

Consuntivi Gruppo IIII

Paolo Pedroni

Con l'indispensabile collaborazione di
G. Boca, G. Bonomi, A. Menegolli, N.Zurlo

CSN3 –Status 2015

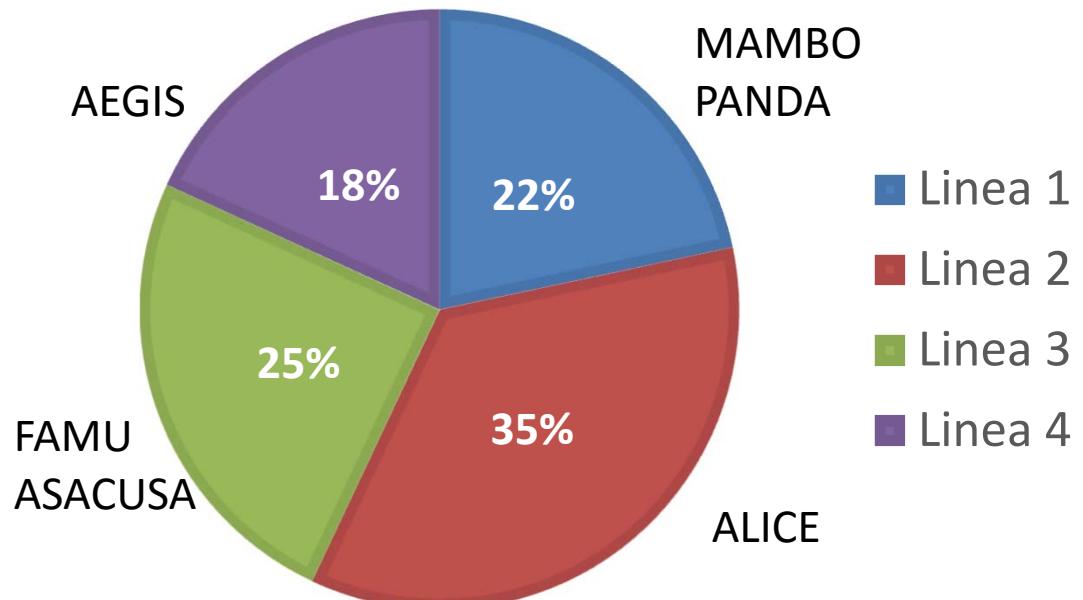
Linea 1: Quark and hadron dynamics (6 sigle)

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

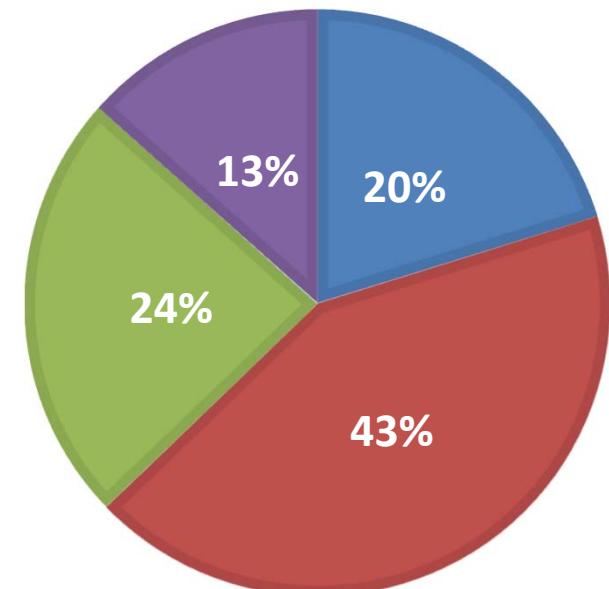
Linea 3: Nuclear structure and reaction dynamics (8 sigle)

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

**Ripartizione FTE (480 FTE)
(Circa 750 ricercatori)**



**Ripartizione Budget
(circa 9MEuro)**



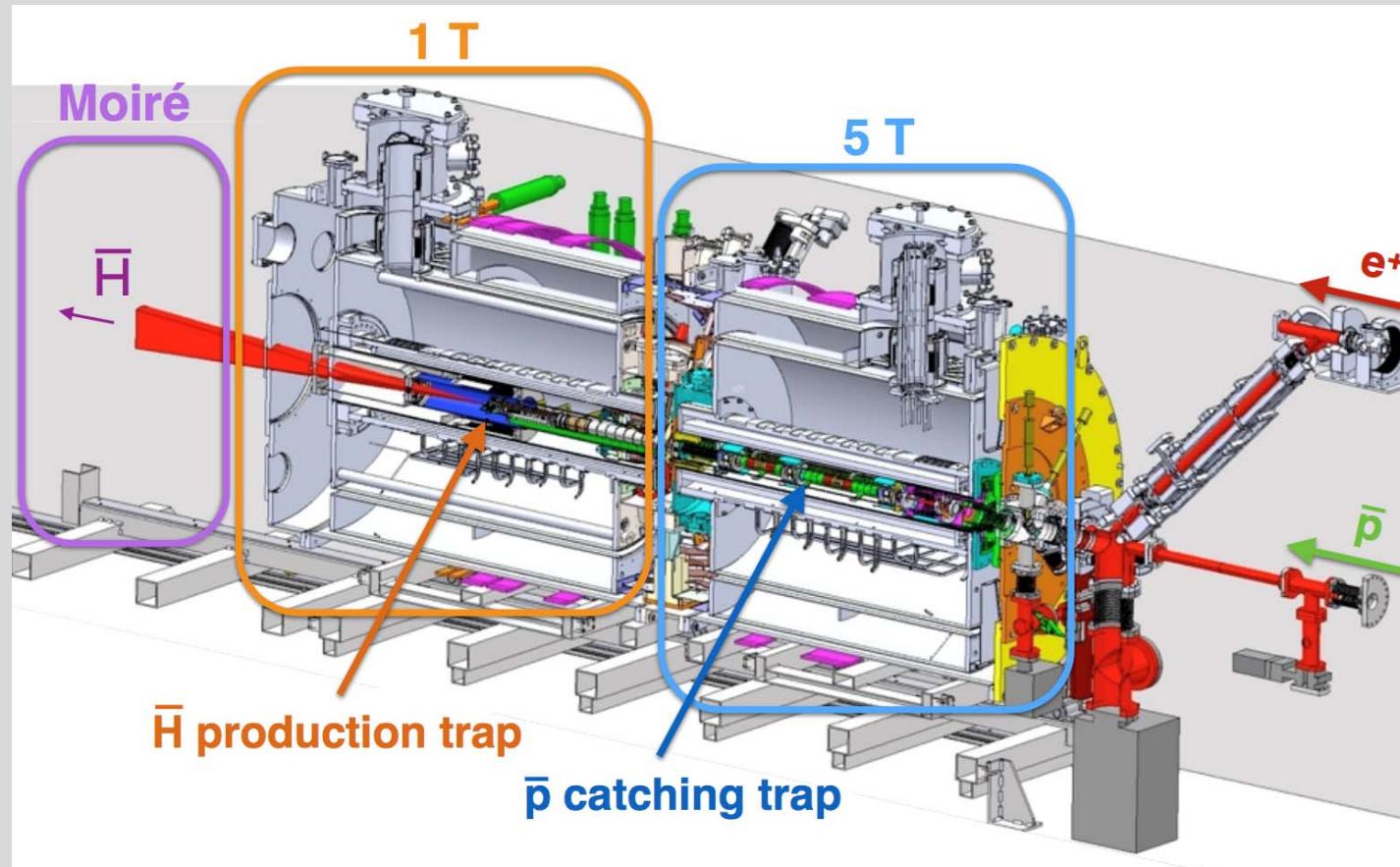
CSN3-Pavia Situazione 2016

Budget: 150 kEuro

sigla	nome cognome	TIPO	Ricerc	Tecnol	Pers.	FTE %
AEGIS	Bonomi Germano	assoc		x		50
	Donzella Antonietta	assoc		x		50
	Fontana Andrea	dip	x			50
	Pagano Davide	assoc	x			30
	Rotondi Alberto	assoc	x			30
	Zurlo Nicola	assoc	x		100	
AEGIS			4	2	6	3.1 TOT
ALICE	Boca Gianluigi	assoc	x			30
	Bonomi Germano	assoc		x		50
	Costanza Susanna	assoc	x			70
	Rotondi Alberto	assoc	x			50
	Pagano Davide	assoc	x			70
	Zenoni Aldo	assoc		x		40
ALICE-DTZ			4	2	6	3.1 TOT
FAMU	De Bari Antonio	assoc	x			40
	De Vecchi Carlo	dip		x		50
	Menegolli Alessandro	assoc	x			40
	Rossella Massimo	assoc		x		20
	Tomaselli Alessandra	assoc		x		30
FAMU			2	3	5	1.8 TOT
MAMBO	Braghieri Alessandro	dip	x			30
	Costanza Susanna	assoc	x			30
	Montagna Paolo	assoc	x			30
	Pedroni Paolo	dip	x			100
MAMBO			4		4	1.9 TOT
PANDA	Boca Gianluigi	assoc	x			20
	Rotondi Alberto	assoc	x			20

sigla	nome cognome	TIPO	Ricerc	Tecnol	Pers.	FTE %
ASACUSA	Artoni Maurizio	assoc	x			30
	Bianconi Andrea	assoc	x			70
	Leali Marco	assoc		x		100
	Mascagna Andrea	assoc	x			100
	Solazzi Luigi	assoc	x			50
	Venturelli Luca	assoc	x			100
ASACUSA			4	2	6	4.5 TOT
TOTALE						14.8

CONSUNTIVO AEGIS-PV 2015/2016



- AEgIS in sintesi
- Risultati 2015 (postroni, antiprotoni)
- Sviluppi delle attività del gruppo di Pavia/Brescia
- Obiettivi per il 2016



A Eg 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



Politecnico di
Milano



University College
London



University of
Bergen



University of
Bern



University of
Brescia



Heidelberg
University



University of Lyon 1



University of
Oslo



Université
Paris Sud



University of
Trento



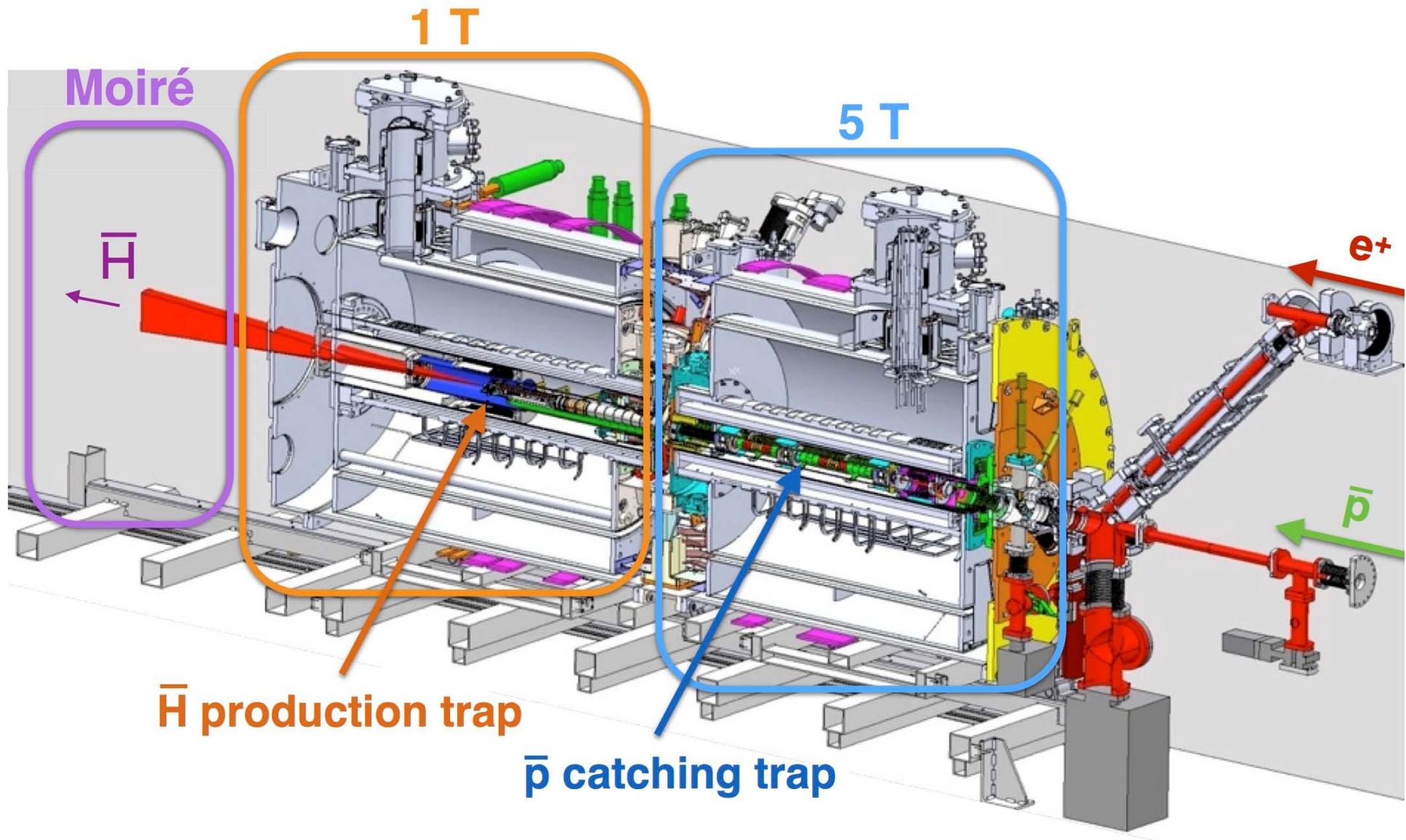
INFN sections of:
Genova, Milano,
Padova, Pavia,
Trento



AEgIS in sintesi

AEgIS apparatus

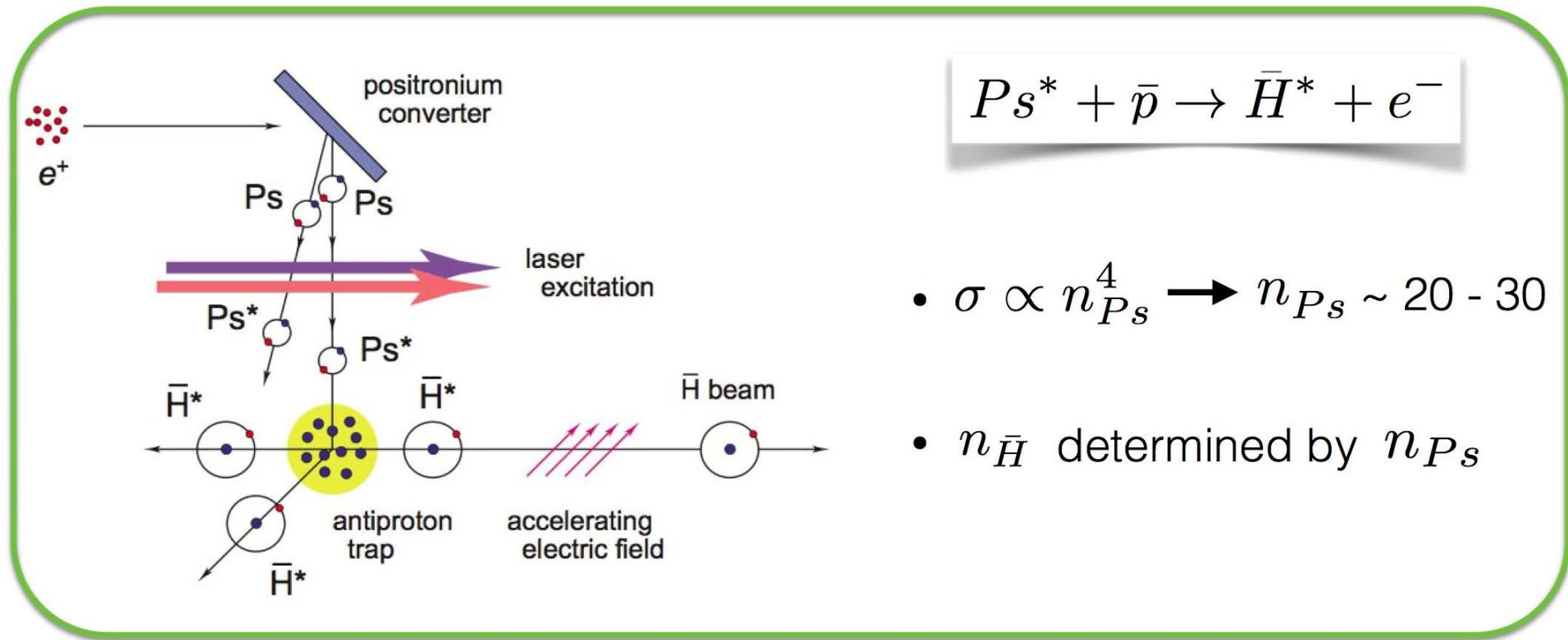
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Antihydrogen production strategy

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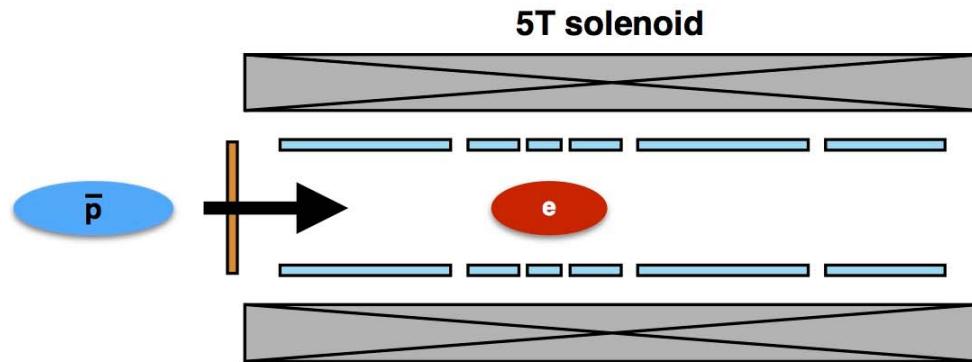
- Rydberg \bar{H}^* atoms produced via **charge exchange**



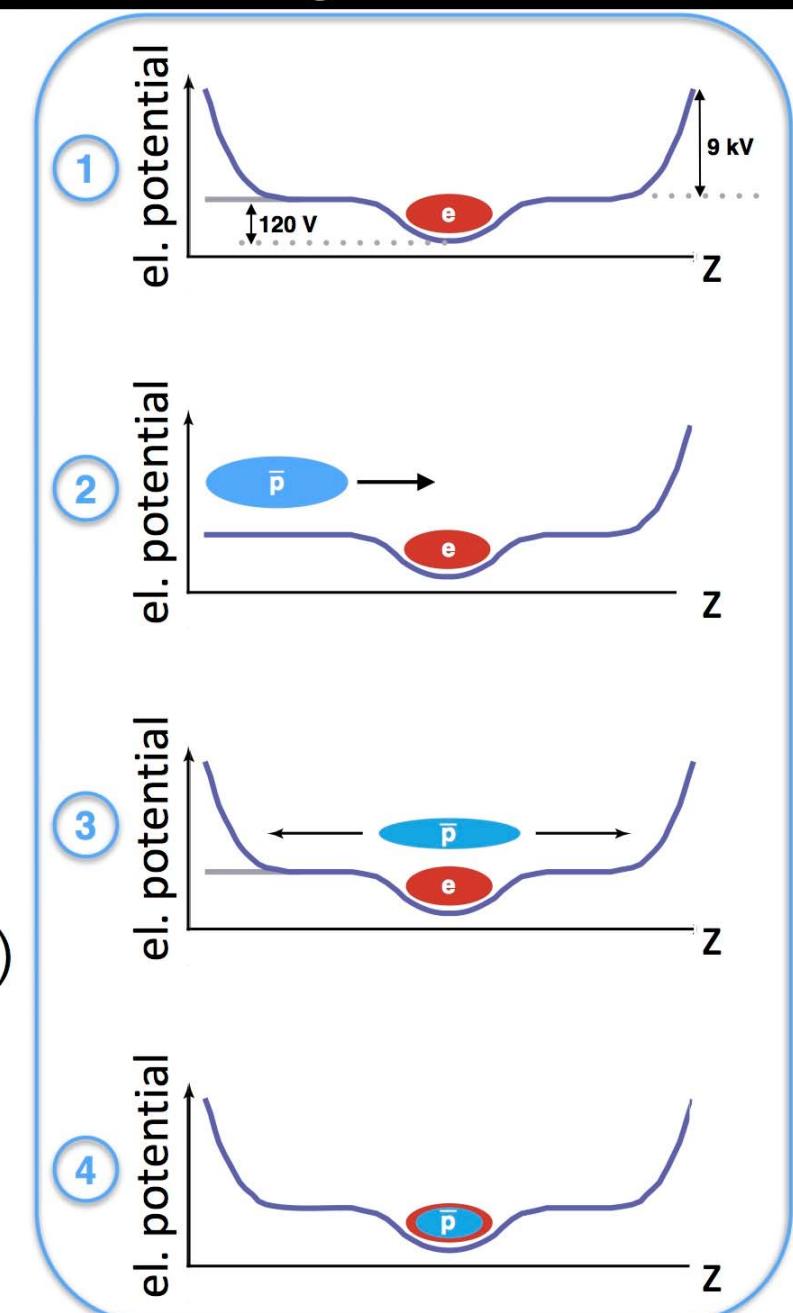
- Temperature of \bar{H} given by the temperature of \bar{p} (goal 100 mK)
- Rydberg \bar{H} : strong dipole moment → **Stark acceleration**

Antiproton capture and cooling

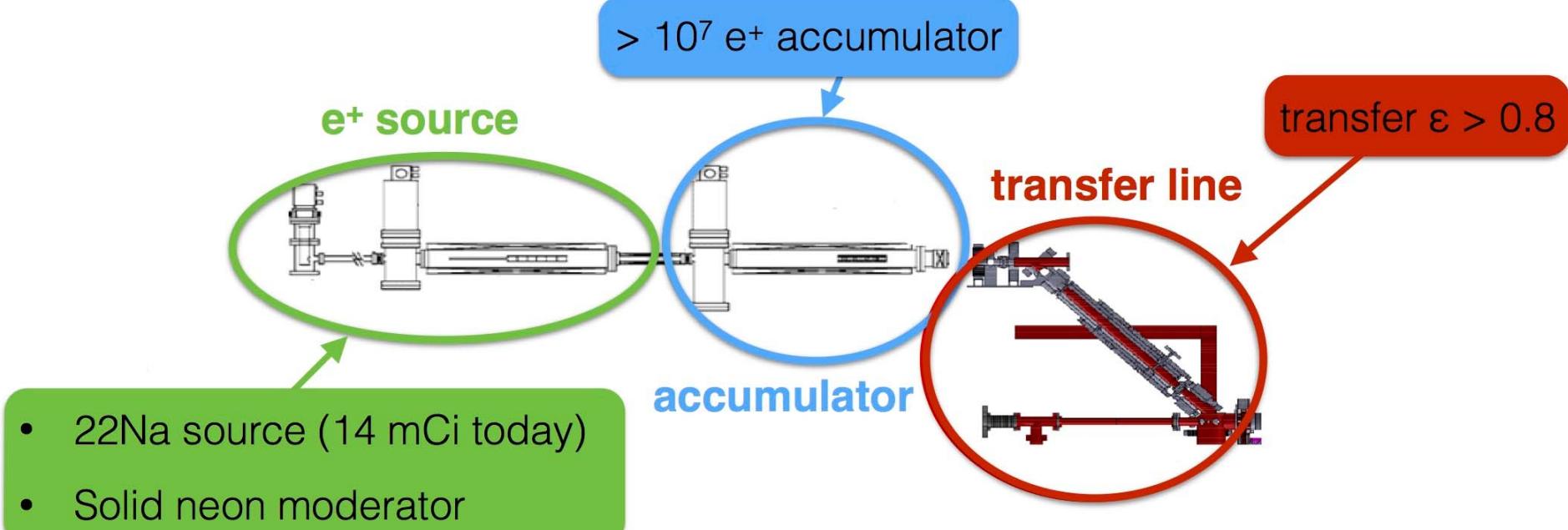
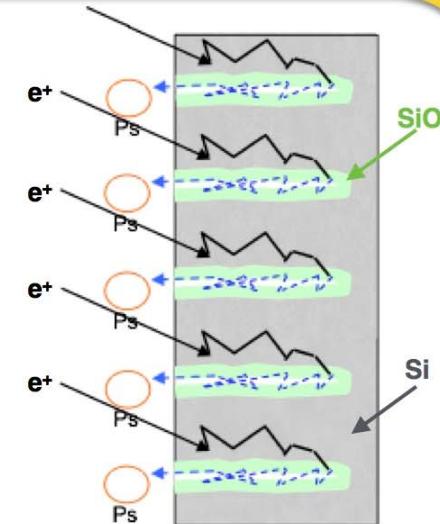
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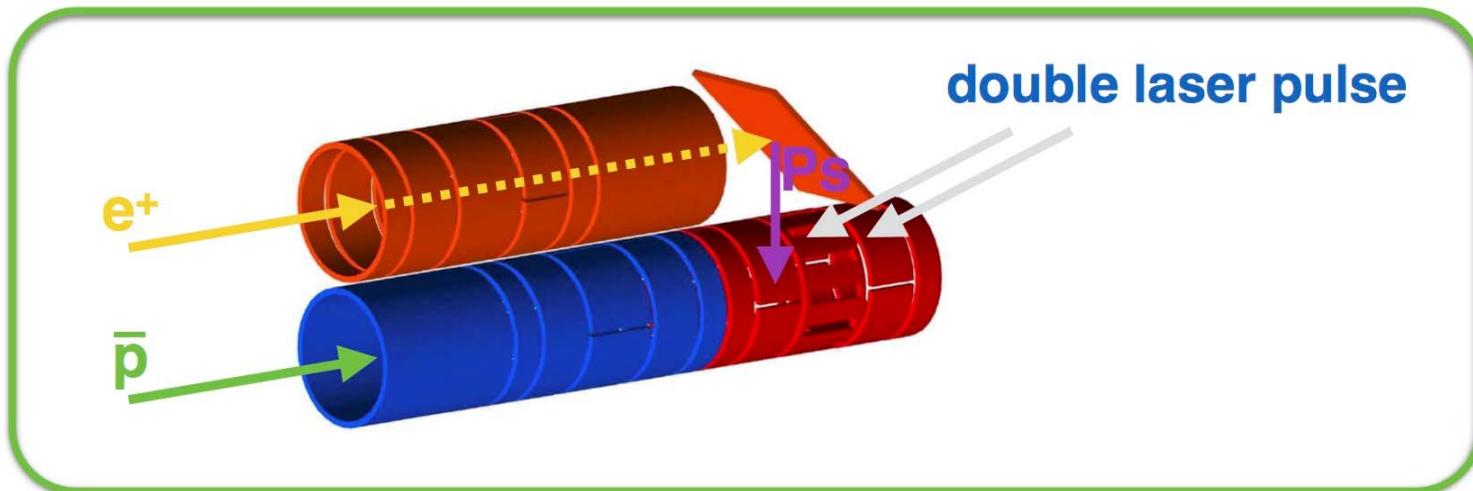


- Electrons ($\sim 10^8$) loaded in the trap
- Thin Al foil (*degrader*) used to select low energy antiprotons
- \bar{p} caught and cooled (electron cooling)
 - ~ 7 K reached
 - 0.1 K goal (laser cooling, ...)
- $\sim 10^5 \bar{p}$ catch per spill



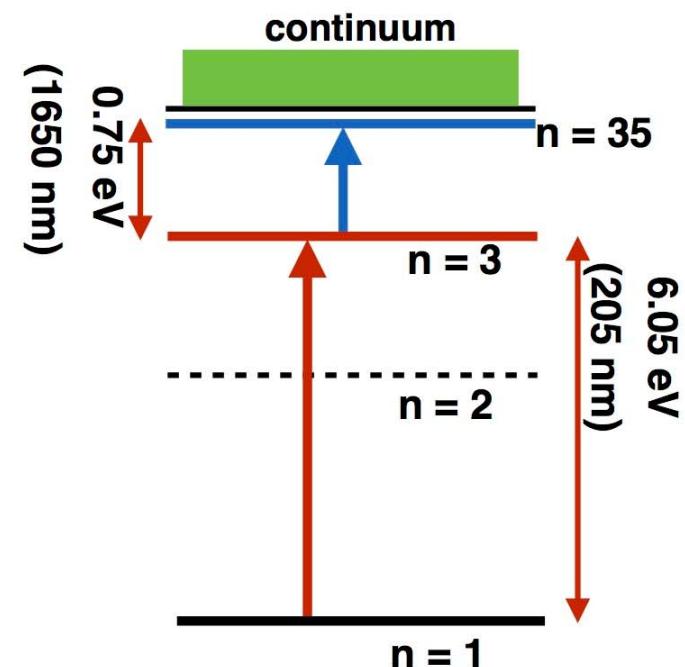
- **Positronium** (Ps) is an exotic atom composed by an e^- and a e^+
- **para-Ps**(125 ps) and **ortho-Ps**(142 ns)
- Ps produced via electron capture of e^+ within a nanoporous silica target





Two stages excitation:

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

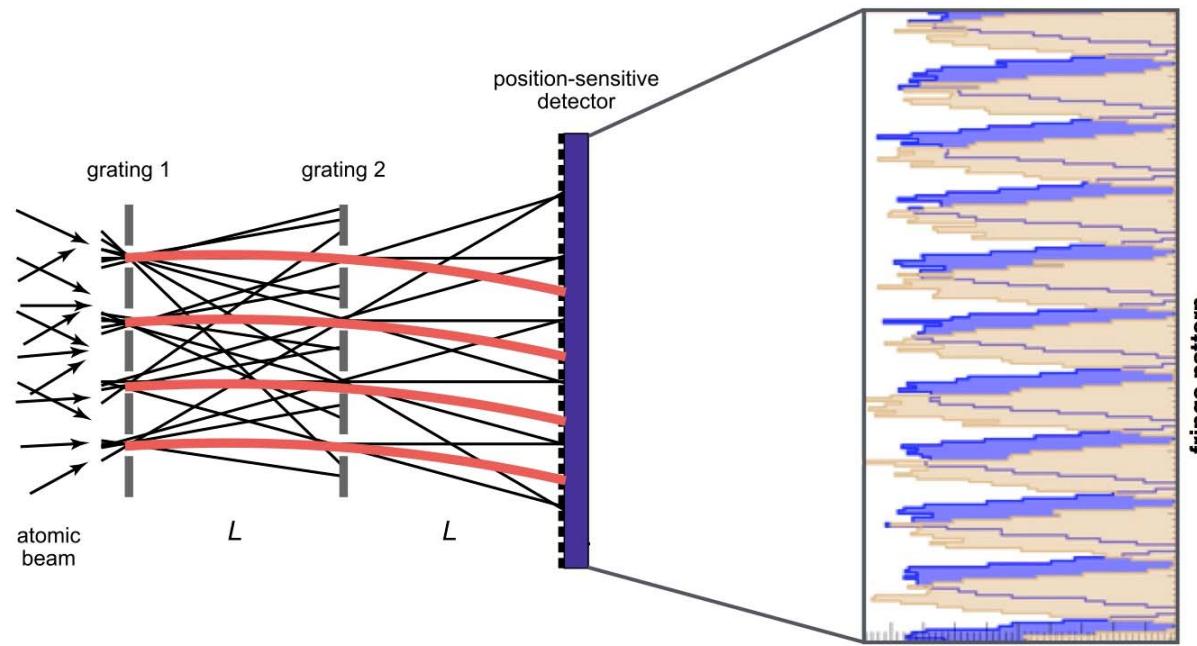


S. Mariazzi *et al.*, Phys. Rev. A 78 (2008) 052512

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

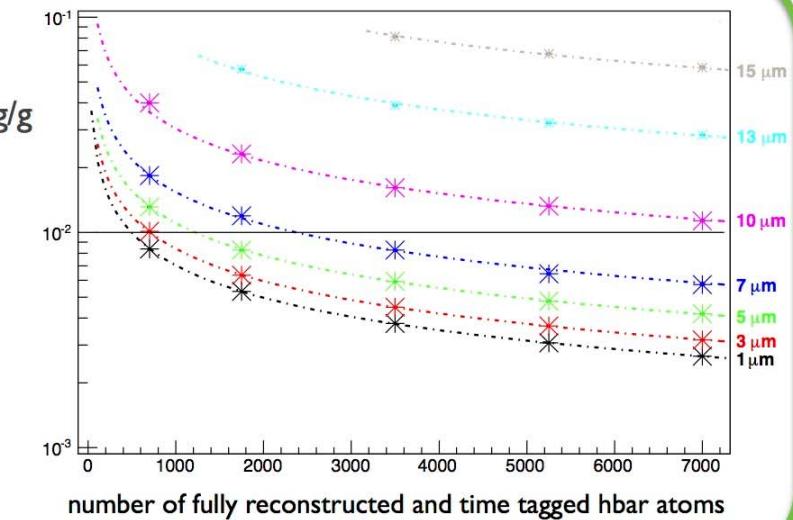
Gravity module

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Measurement accuracy depends on :

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

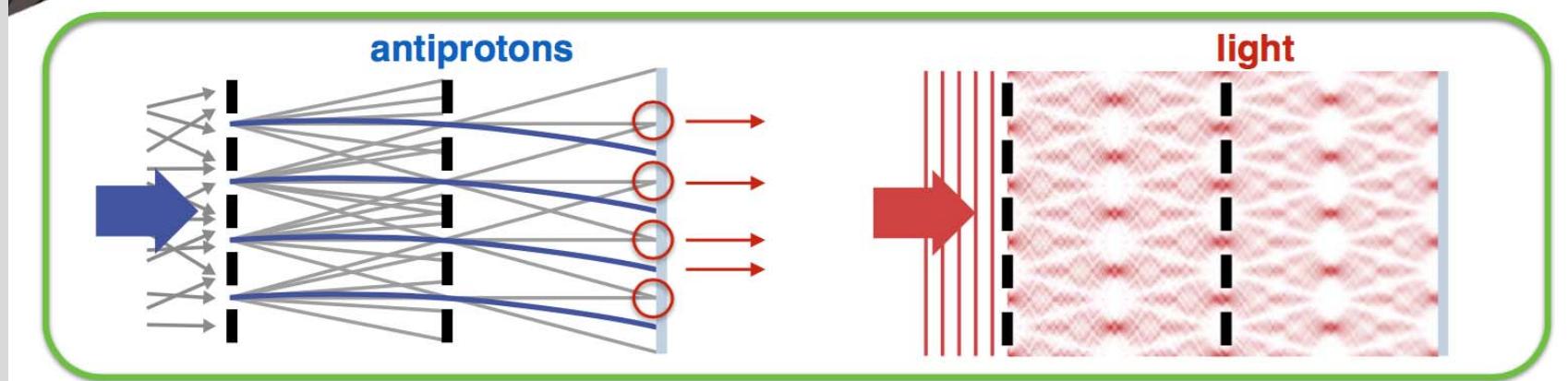
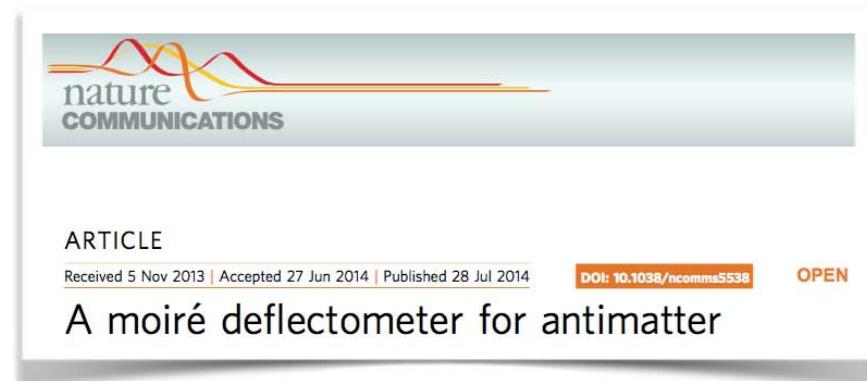
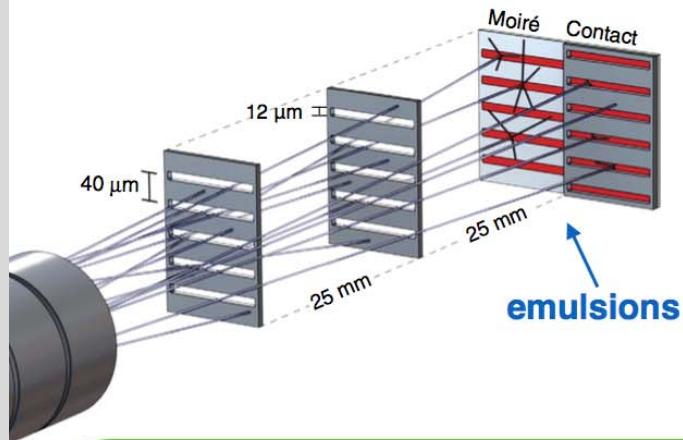


The gravity module was tested with pbars in 2012

Results: (mini) Moiré test with antiprotons

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- AEgIS experiment is taking data
- Small-scale test of the Moiré deflectometer with \bar{p} was performed



NEW in 2015

Pbar Beam monitor (MIMOTERA)



Ultrathin (53 micron) pixel detector for the AeglS beam imaging

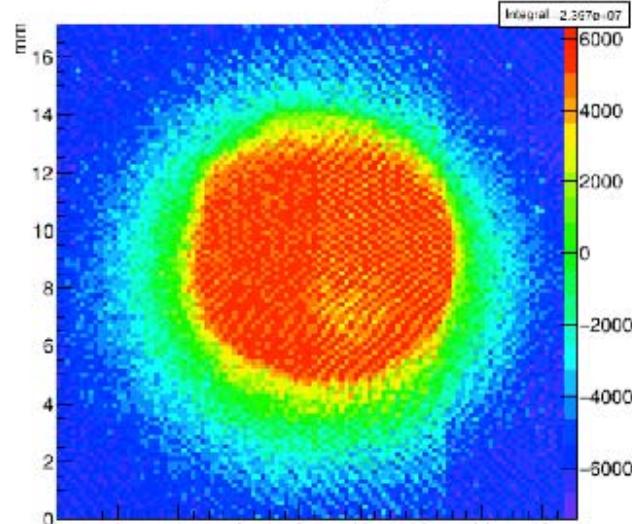
Operated @ 10 K

Mounted in front of the trap
on a movable support
(for e+ and e- trap loading)

NOTE: beam steering is done by us!!!!

Intensity profile of the pbar beam on the MIMOTERA

Run 25061 - Mimito (frame 73)



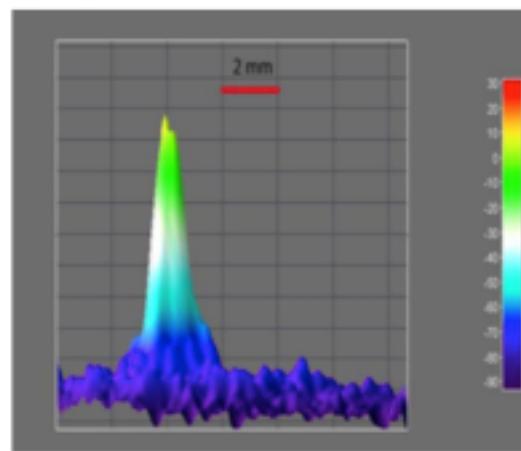
Saturation problem:
energy deposit too high
Signal not linear
Still OK for centering the beam
Under study with lab tests if the info can
be recovered...



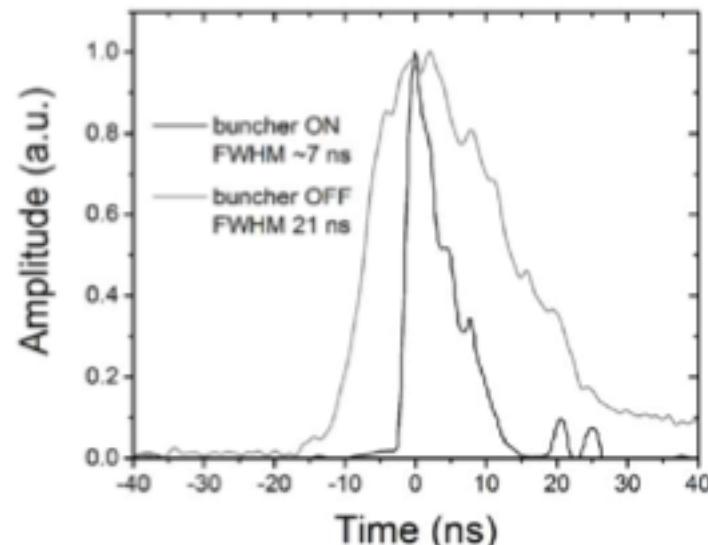
Risultati 2015 - positroni

e+ transport and Ps formation in the test chamber

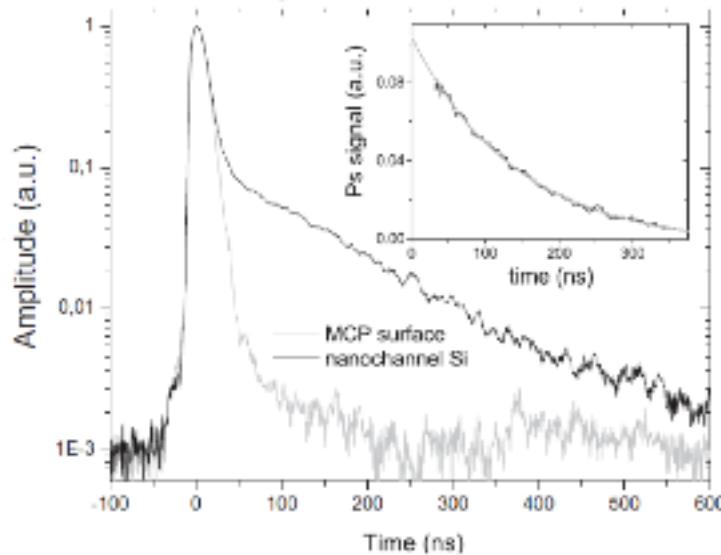
e+ focused on the target and accelerated.
Total width < 4mm



e+ time distribution at the target



Positronium production in the test chamber

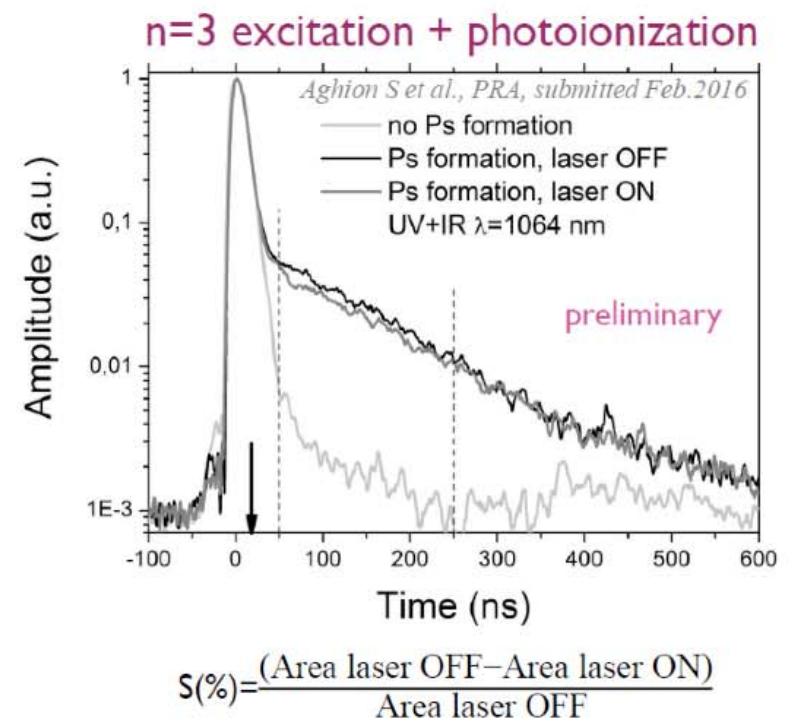
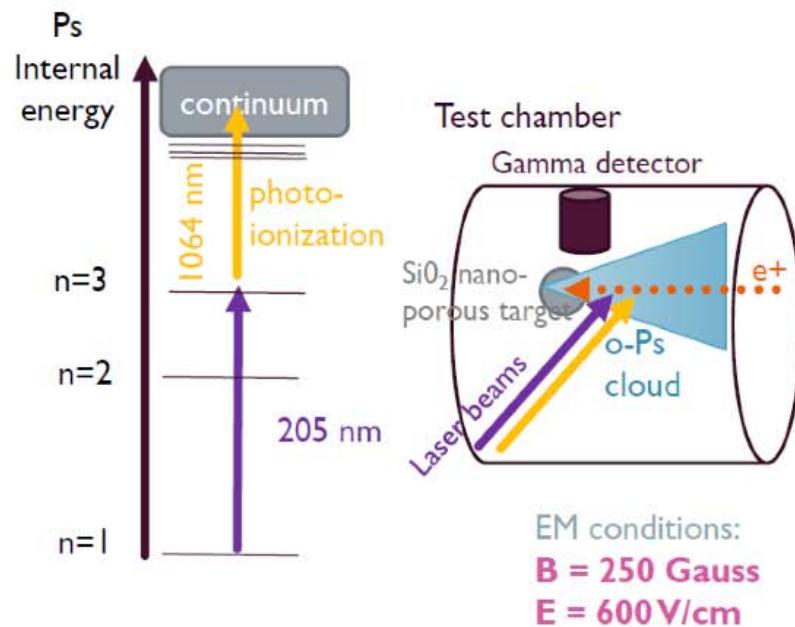


SSPALS (single shot positron annihilation lifetime spectroscopy)^(*) measurements –

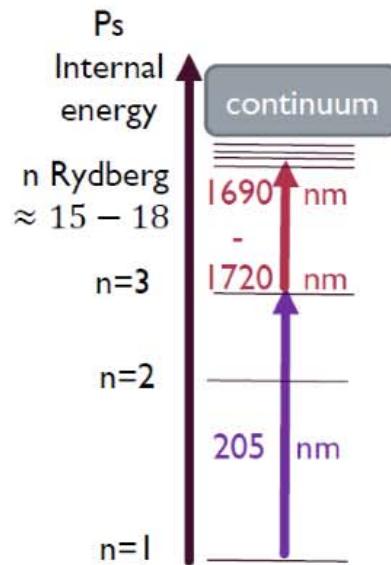
(*)Cassidy D B et al., NIMB 2007, 580, 1338

Average on 10 single shots.

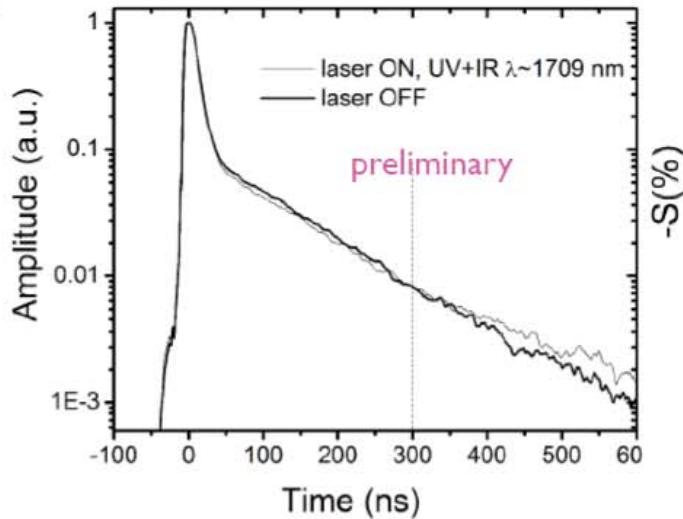
Ps excitation to n=3



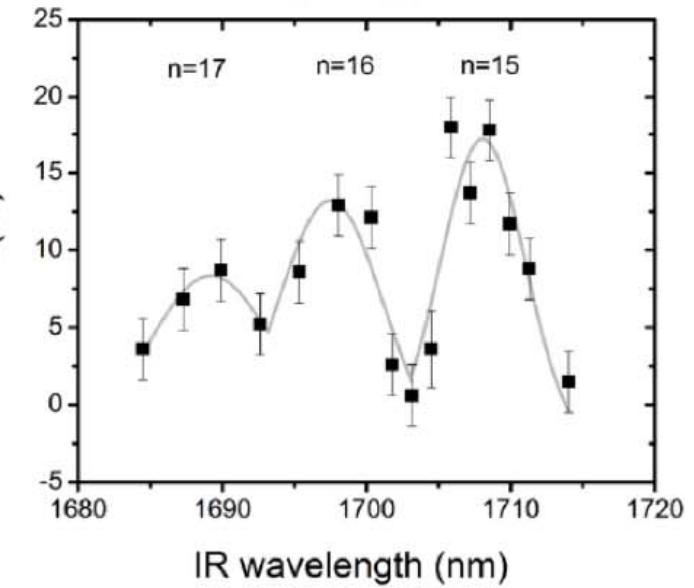
Ps excitation to Rydberg states



Rydberg excitation
($n=1 \rightarrow n=3 \rightarrow n = 15$ transition)

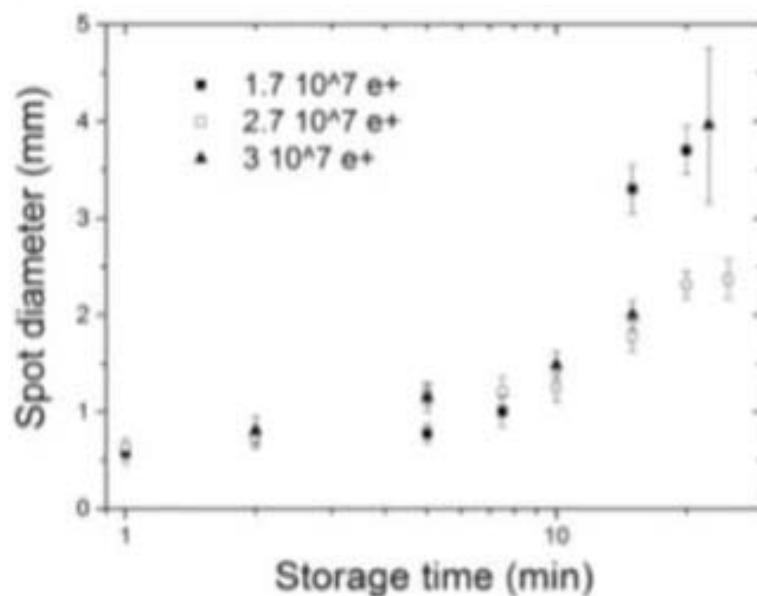
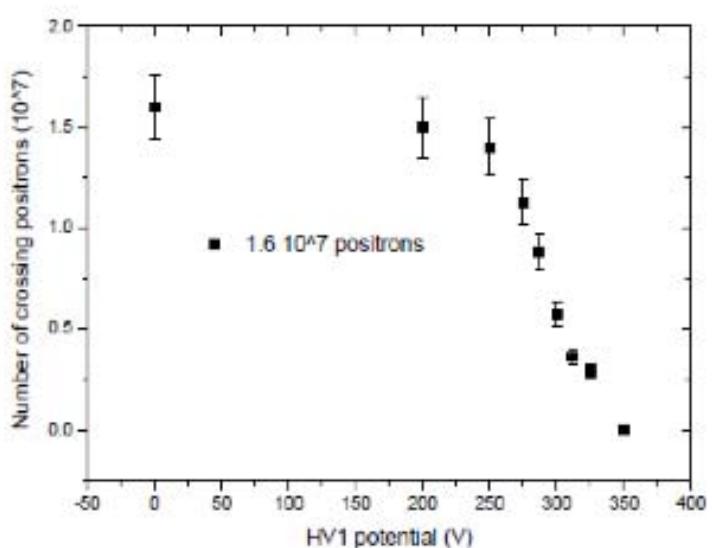


Scan of the Rydberg transitions



Positrons in the main magnets

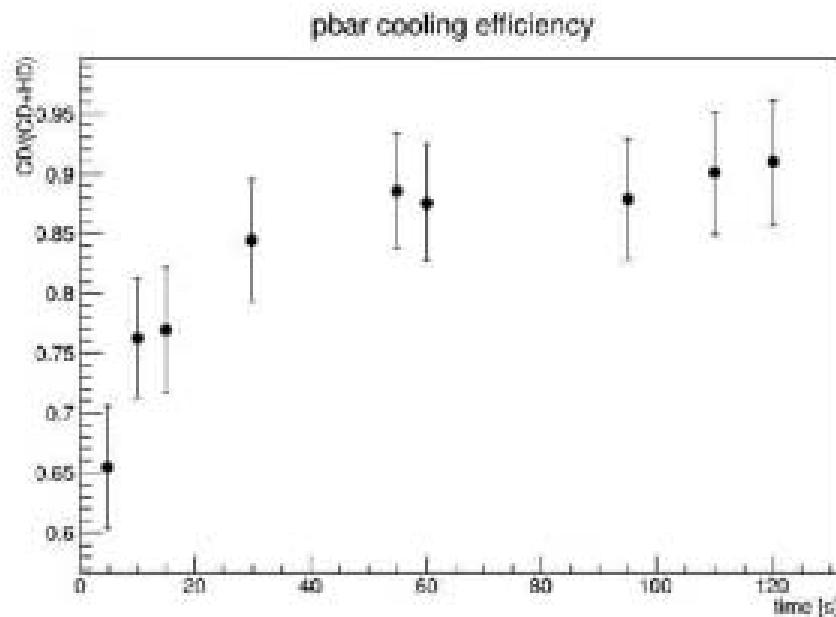
Positrons in the main magnet



- ✖ Routinely $1\text{-}2 \cdot 10^7$ e⁺ in the 5T C-trap
- ✖ e⁺ transfer energy 300 eV (to avoid mag. field reflection)
- ✖ Transfer line, catching and cooling almost lossless: $\epsilon > 95\%$
- ✖ Storage times adequate, good control with RW, no losses

Risultati 2015 - antiprotoni

Antiprotons catching&cooling in 2015



- ✖ e⁻ pre-loaded in the P-trap using heated cathode e-gun N(e⁻) - 10^8 - 10^9
- ✖ pbar cool by collisions with e⁻ that cool by radiation in the 4.5 T field
 - + can cool up to 80-90% of antiprotons within 60s from catching
- ✖ Large initial pbar radii do not have the best subsequent compression efficiency
 - + We use smaller initial electron clouds of 6mm diameter and cool approx. 50-60% of antiprotons within 50s
- ✖ Std. "cold dump" is $\sim 2 \cdot 10^5$ pbar/AD shot
 - + depends on AD and steering conditions

Pbar catching efficiency: $3.6 \cdot 10^5$ Antiproton/shot in 2015 @ 9 KV

1.2% catching efficiency

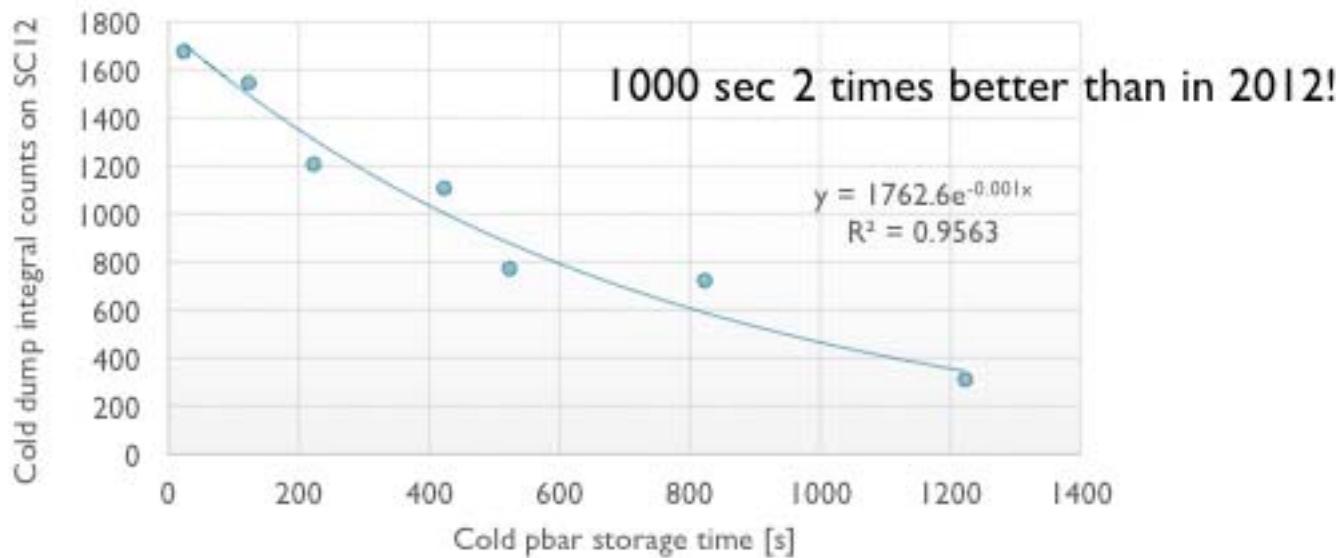
close to simulation results

beam: 5. MeV+ materials as energy degraders

Our best number!

Vacuum issue in the main magnet during the 2015 pbar run

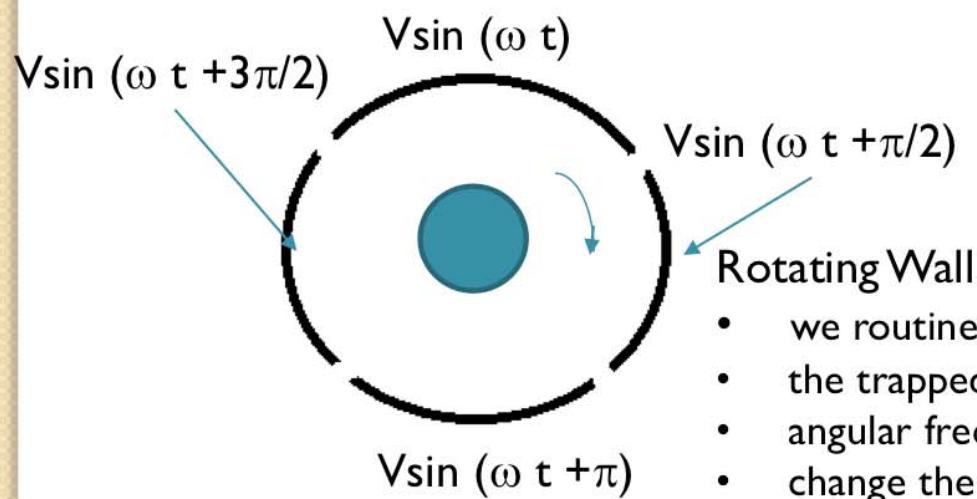
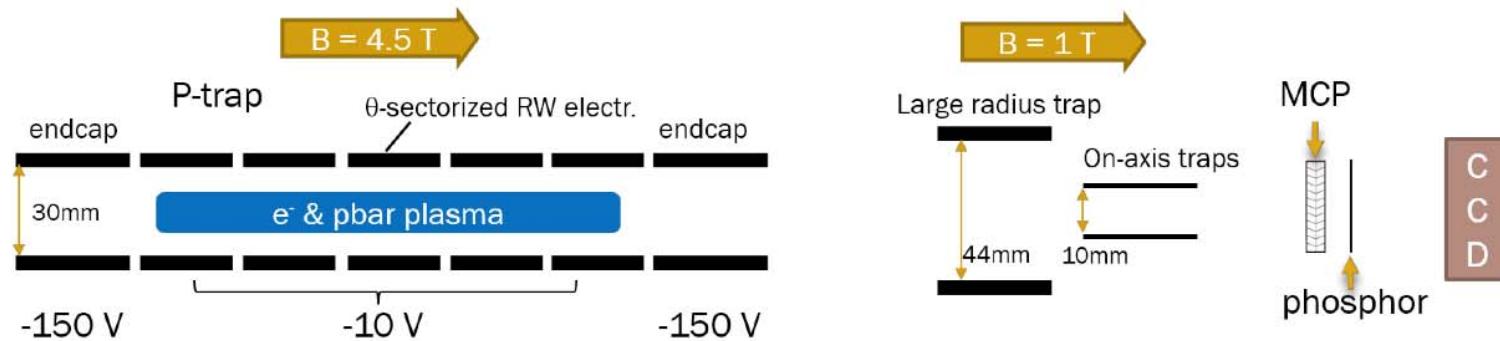
cold pbar lifetime (with electrons) 2014 results



Cold pbar storage time in 2015

- Unstable results
- Lifetime few hundreds seconds but decreasing in few days to few tens secs
- Several partial re-heating of the apparatus to regenerate the pumping efficiency of the cold surfaces
- Leak between OVC and UHV due to a mechanical problem
- It is understood now and fixed (hopefully)

Radial Compression of trapped pbars (2015 run)

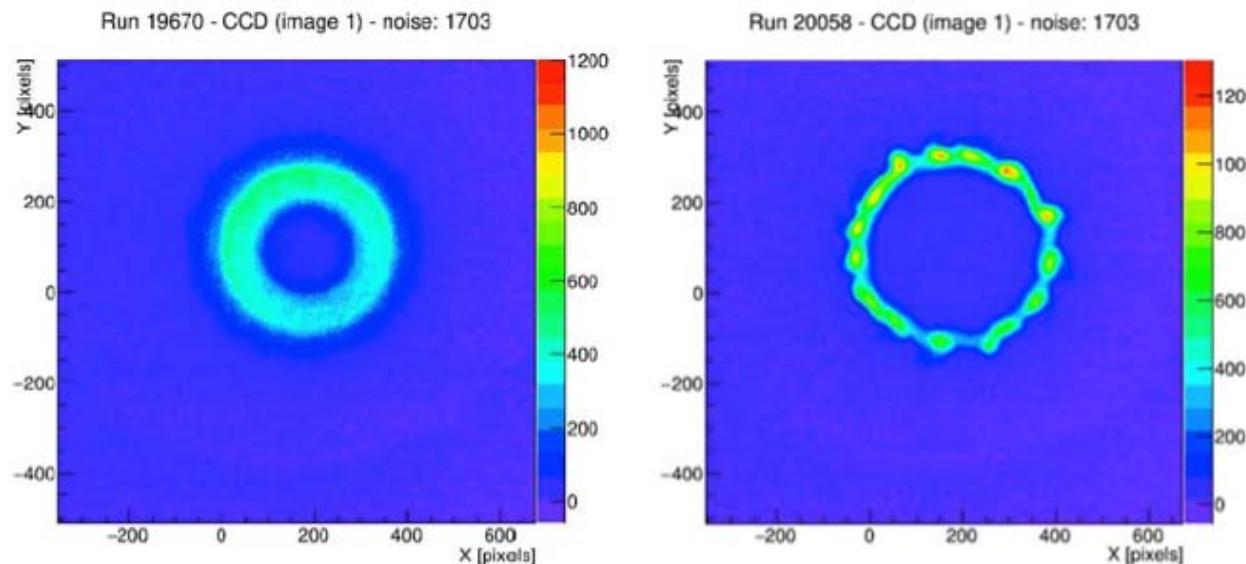


Rotating Wall (RW)

- we routinely use it with electrons
- the trapped plasma rotate as a rigid body
- angular frequency depends on the density
- change the angular frequency the density will change
- use RF electric fields with a proper phase



RW on e- and pbar trapped together: Centrifugal separation



Can we compress e- and pbar trapped together?

Centrifugal separation

expected for pbar and e- in thermal equilibrium in the trap:
it requires high density, Low T

Gently heat the electrons to avoid the separation

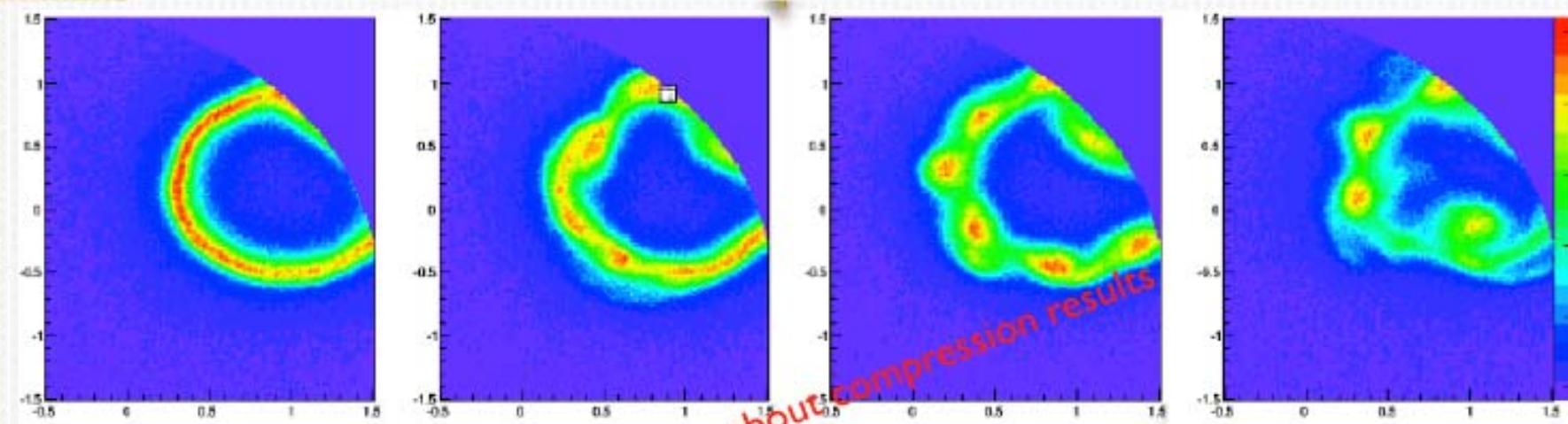
Find the parameters such that electron compression results in pbar compression

Vortices of antiprotons

Observation of ring decay by vortices:

Collective effect

It shows that we have reached the plasma regime for cold pbars



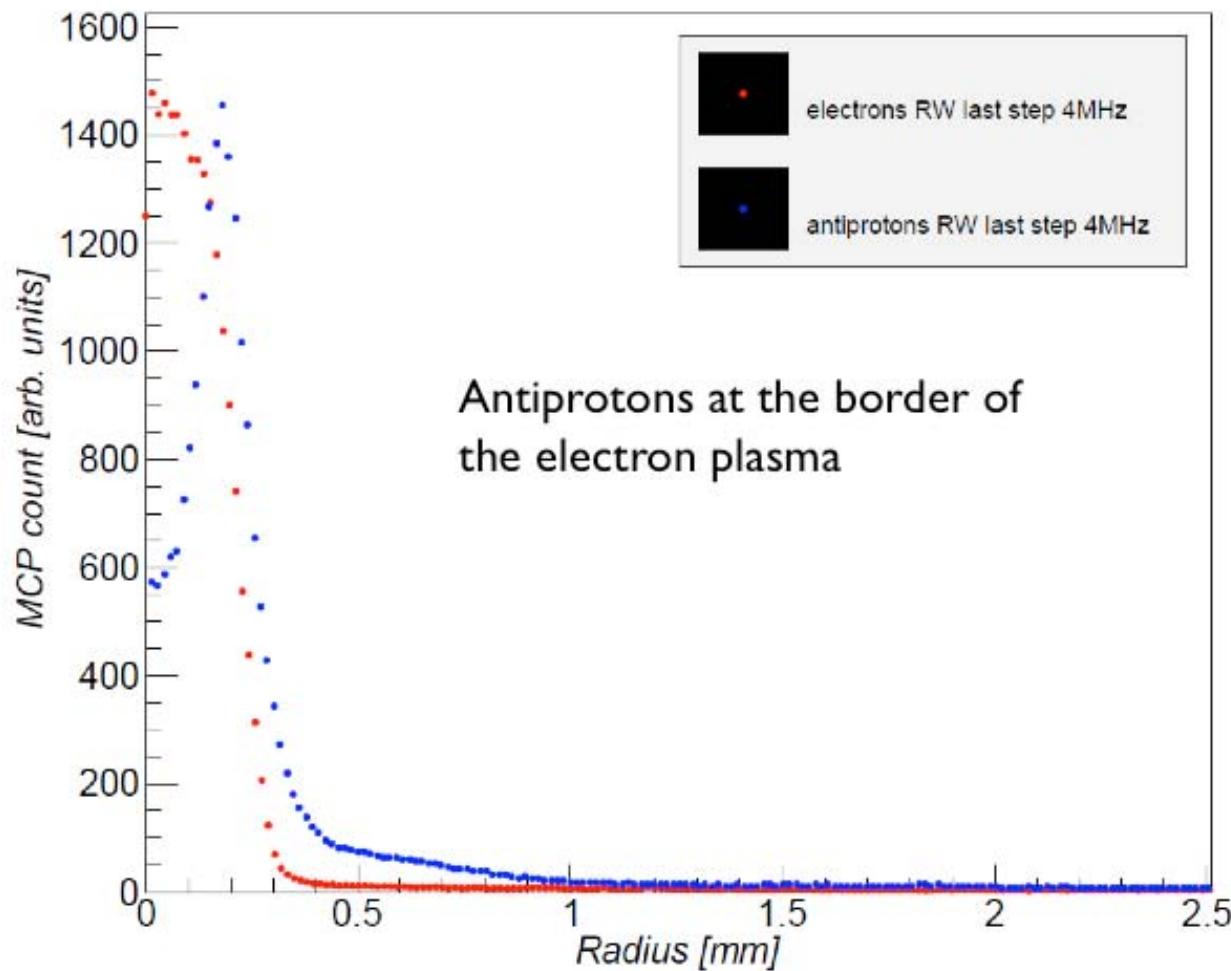
Paper in preparation about compression results
Draft almost ready



Electrons and pbar compression

Radial density (z integrated)

electrons and antiprotons superimposed



Additional results on 2015

Simultaneous work with pbar and e+ in the 5 T magnets

Observed interaction between pbar and e+ in nested traps in the 5 T magnet
(ATHENA style)

Transfer tests toward the 1 Tesla

Better online data analysis

Continuous DAQ improvements

Better user interface on the trap control

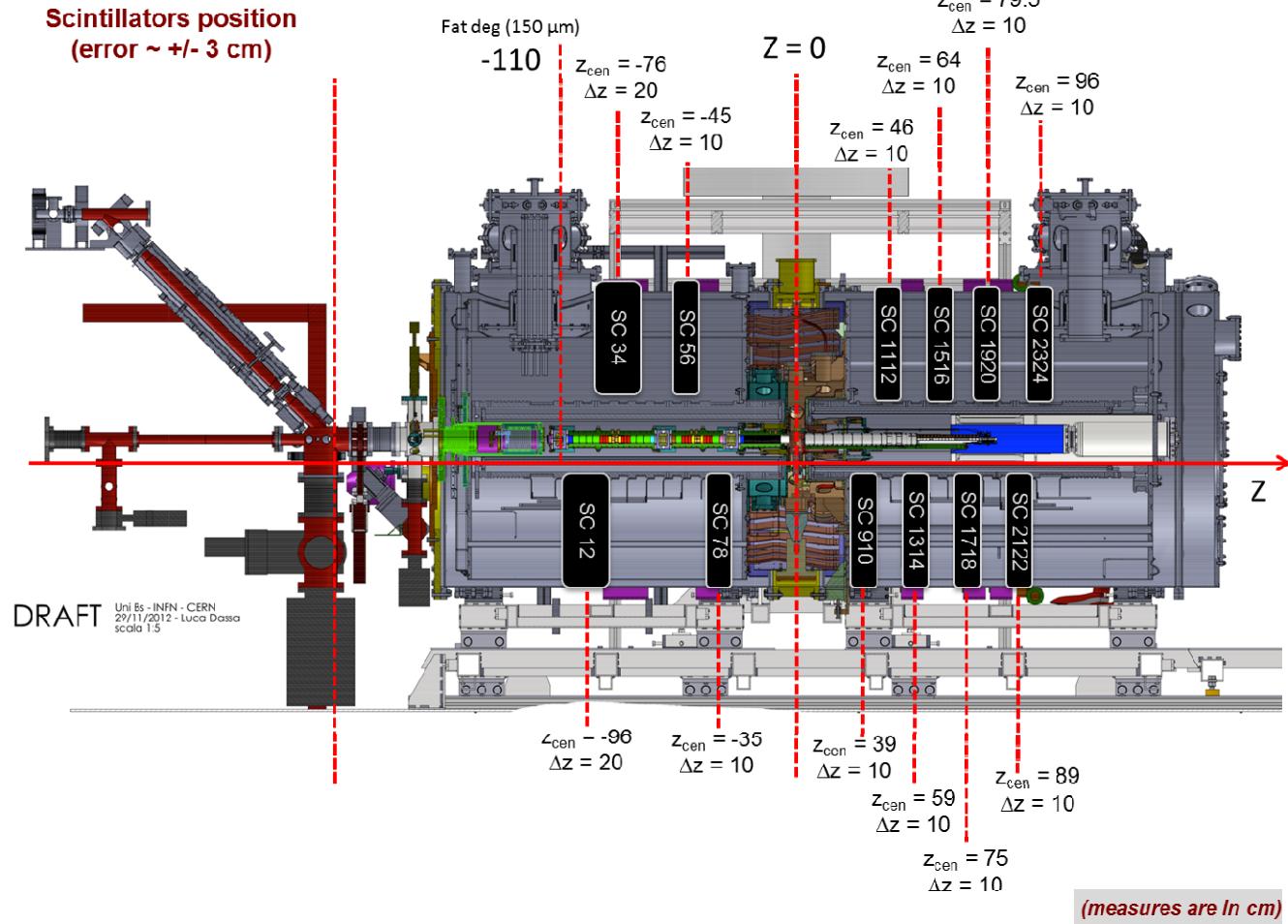
Organization and preparation of public tools for offline data analysis

Sviluppo delle attività del gruppo di Pavia/Brescia

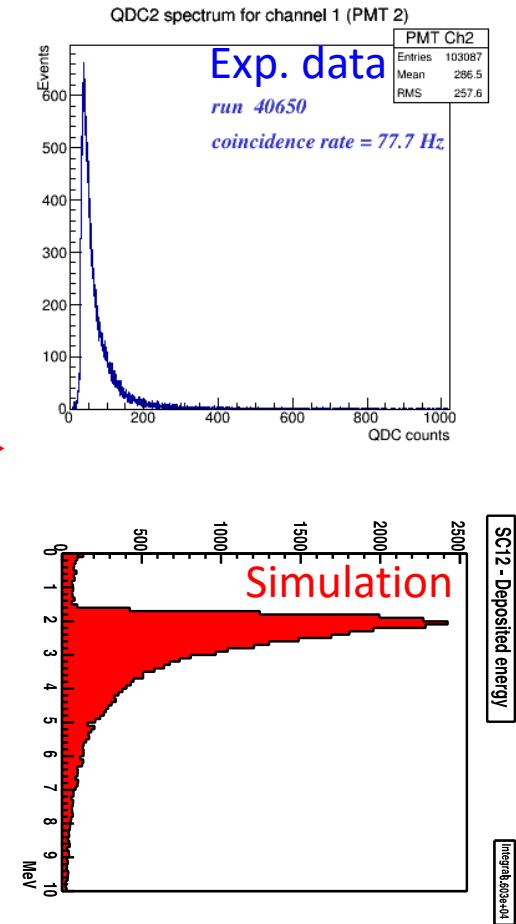
1. **Rivelatori esterni**: fornitura, installazione, manutenzione, calibrazione e utilizzo dei detectors (PMT e HPD) con supporto officina meccanica e servizio elettronico di Sezione
2. **Simulazioni Monte Carlo**
 - a. Nuovo sistema di degrader (Mimotera)
 - b. Inserimento del modulo di simulazione di Hbar in un campo magnetico
 - c. Risposta della catena di acquisizione ad alto rate ($> 1 \text{ MHz}$) per studiare possibili effetti di saturazione
3. **Riscrittura software di analisi online e sua integrazione con DAQ**
4. **Riscrittura software di analisi offline**

new

Scintillation detectors



Calibration with cosmic rays

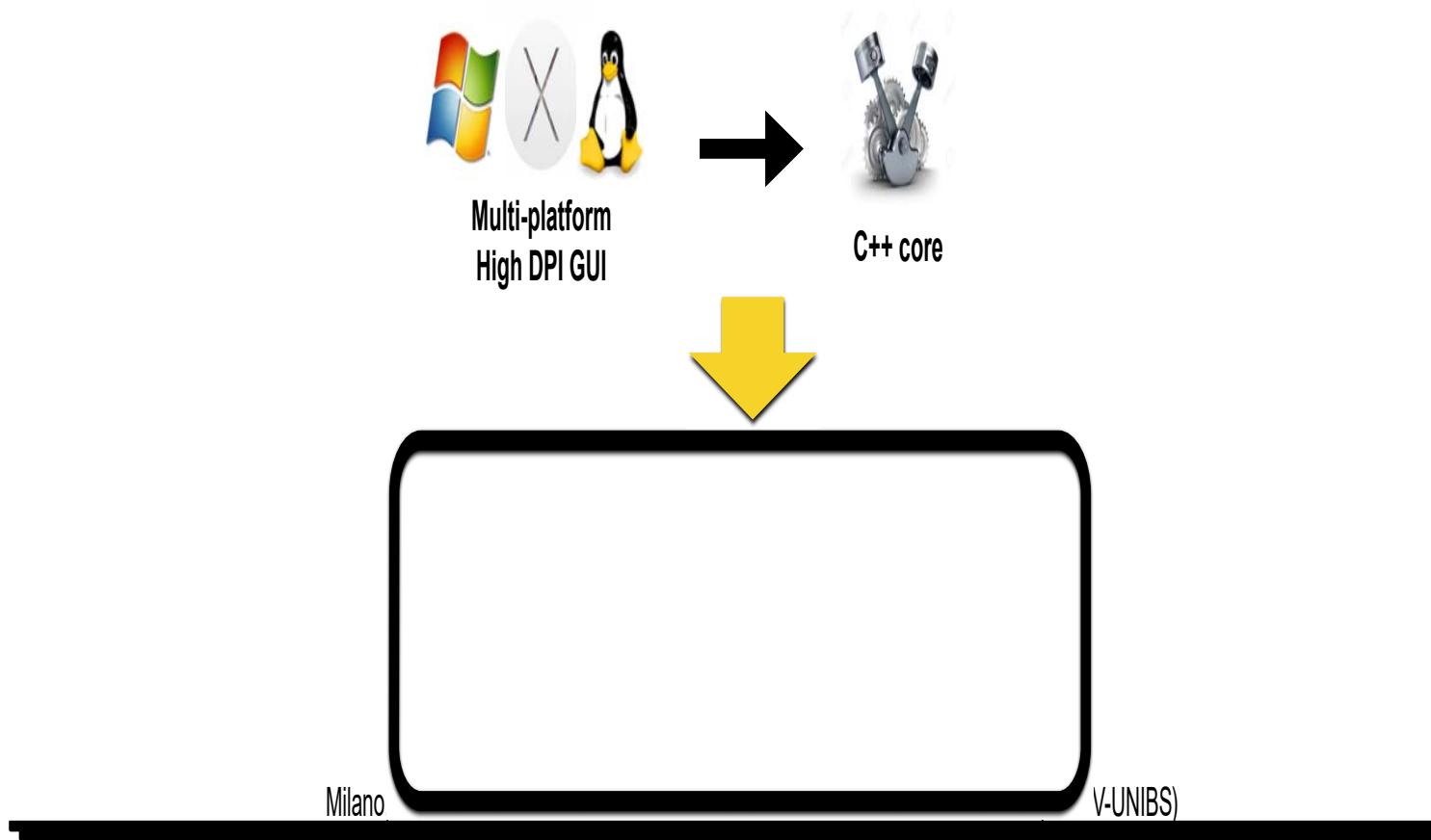


AEgIS data acquisition

- a **multi-port system** has been introduced this year
- it allows to start a new run even though the data from the previous one are still on queue to be written to disk
- some detectors send all the data at the end of the run causing a delay in the closing of the run
- this multi-process approach has required major changes
also for the online software (next slide)

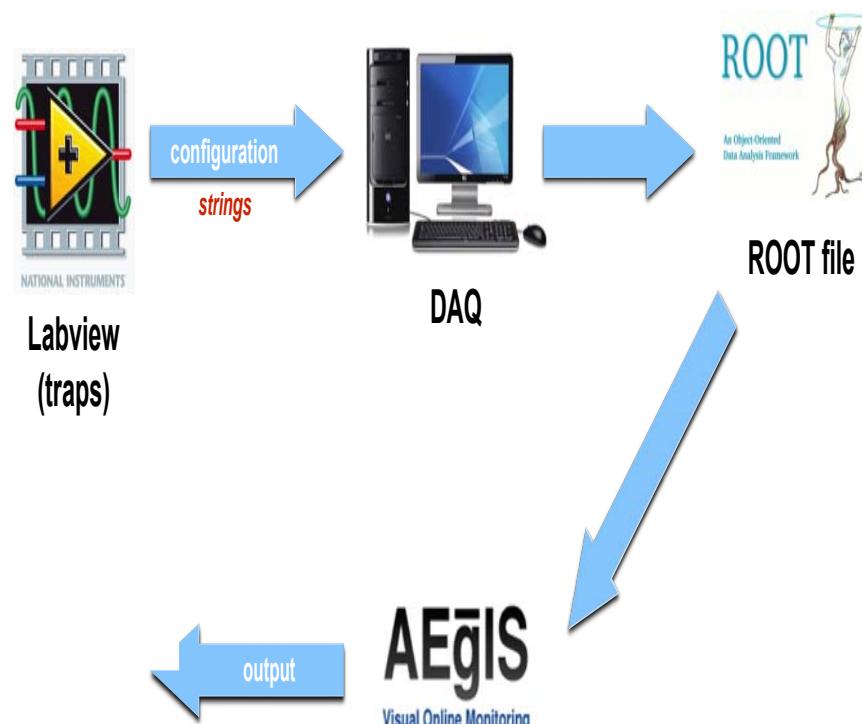
AEglS online software: overview

- provides a set of tools to monitoring the status of data taking in real time

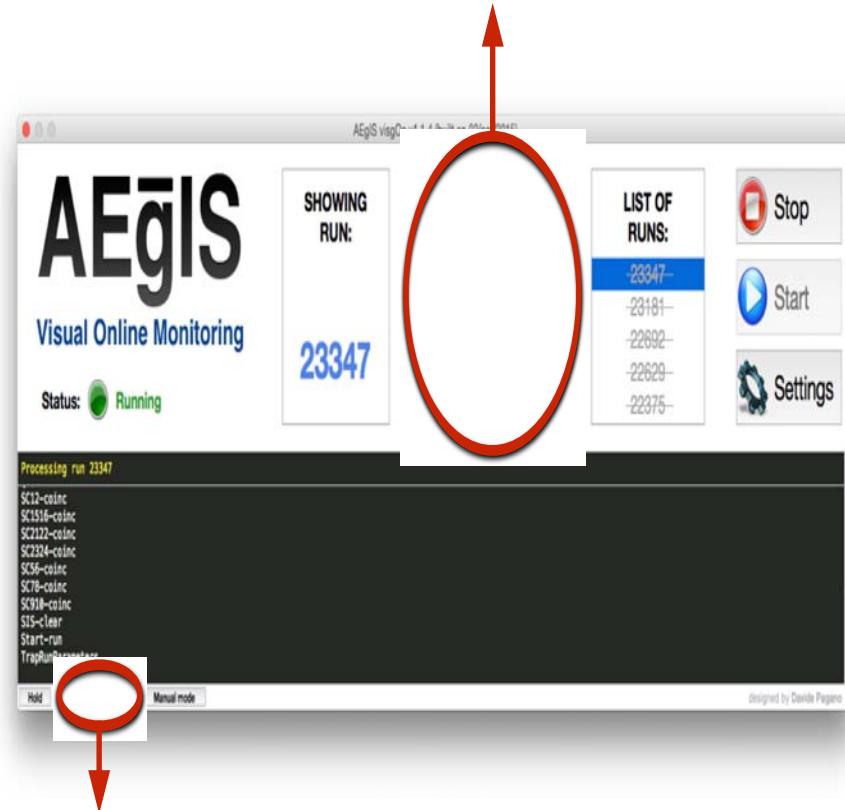


AEglS online software: configuration

- the online software can be configured from the trap labview program



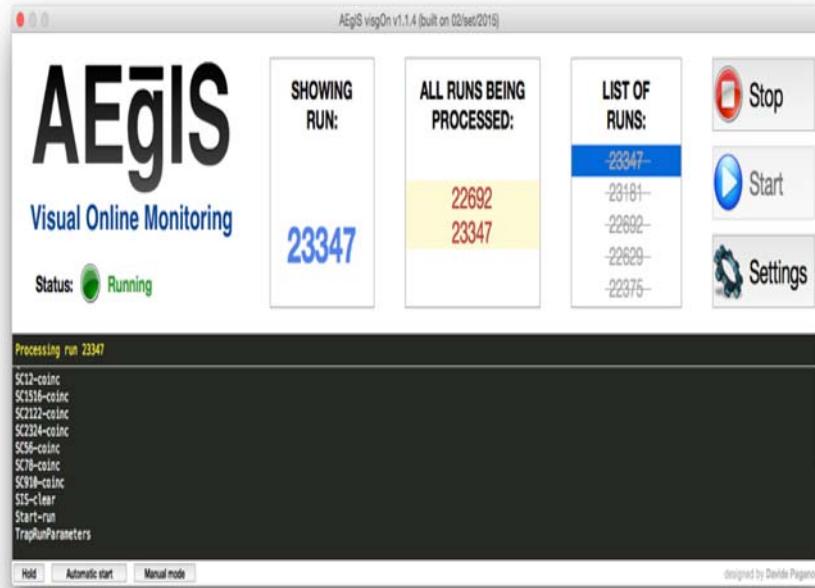
Multi-process...and multi-thread



Automatic processing

New runs are automatically detected and processed

AEgis online software: the GUI





Obiettivi per il 2016

Time schedule

- 2016 run starting now
 - Goals for 2016
 - a) Ps formation in 1 Tesla
 - b) Pbar into the final trap with high efficiency
 - c) Ps excitation in 1 Tesla....??
- Hbar formation: 2017
- 1% g measurement: not before LS2
(we need 100 mK)

Low precision g measurement before LS2:
under study.....

AD Schedule 2016 (Version 2.2 May 31rst, 2016)

Wk	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Apr 4 - Apr 10	14						
Apr 11 - Apr 17	15						
Apr 18 - Apr 24	16	07-15-15-23-23-07					
Apr 25 - May 1	17	MD AD6 AD3	AD5 AD6 AD3	AD5 AD6 AD3	AD5 AD6 AD3	AD5 AD6 AD3	AD5 AD6 AD3
May 2 - May 8	18	AD3 AD5 AD6	AD3 AD5 AD6	AD3 AD5 AD6	AD3 AD5 AD6	AD3 AD5 AD6	AD3 AD5 AD6
May 9 - May 15	19	AD3 AD6 AD5	AD3 AD6 AD5	AD3 AD6 AD5	AD3 AD6 AD5	AD3 AD6 AD5	AD3 AD6 AD5
May 16 - May 22	20	MD AD3 AD5	AD6 AD3 AD5	AD6 AD3 AD5	AD6 AD3 AD5	AD6 AD3 AD5	AD6 AD3 AD5
May 23 - May 29	21	AD5 AD6 AD3	AD5 AD6 AD3	AD5 AD6 AD3	AD5 AD6 AD3	AD5 AD6 AD3	AD5 AD6 AD3
May 30 - Jun 5	22	AD2 AD5 AD6	AD2 AD5 AD6	AD2 AD5 AD6	AD2 AD5 AD6	AD2 AD5 AD6	AD2 AD5 AD6
Jun 6 - Jun 12	23	MD AD2 AD5	TS AD2 AD5	AD8 AD2 AD5	AD8 AD2 AD5	AD8 AD2 AD5	AD8 AD2 AD5
Jun 13 - Jun 19	24	AD3 AD8 AD2	AD3 AD8 AD2	AD3 AD8 AD2	AD3 AD8 AD2	AD3 AD8 AD2	AD3 AD8 AD2
Jun 20 - Jun 26	25	AD6 AD3 AD8	AD6 AD3 AD8	AD6 AD3 AD8	AD6 AD3 AD8	AD6 AD3 AD8	AD6 AD3 AD8
Jun 27 - Jul 3	26	MD AD6 AD3	AD5 AD6 AD3	AD5 AD6 AD3	AD5 AD6 AD3	AD5 AD6 AD3	AD5 AD6 AD3
Jul 4 - Jul 10	27	AD2 AD5 AD6	AD2 AD5 AD6	AD2 AD5 AD6	AD2 AD5 AD6	AD2 AD5 AD6	AD2 AD5 AD6
Jul 11 - Jul 17	28	AD3 AD2 AD5	AD3 AD2 AD5	AD3 AD2 AD5	AD3 AD2 AD5	AD3 AD2 AD5	AD3 AD2 AD5
Jul 18 - Jul 24	29	MD AD3 AD2	AD6 AD3 AD2	AD6 AD3 AD2	AD6 AD3 AD2	AD6 AD3 AD2	AD6 AD3 AD2
Jul 25 - Jul 31	30	AD5 AD6 AD3	AD5 AD6 AD3	AD5 AD6 AD3	AD5 AD6 AD3	AD5 AD6 AD3	AD5 AD6 AD3
Aug 1 - Aug 7	31	AD2 AD5 AD6	AD2 AD5 AD6	AD2 AD5 AD6	AD2 AD5 AD6	AD2 AD5 AD6	AD2 AD5 AD6
Aug 8 - Aug 14	32	MD AD2 AD5	AD3 AD2 AD5	AD3 AD2 AD5	AD3 AD2 AD5	AD3 AD2 AD5	AD3 AD2 AD5
Aug 15 - Aug 21	33	AD6 AD3 AD2	AD6 AD3 AD2	AD6 AD3 AD2	AD6 AD3 AD2	AD6 AD3 AD2	AD6 AD3 AD2
Aug 22 - Aug 28	34	AD5 AD6 AD3	AD5 AD6 AD3	AD5 AD6 AD3	AD5 AD6 AD3	AD5 AD6 AD3	AD5 AD6 AD3
Aug 29 - Sep 4	35	MD AD5 AD6	AD2 AD5 AD6	AD2 AD5 AD6	AD2 AD5 AD6	AD2 AD5 AD6	AD2 AD5 AD6
Sep 5 - Sep 11	36	AD3 AD2 AD5	AD3 AD2 AD5	AD3 AD2 AD5	AD3 AD2 AD5	AD3 AD2 AD5	AD3 AD2 AD5
Sep 12 - Sep 18	37	AD6 AD3 AD2	TS	AD3 AD2 AD2	AD6 AD3 AD2	AD6 AD3 AD2	AD6 AD3 AD2
Sep 19 - Sep 25	38	MD AD6 AD3	AD5 AD6 AD3	AD5 AD6 AD3	AD5 AD6 AD3	AD5 AD6 AD3	AD5 AD6 AD3
Sep 26 - Oct 2	39	AD2 AD5 AD6	AD2 AD5 AD6	AD2 AD5 AD6	AD2 AD5 AD6	AD2 AD5 AD6	AD2 AD5 AD6
Oct 3 - Oct 9	40	AD3 AD2 AD5	AD3 AD2 AD5	AD3 AD2 AD5	AD3 AD2 AD5	AD3 AD2 AD5	AD3 AD2 AD5
Oct 10 - Oct 16	41	MD AD3 AD2	AD6 AD3 AD2	AD6 AD3 AD2	AD6 AD3 AD2	AD6 AD3 AD2	AD6 AD3 AD2
Oct 17 - Oct 23	42	AD5 AD6 AD3	AD5 AD6 AD3	AD5 AD6 AD3	AD5 AD6 AD3	AD5 AD6 AD3	AD5 AD6 AD3
Oct 24 - Oct 30	43	AD2 AD5 AD6	AD2 AD5 AD6	AD2 AD5 AD6	AD2 AD5 AD6	AD2 AD5 AD6	AD2 AD5 AD6
Oct 31 - Nov 6	44	MD AD2 AD5	AD3 AD2 AD5	AD3 AD2 AD5	AD3 AD2 AD5	AD3 AD2 AD5	AD3 AD2 AD5
Nov 7 - Nov 13	45	AD6 AD3 AD2	AD6 AD3 AD2	AD6 AD3 AD2	AD6 AD3 AD2	AD6 AD3 AD2	AD6 AD3 AD2
	AD physics stop November 14th 6AM.						

Injector MD (8:00-18:00) every Wednesday

AD2 (ATRAP)

AD3 (ASACUSA)

AD4 (ACE)

AD5 (ALPHA)

AD6 (AEGIS)

AD8 (BASE)

Based on injector schedule V1.6

Consuntivo fondi CSN: III

Anno: 2015

Sigla: AEGIS

FTE: 2,5+0,5

Persone (Ricercatori + Tecnologi): 4+1

Missioni				
	Assegnato	Speso	%	Note
Meetings	4	4	100,00	
Turni o costruzione	15	14,5	96,67	
Conferenze	0	0		
Totale	19	18,5		

Capitolo	Assegnato	Speso			Note
		Come richiesto	Altro	Variazioni Bilancio	
Consumi	1	0,5	0	-0,5	
Altri Consumi	0	0	0	0	
Costruzione Apparati	0	0	0	0	
Inventario	1	1	0	0	
Licenze	0	0	0	0	
Trasporti	0	0	0	0	
Servizi	3	3	0	0	
Totale	5	4,5	0	-0,5	

Tutte le cifre in kEuro

A Large Ion Collider Experiment



*Gianluigi Boca, Germano Bonomi, Susanna Costanza,
Davide Pagano, Alberto Rotondi, Aldo Zenoni*

INTRO

INFN-PV cluster: il 18 dicembre 2016 il board della collaborazione ha approvato l'ingresso in ALICE del cluster INFN-PV, con membri del Dipartimento di Fisica dell'Università di Pavia e del Dipartimento di Ingegneria Meccanica e Industriale dell'Università di Brescia

membri INFN-PV 2016: Gianluigi Boca, Germano Bonomi, Susanna Costanza, Davide Pagano, Alberto Rotondi, Aldo Zenoni
(3.1 FTE)

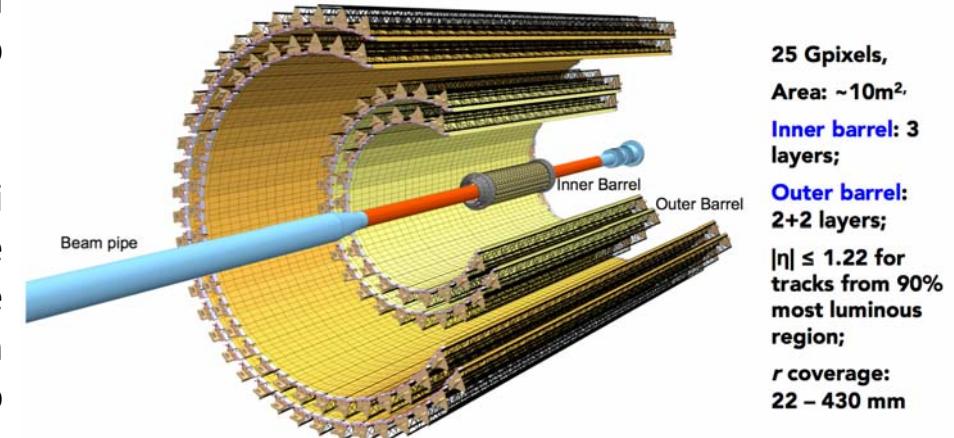
attività in cui abbiamo iniziato a contribuire:

- simulazione del chip pALPIDE per l'upgrade dell'Inner Tracking Silicon detector
- analisi dei dati (decadimento di mesoni charmati D^0)
- QA delle produzioni MC e di ricostruzione

PIXEL DETECTOR SIMULATION

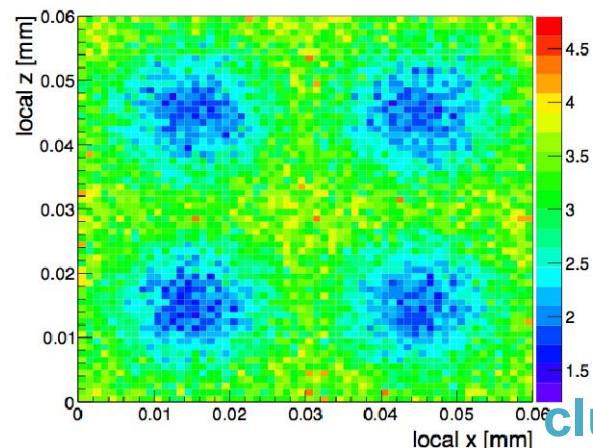
In collaborazione con i colleghi di Torino (M. Masera et al) e Trieste (S. Piano et al.) siamo impegnati nella caratterizzazione e simulazione della risposta dei chip pALPIDE per l'upgrade del rivelatore a pixel ITS.

Essendo disponibile solo la risposta digitale per i nuovi chip, una prima versione completamente parametrizzata della simulazione è stata sviluppata e rilasciata nel software dell'esperimento. Infine, in contatto con il gruppo del CERN, responsabile dello sviluppo dei nuovi chip, stiamo organizzando una presa dati dedicata per ultimare la caratterizzazione del chip ed il conseguente tuning della simulazione.

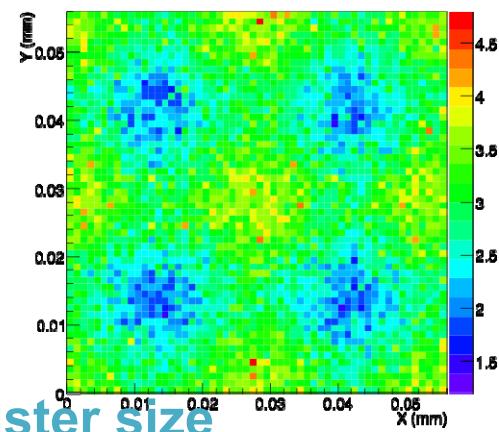


6 GeV pions (normal incidence)

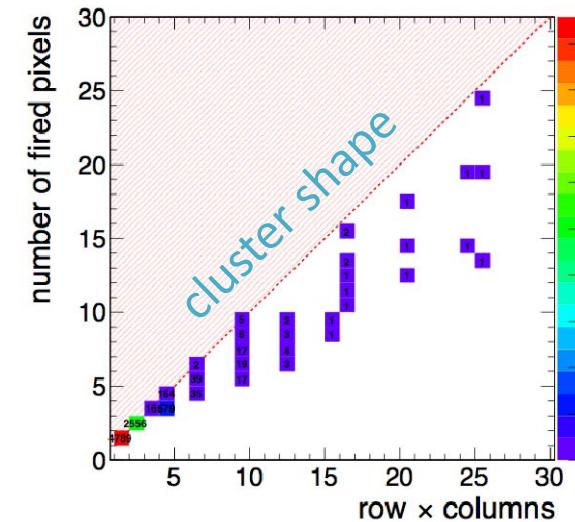
pALPIDE SIMULATION



DATA



cluster size

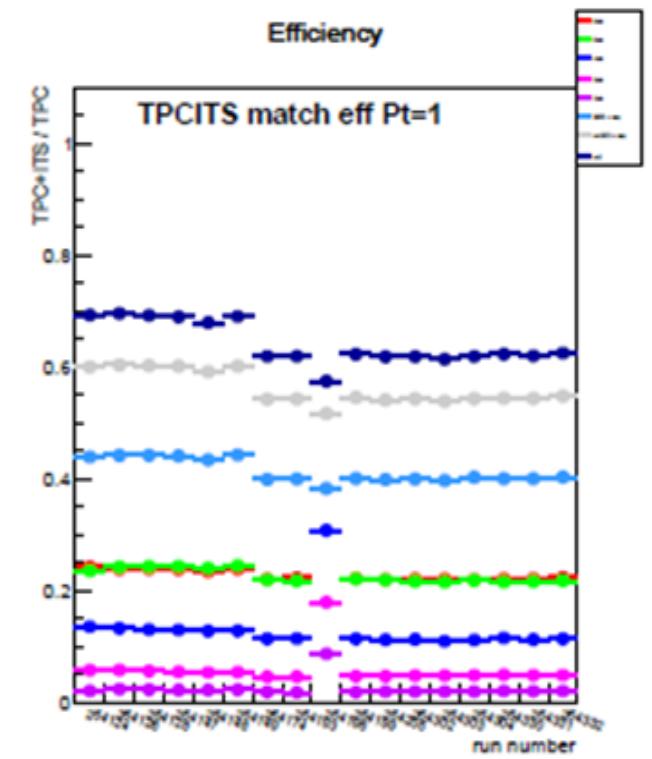
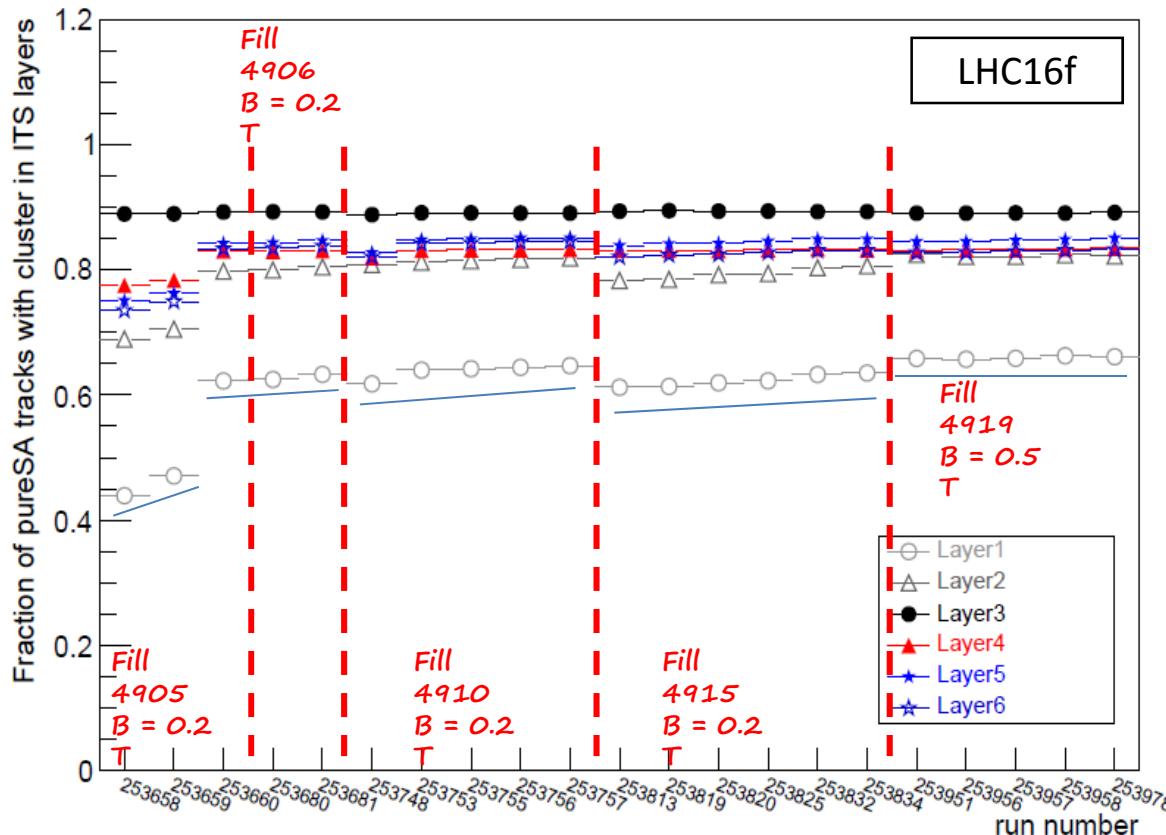


cluster shape

QUALITY ASSURANCE

In collaborazione con una collega di Torino (E. Botta), siamo impegnati nel task di Quality Assurance per il rivelatore ITS: si tratta di effettuare controlli periodici (*trending*) per valutare le prestazioni e il funzionamento del rivelatore ITS, in corrispondenza dei vari step di calibrazione e ricostruzione dei dati raccolti a LHC.

I controlli vanno effettuati anche sulle produzioni Monte Carlo ancorate a specifici set di dati. Oltre al *trending*, è necessario effettuare controlli sui singoli runs (*check*) e fare un confronto diretto tra ogni file di dati e il corrispondente file simulato.



Meeting a cadenza settimanale durante i quali relazionare sulle produzioni che si sono rese disponibili.

ANALISI

Measurement of charm production at central rapidity
in proton-proton collisions at $\sqrt{s} = 7 \text{ TeV}$



The ALICE collaboration¹

ABSTRACT: The p_t -differential inclusive production cross sections of the prompt charmed mesons D^0 , D^+ , and D^{*+} in the rapidity range $|y| < 0.5$ were measured in proton-proton collisions at $\sqrt{s} = 7 \text{ TeV}$ at the LHC using the ALICE detector. Reconstructing the decays $D^0 \rightarrow K^-\pi^+$, $D^+ \rightarrow K^-\pi^+\pi^+$, $D^{*+} \rightarrow D^0\pi^+$, and their charge conjugates, about 8,400 D^0 , 2,900 D^+ , and 2,600 D^{*+} mesons with $1 < p_t < 24 \text{ GeV}/c$ were counted, after selection cuts, in a data sample of 3.14×10^8 events collected with a minimum-bias trigger (integrated luminosity $L_{\text{int}} = 5 \text{ nb}^{-1}$). The results are described within uncertainties by predictions based on perturbative QCD.

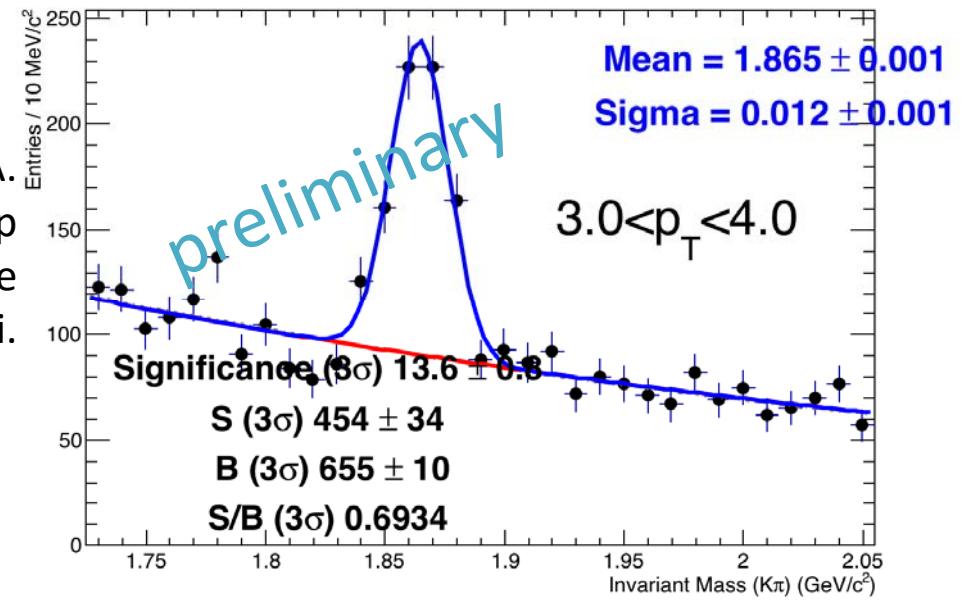
In collaborazione con i colleghi di Padova (A. Dainese et al.) abbiamo iniziato l'analisi dei dati pp per la misura della sezione d'urto di produzione (inclusiva, in funzione di p_T) di mesoni charmati.

Ad aprile ci hanno ufficialmente assegnato
il canale
nei dati pp@8TeV



Produzione di mesoni charmati in pp (nel 2012 pubblicati i dati a 7 TeV - ora analisi dei dati a 8 TeV)

JHEP01(2012)128



Consuntivi FAMU 2015

CdS, 6 giugno 2016



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):
 $r_{ch} = 0.84089(39)$ fm
- Discrepanza di 7σ da CODATA-2010:
 $r_{ch} = 0.87750(510)$ 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:

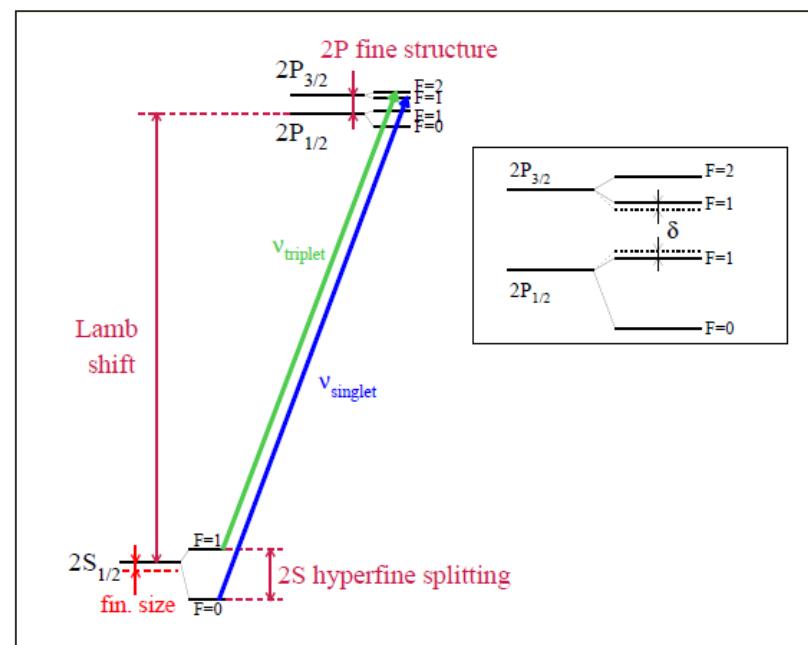
$$r_{ch} = (\int \rho_E(r) r^2 d^3r)^{1/2} : \Delta E_{LS} = 206.0669(25) - 5.2275(10) r_{ch}^2 \text{ meV}$$

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

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

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

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



Metodologia

- L'atomo di μp assorbe un fotone da un laser IR alla lunghezza d'onda della risonanza $\lambda_0 = hc/\Delta E_{HFS}^{1S} \approx 6.8 \text{ } \mu\text{m}$ 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 velocita' del μp .
- In particolare, viene osservato il trasferimento del μ dal protone a nuclei di un gas pesante appropriato, che abbia una dipendenza importante dell'energia dalla rate di trasferimento.
- Il trasferimento del μ è identificato da raggi X caratteristici emessi durante la diseccitazione dell'atomo muonico piu pesante.
- λ_0 (da cui si ricava ΔE_{HFS}^{1S}) viene identificata dalla risposta massimale.

La Collaborazione FAMU (2015)

Responsabile Nazionale: Andrea Vacchi (INFN Trieste)

Sezione	Resp. locale	FTE ricerc.	FTE tecnologi/tecn.	FTE tot
Bologna	G. Baldazzi	2.1	0.3	2.4/10
Milano	R. Ramponi	0.1	0.0	0.1/1
Milano Bicocca	M. Bonesini	3.1	0.7	3.8/8
Pavia	A. Menegolli	1.1	0.4	1.5/5
Roma III	L. Tortora	1.2	0.3	1.5/4
Trieste	A. Vacchi	5.1	0.4	5.5/11

Run FAMU 2014: primi risultati

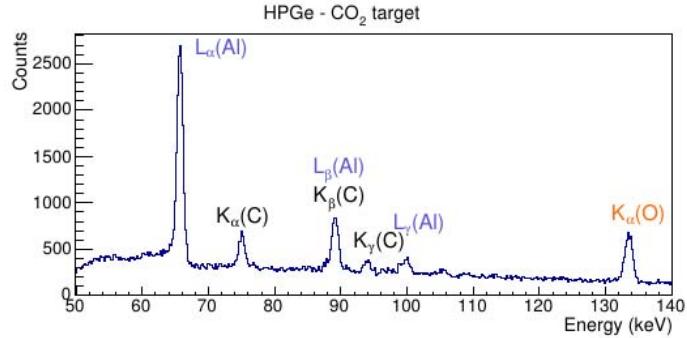
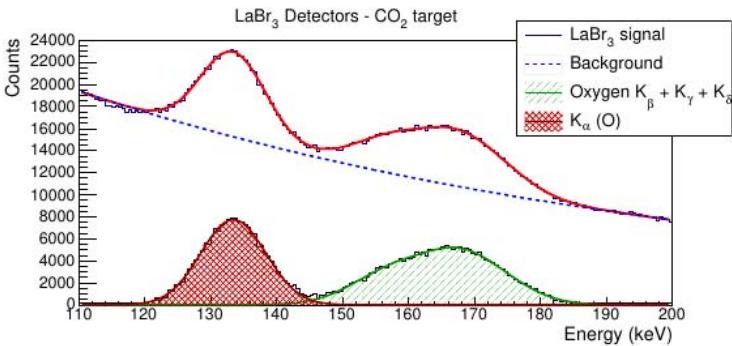
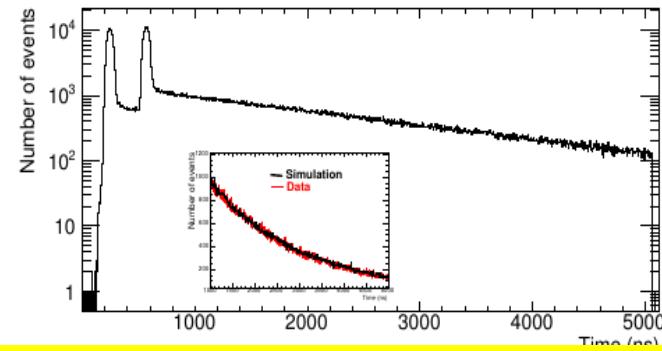


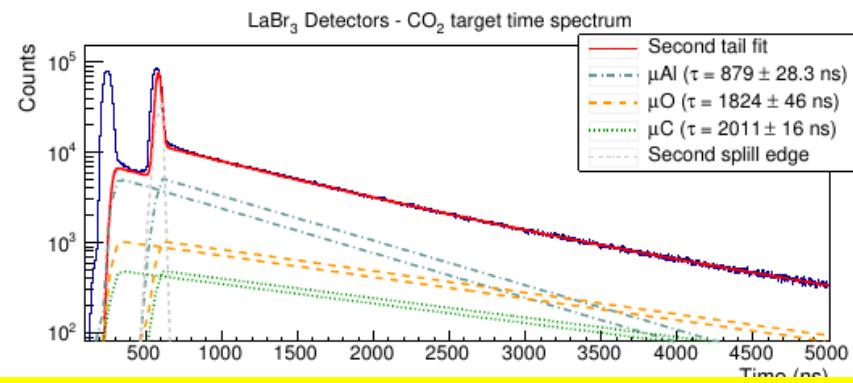
Figure 8. Energy spectrum as measured by the GLP HPGe detector with the $\text{H}_2+4\%\text{CO}_2$ gas target in the region of K spectral lines from μAl to μO . Detected spectral lines are labeled. From this comparison it can be noticed that there was not gas contamination and all measured events in μO spectral lines originated in the gas target.



**Linee dell'Ossigeno
individuate(H_2+CO_2)**



**Tempi di arrivo dei raggi X (coda dovuta
agli X ritardati) - grafite**

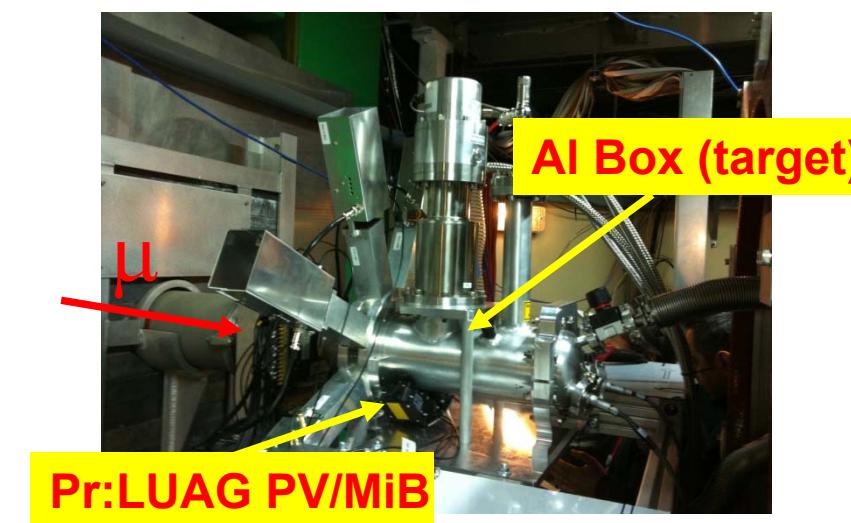
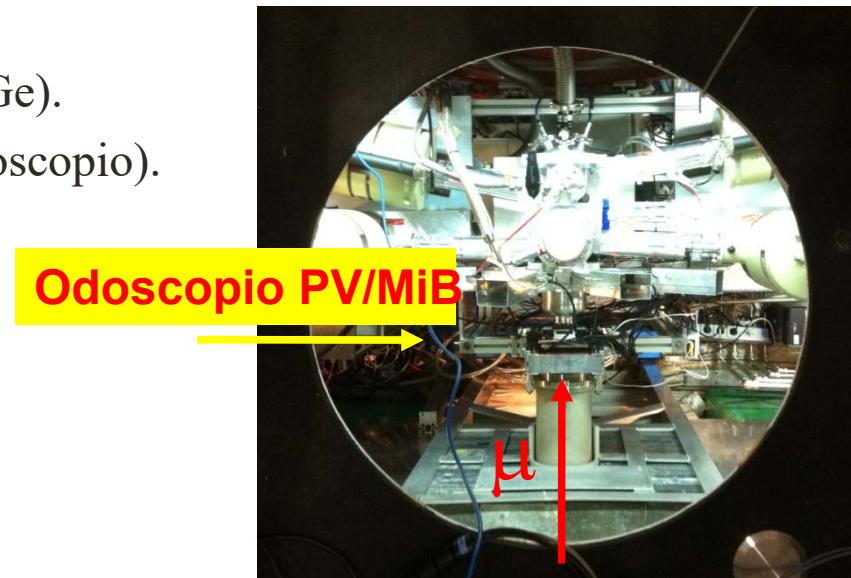
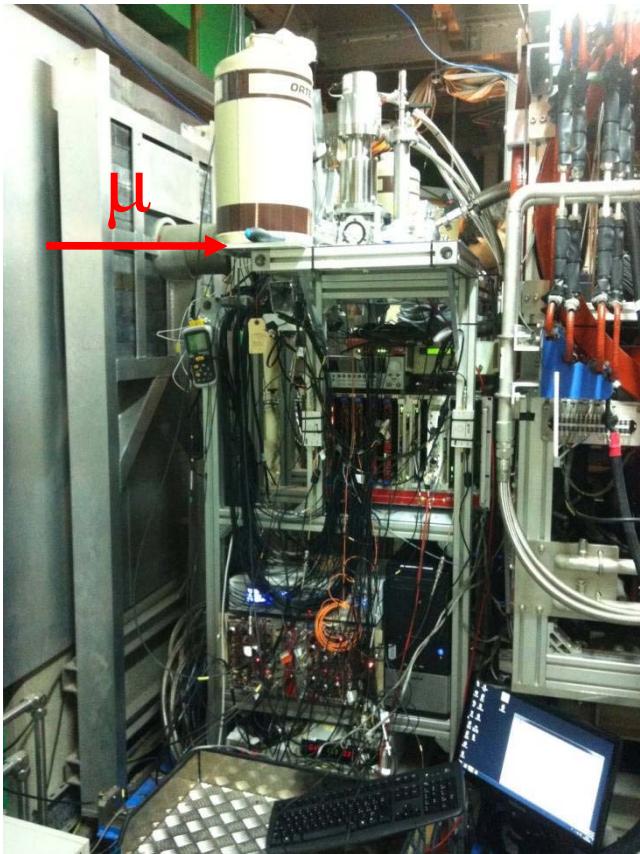


**Coda dello spettro temporale compatibile
con le catture su O e C!**

A. Adamczak et al., “*Steps towards the hyperfine splitting measurement of the muonic hydrogen ground state: pulsed muon beam and detection system characterization*”, Journal of Instrumentation, Volume 11, May 2016.

RUN FAMU 2015/2016

- Test run su fascio di muoni a RIKEN RAL (dicembre 2015 e febbraio 2016) per misura di rate trasferimento di muoni da idrogeno muonico ad atomi pesanti: sono state variate pressione, la temperatura e la concentrazione dei nuclei in diverse miscele di gas.
- Test rivelatori (LaBr₃, Pr:LUAG, HPGe).
- Test monitor dei muoni del fascio (odoscopio).



FAMU-PV: anagrafica 2015

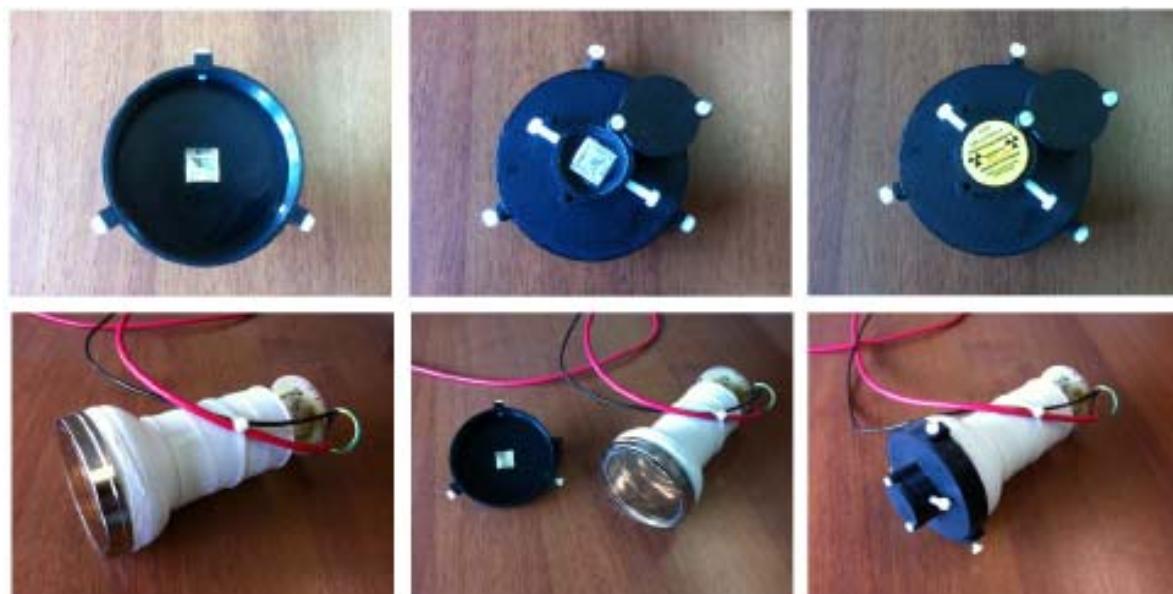
A. De Bari	Ricerc. Universitario	0.4	
A. Menegolli	Ricerc. Universitario	0.4	Responsabile locale
R. Nardò	Tecnologo Universitario	0.2	
M. Rossella	Tecnologo INFN	0.2	
A. Tomaselli	Ricerc. Universitario	0.3	Dipart. di Ing. Industriale e dell'Informazione
TOTALE		1.5	

Finanziamenti 2015:

- Missioni 9k euro;
- Apparati 4k euro.

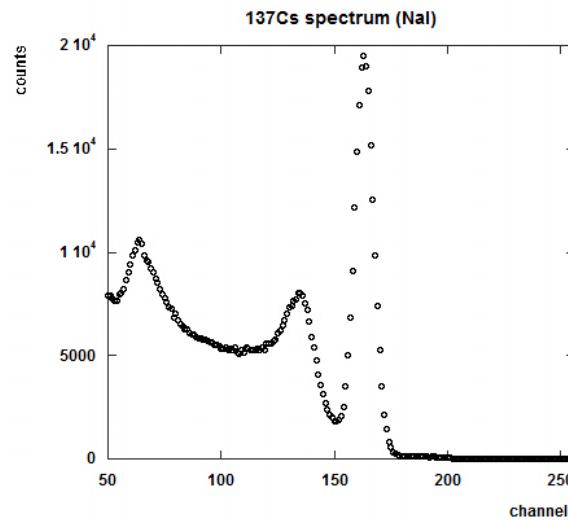
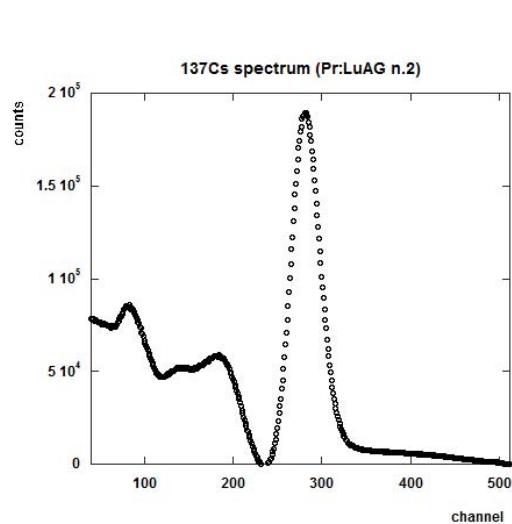
Attività FAMU-PV 2015

Attività di caratterizzazione di cristalli di $\text{Lu}_3\text{Al}_5\text{O}_{12}:\text{Pr}$ (Pr:LuAG) e CeCAAG come rivelatori 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}Cs in un supporto disegnato da Milano Bicocca e realizzato con la stampante 3D di Sezione.

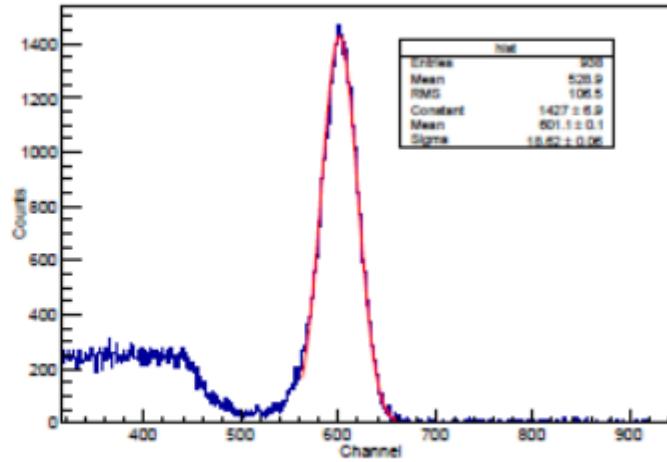
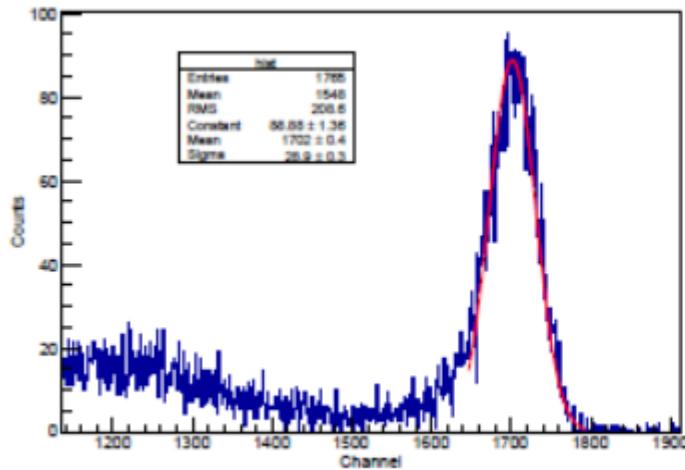
Primi test sul cristallo “nudo” (primavera 2015)



Il picco del ^{137}Cs a 662 keV è ben risolto, ma la risoluzione in energia con PrLuAG è $\sim 13\%$, con NaI $\sim 6\%$. In letteratura si trova riportata una risoluzione in energia di circa 5% con PrLuAG a 662 keV.

- Misure di auto-assorbimento di Pr:LuAG in collaborazione con il gruppo di spettroscopia Raman.
- Test per deposito di riflettore BaSO_4 in collaborazione con il Dipartimento di Chimica Fisica per migliorare l'efficienza di raccolta della luce e quindi la risoluzione in energia.
- Depositi finali di vernice riflettente BaSO_4 e assemblaggio di 5 rivelatori costituiti da 5 cristalli letti da array di SiPMs (in collaborazione con Milano Bicocca).

Test sul cristallo+riflettore+SiPM array (autunno 2015)



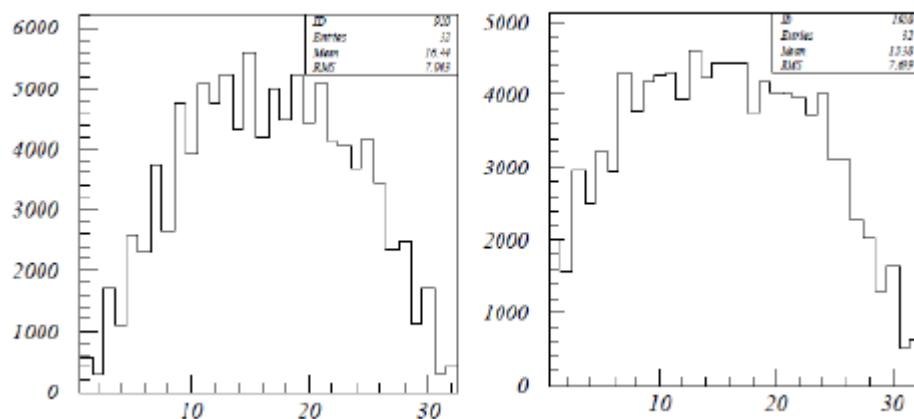
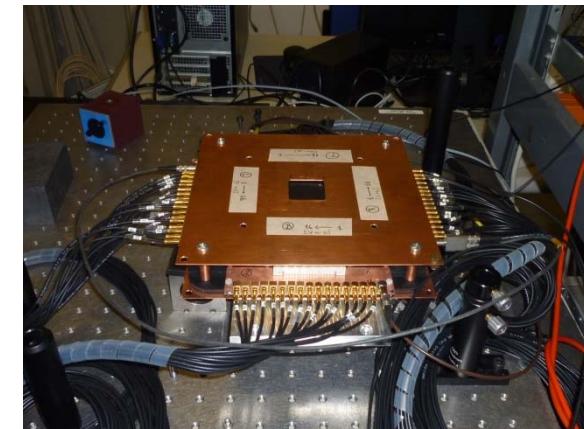
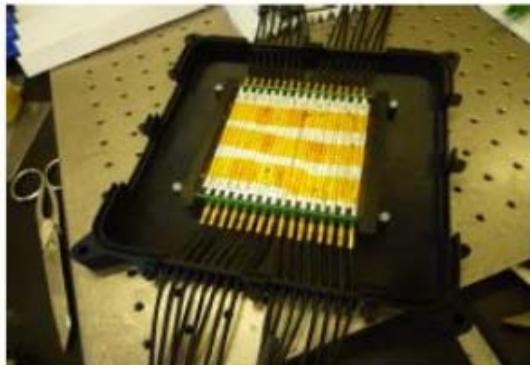
Il picco del ^{137}Cs a 662 keV è ancora ben risolto, e la risoluzione in energia con CeCAAG è $\sim 4\%$ (sinistra) e con Pr:LuAG $\sim 7\%$. In letteratura si trova riportata una risoluzione in energia di circa 5% con PrLuAG a 662 keV letto da PMTs e circa 10% letto da SiPMs.

Installazione 5 Pr:LuAG e 1 CeCAAG e presa dati presso RIKEN-RAL nei test run di Dicembre 2015 (3 giorni) e Febbraio 2016 (6 giorni). Analisi dati raccolti con i nuovi cristalli in corso.



Attività FAMU-PV 2015: nuovo monitor di fascio

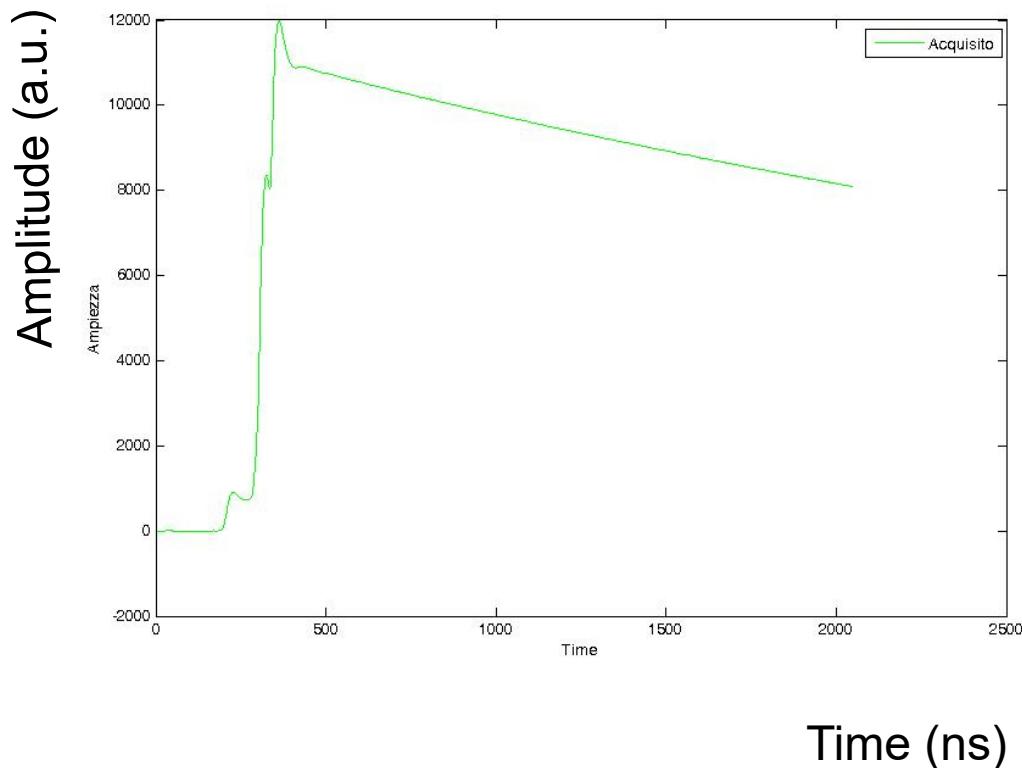
- 2 piani x/y di fibre scintillanti BCF12 (diametro 1 mm) lette da SiPM Advansid 1x1 mm² con celle da 40 μm.
- Boards per alloggiamento SiPM disegnate e realizzate dal Servizio Elettronico della Sezione di Pavia. Meccanica stampata su stampante 3D a Pavia su CAD di INFN Milano Bicocca.



Profilo del fascio (X,Y) misurato dall'odoscopio a 61 MeV/c. RMS del fascio < 1 cm in entrambe le coordinate.

Attività FAMU-PV 2015: elettronica per Germanio MiB

- Disegno e realizzazione da parte del Servizio Elettronico dello stadio di pre-amplificazione per i rivelatori a Germanio di INFN Milano Bicocca in vista dei test run autunno 2016 e 2017.
- I rivelatori al Germanio utilizzati in FAMU sono GEM-Profile-S della Ortec, con tempo di salita di circa 200 ns.



- Esempio di segnale acquisito durante i run di FAMU a RIKEN-RAL con l'attuale elettronica di amplificazione Ortec:

- tempo di salita elevato, non permette di distinguere tra fotoni X primari e ritardati.

Serve una risoluzione temporale di qualche decina di ns.

- Il gruppo FAMU-PV ha iniziato a sviluppare un pre-amplificatore per arrivare a **tempi di salita sotto i 100 ns**. I test sono iniziati con la realizzazione di un pre-amplificatore simil Ortec da utilizzare come punto di partenza:



- Il circuito, disegnato e realizzato presso la Sezione INFN di Pavia, è stato montato sul detector HPGe a Milano Bicocca e testato con:

1) sorgente di Cs-137, riga 661.66KeV:
ampiezza misurata in uscita circa 270 mV

2) sorgente Co-60, riga 1173KeV:
ampiezza misurata in uscita circa 520 mV

In entrambi i casi il segnale presenta un **rise time di ~ 170 ns ed un fall time di ~ 100 μ sec.**

- *Inoltre: studio preliminare di elettronica a basso rumore per amplificazione/shaping per cristalli PrLuAG e LaBr₃ con lettura array SiPMs (vedi preventivi 2017).*

Conferenze 2015

M. Rossella et al., “*Characterization of PrLuAG scintillating crystals for X-ray spectroscopy*”, presented at the 13th Pisa Meeting on Advanced Detectors (Frontier Detectors for Frontier Physics), 24-30 May 2015 La Biodola, Isola d'Elba (Italy)

Pubblicazioni

A. Adamczak et al., “*Steps towards the hyperfine splitting measurement of the muonic hydrogen ground state: pulsed muon beam and detection system characterization*”, Journal of Instrumentation, Volume 11, May 2016.

MAMBO

MAMBO_{nn}

**Studio di fotoreazioni indotte
su nucleoni e nuclei utilizzando gli acceleratori**

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

A2 Collaboration (spokepersons : A. Thomas Mainz
(circa 80 persone) P. Pedroni INFN-PV)

- **ELSA $E_\gamma \leq 3.0$ GeV (Bonn)**

BGO-OD collaboration (spokepersons : H. Schmieden Bonn
(circa 60 persone) P. LeviSandri INFN-LNF)

Sezioni INFN Partecipanti: CT (Me), ISS, LNF, PV, RM2, TO

COLLABORAZIONE MAMBO

Responsabile Nazionale: **ALESSIA FANTINI**

Sezioni INFN partecipanti:

ROMA TOV	Responsabile Locale	RACHELE DI SALVO
LNF	Responsabile Locale	PAOLO LEVI SANDRI
MESSINA	Responsabile Locale	GIUSEPPE MANDAGLIO
PAVIA	Responsabile Locale	PAOLO PEDRONI
ISS-RM	Responsabile Locale	FRANCESCO GHIO
TORINO	Responsabile Locale	GIANPIERO GERVINO

24 ricercatori; 12.1 FTE

MAMBO- Physics Topics

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

- **Threshold meson production:** (test of LET/ ChPT):

Strangeness ($\gamma N \rightarrow \Lambda K$)

π^0 meson 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) η, η' decays

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

Meson photo production on nuclei

- **Search for “missing” baryon resonances**

Vector meson (ϕ, ω) photo production

Use of state-the-art technology (circularly and linearly polarised photon beams; longitudinally and transverse polarised proton/deuteron/ ^3He targets) is required

MAMBO – Mainz- Rivelatore

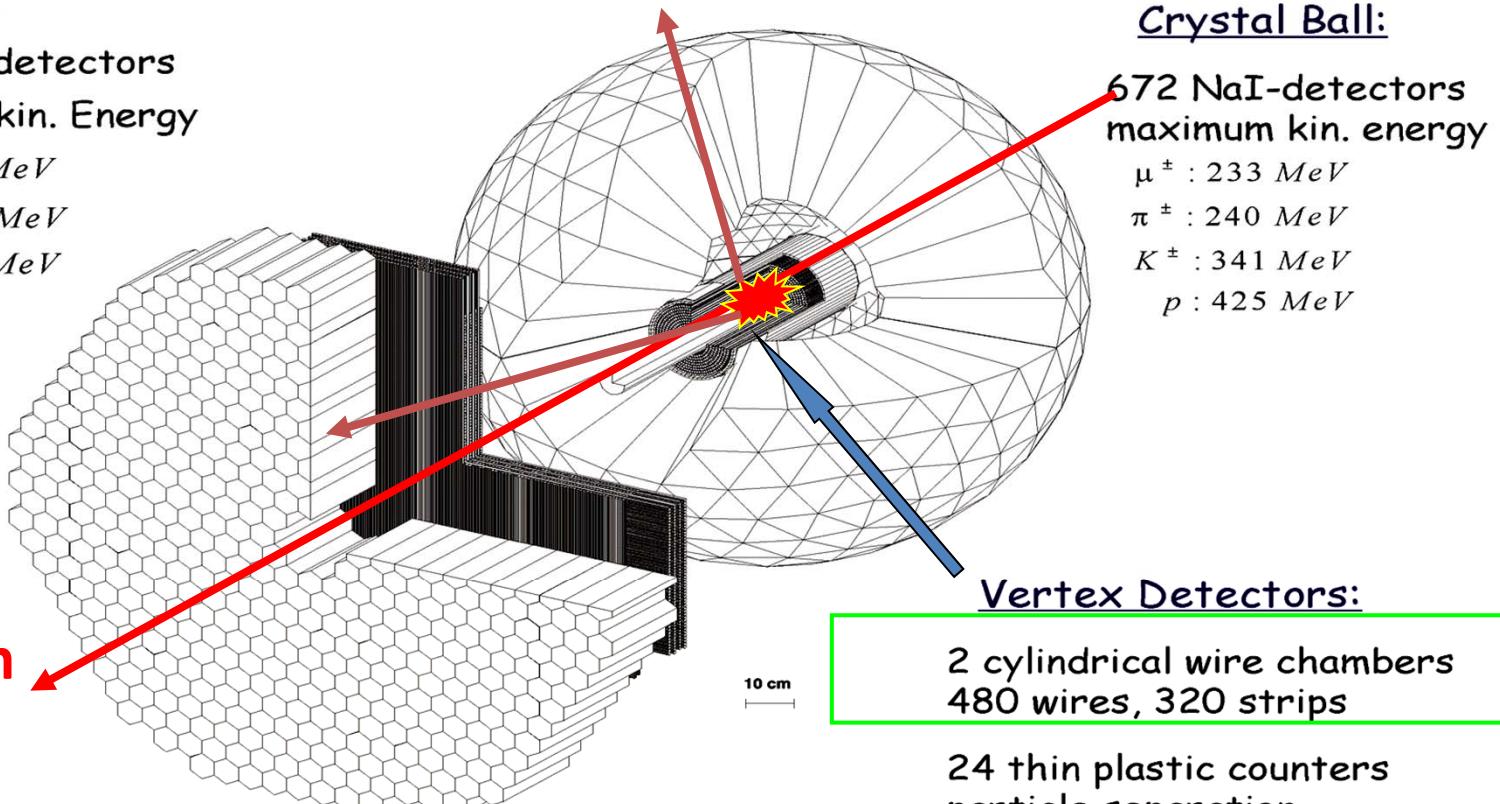
4 π Photon Spectrometer @ MAMI

TAPS:

510 BaF₂-detectors
maximum kin. Energy

π^\pm : 180 MeV
 K^\pm : 280 MeV
 p : 360 MeV

γ beam



MWPC

2 cylindrical detectors (PAVIA)

Crystal Ball:

672 NaI-detectors
maximum kin. energy

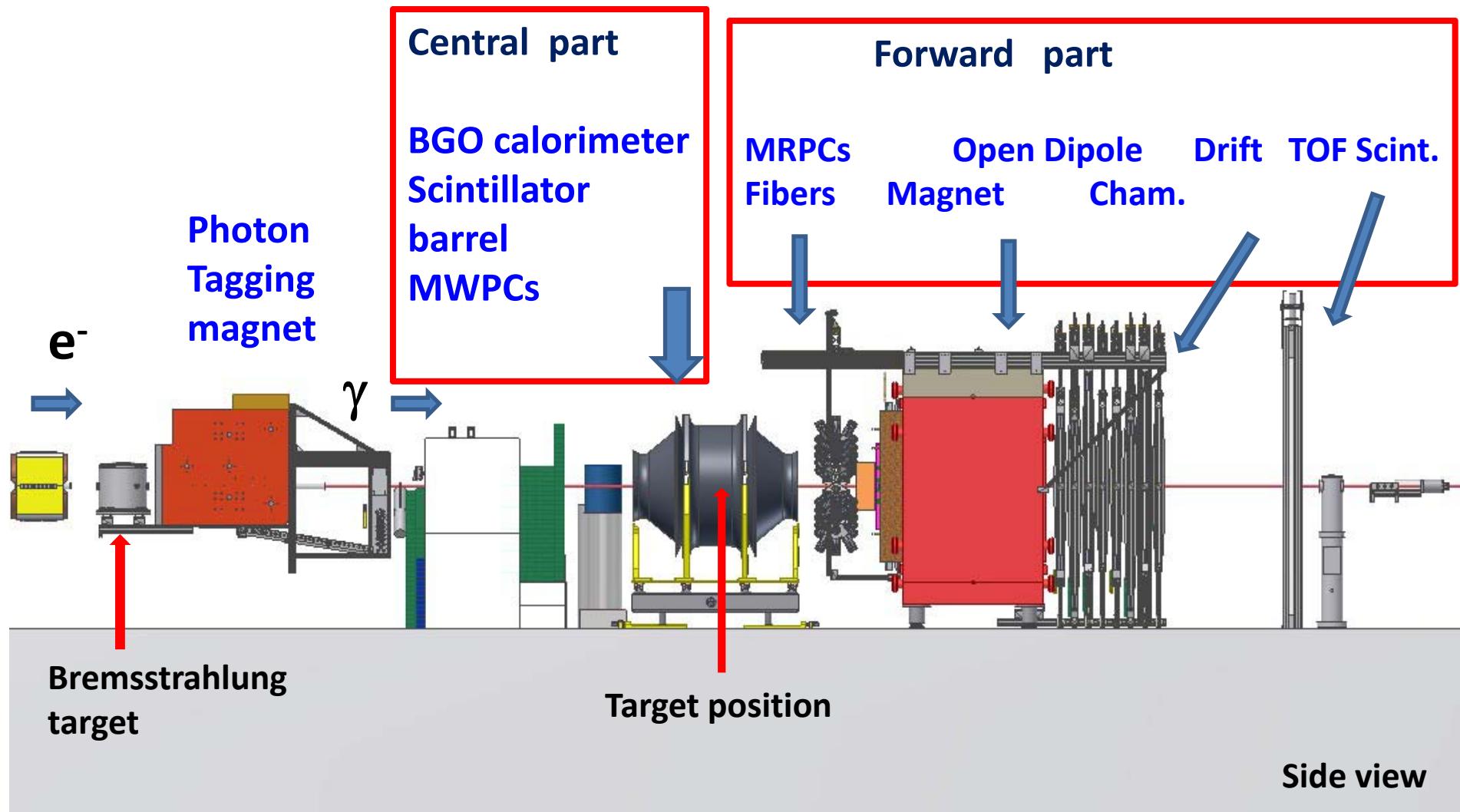
μ^\pm : 233 MeV
 π^\pm : 240 MeV
 K^\pm : 341 MeV
 p : 425 MeV

Vertex Detectors:

2 cylindrical wire chambers
480 wires, 320 strips

24 thin plastic counters
particle separation

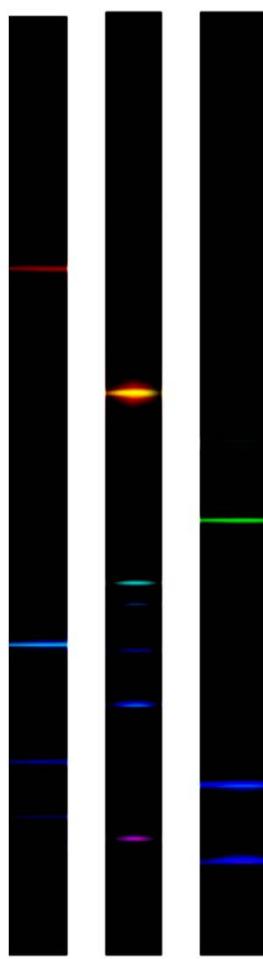
MAMBO – Bonn - Apparato



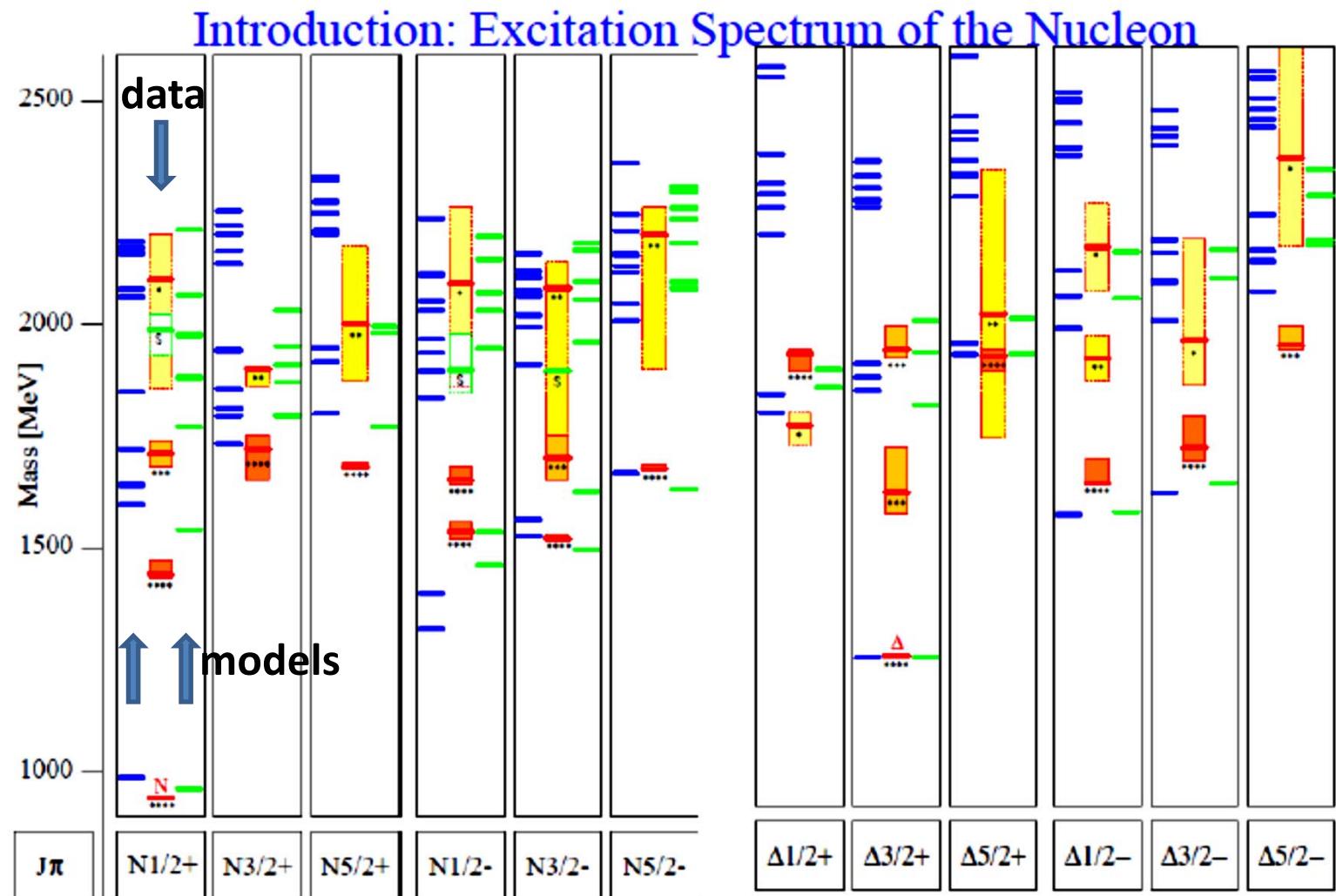
Attività svolta 2015-2016

- **Mainz** : -) manutenzione camere a fili
 -) Prese dati con butanolo (deuterato) (polarizzazione longitudinale e trasversale del bersaglio)
(gran parte del programma di misura per proposal con spokespersons INFN-PV)

- **Bonn** : -) Continuazione commissioning di parti del set-up di rivelazione (MRPCs)
 -) Prime prese dati con buona parte del set-up funzionante
 -) **Manutenzione e commissioning a Bonn del sistema MWPCs**
 -) **Test in fascio e con raggi cosmici delle camere a fili**

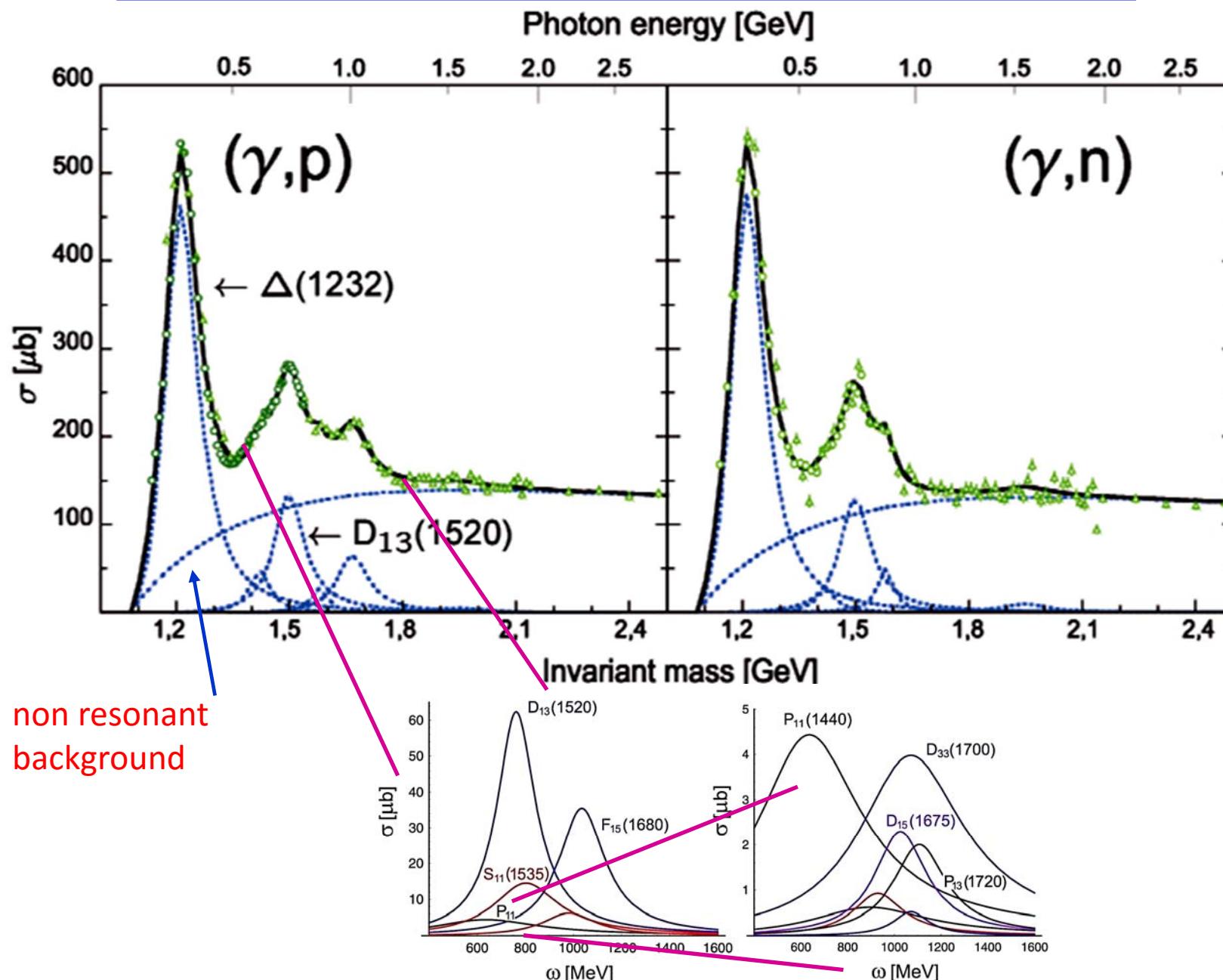


H He Hg
Atom



CQM models
(very similar results from LQCD !)
There are many more predicted states than observed

Unpolarized total cross section



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

Photon polarization		Target polarization	Recoil nucleon polarization	Target and Recoil polarizations
		X Y Z(beam)	X' Y' Z'	X' X' Z' Z' X Z X Z
unpolarized	σ	-	T	-
linear	Σ	H	O_x	T_x
Circular	F	$(-P)$	$(-T)$	L_x
	-	-	C_x	T_z
			C_z	L_z
				$(-L_z)$
				(T_z)
				(L_x)
				$(-T_x)$
				-
				-
				-
				-

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”)

Single and Double Polarised Experiments

Excitation Spectrum

- 1.- Longitudinal PT:** a) E and G of Meson Photoproduction off protons
 b) E and G of Meson Photoproduction off neutrons

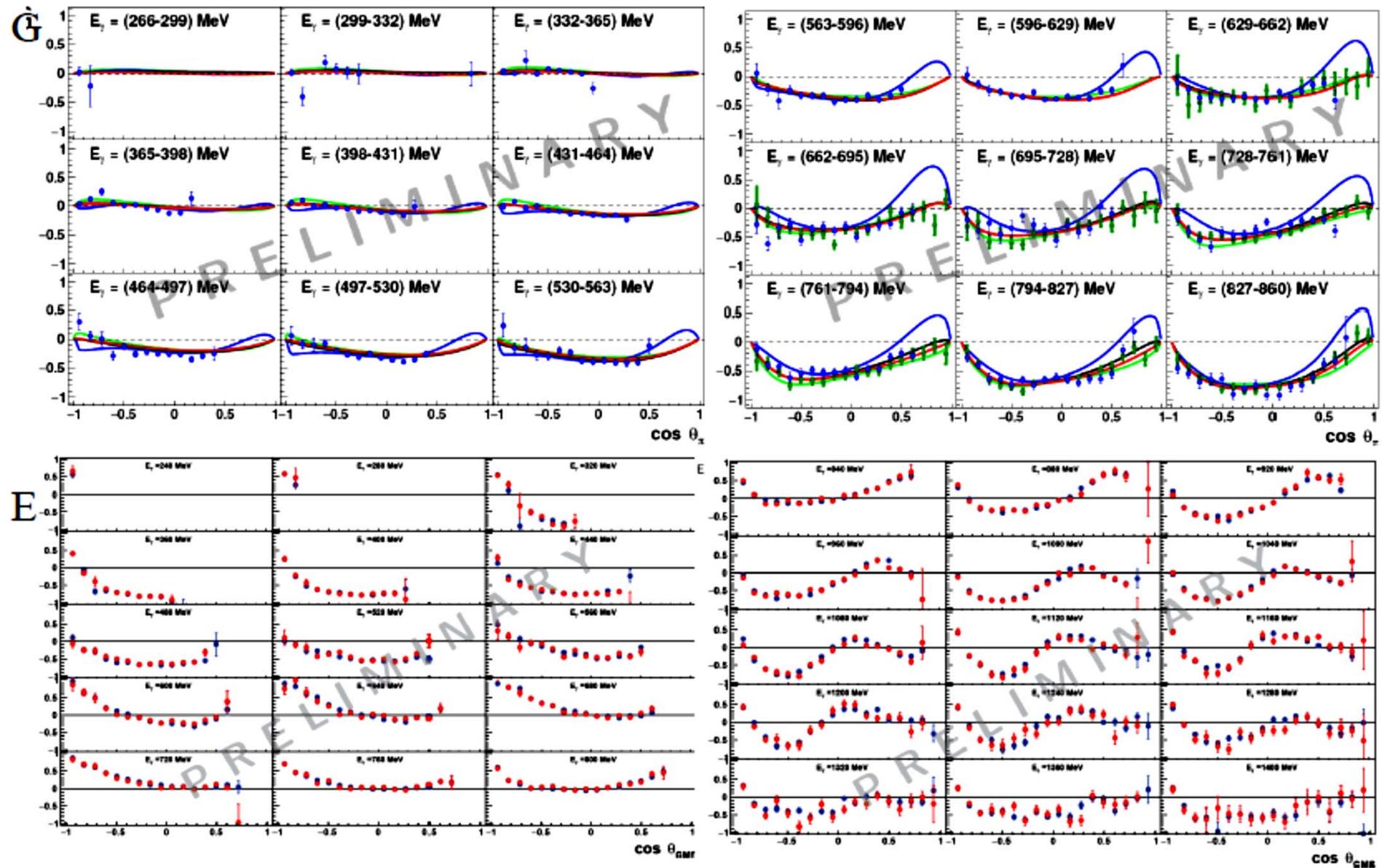
 - 2.- Transverse PT:** a) T and F of Meson Photoproduction off protons
 b) T and F of Meson Photoproduction off neutrons
-

Additional measurements on Fundamental Properties

- 1.- Long. and trans. PT:** Spin Polarisabilities and polarisibilities in Compton process

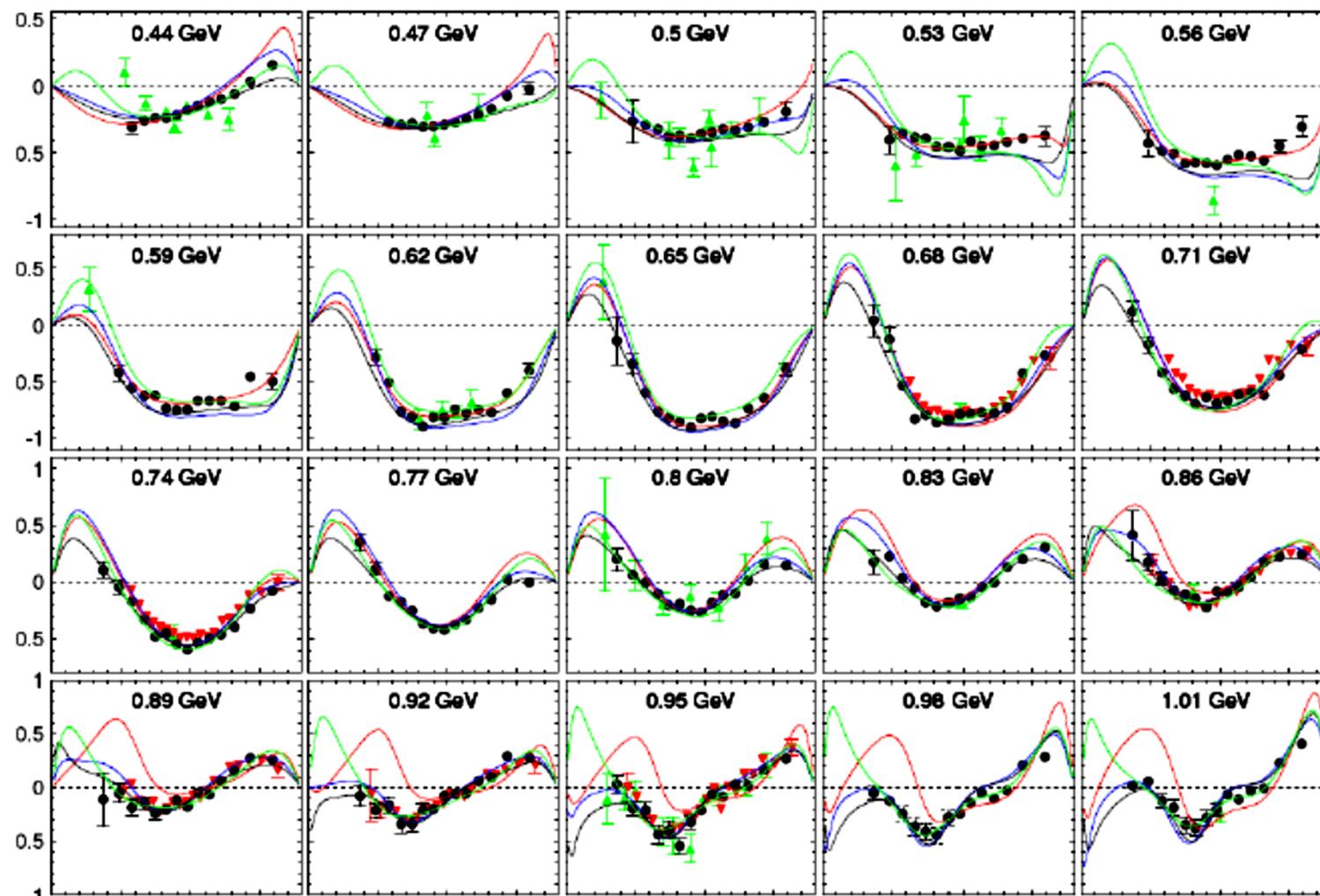
- 2.- Transverse PT:** Transverse asymmetries T and F in π -photoproduction
 in the threshold region $\rightarrow m_u - m_d$

Simultaneous measurement of G and E for π^0 production (F.Afzal, K.Spieker)



T in π^0 -photoproduction

Red line: MAID 2007
blue line: SAID PR15
green line: JUBo2015-B
black line: BG2014-2



2016
New Paper
accepted for
publication
in PRC
J. Annand
et al.

Black Circles – new MAMI Measurement, red triangles Bonn CBELSA, green triangles older data.

The Impact of New Polarization Data from Bonn, Mainz and Jefferson Laboratory on $\gamma p \rightarrow \pi N$ Multipoles

A.V. Anisovich^{1,2}, R. Beck^{1a}, M. Döring^{3,4}, M. Gottschall¹, J. Hartmann¹, V. Kashevarov⁵, E. Klempt¹, Ulf-G. Meißner^{1,6,7}, V. Nikonov^{1,2}, M. Ostrick⁵, D. Rönchen^{1,6b}, A. Sarantsev^{1,2}, I. Strakovsky³, A. Thiel¹, L. Tiator⁵, U. Thoma¹, R. Workman³, Y. Wunderlich¹

arXiv:1604.05704

We find that the new data force the multipoles to get closer to each other, the variance is reduced by about a factor of two.

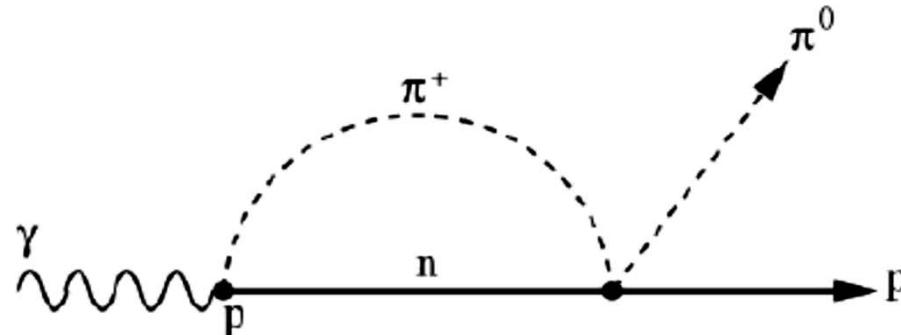
Even more important seems to be that the multipoles converge to similar values in the region of leading resonances while the “background” and the contribution of higher-mass resonances remain less constrained by the new data. Clearly, the aim is to get very similar answers also in the mass range which contains higher-mass resonances. This task will require more precise data, in particular more precise data on polarization observables.

Asymmetries T and F in $\gamma p \rightarrow p\pi^0$ at threshold

→ Study of the dynamic consequences of $m_d - m_u > 0$.

$$m_{\pi^0} = 135 \text{ MeV} \quad \frac{1}{\sqrt{2}} \cdot (|u\bar{u}\rangle - |d\bar{d}\rangle)$$

$$m_{\pi^+} = 139.6 \text{ MeV} \quad |u\bar{d}\rangle$$



Rescattering diagram responsible for the unitary cusp observed in E0+($\gamma p \rightarrow p\pi^0$)

Precision experiment to test the **unitary calculations**

→ [Bernstein et al. arXiv:0902.3412 [nucl-th] (Feb. 2009) and **ChPT calculations**

[V.Bernard, N.Kaiser, and U.G.Meissner, Eur. Phys. J. A11, 209 (2001)] of ImE0+.

Threshold π^0 photoproduction on transverse polarised protons at MAMI, S.Schumann et al.,
PLB 750 (2015) 252- 258

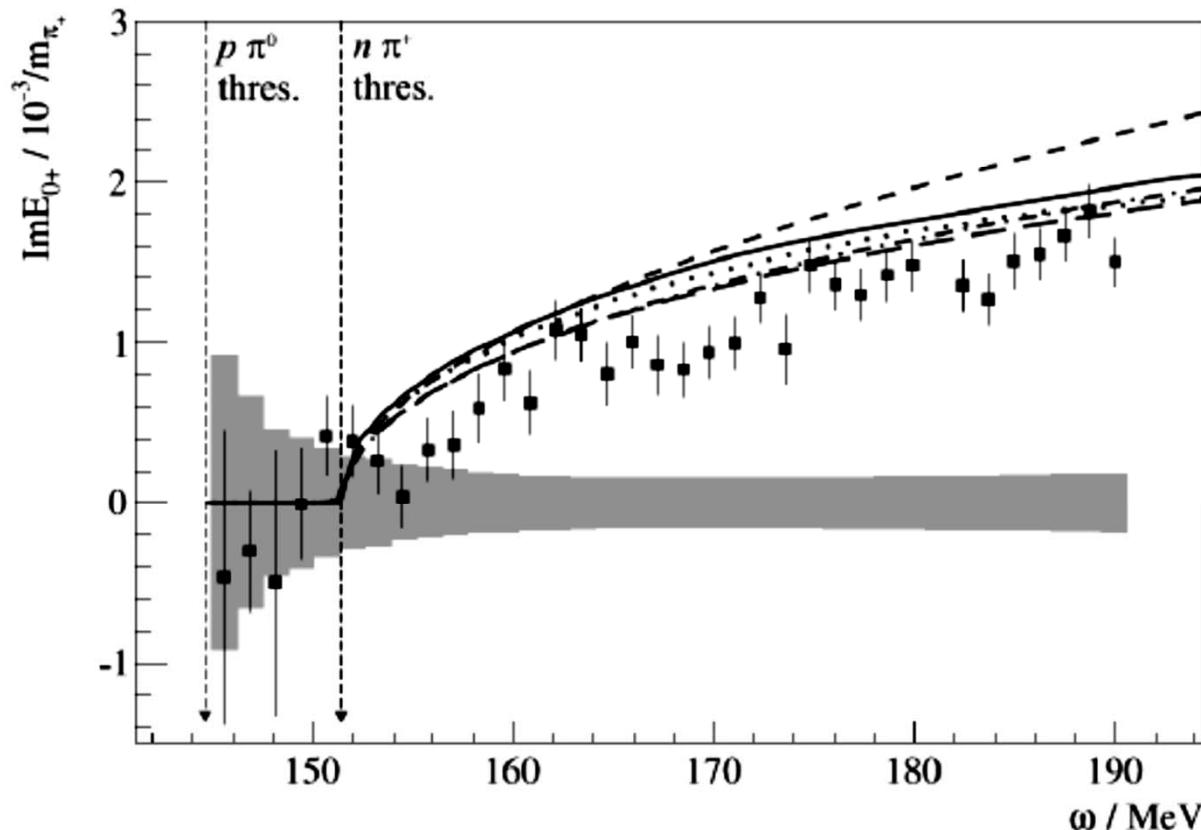
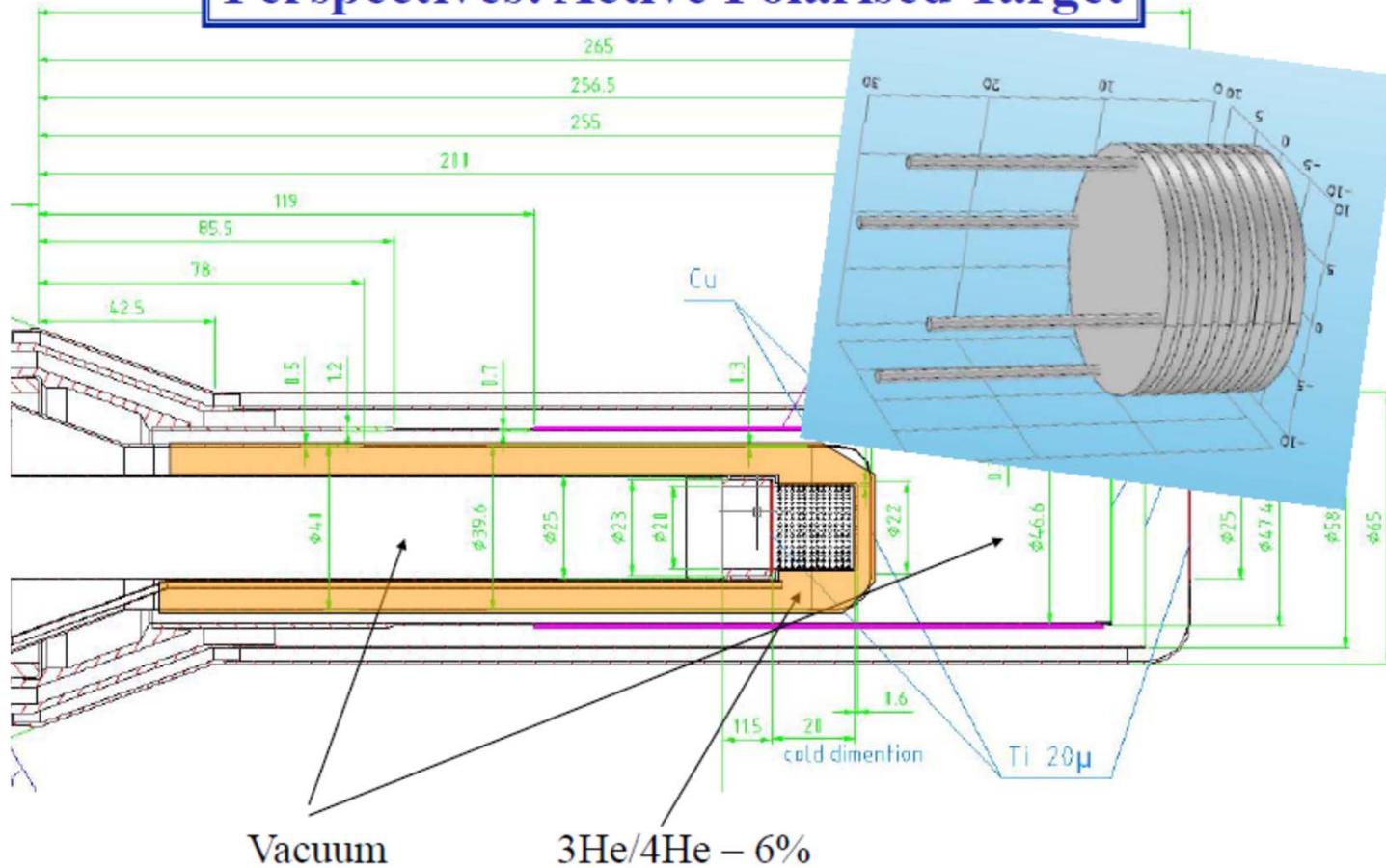


Fig. 5. Imaginary part of E_{0+} from single-energy fits to σ_T . Data points show experimental results with statistical uncertainties (error bars) and absolute systematic uncertainties (grey shaded band). The lines are the DMT model prediction (solid), the naïve parametrisation of Eq. (1) with constant $\beta = 3.35 \cdot 10^{-3}/m_{\pi^+}$ (short-dashed), a prediction of Gasparyan, Lutz [38] (long-dashed), the ChPT4 description in Ref. [8] (dashed-dotted), and a HBChPT4 calculation from Ref. [11] (dotted), scaled by a factor $3.35/2.71$ to match the unitary value of β at the $n\pi^+$ threshold.

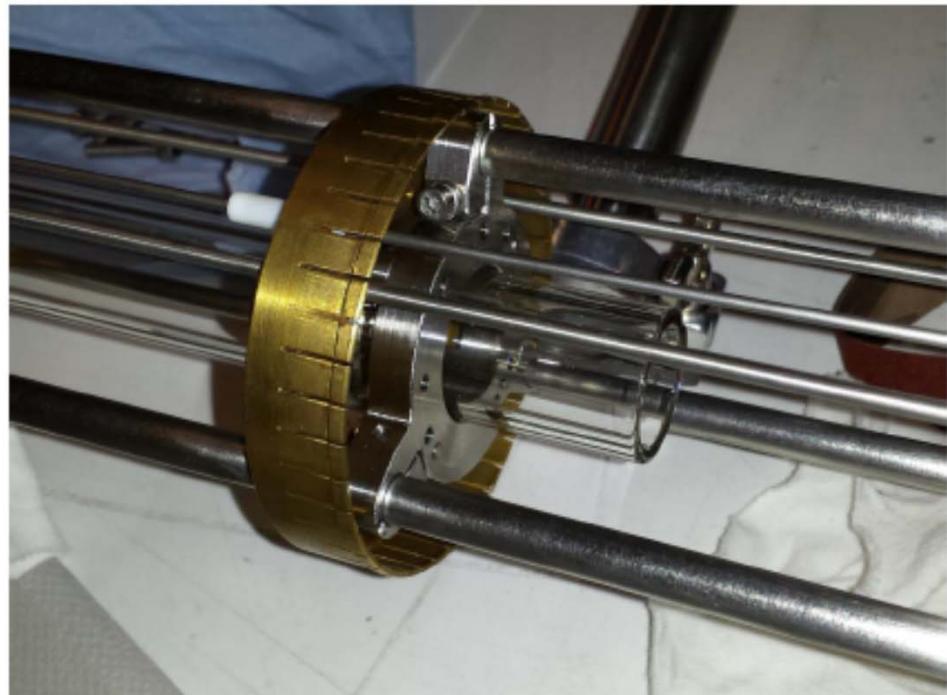
Main problem:
Low energetic recoil
particles
do not escape the
target and
do not reach the
detector.

Perspectives: Active Polarised Target





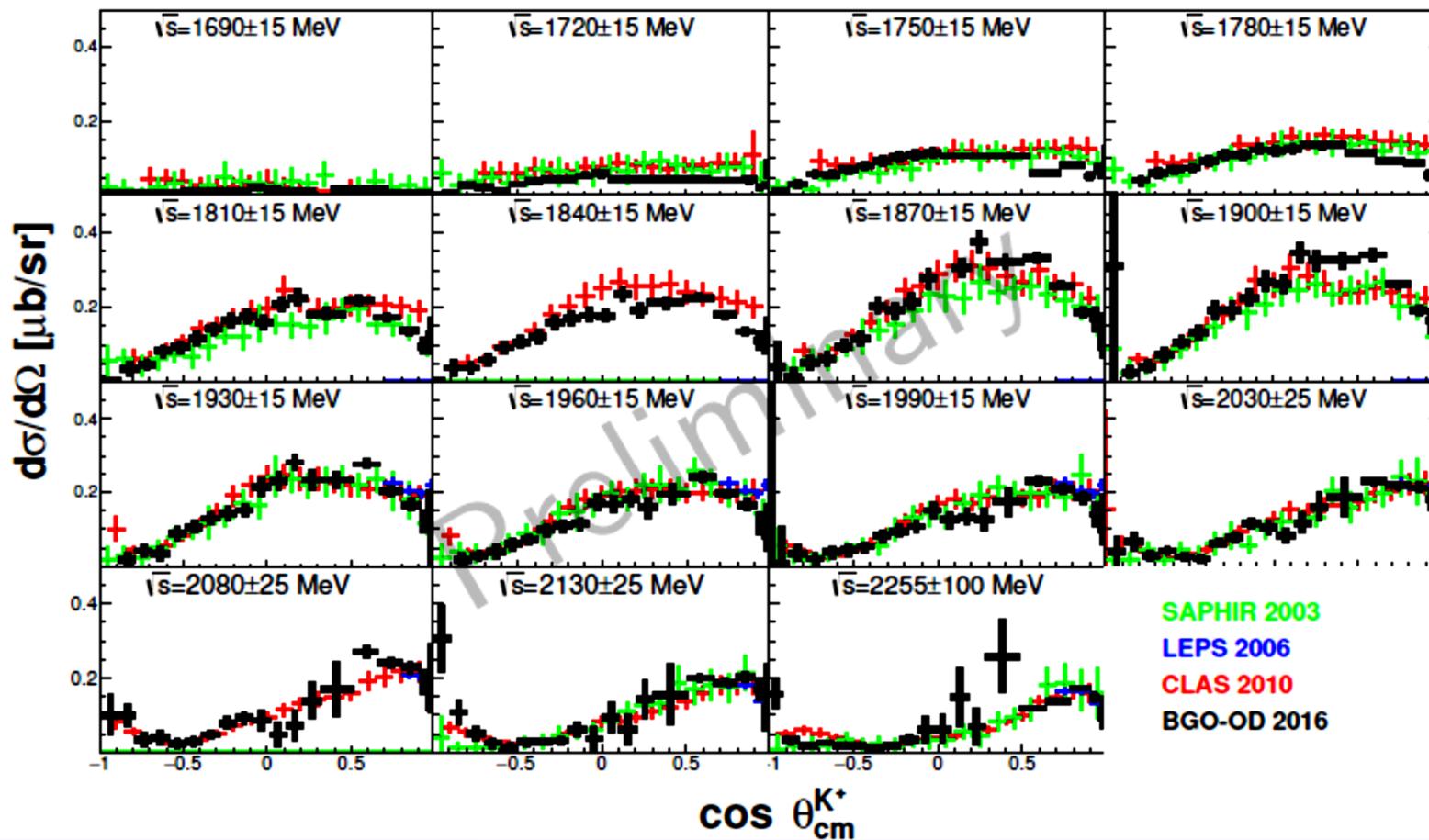
Insert for the January-February 2016 Beamtime.



Results from Bonn

$\gamma p \rightarrow K^+ \Sigma^0$ with no initial particle Identification

BGO-OD (preliminary), CLAS: B. Dey, et al., Phys. Rev. C82 025202 (2010)
SAPHIR: K.-H. Glander et al., Eur. Phys. J. A19 251 (2004), LEPS: M. Sumihama et al., Phys. Rev. C73 035214 (2006)



MWPCs Commissioning

Solved a Relevant Problem on wire PreAmplifiers card
(low efficiency / a lot of noise)

This was found to be due to some serious bug in the PA card design and construction whose effect gets magnified by the relevant noise present inside the BGO-OD front-end electronic chain. This outcome could very hardly be foreseen just from the very first tests performed some time ago in Pavia .

The modified card, even with some tuning to be still completed, is basically giving the expected performances. Three main different types of modifications were performed

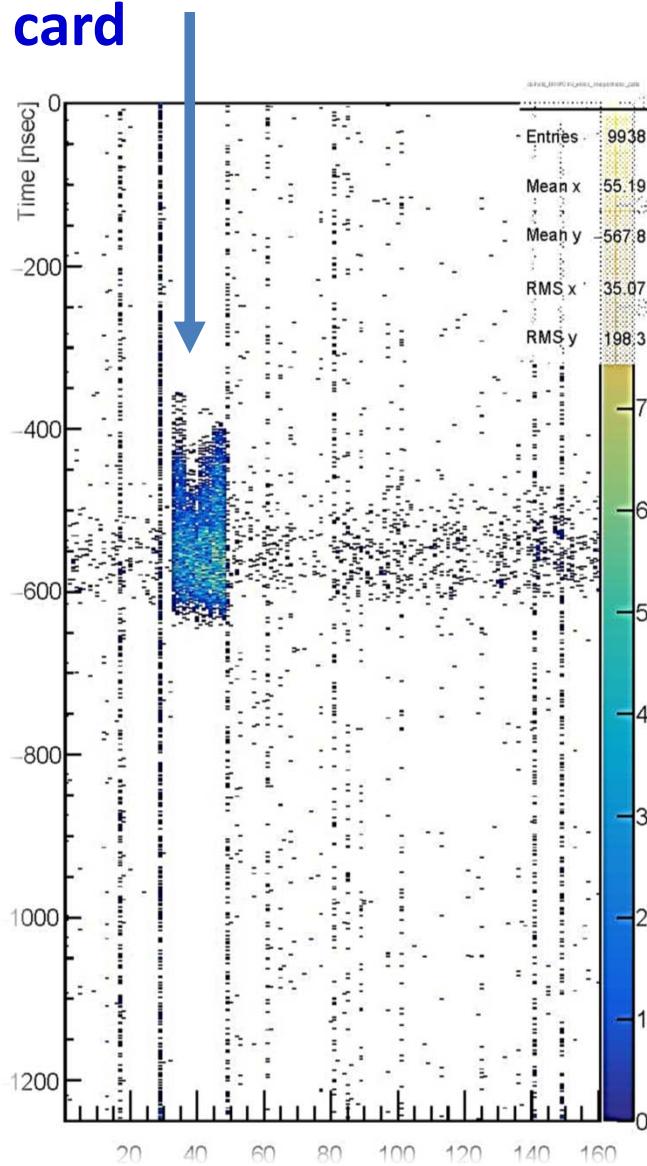
- Filtering of the input signals
- Better signal amplification (the TRA402 negative input is used instead of the positive one)
- Better shaping of the amplified signal

Soluzione trovata grazie al grosso lavoro di Domenico Calabrò ed ai preziosi suggerimenti di Roberto Nardò

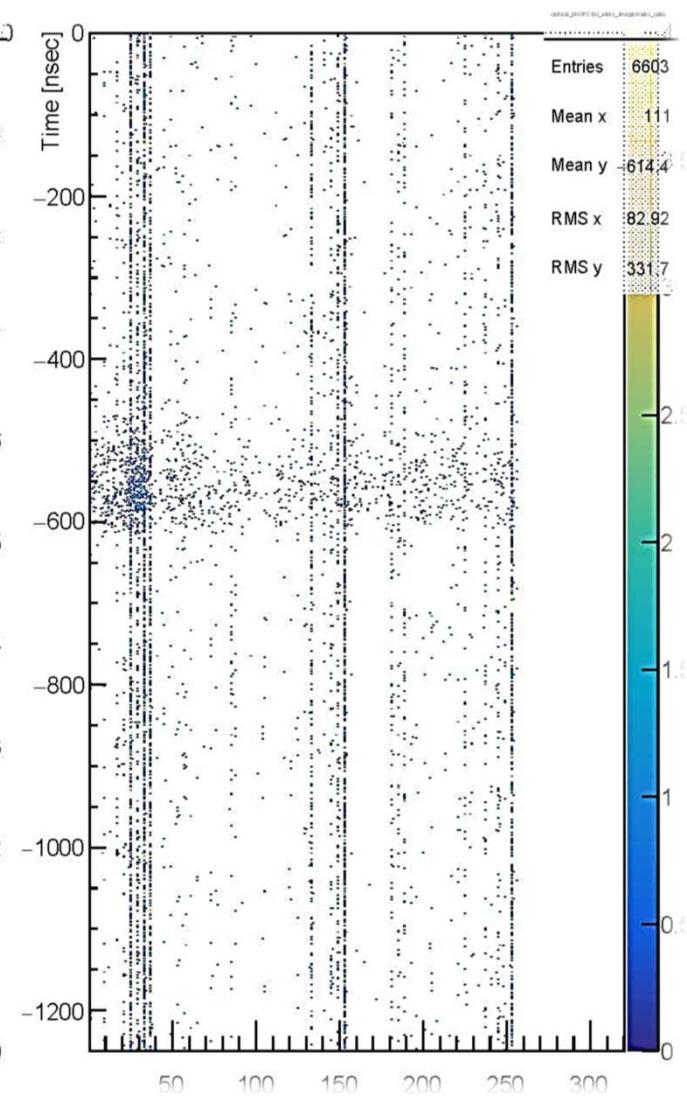
MWPCs Commissioning

Modified card

Time (ns)



Wire number –MWPC 1



Wire number –MWPC 2

Publications (refereed journals)

2011: 4 (1 PLB)

2012: 4 (1 PLB)

2013 10 (2 PRL; 4 PLB)

2014 11 (4 PRL; 1 PLB)

2015 10 (1 PRL; 2 PLB)

Attività prevista 2016-2017

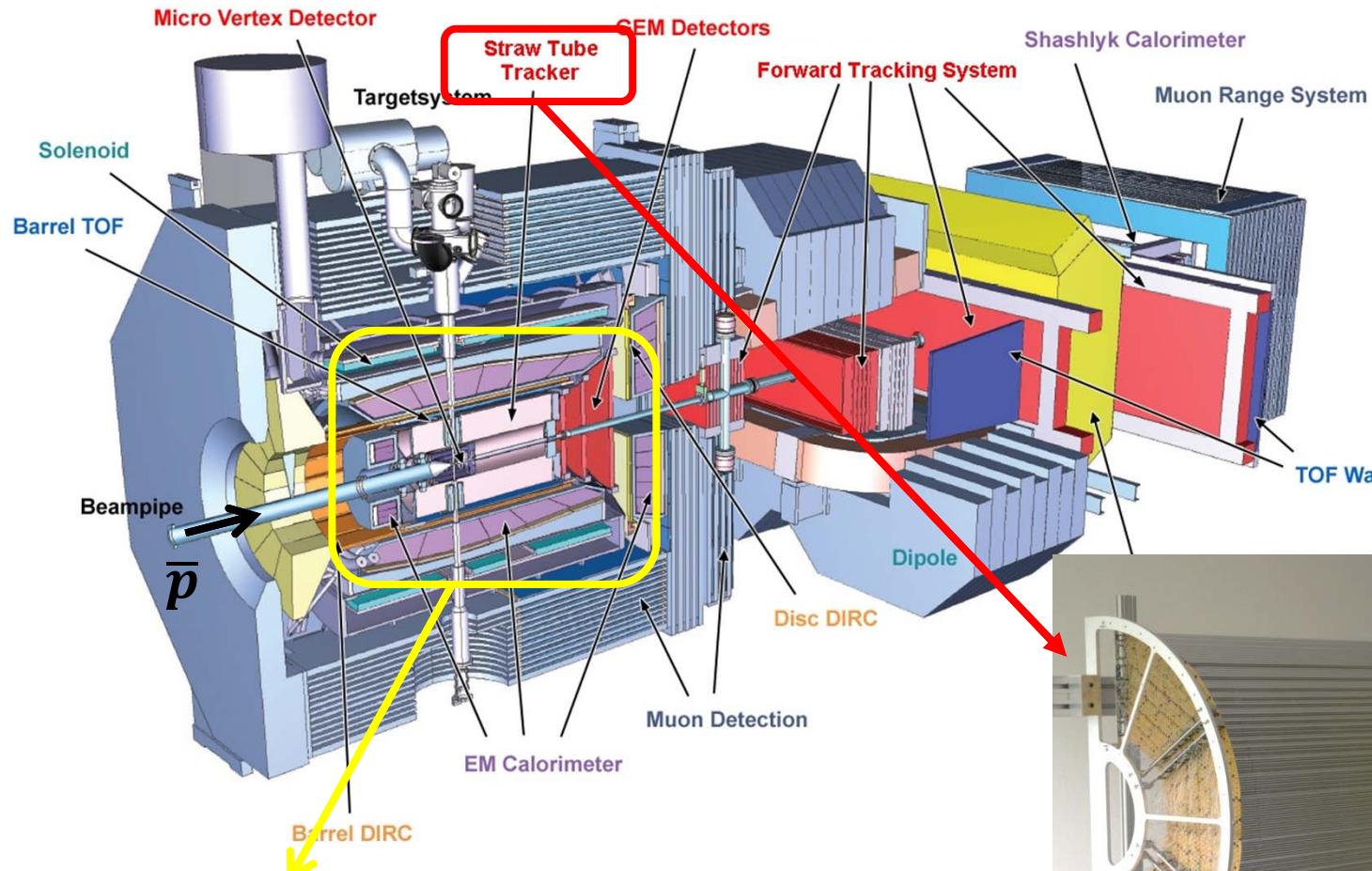
- **Mainz** : -) **manutenzione camere a fili**
 -) Prese dati con bersaglio polarizzato attivo
 -) Prese dati con bersagli protone/deuterio non polarizzati
(misura osservabile P; scattering Compton)
 -) test nuovo rivelatore di Tagging (352 scintillatori)

- **Bonn** : -) **Completamento commissioning camere a fili**
 -) Inizio dei runs di misura veri e propri
 -) **manutenzione camere a fili**

Attività del gruppo di Pavia di PANDA, giugno 2015-giugno 2016

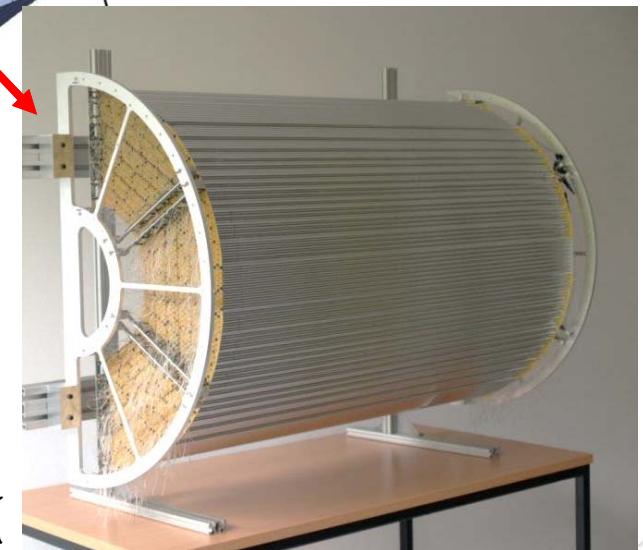
- PANDA nel 2015 ha avuto un revival in Germania a fine settembre 2015, con il suo ‘reinserimento’ tra i 4 ‘pillars’ del progetto FAIR.
- Ora la presa dati e’ prevista ufficialmente nel 2022 ma con interaction rate inizialmente ridotta (2 MHz) e programma di fisica inizialmente ridimensionato. Anche il detector pertanto non sara’ finanziato completamente per il 2022.
- L’attivita’ del gruppo di Pavia e’ consistita nel completamento del software per il Pattern Recognition , per le tracce primarie nella parte centrale del rivelatore (dicembre 2015).
- Rimane la responsabilita’ per il software del Pattern Recognition.
- Rimangono le partecipazione al Publication Committee e nel Collaboration Board di PANDA.

PANDA detector



Tracking systems of the
Target Spectrometer

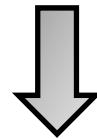
Under construction
@ IKP-FZ Julich



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	3874	98.9
1.0	8		98.5
2.0			99.6
2.0		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

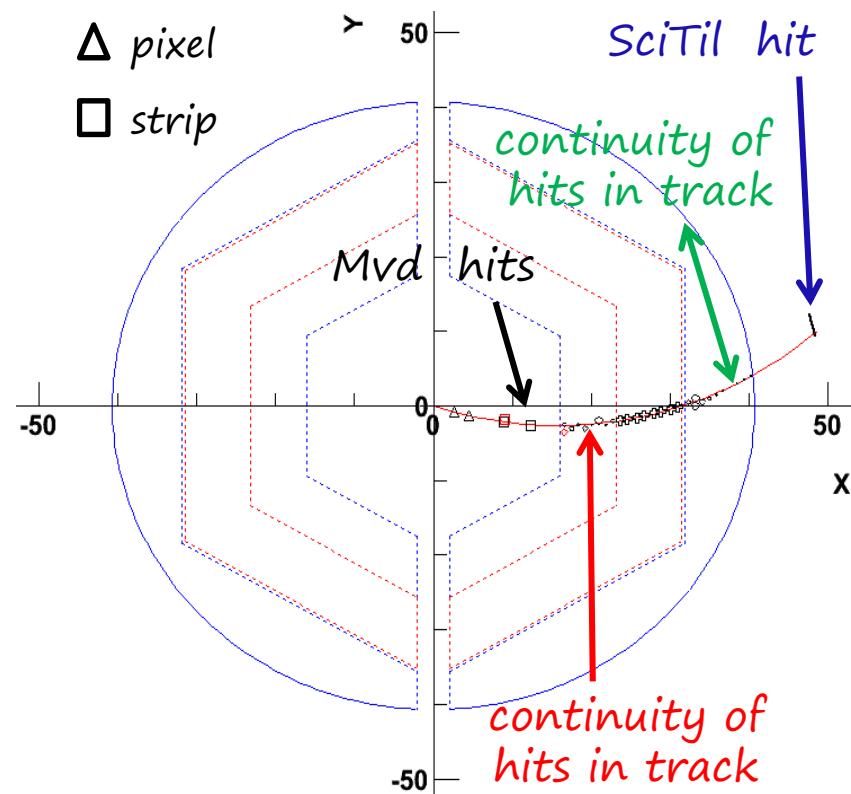
- Subdivide track in arcs crossing a certain STT axial straw sector
- Require continuity of hits in each Stt sector

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)

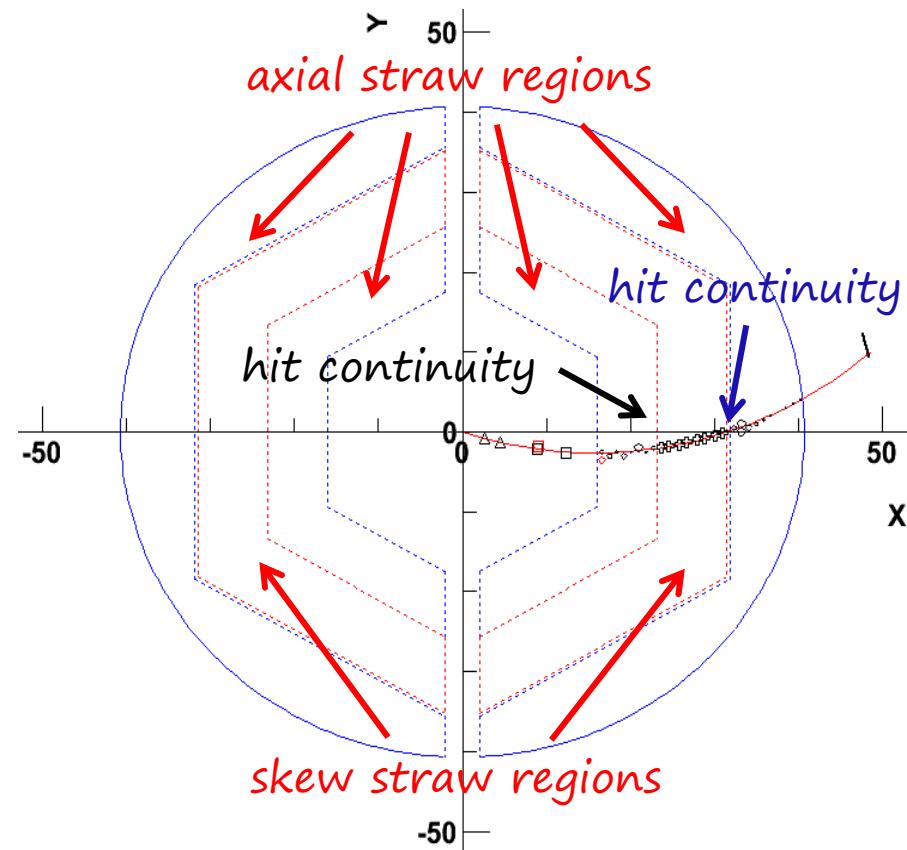
- Require hit in the SciTil system when track reached that
- Require continuity of hits in the MVD system



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.

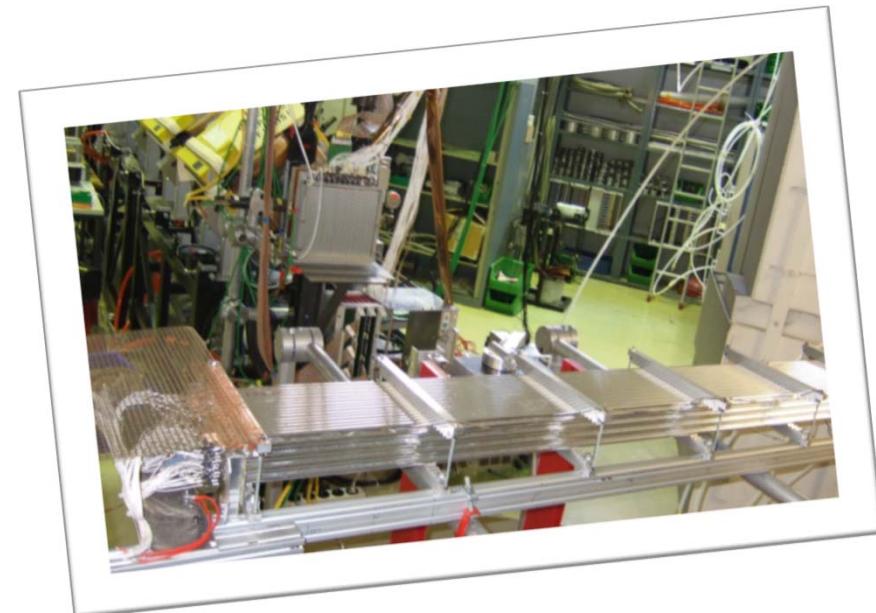
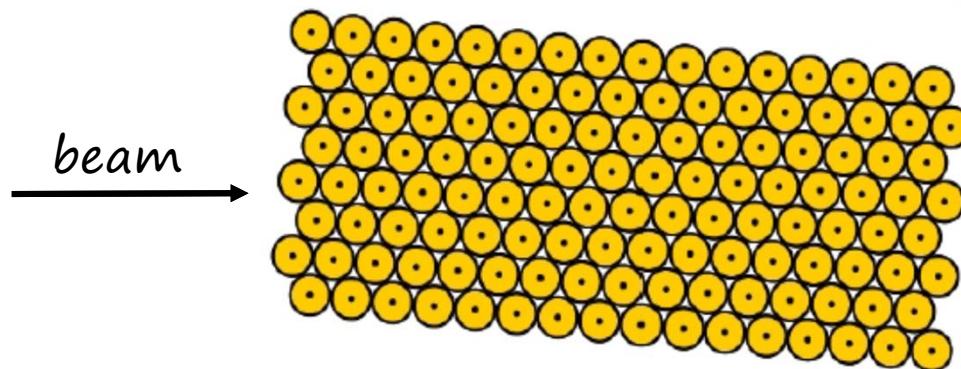
- There is only one skew straw sector so require continuity of skew hits (track STT hits can have only one missing STT hit overall axial + skew)
- First and last hit in skew sector must be at boundary
Exception: for very forward tracks last hit may not be at the boundary if also there are not hits in 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):

- ArCO₂ (90/10) mixture
- 2 bar absolute pressure
- HV = 1800 V, 1850 V