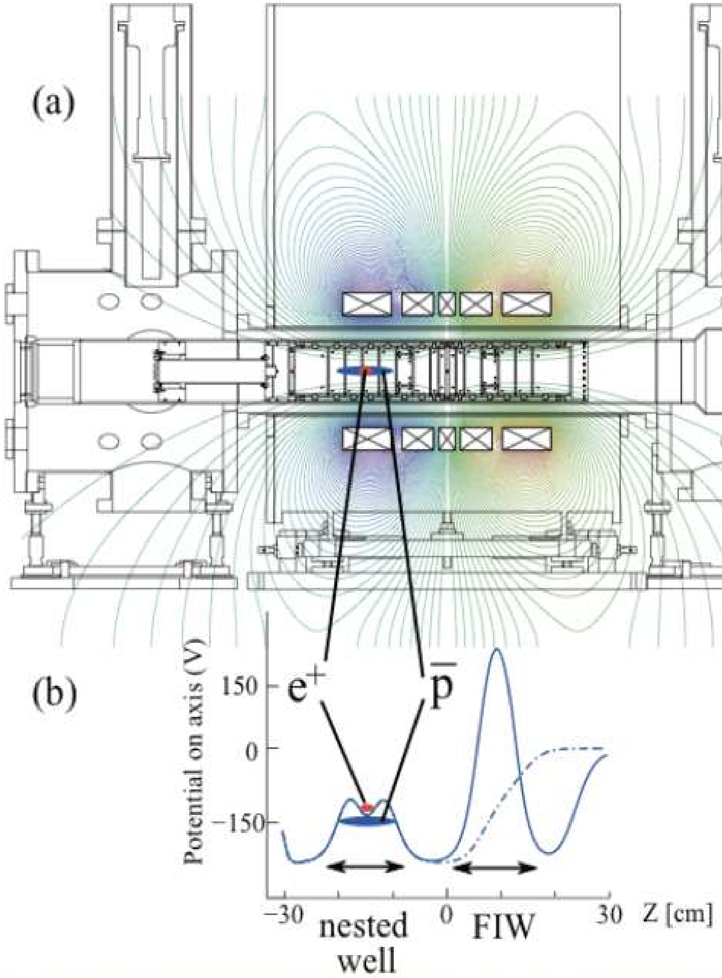


- high sampling rate
- no event loss
- but only for a short time

...can be very useful (ioniz. field?)

→ DAQ will be designed to have a simple ANALOG/DIGITAL switch

Toward production of antihydrogen beams



Y. Enomoto et. al, (Brescia Group)
Phys. Rev. Lett. 105, 243401 (2010)

Mixed 3 million positrons
0.3 million antiprotons

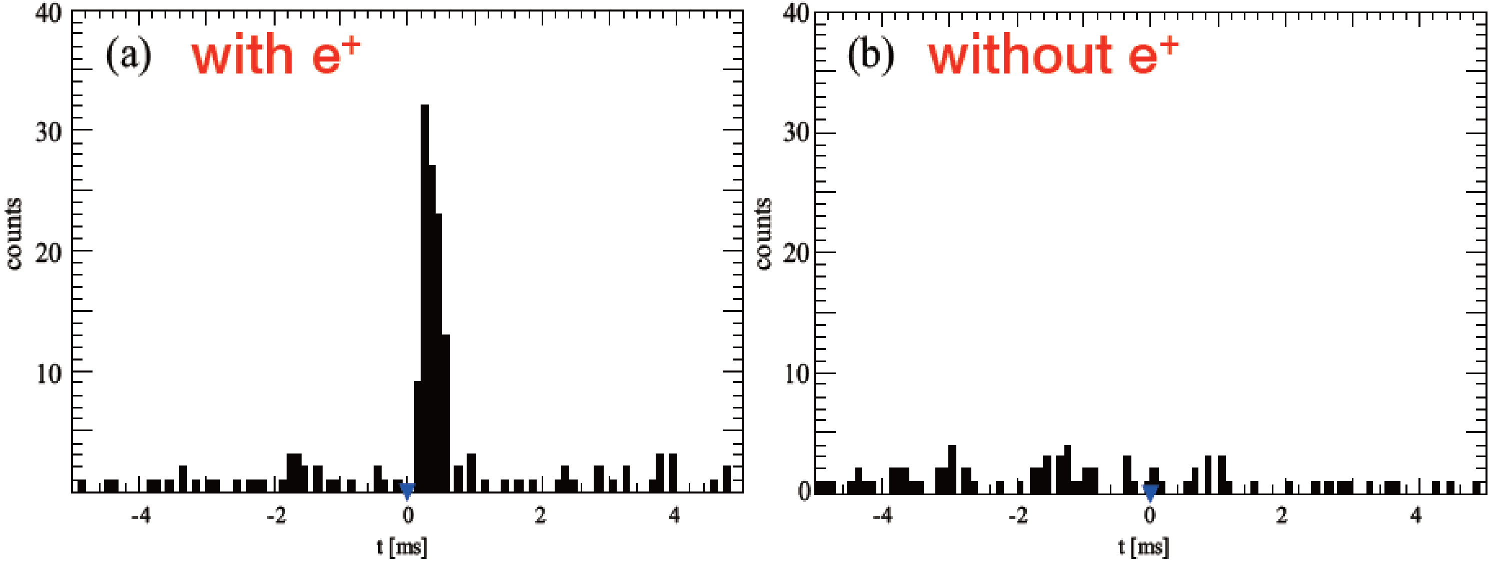
Typically 70 antihydrogen counts detected per mixing cycle.

Implies 7000 antihydrogens formed.

Antihydrogen in *n=45-50* Rydberg state.

$\bar{H}$ detection by field ionization in the trap

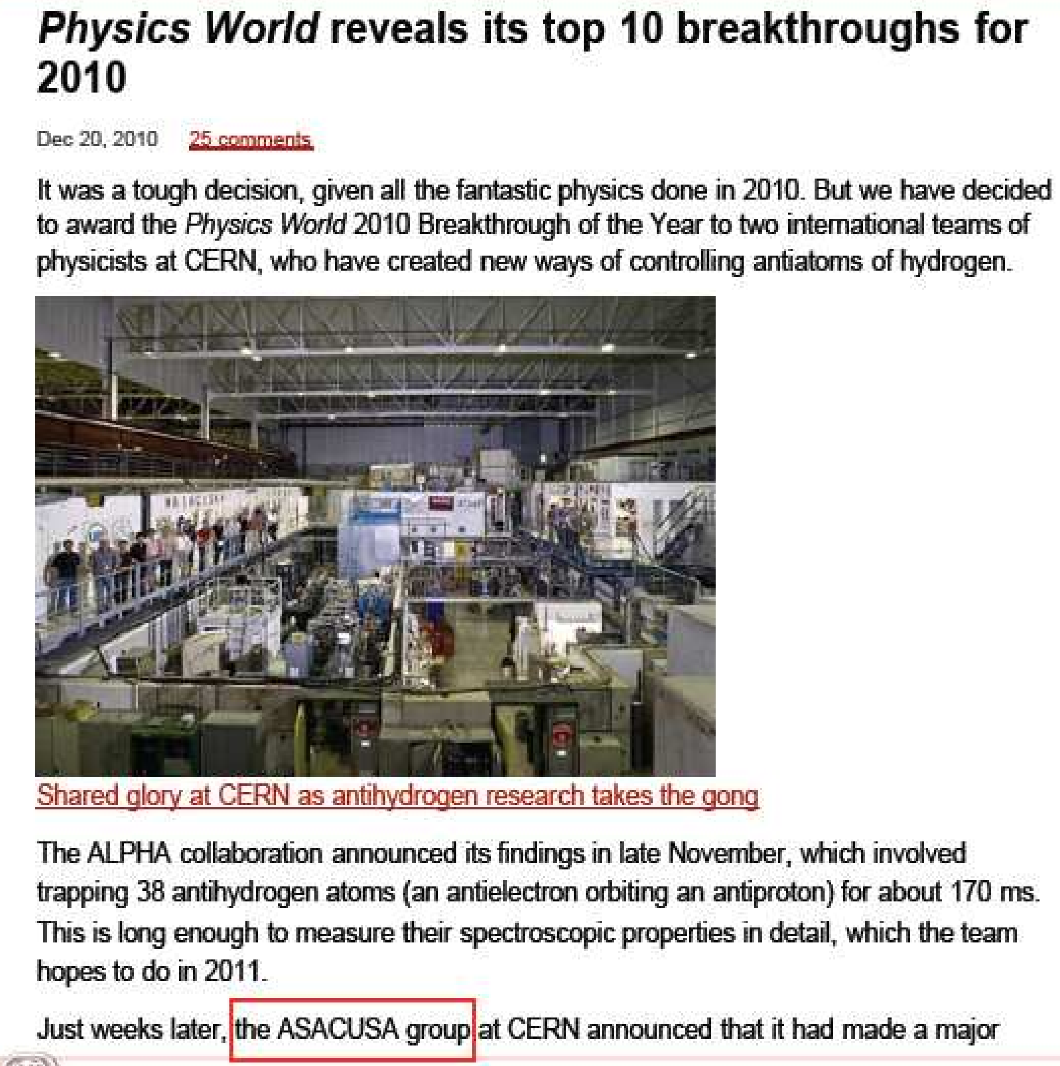
3×10^5 $\bar{p}$s
4×10^6 e^+s
50 $\bar{H}$s field ionized
(5000 Rydberg $\bar{H}$s)



We got this far already in 2010

In 2011, we tried to extract $\bar{H}$s from the trap

$\bar{H}$ production in the “cusp” trap



Physics World reveals its top 10 breakthroughs for 2010

Dec 20, 2010 25 comments

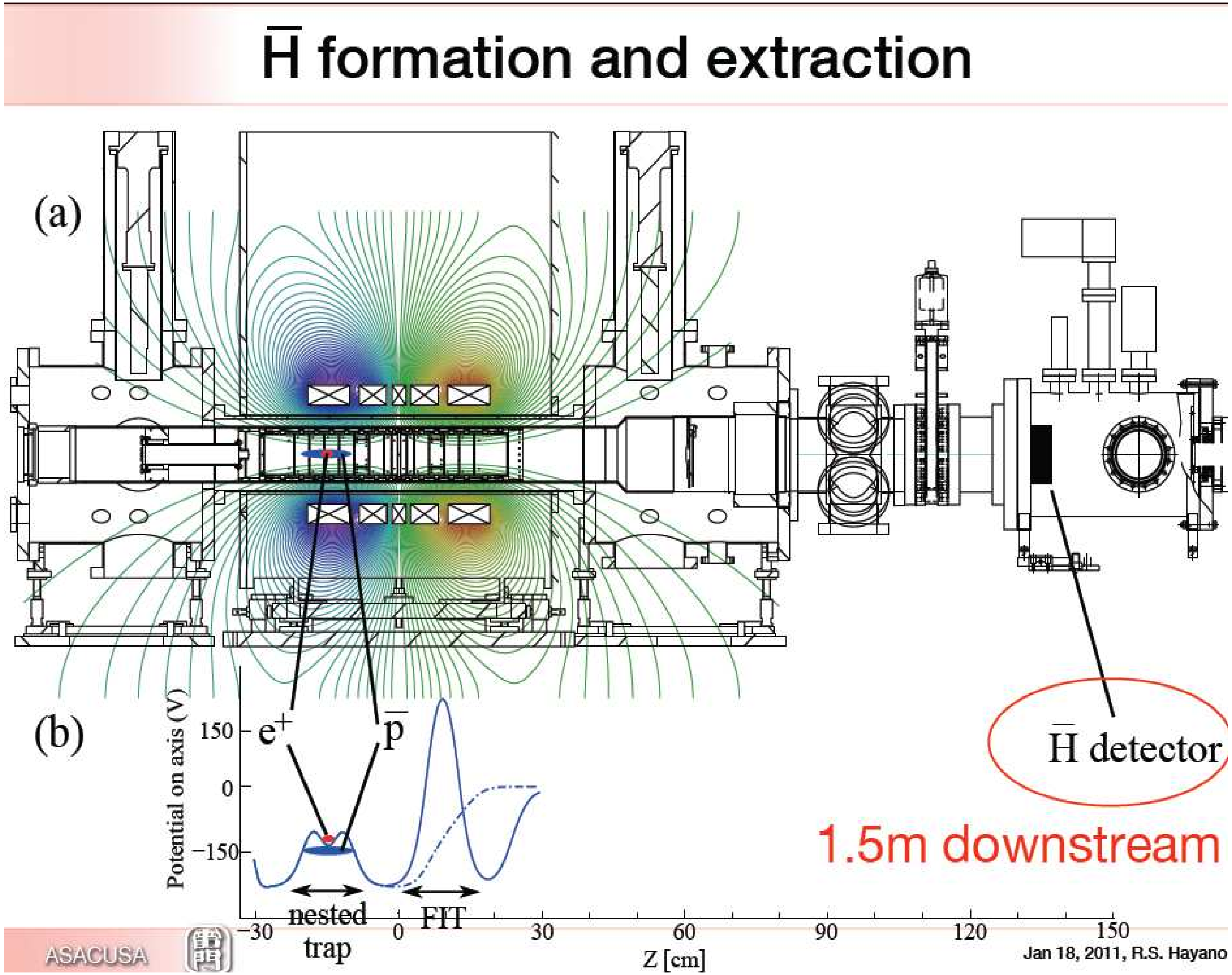
It was a tough decision, given all the fantastic physics done in 2010. But we have decided to award the *Physics World* 2010 Breakthrough of the Year to two international teams of physicists at CERN, who have created new ways of controlling antiatoms of hydrogen.

Shared glory at CERN as antihydrogen research takes the gong

The ALPHA collaboration announced its findings in late November, which involved trapping 38 antihydrogen atoms (an antielectron orbiting an antiproton) for about 170 ms. This is long enough to measure their spectroscopic properties in detail, which the team hopes to do in 2011.

Just weeks later, the ASACUSA group at CERN announced that it had made a major

Enomoto et al. (BS Group) PRL 2010

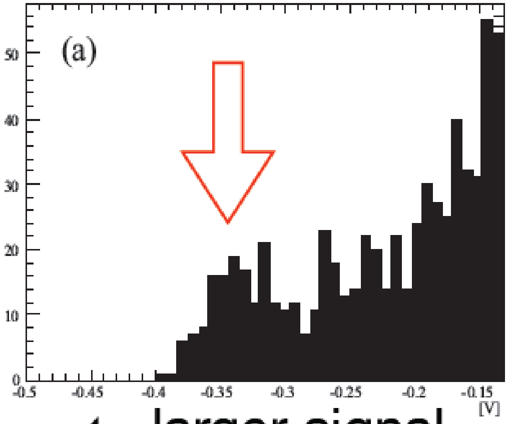


$\bar{H}$ formation and extraction

1.5m downstream

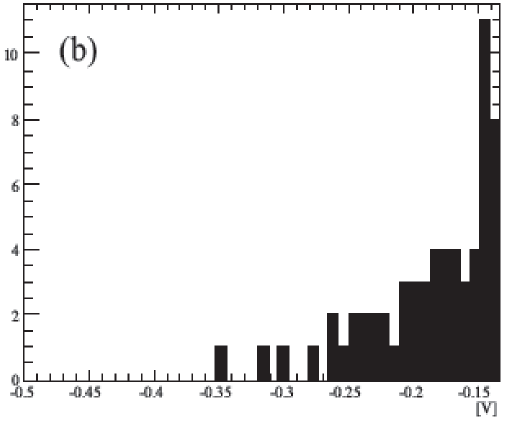
Jan 18, 2011, R.S. Hayano

MCP detector response to $\bar{p}$



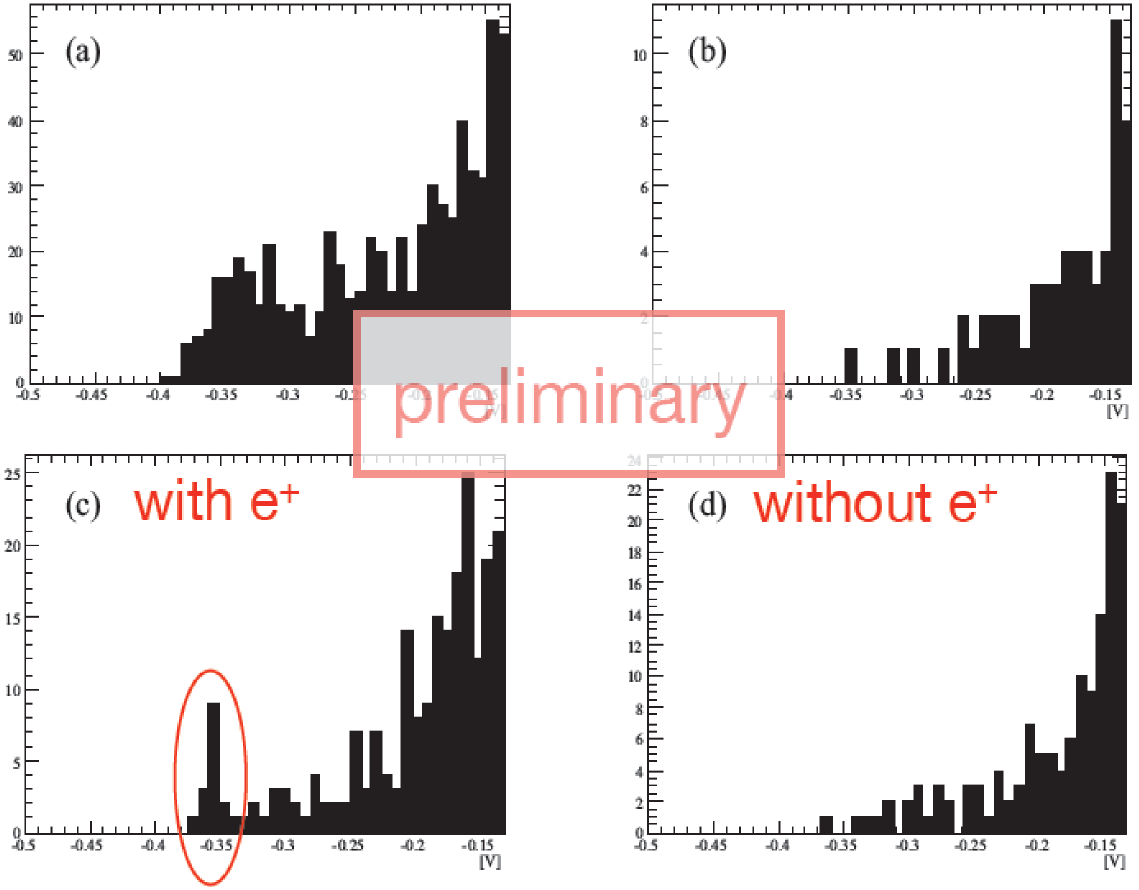
← larger signal

150 eV $\bar{p}$ hit the MCP



MCP biased by -300 V
to repel $\bar{p}$s

MCP detector pulse height w/wo e^+



~26 $\bar{H}$ candidate events (51 mix)

3. Collision experiments

σ_{ann} ($\bar{p}A$) @ low-Energies ($p<100$ MeV/c)

Asacusa Collaboration is (also) studing

σ_{ann} ($\bar{p}$A) @ low-Energies (p<100 MeV/c)

by exploiting the low energy $\bar{p}$ beams (AD & RFQD)

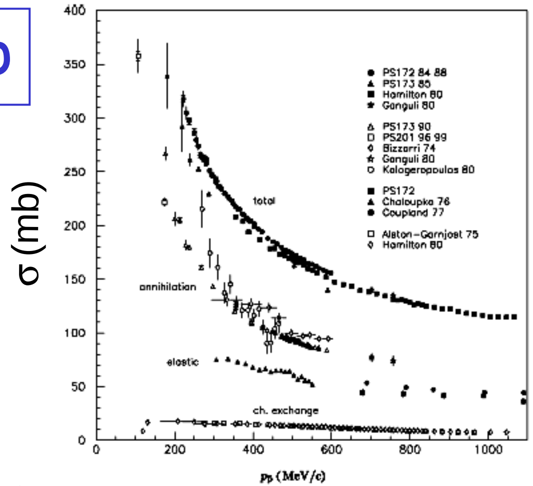
Data useful for:

- studing the Nuclear Force (investigating: the $\bar{N}$-nucleus potential parameters, the processes of nuclear matter excitation following the annihilation,…)
- fundamental cosmology (T>70 keV-annihilation before nucleosynthesis, T<3 keV after nucleosynthesis)

Existing data on $\sigma(\bar{N}N)$ and $\sigma(\bar{N}A)$ @ intermediate energies

p in (200MeV/c, 1000MeV/c)

$\bar{p}p$

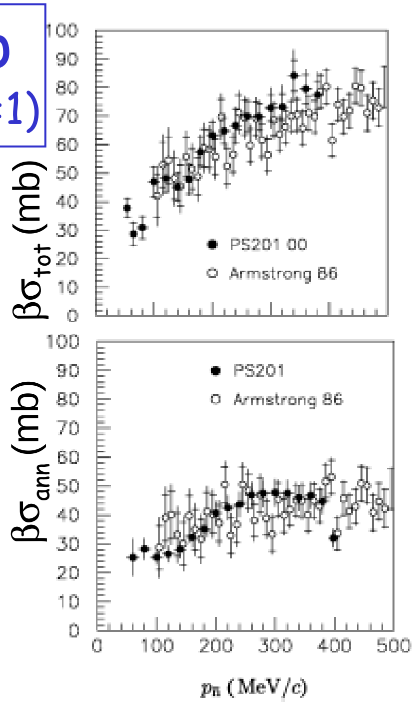


- σ large (Black D. -> σ=120 mb)
- $\sigma_{ann} > \sigma_{el}$ (Black D. -> $\sigma_{ann} = \sigma_{el}$)

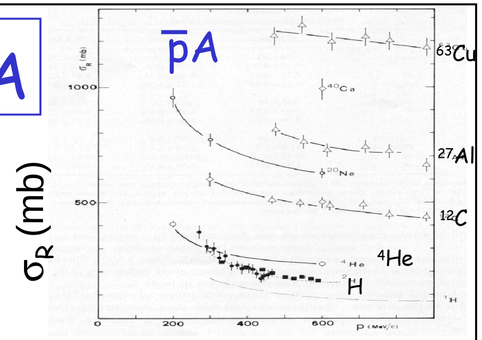
  due to: 1) long range interaction
  2) strong absorption
- Potential models reproduce the data if the annihilation potential is strong up to 1 fm

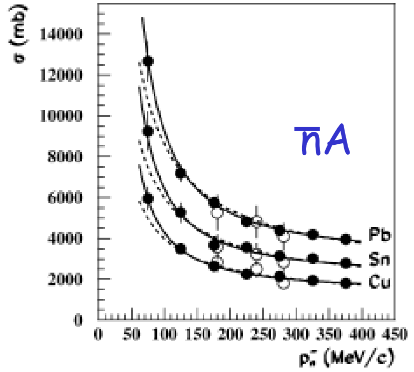
$\bar{n}p$

(I=1)



$\bar{N}A$





$\sigma_{ann}(\bar{n}p) \approx \sigma_{ann}(\bar{p}p)$

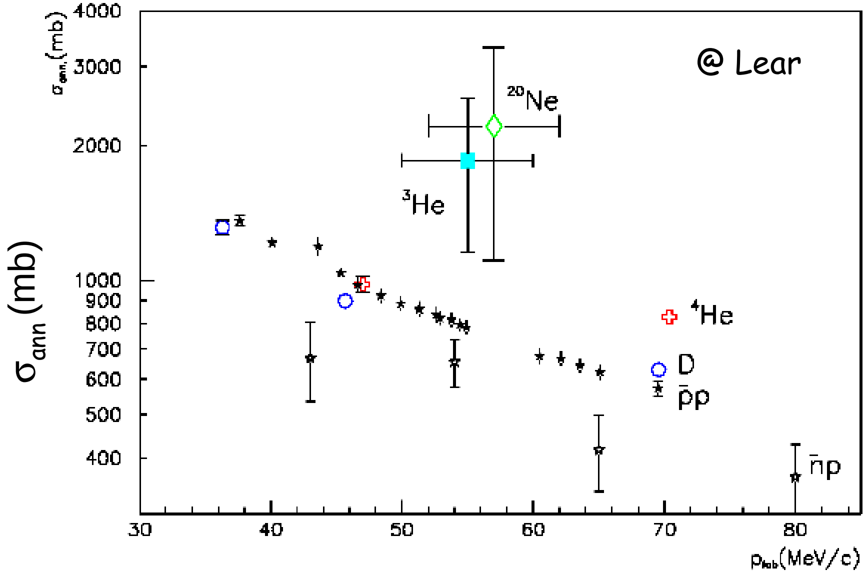
⇔ annihilation is Isospin independent

$$\sigma_{ann} \approx \frac{1}{p}$$ (as predicted)

$\sigma_{ann} \approx A^{2/3}$(as predicted)

Existing data on $\sigma(\bar{N}N)$ and $\sigma(\bar{N}A)$ @ low energies

p <100MeV/c



- $\sigma_{ann}(\bar{p}p) \approx \dfrac{1}{p^2}$

  due to: Coulomb attraction

- $\sigma_{ann}(\bar{n}p) \approx 0.7\ \sigma_{ann}(\bar{p}p)$

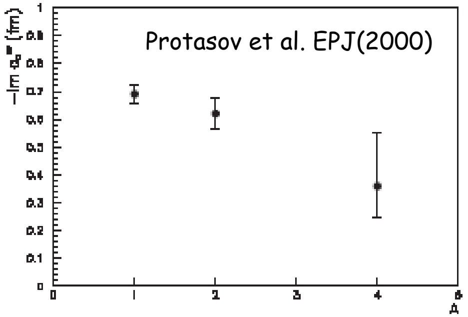
- $\sigma_{ann}(\bar{n}A) \approx A^{2/3}$ (at least for A>12)

- $\sigma_{ann}(\bar{p}A)$ does not increase with A as expected

naive expectation:assuming $|\mathrm{Im}\, a_0| \approx R \approx 1.3A^{1/3}$

$$\Rightarrow \sigma_{ann}(\bar{p}A) \div \left(\frac{Z}{\beta}\right)\frac{A^{1/3}}{p}$$

Imaginary part of S-wave scattering length



Decreases with A (in agreement with atomic data and against the naive picture where it should increases with nuclear size)

The scenario needs clarifications

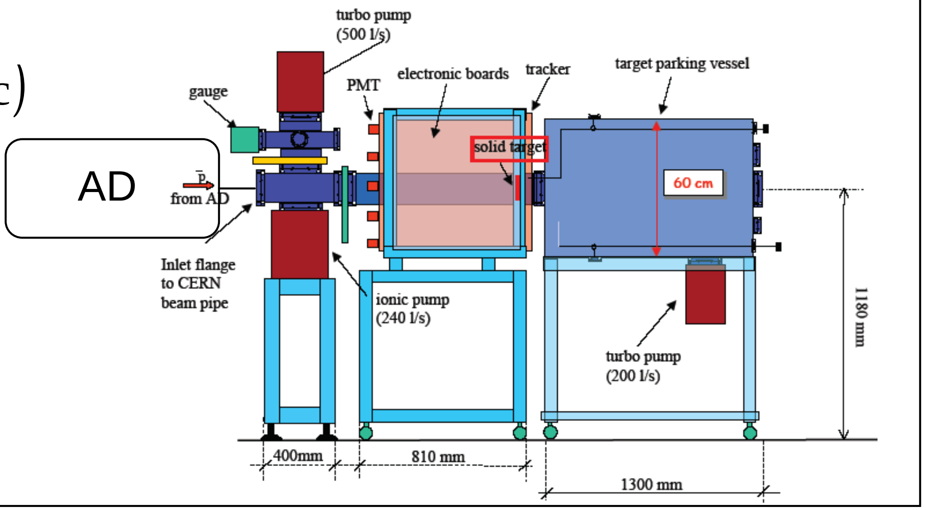
Experimental set-up

ASACUSA for σ_{ann}

2 measurements:

(1) $E_{\bar{p}} = 5.3\,\mathrm{MeV}$ $(p_{\bar{p}} = 100\,\mathrm{MeV/c})$

done !

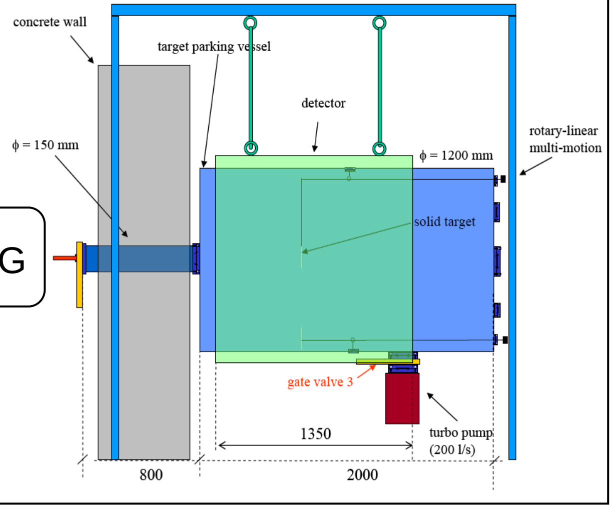


(2) $E_{\bar{p}} \approx 100\,\mathrm{keV}$ $(p_{\bar{p}} \approx 15\,\mathrm{MeV/c})$

in progress

AD — RFQD — DOG-LEG

CERN | ASACUSA

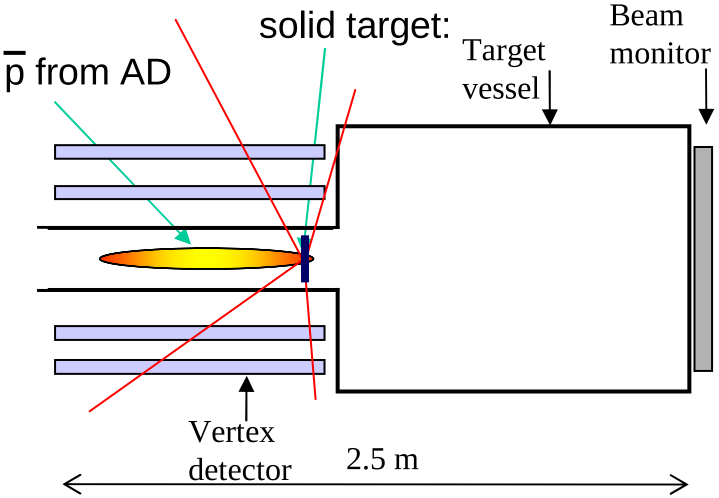


General set-up for E=5 MeV

Main problem: antiproton beam from AD is pulsed (10^7 pbars in 100 ns)
⇔ even a small fraction of annihilations could saturate the acquisition

Solution:

- accurate settings of AD beam: multiple extraction (10^6 in 40ns, 6 times in some seconds), no halo, …
- thin solid targets (only few events per spill)
- vertex detector (to select the annihilations in the target)
- strong reduction of contaminations:
  - target vessel directly connected with AD (no material along the beam before the target)
  - target close to the end of the detector & the end part of the target vessel is very large (to reduce Rutherford scattering background)
  - very long target vessel (to reduce contaminations from the beam annihilations)
- very fast changing of the target

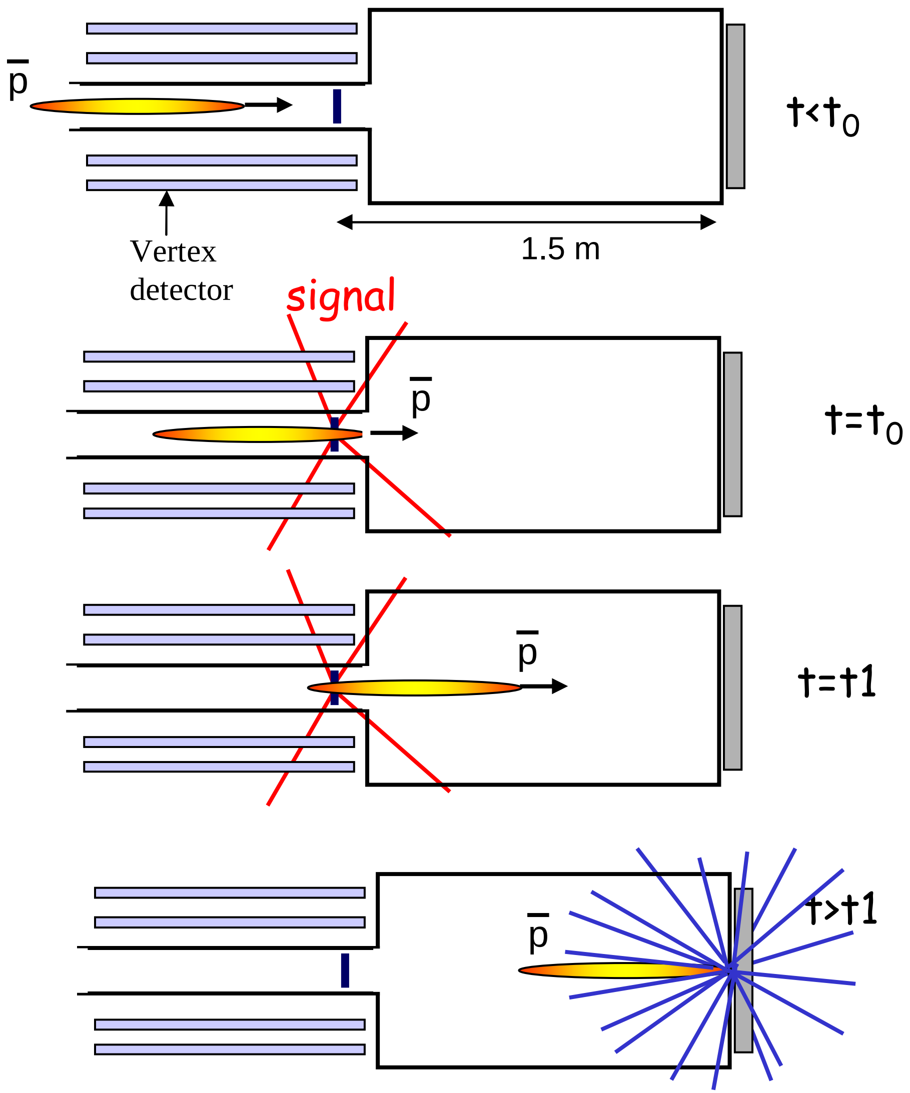


$$\sigma_{ann}(\bar{p}A) \div \frac{N_{events}}{N_{beam}}$$

counted by Vertex detector

counted by Beam monitor &/or by Rutherford wall annihilations

Strategy of the measurement for E=5 MeV



Acquisition in (t_0 , t_1)

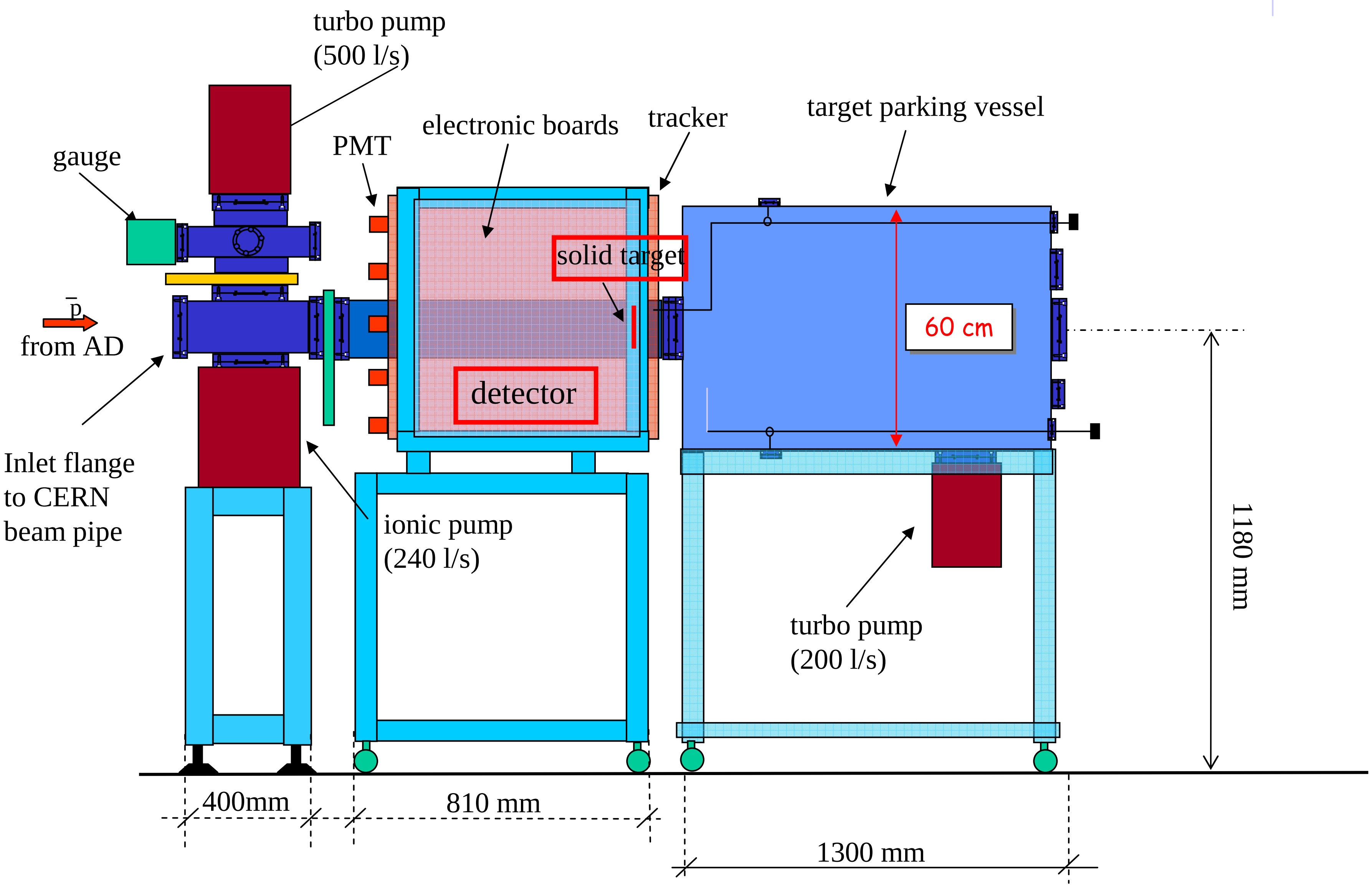
t_{1-} t_0=40ns

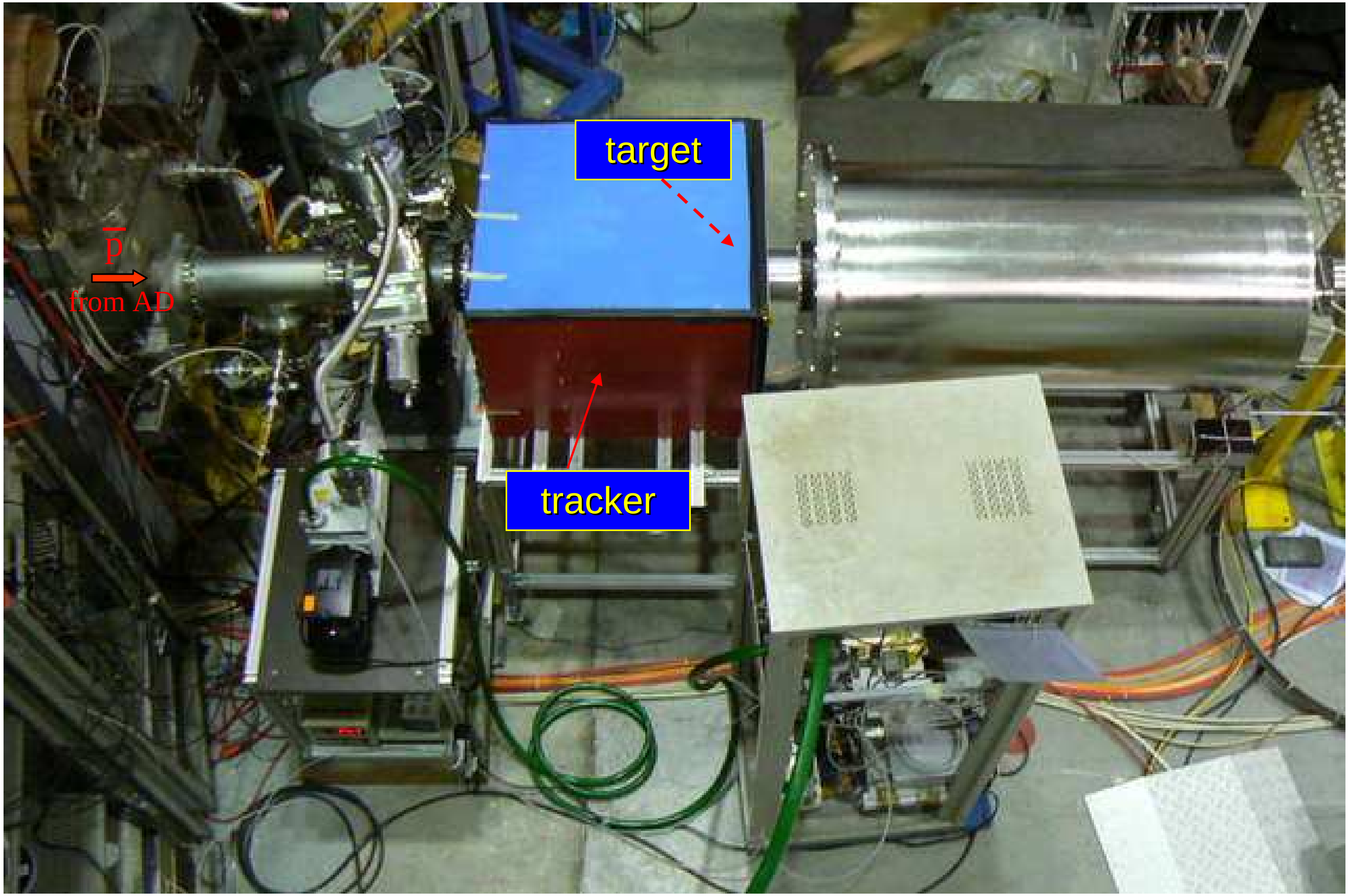
~ few vertices reconstructed per spill (in 40 ns)

Signal and background are well separated in time thanks to:

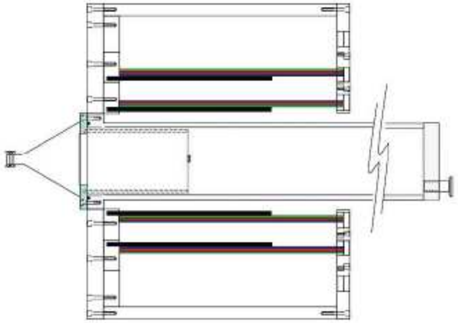
- long target vessel
- short spill lenght

Set-up for E=5 MeV

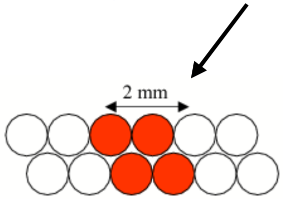


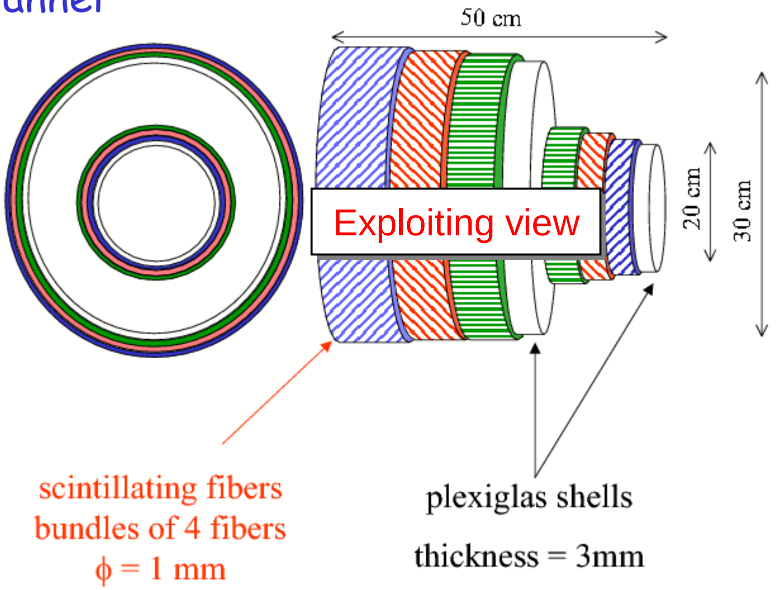

target
tracker
$\bar{p}$
from AD

The Detector

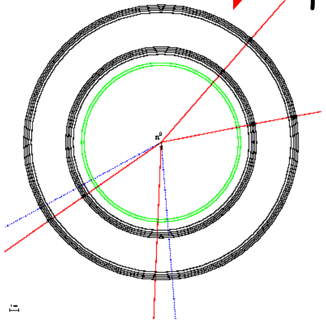


- 2 cylindrical shells around the target
  - 3 double-layers of 1 mm scintillating fibers (1 longitudinal, 2 stereo @ 20 °)
    - 4 neighbouring fibers form a unique readout channel





- Reconstruct (and count) annihilation vertices by tracking the produced pions
  - ~ few vertices per spill (~ 40 ns)
    - Requisites:
      - Good time and spatial resolutions
      - High efficiency



Hardware & Software

Hardware

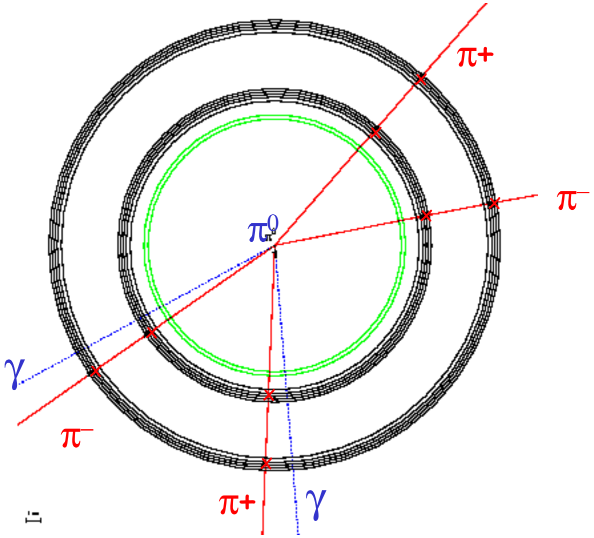
- 10 km of scintillating fibers (Bicron BCF-101, multicladding+extra-mural absorber)

- 2500 channels (4 fibers per channel, 42 Multi Anode 64 channels photomultipliers Hamamatsu H7546B, readout boards with FE-EL Asic by Ideas + FPGA+VME acquisition)

Software

- Monte Carlo simulation program based on Geant package

- Vertex reconstruction program based on a combinatorial algorithm (vertex corresponds to the point of minimal distance between the straight lines passing though the hits of the detector)



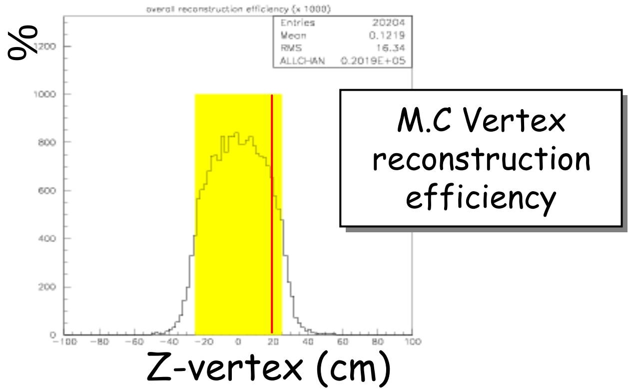
The Detector Performances

Test on prototype with e^- beam @ L.N.F. and on the whole detector with cosmics:

- time resolution ~ few ns
- hit detection efficiency on a layer ~ 99% (95%)

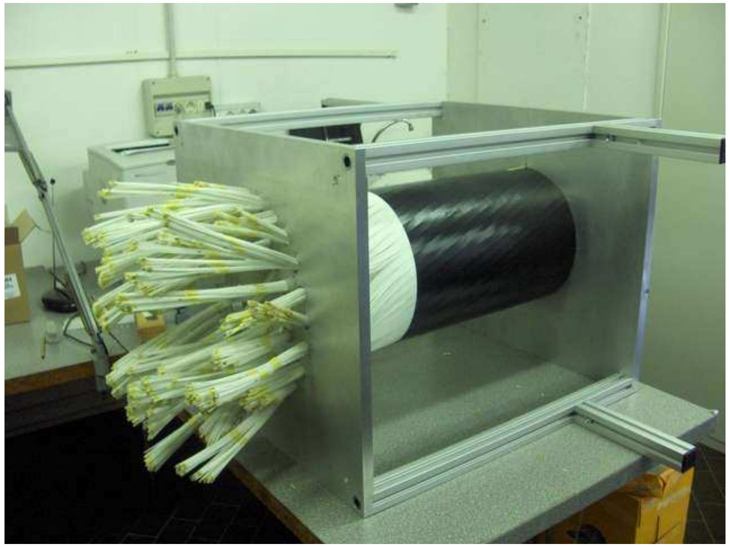
Monte Carlo simulations:

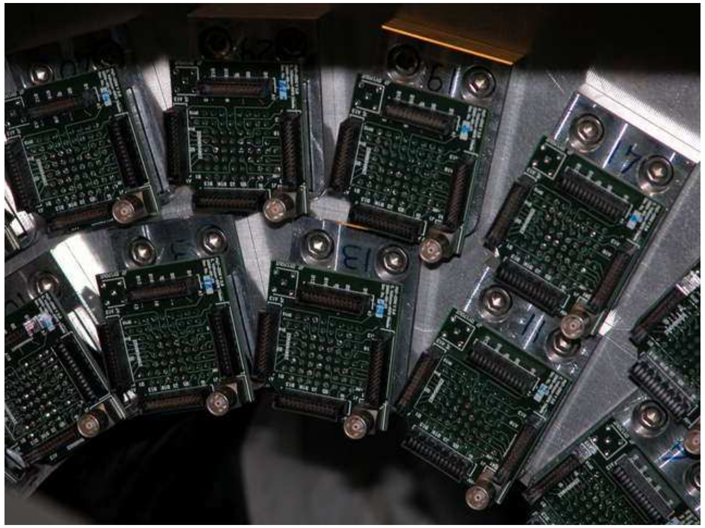
- vertex resolution: $\sigma_{x,y}$ ~ 3mm, σ_z ~ 4mm
- vertex reconstruction efficiency ~ 60-80%

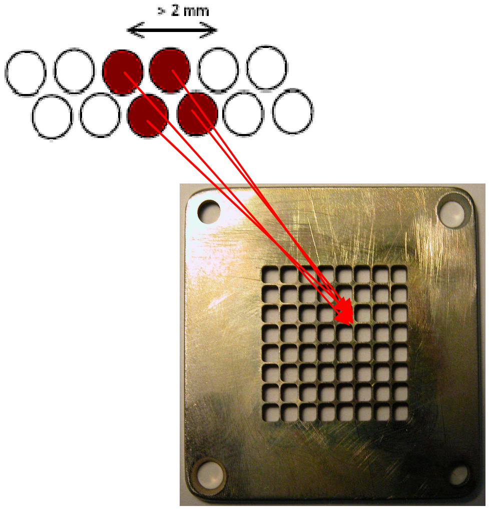


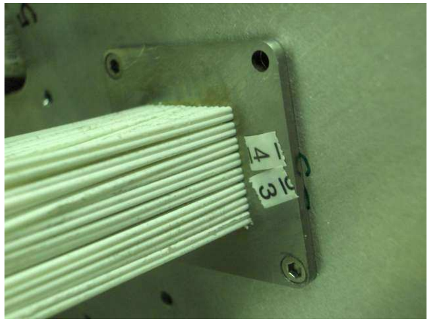
- low contaminations from Rutherford scattering (when the target is @ z=20cm)

The detector

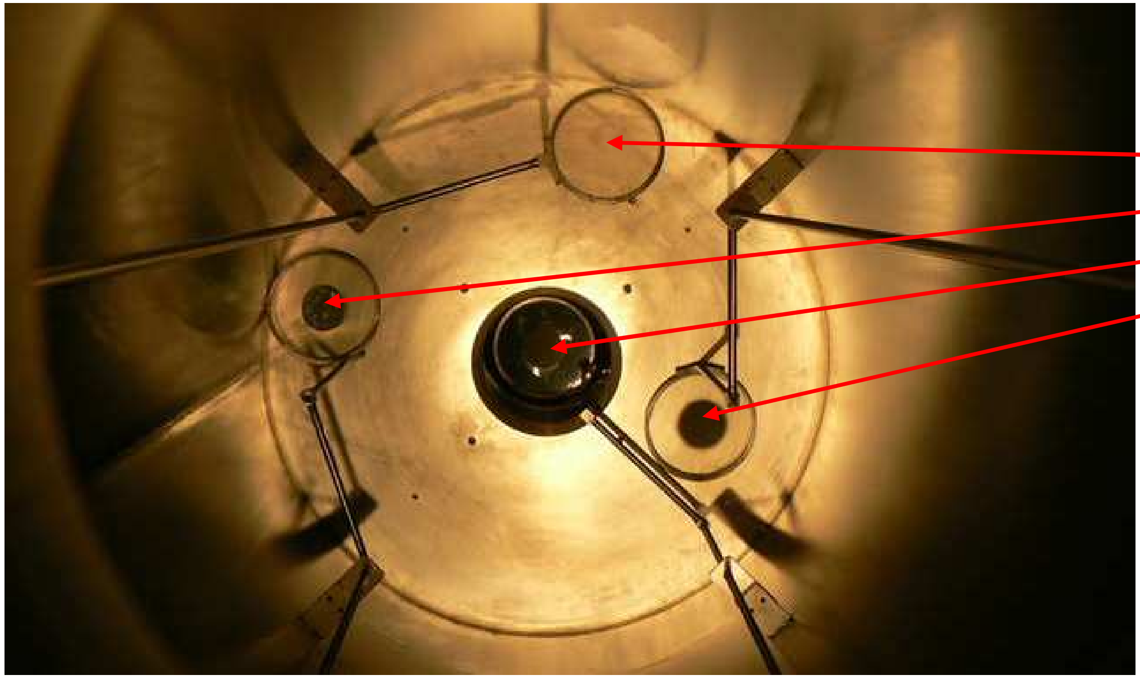








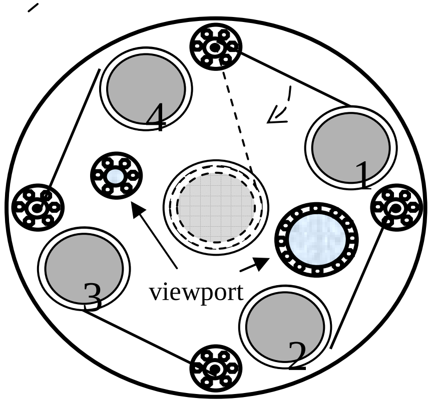
The targets

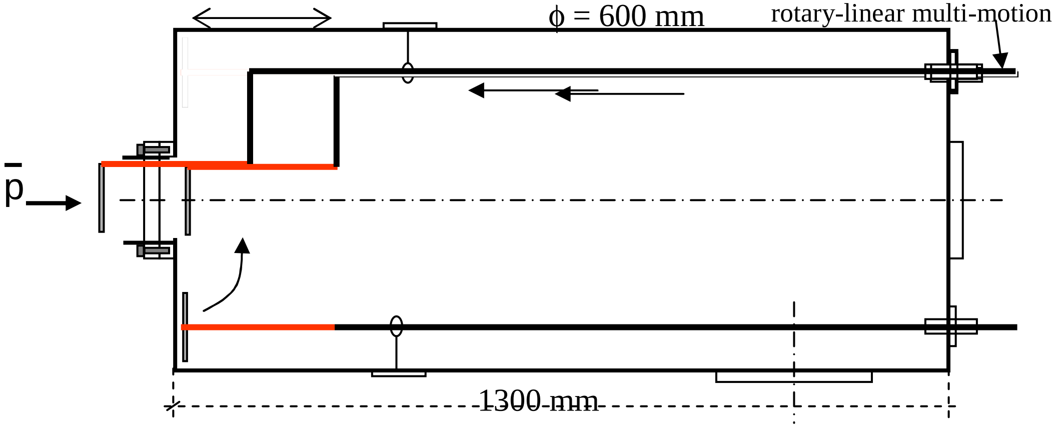


Targets:

- 860 nm of Mylar($C_{10}H_8O_4$);
- 240 nm Ni (Z=28,A=59) + support;
- 400 nm Sn (Z=50,A=119) + support;
- 115 nm Pt (Z=78,A=195) + support;

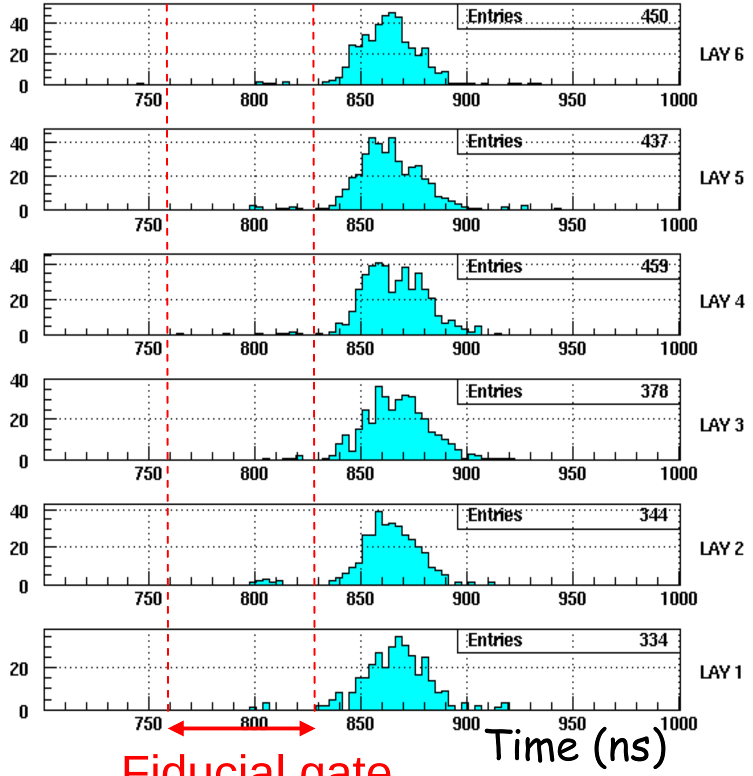
Support:
860 nm of Mylar



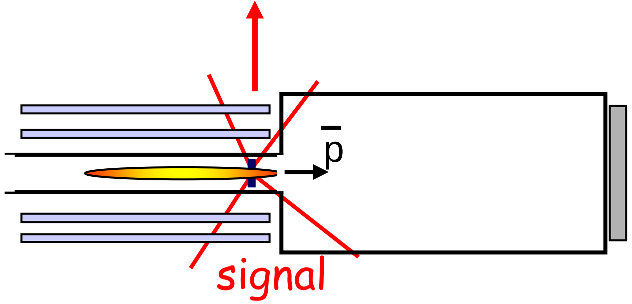


Events reconstruction

times on the 6 layers (one spill)



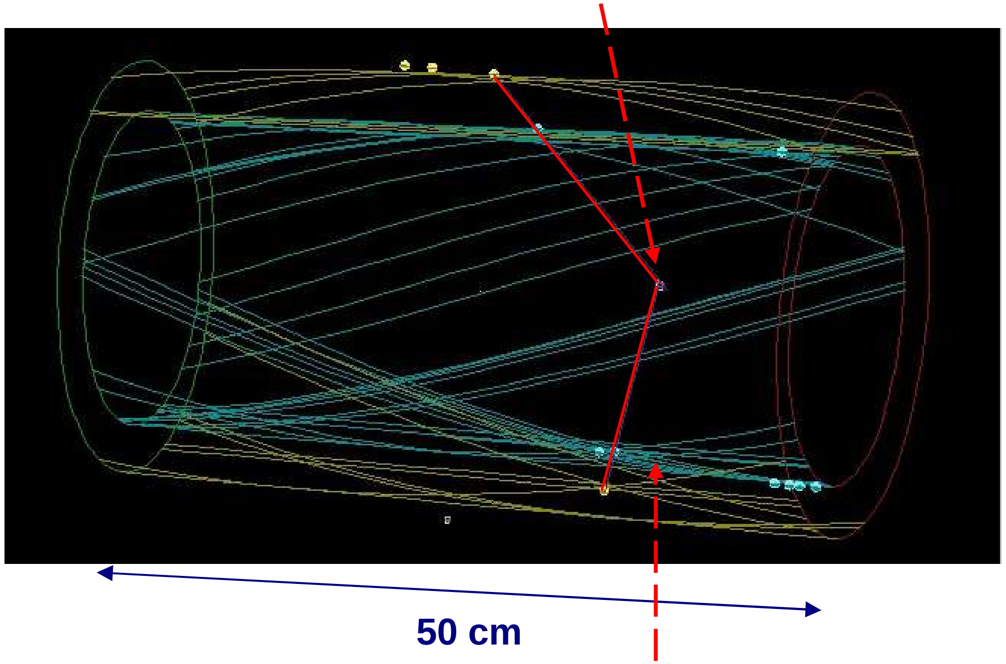
Fiducial gate



Typical event

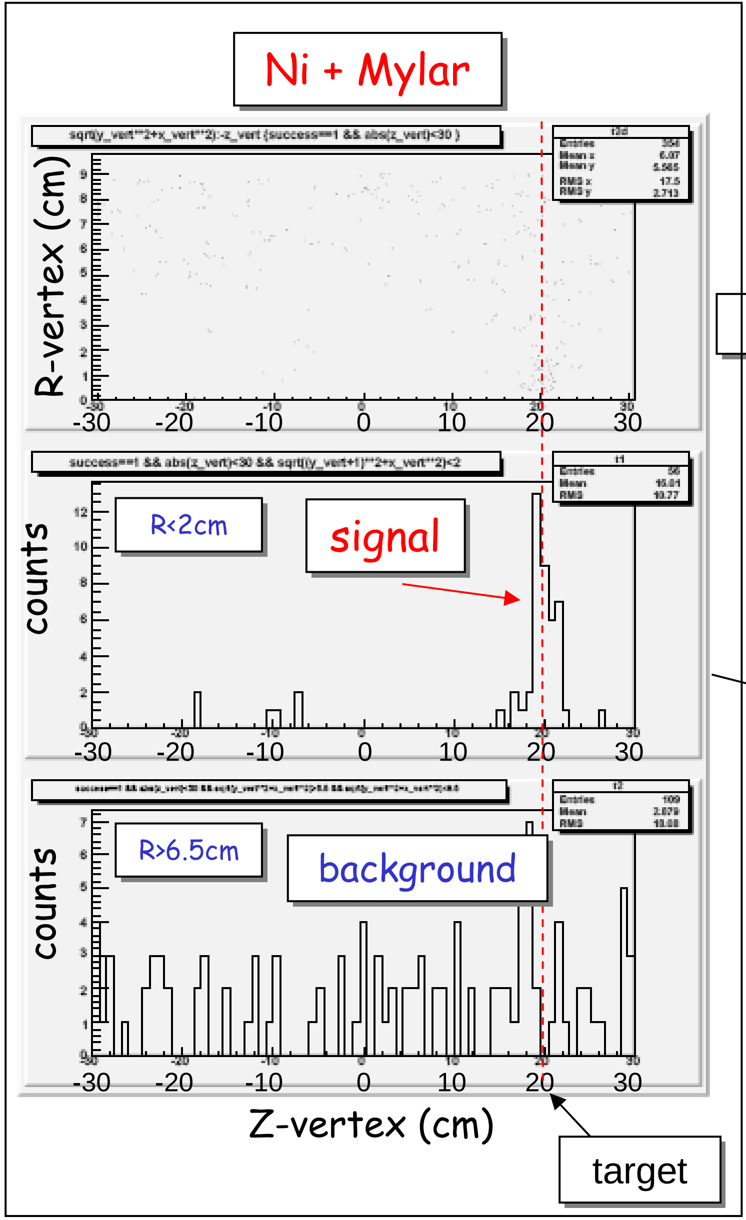
Reconstructed vertex

(in the fiducial time gate)

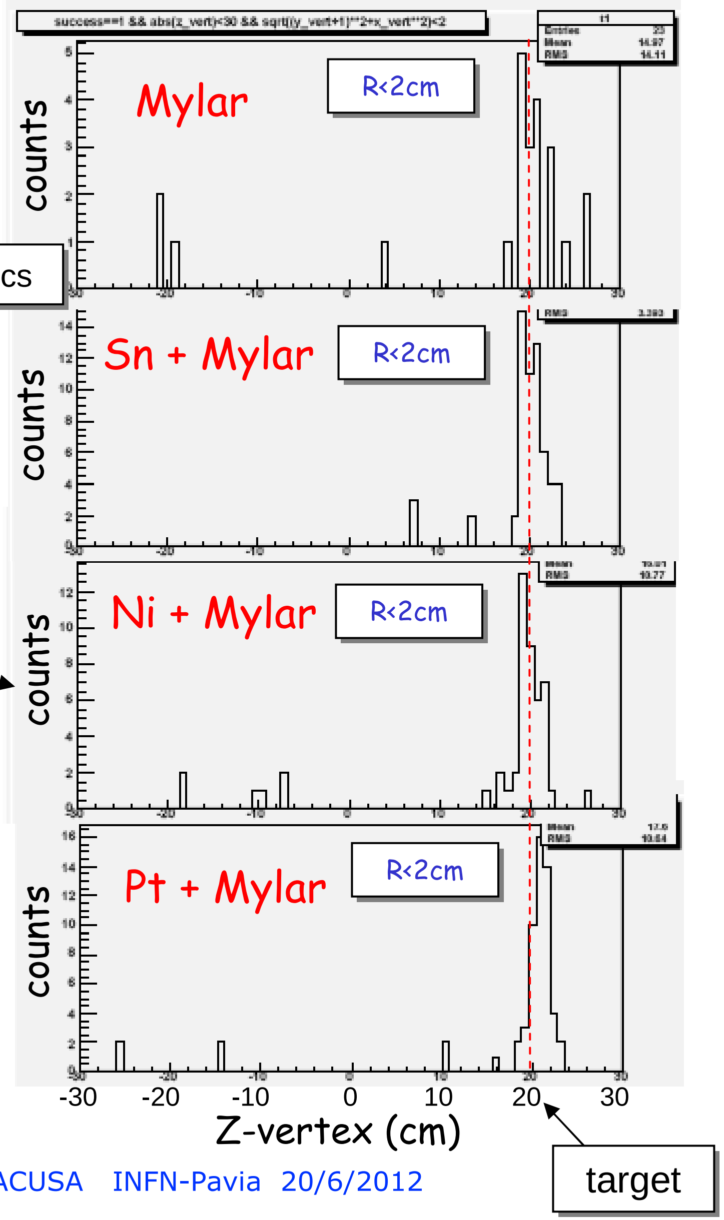


Ni (+Mylar) target
@ z = 12 cm

Vertices



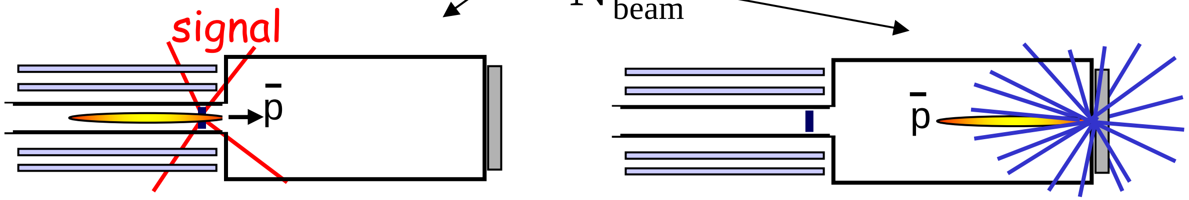
Partial statistics



Relative annihilation cross-section vs A

$E_{\bar p} = 5.3\,\mathrm{MeV}$

$$\sigma_{ann}(\bar p A) \div \frac{N_{events}}{N_{beam}}$$



N.B.: beam counter not-calibrated

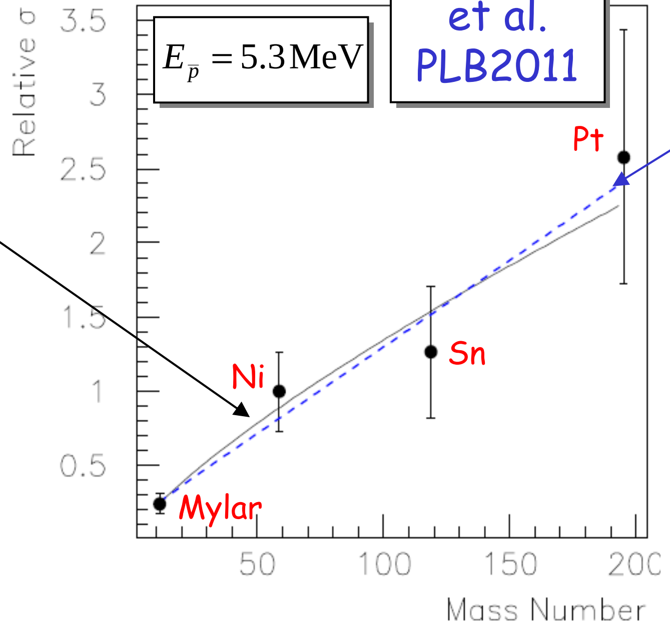
Best fit result with

$$\boxed{\sigma_{ann}(\bar p A) = cA^p}$$

gives

$$p = 0.51 \pm 0.24$$

$$c = 3.49 \pm 2.77$$



Bianconi et al. PLB2011

Best fit result with

$$\boxed{\sigma_{ann}(\bar p A) = c\,\sigma_{sc}}$$

$$\sigma_{sc} = \pi R^2\left(1 + \frac{1}{4\pi\varepsilon_0}\frac{Z e^2 (m+M)}{E R M}\right)$$

$$R = 1.84 + 1.12\,\mathrm{A}^{1/3}$$

$$Z = 0.5\,\mathrm{A}/(1 + 0.0075\,\mathrm{A}^{2/3})$$

See Batty, Friedman, Gal NPA 2001

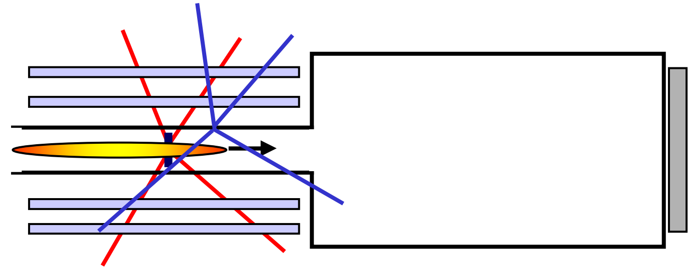
Semiclassical with Coulomb attraction in the strong-absorption limit

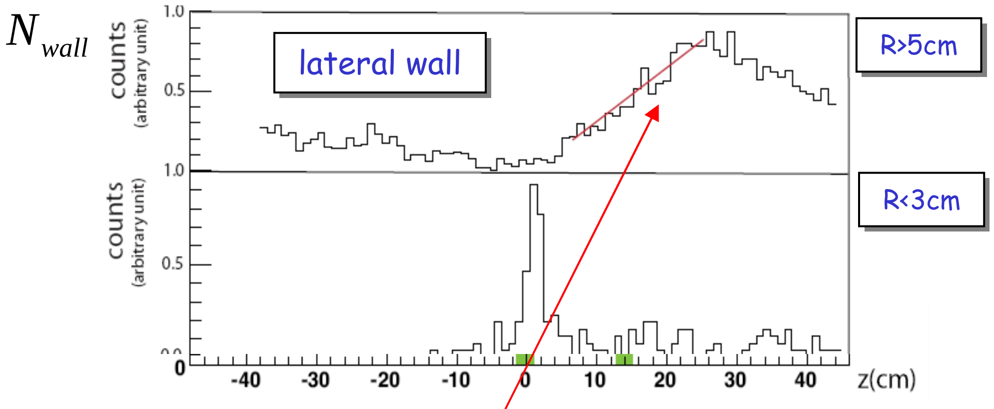
quite good agreement!

Absolute annihilation cross-section

$$E_{\bar{p}} = 5.3\,\mathrm{MeV}$$

Sn target positioned upstream to count Rutherford events





From
$$\frac{d\sigma_{Ruth}}{d\Omega} = \left(\frac{Ze^2}{16\pi\epsilon_0 E}\right)^2 \frac{1}{\sin^4\left(\frac{\theta}{2}\right)}$$

$$\frac{dN_{wall}}{dz} = N_{beam} 2\pi n l \left(\frac{Z\alpha\hbar c}{RE}\right)^2 z \qquad z \geq R/2$$

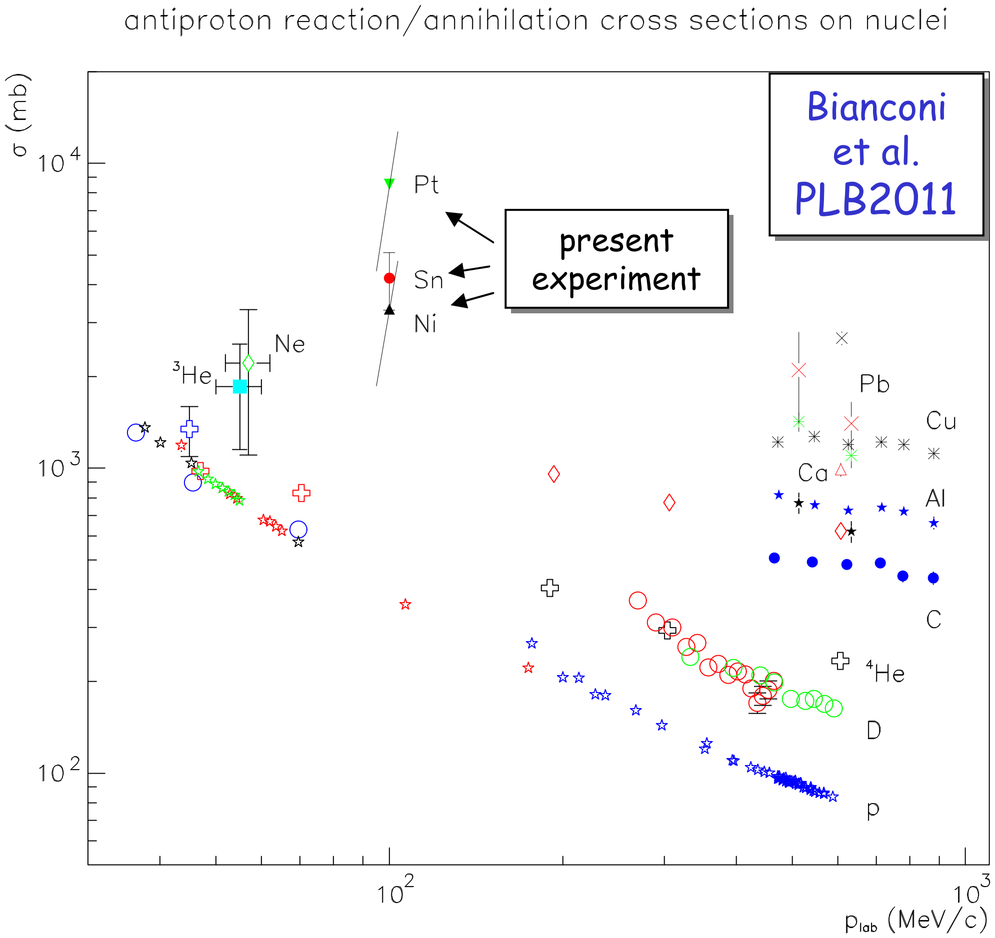
$$\Rightarrow \boxed{\sigma_{ann}(\mathrm{Sn}) = (4.2 \pm 0.9)\,\mathrm{barn}}$$

preliminary

then from relative σ_{ann}:

$$\sigma_{ann}(\mathrm{Ni}) = (3.3 \pm 1.5)\,\mathrm{barn}$$
$$\sigma_{ann}(\mathrm{Pt}) = (8.6 \pm 4.1)\,\mathrm{barn}$$

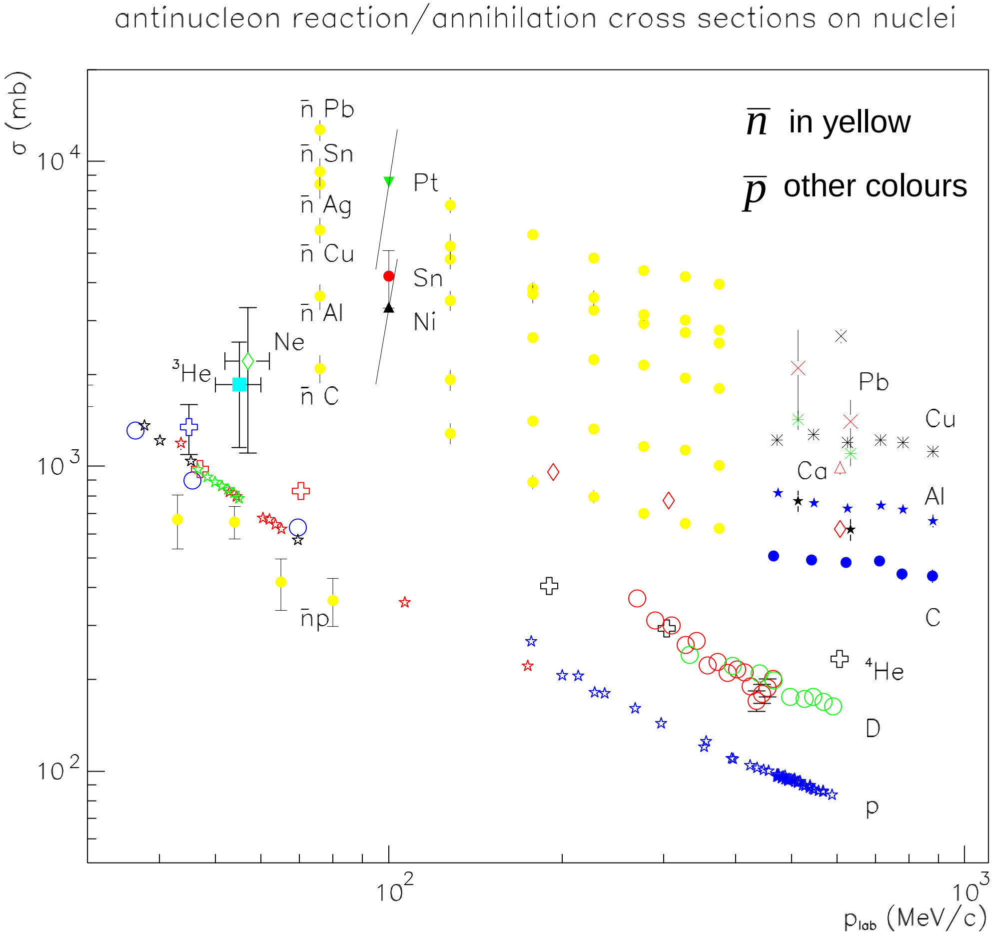
antiproton annihilation cross-section



ASACUSA data:

- the only ones with medium-heavy targets @ very low energies
- in agreement (1-sigma) with theoretical prediction σ_{sc} (Batty, Friedman, Gal NPA 2001)

antinucleon annihilation cross-section



@ p ≈ 100 MeV/c

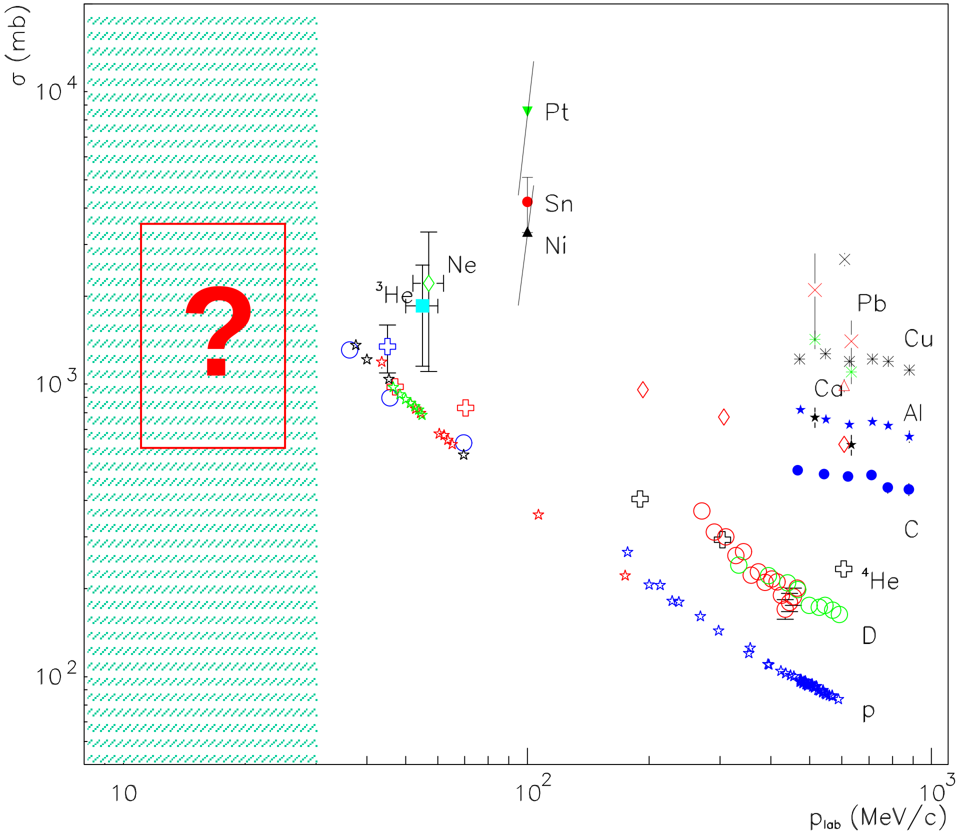
$$\sigma_{ann}(\bar{n}A) \approx \sigma_{ann}(\bar{p}A) \qquad A = 112$$

For very low energies (p<100 MeV/c)

$$\sigma_{ann}(\bar{n}p) \approx 0.7\,\sigma_{ann}(\bar{p}p)$$

σ_{ann} ($\bar{p}$-nucleus) @ 100 keV

antiproton reaction/annihilation cross sections on nuclei

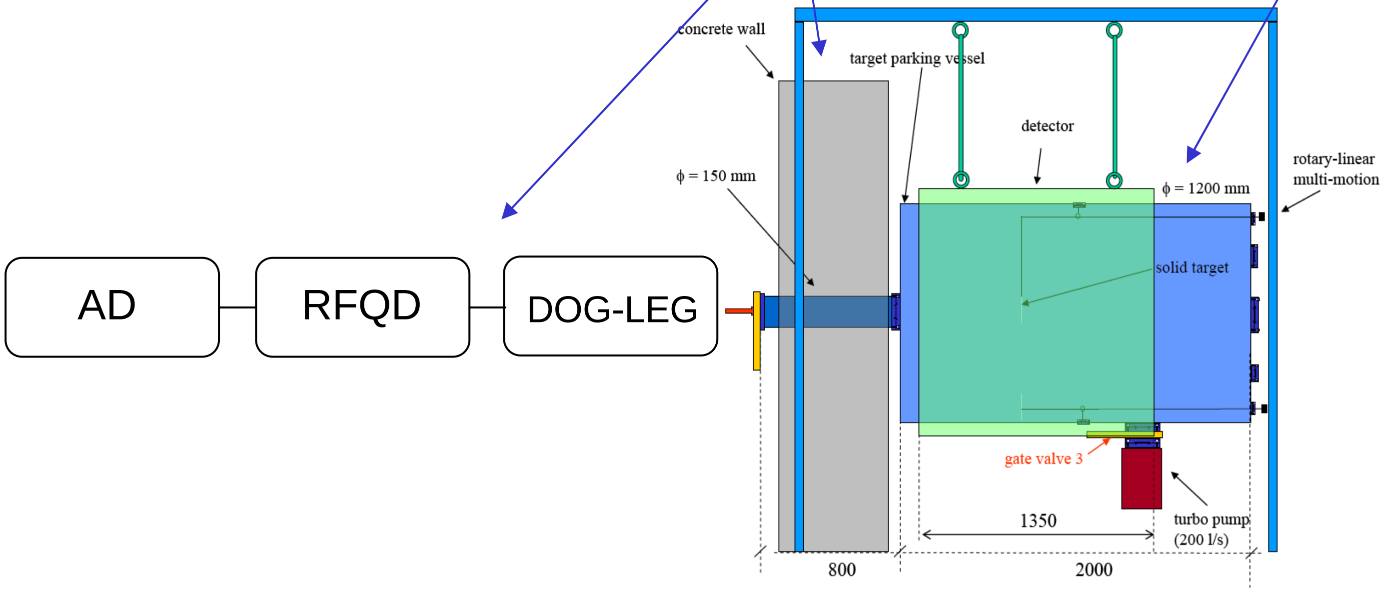


$$E_{\bar{p}} \approx 100\,\text{keV} \Leftrightarrow p_{\bar{p}} \approx 15\,\text{MeV/c}$$

Measurement @ 100 keV

More difficulties:

- further antiproton deceleration - E_{pbar}: 5 MeV->100keV (RFQD & DOG-LEG)
- more background
  - $\pi - \mu - e \quad (\tau = 2.2\mu s)$ from the dog-leg (concrete wall)
  - Rutherford annihilations on the target vessel $\sigma_{Ruth} \div \frac{1}{E_{\bar{p}}^2} \qquad \sigma_{ann} \div \frac{1}{E_{\bar{p}}}$ (huge target vessel)
- very thin targets needed



Why very thin targets ?

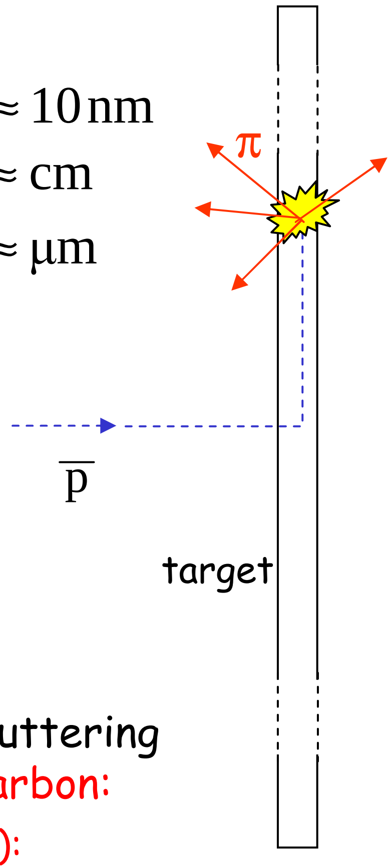
antiprotons scattered at $\approx 90^\circ$ will stop in the target

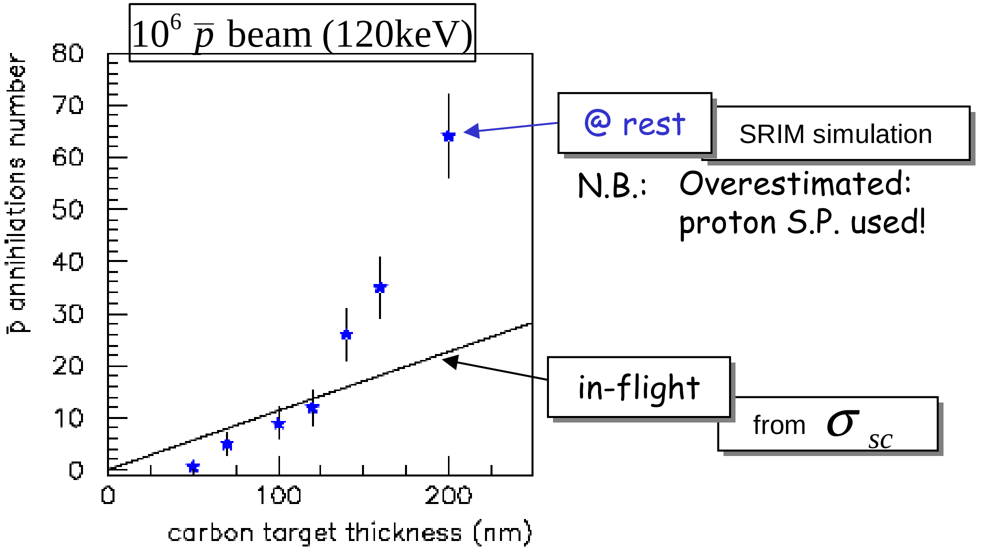
Scale dimensions:

Target thickness $\Delta x \approx 10\,\mathrm{nm}$

Target radius $\mathrm{D} \approx \mathrm{cm}$

antiprotons range $\mathrm{R} \approx \mu\mathrm{m}$
(@100keV)





N.B.: Overestimated: proton S.P. used!

For C target (50 nm) the expected pbars @ rest are much less than in-flight annihilations

⇒ very thin targets needed

Targets made by sputtering
metallic layers on carbon:

Targets (Φ= 5-8 cm):

50-70 nm of C;

some nm of metal (Ni, Sn, Pt, Pd) + support;

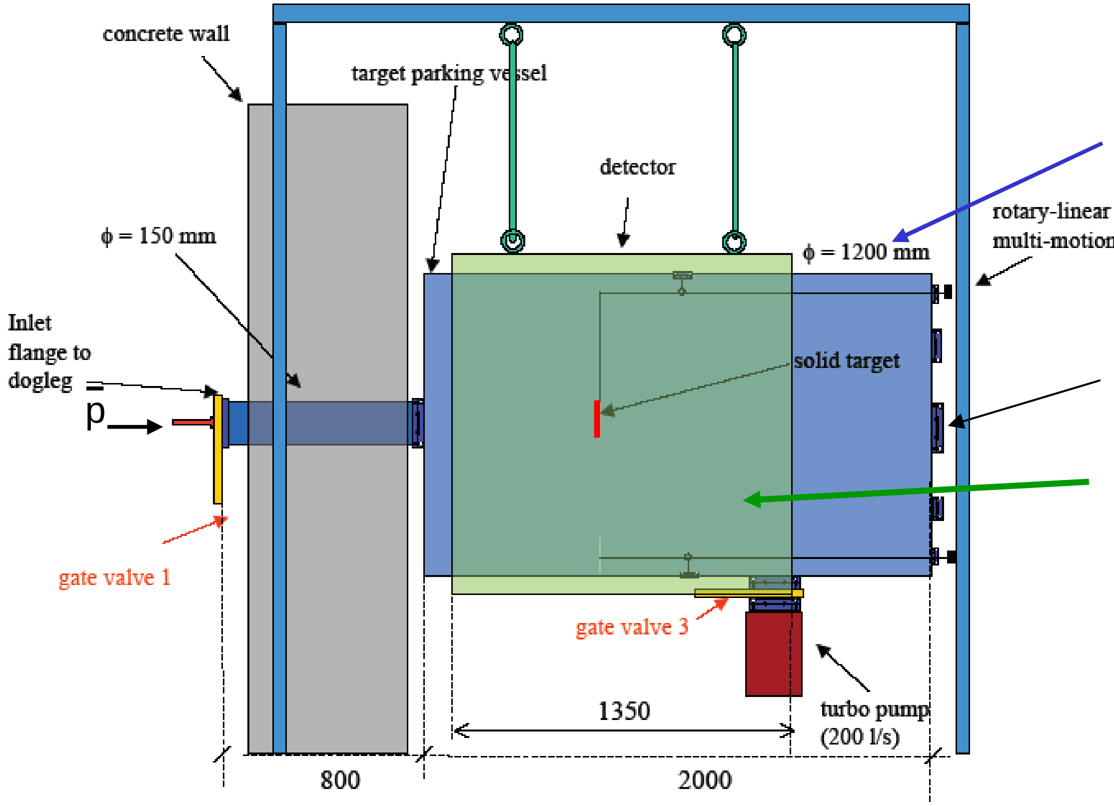
Support:
70 nm of C

Made @ TUM

Set-up for E=100 keV

In order to increase the signal and to reduce the background we need:

new experimental set-up



huge target vessel (L=2m,Φ=1.2m)

To separate signal on the target from other annihilations

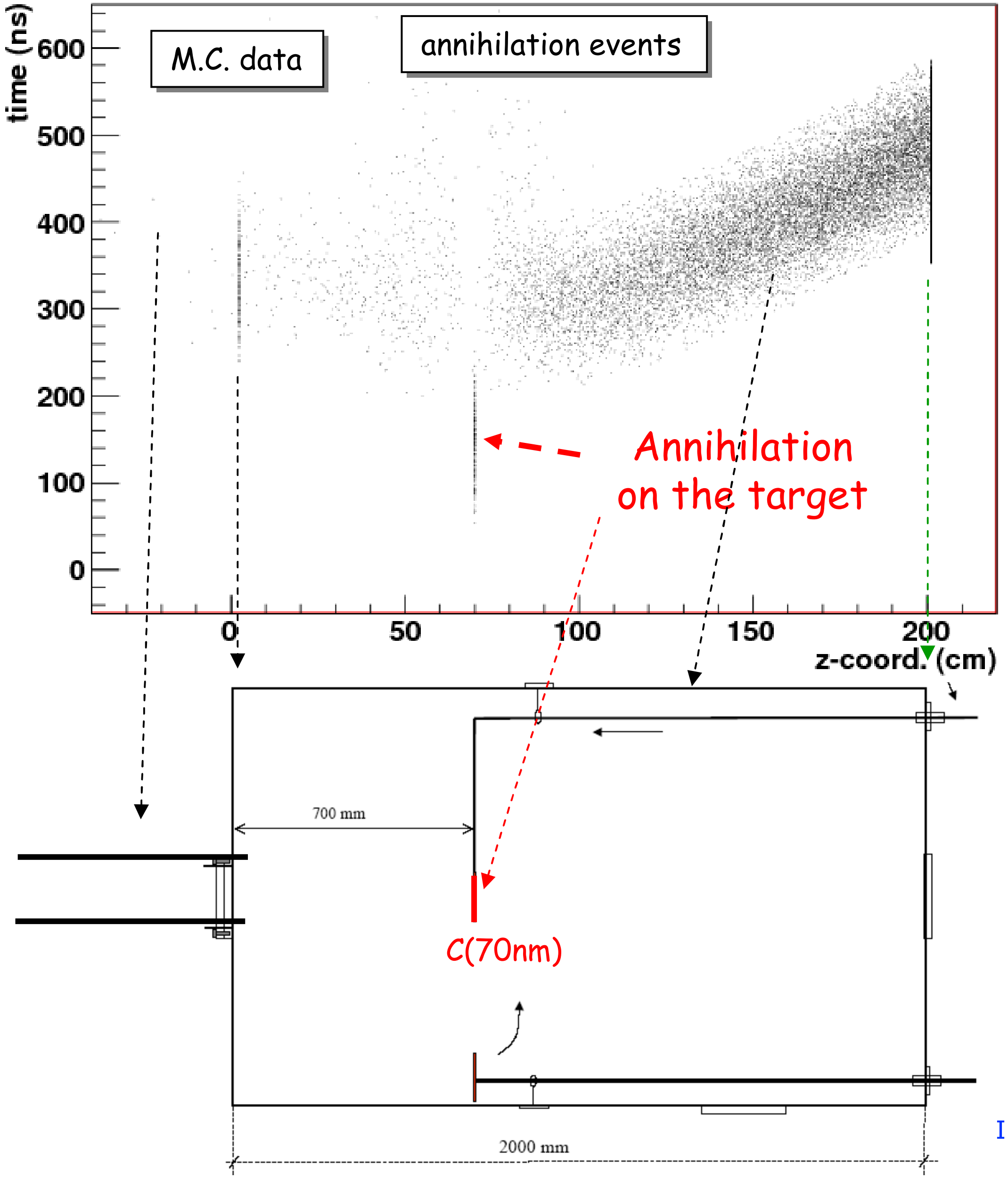
beam monitor

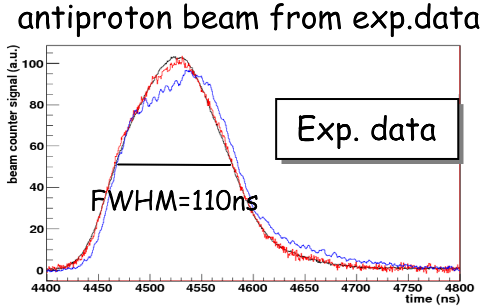
our "Hbar" detector

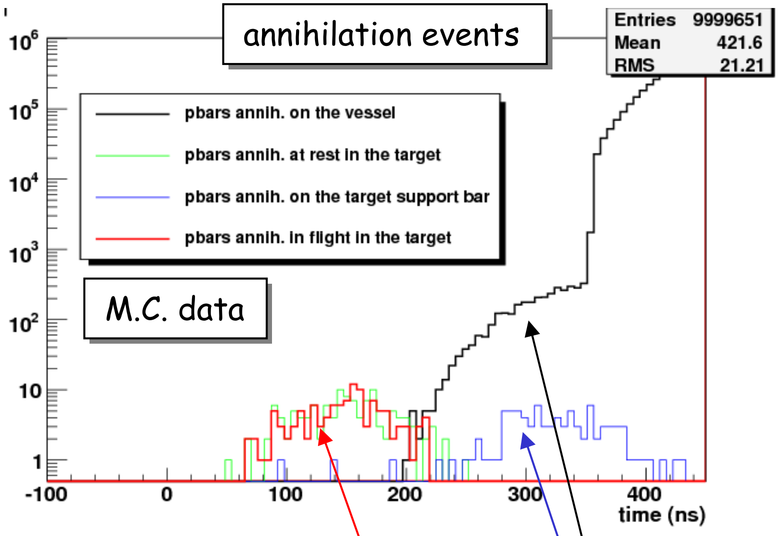
Usable as:

- Large scintillator (only time info with high rate)
- Vertex detector (time + spatial infos but low rate)

Monte Carlo simulations for 100 keV



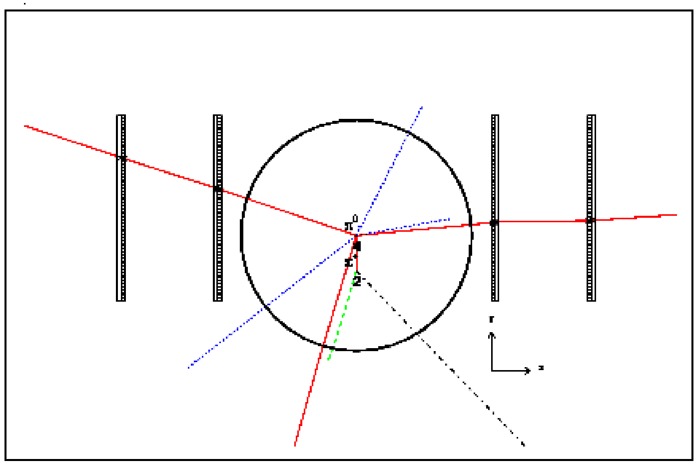


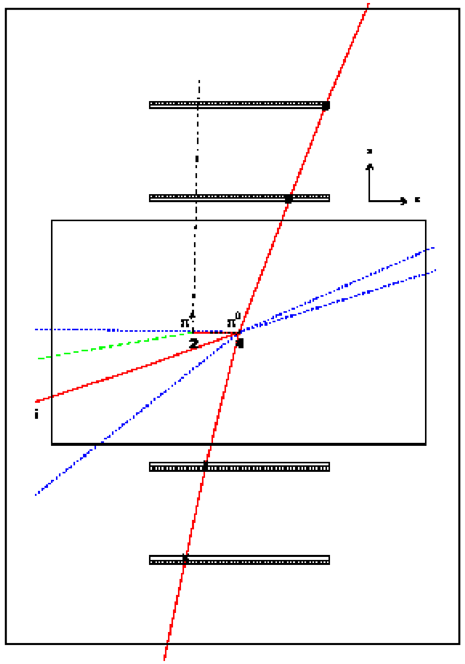


Clear separation
between signal and bckg

Monte Carlo simulations for 100 keV

just for example





For time info →

efficiency= 53%

← Large increase is possible with different configuration of the modules/bars

For space info →

Vertex reconstruction efficiency= 2%

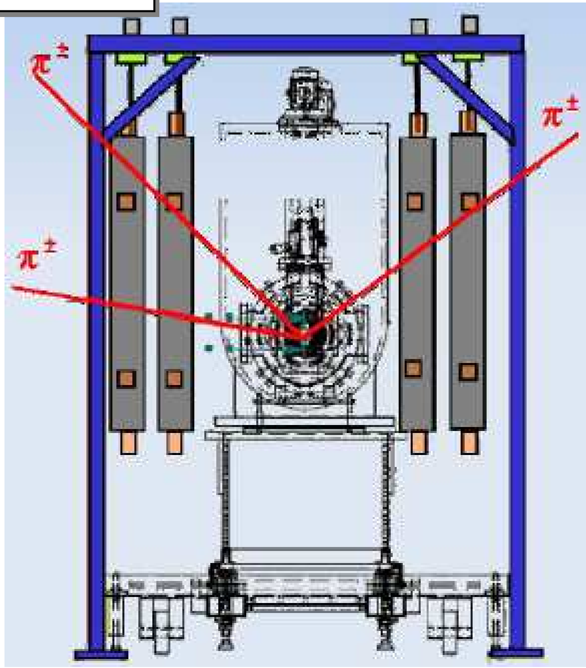
Vertex reconstruction resolution:

$$\sigma_x = 8\,\mathrm{cm} \quad \sigma_y = 2\,\mathrm{cm} \quad \sigma_z = 2\,\mathrm{cm}$$

detector for E=100 keV

Used also for Hbar experiment 4 modules

before 2011



since 2011

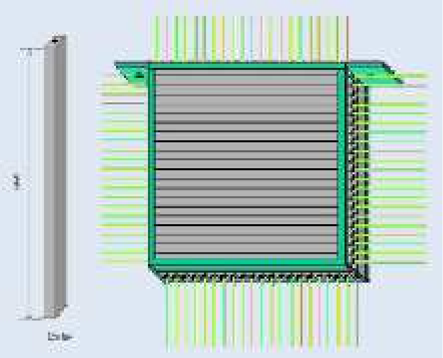
Lighter modules

detector for E=100 keV

Already used for Hbar experiment

4 modules

1 modules = 2 layers

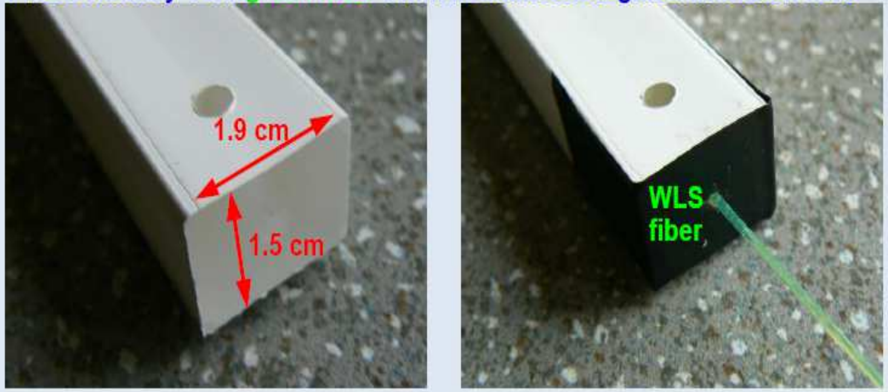


1 layer = 64 scintillator bars (96 cm long)

Polystyrene Dow, Styron 663 W + 1% PPO + 0.03% POPOP, white capstocking (TiO_2) 15 x 19 x 960 mm (by Fermilab)

central hole of diameter 2 mm

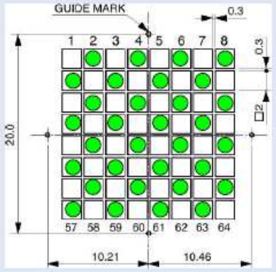
1 WLS Kuraray Y-11 green fiber 1 mm in diameter is glued into each hole



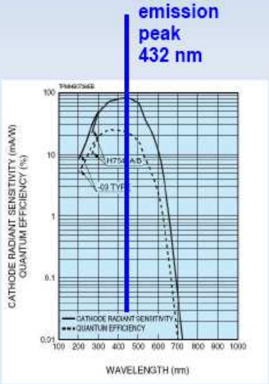
64 bars -> two 64-ch multi-anode PMTs

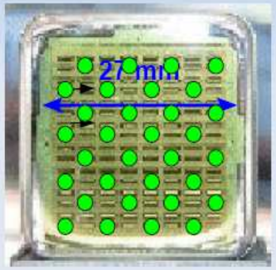
64 channel MULTIANODE PHOTOMULTIPLIER:

- Hamamatsu H7546B
- Q.E. @ 420 nm = 20%
- Anode = 2x2 mm^2
- Gain @ -800 V = 3 10^5
- Rise time = 1.0 ns
- Gain uniformity = 1-2.5
- Crosstalk (opt.+ele.) = 1-2%



WLS fiber emission peak 432 nm





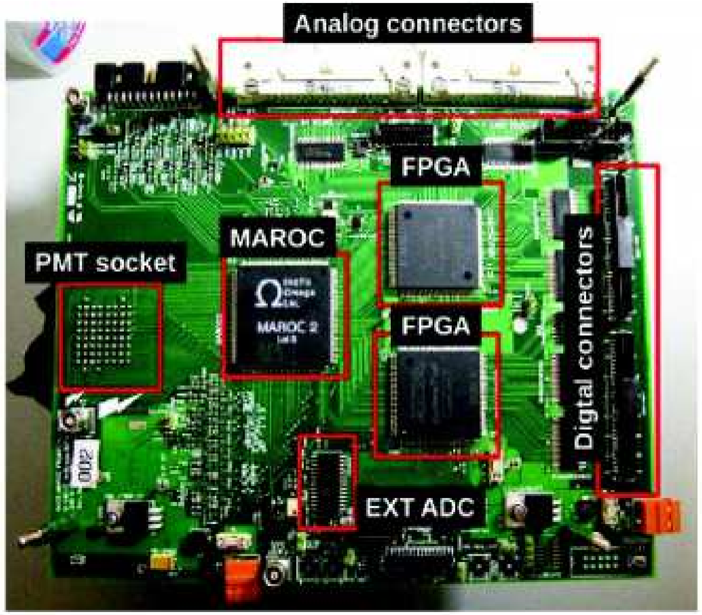
32 fibers / PMT to avoid cross-talk

New frontend board

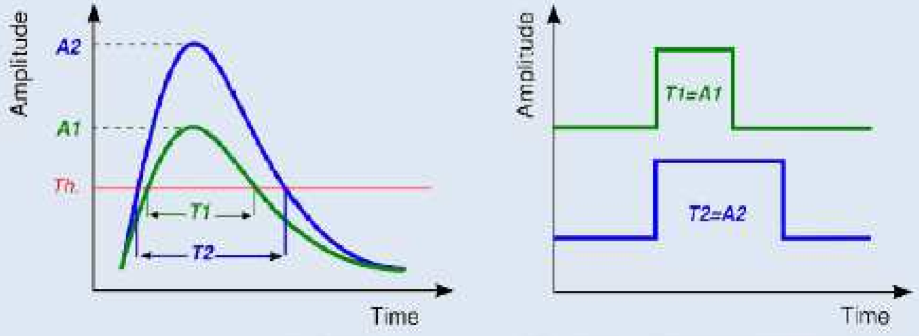
since 2011

MAROC ASIC

calibration input
1 single ASIC (plastic packaging)
Single power rail
Gain and offset uniformity < 2%
Both ANALOG and DIGITAL readout



Time over threshold digital sampling



- high sampling rate
- no event loss
- but only for a short time

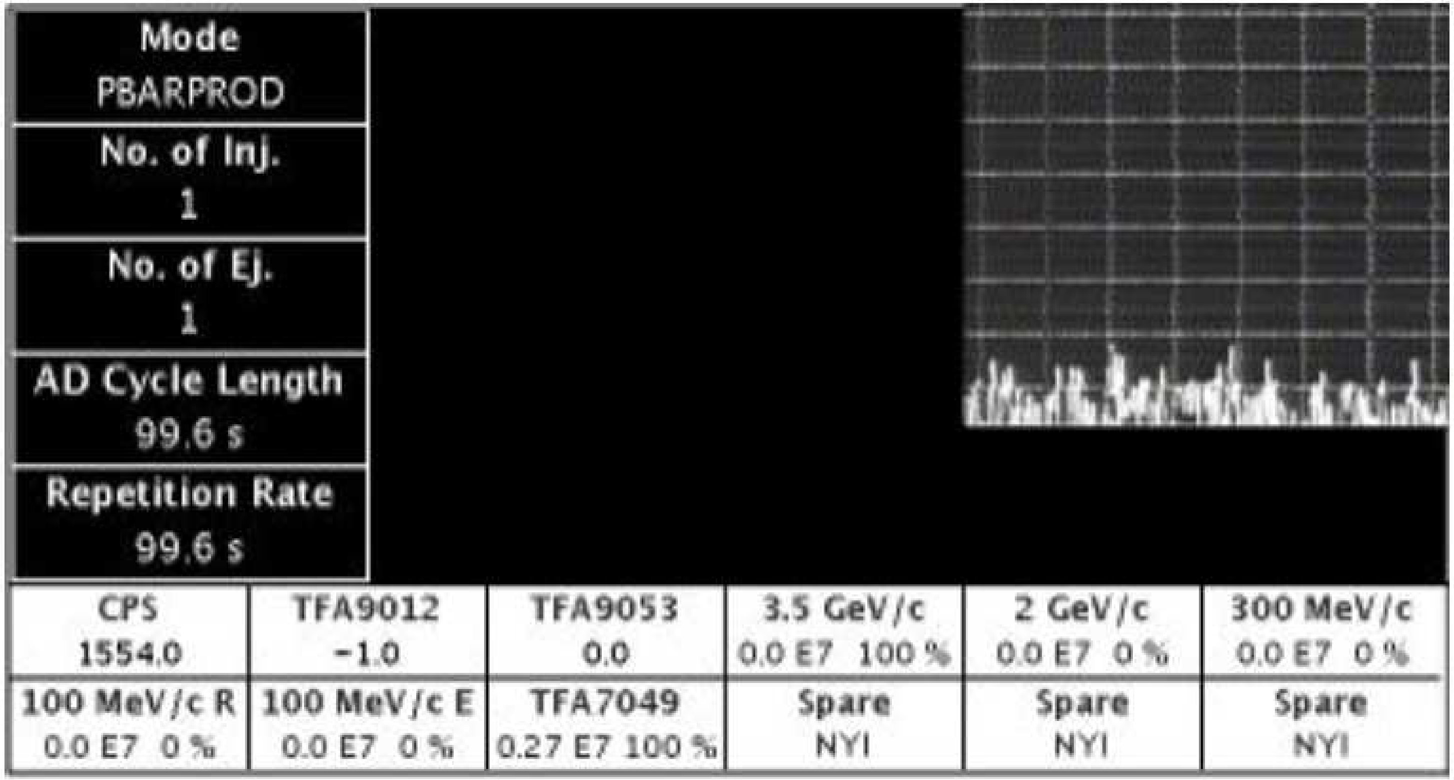
...can be very useful (ioniz. field?)

→ DAQ will be designed to have a simple ANALOG/DIGITAL switch

2011 setup

2011

We were ready, but no beam!



Mode
PBARPROD

No. of Inj.
1

No. of Ej.
1

AD Cycle Length
99.6 s

Repetition Rate
99.6 s

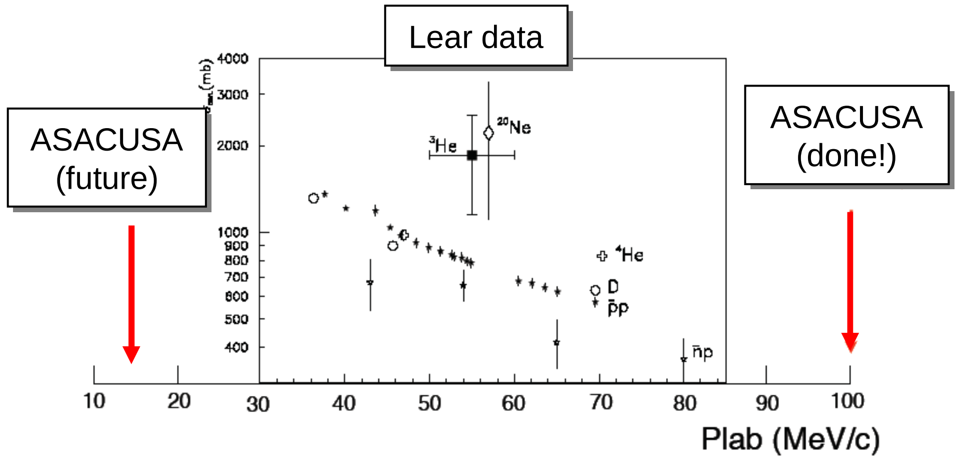
CPS 1554.0	TFA9012 -1.0	TFA9053 0.0	3.5 GeV/c 0.0 E7 100 %	2 GeV/c 0.0 E7 0 %	300 MeV/c 0.0 E7 0 %
100 MeV/c R 0.0 E7 0 %	100 MeV/c E 0.0 E7 0 %	TFA7049 0.27 E7 100 %	Spare NYI	Spare NYI	Spare NYI

Summary σ_{ann} ($\bar{p}$A) @ low-Energies (p<100 MeV/c)

- For the first time the σ_{ann} of antiprotons on medium-heavy nuclei (Ni, Sn, Pt) have been measured @ low energy (5.3 MeV) (on a pulsed beam!) by the ASACUSA Collaboration

- A black disk model with the Coulomb corrections is compatible with the data

- an extension of the measurement down to 100 keV is in progress



2012 beam usage

$\bar{p}$-nucleus $\sigma^{annihilation}$ at 100 keV	C, Ni, Sn, Pt	3 weeks
cusp trap	$\bar{H}$ microwave spectroscopy	11 weeks
$\bar{p}$He laser spectroscopy	T~1.5K, 2 photon	8 weeks

$\bar{p}$He laser spectroscopy statistics limited. ELENA!

ASACUSA: CONCLUSIONI e PROSPETTIVE

- ASACUSA (e in generale exp. @AD):
  - Risultati scientifici di valore
  - Ottimi riconoscimenti:

    - Miglior risultato di fisica del 2010 (ALPHA+ASACUSA) secondo Physics World

    -Pubblicazioni su NATURE:

    1 di ASACUSA(2011), 2 di ALPHA (2010,2012) (+1 su NaturePhysics),

    1 di ATHENA, 1 a LEAR

    -Diverse Press Release del CERN
  - Nuovi investimenti (ELENA)

- Gr.Collegato INFN Brescia:
  - Ben inserito in ASACUSA
  - Poco costoso
  - Importante supporto dell'Universita' di Brescia (ad.es. 50 keuro x ELENA)
  - Attività prevista:

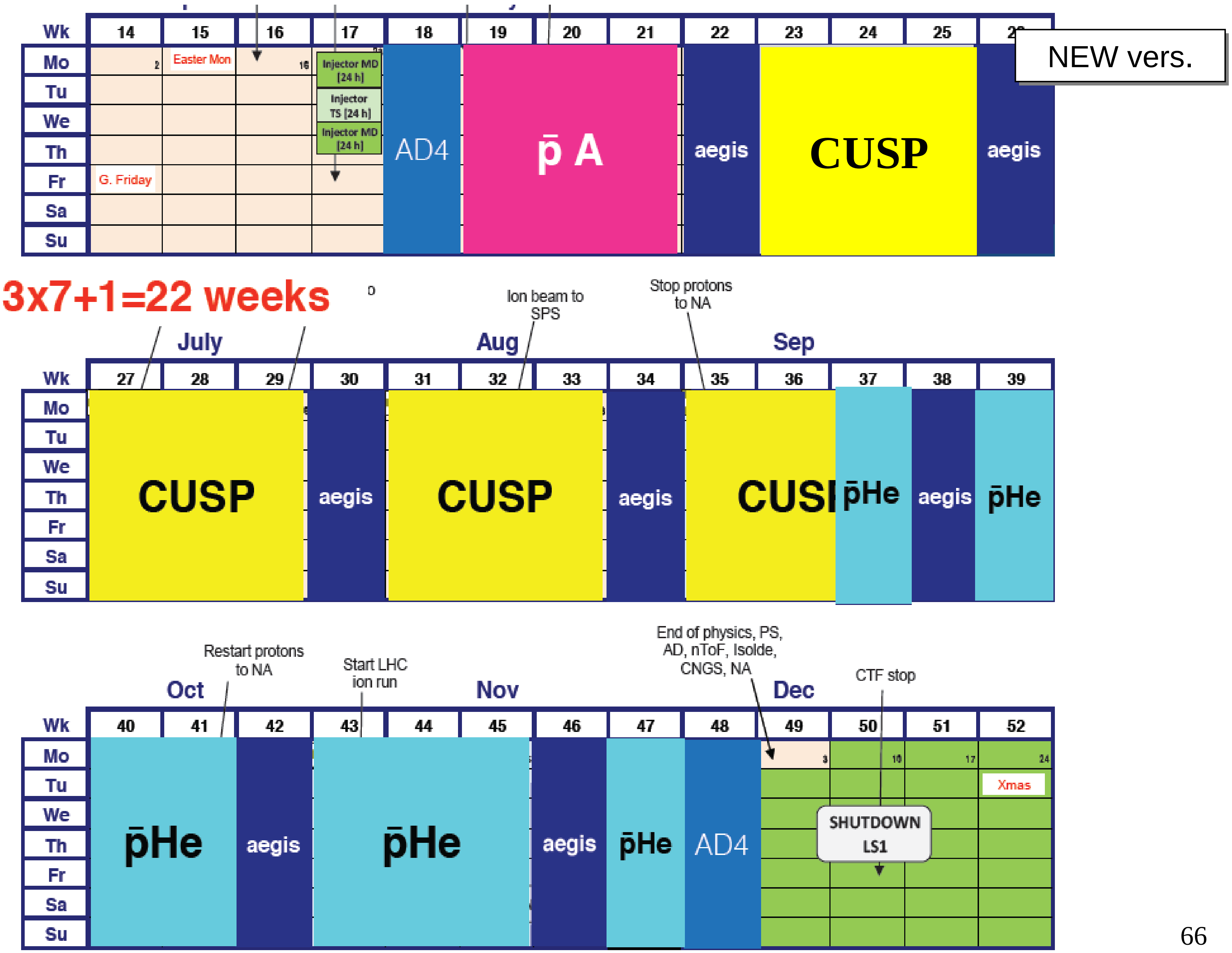
    - nel 2012 conclusione prima fase misura sez. d'urto di annichilazione

    - continuazione di:

    -Antiidrogeno

    -Elio antiprotonico

    - seconda fase misura sez. d'urto di annichilazione(?)



NEW vers.

Wk	14	15	16	17	18	19	20	21	22	23	24	25	2
Mo	2	Easter Mon	16	Injector MD [24 h]	AD4		p̄ A		aegis		CUSP		aegis
Tu				Injector TS [24 h]									
We				Injector MD [24 h]									
Th													
Fr	G. Friday												
Sa													
Su													

3x7+1=22 weeks

0

Ion beam to SPS

Stop protons to NA

July

Aug

Sep

Wk	27	28	29	30	31	32	33	34	35	36	37	38	39
Mo		CUSP		aegis		CUSP		aegis		CUS	p̄He	aegis	p̄He
Tu													
We													
Th													
Fr													
Sa													
Su													

Restart protons to NA

Start LHC ion run

End of physics, PS, AD, nToF, Isolde, CNGS, NA

CTF stop

Oct

Nov

Dec

Wk	40	41	42	43	44	45	46	47	48	49	50	51	52
Mo	p̄He		aegis		p̄He		aegis	p̄He	AD4	3	10	17	24
Tu													Xmas
We											SHUTDOWN LS1		
Th													
Fr													
Sa													
Su													