

# Consuntivi Gruppo III

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Con l'indispensabile collaborazione di  
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# CSN3 –Status 2015

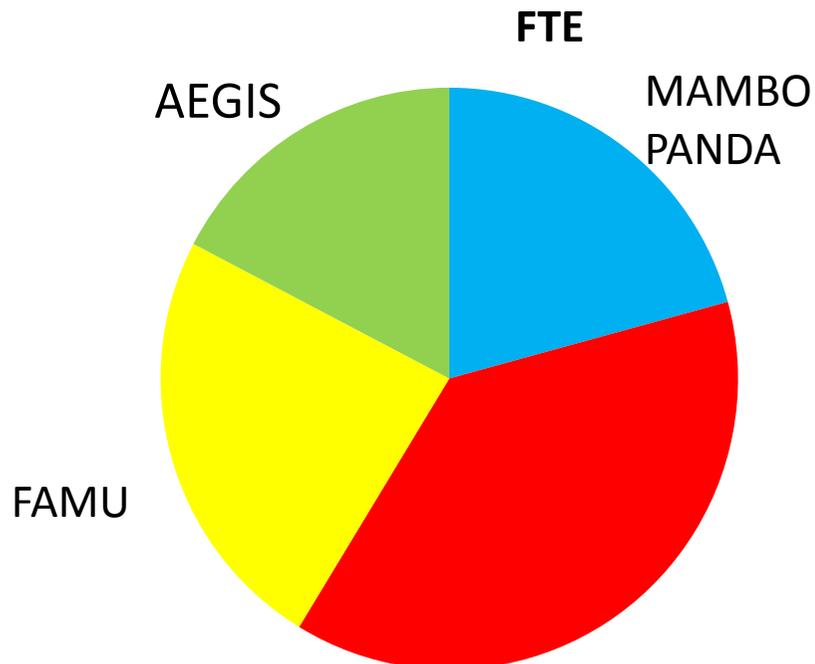
Linea 1: Quark and hadron dynamics (7 sigle)

Linea 2: Phase transitions of nuclear and hadronic matter (2 sigle)

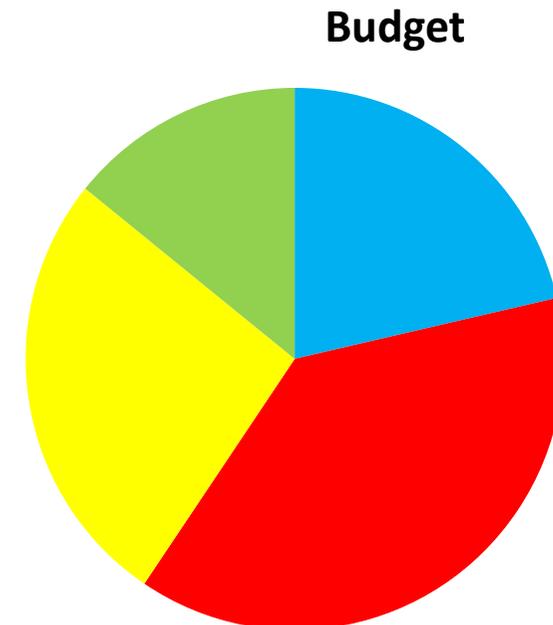
Linea 3: Nuclear structure and reaction dynamics (7 sigle)

Linea 4: Nuclear astrophysics and interdisciplinary researches (6 sigle)

Ripartizione FTE (circa 470 FTE per 660 ricercatori)



Ripartizione Budget (circa 9MEuro)



- Linea 1
- Linea 2
- Linea 3
- Linea 4

# Notizie da CSN3

-) Nuova Sigla: NUMEN (sottoprodotto di Whats-Next)

Misura precisa di elementi di matrice di transizione nucleare necessari per descrivere neutrinoless double beta decay

## The four phases of NUMEN project



### ➤ Phase1: the experiment feasibility

$^{40}\text{Ca}(^{18}\text{O},^{18}\text{Ne})^{40}\text{Ar}$  @ 270 MeV already done: the results demonstrate the technique feasibility.

### ➤ Phase2: toward "hot" cases optimizing experimental conditions and getting first result

Upgrading of CS and MAGNEX, preserving the access to the present facility. Tests will be crucial.

### ➤ Phase3: the facility upgrade

Disassembling of the old set-up and re-assembling of the new ones will start: about 18-24 months

### ➤ Phase4: the experimental campaign

High beam intensities (some  $\mu\text{A}$ ) and long experimental runs to reach integrated charge of hundreds of mC up to C, for the experiments in coincidences, for all the variety of isotopes for  $0\nu\beta\beta$  decay.

PRELIMINARY TIME TABLE

year	2013	2014	2015	2016	2017	2018	2019	2020
Phase1	█	█	█					
Phase2		█	█	█	█	█		
Phase3						█	█	█
Phase4							█	█



-) Nuova Iniziativa per misure di spallazione di interesse in adroterapia  
(misure da effettuare GSI, ...,CNAO, ....)  
(presentazione di M. Durante in CSN3 lunedì)

## -) Situazione Critica dell' esperimento PANDA

=) Review a febbraio dell'intero progetto FAIR da un comitato nominato dal ministero federale tedesco della ricerca

=) **Risultato «formale»:**

la situazione del progetto non cambia sostanzialmente rispetto a prima.  
(ministero ha garantito che saranno tutti i fondi previsti)

C'è stato «solo» un ranking di priorità della fisica dei 4 esperimenti di FAIR.  
PANDA è stato messo in fondo non per suoi problemi particolari ma a causa di ritardi nell'avvio di FAIR che renderanno alcune misure obsolete perché altri (BES, JPARC,...) le faranno prima.

In un mondo ideale dove il flusso di finanziamenti rimane costante e le spese per le varie opere di costruzione sale sperimentali/rivelatori rimangono inalterati, questo comporta "solo" un ulteriore slittamento di "qualche" anno dell'inizio di FAIR-PANDA.

## =) **Situazione «reale»:**

E' in corso una review finanziaria perché - a causa dell'incapacità del management (che nel frattempo è stato dimissionato) -al momento non si sa esattamente nemmeno quanto è stato speso dei finanziamenti ottenuti, quanto è rimasto in cassa e quanto è necessario spendere per completare il progetto.

Ci sono stati diversi problemi, notevoli aumenti dei costi (in parte dovuti a cause imprevedibili). Il management ha nel tempo gestito in maniera inadeguata, nascosto/minimizzato tutti i problemi.

Sola alla fine della review (autunno ?) si tireranno le somme che non saranno piacevoli. Uno degli scenari probabili/possibili è che, dati i (grossi) buchi di bilancio, FAIR verrà (di molto) ridimensionato; per rientrare nel budget si potrebbe anche fare solo la parte «ioni pesanti» del progetto complessivo.

**Al momento futuro di PANDA è totalmente incerto** (si sta come d'autunno sugli alberi le foglie ...)

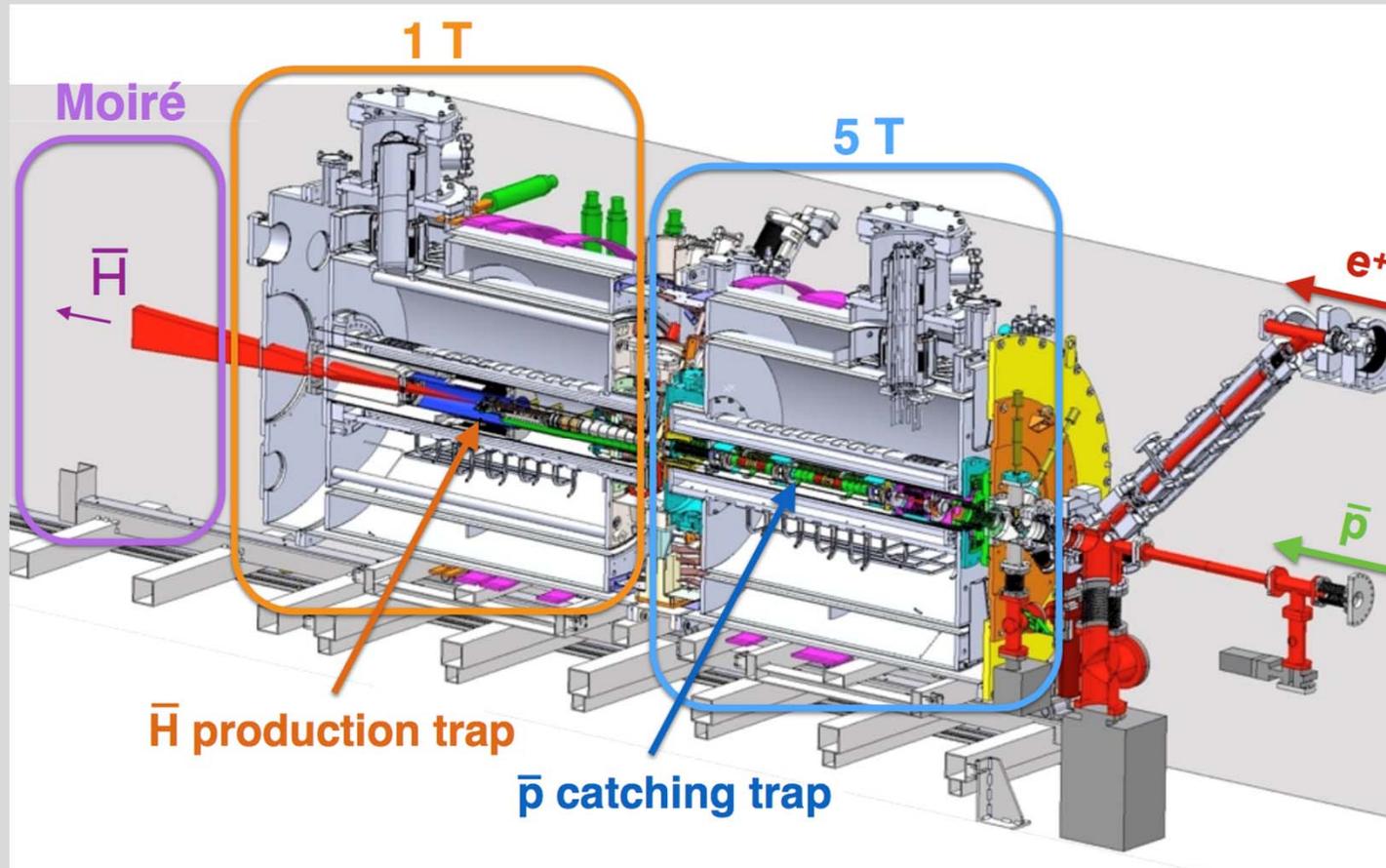
Lunedì discussione in CSN3 su cosa fare con PANDA-Italia (probabile chiusura sigla e/o limitato proseguimento per finire alcune attività iniziate)

# CSN3-Pavia Situazione 2015

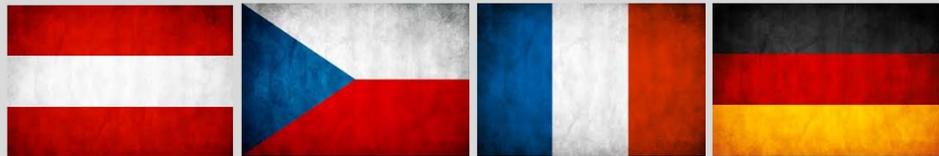
Budget: 89 kEuro

sezione	nome cognome	TIPO	Ricerc	Tecnol	Pers.	FTE
AEGIS	Bonomi Germano	assoc	x			100
	Donzella Antonietta	assoc		x		50
	Fontana Andrea	dip	x			60
	Rotondi Alberto	assoc	x			50
	Zenoni Aldo	assoc	x			40
<b>AEGIS</b>			<b>4</b>	<b>1</b>	<b>5</b>	<b>3.0</b>
FAMU	De Bari Antonio	assoc	x			40
	Menegolli Alessandro	assoc	x			40
	Nardo' Roberto	assoc		x		20
	Rossella Massimo	assoc		x		20
	Tomaselli Alessandra	assoc		x		30
<b>FAMU</b>			<b>2</b>	<b>3</b>	<b>5</b>	<b>1.5</b>
MAMBO	Braghieri Alessandro	dip	x			50
	Costanza Susanna	assoc	x			50
	Pedroni Paolo	dip	x			100
<b>MAMBO</b>			<b>3</b>		<b>3</b>	<b>2.0</b>
PANDA	Boca Gianluigi	assoc	x			50
	Costanza Susanna	assoc	x			20
	Montagna Paolo	assoc	x			30
	Rotondi Alberto	assoc	x			50
<b>PANDA</b>			<b>4</b>		<b>4</b>	<b>1.5</b>
<b>TOTALE</b>			<b>12</b>	<b>4</b>	<b>17</b>	<b>8.0</b>

## CONSUNTIVO AEGIS-PV 2014/2015



- Ultimi risultati
- Run 2014 con antiprotoni
- Sviluppo attività Pavia
- Run 2015 con antiprotoni



# A E $\bar{g}$ I S collaboration



Stefan Meyer Institute



CERN



Czech Technical University



ETH Zurich



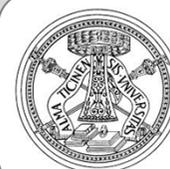
University of Genova



University of Milano



University of Padova



University of Pavia



Institute of Nuclear Research of the Russian Academy of Science



Max-Planck Institute Heidelberg  
Max-Planck-Institut für Kernphysik



Politecnico di Milano



University College London



University of Bergen



University of Bern



University of Brescia



Heidelberg University



University of Lyon 1



University of Oslo



University of Paris Sud



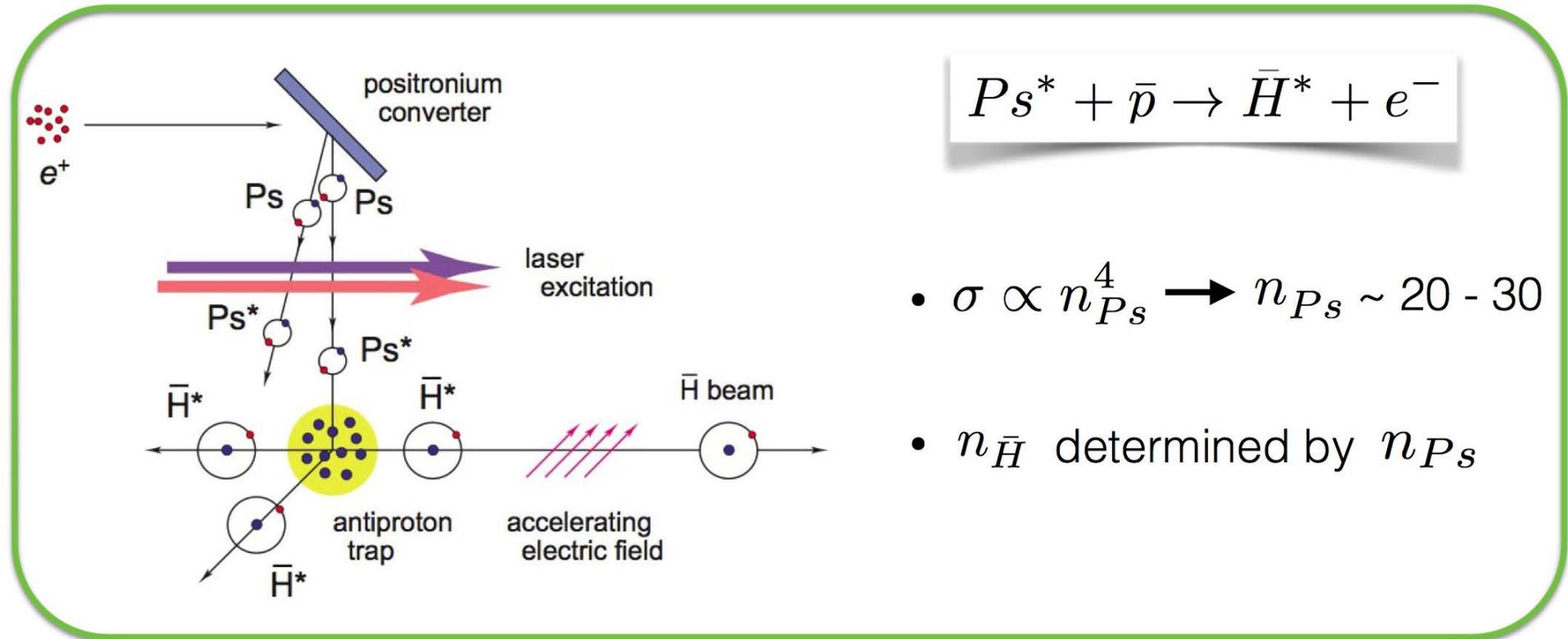
University of Trento



INFN sections of: Genova, Milano, Padova, Pavia, Trento



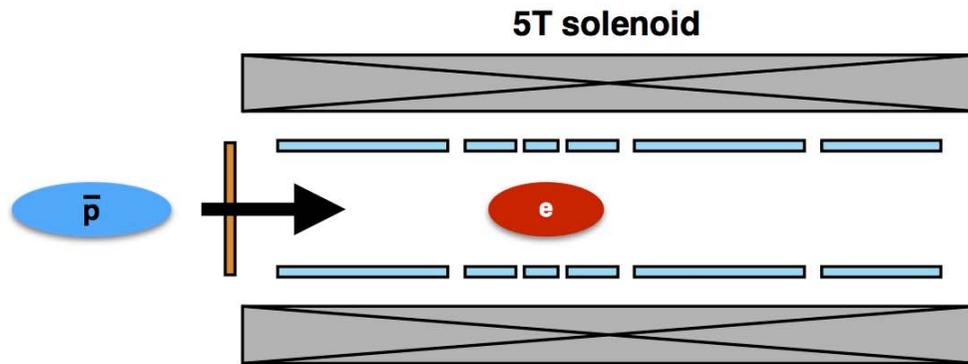
- Rydberg  $\bar{H}^*$  atoms produced via **charge exchange**



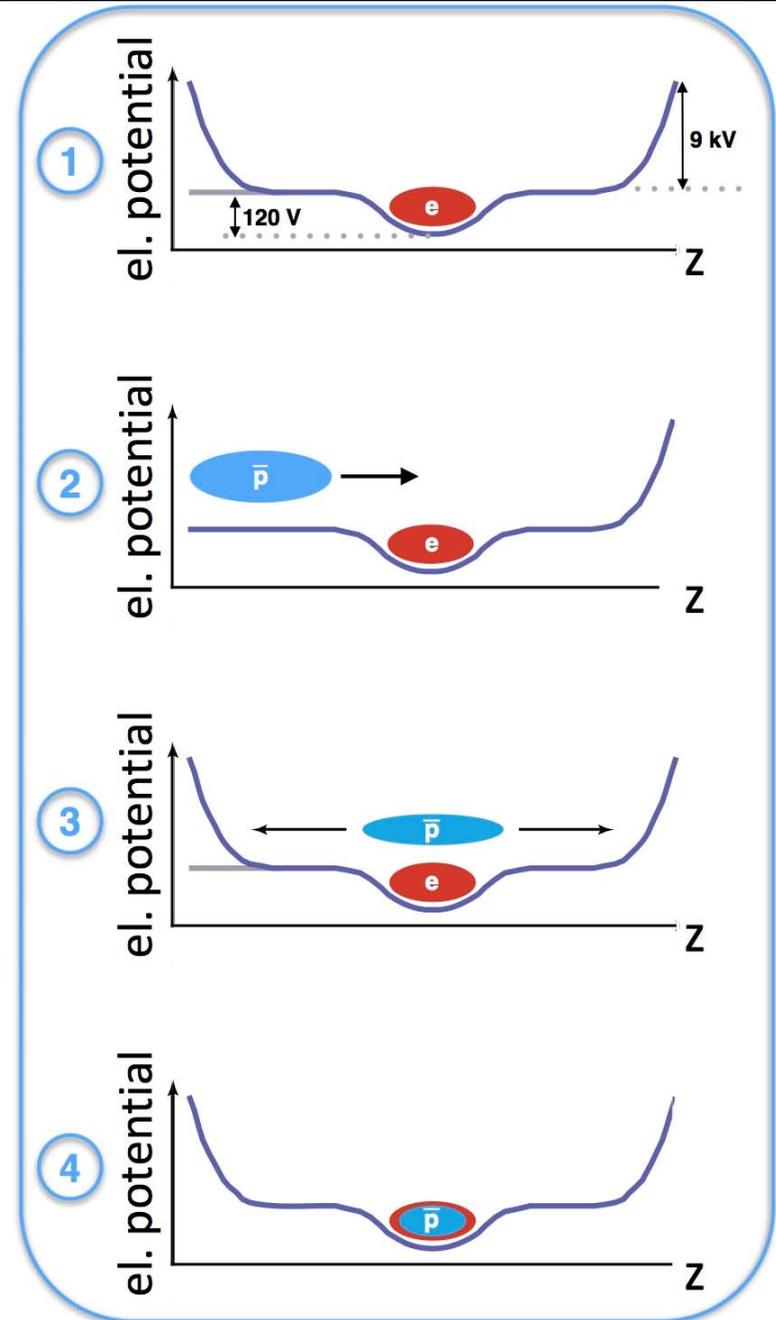
- Temperature of  $\bar{H}$  given by the temperature of  $\bar{p}$  (goal 100 mK)
- Rydberg  $\bar{H}$ : strong dipole moment  $\rightarrow$  **Stark acceleration**

# Antiproton capture and cooling

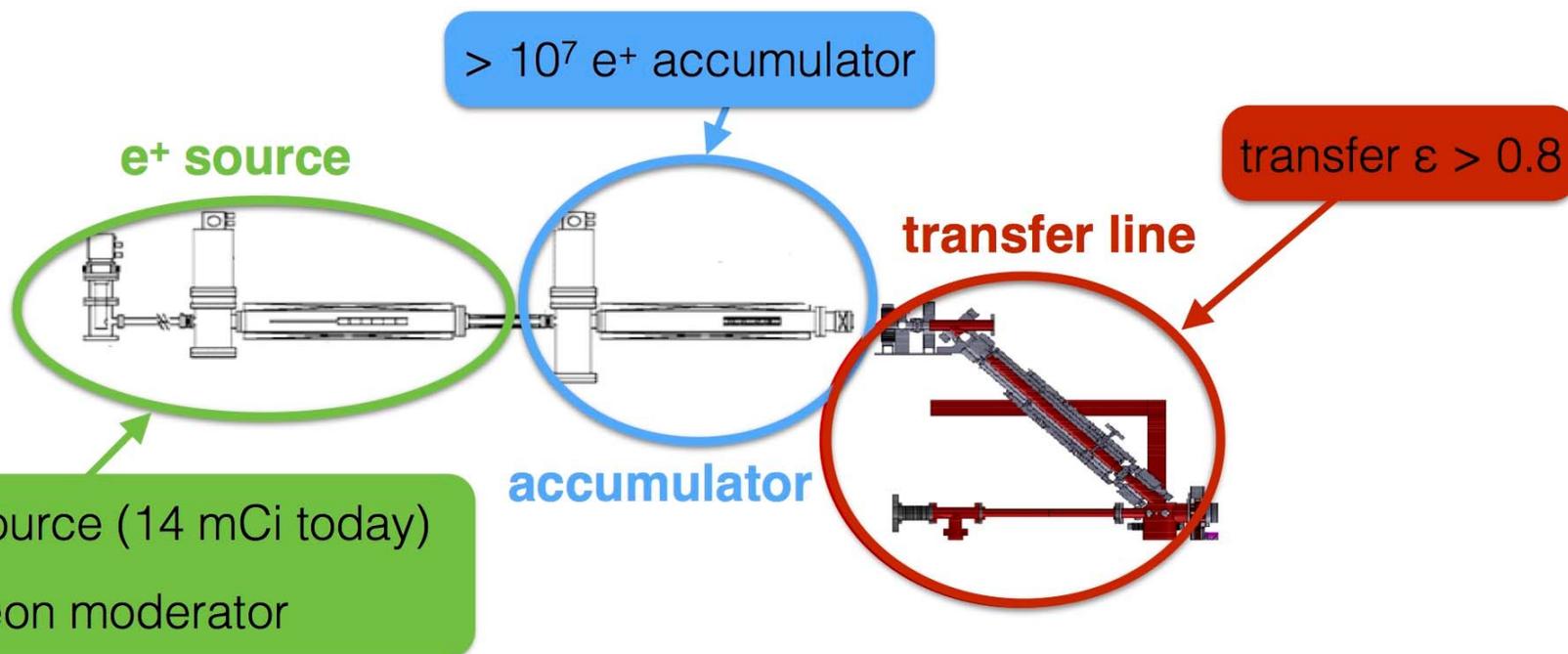
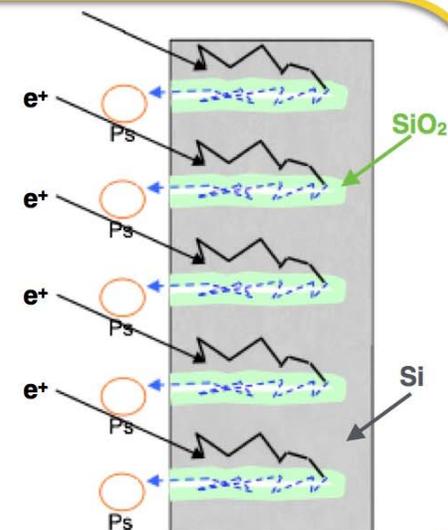
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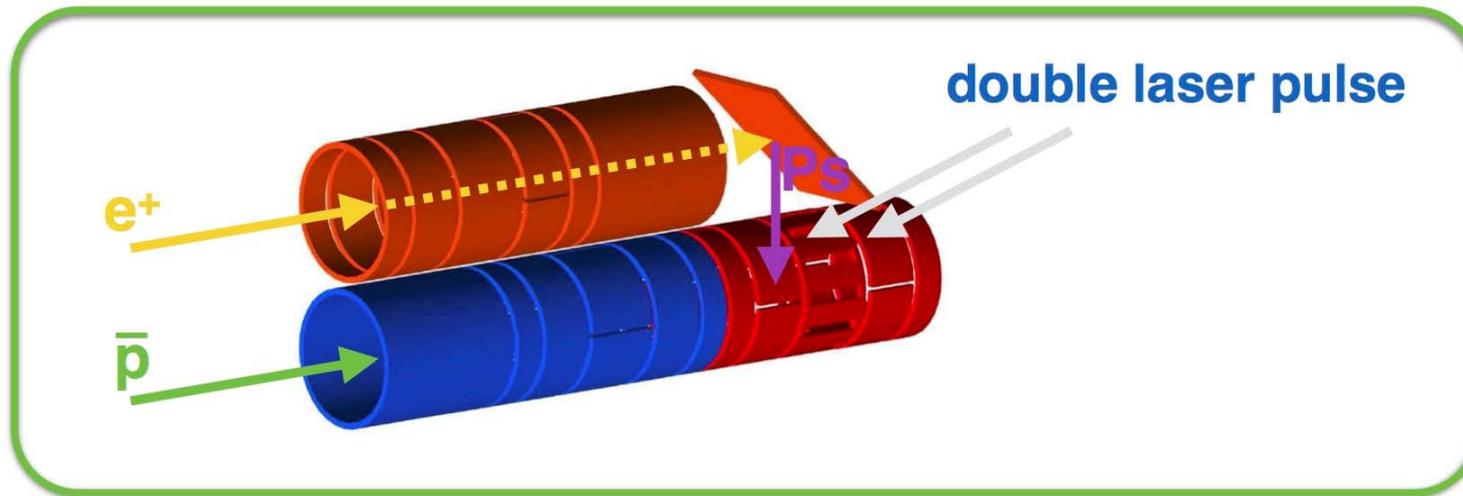


- Electrons ( $\sim 10^8$ ) loaded in the trap
- Thin Al foil (*degrader*) used to select low energy antiprotons
- $\bar{p}$  caught and cooled (electron cooling)
  - $\sim 7$  K reached
  - 0.1 K goal (laser cooling, ...)
- $\sim 10^5$   $\bar{p}$  catch per spill



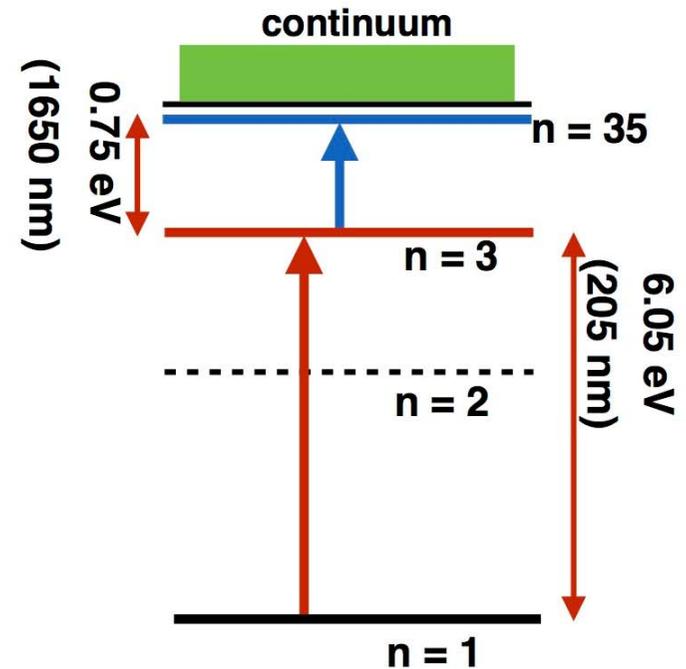
- **Positronium** (Ps) is an exotic atom composed by an  $e^-$  and a  $e^+$
- **para-Ps**(125 ps) and **ortho-Ps**(142 ns)
- Ps produced via electron capture of  $e^+$  within a nanoporous silica target





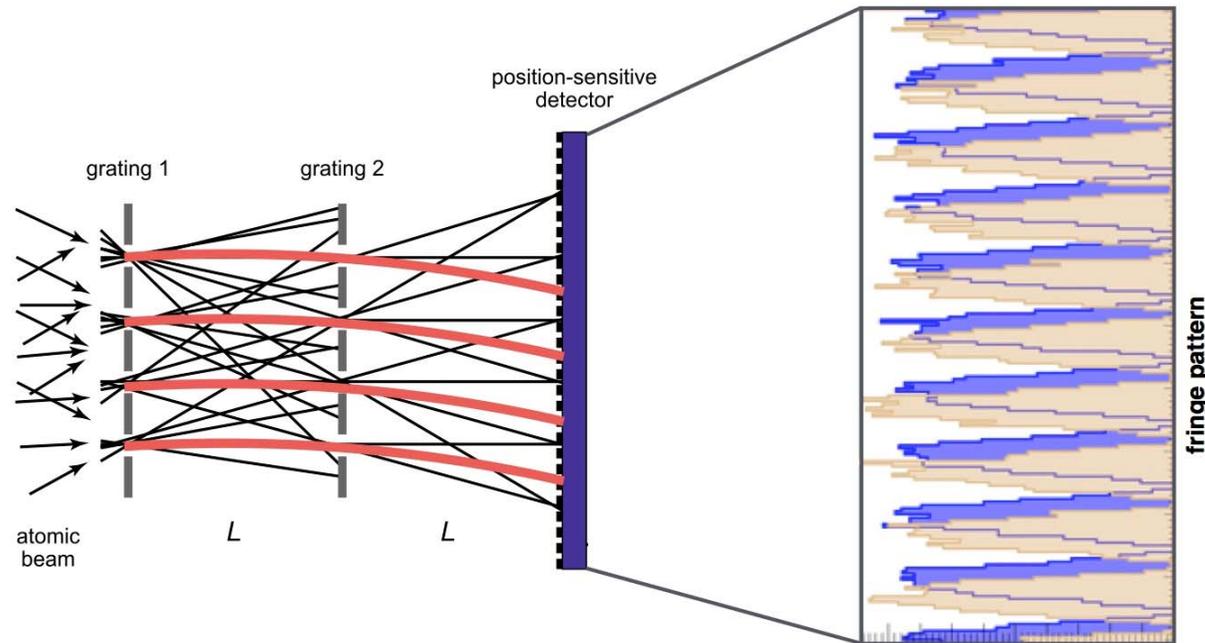
Two stages excitation:

- UV (205 nm):  $n = 1 \rightarrow 3$
- IR (1650-1700 nm):  $n = 3 \rightarrow 25 - 35$



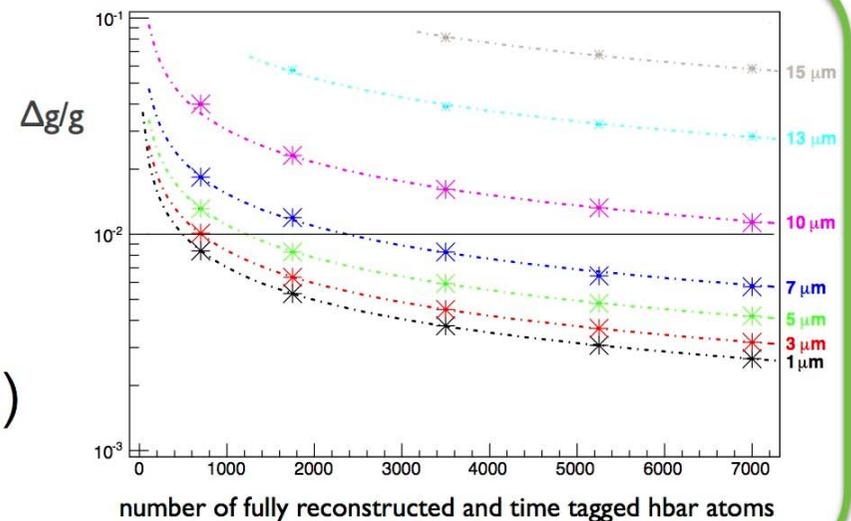
S. Mariazzi *et al.*, **Phys. Rev. A** 78 (2008) 052512

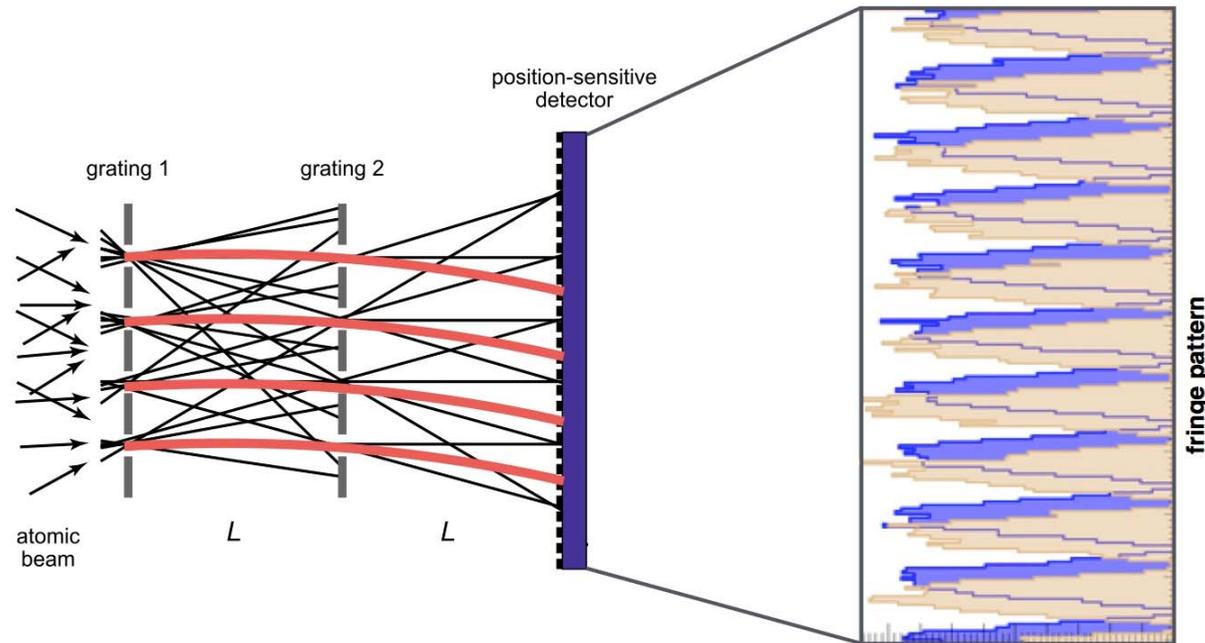
S. Mariazzi *et al.*, **NIM B** 269 (2011) 1527



Measurement accuracy depends on :

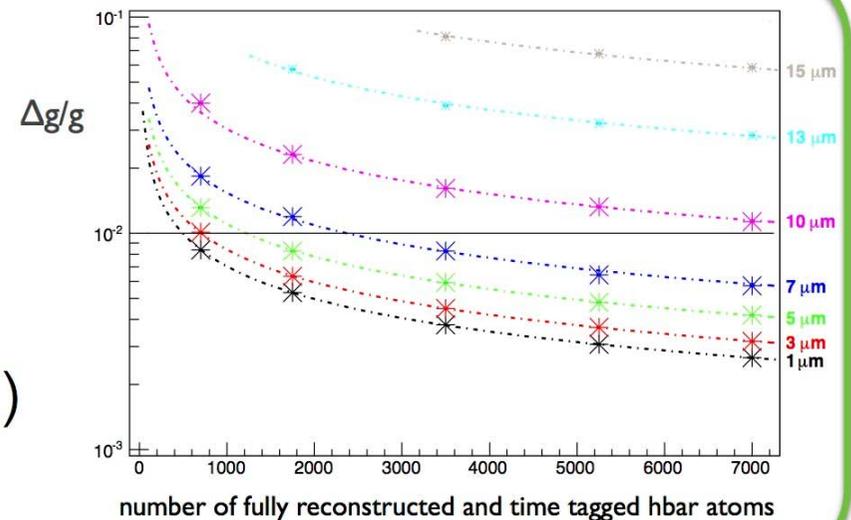
- number of detected vertices
- detector resolution
- alignment, etc... (systematic unc.)





Measurement accuracy depends on :

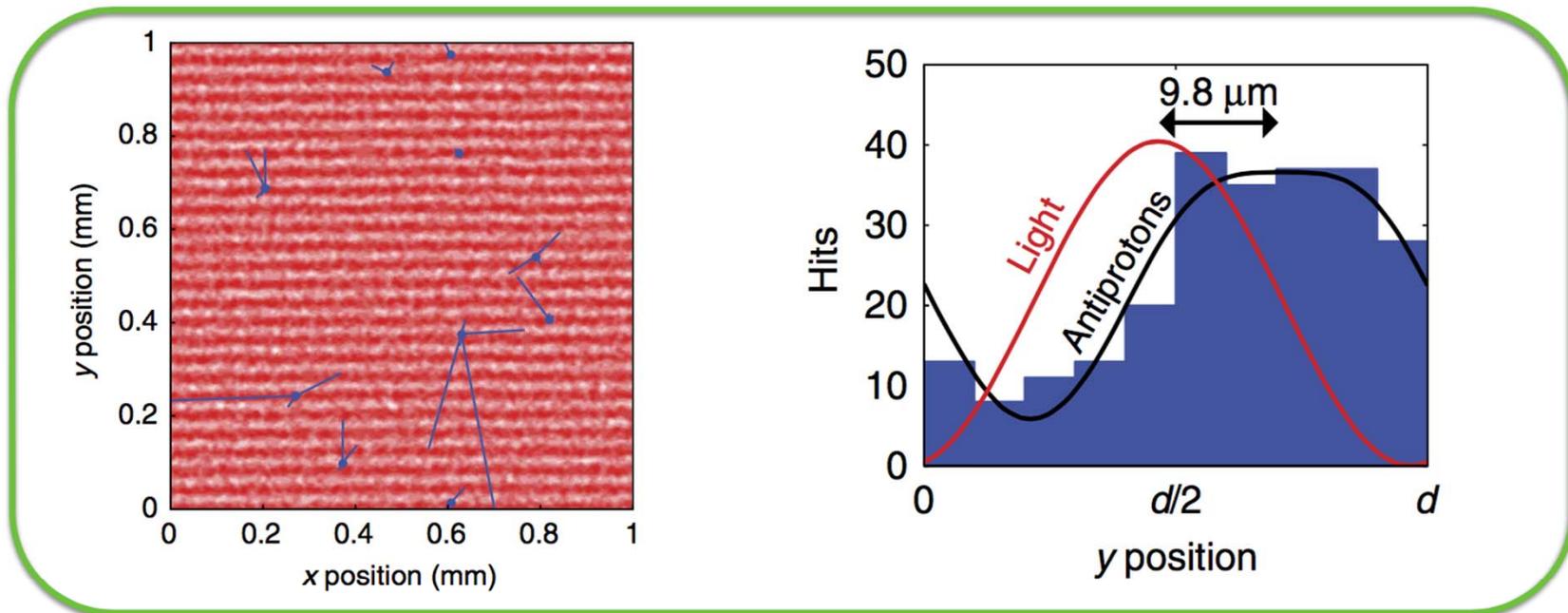
- number of detected vertices
- detector resolution
- alignment, etc... (systematic unc.)



## Results: (mini) Moiré test with antiprotons

18

- 146 antiprotons recorded



$$\Delta y = 9.8 \pm 0.9(\text{stat}) \pm 6.4(\text{syst}) \mu\text{m}$$

- $F = 530 \pm 50 \text{ aN (stat.)} \pm 350 \text{ aN (syst.)}$
- consistent with a  $B \sim 7.4 \text{ G}$

**B ~ 10 G measured at  
the Moiré position**

## the latest results (2014 data)

**Nel 2014 si è preso dati con antiprotone sia nell'apparato principale che in una linea di fascio adiacente dove sono stati testati dei rivelatori per il disegno finale del sistema di rivelazione dell'antidrogeno alla fine del deflettometro di Moire**

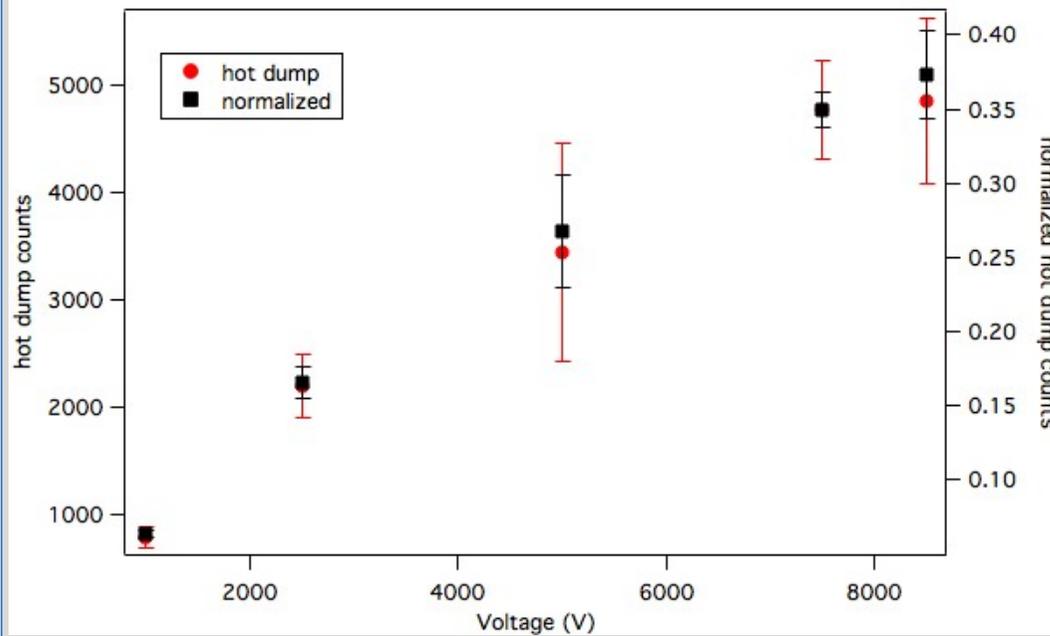
**È stato fatto un grosso passo avanti con gli antiprotoni, ma non si è riusciti a portare il sistema dei positroni ad uno stadio tale da permettere la produzione di positronio nell'apparato principale.**

**I motivi principali sono stati la rottura di alcuni pezzi dell'accumulatore di positroni (e la ditta che l'ha fornito la FirstPoint Scientific nel frattempo è fallita) e problemi nell'iniezione dei positroni nel magnete a 5 T.**

**Qui di seguito ecco alcuni risultati ottenuti sui rivelatori testati nella linea di test e nell'intrappolamento e trasferimento degli antiprotoni**

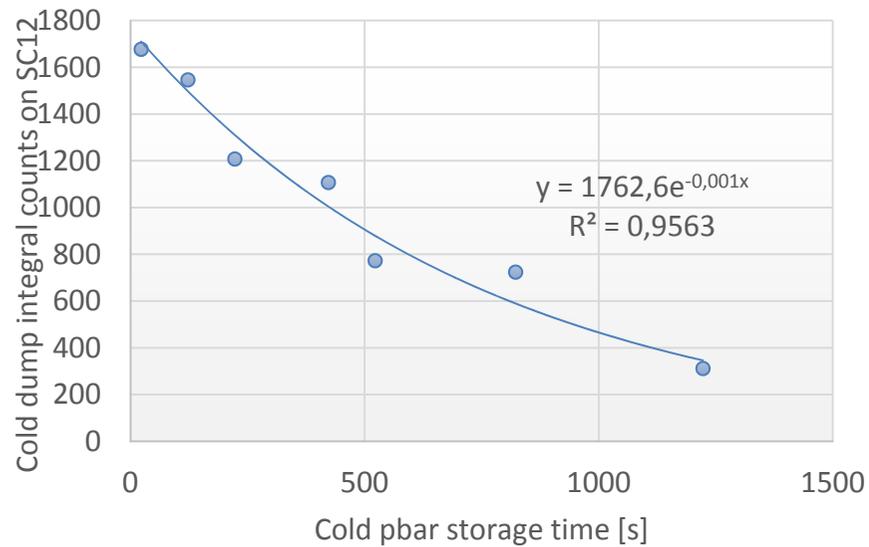
# the latest results (2014 data)

## Antiproton catching efficiency vs. HV

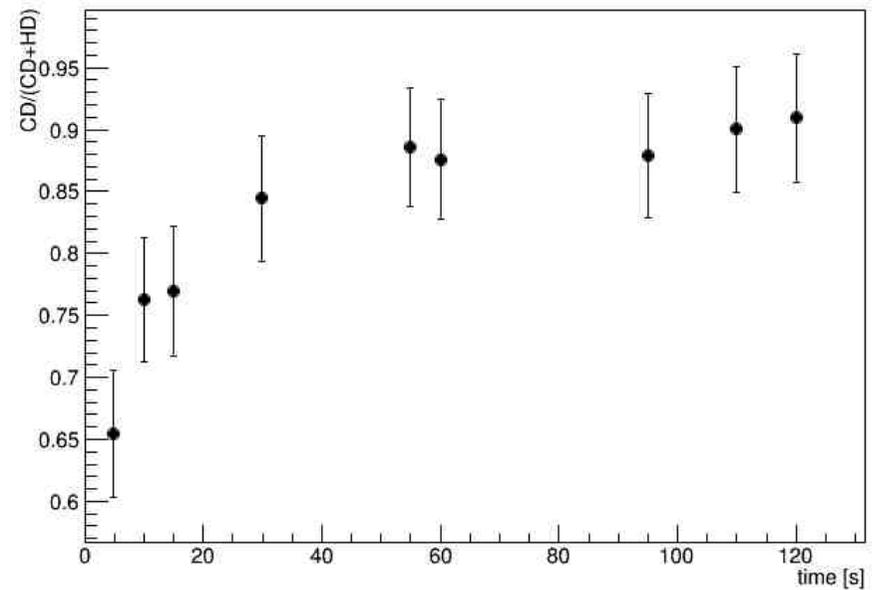


## Antiproton cooling efficiency

### cold pbar lifetime (with electrons)



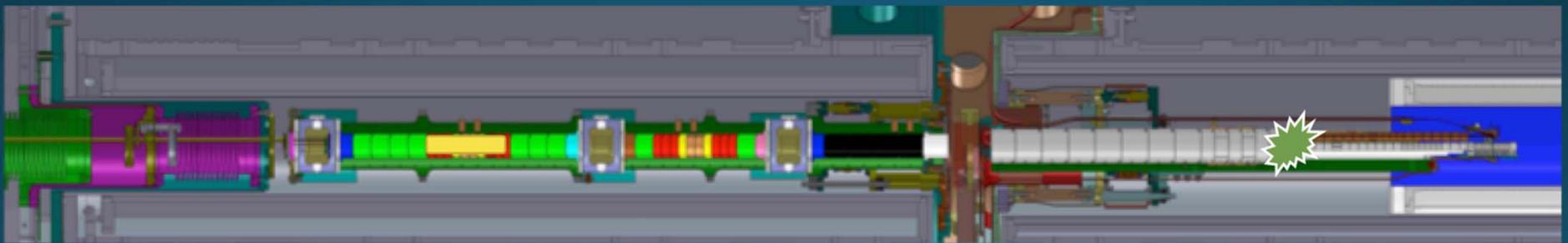
### pbar cooling efficiency



the latest results (2014 data)

# Antiproton transfers into 1T traps

- Quick and dirty but worked on first trial
- Due to the central region piston not retracting we have lost many shifts with irreproducible transfer results! (it took some time to find it – we do not have pos. readout)
- No significant losses were observed up till the 1T Big trap end
- Pbars were lost at the On-axis trap transition (inner diameter 10mm)
- Had to compress the pbars to make them enter the small trap radii in 1T



# the latest results (2014 data)

## Centrifugal separation of antiprotons & e<sup>-</sup>

$$n_1(r, z) \propto \exp\left(-\frac{q_1}{k_B T} \left[ \phi_r(r, z) + \phi_z(r, z) + \omega_r B \frac{r^2}{2} - \frac{m_1 \omega_r^2 r^2}{2} \right]\right)$$

$$n_2(r, z) \propto \exp\left(-\frac{q_2}{k_B T} \left[ \phi_r(r, z) + \phi_z(r, z) + \omega_r B \frac{r^2}{2} - \frac{m_2 \omega_r^2 r^2}{2} \right]\right)$$

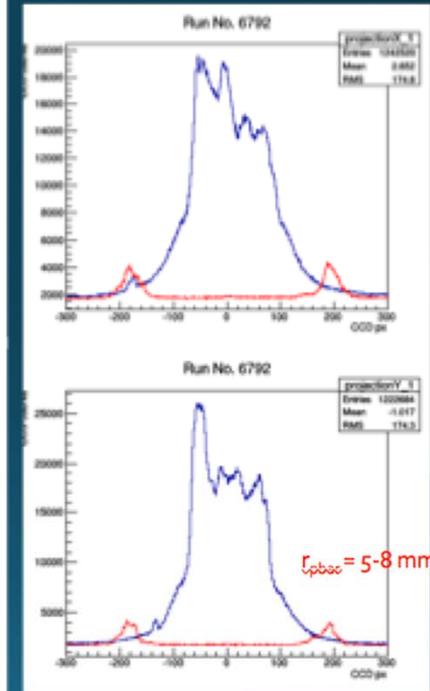
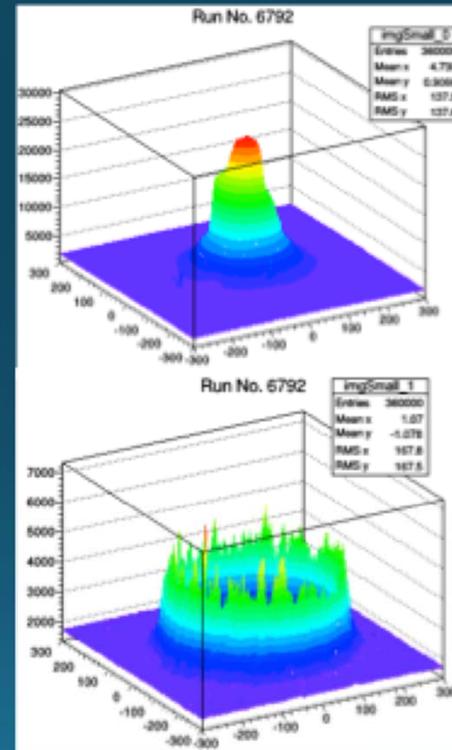
- Separation happens when  $\bar{p}$  and e<sup>-</sup> rotation frequencies match

- This should happen at therm. equilibrium

- plasma has to be either dense or very cold
- Condition for separation to occur:

$$|m_1 - m_2| \omega_r^2 R_p \times R_p > k_B T$$

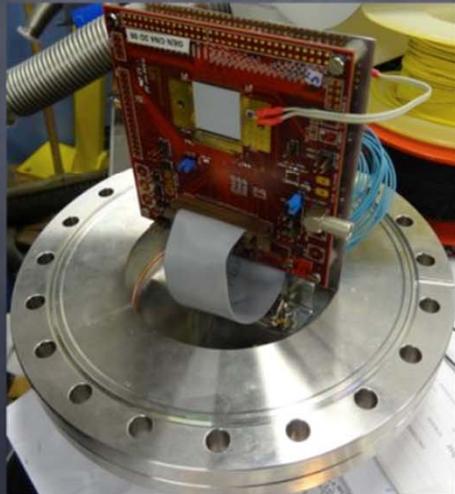
- With rough estimates of e<sup>-</sup> plasma size and density we should have plasma temperature at ~10-20K



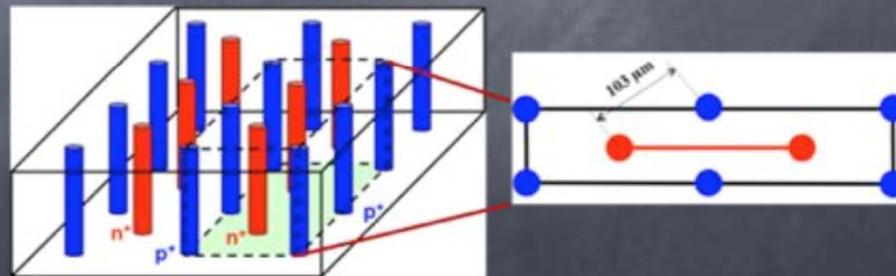
## Test beam with antiproton annihilations in 3D silicon pixel detector

Goal: More information on the signature of the antiproton annihilation event, observation of tracks from the annihilation prongs. Estimation on the resolution of the annihilation point.

- 3D CNM 55 silicon detector with FE-I4 readout system designed for ATLAS IBL.
- $2 \times 2 \text{ cm}^2$ ;  $230 \text{ }\mu\text{m}$  thick,  $50 \times 250 \text{ }\mu\text{m}^2$  pixel size.
- Passivation layer:  $1.5 \text{ }\mu\text{m}$  Al +  $0.8 \text{ }\mu\text{m}$  + doped polysilicon +  $1.150 \text{ }\mu\text{m}$  thermal oxide.
- Saturation occurs at  $\sim 126 \text{ keV/pixel}$ , 35% of all hit pixels were saturated.



The CNM 55 sensor with the FE-I4 R/O chip mounted on a flange.

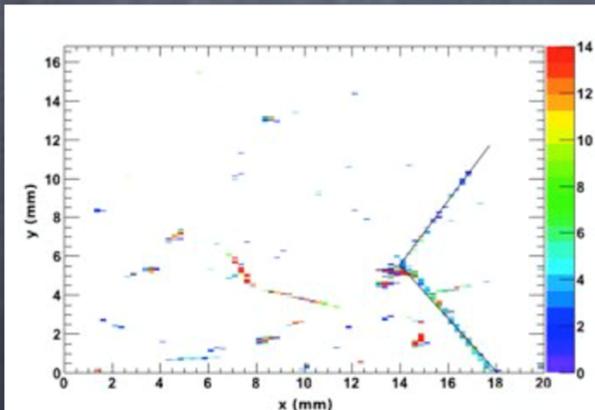


Schematic view of the 3D electrodes.

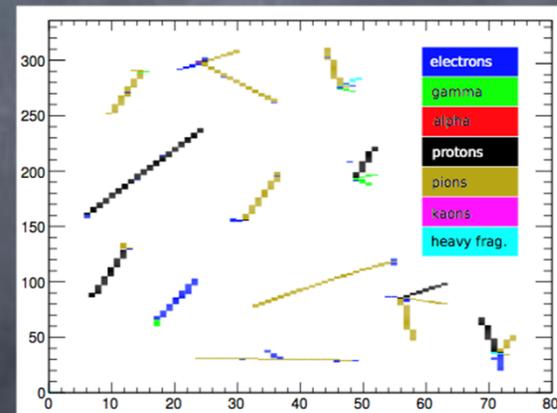
# the latest results (2014 data)

## Results from measurements with 3D pixel detector

- Total energy deposition up to 10 MeV per antiproton annihilation.
- Cluster size ranging from 1 to 80 pixels, with mean value of  $3.93 \pm 0.031$  pixels.
- Identification of tracks from annihilation prongs up to 1.5 cm long.
- Position resolution of  $56.5 \mu\text{m}$  for X and  $24.3 \mu\text{m}$  for the Y coordinate of the annihilation point.
- A better resolution could be achieved by employing weighted fitting with a saturation-free readout.



Sample hitmap of the 3D pixel sensor with two fitted proton tracks coming from an antiproton annihilation.



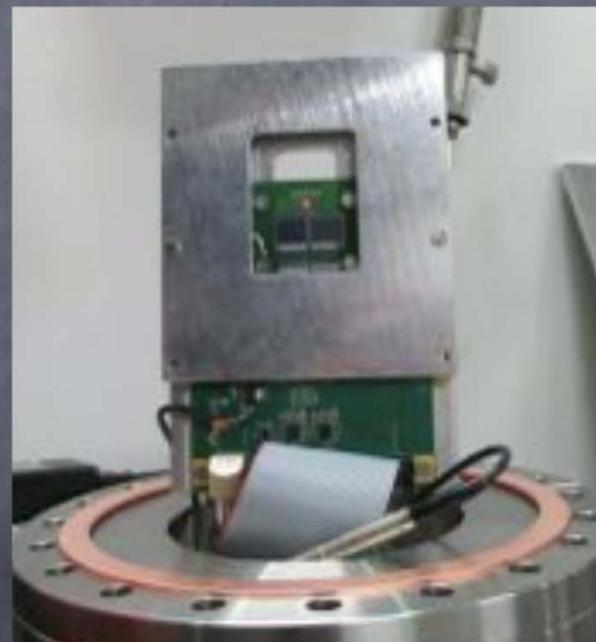
Samples of simulated annihilation events (GEANT4, FTFP) in a silicon pixel sensor.

# the latest results (2014 data)

## Beam test with silicon strip detector

*Goal: To observe and to verify the response to annihilation events of a 1D detector, as the one to be installed in AEGIS. Also to evaluate the performance of the microstrip technology.*

- Planar strip sensors on standard 300  $\mu\text{m}$  thick, MCz n-type wafers.
- p<sup>+</sup> strip implants, with AC coupled aluminum readout strips.
- Two sensors (strip length: 1 cm.)
  - 50  $\mu\text{m}$  strip pitch
  - 80  $\mu\text{m}$  strip pitch
- Alibava R/O system with two Beetle chips, used in the LHCb VELO readout system.
- Dynamic range: from 20 keV (5 noise RMS) up to 800 keV.
- Full depletion voltage: 120 V. Breakdown voltage: 300 V. Maximum applied voltage: 150 V.

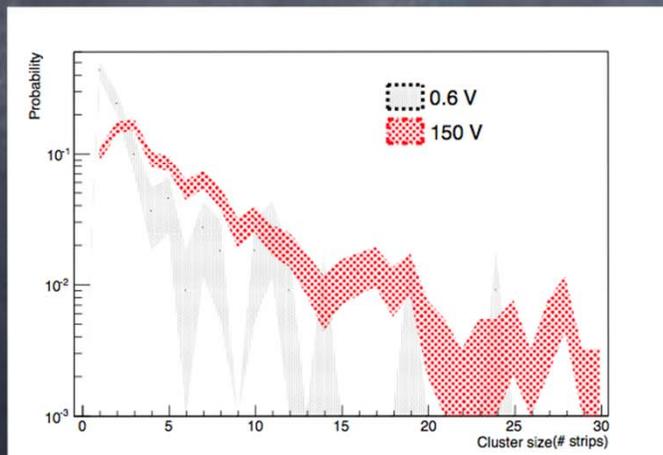


The two microstrip sensors bonded to the Beetle R/O chips, mounted on a flange.

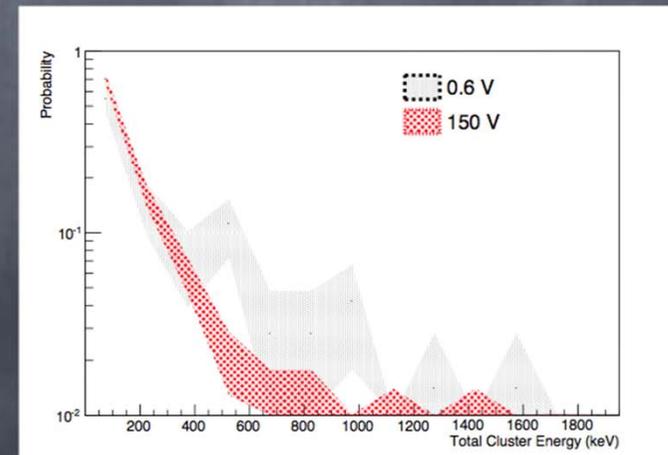
# the latest results (2014 data)

## Results from measurements with silicon strip detector

- The cluster size increases with voltage: sensors become sensitive to long-range particles (pions and high energy protons).
- The total cluster energy is higher at low depletion: the detector is only sensitive to highly ionizing fragments.
- Summary:
  - a thin active volume produces small clusters: better spatial localization of the annihilation event through detection of highly ionizing fragments.
  - A wide dynamic range R/O electronics to avoid signal saturation.

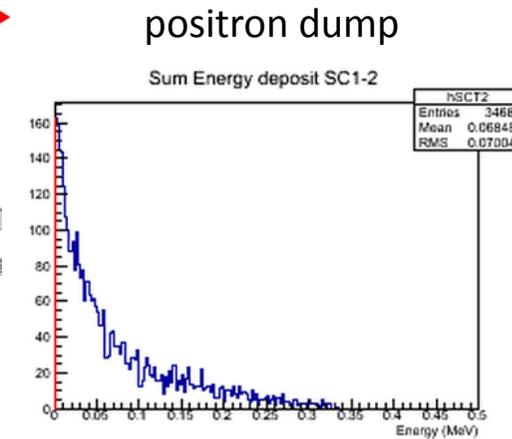
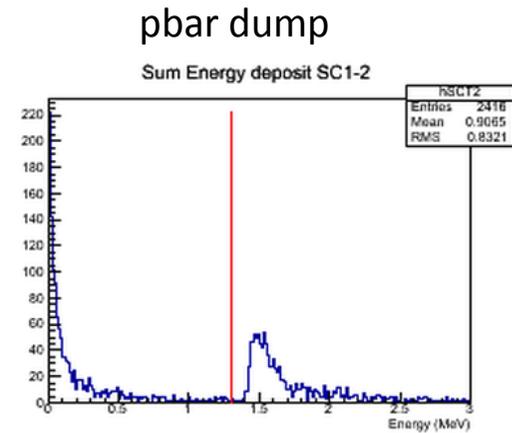
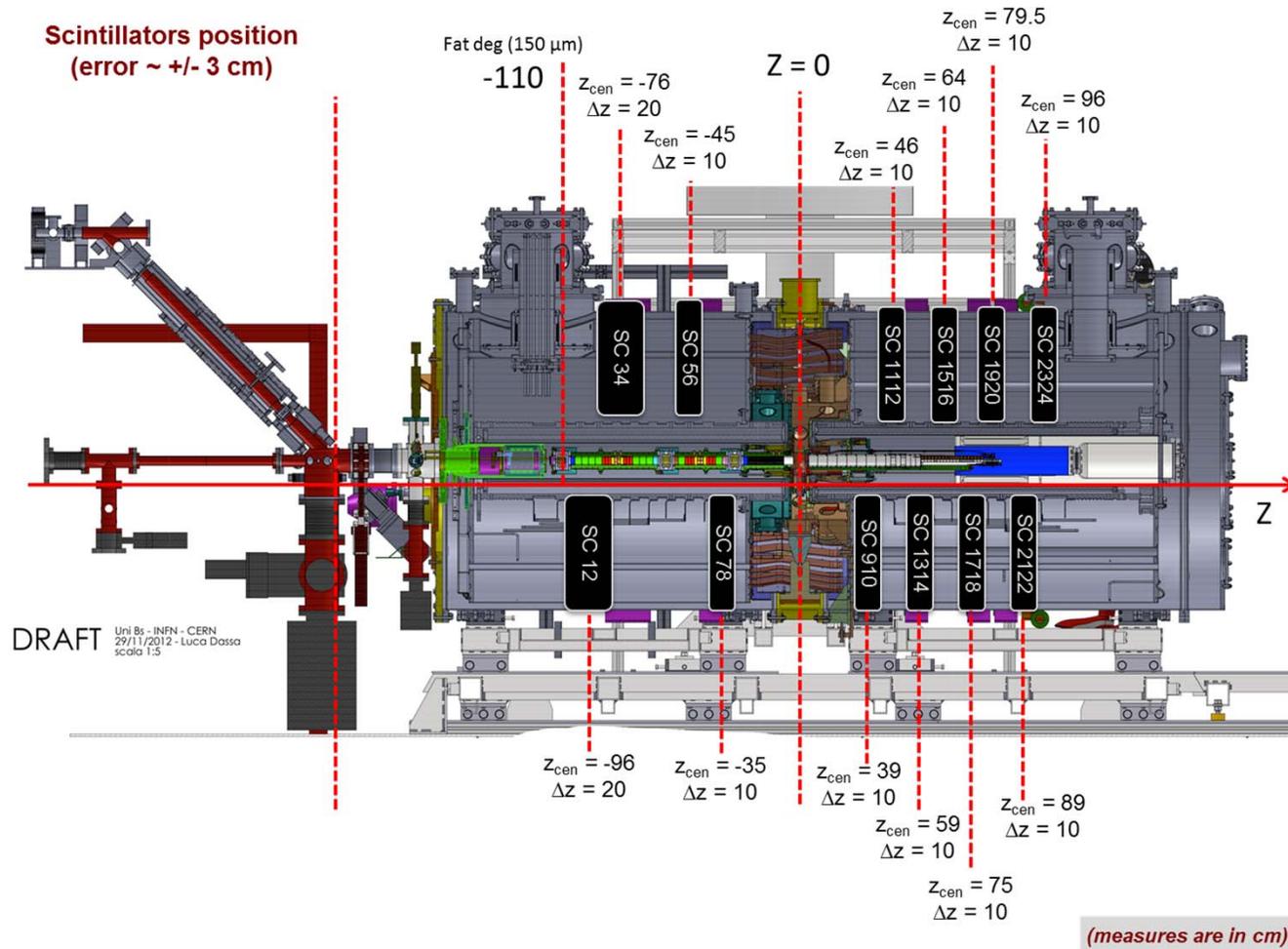


Cluster size distribution, normalized to unit total integral.



Deposited energy distribution of the clusters, normalized to unit total integral.

# Attività del gruppo – 1) rivelatori esterni



System commissioned and running.  
Small intervention from time to time to repair/substitute PMTs

# Attività del gruppo – 2) simulazioni MC

## New Beam Counter: from 5 pads to 112x112 pixels (roughly 1 x 1 cm<sup>2</sup>)

the AEgIS beam line has been simulated with a 75 um Si BC and with a 50 um Si BC. Here's the results.

25 um of Si corresponds to 22 um of Al. In the plots, the x-scale shows the total Al budget (to be added to the Si thickness).

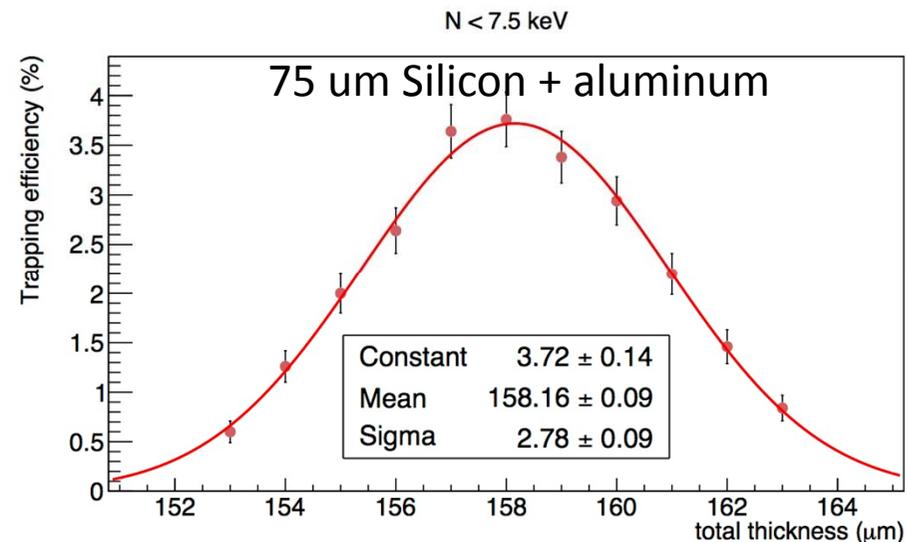
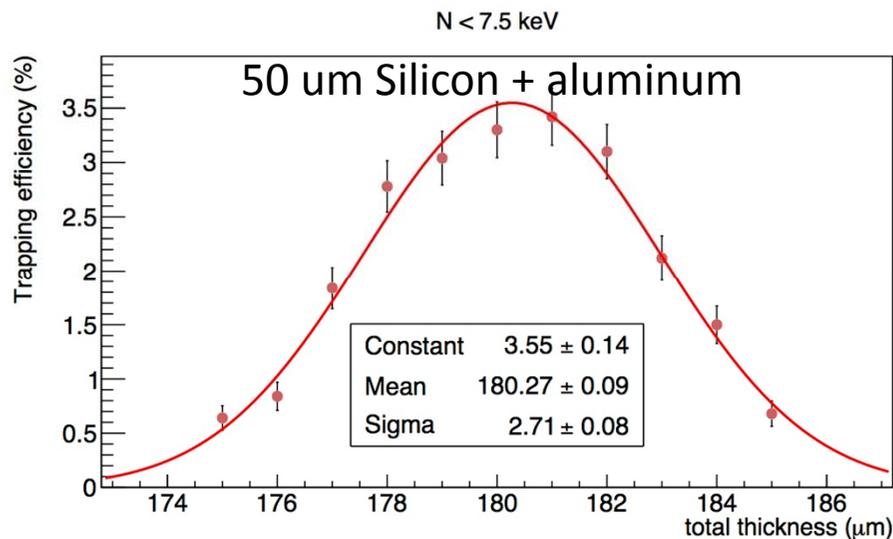
The MC falls “shorter” than the data.

With a 75 um of Si BC indeed the best thickness seems to be around 158 um, while in the 2012 data the best we had it with 173 (18+2+153) um.

In 2014 the best was something in between (3+5+51+104 = 163 um) and (5+16+51+104 = 174 um).

In 2015 since we have 25 um less in Si, and adding the equivalent of 22 um of Al, the proposal of Stefan to have 177 um around the Mimito seems the right choice.

The expected maximum should indeed be (based on 2014 data) between 185 and 196.



As a mayor upgrade we are now adding to our geant4\_vmc code the possibility to track also Hbar particles in a B field – **work in progress (not easy, in collaboration with Vienna)**

## Attività del gruppo – 3) DAQ e online

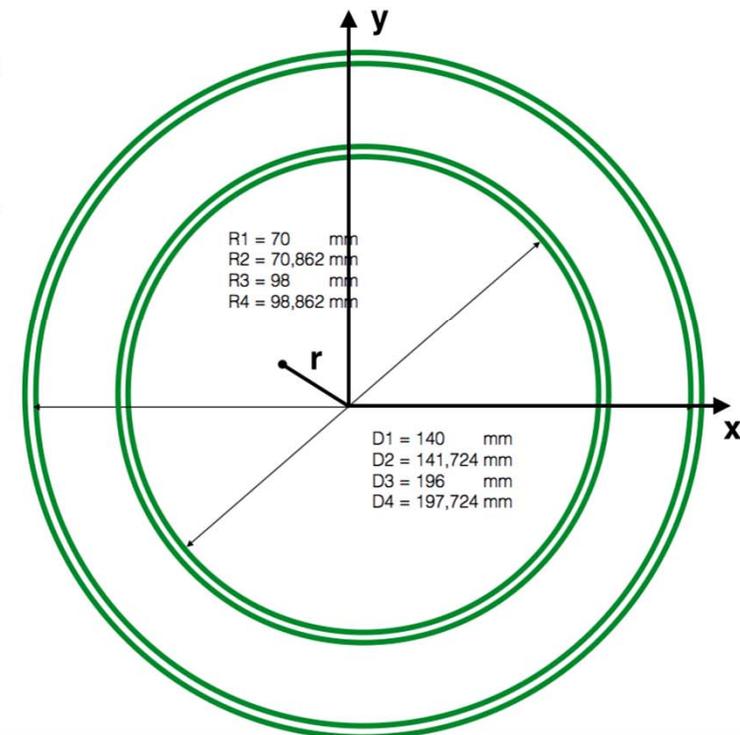
**Per il DAQ si sta testando un nuovo VME OnBoard PC (VP717 che sostituisce il VP110) e si è cambiata la logica di raccolta dati (2 run contemporanei, uno in chiusura e uno in apertura, per ridurre alcuni tempi morti alla fine del run)**



**Per l'online, nel 2015 è stata sviluppata una nuova interfaccia (Xojo) per l'online e tutto il codice ottimizzato (C++). Il sistema è in fase di test e sarà pronto per la**

# Attività del gruppo – 3) FACT reconstruction

- In this talk **first** results from the annihilation vertex reconstruction with the FACT detector is presented
  - Results have been produced using both MC and real data, the latter taken on December 2014
  - FACT consists of 800 circular-shaped fibers arranged in 4 concentric layers
    - layer 1: radius = 70 mm
    - layer 2: radius = 70.862 mm
    - layer 3: radius = 98 mm
    - layer 4: radius = 98.862 mm
- “Superlayer 1”
- “Superlayer 2”
- Reconstruction performance depends on:
    - annihilation  $\mathbf{r}$
    - material budget (MULS)
    - **B** field (very small impact)



# Attività del gruppo – 3) FACT reconstruction

- Annihilation vertex reconstruction with the FACT is not trivial because of the detector design:

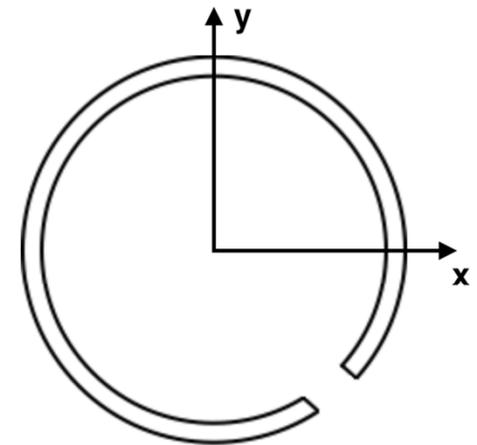
- **just two (double) layers**

(low background rejection, high number of track candidates, etc...)

- because of the low discrimination power between signal and background, candidate vertices are reconstructed using topologies with **3 prongs**
- a comparison of reconstructions made with 2 and 3 prongs will be also presented

- **ambiguity on x- and y- coordinates**

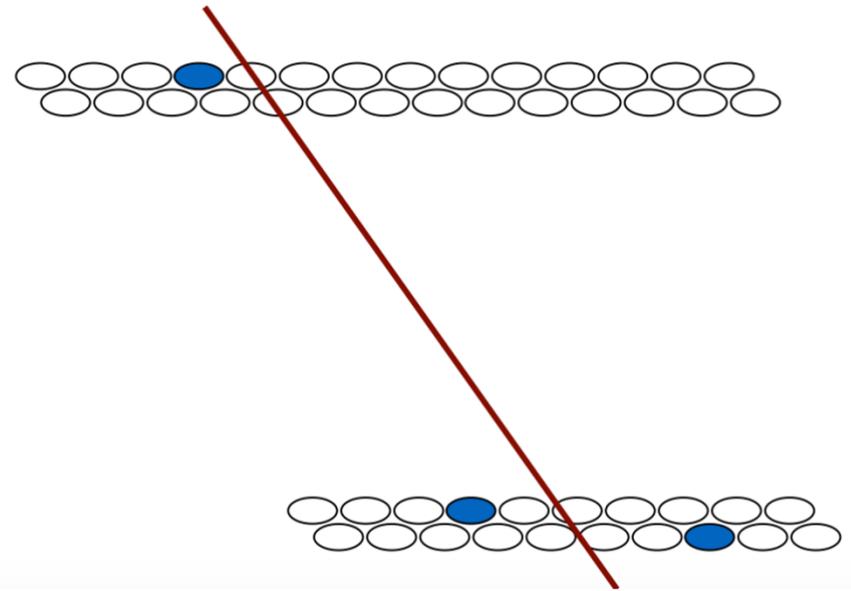
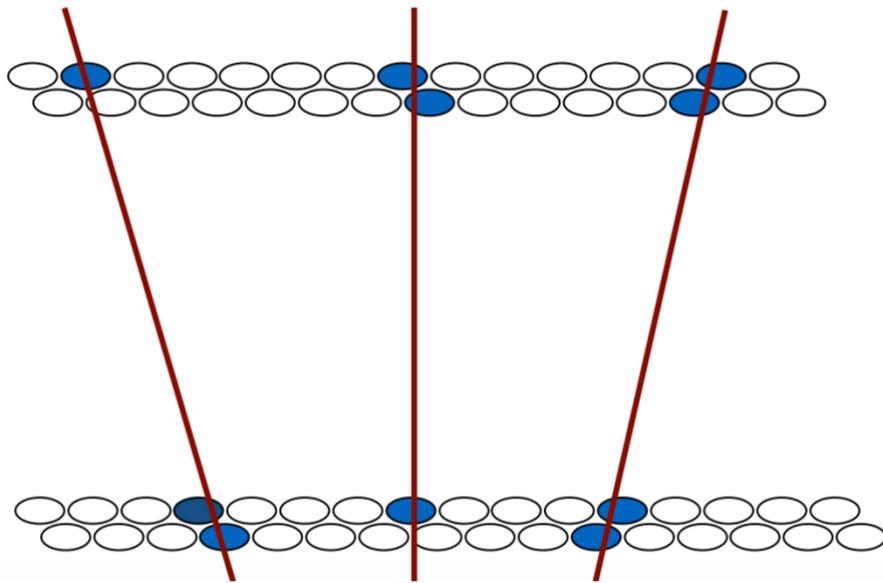
(geometrical issue for off-center annihilations, etc...)



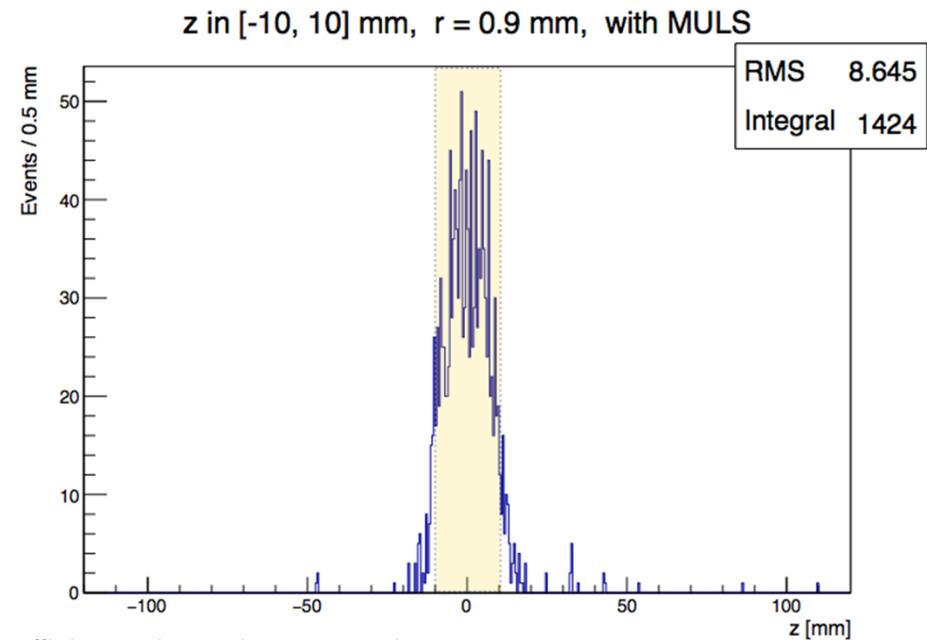
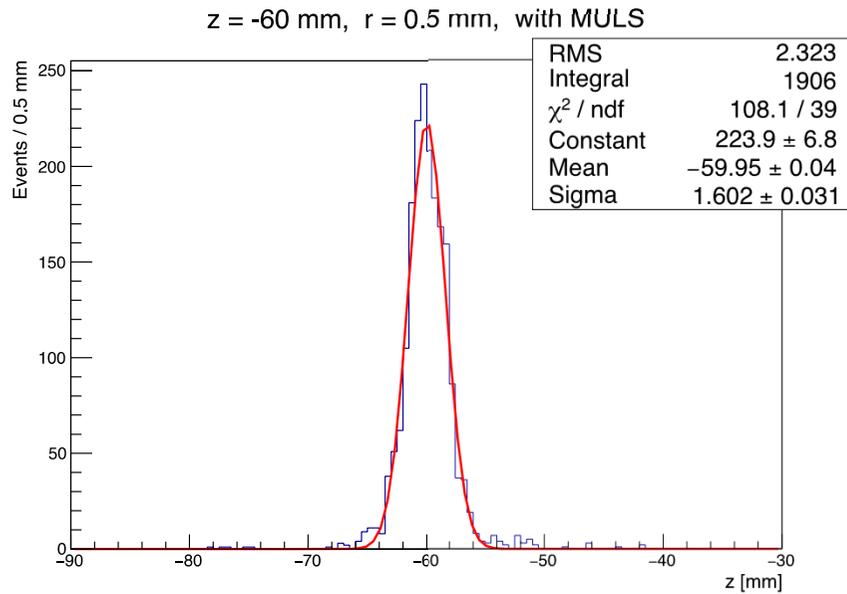
- **no other informations** to discriminate the background  
(TOF, pulse shape, etc...)

# Attività del gruppo – 3) FACT reconstruction

- Candidate tracks are created by fitting at least 3 hits in different layers
- The number of candidate tracks is  $O(N)$  where  $N = n_1 n_2 n_3$  ( $n_1 n_2 n_3 n_4$ ) for 3-layers (4-layers) fits
- Track candidates are requested to pass a quality filter based on  $\chi^2/\text{ndof}$  of the fit



# Attività del gruppo – 3) FACT reconstruction



- The overall vertex reconstruction efficiency depends on several parameters:

- ~50% (MC)\*
- The BR of having at least 3 prongs from a  $p\text{-}p\bar{p}$  annihilation
  - The acceptance term
  - The probability of a prong to fire at least 3 fibers in different layers
  - The annihilation vertex  $\mathbf{r}$
  - The material budget (MULS)
  - The “intrinsic” efficiency of the algorithm

- For  $r = 0$  the algorithm itself is very efficient (>90%)
- As  $r > 0$  mm geometrical effects tend to reduce the efficiency of the algorithm
  - for  $r = 0.9$  (with MULS) the efficiency is ~30%
- Of course the efficiency of the algorithm can be improved at the cost of a worse resolution and larger dependence on the noise

# The 2015 data taking

## AD Schedule 2015 (Version 1.0 Feb 24 th, 2015)

Wk	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Jun 15 - Jun 21	AD setting up						
Jun 22 - Jun 28	AD setting up						
Jun 29 - Jul 5	07-15	15-23	23-07				
Jul 6 - Jul 12	MD	AD5 AD6	AD2 AD5 AD6				
Jul 13 - Jul 19	AD3	AD2 AD5	AD3 AD2 AD5				
Jul 20 - Jul 26	AD6	AD3 AD2	AD6 AD3 AD2				
Jul 27 - Aug 2	MD	AD6 AD3	AD5 AD6 AD3				
Aug 3 - Aug 9	AD2	AD5 AD6	AD2 AD5 AD6				
Aug 10 - Aug 16	AD3	AD2 AD5	AD3 AD2 AD5				
Aug 17 - Aug 23	MD	AD3 AD2	AD8 AD3 AD2				
Aug 24 - Aug 30	AD6	AD8 AD3	AD6 AD8 AD3				
Aug 31 - Sep 6	AD5	AD6 AD8	AD5 AD6 AD8				
Sep 7 - Sep 13	MD	AD5 AD8	AD2 AD5 AD8	AD2 AD5 AD8	AD2 AD5 AD6	AD2 AD5 AD6	AD2 AD5 AD6
Sep 14 - Sep 20	AD3	AD2 AD8	AD3 AD2 AD8	AD3 AD2 AD8	AD3 AD2 AD5	AD3 AD2 AD5	AD3 AD2 AD5
Sep 21 - Sep 27	AD6	AD3 AD8	AD6 AD3 AD8	AD6 AD3 AD8	AD6 AD3 AD2	AD6 AD3 AD2	AD6 AD3 AD2
Sep 28 - Oct 4	MD	AD6 AD8	AD5 AD6 AD8	AD5 AD6 AD8	AD5 AD6 AD3	AD5 AD6 AD3	AD5 AD6 AD3
Oct 5 - Oct 11	AD2	AD5 AD8	AD2 AD5 AD8	AD2 AD5 AD8	AD2 AD5 AD6	AD2 AD5 AD6	AD2 AD5 AD6
Oct 12 - Oct 18	AD3	AD2 AD8	AD3 AD2 AD8	AD3 AD2 AD8	AD3 AD2 AD5	AD3 AD2 AD5	AD3 AD2 AD5
Oct 19 - Oct 25	MD	AD3 AD8	AD6 AD3 AD8	AD6 AD3 AD8	AD6 AD3 AD2	AD6 AD3 AD2	AD6 AD3 AD2
Oct 26 - Nov 1	AD5	AD6 AD8	AD5 AD6 AD8	AD5 AD6 AD8	AD5 AD6 AD3	AD5 AD6 AD3	AD5 AD6 AD3
Nov 2 - Nov 8	AD2	AD5 AD8	AD2 AD5 AD8	AD2 AD5 AD8	AD2 AD5 AD6	AD2 AD5 AD6	AD2 AD5 AD6
Nov 9 - Nov 15	MD	AD2 AD8	AD3 AD2 AD8	AD3 AD2 AD8	AD3 AD2 AD5	AD3 AD2 AD5	AD3 AD2 AD5

AD physics stop November 16th 8AM.

<del>AD3</del>	<del>AD8</del>
<del>AD6</del>	<del>AD8</del>
<del>AD5</del>	<del>AD8</del>
<del>AD2</del>	<del>AD8</del>
<del>AD3</del>	<del>AD8</del>
<del>AD6</del>	<del>AD8</del>
<del>AD5</del>	<del>AD6</del>
<del>AD2</del>	<del>AD5</del>
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<del>AD3</del>	
<del>AD6</del>	

AD MD (7:00-15:00) or Injector Stop 8h

Injector MD (7:00-17:00) every Wednesday

AD2 (ATRAP)    AD3 (ASACUSA)    AD4 (ACE)    AD5 (ALPHA)    AD6 (AEGIS)    AD8 (BASE)

# The 2015 data taking

## OBIETTIVI PER IL RUN 2015

- 1. positroni:**
  - trasferire i positroni nel magnete 1T
  - produrre positronio nel magnete 1T
- 2. antiprotoni:**
  - migliorare l'efficienza di trasferimento nel magnete 1T
- 3. anti-idrogeno:**
  - produzione di anti-idrogeno
- 4. Rivelazione:**
  - rivelare e misurare i parametri di produzione dell'anti-idrogeno

(Misura di g: 2016 e 2017, prima della pausa per l'installazione di ELENA)

# Attività FAMU-PV 2015

CdS, 11 giugno 2015



# Motivazioni: il puzzle del raggio del protone

Misura dello splitting iperfine (HFS) nello stato base dell'idrogeno muonico.

## Il raggio Zemach del protone dal HFS del $(\mu^-p)_{1S}$

- Esperimento basato sul Lamb Shift nel  $\mu^-p$  al PSI (2010):  
 $r_{\text{ch}} = 0.84089(39) \text{ fm}$
- Discrepanza di  $7\sigma$  da CODATA-2010:  
 $r_{\text{ch}} = 0.87750(510) \text{ fm}$   
basato su scattering e-p e spettroscopia H.

Necessità di una misura conclusiva: FAMU @RIKEN-RAL muon facility.

# Struttura del protone

Si considerano le distribuzioni di carica,  $\rho_E(r)$  e magnetica,  $\rho_M(r)$ .

Solo due dei loro momenti sono direttamente legati a quantità osservabili:

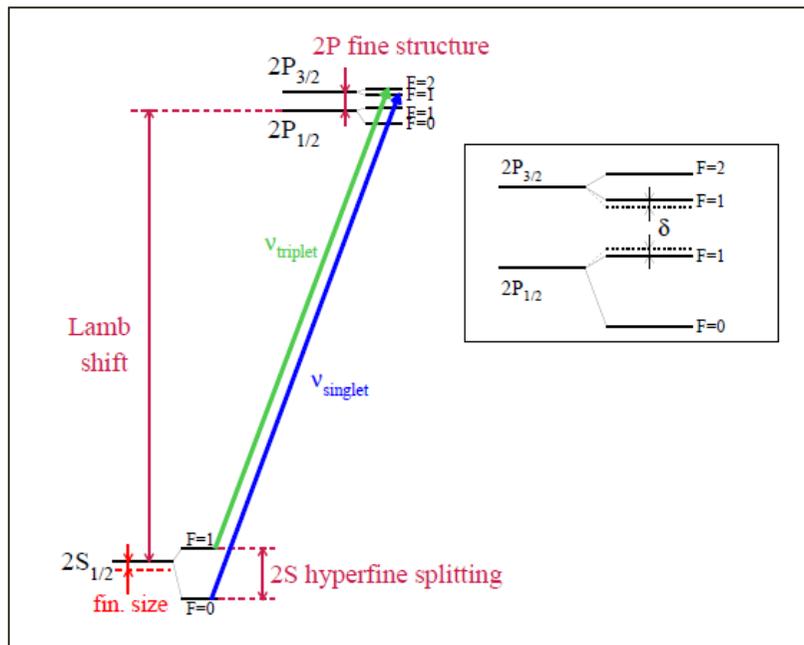
$$r_{ch} = (\int \rho_E(r) r^2 d^3r)^{1/2} : \Delta E_{LS} = 206.0669(25) - 5.2275(10) r_{ch}^2 \text{ meV}$$

$$R_Z = \int (\int \rho_E(r') \rho_M(r-r') d^3r') r d^3r :$$

$$\Delta E_{2S}^{HFS} = 22.9843(30) - 0.1621(10) R_Z \text{ meV}$$

$$\Delta E_{1S}^{HFS} = 184.087X - 1.281Y R_Z \text{ meV}$$

La teoria prevede  $X \approx 15$ ,  $Y < 10$ .



# Metodologia

- L'atomo di  $\mu p$  assorbe una fotone da un laser IR alla lunghezza d'onda della risonanza  $\lambda_0 = hc / \Delta E_{\text{HFS}}^{1S} \approx 6.8 \text{ } \mu\text{m}$  della transizione da singoletto a tripletto (spin flip).
- Quando l'atomo viene de-eccitato collisionalmente allo stato 1S, viene accelerato di 0.12 eV ( $\approx 2/3$  dell'energia di transizione iperfine).
- Questa sequenza di processi viene rivelata tramite i prodotti di reazioni la cui rate dipende dalla velocità del  $\mu p$ .
- In particolare, viene osservato il trasferimento del  $\mu$  dal protone a nuclei di un gas pesante appropriato, che abbia una dipendenza importante dell'energia dalla rate di trasferimento.
- Il trasferimento del  $\mu$  è identificato da raggi X caratteristici emessi durante la diseccitazione dell'atomo muonico più pesante.
- $\lambda_0$  (da cui si ricava  $\Delta E_{\text{HFS}}^{1S}$ ) viene identificata dalla risposta massimale.

# La Collaborazione FAMU (2015)

Coordinatore Nazionale: Andrea Vacchi (INFN Trieste)

Sezione	Resp. locale	FTE ricercatori	FTE tecnologi/tecnici	FTE totali
Bologna	G. Baldazzi	2.1	0.3	2.4
Milano	R. Ramponi	0.1	0.0	0.1
Milano Bicocca	M. Bonesini	3.1	0.7	3.8
Pavia	A. Menegolli	1.1	0.4	1.5
Roma III	L. Tortora	1.2	0.3	1.5
Trieste	<b>A. Vacchi</b>	4.1	0.4	4.5

## FAMU-PV: anagrafica 2015

Nome	Ruolo	FTE	Note
A. De Bari	Ricerc. Universitario	0.4	
A. Menegolli	Ricerc. Universitario	0.4	Responsabile locale
R. Nardò	Tecnologo Universitario	0.2	
M. Rossella	Tecnologo INFN	0.2	
A. Tomaselli	Ricerc. Universitario	0.3	Dipart. di Ing. Industriale e dell'Informazione
TOTALE		1.5	

# Attività FAMU 2015

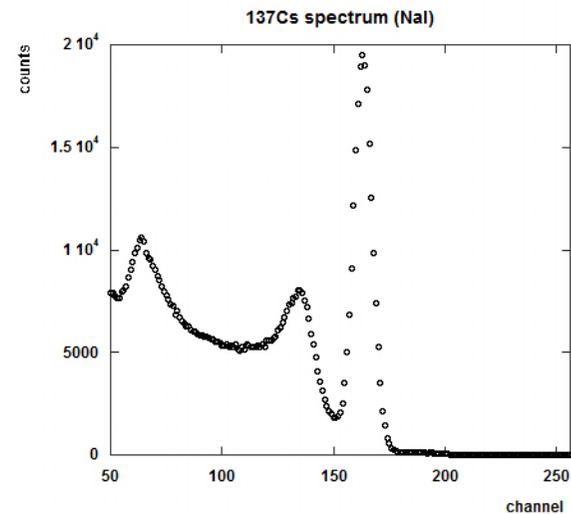
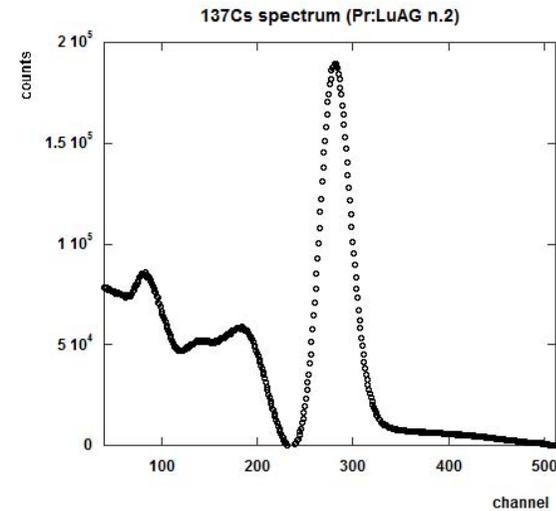
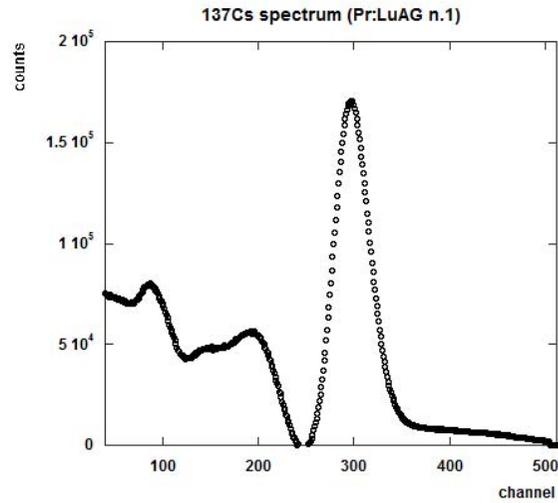
- Misura della rate di trasferimento di muoni da idrogeno muonico ad atomi pesanti: si varieranno la pressione, la temperatura e la concentrazione dei nuclei nella miscela di gas. Caratterizzazione e scelta del rivelatore X più idoneo: test run su fascio di muoni a RIKEN-RAL (novembre 2015).
- Finalizzazione del sistema per il monitor dei muoni del fascio (possibile test run al CERN luglio-agosto 2015).
- Realizzazione del sistema laser.

# Attività FAMU-PV: gennaio-maggio 2015

1) Attività di caratterizzazione di cristalli di  $\text{Lu}_3\text{Al}_5\text{O}_{12}:\text{Pr}$  (Pr:LuAG) come rivelatore X ( $14 \times 14 \times 13 \text{ mm}^3$ ), in vista della realizzazione di un array di cristalli da inserire nel setup del test run 2015 a RIKEN-RAL.



Pr:LuAG accoppiato alla finestra di un PMT Hamamatsu R11065, alloggiato assieme alla sorgente di  $^{137}\text{Cs}$  in un supporto disegnato da Milano Bicocca e realizzato con la stampante 3D di Sezione.



Il picco del <sup>137</sup>Cs a 662 keV è ben risolto, ma la risoluzione in energia con PrLuAG è ~ 13%, con NaI ~ 6%. In letteratura si trova riportata una risoluzione in energia di circa 5% con PrLuAG a 662 keV.

Attività in corso:

- Misure di auto-assorbimento di Pr:LuAG in collaborazione con il gruppo di spettroscopia Raman (Prof. Pietro Galinetto).
- Deposito di riflettore BaSO<sub>4</sub> in collaborazione con il Dipartimento di Chimica Fisica (Prof. Lorenzo Malavasi), per migliorare l'efficienza di raccolta della luce e quindi la risoluzione in energia.
- Collaborazione con il LENA per utilizzo spazi e sorgenti.

Poster presentato alla Conferenza “*Frontier Detectors for Frontier Physics*” (La Biodola, 24-30 Maggio 2015):

## Characterization of Pr:LuAG scintillating crystals for X-ray spectroscopy



R. Bertoni<sup>(1)</sup>, M. Bonesini<sup>(1)</sup>, M. Clemenza<sup>(1)</sup>, A. De Bari<sup>(2,3)</sup>, A. Falcone<sup>(2,3)</sup>,  
R. Mazza<sup>(1)</sup>, A. Menegolli<sup>(2,3)</sup>, M. Nastasi<sup>(1)</sup>, M. Rossella<sup>(3)</sup>

<sup>(1)</sup>INFN, Sezione di Milano Bicocca

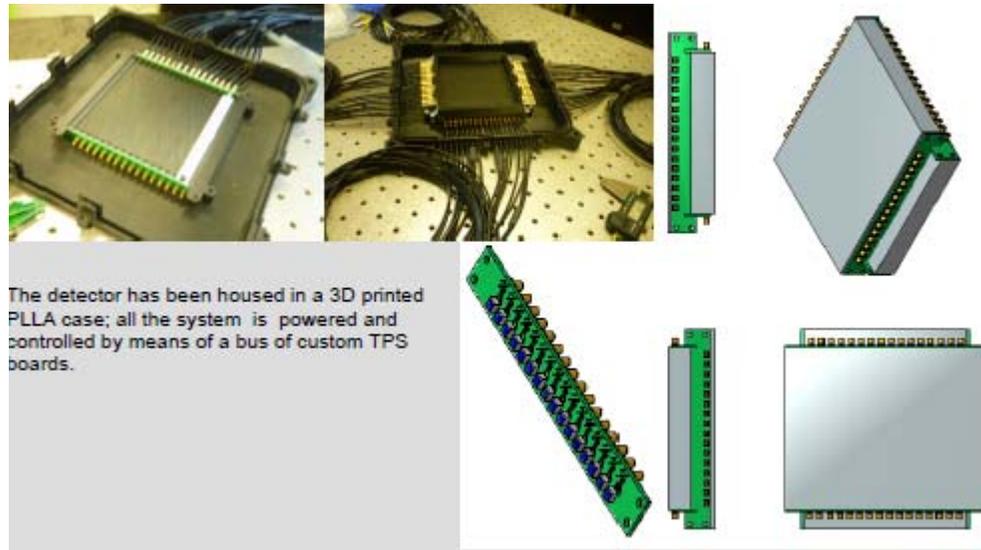
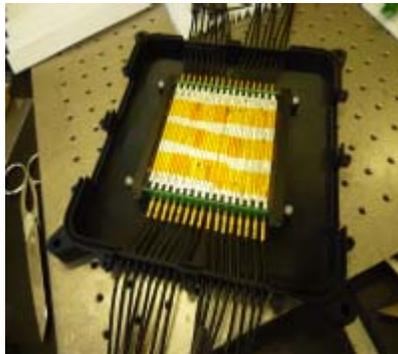
<sup>(2)</sup>Università degli Studi di Pavia

<sup>(3)</sup>INFN, Sezione di Pavia



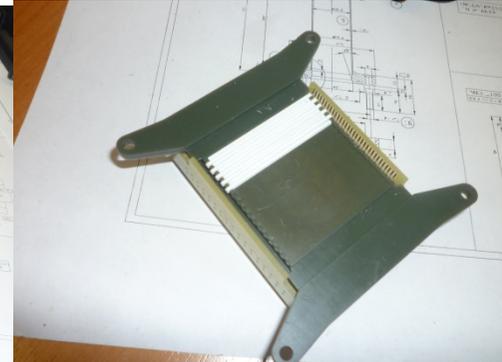
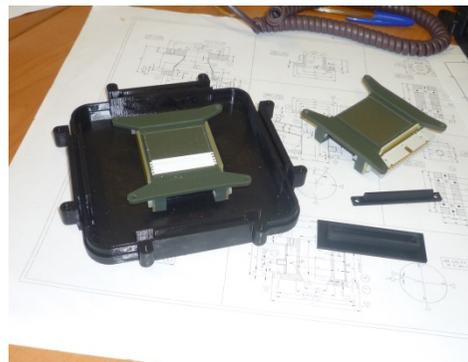
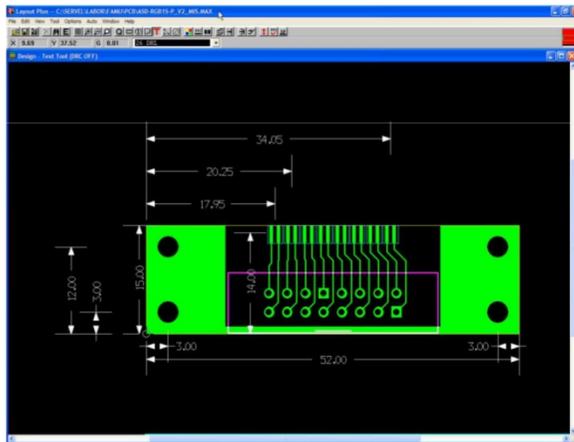
# Attività FAMU-PV: monitor di fascio 2014

- 2 piani x/y di fibre scintillanti BCF12 (diametro 3 mm) lette da SiPM Advansid 3x3 mm<sup>2</sup> con celle da 40 μm.
- 32+32 canali letti da elettronica di front-end sviluppata per SuperB/TPS (alimentazione singola /shaper/discriminatore).
- Segnale analogico letto da QADC CAEN V792 + segnale discriminato (tempo) da TDC CAEN V1190.
- Costruito e testato in < 4 mesi [**aiuto essenziale da INFN PV: M. Rossella, M. Prata, R. Nardò**].
- **Meccanica stampata su stampante 3D a Pavia** su CAD di INFN Milano Bicocca.



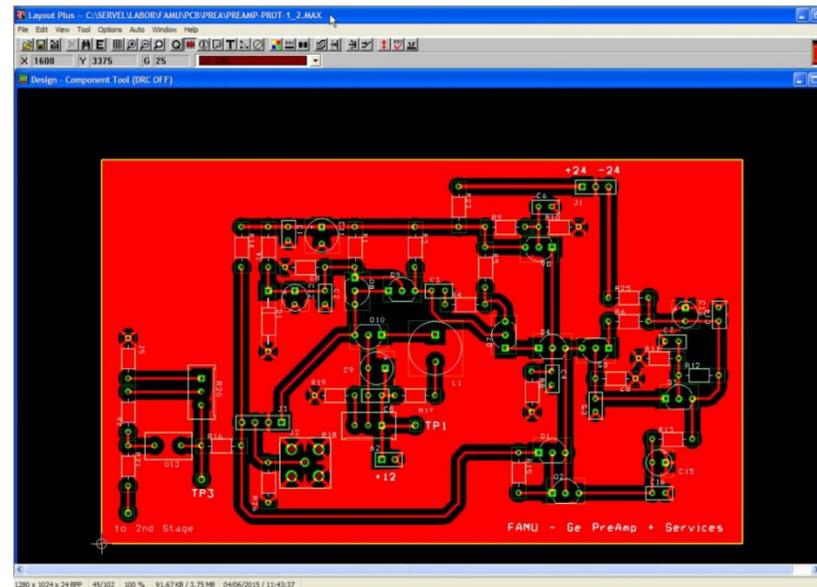
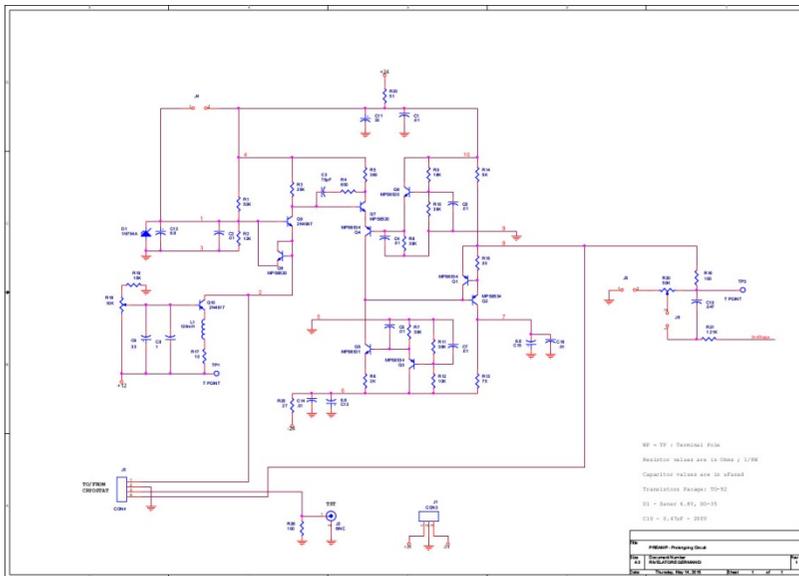
# Attività FAMU-PV 2015: nuovo monitor di fascio

- 2 piani x/y di fibre scintillanti BCF12 (diametro 1 mm) lette da SiPM Advansid 1x1 mm<sup>2</sup> con celle da 40  $\mu\text{m}$ .
- Boards per alloggiamento SiPM disegnate e realizzate dal Servizio Elettronico della Sezione di Pavia.
- Meccanica stampata su stampante 3D a Pavia su CAD di INFN Milano Bicocca.



# Attività FAMU-PV 2015: elettronica per rivelatore a Germanio

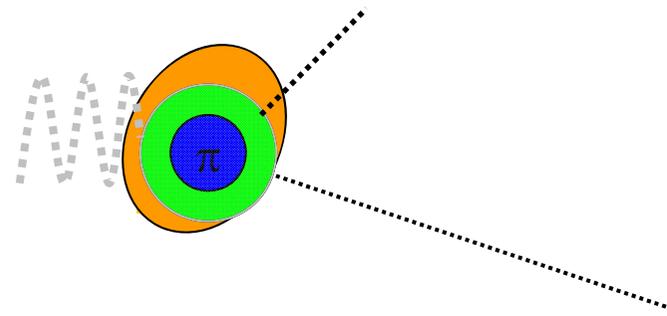
- Disegno e realizzazione da parte del Servizio Elettronico dello stadio di pre-amplificazione per il rivelatore a Germanio di INFN Milano Bicocca, in vista del test run 2015.



## Attività FAMU-PV 2015: prossimi mesi

- Realizzazione di un array di quattro cristalli PrLuAG letti da PMT in vista del test run di FAMU a RIKEN-RAL.
- Finalizzazione della costruzione del monitor di fascio e test run al CERN (luglio/agosto 2015).
- Realizzazione dell'elettronica di lettura dei cristalli di Germanio di INFN MiB.
- Partecipazione al test run di FAMU sul fascio di muoni RIKEN-RAL (novembre 2015).

# MAMiBO<sub>nn</sub>



Studio di fotoreazioni indotte su nucleoni e nuclei utilizzando gli acceleratori

➤ **MAMI**  $E_\gamma \leq 1.6 \text{ GeV}$  (Mainz)

A2 Collaboration

Spokepersons: **A. Thomas** Uni-Mainz  
**P. Pedroni** INFN -Pavia

➤ **ELSA**  $E_\gamma \leq 3.0 \text{ GeV}$  (Bonn)

BGO-OD Collaboration

Spokepersons: **H.Schmieden** Uni-Bonn  
**P. Levi Sandri** INFN -LNF

## **COLLABORAZIONE MAMBO**

**Responsabile Nazionale: ALESSIA FANTINI**

**Sezioni INFN partecipanti:**

<b>ROMA TOV</b>	<b>Responsabile Locale fino ad oggi</b>	<b>ALESSIA FANTINI</b>
<b>LNF</b>	<b>Responsabile Locale</b>	<b>PAOLO LEVI SANDRI</b>
<b>MESSINA</b>	<b>Responsabile Locale</b>	<b>GIUSEPPE MANDAGLIO</b>
<b>PAVIA</b>	<b>Responsabile Locale</b>	<b>PAOLO PEDRONI</b>
<b>ISS-RM</b>	<b>Responsabile Locale</b>	<b>FRANCESCO GHIO</b>
<b>TORINO</b>	<b>Responsabile Locale</b>	<b>GIANPIERO GERVINO</b>

**26 ricercatori; 13.6 FTE**

# MAMiBO<sub>nn</sub>

## Research at Mainz

➤ **MAMI**  $E_\gamma \leq 1.6$  GeV (Mainz)



A2 Collaboration  
(about 80 people)

Spokepersons: **A. Thomas** Uni-Mainz  
**P. Pedroni** INFN -Pavia

## Participant Institutions:

Universities: Mainz, Bonn, Basel, Glasgow, Edinburgh, Jerusalem  
GWU, Umass , KSU (USA), Regina, MAU, Dalhousie (Canada)  
Others: INFN, RBI (Zagreb), INR (Moscow), JINR (Dubna)

# A2@MAMI: Main physics objectives

(mainly involving low cross sections and/or precision measurements)

- **Internal Nucleon structure:**

Can the theory of quark and gluon confinement (NPQCD,  $\chi$ PT) **quantitatively** describe the detailed properties of hadrons?

Compton Scattering ( $\gamma N \rightarrow \gamma N$ )

$\pi^0$  photoproduction at threshold

- **Ambiguity free amplitude analysis of meson photoproduction**

Requires Double polarization measurements:

$\gamma N \rightarrow N\pi(\pi)$ ;  $N\eta$  ( $\rho, \dots$ ) channels

- **Tests of fundamental symmetries (C, CP, CPT...)**

Rare  $\eta, \eta'$  decays

- **In medium properties of hadrons & nuclear physics:**

Meson photo production on nuclei ("neutron skin")

## Experimental set-up

➤ **High intensity/quality tagged photon beam**

➤ **Circularly & Linearly polarized photons**

bremsstrahlung of linearly polarized electrons  
coherent bremsstrahlung (diamond radiator)

➤ **Longitudinally/Transversally polarized protons and neutrons**

Frozen spin (prot./deut.) butanol target / Longitudinally polarised  $^3\text{He}$  gas target / ( R&D for active polarised targets)

➤ **Unpolarised targets**

Liquid:  $^1\text{H}$ ,  $^2\text{H}$ ,  $^4\text{He}$ ; **active** gas  $^4\text{He}$  target ; solid nuclear targets

➤ **Large acceptance hadron detector**

Nucleon recoil polarimeter

# 4 $\pi$ Spectrometer @ MAMI

## TAPS:

510 BaF<sub>2</sub>-detectors  
maximum kin. Energy

$\pi^\pm$  : 180 MeV

$K^\pm$  : 280 MeV

$p$  : 360 MeV

## Crystal Ball:

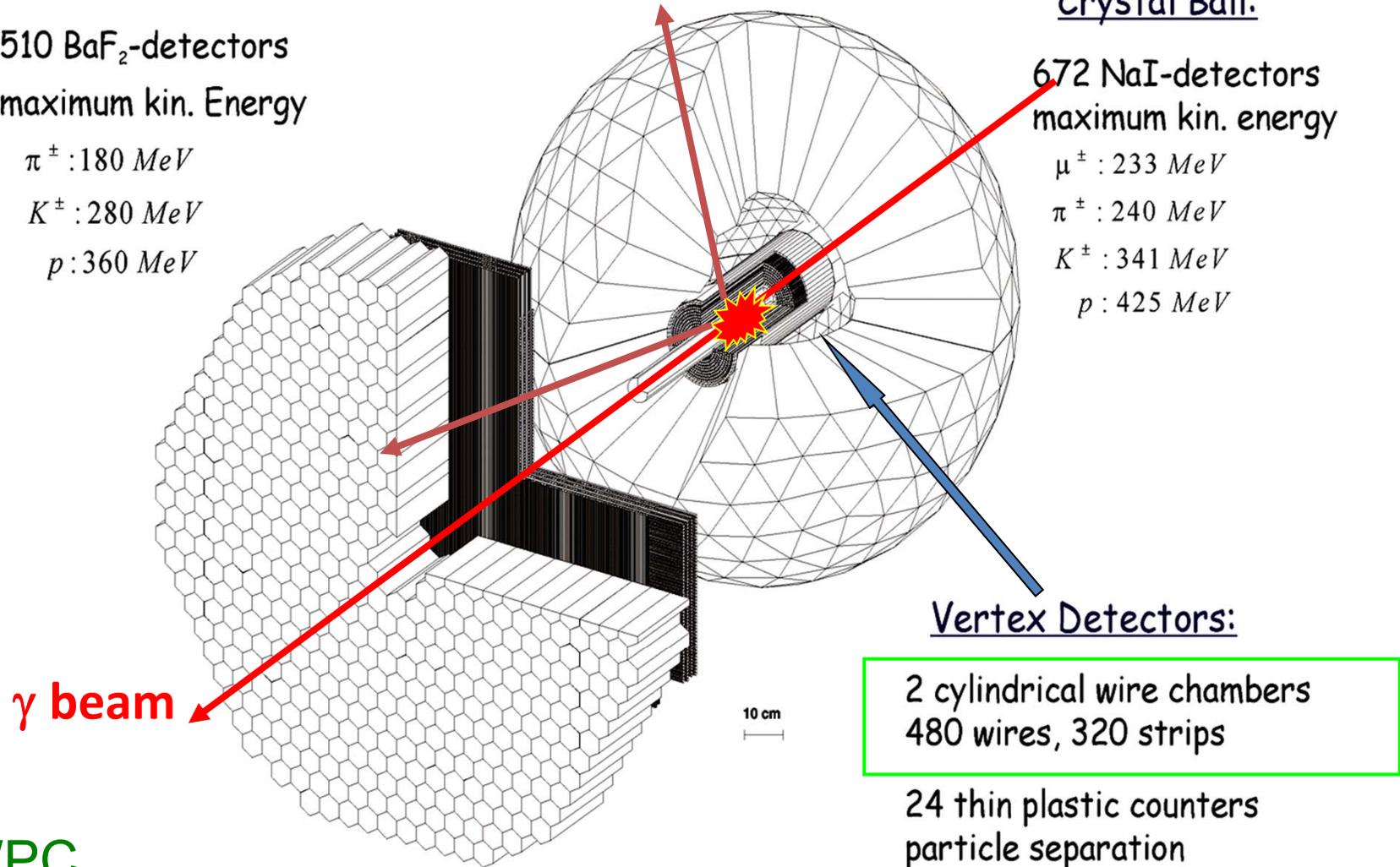
672 NaI-detectors  
maximum kin. energy

$\mu^\pm$  : 233 MeV

$\pi^\pm$  : 240 MeV

$K^\pm$  : 341 MeV

$p$  : 425 MeV



## Vertex Detectors:

2 cylindrical wire chambers  
480 wires, 320 strips

24 thin plastic counters  
particle separation

MWPC

2 cylindrical detectors (INFN - Pavia)

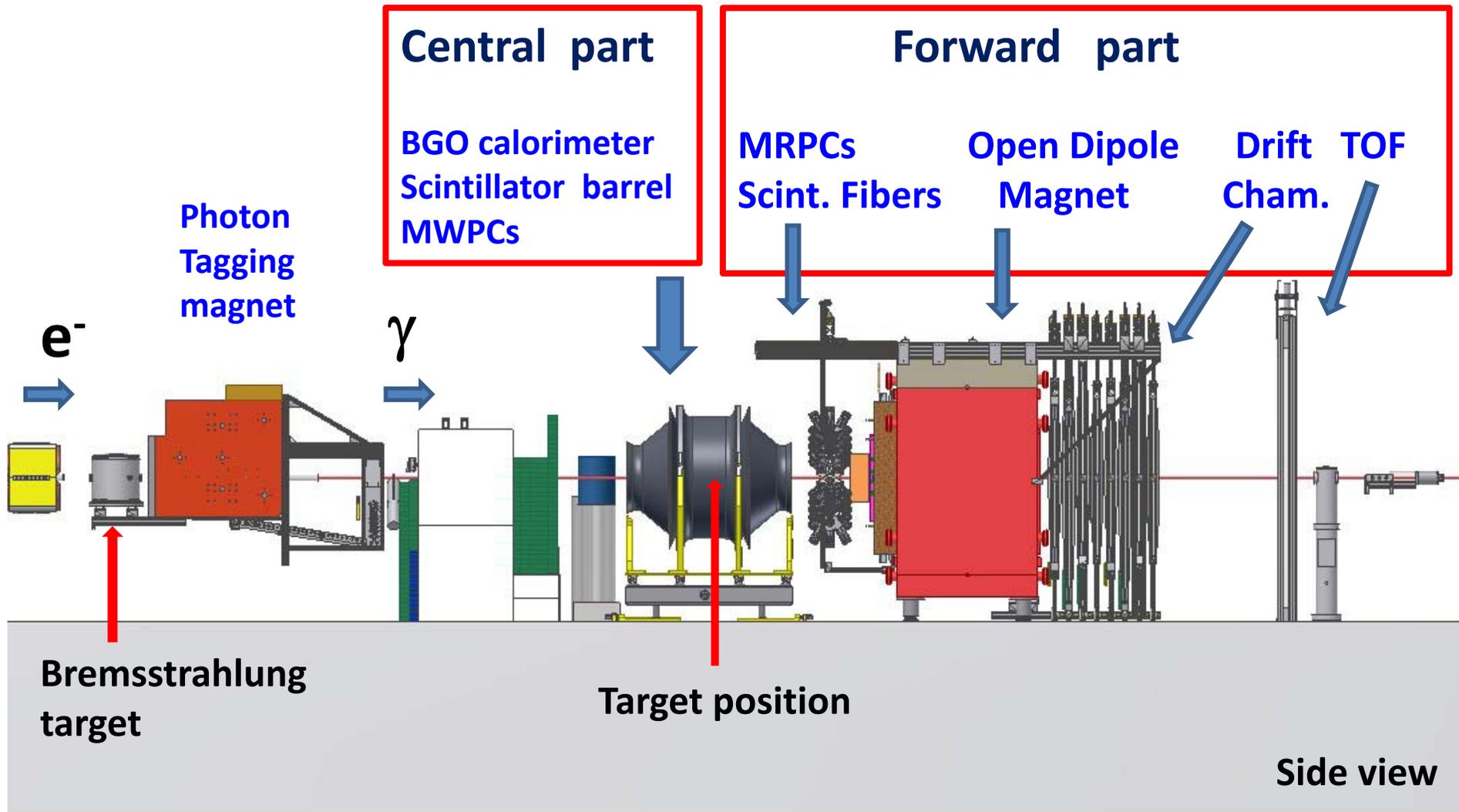
# BGO-OD Bonn: Main physics objectives

(higher nucleon excitation energies)

The goal of this project is the systematic investigation of the photoproduction of mesons off the nucleon. These processes are related to the structure of both, the mesons and baryons involved. The underlying mechanisms must still be considered as poorly understood. Improved experiments will shed new light on the low-energy hadronic aspects of the strong interaction.

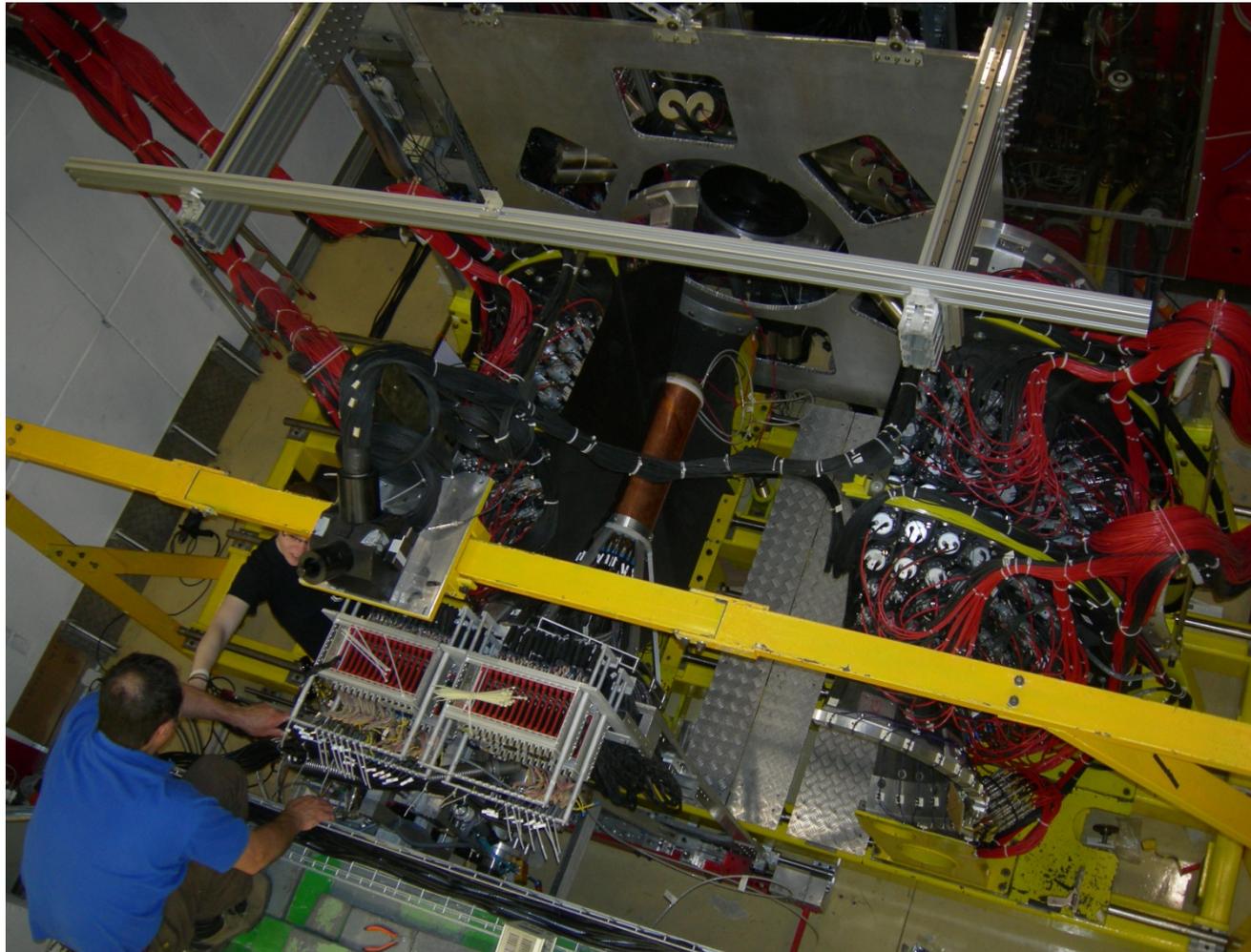
- $\gamma N \rightarrow N\eta (\eta')$  scalar mesons
- $\gamma N \rightarrow N\omega (\rho, \phi)$  vector mesons
- $\gamma N \rightarrow K\Lambda (\Sigma)$  strange mesons

# The BGO-OD apparatus



## ➤ DETECTOR

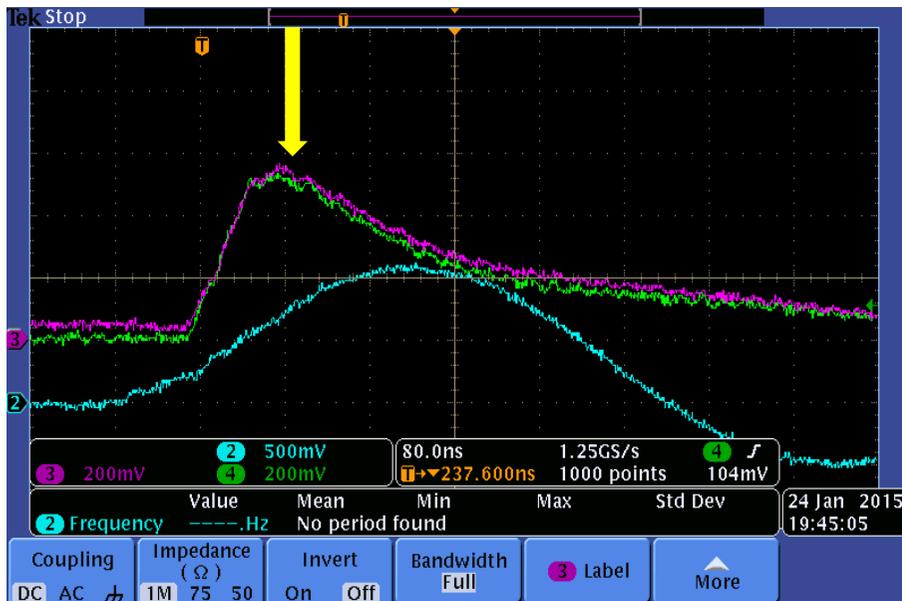
The **MWPCs** set-up has been mounted and fully cabled almost one year ago.



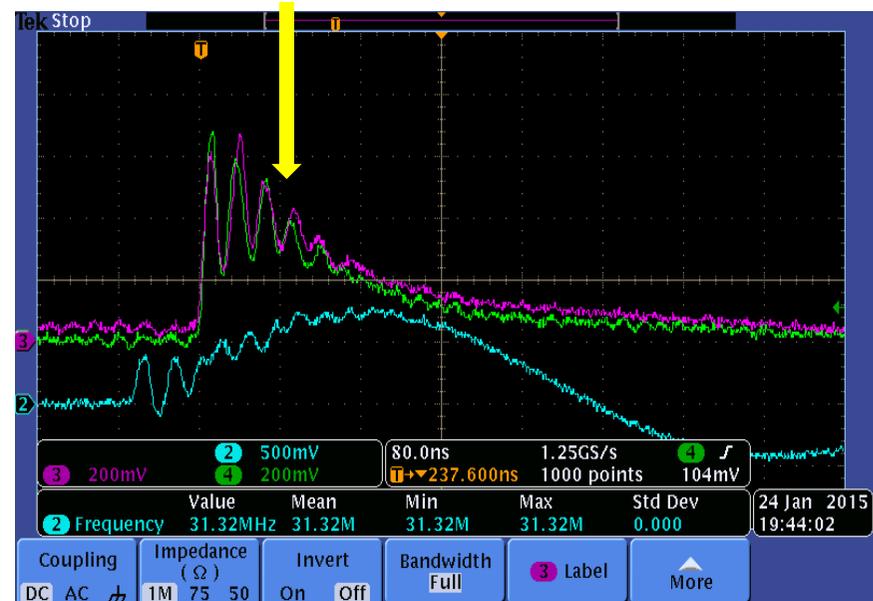
## ➤ MWPCs Commissioning

- **Basic electrical (noise) tests:** preamplifier crates provided with linear power supplies to reduce the overall electronic noise
- **Detector response: Strips**
  - =) shaping cards modified to match the signal characteristics needed by the Wiener ADC/TDC modules

«normal» signal



noisy signal



Source of this 25-30 ns oscillation still not known

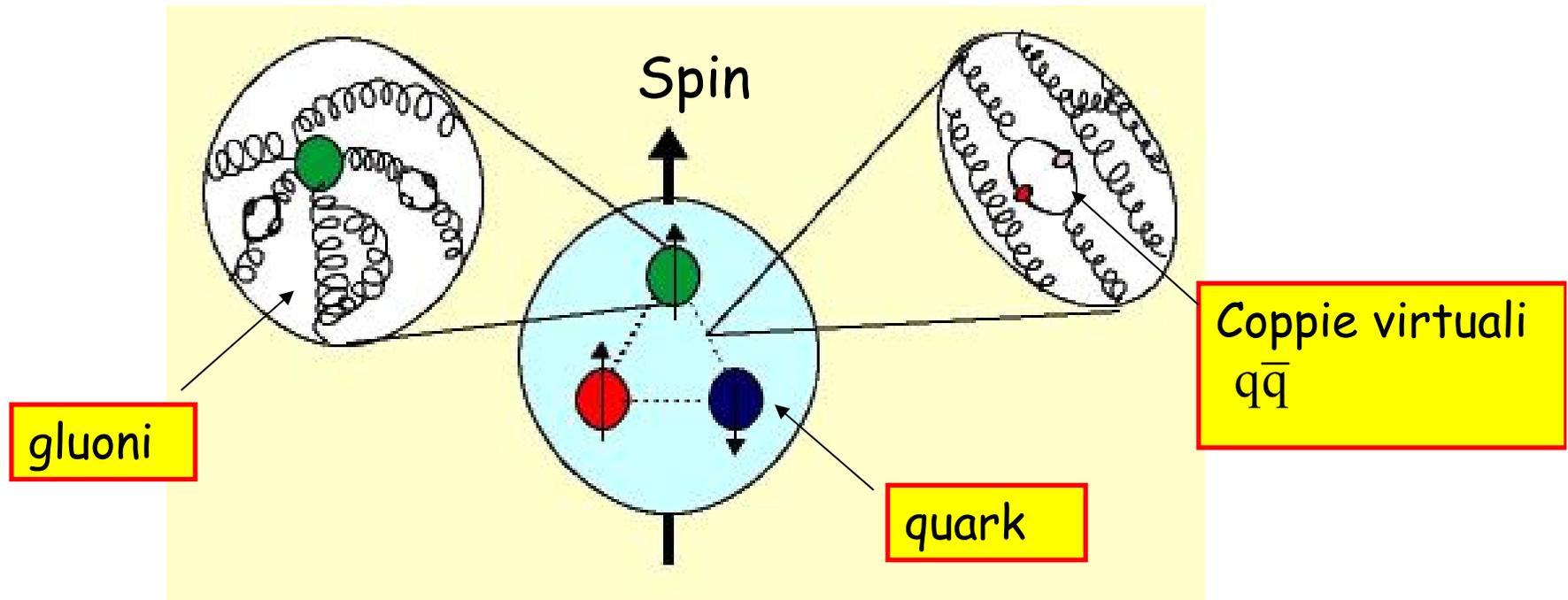
**BGO-OD**

(In blu le parti a resp. italiana)

Photon Tagger	Commissioning – Dic. 2013	← NEWS!
Goniometro (polarizz. fascio)	Commissioning – Nov. Dic. 2014	← NEWS!
Bersaglio criogenico	LH2: Commissioning - Feb.-Marzo 2012	
	LD2: Commissioning – Dic. 2014	← NEWS!
<b>- Regione centrale:</b>		
Calorimetro e.m. di BGO	Commissioning - Feb.-Marzo 2012	
NEWS! →	Commissioning con Campo Magn. – Dic. 2013 e Maggio 2014	
Barrel di scintillatori plastici	Commissioning - Giugno 2012	
MWPC	Installate e testate con cosmici a Bonn	
	Primo test su fascio – Dic. 2014	← NEWS!
	Commissioning previsto a Giugno 2015	
<b>- Regione in avanti:</b>		
MRPC	In fase di installazione a Bonn (12-25 Aprile 2015)	
	Commissioning previsto a Giugno 2015	
MOMO (fibre scintillanti)	Commissioning Feb.-Marzo e Giugno 2012	} Commissioning del tracciamento con campo magnetico – Maggio 2014
SciFi2 (fibre scintillanti)	Commissioning Feb.-Marzo e Giugno 2012	
Dipolo magnetico	Full Field raggiunto a Feb.2013	
4 Muri TOF	Commissioning di 2 muri – Maggio 2013	
NEWS! →	Commissioning di 2 muri – Maggio/Dic. 2014	
Drift Chambers	Commissioning Giugno 2012	↑
<b>- Rivelatori di flusso:</b>		
GIM (alta eff.)	Commissioning Dic. 2014	← NEWS!
FluMO (bassa eff.)	Commissioning Dic. 2014	← NEWS!

Primo run di produzione dati: inizio 22 giugno

# Perché il protone (neutrone) è dotato di spin ?



- Modello "naif"  $Spin = \frac{1}{2} = \sum Spin_{quark}$
- QCD perturbativa  $Spin = \frac{1}{2} = \sum Spin_{quark} + L_{quark} + \Delta_{gluoni} + \Delta_{q\bar{q}}$   
 $\sum Spin_{quark} \simeq 80\%$  dello Spin
- Esperimenti:  $\sum Spin_{quark} \sim 20-30\%$  dello Spin (!)

# Observables for $\gamma N \rightarrow N (\rightarrow N^*) \pi$ photoproduction

Photon polarization		Target polarization			Recoil nucleon polarization			Target and Recoil polarizations			
		X	Y	Z <sub>(beam)</sub>	X'	Y'	Z'	X'	X'	Z'	Z'
unpolarized	$\sigma$	-	$T$	-	-	$P$	-	$T_x$	$L_x$	$T_z$	$L_z$
linear	$\Sigma$	$H$	(-P)	$G$	$O_x$	(-T)	$O_x$	(-L <sub>z</sub> )	(T <sub>z</sub> )	(L <sub>x</sub> )	(-T <sub>x</sub> )
Circular	-	$F$	-	$E$	$C_x$	-	$C_z$	-	-	-	-

**1 unpolarized measurement**

**3 single polarization measurements**

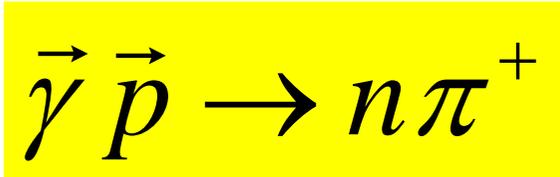
**12 double polarization measurements**

both on the proton and  
the neutron

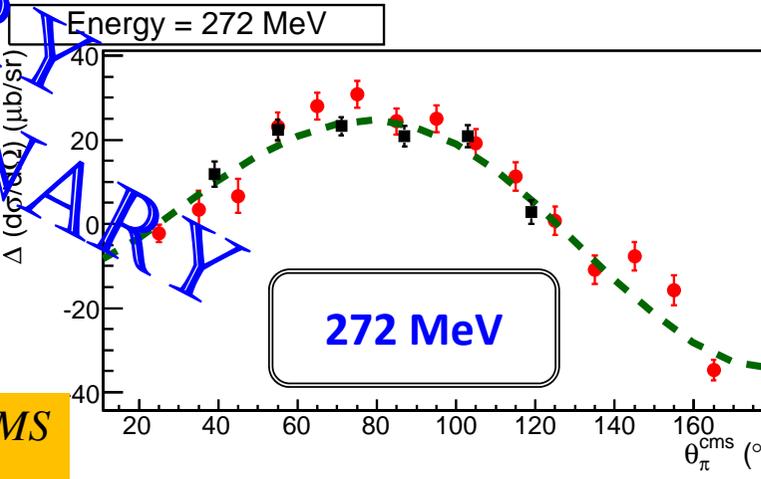
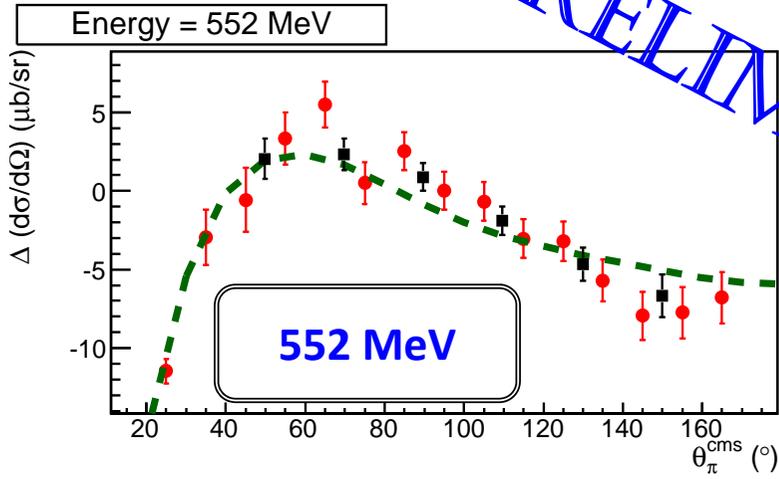
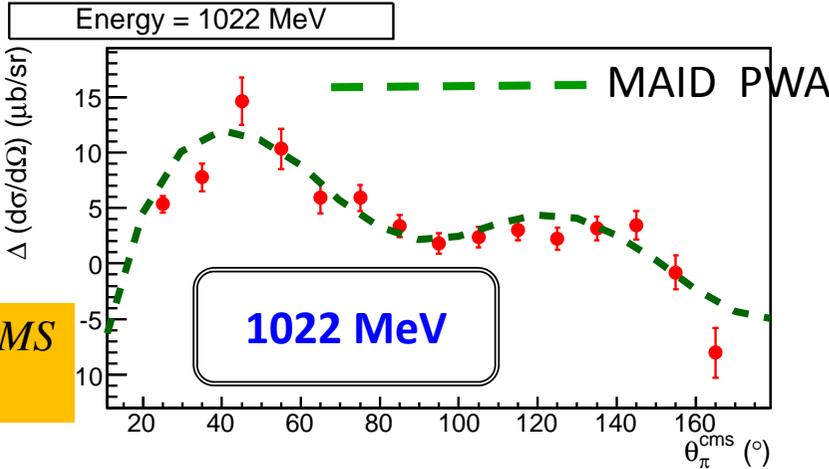
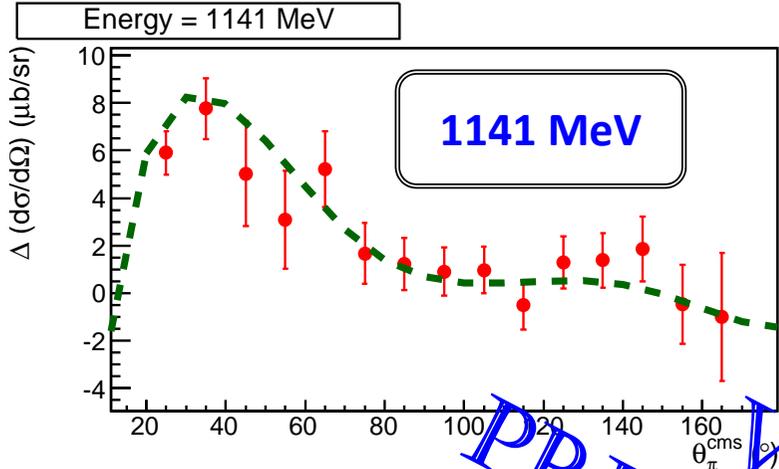


The measurement of 7 (8) (**properly chosen**) observables is necessary to **unambiguously** (in a model independent way) determine the scattering amplitudes (**“complete analysis”**)

$$\left( \frac{d\sigma}{d\Omega} \right)_P - \left( \frac{d\sigma}{d\Omega} \right)_A \quad (\mu b)$$



E. Mornacchi  
Master Thesis



PRELIMINARY

■ Published data -GDH collab. EPJA 21, 323 (04) PRC 74 045204 (06)

■ A2 Data – VERY PRELIMINARY

(about 50 % of the total statistics)

- Nucleon Form factors

## Real Compton Scattering – Hamiltonian

---

Expand the Hamiltonian in incident-photon energy.

0th order → charge, mass

1st order → magnetic moment ↔ **GDH Sum rule**

2nd order → **scalar polarizabilities:**

$$H_{\text{eff}}^{(2)} = -4\pi \left[ \frac{1}{2} \alpha_{E1} \vec{E}^2 + \frac{1}{2} \beta_{M1} \vec{H}^2 \right]$$

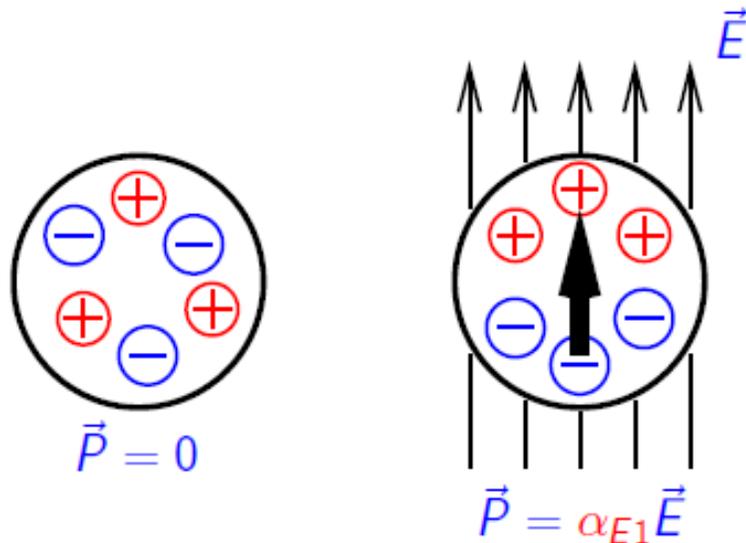
**Polarizabilities:**  
**Fundamental structure**  
**constant characterizing**  
**the nucleon response to**  
**external e.m. fields**

3rd order → **spin (or vector) polarizabilities:**

$$H_{\text{eff}}^{(3)} = -4\pi \left[ \frac{1}{2} \gamma_{E1E1} \vec{\sigma} \cdot (\vec{E} \times \dot{\vec{E}}) + \frac{1}{2} \gamma_{M1M1} \vec{\sigma} \cdot (\vec{H} \times \dot{\vec{H}}) \right. \\ \left. - \gamma_{M1E2} E_{ij} \sigma_i H_j + \gamma_{E1M2} H_{ij} \sigma_i E_j \right]$$

## Scalar Polarizabilities – Conceptual

### Electric Dipole Polarizability

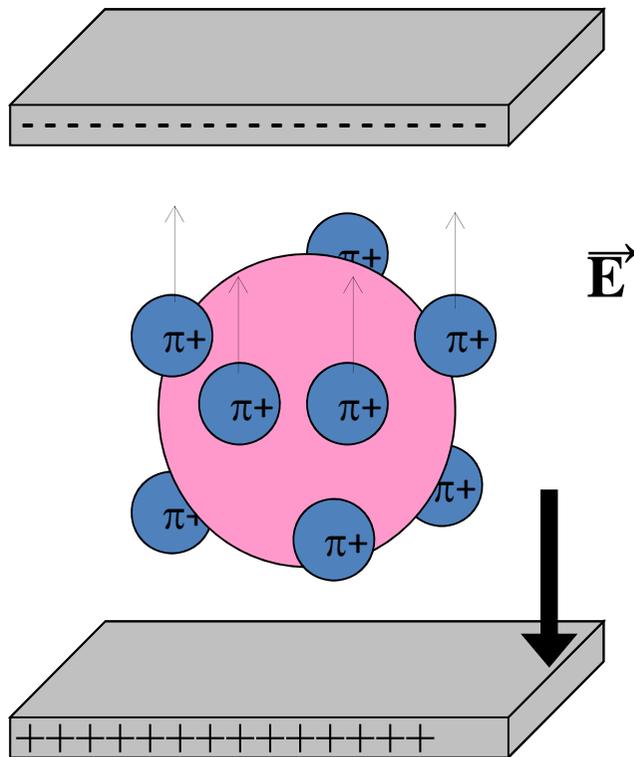


- ▶ Apply an electric field to a composite system
- ▶ Separation of Charge, or **“Stretchability”**
- ▶ Proportionality constant between electric dipole moment and electric field is the electric dipole polarizability,  $\alpha_{E1}$ .

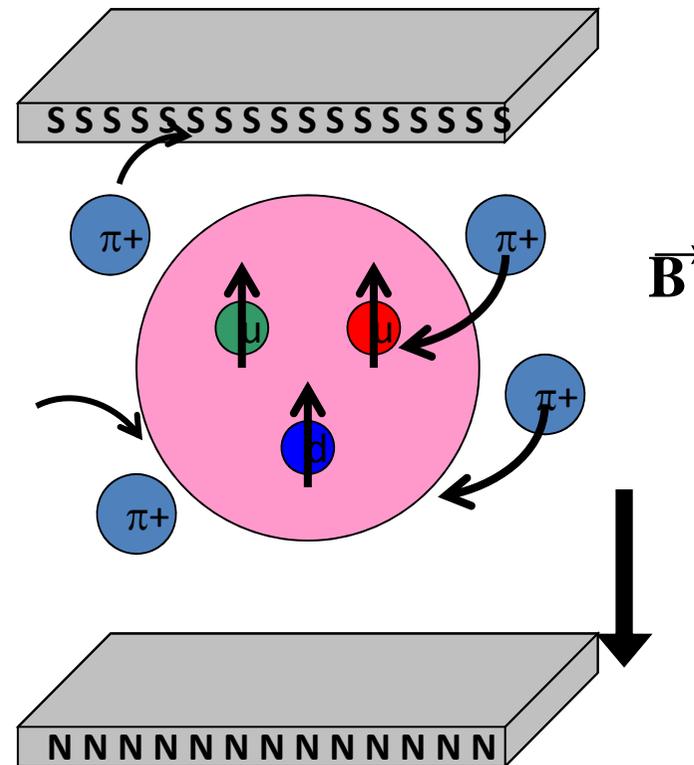
Provides information on force holding system together.

# Scalar polarizabilities

## Proton Electric Polarizability



## Proton Magnetic Polarizability



- $\alpha$ : electric polarizability
- Proton between charged parallel plates:
- “stretchability”

- $\beta$ : magnetic polarizability
- Proton between poles of a magnet:
- “alignability”

# PDG vs. $B\chi PT$

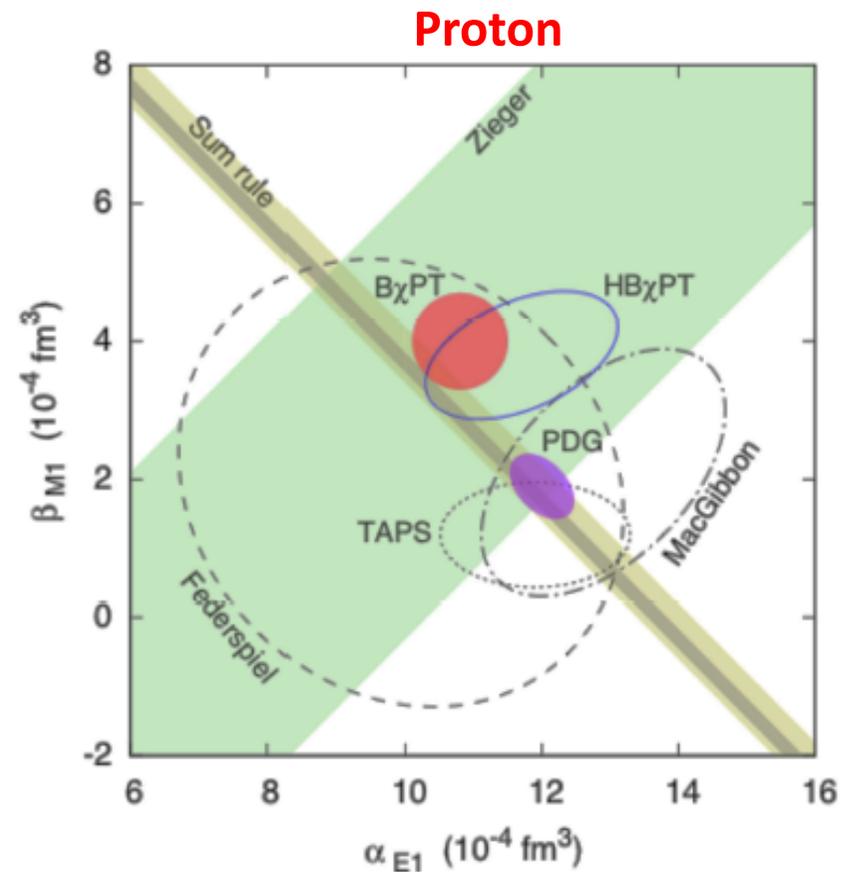
A pure prediction well reproducing most of the data

The  $B\chi PT$  result gives

	PDG	$B\chi PT$
$\alpha_{E1}$	$12.0 \pm 0.6$	$10.8 \pm 0.7$
$\beta_{M1}$	$1.9 \mp 0.5$	$4.0 \mp 0.7$

where the error is an estimation of the  $\mathcal{O}(p^4)$  loop contributions.

Global fit of existing (mostly unpolarised) data



Note also, the significant disagreement for  $\beta_{M1}$ .

$\alpha$ ,  $\beta$  are very poorly known ... (and neutron situation is much worse ...)

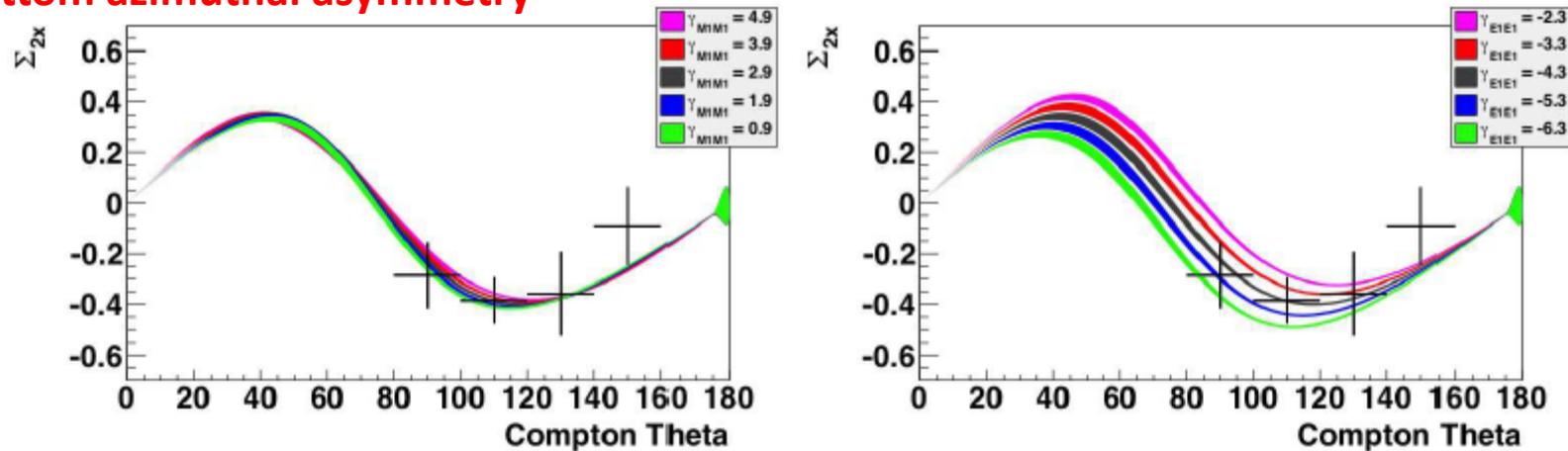
The only way to solve the ambiguity is to use linearly polarised photons (A2-MAINZ is the ONLY world facility where this experiment can be performed)

## Spin Polarizabilities – Current Status

$\gamma$	Theory					Experiment
	$p^4\text{HB}$	$\epsilon^3\text{SSE}$	NNLO	DRs	Kmatrix	
<i>E1E1</i>	-1.4	-5.4	-4.5	-4.3	-5.0	<b>no data</b>
<i>M1M1</i>	3.3	1.4	3.7	2.9	3.4	<b>no data</b>
<i>E1M2</i>	0.2	1.0	-0.9	0.0	-1.8	<b>no data</b>
<i>M1E2</i>	1.8	1.0	2.2	2.1	1.1	<b>no data</b>

First measurement of  $\gamma E1E1$  using a circularly polarized photon beam & a transversely polarized proton target

Top-bottom azimuthal asymmetry  $E_\gamma = 273 - 303$  MeV



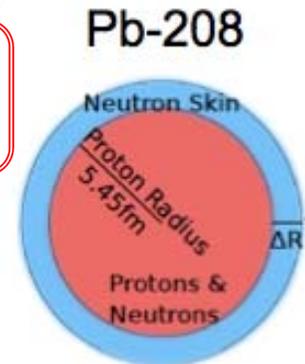
- ▶ First measurement of a double-polarized Compton scattering asymmetry on the nucleon,  $\Sigma_{2x}$ .
- ▶ Curves are from DR calculation of Pasquini et al.
- ▶ Data have sensitivity to the  $\gamma E1E1$  spin-polarizability,

$$\gamma_{E1E1} = (-4.5 \pm 1.5) \times 10^{-4} \text{ fm}^4$$

P. Martel et al., PRL 114 (2015)

# The neutron skin

**Neutron skin thickness  $\Delta r_{np} = R_n - R_p$**   
 where  $R_{n(p)}$  = RMS radii for the n(p) distribution ( $\langle r^2 \rangle^{1/2}$ )



- Sensitive to nuclear dynamics and provides fundamental nuclear structure information
- It constrains poorly established parameters in the EOS of neutron rich matter (density dependence of the nuclear symmetry energy  $E_{sym}$ ):

Baryon density

$$\rho = \rho_n + \rho_p$$

Isospin asymmetry

EOS:  $E(\rho, \delta) = E(\rho, 0) + E_{sym}(\rho)\delta^2 + \mathcal{O}(\delta)^4$

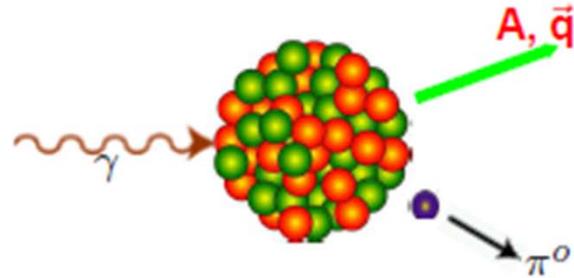
$$\delta = \frac{\rho_n - \rho_p}{\rho}$$

- Important implications in astrophysics (neutron stars):
  - constraint on the mass - radii relationship in neutron stars
  - feasibility of direct URCA cooling mechanisms in neutron stars
  - information on the critical density for the transition between liquid and solid phase



# Coherent pion photoproduction

Photon probe ✓  
Interaction well understood



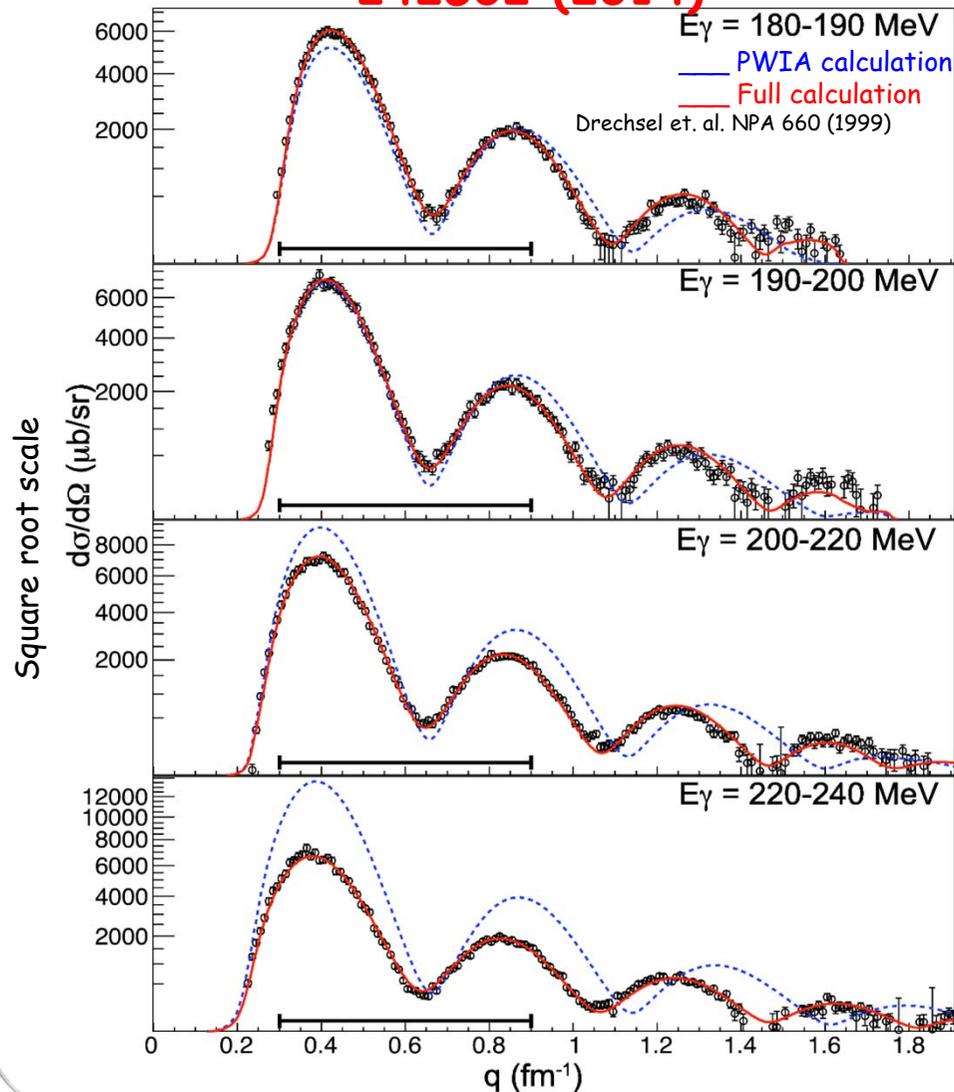
Momentum transfer  $q$   
 $q = P_\gamma - P_\pi$

$\pi^0$  reconstructed from its  
decay in  $2\gamma$

- The target nucleus is left in its ground state  $\rightarrow$  all nucleons contribute coherently to the reaction amplitude
- The photon is uncharged: no Coulomb scattering effects (significant for heavy nuclei for electron scattering)
- The reaction amplitude for  $\pi^0$  production on the nucleus has closely equal probabilities on both protons and neutrons ( $\Delta$  region)
- The  $\pi^0$  production cross section is proportional to  $A^2 F_m^2(q)$ , where  $F_m(q)$  is the matter form factor of the nucleus
- No initial state interactions
- **FSI must be taken into account:**
  - Shift in the  $\theta_\pi$  (difference of the  $\pi$  momentum inside and outside the nucleus)
  - Modification of the outgoing flux ( $\pi$  absorption process)

# $^{208}\text{Pb}(\gamma, \pi^0)^{208}\text{Pb}$ differential cs

C.M. Tarbert, PRL 112,  
242502 (2014)



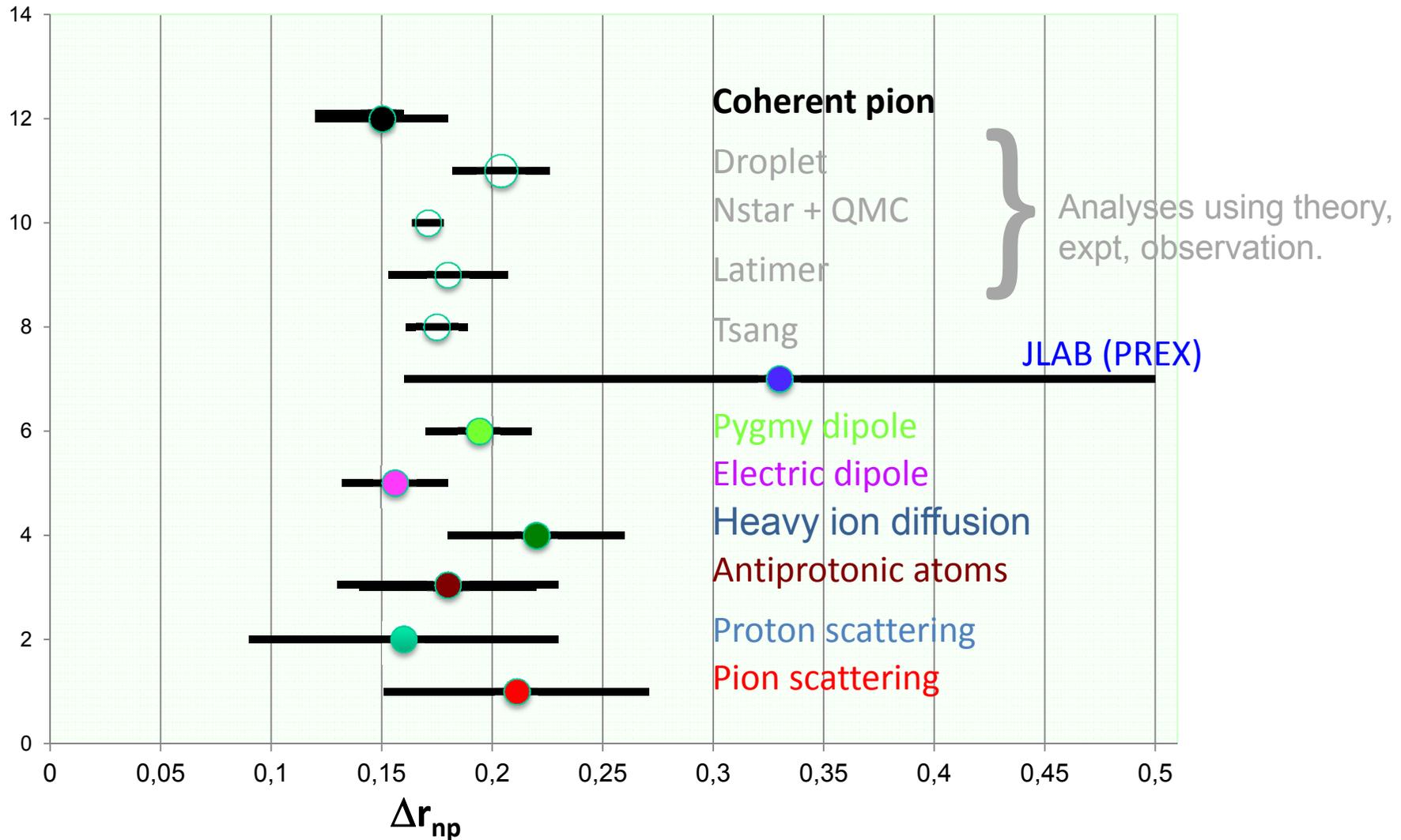
Extract the best fit values  $a_n$   
and  $C_n$  for the neutron  
distribution for each  $E_\gamma$  bin  
(two-parameter Fermi density  
distribution (2pF)):

$$\rho(r) = \frac{\rho_0}{1 + \exp[(r-C)/a]}$$

## Fitting procedure

- Different  $\rho$  for p and n to describe the nuclear shape:  
 $\rho(r) = (Z/A) \rho_p(r) + (N/A) \rho_n(r)$
- Fixed param. (PRC 76 014211 (2011)):
  - $C_p = 6.68$
  - $a_p = 0.447$
- Free param. (grid of 35 pts):
  - $C_n = 6.28-7.07$  fm
  - $a_n = 0.35-0.65$  fm
  - Normalization factor
- Predictions smeared by  $q$  resolution ( $\sigma_q = 0.02-0.03$  fm $^{-1}$ )
- Interpolated fit to experimental data ( $q = 0.3-0.9$  fm $^{-1}$ )

# Comparison with previous measurements



- New result in general agreement with other methods

## **Publications (refereed journals)**

2011: 4 (1 PLB)

2012: 4 (1 PLB)

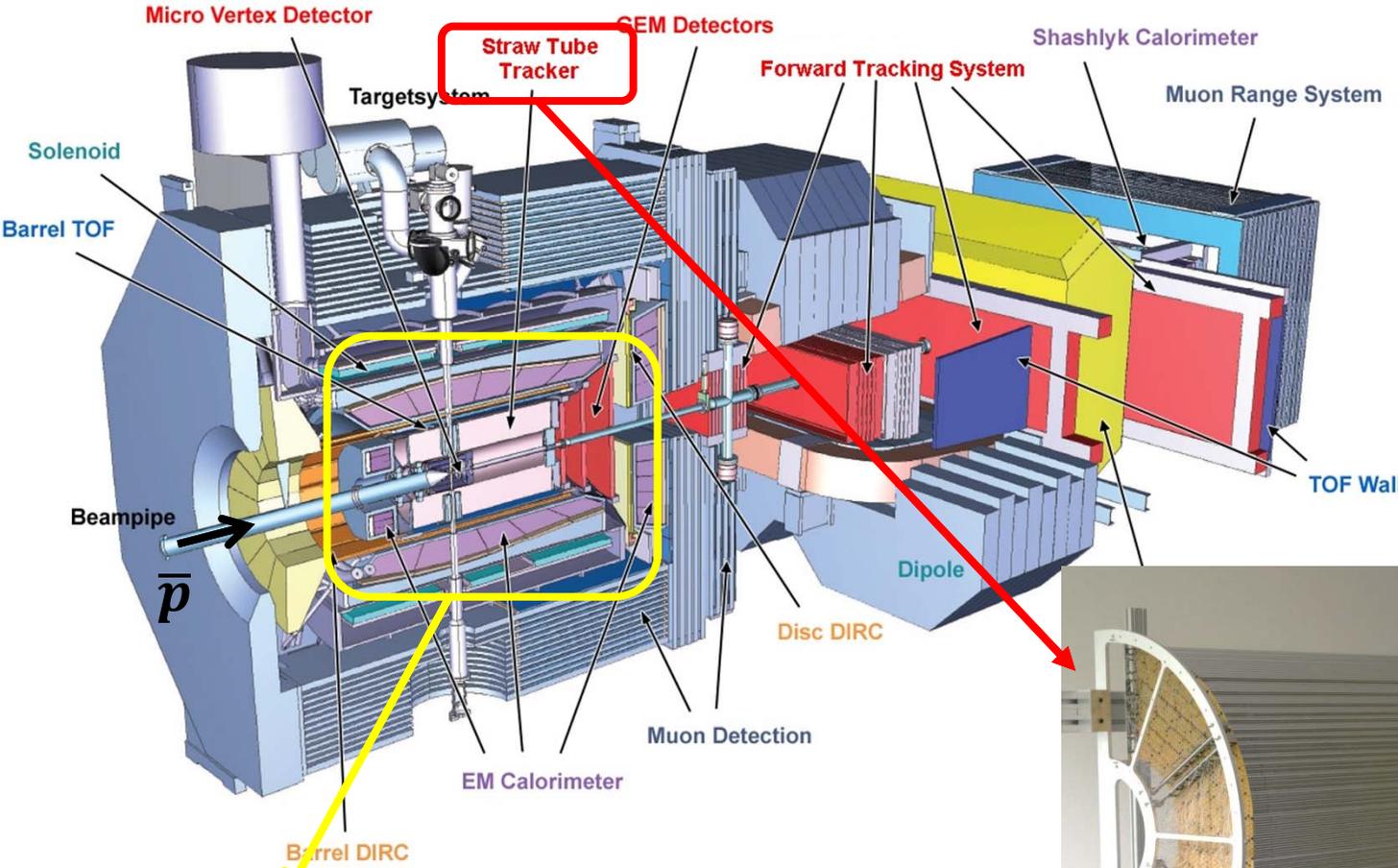
2013 10 (2 PRL; 4 PLB)

2014 11 (4 PRL; 1 PLB)

## Future Planning - Mainz

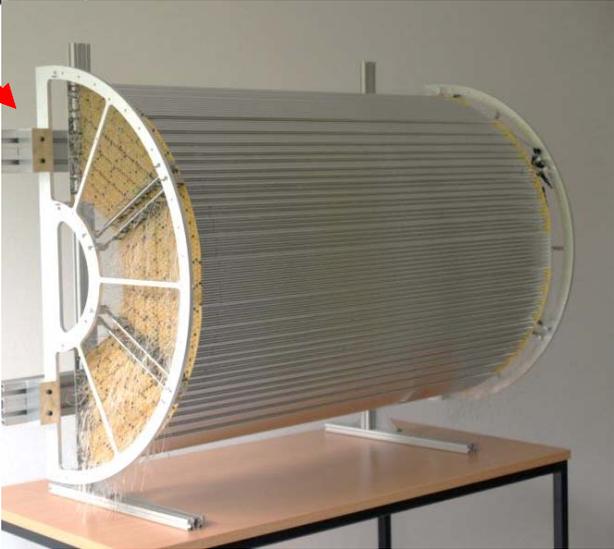
- 2015: End of data taking under the direct responsibility of INFN-PV
- 2016 → start of a joint program with CB@Bonn (baryon resonance studies up to 3 GeV)
- **MAMI will run at least up to 31/12/2024**
- A2 has a 2-3 years backlog of data takings for experiments already approved by the PAC (and many more will come ...)
- Money will be needed (and required to funding agencies....) for the necessary hardware upgrades (ADCs, TDCs, PMTs ...)

# PANDA



Tracking systems of the Target Spectrometer

Under construction @ IKP-FZ Julich



# Attività del gruppo di Pavia

- Contributo al mantenimento del software di PANDA all'interno del framework PandaROOT
- Coordinamento del software di Pattern Recognition per il rivelatore di PANDA
- Sviluppo del software di Pattern Recognition per il tracciatore centrale a Straw Tubes
- Sviluppo del codice di ricostruzione di traccia per il prototipo di tracciatore a Straw Tubes di Jülich
- Partecipazione ad un run di presa dati in fascio (protoni, deuterio) a Jülich con il prototipo di tracciatore a Straw Tubes
- Analisi dei dati raccolti in fascio
- Studi sistematici con simulazioni Monte Carlo delle prestazioni del tracciatore centrale (risoluzione in momento, efficienza di ricostruzione di traccia, ...)
- Mantenimento di GEANE

# Pattern recognition for STT

Efficiency of the Pattern recognition code with the use of both a road finding and a Hough transform algorithms has been shown to be satisfactory in the ideal situation (no pileup)

- In case of pileup caused by the 20 MHz interaction rate:
- the efficiency of finding all true hits belonging to a track decreases
  - the presence of spurious hits increases;
  - many ghost tracks are found



Improvements of the Pattern Recognition software for the MVD + STT trackers in case of the pileup are needed:

- modifications of the code to improve the PR performances
  - finalisation of <<cleanup>> procedures

# Improved PR performances

MC Box Generator; % of reconstructed tracks ('reconstructed track' means tracks found associated to a MC truth track)

$p$ (GeV/c)	Tracks/event	# good gen. tracks	% rec. Tracks
0.3	1	3981	99.1
0.3	4	3986	98.8
0.3	8	3983	97.6
1.0	1	3871	99.4
1.0	4	3875	98.9
1.0	8	3875	98.5
2.0	1	3875	99.6
2.0	4	3858	99.4
2.0	8	3866	98.8
5.0	1	3872	99.5
5.0	4	3831	99.5
10.0	1	3886	99.5

EXCELLENT performance in efficiency!!

# Scheme of the cleanup task

Use the XY positions of the hits to eliminate spurious tracks not having all the hits they should

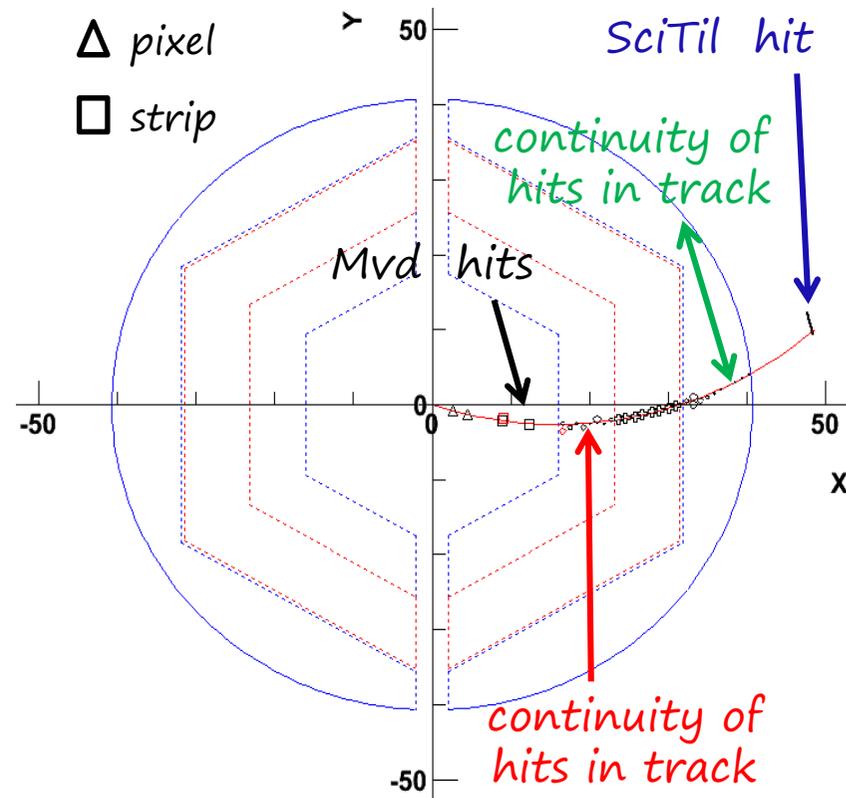
- Subdivide track in arcs crossing a certain STT axial straw sector
- Require continuity of hits in each Stt sector

Exception: allow 1 axial STT missing hit overall due to expected 98 % straw efficiency

- Require that the track has the entrance/exit hits (boundary hits)

Exception: most external hit is not necessarily required to touch the boundary (very forward tracks)

- Require hit in the SciTil system when track reached that
- Require continuity of hits in the MVD system



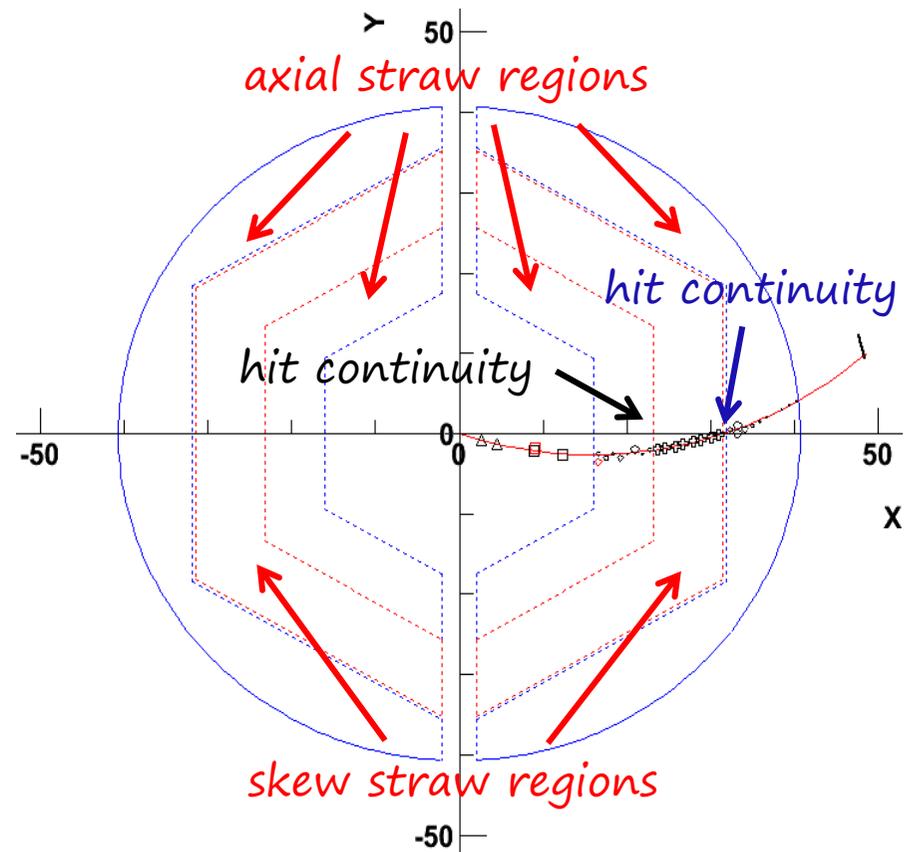
# Scheme of the cleanup task

Use the  $z\phi$  positions of the skew hits to eliminate spurious tracks not having all the hits they should.

- There is only one skew straw sector so require continuity of skew hits (track STT hits can have only one missing STT hit overall axial + skew )
- First and last hit in skew sector must be at boundary

Exception: for very forward tracks last hit may not be at the boundary if also there are not hits in the outer axial sector)

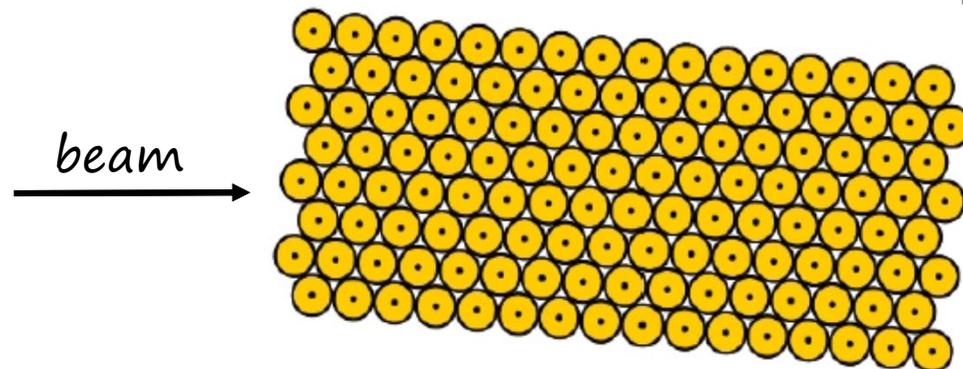
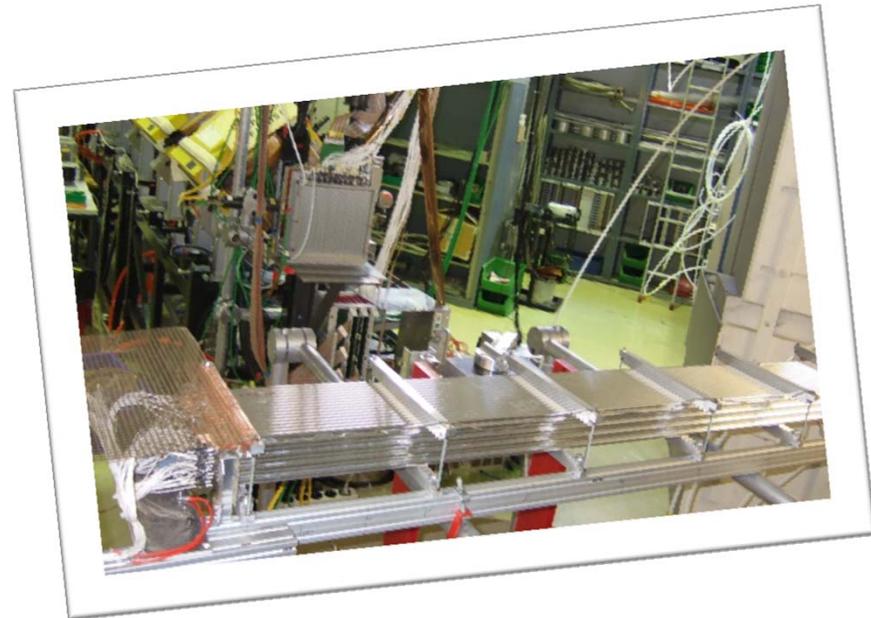
- Continuity of hits at the boundaries between axial and skew straws.



# Beamtime overview

Small prototype of the Straw Tube Tracker (STT) in Jülich available for tests with beam @ COSY

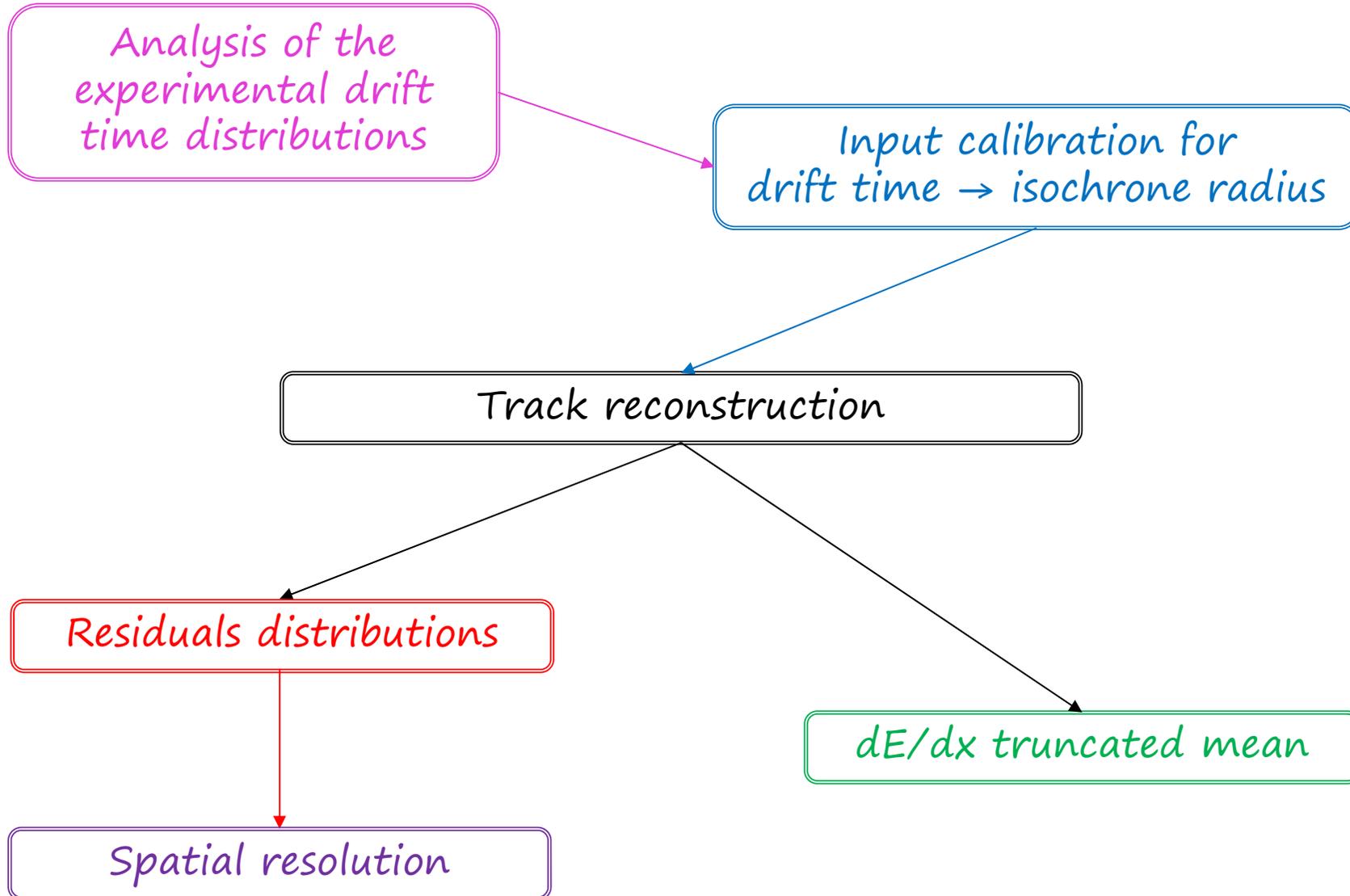
- Prototype with FADC readout
- Placed in the Big Karl area
- Proton and Deuteron beams provided by COSY (July 2014, October 2014, Dec 2014):
  - 0.6 GeV/c
  - 1.0 GeV/c
  - 1.3 GeV/c
  - 2.0 GeV/c



Operation conditions (same as the PANDA STT ones):

- ArCO<sub>2</sub> (90/10) mixture
- 2 bar absolute pressure
- HV = 1800 V, 1850 V

# Analysis procedure



# Analysis procedure

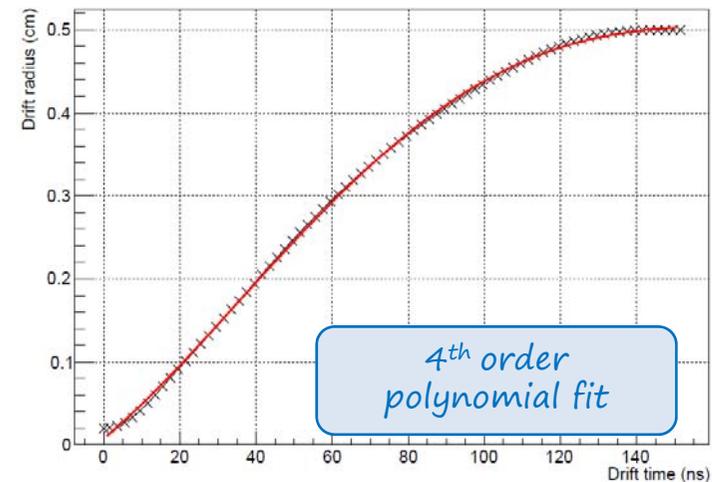
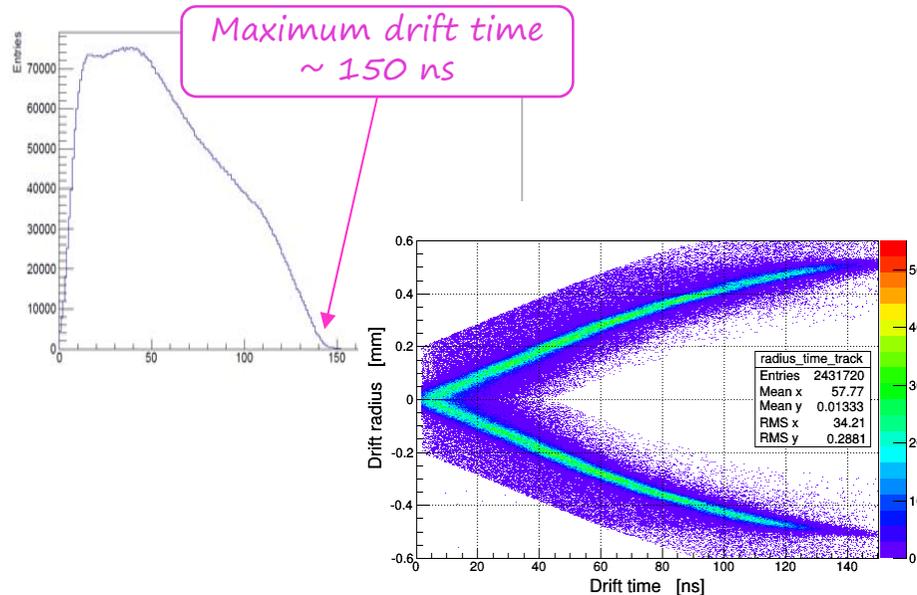
Analysis of the experimental drift time distributions

Input calibration for drift time  $\rightarrow$  isochrone radius

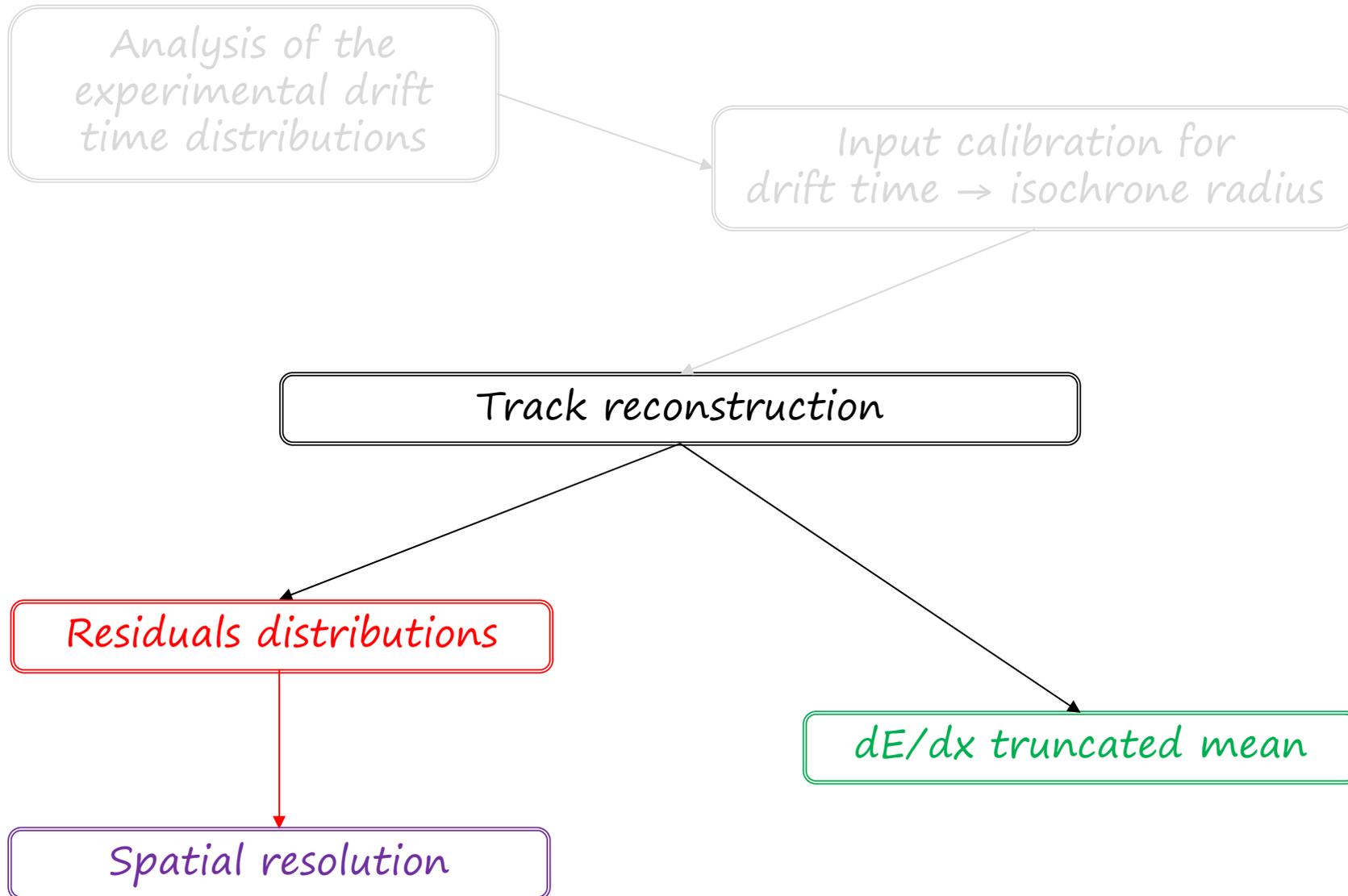
- ▣  $t_0$  and  $t_{max}$  determination for single spectra
- ▣ Offset correction for single spectra
- ▣ Sum of all the spectra

- ▣  $r(t)$  relation obtained in the hypothesis of uniform illumination over the tube volume:

$$r(t_i) = \frac{\sum_{i=1}^{i_t} N_i}{N_{tot}} \cdot (R_{tube} - R_{wire}) + R_{wire}$$



# Analysis procedure

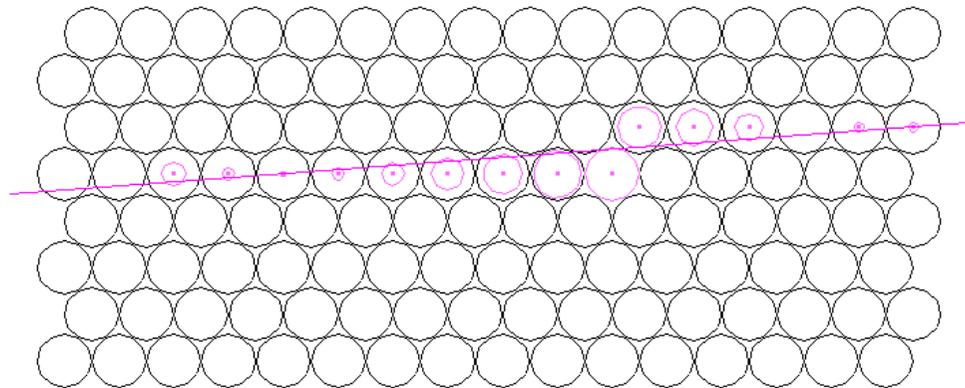


# Track reconstruction

«Ad hoc» algorithm for track reconstruction and  $dE/dx$  determination (in PandaROOT)

Algorithm steps:

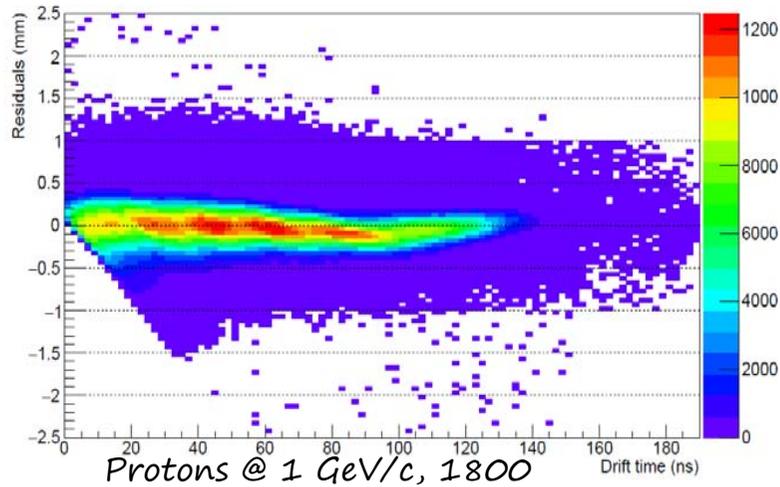
- «Hit producing»:
  - Drift time conversion into isochrone radius
- Track finding (pattern recognition)
  - Cluster formation
- Track fitting:
  - Prefit using points (centers of tubes)
  - Fit using isochrones
  - Fit using points (intersections on isochrones)
  - Refit



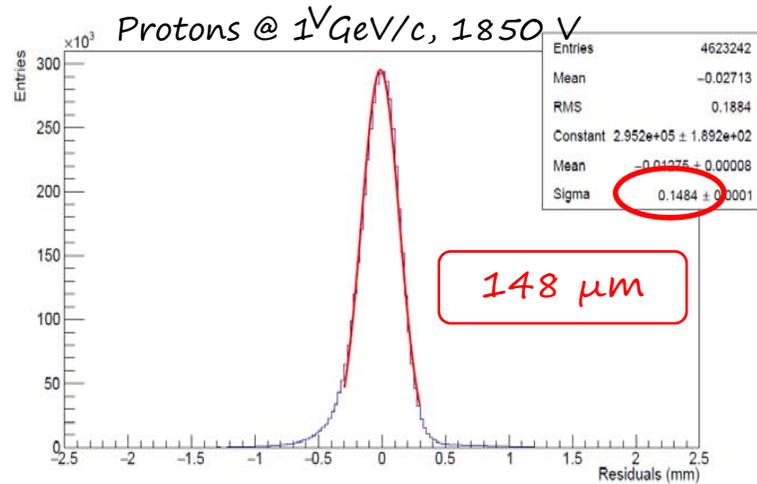
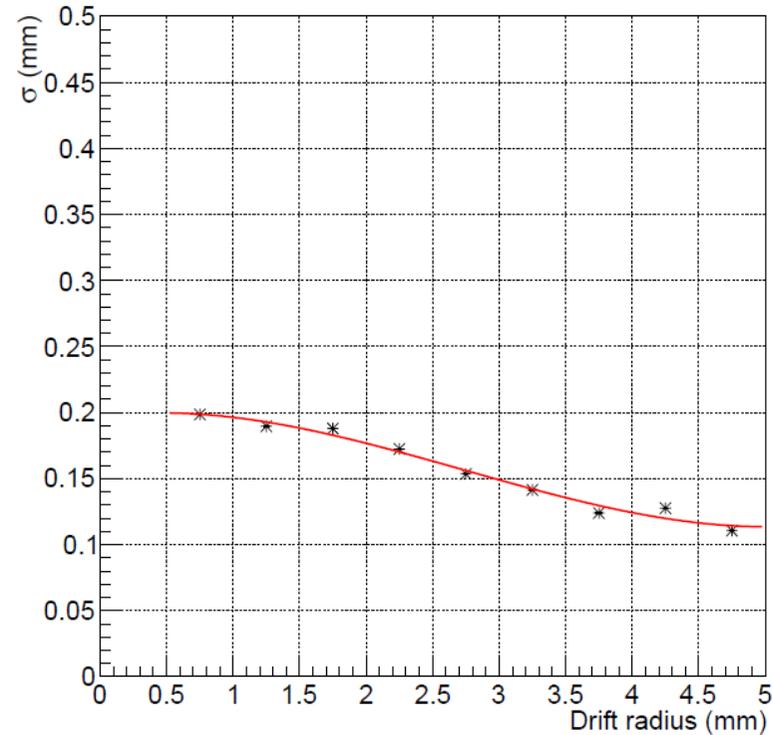
# Residuals distributions & Spatial resolution

$$\Delta r = r_{fit}(a,b) - r_{raw}$$

Protons @ 1 GeV/c, HV 1800 V

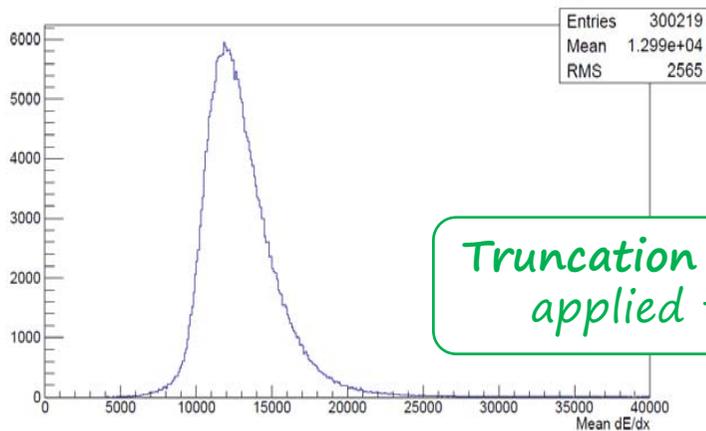


Spatial resolution

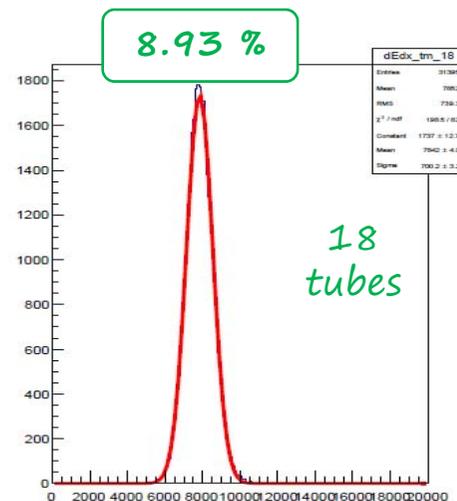
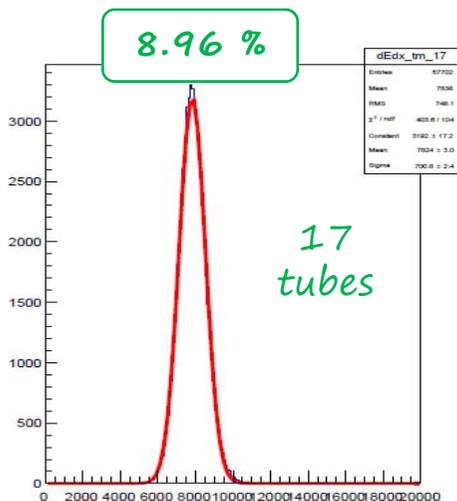
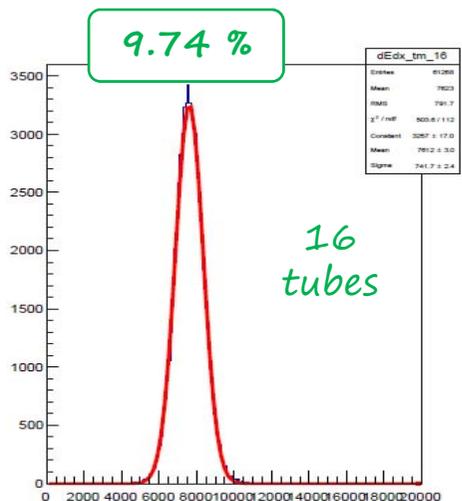
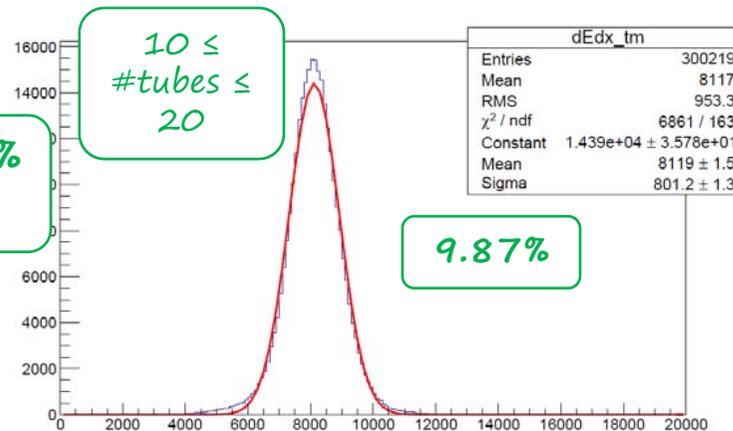


Very similar resolution curves @ 1.3 GeV/c and 2 GeV/c

# dE/dx resolution



Truncation factor: 30%  
applied to dE/dx



Protons @ 1 GeV/c, 1850 V