Pionium Lifetime in DIRAC

Analysis of the 2001, 2002 and 2003 data

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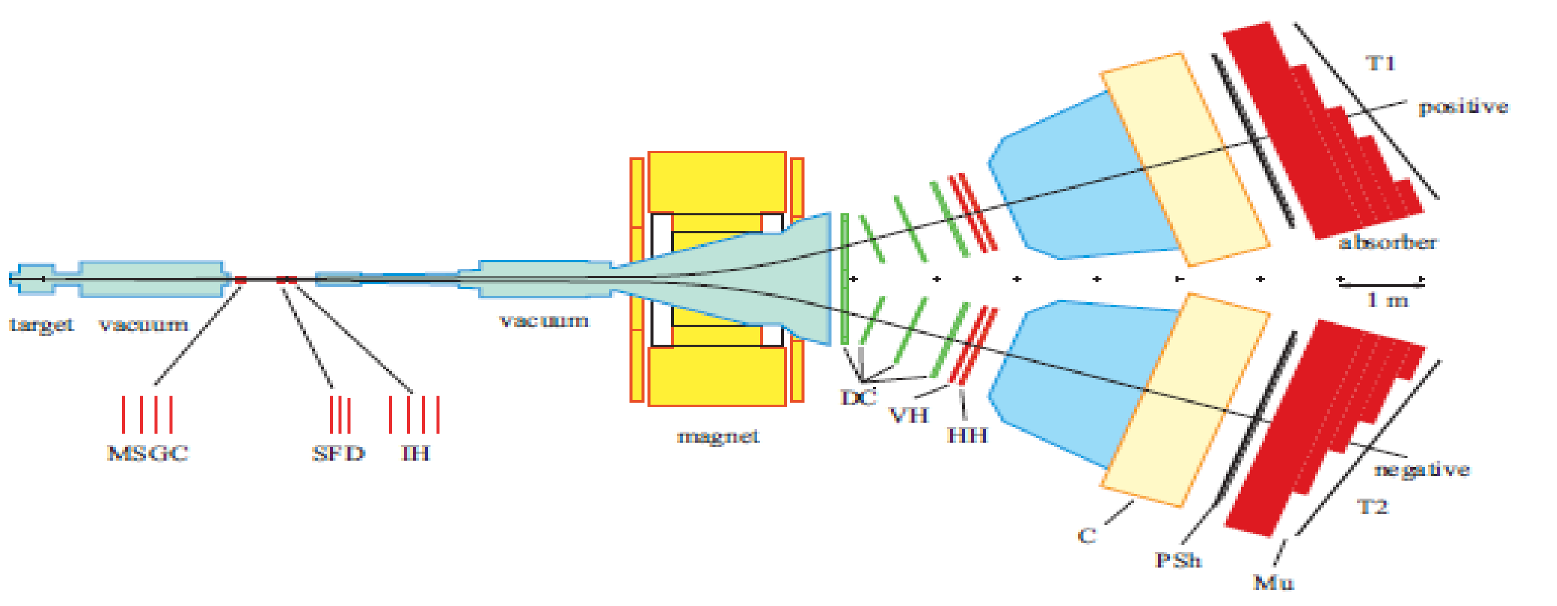
What is new in this method?

GEM/MSGC built at the Santiago de Compostela University

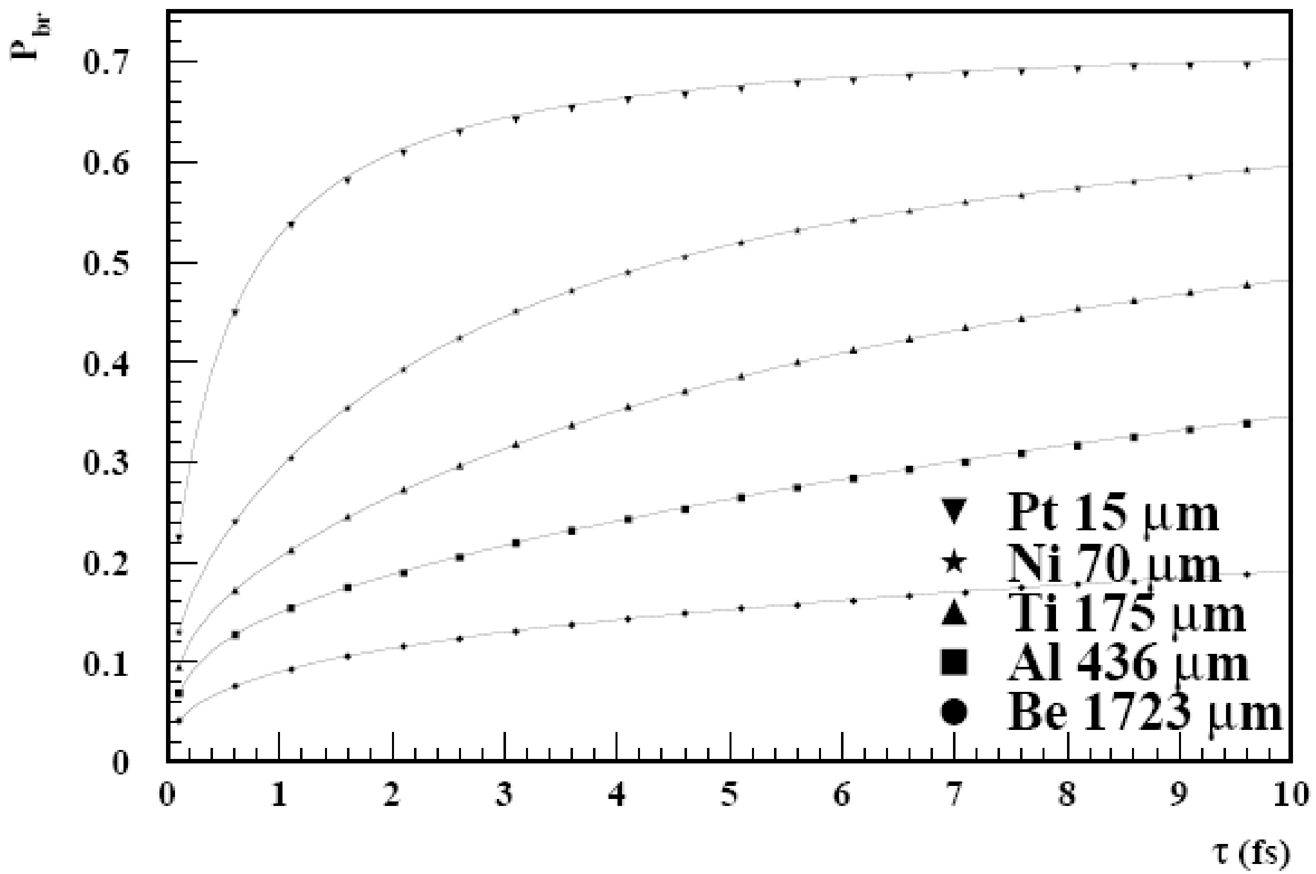
Spatial resolution ~50um
QT resolution ~0.1MeV/c (in QL is 0.55MeV/c)
Systematics due to upstream multiple scattering reduced to almost zero.
20 and 24 GeV/c proton beams at PS accelerator.
94 and 98 um Ni targets

22200 pion pairs from pionium ionization



Breakup probability versus pionium lifetime

The relation between the Pbr and the lifetime is
Know with a precision better than a 1%



Breakup probability

$$P_{Br} = \frac{n_A}{N_A} = \frac{1}{K^{th}} \frac{n_A}{N_C} \qquad \mathrm{P_{Br}} = \frac{\mathrm{N_{AT}}(\Omega)}{\mathrm{N_{CC}}(\Omega)} \frac{1}{\mathrm{K^{exp}}(\Omega)} \qquad \mathrm{K^{exp}} = \frac{\varepsilon_{\mathrm{CC}}(\Omega)}{\varepsilon_{\mathrm{AT}}(\Omega)} \mathrm{K^{th}}(\Omega)$$

QM analytical factor :

$$\mathrm{K^{th}}(\Omega) = \frac{(2\pi\alpha \mathrm{M}_\pi)^3}{\pi} \frac{\sum 1/\mathrm{n}^3}{\int_\Omega \mathrm{A_C}(\mathrm{Q})\, \mathrm{d}^2\mathrm{Q}}$$

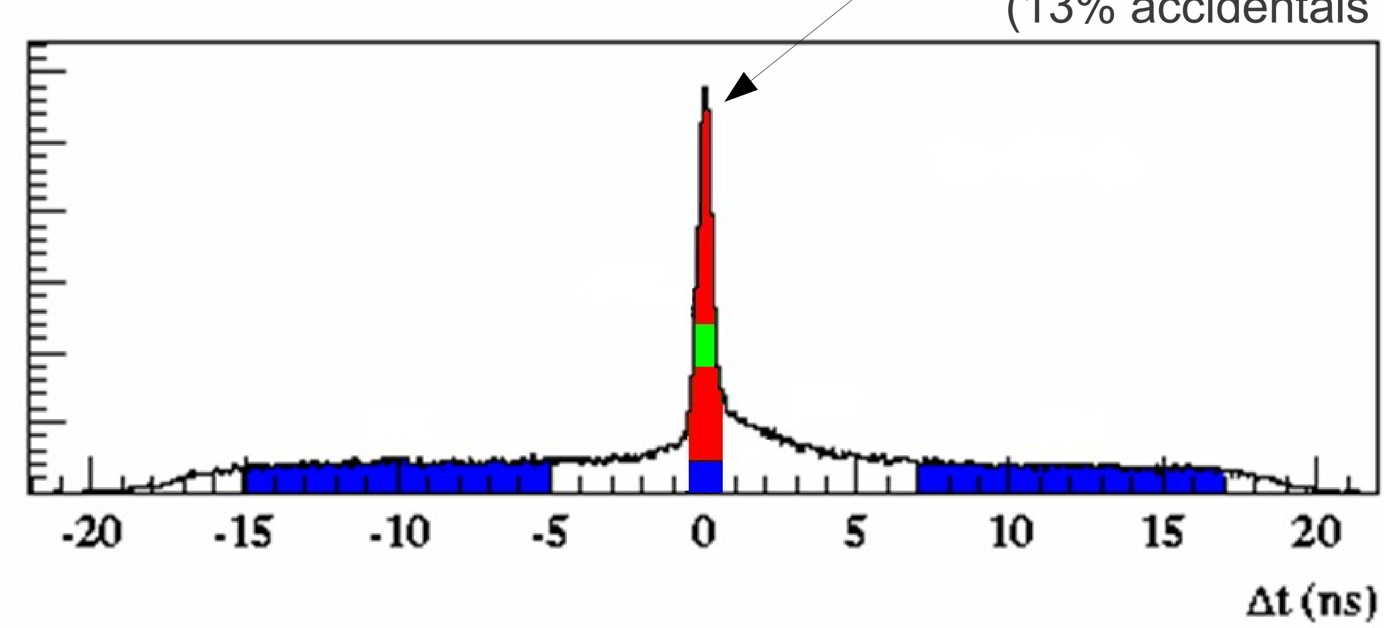
- Aceptance factors epsilon_i detemined by our Monte Carlo method.

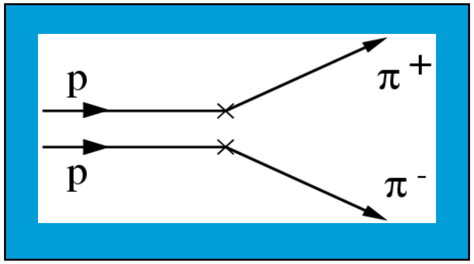
  - Standard choice for $\Omega = (0, \mathrm{Q_T^C}) \times (0, \mathrm{Q_L^C})$

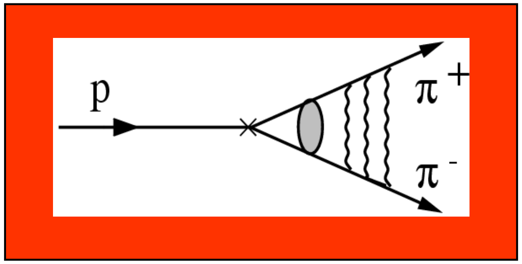
  is Qlc=2 MeV/c and QTc=5 MeV/c.

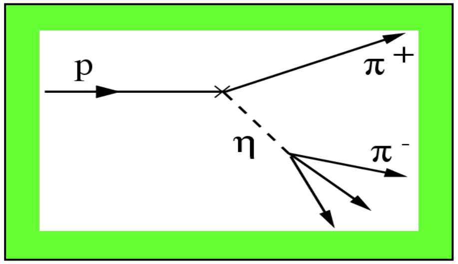
Difference of TOF in the VH

Prompt events =
Delta_T < 0.5 ns
(13% accidentals contamination)









Accidental pairs,
different proton interactions in the target.

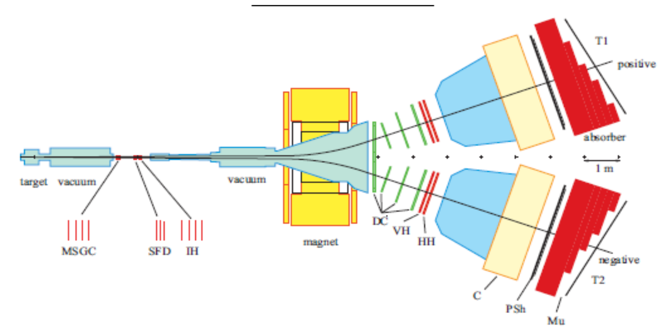
Coulomb pairs.
From short lived sources.
r < 3 fm, < R(A2π)

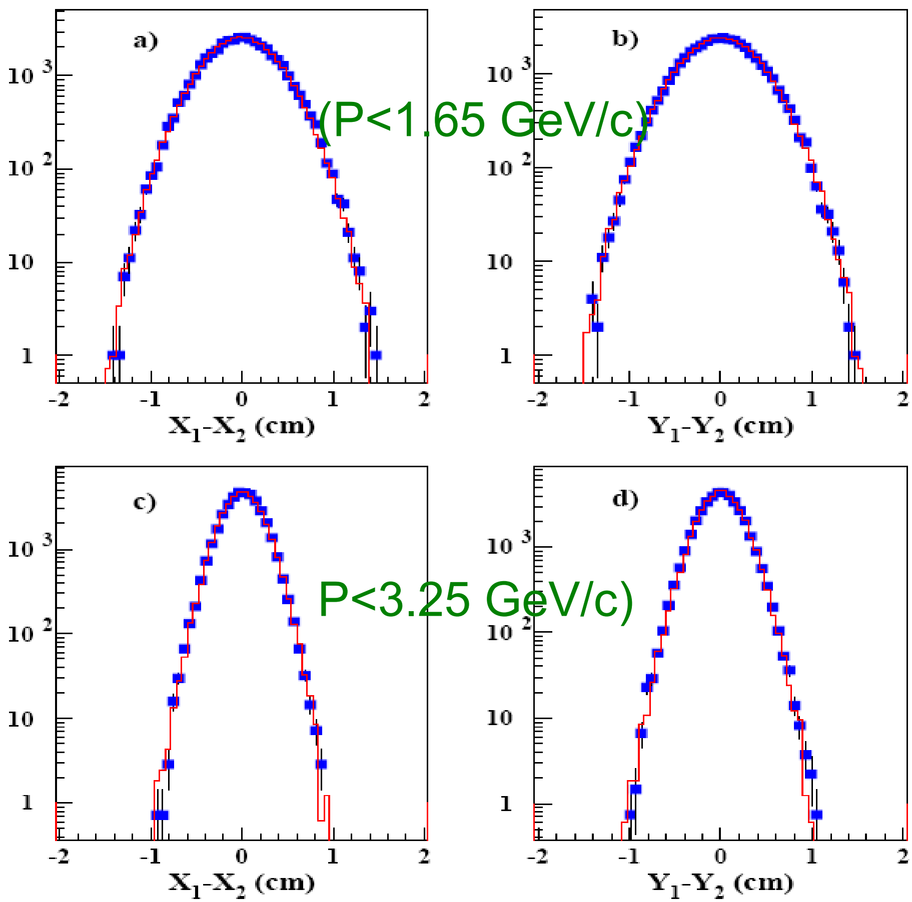
Non Coulomb pairs.
From long lived sources.
r ~ 1000 fm.

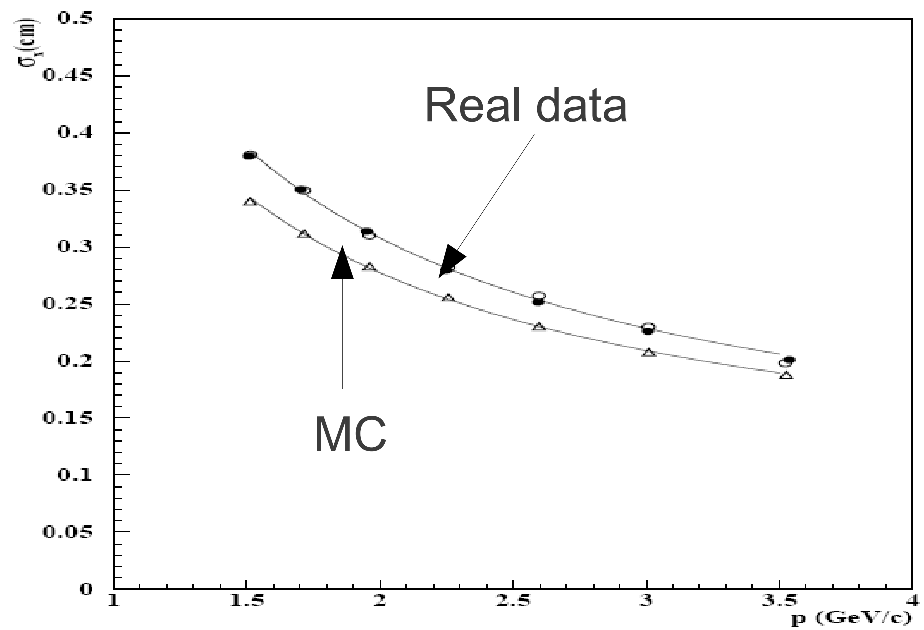
Monte Carlo

Sample	Coulomb	Non Coulomb	Atomic pairs
2001 94um	200,000,000	50,000,000	10,000,000
2001 98um	50,000,000	15,000,000	10,000,000
2002 20GeV/c	110,000,000	30,000,000	10,000,000
2002 24GeV/c	160,000,000	45,000,000	10,000,000
2003 20GeV/c	50,000,000	15,000,000	10,000,000
Total	570,000,000	155,000,000	50,000,000

Upstream multiple scattering



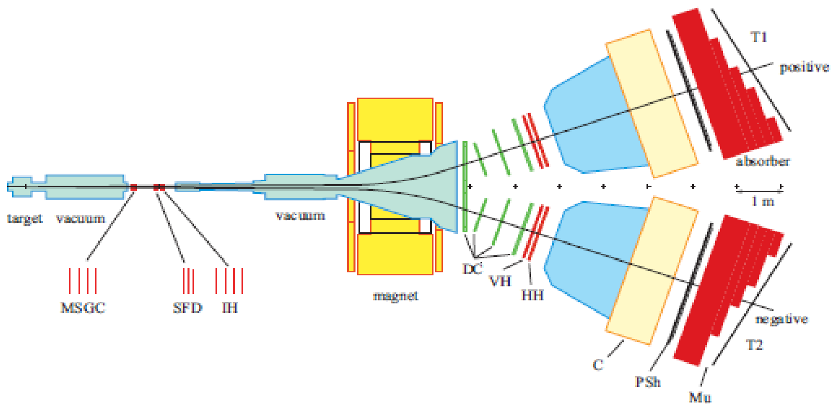


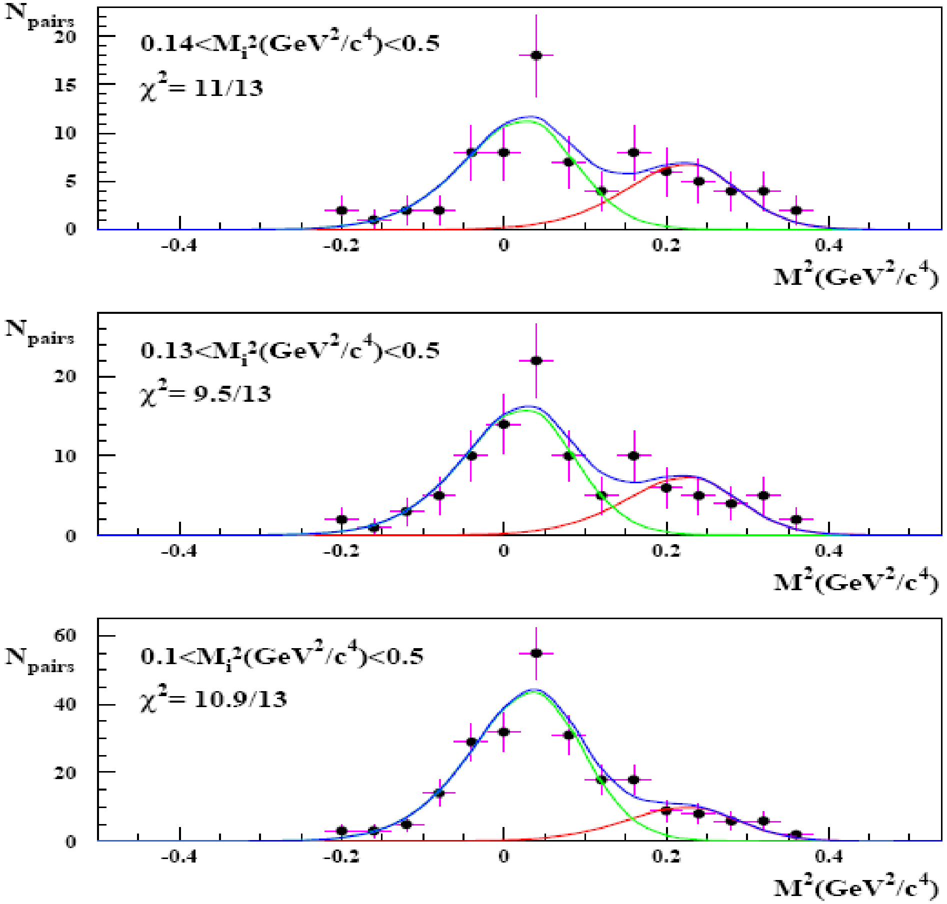


Systematic error in Pbr → 0.04 %

Necesary to increase upstream multiple scattering
in a 15% !! (1.5% of precision)

KK contamination

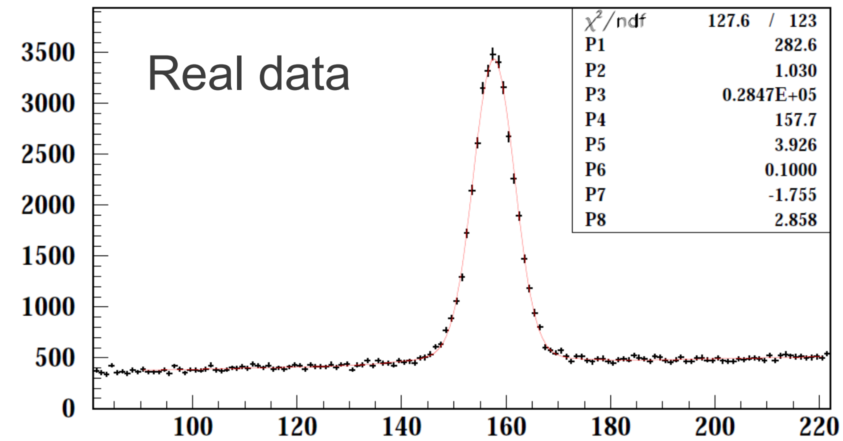


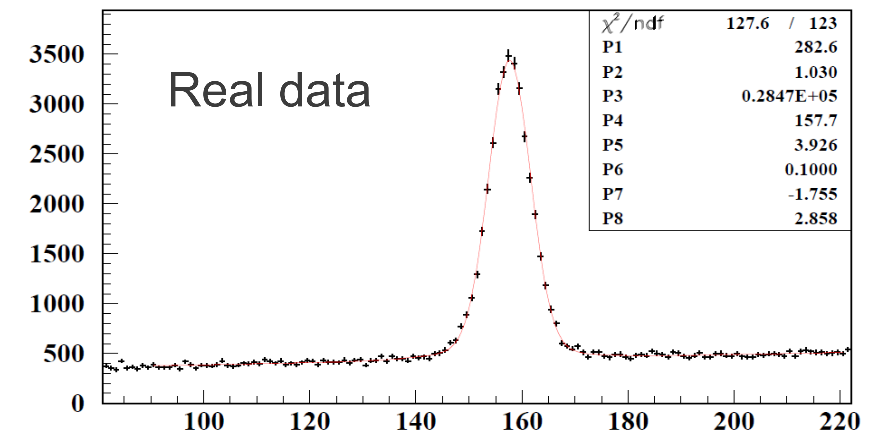


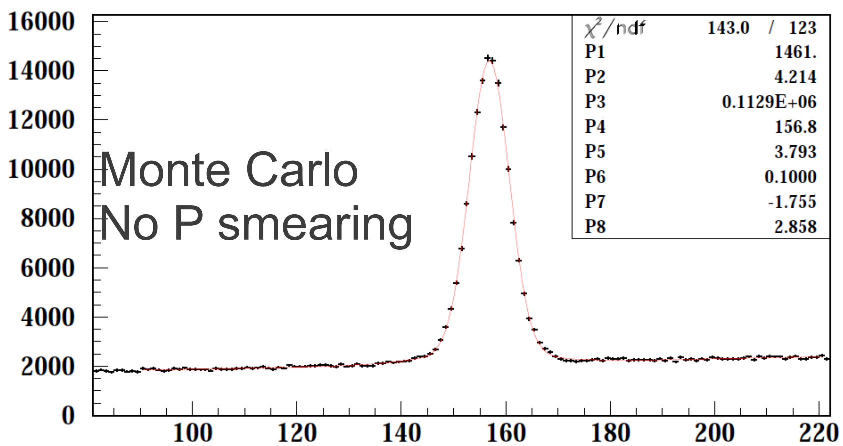
KK/pipi at 2.9 GeV/c → 0.238 +- 0.035 %

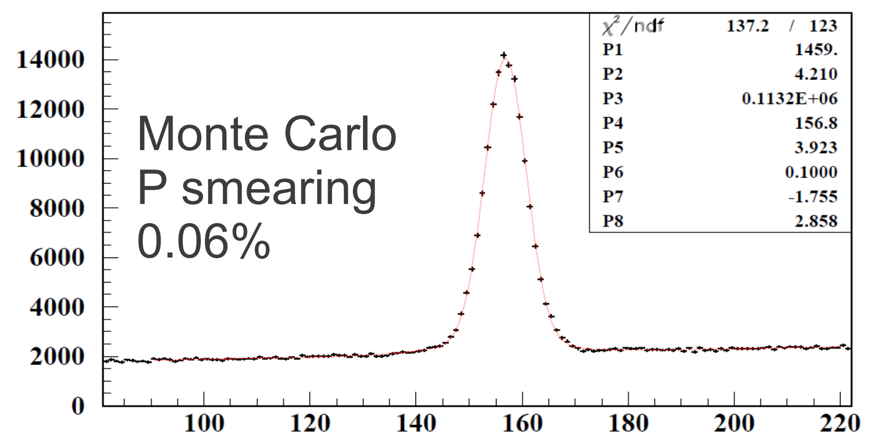
Systematic error in Pbr → 0.24 %

Momentum resolution. Lambda analysis





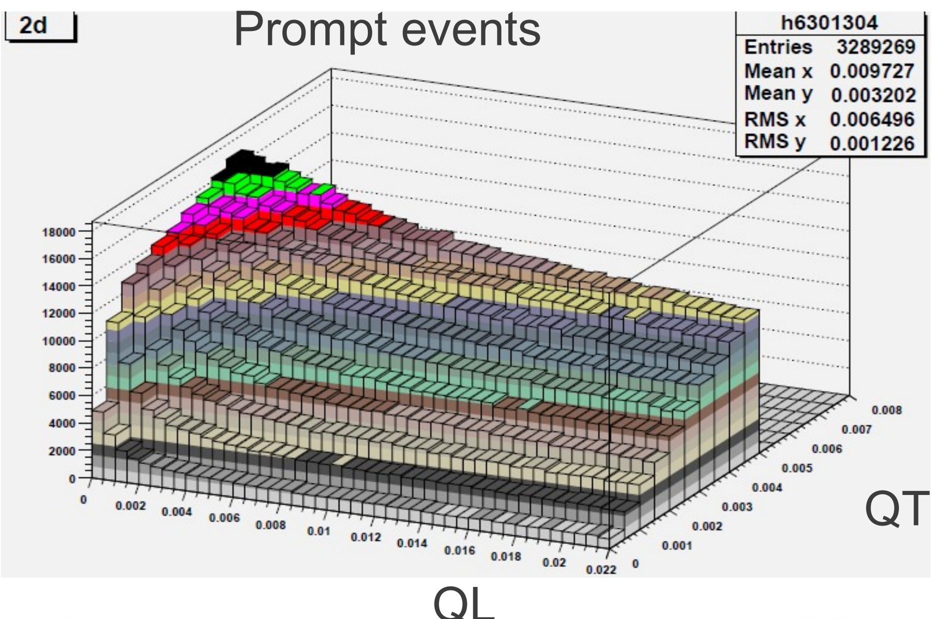


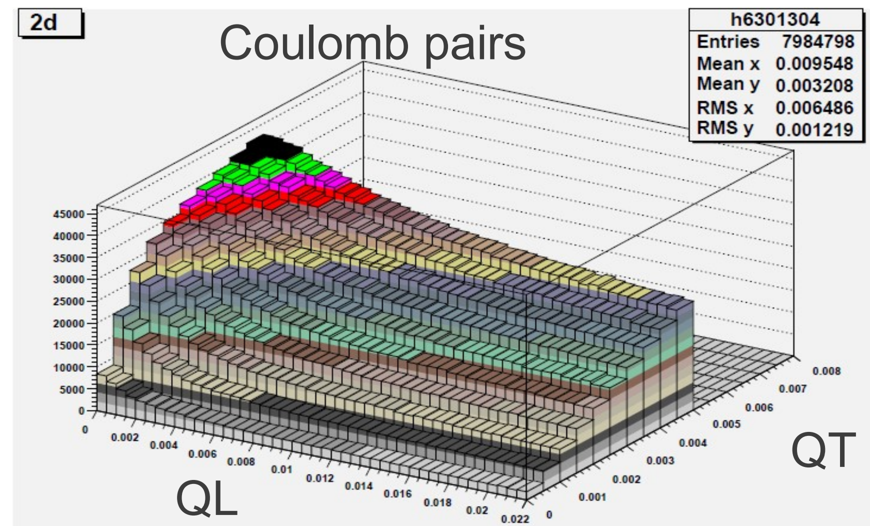


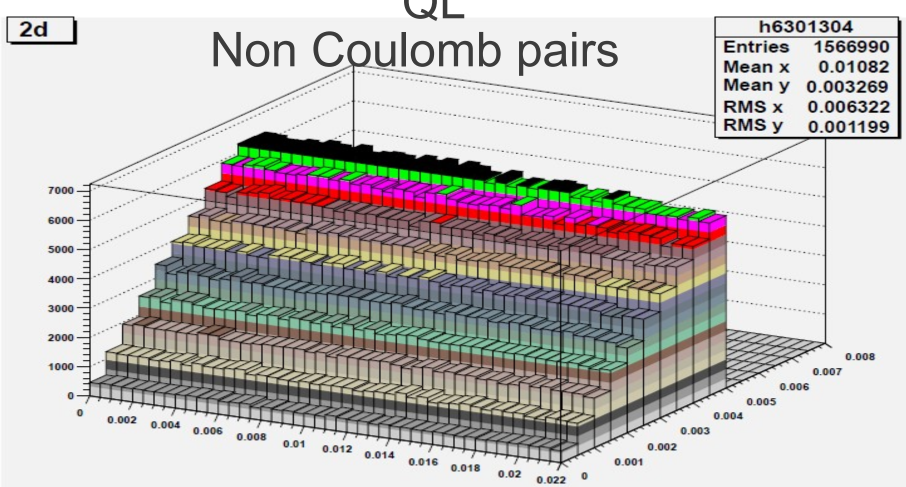
Systematic error in Pbr → 0.6 %

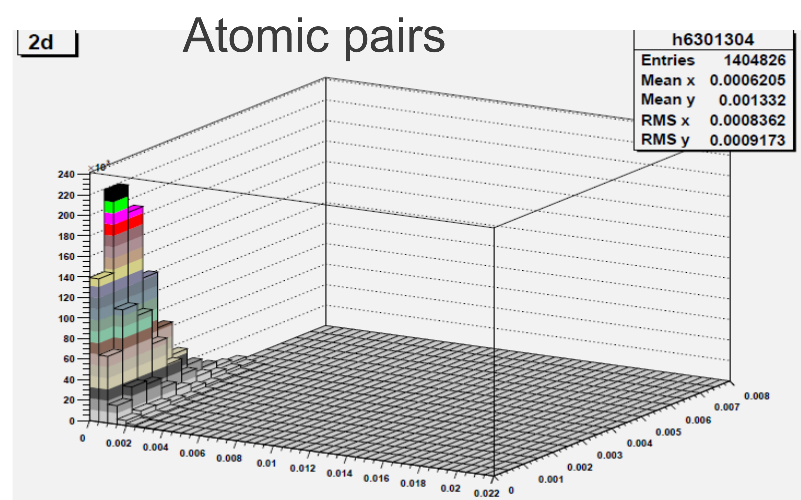
Method

$$\chi^2 = \sum_k \frac{\left(N_p^k - \beta(\alpha_1[\epsilon\frac{N_{KK}^k}{N_{KK}} + (1-\epsilon)\frac{N_{CC}^k}{N_{CC}}] - \alpha_2\frac{N_{AC}^k}{N_{AC}} - \alpha_3\frac{N_{NC}^k}{N_{NC}} - \gamma\frac{N_{AA}^k}{N_{AA}})\right)^2}{N_p^k + \beta^2(\alpha_1^2[(1-\epsilon)^2\frac{N_{CC}^k}{N_{CC}^2} + \epsilon^2\frac{N_{KK}^k}{N_{KK}^2}] + \alpha_2^2\frac{N_{AC}^k}{N_{AC}^2} + \alpha_3^2\frac{N_{NC}^k}{N_{NC}^2} + \gamma^2\frac{N_{AA}^k}{N_{AA}^2})}$$









22200 atomic pairs

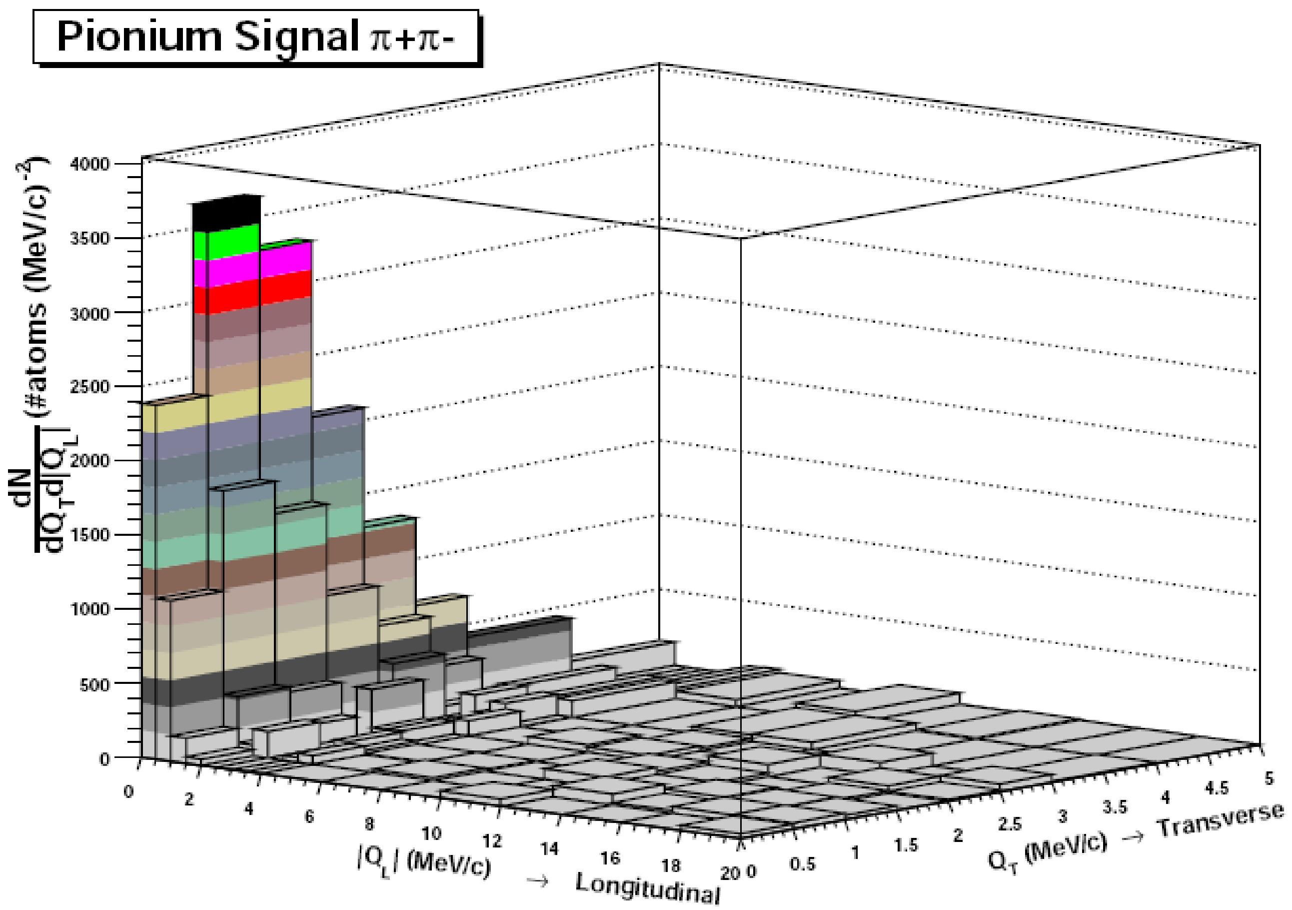
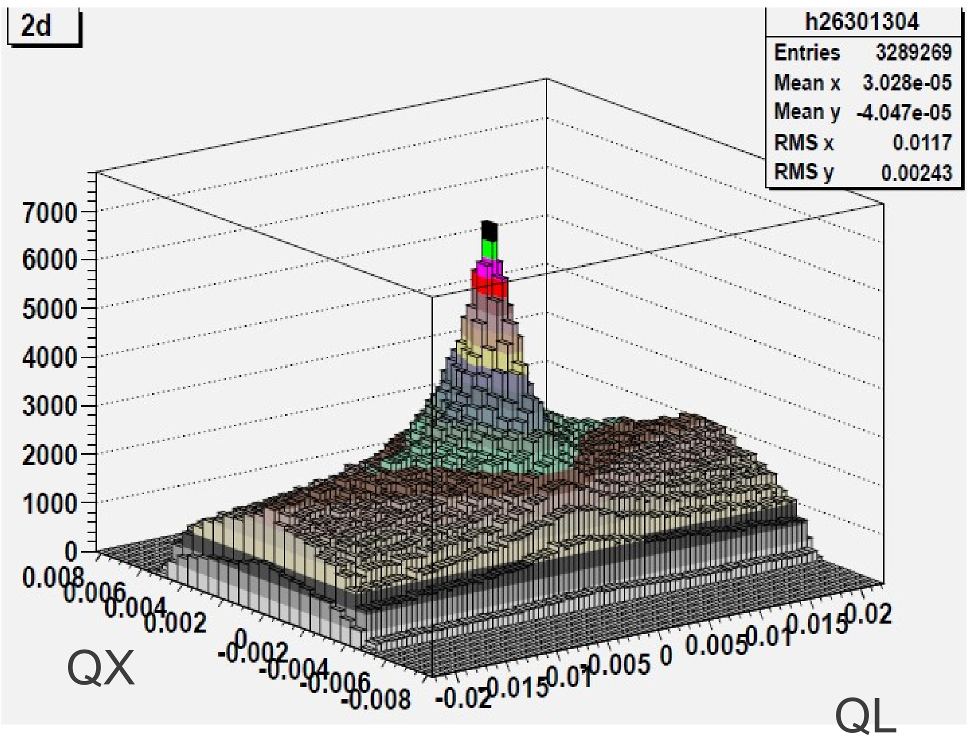


Figure 7.8: *Lego plot showing the pionium break-up spectrum in Ni in the* $(Q_T, Q_L = |Q_Z|)$ *plane, after subtraction of the Coulomb background.*

QL vs QX

Prompt real data



Atomic pairs signal

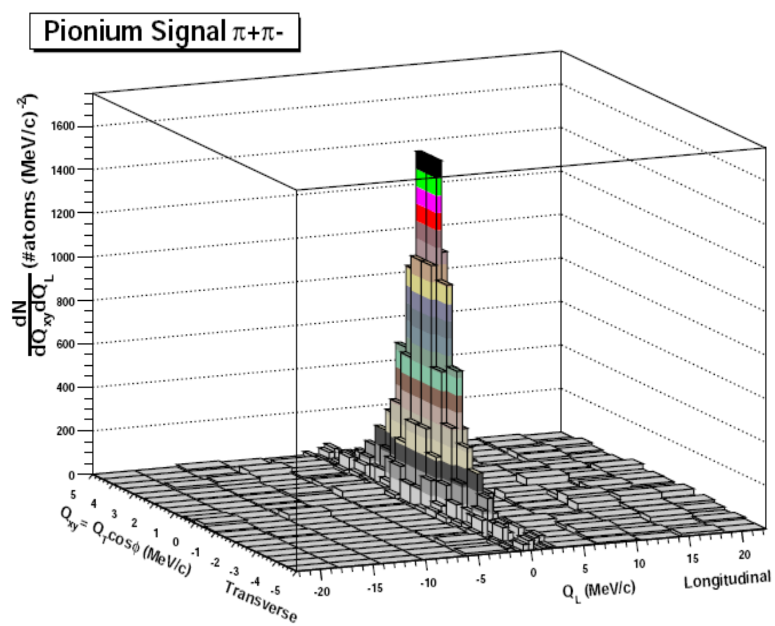
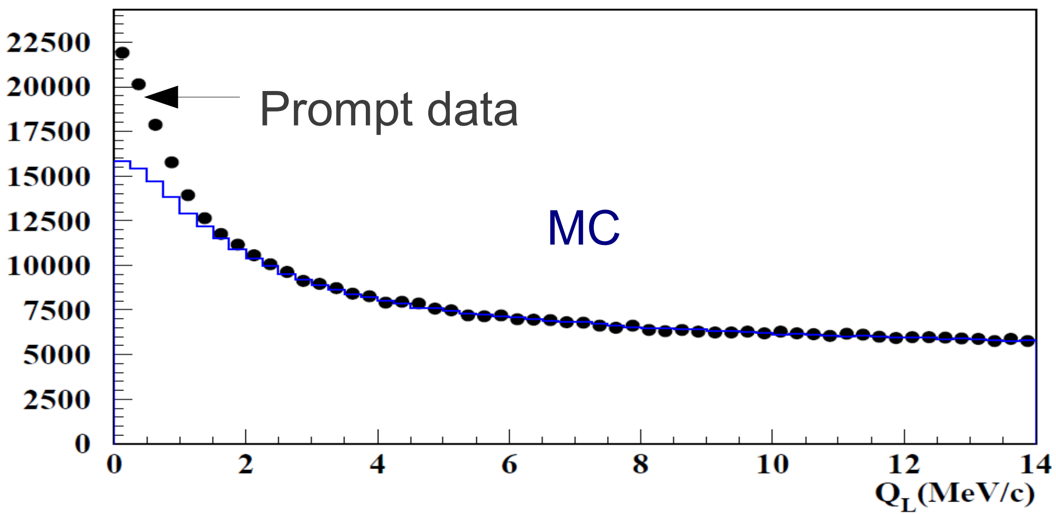
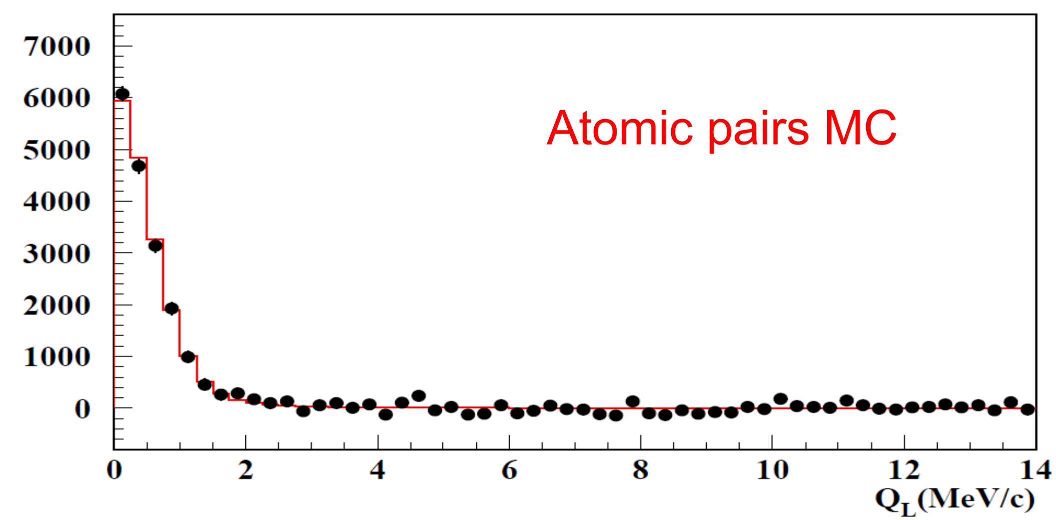


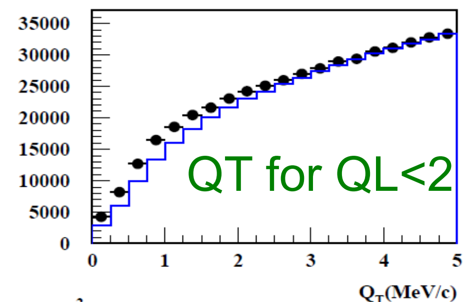
Figure 7.9: *Lego plot showing the pionium break-up spectrum in* Ni *in the* (Q_{xy}, Q_L) *plane, after subtraction of Coulomb background. The transverse component* $Q_{xy} = Q_T\ cos\phi$ *is defined as the product of the measured* Q_T *value times the cosine of a random azimuth.*

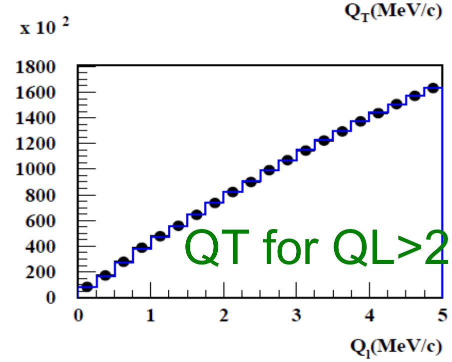
Projections

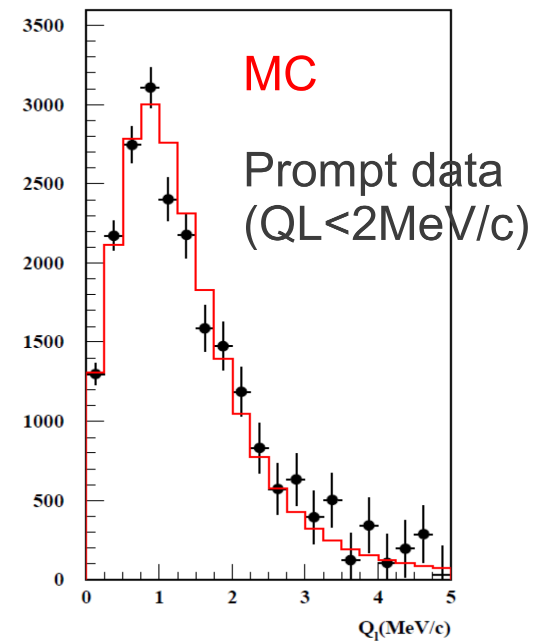
QL for QT<2MeV/c



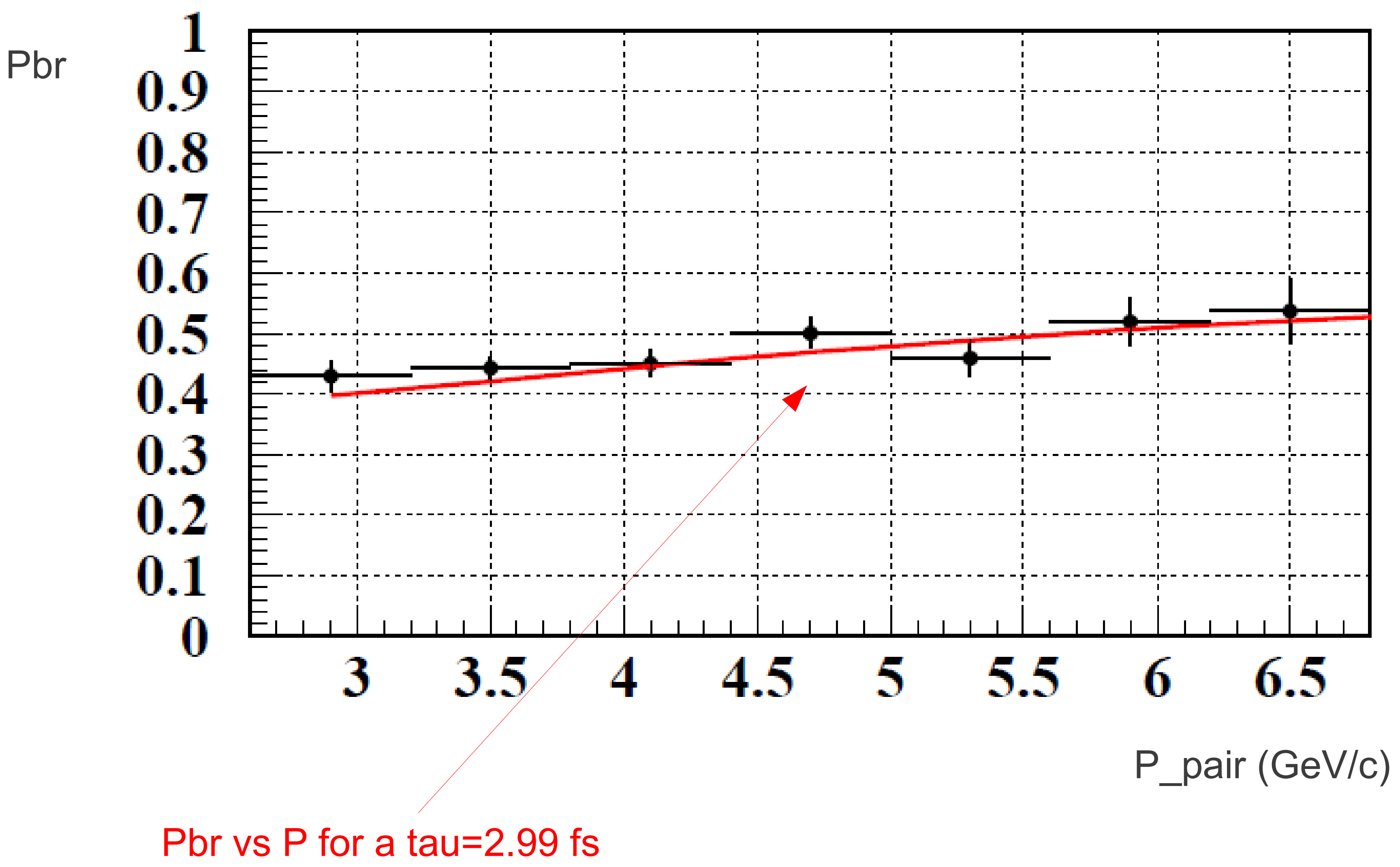




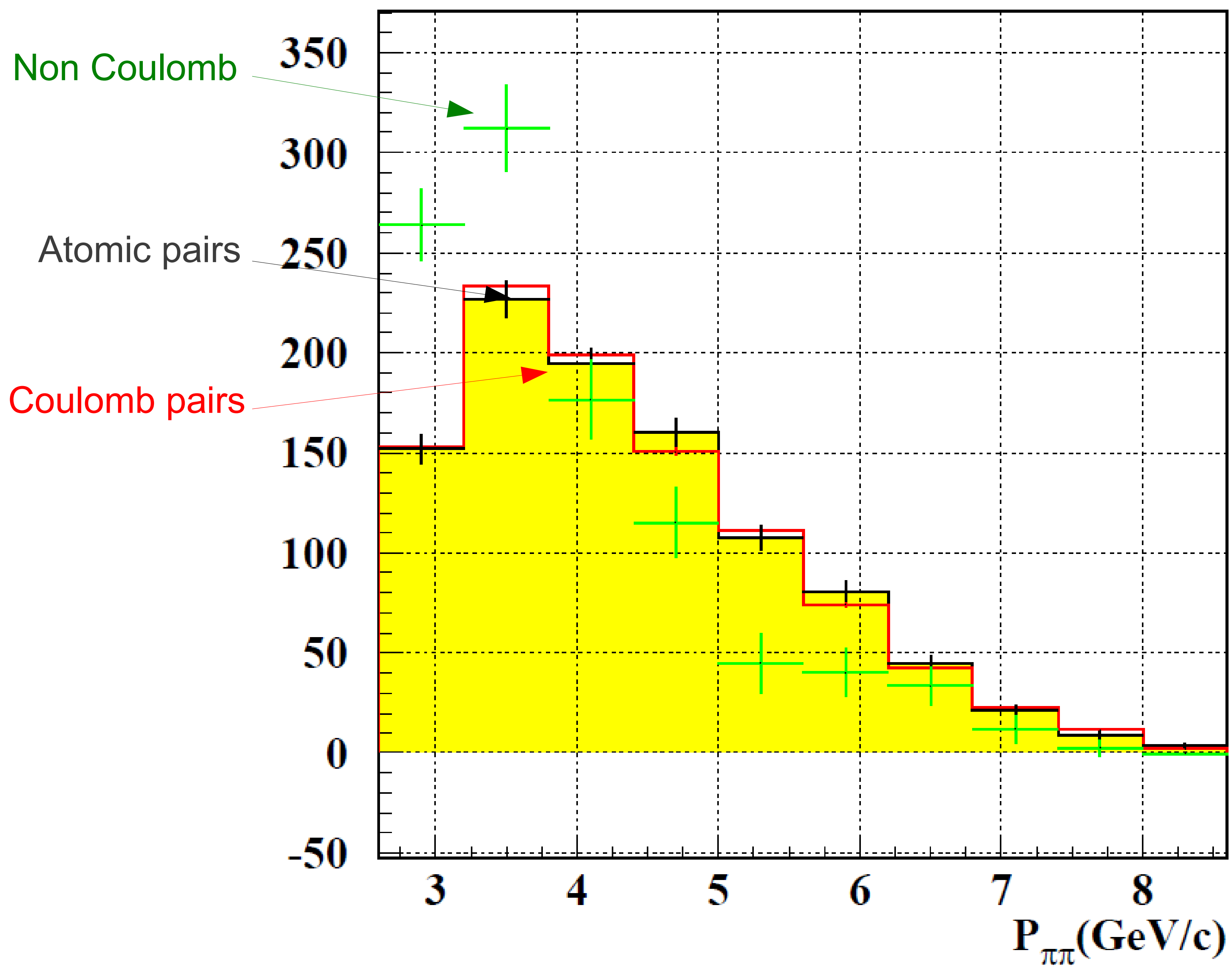




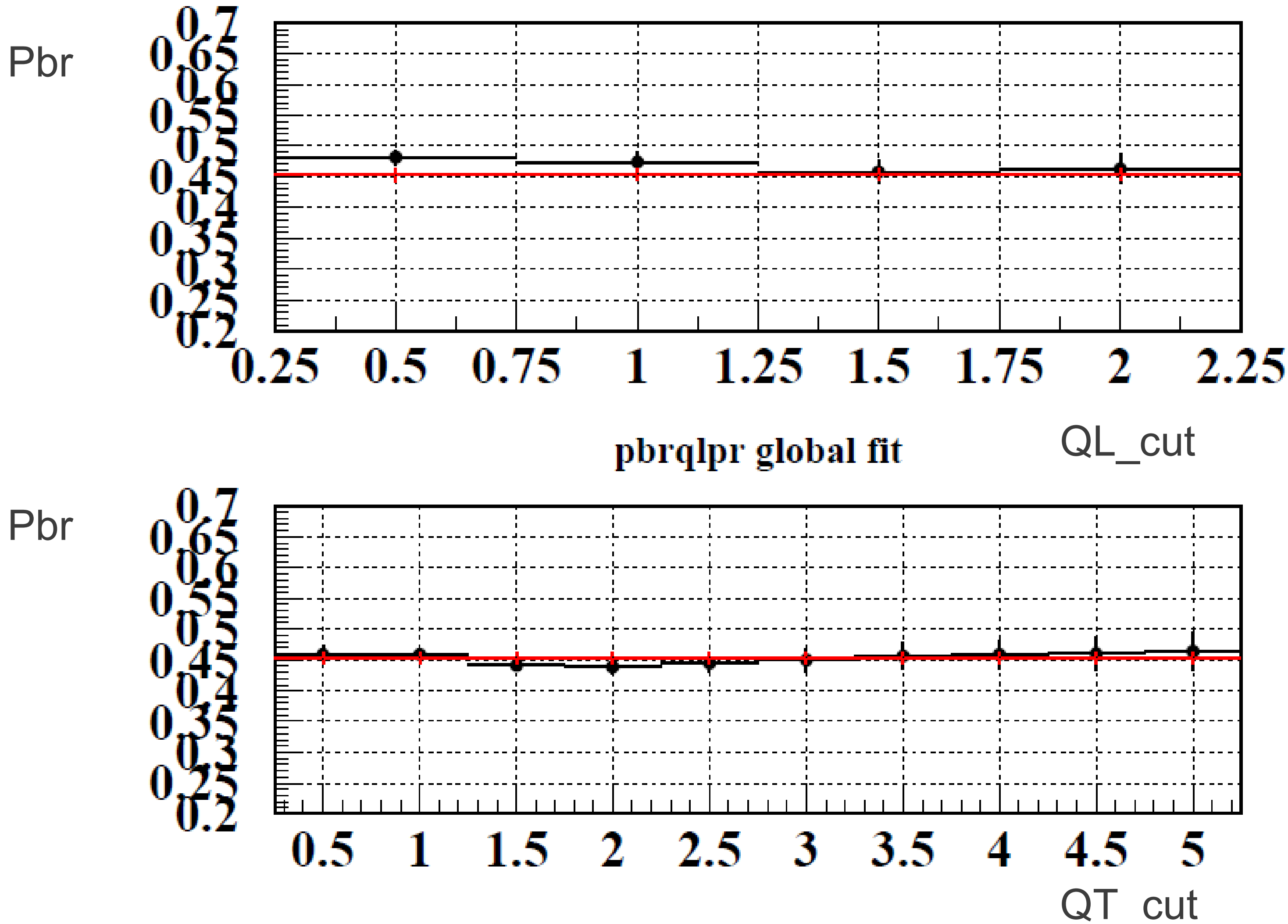
Fit results: Breakup probability versus laboratory momentum



Fit results: Laboratory momentum



Stability of Pbr with QL and QT cut



Systematic errors table

Source	Systematic error
(1) MS Ni (1%)	0.00767
MS Up (8%)	0.00017
Collapsed tracks	0.00144
Finite size	0.00108
Background	0.00014
Trigger simulation	0.00042
KK & pp	0.00110
Lambda (0.00066)	0.00260
Target impurity	0.00131
A2pi-Ni cross section (0.5%)	0.00224
A2pi transport eq. (0.8%)	0.00358
Total (sqrt(es_i^2))	0.00939

(statistical error is 0.0093)

Summary for the Pbr measurements and results

Data Sample	PBR	Chi2/ndf
2001 94um	0.4195 +- 0.0165	267/280
2001 98um	0.4747 +- 0.0280	316/280
2002 20 GeV/c	0.4808 +- 0.0231	301/280
2002 24 GeV/c	0.4311 +- 0.0161	267/280
2003 20 GeV/c	0.4708 +- 0.0295	266/280

DIRAC results

Tau (fs)= 2.99 +0.18 -0.17 (stat) +0.19 -0.17 (syst)
Tau (fs) = 2.99 +0.26 -0.24 (8.7%)
|a0-a2| = 0.2606 +- 0.011 (4.2%)

ChPT calculations

Tau = 2.9 +- 0.1 (3.4%)
|a0-a2| = 0.265 +- 0.004 (1.5%)

Conclusions:

- A new final state, the Pionium, has been copiously produced in the laboratory (**22287 atomic pairs**), and it’s ionization spectrum has been fully mapped in both the longitudinal and transverse projections.

- Making no asumptions on the physics of pNi collisions, we have determined the pionium lifetime (in 1S state), to be **T1s = 2.99 +0.26 -0.24 fs**, using the full DIRAC experiment data sample.

- Given the existence of a rigorouse next-to-leading order calculation in QCD and QED, the pionium lifetime determination has been converted into a 4% measurement of the s-wave isospin pipi scattering length difference |a0-a2| in the process pi+pi- → pi0pi0 at threshold, with the result **|a0-a2|=0.261 +- 0.011 Mpi^-1**