Status report of the DIRAC experiment (PS 212)

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SPS Committee, April 9, 2013

DIRAC collaboration

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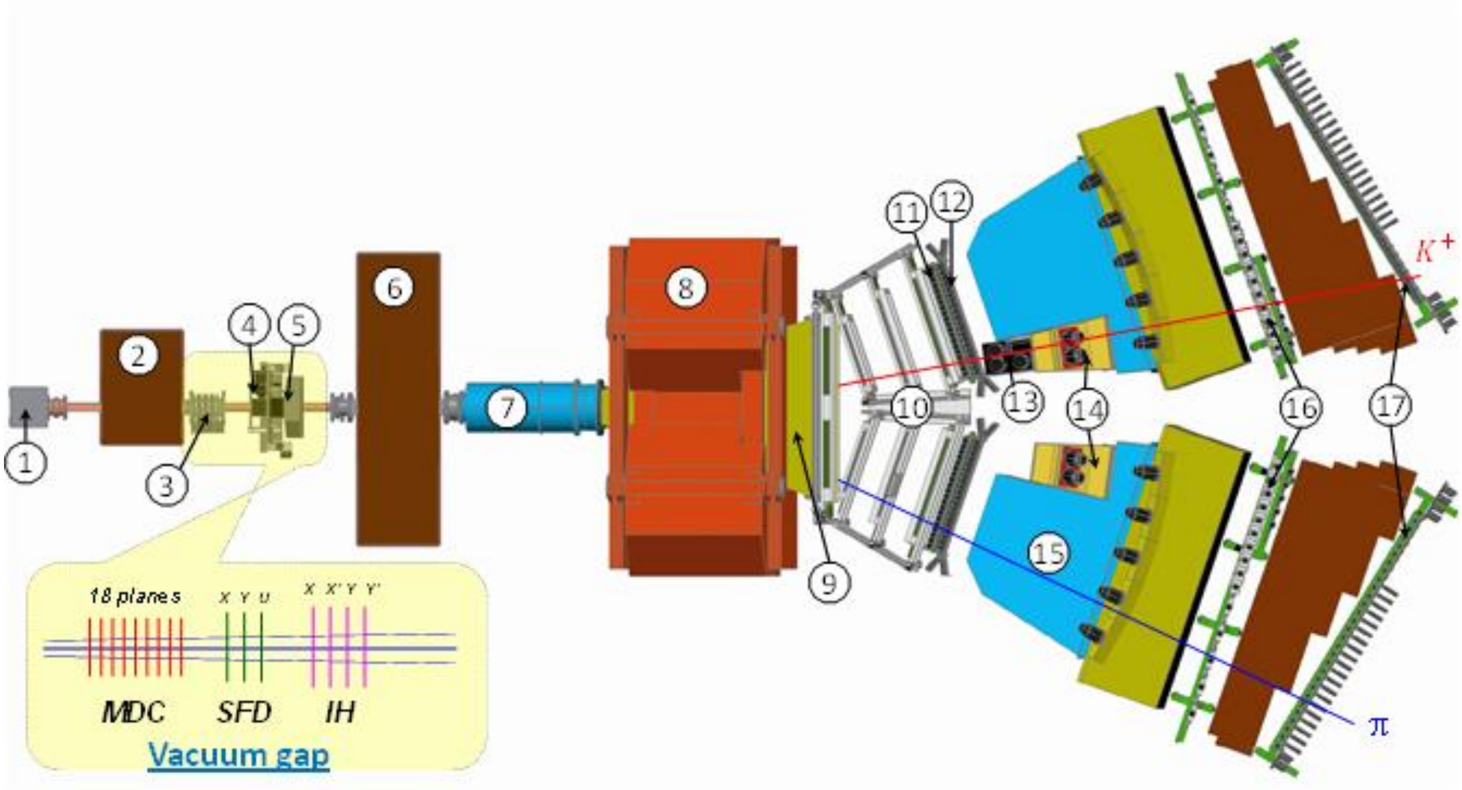
Experimental setup



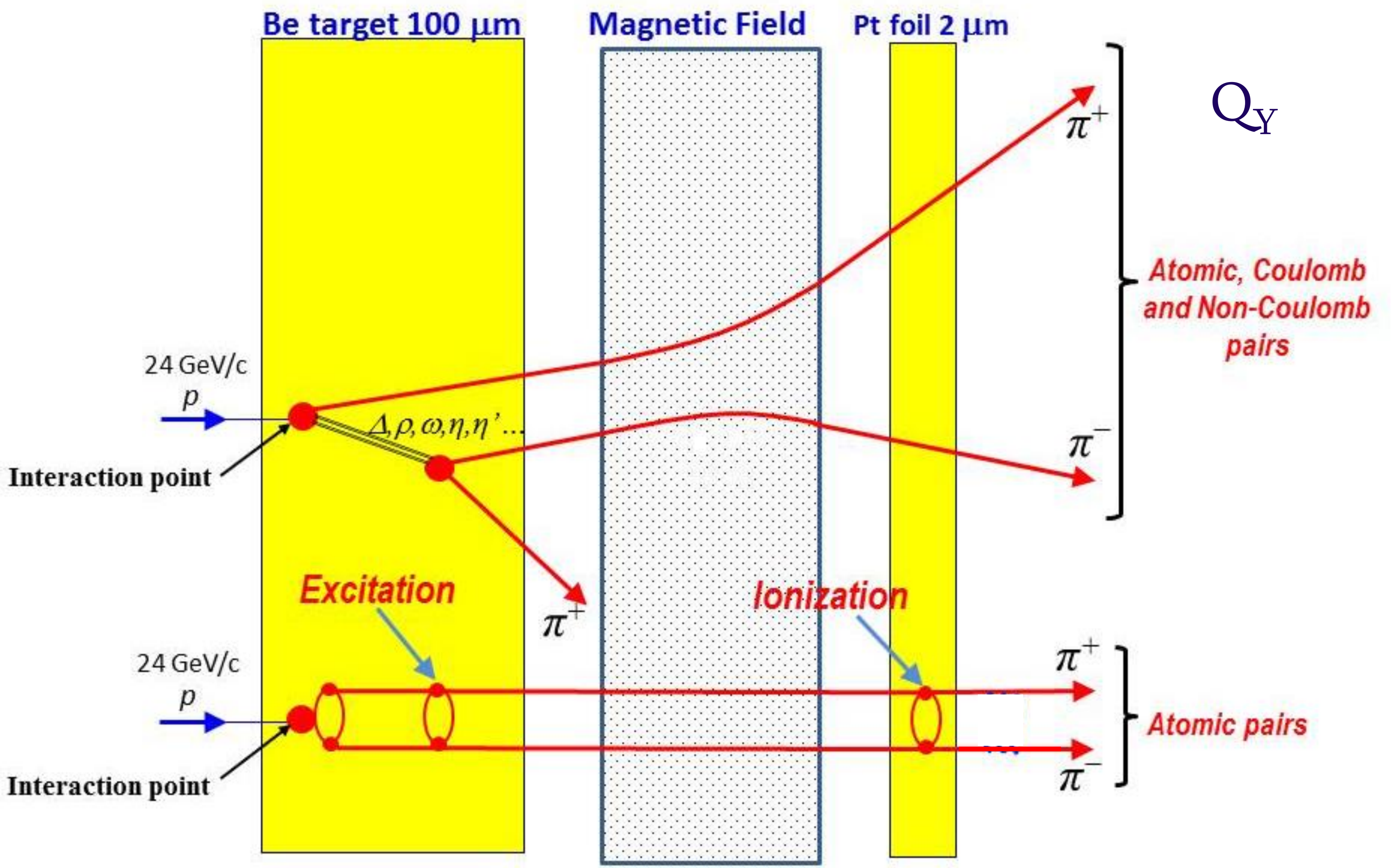
1 Target station with Ni foil; 2 First shielding; 3 Micro Drift Chambers; 4 Scintillating Fiber Detector; 5 Ionization Hodoscope; 6 Second Shielding; 7 Vacuum Tube; 8 Spectrometer Magnet; 9 Vacuum Chamber; 10 Drift Chambers; 11 Vertical Hodoscope; 12 Horizontal Hodoscope; 13 Aerogel Čerenkov; 14 Heavy Gas Čerenkov; 15 Nitrogen Čerenkov; 16 Preshower; 17 Muon Detector

Long-lived $\pi^+\pi^-$ atoms

The observation of $\pi\pi$ atom long-lived states opens the future possibility to measure the energy difference between *ns* and *np* states $\Delta E(ns\text{-}np)$ and the value of $\pi\pi$ scattering lengths $|2a_0+a_2|$.

If a resonance method can be applied for the $\Delta E(ns\text{-}np)$ measurement, then the precision of $\pi\pi$ scattering length measurement can be improved by one order of magnitude relative to the precision of other methods.

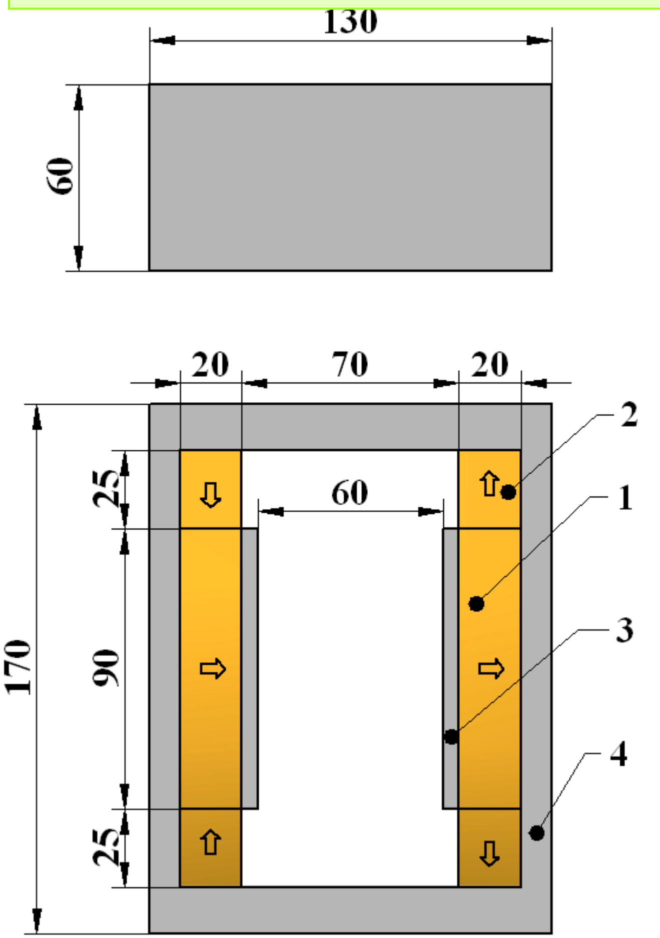
Method for observing long-lived $A_{2\pi}$ with breakup Pt foil



l(2p) = 5.7 cm, l(3p) = 19 cm, l(4p) = 44 cm, l(5p) = 87 cm

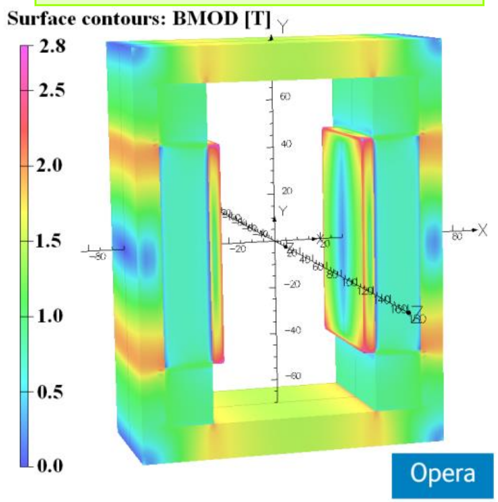
Magnet was designed and constructed in CERN (TE/MCS/MNC)

Layout of the dipole magnet (arrows indicate the direction of magnetization)

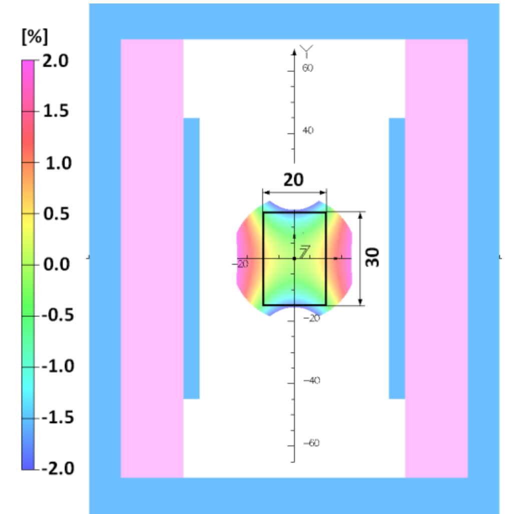


1- PM block Sm2Co17
2- PM block Sm2Co17
3- Pole AISI 1010
4- Return yoke AISI 1010

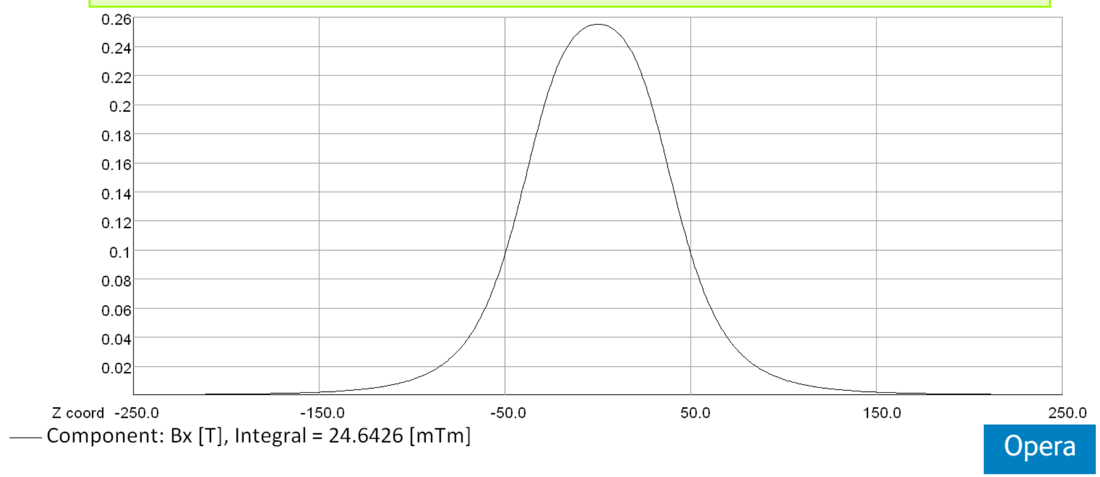
Opera 3D model with surface field distribution



Integrated horizontal field homogeneity inside the GFR X x Y = 20 mm x 30 mm:
$\Delta\int Bxdz / \int Bx(0,0,z)dz$ [%]

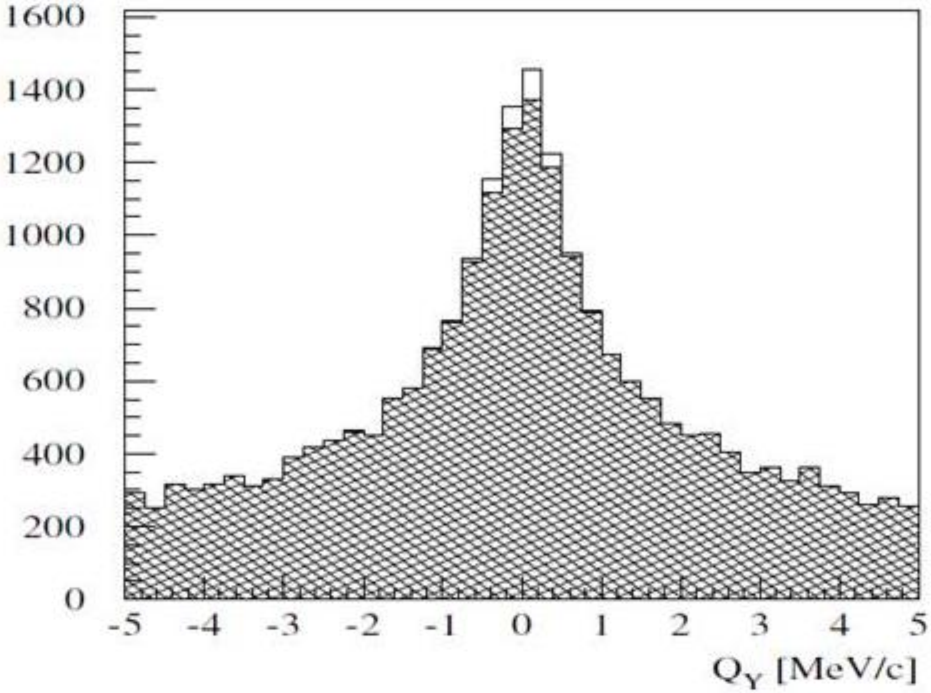


Horizontal field distribution along z-axis at X=Y=0 mm
$\int Bx(0,0,z)dz = 24.6\times10^{-3}$ [Txm]

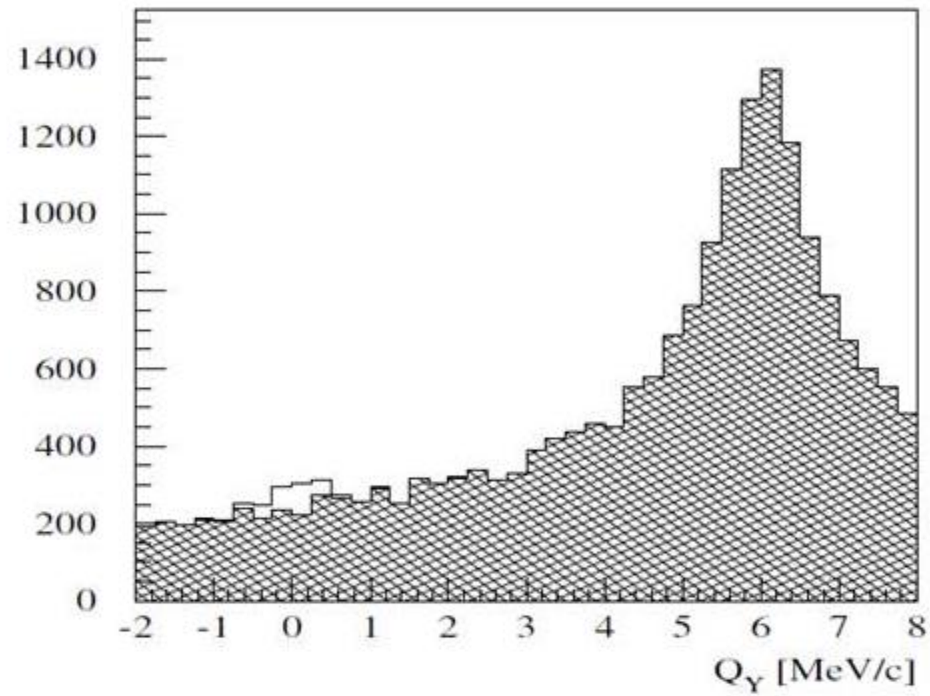


Simulation of long-lived $A_{2\pi}$ observation

V. Yazkov



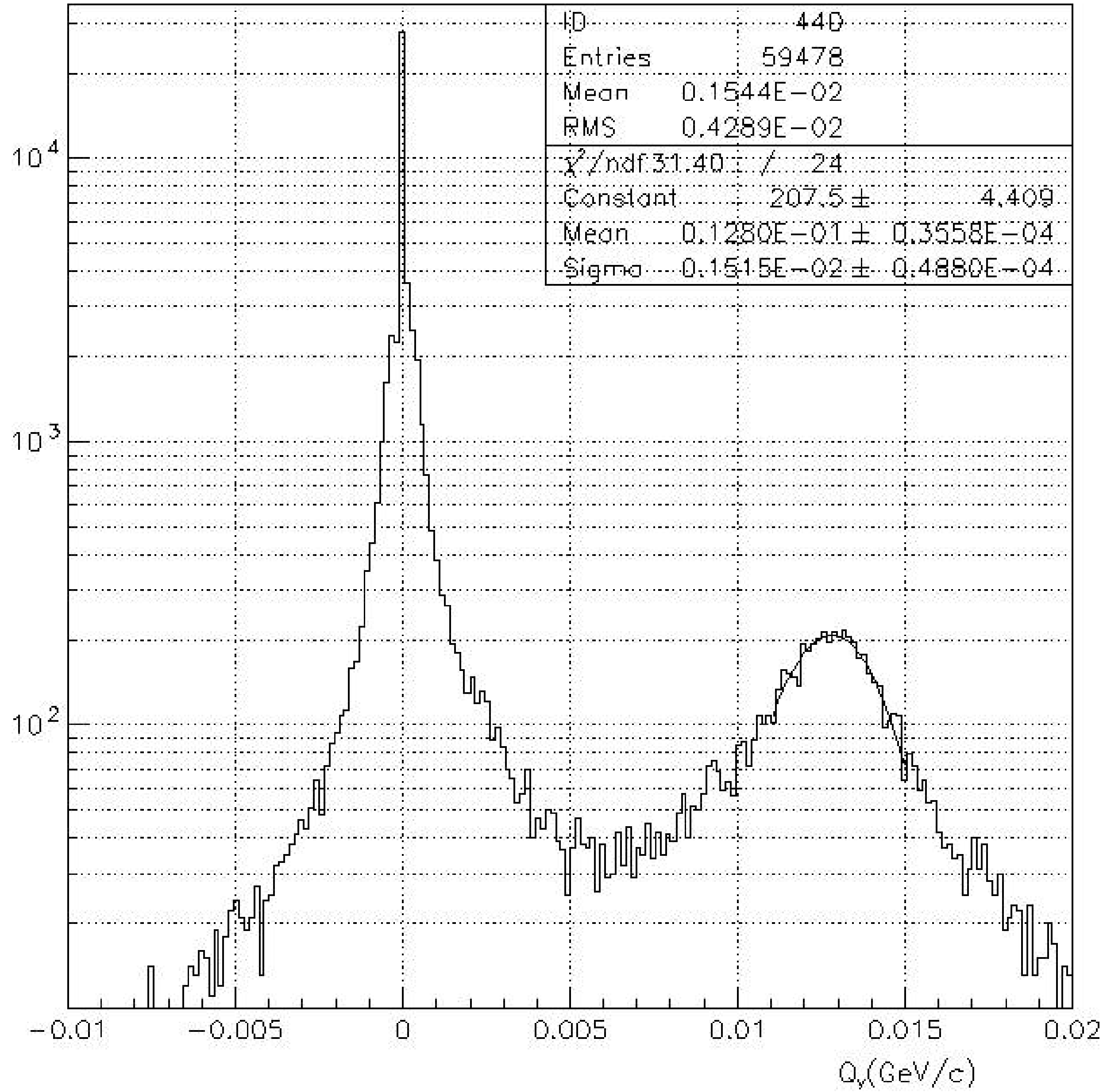
Without magnet



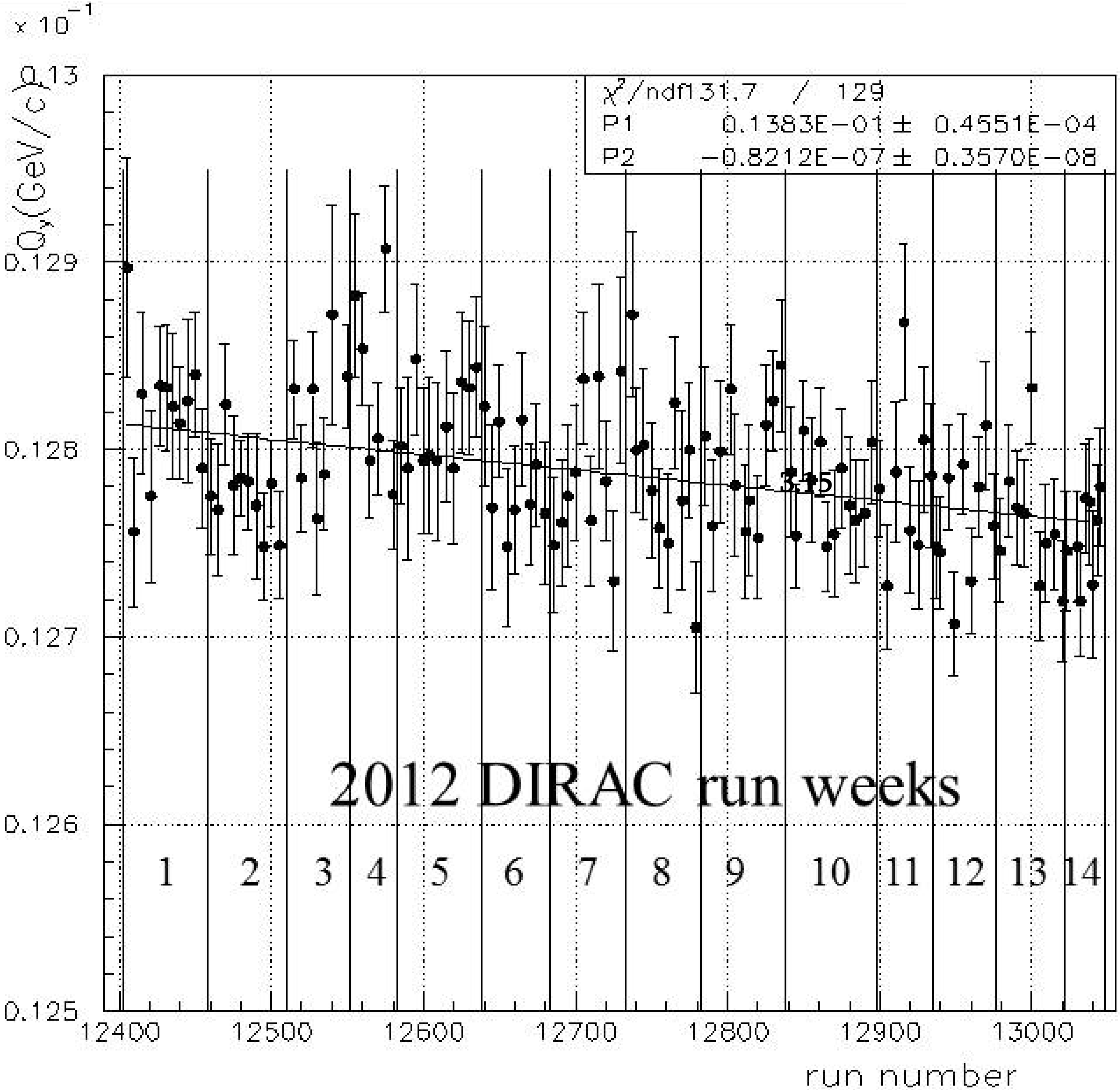
With magnet after Be target

Simulated distribution of $\pi^+\pi^-$ pairs over Q_Y with criteria: $|Q_X| < 1$ MeV/c, $|Q_L| < 1$ MeV/c. Atomic pairs from long-lived atoms (light area) above background (hatched area) produced in Beryllium target.

Q_Y distribution for e^+e^- pair



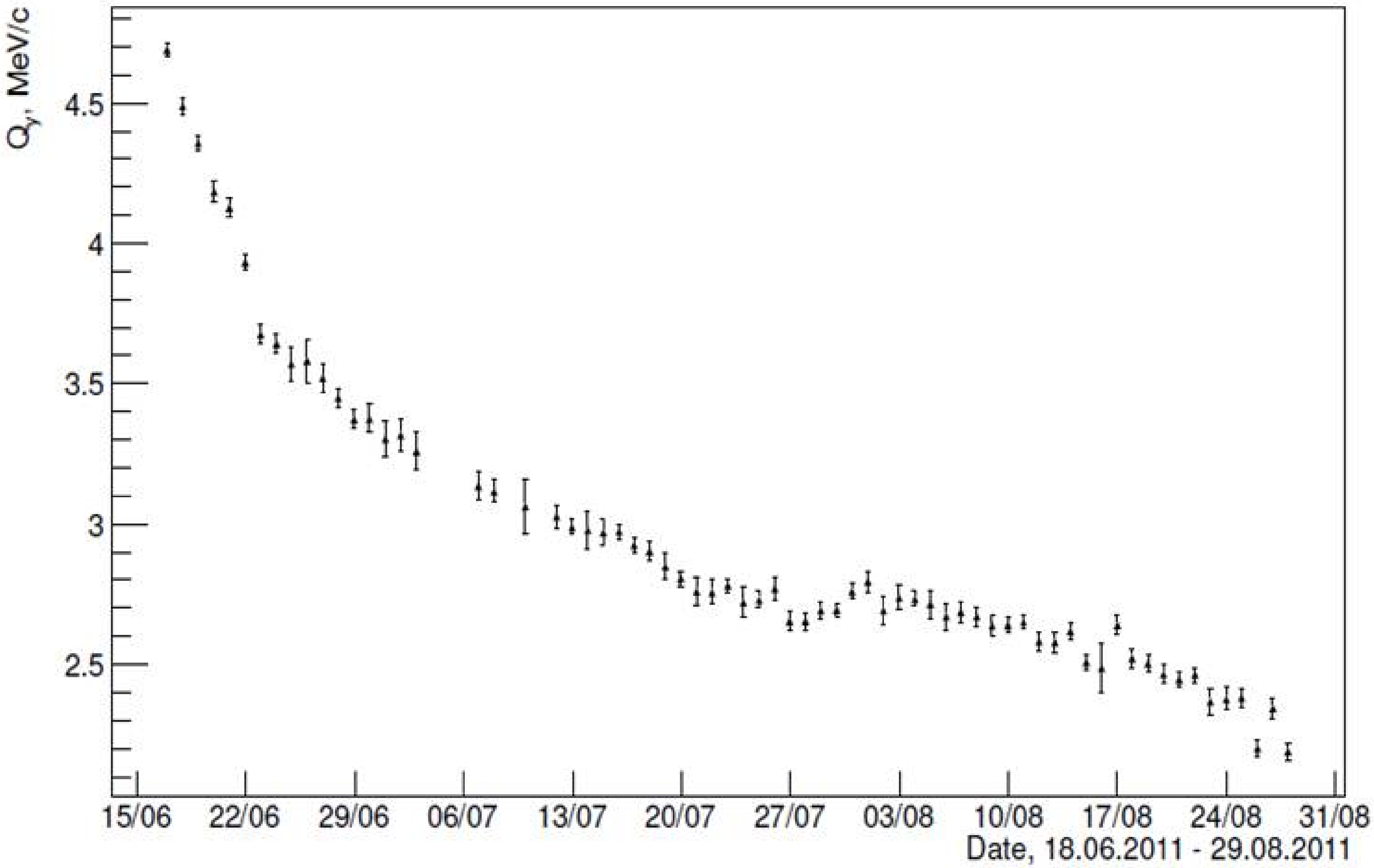
Magnetic field stability measured by Q_Y of the e^+e^- pair



Sm_2Co_{17}

$$\frac{\Delta Q_Y}{Q_Y} = 0.26\%$$

Degradation of the old magnet in June-August 2011



Nd-Fe-B

$$\frac{\Delta Q_Y}{Q_Y} > 50\%$$

The position of the second peak in Q_Y distributions of e^+e^- pairs versus dates.

Schedule of 2011 and 2012 runs data process and analysis

Run 2011 ntuples are ready.

Run 2012 ntuples will be ready in June 2013.

Preliminary results on the search for long-lived $\pi\pi$ atoms are planning on January 2014.

The expected atomic pair signal should be better than 6σ.

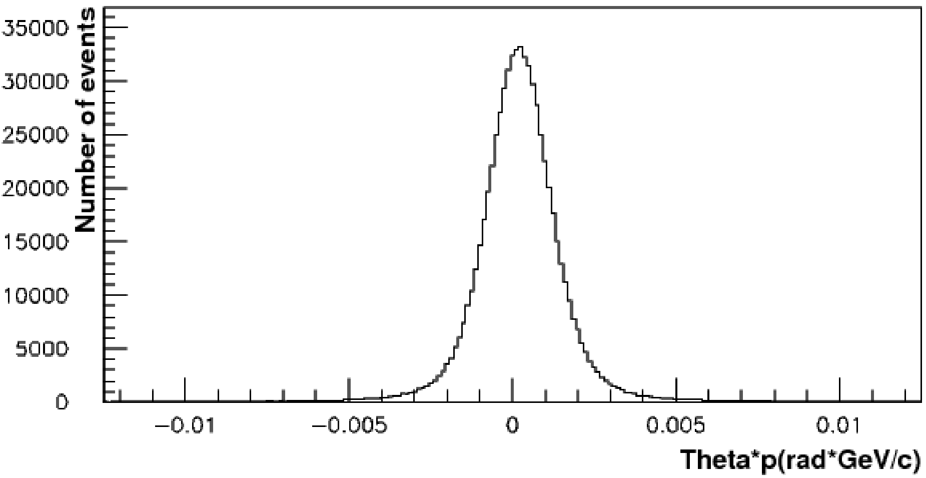
$\pi^+\pi^-$ data

Statistics for measurement of $|a_0-a_2|$ scattering length difference and expected precision

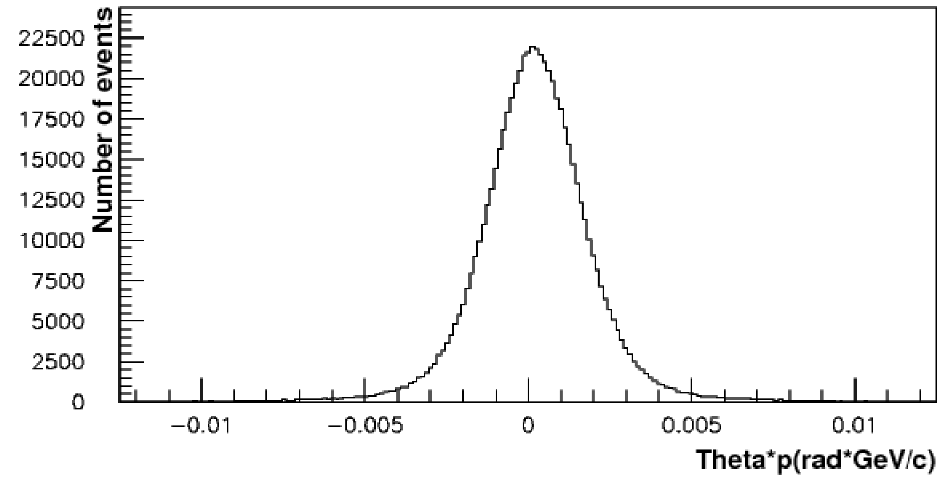
Year	n_A	$\delta_{stat}(\%)$	$\Delta_{syst}(\%)$	$\delta_{syst}(\%)$MS	$\delta_{tot}(\%)$
2001-2003	21000	3.1	3.0	2.5	4.3
2008-2010*	23000	3.1	3.0	2.5	4.3
2001-2003 2008-2010	44000	2.2	3.0 2.1	2.5 1.25	3.7 3.0

* There is 30% of the data with a higher background whose implication will be investigated.

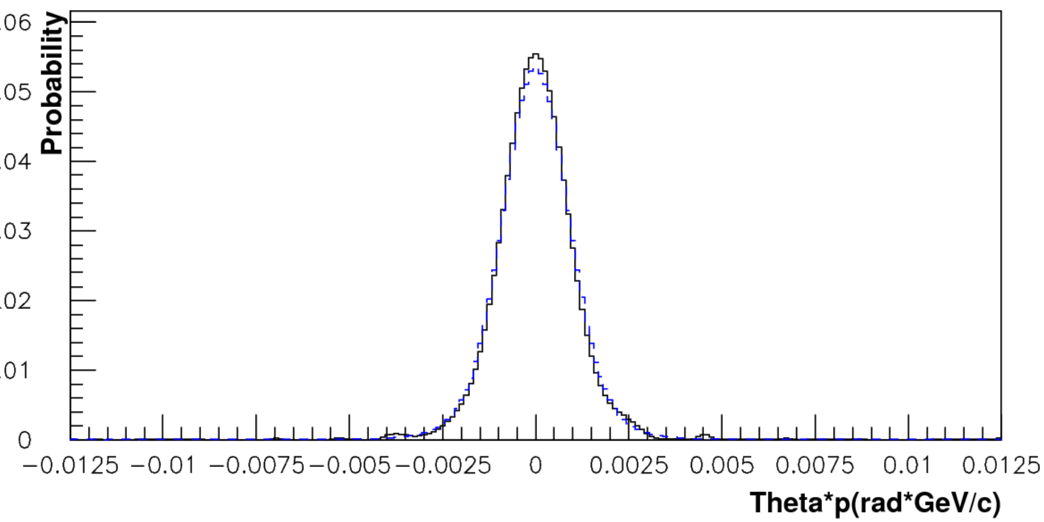
Analysis of multiple scattering in Ni (100 μm)



DC system resolution without scatter



DC system resolution with scatter



Reconstructed and simulated (blue) MS distributions

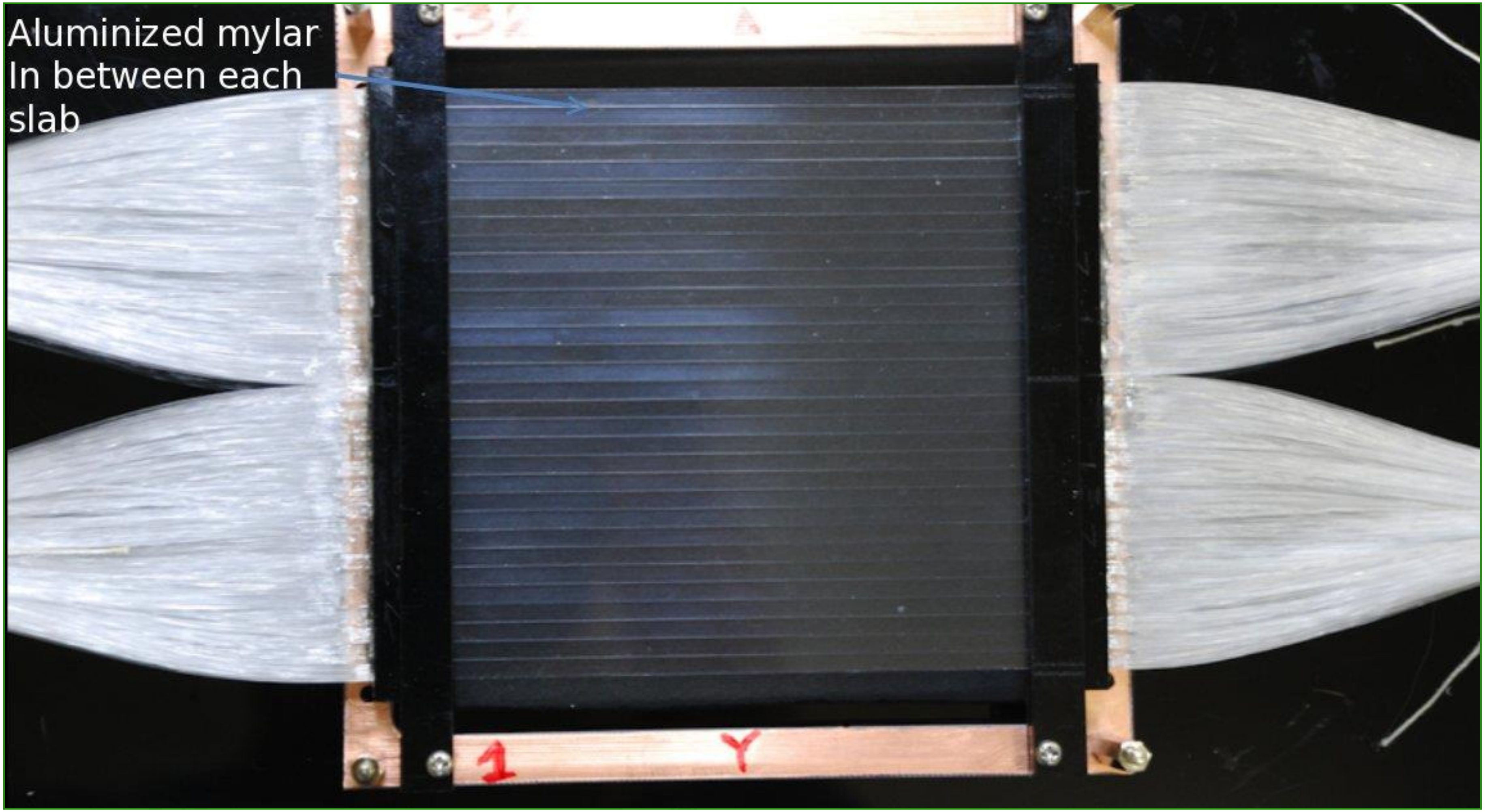
$$\frac{\delta\theta}{\theta} \approx 0.7\%$$

will be less than 0.5%

Run 2011. Analysis of multiple scattering in Ni (100 μm). Only events with one track in each projection were analyzed. δθ/θ ~ 0.7 %. After including in the analysis of all available events the statistics will be doubled and the expected value will be less than 0.5 %.

New dE/dx counter

Scintillator plane for new IH



New dE/dx counter

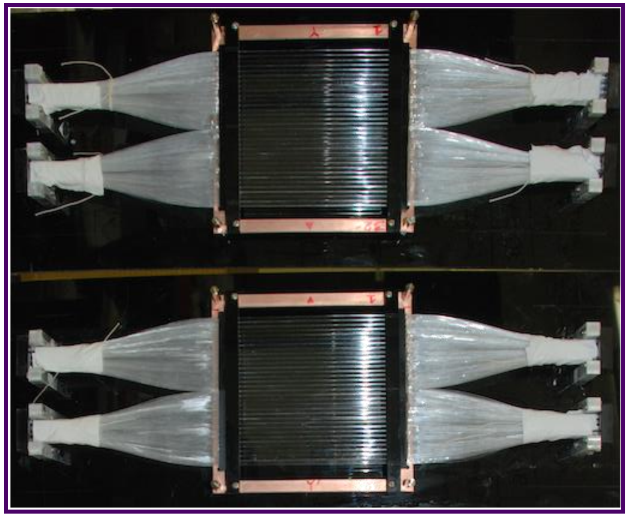
Counter needed to separate the single minimum-ionizing particles (MIPs) and DIRAC pairs (2 MIPs with very small distances).

Required to

- Give constant pulse-height independently of the hit position (Landau tail effect can be removed using multiple laters) with a good resolution,
- Works as a front-end detector accepting about 3 x 10^7 particles/s on a 10 x 10 cm^2 plane,
- Have a good timing resolution.

Solution: Use of

- 32 scintillator slabs with width: 3.5 mm and thickness: 2 mm, read-out from 2 ends,
- Read-out with flexible 28 clear fibres attached to each end of a slab,
- PMT with a ultra bialkali photocathode (Hamamatsu H6568Mod III),
- F1-TDC-ADC to record timing and pulse-height of each hit.



Number of photoelectrons >20

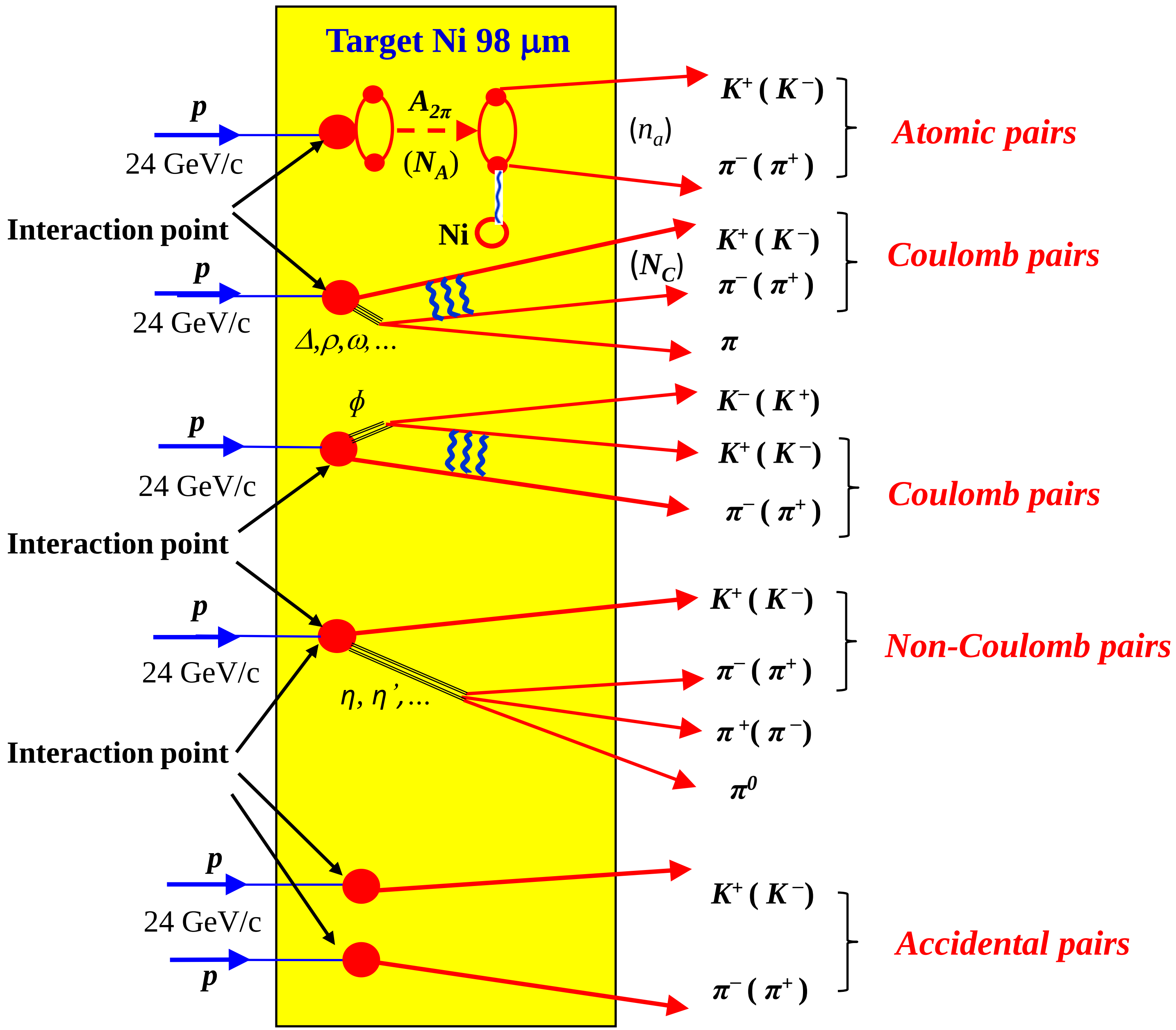
$\sigma_t \approx 200$ps

DIRAC dismantling

February 2013

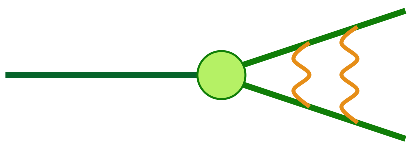
Arpil 2013

Method of ππ and Kπ atoms observation and investigation

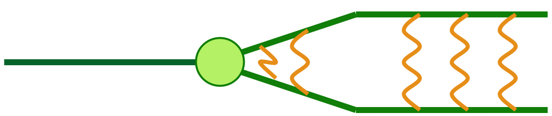


Coulomb pairs and atoms

For the charge pairs from the short-lived sources and small relative momentum Q there is strong Coulomb interaction in the final state. This interaction increases the production yield of the free pairs with Q decreasing and creates atoms.



Coulomb pairs



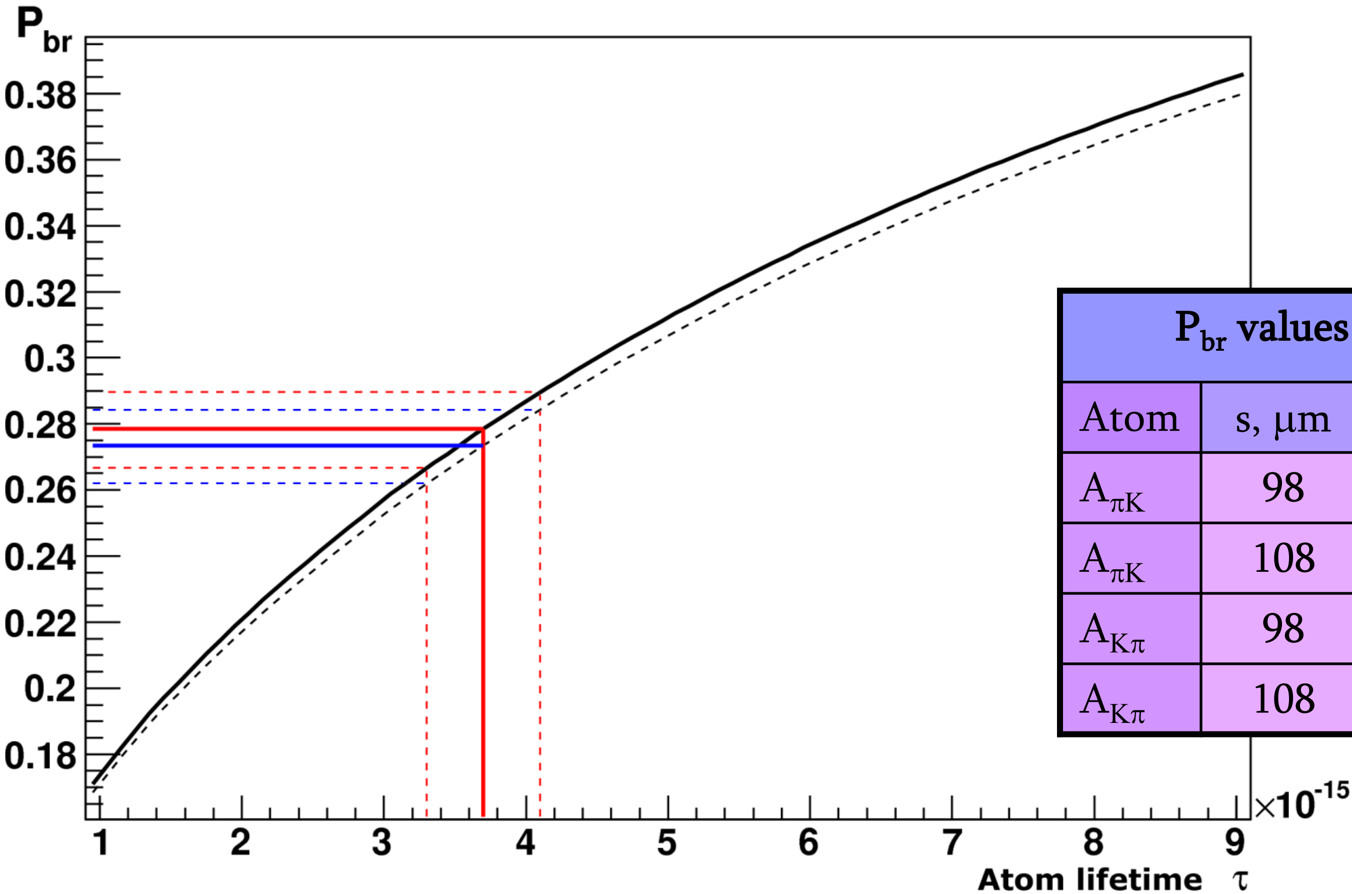
Atoms

There is precise ratio between the number of produced Coulomb pairs (N_C) with small Q and the number of atoms (N_A) produced simultaneously with these Coulomb pairs:

$$N_A = K(Q_0) N_C (Q \le Q_0), \quad \frac{\delta K(Q_0)}{K(Q_0)} \le 10^{-2}$$

$$n_A \text{ - atomic pairs number}, \quad P_{br} = \frac{n_A}{N_A}$$

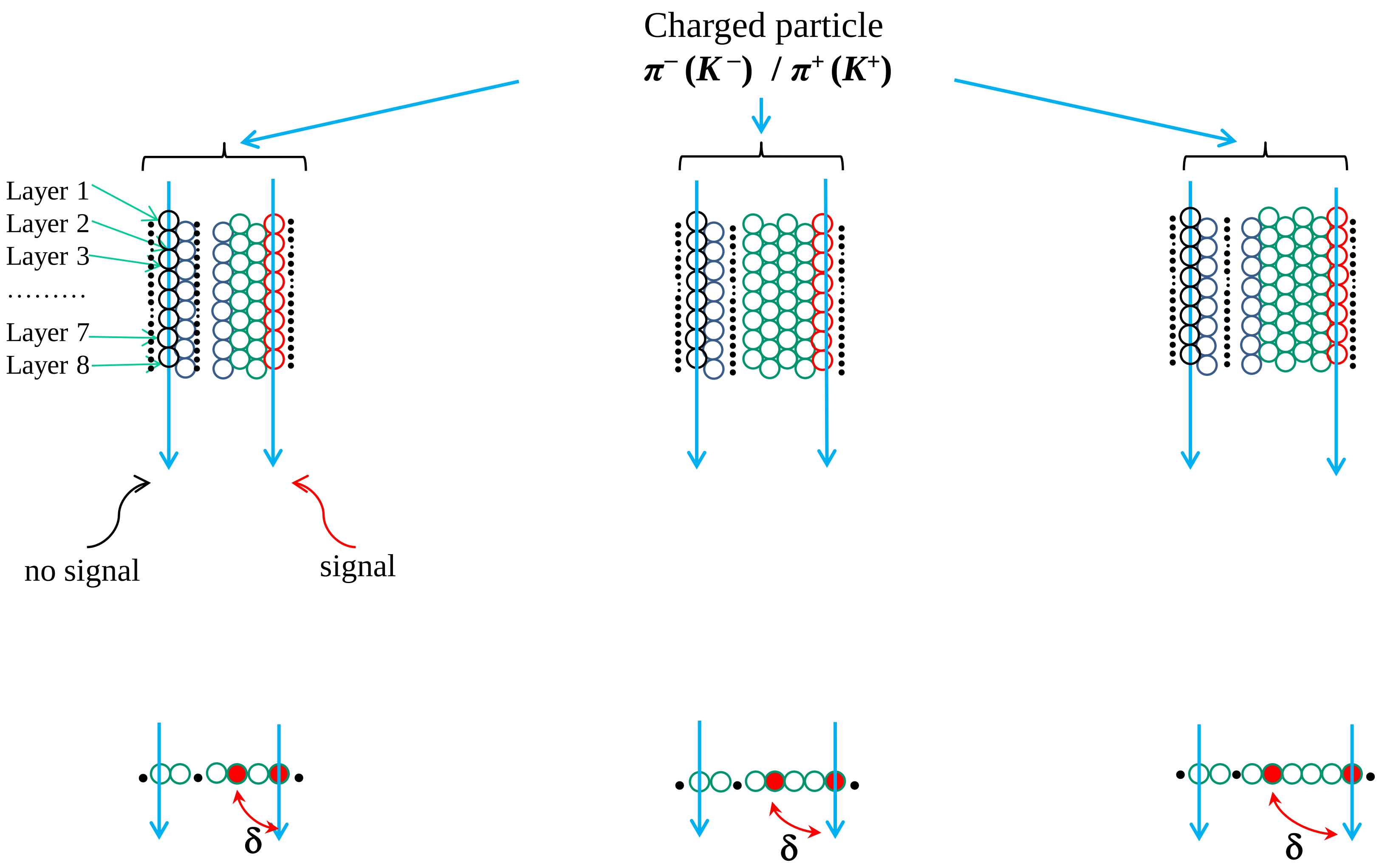
Break-up dependencies P_{br} from atoms lifetime for $K^+\pi^-$ atom ($A_{K\pi}$) and $K^-\pi^+$ atom ($A_{\pi K}$)



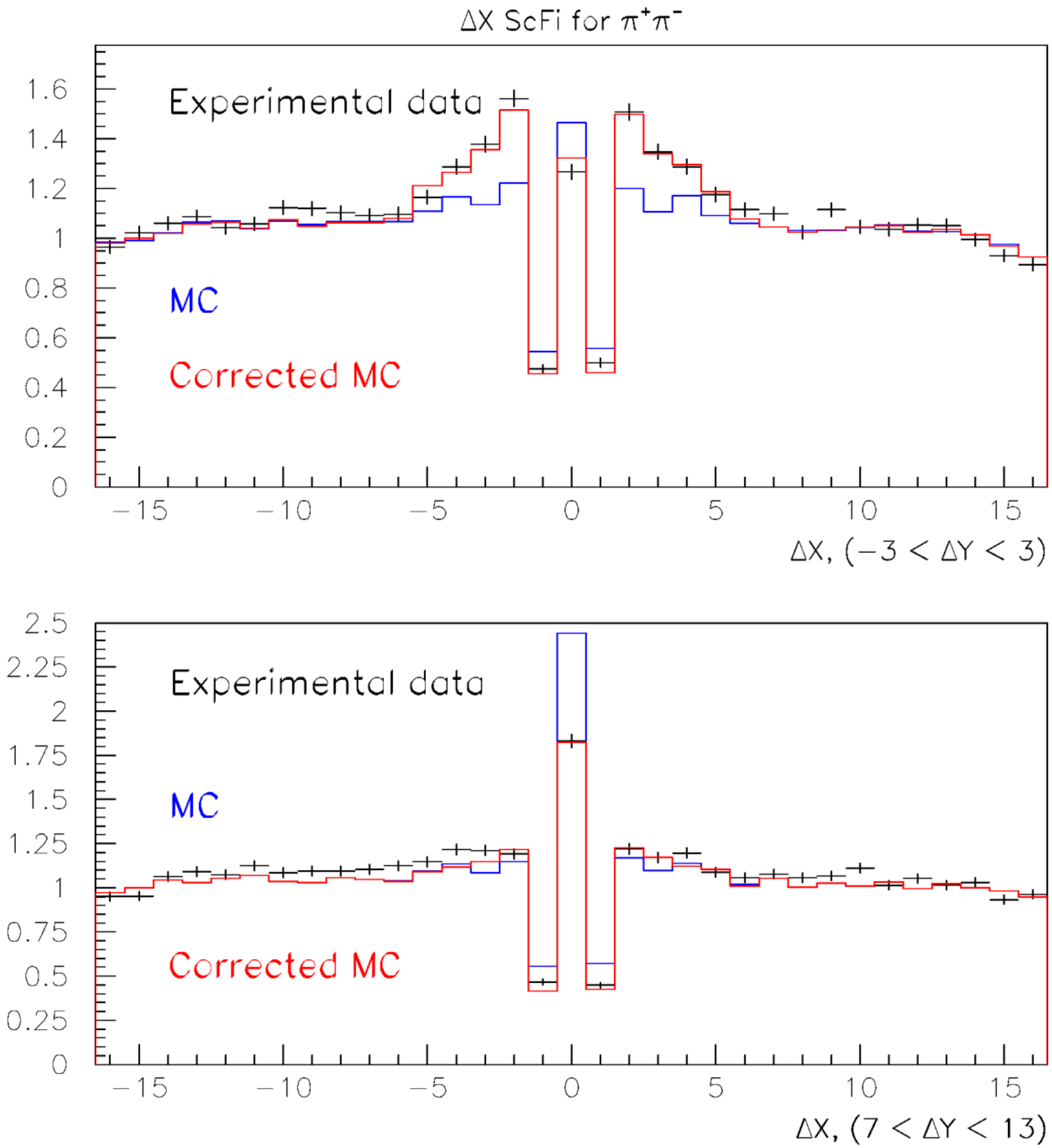
P_{br} values corresponding to τ_{1S}^{th}				
Atom	s, μm	P_{br}	$P_{br}-\sigma$	$P_{br}+\sigma$
$A_{\pi K}$	98	0.274	0.263	0.285
$A_{\pi K}$	108	0.278	0.267	0.290
$A_{K\pi}$	98	0.269	0.258	0.280
$A_{K\pi}$	108	0.273	0.262	0.284

Probability of break-up as a function of lifetime in the ground state for $A_{\pi K}$ (solid line) and $A_{K\pi}$ atoms (dashed line) in Ni target of thikness 108 μm.
Average momentum of $A_{K\pi}$ and $A_{\pi K}$ are 6.4 GeV/c and 6.5 GeV/c accordingly.

Mechanism of production of false pairs with small Q_T

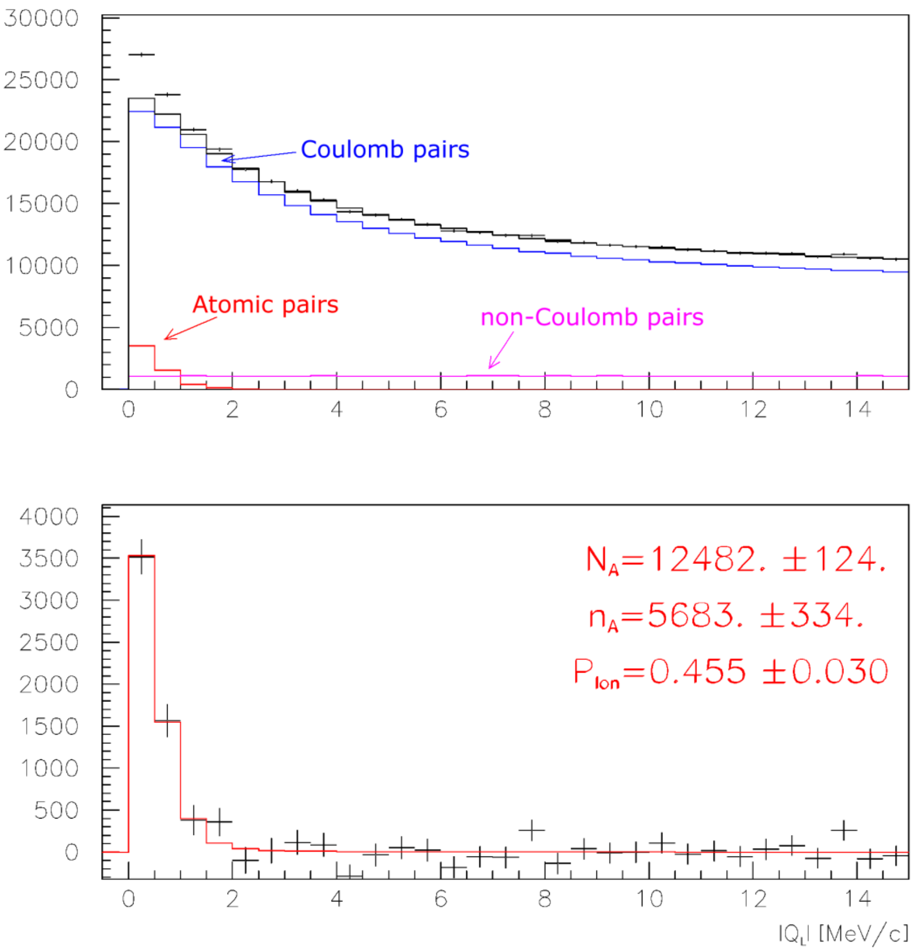


Distribution of $\pi^+\pi^-$ pairs without Coulomb peak (Q_L>10 MeV/c) over distance between tracks in X-plane of SFD

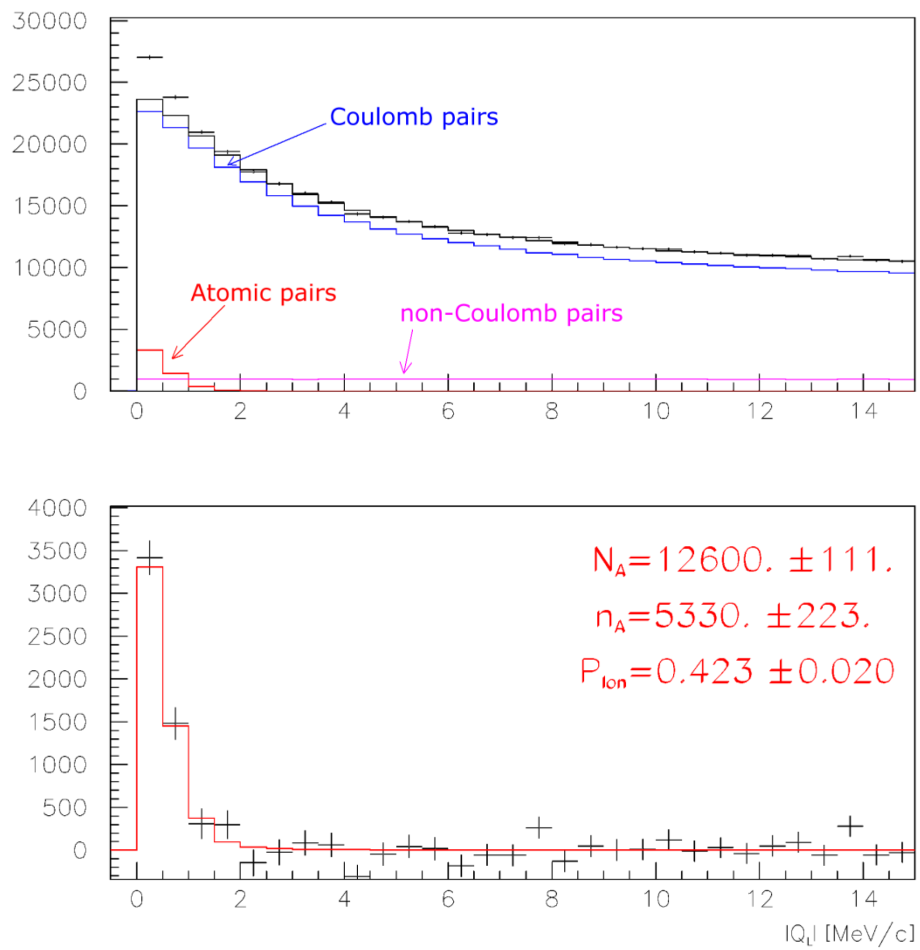


$\pi^+\pi^-$ atoms, run 2008

Run 2008, statistics with low and medium background (2/3 of all statistics). Point-like production of all particles.



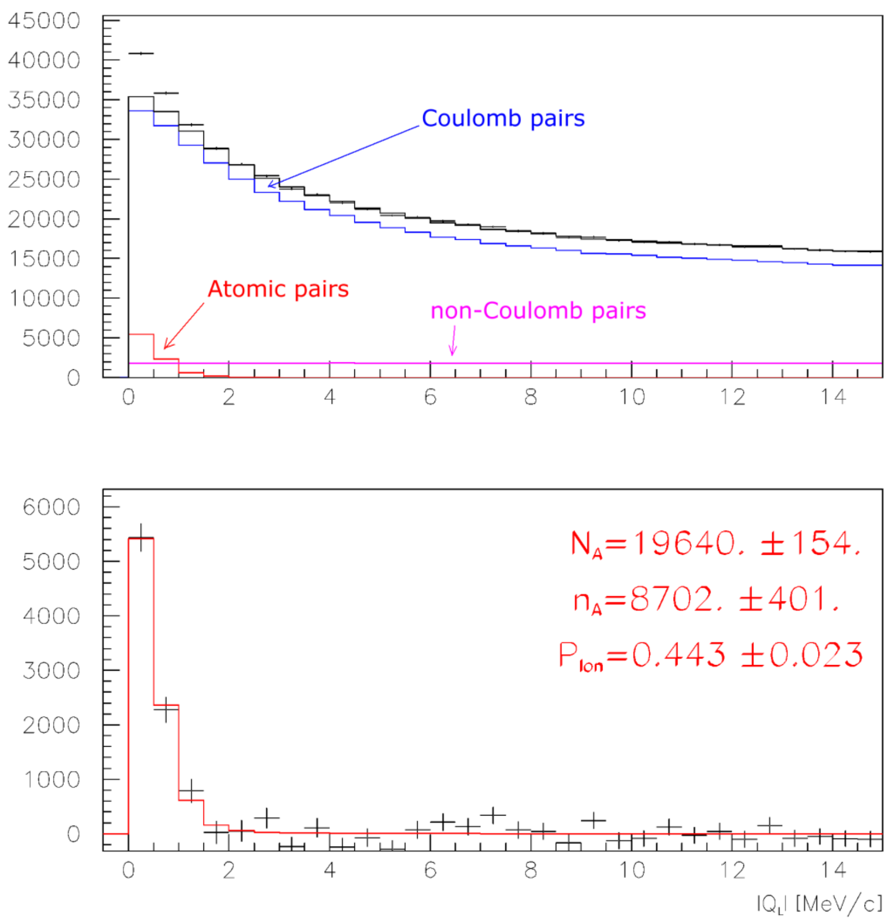
Analysis on Q_L, Q_T < 4 MeV/c



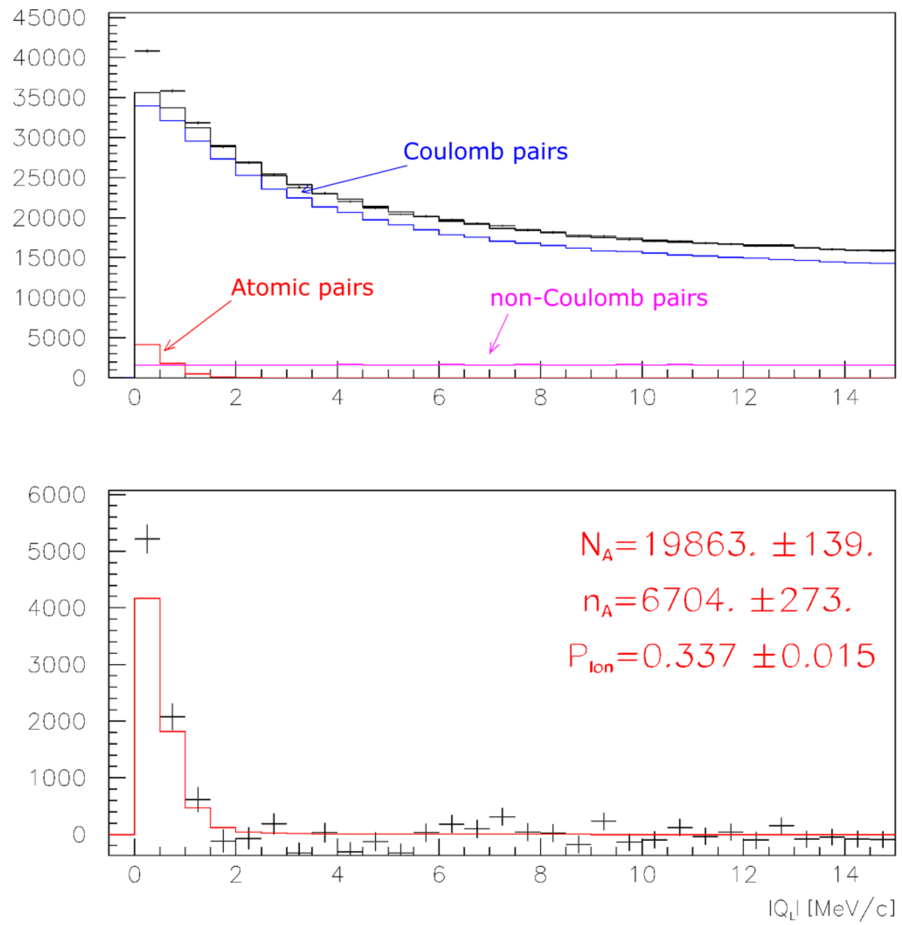
Analysis on Q_L-Q_T, Q_T < 4 MeV/c

$\pi^+\pi^-$ atoms, run 2009

Run 2009, statistics with low and medium background (2/3 of all statistics).
Point-like production of all particles.



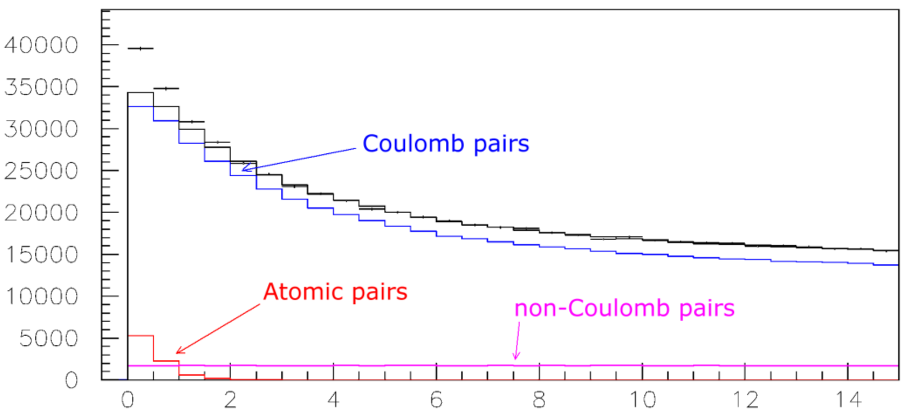
Analysis on Q_L, Q_T < 4 MeV/c

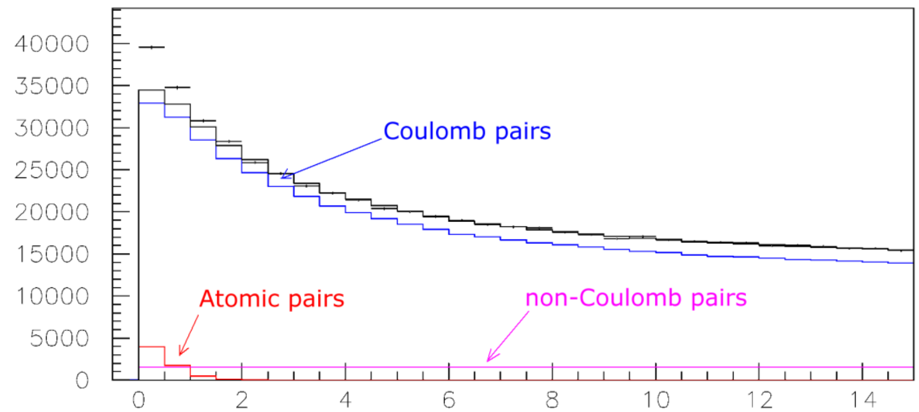


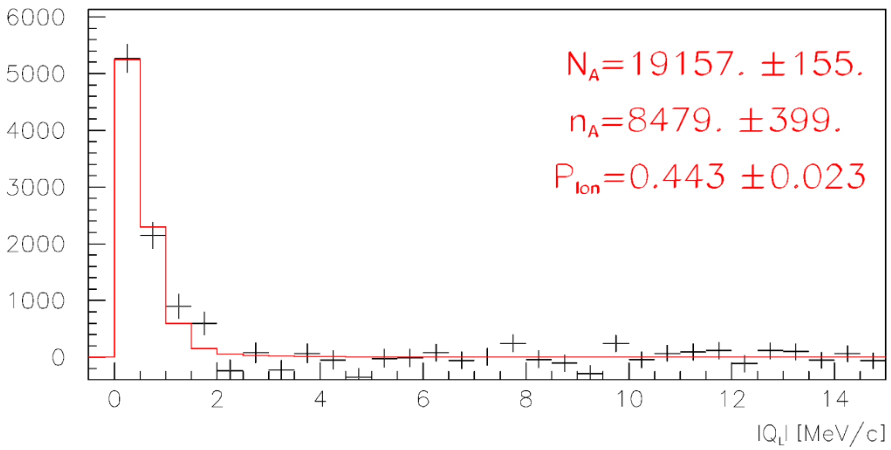
Analysis on Q_L-Q_T, Q_T < 4 MeV/c

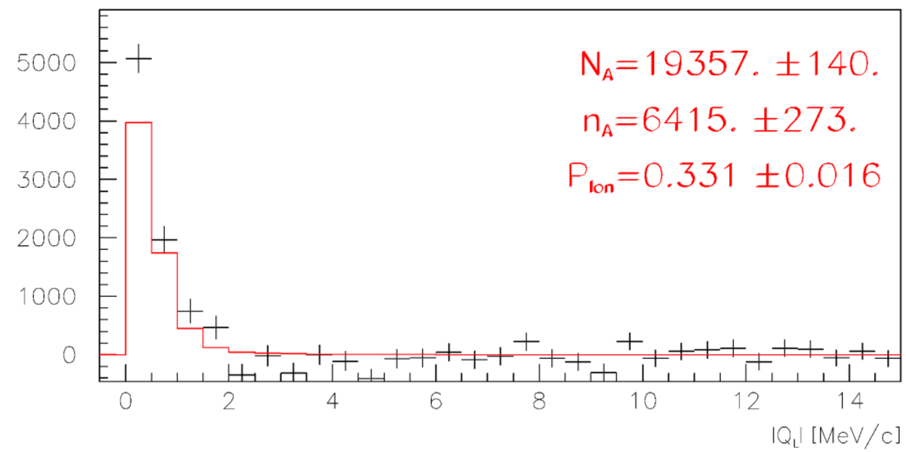
$\pi^+\pi^-$ atoms, run 2010

Run 2010, statistics with low and medium background (2/3 of all statistics).
Point-like production of all particles.







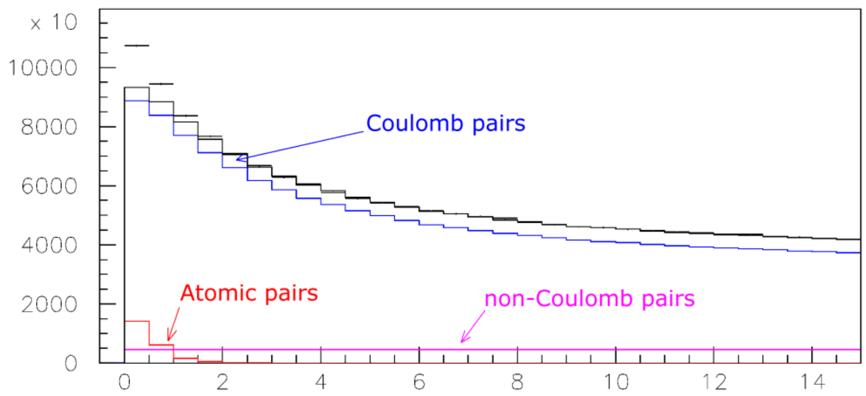


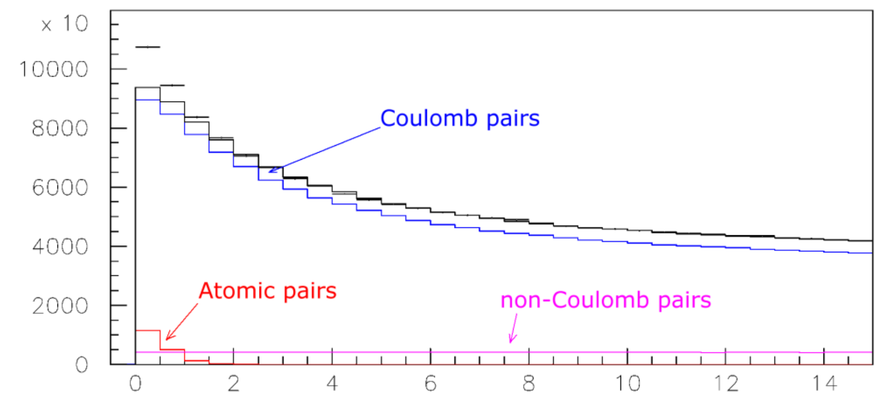
Analysis on Q_L, Q_T < 4 MeV/c

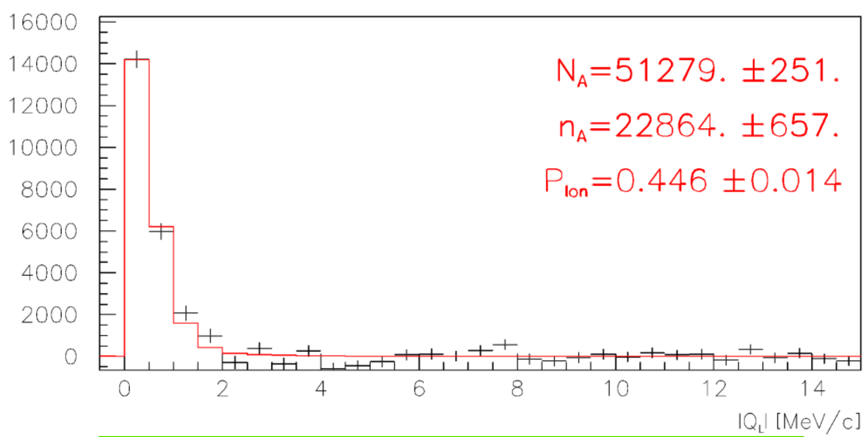
Analysis on Q_L-Q_T, Q_T < 4 MeV/c

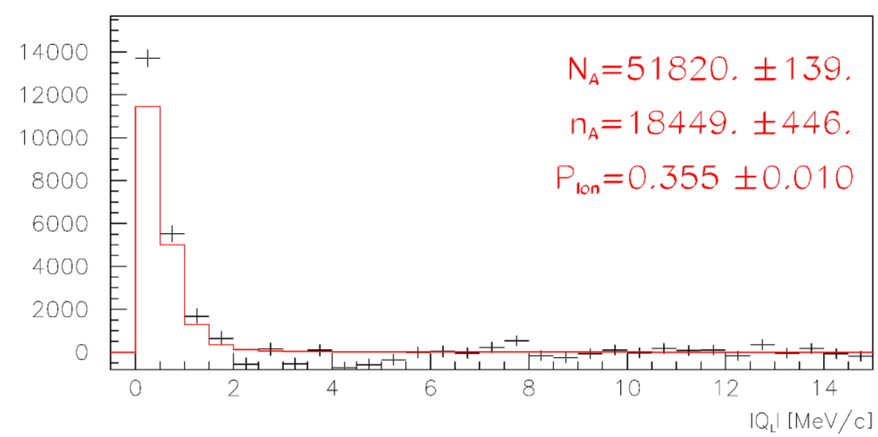
$\pi^+\pi^-$ atoms, run 2008-2010

Run 2008-2010, statistics with low and medium background (2/3 of all statistics). Point-like production of all particles.









Analysis on Q_L, Q_T < 4 MeV/c

Analysis on Q_L-Q_T, Q_T < 4 MeV/c

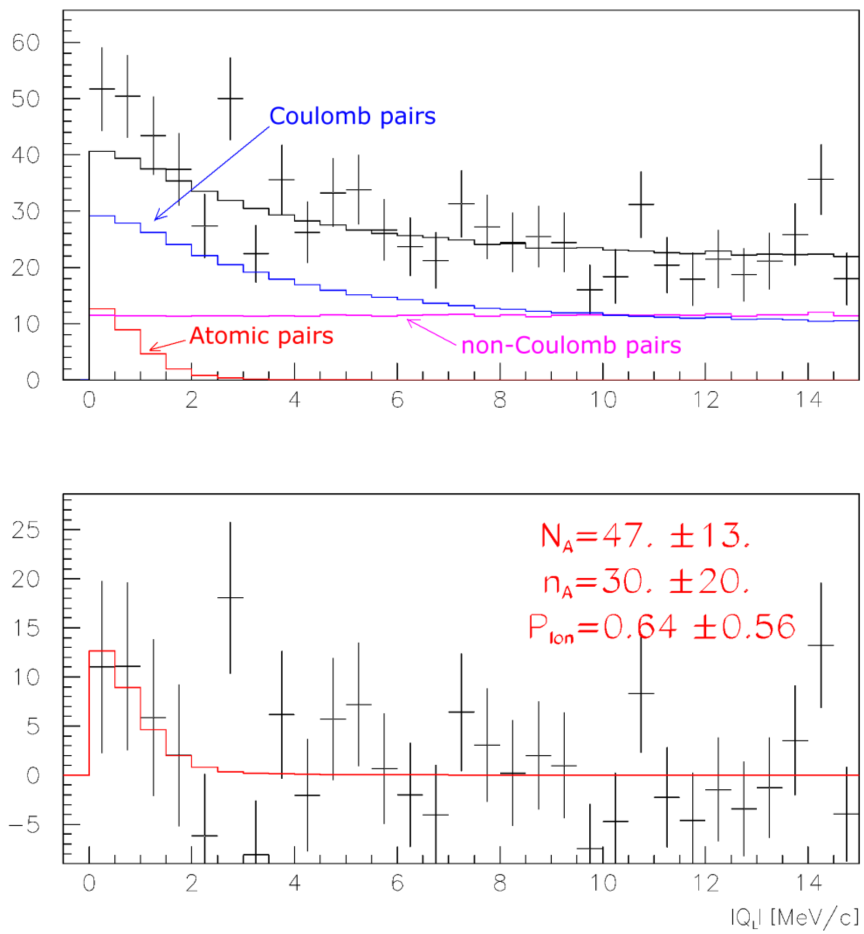
P_{br} (2001-2003) = 0.446±0.0093

$\pi^+\pi^-$ pairs analysis

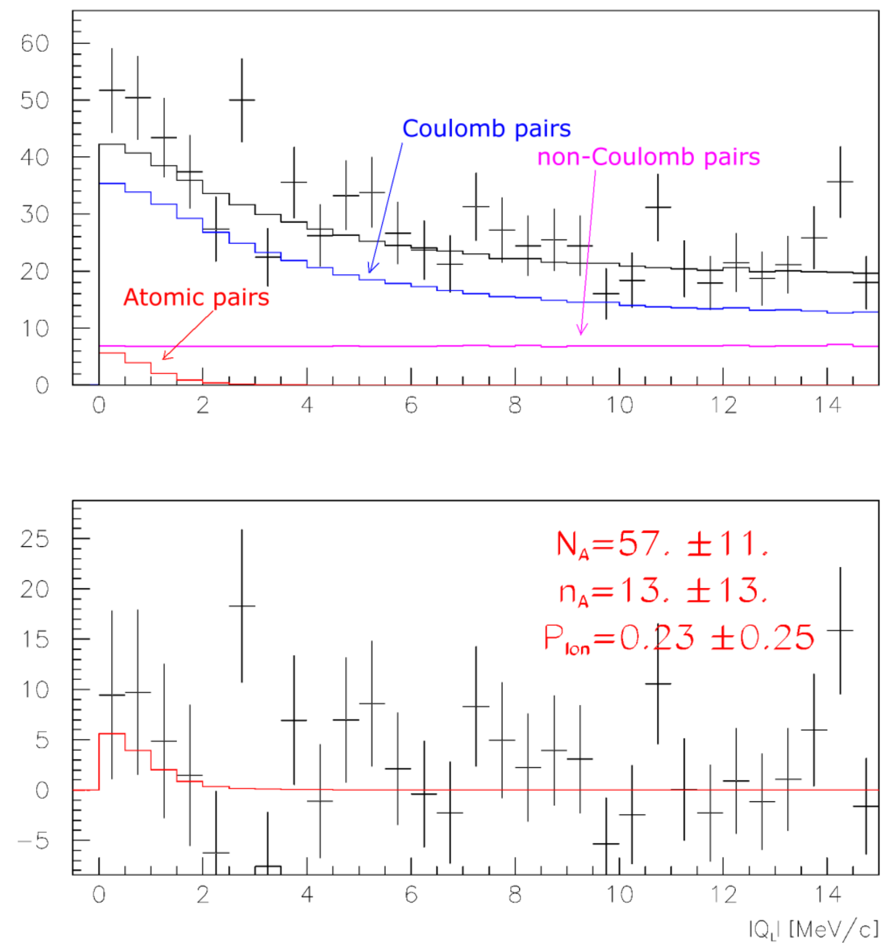
	2008	2009	2010
$N_A(Q_L)$	12480±120	19640±150	19160±160
$N_A(Q_L\text{-}Q_T)$	12600±110	19860±140	19360±140
$n_A(Q_L)$	5680±330	8700±400	8480±400
$n_A(Q_L\text{-}Q_T)$	5330±220	6700±270	6420±270
$P_{br}(Q_L)$	0.455±0.030	0.443±0.023	0.443±0.023
$P_{br}(Q_L\text{-}Q_T)$	0.423±0.020	0.337±0.015	0.331±0.016
P_{br}(2001-2003)=0.446±0.0093			

π^+K^- atoms, run 2008

Run 2008, statistics with low and medium background (2/3 of all statistics).
Point-like production of all particles.



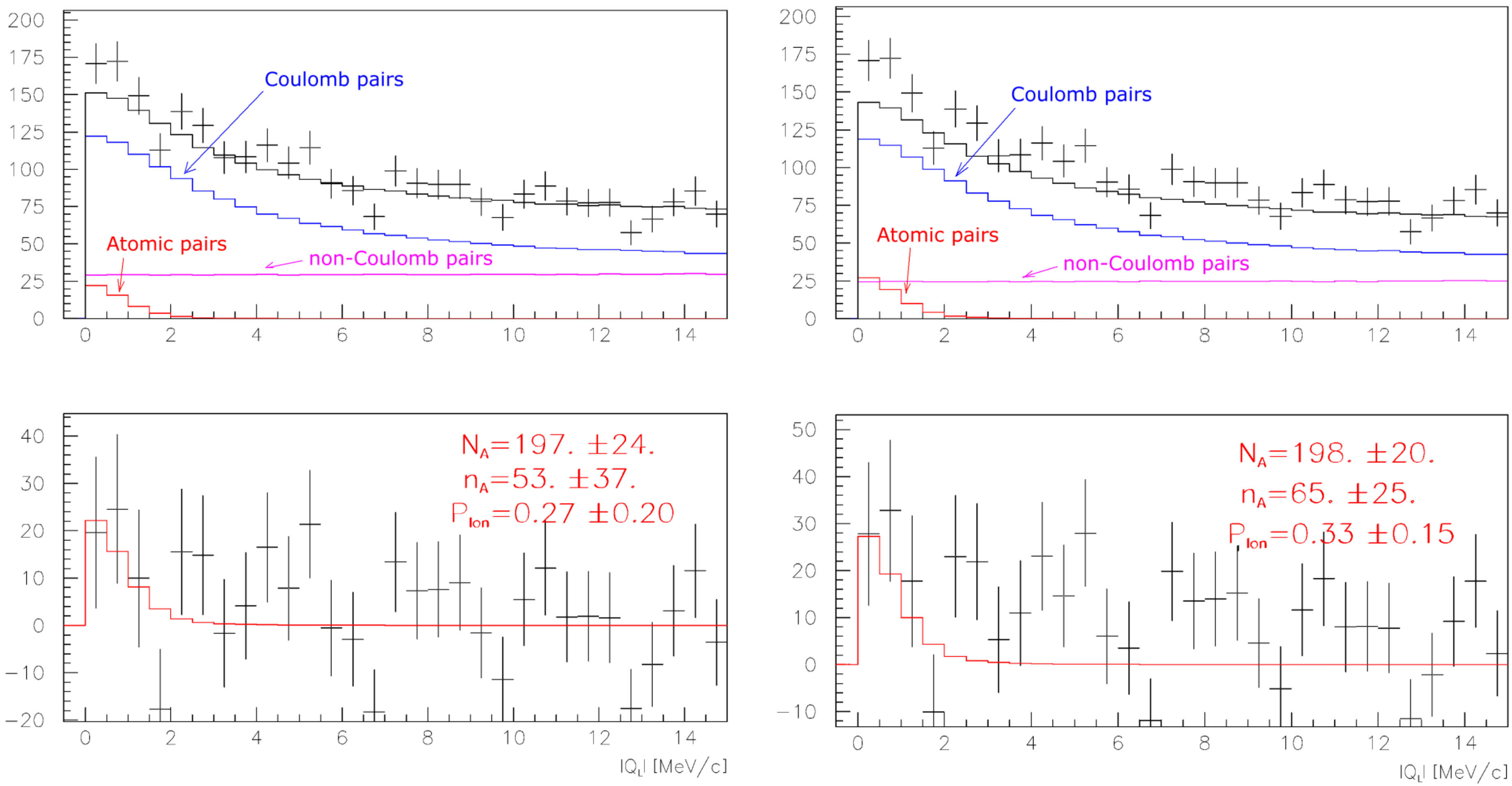
Analysis on Q_L, $Q_T < 4$ MeV/c



Analysis on Q_L-Q_T, $Q_T < 4$ MeV/c

π^+K^- atoms, run 2008-2010

Run 2008-2010, statistics with low and medium background (2/3 of all statistics). Point-like production of all particles.

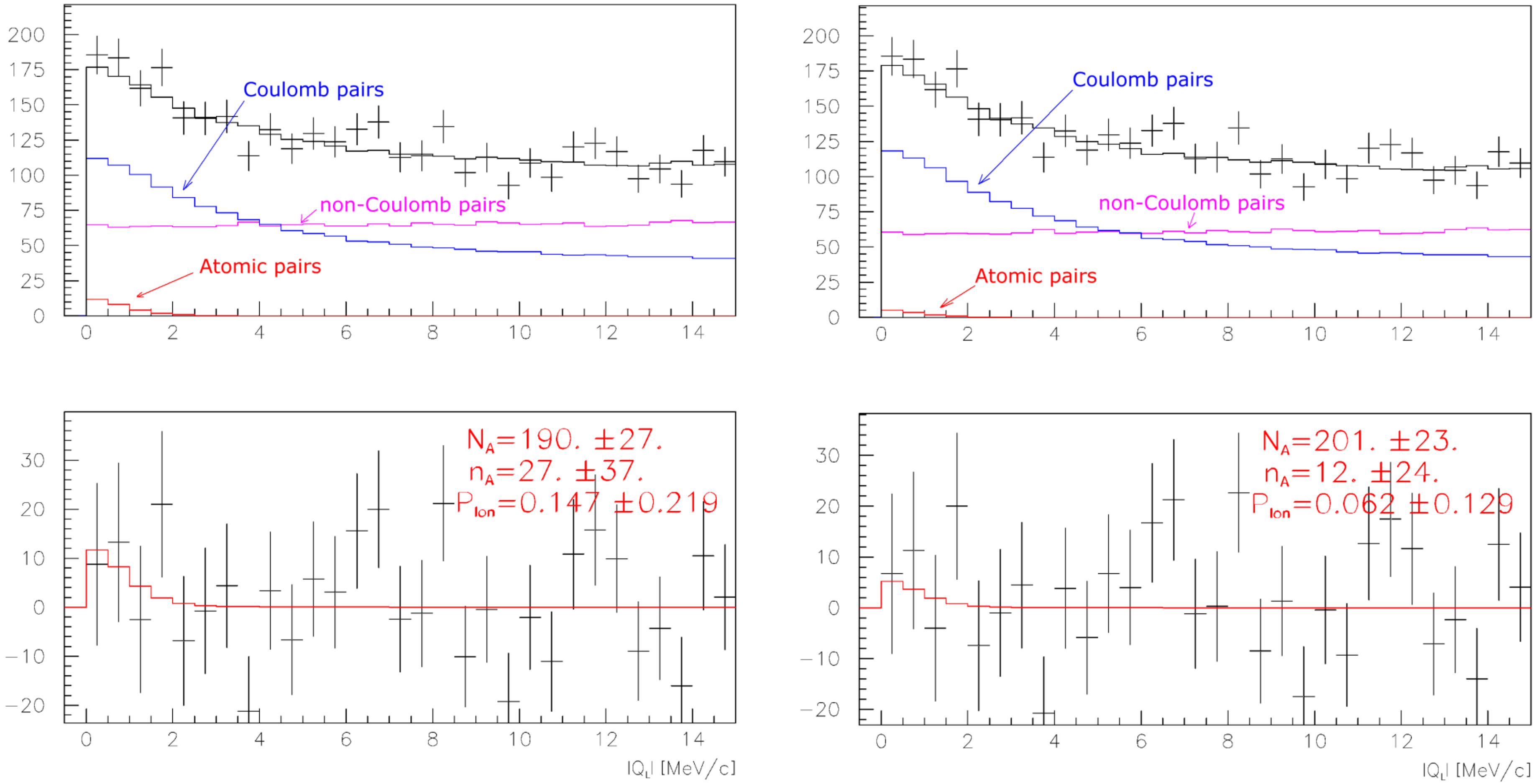


Analysis on Q_L, Q_T < 4 MeV/c

Analysis on Q_L-Q_T, Q_T < 4 MeV/c

$K^+\pi^-$ atoms, run 2010

Run 2010, statistics with low and medium background (2/3 of all statistics).
Point-like production of all particles.

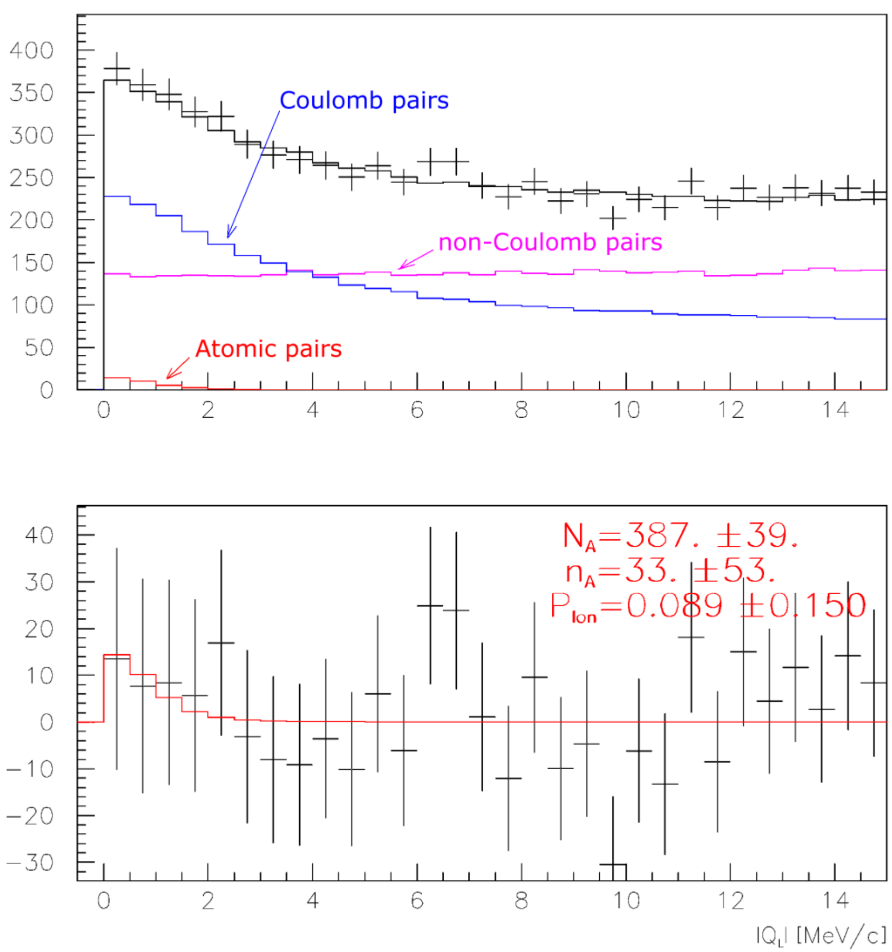


Analysis on Q_L, Q_T < 4 MeV/c

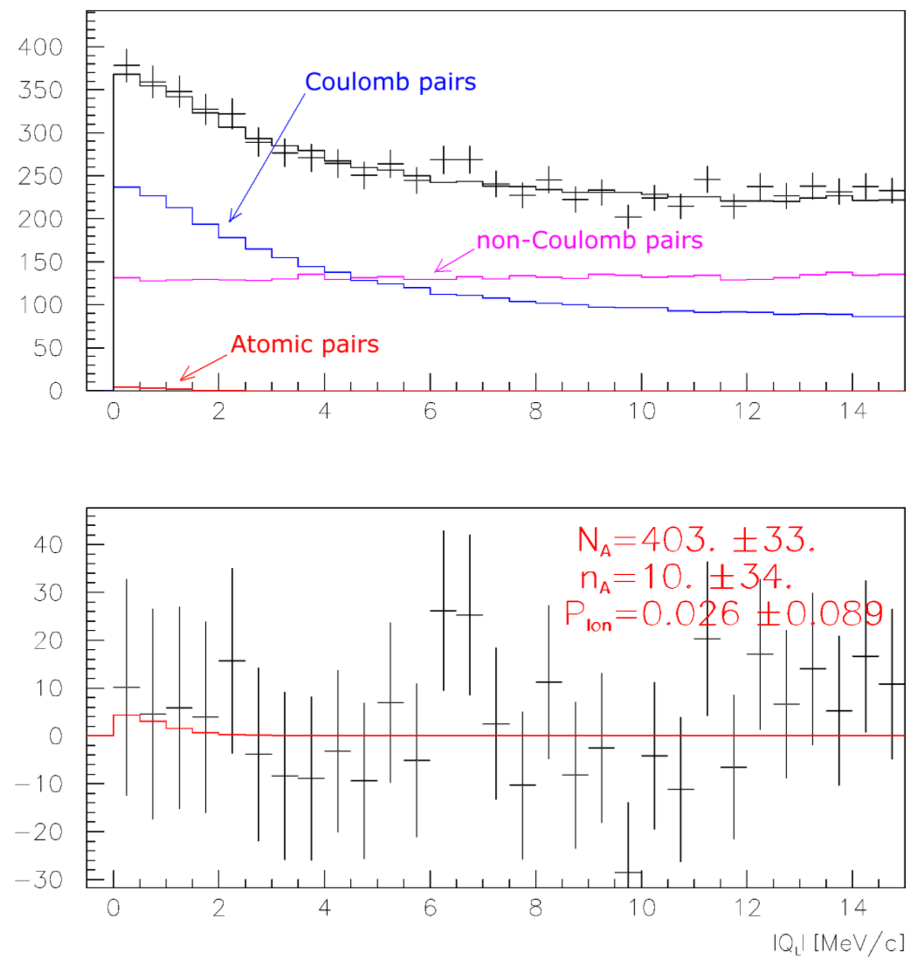
Analysis on Q_L-Q_T, Q_T < 4 MeV/c

$K^+\pi^-$ atoms, run 2009-2010

Run 2009-2010, statistics with low and medium background (2/3 of all statistics). Point-like production of all particles.



Analysis on Q_L, Q_T < 4 MeV/c

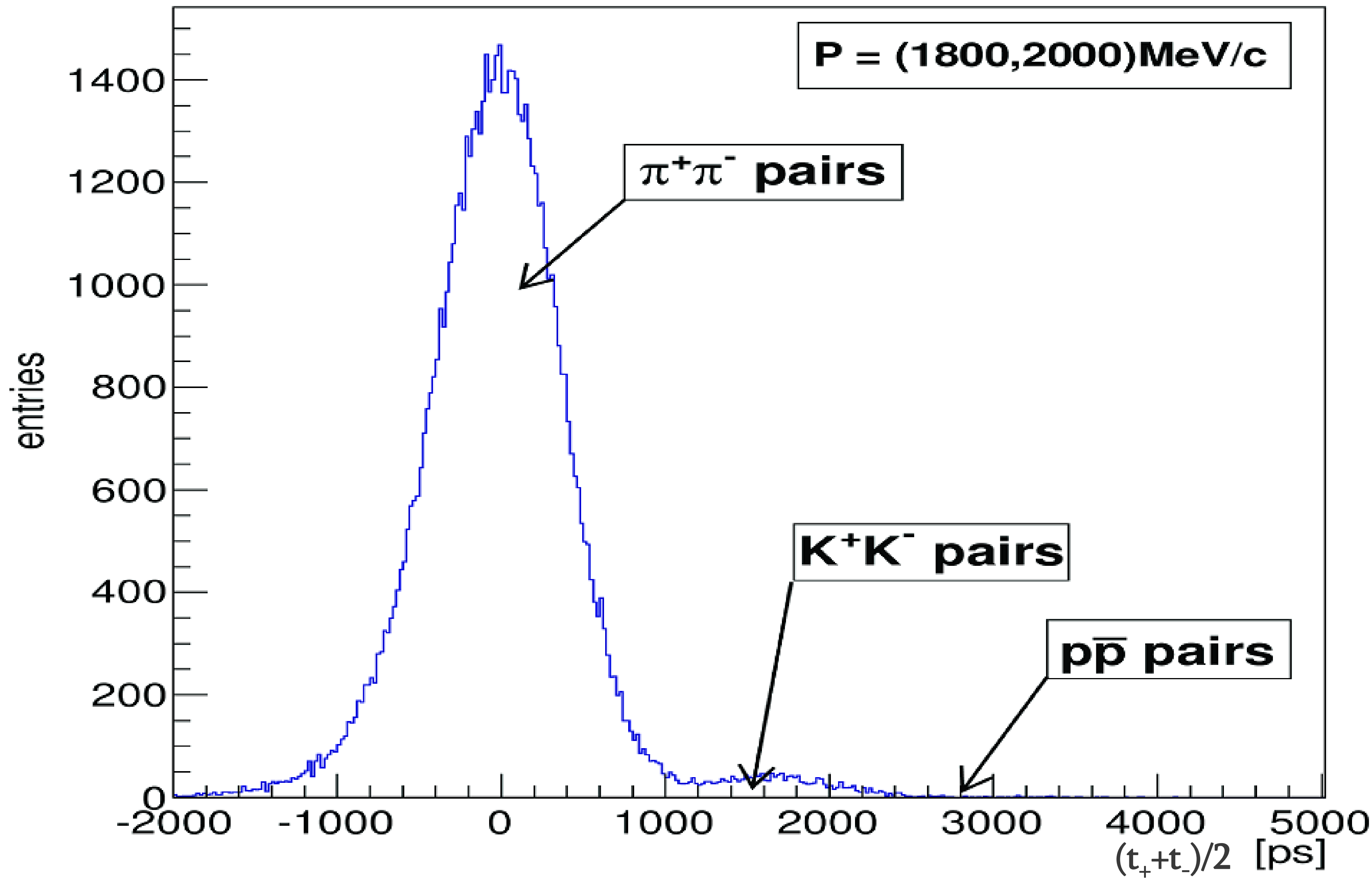


Analysis on Q_L-Q_T, Q_T < 4 MeV/c

π^+K^- and $K^+\pi^-$ pairs analysis

	π^+K^- pairs 2008-2010	$K^+\pi^-$ pairs 2009-2010
$N_A(Q_L)$	200±24	390±40
$N_A(Q_L\text{-}Q_T)$	200±20	400±33
$n_A(Q_L)$	53±37	33±53
$n_A(Q_L\text{-}Q_T)$	65±25	10±34
$P_{br}(Q_L)$	0.27±0.20	0.089±0.150
$P_{br}(Q_L\text{-}Q_T)$	0.33±0.15	0.026±0.089
$n_A(Q_L)$ (sum) = 86±65		
$P_{br}^{theor} = 0.278 \pm {}^{0.012}_{0.011}$		

2010 data: distribution of pairs on $(t_+ + t_-)/2$ for P=(1800, 2000) MeV/c



2010 data: results for kaons and K^+K^- pairs in low momenta

Mom. inter. [MeV/c]	K^+	sse(K^+)	K^-	sse(K^-)	K^+K^-	sse(K^+K^-)
1000-1200	75	± 9	40	± 6	-	-
1200-1400	2032	± 64	1308	± 51	522	± 23
1400-1600	4546	± 95	3628	± 85	1884	± 61
1600-1800	6314	± 112	5450	± 104	2101	± 65
1800-2000	-	-	-	-	2068	± 64

sse(K^+)...standard statistic error for K^+
sse(K^-)...standard statistic error for K^-
sse(K^+K^-)...standard statistic error for K^+K^- pairs

Total number of K^+K^- pairs in low momenta is 6575.

2010 data: results for K^+K^- and $p\bar{p}$ pairs in high momenta

Mom. intervals [MeV/c]	$p\bar{p}$	$\text{error}_{p\bar{p}}$	ratio [%]	$\text{error}_{\text{ratio}}$	K^+K^- pairs	$\text{error}_{K^+K^-}$
3000-3200	85	±14	0.33	±0.18	1366	±105
3200-3400	116	±17	0.56	±0.16	830	±86
3400-3600	96	±17	0.73	±0.19	709	±69
3600-3800	88	±15	0.99	±0.18	326	±52

ratio...ratio between $p\bar{p}$ and $\pi^+\pi^-$ pairs

$\text{error}_{p\bar{p}}$...error of fit for $p\bar{p}$ pairs

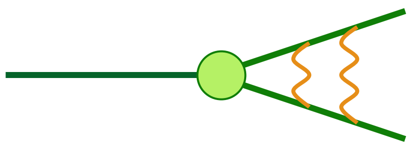
$\text{error}_{\text{ratio}}$...error for the $p\bar{p}$ and $\pi^+\pi^-$ pair ratio

$\text{error}_{K^+K^-}$...error of fit for K^+K^- pairs

Total number of K^+K^- pairs in high momenta is 3231.
The sum of low and high energy kaon pairs is 9806.

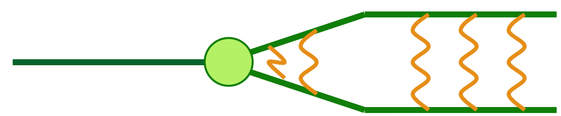
Coulomb pairs and atoms

For the charge pairs from the short-lived sources and small relative momentum Q there is strong Coulomb interaction in the final state. This interaction increases the production yield of the free pairs with Q decreasing and creates atoms.



$\pi^+\pi^-$, $K^+\pi^-$, $K^-\pi^+$, K^+K^-, $\pi^+\mu^-$, $\pi^-\mu^+$

Coulomb pairs



$(\pi^+\pi^-)$, $(K^+\pi^-)$, $(K^-\pi^+)$, (K^+K^-), $(\pi^+\mu^-)$, $(\pi^-\mu^+)$

Atoms

There is precise ratio between the number of produced Coulomb pairs (N_C) with small Q and the number of atoms (N_A) produced simultaneously with these Coulomb pairs:

$$N_A = K(Q_0) N_C (Q \le Q_0), \quad \frac{\delta K(Q_0)}{K(Q_0)} \le 10^{-2}$$

$$n_A \text{ - atomic pairs number}, \quad P_{br} = \frac{n_A}{N_A}$$

K^+K^- atom and its lifetime

Properties of the K^+K^- atom (kaonium or A_{2K}):

$a_B = [\alpha m_K/2]^{-1} = 109.6$ fm … Bohr radius
$|E_{1s}| = \alpha^2 m_K/4 = 6.57$ keV … binding energy
$\tau(A_{2K}) \approx [\Gamma(A_{2K})]^{-1} =$ … lifetime

The lifetime for the kaonium decay into 2 pions is strongly reduced by the presence of strong interaction (OBE, scalar meson f_0 and a_0).

K^+K^- interaction complexity ↓

$\tau(A_{2K} \to \pi\pi, \pi\eta)$	K^+K^- interaction
1.2×10^{-16} s	Coulomb-bound
3.2×10^{-18} s	+ one-boson exchange (OBE)
1.1×10^{-18} s	+ f_0' (I=0) + $\pi\eta$-channel (I=1)

Ref.: S. Wycech, A.M. Green, Nuclear Physics A562 (1993), 446-460;
S. Krewald, R. Lemmer, F.P. Sasson, Phys. Rev. D69 (2004), 016003.

$A_{2\pi}$ and $A_{\pi K}$ production

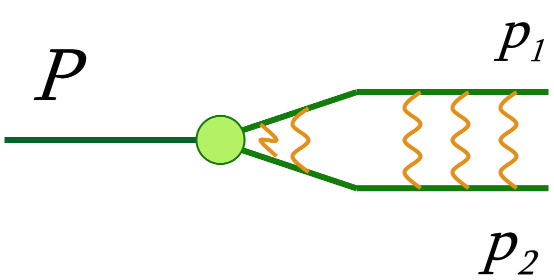
$$\frac{d\sigma^A_{nlm}}{d\vec{P}_A} = (2\pi)^3 \frac{E}{M} \left|\psi^{(C)}_{nlm}(0)\right|^2 \frac{d\sigma^0_s}{d\vec{p}_1 d\vec{p}_2}\Bigg|_{\vec{v}_1=\vec{v}_2} \propto \frac{d\sigma}{d\vec{p}_1} \cdot \frac{d\sigma}{d\vec{p}_2} \cdot R(\vec{p}_1, \vec{p}_2; s)$$

$$\vec{P}_A = \vec{p}_1 + \vec{p}_2$$

for atoms $\vec{v}_1 = \vec{v}_2$ *where* $\vec{v}_1, \vec{v}_2$ *- velocities of particles in the L. S.*
for all types of atoms

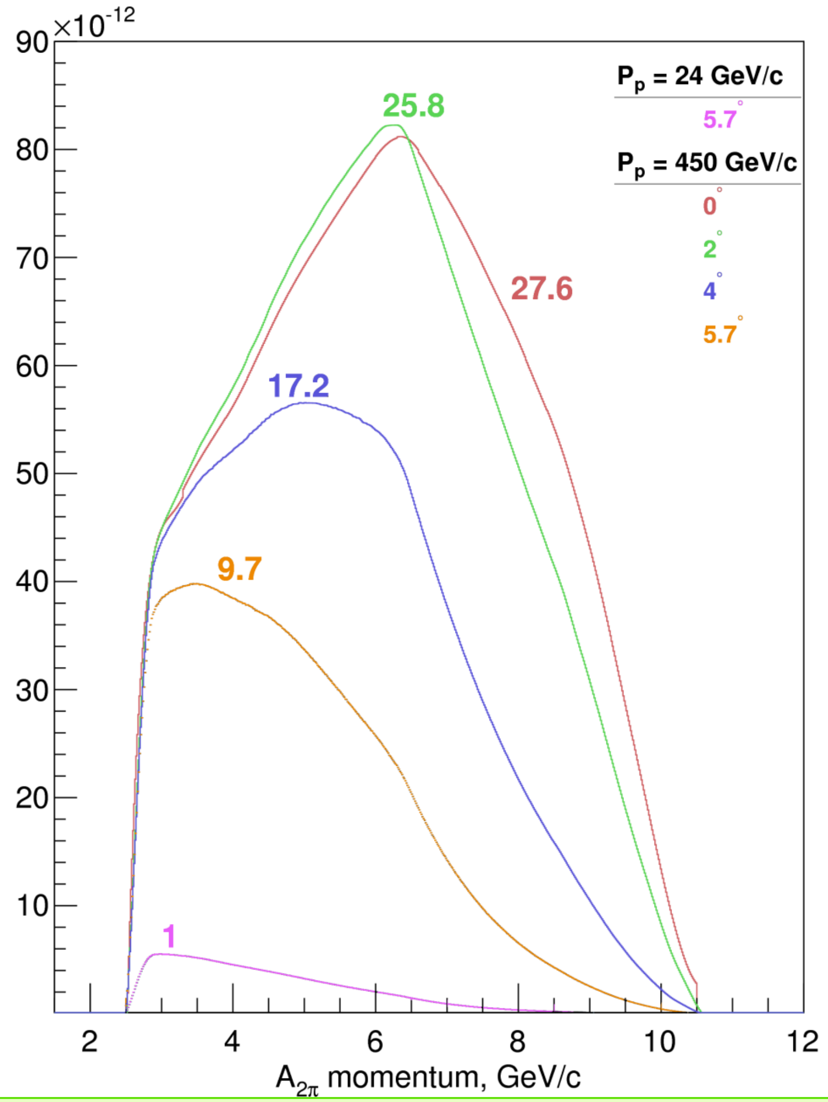
for $A_{2\pi}$ *production* $\vec{p}_1 = \vec{p}_2$

for $A_{\pi K}$ *production* $\vec{p}_\pi = \frac{m_\pi}{m_K} \vec{p}_K$



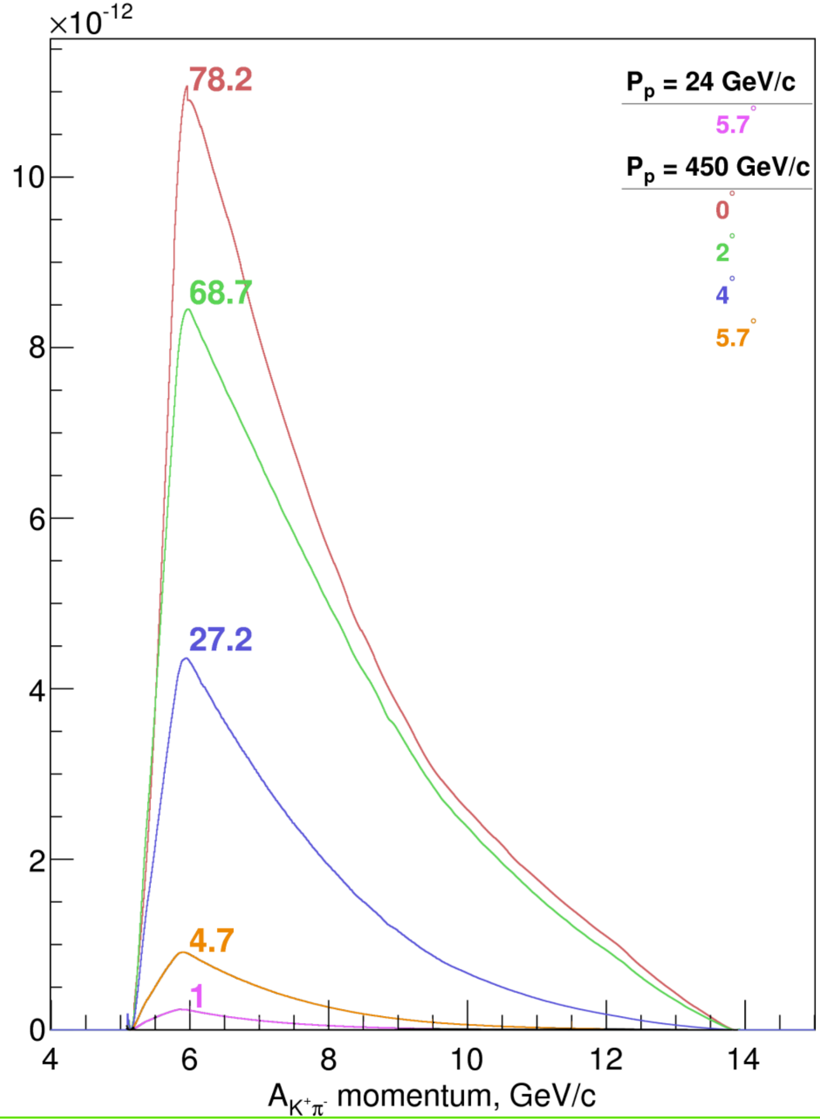
$R(\vec{p}_1, \vec{p}_2; s)$ *- correlatio n function*

Yield of $A_{2\pi}$ per one p-Ni interaction



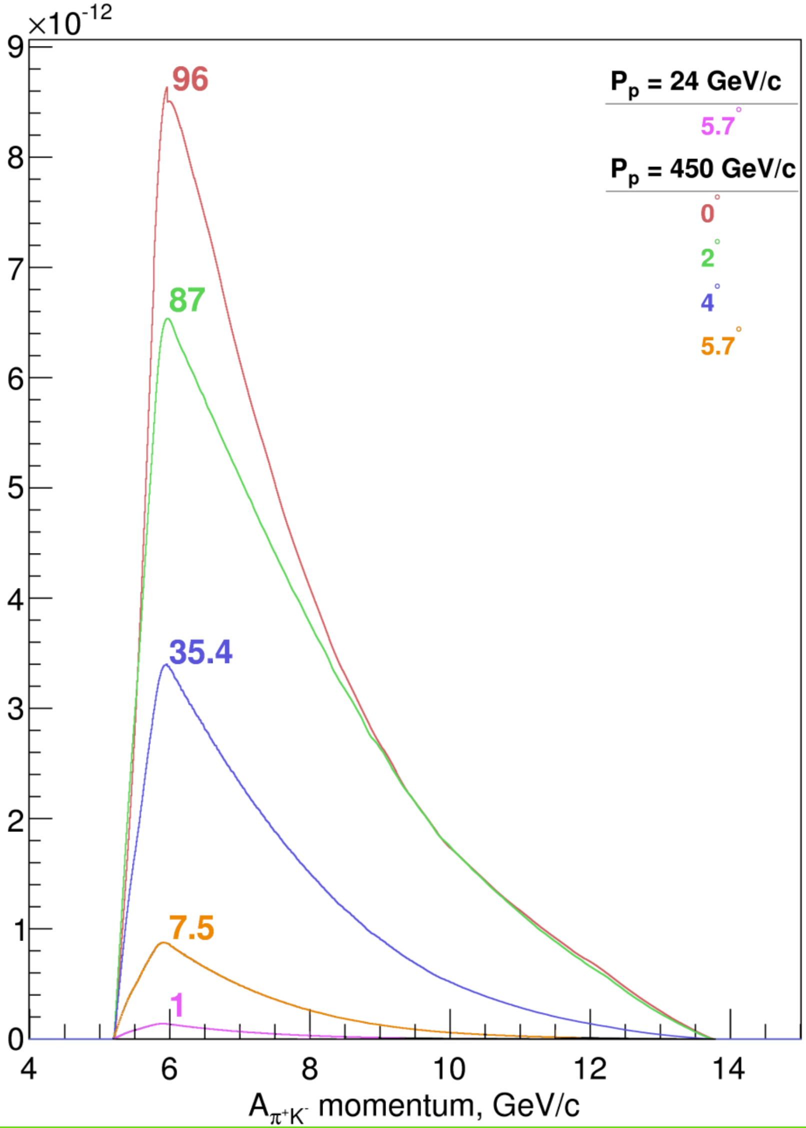
Yield of $A_{2\pi}$ dependence as a function of the atoms angle production and momentum in L. S. Bin = 15 MeV/c.

Yield of $A_{K\pi}$ per one p-Ni interaction



Yield of $A_{K\pi}$ dependence as a function of the atoms angle production and momentum in L. S. Bin = 9.6 MeV/c.

Yield of $A_{\pi K}$ per one p-Ni interaction



Yield of $A_{\pi K}$ dependence as a function of the atoms angle production and momentum in L. S. Bin = 9.6 MeV/c.

Thank you

for your attention!

Experimental conditions (run 2008-2010)

Primary proton beam	24 GeV/c
Beam intensity	$(10.5 \div 12) \cdot 10^{10}$ proton/spill
Single count of one IH plane	$(5 \div 6) \cdot 10^{6}$ particle/spill
Spill duration	450 ms

Ni target		
Purity	99.98%	
Target thickness (year)	98±1 μm (2008)	108 ±1 μm (2009-2010)
Radiation thickness	$6.7 \cdot 10^{-3} X_0$	$7.4 \cdot 10^{-3} X_0$
Probability of inelastic proton interaction	$6.4 \cdot 10^{-4}$	$7.1 \cdot 10^{-4}$

Experimental conditions

Secondary particles channel (relative to the proton beam)	5.7°
Angular divergence in vertical and horizontal planes	±1°
Solid angle	$1.2 \cdot 10^{-3}$ sr
Dipole magnet	B_{max} = 1.65 T, BL = 2.2 Tm

Time resolution [ps]								
	VH	IH				SFD		
plane	1	1	2	3	4	X	Y	W
2008	112	713	728	718	798	379	508	518
2010	113	907	987	997	1037	382	517	527

Experimental conditions

SFD			
Coordinate precision	$\sigma_X = 60\ \mu m$	$\sigma_Y = 60\ \mu m$	$\sigma_W = 120\ \mu m$
Time precision	$\sigma^t_X = 380$ ps	$\sigma^t_Y = 512$ ps	$\sigma^t_W = 522$ ps

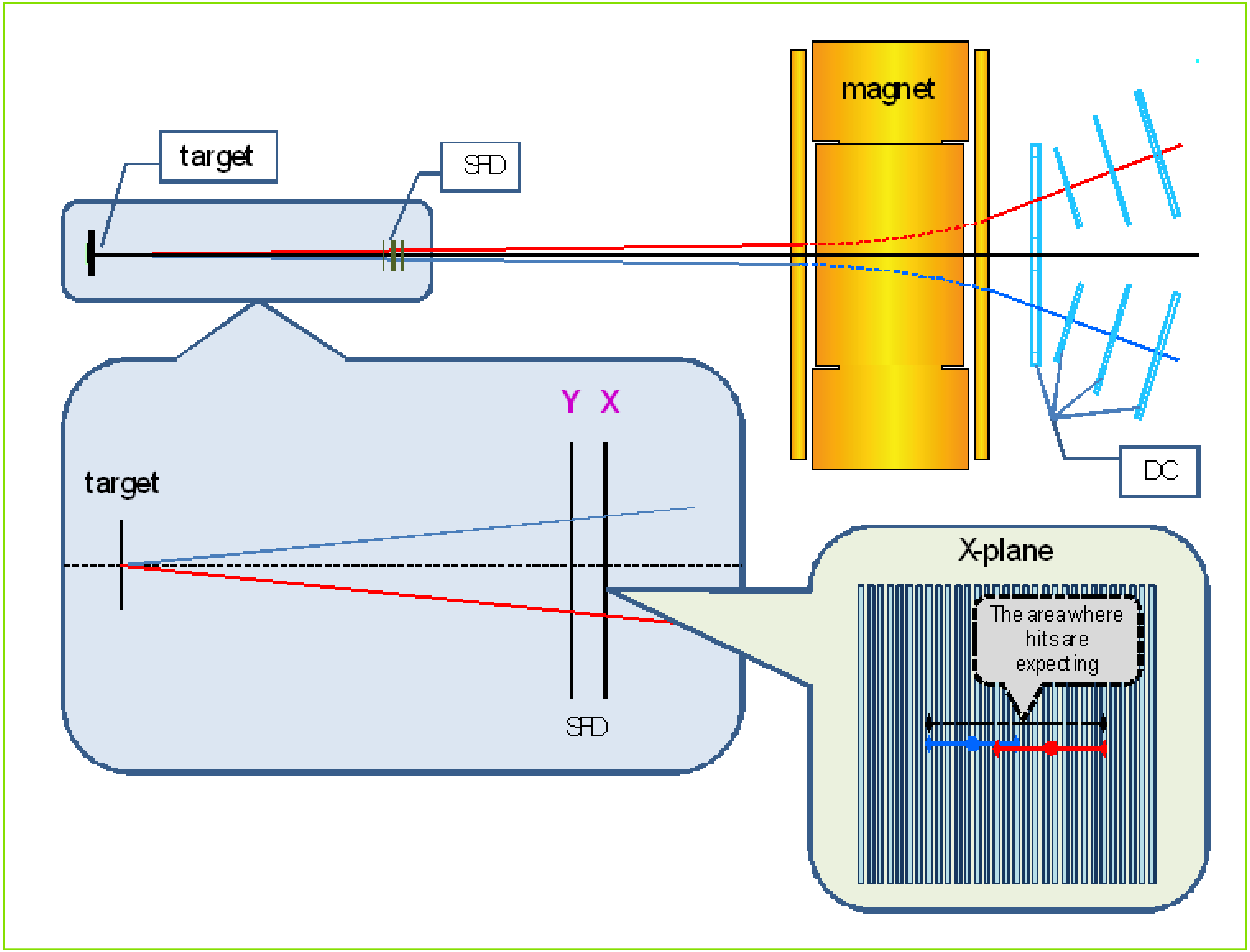
DC	
Coordinate precision	$\sigma = 85\ \mu m$

VH	
Time precision	$\sigma = 100$ ps

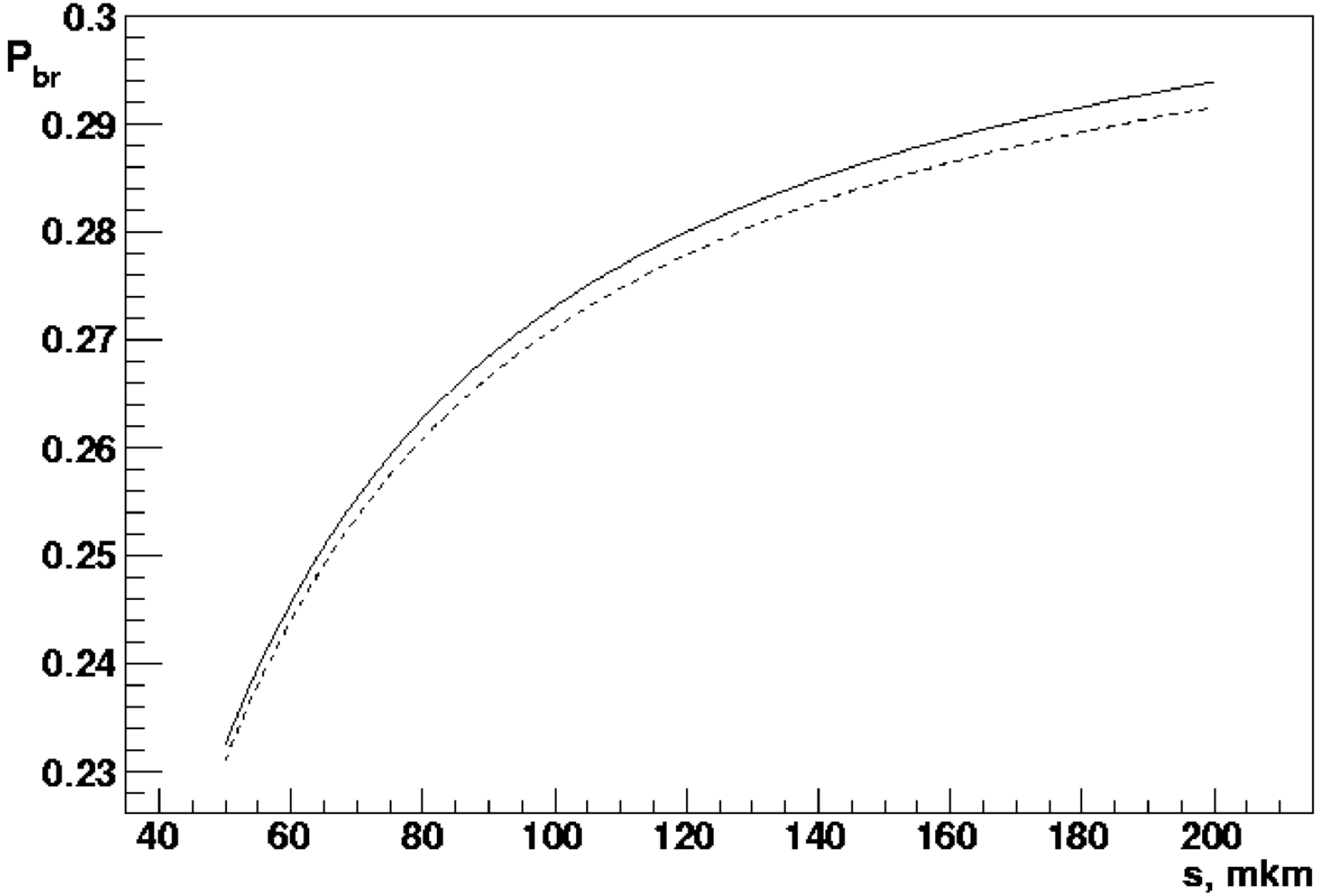
Spectrometer		
Relative resolution on the particle momentum in L.S.	$3 \cdot 10^{-3}$	
Precision on Q-projections	$\sigma_{QX} = \sigma_{QY} = 0.5$ MeV/c	$\sigma_{QL} = 0.5$ MeV/c ($\pi\pi$) $\sigma_{QL} = 0.9$ MeV/c (πK)

Trigger efficiency 98 %	for pairs with $Q_L < 28$ MeV/c $Q_X < 6$ MeV/c $Q_Y < 4$ MeV/c

Extrapolation to the target

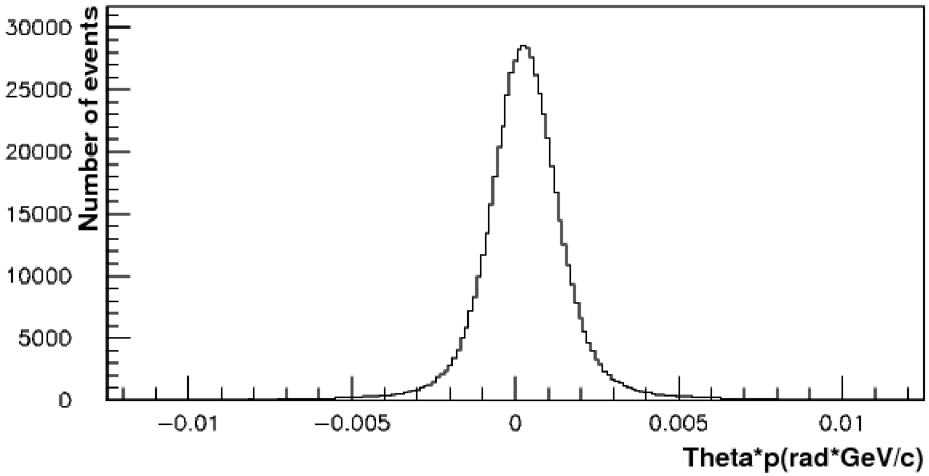


Break-up dependencies P_{br} from the target thickness for $K^+\pi^-$ atom ($A_{K\pi}$) and $K^-\pi^+$ atom ($A_{\pi K}$)

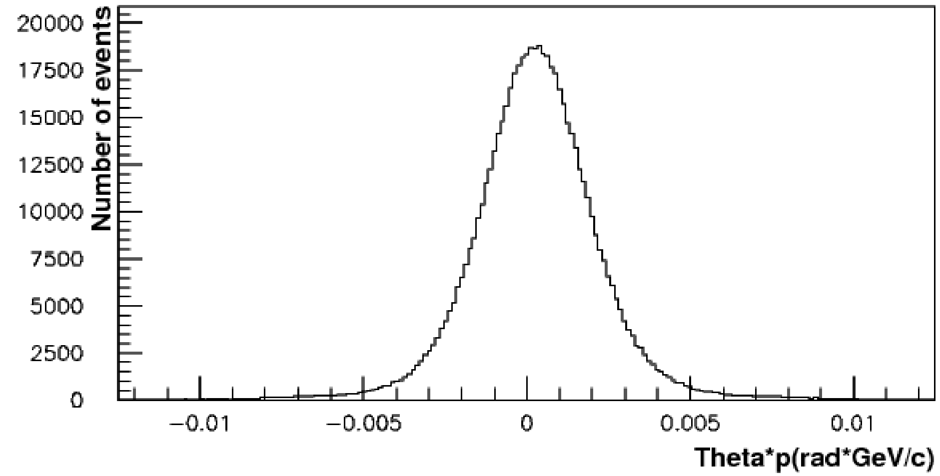


Probability of break-up as a function of Ni target thickness for $A_{\pi K}$ (solid line) and $A_{K\pi}$ atoms (dashed line), $\tau_{1S} = 3.7 \cdot 10^{-15}$ s.
Average momentum of $A_{K\pi}$ and $A_{\pi K}$ are 6.4 GeV/c and 6.5 GeV/c accordingly.

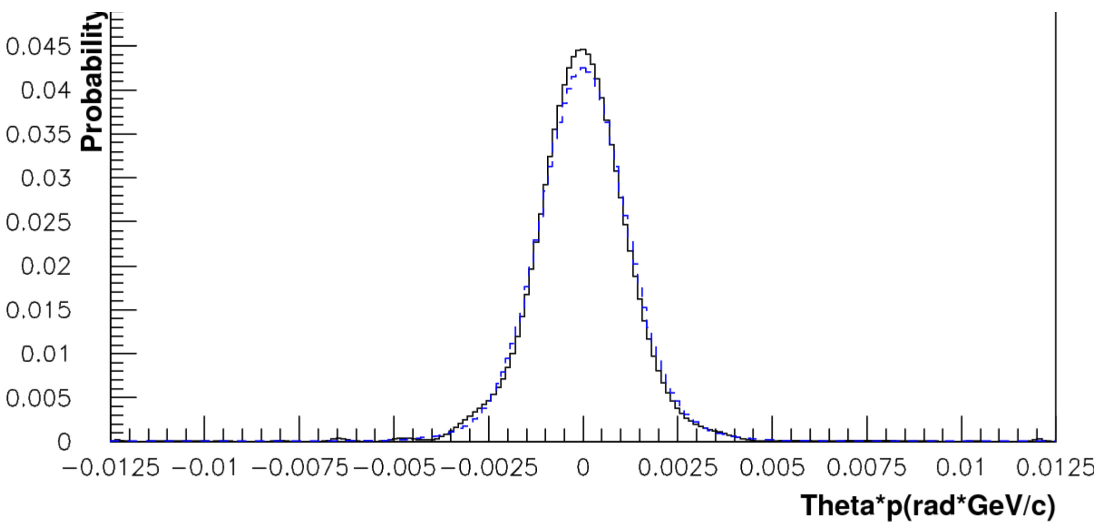
Analysis of multiple scattering in Ni (150 μm)



DC system resolution without scatter



DC system resolution with scatter

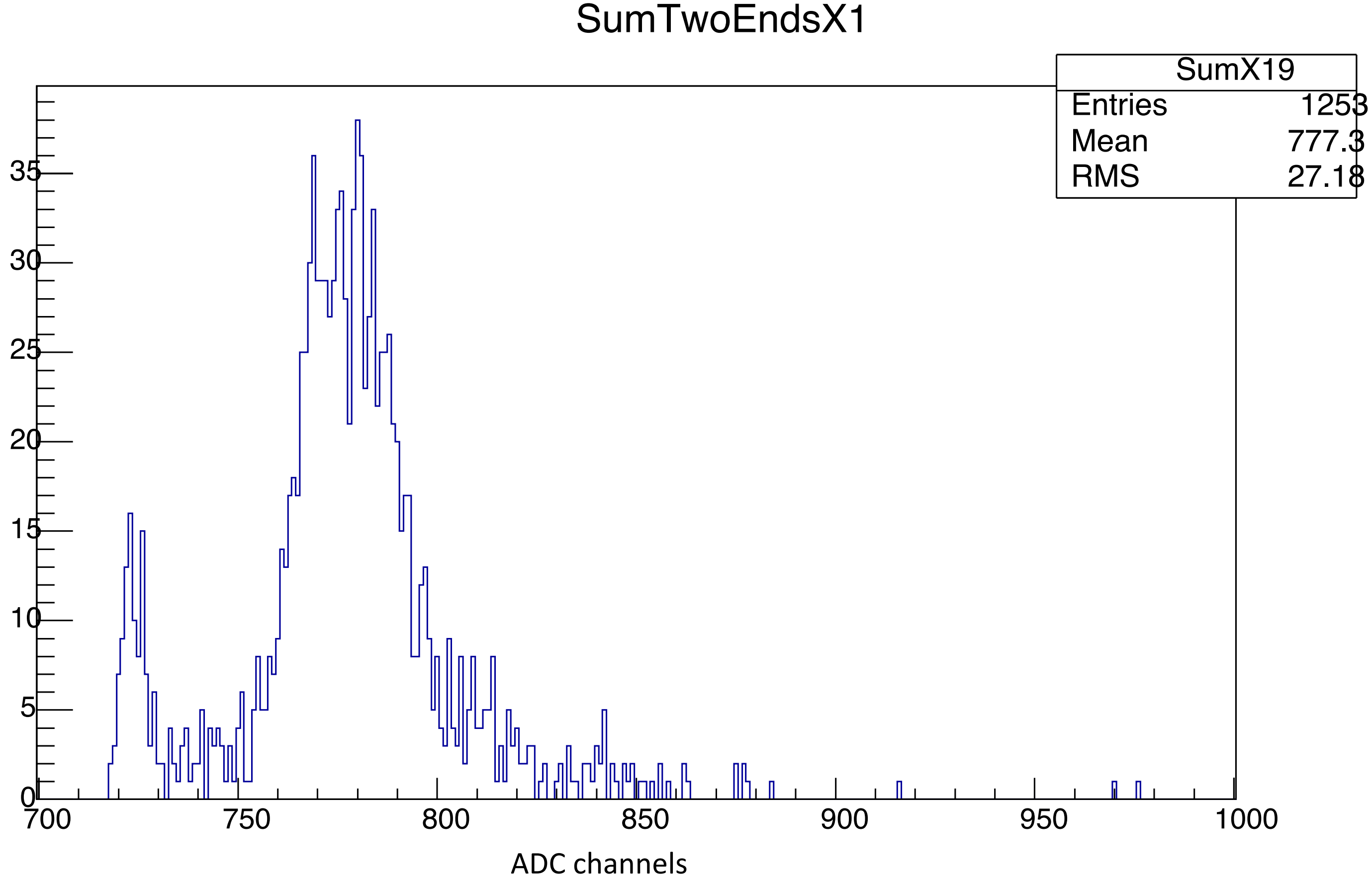


Reconstructed and simulated (blue) MS distributions

Run 2011. Analysis of multiple scattering in Ni (150 μm). Only events with one track in each projection were analyzed. $\delta\theta/\theta \sim 0.7$ %. After including in the analysis of all available events the statistics will be doubled and the expected value will be less than 0.5 %.

Light-yield – pulse-height spectrum

Test in the DIRAC spectrometer (with F1-TDC-ADC; pedestal is not visible)



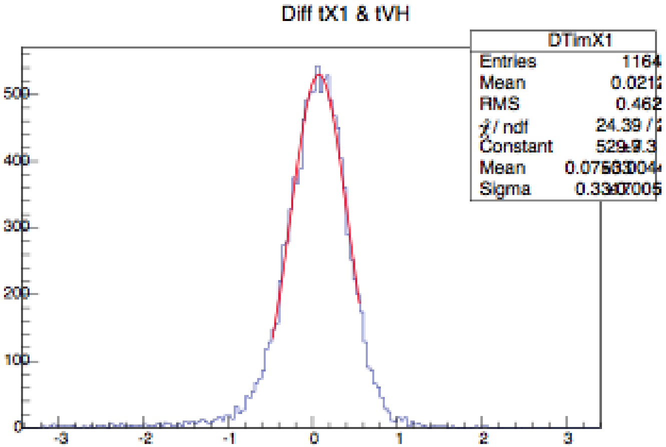
Average number of photoelectrons is larger than 20.

Left-side peak is due to the crosstalk at PMT photocathode (almost 1 PE) and between slabs (a few PE).

Time resolution and efficiency

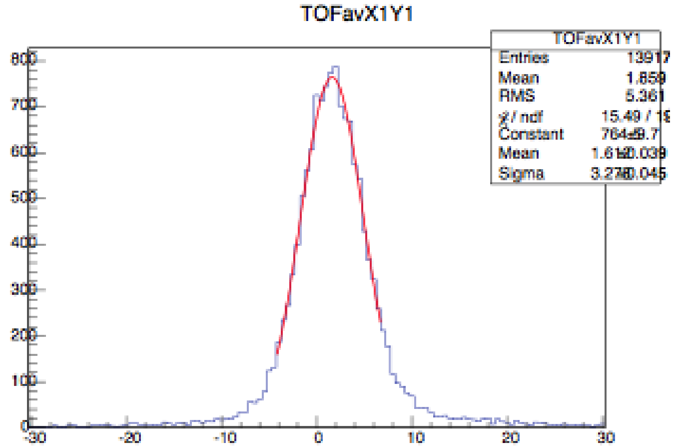
Time resolution

with respect to VH



average
300 ps
RMS

between couples of planes



average
272 ps
RMS

Efficiency

using spectrometer prediction

0.970

using only e^+e^- trigger events

0.993 (better prediction precision)

between mutual planes

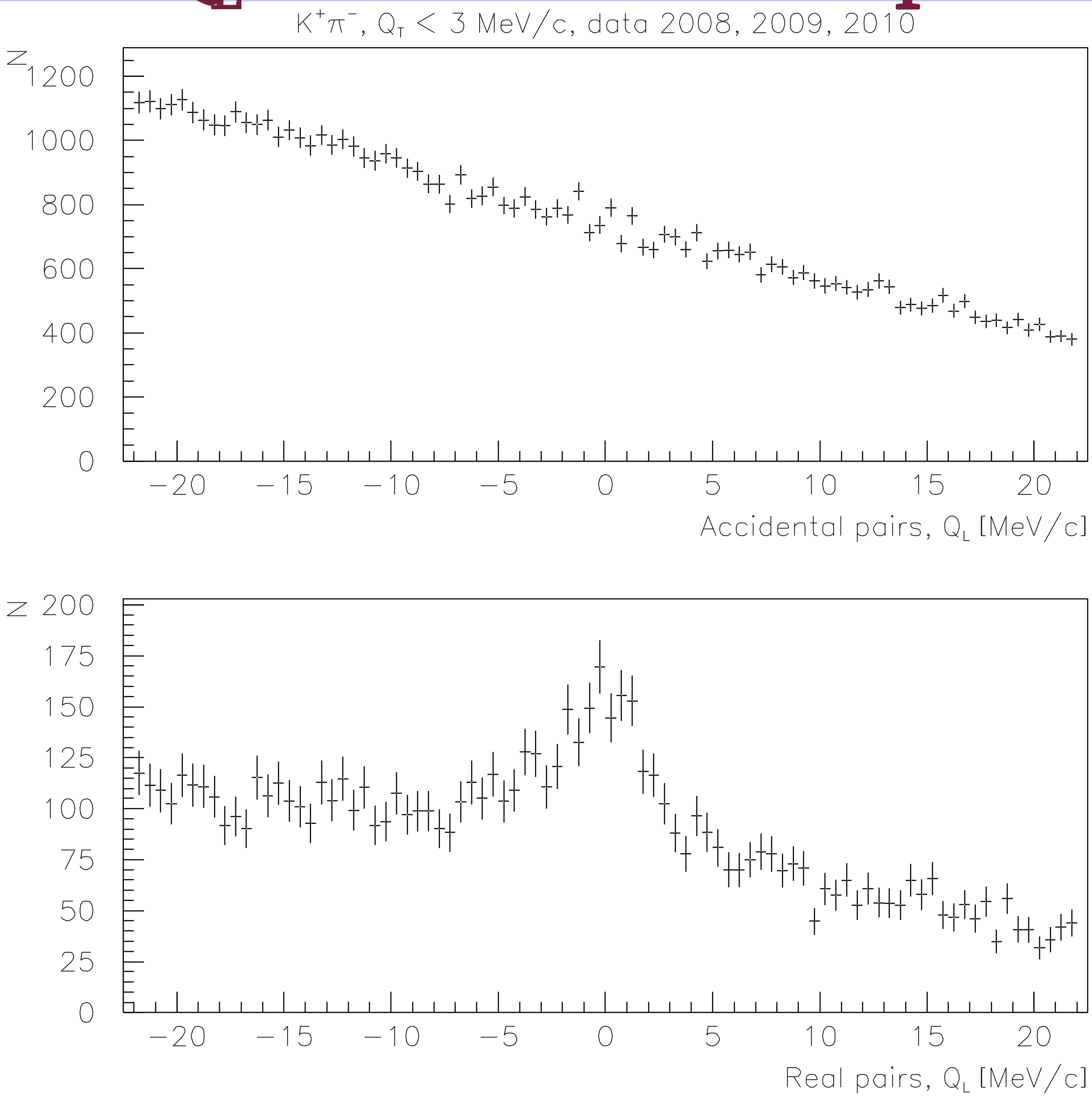
0.988

using only e^+e^- trigger events

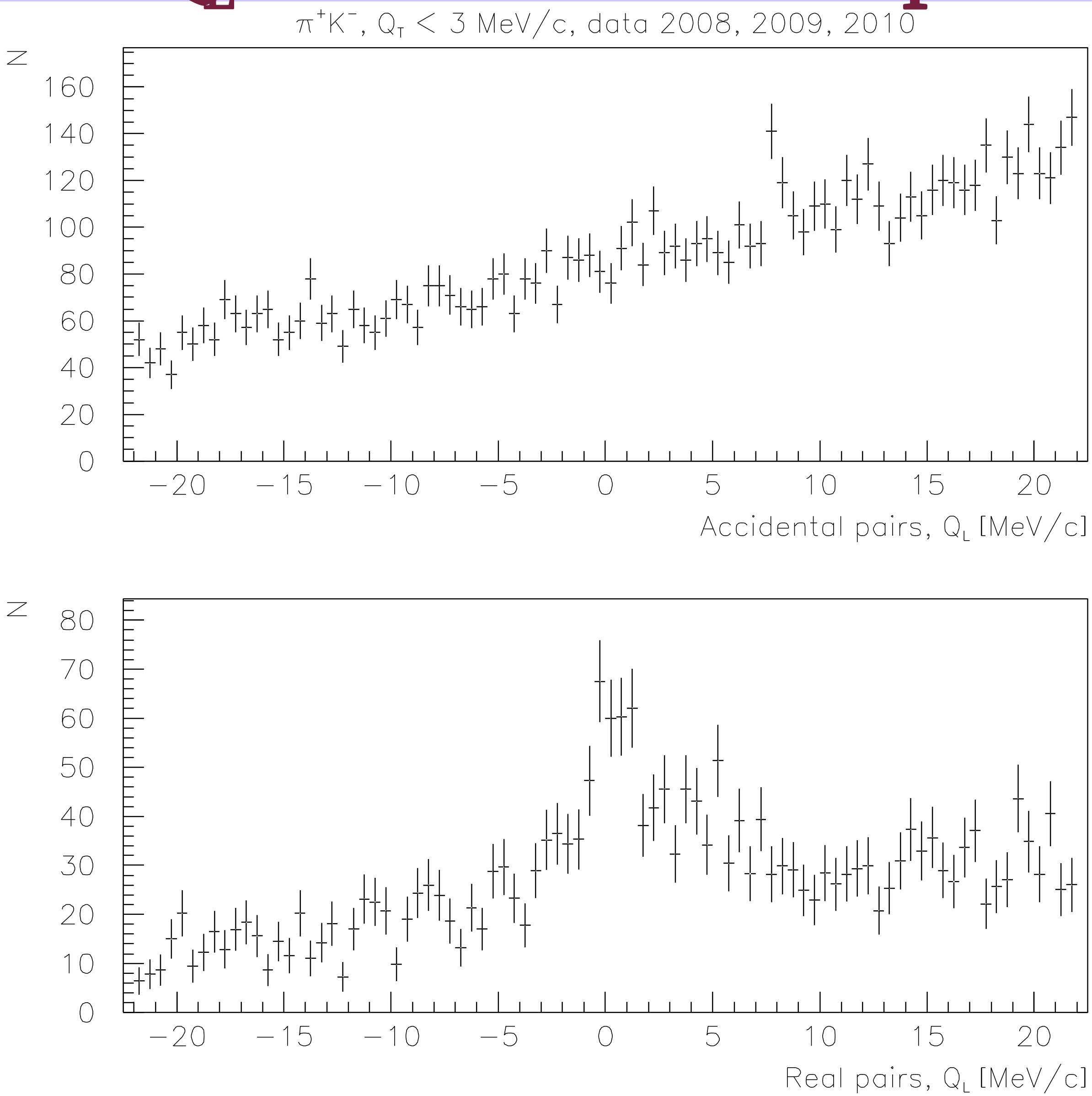
0.994 (better prediction precision)

Efficiency in a high-intensity flux is yet to know.

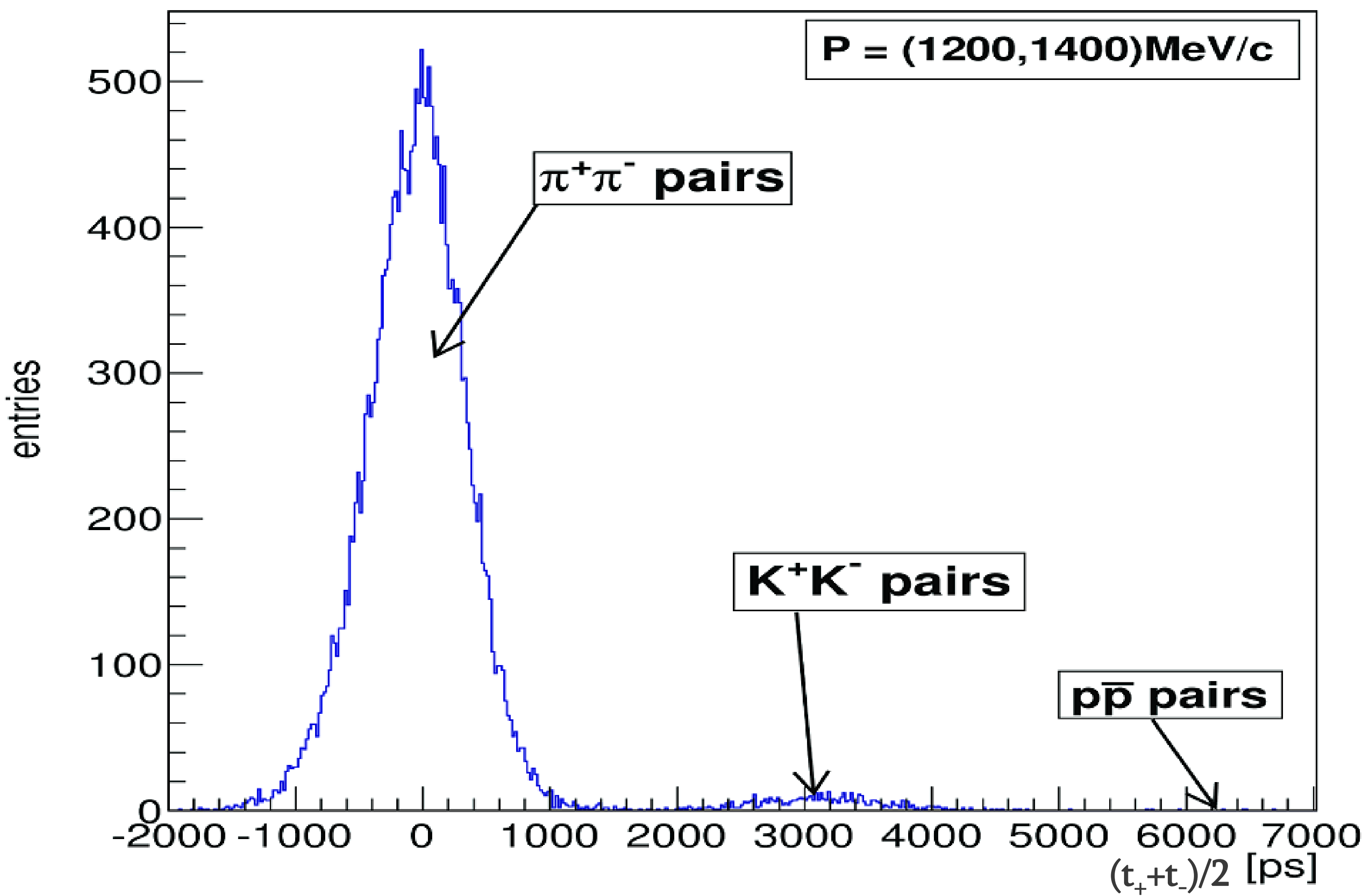
Q_L distribution $K^+\pi^-$ pairs



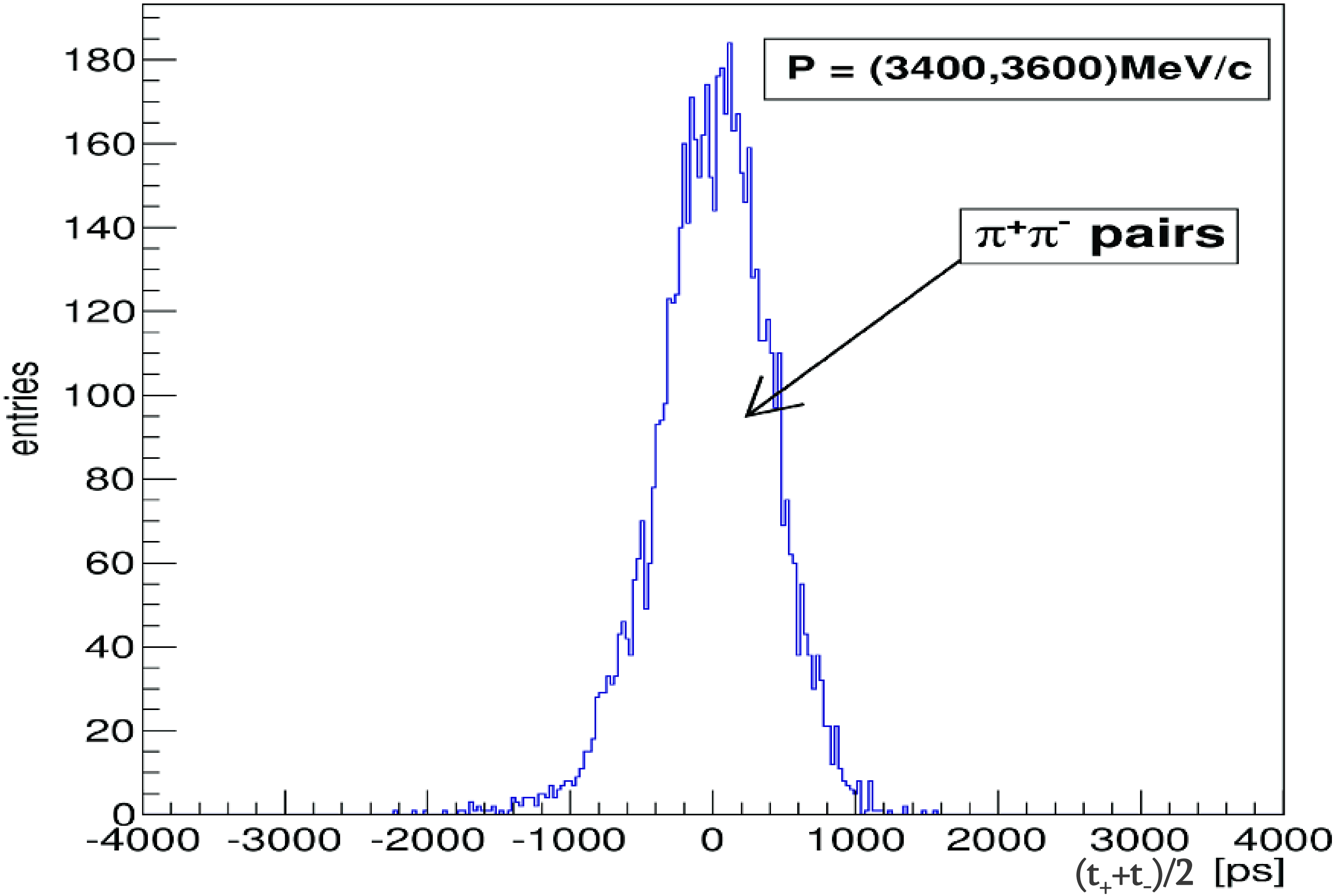
Q_L distribution π^+K^- pairs



2010 data: distribution of pairs on $(t_+ + t_-)/2$ for P=(1200, 1400) MeV/c

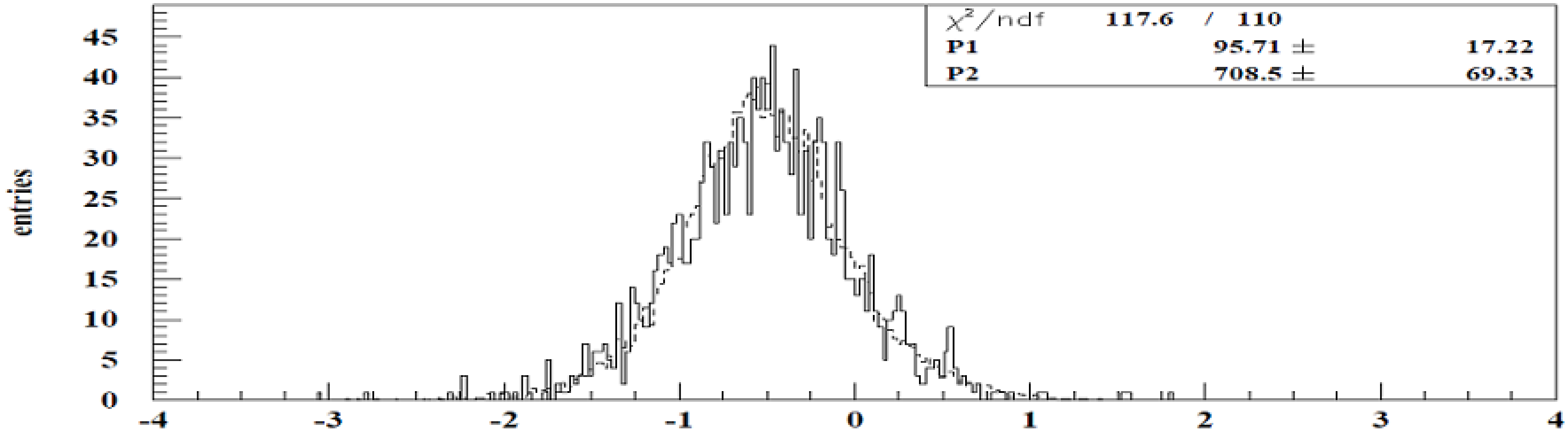


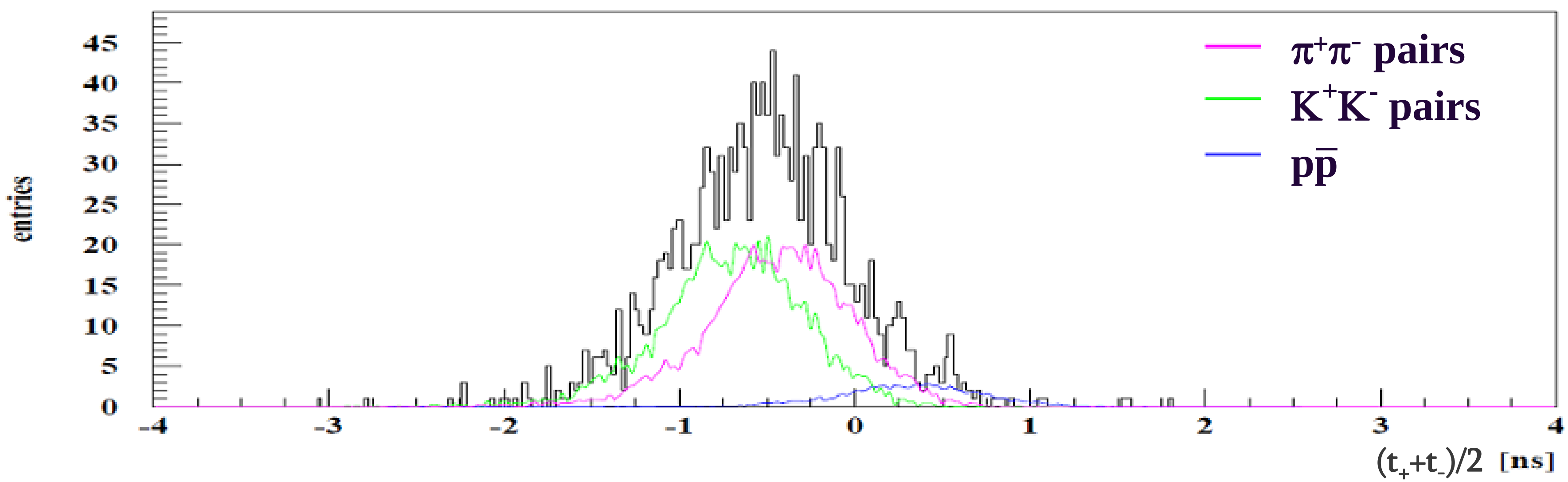
2010 data: distribution of $\pi^+\pi^-$ pairs detected by CHF on $(t_+ + t_-)/2$ for P=(3400, 3600) MeV/c



2010 data: distribution of $\pi^+\pi^-$, $p\bar{p}$ and K^+K^- pairs on $(t_++t_-)/2$ for P=(3400, 3600) MeV/c

No signal in CHF.





K^+K^- atom and its lifetime

Interests in KK physics?

•General:
non-understood KK interplay with the scalar mesons $[I^G(J^{PC})]$
$f_0[0^+(0^{++})]$ and $a_0[1^-(0^{++})]$

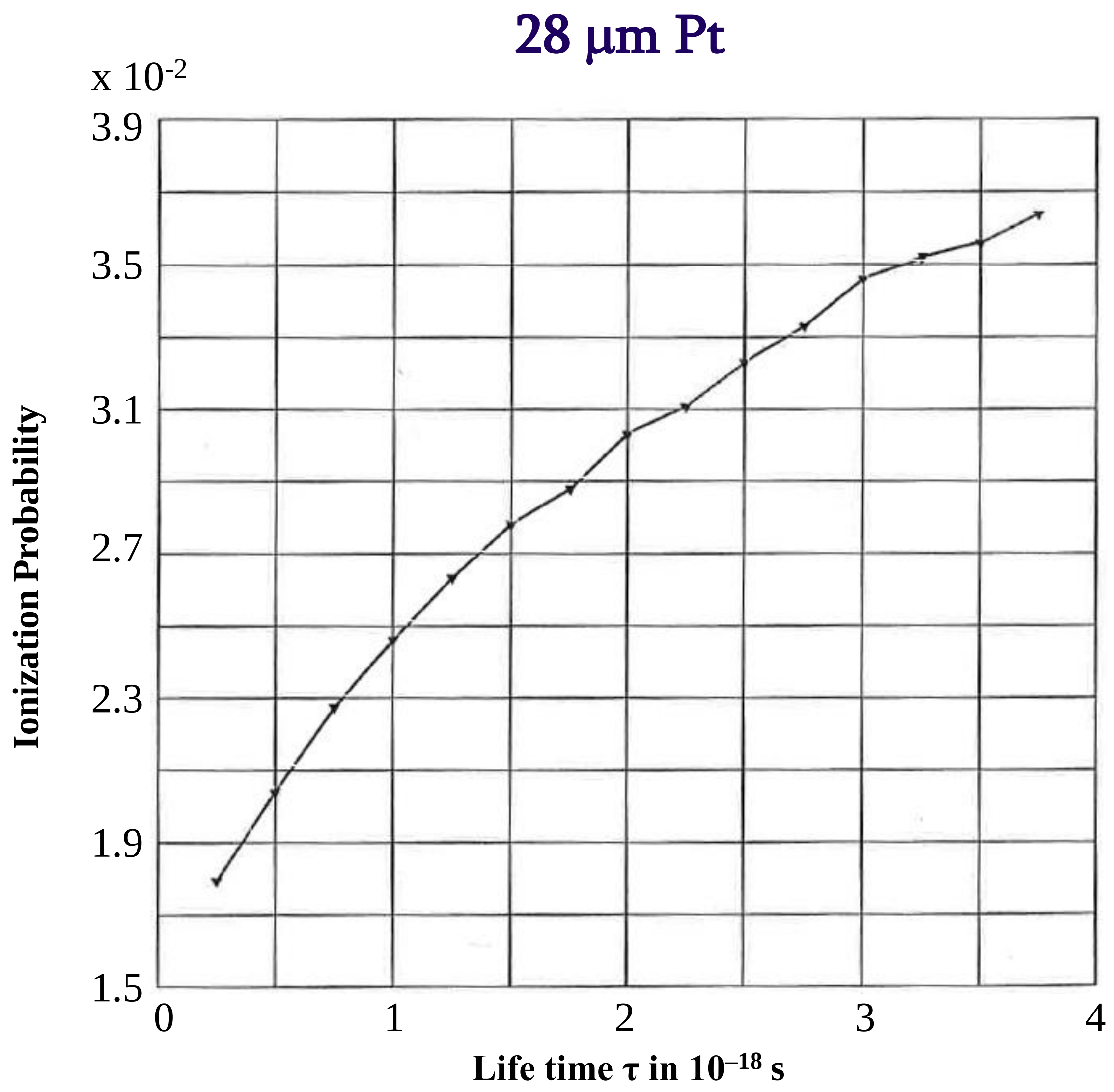
•DIRAC experiment:
study of low-energy K^+K^- scattering → estimate **number of produced atoms A_{2K}**

Kaonium decay width or lifetime "expected":

•Decay width $\boldsymbol{\Gamma(A_{2K}) = [\tau(A_{2K})]^{-1} = \alpha^3 m_K^2\, \mathrm{Im}(a_{KK})}$ … A_{2K} structure dependent:
Strong effects enter by modifying the scattering length a_{KK} .

•DIRAC experiment:
search for "atomic pairs" K^+K^- from A_{2K} ionization
→ upper limit on $\boldsymbol{\tau(A_{2K})}$ → info about scattering length $\boldsymbol{a_{KK}}$!

K^+K^- atoms ionization probability

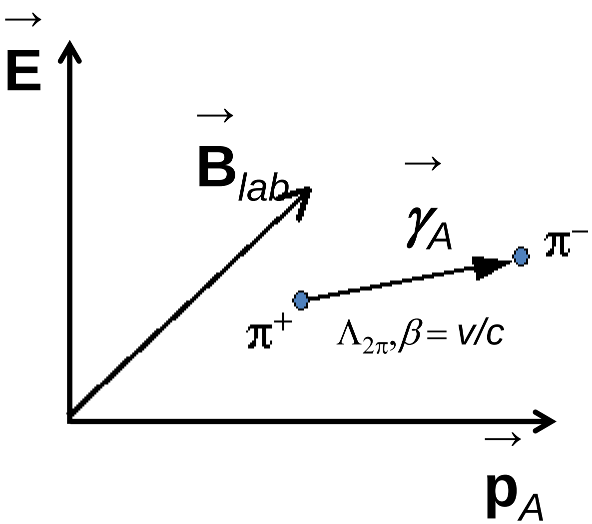


K^+K^- atoms Lorentz factor is $\gamma = 18$

Lamb shift measurement with external magnetic field

L. Nemenov, V. Ovsiannikov, Physics Letters B 514 (2001) 247

Impact on atomic beam by external magnetic field $\boldsymbol{B}_{lab}$ and Lorentz factor γ



$\vec{\gamma}_A$ .... relative distance between π^+ and π^- in $A_{2\pi}$ system

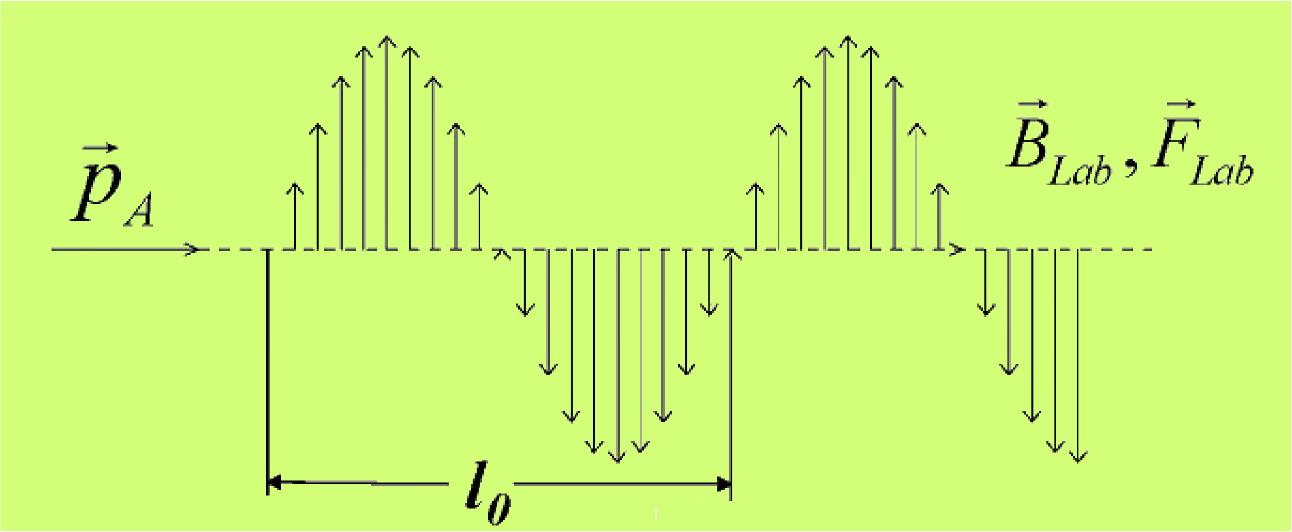
$\vec{\mathbf{B}}_{lab}$ .... laboratory magnetic field

$\vec{\mathbf{E}}$ ...electric field in $A_{2\pi}$ system

$$|\vec{\mathbf{E}}| = \beta\gamma\,\mathbf{B}_{lab} \approx \gamma\,\mathbf{B}_{lab}$$

Resonant enhancement of the annihilation rate of $A_{2\pi}$

L. Nemenov, V. Ovsiannikov, E. Tchaplyguine, Nucl. Phys. (2002)

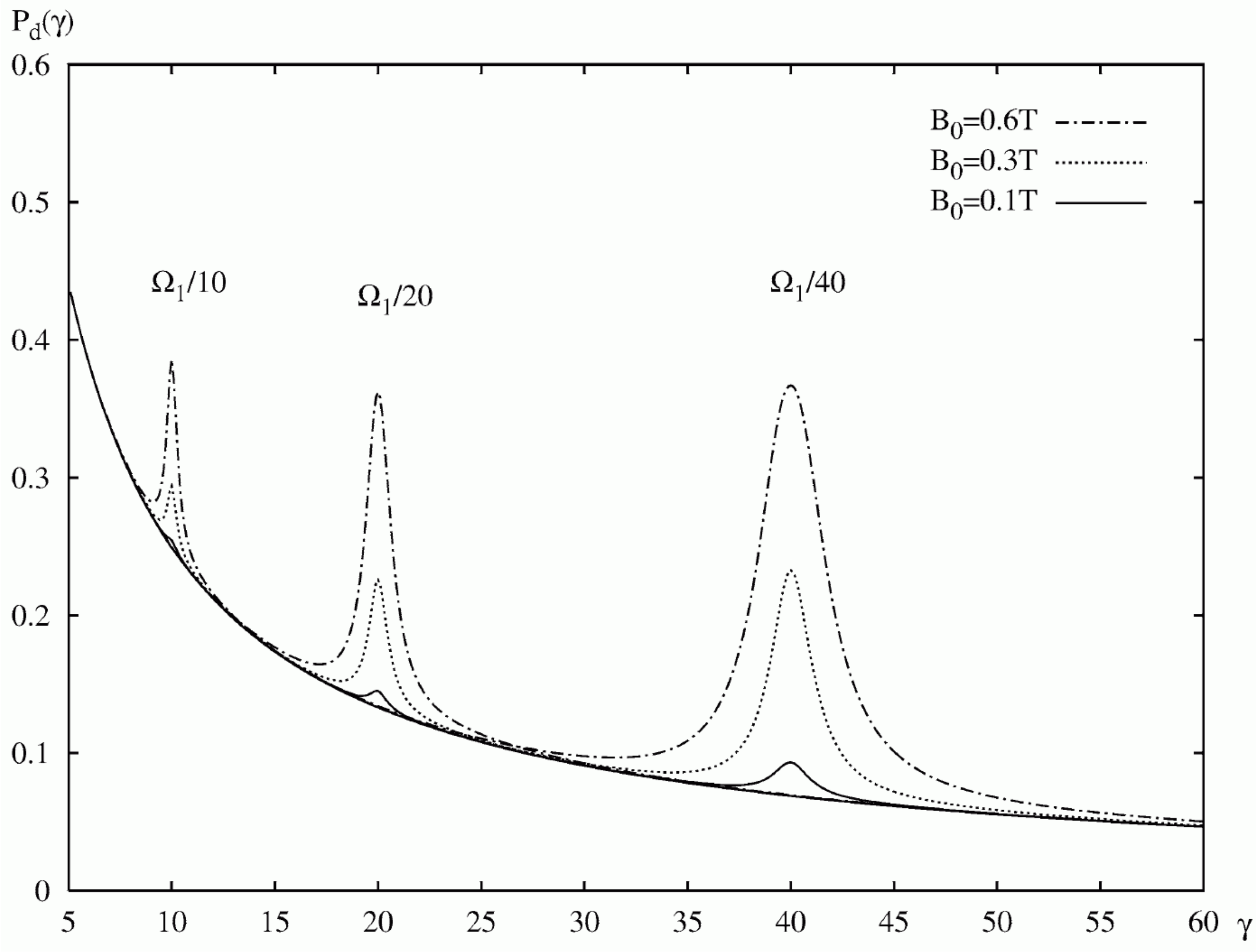


In Lab. System: $T_{Lab} = \dfrac{l_0}{\beta c}, \qquad \omega_{Lab} = \dfrac{2\pi}{T_{Lab}}$

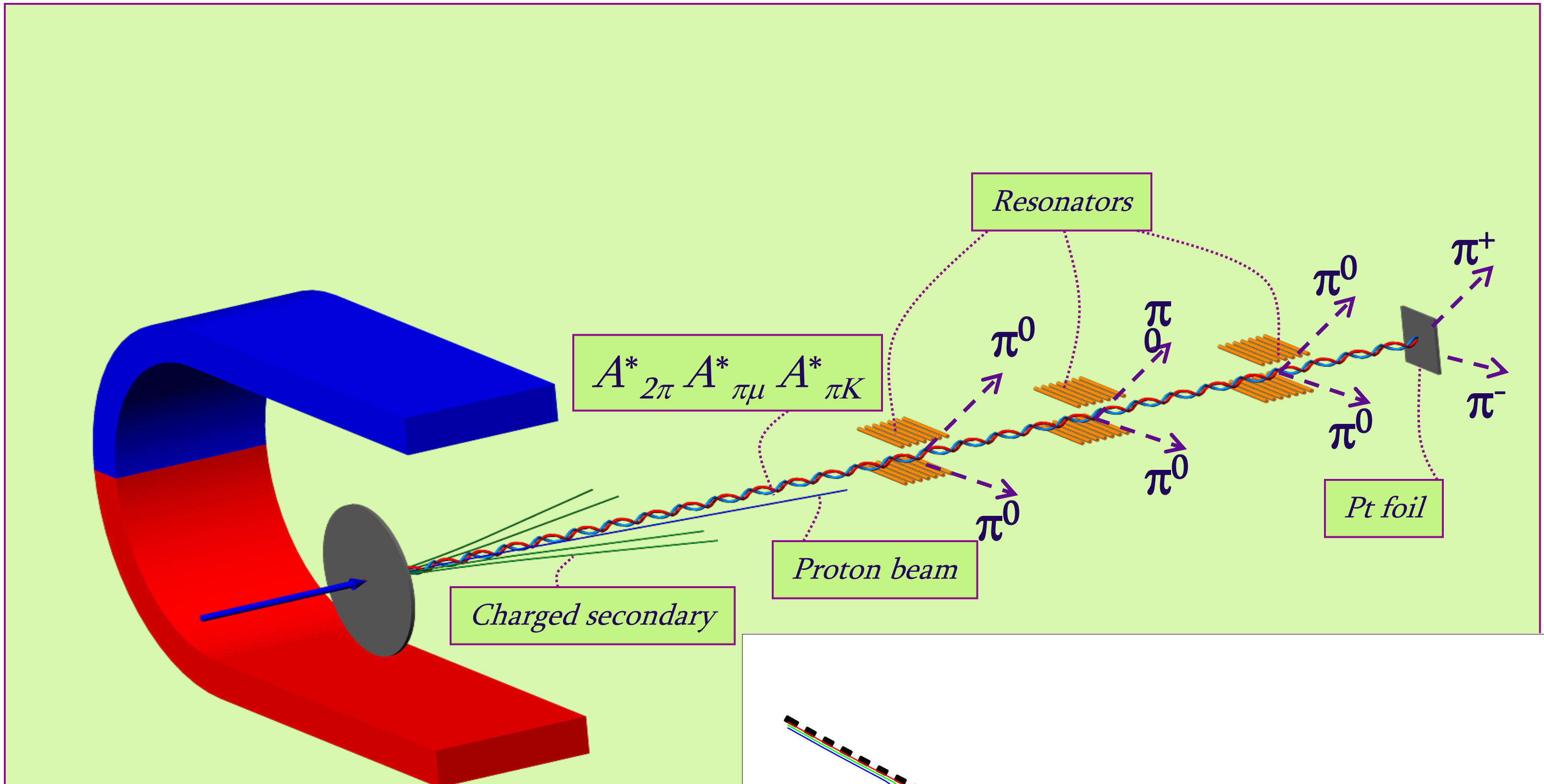
In CM System: $\tilde{\omega} = \gamma \omega_{Lab}, \qquad \tilde{\vec{F}} = \gamma \vec{F}_{Lab} \cdot \cos \tilde{\omega} t, \qquad \tilde{\Omega} = \dfrac{E_{2p} - E_{2s}}{\hbar}$

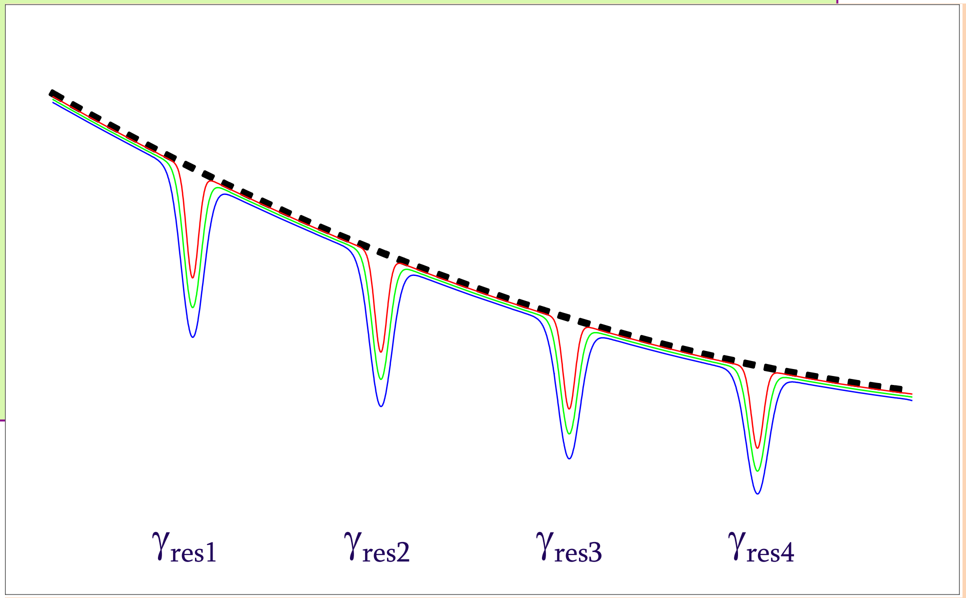
at resonance: $\tilde{\Omega} = \tilde{\omega} = \gamma_{res} \cdot \omega_{Lab} \qquad \Rightarrow \qquad \gamma_{res} = \dfrac{\tilde{\Omega}}{\omega_{Lab}}$

Resonant enhancement



Resonant method





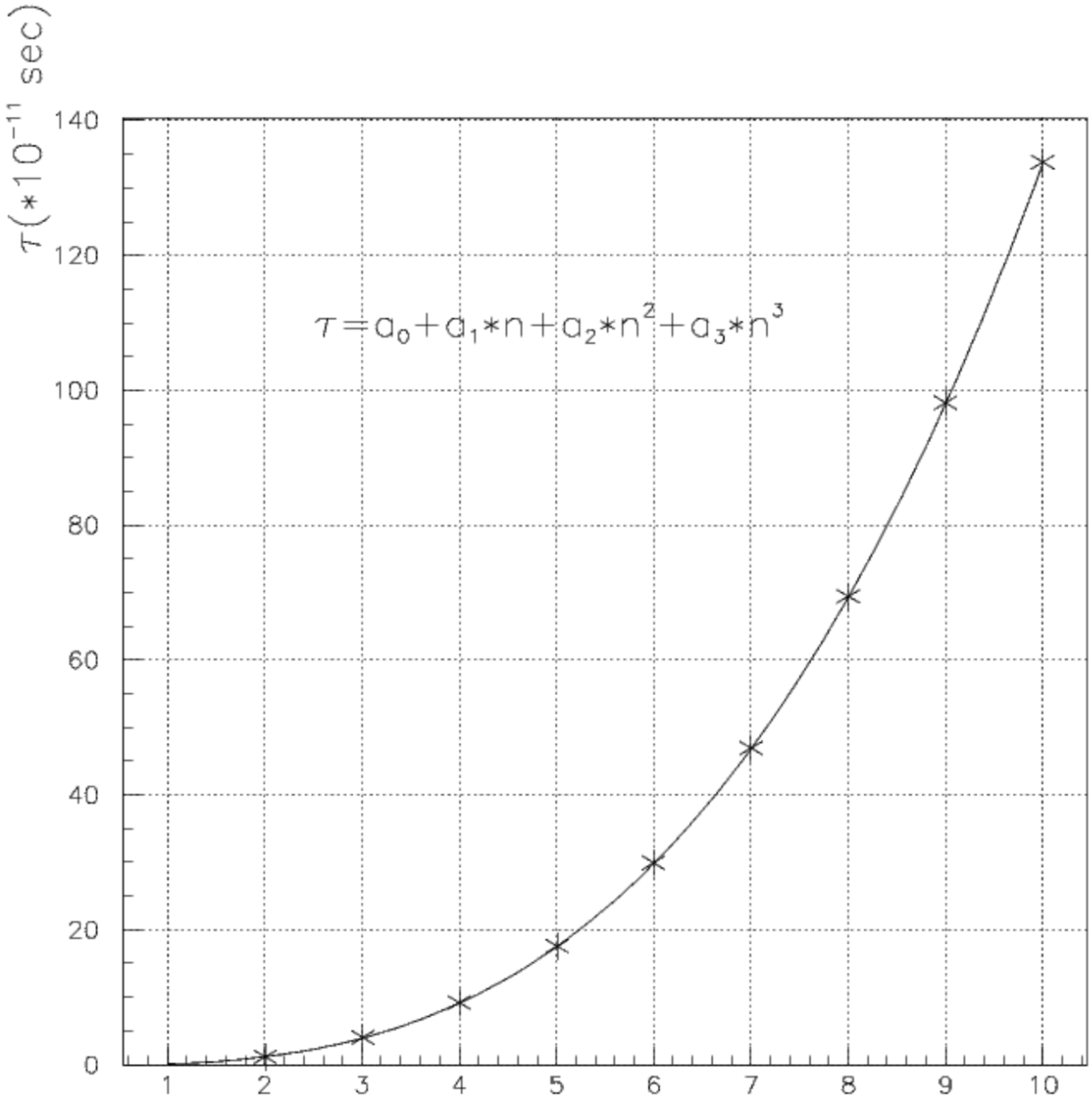
Published results on $\pi\pi$ atom: lifetime and scattering length

DIRAC data	τ_{1s} $(10^{-15}$ s) value	stat	syst *theo**	tot	$\lvert a_0-a_2 \rvert$ value	stat	syst *theo**	tot	Reference
2001	2.91	$^{+0.45}_{-0.38}$	$^{+0.19}_{-0.49}$	$\left[^{+0.49}_{-0.62}\right]$	0.264	$^{+0.017}_{-0.020}$	$^{+0.022}_{-0.009}$	$\left[^{+0.033}_{-0.020}\right]$	PL B 619 (2005) 50
2001-03	3.15	$^{+0.20}_{-0.19}$	$^{+0.20}_{-0.18}$	$\left[^{+0.28}_{-0.26}\right]$	0.2533	$^{+0.0078}_{-0.0080}$	$^{+0.0072}_{-0.0077}$	$\left[^{+0.0106}_{-0.0111}\right]$	PL B 704 (2011) 24

* theoretical uncertainty included in systematic error

NA48	K-decay	a_0-a_2 value	stat	syst	theo	tot	Reference
2009	$K_{3\pi}$	$0.2571 \pm 0.0048 \pm 0.0029 \pm 0.0088$					EPJ C64 (2009) 589
2010	K_{e4} & $K_{3\pi}$	$0.2639 \pm 0.0020 \pm 0.0015$					EPJ C70 (2010) 635

$A_{2\pi}$ lifetime, τ, in np states



n_H	$\tau_H \cdot 10^8$ s	$\tau_{2\pi} \cdot 10^{11}$ s	Decay length $A_{2\pi}$ in L.S. cm for γ=16.1
2p	0.16	1.17	5.7
3p	0.54	3.94	19
4p	1.24	9.05	44
5p	2.40	17.5	84.5
6p	4.1	29.9	144
7p		46.8*	226
8p		69.3*	335

* extrapolated values